RF DIPOLE DESIGN UPDATE

Suba De Silva

Center for Accelerator Science
Old Dominion University
and
Thomas Jefferson National Accelerator Facility

Outline

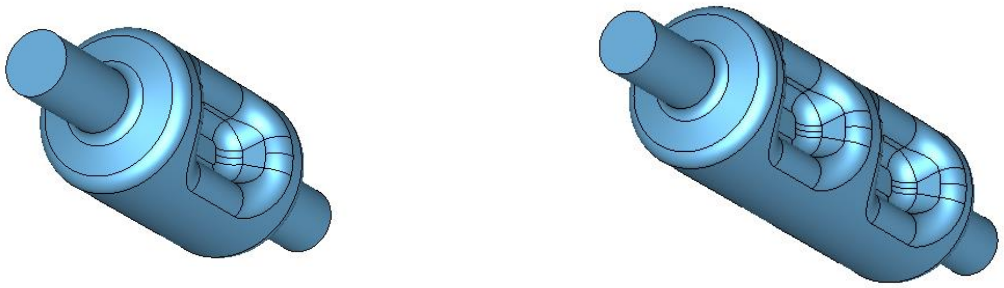
- 1.3 GHz RFD crab cavity design options for ILC
- Fundamental power coupler
- Higher order modes and impedances
- Multipacting analysis
- Mechanical analysis
- Preliminary cryomodule layout
- Summary

Main Goals of the Study

- Transverse voltage: 1.845 MV for 250 GeV and 7.4 MV for 1 TeV
- Cryostat length flange to flange < 3.25 m
- Peak surface fields: E_p < 45 MV/m and B_p < 80 mT
- Total transverse impedance threshold:
  - Horizontal: 48.8 MΩ/m
  - Vertical: 61.7 MΩ/m

1.3 GHz RFD Cavity Design

- Pole separation – 25 mm
- Beam aperture – 30 mm
- Two cavity options considered: 1-cell and 2-cell

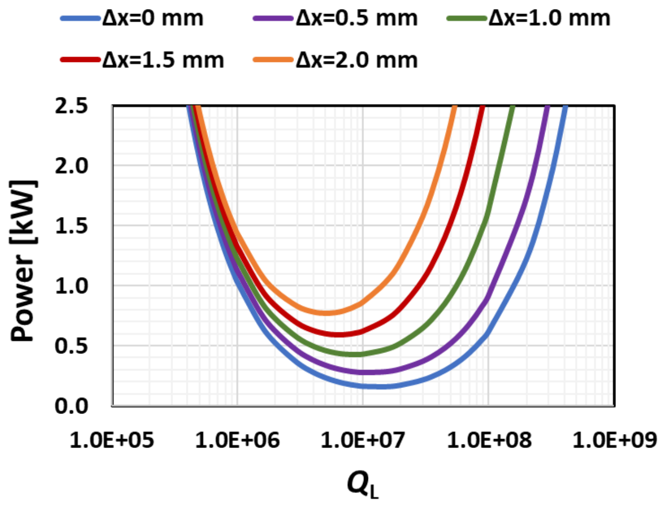


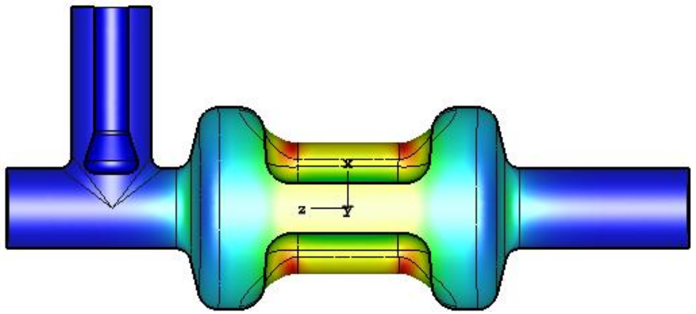
- Meet peak surface field requirements: E_p < 45 MV/m and B_p < 80 mT

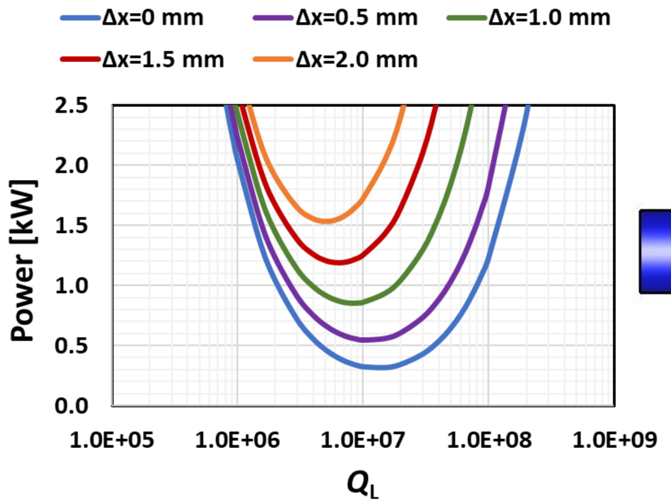
	250 GeV		1 TeV	
Cavity type	1-cell	2-cell	1-cell	2-cell
Max V_t per cavity [MV]	1.35	2.70	1..35	2.70
Total V_t [MV]	1.845		7.4	
Number of cavities	2	1	6	3
V_t per cavity [MV]	0.9225	1.845	1.234	2.467

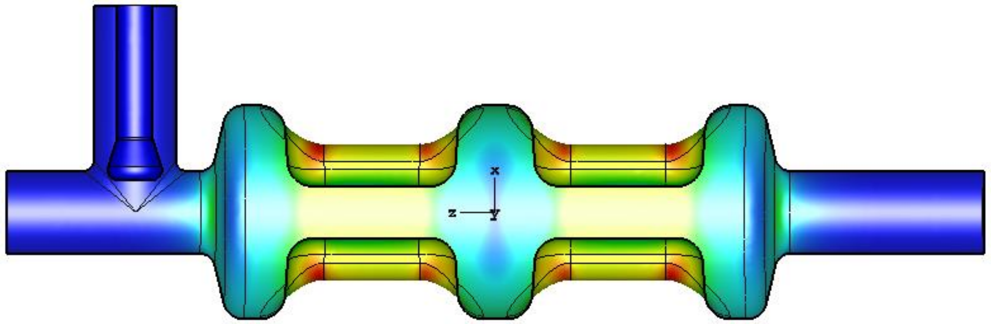
Property	1-cell	2-cell
Operating frequency [GHz]	1.3	1.3
SOM [GHz]	–	1.198
1st HOM [GHz]	2.142	2.039
E_p/E_t^*	3.83	3.85
B_p/E_t^* [mT/(MV/m)]	6.84	6.84
B_p/E_p [mT/(MV/m)]	1.79	1.78
G [Ω]	129.9	132.2
R/Q [Ω] (V^2/P)	444.8	892.7
R_tR_s [Ω^2] (V^2/P)	5.78×10^4	1.18×10^4
Reference length $V/E_t = \lambda/2$ [mm]	115.3	115.3
V_t [MV]	1.35	2.70
E_p [MV/m]	44.8	45.0
B_p [mT]	80.1	80.0
Pole separation [mm]	25	
Beam aperture [mm]	30	
Cavity Length [mm] (flange-to-flange)	310	450
Cavity Diameter [mm]	100.3	103.4
Pole Length [mm]	80	80

