Modeling RF cavities and multipacting with the VORPAL code

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Abstract

Considerable resources are required to run three dimensional simulations of multipacting in superconducting RF cavities. Three dimensional simulations are needed to understand the possible roles of non-axisymmetric features such as the power couplers. The ability to run in parallel is important if self-consistent simulations of the accelerating structures are to be done. The plasma simulation code VORPAL can run in parallel and has the needed models to simulate multipacting in superconductive cavities. VORPAL's general domain decomposition will allow complex geometries to be simulated in parallel and allows the code to scale to over a 1000 processors. VORPAL incorporates the CMEE (Computational Modules of Electron Effects) library to model secondary electron emission. Recent developments include conformal boundaries to model curved cavity surfaces and preliminary tests demonstrating the capability to solve for the mode frequencies.

VORPAL is an established electromagnetic PIC code which is constantly evolving to meet user's needs

- Self-consistent modeling of particle and field dynamics in any physical dimension
- Neutral gas modeling
- Models for secondary electron emission and ionization effects
- Scales to over a 1000 processors in parallel
- Conformal boundaries have recently been developed
- Code (including source) freely distributed to researchers

VORPAL has a variety of models for both electromagnetics and plasma dynamics

Electromagnetics:

- Explicit and implicit Maxwell solvers
- Electrostatic solver

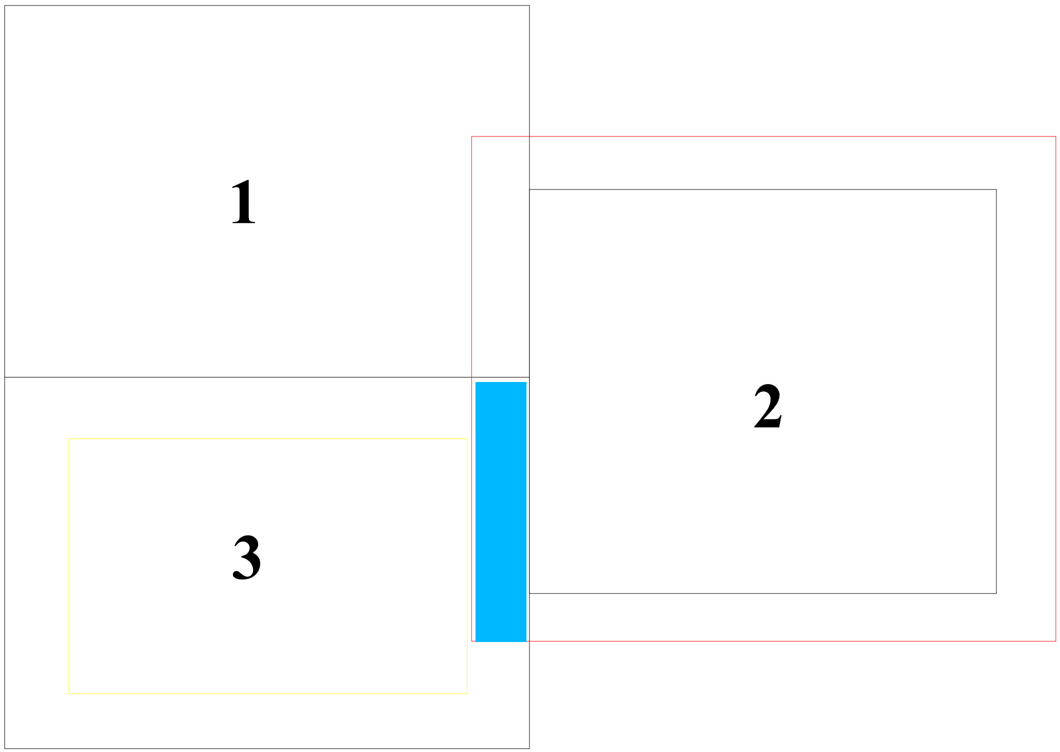
Plasma Dynamics:

