Path to SPS Testing
Prototype Design
ODU/SLAC RF Dipole Cavity

Jean Delayen

Center for Accelerator Science
Old Dominion University

Acknowledgments

- Work performed by
  - Subashini De Silva (ODU)
  - Jean Delayen (ODU)
  - Zenghai Li (SLAC)
  - Julius Nfor (ODU)
  - Rocio Olave (ODU)
  - HyeKyoung Park (ODU/JLAB)

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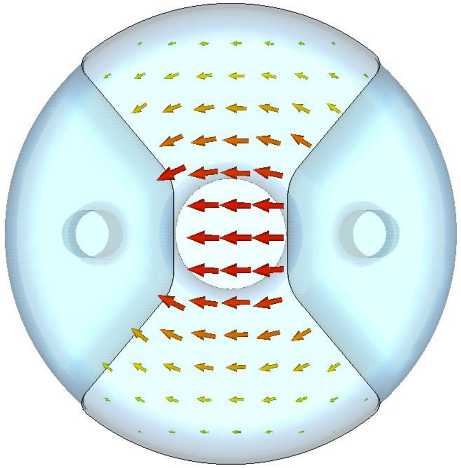
Outline

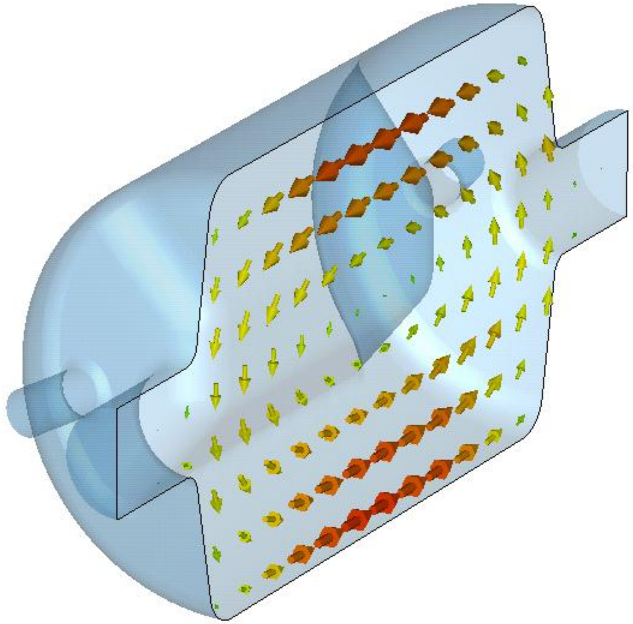
- Proof-of principle design and results
- Prototype design vs proof-of-principle cavity
  - RF parameters
  - Multipacting
  - Field flatness and multipoles
  - Higher Order Mode analysis
- Mechanical analysis
  - Mechanical strength
  - Pressure sensitivity
  - Lorentz force detuning
- Tuner
- Helium tank
- Cryostat concept
- Summary and Future plan

Proof of Principle Design

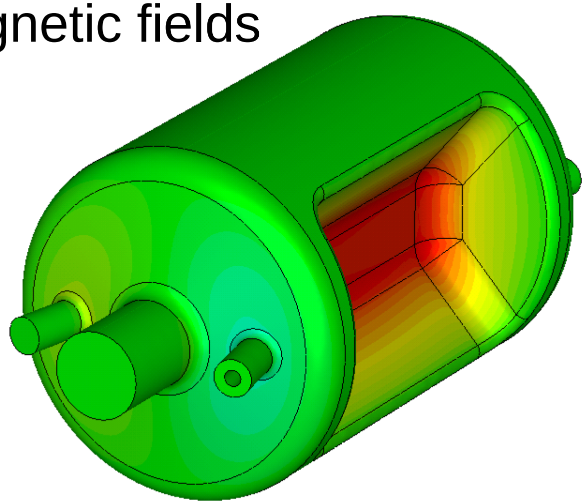
- Design requirements
  - Frequency = 400 MHz
  - Beam aperture = 84 mm
  - Total transverse voltage = 10 MV
  - Transverse voltage per cavity = 3.4 MV

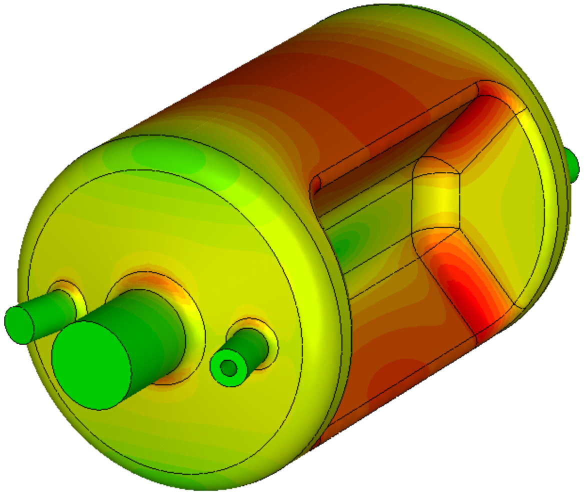
- Transverse electric and magnetic fields



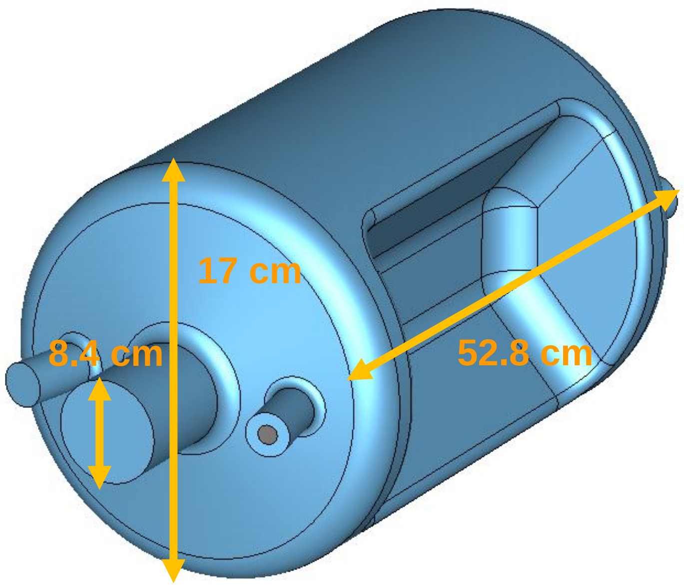


- Surface electric and magnetic fields





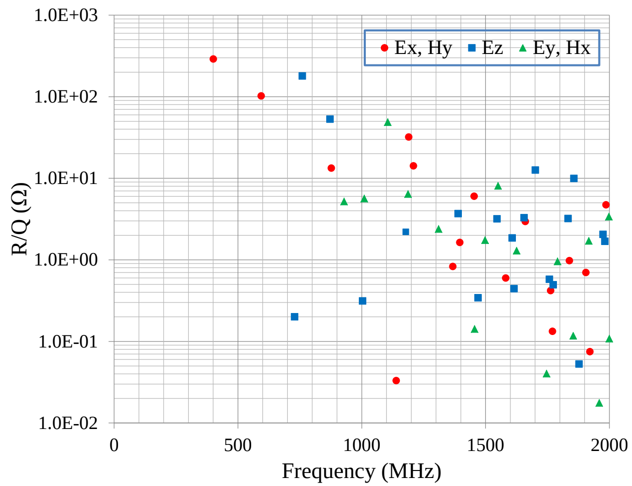
Basic Properties



Property	Value	Unit
V_T^*	0.375	MV
E_p^*	4.02	MV/m
B_p^*	7.06	mT
B_p^*/E_p^*	1.76	mT/(MV/m)
U^*	0.195	J
$[R/Q]_T$	286.95	Ω
Geometrical Factor (G)	140.86	Ω
$R_T R_S$	4.04×10^4	Ω^2
At $E_T^* = 1$ MV/m		

HOM Properties

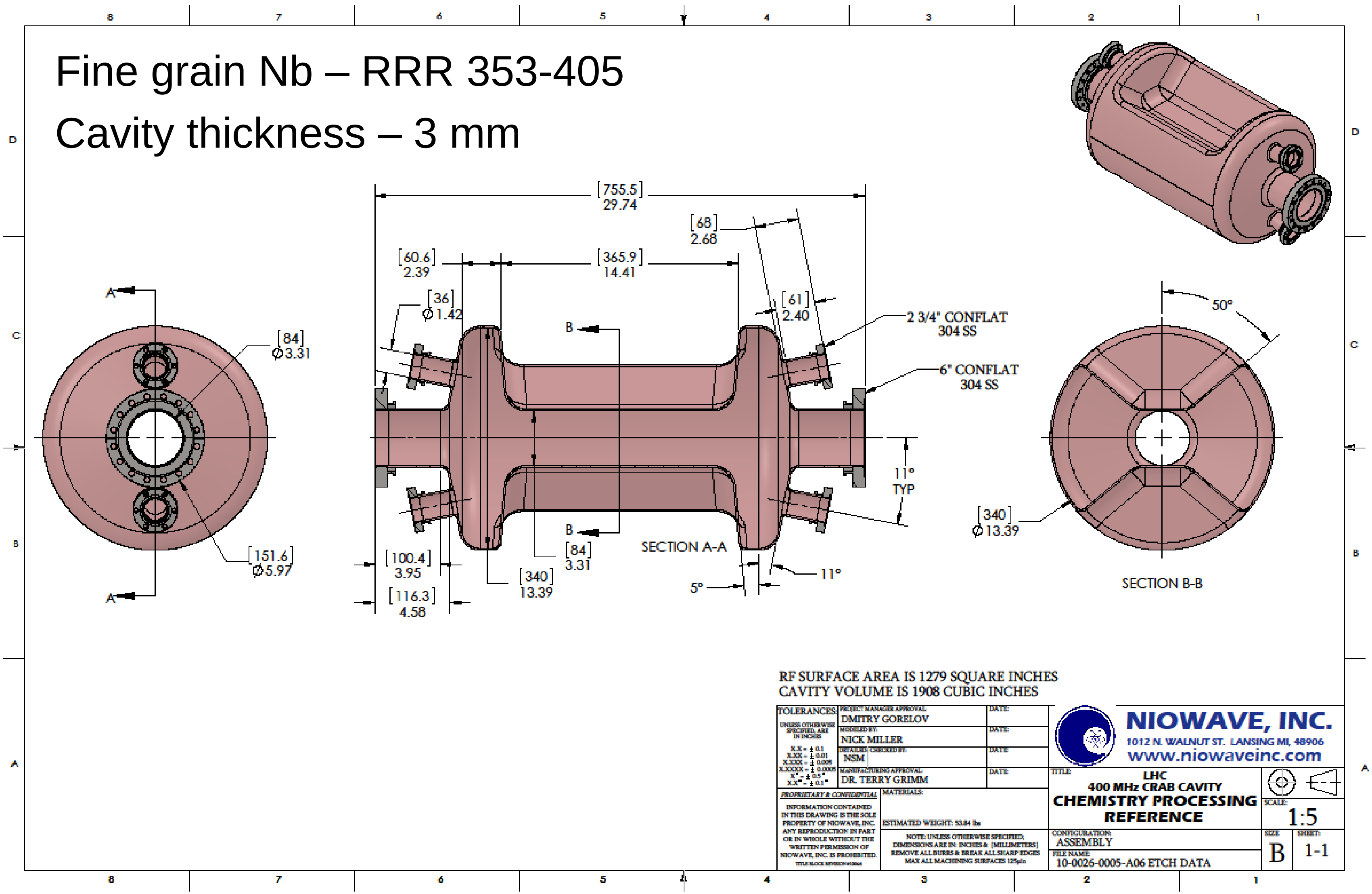
- No lower order modes
- Separation of HOMs from fundamental mode ~ 190 MHz



