



Simulation capabilities for ATF experiments

Benjamin Cowan
Tech-X Corporation

Motivation and outline

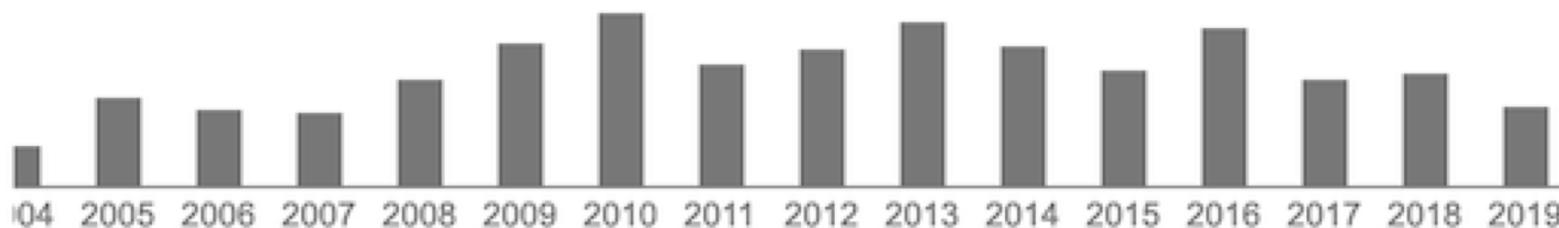
- So you want to do an experiment at ATF...
- But what are the expected outcomes?
- Simulations needed to prepare for ATF use
- ...that are accessible for non-computationalists

Outline:

- Tech-X code capabilities
- Workflow ideas

- Vorpal computational engine
- Multiphysics for electromagnetics, electrostatics, magnetostatics (soon), and structures; kinetic and fluid species
- Cross platform: supercomputers to desktops, including Windows
- User friendly, well documented
- With about 100 FTE-years of investment
- The most frequently cited computational plasma application (at last check)

Cited by 712





LETTER

doi:10.1038/nature12664

Demonstration of electron acceleration in a laser-driven dielectric microstructure

E. A. Peralta¹, K. Soong¹, R. J. England², E. R. Colby², Z. Wu², B. Montazeri³, C. McGuinness¹, J. McNeur⁴, K. J. Leedle³, D. Walz², E. B. Sozer⁴, B. Cowan⁵, B. Schwartz⁵, G. Travish⁴ & R. L. Byer¹

nature
physics

LETTERS

<https://doi.org/10.1038/s41567-019-0610-9>

Generation and acceleration of electron bunches from a plasma photocathode

A. Deng^{1,2,14}, O. S. Karger^{3,14}, T. Heinemann^{4,5,6}, A. Knetsch⁶, P. Scherkl^{4,5}, G. G. Manahan^{4,5}



ARTICLE

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OPEN

Single-stage plasma-based correlated energy spread compensation for ultrahigh 6D brightness electron beams

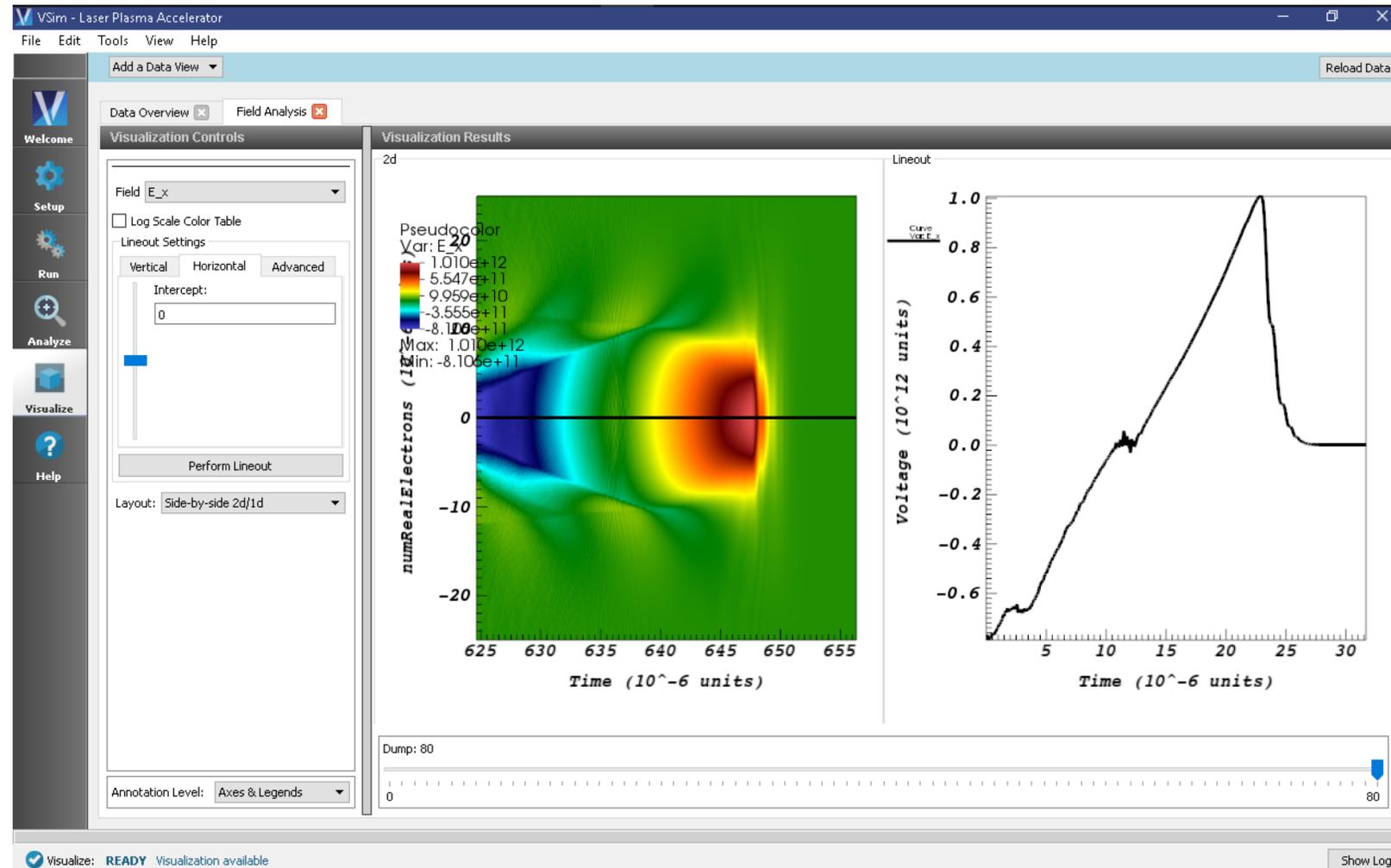
G.G. Manahan^{1,2}, A.F. Habib^{1,2,3}, P. Scherkl^{1,2}, P. Delinikolas^{1,2}, A. Beaton^{1,2}, A. Knetsch³, O. Karger³, G. Wittig³

