PARALLEL-BAR RIDGED WAVEGUIDE DESIGNS

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Acknowledgements

- Subashini de Silva (ODU)
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- Zenghai Li (SLAC)
- Lixin Ge (SLAC)

Parallel Bar Cavity Activities at ODU/JLab

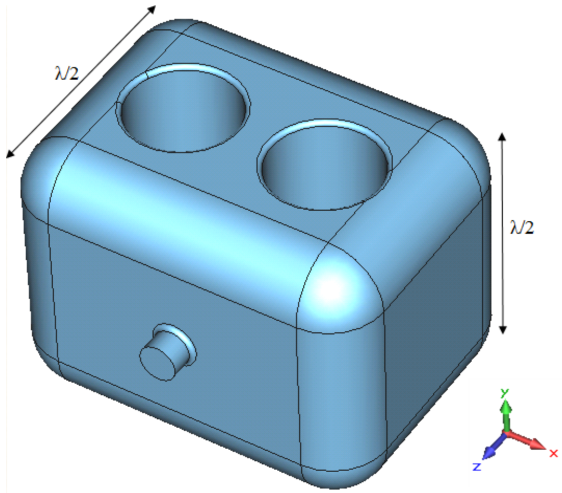
- **Deflecting Cavity**
  - Jefferson Lab 12 GeV Upgrade (499 MHz)
    (DOE-NP, ODU-Niowave P1 STTR completed)
  - *Project-X* (365.6 MHz)
    (ODU-Niowave P1 STTR completed)

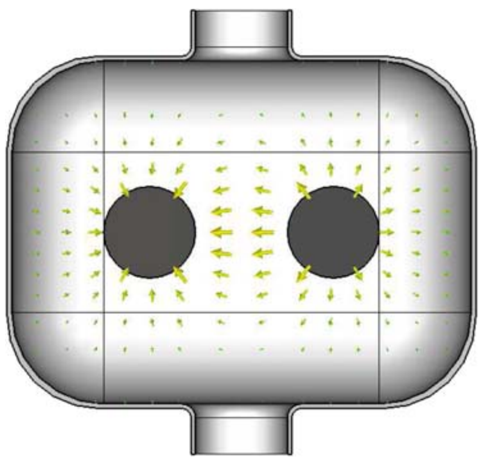
- **Crab Cavity**
  - LHC Luminosity Upgrade (400 MHz)
    (LARP, ODU-Niowave P2 STTR)
  - *Electron-ion Collider* (750 MHz)
    (ODU-Niowave P1 STTR completed, P2 funded)

Parallel-bar Cavity Properties

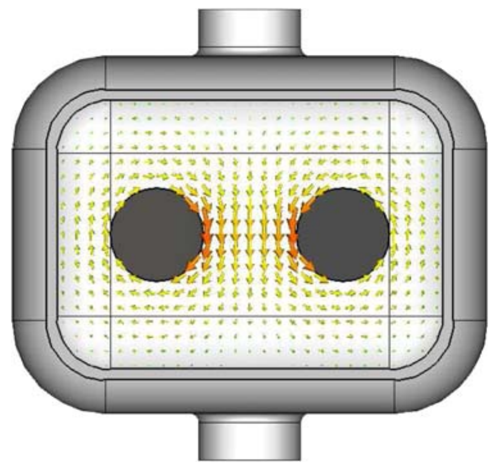
- Compact design
  - Supports low frequencies
- Fundamental deflecting/crabbing mode has the lowest frequency
  - No LOMs, no need for notch filter in HOM coupler
  - Nearest HOM widely separated (~ 1.5 fundamental)
- Low surface fields and high shunt impedance
- Good balance between peak surface electric and magnetic field
  - Criteria: E_p<35 MV/m, B_p<80 mT

Parallel-bar (ODU)



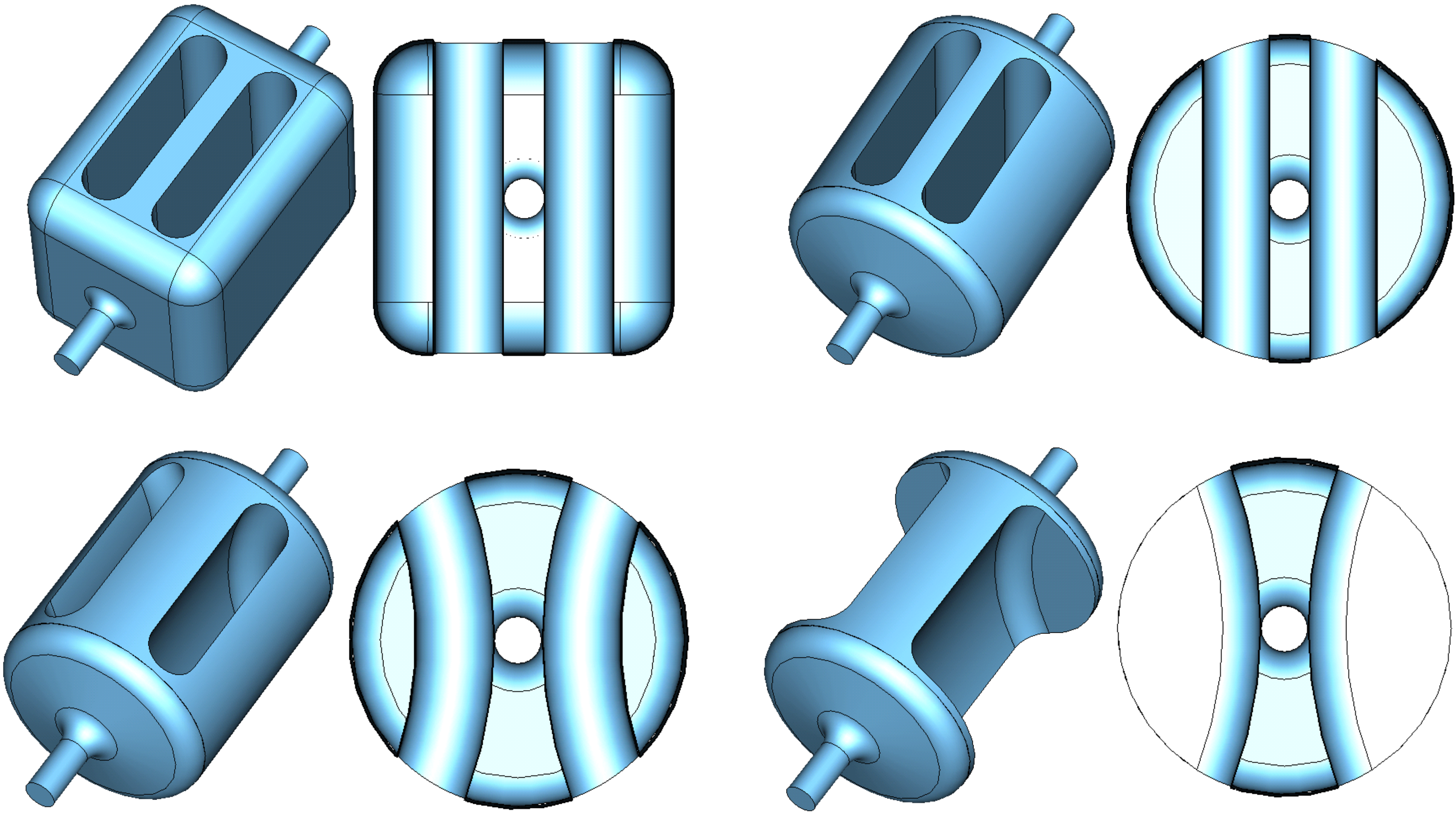


E field on mid plane (Along the beam line)

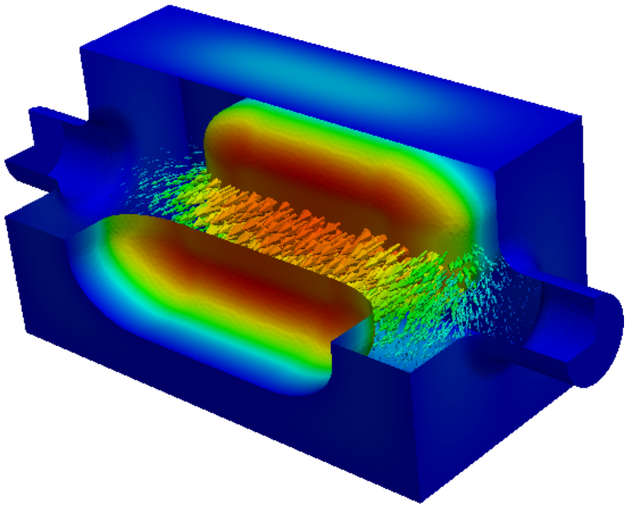


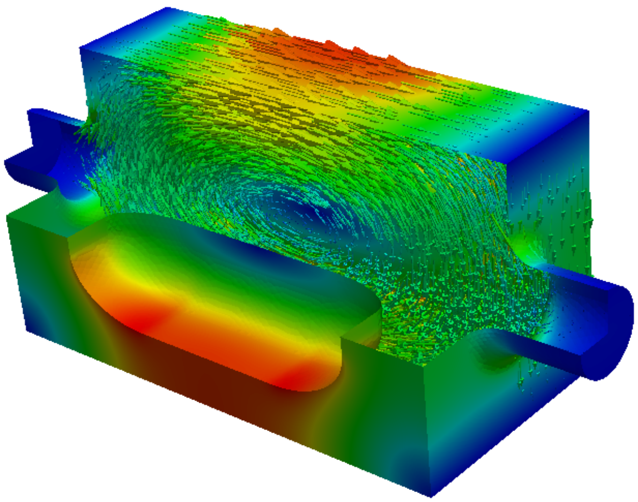
B field on top plane

Evolution of Parallel-bar Designs



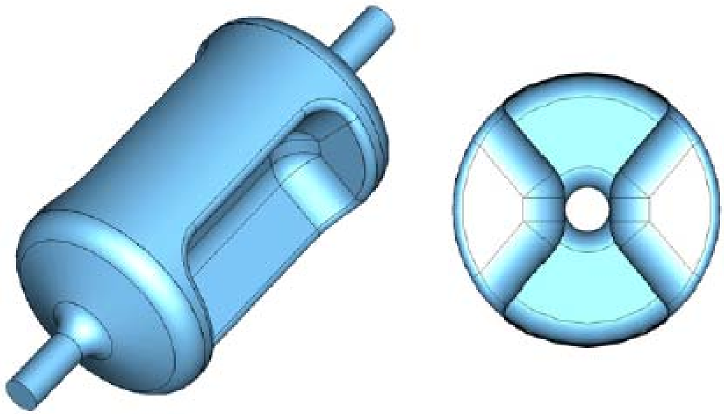
Ridged Waveguide (SLAC)



