Sensitivity Measurements for Mid-T heat treated SRF Cavities

Jennifer Ademoye - SRF R&D team – Jan 15th 2025

Motivation: Higher Performance in RF Cavities

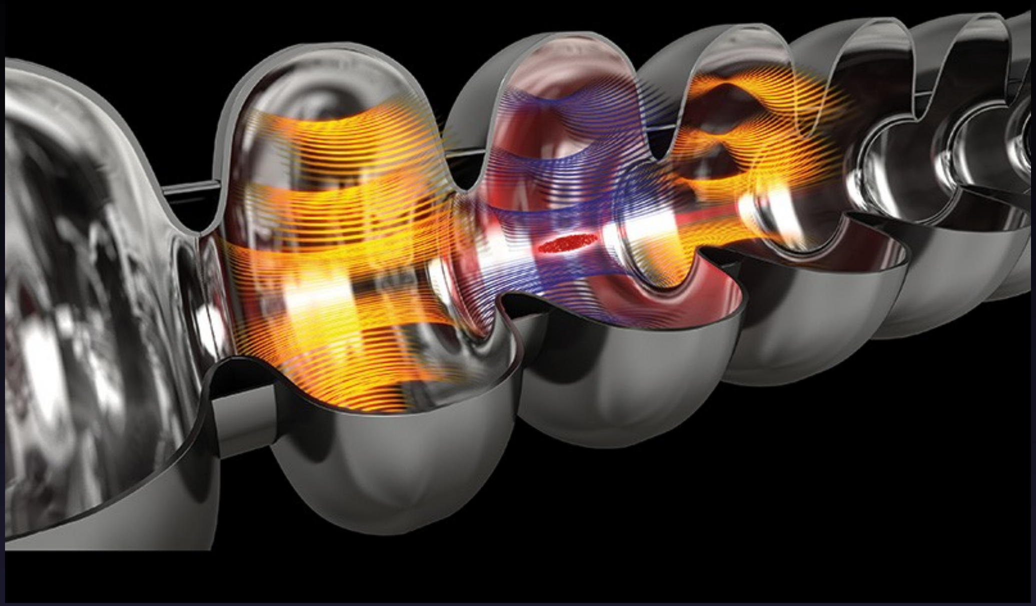
- Interest in Cavities with higher performance (high quality factor Q_0 and high accelerating field E_{acc})

- Q_0/E_{acc} curves higher after mid-T heat treatment compared to no mid-T

- Also higher Sensitivity probably due to flux trapping after mid T heat treatment

- Sensitivity defined as $S = \Delta R_s / B_{trapped}$: Ratio of surface resistance between two measurement types (with and without ext. B) per trapped magnetic field

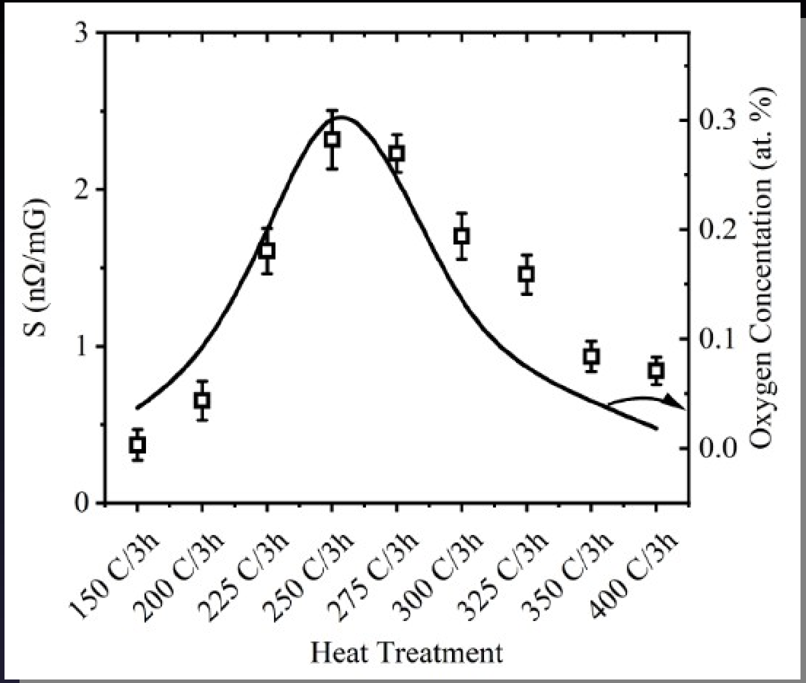
→ Investigation of the correlation between Sensitivity S and mid-T heat treatment

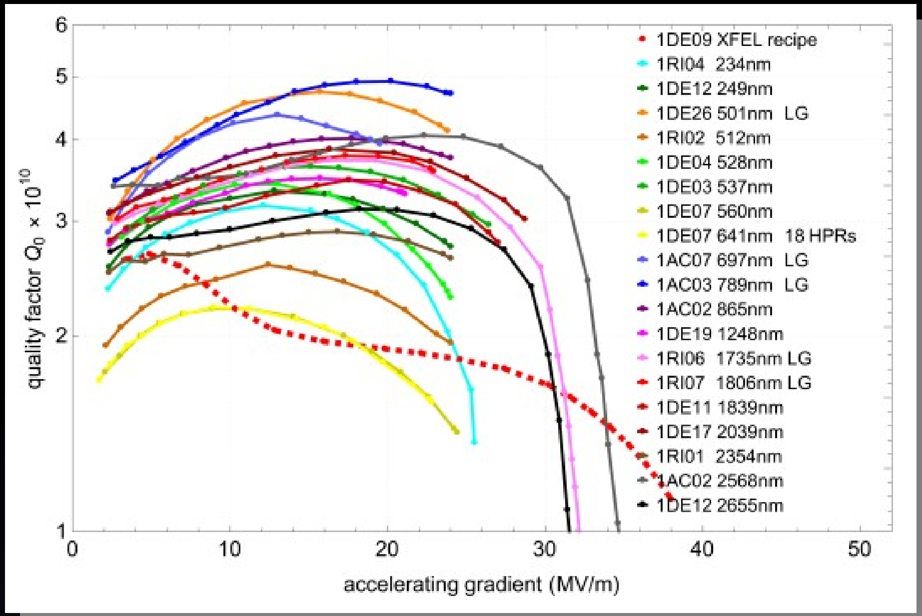


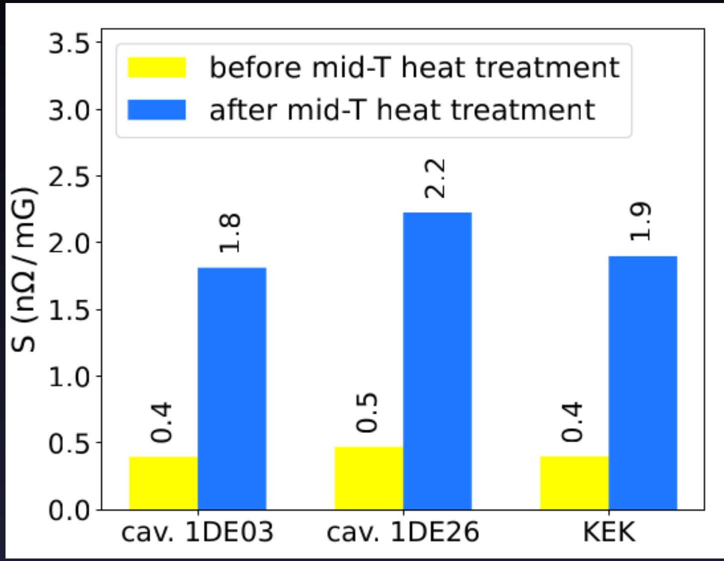
Physical Measurement Properties

Mid-T Heat Treatment

- Medium temperature approx. 250-350 ℃
- ~3-20 h







- Mid-T → higher Q_0/Eacc curve, but earlier quench
- Sensitivity increases with mid-T heat treatment

[Impact of medium temperature heat treatment on flux trapping sensitivity in srf cavities, P. Dhakal, et al. arXiv:2405.10085v1, 2024,
Correlation of SRF performance to oxygen diffusion length of medium temperature heat trrated cavities*. arXiv:2407.07779v1, 2024]

