
Data Analysis and Visualization for Accelerator Simulation

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Particle Accelerators

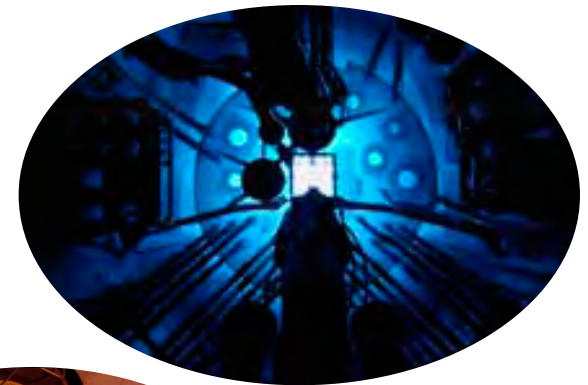
Discovery Science



Medicine and
Biology



Energy and
Environment



Accelerators
and Beams



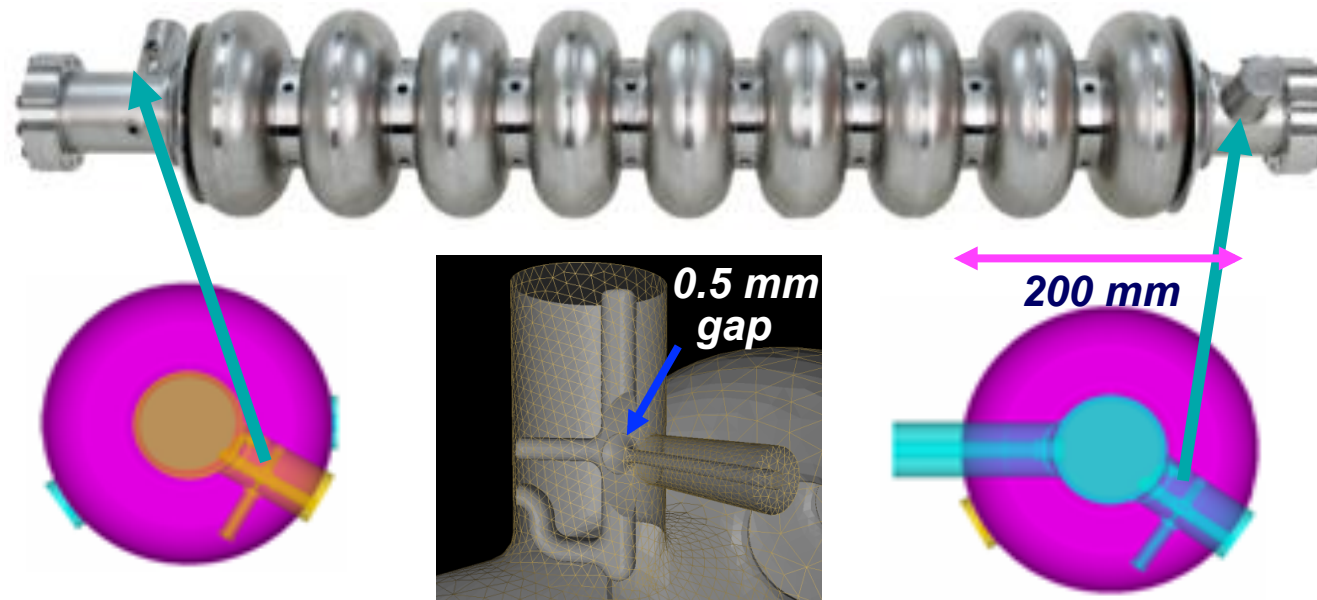
National Security

Industry

Courtesy:
S. Henderson

Motivations for Advanced Modeling Capabilities

International Linear Collider Cavity



Modeling challenges include

- **Complexity** – HOM coupler (fine features) versus cavity
- **Problem size** – multi-cavity structure (e.g., cryomodule)
- **Accuracy** – 10s of kHz mode separation out of GHz
- **Speed** – Fast turn around time to impact design

