Multi-Cavity Trapped Mode Simulation

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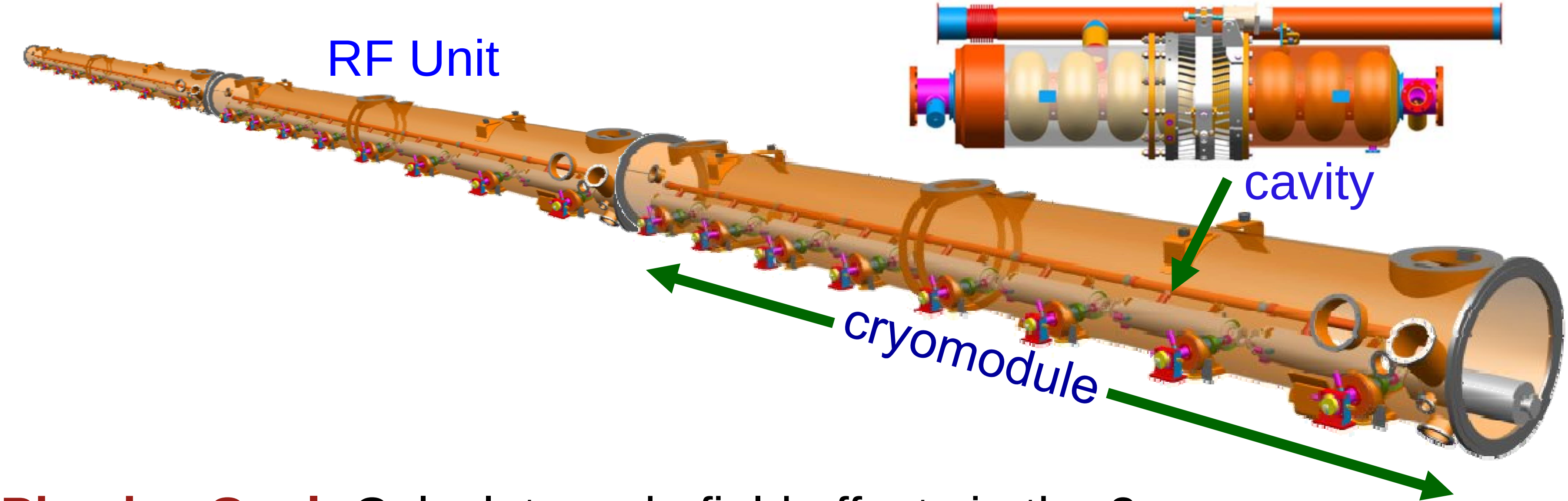
Presented at ILC Wakefest Workshop, Dec 11-13, 2007

* Work supported by U.S. DOE ASCR & HEP Divisions under contract DE-AC02-76SF00515

ILC RF Unit of 3 Cryomodules



Physics Goal: Calculate wakefield effects in the 3-cryomodule RF unit (26 cavities) with realistic 3D dimensions and misalignments

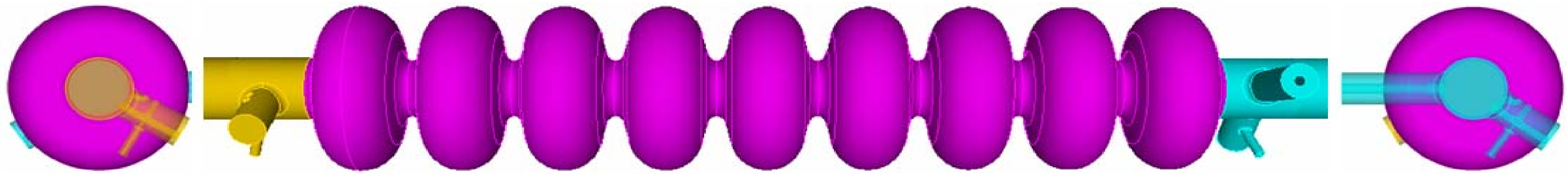
- Trapped mode and damping
- Cavity imperfection effects on HOM damping
- Wakefield effects on beam dynamics
- Effectiveness of beamline absorbers

