The HiPER Experimental Road Map

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On behalf of the HiPER Working Package 10 (Fusion Experimental Programme)

Abstract. WP10 is one of the working packages of the HiPER project and it has the goal of addressing, in a systematic and programmatic way, some of the key experimental uncertainties on the way towards fast ignition (and shock ignition) in a perspective of risk reduction, so to contribute to the definition of the basic characteristics of the HiPER project. The paper describes the key points contained in the short term HiPER experimental road map, as well as the results of two first experiments performed in "HiPER dedicated time slots" in European Laser Facilities

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INTRODUCTION

WP10 is one of the working packages of the HiPER project (the European High Power laser Energy Research facility project [1, 2]) and it has the goal of addressing, in a systematic and programmatic way, some of the key experimental uncertainties on the way towards fast ignition (and shock ignition) in a perspective of risk reduction, so to contribute to the definition of the basic characteristics of the HiPER project. In the near term, this takes place mainly through the definition of a "short-term experimental roadmap", which requires specifying experimental objectives and deciding the access schedule to existing facilities in Europe.

Apart from scientific objectives, WP10 also has some more "political" goals like creating a larger and stronger community working on ICF in Europe, through participation in experiments; strengthening collaboration plans with US and Japan for common experiments and European «HiPER» access to large overseas facilities; and finally defining a collaboration plan with other «emerging» countries, e.g. Korea, India, China, …

One of the tools of WP10 consists in dedicated experimental time slots in European large laser facilities (RAL, LULI, PALS). In the paper, we present the results of two recent experiments respectively done at RAL and LULI. Both experiments were addressed at studying the propagation of fast electrons in hot and compressed matter, in an effort of overcoming the limitation of present day's experiments, which mainly studied fast electron propagation in solid density targets. In this way we try to approach a regime, which is closer to a real fast ignition scenario.

IDENIFICATION OF KEY ISSUES

For each of such sub-programmes, we have identified a number of key issues which deserve to be addressed as a first priority in order to help in the design / definition of the HiPER experimental facility. These includes:

Study of the electron source:

- 2ω vs. ω, study of influence on wavelength on source parameters
- use of well characterized preplasmas and their influence on fast electron generation
- extrapolations of present results and current experiments to higher intensities, higher energies and longer pulses (in the 10 ps regime)

Cone issues:

- coupling of the laser beam of the target with and without the cone

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- cone survival during the implosion (in particular survival of the cone tip)
- sliding of the shell on the cone, generation of instabilities (Kelvin Helmholtz), preheat and ablation of the outer cone surface , entrainment of cone material into the compressed fuel - fuel pollution and quenching of ignition …

Channelling:

- study of channelling / hole boring in preformed ns plasmas using laser beams in the regime ≈100 ps, ≈ 10^{18} W/cm^2. Study of laser propagation in the channel.
- Electron source characteristics from main pulse injection in the channel
- Hydrodynamic designs to minimise electron transport distance and mass per unit area in the path to the ignition hot spot

Issues related to laser technology:

- Laser technology development for superposition of multiple beams
- Multi-beam interaction with mutually coherent vs. incoherent laser beams.

Shock ignition:

- shock formation and shock dynamics at ≈ 10^{16} W/cm^2
- thermal electron transport (in particular magnetized transport) in this intensity regime
- laser-plasma coupling and effect of parametric instabilities at ≈ 10^{16} W/cm^2

Protons:

- study of the proton source and optimisation of conversion efficiency
- study of energy spectrum and possibility of creating more-monochromatic spectra
- focusing of the proton beam in cone geometries

Following such a list of key points, a substantial part of the work has been the discussion of the best use of "HiPER-dedicated time slots" on the European Laser Facilities (CLF, LULI).

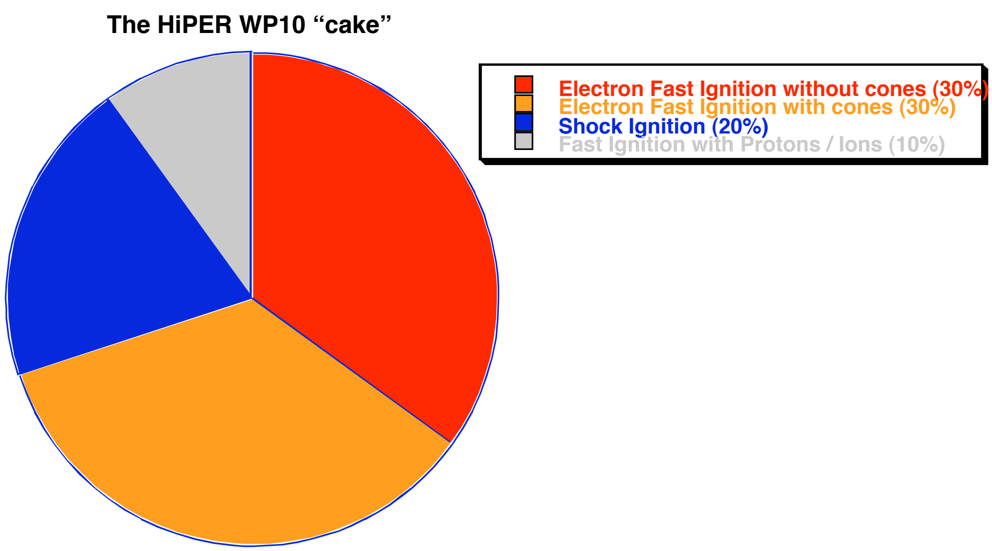

FIGURE 1. Repartition of efforts in the various approaches to ignition in available laser facilities

