COMPACT TEM-TYPE CAVITIES FOR DEFLECTING AND CRABBING APPLICATIONS

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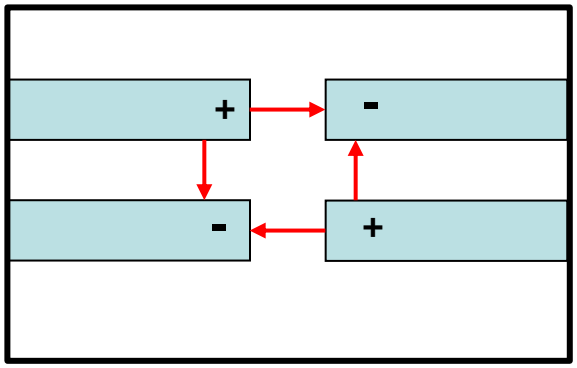
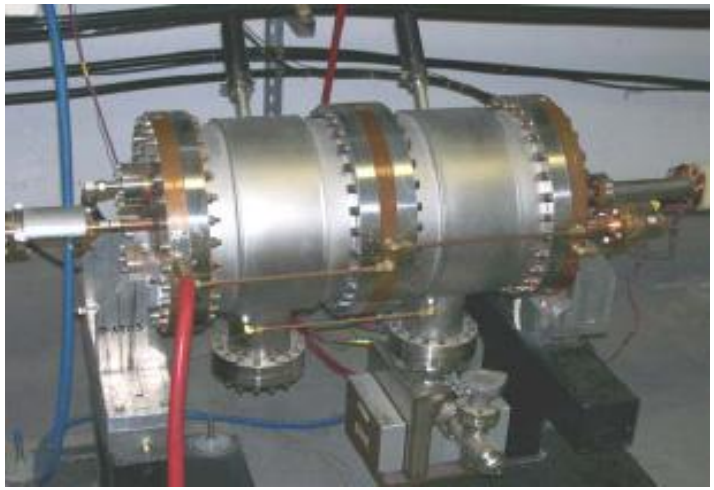
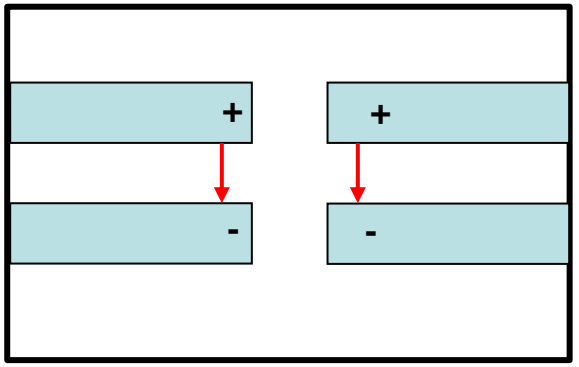
4-Rod Cavity

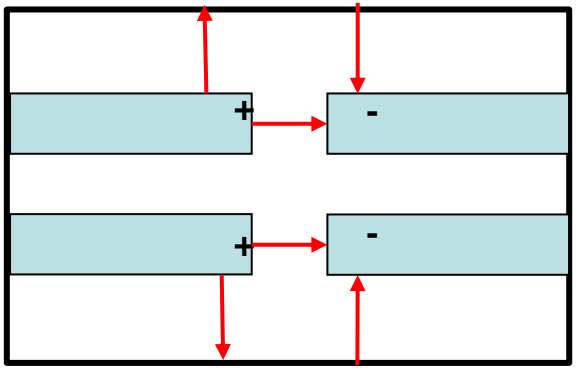


Fundamental deflecting mode

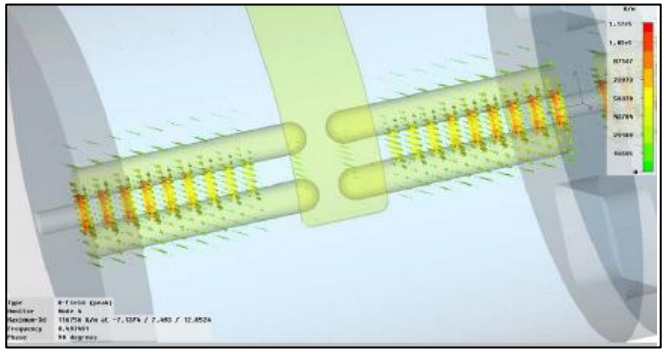
499 MHz NC separator at JLab

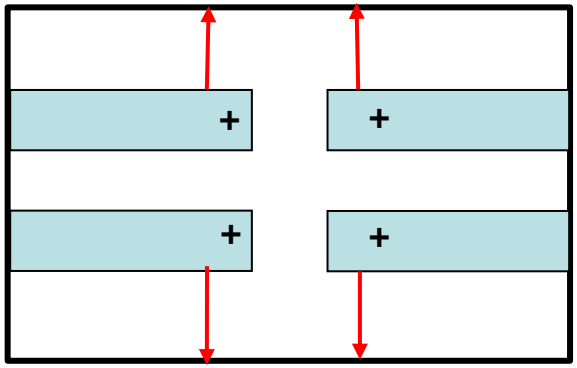




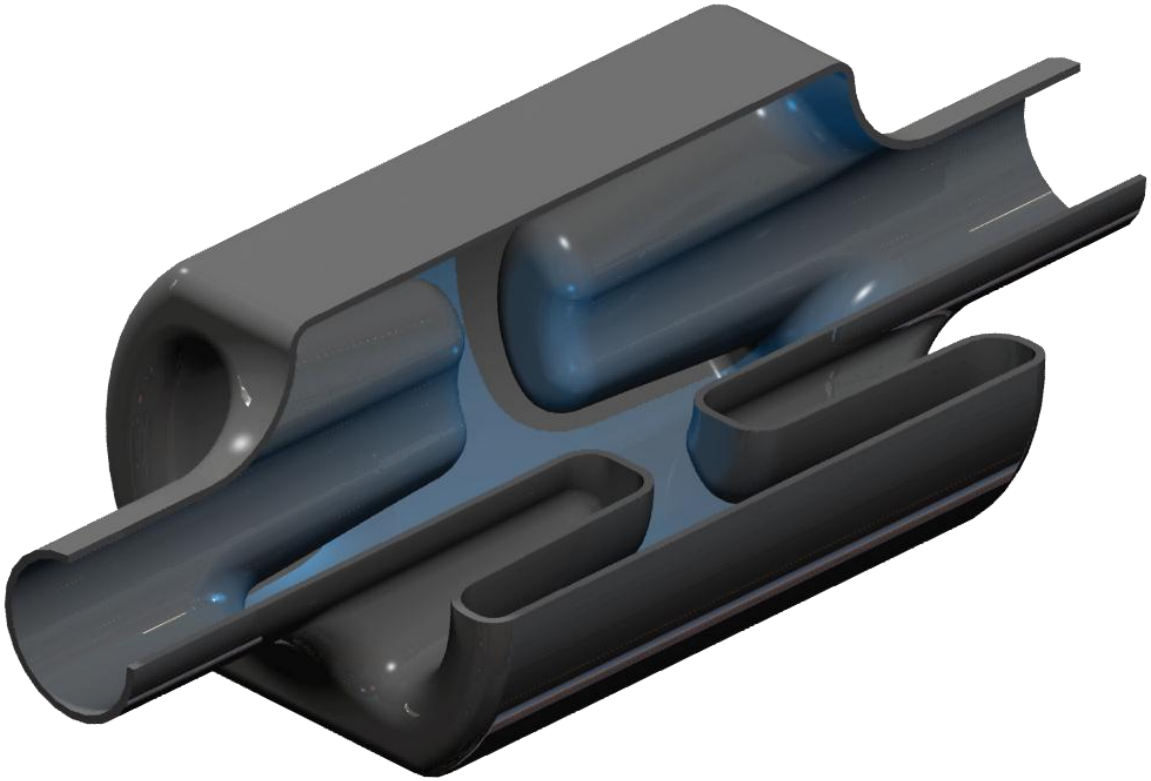


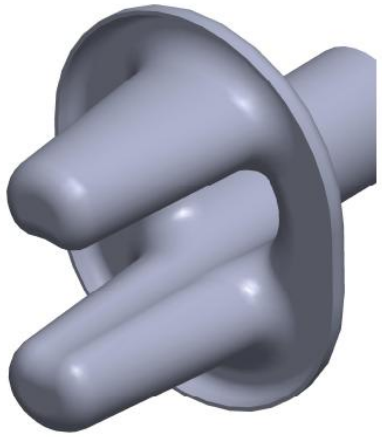
accelerating lower order mode

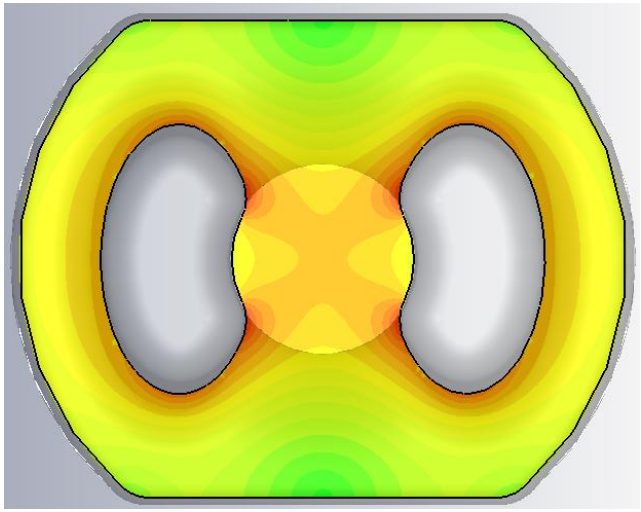




4-Rod Cavity (U. Lancaster/JLab)

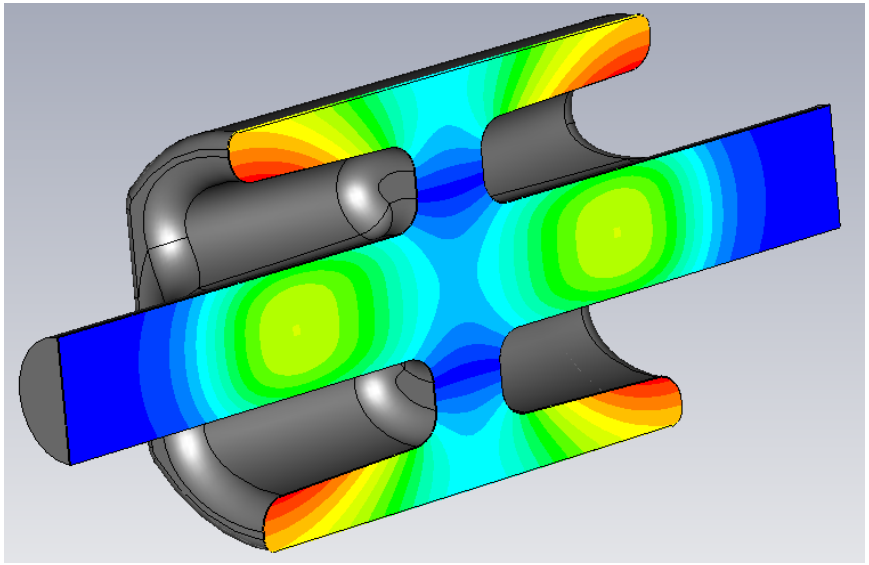




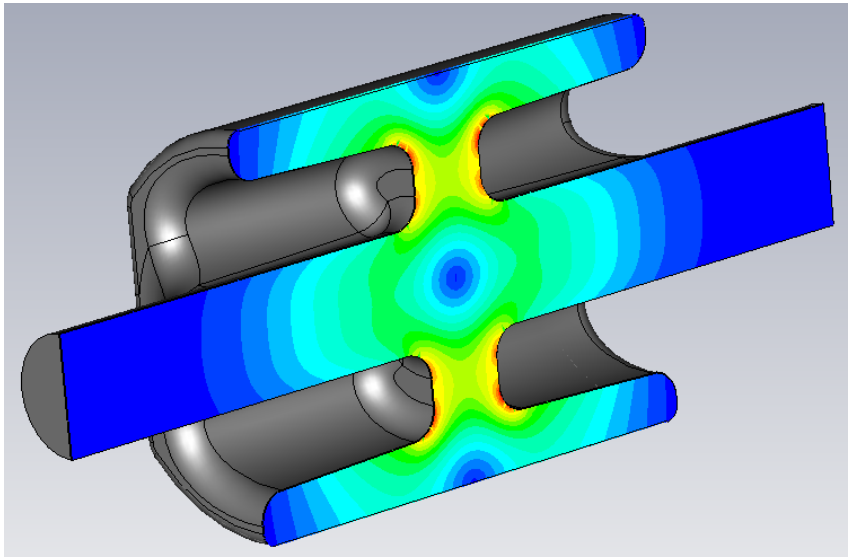


Rod shaping to reduce surface electric and magnetic fields, and the offset nonlinearities

4-Rod Cavity (U. Lancaster/JLab)



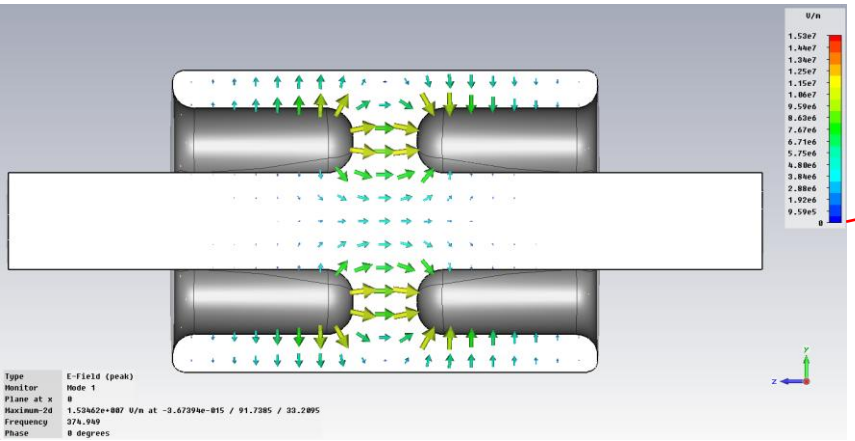
Magnetic Field



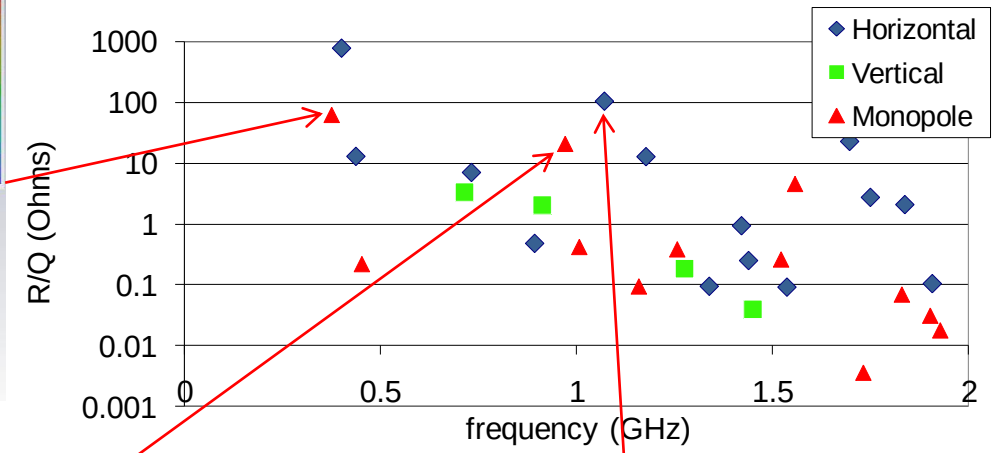
Electric Field

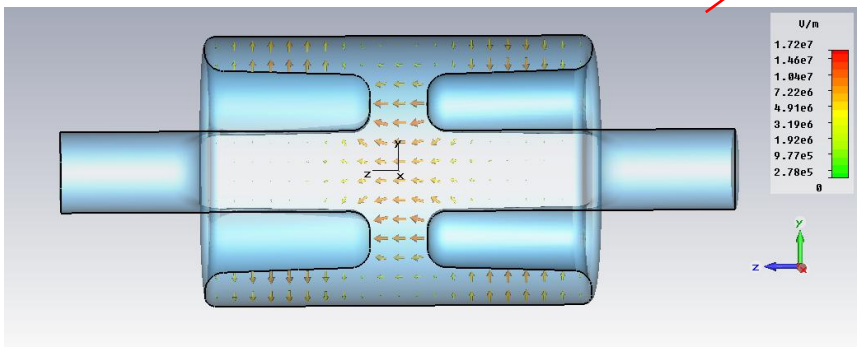
Emax @3MV	32.0 MV/m
Bmax @3MV	60.5 mT
Transverse R/Q	764.6 Ohms

Lower and Higher Order Modes

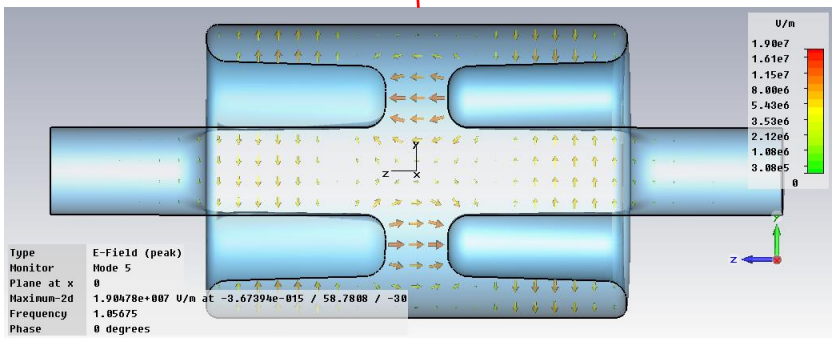


LOM Monopole



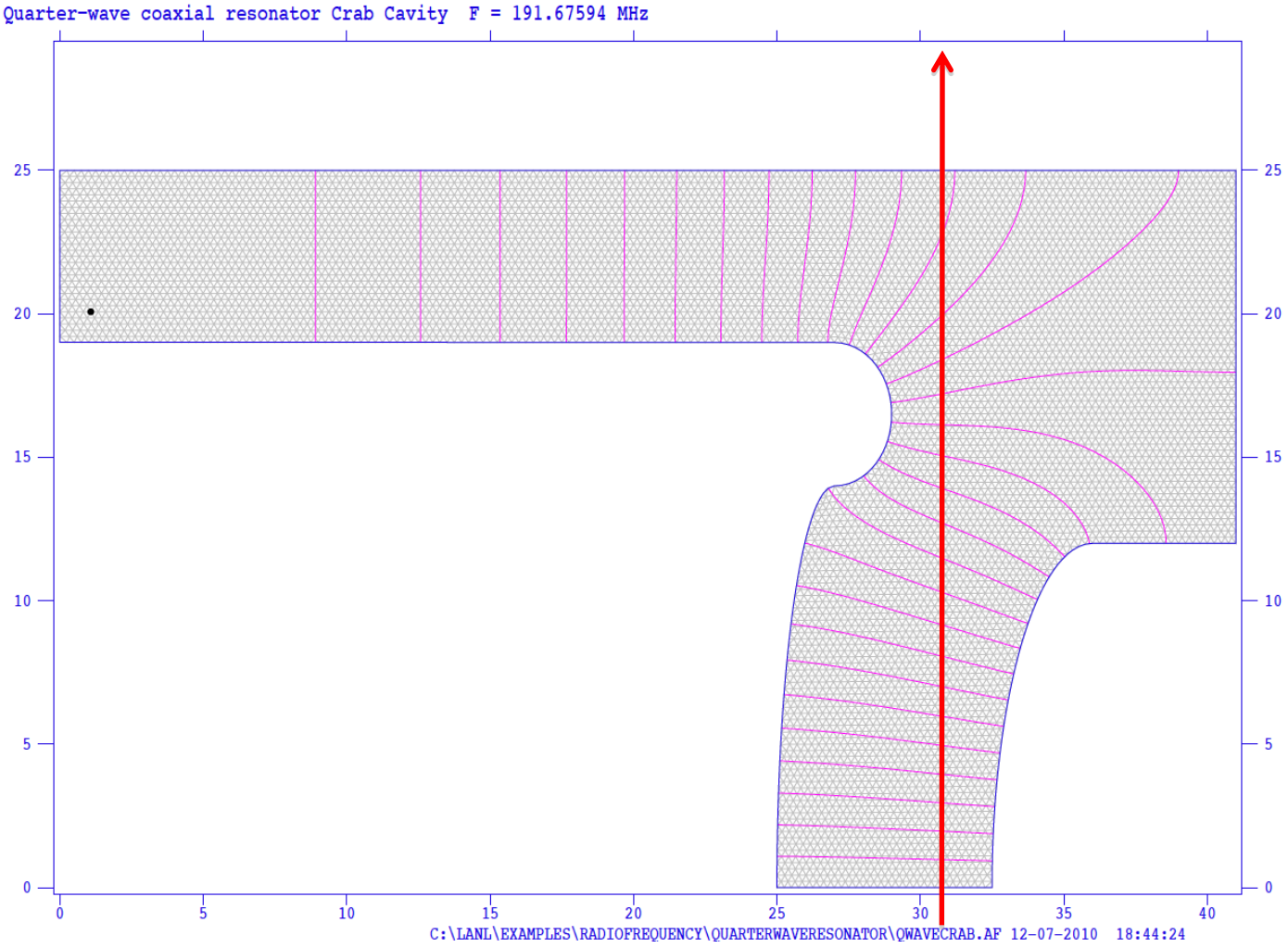


HOM Monopole 3π/4 resonator



HOM Dipole 3π/4 resonator

Quarter-wave (BNL)