Quality factor Q_0 vs. Accelerating field E_{acc}

Q_0 : defined as stored energy per dissipated power in cavity walls

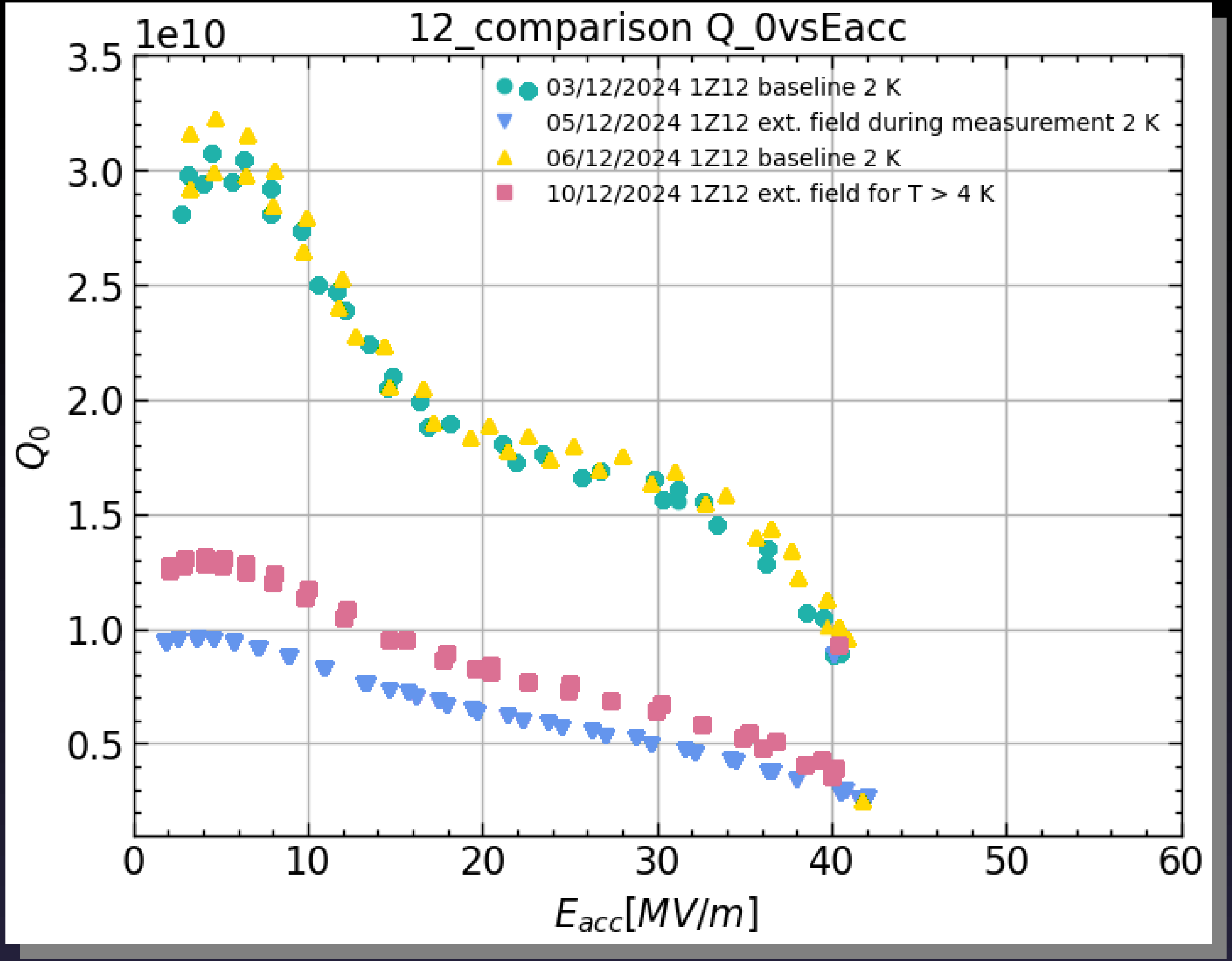
Influences : shape, electropolishing techniques, cleanliness of niobium surface, mid-T heat treatment, etc.

E_{acc}: Average accelerating electric field that electron sees during transit through cavity

To find R_s and later S we use:

$R_s(E_{acc}) = G/Q_0(E_{acc})$

with Geometry factor G=271.5 Ω



Sensitivity S and Surface Resistance R_s

Sensitivity $S = \Delta R_s / B_{trapped}$

dependent on pinning centres in bulk material

Surface resistance:
$R_s(T, B) = R_{BCS}(T) + R_{res} + R_{flux}(B)$

R_{BCS}: temperature dependent contribution by Bardeen Cooper Schrieffer (BCS) theory

$R_{flux}(B)$:impact by normal conducting pinning centers with dependence on magnetic field

R_{res}:constant residual resistance

[Impact of medium temperature heat treatments on the magnetic flux expulsion behavior on srf cavities*, J. C. Wolff, et al. o i : 1 0 . 1 8 4 2 9 / J A C o W - S R F 2 0 2 3 - W E P W B 0 6 5, 2023.]