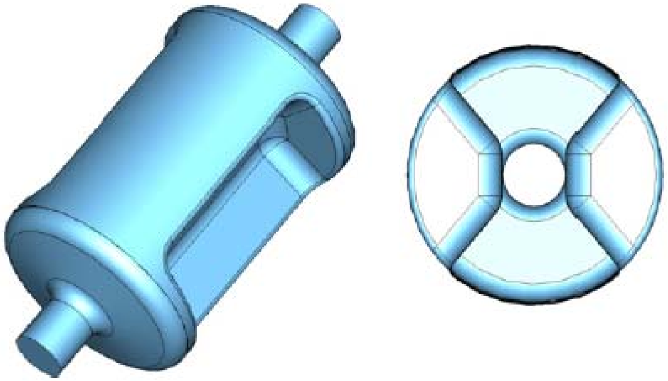


400 MHz LHC Crabbing System

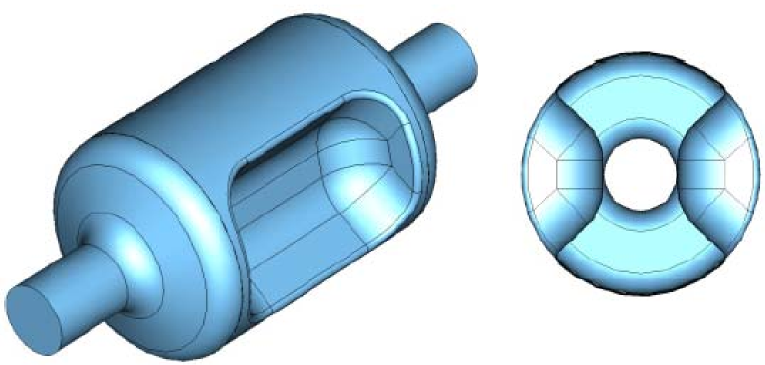
Parallel-Bar / Ridged Waveguide



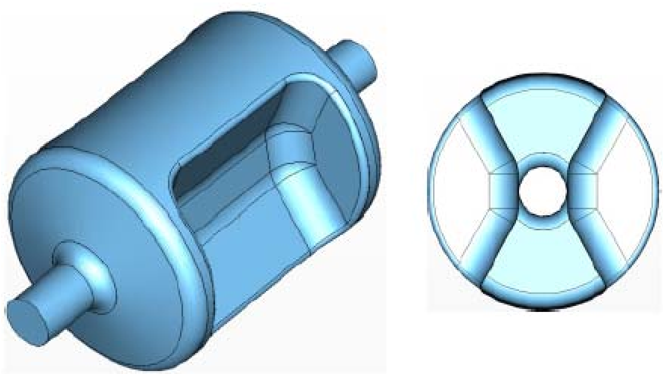
499 MHz JLab Upgrade Deflector
Fabrication under way



400 MHz LHC Crabbing System
Fabrication under way

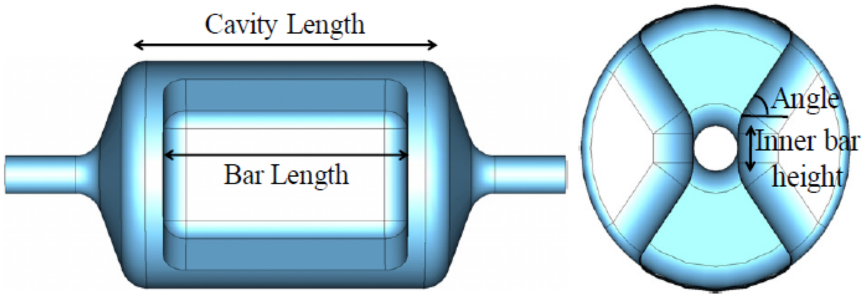


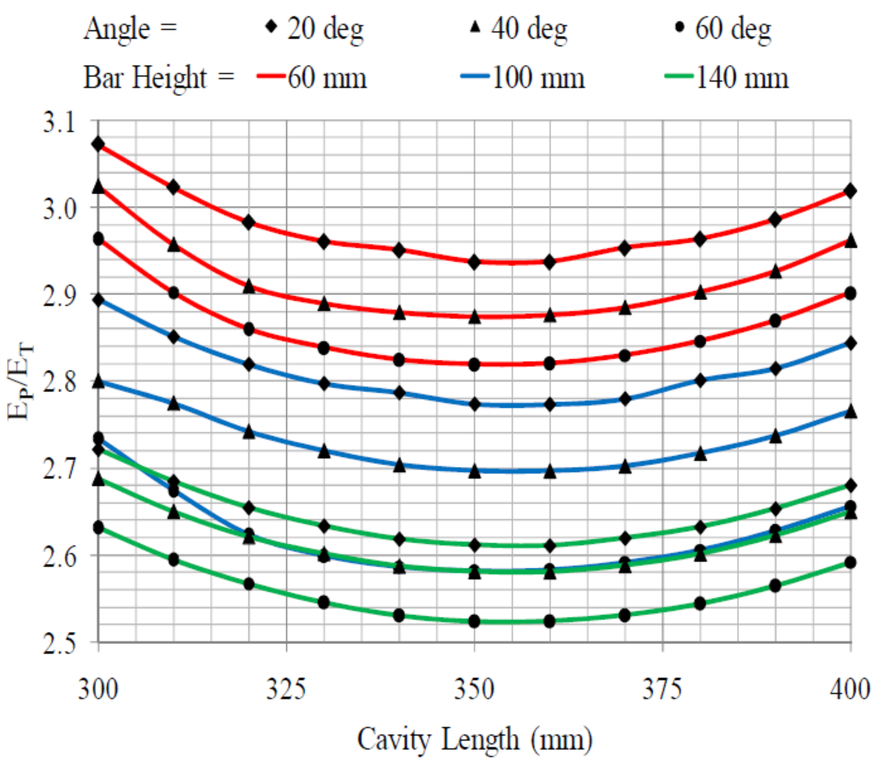
750 MHz ELIC Crabbing System
Final design underway

