RF DIPOLE DESIGN UPDATE

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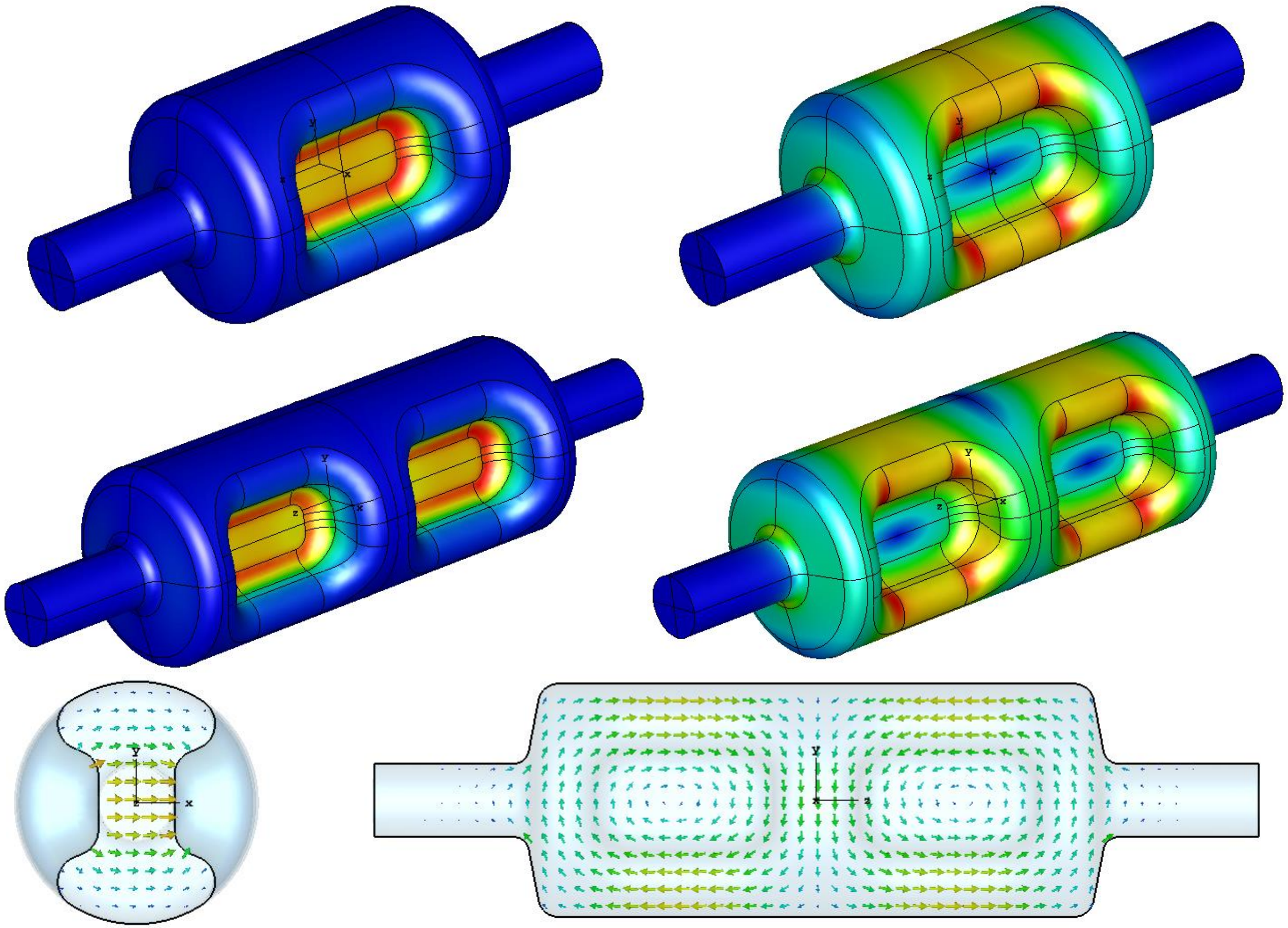
Outline

- 1.3 GHz RF-Dipole cavity design
- Pole separation
- 1.3 GHz RFD crab cavity for ILC
- Fundamental power coupler
- Higher order modes and impedances
- Mechanical analysis
  - Stress analysis
  - Lorentz detuning
  - Pressure sensitivity
- Summary

1.3 GHz RFD Cavity Design



Property	1-cell	2-cell
Operating frequency [GHz]	1.3	1.3
SOM [GHz]	–	1.188
1^{st} HOM [GHz]	2.069	1.932
E_p/E_t^*	4.45	4.57
B_p/E_t^* [mT/(MV/m)]	9.09	8.92
B_p/E_p [mT/(MV/m)]	2.04	1.95
G [Ω]	142.5	147.3
R/Q [Ω] (V^2/P)	182.2	370.7
R_tR_s [Ω^2] (V^2/P)	2.6×10^4	5.5×10^4
Reference length $V/E_t = \lambda/2$ (mm)	11.54	11.54
V_t [MV]	1.0	2.0
E_p [MV/m]	38.58	39.66
B_p [mT]	78.85	77.36
Pole separation, beam aperture (mm)	36	36
Cavity Length [mm]	172.32	297.4
Cavity Diameter [mm]	128.6	114.5
Pole Length [mm]	85	85

1.3 GHz RFD - 36 vs 30 mm Pole Separation

Property	1-cell	2-cell
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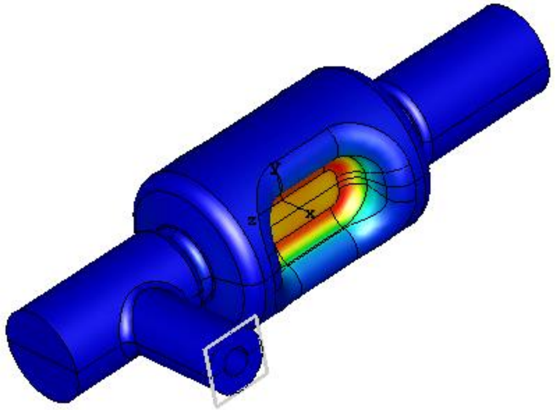
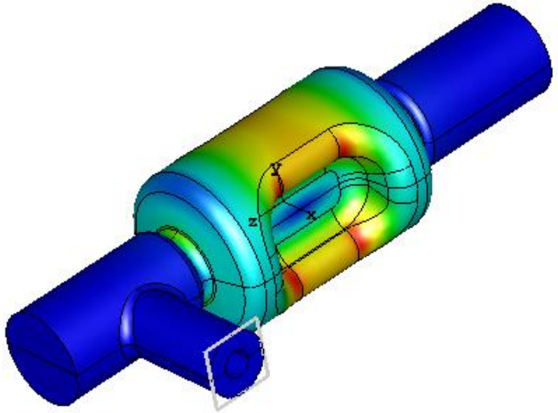
Property	1-cell	2-cell
Operating frequency [GHz]	1.3	1.3
SOM [GHz]	–	1.201
1st HOM [GHz]	2.085	1.960
E_p/E_t^*	3.84	3.98
B_p/E_t^* [mT/(MV/m)]	8.04	7.94
B_p/E_p [mT/(MV/m)]	2.10	1.99
G [Ω]	133.0	137.2
R/Q [Ω] (V^2/P)	280.2	556.7
R_tR_s [$Ω^2$] (V^2/P)	3.7×10^4	7.6×10^4
Reference length $V/E_t = \lambda/2$ (mm)	11.54	11.54
V_t [MV]	1.0	2.0
E_p [MV/m]	33.3	34.54
B_p [mT]	69.7	68.82
Pole separation, beam aperture (mm)	30	30
Cavity Length [mm]	172.32	297.4
Cavity Diameter [mm]	107.4	109.4
Pole Length [mm]	85	85