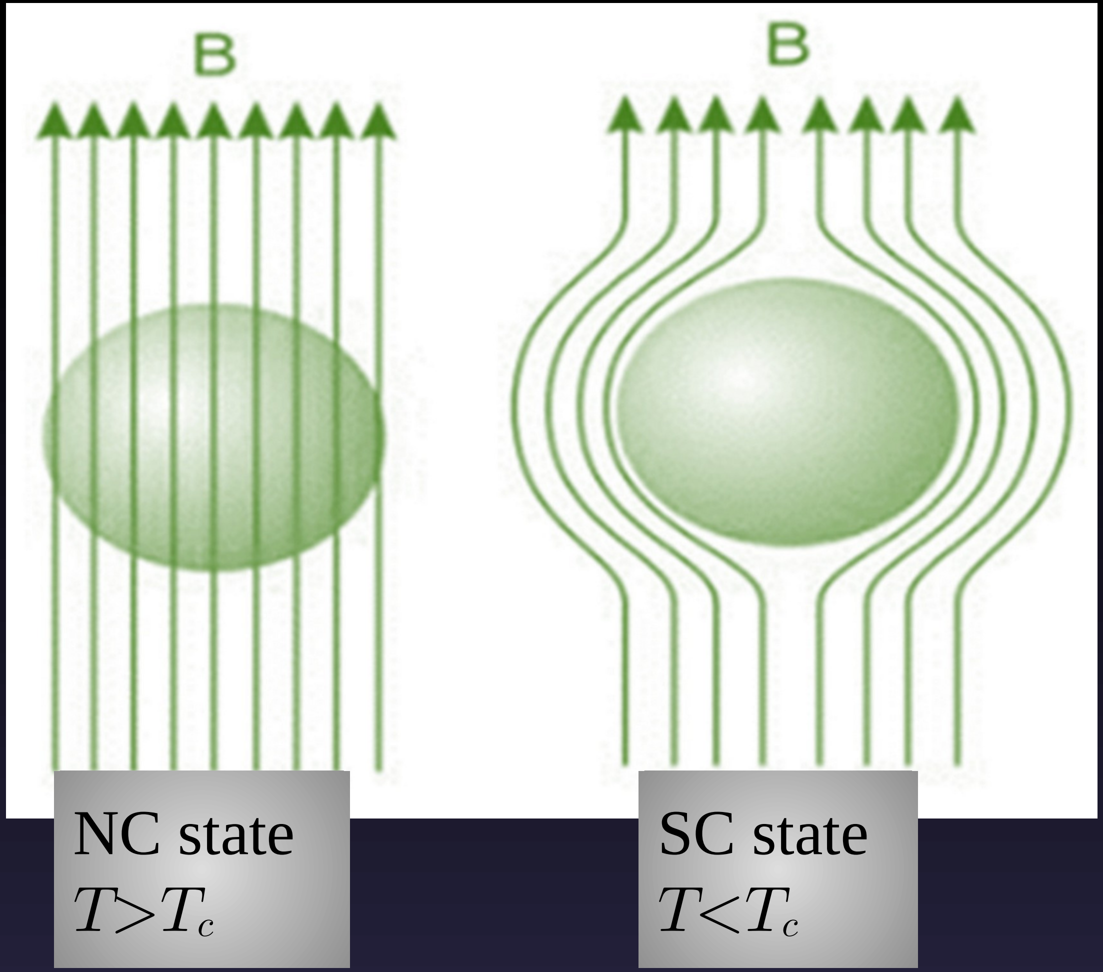
Magnetic Field and the Meissner state

SC: $T<T_c=9.2\,K$, $B<B_c$ = 0.22 T for 2 K

$B_{trapped} = ((B_{nc} - B_{sc})/(M * B_{nc} - B_{nc})) * B_{ambient}$

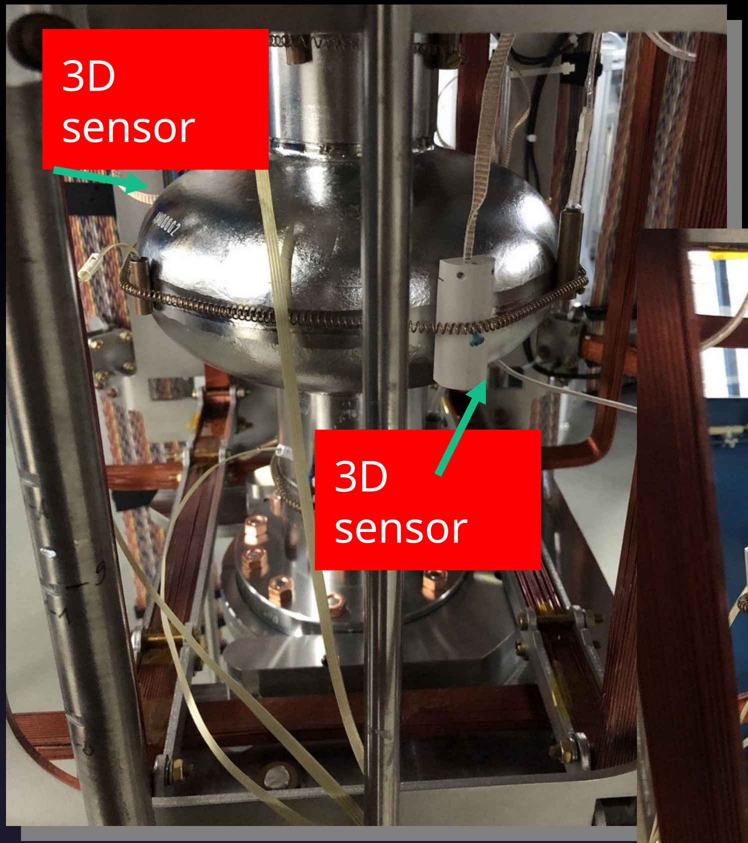
Meissner factor $M = B_{sc,Meissner} / B_{nc}$: difference between theoretical possible and experimentally measured field
M derived from simulation data considering cavity geometry and ideal Meissner state

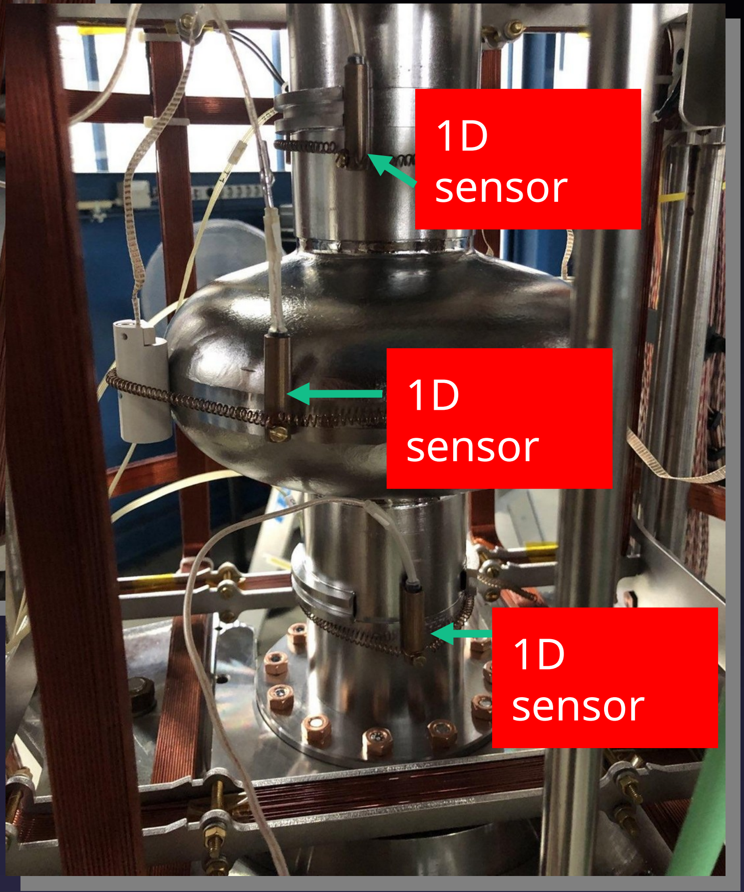
B_{nc} : magn. field in normal conducting state
B_{sc} : magn. field in superconducting state



Measurement Process

Single-cell SRF Cavity





-Niobium SRF cavity
-Two 3D Bartington magnetosensors for magnetic field measurements
-Three 1D Bartington magnetosensors, z-axis

Measurement of magnetic field lines at sensors' location

Measurement Components and Challenges

Server AV2

Filters

Dispatcher Box
X Y Z(sensor 1)
X Y Z(sensor 2)

Measurement Components

Panelmeter: ADC converter, analog-to-digital converter

DecaPSU: Power Supply Unit, supplies sensors with power

sensor 1

sensor 2

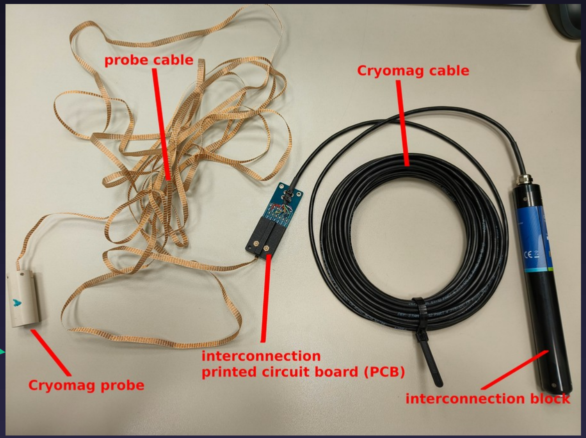
XATC2

3D Sensors with electronic rods

Challenges

-Low Pass Filters: filter out interference signals in 3D sensors that probably stem from conduction wires

-Assembly of electronic rod deviating from Bartington® recommendation



Cavity Measurement Process

Two different measurement modii: with/without Helmholtz-coil for determining ΔR_s → S

Expected magnetic field with activated Helmholtz coils at equator by calculation: 7.2 µT, for I = 23 mA

Ambient field inside concrete pit(without insert): ≤100 nT (offset), included in measured magnetic background field



