Progress on the design and Testing on Longitudinally Split RF cavities

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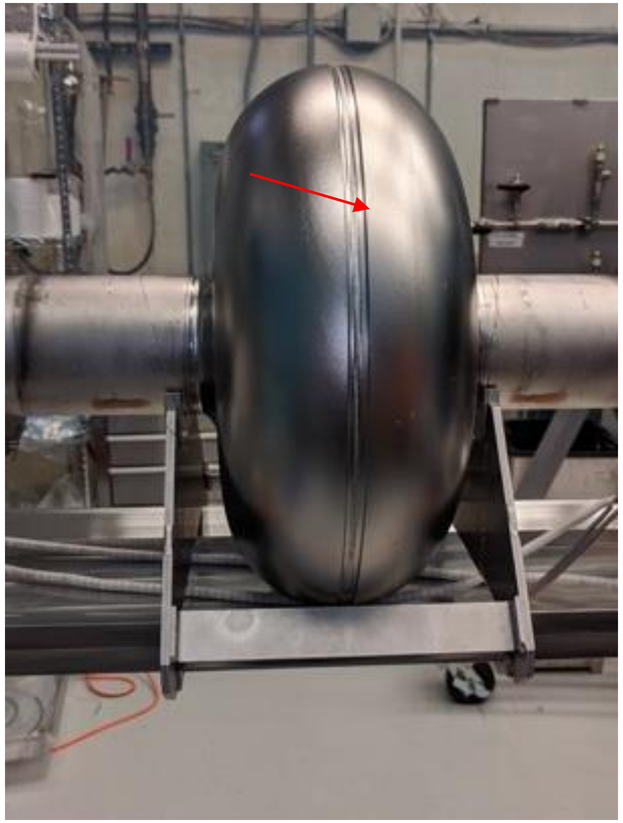
This work has been supported by the IFAST collaboration which has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 101004730.

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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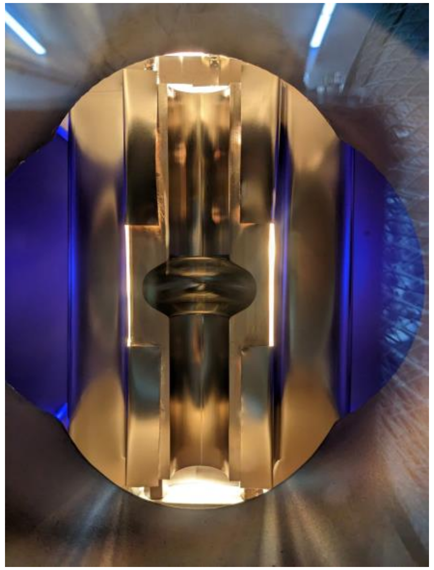
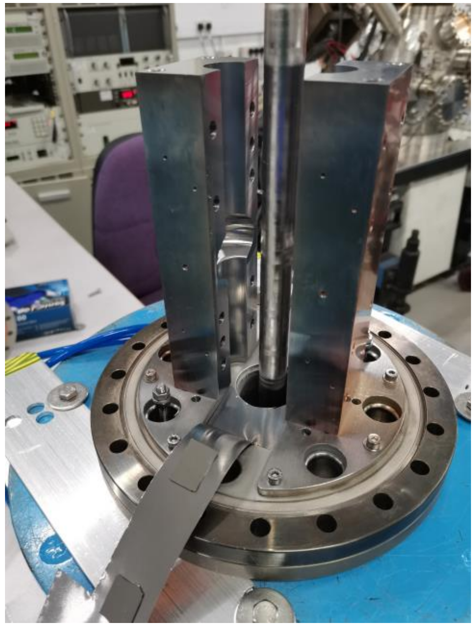
6 GHz Longitudinally split cavity deposition