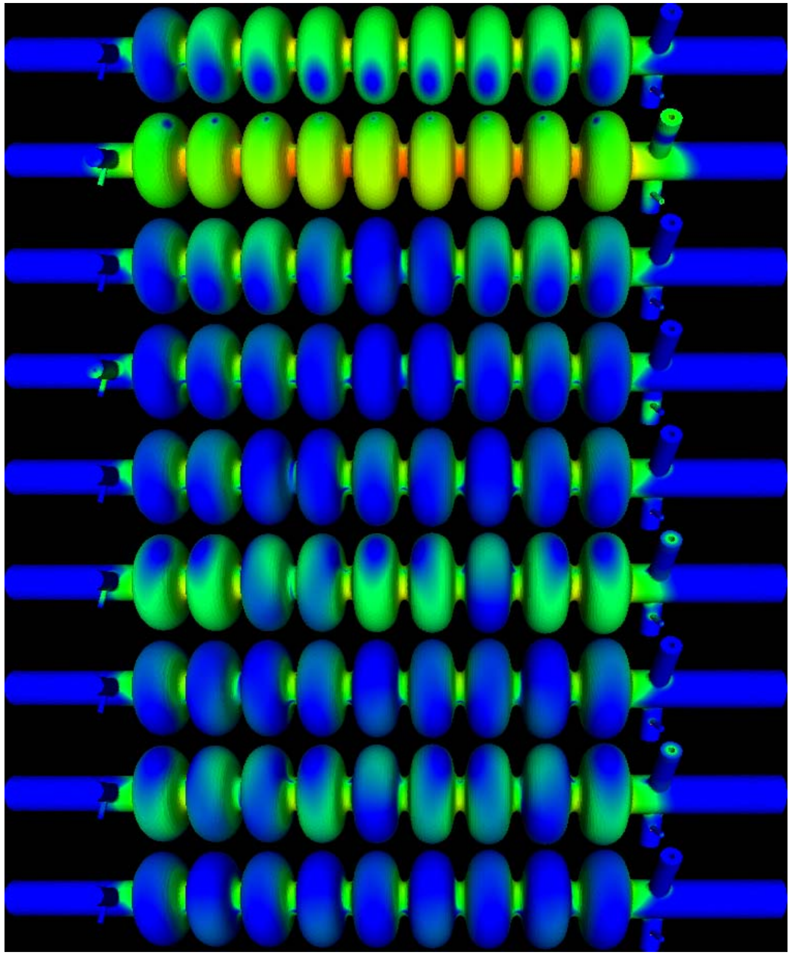
Large Scale EM Modeling

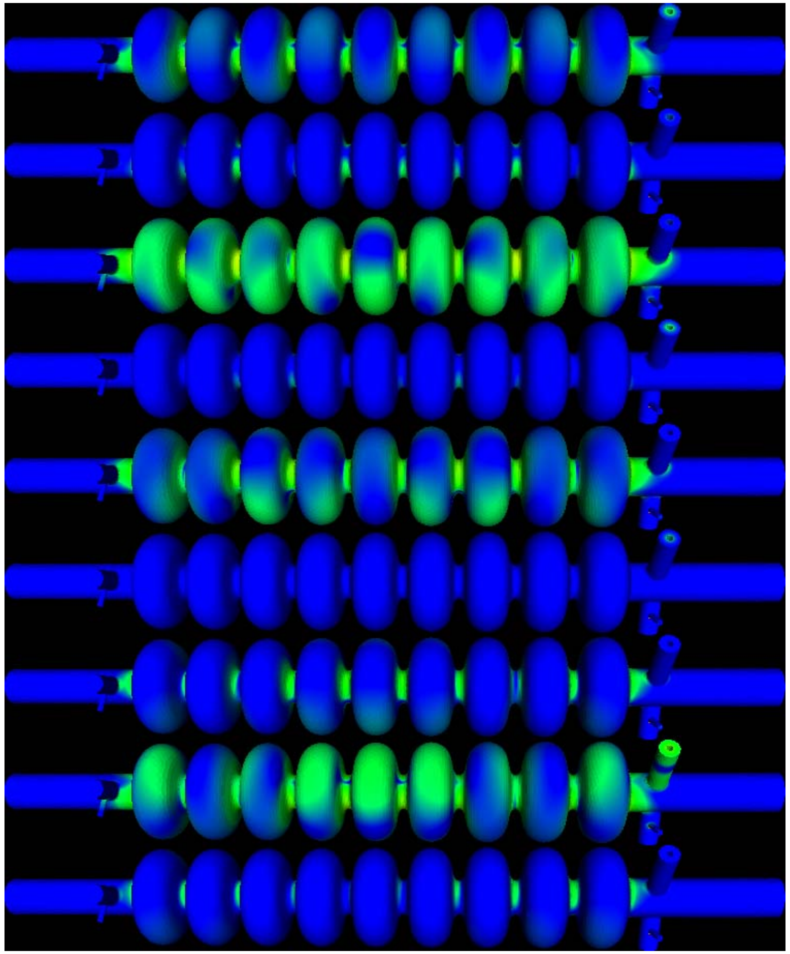
- Unstructured grid with high-order finite element method
- SciDAC supported advances in numerical algorithms
- Parallel computing on NERSC and ORNL machines
- Wakefield simulation approaches:

  - Frequency-domain (using Omega3P) to compute cavity modes and their damping
  - Time-domain (using T3P) to obtain mode spectrum from FFT to determine HOM power