Quarter-wave (BNL)

Preliminary design for eRHIC

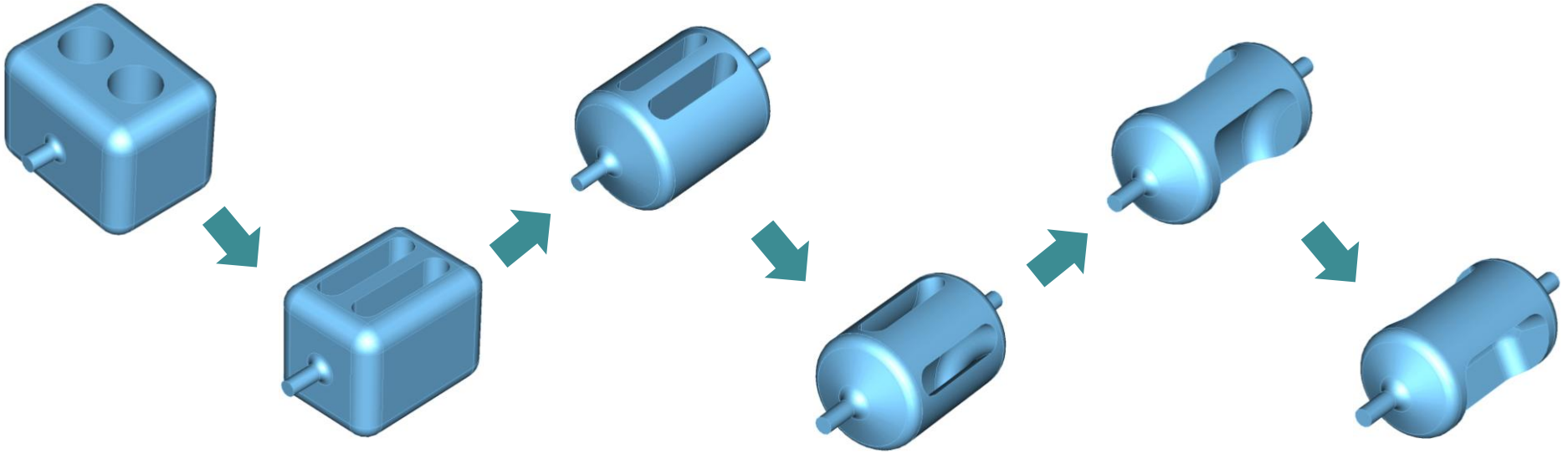
	Units	Parameter
Crab mode frequency	MHz	181
Nearest other mode frequency	MHz	251
Cavity length	cm	75.2
Cavity width	cm	38.1/25.1
Deflecting voltage*	MV	6.1
Peak surface electric field*	MV/m	39
Stored energy*	Joules	100
$R_t/Q\#$	Ohm	291
Accelerating voltage	MV	0

(*) for peak surface magnetic field of 100 mT.

$E_t = 2V_t/\lambda$

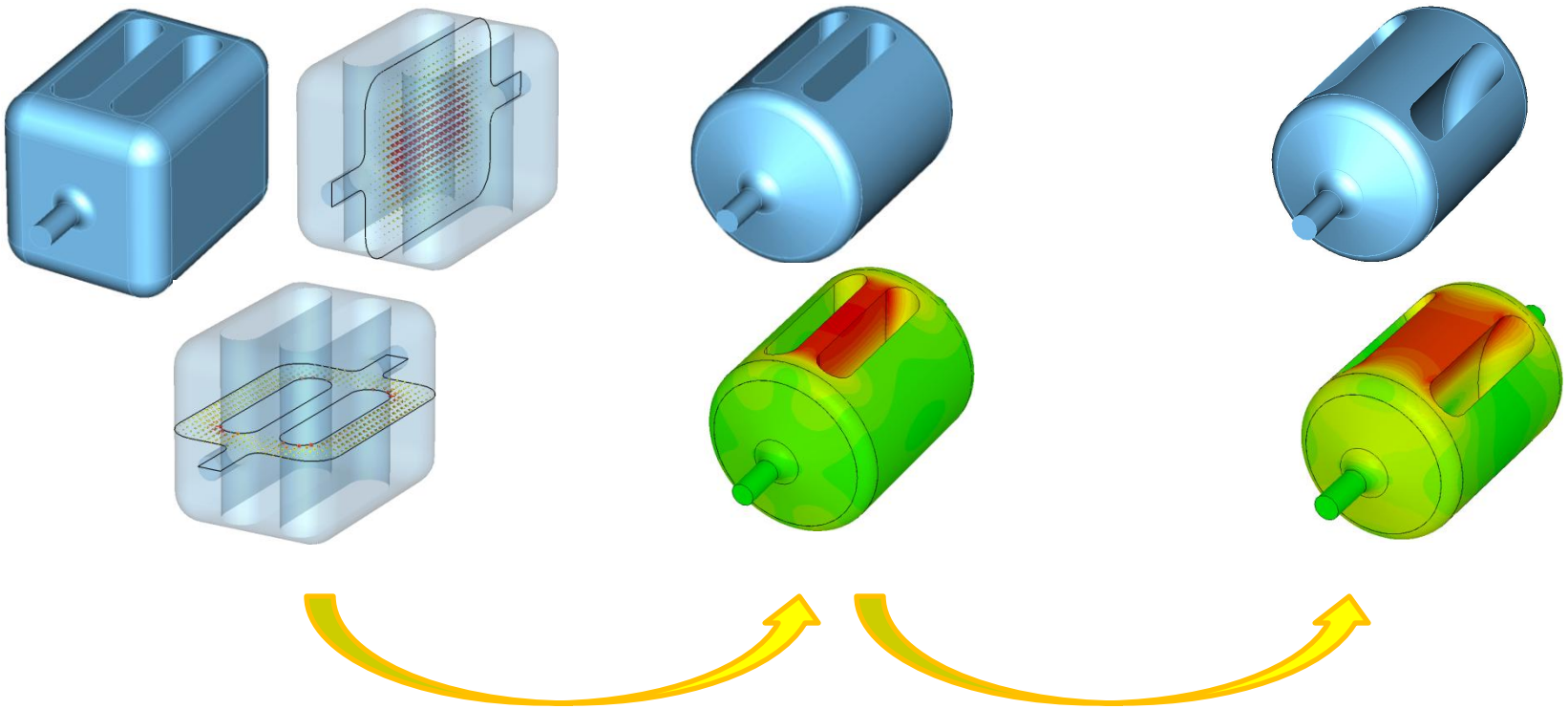
E_p/E_t	5.3
B_p/E_t mT/(MV/m)	13.6

Parallel-Bar Cavity (ODU)



- Aspects of optimization
  - Lower and balanced peak surface fields
  - Stability of the design
    - Cylindrical shape is preferred to reduce flat surfaces
  - Cavity processing
    - Curved end plates for cleaning the cavity
  - Wider separation in Higher Order Mode (HOM) spectrum
  - Multipacting

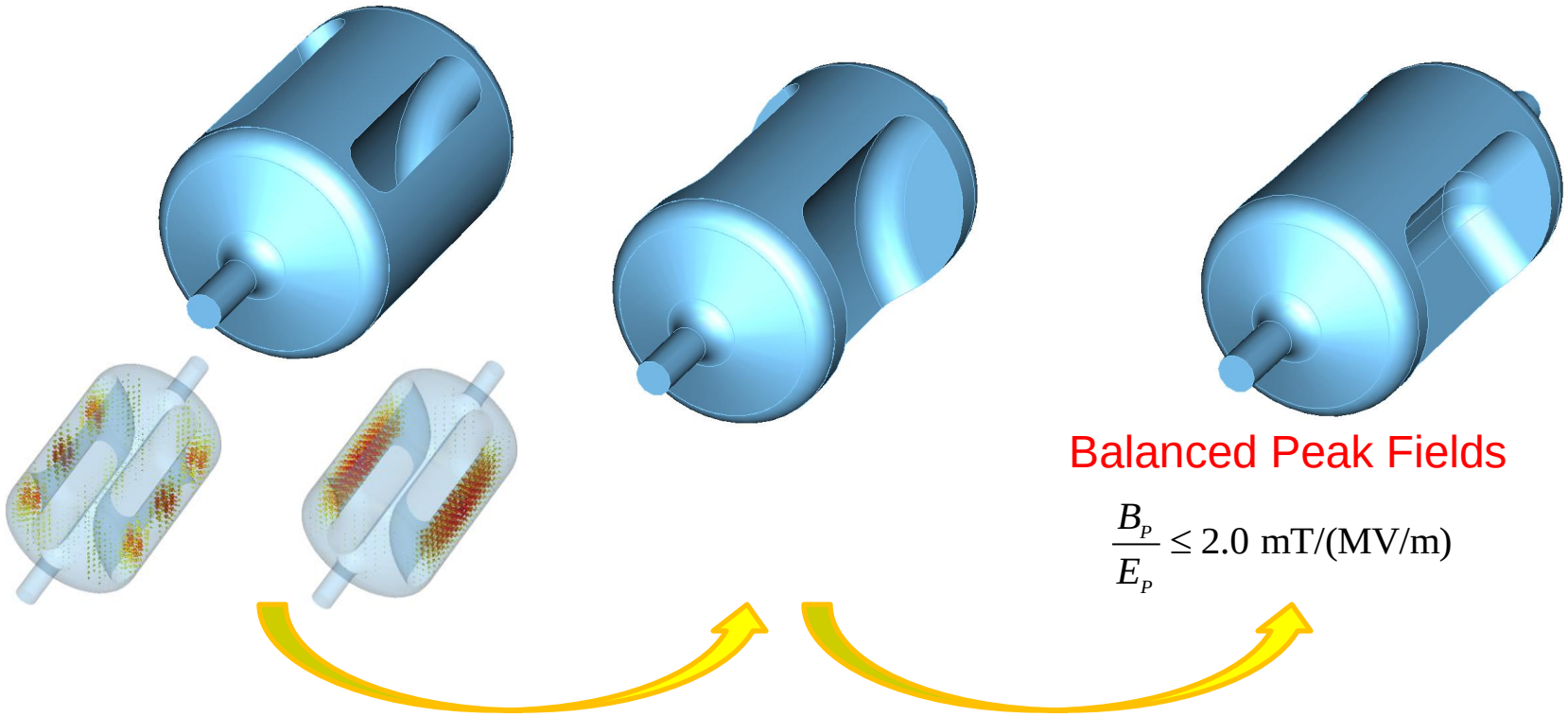
Design Evolution – 499 MHz



- To increase mode separation between fundamental modes
- ~18 MHz → ~ 130 MHz
- To improve design rigidity → Less susceptible to mechanical vibrations and deformations

- To lower peak magnetic field
- Reduced peak magnetic field by ~20%

Design Evolution – 499 MHz



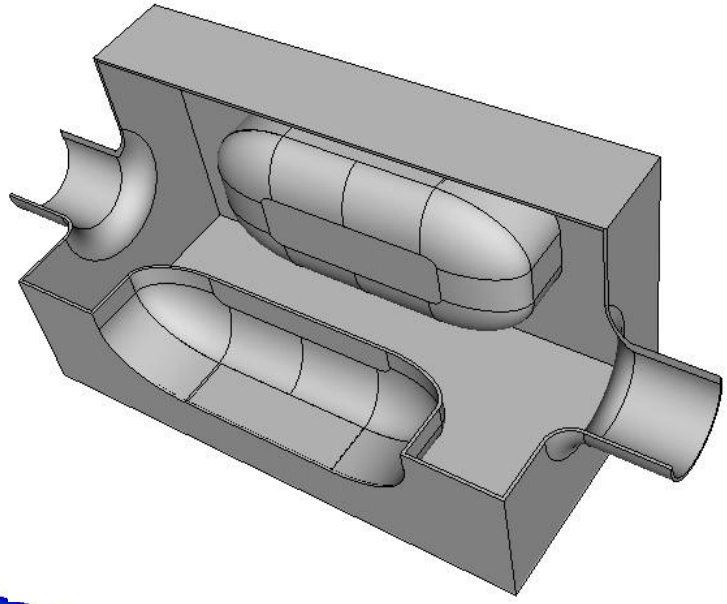
Balanced Peak Fields

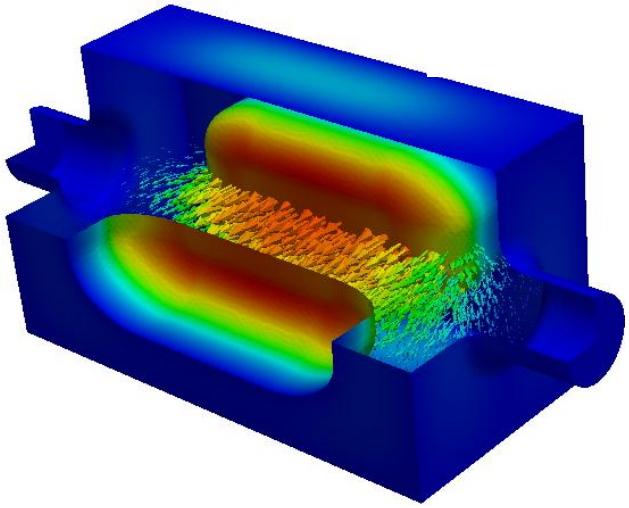
$$\frac{B_P}{E_P} \leq 2.0 \text{ mT/(MV/m)}$$

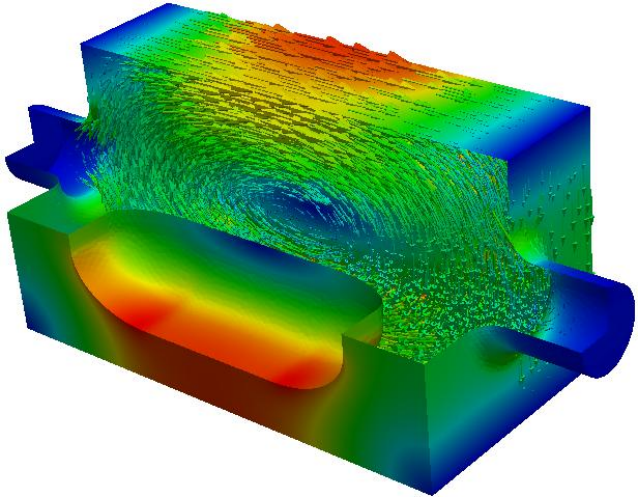
- To remove higher order modes with field distributions between the cavity outer surface and bar outer surface
- Eliminate multipacting conditions

- To lower peak magnetic field
- Reduced peak magnetic field by ~25%
- To achieve balanced peak surface fields
- $B_P/E_P \approx 1.5$ mT/(MV/m)

Ridged Waveguide Cavity (SLAC)







400 MHz LHC Crabbing System – Zenghai Li

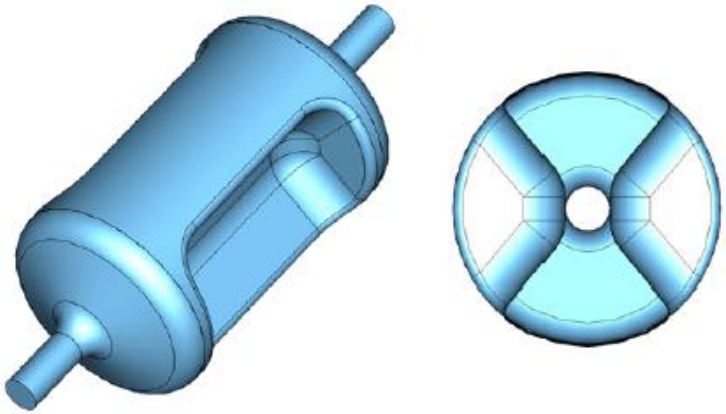
ODU/SLAC Cavity Properties

- 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
- Good uniformity of deflecting field due to high degree symmetry

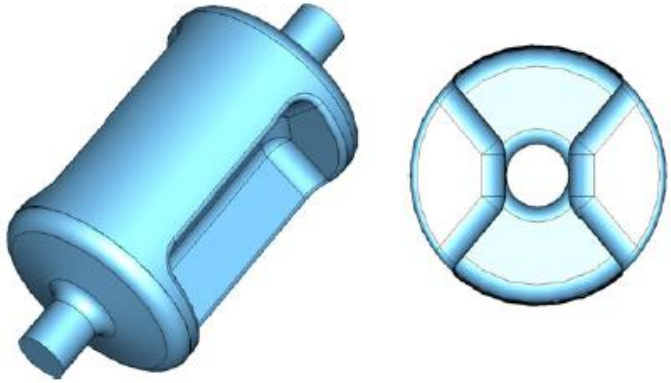
Parallel Bar Cavity Activities at ODU/JLab

- **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)
  - *Medium Energy Electron-ion Collider* (750 MHz)
    (ODU-Niowave P1 STTR completed, P2 STTR)

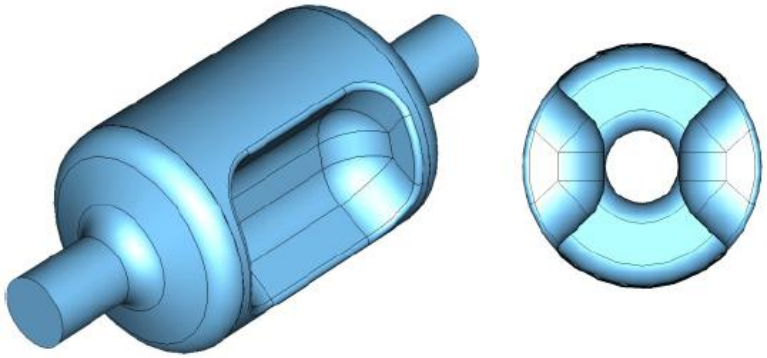
Current Status



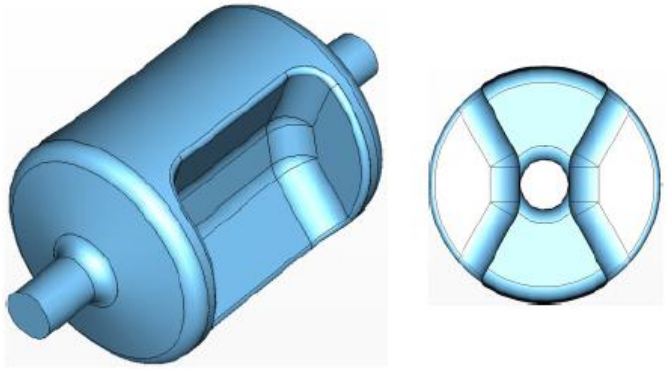
499 MHz JLab Upgrade Deflector
Fabrication under way