Results for Cavity 1Z12

Measurement Process

New single cell medium grain niobium cavity

No mid-T heat treatment

XFEL treatment: 800 °C+ low-T 120 °C

1. 1st baseline measurement

   -cooldown to 2 K, $B_{ext} = 0$

2. Magnetic field measurement

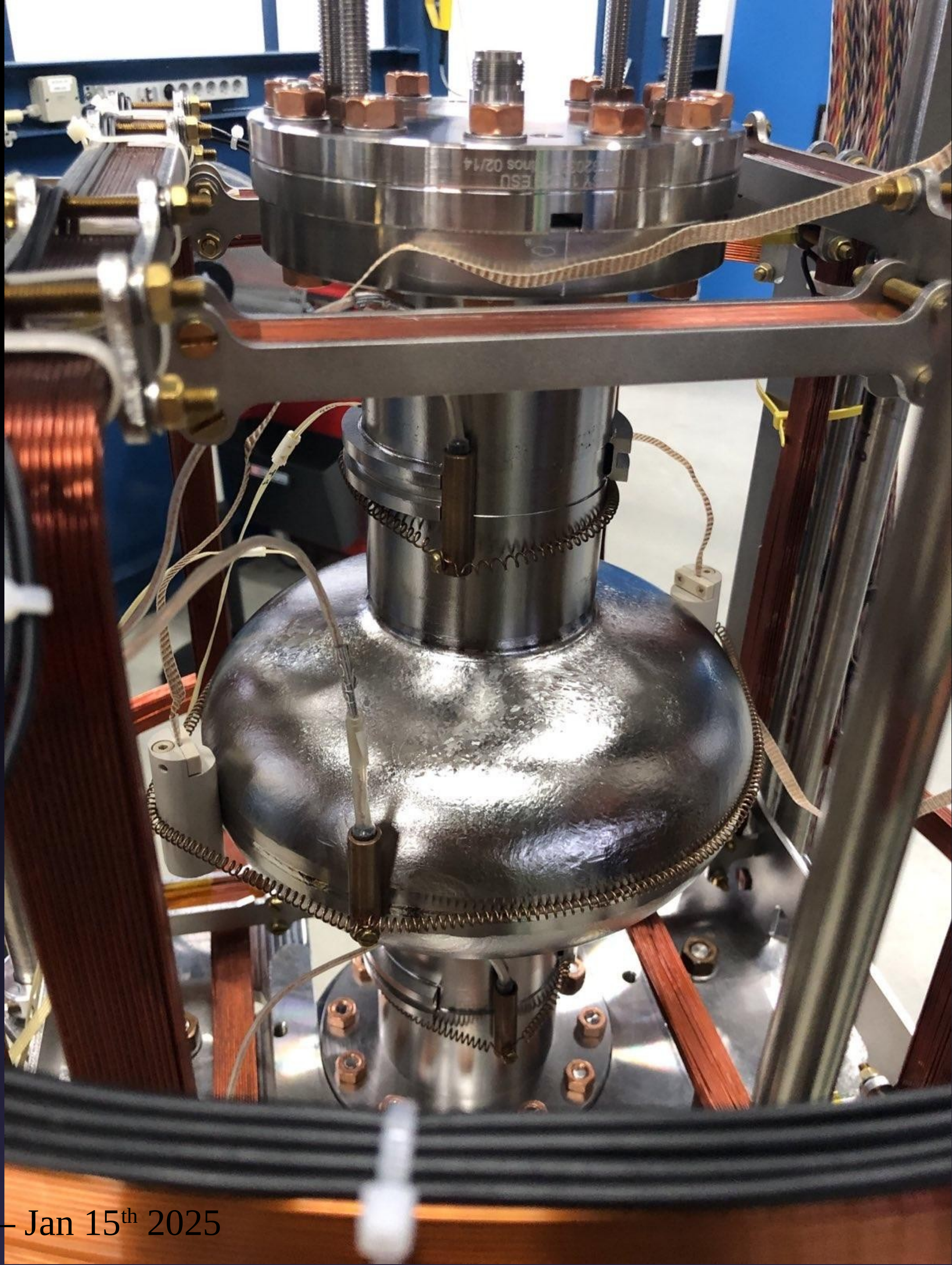
   -warmup to 40 K, $B_{ext} \approx$ 7.2 μT, cooldown to 2 K

3. 2nd baseline measurement

   -warmup to 20 K, cooldown to 2 K, B_ext = 0

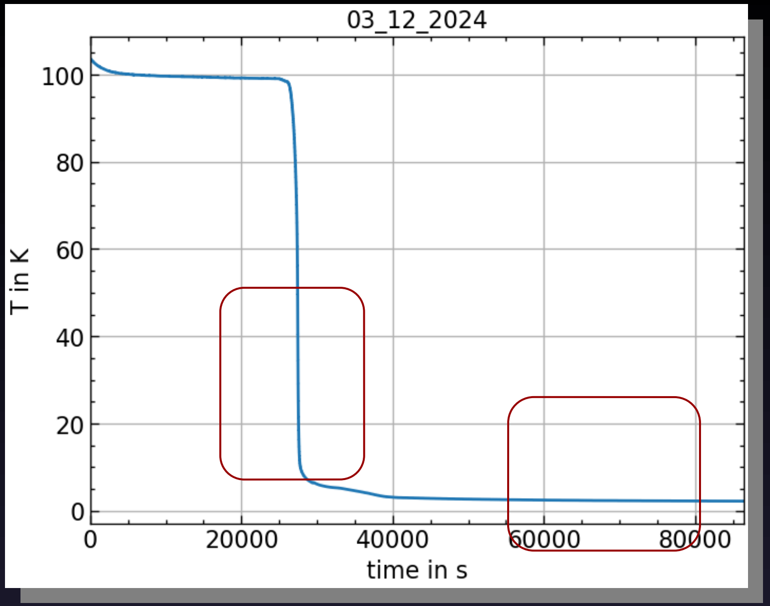
4. Magnetic field measurement

   -warmup to 20 K, $B_{ext} \approx$ 7.2 μT, cooldown to 4 K, $B_{ext} = 0$, cooldown to 2 K



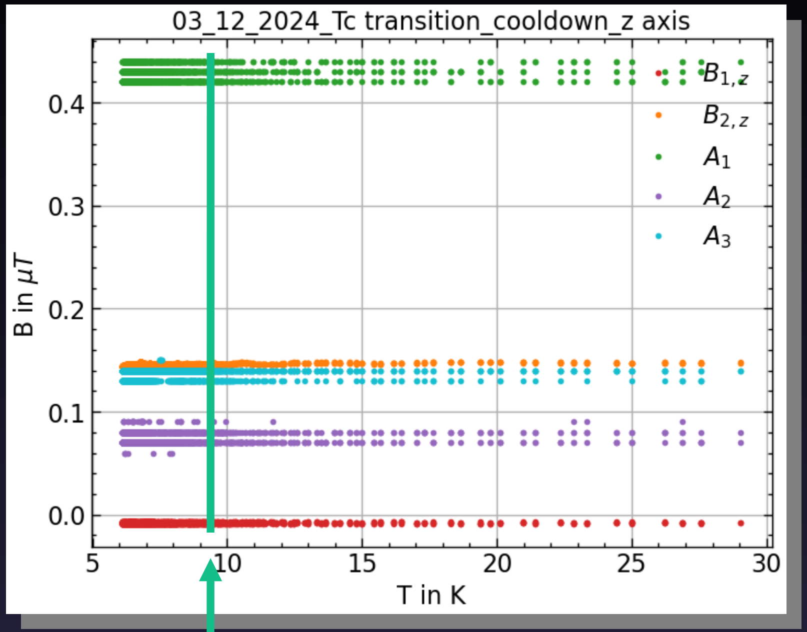
1st baseline measurement

1st baseline measurement
-cooldown to 2 K, $B_{ext} = 0$



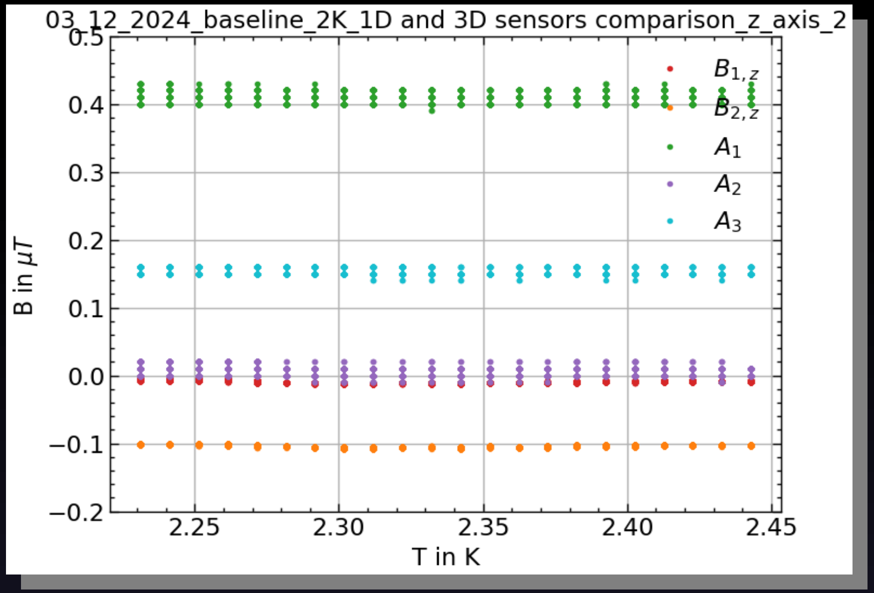
Cooldown from 100 K to 2 K

- B1,z: 3D Sensor z-axis (equator)
- B2, z: 3D Sensor z-axis(equator)
- A1: 1D Sensor (upper beam pipe)
- A2: 1D Sensor (equator)
- A3: 1D Sensor (lower beam pipe)



