ACE3P and Applications to HOM Power Calculation in Cornell ERL

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Outline

<u>ACE3P Electromagnetic Simulation Suite</u>

* Parallel EM Code Development at SLAC
* Parallel Higher-Order Finite-Element Method
* Accelerator Modeling with EM Code Suite ACE3P
* ACE3P Capabilities and Application Examples

<u>HOM Power Calculation in Cornell ERL</u>

* *HOM Power Flow Out of the FPC*
* *HOM Power Deposited in the RF Absorber*
* *HOM Power in the Cavity*

Parallel EM Code Development at SLAC

DOE's High Performance Computing Initiatives and SLAC support

- **1998–2001 HPC Accelerator Grand Challenge**

- **2001-07 Scientific Discovery through Advanced Computation (SciDAC-1) -** Accelerator Science and Technology (AST)

- **2007-12 Scientific Discovery through Advanced Computation (SciDAC-2) -** Community Petascale Project for Accelerator Science and Simulation (ComPASS)

PhD Research:

1998 *- Xiaowei Zhan, Parallel electromagnetic field solvers using finite element methods with adaptive refinement and their application to wakefield computation of axisymmetric accelerator structure, Stanford University.*

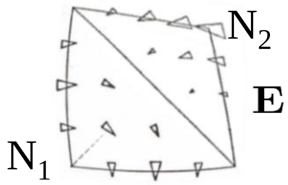
2003 *- Yong Sun, The filter algorithm for solving large-scale eigenproblems from accelerator simulations, Stanford University.*

2009 *- Sheng Chen, Adaptive error estimators for electromagnetic field solvers, Stanford University.*

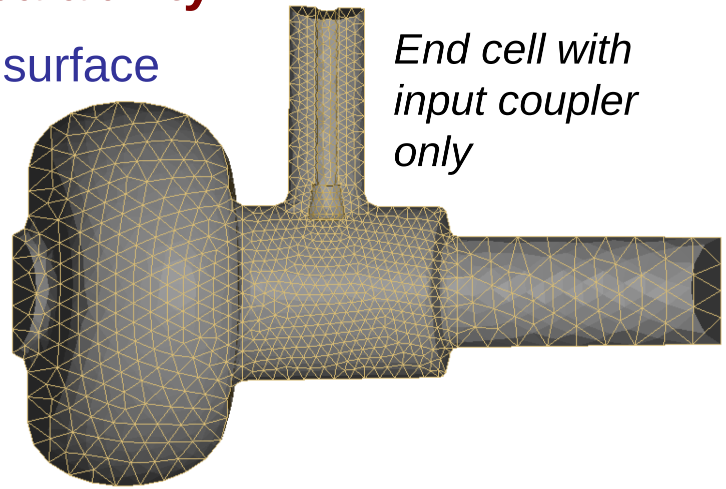
Parallel Higher-Order Finite-Element Method

Strength of Approach – Accuracy and Scalability

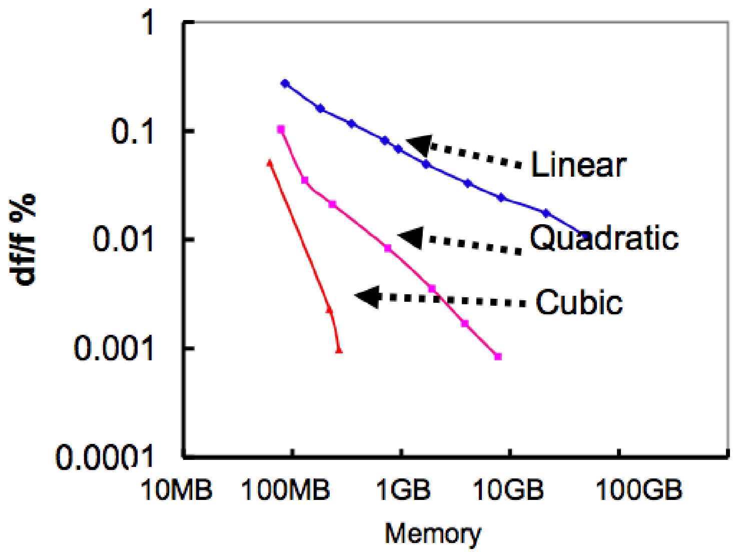
- <u>Conformal</u> (tetrahedral) mesh with quadratic surface
- <u>Higher-order</u> elements (p = 1-6)
- <u>Parallel</u> processing (memory & speedup)



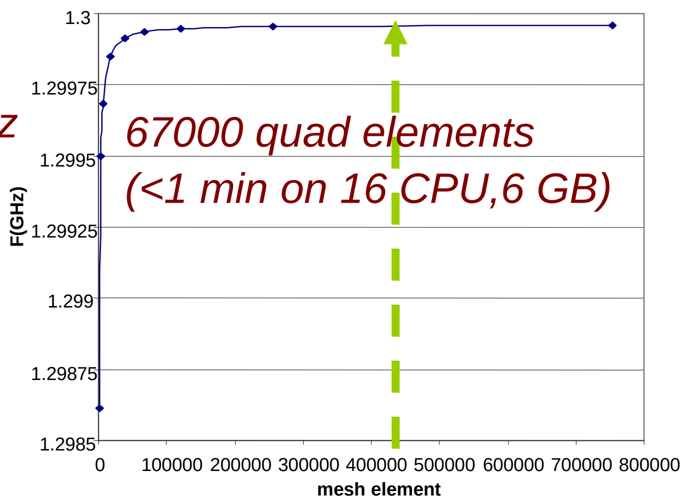
$$\mathbf{E}(\mathbf{x},t) = \sum_i e_i(t) \cdot \mathbf{N_i}(\mathbf{x})$$



End cell with input coupler only



Error ~ 20 kHz (1.3 GHz)



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Accelerator Modeling with EM 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)

