Helmholtz Zentrum Berlin

Mapping Flux Trapping in SRF Cavities to Analyze the Impact of Geometry

F. Kramer, J. Köszegi, O. Kugeler, J. Knobloch

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Surface resistance due to trapped magnetic flux

- Residual resistance increases due to trapped magnetic flux
- Increase fundamental knowledge about trapped magnetic flux
- Different Parameters:
    - **Materials**
    - **Cooldown**
    - **Geometry**

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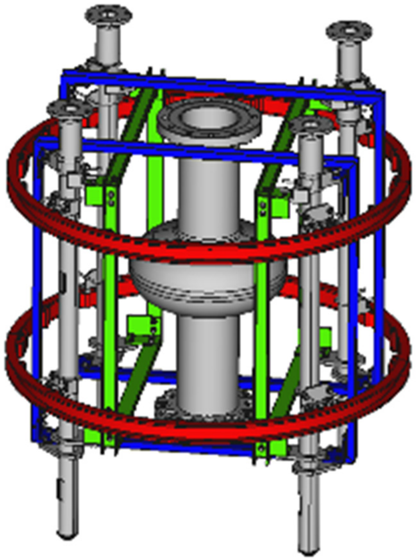
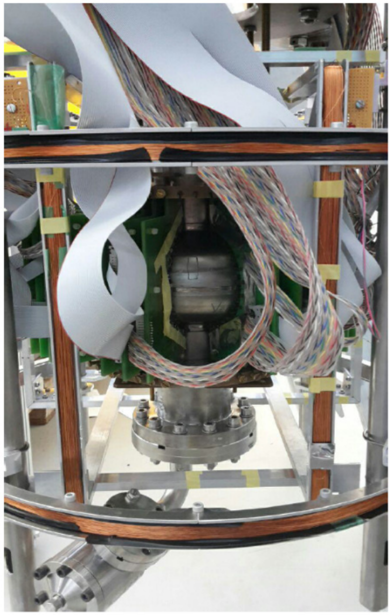
Two main questions:

- How is magnetic flux trapped in the cavity?
  - **How is it distributed?**
  - **How is it Orientated?**
  - **How much is trapped?**
- How does the trapped flux influence the surface resistance?
  - **Average surface resistance**
  - **Local surface resistance**

Magnetic field source:

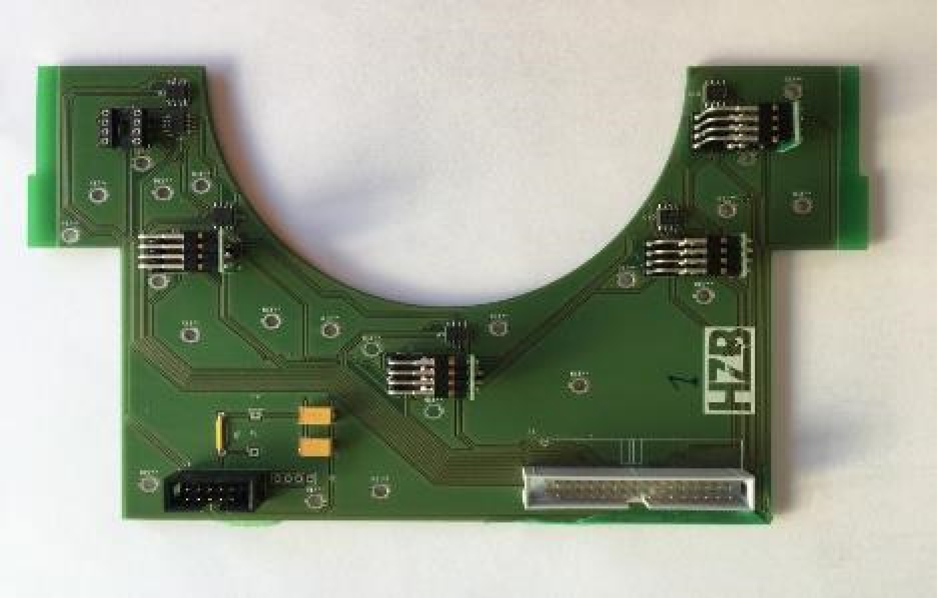
- 1.3 GHz TESLA single cell
- 3 Helmholtz coils in x, y, z
- Apply field in arbitrary direction

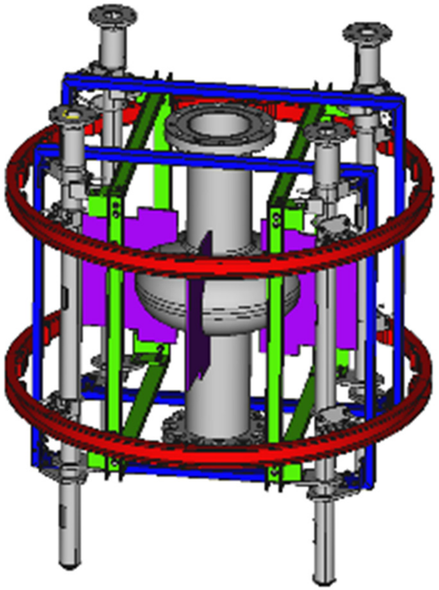


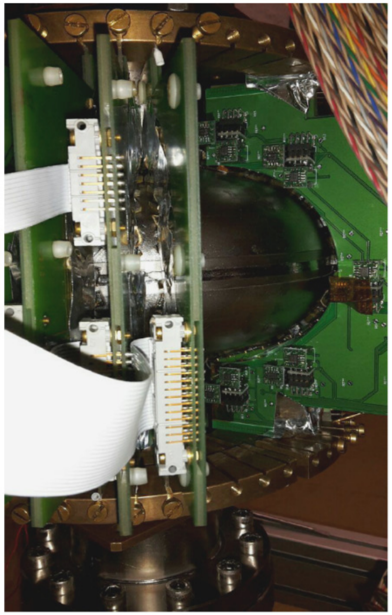


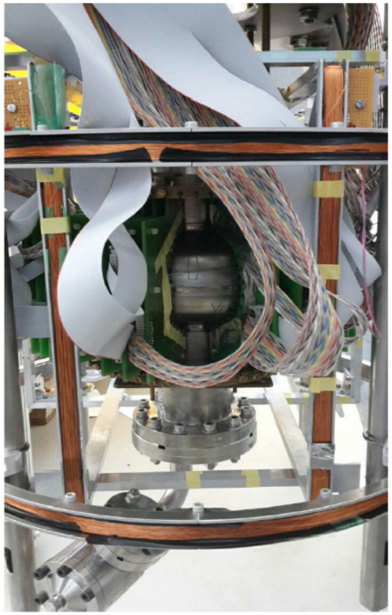
Magnetic field mapping setup:

- 3 sensors in one group (r, z, ϕ)
- 5 groups on one card (rz plane)
- 4 cards around cavity (ϕ)
- Data acquisition hardware: 2 ms for complete cavity map
- Helmholtz coils for x, y, z