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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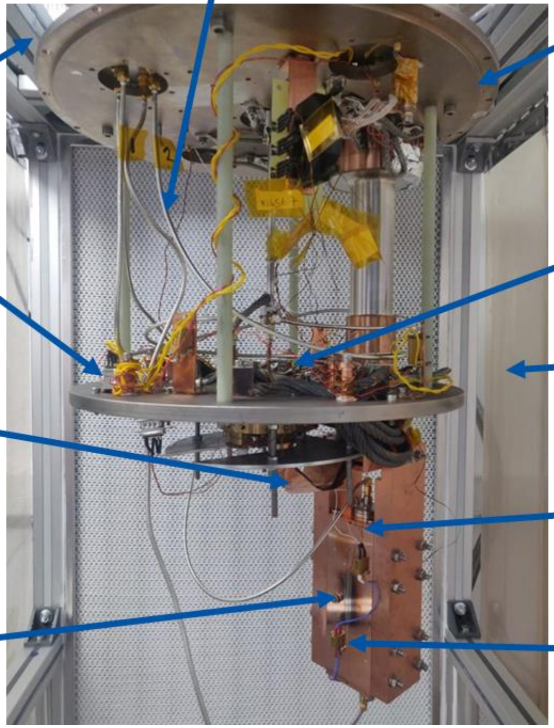
Cavity Design and test facility

- 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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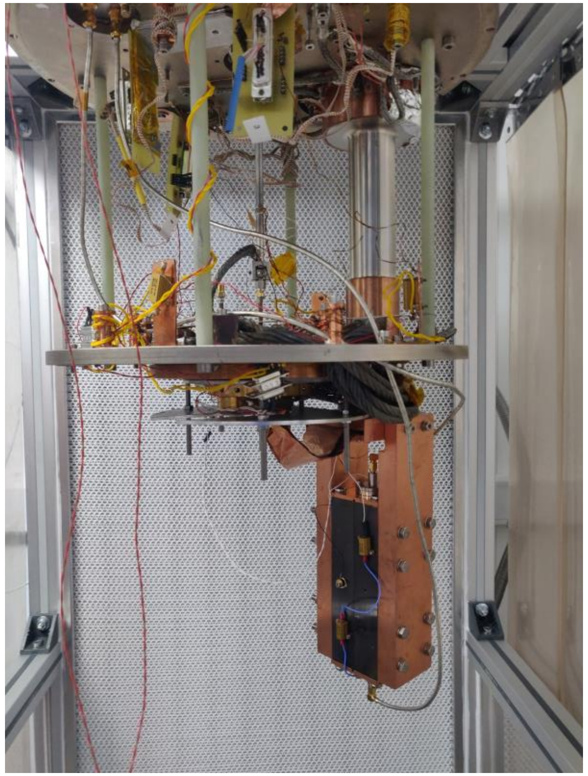
System Improvements for 1.3 GHz cavity upgrade

- 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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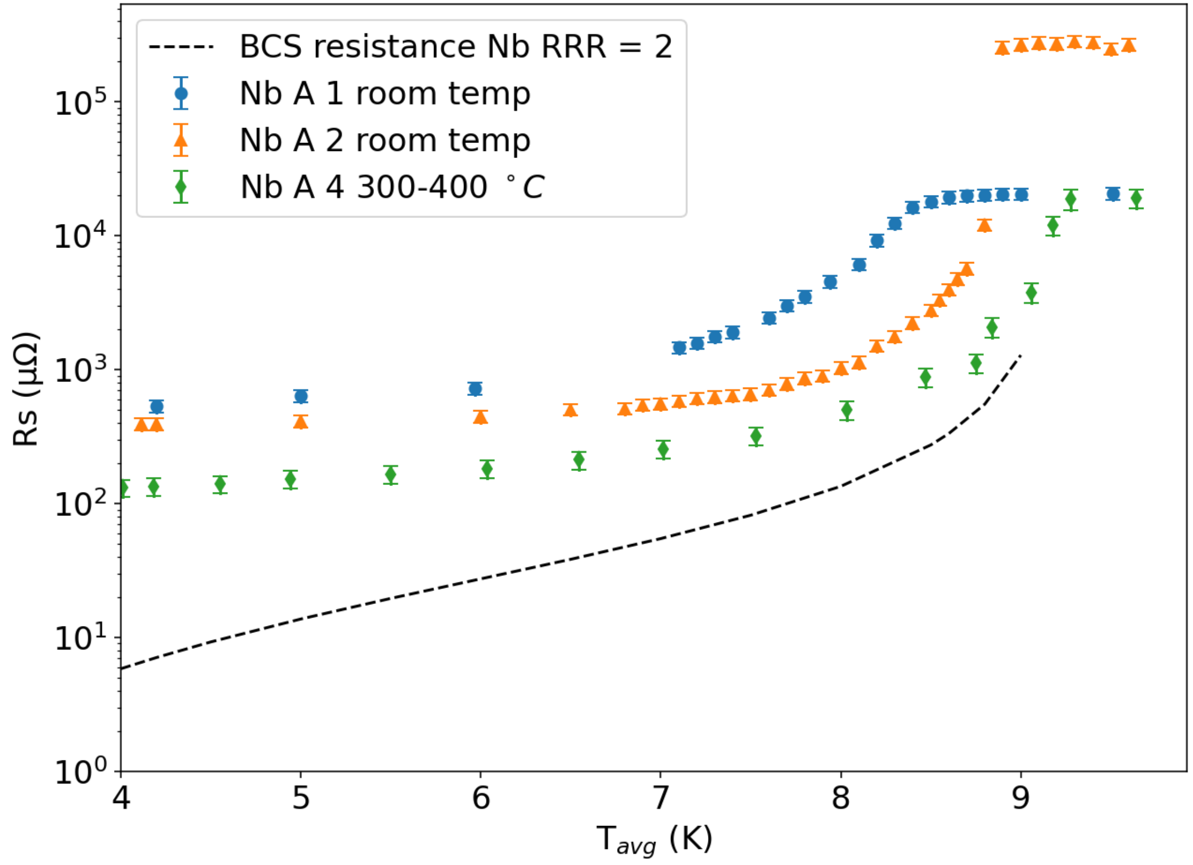
Effect of deposition temperature on R_s (T)



