Advanced Modeling of DR Vacuum Chamber Components

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Outline

- ***EM Modeling Focus Areas***
- *Parallel Finite Element EM Codes/MAFIA*
- *Applications to Beamline Components*

Electromagnetic Modeling Focus Areas

Design and Evaluate the damping ring vacuum chamber

- ***Broadband Impedance*** *– Obtain the broadband impedance from calculating the short-range wakefields of major beamline components: RF cavity, BPM, bellows, pumping slots, tapers and collimators etc.*
- ***Narrowband Impedance*** *– Design for the damping of dangerous modes in RF cavity and BPM to ensure the DR meets beam stability requirements.*
- ***Beam Heating*** *– Identify beam excited trapped modes in the RF cavity and bellows for design modification to avoid excessive heating.*
- ***Device Performance*** *– Determine the signal sensitivity of pickup devices such as BPMs and kickers.*

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SciDAC Computational Tools

- ***SLAC's Parallel Finite Element EM*** *codes provide higher accuracy than standard software (e.g.* ***MAFIA)*** *and can simulate LARGE problems to high resolution with near linear speedup through petascale computing (NERSC, NCCS):*

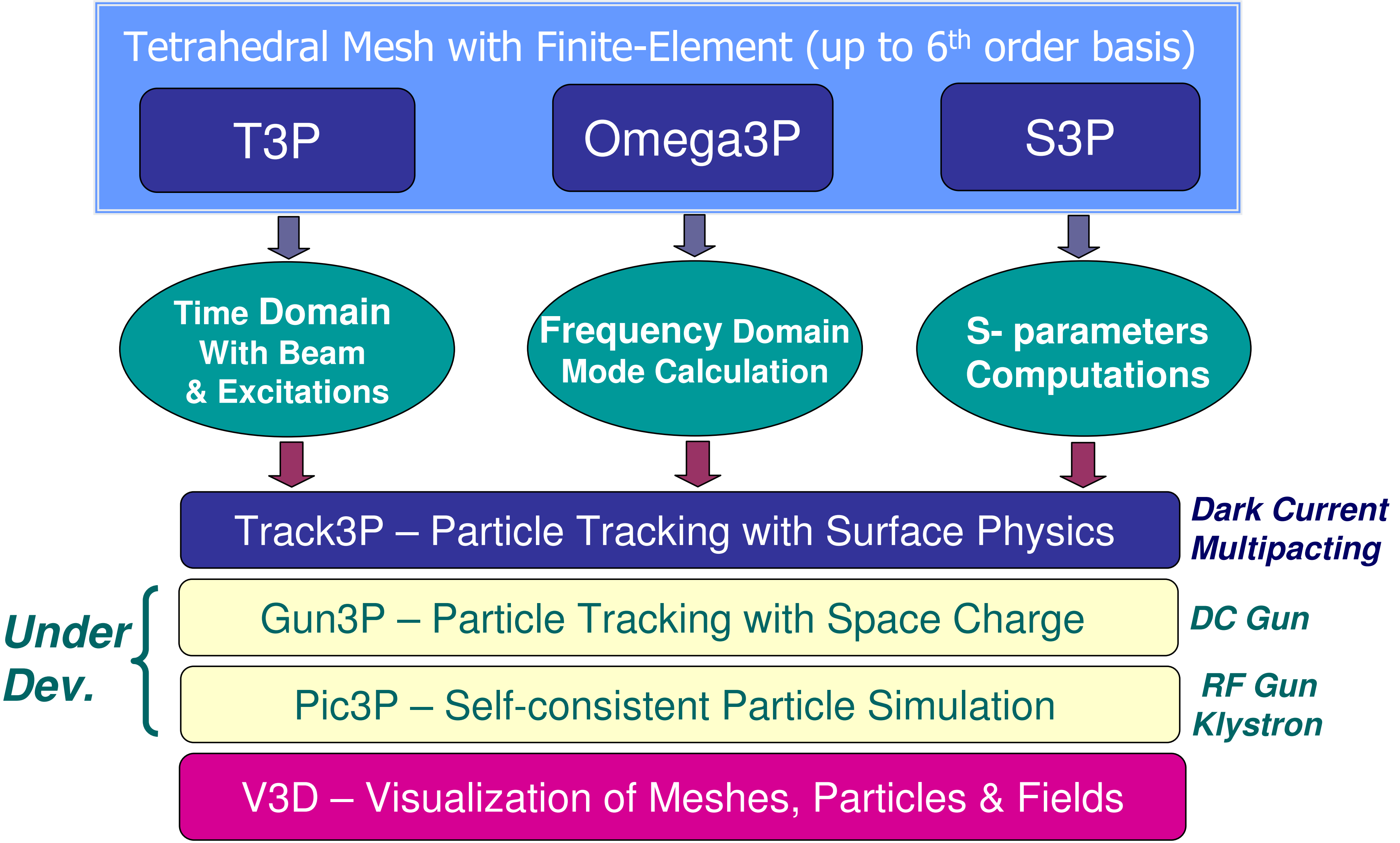
- ***Omega3P*** *– nonlinear eigensolver to find resonant modes in damped RF cavities.*

- ***S3P –*** *frequency domain solver to compute the scattering matrix of RF structures.*

- ***T3P*** *– time domain solver to calculate transients due to external drive and wakefield generated by beam transit.*

(Under development includes indirect wakefield integration for collimator-type structures, and surface impedance BC to model resistive wall wakefields of grooved vacuum chamber).

SLAC 3D Parallel FEM EM Codes



Tetrahedral Mesh with Finite-Element (up to 6th order basis)

