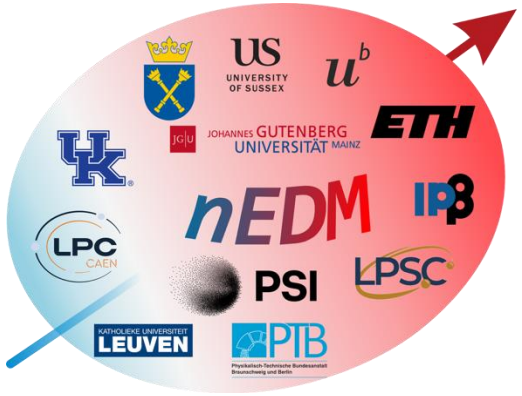
“Magnetics” for fundamental precision experiments



Efrain Segarra

Marie Curie Fellow PSI/ETH

Aug 22, 2025

Perspective from nEDM measurements

- We care about **fT** variations of $\vec{B}$ over **minutes** in a 60L volume

- We need to limit magnetic contamination to $\sim \mathrm{n}A\ \mathrm{m}^2$ of all materials within 5cm of the experimental volume (and in!)

Tools to mitigate this

- We care about **fT** variations of $\vec{B}$ over **minutes** in a 60L volume
  - **Reduce** and **compensate** external field exposure
  - **Measure** field stability within volume

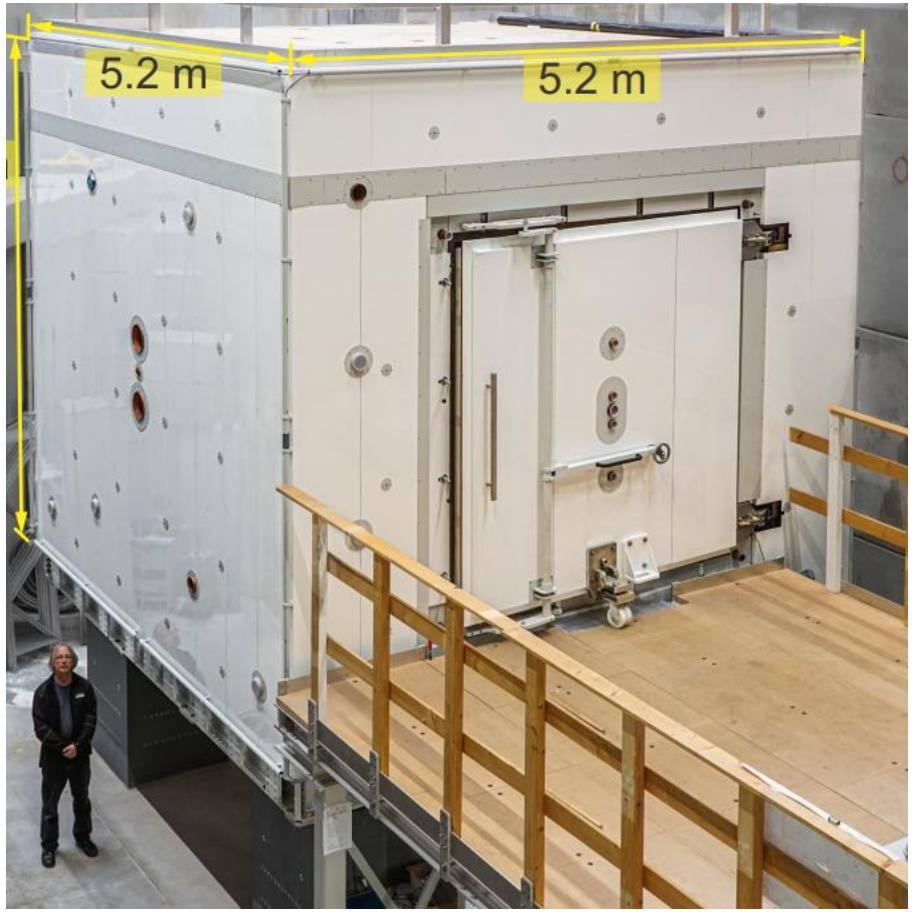
- We need to limit magnetic contamination to $\sim \mathrm{nA\ m^2}$ of all materials within 5cm of the experimental volume (and in!)
  - **Measure** incredibly small magnetizability of all parts

Tools to mitigate this

- We care about **fT** variations of $\vec{B}$ over **minutes** in a 60L volume
  - **Passive** and **active** magnetic shielding
  - **Comagnetometers** (Hg + Cs)

- We need to limit magnetic contamination to $\sim \mathrm{n}A\ \mathrm{m}^2$ of all materials within 5cm of the experimental volume (and in!)
  - **Magnetic gradiometer**

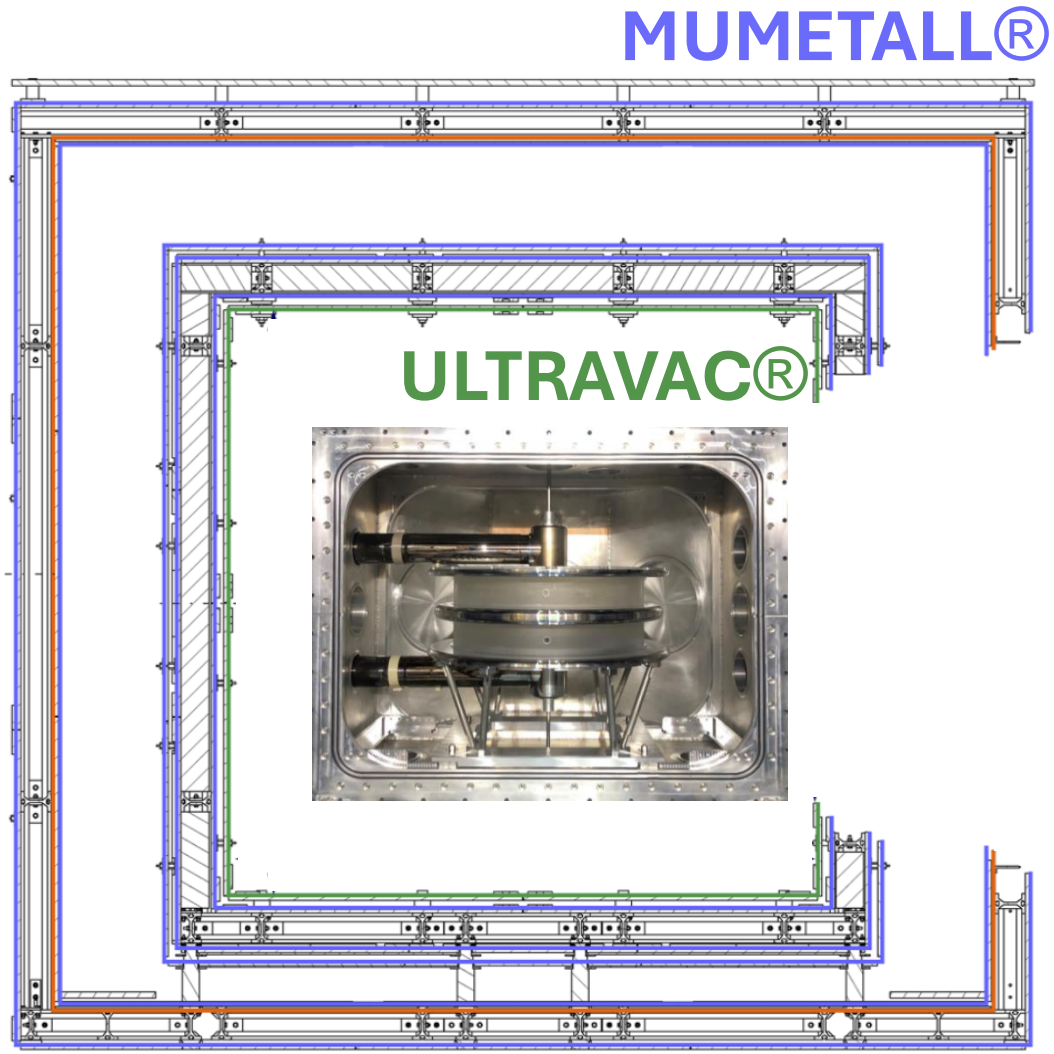
Reducing and compensating external field exposure



Passive shielding

Active shielding

The Magnetically Shielded Room (MSR)