400 MHz LHC Crabbing System
Fabrication completed
Testing underway

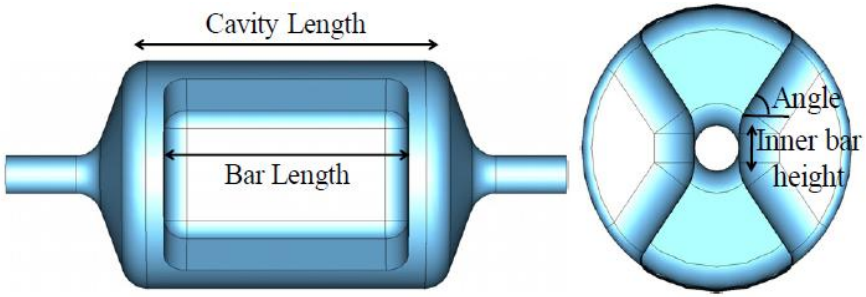


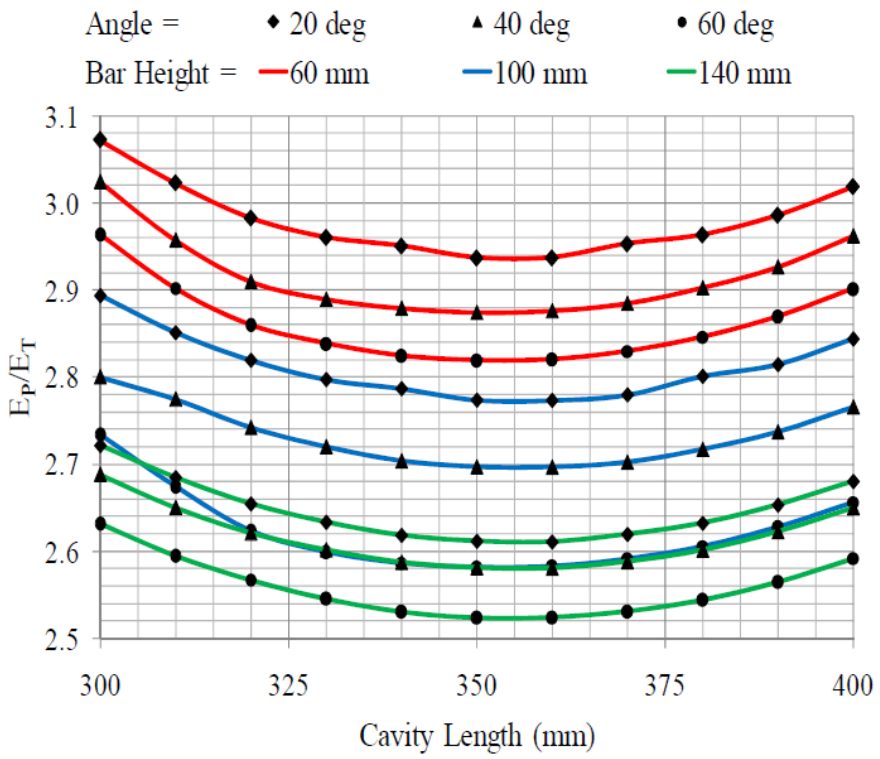
750 MHz MEIC Crabbing System
Fabrication underway

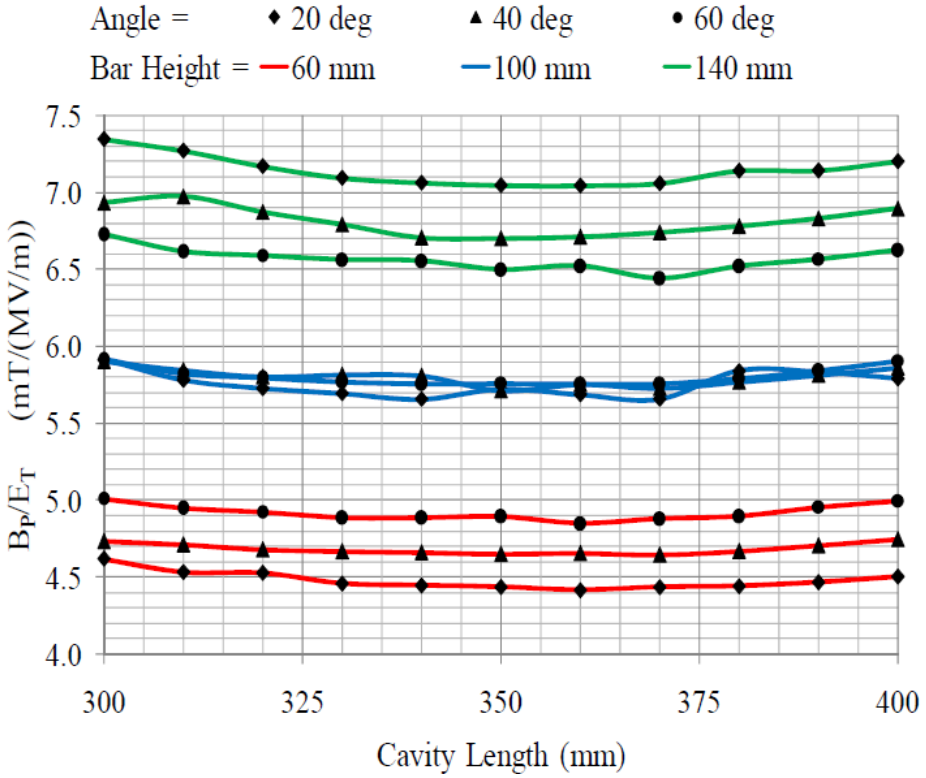


365 MHz Project X Deflector

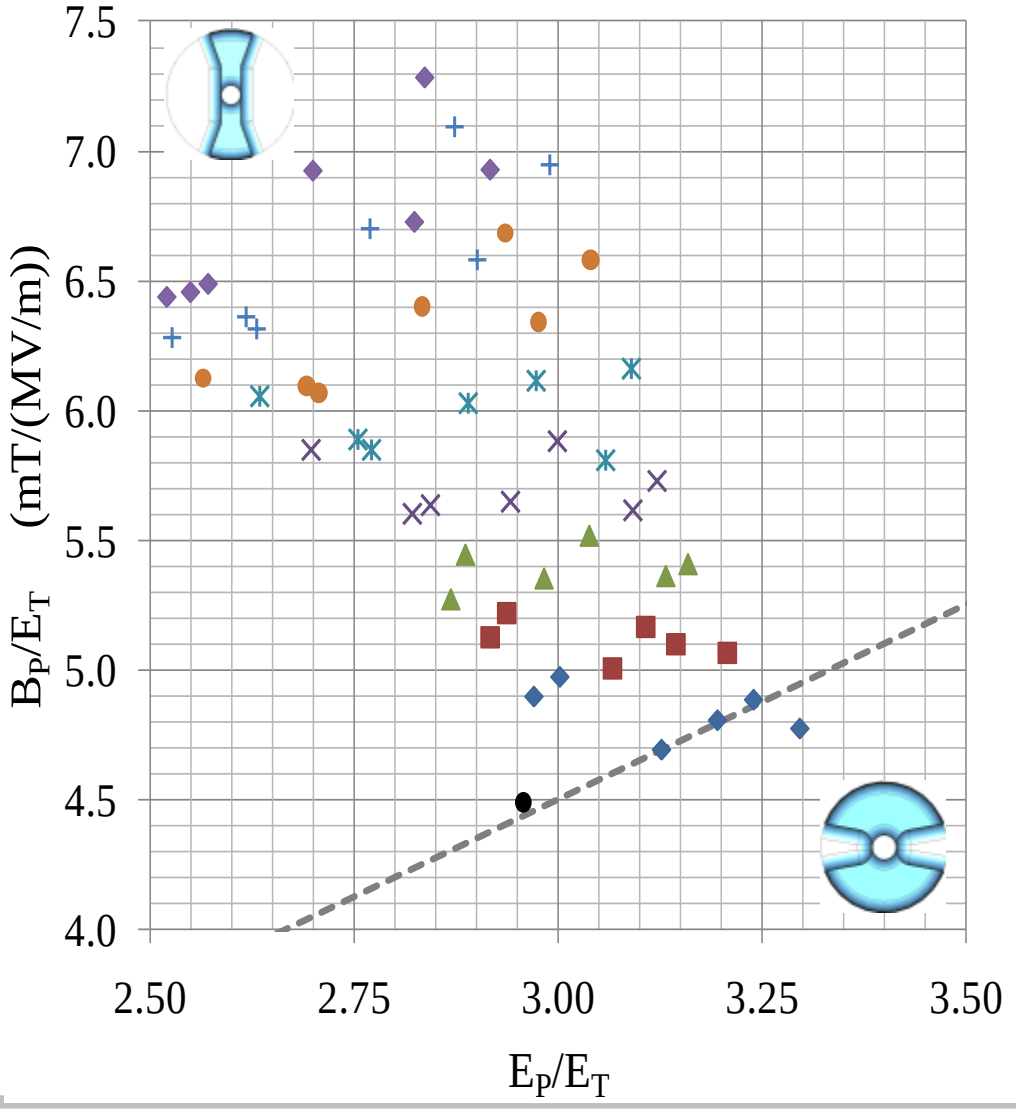
Design Optimization – 499 MHz







Optimization of Bar Shape – 499 MHz

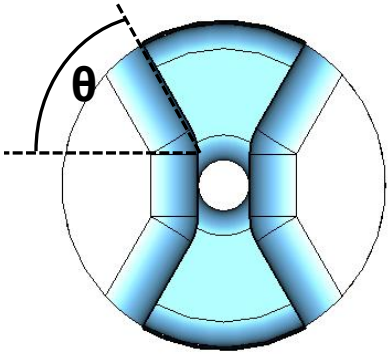


Bar Height
- 50 mm
- 60 mm
- 70 mm
- 80 mm
- 90 mm
- 100 mm
- 110 mm
- 120 mm

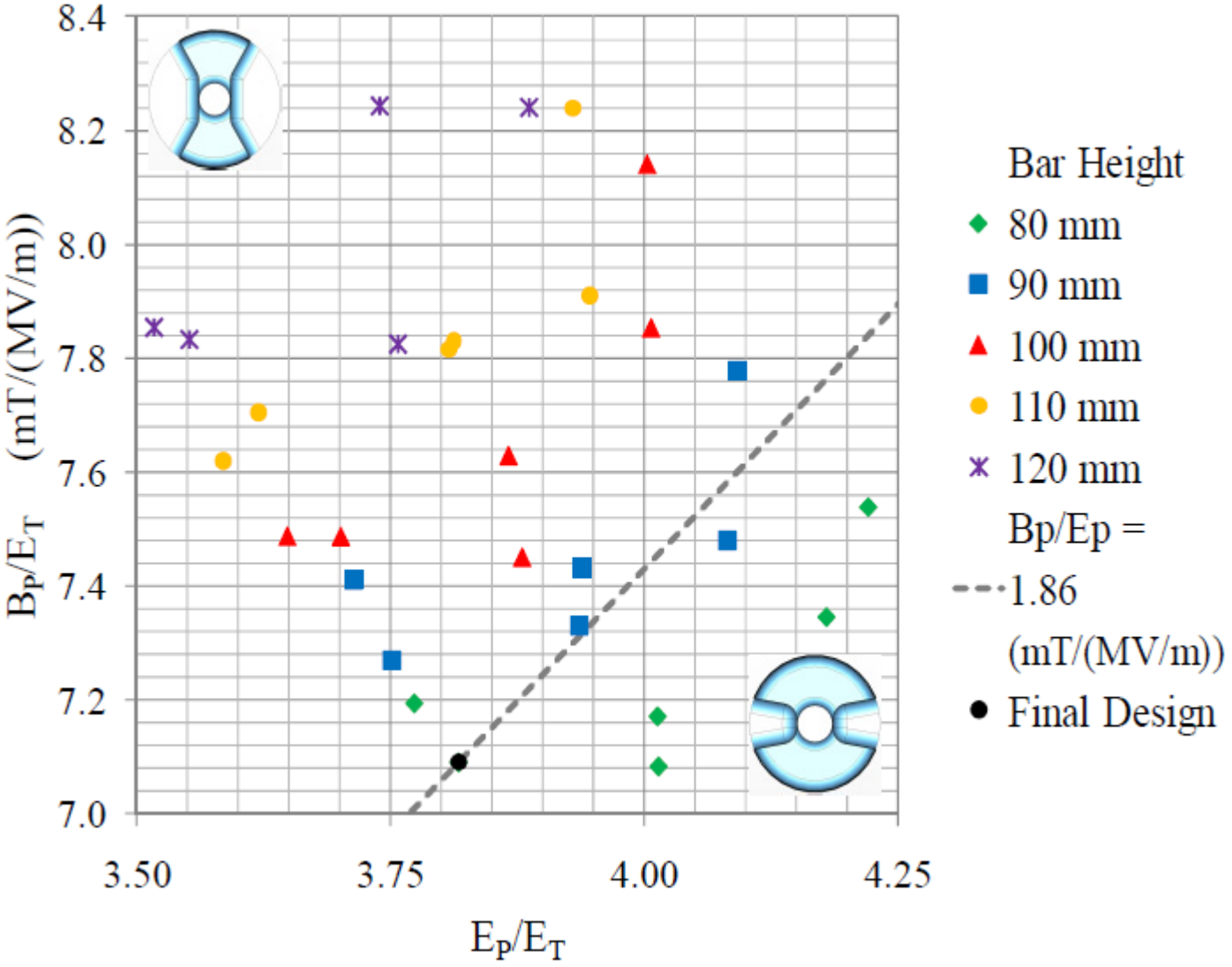
Bp/Ep = 1.5 (mT/(MV/m))

[30 MV/m, 45 mT]