- PIC
- Cold Fluid

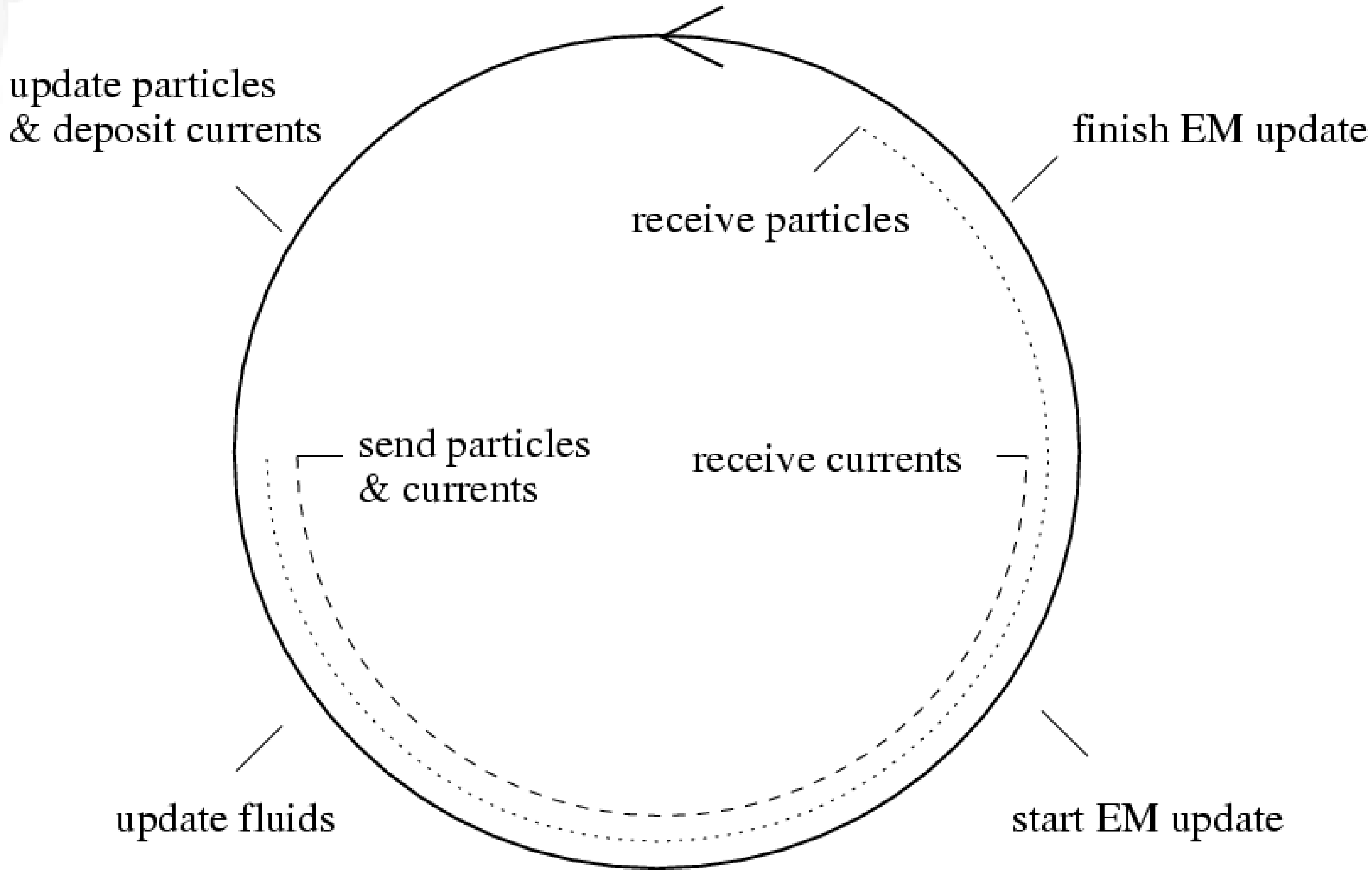
Neutral Gases:

- Warm Fluid
- DSMC (Direct Simulation Monte Carlo)
- Ionization process (via IONPACK)