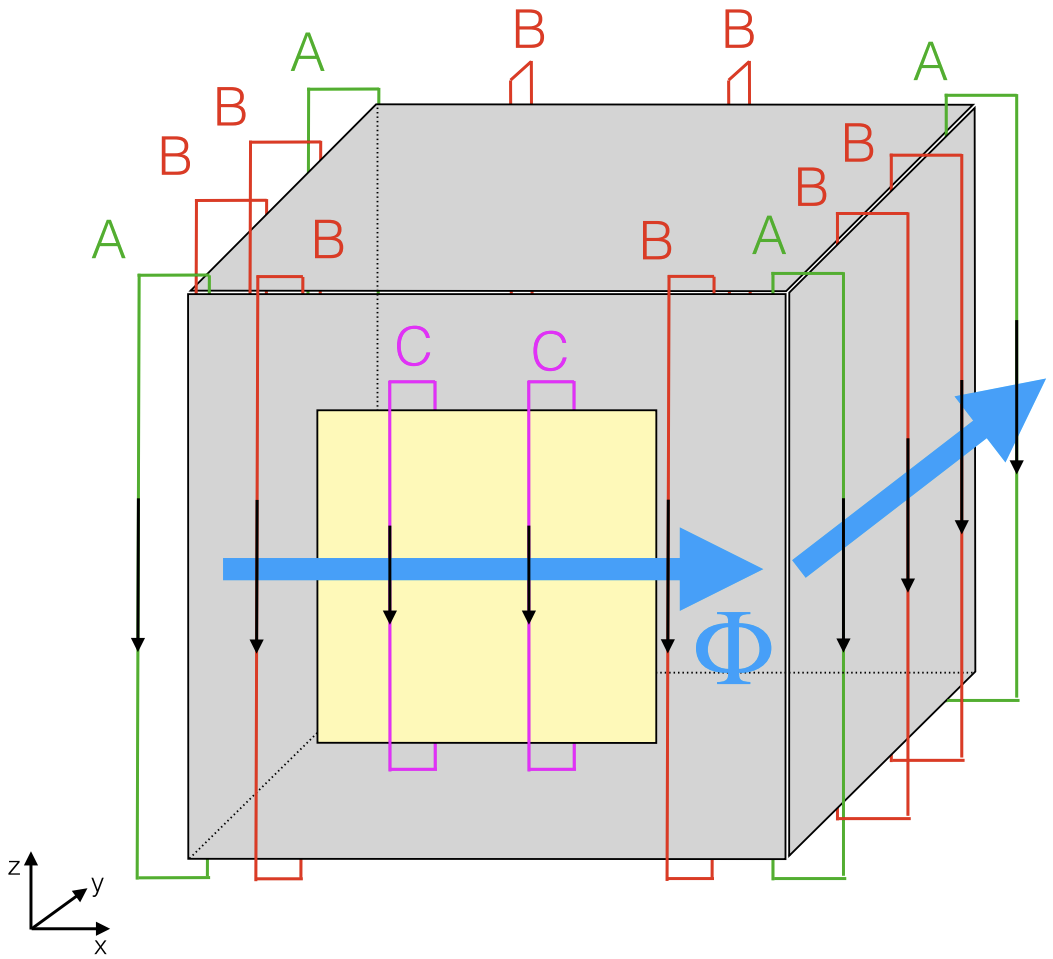


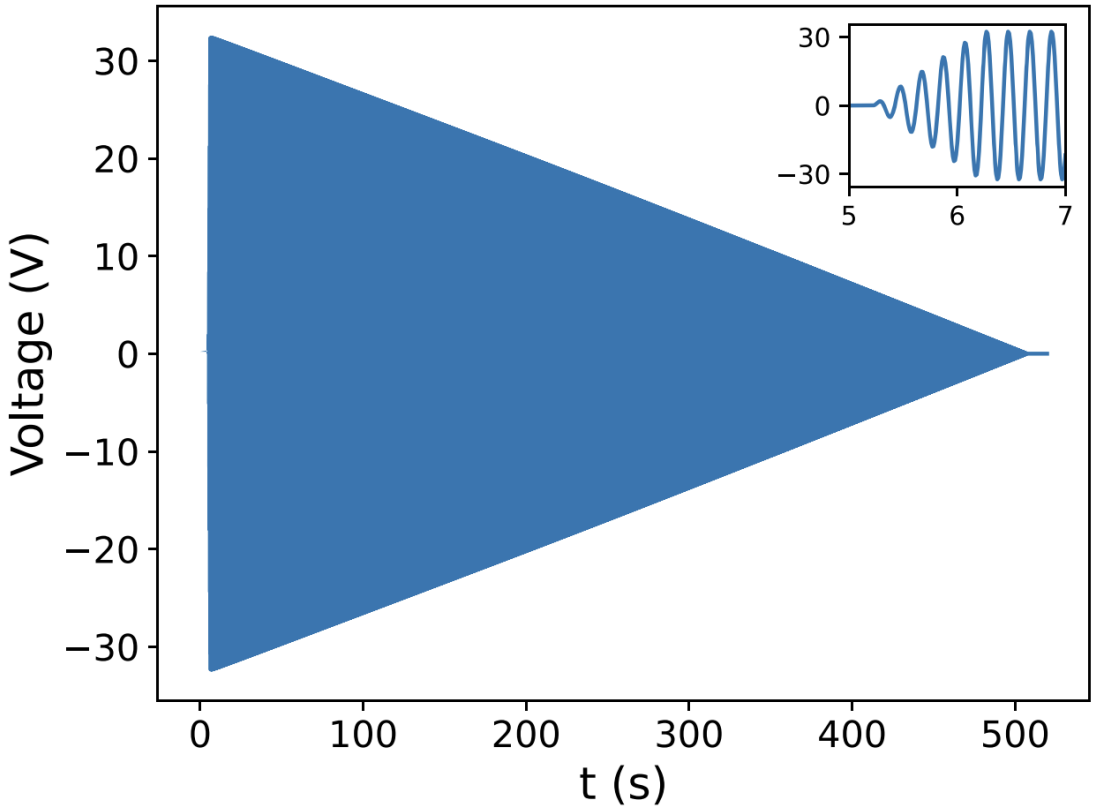
- 6 permeable layers (~75% iron, 15% nickel, +…)
- Shielding factor 10^5 at 0.01 Hz ($1\mu\mathrm{T} \rightarrow 10\mathrm{pT}$)
- Excitation coils to degauss permeable layers

Eur. Phys. J. C **84**, 18 (2024). https://doi.org/10.1140/epjc/s10052-023-12351-8

Rev. Sci. Instrum. 1 September 2022; 93 (9): 095105. https://doi.org/10.1063/5.0101391

The Magnetically Shielded Room (MSR)





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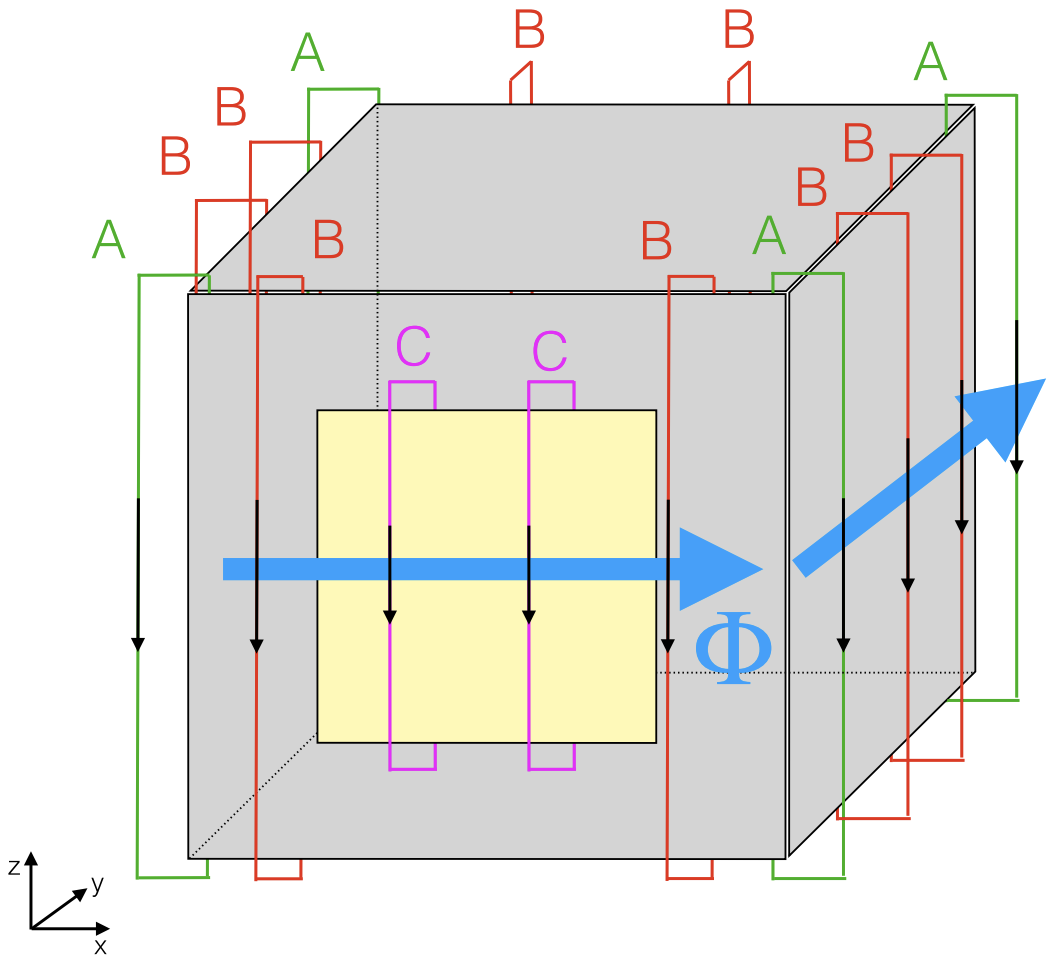

