# Fast protons emission from thin foils irradiated by ultra-sharp and intense laser pulses

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The interest the scientific community show to laser induced proton generation can be easily explained by the number of applications such a beam could be potentially employed in. We can cite as instance the probing of electric fields in plasmas [1], fast ignition applications [2], isotopes production for medical applications [3], and proton therapy [4]. In spite of the large spreading of experimental as well as theoretical and/or numerical studies about fast ions generation in high peak intensity laser matter interaction, some aspects of the main involved processes seem still to ask for a better understanding. Concerning high energy proton generation, this is particularly true for the influence of laser beam incidence angle, polarisation, length and contrast on maximum proton energy scaling laws.

We present here some of the preliminary results of an experiment made at the SLIC Facility at Saclay, using the UHI 10 TW laser whose main features are given later. This laser chain has been recently provided of a Double Plasma Mirror (DPM). The plasma mirror [5] is one of the suggested strategies to improve the beam contrast. The contrast is defined as the ratio between the laser peak and pedestal intensities. A contrast around 10^6 is quite usual for most table top terawatt laser chains. As on-target intensity currently exceeds 10^{18} W/cm^2, this means that the fs part of the pulse actually interacts with a pre-plasma produced by the pedestal in front of the target instead that with the solid target itself. The plasma mirror main concept is the following. The laser beam is focused on an AR coated dielectric plate before it hits the target. The dielectric plate will last transparent until the laser intensity grows enough to create a plasma. The following part of the beam is then reflected by the plasma towards the target. Correctly choosing the incident flux on the dielectric plate, an important fraction of the pedestal can be removed in this way. This system was already successfully tested on the UHI laser [6], improving the contrast of a factor 10^2 with an energy loss around 30%. In the present DPM, the laser beam undergoes twice such an effect. Using a third-order cross-correlator (SEQUOIA), we were able to observe a contrast improvement better than 10^4, with an unchanged focal spot quality (Fig. 1)[7]. As expected the energy loss rises to 50%.
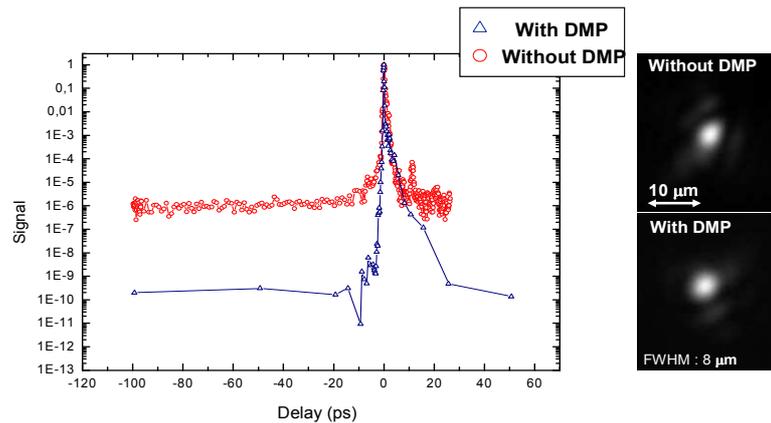
Fig. 1 Cross-correlation measure of beam temporal contrast and focal spot with and without DPM.
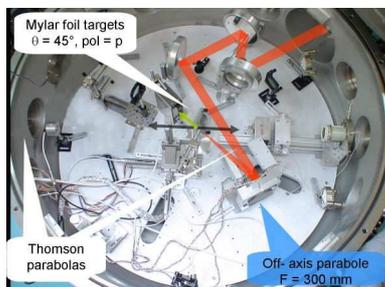
Fig. 2 Top view of the experimental chamber. The laser beam comes from the top right corner. The FWD Thomson parabola is located outside the chamber.
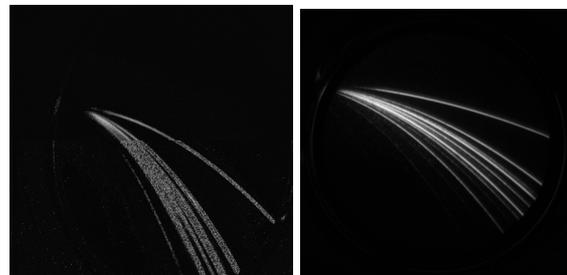
Fig. 3 Typical simultaneous BWD (left) and FWD (right) recording of protons/ions emission.

The experiment was performed in the "Salle Chaude" laboratory at Saclay, a radio-protected room especially devoted to high energy particles generation experiments, using the UHI10 laser which was designed to generate 10 TW ultrashort pulses (65 fs) with a 10 Hz repetition rate. It works according to the standard chirped-pulse-amplification (CPA) technique. Titanium–Sapphire rods are used as lasing medium and the operating wavelength of the system is 790 nm. The p-polarized laser beam was focused with an off-axis f = 300 mm parabola, under a 45° incidence angle, on mylar foils with thickness varying between 0.08 and 105 μm (Fig. 2). Measured FWHM focal spot size was 8 μm. The on-target intensity, using the DPM, was around $5 \cdot 10^{18}$ W/cm^2.

