400MHz Half-Wave Spoke Resonator Crab Cavity For LHC Upgrade

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Fermilab

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Outline

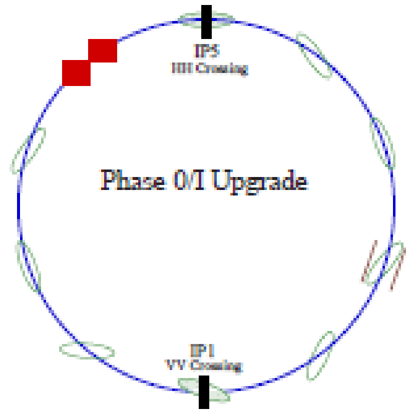
- Design considerations
- Half-wave spoke resonator (HWSR) crab cavity RF parameters
- LOM, HOM-v damping couplers
- HOM-h damping coupler
- FP coupler
- Multipacting analysis
- Summary

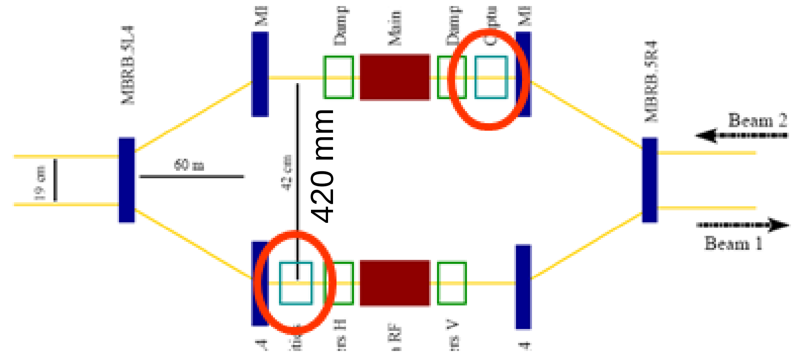
Design Considerations

- Compact size to fit in tight beam line separation
- 400 MHz in frequency
- Effective damping of unwanted modes (LOM & HOMs)
- Alienate potential multipacting conditions
- Tolerance and etc

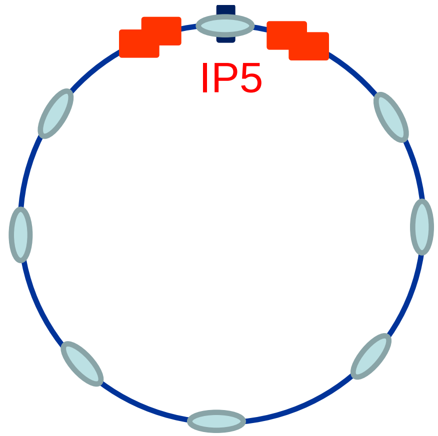
Cavity Size

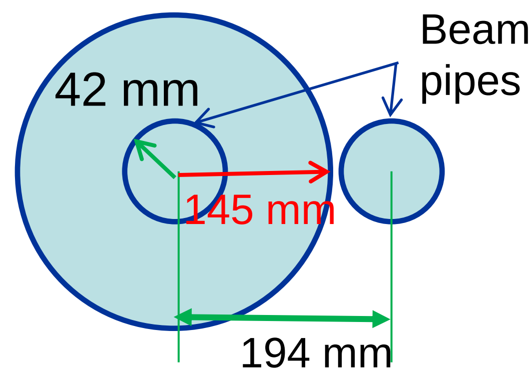
Global Scheme:
Beam-beam
separation: 420mm





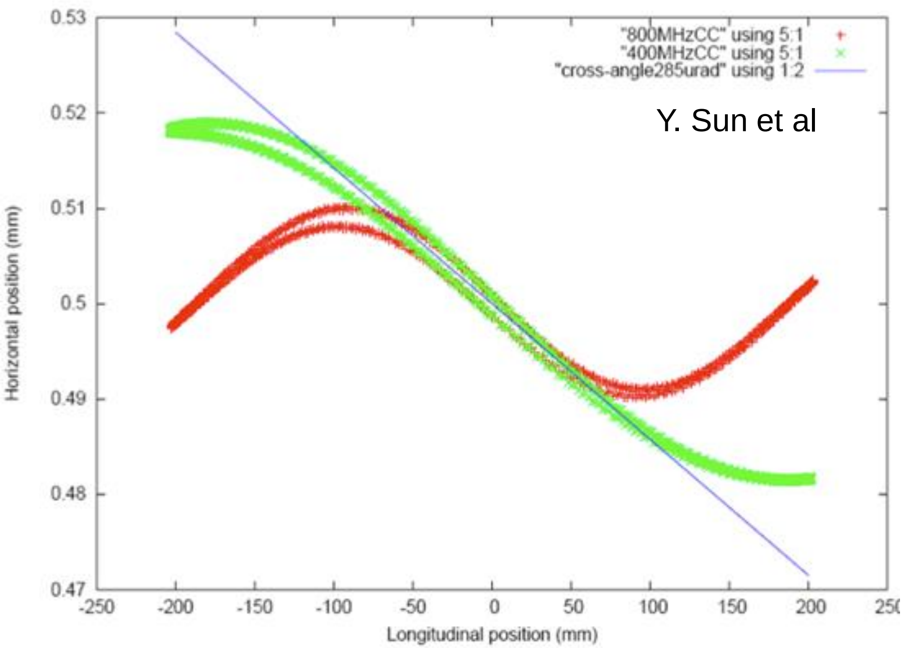
Local Scheme:
Beam-beam
separation: 194mm

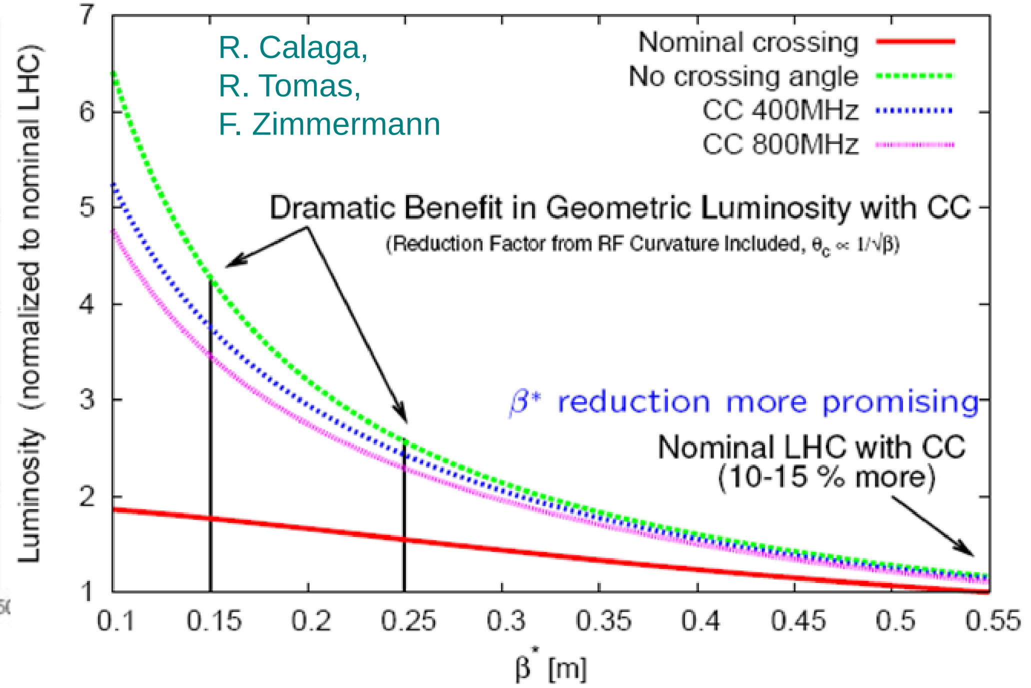




- A single design for both local and global schemes
- **Cavity dimension determined by local scheme (~145 mm)**

