10. KEEP-IN-TOUCH ACTIVITIES IN INERTIAL FUSION ENERGY[1]

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10.1. INTRODUCTION

The keep-in-touch activities in inertial confinement fusion (ICF) dealt with some of the critical problems facing the new developments in ICF, in particular the issues associates with fast ignition fusion targets. The highlights of research associated with ICF were:

- Project HiPER;
- Fast ignition and ICF physics;
- OPCPA laser technology and development of diagnostics of ultra intense lasers;
- Development of simulation infrastructure for multi-scale fast ignition experiments.

10.2. PROJECT HIPER

GoLP has been involved in the planning almost since its inception of HiPER (High Power Experimental Research Facility) (Figure 10.1), a proposal for a European Large Scale Facility for direct drive inertial confinement fusion, fast ignition and laser-plasma experiments in general. It is planned to have 200 kJ in multiple, nanosecond laser beams, intended to achieve compression in a cone, and 70 kJ in a picosecond ignition beam. The energy in the ignition beam could also be channelled into the compression beams for experiments in "conventional" ignition. It will also provide a unique facility for straightforward laser-plasma experiments at high laser powers and for other experiments that require a combination of long and short pulse beams, such as X-ray lasers and experiments relevant to astrophysics. The estimated cost is of the order of 109 M€, compared to 1010 M€ for NIF and LMJ, making it by far the cheapest facility capable of achieving ignition.

10.3. FAST IGNITION AND ICF PHYSICS

10.3.1. A new diagnostic for very high magnetic fields in expanding plasmas

Strong magnetic fields can be generated by intense laser plasma interaction. Magnetic fields of 700(±100) Mega-Gauss were inferred from polarization shifts of low order VUV harmonics induced by the Cotton-Mouton effect. We have proposed *a new diagnostic method for the magnetic field value inside the plasma*, based on the idea of photon acceleration, or photon frequency shift. The frequency shift is also polarization dependent, which means that, by comparing the observed frequency shifts for the two orthogonal polarization states, for photons propagating along a given direction with respect to the magnetic field, we will be able to measure the magnetic field amplitude, as well as the expanding velocity, if the plasma frequency is known.

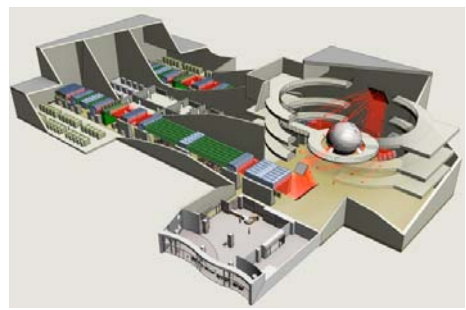


Figure 10.1 - Sketch of the HiPER laser system

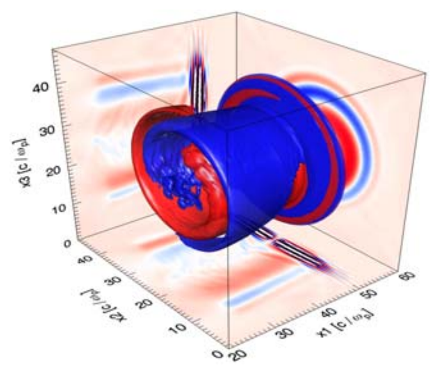


Figure 10.2 - The three-dimensional structure of the longitudinal magnetic field by a circularly polarized laser (blue represents positive and red represents negative), obtained from a 3D PIC simulation. The laser propagates from left tp right along x1, in a moving window (@ c)

10.3.2. A coupled two-step plasma instability in PW laser plasma interaction

One of the most recent, and remarkable, experimental results was the measurement of thermonuclear neutrons from deuterated plastic targets irradiated by the Vulcan

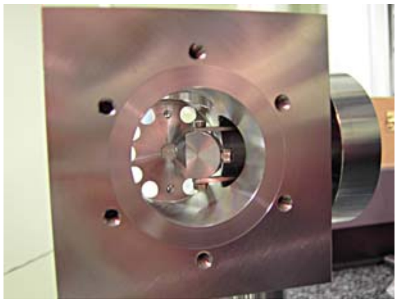
[1] This project has been carried out by "Grupo de Lasers e Plasmas" (GoLP) of "Centro de Física de Plasmas".