Transition T_c

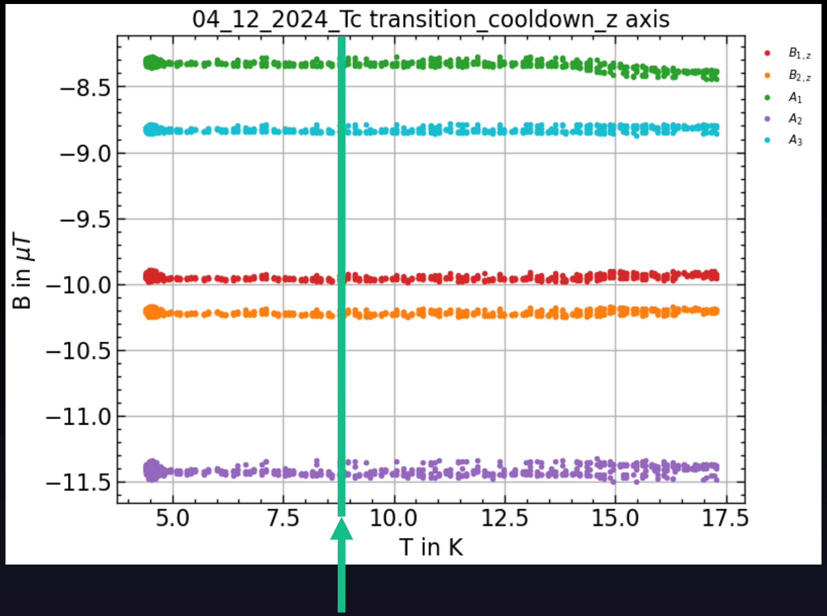
Expectation: no change in magnetic field behaviour as no B_{ext}



Baseline measurement (B_{ext} = 0)

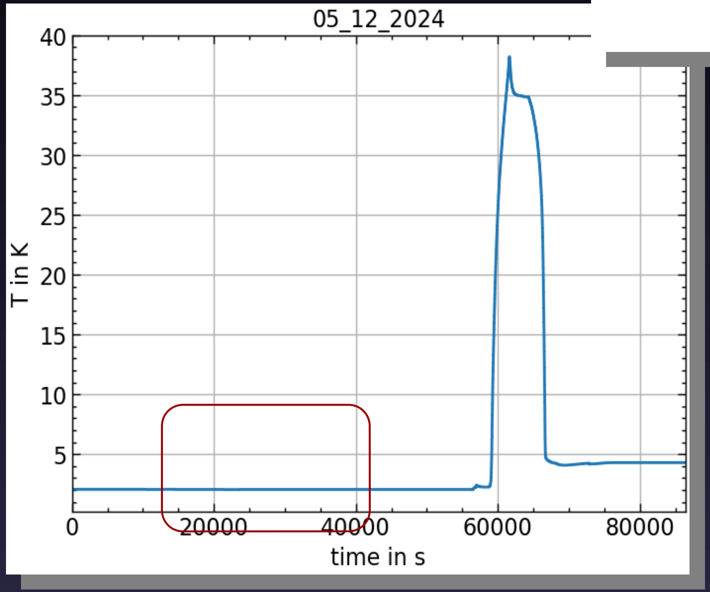
Difference in field between two 3D sensors: 0.1 µT, expected ambient field ≤ 100 nT

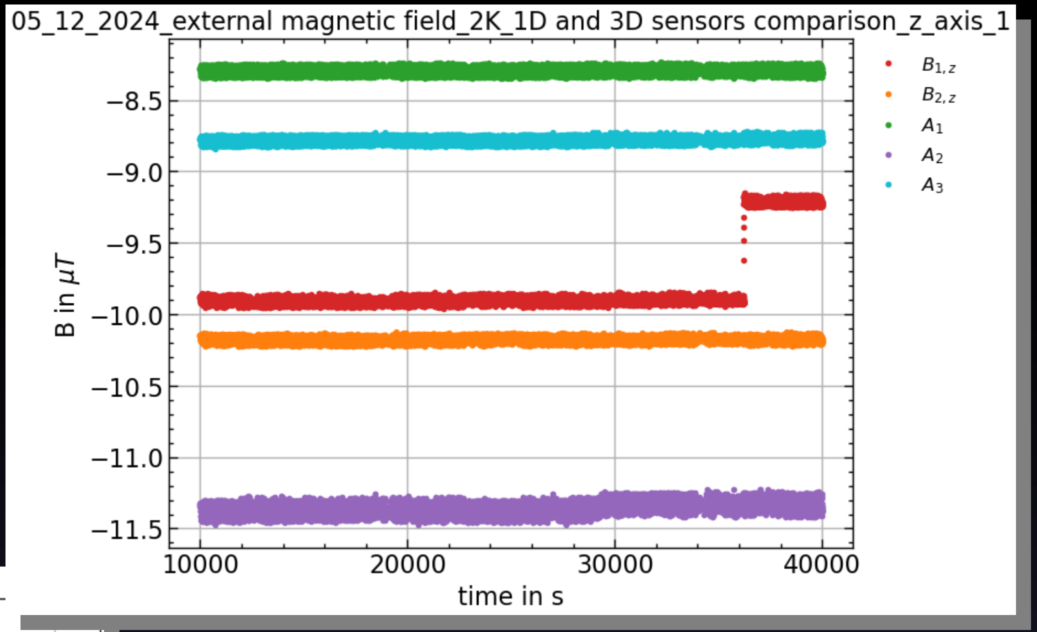
1st Magnetic field measurement



Transition T_c
Expectation: rise in magnetic values at T_c

field measurement
-warmup to 40 K,
B_{ext} ≈ 7.2 μT, cooldown to 2 K



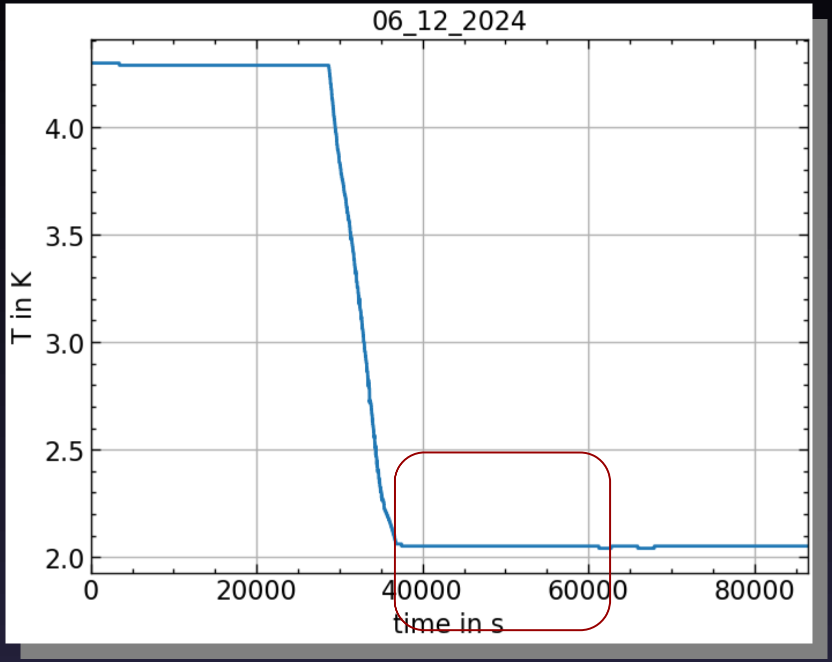


Expectation: higher B values compared to baseline, agreement(?) with calculated value ~7.2 μT