T3P

Omega3P

S3P

Time Domain With Beam & Excitations

Frequency Domain Mode Calculation

S- parameters Computations

Track3P – Particle Tracking with Surface Physics

Dark Current Multipacting

Gun3P – Particle Tracking with Space Charge

DC Gun

Pic3P – Self-consistent Particle Simulation

RF Gun Klystron

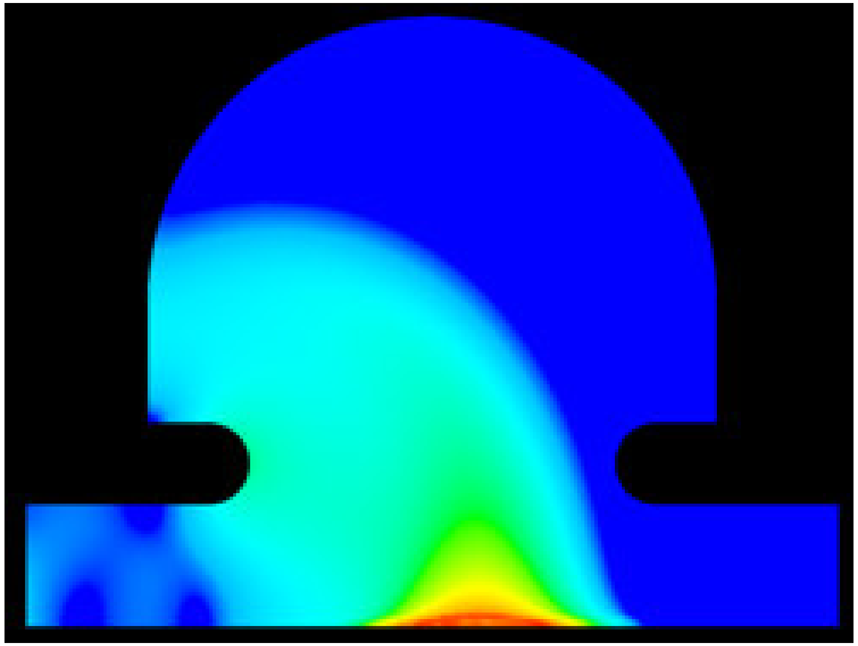
Under Dev.

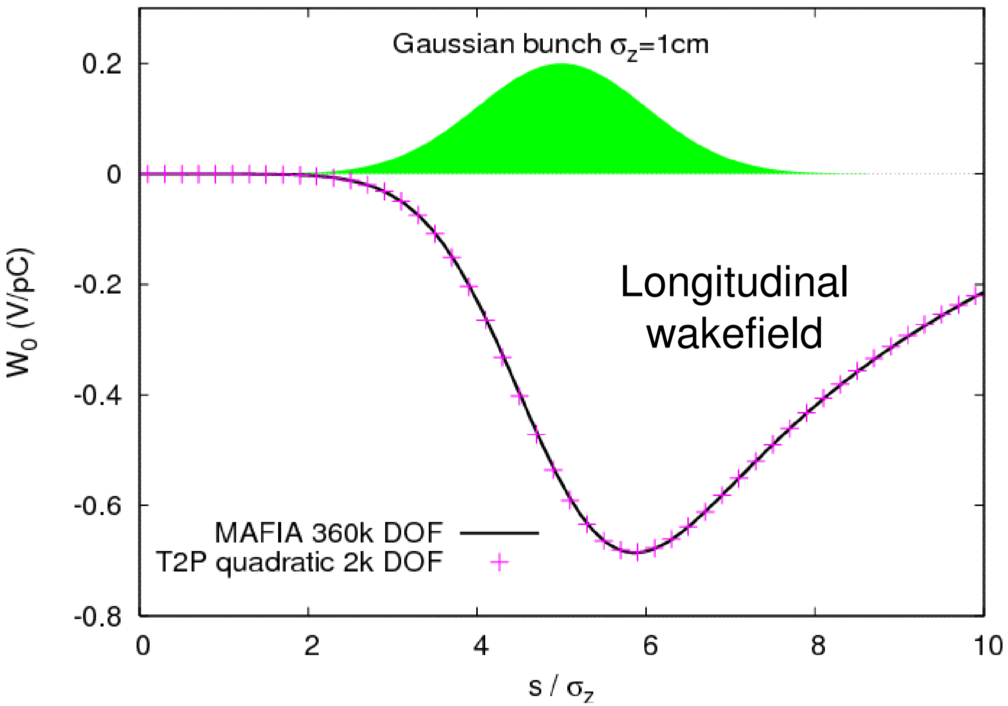
V3D – Visualization of Meshes, Particles & Fields

Programmed in C++ & MPI

FEM Wakefield Computation

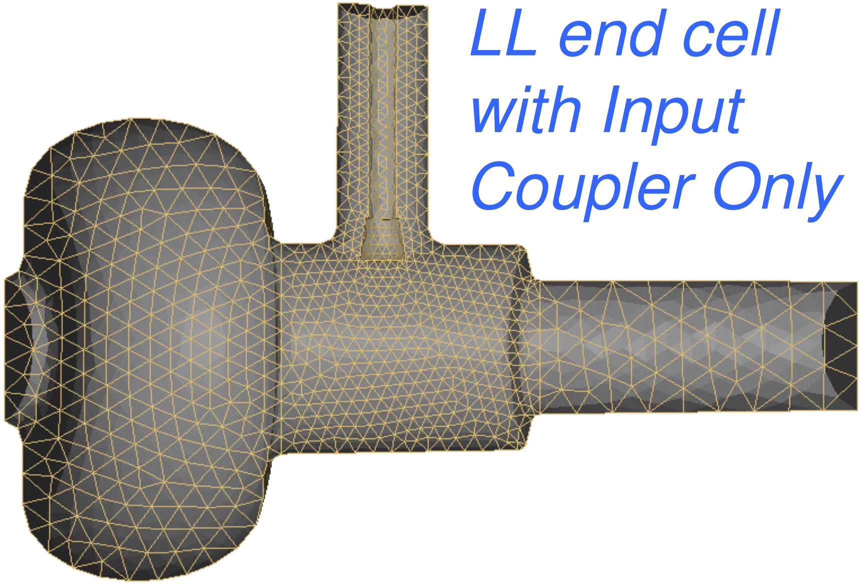
Wakefield Benchmark (2D)



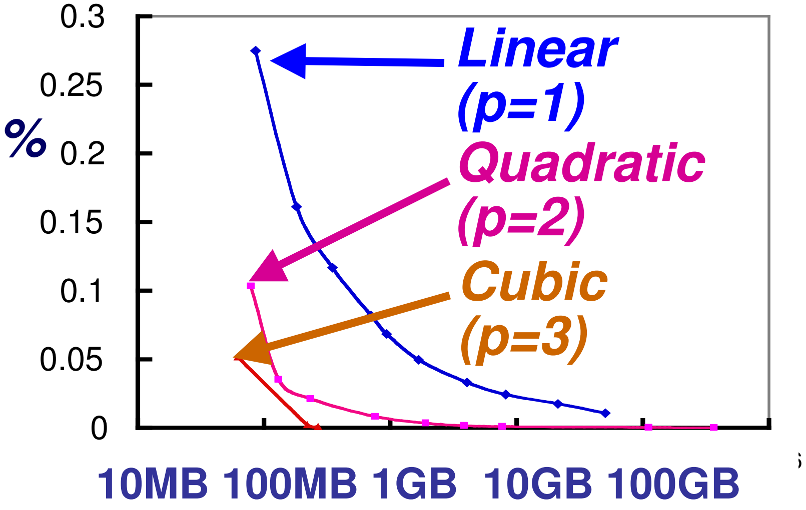


Quadratic elements achieve convergence with far less DOFs than possible with structured grid (2k vs 360k).

