Progress on the design and Testing on Longitudinally Split RF cavities

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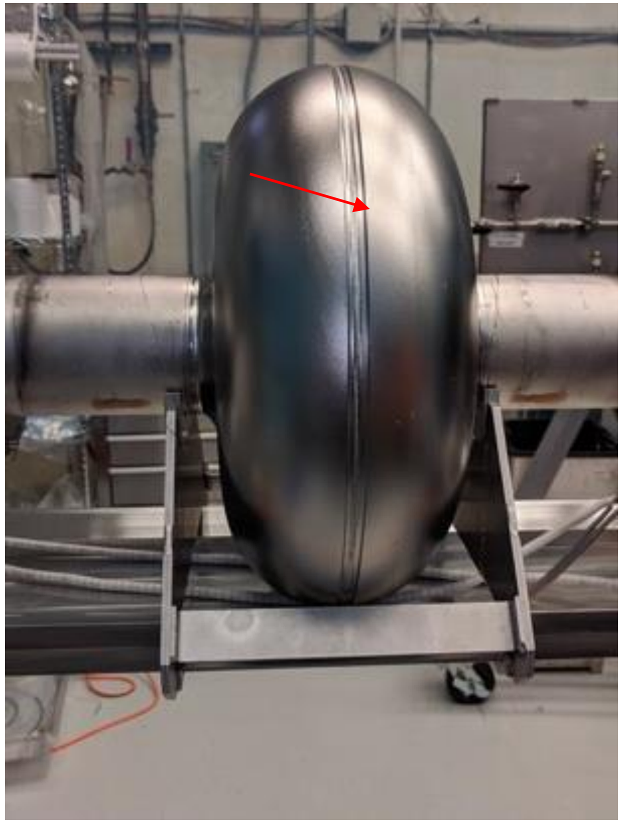
Traditional SRF cavity design

- Traditional SRF Cavities built in 2 halves and welded around the equator
- Surface current goes across the weld minimising the welds impact
- Thin films deposit poorly over the weld meaning this cavity performs poorly as a test cavity
- We are designing a novel cavity that is split longitudinally down its length instead



Traditional cavity produced in 2 cups welded together

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Our Novel Longitudinally Split Cavity

Novel longitudinally split cavity design

- Produced in 2 halves that are split longitudinally
- Can introduce gap between cavity halves that fields can't couple into
  - welds can be further from fields in the cavity
  - Surface electric current doesn't cross a weld
- Can be deposited with both planar and cylindrical magnetrons
- Easier quality control after deposition

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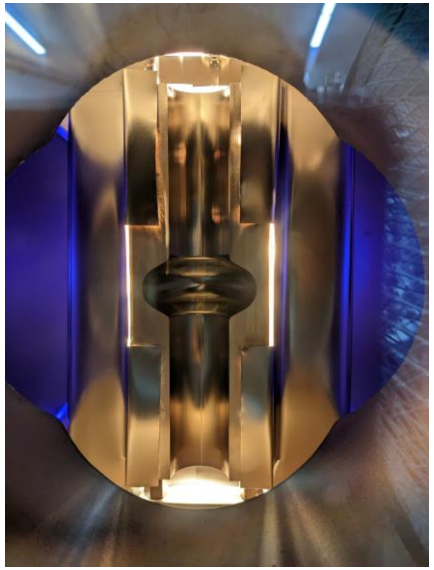
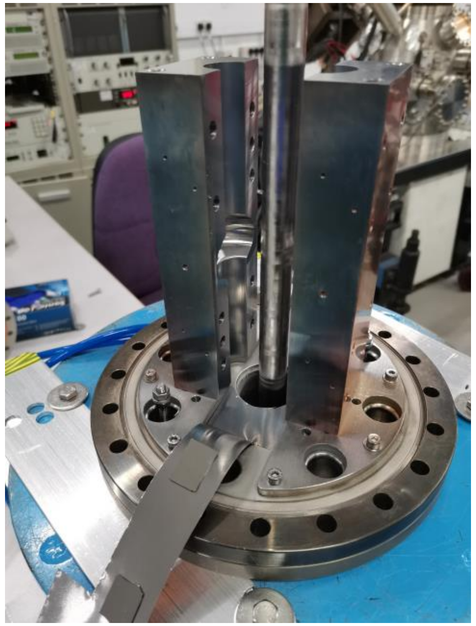
6 GHz Longitudinally split cavity deposition





Two 6 GHz cavity depositions

- Three 6 GHz Cavities have been designed, produced and tested at Daresbury Laboratory
- Machined from copper with Superconducting thin film sputtered onto surface
  - Primarily Niobium
  - Initial test on V_3Si
- Depositions have been performed with both Planar and cylindrical magnetron