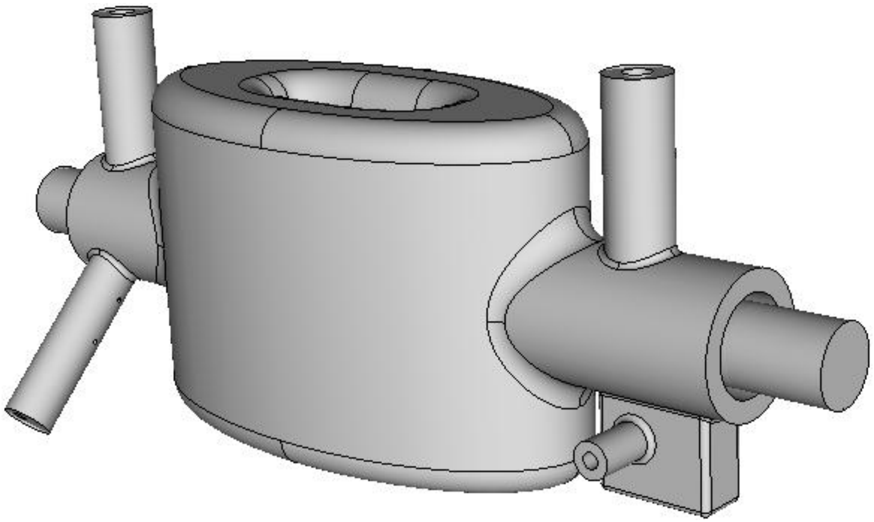
Frequency: 800-MHz vs 400-MHz

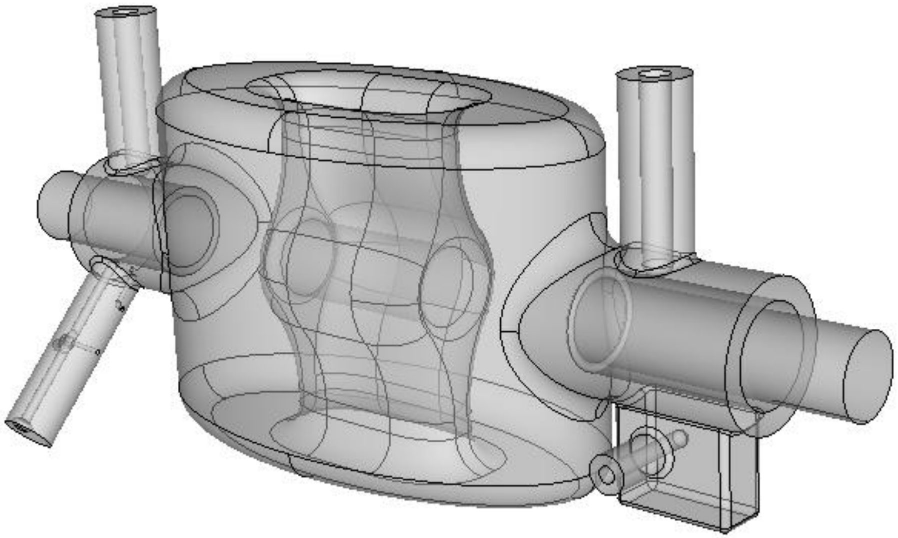




400 MHz is chosen for the present design

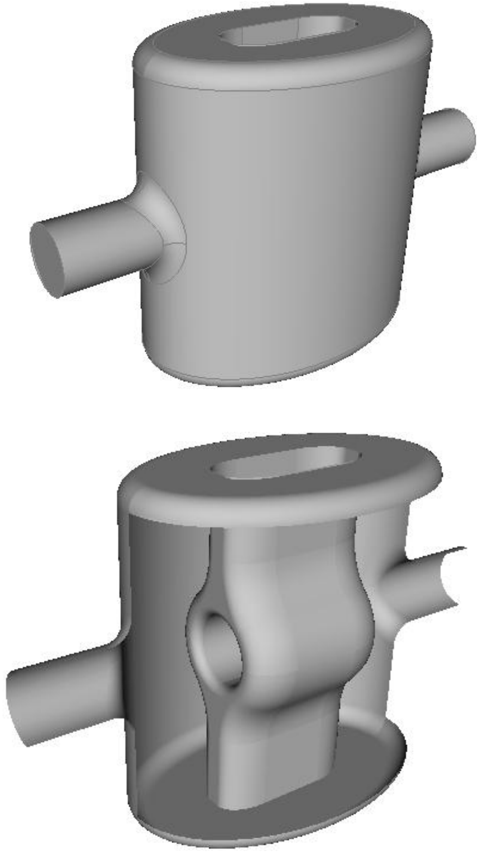
400-MHz HWSR Crab Cavity

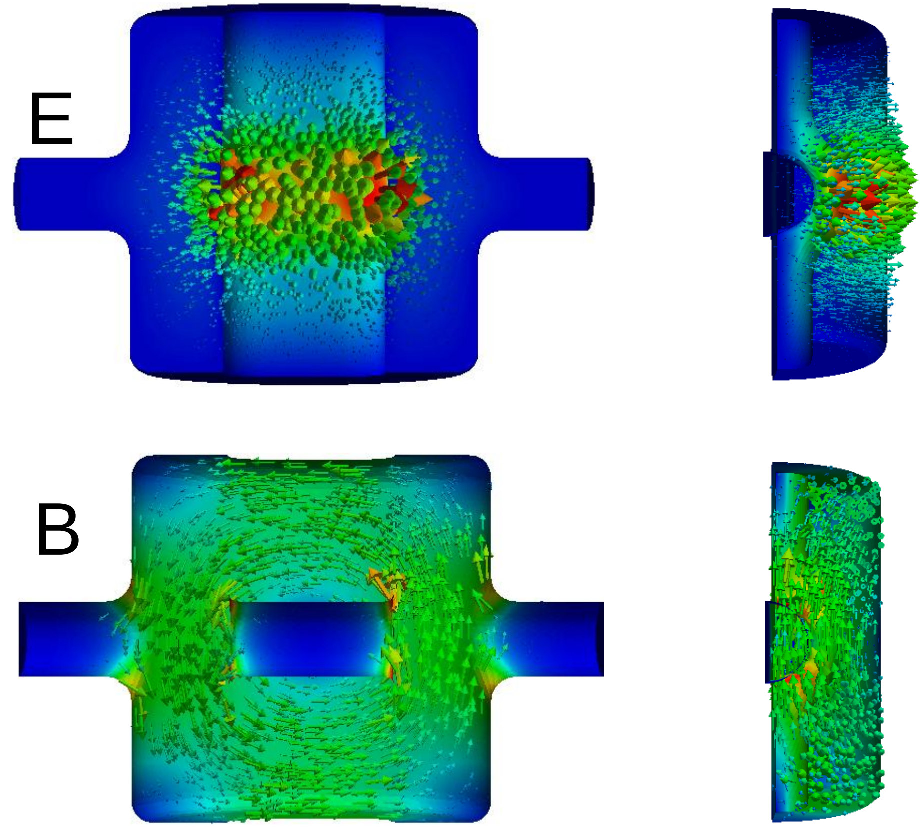




- HWSR design fits both global and local schemes
- **Design concept presented in CM13**
- **Progresses being made since then:**
  - Cavity - surface field and RF parameters optimized
  - Couplers: - LOM/HOM-v, HOM-h couplers optimized
  - Multipacting - analyzed

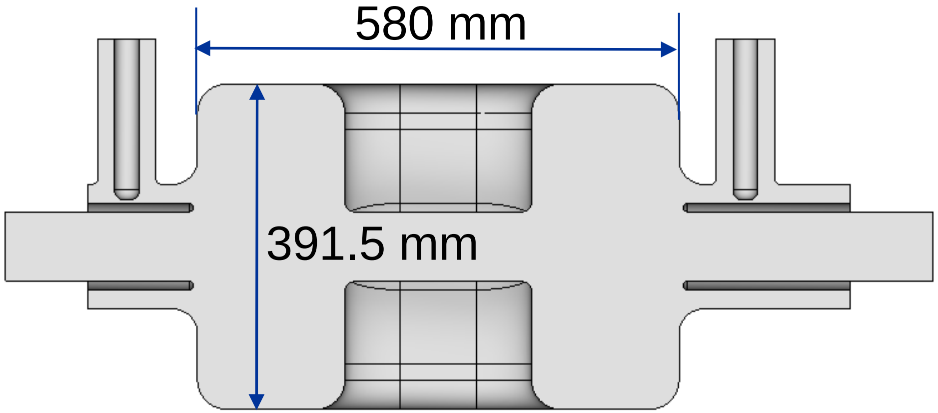
HWSR Deflecting Mode

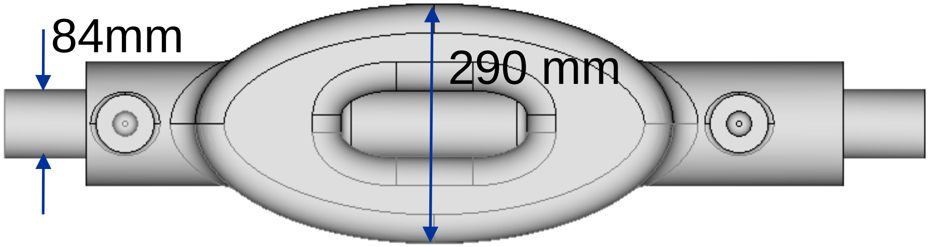




- Frequency determined by longitudinal and vertical dimensions – TE11-like mode
- Horizontal dimension affects mainly efficiency and surface fields

400 MHz HWSR Cavity Parameters

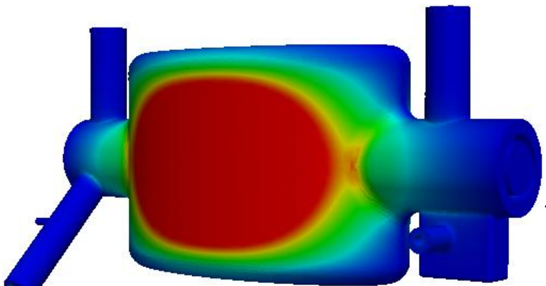


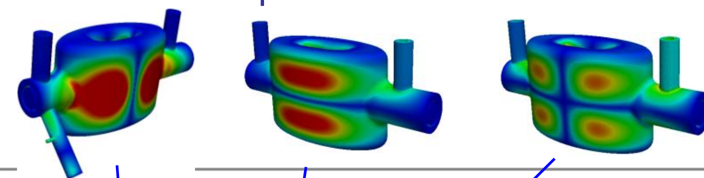


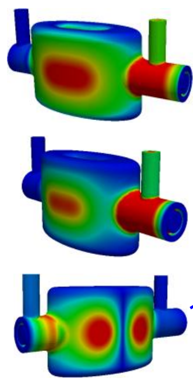
Parameters	
Cavity Width (mm)	**290**
Cavity Height (mm)	391.5
Cavity Length (mm)	580
Beam pipe radius (mm)	**42**
$(R/Q)_T$ (ohm/cavity)	215
E_S/V_T ((MV/m)/MV)	13
B_S/V_T (mT/MV)	19.5

