HZB Helmholtz Zentrum Berlin

A Combined Temperature and Magnetic Field Mapping System for SRF Cavities

J. Köszegi, B. Schmitz, K. Alomari, O. Kugeler, J. Knobloch

https://arxiv.org/abs/1804.03445

Dissipation in SRF cavities is described by:

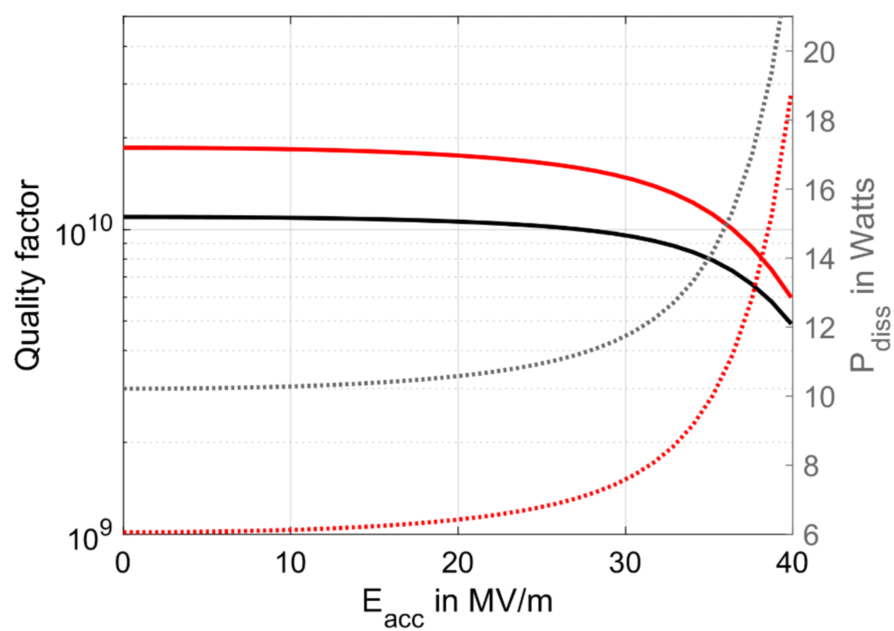
$$P_{\mathrm{diss}} = \frac{V_{\mathrm{c}}^2}{\frac{R_{\mathrm{a}}}{Q_0} G} R_{\mathrm{s}} = \frac{G}{Q_0}$$

- Dissipated power adds for e.g. 800 cavities in the XFEL
- Operation at 2 K
- Limited efficiency of cryo plant (Carnot and technical)
- Cryo plant with Megawatt wall plug power: complex and costly.

$$R_{\mathrm{S}}(T) = \frac{a f^2}{T} \cdot \exp\left(\frac{-bT_{\mathrm{c}}}{T}\right) + \boxed{R_{\mathrm{res}}}$$

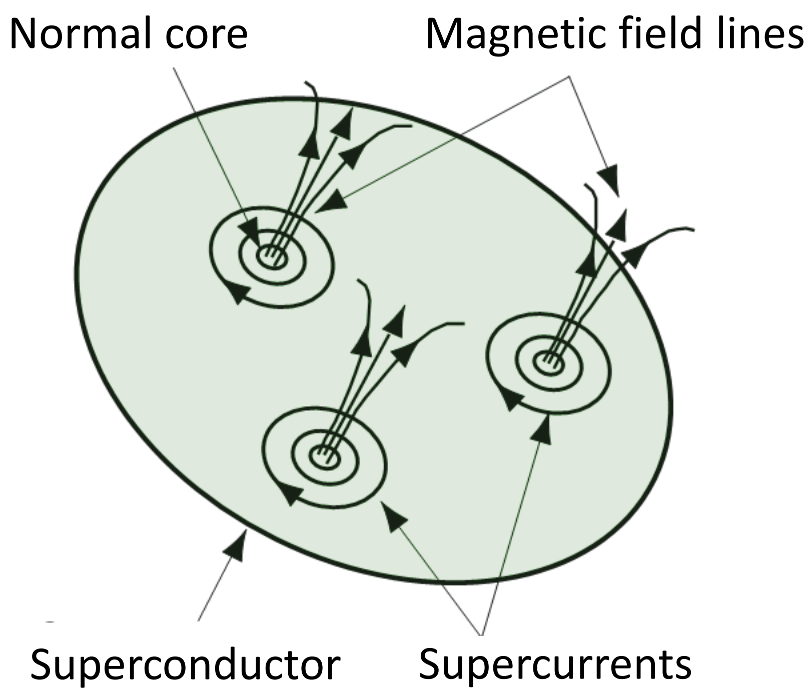
- Decrease in residual resistance to half of the initial value directly reduces dissipation