Strong support

- With 100's of licensing agreements in >15 countries since 2012, including multiple labs in US, UK, Germany, Russia...
- Tech-X supports users with its cadre of application engineers
- Annual user group meetings
- Education support
 - USPAS attendees get free licenses every session
 - Accelerator Physics course being taught this January (J. Rosenzeig and M. Litos) using VSim
 - University class licensing

Features for plasma acceleration

- Full PIC code
- High-order particles
- Controlled dispersion
- Laser envelope model
- Field and impact ionization
- Arbitrary laser, beam, and plasma initial conditions

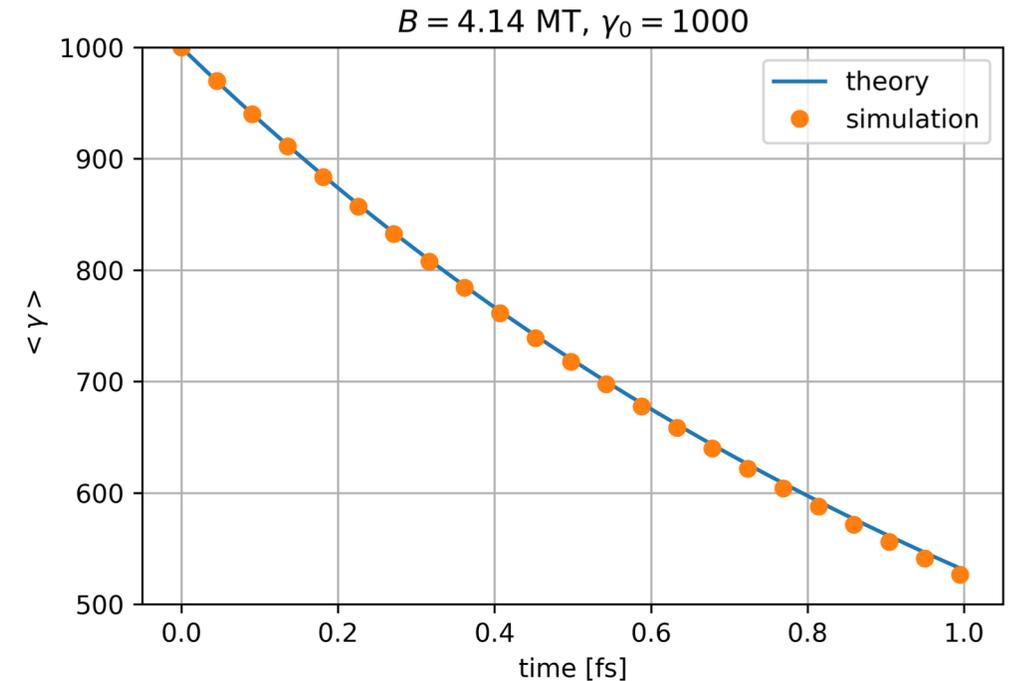


Radiation Reaction in VSim

- Relativistic electrons moving in high fields undergo nonlinear Compton scattering:
 - Emit high energy photons, losing energy and momentum
- Emission rate and energies are based on the quantum parameter

$$\eta = \frac{e\hbar}{m_e^3 c^4} |F_{\mu\nu} p^\nu| \simeq \frac{\gamma}{E_s} \sqrt{(\vec{E} + \vec{v} \times \vec{B})^2}$$

- Benchmarked multiple cases
 - Relativistic electrons in large B field
 - Relativistic electrons in intense EM wave (circularly polarized)
- VSim implementation based on *Ridgers, JCP 2014*



- Cut-cell electromagnetics
- CAD import
- Secondary electron emission for multipacting
- Eigenmode solver
- Parameter sweeping and optimization
- Many forms of field excitation

VSIm - A15 Crab Cavity (text-based setup)