Determining send/receive regions with overlapping slabs allows for general domain decompositions

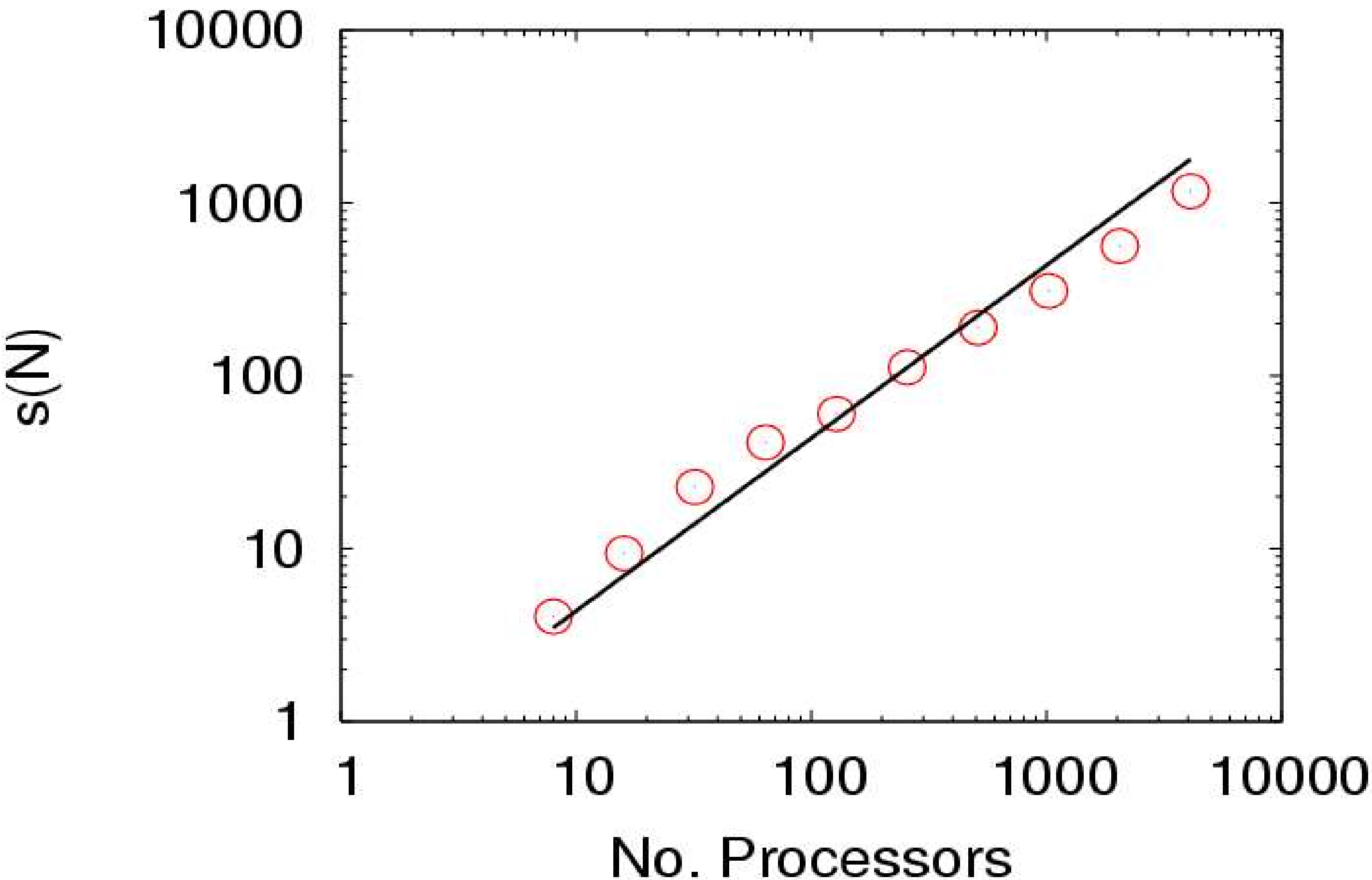


Overlap between communication and computation improves scaling



Vorpal update loop – currents are received while EM update is started

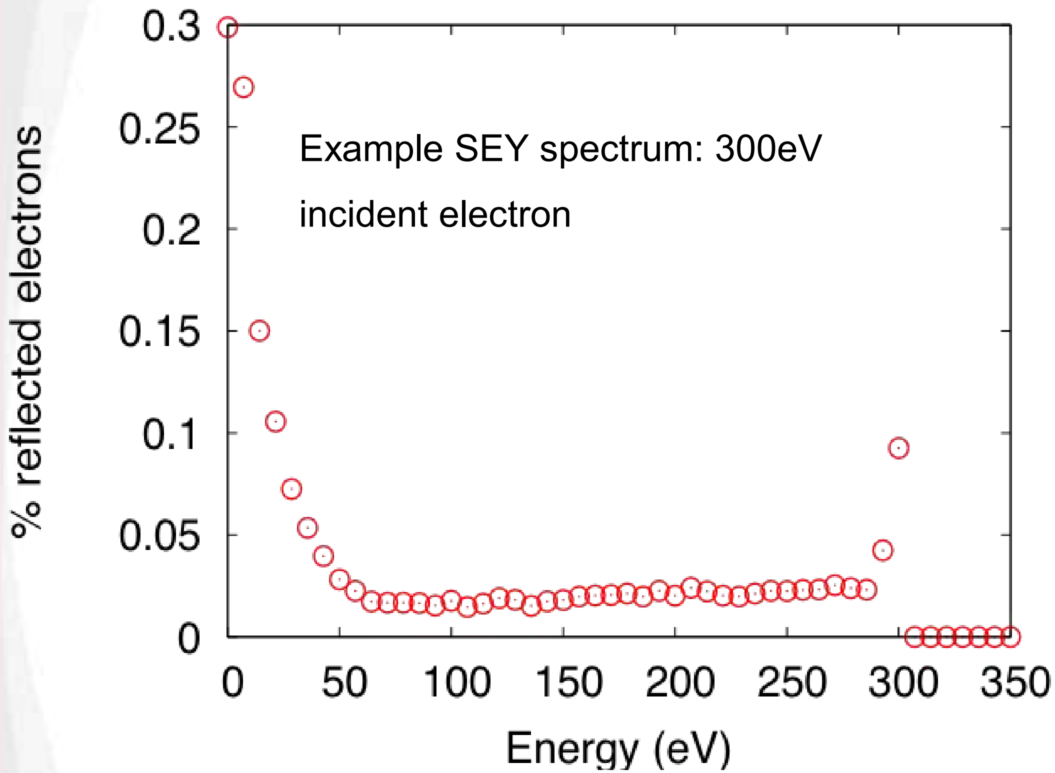
VORPAL scales to over a 1000 processors in parallel



VORPAL incorporates the CMEE library for modeling secondary electron emission

- CMEE = Computational Modules of Electron Effects
- Latest version of CMEE now provides routines for modelling
  - secondary electron yield
  - ion stopping, range, and ion-induced electron yield
  - ion-induced neutral gas desorption
  - neutral gas ionization by electrons and protons

CMEE's secondary electron model deals with diffusive, reflected and true secondary electrons