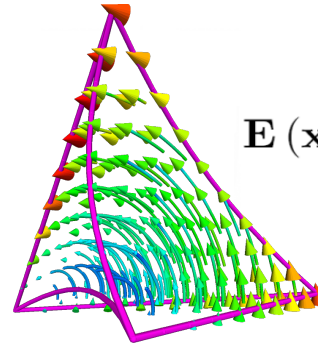
Parallel EM Code Development of ACE3P

- DOE high performance computing initiatives and SLAC support
 - » 15 years of DOE investment in developing ACE3P started from the Computational Grand Challenge and then through SciDAC 1 & 2
 - » SciDAC3 ComPASS (HEP & ASCR)
- Focus in these closely integrated efforts
 - » **Code Development** – Parallel software and infrastructure in Electromagnetics and Multi-physics
 - » **Computational Science R&D** – Efforts in computer science and applied mathematics under SciDAC for accelerator applications
 - » **High-performance Computing** – US DOE computing resources at NERSC to support accelerator modeling and Large scale “Discovery” simulations
 - » **Accelerator Modeling and Simulation** – Solutions to challenging problems in Accelerator Science, Development and Projects

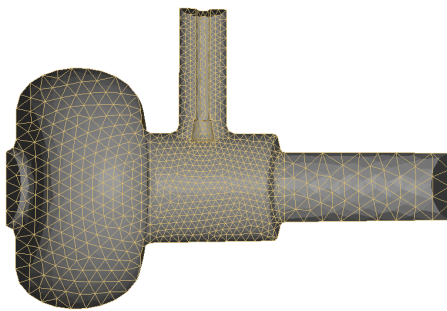
Parallel Higher-order Finite-Element Method

Strength of Approach – Accuracy and Scalability

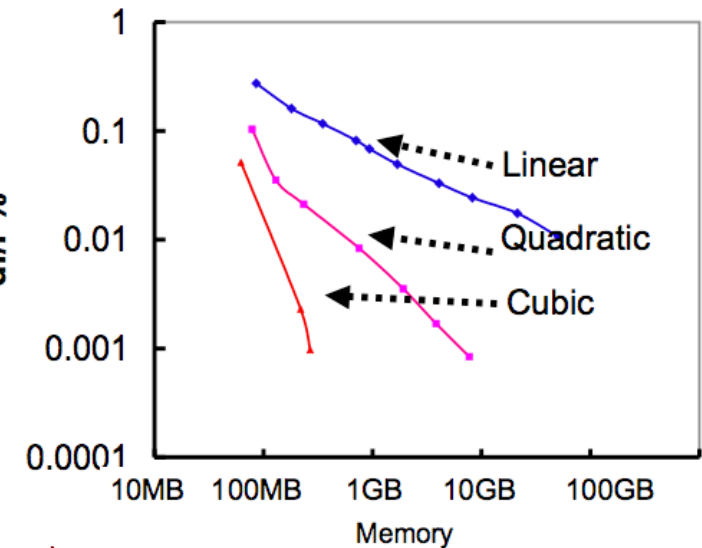
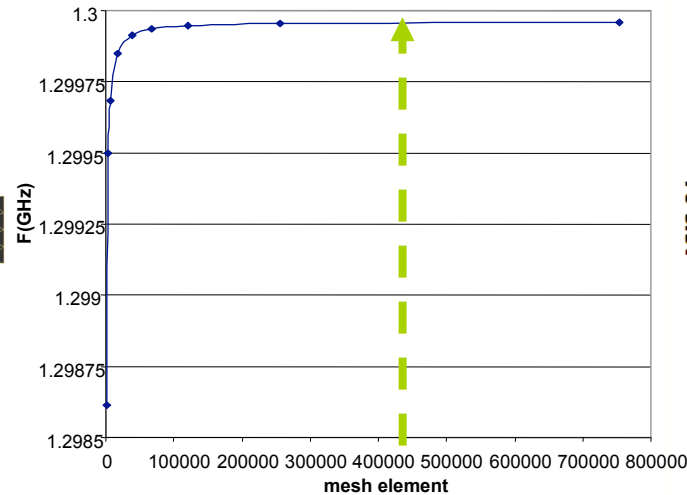
- Conformal (tetrahedral) mesh with quadratic surface
- Higher-order elements ($p = 1-6$)
- Parallel processing (memory & speedup)



