

VORPAL Vital in Discovery of Dream Beams from Laser-Plasma Acceleration

Problem Description

Laser driven plasma wakefield accelerators produce accelerating electric fields of hundreds of GV/m which is thousands of times greater than those produced by radio frequency accelerators, making them attractive as compact next-generation sources of energetic electrons and radiation. Typically, acceleration distances were limited by the lack of a controllable method for extending the distance over which the laser remains focused, which limits beam energy and can lead to a 100% energy spread. A method is required to produce high energy beams with a small energy spread in order to realize cheaper, smaller, and efficient table-top particle accelerators.

Solution

VORPAL was used by researchers at the LOASIS program of Lawrence Berkeley National Laboratory to help discover how guiding the laser using a preformed plasma density 'channel,' which has a minimum density along the laser axis, can control acceleration. They simulated experiments in which the channel was used to guide a relativistically intense laser over ten times the usual diffraction distance, producing electrons with percent level energy spread for the first time in a plasma based accelerator. VORPAL showed that the high-quality electron bunches were formed by a combination of pulse evolution, beam loading, and dephasing (Fig. 1). This process increased beam energy more than two-fold, reduced the beam divergence twenty-fold, and increased spectral density by orders of magnitude over previous experiments. A VORPAL simulation image showing this physics was featured as the cover image of the September 2004 issue of *Nature* as 'Dream Beam The dawn of compact particle accelerators.'

Why VORPAL?

VORPAL provides the parallel architecture needed to simulate computationally expensive laser wakefield accelerators and allow for optimizing parameter scans on reasonable time scales.

"VORPAL simulations were essential to understanding the physical mechanism in LOASIS experiments that produced quasi-monoenergetic electron bunches for the first time from a laser-plasma accelerator," said Cameron Geddes of LBNL. "The flexible input structures gives the control required to set up the problem and scan parameters without modifying code. The standard-compliant HDF5 output together with example scripts for IDL and other languages made it easy to do post-processing and visualization. This allowed us to simulate the experimental setup accurately, validate the simulations against experimental results, then use the simulated time evolution and particle tracking to demonstrate the physics mechanisms at work. We continue to use VORPAL to design and interpret new experiments, including experiments using plasma density gradients and colliding laser pulses to control particle injection to further improve beam quality, and experiments using plasma channels to extend energies to GeV in 2006, and in the future 10 GeV and beyond."

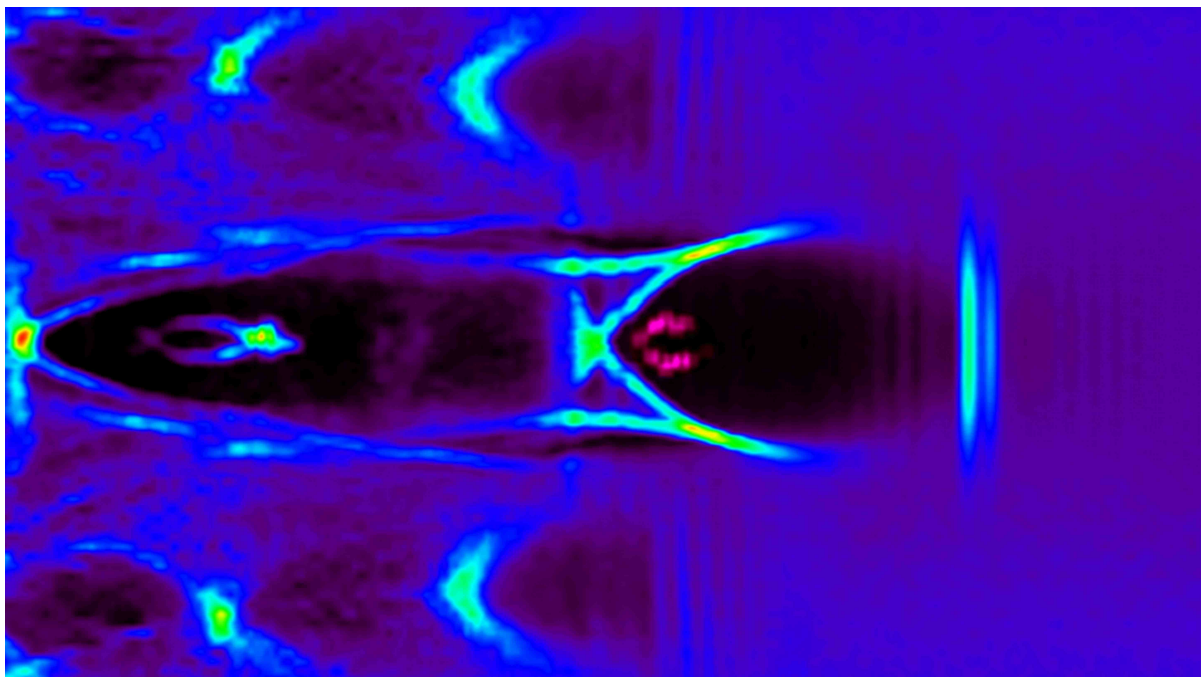


Figure 1: VORPAL results showing the plasma density variation from a laser pulse guided by a preformed density channel. These results match experiment and show the high-quality electron bunch formed when the acceleration length is matched to the dephasing length.

References

- [1] C. G. R. Geddes, Cs. Toth, J. van Tilborg, E. Esarey, C. B. Schroeder, D. Bruhwiler, C. Nieter, J. Cary, W. P. Leemans, High-quality electron beams from a laser wakefield accelerator using plasma-channel guiding, *Nature*, 431, 538-541, (2004)