- 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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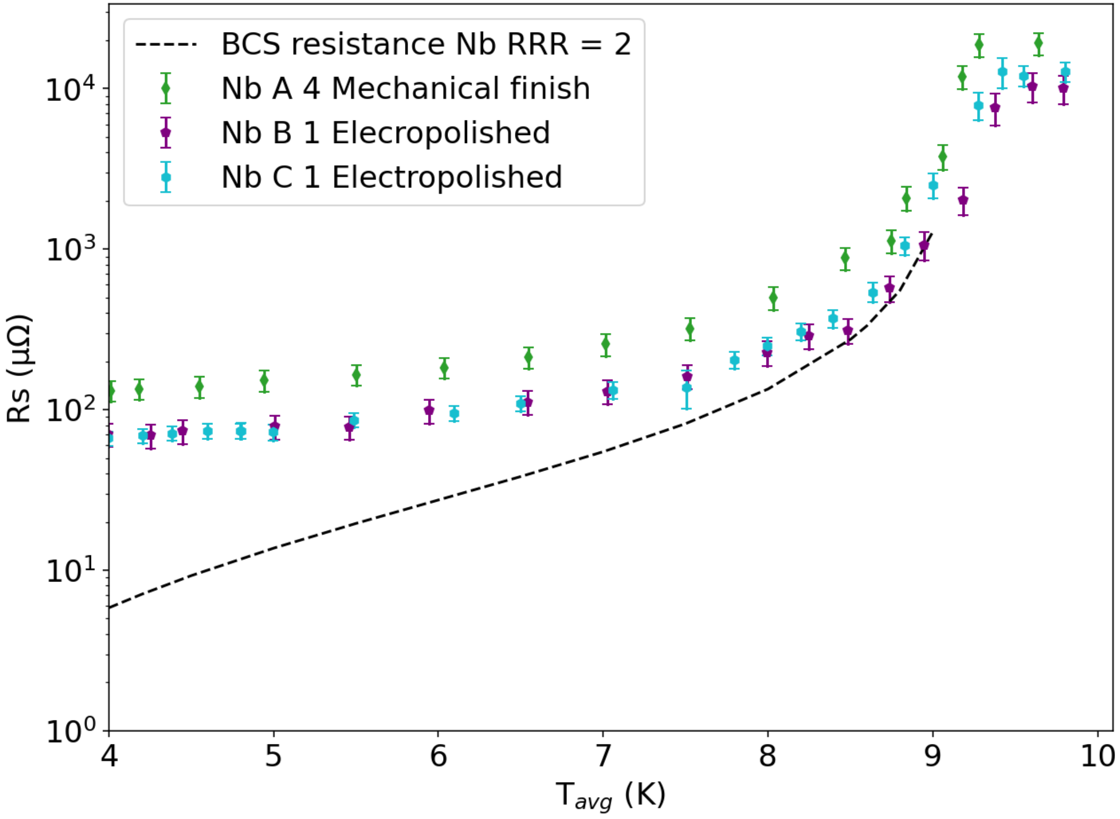
Effect of Substrate preparation on R_s (T)

