7th European Advanced Accelerator Conference

EAAC2025

Contribution ID: **527** Type: **Oral contribution**

All-optic In-plasma Staging of Laser-Wakefield Accelerators Using Density Tailoring

Monday 22 September 2025 16:40 (20 minutes)

The staging of laser-driven plasma accelerators (LPAs) could open up energy frontiers, but achieving in- and out-coupling of laser pulses while preserving beam quality remains a challenge. In this work, we present an all-optical, in-plasma staging scheme that uses refraction in a transverse plasma density gradient to couple the incoming laser into the next LPA stage, eliminating the need for mirrors and magnets. This design can in principle support significant ion motion without substantial emittance degradation, making it well-suited for a broad energy range. With realistic 3D simulations using the quasistatic particle-in-cell code HiPACE++ on GPU, we observe 98% capture efficiency and 3 GeV energy gain in a second stage, driven by a ~10 J laser pulse guided by a hydrodynamic optical-field-ionized (HOFI) channel of matched spot size 37 microns. These results represent a significant step toward practical multistage plasma acceleration, paving the way for the generation of ultra-high-energy electron beams for a wide range of scientific and technological applications.

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Session Classification: PS4: Theory and simulations

Track Classification: PS4: Theory and simulations