Frequency Domain:	**Omega3P**	**– Eigensolver (damping)**
	S3P	**– S-Parameter**
Time Domain:	**T3P**	**– Wakefields and Transients**
Particle Tracking:	**Track3P**	**– Multipacting and Dark Current**
EM Particle-in-cell:	**Pic3P**	**– RF gun (self-consistent)**
Multiphysics:	**TEM3P**	**– Thermal, RF and Structural**

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

Goal is the Virtual Prototyping of accelerator structures

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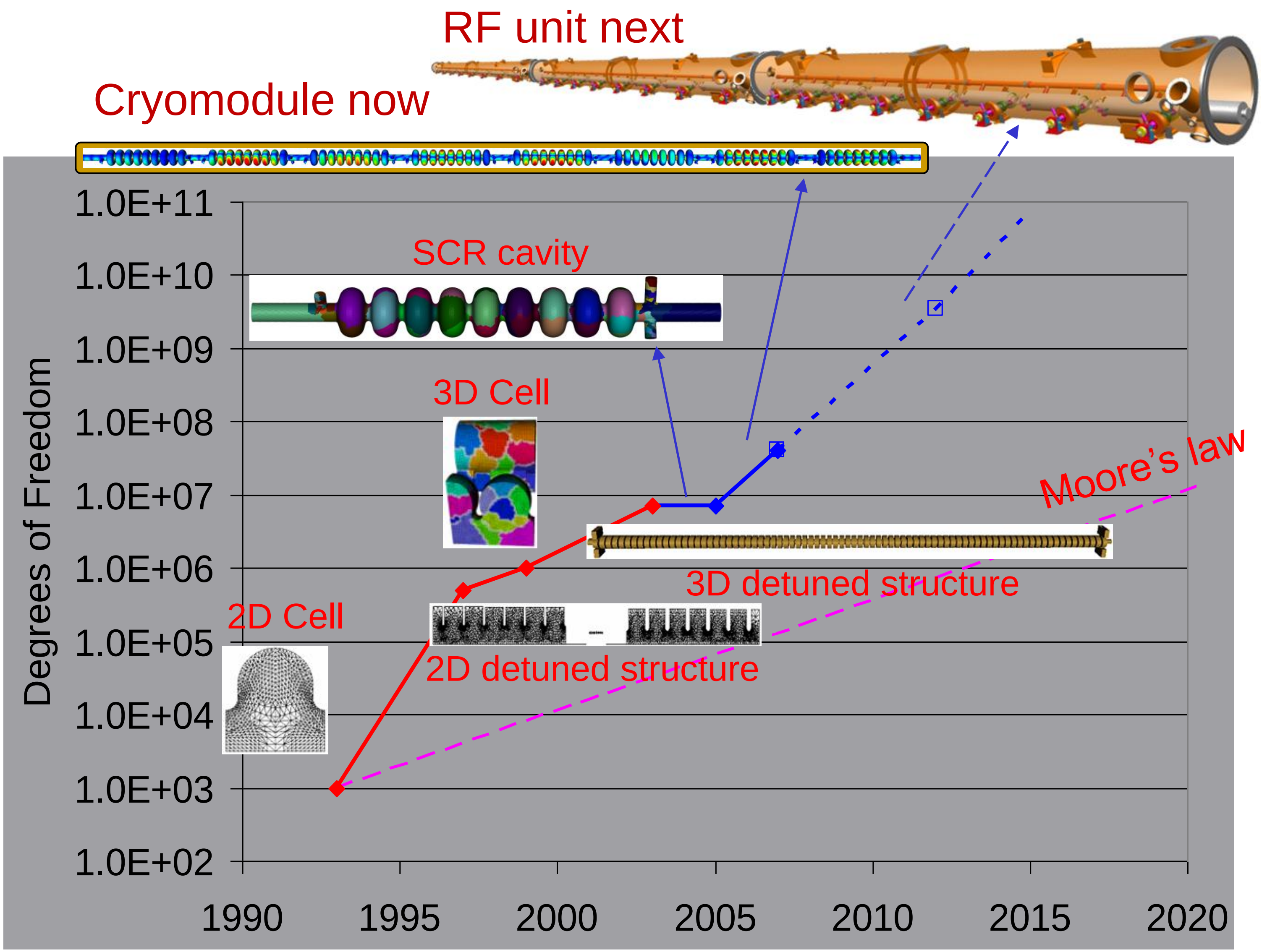
ACE3P Capabilities