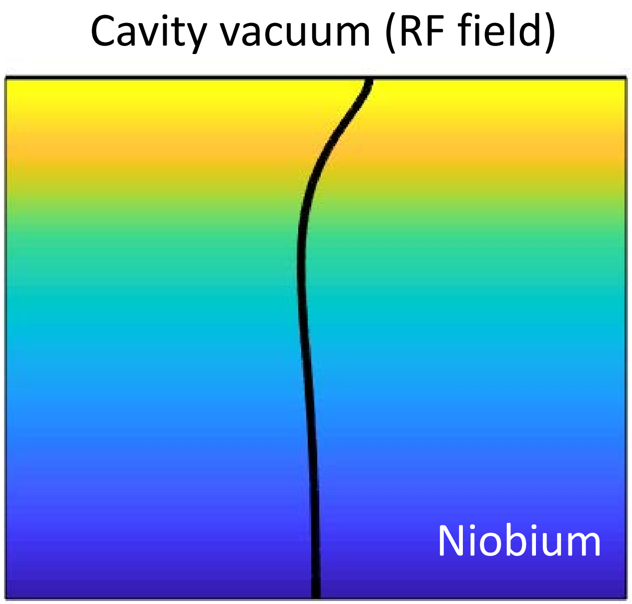
Example for a TESLA cavity (schematic) 20 nΩ -> 10 nΩ



R_s	surface resistance
Q_0	quality factor
V_c	accelerating voltage
R_a	shunt impedance
f	operation temperature
T_c	operation frequency
G	critical temperature
a, b	geometry factor
	cavity material properties (fit parameters)

Trapped magnetic flux: a major cause of increased residual resistance





$$P_{\text{diss}} \propto H_{\text{p}}^2 (\rho_{\text{n}} f)^{1/2}$$

A. Gurevich and G. Ciovati, Phys. Rev. B, vol. 87, p. 054502, 2013

- **Research on trapped flux has proven to hold significant potential for high Q operation**

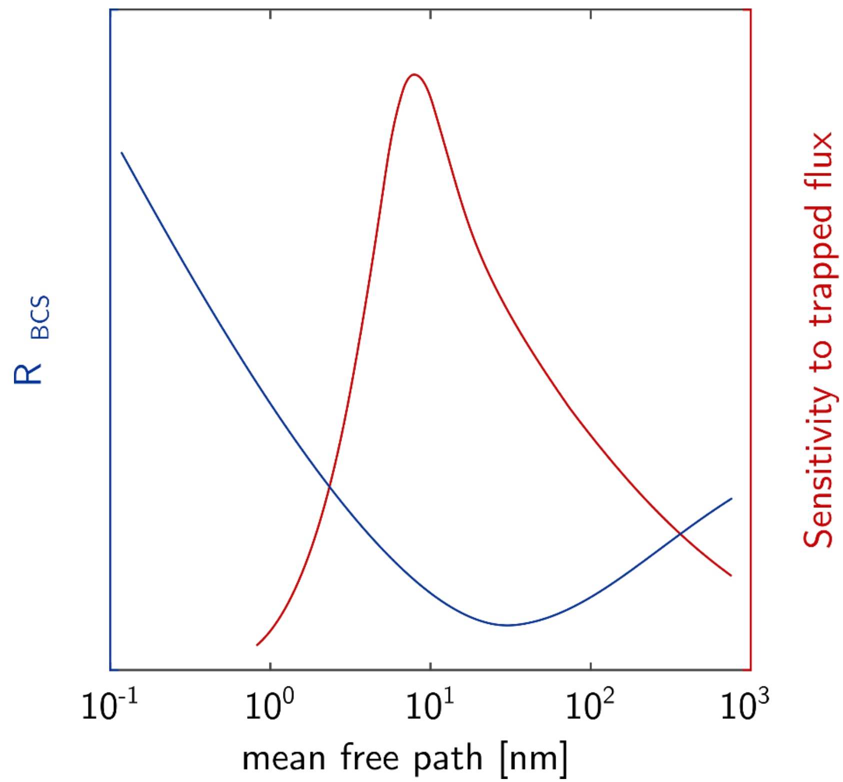
$$R_S(T) = R_{BCS} + R_{res}$$

Current **optimization** of **BCS** resistance modifies **mean free path** in surface layer…