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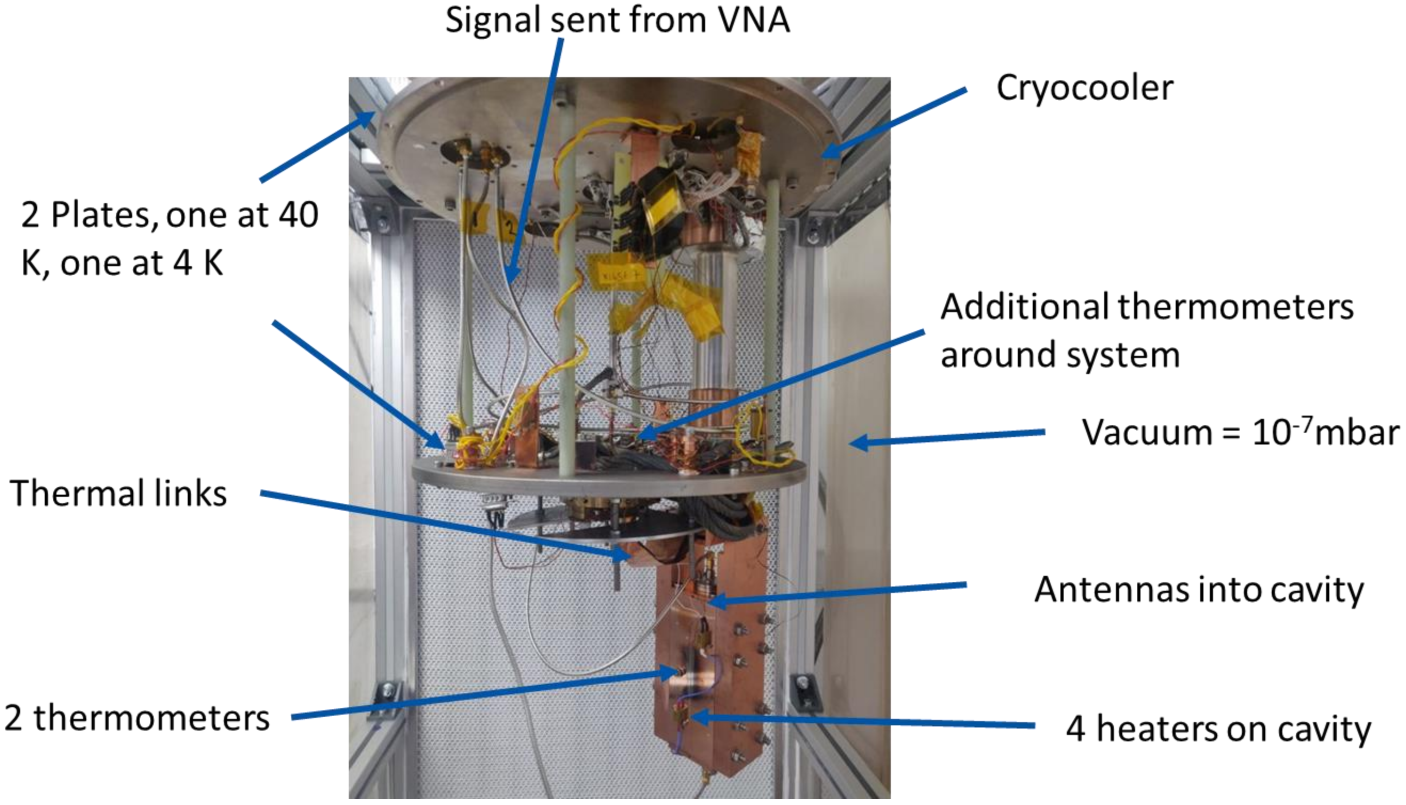
Cavity Design and test facility

- Existing 6 GHz cavity design has an elliptical geometry
- 2 halves can be bolted together for easy assembly in test facility
- Investigated substrate preparation and deposition temperature for Nb thin film