1.3 GHz RFD Cavity



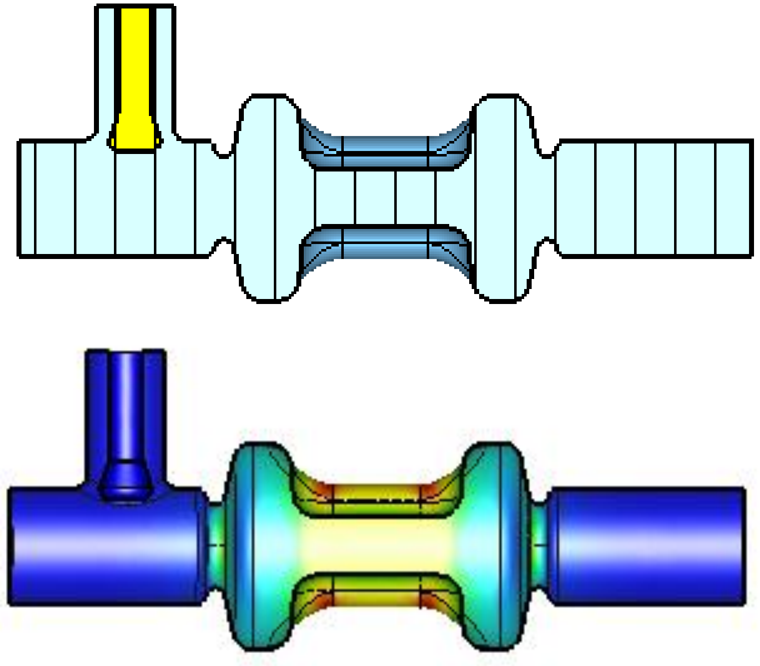


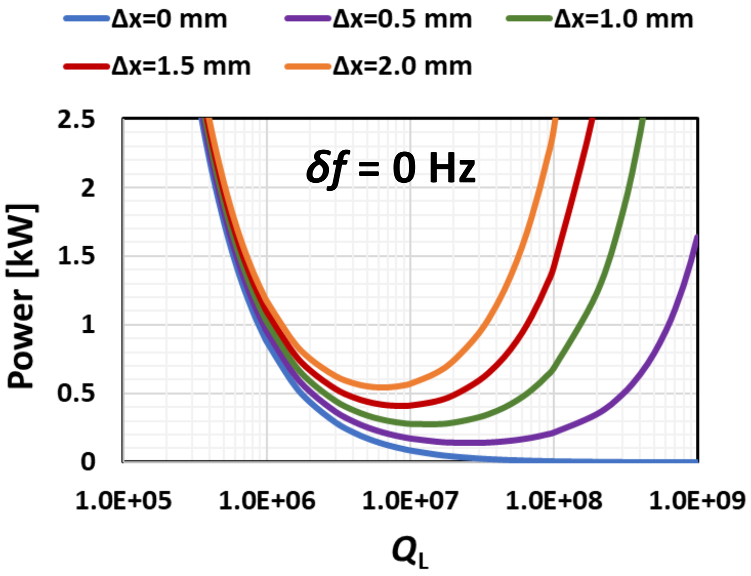
- Pole separation – 30 mm
  - Decided this pole separation from the past experience, to guarantee good high pressure rinsing
- Beam aperture – 40 mm
  - For HOM mode propagation

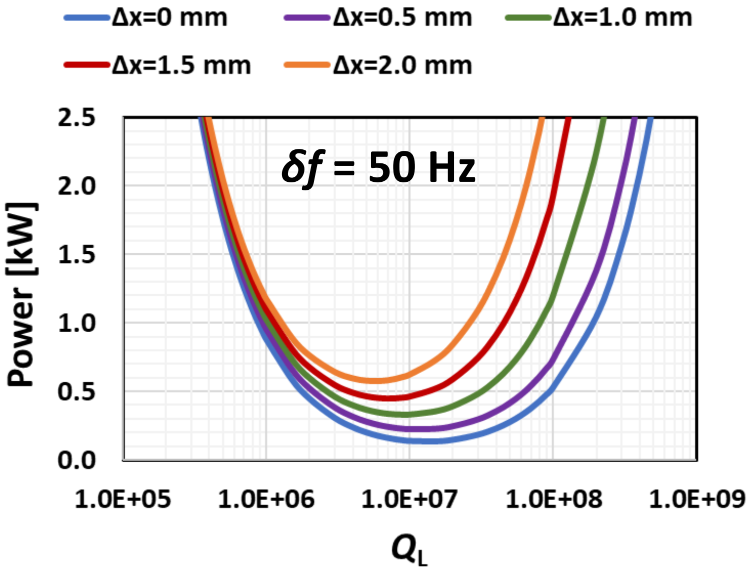
	250 GeV	1 TeV
V_t per cavity [MV]	1.0	1.0
Total V_t [MV]	1.845	7.4
Number of cavities	2	8

Property	1-cell	
Operating frequency [GHz]	1.3	
SOM [GHz]	–	
1^{st} HOM [GHz]	2.08	
E_p/E_t^*	3.87	
B_p/E_t^* [mT/(MV/m)]	8.02	
B_p/E_p [mT/(MV/m)]	2.07	
G [Ω]	133	
R/Q [Ω] (V^2/P)	285	
R_tR_s [Ω^2] (V^2/P)	3.8×10^4	
Reference length $V/E_t = \lambda/2$ (mm)	11.54	
V_t [MV]	1.0	1.15
E_p [MV/m]	34	39
B_p [mT]	70	80
P_{diss} [W] (R_s = 20 nΩ)	0.53	0.7
Pole separation (mm)	30	
Beam aperture (mm)	40	
Cavity Length [mm]	380	
Cavity Diameter [mm]	129.0	
Pole Length [mm]	85	