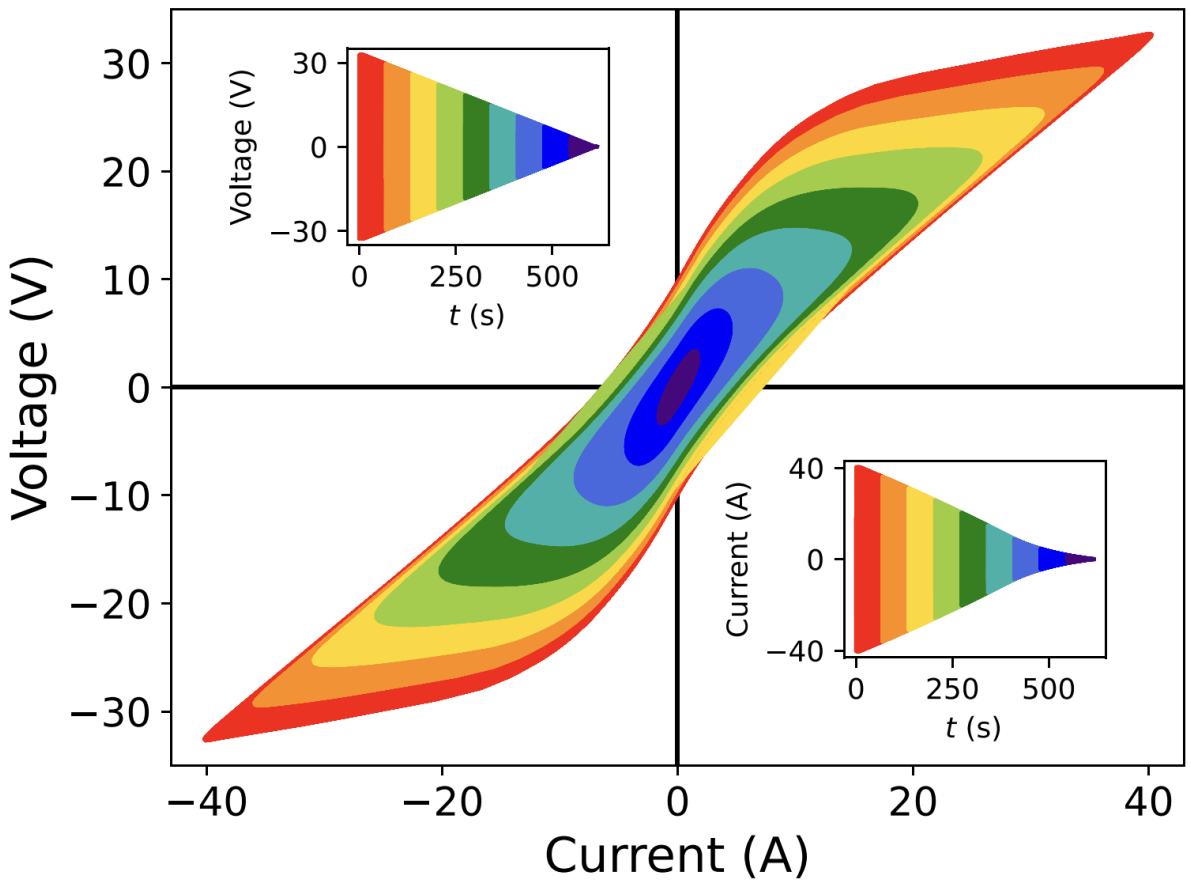

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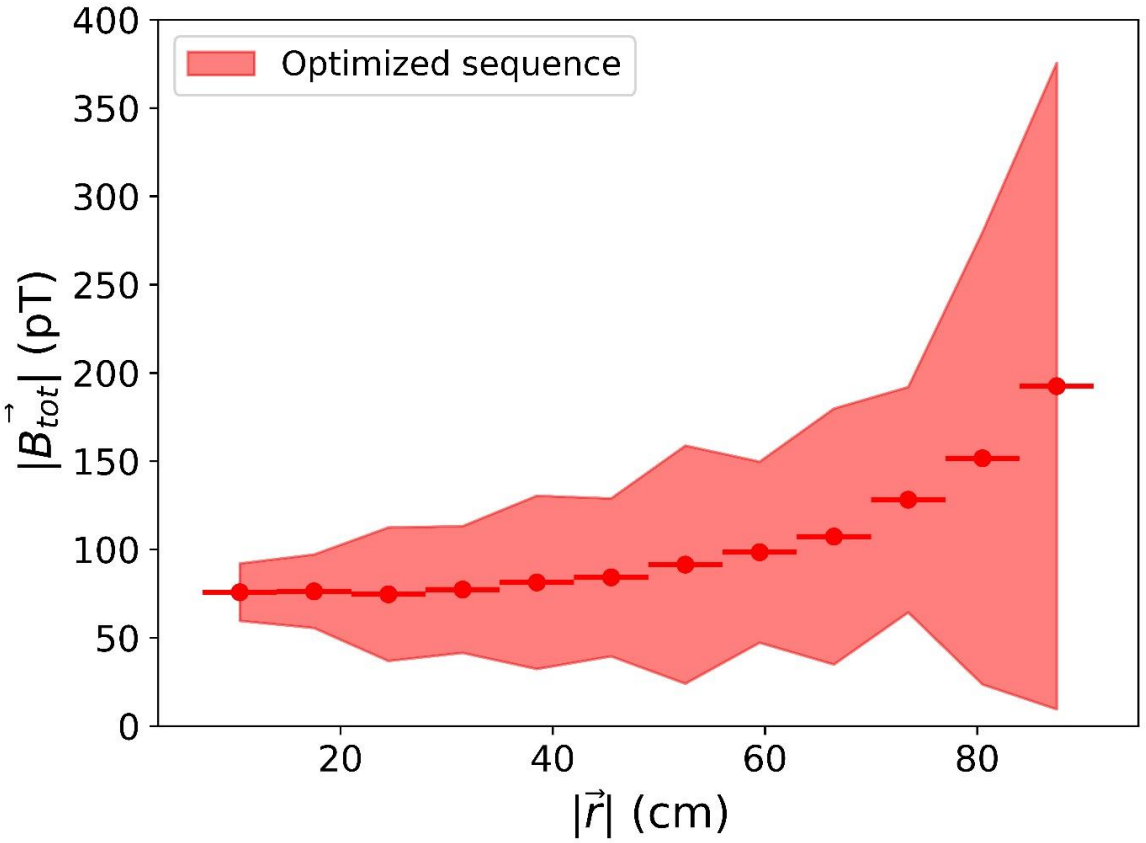

