Simulation capabilities for ATF experiments

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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

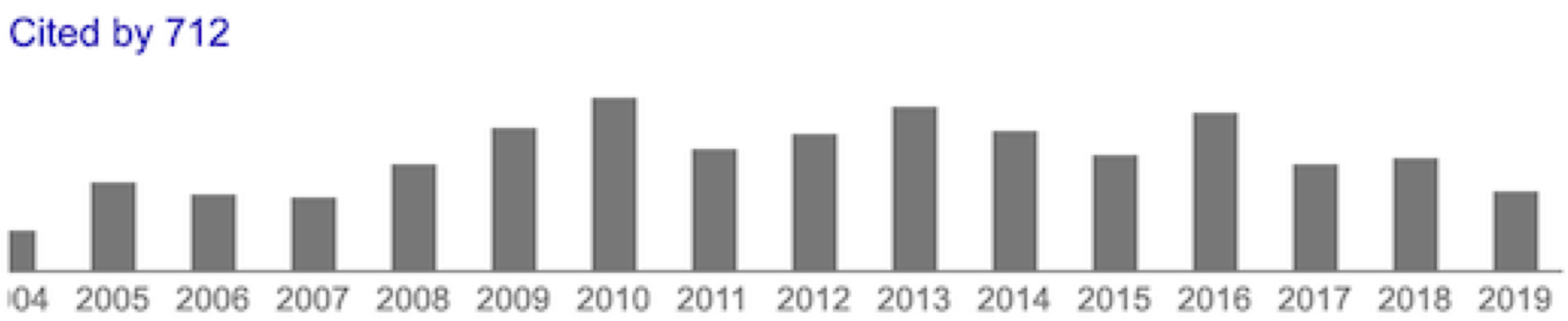
Outline:

- Tech-X code capabilities
- Workflow ideas

The VSim simulation code

https://www.txcorp.com/vsim

- 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)



History of success—past and present

LETTER

doi:10.1038/nature12664

Demonstration of electron acceleration in a laser-driven dielectric microstructure

E. A. Peralta[1], K. Soong[1], R. J. England[2], E. R. Colby[2], Z. Wu[2], B. Montazeri[3], C. McGuinness[1], J. McNeur[4], K. J. Leedle[3], D. Walz[2], E. B. Sozer[4], B. Cowan[5], B. Schwartz[5], G. Travish[4] & R. L. Byer[1]

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. Knetsch[6], P. Scherkl[4,5], G. G. Manahan[4,5],

nature COMMUNICATIONS

ARTICLE

Received 16 Dec 2016 | Accepted 21 Apr 2017 | Published 5 Jun 2017 DOI: 10.1038/ncomms15705 OPEN

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

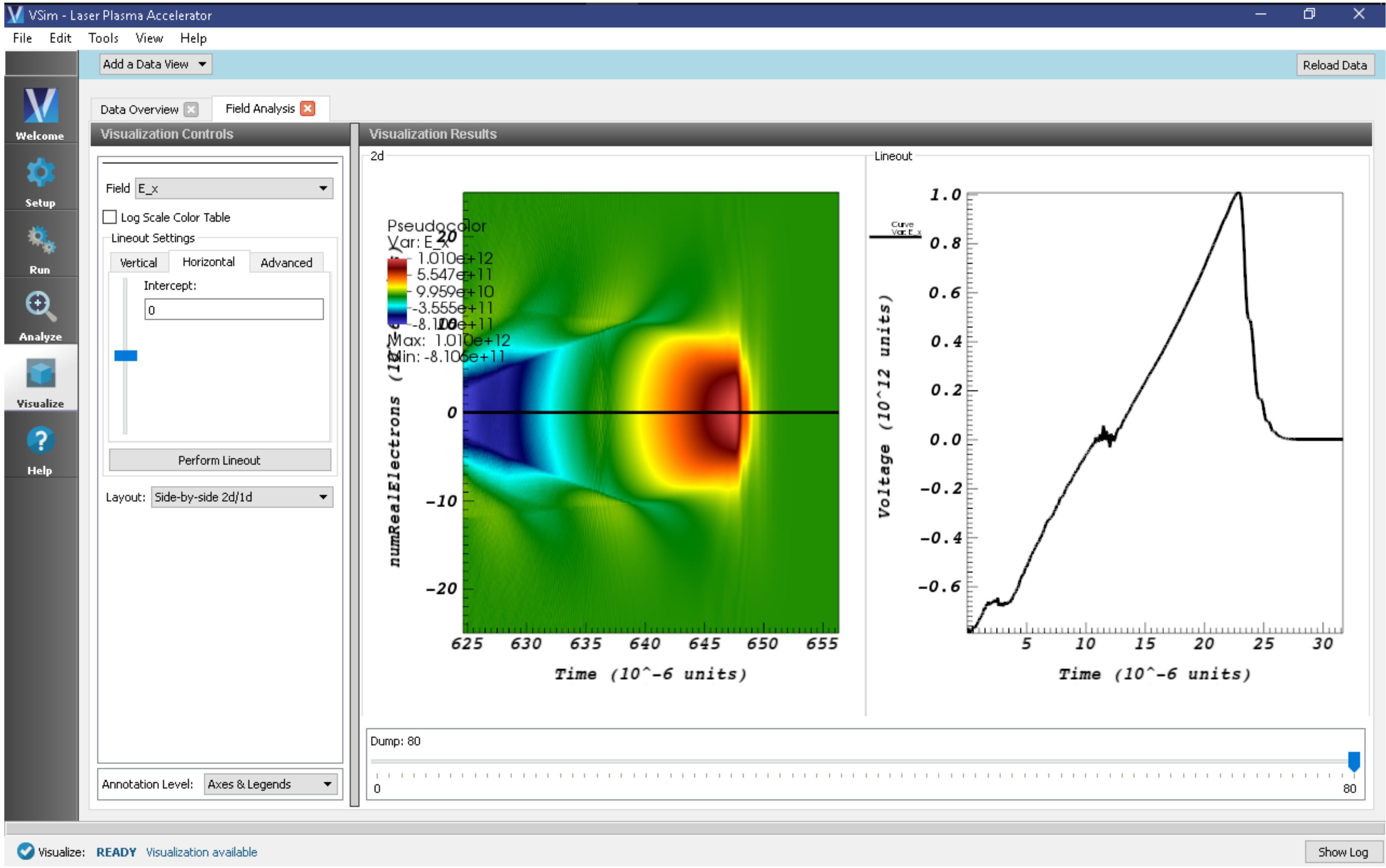
G.G. Manahan[1,2], A.F. Habib[1,2,3], P. Scherkl[1,2], P. Delinikolas[1,2], A. Beaton[1,2], A. Knetsch[3], O. Karger[3], G. Wittig[3],