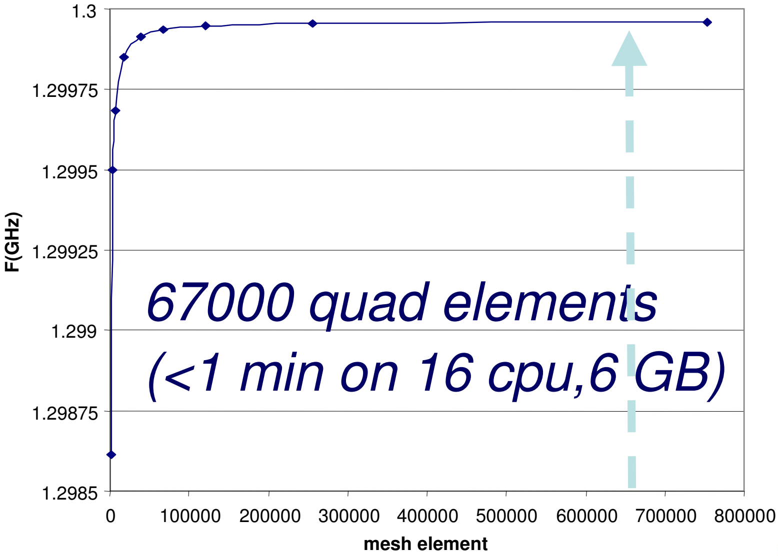
Higher-order FEM + Parallel Processing



LL end cell with Input Coupler Only



Error ~ 20 kHz (1.3 GHz)



67000 quad elements
(<1 min on 16 cpu,6 GB)

- Tetrahedral Conformal Mesh w/ quadratic surface
- Higher-order Finite Elements (p = 1-6)
- Parallel Processing (large memory &1/N speedup)

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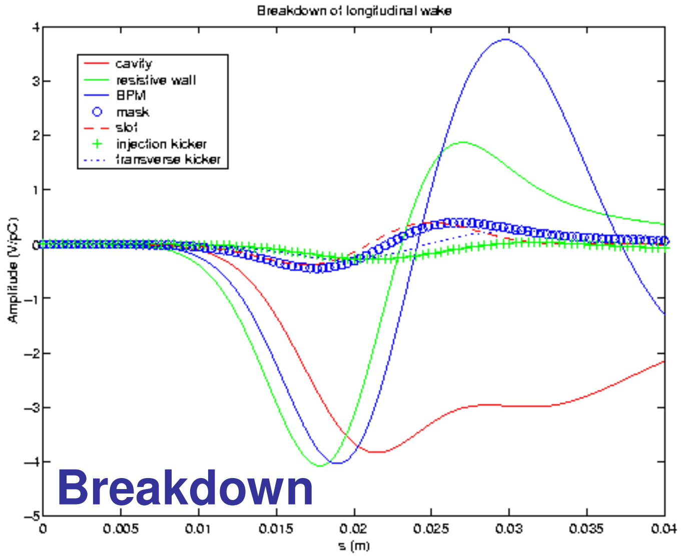
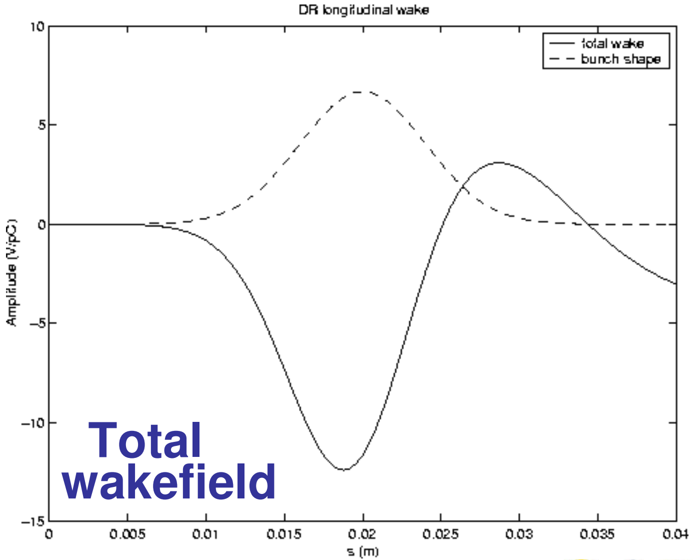
NLC-DR Longitudinal Broadband Impedance

Impedance budget

Component	Quantity	Loss factor (V/pC)	Inductance (nH)
RF Cavity	3	2.976	0.41
BPM	159	2.226	2.97
Slot	102	0.068	0.28
Mask	102	0.168	0.33
Injection kicker	2	0.192	0.21
Transverse kicker	2	0.171	0.21
Resistive wall		1.867	
Total		7.7	4.4

- c.f. PEP-II HER ring:
  Loss factor = 2.5 V/pC
  Inductance = 48 nH





NLC-DR Transverse Broadband Impedance

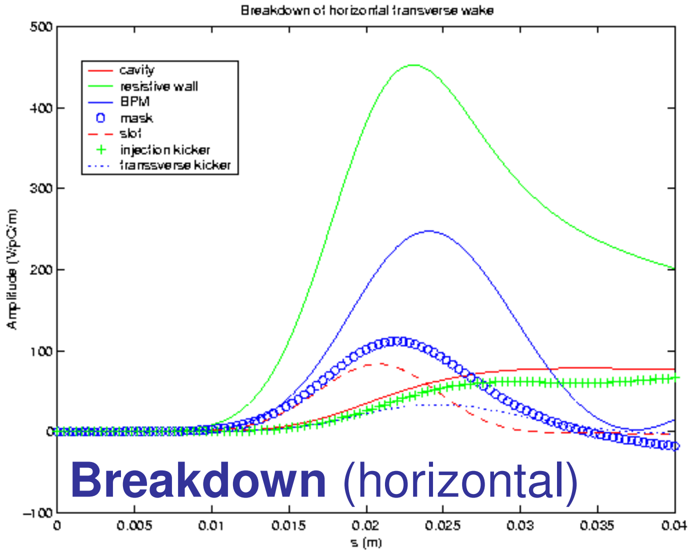
Impedance budget

Component	Quantity	Horizontal kick factor (V/pC/m)	Vertical kick factor (V/pC/m)
RF Cavity	3	36.08	36.08
BPM	159	146.76	146.76
Slot	102	56.34	0.13
Mask	102	77.01	1.22
Injection kicker	2	25.40	2.86
Transverse kicker	2	19.05	0.40
Resistive wall		320.04	320.04
Total		681	508

