LARP

High Luminosity LHC

RF Dipole Cavity Design and Plans

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Outline

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  - 499 MHz / 750 MHz cavity
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  - He-vessel
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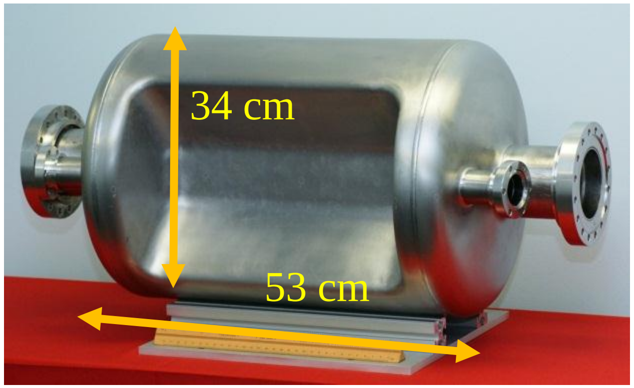
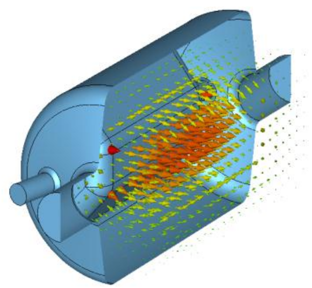
  - Cryomodule integration
- Summary and Plans
- Acknowledgements

Proof of principle design and results

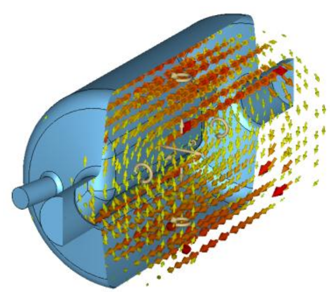


Proof-of-Principle cavity fabricated at Niowave Inc.

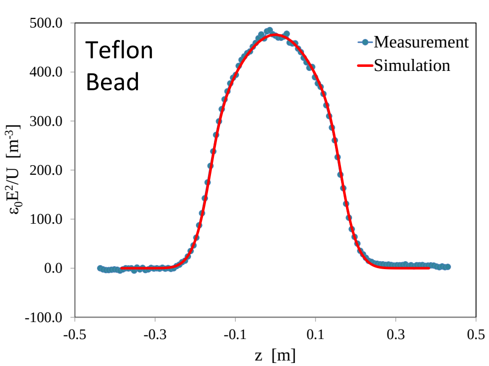
Parameters	Value	Units
Frequency of fundamental	400	MHz
Frequency 1st HOM	590	MHz
Deflecting Voltage (V_T^*)	0.375	MV
Peak Electric Field (E_p^*)	4.02	MV/m
Peak Magnetic Field (B_p^*)	7.06	mT
B_p^*/E_p^*	1.76	mT/ (MV/m)
Stored Energy (U^*)	0.195	J
$[R/Q]_T$	287.0	Ω
Geometrical Factor (G)	140.9	Ω
$R_T R_S$	4.0×10^4	Ω^2
At E_T^* = 1 MV/m		

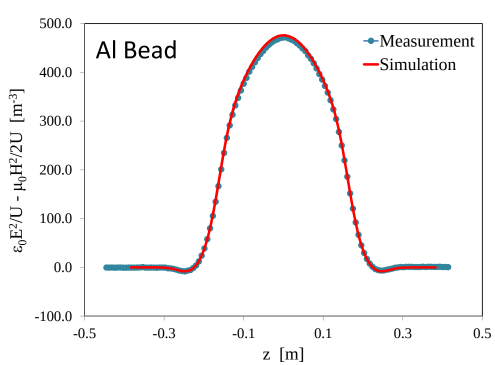


E Field



B Field

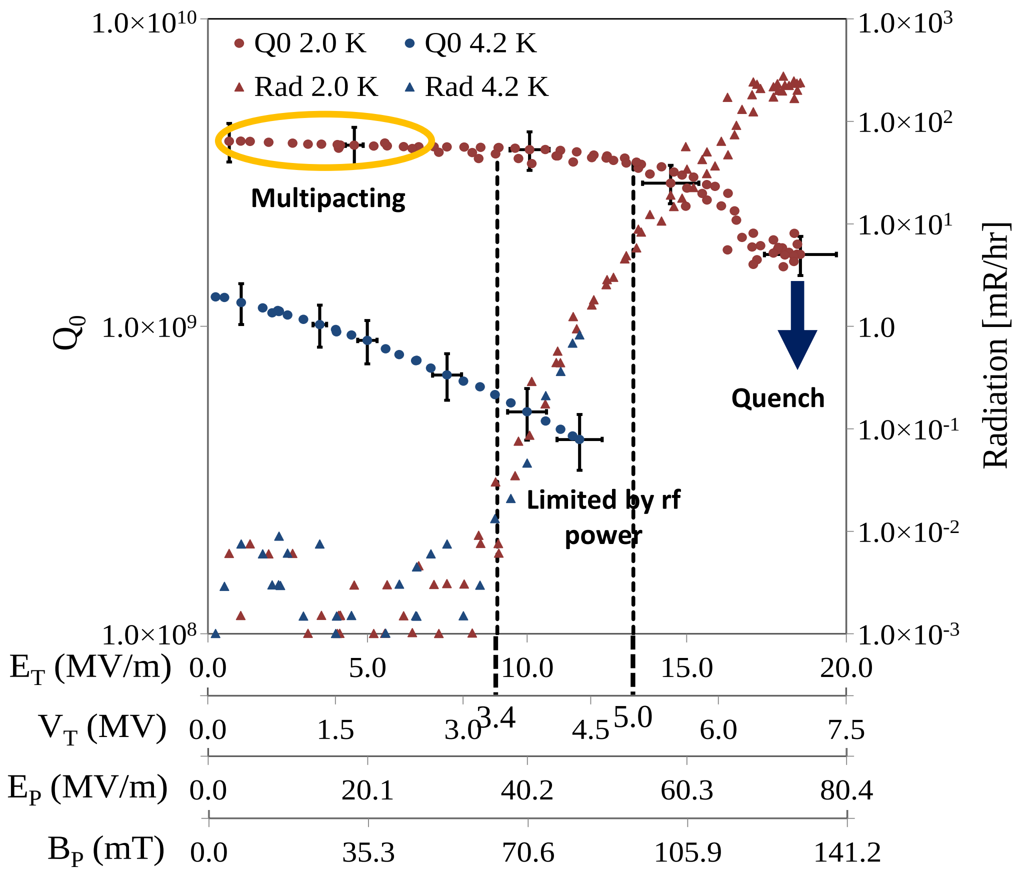




Bead pull measurements of on axis electric and magnetic field components

Proof of principle design and results

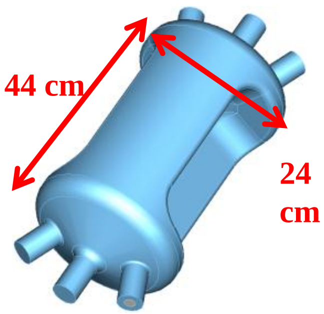
- Surface treatment and rf testing done at Jefferson Lab
- Total design requirement – 13.4 MV
- Design requirement per cavity – 3.4 MV

