Recent results on computation of CLIC rf structures using ACE3P

Arno Candel, *Zenghai Li, Cho Ng, Vineet Rawat,*
Greg Schussman and Kwok Ko

IWLC2010 Workshop, Geneva, Oct 18-22 2010

Work supported by US DOE Offices of HEP, ASCR and BES under contract AC02-76SF00515.

SLAC NATIONAL ACCELERATOR LABORATORY

Parallel Finite Element EM Code Suite ACE3P

Over more than a decade, SLAC has developed the conformal, higher-order, C++/MPI-based parallel finite-element suite of electromagnetic codes for high-fidelity modeling of complex accelerator structures.

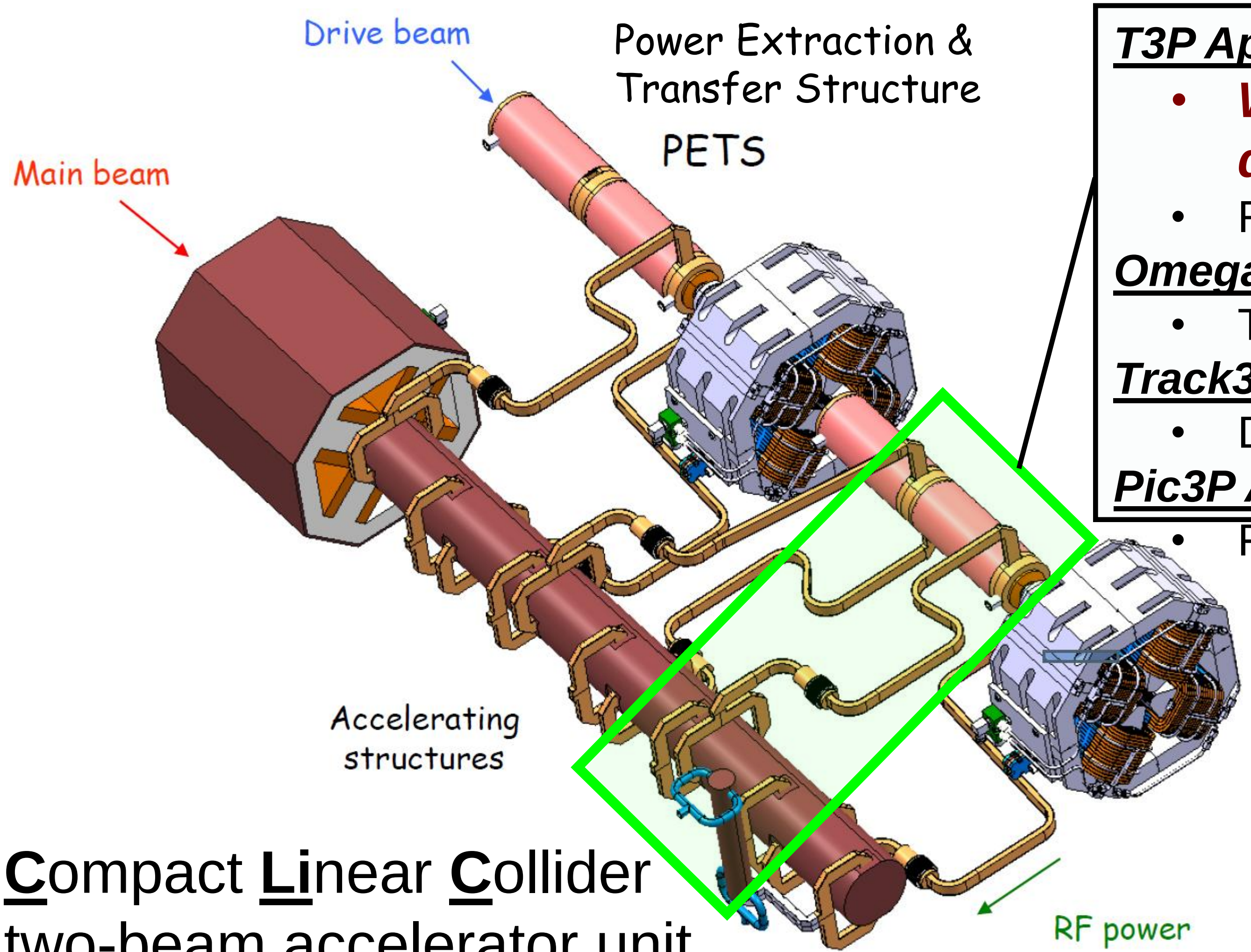
ACE3P (**A**dvanced **C**omputational **E**lectromagnetics **3**D **P**arallel) code suite:

ACE3P Modules		– Accelerator Physics Application
Frequency Domain:	Omega3P	– Eigensolver (nonlinear, damping)
	S3P	– S-Parameter
Time Domain:	T3P	– Wakefields and Transients
Particle Tracking:	Track3P	– Multipacting and Dark Current
EM Particle-In-Cell:	Pic3P	– RF Guns (self-consistent)

Visualization: ParaView – Meshes, Fields and Particles

>>> Aiming at Virtual Prototyping of accelerator structures

CLIC Two-Beam Accelerator



T3P Applications:
- ***Wakefield damping***
- RF power transfer

Omega3P Applications:
- Trapped modes

Track3P Applications:
- Dark current

Pic3P Applications:
- Field emission

Compact **Li**near **C**ollider
two-beam accelerator unit

Picture courtesy CERN

T3P – Finite Element EM Time-Domain Code

Built on the ACE3P parallel Finite Element framework, T3P integrates Maxwell's equations in time to compute transients & wakefield effects.

Combine Ampere's and Faraday's laws

$$\nabla\times\nabla\times\vec{E}+\mu\varepsilon\frac{\partial^2\vec{E}}{\partial t^2}+\mu\sigma_{eff}\frac{\partial\vec{E}}{\partial t}=-\mu\frac{\partial\vec{J}}{\partial t}$$

$$\sigma_{eff}=\omega\varepsilon_0\varepsilon_i$$

T3P models full-wave EM from first principles

Unconditionally stable time integration*

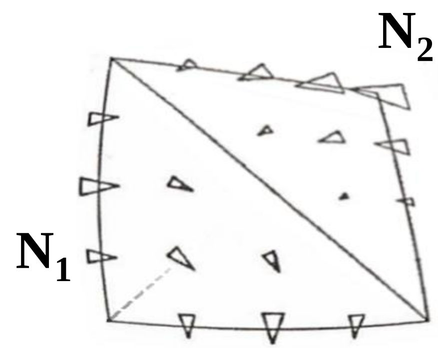
Solve linear system at every time step:

Ax=b

ACE3P Finite Element Method:

