Laser-driven ion acceleration with a hollow beam at PHELIX*

C. Brabetz[1], *S. Busold*[2], *O. Deppert*[2], *D. Schumacher*[3], *B. Zielbauer*[3,4], *and V. Bagnoud*[3,4]
[1]Johann Wolfgang Goethe-Universität, Frankfurt am Main, Germany; [2]Technische Universität Darmstadt, Darmstadt, Germany; [3]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany; [4]Helmholtz-Institut Jena, Jena, Germany

In the framework of the Laser Ion Generation Handling and Transport (LIGHT) research project at GSI, the reduction of the divergence of the laser accelerated ions is a central issue. One solution relies on engineering the electron sheath used in laser-driven proton acceleration (target normal sheath acceleration, TNSA) for reducing the initial divergence of the ion beam. In the experimental campaign conducted in 2013 a hollow laser focal spot has been used to drive proton acceleration. This focal spot is created via a spatial phase shaping element in the laser beam path. A qualitative effect of the focal spot shape on the ion beam divergence was observed as expected, and the energy cut-off in the proton spectrum was higher with the hollow focus.

Report on the 2013 beam time

During the beam time, we have continued our investigations on laser-driven ion acceleration with engineered beams. In total, we had 26 successful high-energy experiment shots on gold foils with different thicknesses with and without the hollow beam during that beam time. We have focused particularly on avoiding strong on-shot wave front distortion in the laser amplifier (astigmatism) because we saw how crucial this is for that kind of experiment. Therefore a newly developed bending mechanism was installed to the main folding mirror in the laser chain, addressing the on-shot astigmatism aberration. These efforts resulted in a significant improvement of the laser beam transport through the PHELIX system, as we could verify from the boost of the maximum proton energy measured by radiochromic film imaging spectroscopy [1].

The dependency of the achieved maximum proton energy and the envelope divergence on the used flat gold foil target thickness was experimentally shown. In contradiction to the widely accepted intensity scaling law of TNSA (the maximum proton energy scales with the square root of the laser intensity), higher proton energies were achieved in presence of the hollow focus. The focal spot size of the hollow focus is roughly two times larger compared to the Gaussian one. This results in an laser intensity drop by a factor of 4 and therefore a two times lower maximum proton energy was expected for the hollow laser beam. In shots with the hollow focus (with a 2π total step height of the phase shaping element) the dependency of the maximum proton energy on the target thickness could be observed (figure 1). With a larger hollow beam (4π) this effect is shifted to thicker targets. For a Gaussian focal spot no scaling was observable. With the optimum target thicknesses it was demonstrated that the half envelope divergence could be decreased by $\approx 3^\circ$ (figure 2) in case of the hollow focus in comparison to the standard Gaussian focal spot.

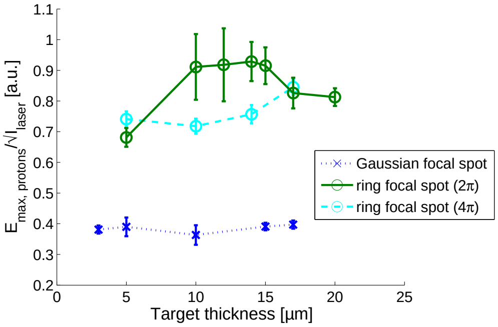

Figure 1: Scaling of the maximum proton energy with different target thicknesses. A connection of the maximum proton energy and the target thickness can be observed as well as a systematically higher scaled proton energy. Shots with the 2π hollow focus are drawn as solid, the 4π hollow focus as dashed, and the Gaussian focus as a dotted line.

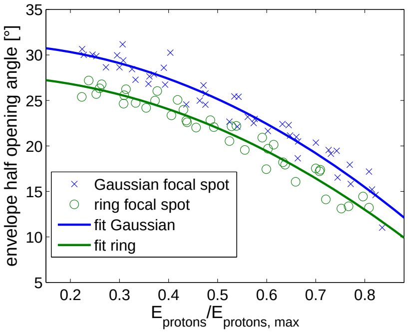

Figure 2: Comparison of different focal spot geometries and their effect on the envelope divergence angle. Each data point represents a RCF layer and the therein measured proton imprint size, scaled by the maximum proton energy of the corresponding shot for comparison. The tendency to achieve a smaller envelope divergence with the hollow beam can be observed, given by the two average lines.

References

[1] F. Nürnberg et al., Rev. Sci. Instrum. 80, 033301, 2009

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