11. KEEP-IN-TOUCH ACTIVITIES ON INERTIAL FUSION ENERGY

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11.1. INTRODUCTION

The keep-in-touch activities on inertial fusion energy have been carried out by "Grupo de Lasers e Plasmas" of "Centro de Física dos Plasmas".

Activities concerning:

- The laser system;
- The target area;
- Experiments;
- Technology;
- Theory and simulation;

were performed in 2002.

11.2. STATUS OF THE LASER SYSTEM

11.2.1. Installation of a new ultra-short pulse main oscillator

In January, a new oscillator was installed at the front end of our Terawatt laser system. This is a commercial Kerr-lens mode-locked Ti:sapphire laser (Coherent Mira 900-F) pumped by an all-solid state Nd:YVO_4 laser (Coherent Verdi 10), shown in Figure 11.1. The oscillator produces pulses shorter than 100 fs at 1053 nm, with a bandwidth of 20 nm. These characteristics will allow us to obtain 200 fs pulses upon amplification to the Joule level and compression.

Figure 11.1 – New ultra-short pulse oscillator

11.2.2. Assembly and installation of a new broadband grating pulse stretcher

As described in the 2001 Annual Report, the introduction of the new oscillator implies that the stretching and compression stages must undergo some redesign in order to accommodate the extended bandwidth. After careful consideration of the bandwidth requirements, pulse constrast and expected final pulsewidth, a decision was taken to assemble a pulse stretcher using as image-relaying element and Offner triplet, which is intrinsically an aberration-free design. This scheme uses a large concave and a convex mirror with a common center of curvature (Figure 11.2). The stretcher has been installed during the fourth trimester and the upgraded laser is currently being characterised.

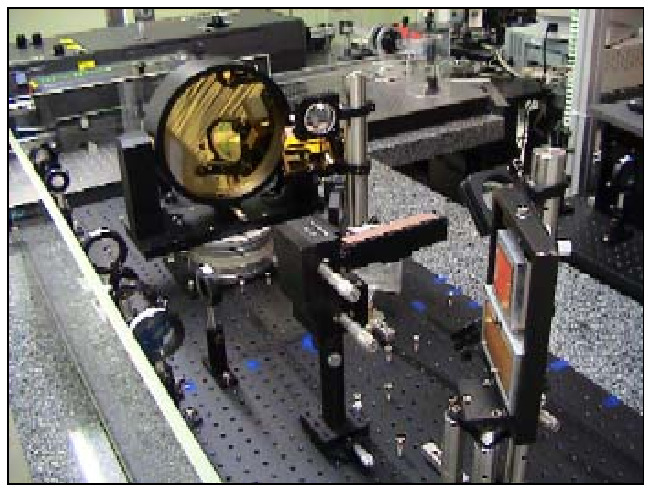

Figure 11.2 – Schematic of the new broadband grating stretcher

11.2.3. Installation of a vacuum spatial filter

During the amplification process, the laser beam must traverse a considerable length of optical components. Diffraction from inhomogeneities in these media, such as surface spots or clipping, results in sudden changes in the beam profile (corresponding to high spatial frequency components). Through amplification, these irregularities grow into instabilities that can become highly damaging to the beam quality and the optical components. The device known as vacuum spatial filter allows these features to be removed, producing a beam with a smooth profile. During this year, we have had built a medium-sized vacuum spatial filter to be used at the output of the 1 Joule amplifier, before the compression gratings. The vacuum chamber has been tested to perform acceptably, and the filtering optics are currently being installed.

11.2.4. Design and modelling of a new vacuum compression stage

An upgrade at the energy level consisting of adding a new, 45 mm rod amplifier is currently being pursued, which will allow the generation of ~5 Joule, 250 fs pulses. At this intensity level, beam propagation in air is enough to induce nonlinear effects in the pulse structure, resulting in self-focusing and filamentation. In order to ensure that the amplified and compressed pulse are optimally delivered to the target, a new compression stage is being designed, where the compression process takes place totally in vacuum. In this fashion, after a pulse emerges from the last amplifier, it enters an image-relaying vacuum spatial filter, and subsequent propagation to the target is all performed in vacuum.