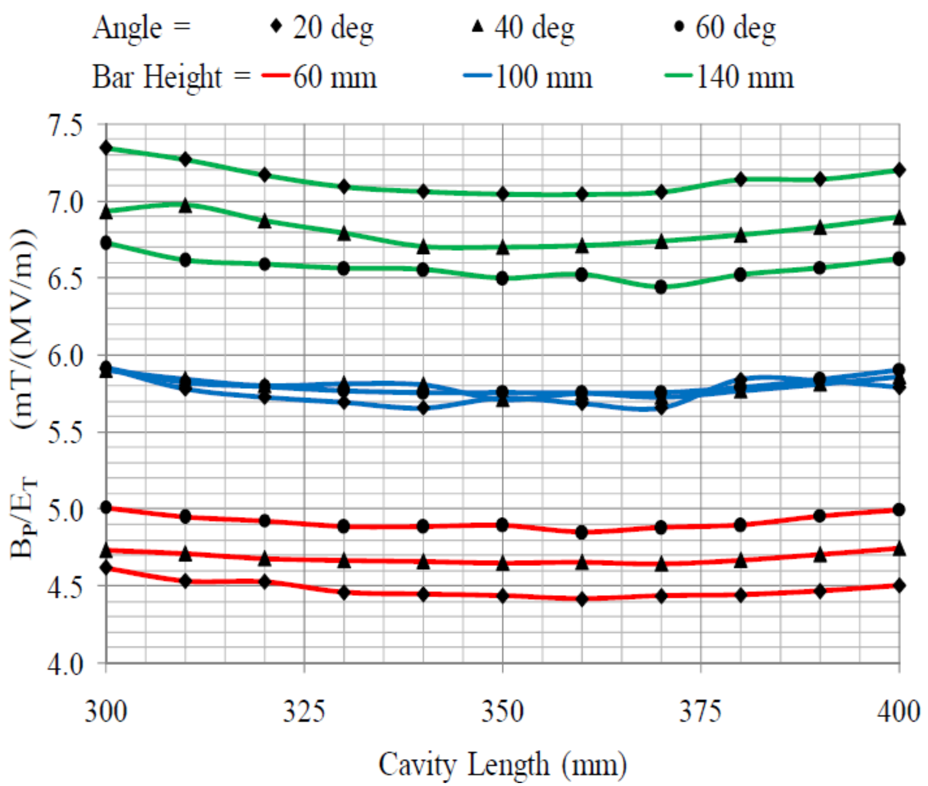


365 MHz Project X Deflector

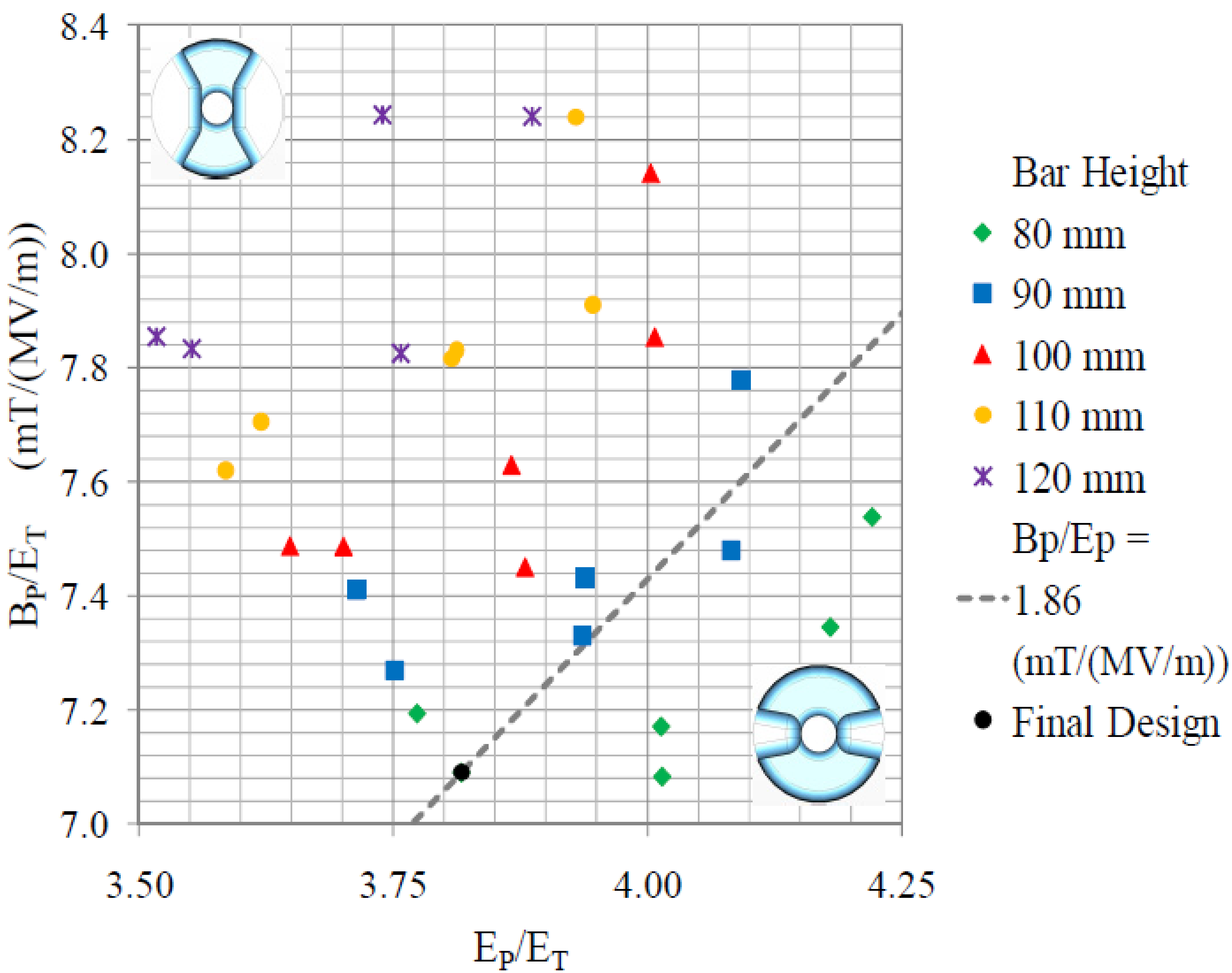
Design Optimization



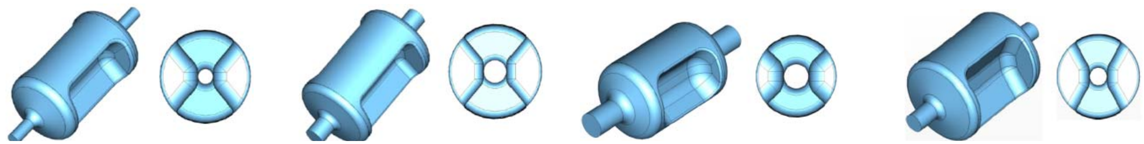




Design Optimization



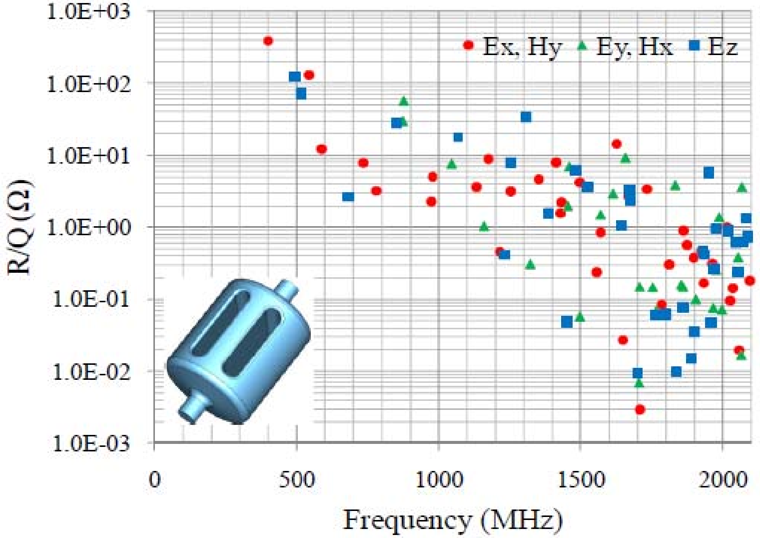
Parallel-Bar / Ridged Waveguide

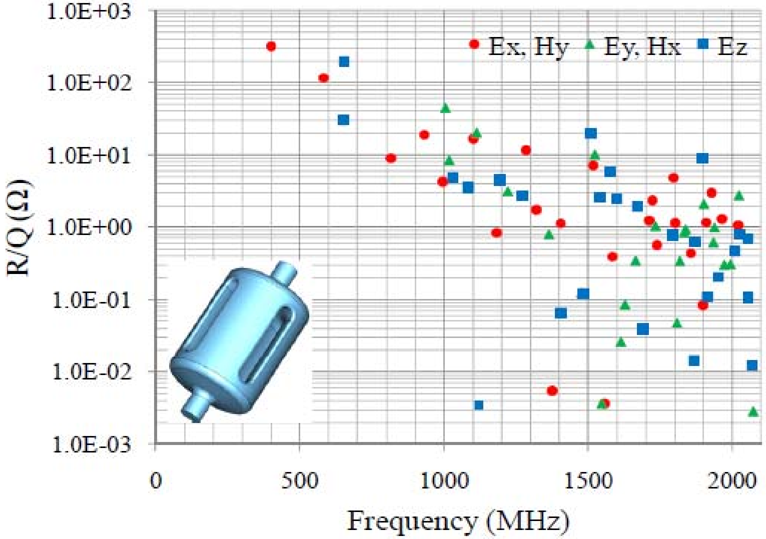


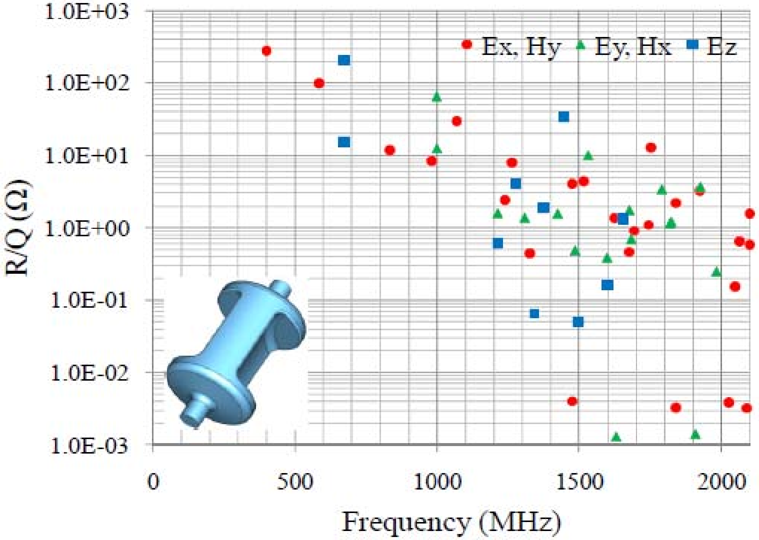
Parameter	499 MHz	400 MHz	750 MHz	365.6 MHz	Units
Frequency of π mode	499.0	400.0	750.0	365.625	MHz
λ/2 of π mode	300.4	375.0	199.9	410.0	mm
Frequency of 0 mode	1033.3	729.4	1314.4	659.7	MHz
Frequency of near neighbour mode	776.6	589.5	1143.1	571.9	MHz
Cavity length	440.0	527.2	300.0	530.0	mm
Cavity diameter	242.2	339.9	193.0	388.4	mm
Bars length	260.0	350.3	185.0	350.0	mm
Bars inner height	50.0	80.0	57.5	85.0	mm
Angle	50.0	50.0	36.2	55.0	deg
Aperture diameter	40.0	84.0	60.0	84.0	mm
Deflecting voltage (V_T^*)	0.3	0.375	0.2	0.41	MV
Peak electric field (E_P^*)	2.85	3.9	4.95	3.61	MV/m
Peak magnetic field (B_P^*)	4.43	7.13	8.74	6.41	mT
B_P^* / E_P^*	1.55	1.83	1.77	1.77	mT/(MV/m)
Energy content (U^*)	0.029	0.19	0.056	0.19	J
Geometrical factor	106.0	138.7	136.9	115.9	Ω
$[R/Q]_T$	977.4	287.2	152.9	378.5	Ω
$R_T R_S$	1.04×10^5	4.0×10^4	2.1×10^4	4.4×10^4	Ω^2