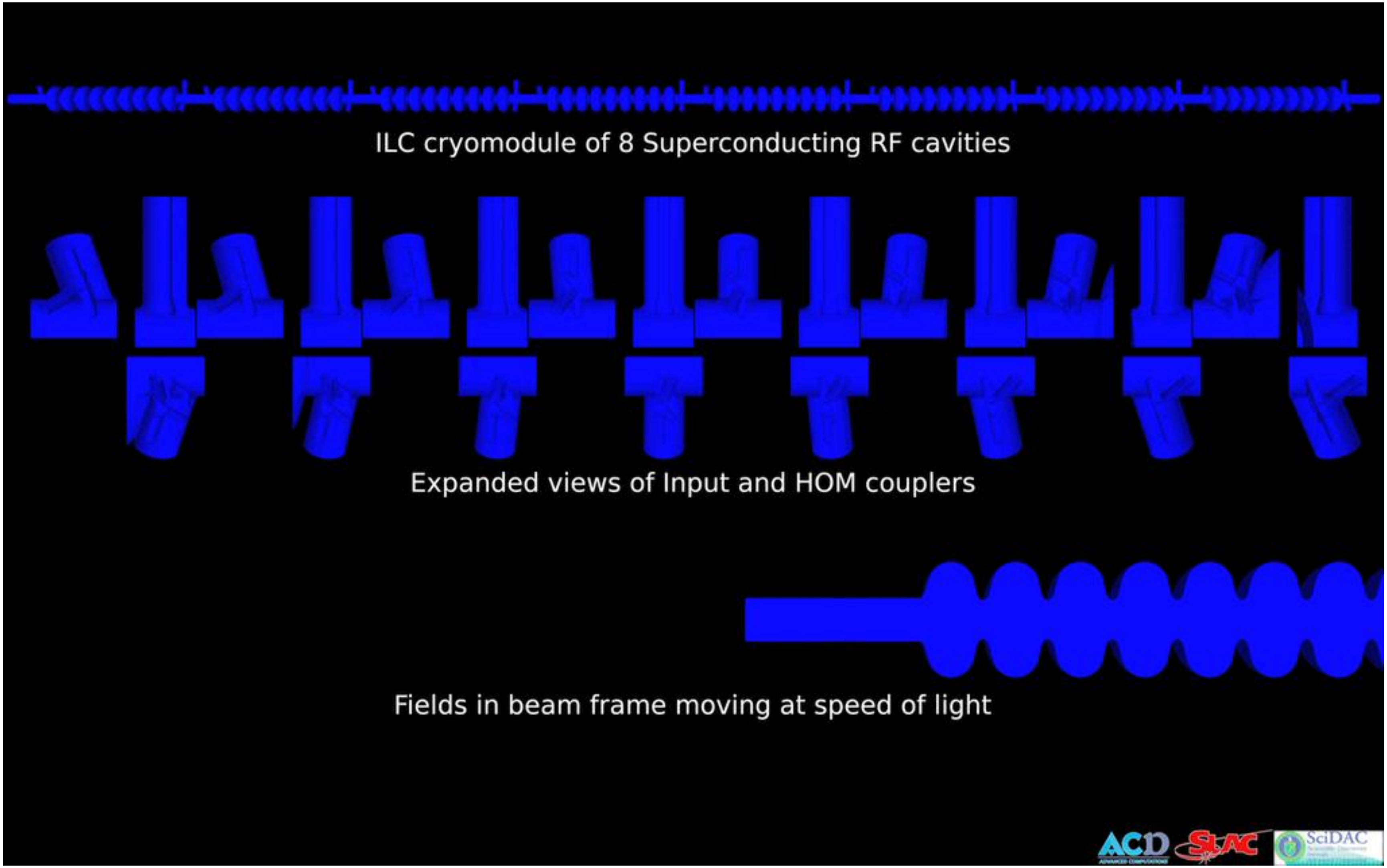
- **Omega3P** can be used to
  - optimize RF parameters,
  - reduce peak surface fields,
  - calculate HOM damping,
  - find trapped modes & their heating effects,
  - design dielectric & ferrite dampers, and others.
- **S3P** calculates the transmission (S parameters) in open structures
- **T3P** uses a driving bunch to
  - evaluate the broadband impedance, trapped modes and signal sensitivity,
  - compute the wakefields of short bunches with a moving window,
  - simulate the beam transit in large 3D complex structures
- **Track3P** studies multipacting in cavities & couplers by identifying MP barriers, MP sites and the type of MP trajectories.
- **Pic3P** calculates the beam emittance in RF gun designs.
- **TEM3P** evaluates multiphysics effects including EM, thermal and structural.

ACE3P's advances focus on solving challenging problems in Accelerator Science and Development