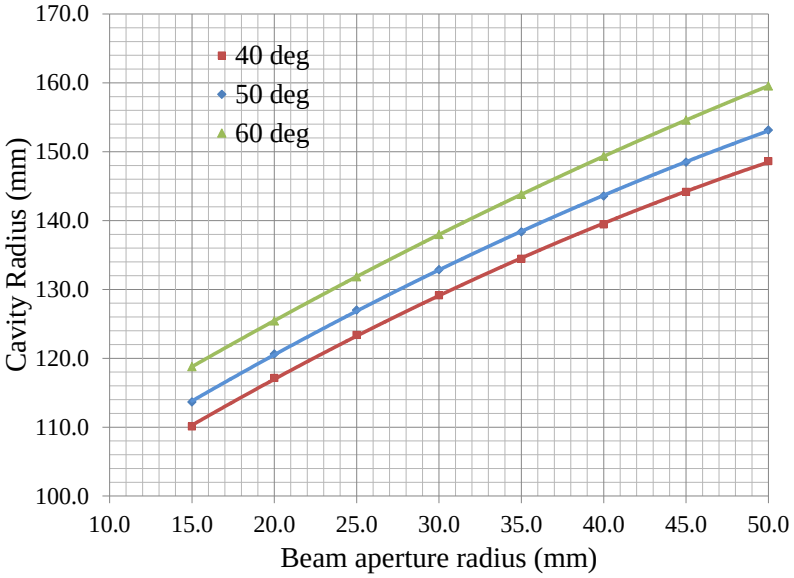
- Final Design



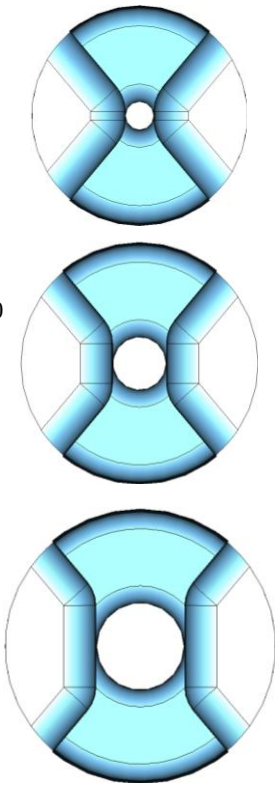
Design Optimization – 400 MHz

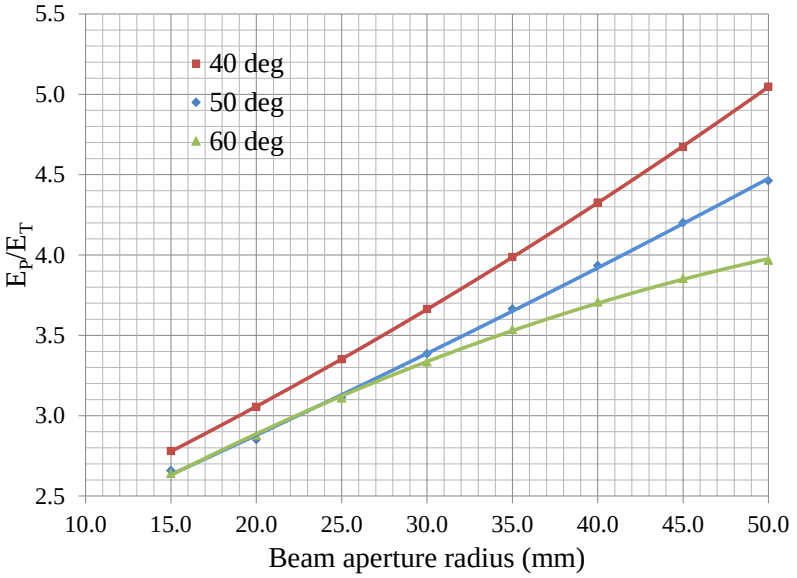


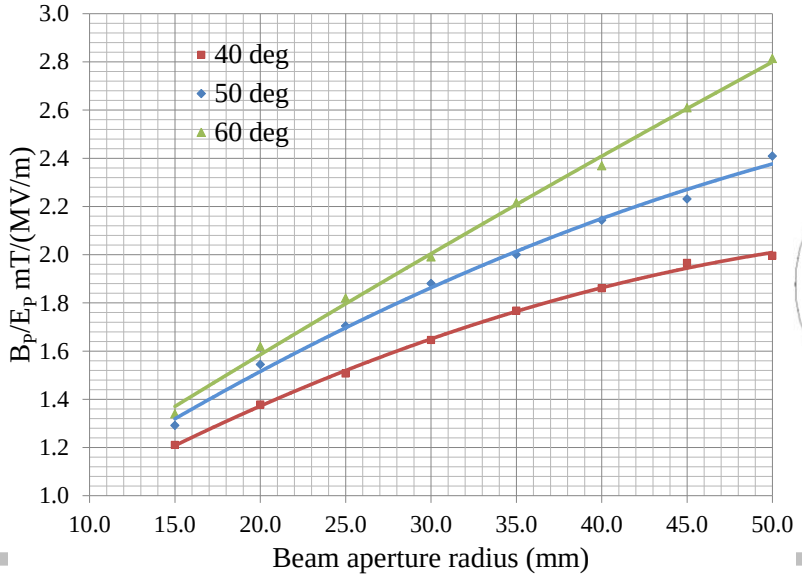
Dependence of Beam Aperture

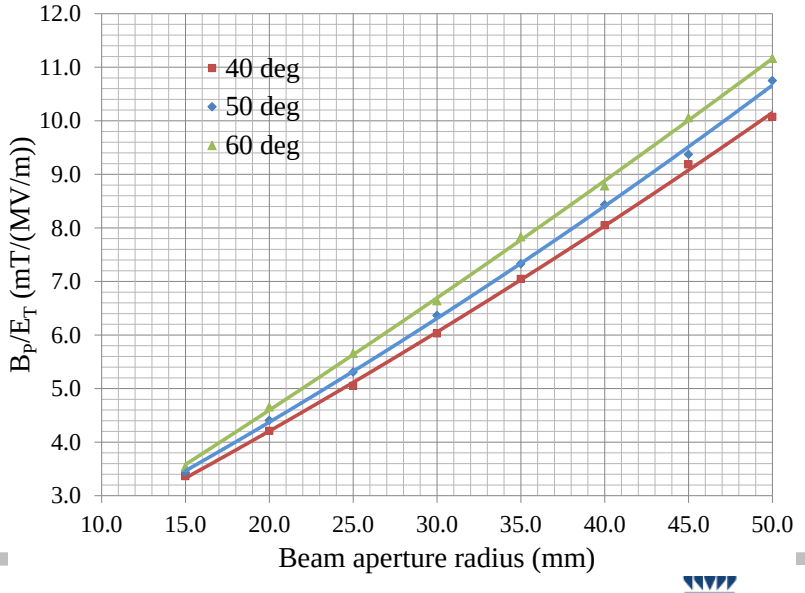


At 499 MHz

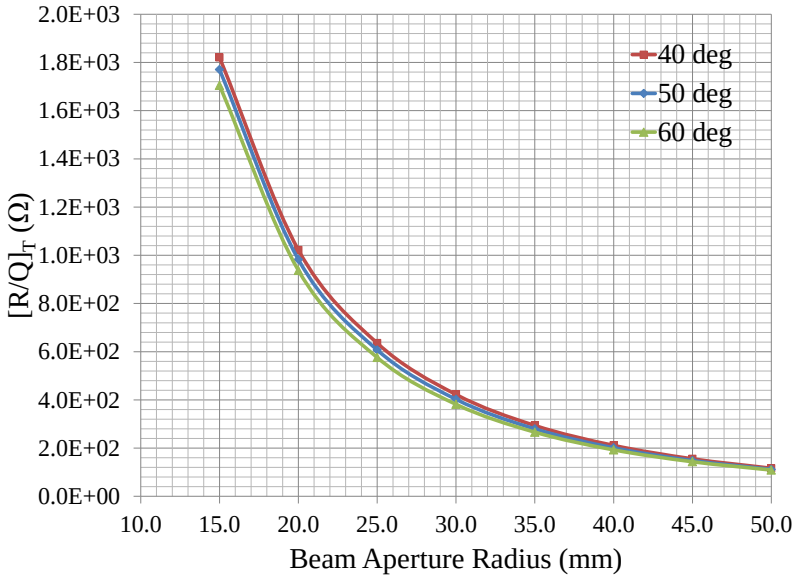




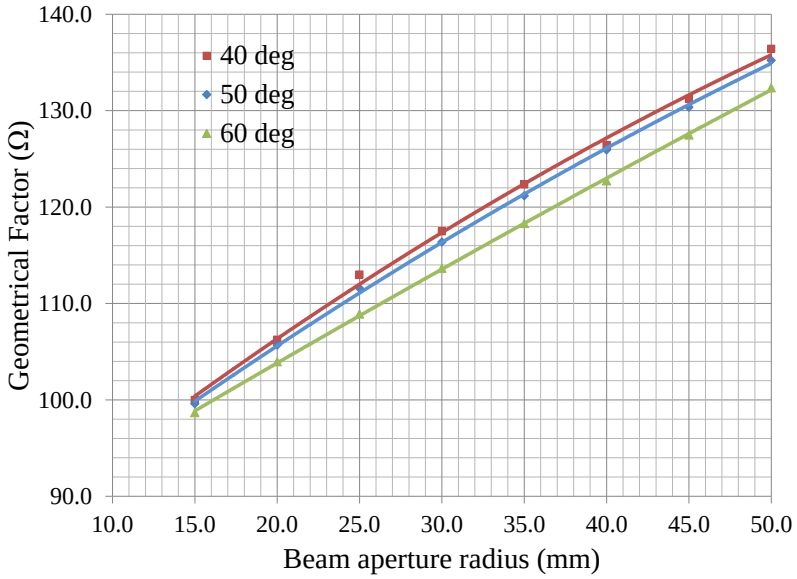


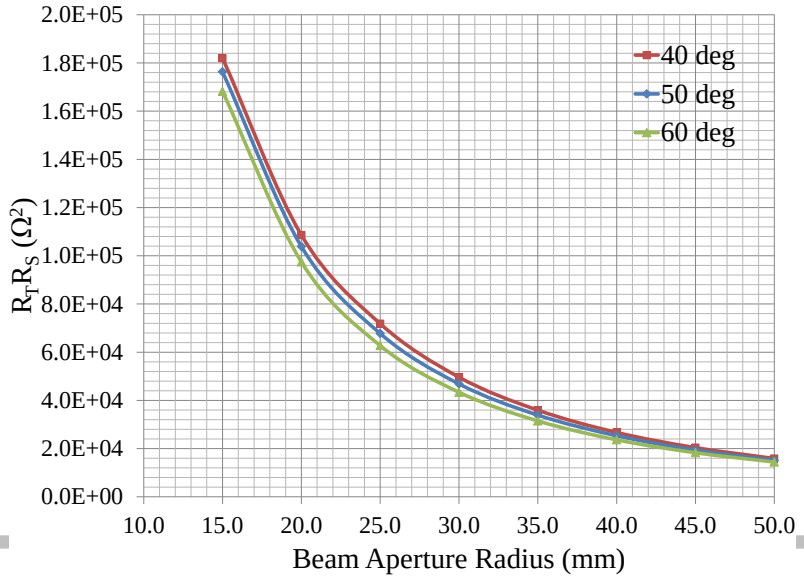


Beam Aperture Dependence

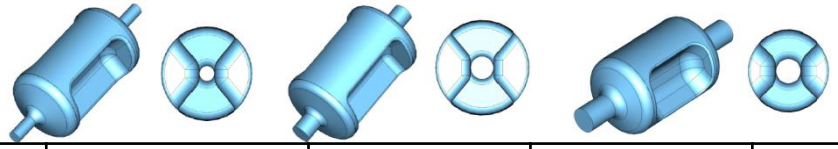


At 499 MHz



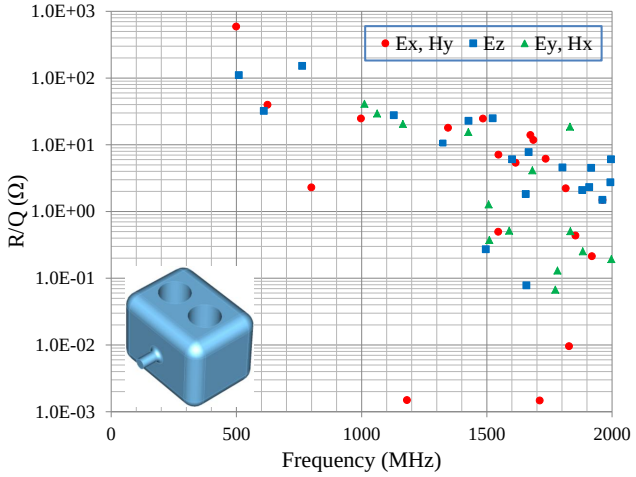


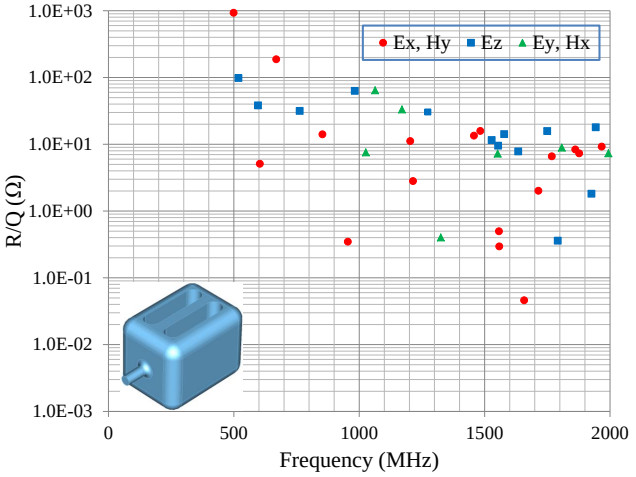
Parallel-Bar / Ridged Waveguide → RF Dipole

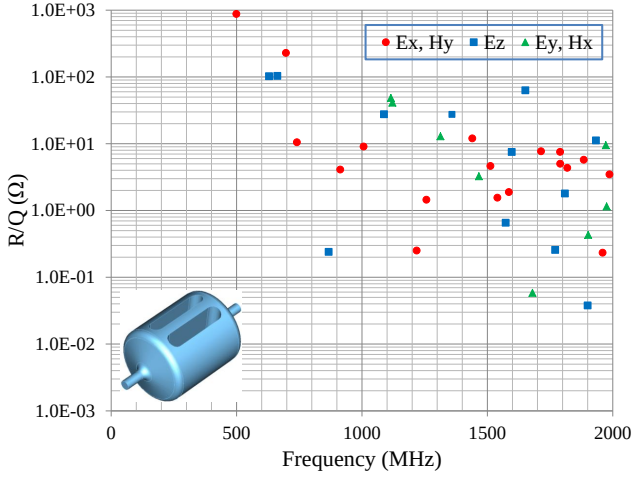


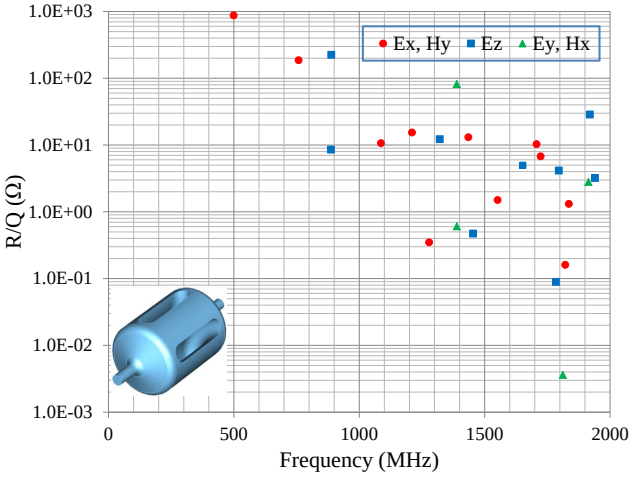
Parameter	499 MHz	400 MHz	750 MHz	Unit
λ/2 of π mode	300.0	375.0	200.0	mm
Frequency of 0 mode	1036.1	887.0	1376.7	MHz
Nearest mode to π mode	777.0	589.5	1062.5	MHz
Cavity reference length	440.0	527.2	270.0	Mm
Cavity diameter	241.2	339.9	95.1	mm
Bars length	260.0	350.0	200.0	mm
Bars inner height	50.0	80.0	63.0	mm
Angle	50.0	50.0	45.0	mm
Aperture diameter	40.0	84.0	60.0	mm
Deflecting voltage (V_T^*)	0.3	0.375	0.2	MV
Peak electric field (E_P^*)	2.86	3.9	4.29	MV/m
Peak magnetic field (B_P^*)	4.38	7.13	9.3	mT
B_P^* / E_P^*	1.53	1.83	2.16	mT / (MV/m)
Geometrical factor ($G = QR_S$)	105.9	138.7	136.0	Ω
$[R/Q]_T$	982.5	287.2	125.0	Ω
$R_T R_S$	1.0×10^5	4.0×10^4	1.7×10^4	Ω^2
At E_T^* = 1 MV/m				

