UK-Jlab-TechX Designs for the LHC Crab Cavity

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Cavity Design Team

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Jefferson Lab

TECH X

EUCARD funding has still not been started at Lancaster so effort has been limited

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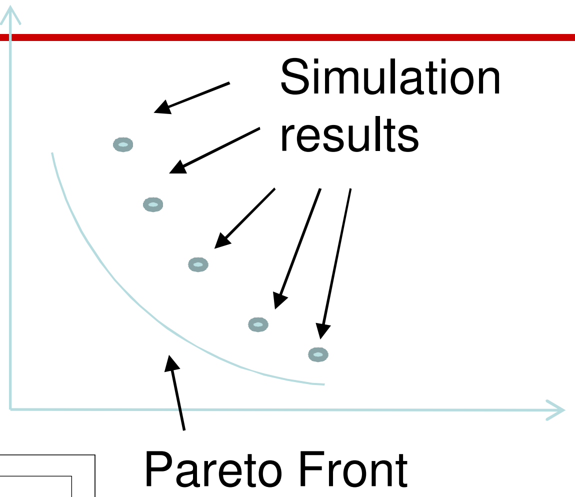
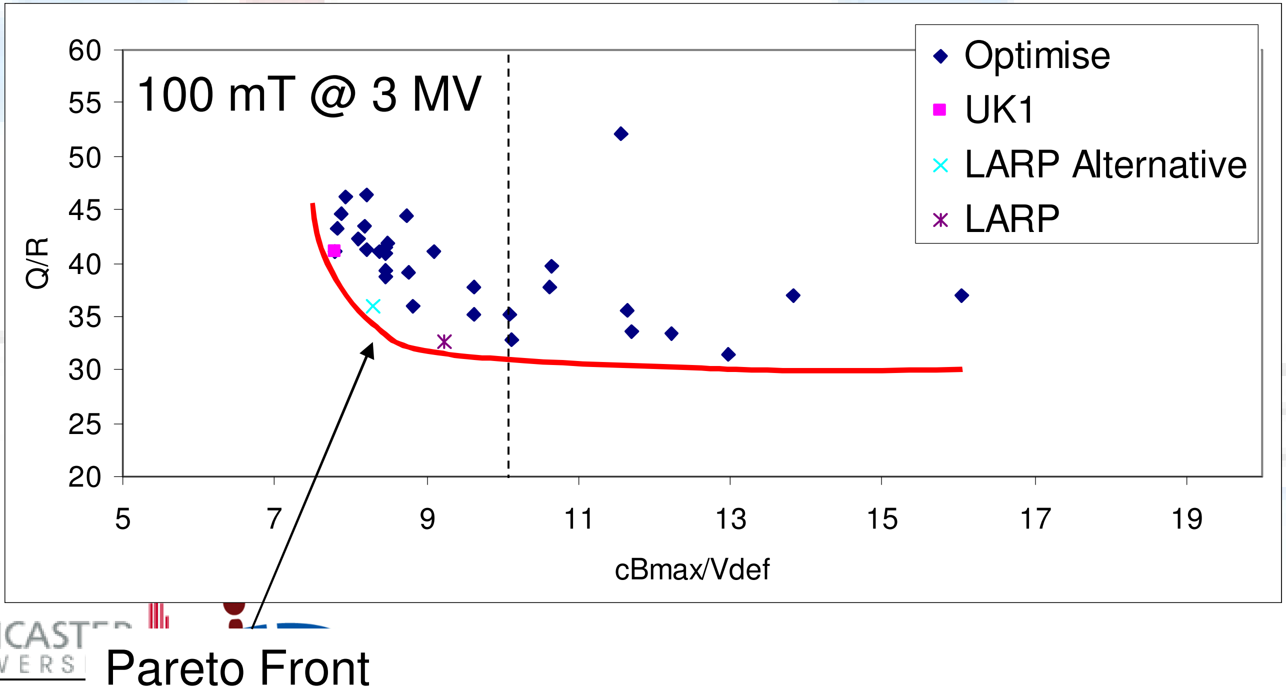
Non-dominated optimisation

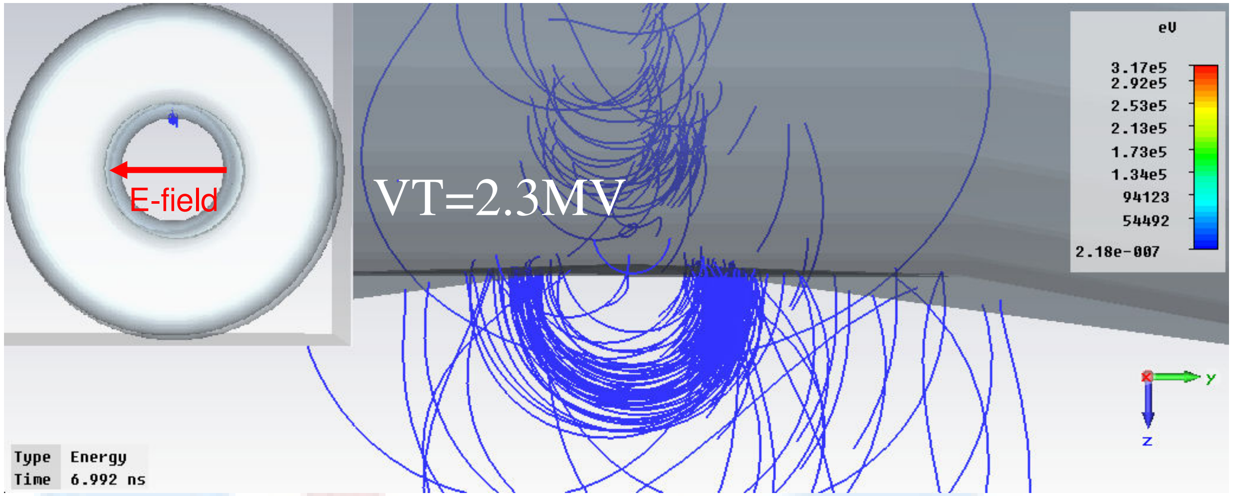
- Optimisation is based on a non-dominated technique where optimal solutions lie on the Pareto front and sub-optimal solutions lie in front of it.

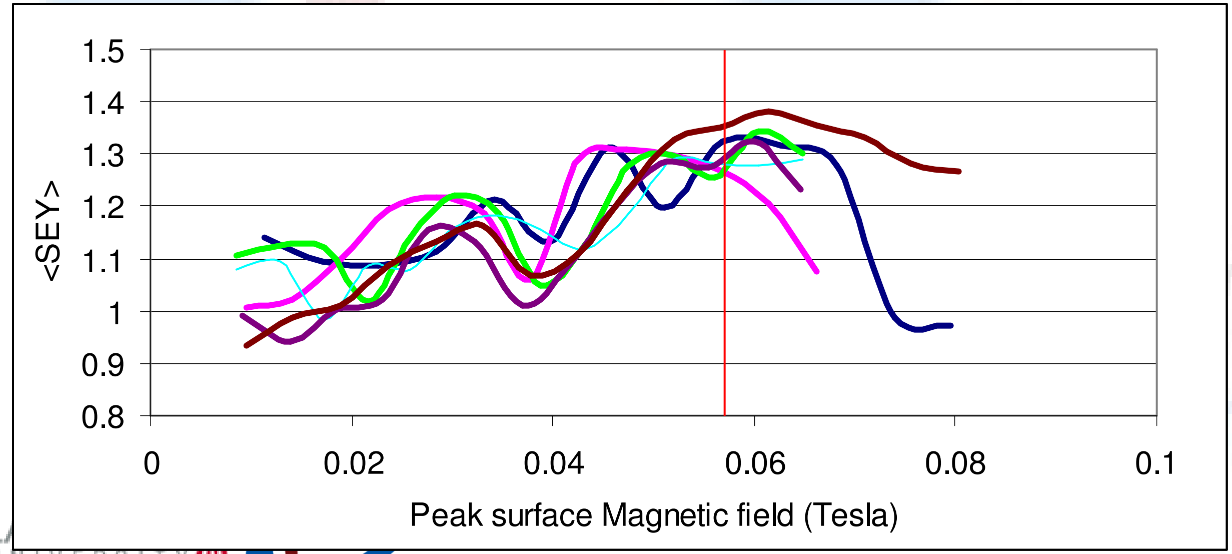




Multipactor studies may change the optimal solutions.

Multipacting



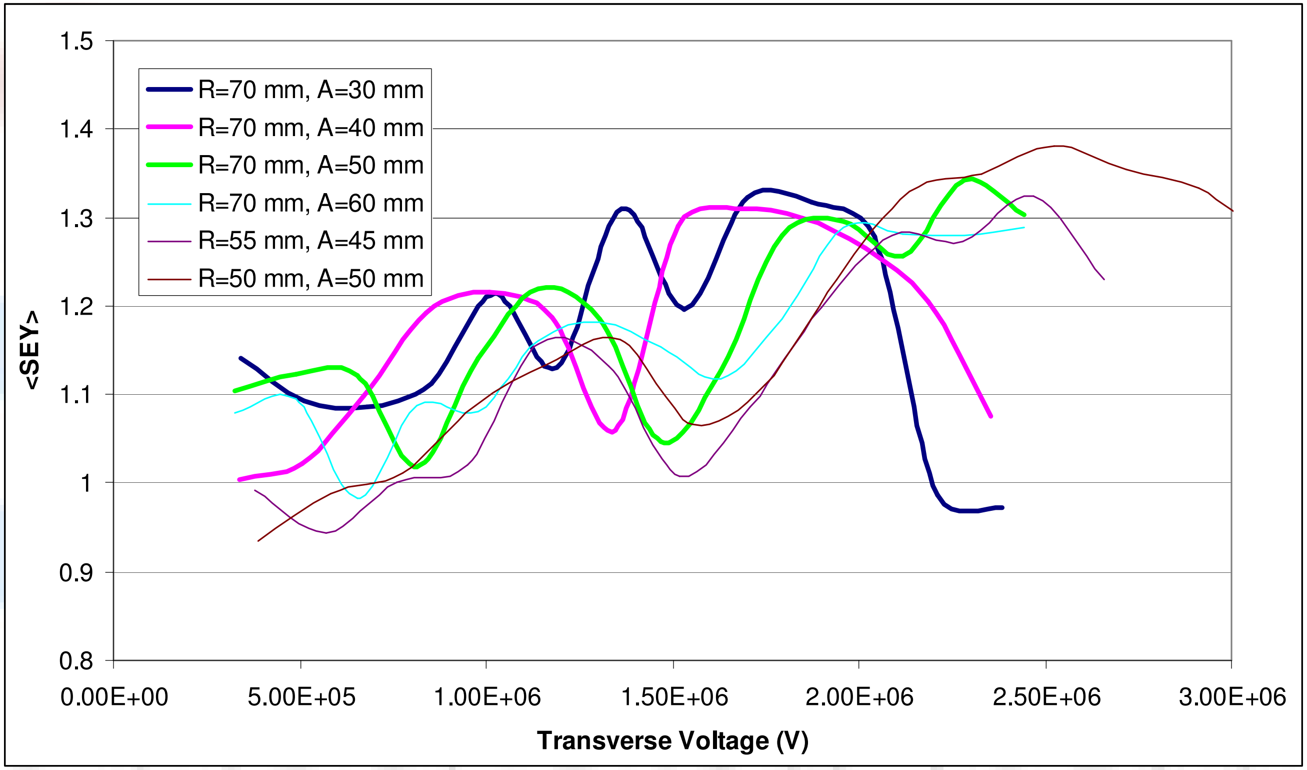


CST-PS simulations clearly show that the multipactor in the iris is directly linked to the cyclotron frequency.

MP always peaks at 57 mT.

Hence low magnetic field structures suppress multipactor.

Multipactor



Hence small iris' and large iris curvature is optimal.