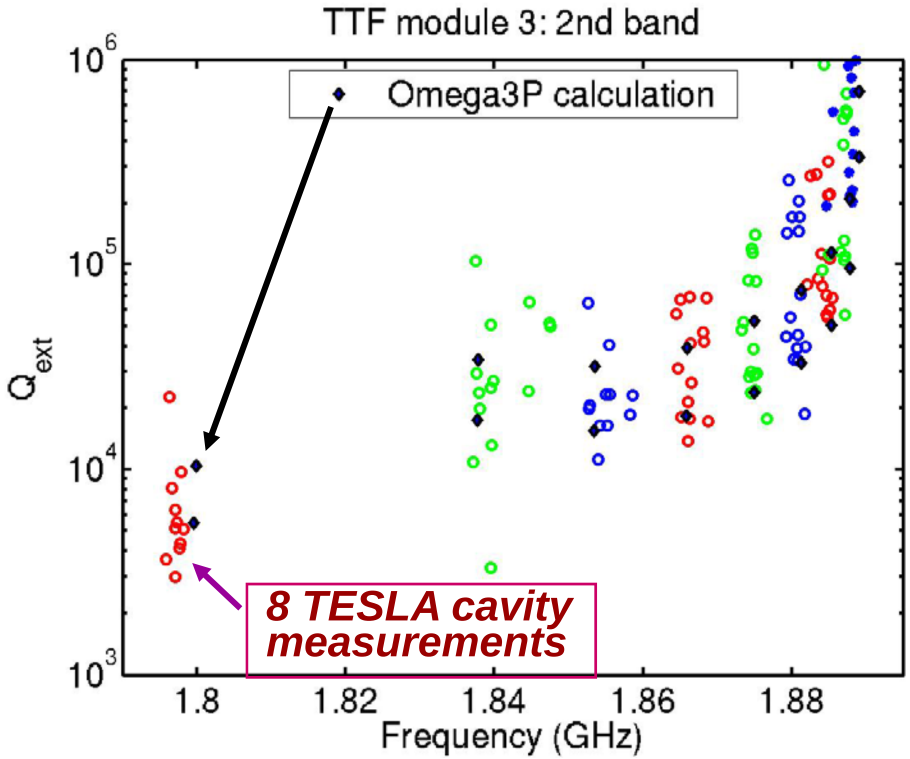
TDR Cavity - 1st Dipole Band w/ Omega3P

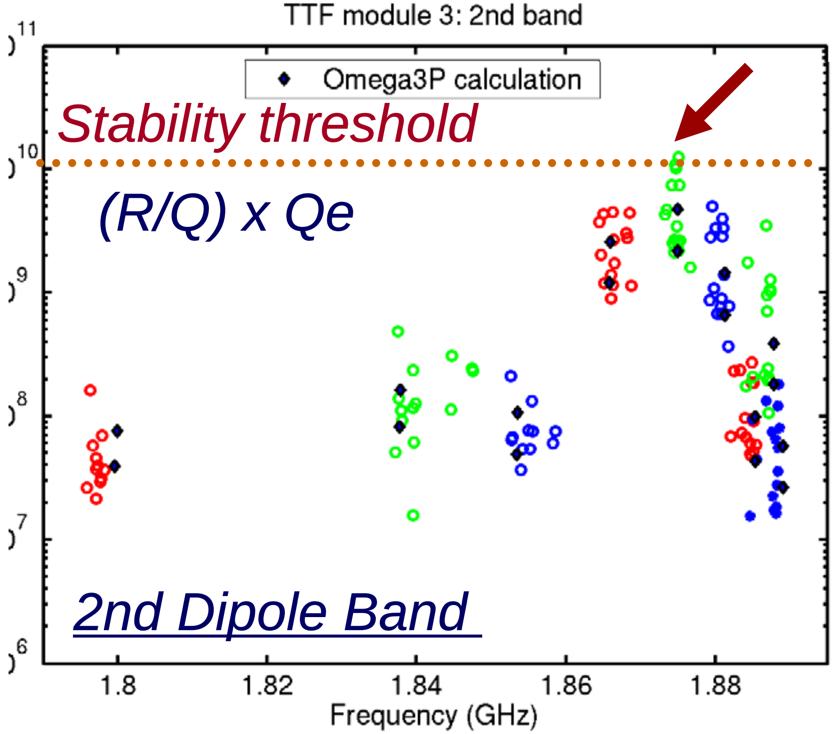






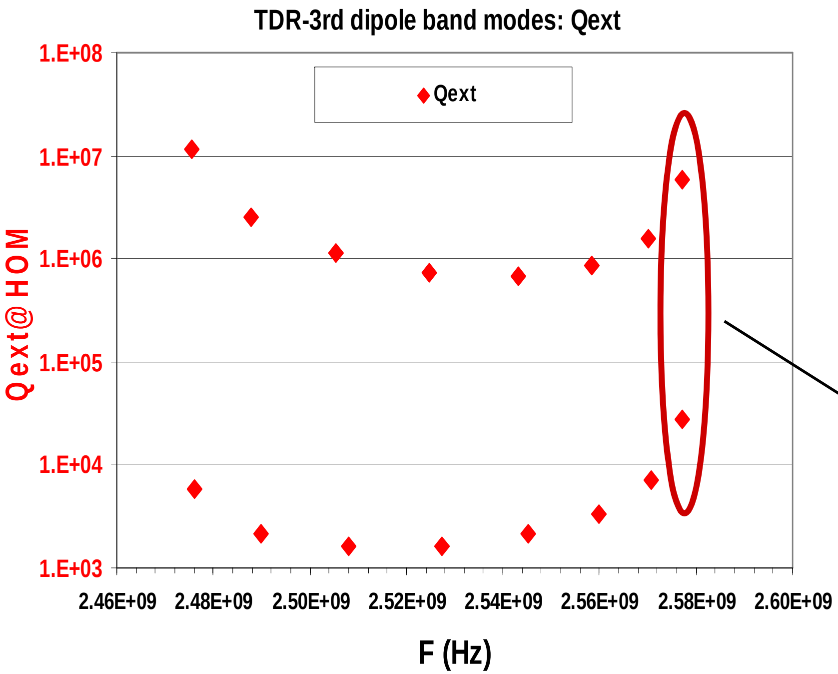
2^{nd} Dipole Band Cavity Modes

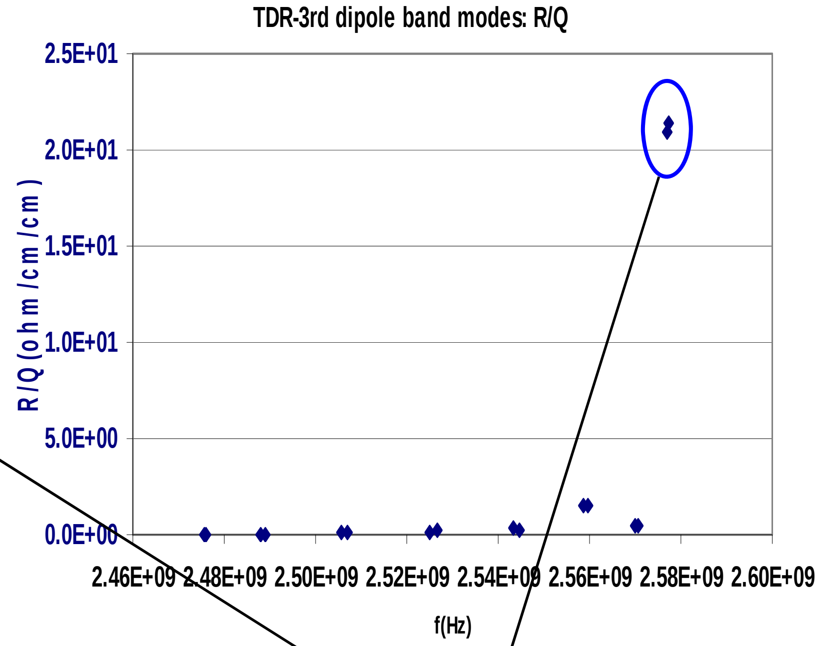




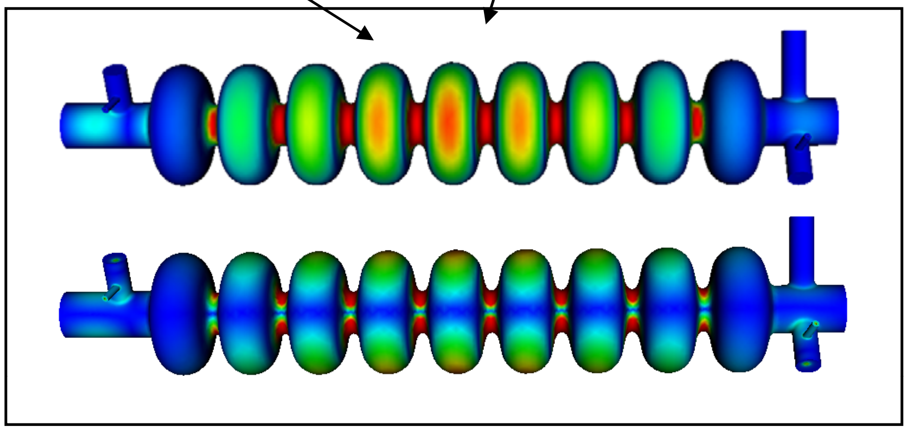
0.53 M quadratic elements, 3.5 M DOFs, 64 CPUs with 120 GB on bassi, 15 minutes for 2 dipole bands

Trapped Modes in 3rd Band





- Frequencies of 3rd band dipole modes above beampipe TE cutoff (2.253 GHz)
- Cross-talk effects between cavities addressed by multi-cavity simulation