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



End cell with input coupler only



*67k quad elements (<1 min on 16 CPU, 6 GB)
Error ~ 20 kHz (1.3 GHz)*

Accelerator Modeling with Code Suite ACE3P

Meshing - **CUBIT** for building CAD models and generating finite-element meshes
<http://cubit.sandia.gov>

Modeling and Simulation – SLAC’s suite of conformal, higher-order, C++/MPI based parallel finite-element electromagnetic codes

https://slacportal.slac.stanford.edu/sites/ard_public/bpd/acd/Pages/Default.aspx

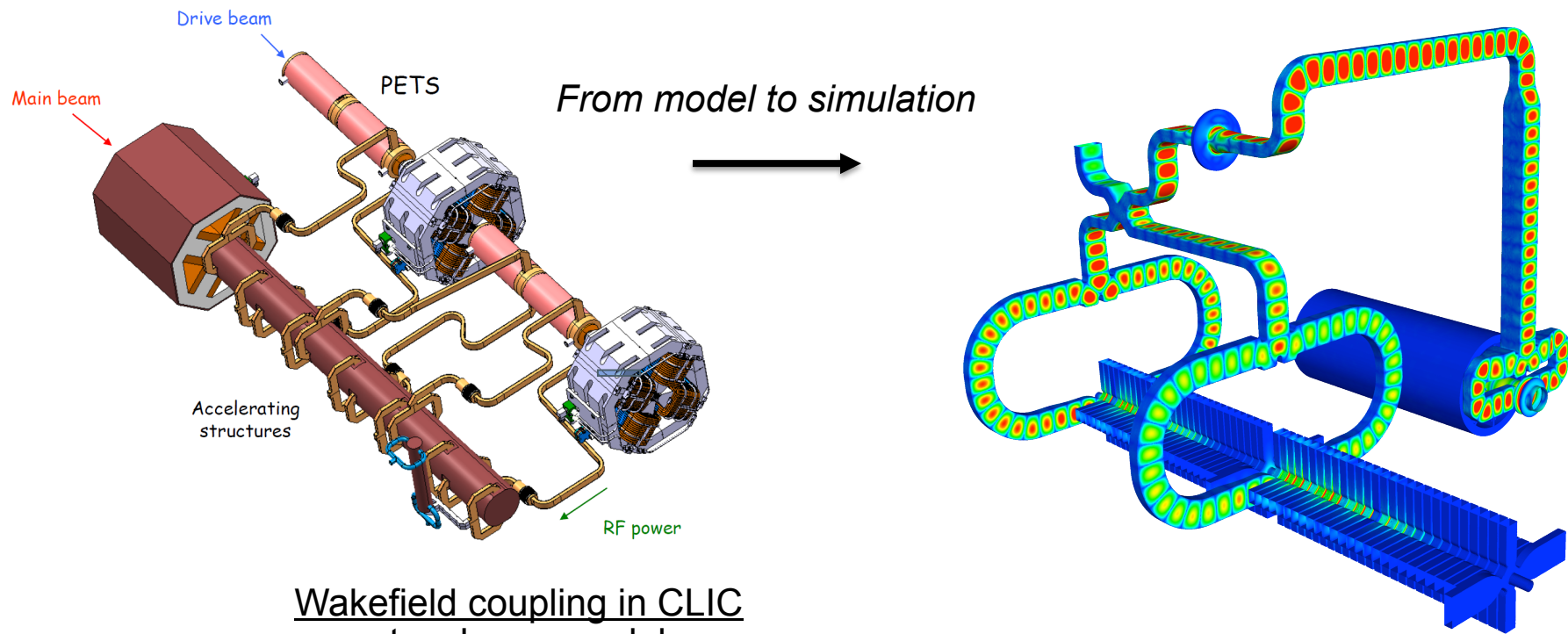
ACE3P (Advanced Computational Electromagnetics 3P)

<u>Frequency Domain:</u>	Omega3P	– Eigensolver (damping)
	S3P	– S-Parameter
<u>Time Domain:</u>	T3P	– Wakefields and Transients
<u>Particle Tracking:</u>	Track3P	– Multipacting and Dark Current
<u>EM Particle-in-cell:</u>	Pic3P	– RF guns & klystrons
<u>Multi-physics:</u>	TEM3P	– EM, Thermal & Structural effects