Fundamental Power Coupler





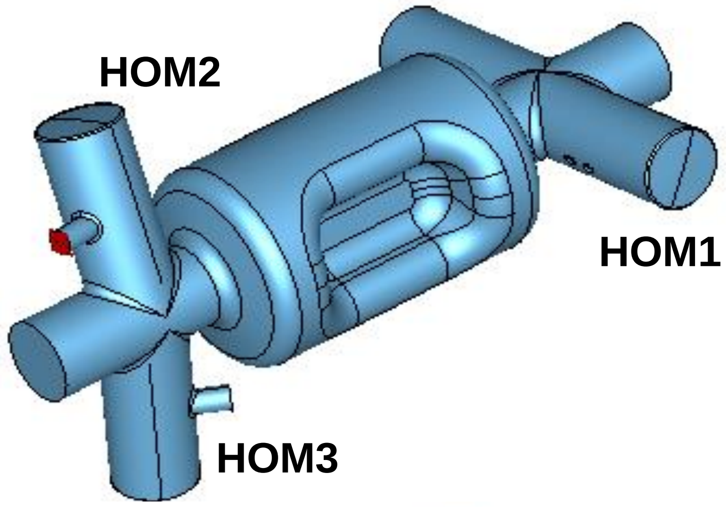


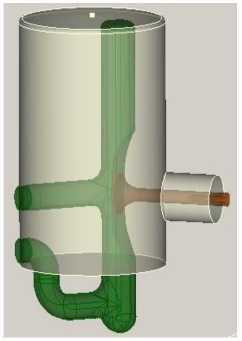


- Coupling using coaxial antenna
  - Similar to LCLS II power coupler
- Beam current: I_b = 10 mA
- Beam offset: Δx = 0.5 mm
- Microphonics: δf = 50 Hz
- Cavity parameters:

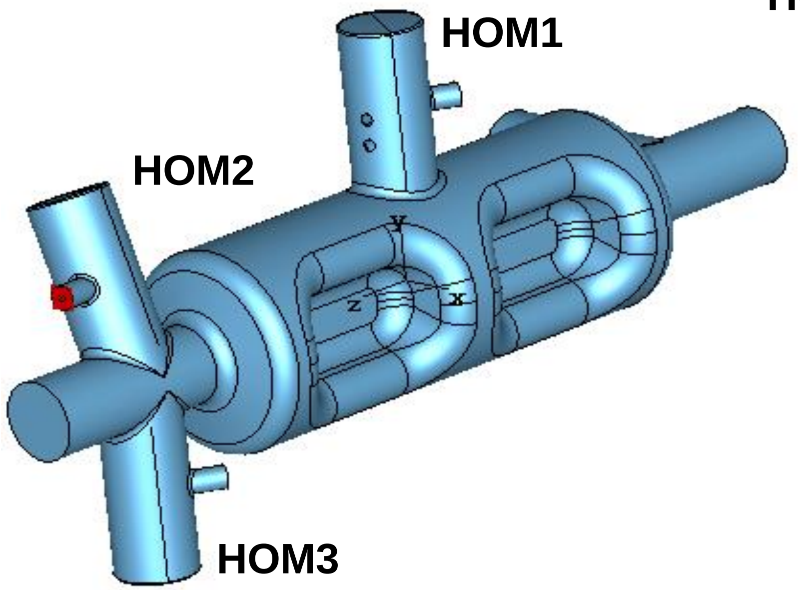
	1-cell	2-cell
R/Q [Ω]	444.8	895.6
V_t per cavity [MV]	1.35	2.7
Q_{ext}	1.5×10^7	
RF Power at the cavity [W]	300	600
RF heating at Cu probe [W]	1.2	2.22

Higher Order Mode Damping





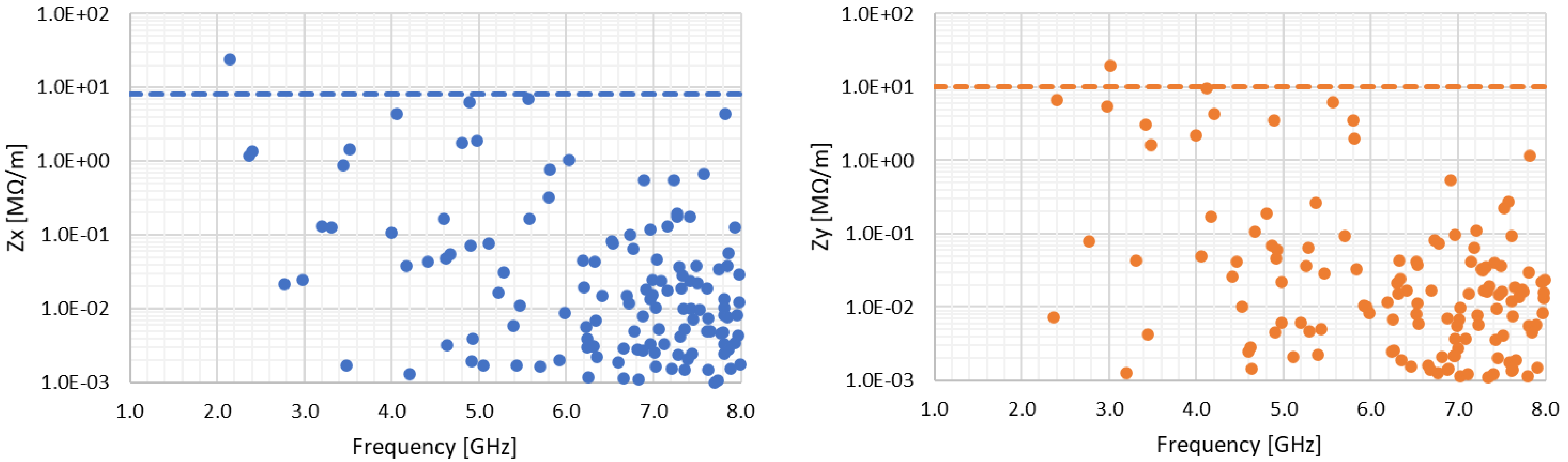
TESLA type
HOM coupler



- Damping using 3 TESLA type HOM couplers
  - Damper design used in the LCLS II cavities
  - 1-cell cavity: All the couplers are placed on the beam
  - 2-cell cavity: Single coupler on cavity body to couple to the trapped modes between the poles
- Further HOM damping schemes to be explored
  - LHC-RFD HOM coupler option
  - Waveguide damping option
- Final choice will be decided based on
  - RF properties including HOM power
  - Engineering and manufacturing complexity

Preliminary Transverse HOM Damping – 1-cell Cavity

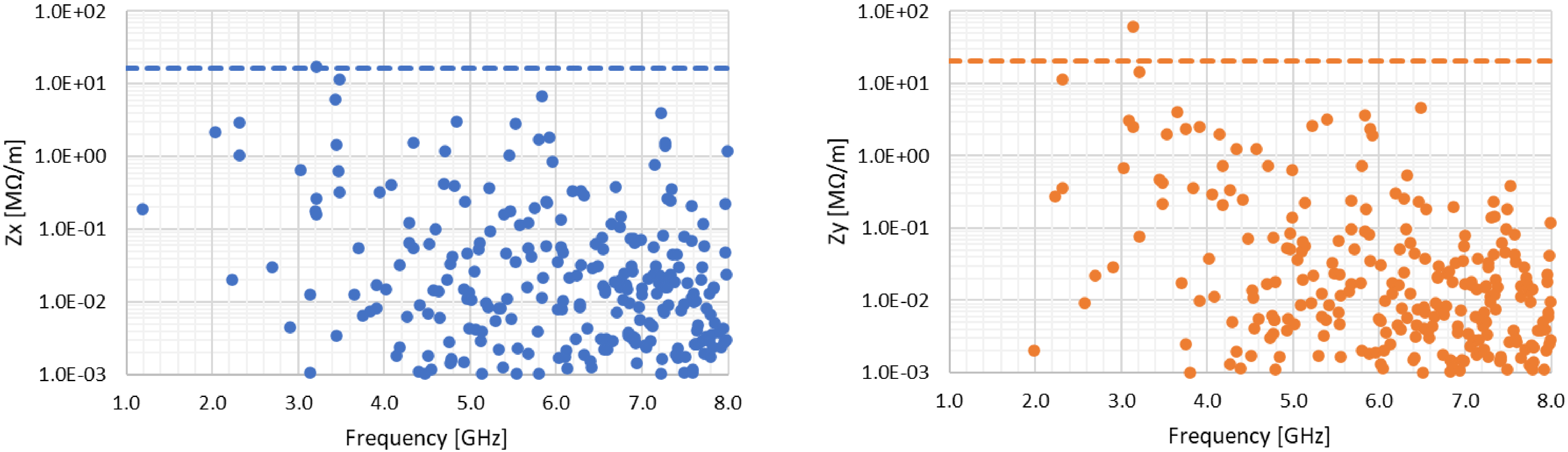
- Impedance threshold: Z_x = 48.8 MΩ/m and Z_y = 61.7 MΩ/m
- Impedance threshold per cavity: Z_x = 8.14 MΩ/m and Z_y = 15.425 MΩ/m (6 cavities)