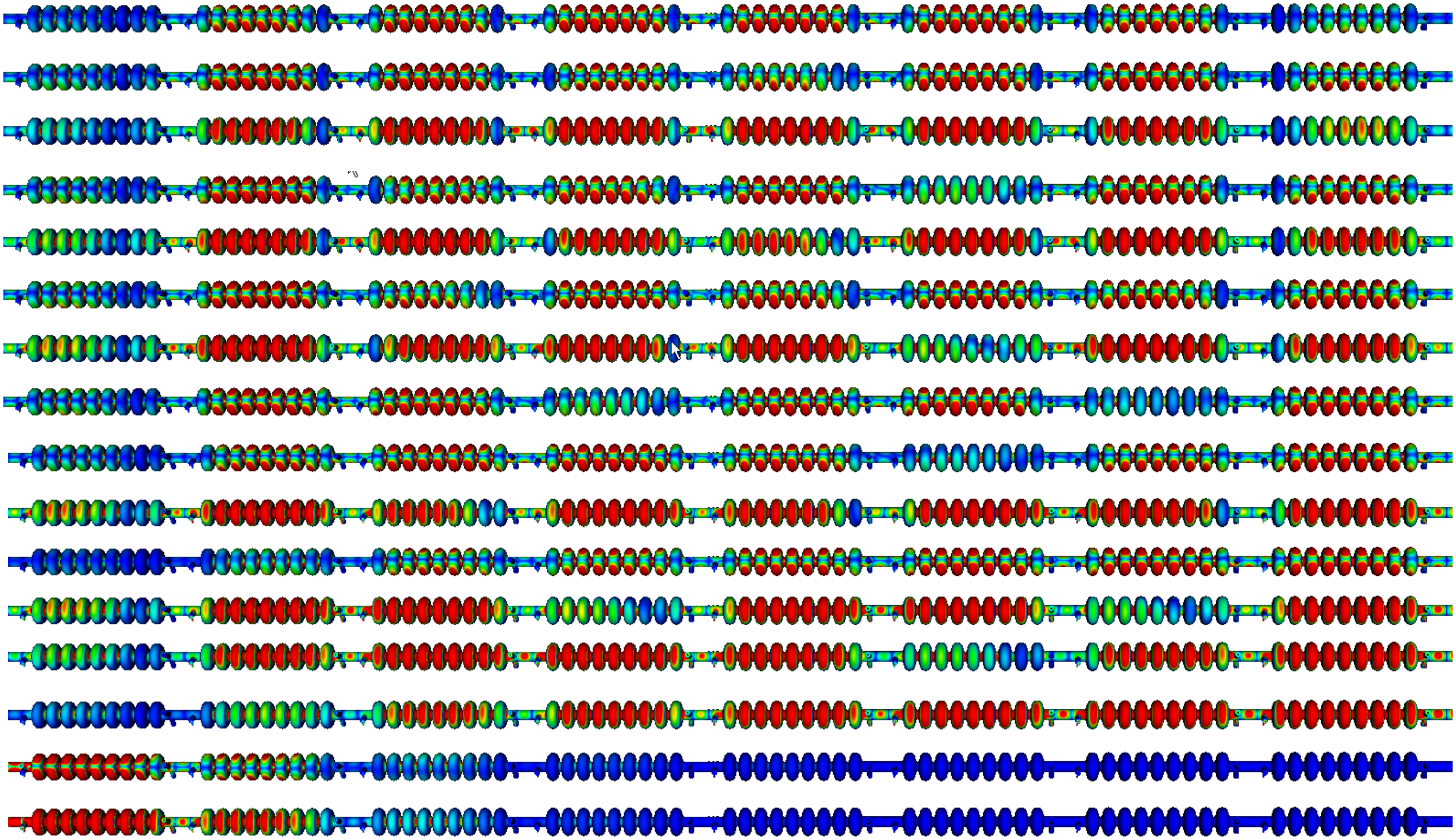


f = 2.577GHz

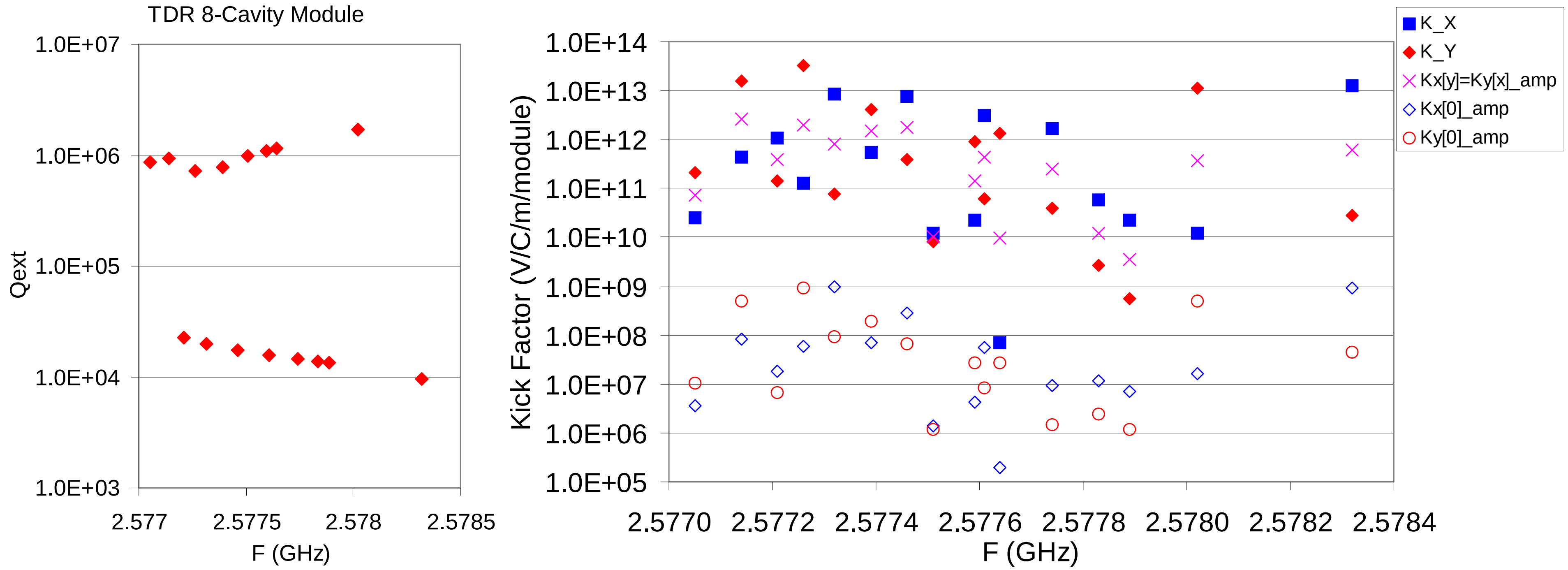
Cryomodule Simulation in Frequency Domain

- ***Mode analysis using Omega3P***
  - Identify trapped modes in the cryomodule
  - Determine damping factors of trapped modes
  - Focus on 3rd dipole band where modes are above beampipe cutoff
- ***Computation requires***
  - 3 million high-order tetrahedral elements
  - 20 million degrees of freedom (DOF)
  - Memory-saving techniques developed for linear solvers to allow solutions of large computational systems
  - 1 hour/mode on seaborg with 1500 processors