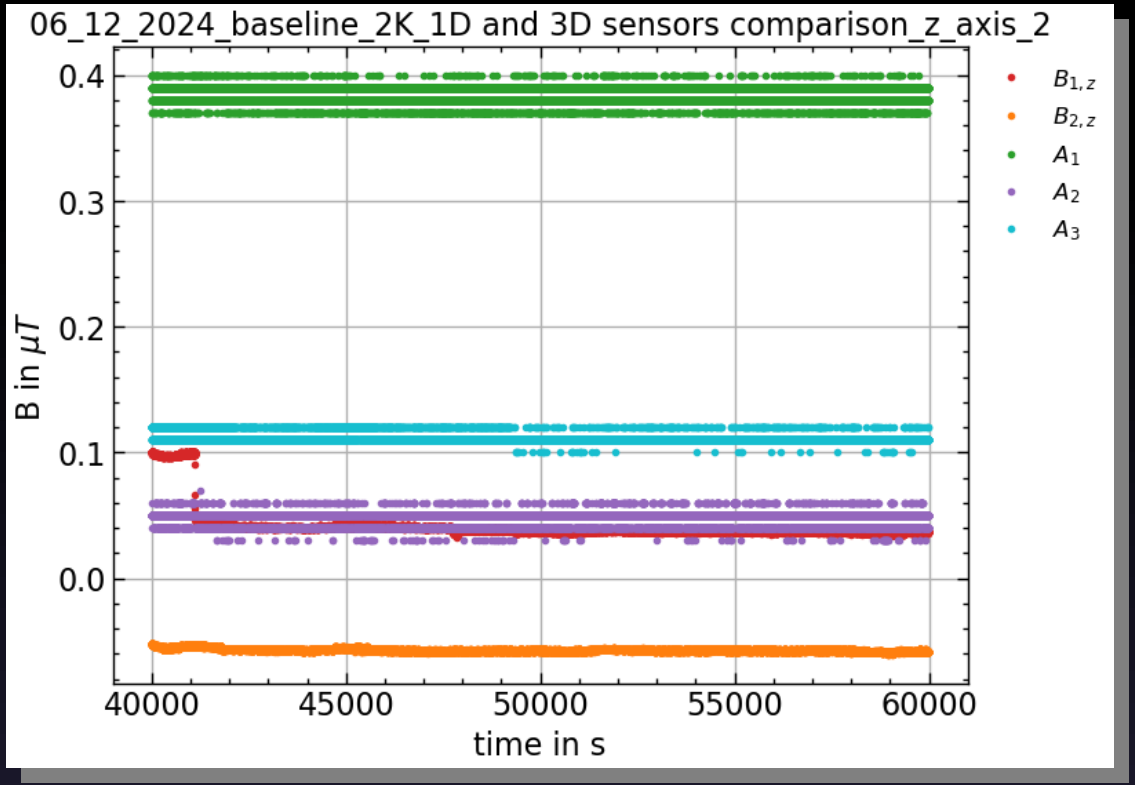
Difference between 3D sensors: 0.3 μT

2nd baseline measurement

2^{nd} baseline measurement
-warmup to 20 K, cooldown to 2 K,
B_{ext} = 0

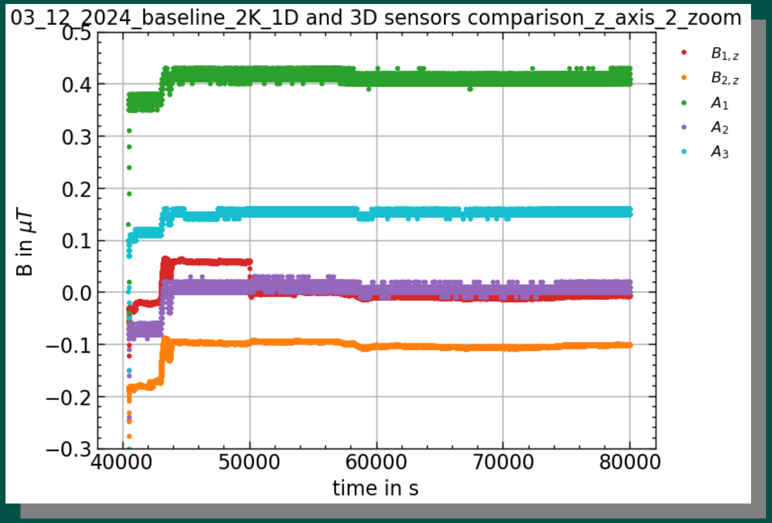


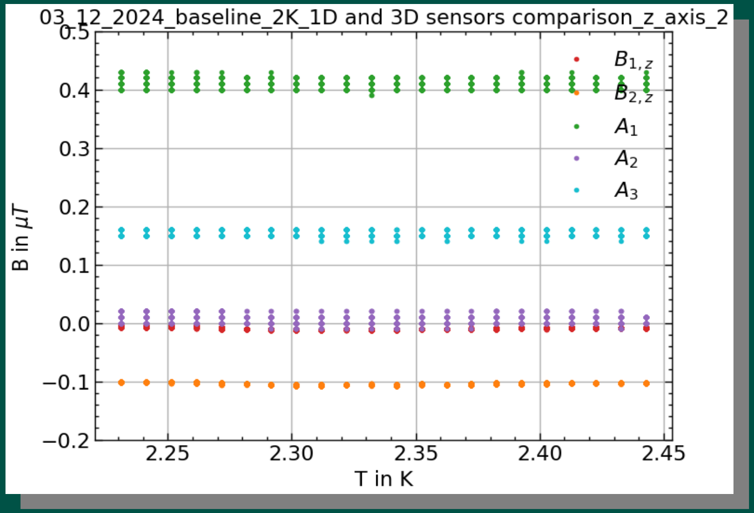
Cooldown to 2 K



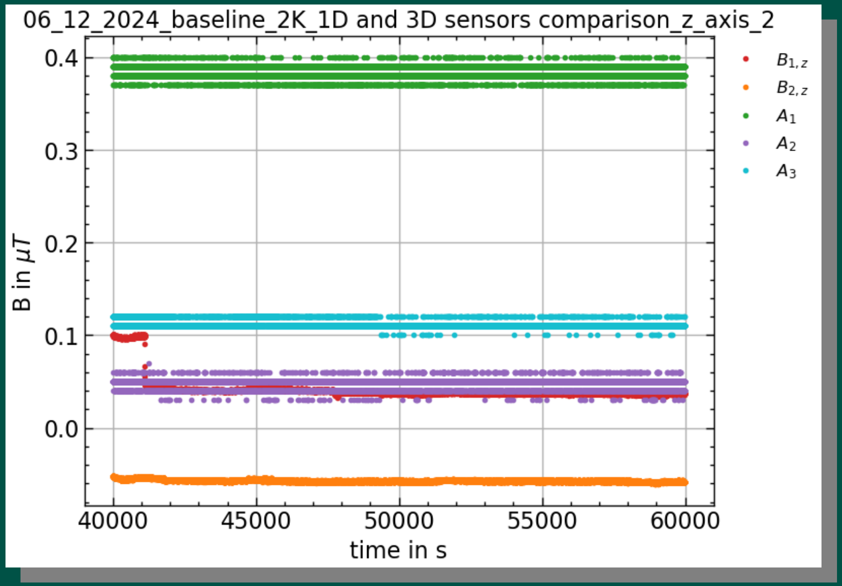
Baseline measurement (B_{ext} = 0)
Expectation: values expected compare to 1^{st} baseline measurement, expected ambient field ≤ 100 nT
Difference between 3D sensors: 0.1 μT