- Impedances calculated using circuit definition
- Modes calculated up to beam pipe aperture cut off frequency

Preliminary Transverse HOM Damping – 2-cell Cavity

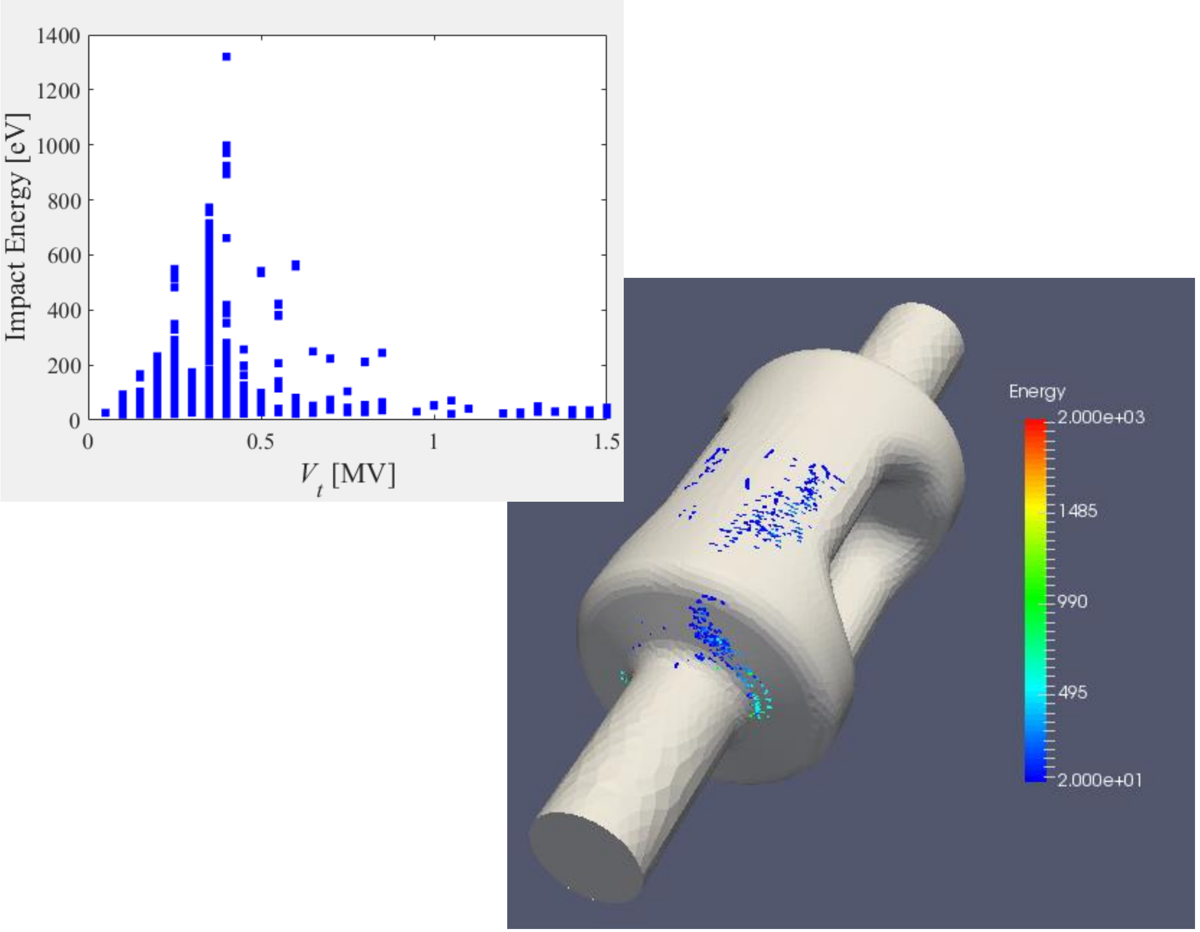
- Impedance threshold: Z_x = 48.8 MΩ/m and Z_y = 61.7 MΩ/m
- Impedance threshold per cavity: Z_x = 16.27 MΩ/m and Z_y = 20.57 MΩ/m (3 cavities)