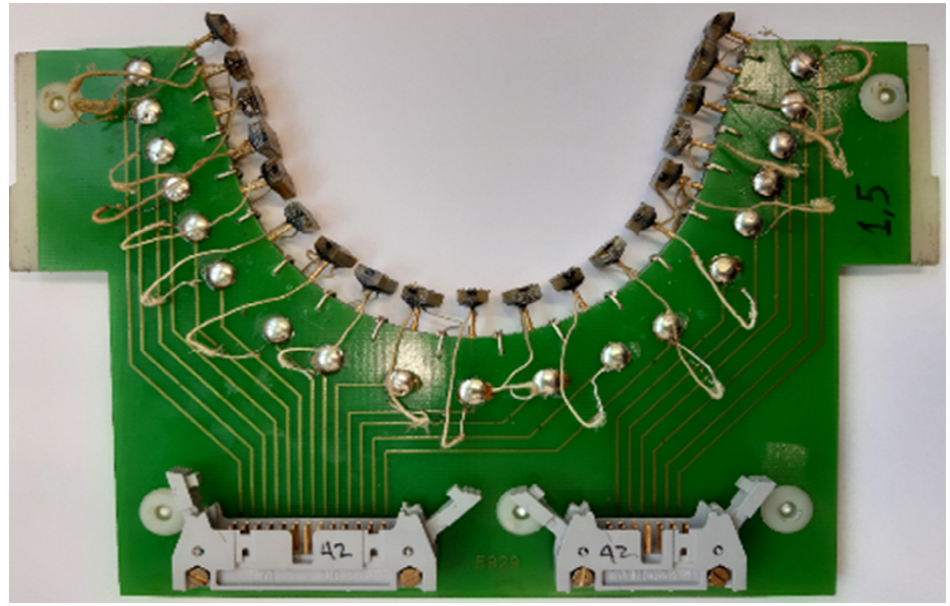


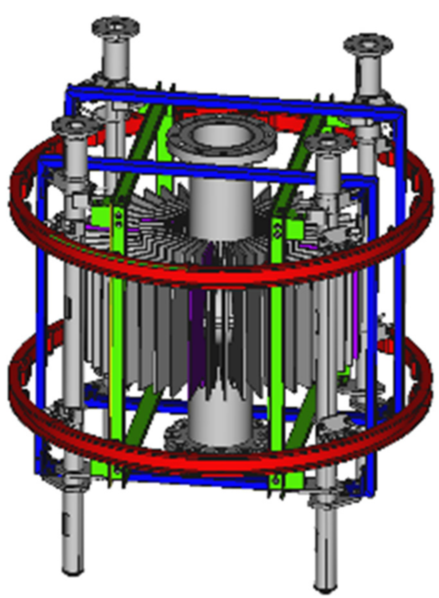


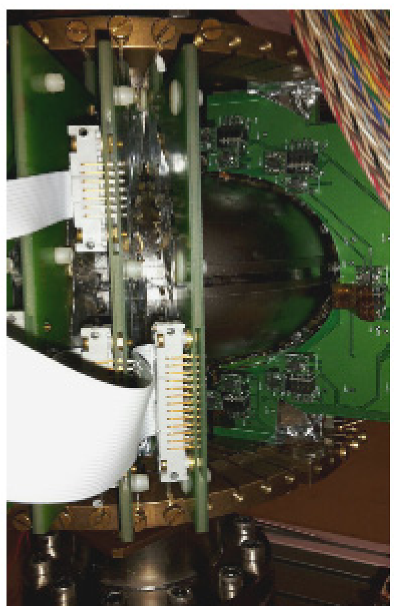


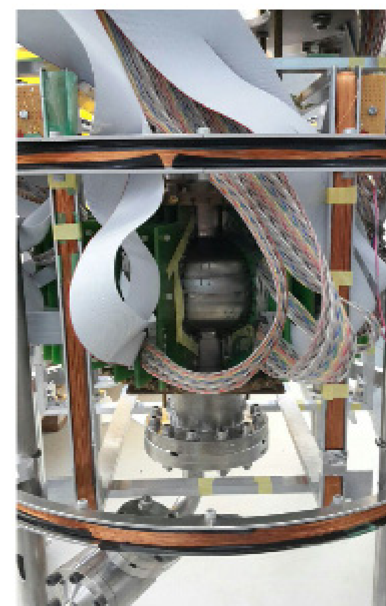
Mapping setup:

- T mapping (from DESY)
- B: 3 sensors in one group (r, z, ϕ)
- B: 5 groups on one card (rz plane)
- B: 4 cards around cavity (ϕ)
- Data acquisition hardware: 2 ms for complete cavity map
- Helmholtz coils for x, y, z









B- & T-map on a 3D model

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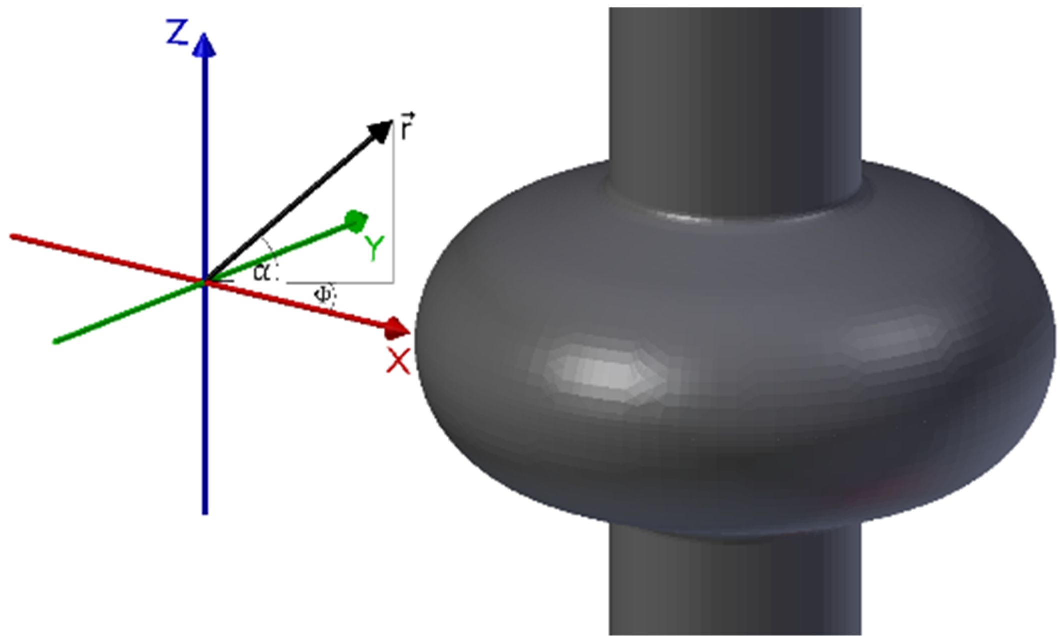
Goal: Investigate trapped flux and surface resistance
for different external magnetic field orientations