- 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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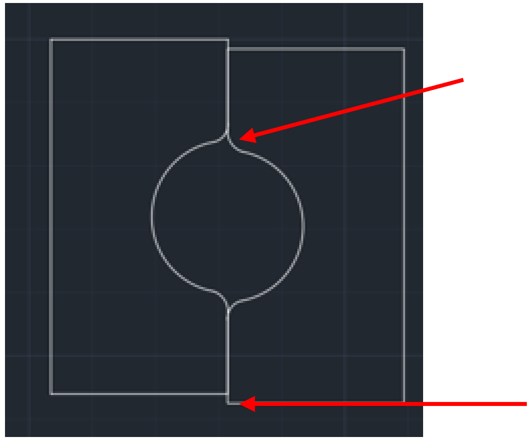
Cavity Optimization for 1.3 GHz test cavity

- 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



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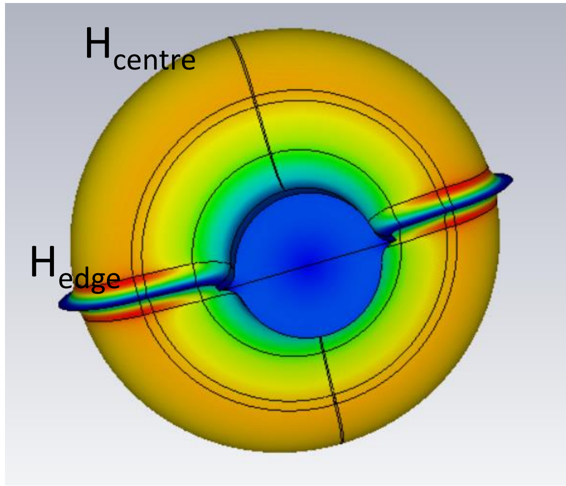
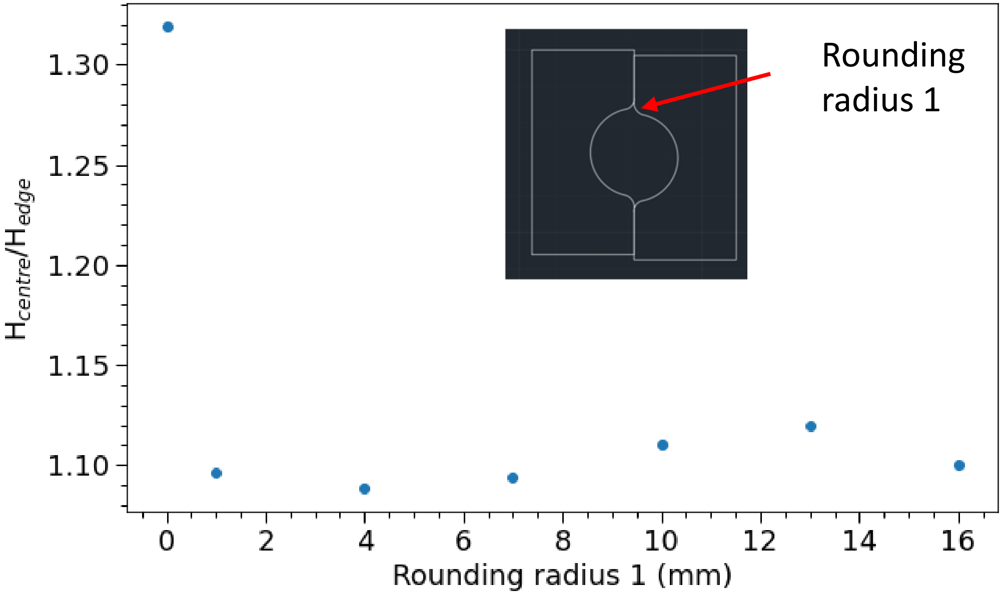
Fields at the cavity edge