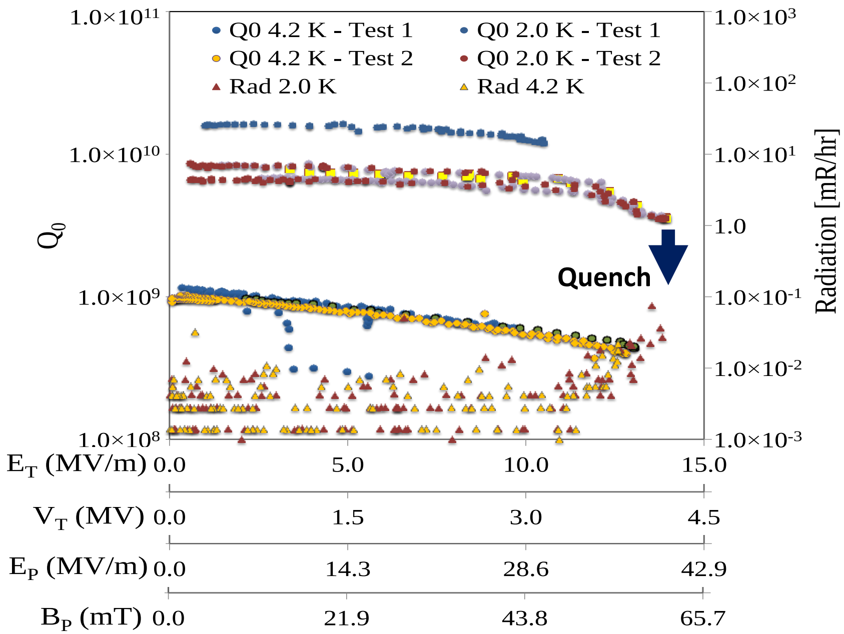


- Design goal can be achieved with three cavities
- Multipacting levels observed below 2.5 MV and processed easily
- Achieved fields at 2.0 K:
  - E_T = 18.6 MV/m
  - V_T = 7.0 MV
  - E_P = 75 MV/m
  - B_P = 131 mT
- RF performance was limited at 7.0 MV due to high field emission
- At 2.0 K with R_s = 11.3 nΩ (R_{res} = 10 nΩ)
  - Expected $Q_0 = 1.25\times10^{10}$
  - Measured $Q_0 = 4.0\times10^{9}$

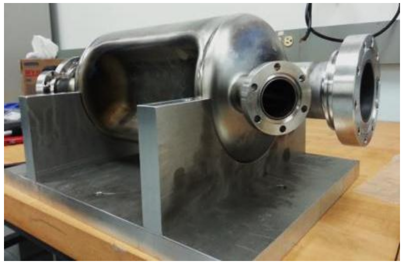
Proof of principle design and results

499 MHz rf-dipole cavity

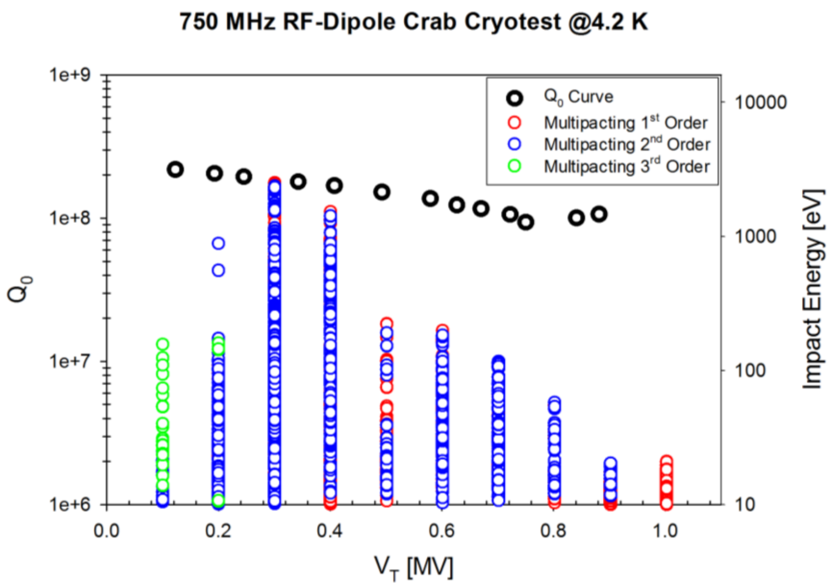




750 MHz rf-dipole cavity

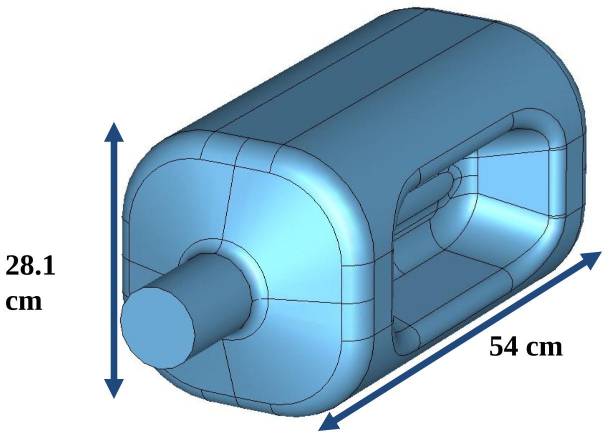


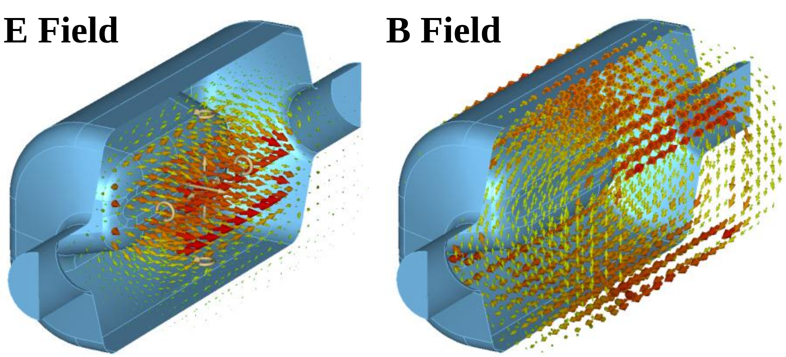
Preliminary Cryo-Test (4.2 K)