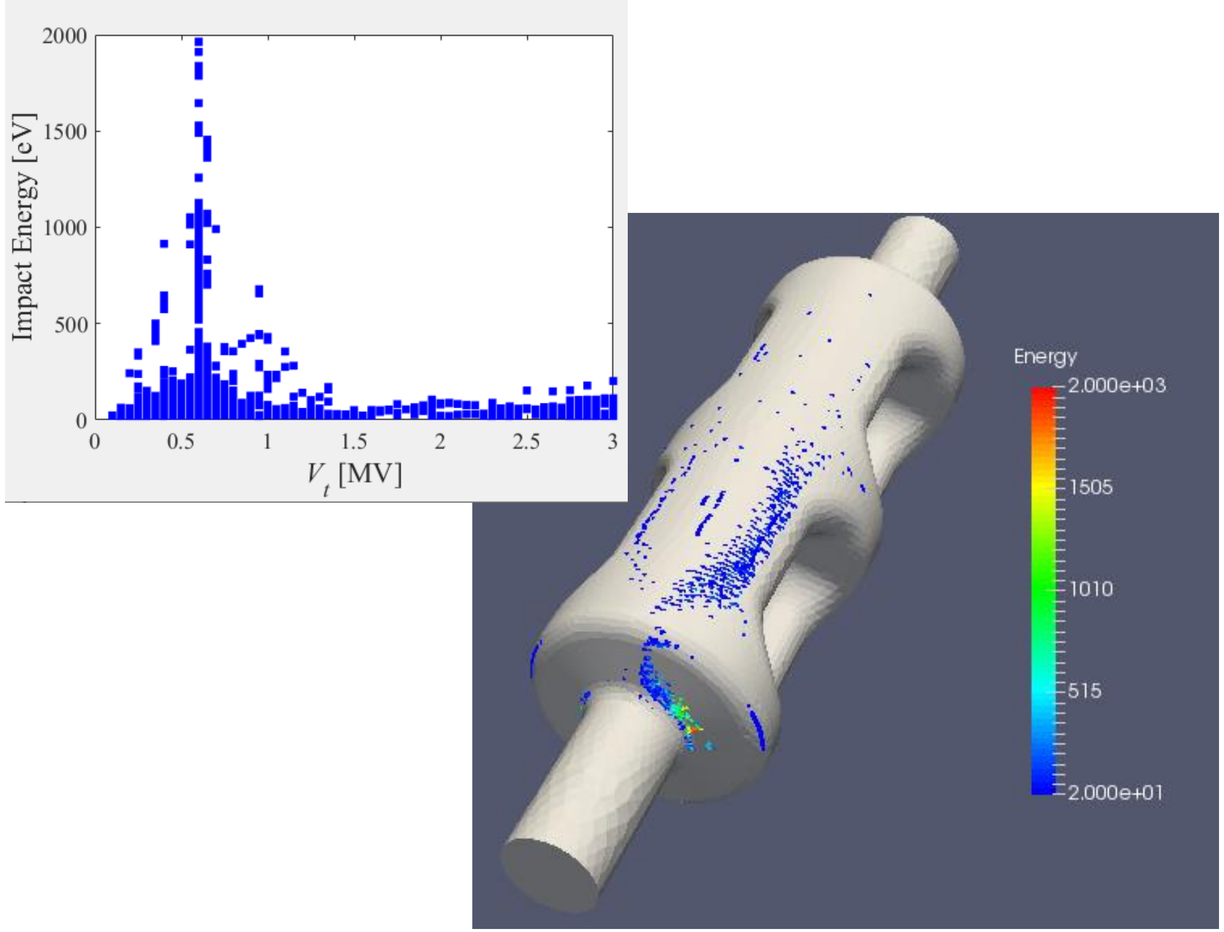


- Impedances calculated using circuit definition
- Modes calculated up to beam pipe aperture cut off frequency

Multipacting Analysis

- Resonant particles traced for 50 rf cycles with impact energy 20-2000 eV
- Simulated for a 1/8th surface area

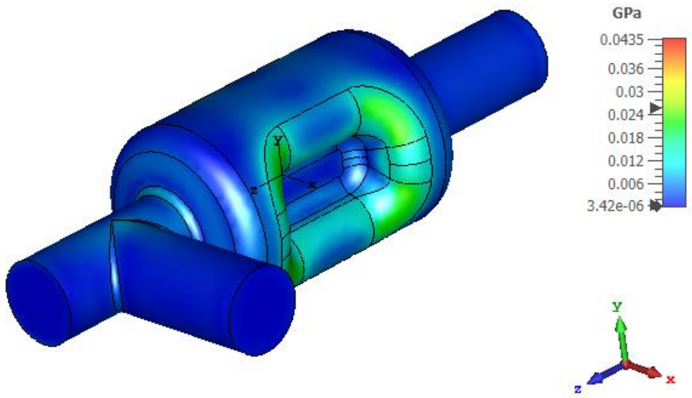


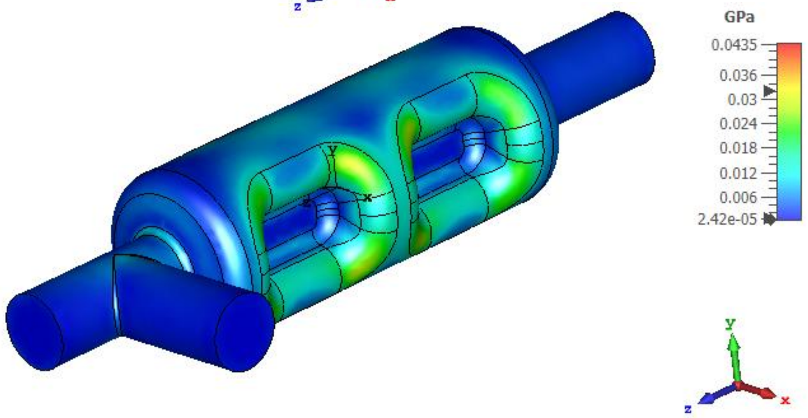


Stress Analysis

- 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
- Cavity thickness – 3 mm
- Boundary conditions – Cavity constrained at beam pipes and FPC
- Allowable stress < 43.5 MPa
- Maximum stress
- Initial analysis shows cavity doesn't require stiffening
- Cavity can be machined with varying thickness

Cavity Type	Max. Stress [MPa]
1-cell	25
2-cell	32

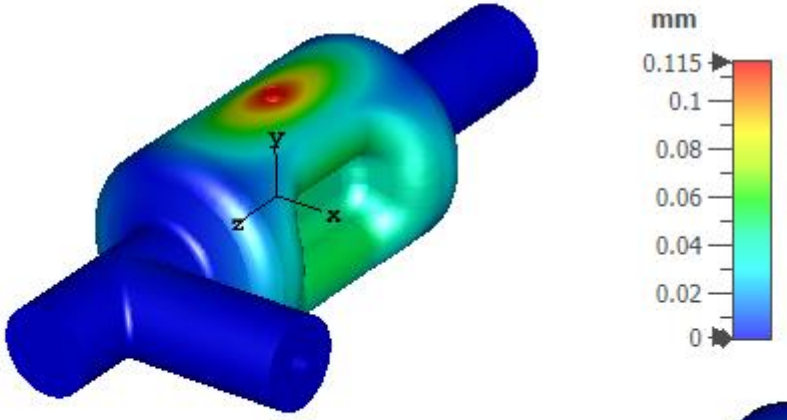


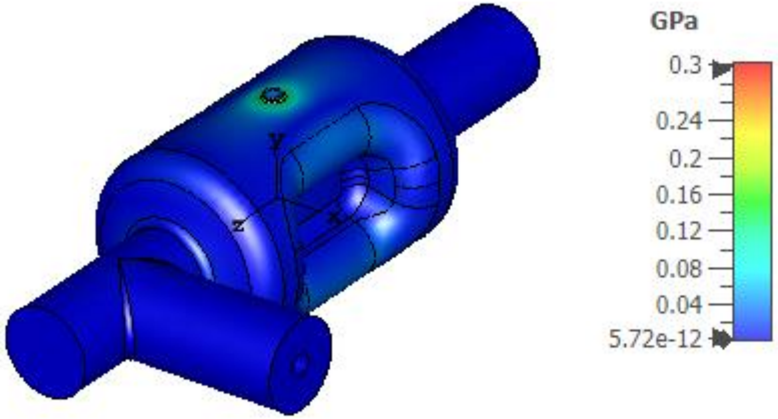


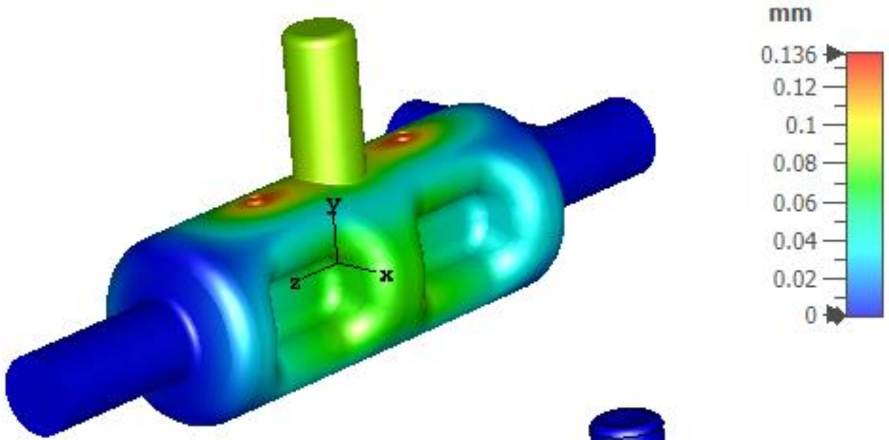
Tuning Sensitivity

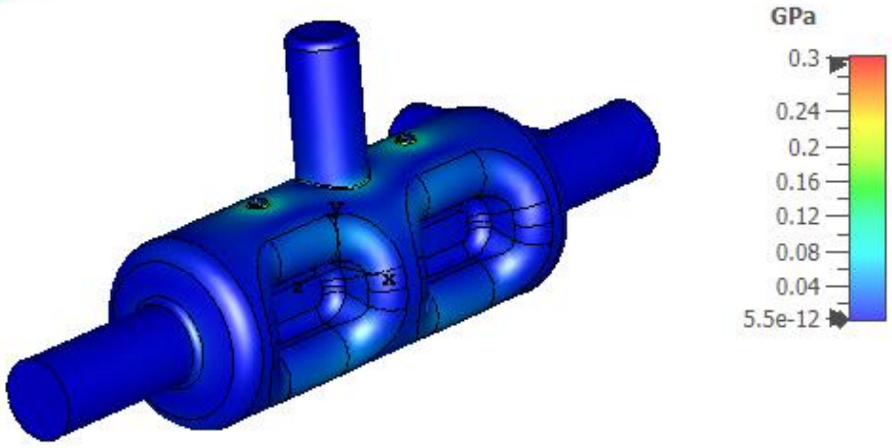
- Nb material properties at cryo temperature
  - Young's modulus – 123 GPa (1.79×10^{7} psi)
- Cavity thickness – 3mm
- Cavity constrained at beam pipe ports and FPC

