Compact Crab Cavity Design and Modeling Using Parallel Code ACE3P

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Outline

- LARP CM16 Ridged Waveguide design
- ACE3P parallel tools for cavity design and modeling
- ODU SLAC joint effort on a common LHC crab design
- ODU prototype cavity MP analysis
- Compact crab cavity damping coupler considerations

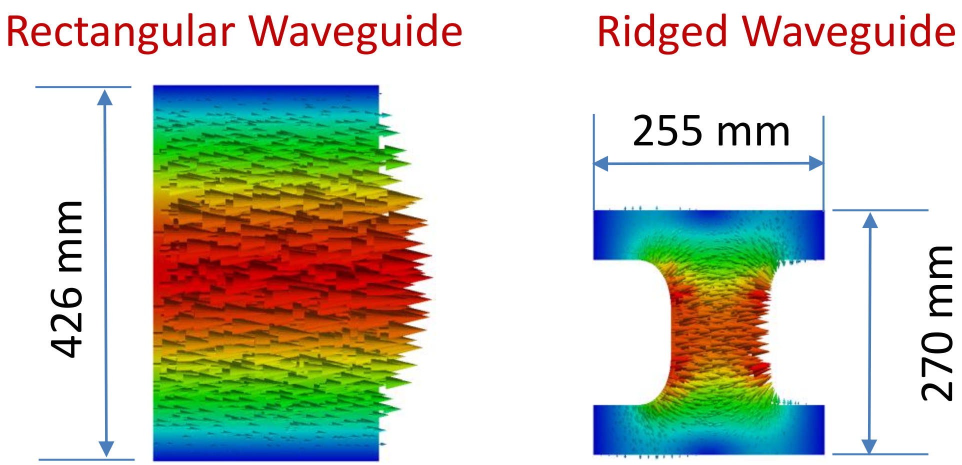
Ridged Waveguide Deflector

for Horizontal & Vertical Crabbing

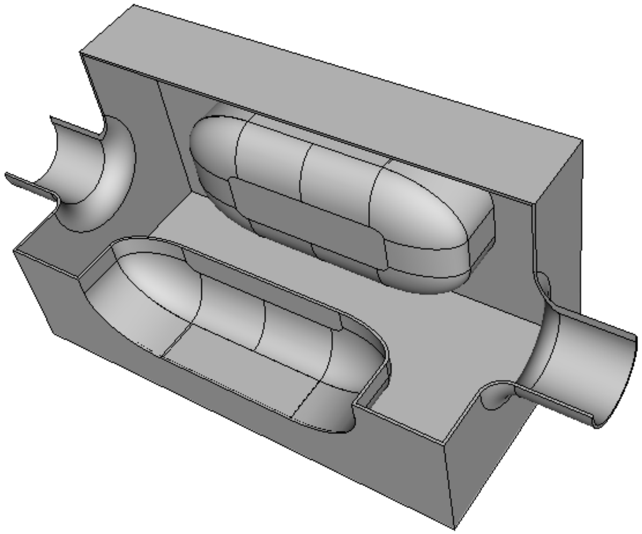
LARP CM16

Ridged Waveguide Deflector for H & V Crabbing

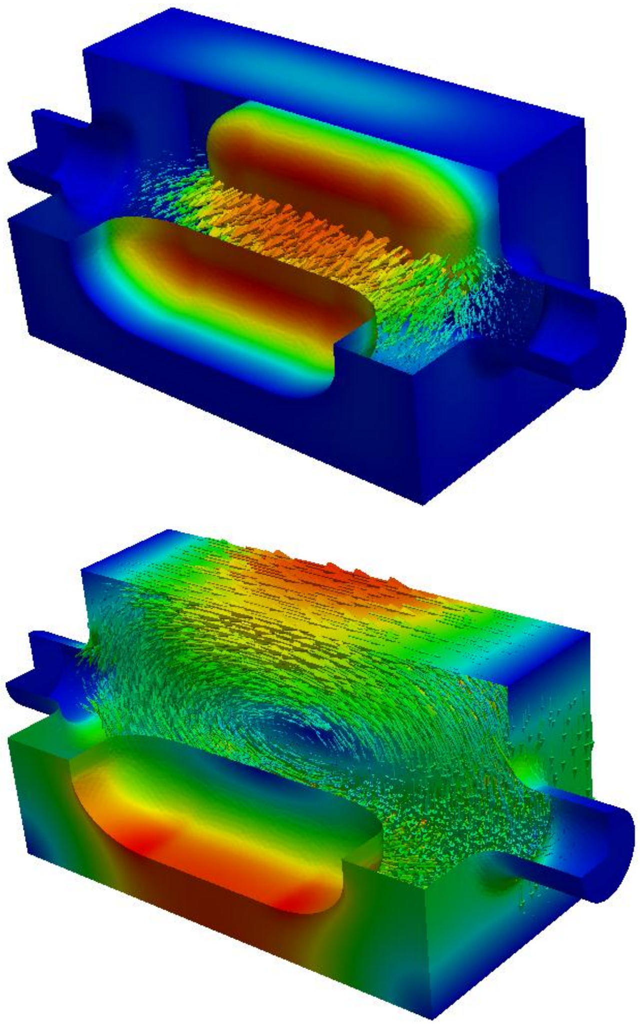
- Waveguide
  TE10 mode
  cutoff: 352 MHz