This is in direct contradiction with the SLAC Track 3P results.

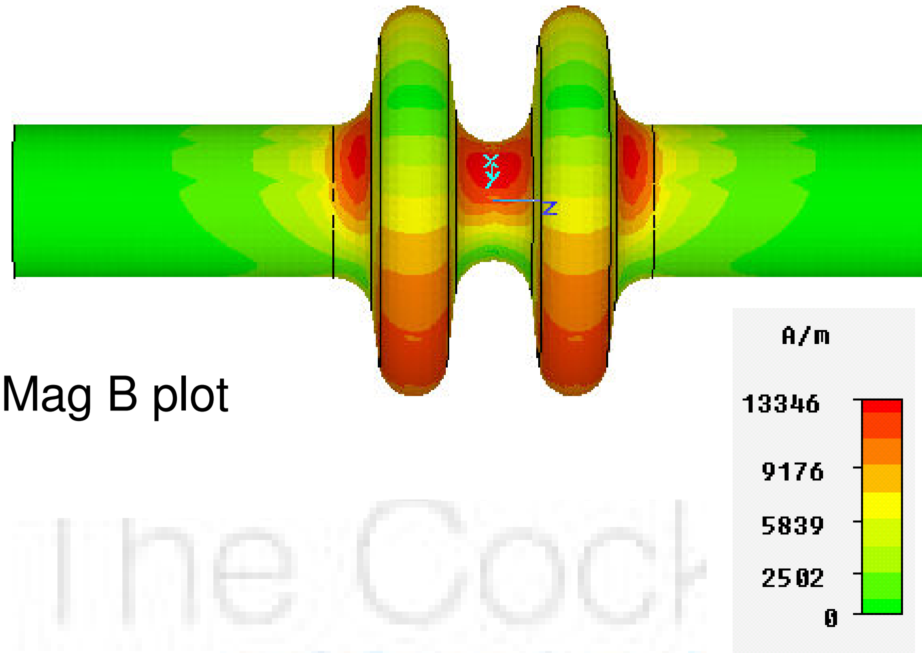
We can achieve 2 MV/cavity with a 70mm iris radius and 50mm curvature.

To achieve 2.5 MV/cavity ~50 mm iris radii are required.

Cavity Shape

Cavity was given a small angle on the wall to simplify acid removal. The angle can be doubled decreasing the equator rounding with little effect on B_{max}

Cavity Dimensions	mm
Cavity Length	187.50
Beampipe Radii	90.00
Iris Curvature	45.00
Iris Radii	70.00
Equator Radii	~230.00
Equator Curvature	40.00



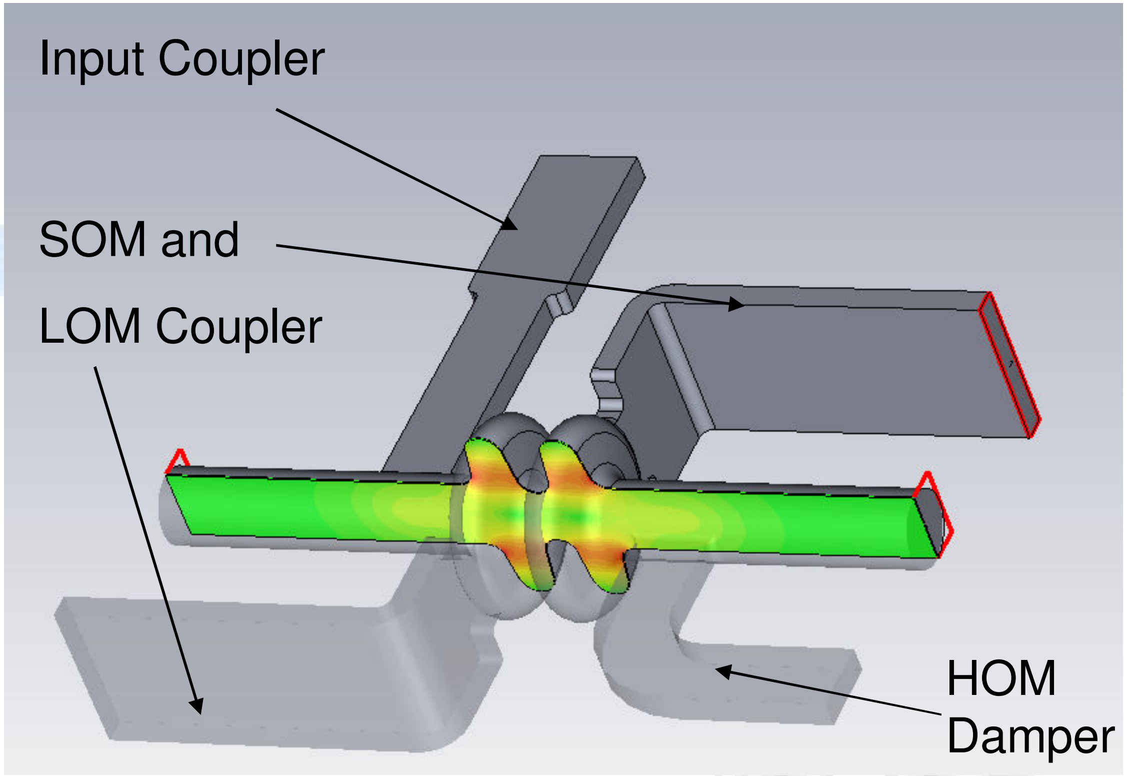
Mag B plot

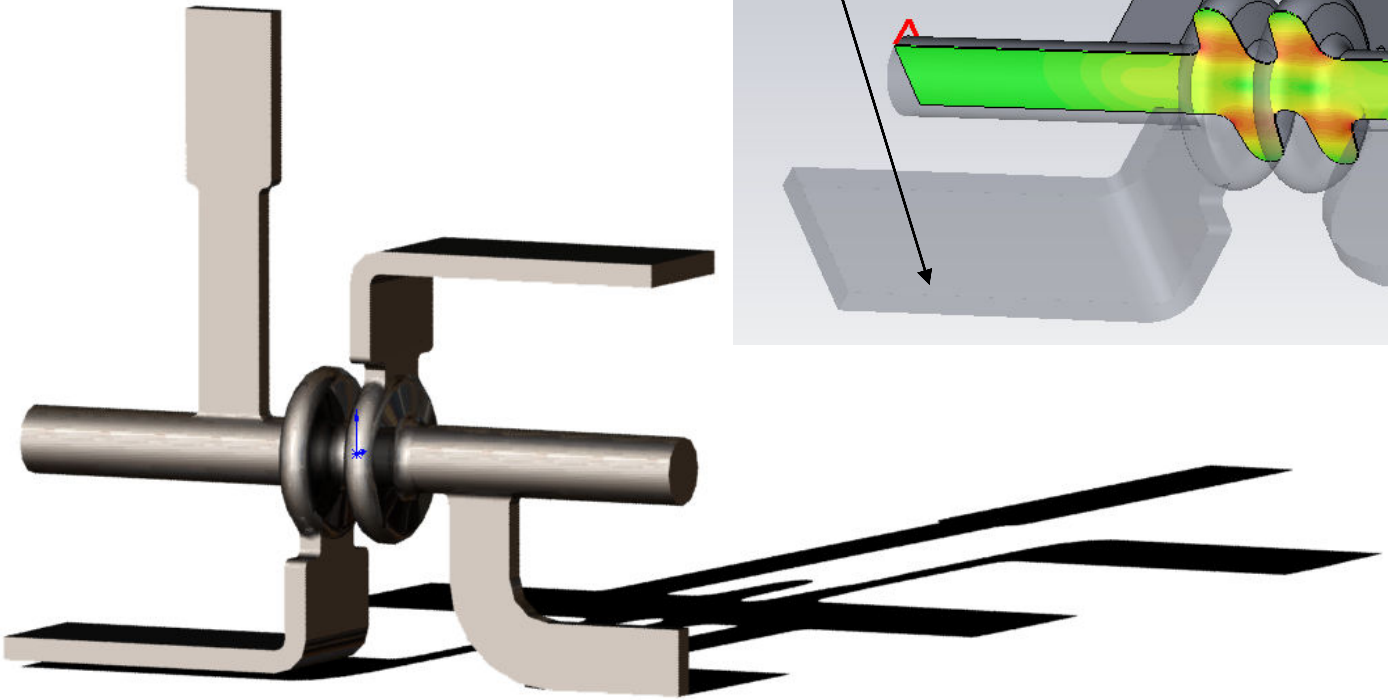
V_T/cB_{max}	0.128	m
V_T/E_{max}	0.102	m
R_T/Q	86.5	Ohms

The cavity is not squashed and relies on the waveguide dampers to polarise the cavity.

On-Cell Damping LHC

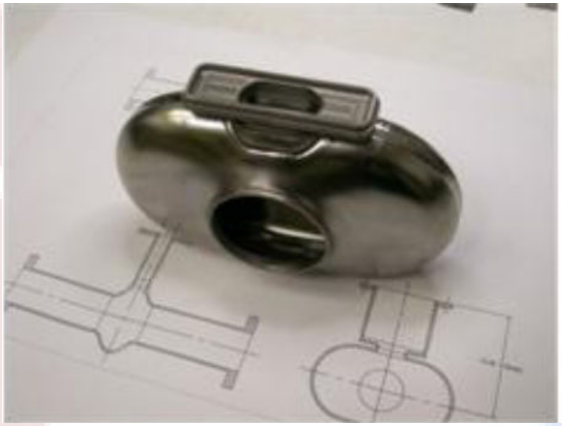
Waveguides are directly coupled to the cavities to provide significant damping. The coupling slots are placed at the field nulls of the crabbing mode to avoid high fields.

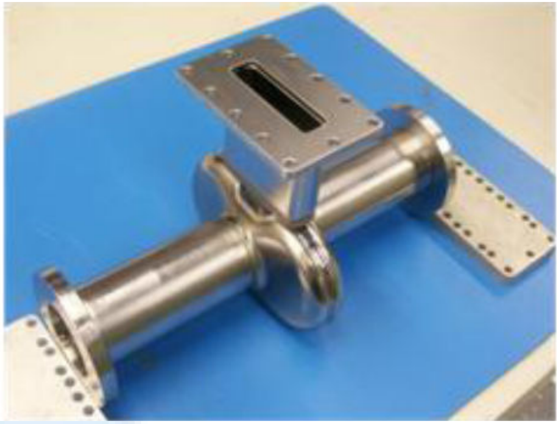




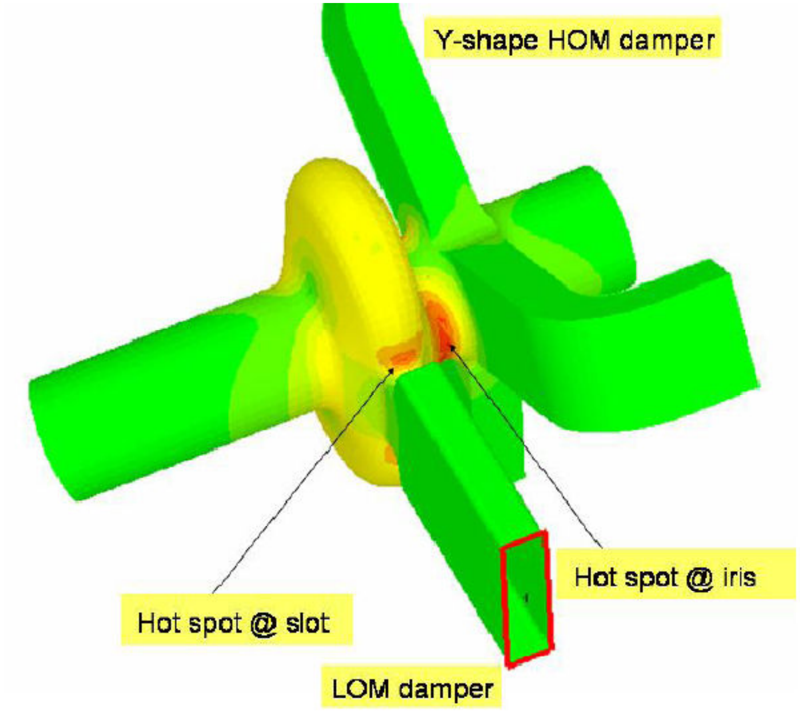
Vertical couplers only to meet the tight horizontal space requirements.