Fabrication

Fine grain Nb – RRR 353-405

Cavity thickness – 3 mm



Surface Treatment, Preparation and Testing

- Bulk BCP – 85 μm
- Heat treatment – At 600^0 C for 10 hours
- Light BCP – ~10 μm
- High Pressure Rinse – 3 passes
- Assembly in the clean room

BCP Cabinet

HPR Cabinet

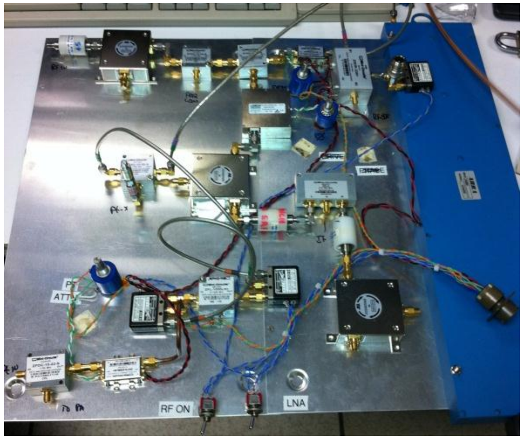
- RF Test Plan
  - High power tests at 2 K and 4 K
  - Rs vs. T
  - Pressure test
  - Lorentz detuning
  - No He processing was done
- RF Tests Performed
  - 2 K high power test
  - Cavity warmed up to 4 K
  - 4 K high power test
  - Cavity cooled down to 2 K
  - 2 K high power test

Assembly

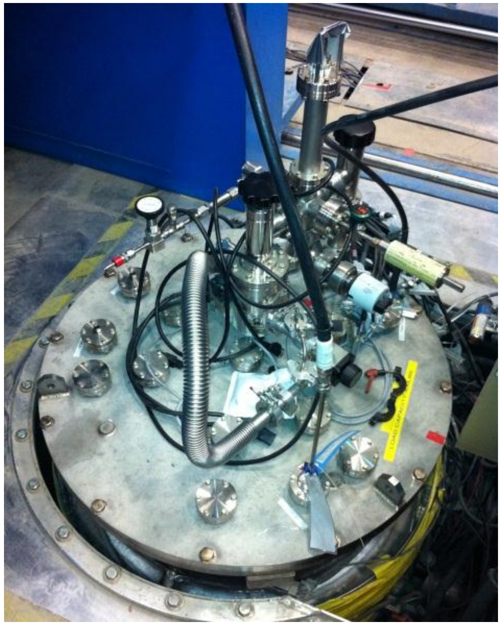
- Followed by a HPR of 3 passes
- Ultrasonic degreased hardware
- Leak tested
- Assembly in clean room

Preparation for Test

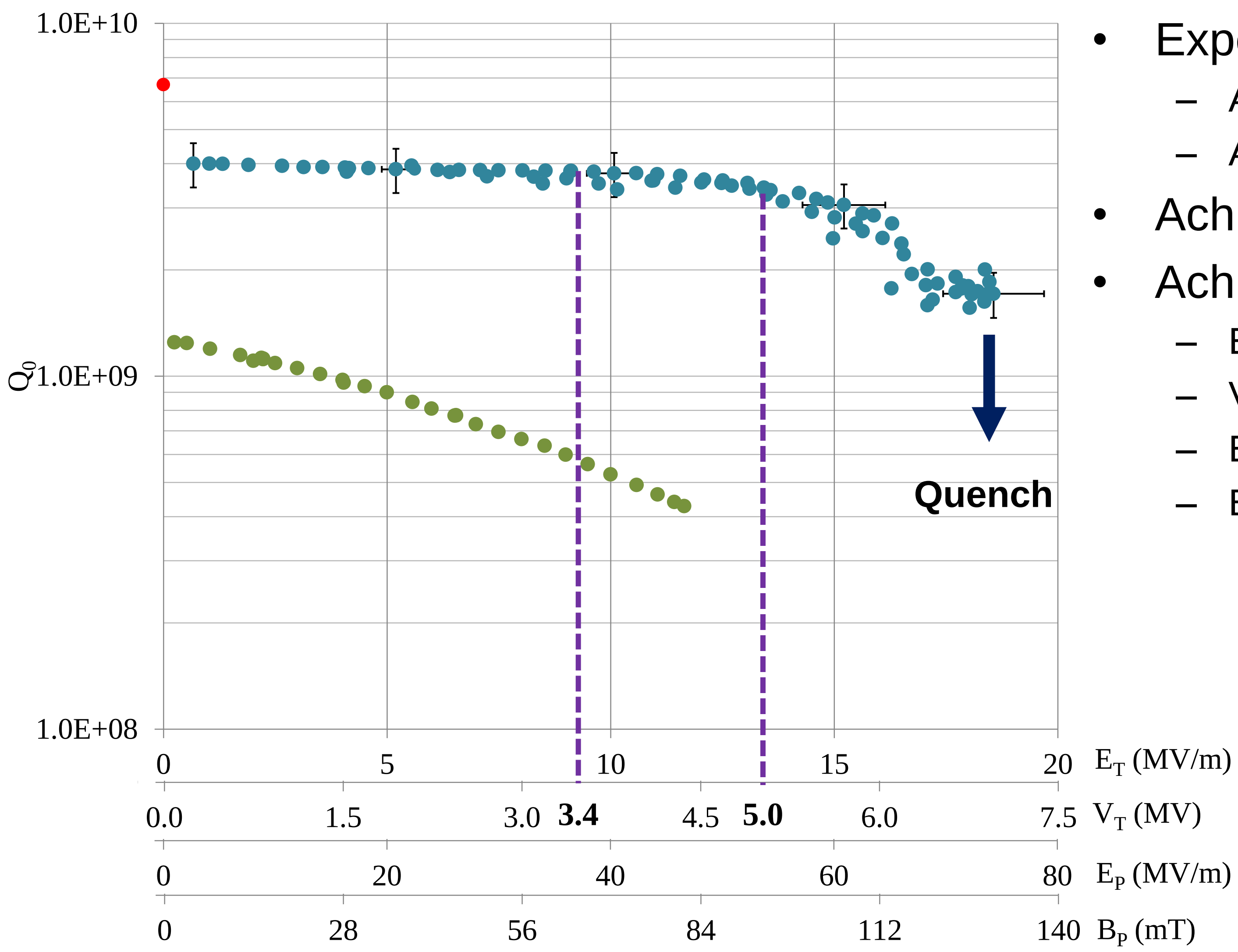
- Cable calibration
  - $Q_1 = 2.76\times10^9$
  - $Q_2 = 8.62\times10^{10}$
- LLRF control



- Test with 500 W rf amplifier

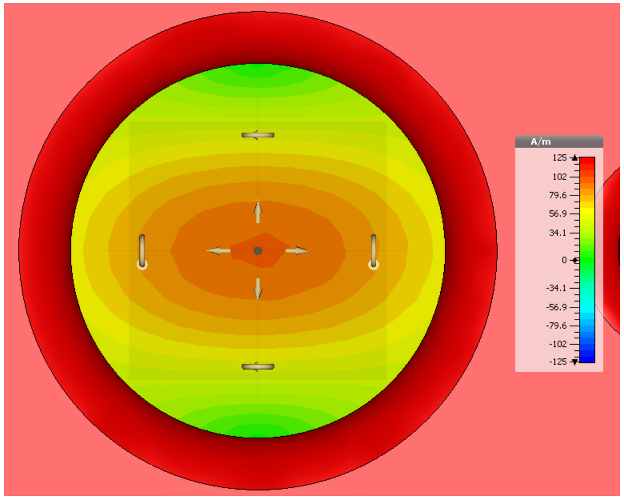


2 K and 4.2 K Test Results

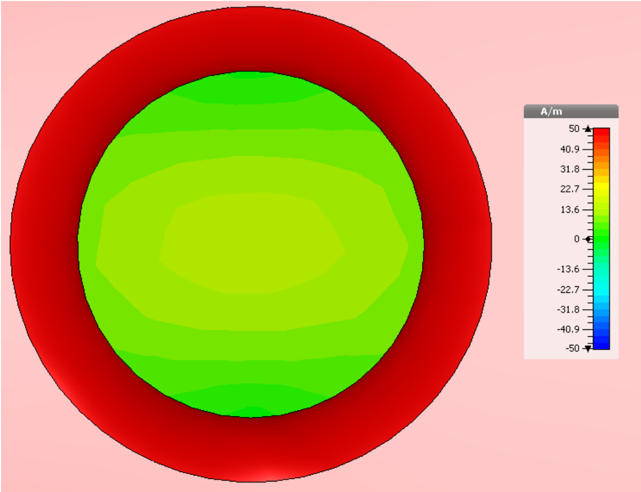


- Expected $Q_0 = 6.7\times10^9$
  - At R_S = 22 nΩ
  - And R_{res} = 20 nΩ
- Achieved $Q_0 = 4.0\times10^9$
- Achieved fields
  - E_T = 18.6 MV/m
  - V_T = 7.0 MV
  - E_P = 75 MV/m
  - B_P = 131 mT