- Ridged Waveguide deflector



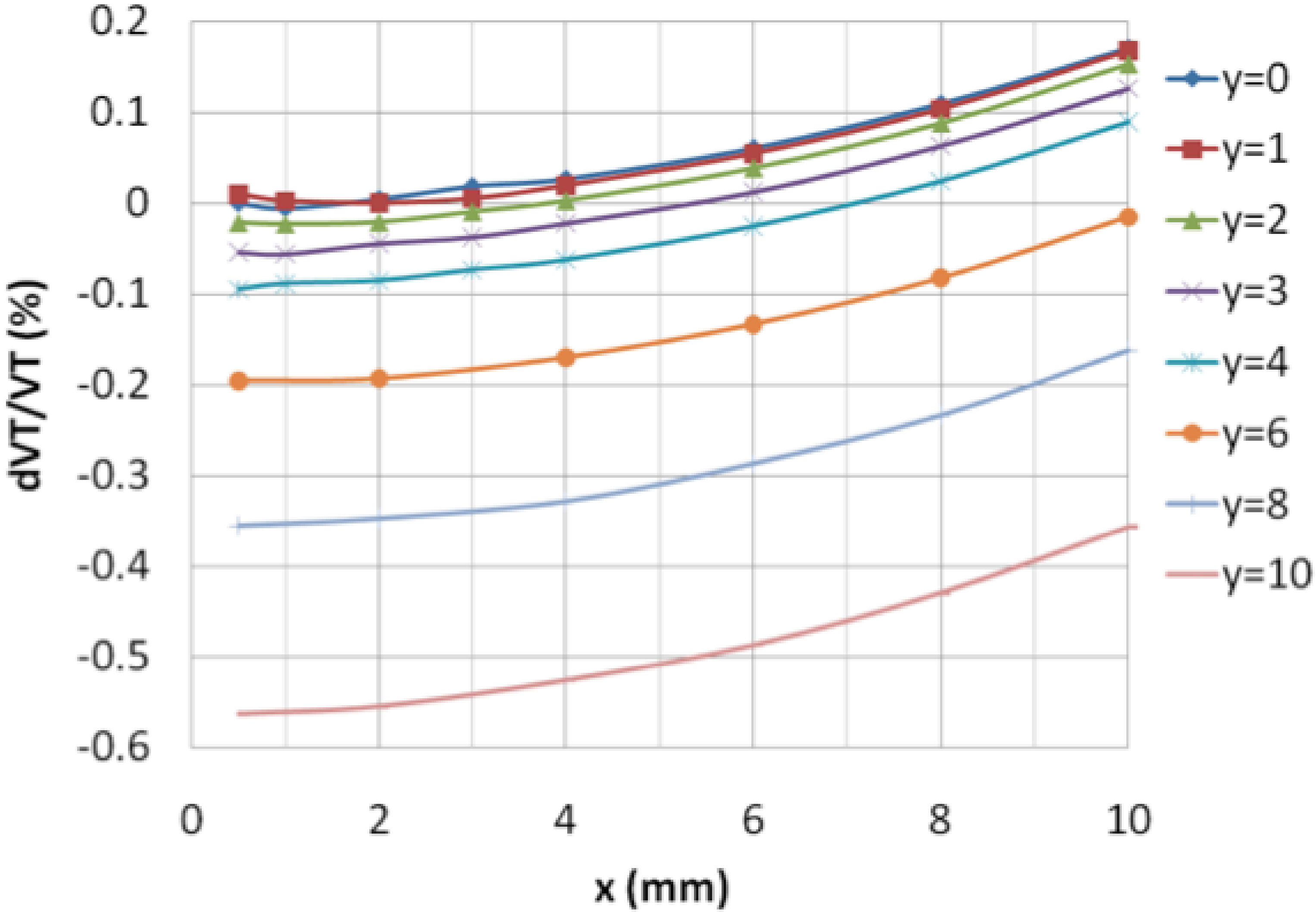
Cavity Parameters



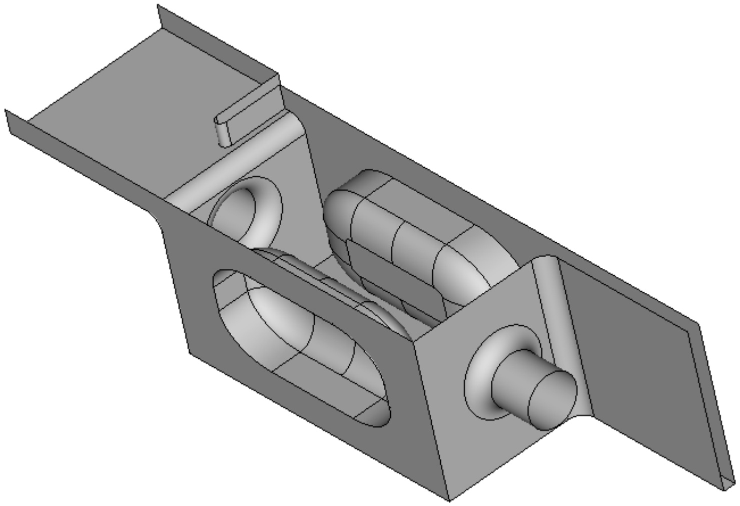
Operating mode Frequency	400 MHz
Operating Mode	TE11 like mode
Lowest acc mode Frequency	671 MHz
Lowest vertical HOM Frequency	617 MHz
Lowest horizontal HOM Frequency	698 MHz
Iris aperture (diameter)	84 mm
Transverse dimension	250 mm
Vertical dimension	270 mm
Longitudinal dimension	525 mm
Transverse Shunt Impedance	330 ohm/cavity
Required deflecting voltage per cavity	5 MV
Peak surface magnetic field	94 mT
Peak surface electric field	45 MV/m

- Transverse dimension: 250mmX270mm
- Fit both H and V crabbing schemes

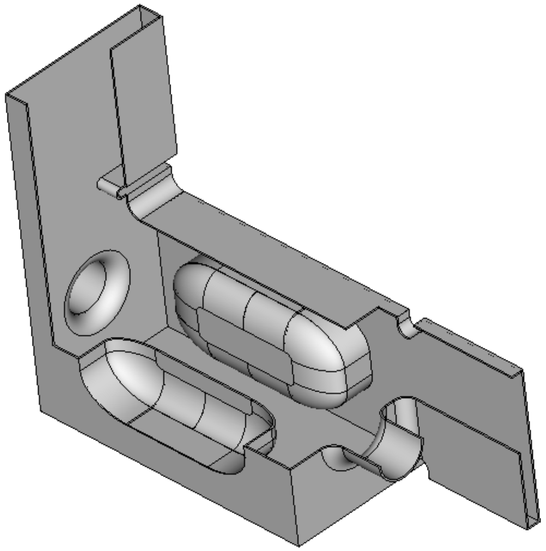
Deflecting Voltage v.s. Position



Waveguide HOM Damping



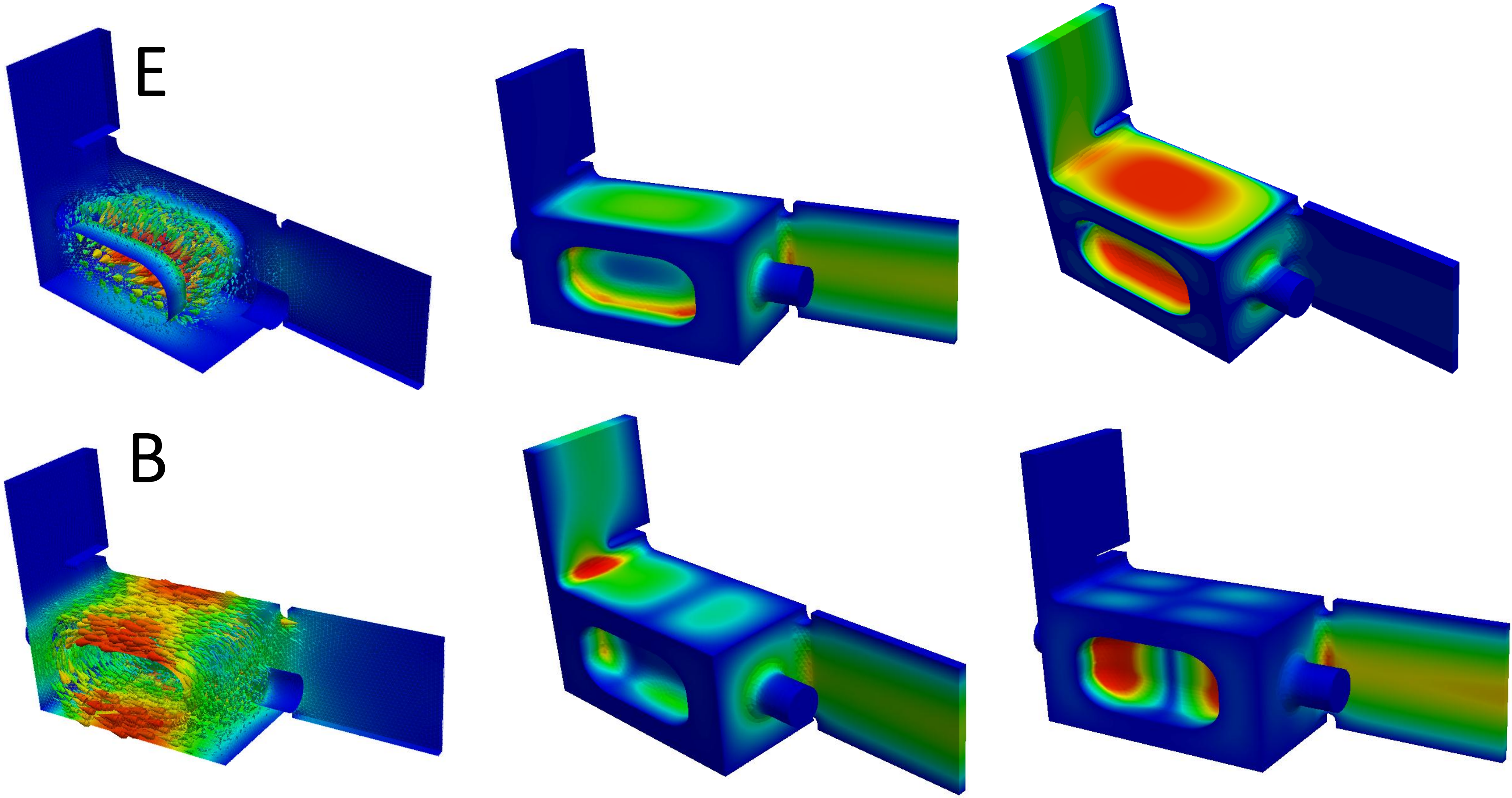
OR



- Waveguide to damp H/V dipole and accelerating HOMs
- No filter needed - operating mode below cutoff of damping waveguides
- Damping coupler could be used as power coupler (evanescence, use taper up waveguide or coax converter)
- WG stub maybe needed to symmetrize field

