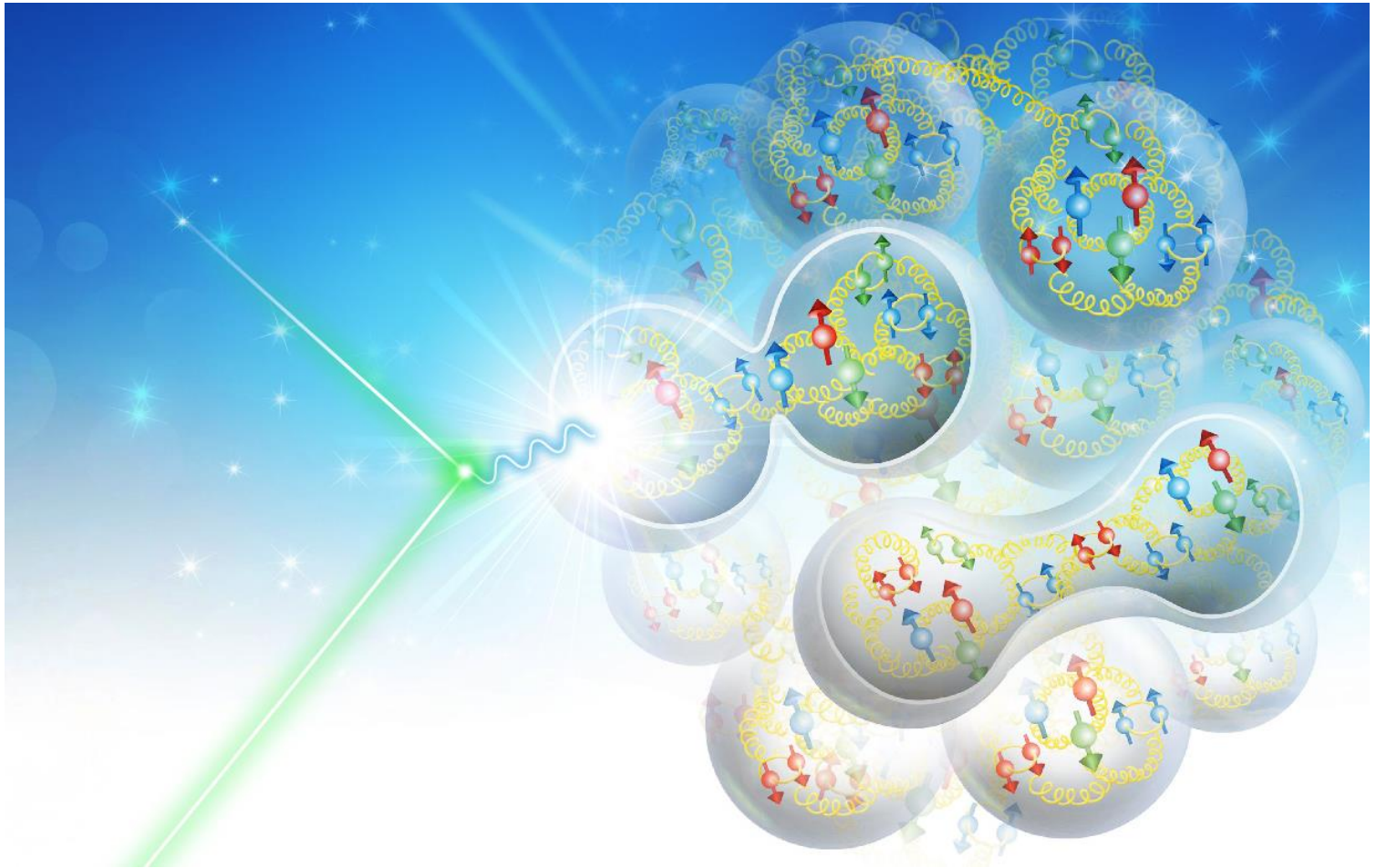
Development of JLEIC Crab Cavity

Work in progress



HyeKyoung Park

JLab/ODU

Acknowledgement

- ODU – Subashini De Silva, Salvador Sosa, Jean Delayen
- JLab SRF – Bob Rimmer, Frank Marhauser, Gunn Tae Park, Haipeng Wang, Jiquan Guo, Shaoheng Wang
- JLab CASA group – Rui Li, Vasiliy Morozov
- JLab Engineering – Josh Armstrong

Outline

- Crab cavity updates from new machine parameters
- Design choice of JLEIC
- HOM and damping
- Wakefields
- Multipoles and dynamic aperture
- Multipacting analysis
- Fabrication
- Summary and plan forward

New Machine Parameters and Its Impact on Crab Cavity

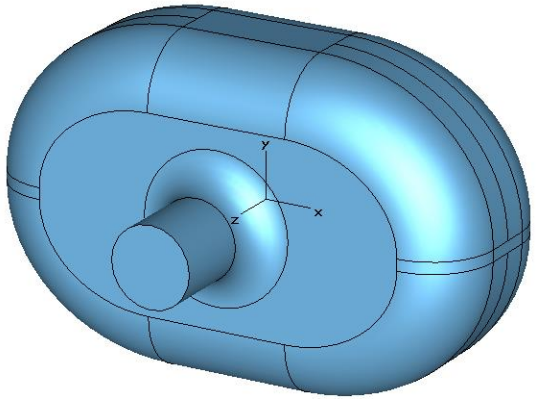
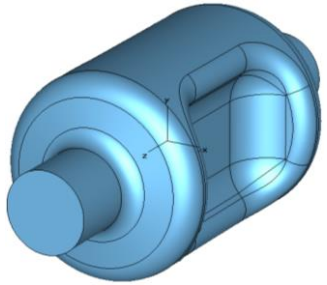
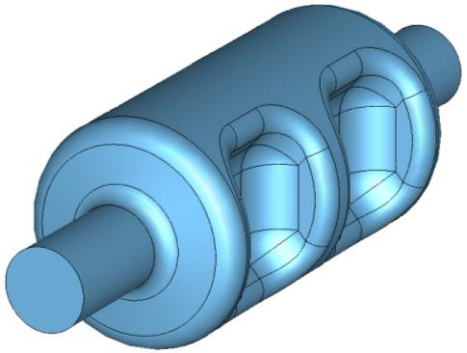
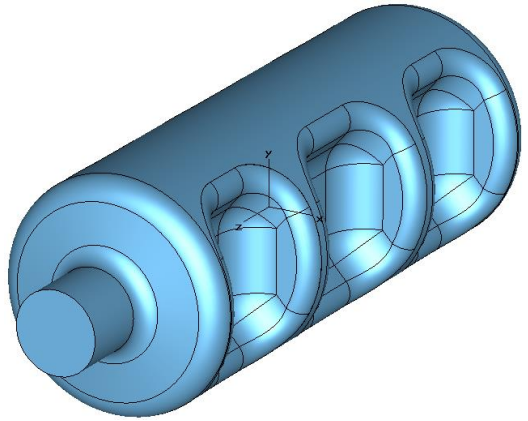
EIC-ACM October 2017

Parameter	Electron	Proton	Units
Beam energy	10	100	GeV
Beam current	0.71	0.75	A
Max beam current	3	0.75	
Bunch frequency	952.6		MHz
Crab crossing angle	50		mrad
Betatron function at IP	10		cm
Betatron function at crab cavity	200	363.44	m
Integrated transverse voltage per beam per side	2.8	20.8	MV

Today

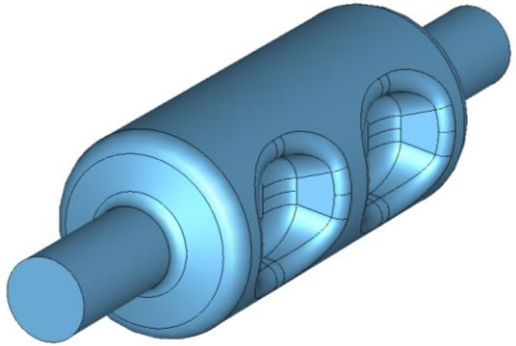
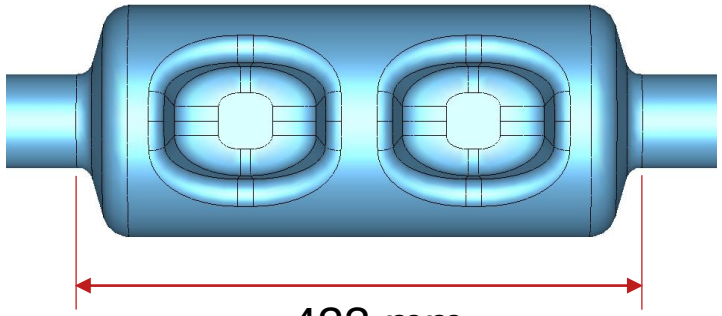
Electron	Proton	Proton
10	100	200
0.75	0.75	0.75
3	0.75	0.75
	952.6	
	50	
10	10	33
200	450	450
2.8	18.7	20.6

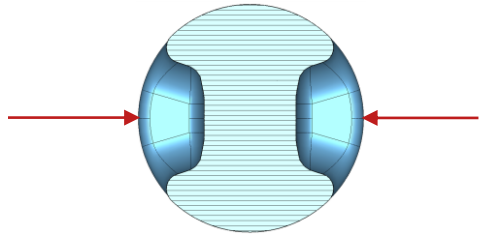
Design Choice – 952 MHz 2-cell RFD

Down-select consideration

- Beam aperture 70 mm in diameter
- Dimensional compactness
- HOM management
- Fabrication