…leading to a **change in sensitivity** to trapped magnetic flux.

research on trapped flux intensified during past years

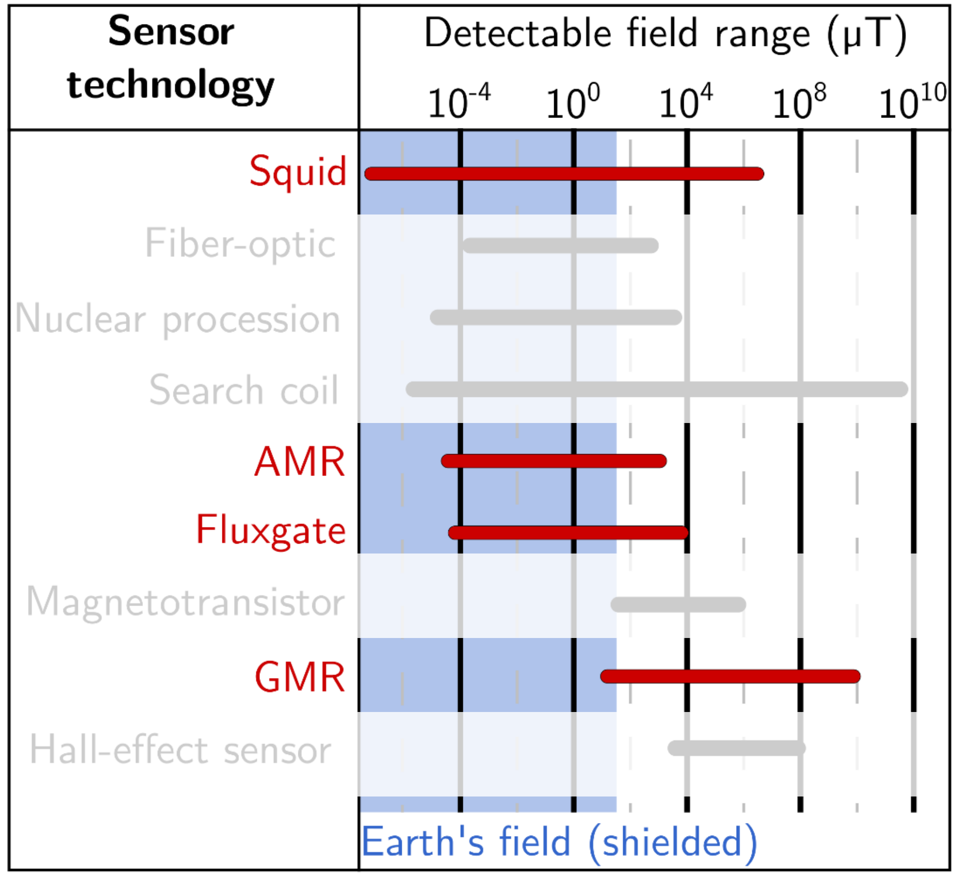
Sketch of dependencies on mean free path



P. Dhakal et. al., arXiv:1205.6736v1, 2012

D. Gonnella et. al., J. Appl. Phys, vol. 119, no. 7, 2016

Aim: Measure and quantify magnetic field during the phase transition and correlate with dissipation



M. Caruso and C. Smith, "A new perspective on magnetic field sensing," Sensors, vol. 15(12), pp. 34–46, 1998

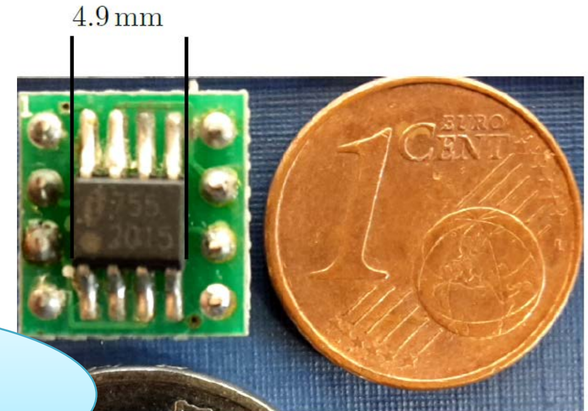
Aim: Measure and quantify magnetic field during the phase transition and correlate with dissipation