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

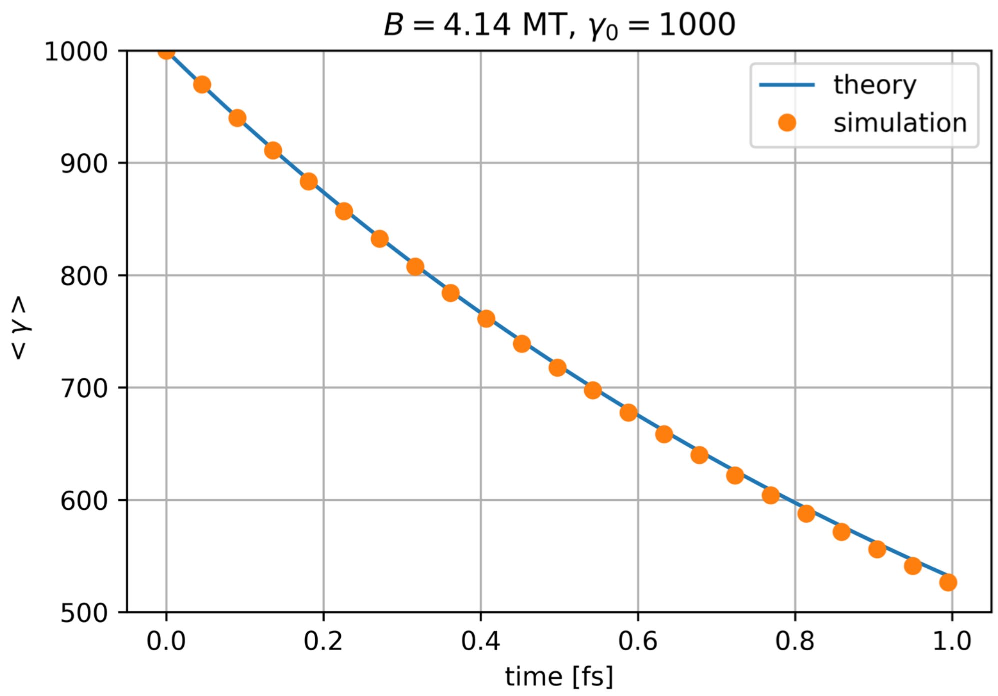


Radiation Reaction in VSim

- 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

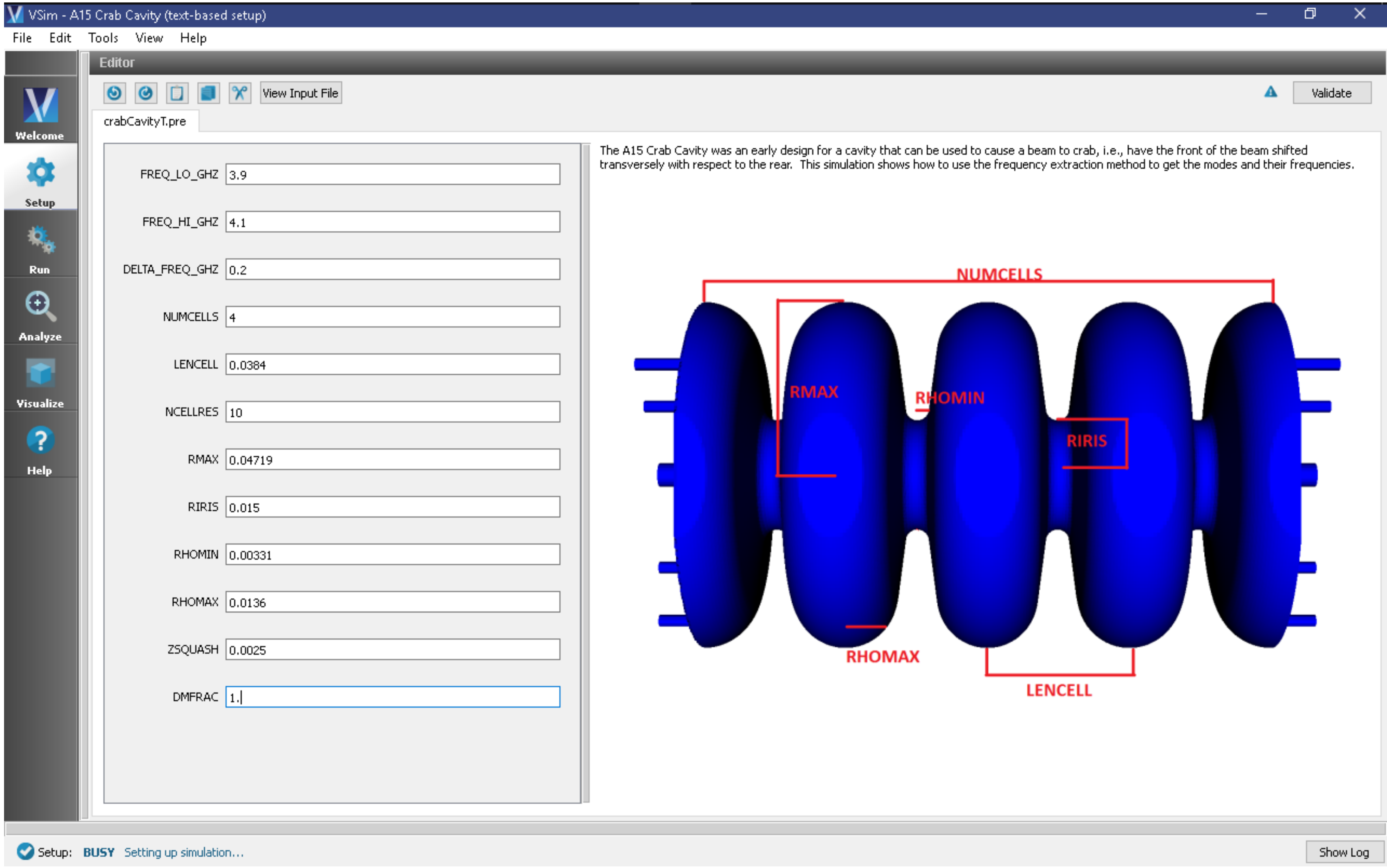
$$\eta = \frac{e\hbar}{m_e^3 c^4}|F_{\mu v} p^v| \simeq \frac{\gamma}{E_s}\sqrt{(\vec{E} + \vec{v} \times \vec{B})^2}$$