11.2.5. Optical Parametric Chirped Pulse Amplification OPCPA

This new amplification technique for high-power lasers makes use of parametric energy transfer in nonlinear crystals, instead of the typical process of population inversion in laser media. OPCPA could advantageously replace pre-amplifiers, and even high energy amplifiers, in traditional CPA chains. In the frame of a new research project, a collaboration was started with researchers from the Rutherford Appleton Laboratory (UK), where this technique was first examined, in order to determine the best parameters for our laser system.

11.3. STATUS OF THE TARGET AREA

11.3.1. Laser diagnostics

A new time-resolved electron density diagnostic based on shearing interferometry was developed. This diagnostic allowed us to measure the radial plasma density profiles of cylindrically symmetric plasmas in the range 10^{16} – 10^{19} cm^{-3} with high accuracy. The time resolution of this diagnostic is the laser pulse duration (aprox. 800 fs). An automatic data treatment scheme allows us to obtain the plasma density profile in a few seconds or a few minutes, depending on the required spatial resolution.

Figures 11.3 shows a shadowgram and a interferogram, and Figures 11.4 and 11.5 shows the retrieved phase and the obtained plasma density respectively of a plasma produced by a laser-triggered high-voltage discharge in a helium gas background.

In order to carry out the experimental program for the 2003 and the following years x-ray based shadowgraphy is now starting to be developed in our laboratory. This technique will allow the qualitative observation of dense plasmas relevant for laser fusion and laser-particle production.

11.4. EXPERIMENTS

Several experiments were performed in the development and optimization of a new method to produce plasma waveguides for high intensity laser pulses. Waveguides up to 25 mm long and good quality have been produced capable of guiding focused high intensity laser pulses.

We have also participated in an international experiment on plasma acceleration of electrons using ultra-short (75 fs) laser pulses produced by the Ti:sapphire Astra laser system, held at the Rutherford Appleton Laboratory, England.