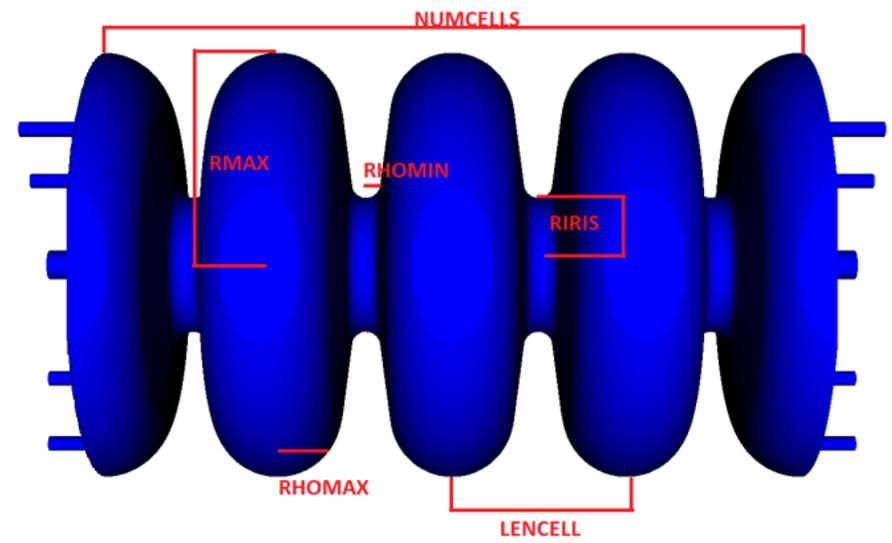
File Edit Tools View Help

Editor

crabCavityT.pre

The A15 Crab Cavity was an early design for a cavity that can be used to cause a beam to crab, i.e., have the front of the beam shifted transversely with respect to the rear. This simulation shows