MULTI-MEV PARTICLE DETECTION
IN RELATIVISTIC LASER-PLASMA INTERACTIONS

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The advent of the lasers in chirped pulse amplification (CPA) mode allowed for the first time the interaction of ultra-short radiation pulses with plasmas at relativistic intensities. The very large electric fields of such pulses can accelerate, directly or via induced perturbations of the electron density, charged particles [Ledingham *et al.* 2000; Cowan *et al.* 2000; Krushelnick *et al*. 1999; Borghesi *et al.* 1999; Gremillet *et al*. 1999, Pukhov *et al.* 1999]. Theoretical studies also predict that energy conversion into energetic electrons should be favoured when the laser pulse propagates in a cavitated structure such as a plasma channel. These issues may have important consequences on laser-driven plasma-based accelerators as well as on inertial fusion energy (IFE), particularly in the Fast Ignitor (FI) scheme.

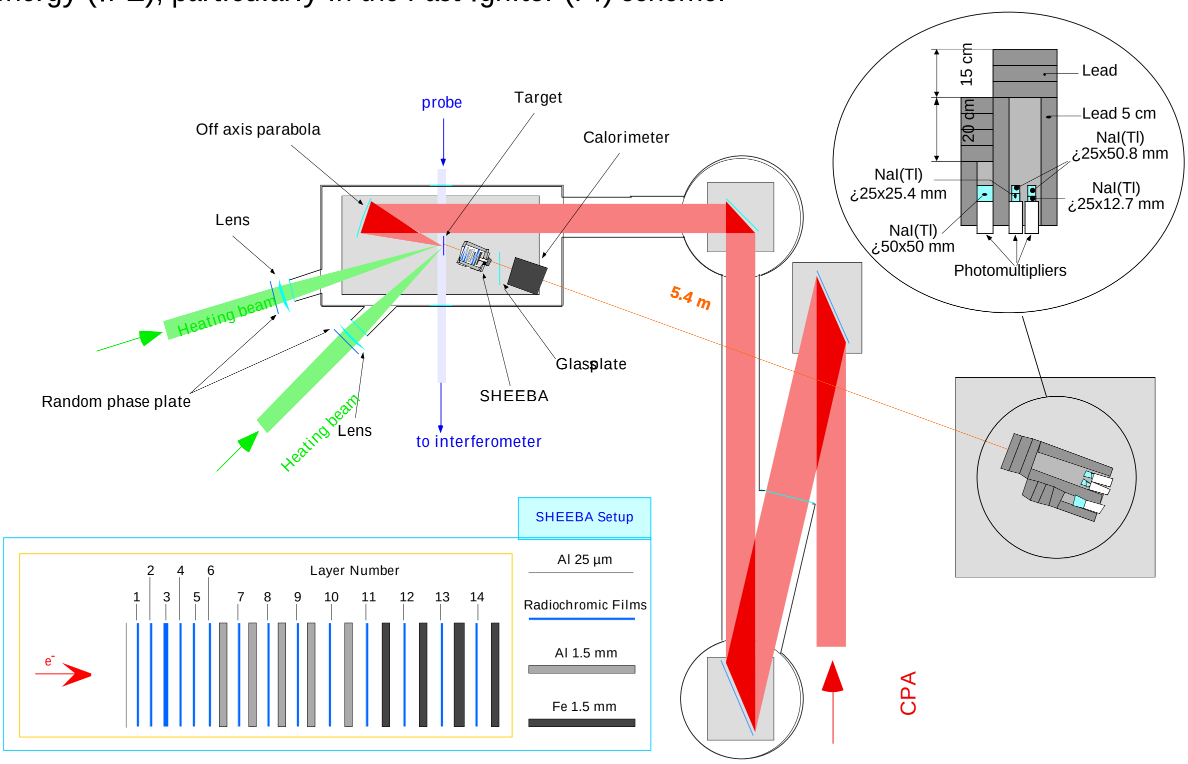

Figure 1 Experimental set up used for the two experiments: in the first one we have used NaI(Tl)-based detectors, while in the second one we have used the radiochromic-based detector SHEEBA.

Here we report on a recent investigation carried out at the Vulcan laser Facility, Rutherford Appleton Laboratory (UK) to study the effect of a precursor channelling pulse on the electron acceleration obtained by the main Vulcan CPA (Chirped Pulse Amplification) laser pulse propagating in an underdense plasma.