PetaWatt laser at the Rutherford Appleton Laboratory. These results indicated temperatures in excess of 100 keV, whereas all other diagnostics indicated target temperatures that did not exceed 1 keV. We explained this in terms *of an ion instability driven by perturbations in the density of the target electrons.* This instability can convert the energy given to the target electrons into ion energy more rapidly than it is converted into electron heating, if the electron collision frequency is small enough. The collision frequency can be reduced sufficiently by a high drift velocity or by the initial heating. The theory reproduced the observed intensity threshold for thermonuclear neutron emission.

10.4. OPCPA LASER TECHNOLOGY AND LASER AMPLIFIER CHAIN

10.4.1. Broadband non-collinear optical parametric chirped pulse amplification

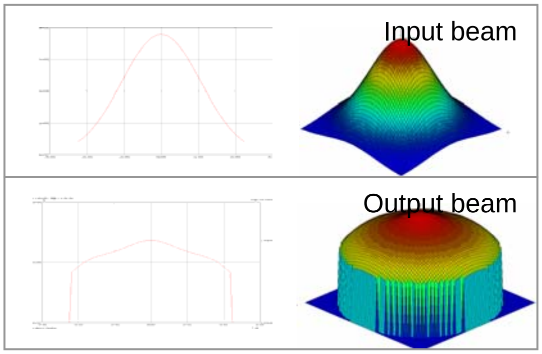
Recent advances in high intensity laser technology, such as the optical parametric chirped pulse amplification technique, allow the amplification of broadband pulses to high energies, by parametric interaction in a non-linear crystal. We have applied the technique developed by GoLP last year to the *comparative study of three non-linear crystals, BBO, LBO and KDP*, in order to evaluate their suitability for ultra-broadband parametric amplification. Although the maximum bandwidth of KDP does not broaden, we show how to avoid its severe narrowing below the degeneracy wavelength. The results show that the OPCPA technique can benefit enormously from this novel geometry, extending further its broadband capability.



10.3 - Experimental set-up, with the nonlinear crystal in the centre of the optical mount

10.4.2. Development of the L2I laser amplifier chain

The MIRO code was used to simulate all the active components of the amplifier section, together with the vacuum spatial filters. A gaussian beam was the injected into the simulated chain and its output amplitude distribution was evaluated as a function of the pumping energy in both amplifiers. This allowed a definition of the optimum input beam diameter for the first amplifier and the magnification ration between the two amplifiers in order to obtain an approximately top-hat output beam. These results will now be confirmed and implemented in the laser chain.



10.4 - Results of the MIRO code, comparing the transverse profile of the input beam with the shape of the beam after the amplification chain

10.5. DEVELOPMENT OF SIMULATION INFRASTRUCTURE FOR MULTISCALE FAST IGNITION EXPERIMENTS

Based on the highly nonlinear and kinetic processes that occur during high-intensity particle and laser beam-plasma interactions, we use *particle-in-cell codes, which are a subset of the particle-mesh techniques, for the modeling of these physical problems.* In these codes the full set of Maxwell's equations are solved on a grid using currents and charge densities calculated by weighting discrete particles onto the grid. Each particle is pushed to a new position and momentum via self-consistently calculated fields. The main code behind our simulation effort is the OSIRIS framework. These codes capture the relevant physics but are also computationally demanding. For problems involving multiple time and length scales, such as fast ignition, standard PIC codes cannot, with the available computing power, perform an accurate modeling. During 2005, we have performed several developments in OSIRIS including further physics (such as ionization, binary collisions), algorithm optimization (higher order deposition schemes), and performance optimization (dynamic load balancing). At the same time, we have started to develop *the set of diagnostics and output information required to couple a PIC code, such as OSIRIS, to other reduced codes*, thus opening the way for a full scale modeling of a fast ignition target.

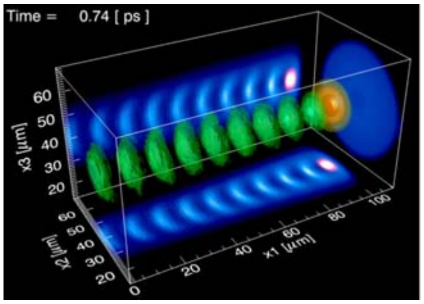


Figure 10.5 - Tunnel ionization of a gas target by an ultra intense laser, demonstrating the formation of the wakefield structure (green) behind the laser pulse (in orange)