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Energy Depletion and Re-Acceleration of Driver Electrons in a Plasma-Wakefield Accelerator

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For plasma-wakefield accelerators to fulfil their potential for cost effectiveness and reduced environmental footprint, it is essential that their energy-transfer efficiency be maximized. A key aspect of this efficiency is the near-complete transfer of energy, or depletion, from the driver electrons to the plasma wake. Achieving full depletion is limited by the process of re-acceleration, which occurs when the driver electrons decelerate to non-relativistic energies, slipping backwards into the accelerating phase of the wakefield and being subsequently re-accelerated. Such re-acceleration is observed here for the first time. At this re-acceleration limit, we measure a beam driver depositing (56 ± 5)% of its energy into a 195-mm-long plasma. Combining this driver-to-plasma efficiency with previously measured plasma-to-beam and expected wall-plug-to-driver efficiencies, our result shows that plasma-wakefield accelerators can in principle reach or even exceed the energy-transfer efficiency of conventional accelerators.

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