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lpaw23@tecnico.ulisboa.pt

Investigation of laser-induced breakdown and target pre-expansion for laser proton acceleration

S. Assenbaum[1,2], C. Bernert[1,2], S. Göde[3], T. Kluge[1], D. Loureiro[3], M. Rehwald[1], M. Vescovi[1,2], L. Yang[1,2], U. Schramm[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] *European XFEL GmbH, Holzkoppel 4, 22869 Schenefeld, Germany*

s.assenbaum@hzdr.de

The upcoming generation of repetition-rate petawatt class lasers drives the development of laser-plasma proton accelerators and enables new applications e.g. in cancer radiotherapy research. To harness the full potential of these laser systems and their applications, it is crucial to characterize and control the density profile of the target at the arrival of the ultra-intense laser peak. Cryogenic solid-density hydrogen jets were successfully demonstrated as a promising target platform to investigate various aspects of the high intensity interaction. In combination with optical and X-ray probing techniques, the unique properties of these jets as self-replenishing, debris free, low-density, pure hydrogen targets provide an ideal test bed to study processes like ionization and pre-expansion that occur during irradiation of the leading edge of the laser pulse.

In this contribution, we present the results of laser-target interaction studies with intensities ranging from the relativistic regime down to the intensities of dielectric breakdown of hydrogen. They were conducted using the cryogenic hydrogen jet platform together with the high-resolution optical probing capabilities at the Draco laser facility at Helmholtz-Zentrum Dresden-Rossendorf and the X-ray free electron laser at the HiBEF facility at European XFEL. Changing the drive laser pulse parameters enabled extensive studies, e.g., of the transition from an initial solid state to a plasma state, i.e., the onset of laser-induced breakdown of the solid defining the starting point of the subsequent pre-expansion. As a further example, insights into pre-plasma formation are obtained by investigating the intensity-dependent evolution of the target density profile. These results, together with technical advancements of the target, will be valuable for optimizing laser-driven proton acceleration at high-intensity laser facilities.