Book of Abstracts

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Contribution: **T1** / Beam Plasmas and Inertial Fusion

Exploring HED physics, ICF dynamics and lab astrophysics with advanced nuclear diagnostics

Chikang Li

Massachusetts Institute of Technology, Cambridge, MA 02139, USA

Significant progress has recently been made in developing advanced nuclear diagnostics for the OMEGA laser facility and the National Ignition Facility (NIF). Both self-emitted fusion products and backlighting nuclear particles have been measured and used to study a large range of basic physics of high-energy-density (HED) plasmas. The highlights of these achievements are manifested by numerous recent publications. For ignition science in inertial-confinement fusion (ICF) experiments, for example, these works have helped to advance our understanding of kinetic effects in exploding-pusher ICF implosions and our understanding of NIF capsule implosion dynamics and symmetry. For basic physics in HED plasmas and laboratory astrophysics, our research contributed to the understanding of nuclear plasma science, the generation and reconnection of self-generated spontaneous electromagnetic fields and associated plasma instabilities, high-Mach-number plasma jets, Weibel-mediated electromagnetic collisionless shocks, and charged-particle stopping power in various laser-produced HED plasmas. In this Tutorials and Topical Lecture, we will present details of these researches.

The work described herein was performed in part at the LLE National Laser User's Facility (NLUF), and was supported in part by US DOE, LLNL and LLE.

Contribution: **T2** / Basic and Astrophysical Plasmas

Detection of the missing baryons by studying the lines from the Warm Hot Intergalactic Medium (WHIM)

F. Nicastro

INAF - Osservatorio Astronomico di Roma

It has been known for decades that the observed number of baryons in the local Universe falls about 30-40% short of the total number of baryons predicted by Big-Bang Nucleosynthesis, inferred by density fluctuations of the Cosmic Microwave Background and seen during the first 2-3 billion years of the universe (redshift z>2-3) in the so called “Lyman-α Forest". While theory provides a reasonable solution to this paradox, by locating the missing baryons in hot and tenuous filamentary gas connecting galaxies, it also sanctions the difficulty of detecting them because their by far largest constituent, hydrogen, is mostly ionized and therefore virtually invisible in ordinary signal-to-noise Far-Ultraviolet spectra. Indeed, despite the large observational efforts, only a few marginal claims of detection have been made so far.
Here I will first review the observational efforts pursued over the past 15 years by several groups and will then present our recent results that show that the missing baryons are indeed found in a tenuous warm-hot and moderately enriched medium that traces large concentrations of galaxies and permeates the space between and around them. The detection of these baryons is hampered by foreground ISM contamination, which is hard to correct for, due to our poor knowledge of inner-shell resonant transitions from metals in the X-ray band. Despite these intrinsic difficulties, I will show that the number of OVII systems detected down to the sensitivity threshold of our data, agrees well with numerical simulation predictions for the long-sought hot intergalactic medium, and its detection adds a fundamental tile to the long-standing missing baryon puzzle. Finally, I will comment on the implications of these new results for future high resolution X-ray missions.

Contribution: **T3** / Magnetic Confinement Fusion

Bolometer Developments in Diagnostics for Magnetic Confinement Fusion

H. Meister1, M. Bernert1, W. Biel2, L.C. Ingesson3, B.J. Peterson4, R. Reichle5, M.L. Reinke6, S. Schmitt7, D. Zhang8

1 Max-Planck-Institut für Plasmaphysik, Garching, Germany
2 Forschungszentrum Jülich, Jülich, Germany
3 Fusion for Energy, Barcelona, Spain
4 National Institute for Fusion Science, Toki, Japan
5 ITER Organisation, St. Paul-les-Durance, France
6 Oak Ridge National Laboratory, USA
7 Fraunhofer-IMM, Mainz, Germany
8 Max-Planck-Institut für Plasmaphysik, Greifswald, Germany

The plasma radiation is an essential part of the energy balance in current and future magnetic confinement fusion experiments and gives crucial insight for the challenges of power exhaust and divertor detachment as well as valuable information to understand plasma instabilities and transport effects. It is typically measured using various types of bolometers. Present day experimental devices, both the tokamak and stellarator, make use of metal resistor bolometers and IR video bolometers (IRVB), depending on the main focus of the respective measurement. The well-established sensor for absolutely calibrated measurements is the metal resistor bolometer. AXUV diodes, often used in conjunction with bolometers, are ideal for observing fast transient events in a plasma due to their very short response times, but their sensitivity varies significantly over the full radiation spectrum and degrades over time. In cases where many lines-of-sight are needed to observe radiation profiles in complex geometries IRVB offers the ability to integrate high channel counts in rather narrow installation volumes. These diagnostic concepts are presented as well as their pros and cons using examples of measurements from various devices like ASDEX Upgrade, JET, LHD and Wendelstein 7-X.

For future devices like ITER and DEMO, new developments are required to adapt sensors and diagnostic schemes to the harsh nuclear environment. An overview will be given over the activities for sensor development and integration challenges, which may also be relevant for long pulse operation in present experiments.

Contribution: **T4** / Beam Plasmas and Inertial Fusion

Optical diagnostics: femtosecond laser measurements of E fields and novel methods for temperature and pressure measurements with atomic and molecular

Richard Miles

Department of Aerospace Engineering, Texas A&M University
Department of Mechanical and Aerospace Engineering, Princeton University.

Understanding the detailed mechanisms associated with time varying nonequilibrium plasmas is of importance for controlled ignition of combusting gases, electric propulsion, chemical processing, flashlamp and laser operation, breakdown suppression, hypersonic flight and, increasingly, for medical applications. Studying the dynamics of these plasmas requires stand-off approaches since conventional probes cause significant perturbations. Local parameters of importance are the electron density and temperature, electric field, ionization and dissociation fractions, molecular vibrational, rotational and kinetic temperature. Several new laser based methods are now being developed to enable measurements of these parameters. For example, electric-field induced second harmonic generation (E-FISH)] is able to provide sub nanosecond time resolved measurement of the local electric field by focusing a short pulse (picosecond or femtosecond) laser to the measurement point and detecting the second harmonic light produced by the nonlinear interaction of the laser with the electric field and the ambient gas or plasma. Femtosecond laser driven two photon absorption laser induced fluorescence (TALIF) and resonant ionization followed by microwave scattering (Radar REMPI) are also effective approaches to the measurement of ions and dissociated species. With nanosecond pulsed frequency tunable lasers, atomic filters and molecular filters can be used to suppress background scattering and select for specific molecular species and energy states. For example, slow light imaging spectroscopy (SLIS) takes advantage of atomic resonant induced dispersion for imaging Raman scattering spectra through time delayed propagation of the selected spectral feature. With proper choice of filters and laser wavelength, pressure can also be measured. The presentation will focus on recently developed methods that are useful for the measurement of rapidly time varying, localized, partially ionized plasmas.

Contribution: **I1.1** / Low-Temperature and Industrial Plasmas

In situ and remote laser diagnostics for material characterization from plasma facing components to Cultural Heritage surfaces

Roberta Fantoni

ENEA – FSN-TECFIS C.R. Frascati, Via Enrico Fermi 45, 00044 Frascati, (Rome), Italy

Optical and spectroscopic techniques offer unique possibilities for non destructive or microdestructive characterization of surfaces, with widespread applications, starting from in-line monitoring of industrial processes. A significant group of industrial applications concerns nuclear grade material characterization and plasma diagnostics relevant to the thermonuclear fusion process. However, technologies and methodologies originally developed for specific in-vessel utilization, can easily find additional in-situ and remote application to environmental and cultural heritage diagnostics addressed to preventive conservation and restoration of surfaces. The development of fast laser scanners, started with IVVS (in-vessel viewing systems), in combination with sensitive CCD detector gave the chance to design and operate portable systems suitable to in situ an remote spectroscopic imaging. At ENEA Frascati different prototypes have been developed and patented to collected reflectance and fluorescence images excited at different ultraviolet and visible laser wavelengths, Raman and LIBS signals. Portable integrated instruments suitable for operation at different distances from a 1.5 to 30 m, have been assembled and operated in laboratory on multilayered samples and in field campaigns on CH painted surfaces. ILS (Integrated Laser System) prototype, realized for remote (LISB/RAMAN/LIF) within the European EDEN project, LIRA (LIBS/Raman) and CALIFFO (LIF) compact low cost instruments, both realized within the COBRA regional project will be presented. Results will be shown for LIBS stratigraphy in comparison with other spectroscopic laboratory techniques, and for LIF/Raman results obtained on historical pigments and modern consolidants in Etruscan tombs and Roman catacombs. Finally the experience gained in miniaturization of LIBS prototypes for in situ use was utilized to design a LIBS head operating from a robotic arm to investigate hydrogen isotope contamination inside fusion vessels during the maintenance procedure.

Contribution: **I1.2** / Beam Plasmas and Inertial Fusion

Development of plasma diagnostics in support of PETAL on LMJ laser facility. First preliminary PETAL experiments

D. RAFFESTIN 1, G. BOUTOUX 2, N. BLANCHOT 3, E. D’HUMIERES 1, I. LANTUEJOUL 2, B. VAUZOUR 2, Ch. REVERDIN 2, D. BATANI 1, V. TIKHONCHUK 1

1 Centre Laser Intenses et Applications, Université de Bordeaux-CNRS-CEA, UMR 5107, F-33405 TALENCE, France
2 CEA, DAM, DIF, F-91680 BRUYERES-LE CHATEL, France
3 CEA, DAM, CESTA, F-33116 LE BARP, France

The PETAPhys project, performed under of the auspice of the “cluster of excellence” LAPHIA of the University of Bordeaux, has provided a support to the commissioning phase of the PETAL laser operation. It was complementary to the Equipex project PETAL+, which delivers the major diagnostic equipment
Within the PETAPhys project, we have developed two simple and robust diagnostics The first diagnostic (Twist) is the optical imaging of the PETAL beam focal spot in the spectral range of the second and third harmonic radiation emitted from the target. The second diagnostic (CRACC X) is a hard X-ray spectrometer consisting in a stack of imaging plates (IP) and filters.
The Petal+ Equipex (funded by the French National Agency for Research, and coordinated by the Bordeaux University) has provided three spectrometry diagnostics for the characterization of the particles generated by PETAL experiments:

- SEPAGE, an inserted diagnostic, composed of two Thomson parabola.
- SPECTIX, an inserted diagnostic, composed of two Braggs crystals with high resolving power.
- SESAME, an electron and proton spectrometer based on a magnetic dipole at two different angles.

At the end of 2017, the first shots on target of the PETAL laser were performed on the LMJ facility. Laser energy ranged from 100 J to 450 J and pulse duration from 600 fs to 11 ps. These experiments aimed at the qualification of the plasma diagnostics and estimation of emission of X-rays, protons, electrons from targets irradiated with PETAL. All dedicated PETAL diagnostics were activated and successfully validated. Preliminary data, with a focus on PETAPhys diagnostics results, will be discussed.

Contribution: **I1.3** / Low-Temperature and Industrial Plasmas

Vacuum ultraviolet absorption spectroscopy of oxygen discharges

1) Jean-Paul Booth, Abhyuday Chatterjee, Olivier Guaitella, 2) Nelson de Oliveira, Laurant Nahon, 3) Sergey Zyryanov, Dmitry Lopaev, 4) Joao Santos Souza, 5) Colin Western

1) LPP-CNRS, Ecole Polytechnique, Palaiseau, France
2) Synchrotron Soleil, Gif sur Yvette, France
3) Lomonosov Moscow State University
4) LPGP, Universite Paris-Sud, France
5) School of Chemistry, University of Bristol, UK

Electrical discharges in oxygen gas are widespread in nature and occur in many plasma applications, including surface treatment and plasma medicine. They are also an ideal archetype for the understanding of molecular plasmas, showing the effects of dissociation/surface recombination, electron attachment, high densities of molecular and atomic metastable states, vibrational excitation and gas heating. Nevertheless, many uncertainties remain about the cross-section and reaction sets, as well as the surface processes, all essential for reliable modelling. We used the unique DESIRS vacuum ultraviolet beamline at synchrotron SOLEIL to perform absorption spectroscopy in the 120-200nm range. Measurements were made in a DC positive column in pure O2. This provides a uniform plasma column with constant reduced field over a wide range of gas pressure and electron density (pressure 0.2-10 Torr, current 5-40 mA), ideal for model validation.

The Fourier-Transform branch was used to record absorption spectra with a resolution of 106, giving complete high-resolution spectra of O2 in the X, a and b states. The absorption cross-sections of O2 X and a are known, allowing absolute densities to be determined. Using a combination of ab-initio calculations and absolute emission spectrometry, we derived the first absolute absorption cross-sections of O2 b, and thus the absolute density of this state.

Using the monochromatic branch of the VUV beamline we performed time-resolved measurements of O2 X and a during full and partial modulation of the discharge current, probing their creation and loss kinetics in the gas phase and on the tube surface. The recovery of the O2 X density in the afterglow shows components with distinct time constants, allowing the O atom and O2 a absolute densities to be calibrated.

Measurements were also performed in a low-pressure (10-50 mTorr) ICP discharge, giving the absolute O2 X, a and b densities as a function of pressure and RF power, allowing recent speculation on the role of metastable states in negative ion destruction to be tested.

Contribution: **I1.4** / Magnetic Confinement Fusion

Imaging Neutral Particle Analyzer Measurements of the Confined Fast Ion Profile and Instability Induced Transport in DIII-D

M.A. Van Zeeland^1, X.D. Du^1, C.S. Collins^1, D. Su^1, W.W. Heidbrink^2

1. General Atomics
2. Univ. of California - Irvine

A new imaging neutral particle analyzer (INPA), which provides unprecedented energy-resolved radial profiles of confined fast ions, has been fielded on the DIII-D tokamak[1]. The INPA is an imaging based, neutral particle analyzer (NPA) diagnostic which measures escaping fast ions that have undergone charge exchange events with a DIII-D neutral beam. The INPA replaces the detector of conventional NPAs with a phosphor scintillator-based detector similar to those used in fast ion loss detectors worldwide. This new wide field-of-view imaging NPA economically provides far more spatial coverage than a conventional NPA, while simultaneously providing comparable energy resolution. The INPA measures charge-exchanged energetic neutrals by viewing an “active” neutral beam through a 1D pinhole camera with a rear collimating slit that defines the neutral particle collection sightlines. The incident neutrals are ionized by stripping foils and the local tokamak magnetic field acts as a magnetic spectrometer to disperse ions on the scintillator. A fast camera provides 2D images of the escaping neutrals mapped to energy and radial position in the plasma. Forward modeling, taking account of instrumental weight and classical beam ion scattering and slowing down distribution function, are in reasonable agreement with INPA images in MHD quiescent plasmas. Conversely, when fast ion-driven instabilities are present, the measured images deviate from classical predictions. Tomographic inversion of the INPA images is also possible and allows estimates of the actual fast ion distribution function at the measured pitch angle.

The local phase space measurements enabled by the INPA are ideally suited to studies of instability-induced fast ion transport, and recent data clearly show transport due to Alfven eigenmodes. Measurements in reversed magnetic shear experiments have revealed large preferential transport of different orbit classes at nearby radii, something that would be impossible to distinguish with fast ion diagnostics that weight broad regions of phase space such as fast ion D-alpha (FIDA) or neutron emission. The 10^4 probed phase space positions also enable, for the first time, measurements of fast ion flow induced by instabilities. INPA data show a large net outflow across the plasma midplane during strong AE activity while at lower amplitude, redistribution occurs from the core to larger radii.

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Contribution: **I1.5** / Magnetic Confinement Fusion

Versatility and Flexibility of the Tracer-Encapsulated Solid Pellet as a Diagnostic Tool in Magnetic Fusion Plasmas

N. Tamura^1, 2, K.J. McCarthy^3, R. Bussiahn^4, the TJ-II Team^3, the W7-X Team^4, the LHD Experiment Group^1

1 National Institute for Fusion Science, National Institutes of Natural Sciences, Toki, Japan,
2 SOKENDAI (The Graduate University for Advanced Studies), Toki, Japan,
3 Laboratorio Nacional de Fusión, CIEMAT, Madrid, Spain,
4 Max-Planck-Institut für Plasmaphysik, Greifswald, Germany

A tracer-encapsulated solid pellet (TESPEL) has been originally developed in NIFS, Japan to promote the study of impurity transport in magnetically-confined high-temperature plasmas. Recently the TESPEL technique has come into use in various fusion devices, such as TJ-II, DIII-D, and W7-X (also been scheduled in RFX-mod2). The TESPEL consists of polystyrene as an outer shell (typical outer dia.: 0.3 - 0.9 mm) and of specific material as a tracer (typically the order of 1E17 particles) in the core. Owing to its structure, the TESPEL can provide a 3D-localized source of the impurity in the confined plasmas. Through the experiment with the TESPEL, it is found that the TESPEL can be utilized for a variety of diagnostic purposes. By an adjustment of the TESPEL size (for reducing a density perturbation amplitude), a transient heat transport study can be performed by using a cold pulse invoked by the TESPEL injection. Especially, a tiny TESPEL can provide an opportunity for studying the transport of heat and impurity inside a magnetic island. Also, by an adjustment of the TESPEL size (for matching the electron amount with a hydrogen pellet) and sharing of the guiding tubes, a detailed and precise comparative study of the ablation physics between a hydrogen ice pellet and the TESPEL (polystyrene pellet) can be performed. Since tiny impurity particles are loaded into the core of the TESPEL, the TESPEL loaded with a multiple-impurity is also possible, which allows us to study the Z-dependence of impurity transport with a single TESPEL injection. The TESPEL loaded with a variety of elements is utilized also for the spectroscopic study on an atomic and molecular physics. In this invited talk, the unique achievements obtained with the TESPEL will be reviewed and future possibilities of the TESPEL as a diagnostic tool will be discussed.

Contribution: **I2.1** / Beam Plasmas and Inertial Fusion

X-ray temporal and spatial diagnosis technology in ShenGuang laser facilities

Feng Wang 1, Xing Zhang 1, Zhurong Cao 1, Xin Hu 1, Zhenghua Yang 1, Zheng Yuan 1, Deng Bo 1, Jin Li 1, Wenyong Miao 1, Jiyan Zhang 1, Jianjun Dong 1, Yongkun Ding 2, Baozhong Mu 3, Jiamin Yang 1, Shaoen Jiang 1, Baohan Zhang

1 Research Center of Laser Fusion, China Academy of Engineering Physics, Mianyang 621900, China;
2 Institue of Applied Physics and Computational Mathematics, Beijing 100094, China;
3 Key Library of Advanced Micro-structure Materials, Tongji University, Shanghai 200092, China;

At present, a relatively complete diagnostic platform for ICF physics has been established on the ShenGuang laser facilities. This report will focus on the development of universal X-ray framing camera, high sensitivity X-ray framing camera and pulse broadening X-ray framing camera on ShenGuang laser facilities. The key technologies of pulse width X-ray framing camera are introduced. The advantages and disadvantages of drift tube with hCOMS and MCP are analyzed. At the same time, the calibration and experimental results of Kirkpatrick-Baez microscope are introduced. The key technologies of Wolter microscope are analyzed, and the problems affecting imaging resolution and depth of field are analyzed in detail. At the same time, a new transmission bandpass technology is introduced. The advantages of the technology are introduced from the basic principles, calibration results and experimental results.

Contribution: **I2.2** / Beam Plasmas and Inertial Fusion

X-Ray Diagnostics and Analysis of Inertial Confinement Fusion Implosions on the National Ignition Facility

Ahtur Pak

Lawrence Livermore National Laboratory

Indirect-drive Inertial Confinement Fusion (ICF) implosions on the National Ignition Facility at the Lawrence Livermore National Laboratory in the US have demonstrated record performance, including hot spot pressures of ~360 Gbar, and yield amplifications of 3x due to alpha-particle self-heating. Work continues toward the goal of ignition by identifying and understanding the principal performance degradation mechanisms to improve the quality of the implosions. Recent experiments have examined the effect of the size of the fuel fill tube on the magnitude of hydrodynamic mix, laser imbalances on the low mode implosion asymmetry, potential x-ray drive losses from hohlraum windows, and the scale of the capsule and hohlraum on overall performance. X-Ray diagnostics ranging from time-resolved and time-integrated imagers and spectrometers to x-ray backlit radiography provide a high-fidelity set of detailed data throughout the implosion history. This talk will discuss the suite of x-ray instruments in use on the NIF, the innovative analysis techniques being applied, and the integration of the x-ray data with modeling and simulations to drive progress in ICF.

Contribution: **I2.3** / Magnetic Confinement Fusion

Real-time Control of Plasma Parameters with Measurements by Faraday-effect Polarimetry On EAST tokamak

H.Q. Liu, L.Q. Hu and EAST diagnostics team

Institute of Plasma Physics, Chinese Academy of Sciences

A primary goal for ITER and prospective fusion power reactors is to achieve long-pulse, steady-state burning plasmas. Realtime control of plasma parameters such as current profile, density profile, position, shape is necessary to extend high-performance plasma regimes to long pulse (while avoiding disruptions) and is required for development of ITER-like discharge scenarios. A double-pass, radially-view, 11 chord, POlarimeter-INTerferometer (POINT) system has been developed and routinely operated on the EAST Tokamak, and provides important plasma current profile, plasma density profile and the vertical position information for plasma control and physics understanding. Digital Phase Detection, which provides real-time 4 ƒÝs Faraday and density output for plasma control, has been developed. With improved optical arrangement, the impact of unwanted light on the Faraday rotation measurements was reduced to 0.5¢Xfor the POINT system [3].

The real-time plasma density profile and current profile reconstruction with POINT diagnostic for EAST plasma control is developed. Plasma current profile reconstruction algorithms using POINT measurements and GPU parallel computation implementation in GPU parallel equilibrium reconstruction code P-EFIT are presented. Real-time POINT diagnostic data acquisition system is designed to satisfy the requirement for real-time reconstruction. The static time-slice and experimental simulation benchmark calculations using experimental magnetic plus POINT data of EAST discharge are conducted, which show that P-EFIT could provide reasonable electron density, plasma current and q profile per 0.7ms in real-time with 65¡Ñ65 spatial grid resolution. These results show that P-EFIT with POINT diagnostic could provide equilibrium reconstruction results for real-time plasma density, plasma current and q profile control which will be applied in the near future.

The vertical position for elongated plasma has to be precisely controlled to optimize performance and prevent disruptions. For a steady-state tokamak reactor (discharge length more than a week), integration of voltage signals arising from flux change is extremely challenging due to zero-offset drift as the measurement is intrinsically inductive. Horizontally-viewing chords at/near the midplane allow us to determine plasma vertical position non-inductively with subcentimeter spatial resolution and time response up to 4 ƒÝs. The polarimeter-based position measurement, which does not require equilibrium reconstruction, is benchmarked against conventional flux loop measurements for short pulse discharges. Its fast time response allows for direct feedback on plasma vertical displacement instabilities.

Above of all, the real-time control of plasma parameters with measurements by POINT on EAST are very promising for future steady-state plasms.

References

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Contribution: **I3.1** / Basic and Astrophysical Plasmas

The impact of improved plasma diagnostics on modeling the X-ray Universe

Junjie Mao

University of Strathclyde
SRON Netherlands Institute for Space Research

Benchmarking astrophysical collisional ionized plasma models with the high-resolution X-ray observations of Perseus galaxy cluster with Hitomi shows that accurate atomic data and plasma models are crucial to for diagnostics of temperature, emission measure, abundance, etc. Although Hitomi spun out of control, several Hitomi-level missions have been proposed and some funded. Here we present a few cases on the improvement of plasma diagnostics on modeling the spectra of X-ray emitting celestial bodies. We focus on collisional ionized and photoionized astrophysical plasmas in the context of current and future X-ray observatories.

Contribution: **I3.2** / Magnetic Confinement Fusion

High rate neutron and gamma ray spectroscopy of magnetic confinement fusion plasmas

M. Tardocchi

Istituto di Fisica del Plasma, CNR, Milan, Italy

This work will address the recent development that has been carried out within the EUROFUSION programme for the forthcoming JET DT campaign. The focus is on the development of compact neutron and gamma-ray spectrometers which combine very high energy resolution and MHz counting rate capabilities and can be used in multi sight-line camera configuration.

A new compact neutron spectrometer based on single crystal diamond detectors has been developed and installed at JET for measurements of the 14 MeV neutron spectrum. The neutron spectrometer is based on a matrix of 12 CVD Single-crystal Diamond pixels and features fast response and compact size. Measurements on a portable DT neutron generator have shown that neutron spectroscopy of the accelerated beam ions at unprecedented energy resolution (~1% at 14 MeV) is possible, which opens up new opportunities for diagnosing DT plasmas.

The talk will also illustrate the recent development of two new neutron spectrometers based on SiC and CLIC scintillator, for 14 MeV and 2.5 MeV neutrons, respectively. SiC offers an even higher resistance to neutron damage than diamonds while the CLIC scintillator opens new opportunities for neutron spectroscopy of D plasmas.

For what concerns gamma ray measurements, the JET gamma ray camera has been recently upgraded with the dual aim to improve the spectroscopic and rate capabilities of the detectors. A new compact spectrometers based on a LaBr3 scintillator coupled to Silicon Photomultiplier has been developed for gamma ray spectroscopy in the MeV energy range and at MHz counting rates. The upgraded system will reconstruct along 19 line of views into the plasma the spatial gamma ray emissivity from the plasma. This includes measurements of gamma rays produced by the interaction of fast ions with beryllium plasma impurities as well of the 4.5 MeV gamma rays from the reaction 9Be(alpha,n)12C.

Phase-enhanced x-ray radiography for dense plasma studies

L. Antonelli 1, F. Barbato 2, D. Mancelli 2, J. Trela 2, G Zeraouli 3, G. Boutoux 2, P. Neumayer 4, s. Atzeni 5, A. Schiavi 5, L. Volpe 3, V. Bagnoud 4 , C. Brabetz 4 , B. Zielbauer 4, P. Bradford 1 , N. Woolsey 1 , B. Borm 6 and D. Batani 2

1)University of York, York, UK
2)Université de Bordeaux, Talence, France
3)CLPU,Salamanca, Spain
4)GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany
5)Universita' degli studi di Roma "La Sapienza", Rome, Italy
6) Goethe-Universität Frankfurt, Frankfurt am Main, Germany

X-ray phase-contrast imaging (XPCI) is a radiography technique that utilises the phase-shift in a spatially coherent x-ray beam to form an image. The technique is established biology and medicine, and with the development advanced x-ray sources such as x-ray free electron lasers applications extending to other research fields. We discuss the development of XPCI on high energy laser systems and the application of this form of radiography to the study of shock waves. Here the x-ray source results from broadband bremsstrahlung emission driven by an intense optical laser striking a small wire. We describe how by controlling the spectrum and size of the source with appropriate positioning of the target and detector it is possible to achieve spatial coherence to obtain phase enhanced radiographs of static objects and dynamic processes. We highlight the power of phase contrast approach through a comparison between standard absorption and phase-contrast radiography. In fact, we find the best outcomes are obtained when combining both techniques in a single measurement.
Our shockwave results, taken on the high intensity laser PHELiX at GSI, Germany, are interpreted using two-dimensional radiation hydrodynamic simulations and a bespoke three-dimensional XPCI synthetic diagnostic. By comparing the numerical XPCI, absorption and combine XPCI-absorption radiographs with measurement we are able to learn more about the laser-interaction physics and shock. This proof-of-principle experiment illustrates the power of XPCI and its potential for use on existing laser-plasma facilities at all scales. We outline our plans to move this technique to OMEGA EP.

Contribution: **I3.4** / Low-Temperature and Industrial Plasmas

Fluorescence measurements of atomic species in discharges and flames

P. Dvořák, A. Obrusník, M. Talába, M. Mrkvičková, J. Kratzer, V. , Procházka, J. Dědina

Masaryk University, Faculty of Science, Brno, Czech Rep. (Dvořák, Obrusník, Talába, Mrkvičková, Procházka),
Institute of Analytical Chemistry of the CAS, v.v.i., Brno, Czech Rep. (Kratzer, Dědina)

Laser-induced fluorescence (LIF) and numerical modeling were used for study of reactive radical species in atmospheric pressure DBDs and flames that are used for atomization of molecular species for purposes of analytical atomic spectroscopy. Neutral radical species play the key role in plasmachemical reactions, e.g. in decomposition of molecules including volatile hydrides that are used as gaseous forms of investigated elements in so-called atomizers.
Here, in a plasma or in a flame, the molecules are atomized and generated free atoms can be detected by means of absorption or fluorescence.

In order to understand the atomization process, the spatial distribution of key radicals (H, O, OH) as well as free atoms of elements to be determined (e.g. Pb)
was studied by means of LIF, which required to solve problems of partial LIF saturation and laser-surface interactions.
In case of the atomizer based on an atmospheric-pressure DBD ignited in Ar + H2 mixture it was observed that concentration of atomic hydrogen reaches 10^21 m^-3, which is by several orders of magnitude higher than the typical concentration of atomized elements.
It was observed that the atomic hydrogen concentration correlates with the observed sensitivity of the atomizer. These facts confirm the theory that the key processes responsible for atomization of hydrides in DBDs are reactions of hydride molecules with atomic hydrogen.
When oxygen was added to the gas mixture, two zones with opposite educing/oxidizing character arose in the DBD.

The plasma chemistry and gas flow was simulated numerically. The simulation results agreed with LIF measurements. It has shown which reactions are responsible for the generation of studied radicals and it has revealed the effect of gas flow on the distribution of reactive radicals.

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Contribution: **I4.1** / Low-Temperature and Industrial Plasmas

EUV-induced microplasmas, created in atomic and molecular gases

A. Bartnik, W. Skrzeczanowski, H. Fiedorowicz, P. Wachulak, T.Fok, L. Wegrzynski

Institute of Optoelectronics, Military University of Technology, Warsaw, Poland

In this work investigations low temperature plasmas, induced in atomic and molecular gases of near atmospheric density, by intense pulses of extreme ultraviolet (EUV), were performed. Various laser-produced plasma (LPP) EUV sources, based on nanosecond laser systems, were employed for creation of such plasmas. The sources were equipped with the reflective EUV collectors for focusing of the radiation onto the gas to be ionized or the gas was injected in the vicinity of the LPP. Reflective collectors were also used in detection systems employed for temporal measurements of the EUV emission from the low temperature PP.
Microplasmas of high electron density were investigated using spectral methods in EUV and optical ranges. Spectra in the EUV range were measured using a grazing incidence, flat-field spectrograph (McPherson Model 251), equipped with a 450 lines/mm toroidal grating. The UV/VIS spectra were measured using an Echelle Spectra Analyzer ESA 4000. The spectra were composed of spectral lines corresponding to radiative transitions in atoms, molecules, atomic or molecular ions. For analysis of the EUV spectra numerical simulations were performed, using a collisional-radiative PrismSPECT code. Parameters of the EUV induced plasmas were estimated by fitting the spectrum obtained from the simulations to the experimental one. For computer simulations of the molecular spectra measured in the UV/VIS range, Specair or LIFBASE codes were employed. Apart from that, the electron temperatures of plasmas created in different gases were estimated employing a Boltzmann plot method. Electron density was estimated based on the Stark broadening.

Contribution: **I4.1** / Low-Temperature and Industrial Plasmas

N2/O2 single streamer discharge studies by OPO based TALIF and LIF diagnostics

Paolo F. Ambrico 1, Martina Mrkvickova 2, Marianna Ambrico 1, Milan Simek 1,3

1. PlasmiLab@CNR Nanotec, Bari, Italy
2. Masaryk University, Brno, Czech Republic
3. CAS IPP, Prague, Czech Republic

A streamer is a form of transient discharge which develops from an electron avalanche in an overvolted gap with high propagation velocity, small streamer channel radius, and high density of free. Laboratory streamers are extremely difficult to observe. By acquiring kinetics series of ICCD images and spectra streamer formation and propagation were captured with a time resolution of 50ps and micrometric spatial resolution. Imaging and emission is a valid means of investigation in this phase. On a longer timescale, the kinetics processes initiated by the streamer discharge are developing. Species produce by streamer impact in N2/O2 mixtures are several. Recently, we investigated the temporal evolution of N2(A) metastable produced by single triggered nitrogen streamer employing nanosecond OPO LIF and emission diagnostics simultaneously and finding evidence that maximum density of N2(A) metastable species occurs in microsecond timescale during the streamer channel decay. Among the produced species atomic oxygen is influencing the kinetics of nonequilibrium discharges. It is a precursor for the ozone formation and formation of NxOy species. The channels for O atom formation are dissociation of oxygen molecule by direct electron impact and by N2(A) metastable. O atom production in nanosecond streamer discharge should be expected so to happen in different time scales. Detection can be accomplished by TALIF. A standard system usually employs narrow line tunable nanosecond dye lasers. Recently TALIF with broadband femtosecond lasers were used to determine space- and time-resolved atomic-oxygen distributions in a nanosecond discharge. We propose an alternative way to detect O atoms through TALIF using nanosecond broadband OPO laser. This is an attractive solution because of the simplicity of the use of commercial OPO lasers. Due to the wide tuning range of OPO associated with non-linear crystals laser setup the detection of N2(A), NO, OH with a single laser optical setup can be accomplished.

Contribution: **I4.2** / Low-Temperature and Industrial Plasmas

Cavity enhanced laser spectroscopy of oxidation chemistry in atmospheric pressure plasmas

Professor Grant Ritchie

Department of Chemistry, Physical and Theoretical Chemistry Laboratory, University of Oxford, South Parks Road, Oxford, OX1 3QZ

Radicals are ubiquitous in both the ambient atmosphere and atmospheric pressure plasmas and are intimately linked to the oxidising capacity of these environments. As such, there is widespread interest in the quantitative detection of these species. In this presentation I will describe several laser based cavity enhanced techniques with the necessary capabilities for probing small levels of transient species; these include optical feedback cavity enhanced absorption spectroscopy[1] and Faraday rotation spectroscopy[2],[3]. Example data on the detection of peroxy radical (RO_2) species are presented: HO_2 in particular has been highlighted as an important intermediate[4], implicated in the production of reactive oxygen species in cold atmospheric plasma sources, and is integral to the complex chemical network which generates hydrogen peroxide as one of the by-products.

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Contribution: **I4.3** / Basic and Astrophysical Plasmas

Multidiagnostics setups for Magnetoplasmas devoted to Astrophysics and Nuclear Astrophysics Research in Compact Traps

E. Naselli (a,b), D. Mascali (a), S. Biri (c), C. Caliri (a), G. Castro (a), L. Celona (a), L.G. Cosentino (a), A. Galatà (d), S. Gammino (a), M. Giarrusso (a), F. Leone (b,e,a), M. Mazzaglia (a), R. Rácz (c), R. Reitano (a,b), F.P. Romano (a,f), G. Torrisi (a)

(a) Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud (INFN-LNS), Catania, Italy
(b) Department of Physics and Astronomy, University of Catania, Catania, Italy
(c) Institute for Nuclear Research, Hungarian Academy of Sciences, Debrecen, Hungary
(d) Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali di Legnaro (INFN-LNL), Legnaro, Italy
(e) Istituto Nazionale di Astrofisica (INAF) - Osservatorio Astrofisico di Catania, Catania, Italy
(f) CNR - Istituto per i Beni Archeologici e Monumentali, Catania, Italy

Magnetized plasmas in compact trap may become experimental environments for the investigation of nuclear beta-decays of astrophysical interest. In the framework of the project PANDORA (Plasmas for Astrophysics, Nuclear Decays Observation and Radiation for Archaeometry) the research activities are devoted to demonstrate the feasibility of an experiment aiming at correlating radionuclides lifetimes to the in-plasma ions charge state distribution (CSD). The paper describes the multidiagnostics setup now available at INFN-LNS, which allows unprecedented investigations of magnetoplasma properties in terms of density, temperature and CSD. The developed setup includes an interfero-polarimeter for total plasma density measurements, a multi-X-ray detectors system for X-ray spectroscopy (including time resolved spectroscopy), a X-ray pin-hole camera for high-resolution 2D space resolved spectroscopy and different spectrometers for the plasma-emitted visible light characterization. A description of recent results about plasma parameters characterization in quiescent and turbulent Electron Cyclotron Resonance-heated plasmas will be given. A complete characterization has been already performed, studying, in particular, the time evolution of X-ray spectra and the change of plasma morphology, including the balance between radiation originated in the plasma core and the one due to plasma losses. Finally, the experimental setup is going to be further upgraded in order to allow measurements of nuclear decays in magnetoplasmas.

Contribution: **I4.4** / Basic and Astrophysical Plasmas

TES detectors applications for scientific instruments in space and ground

P. Bastia

Thales Alenia Space Italia S.p.A.

Transition Edge Sensors (TES) technology is among the most mature within the various Low Temperature Devices. These versatile devices can be used both as microcalorimeters or bolometers and tailored to different types of radiation by proper selection of the absorber layer materials and geometry.
These sensors are designed and produced almost routinely in many laboratories with a good yield of devices reaching the design goals.
The co-developing readout electronics for these TES systems, based on SQUID with various multiplexing schemes (time domain, frequency domain, code domain), is improving with each new instrument design and is foreseeable that instruments in the thousand pixel organization are within reach in the next few years allowing the development of a new generation of spectroscopic/imaging instruments.
In general the current performances of TES-based systems potentially allow to disclose new scenarios in the field of spectroscopy also for laboratory applications.
The talk will present a brief review of the TES detectors characteristics from the system engineering point of view followed by a panorama of current development for their applications in space and on ground.

Contribution: **F1** / Faenov Memorial Session

Progress in X-ray spectroscopy and imaging diagnostics for high energy density studies with lasers.

S.A. Pikuz, I.Yu. Skobelev, T.A. Pikuz, D. Batani, R. Kodama, V.E. Fortov

Joint Institute for High Temperatures, Russian Academy of Science, Moscow 125412, Russia
National Research Nuclear University MEPhI, Moscow 115409, Russia
Open and Transdisciplinary Research Initiatives, Osфka University, Suita, Osaka 565-0871, Japan
CELIA University of Bordeaux CNRS/CEA, UMR 5107 F-33405 Talence, France

Since the studies on hot dense plasma have been encouraged as a promising way to controlled fusion and to address fundamental properties of matter under extreme conditions, the progress in the field has been always linked with the development of appropriate diagnostic approaches and techniques. X-ray spectroscopy and imaging methods prove their capabilities starting from early ICF experiments with kJ ns lasers till nowadays complex experiments on various aspects in high energy density studies.

Particularly, the introduction of spectrometers and imaging schemes equipped with spherically bent crystals remarkably extend the performance of X-ray imaging spectroscopy. The methods to analyze the emission of multicharged ions in a dense plasma has been developed considering resonance spectral line intensities, line profiles, sattelite structures, exotic states emission etc. They were successfully applied in over 500 HED experiments with high power and high-intensity lasers, heavy ion beams, ion traps, X-ray lasers.

Recent achievements in X-ray diagnostics for HED experiments are overviewed considering:

- generation of ultra-intense X-rays in PW laser plasma and the matter states with radiation dominated kinetics;
- charge particle acceleration and intense EM field generation in the interaction of relativistic laser pulses with solids, nanograin and cluster targets;
- supersonic plasma flows and shock waves related to astrophysical phenomena;
- warm dense matter isochorically heated by laser-generated electrons.

The talk is given to commemorate the immense contribution of our colleague and brilliant scientist Anatoly Faenov, who will be in our minds and souls forever.

Contribution: **F2** / Faenov Memorial Session

Relativistic laser plasma of gas cluster targets - particle and X-ray diagnostics

Yuji Fukuda

Kansai Photon Science Institute (KPSI), National Institutes for Quantum and Radiological Science and Technology (QST)

A review of our memorable experimental studies on generation of bright X rays and high energy particles in micron-size cluster targets irradiated by intense, femtosecond laser pulses is presented.

Firstly, the time integrated high-resolution K-shell spectra of a plasma created by femtosecond, superintense laser irradiation of micron-size rare-gas (Ar, Kr, Xe) clusters were measured and analyzed by the Boltzmann equation and a detailed collisional radiative model as a function of time. In addition, the role of hollow atoms in the spectra was investigated.

Secondly, using intense soft x-ray emissions from micron-size CO_2 clusters irradiated by femtosecond laser pulses, nanostructure images of 100-nm-thick foils in a wide field of view mm^2 scale with high spatial resolution 800 nm were obtained with high dynamic range LiF crystal detectors.

Thirdly, the plasma condition in ion acceleration during the formation of a strong dipole vortex structure in subcritical density plasmas created from micron-size CO_2 clusters irradiated by femtosecond laser pulses was verified by measuring soft x-ray spectra of the He and Ly lines of oxygen.

Finally, the nonlinear phenomenon of the generation of the second harmonic of the laser frequency in a femtosecond laser-driven cluster-based plasma was investigated by analyzing satellites of spectral lines of Ar XVII followed by the 2D PIC simulations.

Contribution: **F3** / Faenov Memorial Session

X-ray imaging of bio/medical samples using laser-plasma-based X-ray sources and LiF detector

a) Francesco Flora, S. Almaviva, G. Baldacchini, S. Bollanti, F. Bonfigli, P. Di Lazzaro, M. Francucci, A. Lai, L. Mezi, R.M. Montereali, D. Murra, E. Nichelatti, A. Rydzi, M.A. Vincenti, b) T. Pikuz, c) L. Reale, d) A. Reale, L. Palladino, A. Ritucci, A. Poma, A. Scafati, G. Tomassetti, P. Zuppella, e) M. Richetta, P. Gaudio, f) D. Batani

a) ENEA, Frascati Research Center, Via E. Fermi 45, 00044 Frascati, Italy
b) Osaka University, 2-6 Yamadaoka, Suita, Osaka, 565-0871, Japan
c) Campus Bio-Medico University, Via Álvaro del Portillo 200, 00128 Roma, Italy
d) University of L'Aquila, Coppito, 67010 L'Aquila, Italy
e) Tor Vergata University, Engineering Dept., Via Cracovia 50, 00133 Roma, Italy
f) Université de Bordeaux, CELIA Lab., 351 Course de la Libération, 33405 Talence cedex, France

During a period of approximately thirteen years 1994-2006, Anatoly Faenov and his wife Tatiana Pikuz, accepting the frequent invitations of the Italian Institute of Nuclear Physics (INFN) and of ENEA, cooperated with many italian research laboratories dedicated to EUV and soft X-ray generation, spread in different towns of Italy (L'Aquila, Milano, Padova, Pisa, Roma, etc.).
In spite of the fact that in this period Anatoly and his wife could stay in Italy only about one or two months per year, their activity has been so intense that more than 50 peered reviewed publications have been generated from their experimental and theoretical work (just considering only the results obtained at L'Aquila and Tor Vergata -Rome- Universities and at the ENEA Research Center of Frascati), without mentioning the cultural atmosphere that they stimulated in the field of Science and Humanity.
The numerous experimental spectra obtained at ENEA by their spherically bent mica spectrometers, used in many experiments in the world, together with the corresponding theoretical simulations performed in Moscow, allowed to study the changing role of different excitations mechanisms for various plasma conditions, and to characterize at best the ENEA laser-plasma source and to optimize it for different applications: polychromatic and monochromatic micro-radiography of dried biological samples at 1 keV, soft X-ray contact microscopy (SXCM) of living cells in the water-window spectral region, studies of DNA exposure to soft X-rays, spectroscopy of hollow atoms, etc.
In this memorial presentation, the main results of biological samples imaging on lithium fluoride (LiF) detectors, obtained with the ENEA and Tor Vergata University laser-plasma sources, will be presented. In particular, the improvement of the micro-radiography and of the SXCM techniques when moving from photoresist detectors and photographic films to LiF detectors will be illustrated and discussed, for both dried and wet biological samples.

Contribution: **F4** / Beam Plasmas and Inertial Fusion

Overview on heavy ion beam plasma research with respect to Accelerator Driven High Energy Density Science -Perspectives at HIAF (China) and FAIR (Ge

D.H.H. Hoffmann1,2, Yongtao Zhao1,3,Peter Katrick4, and M.Schanz4

1)Xi'An Jiaotong University, School of Science, Xi'An, China
2) National Research Nuclear University "MEPhI", Moscow
3) Institute of Modern Physics, CAS, Lanzhou, China
4) Helmholtzzentrum GSI-Darmstadt, Germany

High Energy Density Physics (HEDP) with intense heavy ion beams is a complementary tool to induce extreme states of matter. The development of this field connects intimately to the advances in accelerator physics and technology.
At Xi'An Jiaotong University we are starting a group that will build a low energy, high current ion beam facility for basic beam plasma interaction physics and will make use of existing machines at the Gesellschaft für Schwerionenforschung (GSI-Darmstadt), the Institute of Theoretical and Experimental Physics in Moscow (ITEP-Moscow), and the Institute of Modern Physics (IMP-Lanzhou). In this presentation we will discuss the perspectives of High Energy Density Physics at the facilities under construction and partial operation. These are GSI-FAIR in Germany and the High Intensity Accelerator Facility (HIAF) in China.
High intensity particle accelerators like FAIR at GSI Darmstadt and the proposed HIAF facility in China are a new tools to induce High Energy Density states in matter. We will address a topic that has until now not been investigated in detail but is paramount to the operation of high intensity accelerators as drivers for inertial fusion or high energy density physics experiments. This is the
investigation of activation processes of structural components of heavy ion accelerators due to beam loss during operation. This is a crucial issue to optimize the choice of construction materials and maintenance procedures. Significant optimization of the operation schedule can be achieved if the accumulated residual activity is properly controlled and predicted. Radiation may cause changes of the functional properties of the construction materials, which possibly leads to shortening of their lifetime. Replacing of the activated accelerator components is affected by dose-rate restrictions for the "hands-on" maintenance. Handling and final disposal of the accelerator parts after several years of usage is also an important issue directly related to the activation.
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Contribution: **F5** / Faenov Memorial Session

X-ray diagnostics in Laboratory Astrophysics

M. Koenig et al.

1 LULI - CNRS, École Polytechnique, CEA, Université Paris-Saclay, UPMC Univ Paris 06 : Sorbonne Universités -F-91128 Palaiseau cedex, FRANCE
2 Graduate School of Engineering, Osaka University, Suita, Osaka, JAPAN

Keywords: Laboratory Astrophysics, Planetary physics, radiative hydrodynamics, x-ray diagnostic

ABSTRACT.
For more than two decades, we have performed laboratory experiments in connection with astrophysical phenomena or object. Two main topics will be presented: planetary physics and radiative hydrodynamics.
Great progress has been obtained, in the last two decades, measuring equations of state of matter in extreme states and their application to planetary physics. In this context, we present a dedicated diagnostic we developed with A. Faenov a few years ago performing x-ray radiograph with high spatial resolution using a bent crystal (1,2). The experimental data were obtained on the LULI2000 laser facility.
In order to improve our understanding in the field of radiation hydrodynamics, and to validate numerical schemes and assumptions in simulations, we performed hydrodynamics instabilities (RTI) experiments related to supernovae remnants interacting with ISM where they play a major role. Again x-ray radiograph is a key diagnostic, and to overcome spatial resolution (25 µm) at best in laser experiments, we used a new detector as proposed by A. Faenov and T. Pikuz: LiF. I will present the recent data obtained both on LULI2000 and the Japanese XFEL (SACLA) (3)

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Contribution: **F6** / Faenov Memorial Session

X-ray emission from autoionizing states : dielectronic satellites and hollow ions

F.B. Rosmej

Sorbonne University, Faculty of Science
LULI, Ecole Polytechnique

Anatoly Faenov has devoted an important part of his live to the exploration of the X-ray emission of highly charged ions and his very early review [1] became a milestone for generations of scientists. Among many different activities, he explored the X-ray emission from autoionizing states (so-called dielectronic satellite emission [2]) and this became a world wide appreciated and recognized activity for the dense plasma community [1].
The present talk will provide an introductory overview about the dielectronic satellite emission including the important discovery of the effective disappearance of resonance line emission in dense strongly coupled plasmas and its replacement by dielectronic satellite emission [3-6]. The talk will likewise provide an introductory overview about the rapidly growing field of hollow ion X-ray emission in laser produced plasmas [7,8], its correlation to high intensity radiation fields in PW laser produced plasmas [9] and XFEL interaction with matter [10].
We are all grateful to Anatoly Faenov for what he has done for the science, we are grateful to his inventions and discoveries that will certainly impact future generations of scientists. In this spirit the talk will finish with an outlook to the challenging perspectives in X-ray spectroscopy [11,12] that confirms Anatoly's saying: "You never can exhaust satellite transitions".

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Contribution: **F7** / Faenov Memorial Session

Advanced non-LTE radiation kinetics modeling in ATOMIC

1 J. Abdallah, Jr., J. Colgan, M.E. Sherrill and D.P. Kilcrease, 2 C. J. Fontes and P. Hakel

1 Theoretical Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA
2 Theoretical Computational Physics Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

Several applications of the atomic physics and kinetics code (ATOMIC) developed at Los Alamos over the last few decades will be discussed. A brief overview of the codes will be presented.
Modeling calculations using ATOMIC to simulate for high-spectral resolution spectra, resulting form experiments with the petawatt lasers at large intensities using thin foil targets will be presented. Under these conditions strong x-ray radiation of KK hollow atoms (atoms without any n=1 electrons) are produced. The observations of spectra from these exotic states of matter are supported by our detailed kinetics calculations. These are consistent with a picture in which an intense polychromatic x-ray field is formed from Thomson scattering and bremsstrahlung by the electrostatic fields at the target surface These fields drive the KK hollow atom production. This x-ray fields are estimated to have an moderate intensity and is in the range of several KeV.
In addition, the ATOMIC capability of calculating the electron energy distribution function (EEDF) as a function of time from Boltzmann kinetics will be demonstrated. The EEDF is calculated by solving a complimentary set of rate equations that follow the excitation and ionization rates of electrons in and out of prescribed energy bins. This EEDF is then used in the atomic kinetics to calculate state populations. This capability will be demonstrated by model EEDF calculations of gaseous neon in the presence of a XFEL.

passive spectroscopy for magnetized plasma turbulence study

E. Ghorbanpour (a), R. Barni (b), C. Riccardi (b)

(a) Department of physics, University of Guilan, Rasht, Iran

(b) Dipartimento di Fisica Occhialini, UniversitÃă degli Studi di Milano-Bicocca, p.za della Scienza 3, I-20126, Milano, Italy

We present an application of the use of multi-anode photomultiplier tubes to study correlations among fluctuations in the plasma emissivity from the turbulent state of magnetized plasmas.
We discuss experimental results collected in the simply magnetised toroidal device Thorello at Milano University.
Spectroscopy of the hydrogen low temperature plasma is dominated by the Balmer series of atomic transition lines, but it shows also some emission from molecular hydrogen excited states, that could be used to monitor the neutral dissociation degree.
The time-resolved passive spectroscopy allows to measure the spatio-temporal correlations along different viewlines of the plasma profile. We present some results concerning the statistical properties of the fluctuations. A comparison with traditional electrostatic diagnostics was performed too.

Contribution: **O1.2** / Beam Plasmas and Inertial Fusion

New stripe tube technology for ultra fast time response in Inertial Confinement Fusion in China

Feng Wang, Xin Hu, Xing Zhang，Jin Li， Jiamin Yang， Shaoen Jiang

Laser Fusion Research Center, China Academy of Engineering Physics

This report introduces two new design techniques for streak tube. In the research of ICF, it is always a difficult problem to obtain the shape of hot spot. In this paper, a technique called slicing scanning technique is proposed, which can solve this problem to a certain extent. It designs the slit of the stripe tube into multiple slits, and the deflection plate is designed into multiple structures to realize the function of scanning at one time and reading multiple stripes. This technique makes full use of the high time resolution of the streak camera, and records the scanning images of multiple slits on the fluorescent screen, so as to realize the ability of one scan and multiple position acquisition. The current time resolution of the design is 2ps, and the length of the scanning is 200ps. At the same time, 9 slits can be scanned. The Another technology is called scanning framing technology. It can make full use of the scanning function of the streak camera and realize the function of the framing camera. The design of its electronic optical system will be introduced. At present, the sample tube has been developed. It is expected to become a new type of single line of sight recording technology.

Contribution: **O1.3** / Beam Plasmas and Inertial Fusion

Diagnosing forward fast electrons in relativistic laser-foil interactions using terahertz emission

Yutong Li, 1,4,5 Guoqian Liao, 2 Hao Liu,1 Paul McKenna,3 David Neely,2 Jie Zhang1

1) Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China
2) Central Laser Facility, STFC Rutherford Appleton Laboratory, Didcot, OX11 0QX, UK
3) Department of Physics SUPA, University of Strathclyde, Glasgow G4 0NG, UK
4) School of Physical Sciences, University of Chinese Academy of Sciences, Beijing 100190, China
5) Songshan Lake Materials Laboratory, Dongguan, Guangdong 523808, China

Recently Terahertz (THz) emission from intense-laser-produced plasmas has attracted much interest since such an emitter could not only be a potential tabletop brilliant THz source, but also a noninvasive diagnostic for fast electron generation and transport in laser-plasma interactions. Fast electrons are important for laser-driven x-ray sources, proton acceleration and fast ignition of the inertial confinement fusion. Fast electrons in a solid target can be diagnosed with x-ray emission, proton acceleration and optical transition radiation. However, it is quite challenge to measure their temporal evolution. We have systematically studied THz radiation from solid targets driven by relativistic laser pulses and found that THz can be generated due to coherent transition radiation (CTR) of the forward fast electrons when they pass the solid-vacuum boundary. We will show in this presentation how to use the THz CTR to characterize the temporal history, charge, and divergence angle of the fast forward fast electron beam in a solid target.

Contribution: **O1.4** / Basic and Astrophysical Plasmas

Table-top Laser-driven micro-structure electron synchrotron emission for intense radiation

Ye Tian,Xiaoming Lu, Rong Qi,Yinghui Zheng, Chuliang Zhou, Zhongpeng Li,Yushan Zeng, Shiyi Zhou, Yingying Ding,Zhinan Zeng,Jiansheng Liu,Ruxin Li,Zhizhan Xu

State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences

We have proposed a novel intense Terahertz radiation source based on a high intensity femotosecond laser-driven microundulator mechanism[1]. An intense transient radial electric field instantaneously created on the wire after laser irradiation can guide the helical motion of the electron bunch along the wire and induce periodic THz emission. We would present a scheme from laser driven micro plasma structure for magnetic field[2] and x-ray radiation.

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[2]Shiyi Zhou,Yafeng Bai,Ye Tian,Haiyi Sun,Lihua Cao,Jiansheng Liu,Phys. Rev. Lett. 121,255002 (2018)

Contribution: **O1.5** / Magnetic Confinement Fusion

Deep Neural Networks for Plasma Tomography with Applications to JET and COMPASS

D. D. Carvalho, D. R. Ferreira, P. J. Carvalho, M. Imrisek, J. Mlynar, H. Fernandes

Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal
Institute of Plasma Physics AS CR, Prague, Czech Republic

Convolutional neural networks have found applications in many image processing tasks, such as feature extraction, image classification, and object recognition. It has also been shown that their inverse, so-called deconvolutional neural networks, can be used for image generation. This makes it possible to use such networks for plasma tomography. In essence, plasma tomography consists in reconstructing the 2D plasma profile on a poloidal cross-section of a fusion device, based on line-integrated measurements from multiple radiation detectors. Since the reconstruction process is computationally intensive, a deconvolutional neural network trained to produce the same results will yield a significant computational speedup, at the expense of a negligible error. In this work, we discuss the design principles behind such networks, including the use of multiple layers, how they can be stacked, and how their dimensions can be tuned according to the number of detectors and the desired tomographic resolution for a given fusion device. We describe the application of such networks at JET and COMPASS, where at JET we use the bolometer system, and at COMPASS we use the soft X-ray diagnostic based on photodiode arrays.

Contribution: **O1.6** / Low-Temperature and Industrial Plasmas

Characterization of new radio-frequency setup for studying large 2D complex plasmas

V. Nosenko, J. K. Meyer, S. K. Zhdanov, H. M. Thomas

Institut für Materialphysik im Weltraum, Deutsches Zentrum für Luft- und Raumfahrt (DLR), D-82234 Weßling, Germany

Addressing the growing need for larger complex-plasma systems, a new plasma setup was built at the DLR Institute of Materials Physics in Space [1]. It is based on a relatively large (90 cm in diameter) vacuum chamber where a capacitively coupled radio-frequency (rf) discharge is used to suspend a two-dimensional (2D) cloud of polymer microparticles. The discharge is created between the lower rf electrode and the grounded chamber walls, the particles levitate in the plasma (pre)sheath above the electrode. The new setup was characterized using a variety of diagnostics.
The amplitudes of the rf voltage and current measured using the Solayl Vigilant rf probe were 16−32 V and 9−19 A, respectively, depending on the gas pressure and discharge power. The phase angle between the rf voltage and current was ¡Ö 70¡ã. Compared to the Gaseous Electronics Conference (GEC) rf reference cell, the present setup is characterized by relatively high current and relatively low voltage. The basic plasma parameters were measured in the bulk plasma 6.5 cm above the center of rf electrode using the Hiden ESPion rf-compensated Langmuir probe. The electron temperature Te was measured in the range of 0.4−2 eV, depending on the gas pressure and discharge power. The electron density ne was in the range of 0.5•10^9−3.6•10^9 cm^-3. The electron density measurements were corroborated using microwave interferometry technique (Miwitron MWI 2650).
Video microscopy was used to image suspended microparticles. Their coordinates were then calculated in each frame using a Particle Tracking Velocimetry (PTV) technique. The particle velocity fluctuation spectra were calculated and fitted to theoretical dispersion relations to arrive at the particle charge in the range of 2•^4−3.6•10^4 e and screening length in the range of 0.9−1.7 mm.

[1] V. Nosenko, J. Meyer, S. K. Zhdanov, H. M. Thomas, AIP Advances 8, 125303 (2018).

Contribution: **O1.7** / Basic and Astrophysical Plasmas

Evolution of plasma instabilities with slow energy deposition in an exploding wire

G. Rodríguez Prieto, L. Bilbao

INEI, Ciudad Real, UCLM, Spain.
Instituto de Física del Plasma, UBA-CONICET, 1428 Buenos Aires, Argentina

Plasmas are created by means of explosive systems in laboratories to explore plasma densities and temperatures not attainable in a controlled manner with other systems.
In modeling explosions, one of the main characteristics is the delivery of all the energy to the matter to be exploded in a time much shorter than the time of products dynamics.
Therefore, all the high energy delivery systems with a characteristic time on the order of the dynamical motion of resultant elements had received not much attention in the scientific literature.
With an exploding wire system first measurements of the dynamics for the produced shock wave and radial expansion under this experimental condition had been made.
Two cameras has been used in the experiments that added to electrical measurements permit the calculation of the energy given to the wire as a function of time and both shock wave and wire element radial expansions.
One framing camera with arbitrary time between the 16 frames and a minimum of 5 nanoseconds acquisition time for imaging the wire expansion directly and a streak camera with a retro-illumination system; the former used to check the wire radial uniformity in its expansion and the latter to observe the shock wave radial expansion dynamics.
Using last three images from the frame camera, with a fixed interval of 2 microsenconds between frames, time evolution of the instabilities formed after the energy delivery had finished by electrical current interruption are here presented for the first time.

Contribution: **O2.1** / Low-Temperature and Industrial Plasmas

Time-resolved diagnostics of a pulsed magnetron sputtering discharge with a Co target operated in an argon/oxygen gas mixture.

R. Hippler,1,2 M. Cada,1 V. Stranak,3 Z. Hubicka1

1 Institute of Physics, Academy of Science of the Czech Republic, Na Slovance 2, 18221 Prague, Czech Republic
2 Institut für Physik, Universität Greifswald, Felix-Hausdorff-Str. 6, D-17489 Greifswald, Germany
3 University of South Bohemia, Faculty of Science, Branisovska 31, 37005 Ceske Budejovice, Czech Republic

High power impulse magnetron sputtering (HiPIMS) discharges are of interest from a basic point of view and for deposition of functional films. HiPIMS discharges are characterized by large plasma densities and high ionisation fractions. Here we report new results for the diagnostics of a HiPIMS discharge in an argon/oxygen gas mixture with a Co target utilizing energy-resolved mass spectrometry and time-resolved optical emission spectroscopy. Measured ion energy distributions are dominated by Co ions. With increasing oxygen pressure the Co ion density decreases and Co ions are more and more replaced by O ions. The measured discharge voltage for a constant discharge power displays an unusual behavior as function of oxygen gas flow. The discharge voltage increases with oxygen gas flow and, after reaching a maximum, decreases again. This is in part explained by target oxidation and the associated reduction of the sputtering yield. More results will be presented at the conference.