how to use the frequency extraction method to get the modes and their frequencies.

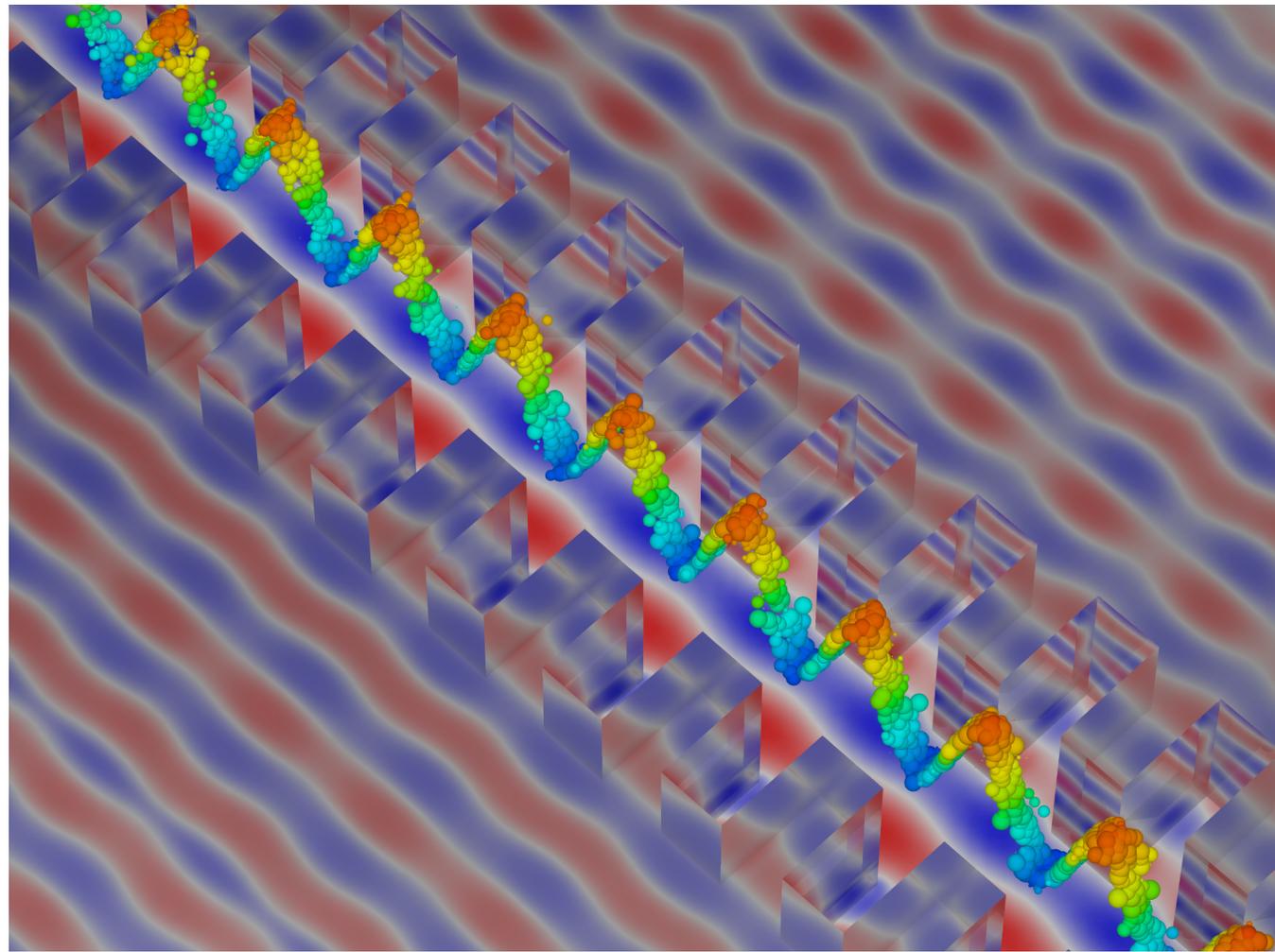
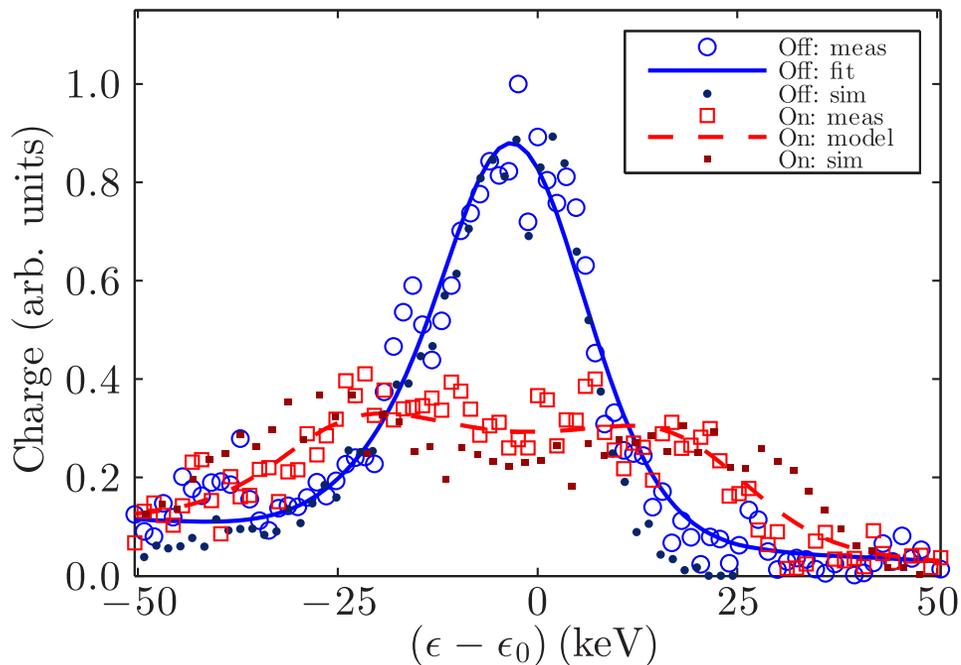
NUMCELLS: 4
 RMAX: 0.04719
 RHOMIN: 0.00331
 RHOMAX: 0.0136
 LENCELL: 0.0384
 RIRIS: 0.015
 ZSQUASH: 0.0025
 DMFRAC: 1.1



