The Cockcroft Institute
of Accelerator Science and Technology

Jefferson Lab

A Four Rod Compact Crab Cavity for LHC

B Hall

Lancaster University / Cockcroft Institute

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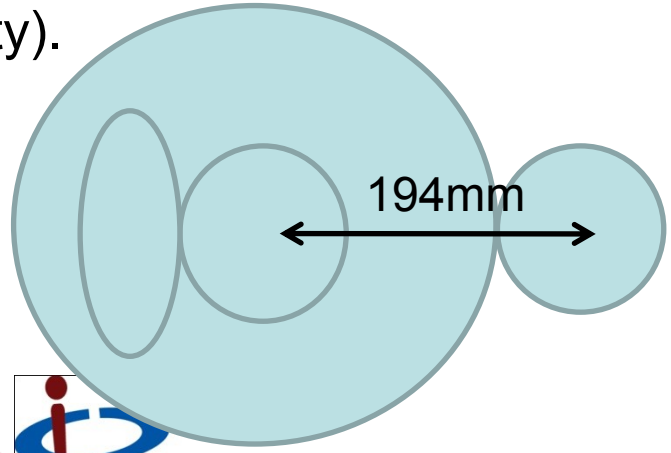
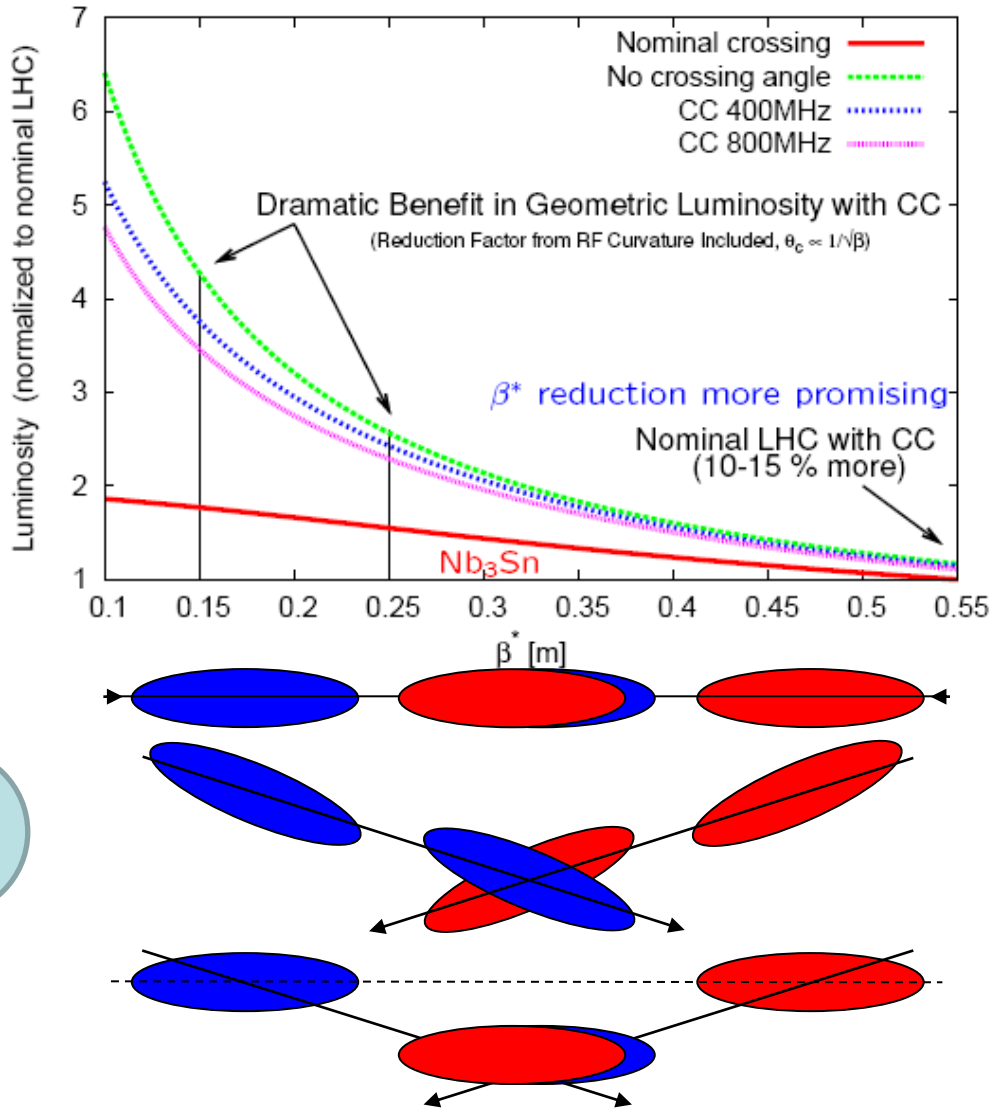
LHC Crabbing upgrade

- Crabbing provides significant Luminosity advantages.
- Local crabbing scheme has been chosen for LHC upgrade.
- Compact size needed do to limited space (~150mm space available compared to ~350 needed for orthodox cavity).

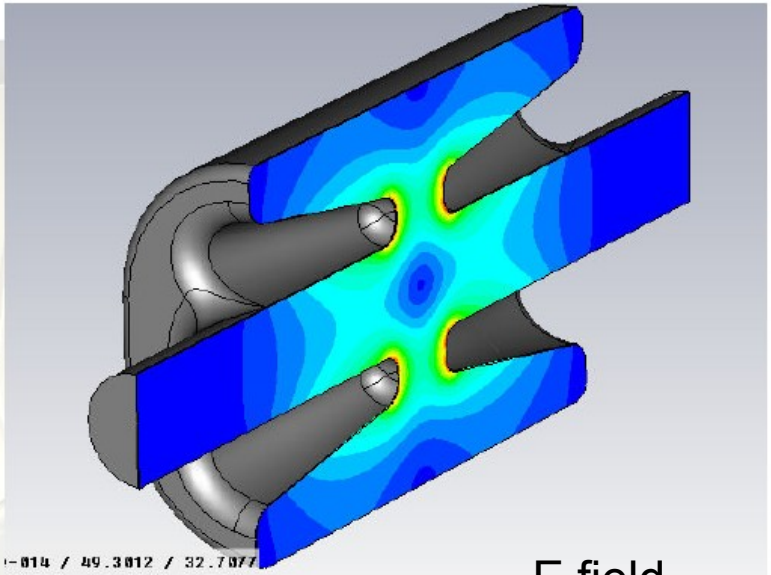




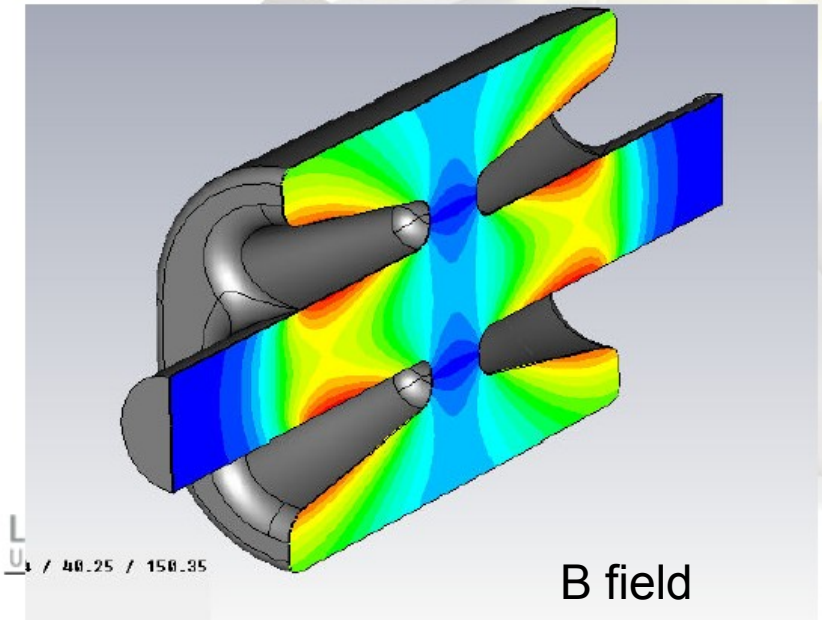
Previous design

The cavity design includes a 280mm / 230 mm diameter squashing to increase coupling to the LOM when a coupler is included.

Cavity fits in all LHC scenarios (90mm aperture) and meets design gradient.



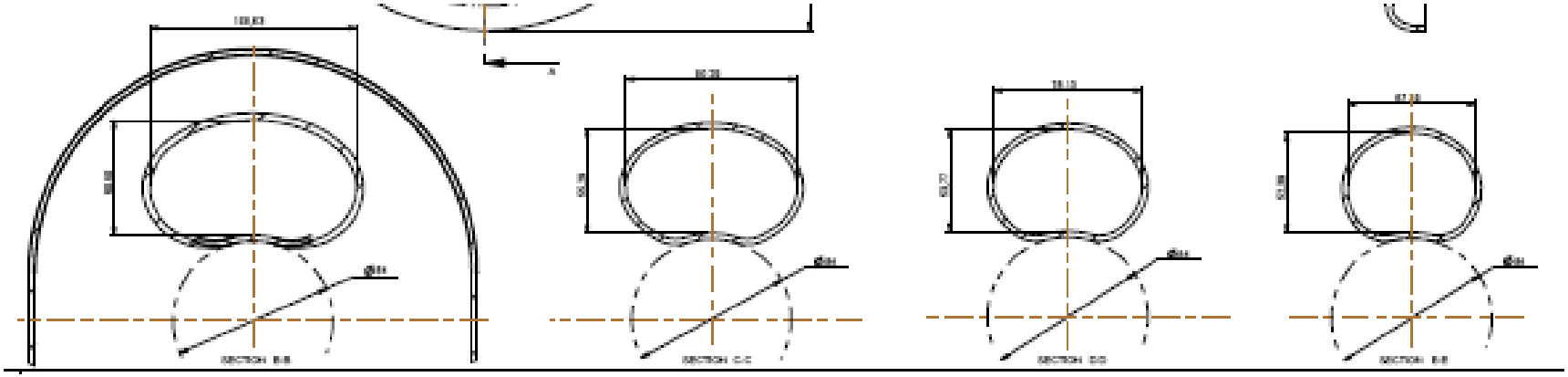
E field



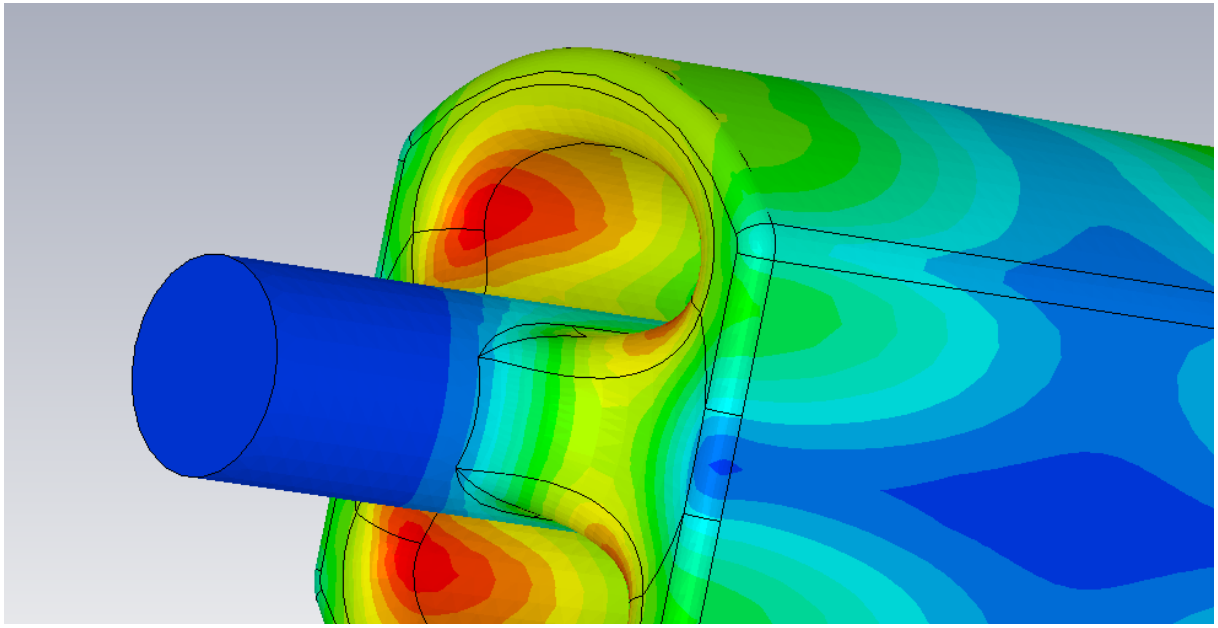
B field

Emax @3MV	37.0 MV/m
Bmax @3MV	68.2 mT
Cavity Q [pert]	11562
Transverse R/Q	802 Ohms