3rd Dipole-Band Trapped Modes in Cryomodule

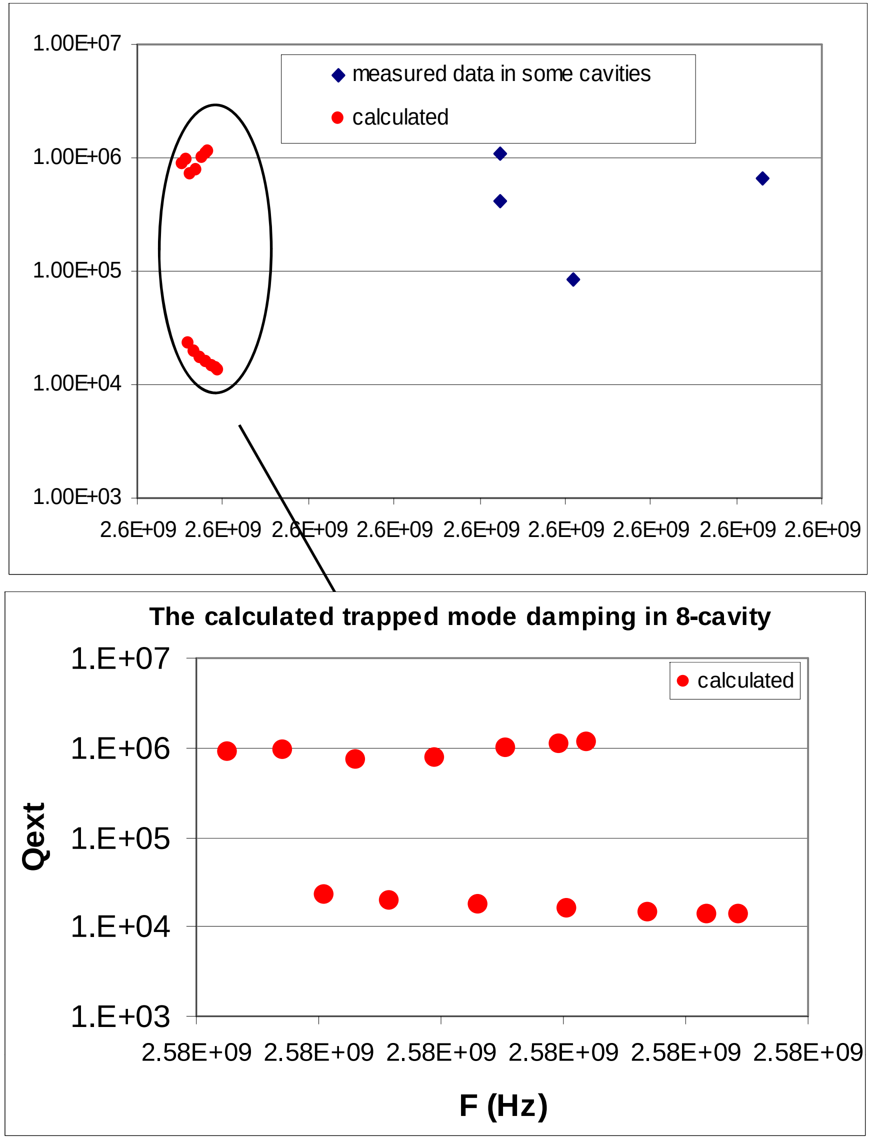


Cryomodule 3rd Dipole-Band Mode - Q_{ext} and Kick



- Modes above cutoff frequency are coupled throughout 8 cavities
- Modes are generally x/y-tilted & twisted due to 3D end-group geometry
- Both tilted and twisted modes cause x-y coupling

Comparison with Measurements



INVESTIGATION OF A HIGH-Q DIPOLE MODE AT THE TESLA CAVITIES

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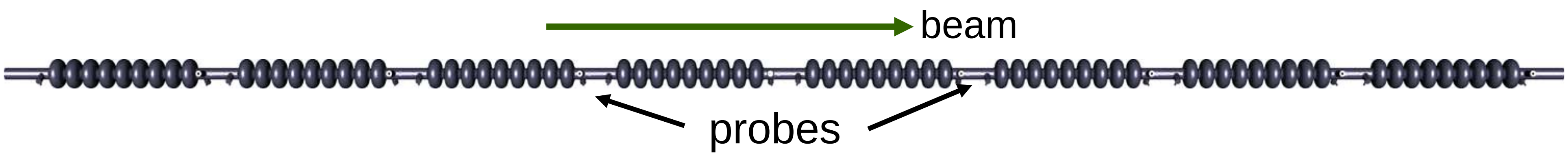
At TTF several experiments have been made in order to study the HOMs. By modulating the beam current [2], several high impedance modes have been found to have a very high Q [3]. Specially a mode around 2.585 GHz, the last of the 3rd dipole band, having an estimated impedance R/Q = 15 Ω/cm^2, was found to be badly damped in 2 cavities of the first module. Nevertheless, the other polarization of the same mode is better damped. It was found that this mode is badly damped in one of the cavities of the 2nd and 3rd modules as well. The results are summarized in Table. 1.

Table 1. Results of HOM investigations for the last mode of the 3rd dipole passband (R/Q = 15 Ω/cm^2)