Fluxgate technology:

- Precise, nT resolution, fast, known
- Several cm in size, expensive

AMR technology:

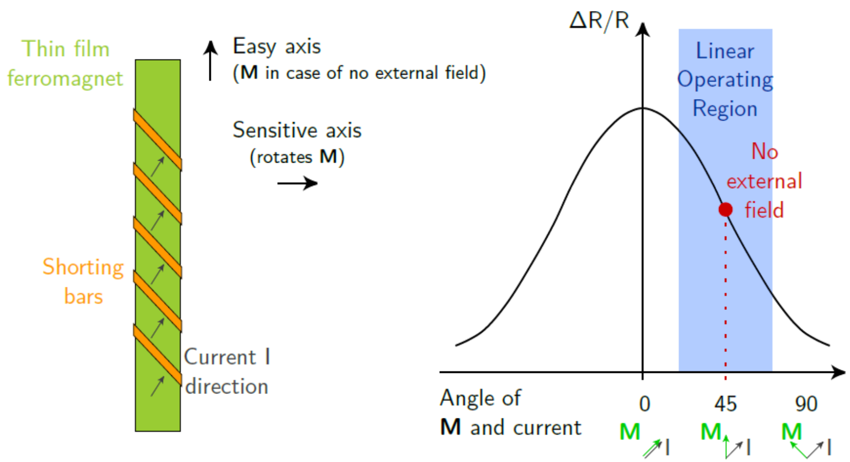
- Affordable, smaller



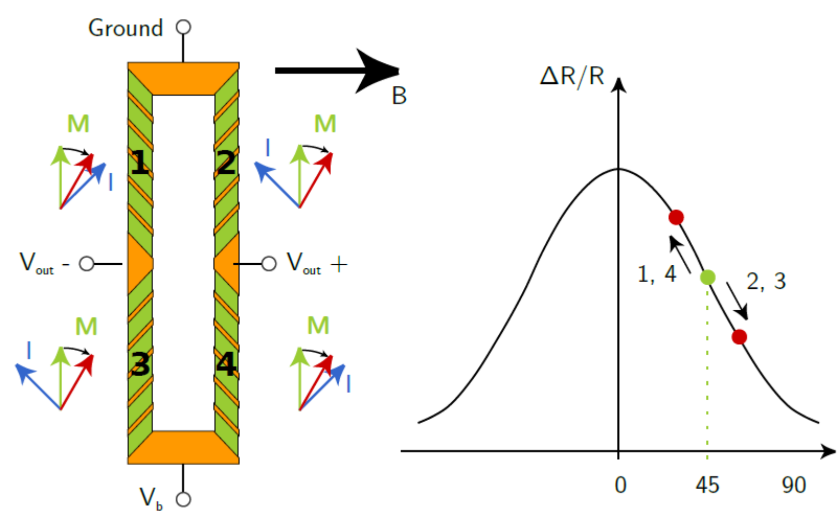
Behavior at cryogenic temperatures?