Cavity Type	Total Displacement	Tuning Sensitivity	Tuning Range
1-cell	0.23 mm	8.5 MHz/mm	1.96 MHz
2-cell	0.27 mm	4.1 MHz/mm	2.23 MHz







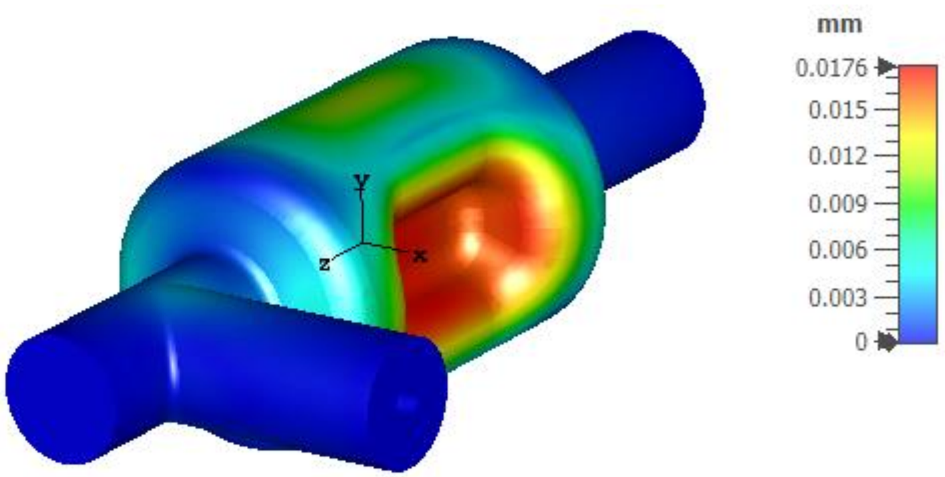


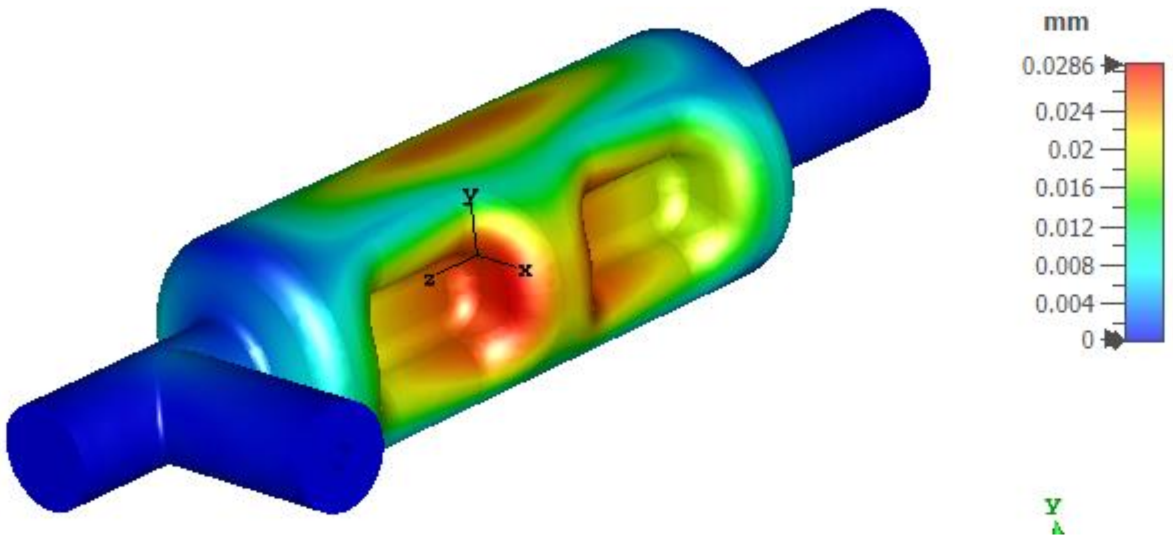
Pressure Sensitivity

- Nb material properties at room temperature
  - Young's modulus – 82.7 GPa (1.2×10^7 psi)
  - Poisson's ratio – 0.38
- Cavity thickness – 3mm
- Cavity constrained at beam pipe ports and FPC
- Stiffening at poles can reduce pressure sensitivity