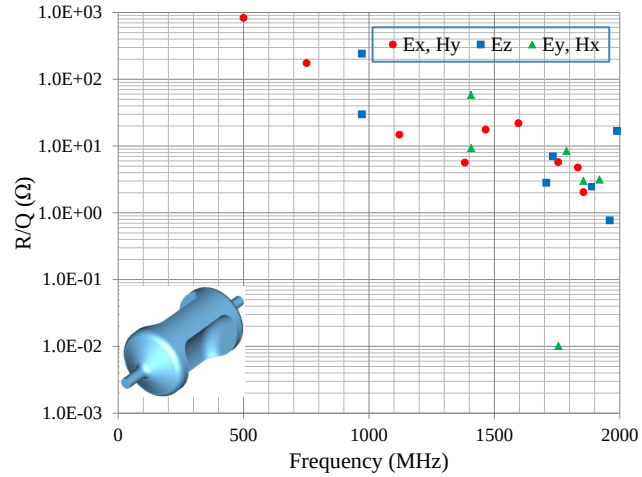
HOM Properties of 499 MHz Cavity

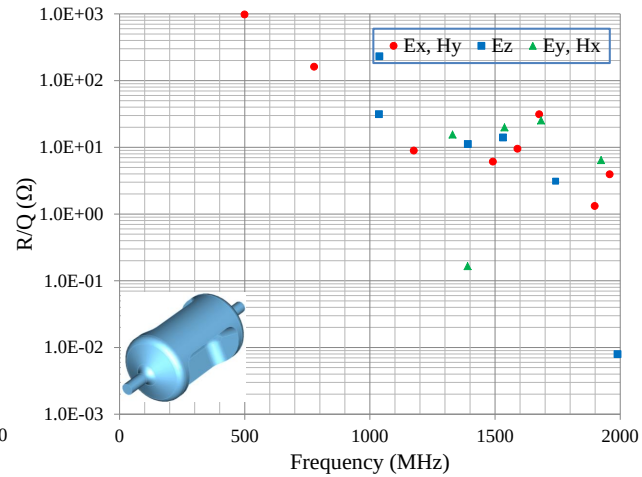






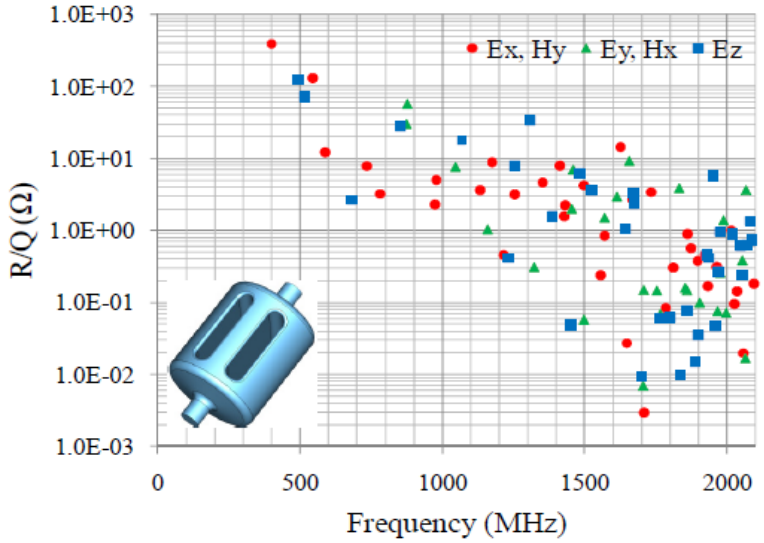


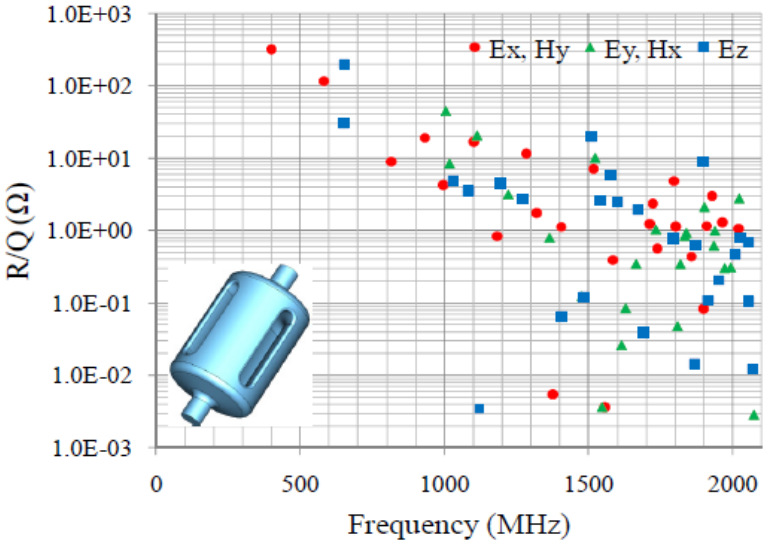


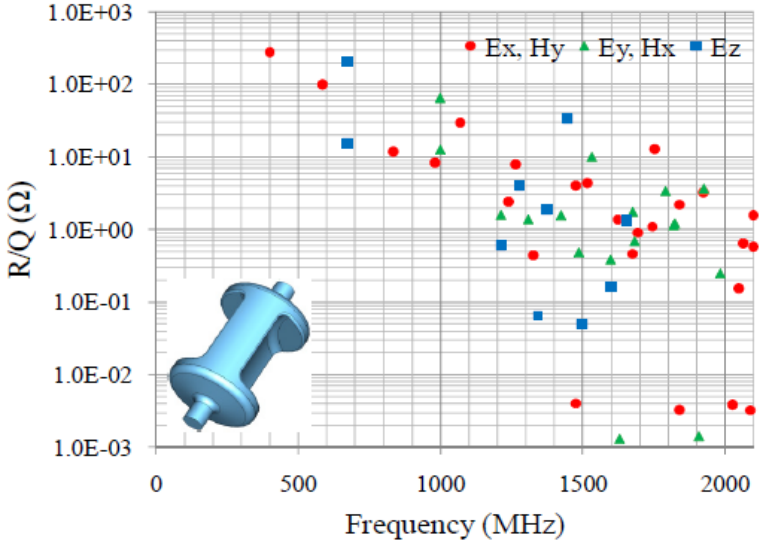


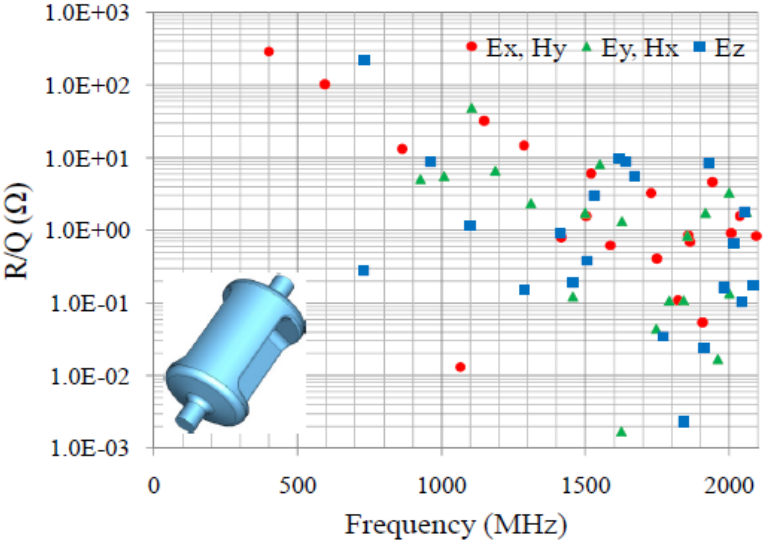
No Lower Order Modes

HOM Properties of 400 MHz Cavity

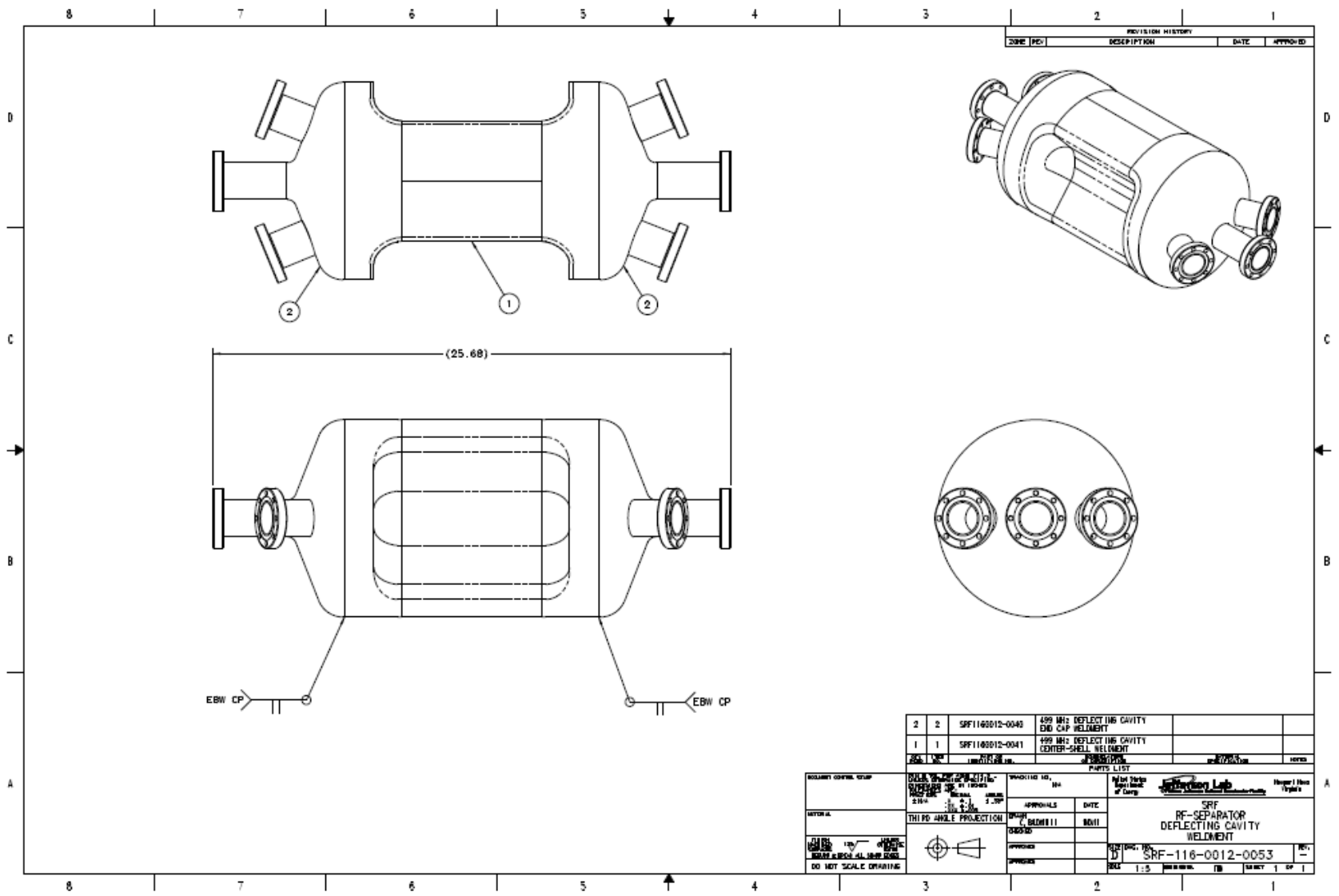




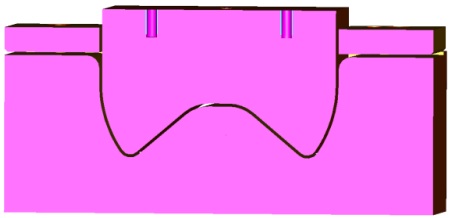




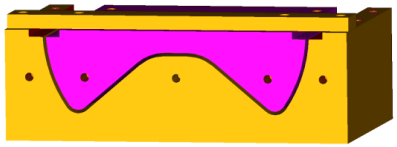
Cavity Drawing – 499 MHz



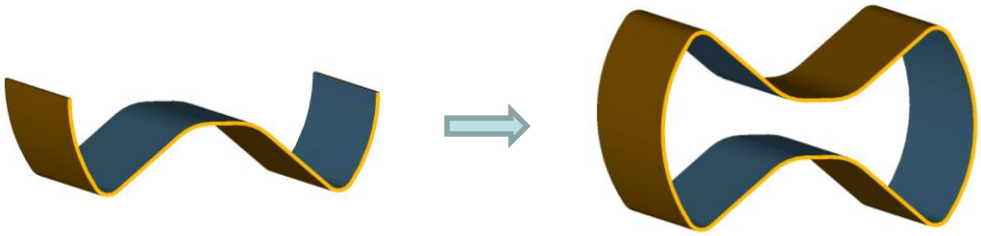
Body Weldment – 499 MHz



Center shell forming
(Die cross section)

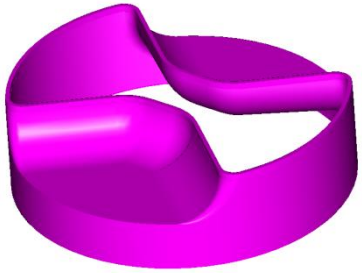


Center shell machining
Weld margin included

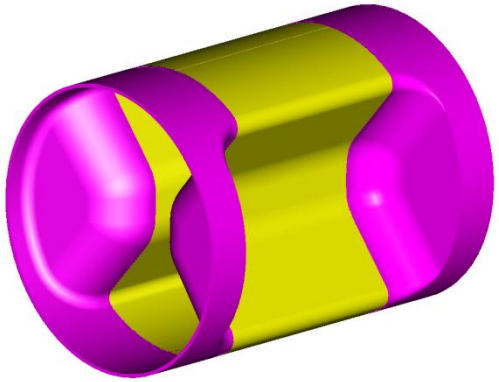


EBW seams: 40% pre-pass, 50kV
48mAmp 6 in/min beam speed
Welding will be both sides to ensure
the smooth surface inside

Center Block – 499 MHz



Machined cavity shoulder



Welding cavity shoulder and center shell

End cap side

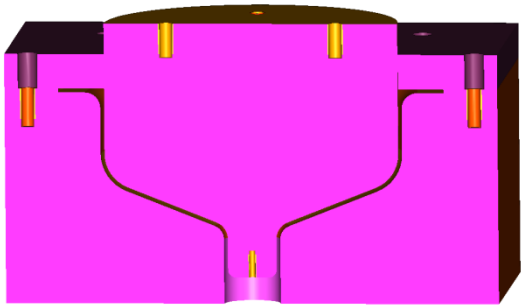
Center shell side

Niobium beam ports with Nb-Ti flanges

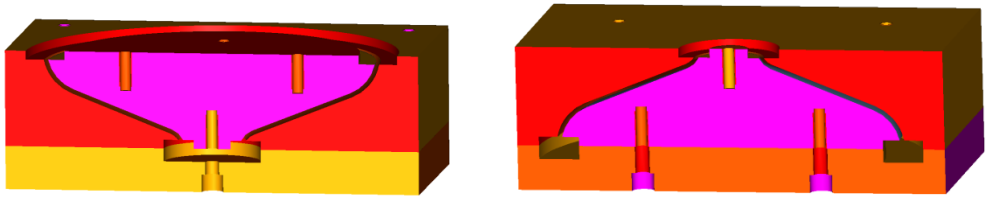
Al-Mg gaskets for final assembly

For tunings and measurements
Indium seal will be used

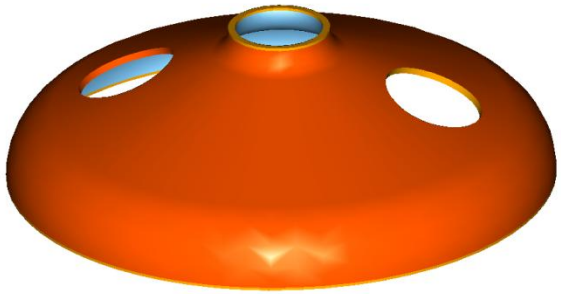
End Cap Weldment – 499 MHz



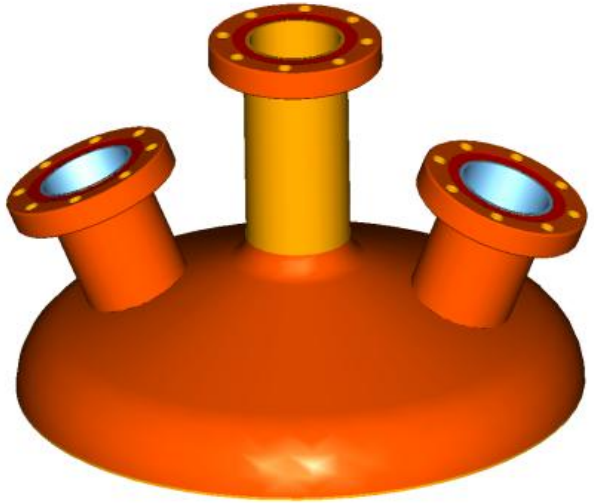
End cap forming



Machining
(Weld and tuning margin included)



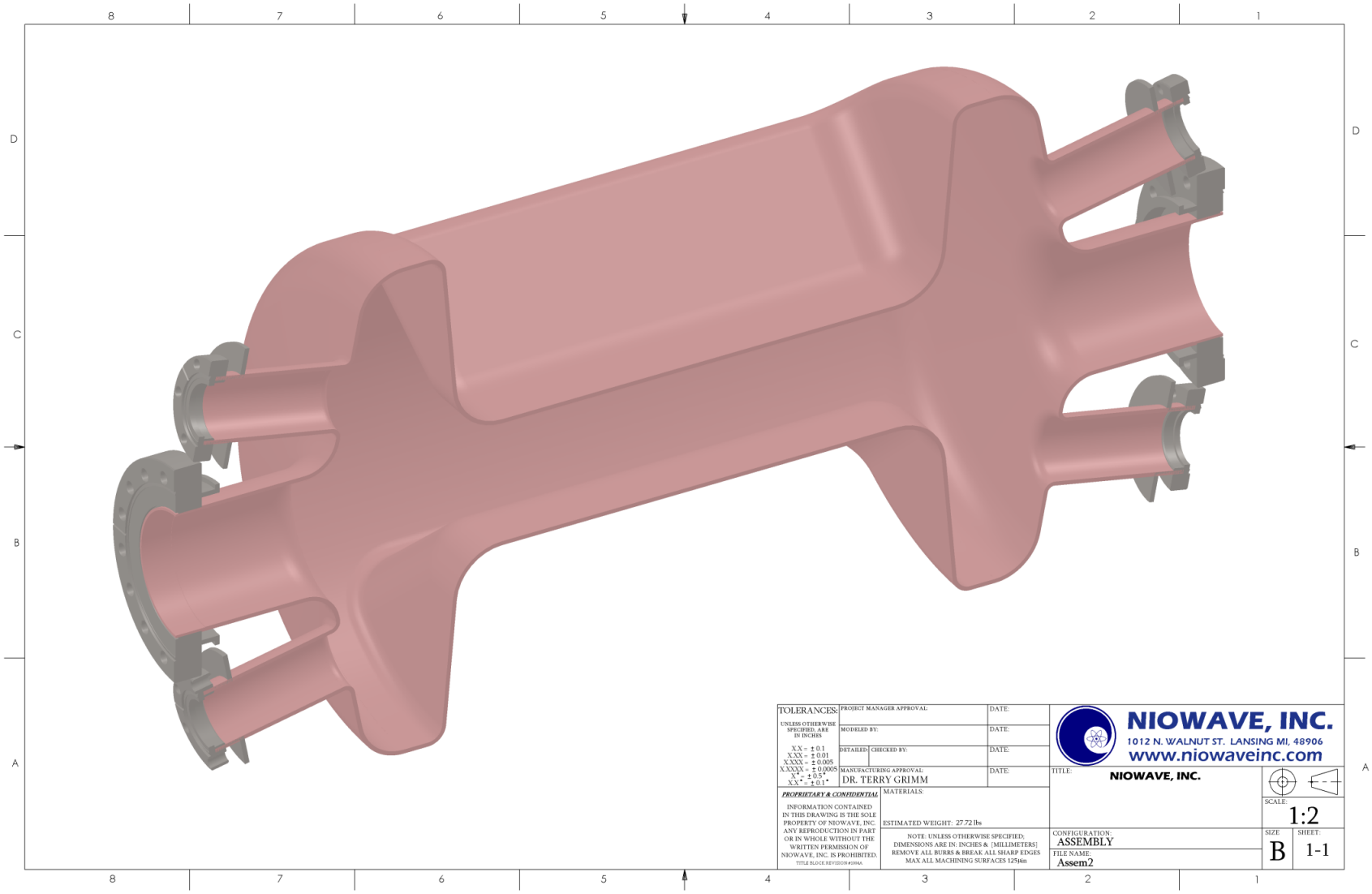
Machining port openings



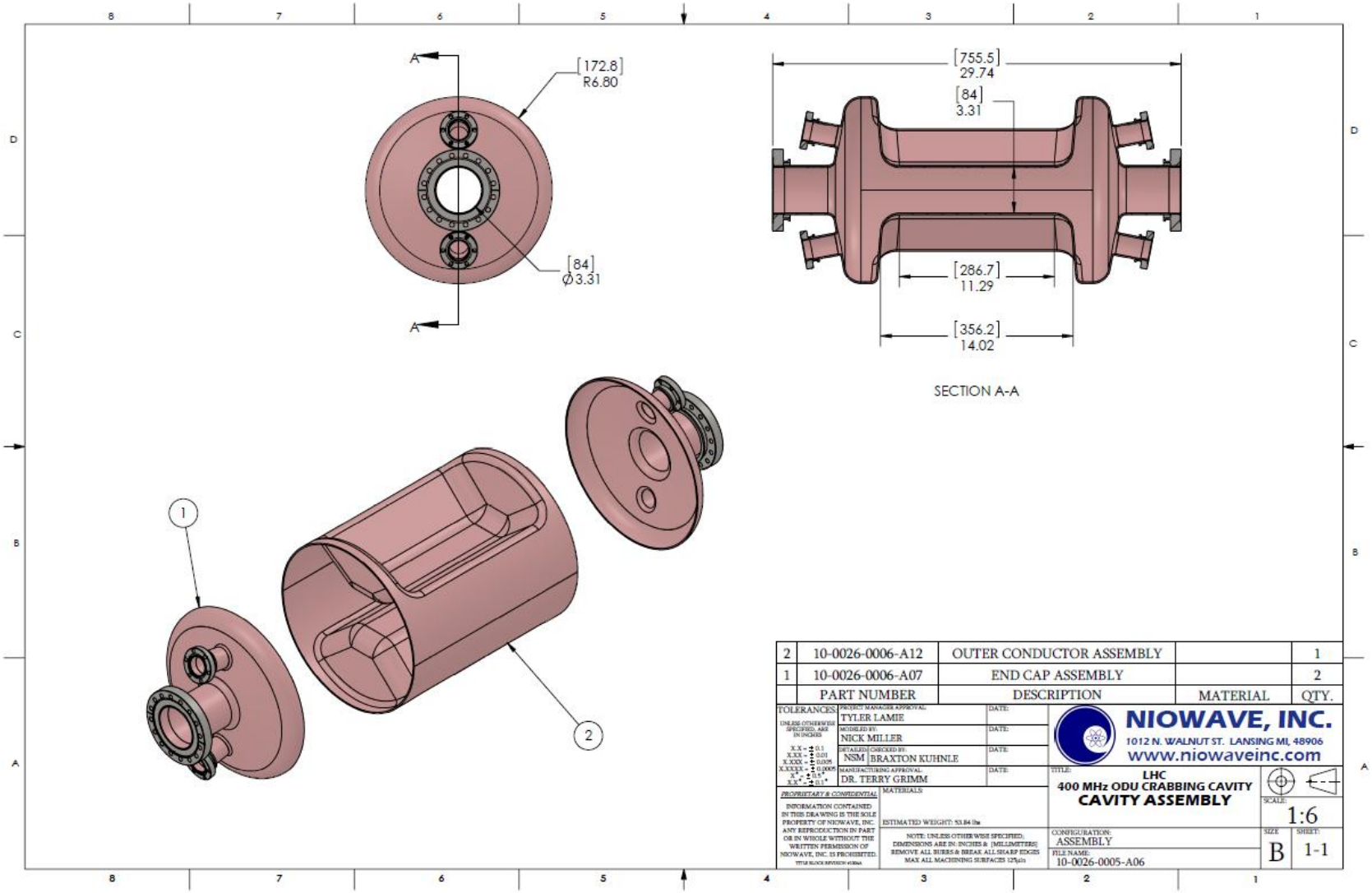
Welding beam port and coupler ports

End Cap Weldment – 499 MHz

LHC Crab Cavity – 400 MHz



Cavity Assembly – 400 MHz



2	10-0026-0006-A12	OUTER CONDUCTOR ASSEMBLY		1
1	10-0026-0006-A07	END CAP ASSEMBLY		2
	PART NUMBER	DESCRIPTION	MATERIAL	QTY.

TOLERANCES: UNLESS OTHERWISE SPECIFIED, ARE IN INCHES
X.X = ±0.1
X.XX = ±0.01
X.XXX = ±0.005
X.XXXX = ±0.0005
X° = ±0.5°
X.X° = ±0.1°

PROJECT MANAGER APPROVAL: TYLER LAMIE — DATE:
MODELED BY: NICK MILLER — DATE:
DETAILED/ CHECKED BY: NSM / BRAXTON KUHNLE — DATE:
MANUFACTURING APPROVAL: DR. TERRY GRIMM — DATE:

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TITLE BLOCK REVISION 050804

MATERIALS:
ESTIMATED WEIGHT: 53.84 lbs
NOTE: UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN: INCHES & [MILLIMETERS] REMOVE ALL BURRS & BREAK ALL SHARP EDGES MAX ALL MACHINING SURFACES 125µin

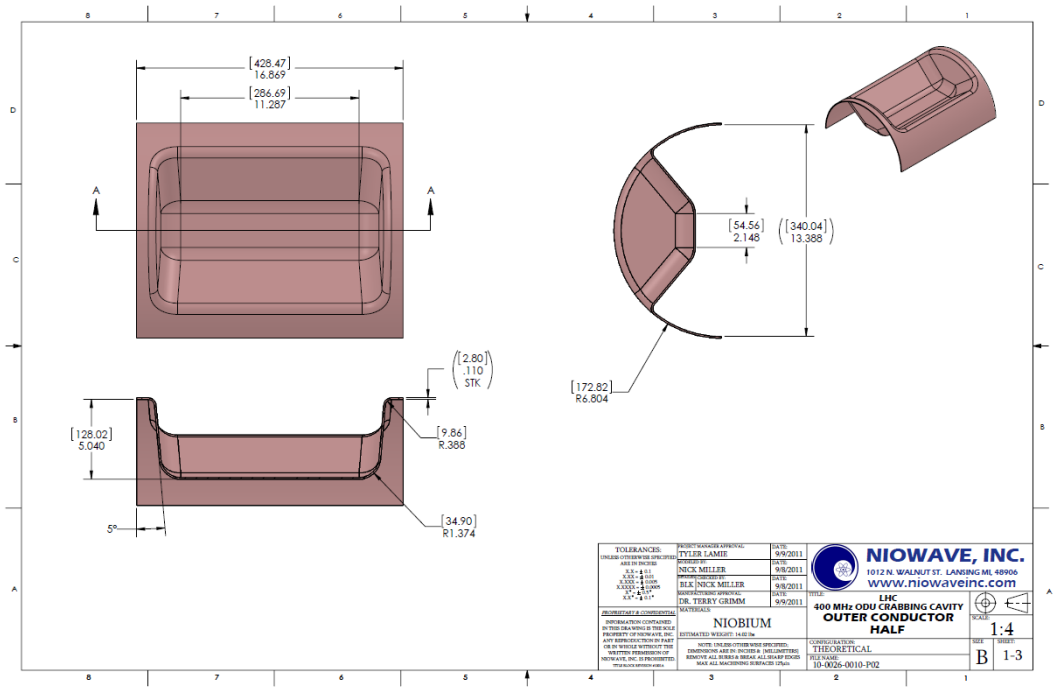
NIOWAVE, INC.
1012 N. WALNUT ST. LANSING MI, 48906
www.niowaveinc.com

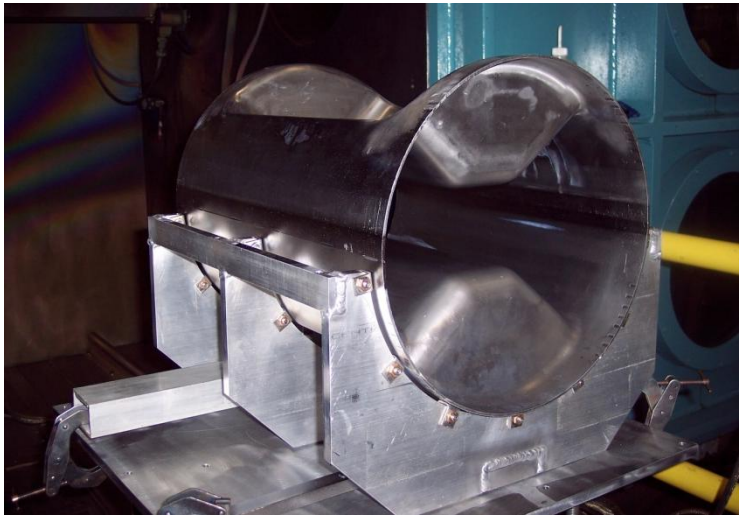
TITLE:
LHC
400 MHz ODU CRABBING CAVITY
CAVITY ASSEMBLY