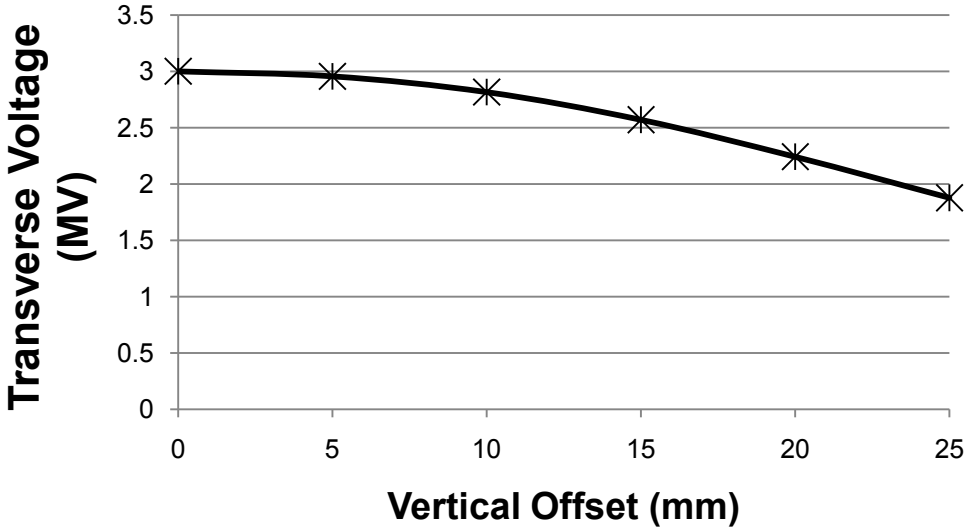
Rod cross-section



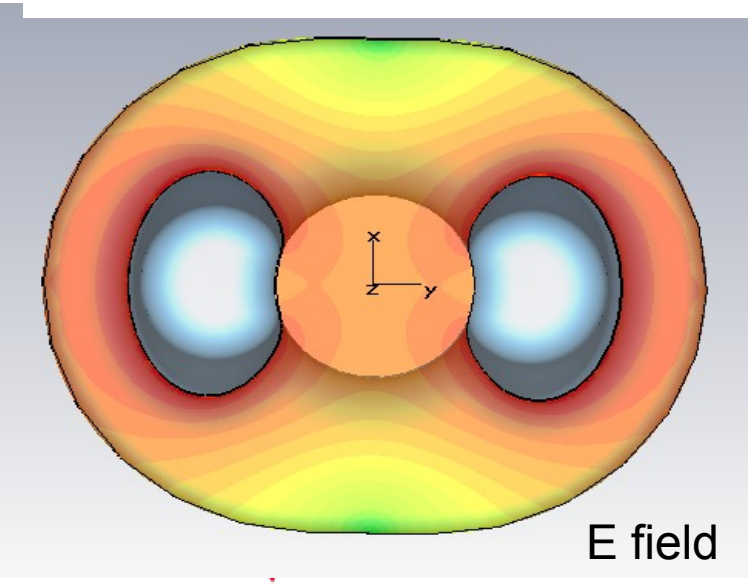
- If the rod is shaped around the beam-pipe a higher gradient can be obtained as the current is spread over a larger area.
- The peak magnetic field also moves to the side of the rods away from the beampipe



Variation in Original Transverse Voltage



In the original design there was some variation in transverse voltage across the cavity aperture which would result in a varying kick across the beam



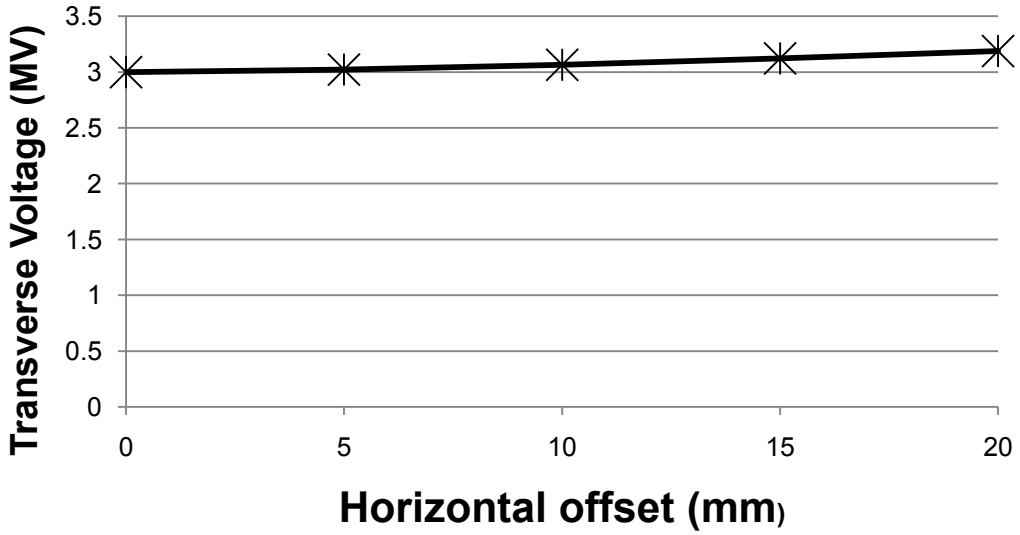
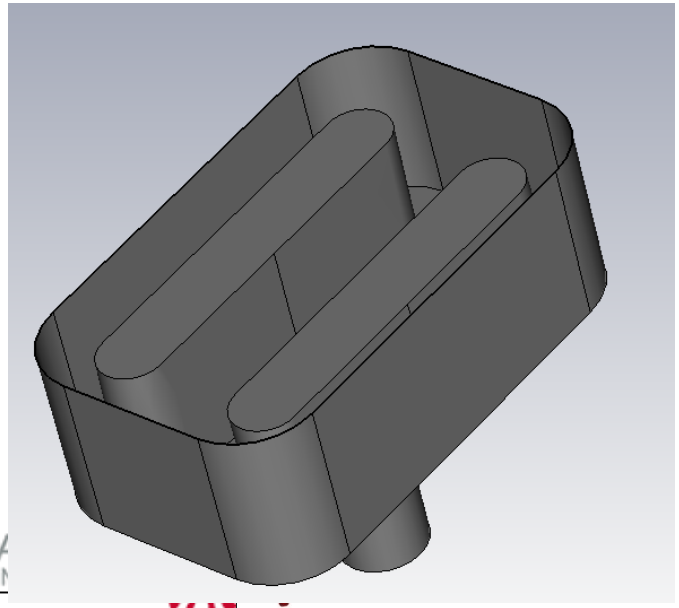
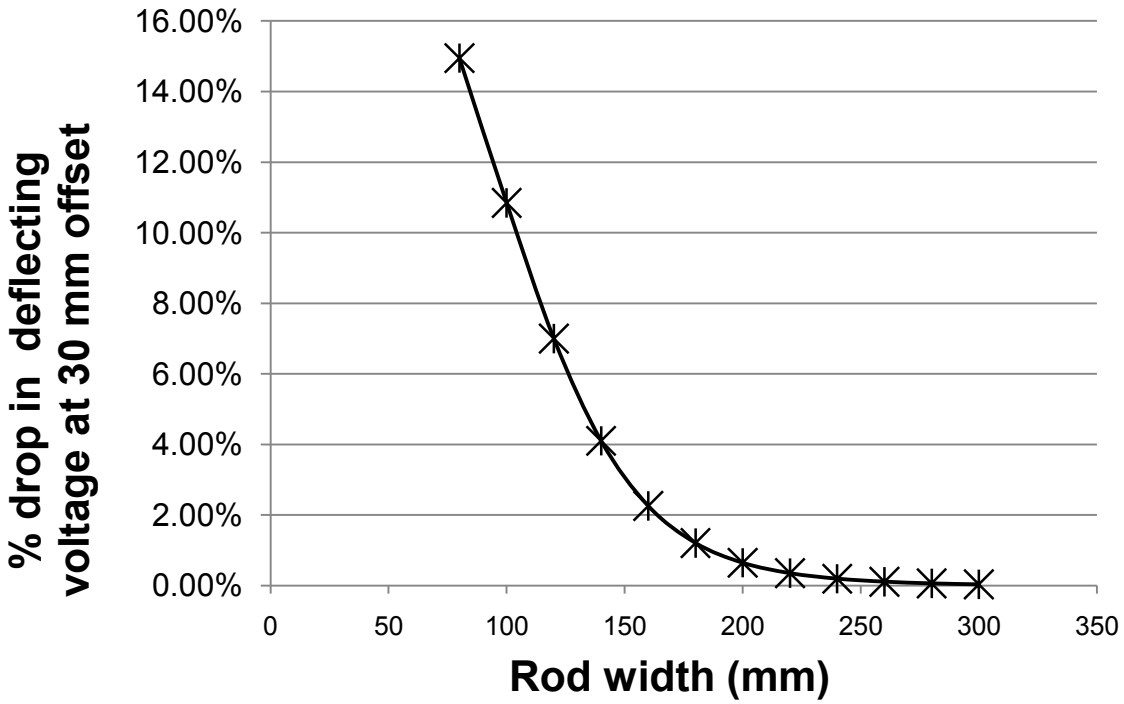


Plate-like rods

- Flatness only a concern across aperture
- Wide flat rods are preferred for minimal voltage variation.