B = 10µT

Polar angle α = [0, 15, 30, 45, 60, 75, 90]°

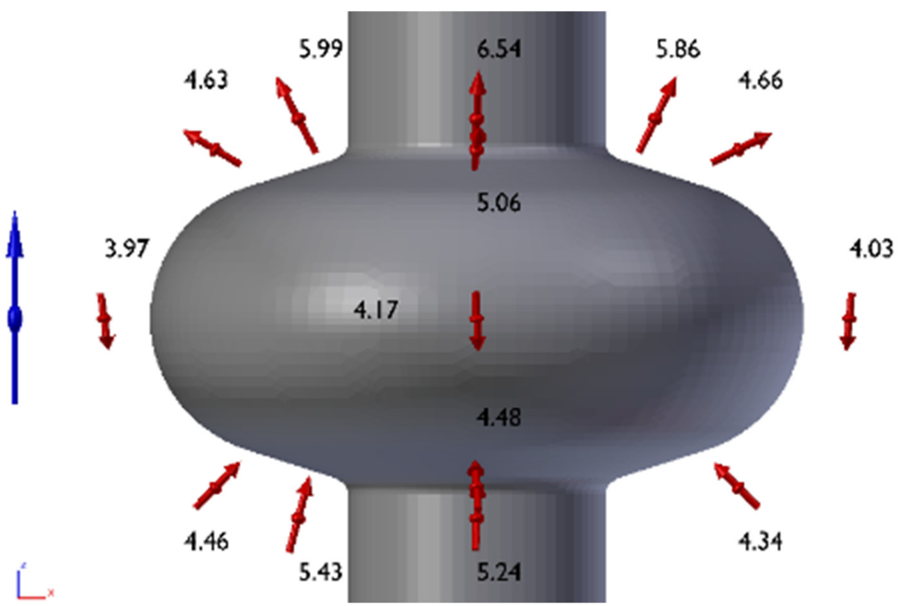
Azimuthal angle ϕ rotated once 90° at $\alpha = 0°$

Cavity: 1DE13, fine grain niobium

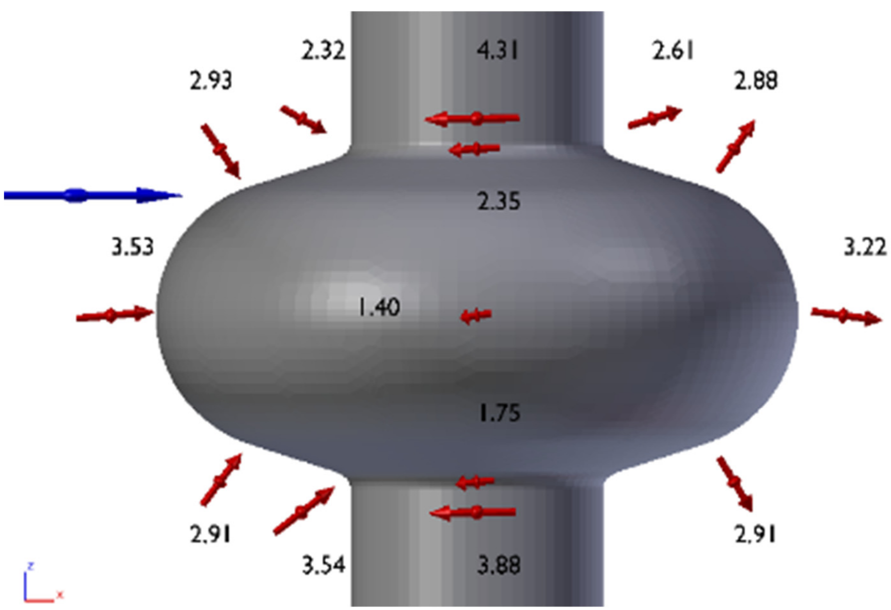


Relative measurements
Calibration point: After phase transition to superconducting with only background field

1. Cooldown with applied field (B=10µT)
2. Turn external field off
3. Measure remaining field



Field applied vertically



Field applied horizontally

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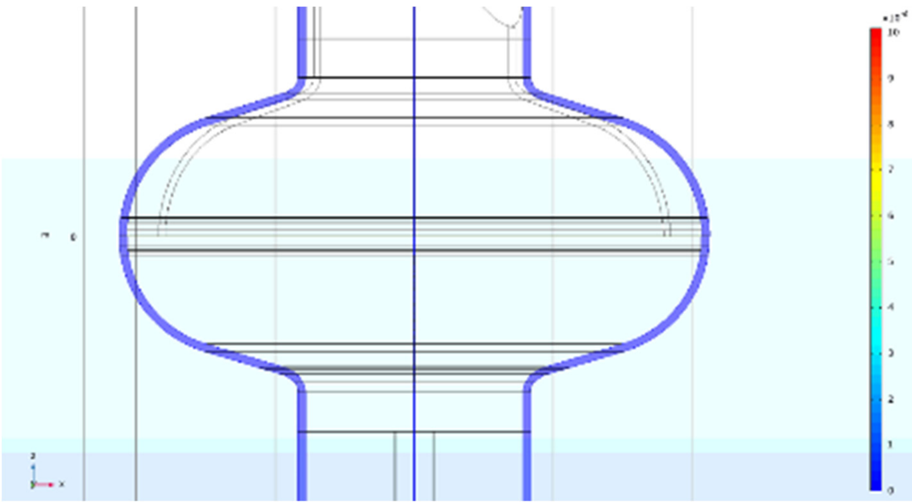
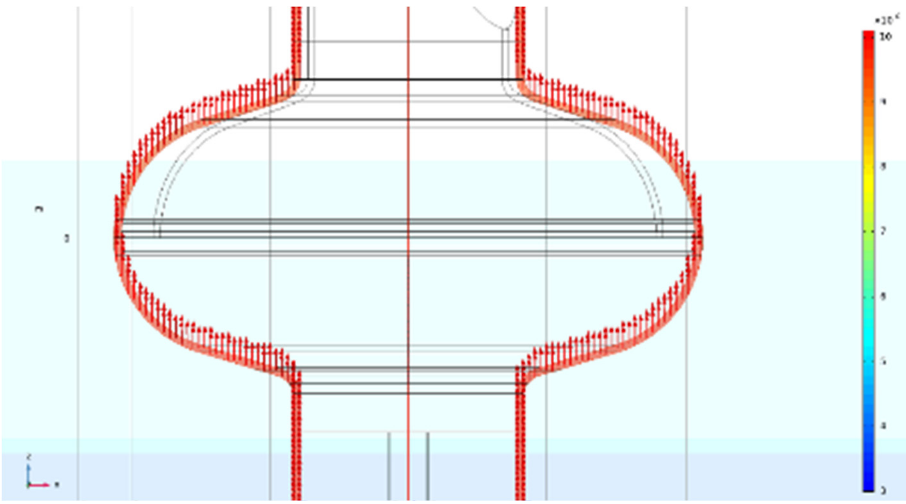
Simulation: Uniform flux density of 10µT in cavity wall
=> Uniform trapping
=> 100% trapping



Applied field in Z-direction

Simulation: Uniform flux density of 10µT in cavity wall
=> Uniform trapping
=> 100% trapping