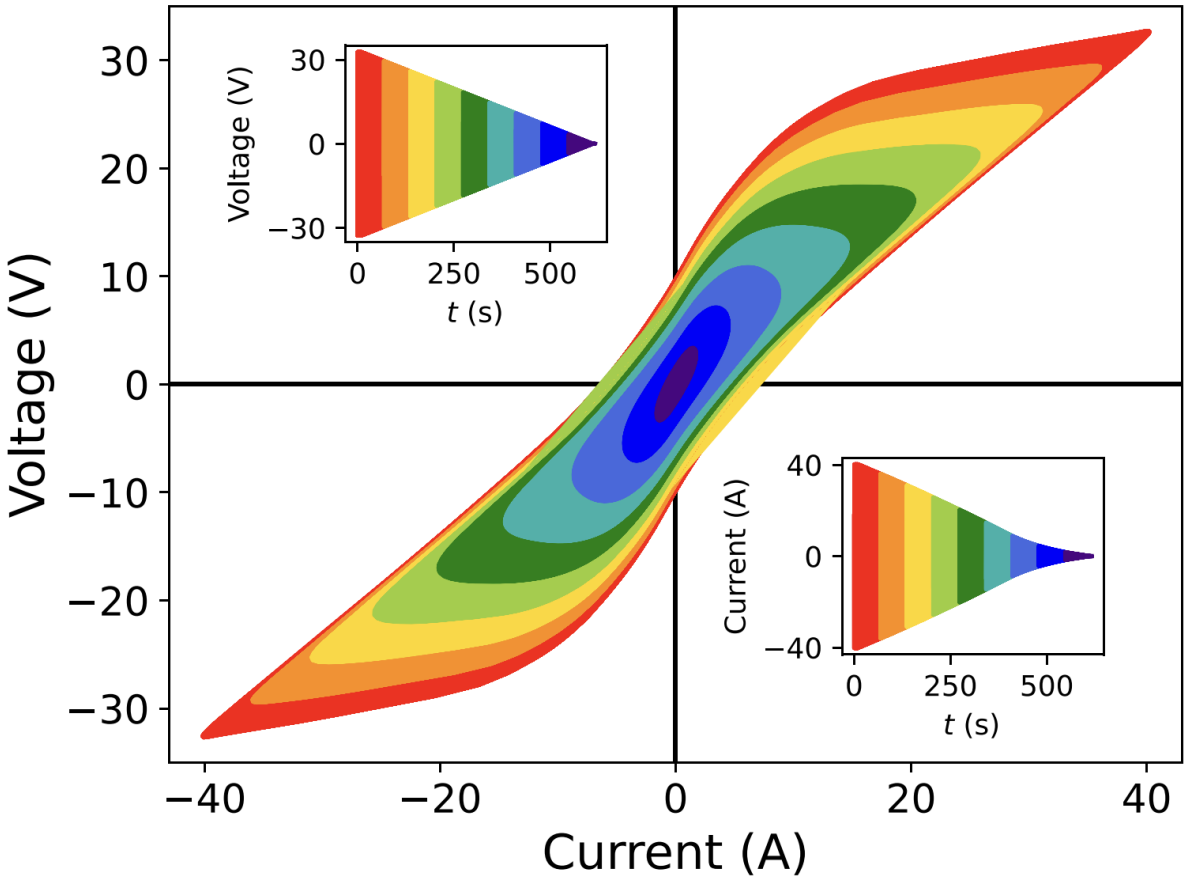

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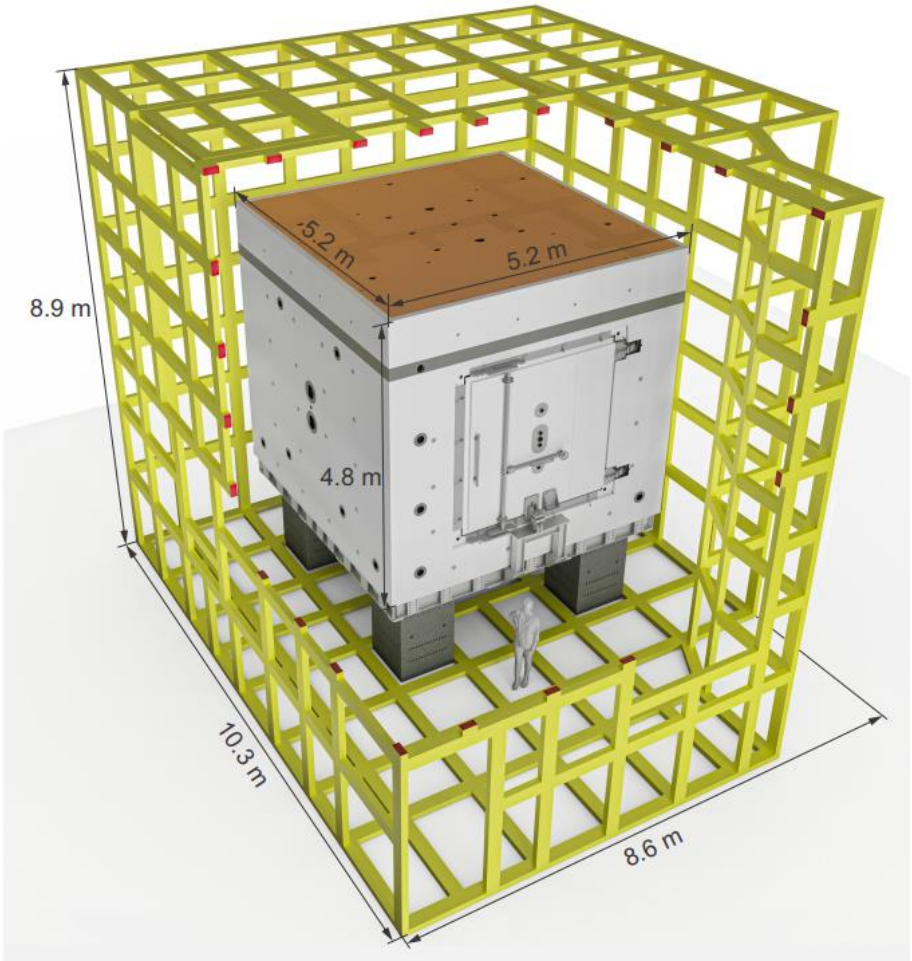
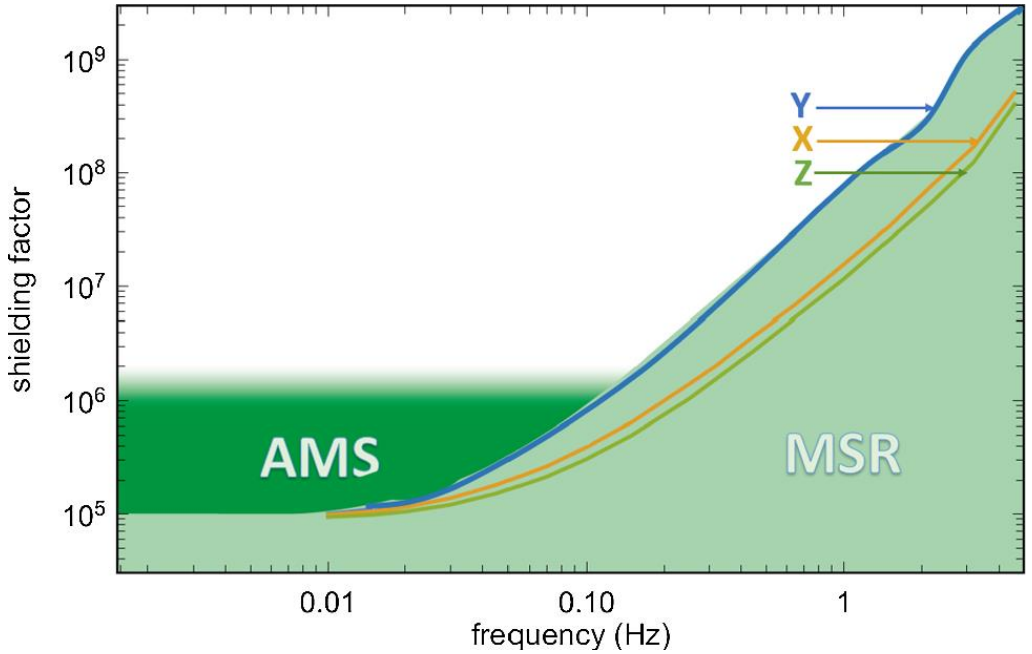
Active magnetic shield (AMS)

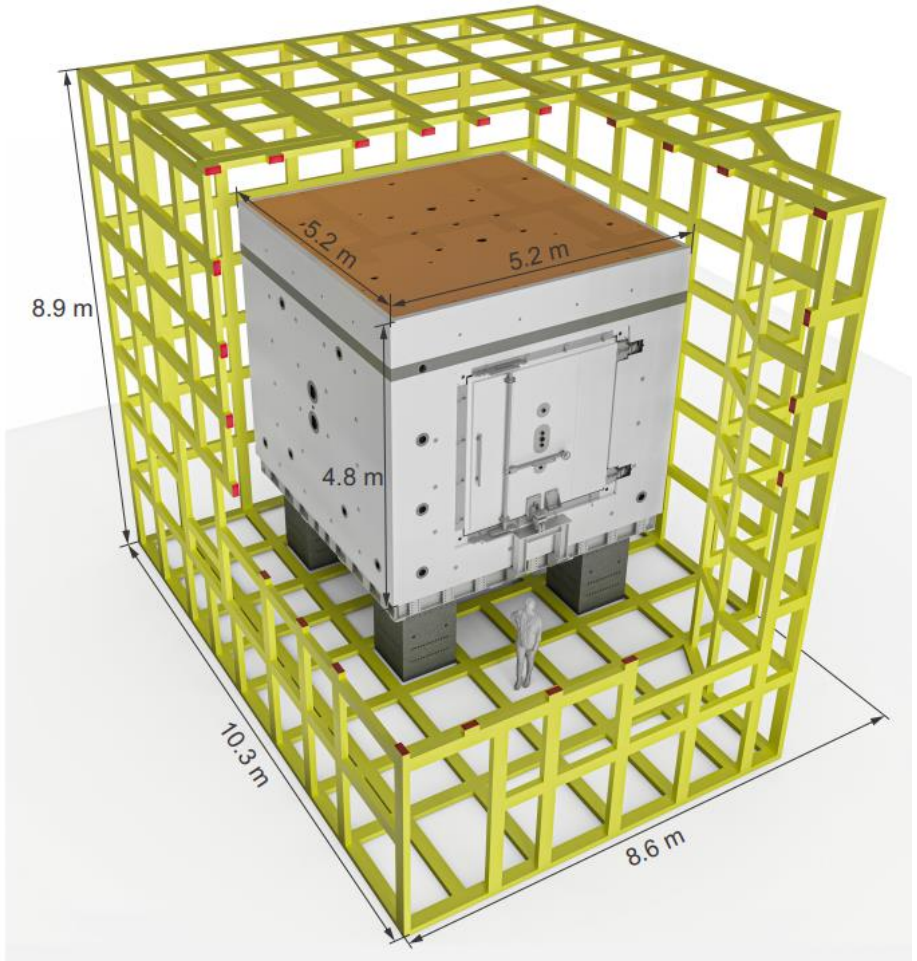


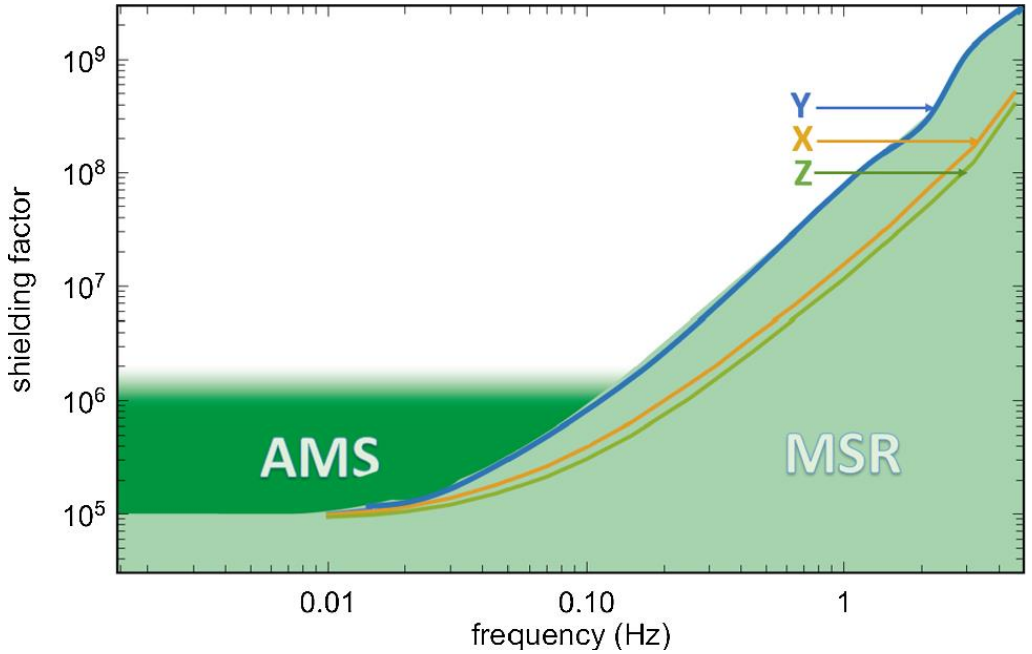


- 8 independent coils
- 55 km of wires
- kW heat dissipated

Eur. Phys. J. C **83**, 1061 (2023). https://doi.org/10.1140/epjc/s10052-023-12225-z

Active magnetic shield (AMS)





3D Fluxgates on the MSR for measuring feedback (solve for I)