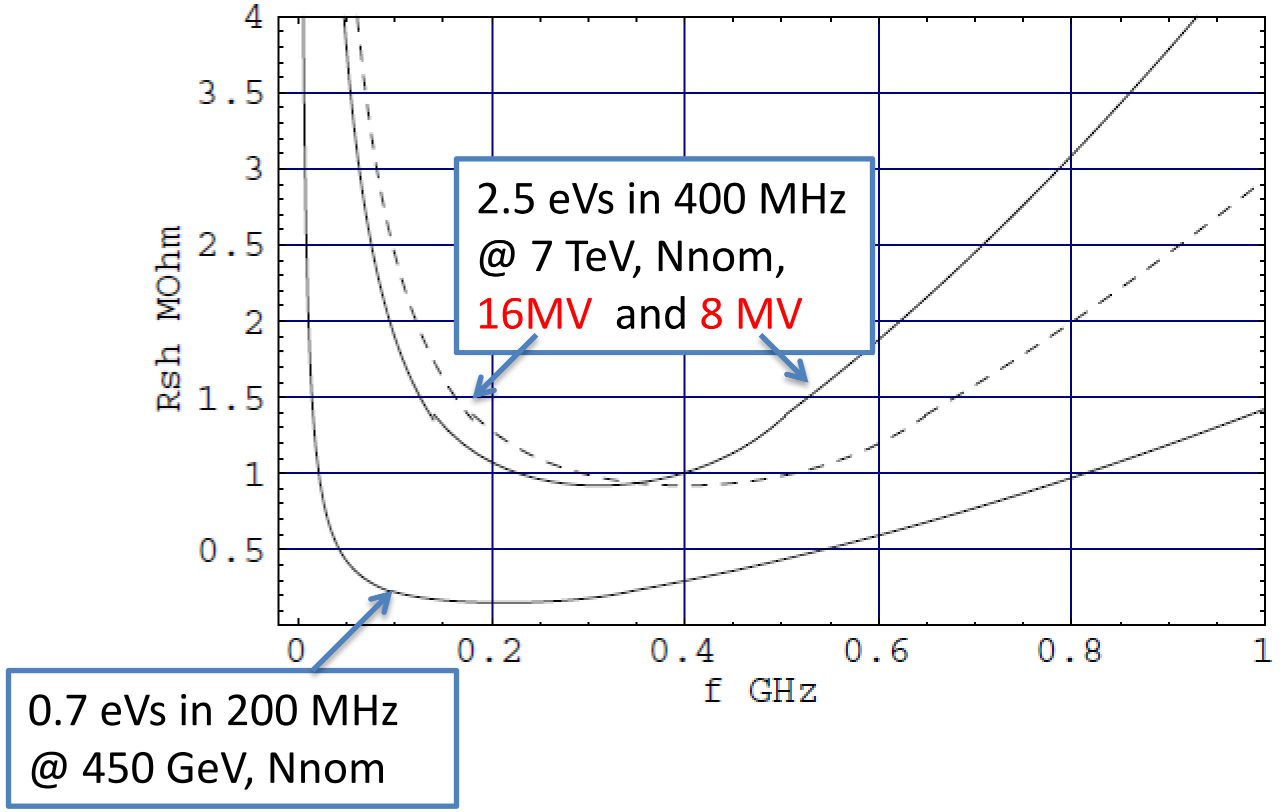
HOM Damping

Operating modes | Accelerating modes | Dipole modes



Impedance budget: frequency dependence

E. Shaposhnikova



200kohm

E. Shaposhnikova

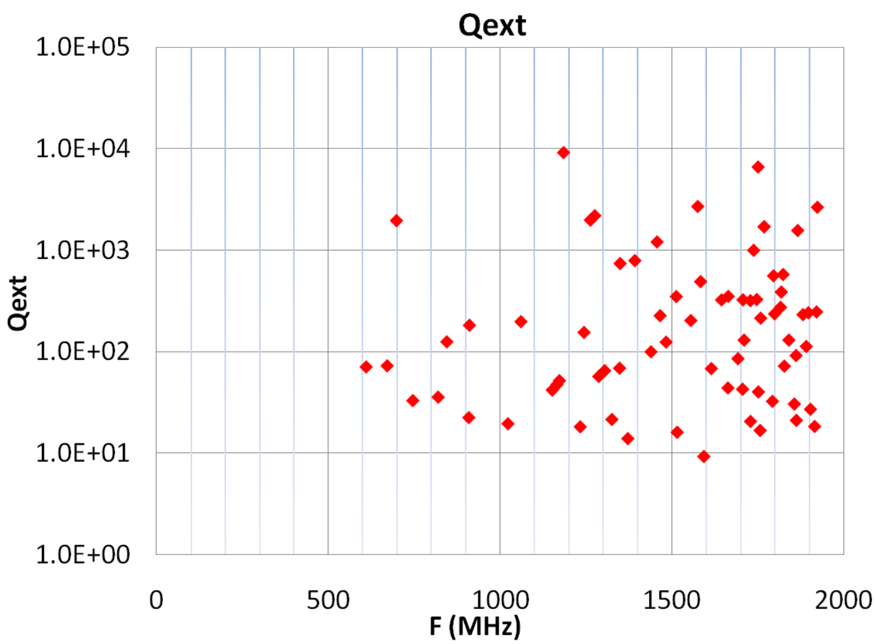
Transverse impedance budget

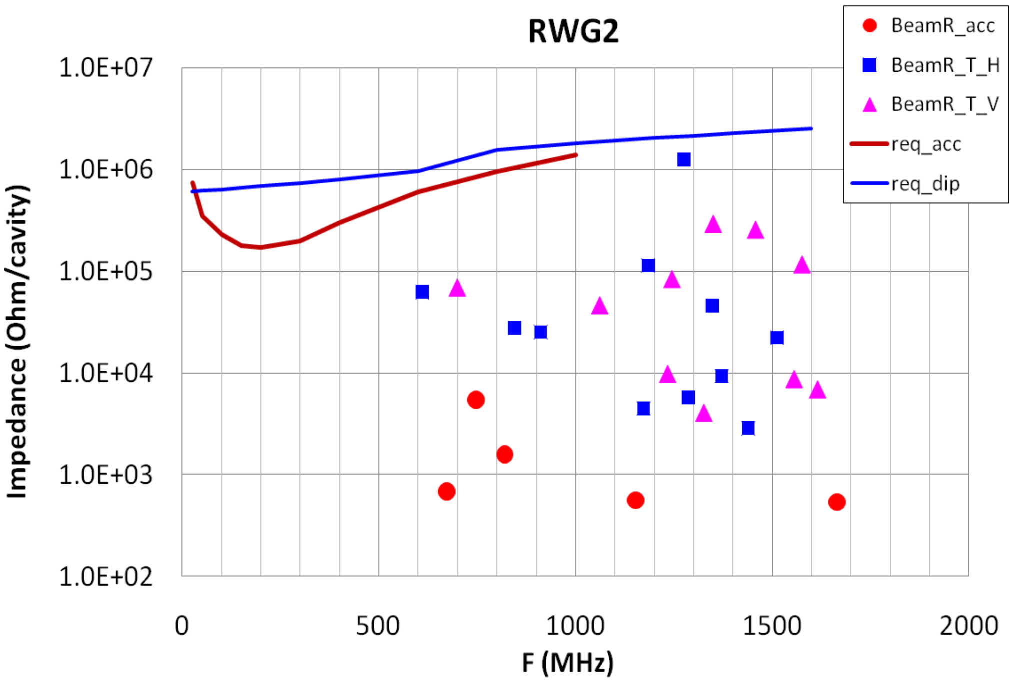
- For nominal intensity at 450 GeV threshold determined by the damping time of 60 ms is 2.5 MOhm/m. With margin for particle distribution - 0.6 MOhm/m
- Approximate frequency dependence
  - 0.6 /(1-f_r/1.6) MOhm/m for f_r [GHz] < 0.8
  - 1.2 (0.5+f_r) MOhm/m for f_r [GHz] > 0.8