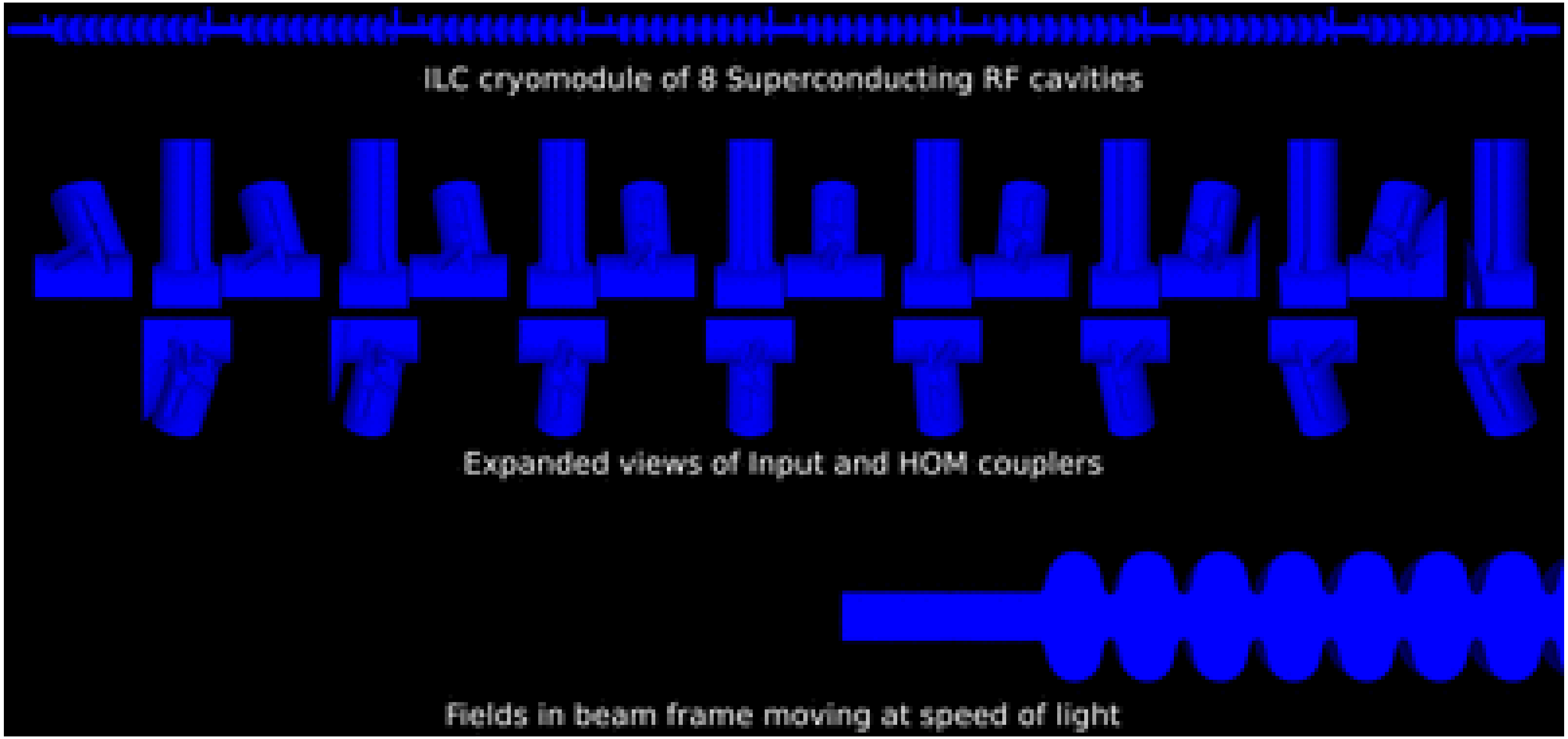
Cavity nr./module	Freq. [GHz]	Q
#3 (S10) / 1	2.5845	$1.1\cdot10^6$
#6 (S11) / 1	2.5862	$8.6\cdot10^4$
#5 (A15) / 2	2.5845	$4.2\cdot10^5$
#7 (S28) / 3	2.5906	$6.5\cdot10^5$

