RFD Crab Cavity HOM re-optimization

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For the RFD team - SLAC, ODU, and FNAL

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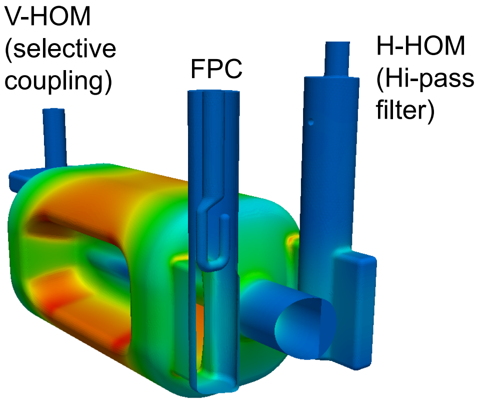
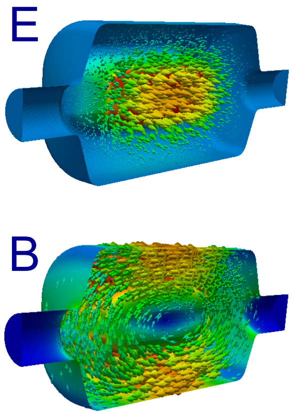
Outline

- 760 MHz mode issue of current prototype cavity
- New cavity design with detuned 760MHz mode
- Dimension sensitivity analysis
- HOM coupler window design
- H-HOM coupler flange position adjustment
- Summary

RFD Prototype Crab Cavity (current design)

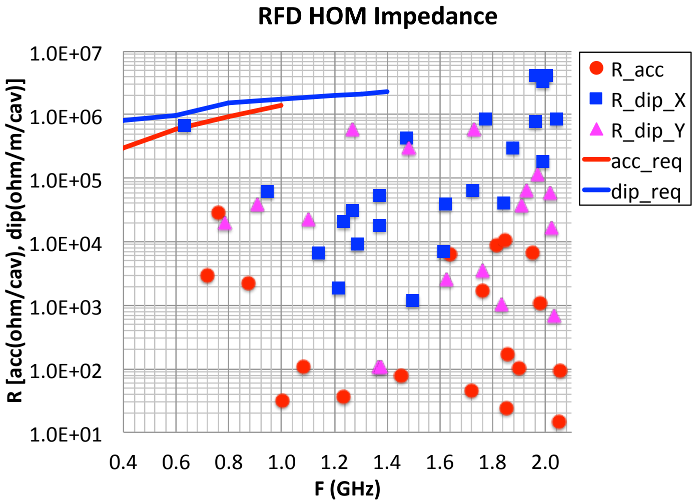


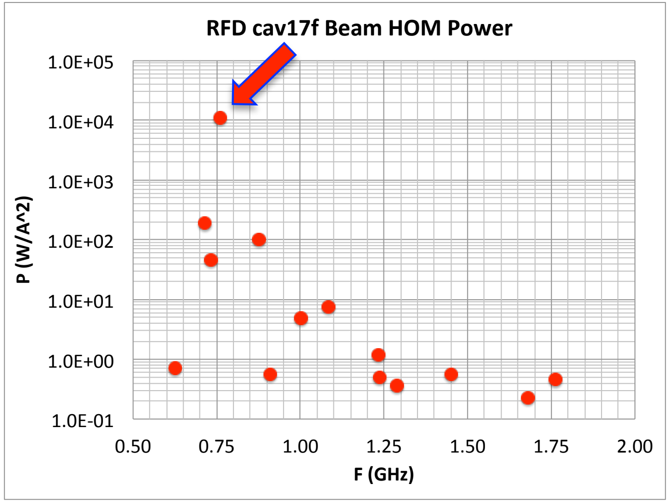


RFD Crab Cavity	
Frequency (MHz)	400
Operating Mode	TE11
Lowest dipole HOM (MHz)	633
Lowest acc HOM	715
High R/Q acc HOM	760.9
Iris aperture (diameter) (mm)	84
Transverse dimension (mm)	281
Vertical dimension (mm)	281
Longitudinal dimension (w/o couplers) (mm)	556
R_T (ohm/cavity)	433
V_T (MV/cavity)	3.34
Bs (mT)	55.5
Es (MV/m)	32.6

- No lower order mode
- Compact, clears the second beam pipe
- Minimal multipole fields with shaped pole face

