State of the Art in Electromagnetic Modeling for the Compact Linear Collider

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ICFA Workshop, SLAC, July 8 2009

Work supported by U.S. DOE ASCR, BES & HEP Divisions under contract DE-AC02-76SF00515

SciDAC – Finite Element Electromagnetics

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Parallel Finite Element EM Code Suite ACE3P

SLAC has developed the conformal, higher-order, C++/MPI-based parallel EM code suite ACE3P for high-fidelity modeling of large, complex accelerator structures.

ACE3P: Parallel Finite Element EM Code Suite

(Advanced Computational Electromagnetics, 3D, Parallel)

	ACE3P Modules	– Accelerator Physics Application
Frequency Domain:	Omega3P	– Eigensolver (nonlinear, damping)
	S3P	– S-Parameter
Time Domain:	T3P	– Transients & Wakefields *(this talk)*
	Pic3P	– EM Particle-In-Cell (self-consistent)
Particle Tracking:	Track3P	– Dark Current and Multipacting
	Gun3P	– Space-Charge Beam Optics
Multi-Physics:	TEM3P	– EM-Thermal-Mechanical

Visualization: ParaView – Meshes, Fields and Particles

Funded by SciDAC1 (2001-2006) and continuing under SciDAC2 (in black)

Under development for ComPASS (2007-2011) (in blue)

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T3P – Finite Element EM Time-Domain Code

Built on the ACE3P parallel Finite Element framework, T3P integrates Maxwell's equations in time to compute transient & 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*

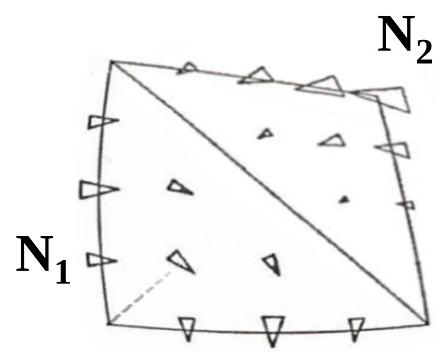
Solve linear system at every time step:

$$Ax=b$$

ACE3P Finite Element Method:

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

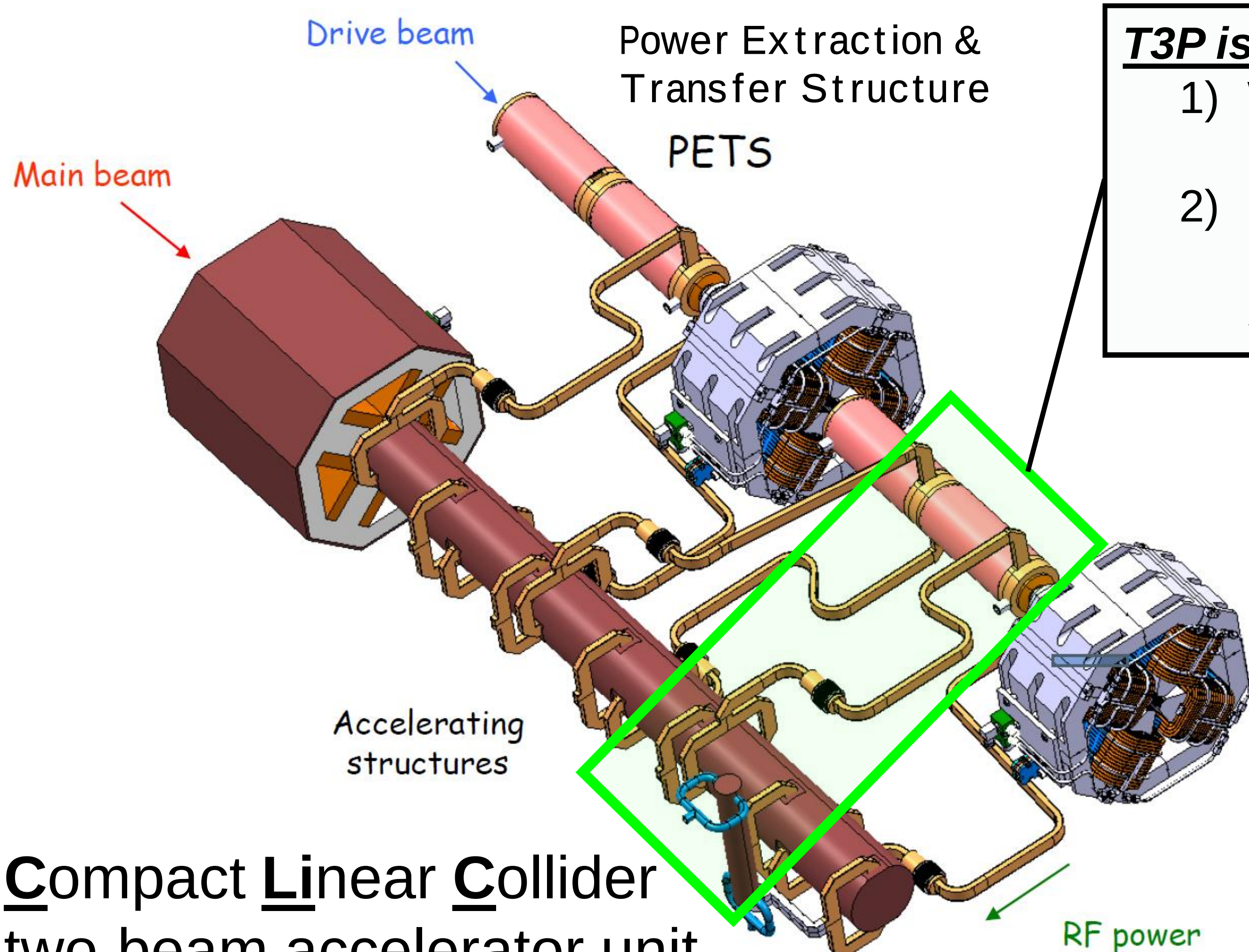
$$\mathbf{E}(\mathbf{x},t)=\sum_i e_i(t)\cdot\mathbf{N_i}(\mathbf{x})$$