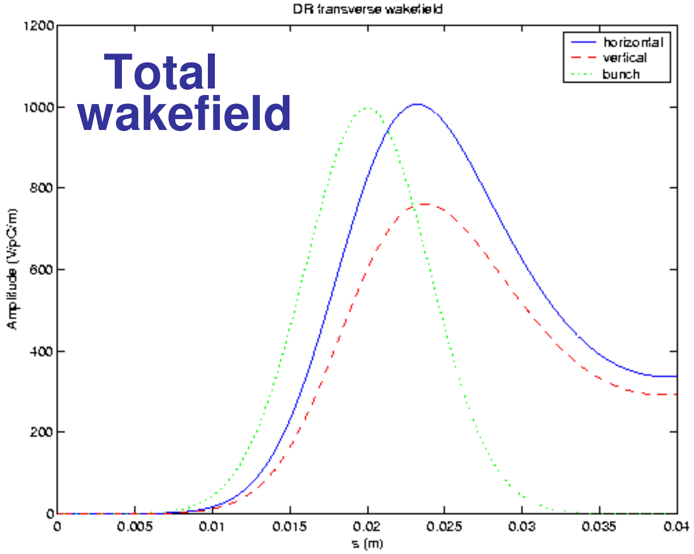
- dominated by resistive wall ~ $1/b^3$:

$$W_1(s) = \frac{L}{b^3\sigma_z^{1/2}}\frac{c}{2\pi}\sqrt{\frac{Z_0}{2\sigma_c}}f(\frac{s}{\sigma_z})$$

$$f(u) = |u|^{1/2}e^{-u^2/4}(I_{-1/4} \pm I_{1/4})|_{u^2/4}$$



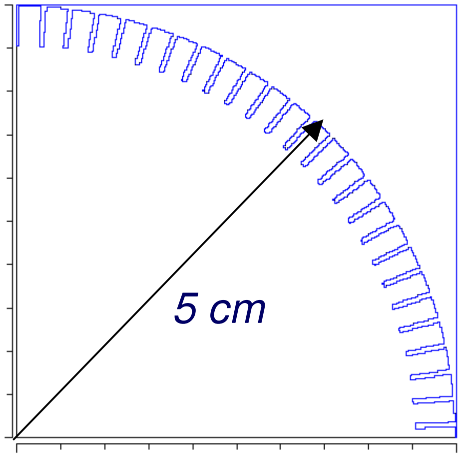
Breakdown (horizontal)

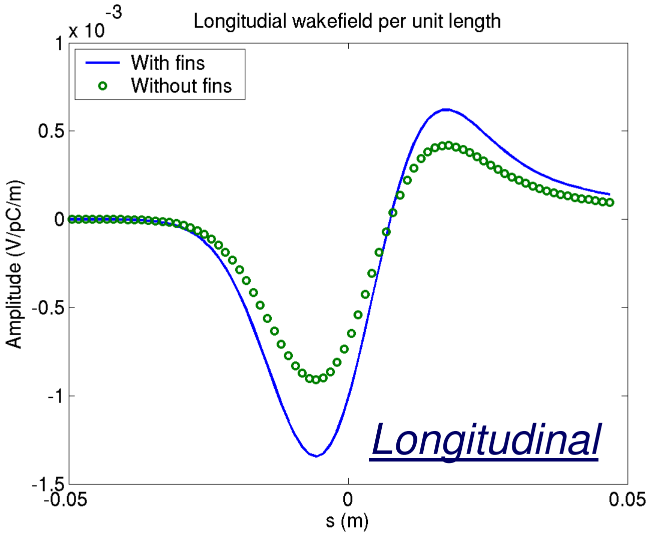


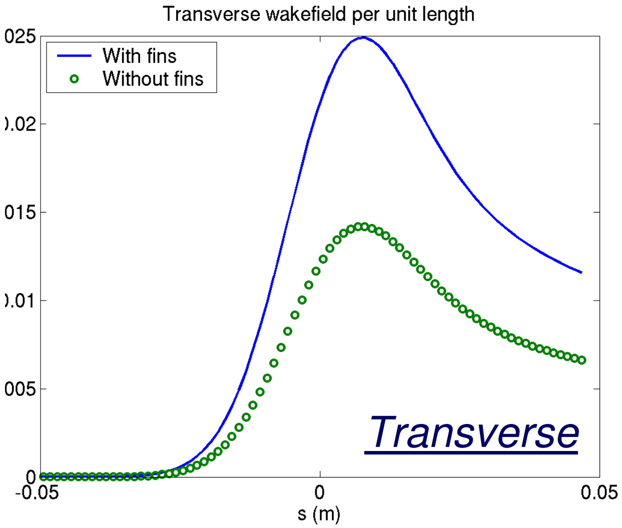
Total wakefield

Resistive Wall Wakefield (MAFIA)

MAFIA model







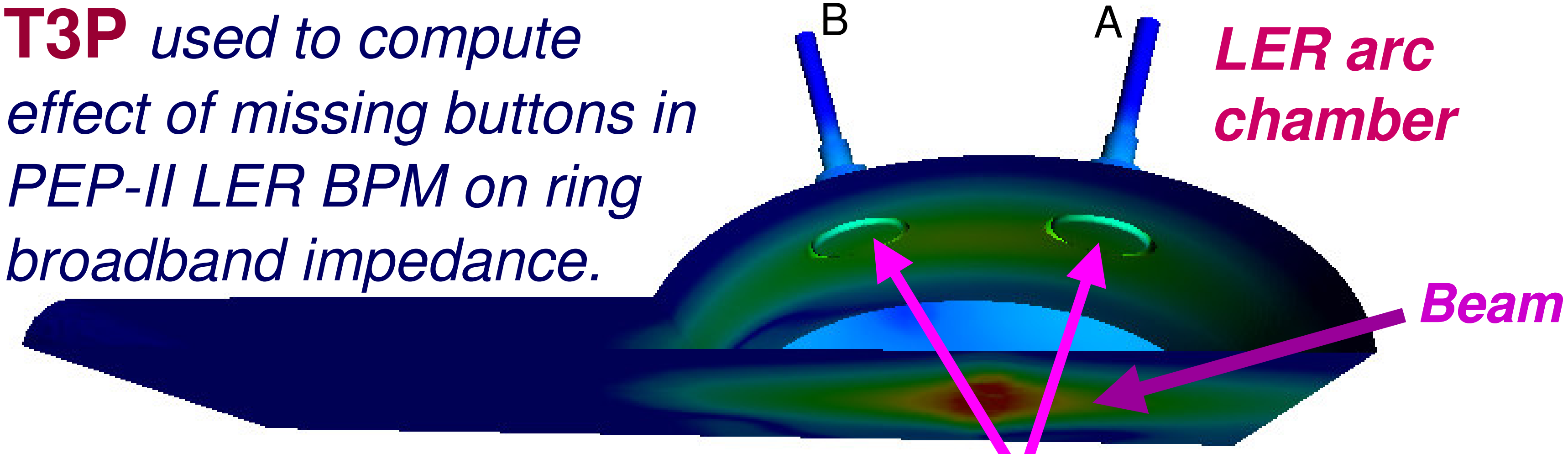
Longitudinal loss factor and transverse kick factor per unit length