Prototype rf-dipole design

Prototype design has improved rf-properties

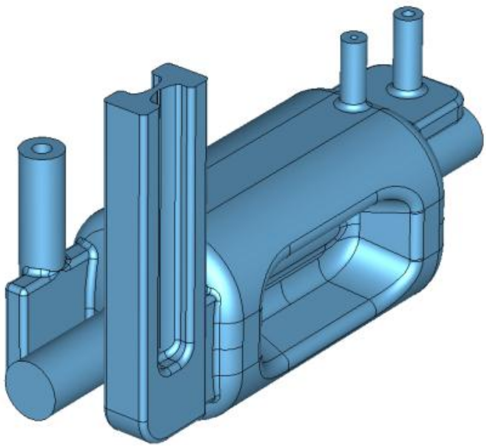




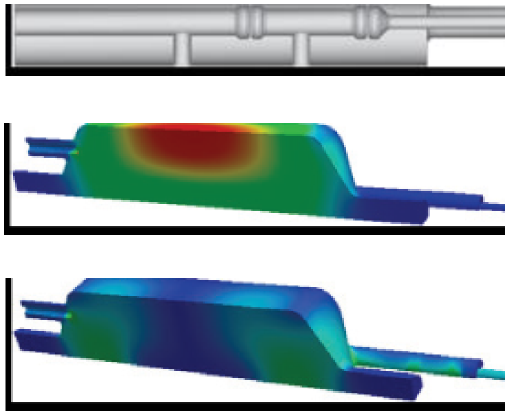
Parameters	Prototype	P-o-P	Units
Frequency of fundamental	400	400	MHz
Frequency of 1st HOM	632	590	MHz
Deflecting Voltage (V_T^*)	0.375	0.375	MV
Peak Electric Field (E_p^*)	3.65	4.02	MV/m
Peak Magnetic Field (B_p^*)	6.22	7.06	mT
Peak Electric Field (E_p^{**})	33.4		MV/m
Peak Magnetic Field (B_p^{**})	55.6		mT
B_p/E_p	1.71	1.76	mT/(MV/m)
Stored Energy (U^*)	0.13	0.195	J
$[R/Q]_T$	427.4	287.0	Ω
Geometrical Factor (G)	106.7	140.9	Ω
$R_T R_S$	4.6×10^4	4.0×10^4	Ω^2
*At E_T = 1 MV/m ** At V_T = 3.35 MV			

Prototype rf-dipole design

HOM Damping

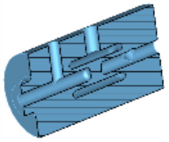


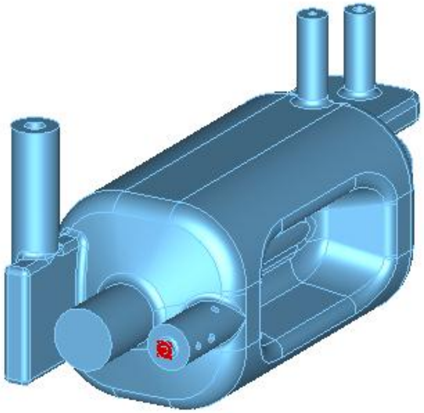
High-pass coaxial filter / Waveguide – Zenghai Li – SLAC



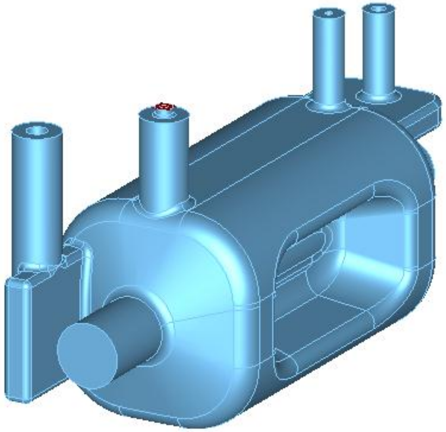
HOM filter for horizontal dipole HOMs –

Binping Xiao – BNL



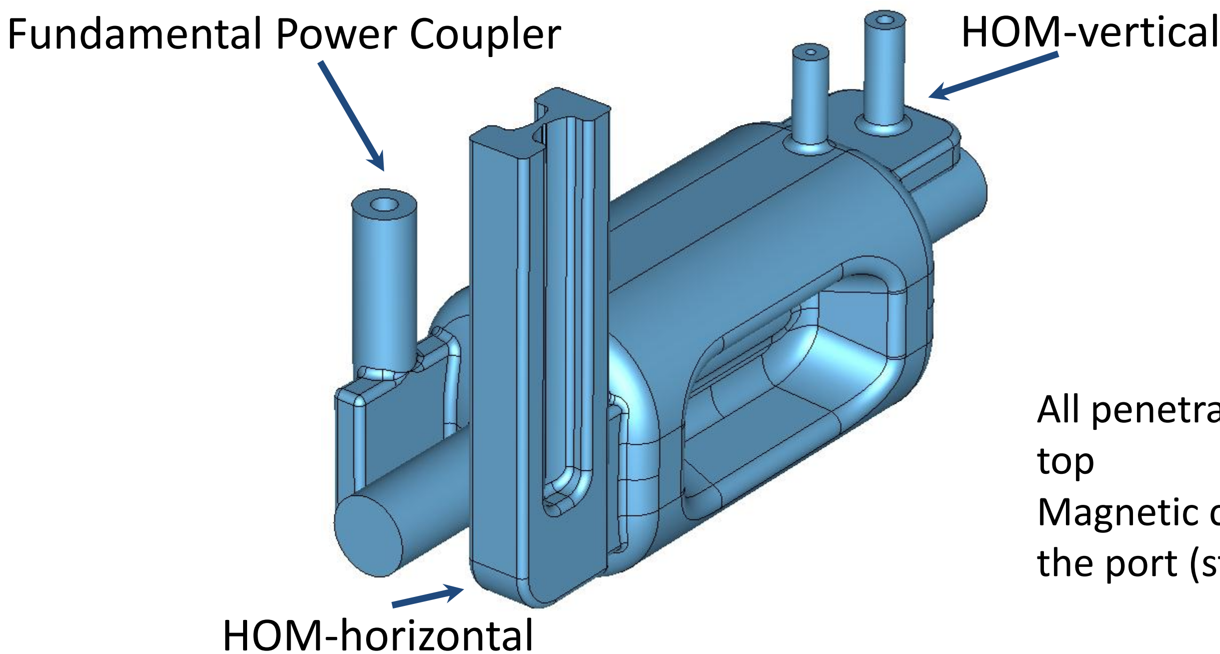


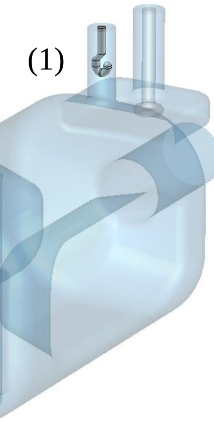
Electric coupling



Magnetic coupling

Prototype rf-dipole design



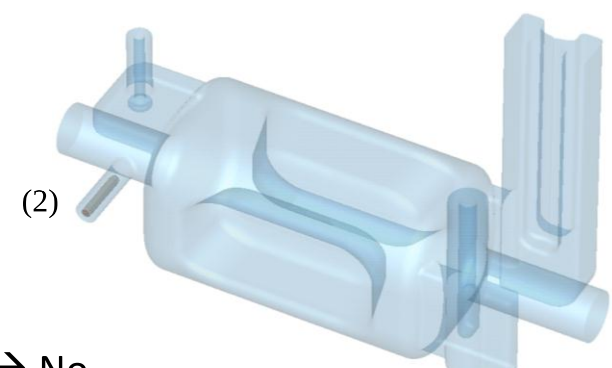


All penetrations to the He tank will be from top

Magnetic coupling → Field enhancement at the port (still below B_{peak})