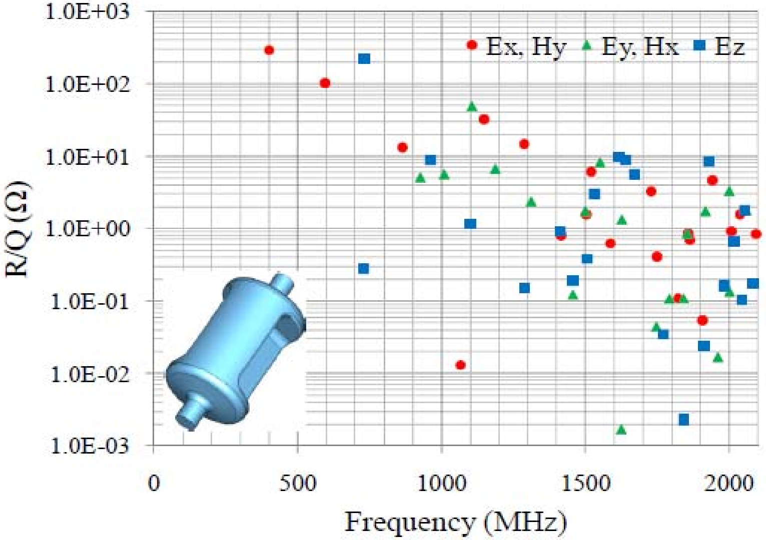
At $E_T^* = 1$ MV/m

HOM Properties of 400 MHz Cavity

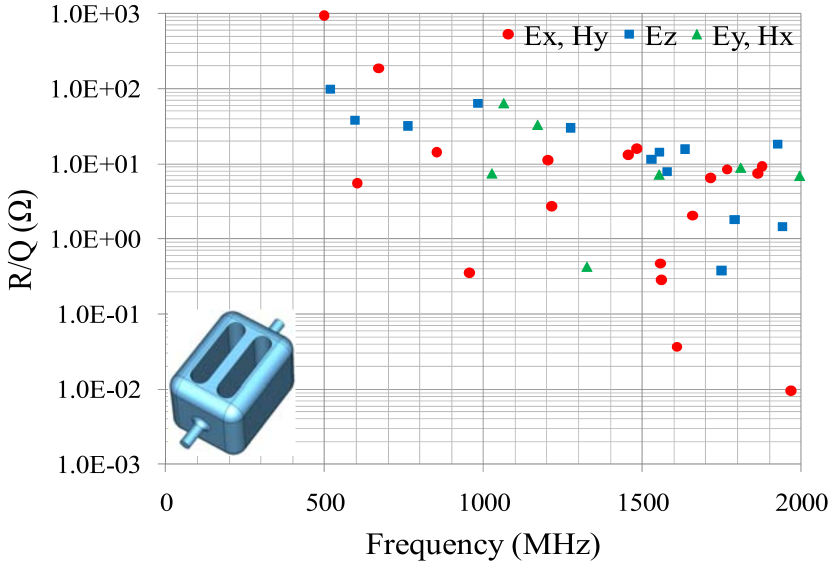


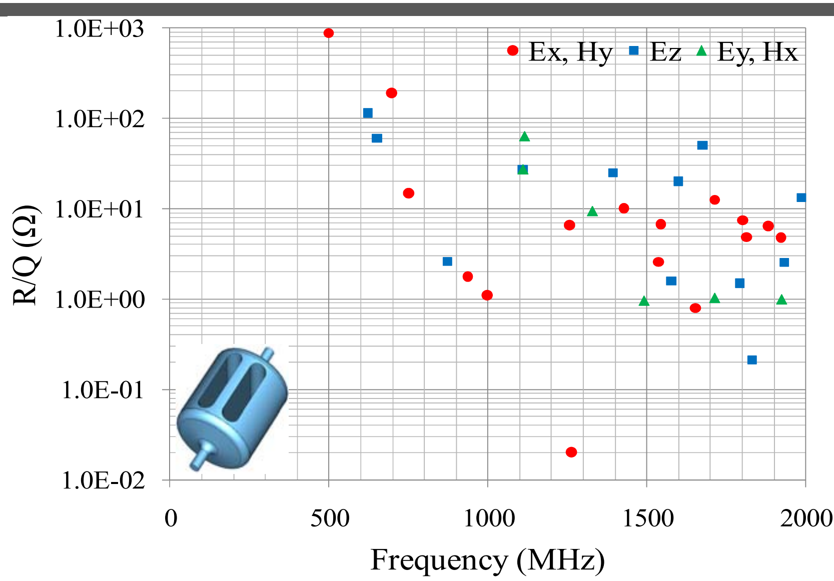


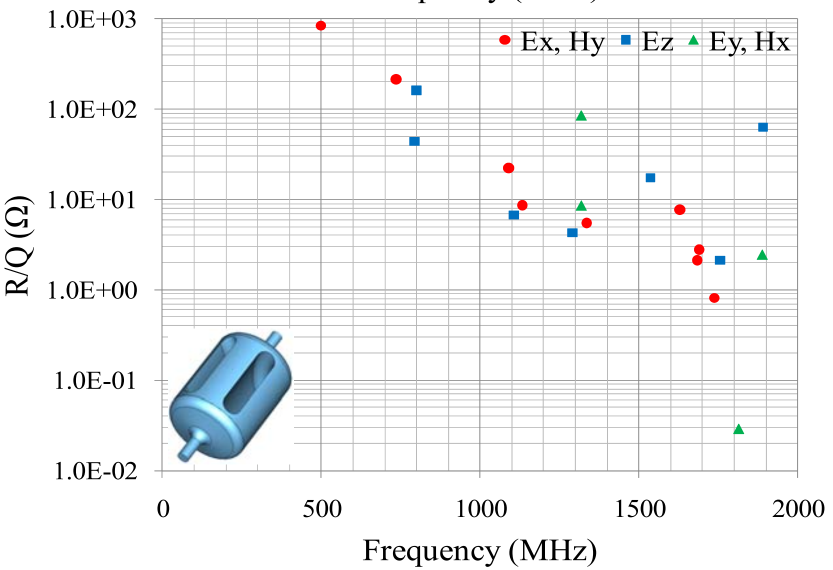


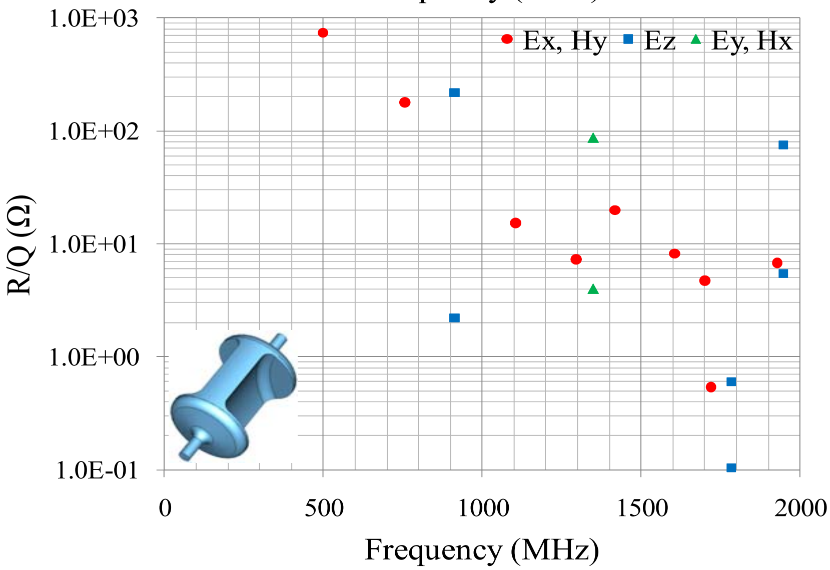


HOM Properties of 499 MHz Cavity

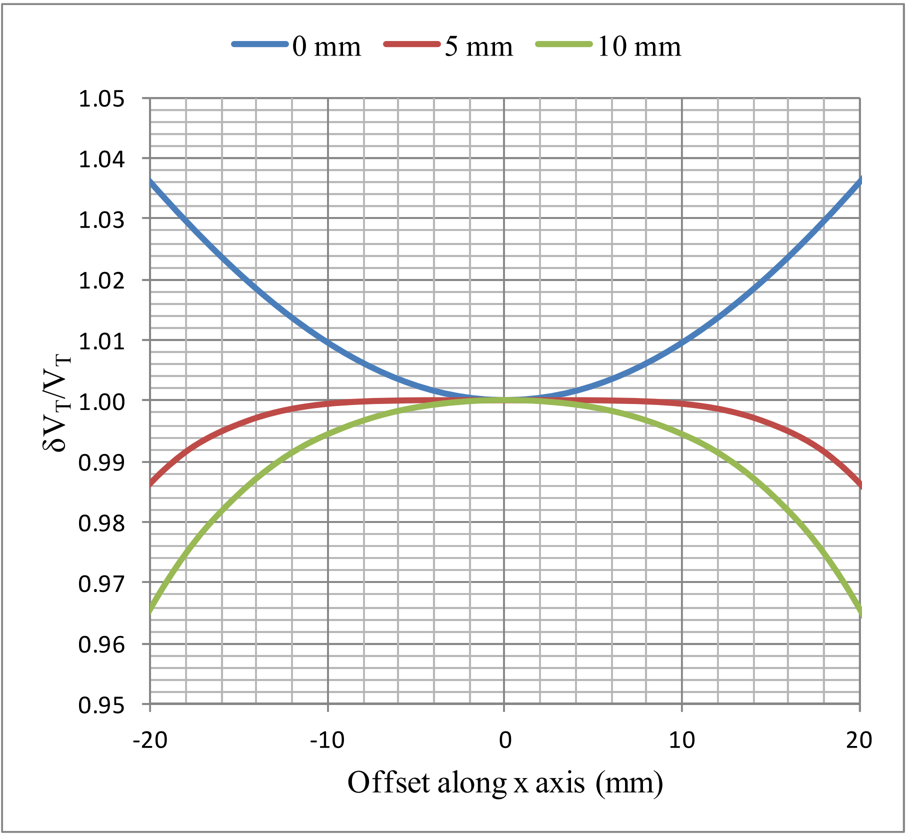


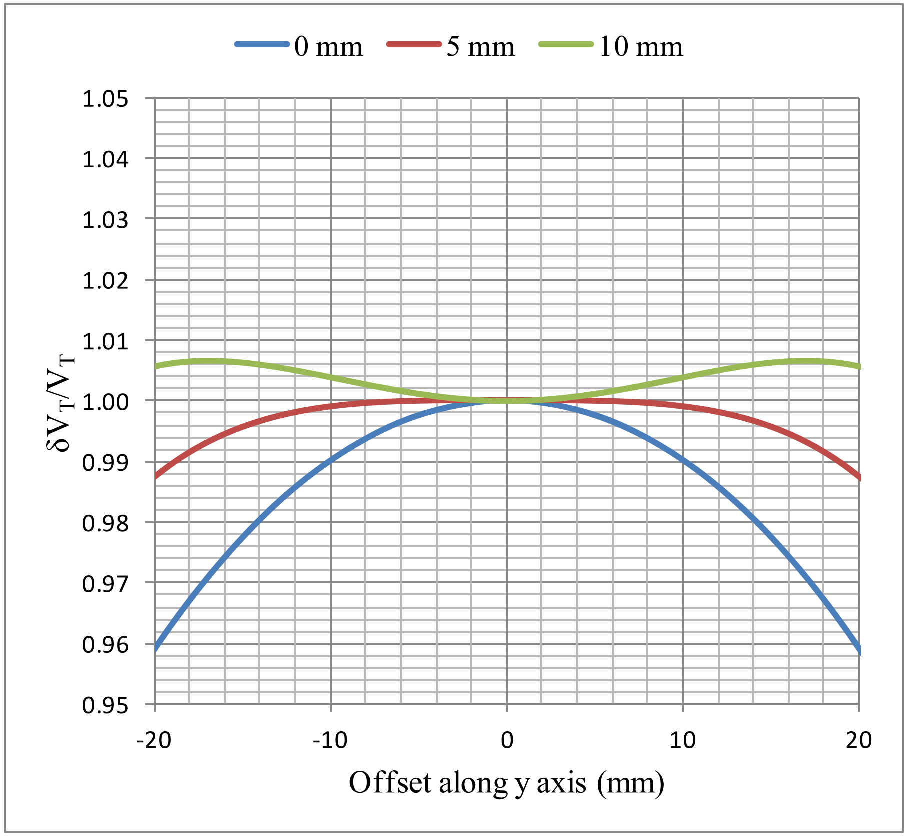




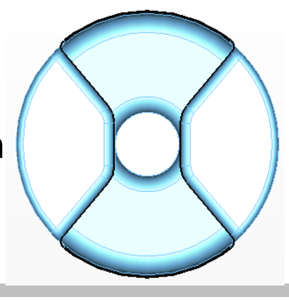


Non-linearities

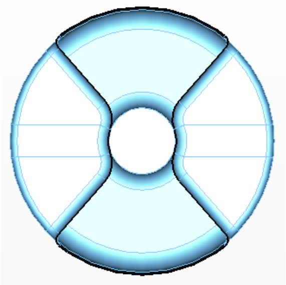




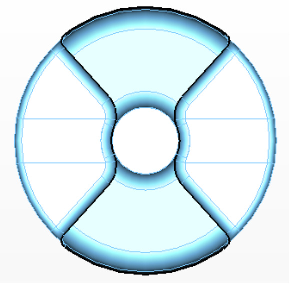
0 mm



5 mm



10 mm



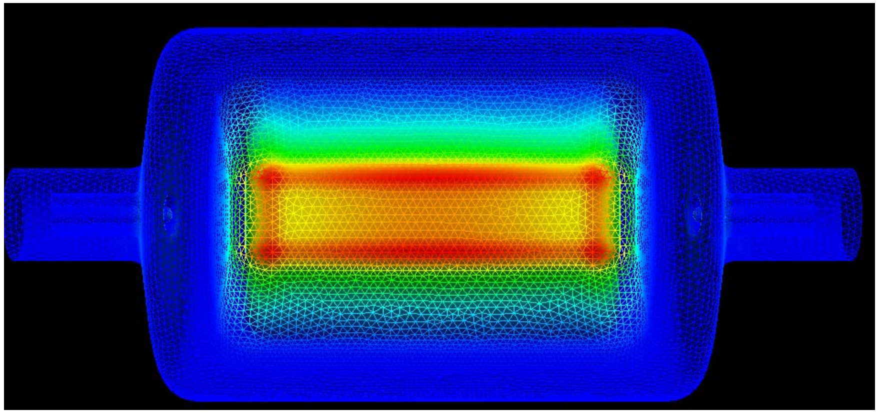
Multipacting Simulations

- Field level scan:
  - 0.045 MV – 5.5MV, interval 0.045 MV
- Initial Particles distributed on all exterior surface
- Each field level ran 50 RF cycles.