Fundamental Power Coupler







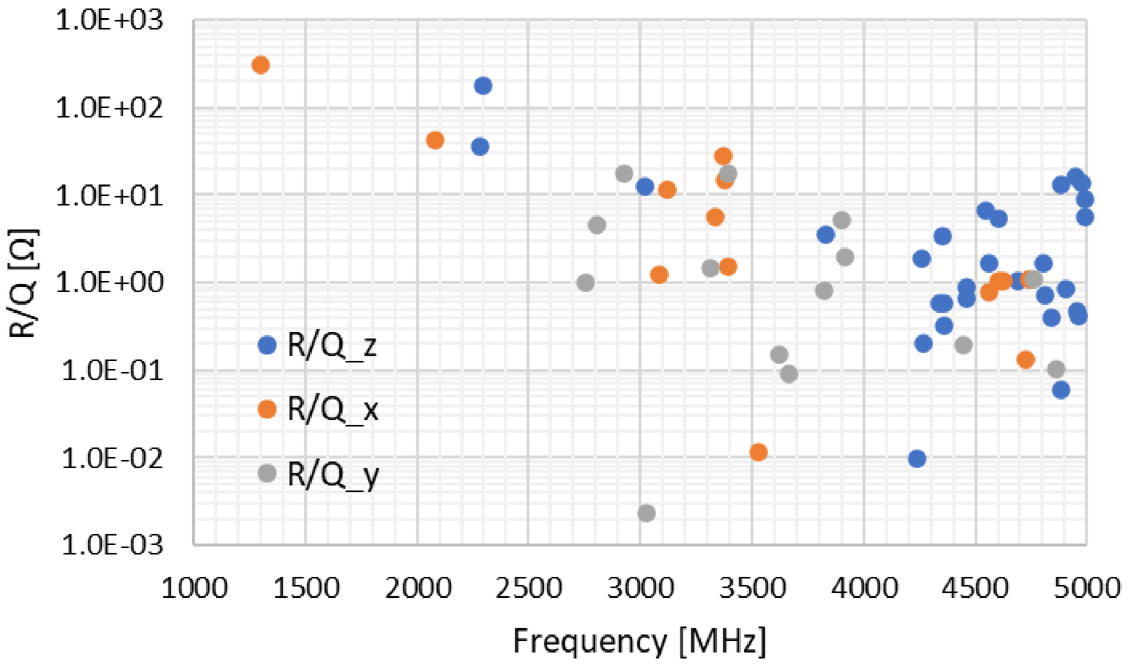
- Coupling using coaxial antenna
  - Similar to LCLS II power coupler
- $Q_{ext} = 1.0\times10^7$ at $\Delta x = 0.5$ mm $\delta f = 50$ Hz
- RF power ≈ 500 W
- RF heating at the Cu probe at 1 MV – 65 mW

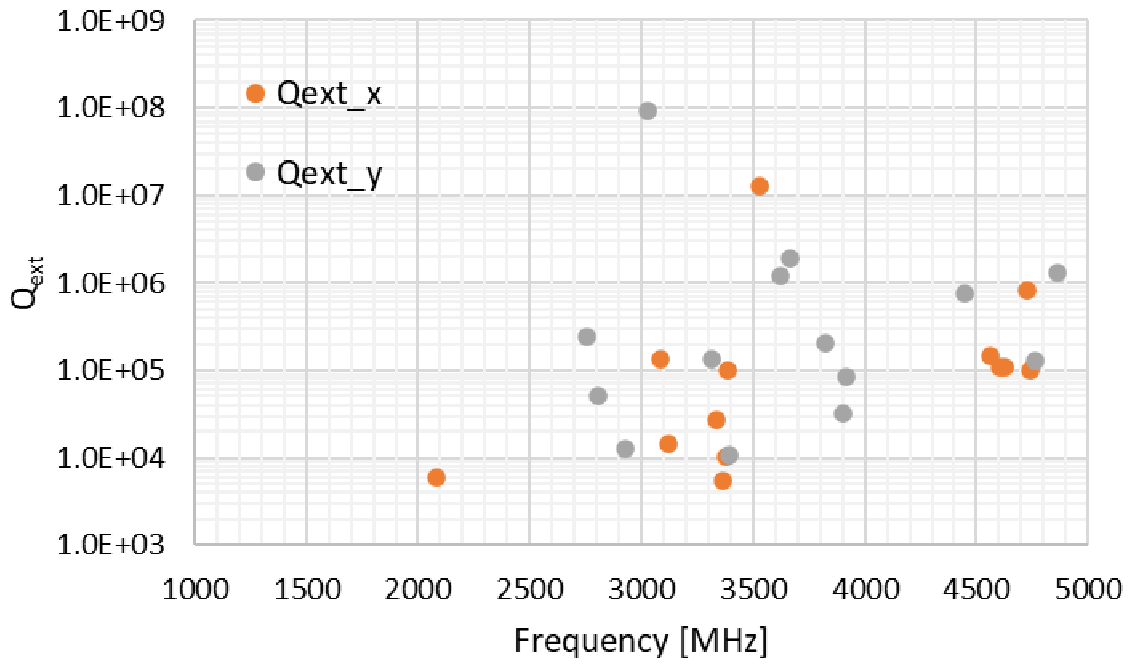
Beam and cavity parameters:

- $I_b = 10$ mA
- $R/Q = 285\ \Omega$ (V^2/P)
- $V_t = 1$ MV

Higher Order Modes

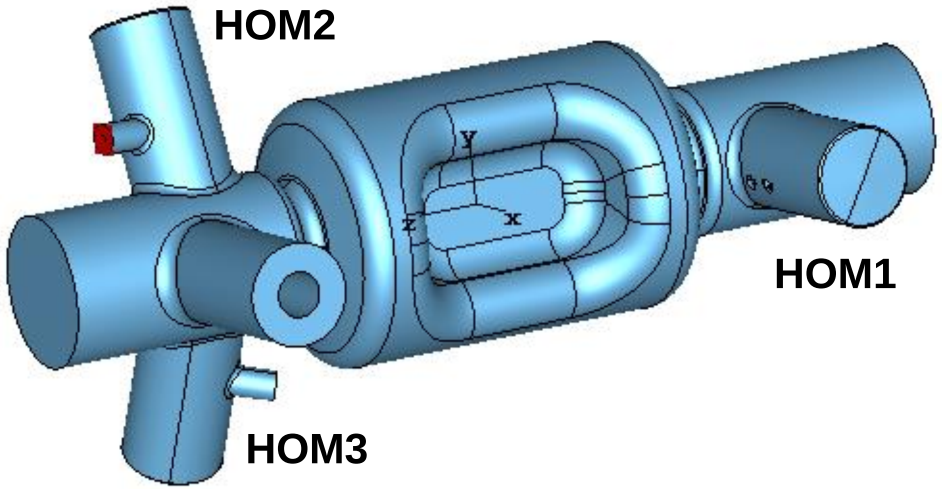
- Impedance threshold: Z_x = 48.8 MΩ/m and Z_y = 61.7 MΩ/m
- Impedance threshold per cavity: Z_x = 5.42 MΩ/m and Z_y = 6.85 MΩ/m (9 cavities per side)

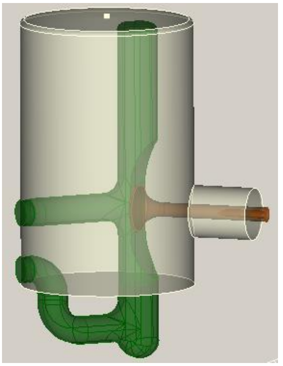




- For longitudinal modes need to evaluate loss factor for short range wakefields with σ_z = 0.3 mm