On-Cell damping





- A prototype of cavity utilising this scheme has been developed at TJNAF, using the ALS crab cavity design.
- The first ANL on-cell damper structure was made directly by machining the equators' slot to match a "saddle" adapter in a 3-D contour.
- Three pieces were EB-welded both from the outside and inside through isises.
- A second adapter joining the "saddle" and waveguide was made for the sequenced EB-welds.



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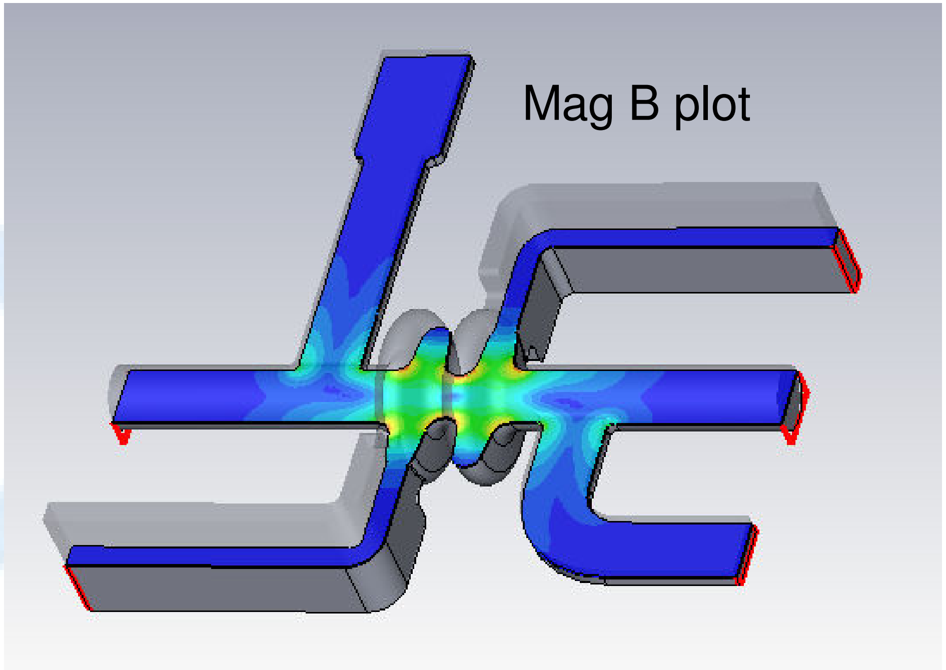
Crabbing Mode

The crabbing mode is unaffected by the waveguide dampers in the equator.

This design has a lower peak E field (27.8 MV/m) than the SLAC design and a peak B field of almost half the BNL design (68.8 mT) at 6.6 MV/m. It does however have a lower R/Q.

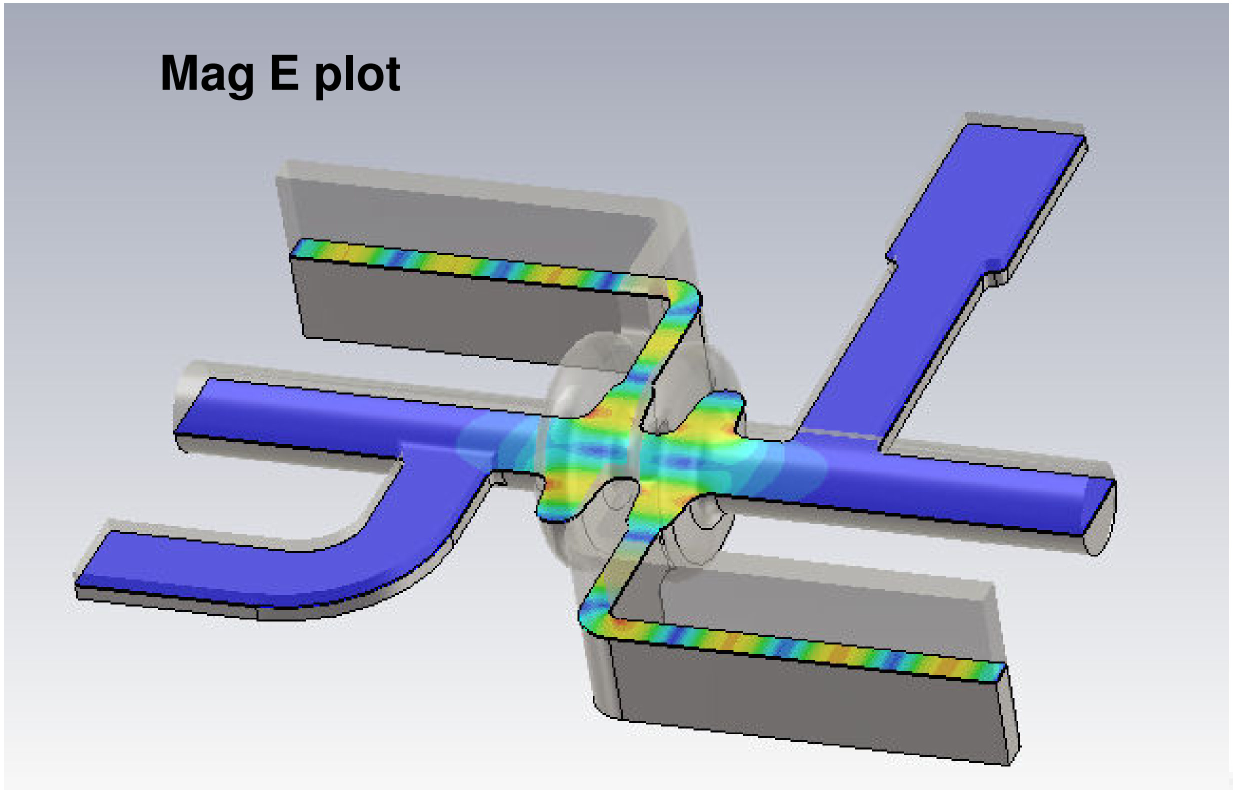


V_T is in volts

freq (GHz)	Q	R_T/Q	V_T/cB_{max}	V_T/E_{max}
0.800	3×10^5	84	0.12	0.089

0 mode is ~5.5 MHz away and has a Q of 3×10^5. This may be a problem.

SOM



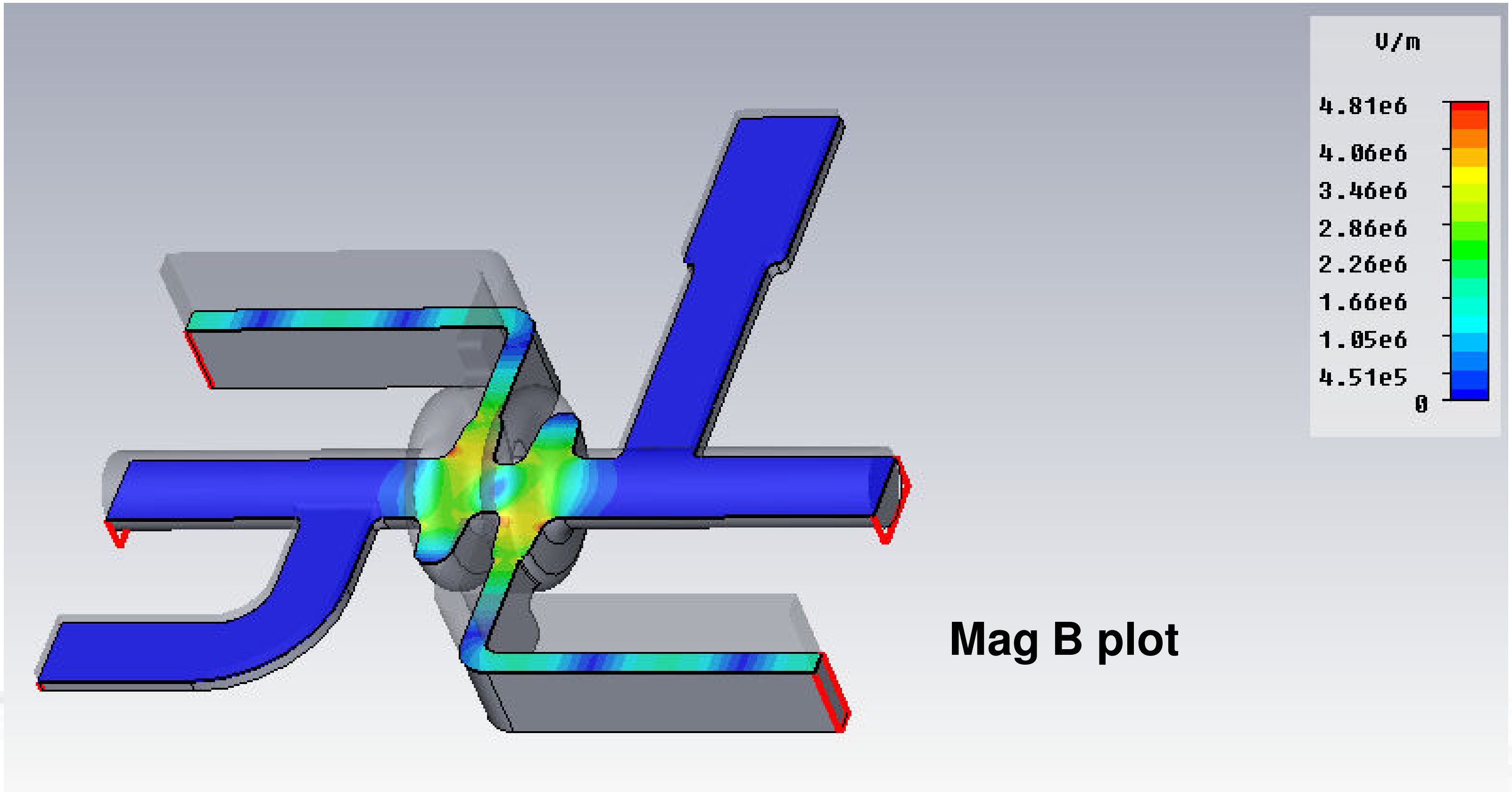
The SOM is at a frequency ~42 MHz below the crabbing mode and has the same R/Q.

The mode in each cell is slightly offset but in equal and opposite directions.