Omega3P – Towards System Scale Modeling

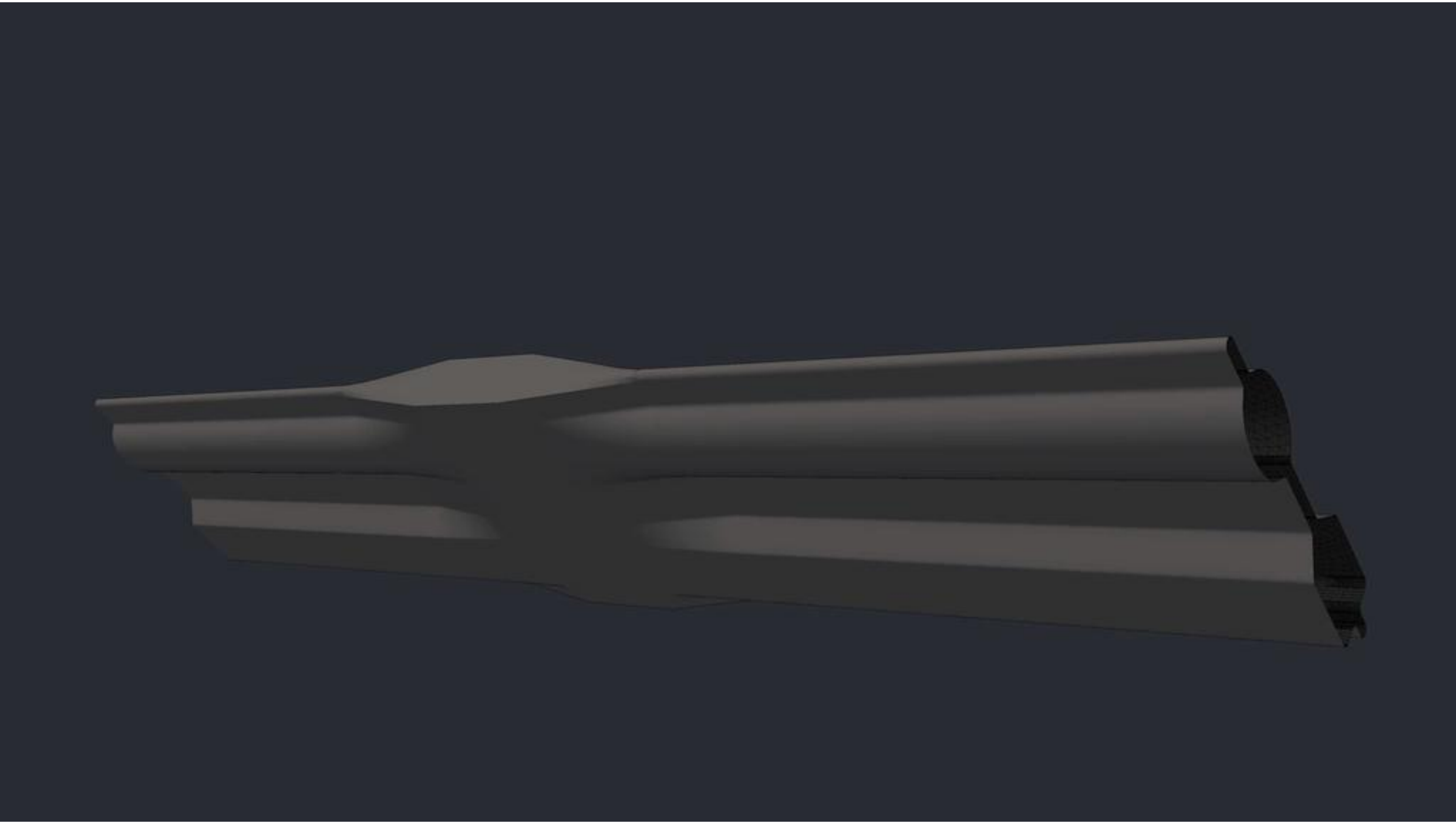


T3P – Beam Transit in ILC Cryomodule



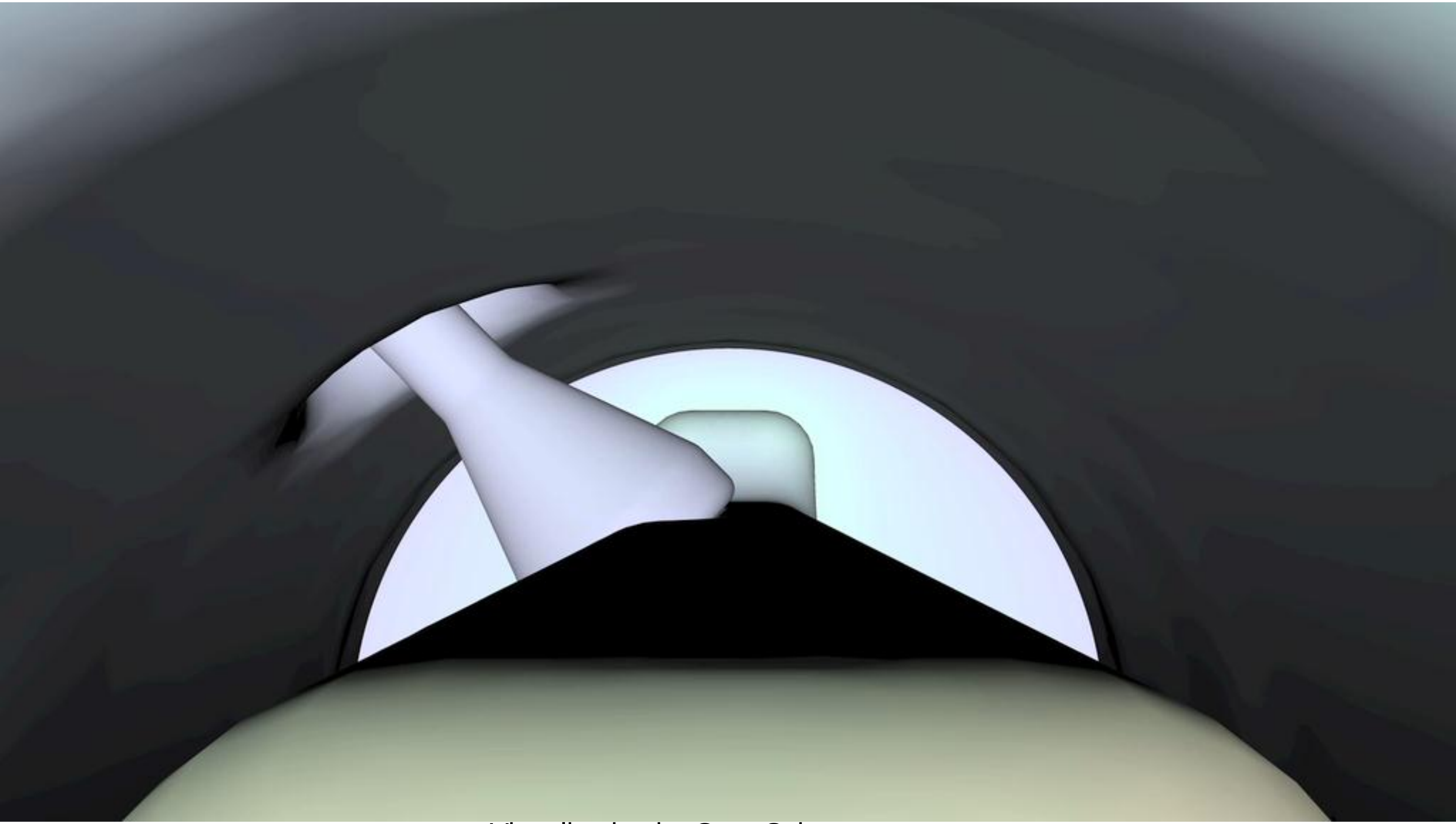
Visualization by Greg Schussman

T3P – Short Bunch Wakefields in ERL Vacuum Device



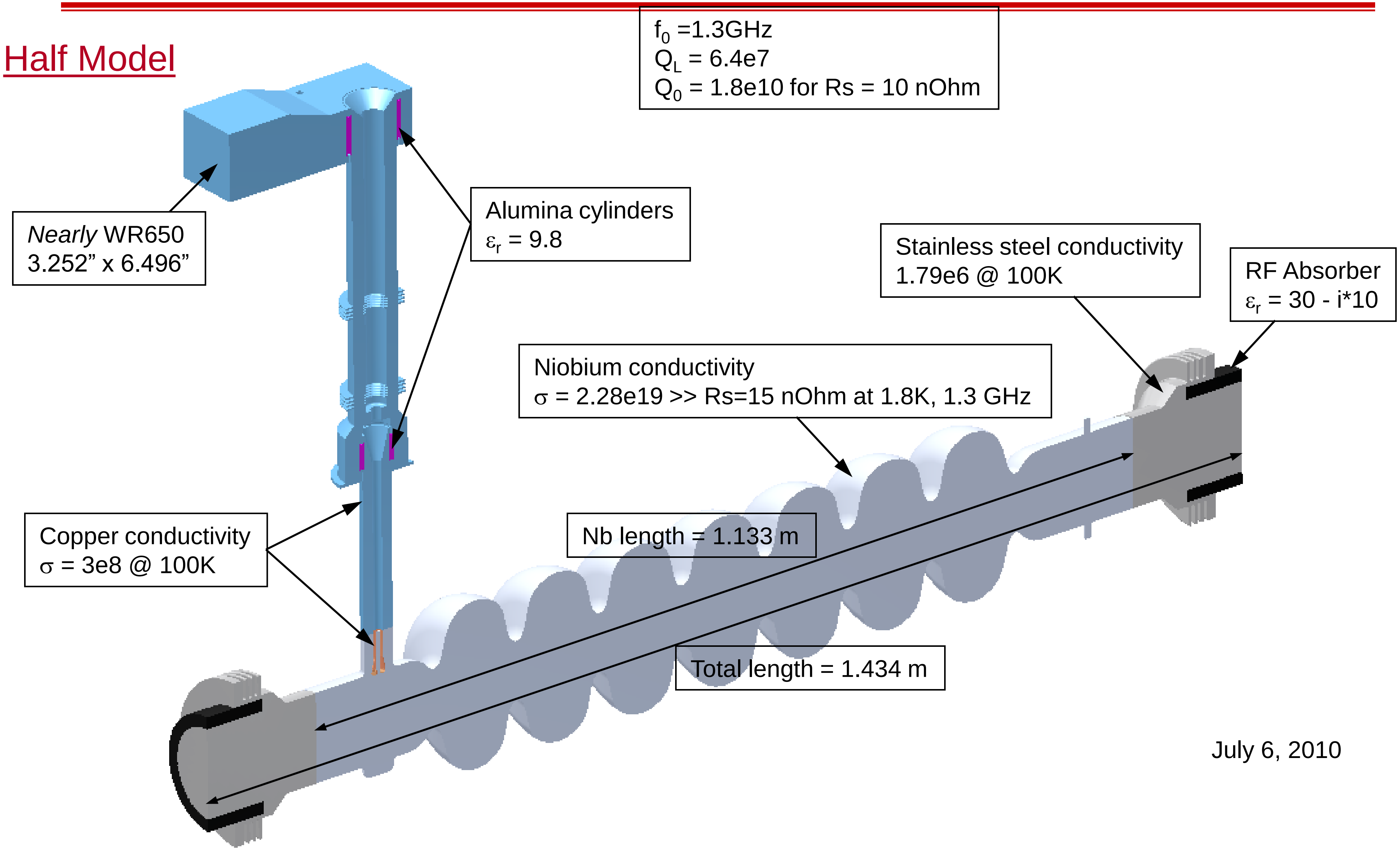
Visualization by Greg Schussman

Track3P – Multipacting in SNS HOM Coupler



Visualization by Greg Schussman

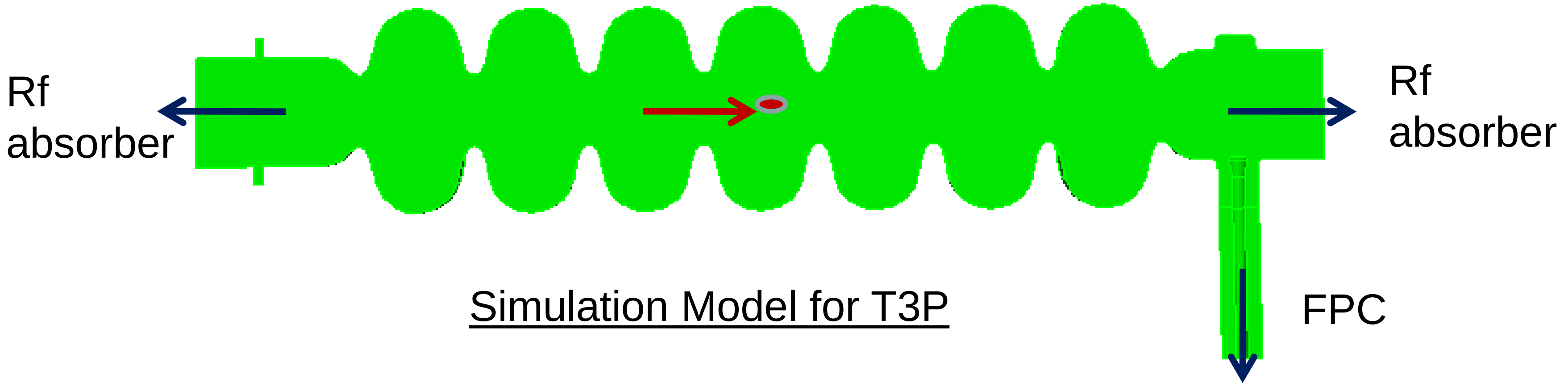
ERL Linac 7.1



July 6, 2010

HOM Power Calculation Using ACE3P

- ***Multipole HOMs will be excited and generate HOM power by the passage of a bunch through the cavity;***
- ***Will start with monopole modes to identify any trapped modes and quantify HOM power;***
- ***Broadband modes can be absorbed by the beampipe rf absorber; how much power goes out of the FPC?***
- ***To what degree are there trapped modes (f, Q & R/Q);***
- ***ACE3P will be used for the HOM power flow calculation.***