$\rightarrow$ 0.8 MOhm/m at 0.8 GHz for ultimate intensity and 0.4 MOhm/m for 2 identical cavities

- Additional factor proportional to local beta-function $\beta/\langle \beta \rangle$

HOM Damping and Cavity Impedance



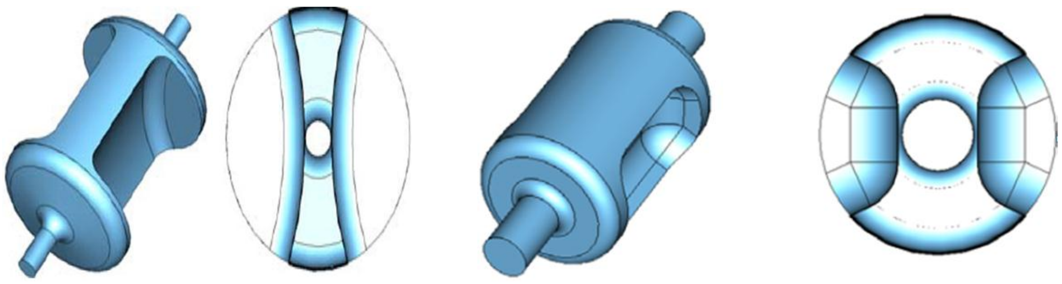


Strong damping achieved with waveguide couplers

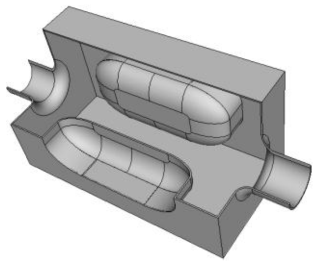
Solid lines: LHC-CC10 requirement

LARP CM16 - Joint Effort

- ODU and SLAC to work on a common design
  - Capabilities in hardware development and measurement
  - Capabilities in RF modeling
  - Expertise in RF design



(Jean Delayen LARP CM16)



(Z Li LARP CM16)

RF Modeling Code Suite ACE3P

ACE3P (Advanced Computational Electromagnetics 3P)

Supported by SLAC and DOE Grand Challenge & SciDAC programs

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 guns & klystrons**
Multi-physics:	**TEM3P**	**– EM, Thermal & Structural effects**

Meshing – CUBIT *http://cubit.sandia.gov;* ***Postprocessing – ParaView*** *http://www.paraview.org*

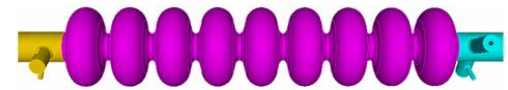
ACE3P capabilities

- Conformal, higher-order finite element – model fidelity
- Parallel computing – problem size and speed
- Run on DOE flagship supercomputers – NERSC/LBNL, NCCS/ORNL
- Codes benchmarked with measurements – design for manufacture

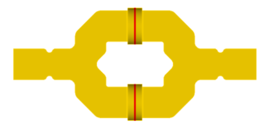
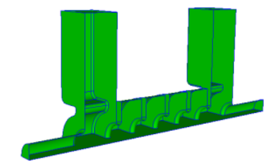
ACE3P user community: code workshop: 2009, 2010, 2011

ACE3P Modules

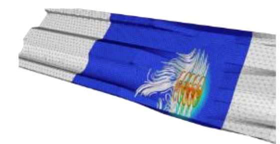
- Omega3P – eigenvalue
  - high precision RF design
  - open cavity HOM damping
  - lossy material

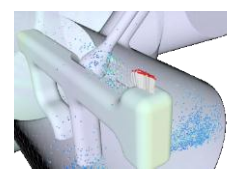
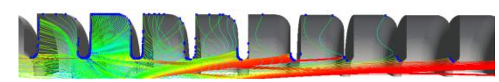
- S3P - S parameter
  - coupler & RF component design
  - impedance boundary

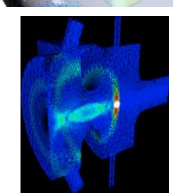
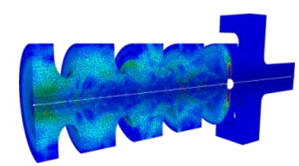
- T3P – beam and port excitation
  - wakefield and impedance
  - trapped modes and signal sensitivity
  - moving window



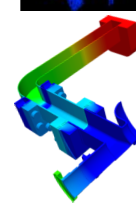
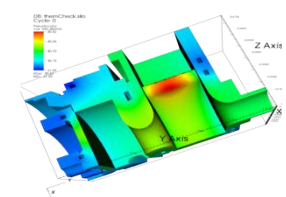
- Track3P – MP and dark current
  - identifying MP barriers & MP sites
  - dark current in high gradient structures

- Pic3P – full wave particle in cell
  - RF gun and RF power source design

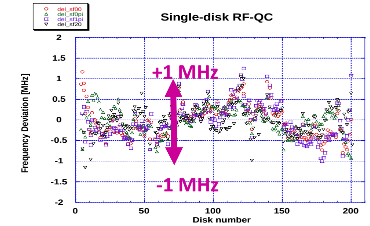
- TEM3P – thermal mechanical
  - integrated EM, thermal and structural effects
  - nonlinear temperature dependence

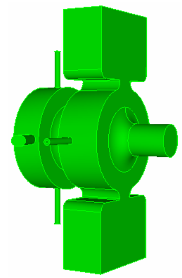
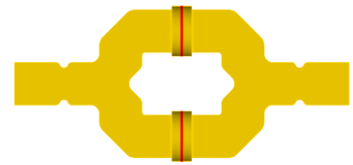
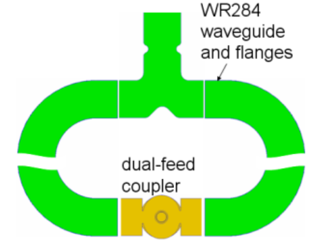
RF Modeling – selected examples

NLC RDDS, HDDS Cell design

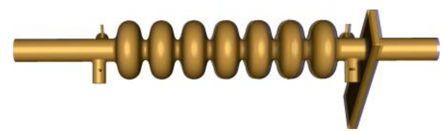
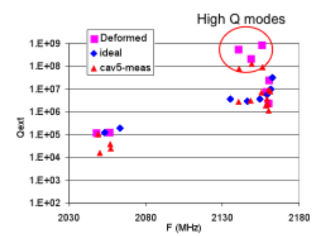


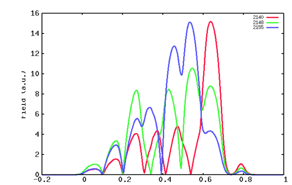


LCLS RF Gun & injector S-band structure design

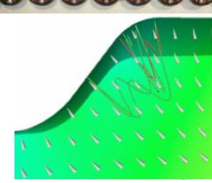
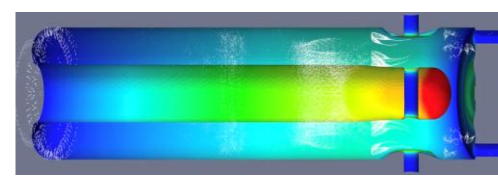




JLab upgrade cavity - Identified the cause of high Q modes



MP barrier Prediction in SCRF cavities

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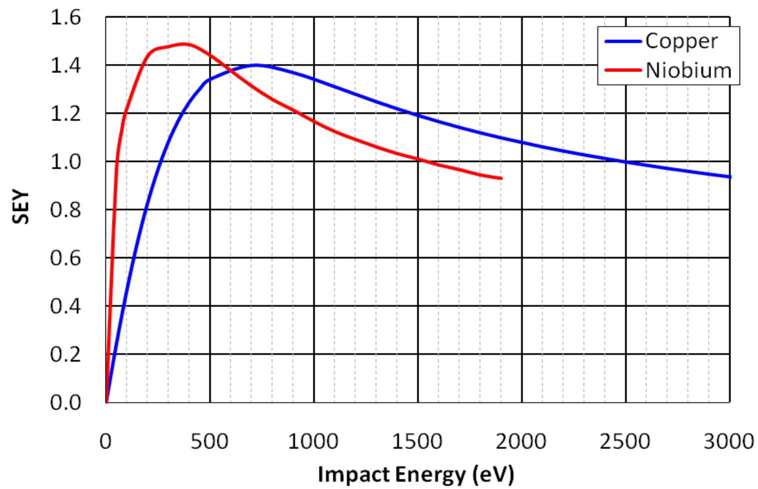
ACE3P - enabling tools: design and performance analysis, cost and time saving