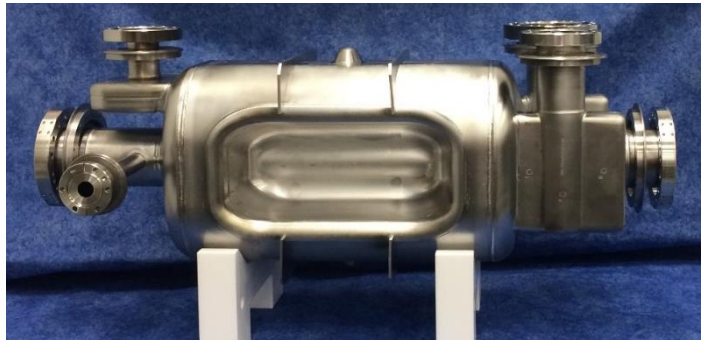
Design Survey

	Squashed Elliptical	Single-Cell RFD	Two-Cell RFD	Three-Cell RFD	Single-Cell RFD	Unit
Frequency	**952.6**				**476.3**	**MHz**
Aperture	**70**				70	mm
LOM	691.9	None	846	756.8, 862.2	None	MHz
LOM Mode Type	Monopole	–	Dipole	Dipole	–	
1st HOM	1040.8	1411.5	1379.5	1335.4	746.2	MHz
E_p/E_t	2.2	5.4	5.66	5.6	3.73	
B_p/E_t	7.7	13.6	11.64	11.4	6.52	mT/(MV/m)
$[R/Q]_t$	49.8	50	147.5	218.8	357	Ω
G	339.8	165.7	169	178.9	130	Ω
R_tR_s	1.7×10^4	8.3×10^3	2.5×10^4	3.9×10^4	4.7×10^4	Ω^2
Total V_t (e/p) (per beam per side)	**2.81 / 20.8**					**MV**
V_t (per cavity)	**1.5**	**0.86**	**1.9**	**3.1**	**3.4**	**MV**
No. of cavities (e/p)	**2 / 14**	**4 / 25**	**2 / 11**	**1 / 7**	**2 / 11**	
E_p	21	30	34	39	40	MV/m
B_p	**70**	**70**	**70**	**70**	**70**	**mT**

Cavity Performance Actuals So Far

Frequency [MHz]	Type	V_transverse [MV]	E_peak [MV/m]	B_peak [mT]
400	LHC P-o-p single cell	7	75	130
400	LHC SPS prototype #1	4.4	42	73
400	LHC SPS prototype #2	5.8	56	96
499	Cebaf deflector P-o-p	4.2	40	61
750	EIC P-o-p	2.7	60	126

Peak magnetic field up to 70 mT seems to be very reasonable.
JLEIC CC expected to have about 30% head room.



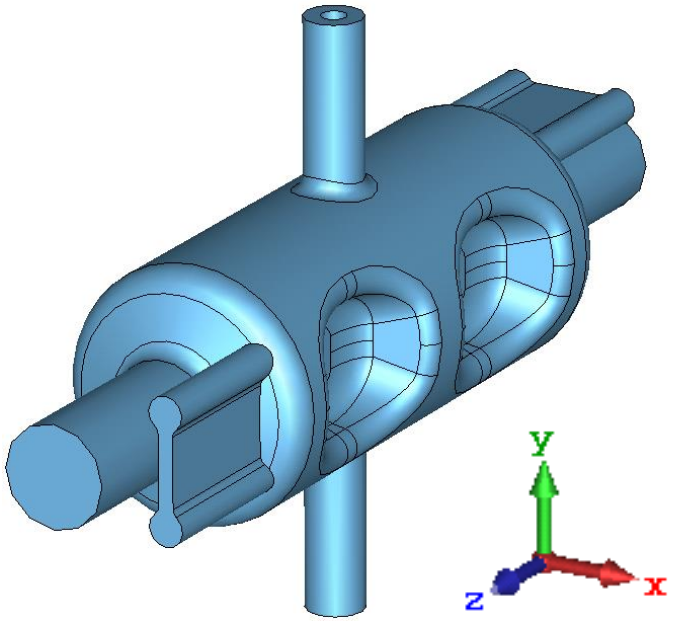
Required Number of Cavities

Cavity voltage or gradient is mostly limited by peak magnetic field.
Cavity RF parameters provide prediction of required number of cavities.

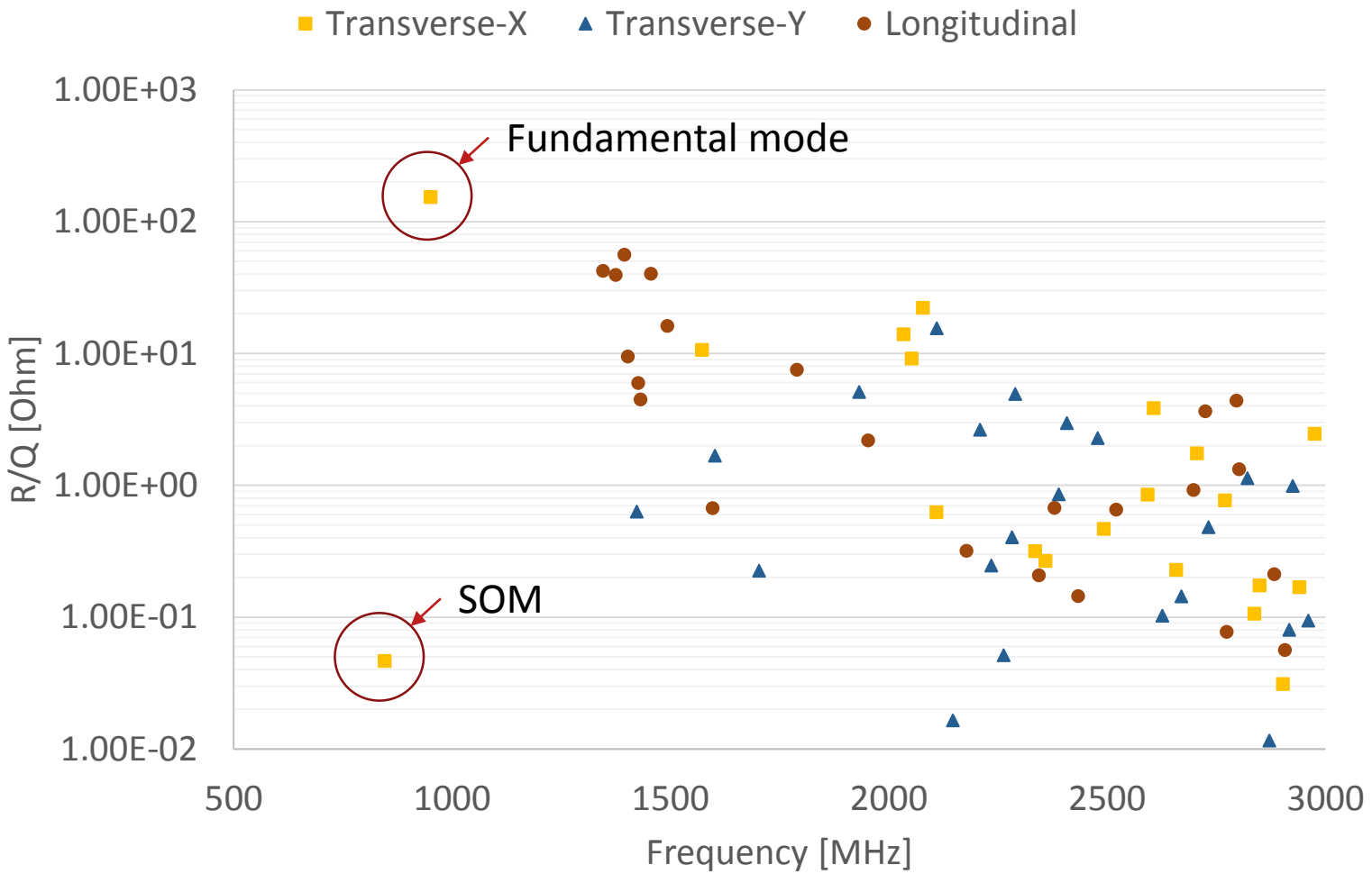
RF Properties	Unit	10 GeV e	100 GeV p	200 GeV p
Required kick	MV	2.8	18.7	20.6
Ep/Et	-	5.66		
Bp/Et	mT/(MV/m)	11.64		
R/Q transverse	Ω	148		
G	Ω	169		
Bp/Ep	mT/(MV/m)	2.06		
Target Bp	mT	70		
Vt at target Bp	MV	1.89		
Required number of cavities/side	-	1.5 → 2	9.9 → 10	10.9 → 11
Power dissipation/cavity	W	4 (assuming total R_s=30nΩ)		

Proposed number of cavities are 2 at electron ring and 12 at ion ring.