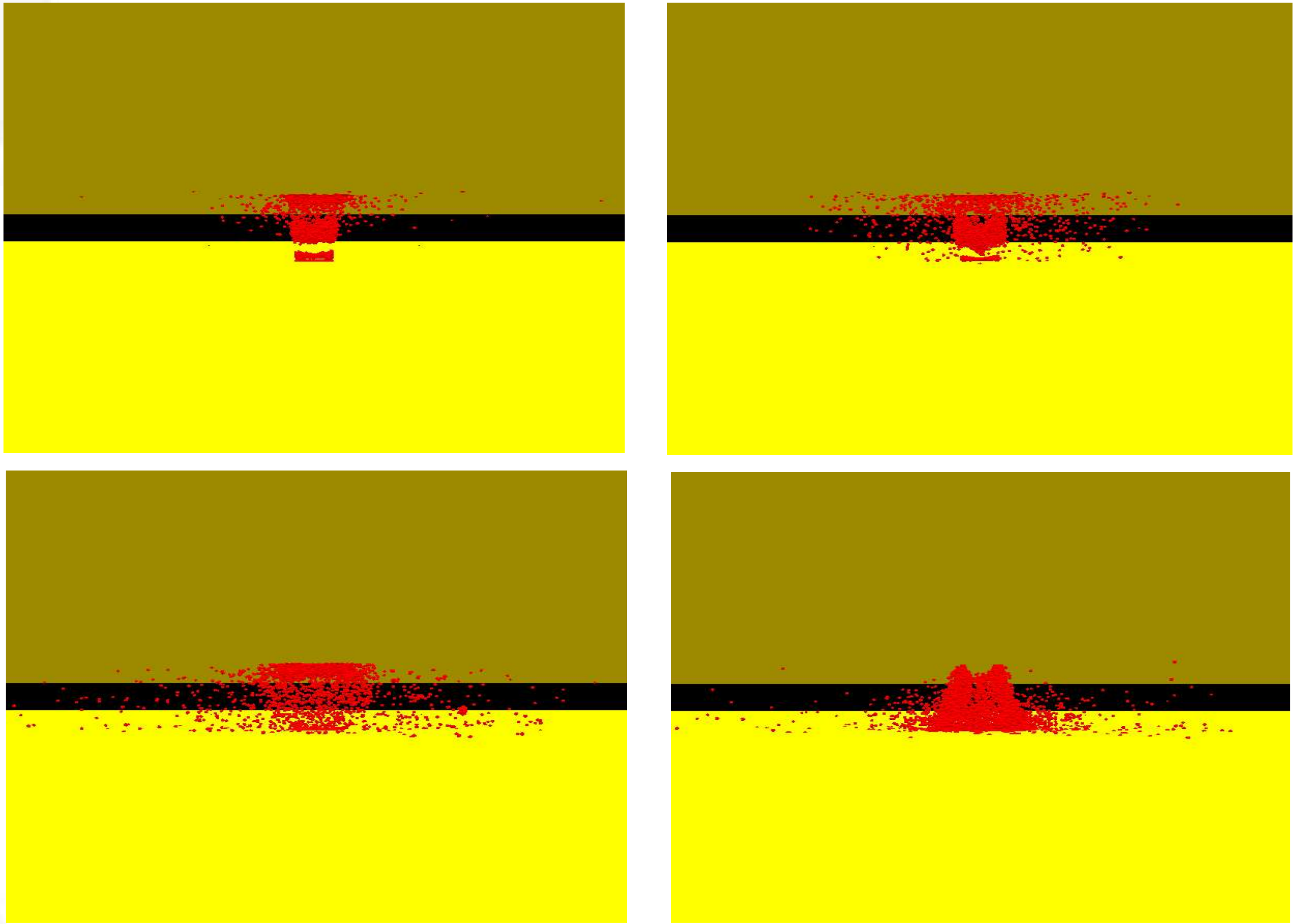


- Uses the POSINST code developed by Furman and Pivi at LBNL

  (see: M. A. Furman and M. Pivi, Phys. Rev. ST Accel. Beams 5, 124404 (2002)).