760 MHz Mode Issue of the current Prototype Cavity





International Review of the Crab Cavity Performance for HiLumi

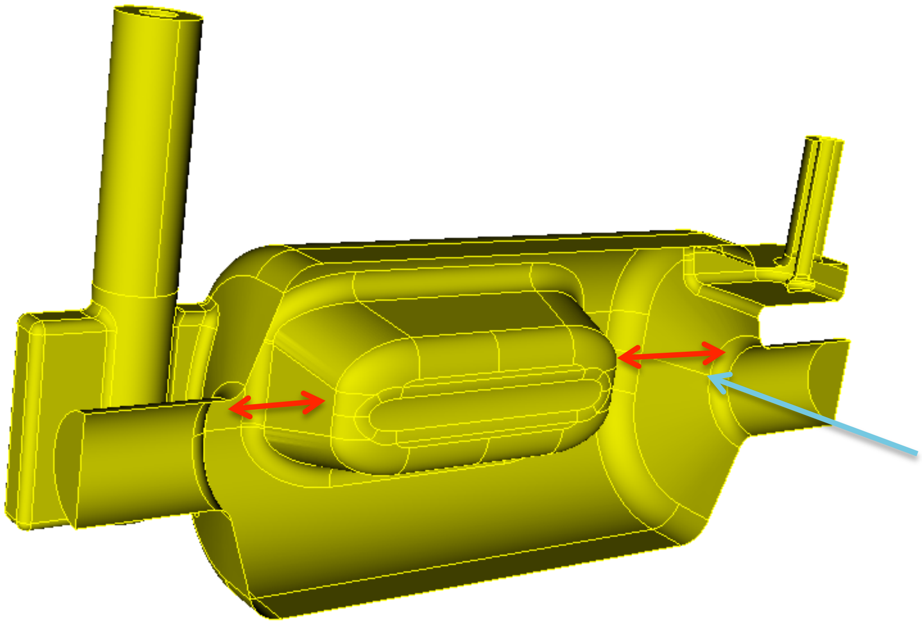
April 3-5, 2017 CERN

Impedance meets beam dynamics requirements
(Elias Métral, Joint LARP CM26/Hi-Lumi Meeting, SLAC, 19/05/2016)

- Acc. HOM mode at 760.94 MHz too close to beam resonance at 761.48 MHz
- Resulting in beam HOM power >10kW
- Design spec for beam power is < 1kW

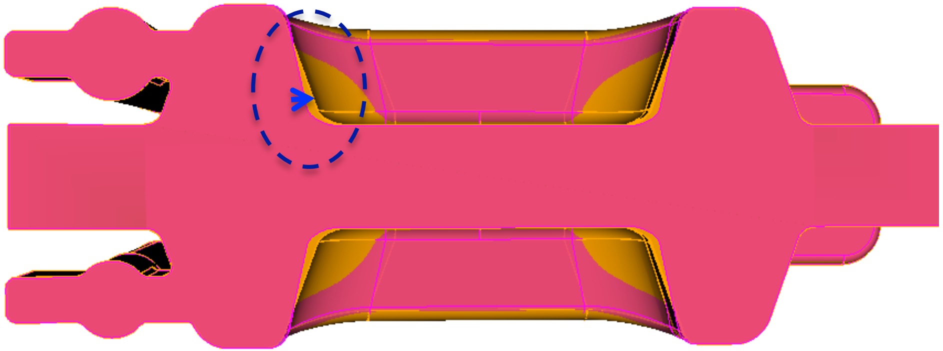
➢ Mitigation: to detune the 760MHz mode away from beam resonance

Effective Geometry Parameters to Detune the 760 MHz mode

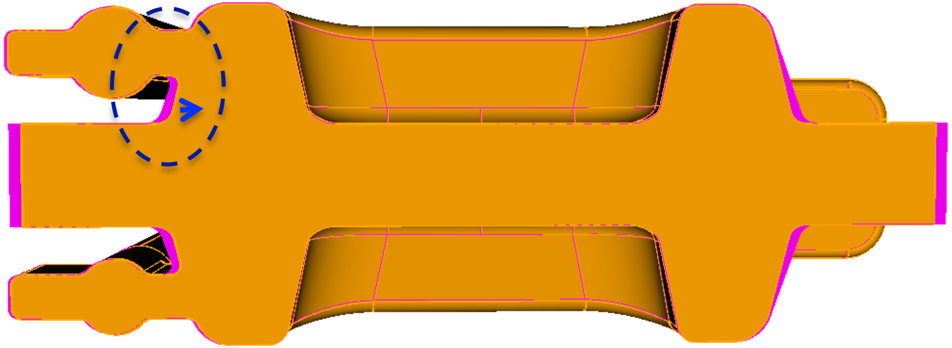


Gap at beam pipe opening has opposite dF sensitivity for the operating mode and the 760MHz mode

"+" or "-" 760 MHz mode frequency?



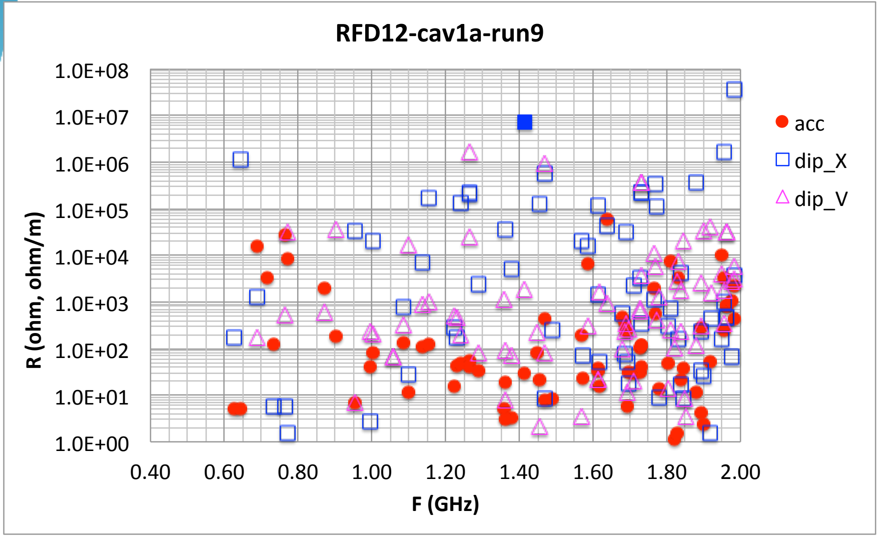
Shrink pole size: to raise 760 mode frequency