Proton emission normally to the target foils planes in the laser propagating direction (FWD) as well as counter-propagating direction (BWD) was simultaneously recorded shot-to-shot using two similar Thomson parabolas. The phosphor screens of the MCPs we used as detector for both of them were imaged on 16 bits CCD. Experimental traces were compared in real-

time to theoretical ones, previously obtained simulating ions flights trajectories inside the parabolas using the SIMION code (Fig. 3).

Detailed data analysis and comparison to numerical results are still in progress. Nevertheless, two main contrast-due effects clearly appear. As already said, laser intensity in high contrast shots is only half of the low contrast shots due to DPM intrinsic working conditions. Despite that, protons produced by high contrast shots show a maximum energy which is around 3 times larger than low contrast ones in FWD direction and this ratio is still larger in BWD direction (Fig. 4). These data clearly put in evidence as a high contrast pulse benefits to proton acceleration whatever they originate from the front side or the rear side of the foil.

The second point that appears from data we collected is the improving of shot-to-shot repeatability using the DPM. In Fig. 5 we report as an example the FWD and BWD maximum proton energies for a 0.8 thickness foil, on a sample of about thirty shots. The average standard deviation realised on similar shot series is $\leq 10\%$ of the mean value for both direction and we did not observe any blank shot. Without using the DMP, more than a shot on two was a blank one for both emission directions, which may mean a maximum proton energy lower than the detection threshold or no proton emission at all. Actually, the error bars concerning no-DPM shots reported on fig. 4 represent the standard deviation of "successful" shots only. The spectral characteristics of the emitted proton beams show the same good reproducibility.

Numerical simulations using 1D as well as 2D PIC codes are presently in progress to reproduce experimental data. Moreover, an experimental campaign to complete and extend presented results is planned before the end of the year. The main aims will be to characterise the emitted proton fluxes on absolute particles number and spatial distribution for different kind of target as well as to study the influence of the laser incidence angle, polarisation and duration.
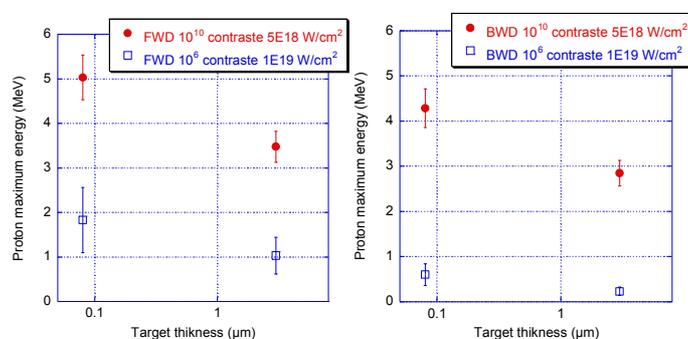
Fig. 4 Maximum proton energy in the high contrast (10^{10}) and in the low-contrast (10^6) case for forward emission (left) and backward emission (right). Here and thereafter, each point represents the average value of at least three measures.
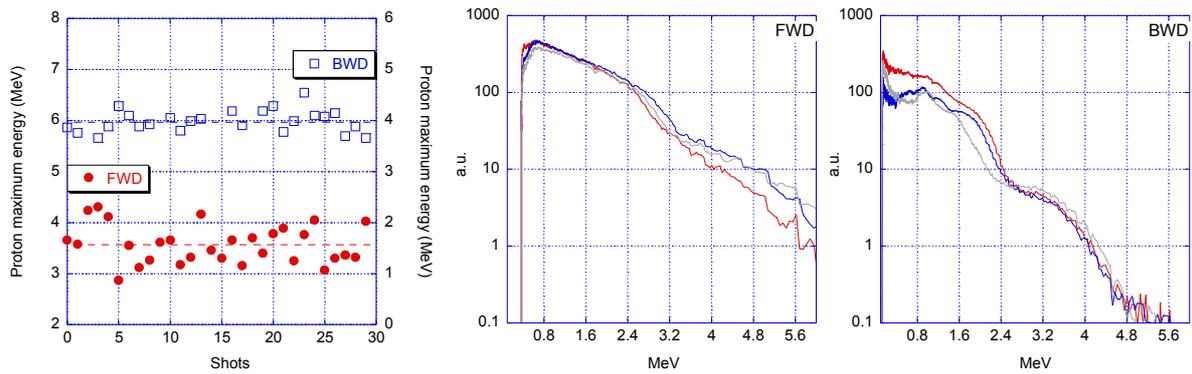
Fig. 5 Statistical fluctuations of maximum proton energies for a given target thickness. Mean values are represented by the dashed lines (left). The center (right) graph represents the spectra of proton emission in the FWD (BWD) direction corresponding to three shots realised under unvaried conditions.

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