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



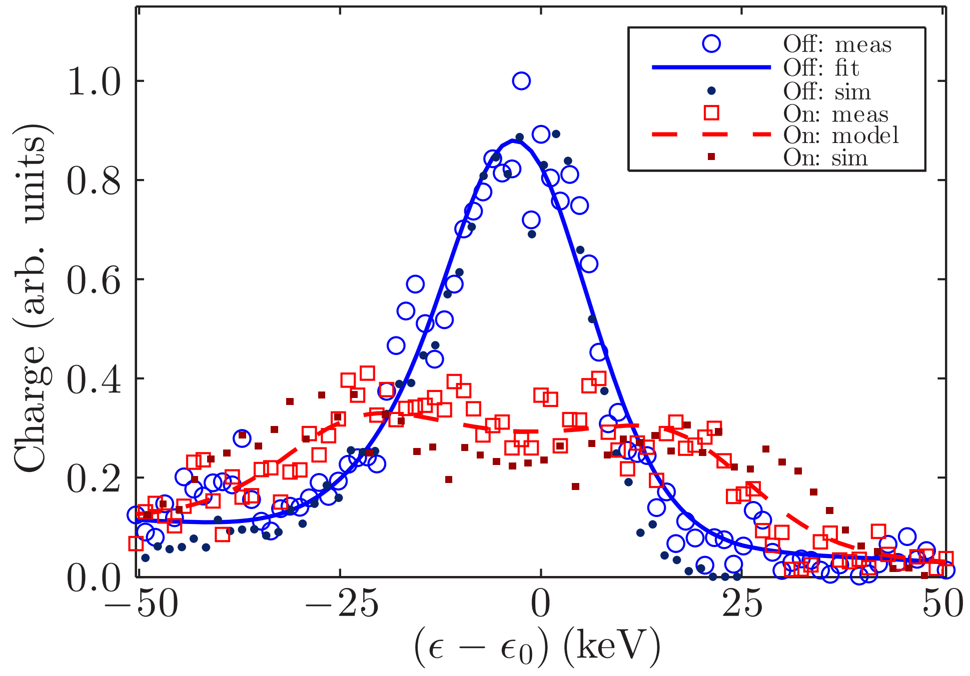
Features for EM structures

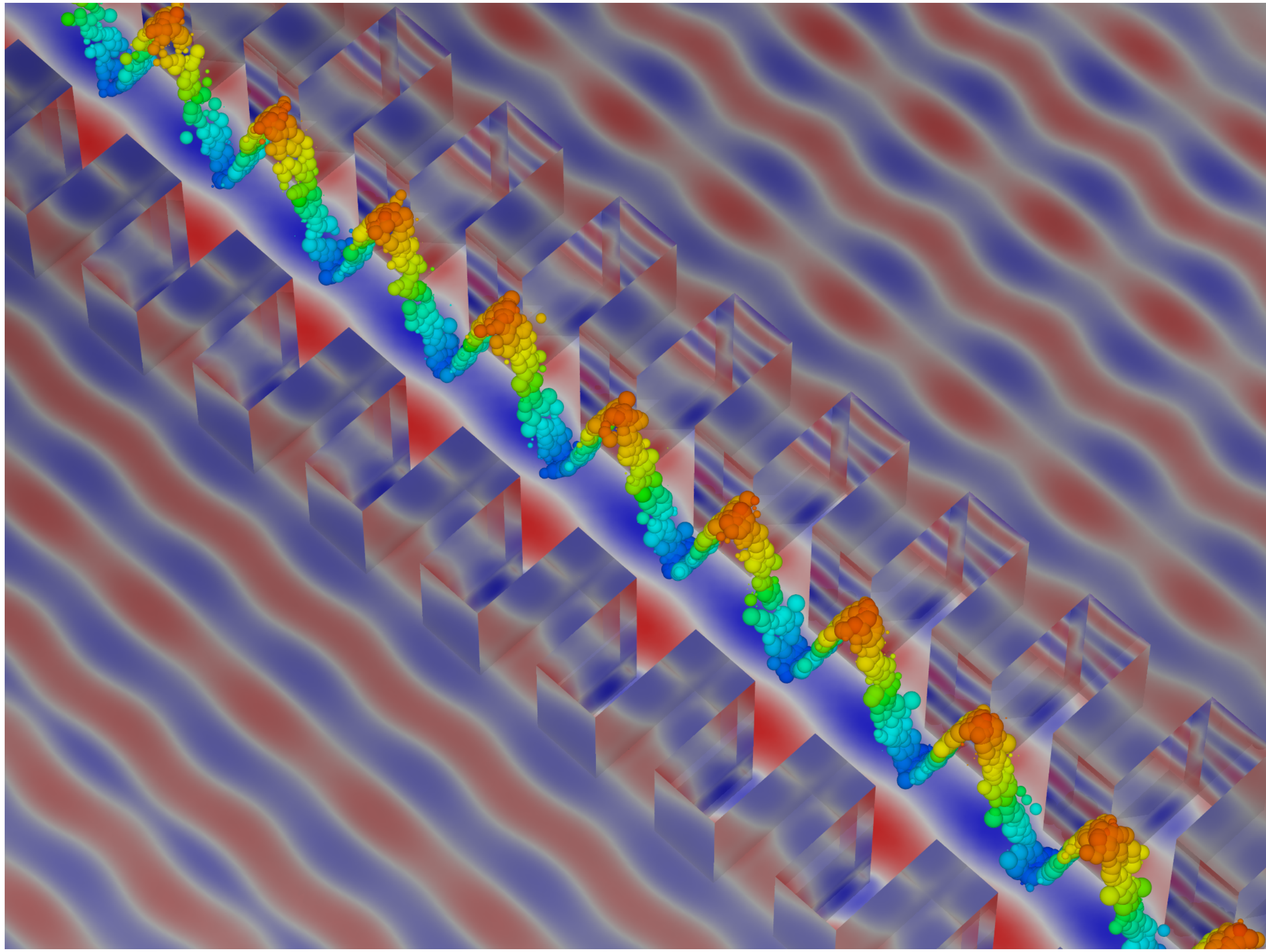
- Cut-cell electromagnetics
- CAD import
- Secondary electron emission for multipacting
- Eigenmode solver
- Parameter sweeping and optimization