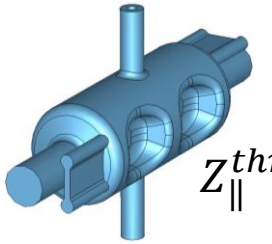
HOMs



Some port modes present

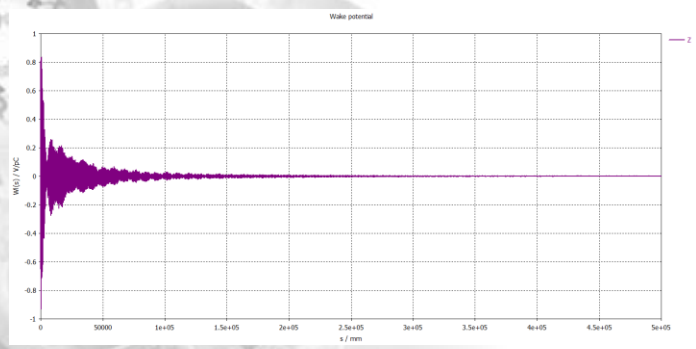


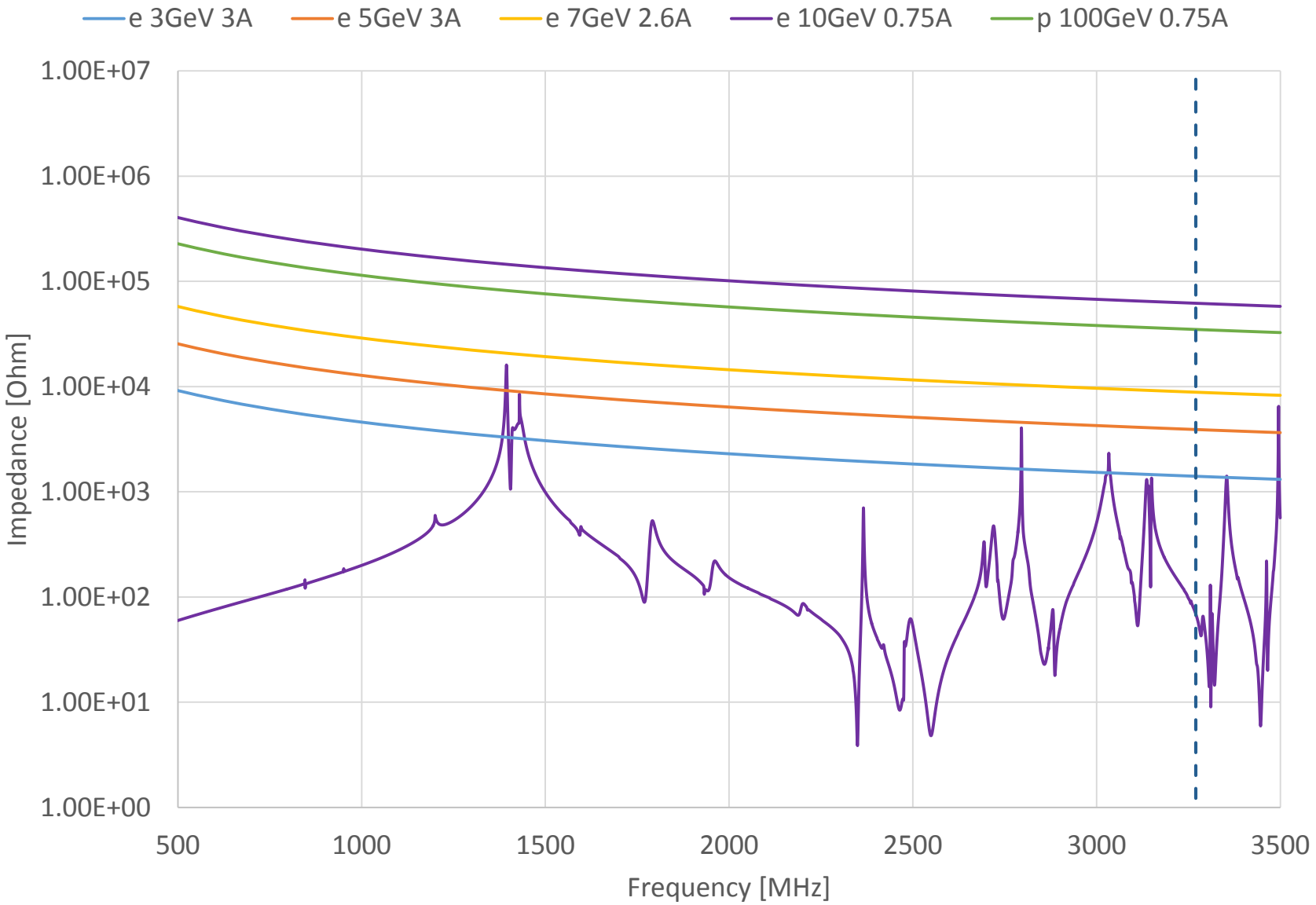
Wakefields – Longitudinal



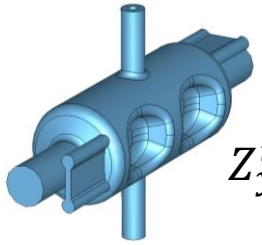
$$Z_{\parallel}^{thresh.} = \frac{1}{N_C} \frac{1}{f_{\parallel,HOM}} \frac{2E_b Q_s}{I_b \alpha \tau_s}$$

	Unit	e	p
N_C	-	4	24
E_b	GeV	3	100
Q_s		.0157	.054
I_b	A	3	.75
α	GeV/c	1.71×10^{-3}	5.69×10^{-3}
τ_s	ms	1	