Either a coax-waveguide adapter or a HOM load can be used for damping.

freq (GHz)	Q
0.758	33
0.755	30

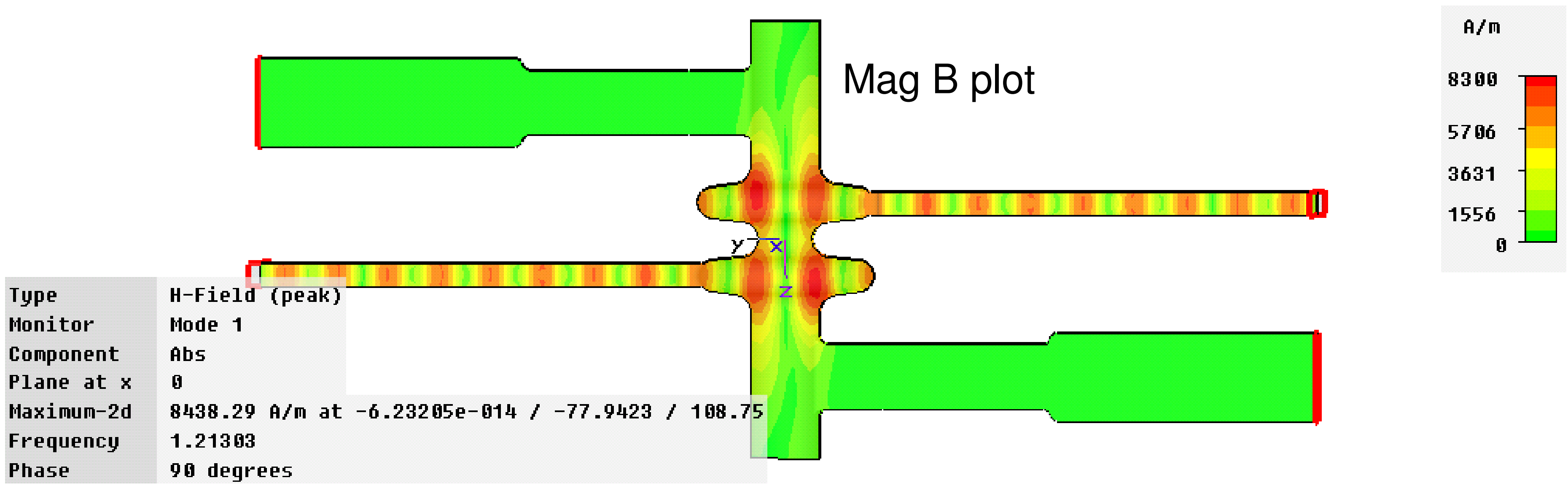
LOM



Mag B plot

f (GHz)	Q	R/Q(0)
0.573	78	20
0.575	79	132

HOMs (monopole)



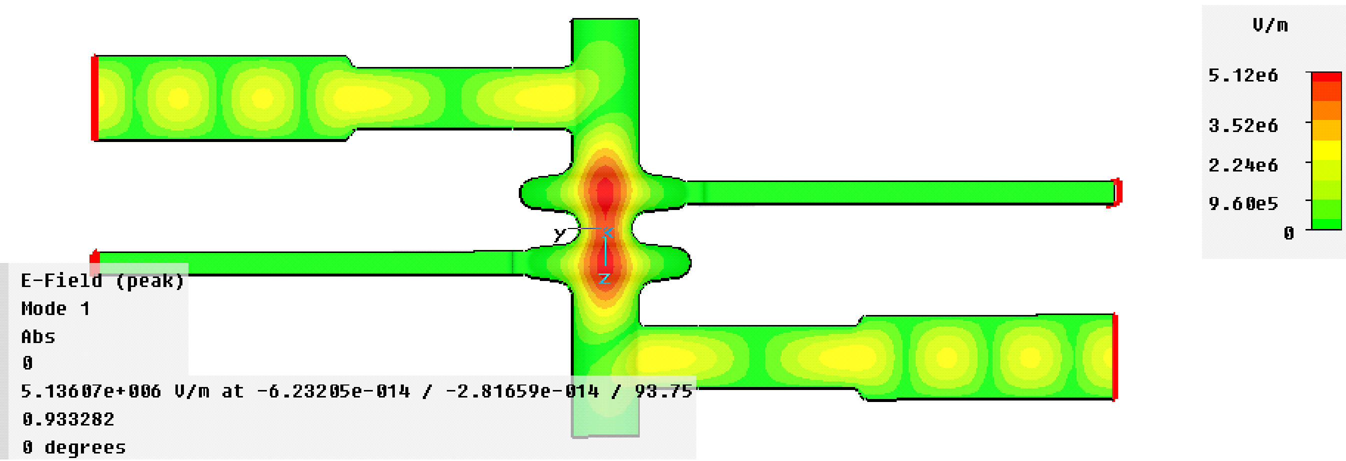
f (GHz)	Q	R/Q(0)
1.214	6.066	1.44233
1.218	1078	1.30734

One of the monopole HOMs has a relatively high Q but it has a small R/Q.