Curved tetrahedral finite elements with higher-order vector basis functions $\mathbf{N_i}$:

$$\mathbf{E}(\mathbf{x},t)=\sum_i e_i(t)\cdot\mathbf{N_i}(\mathbf{x})$$

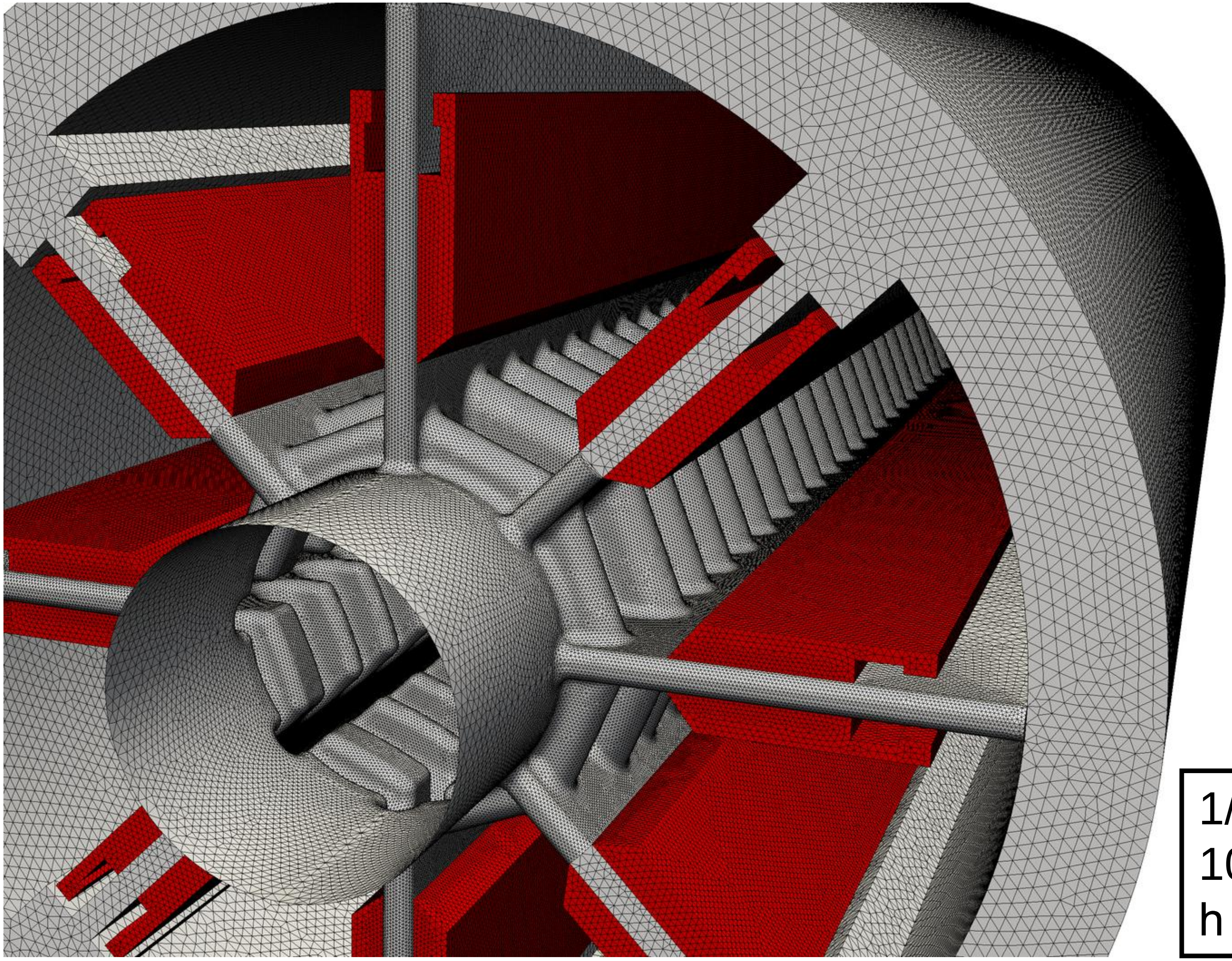


For order p=2: 20 different $\mathbf{N_i}$'s
For order p=6: 216 different $\mathbf{N_i}$'s

SLAC NATIONAL ACCELERATOR LABORATORY

***Navsariwala & Gedney**, *An unconditionally stable parallel finite element time domain algorithm*, Antennas and Propagation, **1996**

Unstructured Mesh Model of PETS

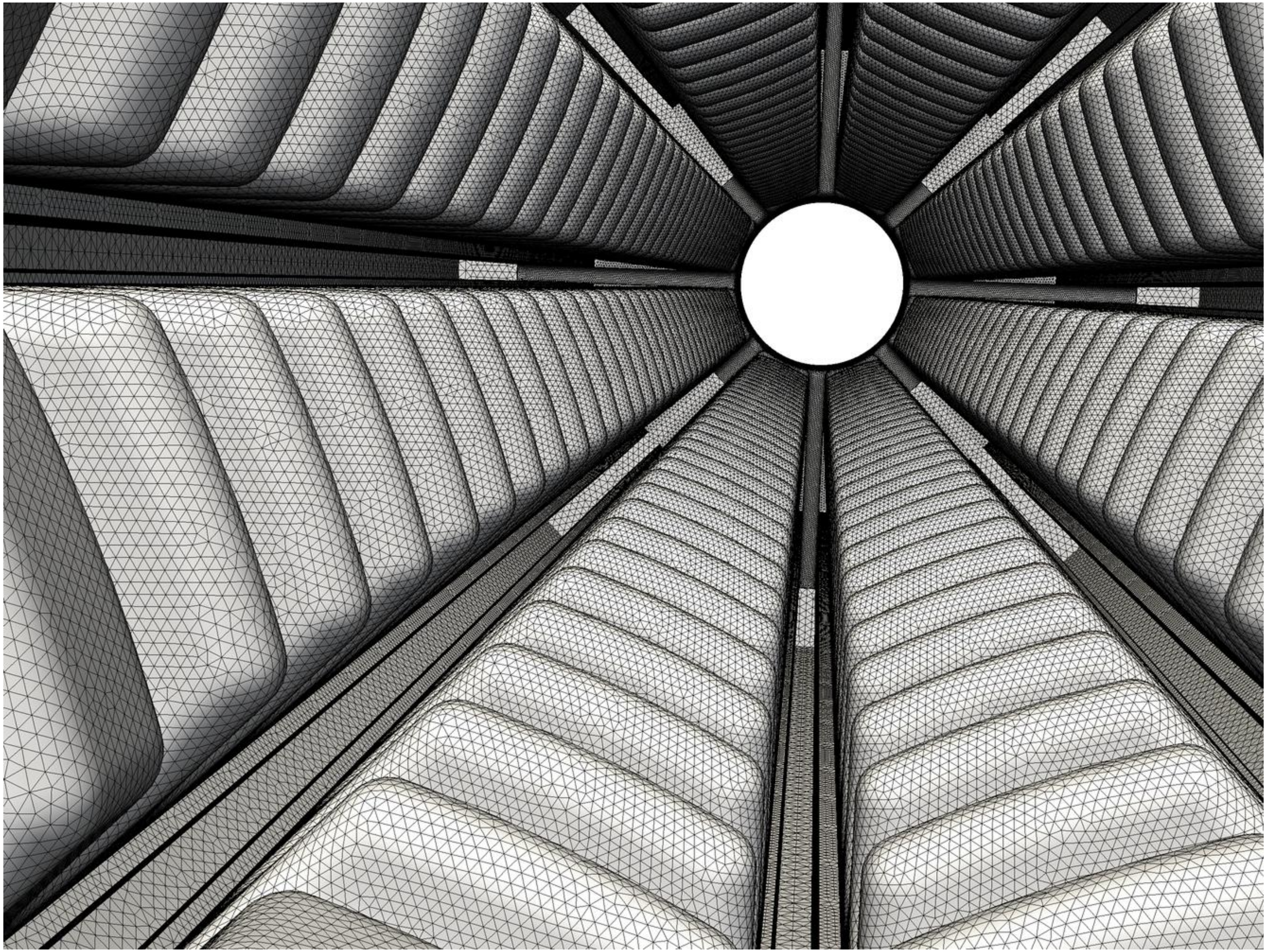


Dielectric absorbers (SiC)

