Recent progress in laser-driven proton acceleration

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Laser-driven proton acceleration is a field that has triggered a tremendous interest after the pioneering experimental work from R. A. Snavely et al. at the Nova Petawatt machine at the turn of the century. Following this break-through, a large amount of work both on the theoretical and experimental sides has been produced to explain the acceleration mechanism, optimize this process and even propose new more promising acceleration schemes. This work has highlighted the need for short pulse lasers with very high intensities, well into the relativistic regime, and also very high temporal contrast ratios.

The current trend for laser-driven acceleration is in driving particles to high velocities from sub-micrometer foils. Using various target materials in the sub-micrometer thickness range, it is possible to produce laminar beams with energies above 80 MeV at the PHELIX facility on a quasi-routine basis. However, our understanding is that the particles generated at PHELIX are produced by the target normal sheath acceleration mechanism which is not the best way to reach even higher energies.

Several interesting regimes have been theoretically predicted to be found when the target thickness drops below a micrometer. First of all, ultra-thin sub-100-nm targets can be employed following the radiation pressure acceleration scheme and second, target above 100 nm should enable an acceleration scheme in the relativistic transparency regime. However, both regimes rely on the target material staying cold until the very last instants before the interaction at relativistic intensities, which is hard to ensure even at the laser facilities that incorporate state-of-the-art temporal profile cleaning techniques. In any case a precise measurement of the plasma state just before and during the interaction is a pre-requisite for a complete understanding of the plasma dynamics leading to the particle acceleration.

The rapidly changing electron density at the laser-target interaction point requires the implementation of time-resolved plasma diagnostics. We have proposed and demonstrated the use of Fourier transform spectral interferometry to characterize the transit time of the laser pulse through the plasma. This diagnostic, completed by a measurement of the transmitted energy and a temporal characterization of the transmitted pulse using FROG, enables differentiating between the hole-boring and relativistic-transparency regimes.

References

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