Contribution: **O3.1** / Magnetic Confinement Fusion

Development and characterization of a new concept of Soft X-Rays diagnostic for tokamaks.

A. Muraro(1), G. Croci(1,2,3), G. Gorini(2,3), G. Grosso(1), M. Nocente(2,3), E. Panontin(2,3), E. Perelli Cippo (1), M. Tardocchi (1), M. Jamalipour(2,3), Z. Hu(2,3), F. Murtas (4), G. Claps(5), F. Cordella(5), D. Pacella (5)

1-IFP-CNR, Via Cozzi 53, Milano, Italy
2- Sez. INFN Milano-Bicocca, Piazza della Scienza 3, Milano, Italy
3- University of Milano-Bicocca, Piazza della Scienza 3, Milano, Italy
4- INFN-LNF, Via Enrico Fermi 40, Frascati, Italy
5- ENEA-Frascati,Via E. Fermi 45, 00044 Frascati, Rome, Italy

To diagnose soft X-ray (SXR) emission from tokamaks represents a unique source of information, since it allows the study of several plasma parameters, such as the electron and ion temperature, the investigation of the ionization equilibrium, particle transport and the study of MHD fluctuations and disruptions. A new SXR diagnostic system called EXODUS (Enhanced X-ray Optimized Detector for Use in multiple Scenarios) is under development with the aim to obtain energy resolved SXR emission profiles from the plasma with a high time resolution (<0.1 ms). The system is based on the Gas Electron Multiplier (GEM) technology coupled with the new data acquisition system especially designed for GEM called GEMINI, which gives the possibility to obtain information about the energy deposited in the detector by the incoming radiation using the so called Time-Over-Threshold technique on each detector channel. The information of the deposited energy allows the study of the SXR emission from the plasma resolved in space, energy and time. There are several advantages in the use of GEM based detector in the harsh environment of a tokamak. First of all, it offers very high rate capabilities (up to 1 MHz/mm2), giving the possibility to obtain sub-ms time resolution together with sub-millimetric spatial resolution. The high counting rate and the high spatial resolution allow the installation of the detector in a pinhole camera very close to the tokamak first wall, producing very high statistic measurements. Finally, if properly designed, GEM detectors are intrinsically insensitive to gamma and neutron irradiation, allowing obtaining an excellent signal to noise ratio.
In this contribution we describe the design and the production of the GEM based detector for the EXODUS system, together with the characterization of the detector response under quasi-monochromatic x-rays beam obtained using fluorescence of different materials.

Contribution: **O3.2** / Magnetic Confinement Fusion

Synthetic conventional reflectometry probing of edge and scrape-off layer plasma turbulence

J. Vicente(1), F. da Silva(1), T. Ribeiro(2), S. Heuraux(3), G.D. Conway(2), C. Silva(1), L. Guimarãis(1), L. Gil(1), E. Seliunin(1), P. Manz(2), J. Santos(1), A. Silva(1) and the ASDEX Upgrade Team

(1) Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal

(2) Max-Planck-Institut für Plasmaphysik, 85748 Garching, Germany

(3) Institut Jean Lamour, UMR 7198 CNRS-University of Lorraine, F-54506 Vandoeuvre, France

Microwave reflectometry techniques have been successfully applied to measure electron density fluctuations with good spatial and time resolutions. However, without a strong modeling effort, turbulence measurements can be essentially qualitative. This has driven the continuous development of both analytical theory and sophisticated numerical codes in support of reflectometry (e.g. [1-3]). Comparisons between experimental and synthetic reflectometry have been performed previously (e.g. [4]). However, only recently a complete chain from measured turbulence properties through a full-wave code simulating reflectometry in realistic gyro-fluid simulations has been implemented, as in [5,6]. In this work, we report on employing the two-dimensional full-wave code REFMUL [3] together with numerical descriptions of microscopic turbulence obtained from both an analytical model (following a Kolgomorov-like wavenumber spectra) and the GEMR code based on gyro-fluid theory [7-8]. Simulations of conventional O-mode reflectometry with fixed frequency probing of edge and scrape-off layer regions were carried out for both turbulence cases separately. Comparisons between synthetic measurements, numerical plasma characteristics, and experimental data from ASDEX Upgrade tokamak were made. As previously described in literature, regimes of linear and non-linear response occurring at low and high turbulence levels, respectively, were observed and further characterized. Turbulence measurements were discussed in light of the knowledge gained by the simulations.

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Contribution: **O3.3** / Beam Plasmas and Inertial Fusion

Picosecond Laser-Driven Transient Electromagnetic Fields for High Energy-Density Beam Tailoring

M. Ehret (1,2), J. Alpiñaniz (3), V. Bagnoud (4), M. Bailly-Grandvaux (1), C. Brabetz (4), E. d'Humières (1), Ph. Korneev (5), S. Malko (3), C. Matveevskii (5), A. Morace (6), L. Volpe (3), M. Roth (2), G. Schaumann (2), V.T. Tikhonchuk (1), and J.J. Santos (1)

(1) Université de Bordeaux, CNRS, CEA, CELIA (Centre Lasers Intenses et Applications), UMR 5107, Talence, France ; (2) Institut für Kernphysik, Technische Universität Darmstadt, Darmstadt, Germany ; (3) Centro de Láseres Pulsados, Salamanca, Spain ; (4) GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany ; (5) National Research Nuclear University MEPhI, Moscow, Russian Federation ; (6) Institute of Laser Engineering, Osaka University, Osaka, Japan

We present experimental studies of a laser-driven open-geometry platform for energy-selective tailoring of laser-accelerated particle beams. A high intensity sub ps-laser pulse drives target-discharge and subsequent propagation of strong transient electromagnetic (EM) fields guided by the target geometry. A sub-mm coil-shaped part of the Cu-target rod creates lensing effects on charged particles. We observed focusing for protons in the 12 MeV energy range over cm-scale distances using 0.5 ps, 50 J laser pulses at 10**19 W/cm**2 [1]. The protons were accelerated by an auxiliary intense short-pulse laser.

Proton-deflectograms capture the time- and spatial-scales: the discharge pulse with a FWHM of ≈ 40 ps propagates with a phase speed of (0.82±0.06)•c, emanating from the laser-plasma interaction spot. While streaming around the coil, the EM fields efficiently focus the probing protons passing inside the coil: e.g. the emittance of 6.3 MeV protons shrinks to 30 % of the initial value. We perform energy-selection of the best focused particles by tuning the delay between the laser pulses driving the discharge and accelerating the proton beam. A quasi-static magnetic field, persisting for > 100 ps, is evidenced based on its polarity. It can be the effect of the ns-scale neutralization current.

Synthetic counterparts of the proton imprints are obtained from simulations of test-particle transport and EM-mode propagation using the PAFIN code [2]. We find EM-pulse amplitudes of tens of GV/m and tens of Tesla. Detailed PIC simulations of the laser-target interaction and the successive propagation of the EM-waves along the target agree in field strength and allow to distinguish between different features – fast electron currents, EM pulses and neutralization waves – difficult to separate solely from the experimental data.

Building upon this, we intend to explore a new all-optical diagnostic platform to extract direct measurements of electric- and magnetic-field amplitudes with a resolution on the fs-scale. We rely on Pockels- and Faraday-Effect to establish a portable high-repetition rate suited set-up.

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[2] M. Ehret, DOI: 10.13140 / RG.2.1.3855.7847

Contribution: **O3.4** / Magnetic Confinement Fusion

Electron Cyclotron Emission Imaging (ECEI) and Microwave Imaging Reflectometry (MIR) Fusion Diagnostics Advances Employing Millimeter-wave System-on-C

J.-H. Yu1, Y. Ye1, Y.-T. Chang1,Y. Zhu1, K.-Y. Lin2, C.-C. Chang3, S.-F. Chang3, and N. C. Luhmann, Jr.1

1 University of California, Davis, California 95616, USA
2 Department of Electrical Engineering, National Taiwan University, Taipei 10617, Taiwan
3 Department of Electrical Engineering, National Chung-Cheng University, Chiayi 62102, Taiwan

Passive ECEI and active MIR provide electron temperature and density fluctuation images. Both require ultra-wideband observations for visualizing the 2-D images, motivating the development of receiver arrays with the mixer diodes mounted directly on printed antennas. These have been employed on numerous fusion devices and contributed to the understanding of phenomena including sawteeth, Alfvén eigenmodes, and ELMs. The passive Schottky diode mixer first down-converts broadband signals, but typically has 20 dB conversion loss which dominates the receiver noise temperature. Consequently, currently employed ECEI and MIR systems have at least 22.8 dB noise figure (55,000 K noise temperature).
Driven by applications including 5G wireless networks and point-to-point communications for wireless back-haul, single-chip mm-wave electronics are providing large improvements in gain, noise suppression, and bandwidth. These advances allow the implementation of multi-function instruments by integrating the RF front-end on a single chip, known as the system-on-chip (SoC) technique. The SoC approach was successfully demonstrated in a proof-of-principle test on DIII-D in early 2018 using commercial E-band (70-80 GHz) receiver chips in an ECEI array. The (3x3 mm2) chip includes a broadband low-noise preamplifier, a down-converting mixer, an IF amplifier, and a local oscillator multiplier with system noise temperature of 5,000 K.
However, fusion plasma diagnostics require operation at specific frequencies with >20 GHz bandwidth limiting the usefulness of commercial products. Therefore, we designed and fabricated customized integrated circuit chips: V-, W-band receivers (55-75 ,75-110 GHz), and V-band (55-75 GHz) transmitters for ECEI and MIR diagnostics. Both the V-band and W-band receivers offer >30 dB signal amplification over 20 GHz bandwidth with <3,000 K noise temperature, thereby permitting direct system noise temperature calibration and local electron equilibrium temperature measurement. The V-band transmitter module is capable of simultaneously transmitting eight independent frequencies covering 55-75 GHz.
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Status of ITER diagnostic development

M.F.M. De Bock, M. Walsh and the ITER team

ITER Organization, Route de Vinon-sur-Verdon, CS 90 046, 13067 St. Paul Lez Durance Cedex, France

The ITER diagnostic suite consist of around 50 different diagnostics, covering magnetic measurements, neutron and fusion product measurements, laser based and microwave measurements and spectroscopy. On top of that in a strongly integrated and nuclear device like ITER supporting services and infrastructure – port plugs, electrical services, nuclear rated feedthroughs for light (windows), electrical power and signals, gas and fluids and mechanical motion – need to be developed in close relation to the actual diagnostic development.

The ITER project has entered it construction phase. The impact on the diagnostic development translates to several early diagnostic systems and services being in manufacturing now and some already being installed and integrated in and on major machine components such as toroidal field coils and vacuum vessel sectors. For diagnostics still in the design phase, the construction of ITER implies that many interfaces are rapidly being frozen, effectively finalizing design choices for these diagnostics.

In this contribution, an overview of the status of the ITER diagnostic development is given based on a number of example diagnostic systems in different stages of maturity and lessons learned that would be beneficial for other diagnostic systems are highlighted.

(The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.)

A 0.89THz heterodyne interferometer to measure electron density for inductively coupled plasma

Jibo Zhang, Haiqing Liu, Xuechao Wei, Yinxian Jie, Liqun Hu

Institute of Plasma Physics Chinese Academy of Sciences (ASIPP)

A heterodyne interferometer operating at the frequency f = 0.89 THz has been designed for measuring electron densities of an inductively coupled plasmas (ICP,13.56MHz) its density is from 1×10^10 to 1×10^13/cm^3 and the pressure is from 1 Pa to 100 Pa. The system is configured as a Mach-Zehnder type interferometer. The light source is hydrogen cyanide (HCN) laser with wavelength of 337m, which has high spatial resolution compared with microwave interferometer. The HCN laser power is up to 17 mW. The intermediate frequency, shifted by 10 kHz, is generated by the Doppler shift with a rotating grating. The spatial and temporal resolution of the HCN interferometry is reach to about 17mm and 100 s respectively. A retro-reflector has been used, so the laser beam can go through the plasma twice. The lowest measurable phase shift of the HCN laser interferometer is in the order of 2°, which corresponds to a line-integrated electron density of about 3.8×10^10 cm^-2. The antenna-coupled ALGaN/GaN-HEMT have been used as detectors which have more higher sensitivity— typical RF responsivity is around 900 V/W — than VDI planar-diode Integrated Conical Horn Fundamental Mixers in the HCN interferometry. The measuring line-integrated electron density of the ICP plasmas is 2.6×10^12 cm^-2, when the Ar pressures is 80pa and the power is about 1800W.

Contribution: **O3.7** / Magnetic Confinement Fusion

Observation of thermal events on the plasma facing components of Wendelstein 7-X

A. Puig Sitjes (1), Y. Gao (2), M. Jakubowski (1), P. Drewelow (1), H. Niemann (1), A. Ali (1), V. Moncada (4), F. Pisano (3), T.T. Ngo (4), B. Cannas (3), M. Sleczka (5), S. Äkäslompolo (1), S. Bozhenkov (1), M. Endler (1), R. König (1), M. Krychowiak (1), S.A. Lazerson (7), J.D. Lore (8), G.A. Wurden (6) and the W7-X Team.

(1) Max-Planck-Institut für Plasmaphysik, Wendelsteinstraße 1, Greifswald 17491, Germany.
(2) Forschungszentrum Jülich GmbH, Jülich 52425, Germany.
(3) University of Cagliari, Piazza d'Armi, Cagliari 09126, Italy.
(4) CEA, IRFM, Saint Paul-lez-Durance F-13108, France.
(5) University of Szczecin, Szczecin, Poland.
(6) Los Alamos National Laboratory, Los Alamos, NM, USA.
(7) Princeton Plasma Physics Laboratory, Princeton, NJ, USA.
(8) Oak Ridge National Lab, Oak Ridge, TN, USA.

Long pulse operation of present and future magnetic fusion devices requires sophisticated methods for protection of plasma facing components from overheating. Typically, thermographic systems are being used to fulfil this task. Steady state operation requires, however, autonomous operation of the system and fully automatic detection of abnormal events. At Wendelstein 7-X (W7-X), a large advanced stellarator, which aims at demonstrating the capabilities of the stellarator line as a future fusion power plant, significant efforts are being undertaken to develop a fully automatic system based on thermographic diagnostics. In October 2018, the first divertor-based experimental campaign has been finished. One of the goals of this operation phase (named OP1.2) was to demonstrate the capabilities of the island divertor concept using an uncooled test divertor made of fine grain graphite tiles. Throughout this campaign, it was possible to test the infrared imaging diagnostic system, which will be used to protect the actively water cooled plasma facing components (PFCs) during the steady-state operation in the next experimental campaign.

An overview of the most relevant thermal events on the PFCs that were observed in OP1.2 using this system are presented. These thermal events include divertor heat loads (strike-lines, leading edges, overloads and detached plasmas), hot spots due to convective loads on the baffles and walls, ECRH shine-through hot spots, NBI fast particle losses, and other events which are a common source of false alarms like surface layers, reflections, dust and flying objects. The detected thermal events are now part of an important and extensive image database which will be used to further automate the system by means of computer vision and machine learning techniques in preparation for steady-state operation, when the system must be able to detect dangerous events and protect the machine in real-time.

Contribution: **O3.8** / Magnetic Confinement Fusion

Neutron shielding assessment of a multi-reflectometer system for DEMO

R. Luís, A. Lopes, Y. Nietiadi, F. Mourão, B. Gonçalves, A. Vale, E. Ricardo, A. Silva, A. Malaquias

Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa 1049-001 Lisboa, Portugal

The DEMO reflectometry diagnostic (RF) is envisaged to provide the electron density profile and to be used as a control diagnostic for the real-time vertical position controller. An innovative concept – the Slim Cassette (SC) – involving the integration of several groups of reflectometry antennas and waveguides into a full poloidal section of the Helium Cooled Lithium Lead (HCLL) breading blanket is currently under study. Such a poloidal section must be seamlessly integrated with the blanket structure, conforming to the blanket cooling services and exhibiting a similar thermo-mechanical behavior as the full blanket segment. To address these requirements, nuclear and thermal analyses were carried out in the past to determine the cooling requirements.

The assessment of how the introduction of the SC in the blanket affects the neutron and gamma fluxes, heat loads and dpa values in the vacuum vessel is mandatory. This paper presents a neutron shielding assessment of a new design of the SC, performed using the Monte Carlo radiation transport code MCNP6. In a first stage, a CAD model the SC was developed, incorporating 72 antennas and corresponding waveguides. This model was then converted to the MCNP format and integrated in the 2017 DEMO neutronics reference model, on the side of an HCLL breeding blanket sector. The simulation results show that the neutron fluxes in the vacuum vessel increase by ~17% after the implementation of the SC. The heat load and dpa hotspots in the vacuum vessel and their possible effects on its integrity are presented and discussed. An attempt is made to extrapolate the results to other diagnostics systems, through a sensitivity analysis where the increase in the fluxes, heat loads and dpa values in the vacuum vessel are estimated as a function of the area of the first wall openings required for their operation.

Electromagnetic Inverse Profiling for Plasma Diagnostics in compact microwave-based Ion Sources

D. Mascali a), G. Torrisi a), E. Naselli a); b, L. Di Donato a);c), G. Sorbello a); c)

a)Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud (INFN-LNS), Via S. Sofia 62, 95123 Catania, Italy
b) Department of Physics and Astronomy, University of Catania, Via Santa Sofia, 64 I-95123 Catania
c) Department of Electrical, Electronics and Computer Engineering (DIEEI), University of Catania,
viale A. Doria, 6 - 95125 Catania - ITALY

In this paper the problem of plasma diagnostics is faced as the solution of a one-dimensional single-view multi-frequency electromagnetic inverse scattering problem. The aim of the problem is to provide effective means for plasma diagnostics by considering the dispersive properties of such medium. The inverse profiling, assessed against full-wave simulated data dealing with reliable benchmarks for microwave imaging, is carried out by exploiting a first order linearized method (Rytov approximation) and Compressive Sensing based approaches in order to attain reconstruction as reliable and accurate as possible. The recovered 1D-plasma density profile allows to complete line-integrated densities measurements already performed by microwave interferometry and polarimetry system VESPRI at INFN-LNS in Catania. This may represent a promising powerful tool for probing plasmas in very compact magnetic traps such as Electron Cyclotron Resonance Ion Sources and open the way to new facilities in plasma microwave diagnostics.

Contribution: **O4.1** / Magnetic Confinement Fusion

High Resolution Probe for filament transport and current density study at the edge region of W7-X

M. Spolaore1, P. Agostinetti1, C. Killer2, R. Cavazzana1, R. Ghirardelli1, G. Grenfell1, O. Grulke2, M. Moresco1, E. Martines1, O. Neubauer3, D. Nicolai3 , G. Satheeswaran 3, B. Schweer3, N. Vianello1 , M. Visentin1 and W7-X Team

1Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete SpA) , Padova, Italy
2Max-Planck-Institut für Plasmaphysik, Greifswald, Germany
3Forschungszentrum Jülich GmbH, Institut fur Energie- und Klimaforschung Plasmaphysik, Partner of the Trilateral Euregio Cluster (TEC), 52425 Jülich, Germany

For the study of electrostatic and magnetic properties of filaments characterizing the edge region of the stellarator experiment W7-X, a specifically designed insertable probe head was constructed within the framework of EUROfusion WP.S1 work package in collaboration between Consorzio RFX, IPP Greifswald and FZJ Julich. The probe head, named High Resolution Probe (HRP), was conceived to be installed on the mid-plane multi-purpose fast reciprocating manipulator on W7-X. Electromagnetic filamentary turbulent structures are found to characterize the edge region of different magnetic configurations [M. Spolaore et al., PoP 2015] including Reversed Field Pinch, stellarator and tokamak, where strong currents are associated also to ELM filamentary structures. The study of those phenomena in W7-X stellarator is of particular interest as the electromagnetic features of filaments are expected to become more relevant with the increase of the local plasma beta. In particular the aim is to provide information about the presence and the features of parallel current density associated to filamentary turbulent or ELM-like structures. Furthermore, the possibility to measure the time evolution of the flow radial profiles using the Mach probe array was considered as a further interesting part of the study, given the strong interplay expected between the turbulent fluctuation and the average flows. Further important information provided is the radial propagation of turbulent flux.

The contribution will present the design development, the R&D studies and the applied solutions for the sensors embedded in the probe head. In particular, the presence of 140 GHz ECRH plasma environment represents one of the main challenges for reliable magnetic fluctuation measurements.

First measurements were performed during the W7-X experimental campaign OP1.2b, where in particular the probe was exploring different magnetic configurations. The respective features of the electromagnetic turbulence will be compared.

Contribution: **O4.2** / Magnetic Confinement Fusion

Conceptual design of JT-60SA edge Thomson scattering diagnostic

Roberto Pasqualotto 1, Hiroshi Tojo 2, Alessandro Fassina 1, Leonardo Giudicotti 1, Vanni Nardino 3, Naoyuki Oyama 2, Stefano Pelli 3, Valentina Raimondi 3, Sergio Ricciarini 3, Sorin Soare 4,5, Sam Davis 6, Carlo Sozzi 7

1 Consorzio RFX, C.so Stati Uniti 4, Padova 35127, Italy
2 National Institutes for Quantum and Radiological Science and Technology (QST), 801-1 Mukoyama, Naka 311-0193, Japan
3 National Research Council, Institute of Applied Physics “Nello Carrara” (CNR-IFAC), via Madonna del Piano 10, 50019 Sesto Fiorentino, Italy
4 Institute of Atomic Physics, 407 Atomistilor St., Magurele 077125, Ilfov, Romania
5 Universitatea "Lucian Blaga" Sibiu, 10 Bld. Victoriei, Sibiu 55002, Romania
6 Fusion for Energy, Boltzmannstrasse 2, Garching 85748, Germany
7 National Research Council, Institute of Plasma Physics (CNR-IFP), via R.Cozzi 53, Milano 20125, Italy

The mission of JT-60SA is to complement ITER in resolving key physics and engineering issues to finally decide an acceptable DEMO plasma design, including practical and reliable plasma control schemes suitable for a power plant. To this purpose diagnostics play a key role. Electron temperature and density profiles will be measured by Thomson scattering systems (TS). They are designed to achieve high spatial resolution, required to identify the pedestal parameters and small structures.
Two TS systems are being designed for JT-60SA, to be procured and installed within 2022. They both use a tangential Nd:YAG laser beam path on the plasma equatorial plane. Tangential ports for injecting the laser beams are situated at Port-1 and Port-8 horizontal port sections. In accordance with this laser beam geometry, Port-1 lower oblique and Port-2 horizontal ports are assigned for the optics collecting the scattered light from the outer edge (low field side) and core of the plasma, respectively.
Design of TS systems is carried out by a joint Japan-EU team. EU is contributing with procurement of the edge TS collection optics and supporting structure, an edge dedicated laser, polychromators and optical fibres for both systems. Key features of the edge TS diagnostic setup and main components will be presented. The collection optics are specifically designed to fit in the port plug tube and to image with suitable resolution the scattering volumes into an array of fibre bundles. The optics is held by a mechanical structure bolted on the floor, decoupled from the cryostat. A set of filter polychromators with APD detectors detect the scattered radiation: their specification and interference filter design will be presented. Simulations of the TS signals provide the expected performance.

Contribution: **O4.3** / Beam Plasmas and Inertial Fusion

Recent progress on Transformational Diagnostic Development at US ICF Research Facilities

James Steven Ross; Joe Kilkenny; Gregory A. Rochau; Johan Frenje; Sean Regan; Craig Sangster; Michael Jones; Thomas J Murphy; Steve Batha; Doug Larson; Scott Winters; Perry Bell;Andrew James Mackinnon; Dave Bradley

Lawrence Livermore National Laboratory
General Atomics
Sandia National Laboratory
MIT
Laboratory for Laser Energetics
Los Alamos National Laboratory

Inertial confinement fusion (ICF) and High energy density (HED) research is currently underway at the National Ignition Facility at LLNL, the Z Machine at Sandia and at the OMEGA Laser Facility at LLE. In support of this research a National Diagnostic Working Group (NDWG) has been formed to coordinate diagnostic development across these facilities. Eight transformational diagnostics have been identified increasing the spatial, temporal and spectral resolution of x-rays, neutrons, gammas and scattered light. Good progress is being made which will be discussed in this presentation. When complete, the new diagnostics will provide unprecedented insight into ICF and HED physics.

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Contribution: **O4.4** / Basic and Astrophysical Plasmas

Diagnostics of Solar Coronal Plasmas with Compressed Sensing

Mark Cheung

Lockheed Martin Solar & Astrophysics Laboratory

We show how compressed sensing techniques can be applied to EUV and X-ray observations to robustly measure the physical properties (e.g. emission measure, temperature, Doppler speeds) of astrophysical plasmas. We show sample applications to EUV narrowband images from the Solar Dynamics Observatory, the Hinode X-ray Telescope, EUV spectra from the Hinode EUV Imaging Spectrometer and synthetic EUV spectra from the proposed NASA Small Explorer mission, the MUlti-Slit Solar Explorer.

Contribution: **O4.5** / Beam Plasmas and Inertial Fusion

Imaging the solid to plasma transition

Gareth O. Williams, Mukhtar Hussain, Jayanath Koliyadu, Thomas Wodzinski, Swen Künzel, Marta Fajardo

GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal

The laser induced solid-to-plasma transition presents a dynamic transformation from the well described solid state to the strongly coupled plasma state. The transition involves a range of comparable parameters, and as such Coulomb, quantum and structural effects, that must be accounted for in models. This constitutes a grand challenge to describe accurately within current theoretical frameworks, making experimental measurements essential. Exploring the effects of electronic excitation and structural changes can elucidate the impact of these two systems, providing valuable constraints to models. The degree to which these plasmas absorb light of a specific frequency, the opacity, can be used to explore the electronic and structural changes and directly compared to models. These laser induced changes can only be resolved with femtosecond time resolution diagnostics, as the equilibration of the electronic and ion systems is on the scale of picoseconds.

Here, we present a femtosecond time resolved imaging system based on the transmission extreme ultra-violet (XUV) light from high harmonic generation. We use a grazing incidence focussing and imaging system that images in transmission a laser heated titanium foil of 100 nm in a single shot. We present the experimental setup and preliminary results of this ultrafast transition.

Contribution: **O4.6** / Low-Temperature and Industrial Plasmas

Optical diagnostics of initial phase of nanosecond discharge in liquid water

Milan Šimek, Petr Hoffer, Václav Prukner, Jiøí Schmidt

Department of Pulse Plasma Systems, Institute of Plasma Physics CAS, Prague, Czech Republic

Initiation and evolution of micro-discharges in liquid water due to highly divergent electric field of (sub)nanosecond duration is a very complex phenomenon involving generation and multiplication of charged species in highly collisional environment. Numerous studies have concluded that discharges in liquid can be formed due to the presence of voids with minimal thermal effects and without any liquid-water phase change. Clear experimental evidence of underlying physical mechanisms is missing mainly because of short time- and small space-scales associated with initial stages of such discharge events. Typically, experimental configurations based on needle-to-plane electrode geometry (typical curvature of the tip of the needle of tens of micrometers) stressed by HV pulses (amplitude of 50-150 kV) are used and such configurations lead to sub-millimetre corona-like structures evolving with velocity of about 200 km/s.

In this work, we have explored the morphology, dynamics, and emission characteristics of the micro-discharges produced in deionized liquid water by applying fast-rising HV pulses in a point-to-plane geometry. We employed the techniques of time-resolved shadowgraphy and interferometry to reveal dynamics of the initial non-luminous pre-discharge phase with resolution of <50 ps and <1 micrometre. We also employed the techniques of time-resolved ICCD microscopy and spectroscopy to register both emission spectra and morphological fingerprints with high spatial (of few micrometres) and temporal (from 0.2 to 2 ns) resolutions of secondary luminous discharge phase.

We succeeded in capturing footprints of shockwaves developing around the streamer head. It comes out that initial non-luminous bush-like phase is followed by inception of a few isolated luminous micro-discharge filaments. After initial expansion and branching of luminous filaments, the length of luminous filaments collapses. We also observed that plasma-induced emission produced by nanosecond HV pulses in liquid water is given by broadband continua.

Supported by the Czech Science Foundation (project no. 18-04676S).

Contribution: **O4.7** / Magnetic Confinement Fusion

New JET Diagnostic Capability to Support the Scenario Development and the Physics Programme at Different Fuel Mixtures.

A. Murari, J. Figueiredo and JET Contributors

1Consorzio RFX (CNR, ENEA, INFN, Universita' di Padova, Acciaierie Venete SpA),Corso Stati Uniti 4, 35127 Padova, Italy.
2Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Portugal

New JET Diagnostic Capability to Support the Scenario Development and the Physics Programme at Different Fuel Mixtures.

by A. Murari, J. Figueiredo and JET Contributors*

EUROfusion Consortium, JET, Culham Science Centre, Abingdon, OX14 3DB, UK
1 Consorzio RFX (CNR, ENEA, INFN, Universita' di Padova, Acciaierie Venete SpA),Corso Stati Uniti 4, 35127 Padova, Italy.
2 Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Portugal

JET next campaigns foresee various scans in the fuel mixture, full T operation and a 50-50 D-T campaign called DTE2 before the end of the decade. The main scientific objectives include the assessment of the isotopic effects on various plasma aspects: mainly on confinement, on the threshold to access the H mode and on ELM behaviour. Another very important subject of investigation will be the physics of the alpha particles. From a technical point of view, the total yield available for the entire D-T phase is expected to be 1.7•10^21 n, about a factor of 6 higher than the previous main D-T campaign on JET, DTE1. Therefore the radiation field will be quite relevant for next step devices, since the neutron flux at the first wall (~10^13 n/s·cm^2), for example, will be comparable to the one in ITER behind the blanket.
From the point of view of diagnostics developments, for many years JET diagnostics have been upgraded in order to provide adequate support for the scientific exploitation of JET programme. The main efforts have concentrated on improving three main aspects of JET measuring capability: 1) the quality of the measurements of the electrons and ions 2) the diagnostic for the fusion products 3) interpretation codes 4) diagnostic technologies for ITER.
In terms of general diagnostic capability, compared to the previous DTE1, JET diagnostics have a much better spatial and temporal resolution of the electrons (about one order of magnitude improvement for each parameter). The accuracy and consistency of the various independent measurements of the same parameter have also increased significantly; the three independent measurements of the electron temperature, for example, agree now well within 10%. On the other hand, various improvements of the active charge exchange are being pursued to overcome the significant difficulties encountered in measuring the temperature

and rotation velocity of the ions. Moreover, solutions have been found to operate some cameras, both visible and IR, even during the full D-T phase to provide imaging of the plasma and the first wall. A new set of reflectometers is expected to provide valuable information about the changes in the turbulence with the different fuel mixtures.
With regard to the fusion products, JET now can deploy a consistent set of techniques to measure the neutron yield and neutron spectra and to diagnose the fast particles. A full calibration of the neutron diagnostics with a 14 MeV source has been successfully completed, complementing the previous calibration for the 2.45 MeV neutrons. Vertical and horizontal lines of sight are foreseen for neutron spectrometry, in order to separate the RF component from the other contributions. Various gamma ray spectrometers are being developed to cover all the various operational scenarios and to discriminate the trapped and passing components of the alphas. The redistribution of the alphas will be measured with the gamma ray cameras, recently upgraded with full digital electronics; new detectors (LaBr3) have been tested to bring the time resolution of the system in the ten of ms range. The lost alphas will also be diagnosed with improved spatial and temporal resolution, using Faraday cups and a scintillator probe, while an upgraded system to detect the TAE modes, and their interactions with the fast ions, has been proved for the first time to work also in divertor configurations.
For most major diagnostics, and in particular for practically all the enhancements, a very significant effort has been exerted to improve JET interpretative capability via the development of specific synthetic diagnostics. From the measurements of the fusion product to the instabilities and tomographies, a series of advanced codes can be now deployed to better link the diagnostic outputs with the physics of the plasma configurations. Interesting developments are also taking place in the fields of data mining, for the efficient retrieval of the information, and in the exploitation of many measurements for real time control.
From a technological perspective, the full T and D-T campaigns will provide a unique opportunity to test ITER relevant technologies. From radiation hard detectors, for example Hall probes, to neutron absorbers and to shielding concepts, the potential of various solutions in real radiation fields will be assessed. The effects of neutrons and gamma on ancillary technologies and systems, such as fibre optics and electronics circuits, are also expected to be sufficiently high to derive useful information about the competitive advantage of various potential solutions.

* See the author list of “X. Litaudon et al 2017 Nucl. Fusion 57 102001

Contribution: **P1.1** / Beam Plasmas and Inertial Fusion

Development of the Space-Resolving Flux Detection Technique for the Localized Radiation Flux Measurement in Inertial Confinement Fusion

Xufei Xie[1], Shenye Liu[1], Lifei Hou[1], Kuan Ren[1], Jinwen Chen[1], Huabing Du[1], Zhichao Li[1], Sanwei Li[1], Dong Yang[1], Liang Guo[1], Xiaohua Jiang[1] , Wenyi Huo[2], Yaohua Chen[2], Ke Lan[2], Feng Wang[1], Jiamin Yang[1], Shaoen Jiang[1], Ding Yongkun[2]

[1] Research Center of Laser Fusion, Chinese Academy of Engineering Physics, Mianyang 621900, China;
[2] Institute of Applied Physics and Computational Mathematics, Beijing, 100088, China.

Hohlraums are often used for the conversion of the laser energy to X-rays in inertial confinement fusion. Traditionally the diagnostic of the X-ray radiation field within the hohlraum mainly relies on soft X-ray spectrometer (such as Dante) or flat-response X-ray diode (FXRD) detector, with spatial coverage larger than the size of the laser entrance hole (LEH), and the radiation fluxes from different positions (laser spot, re-emitted capsule and/or capsule) are combined to produce the measured signal. However, in hydrodynamical simulations distinct differences can be found on the X-ray intensity and energy distribution at different positions, due to the rather discriminated plasma conditions. Therefore, it would be useful to decouple the radiation fluxes from different positions experimentally, for which a novel technique, namely space-resolving flux detection (SRFD), is developed for the localized radiation flux measurement within the hohlraum. The typical spatial coverage of the SRFD system is about 200 um, which is smaller than the LEH size, and the time resolution is about 150 ps, while uncertainty of the measured radiation flux is less than 15%. The radiation fluxes from the laser spot and re-emitted area within a vaccum cylindrical hohlraum are obtained, and good consistence is found between the experimental data and the numerical simulation with two-dimensional (2D) LARED simulation. Then the radiation flux from the capsule within a gas-filled cylindrical hohlraum is measured, and it is also compared with the hydrodynamical simulation. Moreover, this technique is also applied for the radiation flux measurement within octahedral spherical hohlraum, and radiation flux from the laser spot and re-emitted area are obtained. It proves to be a necessary tool for the radiation field diagnostic in novel hohlraums with more than two LEHs.

Contribution: **P1.2** / Low-Temperature and Industrial Plasmas

The Behavior of Enthalpy of ZnO Wurtzite Phase unde Low and High Temperature and Pressure a Molecular Dynamics Prediction

Y. Chergui1,2*, T. Aouaroun3,4, and R. Chemam1 , , ,

1Badji Mokhtar University, Physics Department, Sidi Ammar, Annaba 23000, Algeria
2 University M'Hamad Bougara of Boumerdes, IGEE Institute, Boumerdes 35000 Algeria
3University M'Hamad Bougara of Boumerdes, Faculty of Science, Physics Department, Boumerdes 35000, Algeria
4Unité de Recherche (UR-MPE), University M'Hamad Bougara of Boumerdes, Algeria

In this work we analyze the behavior of enthalpy of ZnO wurtzite phase under low and high temperatures and pressures using Parallel Molecular Dynamics and Dl_poly_4 softward (Cardiff University, Chemistry Department, Wales, UK). Under the range of temperatures 300-3000K, and pressures 0-200GPa. The equilibrium time, the evolution in time, the isothermal and isobaric ensemble is analyzed. This work is in agreement with available results although no more similar data as our knowledge. This data of Zinc Oxide has great value in technology applications under previous conditions

Contribution: **P1.3** / Basic and Astrophysical Plasmas

Positron impact electronic excitation of N2

Jorge L S Lino

Jorge Lino

In this work we present cross sections for positron impact excitation of electronic states of N2 using the called scaling Born positron(SBP) approach. Integral cross sections calculations from the a1Πg states of N2 are reported and comparisons to more sophisticated theories and experimental data are presented.

Contribution: **P1.4** / Beam Plasmas and Inertial Fusion

The HRR Diagnostic program @ CLPU

Luca Volpe

Centro de Lasers Pulsados de Salamanca
CLPU Chair at University of Salamanca

Ti:Sa CPA systems enable to reach High Laser Intensities at a relevant repetition rate opening the way to a new possibilities for experiments in different field of physics. The Centro de Laseres Pulsados is entering now in the operational phase. Indeed after two successful commissioning experiments, VEGA 2 system (the 200 TW) is now in operation and “International recognised” research groups are working with the system.

The combination of laser intensity, short duration and repetition rate offered by VEGA pave the way for new exiting experiments but also represent a scientific and technological challenge for what concern Targetry and Diagnostic techniques.

At CLPU we started a dedicated scientific and technological research line for the implementation of different stages of diagnostic for VEGA target area.

Plasma, particle and radiation beam diagnostics working at HRR are under development and part of such diagnostics are already implemented and used.

Here I will present the current status of diagnostic implementation showing the first main results obtained in the commissioning experiment on the 200 TW system.

Results on Laser Wake Field accelerated electrons (up to 0.5 Gev) together with the resulting X-ray Betatron emission (10 Kev critical Energy) and TNSA accelerated protons (energy up to 10 MeV) will be presented.

Contribution: **P1.5** / Low-Temperature and Industrial Plasmas

Triple Langmuir probe for diagnosis of atmospheric pressure plasma produced by Dielectric Barrier Discharge of parallel plates .

Ivan Alves de Souz (1), Joao Freire de Medeiros Neto (1), Antonia Karla Paixão Silveira (1), Thércio Henrique de carvalho Costa (1), Efrain Pantaleon Matamoros (1), Michelle Cequeira Feitor (1) and Rômulo Ribeiro Magalhães de Souza 2

(1) Federal University of Rio Grande do Norte (UFRN)- Plasma Materials Processing Laboratory (LABPLASMA)

(2) Federal University of Piaui(UFPI)-Postgraduate Program in Materials Science and Engineering. (PPGECM)

This work aimed to characterize a DBD plasma equipment at atmospheric pressure through optical and electrical measurements, seeking to obtain a greater knowledge of the plasma production process and how it behaves through the adopted parameters, such as frequency and voltage applied between electrodes, at a fixed distance of 1.7 mm using air as work gas . In order to measure them, three different plasma diagnosis techniques were applied. The first method was the Lissajous figures, a technique quite effective for a complete electrical characterization of DBD equipment. The second technique used was the Optical Emission Spectroscopy, a tool used for the diagnosis of plasma, being it possible to identify the excited species produced in filamentary and diffuse discharge in the plasma. And finally, the triple Langmuir probe technique was used to obtain the electron temperature and electron density. Based on this study, it was possible to identify the equipment efficiency in different regimes. The electron temperature measurement for both systems analyzed were 27.96 eV and 20.69 eV to the filamentary and diffuse regimes, respectively. The density of electrons number to these regimes were 1.09x10^21 m-3 and 1.56x10 m-3.

Contribution: **P1.6** / Magnetic Confinement Fusion

Synthetic far-infrared laser diagnostic system on HL-2A tokamak

Y.G. Li, Y. Li, Y. Zhou, Z.C. Deng, H.X. Wang, J. Yi, B.S. Yuan, L.M. Yu, K. Yao, J. Cheng, W. Chen, Z.B. Shi, Yi. Liu, Q.W. Yang, and M. Xu,

Southwestern Institute of Physics

A combined far-infrared (FIR) laser Interferometer and Polarimeter system has been successfully commissioned on HL-2A tokamak. The diagnostic system employs two formic-acid (HCOOH, λ=432.5um) laser sources for heterodyne detection, and provides four channels of line-integrated electron densities and four channels of Faraday rotation angles, with spatial resolution of 7.0cm and phase resolution of 1.0deg and 0.1deg. With the extra constraint provided by the measurement of Faraday rotation angle, current density profile can be well reconstructed on HL-2A for physical studies, such as MHD activities. Meanwhile, the high systematic time resolution (1.0μs) makes the Interferometer and Polarimeter have the capability to track plasma fluctuations induced by edge localized mode (ELM), precursor-oscillation of sawtooth, and energetic particles driven instabilities. Particularly, high-frequency reversed shear Alfvénic eigenmode (RSAE) fluctuation (up to 500 kHz) was firstly observed on HL-2A during the high-power neutron beam injection heating (NBI). Furthermore, based on the multi-channel Interferometer and Polarimeter, a high-sensitivity Far-forward Collective Scattering (FCS) diagnostic has been successfully exploited to measure the density fluctuation, covering the wave number range: $k_\perp$<1.6/cm. Experimental results indicate that both turbulence and broadband fluctuations can be effectively measured by the FCS diagnostic. For instance, turbulence-induced density fluctuation variation was distinctly observed after high-power NBI heating. The synthetic FIR laser diagnostic system (Interferometer, Polarimeter, FCS) greatly improves the diagnostic level of HL-2A tokamak.

Contribution: **P1.7** / Beam Plasmas and Inertial Fusion

A neutron-diagnostic method using a BF3 detector array for ultrashort-pulse-laser neutron sources in strong gamma-ray environments

Erfu Guo, Jiabin Chen, Chen Wang, Honghai An, Xiuguang Huang, Wei Wang, and Jiaqin Dong

Shanghai Institution of Laser Plasma

With the rapid development of ultrashort-pulse laser technology, short-pulse, high-flux neutron sources based on the interactions of laser plasmas have become increasingly important. However, the extremely strong gamma rays generated by the interaction between a picosecond laser beam and a target make it difficult to apply traditional neutron-diagnostic methods. Here, we introduce a neutron-diagnostic method that employs a BF3 detector array for use in the strong-gamma-ray environments associated with ultrashort-pulse-laser neutron sources. This method determines the neutron yield by collecting signals from each of six independent BF3 counting tubes, effectively reducing statistical-fluctuation uncertainties. We first propose a time-partition calibration method for the BF3 detector array that uses counts in different time intervals. With this calibration method, the dynamic range for neutron-yield measurements is expanded from 5×10^3~1×10^8 to 8.3×10^2~5×10^10 neutrons. We have applied this neutron-diagnostic method for the first time to the ultrashort-pulse-laser neutron source at the SG-II upgrade facility.

Contribution: **P1.8** / Magnetic Confinement Fusion

First Mirror Test in JET for ITER: Complete overview after campaigns in JET with carbon and metal walls

M. Rubel(1), Sunwoo Moon(1), P. Petersson(1), D. Ivanova(1), A. Widdowson(2), E. Fortuna-Zalesna(3) and JET Contributors

(1) Royal Institute of Technology (KTH), SE-1044 Stockholm, Sweden
(2) CCFE, Culham Science Center, Abingdon, OX14 3DB, UK
(3) Warsaw University of Technology, 02-507 Warsaw, Poland

First Mirror Test (FMT) for ITER was carried during two campaigns in the carbon surrounding (JET-C) and three with the metal wall (JET-ILW). Over 120 test Mo mirrors were exposed during the entire project. This contribution provides an overview of results and analyses of factors decisive for the modification (also degradation) of reflectivity. Examinations were done by optical, electron and ion beam techniques.
In JET-ILW total reflectivity of all mirrors in the main chamber has decreased by 2-3% from the initial value because very thin co-deposit: 5-15 nm containing D, Be, C, O. This has affected the optically active layer (15-20 nm on Mo) and led to increased diffuse reflectivity.
All mirrors from the divertor lost reflectivity by 20-80 dependent on the location and exposure time. Reflectivity loss is connected predominantly with the co-deposition of Be and some C. Nitrogen, nickel and tungsten and dust particles are also present; N reaches 1×10^17 cm^-2, W is up to 3.0×10^16 cm^-2, while the greatest Ni content is in the outer leg: 2.5×10^17 cm^-2. The thickest layers have been found in the outer divertor: 850 nm after ILW1-3, indicating the average growth rate of 4 pm s^-1. This is 20 times less than in JET-C.

Comparison of tests performed in JET-C and JET-ILW show that the degradation of optical properties in a machine with metal wall is distinctly smaller than in the carbon surrounding. However, a long-term exposure and off-normal events may change surface properties of the mirrors. Different ways for mirror surface recovered have been examined, but improvements are still needed. Results obtained for the main chamber mirrors in ILW allow some optimism regarding the diagnostics reliability in ITER, but search for engineering solutions for mirror exchange in a reactor should not be abandoned especially for the divertor mirrors.

Contribution: **P1.9** / Beam Plasmas and Inertial Fusion

Experimental study of driven uniformity of VISAR on ShenGuang-III proto-type laser facility

Ji Yan, Yulong Li, Zanyang Guan, Xing Zhang and Feng Wang

Laser Fusion Research Center, Mian Yang, China

VISAR is a powerful diagnostics to obtain the shock velocity and had been widely used in ICF and HEDP experiments. In this work, the preliminary study of driven uniformity of VISAR was proposed.

Firstly, 1D shock velocity distribution was proposed with ~100ps temporal and ~20μm spatial resolution. Then, the definition of the velocity uniformity δV was described as (Vmax-Vmin)/Vmean, and It represent the spatial uniformity at every 100ps;

Secondly, nearly 50 experimental results that performed on ShenGuang-III proto-type laser facility were studied. Including low shock velocity(~5km/s) from qusi-entropy, medium shock velocity(~20km/s) from indirect-drive and high shock velocity(~50km/s) from direct-drive. Exceed 1000 δV were collected and proposed that while the interference fringe was formed, the δV was better than 5%. Meanwhile, for current VISAR optical configuration, the tolerable angle deviation of reflect probe-light(the same with shock wave front) is ±8%.

At last, a testing experimental is performed using direct-drive to conform the conclusion. 4 laser beams with 500μm CPP and overlapped with intensity 8x1015W/cm2 to produce a ununiformed shock. The target consist with three layers, CH as an ablator, Mo as preheat shield and to observe the uniformity of shock at Mo/Quartz interface while shock break-off from Mo layer, Quartz as a window to observe the interference fringes. The experimental results show that while the interference fringes were formed, the shock velocity uniformity was better than 5%.

In conclusion, for the current VISAR optical configuration(f/4.5#, Magnificaton~15X), if the shock velocity uniformity is worse than 5%(usually it means driven uniformity is worse than 10%), the Interference fringes are faded.

Contribution: **P1.10** / Beam Plasmas and Inertial Fusion

Development of Specific-Region Flux Diagnosis for Inertial Confinement Fusion Experiments

Lifei Hou

Laser Fusion Research Center China Academy Engineering Physics Mianyang 621900, China

For indirect drive Inertial Confinement Fusion (ICF), experiments adopt hohlraums to convert laser energy into x-ray in order to provide a high intensity and uniform radiation field. Due to complexity of the radiation field, traditional instruments for x-ray flux measurement, such as Soft X-ray Spectrometer (SXS) and Flat-Response X-ray Diode (FXRD), are to measure the radiation flux from the hohlraum wall. Then the numerical simulation uses measurement results to assess radiation drive on the capsule or different positions in the hohlraum. However, those methods has some disadvantages. Firstly those radiation flux diagnosis technologies can't measure the radiation intensity on the capsule, laser spot or other part of hohlraums directly, because of their big field of view. Secondly the closure of Laser Entrance Hole (LEH) affects traditional methods measurement badly. And the factor is difficult to be simulated.

In order to avoid the defects of traditional methods, a Specific-Region Flux Detection (SRFD) is proposed that the radiation flux from the capsule or other parts in the hohlraum can be measured directly. The new diagnosis combines the pinhole imaging and FXRD. The limited field of view of the instrument is about 200μm in diameter. The amplification factor is 10. Primary instruments used a pinhole-lens part and the x-ray Image Plate (IP) (with a diaphragm in the center) to determine the measured region. In experiments, the radiation flux from the laser-spot and the re-emitting region on the hohlraum wall has been measured successfully. Then assemblage, collimation and operation are all improved based on the Diagnostic Instruments Manipulator (DIM). At the same time the new Specific-Region Flux Detector used fluorescence Ce:GAGG film (with a diaphragm in the center) to replace the IP for radiography. It means that it is possible to identify the measured area via a online CCD camera instantly. The instrument may be operated easily. The Specific-Region Flux Diagnosis are been applied in the Inertial Confinement Fusion experiments more and more widely for the radiation flux measurement of the capsule or different positions on the hohlraum wall.

Contribution: **P1.11** / Magnetic Confinement Fusion

CXRS-DIAGNOSTICS OF THE T-15MD TOKAMAK

V. Krupin, I. Zemtsov, M. Nurgaliev, L. Klyuchnikov, A. Nemets, N. Naumenko, N. Stupishin, S. Tugarinov

NRC “Kurchatov Institute”
Bauman Moscow State Technical University
B.I. Stepanov Institute of Physics, NASB, Minsk, Republic of Belarus
Budker Institute of Nuclear Physics, Novosibirsk

In 2020 a modernized tokamak T-15MD (R=1.48m, a=0.67m, κ=1.8, I_pl≤2MA, B_t≤2T, discharge duration ≤10s, P_aux≤24MW) will be launched in the “Kurchatov Institute”. For this installation a modern CXRS diagnostics has been developed. It can function both on a diagnostic injector (E_DNB=60 keV) and NBI (E_NBI=80keV). CXRS at the diagnostic beam already has all the necessary equipment and makes it possible to measure local values of the following plasma parameters with high spatial (~3cm) and temporal (~3ms) resolutions: ion temperature, density of deuterium and light impurities (C, O) nuclei, toroidal and poloidal rotation velocity, radial electric field and the density and energy of fast ions. Creating MSE and BES diagnostics is planned on mentioned beams.
The composition of the CXRS-complex and its schematic is presented. Effect of high-power diagnostic beam on the measured parameters is estimated. The attenuation of the diagnostic beam in the plasma is calculated considering its ionization and charge exchange by the protons and impurities (C, O), as well as electron impact ionization. The active and passive components of \lambda=529.1nm line of CVI ion are calculated considering the line fine structure, Doppler, and Zeeman effects.
The active and passive signals emitted by CVI ion are estimated for toroidal and poloidal registration systems. It was established that the acquisition time of the valid signal of 1-3ms for Ti measurements is enough to achieve a statistical error of ~3%. Calculated ratio between the active CXRS-signal and the passive one in the plasma center (up to 2.2) is an order of magnitude higher than on T-10. Also considering that total injection duration, determining the ultimate valid signal acquisition time, at T-15MD is ~100 times higher than on T-10, it can be argued that CXRS-diagnostics of T-15MD will allow reliable measuring of the listed parameters in whole plasma cross-section.

Contribution: **P1.12** / Magnetic Confinement Fusion

ITPA R&D Activities in Support of ITER Diagnostics

D. Mazon1, D.L. Brower2, G. Vayakis3 for the ITPA Topical Group on Diagnostics

1 CEA, IRFM F-13108, Saint Paul Lez Durance, France
2 University of California Los Angeles, Los Angeles, CA 90095-1547, USA
3 ITER Organization, Route de Vinon sur Verdon, CS 90 046 - 13067 Saint Paul Lez Durance Cedex, France

Diagnostic systems are essential for machine protection, safe and reliable operation, and comprehensive understanding of burning plasma behavior in ITER. In order to achieve the above aims, more than fifty sub-systems will be developed for measurement of plasma and plasma facing components in the harsh ITER environment, e.g. higher neutron/γ-ray irradiation and lower accessibility/maintainability compared to that of existing fusion devices. The International Tokamak Physics Activity (ITPA) Topical Group on Diagnostics has been conducting R&D activities to support improved ITER diagnostic performance and diagnostics development. Highlights of the ITPA activity are overviewed, among them:

Optimization of the lifetime of plasma facing mirrors: to qualify an optimum material: the conducted studies show clear decisive advantages of single crystal materials: rhodium (Rh) and molybdenum (Mo) for first mirrors as they demonstrated superior performance under sputtering conditions expected with the in situ cleaning system of ITER. Investigation on mirror protection using specific duct geometries and mirror cleaning using RF plasma sources will be presented.

Plasma Control System Measurement Requirements: in ITER, PCS (Plasma Control System) controls all aspects of operation. A recently launched action demonstrated the use of a LID (line-integrated density) synthetic diagnostic, initially for density control, in IMAS (Integrated Modelling and Analysis Suite) for PCS. Control of the density during discharge ramp up, flat top, and ramp down using gas puffing was achieved.

Development of Escaping α Diagnostics: ITER is designed to produce a self-maintained burning plasma dominated by alpha-particle heating with a fusion power amplification factor, $Q \geq 10$. Good alpha-particle confinement is therefore of paramount importance for the ITER project. A Fast Ion Loss Detector (FILD) is the only diagnostic that is capable of measuring losses with time resolution around 10ms. A new Joint Experiment to support development of a FILD in ITER is currently under consideration.

Contribution: **P1.13** / Magnetic Confinement Fusion

ACTIVATION ANALYSIS OF THE DNFM DIAGNOSTICS DETECTOR MODULE

Kashchuk Yu., Kumpilov D., Obudovsky S., Portnov D., Rodionov R.

Project center ITER, Moscow, Russia

Numerical modelling of Divertor Neutron Flux Monitor (DNFM) activation for standard irradiation scenario on ITER SA2 has been carried out. The calculations were performed using MCNP C-model-181031 of neutron transport and FISPACT activation model.

DPA (displacement per atom) value dynamics during irradiation, activity and inventory dynamics during cooling are obtained. Also contact dose rate as a function of cooling time is calculated. All these modelling results will be presented in the Radwaste Checklist.

As a calculations verification a series of experiments are carried out, where niobium, aluminum and ftoroplast samples were irradiated. Activity measurements were compared to ones obtained in calculations.

Contribution: **P1.14** / Basic and Astrophysical Plasmas

Statistical characteristics of Thomson scattering data

Donald H. McNeill

consultant

Thomson scattering has been widely used to measure the electron temperature of plasmas for over 50 years. It is essentially a counting experiment. The distributions of detected photons (photoelectrons) in a number of channels yield an estimate of the scattered light spectrum and, thereby, of the plasma electron temperature. With repeated measurements, this leads to a range of values of the measured electron temperature for fixed plasma parameters (density and temperature). The spread in the temperature values is typically broader toward high temperatures. This spread is intrinsic to the measurements, as actual data samples and simulations show. Here a two-channel analytic model of the distribution of temperature readings from non-relativistic, thermal plasmas is used to obtain an intuitive picture of the significance of data from this means of measurement. The model is applied to data from two early experiments over an extremely wide range of electron densities: a shock tube with electron densities up to 7•10^22 /m^3 and a microwave heated plasma with densities as low as 5•10^17 /m^3. The model is consistent with the patterns of observed data from these and many other experiments. It can, for example, help identify artifacts of the diagnostic response, such as apparent high temperatures and, supplemented by data from additional detector channels, deviations from a thermal electron population, electron drift, and relativistic effects. This is a chance to look in a modern way at some metrological features of this well-established measurement technique.

Contribution: **P1.16** / Magnetic Confinement Fusion

Preliminary study of a visible, high-resolution spectrometer for DEMO divertor survey

W. Gonzalez, W. Biel, Ph. Mertens, M. Tokar, O. Marchuk, Ch. Linsmeier,

(All)
Forschungszentrum Jülich GmbH, Institut für Energie- und Klimaforschung - Plasmaphysik, 52425 Jülich, Germany

Developments towards DEMO Diagnostic and Control (D&C) system conceptual design are based on a subset of ITER mature diagnostic systems [1], whose eligibility for DEMO has been endorsed by their robustness, long lifetime expectancy and feasible remote maintenance [2], devoted to ensure the machine operation in compliance with safety requirements and high availability. In particular, the evolution of divertor spectroscopic measurements on fusion experiments have demonstrated their potential as diagnostic control method for divertor protection via detachment control [3] [4] (near ultraviolet, 300 – 400 nm) and follow-up and monitoring of the plasma–wall interaction (visible range, 400 – 700 nm) [5]. It makes this method one of the leading candidates for DEMO detachment and radiation control power. In line with the application of a system engineering approach [6], initial assessments of design and feasibility of a VIS high resolution spectrometer for the DEMO divertor survey based on early DEMO control requirements are presented and discussed. The proposed system is located at the equatorial port and it is composed of 3 oblique lines of sights, 9 toroidal mirrors, 6 plane mirrors and 6 spectrometers examining the outer, inner and X-point divertor region, optimized for the monitoring of chord-integrated NUV/VIS signals from divertor plasmas. The wavelengths of interest, spatial resolution and main integration issues are reported.

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Contribution: **P1.17** / Magnetic Confinement Fusion

Benchmarking of CXRS modelling against JET experimental data

S.V. Serov*, S.N. Tugarinov*, M. von Hellermann**

* Institution "Project Center ITER", Moscow, Russia
** FZJ Institute for Energy and Climate Research IEK-4, Juelich, Germany

One of the primary methods of fusion plasma diagnostics is charge exchange recombination spectroscopy (CXRS). It is a spectroscopy of charge exchange-excited emission lines, originating from the region of interaction of fusion plasma with neutral beam. CXRS is widely used at many modern tokamaks to measure radial profiles of ion temperature, ion density and plasma rotation velocity. Charge exchange recombination spectroscopy will be an important diagnostic on the ITER, as it will measure main plasma parameters determining the efficiency of the fusion reaction.
One challenge of CXRS development for ITER is the preparation of CXRS data processing means. For this task, the structure of CXRS spectra should be known in detail. Therefore, it is important to have a modelling tool that will allow predicting CXRS spectra for ITER. In this work predictions were carried out using Simulation of Spectra code, created specially for CXRS spectra modelling. Simulation of Spectra code was benchmarked against experimental results on JET using several different discharges. Simulation of Spectra predictions were reasonably close to the experimental spectra, but some modelling aspects could be improved. It was shown that Simulation of Spectra code could be used to model ITER CXRS spectra, and synthetic spectra is expected to be close to the future experimental results. So it could be used to develop data processing means.

Contribution: **P1.19** / Magnetic Confinement Fusion

Michelson interferometer diagnostic for electron cyclotron emission measurement on SST-1: Overview of system assembly, transmission line layout, in-la

*A. Sinha [1], D. Mohanta [1], S. K. Pathak [1], J Fessey [2], S. Schmuck [2] and P. Trimble[2]

[1] Institute for Plasma Research, HBNI, Bhat, Gandhinagar, India
[2] CCFE-Culham Science Centre, Abingdon, OX14 3DB, UK
* abhishek@ipr.res.in

A fast scan Fourier transform Michelson interferometer has been installed on SST-1 tokamak at IPR. The instrument will measure the electron cyclotron emissions generated from SST-1 high temperature plasmas in the frequency range of 70-500 GHz. The system hardware assembly details have been discussed and basic principle of operation is explained. Assembly of front end system and its interfacing with the back end has been described. To reduce transmission losses, the layout of transmission line from SST-1 hall to the system has been done using oversized S-band waveguides and mitre bends in TE01 mode. The design and simulation of the oversize transmission line has been done using CST microwave studio. Insertion and return loss determined through simulation in the frequency range 70-170 GHz have been verified with laboratory measurements. In-lab calibration of the diagnostics has been carried out with hot – cold technique in the frequency range 70-500 GHz by periodic switching between the cold source (at 77 K) and room temperature source. Digital signal filtering and coherent averaging of the raw data is done to obtain difference interferograms. The difference interferograms are Fourier transformed and by using Rayleigh-Jeans law, the sensitivity of the diagnostics is determined. The in-lab calibration factor has been successfully determined and the presence of water absorption lines was observed at its expected frequencies. To reduce the averaging time and improve the signal to noise ratio during absolute calibration, a new high temperature calibration source has been developed. The developed calibration source can operate at a temperature of 873 K with a maximum temperature variation of 10 K. Radiation temperature of the calibration source has been measured and radiation losses have been calculated in the entire frequency range. Results of transmission line simulation, in-lab calibration and calibration source characterization has been presented in the paper.