Cavity Type	d*f*/d*P* [Hz/mbar]
1-cell	561.3
2-cell	751.5

- Stiffening at poles can reduce pressure sensitivity

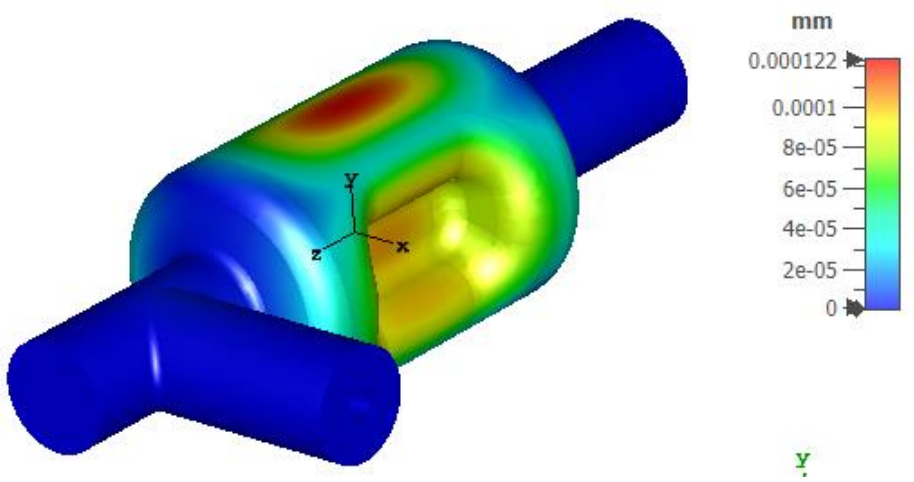


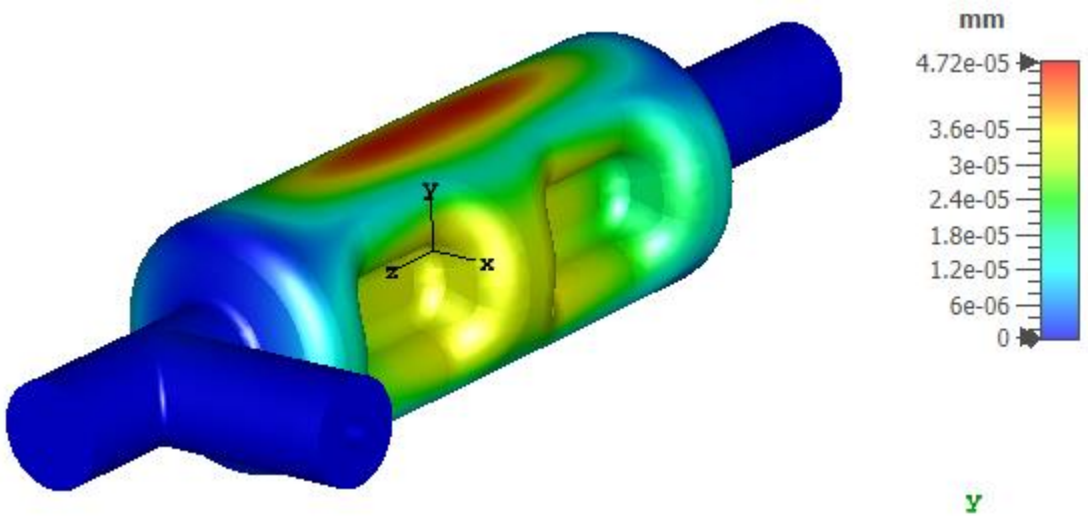


Lorentz Detuning

- Nb material properties at cryo temperature
  - Young's modulus – 123 GPa (1.79×10^{7} psi)
  - Poisson's ratio – 0.38
- Cavity thickness – 3mm
- Cavity constrained at beam pipe ports and FPC
- Lorentz detuning can be reduced by tuner
  - Tuning by push/pull at top and bottom of the cavity

Cavity Type	k_L [kHz/(MV)^2]	Vt [MV]	Δf [kHz]
1-cell	-3.67	1.35	6.7
2-cell	-1.11	2.7	8.1





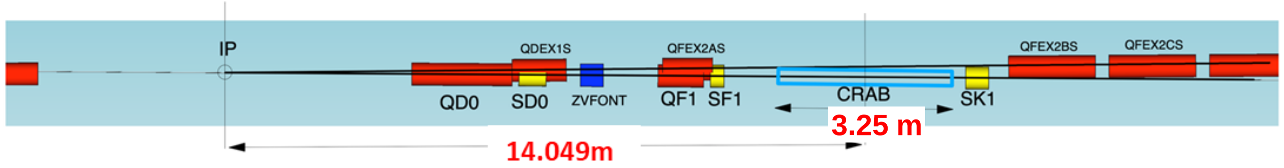
Conceptual He Vessel and Cryomodule Design

- At 1 TeV – Cryomodule required to fit in within 3.25 m
- 1-cell cavity
  - 6 cavities in a single cryomodule
  - 10% extra margin
- 2-cell cavity
  - Minimum 3 cavities in a single cryomodule will deliver required V_t
  - Space available for 4 cavities in a single cryomodule
  - 30% extra margin available with 4 cavities

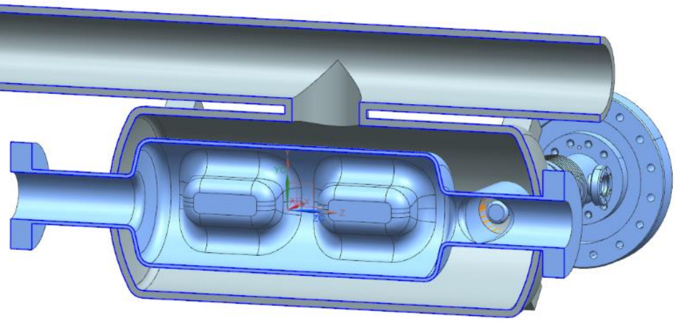
- Cavity thickness – 3mm
- Design concept follows JLab C100 cryomodule
- Second beam pipe – 20 mm beam pipe

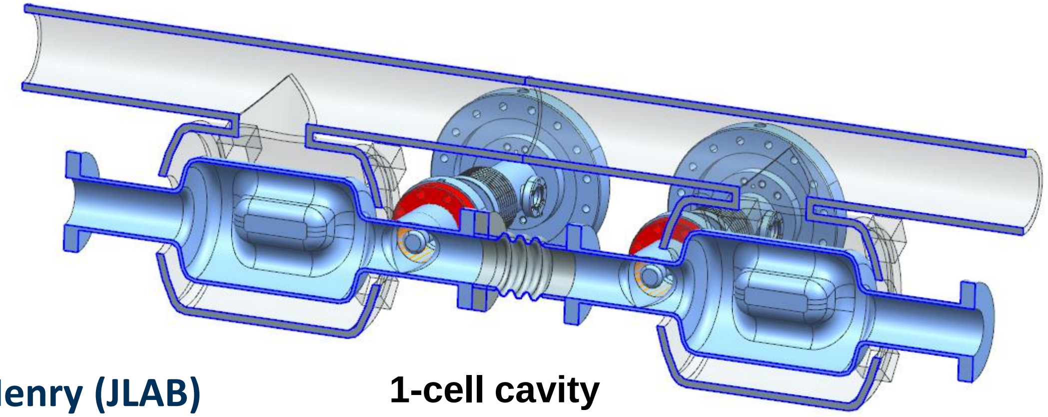
Two beamline separation
14.049m x 0.014rad = 197mm