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

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

T3P Application: CLIC Two-Beam Accelerator



T3P is used to study:

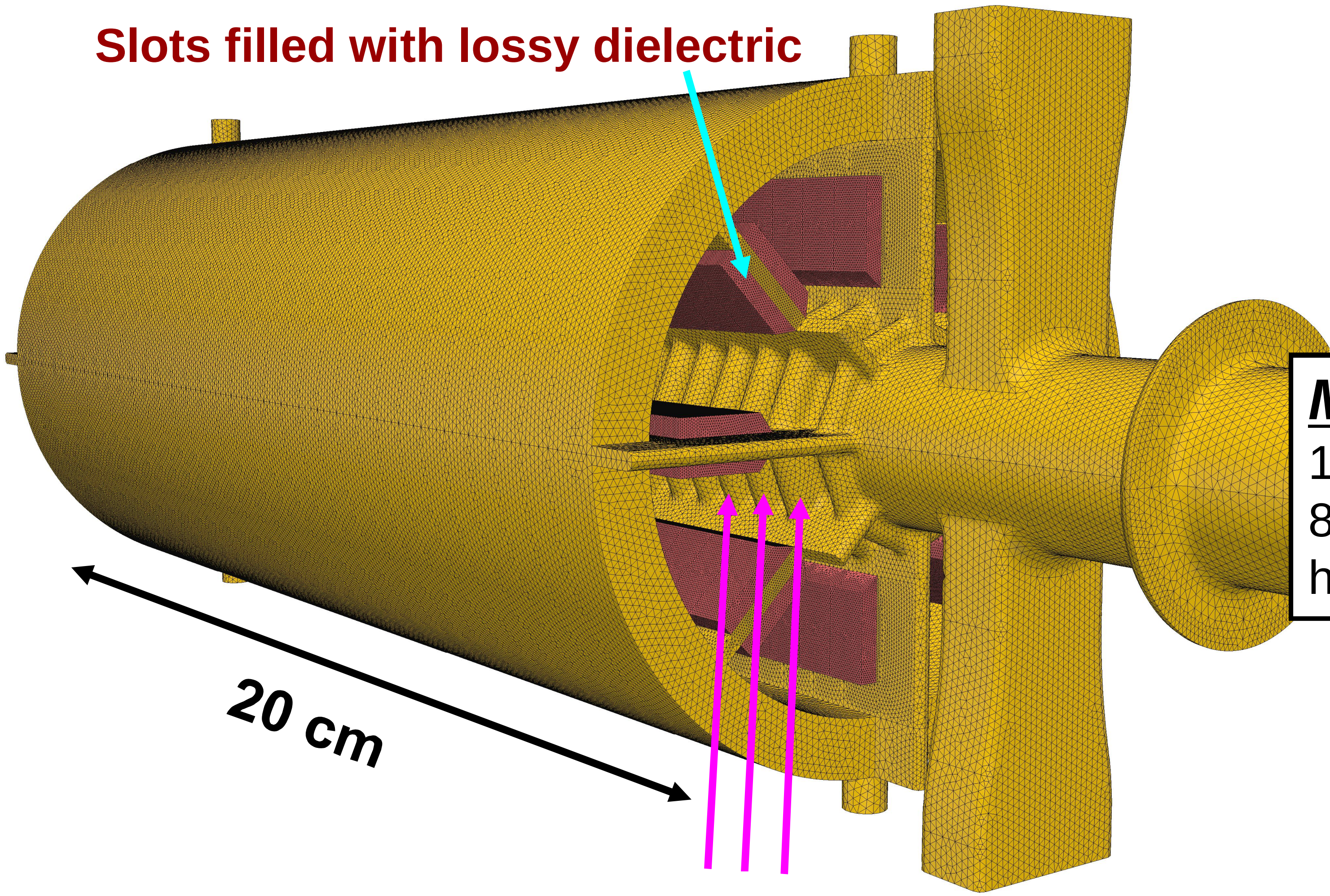
1) Wakefield damping in PETS
2) RF power transfer from PETS to accelerating structures