Pick Up Port Options

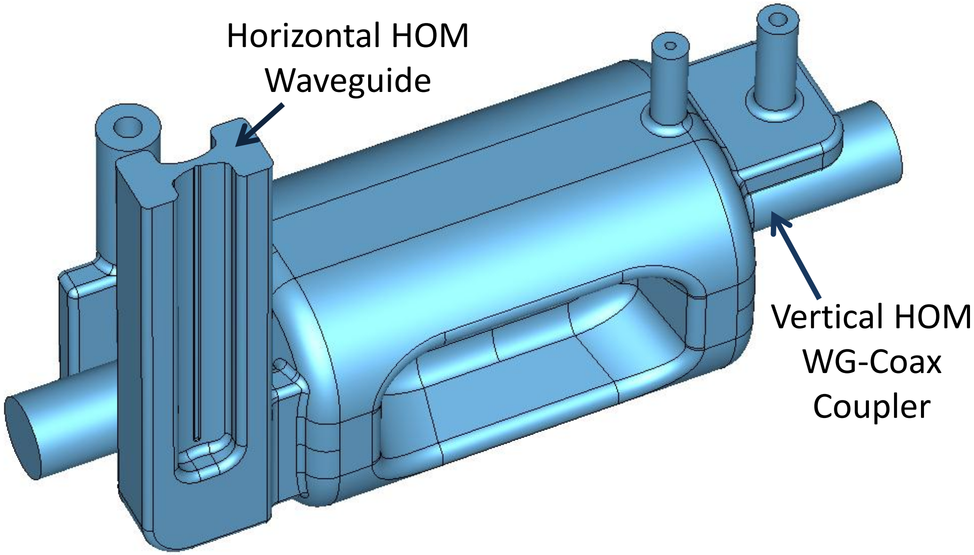
To achieve 1.0 W at 3.4 MV → Q_{ext} = ~3.0×10^{10}

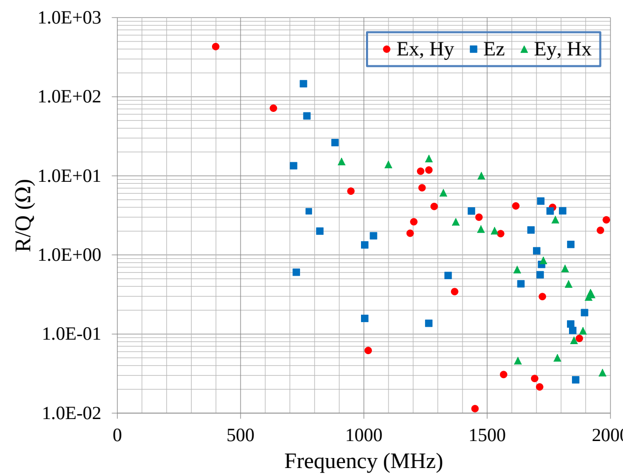


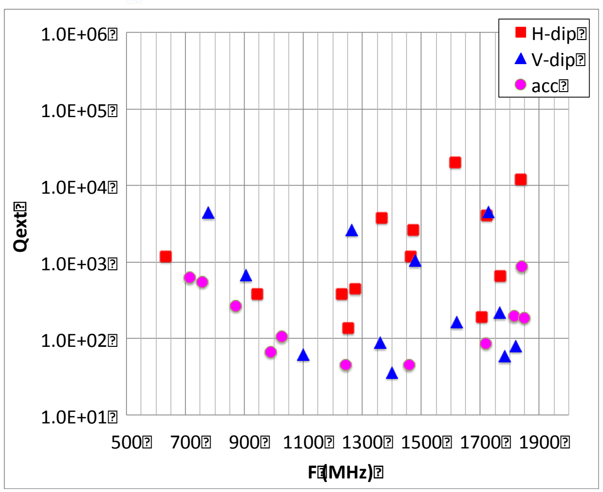
Electric coupling → No field enhancement

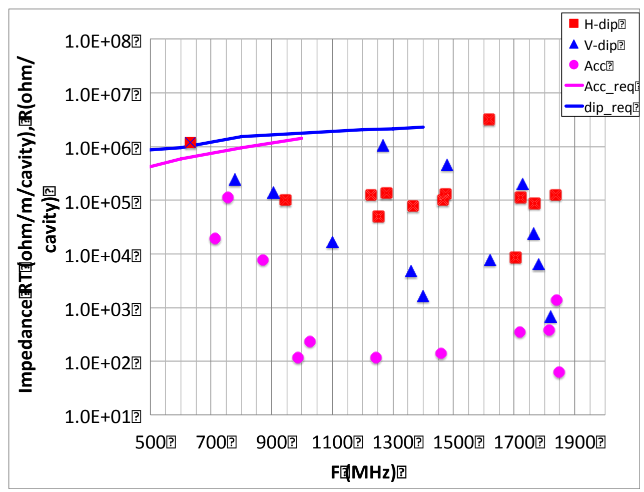
Prototype rf-dipole design

HOM Damping







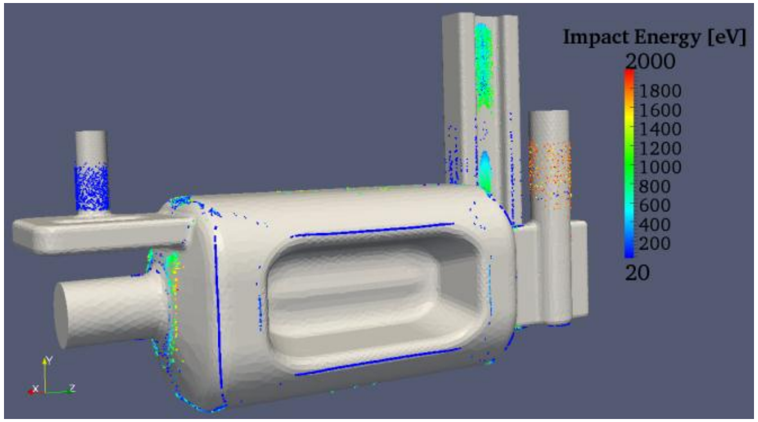


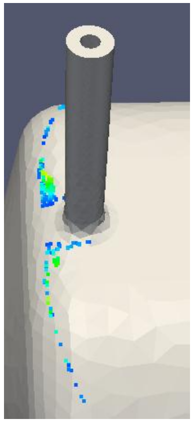
Vertical and horizontal HOM couplers optimized to damp high Q modes at 1.265 and 1.479 GHz