Wakefield	Smooth chamber	Chamber with fins
Loss factor (V/pC/m)	5.0×10^{-4}	7.4×10^{-4}
Kick factor (V/pC/m/m)	0.0090	0.016

Surface impedance boundary condition *in T3P will provide better geometry resolution of grooved vacuum chamber of any cross section.*

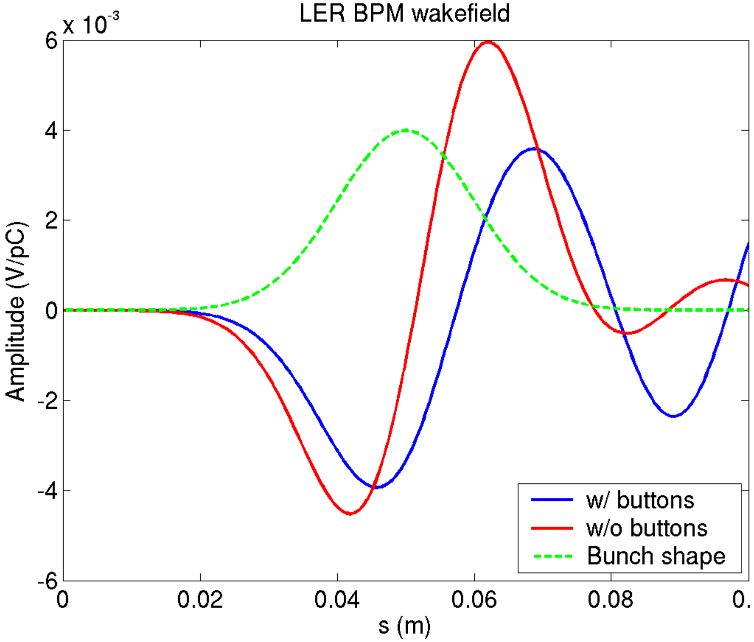
PEP-II LER BPM - Broadband Impedance

T3P *used to compute effect of missing buttons in PEP-II LER BPM on ring broadband impedance.*