Anisotropic **M**agneto**R**esistive effect

2% to 3% effect: R ± ΔR



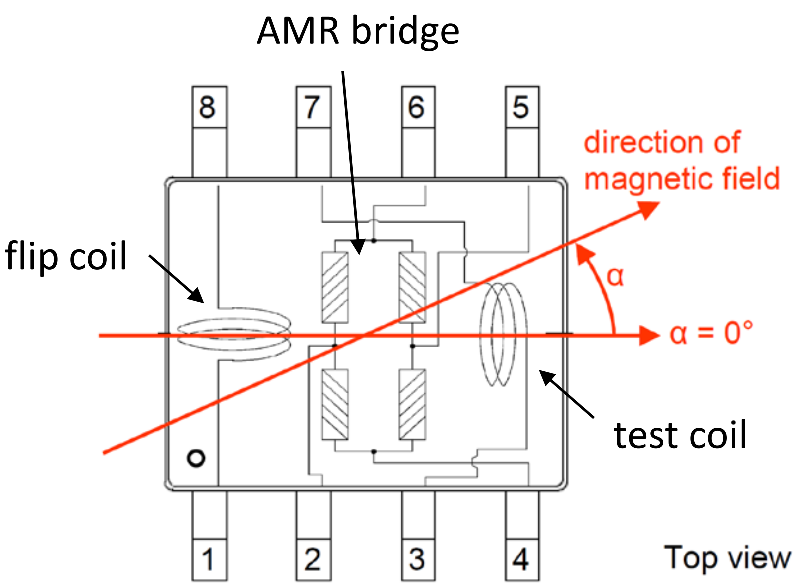
used as bridge: ± ΔR / R



Calibration and sensor testing

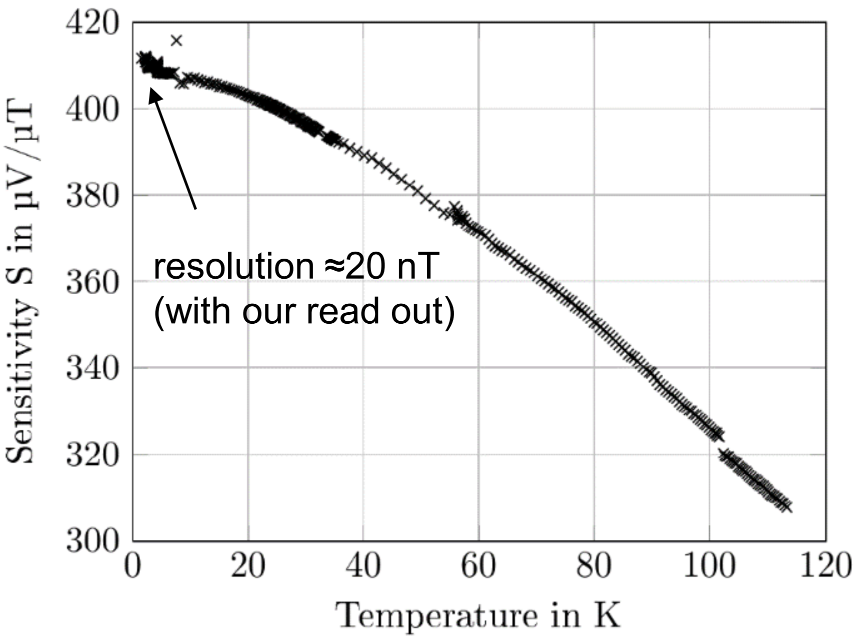
- ~~KMZ51 (Philips)~~
- ~~ZMY20M (Zetex)~~
- AFF755 (Sensitec)

Calibration using internal test coil



Sensitec: AFF755 data sheet

Sensitivity (relative changes):



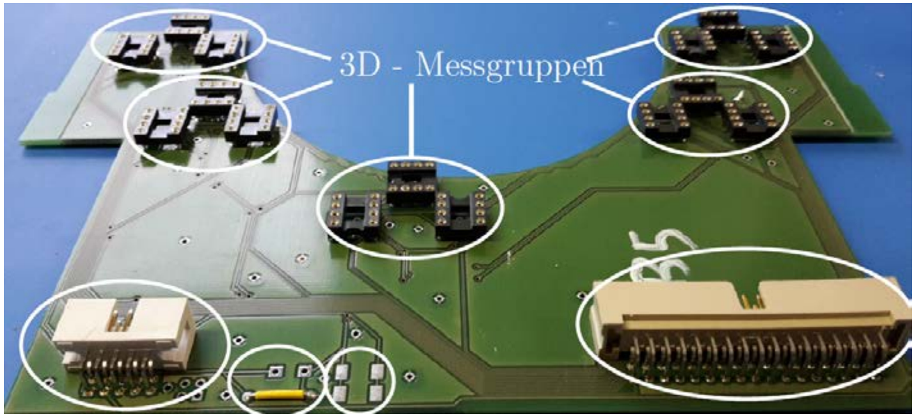
Radiation hardness:

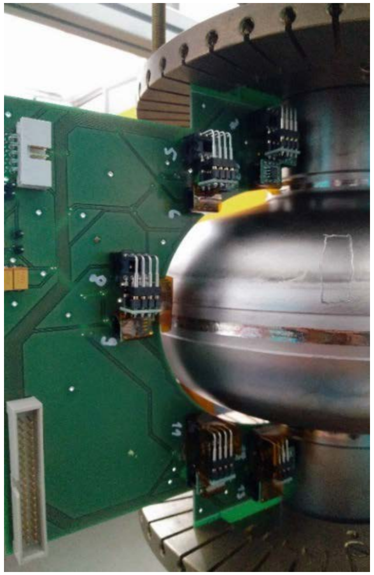
- Literature on similar AMRs: tested up to 10 kGy and in 14 MeV neutron radiation
- AFF755 tested at HZB up to 12 kGy

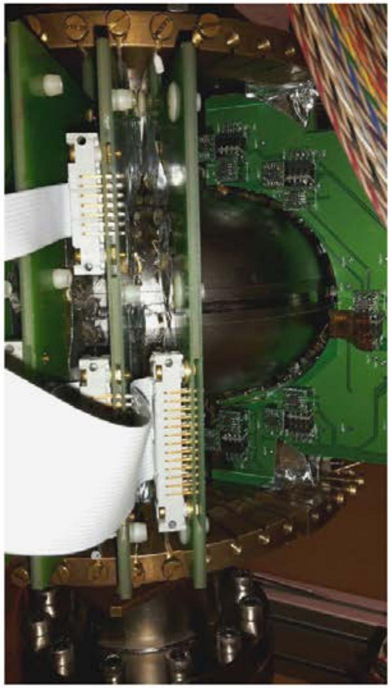
R. Hahn et. al., in 14th Symposium for Magnetoresistive Sensors and Magnetic Magnetometic Measurement Device Systems (2017)

Mapping setup:

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



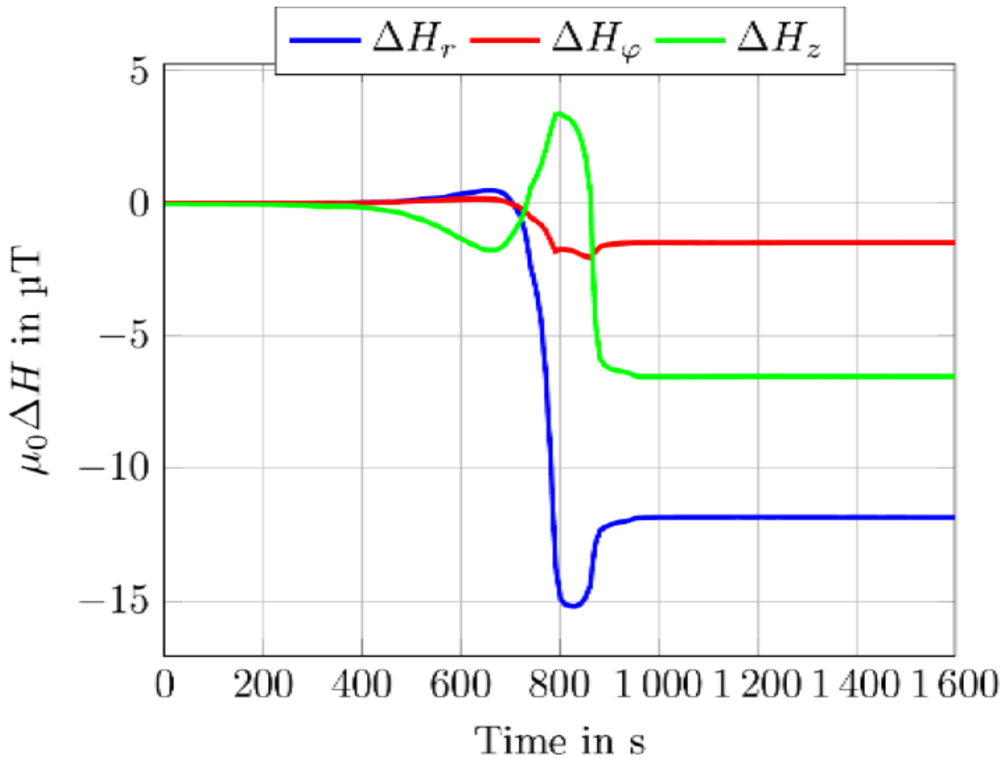


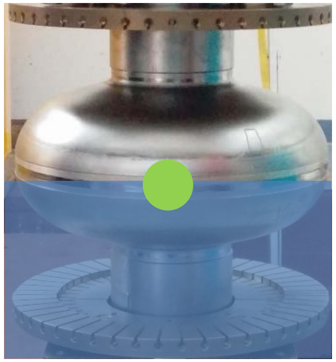


Commissioning results (examples)