1/4 model
10M elements
h ≥ 0.25 mm

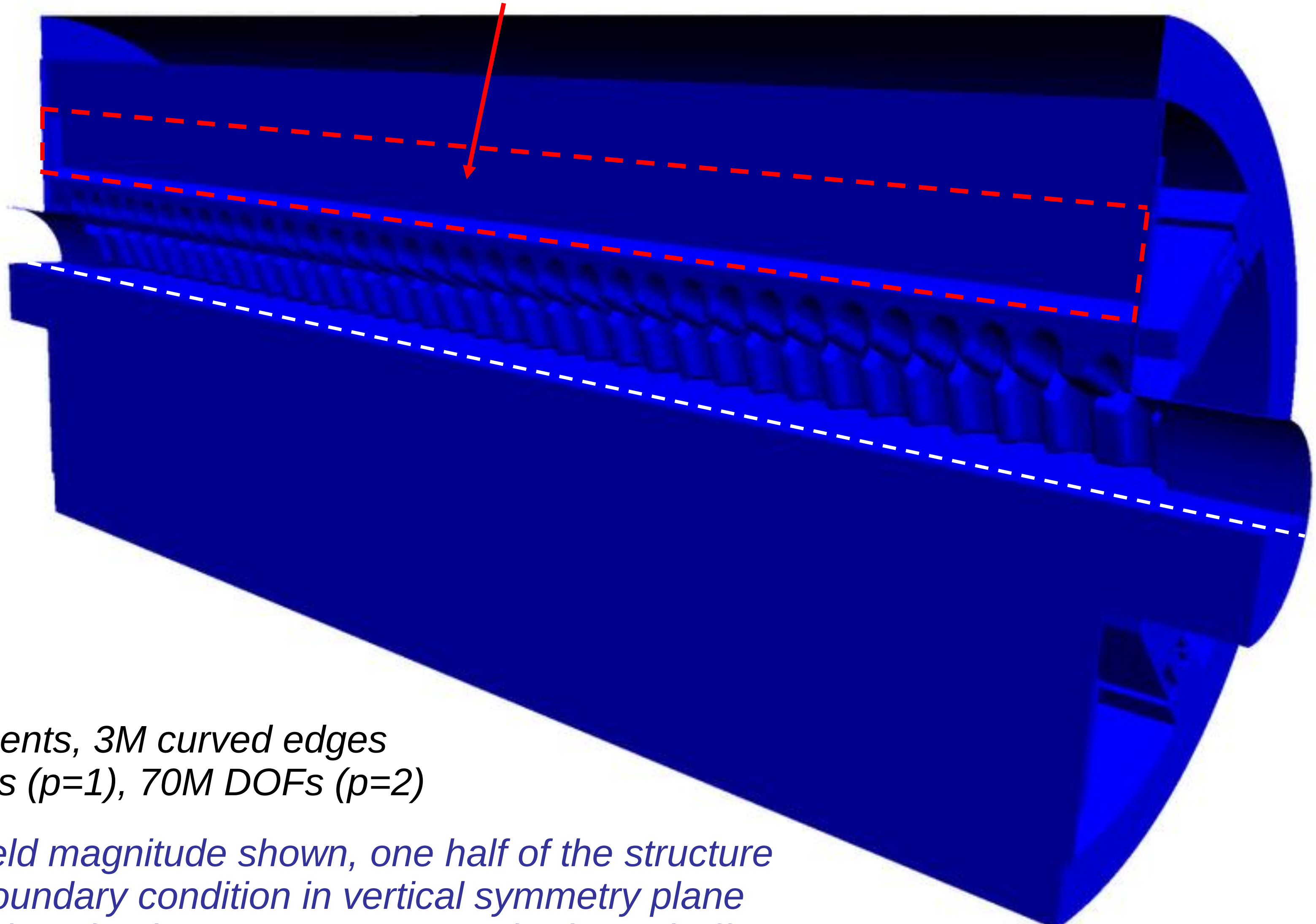
CAD model courtesy CERN (May 09)

Internal View of PETS - Curved Mesh



T3P – PETS Bunch Transit

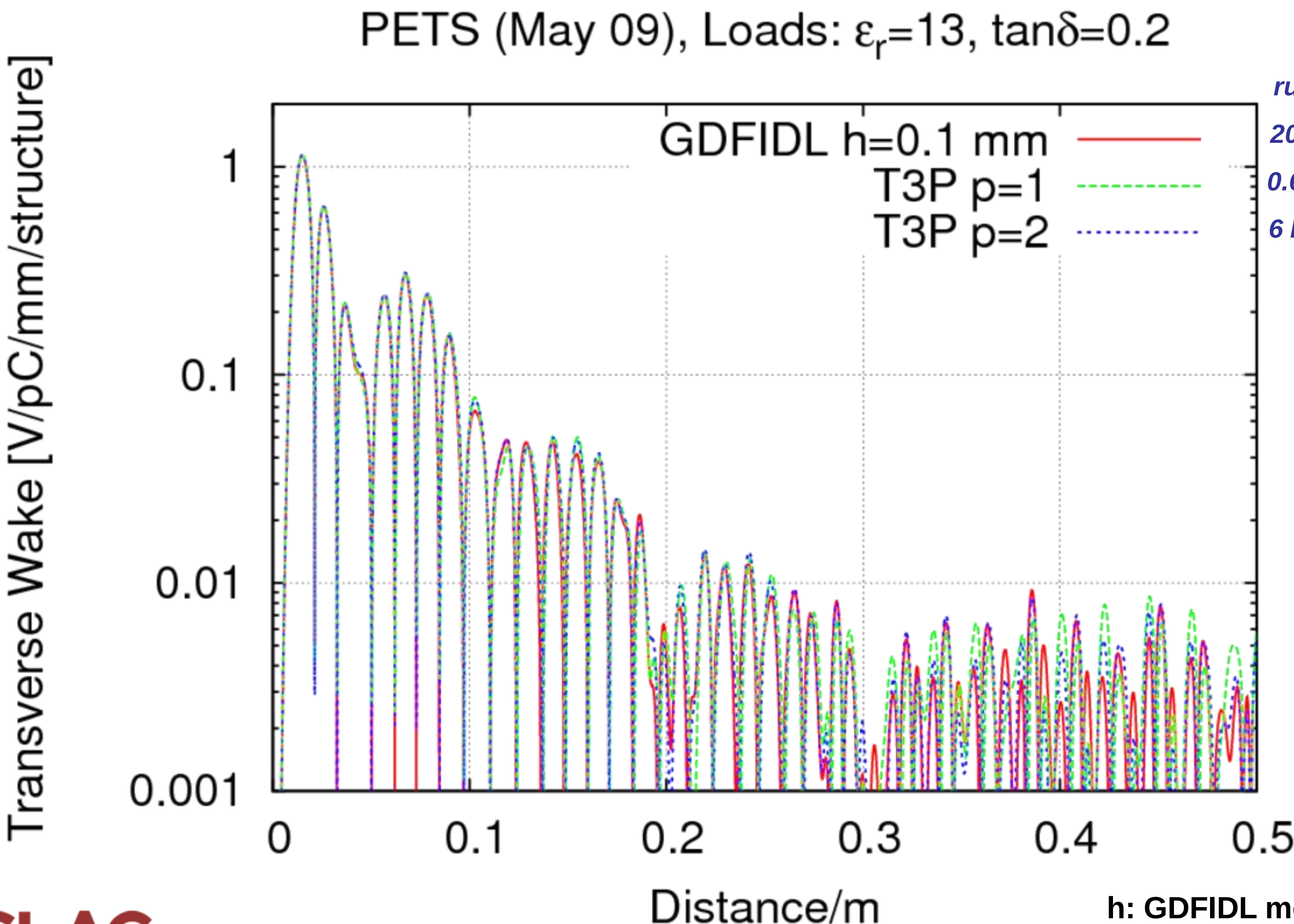
Dissipation of wakefields in dielectric loads: eps=13, tan(d)=0.2