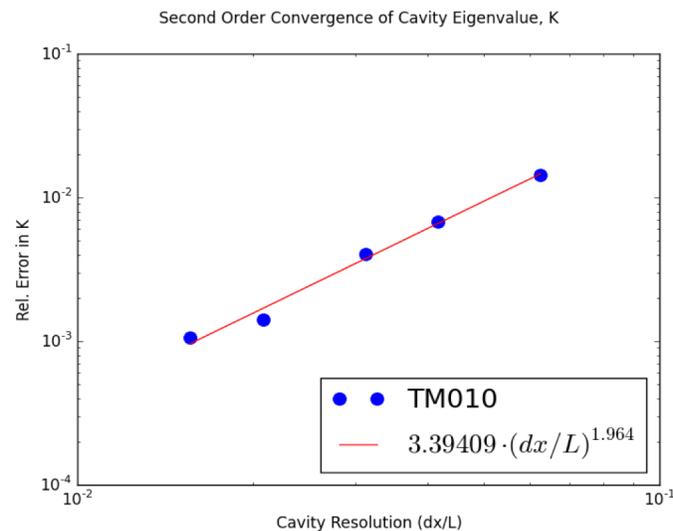
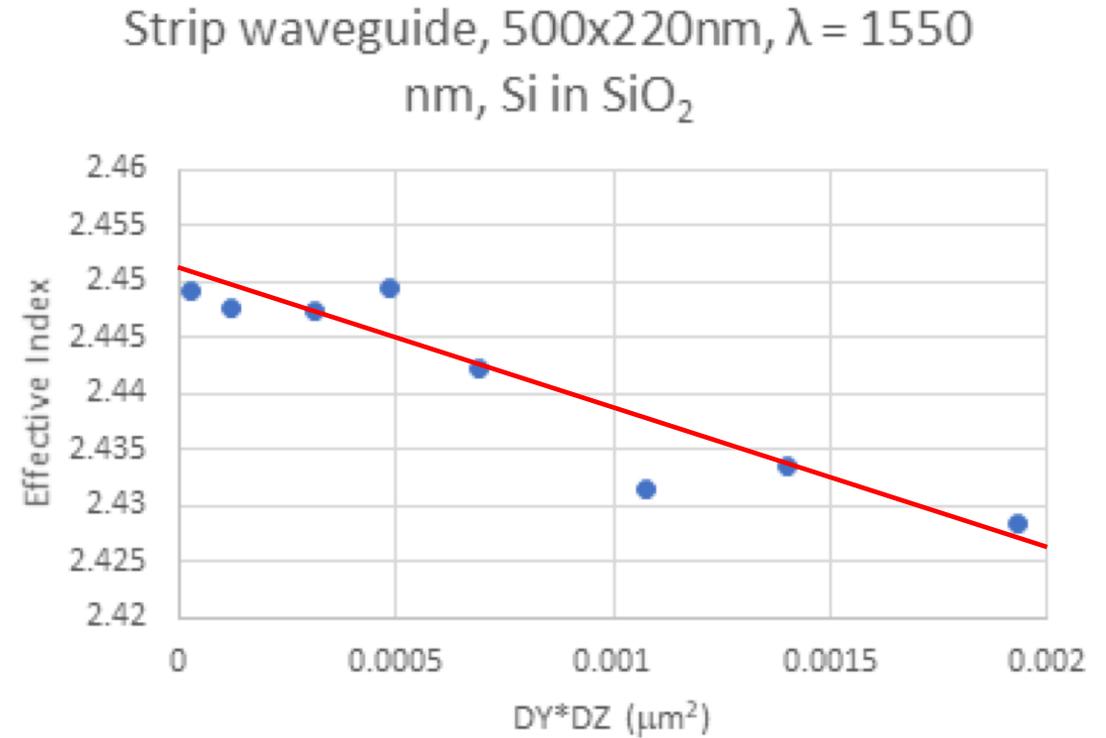
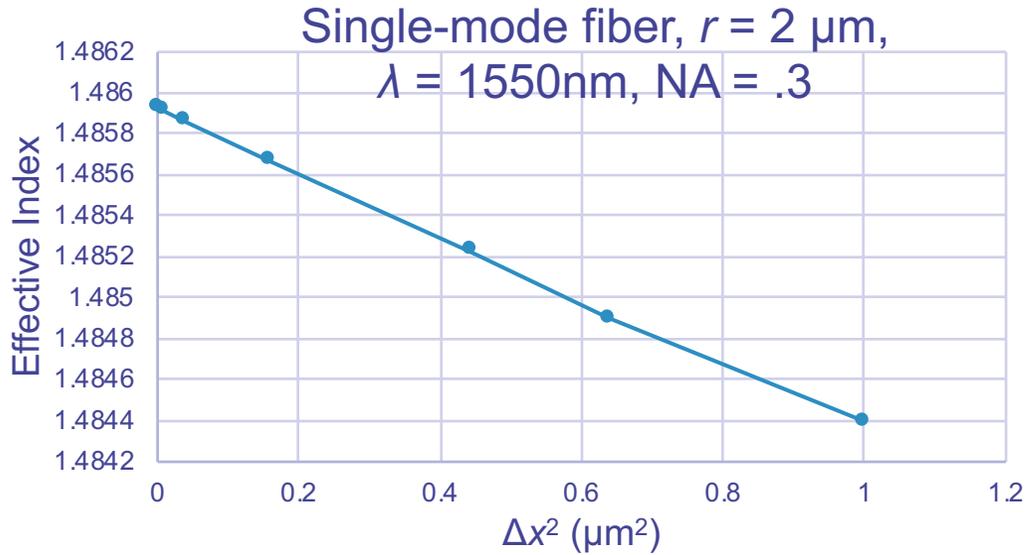
Setup: BUSY Setting up simulation... Show Log