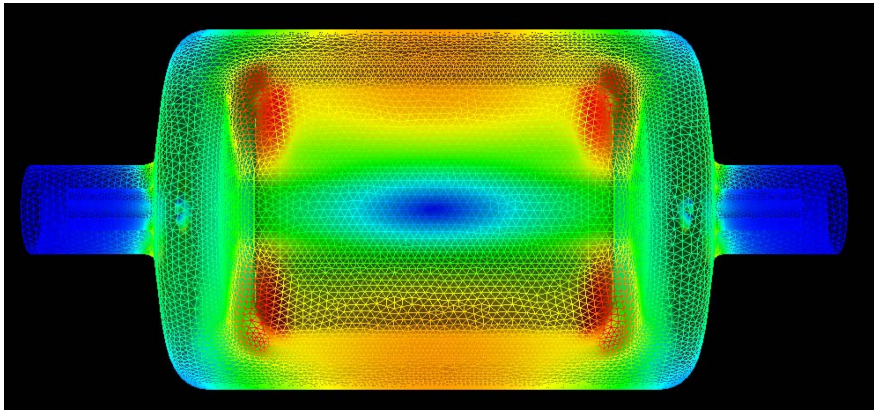
Model Mesh & Fields

- Frequency:400.06686MHz
- 690k tetrahedron mesh

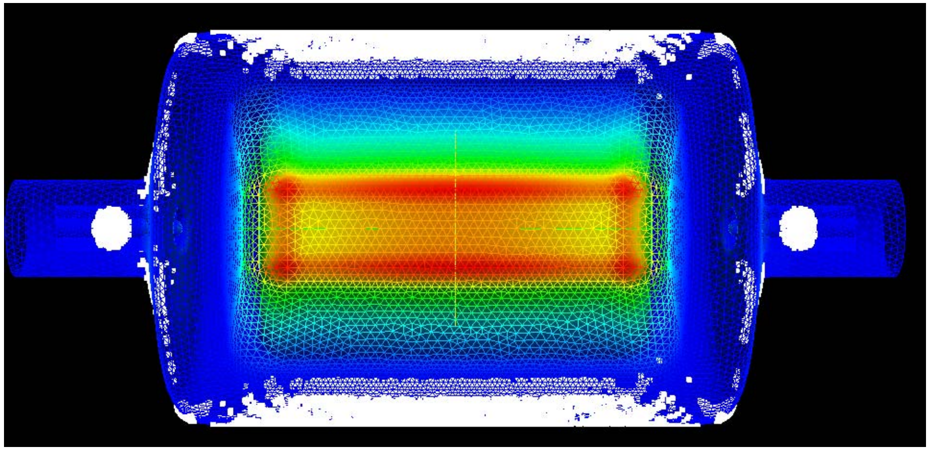
E Field magnitude

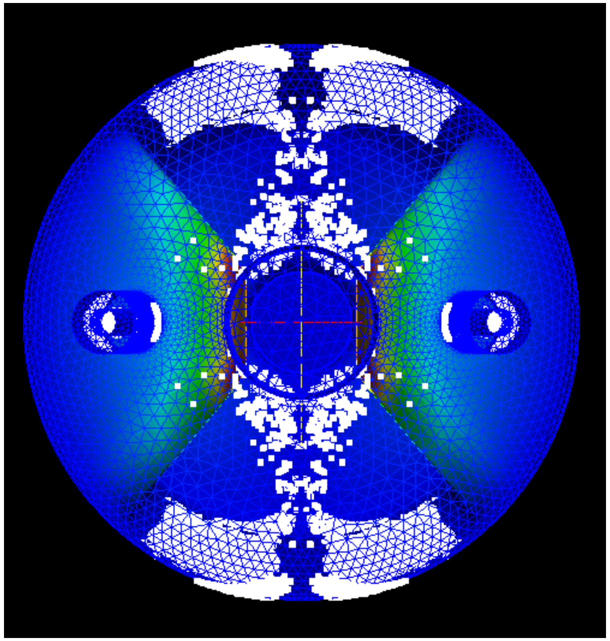


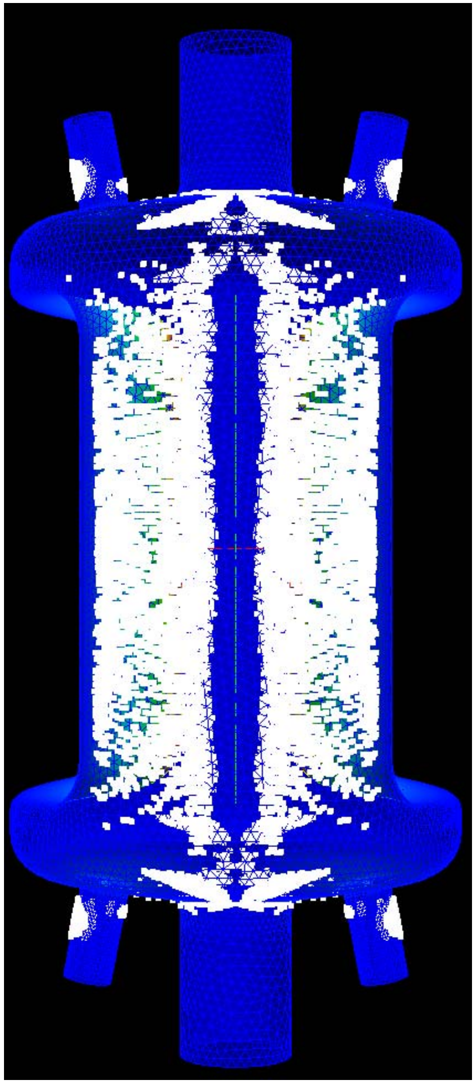
B Field magnitude



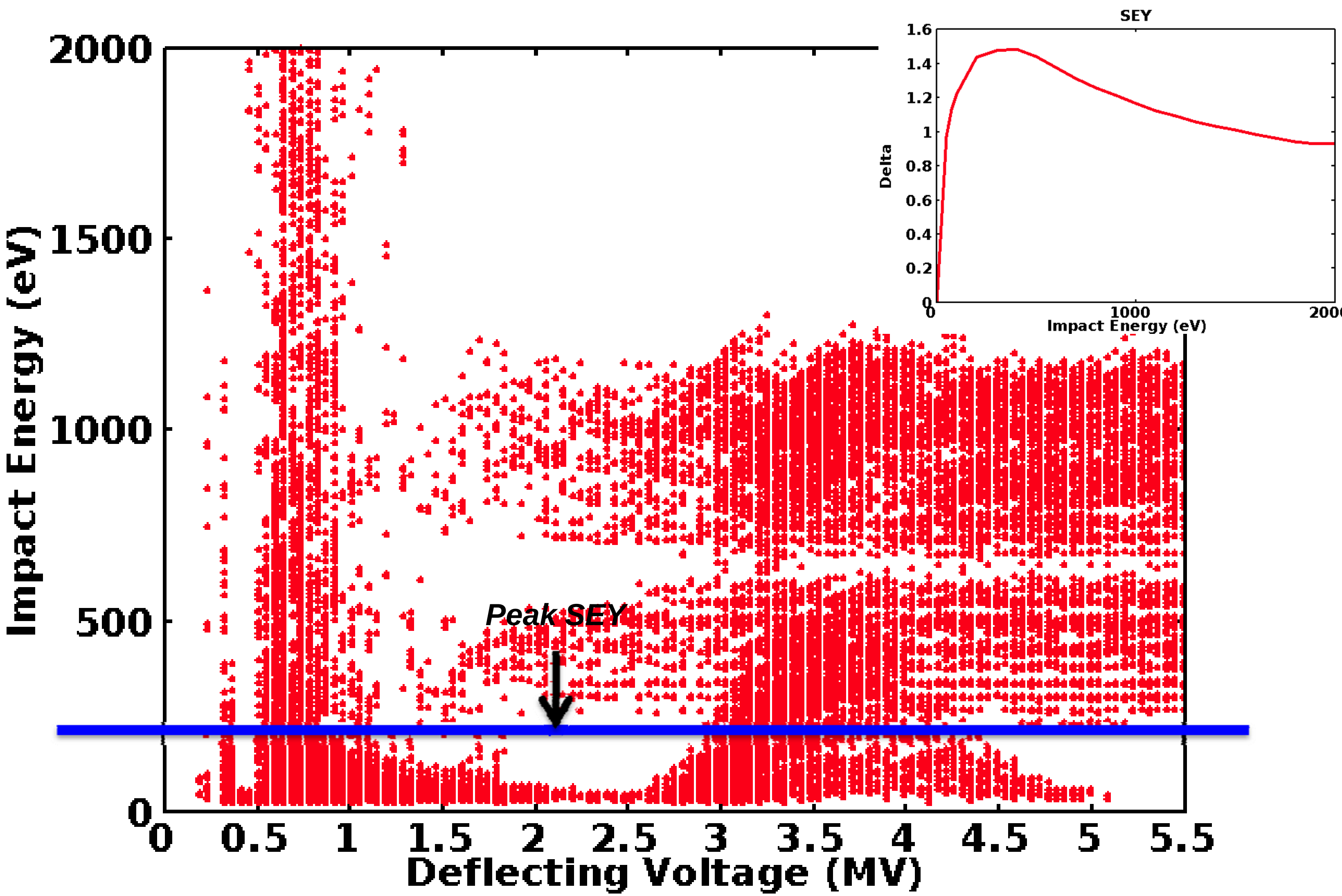
Resonant Particles Distribution



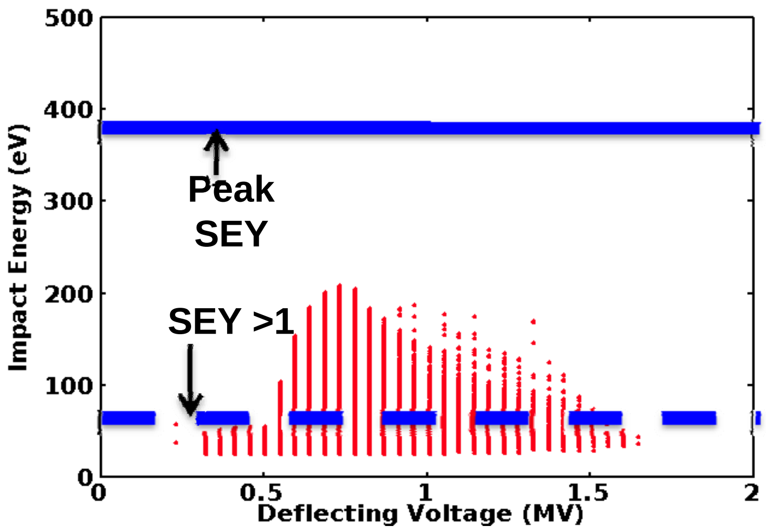


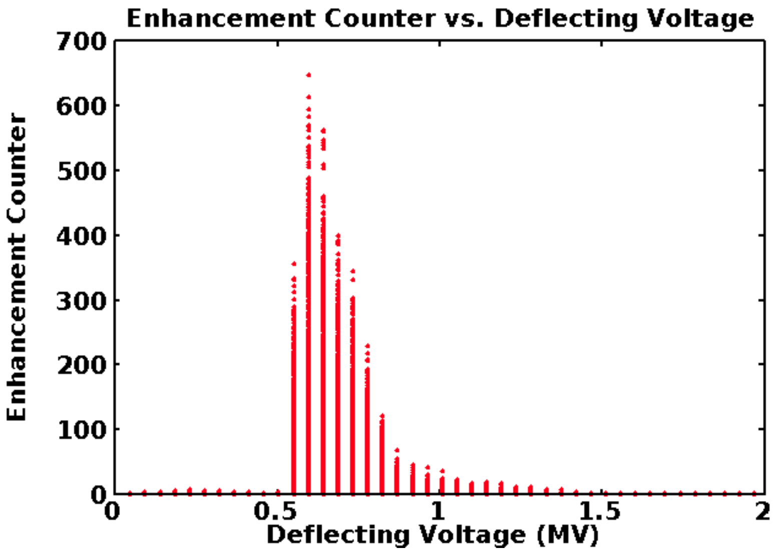


Resonant Particles Distribution



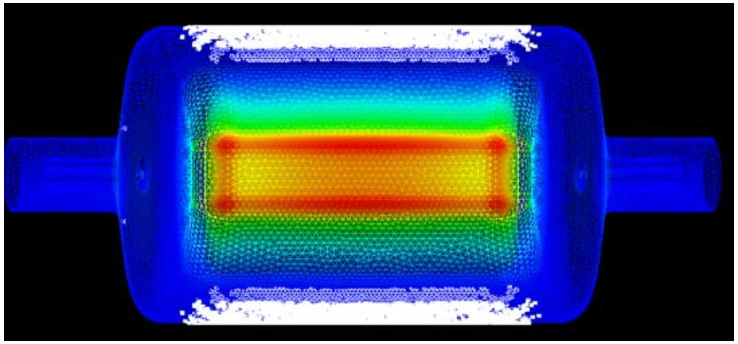
Resonant Particles in Cavity