Applied field in Z-direction

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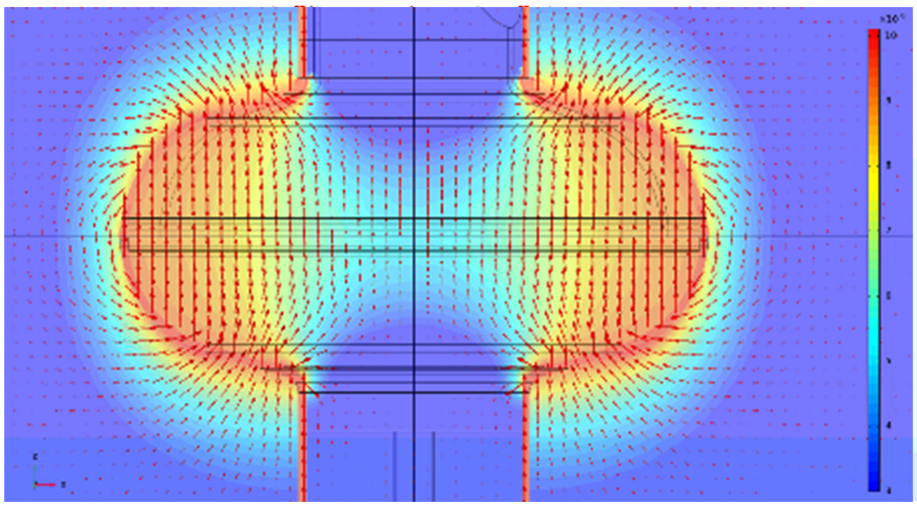
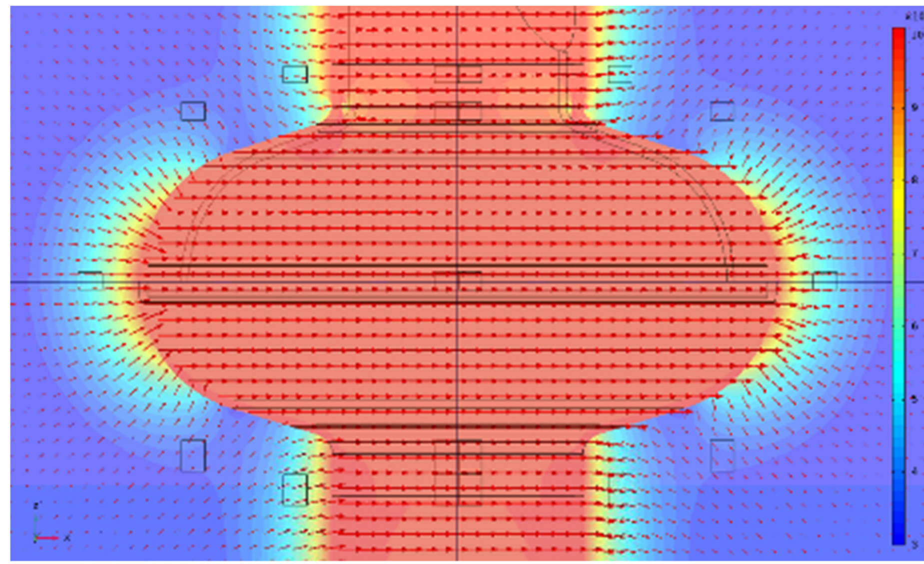


Applied field in Z-direction



Applied field in X-direction

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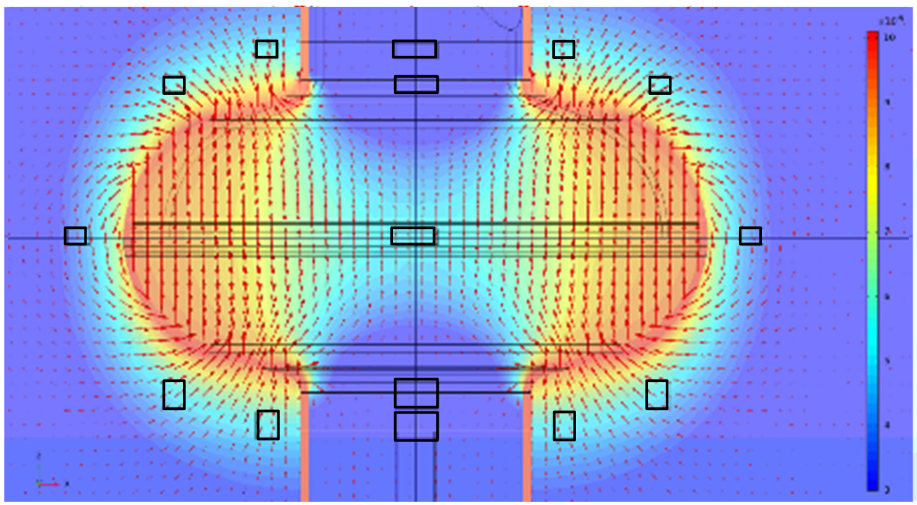
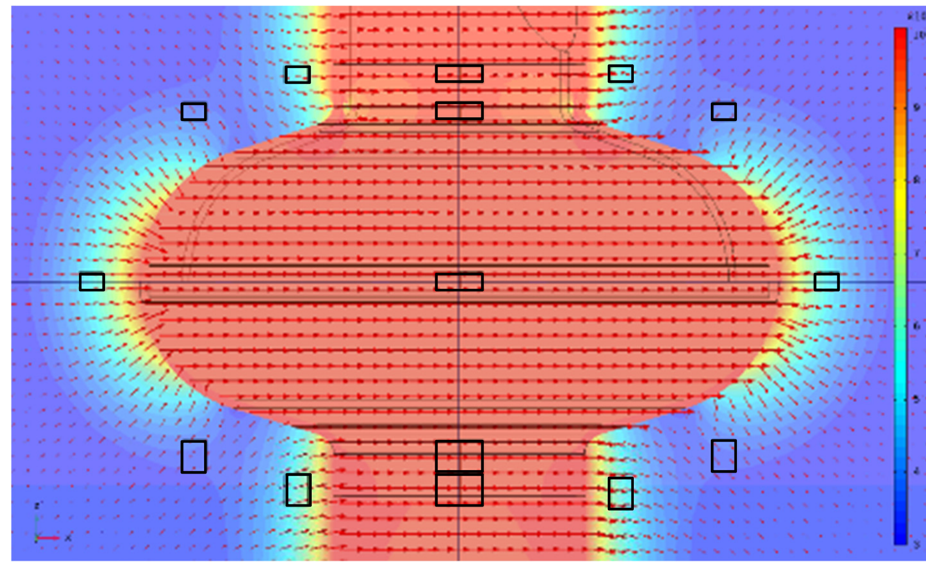