HOMs Dipole

- Horizontal

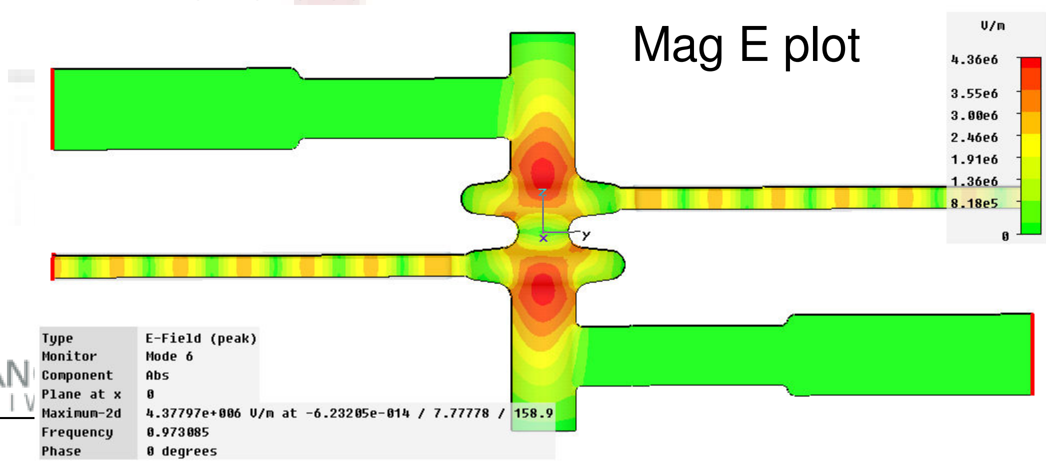
Mag E plot



freq (GHz)	Q
0.932	149
0.989	296

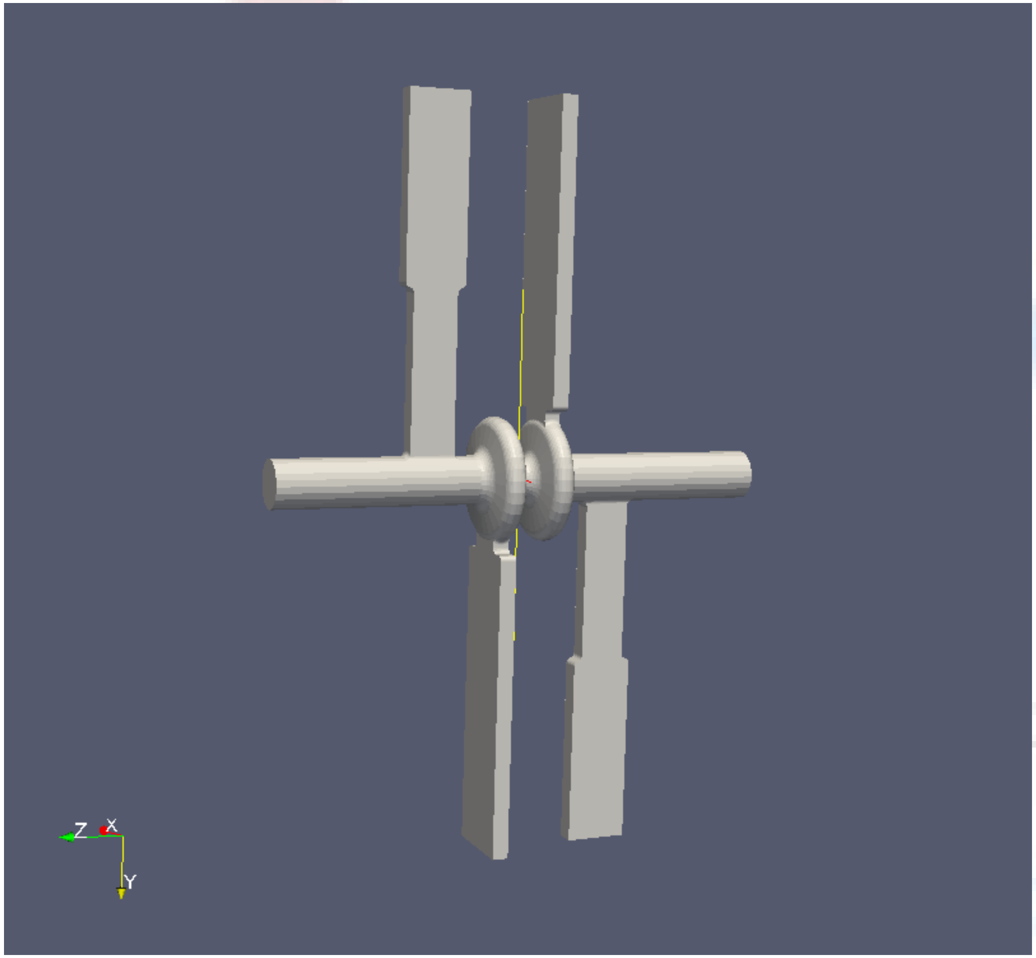
- Vertical

Mag E plot



freq (GHz)	Q
0.921	969
0.9663	90

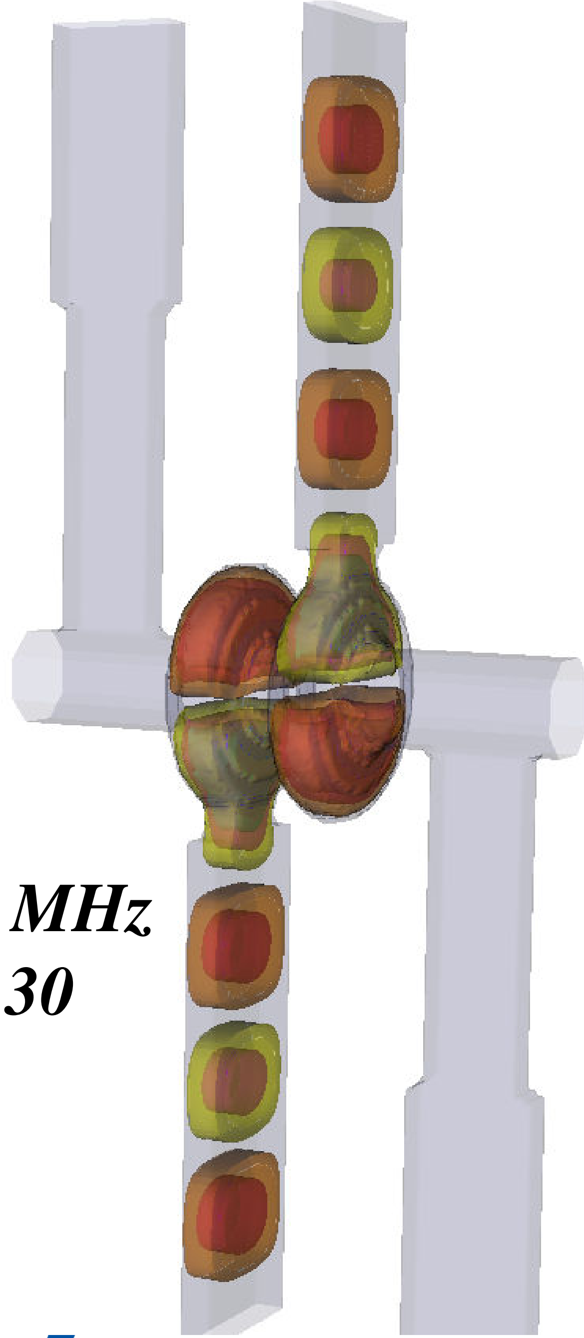
Modelling in VORPAL



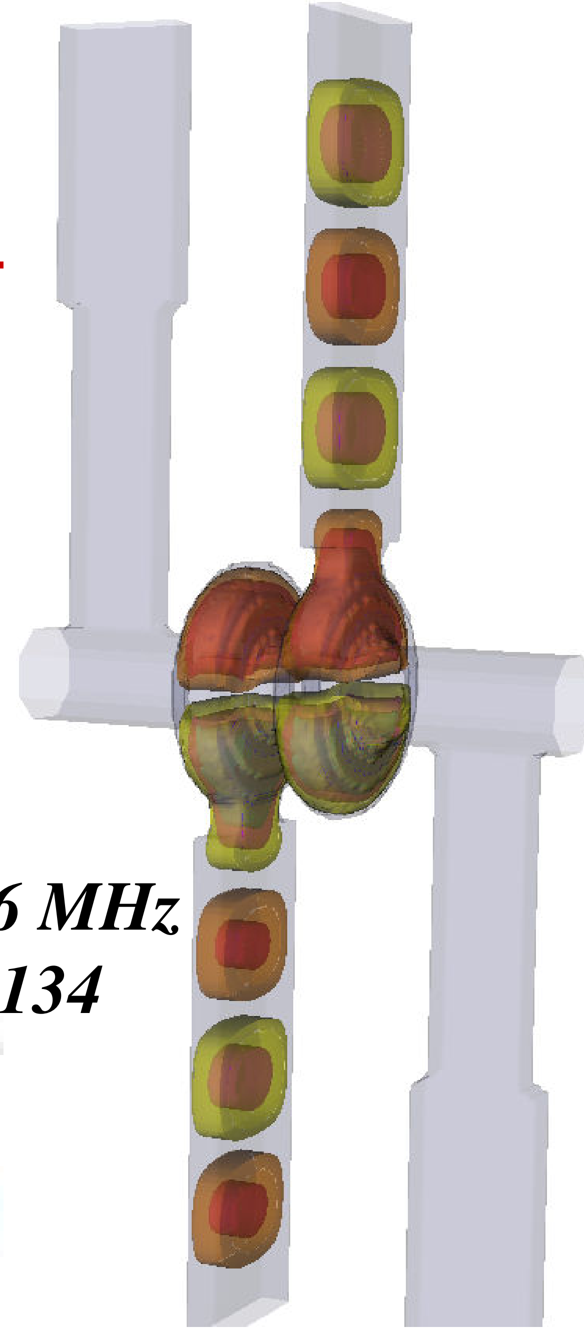
We are also modelling the cavity in VORPAL.

This will be used to verify the design at high accuracy and for multipactor simulations.

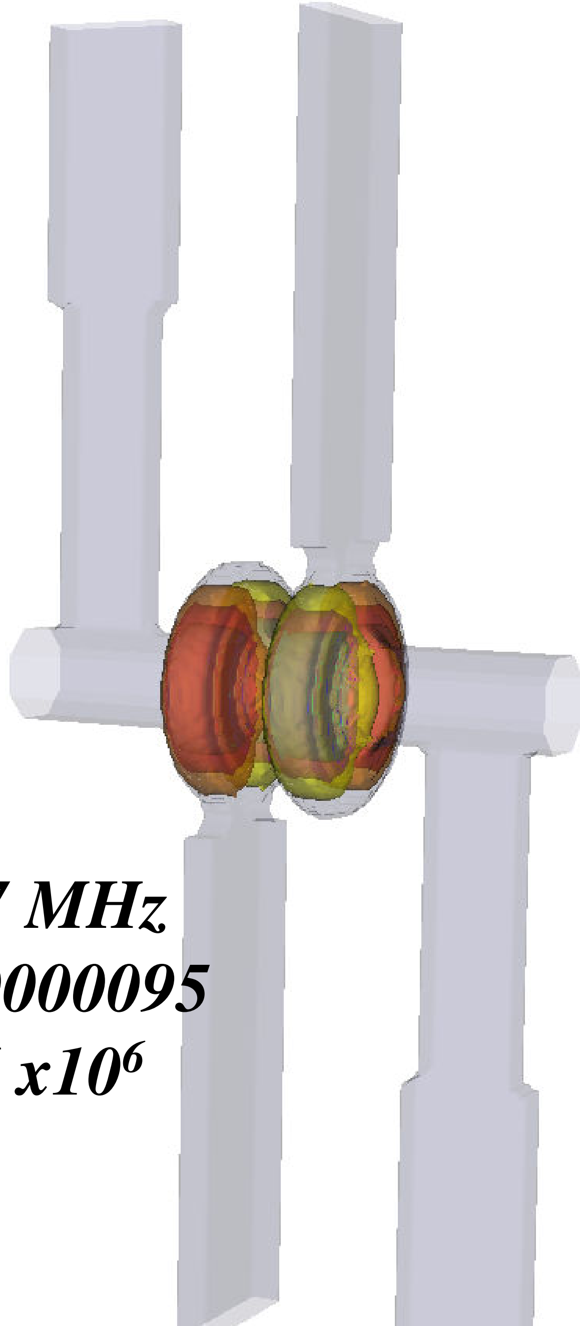
PML's on all boundaries
dx = 0.005 [m]
~2000 processors on Franklin at NERSC



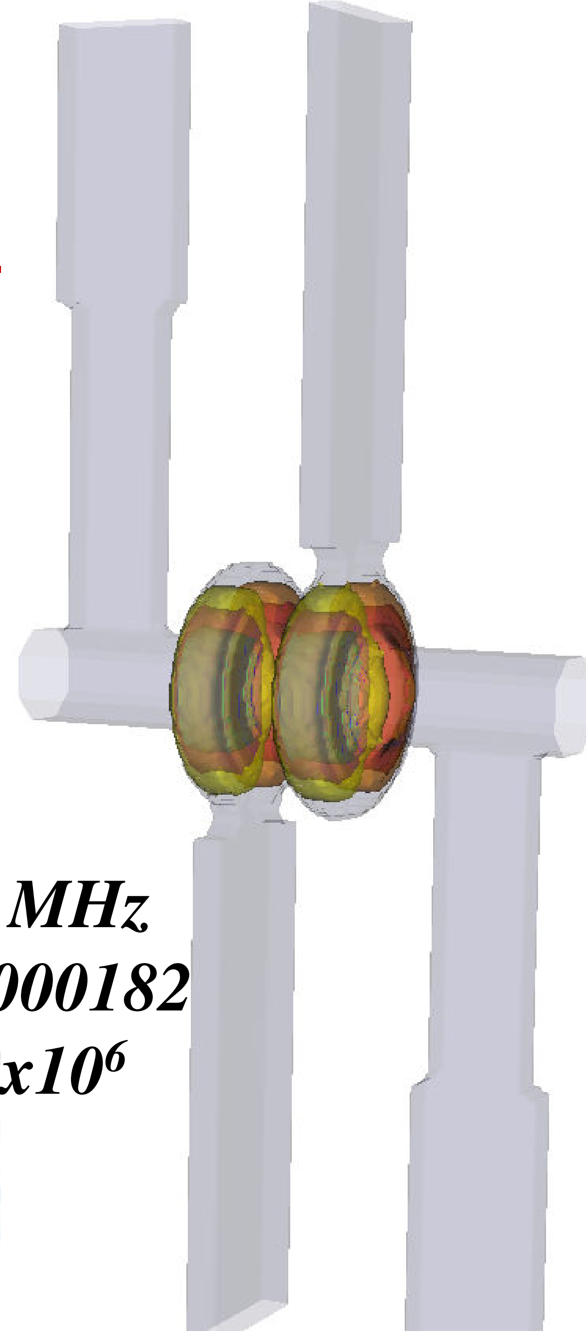
f = 778.38 MHz
1/Q = 0.0130
Q = 76.9



f = 783.06 MHz
1/Q = 0.0134
Q = 74.6



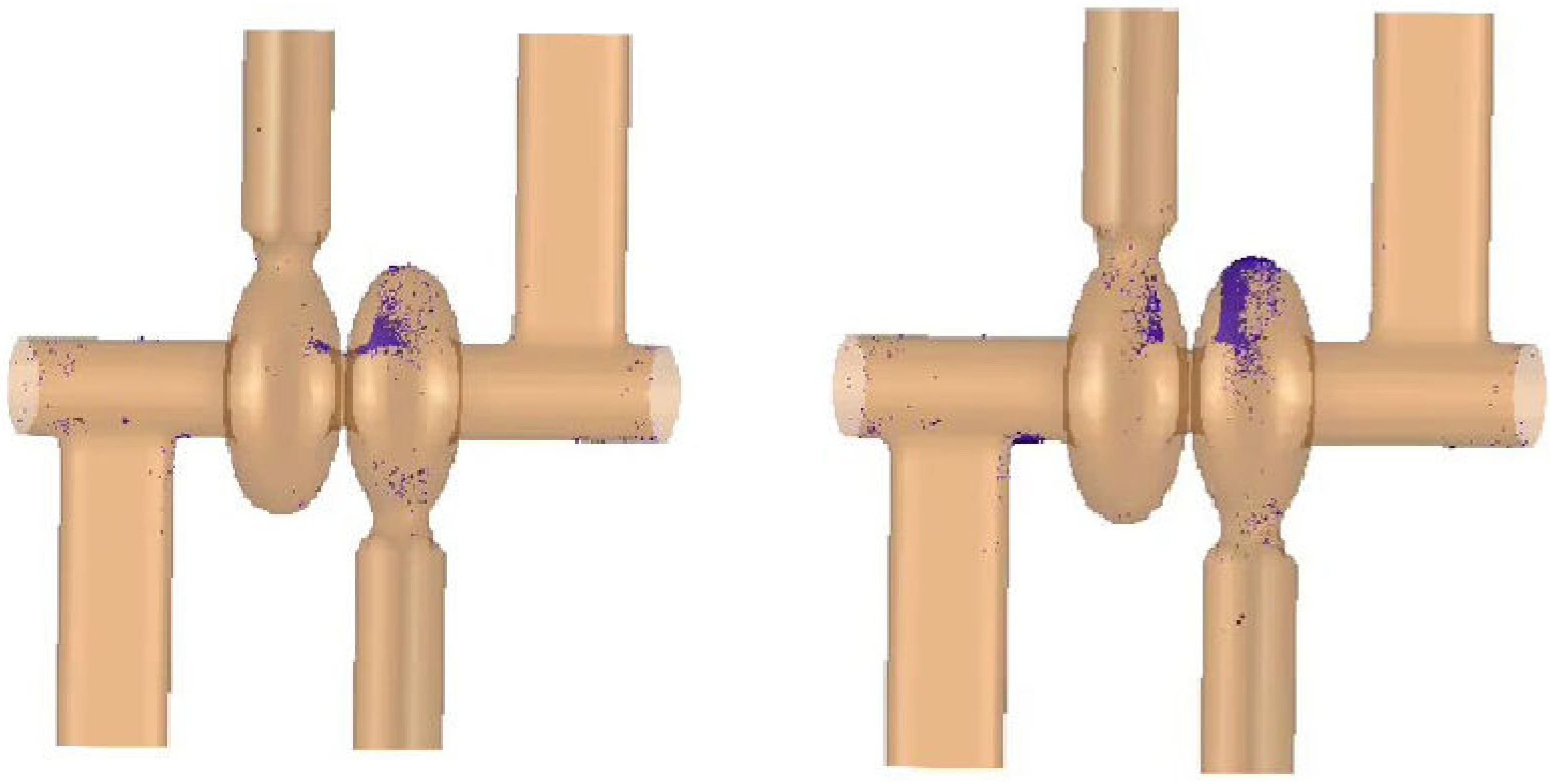
f = 804.597 MHz
$1/Q$ = 0.00000095
$Q = 1.0526 \times 10^6$



f = 808.796 MHz
$1/Q$ = 0.00000182
$Q = 0.5495 \times 10^6$

Prelimanary simulations show possible multipacting in UK crab design

- E_{peak} ~10 MV/m



Multipacting is limited to the iris.