Higher Order Mode Damping



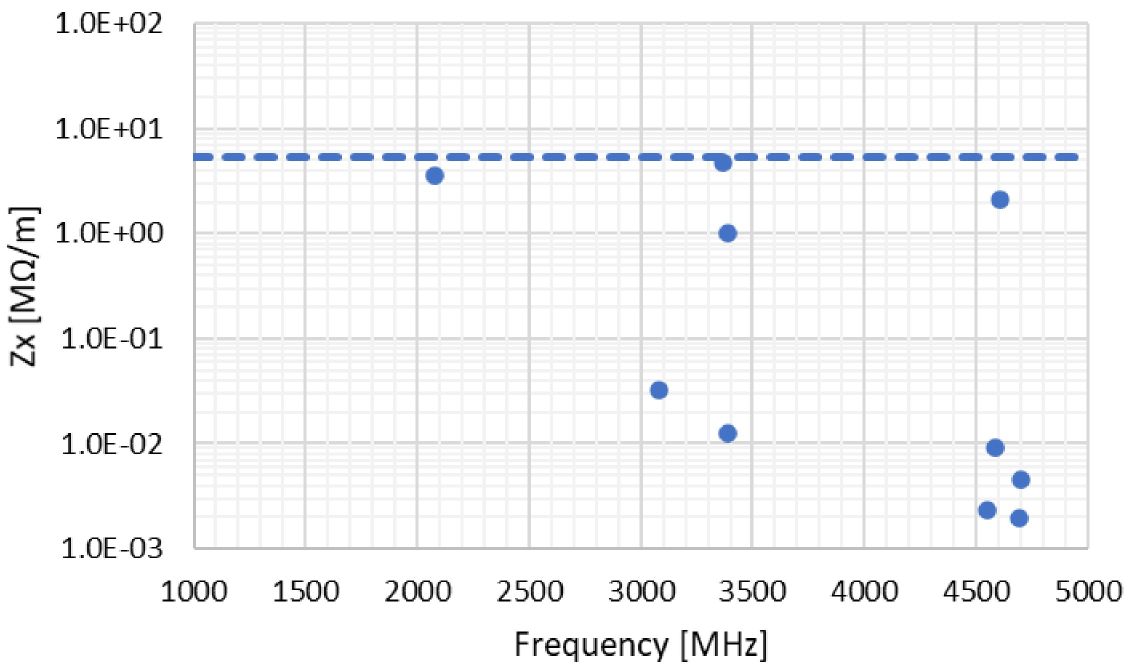


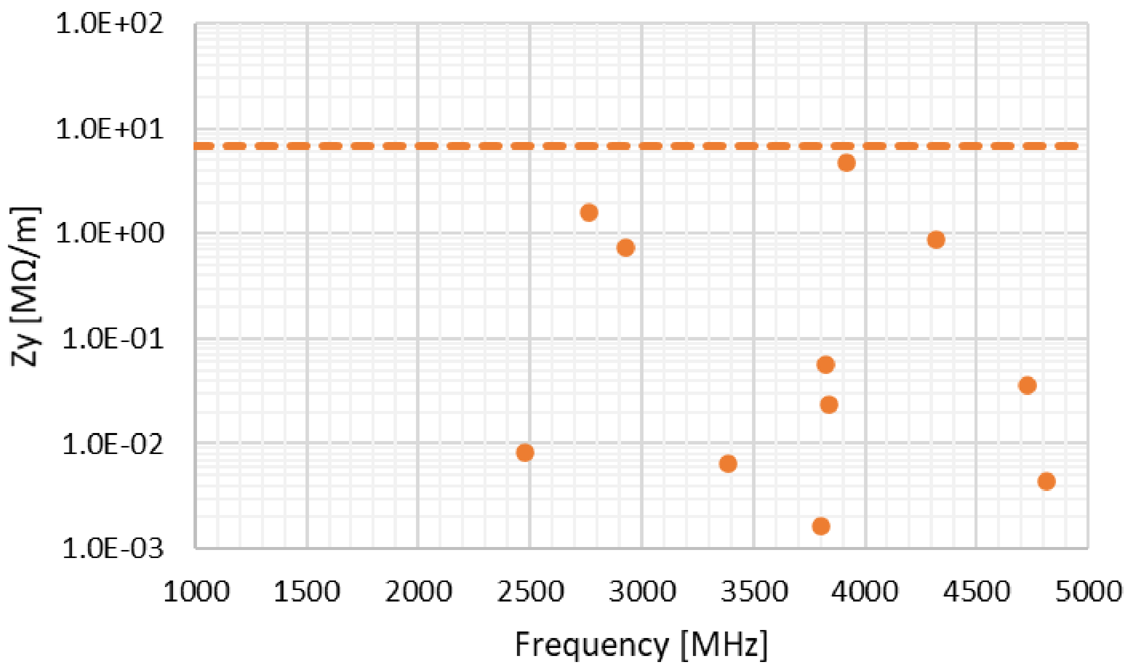
TESLA type HOM coupler

- 1st concept: Damping using 3 TESLA type HOM couplers
  - Damper design used in the LCLS II cavities
  - All the couplers are placed on the beam pipe
- Planning to investigate damping using the scaled LHC-RFD HOM coupler
- Waveguide damping is also a possible option
- Final choice will be decided based on
  - RF properties including HOM power
  - Engineering and manufacturing complexity

Higher Order Mode Damping

- Impedance threshold per cavity: Z_x = 5.42 MΩ/m and Z_y = 6.85 MΩ/m

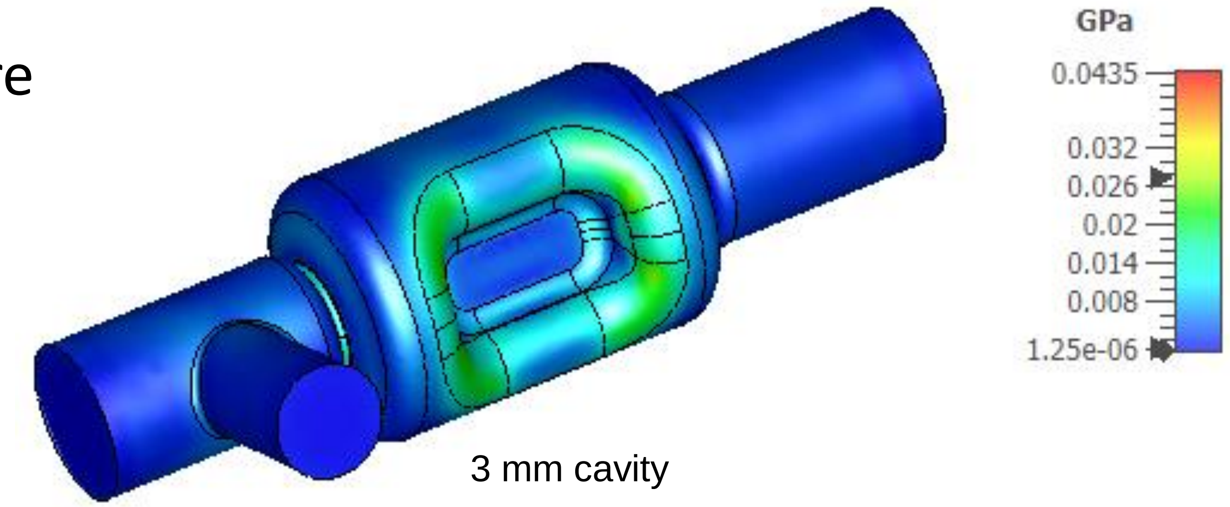




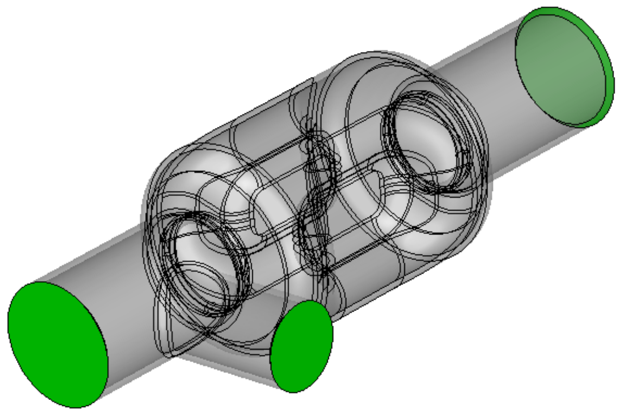
- Impedances calculated using circuit definition
- Need to evaluate up to ~ 20 GHz