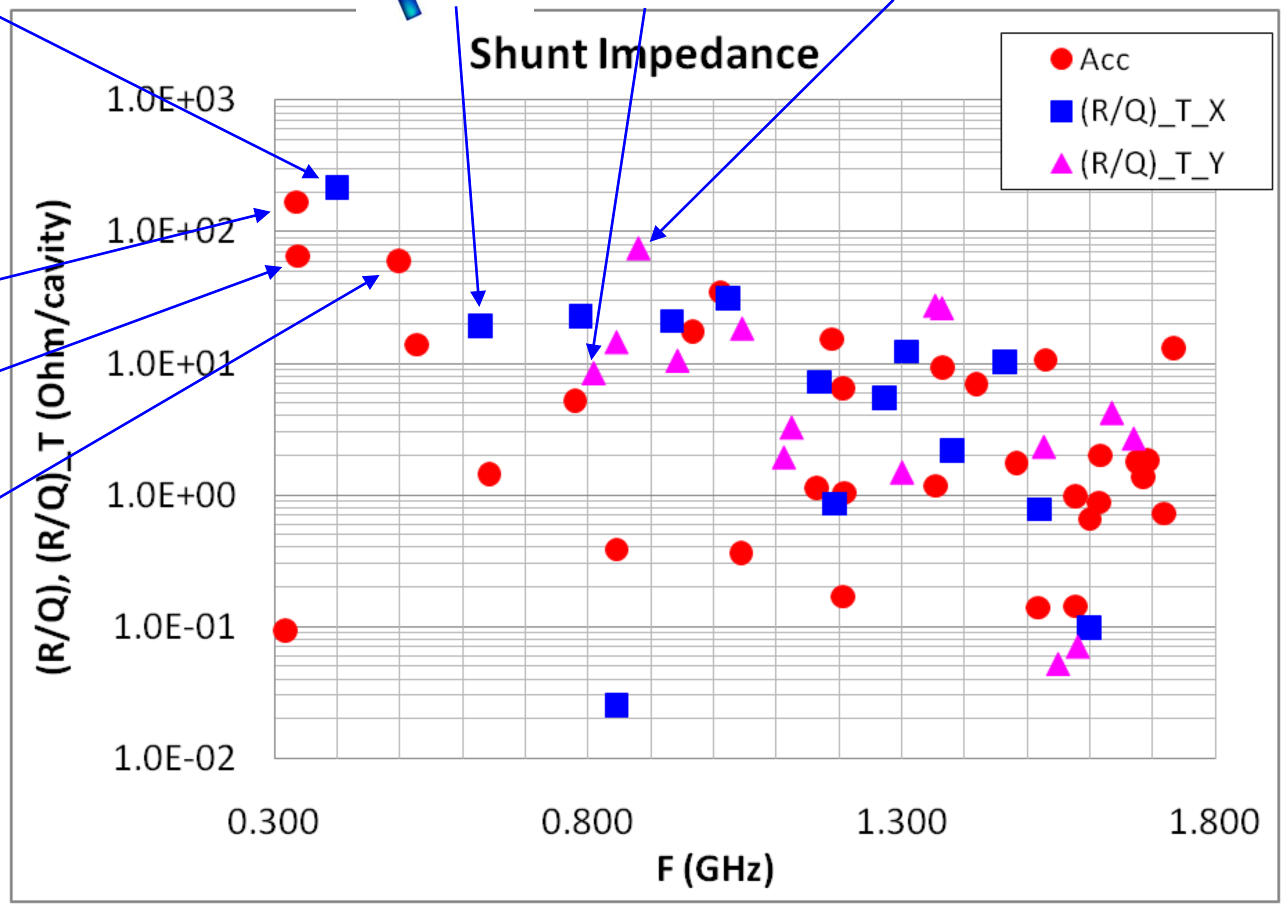
- 8 MV deflecting voltage required
- 2 cavities/beam, 4 MV each

Shunt Impedance









- No SOM !
- LOM 65 MHz below deflecting mode

Impedance Budget (LHC-CC09)

E. Shaposhnikova
LHC-CC09

Summary: longitudinal impedance budget

- Requirement for HOM damping in LHC given so far is 60 kOhm (defined by 200 MHz RF at 450 GeV)
- For nominal intensity
  - in 400 MHz RF system we have 80 kOhm for small emittance beam (1 eVs) at 7 TeV, 300 kOhm for 2.5 eVs
  - in 200 MHz RF system it is 70 kOhm , but the 400 MHz RF system can be used as Landau system
- Assumption: no loss of Landau damping due to broad-band impedance (ImZ/n > 0.1 Ohm, budget estimation in LHC DR - 0.07 Ohm), possible for small emittances (<0.7 eVs) at injection into 200 MHz RF system or at 7 TeV in the 400 MHz RF system (< 1 eVs)

➢ 10 kOhm for upgrade intensity and two identical cavities

16-Sep-09 Impedance & Stability 12

E. Shaposhnikova
LHC-CC09

Summary: transverse impedance budget

- Threshold for the nominal intensity and one cavity at 450 GeV determined by the damping time of 60 ms is 2.5 MOhm/m
- With margin for particle distribution:
  - $0.6/(1-f_r)$ MOhm/m f_r [GHz] < 0.8
  - $1.2(1+2f_r)$ MOhm/m f_r [GHz] > 0.8
  - 3 MOhm/m at 800 MHz → 0.4 MOhm/m for upgrade intensity and 2 cavities
- Additional factor proportional to local beta-function $\beta/\langle\beta\rangle$

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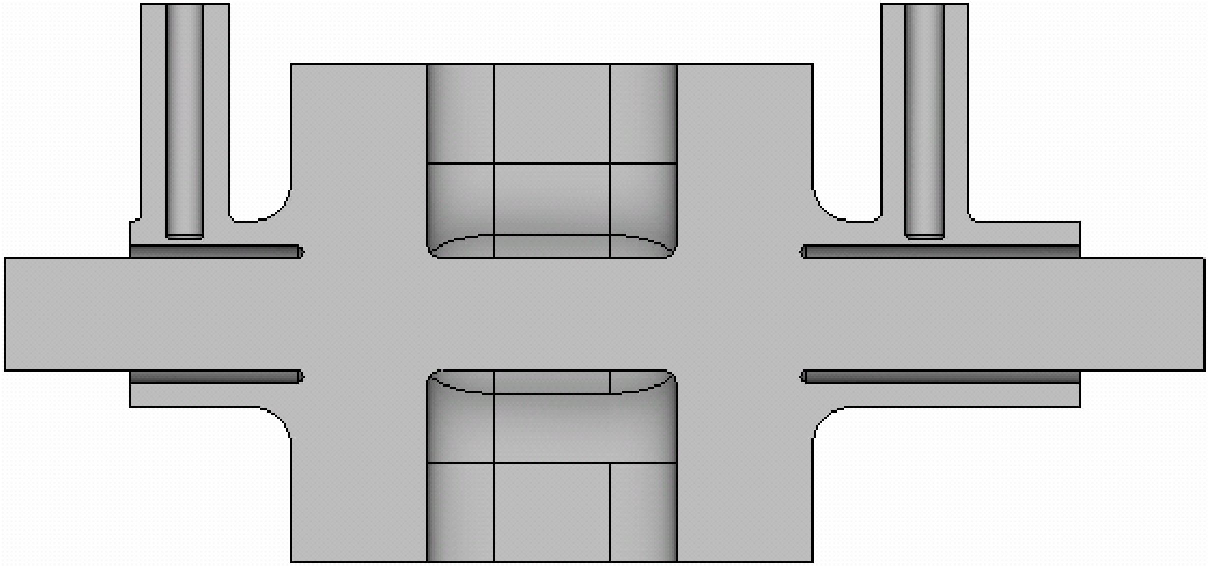
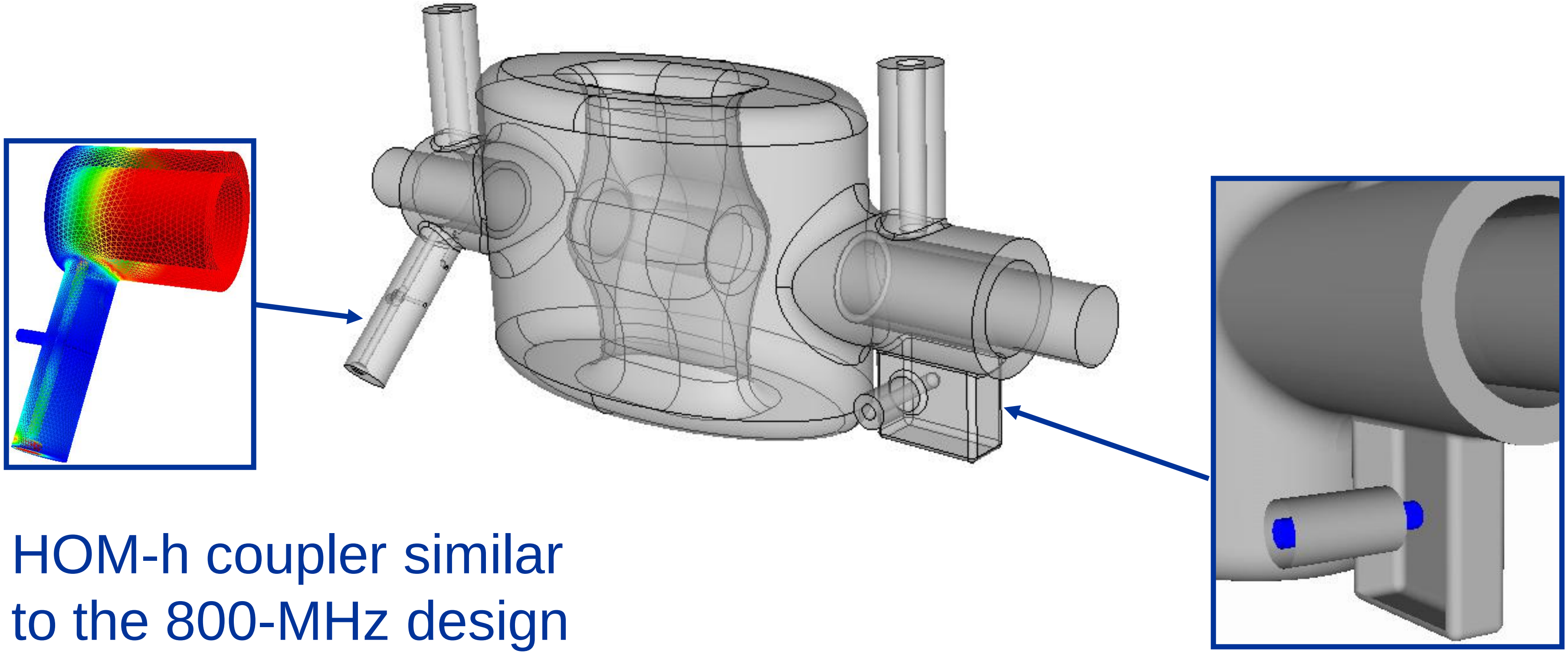
- Longitudinal (R): 80 kohm
- Transverse (Z_T): 2.5 Mohm/m