- POSINST models copper and stainless steel now, with other materials to come

3D VORPAL simulation using CMEE shows multipacting in high power wave guides



Simulation of cavity excitation demonstrates VORPAL's potential

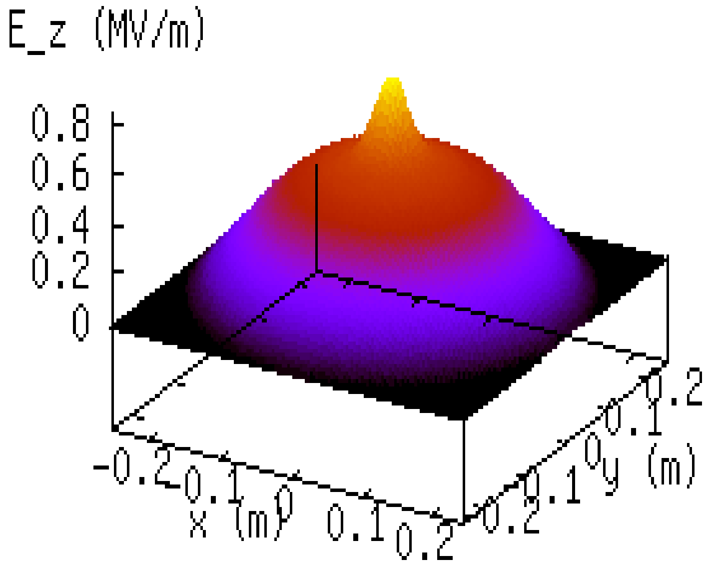
Physical parameters:

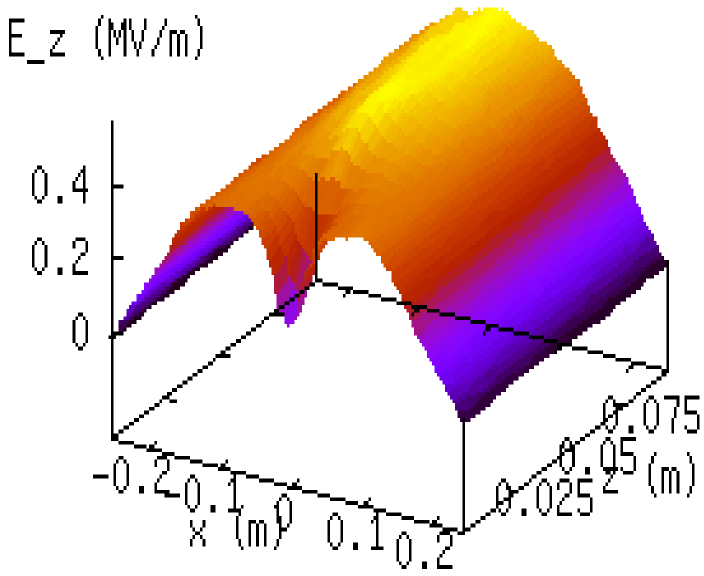
- Cylindrical cavity: radius = 0.5 m, height = 0.1 m
- Frequency of TM010 mode = 459 Mhz
- Cavity driven by current oscillating at resonant frequency located at cavity face.

Simulation parameters:

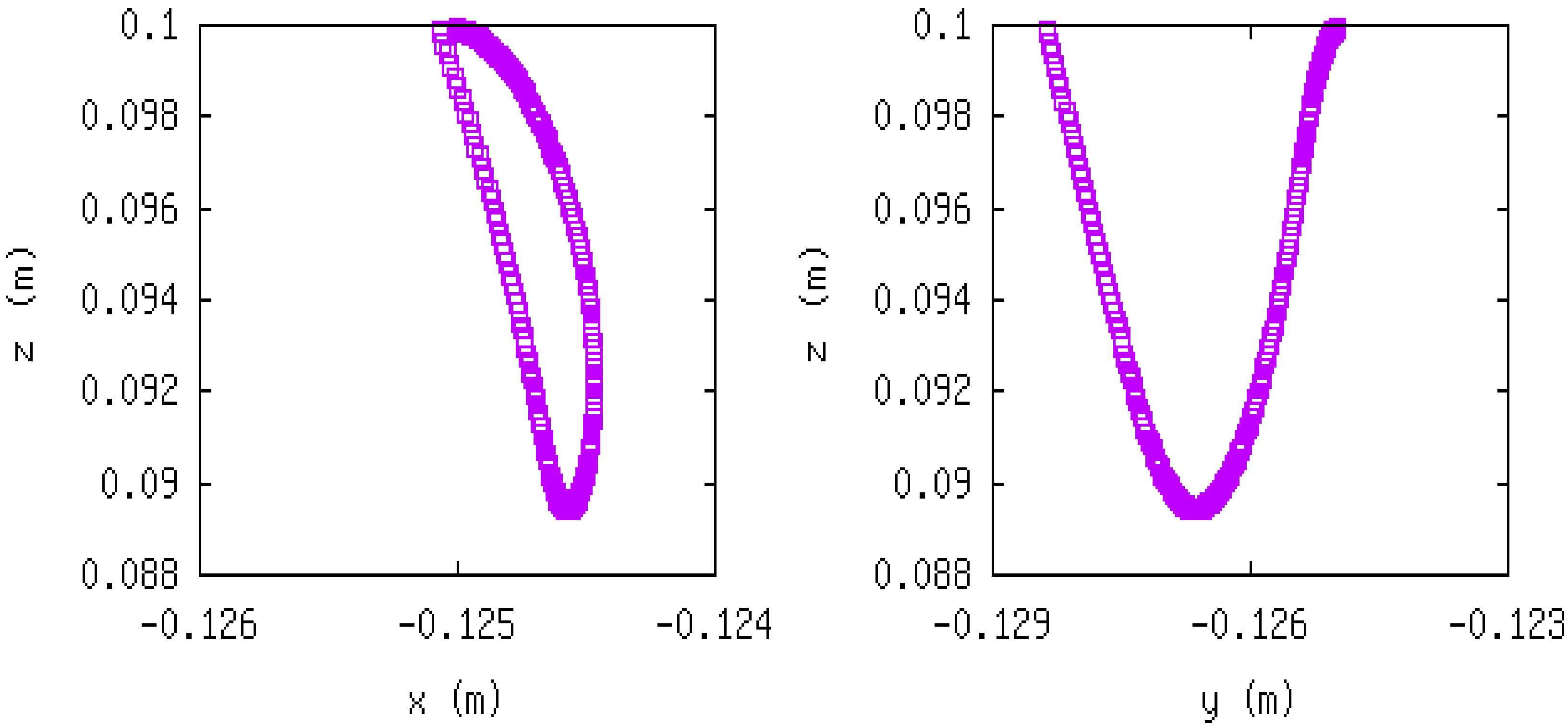
- Grid: 100 by 100 by 20 cells
- Stair step boundaries
- Time step = 9.1 ps (set by Courant condition)

Fields in cavity show TM010 mode structure





Returning electron trajectories can lead to multipacting



10 eV electron released into simulation returns to wall in one oscillation period.