- 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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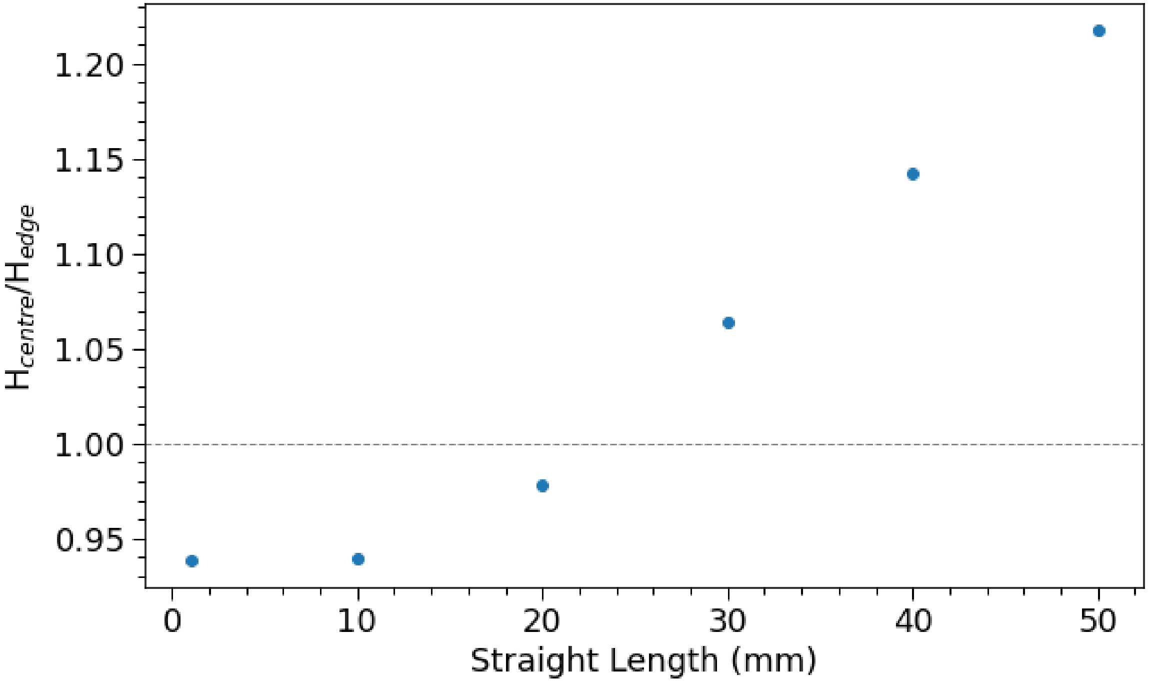
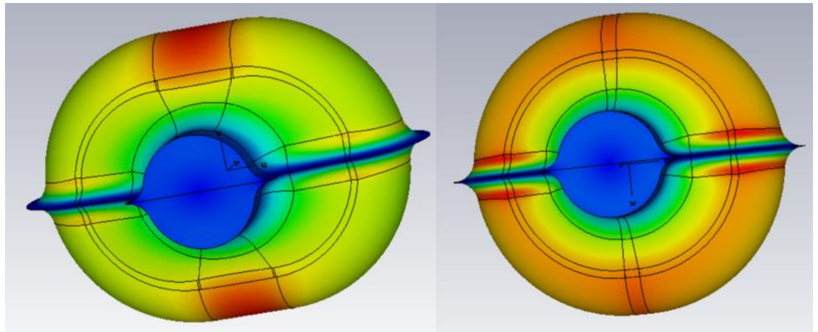
Straight Length