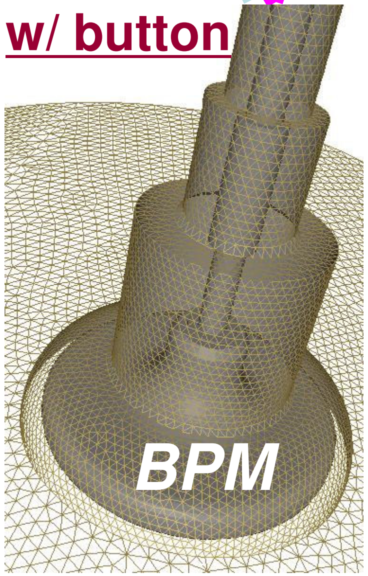


LER arc chamber

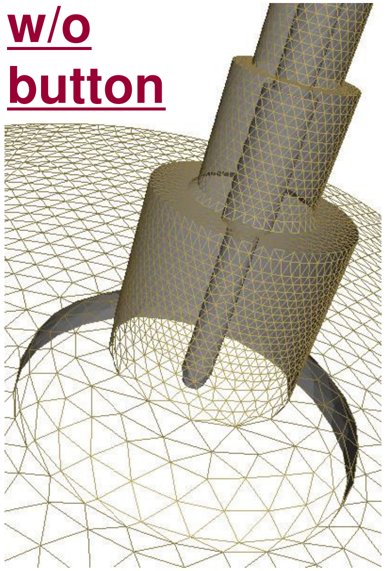
Beam



w/ button

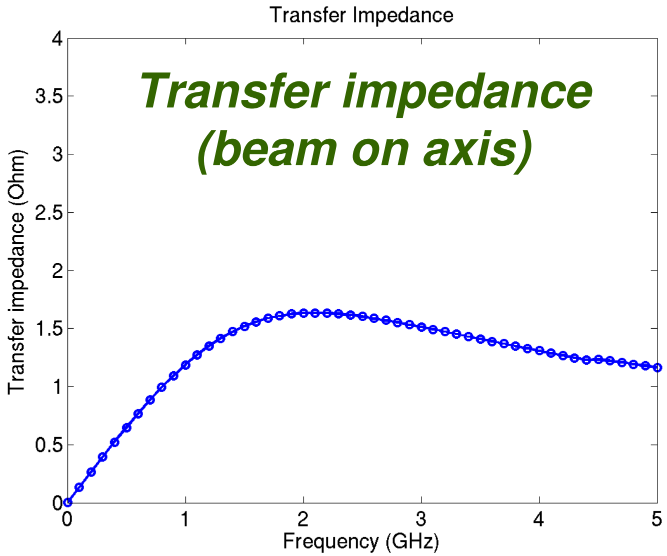


w/o button

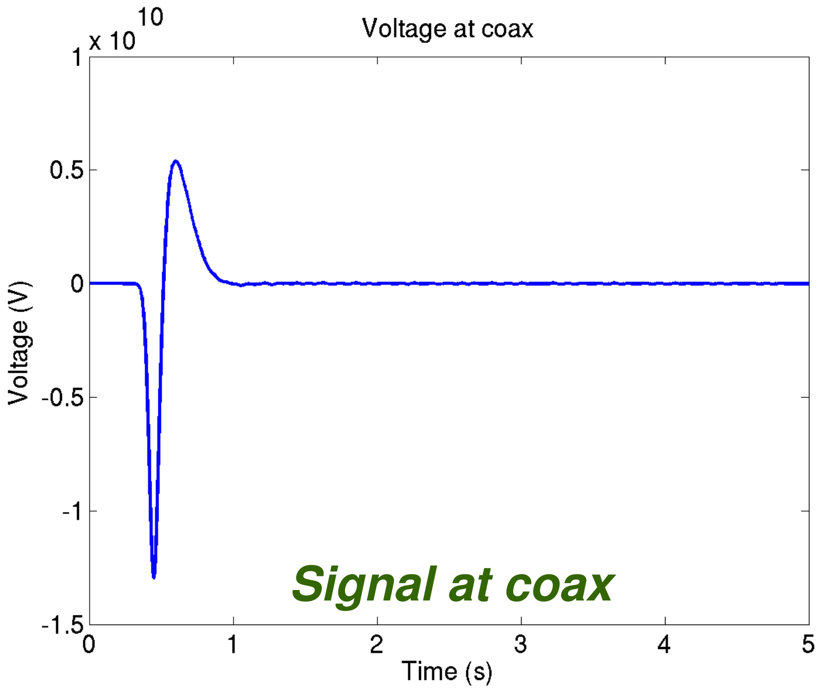


PEP-II LER BPM – Signal Sensitivity

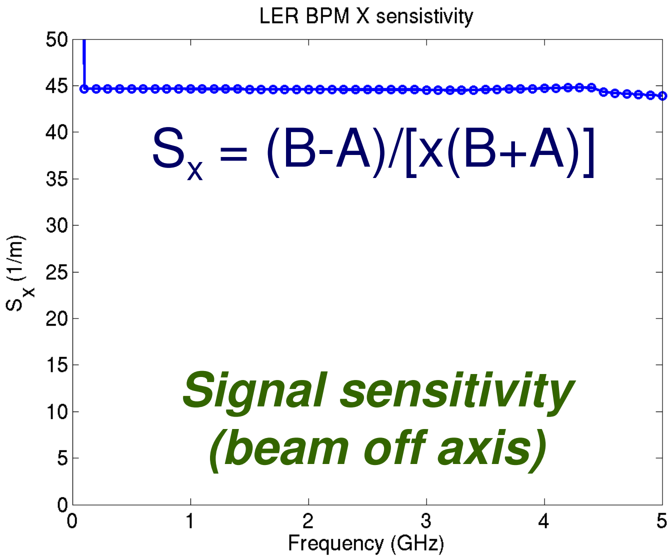
Beam excited signals at the feedthroughs determine the ***transfer impedance*** *and* ***signal sensitivity***.



Transfer impedance (beam on axis)



Signal at coax



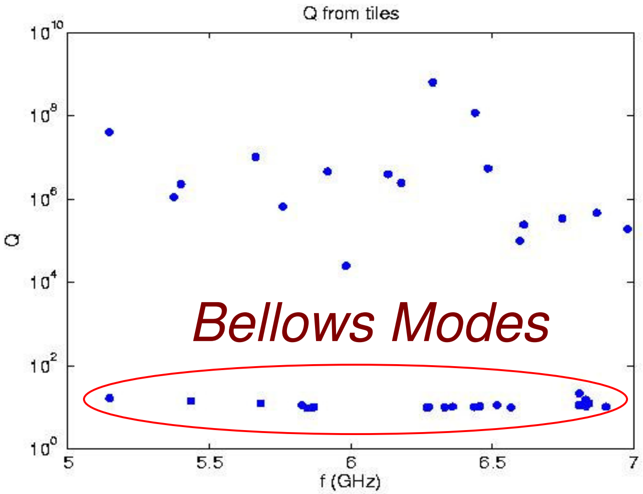
$S_x = (B-A)/[x(B+A)]$

Signal sensitivity (beam off axis)

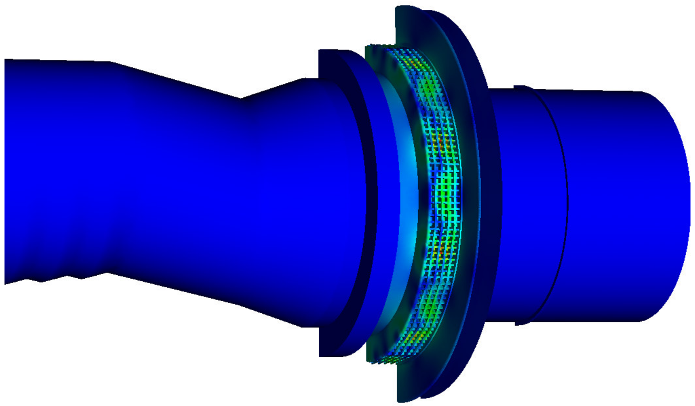
SciDAC Scientific Discovery through Advanced Computing

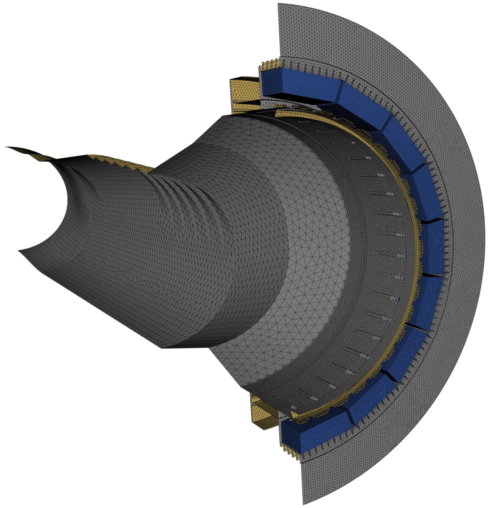
PEP-II Vertex Bellows Heating

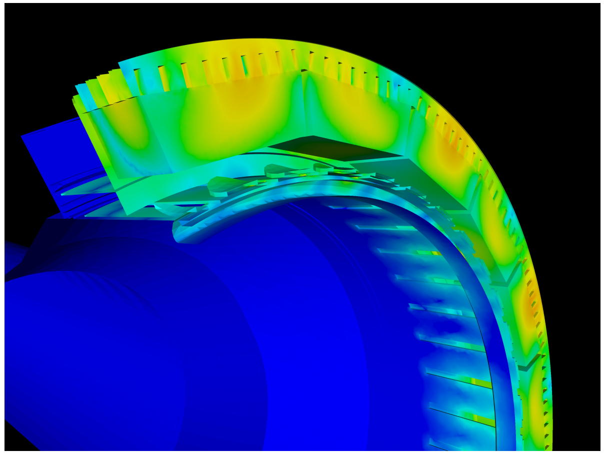
Omega3P *was used to evaluate the damping of localized modes by ceramic tiles mounted on the bellows convolution. Bellows modes were found to be damped to very low Qs.*