LOM/HOM-v Couplers



- On beam pipe coax-coax LOM/HOM-v damping couplers
- To damp accelerating modes and vertical HOMs

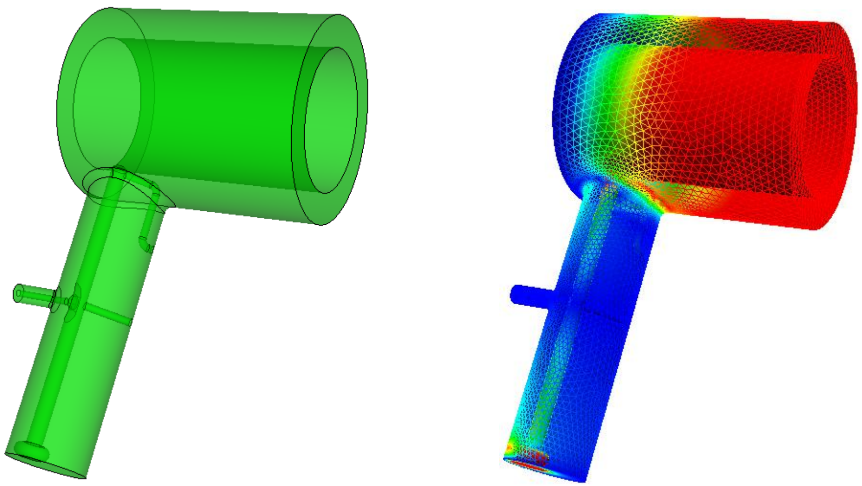
HOM and FPC Couplers

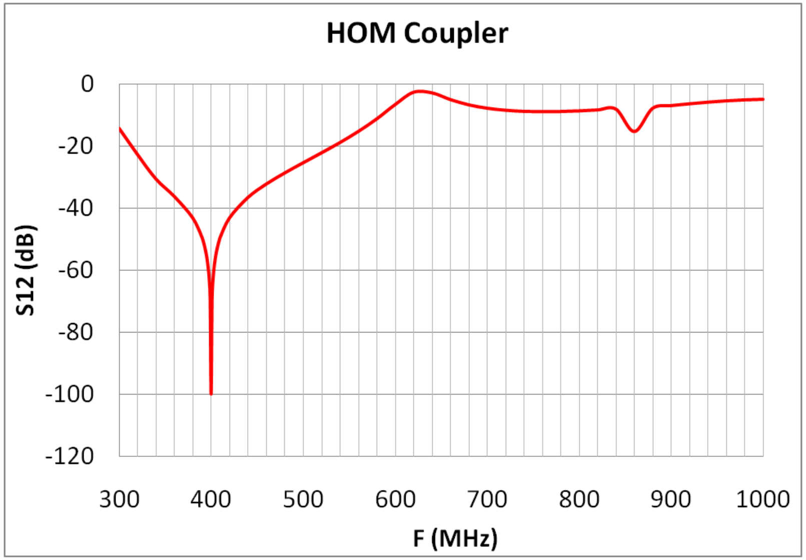


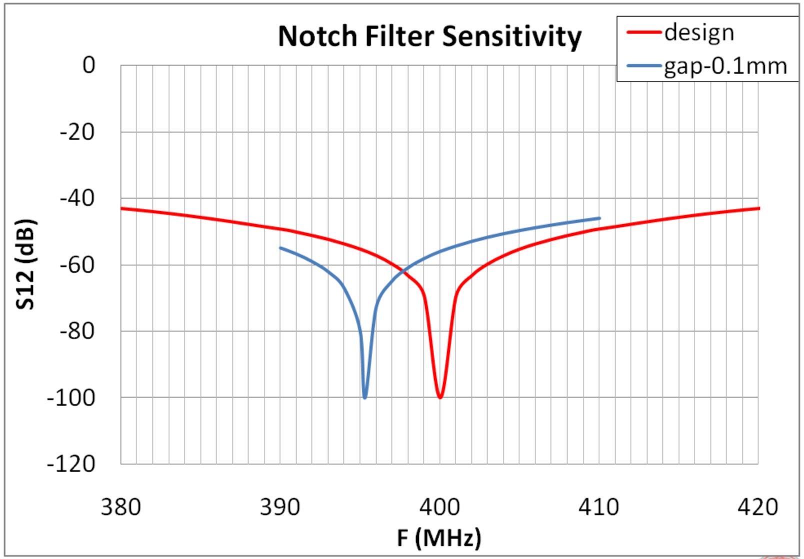
- HOM-h coupler similar to the 800-MHz design
- Notch filter to reject deflecting mode

- Input coupler with magnetic coupling
- Eliminates direct coupling from FPC to LOM/HOM-v

HOM Coupler Notch Filter





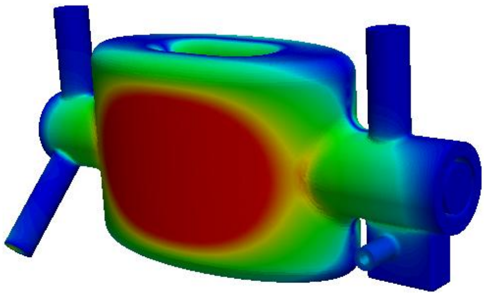


- Notch filter at 400 MHz
- Enhanced damping of the 1st horizontal HOM mode at ~600 MHz
- Filter sensitivity: 1-MHz/20-micron

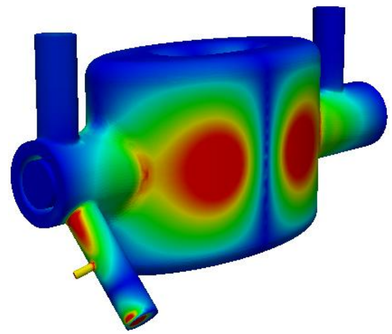
Damping of Dipole Modes

X-Dipole

400MHz operating mode

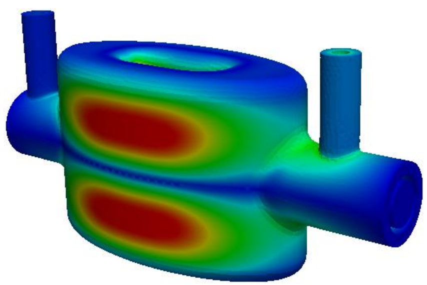


628MHz

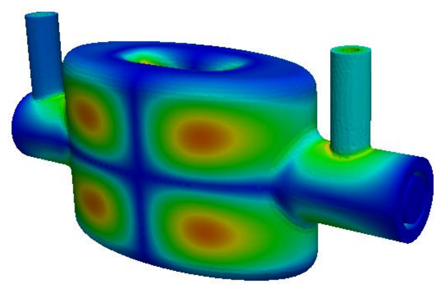


HOM coupler damps X-dipole modes

Y-Dipole



810MHz

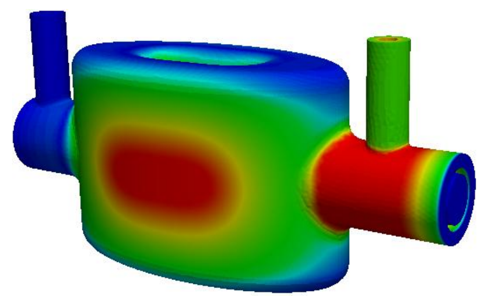


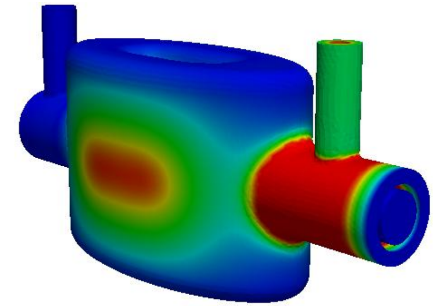
881MHz

LOM/v-HOM couplers damp Y-dipole modes

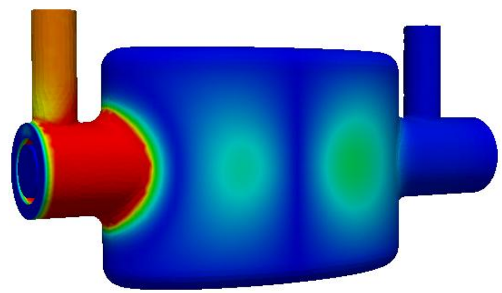
Damping of Accelerating

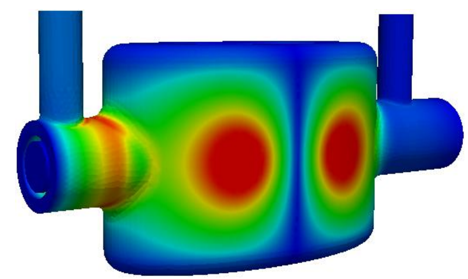
335 MHz, 337 MHz
damp by down stream coupler



