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Effect of driver charge on wakefield characteristics in a plasma accelerator probed by femtosecond shadowgraphy

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High peak current electron beams from laser wakefield accelerators (LWFAs) can excite a high amplitude plasma wave in a subsequent plasma wakefield acceleration (PWFA) stage. The intrinsic short duration of these driver beams enables a new operational regime of PWFAs at plasma densities above $10^{18}\mathrm{cm}^{-3}$ which is important for the acceleration of ultra-short and ultra-low emittance witness bunches. Benefiting from existing femtosecond optical probing techniques at this density regime, direct observation of beam-driven plasma waves becomes possible. Here we present experimental results of optical probing of such beam driven waves, showing the shape and size of the first cavity of the wakefields correlates with the driver beam charge. In addition, precise analysis of the plasma wavelength enables on-shot measurement of the ionisation level caused by the driver beam in a hydrogen-helium mixture, which is particularly important for the study of advanced injection techniques such as Trojan horse injection. The experimental results are supported by 3D particle-in-cell simulations performed with PIConGPU. This method can be extended to a detailed study of driver charge depletion by probing the evolution of the wakefield when propagating through the plasma. This is an important step for further understanding and optimization of high energy efficiency PWFAs.

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