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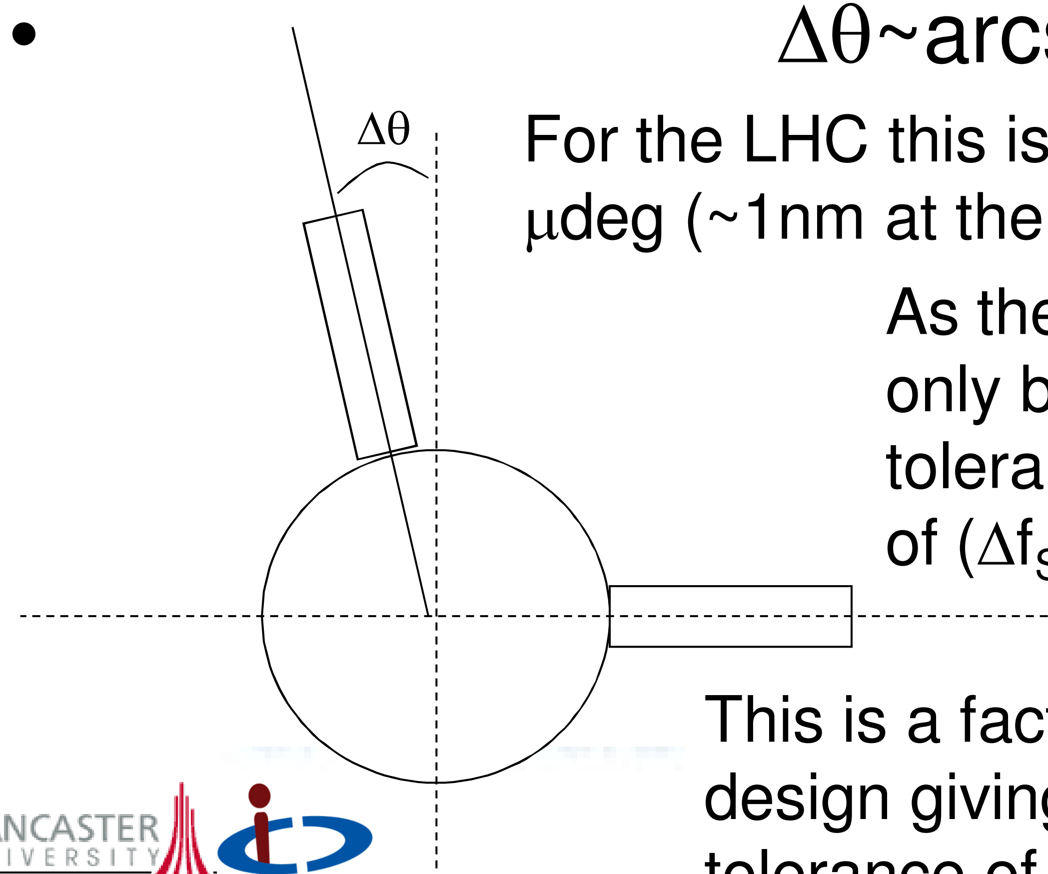
SOM Tolerances

- It is known that for polarised crab cavities the SOM coupler alignment tolerance is given by
- $$\Delta\theta \sim \arcsin(Q_{SOM}/Q_{in})^2$$



For the LHC this is a tolerance of 0.6 μdeg (~1nm at the tip)!!!!!!!

As the UK cavity is polarised only by the SOM coupler this tolerance is eased by a factor of $(\Delta f_{SOM}/\Delta f_{manufacturing})^2$

This is a factor of ~300 for the current design giving a more manageable tolerance of 0.2 mrad

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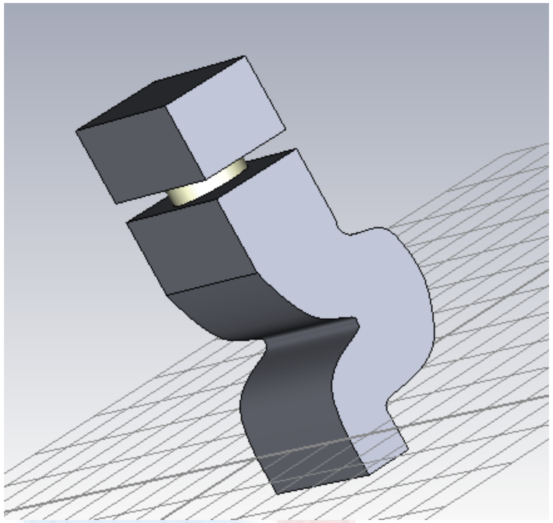
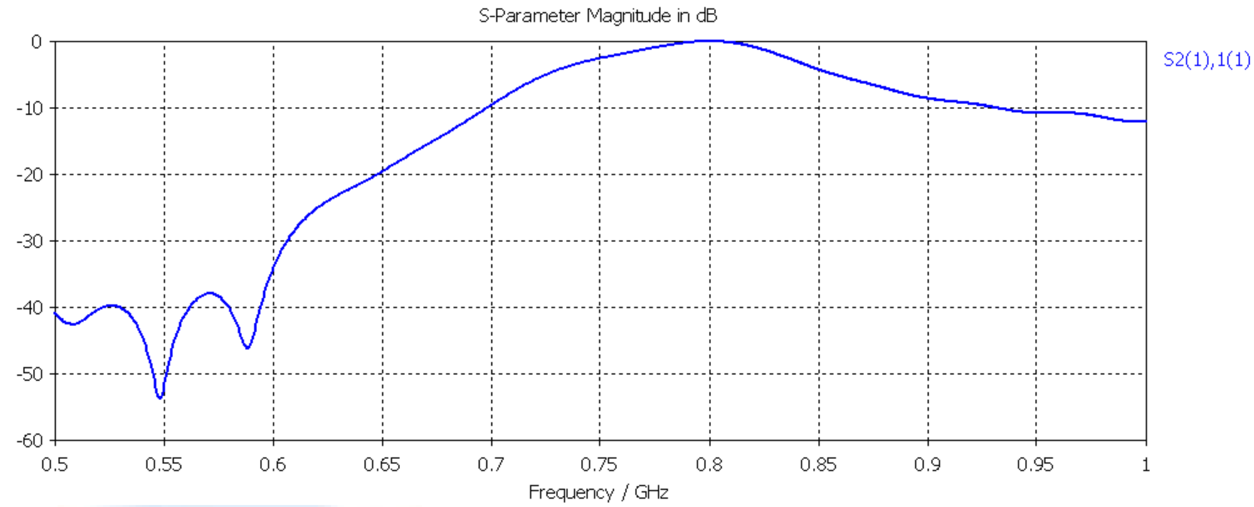
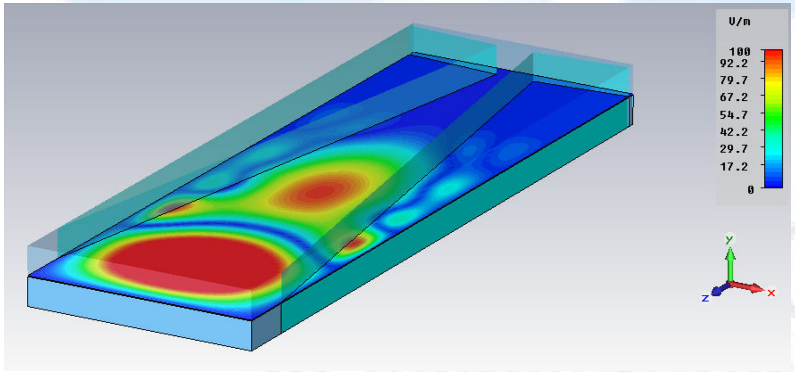
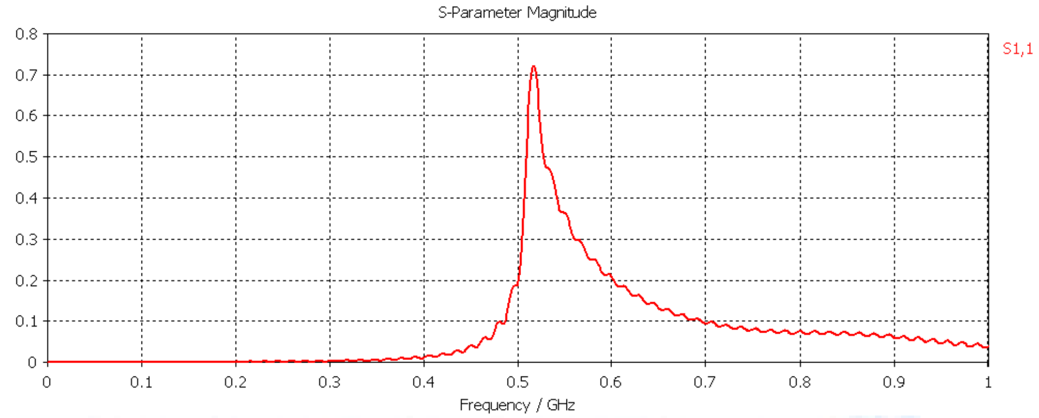
Components









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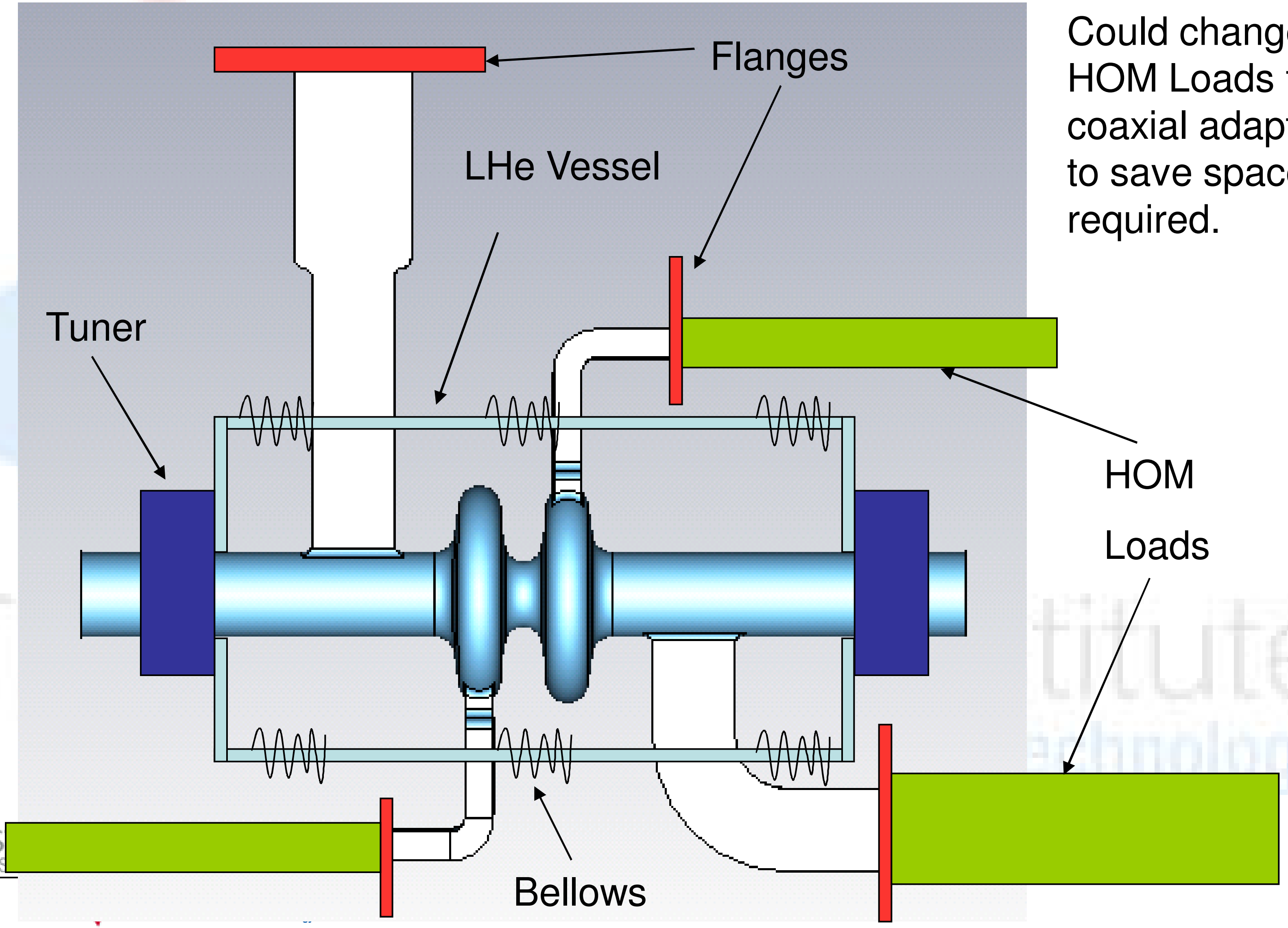
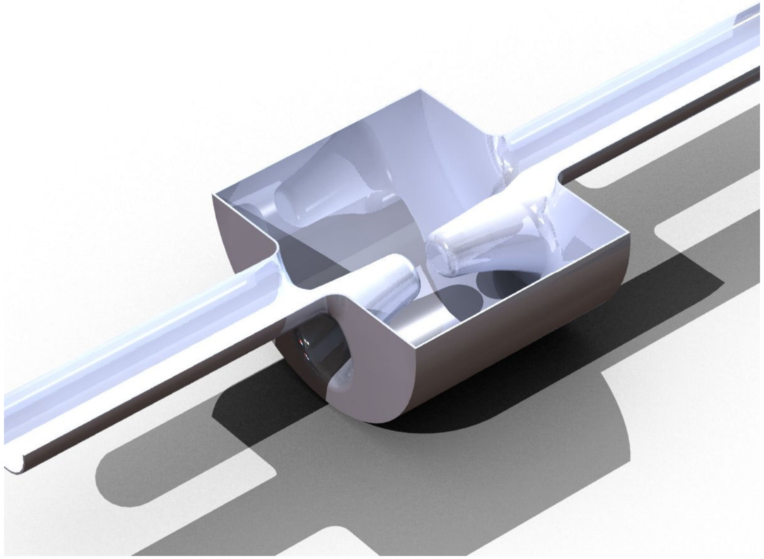
LHe Vessel Conceptual Design



