Seminar

Institute for Plasma Research

Title: Laser-Driven Ion Accelerators: Unlocking the Physics Behind the Future of Compact Beam Technology

Speaker: Dr. Arghya Mukherjee
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Abstract

The interaction of ultrashort, ultra–high-intensity laser pulses (I > 1018 W/cm²) with solid foil targets can generate energetic ion beams with tunable characteristics, including energy, fluence, spectral shape, and time duration [1, 2]. Such laser-driven ion beams are increasingly recognized as viable candidates for frontier applications—ranging from high-resolution radiography [3] and ion-driven fast ignition in inertial fusion [4] to emerging concepts in compact proton therapy [5].

The underlying acceleration dynamics are strongly influenced by laser parameters (intensity, contrast, polarization) as well as target properties such as its thickness, density, geometry, and atomic composition. Depending on these conditions, ions may be accelerated through distinct mechanisms, most prominently target normal sheath acceleration (TNSA) [6] and radiation pressure acceleration (RPA) [7]. Each mechanism exhibits unique scaling behaviors and beam characteristics, and their relative dominance is governed by the precise interplay between laser–plasma coupling and target evolution. Understanding and optimizing these mechanisms is therefore essential for advancing laser-driven sources toward application-ready ion beam parameters.

In this talk, I will provide an overview of the major laser–plasma ion acceleration mechanisms and discuss their underlying physics through established theoretical scaling laws. Building on this foundation, I will present Particle-in-Cell simulation results obtained using the SMILEI [8] code, with a particular focus on the hole-boring (HB) RPA mechanism and its relevance to ion-driven fast-ignition schemes. Finally, I will discuss the characteristics of laser-driven ion beams in the context of application-oriented requirements, highlighting the beam parameters necessary for hadron therapy and assessing the prospects of laser-based accelerators in meeting these clinical specifications.

References:

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[4] Roth et. al., *Phys. Rev. Lett.* **110**, 044802 (2013).
[5] Kroll et. al., *Nat. Phys.***18**, 316–322 (2022).
[6] Schreiber et. al., *Phys. Rev. Lett*. **97**, 045005 (2006).
[7] Macchi et. al., *Phys. Rev. Lett.* **94**, 165003 (2005).
[8] Derouillat et. al., *Comput. Phys. Commun*. **222**, 351-373 (2018).