Visualizing Electromagnetic Field and Particle Simulations in Accelerators with ParaView

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SC09 Ultrascale Visualization Workshop, Portland Oregon
November 16, 2009

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Overview

- Visualization challenges at SLAC
- Using ParaView at SLAC
- Future plans

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Special Accelerator Considerations

- We need a high degree of accuracy
  - 2nd order tetrahedral mesh
  - Up to 6th order fields
- Our simulations have huge dynamic range.
  - Field values span tens of orders of magnitude
  - We care about very big and very small values.
- Our meshes can be large (e.g., 17 million elements for a medium sized problem).

How Have We Used ParaView?

- Visualizing our particles and fields (e.g., Multipacting, PIC)
- Parallel rendering for exploration and movie making.
- Fine tuning meshes before simulation.
- With Ken Moreland at Sandia, we have started a simple toolbar to streamline accelerator visualization workflow.
  - Automatic pipeline construction for mesh, particles, and e and b fields.
  - Heuristic for automatic normalization of fields from wakefield simulations.

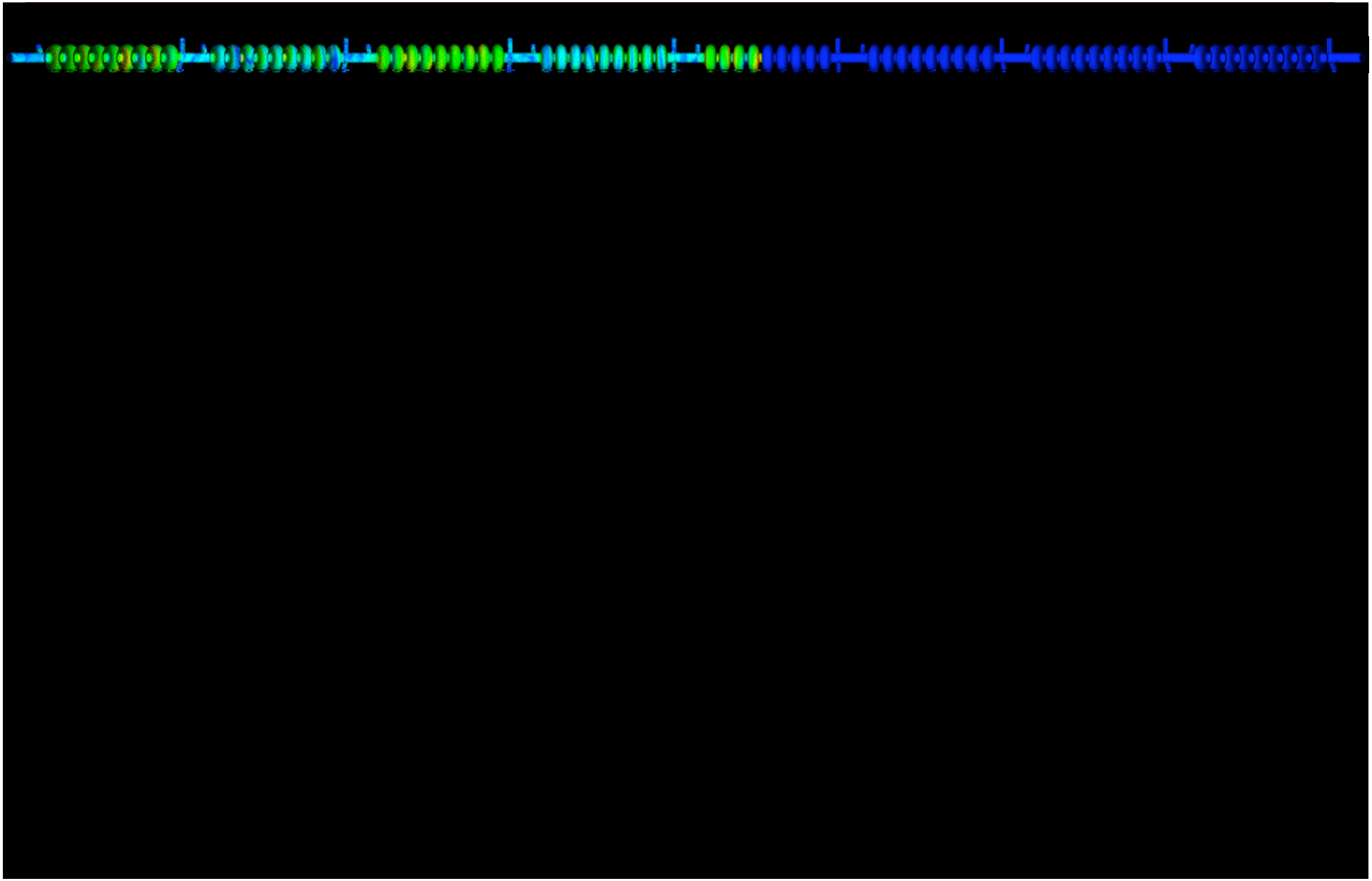
ParaView Generated Movies

- Multipacting
- Wakefield
- Power flow
- 3D Stereo

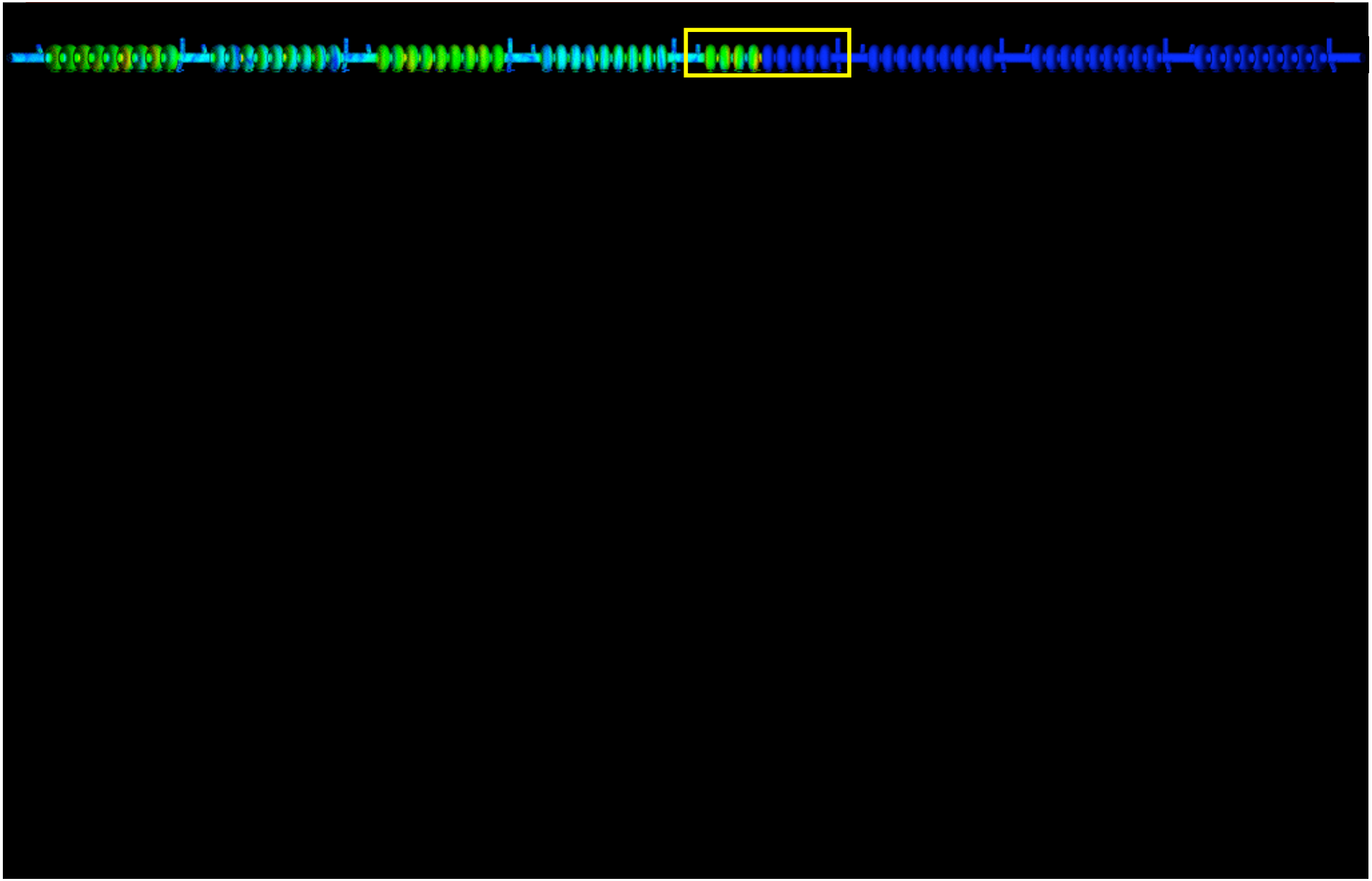
Multipacting Movie

- What is multipacting?
  - Resonant trajectories
  - Enhancement
- Why is multipacting important?
  - Can cause damage to accelerator structure
  - Limits operating power of structure
- Movie Information
  - Meshing and Simulation: Lixin Ge at SLAC
  - Saturated color: particle momentum (energy)
  - White trails: recent particle trajectory
  - Desaturated color: electric field magnitude
  - Wireframe: view dependent mesh exterior
  - Surface: view dependent mesh interior