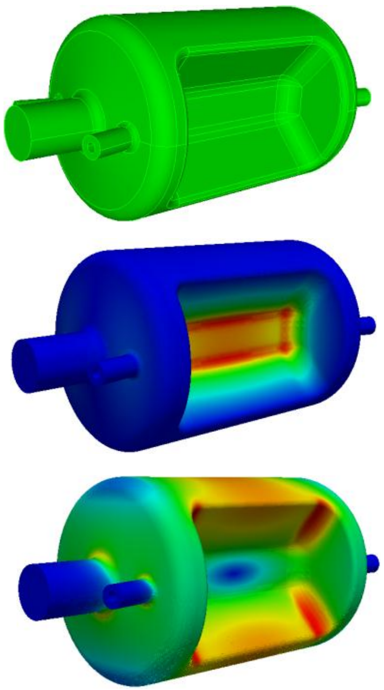
MP Simulation Using Track3P

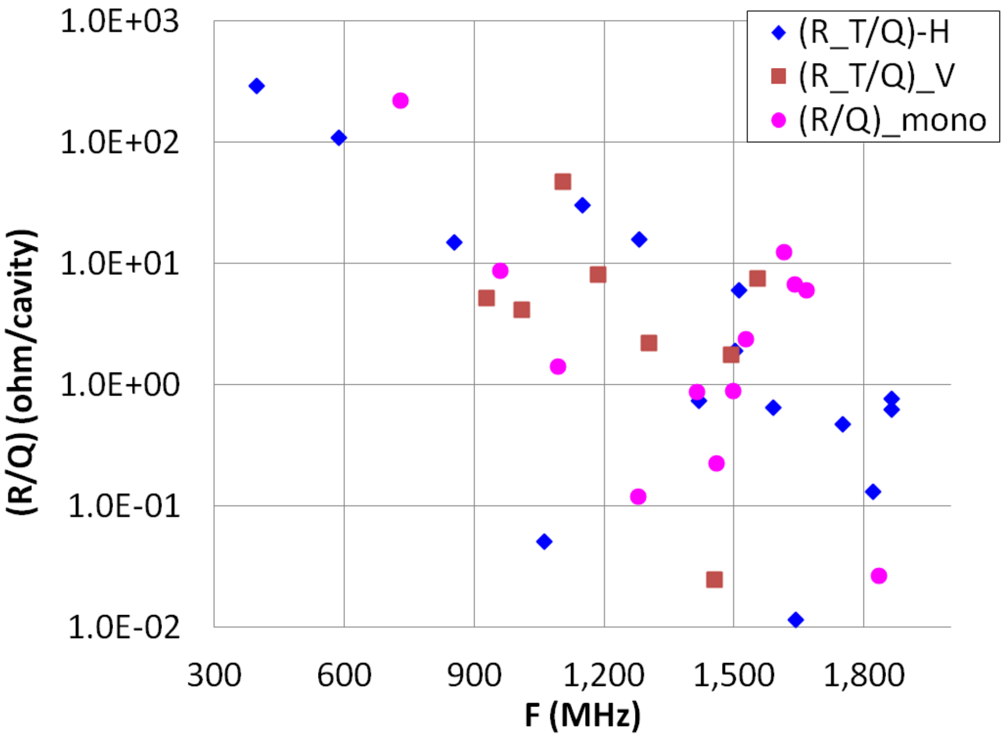
Track3P MP simulation

- Launch electrons on specified surfaces with different RF phase, energy and emission angle
- Determine "resonant" trajectories by consecutive impact phase and position
- Stable resonant MP: trajectories impact at same locations with same energies - Calculate MP order (#RF cycles/impact) and MP type (#impacts /MP cycle)
- Run-away resonant MP: trajectories started resonant with RF and slowly slip away from resonance location and RF phase. Maximum enhancement counter calculated based on given SEY curve



ODU Prototype Cavity



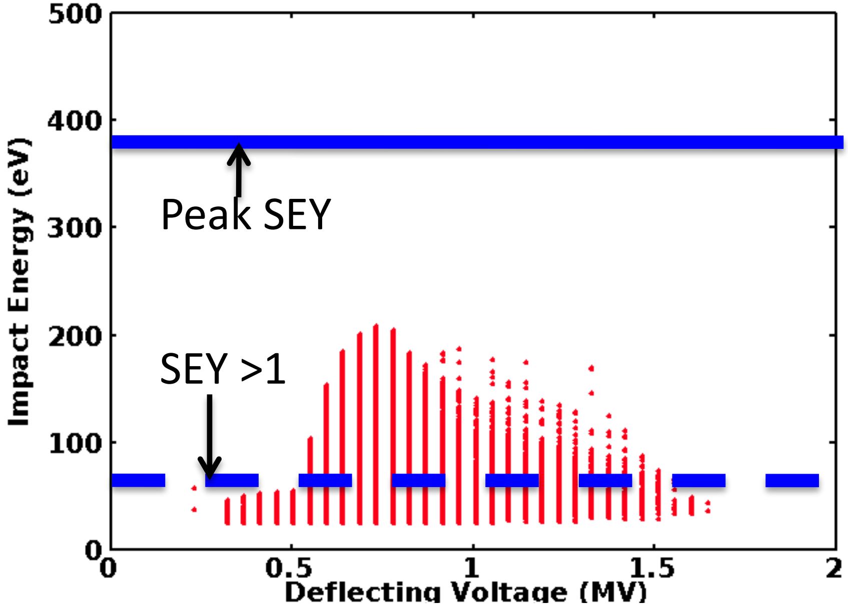


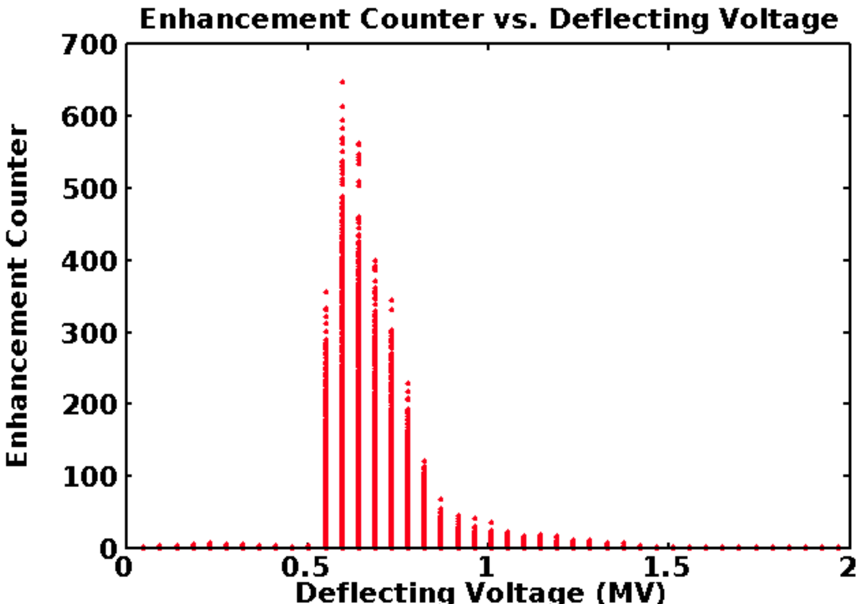
- Perform RF analysis using Omega3P
- Multipacting analysis using Track3P
- Help to understand measurement data through simulation
- Damping coupler development

Multipacting Simulation Using Track3P on ODU Prototype Cavity

- Field level scan:
  - 0.045 MV – 5.5MV, interval 0.045 MV
- Initial Particles distributed on all exterio surface
- Each field level ran 50 RF cycles.
- Determine Stable and “run-away” resonances
- Calculate enhnacement counter (with a pre-defined SEY curve) – indication of hardness