Z. Li – SLAC

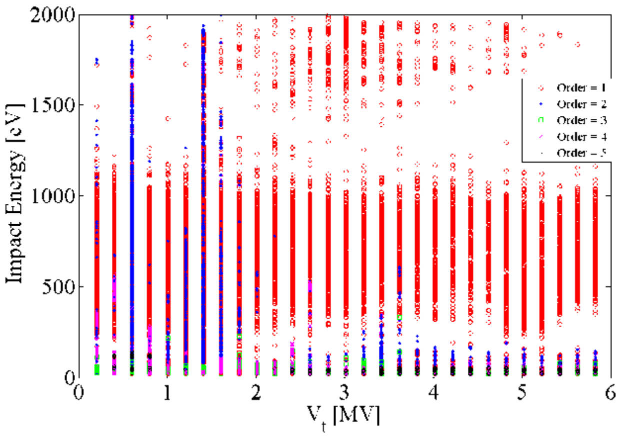
Prototype rf-dipole design

Multipacting analysis





Multipacting expected from magnetic pick-up port on top of cavity not significant



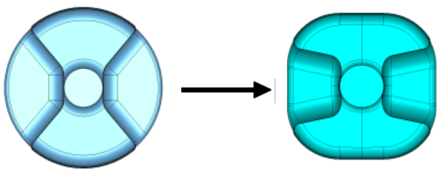
Using Track3P from the ACE3P Code Suite developed at SLAC

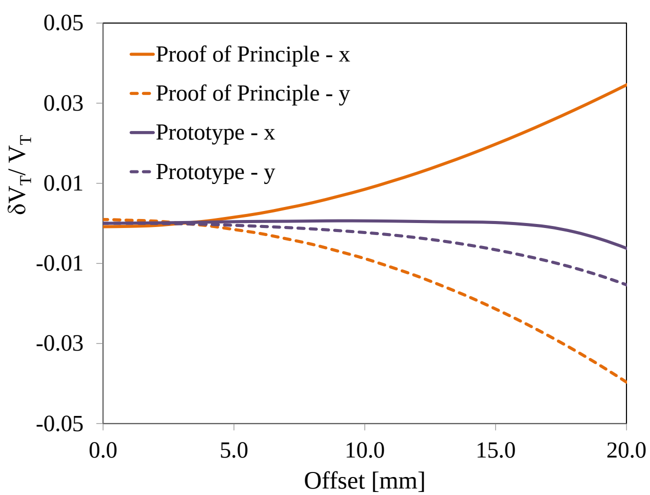
Experience from PoP cavity → multipacting in the cavity not a concern

Prototype rf-dipole design

Multipole analysis

- Curvature around beam aperture to
  - Reduce field non-uniformity
  - Suppress higher order multipole components





Voltage deviation at 20 mm ~ 1%

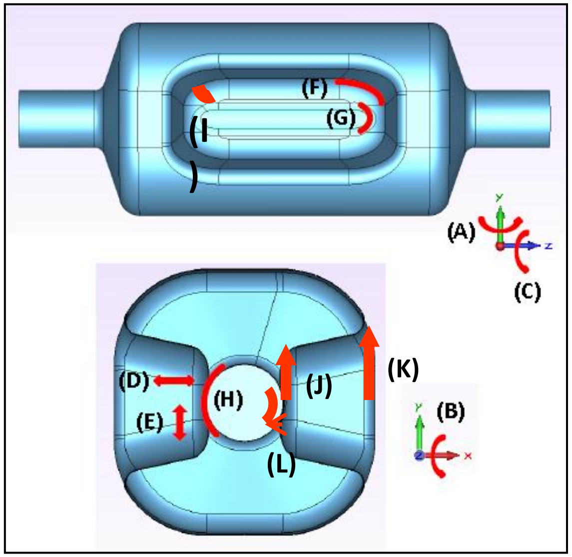
Higher Order Multipole Components

Multipole component		Units
V_T	1	MV
b_1	3.3	mT m
b_2	0.001	mT
b_3	37.4	mT/m
b_4	-1.8	mT/m^2
b_5	-1.9×10^5	mT/m^3

- Multipole component b_3 is reduced below requirements
- No current specifications for other higher order multipole components
- Shift in electrical center due to asymmetry of couplers

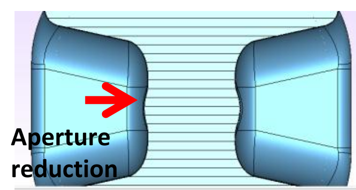
Prototype rf-dipole design

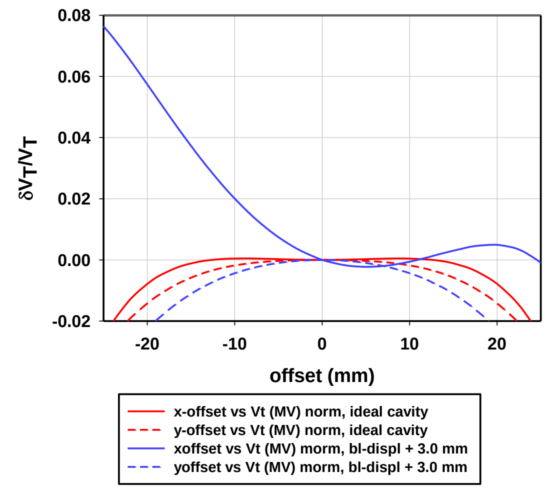
Multipole analysis



- (A) Yaw (rotation about y-axis) of one pole.
- (B) Pitch (rotation about x-axis) of one pole.
- (C) Roll (rotation about z-axis) of one pole.
- (D) Horizontal displacement of one pole.
- (E) Vertical displacement of one pole.
- (F) Blending radius along depth of one pole.
- (G) Blending radius of the feather-like structure near the beam line of one pole.
- (H) Aperture radius in one pole.
- (I) Blending radius at the outer corner of one pole
- (J) Width of pole (uneven) at beamline
- (K) Width of pole (uneven) at outer conductor
- (L) Aperture displacement at beamline

Small individual imperfections have negligible effects on the multipole components, but may shift the electrical center and operating frequency.