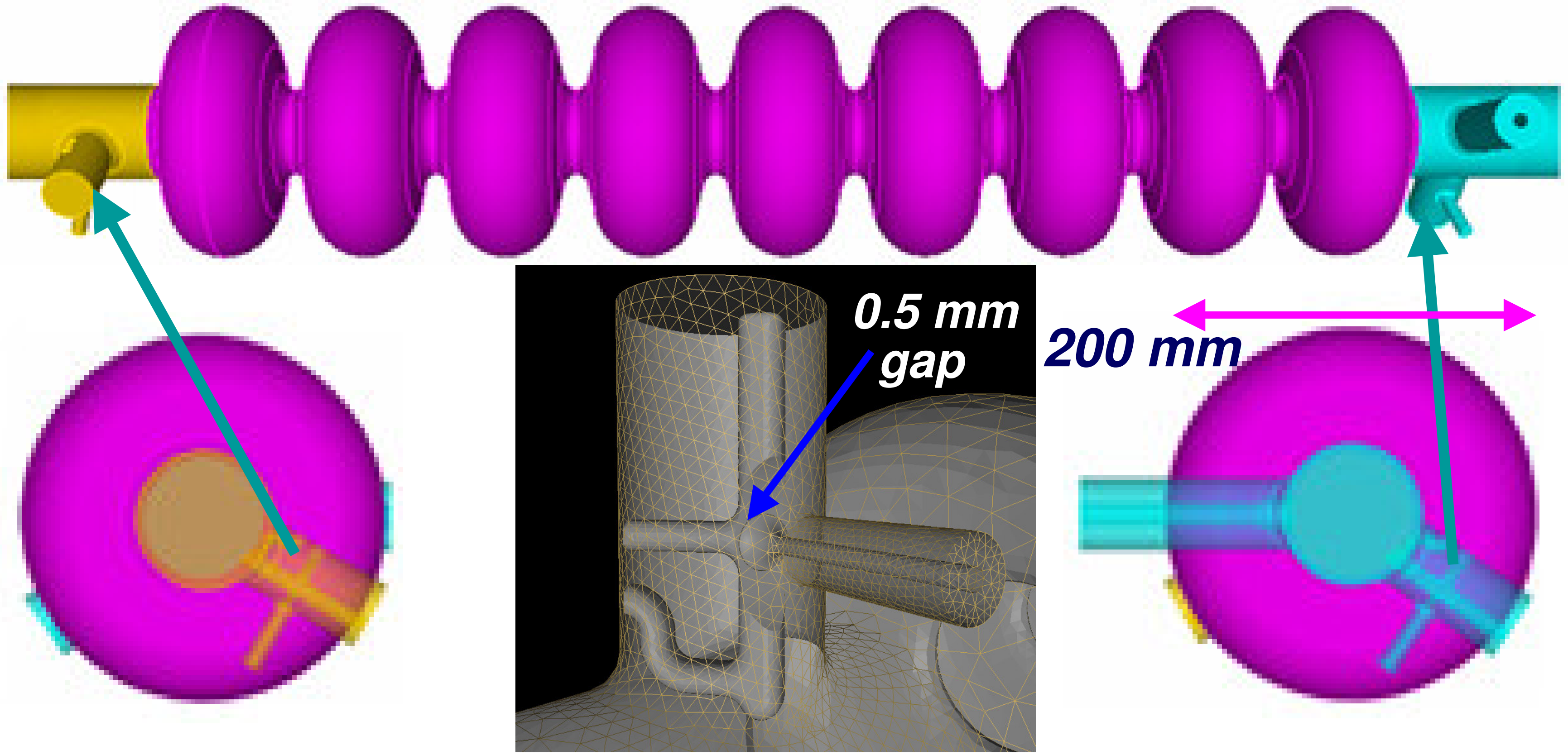
Bellows mode   Ceramic tile absorber   Dielectric loss