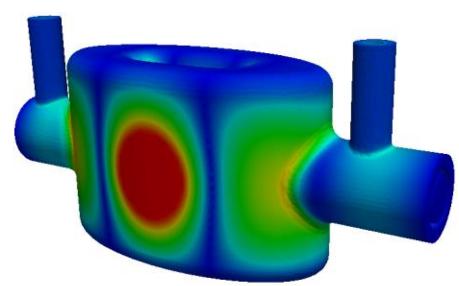


498 MHz, 526 MHz
Damp by upstream coupler



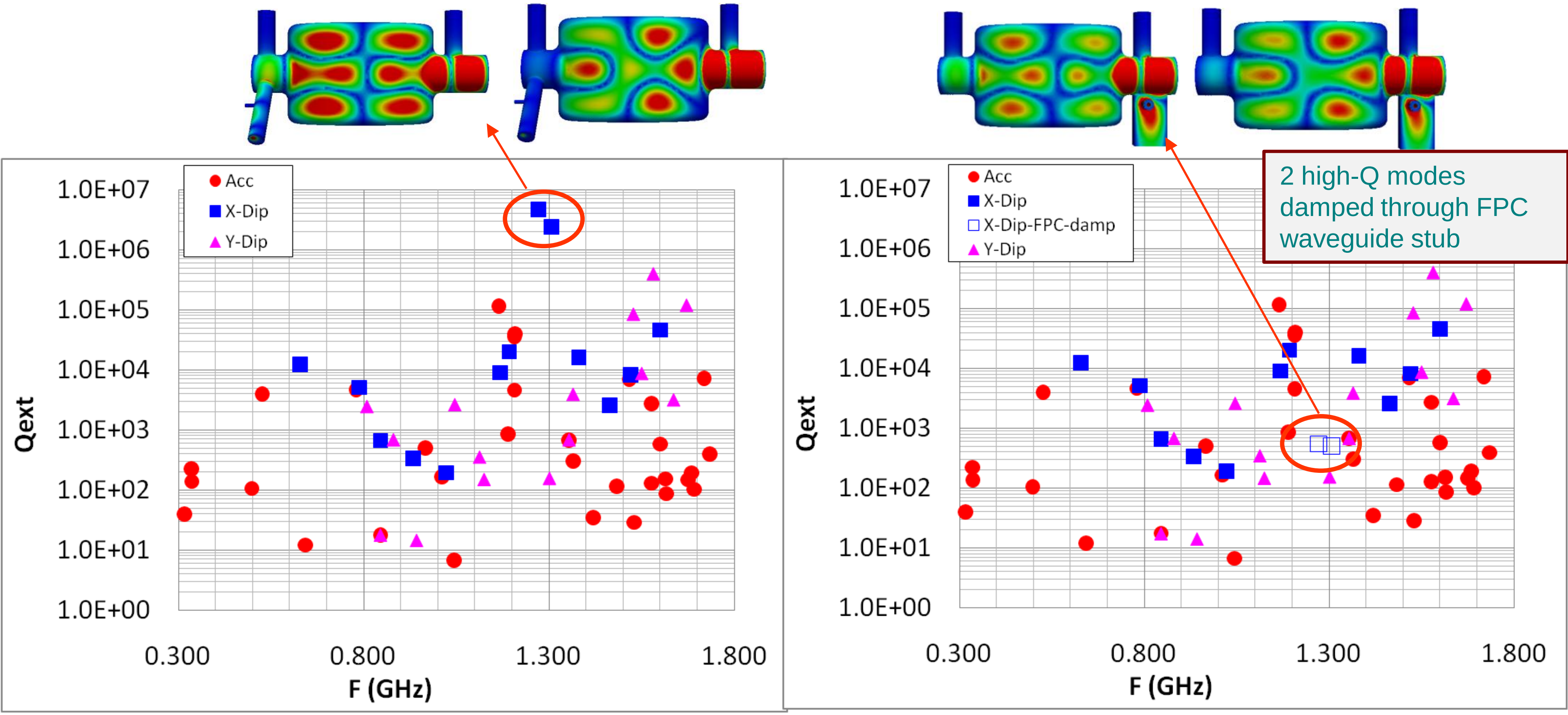


780 MHz



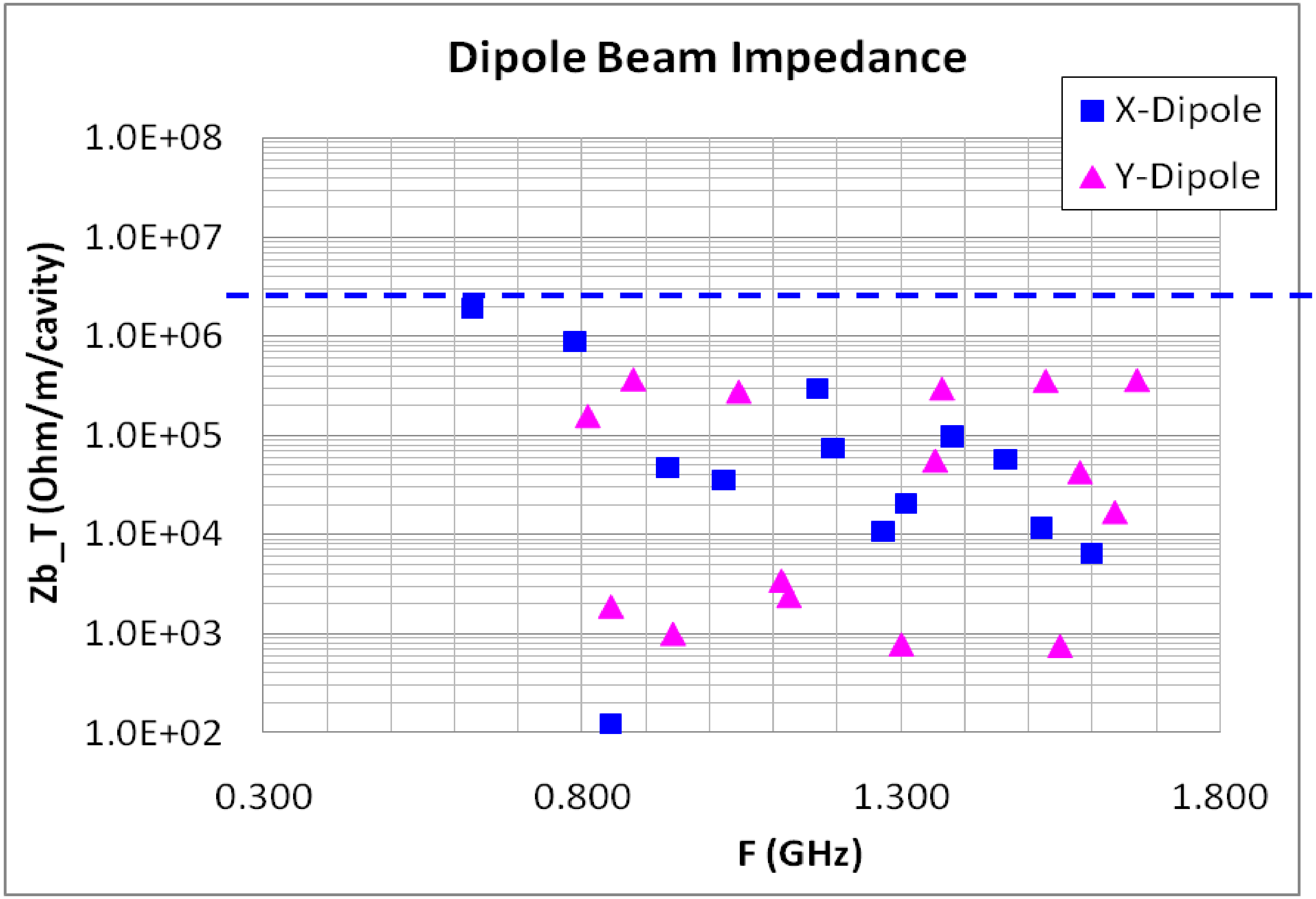
LOM/v-HOM couplers damp accelerating and vertical HOM modes