$$B_i^{\text{meas.}} = B_i^{\text{ext.}} + \sum_k M_{ik}\, I_k$$

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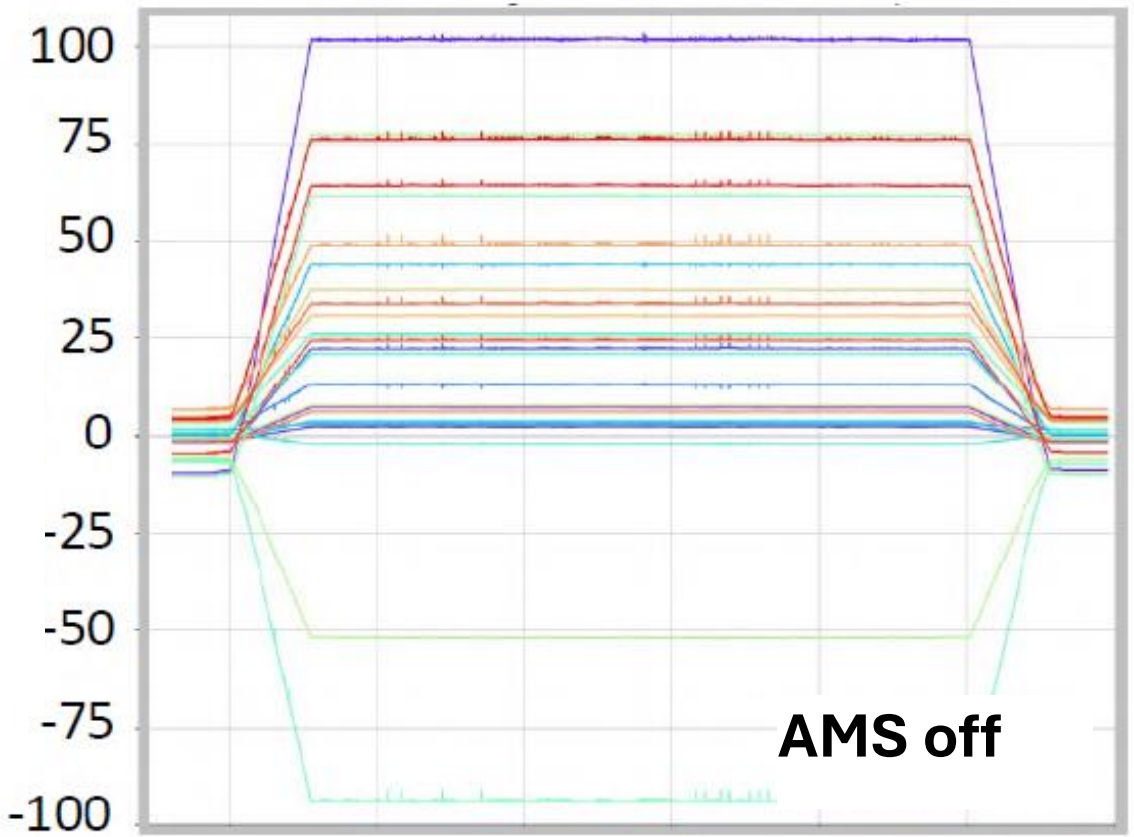
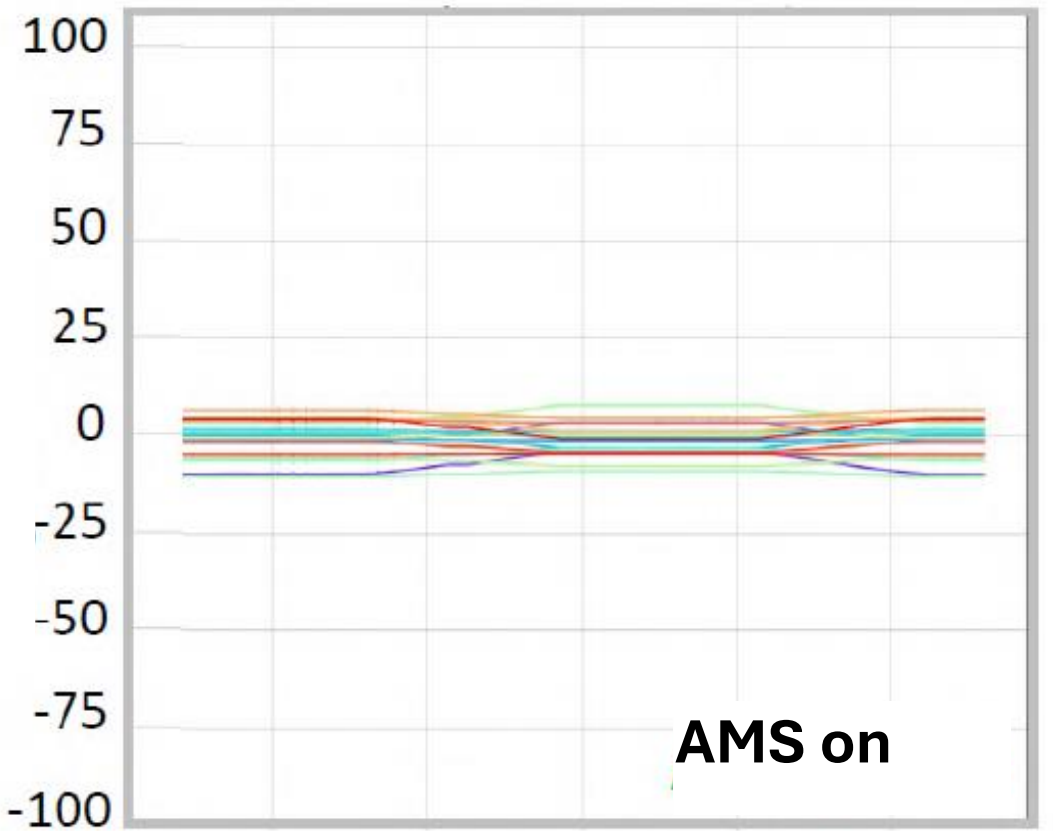
Active magnetic shield (AMS)

$B_{\text{outside MS}R}\ (\mu\text{T})$





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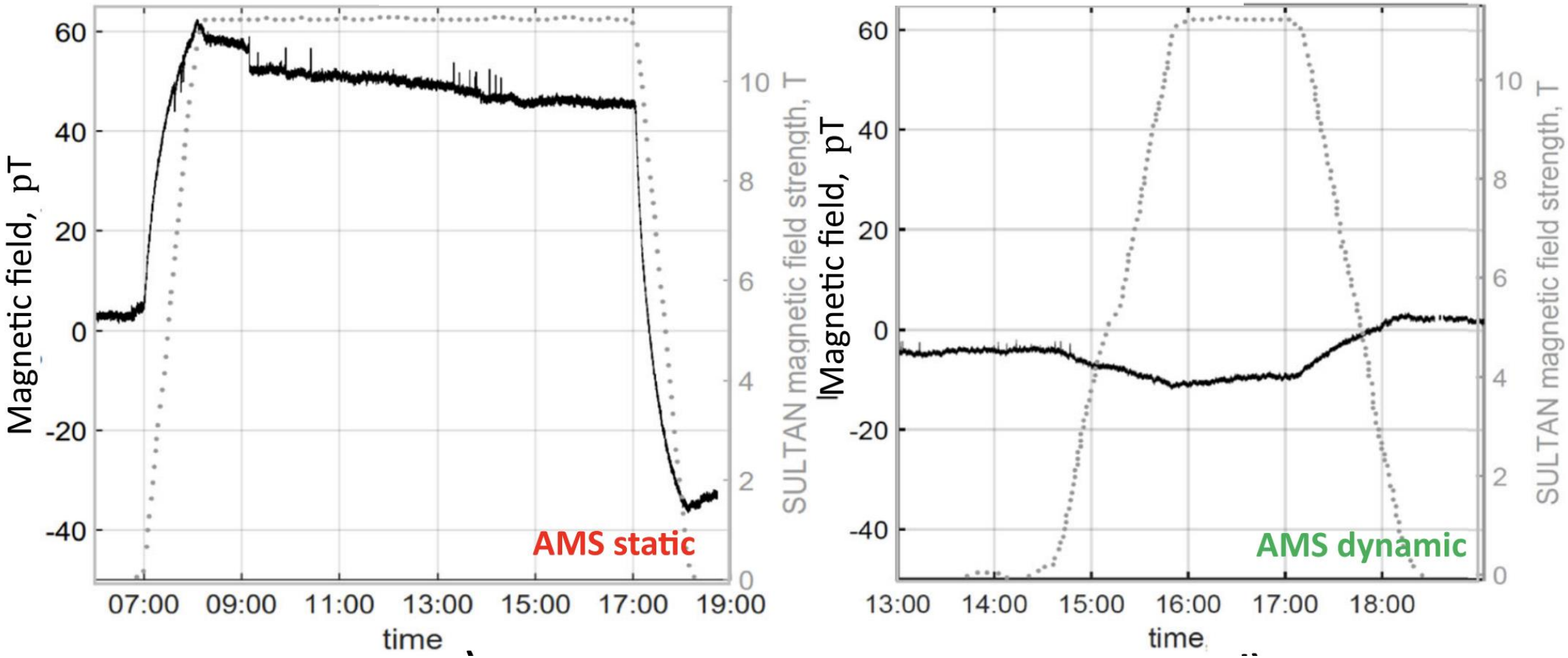
Active magnetic shield + Passive magnetic shield

$B_{\text{inside MS}R}$ (pT)



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Measuring field in the volume

$$f_n \propto |\vec{B}|$$

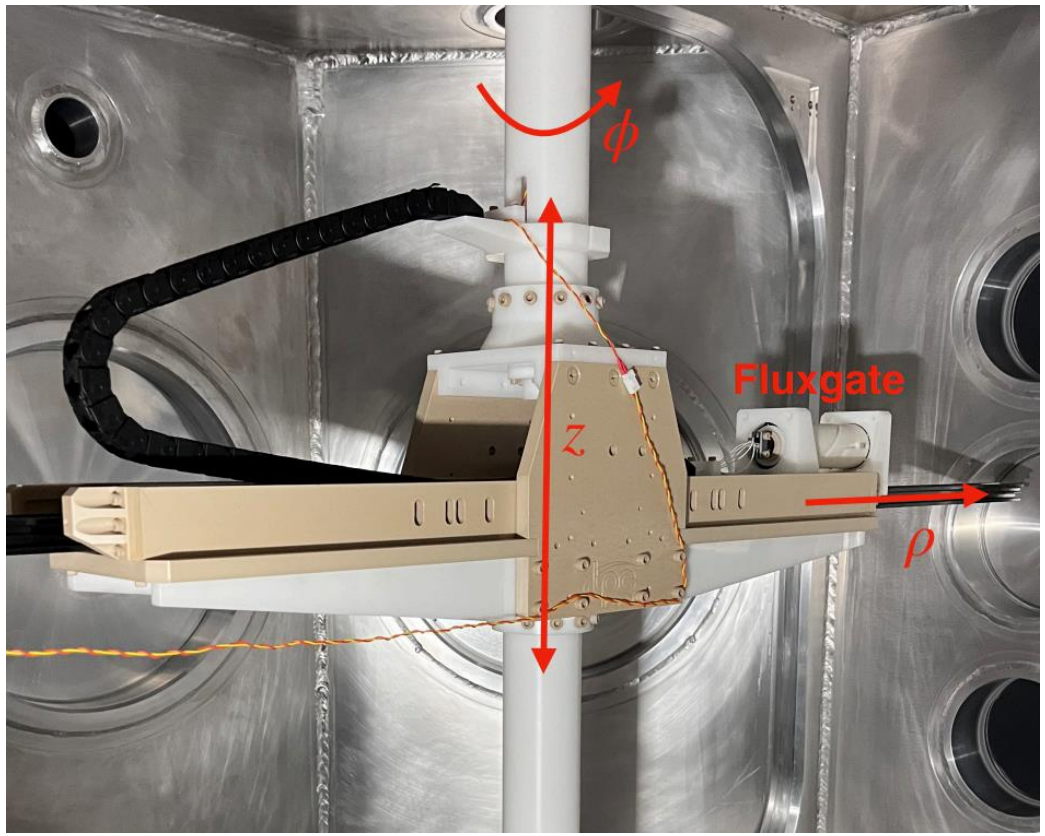
- Reproducibility of field for offline correction of data