Low-field Q



Beam line port

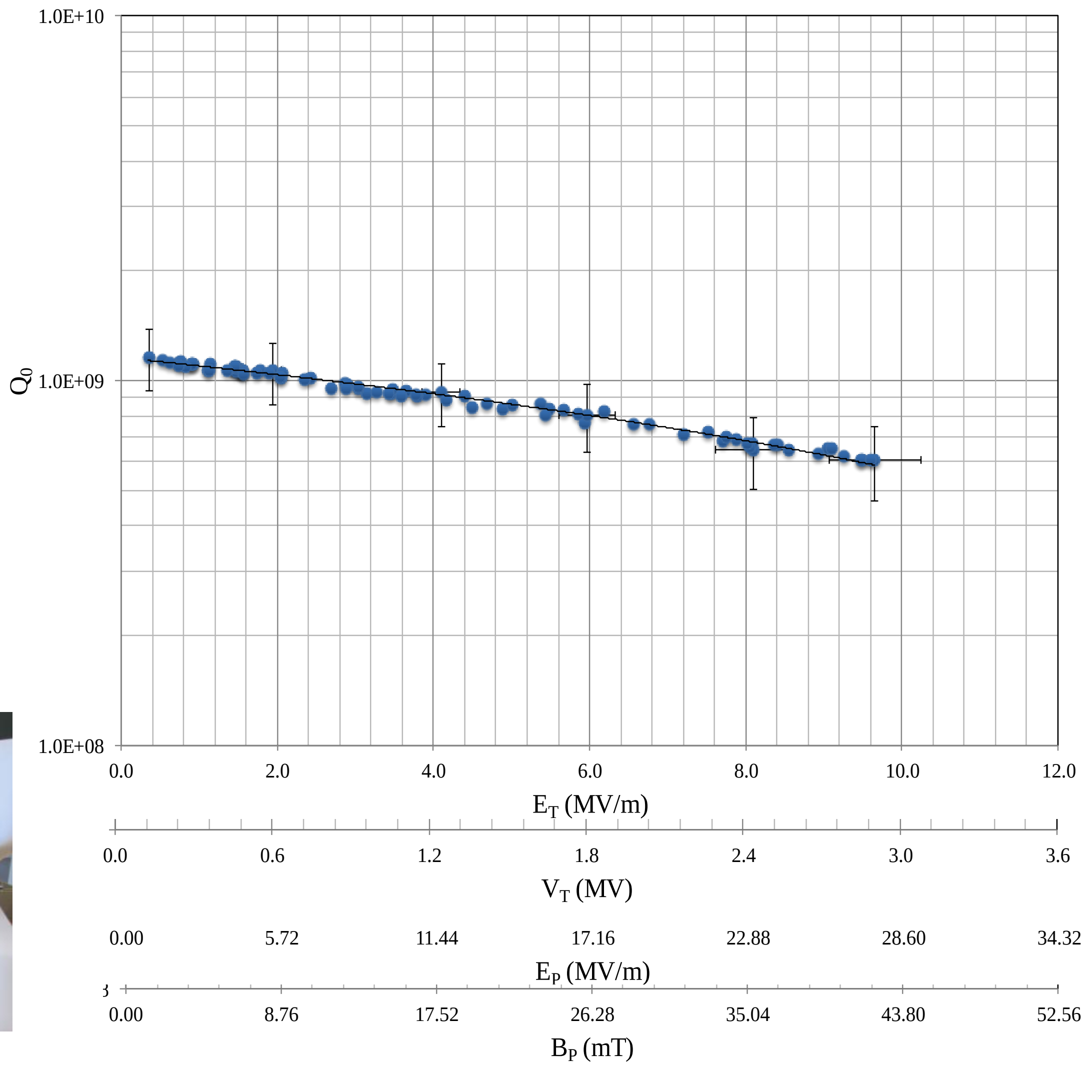


Coupler port

- Calculated Q due to stainless steel flanges : 3.7 10^9
- Measured Q : 4.0 10^9

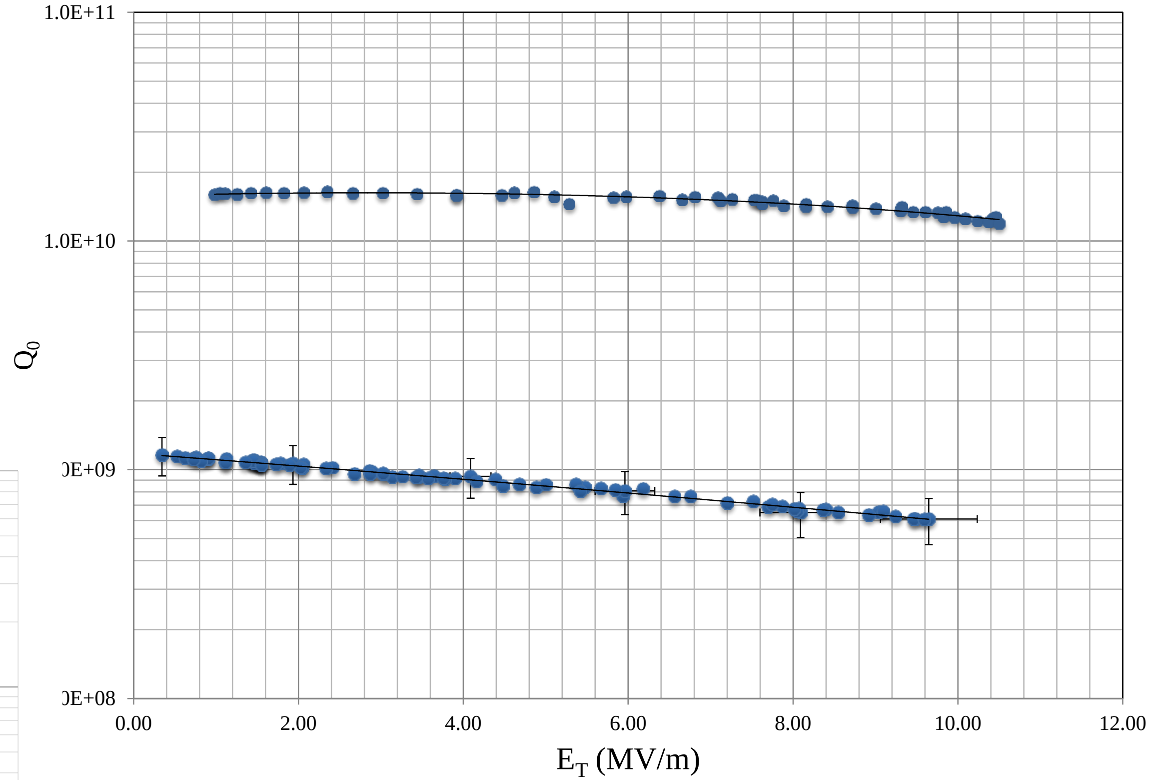
499 MHz Deflecting Cavity for JLab Upgrade

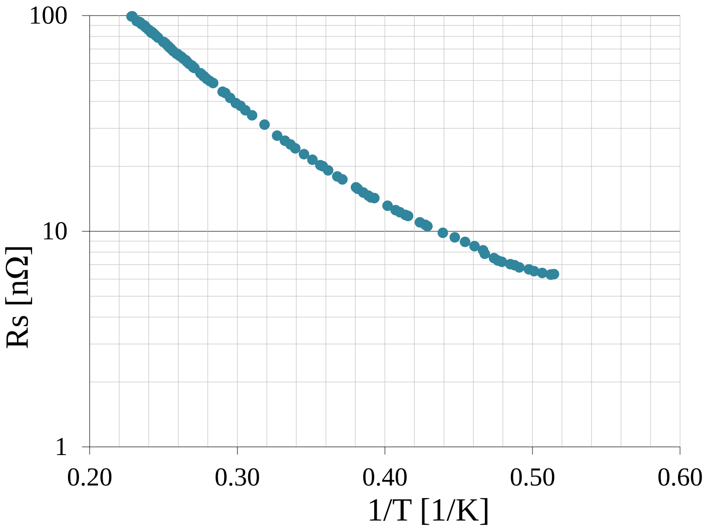
- 4.2 K test yesterday
- Confirms multipacting easily processed and does not reoccur
- $R_{res} < 10\ n\Omega$



499 MHz Deflecting Cavity for JLab Upgrade

- 2 K test last night
- No multipacting
- R_{res} ~ 5 nΩ



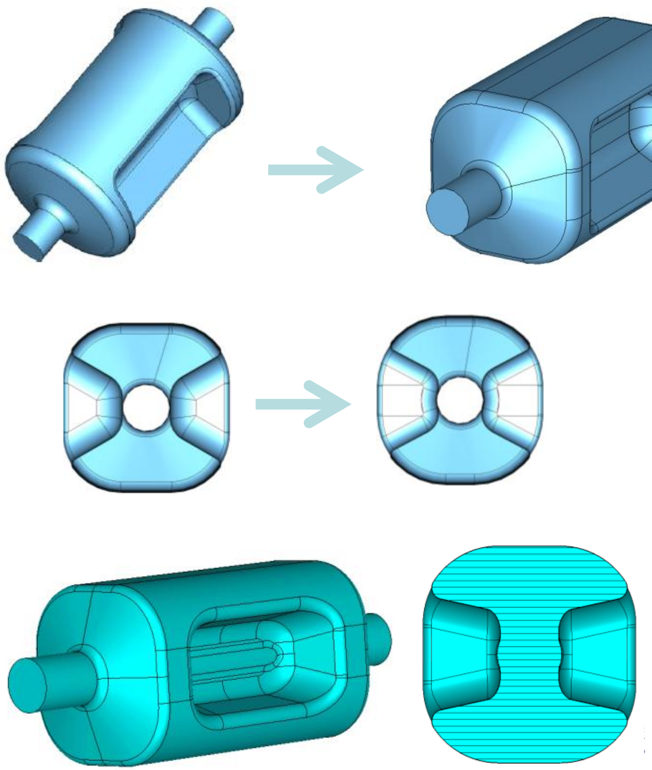


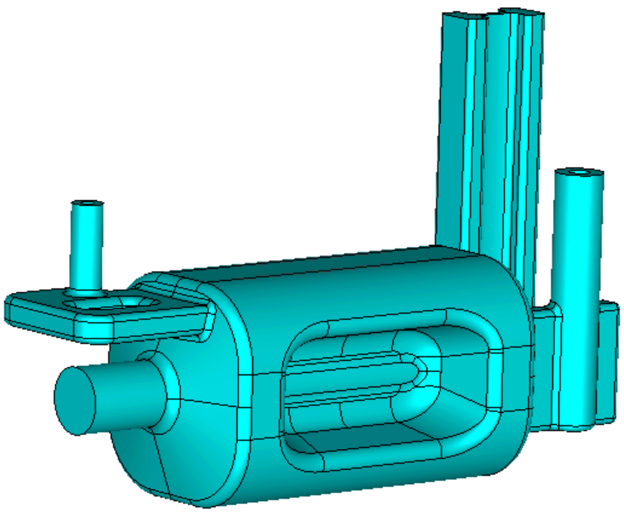
Summary

- Proof-of-Principle cavity achieved 7 MV deflecting voltage cw
- Residual surface resistance a little high (34 nΩ)
  - Consistent with losses in stainless steel flanges
- Multipacting quickly processed and did not reoccur
- Proof-of-Principle cavity has achieved its purpose
- Ready to move on to the prototype cavity
- Reasonably confident that 10 MV can be achieved with 2 cavities

Prototype Design vs. Proof-of-Principle

ODU/SLAC
Cavity Design Evolution

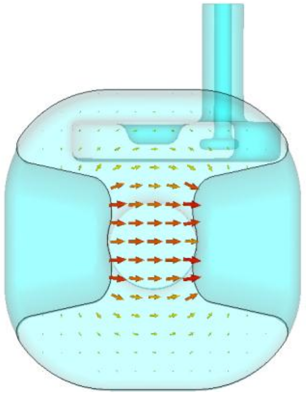


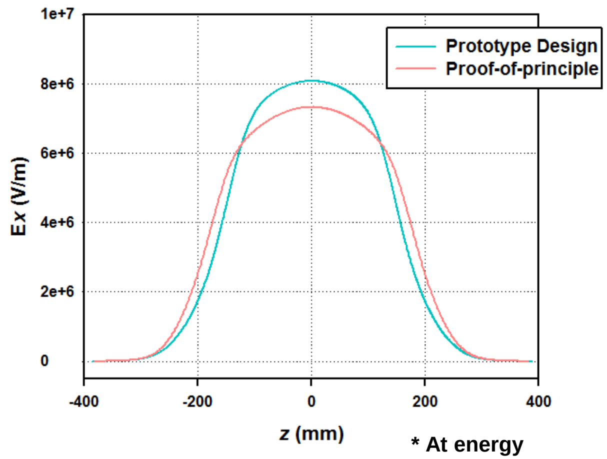


Prototype Design

Cavity Dimensions			
	Prototype Design	Proof-of-Principle	Units
Radius	**140.5**	170	mm
Iris-to-iris Length	535	528	mm
Beampipe aperture	42	42	mm