Damping Qext



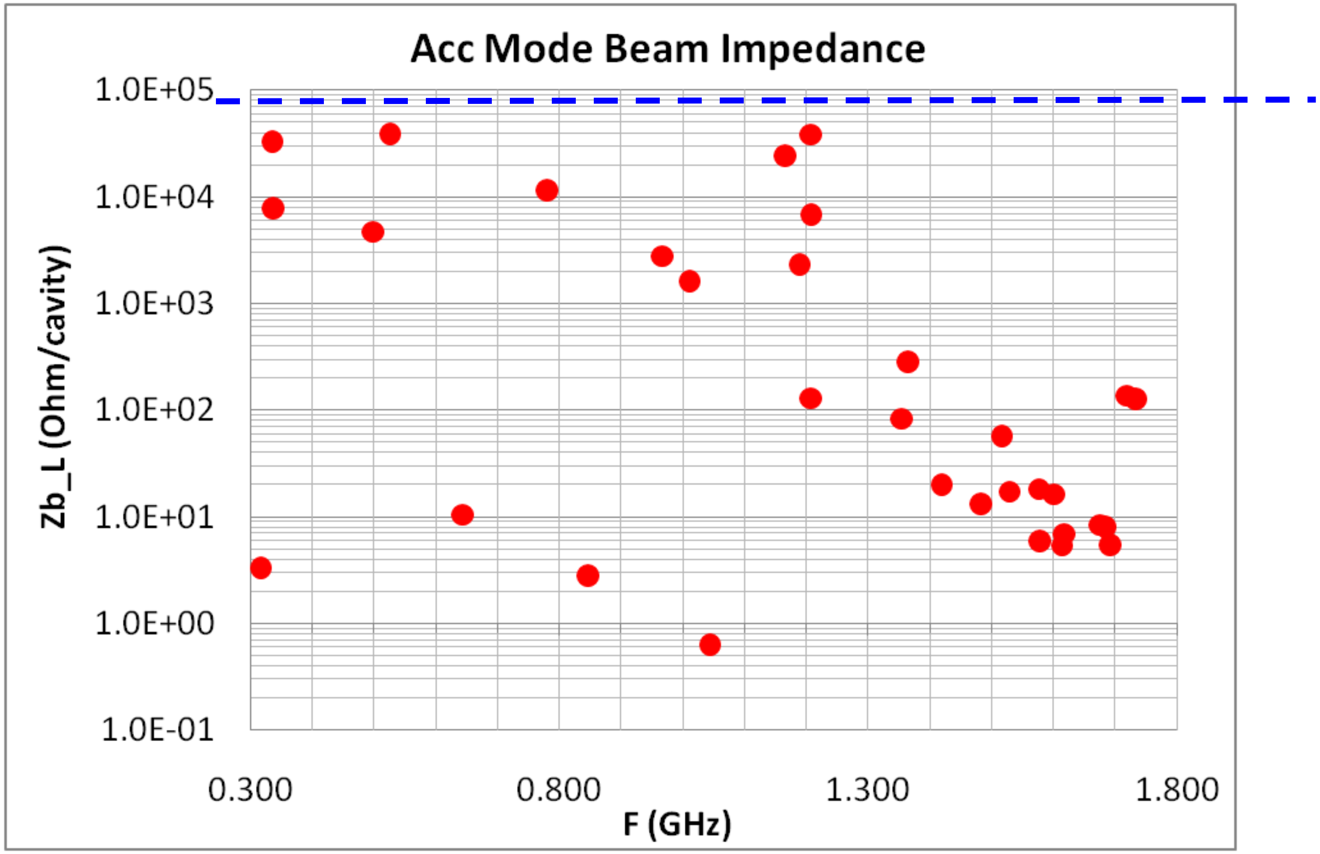
- Effective damping demonstrated with these coupling schemes
- Further optimization under way

Dipole Mode Beam Impedance



- Dashed line is the beam instability requirement for dipole modes

Acc. Mode Beam Impedance

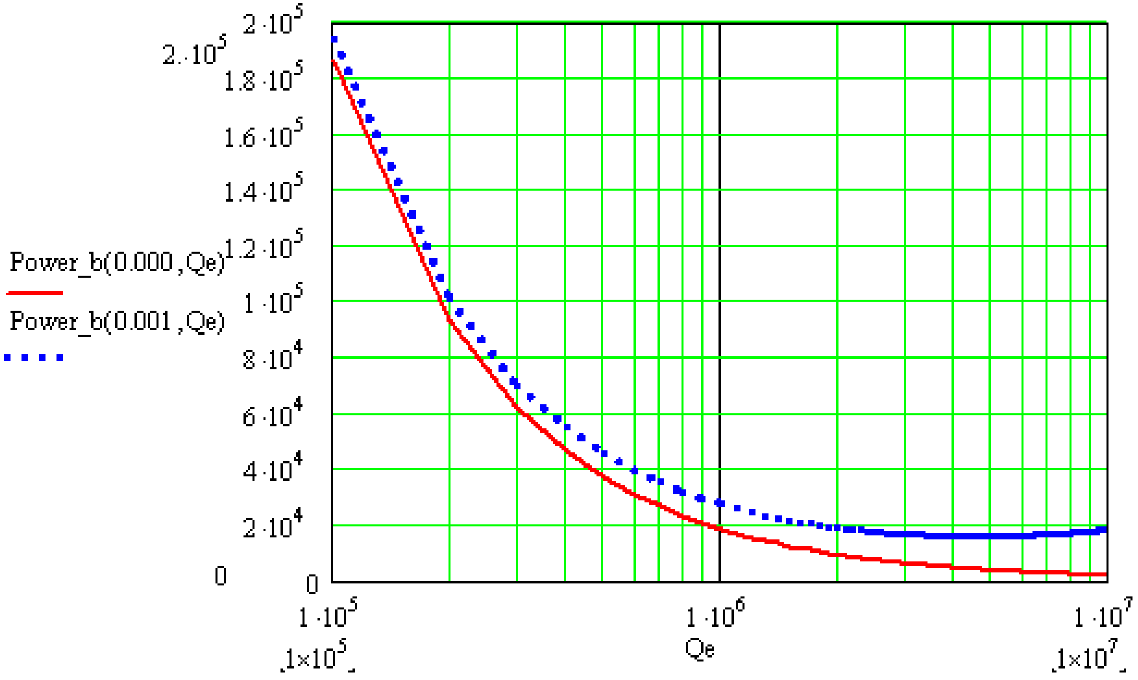


- Dashed line is the beam instability requirement for accelerating modes

Input Power Requirement

- FPC coupler can provide Q_{ext} lower than 10^6
- FPC coupling requirement: a few X 10^6

- V_T=4.0 MV/cavity
- (R_T/Q)=215 Ω/cavity
- $Q_L \cong Q_{ext} = 2*10^6$
- P_{in} (r=0) = 9.3 kW/cavity



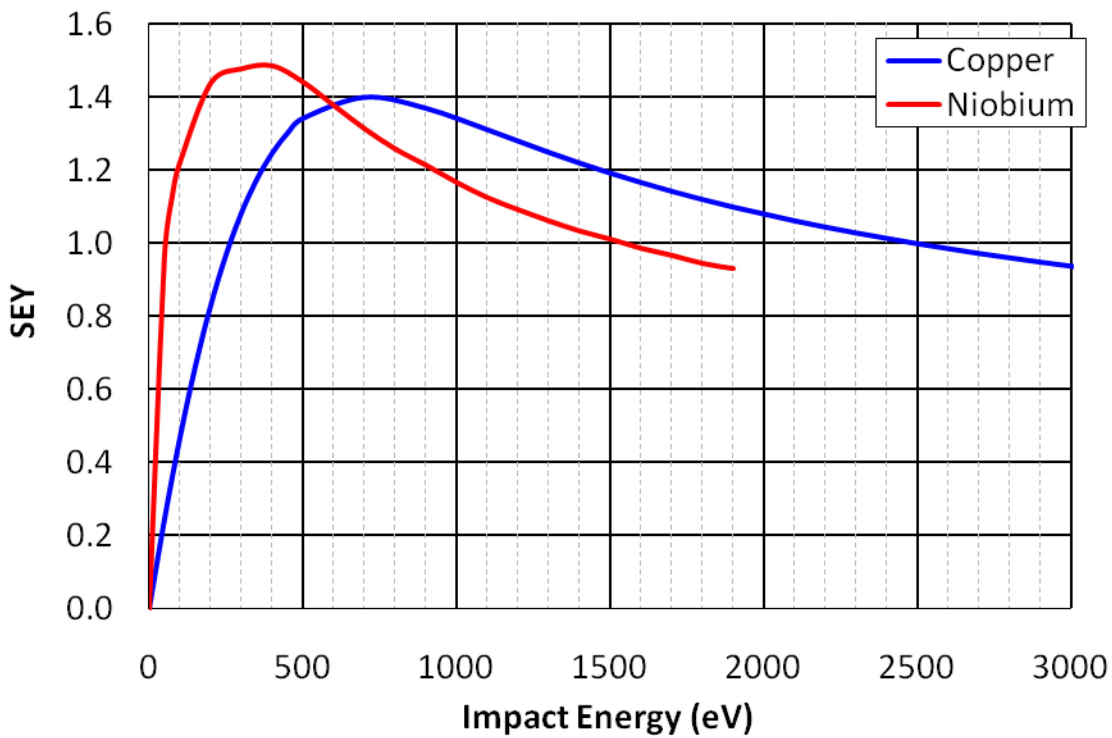
Summary of RF Design

- Cavity optimized
  - Surface B field lowered to <80mT (4 MV $V_{deflect}$)
- LOM and HOM Couplers being optimized
  - Improved damping for “LOM” and HOM-v modes
  - HOM-h coupler effective In damping
  - Damping would satisfy requirement
- FP coupler
  - Design minimized coupling to LOM/HOM-v couplers

Multipacting Analysis

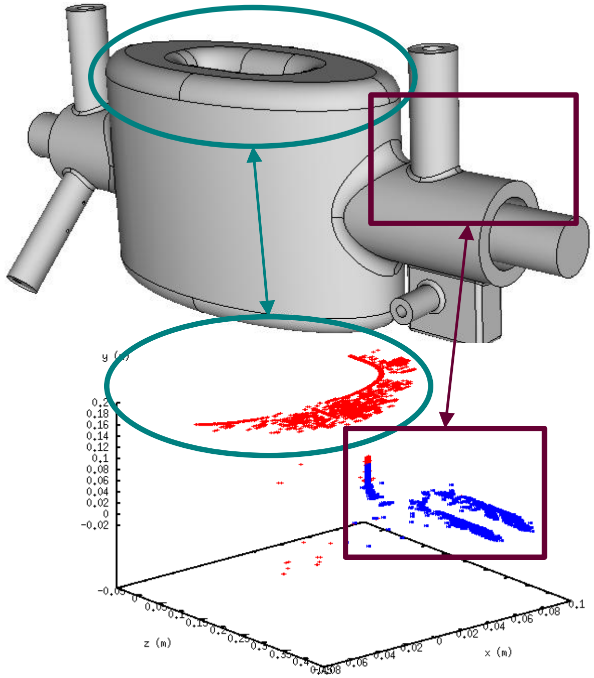
- MP simulation performed for both operating mode and the LOM mode
  - Operating mode: deflecting voltage scanned up to 5MV
  - LOM: beam power scanned up to 10kW (max, on resonance)
- Regions scanned for MP
  - Cavity
  - LOM/HOM-v couplers
  - FPC coupler
  - HOM-h coupler