1. Slow warm up, release of trapped flux
2. Multiple quench spots (Temperature mapping)
3. Combined measurement of temperature and magnetic field during quench

Three AMR sensors located at the equator





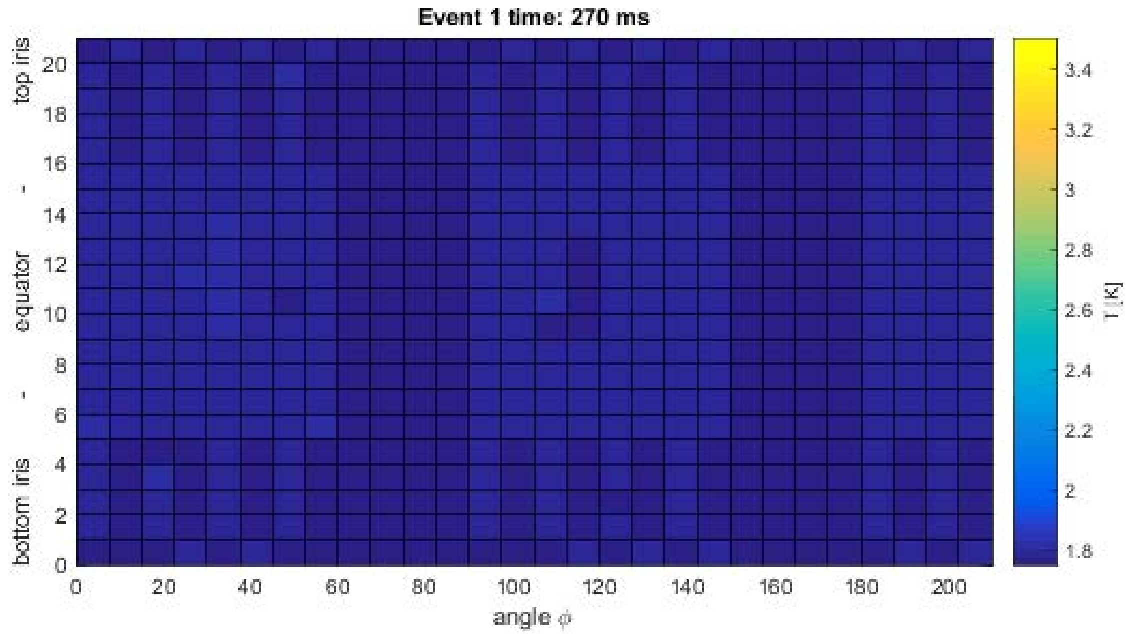
HZB Helmholtz Zentrum Berlin

Commissioning results (examples)

