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Arbitrary Wave Shaping for Controlled Electron Injection Using Co-Propagating Laser Pulses

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We introduce a novel method of controlled electron injection for Laser Wakefield Acceleration (LWFA) operating in the high-intensity "bubble" regime. In this scheme, a fraction of a high-intensity "driver" pulse is diverted and compressed into a low power, few-cycle "satellite" pulse co-propagating alongside the driver. This satellite is tightly focused off-axis where it acts to perturb bubble formation and drive an asymmetric plasma wave before stabilizing on-axis. Doing so allows for manipulation of the particle Hamiltonian; creating a trigger to overcome the wave-breaking injection threshold and lead to efficient particle trapping and acceleration. 2D and quasi-3D Particle-in-Cell (PIC) simulations support this concept, demonstrating that systematic investigation of the two-beam parameter space (e.g. temporal delay, beam displacement, etc.) leads to controllable variance in the electron beam phase space. Results indicate this method could be used to induce self-injection in wakefields at plasma densities and driving laser intensities well below theoretical predictions. Further, adding additional co-propagating satellites proves to distort the initial plasma wave formation in a predictable manner, allowing a controllable mechanism to alter the phase space of injected electrons. Pulses can be placed to increase the transverse momentum on injected electrons which leads to enhanced betatron emission or mitigated for longitudinal injection suitable for mono-energetic acceleration. The results show promise for an all-optical knob to transition between high charge, mono-energetic, GeV particle accelerators to enhanced x-ray sources using betatron radiation through independent tuning of the satellite pulses.

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Primary author: ERNST, Nicholas (University of Michigan)

Co-authors: MA, Yong (University of Michigan); Prof. THOMAS, Alexander (University of Michigan, Gérard Mourou Center of Ultrafast Optical Science); KRUSHELNICK, Karl (University of Michigan)

Presenter: ERNST, Nicholas (University of Michigan)

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