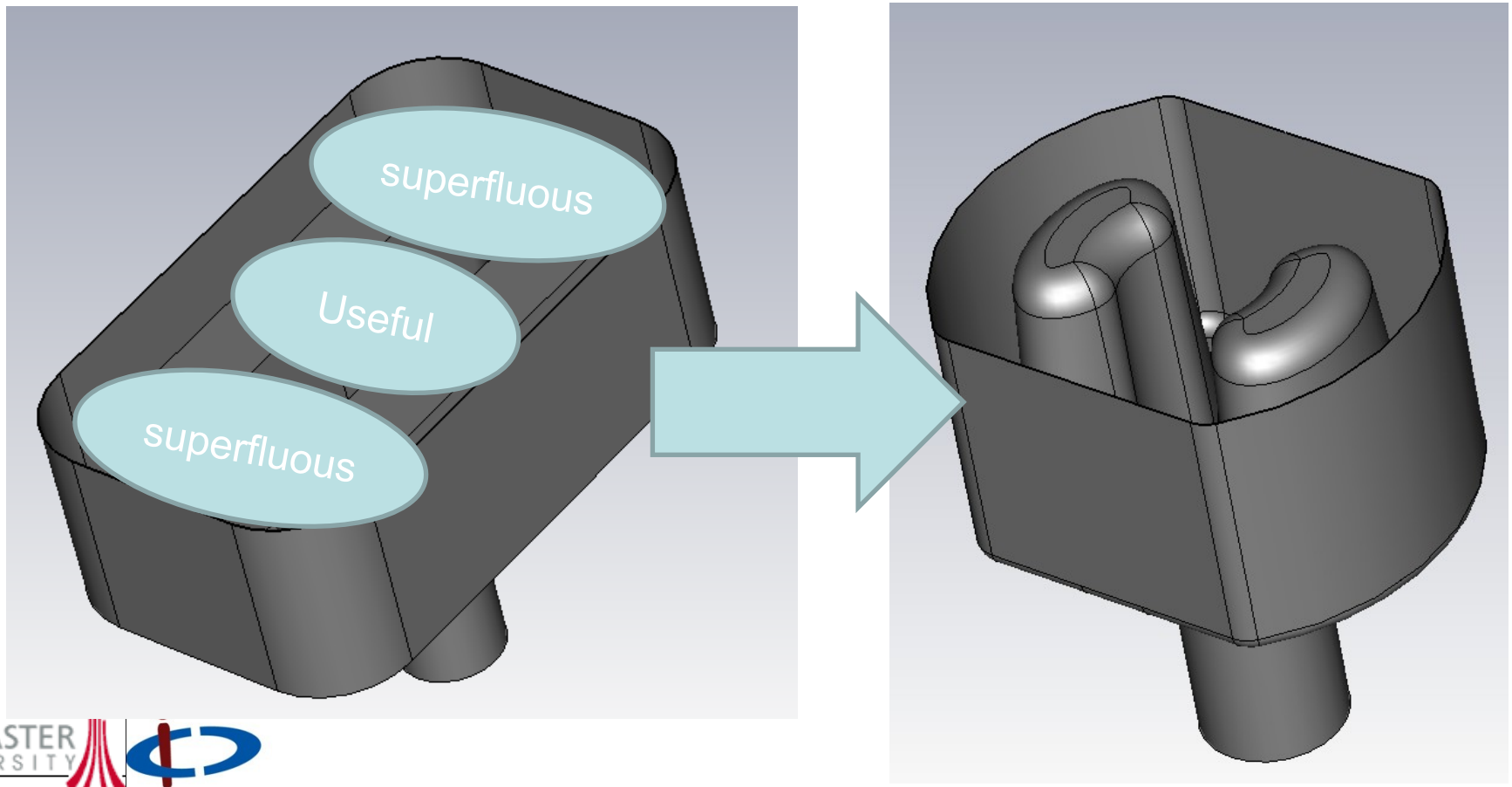




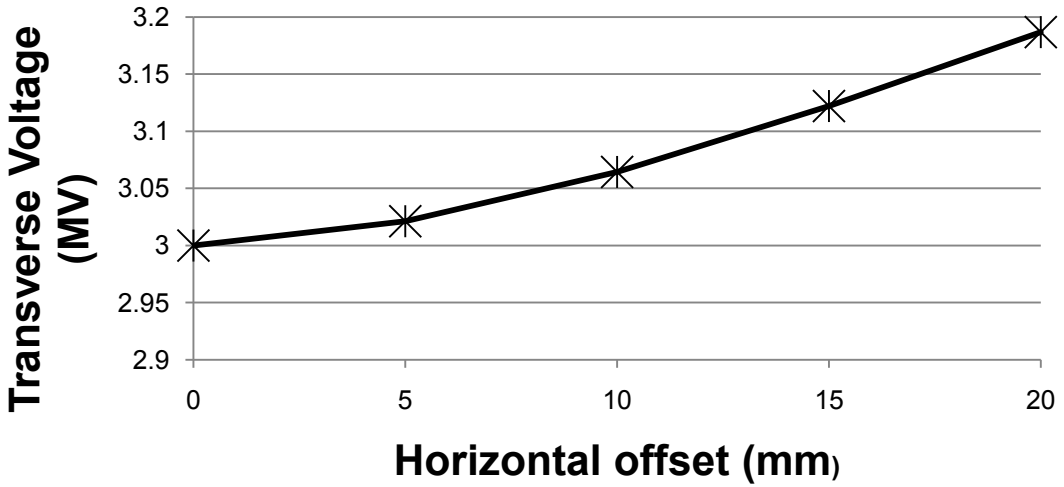
- Wide rods however have high surface fields which makes this design unsuitable.

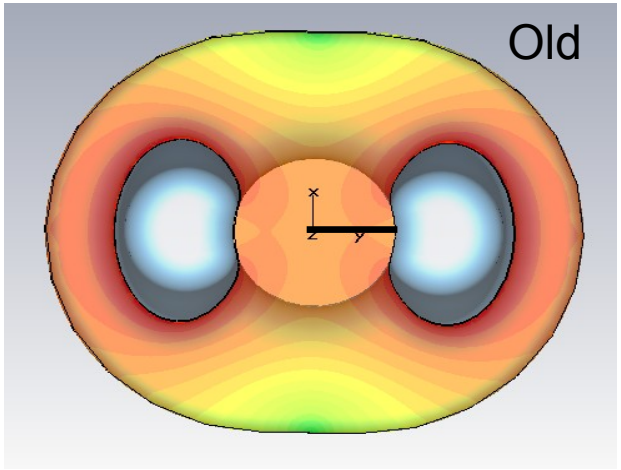
New shape

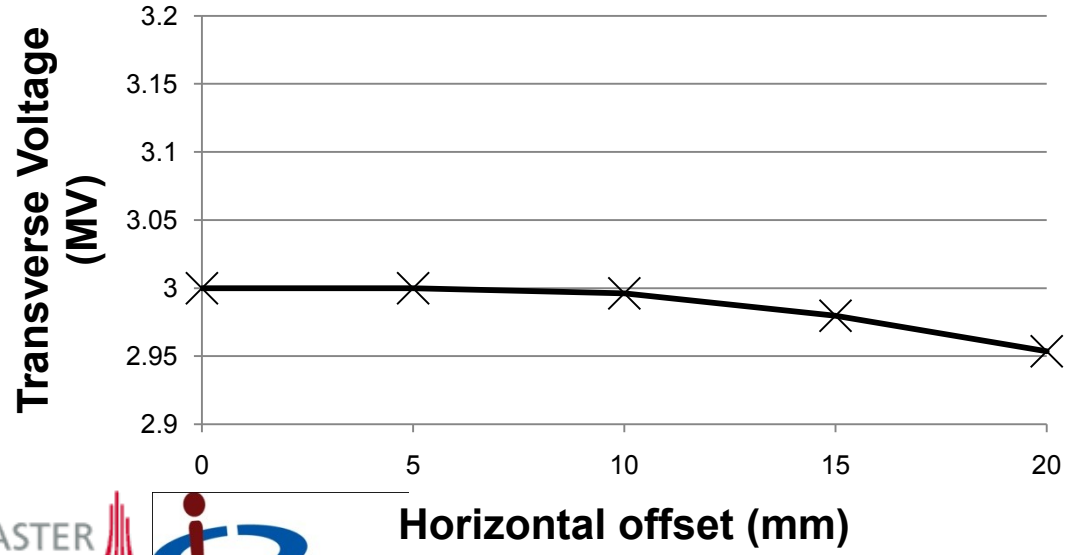
Adding focussing electrodes to narrow rods, can however provide parallel equipotential lines emulating the wider rods.

