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Independent Control of Electron Injection and Acceleration in a Laser Plasma Accelerator

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Numerous studies have explored techniques to optimize electron beam properties, such as energy, energy-spread, charge, and divergence in a laser wakefield accelerator. Controlling electron injection and acceleration independently is key to producing high-quality beams in laser wakefield accelerators. We demonstrate such decoupling using one laser beam focusing in a gas medium thanks to a novel double-compartment gas cell with a modular design.

A nitrogen-doped hydrogen mixture in the first compartment enables ionization injection, while the interface between the two compartments supports density down-ramp injection, and pure hydrogen in the second compartment sustains laser guiding for efficient acceleration. The modular design allows customization of compartment lengths, interface geometry, and face diameters, providing precise control of the plasma density profile. This setup enables independent tuning of beam charge and energy, offering flexible control over key beam parameters.

Experiments at the DRACO laser facility (Helmholtz-Zentrum Dresden-Rossendorf) lead to the identification of many regimes (compartment sizes, pressures, and trigger timing) that generated quasi-monoenergetic electron beams with peak energies up to 300 MeV, FWHM charges up to 40 pC, energy spreads below 10%, and divergences under 1 mrad. These results highlight the potential of density-tailored, modular plasma targets for advanced beam manipulation in compact accelerators.

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