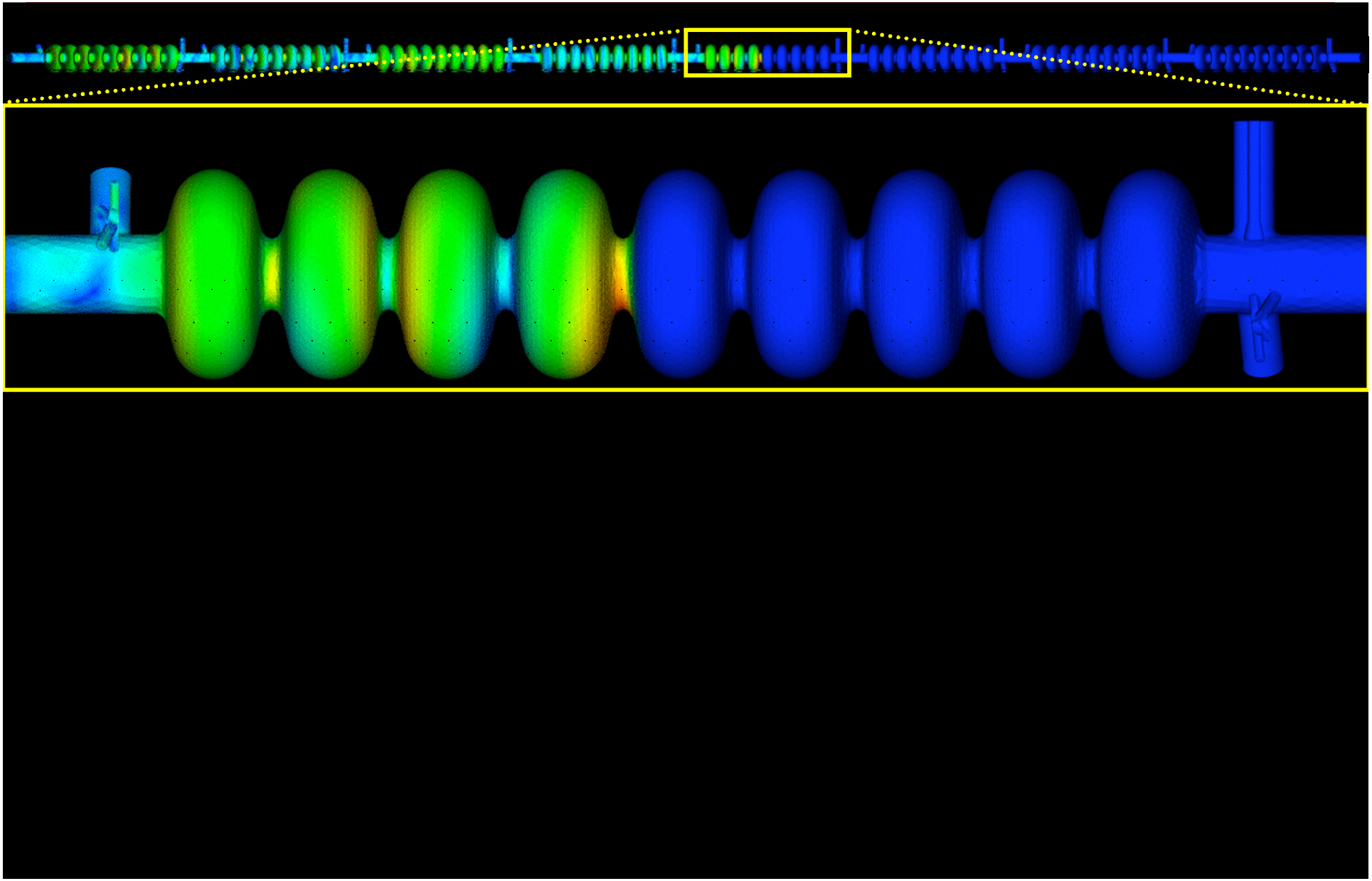
Multipacting Simulation (context)



