Ion energy loss at maximum stopping power in a laser-generated plasma

W. Cayzac[1], V. Bagnoud[1,2], M.M. Basko[3], S. Bedacht[4], A. Blažević[1,2], O. Deppert[4], A. Frank[2], D.O. Gericke[5], L. Hallo[6], A. Knetsch[4], D. Kraus[7], G. Malka[8], A. Ortner[4], K. Pépitone[6], G. Schaumann[4], T. Schlegel[2], D. Schumacher[1], An. Tauschwitz[9,10], J. Vorberger[11], F. Wagner[4], and M. Roth[4]

[1]GSI; [2]Helmholtz institute Jena; [3]KIAM Moscow; [4]Technical University of Darmstadt; [5]University of Warwick; [6]CEA/CESTA; [7]University of California; [8]Univ. Bordeaux-CEA-CNRS CELIA UMR 5107; [9]University of Frankfurt; [10]HIC for FAIR; [11]MPI for physics of complex systems

Ion stopping in plasma is relatively well-understood for projectile velocities much higher than the thermal velocity of plasma electrons ($v_{ion}/v_{th} >> 1$), but large uncertainties remain around the stopping-power maximum, for $v_{ion}/v_{th} \approx 1$. This parameter region is of crucial importance for ICF and especially for the alpha-particle heating of the DT fuel. Yet, its theoretical description is difficult [1] and no experimental data are available in order to benchmark the existing theories and numerical codes. Within this collaboration, first measurements of this kind have been performed and compared with theoretical predictions.
The plasma was generated by the use of 100 μg/cm^2 carbon foils irradiated from both sides by the second harmonic frequency of the PHELIX and nhelix laser systems, where random phase plates were employed to reach a 1-mm-diameter top-hat uniform illumination [2]. This configuration resulted in a spatially quasi-homogeneous and fully ionized plasma slab after a few ns, which has been well-characterized by the joint use of multi-frame interferometry [3] and hydrodynamic simulations with the RALEF2D code [4]. The projectile energy was 0,5 MeV/u, and carbon ions were employed on the basis of Monte-Carlo calculations showing that they become completely stripped in the fully ionized plasma. In this way, the whole set of beam-plasma parameters is known, which enables reliable comparisons of ion energy-loss data with the theory for the first time. The energy loss was predicted theoretically by combining the results of the RALEF2D simulations and of the Monte-Carlo code, according to (i) perturbative stopping-power approaches basing on the first Born approximation: asymptotic Bethe and Bethe-Bloch formulas, standard stopping model (SSM), dielectric theory based on a linearized Vlasov equation, Li-Petrasso model, and (ii) a nonperturbative stopping description using a T-Matrix scheme [5].

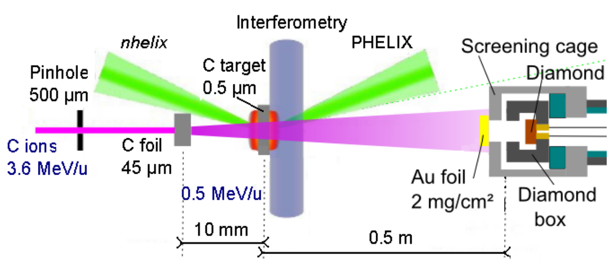

Figure 1: Schematics of the experimental setup.

The experimental setup is shown in Fig.1. The ions were decelerated to 0,5 MeV/u by using a carbon foil of 45 μm thickness. The time-of-flight distance was 50 cm, allowing a 100 keV energy resolution for an optimal test of the theories. The ions were detected on a specifically developed polycrystalline chemical-vapour-deposition (CVD)-diamond detector able to register 20 % of the beam and shielded against any plasma radiation [6].

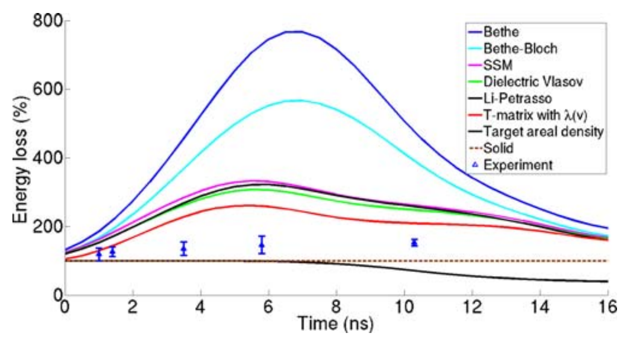

Figure 2: Energy loss as a function of time. 100 % corresponds to the energy loss in the solid foil. The experimental points are compared with the theoretical curves.

A first experimental campaign was conducted, and preliminary results are compared with the theoretical predictions in Fig.2. A maximum increase in energy loss in plasma of 53 % in relation to the cold target is observed. In the time frame where the plasma is hot and highly ionized and hence $v_{ion}/v_{th} \approx 1$, the obtained experimental values are thus significantly smaller than predicted by any theory. The precise interpretation of these discrepancies is in progress and further simulations as well as measurements are planned.
This project has been supported by CEA/CESTA and the Région Aquitaine as well as by BMBF and HIC4FAIR.

References

[1] D.O. Gericke et al., Phys. Rev. E **60**, 904 (1999)
[2] A. Frank et al., Phys. Rev. Lett. **110**, 115001 (2013)
[3] M. Boerner et al., Rev. Sci. Instrum. **83**, 043501 (2012)
[4] An. Tauschwitz et al., High Energy Density Phys. **9**, 158 (2013)
[5] D.O. Gericke et al., Laser Part. Beams, **20**, 471 (2002)
[6] W. Cayzac et al., submitted to J. of Physics, Conf. Ser. (2014)