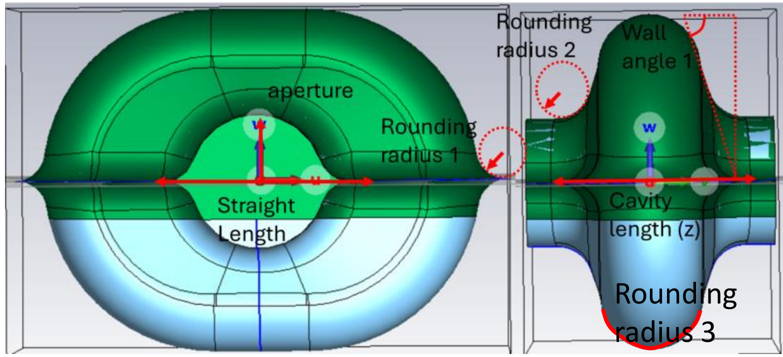
- The cavity geometry can be changed so its transverse cross section becomes elliptical rather than round
- This can be done by adding a straight length between 2 hemispheres to create a racetrack cavity
- Inspired by research for CLIC which shows that a racetrack geometry can be used to reduce or manipulate 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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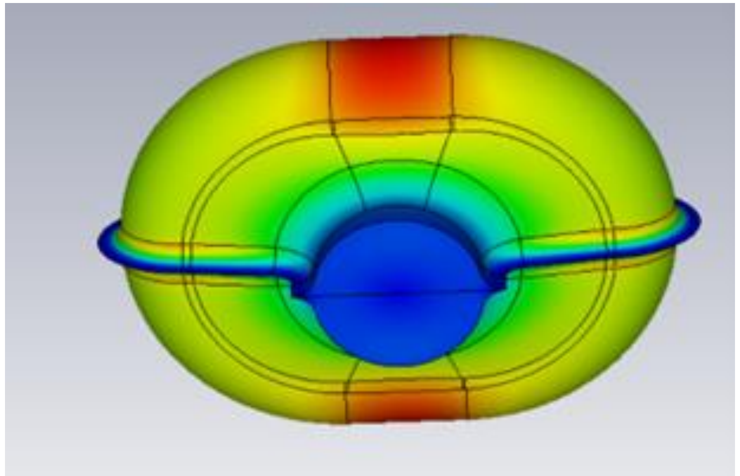
Cavity Optimization for 1.3 GHz test cavity

- 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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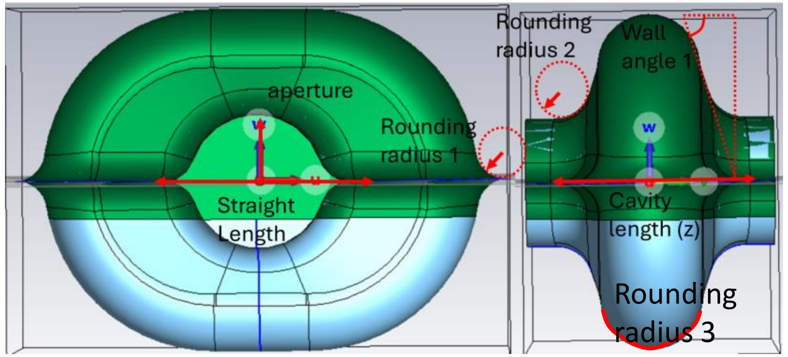
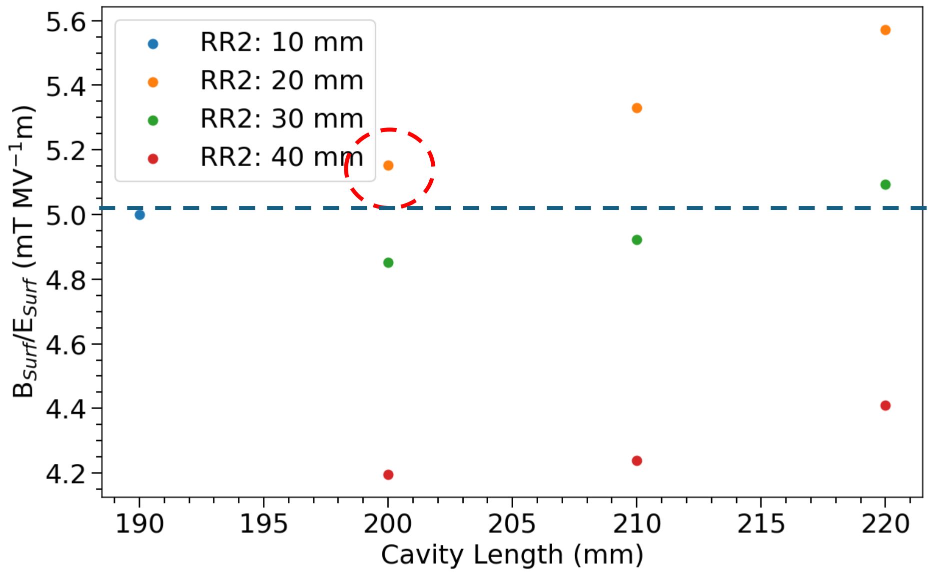
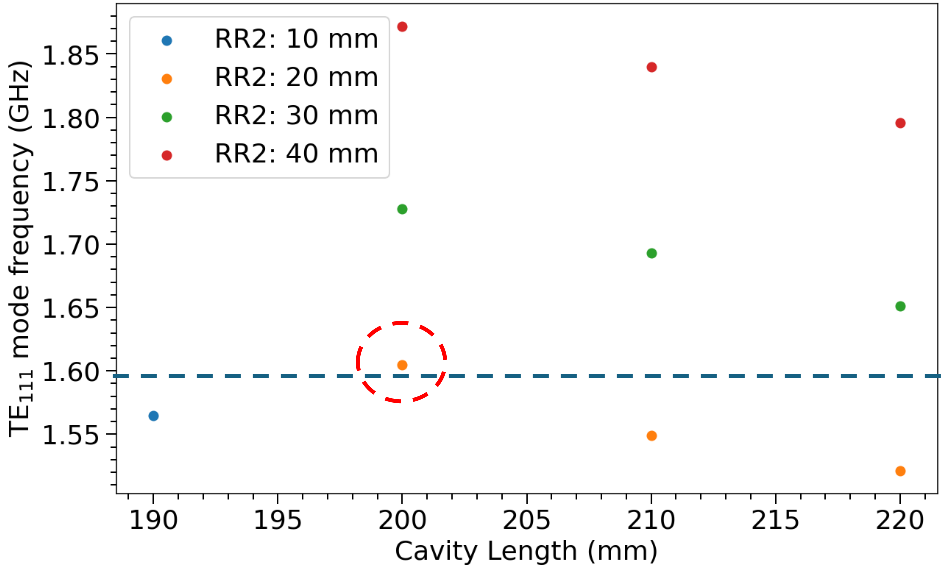
Cavity length

