Tailoring the ion front of short pulse laser accelerated ion beams

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In experiments irradiating thin foil targets with ultra high intensity lasers the emission of an intense and very energetic proton beam was observed [1,2]. These beams contained 1012 protons with energies up to 25 MeV, had an opening angle of around 30° and originated from the non-irradiated rear surface of the target.

The acceleration mechanism for these protons is the Target Normal Sheet Acceleration (TNSA) [3]. The interaction of the laser with the target produces an electron beam with a temperature of several MeV, which is moving through the target. As some of the electrons escape, the target is charging up and the other electrons are confined in a cloud on the rear side of the target. This produces strong electrostatic fields (1012 V/m), which ionizes the atoms on the rear side and accelerates the ions. As the protons, originating from impurities, have the best q/m ratio, they are moving in front of the ions and shield the field. So one always obtains protons independent from the target material.

An important feature of laser ion acceleration is the capability of a transverse intensity modulation with engraved structures on the rear surface [4]. These intensity modulation are recorded with Radio Chromic Film (RCF)[5] or CR-39[6]. With this technique it is possible to determine beam parameters like the source size and the emittance. Furthermore it is possible to tailor the shape of the ion front at the end of the acceleration, when the free expansion starts.

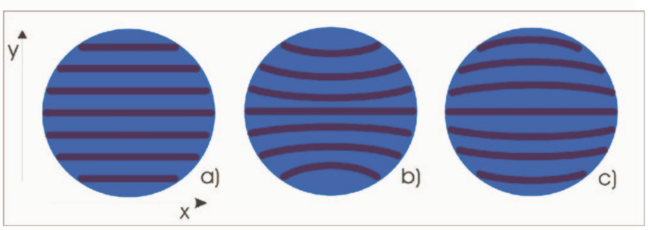

Fig. 1: Schematically drawing of beam pattern deformations observed in laser ion acceleration

In most of the experiments the beam pattern observed in the detector have straight lines or slight deformations like shown schematically in fig. 1. Assuming axial symmetry, it is possible to show, that this straight lines can be directly traced back to a parabolic ion front [7]. Moreover, a parabolic ion front results in equidistant lines, which is in concordant with the experiment.

To get a quantitative description of the shape of the ion front, experimentally obtained beam pattern have been reproduced with a ray-tracing code. In fig. 2 an observed and a simulated pattern are shown. The graph on the right side shows the lineout through the corresponding ion front. A deviations from the ideal parabola is not visible, although the effect onto the deformation of the pattern is significant. In fact, the deviation from the parabola is less than 50 nm. Therefore the deformations allow tailoring the ion front with a precision of less than 1%.

The parabolic ion front seems to be a common feature in laser ion acceleration, as the beam pattern with nearly straight lines has been observed in all experiments using structured targets independently of laser and target parameters.

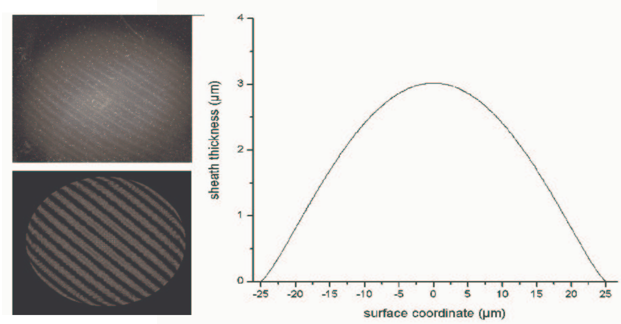

Fig. 2: Experimentally observed and reproduced pattern. On the right side the lineout through the ion front is plotted

Up to now there is no theoretical model predicting a parabolic ion front. Comparisons between proton and light ions indicate a temporal effect responsible for its shape. There is a delay between the acceleration of the protons in the middle of the beam and the edge, resulting in a curved ion front [8].

In general, tailoring the ion front with structured targets will give a further insight into the details of the acceleration process. This is important for using the proton acceleration for studies of the electron transport as well as for a detailed understanding of the influence of the laser focus on the shaping of the beam [9].

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