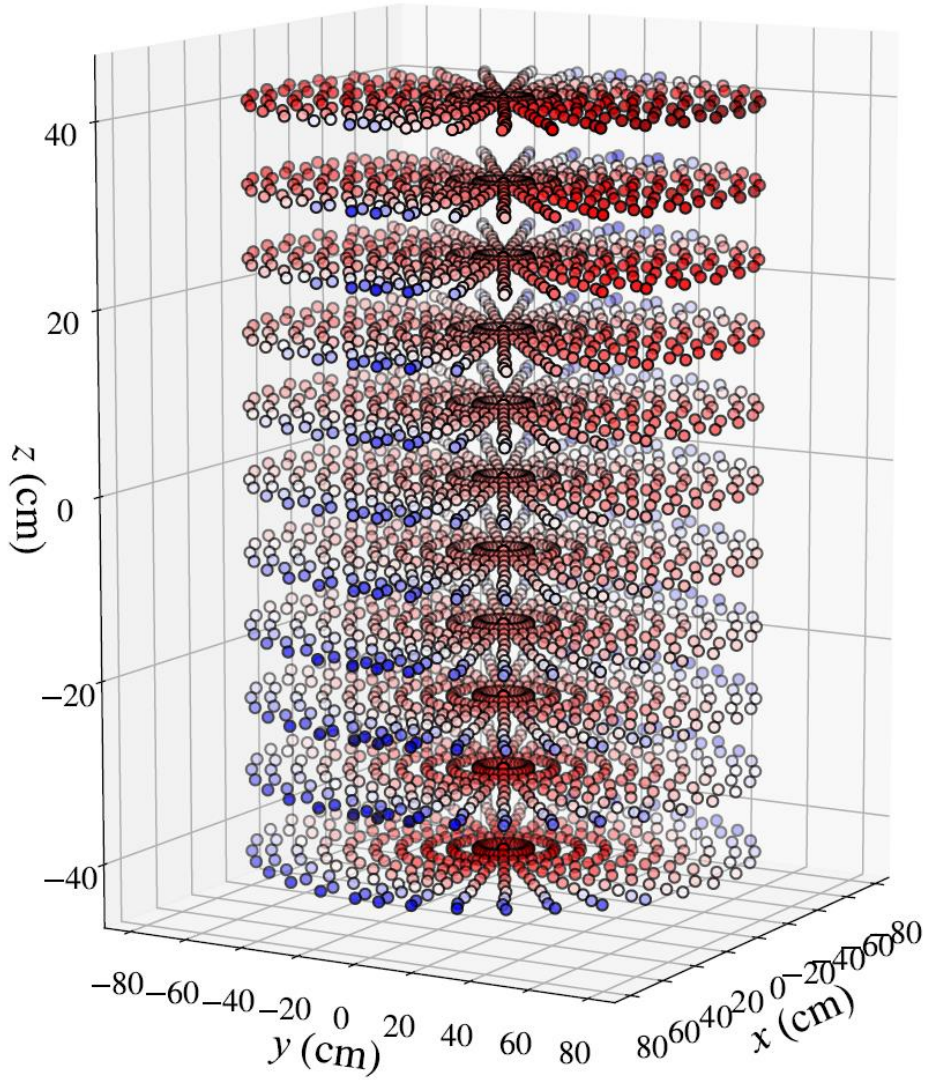
OR

- Reliable reconstruction of field for online correction of data

Measuring field in the volume – offline correction

$$\vec{B}(\vec{r}) = \sum_{l\geq 0}\sum_{m=-l}^{l} G_{l,m}\Pi_{l,m}(\vec{r})$$

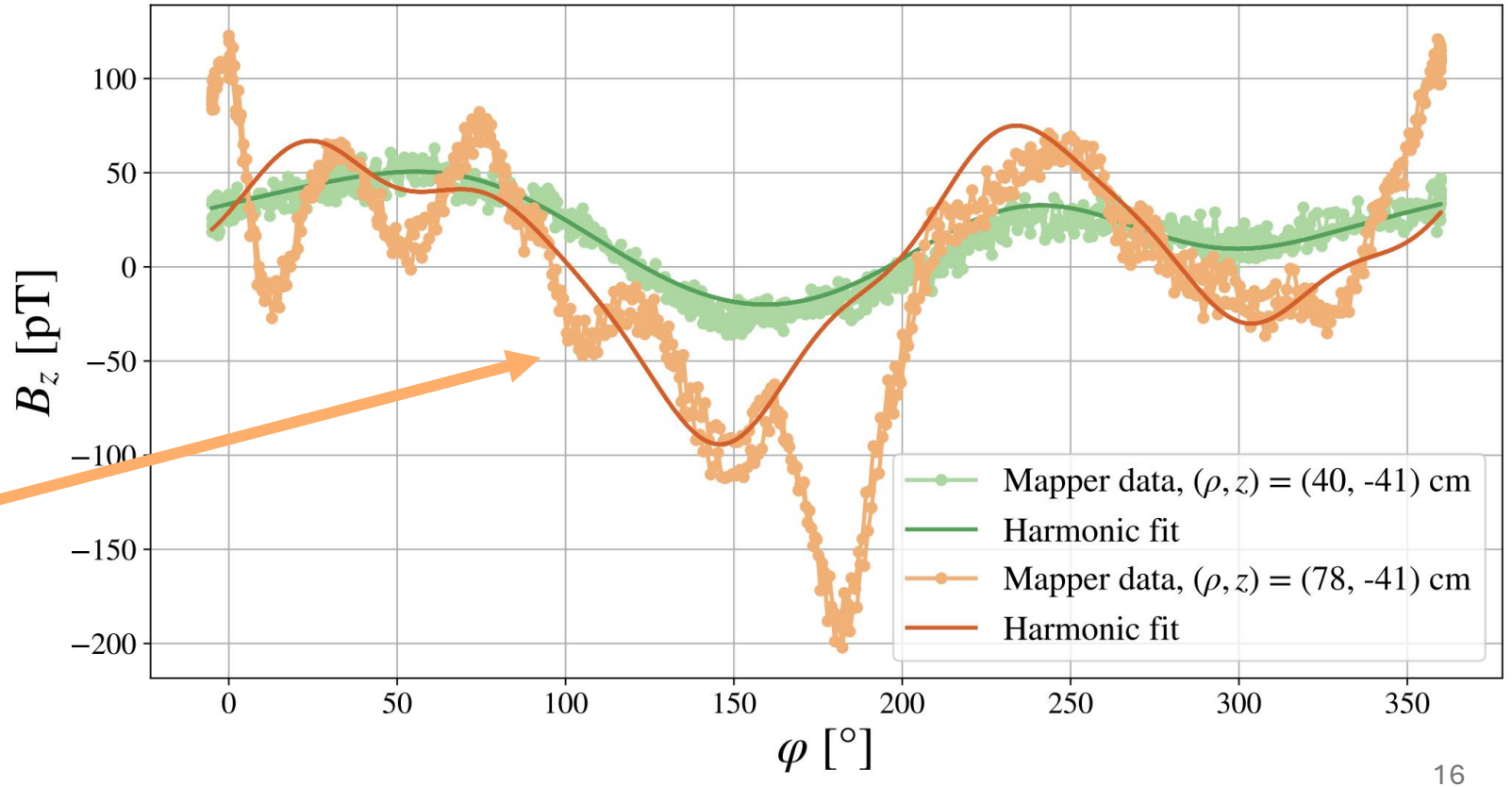




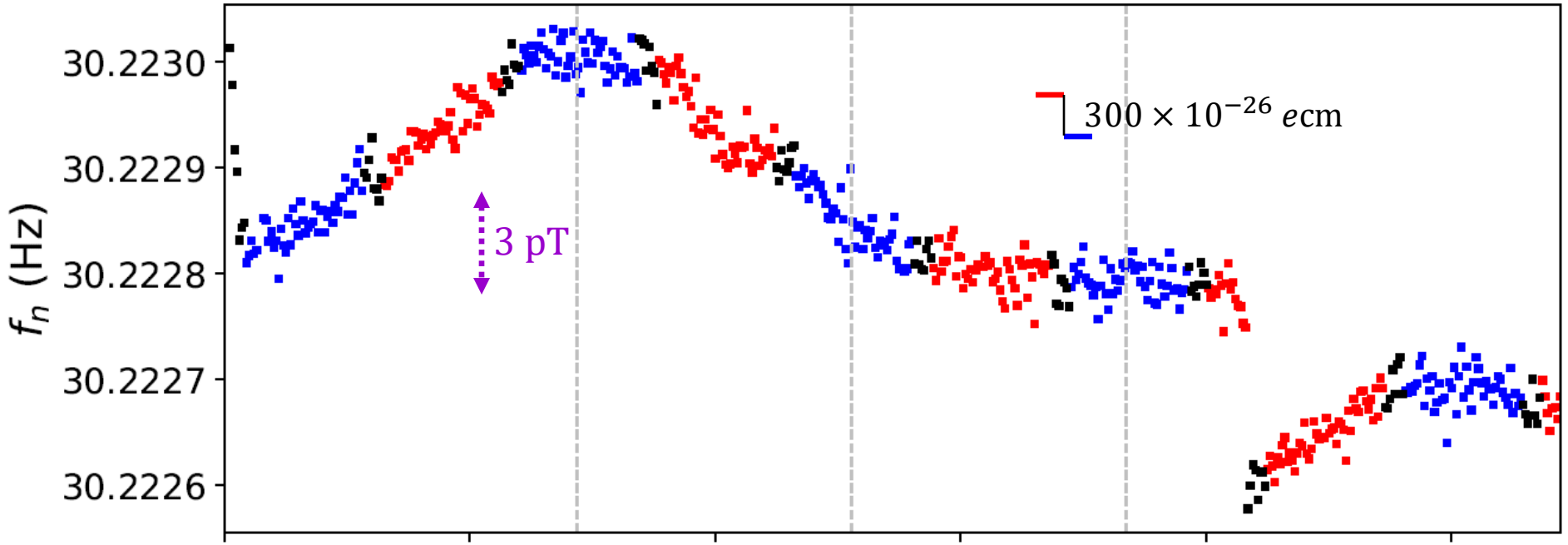
Measuring field in the volume – offline correction