Test system with 6 GHz longitudinally split cavity inserted

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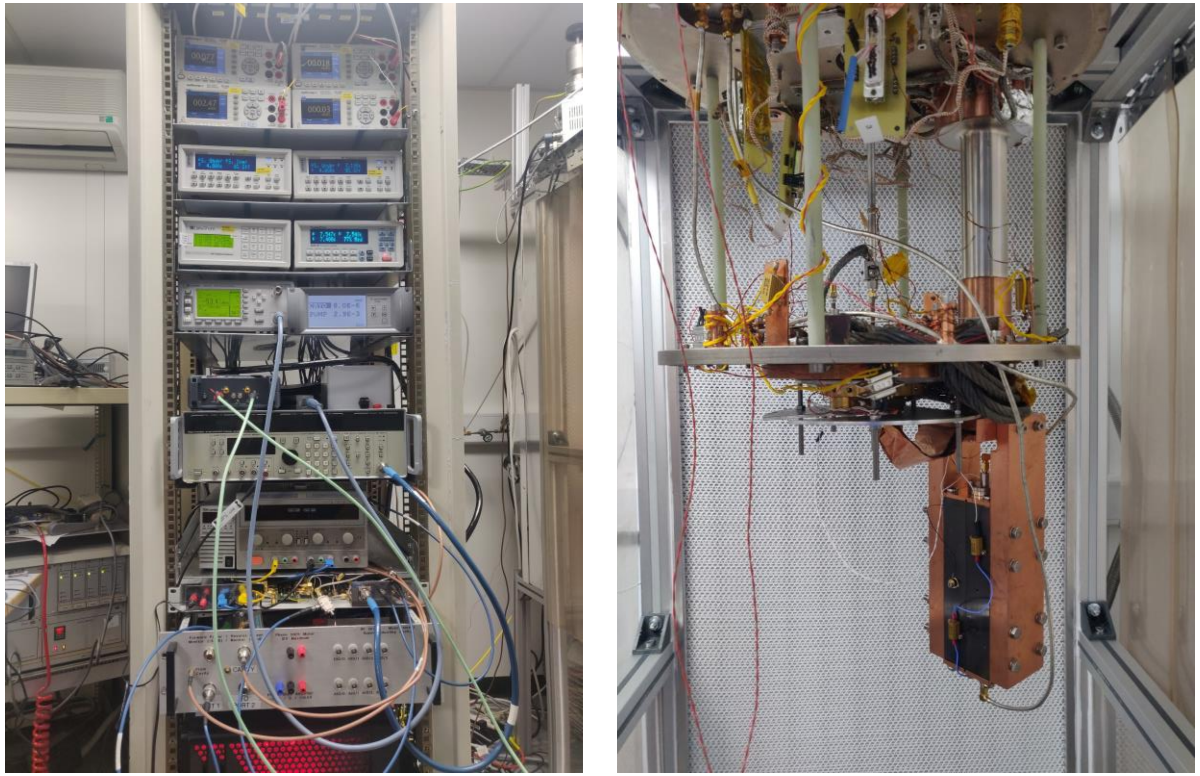
System Improvements for 1.3 GHz cavity upgrade

- Current Measurements on the 6 GHz cavity have been performed using a VNA
- Recording a frequency shift of approximately 100 Hz
  - Relating to an error of less than 1%
- Future cavities will be scaled up to 1.3 GHz
- 1.3 GHz cavity requires a higher level of frequency tracking than the 6 GHz cavity
- Furthermore, improvements to the deposition process mean narrower bandwidth measurements are required
- A Self-exciting loop (SEL) will be implemented in the system for future measurements in order to avoid errors due to frequency fluctuations



Existing system for the 6 GHz cavity

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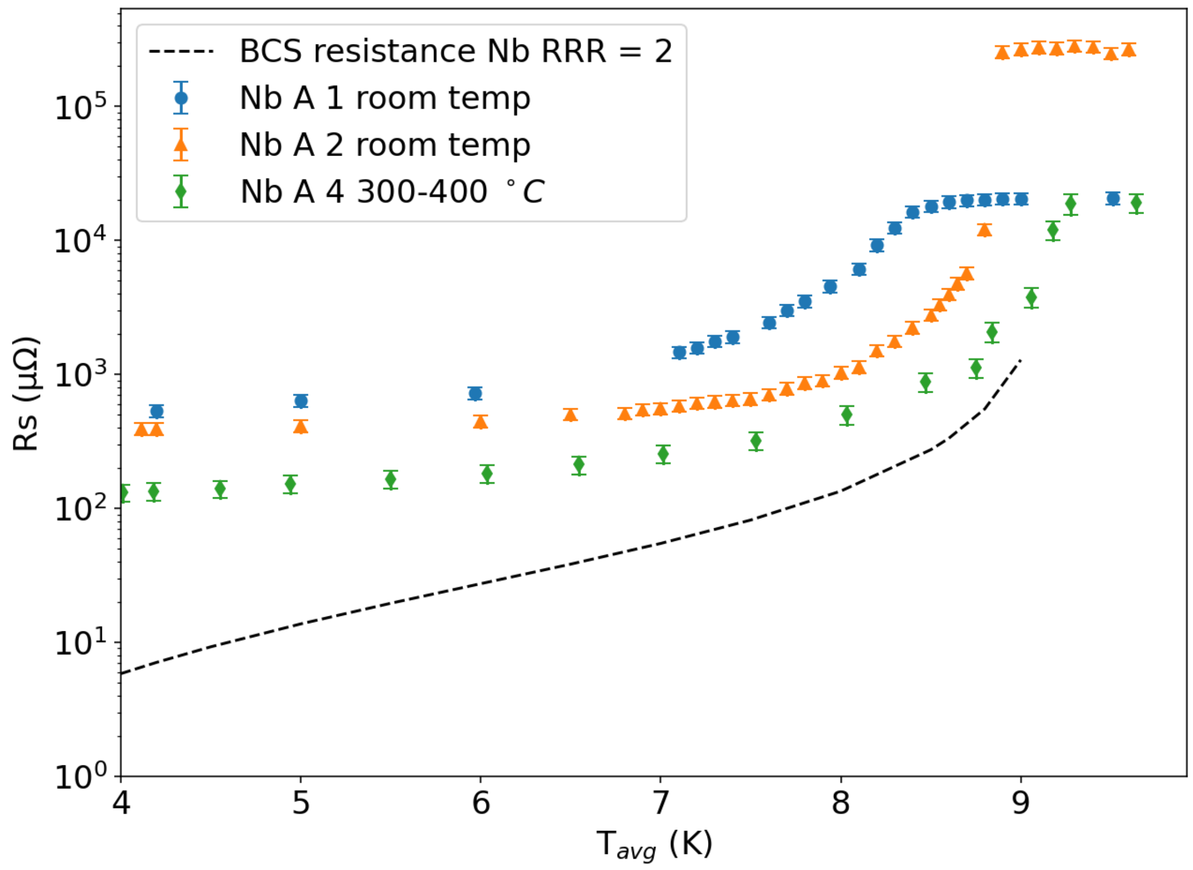
Effect of deposition temperature on R_s (T)