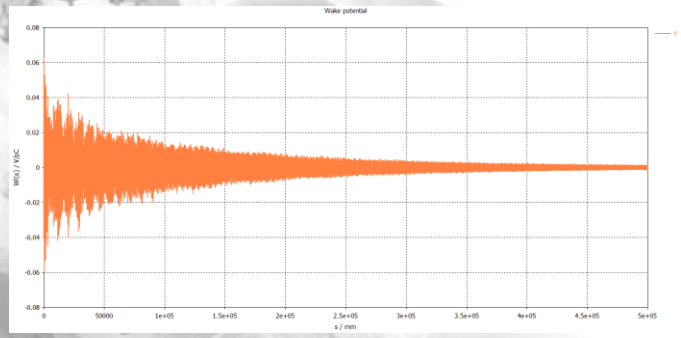


Wakefields – Transverse Y

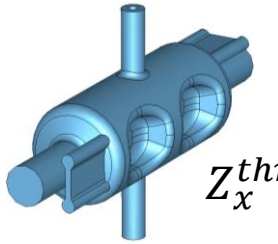


$$Z_y^{thresh.} = \frac{1}{N_C} \frac{2E_b}{f_{rev} I_b \beta_y \tau_y}$$

	Unit	e	p
N_C	-	4	24
E_b	GeV	3	100
I_b	A	3	.75
β_y	m	3	
f_{rev}	kHz	139	
τ_y	ms	1	

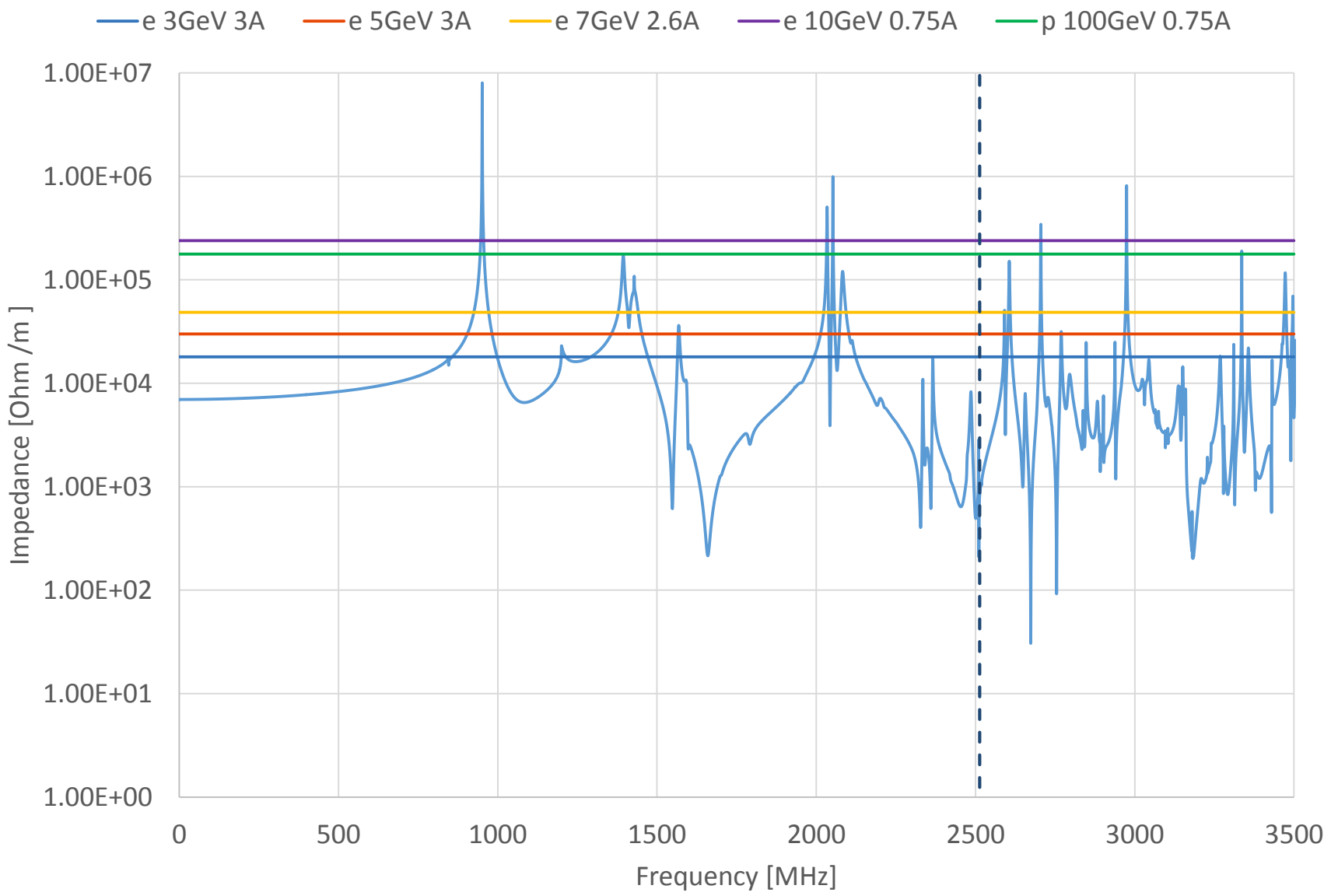


Wakefields – Transverse X

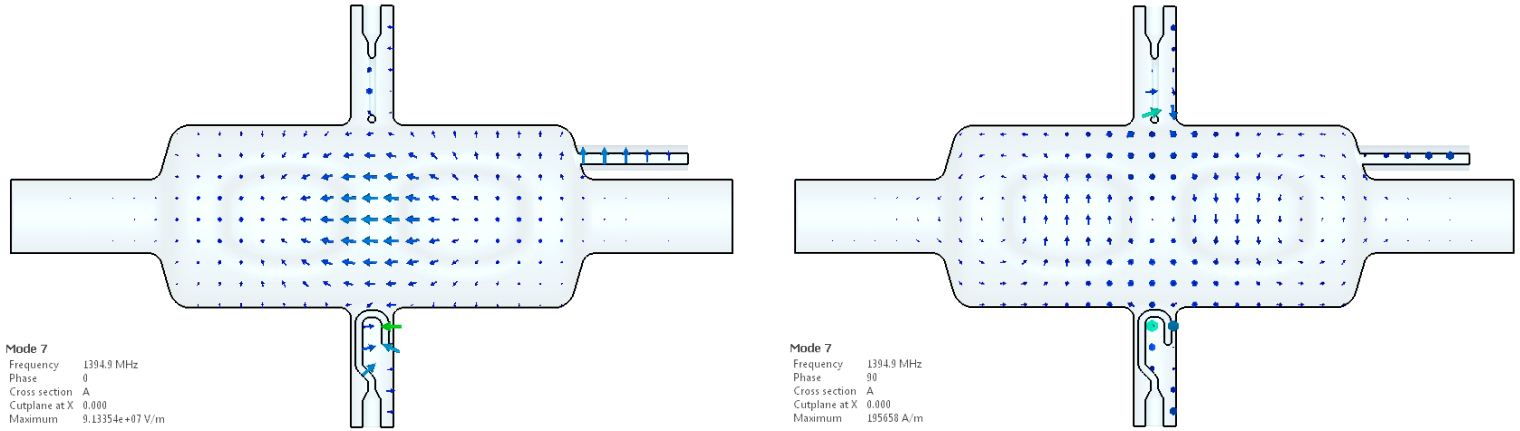


$$Z_x^{thresh.} = \frac{1}{N_C} \frac{2E_b}{f_{rev} I_b \beta_x \tau_x}$$

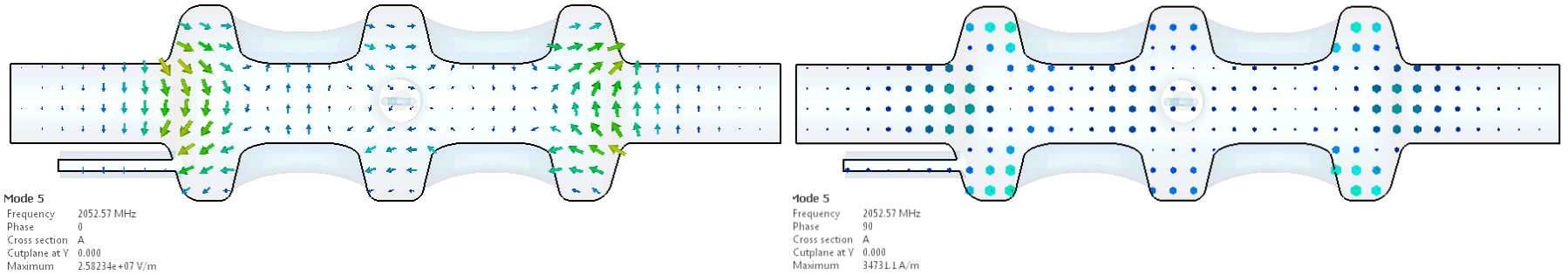
	Unit	e	p
N_C	-	4	24
E_b	GeV	3	100
I_b	A	3	.75
β_x	m	200	450
f_{rev}	kHz	139	
τ_x	ms	1	



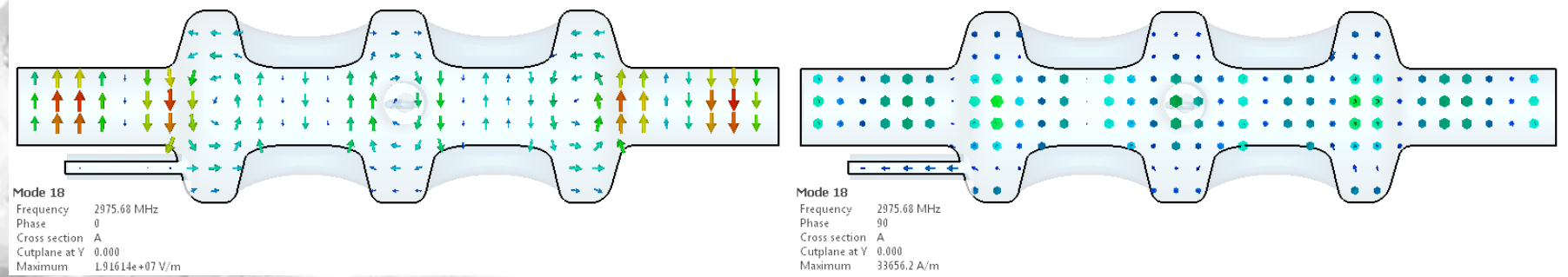
Problem Modes and Further Damping Examples

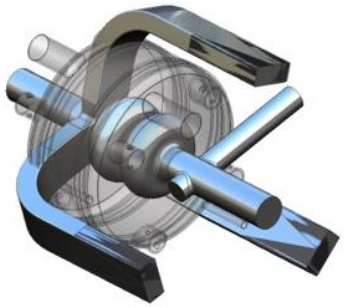


1394 MHz
Impedance high for both long. and trans.-X
Modification of coaxial damper



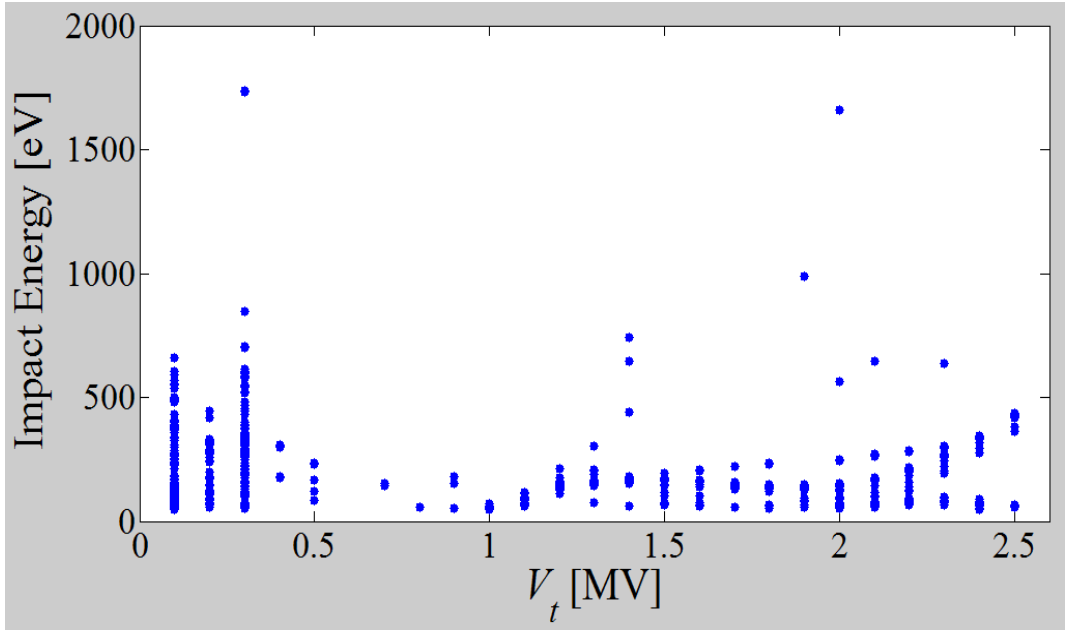
2052 MHz and 2975 MHz
High on trans.-X
Field high near beam pipe
Damping through beam pipe coaxial, beam line absorber, and/or check beam pipe wave guides