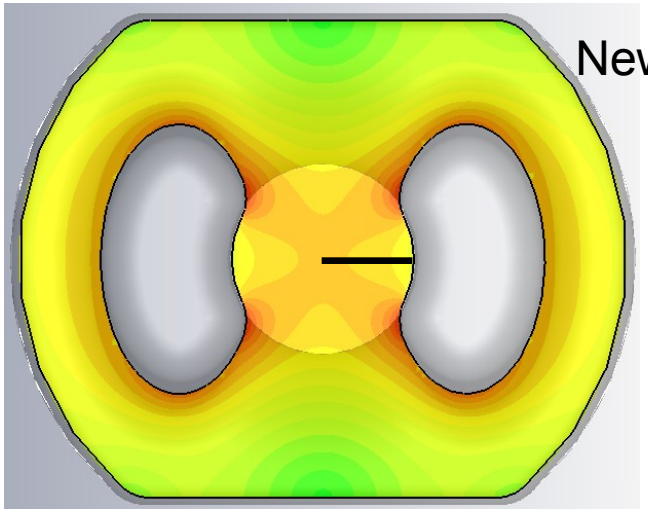


Horizontal variation









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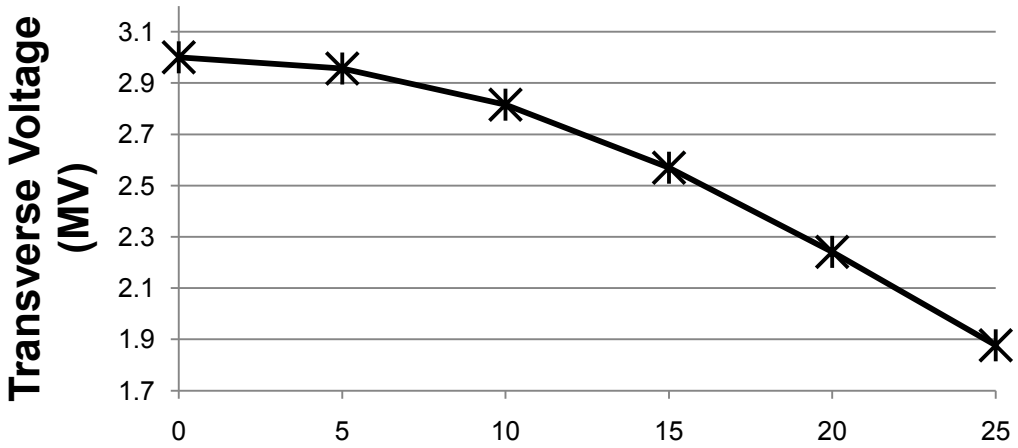
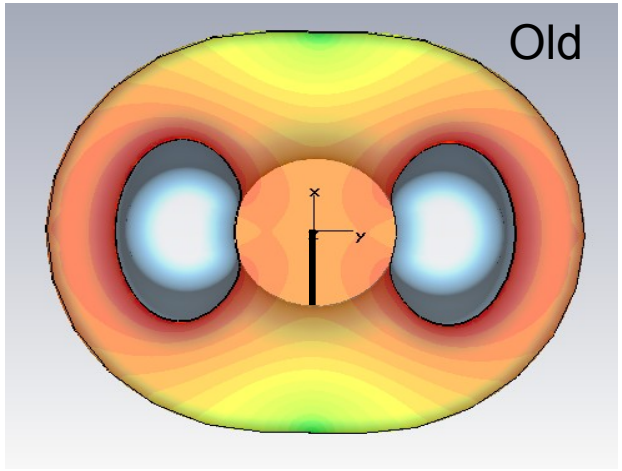
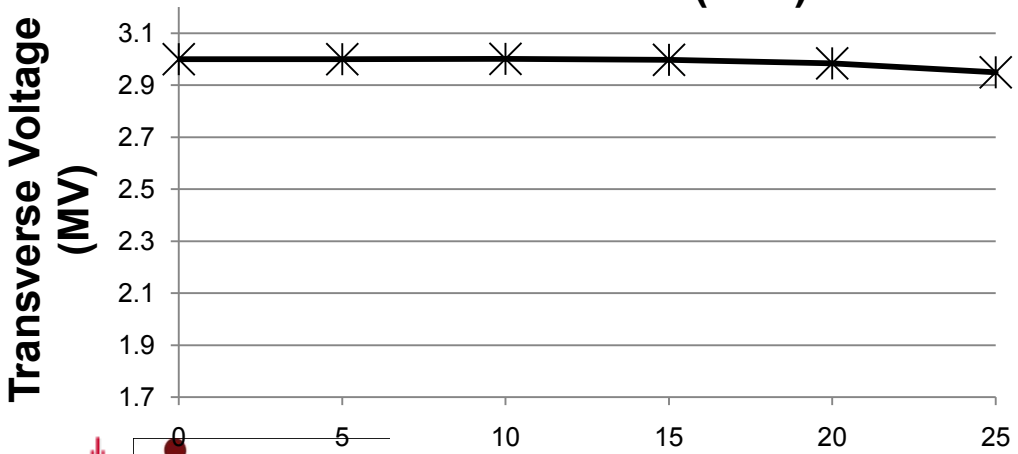
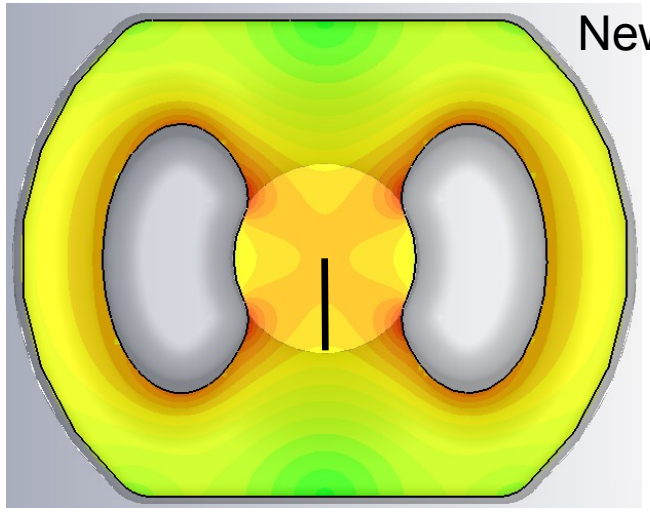
Vertical variation



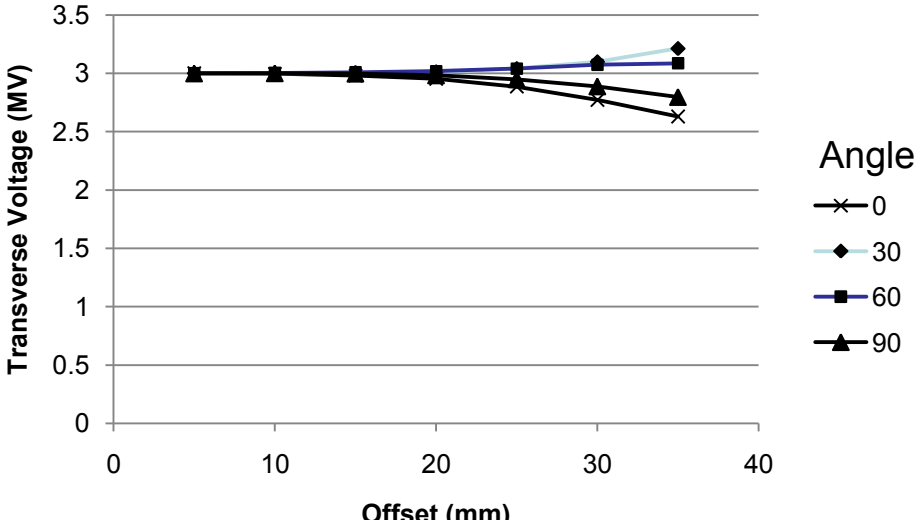


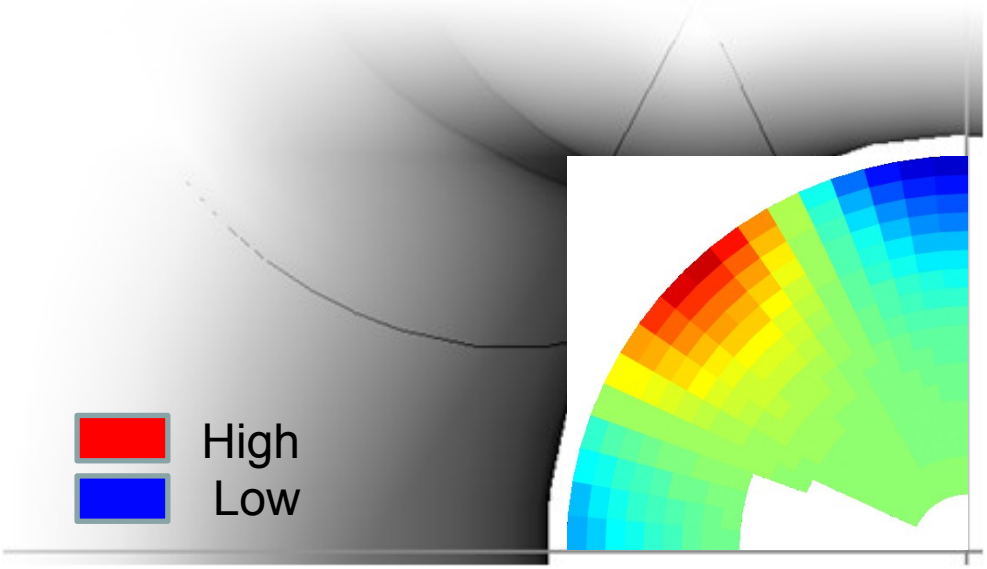




Voltage Variation - deflecting

- Transverse voltage is relatively uniform for the first 20mm [<1% variation]
- Rises to 3.8% at 35 mm (compared to 3.3% for a pillbox cavity)
- Variation at large offset is due to field enhancement at the edge of the rods.
- Azimuthal variation seen primarily at large radii.





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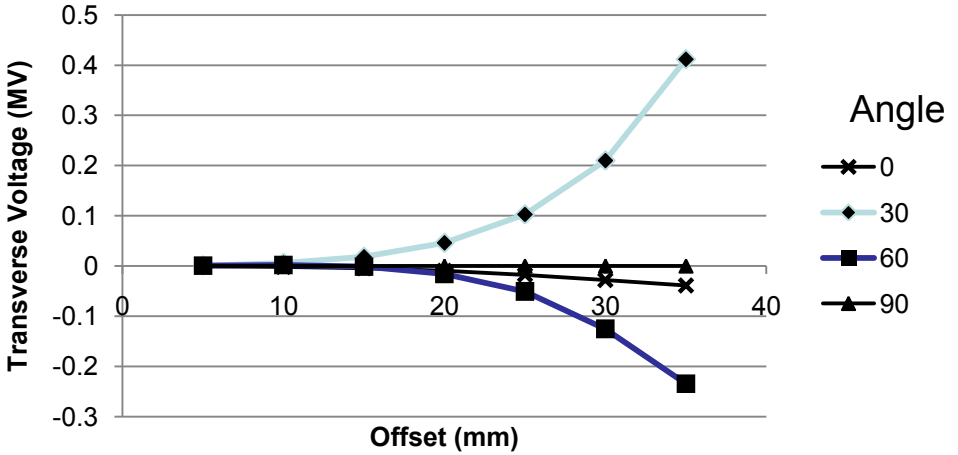
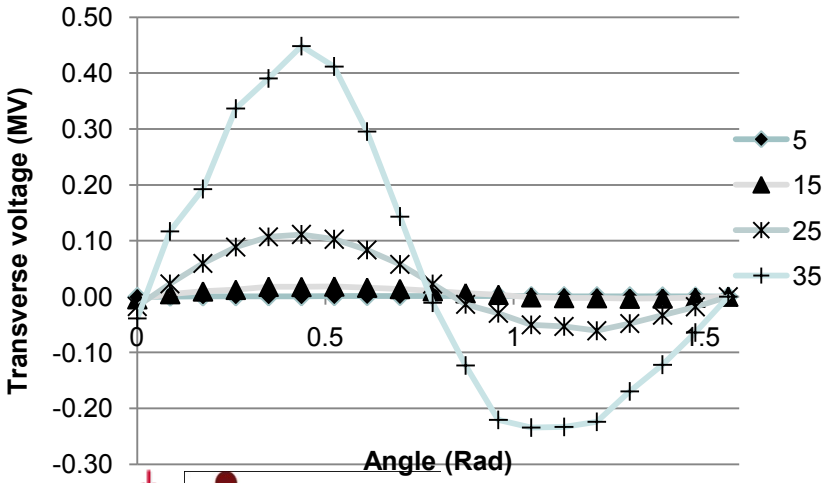
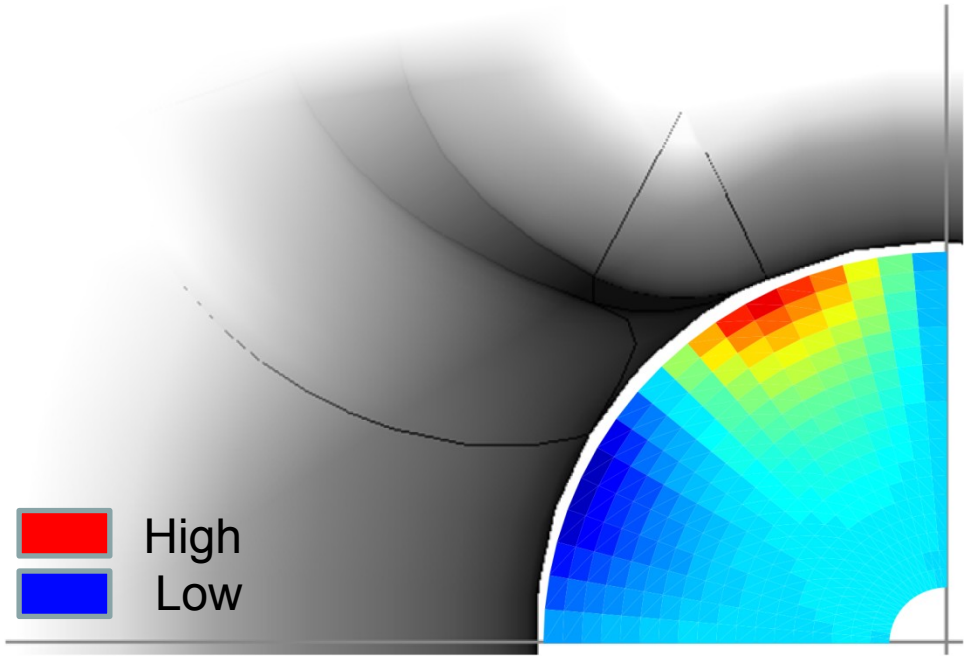
Voltage Variation – parasitic(vertical)

- There is some unwanted kick in the vertical direction.
- Large vertical kick near the edges of the rods due to field enhancement but small away from the rod edges.