- 3 Niobium coatings
- Cylindrical magnetron sputtering for 1 and 2
- Planar magnetron sputtering for 4
- mechanical finish
- Deposition 1 and 2 at room temperature,
- Deposition 4 at T_{dep} = 300-400 °C.
- R_s at T_s = 4.2K improved from 532 +/- 10 μΩ to 131 +/- 5 μΩ
- Critical temperatures ranged from T_c = 8.4 +/- 0.3 K to 9.3 +/- 0.2 K
- System cleanliness could explain further improvements

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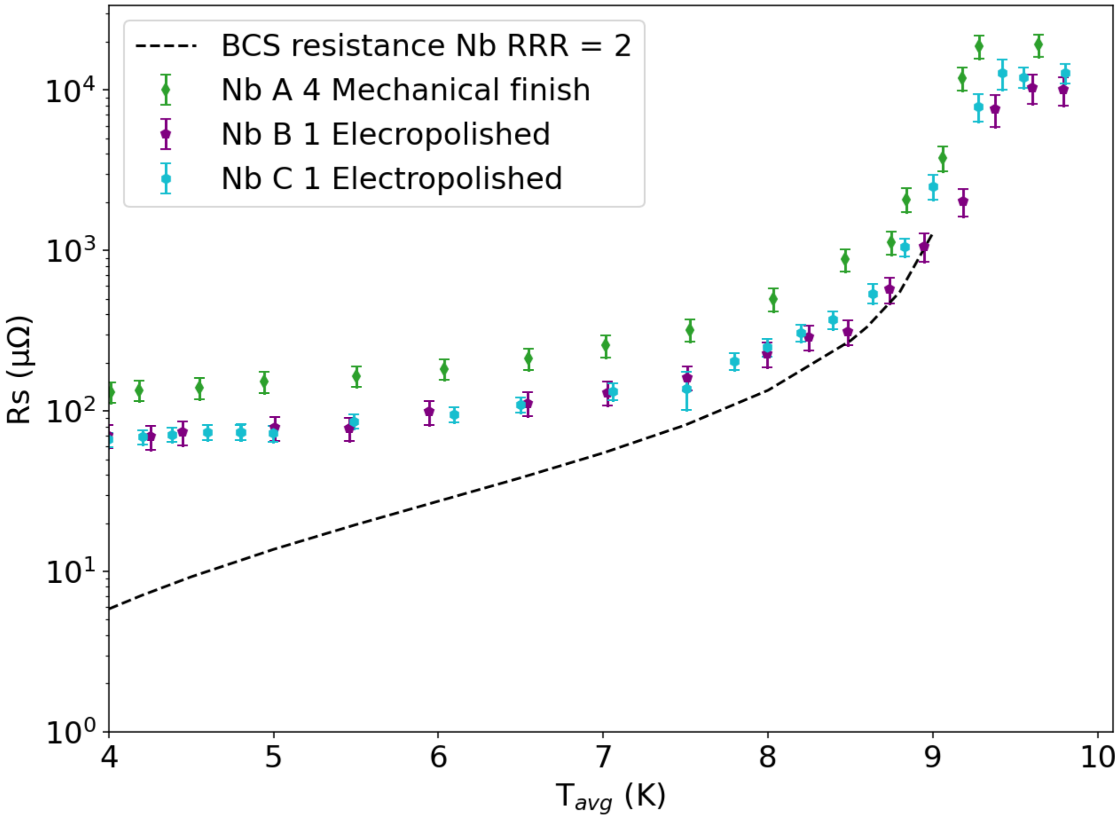
Effect of Substrate preparation on R_s (T)

- Cavity A was finished mechanically
- Cavity B and C were electropolished at IFN/LNFN creating a smoother finish
- All deposited at T_{dep} = 300 – 400 °C
- Lower R_s measured at T_s = 4.2 K from cavity B and C compared to A.
- R_s = 70 µΩ achieved on electropolished cavity
- Still higher than BCS resistance, suggesting that the cavity Geometry or deposition process could still be improved



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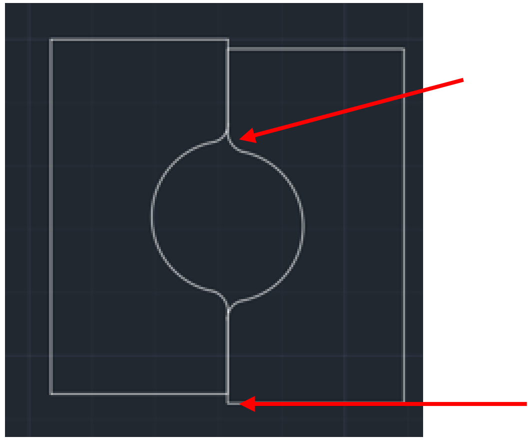
Cavity Optimization for 1.3 GHz test cavity