H. Hayano



2-cell cavity



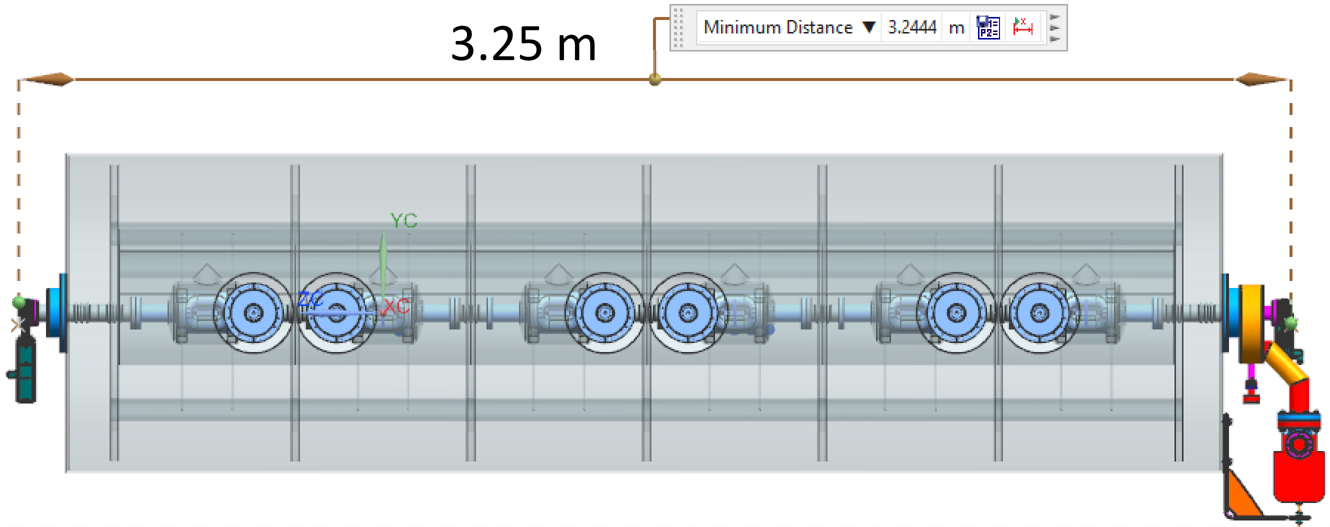


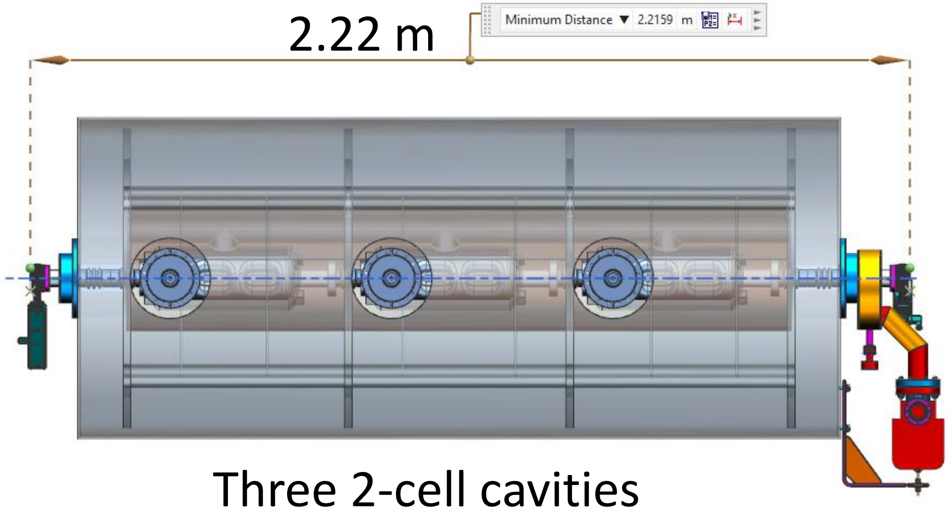
Jim Henry (JLAB)

1-cell cavity

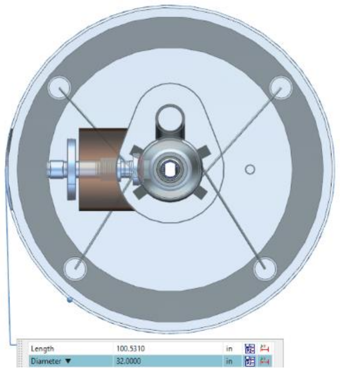
Conceptual He Vessel and Cryomodule Design

- Six 1-cell cavities
- Total achievable V_t = 8.1 MV
- Cryomodule length = 3.25 m
- Cryomodule diameter = 0.82 m

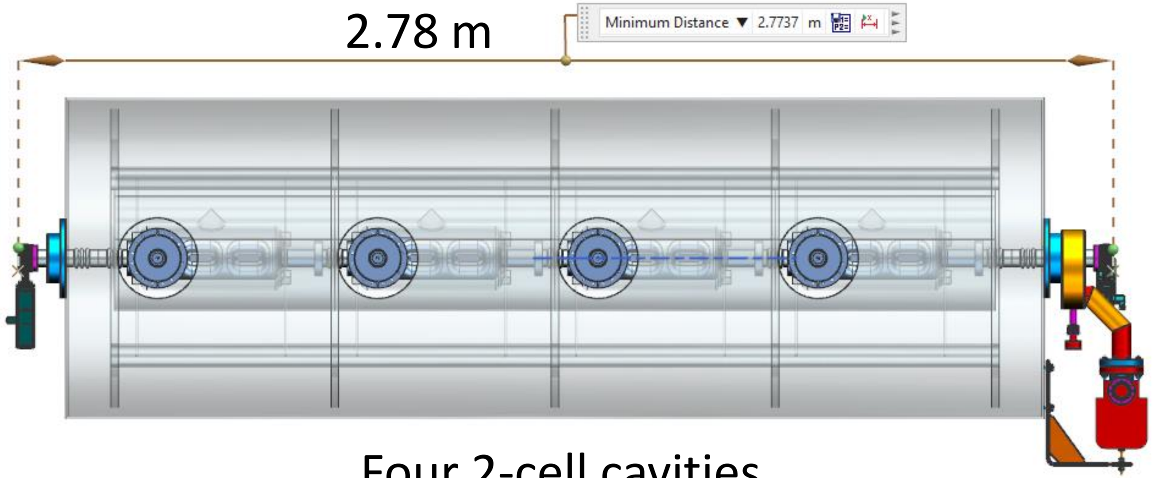




Three 2-cell cavities
Total achievable V_t = 8.1 MV



Jim Henry (JLAB)



Four 2-cell cavities
Total achievable V_t = 10.8 MV

Summary

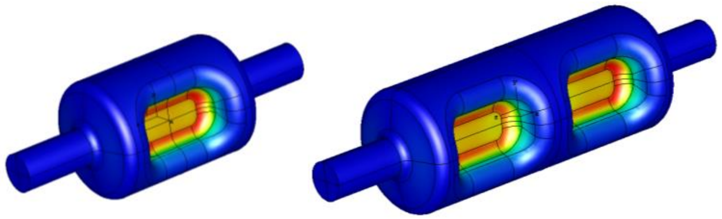
- Two 1.3 MHz rf-dipole cavity options were developed following the reduced beam line space of 3.25 m
  - Cavity design was evaluated with 25 mm pole separation and 30 mm beam aperture
- Both 1-cell and 2-cell designs meet current specifications in:
  - Dimensional requirements, peak surface fields with required transverse voltage
  - An acceptable HOM damping mechanism is identified
  - Requires further analysis on HOM damping
  - Longitudinal effects to be evaluated
- Initial cavity designs are completed with FPC
- Preliminary mechanical analysis is completed
- Several cavity options allows trade off between maximum voltage and margin