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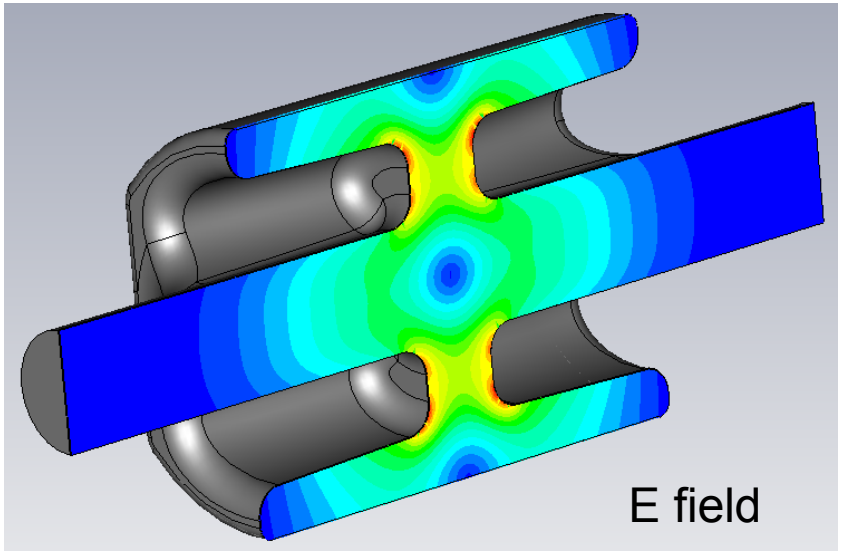
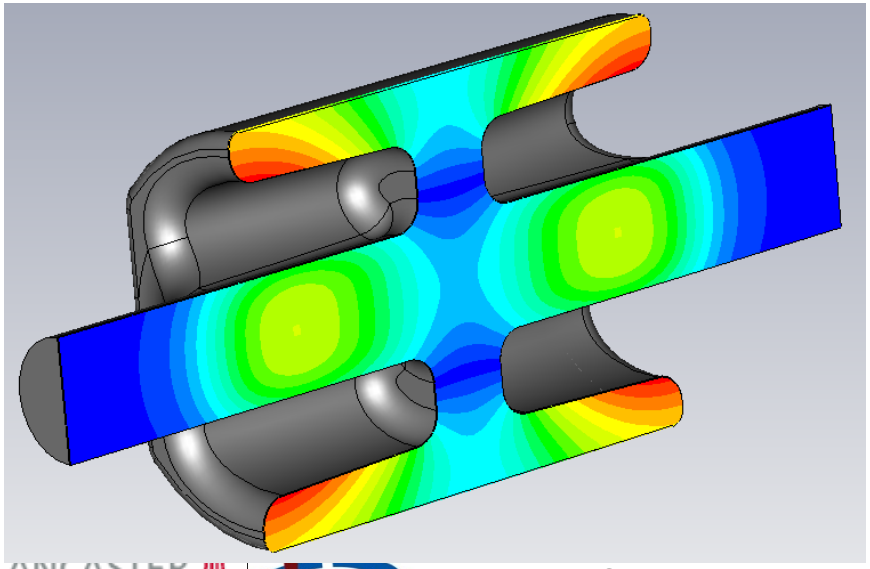
Final Cavity Shape

The cavity design includes a 280mm / 230 mm diameter squashing to increase coupling to the LOM when a coupler is included.

Cavity fits in all LHC scenarios (84mm aperture) and meets design gradient.

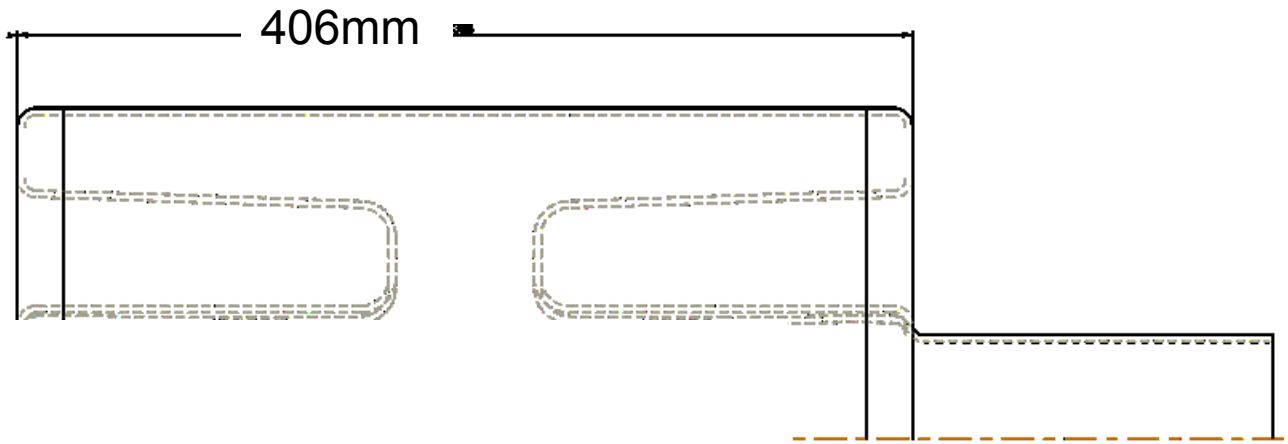




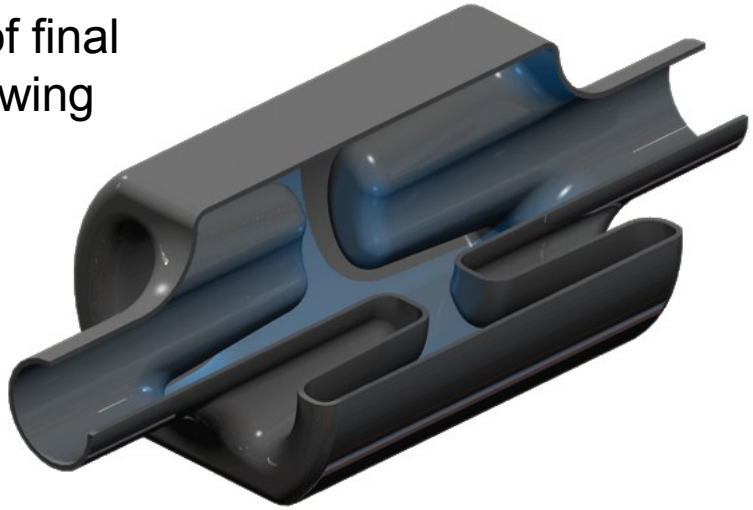
B field

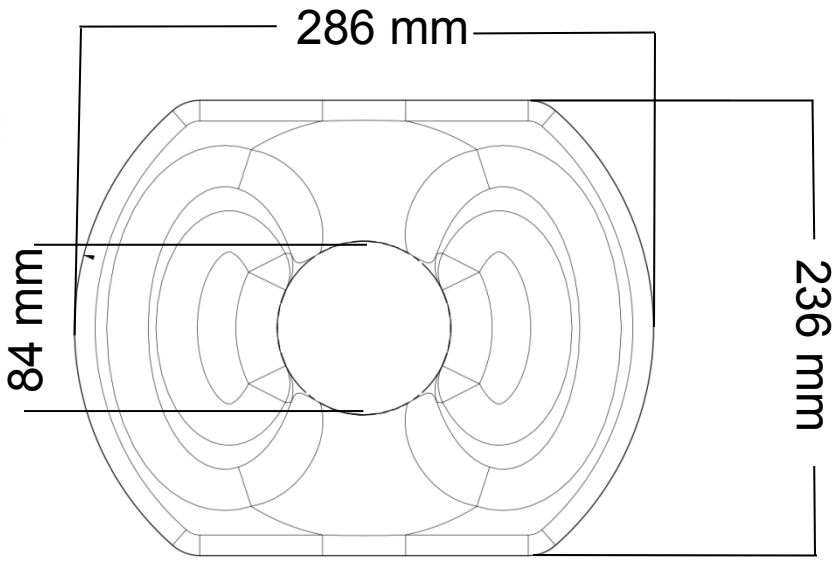
Emax @3MV	32.0 MV/m
Bmax @3MV	60.5 mT
Transverse R/Q	764.6 Ohms

Final Cavity Design

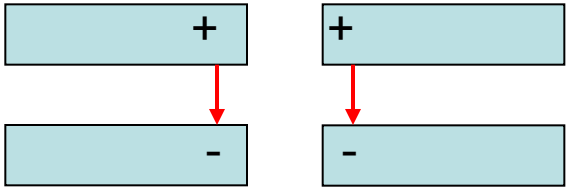


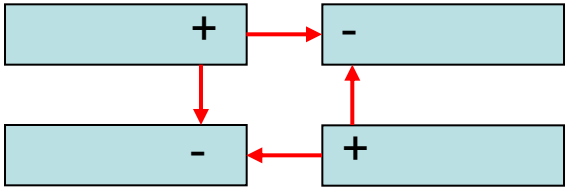
Cut away of final design showing rods,



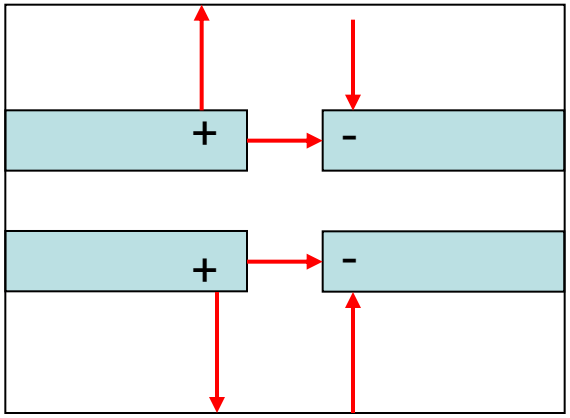


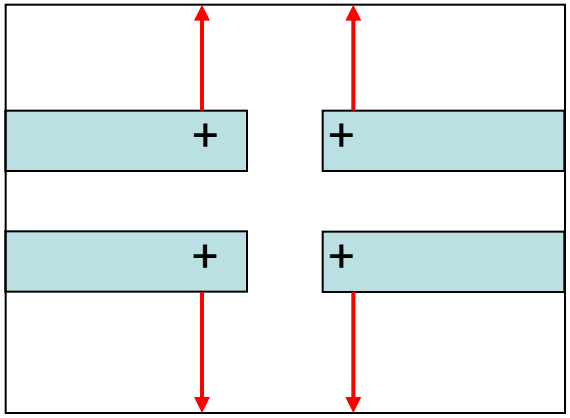
Four TEM modes





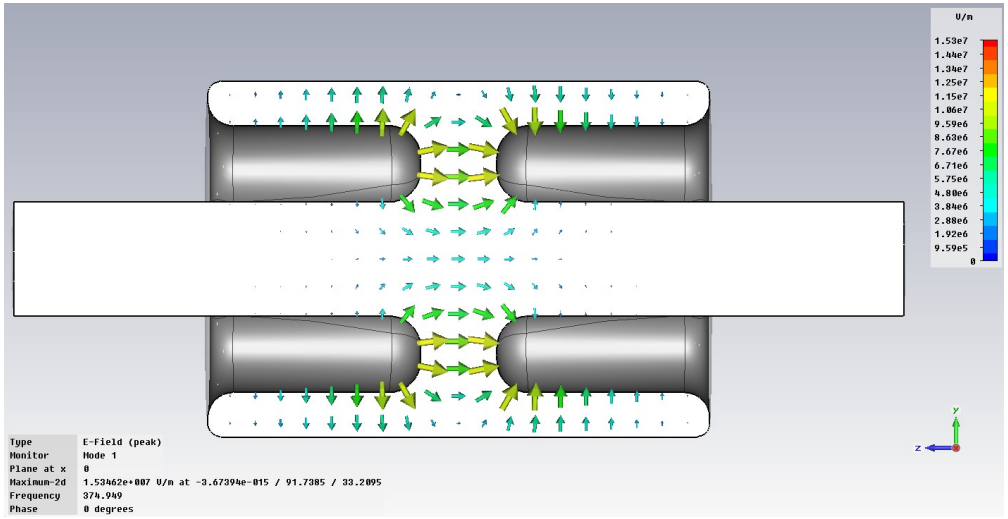
There are two parallel bar TEM modes, only one interacts with the beam and this is our operating mode