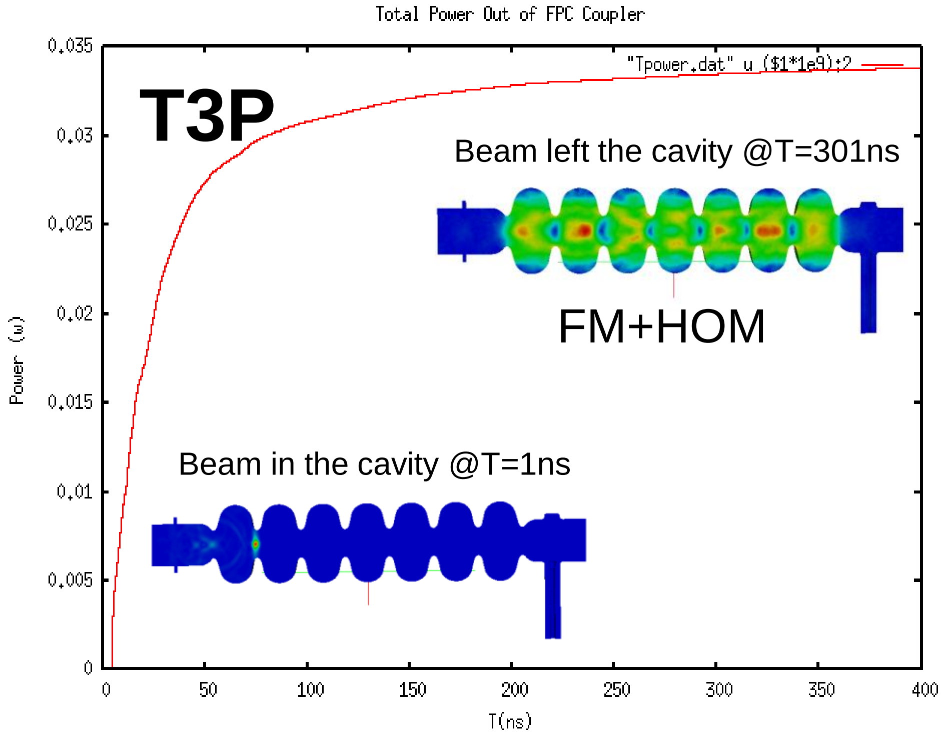


Simulation Model for T3P

Power Flow Out of FPC

Drive a beam along the cavity axis to determine the total power out of the FPC.

For an 1pC, 5mm bunch



- ***The total power out of FPC will increase with shorter bunches.***
- ***At the beginning, most of the HOM power (broadband) goes out of the FPC and the two beampipes;***
- ***A few resonant HOMs excited in the cavity decay slowly;***
- ***The resonant monopole HOMs will generate cryogenic heat loads which have to be minimized.***

Adaptive mesh with 5mm maximum mesh element, 753K total mesh elements, dt=1ps, 4e5 time steps, 1st order, 5K CPU hours

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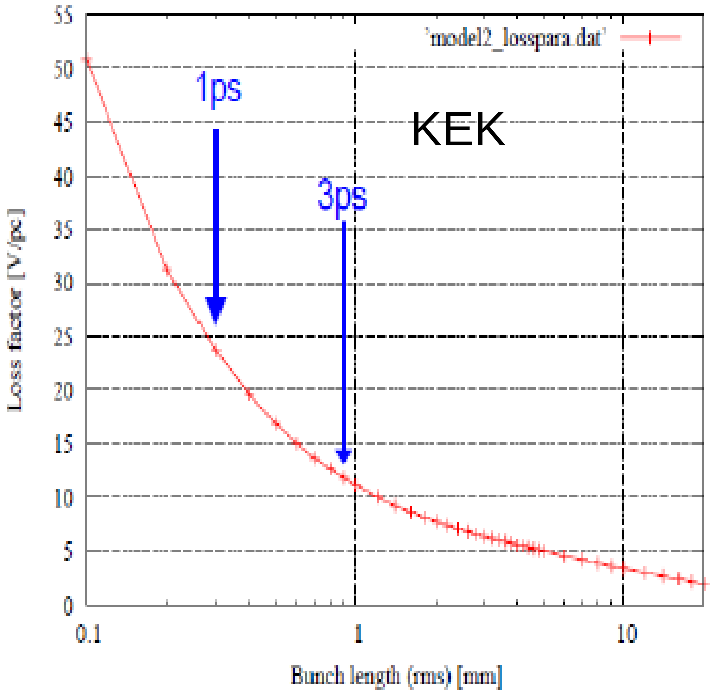
Scaling Curve for HOM Power Flow per KEK

Loss Factor



- ***It is time consuming to run a short bunch (0.6mm) for a long time (>400ns) to obtain the steady HOM power flow out of the FPC;***
- ***Use longer bunches (5mm, 2.5mm,1.25mm) to obtain a scaling curve and extrapolate to 0.6mm for the HOM power flow out of the FPC.***

- Including loss factor for accelerating mode (2V/pC)
- Calculated from only cavity shape, not including RF absorber
- For 3ps bunch length, loss factor of HOM is 12-2=10V/pC

  Power is 10V/pC x 77pC x 0.2A = 154W.

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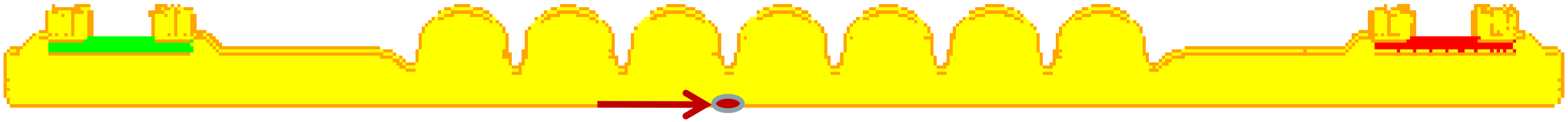
Power Deposited in the RF Absorber

Drive a beam on the cavity axis to determine the total power deposited in the RF absorber.