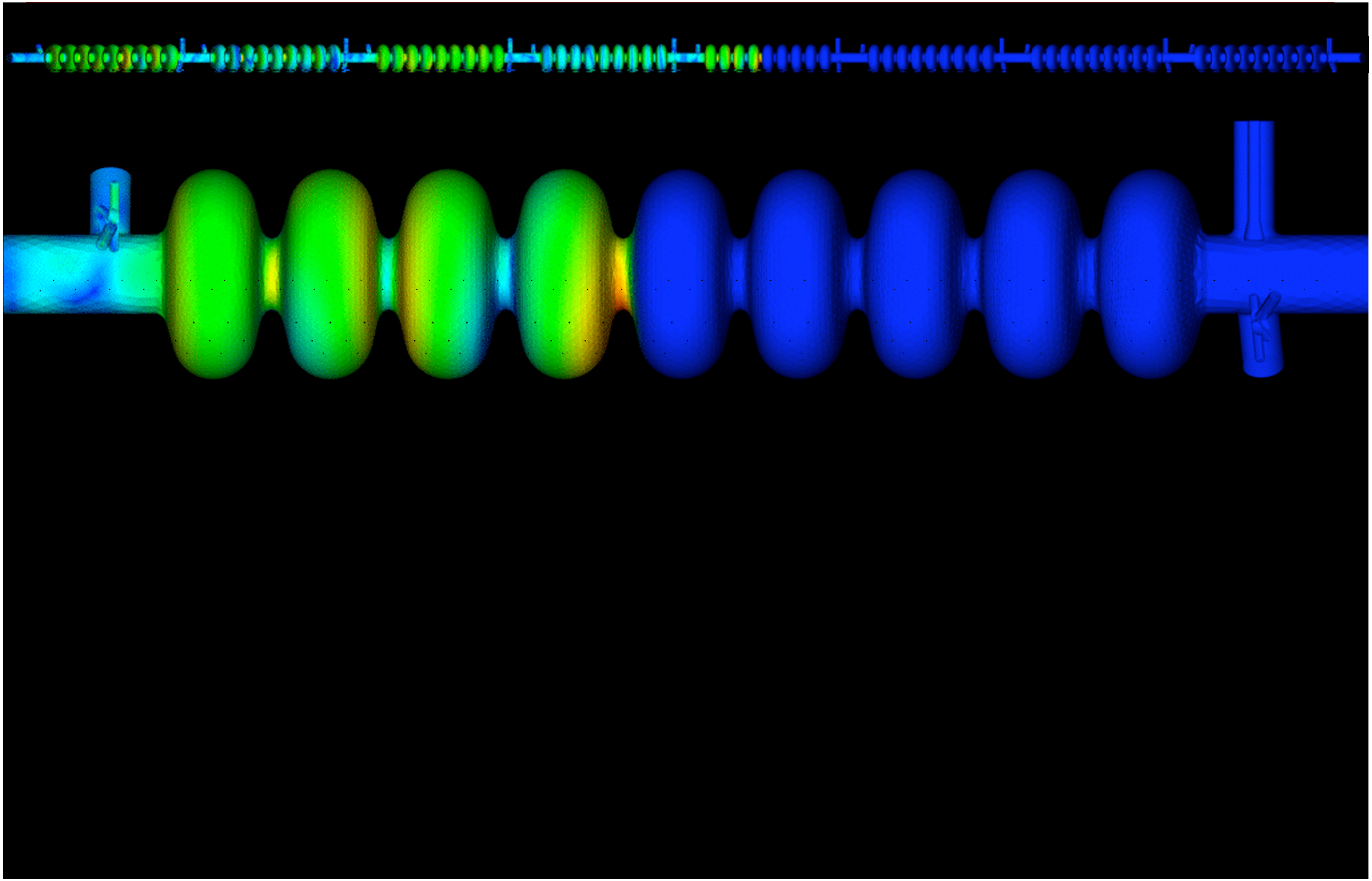
Multipacting Simulation (context)



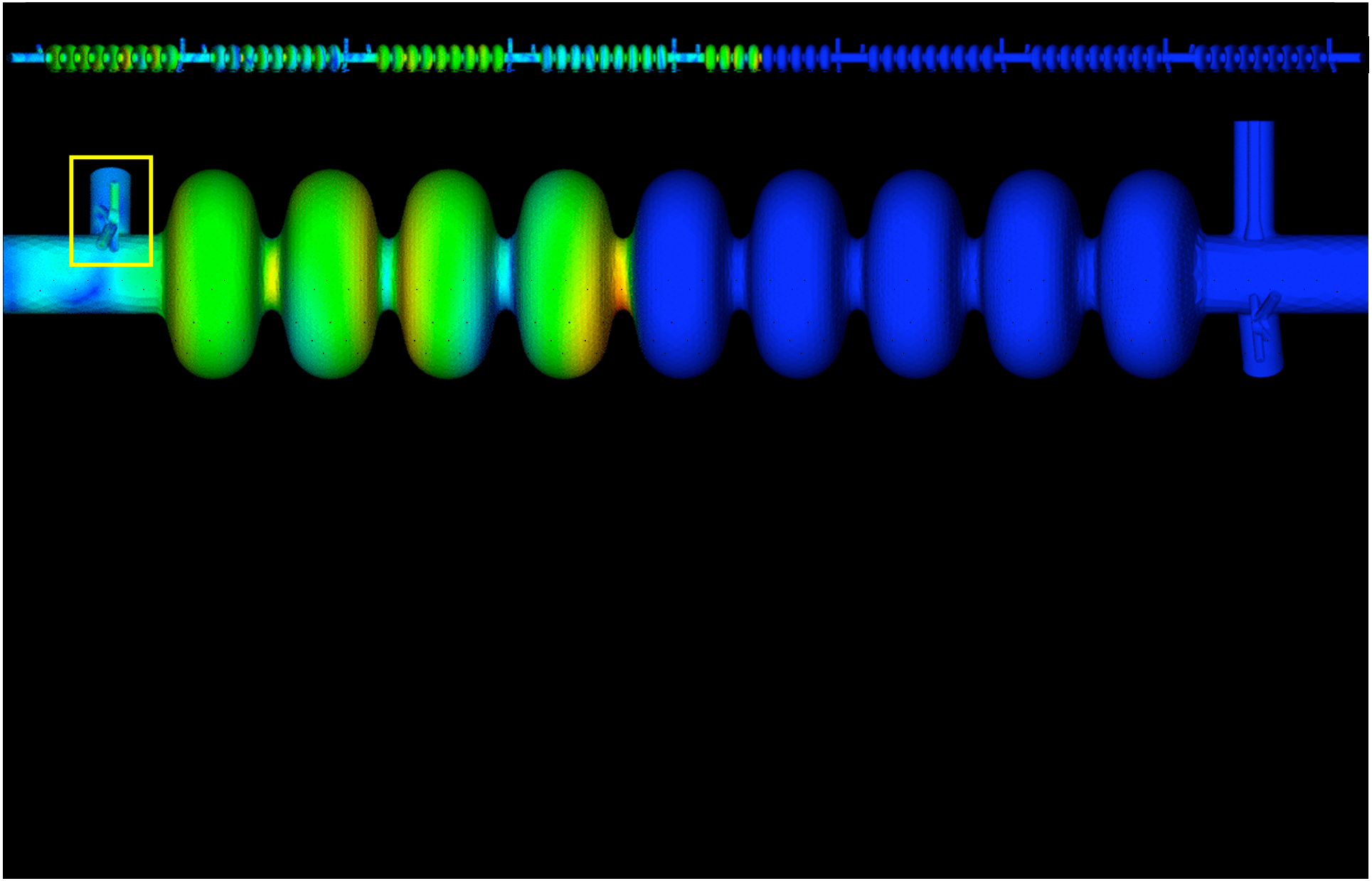
Multipacting Simulation (context)