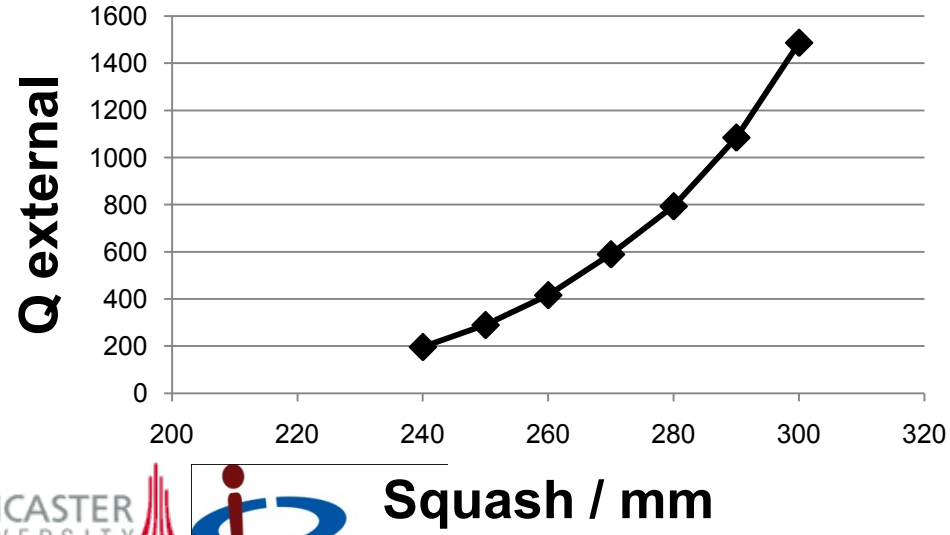




There are also two co-axial like TEM modes (potential difference between rods and outer can), only one of these interacts with the beam, this is our wrong or lower order mode (W/LOM)

Lower Order mode





- The four-rod cavity also has a lower order mode (LOM).
- This mode has an azimuthal magnetic field flowing around the outer can which is ideal for waveguide coupling.
- The fields are weaker far from the rods so the squashed shape enhances coupling.

LOM Frequency	375.18 MHz
R/Q	62.2 Ohms

LOM coupler reduces the frequency of this mode by 20 MHz.

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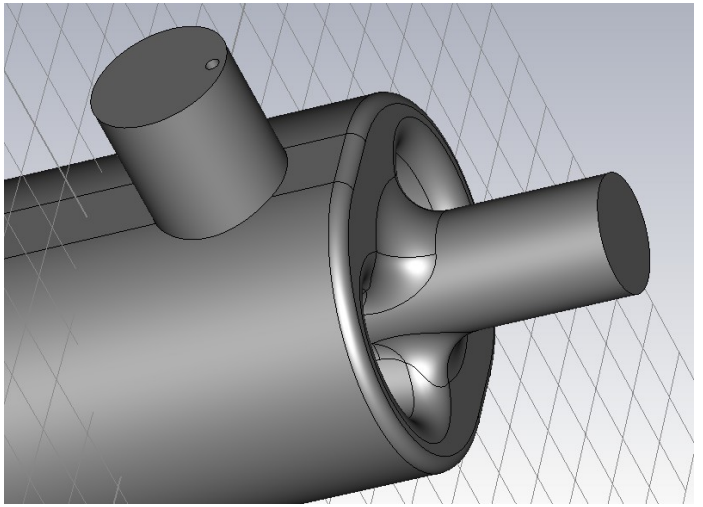
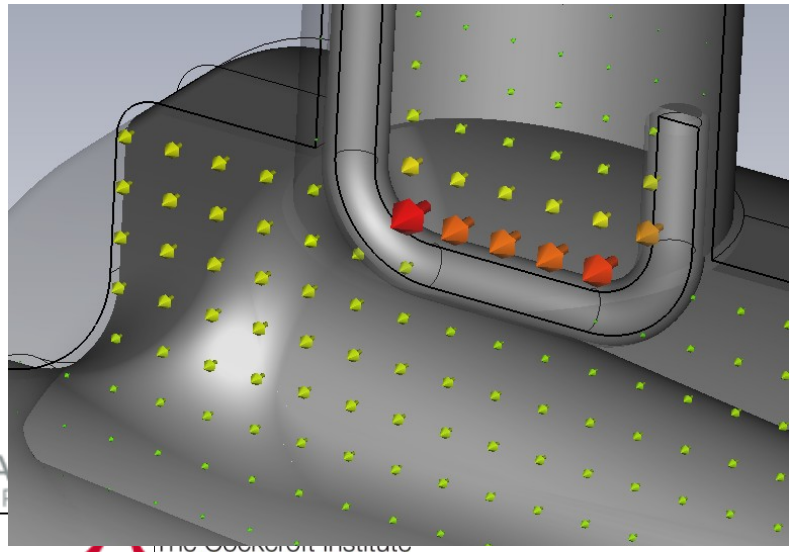
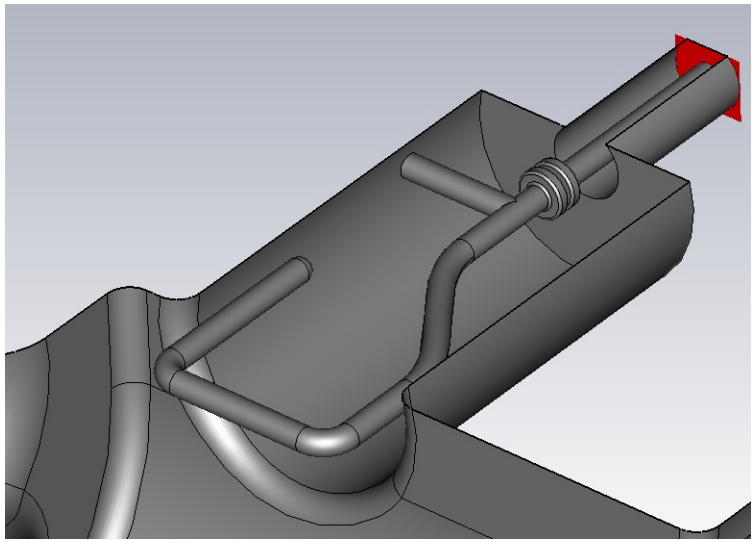
Demountable Coaxial coupler

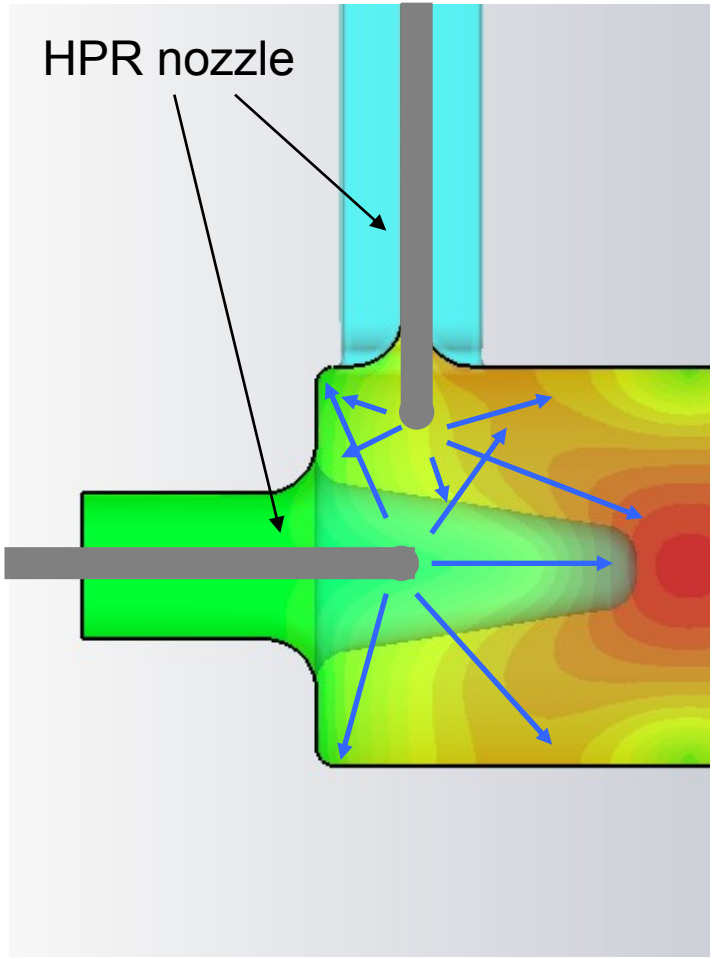
- Demountable HOM style coupler based of the LEP design.
- Pull-out for coupler provides additional access to cavity for cleaning.
- **External-Q's** down to **67** have been achieved for **2 couplers**, depending on the penetration of the hook into the cavity.
- To ensure symmetric fields the couplers can be placed on opposing sides of the can.