- 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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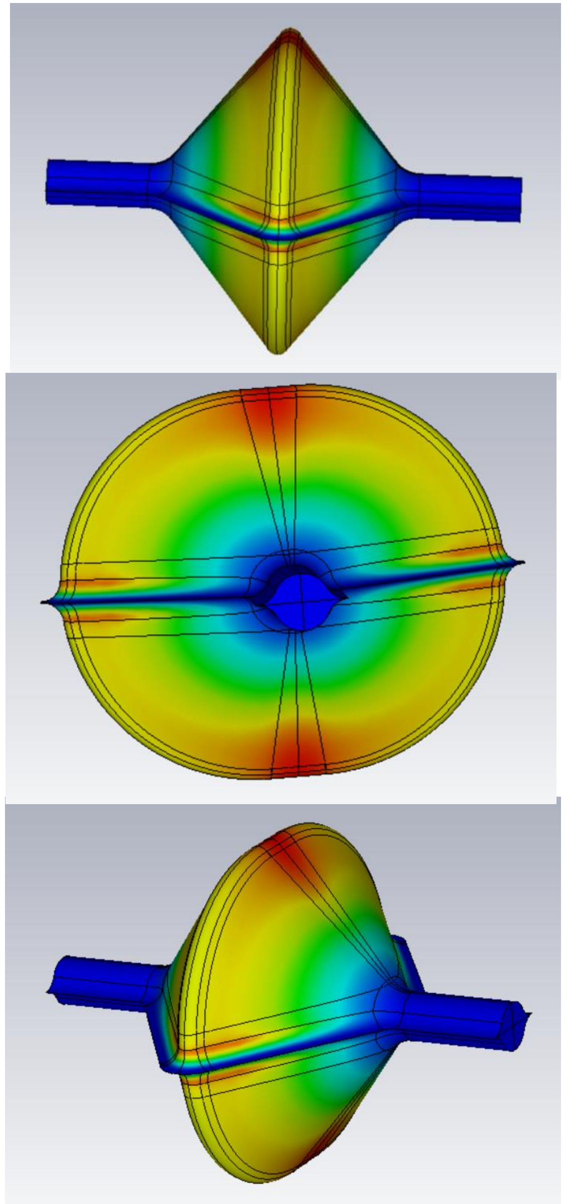
Optimized 1.3 GHz test cavity design

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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Acknowledgements

STFC/CI: O. B. Malyshev, T. Sian, R. Valizadeh, L. Smith, J. Conlon, C. Benjamin, S. Pattalwar, A. Blackett-May, A. Vick, S. Bibby-Trevor, R. McAllister, K. Sian

Lancaster University/CI: G. Burt, N. Leicester, H. Marks, A. Mogheyseh

University of Liverpool/CI: S. Simon, J. Bradley

INFN: C. Pira, E. Chyhyrynets

This work has been supported by: the IFAST collaboration which has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 101004730.