Postprocessing - **ParaView** to visualize unstructured meshes & particle/field data
<http://www.paraview.org/>

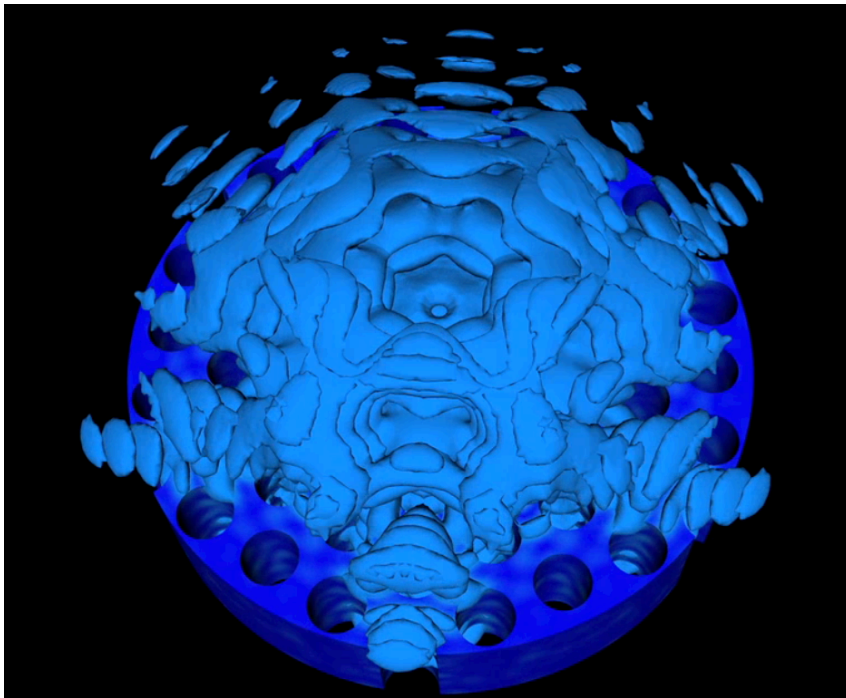
Field Visualization in Large-Scale Accelerator System

- The first-ever simulation of the entire CLIC 3D coupled structure (AS + PETS) was carried out with the T3P module within ACE3P.
- T3P simulation results show much stronger than expected dipole wakefield coupling between the accelerating structure and PETS which is undesirable.
- Time domain simulation generated 15 Tbyte data for postprocessing.

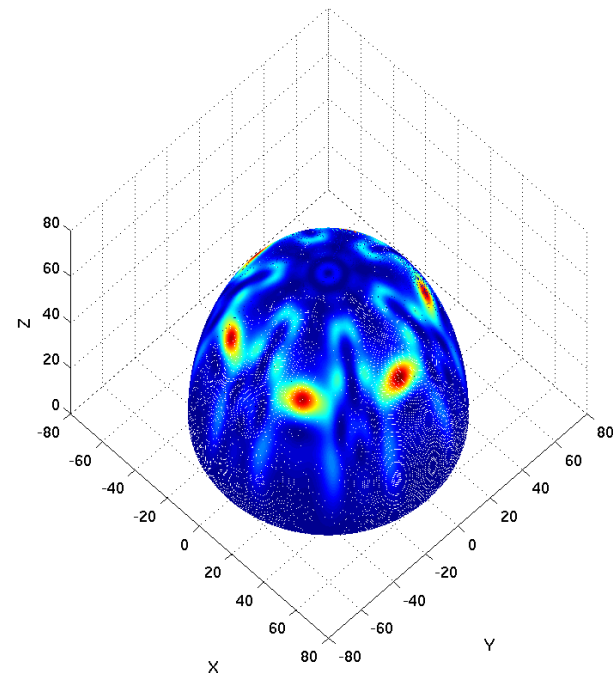


Field Visualization in Unbounded Structure

- Transmission and radiation of accelerating mode
 - » Far-field pattern provides a mechanism of directing laser pulses from free space to excite the defect mode in an experimental setup.
- Improved volume rendering will facilitate the identification of enhanced regions of radiation.