10M elements, 3M curved edges
12M DOFs (p=1), 70M DOFs (p=2)

Electric field magnitude shown, one half of the structure
Electric boundary condition in vertical symmetry plane
Gaussian bunch, sigma=2 mm, 2.5 mm horizontal offset

PETS Wakefield Convergence/Benchmarking



runtime:

20 hours, 80 CPUs

0.6 hours, 1200 CPUs

6 hours, 4800 CPUs

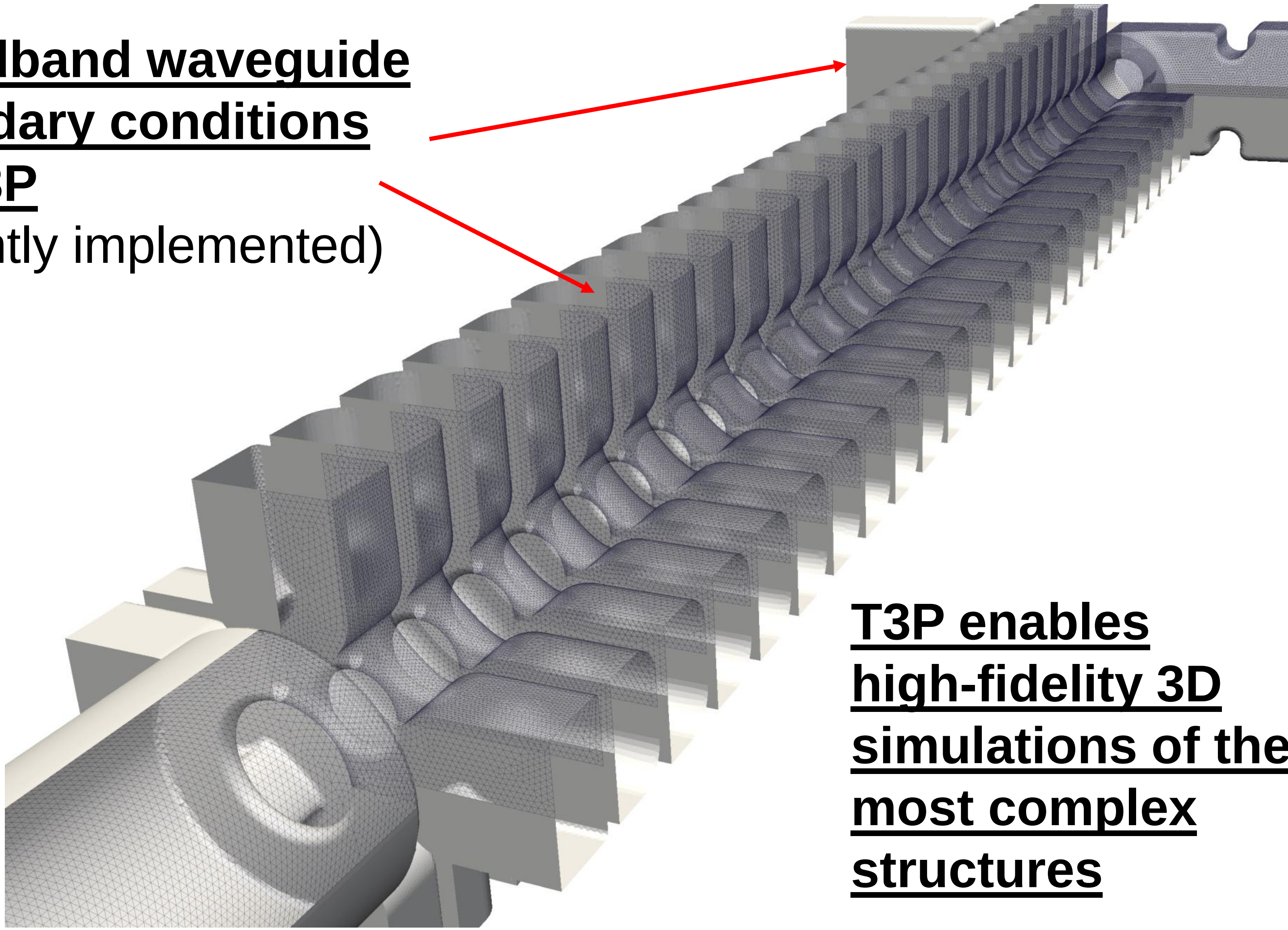
h: GDFIDL mesh step size

p: T3P basis function order

GDFIDL results by Igor Syratchev, CERN

CLIC TDA24 Accelerating Structure

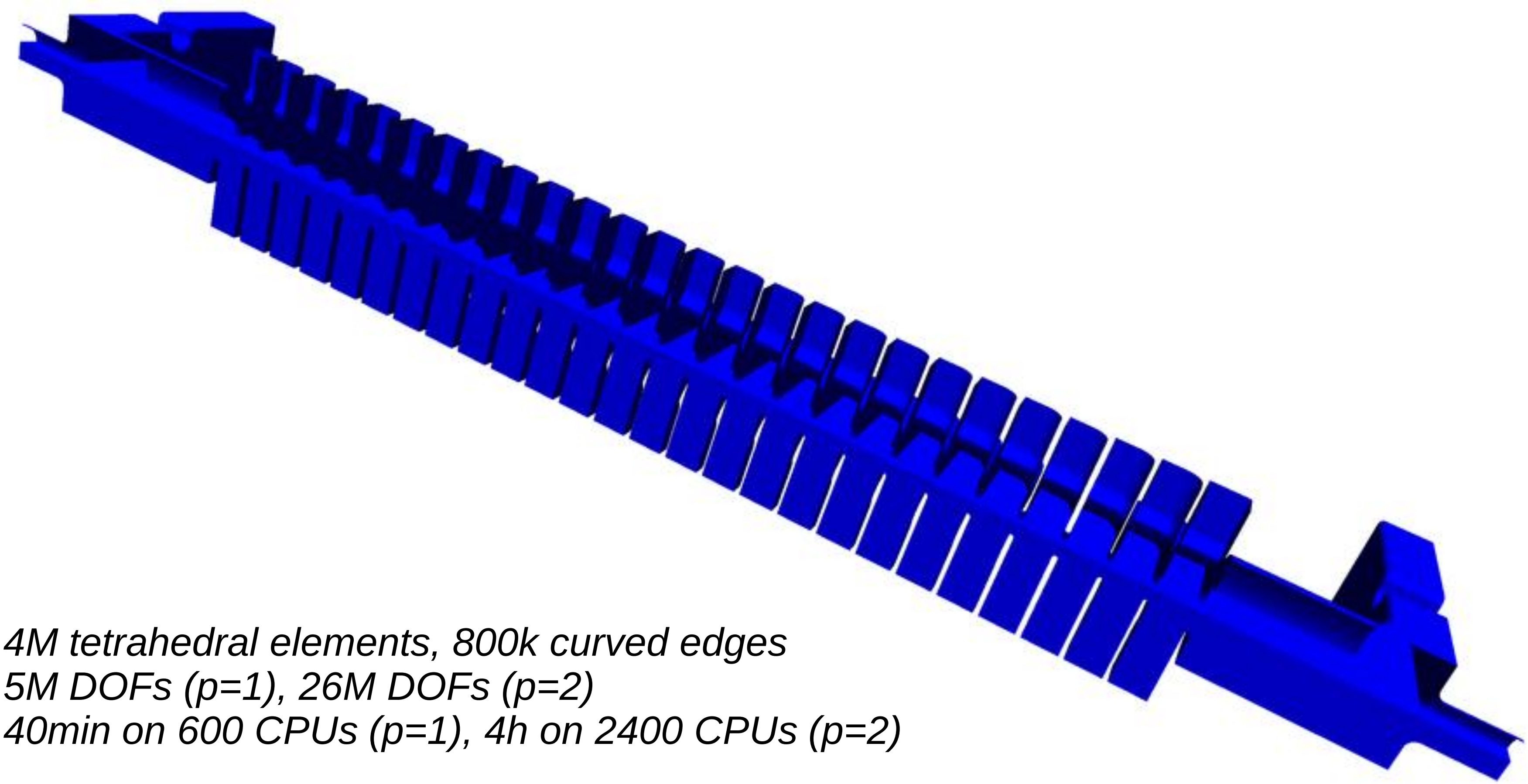
Broadband waveguide boundary conditions for T3P
(recently implemented)