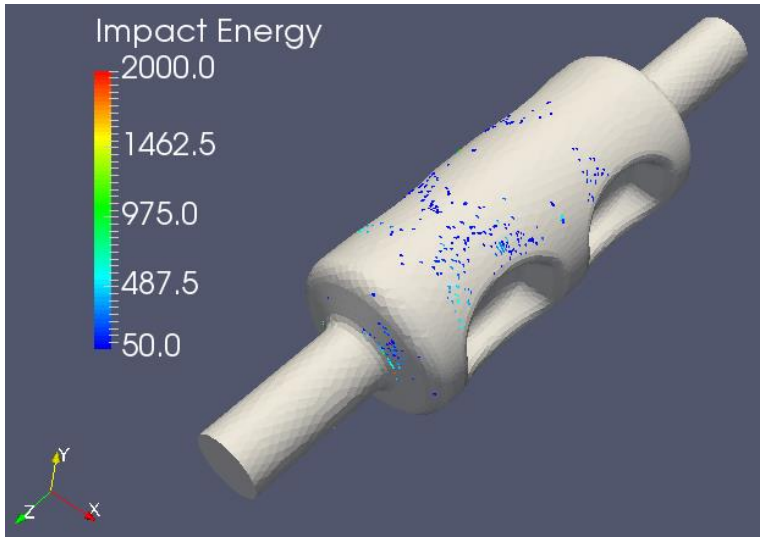


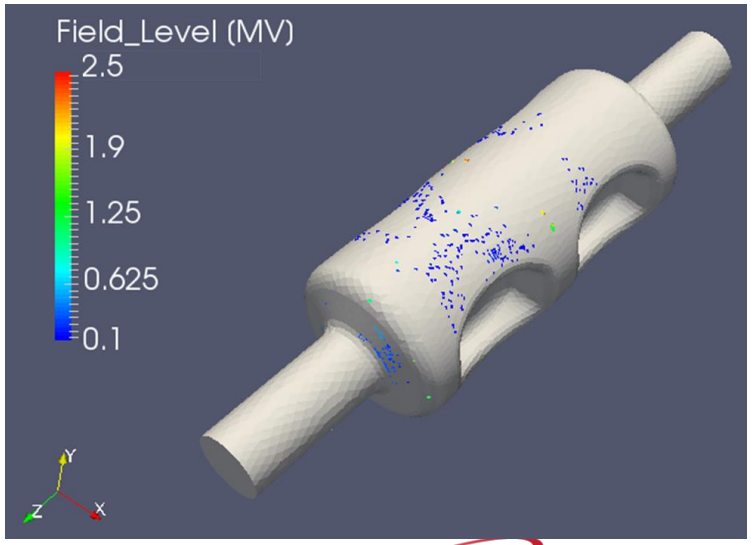


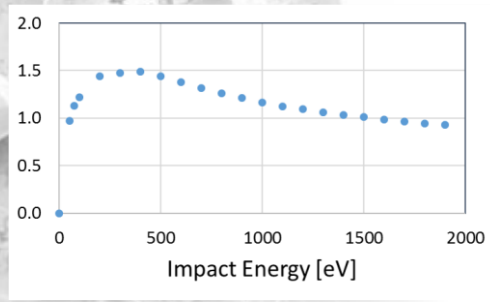
Multipacting Analysis

- Multipacting analysis done using Track3P package in SLAC ACE3P code suite
- Resonant particles are traced:
  - for 50 rf cycles
  - with impact energies 50 – 2000 eV
- Most of the resonant particles have low impact energies and resonance occurs at low transverse voltage (V_t)
- Resonances at operating V_t of 1.5 MV (e) and 1.9 MV (p) have low impact energy.
  - Past experience with other RFD cavities have shown multipacting levels can be processed completely

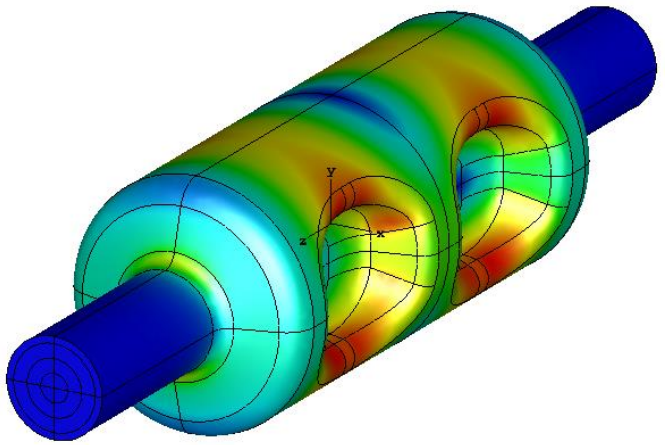


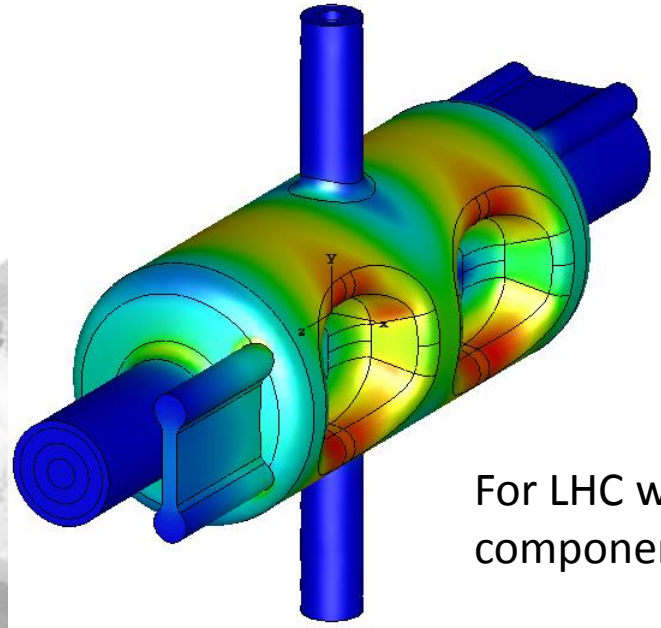






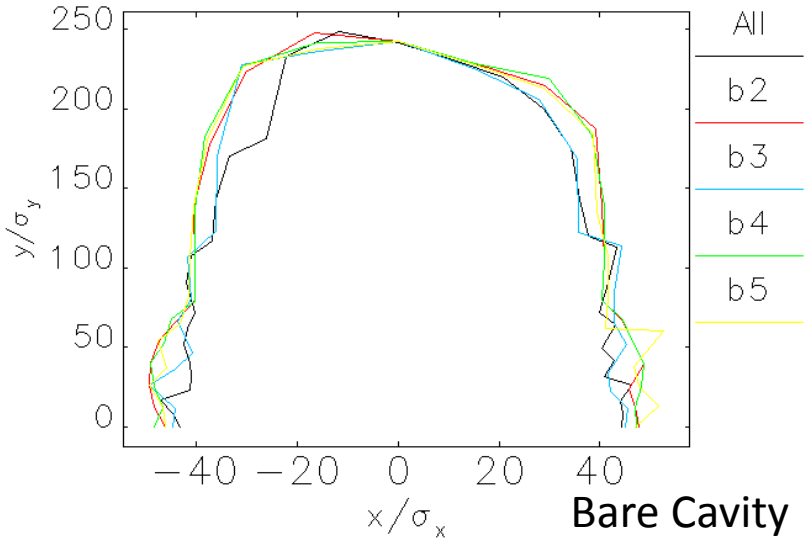
Multipole Analysis



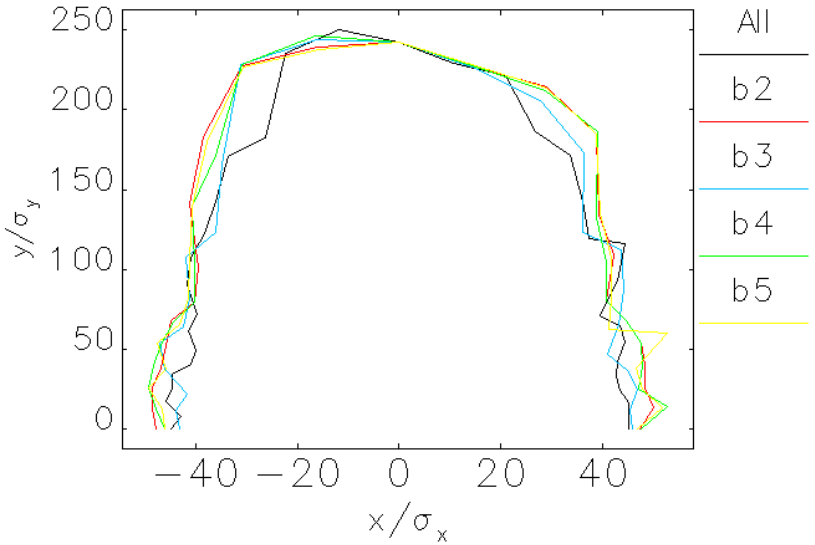


	Bare Cavity	Cavity with HOMs	Unit
V_{acc}	2.5×10^{-4}	12.7	kV
V_t	**1.0**		MV
b_1	3.33	3.33	mT m
b_2	-1.9×10^{-4}	0.85	mT
b_3	968.5	971.7	mT/m
b_4	0.4	103.5	mT/m^2
b_5	-4.1×10^{4}	-4.1×10^{4}	mT/m^3
b_6	-641.5	1702.8	mT/m^4
b_7	-7.0×10^{7}	-7.2×10^{7}	mT/m^5

For LHC we used curved pole shape to decrease multipole components but flat pole is sufficient for JLEIC.



