Ultra-short pulse laser acceleration of protons from cryogenic hydrogen jets tailored to near-critical density

M. Rehwald[1], S. Assenbaum[1,2], C. Bernert[1,2], F.-E. Brack[1], M. Bussmann[1,3], T. E. Cowan[1], C. B. Curry[4,5], F. Fiuza[4], M. Garten[1,6], L. Gaus[1], M. Gauthier[4], S. Göde[7], I. Goethel[1,2], S. H. Glenzer[4], A. Huebl[1,6], J. B. Kim[4], T. Kluge[1], S. Kraft[1], F. Kroll[1], J. Metzkes-Ng[1], M. Loeser[1], L. Obst-Huebl[1,6], M. Reimold[1,2], H.-P. Schlenvoigt[1], C. Schoenwaelder[4,8], U. Schramm[1,2], M. Siebold[1], F. Treffert[4,9], T, Ziegler[1,2] and Karl Zeil[1]

[1] *Helmholtz-Zentrum Dresden - Rossendorf, Institute of Radiation Physics, Bautzner Landstr. 400, 01328 Dresden, Germany*
[2] *Technische Universität Dresden, 01062 Dresden, Germany*
[3] *Center for Advanced Systems Understanding (CASUS), D-02826 Görlitz, Germany*
[4] *High Energy Density Science Division, SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA*
[5] *University of Alberta, Edmonton, Alberta T6G 1H9, Canada*
[6] *now at: Lawrence Berkeley National Laboratory, Berkeley, California, 94720, USA*
[7] *European XFEL GmbH, Holzkoppel 4, 22869 Schenefeld, Germany*
[8] *Friedrich-Alexander Universität Erlangen-Nürnberg, 91054 Erlangen, Germany*
[9] *Technische Universität Darmstadt, 64289 Darmstadt, Germany*

m.rehwald@hzdr.de

Laser plasma-based particle accelerators attract great interest in fields where conventional accelerators reach limits based on size, cost or beam parameters. However, despite the fact that first principles simulations have predicted several advanced ion acceleration mechanisms, laser accelerators have not yet reached their full potential in producing high-radiation doses at high particle energies. The most stringent limitation is the lack of a high-repetition rate target that also provides a high degree of control of the plasma conditions which is required to access these advanced regimes.
In this talk, we show that the interaction of petawatt-class laser pulses with a cryogenic hydrogen jet plasma overcomes these limitations. The micrometer-sized target requires demanding infrastructure to be operated [1] yet provides unique characteristics that are highly desired, as previous studies have already discussed [2]. Controlled pre-expansion of the initially solid target by low intensity pre-pulses allowed for tailored density scans from the overdense to the underdense regime. Our experiment demonstrates that the near-critical density profile produces proton energies of 80 MeV. This energy presents more than a factor of two increase compared to the solid jet target. Our 3D-PIC simulations show the transition between different acceleration mechanisms and suggest enhanced proton acceleration at the relativistic transparency front for the optimal case [3].

References

[1] M. Rehwald et al. *Conference Proc. of IPAC2022* Bangkok, Thailand, 12-17 June 2022; C.B. Curry et al. J. Vis. Exp. **159**, e61130 (2020)
[2] S. Göde et al. Phys. Rev. Lett. **118**, 194801. (2017); L. Obst et al. Sci. Rep. **7**, 10248 (2017); M. Gauthier et al., Appl. Phys. Lett. **111**, 114102 (2017); L. Obst et al. Nat. Com. **9,**, 5292 (2018);
[3] M. Rehwald et al., under review