Contribution: **P1.20** / Magnetic Confinement Fusion

Energy and Pitch Angle Resolved Escaping Beam Ion Measurement by Faraday-cup-based Fast Ion Loss Detector in Wendelstein 7-X

K. Ogawa, S. A. Bozhenkov, S. Äkäslompolo, C. Killer, O. Grulke, D. Nicolai, G. Satheeswaran, M. Isobe, M. Osakabe, M. Yokoyama, R. C. Wolf, and the W7-X team

National Institute for Fusion Science, National Institutes of Natural Sciences, Toki, Japan
SOKENDAI (The Graduate University for Advanced Studies), Toki, Japan
Max-Planck-Institute for Plasma Physics, Greifswald, Germany
IEK4-Plasmaphysik, Forschungszentrum Jülich, Germany

Study of fast-ion losses due to magnetic field ripples and fast-ion-driven magnetohydrodynamic (MHD) modes is an important research topic regarding fusion-born alpha particles in a reactor. In Wendelstein 7-X (W7-X), experiments with neutral beam (NB) injection started in August 2018. To study the beam ion loss, a Faraday-cup-based fast ion loss detector (FILD) was designed and installed on W7-X as a joint cooperative project between National Institute for Fusion Science and Max-Planck-Institute for Plasma Physics. The FILD consisting of a set of apertures and thin aluminum foils is capable of measuring the absolute flux, the pitch angle, and the energy of escaping fast ions simultaneously. Feasibility study for installing the FILD was performed using orbit following simulations with NIFS Lorentz orbit code and with ASCOT guiding center orbit code. It was found that sufficiently high signal consisting of barely co-passing transit and trapped particles is expected in the FILD mounted on the movable Multi-Purpose Manipulator. The layout of apertures and eight Faraday films (two ranges in energy and four ranges in pitch angle) was designed based on the NLSDETSIM code providing energy and pitch angle grid. Electrical current from each Faraday film is carried to the low input impedance current amplifier and an isolation amplifier. Measurements of beam ion losses were performed in MHD quiescent plasmas with short pulse NB injections (~50 keV, 1.5 MW, and 75 degrees injection angles) in reference configurations in September 2018. The FILD revealed that the loss of trapped beam ions having the energy of ~50 keV and the pitch angle of approximately 100 degrees increases/decreases synchronously with the perpendicular NB injection. The signal level was microampere order, as predicted by the ASCOT simulation. The detailed design and the results of the escaping beam ion measurements will be reported in this presentation.

Contribution: **P1.21** / Magnetic Confinement Fusion

Development of capillary plate neutron detector filed with liquid scintillator by using recoiled-particle trajectory analyses

Takeo Nishitani1, Yasunobu Arikawa2, Hidetaka Kishimoto2, Isao Murata2, Kunihiro Ogawa1,3, Neng Pu3, and Mitsutaka Isobe1,3

1National Institute for Fusion Science, National Institutes of Natural Sciences, 322-6 Oroshi-cho, Toki 509-5292, Japan
2Osaka University, Suita 565-0871, Japan
3SOKENDAI (The Graduate University for Advanced Studies), 322-6 Oroshi-cho, Toki 509-5292, Japan

New 14 MeV neutron detector using capillary plate with liquid scintillator is under development aiming at the triton burnup study on the deuterium plasma experiment at the Large Helical Device (LHD). A capillary plate 25 mm in diameter, 10 mm in thickness, and 10 μm pitch honeycomb structure is used as a detector head. The scintillating light trajectory is measured by an Electron-Multiplying CCD (EMCCD) via relay lenses with a minimum temporal resolution of 1 μs. A trajectory of a proton recoiled by a neutron is linear, and the trajectory length depends on the recoiled proton energy. On the other hand, the trajectory of an electron produced by gamma-ray is not straight due to the random walk of the electron in the scintillator. Therefore, we can identify 14 MeV neutrons from 2.45 MeV neutrons and gamma-rays by the trajectory length and the shape.
The basic characteristics have been evaluated by using accelerator-based 2.45 and 14 MeV neutron source at the Osaka University OKTAVIAN facility, and also MeV range hard X-ray at a photon factory. Also, those trajectories are simulated by the Particle and Heavy Ion Transport code System (PHITS). Maximum trajectory length is estimated to be 2 mm and 0.05 mm for 14 MeV neutron and 2.45 MeV neutron, respectively. Measured trajectories are consistent with the simulation by the PHITS code. The developed detector has been installed in the basement of the LHD torus hale just under the vertical collimator embedded in the floor concrete for the second deuterium plasma campaign of LHD in 2018. The trajectories of 14 MeV neutrons are identified. However, noises mainly induced by gamma-rays on the EMCCD are remarkable. Gamma-ray and neutron shields should be improved toward the next deuterium plasma campaign in 2019. This work was supported by JSPS KAKENHI Grant Number 17H03513.

Contribution: **P1.22** / Magnetic Confinement Fusion

JET Enhanced Diagnostic Capabilities and Scientific Exploitation in Support of Deuterium-Tritium Campaigns

J. Figueiredo1,2, A. Murari1,3, C. Perez Von Thun1,4, D. Marocco5, M. Tardocchi6, F. Belli5, M. García Muñoz7, A. Silva2, T. Craciunescu8, P. Blanchard9, I. Balboa10, N. Hawkes10, I. S. Carvalho2, B. Tal11, J. Bernardo2,12, I. Zychor13, V. Kiptily10 and JET contributors*

1 EUROfusion Programme Management Unit, Culham Science Centre, Abingdon, United Kingdom
2 Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Portugal
3 Consorzio RFX (CNR, ENEA, INFN, Universita' di Padova, Acciaierie Venete SpA), Padova, Italy
4 Forschungszentrum Jülich GmbH, Institut für Energie- und Klimaforschung – Plasmaphysik, 52425 Jülich, Germany
5 Unità Tecnica Fusione - ENEA C. R. Frascati,via E. Fermi 45, 00044 Frascati (Roma), Italy
6 IFP-CNR, via R. Cozzi 53, 20125 Milano, Italy
7 Universidad de Sevilla, Sevilla, Spain
8 The National Institute for Laser, Plasma and Radiation Physics, Magurele-Bucharest, Romania
9 Ecole Polytechnique Fédérale de Lausanne (EPFL), CRPP, CH-1015 Lausanne, Switzerland
10 CCFE, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK
11 Wigner Research Centre for Physics, P.O. Box 49, H - 1525 Budapest, Hungary
12 JET Exploitation Unit, Culham Science Centre, Culham, OX14 3DB, UK
13 Narodowe Centrum Badań Jądrowych (NCBJ), 05-400 Otwock-Swierk, Poland

JET upcoming deuterium-tritium campaign, DTE2, is scheduled to take place before the end of 2020. Regarding diagnostic developments, for many years JET diagnostics have been upgraded in order to provide adequate support for the scientific exploitation of a D-T campaign, with particular attention to the experimental and operational conditions expected during deuterium-tritium campaigns. Diagnostic capabilities relevant for burning plasmas conditions have been specifically targeted with the focus mainly on fast ions, instabilities, neutron, gamma, ion temperature and operations support. JET diagnostic capabilities and obtained experimental results relevant for the scientific exploitation of the upcoming DT operations are discussed.

Contribution: **P1.23** / Magnetic Confinement Fusion

Observation of the TESPEL-injected impurities behavior by the PHA system at Wendelstein 7-X

Monika Kubkowska a, Naoki Tamura b,c, Agata Chomiczewska a, Tomasz Fornal a, Marta Gruca a, Natalia Krawczyk a, Sławomir Jabłoński a, Leszek Ryć a, Rene Bussiahn d, Rainer Burhenn d, Ulrich Neuner d, Henning Thomsen d and the W7-X team

a Institute of Plasma Physics and Laser Microfusion, Hery 23, 01-497 Warsaw, Poland
b National Institute for Fusion Science, National Institutes of Natural
Sciences, 509-5292 Toki, Japan
c SOKENDAI (The Graduate University for Advanced Studies), 509-5292 Toki, Japan
d Max Planck Institute for Plasma Physics, 17491 Greifswald, Germany

The PHA system at Wendelstein 7-X (W7-X) is a broad energy range spectrometer dedicated for the observation of impurity behavior during the plasma discharges. The system measures spectra in the range between 0.5 and 20 keV, from integrated signals along three lines of sight that crosses close to the plasma center. During the recent operational phase of W7-X, the TESPEL (tracer-encapsulated solid pellet) injector was commissioned. Impurity pellets with a single tracer element as well as with multiple tracers have been injected into the W7-X plasmas. The multiple tracer injection allows to study the behavior of various impurities in the same plasma conditions. The temporal resolution of the PHA system in the order of 60-100 ms is sufficient to observe differences in impurity transport time of injected impurities. Collected PHA spectra consist of K-alpha lines of vanadium, manganese and nickel in the case of the triple-tracers, and of iron in the case of the single tracer. The temporal evolution of these K-alpha lines has been obtained in various plasma conditions, which will be presented and discussed in the contribution.

Contribution: **P1.24** / Magnetic Confinement Fusion

Hardware design and beam modeling of the imaging heavy ion beam probe diagnostic at ASDEX Upgrade

G. Birkenmeier [1,2], J. Galdon-Quiroga1 [1], V. Olevskaia1 [2], M. Sochor [1], E. Wolfrum [1], G. Anda [3], S. Zoletnik [3], M. Garcia-Munoz [4], J.F. Rivero-Rodriguez [4], E. Viezzer [4], and the ASDEX Upgrade Team [1]

[1] Max Planck Institute for Plasma Physics, Garching, Germany
[2] Physics Department E28, Technical University Munich, Garching, Germany
[3] Wigner RCP, EURATOM Association HAS, Budapest, Hungary
[4] Centro Nacional de Aceleradores (CNA), Universidad de Sevilla, Seville, Spain

A new diagnostic concept consisting of a neutral heavy alkali beam and a compact scintillator based beam detector is developed at the ASDEX Upgrade tokamak. A neutral beam of an energy of 70 keV is injected into the fusion plasma, where it is ionized generating a fan of secondary beams which are deflected by the magnetic field and detected with a scintillator plate in the limiter shadow of the tokamak. Since this diagnostic concept allows to image the light emission of the scintillator by means of a high speed camera, it is called the imaging heavy ion beam probe (i-HIBP). The light pattern on the scintillator contains radial information on the density, electrostatic potential and the magnetic field in the edge region of the plasma. Therefore, the i-HIBP provides radially resolved data with high time resolution for the investigation of the dynamics of the edge current density, pedestal modes and ExB flows several centimeters inside and outside the last closed flux surface. For the design of the i-HIBP, a detailed beam model including the 3D tokamak magnetic field and beam attenuation effects for Cesium and Rubidium atoms is used in order to find the optimum injection scheme for maximum signal intensities within the limited space of the tokamak environment. It is found, that charge-exchange processes have to be taken into account since their contribution to the ionization of the primary beam is of the same order as the electron impact ionization collisions. Based on the optimized injection, the arrangement of the injector outside the vacuum-vessel and the detailed design of the optical in-vessel system is developed. A sensitivity study is carried out in order to determine, which plasma phenomena can be investigated with the i-HIBP within the parameter range of ASDEX Upgrade plasmas.

Contribution: **P1.25** / Magnetic Confinement Fusion

Fast measurements of the ion temperature in the scrape-off layer of the COMPASS tokamak

J. Adamek,1 A. Devitre,2 D. Cipciar,3 J. Horacek,1 M. Peterka,1 M. Tichy,4 R. Panek,1 COMPASS Team

1 Institute of Plasma Physics of the CAS, Prague, Czech Republic
2 Faculté des Sciences et Technologies, Université de Lorraine, Vandoeuvre-lès-Nancy, France
3 Faculty of Science, Masaryk University, Brno, Czech Republic
4 Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic

The ion temperature, Ti, is one of the most important yet elusive parameters of toroidal fusion plasmas. In the scrape-off layer (SOL) of tokamaks, Ti measurements are typically performed with retarding field analyzers and limited to a few kHz. We hereby present a new method, using the ball-pen probe (BPP) [1], which measures Ti with a temporal resolution up to 50 kHz. By design, most of the electrons are screened from the BPP collector, resulting in a symmetric I-V characteristic with floating potential approximately equal to the plasma potential. The electron
branch of the characteristic is the sum of an ion current, exponentially decaying with coefficient Ti , and an electron current, saturated or linearly increasing with the probe voltage. Since the ions are transported to the shielded collector by Larmor motion and E×B drifts [2], Ti is obtained from the exponential part of the electron branch if the collector is retracted by approximately one ion Larmor radius. We have performed a systematic measurements of the Ti in SOL of the COMPASS
tokamak during L-mode discharges. In this contribution we present evaluations of I-V characteristics with respect to Ti with low (1 ms) and high (10 µs) temporal resolution.

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Contribution: **P1.26** / Magnetic Confinement Fusion

Optimization of the collective Thomson scattering system on Wendelstein 7-X

I. Abramovic (1,2), D. Moseev (2), T. Stange (2), S. Marsen (2), W. Kasparek (4), S. K. Nielsen (3), A. Tancetti (3), M. Salewski (3), A. Pavone (2), J. Svensson (2) R. C. Wolf (2), H. P. Laqua (2), N. J. Lopes Cardozo (1) and W7-X Team

(1)Eindhoven University of Technology, Eindhoven (The Netherlands)
(2)Max - Planck Institute fur Plasma Physik, Greifswald (Germany)
(3)Technical University of Denmark, Kgs. Lyngby, (Denmark)
(4)University in Stuttgart, Stuttgart (Germany)

Collective Thomson scattering (CTS) is a microwave diagnostic allowing measurements of a number of plasma parameters such as the bulk ion temperature, plasma composition, drift velocities and fast ion velocity distribution function. A CTS system has been successfully installed and commissioned on the Wendelstein 7-X (W7-X) stellarator during experimental campaigns in 2017 and 2018. A high power gyrotron is used as a source of probing radiation, which is scattered off plasma fluctuations. The scattered radiation is recorded by means of a sensitive heterodyne receiver equipped with a data acquisition system with a sampling rate of 6.25 GSamples/s. The measured spectra are analyzed by the means of the CTS forward model eCTS [1] and the Minerva [2] scientific framework enabling the use of Bayesian inference of relevant plasma parameters. We present these first CTS results and discuss further optimization of the CTS diagnostic. We focus on three topics which impact the inference quality
of plasma parameter values from CTS spectra: appearances of parametric decay instability (PDI), influence of impurities on CTS spectra and the width of the notch filters employed to protect the receiver from high power radiation. PDI’s are three-wave interactions which give rise to radiation interfering with CTS measurements, resulting in strong sidebands in CTS spectra [3]. We discuss the scenarios in which PDI’s have been observed on W7-X and explore the implications of the results for future CTS measurements. Furthermore we show
the results of our study of the influence of the notch width on the inference quality of bulk ion temperature and plasma impurity content. These two topics are considered jointly because the notch filters block radiation in the vicinity of the probing frequency - the region modified by the presence of impurities.

Contribution: **P1.28** / Magnetic Confinement Fusion

Measurement of the electron temperature by soft x-ray pulse height analyzer on J-TEXT

Z. Y. Chen, W. Yan, Z. Y. Yin, Z. J. Yang

International Joint Research Laboratory of Magnetic Confinement Fusion and Plasma Physics, School of Electrical and Electronic Engineering, Huazhong University of Science and Technology

A soft x-ray pulse height analyzer (PHA) to obtain the center electron temperature and to monitor the content of the heavy impurities has been developed in the J-TEXT tokamak. This diagnostic system combined with the fast Silicon Drift Detector (SDD). The fast SDD allow the measurement of x-rays at high count rates, up to 150 kHZ. The performance and first experimental results from the PHA system are presented.

Contribution: **P1.30** / Magnetic Confinement Fusion

Five-channel tunable W-band Doppler backscattering system in the Experimental Advanced Superconducting Tokamak

X. Feng,1 A.D. Liu,1 C. Zhou,1 M.Y. Wang,2 J. Zhang,1 Z.Y. Liu,1 Y. Liu,3 T.F. Zhou,3 S.B. Zhang,3 D.F. Kong,3 L.Q. Hu,3J.X. Ji,1H.R. Fan,1 H. Li,1 T. Lan,1 J.L. Xie,1 W.Z. Mao,1 Z.X. Liu,1 W.X. Ding,1G. Zhuang,1 and W.D.Liu1

1.KTX Laboratory and Department of Engineering and Applied Physics, University of Science and Technology of China, Anhui Hefei 230026,China
2.Department of Physics, Nanchang University, Nanchang 330031,China
3.Institute of Plasma Physics, Chinese Academy of Sciences, Anhui Hefei 230031,China

Doppler backscattering (DBS) system has been widely used in magnetically confined fusion devices to provide the density fluctuation and the perpendicular velocity of turbulence. A 5-channel W-band Doppler backscattering system with X-mode polarization has been designed and installed in the Experimental Advanced Superconducting Tokamak (EAST) to provide five spatially localized measurement locations in 2018 campaign. Through an I/Q -type double sideband (DSB) modulator and a frequency multiplier, an array of five finely spaced (Δf=400 MHz) and flattened frequencies that span 1.6 GHz has been created. The center of the array bandwidth is tunable within the range of 75–97 GHz, which covers most of the W band (75-110 GHz). The radial location coverage is depended on the parameter of discharge, and can always cover the range from the top of pedestal to the core of plasma. The incident angle can be adjusted from -4°to 12°, and the wavenumber range is 4-15/cm with a wavenumber resolution of Δk/k≤0.35.

Contribution: **P1.31** / Magnetic Confinement Fusion

Effect of reflections on 2D tomographic reconstructions of filtered cameras and on interpreting spectroscopic measurements in the JET ITER-like wall d

J. Karhunen 1, M. Carr 2, J.R. Harrison 2, I. Balboa 2, P. Carvalho 3, M. Groth 1, A. Huber 4, B. Lomanowski 5, G.F. Matthews 2, S. Silburn 2 and JET Contributors 6

1 Aalto University, Department of Applied Physics, Espoo, Finland
2 CCFE, Culham Science Centre, Abingdon, UK
3 Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Lisboa, Portugal
4 Institut für Energie- und Klimaforschung – Plasmaphysik, Forschungszentrum Jülich, Jülich, Germany
5 Oak Ridge National Laboratory, Oak Ridge, TN, USA
6 See the author list of X. Litaudon et al., Nuclear Fusion 57 (2017) 102001

Enhanced spatial accuracy and significant reduction of background artefacts have been observed in experimentally resolved 2D line emission distributions in the JET divertor by considering reflections from metallic wall surfaces in generation of tomographic reconstructions of tangentially viewing visible-range spectroscopic divertor cameras [1-3]. Using ray tracing and a model for surface reflectivity and roughness, contributions of divertor and main chamber light sources to divertor camera images via reflections are integrated in the geometry definition of the tomography process [3]. Consequently, comparability between experiments and divertor modelling and localization of line-integrated divertor spectroscopy measurements are improved.

Comparisons between tomographic reconstructions of Balmer D alpha emission in different JET discharges with reflections considered and neglected indicate that reflections intensify the recorded emission by 10—30% in the brightest emission regions extending from the strike points into the divertor volume towards the X-point. In the regions between these main emission clouds and the reflecting surfaces, reflections are found to account for up to 60% of the recorded emission. This implies that neglecting reflections in the reconstruction process overestimates the emission intensity and expands its spatial distribution towards the wall surfaces in the private-flux region or SOL in horizontal and vertical target configurations, respectively, as the reflected light is falsely interpreted as plasma emission.

Mimicking divertor spectroscopy measurements by integrating the tomographic reconstructions along vertical lines-of-sight implies that reflections comprise 10—30% of the observed line-integrated emission. The spatial differences in the reflection contribution between the different lines-of-sight are less pronounced than in the 2D tomographic reconstructions due to the majority of the lines-of-sight passing through the bright emission regions. However, post-processing EDGE2D-EIRENE simulations using the CHERAB code [4,5] and synthetic spectroscopy [6] suggests overestimation of the spectroscopically inferred divertor electron temperature by up to a factor of 2—4, if reflections are neglected.

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Contribution: **P1.32** / Magnetic Confinement Fusion

Simulation of X-ray conversion into primary electrons in GEM-based detector

K. Malinowski^a, M. Chernyshova^a, T. Czarski^a, E. Kowalska-Strzęciwilk^a, P. Linczuk^a, A. Wojeński^b

a- Institute of Plasma Physics and Laser Microfusion, Hery 23, 01-497 Warsaw, Poland
b- Warsaw University of Technology, Institute of Electronic Systems, Nowowiejska 15/19, 00-665 Warsaw, Poland

ABSTRACT

The Gas Electron Multiplier (GEM) is a device that is used in many physical experiments. The GEM device, which was developed at our institute for tokamak research [1], allows visualizing, among others, the energy spectrum of soft-X radiation in the range of 2-20 keV. They observe also additional lines associated with the emission of fluorescent radiation from the materials the detector is built from. This is particularly noticeable in the case of the copper line, when radiation with energies above 9 keV is recorded.

In order to better understand the phenomena accompanying the conversion of X-rays into primary electrons in the GEM-based detector and to get to know their quantitative character, a series of simulations was performed in the Geant4 software [2]. It consisted of simulating the interaction of X-rays of different discrete energies with the structure of the GEM device. The program used allowed taking into account such phenomena as the emission of photoelectrons, Auger electrons and fluorescence. As a result, the energy distributions of primary electrons formed in the area of the detector chamber (drift) were obtained. The distributions of primary electrons, which are the source of electron avalanches in the device under study, are directly responsible for the distribution of pulses on the detector reading anode. Some measurements were also performed, confirming the compatibility of simulated spectra and experimental ones.

The main conclusion from the simulation is the need to eliminate copper from the detector structure, especially from GEM foils and from the reading electrode. An observable, parasitic contribution to the spectrum recorded by the detector also is given by several other materials.

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Contribution: **P1.33** / Magnetic Confinement Fusion

High Bandwidth Diagnostics for MAST-U Using FPGA Technology

Charles Vincent, Graham Naylor, Scott Allan, Roddy Vann, Joe Allen, Ray Sharples

Durham University
York University
United Kingdom Atomic Energy Authority, Culham Centre for Fusion Energy

As simulations become increasingly precise it becomes necessary to constrain and verify results with increasingly precise data. This calls for high bandwidth, cost effective, data acquisition systems. Field Programmable Gate Array (FPGA) technology is a form of hardware programmable computer useful for high bandwidth I/O applications. This makes them ideal for research applications where flexibility is highly valued. I will present two systems built for use on the Mega Amp Spherical Tokamak Upgrade(MAST-U) located at Culham Centre for Fusion Energy (CCFE) in Oxfordshire, UK. The first is a fission chamber acquisition system for neutron detection which provides single pulse counting, DC current measurement and Campbell mode simultaneously at a rate of 1 MHz. The system applies a real-time finite impulse response (FIR) filter to improve neutron pulse detection and increase the Signal-to-Noise Ratio (SNR). Calibration work at the NationalPhysical Laboratory (NPL) has been used to calibrate and benchmark the system. The second is the Synthetic Aperture Microwave Imager 2 (SAMI-2). This diagnostic will measure the edge current density on MAST-U using two-frequency 2-D dopplerbackscattering. Data will be collected from 32 antennas, using a novel planar and sinuous design, at 2 polarisations, and then packaged and sent using 10 Gigabit ethernet to Intelnetwork cards installed in an acquisition PC. Both systems use Consumer-Off-The-Shelf(COTS) components to provide high data rate custom instrumentation. This work is supported by the Engineering and Physical Sciences Research Council[EP/L01663X/1 and EP/s018867/1], and by the RCUK Energy Programme [Grant NumberEP/P012450/1].

Development of NPA Array Using Single Crystal CVD Diamond Detectors

Shuji Kamio, Yutaka Fujiwara, Kunihiro Ogawa, Mitsutaka Isobe, Ryosuke Seki, Hideo Nuga, Takeo Nishitani, Masaki Osakabe, and the LHD Experiment Group

National Institute for Fusion Science, National Institutes of Natural Science
SOKENDAI (The Graduate University for Advanced Studies)

In order to investigate the confinement physics of the energetic particles (EPs), neutral particle analyzer (NPA) array is newly developed using single crystal CVD diamonds in the large helical device (LHD). The diamond detectors are adopted because of their high radiation hardness for the high-neutral flux in the deuterium experiments. For the initial experimental campaign, two detectors were installed at the lower port of the vacuum chamber. The detectors are located at z=-7.77 m to measure helically trapped EPs generated by perpendicularly injected neutral beams.
As the results of the diamond NPA (DNPA) commissioning in the last LHD experimental campaign, it is confirmed that the DNPA successfully detected the EPs. The pulse counting rate due to the neutron-induced noise are several kcps in the highest neutron flux discharge. This noise counting rate is low enough to measure the EPs. We will report the details of the DNPA measurement system and its initial results from these experiments.
As future works, additional seven channels will be installed. The main target of this diagnostic is to reveal behavior of the EPs from the perpendicular neutral beam injectors. The EPs accelerated by ion cyclotron range of frequency wave will also be observed from the next deuterium experimental campaign.

Contribution: **P1.35** / Magnetic Confinement Fusion

Neutron flux evaluation by a single crystal CVD diamond detector in LHD deuterium experiment

Makoto Kobayashi[1,2], Kunihiro Ogawa[1,2], Mitsutaka Isobe[1,2], Takeo Nishitani[1], Shuji Kamio[1], Yutaka Fujiwara[1], Masaki Osakabe[1,2], and the LHD Experiment Group[1]

[1]National Institute for Fusion Science, National Institutes of Natural Sciences
[2]SOKENDAI (The Graduate University for Advanced Studies)

Neutron field generated in the deuterium experiment in the large helical device (LHD) needs to be evaluated for the radiation safety point of view. The diamond detector has potentials for measuring fast neutron, energetic charged particles, and gamma-ray. Also, it has the capability for measuring the neutron capture reaction by lithium and boron which emit alpha particle in the reaction with thermal and/or epi-thermal neutron. In this study, the single crystal CVD diamond detector was newly installed into LHD. The energetic particles caused by the nuclear reaction of neutron in lithium fluoride (LiF) foils were measured during deuterium plasma operation in LHD.

The single crystal CVD diamond detector was placed underneath 9.5L port of LHD. The LiF foils with the 99.62 % Li-6 and 99.9993 % Li-7 enrichments were stuck on the detector. The detector was exposed to the neutron generated in the deuterium plasma in LHD to acquire the pulse heights (PH) by energetic particles.

The pulse height spectrum (PHS) for Li-6 enriched LiF foil showed double peaks. In the $^{6}Li(n,\alpha)^{3}H$ reaction, an alpha particle and tritium with the energies of about 2.1 MeV and 2.7 MeV are generated, respectively. The former particle would be detected in the lower PH region, and the latter would be in higher PH region in PHS. Also, with increasing the thickness of LiF foil, the PHS showed a broad single peaks. The PHS for Li-7 enriched LiF showed a single peak in lower PH region. Also, the count rate with respect to the neutron yield in the plasma drastically decreased compared to that for Li-6 enriched LiF.

In the presentation, the calculation results for neutron transport around the detector and the energetic charged particle transport in the LiF foils will be given for evaluating the application of diamond detectors on neutron measurement.

Contribution: **P1.36** / Magnetic Confinement Fusion

Integrated polychromator and data acquisition system for the laser Thomson scattering diagnostic

A. Lizunov, T. Berbassova, A. Khilchenko, A. Kvashnin, E. Puryga, P. Zubarev

Budker Institute of nuclear physics, 630090 Novosibirsk, Russia

New experiments with bigger electron temperatures in the gas dynamic trap (GDT) magnetic mirror requires a substantial upgrade of the Thomson scattering diagnostic. The paper presents the recently developed polychromator based on interference filters, which has the data acquisition and processing system onboard. The six spectral channels have wavelength pass bands distributed from 900 nm to 1057 nm to enable measurements of the electron temperature in the range from 10 eV to approximately 2 keV. The optimized design of the detection module with the avalanche photodiode (APD) and the signal amplifier yields the transmission factor of 5×10^6 V/W in the bandwidth of 1÷250 MHz in the high-speed acquisition channel. For a 1064 nm laser pulse of 10 ns duration, the amplifier noise is equivalent to 10 photons. Every detection module is also equipped with the low-speed (0÷1 kHz) acquisition channel for separate measurements of background plasma radiation. This option also enables an easy calibration of the spectral response function using a continuous-wave light source. The high-speed detection channel utilizes the “time stretch” principle. It uses the 6 GSample/s analog memory arranged in the switched capacitor array to hold the signal piece of the 200 ns duration, which is then processed by a relatively slow 14-bit digitizer. The acquisition and readout sequence can be cycled at the frequency of up to 25 kHz providing the necessary time resolution in experiments with multiple laser beam pulses. The polychromator onboard data processing electronics is controlled by the System-on-Chip (SoC) solution with the time-critical functions implemented in the Field Programmable Gate Array (FPGA).
Lab test results along with first plasma measurements are shown in the paper. Our design of the data processing facility offers a cost-effective approach for the Thomson scattering diagnostic and similar systems with a large channel count.

Contribution: **P1.37** / Beam Plasmas and Inertial Fusion

Plasma Diagnositcs for Laser Megajoules

Eric Compain, Wilfried Glastre, Grégroy Wauters, Julien Marque, Jean-Baptiste Haumonté

Bertin Technologies

Plasma fusion control implies using several dozens of different diagnostics instruments implemented in harsh environments: high vacuum (10-5 Pa, leakage <10-10 Pa.m^3/s)
and high neutron flux (up to 10^14 n/cm^2.s) and nuclear heating (up to 1000 °C) and magnetic field (up to 6 T) as well as significant electromagnetic noise due to the auxiliary radiofrequency heating systems. Several plants in Europe (ITER, LMJ, JET, W7X, WEST etc.) and over the world (EAST, KSTAR, JT60, etc.) are involved in this work leading
to the design and manufacture of specific innovating diagnostics in. In this market, Bertin Technologies appears as an integrator of advanced technologies with strong skills in Optronics and Image Processing as well as in Neutronics.

The Laser Mega Joule (LMJ) facility is using several diagnostics for analyzing and imaging the target in the scope of VUVs, X-Rays, Gammas and Neutrons. Time resolution of the target emissions leads to use fast electrical devices (sensors and fast oscilloscopes) as ultra-fast cameras.
Bertin Technologies is responsible to integrate the nine first plasma diagnostic analyzers. They comprised 1-D High Voltage streak cameras and 2-D gated detectors (MCP), coupled to CCD read-out systems and embedded control electronic modules designed by BT. They are packaged inside an hermetically sealed chamber surrounded by a W shielding, operating in a harsh environment induced by fluxes of neutrons, X-rays and gammas.

In addition Bertin is also responsible of preliminary & final design, manufacturing, qualification, installation of 3 Plasma Diagnostics in order to perform several key measurments during the fusion reaction. Bertin is currently developping :
- DP5 - VISAR (Velocity interferometer System for Any Refector) and Choc Visualisation for temperature, speed, reflectivity and light emmissivity of materials measurements.
- DP7 & 8 able to perform spectral measurment of the back-scattered light in and outside the vacuum chamber.

UV Timing Fiducial for X-Ray Streak Camera: LMJ Experimental Results

Laurent REMY

CEA, DAM, DIF, F-91297 ARPAJON France

The Laser MegaJoule (LMJ) facility near Bordeaux in France is designed to study the high-energy-density plasma produced by inertial confinement of a deuterium-tritium target. Among all the plasma diagnostics surrounding the target chamber, inserted streak cameras are currently the fastest X-ray imagers available at LMJ for 1D observation of the imploding target. Their temporal resolution can reach less than 20 ps.

Timing is critical to understand the physics of laser-plasma interaction. Analyzing the 1D resulting image requires (i) to know precisely the delay between the time at which the high power laser pulses hit the target and a reference time marker on the image and (ii) to measure sweep speed as it may be altered by the electromagnetic environment.

In this regard, ultra-low jitter UV laser pulses are generated in the vicinity of the streak camera. Two optical fibers illuminate the back of the streak camera photocathode. For the reference time marker, a single UV laser pulse guided by the first fiber is delayed with respect to the LMJ timing system with less than 12 ps RMS jitter. The second fiber guides a 25 UV pulses comb up to 13 GHz repetition rate to measure the streak camera sweep speed inhomogeneity during the experiment.

A timing fiducial prototype for X-Ray streak camera has been installed and successfully tested at LMJ during year 2018. We provide here an overview of both the UV timing fiducial system and the experimental results obtained at LMJ.

Contribution: **P1.39** / Beam Plasmas and Inertial Fusion

3D simulations of Photonis® P510/PSU streak tube

S. Champeaux(1), C. Chollet(1), E. Schyns(2) and C. Goulmy (2),

(1) CEA, DAM, DIF, F-91297 Arpajon, France
(2) PHOTONIS France, Avenue Roger Roncier, 19100 Brive La Gaillarde

Streak cameras are one of the fastest available instruments enabling high speed photonic phenomena to be observed by direct imaging. Streak cameras are routinely operated for experiments on laser facilities. Such opto-electronic instruments offer one-dimensional time-resolved imaging from the IR through X-rays.
Fusion diagnostic community requires optical recording instruments achieving both high resolution and high dynamic range measurements. In this regard, the image converter tube is a key component of a streak camera. In order to meet requirements for fusion diagnostics, the CEA has embarked on a simulation program to support the development of upgraded streak tubes. Improving performances of X-Ray Photonis P853X bilamellar streak tube is one of the CEA main concerns.
3D simulation of streak tubes is carried out by using the commercial software package CST Particle Studio that enables to self-consistently describe the relativistic motion of charged particles in both static and time-varying 3D electromagnetic fields.
In this simulation program, the Photonis P510 cylindrical ps tube of rather simpler geometry is meant as a preliminary step to validate CST Particle Studio Simulations of streak tubes through benchmarking with experiments.
The main features and properties of the P510 tube response in UV-Visible range are retrieved in static mode. The typical limitations of cylindrical geometry are also recovered. The influence of the photocathode emission law on the tube performances is underlined. The sweep mode of operation with a 25 ns time base is also accounted for. Finally, the overall current the tube can deliver without degrading the performances is determined and the regions in the streak tube most susceptible to space charge effects are identified.

Contribution: **P1.40** / Magnetic Confinement Fusion

Development of Electron Cyclotron Emission Imaging system on J-TEXT Tokamak

Z. J. Yang1, X. L. Xie1, X. M. Pan1, C. W. Domier2, Y. L. Zhu2, G. Y. Yu2, J. H. Cao2, J. Zhou1, H. Zhou1, Y. P. Zhang1, N. C. Luhmann, Jr.2

1. International Joint Research Laboratory of Magnetic Confinement Fusion and Plasma Physics, State Key Laboratory of Advanced Electromagnetic Engineering and Technology, School of Electrical and Electronic Engineering, Huazhong University of Science and Technology, Wuhan, 430074, China
2. Davis Millimeter Wave Research Center, University of California, Davis, California 95616, USA

A new electron cyclotron emission imaging (ECEI) system has been developed for J-TEXT. The diagnostic contains two dipole antenna arrays corresponding F band (90-140GHz) and W band (75-110GHz) respectively and totaling 256 channels. The design of ECEI electronics module is improved with the use of lots of digital chips. An excellent optical system which permits the two arrays to focus on a wide continuous range or two separate ranges with high imaging spatial resolution and field curvature correction is designed. An F-band back wave oscillator and a W-band source (active multiplier chain, driven by a USB synthesizer) are adopted as local oscillators (LO). A new generation of LO optics with a hyperbolic lens has been designed for uniform power deposition across the entire antenna array. Remote control for the whole ECEI is realized for the first time. It can control the focusing optics, attenuation and center frequency in electronics module, frequency of LO sources and so on. Based on the new ECEI system, some MHD actives have been observed on J-TEXT.

Contribution: **P1.41** / Beam Plasmas and Inertial Fusion

Neutron Detection System for PW Laser Facility

Hongjie Liu

Research Center of Laser Fusion,CAEP

Scintillator detectors in inertial confinement fusion experiments are predominantly used to measure neutron yield and ion temperature of the primary fusion reactions.The measurement of neutrons on PW laser facilities is much more challenge since it requires the detection system to recover from a high background orders of magnitude stronger than the signal of interest.We optimized the compositions of the liquid scintillator and presented several designs of the neutron detection system using the Geant4 Code and the X-lab Code. Our liquid scintillator is based on PPO, dissolved in xylene and enriched with molecular O2. The detector consists of a 2-3 liters volume of liquid scintillator coupled to a gated MCP. The neutron sensitivity was calibrated on K-400 accelerator. The gating performance under high-intenstiy Gama radiation was experimently checked. The typical flying time spectrum of the neutrons from (p,n) reactions driven by a PW laser was obtained on Xingguang-III facility. The neutron yield in the experiments on Shenguang-II U facility was successfully measured.

Contribution: **P1.42** / Magnetic Confinement Fusion

Assessment of tomography signals in view of neural network reconstruction

Rúben Cardoso, Horácio Fernandes, Diogo R. Ribeiro, Daniel Costa, Diogo Carvalho, Hugo Alves e Humberto Figueiredo

Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico

Tomography conducted on fusion devices can be affected by the reflexion of light on the walls. A study of light behavior inside the metallic section of tokamak ISTTOK was performed and presented, showing that the inner vessel surface acts as an optical system capable of reflecting and focusing light, causing detector measurements that resemble those caused by direct incidences. The method used consisted on a cylindrical gas-discharge lamp placed at various radial and poloidal positions inside the tokamak vessel, the emitted light was detected by two cameras with 16 lines of sight placed on the equatorial plane of the low field side and top part of the tokamak. The acquired signals were analyzed in order to understand the contribution of distance and angle towards the total power detected by each camera's pixel. It is shown that the effects of stray light resultant from reflections on the walls are not negligible and its consideration will allow a correct tomographic reconstruction.

Contribution: **P1.43** / Beam Plasmas and Inertial Fusion

Development of an adjustable Kirkpatrick-Baez microscope for laser driven x-ray sources at CLPU

G. Zeraouli 1,2,*, G. Gatti 1, J. Antonio Perez 1, A. Longman 3, D. Arana 1, D. Batani 4, K. Jakubowska 4, , L. Volpe 1,2, R. Fedosejevs 3 and L. Roso 1,

1 CLPU, Centro de Laseres Pulsados, Building M5, Science Park, Calle Adaja s/n, 37185 Villamayor, Salamanca, SPAIN
2 University of Salamanca, Edificio de Rectorado, Patio de Escuelas, 1, 37008 Salamanca, SPAIN
3 University of Alberta, 116 St & 85 Ave, Edmonton, AB T6G 2R3, Alberta, CANADA.
4 CELIA, Centre des Laser Intenses et Applications, 351, Cours de la Libération, F-33405 Talence cedex, FRANCE

A promising prototype of a highly adjustable Kirkpatrick-Baez (KB) microscope has been designed, built and tested in a number of laser driven x-ray experiments using the high power 200 TW (VEGA-2) laser system of the Spanish Centre for Pulsed Lasers (CLPU). The presented KB version consists of two, perpendicularly mounted, 500um thick silicon wafers, coated with a few tens of nm layer of platinum unlike the conventional, and coated, millimetre thick glass substrates, affording more bending flexibility and large adjustment range. According to simulations, and based on total external reflection, this KB microscope offers a broad-band multi-keV reflection spectra, allowing more spectral tunablity than conventional Bragg crystals. In addition to be vacuum compatible, this prototype is characterised by a relatively small size (21cm×31cm×27cm) and permits remote control and modification of both the radii of curvature (down to 10m) and the grazing incidence angle (up to 60 mrad). A few examples of focusing performance tests, limitations and experimental campaign results are discussed.

Contribution: **P1.44** / Magnetic Confinement Fusion

EVALUATION OF PLASMA PARAMETERS AND EXPERIMENT ON THE PF -30 INSTALLATION

A.M. Zhukeshov, A. U. Amrenova, Z.M. Moldabekov , K.Serik

Kazakh National University named after al-Farabi

The use of focus plasma in thermonuclear reactors last time was discussed by many authors, but now there is no clear understanding of the processes occurring there. The study of dense plasma flows forming in a high-power pulsed discharge is important, first of all, for the understanding of the structure and dynamics of fast and dense plasma formations. With an adequate level of understanding of these processes, new prospects are opening up for the creation of a fusion reactor, in which the main role is not played by plasma heating, but by its formation and structuring. The power of the PF-30 installation is up to 35 kJ, the discharge current is up to 1200 kA, the pulse is 7 μs. The objective of this study is to theoretically calculate the parameters of a dense plasma and then compare with the experiment when operating the PF-30 unit with Meiser-type electrodes with an aspect ratio of 2.6. At first calculated the fundamental parameters of PF device : flight time, velocity and concentration. Further carried out the calculation of energy parameters, include discharge current and neutron yield. Various calculation models were used.

According to the results of a preliminary assessment of the conditions of formation of the plasma focus, it can be concluded that the creation of a plasma focus installation requires limiting parameters for the speed of the storage and switching equipment, taking into account the current state of the techniques. Calculations show that with a discharge current in the kiloampere range, a completely measurable neutron yield is expected, as well as rather high temperatures and densities typical of hot plasma. But despite this, experiments showed that the plasma energy parameters, if not to take measures to significantly reduce the inductance of the system, are insufficient for strong pinch compression.

Contribution: **P1.45** / Magnetic Confinement Fusion

Development of Multi-channel Dual Correlation Reflectometer Based on Multiplexer Technique

P. W. Shi, Z. B. Shi, W. L. Zhong, Z. C. Yang, G. L. Xiao, W. Chen, M. Jiang, J. Wen, K. R. Fang, Yi Liu, Q. W. Yang, M. Xu and X. R. Duan

Southwestern Institute of Physics
PO Box 432, Chengdu 610041, People¡¯s Republic of China

A novel multi-channel dual correlation microwave reflectometer has been developed on the HL-2A Tokamak. The reflectometer is characterized by multiple fixed-frequency array source with a multiplexer technique. The multiplexer-based source provides 31-37GHz microwave. The output powers are around 20dBm with low power imbalance (<3dB), which are enough for dual launchers and separated receivers. Thus, the diagnostic can not only routinely detect density fluctuations and perpendicular flow velocity, but also enable simultaneous measurement of correlation characteristic of density fluctuations with same probing frequencies in radial and toroidal or poloidal directions, depending on the arrangement of antennas. The system has been put into use in the last experimental campaign and the capabilities and flexibilities are demonstrated. Preliminary results about long-range correlation and characterizing instability modes will be presented.

Contribution: **P1.46** / Magnetic Confinement Fusion

The stray laser light simulation and optimized mechanical design of beam dump for Thomson scattering system in HL-2M tokamak

Chunhua LIU, Yuan HUANG, Zhen FENG, Yuqin WANG and Zhipei HOU

Southwestern Institute of Physics

Laser beam dump is one of the critical components of Thomson scattering (TS) system to decrease stray laser light to acceptable level. Two compact beam dumps are needed to absorb residual laser energy of HL-2M TS system. Chevron beam dump has a compact structure, and the lifetime of which manufactured by molybdenum materials, under the harsh thermal and electromagnetic loads could meet the demand of TS system in ITER, as well as TS system of HL-2M. But compared with a beam dump that is setup outside the machine, the stray laser light caused by an inside beam dump maybe much stronger to seriously influence the scattered light measurement, and there is no references discussed the problem before. So it is important to simulate the stray laser light caused by the chevron beam dump.

In order to analyze its mechanical structure and simulate the stray laser light caused by it, bi-directional reflection distribution function (BRDF) of molybdenum is measured by scatterometer at 532 nm. Then the surface properties of Mo material are loaded into the ray-tracing software to simulate the stray laser light emitting from the beam dump. The light source parameters are the same as that of TS system on HL-2M. Light absorbing threshold is 1E-10. the ray-tracing simulation results show that the stray laser light emits in the cone angle of approximate 65 degree. Simulation results show that increase the height of entrance port could not decrease effectively the cone angle. But after a reflecting cover is added in front of the beam dump, the stray laser light emits in the cone angle 23 degree. In this condition, the strength of stray laser light directly entering into collection widow becomes acceptable. So the optimized chevron beam dump could be utilized to absorb laser energy on HL-2M TS system.

Contribution: **P1.47** / Basic and Astrophysical Plasmas

A new double crystal calibration system for absolute X-ray emission measurements

L Hobbs, S Brant, K Brent, D Hoarty and C Bentley

AWE Plc

Over the past few years work has been conducted at AWE to accurately characterise X-ray diffraction crystals to allow for absolute measurements of X-ray emission for our Orion opacity campaigns. Diffraction crystals are used in spectrometers on Orion to record the dispersed spectral features emitted by the laser produced plasma to obtain a measurement of the plasma conditions. Previously based on a Manson X-ray source, our calibration system struggled to attain high signal at the low energies required in calibration, for, for example, use of aluminium as a tracer for higher atomic number experiments. Here we present data from the newly commissioned ctx400 X-ray source, a twin anode, water cooled system, showing it to be a bright source even for ~ 1keV energies.

Contribution: **P1.48** / Magnetic Confinement Fusion

Recent Doppler backscattering applications in Globus-M tokamak

A.Yu. Yashin 1,2, V.V. Bulanin 1,2, A.V. Petrov 1, V.K. Gusev 2, G.S. Kurskiev 2, V.B. Minaev 2, M.I. Patrov 2, Yu.V. Petrov 2

1 Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia
2 Ioffe Institute, St. Petersburg, Russian Federation

Recently, a four-frequency Doppler backscattering (DBS) system was installed on the Globus-M tokamak. In addition to the classical DBS application for determining the mean plasma rotational velocities, DBS was used for the investigation of different plasma oscillatory processes in the spherical Globus-M tokamak. Application of various DBS data processing allowed us to reveal and investigate such plasma oscillations as geodesic acoustic mode, limit-cycle oscillations and Alfvén modes. It has been shown that DBS also allows registering filament-like structures, which manifest as quasi-coherent oscillations in signals of various DBS channels. The multi-frequency DBS system makes it possible to determine localization of plasma oscillations, their poloidal and radial sizes and mode structure. The main results of the DBS application for the study of these oscillations and their interaction with plasma turbulence are presented. A comparison of the DBS data with the data of other diagnostics is also given.

Contribution: **P1.49** / Beam Plasmas and Inertial Fusion

Brilliant and energetic alpha-particle source based on proton boron nuclear fusion

Lorenzo Giuffrida[1], Fabio Belloni[2], G.A.P. Cirrone[1,3], Giada Petringa[3], Valentina Scuderi[1,3], Giuliana Milluzzo[3], Andriy Velyhan[1], Marcin Rosinski[4], Antonino Picciotto[5], Milan Kucharik[6], Jan Dostal[7], Josef Krasa[1], Valeria Istokskaia[1], Pierluigi Bellutti[5], Georg Korn[1], Daniele Margarone[1].

1Institute of Physics ASCR, v.v.i (FZU), ELI-Beamlines project, Prague, Czech Republic,
2European Commission, Directorate-General for Research and Innovation, Directorate Energy, Brussels, Belgium,
3Laboratori Nazionali del Sud, INFN, Catania, Italy,
4Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland
5Micro-Nano Facility, Center for Materials and Microsystems, Fondazione Bruno Kessler, Trento, Italy
6Czech Technical University in Prague, FNSPE, Prague, Czech Republic,
7Institute of Plasma Physics of the ASCR, PALS Laboratory, Prague, Czech Republic

The nuclear reaction known as proton-boron fusion has been triggered with a record yield using a sub-nanosecond laser system focused onto a thick boron nitride target at modest laser intensity (~10^16 W/cm2). The estimated yield leads to values around 10^11 alpha particles per laser pulse, thus orders of magnitude higher than any other result previously reported.
We used a kinetic model for explaining our experimental achievements in term of total amount of alpha particles generated in the laser-matter interaction and their angular distribution. In such model, protons generated inside the plasma, moving forward into the bulk of the target, can interact with B atoms, thus triggering proton boron nuclear reactions.
Furthermore, an overview of results obtained with different laser parameters, experimental setups and target compositions present in literature is reported for a comprehensive overview of the mechanisms involved in this neutron-less nuclear fusion reaction occurring in a laser-generated plasma.

Keywords: proton-boron fusion, alpha-particles, nanosecond laser, neutron-less nuclear reaction

Contribution: **P1.50** / Beam Plasmas and Inertial Fusion

Brilliant and energetic alpha-particle source based on proton boron nuclear fusion

Lorenzo Giuffrida1, Fabio Belloni2, G.A.P. Cirrone1,3, Giada Petringa3, Valentina Scuderi1,3, Giuliana Milluzzo3, Andriy Velyhan1, Marcin Rosinski4, Antonino Picciotto5, Milan Kucharik6, Jan Dostal7, Josef Krasa1, Valeria Istokskaia1, Pierluigi Bellutti5, Georg Korn1, Daniele Margarone1.

1Institute of Physics ASCR, v.v.i (FZU), ELI-Beamlines project, Prague, Czech Republic,
2European Commission, Directorate-General for Research and Innovation, Directorate Energy, Brussels, Belgium,
3Laboratori Nazionali del Sud, INFN, Catania, Italy,
4Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland
5Micro-Nano Facility, Center for Materials and Microsystems, Fondazione Bruno Kessler, Trento, Italy
6Czech Technical University in Prague, FNSPE, Prague, Czech Republic,
7Institute of Plasma Physics of the ASCR, PALS Laboratory, Prague, Czech Republic

The nuclear reaction known as proton-boron fusion has been triggered with a record yield using a sub-nanosecond laser system focused onto a thick boron nitride target at modest laser intensity (~10^16 W/cm2). The estimated yield leads to values around 1011 alpha particles per laser pulse, thus orders of magnitude higher than any other result previously reported.
We used a kinetic model for explaining our experimental achievements in term of total amount of alpha particles generated in the laser-matter interaction and their angular distribution. In such model, protons generated inside the plasma, moving forward into the bulk of the target, can interact with B atoms, thus triggering proton boron nuclear reactions.
Furthermore, an overview of results obtained with different laser parameters, experimental setups and target compositions present in literature is reported for a comprehensive overview of the mechanisms involved in this neutron-less nuclear fusion reaction occurring in a laser-generated plasma.

Keywords: proton-boron fusion, alpha-particles, nanosecond laser, neutron-less nuclear reaction

Contribution: **P1.51** / Magnetic Confinement Fusion

Impact of thermal environment on metal resistor bolometers and concepts for compensation

F. Penzel(1), H. Meister(1), N. Jaksic(1), D. Hermann(1), A. Pataki(1), , L. C. Ingesson(2), R. Reichle(3)

(1) Max Planck Institute for Plasma Physics, Boltzmannstr. 2, 85748 Garching, Germany
(2) Fusion for Energy, c/ Josep Pla nº 2, Torres Diagonal Litoral B3, 08019 Barcelona, Spain
(3) ITER Organization, Route de Vinon-sur-Verdon, CS 90 046, 13067 St. Paul Lez Durance Cedex, France

Metal resistive bolometry is the state of the art measurement technique used in stellarator and tokamak fusion experiments to determine the radiant power from the plasma. The incident power is deduced from the temperature gradient measurement between measurement and reference absorber using a four-wire resistance thermometer in a Wheatstone bridge configuration. Since the measurement principle relies on the temperature gradient measurement, it is intrinsically sensitive to all non-global environmental temperature changes.

High power or long plasma discharges, such as foreseen in ITER or W7-X, create new challenges for the thermal design and signal analysis of the diagnostic as they can generate local thermal fluxes resulting in spurious drift signals. The reduction of this thermal interference by thermal isolation or direct cooling of the sensor is often limited by other design requirements. A compensation method is required which works reliably during a multitude of standard operation conditions and other unforeseen accidental thermal load conditions.

In this paper, two methods of external thermal gradient drift compensation for metal resistor bolometers are described and discussed. A method using thermal finite element modeling and local temperature measurements in order to predict the approximate spurious drift signal and a method compensating the erroneous signals by direct gradient measurement with a completely shadowed bolometer channel. Also, the influence from internal black body radiation of camera sub-components is considered. Finally, the resulting levels of uncertainty with and without the compensation methods are quantified and the advantages and drawbacks of both methods are assessed.

Contribution: **P1.52** / Magnetic Confinement Fusion

Improvement of Light Collection Systems for KSTAR Thomson Scattering Diagnostic

Jong-ha Lee (a), Ha-jin Kim (a), Jong-su Jeon (b), Young-ju Kim (c)

(a) National Fusion Research Institute, Daejeon, Korea
(b) Yoonseul Co., Daejeon, Korea
(c) Yunamoptics Inc., Gyeonggi-do, Korea

A Thomson scattering diagnostic consists of four system : a laser, a light collection system, spectroscopy, and a digitizing system. The Korean Superconducting Tokamak Advanced Research (KSTAR) Thomson scattering system also have four system, however cause of superconducting tokamak, we need a cassette (like as port-plug in ITER) system to diagnose a plasma. This cassette system mounted on the cryostat and the length is 1.8 m long. For this reason, when plasma disruption occurs, the vibration impact is transferred to the collection lens in the cassette as it is, causing the problem of Thomson scattering signal measurement. To solve this problem, an anti-vibration lens support system was installed, and lighten the weight of collection optics (Core , Edge) with upgrade the collection lens performance through new lens design. Simulation of this new lens design has confirmed that vignetting and the modulation transfer function (MTF) are improved compared with previous lenses [1]. For the new design, the core lens, the F-number (F-#) more than doubled from 2.26 (old lens) to 5.9 (new lens), the weight of the core lens was reduced from 26 kg to 18 kg. In case of the edge lens, the F-# increased 1.75 times compared with old lens, and the weight of the lens decreased from 23 kg to 12 kg. KSTAR campaign in 2018, improved light collection optic systems were used and measured Thomson signals without vibration effect. This research explains newly designed lenses and briefly describes collection lens support system.

Contribution: **P1.53** / Magnetic Confinement Fusion

Upgrade of FMCW reflectometer on HL-2A tokamak

YangZC,ShiZB,ZhongWL,ZhangBY,LiangAS

Center for Fusion Science

The measurement of electron density, including profile and fluctuation, is very basic and important for physics research on tokamak.The diagnostic of frequency modulated continuous wave(FMCW) reflectometer is upgraded for a higher spatio-temporal resolution, which is valuable for transport studies and verification of theoretical models.

The Q and V band(30-50, 50-75GHz) FMCW reflectometers have been upgraded to rapid sweeping on HL-2A. Two methods for dynamic calibration of vector controlled oscillator(VCO) are developed, the dispersion of microwave both in waveguide and cable are considered, and the control waveform of VCO is improved by considing of inverse Fourier transform. All the improvements are achieved without any hardware modification, and now the sweeping time is shorten to 6us with the dead time less than 100ns.

The details of the methods for diagnostic improvement will be presented. And the partical transmission during the ELM burst, rebuild of the pedestal, and tearing mode will also be reported.

Contribution: **P1.54** / Magnetic Confinement Fusion

Development of a calibration system for the compact pinhole NPA on HL-2A/M

ZANG Linge1, LU Jie1, LUO Xiaobing2, WAN Lin2, FU Hongtao2, YU Liming1, SHI Zhongbing1, , LIU Yi1, YANG Qingwei1,

1 Southwestern Institute of Physics, Chengdu, Sichuan, China
2 Institute of Nuclear Science and Technology, Sichuan University, Chengdu, Sichuan, China

In the high-temperature fusion plasma, the neutral particle born in the charge-exchange reaction between a hot ion and a neutral, keep almost the same energy with the ion reactant. The neutral particles are not confined by magnetic field, so a significant numbers of them can escape from the plasma without suffering a collision. An equipment to detect these escaped neutrals and provide the energy or/and mass spectrum is named neutral particle analyzer (NPA). In the field of fusion plasma research, NPA is the key tool for ion temperature measurement [1], energetic ion physics study [2], and fusion fuel density ratio (T/D) measurement [3].

The multi-spatial channel compact pinhole NPA (CP-NPA) has been developed for HL-2A tokamak [4]. CP-NPA has 11 spatial channels, with 2.2° view angle for each channel. The system uses a gas stripping cell, electrostatic analyzer, and channel electron multiplier (CEM) detectors. The designed energy measurement range is 1-70keV. Temporal resolution is adjustable. CP-NPA will be installed on HL-2M tokamak as a diagnostic tool for fast ion.

CP-NPA will be maintained and calibrated using an energetic neutral source. This neutral source is based on a small ion accelerator system. The source has the following features: Source Particle: H or/and D; Energy range: 0.5-70keV; Beam current: ~ 20μA; Small energy dispersion; Beam spot: < 5mm2. To calibrate different channels of CP-NPA, we will side lay the CP-NPA and rotate it on a platform. Axis of rotation is at the center line of the slit. In this way, with a single neutral beam, all the detectors could be calibrated.

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Contribution: **P1.55** / Magnetic Confinement Fusion

Hard X-ray pinhole camera system in the HL-2A tokamak

Y.P. Zhang,1,a) D. Mazon,2,a) P.F. Zhang,1 Y. Peysson,2 X.L. Zou,2 J. Zhou,1 H.B. Xu,1 X. Y. Bai,1 J. Zhang,1 T. Hoang,2 L. Delpech,2 A. Ekedahl,2 X.M. Song,1 B. Lu,1 Z.B. Shi,1 Yi Liu,1 Q.W. Yang,1 M. Xu,1 X.R. Duan,1 and the HL-2A team

1 Southwestern Institute of Physics, P.O. Box 432, Chengdu 610041, China
2 CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France

A hard x-ray (HXR) pinhole camera has been developed recently for the HL-2A tokamak to measure the spatial and temporal evolution of the fast electron bremsstrahlung (FEB) emission in the HXR energy range between 20 and 200 keV, enhancing the understanding of the physics on fast electrons [1] and low hybrid waves (LHWs) [2]. The camera has 21 measuring channels, which are arranged on a sector. HXR detection is performed by integrated CdTe semiconductors. With a perpendicular viewing into the plasma on the equatorial plane, the HXR spectra with eight energy channels of width =20 keV are obtained by each chord. The time and space resolution of the camera can reach 4-8 ms and 2-3 cm, respectively.

Measurements of the fast electrons using the camera have been successfully performed in the 2018 HL-2A experiment campaign. A large number of energetic electrons with 40-60 keV are produced during LHCD, and then, these electrons lead to the enhancement of the runaway electron generation. Moreover, the spatial distribution of the energetic electrons during LHCD has a peaked profile, suggesting that the energetic electrons are produced mainly in the plasma core. It also suggests that the energy of the LHW mainly deposited in the plasma core.

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Contribution: **P1.56** / Magnetic Confinement Fusion

Advancements of quasi-optical system for Electron Cyclotron Emission Imaging diagnostic on J-TEXT tokamak

X. L. Xie, Z. J. Yang, J. Zhou, Y. L. Zhu, N. C. Luhmann Jr.,X. M. Pan and G. Zhuang

International Joint Research Laboratory of Magnetic Confinement Fusion and Plasma Physics, School of Electrical and Electronic Engineering, Huazhong University of Science and Technology, Wuhan, 430074, China

The new quasi-optical system of electron cyclotron emission imaging (ECEI) diagnostics on J-TEXT tokamak has been developed and tested. The quasi-optical system consists of two subsystems: the imaging optics for plasma imaging and the local oscillator (LO) optics for mixers driving. For the updated demands, some modification and adaptation are accomplished on the imaging optics subsystem. Some general performance tests such as refractive index, zoom ratio, focus capability and field curvature are completed which match with the simulation value with the permissible scale. As for LO optics subsystem, the test results of two sets of newly designed LO optics, spherical LO optics and hyperbolic LO optics, demonstrate high performance. The uniform power deposition can fully meet driven power of all the mixers to minimize insertion loss and elevate the power coupling efficiency. Despite of this, for the various experimental requirements on J-TEXT, the entire optical system is capable of fine real-time adjustment via a novel default remote control system.