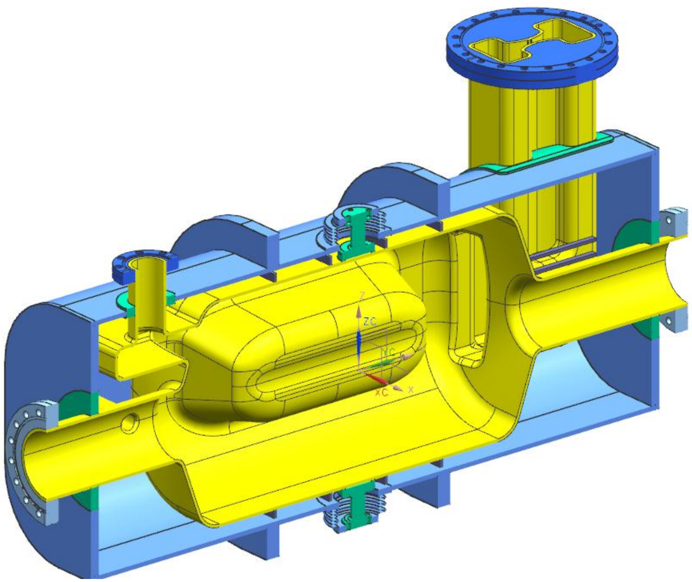


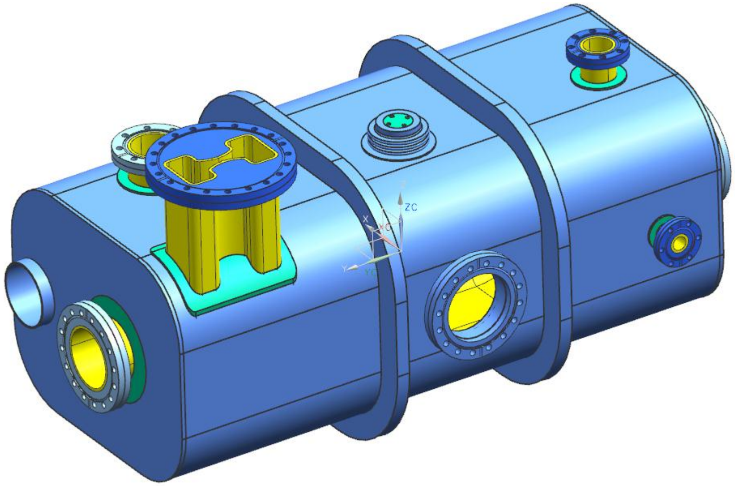


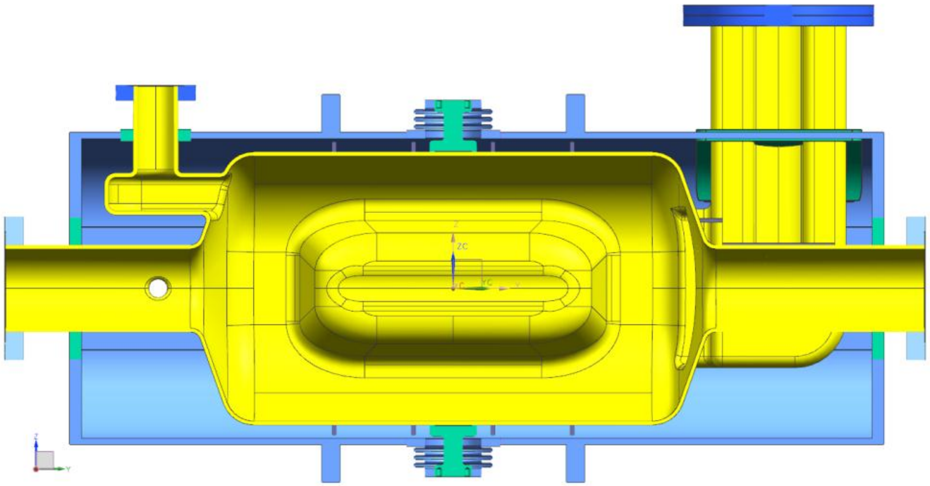
- Strength of the multipole components is mainly determined by the aperture region of the poles near the beamline.
- Analysis focused on individual imperfections of the ideal cavity poles due to fabrication or welding errors (no deformations due to tuning processes considered).

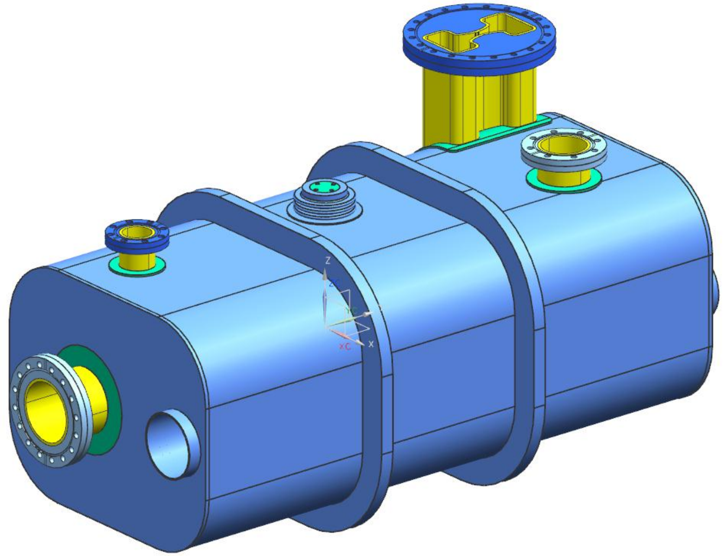
The largest frequency shift observed is produced by the horizontal aperture reduction (or displacement) of a pole → loss of field uniformity across aperture

