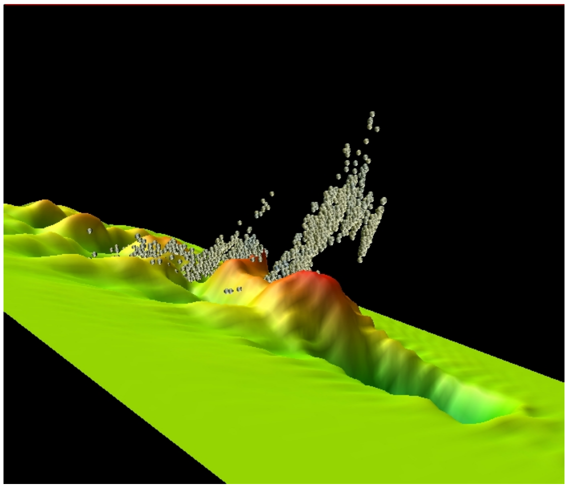
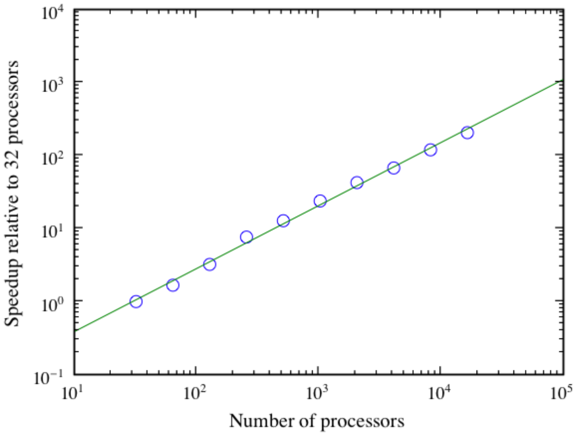
Modeling Laser Wakefield Particle Accelerators with VORPAL

What is LPA?



An intense, short laser pulse propagating through a plasma can lead to the separation of electrons and ions capable of producing accelerating electric fields of hundreds of GV/m. This field strength is thousands of times greater than those produced by radio frequency accelerators, which makes them attractive as compact next-generation sources of energetic electrons and radiation. VORPAL is capable of simulating laser plasma accelerators (LPA) using several different models; full particle-in-cell (PIC), envelope, and fluid. The modular structure of VORPAL allows users to combine these models, for instance modeling the bulk plasma as a fluid, and the beam as PIC.

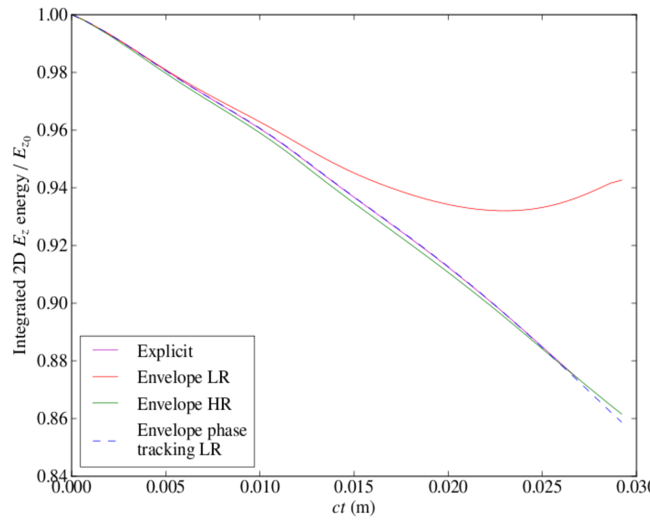


Full PIC models take advantage of VORPAL scaling

The full PIC model of laser-plasma interaction includes the most physics of any of the models available in VORPAL. Because these models are the highest fidelity, they are also the most computationally intensive. By exploiting the ability of VORPAL to scale to tens of thousands of processors, one can still perform even the most challenging LPA simulations.

Full PIC modeling resolves the laser wavelength. Due to the fine resolution, the acceleration of the particles can be followed until full laser energy depletion. Any waves that can result from the interaction of the laser with the plasma are also resolved which is vital to see if their effect is important.

Envelope



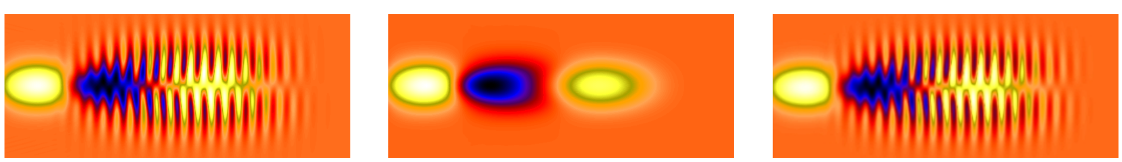
The envelope model of LPA is a reduced model that allows particle trapping and acceleration, but does not require resolving the laser wavelength. This model averages over the fast laser oscillations, needing only to resolve the longer plasma wavelength. Speedup times for simulations can be several orders of magnitude with higher gain at low density where the plasma wavelength is much longer than the typical laser wavelength. The envelope model uses the particle-in-cell method to follow particle motion, which enables the user to resolve self-particle trapping and self-consistent acceleration by the wakefield. The envelope model is limited in that small-scale features (on the order of the laser wavelength) are not resolved. Such small-scale features include, for instance, possible scattered waves.

Fluid

A further simplification is that VORPAL can model the electron plasma in an LPA as a cold, relativistic fluid. This approach is physically correct, because the electrons in LPA experiments typically have temperatures of 10 eV or less and there is no significant heating during interaction with the ultra short laser pulse that is required to drive a strong plasma wakefield. The primary benefit of using a fluid model is the complete elimination of particle-driven numerical noise and, therefore, of any artificial kinetic effects which can sometimes occur with PIC. The cold, relativistic fluid model in VORPAL has been shown to converge quadratically with corresponding PIC simulations in 2D and 3D, and to scale well to thousands of cores for large problem sizes. This algorithm is uniquely powerful in that it can correctly model density gradients and vacuum interfaces without any artificial density spikes which are ubiquitously seen in other algorithms. The implementation works seamlessly with many other VORPAL capabilities, enabling one to use hybrid fluid/PIC with macroparticles representing an externally injected electron beam thus providing very low noise fields to accelerate the particles. As with any fluid algorithm, kinetic effects in the plasma are not resolved.

VORPAL PIC Model **VORPAL Envelope Model** **VORPAL Fluid Model**

Wake Field



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