$$\vec{B}(\vec{r}) = \sum_{l\geq 0} \sum_{m=-l}^{l} G_{l,m} \Pi_{l,m}(\vec{r})$$

Closer to MSR walls where relaxation is still underway due to degaussing



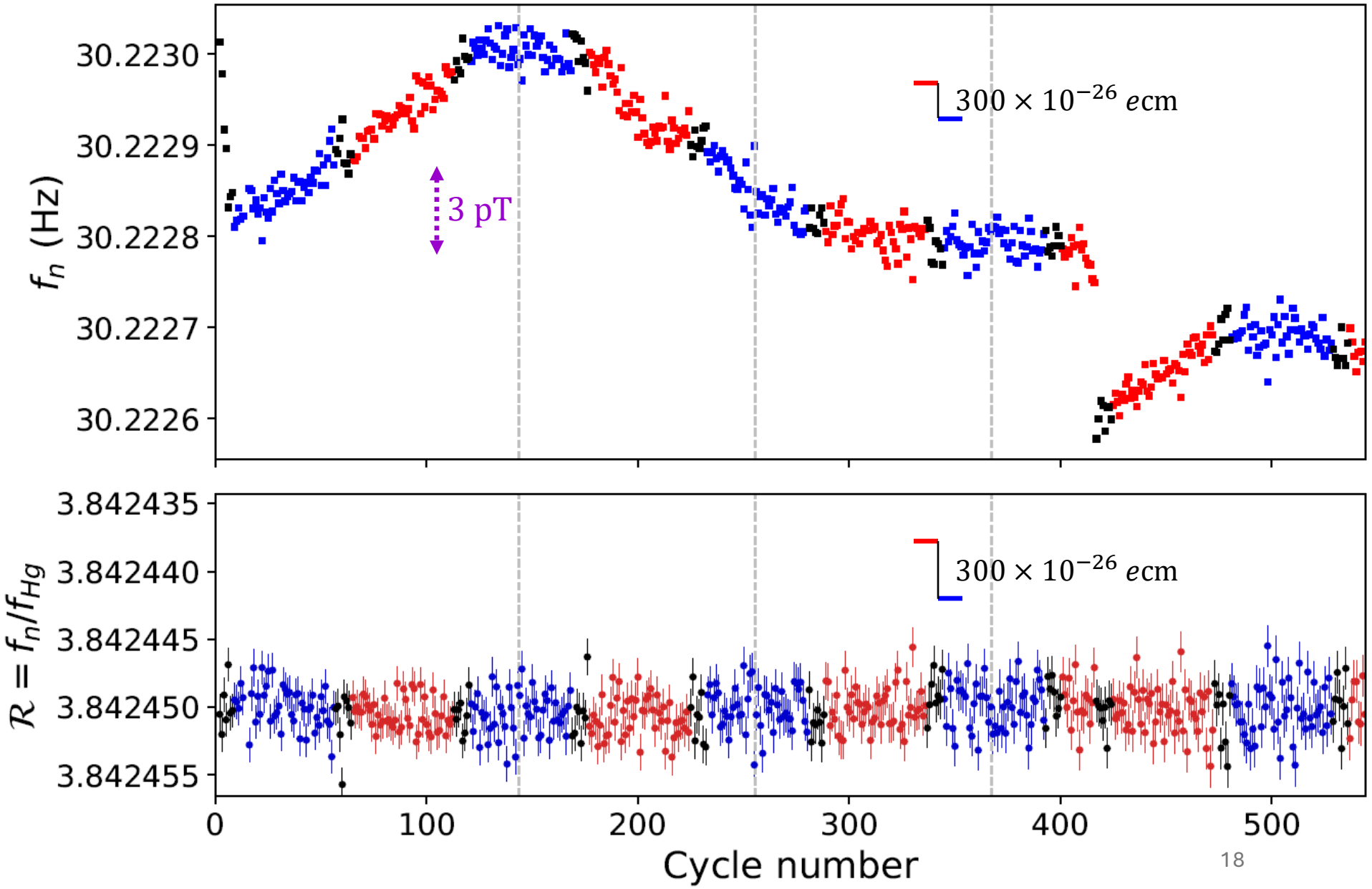
Measuring field in the volume – online Hg correction



Measuring field in the volume – online Hg correction

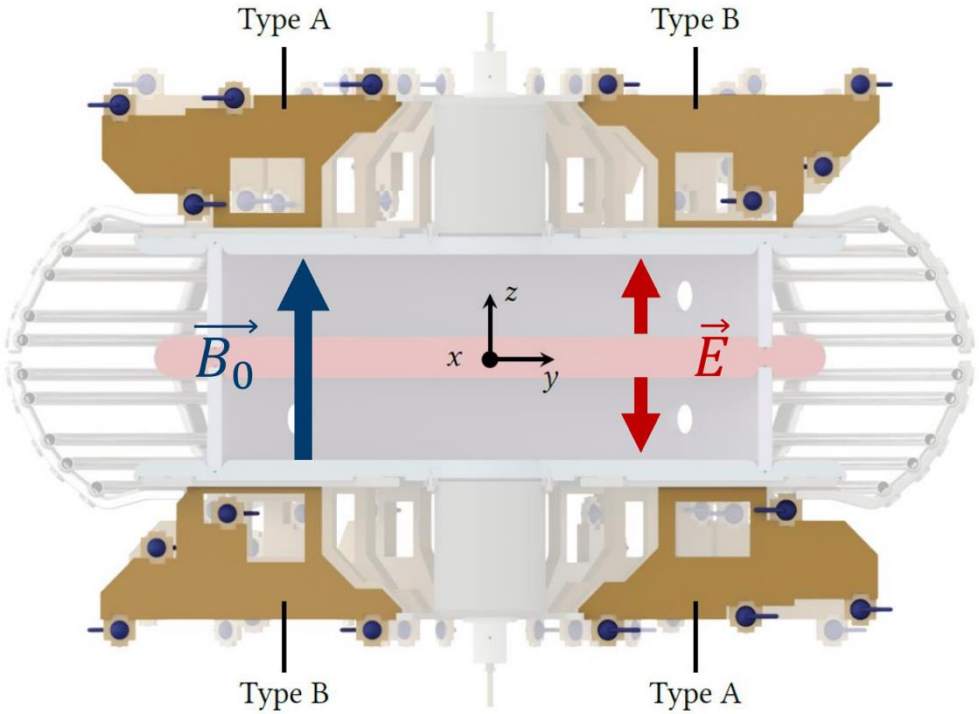
Magnetic fluctuations are corrected for at each cycle with the Hg magnetometer by measuring

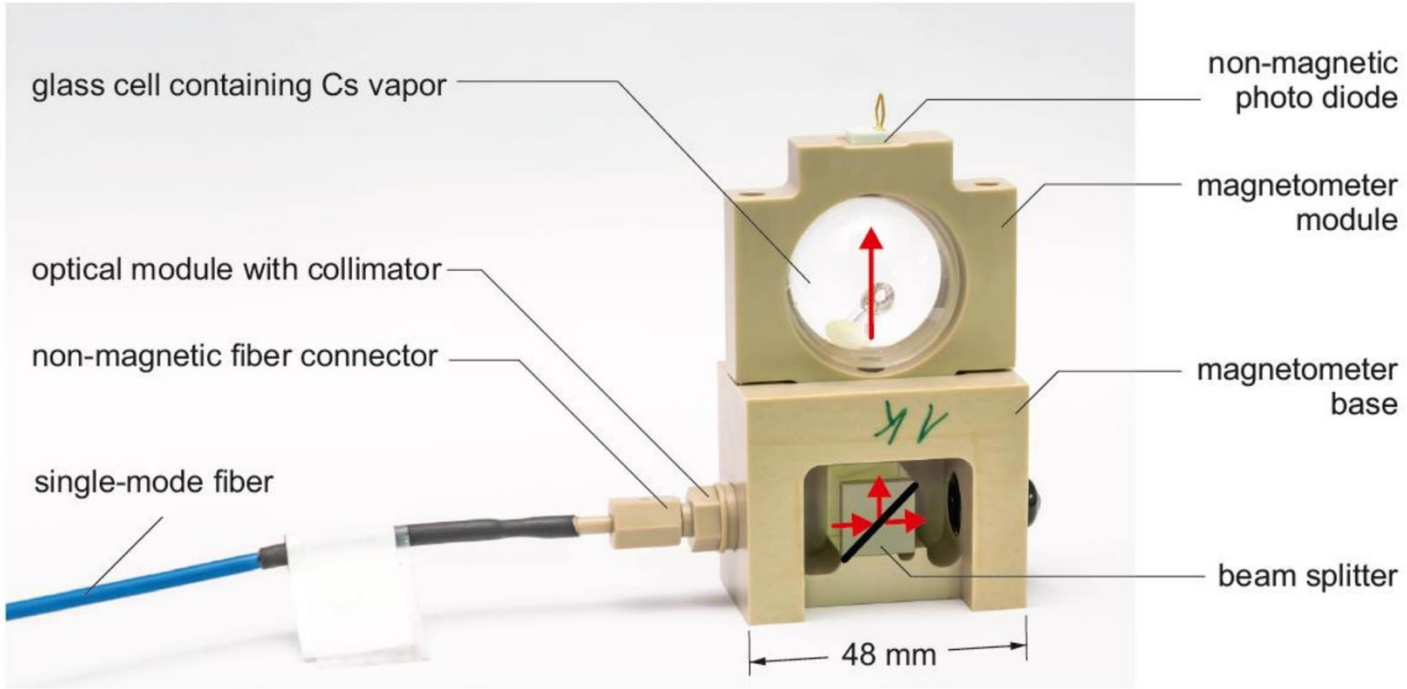
$$f_{\mathrm{Hg}} = \frac{\gamma_{\mathrm{Hg}}}{2\pi} B$$