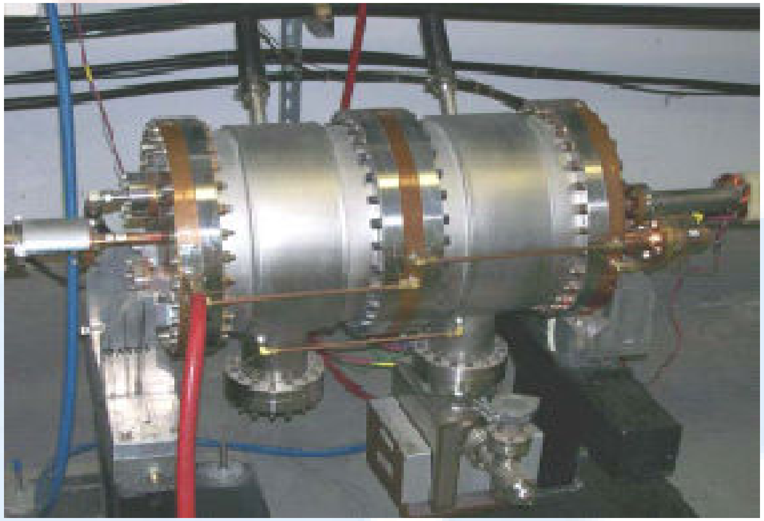
Could change HOM Loads for coaxial adapters to save space if required.

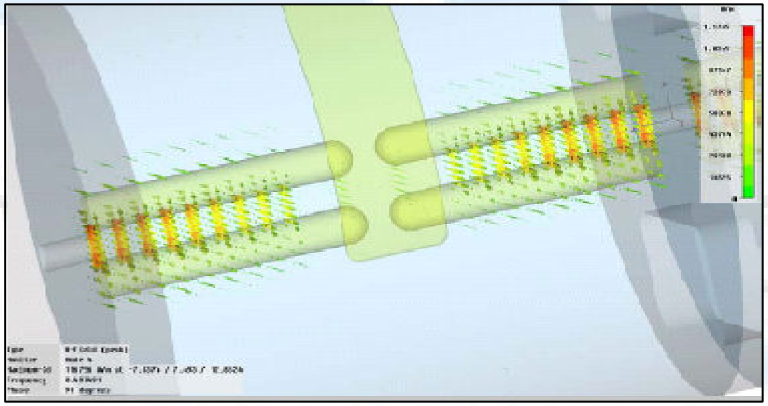
Cavity Prototype

- UK have some funding for a cavity prototype.
- UK and Jlab have significant expertise in cavity measurements and verification.
- Beadpull and wire tests could be performed, as well as coupler verification and possibly even microphonic studies.
- The funding is likely to stretch to a Niobium cavity.
- It is also undecided if the elliptical or compact cavity should be constructed. Will likely depend on results of the down select of elliptical cavities.



Initial Studies for a Compact CC





- CEBAF separator cavity is:
  - 499 MHz,
  - 2-cell, 8 rods
  - ~λ long
  - ~0.3 m diameter,
  - can produce 600kV deflecting voltage (on crest) with 1.5kW input RF power.
- Q_{cu} is only ~5000 (structure wise), the stainless steel cylinder only takes less than 5% of total loss.
- The maximum surface magnetic field at the rod ends is ~8.2 mT.
- Water cooling needed on the rods.
- If Nb used for this type of cavity, the $V_{\perp}$ is ≈ KEKB CC.
- Microphonics and fabrication issues to be resolved.

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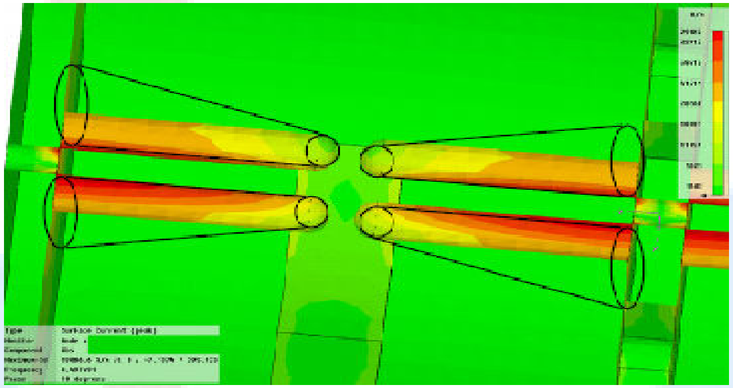
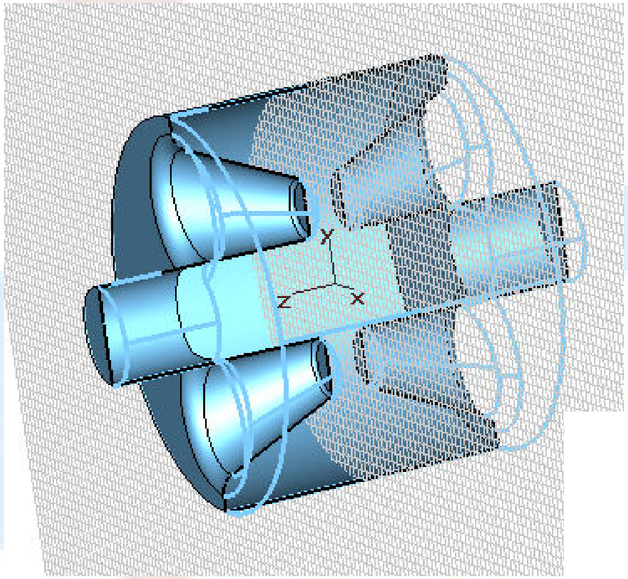
JLab Rod Cavity (SRF)



- **There are both magnetic and electric fields providing deflecting kick, $E_{\perp} \approx B_{\perp}$.**
- **The cavity tuner is in low field region. No field enhancement there.**
- **As rod separation increases, the B_x and E_y fields drop quickly.**

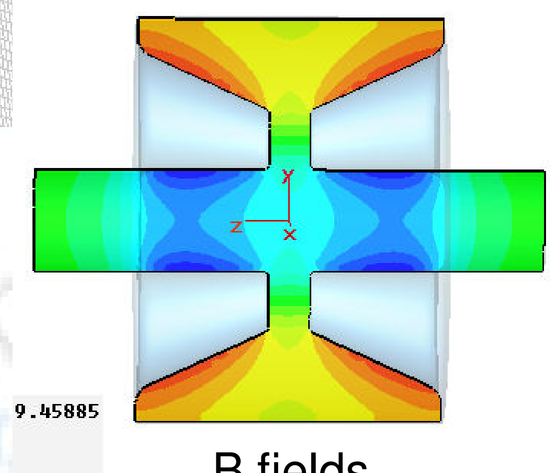
- Use “π” mode for separating three beams in CEBAF.
- Can a SRF version be made to work?
- Need to reduce the surface magnetic field at the rod ends.
- Need high B/E field near the beam path.
- Using cone shape electrodes can certainly reduce rod vibration and microphonics.
- Since there is a low loss on the cylinder can:
  – could make cavity cylinder in low RRR Nb, with rods in high RRR Nb?

Initial Modified 2-Rod Design

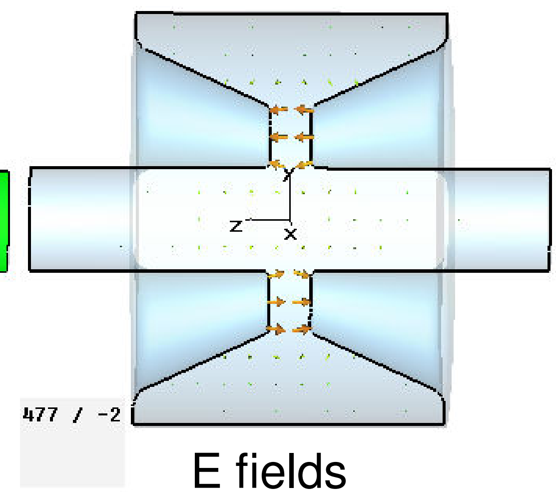


- Modification of existing CEBAF 2-rod separator cavity (collaboration with H Wang at JLab):
  - Has a 10 cm diameter beam-pipe,
  - Has 40 cm diameter for both frequencies.