FAST ELECTRON PROPAGATION IN SHOCKED TARGETS

Several experiments have been allocated to HiPER slots and one of the first to be performed concerned "Fast electron propagation in shock compressed planar targets" done at LULI, in March 2008, by a team including the University of Milano Bicocca (D.Batani, PI of the experiment and co-workers), the University of Strathclyde

(P.McKenna, et al.), CELIA Bordeaux (J.Santos et al.) and LULI itself (M.Koenig, S.Baton, et al.). The in-principle scheme of the experimental set-up and of used targets is shown in Fig.2. Fast electrons produced on target "rear side" b a high-intensity ps-beam were propagating in a multilayered target compressed by a planar shock created by a high-energy laser beam on the target "front". A Cu layer acted as a tracer emitting K-α Cu photons, which were used as a diagnostics of fast electron propagation.

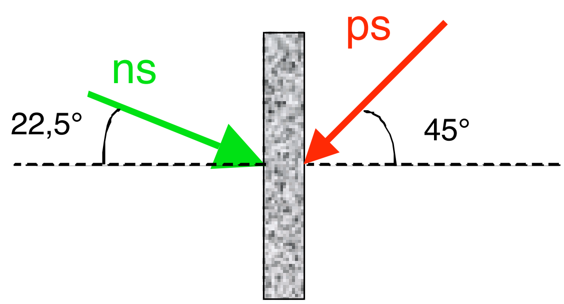

FIGURE 2. in principle scheme of the experiment at LULI2000 on fast electron propagation in shocked targets. The target included a Kα layer to allow the diagnostics of fast electron transport.

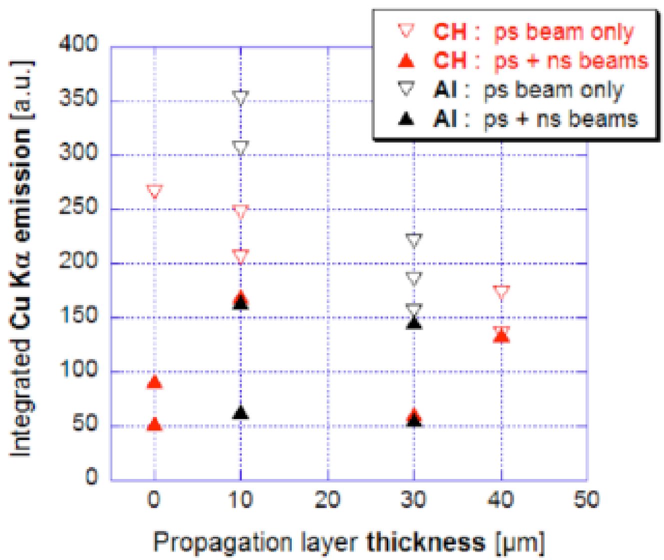

FIGURE 3. Kα yield results from the shocked targets experiment

A brief summary of experimental results is shown in Fig. 3 (see also [3]). One key point to take into account in analyzing the results is that the total areal mass of the target (rd) is not affected by planar shock compression. Therefore the penetration of fast electrons in matter only changes because of the changes in stopping power and, above all, of the changes in electrical conductivity of the heated and compressed targets, affecting the generation of resistive electric fields. From this experiment we got 3 expected results and one unexpected result:

- for uncompressed target Kα yield is larger for Al than for CH (consistently with the presence of *electric inhibition* of fast electron propagation in the insulator material);
- Kα yield is larger for uncompressed Al than for compressed Al, again due to the decrease in electrical conductivity for heated Al;
- Kα yield in compressed Al and CH is comparable (in both case the state of the target is a warm dense material with little differences);
- Kα yield is larger for uncompressed CH than for compressed CH

This last results is in contradiction with experimental data obtained in [4], and more in general does not at first seem compatible with the idea of electric inhibition. Indeed eh electrical conductivity of shocked plastics should be much larger than that in a target which is (at least initially) cold. At the moment the analysis of the experimental results seems to point to different refluxing conditions in order to explain the increase in Kα yield is larger for uncompressed CH targets. Indeed the presence of the ns laser beam creates a longer plasma gradient on the target "rear" side, thereby affecting, and reducing, fast electron refluxing.