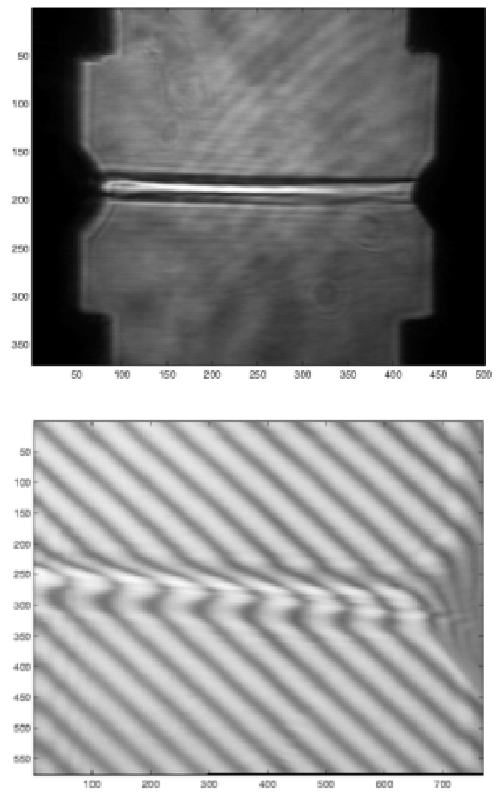

Figure 11.3 – Shadowgram and interferogram of plasma channel

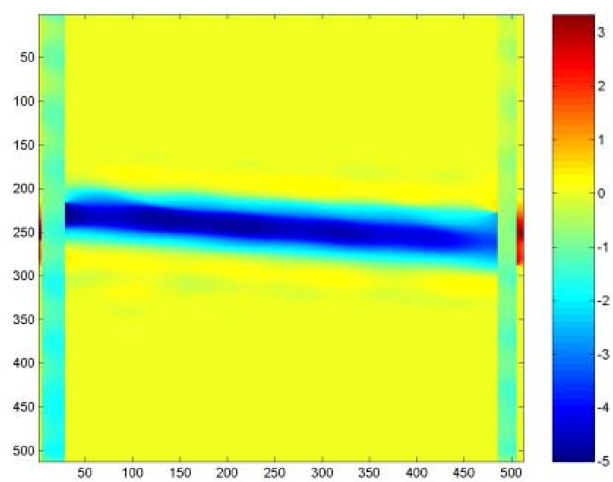

Figure 11.4 – Retrieved phase of plasma channel

In 2003 a new set of experiments will test the laser triggered discharge scheme in a supersonic gas jet. This a fundamental step in order to obtain the high-gradient vacuum-gas interface necessary to inject a high intensity laser pulse in the waveguide. We plan to optimise this scheme and use it to accelerate electrons. This scheme will also be tested with different gases for other applications.

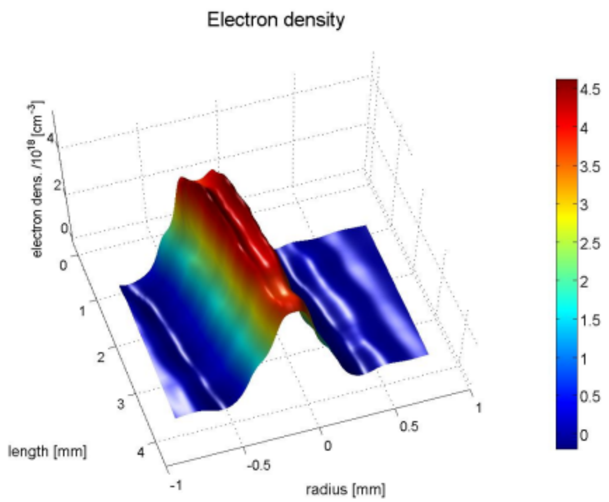

Figure 11.5 – Retrieved plasma density of plasma channel

11.5. TECHNOLOGY

The experimental program for 2003 and the next years require the use of high quality supersonic gas nozzles (Laval nozzles) of different densities and sizes (including non-cylindrical shapes). Cylindrical gas nozzles were designed and are currently being produced and tested. These nozzles are being produced in metals by electrical discharge machining. For the laser triggered discharge scheme, however, the nozzle must be produced in a insulator material. A production technique based on plastic injection molding will be tested soon.

A specially shaped vacuum chamber to fit in the magnet of the charged particle energy spectrometer is now in construction. This vacuum chamber will avoid the scattering of the low energy particles in the air-vacuum interface that are affecting the measurements.

11.6. THEORY AND SIMULATION

During 2002, our efforts were focussed on issues relevant to the fast ignitor scheme for inertial fusion. With a combination of relativistic kinetic theory, relativistic fluid theory, and massively parallel fully explicit particle-in-cell simulations, some of the questions raised by the recent experimental and theoretical developments in fast ignition were addressed. In particular, three areas can be identified:

- *The role of collisionless instabilities for the transport of ultra high current electron beams*. Demonstration was made that electron beams for fast ignition have such a high transverse temperature that the purely transverse electromagnetic instability will be strongly suppressed for fast ignitor conditions. Furthermore, our theoretical and numerical work demonstrates that for these beams the longitudinal mode is also important, and from the coupling of the purely transverse and the purely longitudinal unstable modes, can be filamented, but the filaments show a well defined tilting that can seed whole beam instabilities.
- *Ion acceleration in laser-thin solid interactions*. Identification was made a new acceleration regime whereby, ions are accelerated in a high-Mach number collisionless shock launched from the front of the target. Simulation results provide clear signatures in the proton spectrum that match nicely the experimental results.
- *Spherical targets vs cone shaped targets for fast ignition*. Detailed two-dimensional PIC simulations were performed that show that coupling of the laser energy to the electrons in the target is more efficient with cone-shaed targets as compared with spherical targets. This agrees with recent experimental results at Rutherford Lab and Osaka. The mechanism for the "enhancement" has been identified: our results also show that for cylindrical targets most of the energy in the electrons flows around the target, much in the same way that strong electron transport has been observed in the past in experiments and simulations of CO_2 lasers interacting with overdense targets.