- At 400 MHz, and $V_\perp$ = 3 MV:
  - single cell (length = 30 cm)
  - R/Q = 700 Ohms
  - Emax = 90 MV/m
  - Bmax = 120 mT



B fields



E fields

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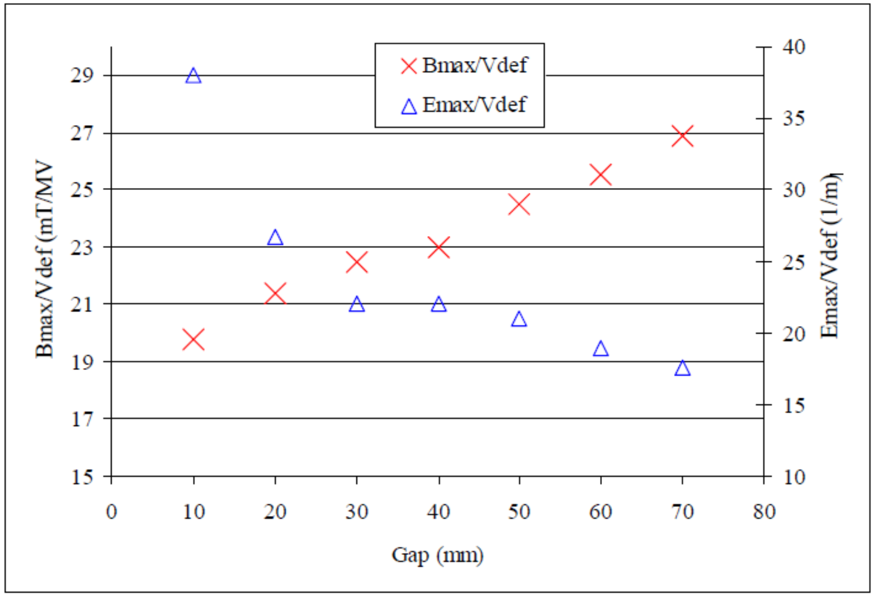
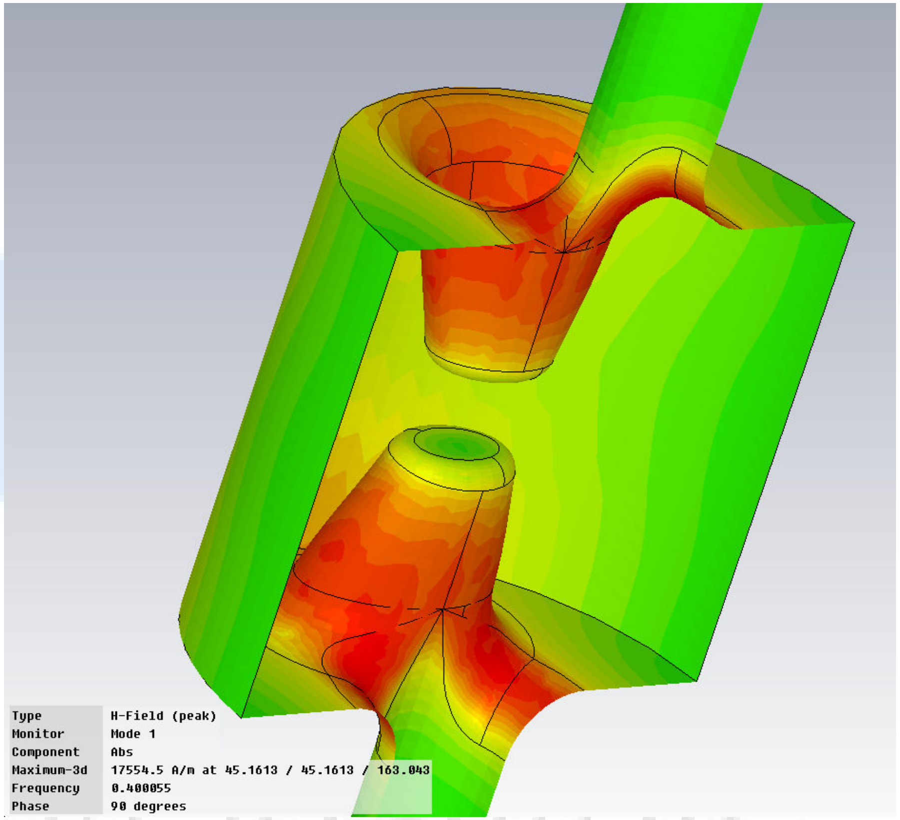
Optimisation of cavity

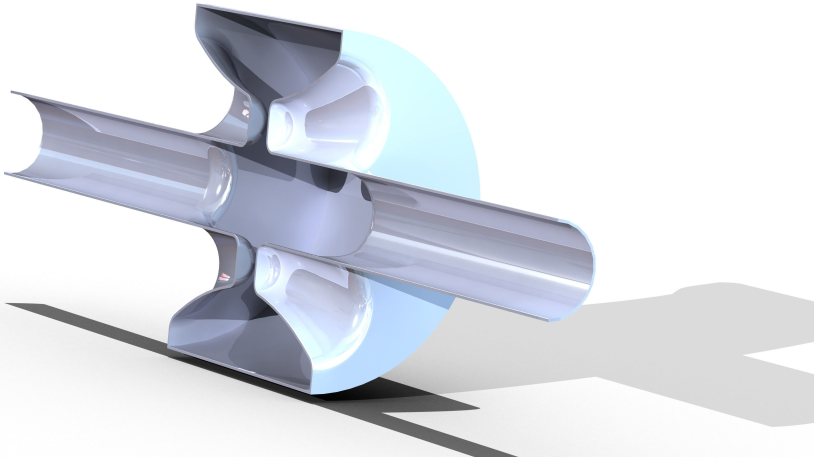


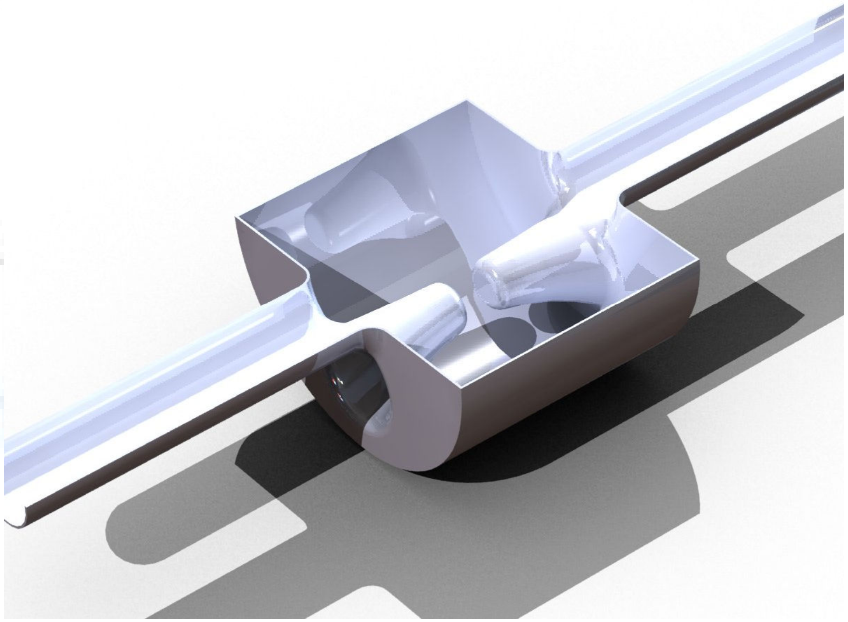


- Unlike other crab designs, the 4 rod cavity has high electric fields.
- Cavity rod shape has been optimised to keep E and B field within tolerable limits.

Improved 2-rod design

- Improved conical rod shape and removing sharp edges on the beampipe has achieved much lower surface fields.
- We still have a lot of parameter space to cover for optimisation (may possibly use an evolutionary algorithm).
- At 3 MV we now achieve
  Emax=40 MV/m
  Bmax=53 mT





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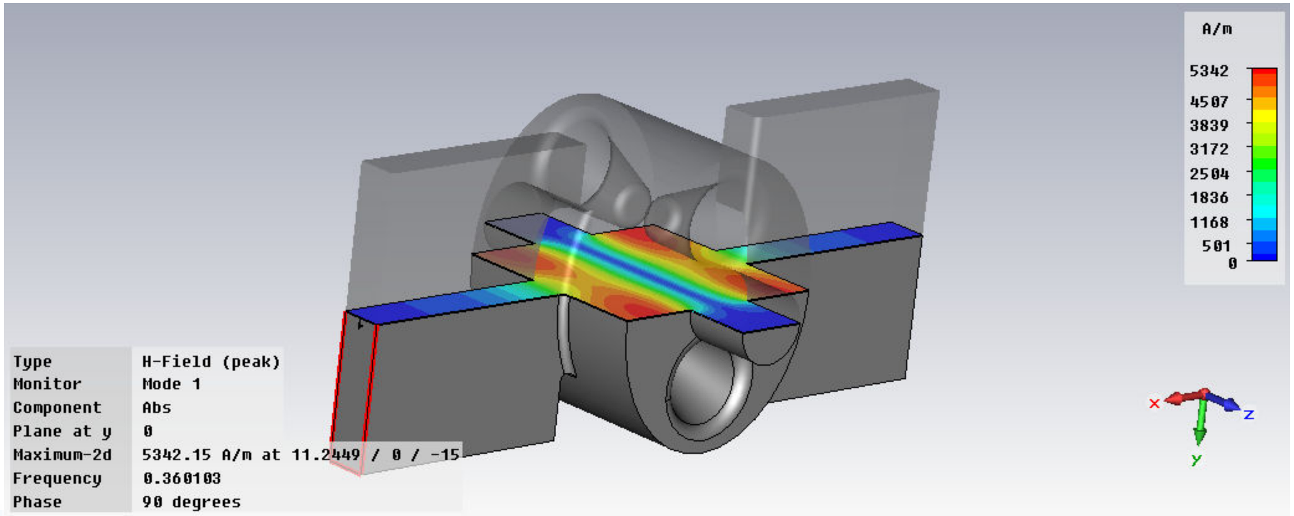
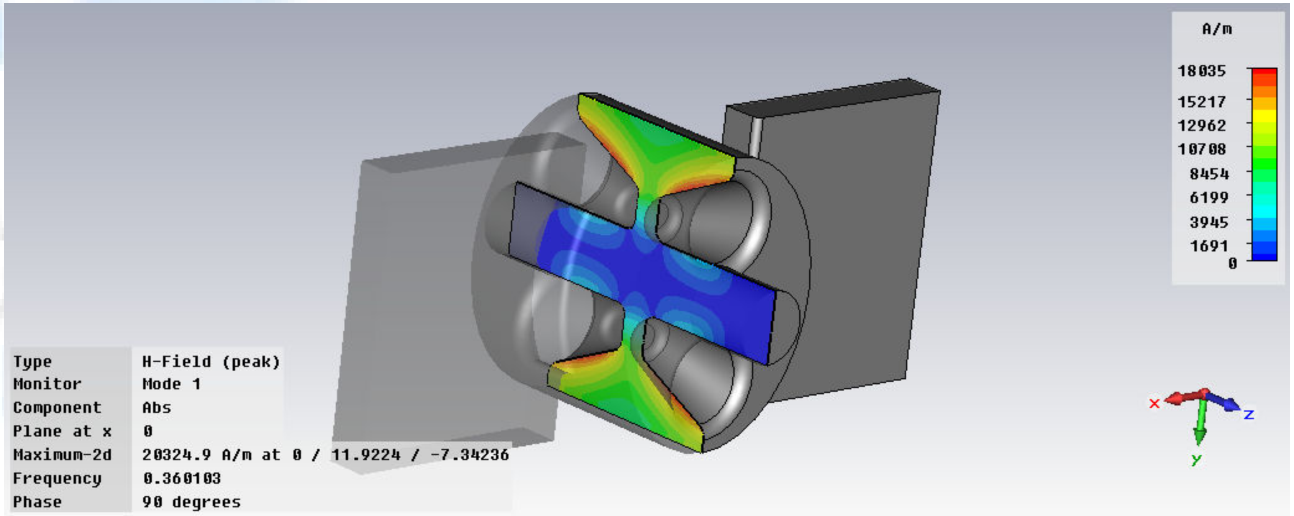
Degenerate Mode Couplers

This cavity doesn't have a LOM and a SOM. Instead it has a degenerate LOM-like accelerating mode.

As the crabbing mode has low fields on the outer conductor we can easily add waveguide couplers to the walls which damp this mode to an external Q ~100.

Mode	Frequency (GHz)
LOM	0.3356
Operating mode	0.4000
1^{st} dipole HOM	0.4866
1^{st} monopole HOM	0.5178





Conclusion

- On-cell waveguide damping development is underway at Jlab for ANL.
- On-cell damping is also a suitable solution for LHC and meets all requirements.
- It is probably the easiest of the designs to manufacture and process.
- The non-squashed cavity also has much looser tolerances on the couplers.
- Multipactor simulations have some question marks for all cavities.
- 4-rod compact cavities could also meet the LHC requirement for a 400 MHz cavity. A full design is expected within 12 months.

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