- Future cavity will be scaled up to a1.3 GHz cavity and redesigned for measurements in an updated system
- Cavity improvements focused on designing a cavity thin film testing
- The 1.3 GHz cavity geometry has been optimized in order to measure surface resistance (R_s) and critical temperature (T_c) at a range of RF magnetic fields of up to 80 mT
- Longitudinally split cavity design results in new considerations compared to a traditional cavity:
  - Misalignments (offsets) can occur when assembling. It is possible for up to a 500 µm offset to occur between the cavity halves
  - Small amounts of rounding at cavity edge can result in field enhancement



Rounding at the edge of the cavity – some amount of rounding is unavoidable

Offset

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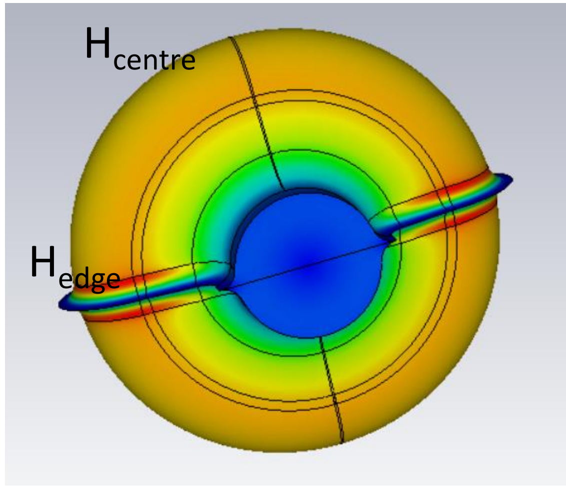
Fields at the cavity edge

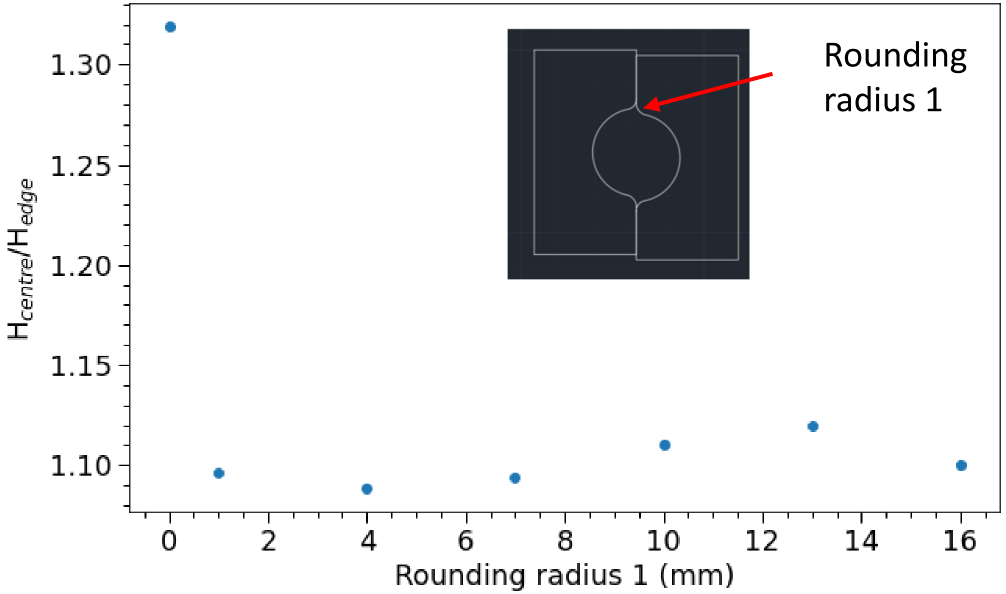
- To account for effects along the cavity split, H_{centre} and H_{edge} are considered separately
- A test cavity with the peak magnetic field at it's equator will perform better than one where it's at the cavity edge, as a misalignment (offset) in the cavity will result in less field enhancement
  - $H_{centre} > H_{edge}$
  - Field enhancement in the cavity means that an incorrect relationship between H_{pk} and R_s may be found
- Minimising sharp edges at the split can also reduce field enhancement
  - Adding an additional rounding radius (rounding radius 1) to the edges of the cavity can reduce ratio of H_{centre} and H_{edge} when there is a 500 µm offset

H_{edge} is the peak field in an area from the cavity split reaching 20 mm in each direction

H_{centre} is the peak field in the rest of the cavity away from the cavity split