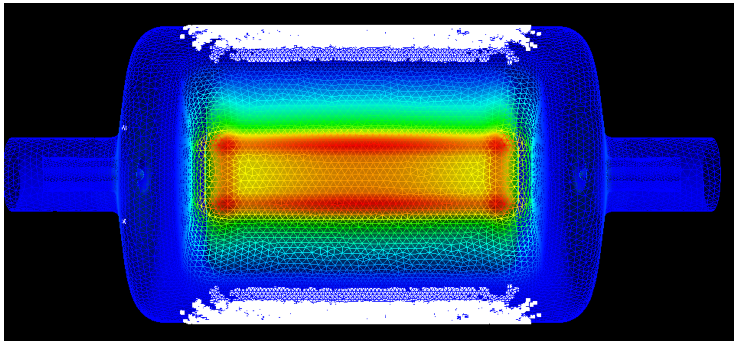
Resonant Particles in Cavity



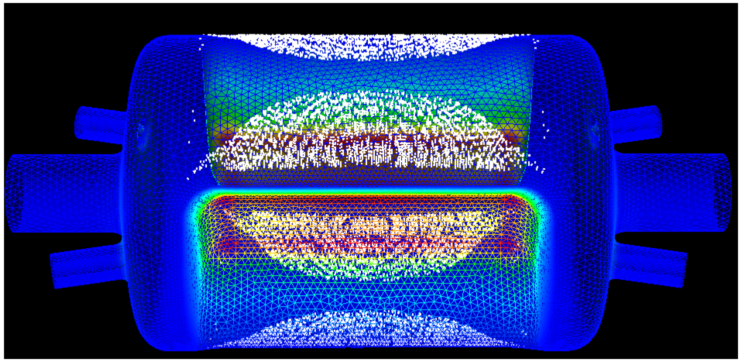


- **One point first order**
- **Impact energy below the peak value**
- **Large enhancement counter region: 0.6MV ~1.0MV**

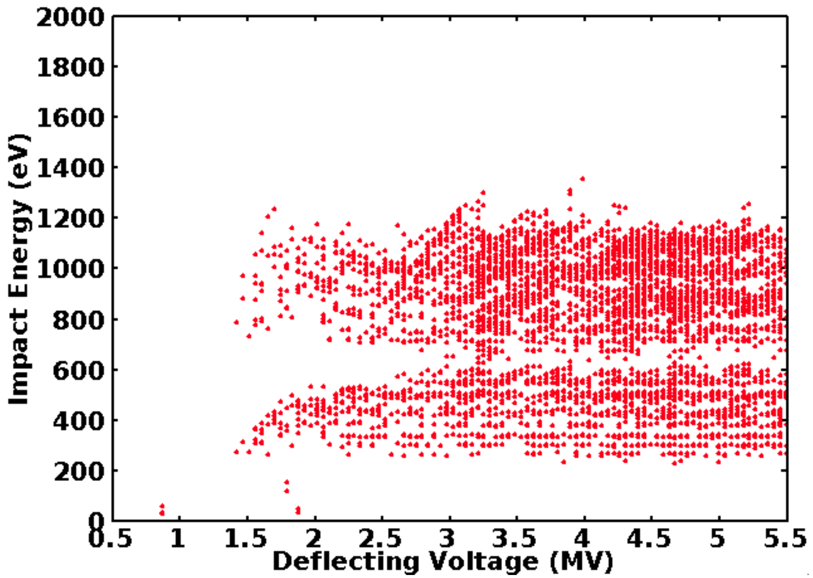
Resonant Particles Distribution at all field levels

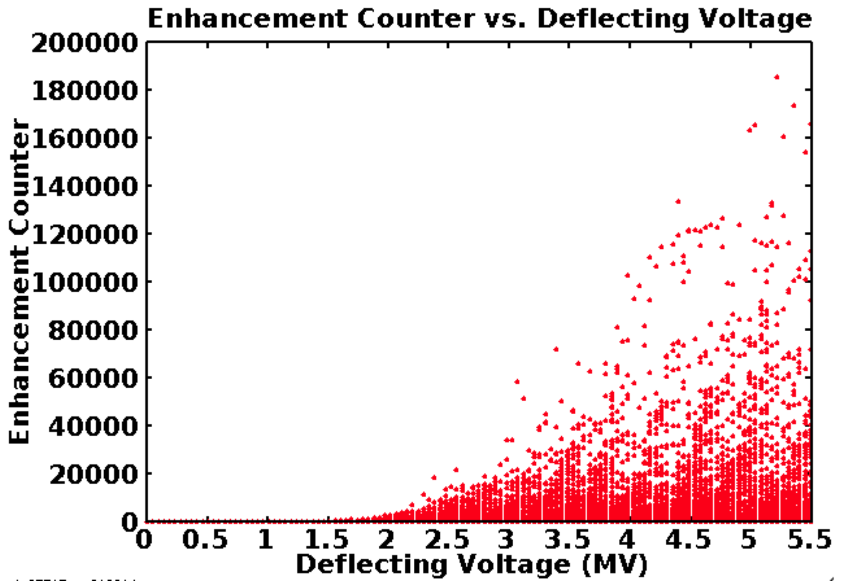


Resonant Particles Distribution at 0.6MV



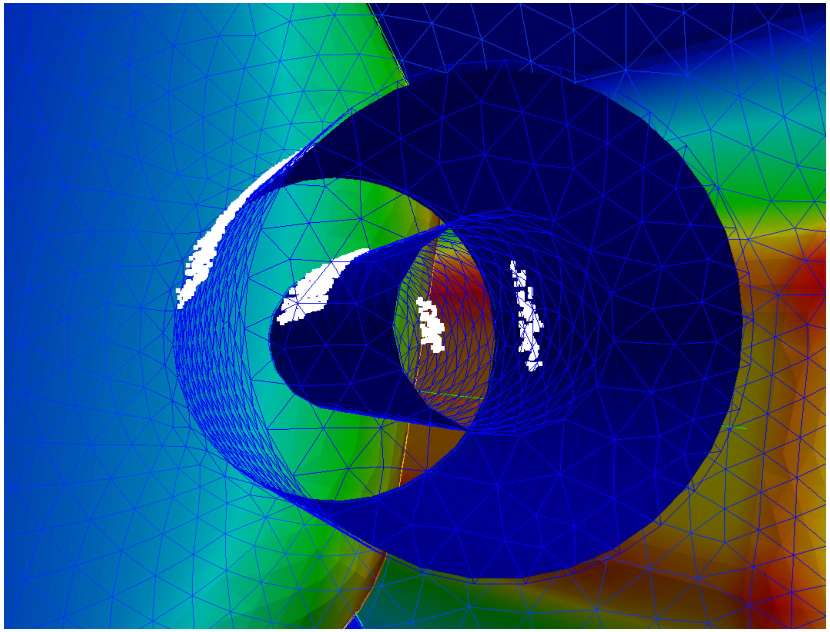
Resonant Particle in the Coaxial Coupler



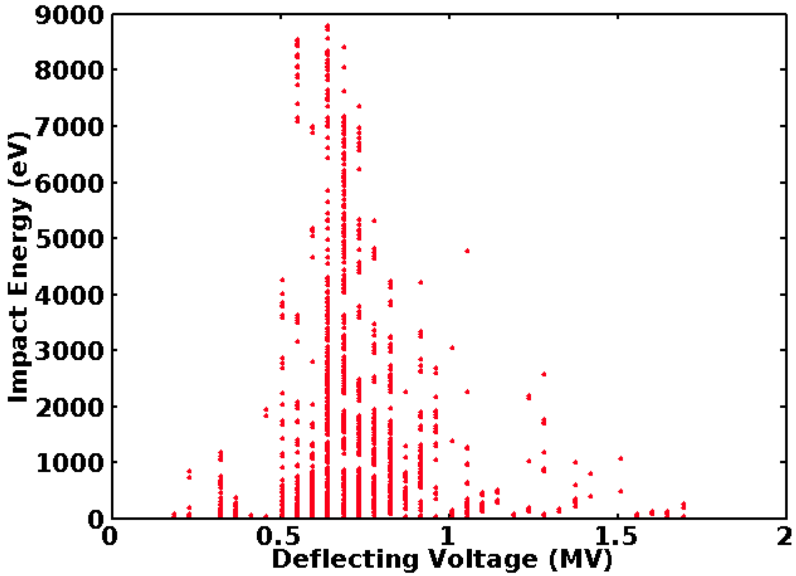


(coupler not final design)