Dressed Cavity



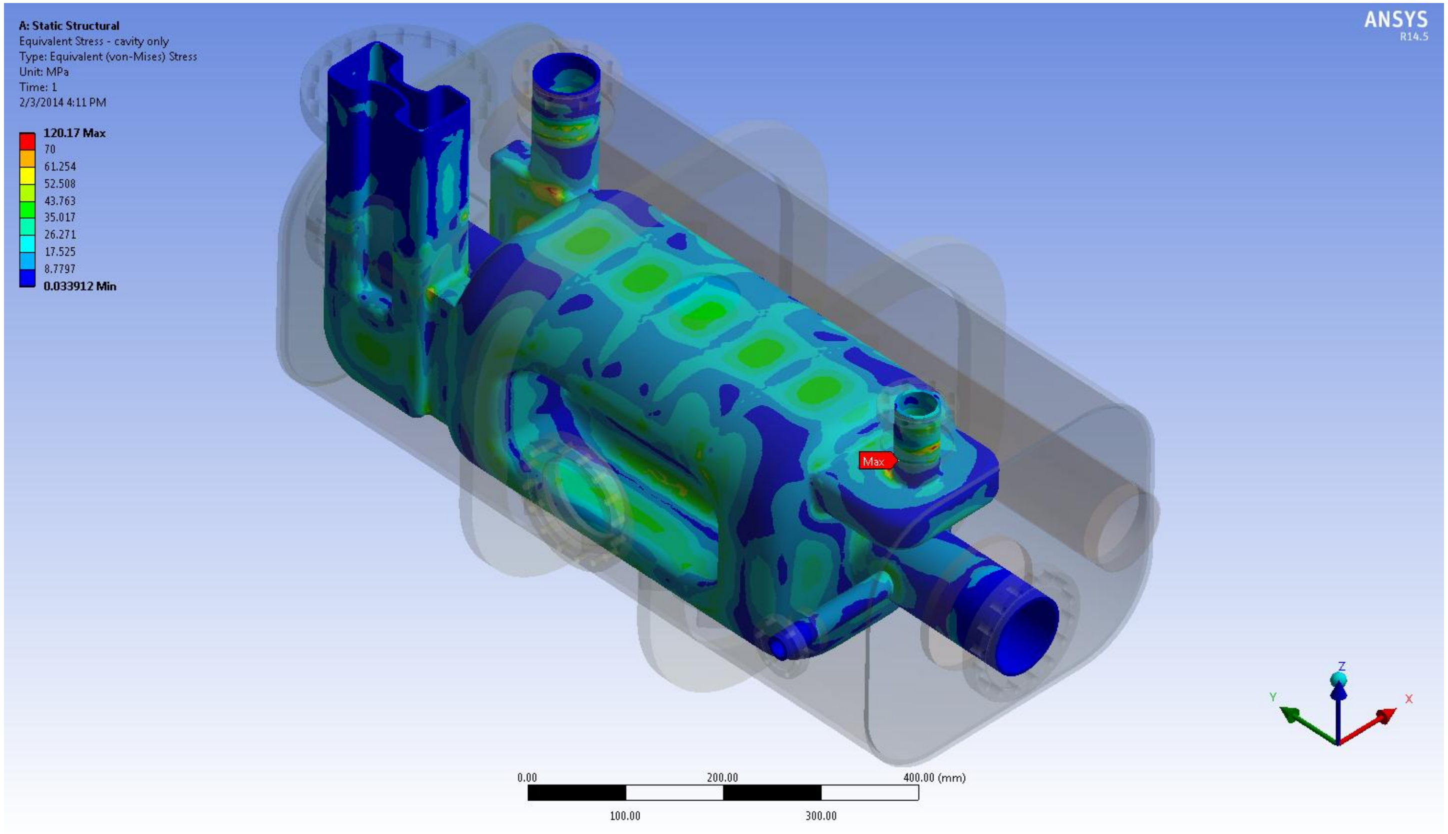






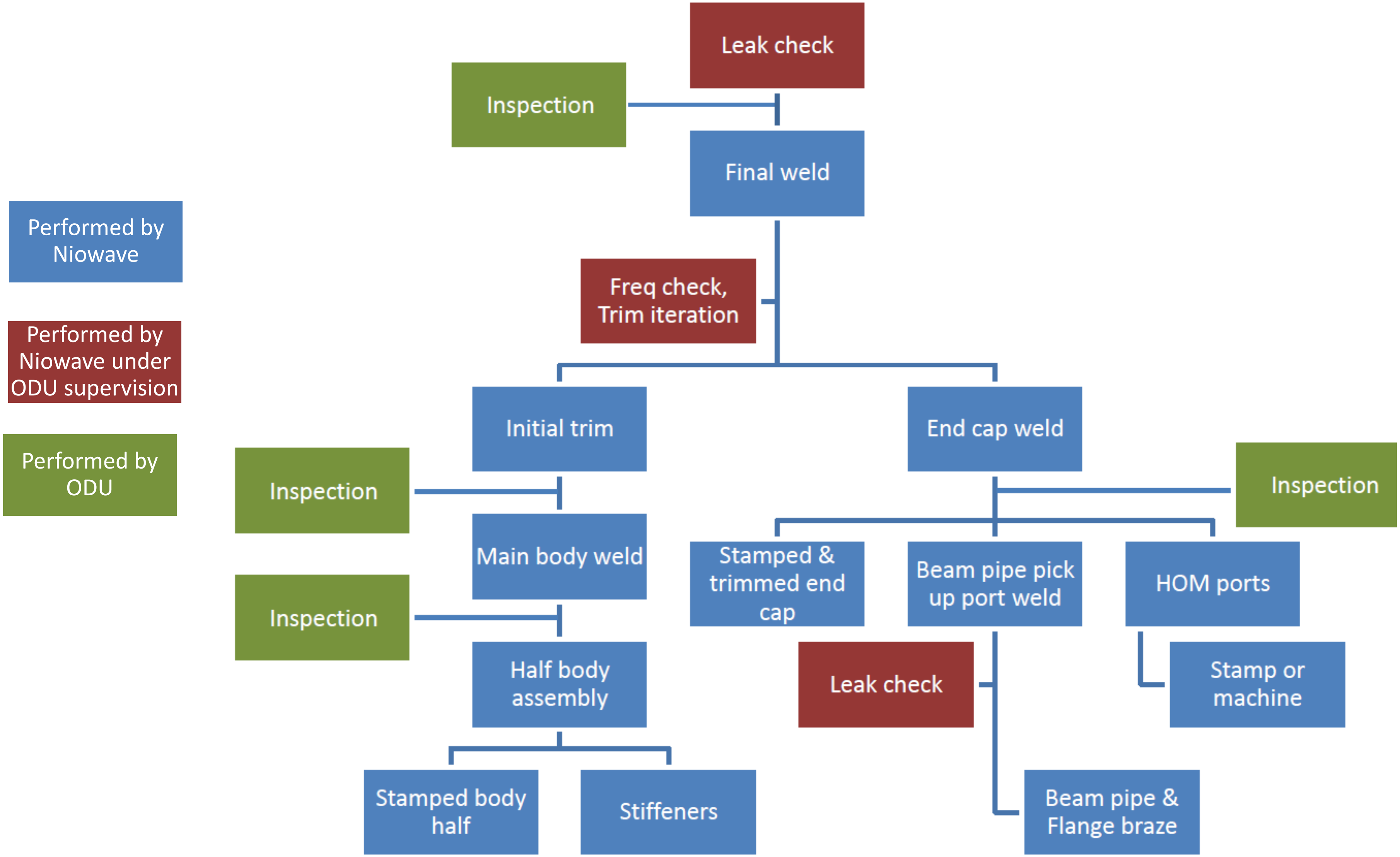
Mechanical analysis – Integrated

Courtesy of Tom Nicol / Fermi



- 2.6 bar Helium pressure, stress less than stand alone cavity
- High stress area changes – easier to strengthen

Cavity Fabrication Plan



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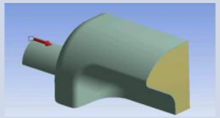
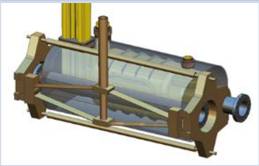
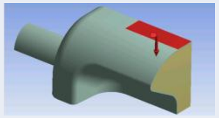
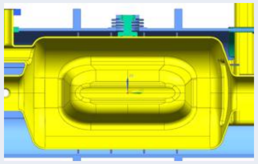
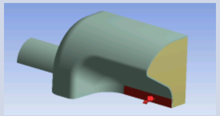
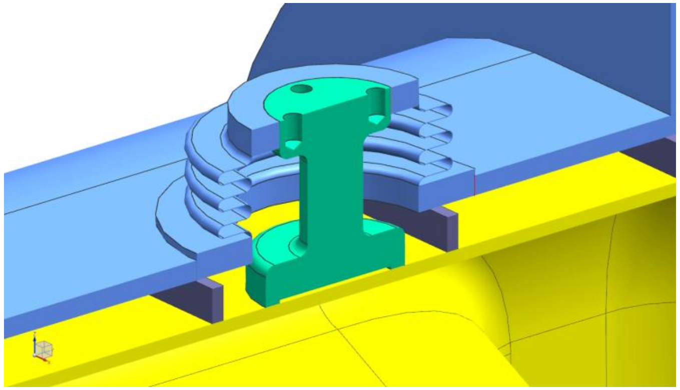
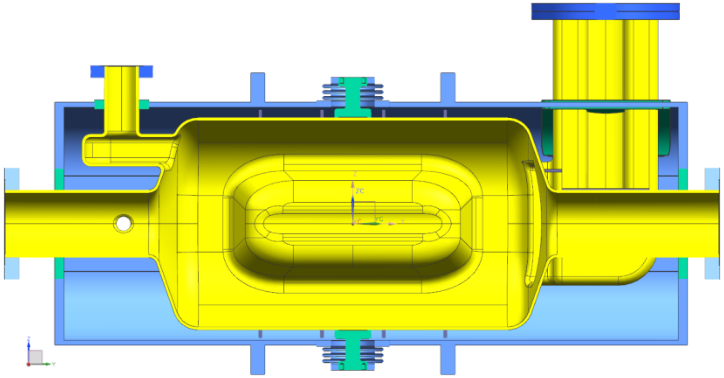
Design Study – Tuner

