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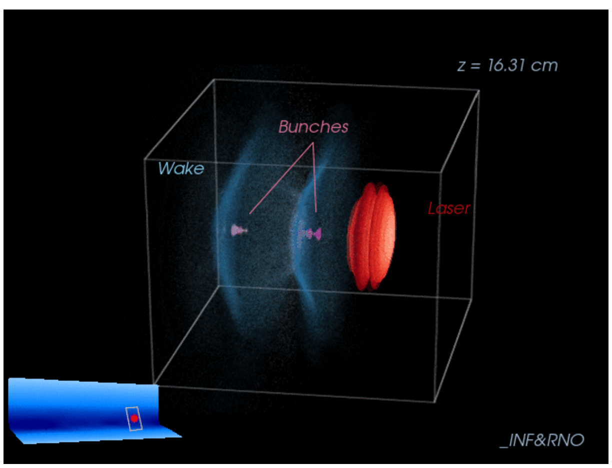
Petawatt Laser Guiding and Electron Beam Acceleration to 8 GeV in a Laser-Heated Capillary Discharge Waveguide

Researchers at Berkeley Lab's BELLA Center set a new world record in plasma-based laser-driven electron acceleration producing beams with an energy of up to 8 GeV in a 20 cm-long laser-heated discharge capillary

Laser plasma accelerators are characterized by large acceleration gradients of tens to hundreds of GV/m, which are several orders of magnitude larger than in conventional radio frequency technology. This could allow for compact, low-cost, accelerators in a variety of applications, including free-electron lasers, Thomson sources, and electron-positron colliders with TeV energy.

Efficient laser-plasma acceleration requires guiding a short and intense laser pulse in plasma over long distances (20 cm in this experiment), much longer than the characteristic laser diffraction length (~1.3 cm for the BELLA laser at Berkeley lab). If the laser remains guided, the amplitude of the plasma wave (or wake) that the laser generates remains high, and so a particle beam injected in this plasma wave can be continuously accelerated by the high fields associated with the wake.

Guiding of the laser pulse is achieved via a plasma channel, which confines a laser pulse in a similar way to an optical fiber. A capillary discharge is commonly used to create a plasma channel. However, achieving the right channel properties at the low plasma density required for high-energy beams is challenging. In this work, the plasma channel produced by the capillary discharge was modified by means of a nanosecond-long "heater" laser pulse that was used to locally heat the plasma, reduce the on-axis density, and increase the guiding strength of the plasma channel. This allowed for the production and acceleration of electron beams with quasi-monoenergetic peaks up to 8 GeV, double the energy that was previously demonstrated [1]. Edison Supercomputer at the National Energy Research Scientific Computing (NERSC) center was used extensively to simulate the channel formation using the magneto-hydrodynamic code MARPLE, and to model electron acceleration using the particle-in-cell code INF&RNO. These simulations were instrumental in understanding and optimizing the experiment.



Plasma waves (blue) excited by the PW BELLA laser pulse (red) as it propagates in a plasma channel. Background electrons are trapped and accelerated to a energy of up to 7.8 GeV in the plasma wave (pink/purple). The inset image (bottom/left) shows the position of the laser (red dot) along the 20 cm plasma (blue).

REFERENCES

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[1] Gonsalves et al., Phys. Rev. Lett. 122, 084801 (2019), doi.org/10.1103/PhysRevLett.122.084801

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