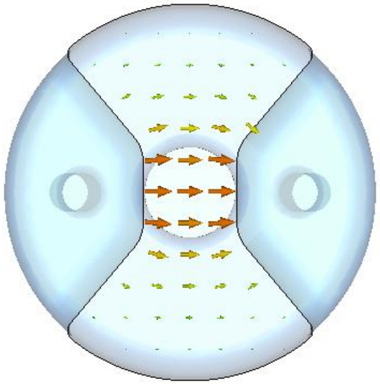
Prototype Design vs. Proof-of-Principle

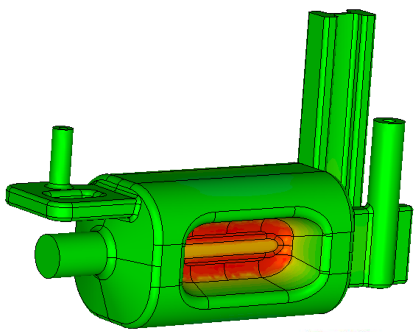




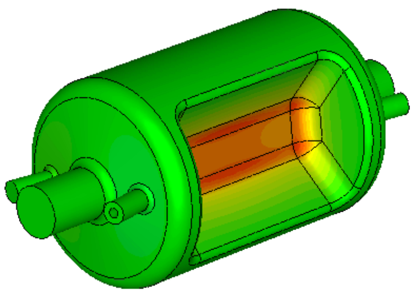
* At energy content of 1 J

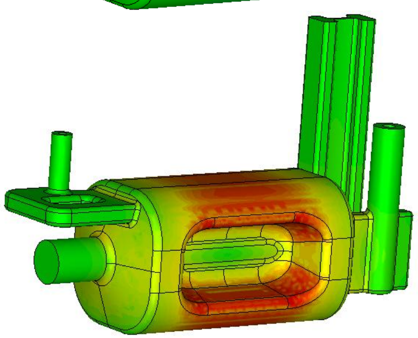
Transverse Electric Field



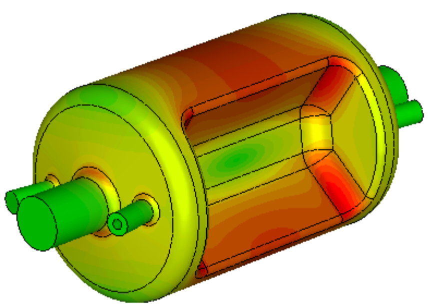


Surface Electric Field





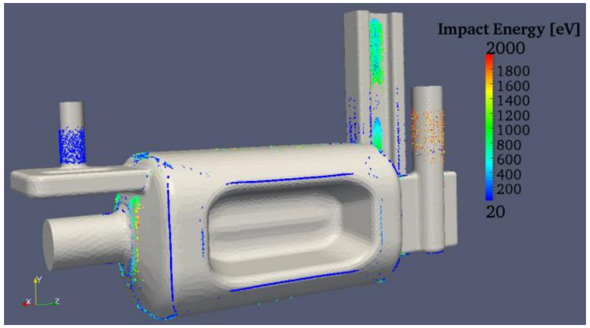
Surface Magnetic Field

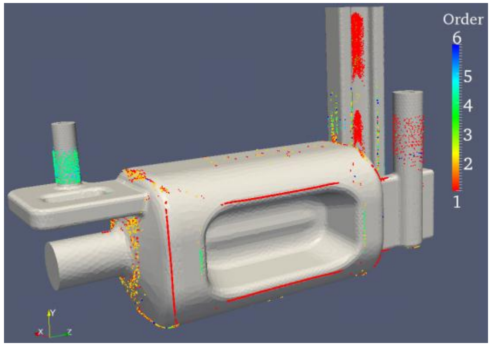


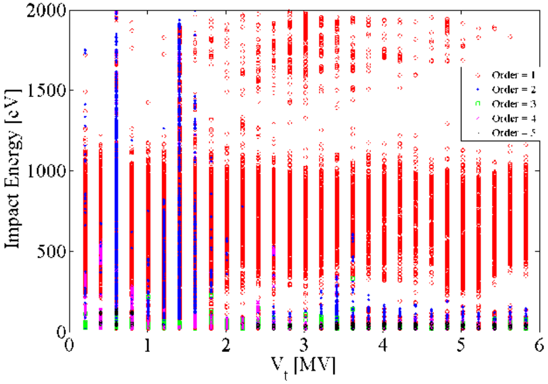
Prototype Design vs. Proof-of-Principle

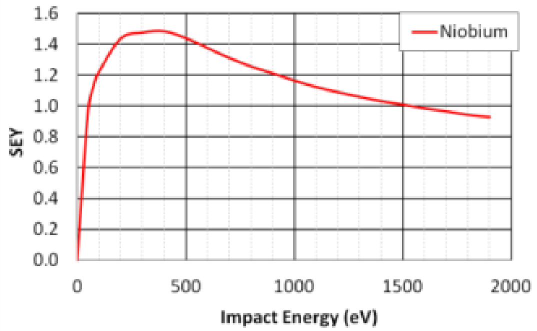
Multipacting Simulations

Prototype design



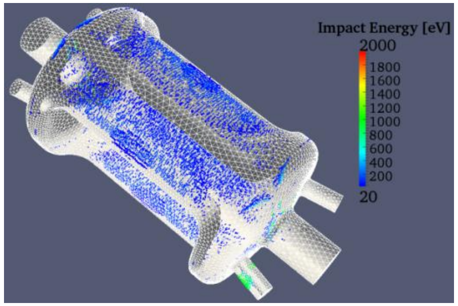


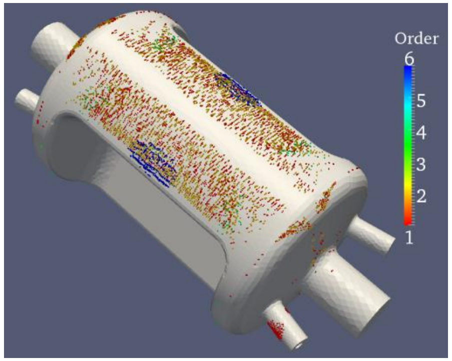


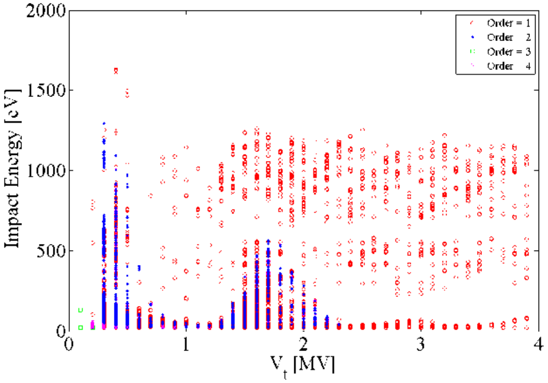


Using Track3P from the ACE3P Code Suite developed at SLAC

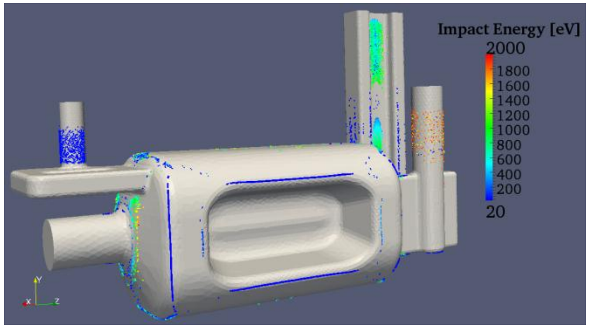
Proof-of-Principle

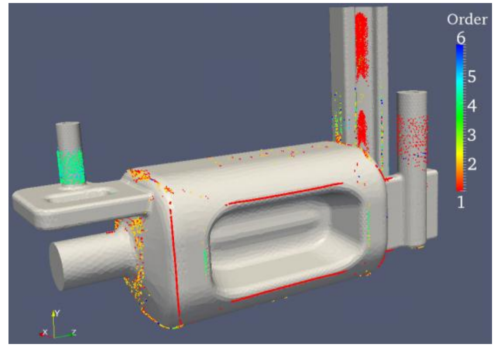