Stress Analysis

- Analysis at 2.2 atm external pressure
- Nb material properties at room temperature
  - (JLAB-TN-09-002 – C100 Cryomodule Niobium Cavity Structural Analysis)
  - Young's modulus – 82.7 GPa (1.2×10^{7} psi)
  - Poisson's ratio – 0.38
- Allowable stress < 43.5 MPa



3 mm cavity



Boundary conditions

- Maximum stresses

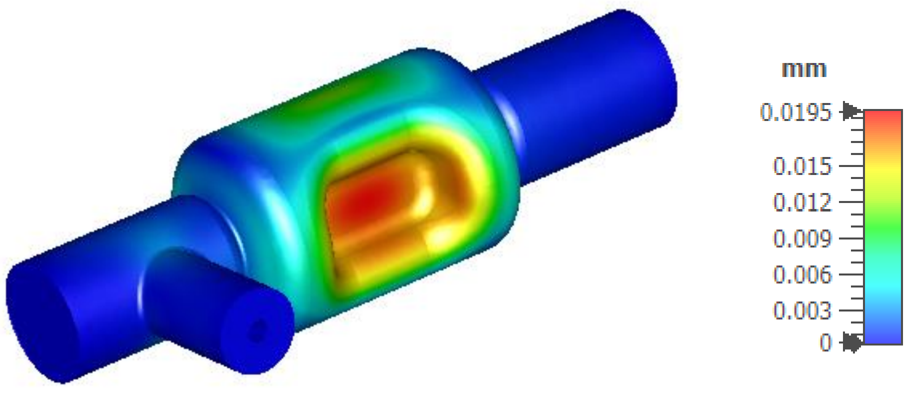
Cavity Thickness [mm]	Max. Stress [MPa]
2.5	36
3.0	27

- Initial analysis shows cavity doesn't require stiffening

Mechanical Analysis

Pressure Sensitivity

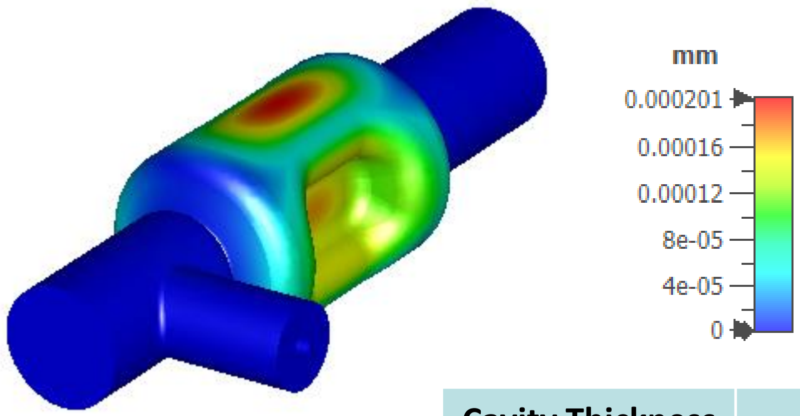
- Nb material properties at room temperature
  - Young's modulus – 82.7 GPa (1.2×10^7 psi)
  - Poisson's ratio – 0.38
- Stiffening at poles can reduce pressure sensitivity



Cavity Thickness [mm]	df/dP [Hz/mbar]
2.5	728
3.0	509

Lorentz Detuning

- Nb material properties at cryo temperature
  - Young's modulus – 123 GPa (1.79×10^7 psi)
  - Poisson's ratio – 0.38
- Lorentz detuning can be reduced by tuner
  - Tuning by push/pull at top and bottom of the cavity