Tuning option	Hz/N	kHz/ mm	Note	
	-5	-90	Requires too large force	
	74	450	Force vs. frequency change in the practical range	
	71	930	Twice sensitive than above option at sensitivity vs cavity deformation	Same as above





Simulations done with cavity with stiffeners and 2K material properties

Tom Nicol/Fermilab

- **Tuning from the top and/or bottom of the cavity**
- **Use as many common components as possible from other cavity designs.**
- **Thermal study needs to be done.**

Wave guide / window

13kW FPC wave guide / JLAB

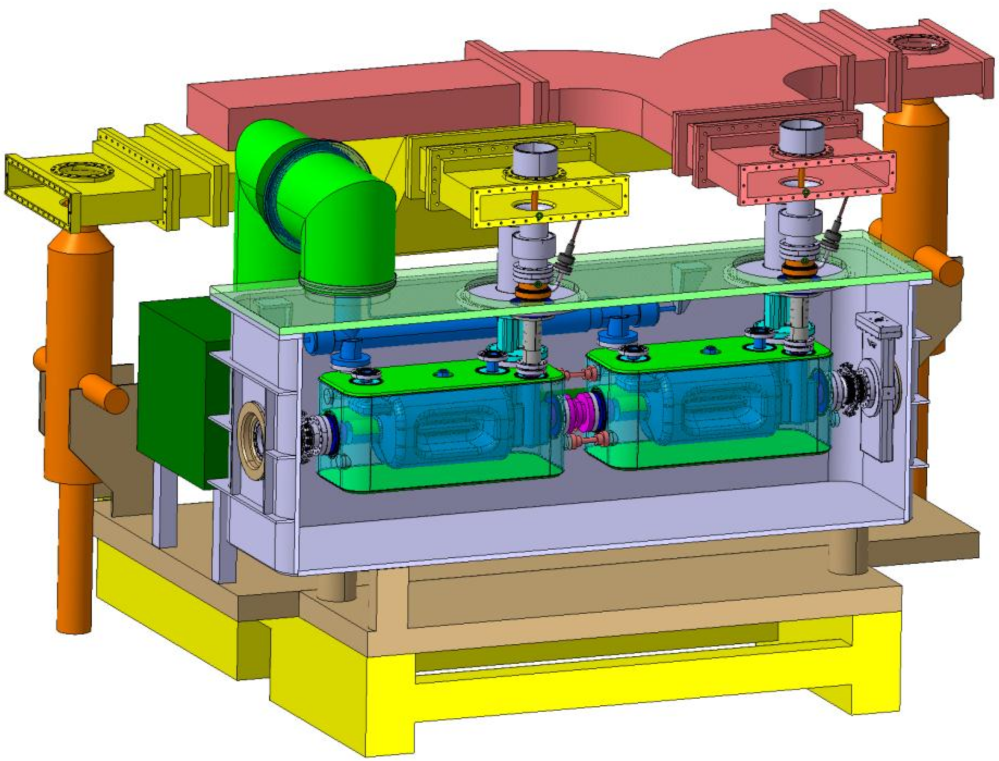
- Bellowed wave guide
- Wave guide cross section will be simplified after the evanescent field decay

Fabrication expertise available
Rectangular knife edge flanges are reliably used at JLAB.

LARP

High Luminosity LHC

Cryomodule concepts



Courtesy of CERN Eng team and Tom Nicol/Fermi Lab

- Multiple designs explored
- Working toward to make the design as common as possible

Summary and Plans

Proof-of-principle cavity:

- First cryogenic tests of proof-of-principle cavities completed
- Proof-of-Principle cavity achieved 7 MV deflecting voltage CW → cavity performance exceeded design specifications
- Multipacting conditions were quickly processed and did not reoccur
- Consistent results with 499 MHz and 750 MHz rf-dipole cavity
- 400 MHz cavity will be reprocessed and tested for improved Q_0 at CERN in a few weeks

Summary and Plans

Prototype cavity design:

- Electromagnetic design frozen
- Design specifications have been achieved in HOM damping with current HOM couplers
  - Other options under study in preparation for CC Technical Review
- Multipacting not a concern inside the cavity given previous experience with PoP cavity
- Multipole analysis complete
  - Very robust geometry in terms of multipole components vs fabrication imperfections
- Cavity room temperature model will be ready to be delivered to Niowave in April
  - Finalizing location of pick-up port
  - Finalizing optimization / length of HOM dampers – Z. Li

Summary and Plans

Prototype cavity engineering/fabrication:

- Mechanical study of pressure sensitivity and corresponding stresses of the rf-dipole cavity to meet the specifications for SM18 and SPS tests
- Analysis of Lorentz force detuning
- Study of tuner options
  - CEA Saclay tuner
  - Plunger tuner (selected)
- He vessel design – work in progress with Fermilab
- Detailed cryomodule design – work in progress with CERN
  - Plans for travel/stay at CERN to consolidate design
- Engineering analysis of integrated system
  - Including all components (cavity, He vessel, tuner, coupler, support…)
  - Structural
  - Thermal
- Engineering design and fabrication of components for processing
  - chemistry, high-pressure rinsing, baking…
- Engineering design and fabrication of components for cryogenic testing of cavities

Acknowledgements

- **ODU** – Subashini De Silva, Rocio Olave, HyeKyoung Park, Chris Hopper, Alex Castilla, Kevin Mitchell
- **JLab** – Peter Kneisel, Tom Powers, Kirk Davis, Joe Preble, Tony Reilly, James Henry, Joe Matalevich
- **SLAC** – Zenghai Li
- **Niowave** – Terry Grimm, Dmitry Gorelov, Chase Boulware
- **Fermilab** – Tom Nicol
- **Daresbury** – Shrikant Pattalwar, Thomas Jones
- **CERN** – Rama Calaga, Ofelia Capatina