- Many forms of field excitation



Features for dielectric acceleration

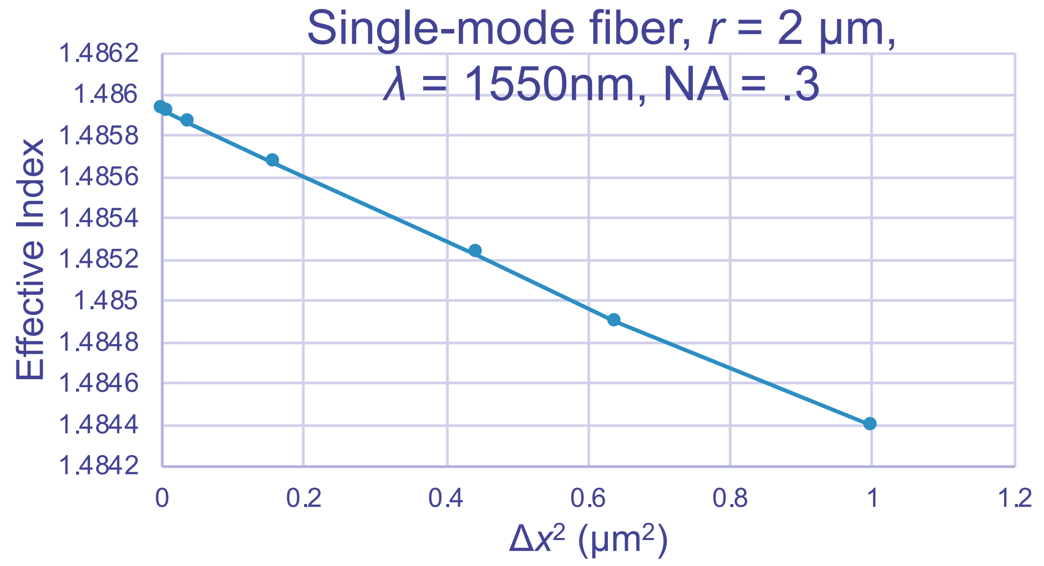
- Nonlinear, isotropic and anisotropic dielectrics
- Second-order dispersive dielectrics
- Beam self-field initialization
- Direct particle-material interactions