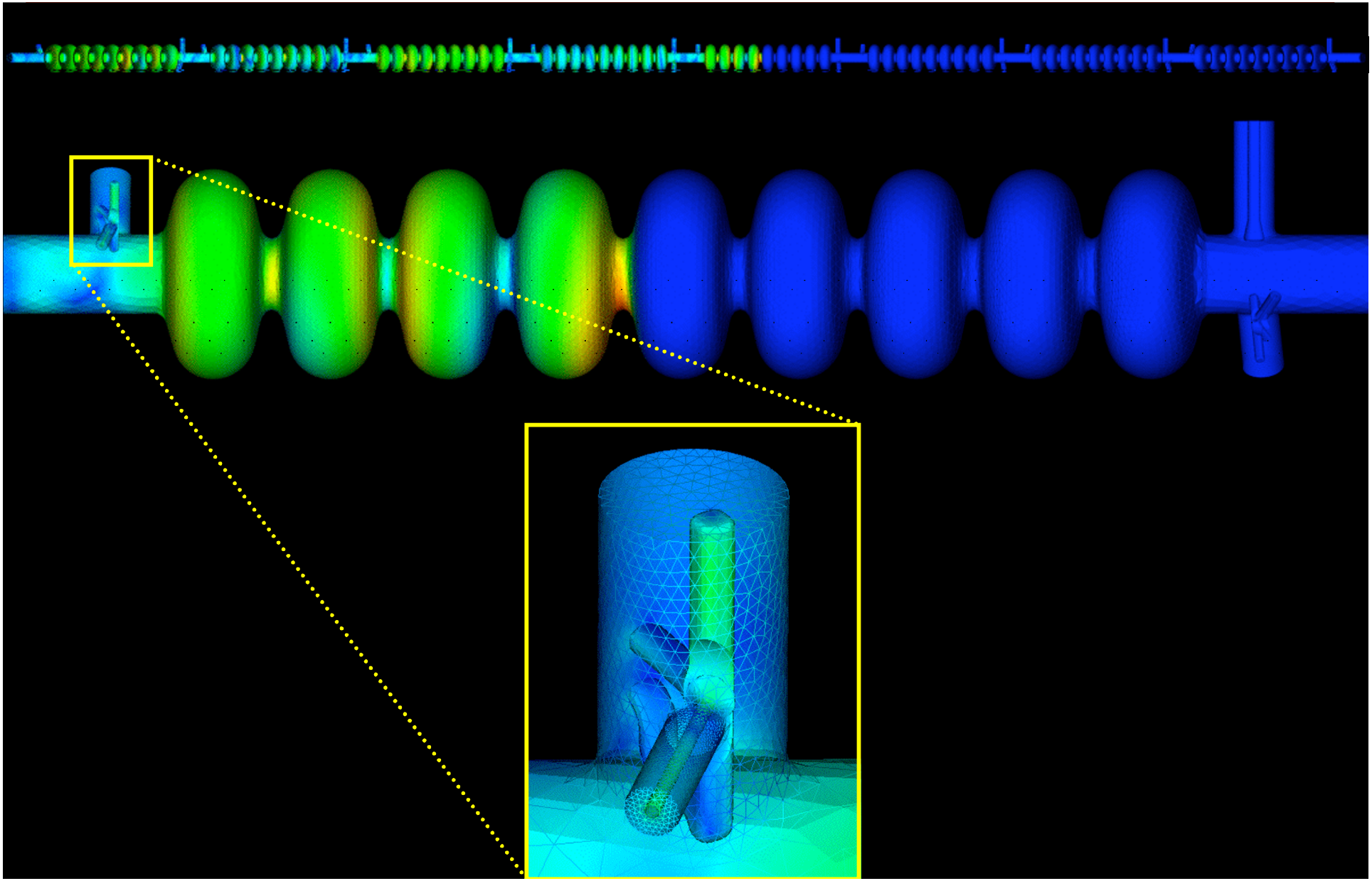
Multipacting Simulation (context)