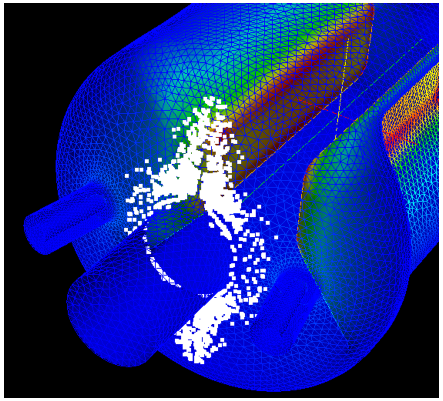
- Two points (inner and outer conductors) first order
- Impact energies are lower on inner conductor than those on outer conductor
- Higher enhancement counter than in the cavity

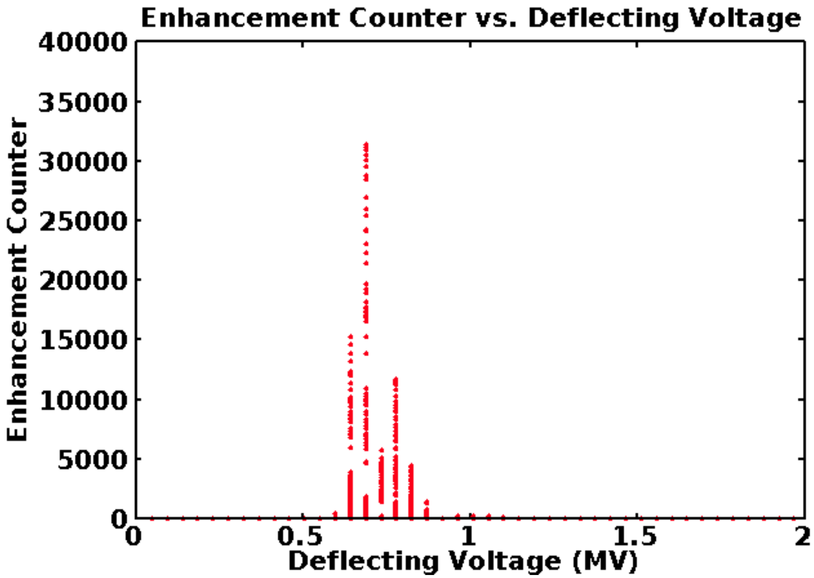


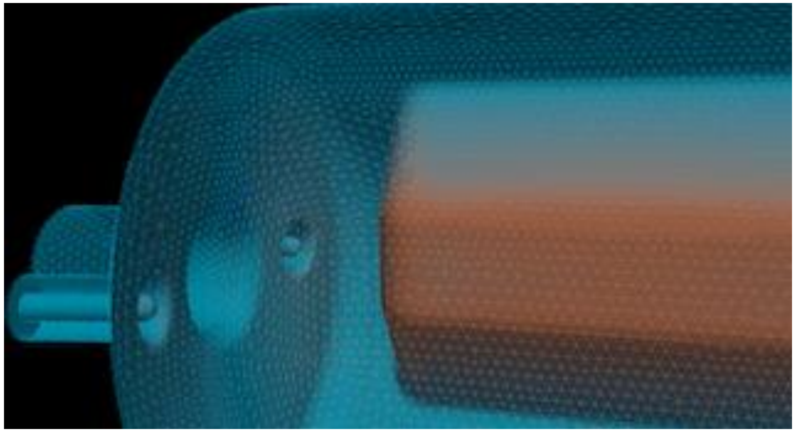
Resonant Particles Around Beam Pipe Opening



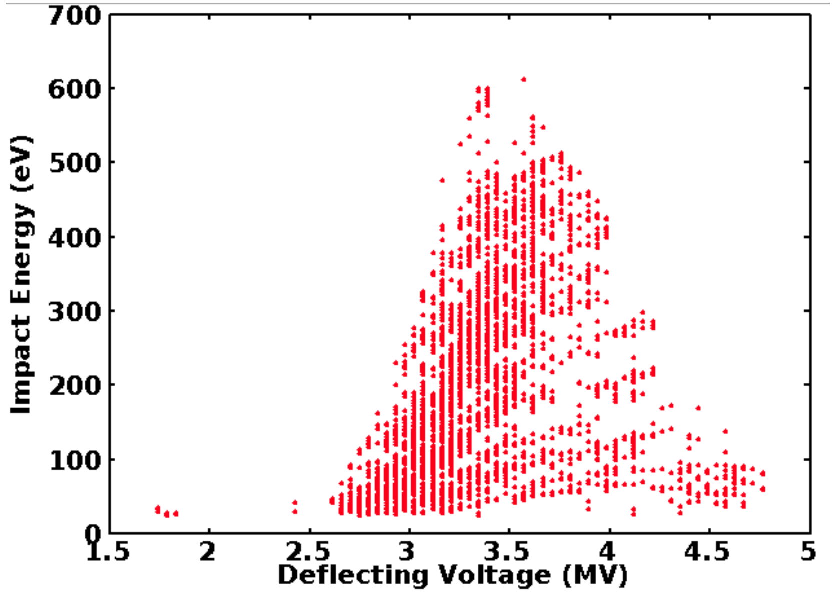
- One Point First Order resonant particles
- Peak enhancement happens between 0.65 MV and 0.85 MV

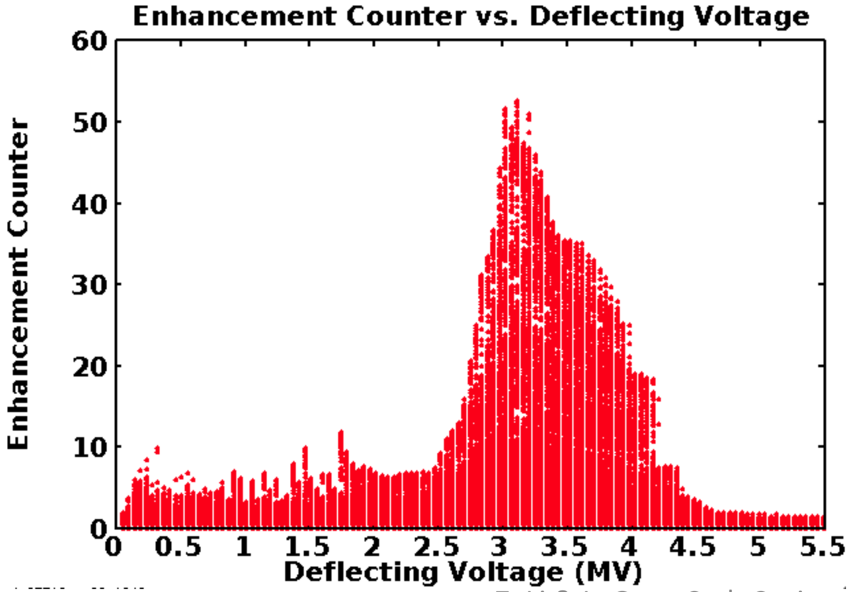




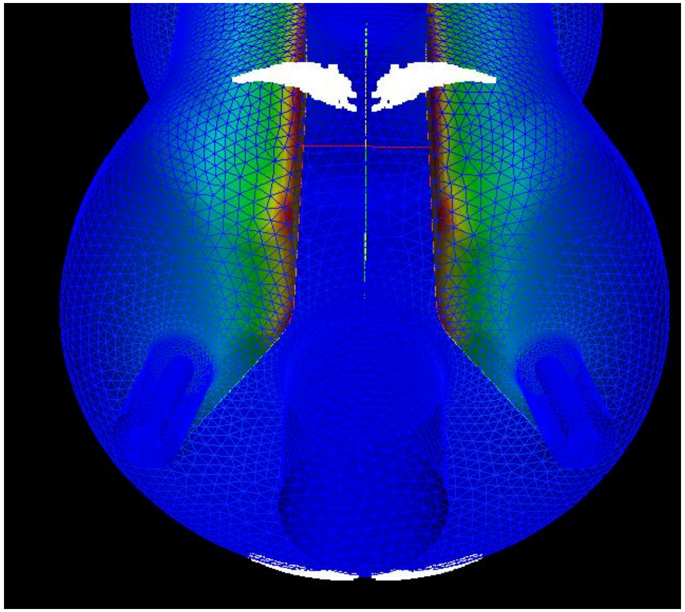


Resonant Particle On The End Cap

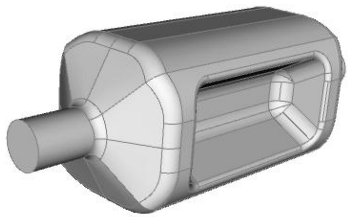




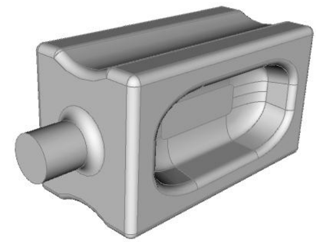
- One Point First Order resonant particles.
- Peak enhancement counters are between 3 MV ~ 4 MV
- Peak value is around 50