H_{pk} is the peak field in the whole cavity





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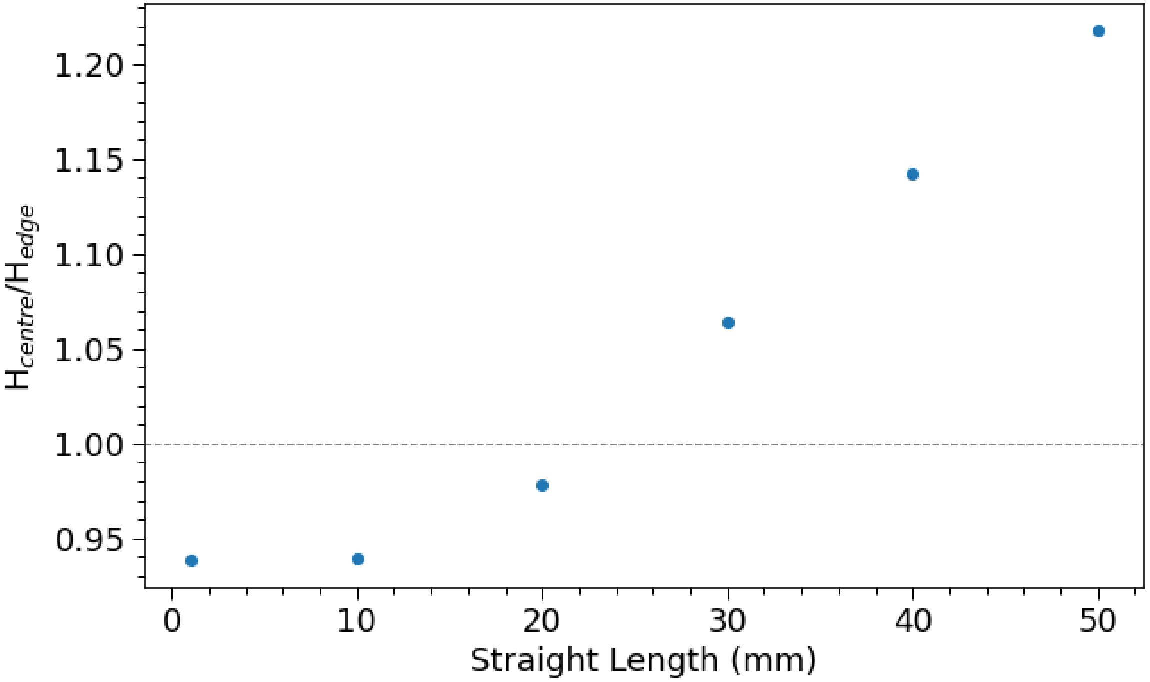
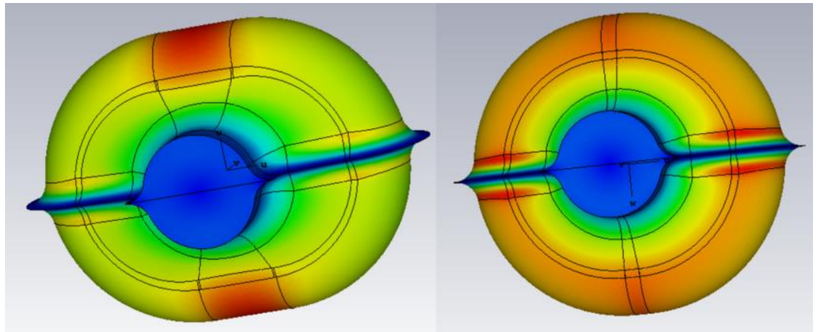
Straight Length

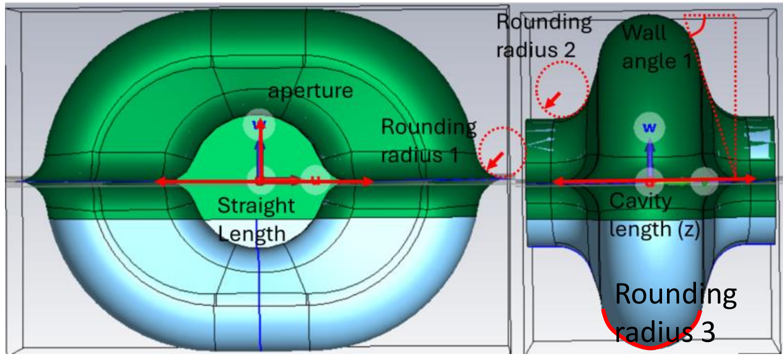
- The cavity geometry can be changed so its transverse cross section becomes elliptical rather than round
- This can be done by adding a straight length between 2 hemispheres to create a racetrack cavity
- Inspired by research for CLIC which shows that a racetrack geometry can be used to reduce or manipulate the location of peak magnetic fields
- Increasing straight length was found to move the peak magnetic field from the edge to the equator where misalignment in the cavity would have less impact



Ratio of H_{centre} to H_{edge} when there is a 500 micron offset



Constant Parameters	Value
Rounding radius 1	9 mm
Wall angle	1.46 rad
Aperture	35 mm
Rounding radius 2	12 mm
Cavity length	115.4 mm



