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From Zero to a Billion Electron Volts in 3.3 Centimeters

Experiments achieve highest electron beam energies yet from laser wakefield acceleration, offering the potential of high electron energies over distances much smaller than existing machines.

PHILADELPHIA, Pennsylvania, Oct. 30, 2006 – Scientists at the Department of Energy's Lawrence Berkeley National Laboratory, in collaboration with researchers at the University of Oxford, have accelerated electron beams to energies exceeding a billion electron volts (1 GeV) in a distance of just 3.3 centimeters. The researchers anticipate that billion-electron-volt beams from laser wakefield accelerators will open the way to very compact high-energy experiments and superbright free-electron lasers.

By comparison, the Stanford Linear Accelerator Center (SLAC) boosts electrons to 50 GeV over a distance of two miles (3.2 kilometers). The Berkeley Lab group and their Oxford collaborators achieved 1/50th of SLAC's beam energy in just 1/100,000th of SLAC's length.

In laser wakefield accelerator experiments, a laser pulse is sent through a plasma to create a plasma wave "wake," in which bunches of free electrons are trapped and ride along, much like surfers riding the wake of a motorboat.

Eventually the trapped electrons outrun the wake, which limits how far they can be accelerated and thus limits their energy. The Berkeley Lab and Oxford researchers were able to increase the acceleration length by lowering the plasma density in order to increase the wake speed, and by using a capillary channel guide carved into sapphire to maintain the collimation of the laser beam.

Hydrogen gas flows into the capillary, which has electrodes placed near each end. A capacitor discharges current from electrode to electrode through the capillary, forming a plasma by heating hydrogen gas enough to disintegrate its atoms into their constituent protons and electrons. A channel forms with low plasma density in the hot center and high density against the channel's cool sapphire walls. Much like an optical fiber, each cross section of the channel acts like a positive lens, continually focusing the beam toward the center of the channel.

After a brief, carefully timed delay, the drive pulse from a 40 trillion watt laser generates an intense and powerful wake in the plasma, trapping bunches of free electrons and accelerating them to over 1 GeV within the capillary's 3.3 centimeter length, the longest distance over which such intense laser pulses have ever been channeled.

The intense electron bunches reached 1 GeV with electron energies within each bunch varying at most 2.5 percent. This is the first time a laser-driven accelerator has reached beam energies typically found in conventional synchrotrons and free-electron lasers.

The Berkeley Lab and Oxford collaborators are now working on injection, the insertion of an already energetic beam into an accelerating cavity, and on staging the handoff of an energetic beam from one capillary to the next and subsequently to others, until very high energy beams are achieved. The researchers believe they can reach 10 GeV with an acceleration structure less than a meter long.

These results are essential steps to realizing the potential of laser wakefield accelerators to provide high electron energies over distances much smaller than existing machines. In addition, other experiments (and theory) indicate that the duration of the high energy electron beams are tens of femtoseconds (a femtosecond is 1×10^{-15} seconds, or one quadrillionth of a second) in duration, orders of magnitude shorter than existing machines, which will allow unique opportunities in ultrafast science.

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GeV electron beams from cm-scale laser driven plasma based accelerators.

Invited Session UI2: Advances in Laser and Plasma Based Accelerators
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Philadelphia Marriott Downtown - Grand Salon CDE

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