Applied field in Z-direction

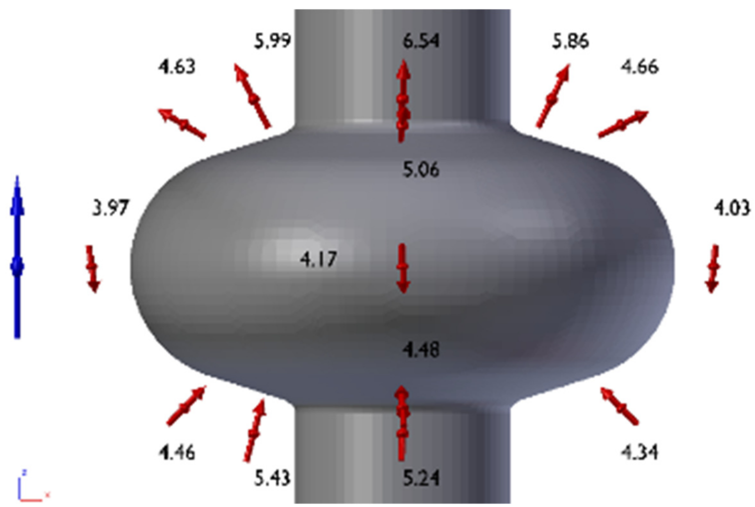


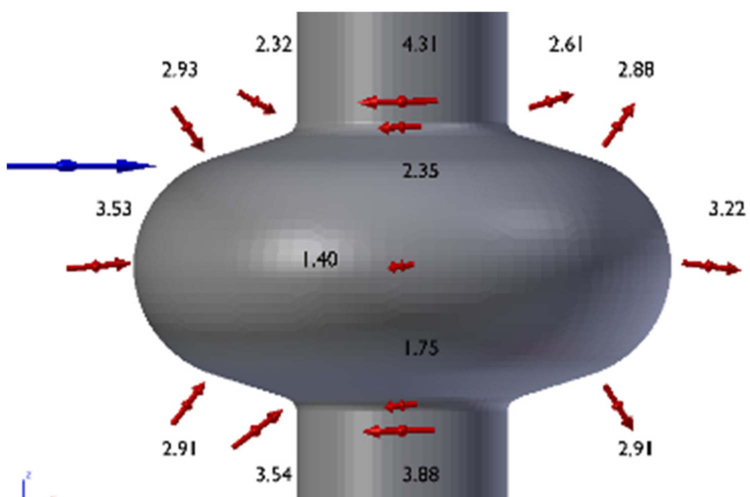
Applied field in X-direction

HOW IS THE FLUX TRAPPED?

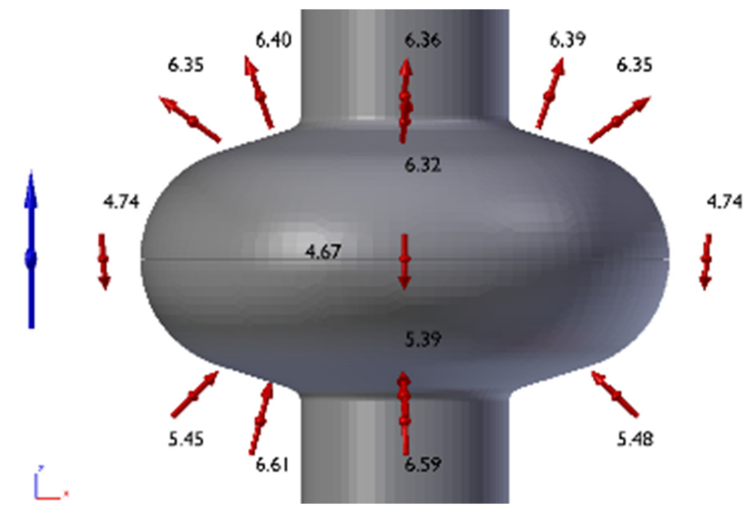
Comparison measurement ⇔ simulation: Homogenous trapping without reorientation of flux lines

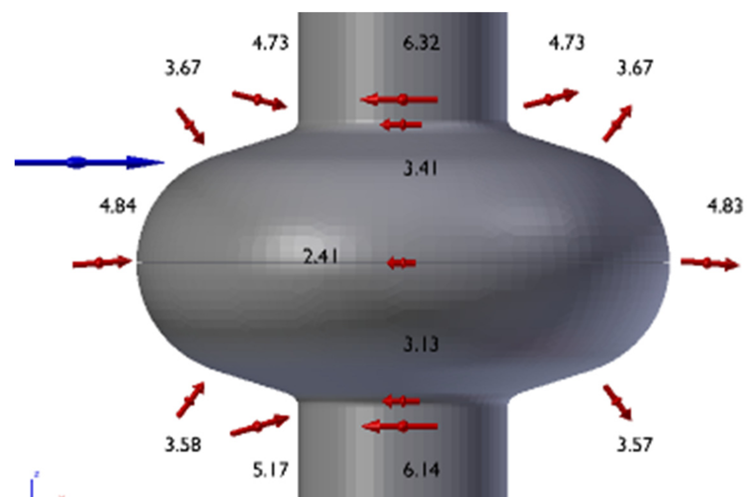
Measurement





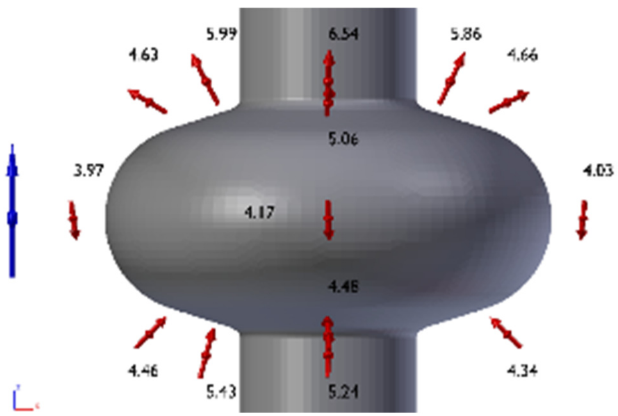
Simulation



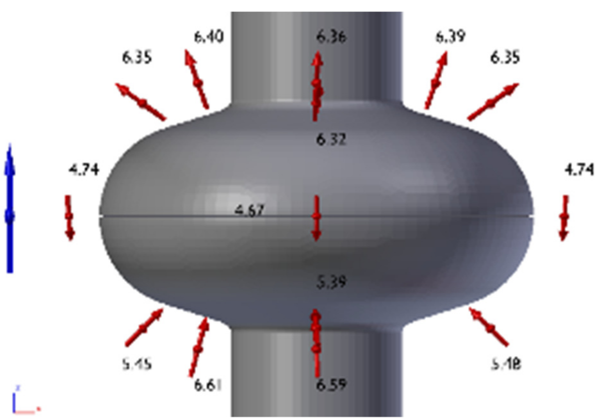


Dividing the measured magnitude by the simulated magnitude gives an estimation about how much flux is being trapped

Measurement



Simulation



Flux trapping averaged over all sensor positions

α [deg]	$<\|B_{meas}\|/\|B_{sim}\|>$ [%]
0 (horizontally)	66±2
15	52±3
30	80±12
45	76±1.3
75	71±6
90 (vertically)	88±3

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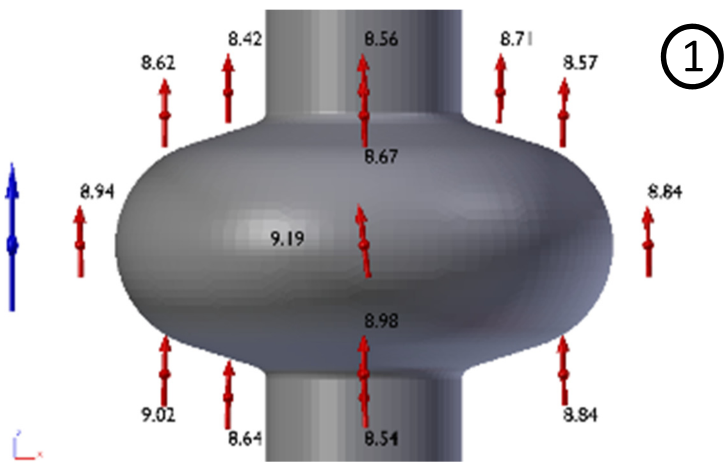
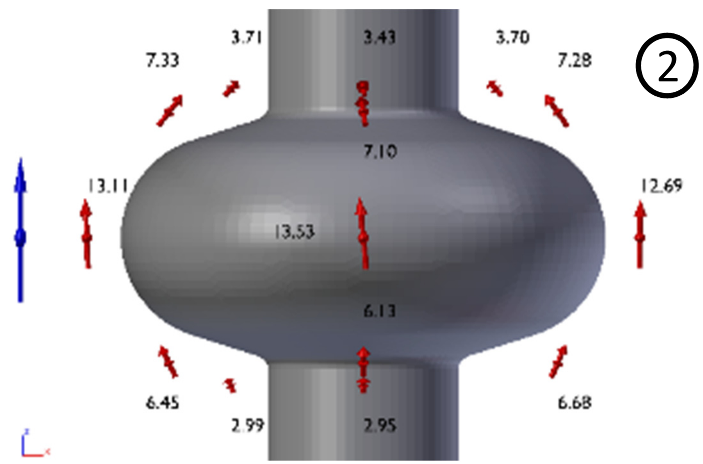
Distribution of flux during cooldown