Contribution: **P1.57** / Magnetic Confinement Fusion

Spectrometer of fast neutrons and gamma rays based on stilbene scintillator in the Gas Dynamic Trap device

E.I. Pinzhenin, A.D. Khilchenko, P. V. Zubarev, A. N. Kvashnin.

Budker Institute of Nuclear Physics, Novosibirsk, Russia

The report present results of development, calibration and first plasma experiments in the Gas dynamic trap of neutron/gamma spectrometer based on stilbene sctitillator, PMT 9266B and Field-Programmable Gate Array (FPGA). Frequency gradient analysis method was implemented for identification neutrons and gamma events. Spectrometer operated in real time and count rate up to 2 10^5/sec was shown in experiments of neutron registration in GDT. Radionuclide gamma sources were used for energy scale calibration of spectrometer gamma channel. The neutron channel energy calibration was carried out using accelerator-based neutron sources with deuterium-deuterium (2.45 MeV) and deuterium-tritium (14.1 MeV) fusion reactions. Efficiency of neutron/gamma separation and energy resolution of the spectrometer were studied in wide range of spectrometer operation conditions.

The stilbene based neutron/gamma spectrometer was used in GDT deuterium plasma campaign. The registered spectrum of recoil protons (in neutron channel of the spectrometer) corresponded to energy of 2.45 MeV. The experiments with Electron cyclotron heating of GDT plasma shown that population of electrons with energy more than 100 keV was formed in some experimental conditions. The properties of the bremsstrahlung, which is formed when such particles are lost, were studied using the stilbene based spectrometer. These results will be presented in a report.

Contribution: **P1.58** / Magnetic Confinement Fusion

Impact of injecting different TESPEL-types on Wendelstein 7-X plasmas

R. Bussiahna, N. Tamurab,c, K.J. McCarthyd, M. Beurskensa, S. Bozhenkova, H. Damma, G. Fucherta, E. Pascha, E. Edlunde, M. Porkolabf, Z. Huangf, L.-G. Böttgera,g, O. Grulkea,g, A. von Stechowa, , R. Burhenn (a), B. Buttenschön (a), K.J. Brunner (a), J. Knauer (a), , A. Langenberg (a), O. Marchuk (h), N. Pablant (i), N. Chaudhary (a), , M. Hirsch (a), U. Höfel (a), J. W. Oosterbeek (a), the LHD experiment group and the W7-X team,

(a) Max-Planck-Institut für Plasmaphysik, Teilinstitut Greifswald, Germany
(b) National Institute for Fusion Science, National Institute of Natural Science, Toki, Japan
(c) SOKENDAI (The Graduate University for Advanced Studies), Toki, Japan
(d) Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Madrid, Spain
(e) SUNY Cortland, Cortland, NY, USA
(f) MIT Plasma Science and Fusion Center, Cambridge, MA, USA
(g) Technical University of Denmark, Kongens Lyngby, Denmark
(h) Forschungszentrum Jülich GmbH, Institut für Energie- und Klimaforschung - Plasmaphysik, Jülich, Germany
(i) Princeton Plasma Physics Laboratory, Princeton, NJ, USA

A newly installed tracer-encapsulated solid pellet (TESPEL) injection system was commissioned during the OP1.2b operational phase of Wendelstein 7-X (W7-X). A TESPEL consists of a hollow polystyrene shell, filled with specific tracer materials (typically 1e16 - 1e17 particles). While interacting with the hot plasma, the outer surface of the injected TESPEL is continuously ablated, thereby initially releasing particles of the polystyrene shell. At the end of the ablation process, the inner tracer material is suddenly released to the plasma. This method allows tracers to be deposited at a programmable location along the injection axis in a well-defined region of the plasma core, which is highly beneficial for impurity transport studies. The shell type (diameter and wall thickness) as well as the TESPEL speed are sensitive parameters for the penetration depth of the TESPEL and thus the impact on the plasma parameters, in particular plasma density and temperature. One of the significant effects caused by TESPEL injections is a transient reduction of the electron and ion temperature. In some cases, the electron temperature is increased after TESPEL injection above the pre-injection level. This might be attributed to a transient reduction of gradient-driven turbulence, as observed in density fluctuation spectra after TESPEL injection.
In this contribution, we report on the impact of different TESPEL configuarations (shell type, tracer species and amount) on the W7-X plasmas, i.e. plama parameters and resulting effects.

Contribution: **P1.60** / Magnetic Confinement Fusion

Two-crystal upgrade for High-Resolution X-ray Imaging Crystal Spectrometers on EAST

Bo Lyu

Institute of Plasma Physics, Chinese Academy of Sciences

Efforts to improve the performance of the X-ray imaging crystal spectrometers (XICS) were dedicated to identifying the solutions for both high time resolution and measurable temperature ranges with a focus on diagnosing the radio-frequency (RF) heated plasma rotation. Newly developed large-area pixelated two-dimensional detector was deployed for the first time on tokamaks to enable time-resolved and Bragg-diffracted X-ray imaging with good framing rate and water-cooling for in-vacuum long-pulse operations. Since measurable temperature ranges depends strongly on the species of the impurities, in order to effectively extend the measurable temperature limit, a two-crystal assembly was designed to employ both helium-like (He-like) and hydrogen-like (H-like) argon crystal slices such that two different spectra were recorded on the same detector by exploiting the detector width. High-quality He- and H-like spectra were observed simultaneously for the first time on one detector for a wide range of plasma parameters for inferring both ion temperature and rotation profiles to support studies on spontaneous rotation and RF physics. In addition, Abel-like inversion was applied to the line-integrated measurement, which was further complemented with comparison to the CXRS measurements to verify the obtained data. Eyeing on the development of XICS for ITER and CFETR, a crystal for measuring neon-like Xenon spectra was added to the poloidal XICS system and tested for Te up to 10keV for potential applications of Xe for future fusion reactor diagnostics.

Contribution: **P1.62** / Magnetic Confinement Fusion

A new electronic system for bolometric diagnostic based on metal foils on FTU device

G. Apruzzese, C. Neri, C. Monti, F. Pollastrone, A. Grosso, V. Piergotti, G. Rocchi, A. Sibio, B. Tilia and FTU Team

ENEA, Fusion and Technologies for Nuclear Safety Department,
C.R. ENEA Frascati, via E. Fermi 45, 00044 Frascati (Rome), Italy

Measurements of total radiated power are very important in tokamak plasma, especially in the divertor region where they are required for heat flux active control. Bolometric detectors based on metal foil are being used, with a golden absorber and more recently with a platinum absorber. In the last years on FTU tokamak a new compact electronic system has been developed in order to drive processes and acquire the signals from resistive bridge-based bolometer heads. The test carried out on the bolometric prototype has demonstrated its functionality moreover several improvements had to be considered. Since 2018 an update version of electronic system, including also the in-situ calibration, is under development. The aim of the project is to design and successively implement an architecture and a system sufficiently general in order to be applied to large fusion experimental machines or reactors, along their experimental life. The new project has been conceived for high reliability and lasting time. In this work, the new architecture of the new electronic system for the bolometric diagnostic will be presented and its improvements compared to the first protype.

Contribution: **P1.63** / Beam Plasmas and Inertial Fusion

Innovative X and gamma rays detection with Silicon and gas detectors coupled to microchip electronics for laser produced plasmas

D. Pacella1, G. Claps1, F. Cordella1, F. Murtas2, D. Batani3, O. Turianska3 , D. Raffestin3, L. Volpe4, G. Zeraouli4, J.A. Perez-Hernandez4, S. Malko4

1ENEA Fusion and Nuclear Safety Department, Via E. Fermi 45, 00044, Frascati, Italy
2INFN – Laboratori Nazionali di Frascati, Via Enrico Fermi 40, 00044 Frascati, Italy
3CELIA Université Bordeaux, 49 rue Pierre Noailles, 33405 Talence, France
4CLPU, Centro de Laseres Pulsados, Calle Adaja 8, 37185 Villamayor – Salamanca, Spain

Soft-X, hard-X and gamma rays produced in Laser Produced Plasmas (LPPs) are measured since many years with passive detectors (like X-ray film or Imaging Plate) or with indirect conversion, as the case of CCD and MCP. In the first case, the sensitivity is very poor, the response is not linear and is affected by background radiation. In the second case, multiple conversions imply a degradation of information, an increase in noise and a lack of energy sensitivity. Direct conversion of X and gamma radiation for laser plasma is now possible thanks to new hybrid detectors, made of solid state or gaseous sensors coupled with ASICs. Both type of detectors have been studied using the laser systems ECLIPSE in Bordeaux and, more recently, VEGA in Salamanca, a laser delivering hundreds of TW in about 30 fs pulse duration.

We first tested the gas detector with triple Gas Electron Multiplier (GEM) with front-end electronics based on four medipix chips. Its response, per pixel, is proportional to the charge released and, due to the GEM gain, the detector has a high dynamic range (up to 6 orders of magnitude), allowing even the detection of single photons. Thanks to the microchip design, thresholds can be adjusted in order to cut off the noise (noise-free) or reject unwanted radiation background. This detector has 512x512 pixels and offers good imaging properties, high efficiency, and absolute calibration. A scan in threshold allowed the discrimination of the spectra produced by laser on different solid targets. It offers a good immunity to EMP, as checked at VEGA laser facility. In these experiments, where the formation of warm dense matter produced by blast waves has been studied, the GEM detector has been filtered with different absorbers placed on the active area, in order to infer the electron temperature of the coronal plasma produced by the laser on the target.

The second innovative technique, successfully tested at VEGA in 2018, uses a Timepix3 C-MOS detector for hard-X and gamma rays measurements. This detector is realized with an ASIC of 256 x 256 pixels, bump-bonded with 300 µm thick Silicon pixellated layer. Each pixel is 55 µm x 55 µm and the active area is 14 mm x 14 mm. Since 300 µm is too thin for an efficient release of energy for the gammas, the detector is mounted in side-on configuration. In this case, the incoming radiation interacts with the Silicon through the entire depth of 14 mm, producing traces formed by multiple Compton electrons scattering. A variety of parameters have been defined: Cluster Size (CS), Time over Threshold (ToT), Linearity, Roundness, etc. Based on the ToT cluster value, we characterized the detector response using some known gamma sources and the Geant4 Monte Carlo simulations. This allows the discrimination between various energy bands for the gamma photons coming from the plasma. This technique allows the evaluation of the radiation maximum energy, up to many MeV. Experiments at VEGA-2 for the generation of energetic gammas revealed spectra arriving up to 4 MeV. A few shots had to be summed in order to have good statistics for the trace analysis. The obtained spectra were compared to results of another diagnostic: a bremsstrahlung canon providing a low-resolution hard X-ray spectrum (a stack of imaging plates separated by various filters).

The tested innovative detectors also have the advantages of being compact and cheap, opening therefore new perspectives for advanced evaluation of X and gamma radiation, produced in laser-plasma experiments, with high efficiency, high sensitivity, noise-free, rejection of background and flexibility.

Contribution: **P1.64** / Low-Temperature and Industrial Plasmas

Comprehensive quantitative plasma diagnostic using a mid-infrared frequency comb analysing an industrial plasma processes

Norbert Lang*1, Alexander D. F. Puth1, Sarah-Johanna Klose1, Grzegorz Kowzan2, Stephan Hamman1, Jürgen Röpcke1, Piotr Masłowski2, and Jean-Pierre H. van Helden1

1 Leibniz Institute for Plasma Science and Technology (INP),
Felix-Hausdorff-Straße 2, 17489 Greifswald, Germany
2 Institute of Physics, Faculty of Physics, Astronomy and Informatics,
Nicolaus Copernicus University, ul. Grudziądzka 5, 87-100 Toruń, Poland

We report on the use of mid-infrared broadband direct frequency comb spectroscopy (DFCS) as a novel plasma diagnostic applied to spectroscopic investigations of plasma nitrocarburizing processes. Active screen plasma nitrocarburizing (ASPNC) is an advanced technology for the hardening of steel components using pulsed N2-H2 plasmas with an active screen made of solid carbon to produce carbon-containing species, which support the generation of anti-corrosive layers of high quality. To gain further insights in the treatment process of the materials, spectroscopic investigations are carried out in a specially designed and downscaled plasma nitriding reactor based on an industrial scale ASPNC reactor.

With the wide spectral coverage of broadband DFCS many molecular species can be detected simultaneously with high sensitivity and time-resolution yielding comprehensive data on their kinetics in the plasma and their interactions with a surface. Our frequency comb has a repetition rate of 250 MHz and operates around 3.2 µm. The broadband transmission was analysed with a special kind of Fourier transform spectrometer (FTS), which has an optical path difference that is precisely matching the repetition rate of the FC. Consequently, the spectra are free from distortions caused by the instrumental line shape, which usually limits the resolution of FTS. The spectral coverage of the comb enables to record complete rovibrational bands of CH4, C2H2, C2H6, HCN, and NH3 in a single measurement with sub-nominal resolution. Furthermore, varying the repetition rate of the comb, the Doppler-limited line profiles of individual transitions could be analyzed with unmatched precision. As a result, this allowed not only for the determination of the absolute number densities of all identified absorbers, but also for the analysis of their translational temperatures as well as their internal rotational population distributions. The influence of process parameters, such as pressure and screen plasma power on these findings will be discussed.

Contribution: **P1.65** / Magnetic Confinement Fusion

Neutron diagnostics for DEMO

M. Cecconello[1] , S. Conroy[1] , G. Ericsson[1] , A, Hjalmarsson[1] , T. Franke[2] and W. Biel[3],

[1] Department of Physics and Astronomy, Uppsala University, EURATOM-VR Association, Uppsala, Sweden
[2] Max-Planck-Institut für Plasmaphysik and EUROfusion Power Plant Physics and Technology (PPPT) department, Garching, Germany
[3] Institute of Energy- and Climate Research, Forschungszentrum Jülich GmbH, Germany and Department of Applied Physics, Ghent University, Belgium

DEMO is the required step after ITER for the realization of a commercial fusion power plant and the first demonstration fusion power plant delivering electricity to the grid in the second half of the century.
The extremely harsh conditions in DEMO coupled with the limited access to the plasma pose unprecedented challenges to the diagnostics necessary to operate safely.
Neutron Diagnostics (NDs) are essential in DEMO for the measurement of the fusion power Pf density profile, the ion temperature in the core and expected to contribute to the real-time feedback plasma shape and position control system.
This paper discusses the conceptual design of the DEMO NDs in terms of their expected performances in delivering the required measurements during the flat-top (burn) phase. These include a Neutron Activation System (NAS), Fission Chambers (FCs) and Neutron Cameras (NCs).
The NCs system consists of two identical sets of horizontal and vertical NCs for a total of 50 lines of sight with diamonds and U238 FCs located outside the bio-shield. The two NCs will measure Pf with an accuracy better than 10 % up to 0.85 of the normalized poloidal flux coordinate with a time resolution equal to the energy confinement time (0.4 s) and the plasma position with the time resolution required by the plasma control system (1 ms).
The direct to scattered ratio is greater than 10 (10 MeV acquisition threshold). Integration of the NCs in DEMO is discussed. A set of ten U238 FCs will cover the flat-top dynamic range while four microFCs will complement the NCs for the plasma position measurement. Finally, six NASs will provide the absolutely calibrated local neutron fluence, which, in combination with Monte Carlo neutron transport codes, will support the absolute calibration of the FCs and NCs which is also briefly described.

Contribution: **P1.66** / Beam Plasmas and Inertial Fusion

Electron Optic modelling of Bilamellar Streak Tubes

Steven James, Anthony Meadowcroft, Kevin Oades

AWE Plc
Aldermaston
Reading
RG7 4PR

Bilamellar streak tubes are commonly used to measure transient optical phenomena with picosecond duration. Although such electron-optic devices have demonstrated temporal resolutions of less than 1 ps, the single laser-shot dynamic range is limited by space charge effects. The use of a slot aperture in the temporally dispersing direction is commonly employed to improve the temporal resolution by excluding populations of electrons at large ejection angles, but at the cost of reduced throughput. Such rejected electrons will still contribute to space charge effects in the tube including the acceleration region where the electrons have low velocity.

The electron behaviour was investigated a using computational tool (SIMION ion optics simulation program) to model the behaviour of electrons within such structures. The model was validated by comparing simulations with experimental results and examine the trade-off between throughput and temporal resolution. Estimates of the internal structure of the tubes are combined with realistic secondary electron energy distributions and emission angles in a high-speed Laplace solver and ion tracker. Based on these results, potential improvements to the tube design are examined and future work with Particle-in-cell simulations (CST) are discussed.

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Radiography of inertial confinement fusion implosions using hard X-rays generated by a short pulse laser

Yuchi Wu, Chao Tian, Minghai Yu, and Yuqiu Gu,

Science and Technology on Plasma Physics Laboratory, Research Center of Laser Fusion, China Academy of Engineering Physics, People's Republic of China

Short-pulse laser-driven hard X-rays can be used to achieve time-resolved radiographic images of implosion targets in inertial confinement fusion. This measurement technique is based on point-projection radiography at photon energies above 10keV. The backlighter source is generated by a short pulse beam driving a metal microwire on a low-Z substrate. We have successfully applied this radiography technique to the study of the compression of direct-drive and indirect-drive double shell targets on the SG-II Upgraded laser facility. Since the SG-II Upgrade laser facility is mainly designed for indirect drive, it will lead to high direct illumination non-uniformity of the target surface. 2D nonuniformities of the inner shell were clearly shown by these images. Furthermore, with indirect-drive approach, the image of the target near peak compression was obtained successfully with an Au microwire. Radiation hydrodynamic simulations were also carried out, and calculations agree well with the experimental results. Using the radiography images, areal densities of the targets are evaluated. The results are helpful for better understanding of the hydrodynamics of double shell and even triple shell target implosions.

Contribution: **P1.69** / Magnetic Confinement Fusion

Ion Collection by Flush Mounted Probes in Particle-in-cell Simulation

Aleš Podolník, Michael Komm, Renaud Dejarnac, James P. Gunn, Radomír Pánek

Charles University in Prague, Faculty of Mathematics and Physics, Institute of Plasma Physics of Czech Academy of Sciences
Institute of Plasma Physics of Czech Academy of Sciences
Institute of Plasma Physics of Czech Academy of Sciences
CEA, IRFM
Institute of Plasma Physics of Czech Academy of Sciences

Flush mounted probes (FMPs) are Langmuir probes designed particularly to survive high heat fluxes by the means of elimination of protruding electrode, which can be easily damaged in such environment. The interpretation of probe measurements is however affected by the magnetic field, mostly by its inclination with respect to the probe surface.

In this contribution, a study of ion collection by the probe will be presented, mostly aimed at description of the flux deposition atop the probe. It will be shown that distinct spatial features are present and their origin will be discussed. Magnitude of these features will be assessed with respect to the magnetic field inclination angle and magnitude. An effect of non-saturation of ion current part of current-voltage characteristic will be evaluated in the Larmor radius scan and methods of compensation for results measured by FMPs will be presented.

Results were obtained by particle-in-cell simulation code SPICE in both 2D and 3D geometry. Current-voltage characteristics of flush-mounted probes as well as steady state simulations will be evaluated for plasma conditions present in COMPASS tokamak scrape-off-layer. The probe geometry is based upon a probe briefly used in the device.

Contribution: **P1.70** / Magnetic Confinement Fusion

Mineral insulated cable assessment for inductive magnetic diagnostic sensors of a hot-wall tokamak

A. Torres 1,2, K. Kovarik 1, T. Markovic 1,3, J. Adamek 1, V. Weinzettl 1, I. Duran 1, B. B. Carvalho 2, H. Fernandes 2, J. Havlicek 1, M. Hron 1, R. Panek 1, O. Peroutka 1, K. Samec 1, D. Sestak 1

1 Institute of Plasma Physics of the CAS, Prague, Czech Republic
2 Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal
3 Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic

The COMPASS-U tokamak [1], designed to be a 5 T magnetic field device with a full-metal first wall and working at plasma-facing component temperatures up to 300 ºC, will start its operation in 2022 at IPP Prague. This device will address ITER and DEMO relevant plasma exhaust physics, including operation with liquid metal divertor.

Inductive magnetic diagnostics based on conductive loops of different geometry and orientation are crucial for magnetic confinement fusion devices. Due to the high temperatures of the vacuum vessel upon which they will be operated, a suitable cable insulation needs to be chosen carefully. In a number of existing experiments (e.g. KSTAR, DIII-D, TCV, JET) sensors made out of mineral-insulated cables (MIC) have proven to be compatible with high baking temperatures and thus are considered. However, the steel sheath of MIC affects the response of the sensor to the magnetic field at higher frequencies. Thus, it is crucial to ensure that the sensor cable has satisfactory parameters for real-time plasma control feedback and magnetic equilibrium reconstruction. For that end detailed characterization and testing of multiple cable samples was conducted.

Firstly, this contribution details the design challenges, such as spatial constraints at different positions across the vacuum vessel. Then, it reports on the testing of MgO MIC of different manufacturers and diameters ranging from 0.5 to 3.2 mm. Tests of prototype coils made of these cables were also performed. A range of electrical property measurements, such as frequency attenuation, resistance and capacitance, for each cable and sensor is presented, both at low and high temperatures up to 300ºC. Based on the presented results and taking all constraints into consideration, conclusions towards the final design of the sensors are drawn.

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Contribution: **P1.71** / Low-Temperature and Industrial Plasmas

Electric Characterization of Homemade AC Glow Discharge Plasma and Application on Fish Protein Films for Food Packaging

Magno Pinto Collares (a), Juan Rodrigo Meireles Oliveira (a), Viviane Patrícia Romani (b), Vilásia Guimarâes Martins (b)

(a)Plasma Laboratory - Institute of Mathematics, Statistics and Physics, Fereral University of Rio Grande, Rio Grande do Sul, 96203-900 Brazil.
(b)School of Chemistry and Food,Fereral University of Rio Grande, Rio Grande do Sul, 96203-900 Brazil.

The main objective of this work is the electrical characterization of homemade AC glow discharge plasma to define the operational range of pressure and power. The AC glow discharge plasma was applied on a fish protein film for food packaging. The voltage-current characterization of AC glow discharge showed that plasma was operating at abnormal mode due to rising of voltage for all pressure tested.[1-2] For this application a synthetic air (N2:O2 = 8:2) was used as plasma gas. After electrical characterization were done three plasma operation pressures and three plasma operation powers were defined, 7.5 mtorr, 10.0 mtorr, 15.0 mtorr, and 5 w, 8 w and 11 w respectively. For these operational conditions an initial study using a single Langmuir probe showed typical values for electrons temperature and electrons densities. [3] The statistical method Design of Experiments was applied to find parameters that affect fish protein film properties. The parameters that were used for these experiments were time of exposure, plasma power and chamber pressure. The plasma parameters level used in the experiments were enough to affect the films properties as physical-chemistry, microstructure and thermal stability. For instance, the time of plasma application yielded changes on the mechanical performance, and water vapor permeability, and solubility in water and on the films colors. [4]

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Contribution: **P1.72** / Beam Plasmas and Inertial Fusion

Design and experiment of short pulse laser plasma x-ray using source coded

Tiankui Zhang

Science and Technology on Plasma Physics Laboratory, Laser Fusion Research Center, China Academy of Engineering Physics, Mianyang 621900, China

In order to carry out research on inertial confinement fusion capsule diagnostic, shock wave measurement, equation of state measurement and Rayleigh-Taylor instability diagnostic, it needs to develop backlight radiography with high temporal and spatial resolution. Laser plasma x-ray source possess many advantages, such as short-pulse, high brightness, and tunable photon energy. However, the radiography spatial resolution is limited by source size. In spite of the spatial resolution of the 10 microns can be achieved by microstructural targets, the signal-to-noise ratio is poor because of low yield, and it is difficult to improve spatial resolution even more. A new laser plasma x-ray source backlight radiography technique based on coded source technique is present here. To tackle the difficulty of non-uniform spatial distribution in process of design of source coded, the adaptable source coded mask and the inversion algorithm with strong robustness are studied. The experiment of source coded radiography using laser plasma x-ray source is also carried out.

Contribution: **P1.73** / Magnetic Confinement Fusion

Absolute spectral calibration of Thomson scattering systems using Rayleigh scattering

E R Scott (1), S A Bozhenkov (1), M N A Beurskens (1), G Fuchert (1), M Hirsch (1), P Nelde (2), E Pasch (1), R C Wolf (1), and the W7-X Team

(1) Max-Planck-Institut für Plasmaphysik, D-17491 Greifswald, Germany
(2) Technische Universität Berlin, D-10623 Berlin, Germany

A novel calibration method for Thomson scattering (TS) diagnostics has been demonstrated on the Wendelstein 7-X stellarator (W7-X). Utilizing an optical parametric oscillator (OPO), Rayleigh scattering measurements were performed in-situ in argon, nitrogen, and air at pressures from 0 to 1024 mbar and wavelengths between 730 and 1070 nm. Unlike previous spectral calibration techniques, these measurements cover all optical components within the TS system, including the first vacuum window; are performed using the same observation geometry as the TS system, for example, the distance and angle of the scattering volume relative to the collection optics, by directing the OPO beam along the same path used by the TS lasers; and can, in principle, directly calibrate each filter channel for absolute plasma density. Despite high stray light levels, filter curves for each channel within multiple polychromators were measured, with the linear dependence of Rayleigh scattering on gas pressure clearly visible. The complete calibration system, planned for future W7-X operational campaigns, will aim to further reduce stray light, thereby decreasing the required gas pressure and allowing in-situ calibration measurements on service days; better match the OPO beam divergence and beam size to the installed Nd:YAG lasers; and decrease the OPO bandwidth using an injection seeder to better reproduce the filter edges.

Contribution: **P1.74** / Low-Temperature and Industrial Plasmas

Plasma diagnostics in hybrid reactive pulsed HiPIMS magnetron sputtering system combined with RF-ECWR plasma

Zdenek Hubicka, Martin Cada, Vitezslav Stranak, Rainer Hippler

Institute of Physics CAS, Na Slovance 2, Prague 8, 182 21, Czech Republic

Low temperature hybrid plasma sources are recently very popular tools for technological applications in thin film depositions. These plasma sources are very flexible and plasma parameters can be tuned in a wide range. A reactive hybrid high power impulse magnetron sputtering (HiPIMS) system with two magnetrons combined with a radio frequency electron cyclotron wave resonance (ECWR) plasma source was investigated as a tool for technological processes as deposition of thin films for ternary oxides as CuFeO2, working as semiconductor photocathodes in water splitting applications. One great benefit of this plasma system is the possibility to operate the process at very low pressures ≈ 10-2 Pa. These conditions are very suitable for low temperature crystallization of deposited semiconductor thin films and are able to obtain interesting semiconductor properties. The plasma is generated in the gas mixture of Ar+O2 and both metallic magnetron targets Cu and Fe are reactively sputtered in HiPIMS+ECWR plasma. The non-stationary pulsing plasma was analyzed in the position of the substrate by a planar fast sweep high frequency time resolved Langmuir probe. The time evolution of electron concentration, electron temperature and plasma potential was obtained during the pulsing cycle. This probe was not influenced by any contamination deposited on the probe surface. The flux of reactively sputtered neutral and ionized particles was measured by a modified QCM sensor, with biased collecting electrode and auxiliary electron magnetic filter together with a RF ion probe suitable for total ion flux measurements. Plasma parameters were investigated on the reliance of the RF power applied in ECWR plasma, on pulse power in both HiPIMS magnetrons and on oxygen concentration in the plasma. Measured plasma parameters were strongly dependent on the applied RF power in ECWR plasma and oxygen concentration in the reactive sputtering process.

Contribution: **P1.75** / Magnetic Confinement Fusion

Utilizing silicon photomultiplier detectors for low light level high frequency measurements in fusion diagnostics

D. Dunai 1, S. Zoletnik 1, M. Lampert 1, D. Réfy 2 and W7-X Team 2

1 Wigner Research Centre for Physics, Budapest, Hungary
2 Max Planck Institute for Plasma Physics, Greifswald, Germany

In several fusion diagnostics (BES, FILD, GPI, ultrafast spectroscopy, etc) similar criteria are present for the optimal detector choice. In these applications typically visible light is measured and the incoming photon flux varies between 107 -1011 photons/sec. The number of channels is small compared to a CMOS camera and it is usually between 16-128. From constraints of the optics mostly relatively large surface detectors are needed (1-20 mm2). The detectors are either coupled to fiber optics or they are placed in the image plane of a direct imaging optics. The required bandwidth is between 100kH and 1MHz. Traditionally Photomultiplier tubes (PMT) and photo diodes (PD) were used for fast systems, later avalanche photo diodes (APD) were also applied. The selected detector will determine the resulting signal quality and therefore for the physics capabilities of the diagnostic.
A new detector type has been developed in recent years; the silicon photomultiplier (SiPM). SiPM detectors are solid state photodetectors, which were developed for photon counting applications. Based on an actual BES application a study has been done to test and characterize the SiPM detectors. In some BES the detectable photon flux will only be 107-108 photons / sec. It was shown that these detectors can also be applied to continuous measurements not just to photon counting applications. After careful tests the APD matrix detector of JET lithium BES diagnostic was replaced with SiPM matrix detectors. Also the scrape off layer channels of the Wendelstein 7-X alkali BES diagnostics were built partially with SiPM detectors. In this paper the performance of these detectors in fusion environment will be presented in comparison with APD detectors via some examples from the laboratory and from actual plasma measurements. The photon flux range where the SiPM should be considered will also be discussed with actual experimental examples.

Contribution: **P1.76** / Beam Plasmas and Inertial Fusion

Bremsstrahlung Cannon for the characterization of hot electrons generated in high-intensity laser-plasma interactions

O.Turianska1, D.Raffestin1, D.Batani1, A.Tentori1, S.Malko2, G.Zeraouli2, J.A.Perez-Hernandez2, L.Volpe2, A.Martyneko3,4

1) CELIA, University of Bordeaux, France
2) CLPU Laser-Plasma Chair at University of Salamanca, Spain
3) National Research Nuclear University MEPhI, Moscow, 115409, Russia
4) Joint Institute for High Temperature, Russian Academy of Science, Moscow, 12412, Russia

We performed an experiment at the laser VEGA-2 of Centro de Láseres Pulsados in Salamanca dedicated to the study of hot electron driven blast waves in solid materials.

The laser was delivering 6 J on target in a pulse duration of 30 fs with an estimated intensity on target of about 5×10^{19} W/cm^2. In these conditions, a significant part of absorbed laser energy goes into the generation of hot electrons.

Several diagnostics were used in order to characterize the average energy of hot electrons and the efficiency of conversion from laser light to energy in the hot electron beam. One of such diagnostics consisted in a stack of detectors (Imaging plates, IP) separated by filters of different material and different thickness (so called “bremsstrahlung cannon”, BSC). This allow for a low-spectral resolution characterization of the hard X)-ray radiation emitted from the laser-irradiated targets. Bremsstrahlung spectra are usually characterized by an exponential decay vs. photon energy and the slope of this exponential is taken as representative of the temperature of hot electrons.

Experimental results obtained for different target types and configurations will be presented in the poster. In order to correctly describe the response of the BSC, we performed Monte Carlo simulations of the penetration of X-rays into the stack assuming a given input spectrum and calculating the signal released in each IP. This allows taking into account the scattering of X-rays and the effects related to secondary electrons which can be produced in the interaction of X-rays with the materials of the BSC. We changed the value of the hot electron temperature in the bremsstrahlung spectrum in order to achieve the best agreement with experimental data.

Finally, we critically discus the assumption of an exponential bremsstrahlung spectrum.

Contribution: **P1.77** / Magnetic Confinement Fusion

Designing for Remote Handling: the case-study of the ITER Plasma Position Reflectometry in-vessel antennas

Alberto Vale, Fernando Mourão, Paulo Varela

Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa

The ITER Plasma Position Reflectometry (PPR) system consists of four reflectometers designed to measure the edge density profile at four locations known as gaps 3, 4, 5, and 6. The systems of gaps 4 and 6 have the antennas installed inside the vacuum vessel in small apertures between blankets. To prevent damage, the antennas need to be removed/(re)installed by RH before/after the removal/reinstallation of the blanket shield modules just above and below them.

The RH operations shall be performed by the Blanket Remote Handling System (BRHS) and require a tool not yet available in the ITER Remote Maintenance System. This tool shall be compliant with the ITER Remote Handling Code of Practice and shall be able to interact with the BRHS and other tools, such as bolt runners.

Herein, we describe a conceptual design of this tool that considers guidance and security to overcome some of the identified RH issues. The tool was designed to remove and (re)install the antenna in a single step using the translation and rotation capabilities of the BRHS to bolt/unbolt the antenna to/from the support without extra operations. Thus, the tool provides the means to lock to the antenna when unbolted from the support and to unlock from it when bolted to the support.

The space required to remove and (re)install the antenna is reduced as much as possible between the blanket shield modules. However, the aperture of the tool is dimensioned according to the maximum positioning error allowed for the BRHS with a diagonal shape to guide the tool along the antenna. The design is implemented using pop-up fasteners and standard sizes authorised by the ITER Organization. A set of mechanical benchmarks are presented based on the CAD model of the tool.

Contribution: **P1.78** / Beam Plasmas and Inertial Fusion

Use of VISAR for Equation of State Measurements of Diamond up to 4 Mbar

D. Mancelli1,3, D.Batani1, I. Errea2,3, J. Trela1, K. Jakubowska4, A. Martynenko5, P. Neumayer6, O.Rosmej6, R. Benocci7

1 Universitè de Bordeaux, CNRS, CEA, CELIA, Talence, France
2 Fisika Aplikatua 1 Saila, Bilboko Ingeniaritza Eskola, University of the Basque Country (UPV/EHU), Bilbao, Basque Country, Spain
3 Donostia International Physics Center (DIPC), Donostia-San Sebastian, Basque Country, Spain
4 IPPLM Warsaw, Poland
5 National Research Nuclear University MEPhI, Department of Plasma Physics - Moscow, Russia
6 GSI, Darmstadt, Germany
7 University of Milano-Bicocca, Department of Earth and Environmental Sciences, Piazza della Scienza 1, 20126 Milano, Italy

Laser driven dynamic compression allows reaching high pressures in plane geometry [1]. It is used as a standard method for studying the equation of state (EOS) of matter in extreme states.
In our experiment, we used the laser PHELiX to generate a strong shock in polished diamond monocrystals of type Ib with 100 orientation, and studied the dynamics of the shock inside diamond. The PHELiX facility at GSI in Germany is a Nd: glass system converted at 2ω, with energy EL > 100J and pulse duration of 1ns.
We used multilayer targets with a plastics ablator (5 µm) followed by a nickel pusher (20 µm) and the diamond monocrystal (of thickness about 250 µm). Finally, on half of the diamond rear side we placed a 20-µm Ni step. This target geometry allows to measure shock velocity in Nickel and in diamond simultaneously.
As diagnostics, we used two VISAR (velocity interferometer system for any reflector [2]) interferometers, using a seeded laser at 600nm as probe, synchronized with the main beam. The VISAR allows to measure the shock transit time in the various materials trough the jumps in reflectivity and fringe jumps, from which we can get the average shock velocity in each material. In addition, the fringe shift provides an additional information on the instantaneous velocity of the reflecting surface. We can measure the shock transit time in Ni and in diamond but also continuously follow the evolution of the shock in time from the fringe shift in the VISAR.
Probing shock propagation inside target allows getting information on Diamond EOS point along its Hugoniot. In our experiment, we generated pressures up to 4 Mbar. We get evidence that the VISAR probe laser is reflected by the shock front traveling in the transparent diamond, hence in our case the velocity measured by VISAR corresponds to the instantaneous shock velocity. Such instantaneous shock velocity coincides with the average velocity proving that a stationary shock is obtained in our conditions.
Our results prove that shock compression brings diamond to a reflecting state. Preliminary analysis of shock dynamics is compatible with the results hydrodynamics simulations performed using MULTI 1D radiative hydrodynamic code [3] with known EOS table (SESAME 7830 [4]) for Diamond.

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Contribution: **P2.2** / Magnetic Confinement Fusion

New Infrared imaging diagnostic for the Neutral Beam Heating System at the TJ-II stellarator

M. Liniers, J.A. Quintana, B. Rojo, F. Martín-Díaz, F. Miguel, J.A. Sebastián, R. Carrasco, A. Soleto, E. Sánchez, A. Jiménez, E. de la Cal, E. Ascasíbar

Laboratorio Nacional de Fusión-CIEMAT, Av. Complutense 40, 28040 Madrid, Spain

Analysis of the beam heated plasmas in magnetically confined fusion requires knowledge of the heating power and fuel particles absorbed in the plasma. This is obtained through a combination of beam and plasma diagnostics with computer simulation codes.

The Neutral Beam Injection system at TJ-II delivers to the stellarator plasma two H0 beams of 34 keV energy and 1.4 MW total power in Co-Counter configuration.

The new IR imaging system will provide a reliable estimation of the beam power lost by shine-through and reionization. It consists of an IR camera in the Mid-wave spectral range (3-5.5 µm) with good spatial (640x512 pixels) and temporal (<4 kHz) resolution, with a line of sight along the beam injection axis. The new IR window provides an extended field of view that allows to obtain thermal images of all the critical in-vessel components: the Beam Stop (far along the beam path), the Target Calorimeter (in the stellarator vacuum vessel entrance area) and the final section of the beam Duct (close to the injection port).

Due to the tight space constraints in the beam duct area, a thorough study has been necessary to optimize the design of the optical system (camera, window, mirror and support system). The image quality of the Regions of Interest has been established and their irradiation properties on the camera sensor have been characterized.

The system has been fully commissioned and is now operative, routinely providing thermographic data of the regions of interest during the last TJ-II experimental campaign.

The IR diagnostic is described in detail and its application to the beam power balance is discussed in several examples on different Regions of Interest.

Contribution: **P2.3** / Basic and Astrophysical Plasmas

Time resolved X- ray emission diagnostics in an axis-symmetric simple mirror trap

G. Castro1, G. Litrico1, A. Muoio1, M. Mazzaglia1, D. Mascali1, R. Miracoli1,2, E. Naselli1,3, G. Torrisi1 S. Tudisco1, S. Gammino1

1 - INFN – Laboratori Nazionali del Sud, Catania, Italy
2 - ESS Bilbao, Zamudio, Spain
3 - Università degli studi di Catania, Catania, Italy

The time-resolved characterization of the X-ray emission represents an innovative technique to investigate the heating mechanism of the worm/hot electron component in ECRIS devices. In this paper, the technique has been applied to characterize the average and end point energy of the X-rays generated by an axis-symmetric simple mirror trap, with resolution of the order of 10 µs. Particular attention has been paid to the ignition and turning off phase. This approach permitted to estimate confinement time of the warm/hot electron population, and put in evidence after-glow effects for hundreds µs and instability effects. Further developments and perspectives of the technique will be highlighted.

Contribution: **P2.4** / Basic and Astrophysical Plasmas

Electron beams as plasma diagnostics tools: modelling approach and first experiments

A. Galatà (c), F.Odorici (a), G. Castro (b), L. Malferrari (a), D. Mascali (b), A Montanari (a)

a) INFN-LNL, Viale dell'Università, 2 35020 Legnaro Italy
b) INFN-Bologna, Viale B. Pichat, 6/2, 40127 Bologna, Italy
c) INFN-LNS, Via S. Sofia 62, 96123 Catania, Italy

Externally injected electrons can be successfully used as a diagnostic probe to deduce characteristics and dynamics of magnetically confined plasmas typical of Electron Cyclotron Resonance and Microwave Discharge Ion Sources (ECRIS and MDIS), as well as to improve their performances and/or stability. To this scope, numerical simulations are a powerful tool to predict the effect of the interaction of an electron beam with the plasma: this paper presents a numerical code describing the dynamics of an electron beam, generated by an e-gun, propagating inside a plasma trap, with a magnetic configuration typical of MDIS. The results will focus on several effects like ionizations, a possible plasma heating and the influence of the space charge of the beam itself and the ionizations it creates on the plasma density. They will also show the role played by the position of the e-gun with respect to the magnetic field profile, as well as its inclination angle. First experimental results will be shown.

Contribution: **P2.5** / Magnetic Confinement Fusion

Temperature Calculation Using a Multispectral Infrared Camera

Marc-Antoine Langevin, Serge-Olivier-Adam Gnessougou, Alexandrine Huot, Alain De Champlain

Telops
Université Laval

Over the past few years, two-color pyrometry was proven to be a fast and reliable non-invasive method to accurately determine the temperature of materials by overcoming emissivity issues usually encountered by thermal infrared cameras. However, the need for two cameras at the same time makes this method expensive. In this work, a single Telops MS M350 equipped with a fast rotating spectral filter wheel was used to accurately determine the temperature of composite materials attacked by a kerosene flame. The method was previously validated with a steel plate equipped with embedded thermocouples.

Contribution: **P2.6** / Magnetic Confinement Fusion

Real-time multi-threaded reflectometry density profile reconstructions on COMPASS tokamak

P. D. Lourenço[1], J. M. Santos[1], O. Bogar[2,3], A. Havranek[3], J. Havlicek[3], J. Zajac[3], M. Hron[3], H. Fernandes[1],

[1] Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal

[2] Institute of Plasma Physics of the Czech Academy of Sciences, Za Slovankou 3, 182 00 Prague 8, Czech Republic

[3] Faculty of Mathematics, Physics and Informatics, Comenius University in Bratislava, Bratislava, Slovakia

The recent implementation of a real-time plasma position reflectometry diagnostic system at the COMPASS tokamak enables the use of this diagnostic in closed-loop plasma position control experiments. Of the different stages of this implementation based on the Multi-Threaded Application Real-Time executor (MARTe), reconstruction of O-mode density profiles is the most time-sensitive, due to the computation of a large number FFT operations on long data arrays produced for each reflectometry profile measurement.

MARTe is a highly modular and portable control framework written in C++ that allows the integration of external libraries and code into the real-time designs. This becomes relevant at the level of task parallelization and advanced numerical operations on multi-core environments. Although MARTe already provides a practical set of tools to create and manage segregated or real-time threads, APIs as OpenMP provide a straightforward way to run parallel operations on specific stages of complex pipelined processes. These are often related to computationally demanding signal processing algorithms such as time-frequency domain transforms. The FFTW C library is a highly optimized and performant implementation of the FFT algorithm which, like OpenMP can be integrated into this MARTe application.

Herein, we present the reconstruction of density profiles on MARTe, using both OpenMP and FTTW libraries, along with estimations for plasma separatrix position. Systematic results have shown that the implemented solution allows the total latency of the system, from data acquisition to position delivery to main controller, to remain under the COMPASS slow control cycle maximum data latency of 450usec. The obtained results further confirm the validity of this technique for plasma position control purposes.

Contribution: **P2.7** / Magnetic Confinement Fusion

Forward Modelling an Imaging Motional Stark Effect Diagnostic for Edge Current Density Measurements on MAST-U

S. Gibson, A. Thorman, C. A. Michael, N. C. Hawkes, M. Carr, R. M. Sharples and J. Howard

Centre for Advanced Instrumentation, Durham University, Durham, DH1 3LE
CCFE, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK
Plasma Research Laboratory, Australian National University, Canberra, Australia

The motional Stark effect (MSE) diagnostic measures the polarisation angle of emission produced by neutral beam atoms due to their motion through a magnetic field. These measurements are used as a constraint in equilibrium reconstruction codes from which the magnetic pitch angle, q and current profiles are inferred. The MSE diagnostic on MAST has been used previously to investigate the evolution of the edge bootstrap current during H mode. The spatial resolution of the existing MAST-U MSE system is R ~ 2-3cm, comparable to the length scale of the pedestal width, which is insufficient to finely resolve these structures. The imaging motional Stark effect (IMSE) diagnostic is a polarisation interferometer which captures 2D snapshot images of neutral beam emission. By encoding polarisation information as an interference pattern using birefringent waveplates, the IMSE diagnostic can provide a 2D measurement of the polarisation angle. This means the system is suitable for measuring pedestal features, internal magnetic fields and q profile evolution.

An IMSE system has been designed and forward-modelled for implementation on MAST-U. The MSE spectrum was modelled using MSESIM which includes realistic spectral broadening effects; finite collection volume, variation in beam velocity distribution and beam divergence. The optical system was also designed considering non-ideal effects, such as non-axial ray incidence on the waveplates. Synthetic diagnostic images are presented which show the performance of the system in a range of typical MAST-U plasma scenarios. These images demonstrate that in MAST-U H mode plasmas the diagnostic would be capable of recovering edge current features with a width on the order of ~2cm. When accounting for shot noise, the system performance is expected to be comparable to the existing diagnostic.

Contribution: **P2.8** / Basic and Astrophysical Plasmas

A wave absorption diagnostic for electron plasma waves

F. Skiff, R. Hood, and L. Beving

Department of Physics and Astronomy, University of Iowa

We explore a new kind of wave absorption diagnostic using electron plasma waves. A major difficulty faced by radio-frequency probes is the fact that the probe modifies its immediate environment. In addition, there are complexities which arise because of the details of particle orbits in the probe vicinity. We explore a probe which provides information from wave transmission through a ~ 1cm region between two antenna structures. Information from electron plasma wave dispersion provides information on electron density, temperature, flow, and the suprathermal paricle distribution function. The theory and model for the probe is based on solving the integral equation as in the second part of Landau's classic paper on wave damping.

Contribution: **P2.9** / Magnetic Confinement Fusion

Thomson Scattering Systems on Advanced Beam Driven C-2W FRC Experiment

Kan Zhai, Tania Schindler, Angelica Ottaviano, Eli Parke, James Sweeney, Matthew Thompson

TAE Technologies, Inc.

The goal of the recently constructed C-2W Field Reversed Configuration (FRC) fusion experiment is to increase the electron temperature with the upgraded neutral beam driving, active plasma edge control, and the ramping up of the magnetic field. Electron temperature (Te) and density (ne) profiles measurement with high temporal and spatial resolution is critical to the success of the C-2W experiment. In parallel with the C-2W machine construction, a suit of Thomson scattering system has been designed, built, and commissioned. The suit consists of two subsystems that measure Te and ne profiles at the machine central plane of the FRC plasma and at the plasma jet region of the open field line plasma. Both systems are designed and optimized for the measurement of Te and ne in the range of from 1×1012 cm-3 to 2×1014 cm-3 and from 10eV to 2keV. The central system uses a high repetition Nd:YAG laser up to 20kHz and covers radially from r = -9cm to r = 64cm at 16 locations. The jet system measures Te and ne profiles at 100Hz covering 5 radial locations from r = -5cm to r = 15cm in the open field line region at the south end of the confinement vessel. The system design, polychromator spectral calibration, system absolute calibration with Rayleigh and Raman scattering, data analysis algorithm, and the Te and ne profiles of some typical shots will be presented.

Contribution: **P2.10** / Magnetic Confinement Fusion

A new dual-HCN laser diagnostic system on J-TEXT

Gaoli, Zhou jingjun,Shi Peng,Zhou yinan

State Key Laboratory of Advanced Electromagnetic Engineering and Technology, Huazhong University of Science and Technology

A new dual-HCN laser diagnostic system is under construction on J-TEXT. This system is proposed to incorporate heterodyne interferometer and collective scattering measurement. Thus, this system could measure line-integral electron density and density fluctuation simultaneously, with a temporal resolution of <1 us. The laser sources consist of two separately pumped HCN gas lasers at 337 um, which are capable to maintain more than 30mW/cavity for 10 hours without manual control. The beat frequency is about 2.6MHz when there is a 10um cavity length difference.

The diode mixers are used to detect the phase signals. The FPGA based data acquisition system is developed to sampling the beat frequency signals. And the real-time density calculation code based on MATLAB is also presented.

Contribution: **P2.11** / Magnetic Confinement Fusion

Three dimensional tomographic reconstruction of edge impurity emission base on the imaging system on the J-TEXT tokamak

Zhipeng Chen, Minghui Xia, Xiaolong Zhang, Xing Xu, Da Li, Song Zhou and J-TEXT team

International Joint Research Laboratory of Magnetic Confinement Fusion and Plasma Physics, State Key Laboratory of Advanced Electromagnetic Engineering and Technology, School of Electrical and Electronic Engineering, Huazhong University of Science and Technology, Wuhan, 430074, China

A visible light imaging system has been installed on the J-TEXT tokamak to measure the spatial distribution of visible emission in the vacuum chamber. The system views the plasma tangentially from the mid-plane of the vacuum vessel. A spatial calibration based on Tsai's method is adopted to build the relationship between the tokamak 3-D space coordinate and the 2-D image coordinate. Base on this image system, the spatial distribution of edge impurity emission under different scenarios, e.g. limiter and divertor configuration, has been measured. Cooperated with PDA arrays and magnetic field topology at edge, a three dimensional tomographic reconstruction technique is used to calculate the 3D emission profiles from the camera image data. Furthermore, edge impurity emission under different phase of the resonate magnetic perturbation has also been measured. And this tomographic technique are tested to analyze the impurity distribution under the 3D magnetic topology at the edge.

Contribution: **P2.12** / Magnetic Confinement Fusion

Overview of C-2W Field-Reversed Configuration Plasma Diagnostics

H. Gota, M.C. Thompson, T. Schindler, S. Putvinski, M.W. Binderbauer, and the TAE Team

TAE Technologies, Inc.

The new C-2W experiment (also called “Norman”) at TAE Technologies, Inc. studies the evolution of field-reversed configuration (FRC) plasmas sustained by neutral beam injection. Data on the FRC plasma performance is provided by a comprehensive suite of diagnostics that includes over 600 magnetic sensors, electrical probes, four interferometer systems, multi-chord far-infrared polarimetry, two Thomson scattering systems, ten types of spectroscopic measurements, multiple fast imaging cameras with selectable atomic line filters, bolometry, reflectometry, neutral particle analyzers, and fusion product detectors. Most of these diagnostic systems are newly built using experience and data from the preceding C-2U experiment [1,2] to guide the design process. In addition, extensive ongoing work focuses on advanced methods of measuring the internal FRC magnetic field profile to facilitate equilibrium reconstruction and active control of the plasma. Diagnostic suite on C-2W as well as newly obtained experimental results will be presented.

[1] H. Gota et al., Nucl. Fusion 57, 116021 (2017).
[2] M.C. Thompson et al., Rev. Sci. Instrum. 87, 11D435 (2016).

Development of Wide-Frequency Range Antenna Array for Microwave Imaging Diagnostics

Daisuke Kuwahara, Naoki Ito(1, Hayato Tsuchiya(2, Tokihiko Tokuzawa(2, Tomokazu Yoshinaga(3, Yoshio Nagayama(4, Soichiro Yamaguchi(5, Yuichiro Kogi(6, Atsushi Mase(7

Chubu University, 1)National Institute of Technology, Ube College, 2)National Institute for Fusion Science, 3)National Defense Academy, 4)Nihon University, 5)Kansai University, 6)Fukuoka Institute of Technology, 7)Kyushu University

Microwave diagnostic system has difficulties in terms of multi-channelization. Our group had solved this problem by developing a Horn-antenna Mixer Array (HMA), a 50 - 110 GHz 1-D heterodyne-type antenna array, which can be easily stacked as a 2-D receiving array. However, the HMA still evidenced problems owing to the requirement for local oscillation (LO) optics and an expensive high-power LO source. To solve this problem, we have developed a new multi-channel receiver antenna array, named local oscillator integrated antenna array (LIA), in which each channel has an internal LO supply using a frequency multiplier integrated circuit. Therefore, the proposed antenna array eliminates both the LO optics and the high-power LO source. In addition, it can install a first stage amplifier (RF Amp.) easily. The RF antenna is quite important in a case of a detecting weak signals, such as an electron cyclotron emission diagnostics and a reflectometry. Now, the LIA has wide frequency range lineup, Q-band (33 – 50 GHz), V-band (50 – 75 GHz), and E-band (60 – 80 GHz), and installed several plasma devices as an interferometer, a reflectometer, and electron cyclotron emission diagnostics. In presentation, detail of the LIA and examples of application will be shown.

Contribution: **P2.14** / Magnetic Confinement Fusion

Velocity-space sensitivity of the Neutron Camera Upgrade on MAST-U

A. Sperduti, A.S. Jacobsen, M. Cecconello and J. Eriksson

Department of Physics and Astronomy, Uppsala University, EURATOM-VR Association, Uppsala, Sweden.

CCFE, Culham Science Centre, Abingdon, Oxfordshire OX14 3DB, United Kingdom.

The study of the fast-ion distribution plays a crucial role in the prediction of the confinement of fusion-born alpha-particles and therefore of the performance of future fusion devices and reactors such as ITER and DEMO. In particular, the interaction between Fast Ions (FIs) and MHD instabilities is of interest, since the FIs, which deliver a large fraction of heating, can be redistributed both spatially and in velocity space by MHD instabilities, resulting in a lower fusion power generation. The Mega Ampere Spherical Tokamak Upgrade (MAST-U) will provide fundamental information regarding FI confinement on ITER thanks the super-Alfvénic nature of the neutral beam injected deuterons, which will trigger MHD instabilities leading to FIs loss and redistribution in a way that mimics the fusion-born alphas in ITER.

On MAST-U the behaviour of FIs will be directly studied by several dedicated FI diagnostics (FI deuterium-alpha spectroscopy (FIDA), a FI loss detector (FILD) and a solid-state neutral particle analyzer (ssNPA)) and indirectly by measuring the beam-thermal dominated neutron emissivity using the Neutron Camera Upgrade (NCU). The sensitivity of a given FI diagnostic to certain parts of the velocity phase space is determined by its detection method, geometry, instrumental broadening, etc., and is described by so-called FI weight functions. The weight functions of the NCU are here derived and discussed in terms of the additional information they will provide and its complementarity to that provided by the FIDA and FILD diagnostics. Finally, a comparison between synthetic spectra calculated using the weight functions and the Directional RElativistic Spectrum Simulator (DRESS) code is presented and discussed.

Contribution: **P2.15** / Magnetic Confinement Fusion

Validating the ASCOT modelling of NBI fast ions in Wendelstein 7-X

S. Äkäslompolo 1, A. Ali 1, J. Baldzuhn 1, C. Biedermann 1, S. Bozhenkov 1, C.P. Dhard 1, P. Drewelow 1, M. Endler 1, J. Fellinger 1, O. Ford 1, Y. Gao 4, B. Geiger 1, J. Geiger 1, D. Hartmann 1, M. Isobe 2, M. Jakubowski 1, C. Killer 1, J. Kontula 8, T. Kurki-Suonio 8, S. Lazerson 7, P. McNeely 1, T.W.C. Neelis 1, H. Niemann 1, Y. Kazakov 3, K. Ogawa 2, F. Pisano 5, P. Zs. Poloskei 1, K. Rahbarnia 1, N. Rust 1, J. Schmitt 1, A. Puig Sitjes 1, M. Sleczka 6, L. Vano 1, A. van Vuuren 1, G. Wurden 8, R.C. Wolf 1, The Wendelstein 7-X Team

1 Max-Planck-Institut für Plasmaphysik, Teilinstitut Greifswald, Greifswald, Germany
2 National Institute for Fusion Science, Toki City, Japan
3 LPP-ERM/KMS, Brussels, Belgium
4 Forschungszentrum Jülich, IEK-4, Jülich, Germany
5 University of Cagliari, Cagliari, Italy
6 University of Szczecin, Szczecin, Poland
7 Princeton Plasma Physics Laboratory, Princeton, NJ, U.S.A.
8 Aalto University, Finland

The first fast ion experiments in Wendelstein 7-X were performed in 2018. They are one of the first steps in demonstrating the optimized fast ion confinement of the stellarator. The fast ions were produced with a neutral beam injection (NBI) system, consisting of two sources injecting hydrogen at up to 55 keV at 2x1.8MW for up to 5s. Determined by the limitations of the beam duct between the superconducting coils, the injection geometry is close to radial.

The fast ion distribution function in the plasma and at the wall is being modelled with the ASCOT suite of codes. They calculate the ionization of the injected neutrals and the consecutive slowing down process of the fast ions. As the codes predicted, there are multiple fast ion hot spots on the plasma facing components due to coil ripple losses. This contribution presents a comparison between predicted and measured fast ion signals.

The fast ions were detected with infrared cameras (IRC), a fast ion loss detector (FILD), fast ion charge exchange spectroscopy (FIDA), and post-mortem analysis of plasma facing components. The primary output of the code is the multidimensional fast ion distribution function within the plasma and the distribution of particle hit locations and velocities on the wall. Models producing synthetic IRC frames and FILD signals have been created for this work, while the synthetic FIDA signal is produced with the established FIDASIM code.

This contribution presents a detailed comparison between experimental results and ASCOT modelling.

Contribution: **P2.16** / Magnetic Confinement Fusion

Upgrades to the KSTAR ECE diagnostic with a W-band radiometer

K.D. Lee and Y.S. Kim

National Fusion Research Institute

The last KSTAR ECE diagnostic system with a 48 channel D-band heterodyne radiometer (110–162 GHz) has been routinely operated for electron temperature profile measurements in the high and/or low field sides. However, because the overlap between the second and the third harmonic emission frequencies in the high field side during the 2.0 T operation of KSTAR is not avoidable, a 28 channel W-band heterodyne radiometer (78–110 GHz) was installed additionally to measure the electron temperature in the low field side. As main components of the W-band ECE system, a 94 GHz local oscillator, two double balanced mixers, and two bandpass filters (78-93 GHz and 95-110 GHz) are used to obtain two separate IF frequencies (1 to 16 GHz). Subsequently two sets of second down-conversion modules with a 7 GHz local source and 4 sets of 8 channel detector modules (2-9 GHz) with 1 GHz step are used. In this article, laboratory test results of the W-band radiometer are described in detail and preliminary ECE measurement results on KSTAR are presented.

Contribution: **P2.17** / Magnetic Confinement Fusion

Estimates of TPR spectrometer instrumental signal-to-background ratios and count rate limits for ITER like plasmas

Benjaminas Marcinkevicius, Erik Anderson Sunden, Anders Hjalmarsson

Uppsala University

The work presented is a realistic simulation of the response function for a detection efficiency optimized Thin-foil proton recoil (TPR) neutron spectrometer with an energy resolution of 4.6% for 14MeV neutrons. The TPR spectrometer consists of a thin foil acting as neutron-to-proton converter followed by a proton telescope consisting of two dE and E detectors operating in coincidence mode. In this work, two different spectrometer designs were considered using segmented and non-segmented detectors. The TPR spectrometer response functions were simulated in the energy range 9 – 18MeV in steps of 40 keV for the two designs using the dedicated Monte Carlo code GEANT4. The resulting simulated response functions were broadened using experimentally determined energy resolutions of the detectors, in order to produce more realistic response functions. Using these broadened response functions together with an ITER like neutron spectrum and neutron induced background simulations, dE-E energy deposition plots were created. The energy-cuts, for 14 MeV neutron signal identification, were applied to the dE-E plots leading to an estimate of the expected signal-to-background ratio. In addition, random coincidence count rate dependence on the neutron rate and its influence on the signal-to-background ratio was estimated. The simulations confirm that with the use of segmented detectors the spectrometer design can achieve higher efficiency at the same resolution as the non-segmented. Moreover, the dE-E energy cuts show a great prospect of increasing the signal-to background ratio for the TPR spectrometer. The presented work shows that the system count rates and signal to-background ratios are sufficient to estimate ion temperature and fuel ion density ratios for selected ITER plasma scenario. However, multiple combinations of the spectrometers may be necessary to cover the whole span of ITER like plasma conditions.

Contribution: **P2.18** / Magnetic Confinement Fusion

Development of Li, Na, K, Rb and Cs thermionic ion sources using SiC block heater technology

G. Anda, S. Bató

Wigner RCP, Association EURATOM, Budapest, Hungary

At Alkali Beam Emission Spectroscopy [1] and at Atomic Beam Probe (or also called imaging heavy ion beam probe [2]) systems the ion emission capacity of the ion source is critical to obtain reasonable information about fusion plasmas. The common way to heat up a thermionic ion emission material is resistive, usually using Molybdenum or Tungsten filaments. The filaments are embedded into alumina to increase their lifetime, but the power density and the temperature are strongly limited to about 150W/cm2 and 1200℃.