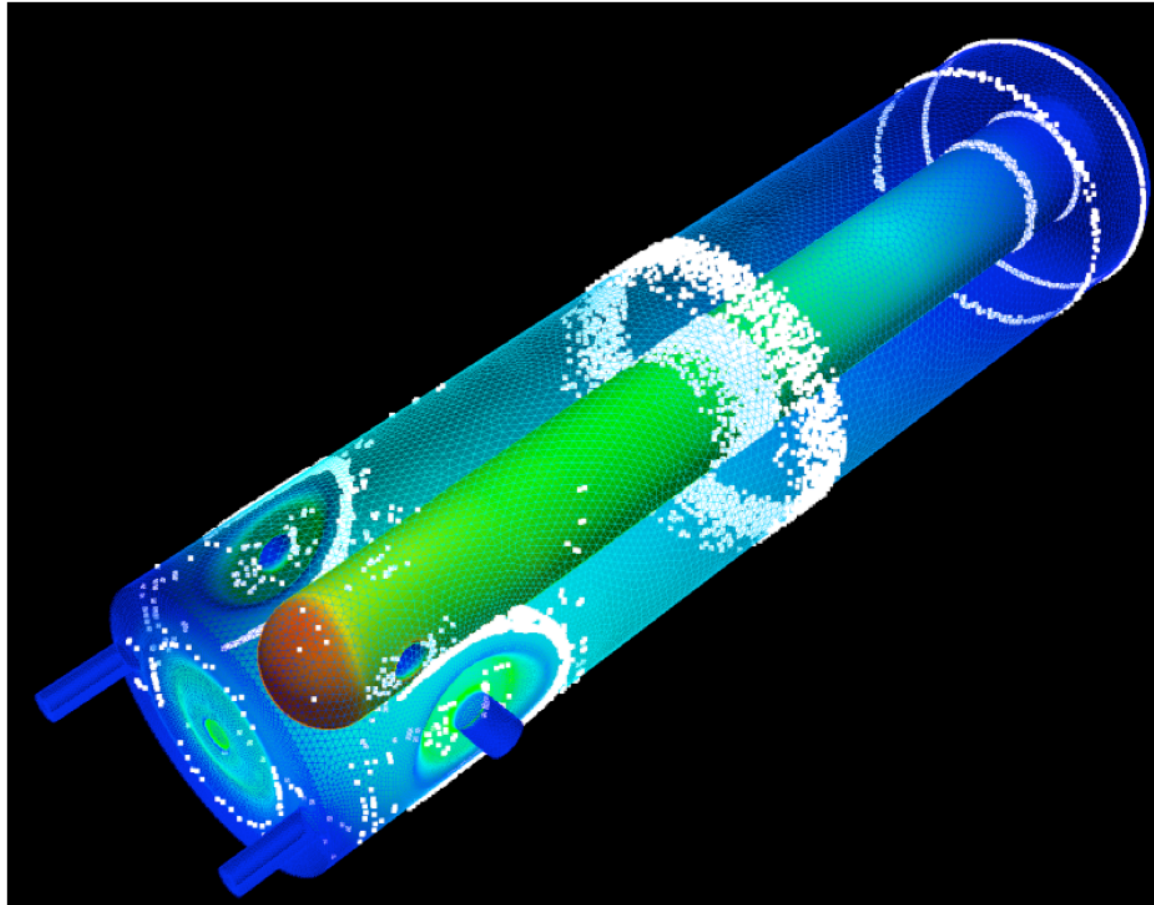


Radiation of accelerating mode



Far-field radiation pattern

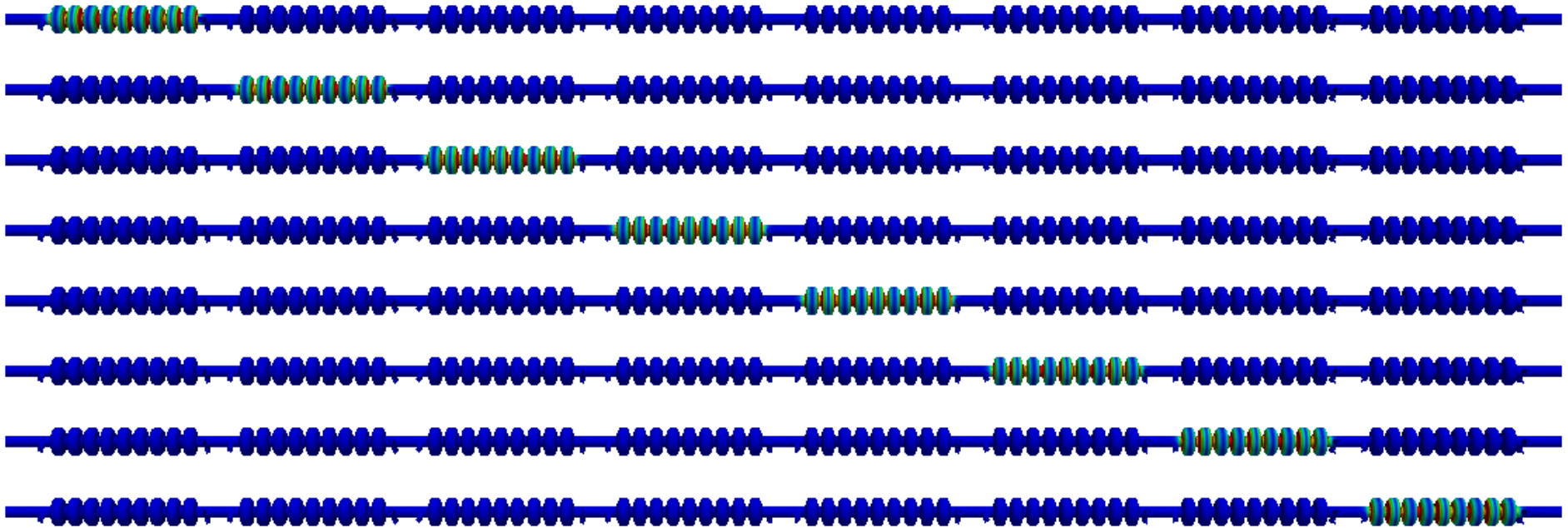
Particle Visualization in Complex Geometry



- Efficient methods to identify locations of multipacting will expedite the analysis of simulation results.