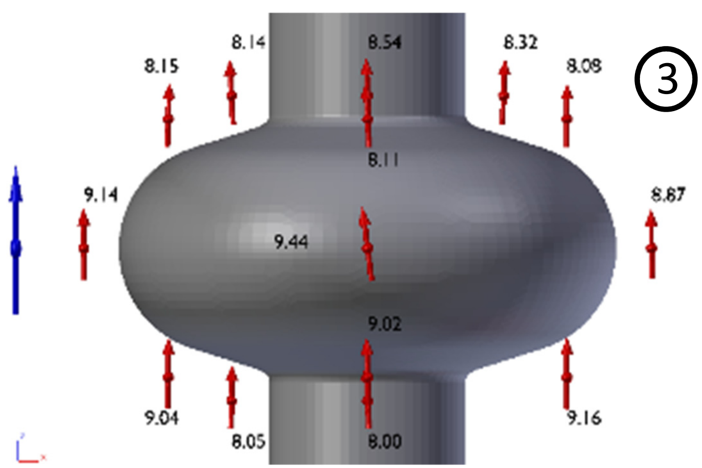
Normal conducting, HHC turned on (full trapping)

Superconducting, cooled down without field, HHC turned on (full expulsion)





Superconducting, cooled down with applied field, HHC still turned on (partial trapping)



Interpolate linearly between extreme cases:

$$q = 1 - \frac{B_{100} - Bpart_{ial}}{B_{100} - B_0}$$

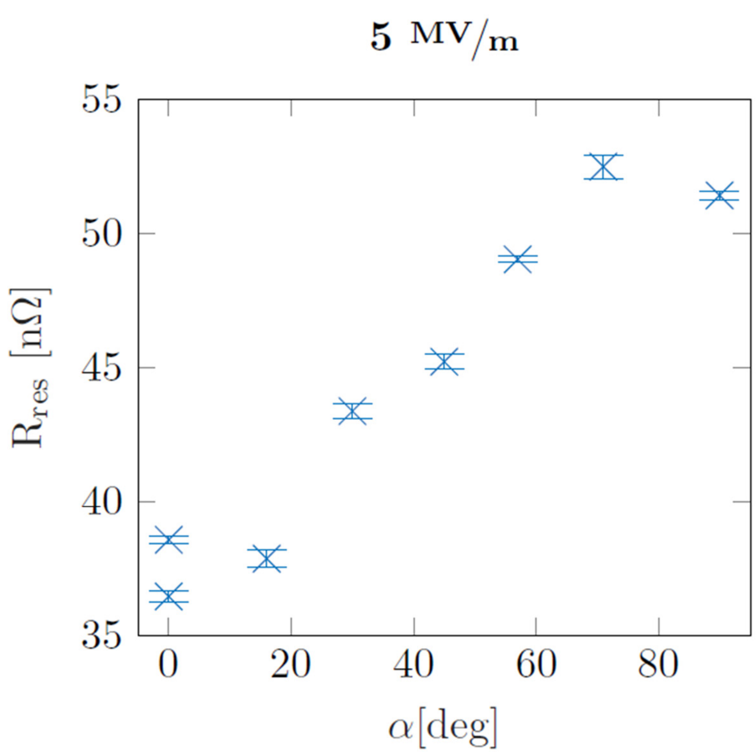
Flux trapping averaged over all sensor positions, estimated with two different methods

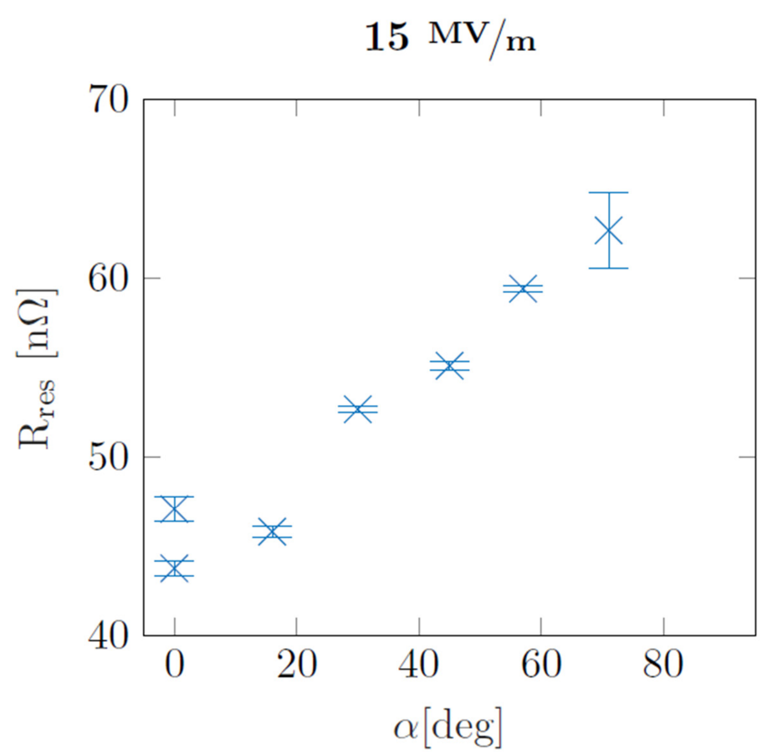
α [deg]	$\langle q \rangle$ [%]	$\langle \lvert B_{meas} \rvert / \lvert B_{sim} \rvert \rangle$ [%]
0	81±2	66±2
90	93±4	88±3

- 80 - 90% of flux is being trapped
- Data of full expulsion only available for $\alpha=0^\circ$ and $\alpha=90^\circ$ because they were tested after baseline measurements

Q_0 was measured for different polar angles for
E_{acc} = 2.5; 5; 7.5; 10; 12.5; 15; 17.5 MV/m
T = 1.51; 1.61; 1.72; 1.8; 1.86 K