Bare Cavity

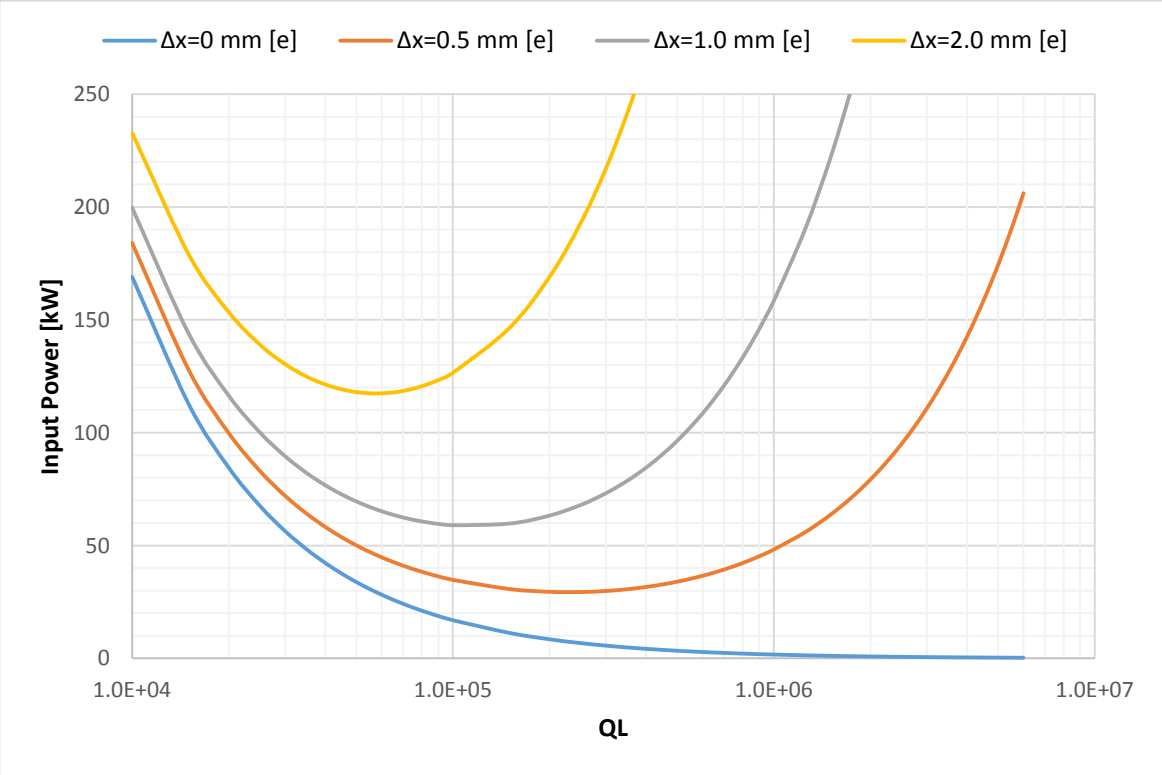


Cavity with HOM dampers

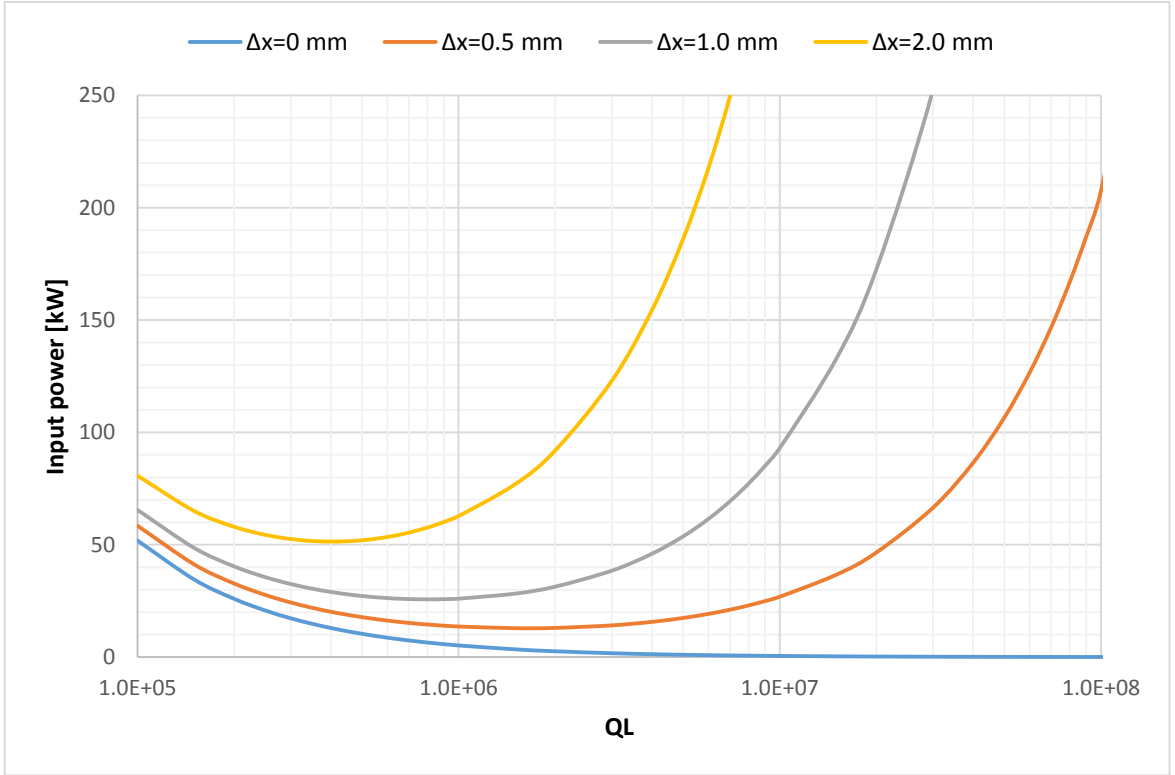
Input Power

$$P_g = \frac{(1+\beta)^2}{4\beta R_t} \times \left\{ \frac{1}{\cos\alpha_L} \left(|V_t| + \frac{I_b R_t}{1+\beta} k\Delta x \sin\phi_c \right) \right\}^2$$

Electron ring: maximum requirement case of 7GeV 3 A, 2 cavities per side

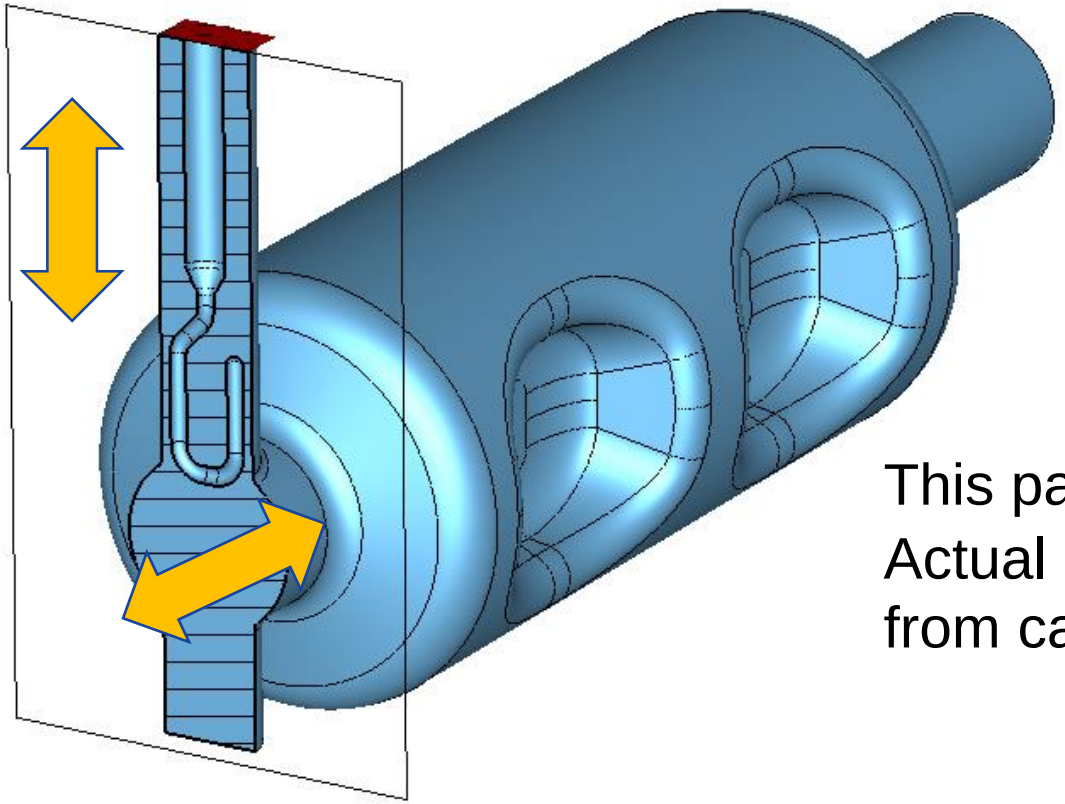


Ion ring: maximum requirement case of 200GeV 0.75A, 12 cavities per side



Power Coupling

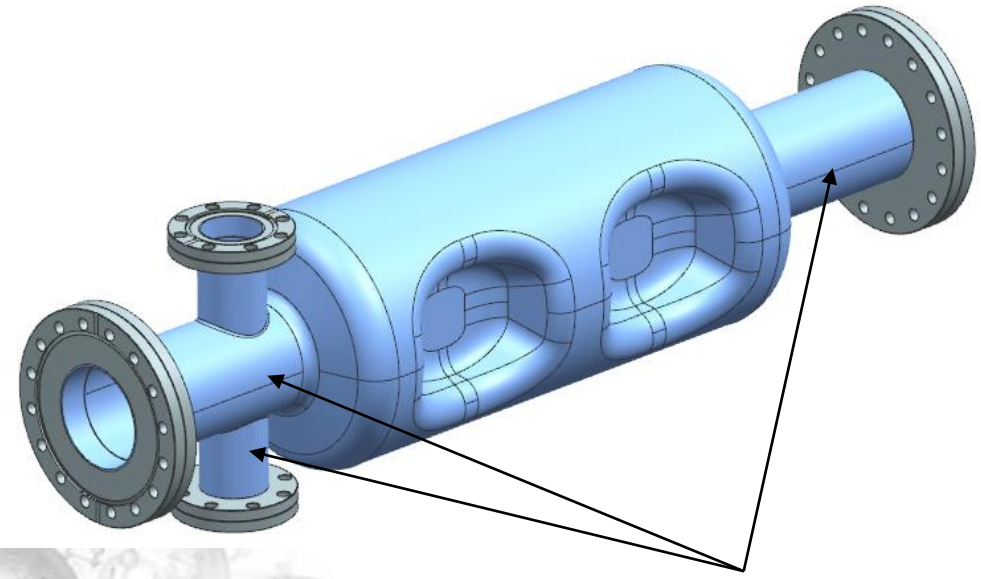
- Power coupler location and coupling capacity, preferably same type and location for both electron and ion cases.
- Electron ring $Q_L=6\times10^4 – 2\times10^5$
- Ion ring $Q_L=4\times10^5 – 2\times10^6$