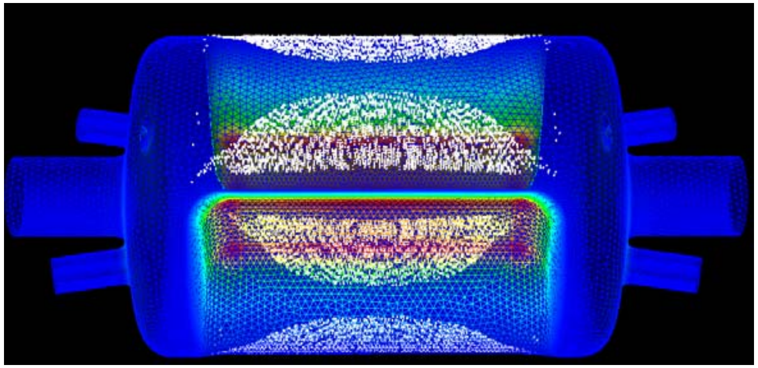


- One point first order
- Impact energy below the peak value, 400eV.
- Large enhancement counter region: 0.6MV ~1.0MV

Resonant Particles Distribution at all field levels

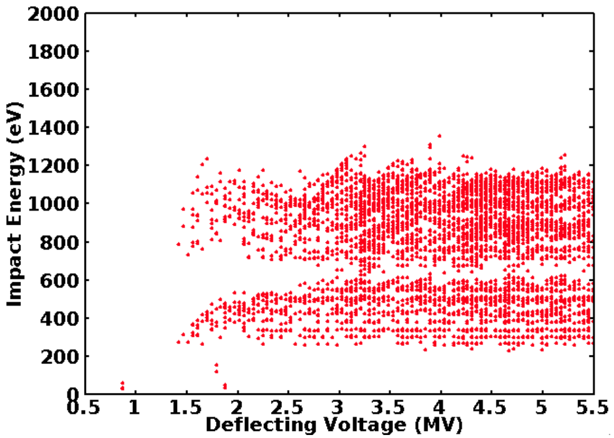


Resonant Particles Distribution at 0.6MV

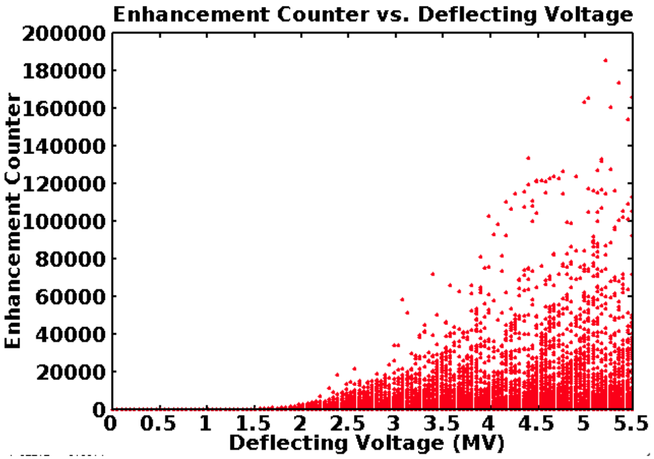


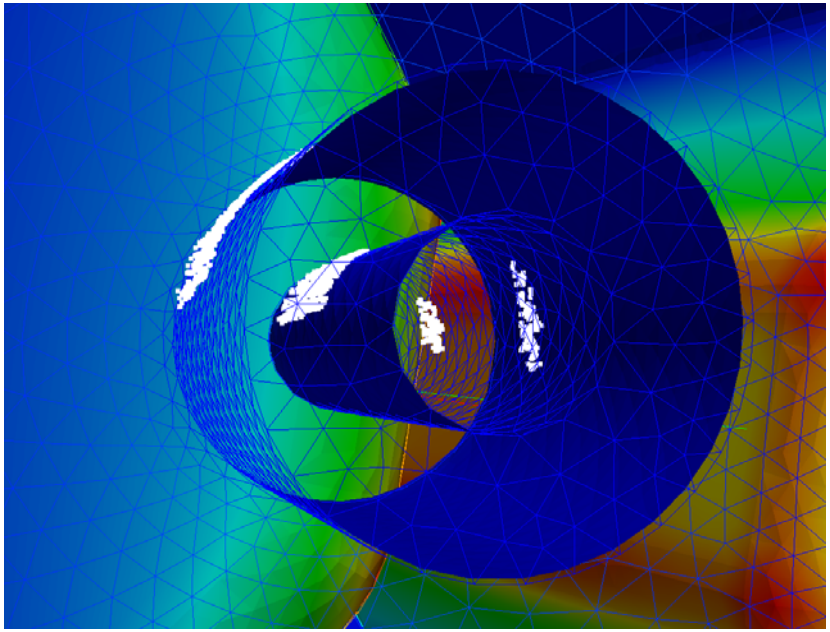
Resonant Particles in Coupler Region

Deflecting Voltage vs. Impact Energy for resonant particles



Deflecting Voltage vs. maximum enhancement counters for all particles in 50 RF cycles.