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

Picture courtesy CERN

Unstructured Mesh Model of PETS

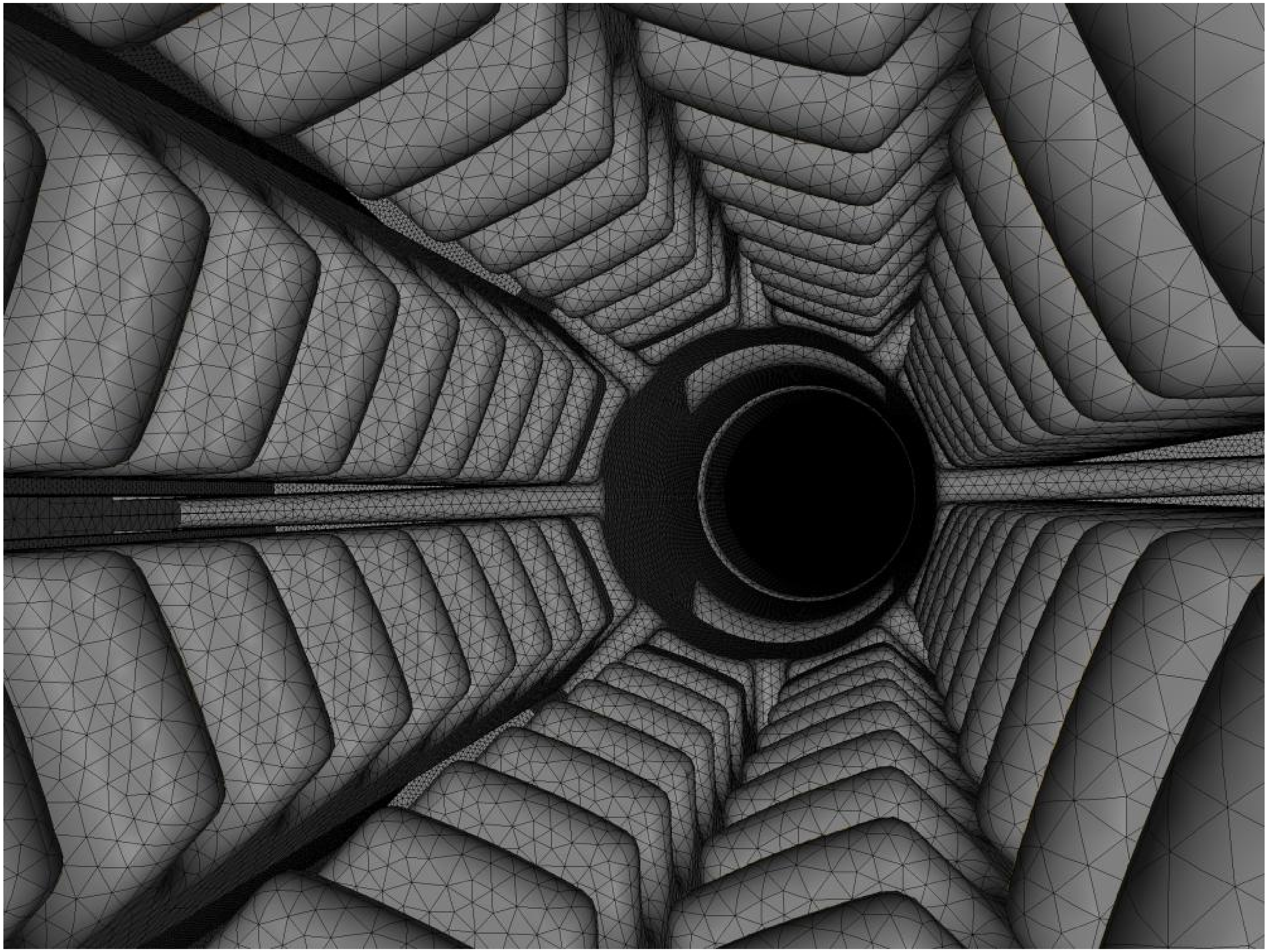
(Power Extraction & Transfer Structure)