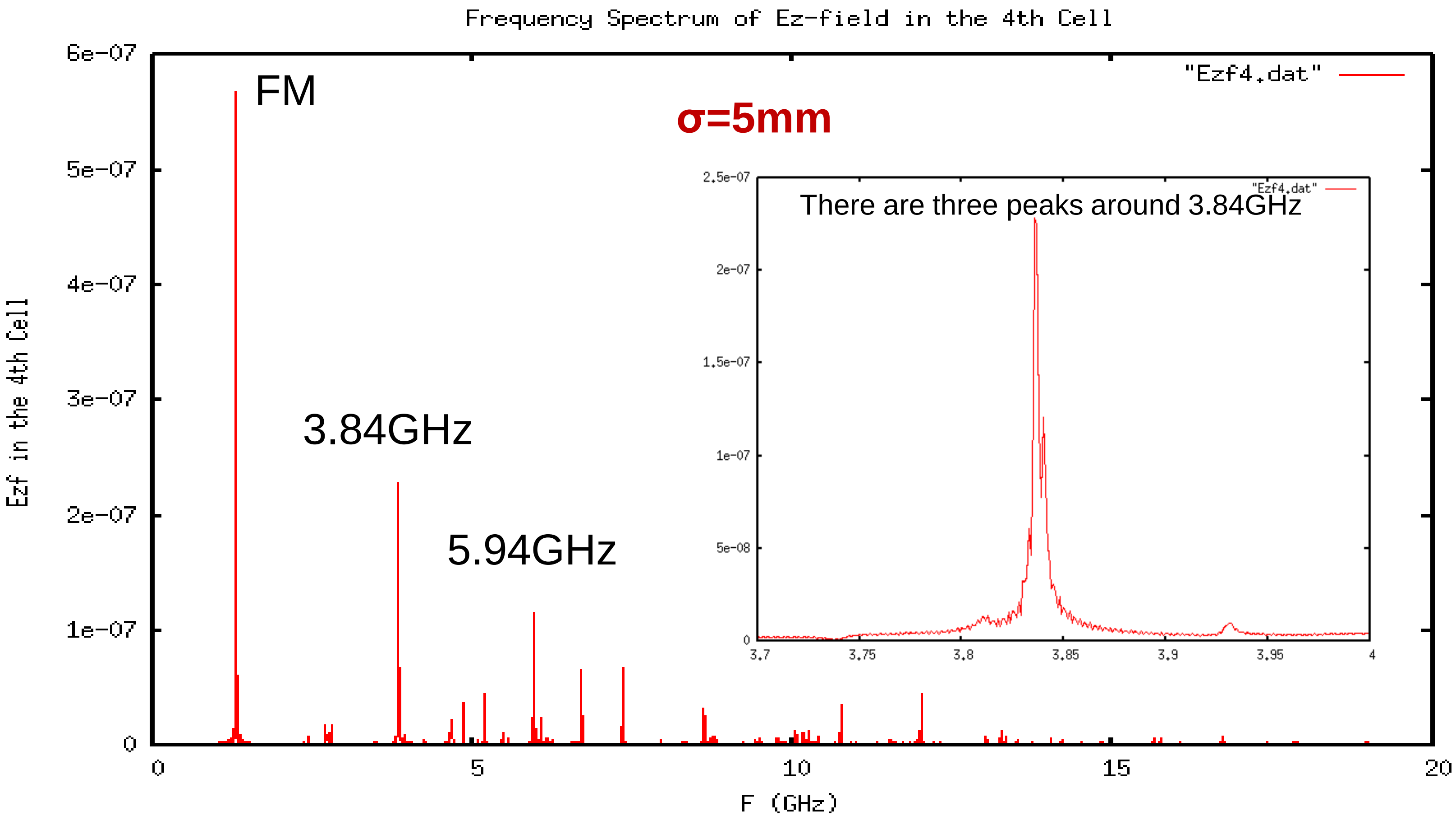


Simulation Model for T3P

This is a 2D problem. Will simulate the long-range wakefields with a 10 degree slice at 0.6mm bunch length.

The simulation is underway.

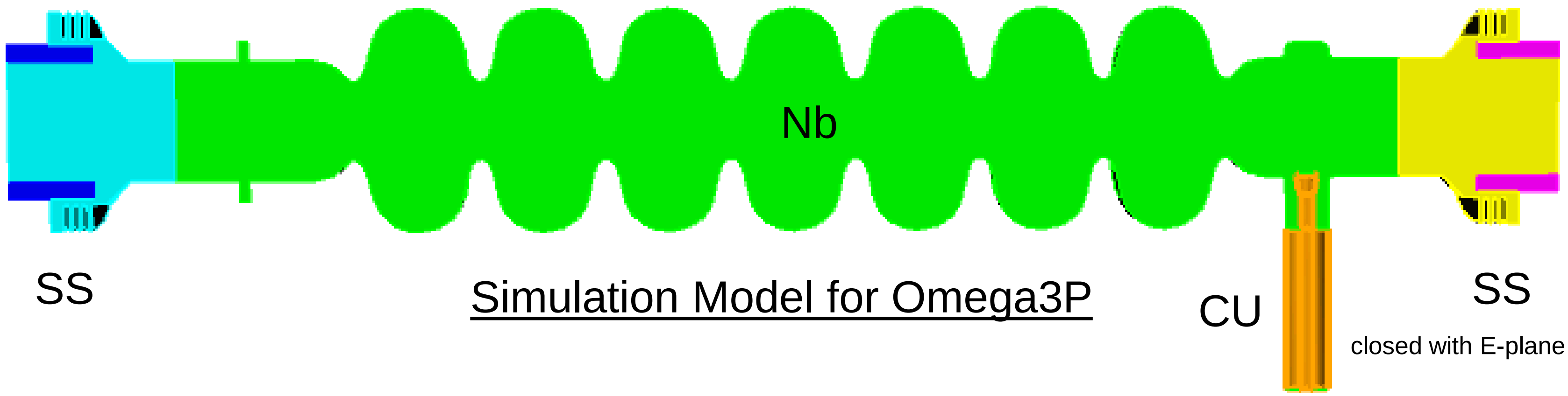
HOM Power in the Cavity



- Identify a few resonances by a T3P run and FFT;
- Determine field distribution and rf parameters of these modes using Omeag3P.