Comparison baseline measurements

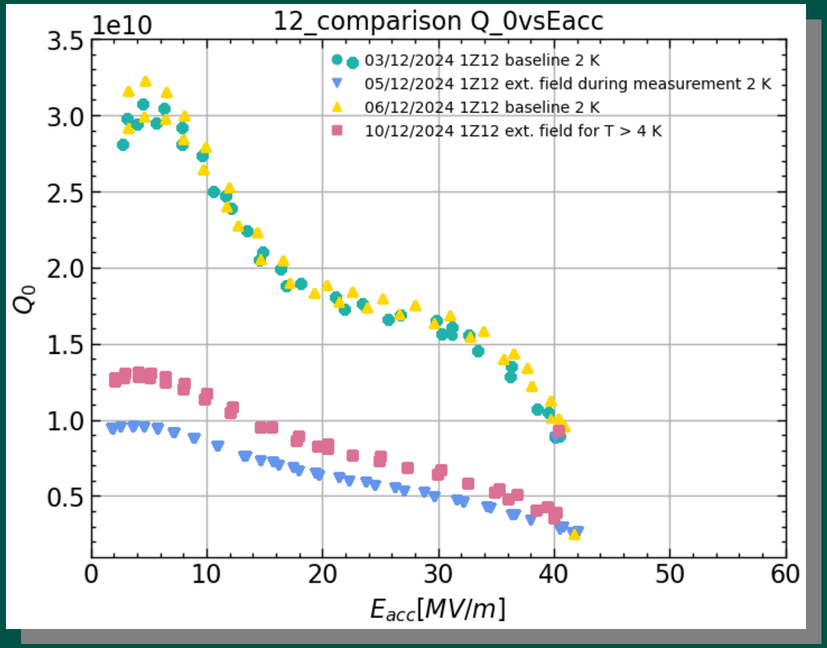




1st baseline measurement over time and temperature

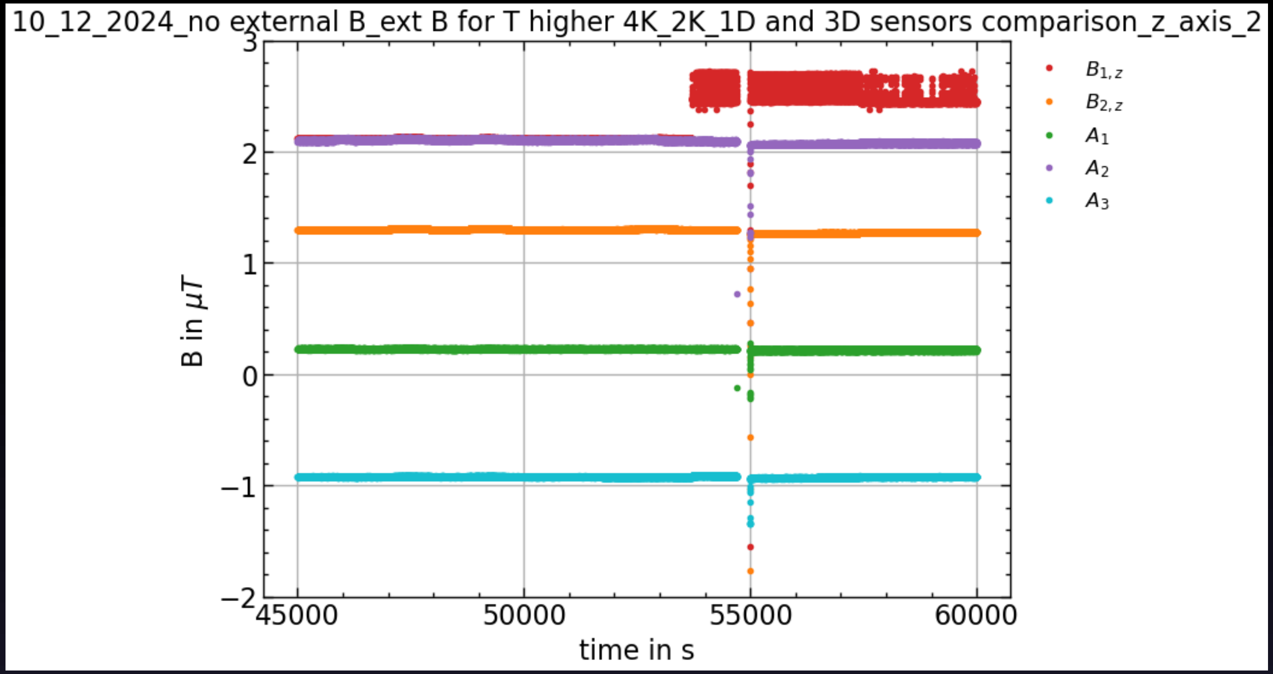


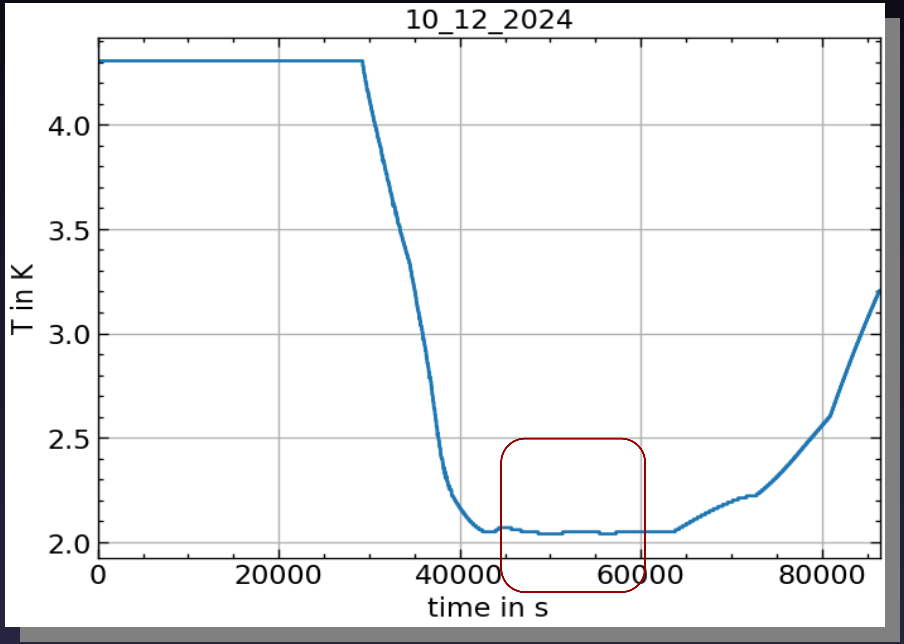
2nd baseline measurement over time



2^{nd} Magnetic field measurement

Field measurement
-warmup to 20, B_{ext} ≈7.2 μT,
cooldown to 4 K, B_{ext} = 0,
cooldown to 2 K

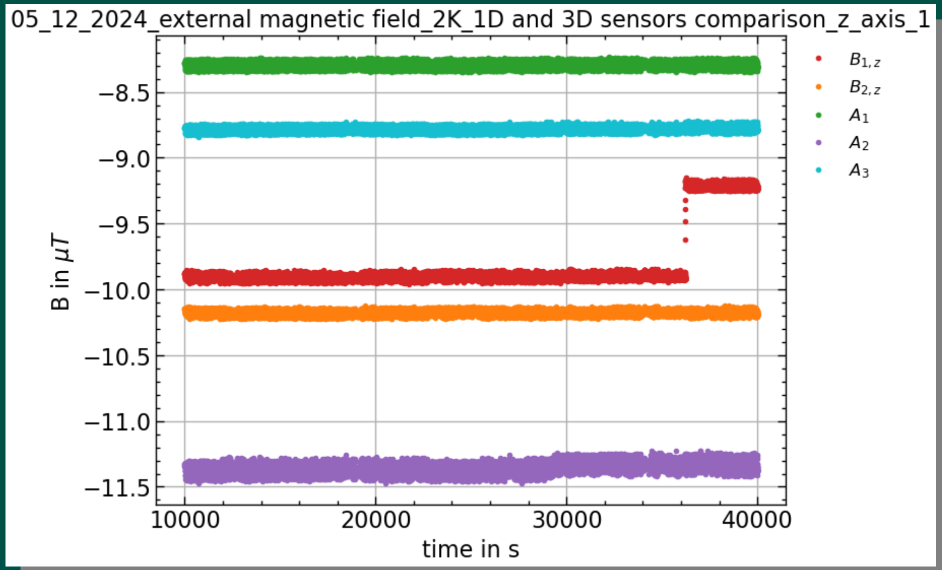




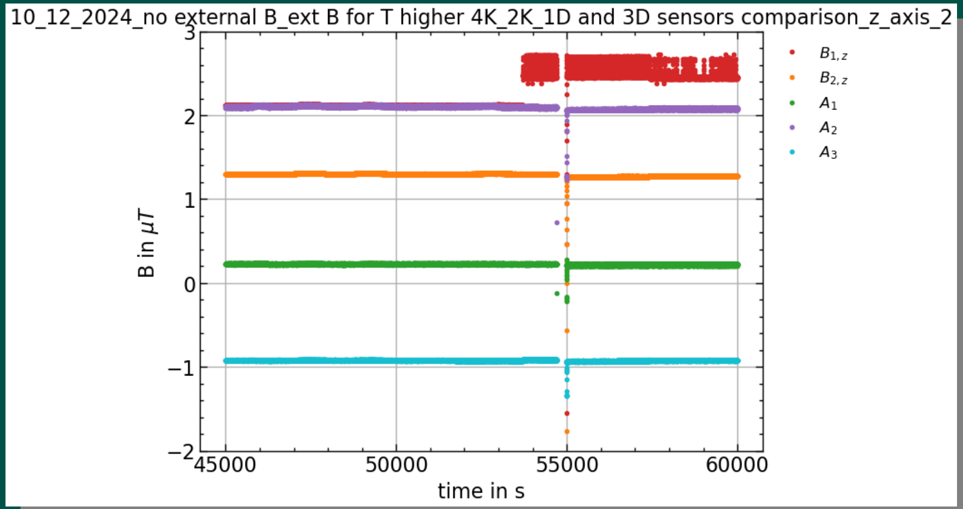
Expectation: magnetic field values expected lower as in first magnetic field measurement as field not applied during measurement