Mesh:
1/4 model
8.7M elements
h ≥ 0.3 mm

CAD model courtesy CERN

Internal View of PETS - Curved Mesh



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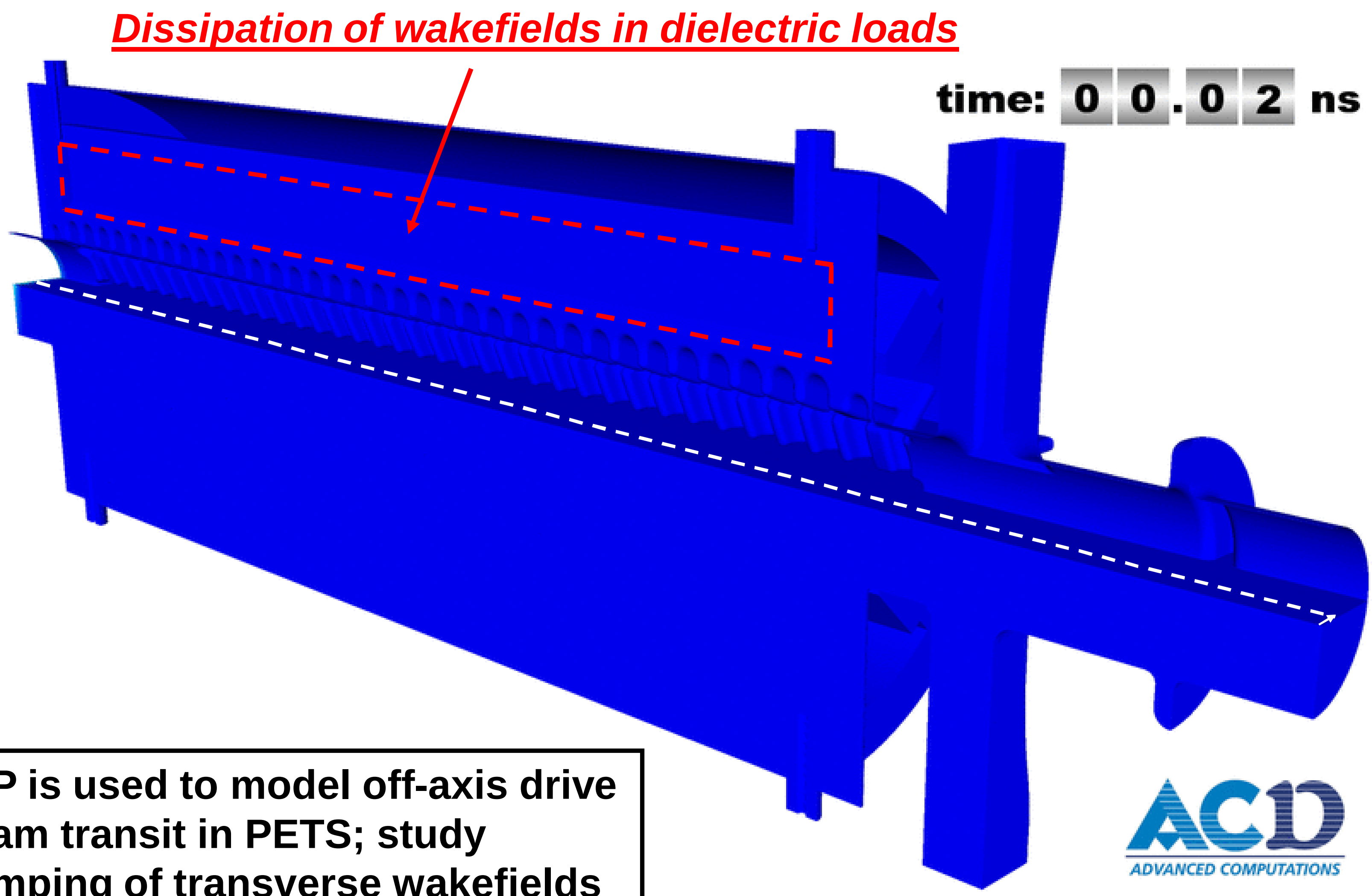
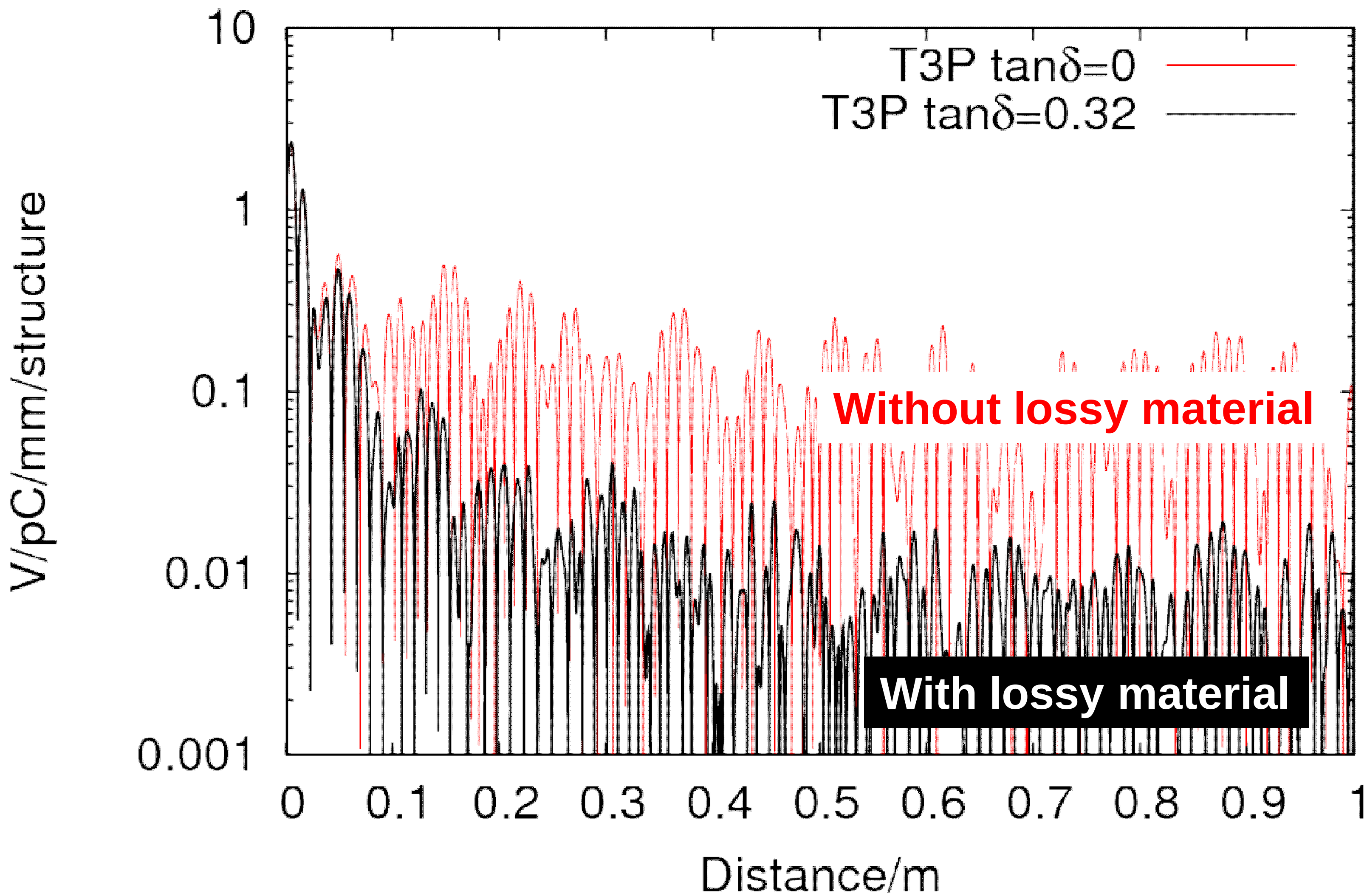
T3P – PETS Wakefield Damping