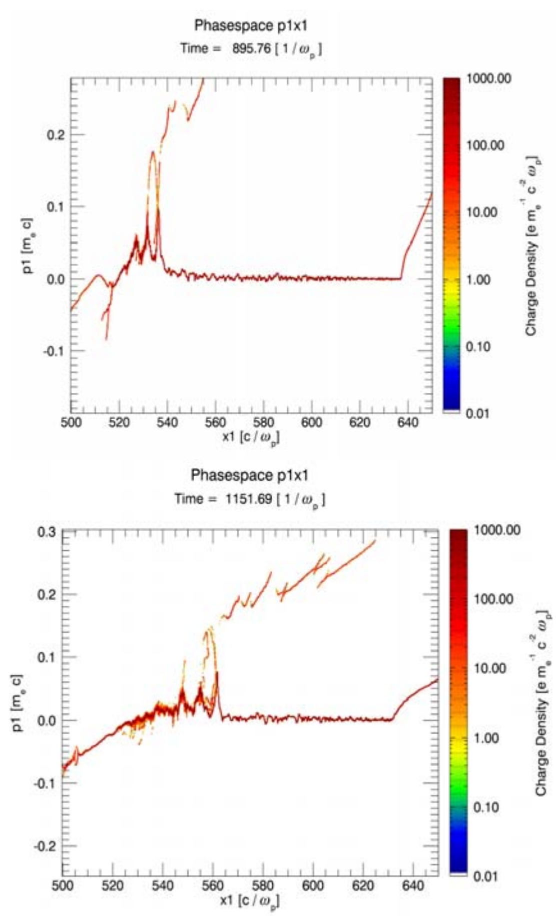

Figure 11.6 - Temporal evolution of the ion phase space p1x1. x1 is the propagation direction of the laser, which hits the target from the left (@ ~ 535 c/ω_{pe0}). Laser parameters: a0 = 16, pulse duration 100 fs. target density n_{target}/n_{cr} = 10.

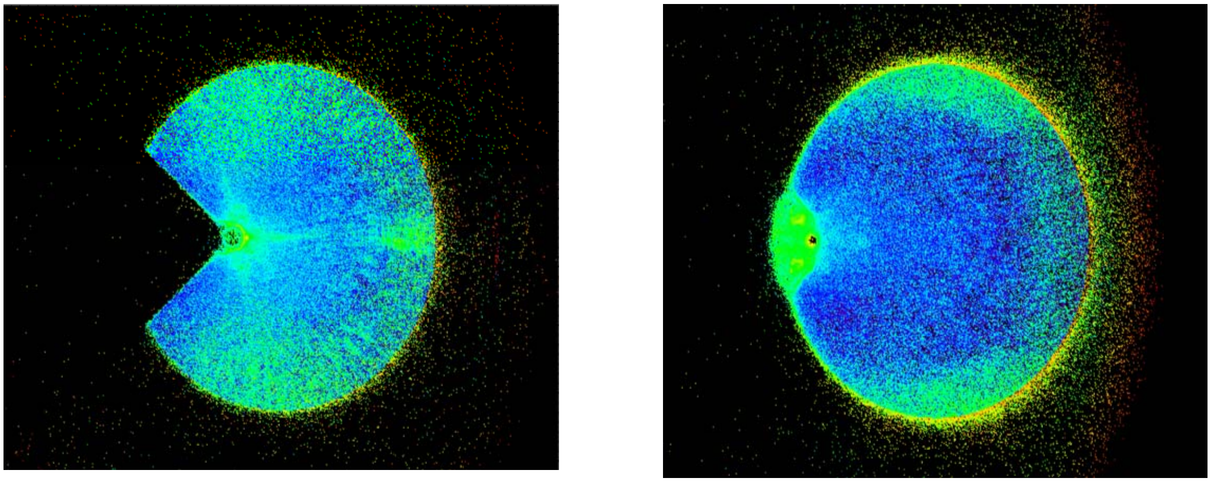

Figure 11.7 - Comparison of the energy deposition in the electrons for a cone-shaped target vs a cylindrical target, showing that in the cylindrical target the most energetic particles go around the central region (log color code Energy (MeV) – from 0.001-blue to 1-red)