A new method is developed for ion source heating based on Silicon Carbide (SiC) volume heater. The used SiC disc is also heated resistively, but the power density and temperature limit is much higher, about 500W/cm2 and 1400℃. Additionally, the heating system is very robust, resists immediate power shutdowns or abruptly increased heating power, as well.

The production method of the ion emission material surface is also improved. The conventionally used β-Eucryptite and melting technique limited the ion current density to about 1.5 – 2mA/cm2 (at Lithium ion sources). With small modifications of the constituent and the production it was enhanced to about 3-3.5mA/cm2 (at Lithium ion sources). These modifications can be used similarly at the mentioned alkali ion sources, as well.

In this paper the SiC block heater and the production technology of the emission surface of the alkali ion sources are described. Ion emission capacity of Li, Na, Rb and Cz sources are also presented.

[1] Development of a high current 60 keV neutral lithium beam injector for beam emission spectroscopy measurements on fusion experiments, G. Anda et al, Review of Scientific Instruments, 89, 013503 (2018)

[2] Hardware design and beam modelling of the imaging heavy ion beam probe diagnostic at ASDEX Upgrade, G. Birkenmeier at al, ECPD 2019, poster

Contribution: **P2.19** / Magnetic Confinement Fusion

Preliminary design of quasioptic system for the interferometer for COMPASS-U tokamak

M.Varavin 1,2, J.Zajac 1, S. Mizrakhy 3, P.Nesterov 3, V. Bezborodov 3, F.Jaulmes 1, M. Imrisek 1, S. Nanobashvili 4, P.Bilkova 1, O.Bogar 1,5, M.Hron 1, R.Panek 1, V.Weinzettl 1, F.Zacek 1

1Institute of Plasma Physics of the Czech Academy of Sciences, Prague, Czech Republic
2Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University, Prague, Czech Republic
3Usikov Institute of Radio physics and Electronics, Kharkiv, Ukraine
4Andronikashvili Institute of Physics, Tbilisi, Georgia
5Faculty of Mathematics, Physics and Informatics, Comenius University in Bratislava, Bratislava, Slovakia

The high magnetic field tokamak COMPASS-U [Panek et al., Fus. Eng.des. 123 (2017) 11-16], will be designed and built in the Institute of Plasma Physics in Prague. High plasma densities in COMPASS-U up to 5x1020 m-3 will require a new design of the microwave interferometer. The solution for line-average electron density measurements will be based on the "unambiguous" measurement [Varavin M. et al., Telecommunications and Radio Engineering 73 (10) (2014) 935–942]. A study of quasi-optical antenna system with respect to plasma shape for the different expected plasma density profiles is presented. Ray tracing calculations using the FIESTA-8 code demonstrate the propagation of the probing waves through COMPASS-U plasma. Beam attenuation on the receiving antenna given by the refraction is calculated. Both plasma equilibrium and profiles are simulated using METIS. The quasioptic beam liner system and HFS mirror are also described. The interferometer will provide information on the line-average electron density in real-time.

Contribution: **P2.21** / Beam Plasmas and Inertial Fusion

The development of high performance streak cameras for ICF applications

Xing Wang,Jinshou Tian, Wei Zhao

Xi'an Institute of Optics and Precision Mechanics, Chinese Academy of Sciences

We present our recent development of high performance streak cameras in XIOPM. The temporal resolutions of these streak camera are from nanosecond to femtosecond. The highest temporal resolution we have achieved was 450 fs, which is the best value for practical applications in China. The maximum synchroscan frequency is 300 MHz. To our knowledge, this is the highest level in the world. The dynamic range is 10000:1@100 ps temporal resolution. The static and dynamic spatial resolutions of the streak cameras are higher than 25 lp/mm and 10 lp/mm @CTF=10% respectively. The photocathode sensitivity is more than 100 μA/1m. The streak cameras have been used in diagnosis of the X-rays in laser plasma, measurement of the laser-induced fluorescence lifetimes, analysis of the pulsed laser and so on. In addition, XIOPM also developed three types of compact streak cameras. The dimensions of the subcompact streak tube is just Φ60 mm x 110 mm. Apart from the small size and light weight, the compact streak tubes also have large effective photocathode area, 100 times higher luminous gain than the conventional streak tubes, which makes them suitable for 3D imaging.

Contribution: **P2.22** / Magnetic Confinement Fusion

Development of a new bolometric camera for vertical view in WEST

P. Devynck, F. Faïsse, J. M. Verger

CEA, IRFM, F-13108 St. Paul-lez-Durance cedex, France

WEST the French tokamak is equipped with two divertors at the top and bottom of the machine. As the new holding structures of the top divertor are occupying most of the space in the vertical ports, it was necessary to redesign the vertical bolometer and bring it closer to the plasma to recover the view of the full poloidal section. We present here the solutions which were adopted to fulfill this goal.
The new bolometric top view is composed of two independent cameras of 16 lines each mounted in a single camera head. One is wide angle and covers more than 80% of the poloidal cross section. The other one is narrow angle and concentrates the lines of sight (LOS) on the low divertor.
The new bolometric cameras use metallic foil bolometer detectors that need to be cooled down permanently under 80° C while allowing the baking of the machine at 200°C. For this purpose, two water loops are used. The first one at 35 bars, 70 °C during plasma operation cools down the slit plate (while allowing rising the water temperature up to 200° C during machine baking). The second one at 6 bars, 25 °C cools down permanently the holding structures of the detectors. As the space is very limited in the vertical port and in order to reduce the risk of water leaks and also to simplify the design of the camera, the entire camera head was designed using an original solution of 3D printing in Inconel. The overall design of the two cameras with the vertical views, as well as the alignment procedure that was chosen to position the LOS in the machine will be described. The details of the 3 D printed camera head will be shown. The results of the different tests that were carried out it will be discussed. These tests are: the waterproofness of the circuits, the resistance to high pressures (45 bars), the compatibility of the internal structure (observed with Xray tomography) with the harsh environment of a tokamak.

Contribution: **P2.23** / Magnetic Confinement Fusion

First neutron spectroscopy measurements with a compact C7LYC based detector at EAST

D. Rigamonti1, L. Giacomelli1, M. Rebai1, G. Gorini2,1, M. Nocente2,1, M. Tardocchi1, G. Q. Zhong3, R. J. Zhou3, L. Q. Hu3, F. Camera4, L. Ge5, Y. Zhang5, T. S. Fan5 and EAST Team3

1Istituto di Fisica del Plasma “P. Caldirola”, CNR, Milano, Italy
2Dipartimento di Fisica “G. Occhialini”, Università degli Studi di Milano-Bicocca, Milano, Italy
3Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031, China
4Department of Physics-University of Milan and INFN, Milan, Italy
5School of Physics, State Key Lab of Nuclear Physics and Technology, Peking University, Beijing, China

A new C7LYC based neutron spectrometer has been recently installed at the Experimental Advanced Superconducting Tokamak (EAST). The detector is placed along a dedicated line of sight and it is based on an inorganic scintillator crystal C7LYC (Cs2LiYCl6: Ce) enriched with 7Li coupled to a photo multiplier tube. The absence of 6Li makes the C7LYC insensitive to thermal neutrons while the detection of 2.5 MeV neutrons is based on nuclear reaction with 35Cl(n,p)35S. This reaction has a positive Q-value of 0.617 MeV and, being a two-body reaction, produces a univocal peak in the recorded pulse height spectrum. The C7LYC crystal is very interesting as a fast neutron spectrometer also thanks to its capability to discriminate between neutron and gamma-rays (n/g). The discrimination is based on the pulse shape due to the different scintillation times between n/g induced events. In this work we present the first 2.5 MeV neutron spectroscopy measurements on EAST in D plasmas when NBI was applied. A successful comparison with the expected neutron spectra based on GENESIS simulations is also given. The clear response function of the C7LYC detector to 2.5 MeV neutrons together with its good capability in the n/g discrimination, makes this detector an interesting spectrometer for D plasma diagnostics. In particular, its compactness allows for integration in cameras with multiple lines of sight where space constraints are present.

Contribution: **P2.25** / Magnetic Confinement Fusion

Benchmarking of the EM modelling of the ITER plasma position reflectometry in-vessel antennas using prototype tests

J. H. Belo, P. Varela, A. Silva

Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal.

The ITER Plasma Position Reflectometry (PPR) system is being developed to measure the edge plasma density profile by probing the plasma from four locations, known as gaps 3, 4, 5, and 6, using O-mode FM-CW reflectometers operating in the frequency range 15-75GHz. It is intended to supplement or correct the magnetic diagnostics for plasma position control, in particular during long discharges, where the position deduced from the magnetics is prone to substantial error. The systems of gap 6 and gap 4 have their bi-static pyramidal horn antennas located in-vessel, positioned in narrow (horizontal) openings between two successive blanket modules – the gap 6 antennas installed on the high-field side, whereas those of gap 4 on the low-field side. Studies have shown the importance of considering/modelling (the openings/apertures formed by) the main surfaces of the blanket modules, namely: the bottom (top) surface of the top (bottom) blanket module, including the cut-outs in gap 6, as they strongly shape the radiation pattern, most notably at lower frequencies; and the (slanted) first-wall panels, which may give rise to multiple reflections between the target and the first-wall panels that could hinder the PPR's performance and the ability to meet the measurement requirements. On the other hand, in the case of gap 4, the fact that the height of the aperture between blankets decreases towards the plasma also imposes significant challenges to the performance of the system. An assessment of these issues is presented via 3D electromagnetic simulations performed with CST Microwave Studio as well as Ansys HFSS. Comparisons to laboratory measurements of a prototype of the antennas and mock-ups of the gaps reveal good agreement.

Contribution: **P2.26** / Magnetic Confinement Fusion

Study of N2 transport with residual gas analysis in fusion devices

A. Drenik1, D. Alegre2, S. Brezinsek3, T. Dittmar3, D. Douai4, I. Jepu5, U. Kruezi6, T. Loarer4, G. Meisl1, M. Oberkofler1, T. Reichbauer1,7, V. Rohde1, A. Widdowson5, R. Zaplotnik8, E. Pawelec9, T. Lunt1, the ASDEX-Upgrade team*, the EUROfusion MST1 team** and the JET contributors***

1Max-Planck-Institut für Plasmaphysik, 85748 Garching b. München, Germany
2Laboratorio Nacional de Fusión, CIEMAT, Avda Complutense 40, 28040 Madrid, Spain
3Forschungszentrum Jülich GmbH, IEK - Plasmaphysik, 52425 Jülich, Germany
4CEA IRFM, EURATOM Assoc, F-13108 St Paul Les Durance, France
5Culham Centre for Fusion Energy, Abingdon, Oxon, OX14 3DB, United Kingdom
6ITER Organization, Route de Vinon-sur-Verdon, CS 90 046, 13067 St Paul Lez Durance Cedex, France
7Technische Universität München, 85748 Garching b. München, Germany
8Jožef Stefan Institute, Jamova 39, SI-1000 Ljubljana, Slovenia
9Uniwersytet Opolski, 45-040 Opole, pl. Kopernika 11a, Poland
*See the author list of “A. Kallenbach et al, 2017 Nucl. Fusion 57 102015”
**See the author list "H. Meyer et al 2017 Nucl. Fusion 57 102014"
***See the author list of “X. Litaudon et al 2017 Nucl. Fusion 57 102001”

Residual gas analysis (RGA) has traditionally been in the service of vacuum groups at fusion devices. Recently, however, it has been developed into an experimental diagnostics which provides valuable insight into plasma wall interaction, transport of impurities, plasma isotope ratio and seeding and fueling efficiency. In this contribution, we present the most illustrative results from the JET, ASDEX Upgrade and WEST fusion devices.

RGA is performed with magnetically shielded, differentially pumped mass spectrometers (MSs). As plasma discharges last typically between 5 and 30 seconds, the MSs are set to measure intensities at a limited number of discrete masses, aiming at the acquisition time between 0.3 and 1.5 s. In the mixed D-H environment of a fusion device, the hydrogen containing molecules can appear in any of the possible isotope configurations. A statistical model is used to evaluate the average hydrogen isotope ratio, and deconvolute their contributions to the recordings.

During discharges, the most prominent intrinsic impurity is methane, likely caused by erosion of impurities on plasma facing components (PFCs) Slight discrepancies between the methane and plasma isotope ratio offer insight into the residual fuel content in the wall.

In impurity seeded discharges, which is particularly required in fusion devices with metallic walls, the content is dominated by the seeded impurity. In case of N2-seeding, the formation of ammonia is clearly observed in the residual gas, and the detected content is proportional to the nitrogen density in the core plasma. Detection of ammonia makes RGA a very attractive diagnostic for ITER, where the characterization of tritiated ammonia formation will be required for fuel balance calcuations. Moreover, analysis of ammonia and N2 content very clearly demonstrates an imperfect N2 seeding efficiency in various seeding configurations.

Contribution: **P2.27** / Magnetic Confinement Fusion

Benchmarking 2D against 3D FDTD codes in the assessment of reflectometry performance in fusion devices

F. da Silva, (a) S. Heuraux, E. Ricardo, (b) T. Ribeiro, A. Silva

Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Av. Rovisco Pais, nº1, Lisbon, Portugal
(a) Institut Jean Lamour UMR 7198 CNRS-Université de Lorraine, ARTEM BP 50840, F-54011 Nancy, France
(b) Max-Planck-Institut für Plasmaphysik, Garching D-85748, Germany

Reflectometry, an important technique to diagnose fusion plasmas, is foreseen in the coming generation of machines such as DTT, ITER and DEMO. There is a real need to predict the behavior and capabilities of these new reflectometry systems. Synthetic diagnostics using FDTD time-dependent codes permit a comprehensive view of reflectometry, including aspects such as propagation in the plasma, the system location within the vacuum vessel, its access to the plasma or the signal processing techniques. To obtain a relevant description of the phase, the spatial discretization used in FDTD is a small fraction of the wavelength a fact that together with the physical size of the regions interest considered leads to very large simulations domains. Time evolution also happens with a short time discretization of the probing wave period due to the need to comply with CFL condition. These two facts make reflectometry simulation computational demanding, the reason to mainly use 2 dimensional codes (as REFMUL or REFMULF). REFMUL3, a newly performing parallel code gives access to 3D simulations, although much more costly than 2D ones. We are benchmarking the two types of codes to assess the main differences, as the amplitude of reflected signal, and compromises done when using 2D versus 3D. This is essential to improve data processing for the initialization problem and density profile reconstruction, taking into account multi-reflections and edge turbulence effects on the probing beam or to extract the properties of the density fluctuations.

Contribution: **P2.28** / Basic and Astrophysical Plasmas

Charged particle detector for Breit-Wheeler pair-production experiments

D. Khaghani (1), J.-L. Dubois (1), L. Esnault (1), S. Hulin (2), E. d'Humières (1), S. Jequier (1), P. Lageyre (1), L. Lancia (3), X. Ribeyre (1), V. Tikhonchuk (1)

(1) Univ. Bordeaux-CNRS-CEA, Centre Lasers Intenses et Applications, UMR 5107, 33405 Talence, France
(2) CEA, DAM, CESTA, France
(3) LULI, CNRS, École Polytechnique, CEA, Université Paris-Saclay, Sorbonne Université, F-91128 Palaiseau, France

We present a device for positron detection in the framework of quantum-electrodynamics (QED) laser experiments. This instrument is a crucial element of a large project aiming at demonstrating for the first time the creation of electron-positron pairs via the so-called Breit-Wheeler (BW) process in the laboratory. This QED phenomenon occurs when the collision of two high-energy photons gives rise to the creation of an electron and a positron [1]. The cross section of the BW process is in the order of 10^{-25} cm^2, and the product of the photon energies must be above a threshold of 0.25 MeV^2 in the optimal case of a head-on collision. In the proposed experimental scheme [2], the two necessarily intense gamma-ray sources are driven by ultra-high-intensity (UHI) laser pulses. Furthermore, the large gamma-ray flux being generated can also cause pair productions via other processes (Bethe-Heitler and multiphoton-collision) which are irrelevant in our study. In a nutshell, the small production of BW pairs, the typical electronic noise of UHI laser experiments and the “pollution” by other pair-production processes make the detection of BW pairs a highly challenging task.

To address the electronic noise issue, the instrument must be capable of segregating positrons from electrons. An appropriate design is the magnetic lens, it consists of an assembly of electromagnetic coils ordered so that the magnetic field lines form a quasi-circular loop. Iron cores can be placed within the coils for their magnetic susceptibility properties strengthening the field intensity. As a result, charged particles entering the device are deflected according to the polarity of their charge in- or outwards with respect to the optical axis, or line of sight. Moreover, magnetic lenses allow us for compensating the small pair production with large numerical apertures.

The next step towards detection consists in the conversion of particles into light signal for their monitoring on a camera device. We plan to address the parasitic pair production problem at this stage. We will realize a photon counting channel in a glass medium by utilizing the Cherenkov effect, whose assets are its short-lived nature and the linearity of its response. Then, the light signal is being conducted thanks to an optical fiber to a streak camera, performing a time-resolved detection. Overall, we will be able to know the energy of the detected positrons and when they were produced, which speaks whether they qualify or not for a BW origin. Furthermore, this method prevents from disruption due to electromagnetic pulses as the electronic parts can be set away from the laser interaction area.

We will present simple methods that help for dimensioning the instrument, from the physics laws that govern the magnetic lens optics to numerical tools that simulate its behavior. We have also performed measurements on a prototype, and we will discuss the results.

This project is supported by the French National Research Agency (Nr. ANR-17-CE30-0033 – Project Leader: Xavier Ribeyre).

[1] Breit, Gregory, and John A. Wheeler. "Collision of two light quanta." Physical Review 46.12 (1934): 1087.
[2] Ribeyre, X., et al. "Pair creation in collision of γ-ray beams produced with high-intensity lasers." Physical Review E 93.1 (2016): 013201.

Contribution: **P2.29** / Magnetic Confinement Fusion

Comparison of Phase-extraction Methods of Dispersion Interferometers

J. Knauer (1), K. J. Brunner (1), J. Meineke (1), B. Kursinski (1), M. Stern (1), T. Akiyama (2), M. Hirsch (1), H. Laqua (1), R. C. Wolf (1) and the W7-X team

1) Max-Planck-Institute for Plasma Physics, Wendelsteinstr. 1, 17491 Greifswald, Germany
2) National Institute for Fusion Science, 322-6 Oroshi, Toki, Gifu 509-5292, Japan

Interferometry in fusion experiments traditionally had to deal with the influence of vibrations onto the line integrated density measurement. The “standard” compensation method of two-color interferometry is limited by the accuracy with which the two laser beams can be aligned. In the light of increasing size of fusion experiments such as ITER or DEMO this becomes an increasingly difficult task.
Dispersion interferometry benefits from its robustness against machine vibrations, since it promises complete compensation and therefore a stable line integrated density measurement. For this reason it is being employed in an increasing number of experiments.
The analysis of the interferogram is however more complicated and less standardized than that of the two-colour interferometry technique. So far three methods were developed at different fusion experiments. On TEXTOR gradient estimation at the zero-crossing was used. At LHD the ratio of the frequency components comprising the diode signal was employed and at W7-X a direct integration method was recently developed.
In this paper we present a comparison of these methods in an attempt to establish a standard method for dispersion interferometry according to different usage requirements (i.e. high bandwith, accuracy of phase determination). The ease of calibration, resilience towards fringe jumps as well as high-frequency performance and latency are considered.
This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the EURATOM research and training program 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Contribution: **P2.30** / Magnetic Confinement Fusion

ISTTOK poloidal field coils positioning assessment

A. Torres 1, B. B. Carvalho 1, D. Corona 1, H. Figueiredo 1, H. Alves 1, H. Fernandes 1

1 Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal

The construction of any machine have inherent structural fixing errors. With aging and stresses these tend to increase and can particularly deform the original structures leading to significant deviations from original designs. To assess ISTTOK poloidal coils fixtures after almost 30 years of operation at IST, Lisbon a series of tests were conducted.
Due to its inherent robustness and reliability, the magnetic diagnostic is the prime candidate for real-time plasma position control applications. ISTTOK is equipped with a set of digital integrators for magnetic reconstruction in line with W7-X and in the future with ITER. Incoherence in the data analysis of the poloidal Mirnov coils array suggested a misalignment of the poloidal field (PF) coils. This contribution explores this possibility, relying on the analysis of the magnetic diagnostic data in order to determine the magnetic position of the PF coil circuits. A significant deviation on the positions of said coils was found and a back-propagated correction based on vacuum measurements is proposed for future magnetic data analysis both for real-time control applications and equilibrium reconstruction codes.

Contribution: **P2.31** / Magnetic Confinement Fusion

Design status of the in-vessel components for the ITER plasma position reflectometers of gaps 4 and 6

P. Varela, J. H. Belo, A. Silva, F. da Silva

Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049-001, Lisboa, Portugal

The aim of the ITER Plasma Position Reflectometry diagnostic is to provide the Plasma Control System with real-time measurements of the edge density profile at four locations, known as gaps 3, 4, 5, and 6, which can be used to complement the magnetic measurements of the plasma-wall gaps or to correct potential drifts of the magnetics during long pulses. The systems of gaps 4 and 6 will have components placed inside the vessel: (i) antennas, installed in small apertures between blankets; and (ii) waveguide components, which comprise the transmission lines connecting the antennas to the double in-waveguide vacuum windows. Herein, we provide a comprehensive description of the design status of these components and of the work performed so far, ranging from the electromagnetic simulations performed during the design phase to the results of the prototype tests, conducted to evaluate the performance and the need for further risk mitigation actions. The results show that the waveguide components can all be designed such that the overall losses are minimised, in particular, the oversized bends – 90-degrees in both gaps, just before the antennas, and 125-degrees in gap 4, in the transition to the port extension. Concerning the antennas, the results indicate that both systems might face difficulties in complying with the measurement requirements, in particular in the lower frequencies. Finally, the predicted results closely match the ones from the prototype tests showing the important role of the simulations during development, reducing the need for prototyping and consequently the development costs.

Contribution: **P2.32** / Beam Plasmas and Inertial Fusion

Diagnostics and stabilisation of fusion relevant, laser-accelerated high-energetic proton beams with miniaturised Rogowski coils

J. Gruenwald1, M. Peres Alonso2

1Gruenwald Laboratories, Taxberg 50, 5660 Taxenbach, Austria
2Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa Portugal

Rogowski coils have been used to diagnose high energetic electron or proton beams since the seventies of the last century but usually these measurements were restricted to a single point on the beam axis.
A new experimental concept is presented to measure the axial and radial density profiles of the laser-accelerated proton beam. We propose to use arrays of miniaturised Rogowski coils to measure the current contributions parallel to the driving laser beam with a spatial resolution in the mm range. 3-D CAD models of the experimental setup are presented along with first simulations of the field gradients, which are to be expected within the coils. The main advantages of this plasma diagnostics method are the simplicity and robustness of the setup as well as the fact that it is a passive measurement technique, which has no influence on the plasma itself. As Rogowski coils do not have a ferromagnetic core, non-linear effects resulting from such a core can be omitted as well, which increases the reliability of the obtained data. They also allow to measure fast signals that carry high currents (up to several hundred kA). It will be shown how miniaturized Rogowski coils can be used to diagnose and stabilize high-energy proton beams that are relevant for aneutronic fusion technologies.
This measurement technique may not only be used in laser-plasma accelerators but also in classical accelerator experiments and novel types of fusion reactors.

Contribution: **P2.33** / Magnetic Confinement Fusion

Tomographic reconstruction of COMPASS tokamak edge turbulence from single visible camera data and automatic structure tracking

Jordan Cavalier (1,2), Nicolas Lemoine (2), Frederic Brochard (2), Vladimir Weinzettl (1), Jakub Seidl1 (3) , Scott Silburn(3), Patrick Tamain (4), Renaud Dejarnac (1), Jiri Adamek (1), and Radomir Panek (1)

Affiliation
1 Institute of Plasma Physics of the CAS, Prague, Czech Republic
2 Institut Jean Lamour IJL, Université de Lorraine, Vandoeuvre-lès-Nancy, France
3 CCFE, Culham Science Centre, Abingdon, Oxon, OX14 3DB, United Kingdom
4 CEA-IRFM, F-13108 St. Paul-lèz-Durance, France

Fast cameras have become a popular diagnostic but it remains difficult to get quantitative results from it. The reason why is that the light comes from the whole plasma volume while information from a poloidal plane are required to get a good estimate of structures size and velocity. This supposes to perform a tomographic inversion of a whole movie in order to get good statistics on turbulence dynamics. A mathematical method making it possible to invert the images from one camera using the hypothesis that emissivity is constant along magnetic flux tubes developed by Nguyen van Yen [1] is first presented in this contribution. Then, we carefully checked the validity of the method, first using synthetic diagnostic data from the TOKAM3X code [2] and then comparing experimental data from one fast visible camera and divertor probes obtained on the COMPASS tokamak [3]. Finally using the Track software [4], turbulent structures can be automatically detected and tracked over several images and the shear flow layer can be inferred. As a result, their size, aspect ratio and velocity can be calculated all along records of more than tens of thousand of images, allowing to get a statistical view of turbulence in the SOL of fusion machines.

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Contribution: **P2.34** / Magnetic Confinement Fusion

First measurement of impurity density with the combination of the CXRS and BES systems on EAST tokamak

Yingying Li1), Wei Tao2), Yixuan Zhou2), Di Jiang1), Jia Fu1), Yuejiang Shi3), Bo Lyu1), Baonian Wan1)

1) Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031, China
2) Department of Engineering and Applied Physics, University of Science and Technology of China, Hefei 230026, China
3) Department of Nuclear Engineering, Seoul National University, Seoul 151-742, South Korea
Corresponding author: liyy@ipp.ac.cn

Charge exchange recombination spectroscopy (CXRS) is an active technique used to obtain density of fully ionized light impurities, such as carbon, helium, lithium and so on. For the derivation of impurity density, the neutral beam density required is typically calculated using a beam attenuation model or from beam emission spectroscopy (BES). The accuracy of impurity density depends on the error of beam density calculation. Absolute intensity calibration is inevitable and performed during the maintenance of tokamak. Nevertheless, the performance of the optical system can undergo degradation due to frequent wall conditioning, radiation and so on in the experimental campaigns, increasing further the measurement uncertainty. Another promising method based on cross-calibration of CXRS and BES signal is developed, which has been applied to the measurement of carbon impurity concentration of ITER CXRS prototype on TEXTOR.
On EAST, BES shares the identical viewing optics with core CXRS and has recently been upgraded for the successful measurement of Da lines emitted from the neutral beam particles in the latest experimental campaign. The impurity spectrum obtained by CXRS and simultaneous beam emission line from BES system are from the same lines-of-sight. This offers the possibility to measure the impurity density with the combination of CXRS and BES. In this paper, an overview of the experimental layout the CXRS and BES on EAST will be shown, and the first experimental results are presented.

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Contribution: **P2.36** / Low-Temperature and Industrial Plasmas

The spectroscopy diagnostics for the ESTHER facility

R. B. Gomes1, M. L. Da Silva1, V. F. Villace2 and R. Ferreira1.

1) Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal.
2) ATG Europe B.V. for ESA - European Space Agency, ESTEC, Keplerlaan 1 - P.O. Box 299, 2200 AG Noordwijk ZH, The Netherlands.

The European Shock-Tube for High Enthalpy Research (ESTHER) is in its final phase of commissioning. The main goal of this facility is to study spacecraft re-entry plasmas on different planetary atmospheres (Earth, Venus, Mars, Titan, Gas Giants). The tools considered for this objective are based on ultrafast spectroscopy techniques which should cover a broad spectral region from VUV to MIR. This will provide insight on the absolute heat flux that planetary exploration vehicles heat shields are expected to withstand.
This will be achieved using 3 distinct spectrometers. One will cover the VUV spectral region in the 120-300 nm range. A visible/NIR setup in the 300-850 nm range, and a MIR setup in the 1.5-5 µm range. The VUV spectrometer has been developed from scratch and is based on a McPherson 234/302 model with custom designed collection optics and a Hamamatsu C10910-03F streak camera with VUV optimized input optics. For the visible and MIR spectrometers two distinct HR640 Jobin-Yvon spectrometers, dully refurbished, will be used. These will be equipped with suitable gratings blazed at adequate wavelengths to cover the mentioned spectral regions (500 nm for the visible, 1600 and 4000 nm, for the MIR). The detection system for the visible spectrometer is a reconditioned Hamamatsu's streak camera model C-1587 while for the MIR it is foreseen to couple a Fast-IR Telops camera capable to provide frame rates up to 10 µs/frame with sensitivity from 1.5 to 5.5 µm.
In this paper we present a detailed description of the developed spectroscopy diagnostics, the most recent installation status and some preliminary system calibrations.

Contribution: **P2.37** / Magnetic Confinement Fusion

On the reconstruction method of hollow density profiles using relfectometry data in fusion plasmas

S. Heuraux (a), R.B. Morales (b), F. da Silva (c), S. Roland (d) and S. Hacquin (d)

(a) IJL, UMR 7198 CNRS, University of Lorraine, Nancy 54011, France
(b) UKEA, Abingdon - OX14 3DB - United Kingdom
(c) IPFN-IST Av. Rovisco Pais, nº1, Lisbon, Portugal
(d) IRFM, CEA, Cadarache, Saint-Paul-lez-Durance, France

In fusion plasmas many sources of perturbations generate hollow regions in the cut-off frequency profile. Inside the hollow zones in the density profile, the probing microwaves exhibit no specular reflections, so they are refereed to as blind areas. Even though no reflections occurs inside the blind areas, the higher probing frequencies that propagate through them carry information that can be used to estimate their size. The information used is the signature imprinted in the time-of-flight signal.

Standard reconstruction algorithms based on the WKB approximation of the reflectometer signal do not handling well non-monotonic profiles ignores all full-wave features present in experimental signals. These full-wave features are investigated here with the use of full-wave simulations in 1D, with a special attention paid to the perturbed frequency band. The simulated signals of time-of-flight variations, coming from sine shaped perturbations, are used to build a database of perturbation signatures on 5 dimensions of parameters assoicated to plasma and index parameters. The database is then used in a synthetic example to invert the perturbation signature and determine its size. The same procedure is also demonstrated with experimental reflectometry data from plasma scenario having a magnetic island during a Tore Supra discharge. The new adapted reconstruction scheme, when compared to the standard one improves the description of the density profile inside the blind area and also over 10 cm after it. This technique is pioneer in describing blind areas. The consecquences on the intialization problem will also be discussed.

Contribution: **P2.38** / Magnetic Confinement Fusion

Studies of the Microwave Reflectometer Design for the COMPASS-U

O. Bogar^{1,2}, A. Casolari^{1}, P. Bilkova^{1}, F. Jaulmes^{1}, M. Imrisek^{1,3}, M. Farnik^{1,4}, V.Weinzettl^{1}, M.Hron^{1},R. Panek^{1}

1 Institute of Plasma Physics, The Czech Academy of Sciences, Prague, Czech Republic
2 Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovakia
3 Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic
4 Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Prague, Czech Republic

The COMPASS-U tokamak is designed for unique high magnetic field and high plasma density operation (R= 0.89 m, a= 0.28 m, B_T=5 T, I_p<2 MA, P_NBI=4 MW). The scientific program is aimed on studies of enhanced confinement modes, edge plasma physics and high divertor power fluxes.

The METIS simulation of baseline scenario predicts $\langle n_e \rangle = 3.3\cdot 10^{20}$ m^{-3} in H-mode and $\langle T_e \rangle$=1.8 keV. A new microwave reflectometer system is included in the diagnostic setup for the first phase of the COMPASS-U tokamak operation. The main task of the system is to measure electron density profiles in the pedestal region with high temporal resolution. The reflectometer system should also measure densities and positions of the separatrix on the outer midplane. These requirements delimit our choice of the frequency range and the wave polarization for the proposed system. Presented studies lead to employ a combination of X and O mode polarization in frequency range 40-140 GHz. We require a capability to increase frequency range up to 170 GHz for the B_T=5 T scenario with full power of the additional heating.
The design with bistatic antenna arrangement offers many free parameters. Their suitability for different operational and design constraints is discussed. The propagation and reflection of the reflectometer probe beam is calculated by beam tracing simulation code TORBEAM for different plasma shapes. Simulations also show the dependence of the received beam power on the vertical plasma movement, the antenna angle and the plasma scenario.

Contribution: **P2.39** / Magnetic Confinement Fusion

Real-time detection and correction of frequency sweeping non-linearities of FMCW reflectometer microwave sources

Jorge M. Santos, António Silva

Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

Density profile FMCW reflectometry will be used to complement or replace magnetic measurements for plasma position control in future plasma fusion reactors, such as ITER and DEMO. Although FMCW reflectometry is a well established diagnostic technique, on present experimental devices with short discharges (typically of a few seconds), on-line measurement quality validation and correction is not a common practice. One of this technique main requirements is to ensure that the microwave sources always produce a linear frequency sweep within the probing frequency range. Failing to do so leads to inaccurate density profile reconstruction and, hence, to erroneous plasma position feedback to the tokamak control loops.

Traditionally, static calibrations are used to build the voltage ramps driving the reflectometer's VCO sources. By using extra signals like frequency markers or calibrated delay lines, the experimental reflectometry measurements can be further calibrated, off-line, to improve frequency sweep linearity related distortions. We herein propose a technique to monitor and re-calibrate in real-time the linearity of the frequency sweeps of FMCW reflectometers. It can be applied in the long duration discharges of future devices either to correct thermal or electronic drifts of the probing frequency sources or to generate alarm signals when measurement anomalies or fundamental diagnostic malfunctions are detected. Experimental data is presented showing the benefits of the proposed technique.

Contribution: **P2.40** / Magnetic Confinement Fusion

Assessment of a multi-reflectometers positioning system for DEMO plasmas

E. Ricardo*, F. da Silva*, S. Heuraux**, A. Silva*

*Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Av. Rovisco Pais, nº1, Lisbon, Portugal
**Institut Jean Lamour UMR 7198 CNRS-Université de Lorraine, ARTEM BP 50840, F-54011 Nancy, France

The design of the DEMO plasma position reflectometer involves the assessment of the measurement performance of different poloidal views and geometries, with different plasma configurations. Even though DEMO will be based on an operation scenario, the sensitivity to the effects of the plasma displacements, plasma curvature, turbulence and MHD activity in the reflectometry measurements have to be known to define an appropriated procedure fulfilling the DEMO requirements in any case if it is possible. In this work we evaluate the measurement performance of 16 gaps of the DEMO Plasma Position Reflectometer using a synthetic Ordinary Mode (O-mode) reflectometer. The gaps are located at different locations along the DEMO wall, covering different plasma-wall configurations. The antennas were aligned perpendicularly to the separatrix, with the aim of trying to optimize the separatrix position measurement. The 2015 baseline scenario from the official EUROFUSION plasma database was used to produce the plasma model. By aligning the antennas perpendicularly to the separatrix, simulations shown that the separatrix position error of 15 gaps is in the order of the required value for the plasma position control system. 11 positions can provide confident results for the baseline scenario, having a position error below the requirement (1 cm). The locations at the top of the DEMO plasma are close to the limit of requirements for the plasma positioning. We concluded that aligning the emitting antennas perpendicularly to the separatrix is fundamental to improve the reflectometer accuracy for the positions around the tokamak's wall. Even using this principle, the locations near the divertor lose the signal due to the abrupt plasma curvature.

Contribution: **P2.41** / Faenov Memorial Session

Calculation of absolute values of laser plasma X-ray emission intensity generated during Si foils irradiation by picosecond laser pulses with intensit

Ryazantsev S.N.(1,@), Skobelev I. Yu. (1,2), Pikuz T. A. (1,3), Durey P.(4), Doehl L.(4),Farley D.(4), Baird C. (4), Lancaster K.(4), Murphy C.(4), Booth N.(5), Spindloe C.(5), McKenna P.(6), Hansen S.B.(7), Colgan J. (8), Kodama R. (3,9), Woolsey N.(4),Faenov A. Ya.(1,9), Pikuz S. A. (1,2)

1 Joint Institute for High Temperatures of the Russian Academy of Sciences, Izhorskaya 13 Bldg 2, Moscow 125412, Russia
2 National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe Shosse 31, Moscow 115409, Russia
3 Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan
4 York Plasma Institute, Department of Physics, University of York, Church Lane, Heslington, York YO10 5DQ, United Kingdom (Great Britain)
5 Central Laser Facility, Rutherford Appleton Laboratory, Harwell Campus, Didcot, Oxfordshire OX11 0QX, United Kingdom (Great Britain)
6 University of Strathclyde, Richmond 16, Glasgow G1 1XQ, United Kingdom (Great Britain)
7 Sandia National Laboratories, Albuquerque, New Mexico 87123, United States
8 Theoretical Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, United States
9 Open and Transdisciplinary Research Initiative, Osaka University, 1-1 Yamadaoka, Suita, Osaka 565-0871, Japan

X-ray spectroscopy is a high-efficiency method of plasma investigation. It is well-known that ratios of spectral lines intensities radiated by a plasma depend on its parameters. So, it is possible to determine them by comparing experimental values with theoretical ones calculated for exact values of electronic temperature and density. The method accuracy directly depends ona an X-ray detector system instrumental errors. Them can be obtained from a summarized hardware function of data acquisition equipment, which includes hardware functions of all parts of a spectrometric route. Most of them are strongly non-linear and can dramatically effect on the lines intensity and as result on line ratios. In experiments for interaction of petawatt laser pulses with thin Si foils described in this paper the spectrometric route consists of filters (thin films made of different materials), spherically bent α-quartz crystals, image plates and CCD. Instrumental functions for all the parts are given. Result of influence on registered spectra is shown and discussed.

Contribution: **P2.42** / Magnetic Confinement Fusion

Characterization of modified 90deg cylindrical energy analyzer with electron beam

R. Sharma, I. S. Nedzelskiy, A. Malaquias, R. Henriques

Instituto de Plasma e Fusão Nuclear, Instituto Superior Tecnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal.

The Heavy Ion Beam Diagnostic (HIBD) installed on the small tokamak ISTTOK [1] is based on Xe+ species primary beam injection (E0 = 20 keV) and a multiple cell array detector (MCAD) for secondary, Xe2+, ions detection. In this mode of operation, the use of standard Proca-Green 30o energy analyzer for the plasma potential measurements is of reduced applicability. A compact multiple-channel multi-slit 90° cylindrical energy analyzer (CEA) with combined MCAD and split-plate (SPD) detection was proposed for the plasma potential and potential fluctuations measurements by HIBD. The simulations using SIMION code predicts significant improvements of energy resolution and strong decrease of the angular aberration coefficient due to lensing properties of fringing field and deceleration of ions inside CEA with detection at decelerating potential.
Recently, the simulations have been optimized to include the real dimensions of the CEA housing chamber and the secondary electron emission (SEE) from the detector plate. To shield the electric field perturbations introduced by the chamber, two guard rings (GR) have been added on top and bottom between CEA plates. To overcome the SEE effect, the detector part has been modified by adding two grids and ions detection at zero potential. The GR dimensions and position, and the distances between the grids and detector plate have been optimized by SIMION code. This article presents the results of numerical simulations and experiments, obtained with the modified CEA in normal and two-times deceleration modes using electron beam. A very good agreement between the experimental results and the numerical simulation predictions has been observed. The energy resolution of (ΔE/E0) ~ 2.4×10^-3 has been obtained in deceleration mode insensitive to the Δθin = ±1° change of the analyzed beam entrance angle.

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An absolutely-calibrated extreme UV imaging spectrometer for the WEST tokamak

R. Guirlet, I. Song, T. Batal, G. Moureau, C.R. Seon, C. Desgranges, O. Meyer, J.L. Schwob, W. Choe

CEA, IRFM, F-13108 St-Paul-lez-Durance, France
National Fusion Research Institute (NFRI), Republic of Korea
Korea Advanced Institute of Science and Technology (KAIST), Republic of Korea
Hebrew Univ Jerusalem, Racah Inst Phys, Jerusalem, Israel

A Compact Advanced EUV Spectrometer (CAES) identical to the one operated on the KSTAR tokamak [1] has been manufactured and interfaced with the WEST tokamak. The spectrometer is equipped with a curved, holographic grating illuminated at an angle of 4.5°. Its wavelength range is 2-7 nm where a group of W spectral features including a quasi-continuum spectrum lies. The spectrum emitted in this range by the WEST plasmas has been observed in various conditions with the grazing incidence spectrometer [2]. The W features (lines and quasi-continuum) are very clear. It is also seen that, despite the absence of carbon on the plasma facing component surfaces, C Lyman series lines are present. This stresses the interest of the CAES in the future campaigns.
The spectrometer is equipped with a horizontal slit allowing the spectrometer a resolution in the vertical direction of the plasma. A variable binning of the CCD detector allows to adapt the vertical resolution to the desired value, depending on the plasma conditions. The design of the interface with the tokamak and of the supporting frame is such that the inner half of the plasma below the midplane will be observed.
The spectrometer elements have been aligned in the laboratory with a He-Ne laser. The line of sight in the tokamak has been checked during the last maintenance shutdown.
The next step is the absolute brightness calibration. This is done using an extreme UV source produced by a 5 keV electron beam hitting a target [3], resulting in the emission of the target material K-α line. For the wavelength domain of the CAES, four targets are used: O (23.7 Å), N (31.6 Å), C (44.4 Å) and B (67.0 Å), thus covering the entire wavelength domain of the spectrometer. The absolute photon flux is measured with a gas proportional counter symmetric to the spectrometer line of sight with respect to the electron beam.
Two calibration procedures are used. The first one consists of calibrating the spectrometer without the horizontal slit, i.e. without the vertical spatial resolution. The other procedure consists of calibrating the spectrometer with its vertical resolution, which necessitates to move the photon source along the vertical direction. Although the second procedure is longer, it is the only one which allows to correct for sensitivity and potential geometrical etendue variations along the vertical direction.
The results of both procedures are combined to provide wavelength dependent brightness calibration coefficients. A method has been designed to adapt these coefficients to the chosen vertical binning and resolution.

The spectrometer is installed on the WEST tokamak. The control and data acquisition programme is in progress so that the CAES is expected to be operational in the course of the coming experimental campaign.

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Contribution: **P2.44** / Beam Plasmas and Inertial Fusion

Comparative analysis of the characteristics of the plasma stream in the MPC facility, depending on different kind of working gases

T.M. Merenkova, D.G Solyakov, Y.E. Volkova, M.S. Ladygin, A.K. Marchenko, , Yu.V. Petrov, V.V. Chebotarev, V.A. Makhlaj, D.V. Yeliseyev

National Science Center "Kharkov Institute of Physics and Technology",
Institute of Plasma Physics, 1, Akademicheskaya St., Kharkov, 61108, Ukraine

The present paper devoted to researches of features of discharge evolution and current-voltage characteristics of magneto-plasma compressor (MPC). The working regimes could be varied by choosing the quantity and kind of gas, supplying the MPC. Helium, nitrogen, argon were used as working gases. Both temporal and spatial distributions of plasma density and currents in plasma as well as radial distributions of energy density in plasma streamers generated by MPC have been measured.

Position of compression zone, it effective diameter, compression ratio and spatial profiles of energy density are analyzed. The comparative analysis of plasma steams parameters for the three working gases was carried out. Significant reduction of the initial concentration (for example, due to the transition from helium to argon) leads to significant change of current distribution in plasma stream. The generation of toroidal current vortex, and displacement of the current from the axial area are observed.

Contribution: **P2.45** / Faenov Memorial Session

X-ray daignostics of hydrodynamic phenomena in laser-induced astrophysically-relevant plasma

Filippov E.D., Revet G., Skobelev I.Yu., Ryazantsev S.N., Chen S.A., Fuchs J. and Pikuz S.A., ,

Joint Institute for High Temperatures, RAS, 125412, Moscow, Russia
National Research Nuclear University MEPhI, 115409, Moscow, Russia
LULI-CNRS, École Polytechnique, CEA: Université Paris-Saclay; F-91128 Palaiseau cedex, France

This work is devoted to the x-ray studying the astrophysically-relevant phenomena in laser-induced plasma and particularly to accretion dynamics of young stars in laboratory. The experiments were conducted in laboratory LULI of Ecole Polytechnique in Palaiseau, France. In order to investigate the accretion dynamics in the laboratory we created a collimated narrow (1 mm diameter) plasma stream by imposing a strong (Bz=20 T) external and uniform poloidal magnetic field onto an expanding high-power laser (0.6 ns duration, 10^13 W/cm^2) ablated plasma. X-ray spectroscopy was applied as one of basic tools to study dynamics and measure parameters of jets. Particularly, this experimental platform allowed to research influence of differently oriented magnetic field on collimation of plasma astrophysically-relevant jet. Then, these plasma streams were used to simulate formation of accreting columns in young stars at presence of magnetic field. Experiment was performed when expanding plasma stream impacts on solid obstacle mimicking stellar photosphere. As a result, simultaneous measurements of plasma parameters by means of optical interferometry and x-ray spectroscopy allowed to discover formation of plasma shell with temperatures of about hundreds eV that envelops shocked core. The presence of this shell can be a reason of reducing escaped x-ray emission in astrophysical observations.

Contribution: **P2.46** / Faenov Memorial Session

Research network and contribution of Prof. A. Faenov in high energy density experimental science and X-ray diagnostics

T.Pikuz1,2, S. Pikuz2, I. Skobelev2

1 Institute of Open and Transdisciplinary Research Initiatives, Osaka University, Suita, Osaka, 565-0871, Japan
2 Joint Institute for High Temperatures, Russian Academy of Sciences, Moscow, Russia

This presentation will give the compact overview of Anatoly's research activity in relation to his broad international collaboration. We will draw the network connecting institutions and experimental facilities all over the world, where Anatoly found colleagues been infatuated with plasma physics both in theory and experiment. We will show how this network grew and spread on time together with development of laser systems from GW to sub-PW power, together with discovering of new phenomena in the behavior of laser produced plasma and together with development of new diagnostics methods.

Contribution: **P2.47** / Magnetic Confinement Fusion

Near-wall plasma acceleration measurements with the incoherent and coherent Thomson scattering diagnostics at Magnum-PSI

J. van den Berg, H.J. van der Meiden, J.W.M. Vernimmen, I.C.M. Classen

DIFFER - Dutch Institute for Fundamental Energy Research,
De Zaale 20, 5612 AJ Eindhoven, the Netherlands

Plasma acceleration towards the wall is a key aspect of Debye sheath formation, and marks a region of interaction between plasma bulk and sheath. The processes that occur in this region can influence the transfer of particles and energy to the wall.
In the quest to long-term operation of high-power magnetically confined fusion devices, it is crucial to control these particle and heat loads. Therefore, understanding of the near-wall plasma behavior is important.

This research aims at the application of the non-intrusive incoherent and coherent Thomson Scattering diagnostics (TS & CTS, resp.) in the near-wall region of the Magnum-PSI linear plasma generator.
Together, these diagnostics provide direct, local measurements of electron density (n_e), electron and ion temperature (T_{ei}) and ion bulk velocity (v_i). By incrementally moving the plasma target along the magnetic field, an axial profile of these parameters can be obtained.
Incoherent TS is routinely used on Magnum-PSI to measure radial profiles of electron temperature T_e and density n_e. For suppression of stray light close to the target, a 0.5 mm diameter wire was placed in the intermediate focus plane of the spectrometer.
To enable measurements close to the target, a stray light suppression up to a factor 10^4 was achieved, while retaining high transmission.
Dedicated measurements with this adapted system yielded axial and radial profiles of T_e and n_e down to 1.2 mm from the target.
The application of a 1064 nm Nd-YAG laser for CTS in low-temperature, high-density plasmas was first demonstrated in 2015 on the Pilot-PSI device and provided measurements of ion temperature T_i and velocity v_i. This diagnostic has now been set up on the Magnum-PSI device, with a different scattering geometry (scattering angle 13°), as well as measures for laser stray light mitigation. Important aspects of the data analysis are reported.

Contribution: **P2.48** / Basic and Astrophysical Plasmas

Stark width and shift of He I spectral lines at plasma conditions of astrophysical interest

M. A. Gigosos (1), R. Florido (2), M. A. Schaeuble (3), T. Gomez (3), T. Nagayama (3), J. Bailey (3),

(1) Departamento de Física Teórica, Atómica y Óptica, Universidad de Valladolid, Spain
(2) iUNAT-Departamento de Física, Universidad de Las Palmas de Gran Canaria, Spain
(3) Sandia National Laboratories, Albuquerque, New Mexico, USA

Analysis of Stark-broadened spectral line profiles is one of the most often used plasma diagnostics techniques, especially to determine the electron density in both laboratory and astrophysical plasmas. Within the framework of the Z Astrophysical Plasma Properties collaboration [1], there is a renewed interest on the modeling of Stark-broadened line shapes because of its application to different topics under investigation, such as stellar interior opacities or white dwarf photospheres [2]. In connection with the latter topic, it is critical to have a benchmarked model to univocally correlate line shapes to plasma temperature and density, particularly for the case of H and He spectral lines. In this work, we present updated calculations of Stark width and shift for three different spectral lines of He I with diagnosis potential, that had already been studied in a previous work [3]. Calculations are performed using a computer simulation technique, wherein the plasma behavior is numerically represented to follow a classical particle dynamics. Here, previous work has been extended to include a full dipolar coupling among states with principal quantum number from n=2 to n=5 (i.e. quenching effect is taken into account). Differences between calculations including quenching effect or not are discussed. Updated line shift results show a noticeable improvement when compared with published experimental data.

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Contribution: **P2.49** / Beam Plasmas and Inertial Fusion

Time resolved x-ray imaging of hot electron generation at shock ignition relevant laser intensities

O. Renner,1,2 L. Antonelli,3 F. Baffigi,4 D. Batani,5 T. Chodukowski,6 G. Cristoforetti,4 R. Dudzak,1,2 E. Filippov,7 L.A. Gizzi,4 L. Juha,1,2 M. Krupka,2 M. Krus,1,2 D. Mancelli,5 A. Martynenko,7 V. Ospina,8 T. Pisarczyk6, Z. Rusiniak6

1 Institute of Physics of ASCR & ELI-Beamlines, Prague, Czech Republic
2 Institute of Plasma Physics of ASCR, Prague, Czech Republic
3 York Plasma Physics Institute, University of York, United Kingdom
4 Istituto Nazionale di Ottica, CNR, Pisa, Italy
5 Université Bordeaux, CNRS, CEA, CELIA, Talence, France
6 Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland
7 Joint Institute of High Temperature of RAS & MEPHI, Moscow, Russian Federation
8 CLPU, University of Salamanca, Spain

Despite generally acknowledged importance of the hot electron (HE) role in a development of shock ignition approach to inertial confinement fusion [1], the detailed mechanisms of their generation and impact on formation and dynamics of strong shocks are not fully understood yet. Considerable efforts directed at development of new theoretical approaches which allow complex treating of parametric instabilities, HE generation, energy deposition, and effects on hydrodynamics [for references, see e.g. 2] resulted in advancement of numerical codes which need reliable experimental results for their verification. Here we report time resolved measurements of HE generation that bring new data suitable for benchmarking the codes and, in the same time, contribute to the development of advanced methods for HE diagnosis. We describe alternate experimental setups combining spherically bent diffraction crystals with the X-ray streak camera to obtain magnified time resolved monochromatic images of K-shell emission which can be related to the HE action in relatively cold laser irradiated targets [3]. Finally we present first experimental results obtained at the PALS facility (laser wavelength 1.315 µm, pulse duration 0.3 ns, focal spot size 100 µm) where the laser-plasma coupling was studied using bare or plastic coated Cu targets of different thickness at intensities up to 1.5E16 W/cm2. The observed dependencies of the duration, relative delay vs the laser beam maximum, and integrated Cu Kα emissivity are discussed with respect to alternate mechanisms of the HE production.

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Contribution: **P2.50** / Beam Plasmas and Inertial Fusion

Soft X-ray measurement with a gas detector coupled to microchips in laser plasma experiments at VEGA-2

G. Claps1, F. Cordella1, D. Pacella1, A. Romano1, F. Murtas2, D. Batani3, O. Turianska3, D. Raffestin3, L. Volpe4,5, G. Zeraouli4,5, J.A. Perez-Hernandez4, S. Malko4,5

1ENEA Fusion and Nuclear Safety Department, Via E. Fermi 45, 00044, Frascati, Italy
2INFN – Laboratori Nazionali di Frascati, Via Enrico Fermi 40, 00044 Frascati, Italy
3CELIA Université Bordeaux, 49 rue Pierre Noailles, 33405 Talence, France
4CLPU, Centro de Laseres Pulsados, Scientific Park, Building M5, C/Adaja 8, 37185 Villamayor – Salamanca, Spain
5CLPU Laser-Plasma Chair at University of Salamanca, Salamanca Spain

In this work an innovative usage of the GEMpix for soft x-rays (SXR) measurements is proposed. The GEMpix is a proportional gas detector based on three consecutive Gas Electron Multiplier (GEM) foils with a front-end electronic based on four Timepix microchips, with 512×512 squared pixels, each one 55 µm wide. It gives the possibility to work on Time over Threshold (ToT) mode where each pixel provides a digital measure of the released charge in the gas mixture. In addition, the charge can be amplified through the GEM foils with 4 order of magnitude spanning gain offering, in this way, a big dynamic range and adjustable sentitivity. Thanks to the microchip design, thresholds can be changed in order to cut the noise off (noise-free) or reject unwanted radiation background. This detector offers good imaging properties, high efficiency, and absolute calibration. A scan in threshold allowed the discrimination of the spectra produced by laser on different solid targets. It offers a good immunity to Electromagnetic Pulse (EMP), as checked at VEGA-2 laser facility (hundreds of TW in about 30 fs). In these experiments, where the formation of warm dense matter produced by blast waves has been studied, three different absorbers in the SXR bands have been placed on the active area of the detector, in correspondance of the three ASICs, while the forth one was left without absorber for normalization. With this configuration an estimation of the electron temperature of the coronal plasma produced by the laser on the target has been done for single shot. SXR emissions measured with GEMpix have been also cross-checked and compared with the signals produced by a SXR Kirkpatrick-Baez microscope and a photodiode.
GEMpix revealed innovative and attractive features, compared to the state of the art where passive films or detector based on indirect conversion are used, for a SXR imaging and spectral analysis to infer the electron temperature.

Contribution: **P2.51** / Magnetic Confinement Fusion

Modelling of the NBI contribution to the neutron energy spectra for the ITER Vertical Neutron Camera

T. M. Kormilitsyn, G. E. Nemtsev, Yu. A. Kashchuk, D. V. Portnov

Project Center ITER, Kurchatov sq. 1, bld. 3, 123182, Moscow, Russia

The study of fast ion behavior in reactor conditions is among the major goals of the ITER project. Additional heating by NBI creates population of suprathermal ions with an anisotropic distribution in velocity space. The ITER Vertical Neutron Camera (VNC) is a multichannel collimator system designed for measuring the neutron emissivity profile and spectra. The energy spectrum measurements of neutrons made by the VNC will contribute to the reconstruction of the ion temperature, fuel ratio and fast ions' distribution function. It will help determine the consequences of instabilities that cause the redistribution of fast ions in the plasma and to the assessment of their impact on plasma heating and resulting neutron spectrum.

In this paper, the results of neutron spectra calculation for the ITER VNC are presented. The developed software allows for the simulation of particle spectra resulting from interaction of suprathermal ions with thermal background plasma. The method relies on direct reaction rate calculation and explicit fusion reaction kinematics modelling.

Assessment of the D-T neutron spectra is carried out for D-NBI heated baseline D-T ITER operation scenarios. It is shown that neutron flux resulting from fast ("beam") D with thermal T ion interaction dominates at En > 16 MeV part of the spectra. Thus, it looks possible to assess fuel ratio based on calculated "thermal-thermal" and "beam-thermal" neutron energy spectra. Also the accuracy of the ion temperature assessment is shown to become worse for low-density phase of ITER operation.

Contribution: **P2.52** / Basic and Astrophysical Plasmas

Pump and probe diagnostic technique for turbulence studies in ultra-cold plasmas

R. Giampaoli, J.D. Rodrigues, J.A. Rodrigues, J.T. Mendonça

Instituto de Plasmas e Fusão Nucluear, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal.

Blackett Laboratory, Imperial College, Prince Consort Road, London SW7 2BZ, UK.

Departamento de Física, Faculdade de Ciências e Tecnologia, Universidade do Algarve, 8005-139 Gambelas, Faro, Portugal.

The production of ultra-cold neutral plasmas in magneto-optical traps, with ion temperatures below 1 Kelvin and electron temperatures of a few Kelvin, has opened a range of opportunities to study astrophysical plasmas in the laboratory. Evidence of mutual forces between ultra-cold atoms mediated by scattered photons has been frequently pointed out in literature, but plasma-like dynamics in these media have been scarcely investigated.

The goal of our work is to develop a novel diagnostic technique based on resonant laser absorption, that allows to study density correlations, elementary excitations, disorder-induced heating and turbulent dynamics in ultra-cold atomic clouds.

We propose a pump and probe absorption diagnostic technique, integrated with a large magneto-optical trap, that allows to directly retrieve the density distribution of the plasma without relying on column density integrated signals and on the assumption of spherical symmetry. Later on, as an important new application of this diagnostic method, we intend to use our experimental setup to study the bubble turbulent regime arising in optically thick media.

Contribution: **P2.53** / Beam Plasmas and Inertial Fusion

Gamma rays detection in laser produced plasmas with Silicon C-MOS imager by means of trace analysis

G. Claps1,2, F. Cordella1, D. Pacella1, F. Murtas2, D. Batani3, O. Turianska3 , D. Raffestin3, L. Volpe4,5, G. Zeraouli4,5, J.A. Perez-Hernandez4, S. Malko4,5

1ENEA Fusion and Nuclear Safety Department, Via E. Fermi 45, 00044, Frascati, Italy
2INFN – Laboratori Nazionali di Frascati, Via Enrico Fermi 40, 00044 Frascati, Italy
3CELIA Université Bordeaux, 49 rue Pierre Noailles, 33405 Talence, France
4CLPU, Centro de Laseres Pulsados, Scientific Park, Building M5, C/Adaja 8, 37185 Villamayor – Salamanca, Spain
5CLPU Laser-Plasma Chair at University of Salamanca, Salamanca Spain

A new approach for Hard-X and gamma rays measurements has been successfully tested at VEGA-2 laser facility in 2018, using a Timepix3 C-MOS detector. It consists of an ASIC of 256 × 256 pixels, bump-bonded with 300 μm thick Silicon pixelated layer. Each pixel is 55 μm × 55 μm and the active area is 14 mm × 14 mm. The full electronic chain is integrated underneath the pixel. Since 300 μm of the silicon thickness is too thin for an efficient release of energy for the gammas, the detector is mounted in side-on configuration. In this case, the incoming radiation interacts with the Silicon through the entire length of 14 mm, producing traces due to multiple Compton electrons scattering. A variety of parameters have been defined: Cluster Size (CS), Time over Threshold (ToT), Linearity, Roundness, etc. Based on the ToT cluster value, we characterized the detector response in laboratory using some known gamma sources (137Cs, 60Co, etc.) and the Geant4 Monte Carlo simulations. This allows the discrimination between various energy bands for the gamma photons coming from the plasma. This technique allows the evaluation of the radiation maximum energy, form 80 keV up to many MeV. In laser plasma experiments radiation is produced in less than a nanosecond, so the standard spectroscopic techniques (like scintillator or Hp Ge) cannot be used because of the pile up of all the photons. With the proposed technique each gamma produces its trace in the silicon sensor, separated by the others, once the incoming flux is properly reduced by distance or shielding. More shots have to be integrated to have enough statistic for the trace analysis. Experiments at VEGA-2 for the generation of energetic gammas revealed spectra arriving up to 4 MeV. The technique was used also in experiments at VEGA-2 facility designed to study the formation of the warm dense matter. The obtained spectra were compared to results of another diagnostic: a bremsstrahlung cannon providing a low-resolution hard X-ray spectrum (a stack of imaging plates separated by various filters).

Contribution: **P2.54** / Magnetic Confinement Fusion

ST40 First Results and Diagnostics Systems Upgrade

Jonathan Wood and Tokamak Energy Ltd. Team

Tokamak Energy Ltd.