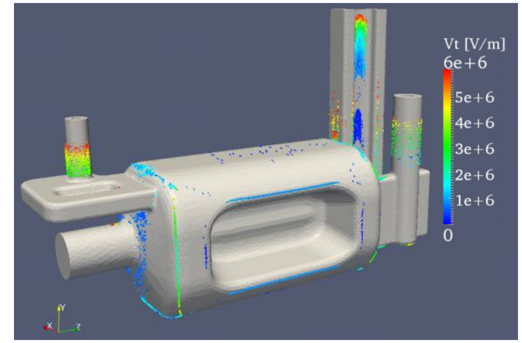


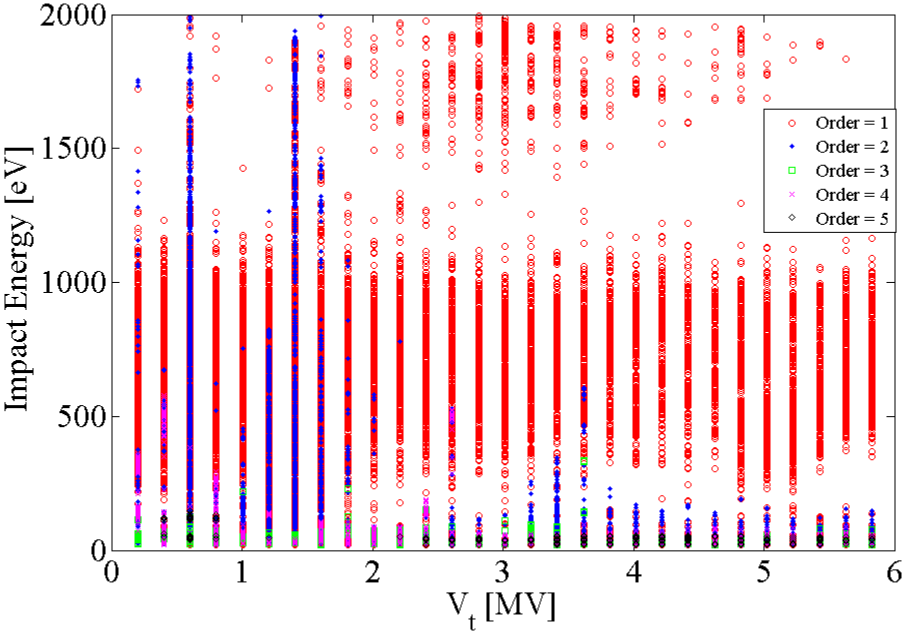


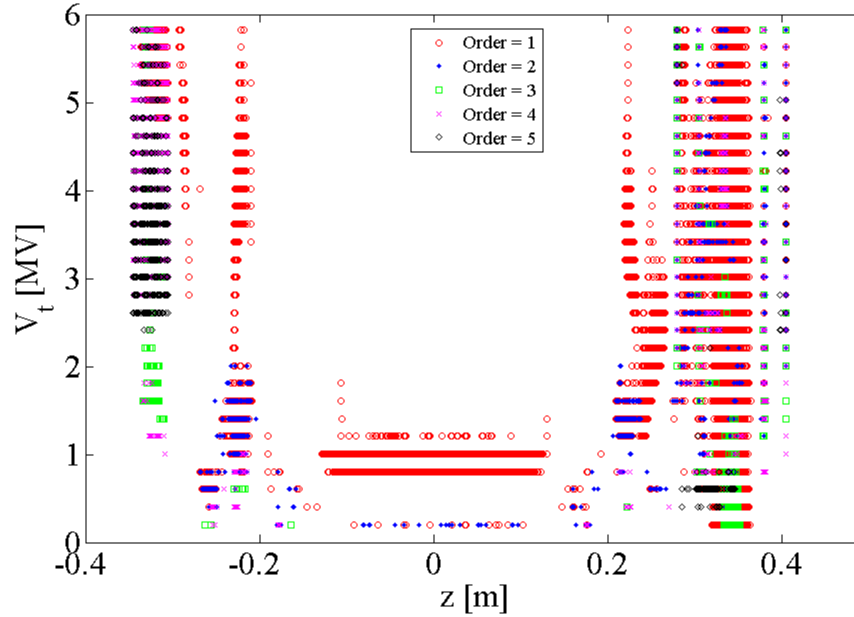
Multipacting Simulations



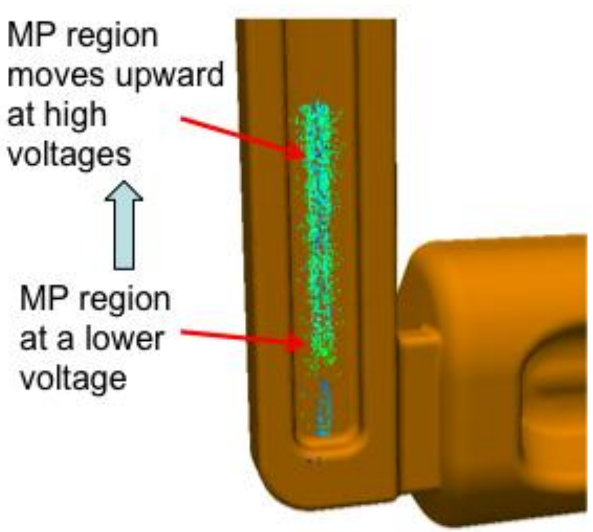


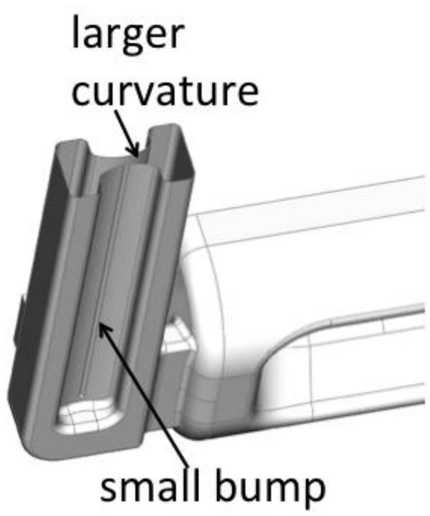


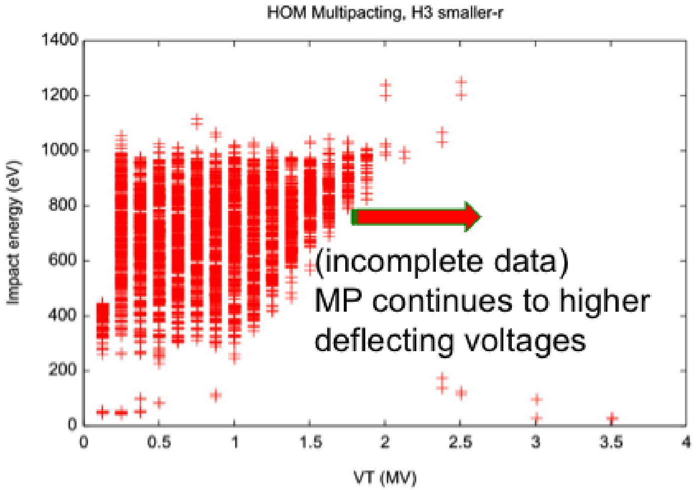


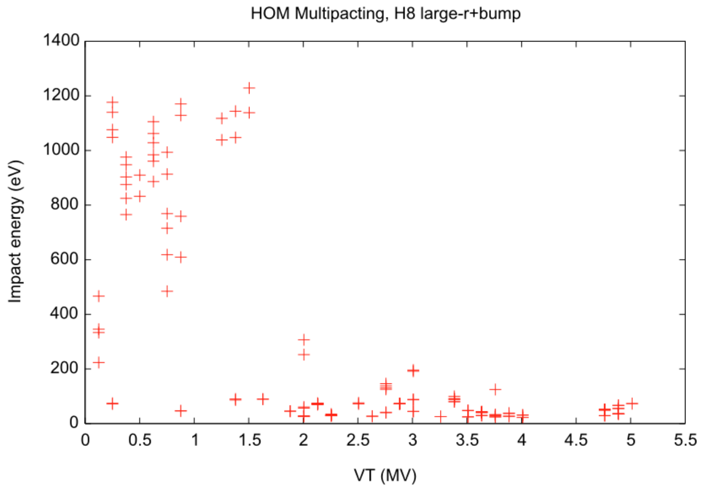


Multipacting Simulations



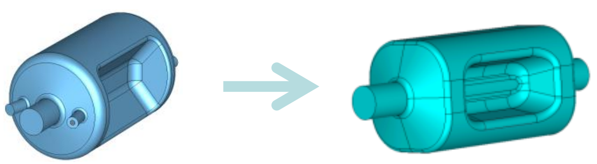




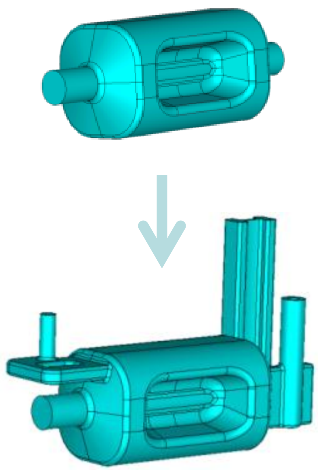


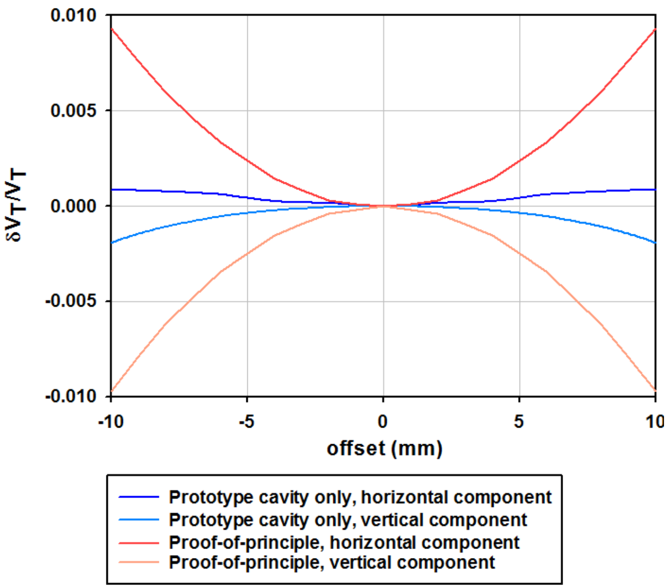
Prototype Design vs. Proof-of-Principle

Field flatness / Multipoles

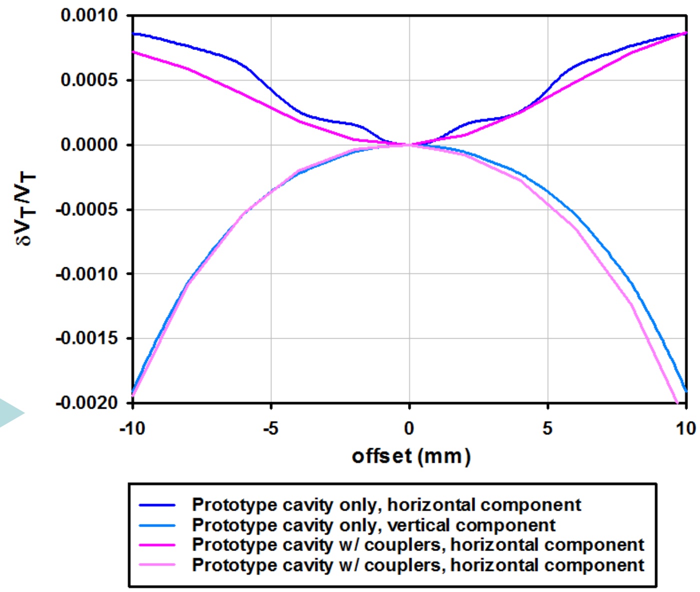


Multipole Components			
	Prototype Design	Proof-of-Principle	Units
b_3	**455.2**	3.0×10^{3}	mT/m
b_4	24.62	0	mT/m^2
b_5	$-2.19\text{x}10^{6}$	-4.6×10^{5}	mT/m^3
At V_T = 10 MV			



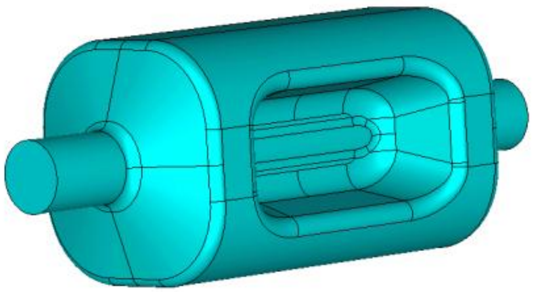


Shift in electrical center of 55 μm due to the asymmetry introduced by the couplers