Multipacting Simulation (context)



Multipacting Simulation (context)



Multipacting Simulation

Rendered in parallel, on a 4 processor Sun Ultra 40

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Wakefield Movie

- What is a wakefield?
  - Electromagnetic fields behind a particle bunch
  - Analogies:
    - Waves from a boat on a smooth lake
    - Turbulence left behind an aircraft
- Why are wakefields important?
  - Can cause harmful surface heating
  - Can kick bunch particles sideways, off path
- Movie Information:
  - Context: CLIC PETS
  - Meshing and Simulation: Arno Candel at SLAC
  - CAD Model: CERN
  - Field scaling is: **`sqrt(mag(efield))`**

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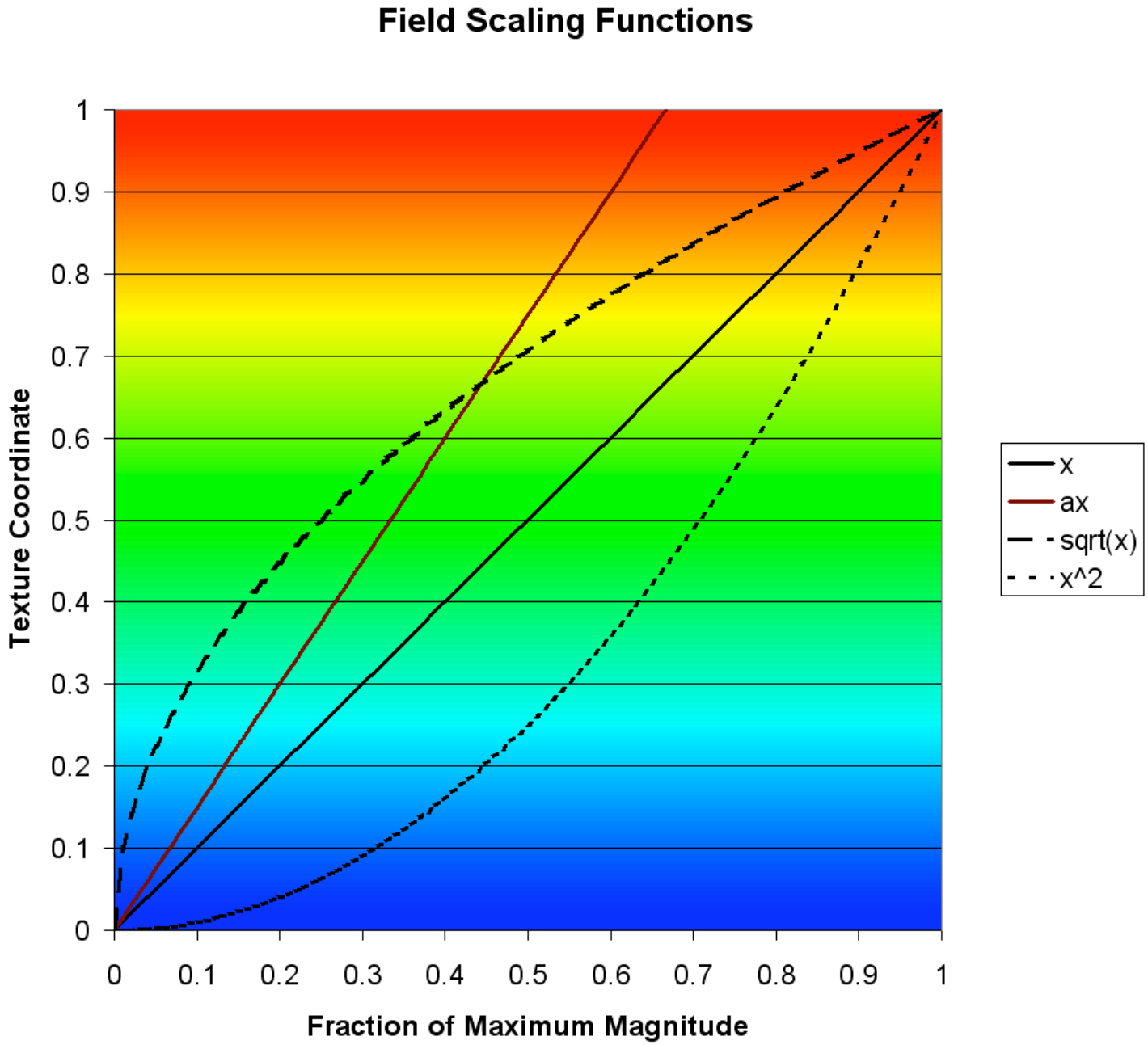
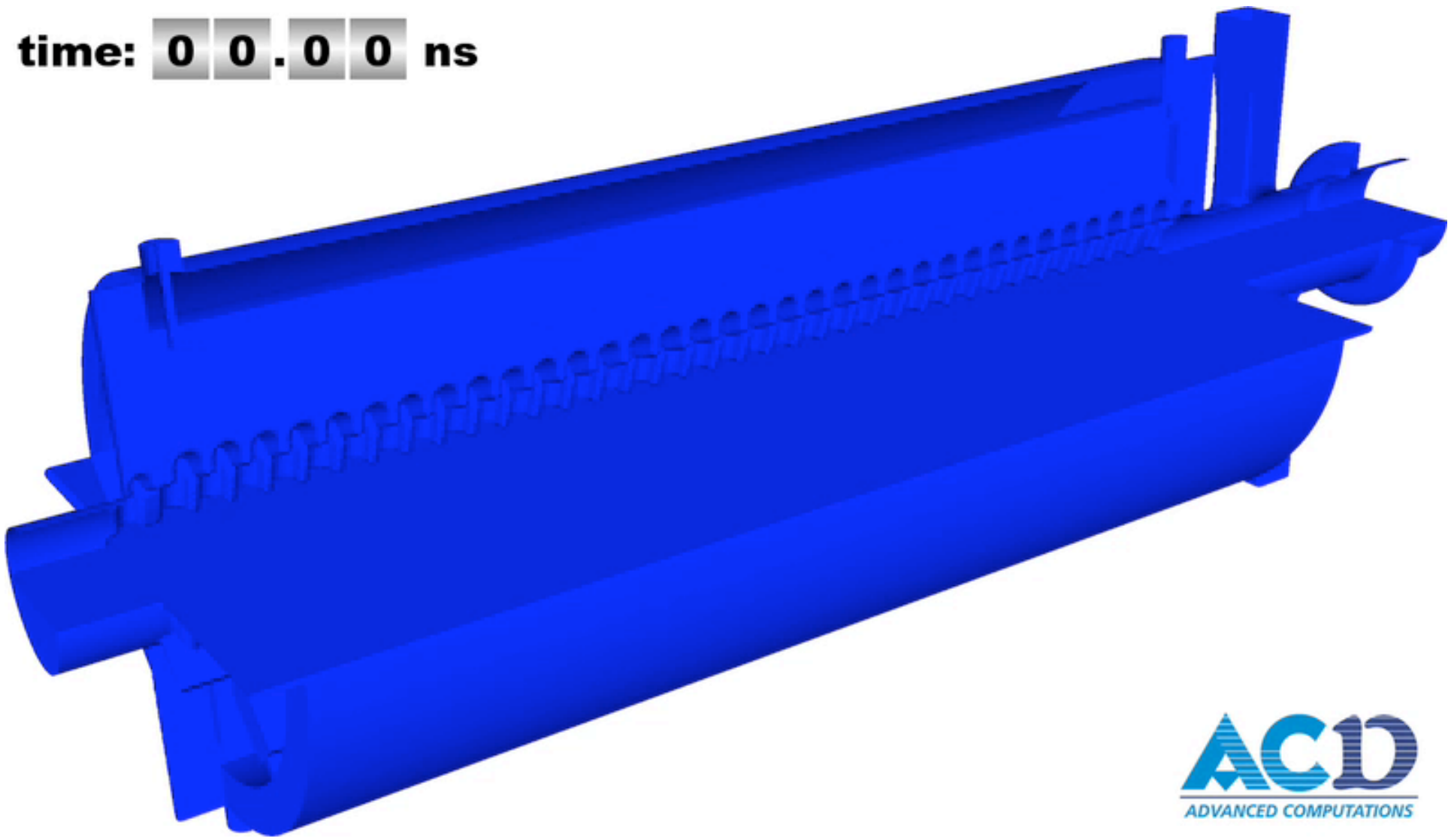

Field Scaling Functions
Texture Coordinate
Fraction of Maximum Magnitude
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
x
ax
sqrt(x)
x^2


time: 0 0.0 0 ns
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Power Flow Movie

- What is power flow in this movie?
  - One accelerator is used to power another.
  - Power flow shows where the resonant fields build up for particle acceleration.
- Why is power flow important?
  - Analogy: buildup of large waves for surfing
  - Is the (very complicated) structure operating as intended?
- Movie Information:
  - Context: CLIC structures
  - Meshing and Simulation: Arno Candel at SLAC
  - 17 million quadratic elements
  - CAD Model: CERN
  - Field scaling is linear power: **`(efield.efield + bfield.bfield)`**
  - Filling takes a very long time, so this movie is highly accelerated.