ST40 is a high field low-aspect ratio spherical tokamak (R=0.4-0.5m, R/a=1.6-1.8, Ip=2MA, Bt=3T, κ=2.5-3.0, pulse length~1-2sec and 2MW NBI) built and operated by Tokamak Energy Ltd.

The first programme of ST40 operations took place in spring 2018. The main aim was to optimise Merging/Compression (MC) start-up by maximising the thermal energy and plasma current. A multi-chord UV/VIS HD Spectrometer (minimum exposure: 0.5ms, spectral range: 200-720nm, instrumental resolution: ~0.05nm) was used to measure ion temperatures via Doppler broadening of passive spectra (e.g. C-V, B-IV and C-III). The results show that ST40 achieved ion temperatures >1.5keV. The line broadening measurements were statistically significant and consistent with a Gaussian distribution, and radial/tangential measurements were in good agreement, strongly supporting a thermal distribution.

In the next campaign (scheduled to begin in 2019), the ST40 diagnostic set will be upgraded to give more detailed measurements of kinetic profiles, such as Ti, Te and plasma density. The diagnostic system upgrades include: Diagnostic Neutral Beam Injector (DNBI) for active spectroscopy, Crystal X-ray Spectrometer, Soft X-ray Tomography (SXR), Neutral Particle Analyser (NPA), Near-InfraRed (NIR) interferometer, Submillimetre (SMM) interferometer and Electron Cyclotron Emission (ECE) radiometer. One of the primary missions of ST40 is to confirm the predictions of favourable energy confinement in spherical tokamaks at high toroidal fields. The planned diagnostic upgrades will allow the necessary measurements to be made.

In this poster we present both experimental results from the first campaign and give details about the diagnostic upgrades for the next ST40 campaign.

Contribution: **P2.55** / Magnetic Confinement Fusion

Lessons learned from operating infrared diagnostics during initial divertor campaign

H. Niemann 1, M. W. Jakubowski 1, A. Ali 1, P. Drewelow 1, A. Puig Sitjes 1, B. Cannas 3, Y. Gao 1, F. Pisano 3, R. König 1, T. Sunn Pedersen 1, W7-X Team

1 Max-Planck-Institute for Plasma Physics, Wendelsteinstraße 1, 17491 Greifswald
2 Forschungszentrum Jülich GmbH, 52425 Jülich, Germany
3 University of Cagliari, Cagliari, Italy

Steady state magnetic fusion devices require continuous monitoring of water-cooled plasma facing components. Infrared (IR) camera systems are used on many fusion devices to fulfill this task. Wendelstein 7-X aims at quasi-steady state operation with up to 10 MW of heating power for 30 minutes. Power exhaust will be handled predominantly via 10 water cooled CFC based divertor units designed to withstand convective loads of 10 MW/m 2 locally in steady state. In the recent campaign test divertor units were used, which allowed for extensive tests of the infrared systems. At W7-X each divertor is observed with an imaging system, consisting of an infrared camera and visible cameras with filters.
Nine immersion tubes and one endoscope were used in the last experimental campaign of W7-X to monitor the heat and particle flux onto the divertors. A mid-wavelength (3-5 µm) CMOS infrared camera (1280x1024 pixels, 100 Hz) was mounted on the endoscope, while long-wavelength (8-10 µm) micro-bolometer cameras (1024x768 Pixel, 100 Hz) with wide-angle lenses were inserted into the immersion tubes between the magnetic coils. The thermographic diagnostics have to identify areas with too high temperature, distinguish them from other events like e.g. surface layers, and send alarms to the Fast Interlock System. W7-X 3D geometry makes the endoscopes particularly sensitive to the spatial calibration of the cameras since hot spots can be expected anywhere and a full segmentation of the field of view is necessary. The present systems could achieve spatial resolution of 5 mm in the most loaded part of the divertor, however only 10-20 mm in the remote part, which would be insufficient for the high heat flux divertor. As a consequence a redesign of the diagnostic is ongoing.

Contribution: **P2.56** / Magnetic Confinement Fusion

Plasma density profile measurements using HIBP in the TJ-II stellarator

P.O. Khabanov[1,2], A.V. Melnikov[1], L.G. Eliseev[1], N.K. Kharchev[3], V.P. Shevelko[4], M.A. Drabinskiy[1,2]

1)NRC 'Kurchatov Institute', Moscow, Russia
2)Moscow Institute of Physics and Technology, Dolgoprudny, Russia
3)General Physics Institute, Moscow, Russia
4)Lebedev Physical Institute, Moscow, Russia

TJ-II is a low magnetic shear stellarator with major radius R=1.5 m, average minor radius a<0.22 m and toroidal magnetic field on axis up to 1 T. Both ECRH and NBI plasmas can be studied in the device with the discharge duration up to 300 ms. TJ-II is equipped with the unique dual Heavy Ion Beam Probe (HIBP) diagnostics, which is capable to measure local values of the plasma electrostatic potential and its fluctuations from the edge to the core of the plasma column. The injector of the primary Cs+ beam is coupled with the energy analyzer, which detects the secondary Cs++ beam from a certain plasma area – sample volume (SV) with a radial size below 1 cm. Cs++ ions are born due to collisions of the primary beam with plasma particles. Total current of the secondary beam on the detector is proportional to the primary beam current, plasma density at the SV, effective ionization cross-section and attenuation factors, which represent beam attenuation along primary and secondary trajectories. As soon as TJ-II geometry allows HIBP to scan from the low field side through the plasma core to the high field side, the inverse problem can be stated so the radial electron density distribution can be obtained from the radial distribution of the total secondary beam current. In previous works it was assumed that the dominating mechanism of heavy ions ionization from Cs+ to Cs++ state is the electron impact ionization. In the present work it is shown that in conditions of TJ-II plasmas the proton impact ionization cross-section is comparable with the electron impact ionization cross-section and cannot be neglected. As a result the plasma density profile is reconstructed using HIBP total secondary current.

X-ray temporal and spatial diagnosis technology in ShenGuang laser facilities

Feng Wang 1, Xing Zhang 1, Zhurong Cao 1, Xin Hu 1, Zhenghua Yang 1, Zheng Yuan 1, Deng Bo 1, Jin Li 1, Wenyong Miao 1, Jiyan Zhang 1, Jianjun Dong 1, Yongkun Ding 2, Baozhong Mu 3, Jiamin Yang 1, Shaoen Jiang 1, Baohan Zhang

1 Research Center of Laser Fusion, China Academy of Engineering Physics, Mianyang 621900, China;
2 Institue of Applied Physics and Computational Mathematics, Beijing 100094, China;
3 Key Library of Advanced Micro-structure Materials, Tongji University, Shanghai 200092, China;

At present, a relatively complete diagnostic platform for ICF physics has been established on the ShenGuang laser facilities. This report will focus on the development of universal X-ray framing camera, high sensitivity X-ray framing camera and pulse broadening X-ray framing camera on ShenGuang laser facilities. The key technologies of pulse width X-ray framing camera are introduced. The advantages and disadvantages of drift tube with hCOMS and MCP are analyzed. At the same time, the calibration and experimental results of Kirkpatrick-Baez microscope are introduced. The key technologies of Wolter microscope are analyzed, and the problems affecting imaging resolution and depth of field are analyzed in detail. At the same time, a new transmission bandpass technology is introduced. The advantages of the technology are introduced from the basic principles, calibration results and experimental results.

Contribution: **P2.58** / Beam Plasmas and Inertial Fusion

New stripe tube technology for ultra fast time response in Inertial Confinement Fusion in China

Feng Wang, Xin Hu, Xing Zhang, Jin Li, Jiamin Yang, Shao'en Jiang

Laser Fusion Research Center, China Academy of Engineering Physics

This report introduces two new design techniques for streak tube. In the research of ICF, it is always a difficult problem to obtain the shape of hot spot. In this paper, a technique called slicing scanning technique is proposed, which can solve this problem to a certain extent. It designs the slit of the stripe tube into multiple slits, and the deflection plate is designed into multiple structures to realize the function of scanning at one time and reading multiple stripes. This technique makes full use of the high time resolution of the streak camera, and records the scanning images of multiple slits on the fluorescent screen, so as to realize the ability of one scan and multiple position acquisition. The current time resolution of the design is 2ps, and the length of the scanning is 200ps. At the same time, 9 slits can be scanned. The Another technology is called scanning framing technology. It can make full use of the scanning function of the streak camera and realize the function of the framing camera. The design of its electronic optical system will be introduced. At present, the sample tube has been developed. It is expected to become a new type of single line of sight recording technology.

Contribution: **P2.59** / Magnetic Confinement Fusion

First Results from an Event Synchronized - High Repetition Rate Thomson Scattering System at Wendelstein 7-X

H. Damm1, E. Pasch1, J. Baldzuhn1, S. Bozhenkov1, K.J. Brunner1, R. Bussiahn1, A. Dinklage1, G. Fuchert1, N. Tamura2,3, E.R. Scott1 and the W7-X Team

1 Max-Planck-Institut für Plasmaphysik, 17491 Greifswald, Germany
2 National Institute for Fusion Science, National Institutes of Natural Sciences, 509-5292 Toki, Japan
3 SOKENDAI (The Graduate University for Advanced Studies), 509-5292 Toki, Japan

Studies of the plasma response after fast perturbations may reveal the nature of fast relaxation mechanisms. While fast sampled radiometry, reflectometry and interferometry provide insights in the electron temperature or density dynamics exclusively, via Thomson Scattering (TS) spatio-temporal dynamics of both, electron density (ne) and temperature (Te), can be measured simultaneously.
The Wendelstein 7-X (W7-X) TS diagnostic was upgraded to acchive higher temporal resolution of the stroboscobic measurment combined with adjustable measuring times. The three existing Nd:YAG lasers are employed to emit “bursts”, sets of up to four laser pulses, every 200ms (5Hz). Merging the lasers, twelve consecutive measurements per burst are possible. Typically, 100µs spacing between the pulses was chosen to cover 1.2ms per burst. It can be tuned from 2µs to 5.000µs depending on the requirements resulting in measurment intervals of different duration.
Moreover, a system was developed to detect various plasma events and subsequently transmit a trigger to the TS lasers within less than 8µs. Unpredictable, short-lived plasma events would only be captured by coincidence otherwise. The trigger system allows for firing the TS lasers with a certain variability to match event and measurement, but sticking to the average 5Hz repetition frequency to advert the risk of laser damage in any case. Delays may be added in the case of precursor detection, to observe later events in a repetitive series of events or to study later phases of events of long duration. Thus, the “burst mode” can be employed to match individual experimental requirements, in contrast to the 30Hz standard mode.
For the first time, it was possible to study predictable and unpredictable short, transient plasma events by consecutive TS measurements at W7-X. Exemplarely for all different types of events analysed, cases of fast ne and Te evolution after impurity injection via Tracer-Encapsulated Solid Pellet are presented.

Contribution: **P2.60** / Faenov Memorial Session

High energy density plasma generation with ultra-intense (I ~ 10^22 W/cm2) relativistic femtosecond laser pulses

M.A. Alkhimova1,2, A.Ya. Faenov1,2, T.A. Pikuz2,4, I.Yu. Skobelev2,3, S. A. Pikuz2,3 M. Nishiuchi5 , H. Sakaki5, A. S. Pirozhkov5 , A. Sagisaka5, N.P. Dover5, Ko. Kondo5, K. Ogura5, Y. Fukuda5, H. Kiriyama5, M. Kando5, R. Kodama1,4,6, K. Kondo5.

1-Institute for Academic Initiatives, Osaka University, Osaka, Japan
2-Joint Institute for High Temperatures, Russian Academy of Sciences, Moscow, Russia
3-National Research Nuclear University «MEPhI»,Moscow, , Russia
4-Graduate School of Engineering, Osaka University, Osaka, Japan
5-Kansai Photon Science Institute(KPSI), National Institutes for Quantum and Radiological Science and Technology(QST), Kizugawa, Kyoto, Japan
6-Photon Pioneers Center, Osaka University, Osaka, Japan

Plasma formed by femtosecond laser pulses with ultra-relativistic intensities on thin solid-state foils is of great interest since such plasma is an effective source of ultra-bright X-ray and gamma radiation, beams of high-energy ions, electrons and neutrons. Such sources are widely used in high energy density physics, laboratory astrophysics, materials science, medicine, bioengineering, and inertial thermonuclear fusion. However, the characteristics of these sources are extremely sensitive to plasma parameters, and those, in turn, strongly depend on the experimental conditions. Just X-ray radiation diagnostic allows to provide the monitoring of plasma source parameters. This work we focused on studying features of X-ray emission from plasma generated by femtosecond laser pulses when its intensity on target surface reached ultra-relativistic value Ilaser ~10^22 W/cm2. We report about x-ray spectroscopy measurements that were done at recent experiments on J-KAREN-P laser facility, following plasma parameters determination using also plasma zones conception, and results. We shown that at laser intensity on target ~ 9 × 10^21 W/cm2 the matters state with ultra-high energy density ~ 7.8 × 10^8 J/cm^3 reached in the laser target interaction region.

Contribution: **P2.61** / Magnetic Confinement Fusion

The effect of high magnetic field for Langmuir probe

Ding Li, and Chao Dong

Center for Plasma Physics, Institute of Physics,
Chinese Academy of Sciences, Beijing

Recently, the high magnetic field tokamaks have attracted wide attention. It is urgent to investigate the influence of high magnetic field on plasma diagnostics. Especially in the edge plasma of high magnetic field tokamak, the Larmor radius is much smaller than in the core plasma. For Langmuir probe, the assumption of weak magnetic field might be no longer valid since the ion Larmor radius might be significantly smaller than the size of probe. The effect of high magnetic field should be considered in order to derive the electron and ion current. The collision effect should be taken into account as well. A theoretical model is proposed to develop for Langmuir probe by including the effect of high magnetic field.

Contribution: **P2.62** / Basic and Astrophysical Plasmas

First characterization of EMP generated during Vega 2 laser pulse interaction with Al foil target.

M. De Marco1, K. Nelissen2, V. Ospina1,3, M. Liszi3, I. Drotr4, C. Kamperidis2 , G. Gatti1 and L. Volpe1,3

1) Centro de Lseres Pulsados (CLPU), Calle del Adaja 8, Villamayor 37185, Salamanca, Spain
2) ELI-ALPS, ELI-HU Non-Profit Ltd., Dugonics tér 13, Szeged 6720, Hungary
3) University of Salamanca, Patio de Escuelas 1, Salamanca 37008, Spain
4) Radiofrequency Test Laboratory (RFTL) - Szchenyi Istvn University, Egyetem tr 1, Gyr 9026, Hungary

When a high intense laser pulse interacts with a solid target a big amount of electron escapes the targets and a fraction of them are accelerated at relativistic velocity. This mechanism triggers the generation of giant electromagnetic pulse (EMP) with electric field strength of tens of kV/m and a very broad band spectrum ranging from MHz to hundreds of GHz.
In high intense laser target interaction experiments the generation of EMP can represent an issue for the well operation of the most electronic devices and for the well performing of the experimental measurements. The EMP interfere with the electronics and the diagnostics leading to the bad operation of them and sometimes even with the destruction. The developing of large scale laser facility as Centro de Láseres Pulsados (CLPU) with high repetition laser working in symbiosis with beamlines and secondary sources requires a full understanding of the phenomenon and well-defined strategy for the mitigation of the EMP.
Up to now the studies done on the EMP are mainly confined to the picosecond regime and not much can be found in the literature on the fs-class multi-Joule laser experiments. The first experimental campaign on the EMP measurement at CLPU centre is reported in this work and the generation of the EMP during 200 TW fs laser pulse interaction with a 10µm foil target is presented. The generation of X-Ray k-alfa and protons is also monitored and correlated with the EMP. Finally, the results of the finite element method (FEM) simulations are presented showing a good agreement with the experimental results.

Contribution: **P2.63** / Beam Plasmas and Inertial Fusion

Characterization of a capillary-discharge plasma for guided laser wake-field acceleration

J. Hawke, K. Kruchinin, A. Molodozhentsev, D. Kocon, M. Nevrkla, and G. Korn

ELI-Beamlines, Institute of Physics of the Czech Academy of Science, Prague, 18221, Czech Republic

The concept of laser wake-field acceleration (LWFA) allows for the compact acceleration of high-quality electron beams usable in next generation free-electron laser (FEL) light sources. In a capillary discharge, the radial electron density distribution takes on a "hollow out" profile that effectively creates a guiding plasma channel. The formation of a plasma channel is necessary for the efficient transport of the laser beam over long distances by avoiding the laser diffraction limit.

The target plasma is generated via a capacitive discharge circuit designed to provide a discharge of approximately 20 kV and up to 200 A over 1-3 cm long sapphire capillary with varying edge length from 150 µm to 500 µm with a total discharge length of 600-700 ns. Inside the capillary a continuous hydrogen gas flow is controlled via multiple input channels with separate mass flow controllers, allowing some tailoring of the initial gas density profile and plasma profile. With further plasma control achieved by modifications to the target geometry by laser micro-machining.

Utilizing plasma emission spectroscopy to image the total tangential capillary profile with a very high spatial resolution during active experiments with "offline" plasma target measurements to include the longitudinal spectral profile, allowing for density profile measurements. A suite of laser diagnostics positioned before and after the plasma target will provide additional information on the plasma and driving laser, critical for operation. With active diagnosis of the electron plasma density being essential, in order to optimize the injection and acceleration processes for LWFA.

An overview of the plasma diagnostics test-setup including design features and a description of all the instrumentation used to characterize the plasma target and diagnostic systems will be presented. This work is performed as part of a cooperative LWFA driven FEL development project between ELI-Beamlines, the University of Hamburg, and DESY.

Contribution: **P2.64** / Magnetic Confinement Fusion

Validation of the edge density profiles from the ICRF antenna reflectometer on ASDEX Upgrade

E. Seliunin1, C. Silva1, P. Manz2, G.D. Conway2, L. Gil1, L. Guimarãis1, S. Heuraux3, C. Moon2, T. Pütterich2, A. Silva1, F. da Silva1, U. Stroth2,4, J. Vicente1, E. Wolfrum2, W. Zhang2, the ASDEX Upgrade team and the EUROfusion MST1 team*.

1Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal
2Max-Planck-Institut für Plasmaphysik, Boltzmannstr. 2, 85748 Garching, Germany
3Institut Jean Lamour UMR 7198 CNRS-Université de Lorraine, ARTEM BP 50840, F-54011 Nancy, France
4Physik-Department E28, Technische Universität München, 85747 Garching, Germany
*See the author list "H. Meyer et al 2017 Nucl. Fusion 57 102014"

A new multichannel X-mode reflectometer diagnostic (RIC) was recently installed in ASDEX Upgrade (AUG) to provide the electron density profiles in front of an ICRF antenna [1]. The diagnostic was designed to measure density profiles up to 2 x 10^19 m-3 in the typical 1.5 - 2.7 T magnetic fields of AUG. Profiles can be measured every 25 µs simultaneously in 3 different poloidal positions. The main objective of this work is to assess the measurement capabilities of the RIC diagnostic for the scrape-off layer (SOL) density profiles. RIC density profiles are compared with radial profiles from Langmuir probes, lithium beam and O-mode reflectometry for a wide variety of plasma conditions. Although a good agreement between the different diagnostics is generally found at low discharge densities, RIC measurements often show steeper profiles at high discharge densities. In addition, a poorer agreement with the other diagnostics is seen at low outer wall clearance. Different effects such as the SOL density fluctuations induced by filaments and the uncertainty associated with determining the location of the start of X-mode upper cutoff reflection are being assessed to explain the experimental observations. The 2D full-wave code REFMULF [2] compiled for X-mode simulations, will be applied to model the reflectometry diagnostic under different conditions of SOL turbulence with the physical understanding emerging from the simulations applied for a better understanding of the experimental results.

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 / m and ~10 ps, respectively. To create a suitable x-ray source for Compton radiography, metal wire target were irradiated with short pulse petawatt laser in SG-II-U laser facility. In this paper, we describe the experiment to develop the source and characteristics of the x-ray source include spectrum, conversion efficiency and x-ray spot.

Characterization of a high energy x-ray source produced by the SG-II-U laser facility

Minghai Yu

Science and Technology on Plasma Physics Laboratory, Research Center of Laser Fusion, China Academy of Engineering Physics, Mianyang, China

High energy and short pulse x-ray sources produced by petawatt laser are widely used to diagnose and image in the internal confinement fusion (ICF) and high energy density physics experiments. In the ICF implosion experiments, the area density and symmetry of the fuel capsule near peak compression can be determined using the Compton radiography, which obtains high energy x-ray point-projection radiography with high spatial and temporal resolution of ~10 &mu

Contribution: **P2.66** / Magnetic Confinement Fusion

Validation of Coherence Imaging Spectroscopy at the Wendelstein 7-X stellarator

Valeria Perseo*, Dorothea Gradic*, Ralf Koenig*, Oliver Ford*, Florian Effenberg**, David Ennis***, Thomas Sunn Pedersen*, W7-X Team*

(*) Max-Planck-Institute for Plasma Physics, Greifswald, Germany
(**) University of Wisconsin, Madison, USA
(***) Auburn University, Auburn, USA

Coherence Imaging Spectroscopy (CIS) is a camera-based interferometry diagnostic capable of measuring 2D impurity flow Doppler velocities for a selected visible emission line from the plasma. Its 2D measurement capabilities and its high optical throughput are ideal for investigating the impurity behaviour in the complex 3D magnetic island topology of Wendelstein 7-X (W7-X).
Two systems have been installed, in order to monitor one island divertor from nearly perpendicular views, and thus obtain improved emission and flow interpretation.
High wavelength calibration accuracy is required for measuring low impurity ion flow velocities, typical of the edge of fusion devices.
A new level of precision in the calibration process is met at W7-X thanks to the installation of a continuous tunable laser, commercially available only since 2015. Our specific prototype model was successfully adapted to our challenging requirements. Its wide spectral range from 450 to 650 nm gives us the flexibility to study different ions in succession, while its stability of ±0.01 pm allows steps forward in facing the challenge of 30 minutes long operations. The accuracy of the laser relies on a feedback controlled tuning process, involving the use of a high finesse wavemeter for constant monitoring that assures the emission reliability over an entire operation day. This new calibration source also opened up new investigation possibilities on temperature stability and wavelength response of the CIS components, which will be reported on. Further issues addressed here are the system optimisation with respect to contrast losses due to line of sight integration, and the effect of other disturbing impurity lines within the optical filter range.
The CIS diagnostic was fully operational throughout the last W7-X experimental campaign. Measured velocities on the order of km/s were observed, validated by comparisons to measurements with a high resolution Echelle spectrometer and dedicated EMC3-EIRENE simulations.

Contribution: **P2.67** / Magnetic Confinement Fusion

Steady-state thermal analyses of the in-vessel antennas of the ITER plasma position reflectometry system

Y. Nietiadi, C. Vidal, R. Luís, P. Varela

Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa

The ITER Plasma Position Reflectometry (PPR) system will use four independent reflectometers to measure the plasma edge density profile at four locations, known as gaps 3, 4, 5, and 6. The reflectometers at gaps 4 and 6 will have the antennas installed inside the vacuum vessel (VV) in small apertures between blanket modules, directly exposed to the plasma and subjected to very high nuclear and thermal loads. This paper presents the results of the steady-state thermal analyses of the in-vessel antennas and supports. To carry out these analyses, CAD models of these components and surrounding surfaces were used to develop finite element models (FEMs) in ANSYS Workbench. The nuclear heat loads were input as internal heat generation, while a thermal map of the VV was applied to the inner shell sections of the VV.

In the above analyses, the plasma radiation is modelled as a power density of 350 kW/m2 applied on the plasma-facing apertures. However, we followed and compared two different approaches: (i) we first determine the heat flux on each component resulting from the different view factors through which the components are exposed to the plasma radiation and then run a second analysis to determine the thermal loads on the components; and (ii) we apply the plasma radiation to the aperture and determine the thermal loads on the components in a single run. We found both methods to produce very similar results.

The estimated operation temperatures of the antennas are above 450ºC, the maximum allowable temperature for ITER-grade stainless steel 316L(N)-IG under irradiation. As these temperatures depend on the capacity to transfer heat to the VV, kept at a much lower temperature, we carried out a sensitivity analysis to assess the evolution of these temperatures with the number/location of the attachments between the antenna support and the VV.

Contribution: **P2.68** / Beam Plasmas and Inertial Fusion

Generation and characterization of a low pressure DC glow discharge for beam propagation experiments

L. Courtois(1), Th. Lahens(1), P. Grua(1), F. Dorchies(2) and C. Fourment(1)

(1) CEA-CESTA, Le Barp, F-33116 France
(2)Universite de Bordeaux-CNRS-CEA, CELIA, Talence F-33405 France

We are designing an experiment to investigate the propagation of a high-current relativistic pulsed electron beam (4MeV, 2kA, 60ns) in plasmas. We have built a prototype plasma cell which consists of a 5 cm diameter glass tube, a few tens of cm long, in which we generate a DC glow discharge. The main parameter for the beam propagation is the electron density, which is estimated from electrostatic probes measurements in the largest part of the discharge (i.e. the positive column), in different gases (Argon, Helium or Nitrogen) and range of pressure (0.1 – 10 mBar). Although a usual theory for the interpretation of the data gives the expected order of magnitude for the electron density (~ 10^10 cm-3), the corresponding temperature is surprisingly high (up to 20 eV). We discuss this result and present alternative measurements lying on the plasma electromagnetic response in the HF band. We present also an additional inductive heating to reach higher electron densities.

Contribution: **P2.69** / Magnetic Confinement Fusion

Feasibility study for an edge main ion charge exchange recombination spectroscopy system at ASDEX Upgrade

P. Cano-Megias(1) , E. Viezzer(2), M. Cavedon(3), D. Cruz-Zabala(2), R. Dux(3), B. Geiger(3), A. Jansen van Vuuren(3), R. Chacartegui-Ramirez(1) and the ASDEX Upgrade team(3)

(1) Dpt. of Energy Engineering, University of Seville, Camino de los Descubrimientos, s/n. 41092, Seville, Spain
(2) Dpt. of Atomic, Molecular and Nuclear Physics, University of Seville, Avda. Reina Mercedes, 41012 Seville, Spain
(3) Max Planck Institute for Plasma Physics, Boltzmannstr. 2, 85748 Garching, Germany

Charge exchange recombination spectroscopy (CXRS) is the most common technique to evaluate the ion temperature and rotation in tokamaks. The technique is based on the observation of spectral lines, typically fully-ionized impurities which emit light after a charge exchange reaction with diagnostic neutrals. The Doppler shift, width and intensity of the line allow for the evaluation of rotation, temperature and density, respectively.

Main ion (typically deuterium) properties are usually assumed equal to those of the impurities or are inferred from them via neoclassical models. The development of a main ion CXRS diagnostic would allow the direct evaluation of the main ion temperature and rotation and enables the direct comparison of experimental measurements against transport models.

Compared to the impurity spectrum, the deuterium spectrum has substantially more contributions (beam, fast-ion and cold edge emission, impurity lines) and needs to be corrected for spatial distortions (due to halo effects) and atomic physics effects. This has prevented the analysis of deuterium properties until recently. In the last years, substantial effort and progress in resolving the main ion spectra have been made [1, 2, 3].

Main ion measurements in the core of the ASDEX Upgrade tokamak (AUG) have been reported in [4]. In the edge region, due to steep gradients, an iterative approach is adopted. A forward model (based on a collisional radiative model implemented in FIDAsim [5, 6]) together with fitting routines (following [7]), allows for iterative corrections to the profiles and enable to resolve the underlying deuterium properties.

A sensitivity study has been carried out to address the impact of different plasma parameters on the synthetic D-alpha spectra and shows similar characteristics as observed on DIII-D. First edge main ion temperature and rotation measurements, which are indicative of the feasibility of the diagnostic, are also presented.

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Contribution: **P2.70** / Magnetic Confinement Fusion

Upgrade of the Edge Charge Exchange Recombination Spectroscopy System at the High Field Side of ASDEX Upgrade

D.J. Cruz-Zabala(1,2), E. Viezzer(1,2), M. Griener(3), U. Plank(3), M. Cavedon(3), V. Rohde(3), G. Fuchert(4), R. Dux(3), P. Cano-Megias(5,2), A. Jansen van Vuuren(3), T. Pütterich(3), J. Garcia Lopez(1,2) and ASDEX Upgrade team(3),

1 Dept. of Atomic, Molecular and Nuclear Physics, University of Seville, Avda. Reina Mercedes, 41012 Seville, Spain
2 CNA (U. Sevilla, CSIC, J. de Andalucia), Seville, Spain
3 Max-Planck-Institut für Plasmaphysik, Boltzmannstr. 2, 85748 Garching, Germany
4 Max-Planck-Institut für Plasmaphysik, Wendelsteinstr. 1, 17491 Greifswald, Germany
5 Dept. of Energy Engineering, University of Seville, Camino de los Descubrimientos, s/n. 41092, Seville, Spain

The most common technique to measure impurity properties is Charge Exchange Recombination Spectroscopy (CXRS). This technique exploits the light emitted due to charge exchange between neutral particles, that are injected via a neutral beam or a gas puff, and ionized plasma impurities. Usually, the edge CXRS measurements are taken at the Low Field Side (LFS) for technical simplicity, but several studies [1, 2, 3] have shown that there are poloidal asymmetries in the impurity properties between the LFS and the High Field Side (HFS). In this work, the upgrade of the edge HFS CXRS system of ASDEX Upgrade is presented. The goals of this upgrade are to increase the functionalities and to improve the resolution of the diagnostic.

The system is formed by a new gas box and two optical heads. The gas box injects thermal neutrals in the plasma using a piezoelectric valve [4]. The valve has been characterized, tested and calibrated for several gases such as He, D2, N2 and Ar. This new gas box enables the accurate control of the flowrate and increases the functionalities compared to the old system. The existing poloidal optical head has been replaced with a new one to increase the radial resolution. The number of lines of sight (LOS) of the poloidal optical head has been increased from 8 to 16 covering around 7 centimeters of the plasma edge, which is also viewed by the toroidal optical head.

The neutral deposition profile has been simulated using the FIDASIM code [5, 6]. A realistic gas cloud geometry has been implemented in the code. This enables the calculation of the radiance profile of a certain species. The radiance obtained using FIDASIM and KN1D [7] will be compared. The first measurements of impurity temperature, density and rotation utilizing the upgraded diagnostics will be presented.

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Contribution: **P2.71** / Magnetic Confinement Fusion

Measurement accuracy of ITER diagnostic pressure gauges

F. Mackel(1), A. Arkhipov(1), G. Haas(1), J. Koll(1), H. Meister(1), F. Seyvet(2), S. Terron(2) and P. Andrew(3)

(1) Max-Planck-Institute for Plasma Physics, Garching bei München, Germany
(2) Fusion for Energy, Barcelona, Spain
(3) ITER Organization, St.-Paul-lèz-Durance, France

Pressure gauges for ITER are based on the established ASDEX pressure gauge, successfully operating in many fusion devices worldwide. One of the requirements to diagnostic pressure gauges for ITER is aimed at the measurement accuracy, which shall be better than 20 % in pure hydrogen gas. In order to estimate the accuracy, three major sources of error were identified, their impact studied in dedicated experiments and conclusions drawn for the application in ITER.

Long pulse operation in ITER imposes changing heat loads and thermal boundary conditions. Consequently, the neutral gas density inside the gauge head and thus the measuring signal changes according to the ideal gas law at constant gas flux to the aperture. To account for this effect, a thermocouple was integrated into the baseplate of the ITER design. Measurements on prototypes demonstrate the benefit of this approach but also point out that the position of the measuring point should be chosen carefully.

The toroidal plasma current in ITER will underlie variations leading to a changing inclination of the magnetic field at the gauge positions. The gauges allow for a change of ±20° with respect to their main axis. However, testing showed that the angle may have an effect on the measured ion current depending on the orientation of the magnetic field component with respect to the slits in the acceleration grid leading to requirements on the design integration in ITER to minimize the influence of this effect.

Finally, the repeatability of readings of the gauges is determined by tests in identical boundary conditions over several cycles. Experiments in hydrogen atmosphere at pressures ranging from 0.01 Pa up to 30 Pa and magnetic fields up to 8 T demonstrated that the deviation from the mean is significant, despite high attention was paid to establish identical conditions.

Contribution: **P2.72** / Magnetic Confinement Fusion

Heavy Ion Beam Probe diagnostics for the T-15U tokamak

Drabinskiy Mikhail (1,2), Alexander Melnikov (1), Khabanov Philipp (1,2), Eliseev Leonid (1), Ilin Arkady (1,2), Sarancha Georgy (1,2), Vadimov Nikita (1,2)

1 - National Research Center "Kurchatov Institute", Moscow, Russia
2 - Moscow Institute of Physics and Technology (State University), Dolgoprudny, Russia

Heavy Ion Beam Probe (HIBP) is a unique diagnostics which provides electric potential, plasma density and poloidal magnetic field measurements in bulk plasma area. At the moment the D-shaped T 15MD tokamak (R = 1.5 m, a = 0.67 m) is under construction in the National Research Center "Kurchatov Institute". The HIBP is planned to install at T-15MD. This paper is dedicated to the conceptual design of HIBP for T-15MD.

Conceptual design includes the principal scheme of HIBP elements location (injector, beamlines, energy analyzer). This scheme is obtained by numerical calculation of ion trajectories for T-15MD parameters and geometry. The ion trajectories calculation gives us the detector grid (possible measurements area).

To provide the most effective measurements we should obtain probing beam with maximum current and focus it in the sample volume. Due to T-15MD geometry the focal length will be about 3-5 meters from injection point. So we should build long focus ion optics system. To solve this task the high-voltage experimental stand is designed. Also the experimental stand will allow us to adjust and calibrate energy analyzer and study the thermionic emitters' lifecycle.

Before the experimental studies the numerical modeling of experimental stand operation was carried out. Also the electric field strength in high-voltage stand environment is calculated to prevent the electric breakdown since the energy of probing ions is about 100-400 keV.

The work is presenting the conceptual design of HIBP for T-15MD, the principal scheme of HIBP elements location, the high-voltage experimental stand design and modeling of its operation.

Contribution: **P2.73** / Magnetic Confinement Fusion

New capabilities of the Incoherent Thomson scattering diagnostic in TCV: divertor & real-time measurements

H. Arnichand, P. Blanchard, Y. Andrebe, F. Felici, C. Galperti, J. Decker, B. Duval, P.-F. Isoz, P. Lavanchy, X. Llobet, B. Marlétaz and the TCV team,

Ecole Polytechnique Fédérale de Lausanne (EPFL), Swiss Plasma Center (SPC), CH-1015 Lausanne, Switzerland

Measurement of incoherent Thomson scattering (TS) is used since early fusion research to estimate electron temperature and density of a plasma [1]. This work reports developments of the incoherent TS diagnostic capabilities in the Tokamak à Configuration Variable (TCV) [2,3]. Their goals are to (i) diagnose the TCV divertor region, and (ii) provide Te and ne profiles of the plasma bulk in real-time. These two new TS diagnostic capabilities are implemented within the framework of a TCV upgrade that will insert baffles in the lower divertor region [4].

20 new TS spectrometers are being installed to access electron temperatures down to ~1eV, for densities above ~1.5x10^19m-3 within the TCV divertor region. They will measure the Thomson light scattered along the vertical propagation path of the three legacy Nd:YAG lasers. The light at each of the 20 measurement plasma volumes is collected by three optical fibers with a laser-mapped spatial resolution of 6 mm each, providing a vertical spatial resolution of 18mm. Interference filters with central wavelengths from 1025 to 1061 nm and widths as low as 2 nm are employed to obtain the spectroscopic resolution required at these low temperatures.

The acquisition chain and analysis of the TS signal will be integrated into the TCV monitoring and control system [5] to provide electron density and temperature profiles in real-time, at a sampling rate up to 60 Hz. The real time electron property profiles complement existing systems provided by the far-infrared interferometer and the soft X-ray diagnostics. The latter are restricted to provide integrated values of the electron density and temperature respectively, but at higher sampling rates (10 kHz and 20 kHz respectively). The whole diagnostic ensemble will be integrated into TCV's control system to improve the accuracy and robustness of real-time plasma profile and equilibrium estimation for control purposes.

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Contribution: **P2.74** / Magnetic Confinement Fusion

HIBP energy analyzer calibration and adjustment on T-10 tokamak

L.G. Eliseev (1), M.A. Drabinskiy(1,2), P.O. Khabanov (1,2), N.K. Kharchev (1,3), A.V. Melnikov (1)

1) NRC 'Kurchatov Institute', Moscow, Russia
2) Moscow Institute of Physics and Technology, Dolgoprudny, Russia
3) General Physics Institute, Moscow, Russia

Heavy Ion Beam Probe (HIBP) is a unique plasma diagnostics to measure local values of the electrostatic plasma potential and its fluctuations in bulk plasma of a tokamak and stellarator. T-10 is a circular tokamak with major radius R = 1.5 m, minor radius r = 0.33 m, plasma current up to 300 kA, toroidal magnetic field on axis up to 2.5 T. To probe plasmas in T-10 Tl+ ions with energies up to 330 keV are used. Primary Tl+ beam is injected into plasma perpendicular to magnetic field, beam ions are ionized due to collisions with plasma particles and secondary Tl++ beam goes to the energy analyzer, which contains adjustable position sensitive detector. Plasma electrostatic potential is derived from the energy difference between primary and secondary beams. As soon as the absolute value of the plasma potential in T-10 is in the range of 500-800 V at the plasma core, the analyzer should be able to measure secondary beam energy with the accuracy of 10^-5. This requires precise detector positioning and calibration. The procedure of the energy analyzer adjustment and calibration using He target and its results are described.

Contribution: **P2.76** / Beam Plasmas and Inertial Fusion

Characterization of the pre-plasma formation for high intesity laser-solid target experiment.

S. Malko(1,2), C. Salgado(1,2), G. Gatti (2), R. Fedosejevs(3), J.A.Perez-Hernandez(2), L.Volpe (1,2)

(1)CLPU Laser-Plasma Chair at University of Salamanca, Salamanca Spain
(2)Centro de Laseres Pulsados, Building M5, Science Park USAL, Calle Adaja,37185 Villamayor,Salamanca, SPAIN
(3)University of Alberta, Edmonton,Alberta,Canada

The interaction of ultrashort and ultraintense laser pulse with thin solid target is strongly dependent on preformed plasma prior to the main short pulse generated by pre-pulse and an incoherent nanosecond pedestal. In various laser-solid target experiments it is crucial the front-side target state in the time of the main pulse arrival. To investigate the influence of amplified spontaneous emission (ASE) levels and pre-pulses on the solid target we used time-resolved reflectometry diagnostic. The laser-solid target experiment was carried on at CLPU VEGA-II 200 TW laser facility. The 30 fs VEGA-II laser pulse was focused onto thin Al foil yielding intensity of 10^20 W/cm^2 to produce TNSA protons. The front side diagnostics was implemented to observe the reflection of the frequency doubled 400 nm s-polarized laser probe (taken by pick-up mirror on the VEGA-II path) focused onto the target front side within 90 um FWHM focal spot and incidence angle of 20 degrees yielding intensity below 10^12 W/cm2. The delay between probe and main laser pulses was varied between - 20 to +20 ps allowing to look the target surface before and after of main laser pulse interaction. Here we report the implemented diagnostics scheme and experimental results for different energies of the main VEGA-II laser pulse.

Contribution: **P2.77** / Beam Plasmas and Inertial Fusion

Characterization of the Analogue Performance of Multi-Anode Microchannel Plate Photomultiplier Tubes and Waveform Digitizing Integrated Circuits

James Milnes, Tom Conneely and Paul Hink (1), Jon Lapington and Steve Leach (2)

(1) Photek Ltd, 26 Castleham Road, St Leonards on Sea, TN38 9NS UK

(2) Space Research Centre, Dept of Physics & Astronomy, University of Leicester, University Road, Leicester LE1 7RH UK

Two widely used photodetectors for plasma diagnostics applications are single channel Microchannel Plate Photomultiplier Tubes (MCP-PMT) and streak tubes. Easy to use MCP-PMTs provide multi-GHz bandwidth light detection using high speed digital oscilloscope readout while streak tubes provide up to THz bandwidth sensitivity over many parallel channels using CCD/CMOS readout. Given recent developments in high readout density Multi-Anode (MA-MCP-PMTs) and multi-channel high speed waveform digitizing chips that use application specific integrated circuits, it is now possible to consider easy to use high channel count multi-GHz MCP-PMT detection systems for applications such as time resolved spectroscopy. Photodetectors evaluated include two AuraTek high readout density MA-MCP-PMTs, a 53 mm square device with 4096 individual anodes in a 64 x 64 format and a 40 mm round device with 32 x 32 channels, both having 0.828 mm anode pitch. Here we present a comprehensive analysis of the analogue performance of both devices, looking at the analogue pulse shape, inter-channel cross-talk, single and multi-photon timing resolution, correlated noise and response uniformity. We will show a modelling comparison of the induced charge effect in the cross-talk and show the first results from using a multi-anode MCP-PMT with the waveform sampling and digitizing TARGET Chipset consisting of TARGET C (digitizer) and T5TEA (trigger). In addition, initial results using a developmental waveform digitizer from Nalu Scientific, the ASoC, having 0.8 GHz bandwidth and full digitization on-chip will be presented. The data demonstrate that high channel count GHz bandwidth waveform digitizing light detectors are ready for use in Plasma Diagnostics.

Contribution: **P2.78** / Basic and Astrophysical Plasmas

Stark width and shift of He I spectral lines at plasma conditions of astrophysical interest

M. A. Gigosos (1), R. Florido (2), M. A. Schaeuble (3), T. Gomez (3), T. Nagayama (3), J. Bailey (3),

(1) Departamento de Física Teórica, Atómica y Óptica, Universidad de Valladolid, Spain
(2) iUNAT-Departamento de Física, Universidad de Las Palmas de Gran Canaria, Spain
(3) Sandia National Laboratories, Albuquerque, New Mexico, USA

Analysis of Stark-broadened spectral line profiles is one of the most often used plasma diagnostics techniques, especially to determine the electron density in both laboratory and astrophysical plasmas. Within the framework of the Z Astrophysical Plasma Properties collaboration [1], there is a renewed interest on the modeling of Stark-broadened line shapes because of its application to different topics under investigation, such as stellar interior opacities or white dwarf photospheres [2]. In connection with the latter topic, it is critical to have a benchmarked model to univocally correlate line shapes to plasma temperature and density, particularly for the case of H and He spectral lines. In this work, we present updated calculations of Stark width and shift for three different spectral lines of He I with diagnosis potential, that had already been studied in a previous work [3]. Calculations are performed using a computer simulation technique, wherein the plasma behavior is numerically represented to follow a classical particle dynamics. Here, previous work has been extended to include a full dipolar coupling among states with principal quantum number from n=2 to n=5 (i.e. quenching effect is taken into account). Differences between calculations including quenching effect or not are discussed. Updated line shift results show a noticeable improvement when compared with published experimental data.

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Contribution: **P3.1** / Magnetic Confinement Fusion

A real-time model to resolve the velocity-space of fast-ion losses detected in ASDEX Upgrade and MAST Upgrade

J.F. Rivero-Rodriguez1,2, M. Garcia-Muñoz2,3, J. Galdon-Quiroga4, J. Gonzalez-Martin1,2, J. Ayllon-Guerola1,2, D. Garcia-Vallejo1, R. Martin5, K.G. McClements5, M. Rodriguez-Ramos2, L. Sanchis-Sanchez2,3, S. Zoletnik6, the ASDEX Upgrade Team4 and the MAST-Upgrade Team5

1 Department of Mechanical Engineering and Manufacturing, University of Seville, Camino de los Descubrimientos s/n, 41092 Seville, Spain.
2 Centro Nacional de Aceleradores (CNA) (Universidad de Sevilla, CSIC, Junta de Andalucía).
3 Department of Atomic, Molecular and Nuclear Physics, University of Seville, 41012 Seville, Spain.
4 Max-Planck-Institut für Plasmaphysik, Garching, Germay.
5 CCFE, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK.
6 Wigner RCP, Budapest, Hungary.

A forward model to resolve the fast-ion loss velocity-space on a fast-ion loss detector (FILD) probe head (FILDSIM) [1] has been extended, making it possible to perform real-time analysis of the FILD data (“real-time FILDSIM”).

Parametric pre-processing with FILDSIM makes it possible to perform real-time mapping of the raw FILD measurements to the velocity-space of the fast-ion distribution reaching the FILD probe, which depends on the local magnetic field at the probe head. Such parametric pre-processing facilitates the study of fast-ion losses in stages of the discharge other than the flat-top, such as the ramp-up phase when changes in the local magnetic field at the probe head cannot be neglected.

Additionally, real-time FILDSIM combines for the first time a high sampling rate camera and a high resolution camera that simultaneously record the FILD scintillator signal, producing a fast, high resolution video.
Real-time FILDSIM has been applied to the existing and newly installed FILDs in ASDEX Upgrade [2,3] and will be used for the forthcoming FILD in MAST-Upgrade [4]. Due to the larger size of the MAST-U FILD probe, the approximation used in FILDSIM of a uniform magnetic field in the FILD region has been generalised to the case of a non-uniform field, with gyro-orbits calculated numerically in this field.

Real-time FILDSIM streamlines FILD data analysis by combining the various data acquisition systems, and reducing the need for human intervention and computing time in resolving the fast-ion loss velocity-space.

[1] J. Galdon-Quiroga et al., Plasma Phys. Control. Fusion 60, 105005 (2018)
[2] M. Garcia-Muñoz et al., Rev. Sci. Instrum. 80, 053503 (2009)
[3] J. Gonzalez-Martin et al., Rev. Sci. Instrum. 89, 10I106 (2018)
[4] J.F. Rivero-Rodriguez et al., Rev. Sci. Instrum. 89, 10I112 (2018)

Contribution: **P3.2** / Magnetic Confinement Fusion

First Measurements of a Magnetically Driven Fast-Ion Loss Detector on ASDEX Upgrade

J. Gonzalez-Martin1,3, J. Ayllon-Guerola1,3, M. Garcia-Munoz2,3, A. Herrmann4, B. Sieglin4, S. Zoletnik5, A. Kovacsik5, J. Galdon-Quiroga4, P. Leitenstern4, J. Rivero-Rodriguez1,3, L. Sanchis-Sanchez2,3, M. Rodriguez-Ramos2,3, J. Dominguez1, AUG and MST1 Teams

1 Department of Mechanical Engineering and Manufacturing, University of Seville, Spain.
2 Department of Atomic, Molecular and Nuclear Physics, University of Seville, Spain.
3 Centro Nacional de Aceleradores (CNA) (Universidad de Sevilla, CSIC, Junta de Andalucía).
4 Max-Planck-Institut für Plasmaphysik, Garching, Germany.
5 Wigner RCP, Budapest, Hungary.

A new scintillator-based fast-ion loss detector (FILD)1 has been deployed ~45º below the midplane of the ASDEX Upgrade tokamak. Port unavailability at this remote location requires an in-situ magnetically driven manipulator2 to move the diagnostic head (containing a scintillator screen, Faraday cup, thermocouple and collimator systems) horizontally through the scrape off layer. The linear displacement is produced by an externally energized coil which tries to align its axis with the existing toroidal magnetic field. The collimator slit position is given by force balance between a retaining spring and the energized solenoid, whose current is regulated faster than half a millisecond, enabling self-adaptive real-time control of the probe head location based on its temperature. Linear and non-linear dynamic simulations3 are used to optimize the controller. First measurements have allowed to validate the model. The scintillator image is transferred to a vacuum window using a 3.5m quartz image guide. The light acquisition system is composed by a charge coupled device (CCD) camera, for high velocity-space resolution, and by an 8x4 channels avalanche photo diode (APD) camera, for high temporal resolution (up to 2MHz). Initial measurements of this new probe are compared against the other four FILDs on ASDEX Upgrade, which together make up a full poloidal suite that covers the entire low field-side. Moreover, first results on radially resolved fast-ion loss profiles and safe measurements during high power pulses are discussed.

[1] M. Garcia-Munoz et al., Review of Scientific Instruments 80, 053503 (2009)
[2] J. P. Gunn and J.-Y. Pascal, Review of Scientific Instruments 82, 123505 (2011)
[3] J. Ayllon et al., Review of Scientific Instruments 87, 11E705 (2016)

Contribution: **P3.3** / Magnetic Confinement Fusion

Design of embedded electrostatic sensors for the RFX-mod2 device

S. Spagnolo, M. Spolaore, M. Bernardi, R. Cavazzana, S. Peruzzo, M. Dalla Palma, G. De Masi, G. Grenfell, N. Marconato, E. Martines, B. Momo, N. Vianello, M. Zuin

Consorzio RFX, Associazione EURATOM-ENEA sulla Fusione, 35127 Padova, Italy

RFX-mod experiment is currently under a challenging upgrade of the machine assembly. One of the main purpose of RFX-mod2, the upgraded device, is the achievement of better performances by decreasing the tearing modes amplitude in Reversed-Field Pinch (RFP) configuration thanks to a higher plasma-shell proximity [1, 2]. Moreover, most of the innovations characterizing the device and its diagnostics are conceived with the aim to operate in both RFP and tokamak configurations.

This attention on the different configurations is taken into account in the electrostatic sensors design and layout. RFX-mod2 will be equipped with poloidal and toroidal arrays of electrostatic sensors, measuring plasma density and temperature, plasma potential, particle and energy fluxes and floating potential fluctuations.

Two toroidal arrays of 72 sensors each (one on the high field side and one on the low field side) are foreseen. Moreover, four poloidal arrays of 28 elements will be housed. A such large amount of sensors is due to the requirement of a better characterization of the numerous instabilities observed in RFP plasma edge, along with the possibility to study the plasma shape in different tokamak configurations (circular, single null, double null).

Two different kinds of Langmuir probes configurations will be installed: the so-called single probe and 5-pin balanced triple probe. The conceptual design of the sensors takes inspiration from the model successfully installed on RFX-mod [3], that allows to remove tiles in case of damage, by means of a remote handling manipulator. Each sensor is composed by two parts: the tile side houses pins directly faced to the plasma and connected by springs to the shell side, where specific contacts, conveniently isolated, carry the signals to the cables.

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[2] R. Cavazzana et al., IAEA-CN-258 - EX/P8-7 (2018)
[3] G. Serianni et al., Review of Scientific Instruments 74 1558 (2003)

Contribution: **P3.4** / Magnetic Confinement Fusion

Design of a new reflectometric system for real time plasma position control on the RFX-mod2 device

G. De Masi(1), R. Cavazzana(1), P. Bettini(1,2), G. Marchiori(1), M. Moresco(1), S. Peruzzo(1), D. Voltolina(2), M. Bernardi(1), A. Tiso(1),

1 Consorzio RFX, Corso Stati Uniti, 4 - 35127 Padova, Italy
2 Centro Ricerche Fusione (CRF), University of Padova - 35127 Padova, Italy
3 Department of Industrial Engineering, University of Padova - 35131 Padova, Italy

A diagnostic technique capable of feeding back a reliable real time plasma position estimate alternative to direct magnetic measurements is a crucial topic for position and shape control on future fusion devices. Featuring a high temporal and spatial resolution and being suitable for harsh fusion reactor experimental conditions (long pulses, high neutron fluxes), reflectometry has been proposed as a good candidate for this task. In this respect, some successful tests (limited to the horizontal plasma column control) have been performed on ASDEX-Upgrade [1,2].
In this contribution, we present the main features of a new reflectometric system, specifically designed for real time horizontal and vertical position control studies, to be installed on RFX-mod2 [3] (R=2.0 m, a=0.49 m), the upgraded version of the RFX-mod (R=2.0 m, a=0.46 m). RFX-mod2 is presently under construction and will operate in Reversed Field Pinch (RFP) and tokamak configuration.

The new reflectometric system will be composed by four ultrafast K-band units (18-26 GHz) at the same toroidal section: two on the equatorial plane (from inner High Field side and outer Low Field Side respectively) and two at the vertical top/bottom ports. Each unit will be an independent system connected to a bistatic antenna configuration. The reflectometers are designed to operate in X-mode on tokamak plasmas (Bt0=0.5 T; Ip=50-150 kA) in circular and shaped configuration (upper and lower Single Null, Double Null). They will provide the high time resolution edge density profiles needed at first for the development and validation of real time algorithms for basic vertical and horizontal position and to a broader extent, to address the issues linked to the reconstruction of the Last Closed Flux Surface by means of reflectometric data.

[1] Santos J. et al., Nucl. Fusion 52, 2012, 032003
[2] Santos J. et al., IEEE Transactions on Nucl. Science, Vol. 62, No. 3 (2015)
[3] Peruzzo S. et al., Fus. Eng. Des., Vol. 123, Pages 59-62 (2017)

Contribution: **P3.5** / Magnetic Confinement Fusion

Neutral gas analysis for JET DT operation

Uron Kruezi [(a),b,**], I. Jepu [b], G. Sergienko [c], T. Keenan[(a),b,**], C. C. Klepper [d], A. Widdowson [b]

[a] CCFE, Culham Science Centre, Abingdon, OX14 3DB, UK
[b] ITER OrganiZation, Route de Vinon-sur-Verdon, 13067 St. Paul-lez-Durance, France
[c] Forschungszentrum Jülich GmbH, Institut für Energie- und Klimaforschung – Plasmaphysik, 52425 Jülich, Germany

[d]Oak Ridge National Laboratory, Oak Ridge, TN 37831-6169, USA

[**] Currently at the ITER organization

Neutral gas analysis, the measurement and evaluation of total and partial pressures is a key technique to study the impact of neutral gas dynamics on retention, recycling and release processes of fuel or impurity species in fusion devices. At JET, the experiment closest to ITER in terms of operating parameters and size, various detectors and techniques for partial pressure and absolute pressure measurements are deployed together to characterise neutral gas dynamics during and after plasma operation on various toroidal and poloidal locations. An ongoing, extensive modification of JET's sub-divertor neutral gas diagnostic system aims at retaining and extending established measurement capabilities through the next Deuterium-Tritium (DT) campaign. To achieve DT compatibility, a separation of radiation-sensitive electronics from the sensor and adequate radiation shielding is required., as well as utilisation of a DT compatible differential pumping system with adjustable throughput to account for the strong pressure variation in the sub-divertor region. Finally, the sub-divertor neutral gas diagnostic will be equipped with multiple Residual Gas Analysers (RGAs), utilising quadrupole mass spectrometry and electrostatic ion–trap-principles, all operating with remote electronics located behind the biological radiation shield. These RGAs will record data in a fast selected discrete mass mode during plasma pulses (cycle ~2s) and will automatically switch back to a continuous scan (cycle ~100s) afterwards. They will be complemented by a newly improved Penning gauge spectroscopy configuration in particular supporting the He and D2 separation relevant for DT operation. The distance between these devices and their associated control unit is typically 15m. A newly developed RGA with a cable length of 80m [1], compatible with the ITER environment, will also be employed for the first time. This set-up and its operation in DTE2 will provide vital input to the development of the ITER DRGA in the most relevant environment currently available.

Contribution: **P3.6** / Magnetic Confinement Fusion

First Fe XXIV, Ar XVII and Ar XVIII spectra measured on WEST using a 2D imaging X-Ray spectrometer

D. Vezinet, G. Colledani, C. Fenzi, G. Moureau, G. Bertschinger

CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France

A new 2D X-ray imaging spectrometer was recently installed on the WEST tokamak, equipped with a remote-controlled rotating stage allowing to choose one of 3 crystals for each plasma. The crystals is optimized for focusing on the - intrinsic - FeXXIV K-alpha spectrum (~1.86 A), and – injected - Ar XVII K-α spectrum (~3.97 A) and ArXVIII Lyman-α spectrum (~3.73 A) respectively. These intervals have been chosen to derive electron measurements (via line ratios), ion temperature measurements (via Doppler broadening) and ultimately plasma rotation measurements (via Doppler shift) in the core of WEST plasmas, up to mid radius or even further.
After an in-situ alignment of each crystal, with visible light sources, with the whole setup in the year 2017, it was proven that the alignment was correct as the very first line-of-sight-integrated spectra could be obtained for each crystal during the latest WEST experimental campaign (October-December 2018). The first line-of-sight integrated temperature estimations are now available.
In parallel, a synthetic diagnostic is being prepared, as well as a set of numerical tools for spatial and spectral deconvolution.
The setup of the diagnostic will be presented, as well as the first images and temperature estimates in WEST plasmas. The next steps, such as tuning the Ar injection strategy or performing a metrology campaign for the synthetic diagnostic (and devlopping it), will be presented for discussion.

Contribution: **P3.7** / Magnetic Confinement Fusion

A first full wave simulation assessment of reflectometry for DTT

F. da Silva, (a) G. De Masi, (b) S. Heuraux, J. Ferreira, E. Ricardo, (c) T. Ribeiro, (d) O. Tudisco, (a) R. Cavazzana, (d) O. D'Arcangelo and A. Silva

Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Av. Rovisco Pais, nº1, Lisbon, Portugal
(a) Consorzio RFX, 35127 Padova, Italy
(b) Institut Jean Lamour UMR 7198 CNRS-Université de Lorraine, ARTEM BP 50840, F-54011 Nancy, France
(c) Max-Planck-Institut für Plasmaphysik, Garching D-85748, Germany
(d) Associazione EURATOM-ENEA-CR Frascati, 00044 Frascati, Italy

The Divertor Test Tokamak (DTT) facility is a new machine proposed to study the exhaust solutions in tokamaks with a special look on DEMO. ITER will operate in a detached condition, having a radiating volume in front of the divertor. However this solution may prove inadequate and consequently, the need for sound alternatives is felt. As in all fusion machines, there will be a need for diagnostics to gather knowledge about the physical processes occurring in the plasma, for engineering needs and control. Reflectometry has become one of the most important techniques to diagnose fusion plasmas and consequently, its use is foreseen in the forthcoming generation of machines such as ITER and DEMO. Also for DTT this diagnostic can be a useful asset, therefore assessing the different areas and applications that could be deployed on DTT is of major importance. We propose to use numerical simulation using finite-difference time-domain codes (FDTD) of the REFMUL* family to implement synthetic reflectometry diagnostics which include aspects such as propagation in the plasma, optimization of the system location within the vacuum vessel, its access to the plasma (waveguide and antennas), or the signal processing techniques. As an input to the synthetic diagnostic setup we are using the available DTT 2D CAD model and an estimated equilibrium model.

Contribution: **P3.8** / Magnetic Confinement Fusion

Development of an E parallel B type neutral particle analyzer with high time resolution in the Large Helical Device

Yutaka Fujiwara1, Shuji Kamio1, Kunihiro Ogawa1,2, Mitsutaka Isobe1,2, Ryosuke Seki1,2, Hideo Nuga1, Takeo Nishitani1, Masaki Osakabe1,2, and the LHD Experiment Group1

1 National Institute for Fusion Science, National Institutes of Natural Science
2 SOKENDAI (The Graduate University for Advanced Studies)

In order to study fast ion confinement and transport mechanisms both in quiescent plasmas in the presence of magneto-hydrodynamic (MHD) activity, an electric field parallel to magnetic field type neutral particle analyzer (E//B-NPA) was installed using micro-channel plate (MCP) in the Large Helical Device (LHD). The E//B-NPA is an established diagnostic used to measure the energy distribution of charge exchange neutral particles escaping from plasmas corresponding to hydrogen, deuterium, and tritium, respectively. The LHD experimental campaign have been started the deuterium experiments since 2017. To obtain more details of MHD behavior, we improved on time resolution performance of the E//B-NPA using a discriminator and latching scaler system. For the last LHD experimental campaign, the E//B-NPA was installed on the equatorial plane of the vacuum chamber to measure the passing energetic particles generated by tangentially injected neutral beams. As the results of the E//B-NPA commissioning, it is confirmed that the E//B-NPA successfully detected the energetic particles and obtained the energy distributions corresponding to hydrogen and deuterium, respectively. We will report the details of the E//B-NPA measurement system and its first results from these experiments.