The experimental set up is shown in fig. 1. The plasma was, by irradiating a 0.3 m thick plastic foil (FORMAVAR) with two heating laser beams (λ = 527 nm, τ = 1 ns, 100J per beam) at I=5 10^{14} W cm^{-2}. On this plasma was focused (off-axis parabola f/3.5) a CPA laser beam (λ =1053 nm, Δt=1 ps, up to 100 J for the first experiment and up to 120 J for the second one) 1.3 ns after the heating beams. The peak density at that time was estimated to be $n_C/10$. In some cases another CPA pulse, collinear and anticipated with respect to the main pulse, was used to create a channel into the plasma. This channel was characterized by Nomansky interferometer using a UV laser pulse (λ =267 nm, Δt=1 ps).

In the first experiment, the fast electrons generated during the interaction were studied via bremsstrahlung emission technique using a set of four NaI(Tl) scintillators coupled to photomultipliers, placed at 5.4 m from the target, after 15 cm of lead, used as a filter. These detectors were shielded from the background using 5 cm of lead. Transmitted laser radiation was detected by a calorimeter.

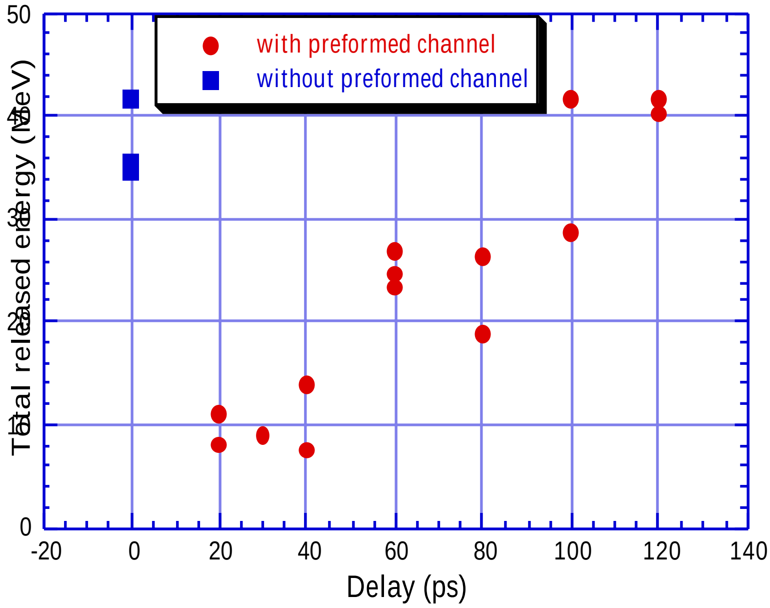

Figure 2 Gamma rays energy detected at different delays

A series of shots was performed varying the delay between the channelling pulse (25J, 1ps) and main pulse (50J, 1 ps), in a range of 20-120 ps. The signals acquired from the scintillator-based detectors is shown in fig. 2, where there is a clear evidence that the signal increases with the delay. In the plot there are also reported the data related to the single CPA pulse (75J) directly interacting with the plasma (no preformed channel).

The interferometry shows the presence of a well-formed channel with some perturbations in the density profile that decrease when the delay increases. There is also evidence for the

formation of filaments and chaotic structure in the case of single pulse and sometime with preformed channel [Gizzi et al. 2001].
In order to investigate spectral and angular distribution of the electrons generated by the CPA pulse-plasma interaction, we have developed a new multi-layer radiochromic-film based dectector (SHEEBA), used in a second experiment. In this case the same set up was used, putting SHEEBA at 2 cm from the target in the direction of the CPA beam.
We have investigated the case with a preformed channel (channelling pulse of 25 J 90 ps before the main pulse of 75 J) and without channel (only main pulse of 120 J). The analysis of SHEEBA data was effectuated by a Montecarlo simulation code based on the library GEANT 4.2.0 [Geant4] and a deconvolution code.

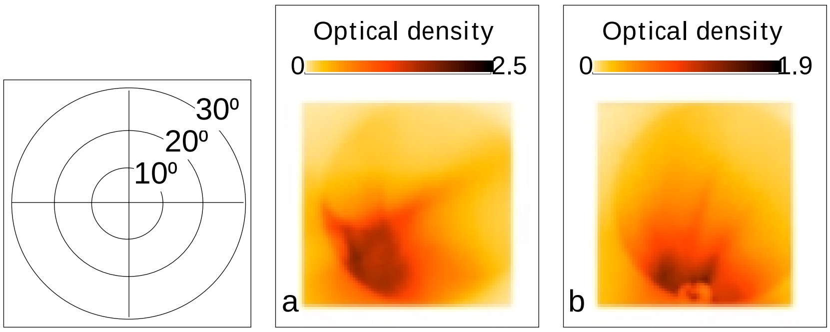

Figure 3. The sixth radiochromic layer of SHEEBA for: a) without preformed channel; b) with the channel preformed 90 ps before interaction.