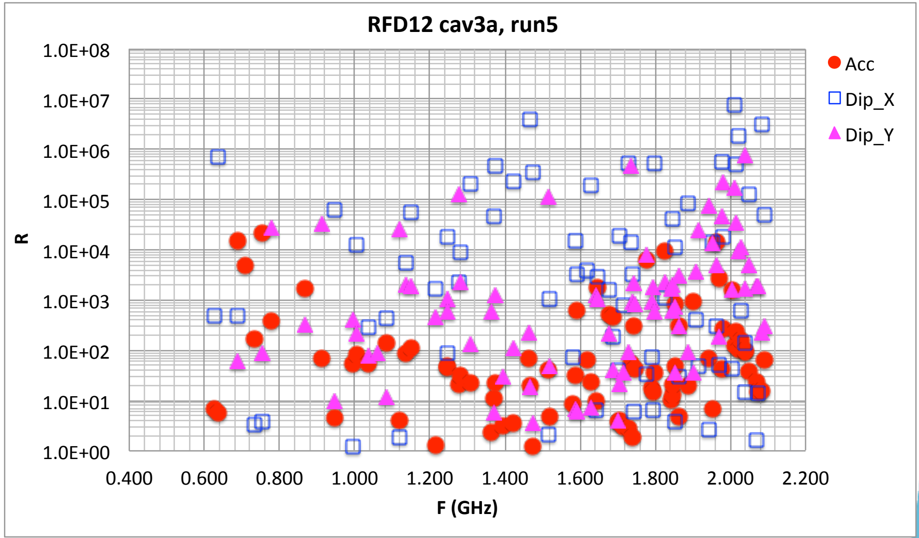
Shrink gap from the end-plate: to lower 760 mode frequency

- Either "+" or "-" 6 MHz detuning of the 760 MHz mode from the beam resonance (761.5MHz) achievable by modifying the end-gaps

+/- 6MHz Detuning Solutions



+6MHz solution

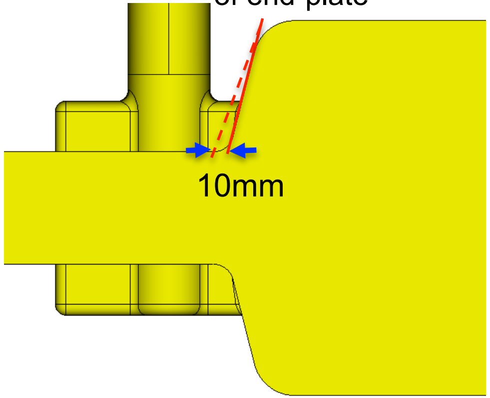


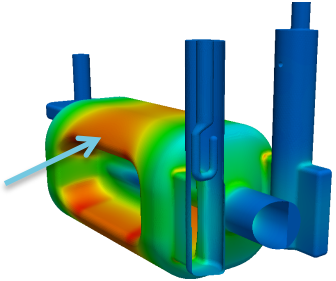
-6MHz solution (choice for re-design)

- "-6MHz" solution is the choice for the re-design
  - Shorter cavity, major changes are at the ends
  - Better damping of HOMs – however still need some more retuning of HOM couplers

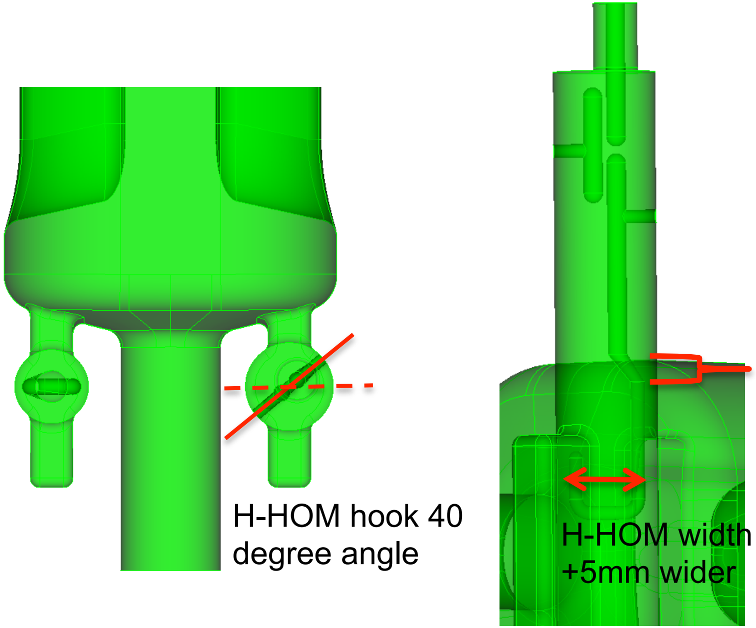
Major Changes in New Cavity Design (cav3a-run14)