In collaboration with MSU – J. Popielarski

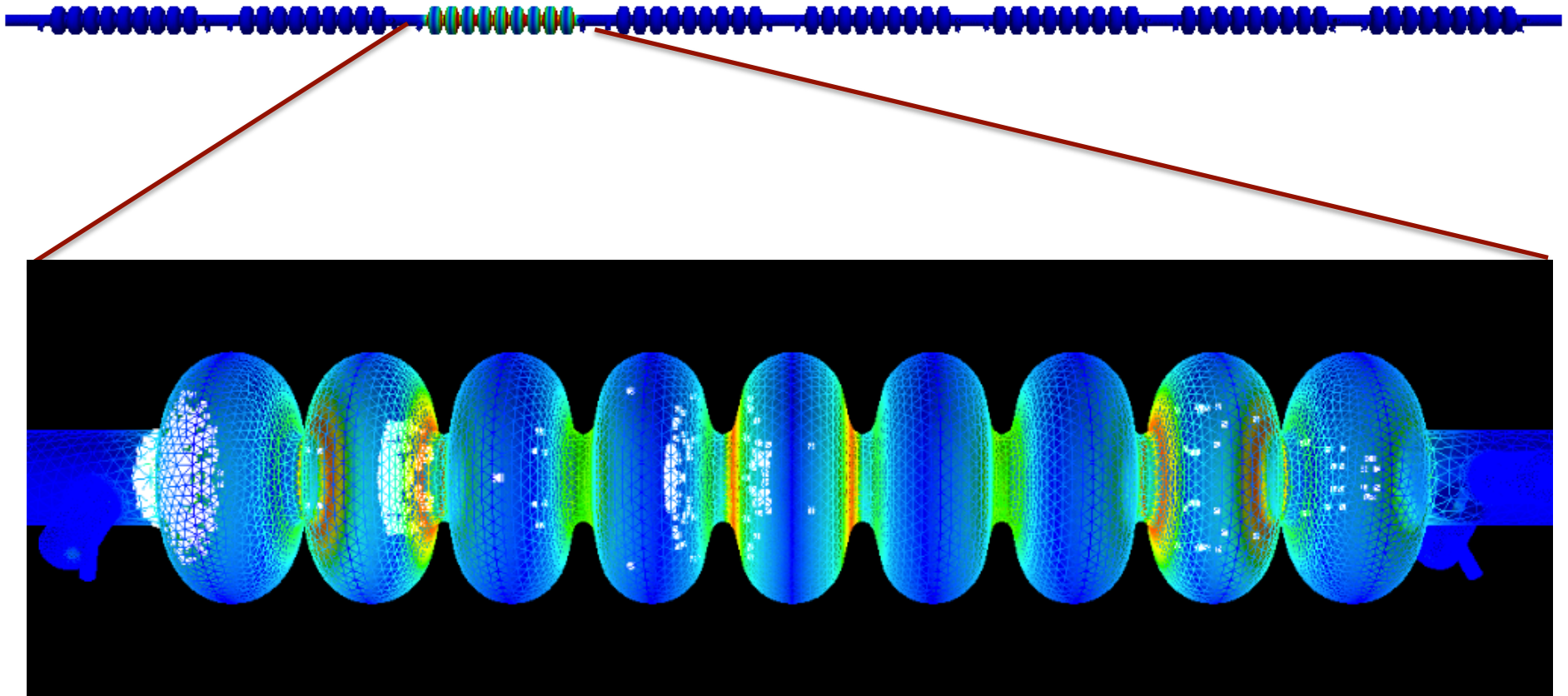
Field Visualization in Long Structure



Accelerating modes in cavities of ILC cryomodule

- Requires robust zoom-in capabilities to capture the fine detail of field distributions in structures with large aspect ratios.
- Allows the loading of multiple field solutions with different amplitudes and phases simultaneously on the same mesh in ParaView.

Particle Visualization in Long Structure



- Challenges remain in tracking the movements of a large number of particles in end-to-end simulations.

ACE3P User Community

- Three Code Workshops have been held at SLAC
 - » CW09 – 1 day/15 attendees/13 institutions
 - » CW10 – 2.5 days/36 attendees/16 institutions
 - » CW11 – 5 days/42 attendees/25 institutions
- ACE3P user base has been growing
 - » more than 60 active users share a dedicated computer allocation at NERSC;
 - » ACE3P simulation results have been presented by many users in conference proceedings and refereed journals. More than 25 abstracts in IPAC 2012 include ACE3P in their research efforts;
 - » beta version of user manual is available.
- ParaView is used as the tool for visualization of simulation results.

CW11 Code Workshop, SLAC, October 10-14, 2011
<http://www-conf.slac.stanford.edu/cw11/default.asp>

Agenda

	10/10 Monday	10/11 Tuesday	10/12 Wednesday	10/13 Thursday	10/14 Friday
8.30 am to 10.10 am	ACE3P CUBIT	Cavity Design - Omega3P - Cavity w/ coax coupler	Beam-cavity - T3P	Traveling Wave Cavity Design - Omega3P - Periodic structure	Parallel Session: RF Gun - Pic3P RF Gun - TEM3P
Refreshments					
10.30 am to 12.15 pm	CUBIT ParaView	- Cavity w/ WG coupler	- Pillbox w/ closed WG - Pillbox w/ open WG - Pillbox with absorber	Component Design - S3P - Coax WG - Window - 90 degree bend - WG Load	RF Gun - Pic3P RF Gun - TEM3P
Lunch on your own					
1.30 pm to 3.10 pm	Standing Wave Cavity Design - Omega3P	Multipacting - Track3P	- BPM - Taper	Multipacting - Track3P - Coax WG	LCLS Tour
Refreshments					
3.30 pm to 5.15 pm	- Pillbox Cavity - Rounded top cavity	- Pillbox cavity User Talk - BNL Pay Your Own Buffet Dinner	Computing @ NERSC User Talk - CERN	- Coupler w/ window	Soccer Friendly



Summary

- Large data-sets generated in system-scale simulation require efficient methods to process data and visualize results.
- Improved techniques are required to visualize fields and particles in long accelerator structures with large aspect ratios, and in structures with complex geometries.
- Addressing the above issues will also benefit the ACE3P user community in analyzing simulation results.