1. Slow warm up, release of trapped flux

2. Multiple quench spots (Temperature mapping)

3. Combined measurement of temperature and magnetic field during quench

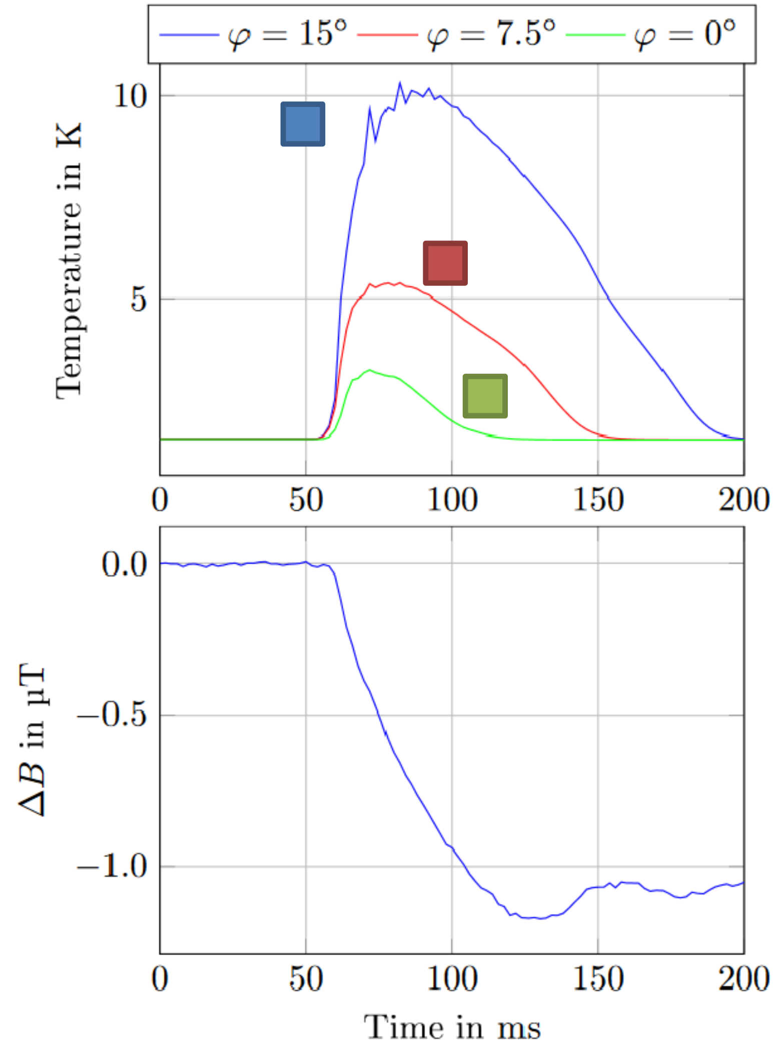


Commissioning results (examples)

1. Slow warm up, release of trapped flux

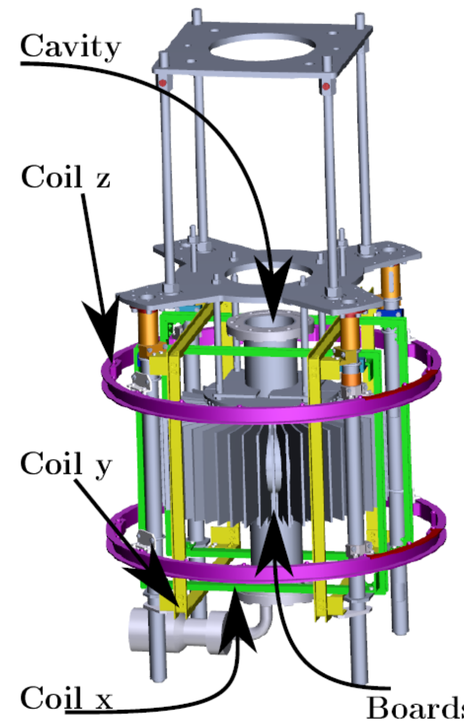
2. Multiple quench spots (Temperature mapping)

3. Combined measurement of temperature and magnetic field during quench



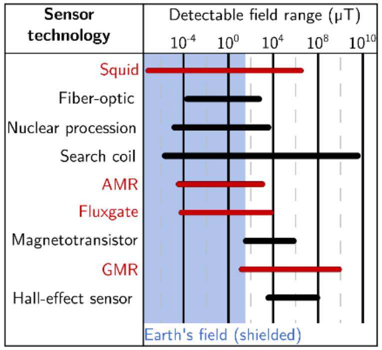
Summary

- AMR sensors commissioned at cryogenic temperature with resolution in the order of 20 nT (at 1.8 K)
- 3D mapping developed for relative changes in magnetic field
- Successful combination of magnetic field and temperature mapping
- Flux expulsion, trapping, and release during phase transitions and during quench measured
- 2 ms resolution for complete cavity map
- Tested in up to 12 kGy
- Details: https://arxiv.org/abs/1804.03445



Outlook

- Implementation of absolute measurement (< 1 µT)
- Reduce size of magnetic field PCB
- Advance beyond AMR?



THANK YOU FOR YOUR ATTENTION!

We would like to acknowledge the colleagues from DESY for contributing the temperature mapping system, A. Denker for the collaboration on the radiation test, our colleagues, especially Y. Tamashevich and T. Junginger, as well as our engineers.