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Overcoming the Limitations of Laser-Wakefield Acceleration with Structured Light Fields

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For the last few decades, the development of Laser-Plasma Accelerators (LPAs) has attracted high interest due to the capacity of plasma to produce and sustain extremely high electric fields. The accelerating gradients in plasma accelerators can exceed 100 GV/m, which is three orders of magnitude larger than those obtained in metallic-cavity accelerators. This promisingly offers very compact alternatives to conventional linear machines . However, a high field is not the only ingredient required for achieving high multi-GeV energy gains. The accelerated beam must also follow this field over long distances. Currently, the identified main challenges for LPAs include the diffraction and depletion of the driver laser, as well as the dephasing of the accelerated beam with the driven plasma waves. Diffraction and pump depletion cause the laser intensity to decrease during acceleration, eventually suppressing the wakefield. Dephasing results from the mismatch between the phase velocity of the accelerating field and that of the electron beam, leading the electron beam toward a decelerating phase of the wake.

In this context, we discuss two approaches for overcoming these limitations and increasing the beam energy. First, we present the experimental demonstration of quasi-monoenergetic electron beam acceleration at the GeV level in a plasma waveguide created by a quasi-Bessel beam shaped by an axiparabola mirror. Another concept involves advanced optical shaping of the laser driver, allowing diffraction-free propagation over a long distance while controlling the group velocity of the laser. This approach significantly extends the effective dephasing length.

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