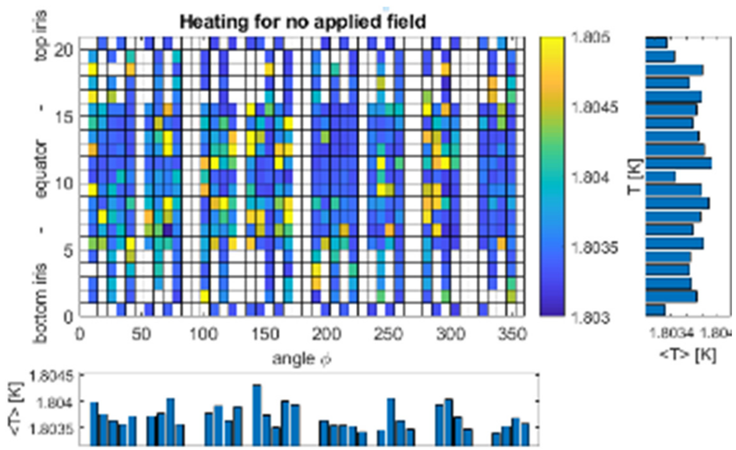
Using $R_s = \left(\frac{af^2}{T}\right)\exp\left(-\frac{bT_c}{T}\right) + R_{res}$, the residual resistance was calculated



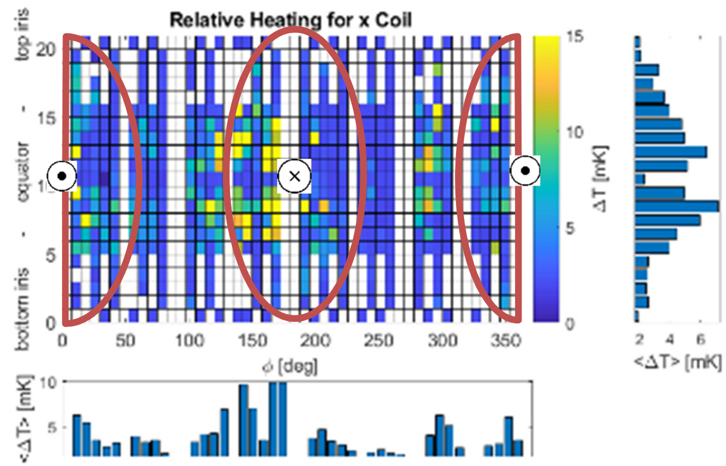


Moving hotspots for different applied fields

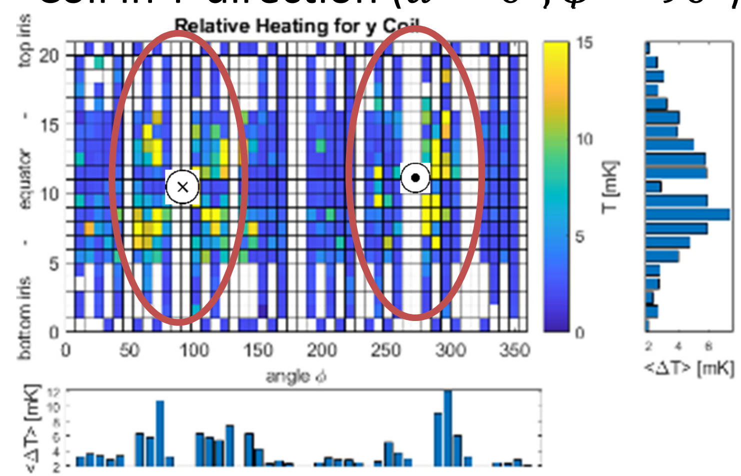
Without Coil



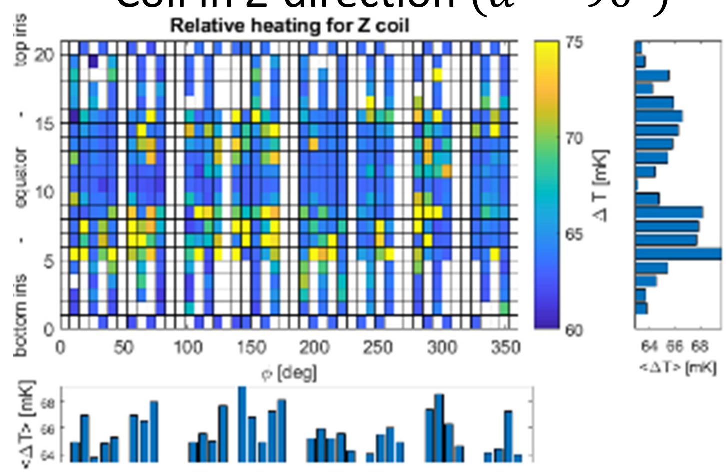
Coil in X-direction $(\alpha = 0°, \phi = 0°)$



Coil in Y-direction $(\alpha = 0°, \phi = 90°)$



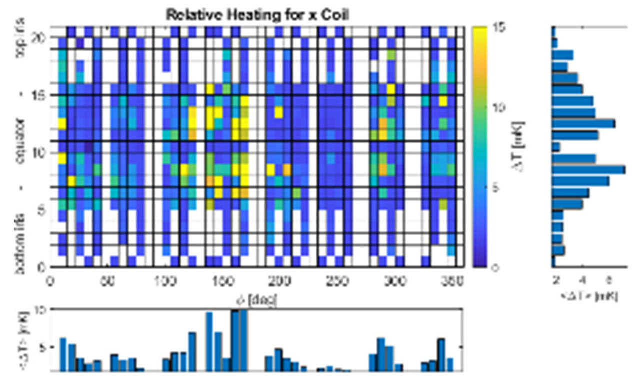
Coil in Z-direction $(\alpha = 90°)$



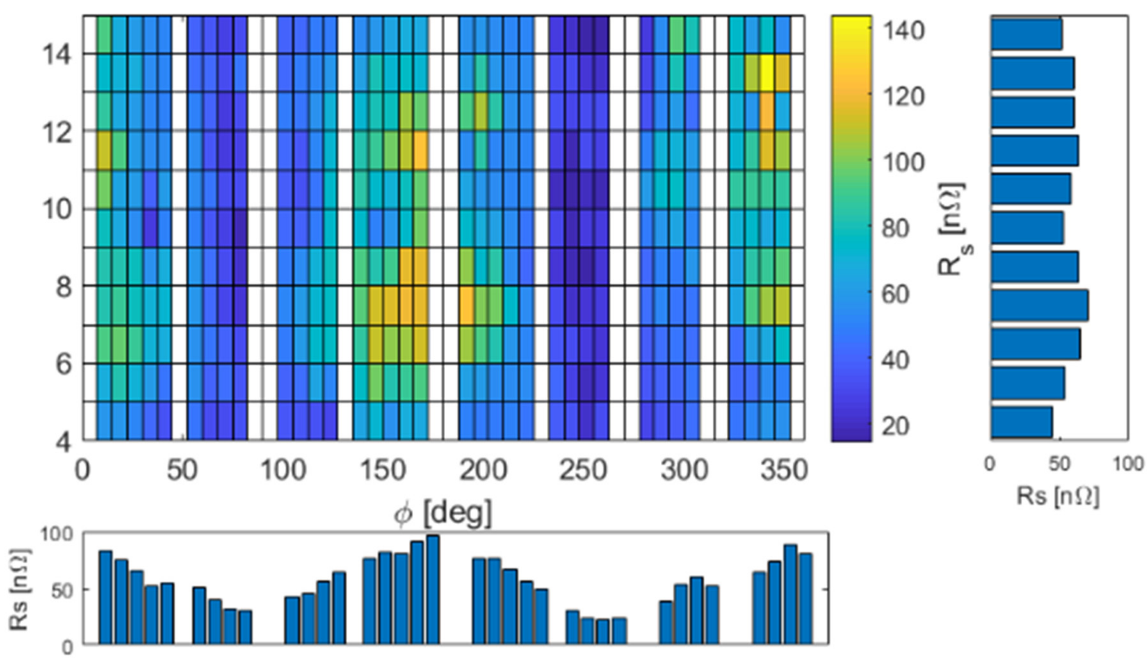
LOCAL SURFACE RESISTANCE

- $R_s \sim \Delta T$
- Average middle section of T-maps
- Assume uniform heating for no applied field
- Calibrate thermal connection of sensors