Detuning of the 760MHz mode



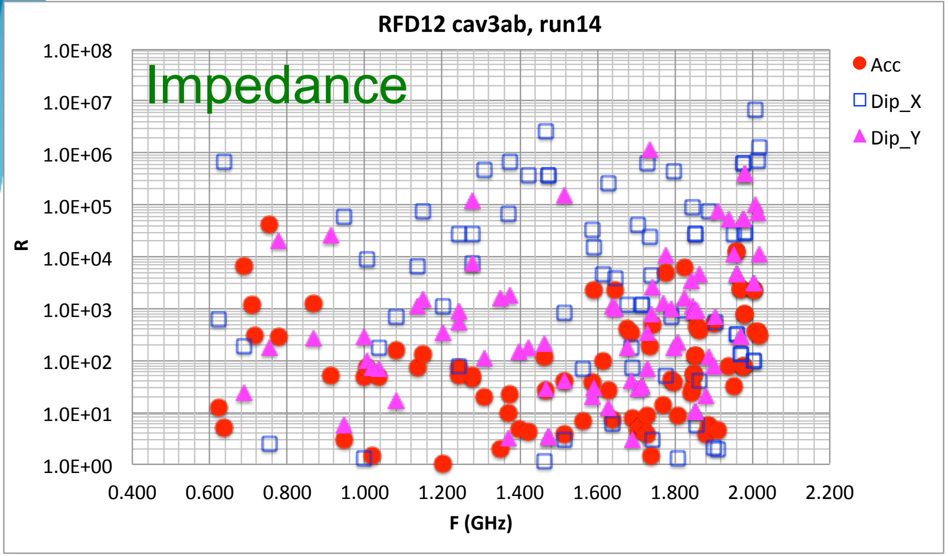


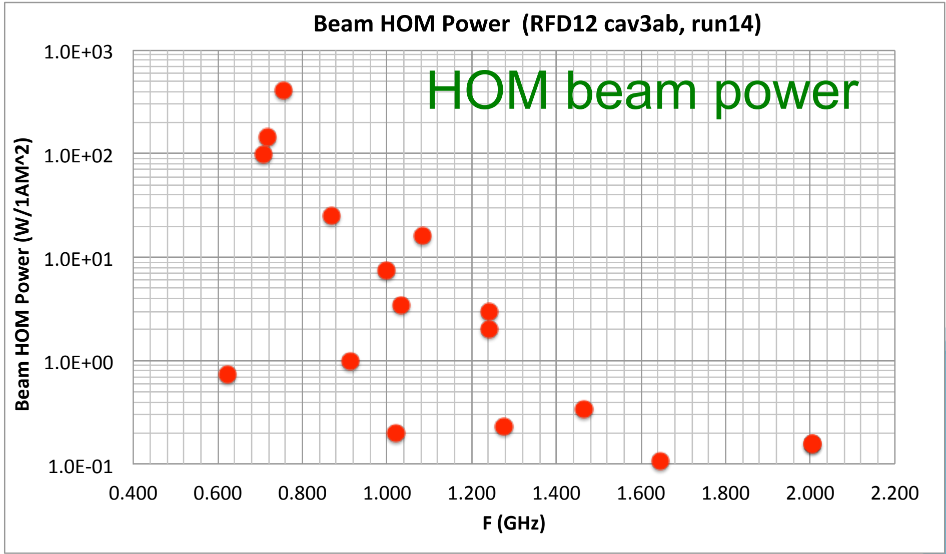
Improving HOM damping for the new design



- More than 5 MHz detuning of the high R/Q 760MHz mode obtained
- Effective HOM damping achieved

"-6MHz" solution: 760.9MHz detuned to 755.3MHz





- HOM impedance spectrum provided to CERN beam dynamics team for beam instability analysis

- HOM power calculated for 1-AM beam
- σ_z=76mm factor included in power calculation

Beam HOM power well below design requirement of 1 kW

New Design Parameter Comparison

RFD Crab Cavity		
	Current Prototype	New Design
Frequency (MHz)	400	400
Lowest dipole HOM (MHz)	633	635
Lowest acc HOM	715	717
High R/Q acc HOM	760.9	755.3
Transverse dimension (mm)	281	280
Vertical dimension (mm)	281	280
R_T (ohm/cavity)	427	427
V_T (MV/cavity)	3.34	3.34
Bs (mT)	55.5	55.4
Es (MV/m)	32.6	32.7

- Frequency of 760.9 MHz mode lowered by 5.6 MHz (~6 MHz below resonance)
- Operating mode: high shunt impedance and low surface fields preserved

Multipole $B_{3,}$ $B_{5,}$ B_7

Assume Def mode symmetry (only cos term)

$$E_{acc}(r,\varphi) = \sum_n E_{acc}^n r^n \cos(n\varphi) \qquad (e^{j\omega z.c} \text{ included in } E_{acc}^n)$$

$$\Delta\vec{p}_\perp^{(n)}(r,\varphi) = \frac{1}{c}\int_0^L F_\perp\,dz = \frac{je}{\omega} n r^{n-1}\left(\hat{u}_r \cos(n\varphi) + \hat{u}_\varphi \sin(n\varphi)\right)\int_0^L E_{acc}^n(z)\,dz$$

$$b_n = \int_0^L B^{(n)}\,dz = \frac{1}{ec}\int_0^L F_\perp^{(n)}\,dz = \frac{nj}{\omega}\int_0^L E_{acc}^{(n)}\,dz$$

$$\Delta\vec{p}_\perp^{(n)}(r,\varphi) = e\vec{V}_T(r,\varphi) = e\sum_n b_n r^{n-1}\left(\hat{u}_r \cos(n\varphi) + \hat{u}_\varphi \sin(n\varphi)\right)$$

$$V_{def} = b_1$$

Component	Value
Vt (total)	10 MV
b3	429 mT/m^2
b5	-1.8e6 mT/m^4
b7	-4.9E+08 mT/m^6

