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Enabling energy-doubling at CLARA FEBE: High-quality beam generation in plasma wakefield acceleration

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Plasma-wakefield acceleration (PWFA) has gained global attention for the achievable ultra-high accelerating gradients, which will drastically reduce the price, footprint, and carbon load of accelerators to be used for medical applications, free electron lasers (FEL), and future high-energy physics experiments. The Compact Linear Accelerator for Research and Applications (CLARA) at the Daresbury Laboratory is a state-of-the-art electron accelerator for a future FEL test facility, capable of producing 250-MeV electron bunches. Recently, a new beamline attached to CLARA, the Full Energy Beam Exploitation (FEBE) facility, has been designed to provide ultra-short and low-emittance electron bunches. Here, by employing the Fourier-Bessel particle-in-cell (FBPIC) code, we investigate PWFA with a two-bunch configuration at FEBE to double the energy of the externally injected witness bunch while maintaining incoming beam quality as much as possible. Simulation results indicate that the driver's trailing portion is tightly focused by the transverse wakefield, leading to a surging beam density and a transition from the linear to the non-linear regime. A flattened wakefield due to beam loading is achieved with appropriate tailoring of the witness bunch's longitudinal current profile. Tolerance analysis for bunch parameters is presented. Moreover, we explore the impacts of plasma-density profiles on beam quality.

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