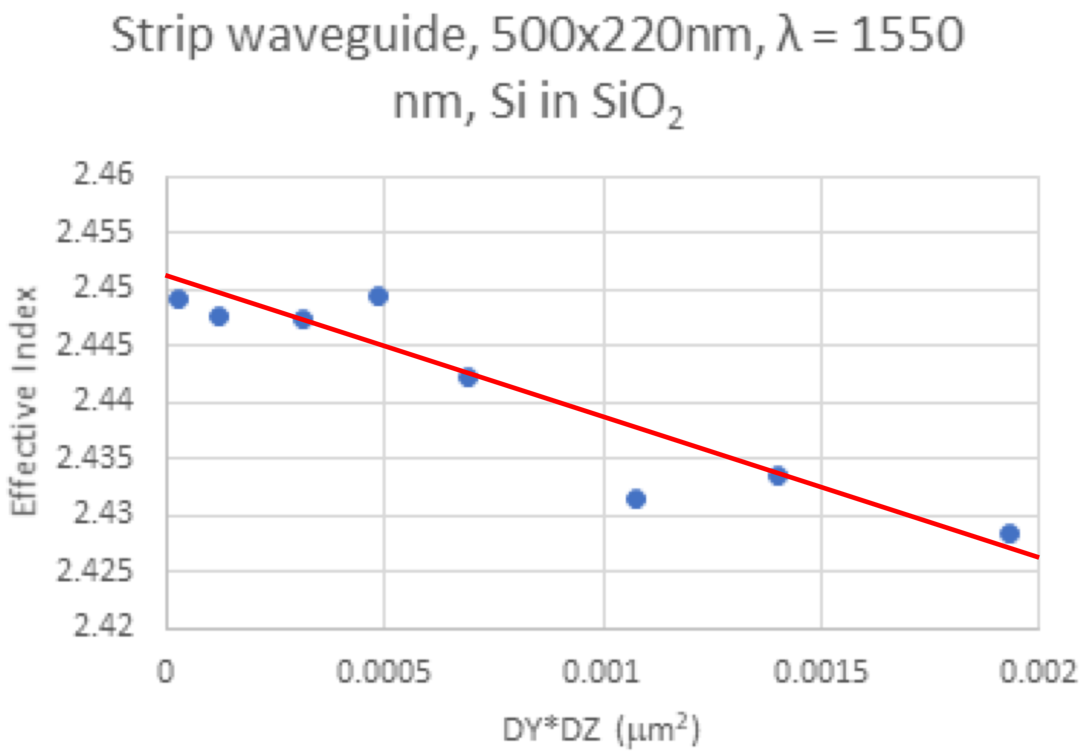


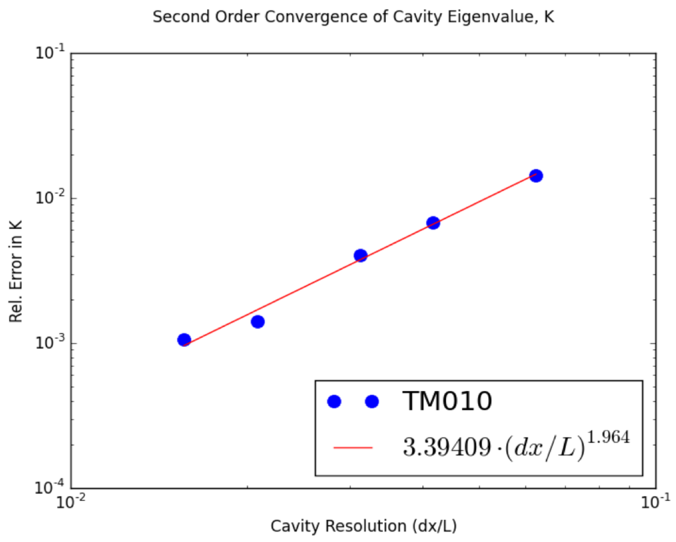


Wootton et al., Opt. Lett. 2016

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