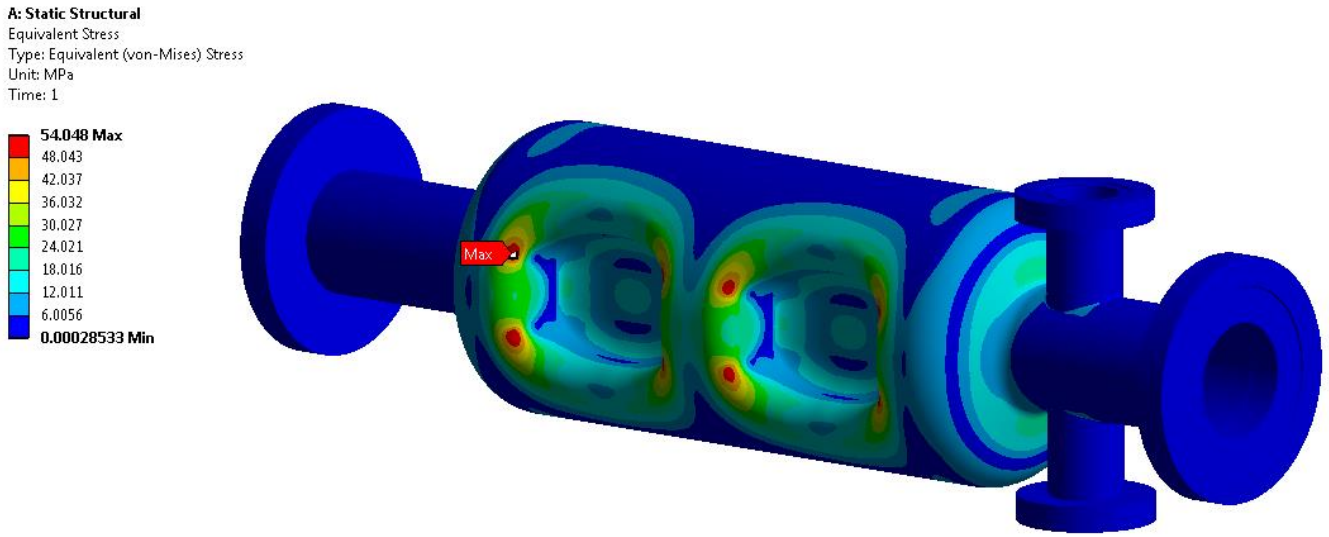
This particular geometry $Q_{ext}=8.25\times10^4$
Actual port expected to be larger and away from cavity.

Fabrication

- Proof of principle bare cavity will be fabricated first.
- Cavity meets pressure safety requirement.
- Nb has been ordered.



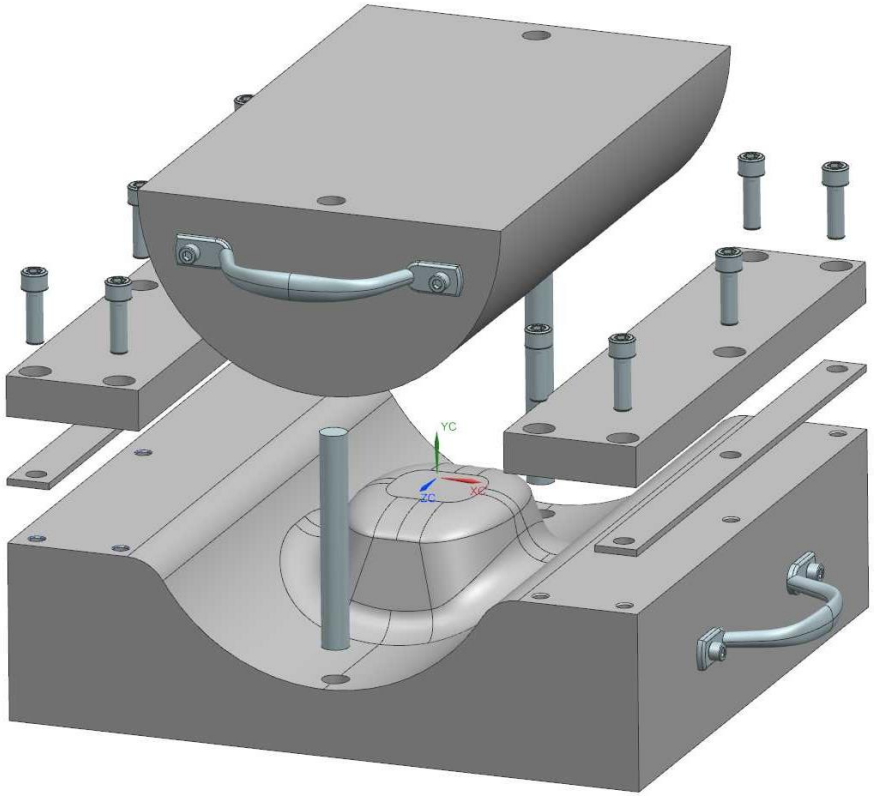
Beam pipes are made
Being trimmed for brazing

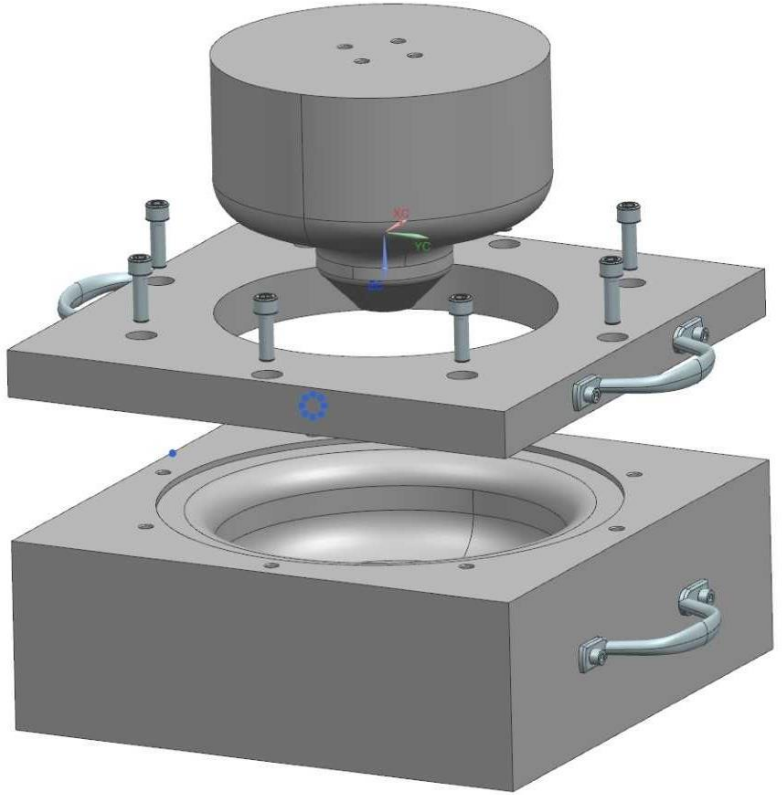


Structural analysis
Room temperature material property
External pressure 2.2 atm
Thickness 2.7 mm considering tolerance, material removal and thinning during forming
Results satisfactory

Fabrication Plan of Crab Cavity

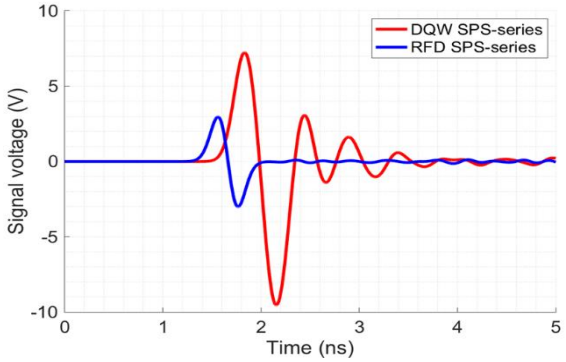
- Procurement of forming dies in progress.



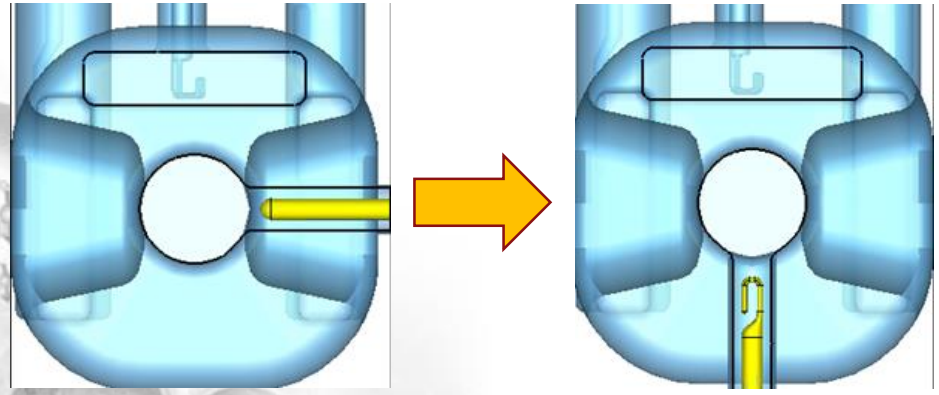


Lessons Learned from LHC SPS Test

- Careful pick up probe design to minimize beam interaction.