FAST ELECTRON PROPAGATION IN CYLINDRICALLY COMPRESSED TARGETS

The experiment on fast-electron transport in cylindrically compressed matter involved LULI, Milano-Bicocca, CELIA, RAL, Bologna, Pisa, Roma, York, UCSD, LLNL and Madrid. It is a first example of a very large European collaboration, also involving the US. A good amount of hydrodynamics design was performed in preparation of the experiment.

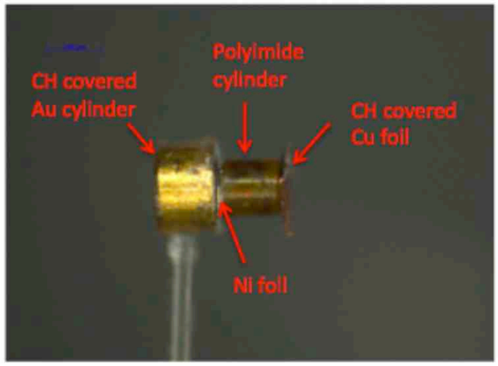

FIGURE 4. Example of a target used in the experiment (thanks to Ch.Spindloe, M.Tolley and all the RAL target prep group)

Fig.4 shows an example of a target used in the experiment (produced by the RAL target prep group). Four ns laser beams were perpendicularly focused on the plastic cylinder to drive its implosion. The ps beam was focused along the axis of the cylinder onto the Ni foil to generate a fast electron beam propagating into the compressed cylinder (filled with foam) and finally reaching a plastic-covered Cu foil on target rear. A Kα imager looking at the Kα emission from this foil was used to evaluate fast electron propagation in the compressed target.

Fig.5 shows an example of proton radiography image. This was obtained by focusing another ps laser beam onto a foil target to produce a proton beam propagating through the cylinder. The mages formed on RCF films allowed for an evaluation of target compression and allowed to determine the stagnation time.

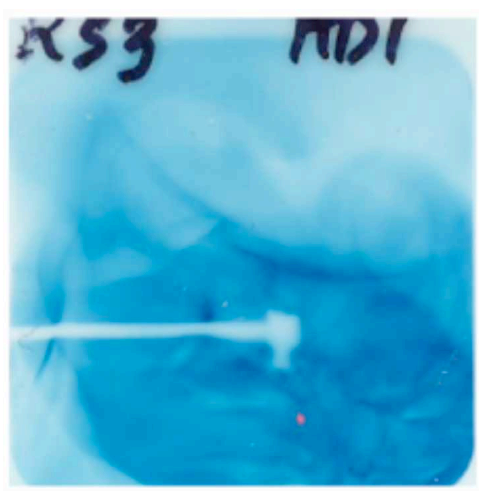

FIGURE 5. Example of proton radiography image from the RAL cylindrical compression experiment

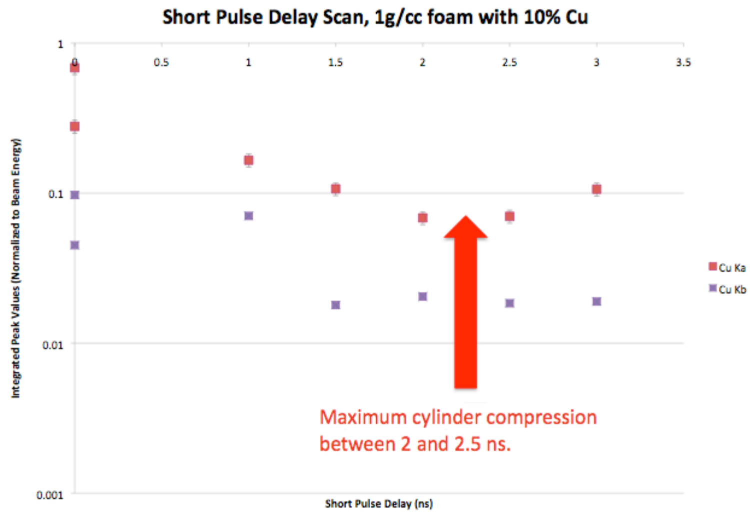

FIGURE 6. Example of proton radiography image from the RAL cylindrical compression experiment

Fig. 6 shows a graph of the experimental Kα yield vs. the delay between the ns laser beams (driving the compression of the cylindrical targets) and the ps laser beam, producing the fast electron beam. This clearly sows a minimum in fast electron propagation to the rear Cu foil.

Investigation is still under way in order to carefully model the results of the experiment and, in particular, model energy deposition in the compressed core as the fast electrons propagate in the cylindrical target.

CONCLUSIONS

The HiPER programme is stimulating advanced research on fast ignition (and other approaches like shock ignition) and several experiments have, are taking or will take place in European large scale laser facilities. Such experiments are addressed at physically studying some definite points, which are of key interest to assess the feasibility of such ignition schemes. This is also stimulation collaboration and the growth of a scientific community working on IFE in Europe.

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