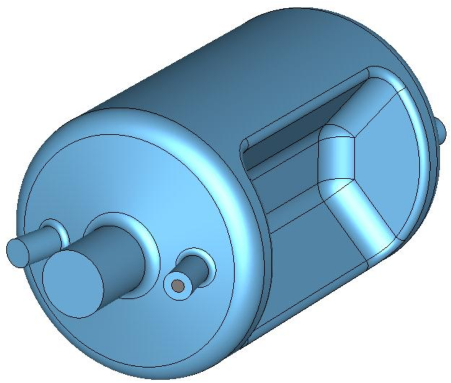


Prototype Design vs. Proof-of-Principle

Higher order mode analysis

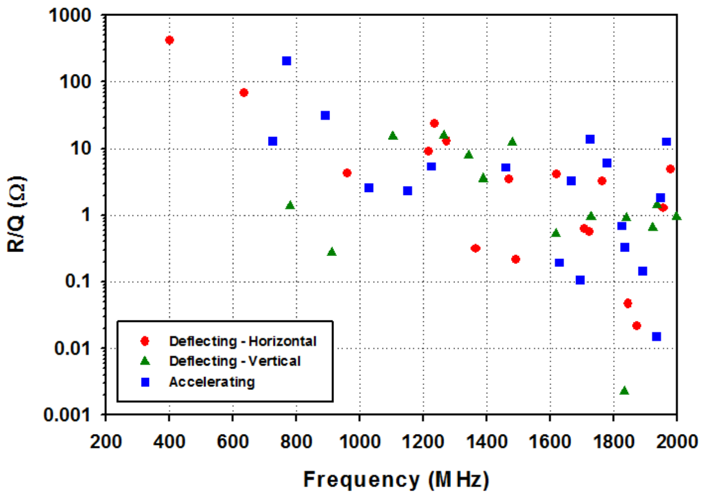


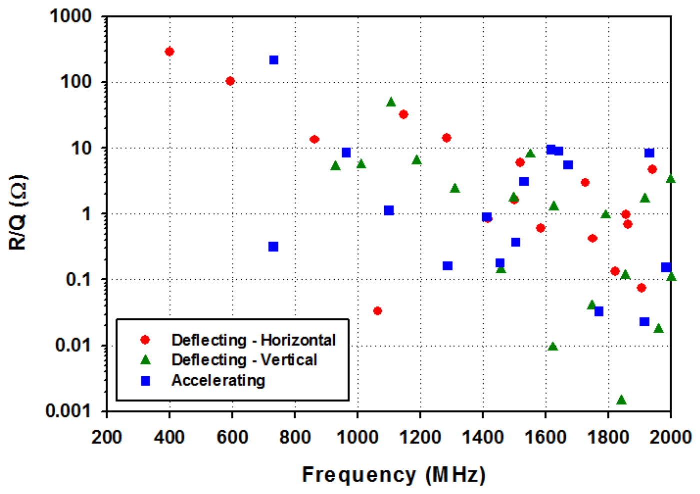
Wide frequency separation between modes



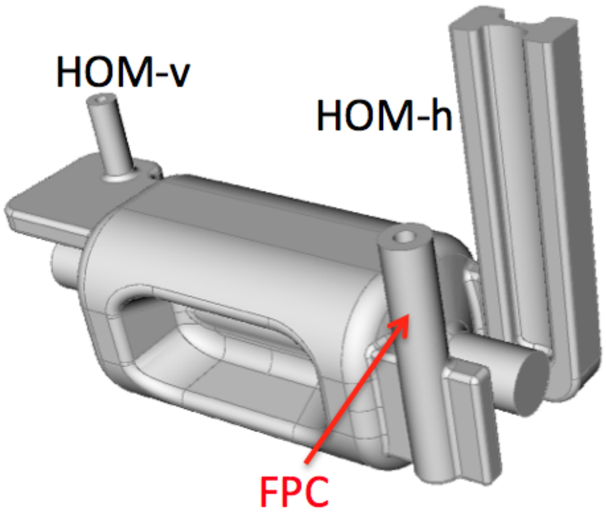
Nearest cavity mode ~230 MHz away

Nearest cavity mode ~190 MHz away

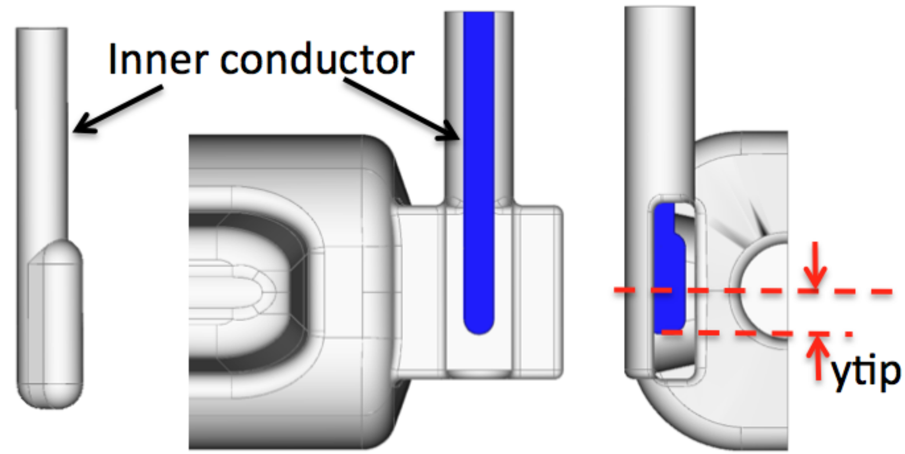


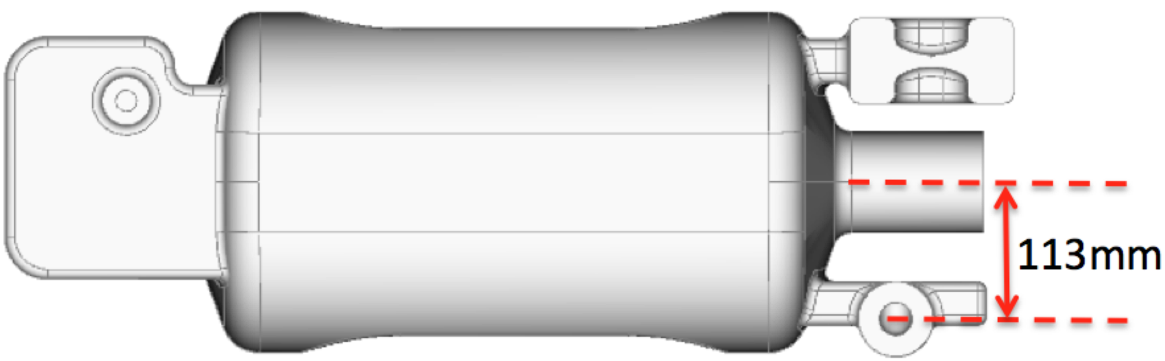


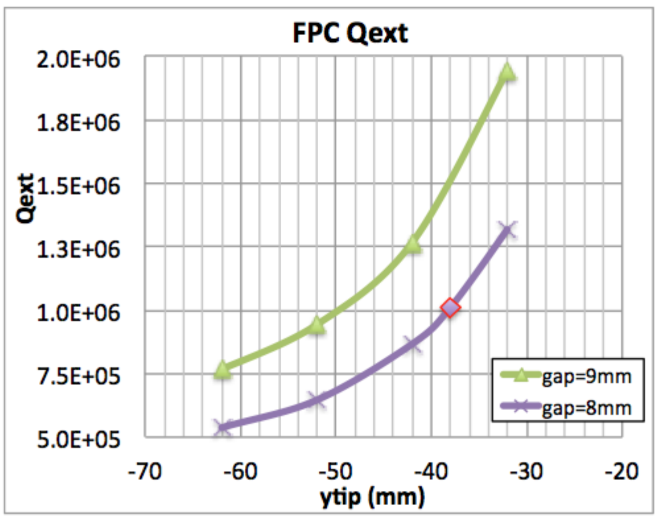
Couplers



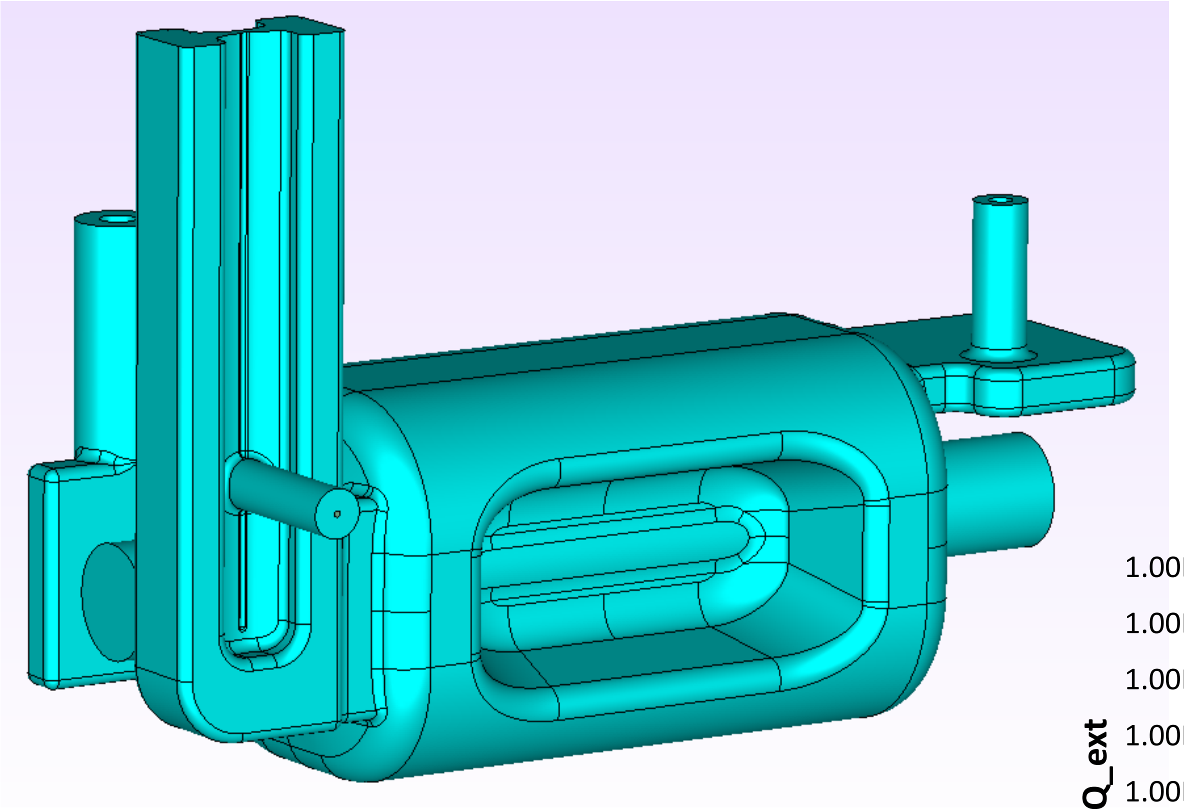
- Outer diameter: 62 mm
- Inner diameter: 27 mm

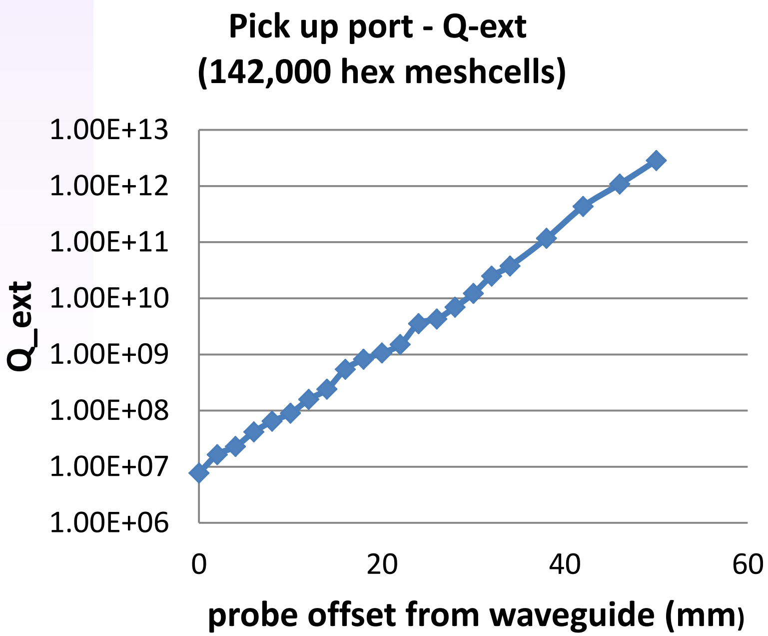






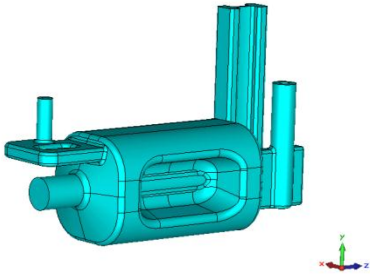
Pick-up Port

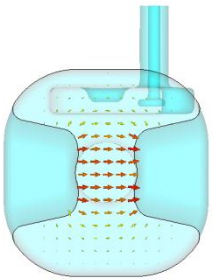


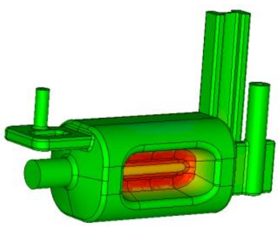


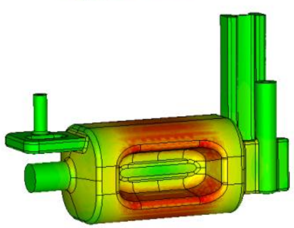
Pick up port - Q-ext
(142,000 hex meshcells)
1.00E+13
1.00E+12
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
1.00E+06
Q_ext
0
20
40
60
probe offset from waveguide (mm)

Prototype Design vs. Proof-of-Principle

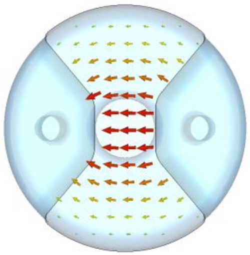


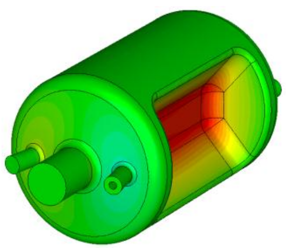


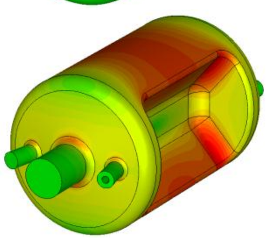




RF PARAMETERS	Prototype design	Proof-of-Principle	Units
Deflecting voltage (V_T^*)	0.375	0.375	MV
Peak electric field (E_P^*)	3.66	4.02	MV/m
Peak magnetic field (B_P^*)	6.14	7.06	mT
B_P / E_P	1.67	1.76	mT / (MV/m)
Stored Energy (U*)	0.13	0.195	J
Geometrical factor ($G = QR_S$)	106	141	Ω
$[R/Q]_T$	427.2	287	Ω
$R_T R_S$	4.54×10^4	4.04×10^4	Ω^2
* at E_T = 1 MV/m			
At V_T = 3.4 MV			
Peak electric field (E_P)	33.2	36.5	MV/m
Peak magnetic field (B_P)	55.7	64.0	mT