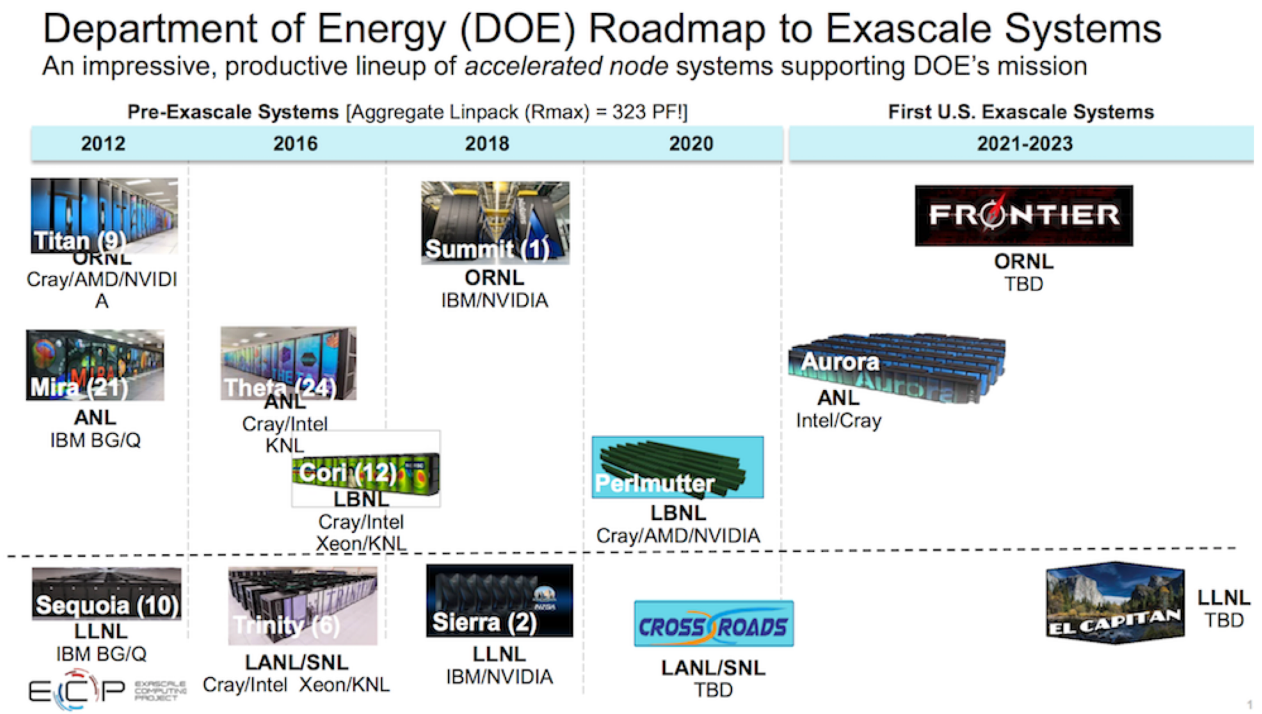


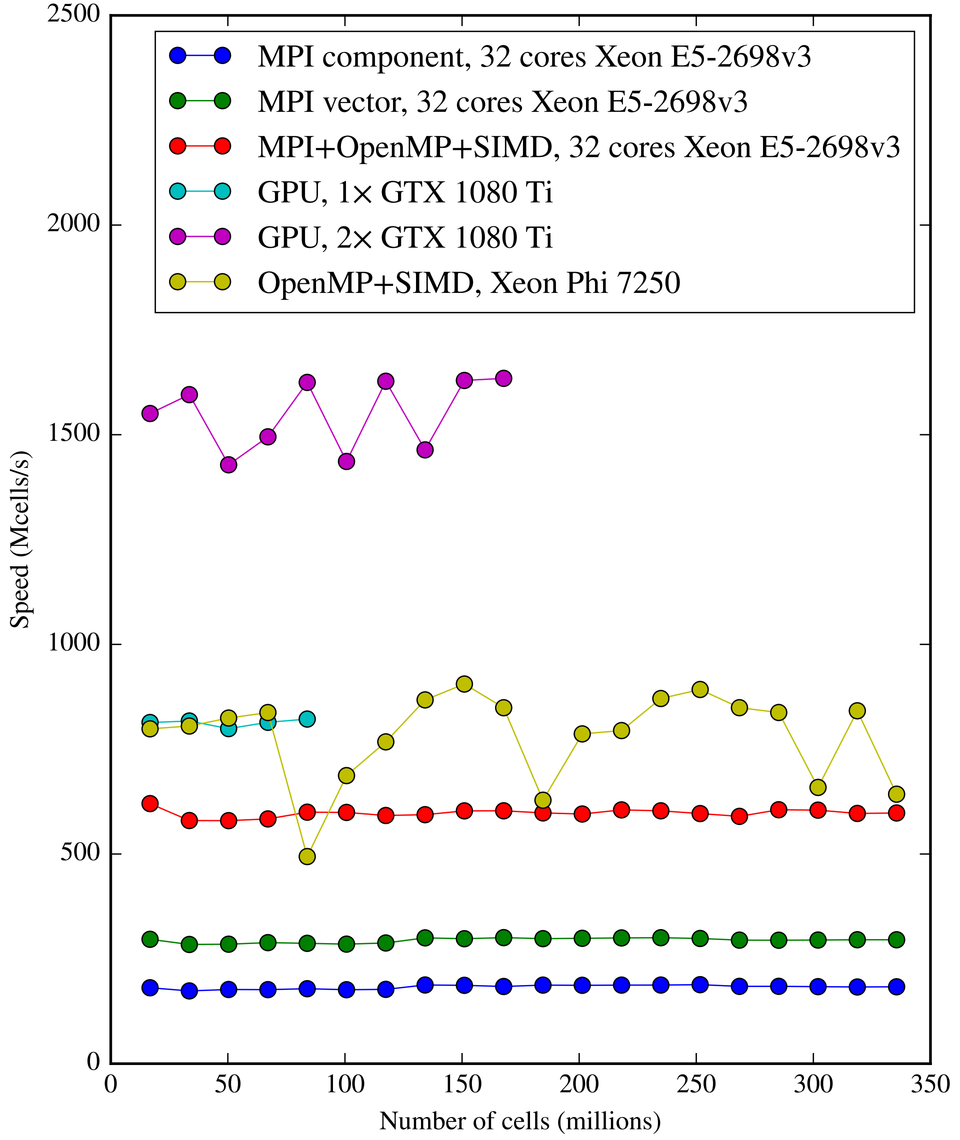




Performance

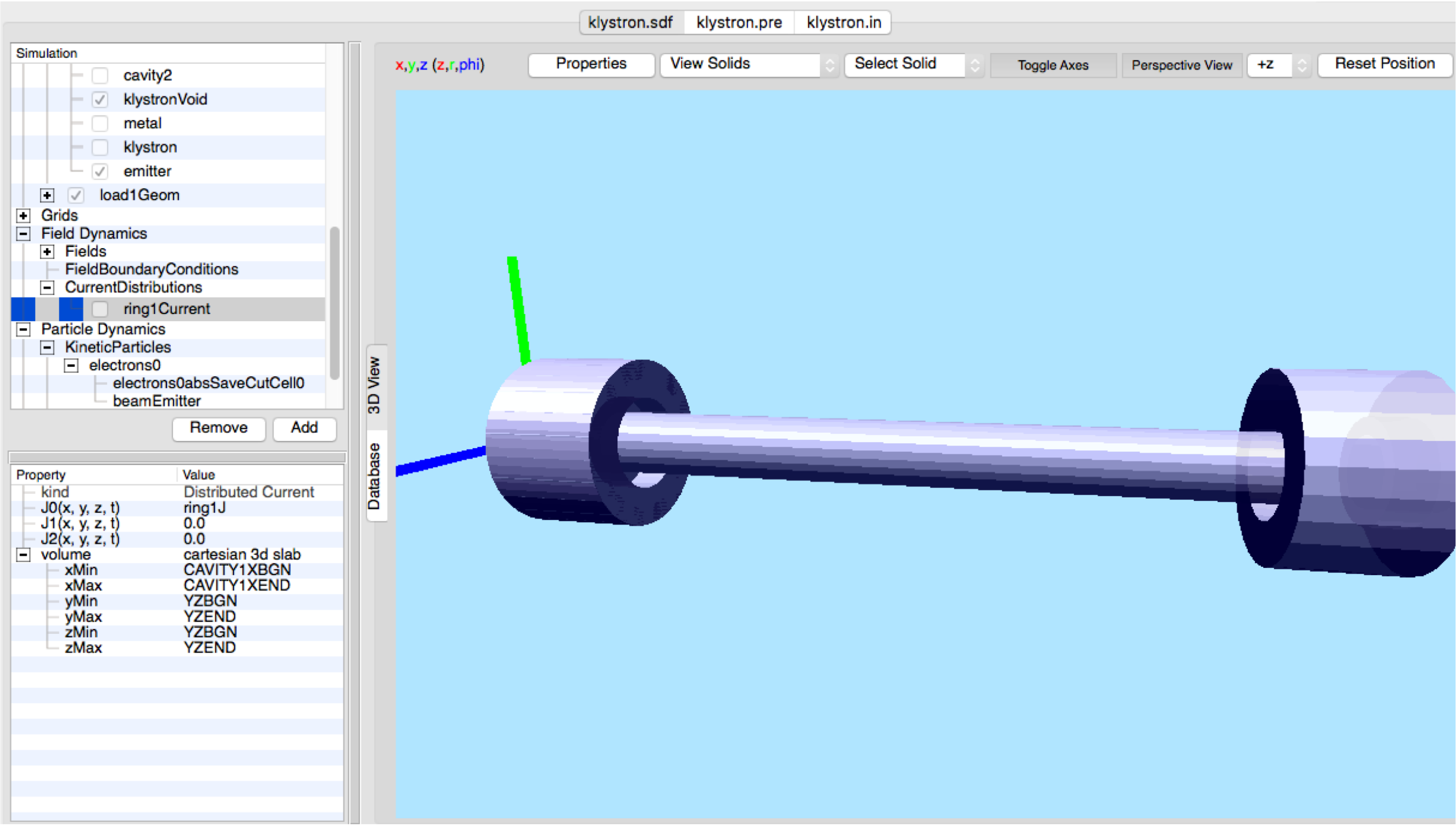
- VSim moving to advanced architectures
  - GPUs
  - Many-core CPUs with vector instructions
- Including all features: Fields, particles, materials, reactions (including RR),...