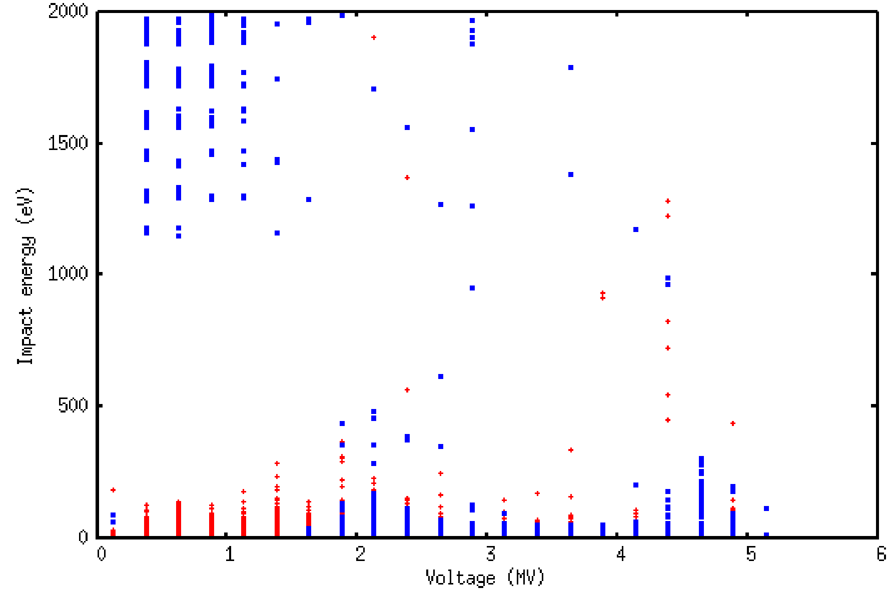
SEY for Niobium and Copper

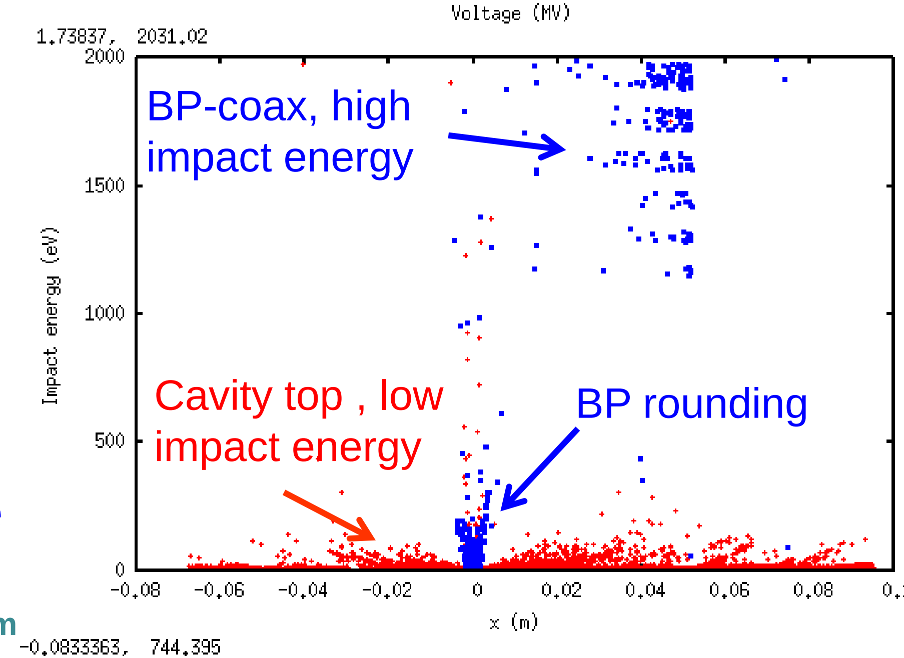


Niobium: cavity body, HOM coupler loop
Copper: Inner conductor of FPC and LOM/VHOM couplers

MP Of Operating Mode (1)

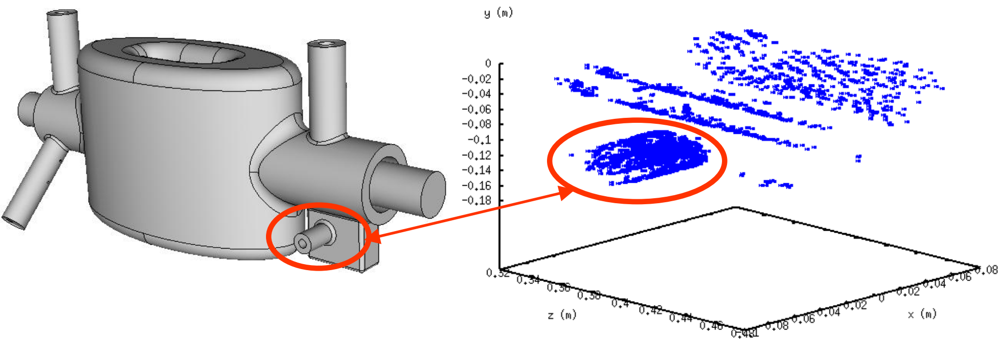


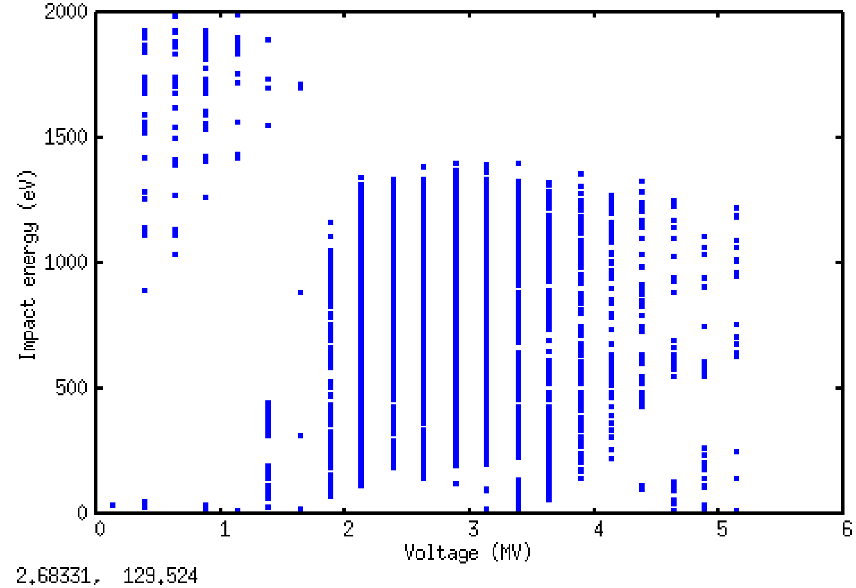




- Resonant trajectories found at different field levels at various locations
- Impact energy of most resonant trajectories not around the SEY peak
- Only low impact energy resonant trajectories at around operating voltage