T3P enables high-fidelity 3D simulations of the most complex structures

TDA24_vg1.8 *CAD model courtesy CERN*

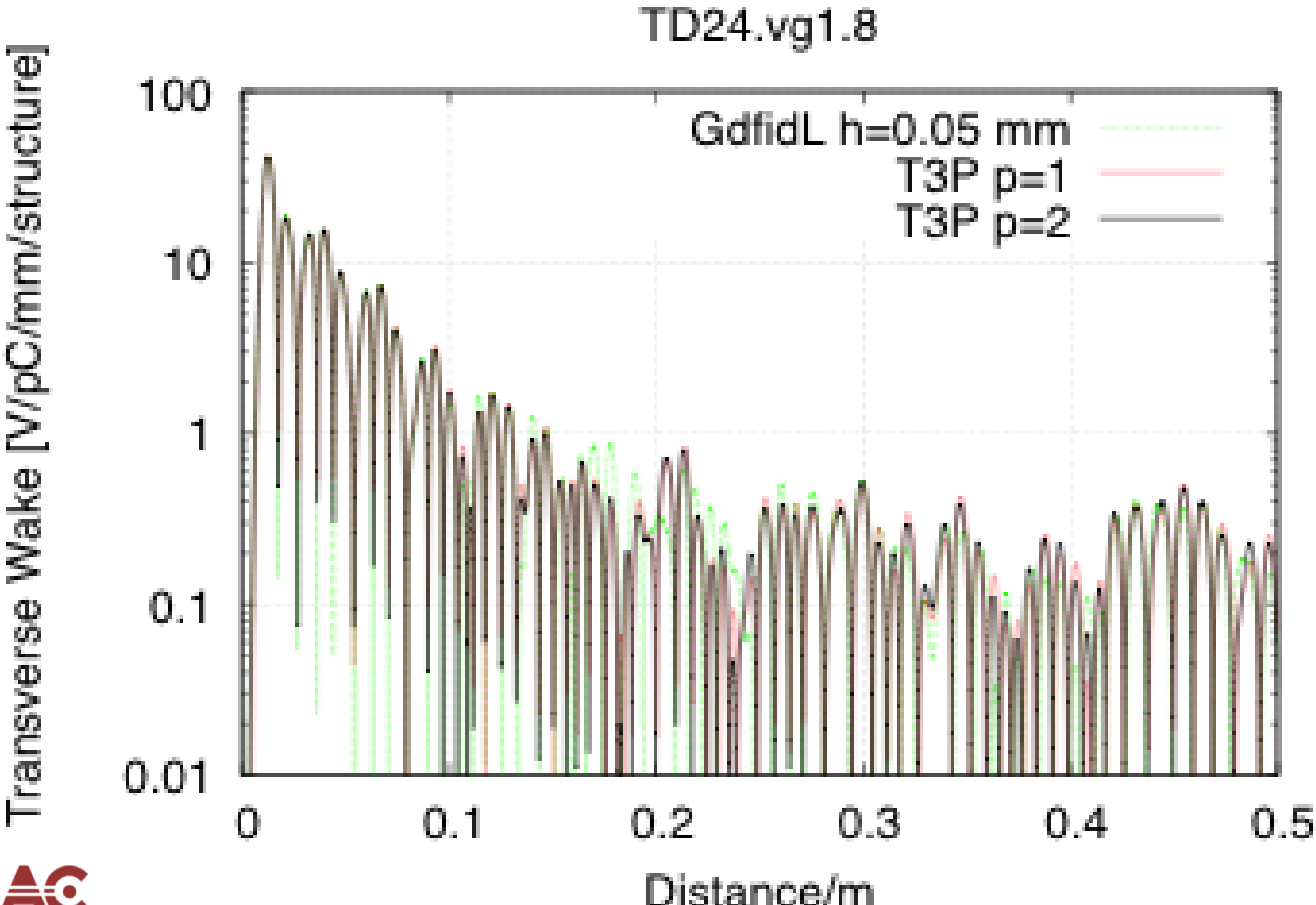
T3P: TDA24 Bunch Transit



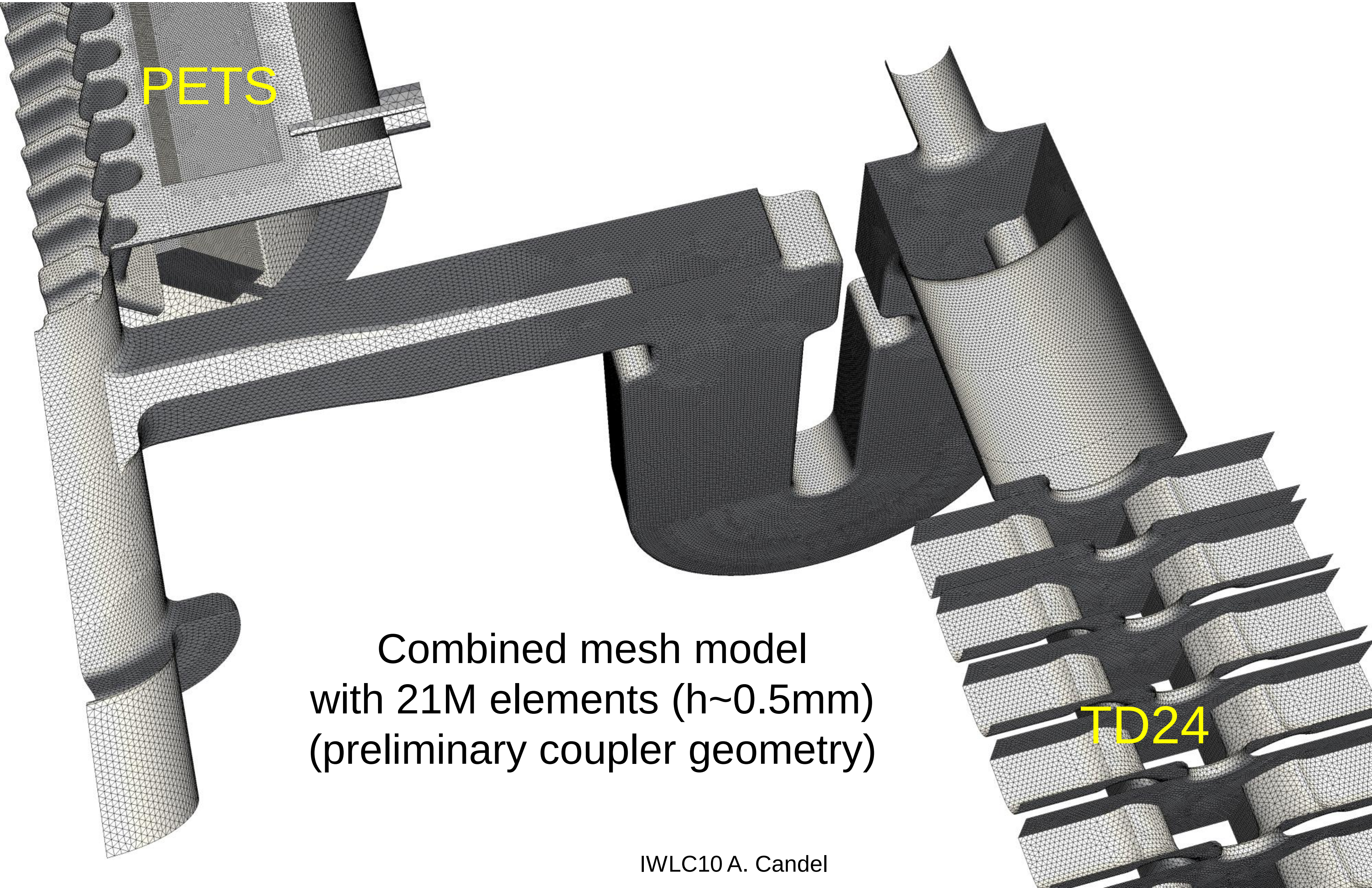
4M tetrahedral elements, 800k curved edges
5M DOFs (p=1), 26M DOFs (p=2)
40min on 600 CPUs (p=1), 4h on 2400 CPUs (p=2)