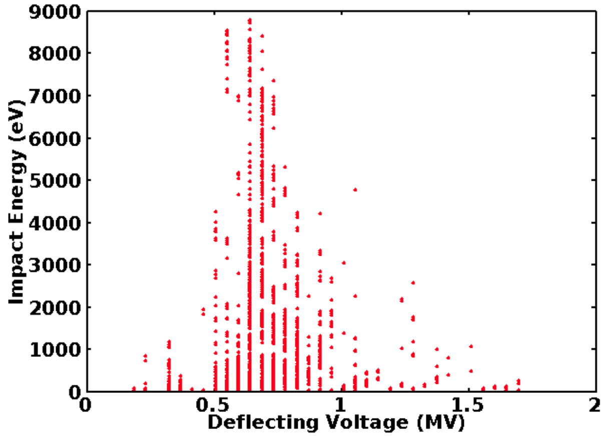




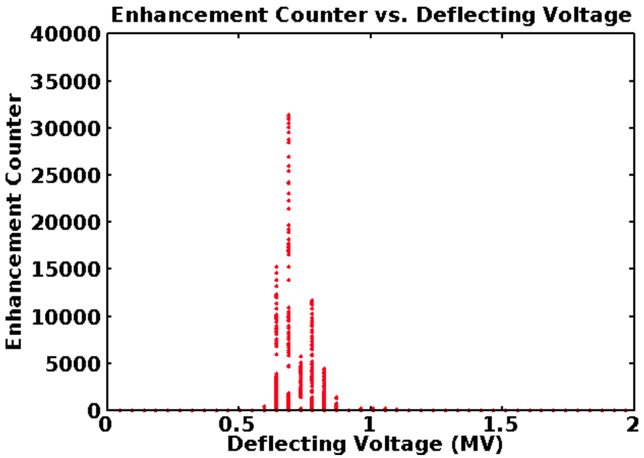
- Two points (inner and outer conductors) first order
- Impact energies are lower on inner conductor than those on outer conductor
- Enhancement counter reached 10^4

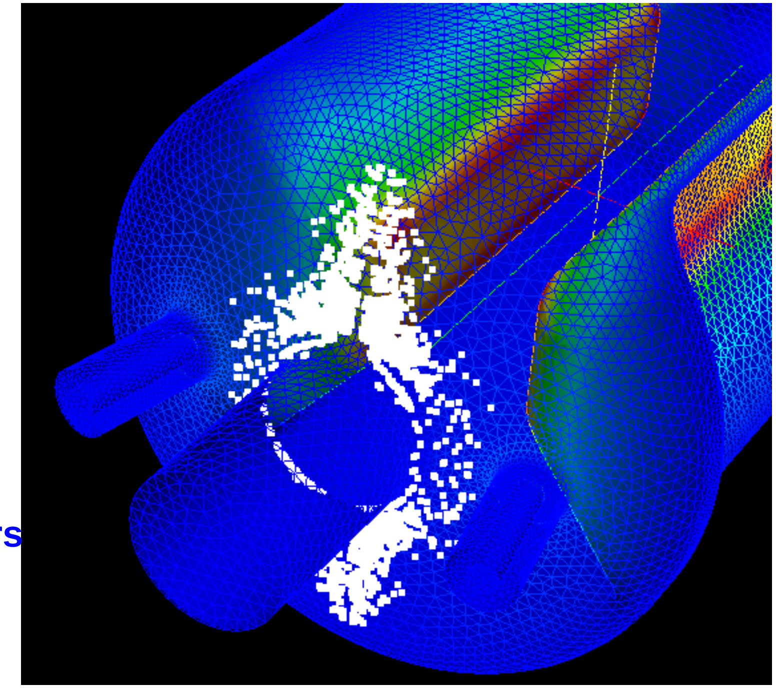
Resonant Particles in Beam Port Region

Deflecting Voltage vs. Impact Energy for resonant particles



Deflecting Voltage vs. maximum enhancement counters for all particles in 50 RF cycles.

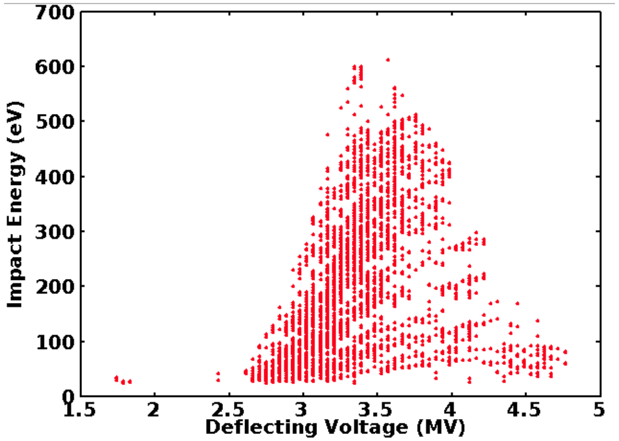




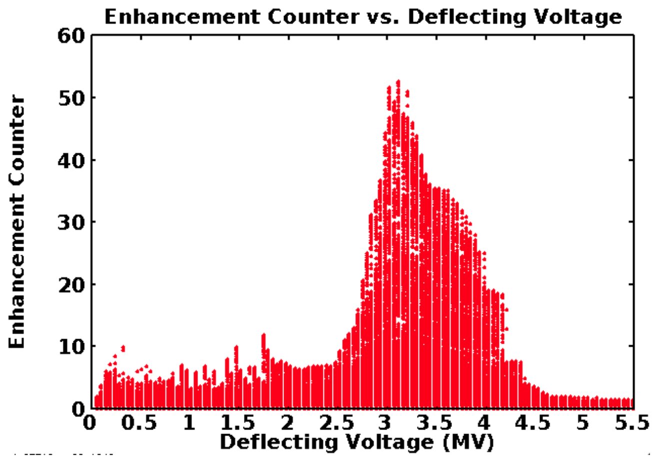
- One Point First Order resonant particles
- Peak enhancement happens between 0.65 MV and 0.85 MV

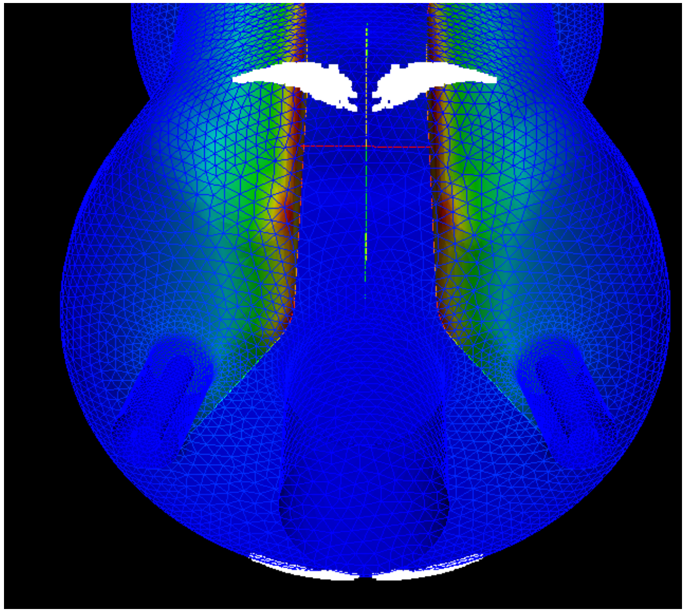
Resonant Particles in High B Field Region

Deflecting Voltage vs. Impact Energy for resonant particles



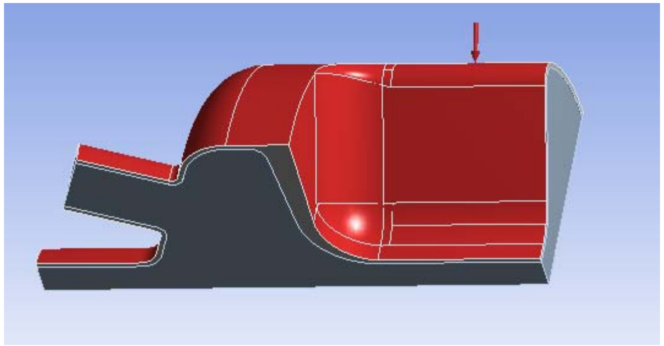
Deflecting Voltage. maximum enhancement counters for all particles in 50 RF cycles.



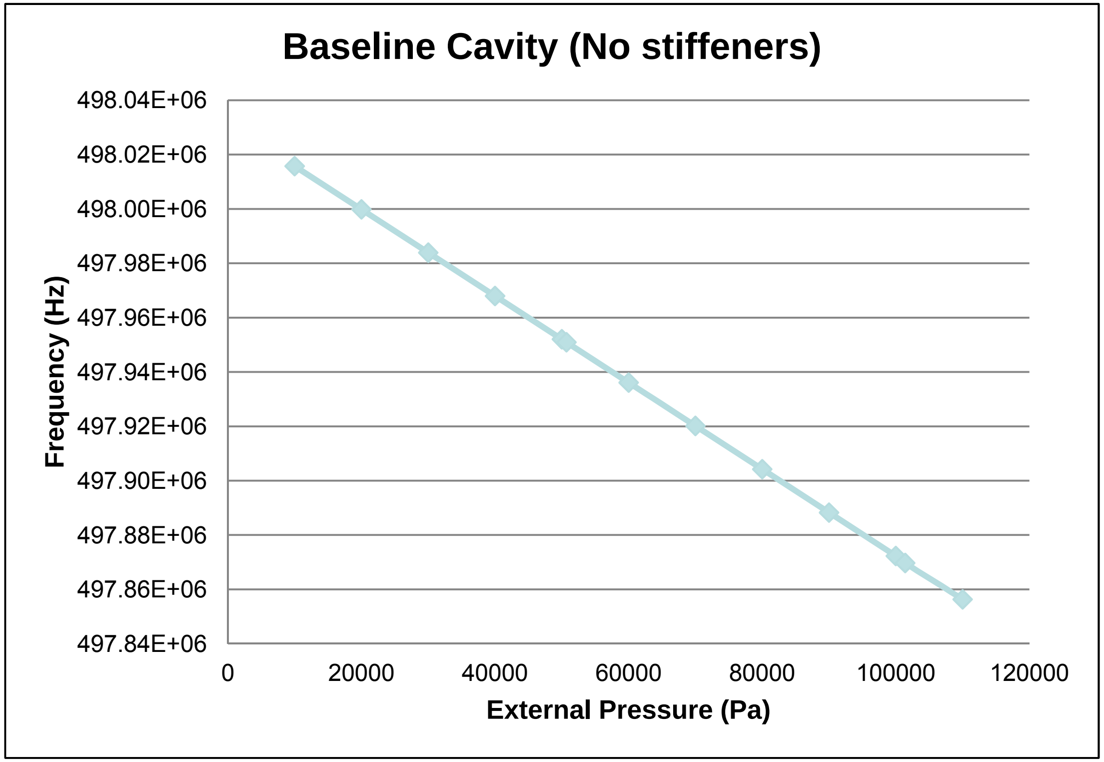


- **One Point First Order resonant particles.**
- **Peak enhancement counters are between 3 MV ~ 4 MV**
- **Peak value is around 50**

