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)

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

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

## ACE3P (Advanced Computational Electromagnetics 3P)

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**Postprocessing** - ParaView to visualize unstructured meshes & particle/field data
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

- 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.

Accelerating modes in cavities of ILC cryomodule
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.
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.