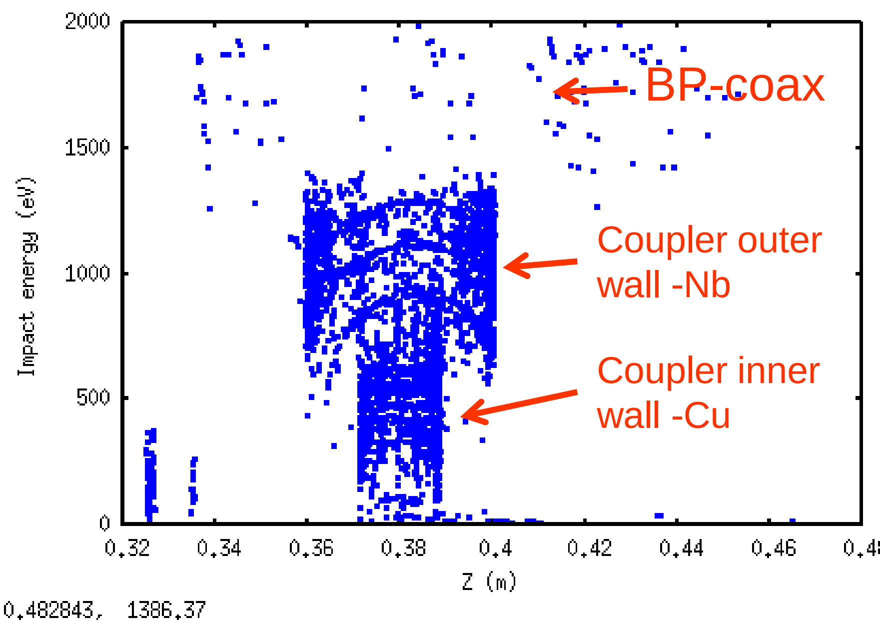
MP of Operating Mode (2) - FPC Coupler



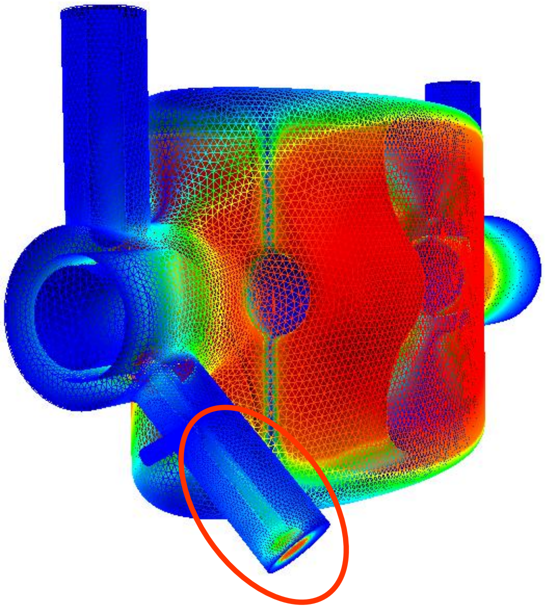


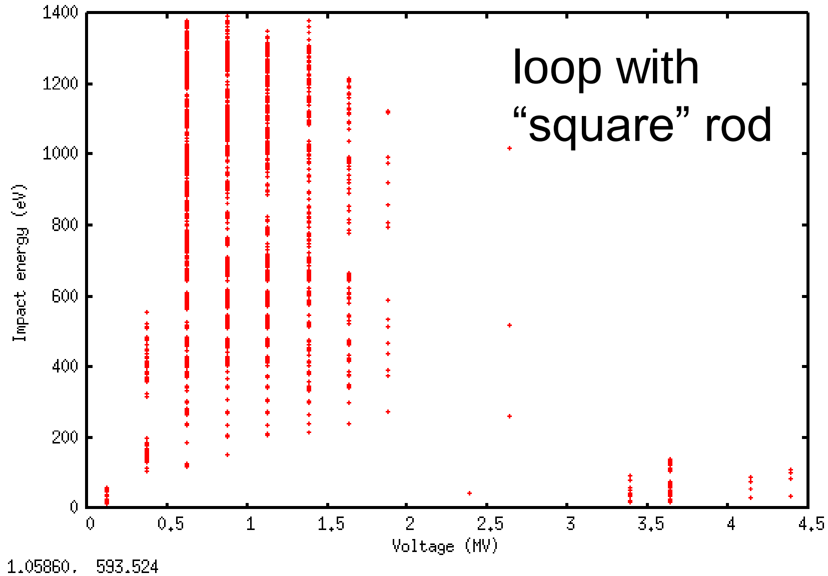
Resonant trajectories in the coax coupler region

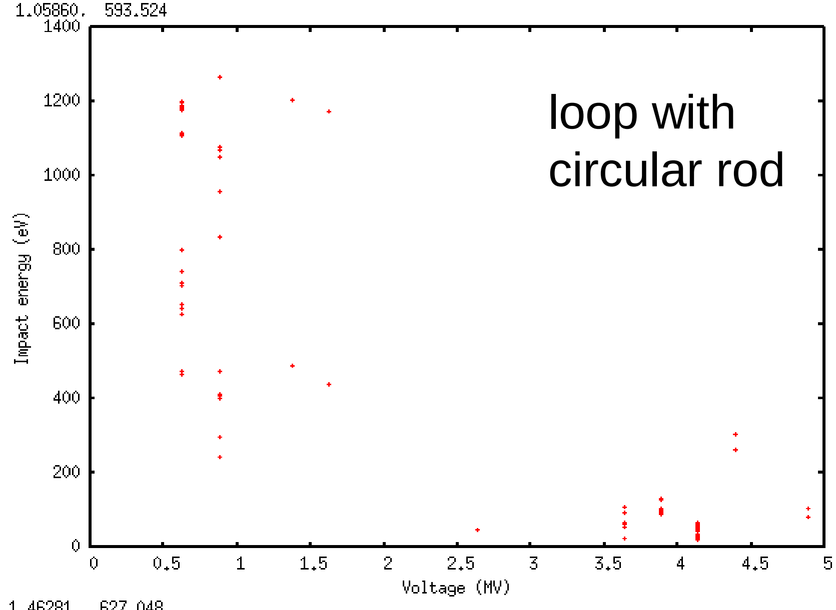
- Impact energy higher on outer surface (Nb) , lower on inner wall (Cu)
- Use coax of different impedance may help to mitigate the problem



MP of Operating mode (3) - HOM Coupler







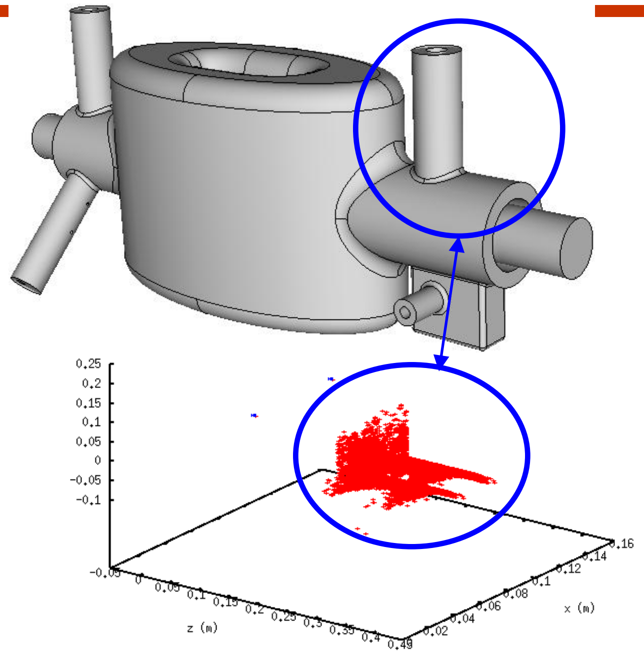
- **“square” rod**

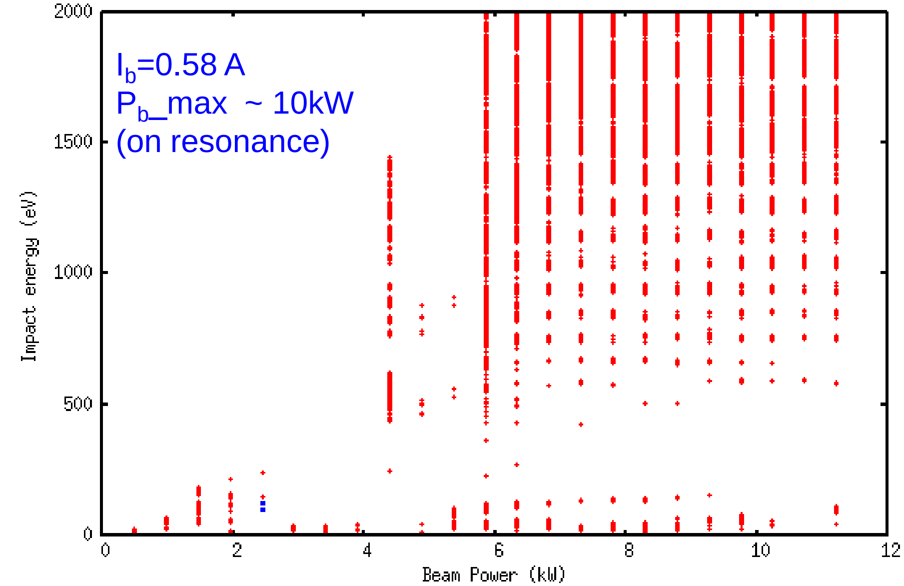
  2-point MP between straight section of the loop and outer cylinder wall

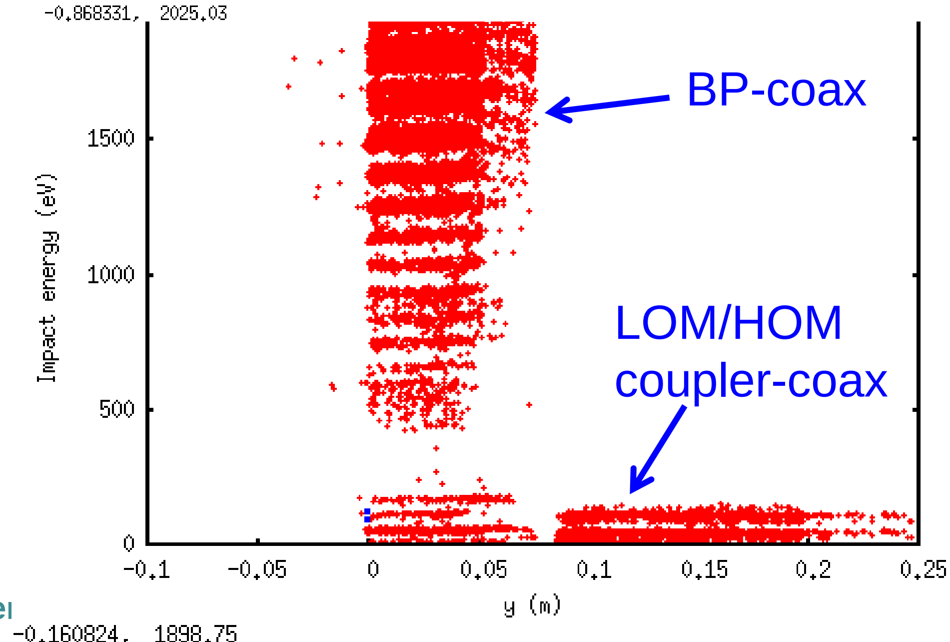
- **Circular rod**

  MP significantly suppressed

MP of LOM Accelerating Mode







- Max beam power ~10 kW
- Resonant trajectories in BP coax above 4 kW beam power, with mostly high impact energy
- Resonant trajectories in coupler coax, with mostly low impact energy

Summery of Multipacting

- Resonant trajectories identified
- Impact energy of most resonant trajectories NOT at the peak of the SEY
- Means to mitigate resonant trajectory conditions being considered

Summary

- 400-MHz HWSR cavity fits both local and global schemes
- Cavity shape optimized to lower surface fields
- LOM/HOM-v/HOM-v couplers being optimized
  - effective in damping
  - current design meets beam instability requirements
- First round of MP analyses performed
  - MP characteristics being analyzed
  - Means to mitigation/improve of MP conditions considered
- **Cavity model provided for engineering studies (AES SBIR)**
- **Further cavity optimization in progress**

Simulation performed using ACE3P suite of codes developed under the support of DOE SciDAC program