Making a comparison with the images of the sixth radiochromic layer of SHEEBA for the two cases shown in fig. 3, we can observe that there are no substantial differences on the angular distribution for high energy electrons (>0.5 MeV).
Finally, the overall spectrum of the electrons, as reconstructed from SHEEBA data, is shown in fig. 4, were two electron populations at two different temperatures are apparent. In absence of preformed channel the temperatures are 133±23 keV and 5.23±0.84 MeV, respectively. In the case of preformed channel, the high energy electron population has a temperature of 4.71±0.71 MeV.
In conclusion, the scintillator-based detectors show that the bremsstrahlung signal is maximum in the single pulse case (no channel pre-forming pulse). In presence of a pre-formed channel the signal increases with the delay between the two pulses, up to the level observed with the single pulse. This is in agreement with the data from SHEEBA, showing no substantial difference between preformed channel at 90 ps of delay and single pulse. The interferometric data show that the channel has a diameter larger than twice the focal spot (15 μm) at that time, with some filaments at the exit of plasma. Filamentation is enhanced in the single pulse case. Probably the high energy electrons are generate in these filaments, which could explain also the structured angular distribution of the electrons.

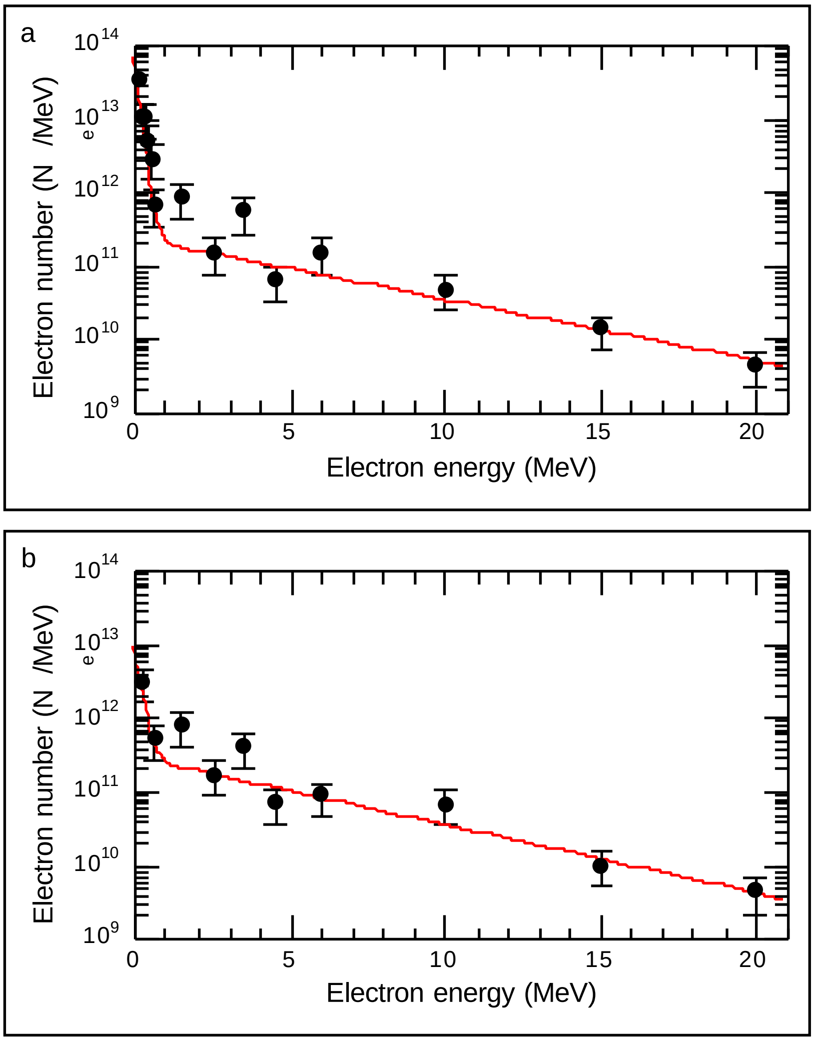

Figure 4 Reconstructed spectral distribution of the electrons for: a) without preformed channel; b) preformed channel

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REFERENCES

GIZZI L.A. et al. 2001, accepted for publication, Laser Particle Beam **19**

COWAN T.E. *et a*l. 2000 Phys. Rev. Lett. **84**, 903

LEDINGHAM K.W.D. *et al.* 2000 Phys. Rev. Lett. **84**, 899

KRUSHELNICK K. *et a*l. 1999 Phys. Rev. Lett. **83**, 737

BORGHESI M. *et al.* 1999 Phys. Rev. Lett. **83**, 4309

PUKHOV A. *et al.* 1999 Phys. Plasma **6**, 2847

GREMILLET L. *et al.* 1999 Phys. Rev. Lett. **83**, 5015

GEANT4: LCB Status Report/**RD44**, CERN/LHCC-98-44, (1998)