Cryomodule Simulation in Time Domain

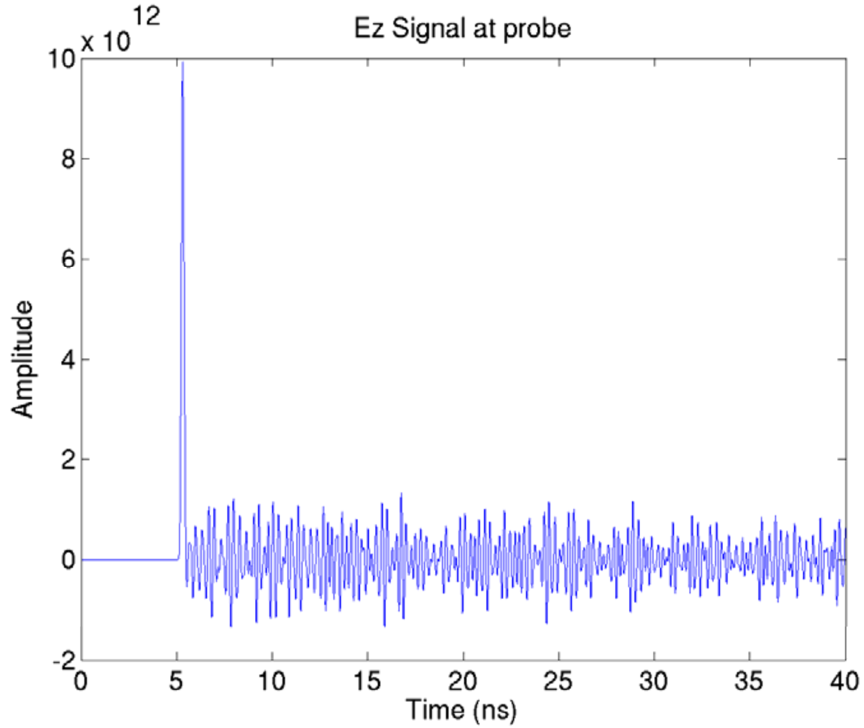


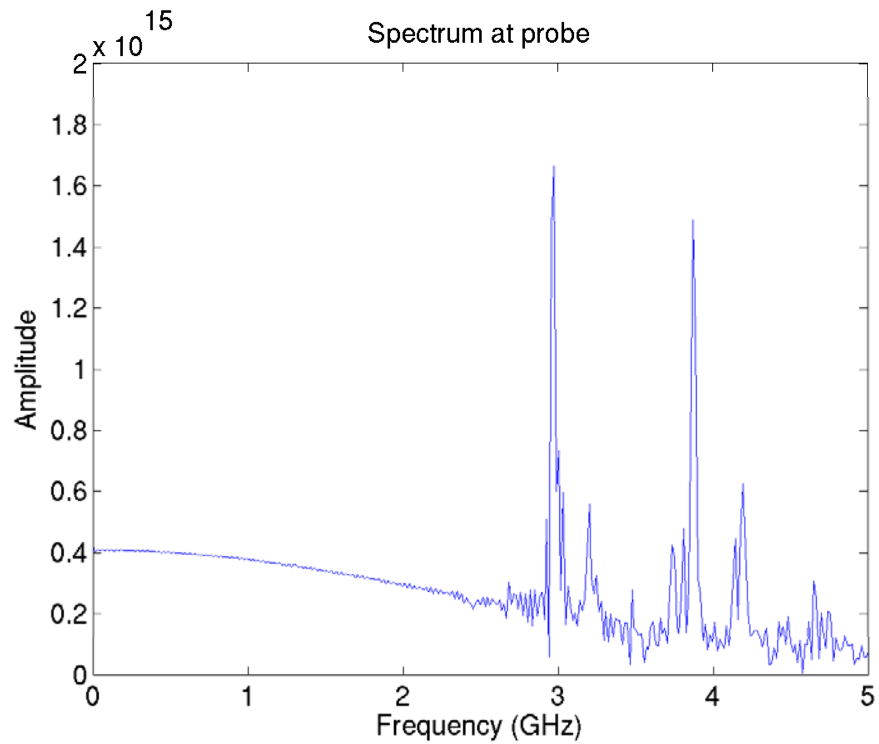
- ***Direct simulation using T3P***
  - Determine mode spectrum in the cryomodule
  - Focus on possible localized modes in beampipe regions
- ***Computation requires***
  - Same mesh used for Omega3P mode analysis
  - 3 million high-order tetrahedral elements
  - 20 million degrees of freedom (DOF)
  - 256 MSPs on NCCS phoenix with a total runtime of 300 hours
  - 0.5 terabytes data (stored on HPSS and then transferred to SLAC)

Beam Transit in Cryomodule



Electric Field Monitored in Beampipe

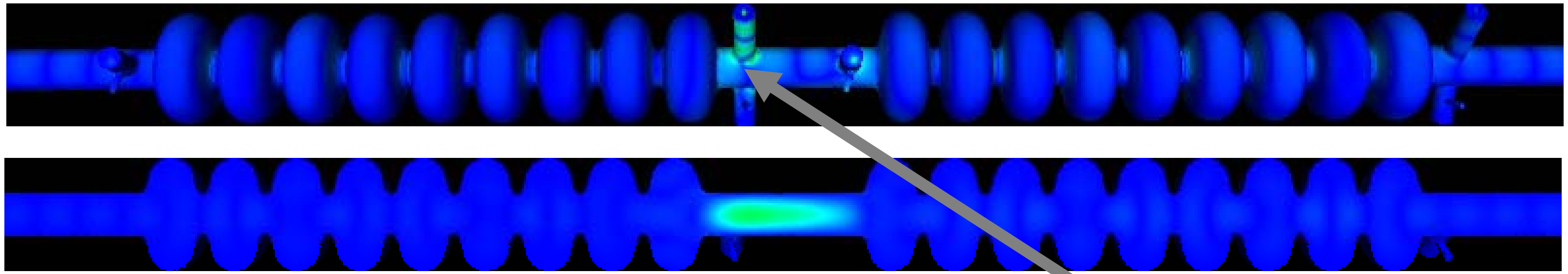


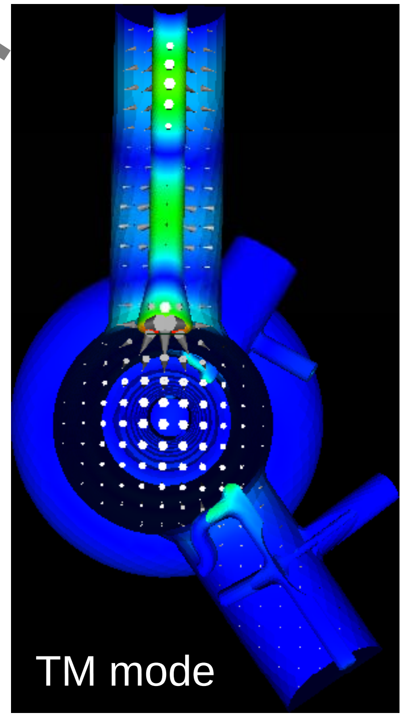


- Peak at around 2.94 GHz (TM cutoff)
- Search for trapped modes around this frequency using eignesolver Omega3P

Trapped Mode using Omega3P

Electric field





Trapped mode

- TM-like mode localized in beampipe between 2 cavities
- Frequency = 2.948 GHz, slightly higher than TM cutoff at 2.943 GHz
- R/Q = 0.392 Ω; Q = 6320
- Mode power = 0.6 mW

Future Work

- Include cavity imperfection in cryomodule to study its effects on wakefields
- Study effects of trapped modes on local heating in beampipe region
- Modeling the entire RF unit