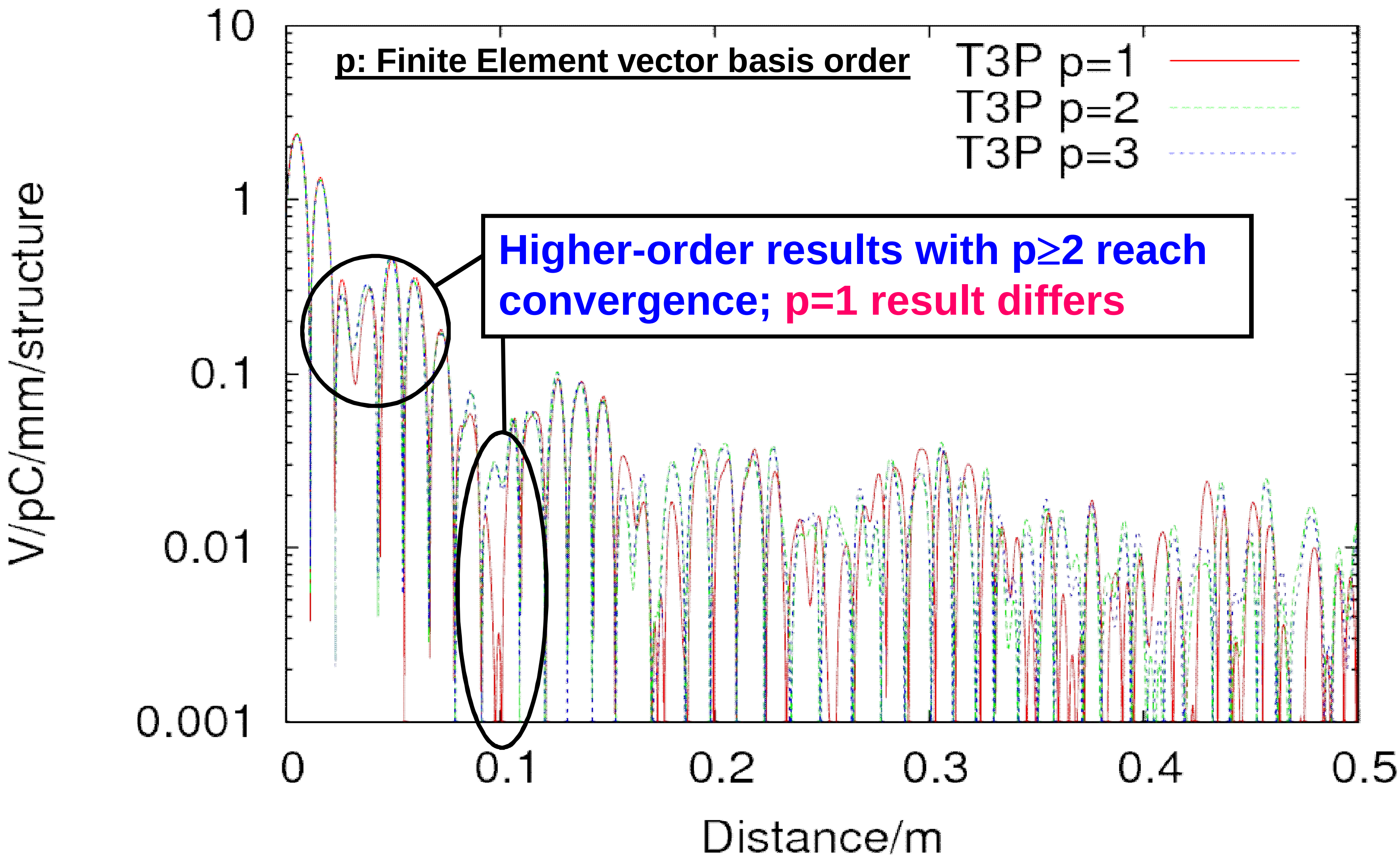


T3P is used to model off-axis drive beam transit in PETS; study damping of transverse wakefields