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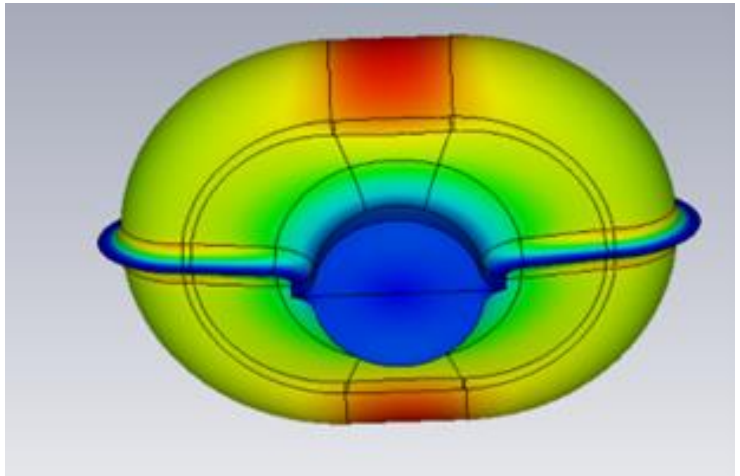
Cavity Optimization for 1.3 GHz test cavity

- Cavity being designed for SRF testing can be optimized to avoid field emission
  - Field emission can cause localised temperature increases, increasing R_s and reducing Q factor
  - This should be avoided in order to measure only the effect of the change in magnetic field
  - Therefore at the maximum magnetic field of 80 mT, E_{pk} should be less than 15 MV m^{-1} (B_{pk}/E_{pk} > 5 mT MV^{-1} m)

- In order to avoid overlapping HOMs, the TE_{111} mode should be greater than 1.6 GHz.



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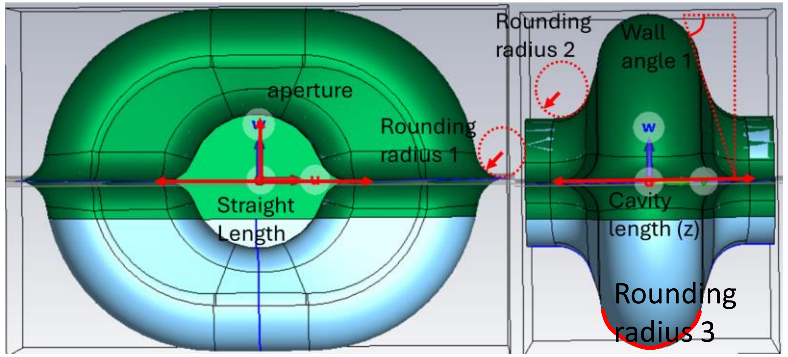
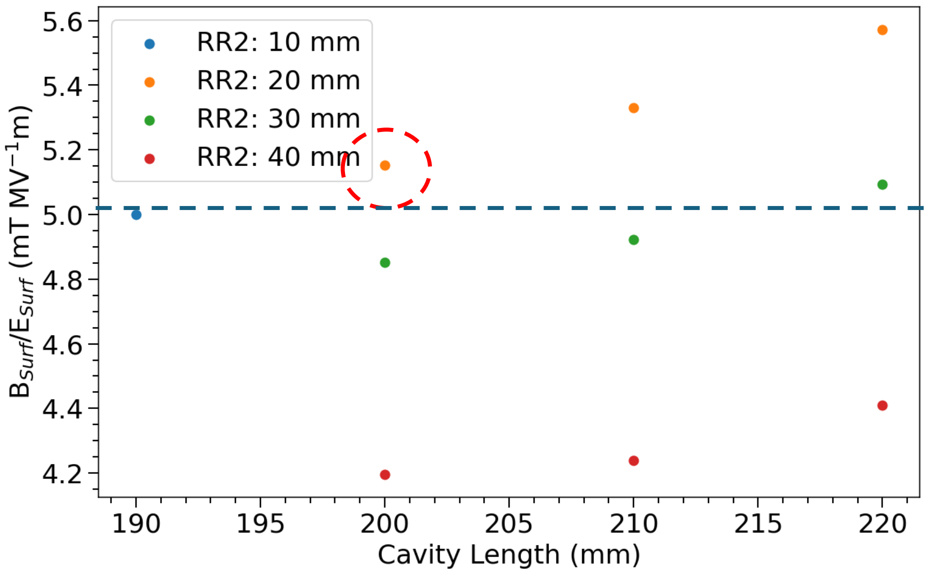
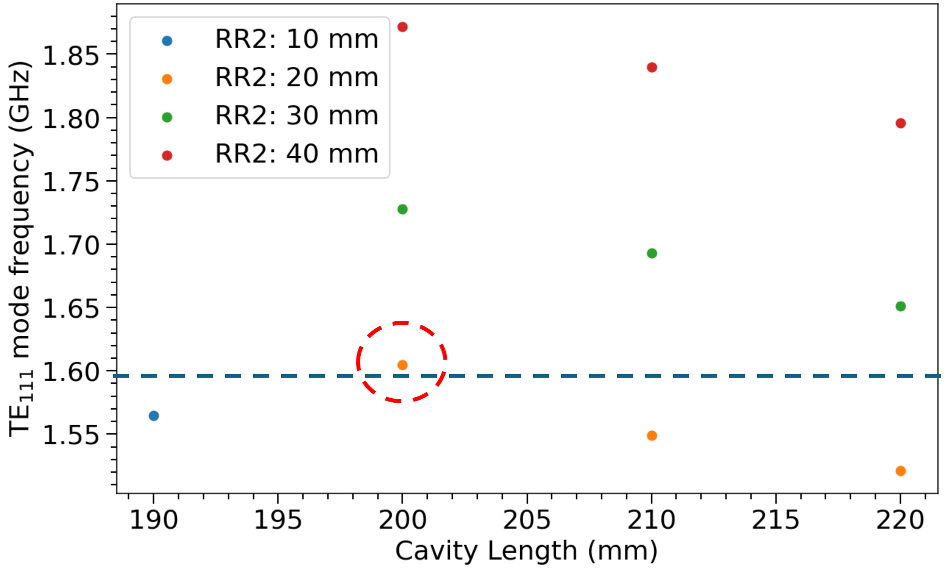
Cavity length