Prototype is superior to Proof-of-Principle across all parameters
Electromagnetic design is now frozen
Multipacting studies in waveguide couplers under way

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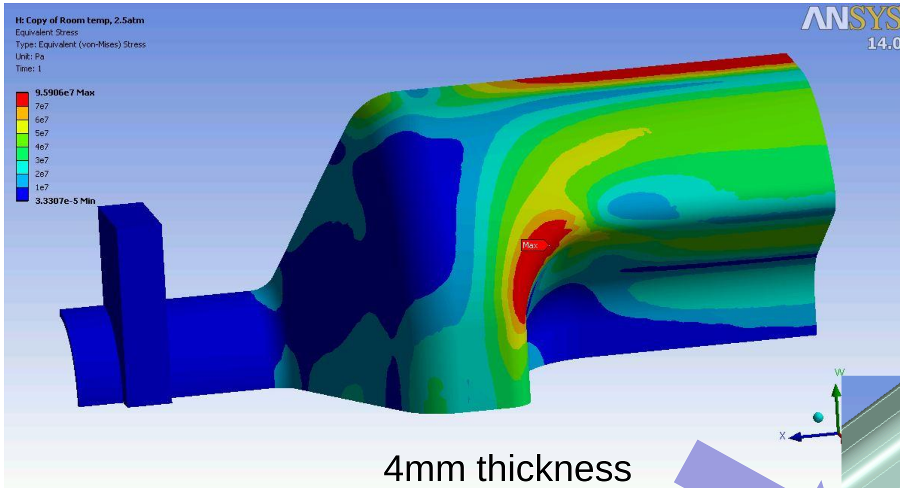
Mechanical Analysis

Mechanical strength – Stress

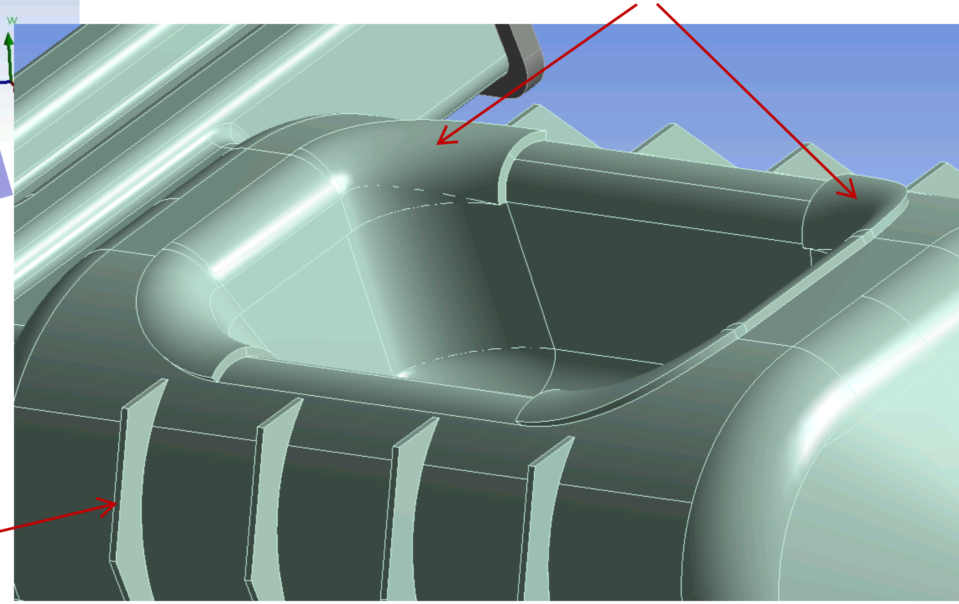


4mm thickness

Weak area identified
(LHC crab cavity meeting, December 2012)

Worst case scenario:
Allowable stress 70 MPa
at room temperature and 2.6 bar external pressure

4mm thick formed plate added

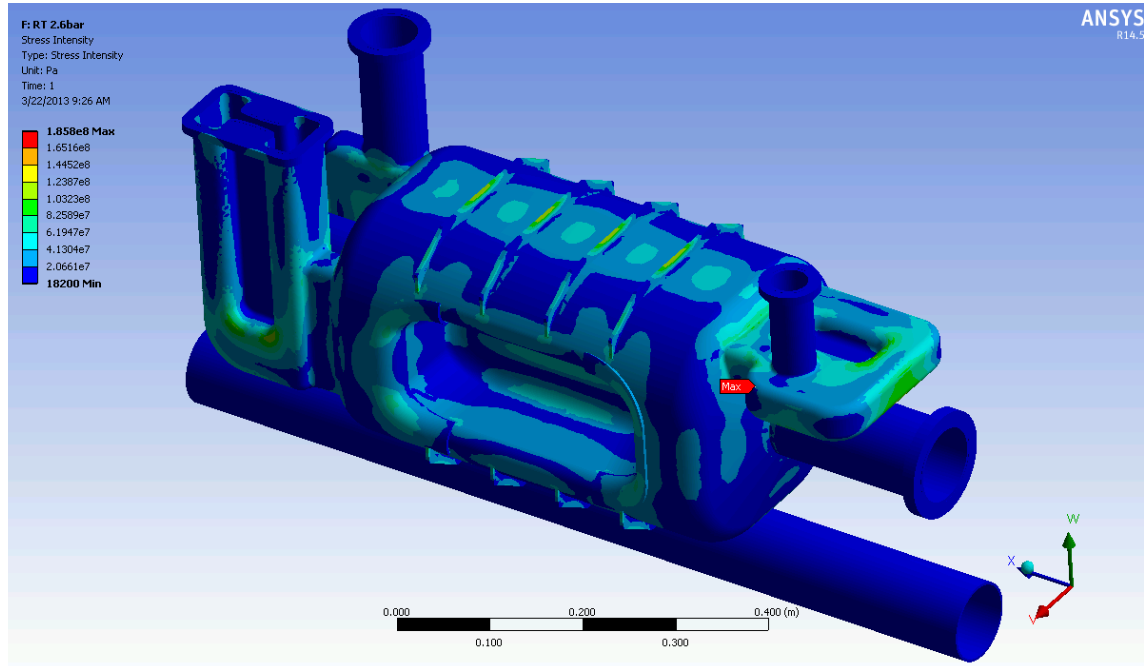


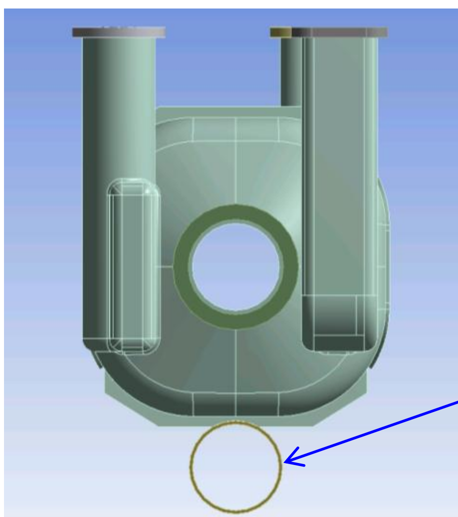
4mm thick stiffeners added

Mechanical Analysis

Results (Stress intensity)

- Main body below 70 MPa
- Stress concentration at coupler ports – solved by machining instead of stamping (flexibility to increase thickness at high stress areas)



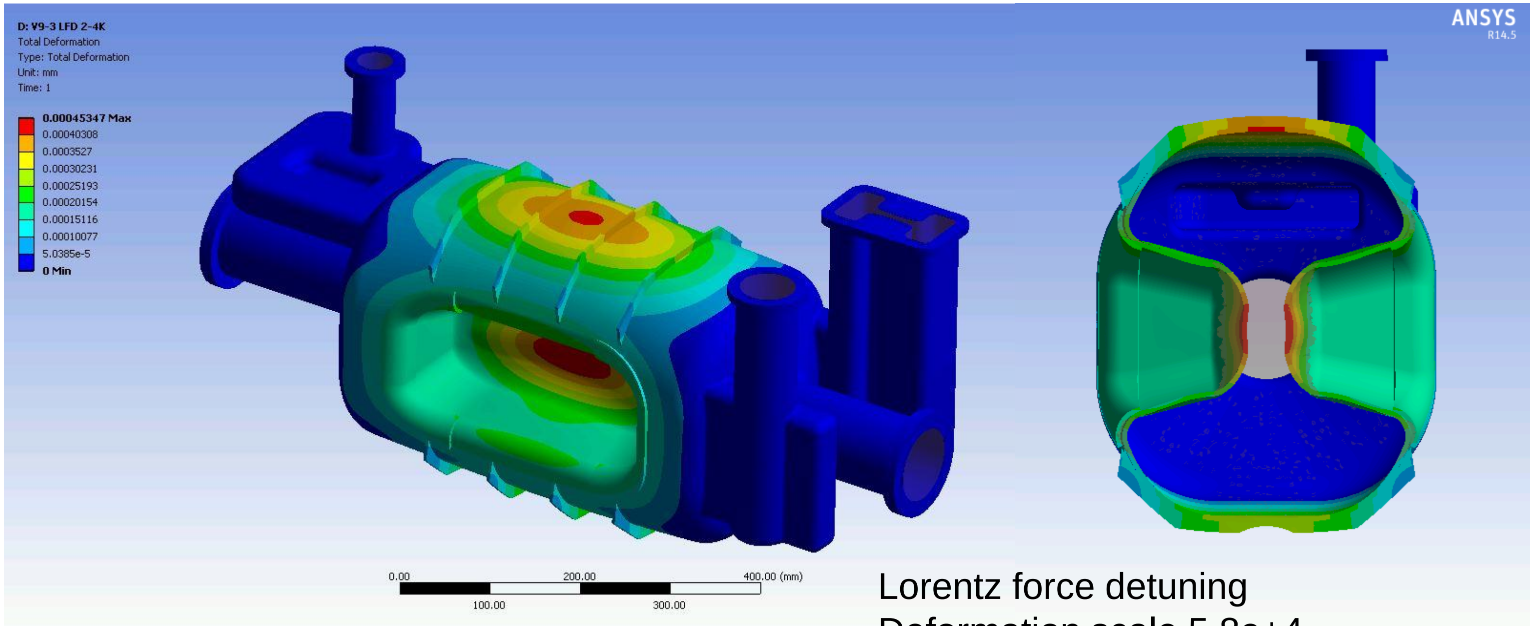


Adjacent beam pipe is not needed for SPS test. Then, stiffener will be identical top and bottom and still meets the requirements.