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- Multipole components roughly unchanged as compared with current design
- Within design requirement

Multipacting Analysis – FPC end

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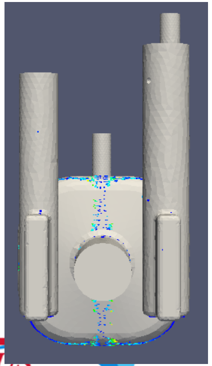
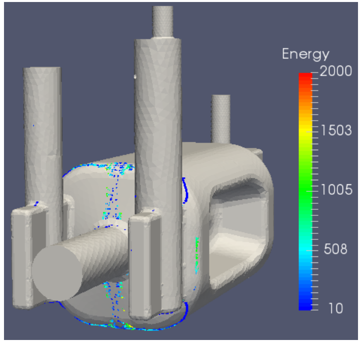
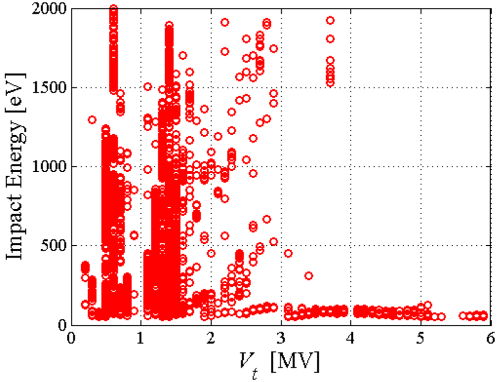
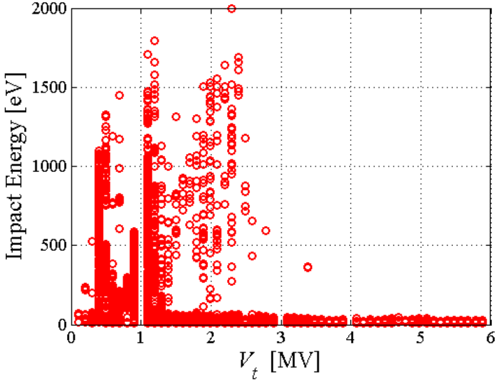





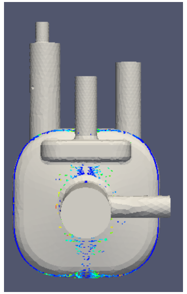
Fabricated Prototype Cavity

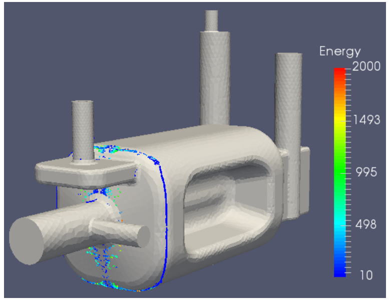


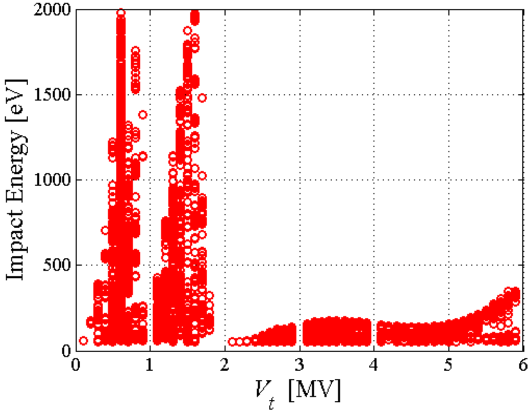
New Cavity Design

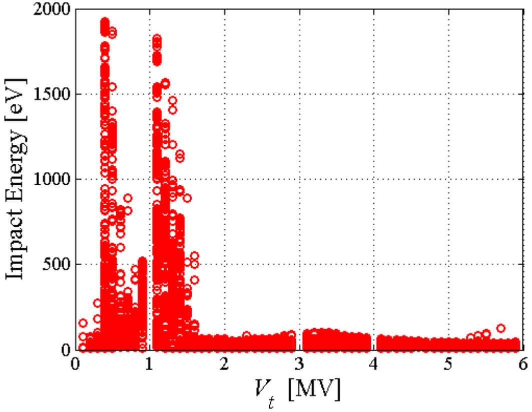
No significant difference in MP characteristics that would be of concern in new design