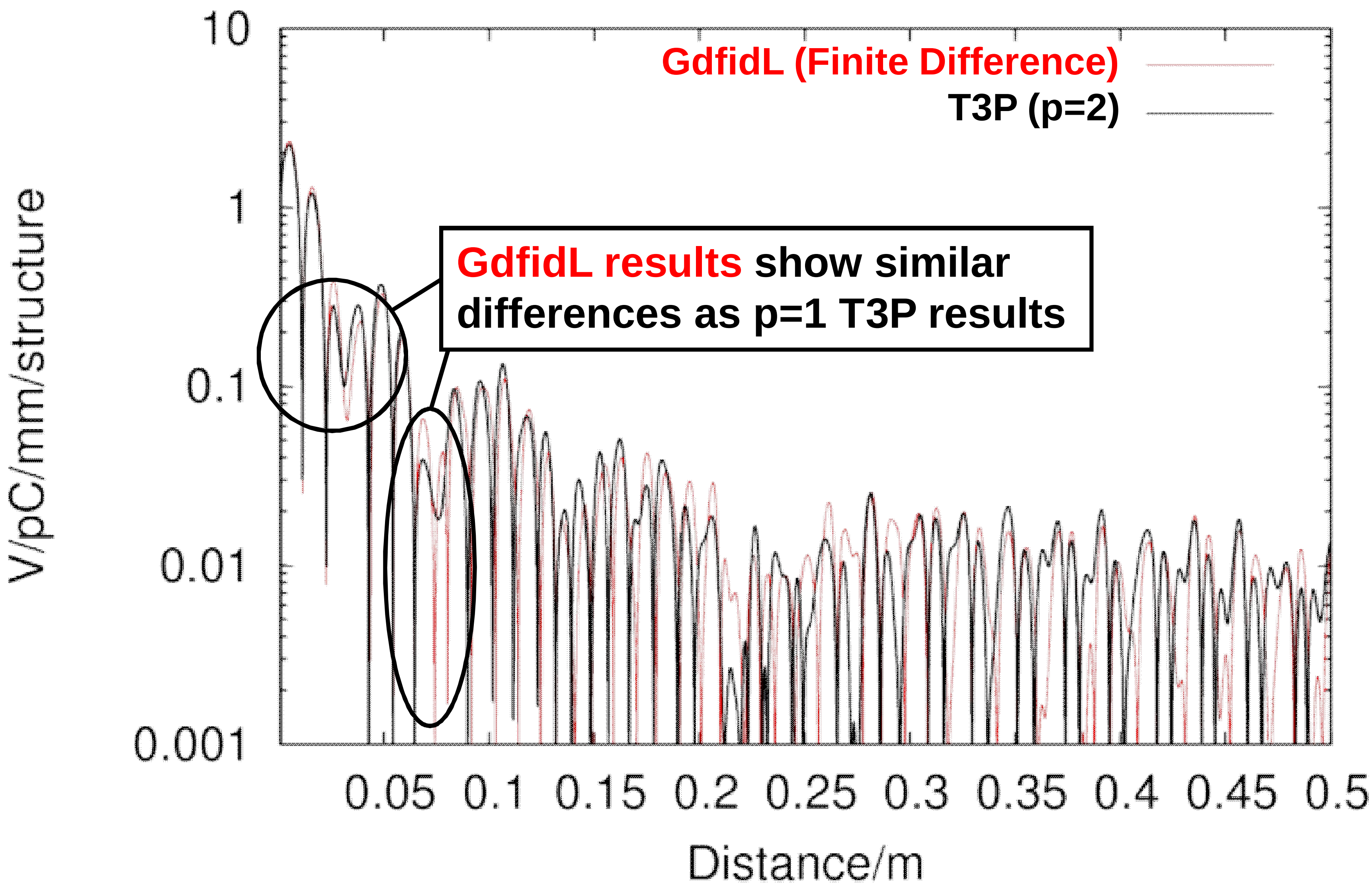
T3P – PETS Wakefield Damping on/off



T3P – PETS Wakefield Convergence

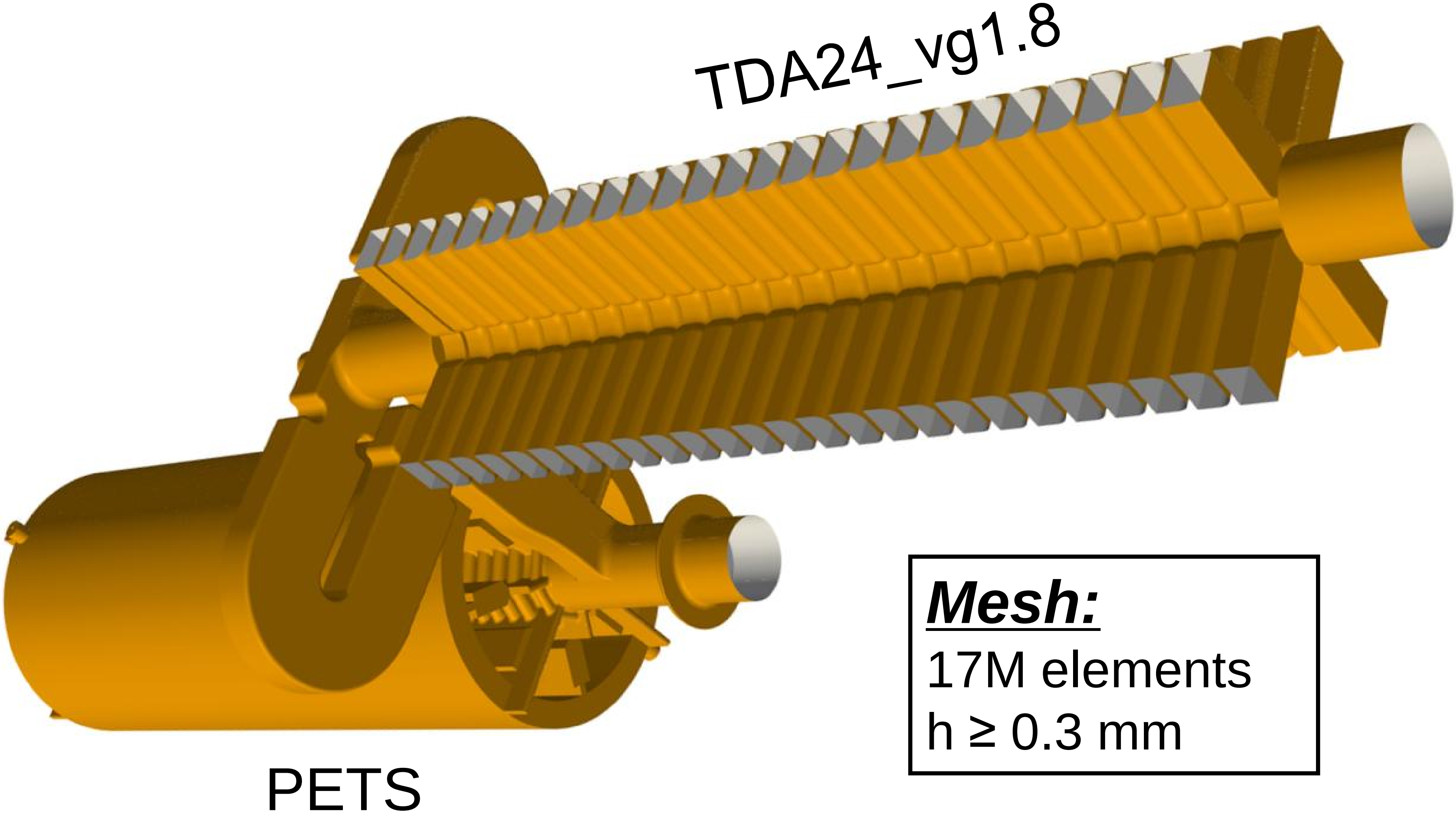


Benchmarking: T3P vs. GdfidL



Slightly simplified geometry - GdfidL results courtesy CERN