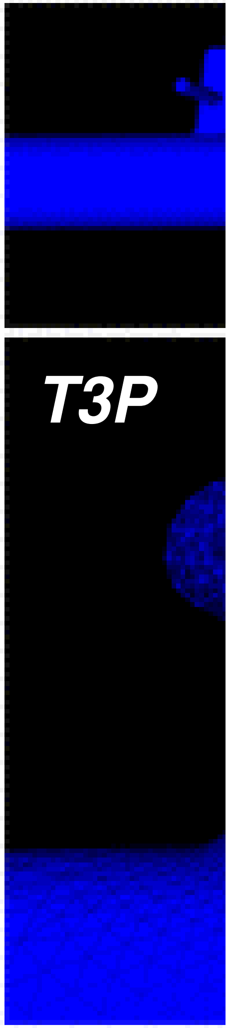


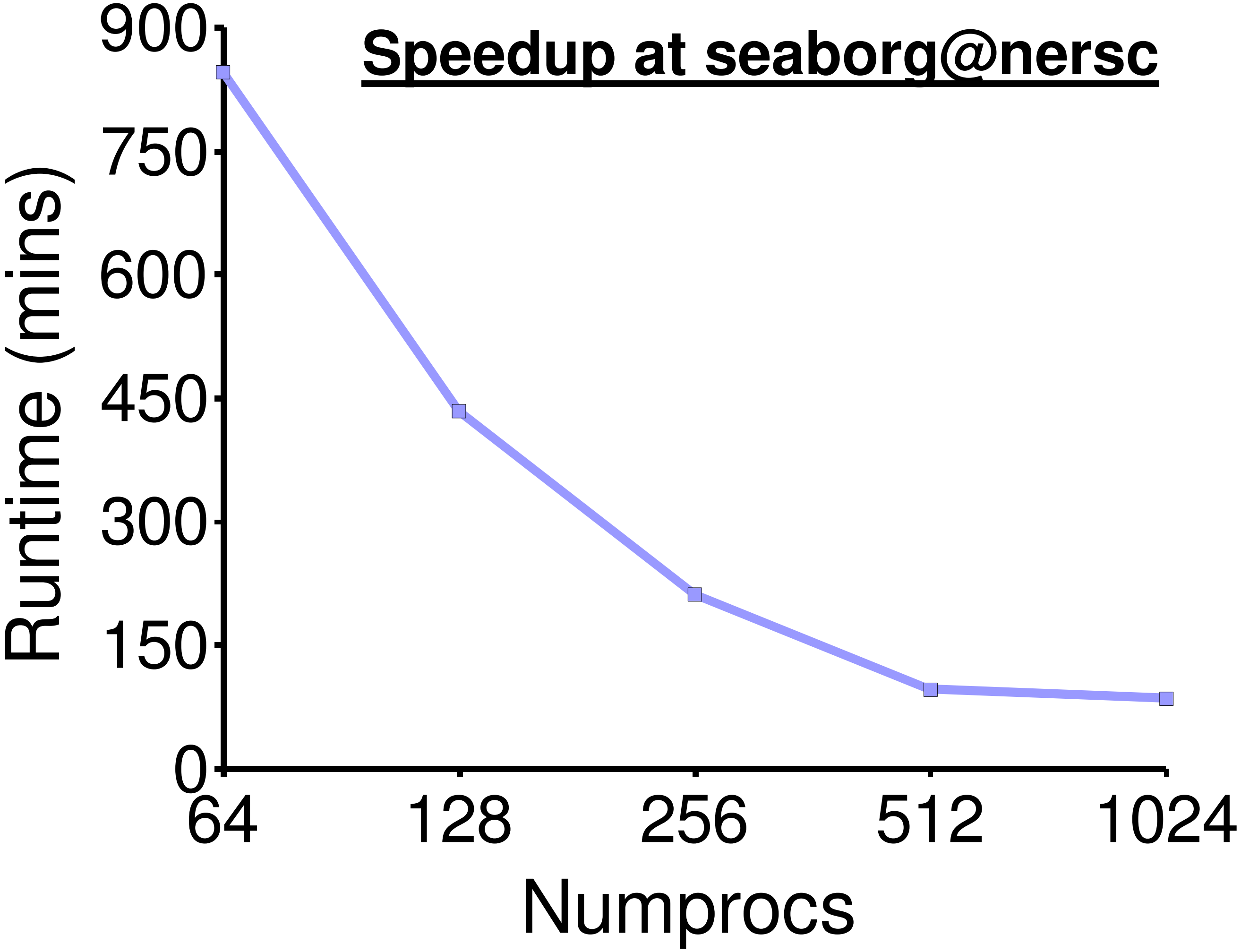
High Fidelity Modeling of TDR Cavity

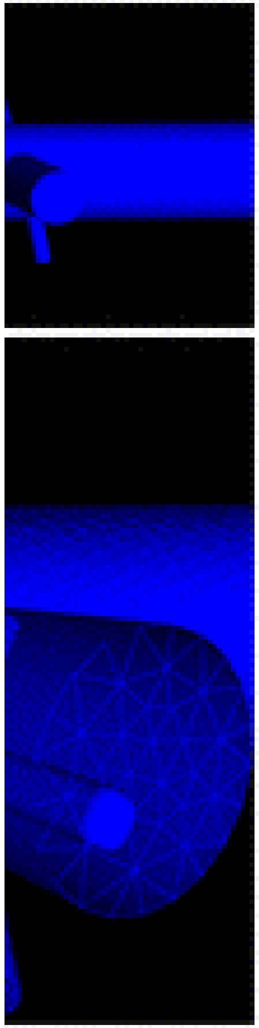


- ***Complexity*** – ***HOM coupler*** *(fine features)versus cell*
- ***Problem size*** – *multi-cavity structure, e.g. cryomodule*
- ***Accuracy*** – *10's kHz mode separation out of GHz*
- ***Speed*** – *Fast turn around time to impact designs*

TDR Cavity – Wakefields (T3P)



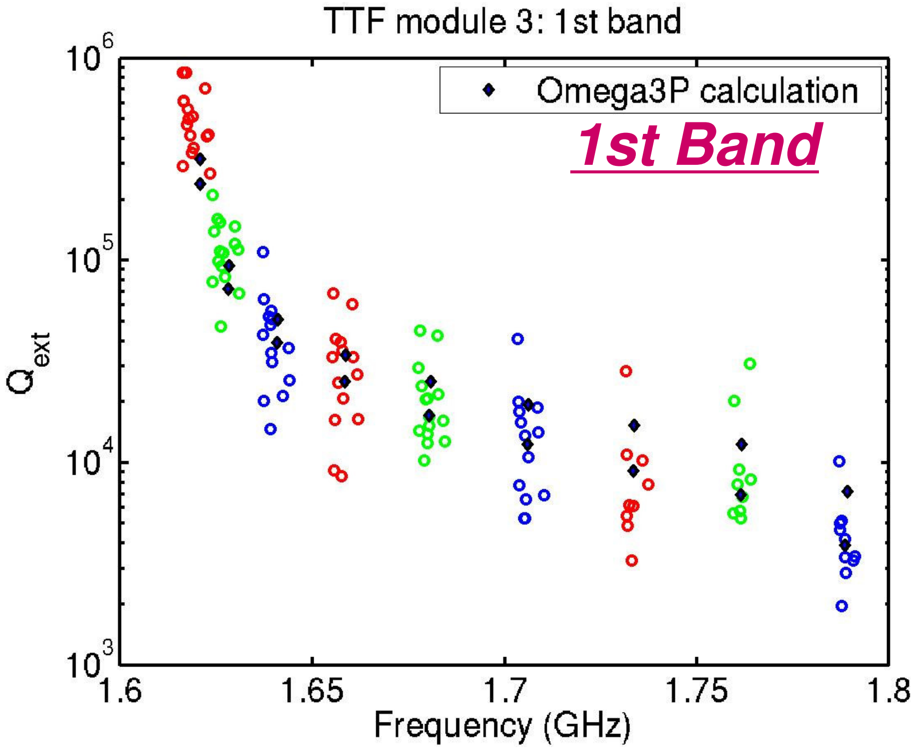




1.75 M quadratic elements, 10 M DOFs, 47 min per nsec on Seaborg 1024 CPU with 173 GB memory – CG and incomplete Cholesky preconditioner

TDR Cavity – HOM Damping (Omega3P)

*Comparison measurements (color) with **Omega3P** (black) complex eigenmode solutions* ($Qe=f_{real}/2f_{imag}$)



0.53 M quadratic elements, 3.5 M DOFs, 512 CPU with 300 GB on Seaborg, Second Arnoldi with MUMPs, 1 hour per dipole band

Omega3P/T3P comparison