Multipacting Analysis – V-HOM end









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Fabricated Prototype Cavity

New Cavity Design

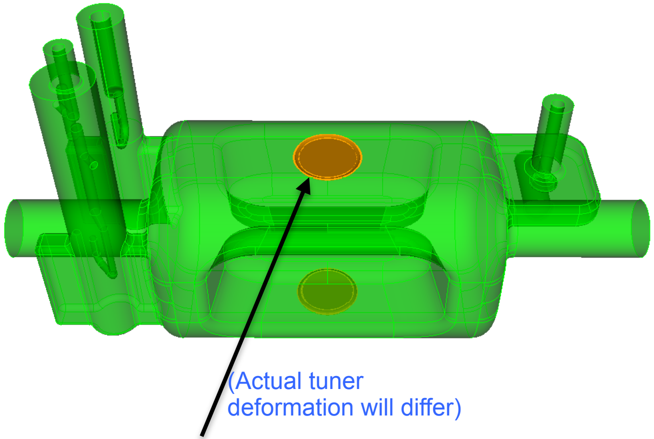
No significant difference in MP characteristics that would be of concern in new design

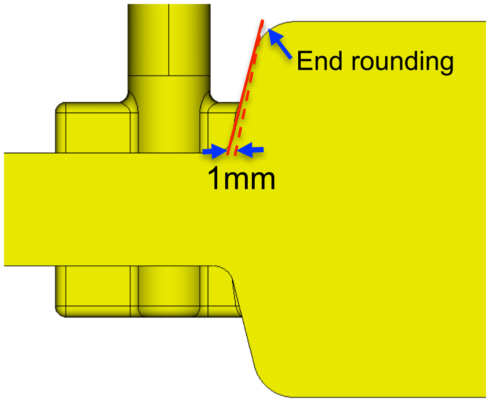
Tuner & Dimension Sensitivity

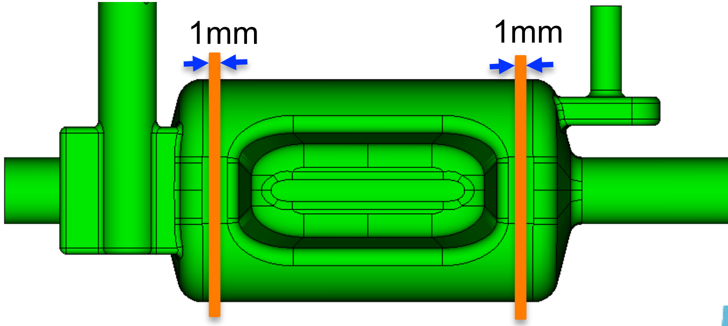
"Tuner": r=50 mm

End plate tilt & rounding

Trimming







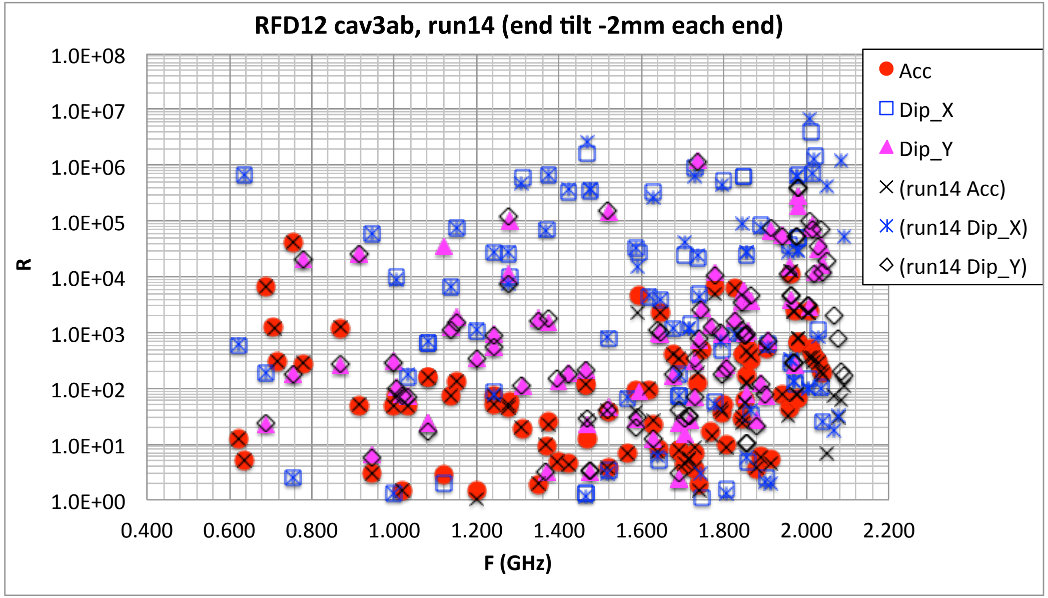
(Tuner radius=50mm)	operating mode	755 MHz mode
dF (MHz)/mm_each_side	0.1926	0.0244

Dimension sensitivity (dF (MHz))	operating mode	755 MHz mode
end plate tilt (-1mm_each_side)	0.1355	-0.4266
cavity end rounding (+1mm_each_end)	0.0218	0.2201
Cavity trim (-1mm_each_side)	0.2602	0.2027

755MHz mode frequency (>5MHz from beam resonance) could be maintained with reasonable geometry tolerance