Resonances around 3.84GHz

Four combinations of electric and magnetic boundary conditions at two ends of the cavity are used.



Simulation Model for Omega3P

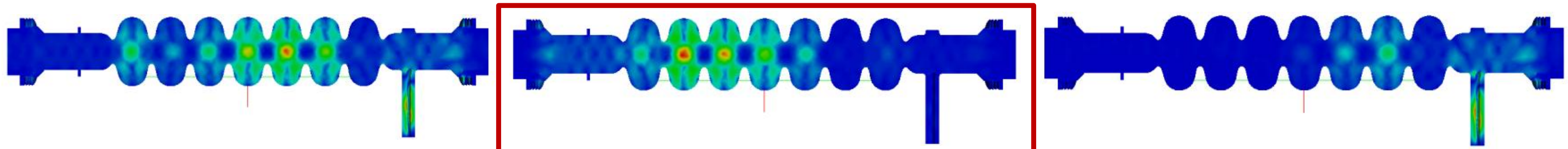
Two ends	F(GHz)	R/Q (Ω/cavity)	Q0	Qload (absorber)	F(GHz)	R/Q (Ω/cavity)	Q0	Qload (absorber)	F(GHz)	R/Q (Ω/cavity)	Q0	Qload (absorber)
EE	3.8367	4.8	1.8e5	1936	**3.8399**	**28.6**	**3.9e5**	**3499**	3.8420	5.6	3.6e4	425
MM	3.8363	3.9	2.2e5	1885	***3.8398***	***31.9***	***5.5e5***	***4059***	3.8411	10.9	6.6e4	606
ME	3.8365	4.3	2.1e5	2048	**3.8398**	**30.5**	**5.7e5**	**4331**	3.8420	5.6	3.6e4	425
EM	3.8365	4.6	1.9e5	1781	**3.8399**	**30.1**	**3.8e5**	**3339**	3.8411	10.7	6.4e4	605

The strongest resonance is around 3.84GHz, 30Ω/cavity of R/Q and 3300 ~ 4300 of loaded Q in RF absorber.

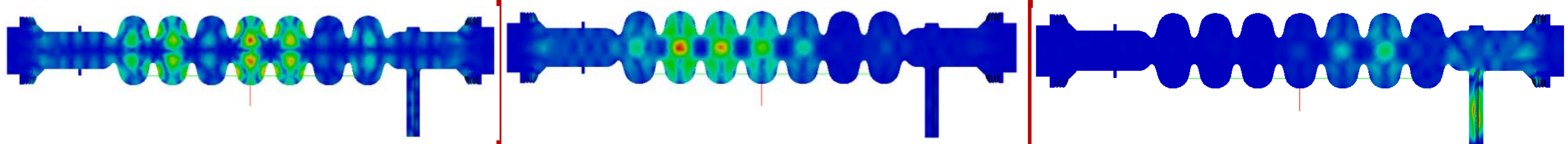
Field Patterns around 3.84GHz

Two ends with EE-BCs

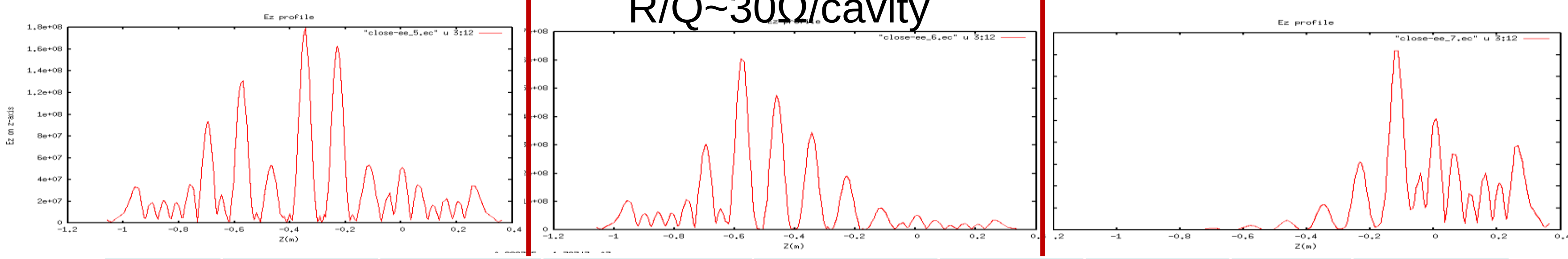
E-amplitude



B-amplitude



R/Q~30Ω/cavity



Two ends	F(GHz)	R/Q (Ω/cavity)	Qload (absorber)	Qext (FPC)	Q(Nb)	Q0 (SS))	Q0 (Cu)	Q0
EE	**3.8399**	**28.6**	**3499**	**Will calculate with full FPC coupler**	2.6e10	***3.9e5***	2.1e7	**3.9e5**

***The power heating dominated is at the bellows. Will search for all resonances identified by T3P up to 10GHz, then calculate their RF parameters by Omega3P to evaluate their heating effect*.**

Summary

- SLAC Parallel Finite-Element (FE) electromagnetic (EM) method demonstrates its strength in high-fidelity, high-accuracy modeling for accelerator design, optimization and analysis;
- ACE3P's advanced capabilities, contained in the Omega3P, S3P, T3P, Track3P, and Pic3P modules, have enabled challenging problems to be solved with benefits to accelerators worldwide;
- ACE3P is an effective tool to simulate the HOM power flow in Cornell ERL that can help in designing the cryomodule cooling requirements;
- ACE3P can also be used to find the dipole modes that contribute to BBU, and 3D treatment answers how much power goes out of the FPC in both polarizations.
- Close collaboration between Cornell and SLAC will continue.

Thanks to my colleagues for their contributions to this talk. Special thanks to Eric Chojnacki and Georg Hoffstaetter for providing the model and for valuable discussions.