CONFIGURATION: ASSEMBLY
FILE NAME: 10-0026-0005-A06

SCALE: 1:6
SIZE: B
SHEET: 1-1

Fabrication of the Body – 400 MHz

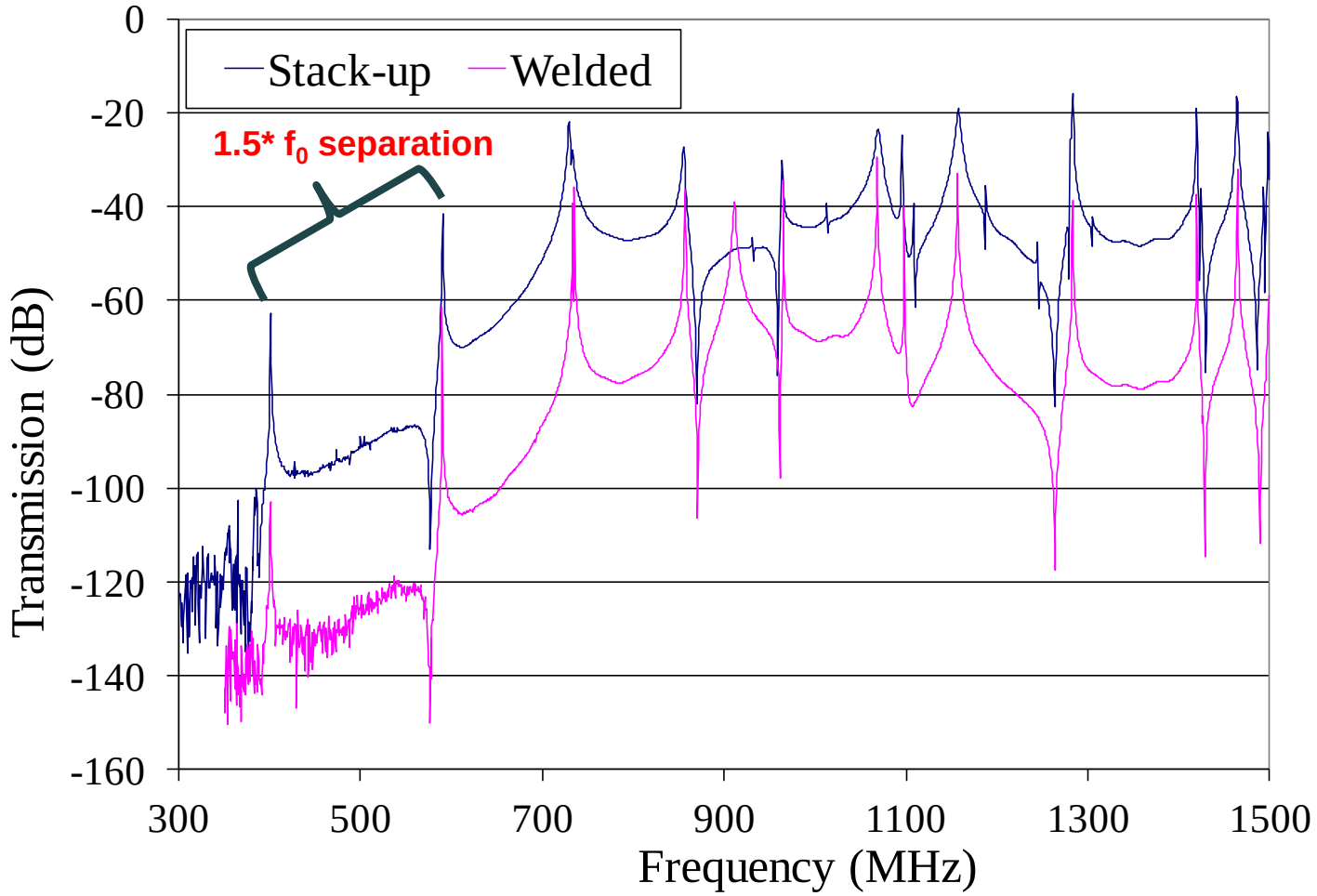




End Cap Fabrication – 400 MHz

Leak-Check of Welded Cavity

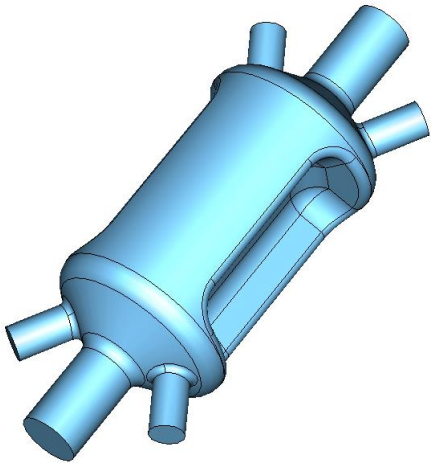
Frequency Measurements – 400 MHz

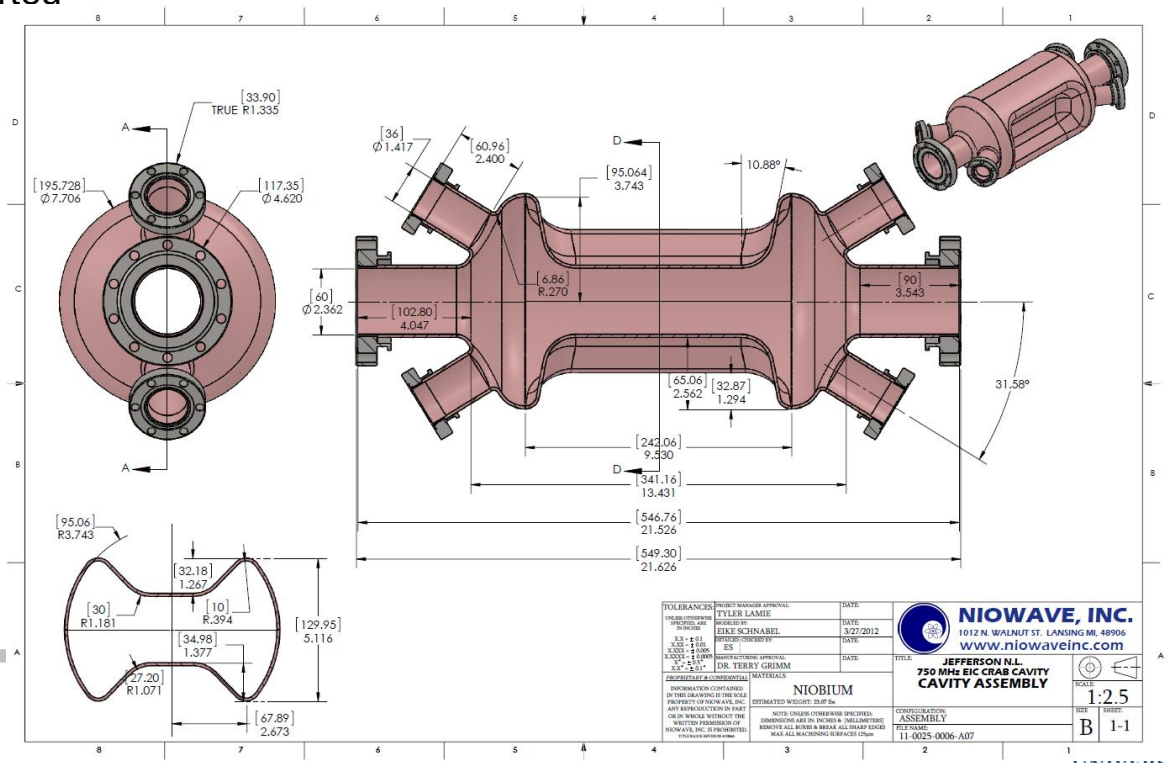


750 MHz Crabbing Cavity

- Crabbing cavity for proposed Medium-Energy Electron-Ion Collider (MEIC)
- Desired net deflection
  - e- beam: 1.5 MV
  - p beam: 8 MV
- Fabrication
  - Beam ports are finished
  - Center body fabrication - started

Parameter	750 MHz	Unit
Nearest mode to π mode	1062.5	MHz
Deflecting voltage (V_T^*)	0.2	MV
Peak electric field (E_P^*)	4.29	MV/m
Peak magnetic field (B_P^*)	9.3	mT
Geometrical factor ($G = QR_S$)	136.0	Ω
$[R/Q]_T$	125.0	Ω
At E_T^* = 1 MV/m		

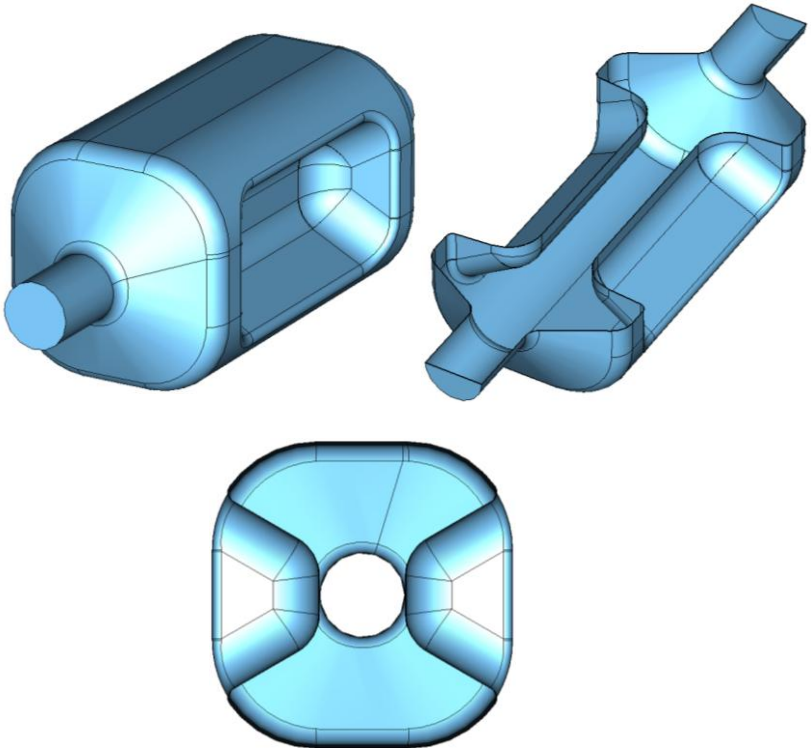


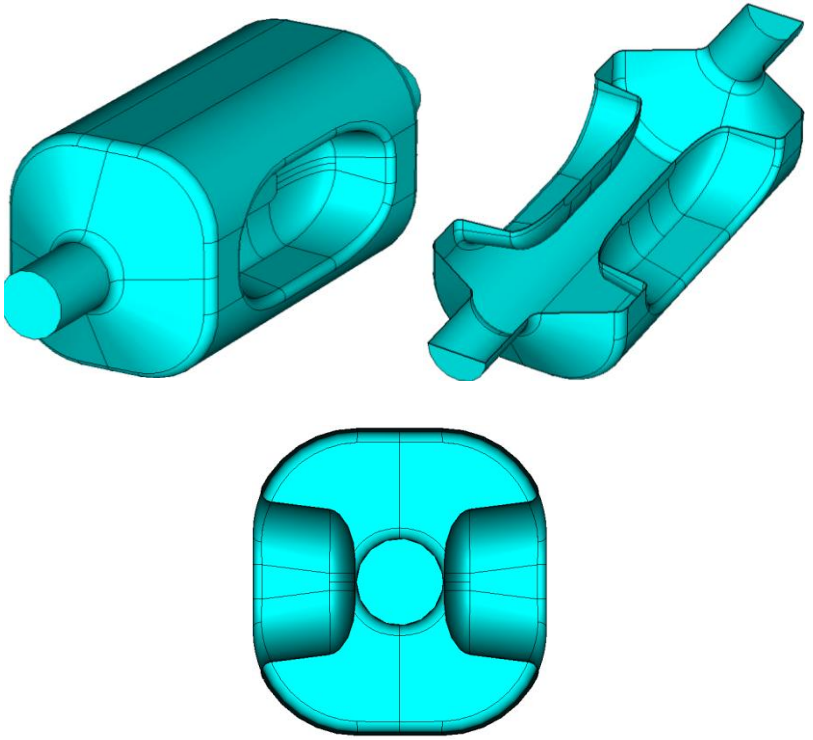


*** Work in progress by; Alex Castilla**

ODU/SLAC 400 MHz Square Cavity Options

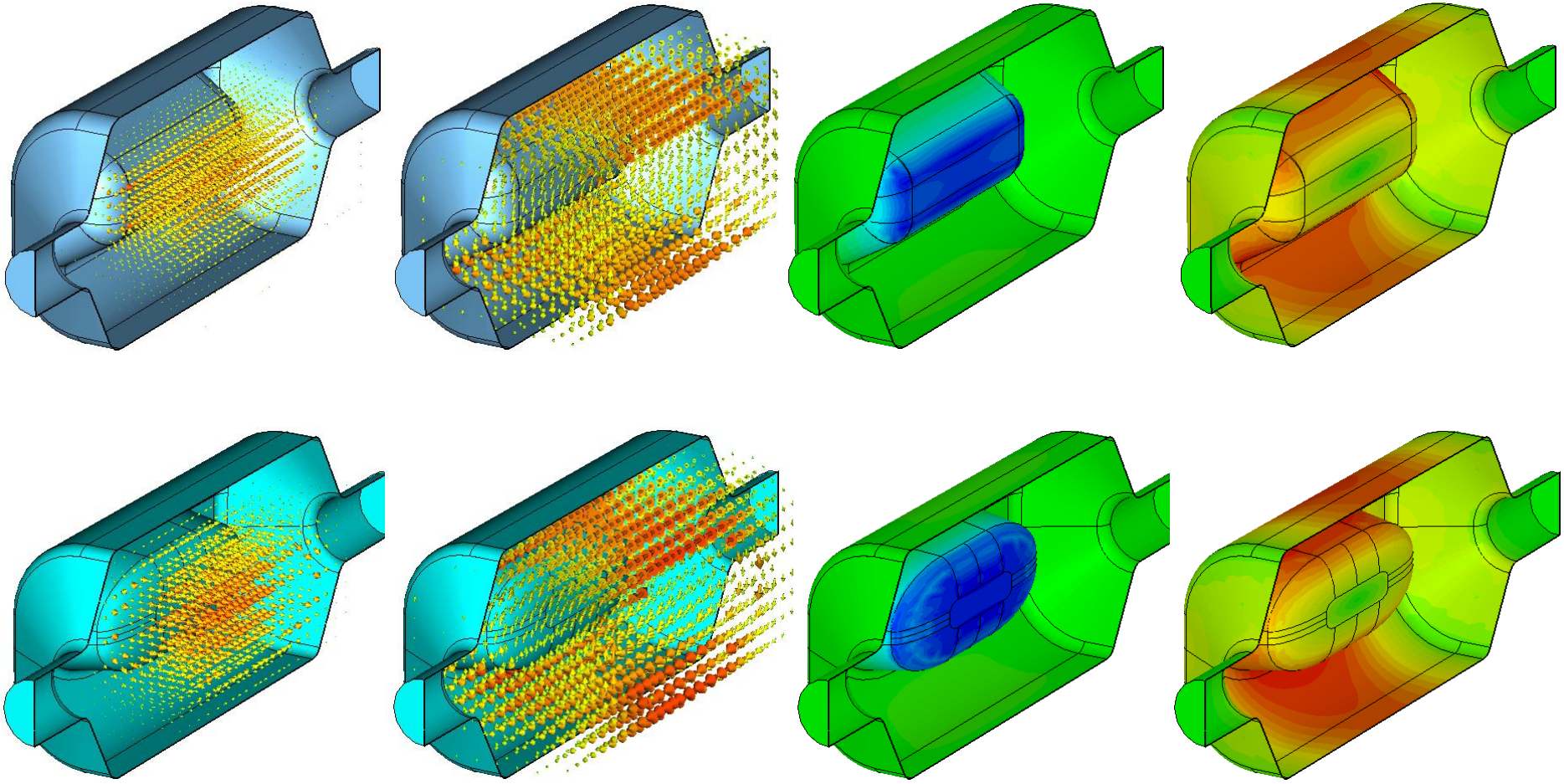
- Designs are fairly similar in structure and properties
- Final choice depends on final specifications
  - Field uniformity
  - Impedance budget



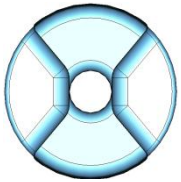
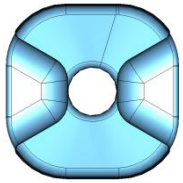
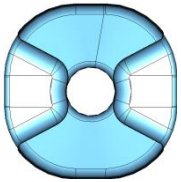
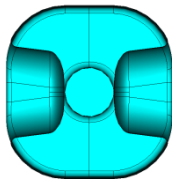


Field Distribution

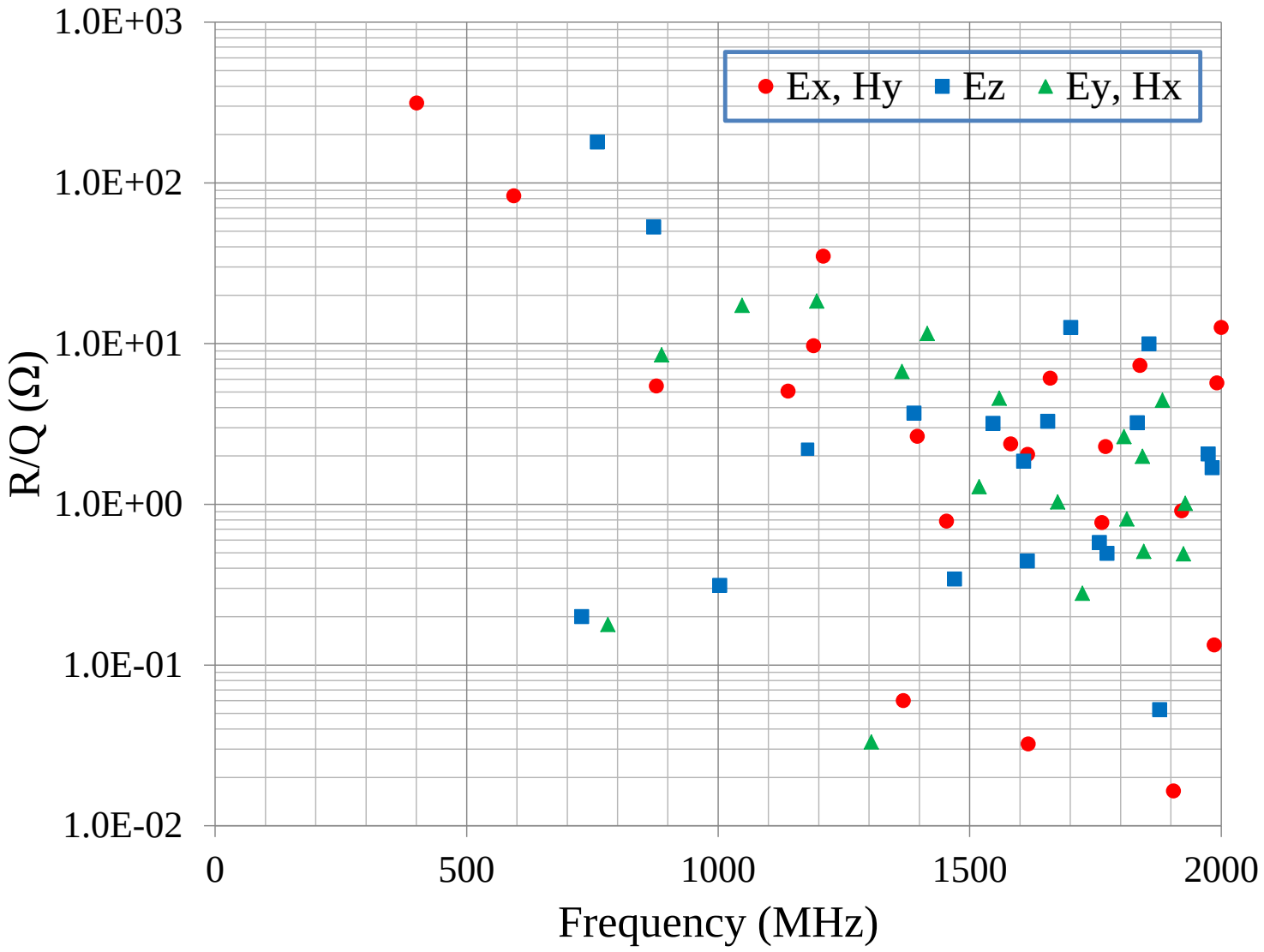
E Field | H Field | Peak E Field | Peak H Field