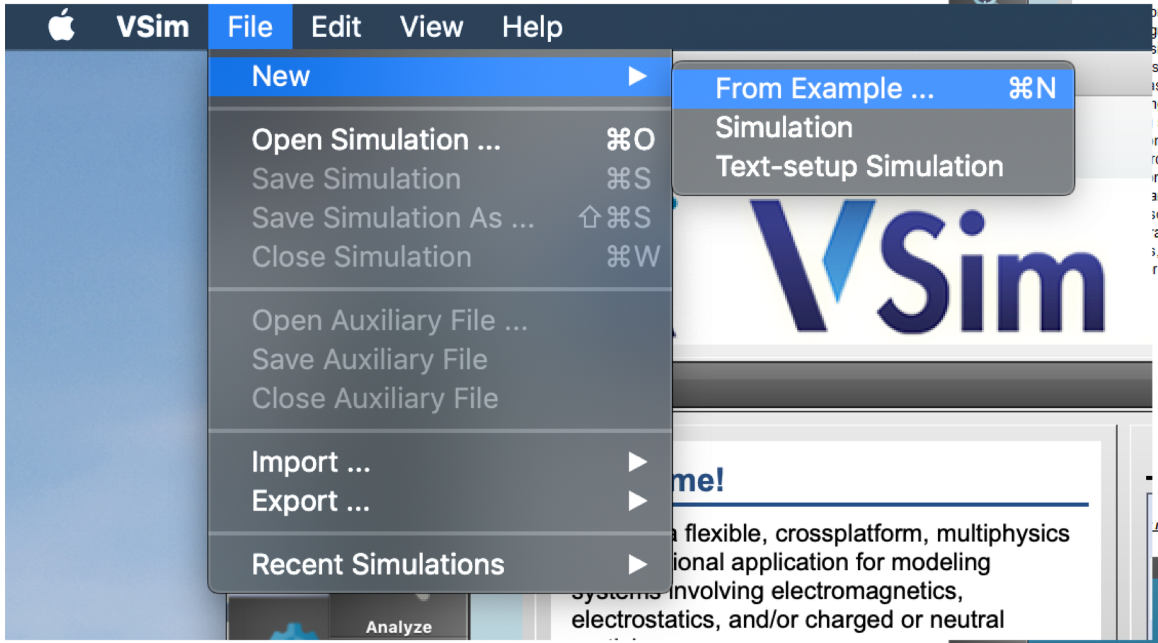
VSim GUI

- 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



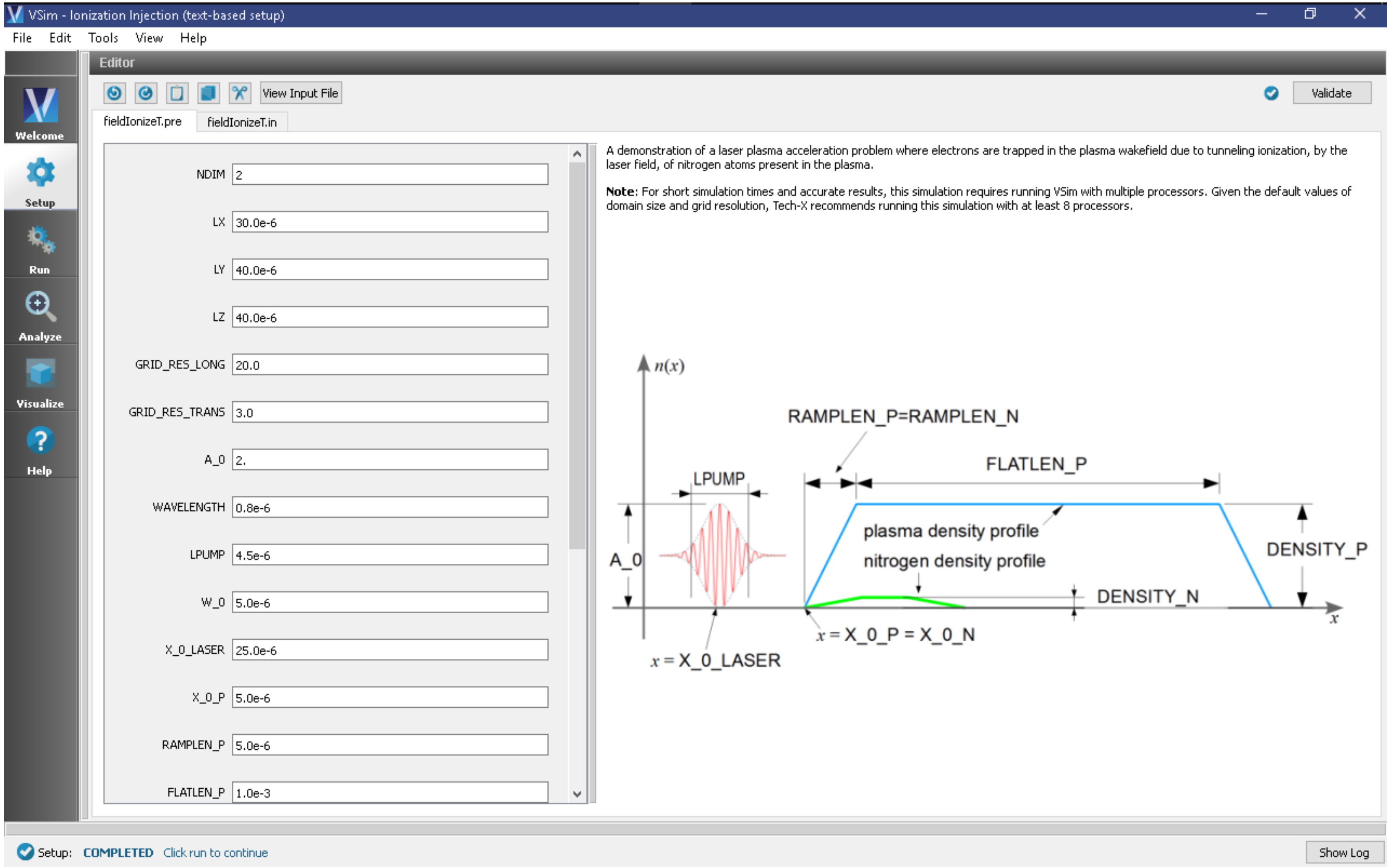
Examples

- VSim comes with an extensive example library



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



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