Impact of End-plate Tilt Angle on HOM

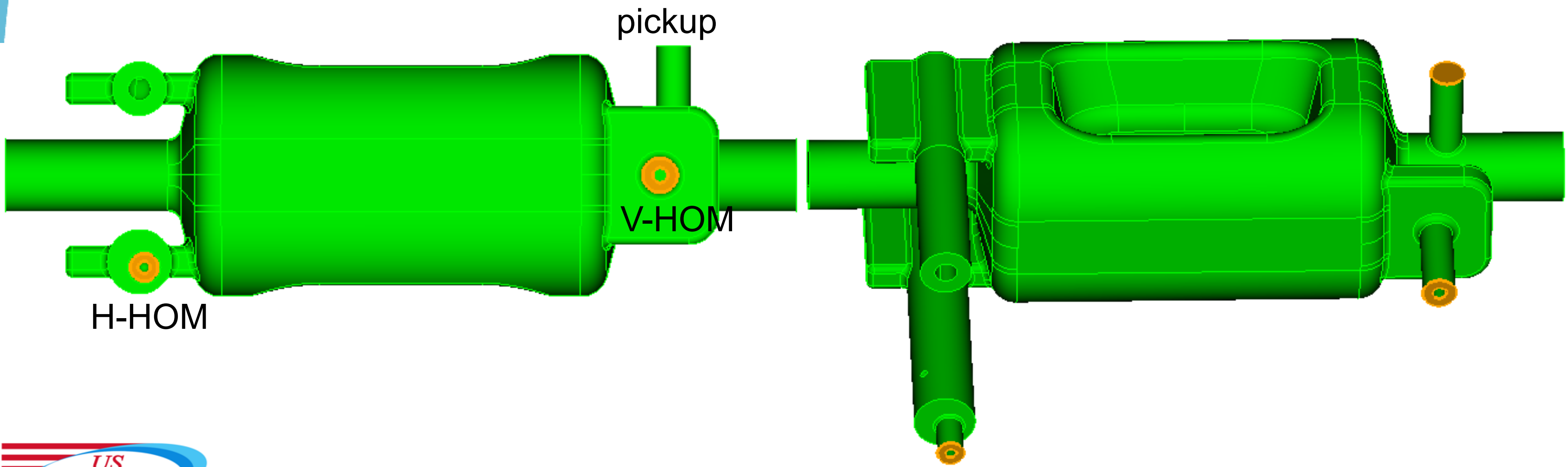
- Comparison between a 2mm end-plate tilt difference



- Tolerance of HOM damping on other major parameters being analyzed…
- (Dimension tolerance seems reasonably in-sensitive)

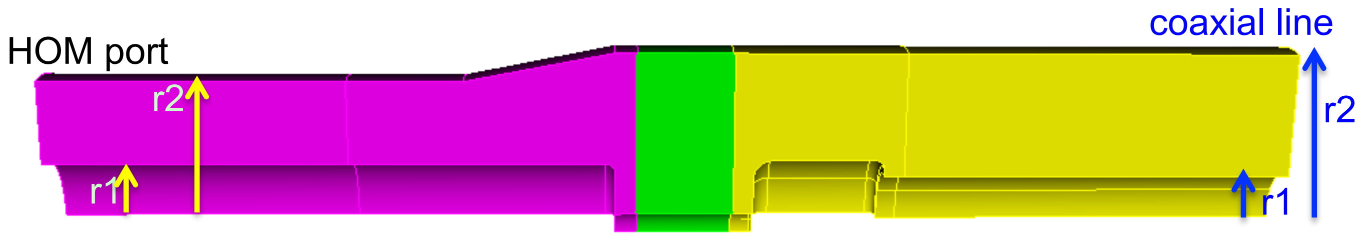
Simplifying Port Interface

- Current design has different H-HOM and V-HOM port sizes
  - Require different RF window designs for each port
- In process making ports the same size – H-HOM, V-HOM, Pickup
  - 40 mm outer diameter, 50 Ohm impedance
  - One RF window design for all



HOM Coupler RF Window

- DQW coax window - CERN design

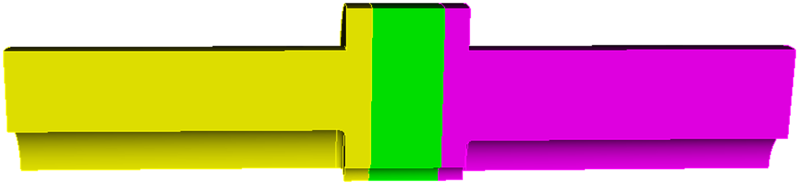


- Interface dimensions for current DQW and RFD designs

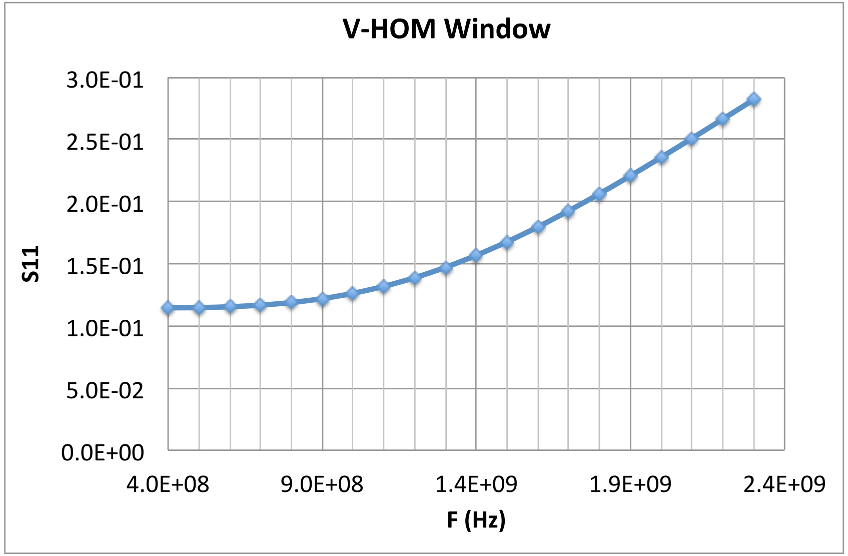
(mm)	DQW	RFD H-HOM	RFD V-HOM
HOM port: r1	8.418	7.00	8.70
HOM port: r2	17.056	16.10	20.00
Coaxial line: r1	7.00		
Coaxial line: r2	20.065		