400 MHz Square Cavity Design Properties

Parameter					Unit
Frequency of 0 mode	729.5	727.4	757.0	712.4	MHz
Nearest mode to π mode	593.4	593.2	581.8	612.5	MHz
Cavity reference length	520.0	597.2	597.2	597.2	mm
Cavity diameter	339.8	295.0	295.0	295	mm
Bars length	345.0	350.3	350.3	350.3	mm
Bars height	80.0	85.0	85.0	136.0	mm
Angle	50.0	30.0	30.0	11.0	Deg
Aperture diameter	84.0	84.0	84.0	84.0	mm
Deflecting voltage (V_T^*)	0.375	0.375	0.375	0.375	MV
Peak electric field (E_P^*)	3.82	3.86	4.23	3.75	MV/m
Peak magnetic field (B_P^*)	7.09	6.9	7.69	6.85	mT
B_P^* / E_P^*	1.86	1.79	1.82	1.83	mT / (MV/m)
Non-Uniformity at 15 mm offset in x	2.06	2.83	0.45	2.08	%
Non-Uniformity at 15 mm offset in y	2.23	3.11	0.98	2.19	%
Geometrical factor ($G = QR_S$)	119.7	115.0	108.5	152.9	Ω
$[R/Q]_T$	312.2	315.7	336.4	331.1	Ω
$R_T R_S$	3.7×10^4	3.6×10^4	3.7×10^4	5.1×10^4	Ω^2
At E_T^* = 1 MV/m					

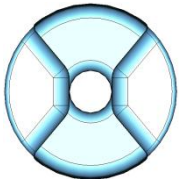
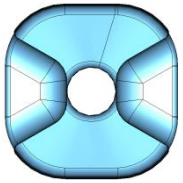
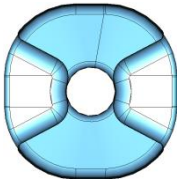
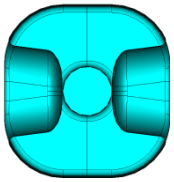
Square Cavity – HOM Properties



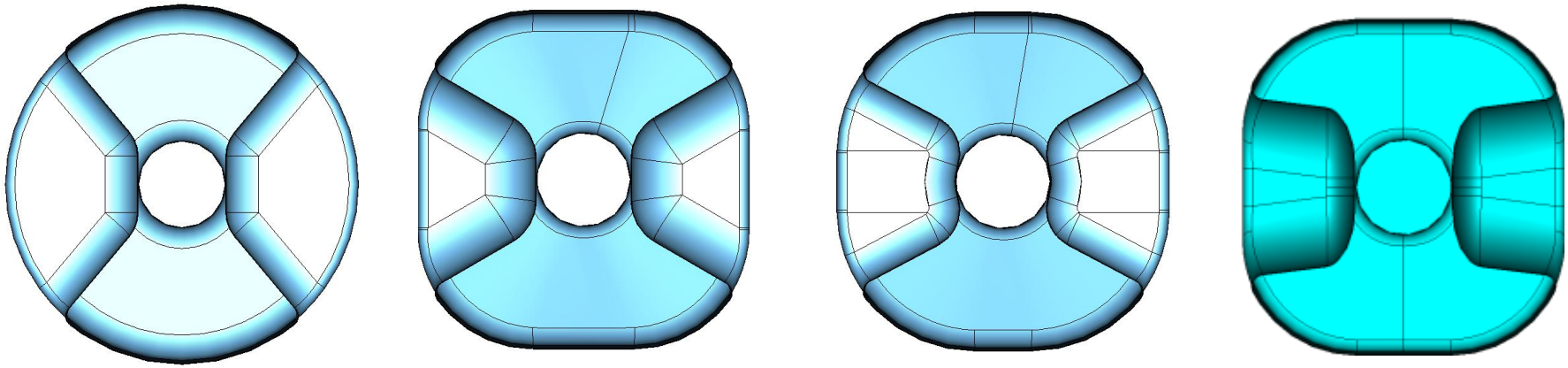
Power Dissipation

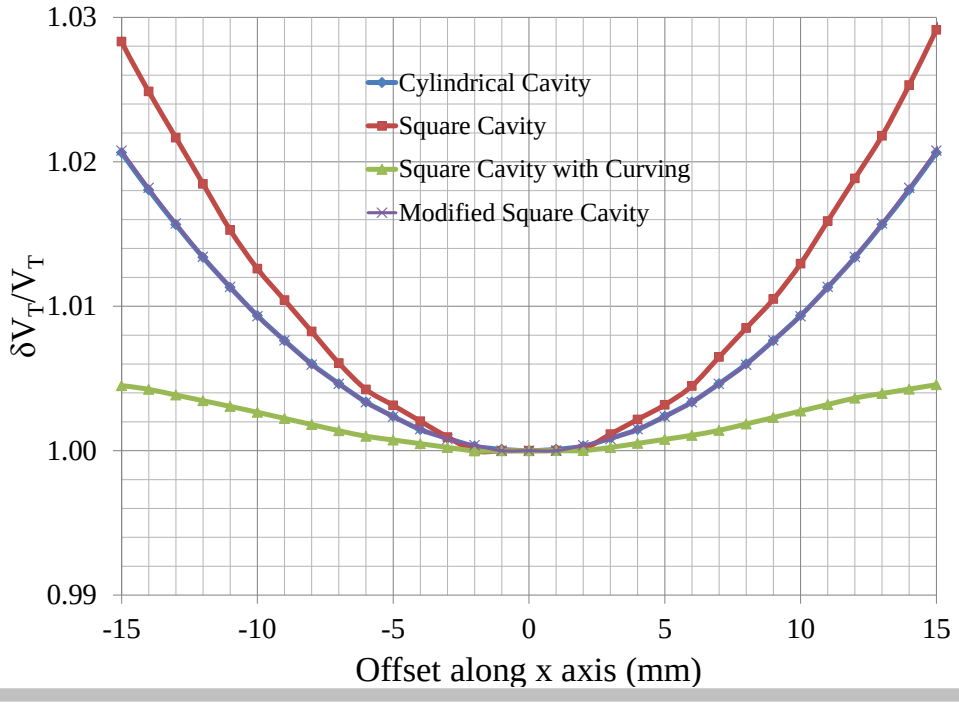
- Surface resistance of Nb at 400 MHz
  - 4.5K: 95 nΩ→105 nΩ
  - 2K: 1.3 nΩ→10 nΩ

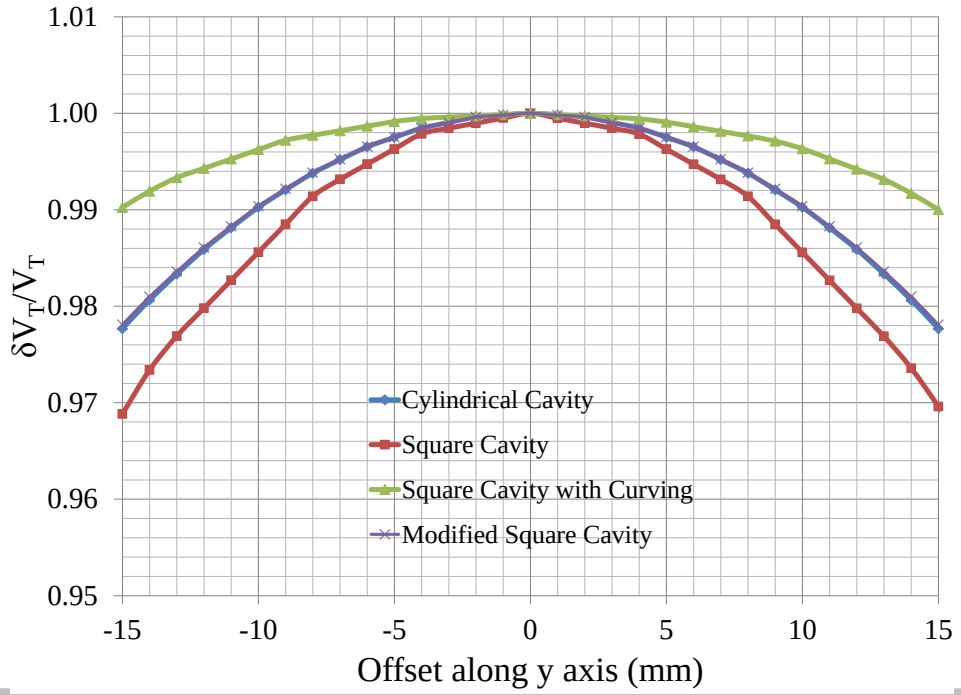
$$P = \frac{V^2}{\left(QR_s\right)\left(R/Q\right)} R_s$$

Parameter					Unit
Deflecting voltage (V_T^*)	0.375	0.375	0.375	0.375	MV
Peak electric field (E_P^*)	3.82	3.86	4.23	3.75	MV/m
Peak magnetic field (B_P^*)	7.09	6.9	7.69	6.85	mT
B_P^* / E_P^*	1.86	1.79	1.82	1.83	mT / (MV/m)
E_P at 3 MV	30.6	30.9	33.8	30.0	MV
B_P at 3 MV	56.7	55.2	61.5	54.8	mT
E_P at 5 MV	51.3	51.5	56.4	50.0	MV
B_P at 5MV	94.5	92.0	102.5	91.3	mT
$R_T R_S$	3.7×10^4	3.6×10^4	3.7×10^4	5.1×10^4	Ω^2
P at 4.5 K at 3 MV	25.5	26.3	25.5	18.5	W
P at 2K at 3 MV	2.43	2.5	2.43	1.76	W
At E_T^* = 1 MV/m					

Square Cavity – Non-Uniformity





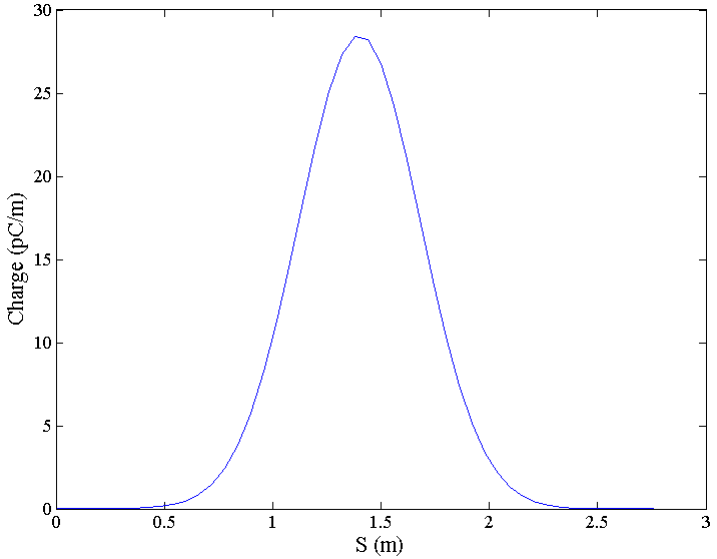


Wakefield and Impedance

- T3P – EM Time Domain Solver in the SLAC ACE3P Suite

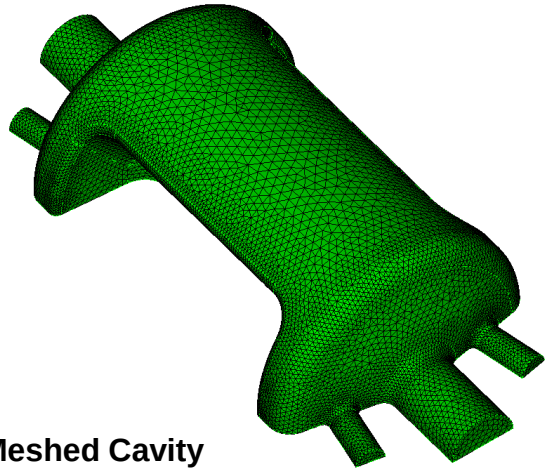
- Bunch Parameters
  - σ = 0.014 m
  - charge = 1 pC

$$\lambda(s) = \frac{1}{\sigma\sqrt{2\pi}} \exp[-\frac{(s-s_0)^2}{2\sigma^2}]$$



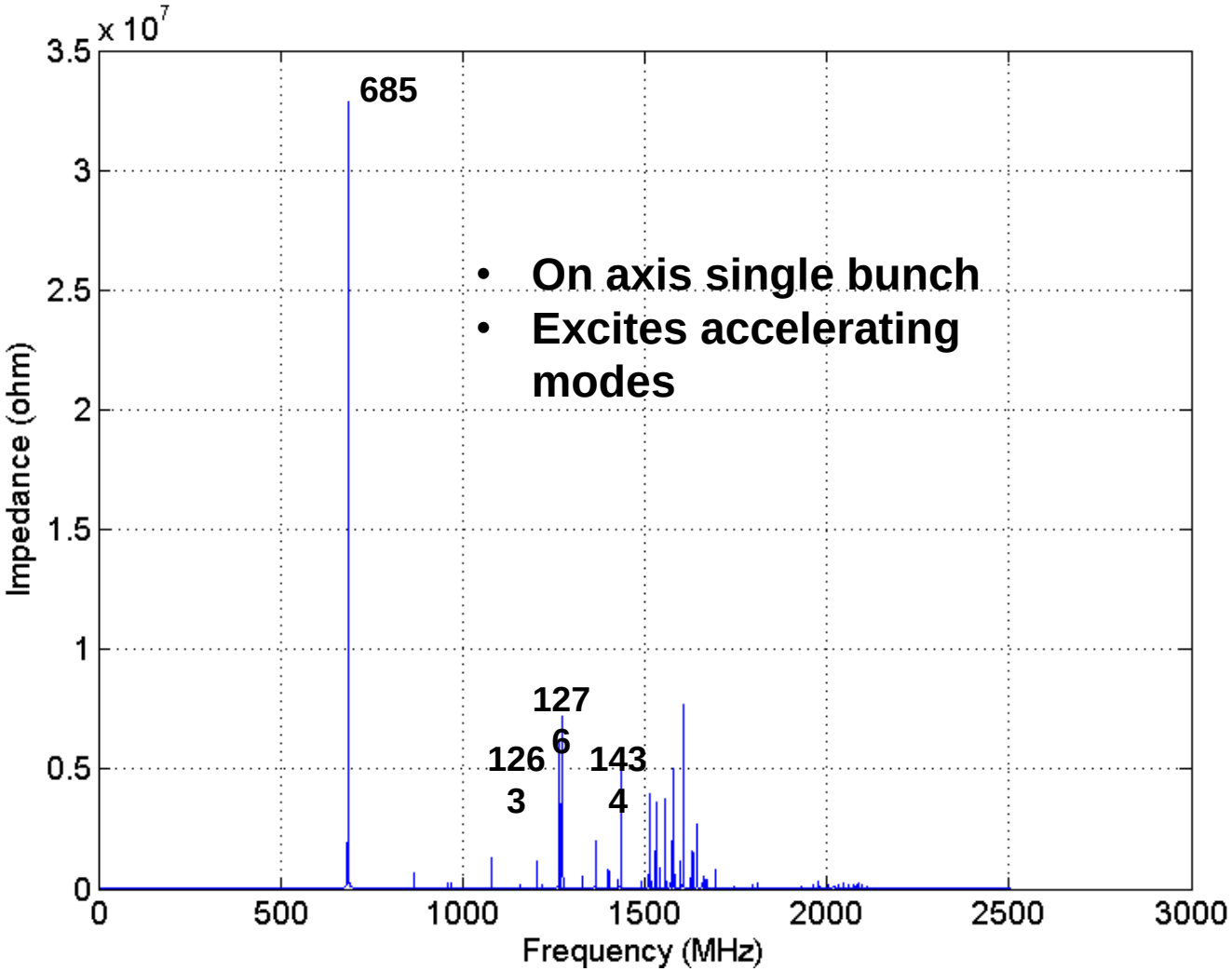
- Wakefield Parameters
  - # of points = 50,000
  - Time stamp (dt) = 0.2 ns
  - Maximum wakefield distance (S) = 3000 m
  - RMS frequency for a 1.4 cm bunch ≈ 5 GHz

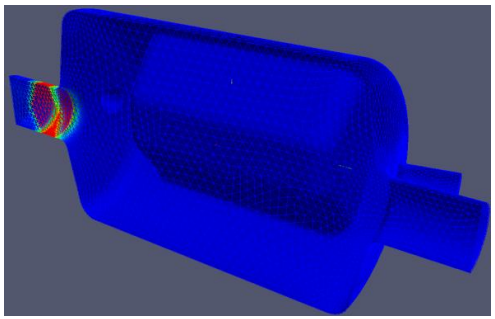
$$f_{RMS} = \frac{c}{\sqrt{2}\pi\sigma}$$