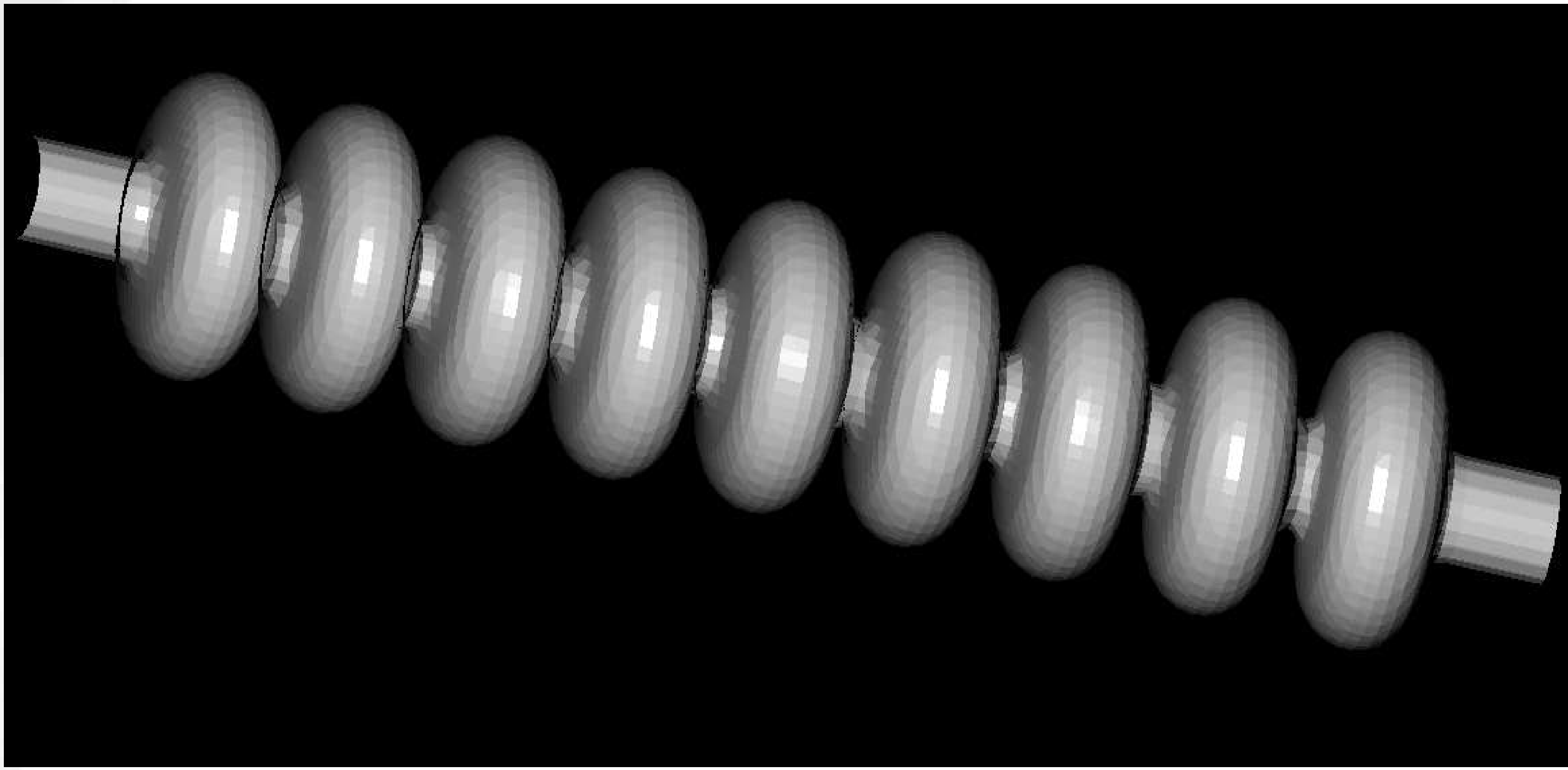
VORPAL can generate conformal boundaries for general surfaces

- Any surface that can be described by a function, $f(x,y,z) = 0$, is possible
- OO interface will allow for other surface descriptions such as CAD
- Multiple boundaries can be combined including boundaries that are specified in different ways
- Time dependent boundaries are a possibility

Boundary objects stores all the geometric data needed by multiple boundary models

- The fractions of both the cell edges and faces cut by the boundary are stored
- The parameters can then be provided to the boundary model being used
- Multiple boundary models are under active development:
  - Stair-step
  - Dey-Mittra
  - Zagordnov

Wire frame visualization of VORPAL's conformal boundaries



Conformal boundary for cavity described in
Aune et al, PR/STAB 3, 092001 (2000)

Preliminary results show VORPAL can calculate cavity mode frequencies

- Method developed by Smithe – *D. Smithe and L. Ludeking, Comp Phys Comm 106, 95 (1997)*
- Algorithm is based on Maxwell FDTD operator
- Tests to estimate time needed to achieve to one part in 10^4 accuracy for 10^6 degrees of freedom:

  20 nodes, 2 Ghz Opteron: 100 seconds

  380 nodes, 375 Mhz Power3: 50 seconds

Summary

VORPAL can provide self-consistent modeling of multipacting in SRF cavities:

- Good scaling beyond a 1000 processors allows for simulations of 3D dynamical effects and efficient mode frequency calculations
- Secondary electron emission models and self-consistent particles can model the effects of multipacting on cavity operation
- Accurate modeling of these effects can save time and money by reduced the need for cavity prototypes