Features for dielectric acceleration

- Nonlinear, isotropic and anisotropic dielectrics
- Second-order dispersive dielectrics
- Beam self-field initialization
- Direct particle-material interactions



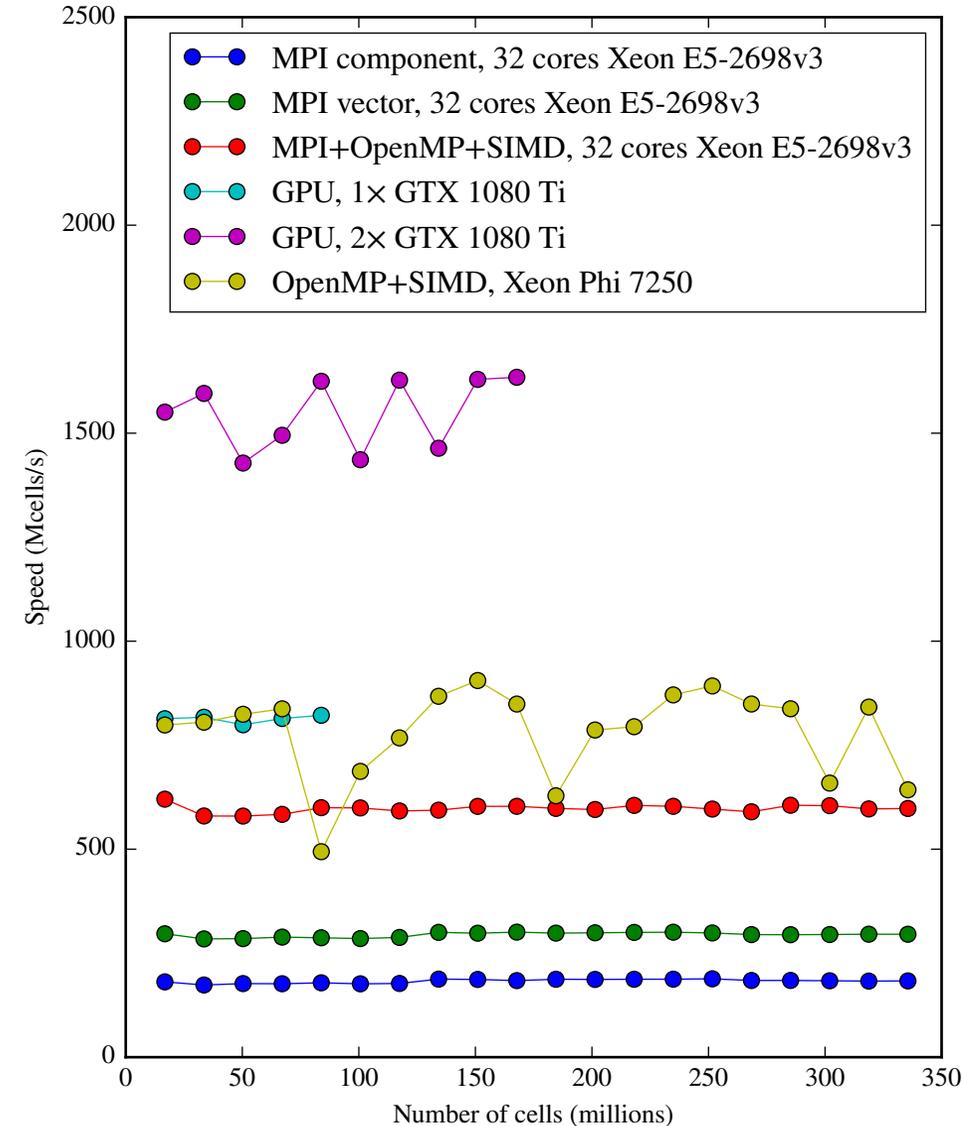
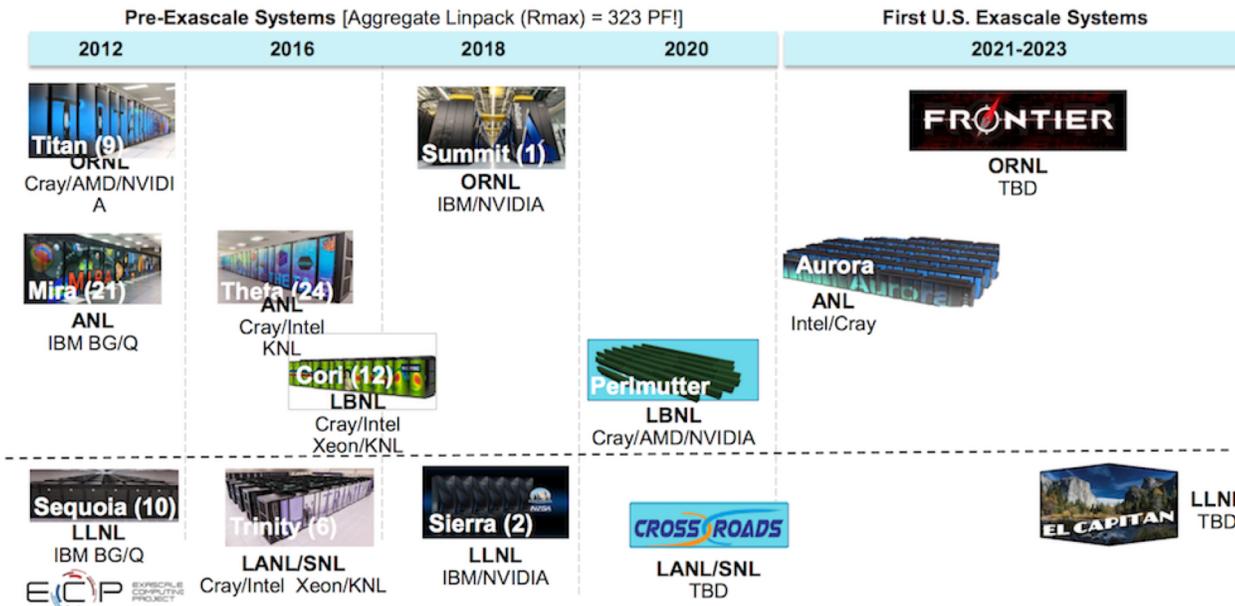
Convergence plots show second-order accuracy for mode and time domain solver