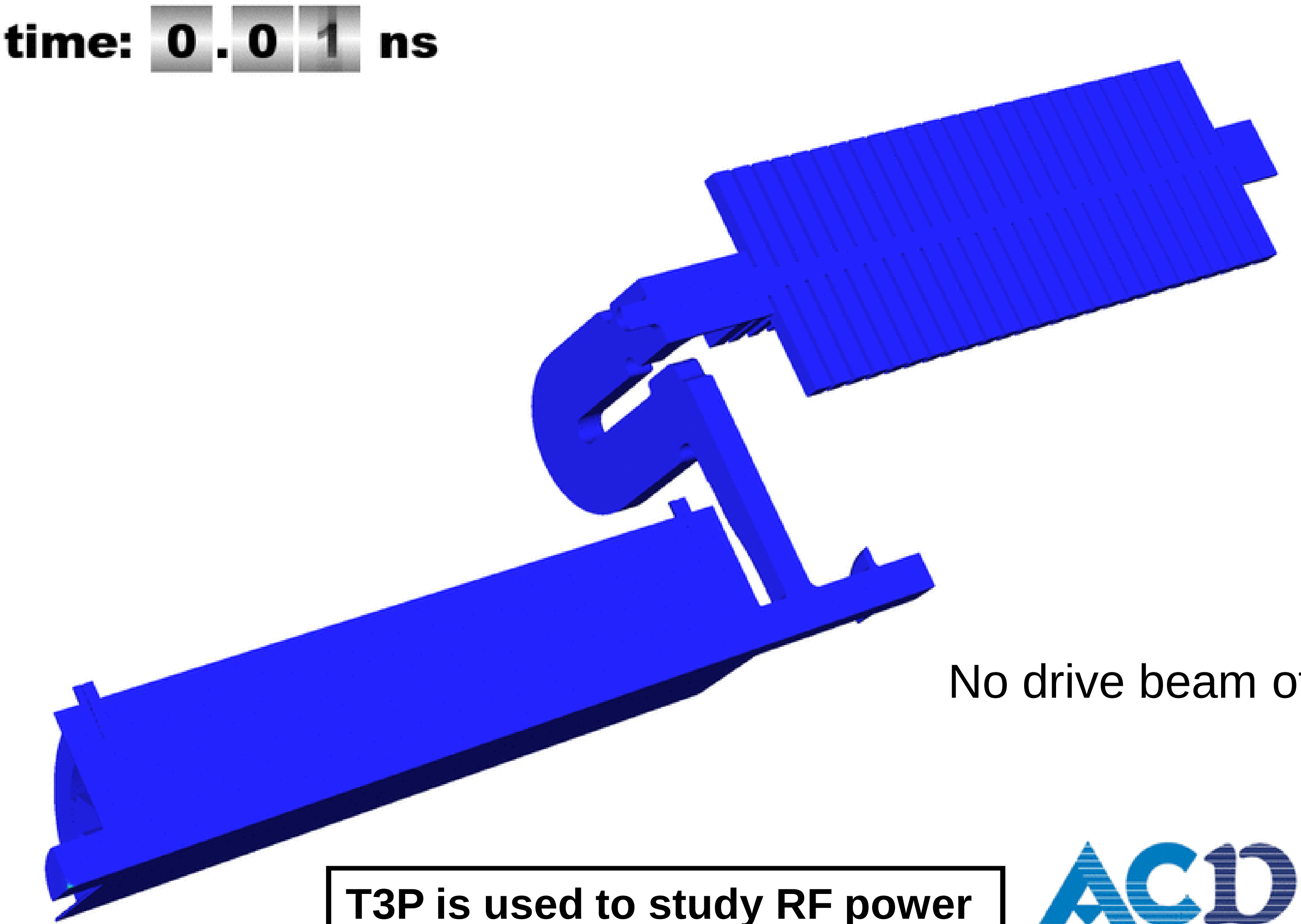
CLIC Coupled Structure Model for T3P



Mesh:
17M elements
h ≥ 0.3 mm

CAD model courtesy CERN

T3P Simulation of RF Power Transfer



No drive beam offset

T3P is used to study RF power transfer from the PETS to the accelerating structures