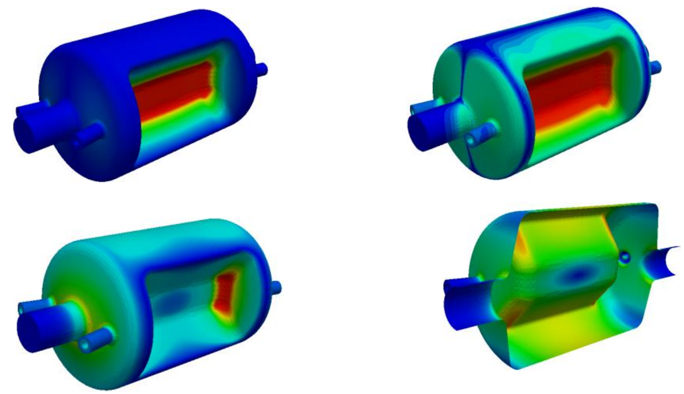
Damping Coupler Consideration



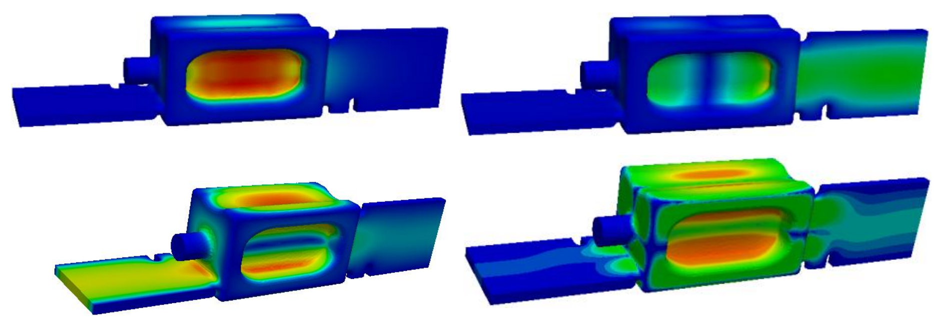
(Jean Delayen, Subashini de Silva)



- Coaxial coupler
  - Compact
  - Need high band-pass filter
  - Center conductor heating ?
  - Need to evaluate achievable Qext

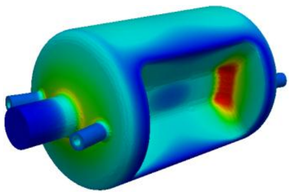


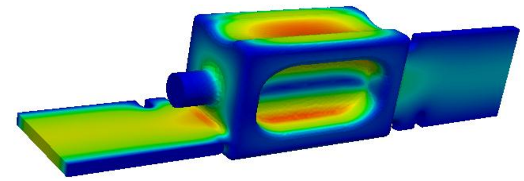
- Waveguide coupler
  - Low Qext
  - more bulky
  - Multipacting?
  - Static heating

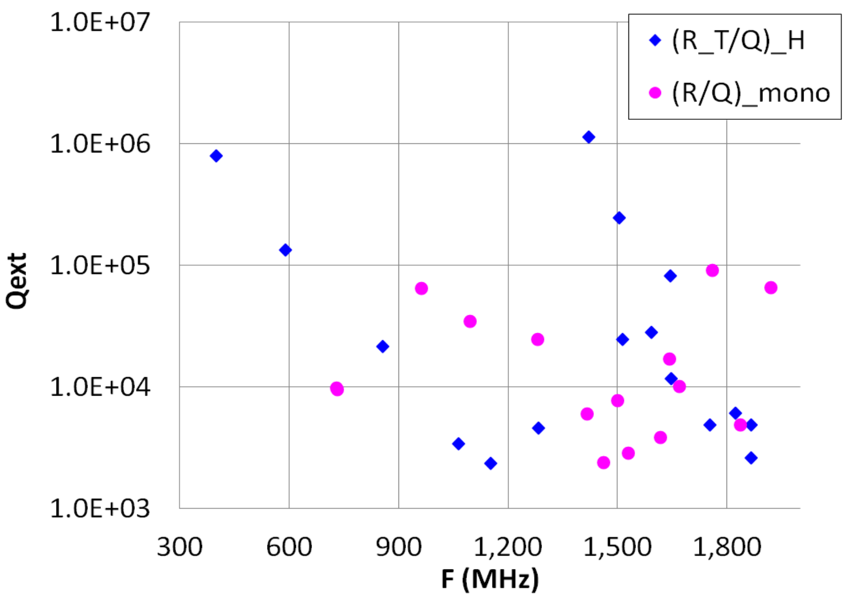


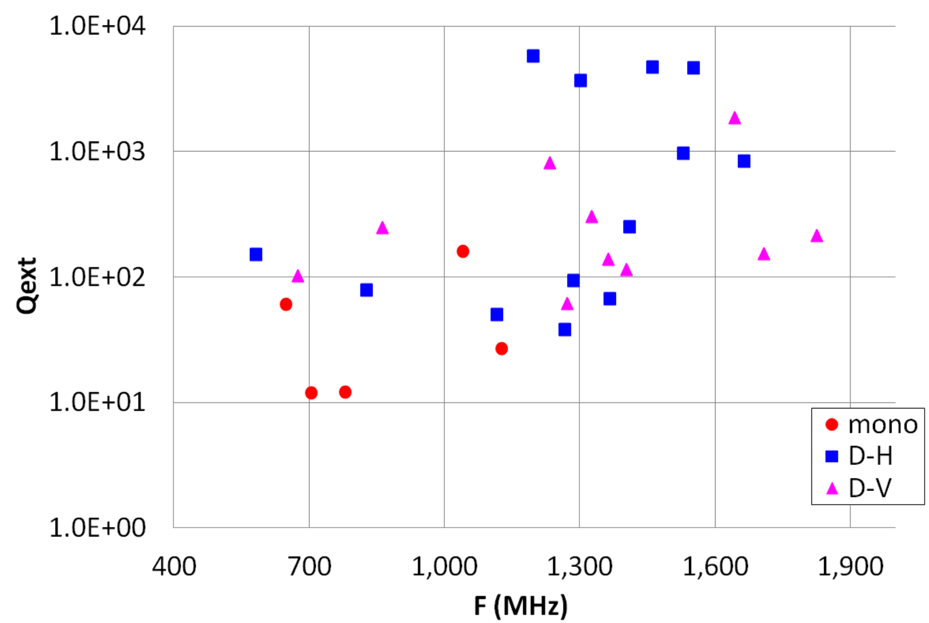
Effective Damping – Choice for Coupler?

- Both scheme could provide required damping
- These two plot just for demonstration, not for comparison. Neither was optimized
- Will work out steps for developing a coupler design for LHC









Conclusion

* ODU SLAC joint effort for LHC crab cavity development and modeling
* A compact cavity design is in good shape
* Working in progress on a common cavity design/optimization
  - Optimize cavity shape
  - Develop damping couplers
  - Utilize advanced simulation tools to help understand measurement data of prototype cavity