Cavity Cleaning

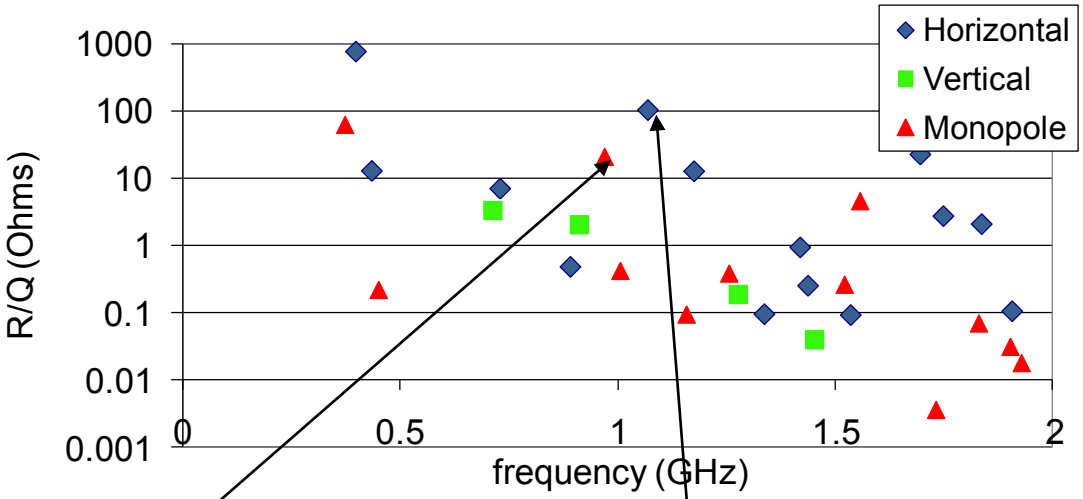


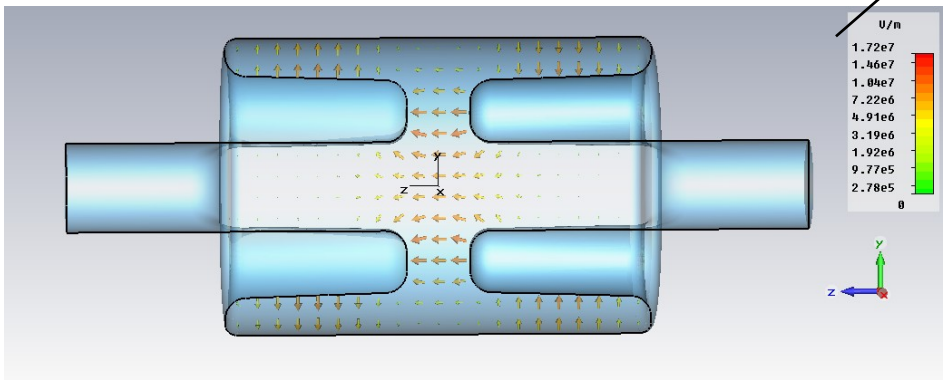
- Beam-pipe is large and can be used as access for cleaning.
- Large demountable LOM couplers can also be used for cavity cleaning and/or draining acid.

Higher Order Modes

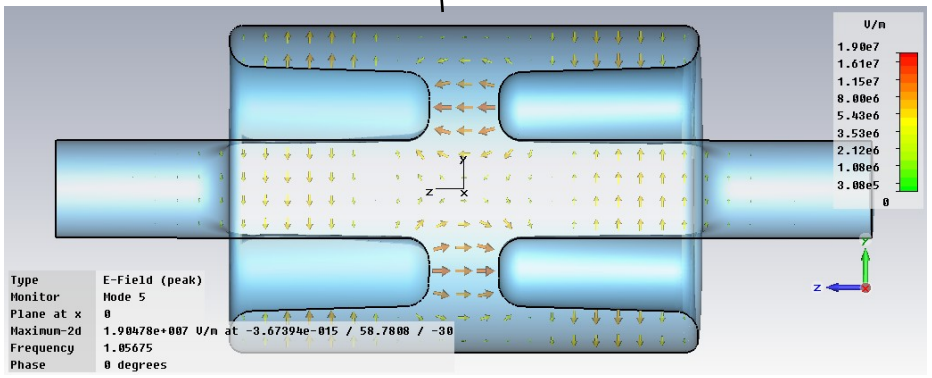
We also have some TEM HOMs.

As the cavity is compact in the vertical plane most of the TM modes are at higher frequencies, and the TE modes have low shunt impedances.





Monopole 3π/4 resonator



Dipole 3π/4 resonator

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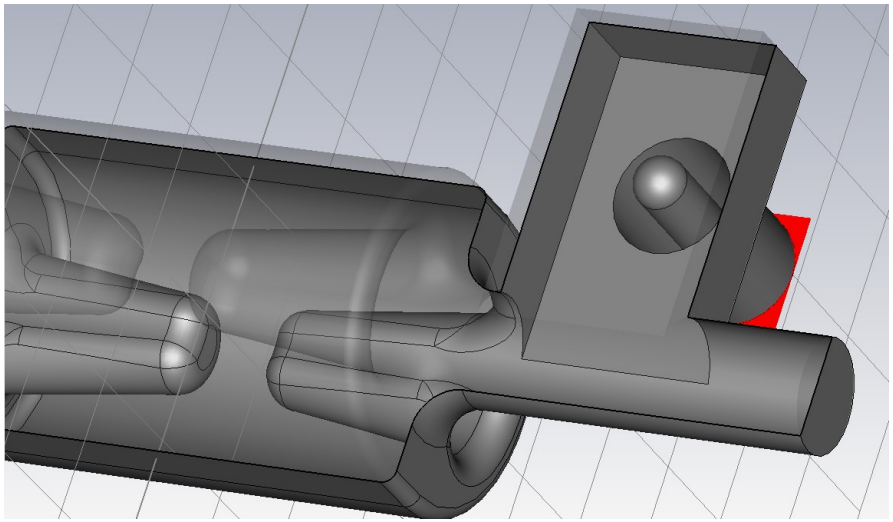
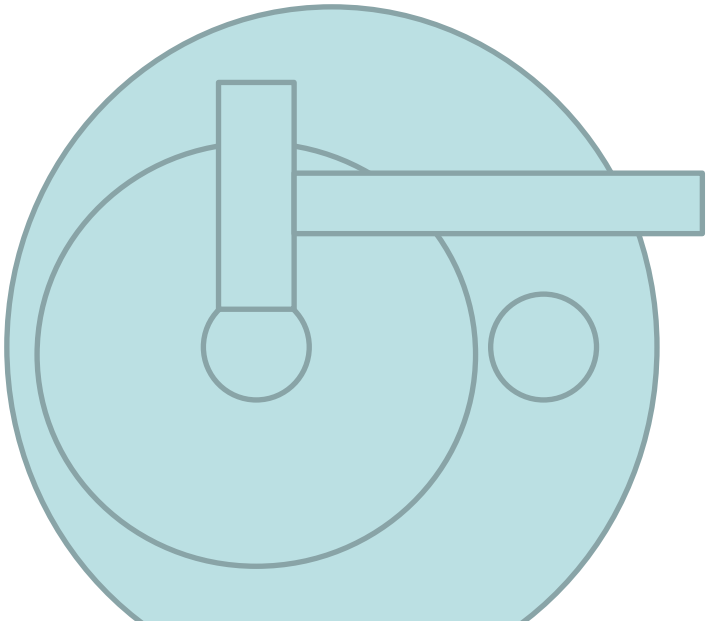
Input coupler

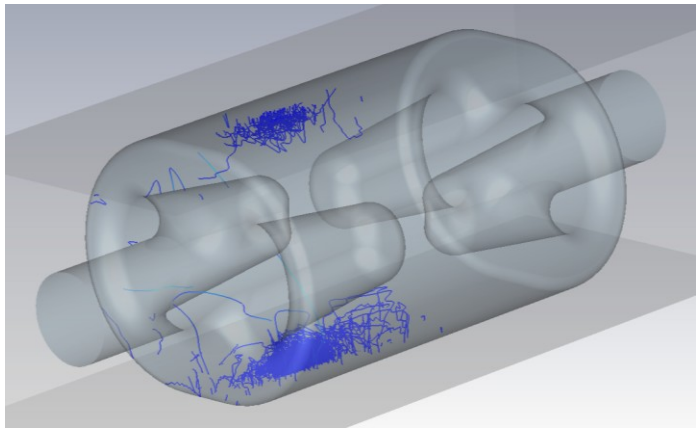
- Capacitive coupling would require a horizontal electrode which would interfere with the opposing beamline.
- Magnetic coupling is required (either a loop or waveguide)
- A waveguide coupler at 400 MHz would be large compared to the cavity and would have a large heat leak.
- Instead we propose a cut-off waveguide to couple to the cavity and then use a waveguide to coaxial transition.

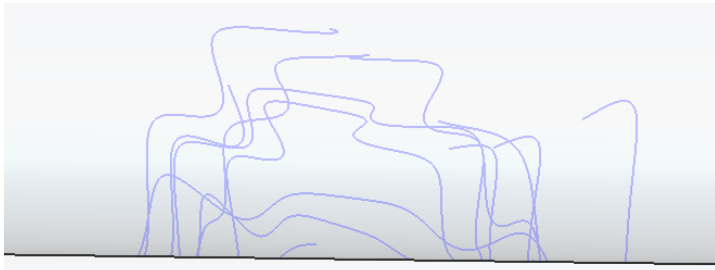


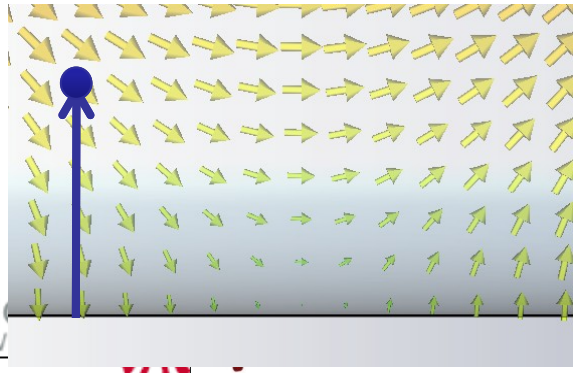


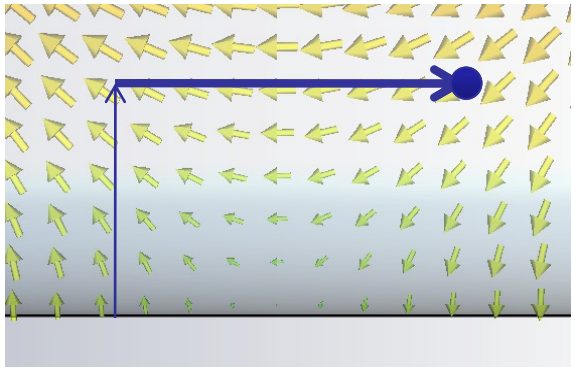
Multipacting

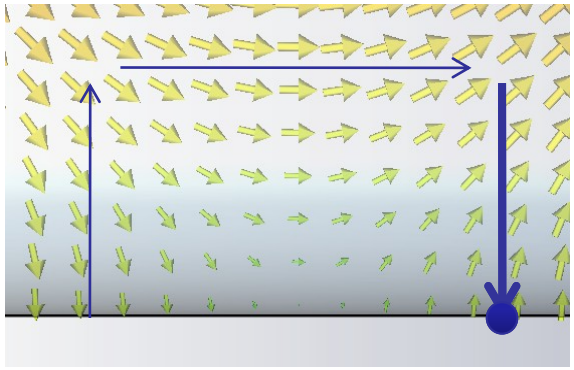
- Some multipacting on the outer can has been found at low E field. V_t ~ 150 kV.
- As cavity voltage increased the multipacting is pushed towards the base of the rods.
- This is close to the region where we plan to place the LOM coupler so this may disrupt the multipactor.
- Outer can trajectories follow a square step like path over several phases. There are 3rd and 7th order trajectories.