Contribution: **P3.9** / Magnetic Confinement Fusion

The He/Ne beam diagnostic for line-ratio spectroscopy in the island divertor of Wendelstein 7-X

T Barbui1, F. Effenberg1, E. Flom1, M. Jakubowski2, R. König2, M. Krychowiak2, S. Loch3, J. Muños Burgos4, O. Schmitz1 and the W7-X Team2

1 University of Wisconsin, Madison WI, USA
2 Max-Planck-Institut für Plasmaphysik, Greifswald, Germany
3 Auburn University, Auburn AL, USA
4 Astro Fusion Spectre, San Diego CA, USA

A dedicated line-ratio spectroscopy system on thermal helium (He) and neon (Ne) was implemented at Wendelstein 7-X to measure radial profiles of electron density ne(r) and temperature Te(r) in front of the horizontal target in the island divertor of W7-X.
The injection system consists of two boxes with 5 fast piezo valves each, mounted directly behind the divertor plates in one upper and one lower divertor module, which are magnetically connected in the iota=5/5 standard island divertor configuration. The observation system includes 54+54 lines-of-sight in the radial and poloidal direction. These lines are channeled to a 20cm and a 32cm focal length Czerny-Turner spectrometer connected to a CCD camera, allowing observation of the He and Ne lines as well as impurities and hydrogen (H) lines with high spectral resolution (up to 0.07 nm). The spatial resolution of the diagnostic is 3 mm in the radial direction and 20 mm in the poloidal direction. The time resolution is 25 ms.
In this work the results from the last divertor campaign of W7-X (OP1.2b) are presented.
He has been used to measure radial Te and ne profiles across the magnetic island in the divertor. A poloidal scan of the island has been carried out exploiting the arrangement of the 5 valves. Hollow temperature profiles were measured in correspondence of the island center. The Te profiles become flat/moderately steep when the island width is increased by application of the divertor control coils. Density profiles were found flat inside the island and independent on its width.
Ne has been tested in order to extend the applicability of the diagnostic to the detached divertor regime at very low Te (≪10eV). Results from Ne injection and the status of the development of a dedicated collisional-radiative model for Ne are here presented.

Contribution: **P3.10** / Magnetic Confinement Fusion

Measurement and automatic Bayesian inference of the effective plasma charge Zeff from visible Bremsstrahlung in W7-X

Andrea Pavone1, Uwe Hergenhahn1, Maciej Krychowiak1, Victoria Winters2, Petra Kornejew1, Ralf Koenig1, Jakob Svensson1, Sehyun Kwak1, Udo Hoefel1, Matthias Hirsch1, Kai-Jakob Brunner1, Golo Fuchert1, Ekkehard Pasch1, Evan Scott1, Jens Knauer1, Marc Beurskens1, Robert Wolf1 and the W7-X Team1

1: Max Planck Institute for Plasma Physics, Wendelsteinstr. 1, 17491 Greifswald, Germany
2: University of Wisconsin-Madison, Madison, WI 53706-1609, USA

The effective charge Zeff is an indicator of the overall contamination of a low-Z impurities hydrogen plasma. Experimental Zeff derivation from the intensity of plasma Bremsstrahlung is demonstrated at several fusion experiments. In this contribution, we will introduce the diagnostic set-ups and the Bayesian modeling allowing the inference of Zeff at the W7-X stellarator. First results from the operational campaigns in 2017 and 2018 are shown.

A measurement of the visible plasma radiation along a single line-of-sight traversing the core plasma has been realized using a compact USB-spectrometer with a time resolution of 100 ms. A spectral region that is free from line emission is selected for the analysis of the Bremsstrahlung emission. Electron temperature and density profiles are needed to model the emission. The electron temperature profile is derived from either the electron cyclotron emission or the Thomson scattering diagnostic; the electron density profile shape information is derived from Thomson scattering and its absolute values from a robust single line-of-sight interferometer measurement. The Minerva framework is used to fit the profiles with Gaussian processes and to develop a Bayesian model of the diagnostic to infer line-of-sight averaged Zeff. The sensitivity of the diagnostic allows to measure Zeff at lowest core electron densities observed in the last campaign of 0.9x10^19 m^-3 with a statistical relative error of ~40% (Zeff = 2.5, 100 ms integration time) The analysis is automatized to routinely provide the results after a plasma discharge.

Two additional detectors sharing the same line-of-sight allow to observe the Bremsstrahlung in the near infrared (750-950 nm, spectral resolution ~1 nm, typical time resolution 50 ms), and in the visible light (523 nm and 630 nm, no spectral resolution, time resolution 100 kHz). Another, more versatile system with 27 lines of sight, already calibrated and collecting signals routinely, is also described.

Contribution: **P3.11** / Low-Temperature and Industrial Plasmas

Study of the energy distribution within plasma flow generated by magnetoplasma accelerator

Nora Trklja, Predrag S. Iskrenović, Ivan B. Krstić, Milorad M. Kuraica, Bratislav M. Obradović, Jagoš Purić

Faculty of Physics, University of Belgrade

Magnetoplasma accelerator (MPA) compress and accelerate plasma formed within the electrode system during the process of capacitor discharge. Electrode system is positioned in the vacuum chamber. The lifetime of the compressed plasma flow is around 150 μs, plasma velocity is up to 100 km/s, the order of electron density is 10^23 and temperature around 2 eV. MPA can be used for material treatment with plasma, it is of interest for industry application as well as for fusion related experiments (investigation of candidates for plasma facing components).
The total amount of energy stored in the capacitor bank is 6.4 kJ. Discharge is realized in residual gas regime with 11 mbar gas pressure in chamber. Current signal is measured by Rogowski coil. Energy transported to the target by plasma flow has been determined using K type thermocouple and voltage device. Brass target with known specific heat capacity has been used for energy calibration process. Energy distribution along z axis (axis of discharge) has been obtained for different working gasses: Hydrogen, Helium with 5% of Hydrogen and Argon. Process of plasma flow formation and distribution of plasma parameters along z axis strongly depend on the type of the gas.
During present experimental session the process of plasma-steel (type 4320) interaction has been investigated, too. Helium with 5% of Hydrogen was used as working gas. Every shot transports around 15 J of energy from the plasma to the target. Roughness and hardness of steel (type 4320) are measured before and after plasma treatment. Plasma shots make steel less rough and firmer.
Additionally, spectral analysis has been done and average value of the electric field within compressed plasma flow has been determined according to the distance between allowed and forbidden components of the He I 492.1 nm spectroscopic line in plasma-target region.

Contribution: **P3.12** / Magnetic Confinement Fusion

Steady-State Dispersion Interferometry for Real-time Density Feedback in Fusion Devices

K. J. Brunner (1), J. Knauer (1), J. Meineke (1), B. Kursinski (1), M. Stern (1), H. Trimiño Mora (2,1), T. Akiyama (3), P. Kornejew (1), M. Hirsch (1), H. Laqua (1), R. C. Wolf (1), and the W7-X team

(1) Max-Planck-Institute for Plasma Physics, Wendelsteinstr. 1, 17491 Greifswald, Germany
(2) University of Rostock, Universitätsplatz 1, 18055 Rostock, Germany
(3) National Institute for Fusion Science, 322-6 Oroshi, Toki, Gifu 509-5292, Japan

Interferometry in fusion experiments is prone to the influence of vibrations onto the density measurement. The “standard” compensation method of two-color interferometry is limited by the accuracy, with which both lasers can be aligned. For larger fusion experiments, such as ITER or DEMO, this becomes a highly difficult task. Dispersion interferometry promises complete compensation by eliminating the need to co-align separate lasers. However, so far reliable real-time low-latency processing of dispersion interferometry data has not been shown. This is however a necessity as interferometry is the default density feed-back diagnostic and particularly important for long discharges like the ones planned at the Wendelstein 7-X (W7-X) stellarator and ITER.

We recently reported the development of a novel method to process dispersion interferometry data. The method is ideally suited for a Field Programmable Gate Array (FPGA) based implementation for real-time processing. It has been shown to operate reliably during the OP1.2 campaigns at W7-X and established itself as the routine density feed-back diagnostic up to very high densities of 1.6×10^{20} m^{-2}. In this function we found that the W7-X interferometer’s phase drifts significantly due to changes in the ambient environmental parameters. These drift can result in phase changes of well over 1×10^{19} m^{-2} over several seconds, which is not acceptable from a control perspective.

Here we present the novel phase extraction method. In addition we have developed a real-time capable low-cost phase drift compensation method that can easily be retrofitted to many already existing devices and is applicable to both dispersion and two-color interferometers. This is the first implementation of such a compensation scheme finally making interferometry steady-state capable.

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the EURATOM research and training program 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Contribution: **P3.13** / Magnetic Confinement Fusion

Measurement of impurity photon fluxes in different plasma operation regimes during operation phase 1.2b in Wendelstein 7-X

P. Kornejew1, T. Barbui3, S. Brezinsek2, F. Effenberg3, J. H. Harris4, M. Jakubowski1 R. König1, M. Krychowiak1, O. Schmitz3, T. Sunn Pedersen1, E. Wang2, V. R. Winters3, G. Wurden5 and the W7-X team

1Max Planck Inst. for Plasma Physics, 17491 Greifswald, Germany
2Forschungszentrum Jülich GmbH, IEK-4, 52425 Jülich, Germany
3University of Wisconsin-Madison, Madison, WI USA 53706
4Oak Ridge National Laboratory, Oak Ridge, TN USA 37830
5Los Alamos National Laboratory, Los Alamos, NM USA 87545

For the last experimental campaign, the five-fold symmetric stellarator Wendelstein 7-X was outfitted with 10 uncooled graphite divertors and a first wall composed of graphite tiles and stainless steel surfaces. The interaction of the plasma with the divertors and the first wall as well as gas puffs using the divertor gas injection system influenced the impurity transport in different plasma regimes.
In this work, a low time resolution, high spectral resolution Echelle overview spectrometer (ESA3000), measuring the full spectrum between 300 and 800 nm with a spectral resolution of < 0.02 nm is used to compliment the ORNL Filterscopes system1, 2 viewing the first wall along 9 different sight lines in the mid plane of the torus.
Various regimes of plasma operation (detached and attached, puffing different gases into the divertor plasma) are compared with respect to photon fluxes of impurities.
The filter transmission ranges of the filterscope are checked for disturbing spurious lines to ensure a proper measurement of the lines of interest of different ionization stages of C, O, B, Ar, N, Ne, He. The overview spectra will be used to optimize the set of filters and their characteristics for the next campaign.
References:
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Contribution: **P3.14** / Magnetic Confinement Fusion

Plasma boundary reconstruction in ISTTOK using magnetic diagnostic data

Rafael Santos, Rui Coelho, Paulo Rodrigues, Blaise Faugeras, Horácio Fernandes, Bernardo Brotas, Doménica Corona, Humberto Figueiredo, Hugo Alves

Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal; CNRS Laboratoire J.A.Dieudonné, Université de Nice-Sophia-Antipolis, Nice, France

Plasma boundary reconstruction is one of the main tools to guarantee a reliable control and tokamak performance. In the ISTTOK tokamak this reconstruction is currently addressed online using weighted measurements from the magnetic sensors surrounding the device, not up to par when compared to methods that rely on a calculated magnetic flux map and intersection with the wall. To explore the feasibility of the latter approach, we show that via square wave input response curves and pre-processing of the poloidal field coil currents, it is possible to build for ISTTOK a simple scaling model for the effective equilibrium magnetic fields, and perform plasma boundary reconstruction using the algorithm VacTH. This algorithm, included in the NICE numerical code suite, relies on the decomposition of the poloidal flux in toroidal harmonics. The reconstructed plasma boundary is shown for a given discharge for several time frames and the shape and position of the boundary is shown to evolve consistently with the typical timescale evolution of ISTTOK discharges. Finally the need for further work is discussed regarding a more accurate quantification of the effects of the eddy currents in the copper shell present in ISTTOK, as well as alternative plasma boundary characterization methods in order to validate the results obtained here.

Contribution: **P3.15** / Beam Plasmas and Inertial Fusion

Determination of accurate spectra for laser-accelerated MeV ions by CVD diamond-detector setups optimized for experiments subject to intense EMPs

M. Salvadori(1,2,3), F. Consoli (3), M. Cipriani (3), M. P. Anania (4), P. L. Andreoli (3), P. Antici (2), F. Bisesto (4), R. De Angelis (3), M. Ferrario (4), M. Galletti (5), D. Giulietti (6), M. Migliorati (1,7), R. Pompili (4), C. Verona (8), A. Zigler (4,9)

1) University of Rome 'La Sapienza', Rome, Italy
2) INRS-EMT, Varennes, Québec, Canada
3) ENEA - C.R. Frascati – Dipartimento FSN, Frascati, Italy
4) INFN-LNF, Frascati, Italy
5) GoLP Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal
6) Physics department of the University and INFN of Pisa, Pisa, Italy
7) INFN Sez. Roma, Rome, Italy
8) University of Rome "Tor Vergata", Industrial Engineering Department, Roma, Italy
9) Racah Institute of Physics, Hebrew University, Jerusalem, Israel

Time-of-flight (TOF) measurements are a powerful and effective method to obtain timely spectra of particles accelerated via laser-plasma interaction experiments. However, the intense interactions achieved in high power laser facilities usually generate strong Electromagnetic Pulses (EMPs), which remarkably affect the signal-to-noise ratio of electronic devices placed close to the vacuum chamber, and, in some cases, they can even destroy them. This is an important issue when dealing with TOF detectors in these conditions. For this reason, chemical-vapor-deposited (CVD) mono-crystalline diamond detectors, were developed and optimized together with an improved readout system to operate in these critical environments. They were employed in the TOF setup to perform accurate measurements of energetic protons in experiments performed at the femtosecond FLAME facility, characterized by a hundreds-of-terawatt laser power and an ~1019 W/cm^2 intensity on solid targets, in conditions where intense EMPs were present. In this work we report on experimental results and on details of the procedure to obtain quantitative spectra for the laser-accelerated particles from diamond-detectors measurements. This was achieved from the accurate characterization of the overall readout system and from the absolute single-particle calibration of the detector with the products of the radioactive decay of 241Am. The fast response of these detectors allows for associated energy resolutions that can be much higher than those achievable with a classical Thomson spectrometer.

Contribution: **P3.16** / Magnetic Confinement Fusion

ELM-resolved, Optical Radiance Measurements of Low Intensity Impurity Emission in WEST Plasmas with Staggered Wavelength Filters

A.L. Neff(a,b), E.A. Unterberg(b), C.C. Klepper(b,c), O. Meyer(c), K. Davda(b,d), D.T. Fehling(b), J.Y. Pascal(c), J.H. Harris(c), and the WEST team(e)

(a)Oakridge Institute for Science and Education (ORISE), Oak Ridge, TN, USA
(b)Oak Ridge National Lab, Oak Ridge, TN, USA
(c)CEA, IRFM, F-13108 Saint Paul-lez-Durance, France
(d)University of Tennessee, Bredesen Center, Knoxville, TN, USA
(e)http://west.cea.fr/WESTteam

ELM-resolved acquisition of atomic line emission through the use of a filterscope has been implemented on the WEST tokamak at multiple poloidal locations. Filterscopes consist of a fiber-optic-based transmission from the tokamak to specifically engineered optical bandpasses and photomultiplier tubes (PMT) that collect the emission intensity to measure a radiance, L [W/cm^2/str], over the specified bandpass. This diagnostic records plasma-wall interaction (PWI) properties (e.g. impurity emission and recycling of main fuel ions) up to a max acquisition rate of 100 kHz. These PMT radiometric measurements are calibrated into a line-normalized radiance, L_N [photons/sec/cm2/str], to be compared with traditional spectrometers, both of which can later be converted to a particle flux. Low intensity emission peaks are difficult to quantify due to often comparable continuum levels, thus a secondary filter shifted (~1 nm away) to a judiciously-selected, line-free region to allow for background subtraction. The system installed on WEST currently targets tungsten (W) gross sputtering specifically and divides each sightline using beam splitters to 3 separate filters: A filter pair for the monitoring of the spectral region near the neutral W line emission (W-I) with line/background filters centered at 400.9 nm and 403.1 nm, respectively, and a neutral deuterium (D) line filter centered at Balmer-alpha, D_alpha (656.1 nm) emission related to fuel gas recycling. The two L_N signals near W-I are then subtracted from each other yielding only the W-I L_N. This radiance is then converted to a particle flux using S/XB coefficients. W-I LN data from a recent WEST experimental campaign will be presented and compared with plasma parameters and traditional spectrometer measurements of W-I line emission to demonstrate the capabilities of this staggered-filter filterscope method. Specifically, the choice of WEST-specific bandpass curves for the W-I L_N, described in [1], will be validated based on this latter comparison.

[1]O. Meyer, et al., RSI 87, 11D105 (2018)

Contribution: **P3.17** / Magnetic Confinement Fusion

Role of JETPEAK database in validation of synthetic neutron camera diagnostics and ASCOT-AFSI fast particle and fusion product calculation chain in JE

Paula Sirén_ab, Jari Varje_b, Henri Weisen_c, Luca Giacomelli_d, JET contributors*,

a_VTT Technical Research Centre of Finland, P.O Box 1000, 02044 VTT, Finland
b_Aalto University, Department of Applied Physics, P.O. Box 11000, FI-00076 Aalto, Finland
c_SPC, station 13, EPFL, 1015 Lausanne, Switzerland
d_Instituto de Fisica del Plasma "P. Caldirola", Milano, Italy

Utilisation of the JETPEAK database for diagnostics data and simulations has been demonstrated to enable efficient interpretation of synthetic neutron diagnostics and validation of fast particle and fusion product calculation chain. This chain is provided by the connection of ASCOT-AFSI codes through automatisation of the simulation and further analysis.
Synthetic diagnostics modules connected to the database are implemented as a part of a calculation chain: the ASCOT code defines the reactant distribution functions and the additional AFSI module creates fusion products as 4D (R, z, E, pitch) distribution for synthetic diagnostics block. The most comprehensive and systematic validation of ASCOT-AFSI (as established tool) against the experimental data is now presented in this contribution. In the validation process, synthetic neutron production rates (JET ILW) calculated based on the set up of JET neutron camera (KN3) lines of sight are used.
One of the most significant and valuable new features presented in this work is the use of systematic and physically relevant inputs via the JETPEAK database, which includes time averaged data profiles from selected stationary phases. Now the chain of analysis has been automated using automatically created inputs via JETPEAK and the execution of different modules. The final step in the validation can also be completed via the connection to the database: synthetic production rates have been compared with the experimental post-processed values and included in the database for further needs.
This contribution presents the workflow of the automatised analysis chain with a large number of physically selected plasma samples and it is focused on the role of synthetic diagnostics as a useful tool in the validation process. ASCOT-AFSI has been updated with several physical corrections and this demonstrates its strength as a tool in fast particle and fusion product studies. Additionally, the prospects of the database connection in validation of different blocks in the calculation chain via synthetic diagnostics as well as in quick intershot analysis are demonstrated.

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Contribution: **P3.18** / Magnetic Confinement Fusion

Synthetic diagnostic for the JET scintillator probe lost alpha measurements

J. Varje (1), V. Kiptily (2), P. Sirén (1,3), H. Weisen (4) and the JET contributors (*)

1 Department of Applied Physics, Aalto University, P.O. Box 11100, 00076 AALTO, Finland
2 CCFE, Culham Science Centre, Abingdon, OX14 3DB, UK
3 VTT Technical Research Centre of Finland, P.O. Box 1000, 02044 VTT, Finland
4 SPC, station 13, EPFL, 1015 Lausanne, Switzerland
* See the author list of X. Litaudon et al 2017 Nucl. Fusion 57 102001

The JET tokamak features a scintillator-based lost alpha diagnostic probe [1] which directly measures lost fast ions, including fusion alphas. Light emitted as the particles hit a scintillator plate inside the probe is imaged and mapped to the gyroradius and pitch angle of the incoming particles. Synthetic diagnostics using particle trajectory following can then be used to interpret these measurements and determine the origin of the losses and map them to the fast ion distribution function.

In this contribution we present a newly developed synthetic diagnostic for the JET lost alpha scintillator probe, based on the ASCOT fast ion orbit following code and the AFSI fusion source integrator. A 3D first wall geometry with the scintillator probe has been implemented based on defeatured CAD models. ASCOT follows trajectories of fusion products intersecting the probe, including thermonuclear and beam-produced ions generated by AFSI, and calculates the velocity space distribution of the lost particles. These can be compared with the gyroradius and pitch angle of the losses measured by the diagnostic. The code has previously been applied to similar fast ion loss studies for other tokamaks, including AUG [2] and ITER [3].

We demonstrate results from applying the synthetic diagnostic to JET discharges with various operating scenarios, and compare the simulated results to the experimental measurements. The simulated fast ion losses were found to agree with the measured distribution of the lost particles in different heating phases. Finally, extrapolated simulations for DT alphas are presented to estimate the performance of the diagnostic in the upcoming DT campaign.

[1] S. Baeumel et al 2004 Review of Scientific Instruments 75 3563
[2] O. Asunta et al 2012 Nucl. Fusion 52 094014
[3] M. Garcia-Munoz et al 2016 Review of Scientific Instruments 87 11D829

Contribution: **P3.19** / Magnetic Confinement Fusion

New tomography postprocessing method for radiated power analysis

Jakub Svoboda, Jan Mlynar, Marco Sertoli, Martin Imrisek, Ondrej Ficker

Institute of Plasma Physics of the Czech Academy of Sciences, IPP CAS, CCFE, IPP CAS

The JET tokamak is equipped with extensive diagnostic systems for tomography, including bolometers and soft X-ray (SXR) detectors. Tomographic reconstructions presented in this contribution were obtained using algorithm based on Tikhonov regularization and Minimization of Fisher information. New method for subsequent interpretative analysis of the tomographic reconstructions will be introduced. It is based on comparison of radiated power from different regions of reconstruction, that can be defined by a rectangle, or by flux surface values. The method was also used for comparative analysis of data obtained by reconstructing signals from different detectors. Application of the method in concurrent and separate interpretation of reconstructions from SXR and bolometers' signals will be presented.

Contribution: **P3.20** / Magnetic Confinement Fusion

Extraction of the plasma current contribution from the the numericallyintegrated magnetic signals in ISTTOK

D. Corona, J. Mora, A. Torres, E. Aymerich, B. B. Carvalho, H. Figueredo, H. Alves, H. Fernandes

Instituto de Plasmas e Fusão Nuclear, IST, Universidade de Lisboa
Instituto Tecnologico de Costa Rica
DIEE Department of Electrical and Electronic Engineering, University of Cagliari

ISTTOK's power supply systems allow the fast reversal of the plasma current while maintaining a finite plasma density between consecutive flat tops. This makes it possible to achieve a much longer plasma duration in comparison to single mode operation, which is limited by the saturation of the iron core magnetization. The reliable success of the plasma current inversions in AC mode demands a highly accurate plasma position control just before the reversal of the plasma current and also during its restarting, due to the delicate and inherently unstable residual plasma that lingers on during the time span it takes to complete an inversion. The plasma centroid position is estimated from the reconstruction of the signals obtained from a poloidal array of twelve magnetic probes. In the previous setup, this reconstruction relied on a cylindrical approximation algorithm and the error fields generated by active coils and currents in the passive structures were not taken into account, leading to some centroid position inaccuracy. Although this approach has been able to produce flat top current AC discharges with reasonable reliability, a better solution was implemented as a preferred estimator. The signals are now cleaned from the error fields following a method that relies on state-space models that use data collected from a systematic vacuum calibration procedure. Also, the plasma centroid position is estimated using a multi-filament current model. Furthermore, the recent implementation of numerical integrators in the real time ATCA based data acquisition system substantially improved the real time conditioning of the magnetic signals measurements. First results demonstrate that this new approach delivers a more reliable estimation of the plasma current centroid position with noticeable improvement on control performance, which is paramount to the success ratio of the AC plasma current switching.

Contribution: **P3.21** / Magnetic Confinement Fusion

Calibration of Vacuum Ultraviolet Spectroscopy Diagnostic on J-TEXT tokamak

Haisen Mo, Zhifeng Cheng, Xiaolong Zhang and the J-TEXT team

International Joint Research Laboratory of Magnetic Confinement Fusion and Plasma Physics, State Key Laboratory of Advanced Electromagnetic Engineering and Technology, School of Electrical and Electronic Engineering, Huazhong University of Science and Technology, Wuhan, 430074 People's Republic of China
School of Physics, Huazhong University of Science and Technology, Building 15, Wuhan, 430074 People's Republic of China
Advanced Energy Research Center, Shenzhen University, Shenzhen, 518060 People's Republic of China

A normal incidence vacuum ultraviolet spectroscopy diagnostic with wavelength range from 30 to 300 nm has been developed on J-TEXT tokamak for studying impurity transport on J-TEXT tokamak. It is very easy to achieve the wavelength calibration with some typical strong lines of carbon and oxygen. Several impurity ions (such as C V, C IV, Si XII, O IV, O VI, etc.) were identified. The accurate radiation profiles are necessary for impurity transport study. This needs a reliable calibration on the intensity response and an alignment on the optical path of the diagnostic system. Due to the limited spectral line candidates in the VUV wavelength range and the weak observability of the candidates, conventional branching ratio method is not applicable for the intensity response calibration. A modified branching ratio method based on the simulation of an impurity transport code – STRAHL is introduced to enrich the spectral line candidates. The code can provide a reasonable strength ratio of different spectral lines from the same ions with the measured plasma parameters. The alignment of the optical path will be achieved by utilizing a customized mask with aperiodic slots located between the entrance slit and the plasma as planned. The result of calibration will be presented and discussed in the conference.

Contribution: **P3.22** / Magnetic Confinement Fusion

Determination of the Fast-Ion Phase-Space Coverage for the FILD Spatial Array of the ASDEX Upgrade Tokamak

J. Ayllon-Guerola[1,2], L. Garcia-Baquero[2], J. Galdon-Quiroga[5], M. Garcia-Munoz[2,3], L. Stipani[4], J. Gonzalez-Martin[1,2], J. Rivero-Rodriguez[1,2], M. Rodriguez-Ramos[2], L. Sanchis-Sanchez[2,3], A. Herrmann[5], and the ASDEX Upgrade Team

[1]Department of Mechanical and Manufacturing Engineering, University of Seville, C/Camino de los Descubrimientos s/n, Isla de la Cartuja, Seville, Spain
[2]CNA (U. Sevilla, CSIC, J. de Andalucia), Seville, Spain
[3]Department of Atomic, Molecular and Nuclear Physics, Faculty of Physics, University of Seville, 41012 Seville, Spain
[4]Ecole Polytechnique Federale de Lausanne (EPFL), Centre de Recherches en Physique des Plasmas
Association Euratom-Confederation Suisse, CH-1015 Lausanne, Switzerland
[5]Max-Planck-Institut für Plasmaphysik, Garching, Germany

In the ASDEX Upgrade tokamak, a spatial array of reciprocating fast-ion loss detectors (FILD)[1] is currently being completed with the imminent commissioning of the last new system[2,3]. This array of five scintillator-based FILD systems provide time-resolved velocity-space measurements of escaping ions at five different positions in the tokamak probing a large escaping ion phase-space volume.

The FILDSIM[4] code, useful in the design of FILD probes, has been extended with a module to perform the back-tracing of charged particles in a tokamak magnetic configuration. This allows to identify their best location and determine their phase-space coverage as a function of the detectors radial position and most important plasma parameters, e.g. plasma shape.

In this work, the geometrical configuration (heat shielding, scintillator and collimator geometries) of each detector has been optimized using FILDSIM to provide maximum detection range and resolution within specific predefined ranges of particle energy and pitch angle. Full orbit simulations allow us to determine the fast-ion phase-space coverage of the array, as a function of the plasma shape, safety factor and including the realistic 3D machine geometry. FILD measurements at multiple locations are used to reconstruct the escaping ion phase-space.

[1] M. Garcia-Munoz et al., RSI 80, 053503 (2009)
[2] J. Ayllon-Guerola et al., RSI 87, 11E705 (2016)
[3] J. Gonzalez-Martin et al., RSI 89, 10I106 (2018)
[4] J. Galdon-Quiroga et al., Plasma Phys. Control. Fusion 60, 105005 (2018)

Contribution: **P3.23** / Magnetic Confinement Fusion

Multispectral Advanced Narrowband Tokamak Imaging System (MANTIS)

A. Perek,a,1 W.A.J Vijvers,a I.G.J. Classen,a T. Ravensbergen,a M. de Baar,a B.P Duval,b Y. Andrebe,b C. Galperti,b B. L. Linehanc and K. Verhaeghd

a. DIFFER — Dutch Institute for Fundamental Energy Research, De Zaale 20, 5612 AJ Eindhoven, Netherlands
b. Ecole Polytechnique Fédérale de Lausanne (EPFL), Swiss Plasma Center (SPC), CH-1015 Lausanne, Switzerland
c. Plasma Science and Fusion Center, Massachusetts Institute ofTechnology, 77 Massachusetts Avenue, NW17 Cambridge, MA 02139, U.S.A
d. York Plasma Institute, University ofYork, Heslington, York YO10 5DQ, U.K

This work presents a novel, real-time capable, 10-channel Multispectral Advanced Narrowband Tokamak Imaging System (MANTIS). The system was build as an extension to an MIT optical design [1] with real-time capabilities [2]. The hardware and software requirements are presented together with the complete system architecture. Tailored real- time algorithms exploiting the system capabilities are presented together with benchmarks comparing polling and event based synchronisation. The real-time performance is demonstrated with a density ramp discharge performed on TCV and differences between different plasma species behaviours are qualitatively described. The image quality of the system is assessed with emphasis on effects resulting from the narrowband interference filters. Some filters are found to create an internal reflection images that are correlated with the filters' reflection coefficient. This was measured for selected filters where significant absorption (up to 65% within ~ 70nm of the filter center) was measured. The majority of this was attributed to the filter's design and several filters' performance is compared.

1 B.L. Linehan et al. Rev Sci Instrum 89, 103503, 2018
2 W.A.J. Vijvers et al. JINST 12, C12058, 2017

Nonlinear oscillations of a single dust particle as the basis of the method for the DC plasma diagnostics

Alexandra Kartasheva, Yuri Golubovskii, Victor Karasev

Saint Petersburg State University,
3B Universitetskaya Emb., St Petersburg 199034, Russia

Complex plasmas consist of electrons, ions, neutrals, and solid microparticles interacting with each other. The describing of the properties of dust particle requires precise knowledge of the background plasma parameters, as well as a rigorous theoretical relationship between the plasma characteristics and parameters of dust particles. Alternatively, the exact knowledge of dust particle parameters can be used to diagnose the plasma environment. For example, the electric field profile of plasma area can be derived from the experimental investigation of the dynamics properties of dust particle, which is trapped in the observable plasma area. This techniques can be used to diagnose plasma when the application of other methods, in particular the electrostatic probe method, is impossible. In other words, the dust particle can be used as a probe to determine plasma parameters.

In the paper the noninvasive method of the discharge current modulation is used to obtain the nonlinear (large amplitude) vertical oscillations of a single dust particle trapped in a standing striation. The anharmonic effects of the dust particle oscillations such as parametric instabilities and hysteresis are obtained. The theory of the anharmonic oscillator provides a good quantitative description of the experimental data. The values of the thresholds of excitation of parametric instabilities, the anharmonic coefficients and the critical values of the oscillation amplitude for the hysteresis were calculated. The potential well, in which the microparticle oscillates, was calculated using the values of anharmonic coefficients. The vertical electric field in the vicinity of the dust particle equilibrium position was reconstructed.

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Contribution: **P3.25** / Magnetic Confinement Fusion

Doppler Coherence Imaging Spectroscopy on the HL-2A tokamak: Calibration and Preliminary Results

J. S. Allcock (1, 2), T. Long (3), L. Nie (3), R. M. Sharples (1), S. A. Silburn (2), J. R. Harrison (2), N. J. Conway (2), X. Min (3)

(1) Centre for Advanced Instrumentation, Department of Physics, Durham University, Durham, DH1 3LE, United Kingdom
(2) CCFE, Culham Science Centre, Abingdon, Oxon OX14 3DB, United Kingdom
(3) Center for Fusion Science, Southwestern Institute of Physics, No. 5, Huangjing Road, Shuangliu, Chengdu, China

Doppler Coherence Imaging Spectroscopy (CIS) has been installed on the HL-2A tokamak, and used to image scrape-off layer (SOL) impurity flows, with a novel method for spectral calibration. CIS is a passive, interferometric technique for imaging the low-order moments of an isolated spectral feature. Bulk flow of the emitting species results in Doppler shifted emission — this manifests as a shift in the phase of the interference fringes. Here, we report preliminary measurements of intrinsic C2+ and He+ impurity flows via spectral lines at 464.9 nm and 468.6 nm, respectively. The HL-2A CIS instrument views the high-field side SOL tangentially at a time resolution approaching 1kHz.

A reference phase image is required to absolutely calibrate the zero point of the flow measurements; it is obtained by illuminating the instrument at the rest wavelength of the targeted spectral line. A bespoke tunable laser and high accuracy wavemeter can be used for this purpose. It has been demonstrated elsewhere that an off-the-shelf source — such as a spectral lamp line — can be used to model the zero-flow reference image, provided that the source is nearby (+/- 3.5 nm) and that the CIS instrument has been well characterised.

We present an extension to this method, using a smaller and sparser set of wavelength measurements for the necessary instrument characterisation than in previous work, with an acceptable trade-off in accuracy. In this procedure, bandpass filters isolate a number of spectral lines in-turn, and a novel algorithm for inference from phase-wrapped data combines the measurements. The result is a zero-flow reference image for the aforementioned C and He impurity lines that is obtained using Cd and Zn spectral lamps, forgoing the cost of a tunable laser. The method is directly compared with tunable laser measurements.

Non-magnetic edge diagnostics for detecting the separatrix position

Katerina Jirakova 1,2, Jiri Adamek 1, Michael Komm 1, Ondrej Kovanda 1,3, Jakub Seidl 1, Petr Vondracek 1,3

1 Institute of Plasma Physics, Czech Academy of Sciences, Prague
2 Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University, Prague
3 Faculty of Mathematics and Physics, Charles University, Prague

The separatrix is arguably the most important boundary in a tokamak. It is surprising, therefore, that in experiment its position may not always be exactly known. The magnetic equilibrium reconstruction, which commonly provides the separatrix position, can be afflicted by random and systematic errors resulting in uncertainties of a few centimetres. These uncertainties can readily be observed, for instance, when mapping profiles measured by edge diagnostics to the outer midplane. Many tokamaks, such as ASDEX-Upgrade, TCV or COMPASS, alleviate such imprecisions in the reconstruction by introducing corrections to the equilibrium reconstruction. However, such corrections may sometimes lack the foundation of a rigorous analysis, relying instead on assumptions such as poloidal symmetry.

The goal of this contribution is to provide solid experimental evidence for the accuracy and reliability of such corrections. The data was measured by edge diagnostics of the COMPASS tokamak, in particular the horizontal and vertical reciprocating probes equipped by probe heads with Langmuir and ball-pen probes. It is shown that these measurements allow for routine detection of fundamental edge plasma processes, such as the velocity shear layer. Using the radial location of these processes as spatial markers, it is possible to compare the relative spatial order of the physical processes and of the separatrix location provided by the equilibrium reconstruction.

The analysis results indicate systematic differences between the probe data and the reconstruction, depending most strongly on plasma shaping. While efforts to optimise and correct the reconstruction code are ongoing, separatrix position inferred from probe measurements is vital for benchmarking the results, correcting edge diagnostics measurements, and eventually serving as input for the equilibrium reconstruction. Furthermore, a systematic analysis of the processes occurring in the vicinity of the separatrix may provide deeper understanding of the edge transport barrier, edge turbulence or heat flux scalings.

Contribution: **P3.27** / Magnetic Confinement Fusion

New Pressure Gauges for Long-Pulse Operation in the Wendelstein 7-X stellarator

U. Wenzel, G. Schlisio, M. Mulsow, T.S. Pedersen, M. Marquardt, Y.P. Hartmann

Max Planck Insitute for Plasma Physics, Wendelsteinstr. 1, 17491 Greifswald, Germany

Neutral pressure gauges of the ASDEX type are state-of-the-art for the measurement of the neutral pressure in magnetic fusion devices. For long-pulse operation as in Wendelstein 7-X and in ITER the current design with tungsten cathodes is not robust enough. In Wendelstein 7-X the high heating current in the order of 14-20 A caused often problems. The tungsten cathodes were deformed by the strong j x B force.

In the hope to reduce this force, we have changed the design of the electron emitter. The tungsten cathode was replaced by a LaB6 crystal emitter. Nine of these new pressure gauges were operated during the last experimental campaign in the Wendelstein 7-X. As expected, the heating current was drastically reduced to 2 A. We think that the reduced j x B force is the reason for the very good performance of the LaB6 pressure gauges.

We will discuss the requirements of the pressure gauges for long-pulse operation and show how they are met with the new design. We will show how the LaB6 pressure gauges are used for the measurement of the neutral compression and the particle exhaust by the island divertor in Wendelstein 7-X.

Contribution: **P3.28** / Magnetic Confinement Fusion

Experimental Validation of Plasma Tomography Algorithms at ISTTOK

(1) D. Hachmeister; (2) D. R. Ferreira; (3) D. D. Carvalho; (4) R. Cardoso (5) H. Alves; (6) H. Figueiredo; (7) H. Fernandes

(1,4) Instituto Superior Técnico; (2,3,5,6,7) Instituto de Plasmas e Fusão Nuclear

Plasma tomography is an ill-posed problem due to the scarce number of lines of sight available in fusion reactors. Algorithms based on Tikhonov Regularization and Minimum Fisher Information try to overcome this issue by introducing certain regularization parameters that require empirical tuning. In general, to validate the implementation of these algorithms, either artificial phantoms are used, or one must rely on information provided by other diagnostics. In this work, an experimental setup was developed that allows the use of physical phantoms to tune and validate the reconstruction algorithms. The setup was assembled in a mockup that resembles the ISTTOK tokamak with a cylindrical gas-discharge lamp (50x4 mm) placed perpendicular to the poloidal plane at multiple radial and angular positions. It is assumed that this physical phantom acts approximately as a point source in the emissivity profile. Knowing these profiles a priori, it is possible to compare them with the reconstructions produced by the algorithm, tuning and optimizing the reconstruction parameters. After this algorithm validation with the physical phantoms, several reconstructions were successfully computed for some tokamak discharges.

Contribution: **P3.29** / Basic and Astrophysical Plasmas

Formation of Nonlinear Solitary Vortical Structures by Coupled Electrostatic Drift-Ion-Acoustic Waves

L.Z. Kahlon

Forman Christian College (a Chartered University), Lahore Pakistan

Propagation of coupled electrostatic drift and ion-acoustic waves (DIAWs) is presented. It is shown that nonlinear solitary vortical structures can be formed by low-frequency coupled electrostatic DIAWs. Primary waves of distinct (small, intermediate and large) scales are considered. Appropriate set of 3D equations consisting of the generalized Hasegawa–Mima equation for the electrostatic potential (involving both vector and scalar nonlinearities) and the equation of motion of ions parallel to magnetic field are obtained. According to experiments of laboratory plasma mainly focused to large scale DIAWs, the possibility of selforganization of DIAWs into the nonlinear solitary vortical structures is shown analytically.

Peculiarities of scalar nonlinearities in the formation of solitary vortical structures are widely discussed.

Contribution: **P3.30** / Beam Plasmas and Inertial Fusion

Comparative analysis of plume specifications produced by interaction of nanosecond laser with Aluminum- and Mylar-foil targets using

Nader Morshedian, Mojtaba Kabir

Research School of Plasma and Fusion, Nuclear Science and Technology Research Institute, Tehran, Iran

The plume expansion of Aluminum-foil (AF) and Mylar-foil (MF) in front and back sides of the targets have been studied by shadowgraphy technique in background air at atmospheric pressure. The expansion velocity of plumes and the threshold number of laser shot to make a hole in the foils have been compared. The results show that for MF with 0.2 mm thickness after two laser shot a hole could be made while for AF regarding four times thinner than MF, i.e. 0.05 mm, the hole is appeared after 7-8 laser shot. The generation of plume both in front and back sides of AF are significantly energetic than MF. The maximum expansion velocity in front and back sides are about 3.2*10^6 cm/s and 2.5*10^6 cm/s for AF and 9*10^5$ cm/s and 6*10^5 cm/s for MF, respectively.

Contribution: **P3.31** / Faenov Memorial Session

Evaluation of photoluminescence response of LiF imaging detector at PETRA III x-ray source

S.S. Makarov1,2, S.A. Pikuz1 ,S.N. Ryazantsev1, A.Ya. Faenov1,3, T.A. Pikuz1,3, A.V. Buzmakov4, M. Rose5, T. Senkbeil6, Andreas von Gundlach6, S. Stuhr6, Ch. Rumancev6, D. Dzhigaev5, P. Skopintsev5, S. Lazarev5,7, I. Zaluzhnyy5 , J. Viefhaus5 , A. Rosenhahn6, I. Vartaniants5

1) Joint Institute for High Temperatures, Russian Academy of Sciences, Moscow, Russia
2) Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
3) Institute for Open and Transdisciplinary Research Initiatives, Osaka University, Suita, Osaka, 565-0871, Japan
4) FSRC «Crystallography and Photonics» RAS, Leninskiy Prospekt 59, 119333, Moscow, Russia.
5) Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany
6) Analytical Chemistry - Biointerfaces, Ruhr-University Bochum, Bochum, Germany
7) TPU (National Research Tomsk PolytechnicUniversity), Tomsk, Russia

The results of measuring the metrological properties of the lithium fluoride crystal detector with focused soft X-ray at 500eV (PETRA III facility, DESY, Germany) are reported. The LiF detector response function was determined for the x-ray deposed dose up to several kJ/cm3. Using this dependence, we established the dynamic range of LiF (up to 1e7) for our experimental parameters. Also the threshold for the creation of CCs was estimated. The spatial resolution achieved 0.13 um in the experiments and was only limited by the resolution of readout system. We have also demonstrated the submicron imaging capability of the x-ray beam distribution. LiF images showed the features in the x-ray beam (about 0.13 μm in size), that correspond to theoretical calculations. These data make it possible to extend the using LiF as a detector for the diagnostic and characterizing of X-ray beams in experiments on the study of nanoscale objects.

Contribution: **P3.32** / Beam Plasmas and Inertial Fusion

HED plasma diagnostics set on the Laser MégaJoule facility

T. Caillaud, E. Alozy, M. Briat, A. Chaleil, P. Cornet, A. Dizière, O. Dubos, A. Duval, J. Fariaut, D. Gontier, T. Jalinaud, O. Landoas, B. Marchet, G. Oudot, G. Soullié, P. Stemmler, C. Reverdin, R. Rosch, A. Rousseau, B. Rossé, C. Rubbelynck, I. Thfoin, P. Troussel, B. Vauzour, B. Villette, M. Burillo, C. Chollet, L. Remy, P. Prunet, G. Boutoux, J.L. Ulmer, J.P. Lebreton, M. Prat, J.P. Jadaud, R. Wrobel, X. Rogue

CEA, DAM, DIF, F-91297 Arpajon, France

High energy density laser matter interaction by focusing Laser MégaJoule (LMJ) beams on target creates strong plasma conditions. Simulation program leaded at CEA requires experimental validation of the advanced theoretical models in the basic science, the equation of state, the atomic and nuclear physics domains. For these purposes, we have developed a set of plasma diagnostics such as x-ray imagers and spectrometers, VISAR, UV or visible spectrometers, charged particle spectrometers and neutron time of flight. Over 30 diagnostics are planned to be manufactured with high spatial, temporal and spectral resolution in these fields. These diagnostics are installed around the target chamber depending on the experimental configuration. The facility schedule relies on two periods of experimental campaigns per year leading to the first neutron experiment that will be conducted at the end of this year on LMJ. We will present the LMJ plasma diagnostics developed at CEA and their performances. We will also present diagnostics that are under development.

Contribution: **P3.33** / Magnetic Confinement Fusion

Development of a Laser-Induced Rydberg Spectroscopy diagnostic on NSTX/NSTX-U

A. Diallo, L. Reymond, and V. Vekselman

Princeton Plasma Physics Laboratory, Princeton University, Princeton, NJ, USA
Swiss Plasma Center, Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland,

The electric field (E) plays a crucial role in the edge dynamics, the overall plasma confinement, and therefore fusion performance. The electric field profile is among the plasma parameters that are the most difficult to measure and hence has been largely neglected for many years. Here, we discuss a novel diagnostic allowing direct measurements of the local electric field in the edge region in NSTX/NSTX-U. This laser based diagnostic's principle consists of depleting the naturally populated $n = 3$ level to a Rydberg state –sensitive to electric fields– that will result in a suppression of part of the Dapha emission. We refer to this approach as Laser-Induced Rydberg Spectroscopy (LIRyS).

Contribution: **P3.34** / Magnetic Confinement Fusion

DEVELOPMENT OF SODIUM ATOMIC INJECTOR FOR BEAM EMISSION SPECTROSCOPY (BES) DIAGNOSTIC OF URAGAN-2M STELLARATOR

A.D. Komarov, L.I. Krupnik, A.A. Chmyga, G.N. Deshko, A.V. Klosovskiy, A.S. Kozachek, S.M. Khrebtov, S.M. Maznichenko, V.A. Volkov

Institute of Plasma Physics, National Science Center “Kharkiv Institute of Physics and Technology”Kharkiv, Ukraine

The main idea of this report is improvement of the light atomic injector for BES diagnostic. BES complex consist of the neutral beam injector (including the ion beam accelerator and neutralizer) and the secondary light signal registration system. Diagnostic is used to study space plasma density profiles, impurity ions and magnetic field distribution in the edge zone of fusion plasmas. This method is based on the detection of the probe beam glow of atoms excited by the plasma electrons and impurity ions.
This report describes the investigation of ion injector based on 5-electrode lens that can give the ion current of 2…3 mA for the energy of the sodium ion beam of 25 keV, and the beam diameter of 17 mm in the neutralization area.
The two types of neutralizers – with open evaporators (with flowing and supersonic sodium vapor stream) were investigated. Neutralization of the beam was carried out on sodium vapor at an evaporator temperature of up to 300 0C degrees.
Based on the tests of 2 types of neutralizers, a new neutralizer design was developed. This neutralizer can work with a flowing stream of sodium vapor and with supersonic vapor stream in pulse regime. This type of neutralizer will significantly reduce the vapor pressure of sodium in the vacuum volume of the diagnostic complex.

Contribution: **P3.35** / Magnetic Confinement Fusion

A flexible and compact electronic system for the bolometric diagnostic with on-line calibration capability

C. Neri, G. Apruzzese, C. Monti, F. Pollastrone, V. Piergotti, B. Tilia

ENEA - Frascati
via E. Fermi 45, 00044 Frascati (Rome) ITALY

At ENEA Frascati laboratories is in development an updated electronic system for the bolometric diagnostic. The system is based on the more recent electronic technology and it is able to manage a large number of channels. It is flexible, reliable and compact in order to be suitable for applications on large fusion experimental machines or reactors.

The system has been conceived to be applied to bolometric detectors based on resistive bridge, it is based mainly on the digital signal processing technology to guaranty high accuracy, high dynamics and an high signal to noise ratio. It is also able to manage large offset of the bridges and It has an embedded acquisition capability.

A further important feature of the system is the embedded on-line calibration capability of the sensor detectors that allows the calibration of each channel in parallel and in a very short time with the bolometer heads installed and without any manual intervention on the lay-out, thus allowing the calibration also soon before the plasma experiment.

The paper describe the main concepts, the general architecture of the system and in detail the on-line calibration functionality.

Contribution: **P3.36** / Magnetic Confinement Fusion

Hard X-ray Bremsstrahlung of Relativistic Runaway Electrons in JET

V.V. Plyusnin(1), V.G. Kiptily(2), A.E. Shevelev(3), E.M. Khilkevitch(3), S. Gerasimov(2), J. Mlynar(4) and JET contributors*

(1) Instituto de Plasmas e Fusão Nuclear, Instituto Superior Tecnico, Universidade de Lisboa, Lisboa, Portugal;
(2) CCFE, Culham Science Centre, Abingdon, OX14 3DB, UK;
(3) Ioffe Institute, St. Petersburg, 194021, Russia;
(4) Institute of Plasma Physics of the CAS, CZ-18200 Prague 8, Czech Republic;
*See the author list of X. Litaudon et al 2017 Nucl. Fusion 57 102001

A capability to avoid/suppress a detrimental runaway electron (RE) generation is one of the main requirements to the functional properties of disruption mitigation system in ITER (ITER DMS). An understanding of the physics of RE generation during disruptions should support the DMS design for reliable suppression/avoidance of RE.

RE interacting with plasma particles produce a bremsstrahlung in MeV energy range (hard X-rays (HXR) and gamma-rays). Hitting the plasma-facing components (PFCs) RE produce HXR/gammaÕs and photo-neutrons also. Measurements of HXR/gammaÕs and photo-neutrons provide detailed information on runaway generation dynamics and serve as a key approach in RE physics study. This report presents an analysis of the HXR/gamma data measured during RE generation in JET.

The spatial distribution of HXR sources in JET plasmas has been measured with the JET neutron/gamma-ray profile monitor. The HXR spectra have been measured with the sets of horizontally and vertically viewing NaI(Tl), BGO and LaBr(3) spectrometers. Inferred RE energy values have been used for characterization of RE generation dynamics in JET. As well the mapping of HXR sources and measured spatial characteristics of the HXR bremsstrahlung have been used to study the RE energy evolutions.

Angular distribution of the HXR radiation from relativistic RE scattered off by nuclei should have a strong anisotropy in the direction of electron motion with half-width of radiation pattern inversely proportional to the Lorentz parameter (i.e. to RE energy). The measurements of HXR radiation in poloidal plane revealed also a significant azimuthal asymmetry of the emission with surprisingly narrow radiation patterns. Performed analysis has shown that observed poloidal asymmetry of the HXR emission patterns could be linked to the properties of the motion of relativistic electrons scattered on high-Z nucleus in the presence of magnetic field and Compton scattering of the radiated HXR bremsstrahlung from RE.

Contribution: **P3.37** / Magnetic Confinement Fusion

Mitigation of EC breakdown in the gyrotron transmission line of the ITER Collective Thomson Scattering diagnostic

Axel W. Larsen1, Søren B. Korsholm1, Bruno Gonçalves2, Heidi E. Gutierrez1, Elsa Henriques4, Virginia Infante4, Thomas Jensen1, Martin Jessen1, Esben B. Klinkby3, André Lopes2, Raul Luis2, Volker Naulin1, Stefan K. Nielsen1, Erik Nonbøl3, Jesper Rasmussen1, Mirko Salewski1, Alberto Vale2, Arianna Taormina1, Claus Møllsøe1

1Technical University of Denmark, Department of Physics, 2800 Kgs. Lyngby, Denmark
2Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Univ. Lisboa, Portugal
3Technical University of Denmark, Center for Nuclear Technologies, 4000 Roskilde, Denmark
4IDMEC, Instituto Superior Técnico, Univ. Lisboa, Portugal

The ITER Collective Thomson Scattering (CTS) diagnostic will diagnose the velocity distribution of the fusion-born alpha particles in ITER by observing the scattering of a high-power (1 MW) microwave beam from seven different volumes inside the plasma. The ITER CTS diagnostic is located in equatorial port plug #12, which is a remote handling port plug. Due to the estimated level of the ECE background, the CTS diagnostic will inject 60 GHz microwaves in X-mode from the low field side, which means that the fundamental ECE resonance (for the ITER baseline scenario) will be encountered inside the port plug, where the CTS front-end components are located. The neutral gas pressure is expected to increase during ITER pulses, which may cause the pressure, in the CTS high-power microwave transmission line, to rise above the threshold for EC breakdown.

Due to the hostile, restrictive, and nuclear environment, it was not possible to implement most standard methods of avoiding EC breakdown, so a detailed study (including a RAMI FMECA) was carried out to determine the best way possible to avoid EC breakdown inside the port plug. The conclusion of these studies was that the ITER CTS diagnostic will include a longitudinally-split electrically-biased corrugated waveguide (SBWG), located at the location of the fundamental 60 GHz EC resonance. The SBWG works by applying a DC voltage across the two electrically isolated halves of the waveguide, causing any free electrons to diffuse out of the resonant region before they have a chance to cause an ionization avalanche and thus a gas breakdown.

Here I will present the results of the work that has been performed. The present and near-future work is focused on consolidating a robust SBWG design and manufacturing method, as well as modelling the high-power microwave transmission through the EC resonance inside the SBWG.

Contribution: **P3.38** / Magnetic Confinement Fusion

Study of Runaway Electrons in GOLEM Tokamak

Pravesh Dhyani1, Vojtěch Svoboda1, Jan Mlynář1,2, Jaroslav Čeřovský1,2, Ondřej Ficker2, Vladimir Linhart3, Jan Stockel1,2

1Department of Physics, Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University, Prague, Czech Republic
2Institute of Plasma Physics, Czech Academy of Sciences, Prague, Czech Republic
3Department of Dosimetry and Application of Ionizing Radiation, Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University, Prague, Czech Republic

High loop voltage and low-density discharges at GOLEM tokamak present favorable conditions for the study of runaway electrons. In this paper, we discuss the interplay between magnetic hydrodynamic (MHD) fluctuations and runaway electrons. In quasi-periodic events, it was observed that tearing modes strongly destabilize during the large HXR generation due to the runaways. Tearing modes become stable, when HXRs are suppressed. Causality of the events is still not clear, since, during the HXRs generation, toroidal electric field also increases, as indicated by loop voltage signal. A detailed analysis will be presented at the conference.

Contribution: **P3.40** / Faenov Memorial Session

Analysis of plasma conditions at the initial stage of high-intensity laser pulse interaction with solids using time and space integrated X-ray spectra

A.S. Martynenko 1,2, S.A. Pikuz 1,2, I.Yu. Skobelev 1,2

1Joint Institute of High Temperature of RAS, Moscow, Russian Federation
2 National Research Nuclear University MEPhI, Moscow, Russian Federation

Study of the interaction of high-power laser radiation with matter remains a very important and interesting topic for over half a century (especially after the appearance of facilities with laser radiation fluxes reaching values of the order of 1022 W/cm2) in experiments on the interaction of super intense pulses with solid-state, and especially with thin and structured targets. One of the main diagnostic tools here is X-ray spectroscopy of multiply charged ions based on further analysis of relative intensities of the spectral lines of H- and He-like multiplies charged ions. For the purpose of better determination of the plasma parameters, we proposed an additional analysis of spectral lines widths [1]. The main problem here is that typical experimental spectrum in time and space integrated one. Nevertheless, one can take into account the relative “weights” of different stages of plasma expansion and based on the assumed plasma expansion model calculate the integrated spectrum. We used an atomic kinetics simulation code to obtain such calculations for Al plasma which showed an unnecessity of usage of time-dependent simulation in the calculation (assuming a general adiabatic plasma expansion case). It also gave us information about the impact of late stages of the expansion and allowed us to estimate the role of plasma expansion type. We present these results which can be used to value the target density at the moment of laser arrival to evaluate its contrast.

Contribution: **P3.41** / Magnetic Confinement Fusion

ISTTOK Tokamak plasmas impurity content evolution during post-shutdown recovery

R. B. Gomes, J. P. S. Loureiro, H. Fernandes, H. Figueiredo and H. Alves

Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

The understanding of post-shutdown tokamak recovery for stable plasma operation has been a long-lasting challenge. Time to achieve this state strongly vary depending on shutdown duration and implemented maintenance tasks. Although ISTTOK is a versatile machine with regards to the installation of new diagnostics/systems this factor is the main limitation on the effective up/downtime periods.

Wall conditioning on ISTTOK is performed by discharge cleaning. During the recovery phase this is alternated with standard plasma operation. The main responsible for the improvement on plasma stability and reproducibility is the reduction of the plasma impurity content. In order to assess the temporal evolution of this parameter, along the conditioning phase, a broadband spectrometer has been used to monitor the produced radiation within the full 200 to 1050 nm spectral range.

For the purpose of this study the spectra acquired during a 3 months' time span and corresponding to approximately 100 discharges were analyzed. The obtained results demonstrated a significant decrease on overall impurity content with the most significant reduction on oxygen and carbon line intensities, mostly due to water and atmospheric contaminants. While oxygen and nitrogen contribution evolves to residual values the carbon amount achieves a saturation at a higher relative level since ISTTOK's main poloidal limiter is built from graphite tiles and acts as a source during operation. These results will be compared with data obtained from plasma resistivity evolution for the aforementioned discharges.

Contribution: **P3.42** / Magnetic Confinement Fusion

In situ HIBP energy analyzer calibration on the T-10 tokamak

L.G. Eliseev[1], M.A. Drabinskiy[1,2], P.O. Khabanov[1,2], N.K. Kharchev[3], A.V. Melnikov[1,2]

1) NRC 'Kurchatov Institute', Moscow, Russia
2) Moscow Institute of Physics and Technology, Dolgoprudny, Russia
3) General Physics Institute, Moscow, Russia

Heavy Ion Beam Probe (HIBP) is a unique plasma diagnostics to measure local values of the electrostatic plasma potential and its fluctuations in bulk plasma of a tokamak and stellarator. T-10 is a circular tokamak with major radius R = 1.5 m, minor radius r = 0.33 m, plasma current up to 300 kA, toroidal magnetic field on axis up to 2.5 T. To probe plasmas in T-10 Tl+ ions with energies up to 330 keV are used. Primary Tl+ beam is injected into the plasma perpendicular to toroidal magnetic field, beam ions are ionized due to collisions with plasma particles and secondary Tl++ beam goes to the parallel plate energy analyzer, which contains adjustable position sensitive detector, the secondary beam energy can be derived from the beam vertical displacement on the detector. Plasma electrostatic potential is calculated from the energy difference between primary and secondary beams. As soon as the absolute value of the plasma potential in T-10 is in the range of 500-800 V at the plasma core, the analyzer should be able to measure secondary beam energy with the accuracy of 10^-5. This requires precise detector positioning inside the analyzer and calibration. Fine detector positioning allows to obtain proper gain G and dynamic factor F dependencies on beam entrance angle into the analyzer. Calibration allows to measure G and F values as functions of beam entrance angle. The procedure of the in situ energy analyzer calibration using He gas target with toroidal magnetic field 2.4 T and detector position adjustment are described and results are presented.

Contribution: **P3.43** / Beam Plasmas and Inertial Fusion

Comprehensive diagnostics of hot electron emission from plasmas produced by sub-nanosecond terawatt laser on thin foil metal targets

M. Krupka (1,2,3), J. Krása (1), R. Dudžák (1,2), J. Cikhardt (2,4), M. Kálal (2,3), T. Burian (1,2), D. Klír (2,4), K. Řezáč (2,4), J. Dostál (2), M. Pfeifer (1,2), T. Pisarczyk (5), T. Chodukowski (5), and Z. Rusiniak (5)

1) Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic
2) Institute of Plasma Physics, Czech Academy of Sciences, Prague, Czech Republic
3) Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Prague, Czech Republic
4) Faculty of Electrical Engineering, Czech Technical University in Prague, Czech Republic
5) Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland

Interaction of high-power and high-energy lasers with matter generates plasmas emitting considerable amounts of relativistic electrons. In this contribution such plasmas were produced by the PALS kJ laser facility delivering the beam with intensity of the order of 3×10^16 W/cm^-2 in 400 ps on thin foil metal targets. To study the electron emission in both the backward and forward directions with respect to the incident laser beam trajectory, an array of electron spectrometers was employed to record the electron emission from the plasma in various angles around the target. For experimental determination of the total number of hot electrons escaping from the plasma through the plasma barrier a target probe was used in order to measure the target return current which neutralizes the positive target charge produced by these escaping hot electrons. Together with this diagnostics the femtosecond interferometry was employed to evaluate the electron density spatial profiles in the plasmas observed in chosen time periods.

The results obtained with the used sophisticated diagnostics enabled to obtain various characteristics of the hot electrons. Besides the basic characteristics of the used diagnostics the angular dependence of the electron energy spectra ranging up to 3 MeV will be presented as well as the total emitted charge and the electron densities measured in the laser generated plasma plumes.