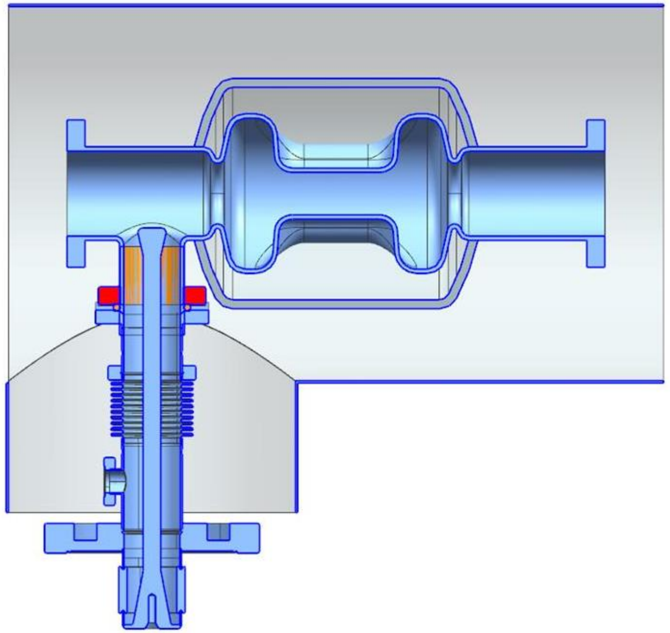
Stored energy = 0.45 J at 1 MV

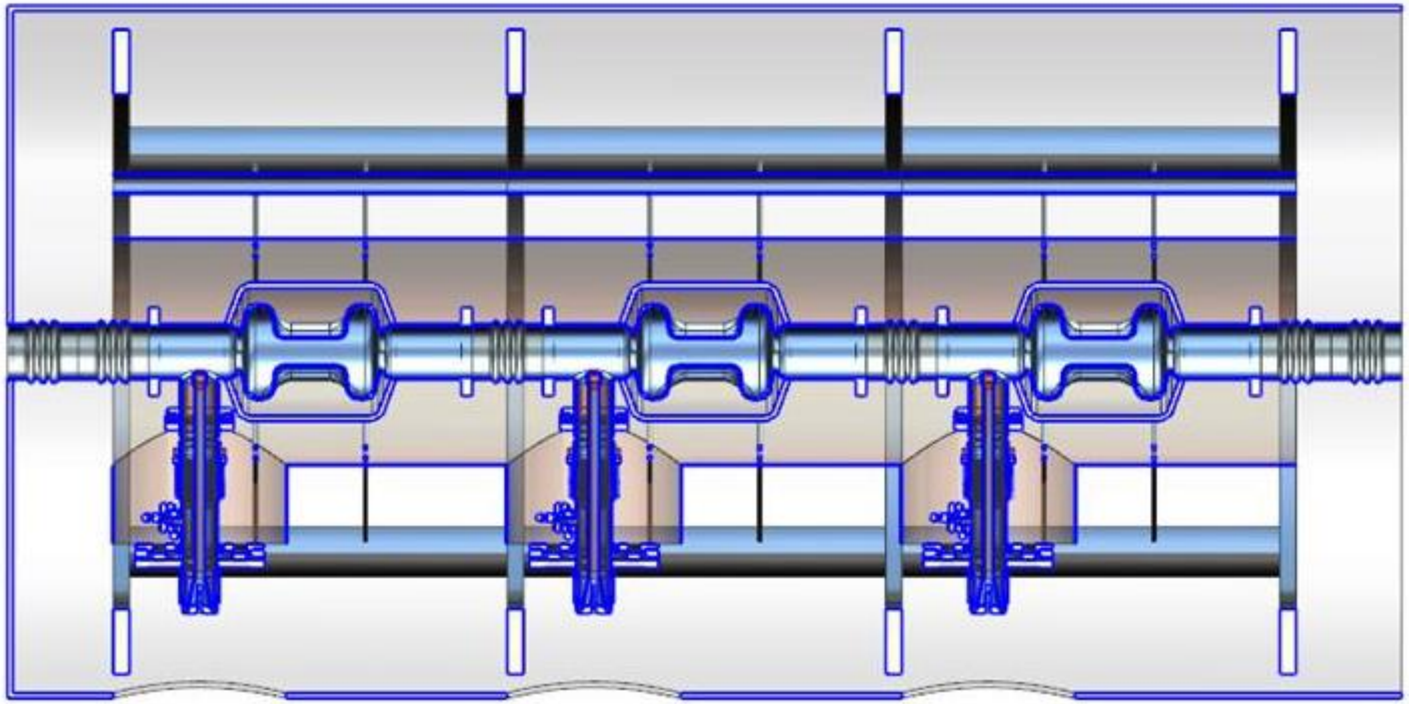
Cavity Thickness [mm]	k_L [kHz/(MV)^2]
2.5	– 7.44
3.0	– 5.04

Conceptual He Vessel and Cryomodule Design

- Cavity thickness – 3mm
- 3 cavities per cryomodule

- Second beam pipe:
  - 20 mm beam pipe
  - Outside the He vessel and within the cryomodule

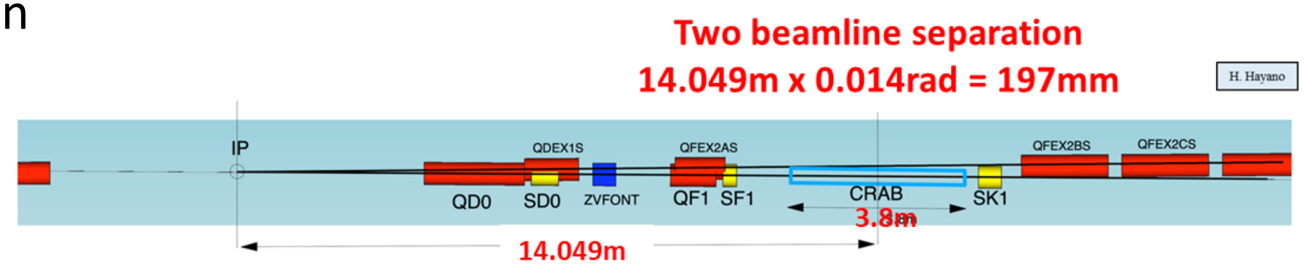


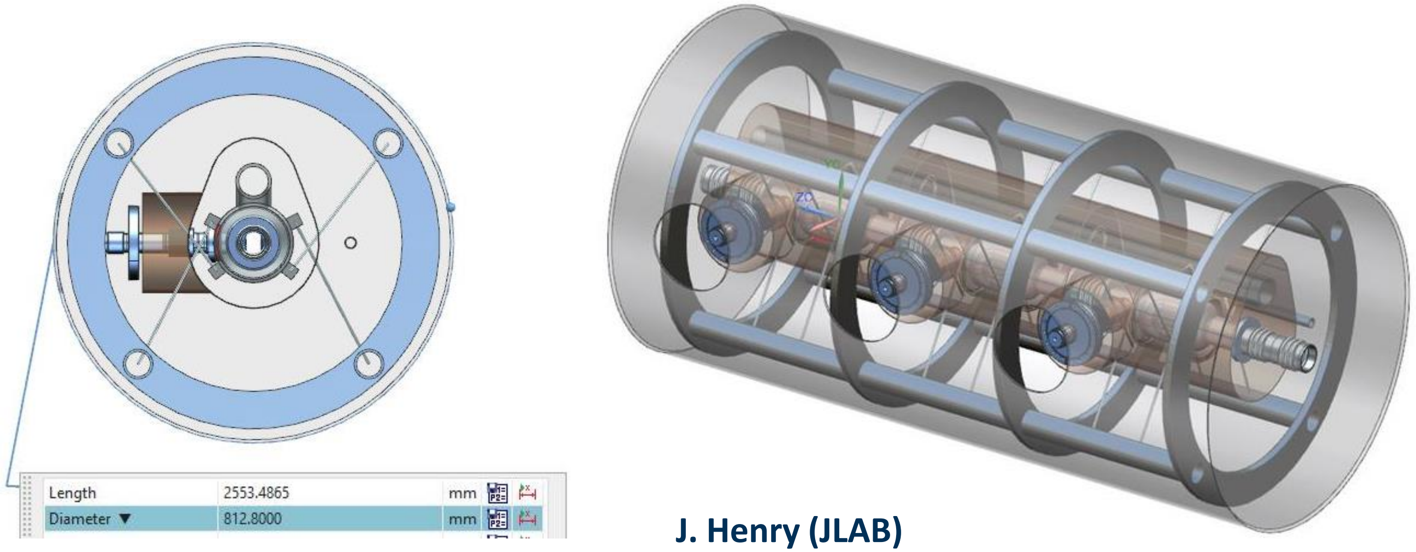


J. Henry (JLAB)

Conceptual He Vessel and Cryomodule Design

- 1 cryomodule for 1.845 MV at 250 GeV
  - 3 cavities in a single cryomodule allow operation with a cavity failure
- 3 cryomodules for 7.4 MV at 1 TeV
- Cryomodule size: length ~ 1.64 m and diameter ~ 0.82 m
- Design concept follows JLab C100 cryomodule