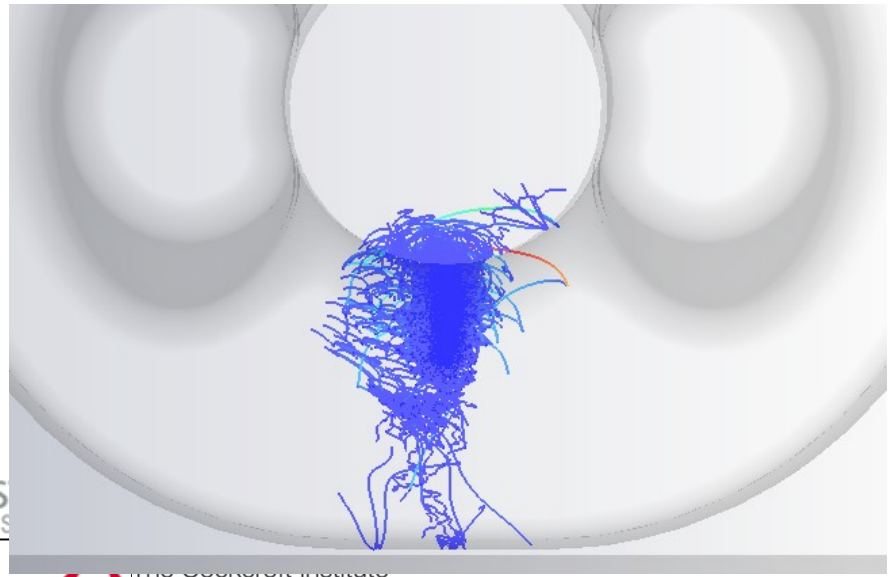


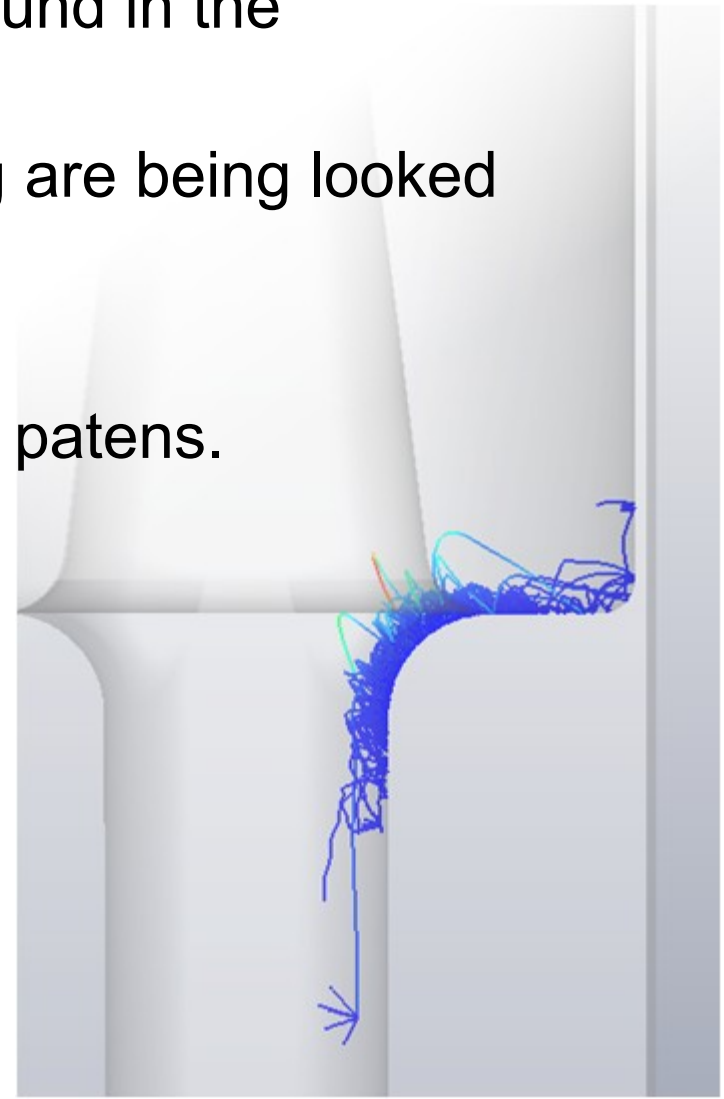




Multipactor Trajectories

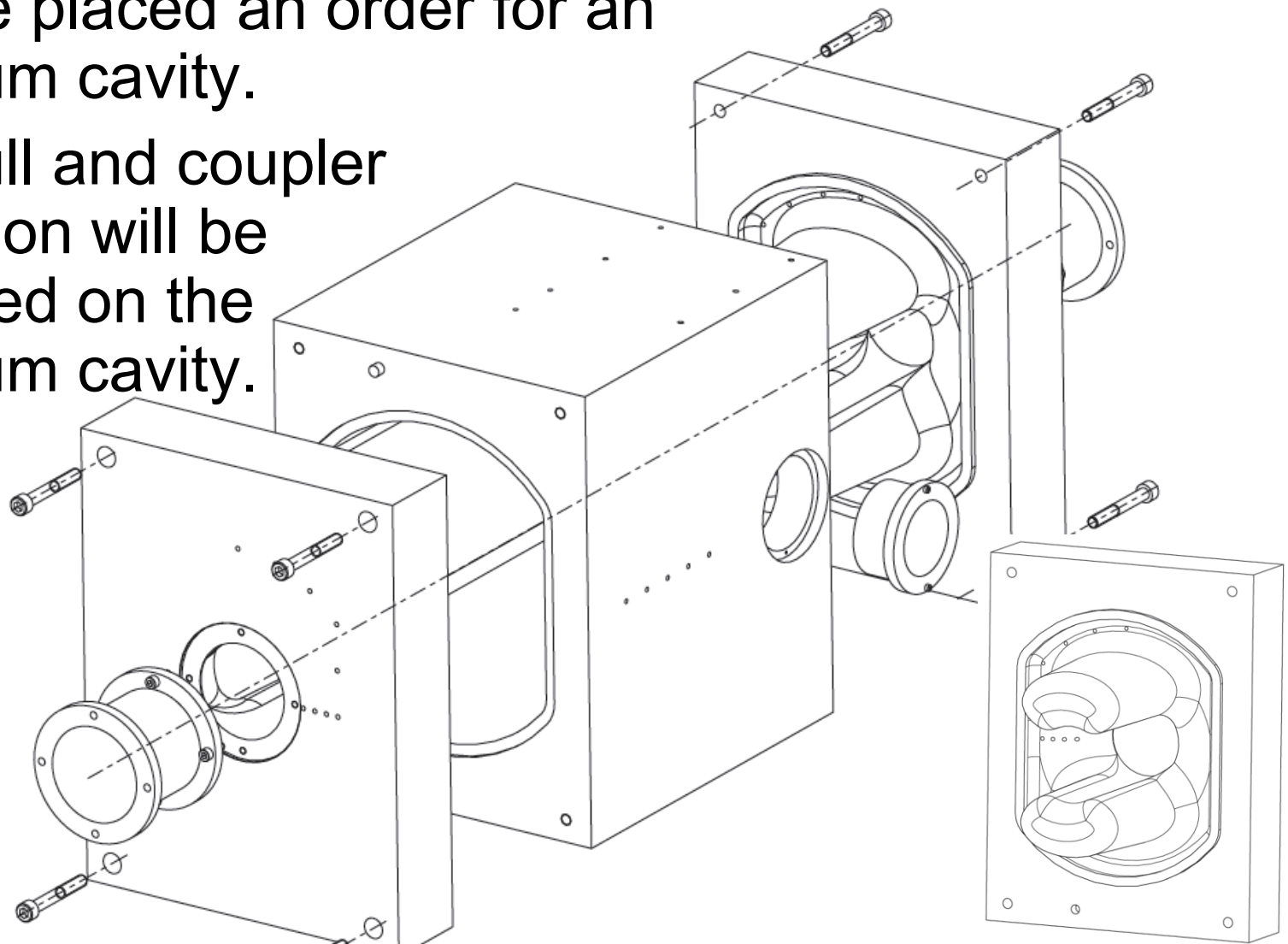
- Multipacting on the beam pipe was found in the racetrack model ~1.6MV.
- Methods of removing the multipacting are being looked into, including;
  - Altering the beam pipe shape,
  - Adding ridges to disrupt local field patens.





Cavity Prototype

- UK have placed an order for an aluminium cavity.
- Bead pull and coupler verification will be preformed on the aluminium cavity.



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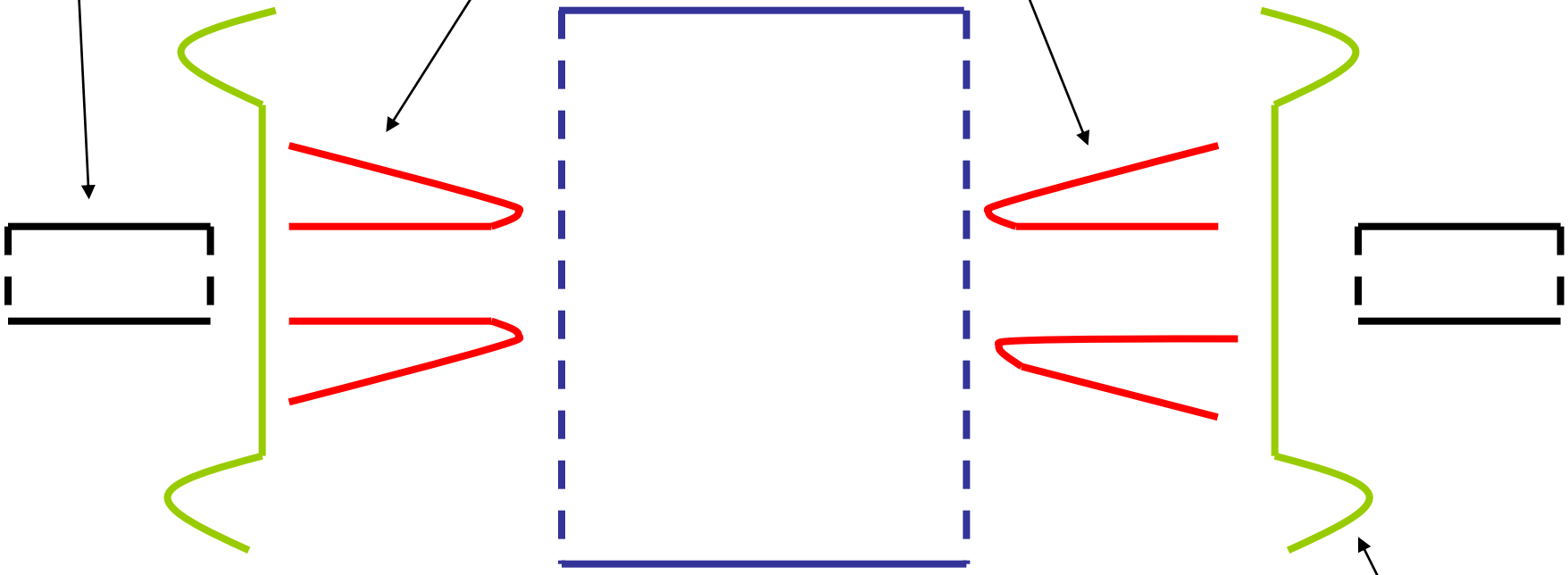
Niobium cavity construction (without couplers)

Beam-pipe (rolled)

Rods x 4 (pressed or hydroformed)

Rods and base may be deep drawn or extruded as 1 piece.

Some components could possible be machined from solid Nb instead



Shell (rolled)

End caps would be pressed

Conclusion

- A new cavity shape is proposed for the LHC.
- The crabbing TEM mode allows a very transversely compact design.
- The compact size does not impact of the cavity fields greatly.
- Coupler designs are under investigation.
- A prototype is on order.