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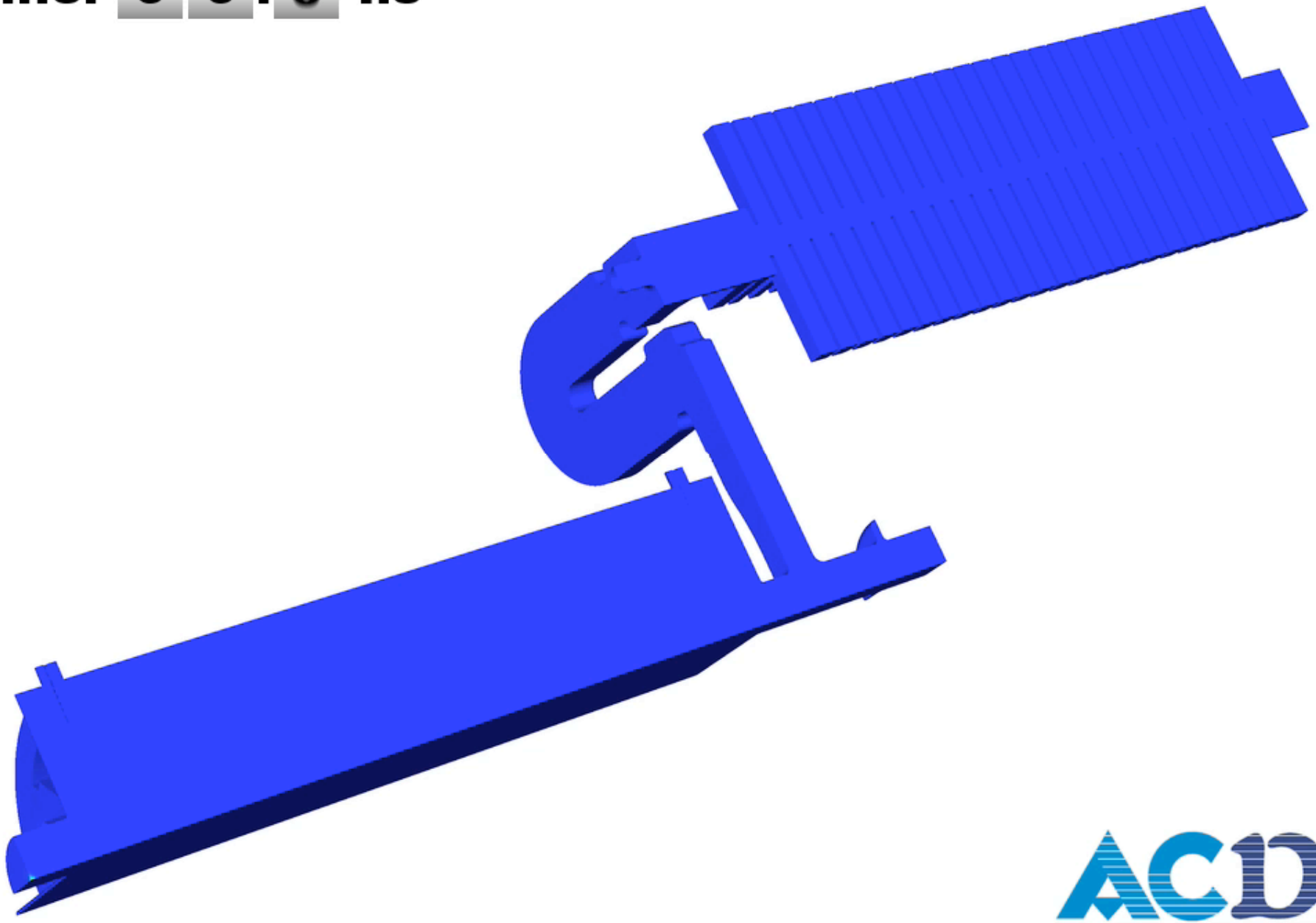
time: 0 0.0 ns



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3D Stereo Movie

- What is 3D Stereo?
  - Left eye and right eye see slightly different images.
  - Appears truly 3D, not just perspective projection of 3D onto 2D.
- Why is 3D Stereo important?
  - Provides more accurate sense of true 3D structure.
  - Effectively shows depth relationships.
  - Useful for very complex structures (accelerator structure, particle paths)
- Movie Information:
  - Same as previous movie.
  - **Left Eye Only!** Please see true stereo at the SLAC National Accelerator Center exhibit (Booth 901).

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Power Flow in the CLIC Two-Beam Accelerator

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SciDAC Scientific Discovery through Advanced Computing

Our Plans for ParaView

- Support for massively parallel visualization
  - Compile and make available on
    - DaVinci at NERSC
    - Lens at ORNL
- SBIR Phase II with Kitware
  - Collaborative Visualization
  - Higher order fields (up to 6th order)
  - Higher order geometry (2nd order)
  - Interactor for structures with high aspect ratio
- Possible SBIR Phase II with Kitware
  - Comparative visualization

Thank you.