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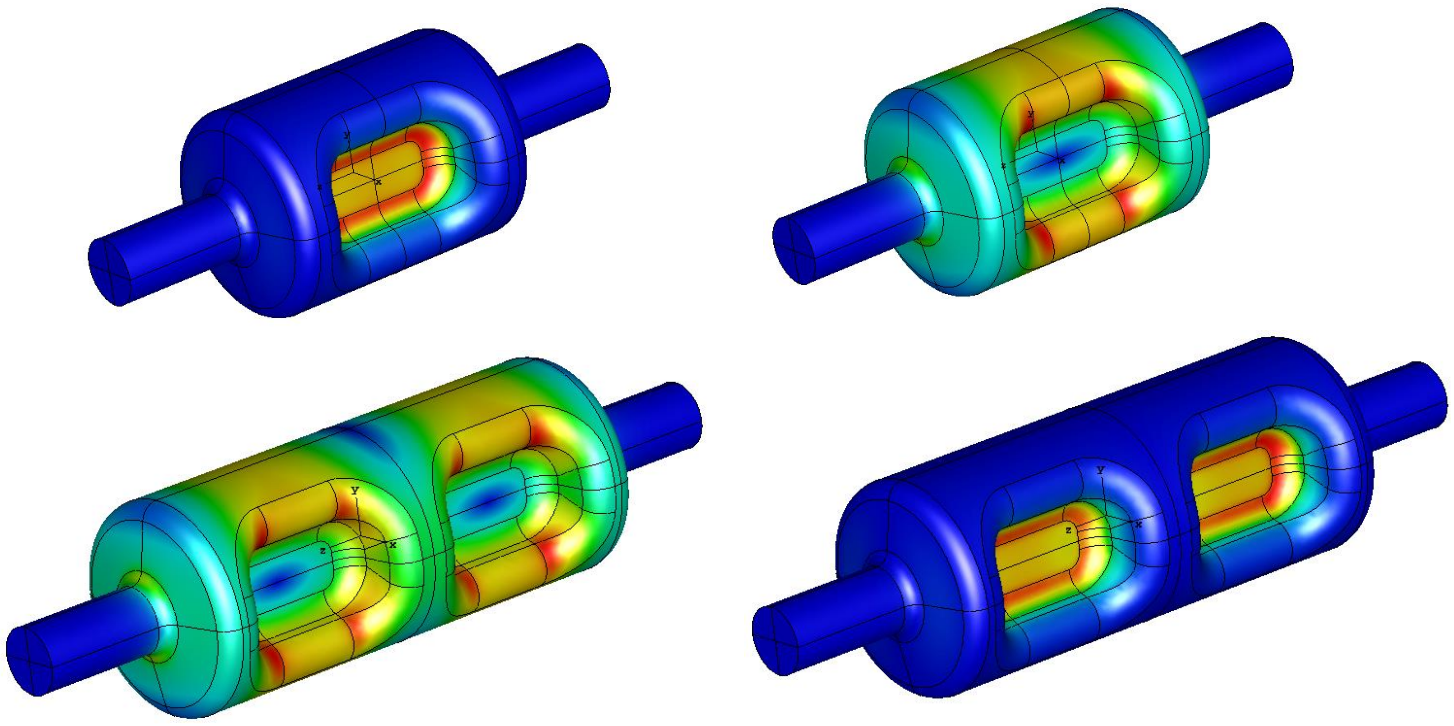
Summary

- Current work focused on the single cell 1.3 GHz RFD design for the ILC crab cavity design
  - 2-cell cavity design can be considered
- Cavity design is evaluated with 30 mm pole separation and 40 mm beam aperture
- Initial cavity design is completed with FPC
- An acceptable HOM damping mechanism is identified and further options will be evaluated
  - Longitudinal effects to be evaluated
- Preliminary mechanical analysis is completed

Back Up Slides

Cavity Design

- 30 mm beam aperture
- Two designs options
  - Single cell cavity
  - 2 cell cavity



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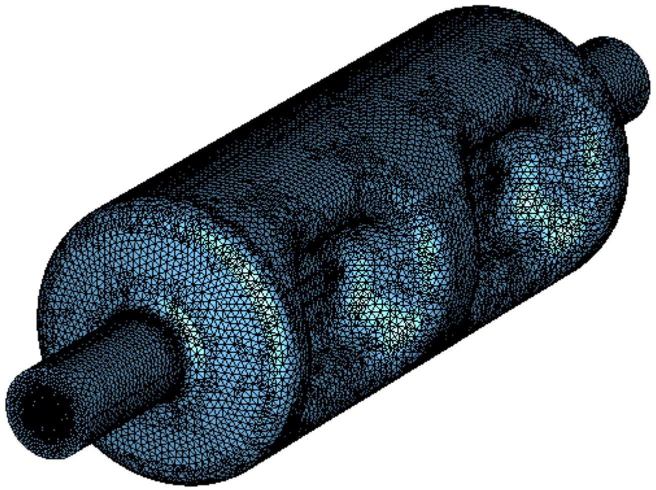
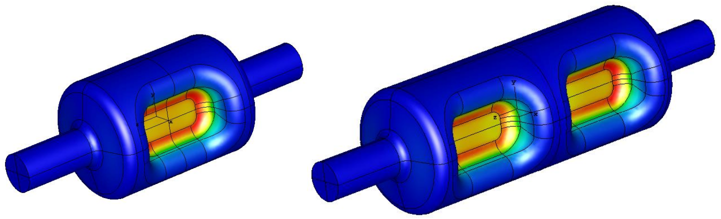
V_t [MV]	1.0	2.0
E_p [MV/m]	33.3	34.54
B_p [mT]	69.7	68.82
Total V_t [MV]	1.845	1.845
No. of cavities	2	1
Pole separation, beam aperture (mm)	30	30
Cavity Length [mm]	172.32	297.4
Cavity Diameter [mm]	107.4	109.4
Pole Length [mm]	85	85

Multipole Components

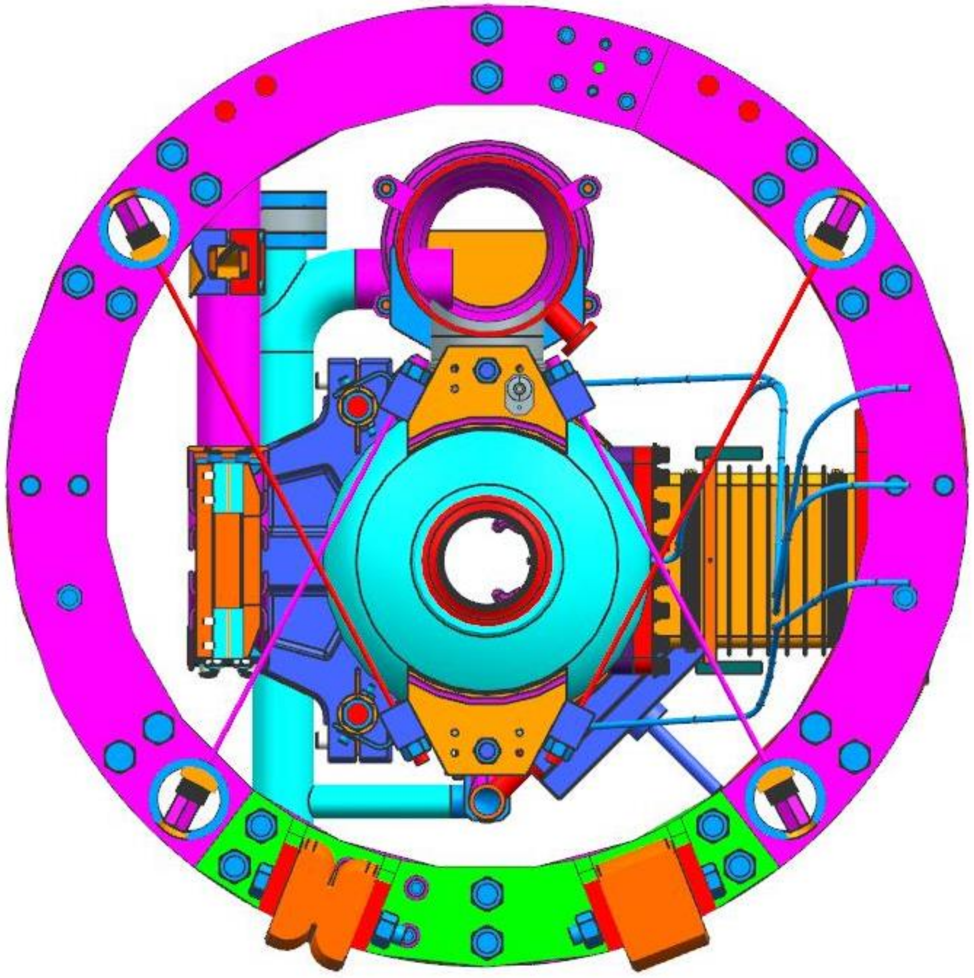
- Higher order multipole components for the bare cavity
- Requires a finer mesh along the beam center