ADVANCED COMPUTATIONS

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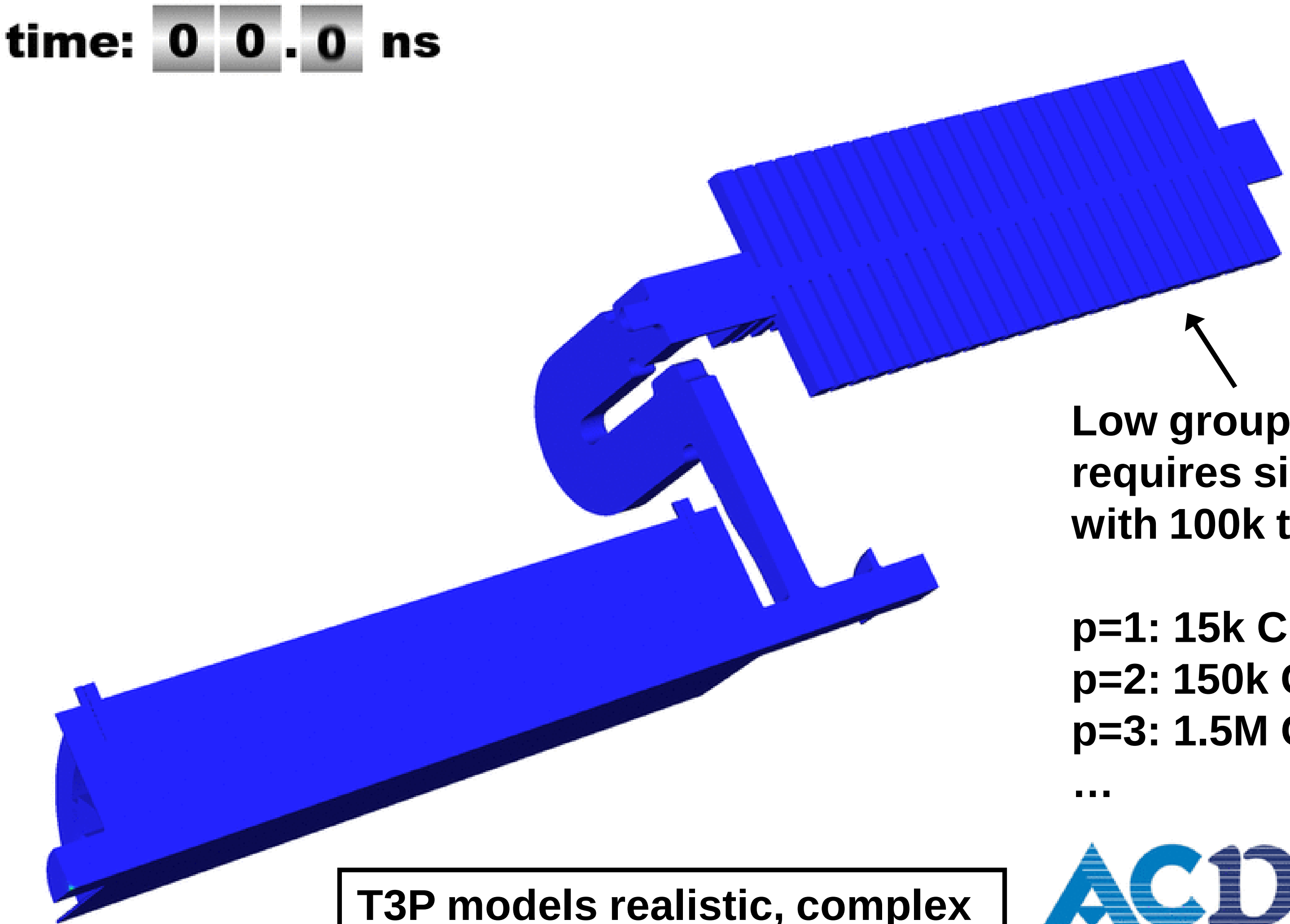
T3P Simulation of RF Power Transfer



Low group velocity requires simulations with 100k time steps

p=1: 15k CPU hours
p=2: 150k CPU hours
p=3: 1.5M CPU hours
…

T3P models realistic, complex accelerator structures with unprecedented accuracy

ADVANCED COMPUTATIONS

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Summary

- **SLAC's Advanced Computations Department** has developed the **Parallel Finite Element ACE3P Code Suite** for high-fidelity electromagnetic modeling of complex accelerator structures, using conformal geometry and higher-order field representation.
- **ACE3P** modules run on NCCS and NERSC supercomputers and provide state of the art simulation capabilities for accelerator applications.
- **T3P** is used for transient and wakefield simulations to investigate the CLIC two-beam accelerator concept.
- **T3P** was applied to verify wakefield damping in the CLIC PETS, and to model the RF power transfer from the PETS to the accelerating structure.

We acknowledge our SciDAC and CERN collaborators

SLAC NATIONAL ACCELERATOR LABORATORY Work supported by U.S. DOE ASCR, BES & HEP Divisions under contract DE-AC02-76SF00515 SciDAC Scientific Discovery through Advanced Computing