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Anomalous stopping of laser-accelerated intense proton beam in dense ionized matter

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By irradiating a thin foil with ultrahigh-intensity lasers, multi-MeV ions with unprecedentedly high intensity (10 19-20cm−3) in ps time scale can be generated through various accelerating mechanisms. Such ion beams opened up new perspectives for many fields of research and application, such as inertial confinement fusion, ion fast ignition, and ion driven high energy density matter. During the interaction of such high-intensity ion beam with dense plasma, complicated, nonlinear behaviors are expected to emerge, while are far more to be understood. An accurate understanding of the complicated, nonlinear behaviors that might emerge during the intense beam stopping and transportation in dense plasma is crucial for all these applications.

We measured the energy loss of laser-accelerated protons in dense plasma at the XG-III laser facility of Laser Fusion Research Center in Mianyang. The dense ionized target is produced by irradiating a Tri-Cellulose Acetate (TCA) foam sample with soft X-rays from a laser-heated hohlraum. Thus the temperature and density are homogeneous across the ionized target. This state can be maintained for a period of more than 10 nanoseconds, which is orders of magnitude longer than the beam duration and beam-plasma interaction time scale. Therefore, the target can be considered to be quasi static.

Two experimental campaigns are carried out. In the first experimental campaign [1], we sent the laser accelerated ion beams directly into the plasma target, and observed that the energy spectra of the ions were significantly downshifted after passing though the dense plasma. This energy downshift was far beyond the Bethe-Bloch predictions. However, the large energy spread of the incident beam makes it difficult to correctly interpret the results.

In the second experimental campaign [2], we improve the precision of the measurement by using a magnetic dipole to trim out a quasi-mono-energetic proton beam. We observed that the energy loss is enhanced by one order of magnitude in comparison with the predictions from individual-proton stopping theories, Bethe-Bloch, Li-Petrasso (LP), and Standard Stopping Model (SSM). Through PIC simulation, we attribute the high degree of enhancement to a strong decelerating electric field induced by the intense proton beam. This collective effect is the primary cause for the anomalous stopping, and it is likely to have a major impact on nuclear fusion scenarios like fast ignition, alpha-particle self heating, as well as ion driven inertial confinement fusion.

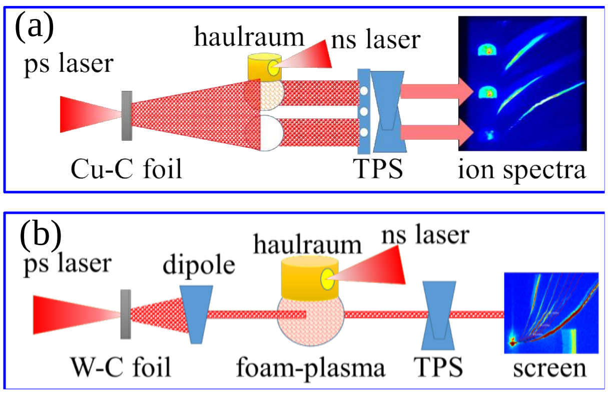

Fig. 1 Experimental Setup. (a) Laser-accelerated broad-energy-range proton beam stopping in plasma. (b) Quasi-mono-energetic proton beam stopping in plasma

References

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