Mechanical Analysis

Pressure Sensitivity	-30 Hz/torr
Tuning Sensitivity	+90 kHz/mm
Lorentz Force Detuning	-20 Hz/(MV/m)^2

All characteristics improved from the proof of principle cavity design



Lorentz force detuning
Deformation scale 5.8e+4

Niobium property at 2-4K
Picture not showing adjacent beam pipe but included in the analysis

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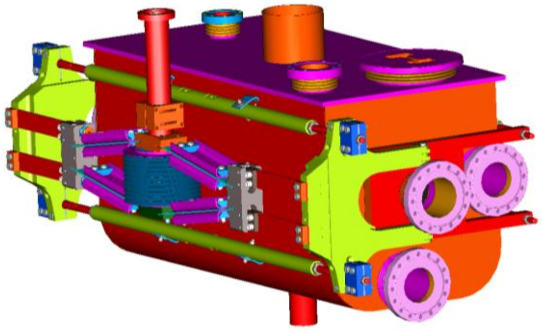
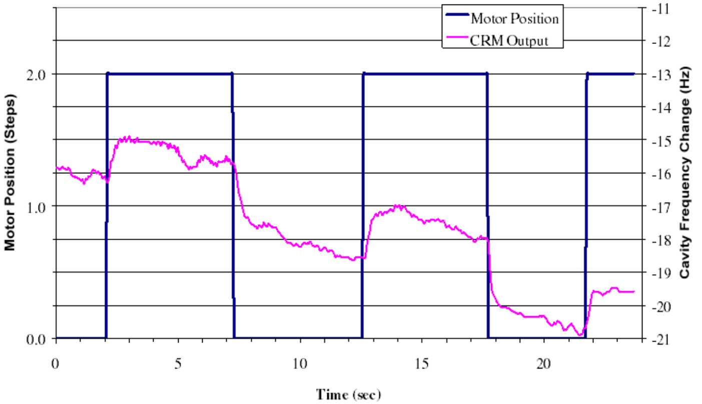
Tuner Options





- JLAB scissor jack tuner fits with minimal scaling
- Tuner can be driven by stepper motor or pneumatic control
- Proven performance of JLAB mechanical tuner

  Resolution/Deadband/Hysteresis < 2 Hz

  Frequency drift due to Helium pressure fluctuations

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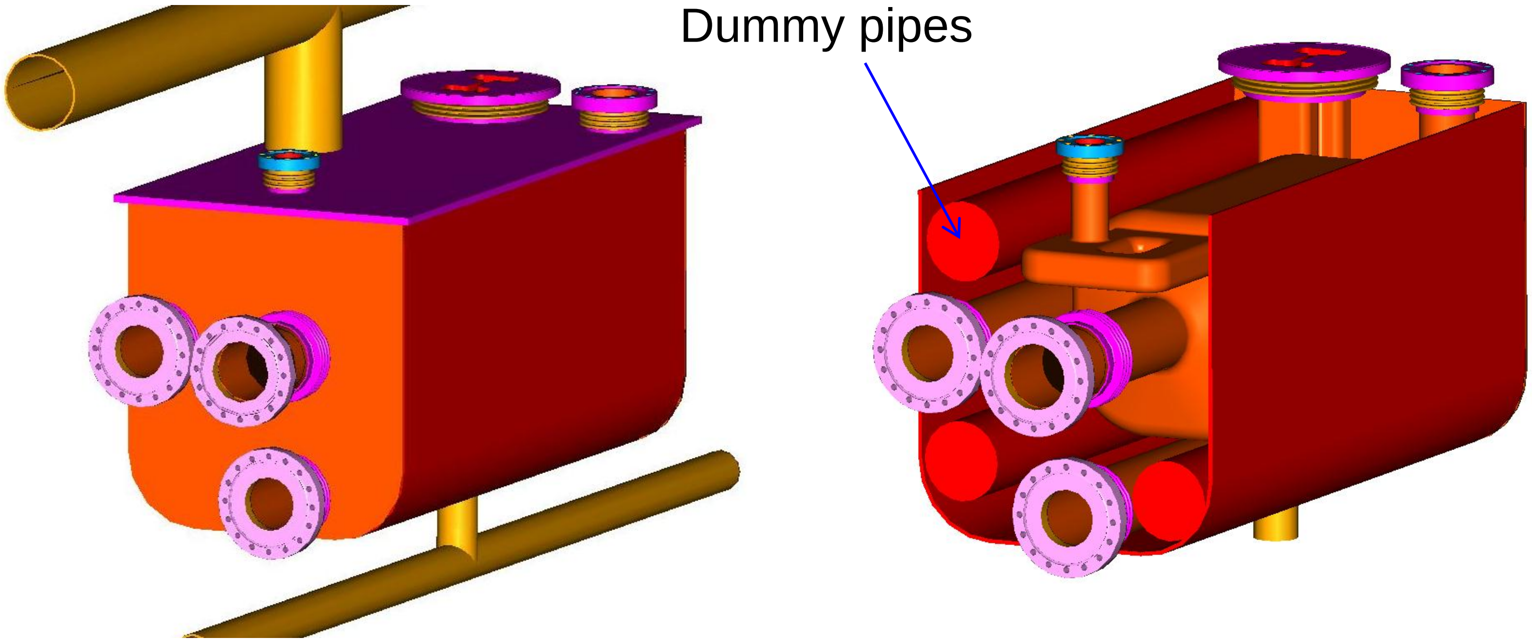
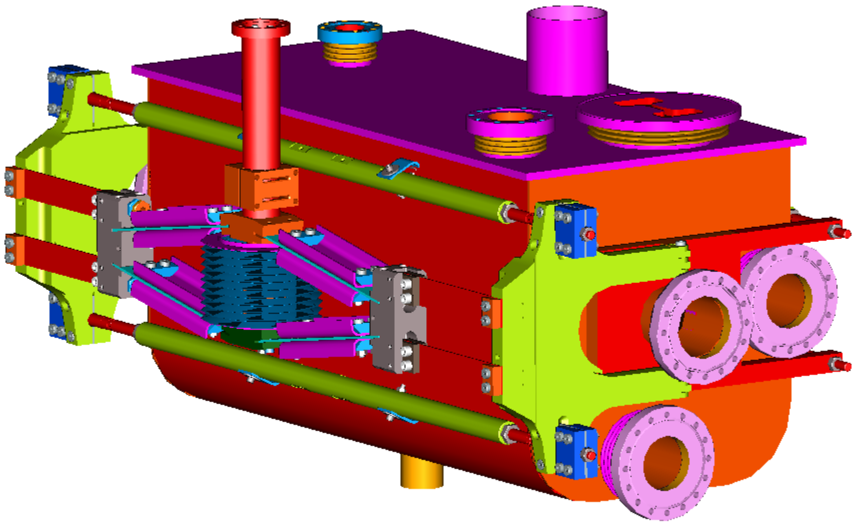
Helium Tank



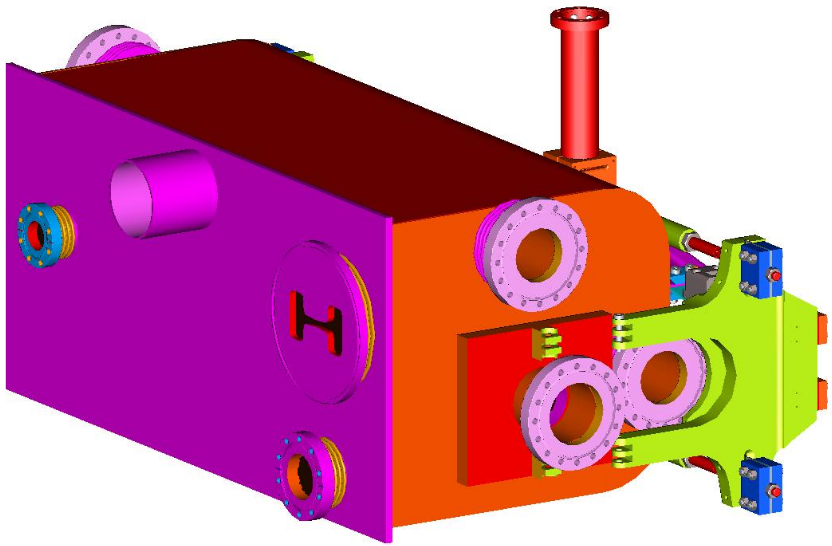
- Simple stainless steel construction
- All cavity and Helium ports on flat surface
- Bellows connections to compensate thermal contraction
- Dummy pipes or internal structure to reduce Helium volume if required.

Cryostat Concept

Helium tank/Tuner Assembly



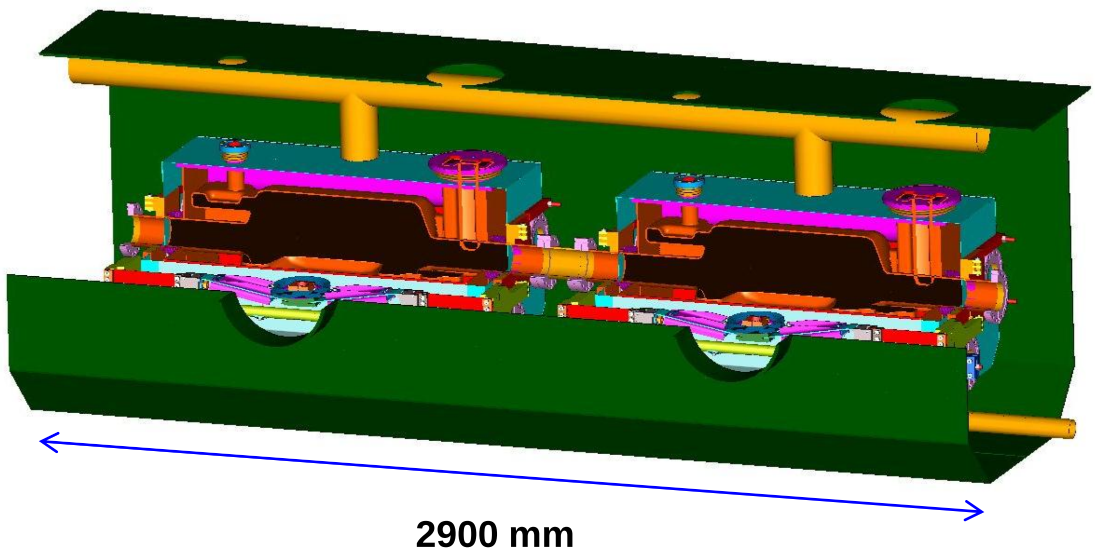
Horizontal beam deflection

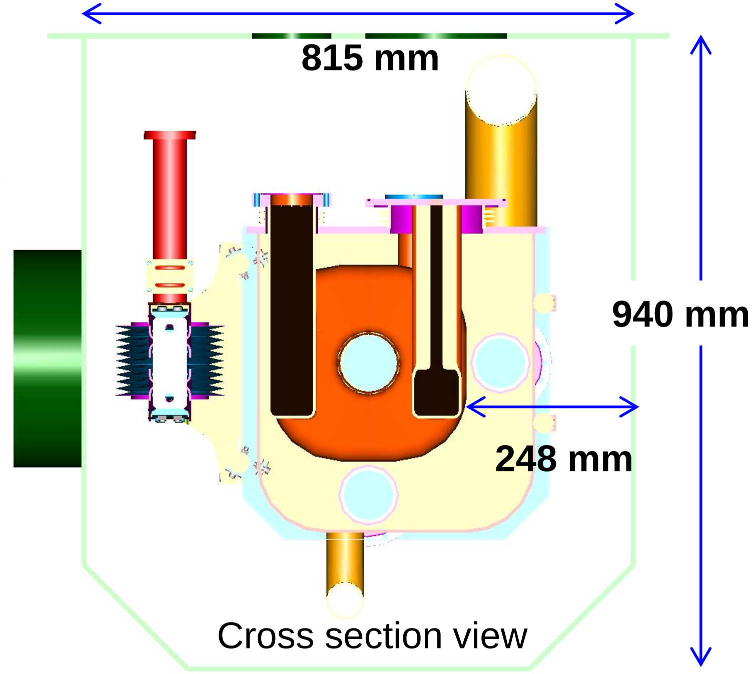


Vertical beam deflection

Ongoing brain-storming to use identical helium tank for both configuration if it is beneficial

Cryostat Concept





- Cryostat concept including as many parts as possible
  - He tank/tuner assembly
  - Magnetic shielding
  - Helium supply and return lines
- Envelope for SPS (520x1200x3100mm) can be met without the adjacent beam pipe

Summary and Future Plan

- “Final” prototype cavity design
  - Better electromagnetic properties than proof-of-principle
  - Includes power and HOM couplers
  - Complies with safety requirements
  - Complies with dimensional requirements
- Integrated system design study ongoing
  - More complete layout
  - Mechanical tuner
  - Helium tank
  - Cryostat concept
- Ready to build and test “final” prototype cavity