- Increasing the cavity length significantly improves the ratio of B_{pk}/E_{pk} (where B_{pk} and E_{pk} are the peak magnetic field on the surface of the cavity)
- However it brings down the TE_{111} mode
- Between 200 and 300 mm significant improvements to B_{pk}/E_{pk} can be found
- Scanning multiple parameters simultaneously allowed all targets to be met

Constant Parameters	Value
Rounding radius 2	12 mm
Straight Length	300 mm
Aperture	35 mm
Rounding radius 3	30 mm
Cavity length	200 mm







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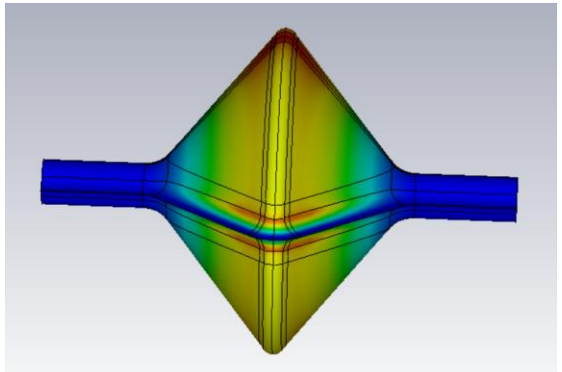
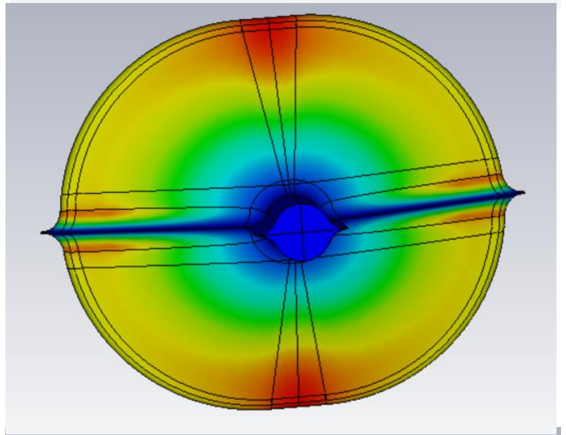
Optimized 1.3 GHz test cavity design

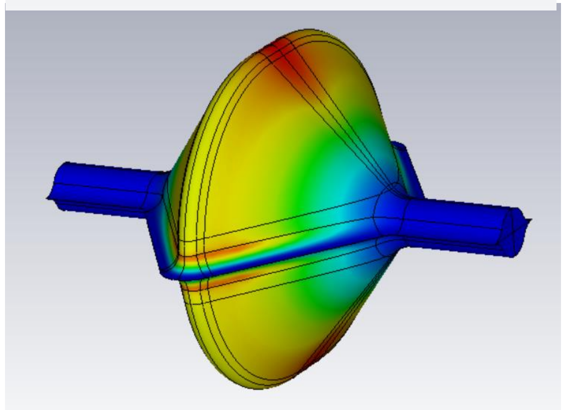
The final cavity design:

- Is longer than a traditional cavity (200mm for a 1.3 GHz cavity)
- Is racetrack shaped (300 mm straight length)
- Has a rounded edge on the split (12 mm rounding)
- Has smaller rounding radii at the join between the cavity and the beampipe (20 mm and 30 mm)
- Has a small beampipe aperture (15 mm)

- B_{pk}/E_{pk} of 5.2 mT m MV^{-1} relating to a peak electric field of 8.82 MV m^{-1} when an 80 mT field is applied
- TE_{111} mode = 1.62 GHz
- $B_{centre}/B_{edge} > 1$
- Field enhancement could cause peak fields of up to B_{pk} = 80.08 ± 0.02 mT with a 500 µm offset.
- Power dissipated in cavity = 46.1 W







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Next steps

- Mechanical design considerations such as
  - Couplers
  - Manufacturing process decisions
  - Clamp design for cryocooled experiment under construction
  - Aiming to produce a 1.3 GHz cavity by the end of the year in order to begin testing in 2025

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Conclusion

- 70 μΩ surface resistance achieved for 6 GHz split cavity
  - Deposited at 300-400 °C
  - Electropolished substrate
- A new 1.3 GHz cavity has been designed with a novel geometry
  - To improve SRF thin film test accuracy
  - Aiming to produce cavity ready for testing by the end of this year
- System upgrades including the addition of an SEL will allow for further improvements

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