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All-optical control of electron injection for GeV-scale acceleration in mm-scale, tapered plasmas.

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The accelerating bucket of a laser-plasma accelerator (a cavity of electron density maintained by the pulse radiation pressure) evolves slowly, in lock-step with the optical driver, and readily traps background electrons. The trapping process can thus be controlled by purely optical means.

Sharp gradients in the nonlinear refractive index produce a large frequency red-shift, localized at the leading edge of the pulse. Negative group velocity dispersion associated with the plasma response compresses the pulse into a relativistic optical shock (ROS), slowing the pulse (and the bucket), reducing the electron dephasing length, and limiting energy gain. Even more importantly, the ponderomotive force of the ROS causes the bucket to constantly expand, trapping copious unwanted electrons, polluting the electron spectrum with a high-charge, low-energy tail.

We show that a negatively chirped drive pulse with an ultra-high (~400 nm) bandwidth: extends the dephasing length; prevents ROS formation through dephasing; and almost completely suppresses continuous injection. High quality, GeV-scale electron beams can be thus produced with 10-TW-class lasers (rather than PW-class) in mm-scale (rather than cm-scale), high-density plasmas. Plasma density tapering further delays dephasing, providing additional boost in beam energy.

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