Pressure Sensitivity



- 1/8 model
- Fixed support at the beam pipe ends
- Varying external pressure up to 1 atm
- The inside vacuum is deforming by the cavity deformation
- The deformed vacuum is extracted and the frequency is solved by ANSYS high frequency eigen solver
- The frequency is not 499 MHz before the deformation because the cavity is oversized anticipating the thermal shrink at 2-4K



Pressure sensitivity -212 Hz/torr

Pressure Sensitivity

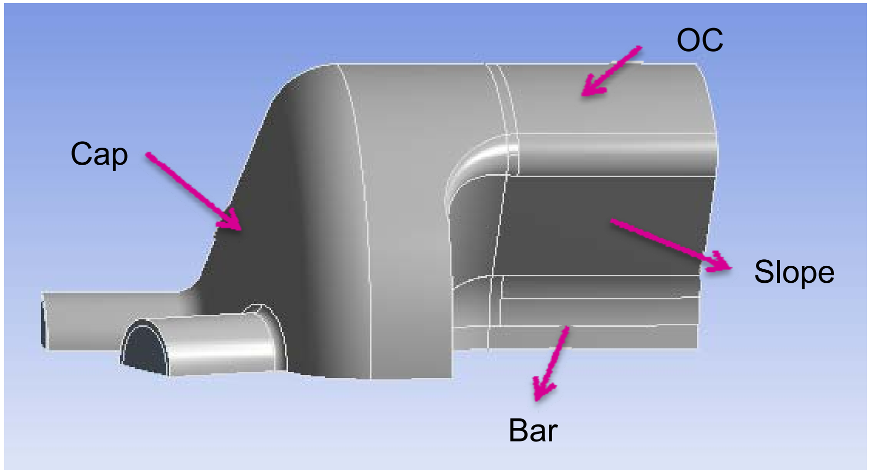
Effect of surface's deformation to the frequency shift

One surface is artificially fixed (no deformation) at a time and the vacuum load is applied.

Mechanical stability of the cap is most helpful to decrease the frequency change.

The 'Bar' needs to be constrained against the pressure.

The surfaces 'slope' and 'OC' seem to compensate each other. Constraining one against the other does not help.

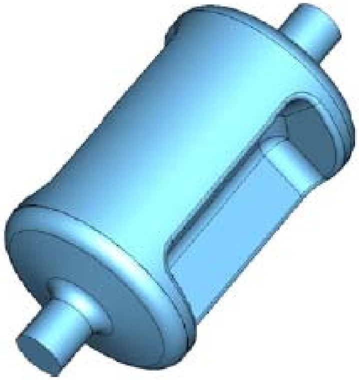


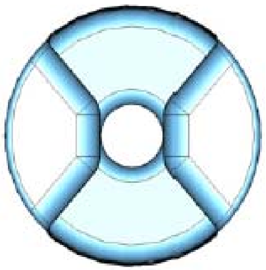
Fixed surface	F1 (Hz)	F2 (Hz)	F2-F1 (Hz)	Hz/Torr	Deformation (mm)			
					Bar	OC	Slope	Cap
Bar	498031682	498139282	107601	141	0	0.073	0.060	0.02
Cap	498031682	498026821	-4861	-6	0.0017	0.040	0.100	0
OC	498031682	497959878	-71804	-94	0.0028	0	0.100	0.02
Slope	498031682	498076554	44872	59	0.0036	0.045	0	0.02
Bar and Cap	498031682	498112353	80671	106	0	0.055	0.066	0
Cap and Slope	498031682	498064828	33146	44	0.0037	0.038	0	0

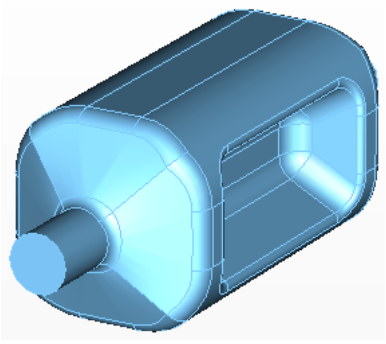
F1: Frequency before the deformation
F2: Frequency after the deformation

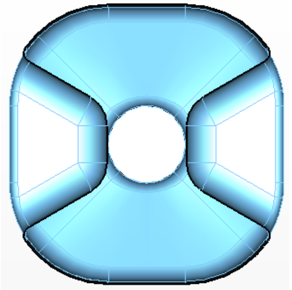
Cylindrical and “Square” Outer Conductor

Parameter	Rectangular Shaped	Cylindrical Shaped	Unit
Frequency of π mode	400.0	400.0	MHz
λ/2 of π mode	374.7	374.7	mm
Frequency of 0 mode	728.3	729.5	MHz
Nearest mode to π mode	584.1	593.4	MHz
Cavity reference length	597.1	520.0	mm
Cavity diameter	295.0	339.8	mm
Bars length	350.3	345.0	mm
Bars height	80.0	80.0	mm
Angle	30.0	50.0	Deg
Aperture diameter	84.0	84.0	mm
Deflecting voltage (V_T^*)	0.375	0.375	MV
Peak electric field (E_P^*)	4.09	3.82	MV/m
Peak magnetic field (B_P^*)	6.99	7.09	mT
B_P^* / E_P^*	1.71	1.86	mT / (MV/m)
Geometrical factor ($G = QR_S$)	147.2	119.7	Ω
$[R/Q]_T$	311.3	312.2	Ω
$R_T R_S$	4.6 10^4	3.7 10^4	$Ω^2$
At E_T^* = 1 MV/m			

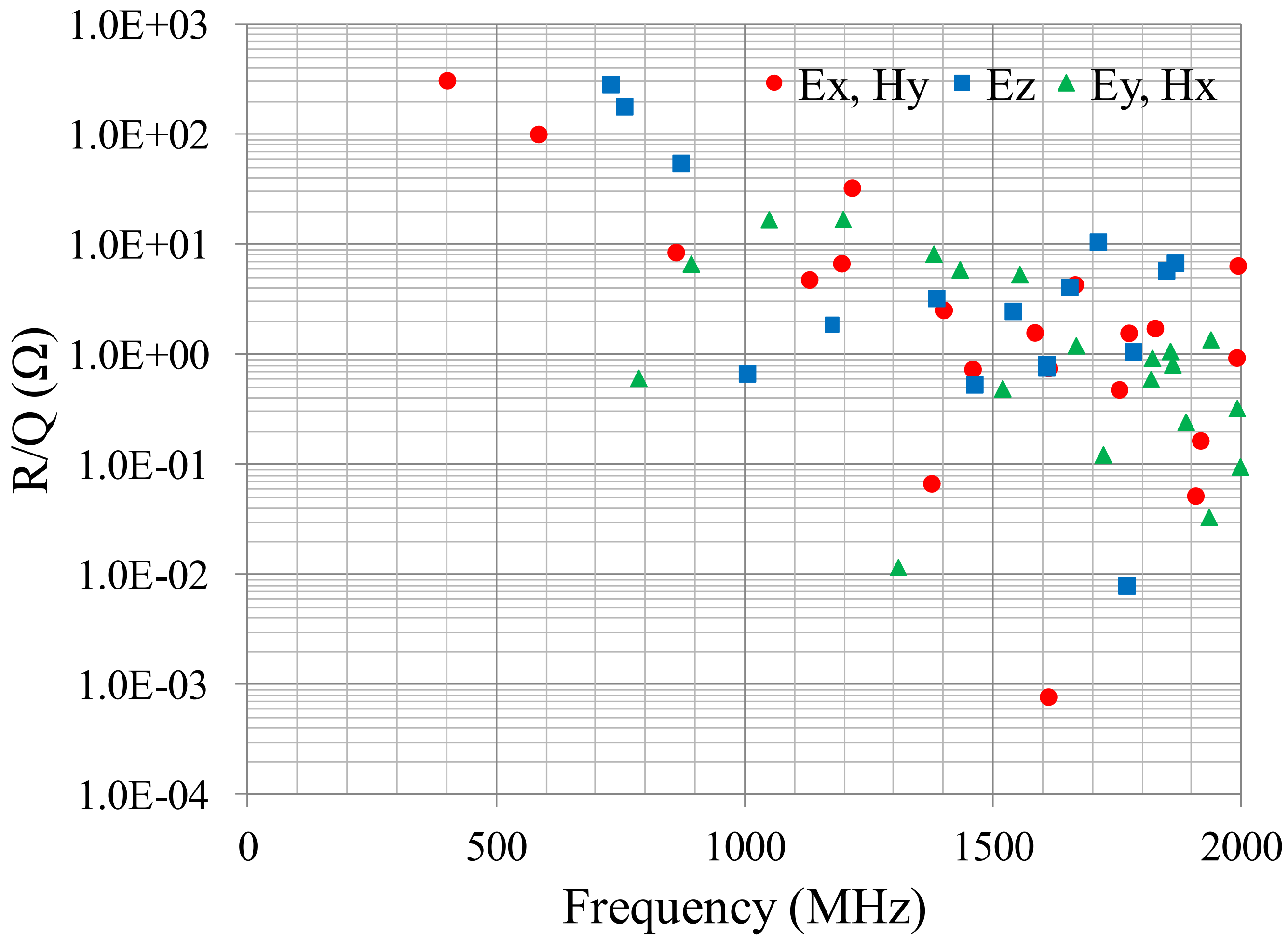








Higher Order Modes "Square Cavity"



Some Numbers

- Surface resistance of Nb at 400 MHz
  - 4.5K: 95 nΩ→105 nΩ
  - 2K: 1.3 nΩ→10 nΩ
- Power Dissipation:

$$P = \underbrace{\frac{V^2}{(QR_s)(R/Q)}}_{4\times10^4\ \Omega^2} R_s$$

  - At 3 MV
    - Ep=32.5 MV/m
    - Bp=56 mT
    - P= 2.25W per cavity at 2K and 22.5W at 4.5K
  - At 5 MV
    - Ep=54.5 MV/m
    - Bp=93 mT
    - P= 6.25W per cavity at 2K and 62.5W at 4.5K

Next Steps

- Test “proof of concept” cavity
- Design of “beam line suitable” cavity and ancillary
  - Appropriate dimensions
  - Use genetic algorithm
  - Multipacting
  - Higher order mode couplers
  - Fundamental power coupler
  - Frequency tuners (coarse and fine)
  - LLRF and microphonics
  - Helium tank
  - Cryostat

Parting Words

- ODU-SLAC collaboration in place and is fruitful
  - Multipacting analysis
  - HOM analysis
  - Coupler design

- We are ready to design and develop next cavity

- Need for a list of parameters and specifications