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Advancing Hybrid Laser- and Beam-Driven Plasma Accelerators: High-Energy and High-Quality Witness Beams

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Hybrid laser- and electron beam-driven plasma wakefield accelerators (L-PWFAs) combine the compactness of laser wakefield acceleration (LWFA) with the beam quality and stability of particle-driven wakefield acceleration (PWFA). In this scheme, an LWFA stage generates a high-current electron bunch that drives a PWFA stage, where a witness bunch is internally injected and accelerated.
Our earlier experiments demonstrated witness beams with reduced divergence and energy spread—key for applications such as brilliant X-ray generation—but with limited energy gain, yielding transformer ratios below unity. In this work, we demonstrate high-quality witness beams with energies significantly exceeding that of the driver beam, reaching transformer ratios approaching 2. These advances are facilitated by precise control of plasma density and beam parameters, aided by advanced diagnostics: A few-cycle optical probe enables retrieval of the local plasma density and visualization of wakefield morphology changes due to driver depletion. These measurements are complemented by transition radiation diagnostics that allow relative localization of the driver and witness beams.
In conclusion, our PWFA stage acts as both an energy and beam quality transformer, enabling true gains in overall beam brightness, enhancing the potential for future applications like next-generation light sources.

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