- Calculate local surface resistance



Applied field in X-direction



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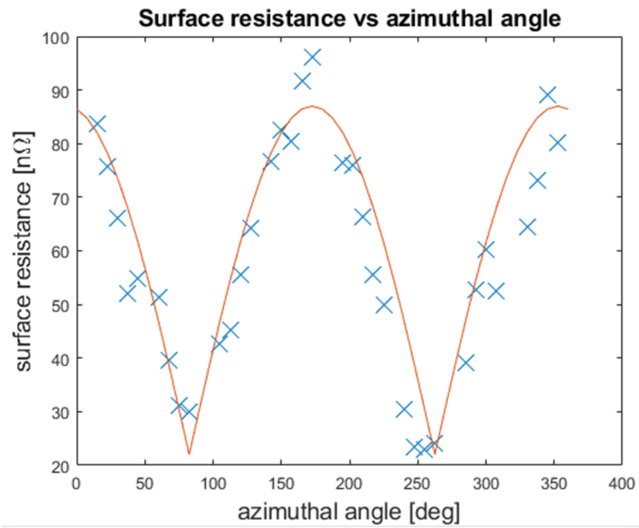
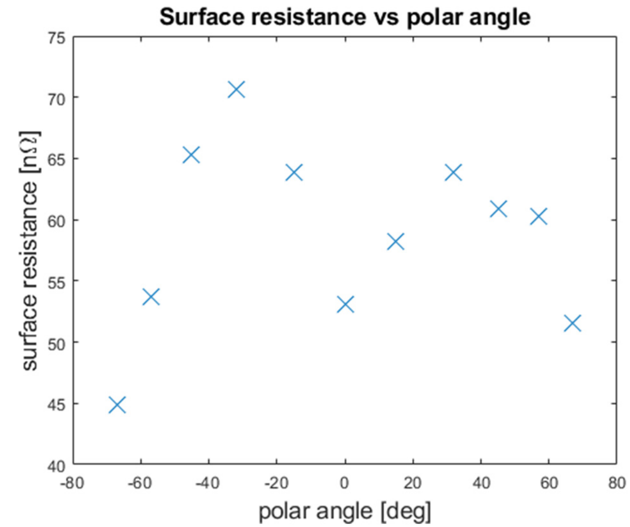
Surface resistance seems to depend on angle between frozen flux and surface

X

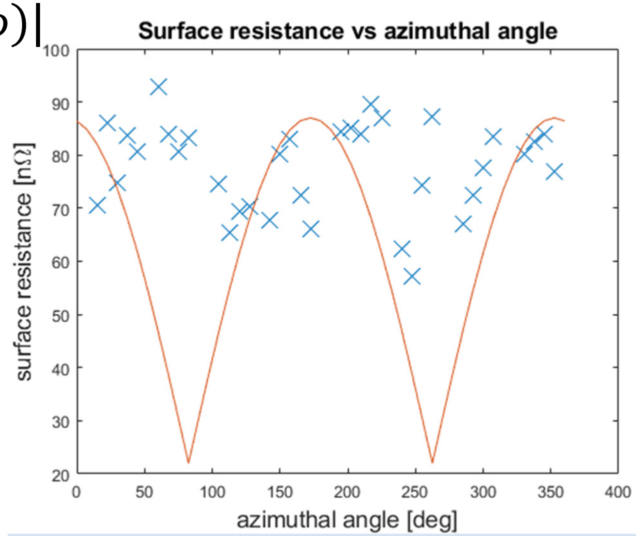


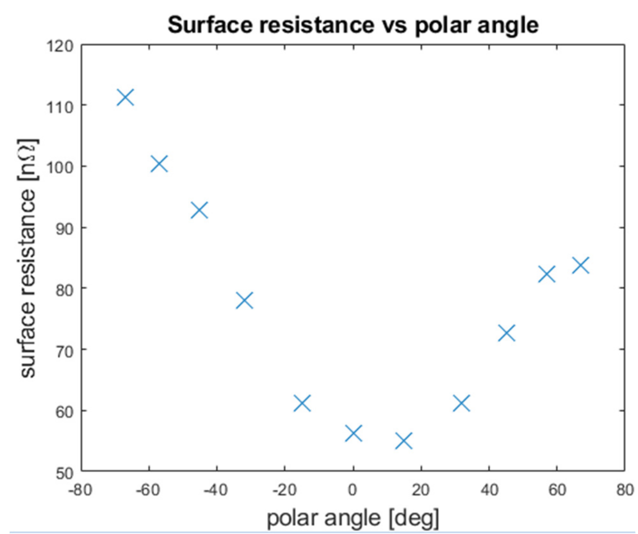


× Surface resistance

— $\sim |\cos(\phi)|$

Z





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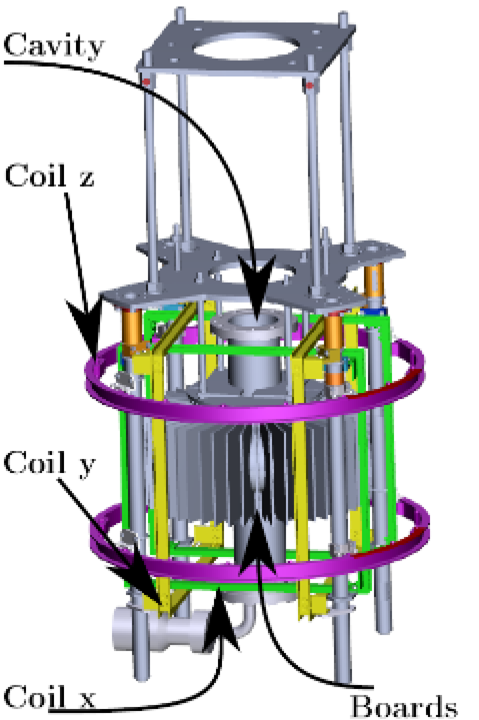
Summary

- Apart from top-bottom asymmetry, homogeneous trapping without reorientation of flux lines was observed
- Estimation of amount of trapped flux possible, but has to be treated with care
- R_{res} depends on polar angle of external magnetic field
- Highest increase in surface resistance where the trapped flux is perpendicular to surface
- Details: B.Schmitz et al., “Magnetometric mapping of superconducting RF cavities”, https://aip.scitation.org/doi/10.1063/1.5030509



Outlook

- Look into dynamic processes (e.g. phase transition, quench studies)
- Flux trapping in LG material

THANK YOU FOR YOUR ATTENTION!