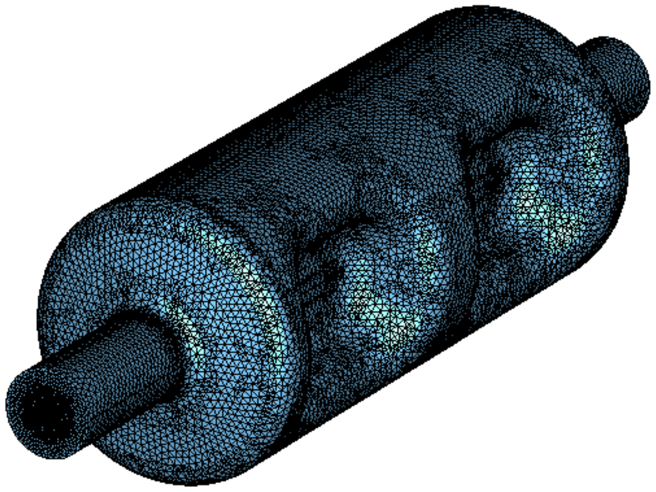
Back Up Slides

Multipole Components

- Higher order multipole components for the bare cavity

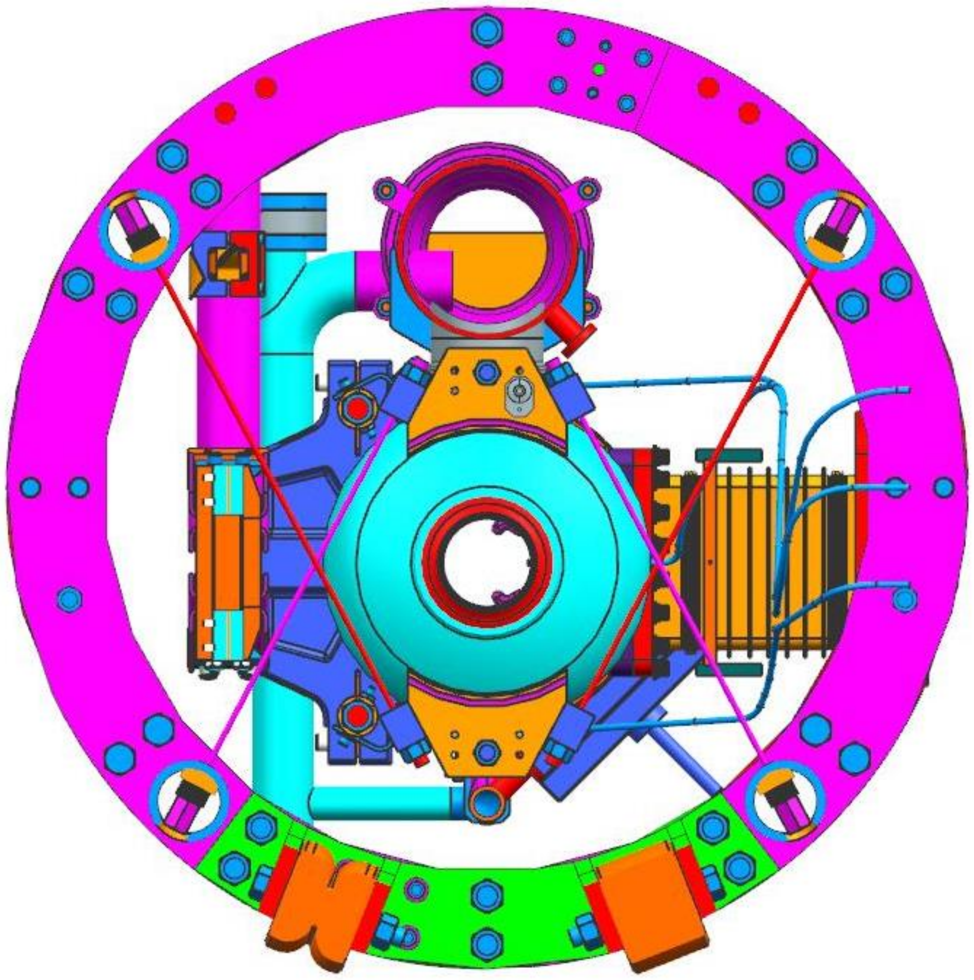
- Requires a finer mesh along the beam center



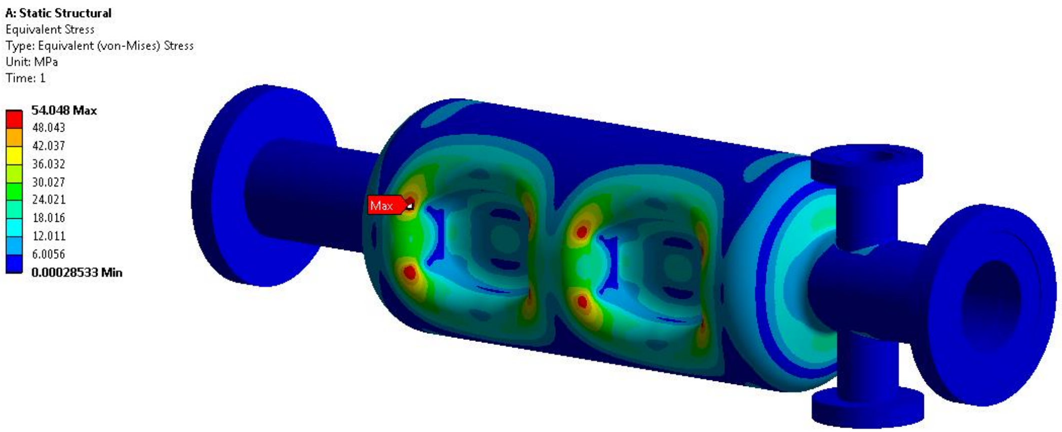


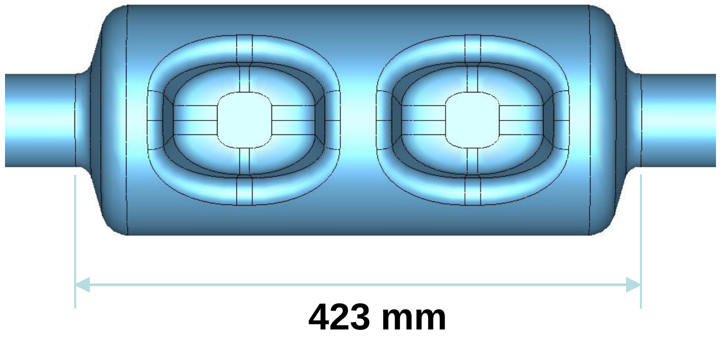
Component	Units	1-cell	2-cell
V_z	[V]	0.575	-77.25
V_t	[V]	1.0E+06	1.0E+06
b_0	[mT/m²]	0	0
b_1	[mT/m]	3.3	3.3
b_2	[mT]	-0.0013	-0.00045
b_3	[mT m]	2275.8	2106.6
b_4	[mT m²]	9.2	3.2
b_5	[mT m³]	-1.39E+6	-1.43E+6
b_6	[mT m⁴]	-4.83E+4	-1.68E+4
b_7	[mT m⁵]	-1.97E+9	-1.89E+9

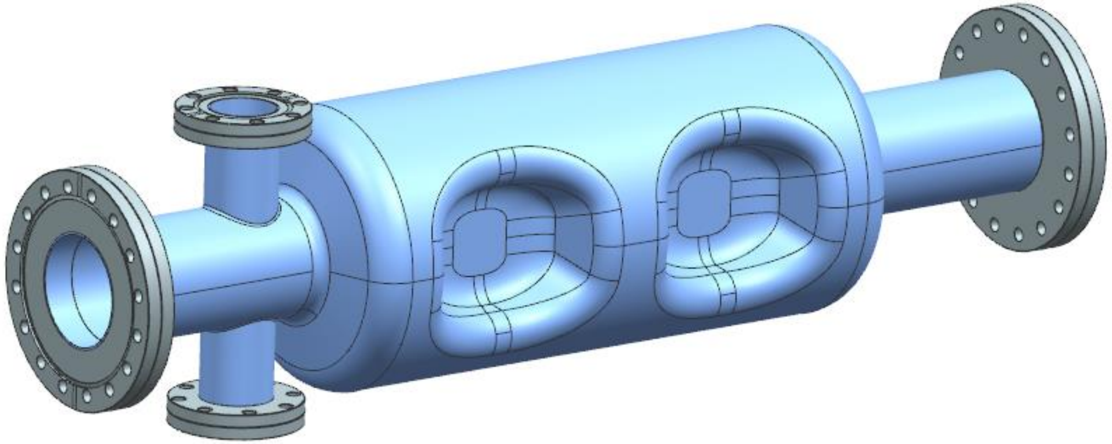
C100 Cryomodule Design

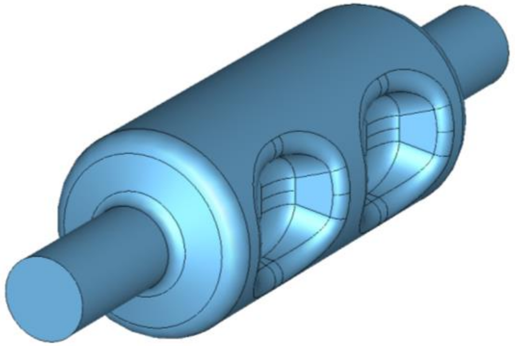


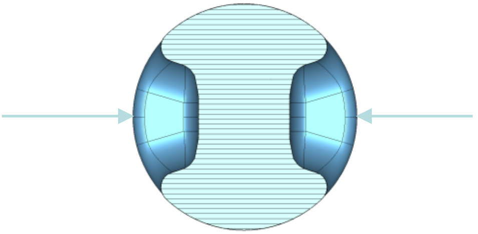
Final Design for JLEIC Crabbing System - 952 MHz 2-cell RFD











Subashini De Silva, HyeKyoung Park

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

Subashini De Silva, HyeKyoung Park

Supported by grant from the state of Virginia through SURA