RFD V-HOM Window - preliminary

- RFD V-HOM port (50 ohm) to CERN coaxial line window (in progress…)
  - 10-mm ceramics thickness

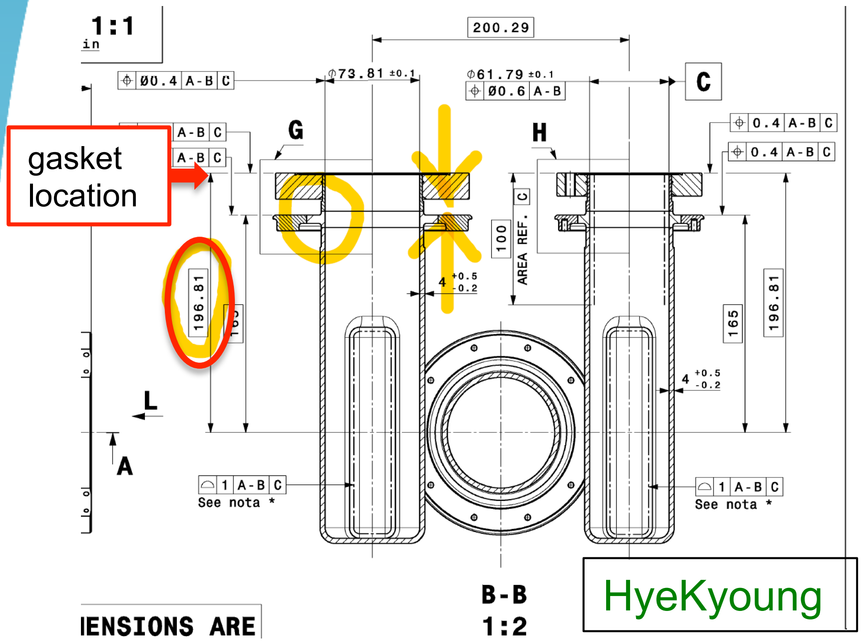


- Will modify the RFD H-HOM port to the same port dimension as the V-HOM

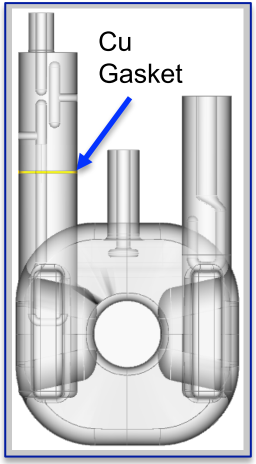


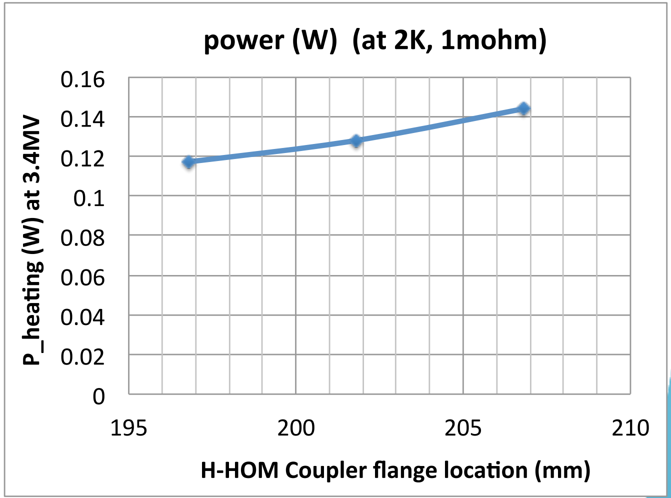
Gasket RF Heating vs Gasket/Flange y-Position

- Space between H-HOM flange and He-vessel was found a little too tight
- Increase the space by 5mm or more could ease assembly



RF heating of 3mm copper gasket (at 2K)





Space between H-HOM flange and He-vessel could be increased by 5 mm with minimal increase of RF heating

Summary

- A new cavity design was developed to minimize beam HOM power to below design spec of 1kW
  - Problematic 760MHz high R/Q accelerating mode detuned to ~6MHz below beam resonance
  - Comparable RF parameters to the original design (R_T, E_s, B_s, multipole, Multipacting …)
  - HOM couplers re-tuned to effetely damp the HOM modes

- Cavity dimensions are being finalized
  - New HOM impedance is being validated via beam dynamics analysis

- HOM coupler RF window is being optimized