Difference between 3D sensors: ~ 1 μT

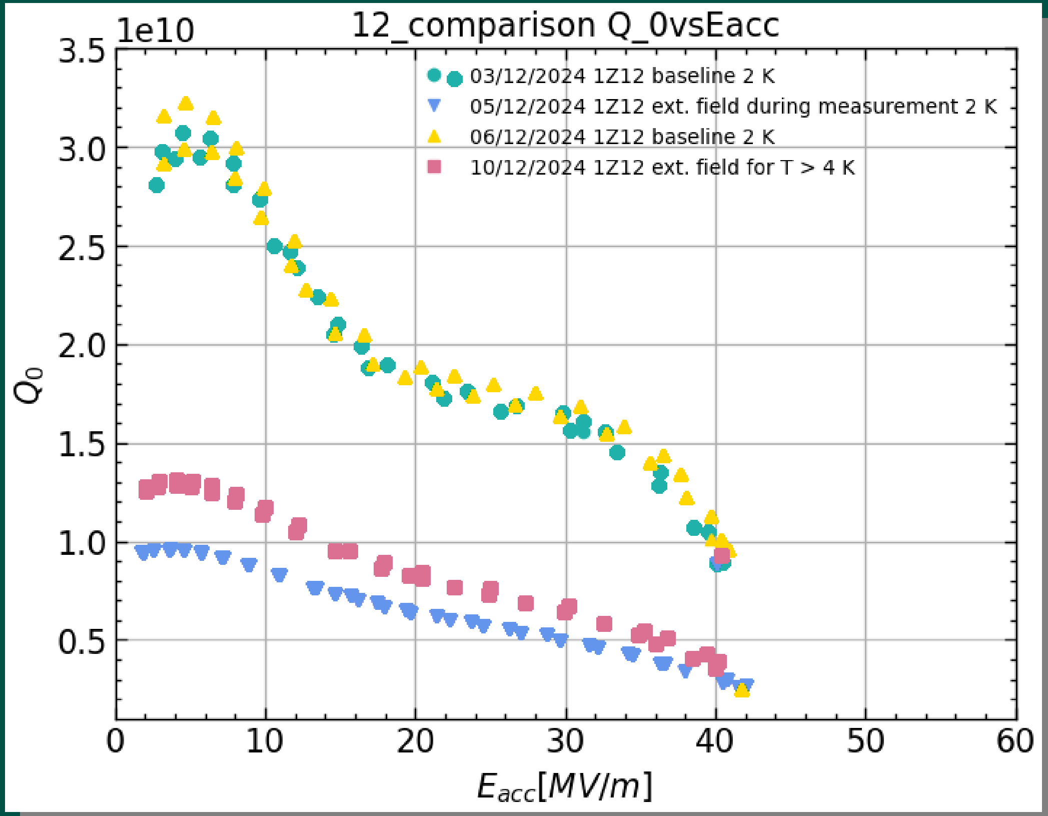
Comparison magnetic field measurements



1st magnetic field measurement



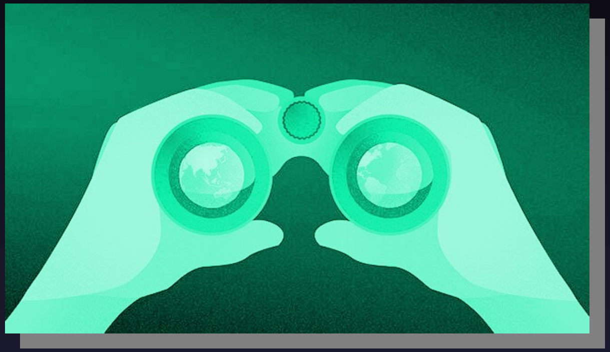
2nd magnetic field measurement



With B_{ext}: trapped magnetic field results in lower Q_0 because of disturbance of the Meissner effect

Without B_{ext}: higher performance of Meissner effect

Near-future Outlook

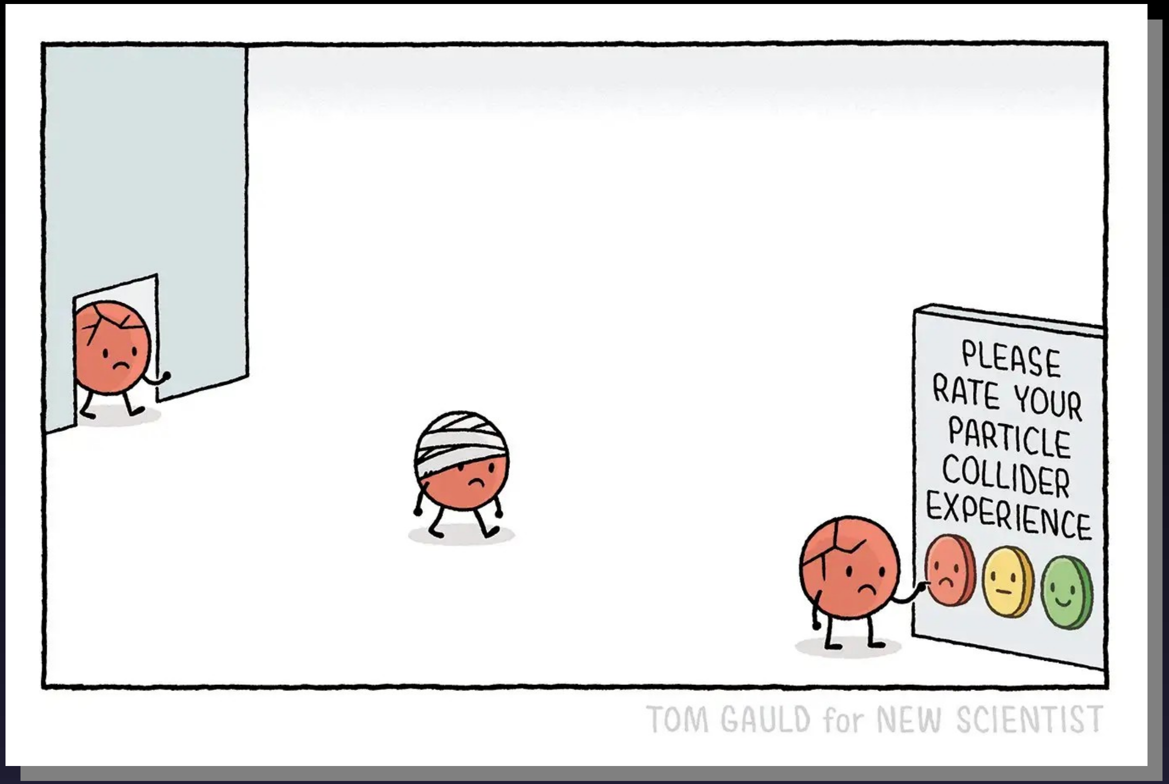


-Understanding data: differences in sensors, noise in data, validity of results

-Determining S from Q_0/E_{acc} measurements

-Comparison between XFEL-type and mid-T baked cavities

Further Resources!



- -Correlation of srf performance to oxygen diffusion length of medium temperature heat treated cavities*, C. Bate, et al. arXiv:2407.07779v1, 2024.
- -Further improvement of medium temperature heat treated srf cavities for high gradients*, L. Steder, et al. arXiv:2407.12570v1, 2024.
- -Impact of medium temperature heat treatment on flux trapping sensitivity in srf cavities*, P. Dhakal, et al. arXiv:2405.10085v1, 2024.
- -Impact of medium temperature heat treatments on the magnetic flux expulsion behavior of srf cavities*, J. C. Wolff, et al. 2023.
- -Rf superconductivity for accelerators, H. Padamsee, et al. (book)