Electric field magnitude shown, one half of the structure
Electric boundary condition in vertical symmetry plane
Gaussian bunch, sigma=2 mm, 1 mm horizontal offset

T3P: Numerical Convergence

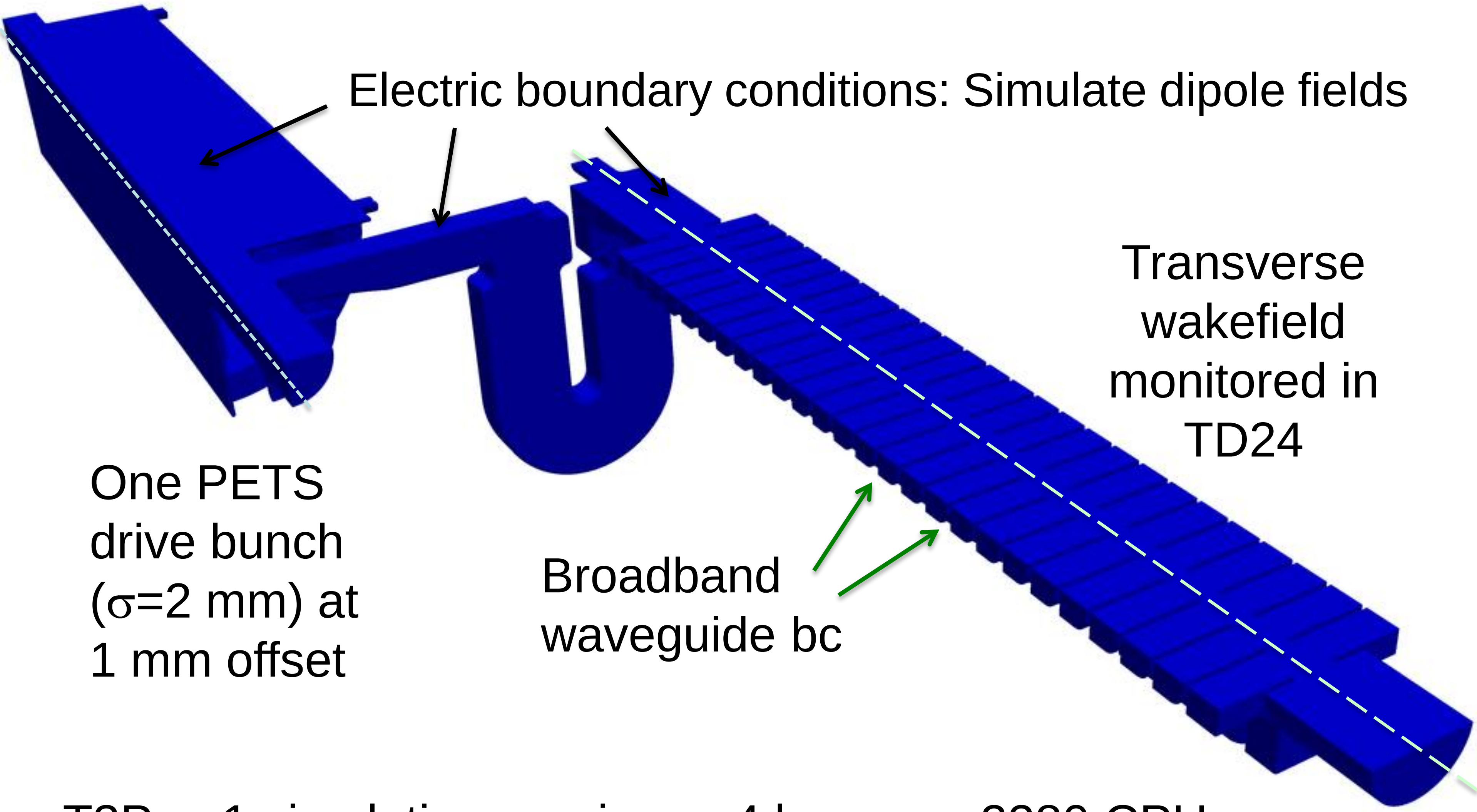


T3P: Wakefield Coupling PETS <-> TD24



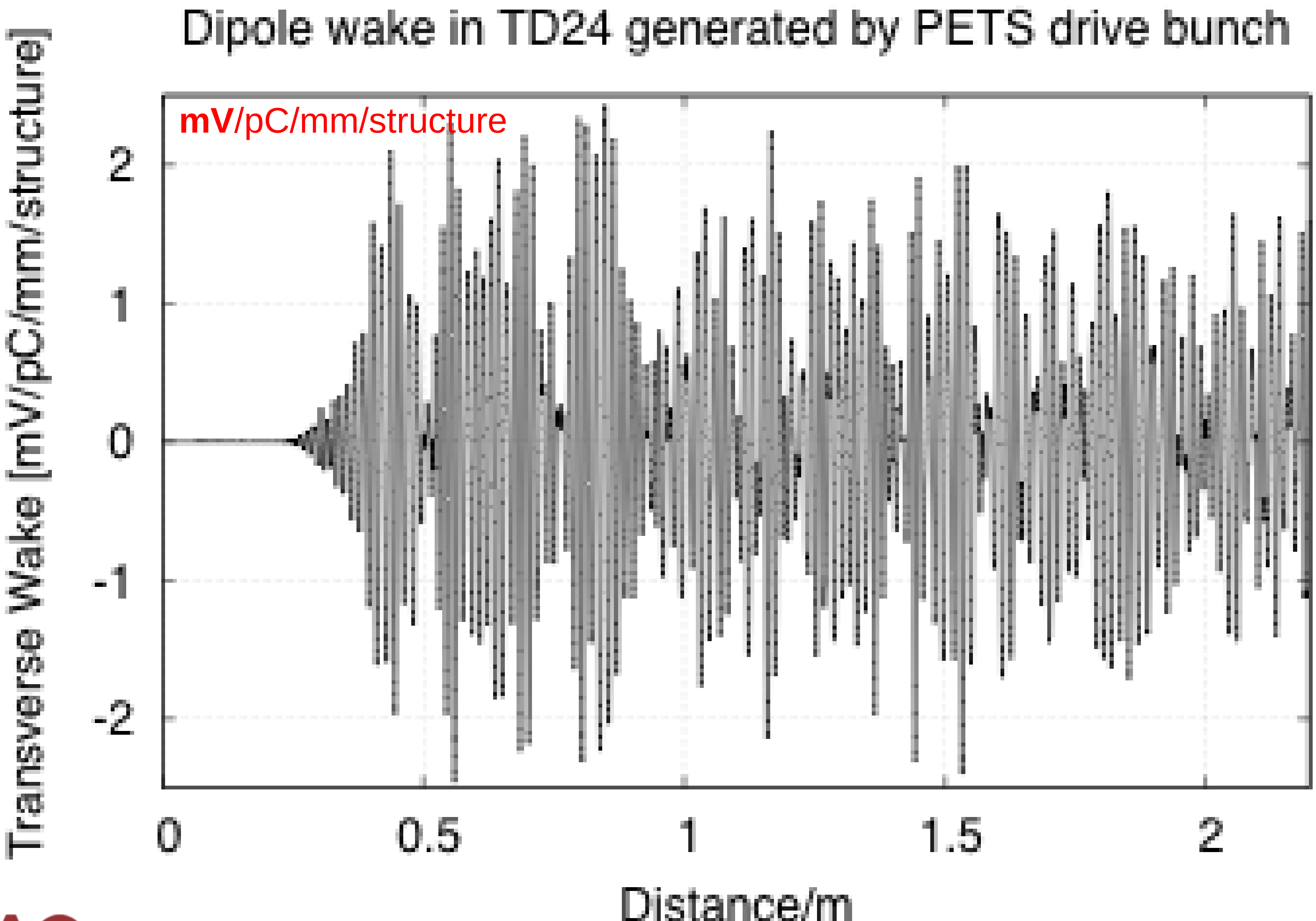
Combined mesh model
with 21M elements (h~0.5mm)
(preliminary coupler geometry)