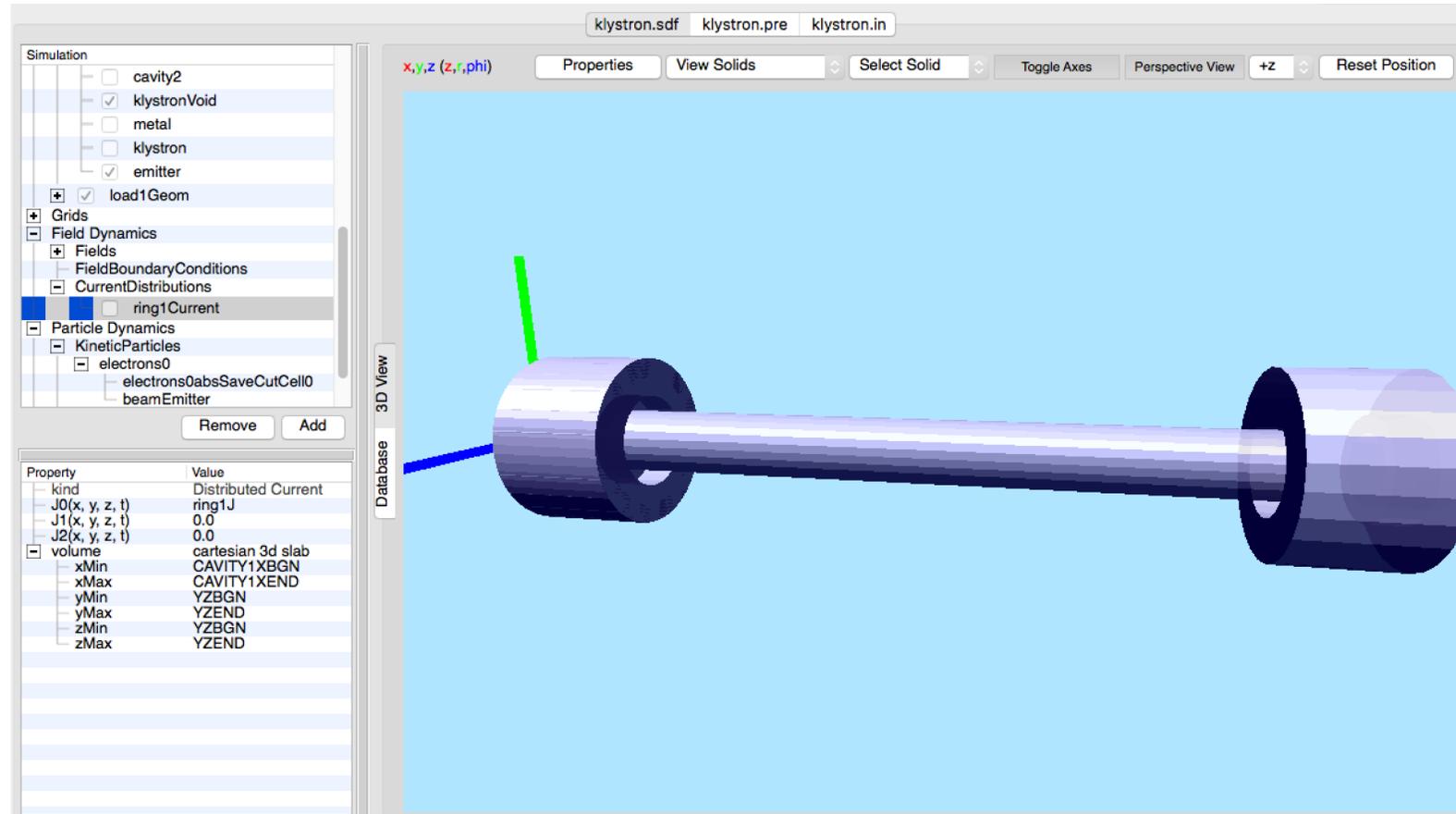
- VSim moving to advanced architectures
 - GPUs
 - Many-core CPUs with vector instructions
- Including all features: Fields, particles, materials, reactions (including RR),...

Department of Energy (DOE) Roadmap to Exascale Systems

An impressive, productive lineup of *accelerated node* systems supporting DOE's mission

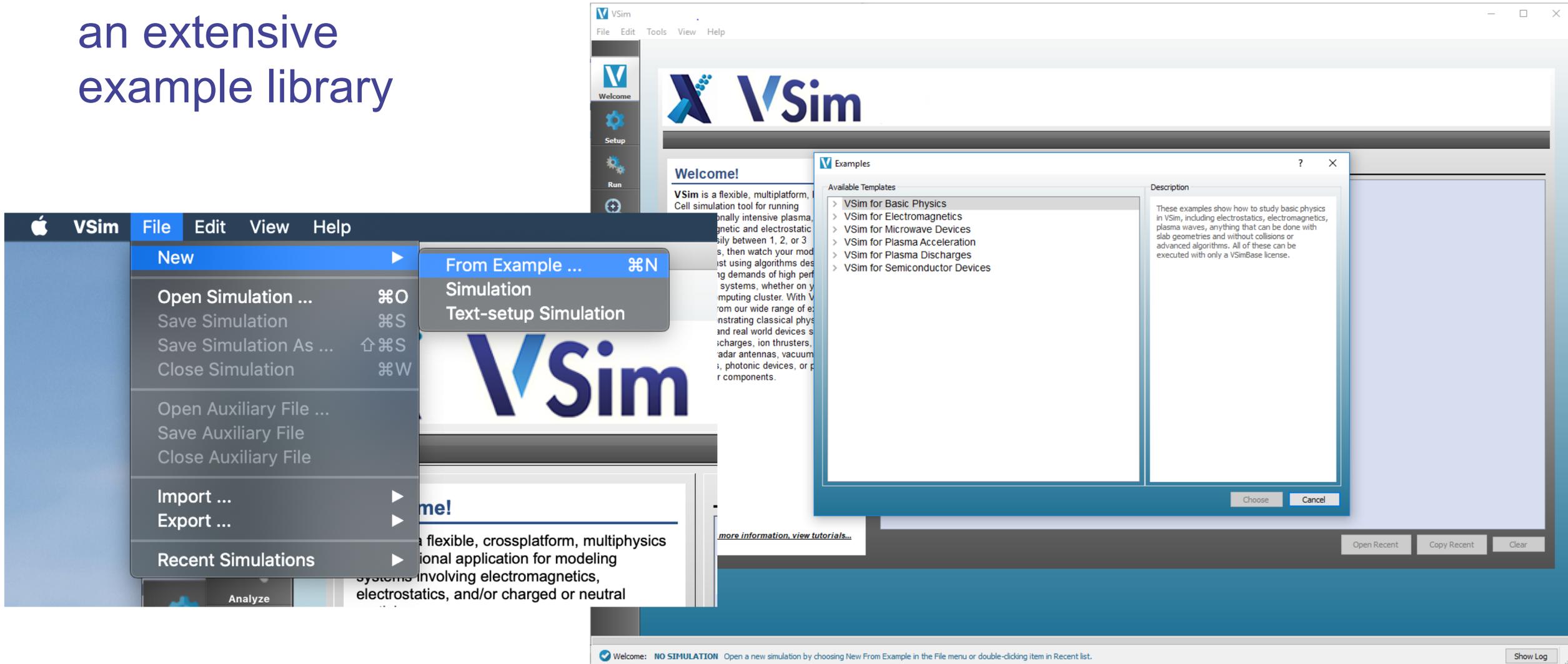


- Entire simulation workflow runs through GUI
- Geometry creation
 - From primitives
 - Import from CAD
- Choose simulation dimension and solvers
- Set up fields and particles
- Create custom functions
- Add reactions, diagnostics,...
- Run simulation
- Visualize and analyze results