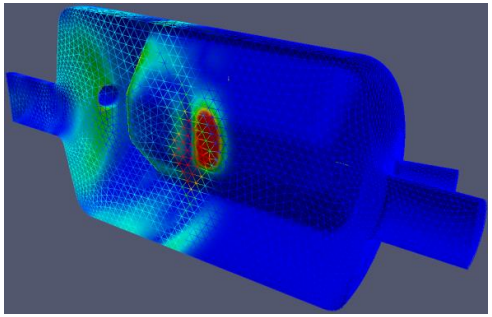


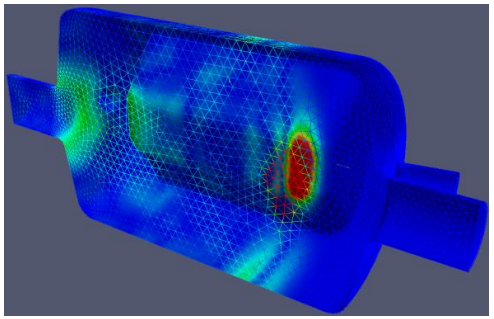
Meshed Cavity
No. of elements = 324560

Single Bunch Wakefields

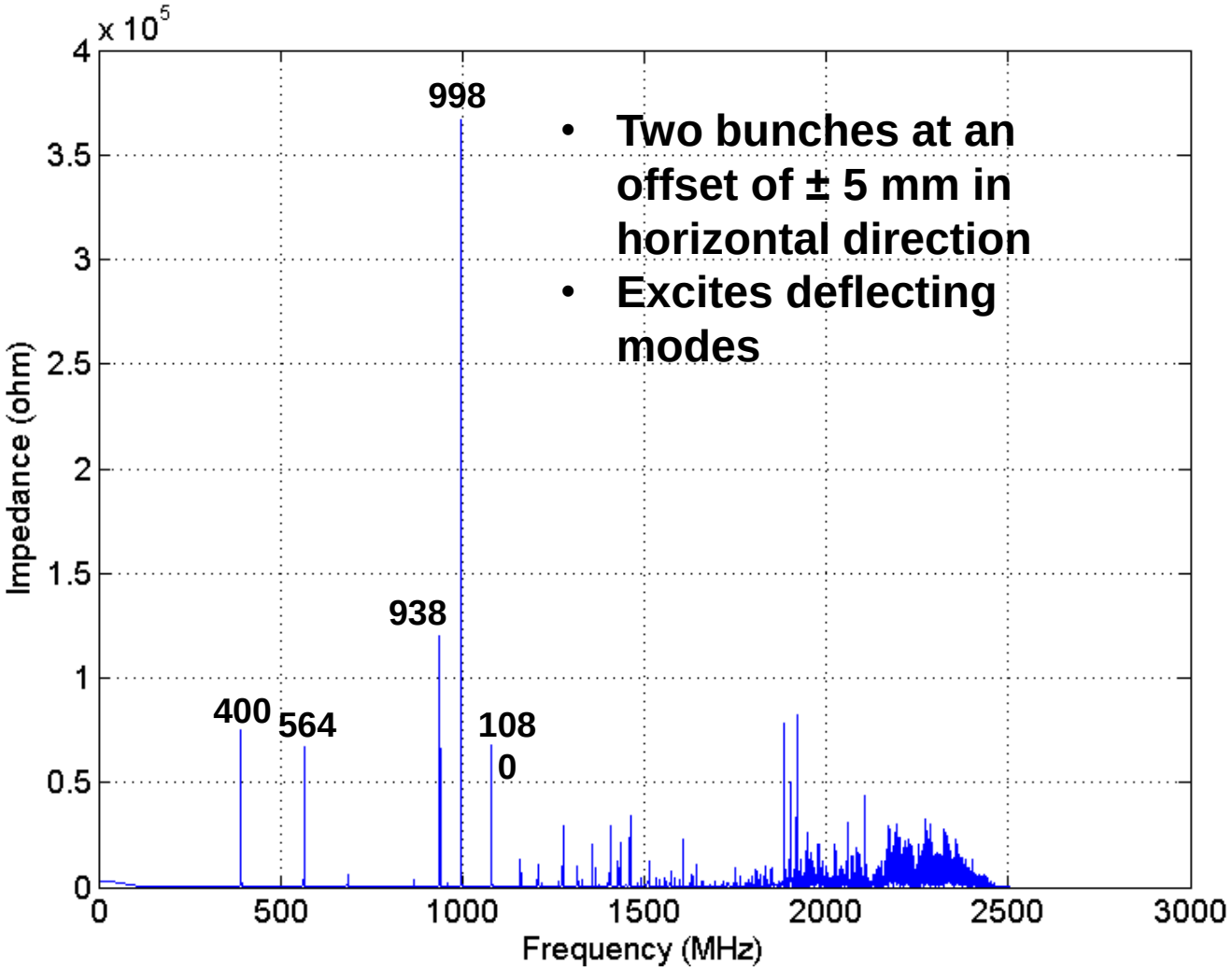




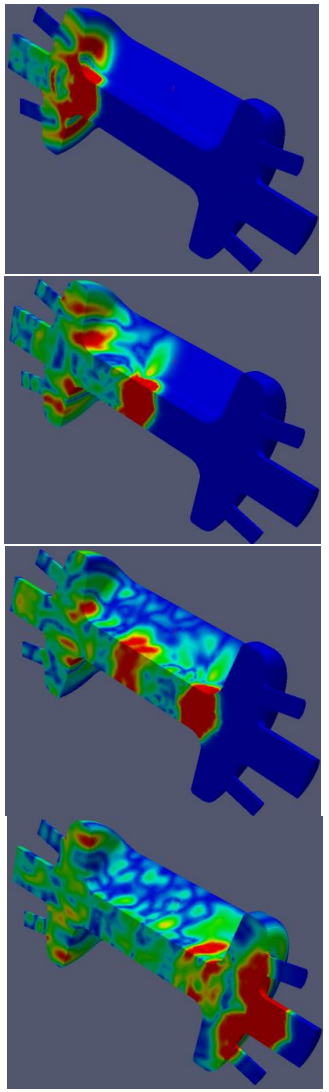




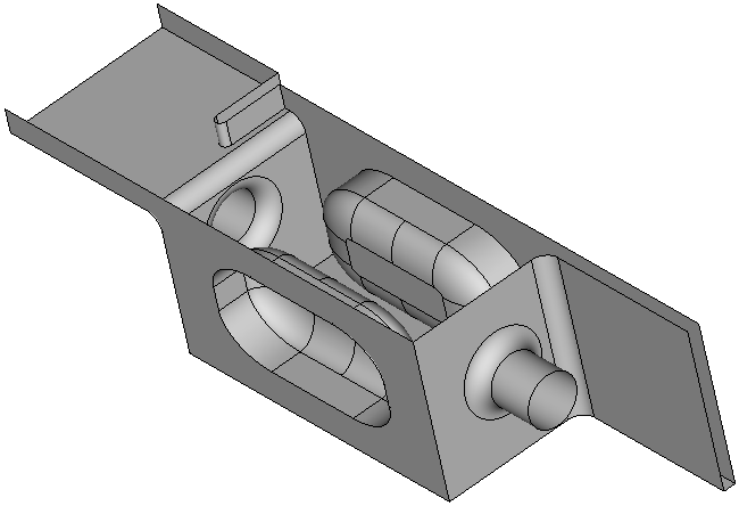
Two Bunch Wakefields



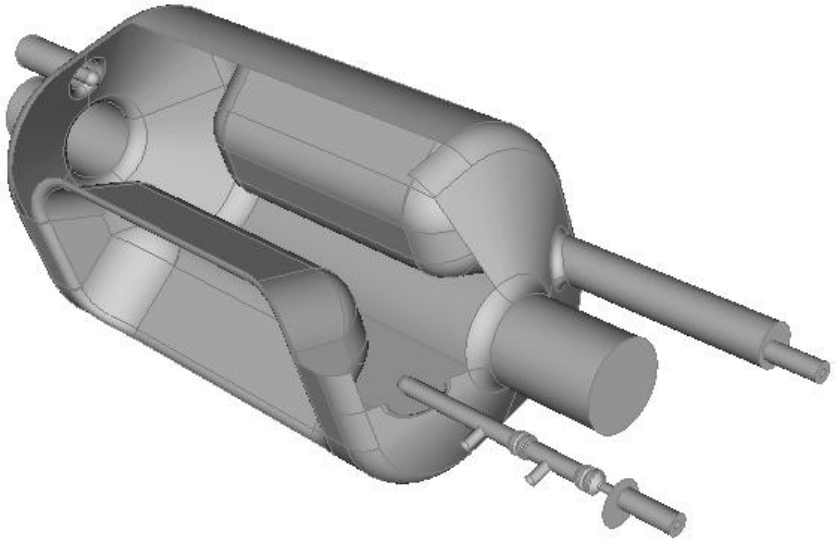
- Two bunches at an offset of ± 5 mm in horizontal direction
- Excites deflecting modes



HOM Damping



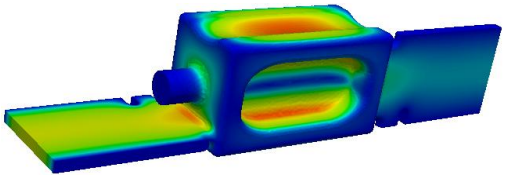
OR

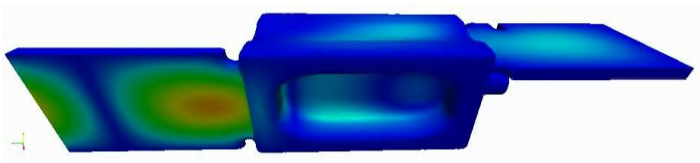


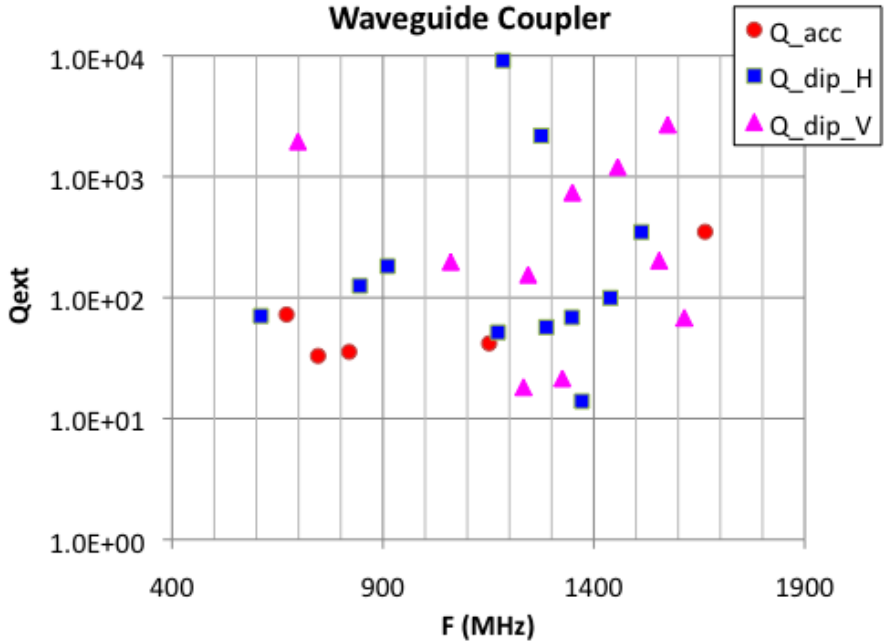
- Waveguide to damp H/V dipole and accelerating HOMs
- No filter needed
- One WG in each plane is enough for damping. WG stub maybe needed to symmetrize field

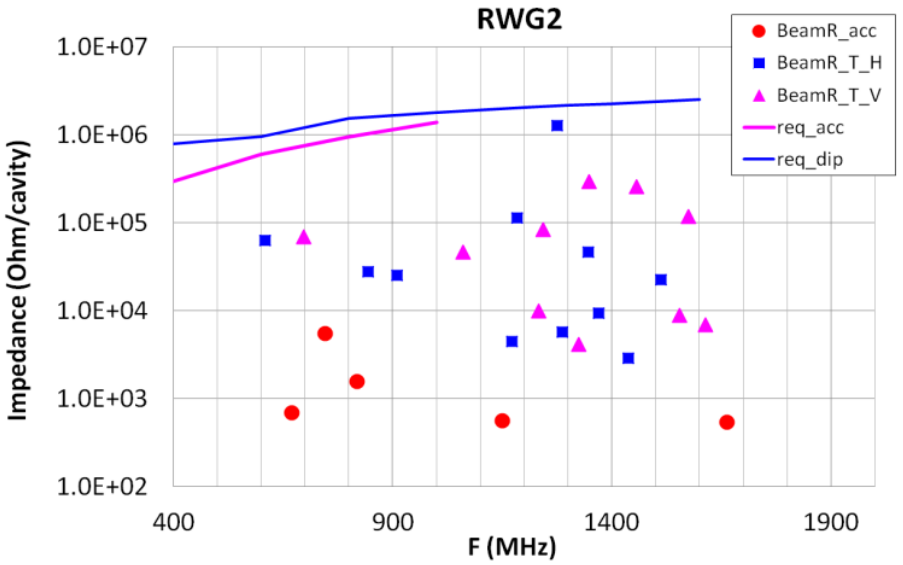
- Coaxial high-pass filter coupler
- Next HOM ~200MHz higher than operating mode. A two-stage high-pass filter maybe adequate
- Compact

Qext with Waveguide Coupler



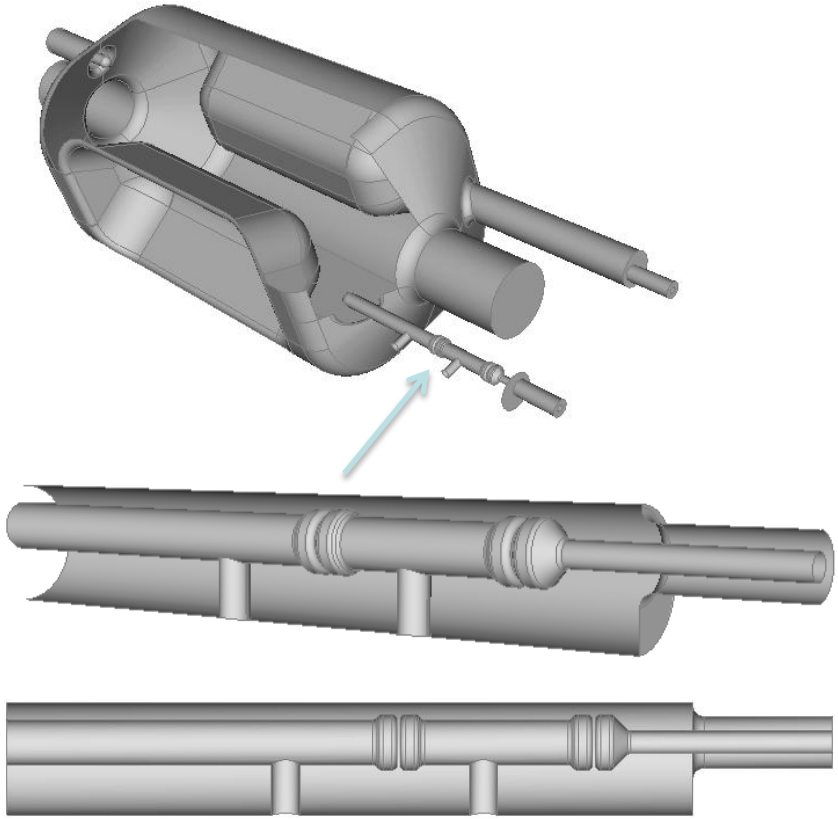


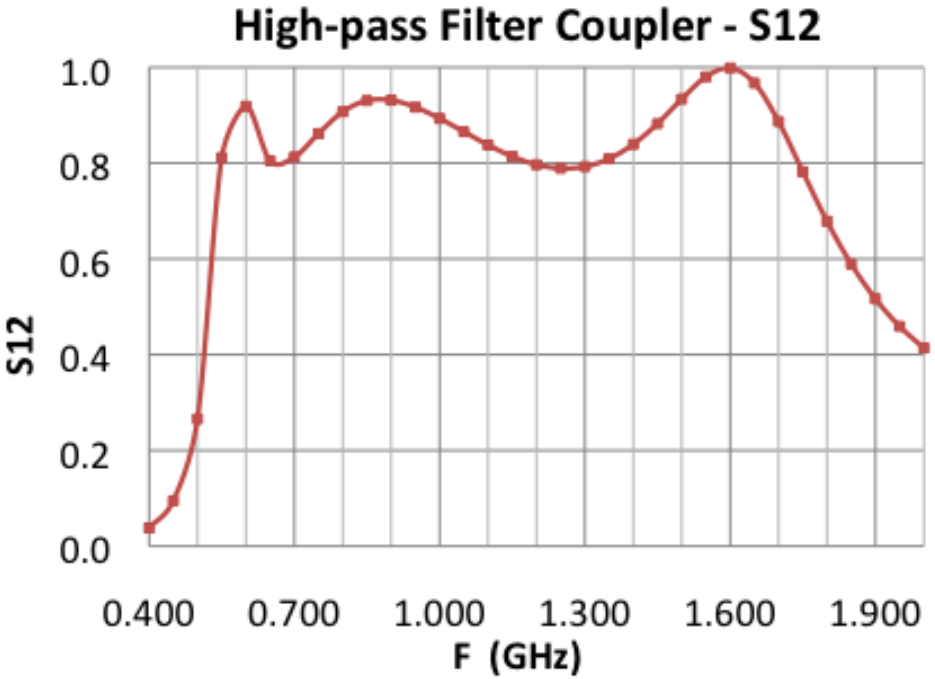




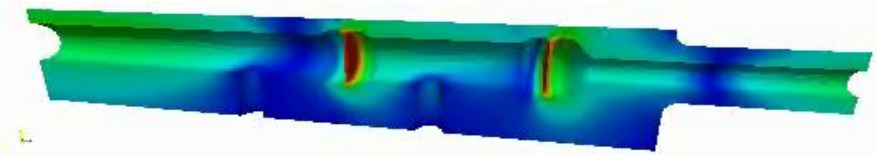
Strong damping achieved with waveguide couplers

High-Pass HOM Damper

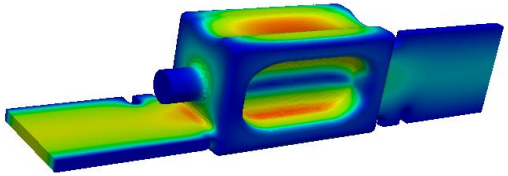


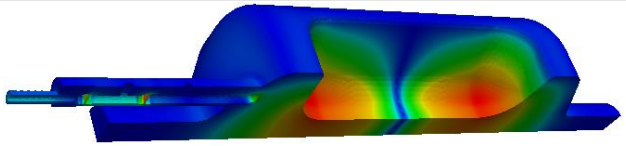


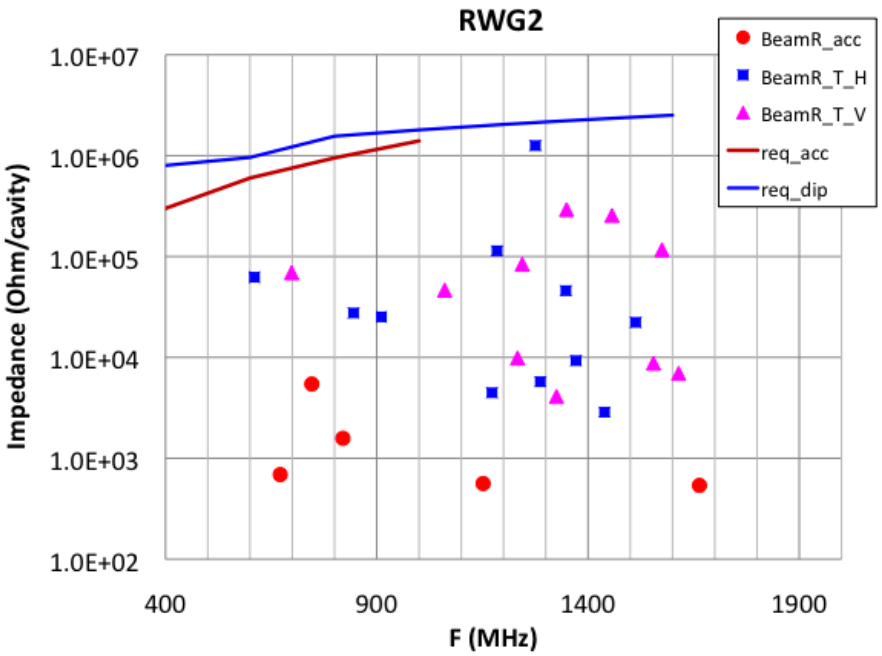
Two-stage high-pass coupler

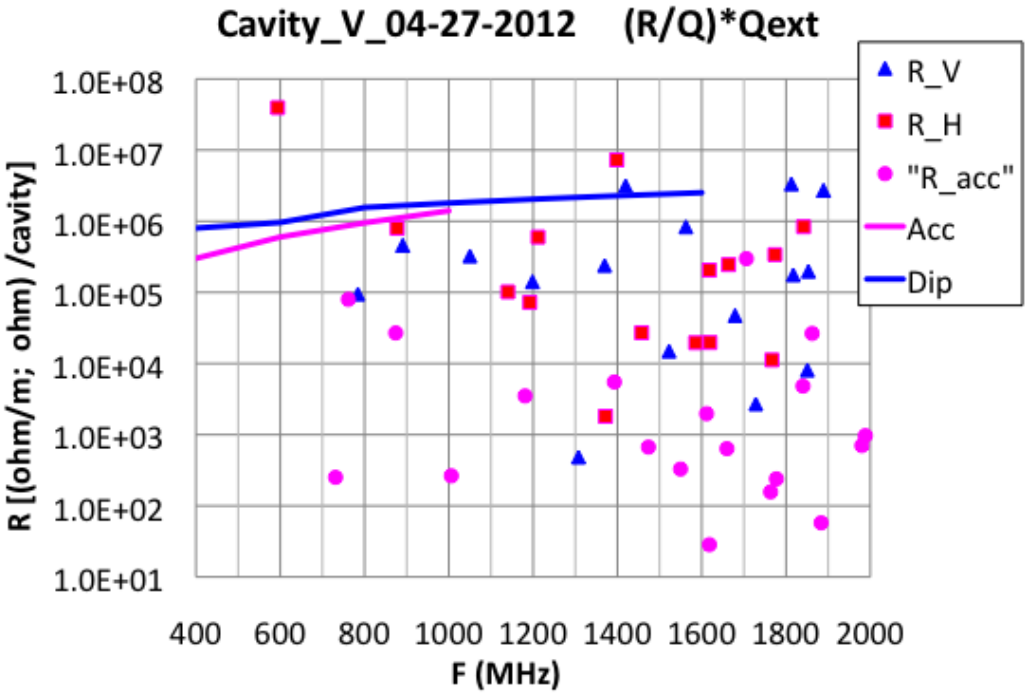


Waveguide vs Coaxial Coupler









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