Contribution: **P3.44** / Magnetic Confinement Fusion

Nuclear Analysis of the ITER Collective Thomson Scattering system

André Lopes - 1, Raul Luís - 1, Esben Klinkby - 2, Erik Nonbøl - 2, Bruno Gonçalves - 1, Martin Jessen - 3, Søren B. Korsholm - 3, Axel W. Larsen - 3, Bent Lauritzen - 2, Yohanes Nietiadi - 1, Jesper Rasmussen - 3, Mirko Salewski - 3, Catarina Vidal - 1

1 - Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa 1049-001 Lisboa, Portugal
2 - DTU Nutech, Technical University of Denmark, Frederiksborgvej 399, DK-4000 Roskilde, Denmark
3 - DTU Physics, Technical University of Denmark, Fysikvej, 2800 Kgs. Lyngby, Denmark

The Collective Thomson Scattering (CTS) system will be the ITER diagnostic measuring the plasma alpha-particle velocity distribution. Using mirrors, a 1 MW microwave beam is directed into the plasma via an opening in the diagnostic first wall. The microwaves will scatter off fluctuations in the plasma, and the scattered waves are captured and transmitted through a series of mirrors and waveguides. The system will be installed in drawer #3 of the Equatorial port plug #12. Several of the plasma-facing components of the CTS system will be directly exposed to neutron radiation from the plasma, which can affect the performance of the components and potentially reduce the lifetime of the diagnostic system.

In this work, a full neutronics analysis is presented for the CTS system, including neutron and gamma fluxes and nuclear heat loads for the main components of the system, evaluated with the Monte Carlo radiation transport code MCNP6. A system-specific MCNP model of the CTS components has been developed based on up-to-date CAD models of the CTS components available in the ITER ENOVIA database, and subsequently integrated into the updated ITER reference model of the port plug drawer. The displacements per atom (DPA) for several critical components of the system are estimated using FISPACT-II.

The simulations performed with the new model of the CTS system present new challenges, in part due to the higher degree of complexity associated with each design iteration. In this study we present results obtained with the new detailed MCNP model. In particular, the effects of additional shielding surrounding the mirrors and introduction of new cooling pipes are investigated. In summary, this work provides a neutronics analysis of the CTS system, aiming at demonstrating the compliance of the system with the ITER neutronics design criteria.

Contribution: **P3.45** / Magnetic Confinement Fusion

A novel on-site self-calibration linearization method for frequency modulated continuous wave reflectometry

J. Zhang, A.D. Liu, C. Zhou, M.Y. Wang, X. Feng, Z.Y. Liu, S.B. Zhang, D.F Kong, J.X. Ji, H.R. Fan, H. Li, T. Lan, J.L. Xie, W.Z. Mao, Z.X. Liu, W.X. Ding, G. Zhuang and W.D. Liu

1. KTX Laboratory and Department of Engineering and Applied Physics, University of Science and Technology of China, Anhui Hefei 230026,China
2. Department of Physics, Nanchang University, Jiangxi Nanchang 330031, China
3. Institute of Plasma Physics, Chinese Academy of Science, Anhui Hefei 230031, China

The Frequency Modulated continuous Wave (FMCW) profile reflectometer system applied on EAST (Experimental Advanced Superconducting Tokamak) will provide measurements of the electron density profile over a frequency range of 32-50GHz (Q band) and 50-75GHz (V band) with simultaneous operation in both O and X mode polarizations. The sweep rate is about 2 GHz/µs. For FMCW system, it's important to do linearity calibration since we need a good intermediate frequency (IF) signal and an accurate frequency-time curve for the reconstruction of profile. To get the linear sweep frequency, the voltage input in the voltage controlled oscillator (VCO), which is the source of the system, need to be adjusted. The way to make the frequency linear is based on the linear fitting of the phase of IF signal, which is obtained by digital complex demodulation method (CDM). The linearization method is simple and useful.

Contribution: **P3.46** / Beam Plasmas and Inertial Fusion

Neutron Imaging System for Inertial Confinement Fusion in LFRC

Zhongjing Chen, Xing Zhang, Feng Wang

Laser Fusion Research Center, CAEP

Neutron Imaging System (NIS) is used to image the burn volume and cold fuel volume of imploding fusion capsules. In this work, we present a design of neutron imaging system for inertial confinement fusion in LFRC. Based on the limitation of the neutron yield, the penumbral aperture has been chosen. A geometry model has been developed to assess the performance of the aperture, including the spatial resolution, the field of view and the signal-to-ratio of the measured image. This model has been validated with a good agreement of the performances of OMEGA-NIS assessed by the model and the measured results. The spatial resolution of NIS is 17μm with the field of view to be 200 μm. A signal to ration of 10 can be guaranteed with the neutron yield to be more than 1e13. The system has been constructed with a capillary-array neutron image detector, and tested with the X-ray source and neutrons from imploding fusion capsules. The spatial resolution of neutron image detector can be within 1 mm. The preliminary results of neutron image measurement will be presented in this presentation.

Contribution: **P3.47** / Beam Plasmas and Inertial Fusion

The Monochromatic radiography and aplications in hydrodynamic measurements on Shenguang facility

Bolun Chen, Zhenghua Yang, Feng Wang

Laser Fusion Research Centre, China Academic of Engineering Physics

The monochromatic backlight imaging system（MBIS）based on the spherically bent crystal is developed and used to measure the hydro-instability and the implosion hydrodynamic. The system is optimum by the relations between the setup parameters and the performance parameters deduced by the geometry optics. The Crystals were bent in the lab with ROC 250mm. A smaller backlight foil which is usually less than 300μm in diameter is used to improve the spatial resolution in both meridian and sagittal planes. The large FOV with homogenous backlighting background is obtained due to the semi-point project setup which the backlight profile is smoothed. The x ray is reflected by the crystal following the Bragg law $2d\sin\theta = n\lambda$. The Bragg angle is matched to the He-like emission spectrum of the backlighter and chosen to near the normal incidence. The noise coming from the diagnostic hole of the hohlraum and the stagnated emission of the compressed capsule are cut down by the high spectral resolution and the setup of the MBIS. Combining with the streak camera, the MBIS is performed to measure the implosion trajectory. The whole trajectory including the stagnation phase was obtained due to the mitigation of the core emission. With little modifications, the MBIS also used to measure the fluoresce signal doped in the modulation samples to research the hydro-instability.

Contribution: **P3.48** / Magnetic Confinement Fusion

Coherence Imaging Diagnostic for ITER

M. Kocan1, M. Blacksell2, J. Howard2, S. Hopkins3, R. Beeby3, C. Hughes3, R. Garrett3, C. Guillemaut4, R. Huxford5, R. Barnsley1 and M. Walsh1

1 ITER Organization, Route de Vinon-sur-Verdon, CS 90 046, 13067, St Paul lez Durance Cedex, France
2 Research School of Physics and Engineering, The Australian National University, Canberra, ACT 2601 Australia
3 Australian Nuclear Science and Technology Organisation, New Illawarra Rd, Lucas Heights NSW 2234
4 Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade Lisboa, Lisboa, Portugal
5 RBH Optics, 26 Park Close, West Sussex, RH15 8HL, England

The impurity transport in the ITER divertor region will impact the power exhaust, tritium co-deposition and the transport of impurities to the core plasma. This impurity transport is affected by hydrogenic flows. The understanding of flows is thus important for the optimisation of the divertor operation and for the validation of models of the divertor performance in ITER and future fusion reactors.

Conceptual design of the ITER coherence imaging diagnostic has been developed in collaboration with the Australian National University and the Australian Nuclear Science and Technology Organisation. The diagnostic is designed to deliver measurements of the plasma flow velocity and temperatures in the ITER divertor region with the required spatial, temporal and velocity resolution.

The diagnostic consists of an optical imaging system featuring a mirror cleaning system and a shutter for a pair of mirrors closest to the plasma, a system for compensating differential motions between the vacuum vessel and the tokamak building and a polarimeter/interferometer to analyze the spectrum and polarization properties of Doppler broadened emission lines and polarized multiplets. A system of mirrors and lenses transfers the signal from the plasma to the interferometer over a total length of approximately 30 meters. This optical system is designed to minimize the impact on the signal polarization, whilst keeping the total signal transmission in the visible waveband (450-700 nm) maximised. The design includes a laser calibration system to monitor the polarization properties of the first mirror between plasma discharges.

This contribution will describe the conceptual design of the ITER coherence imaging system and will also address a range of physical and engineering challenges experienced during design of this diagnostic.

Contribution: **P3.49** / Magnetic Confinement Fusion

Development of AXUV bolometer for disruption mitigation study in KSTAR

Juhyeok Jang, Jayhyun Kim, Junghee Kim, Seungtae Oh, Jeongwon Lee, Byung-Ho Park

National Fusion Research Institute (Daejeon, Republic of Korea)

Mitigating large heat load during disruption is one of challenging issues for stable operation of ITER. Shattered pellet injection (SPI) is a promising technique for disruption mitigation. For disruption mitigation by SPI, it is important to know how much plasma energy can be dissipated through radiation. In addition, if SPI radiation is not uniform, first wall can be damaged by highly localized radiation. For these reasons, measurement of poloidal and toroidal distribution of plasma radiation is necessary for successful SPI. In this study, AXUV-based fast bolometry is developed for disruption mitigation study in KSTAR. AXUV16ELG photodiodes are used as detectors. Since they have non-flat responsivity from visible to UV range, multiple filters are used to measure different wavelength range simultaneously. Al filters block photons energy below 15 eV, and Al/LiF/Parylene-N filters block photon energy below 200 eV. Whole wavelength range is measured by unfiltered AXUV channel. Two poloidal arrays are installed at D-port, the other two are located at O-port. With tomographic reconstruction techniques, each pair of poloidal arrays provides poloidal cross sectional images of plasma radiation. Four toroidal arrays are installed at four different toroidal positions near SPI. Each of them has wide poloidal view and narrow toroidal view, which enables measurement of total radiated power in each poloidal plane. ACQ424ELF-32 modules are used to acquire fast signal up to 1 MHz. Kapton-coated twisted pair wires are used to transmit signal to DAQ.

Contribution: **P3.50** / Magnetic Confinement Fusion

High Availability methods in ATCA-based control and data acquisition for fusion diagnostics

M. Correia1, J. Sousa1, A.J.N Batista1, R.C. Pereira1, A.P. Rodrigues1, P.F. Carvalho1, A. Combo1, B. Santos1, B.B. Carvalho1, J.M. Cardoso2, B. Gonçalves1

1 Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal.
2 LIBPhys-UC, Physics Department, University of Coimbra, P-3004-516 Coimbra, Portugal

Near steady-state operation of plasmas in fusion machines controlled by systems with high acquisition channel density require much reduced downtime (High Availability or HA). To achieve adequate HA for scalable, high performance systems, various techniques have been developed and implemented on an ATCA-based platform: remote hardware management, modules hot-swap, modularity, firmware update support (Serviceability); fault detection and mitigation; scalable redundancy schemes (N + M); resilience to errors, electromagnetic fields and neutrons; relocation of sensitive hardware from hazardous radiation locations; time-stamping (absolute-time applicable standards: IEEE-1588, White Rabbit and IRIG), synchronization and real-time event management embedded on the acquisition hardware; choice of instrumentation standards, based on modularity, scalability, hardware management capability, embedded HA schemes, data processing/transfer capability; “universal” common device driver software layer supporting the HA methods; high-performance and computational power techniques to process real-time complex algorithms (e.g. in GPU, FPGA); centralized hardware management including firmware updating methods.
An overview of the application of these techniques in prototypes of systems targeting current and future fusion experiments will be presented, including the hardware, firmware, gateware and software development details.

Contribution: **P3.51** / Magnetic Confinement Fusion

DESIGN OF A COMPACT COHERENT RF BACK-END FOR AN ULTRA-WIDEBAND MILLIMETER WAVE REFLECTOMETER

José Dias, António Silva, Bruno Gonçalves

Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa,
Av. Rovisco Pais, 1049-001 Lisboa, Portugal

On the next experimental fusion reactors, the number of suitable diagnostics to measure relevant plasma quantities are very limited. Millimeter wave diagnostics are one of the obvious choice due to the limited in-vessel access requirements and front-end robustness. FMCW reflectometry is a well establish technic to measure electron density profiles and to provide feedback for plasma position and shape control. To get the required poloidal and toroidal plasma coverage a large number of channels must be used, generating the need for compact and modular millimeter wave back-ends. As the telecommunication industry is focused on the next network generation, such as 5G, manufacturers are releasing high performance Monolithic Microwave Integrated Circuits (MMIC) in a large scale and at affordable prices. For such reasons a prototype of a coherent fast frequency sweeping RF back-end is being developed at IPFN-IST using commercial MMICs. One of the design goals for the back-end prototype centres on the flexibility of the system, so that it can easily match to the required frequency ranges. The back-end alone covers the NATO J-Band (10 GHz to 20 GHz) and it is design to drive external full band frequency multipliers resulting in an ultra-wideband coverage up to 140 GHz, but not limited to. The use is not restricted to fusion plasma diagnostics and can be extended to other FMCW radar applications. This work presents the selected architecture, discussing the main key design features and the prototype performance based on the measured testing data.

Contribution: **P3.52** / Beam Plasmas and Inertial Fusion

Modeling of K-alpha emission and high density effects in laser-plasma interaction experiments relevant for shock-ignition

R. Florido (1), J. M. Martín-González (1), M. A. Gigosos (2), L. Antonelli (4), F. Baffigi (3), F. Barbato (5), D. Batani (6), G. Cristoforetti (3), L. A. Gizzi (3), Ph. Nicolai (6), O. Renner (7,8), V. Tikhonchuk (6)

(1) iUNAT - Departamento de Física, Universidad de Las Palmas de Gran Canaria, Spain; (2) Departamento de Física Teórica, Atómica y Óptica, Univ. de Valladolid, Valladolid, Spain; (3) Intense Laser Irradiation Laboratory, INO-CNR, Pisa, Italy; (4) Department of Physics, University of York, York, United Kingdom; (5) Empa Swiss Federal Laboratories for Materials Science and Technology, Dübendorf, Switzerland; (6) Centre Lasers Intenses et Applications, Université de Bordeaux-CNRS-CEA, Talence, France; (7) Institute of Physics & ELI-Beamlines, Czech Academy of Sciences, Prague, Czech Republic; (8) Institute of Plasma Physics & PALS Facility, Prague, Czech Republic.

In the context of the shock-ignition (SI) approach to ICF, characterization of hot-electrons (HE) driven by parametric instabilities is of a great interest because of their important role on the shock formation and their propagation in the compressed shell. K-alpha emission has been largely used for the study of HE generation in laser-produced plasmas. In a previous work, combined K-alpha imaging and spectroscopic data obtained from planar-targets irradiated at SI-relevant laser intensities at the PALS facility were interpreted mainly relying on Monte Carlo simulations for cold target material [1,2]. However, in this work we follow an atomic-kinetics and collisional-radiative approach [3] in an effort to provide a self-contained description of the experiments from an atomic-physics perspective. Post-processing of hydrodynamic simulations is performed –also including a simple but efficient HE transport model– to thus modeling the K-alpha emission spectrum from the tracer Ti layer embedded in the plastic target. Simulations suggest that the Ti layer is heated to a few tens of eV and electron density goes easily above 1e23 cm^-3. At these conditions, it is interesting to investigate how the plasma environment and high density effects impact the atomic kinetics and the corresponding radiative properties. Thus, we study the influence of using different continuum-lowering models and other effects, such as electron degeneracy, on the ionization balance and the formation of the characteristic K-alpha emission. Diagnostic aspects of these spectral features depending on parameters of HE distribution and high-density effects are assessed.

Acknowledgements
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Contribution: **P3.53** / Magnetic Confinement Fusion

Investigations of laser ablation behavior for developing ultrashort pulse laser-based diagnostics in magnetic confinement fusion device

Dongye Zhao a, b, Sebastijan Brezinsek a, Jannis Oelmann a, Marcin Rasinski a, Rongxing Yi a, Hongbin Ding c, Christian. Linsmeier a

a Forschungszentrum Jülich, Institut für Energie- und Klimaforschung - Plasmaphysik, Partner of the Trilateral Euregio Cluster (TEC), 52425 Jülich, Germany
b Southwestern Institute of Physics, P.O.Box 432, Chengdu, Sichuan, 610041, China.
c Key Laboratory of Materials Modification by Laser, Ion and Electron Beams, Chinese Ministry of Education, School of Physics, Dalian University of Technology, Dalian, 116024, P R China

The surface composition analysis of Plasma Facing Materials (PFMs) is very important for understanding Plasma Wall Interaction and improving the performance of the Magnetic Confinement Fusion (MCF). Laser-based diagnostics are presently the best-known possibilities to characterize the PFMs accurately at the running MCF. Ultrashort pulse, in the region of picosecond (ps) to femtosecond (fs), laser-based diagnostics have been proposed and used to high depth-resolved diagnose the PFMs expecting the fact of the extremely high power density with smaller thermal effects and resulting in a significantly improved depth resolution up to several ten nanometres [1].

In this work, the ps and fs laser ablation behavior of the PFMs were investigated in the ultrahigh vacuum condition for the propose of developing ultrashort pulse laser-based diagnostics in MCF devices. The ablation depth and cross-section of the craters were determined by Confocal Microscopy (CM) method. The ablation mass loss was measured by CM and Quartz-Micro Balance (QMB) techniques. The results show that the ablation depth has a logarithmic dependence with the increasing of the laser fluence at a low laser fluecne region. The emission light from laser-induced tungsten plasma can be observed under the mass loss of 5 ng per laser pulse and the corresponding depth-resolution is in the order of 10 nm scale. The cross-section of the crater ablated by ps and fs laser is like the square shape and gauss shape at low fulence region, respectively. Moreover, the thermal diffusion in the depth and lateral direction in the ultrashort laser ablation was investigated by a Scanning Electron Microscopy (SEM) combined with Focused Ions Beam (FIB) technique. Because the strong thermal diffusion brings an error source for the quantitative analysis due to the component re-distribution and impurity segregation, which should be minimized in laser-based diagnostics.

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Contribution: **P3.54** / Magnetic Confinement Fusion

Retarding field analyzer for the Wendelstein 7-X plasma boundary

M. Henkel1, Y. Li*1,2, Y. Liang1, P. Drews1, A. Knieps1, C. Killer3, D. Nicolai1, D. Höschen1, A. Langenberg3, N. Pablant4, G. Satheeswaran1, S. Liu2, O.Grulke3, M. Jakubowski3, S. Brezinsek1, O. Neubauer1, B. Schweer1, J. Cai2 and the W7-X team3

(1)Forschungszentrum Jülich GmbH, Institut für Energie- und Klimaforschung – Plasmaphysik, Partner of the Trilateral Euregio Cluster (TEC), 52425 Jülich, Germany
(2)Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031, China
(3)Max-Planck-Institut für Plasmaphysik, Greifswald, Germany
(4)Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, New Jersey 08543-0451, USA

Ion temperature, Ti, in Wendelstein 7-X (W7-X) plasma boundary has been successfully measured during the last experimental campaign OP1.2b by a retarding field analyzer (RFA) probe, which was previously commissioned at EAST [1] and subsequently tested on W7-X at the OP1.2a campaign. The probe consists of two identical analyzers mounted back to back. For each side, the RFA consist of an front plate with 3 entrance orifices (width 300 µm , length 8 mm per orifice), an newly installed thin plate with 3 entrance slits (width 30 µm, length 8 mm per slit and thickness 50 µm) stick to the front plate, three successive grids, and three collector plates. Due to the difficulty in obtaining the Ti in OP1.2a, The RFA system has been upgraded with respect to both the probe mechanical structure and the electronics. The carbon cover of the probe was replaced by a boron nitride cover. Two Langmuir pins of the previous design have been extended to five pins at the top of the RFA probe to simultaneously measure the electron density, electron temperature and the turbulence information. The sampling circuits of three grids were also upgraded to prevent the damage caused by arcing between the grids. The probe has been successfully operated in high density discharges (nel>7×1019m-2). Ion temperature profiles have been obtained by fitting the curve of the collector current as a function of the retarding voltage. The Ti measured by RFA has been compared with the X-ray Imaging Crystal Spectrometer (XICS) diagnostic at W7-X plasmas boundary.

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Contribution: **P3.55** / Magnetic Confinement Fusion

MicroTCA control and data acquisition platform for Plasma Diagnostics

J. Sousa, M. Correia, R.C. Pereira, A.P. Rodrigues, P.F. Carvalho, A. Combo, B. Santos, B.B. Carvalho, A.J.N. Batista, J.M. Cardoso(b), B. Gonçalves

Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal.
(b) LIBPhys-UC, Physics Department, University of Coimbra, P-3004-516 Coimbra, Portugal

Following the successful deployment of an instrumentation platform for fusion diagnostics[1], based on the PICMG 3.0 Advanced Telecommunications Computing Architecture (ATCA), the next step was to extend the platform by developing an autonomous control and data acquisition system, still able to maintain desirable performance characteristics in speed, channel density and availability, at a cost suitable for smaller systems. For this new endeavour, software and firmware have been ported to the MicroTCA standard using mostly in-house developed hardware, preserving many of ATCA’s benefits in performance in a smaller form-factor.
The first instance of the proposed platform comprises a MicroTCA 1U shelf with 6 Advanced Mezzanine Card (AMC) slots, MicroTCA Carrier Hub (MCH) module, AMC to FMC carrier modules, 500 MSPS to 2 GSPS ADC FMC modules, timing and synchronization input/output (IO) module, or other Commercial Off-The-Shelf (COTS) modules. Data is handled by the MCH, featuring PCIe Gen 3 switching to a host computer, as well as performing clock distribution and IPMI-based hardware management for High Availability (HA). This compact, flexible and scalable platform may either integrate a large-experiment system infrastructure, as well as being configured as a lower-cost, self-contained platform for smaller experiments or development and testbench purposes.
This submission will focus primarily the development of the MCH module, which is key to introduce the platform architecture.

[1] ITER prototype fast plant system controller (https://doi.org/10.1016/j.fusengdes.2011.04.062)

Contribution: **P3.56** / Magnetic Confinement Fusion

Modernization of the filtration system for diagnostics of the Doppler reflectometry of the L-2M stellarator for operation with high power of ECR heati

A.A. Kharchevskii 1, N. N. Bogachev 1,2,3, D. V. Malakhov 1,2,3, and N N Skvortsova 1,4

1 Prokhorov General Physics Institute of the Russian Academy of Sciences
2 MIREA – Russian Technological University
3 Pirogov Russian National Research Medical University
4 National Research Nuclear University MEPhI

The study of the properties of edge plasma in toroidal traps is associated with the search for ways to increase the efficiency of the thermonuclear reactor. Diagnostics of high-temperature plasma in magnetic confinement systems is connected to a variety of problems and requires atypical engineering solutions.

Doppler reflectometry (DR) is one of the methods for measuring the rate of poloidal plasma rotation in tokamaks and stellarators. The Doppler reflectometer is designed to work as part of the stellarator L2-M in GPI RAS for above described measurement, as well as to measure the spatial frequency spectra of plasma density fluctuations.

The powerful sources of microwave radiation (gyrotrons) used to heat the plasma interfere with the detection of low-power diagnostic signals, such as DR signal. The commissioning of the gyrotron complex MIG-3 at the L-2M had made it possible to bring the record power density input plasma to 3.4 MW/m^3. After that, we have received a noisy interference DR signal (with a large component with gyratron working frequency) in our experiments, which could not be processed and analyzed. We upgraded the filtering system in the receiving path of the Doppler reflectometer to ensure high suppression at a frequency of 75.3 GHz and low attenuation at a diagnostic frequency of 30-40 GHz. Another pin-waveguide filter (PWF) and a new compact bandstop filter based on a Fabry-Perot resonator (BFFPR) was added to the filter system. BFFPR was calculated theoretically, modeled in two CAD systems (EMPro and CST) and constructed. The characteristics of PWF and BFFPR were measured using an MVNA-8-350 mm network vector analyzer of the millimeter range. The introduction of these filters into the filter system made it possible to successfully carry out experimental measurements of the DR spectra in the L-2M stellarator with a record proportional supply of ECR heating energy.

Contribution: **P3.58** / Beam Plasmas and Inertial Fusion

Proof of concept of Talbot-Lau phase contrast imaging with a high repetition rate laser X-ray backlighter

(1) V. Bouffetier, L. Ceurvorst, F. Dorchies, S. Hulin, T. Goudal, A. Casner, (2) M. Pia-Valdivia, D. Stutman

(1) Centre Lasers Intenses et Applications (CELIA), Université de Bordeaux-CNRS-CEA, France
(2) Department of Physics and Astronomy, Johns Hopkins University, Baltimore, Maryland 21218, USA

The development of high-power lasers has enabled the creation of high energy density plasmas in laboratory. Current experiments in this field rely on X-ray radiography to measure the evolution of the plasmas being generated. However, the lack of contrast of this method for low Z materials prohibits the observation of micro-metrical details.
In such media, the complex index of refraction being n=a+ib with b the part related to classical attenuation radiographies and a>>b related to the refraction enables better capacity in phase imaging.

The Talbot-Lau interferometer is a grating interferometer based on the Talbot and Lau effects and is an accurate diagnostic for phase imaging with a micro-metrical spatial resolution. Currently, this technology is present in the literature with a preference for synchrotrons or high-power lasers to generate the source radiation.
Here, we examine for the first time the feasibility of Talbot-Lau phase contrast using an X-ray source irradiated by a high repetition rate laser.

During this study, we did a proof of concept to validate the feasibility of phase contrast imagery on the high repetition rate laser ECLIPSE at CELIA laboratory at the University of Bordeaux. We accumulated 100 to 1000 laser pulses to realize our radiographies with a laser at 100mJ with a pulse duration of 1.5ps and a focal of 10µm at the repetition rate of 10Hz.

We studied the evolution of contrast and SNR of the radiographies vs the number of pulses accumulated to determine the threshold of photons necessary to image a sample with a Talbot-Lau interferometer under polychromatic and partially coherent X-rays. To support our discussion, we then proceeded to the reconstruction of phase images of the sample to demonstrate the feasibility of such a technique on future high repetition rate laser facilities.

Contribution: **P3.59** / Beam Plasmas and Inertial Fusion

Pointing and contrast quality free high-power-laser X-ray radiography generation at the LMJ-PETAL facility

1 G. Revet, D. Raffestin, A. Casner, D. Batani

1 Université de Bordeaux-CNRS-CEA, CELIA, UMR 5107, F-33405 Talence, France

From laboratory astrophysics [1] to Inertial Confinement Fusion experiments [2], X-ray radiography is an efficient and time-tested tool to probe the laser-created plasmas in a high energy density regime. It consists in the generation of small (tens of microns) X-rays source, which allows to create a sufficiently sharp projected 2D transmission image of the plasma. Both spatial and temporal shortness of the X-ray emission source are required in order to get a good spatial and temporal resolution of the probed plasma dynamic. In addition, a relatively small X-ray energy range is mandatory in order to make the deconvolution from the measured X-ray transmission up to the plasma density.

In this view, short and long laser pulses were investigated. Nanosecond laser pulses, via imploded capsule [3] or shielded foil targets [1], allow to get ns-duration and relatively broadband X-ray sources. The short pulse allows the possibility to get temporally shorter X-ray source. Hitting a directed stalk with a short pulse, which generate X-ray in a point-source-like, along the axis defined by the stalk, is one of the way.

However, the short pulse methods are pointing and contrast quality dependent. We present here a refined setup which allows overriding such constraints. Using PETAL [4] (PETawatt Aquitaine Laser, ~ 0.5kJ/0.5ps/~10^19 W.cm^(-2)) of the LMJ-PETAL facility, a thick (~100 µm) laser-hitted plane target, allows generating the hot electrons population which is sent through the target up to a directed stalk, situated at the opposite side of the target. The prepulse, generating unwanted thermal and large spatial scale X-ray emission in the front-face pre-plasma is blocked via an appropriately positioned shielding. The laser pointing precision is bypassed thanks to the spread of the hot electron through the transit within the target, before reaching the stalk. Finally, the choice of two different materials, for the laser-hitted target and the stalk, allows appropriate filtering of the remaining unwanted Kα, Heα or broadband emission emanating from the laser-hitted target. The use of specific detector allows at the end to better isolate the wanted Kα from the hard X-ray emanating from the Bremsstrahlung emission within the stalk itself.

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Contribution: **P3.60** / Magnetic Confinement Fusion

Integrated software for the analysis of high-resolution scattering signals during mm-wave beam injection

B. Baiocchi1, W. Bin1, A. Bruschi1, L. Figini1, U. Tartari1, E. Alessi1, O. D'Arcangelo2

1 Institute of Plasma Physics, National Research Council of Italy via R. Cozzi 53, 20125 Milan, Italy
2 ENEA, C. R. Frascati via E. Fermi 45, 00044 Frascati (Roma), Italy

Recently, during Collective Thomson Scattering (CTS) measurements at mm-waves aimed at studying the ion dynamics in fusion plasmas, strong signals of scattering of the injected beam with non-CTS origin have been detected. A possible explanation of these signals in terms of a parametric decay (PD) of the injected wave with power threshold much lower than previously envisaged by theory was proposed. The experimental activity with CTS diagnostic at FTU is finalized to two aims: the characterization of the thermal ion distribution function and the investigation of the possible low power PD processes foreseen by the recent models. In order to ease the data analysis, a set of data processing tools has been integrated on purpose, with an activity started in 2014. Here we present the last implementation of an integrated data analysis tool, finalized to the investigation of the signals detected with the CTS diagnostic. The last version of the software integrates information from the raw spectra of scattered radiation with the modeled ECE emission to provide calibrated spectra improved with respect to the previous ones. The correct calibration of the signals on the real line of sight of the beams should to be helpful to better distinguish high power anomalous emissions from the less powerful CTS radiation. In addition it compares the calibrated spectra with the ones predicted considering the local scattering parameters evaluated from beam-trajectories calculated on the base of the actual aiming of the launched and received beams, moved during the pulse, allowing then to extract information on the ion dynamic and composition of the plasma. The last version of the software takes into account also multi-reflection beam-tracing simulations in both polarization modes in support to the investigation of the appearance, the causes and the location of the anomalous emissions and it is here presented.

Contribution: **P3.61** / Beam Plasmas and Inertial Fusion

Use of 3-frame complex interferometry to optimize the operation of the capacitor coil targets for laser-driving of strong magnetostatic fields

T. Pisarczyk(1), J.J. Santos(2), R. Dudzak(3),4, A. Zaras-Szydowska(1), M. Ehret(1,5), Z. Rusiniak(1), J. Dostal(4,3), T. Chodukowski(1), O. Renner(3,4), Yu. Gus'kov(6,7), Ph. Korneev(7,6), T. Burian(3,4), D. Makaruk(1), M. Rosinski(1), M. Kalal(9,4), M. Krupka(4,3,9), M. Pfeifer(3,4), D. Klir(8,4), J. Cikhardt(8,4), J. Krasa(3), S. Singh(3), S. Borodziuk(1), M. Krus(4), L. Juha(3,4), J. Hrebicek(3,4), J. Golasowski(3,4) and J. Skala(3,4)

(1) Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland
(2) Univ. Bordeaux, CNRS, CEA, CELIA, UMR 5107, F-33405 Talence, France
(3) Institute of Physics, Czech Academy of Sciences, 182 21 Prague, Czech Republic
(4) Insitute of Plasma Physics, Czech Academy of Sciences, 182 00 Prague, Czech Republic
(5) Institut fur Kernphysik, Technische Universitat Darmstadt, 64289 Darmstadt, Germany
(6) P.N. Lebedev Physical Institute of RAS, Moscow, Russian Federation
(7) National Research Nuclear University MEPhI, Russian Federation
(8) Faculty of Electrical Engineering, Czech Technical University, 166 27 Prague, Czech Republic
(9) Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University, 115 19 Prague, Czech Republic

Recently developed three-frame complex-interferometry system irradiated by a Ti:Sa laser with 40 fs pulse has been installed at the PALS laser facility. By means of this unique diagnostic were performed first simultaneous measurements of B-field in the coil of the capacitor-coil targets (CCT) and self-generated B-field of the diode plasma in between the CCT-plates. Measurements of the coil B-field were performed via Faraday effect in TGG crystals (with Verdet constant VTGG = 60 rad/T/m) at the coil vicinity. CCT were irradiated by the 1st harmonic frequency of the PALS iodine laser (λ = 1315 nm) with energy in the range 250-500 J and pulse duration of 350 ps. Within the investigation were studied CCT with different distances between plates and different grounding.
We applied simultaneously a current probe for determination of the total return current related to electrons escaping completely from the diode. Electron and ion emission spectra were measured by means of the routine diagnostics available at PALS.
Obtained information about current density distributions in the diode in correlation with measurements of the current flow in the coil, together with electron and ion emission measurements and measurements of the return current are fundamental for the optimization of the CCT performance (maximum B-field in the coil) and suggest modifications of their design and fabrication according to the possible laser irradiation conditions.
This research was supported by the Access to the PALS RI under the EU LASERLAB IV project (Grant Agreement No. 654148); by the Ministry of Science and Higher Education, Republic of Poland (Decision no. 3880/H2020/2016/2/2018/2) and by the Ministry of Education, Youth and Sports of the Czech Republic (projects No. LM2015083 (PALS RI) and No. EF16_013/0001552) as well as by the Czech Science Foundation (grants No. P205/11/P712 and No. GA19-24619S).
This research was also carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programs 2014-2018 under grant agreement No 633053. The views and opinions

expressed herein do not necessarily reflect those of the European Commission.

Contribution: **P3.62** / Magnetic Confinement Fusion

Integrated Zeff Analysis on the DIII-D Tokamak

K.Callahan [1], W.Heidbrink [1]; B.Grierson [2], C.Chrystal [3], J.Herfindal [4], S.Haskey [2]

[1]- University of California, Irvine; [2]- Princeton Plasma Physics Lab; [3]- General Atomics; [4]- Oak Ridge National Lab

The integration of filterscope and spectrometer measurements of the visible bremsstrahlung continuum from the DIII-D tokamak has been implemented in the plasma profile analysis module OMFITprofiles [Logan et. al. Fus. Sci. & Technol. 74 125-134 (2018)] to determine the plasma Zeff. Emission from 5215-5245 A is measured by 16 filtered visible bremsstrahlung measurements (filterscopes) oriented on the midplane of DIII-D with a sampling rate of 20 kHz. The charge exchange recombination spectroscopy (CER) system utilizes scanning spectrometers, and typically measures emission near 5291 A with 80 spatial views. With both the filterscope system, and the background continuum from the CER system, independent and redundant line integrated measurements of visible bremsstrahlung radiation are made across the midplane of DIII-D and are now combined for the first time in an integrated manner. These measurements are inverted with respect to magnetic flux coordinate ρ by either Abel inversion or least squares minimization to infer the plasma emissivity profile. Zeff is derived from the emissivity profile from a calculation involving electron density and temperature from the Thomson scattering diagnostic. This analysis has been applied for a range of plasma conditions including L-mode, H- mode and H-mode with impurity seeding. This plasma Zeff inferred from VB is shown to be in good agreement with the Zeff computed from the active CER impurity density profile measurements under normal operating conditions where carbon is believed to be the dominant impurity species of the plasma. The analysis that has been developed is useful for cross checking diagnostics and measuring Zeff when impurities besides carbon have a significant presence and cannot be easily monitored with CER measurements.

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Contribution: **P3.63** / Low-Temperature and Industrial Plasmas

Investigation of optical amplification of CuII 224.7nm line in multiple Grimm discharge

Ivan B. Krstić, Bratislav M. Obradović, and Milorad M. Kuraica

University of Belgrade, Faculty of Physics, PO Box 44, 11001 Belgrade, Serbia

In this study the resonance energy transfer from metastable argon ion to copper atom in an argon glow discharge is used to achieve inverse population of the upper energy level of the line CuII 224.7 nm. This resonance energy transfer is very efficient due to small difference between the energy levels of ArII (3p5,2P1/2) and CuII (4p,3P2). In order to examine the possibility of obtaining the inverse population of this copper ion level arrangement of eight in line connected Grimm-type abnormal glow discharges has been assembled. The length of the active medium is changed, by varying the number of the active discharges and the intensity of the CuII line is monitored. It has been found that the increase of the line intensity is not a linear function of the active medium length. This can be considered as the first indication of a possibility to achieve an inverse population. Since the intensity of this copper ion line depends on the discharge current, dependence of the CuII line intensity on the plasma length for different currents is recorded. In order to achieve higher line intensity of CuII 224.7 nm line, instead of DC power supply, a laboratory made pulse generator has been used. The device enables high intensity current pulses through the discharge and consequently increased the population of the excited level of copper ion. To determine parameters, for the most efficient pulse regime, dependence of the CuII line intensity on pulse duration has been studied.

Contribution: **P3.64** / Magnetic Confinement Fusion

Extracting T_e measurements from a pixelated multi-energy soft x-ray diagnostic in the Madison Symmetric Torus

P. D. VanMeter (1), L. F. Delgado-Aparicio (2), L. M. Reusch (1), D. J. Den Hartog (1)

(1) University of Wisconsin-Madison, Madison, WI, USA
(2) Princeton Plasma Physics Laboratory, Princeton, NJ, USA

A multi-energy soft X-ray (ME-SXR) diagnostic based on the PILATUS3 100K x-ray camera, produced commercially by DECTRIS Ltd., has been installed on the Madison Symmetric Torus (MST) reversed-field pinch. This photon-counting camera consists of a two-dimensional array of ~100,000 pixels for which the lower photon absorption cutoff energy can be independently set. This allows it to be configured for a unique combination of simultaneous spatial and spectral resolution. Data has now been collected for MST standard, improved confinement, and quasi-helical plasmas, but analysis of this data is complicated by the presence of bright Al+11 and Al+12 emission lines at ~2 keV. In order to properly interpret this data a full forward model has been developed which produces realistic chord-integrated ME-SXR synthetic measurements given the underlying T_e, n_e, neutral density, and impurity density profiles. A method for using this model in a Bayesian framework to extract equilibrium T_e measurements from MST high-temperature plasma data is presented. Resulting profiles show good agreement with Thomson scattering measurements in the core. Future work will extend this method by integration with other diagnostics (Thomson scattering, x-ray tomography, and FIR interferometry) to constrain the resulting plasma profiles using all available information. Work supported by the US DOE.

Contribution: **P3.65** / Beam Plasmas and Inertial Fusion

Novel gel dosimetry diagnostic for the secondary sources of ZEUS 45TW laser system at CPPL

E. L. Clark1 , , A. Grigoriadis1, I. Tazes1, G. Andrianaki1,3, I. Fitilis1,2, , S. Petrakis1,2, A. Skoulakis1, E. Kaselouris1,2, T.G. Maris5, I. Tsiapa5, M. Bakarezos1,2, I. K. Nikolos3, V. Dimitriou1,2, E. P. Benis4, N. A. Papadogiannis1,2 and M. Tatarakis1,2,

1 Centre for Plasma Physics & Lasers - CPPL, TEI of Crete, Greece
2 School of Applied Sciences – TEI of Crete, Greece
3 School of Production Engineering & Management, Technical University of Crete, Greece
4 Department of Physics, University of Ioannina, Greece
5 Department of Medical Physics, University of Crete, Greece

A novel polymeric gel was synthesized and a Magnetic Resonance Imaging (MRI) setup was properly customized to characterize the secondary sources generated by high intensity laser-matter interaction. The 45 TW Zeus laser at the Centre for Plasma Physics and Lasers of the TEI of Crete at Rethymno, Greece is used to generate secondary sources of electrons, ions and neutrons as well as X-rays with various applications in medical physics, radiation testing and homeland security applications. Here we report preliminary results of a Vinyl-Pyrrolidone (VIP) based polymer gel irradiated by secondary sources generated from interaction of the high-power laser with solid foil targets. The gel was properly synthesized to increase the sensitivity for the irradiation of the specific sources and an MRI setup was properly configured to probe the dose distribution of the irradiated gel. Polymer gel data have been compared to other dosimetric measurement data both qualitatively and quantitatively. Also, we report simulations using the EPOCH particle in cell (PIC) code and FLUKA that provide useful information for the experimental data.

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Contribution: **P3.66** / Low-Temperature and Industrial Plasmas

Langmuir probe diagnostics of an impulse magnetron discharge with hot Cr target

Alexander V. Tumarkin (1) (presenter), Andrey V. Kaziev (1), Kseniya A. Leonova (1), Maxim M. Kharkov (1), Dobrynya V. Kolodko (1, 2), Andrey Yu. Khomyakov (1, 3)

(1) National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)
(2) Kotel'nikov Institute of Radio Engineering and Electronics, Fryazino Branch, Russian Academy of Sciences
(3) Prokhorov General Physics Institute, Russian Academy of Sciences

Development of new approaches in magnetron sputtering receives continuously growing attention as industrial demand grows for coatings with outstanding performance. In present contribution we focus on poorly explored options in the magnetron deposition involving the use of uncooled targets. In a magnetron with hot (or liquid) target, the deposition rate increases several orders of magnitude as compared to conventional magnetron sputtering, due to complicated evaporation and sputtering interplay. Moreover, it can be operated in the self-sputtering gasless regime when the density of target's atoms (both evaporated and sputtered) is sufficient for the discharge operation, and no Ar gas is used. This leads to minimum level of defects in films coupled with unprecedented deposition rates. The use of high-power impulses elevates the metal ionization degree that is crucial for tailoring the film properties.

Impulse magnetron discharge (pulse duration 3–20 ms) with uncooled Cr target has been investigated with a specially designed Langmuir probe setup in a wide range of parameters (magnetic field, discharge power, Ar pressure). The spatial distributions of electron temperature and plasma density have been systematically measured at a range of discharge power values starting from the cold solid target and ending in the gasless self-sputtering mode. It has been shown that in the gasless high-power pulsed discharge with hot Cr target, plasma density increases by an order of magnitude as compared to dc discharge with the same hot target. It has been shown that the electron temperature drops abruptly to values ~ 1 eV after entering the self-sputtering regime.

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Contribution: **P3.67** / Low-Temperature and Industrial Plasmas

Diagnostics of ion fluxes in low-temperature laboratory and industrial plasmas

Dobrynya V. Kolodko (1, 2) (presenter), Dmitry G. Ageychenkov (1), Andrey V. Kaziev (1), Kseniya A. Leonova (1), Maxim M. Kharkov (1), Alexander V. Tumarkin (1)

(1) National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)
(2) Kotel'nikov Institute of Radio Engineering and Electronics, Fryazino Branch, Russian Academy of Sciences

The effectivity of industrial plasma processing devices strongly depends on the plasma parameters such as electron and ion densities, electron temperature, plasma potential, and ion composition. The latter is of substantial importance since many of the surface modification processes in plasma require certain amounts of species bombarding the substrate. At present, none of the commercially available methods except for in situ measurements of particle fluxes is capable of providing accurate data for composition of ions incident at the substrate. It is therefore vital to study the interplay between these local measurements and the results of conventional diagnostics (e.g. optical emission spectroscopy (OES)) and to develop an approach to indirectly estimate the ion fluxes.

We studied the ion fluxes on metal surfaces in the inductively coupled plasma (ICP) reactor as a test facility. Inert gases (Ar, He) and their mixtures were used, with pressures in the range 0.1–5 Pa. The gas composition was independently monitored by the quadrupole analyzer. The ion fluxes were sampled in situ using a specially designed electrostatic extractor and then analyzed with a custom-built magnetic sector mass-separator. All measurements were accompanied by OES. The correlations of measured data are discussed.

The mass spectroscopy diagnostics unit is suitable for ion content studies in the industrial plasma facilities. It will be further used in studies of dc and impulse magnetron discharges with hot target where the ion composition of plasma greatly affects the electron kinetics.

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Contribution: **P3.68** / Magnetic Confinement Fusion

A novel spectroscopic method for measurement of H isotopes on PFC material by LIBS on linear plasma device PSI-2

X. Jiang, G. Sergienko, B. Schweer, A. Kreter, S. Brezinsek, Ch. Linsmeier

Forschungszentrum Jülich GmbH, Institut für Energie- und Klimaforschung - Plasmaphysik, 52425 Jülich, Germany

Various spectroscopy methods have been studied as analytical tools for plasma facing component (PFC) material diagnostics on plasma devices such as ITER. Laser induced breakdown spectroscopy (LIBS) is a strong candidate due to its capability of reliable, fast and in situ measurement of element content on complex plasma facilities [1] and to carry out measurements in the extreme environment (e.g., strong magnetic field, radioactive, high temperature, low pressure etc...). However, improvement of the measurement sensitivity is still in need. In this particular case, LIBS is used to carry out in situ measurement of hydrogen isotopes in fusion plasma devices. Previous work has shown the successful monitoring of D and H contents on W surface [2]. Further development is aiming at measuring D, H, T at the same time. There are many aspects of this issue, in the current work, we focus on the spectroscopic method.

The Balmer-alpha lines of H isotopes are very close to each other. Hα (656.289 nm) is roughly 0.2 nm away from Dα (656.104 nm) and Dα is only 0.05 nm away from Tα (656.045 nm). In the fusion reaction, the amount of tritium fuel is much smaller than deuterium and the T content on PFC surface is even smaller than that of D. Therefore, the measurement requires high resolution and low detection limit at the same time. In our last measurement [2] the monochromator at first order was replaced by the Littrow spectrometer at second order. Higher orders provide better resolution and are frequently used in the detection of very close lines. However, the intensity is not guaranteed and the influence from other orders, as well as other orders from other elements cannot be neglected. This may result in the use of band filters which also causes the loss of emission light. In this work, we go back to the monochromator at first order with an open slit and use a thin wire to distinguish the isotope lines. In this way, most of the emission light passes through the slit and the grating area is used more efficiently. The resolution is provided by the thin wire. Instead of thin and weak emission lines, we obtain the sharp and clear images of the wire at each isotope wavelength centre. A self-developed image processing programmed is developed to extract information from the 'reversed' spectrum. This method is then tested on W with D/H emission during in situ measurement on PSI-2. Several issues regarding the settings of this method are raised and discussed in this work. The result shows the viability of an alternative and novel way of spectroscopy and provides a practical improvement of the measurement sensitivity of LIBS for PFC material diagnostics.

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Contribution: **P3.69** / Low-Temperature and Industrial Plasmas

Direct ion content measurements in a non-sputtering magnetron discharge

Andrey V. Kaziev (1) (presenter), Dobrynya V. Kolodko (1, 2) , Dmitry G. Ageychenkov (1), Alexander V. Tumarkin (1), Maxim M. Kharkov (1), Tatiana V. Stepanova (1)

(1) National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)
(2) Kotel'nikov Institute of Radio Engineering and Electronics, Fryazino Branch, Russian Academy of Sciences

Non-sputtering magnetron discharge (NSMD) is a peculiar intermediate regime between high-power pulsed magnetron discharge and an arc. It is characterized by low operating voltage (< 120 V) and relatively high plasma density (n ~ 1E18 1/m3 at p ~ 1 Pa; n ~ 1E21 1/m3 at p ~ 100 Pa) coupled with nearly uniform spatial distribution of electron temperature and density in the discharge gap. The potential distribution in NSMD plasma exhibits an anode sheath with positive potential drop of about 40% of the discharge voltage, which is unusual both for conventional magnetron discharges and for high-power pulsed magnetron regimes. The cathode sheath encompasses 60% of the discharge voltage, so the energy of ions incident at the cathode surface does not generally exceed 50 eV, and the sputtering effect should be negligible. The absence of metal species in NSMD so far has been demonstrated only indirectly by optical emission spectroscopy.

In present contribution we report the first direct measurements of ion fluxes in NSMD with Al cathode in Ar/O2 mixtures. The diagnostic unit comprising the electrostatic lens ion extractor, magnetic sector mass-analyzer, and a vacuum electron multiplier was calibrated and then used to record the time-resolved ion counts of Al+, Ar+, Ar2+ both in NSMD and arc regimes. The results clearly indicate that in NSMD the dominant species are Ar ions while Al ion signal is lower than the sensitivity limit, in contrast to the arc discharge. The absolute values of fluxes are obtained as well. The capabilities of the diagnostics setup and its sensitivity limits are discussed.

The NSMD might find applications in semiconductor or polymer etching processes as well as a promising concept for electric power switches and space thrusters.

The study was supported by the National Research Nuclear University MEPhI Competitiveness Growth Program.

Contribution: **P3.71** / Beam Plasmas and Inertial Fusion

XUV wave front from high harmonic generation dependence on driving laser conditions in the IR

Thomas Wodzinski (1,2), Swen Künzel (1), Jayanath C.P. Koliyadu (1), Barbara Keitel (2), Elke Plönjes-Palm (2), and Marta Fajardo (1)

(1) GoLP/Instituto de Plasmas e Fusao Nuclear, Instituto Superior Tecnico, 1049-001 Lisboa, Portugal
(2) Deutsches Elektronen-Synchrotron DESY, Notkestrasse 85, 22607 Hamburg, Germany

With high harmonic generation (HHG) spatially and temporally coherent XUV to soft x-ray (10 nm to 120 nm) table-top sources can be realized by focussing a driving infrared (IR) laser on a gas target. For applications like coherent diffraction imaging the number of photons should be maximized to increase the signal to noise ratio. Therefore, the focus of the XUV beam has to be optimized. Wave front distortions lead to a degrading of the focus. A correlation between aberrations of the driving IR laser and the HHs beam has been found by Gautier et al. (2008) and Valentin et al. (2008). This means that the wave front of HHs can be optimized by manipulation of the wave front of the driving IR laser. In this work the dependence of the XUV wave front on the IR laser conditions is studied. HHs are generated with argon at pressures of 20 mbar to 30 mbar with IR laser pulses of 35 fs at 1 kHz with energies of 2 mJ to 4 mJ per shot. In a collaboration with DESY the wavefronts and intensities of both the HHs and IR laser are measured with wave front sensors built at Laser Laboratorium Göttingen (LLG). The wave front of the IR laser is manipulated with a deformable mirror. We present the dependence of the HH aberrations and signal on the IR wavefront aberrations together with comparisons of the back-propagated intensity profiles along the gas cell.

Contribution: **P3.72** / Beam Plasmas and Inertial Fusion

XUV interferometry in femtosecond laser generated relativistic solid density plasmas

Subhendu Kahaly

ELI-ALPS, ELI-HU Non-Profit Ltd., Dugonics tér 13, Szeged 6720, Hungary

State of the art high-power high-contrast femtosecond lasers have allowed us to achieve light induced coherent control of relativistic solid density matter, thus opening novel vistas for basic sciences, as well as for scientific and societal applications. The usual trend in this research field has been to attain the highest possible laser intensities on target, by focusing Fourier-Transform Limited ultrashort laser pulses close to their diffraction limit. Such focussed ultrashort intense light can transform any solid surface into an instantly ionised plasma reflector. This type of exotic plasma optics can operate at ultra-high intensities making them extremely attractive for fundamental studies in relativistic optics(1) as well as applications in attosecond pulse generation(2,3) and laser particle acceleration schemes(4).
In this presentation I would review how they can act as tuneable reflective(2) or diffractive(3) elements which can be controlled for surface sharpness(5), shape(1,6), structure(7) and how high harmonic XUV interferometry,(8,9,10) can be utilised as a diagnostic tool to investigate the ensuing plasma dynamics. These type of metrology schemes allow one to access relativistic plasma dynamics on a sub-cycle scale and pave the way for more advanced implementations for further scientific applications at facilities like ELI-ALPS(11).

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Contribution: **P3.73** / Magnetic Confinement Fusion

Overview of the Real-Time Fast-Data Acquisition and Processing System for the ITER Radial Neutron Camera

R. C.Pereira 1, N. Cruz 1, B.Santos 1, M. Riva 2, C. Centioli 2, D.Marocco 2, F. Pompili 2, S. Podda 2, P.F Carvalho 1, F. Pollastrone 2, J.M. Cardoso 3, A. Fernandes 1*, J. Sousa 1, B.Gonçalves 1, B. Esposito 2

1 Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal
2 ENEA C.R. Frascati, Dipartimento FSN, Via E. Fermi, 45-Frascati, 00044 Rome, Italy
3 LIBPhys-UC, Dept. de Física, Universidade de Coimbra, 3004-516 Coimbra, Portugal
* contribution up to June 2018, since then the Co-author left the institution

This contribution summarizes the design, prototyping and testing activities of the ITER Radial Neutron Camera (RNC) real-time fast-Data AcQuisition and Processing (DAQP) system. The ITER program assigns to the RNC the primary role of measuring the neutron- and α-source profile, i.e. the local profile of the plasma neutron emission (neutron emissivity, s^{-1} m^{-}&#x00B3), for advanced plasma control purposes (real-time plasma burn control). Accordingly, the DAQP is designed to provide the neutron emissivity every 10 ms (together with streaming of the detected events waveforms to the ITER databases) as a result of a spatial inversion procedure from the 26 RNC line-of-sight neutron flux measurements. A maximum of 2 Mevents/s are expected per detector (candidates are ^{238}U fission chambers, CVD diamonds and organic scintillators) and up to 0.5 GB/s sustained data per channel will be produced.

The DAQP covers the whole electronic chain including detectors signal conditioning, efficient data buffering, detected event waveform streaming and processing based on FPGA devices, synchronization, standardization and scalability. The DAQP system provides real- time pulse height spectra capability with counting of DD and DT neutrons. Pulse shape discrimination to distinguish between neutron and gamma-rays in scintillators is also featured. Three distinct direct memory access channels for PCI Express® along with a custom device driver featuring polling mechanism are implemented. This system architecture allows performance improvement reaching sustainable 2 GB/s of data throughput with 4 DAQP channels on one host and a peak rate up to 3.2 GB/s in case of continuous acquisition due to significant pile-up occurrence (keeping data integrity of both event and processed DMAs). We present results of the performance tests with simulated signals and the experimental validation of the real-time processing algorithms using CVD diamonds and organic scintillators detecting 14 MeV neutrons (flux up 4e10 n/cm² s) from the Frascati Neutron Generator.

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Contribution: **P3.74** / Magnetic Confinement Fusion

A Hard X-ray pinhole camera system in the HL-2A tokamak

Y.P. Zhang 1, D. Mazon 2, P.F. Zhang 1, Y. Peysson 2, X.L. Zou 2, J. Zhou 1, H.B. Xu 1, X. Y. Bai 1, J. Zhang 1, T. Hoang 2, L. Delpech 2, A. Ekedahl 2, X.M. Song 1, B. Lu 1, Z.B. Shi 1, Yi Liu 1, Q.W. Yang 1, M. Xu 1, X.R. Duan 1 and the HL-2A team

1 Southwestern Institute of Physics, P.O. Box 432, Chengdu 610041, China
2 CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France

A hard x-ray (HXR) pinhole camera has been developed recently for the HL-2A tokamak to measure the spatial and temporal evolution of the fast electron bremsstrahlung (FEB) emission in the HXR energy range between 20 and 200 keV, enhancing the understanding of the physics on fast electrons [1] and low hybrid waves (LHWs) [2]. The camera has 21 measuring channels, which are arranged on a sector. HXR detection is performed by integrated CdTe semiconductors. With a perpendicular viewing into the plasma on the equatorial plane, the HXR spectra with eight energy channels of width Δ<i>hν</i>=20 keV are obtained by each chord. The time and space resolution of the camera can reach 4-8 ms and 2-3 cm, respectively.
Measurements of the fast electrons using the camera have been successfully performed in the 2018 HL-2A experiment campaign. A large number of energetic electrons with 40-60 keV are produced during LHCD, and then, these electrons lead to the enhancement of the runaway electron generation. Moreover, the spatial distribution of the energetic electrons during LHCD has a peaked profile, suggesting that the energetic electrons are produced mainly in the plasma core. It also suggests that the energy of the LHW mainly deposited in the plasma core.

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Contribution: **P3.75** / Magnetic Confinement Fusion

Observation of energetic particle transport via passive beam emission spectroscopy diagnostic system on HL-2A tokamak

Rui Ke 1, Guangzhou Hao 1, William W Heidbrink 2, George R McKee 3, Zheng Yan 3, Ting Wu 1, Yifan Wu 1, Ping Lu 1, Jianyong Cao 1, Xianming Song 1, Min Xu 1, and HL-2A team

1 Center for Fusion Science, Southwestern Institute of Physics, Chengdu, China
2 Department of Physics and Astronomy, University of California, Irvine, CA, USA
3 Department of Engineering Physics, University of Wisconsin, Madison, WI, USA

A newly developed beam emission spectroscopy (BES) diagnostic system has been installed on HL-2A tokamak. Initial 32 channels has been deployed and high spatial ($\Delta r \leq 1$ cm, $\Delta z \leq 1$ cm) and temporal ($\Delta r = 0.5$ μs) have been achieved [1]. In last campaign, a new neutral beam line has been installed on HL-2A tokamak, providing an opportunity to utilize BES system to study the energetic particle transport on edge region during core plasma instabilities [2]. Passive FIDA signal has been measured by BES with the original beam line, which is the BES optical system focused on, off and the new beam line on. The BES response suggest that the energetic particle modes in the core region may induce the transport of passing fast ions to the edge region.

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Contribution: **P3.76** / Magnetic Confinement Fusion

Plasma Diagnostics for the Distribution Function momentum determination, an experimental approach

M. Zerbini

ENEA , Fusion and Nuclear Safety Department, C. R. Frascati, Via E. Fermi 45, 00044 Frascati (Roma), Italy

As well explained by major Authors (Kittel1958, Hutchinson1987) the full knowledge of magnetised plasma defined as an assembly of electrons, ions and neutral molecules, confined in a magnetic field, ideally consists in the determination of the distribution functions of the single species present in the system.
This is of course an unattainable task, which can be reduced to the practical, viable option of determining the moments of the distribution functions, i.e. their volume average weighted by different power of the particles velocity:

$M^k \int f(v) v^k \, d^3v$

For k=0 the above zero-order moment represents the plasma particle density, for k=1 the particle velocity, and so on, with the higher order moments describing more and more complex thermodinamic quantities. In this work we will approach the diagnostic measurement from this rigorous side, to then match the mathematical meaning of each measurement with the corresponding experimental technique. This will lead to the particular example of the multifunctional THz-TDS diagnostic, a moniker for Far Infrared and Millimeter Waves, which can be regarded as the experimental realization of a tensorial description of the plasma.

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Contribution: **P3.77** / Magnetic Confinement Fusion

Plasma Cleaning of Steam Ingressed ITER First Mirrors

K. Soni a , L. Moser a, R. Steiner a, D. Mathys b, F. Le Guern c, J. Piqueras c, L. Marot a, and E. Meyer a

a Department of Physics, University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland
b Swiss Nanoscience Institute, University of Basel, Klingelbergstrasse 50/70, 4056 Basel, Switzerland

Metallic First Mirrors (FMs) will play a crucial role in ITER optical diagnostic systems. Being the first element of the optical path which allows light to cross the neutron shielding, FMs will be placed close to the plasma and, therefore, will be subject to erosion and/or deposition which will impact the optical properties of the mirrors greatly. To cope with the deposition, an in situ plasma cleaning method will be implemented on the FMs, capacitively coupled discharges being currently considered as the preferred choice [1]. In addition to erosion and deposition, the FMs could also be vulnerable to a 'Vacuum Vessel Ingress of Coolant Event' or VVICE in ITER. The VVICE could occur from an accidental rupture of the cooling loops inside the vacuum vessel or damage of the cooling pipes due to runaway electrons generated during plasma disruptions.

During a VVICE, the FMs are expected to be exposed to steam at a pressure of about 1.5 bar and a temperature up to 250 ºC. In order to investigate the impact of a VVICE on the optical properties of FMs, several type of mirror samples were subjected to a steam and humidity test simulating such an event [2]. Both rhodium and molybdenum mirrors, candidate material for ITER FMs, observed loss in specular reflectivity. Subsequently, the steam ingressed mirror samples were treated with plasma cleaning to study optical recovery.

Plasma cleaning experiments were performed in a high vacuum system with 13.56 MHz capacitively coupled radio frequency plasma and by employing argon and/or hydrogen as process gas (with 200 eV ion energy). Initial and final ex situ reflectivity measurements, chemical surface analysis using in vaccuo X-ray photoelectron spectroscopy, scanning electron microscopy, focused ion beam and roughness measurements using profilometry, were carried out for each sample to evaluate the cleaning efficiency. Using the plasma cleaning technique, it was possible to remove the steam ingress induced contamination from the mirror surfaces and restore the optical properties of the mirrors to the pristine levels.

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