Examples

- VSim comes with an extensive example library



The screenshot displays the VSim software interface. The 'File' menu is open, showing options like 'New', 'Open Simulation ...', 'Save Simulation', and 'Recent Simulations'. The 'New' submenu is expanded, highlighting 'From Example ...'. An 'Examples' dialog box is open, listing available templates such as 'VSim for Basic Physics', 'VSim for Electromagnetics', and 'VSim for Microwave Devices'. The dialog also includes a 'Description' field and 'Choose' and 'Cancel' buttons.

File Menu:

- New
- Open Simulation ... ⌘O
- Save Simulation ⌘S
- Save Simulation As ... ⇧⌘S
- Close Simulation ⌘W
- Open Auxiliary File ...
- Save Auxiliary File
- Close Auxiliary File
- Import ...
- Export ...
- Recent Simulations

Examples Dialog - Available Templates:

- > VSim for Basic Physics
- > VSim for Electromagnetics
- > VSim for Microwave Devices
- > VSim for Plasma Acceleration
- > VSim for Plasma Discharges
- > VSim for Semiconductor Devices

Examples Dialog - Description:

These examples show how to study basic physics in VSim, including electrostatics, electromagnetics, plasma waves, anything that can be done with slab geometries and without collisions or advanced algorithms. All of these can be executed with only a VSimBase license.

Status Bar:

Welcome: NO SIMULATION Open a new simulation by choosing New From Example in the File menu or double-clicking item in Recent list. Show Log

Custom workflows

- Add parameters that can be set in GUI
- Supercomputer workflow
 - Generate text input from GUI, transfer to supercomputer
 - Visualize using GUI on supercomputer
 - Try out using small-scale simulation
- Custom updates and solvers
- Scripting for parameter scans and optimization

VSim - Ionization Injection (text-based setup)

File Edit Tools View Help

Editor

fieldIonizeT.pre fieldIonizeT.in

NDIM 2

LX 30.0e-6

LY 40.0e-6

LZ 40.0e-6

GRID_RES_LONG 20.0

GRID_RES_TRANS 3.0

A_0 2.

WAVELENGTH 0.8e-6

LPUMP 4.5e-6

W_0 5.0e-6

X_0_LASER 25.0e-6

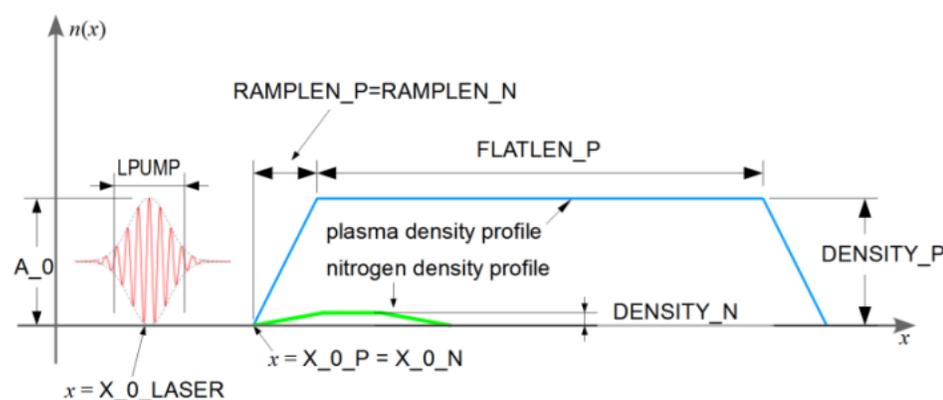
X_0_P 5.0e-6

RAMPLEN_P 5.0e-6

FLATLEN_P 1.0e-3

A demonstration of a laser plasma acceleration problem where electrons are trapped in the plasma wakefield due to tunneling ionization, by the laser field, of nitrogen atoms present in the plasma.

Note: For short simulation times and accurate results, this simulation requires running VSim with multiple processors. Given the default values of domain size and grid resolution, Tech-X recommends running this simulation with at least 8 processors.



The diagram illustrates the laser plasma acceleration setup. The vertical axis is $n(x)$ and the horizontal axis is x . A red laser pulse labeled LPUMP is shown at $x = X_0_LASER$ with amplitude A_0 . The plasma density profile (blue line) starts at $x = X_0_P = X_0_N$ and has a flat region of length $FLATLEN_P$. The nitrogen density profile (green line) is shown below the plasma density profile. The laser pulse length is $RAMPLEN_P = RAMPLEN_N$. The density profiles are labeled $DENSITY_P$ and $DENSITY_N$.

Setup: COMPLETED Click run to continue

Show Log

Contributions for ATF

- Make available at NERSC, other supercomputing centers
 - License for ATF users at supercomputers
 - Small-scale, short-term licenses for simulation setup
- Creation of ATF-specific examples
 - Cover major ATF use areas
 - Work with Tech-X Application Engineers
- ATF “library”
 - Inputs for ATF beam and laser pulse from experimental data
 - Parameterized
- Trainings, user group meetings