T3P: Wakefield Coupling PETS <-> TD24

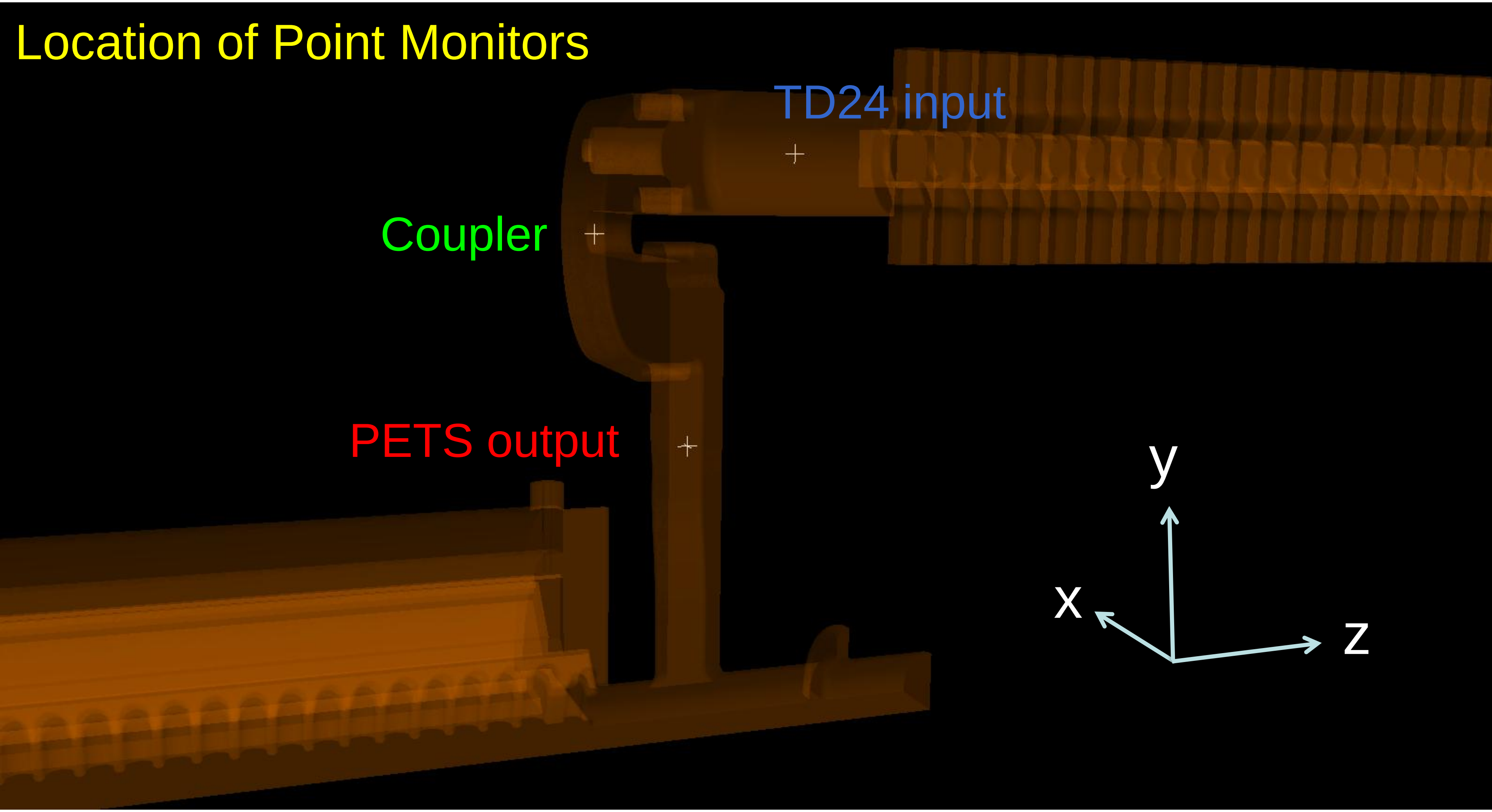


T3P p=1 simulation requires ~ 4 hours on 2280 CPUs

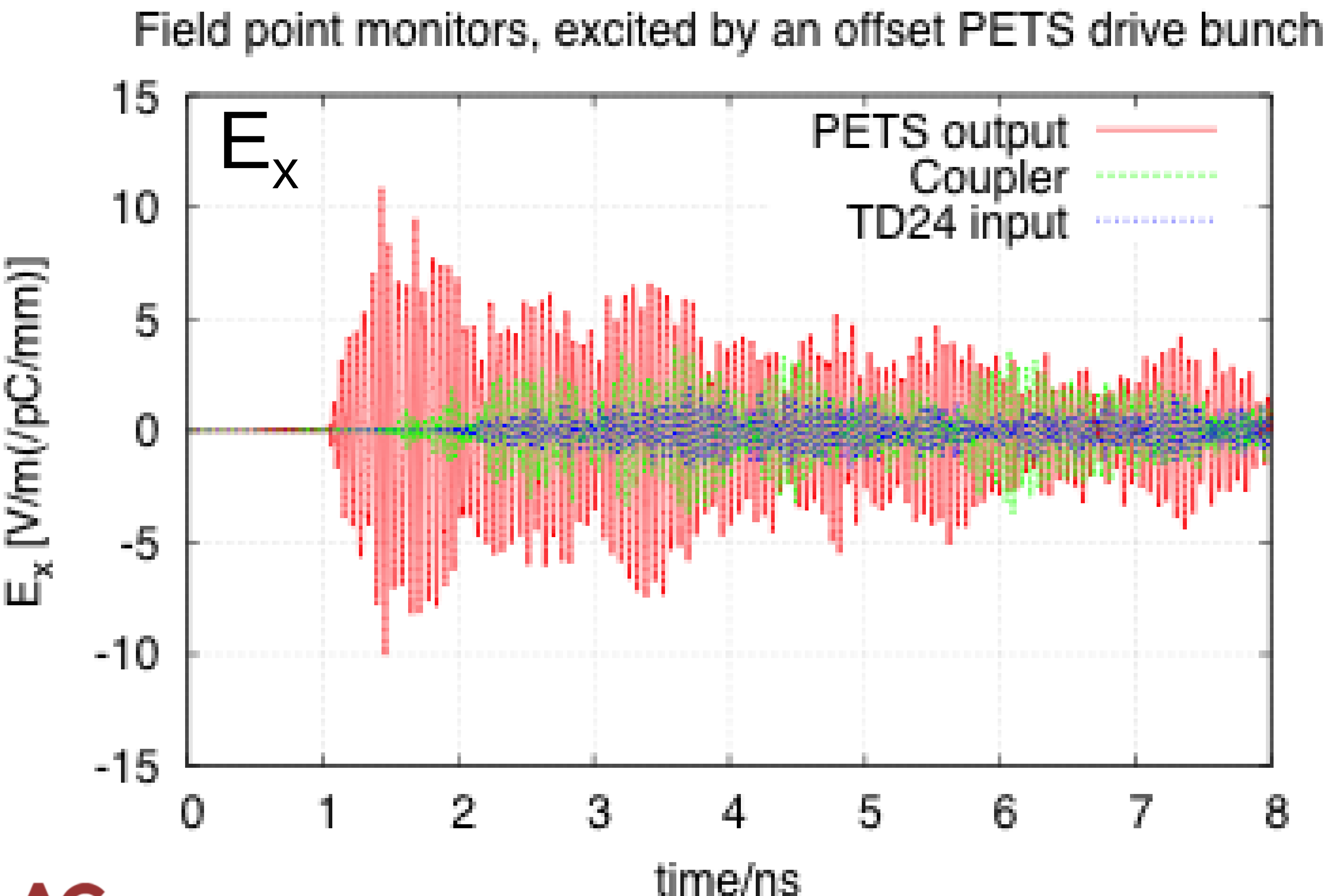
T3P: Wakefield Coupling PETS <-> TD24



T3P: Wakefield Coupling PETS <-> TD24

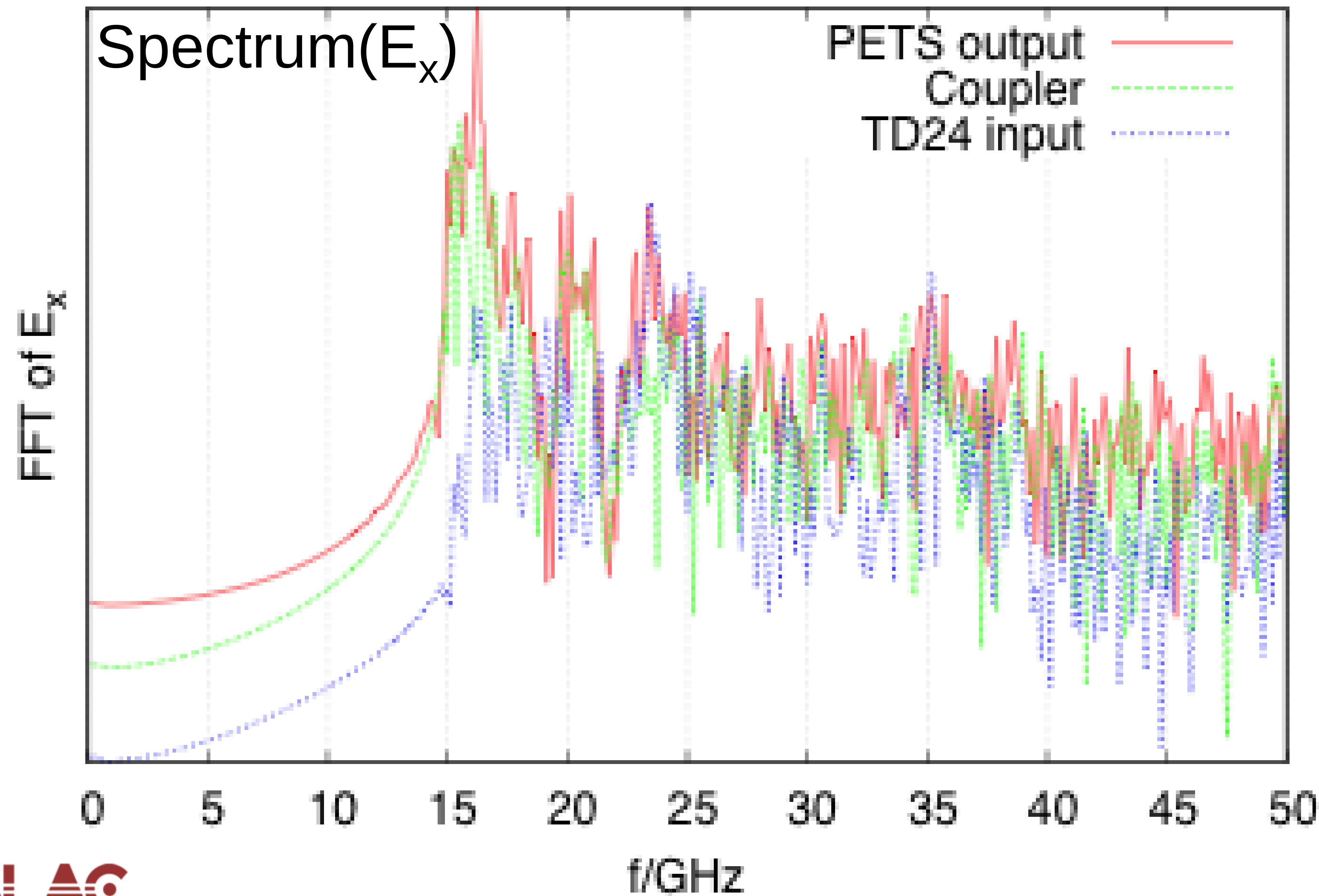


T3P: Wakefield Coupling PETS <-> TD24



SLAC NATIONAL ACCELERATOR LABORATORY

T3P: Wakefield Coupling PETS <-> TD24



SLAC NATIONAL ACCELERATOR LABORATORY

Summary

- **SLAC's Advanced Computations Department** has developed the **Parallel Finite Element ACE3P Code Suite** for high-fidelity electromagnetic modeling of complex accelerator structures
- **ACE3P** codes use **conformal geometry and higher-order field representation** to deliver **unprecedented simulation accuracy**
- **ACE3P** modules run on **leadership-class supercomputers** and provide state of the art simulation capabilities for accelerator applications, such as the **CLIC two-beam accelerator concept**
- **T3P** was applied to wakefield computations in the PETS, the TD24 accelerating structure, and results agree with GdfidL results
- **T3P** was used to **predict wakefield coupling effects in the combined system of PETS and TD24**
- We expect to simulate more realistic geometries in the future

We acknowledge our SciDAC and CERN collaborators