Beam induced voltage



Design change

- JLab experience of LHC crab cavity

Fabrication

Processing

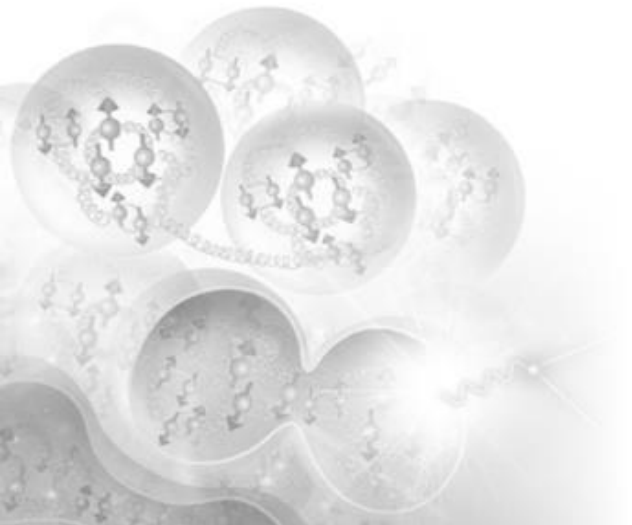
Assembly

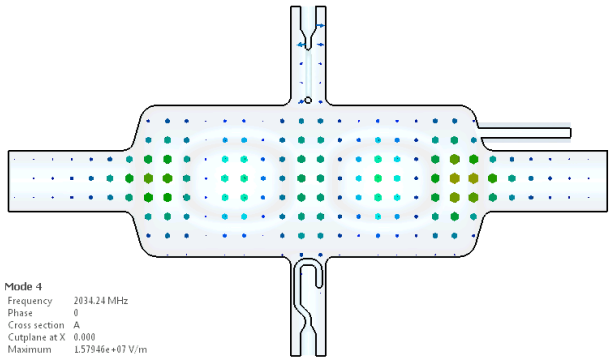
Test

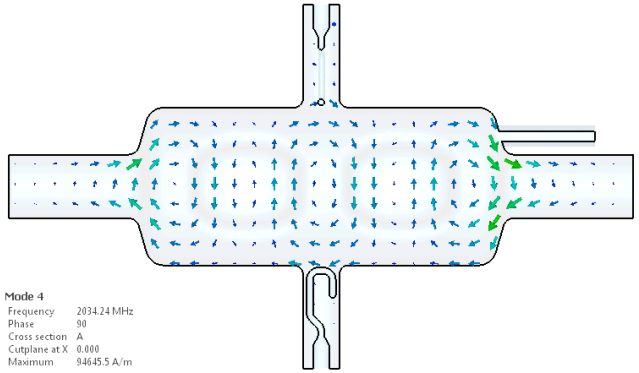
Summary and Plan Forward

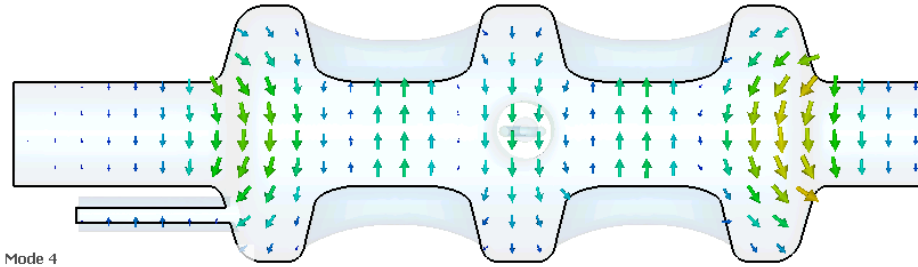
- Number of cavity designs have been studied and down selection is made.
- HOM spectrum (frequency and R/Q) has been characterized and development of damping scheme is on going.
- Close collaboration with beam impedance group to specify the damping requirements.
- Design of bare cavity is complete and fabrication has been initiated.
- Collaboration between ODU, JLab, BNL and CERN to incorporate lessons learned from SPS crab cavity test to JLEIC crab cavity.
- To be completed
  - Wakefield analysis and damper design.
  - In parallel completion of bare cavity.
  - Bench test and cryogenic test to confirm the study results.
  - Design of prototype cavity incorporating bare cavity test and damper design.
  - Continuing full involvement in crab SYSTEM (including beam physics and engineering).

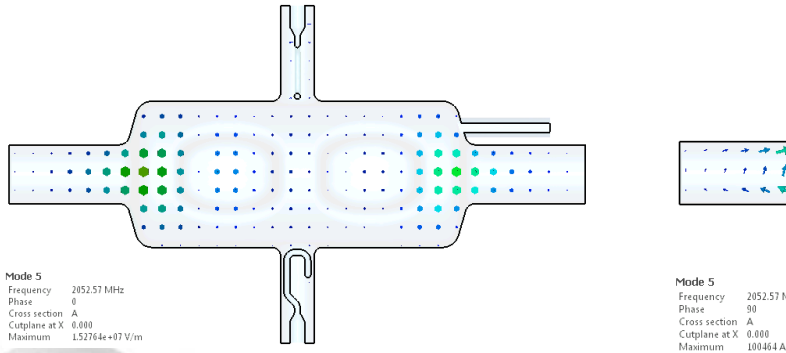
Thank you!

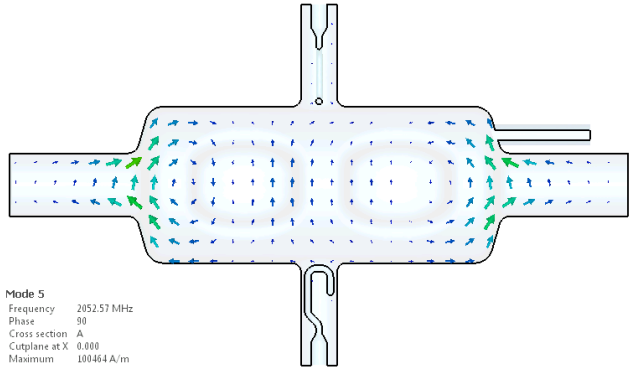


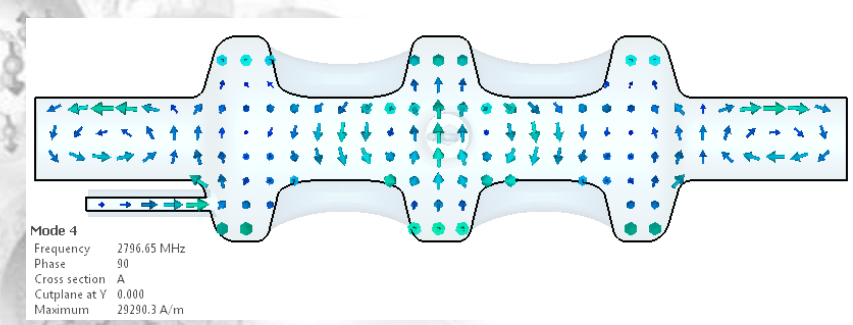

Mode 4
Frequency 2034.24 MHz
Phase 0
Cross section A
Cutplane at X 0.000
Maximum 1.57946e+07 V/m

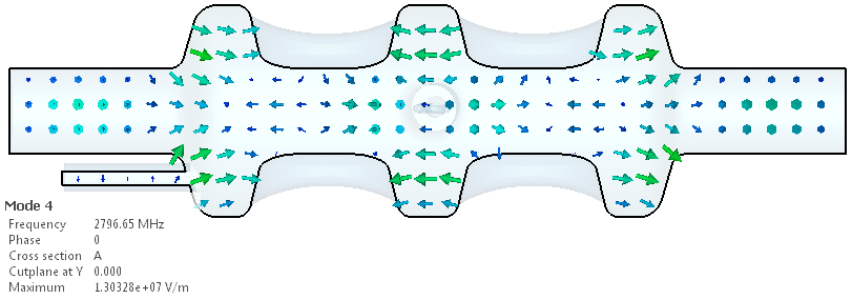

Mode 4
Frequency 2034.24 MHz
Phase 90
Cross section A
Cutplane at X 0.000
Maximum 94645.5 A/m


Mode 4
Frequency 2034.24 MHz
Phase 0
Cross section A
Cutplane at Y 0.000
Maximum 2.10298e+07 V/m


Mode 5
Frequency 2052.57 MHz
Phase 0
Cross section A
Cutplane at X 0.000
Maximum 1.52764e+07 V/m


Mode 5
Frequency 2052.57 MHz
Phase 90
Cross section A
Cutplane at X 0.000
Maximum 100464 A/m


Mode 4
Frequency 2796.65 MHz
Phase 90
Cross section A
Cutplane at Y 0.000
Maximum 29290.3 A/m


Mode 4
Frequency 2796.65 MHz
Phase 0
Cross section A
Cutplane at Y 0.000
Maximum 1.30328e+07 V/m

EIC Accelerator Collaboration Meeting

October 29 - November 1, 2018

Beam energy	GeV	3	5	6.9	9	10	12
Beam current	A	3	3	**2.6**	1	0.67	0.17
Total SR power	MW	0.4	2.9	8.8	9.8	**10.0**	5.3
Energy loss per turn	MeV	0.12	0.93	3.4	9.8	14.9	**30.8**
Energy spread	10^{-4}	2.8	4.6	6.4	8.3	9.3	11.1
Transverse damping time	ms	375	81	31	14	10	6
Longitudinal damping time	ms	187	40	15	7	5	3
Normalized hor. emittance	um	9.6	44	116	258	354	612
Normalized ver. emittance	um	1.1	5.0	13.1	28.9	39.7	68.6