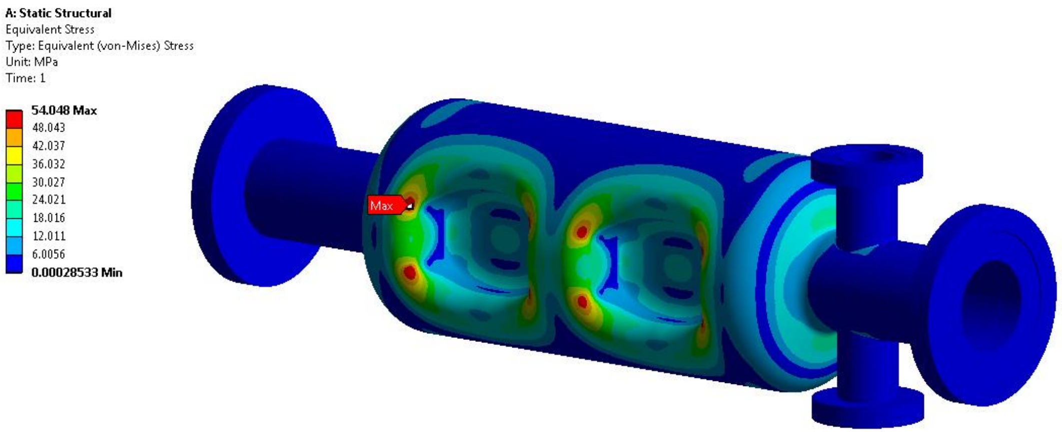


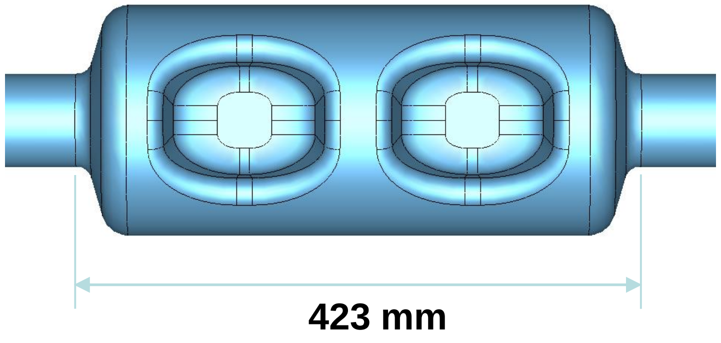
Component	Units	1-cell	2-cell
V_z	[V]	0.575	-77.25
V_t	[V]	1.0E+06	1.0E+06
b_0	[mT/m²]	0	0
b_1	[mT/m]	3.3	3.3
b_2	[mT]	-0.0013	-0.00045
b_3	[mT m]	2275.8	2106.6
b_4	[mT m²]	9.2	3.2
b_5	[mT m³]	-1.39E+6	-1.43E+6
b_6	[mT m⁴]	-4.83E+4	-1.68E+4
b_7	[mT m⁵]	-1.97E+9	-1.89E+9

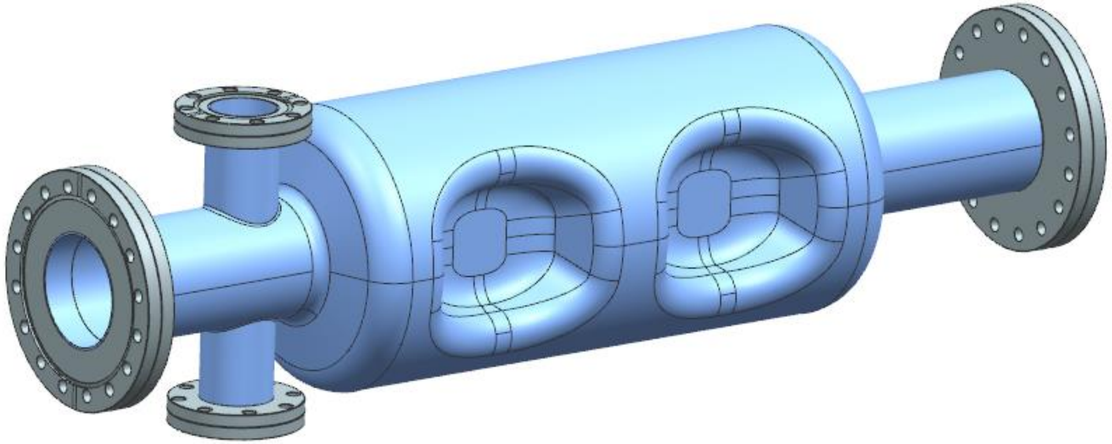
C100 Cryomodule Design

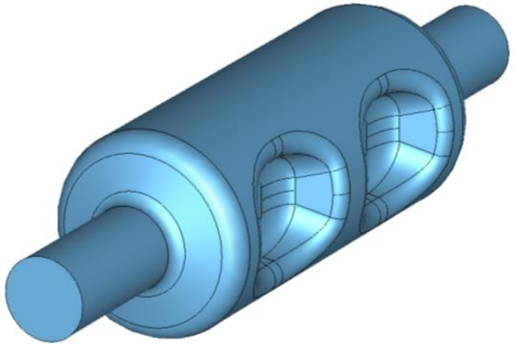


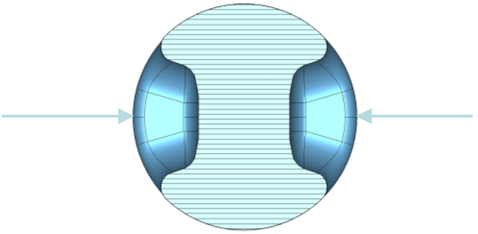
Final Design for JLEIC Crabbing System - 952 MHz 2-cell RFD











Ø 173 mm

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Supported by grant from the state of Virginia through SURA

952 MHz RFD - Fabrication in Progress

- Material cost – sheet Nb forming instead of machining
- Avoid weld seams at high mechanical stress area and high surface magnetic field area
- Use of simple weld only – high production yield
- Strategy relevant to final cavity with HOM dampers

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