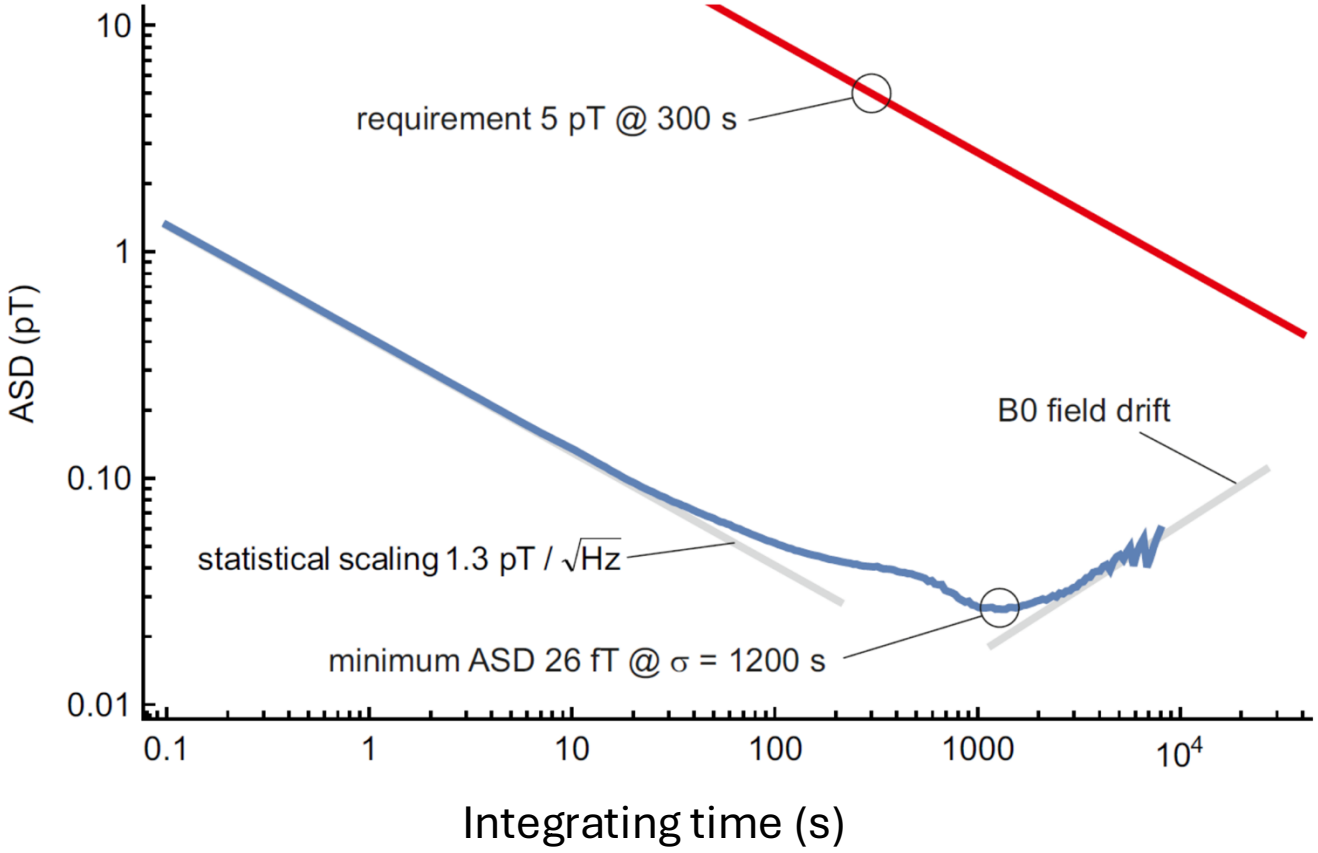
Measuring field in the volume – online Cs correction

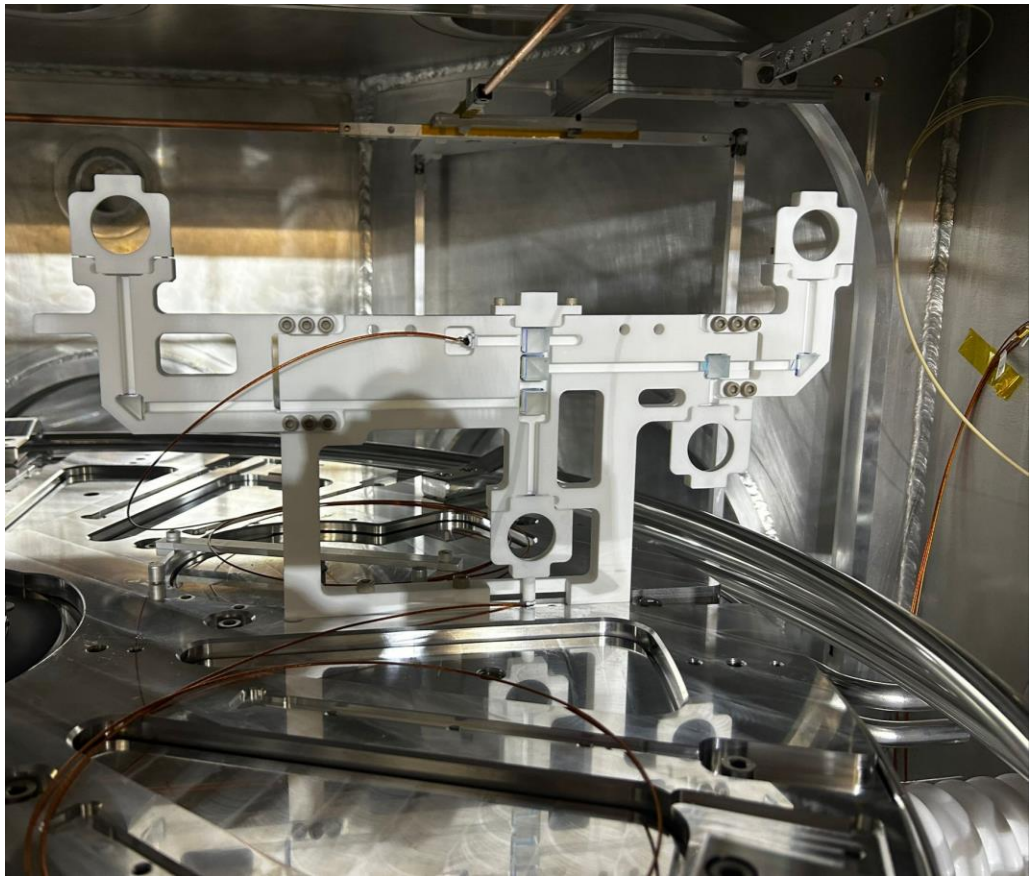
$$\vec{B}(\vec{r}) = \sum_{l\geq 0}\sum_{m=-l}^{l} G_{l,m}\Pi_{l,m}(\vec{r})$$





Cs Magnetometry sensitivity: fT in minutes



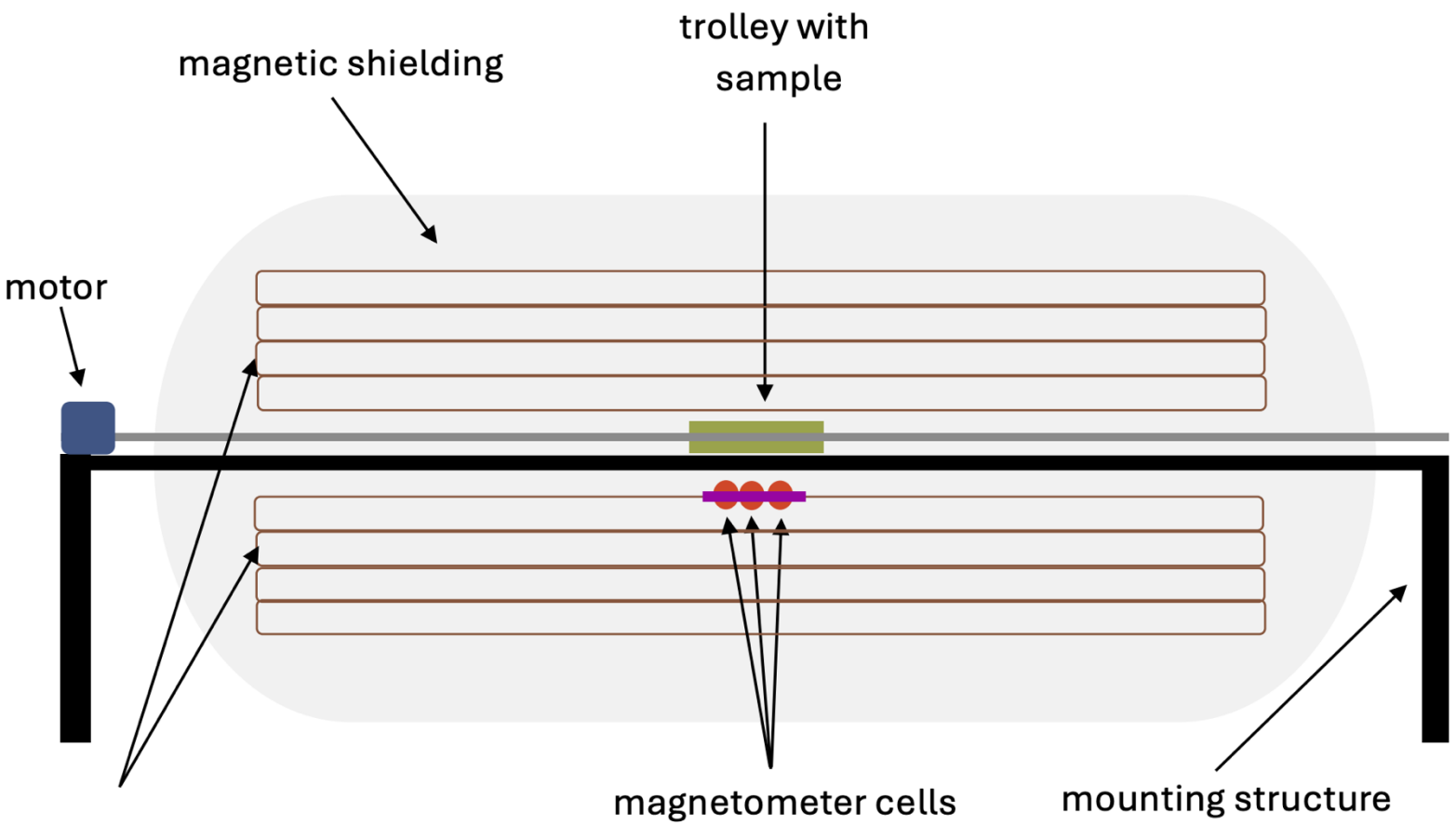


Reliable reconstruction → control magnetization

…and no dipole fields to skew EDM measurement

(must be correlated with $\vec{E}$)

Measuring material magnetization

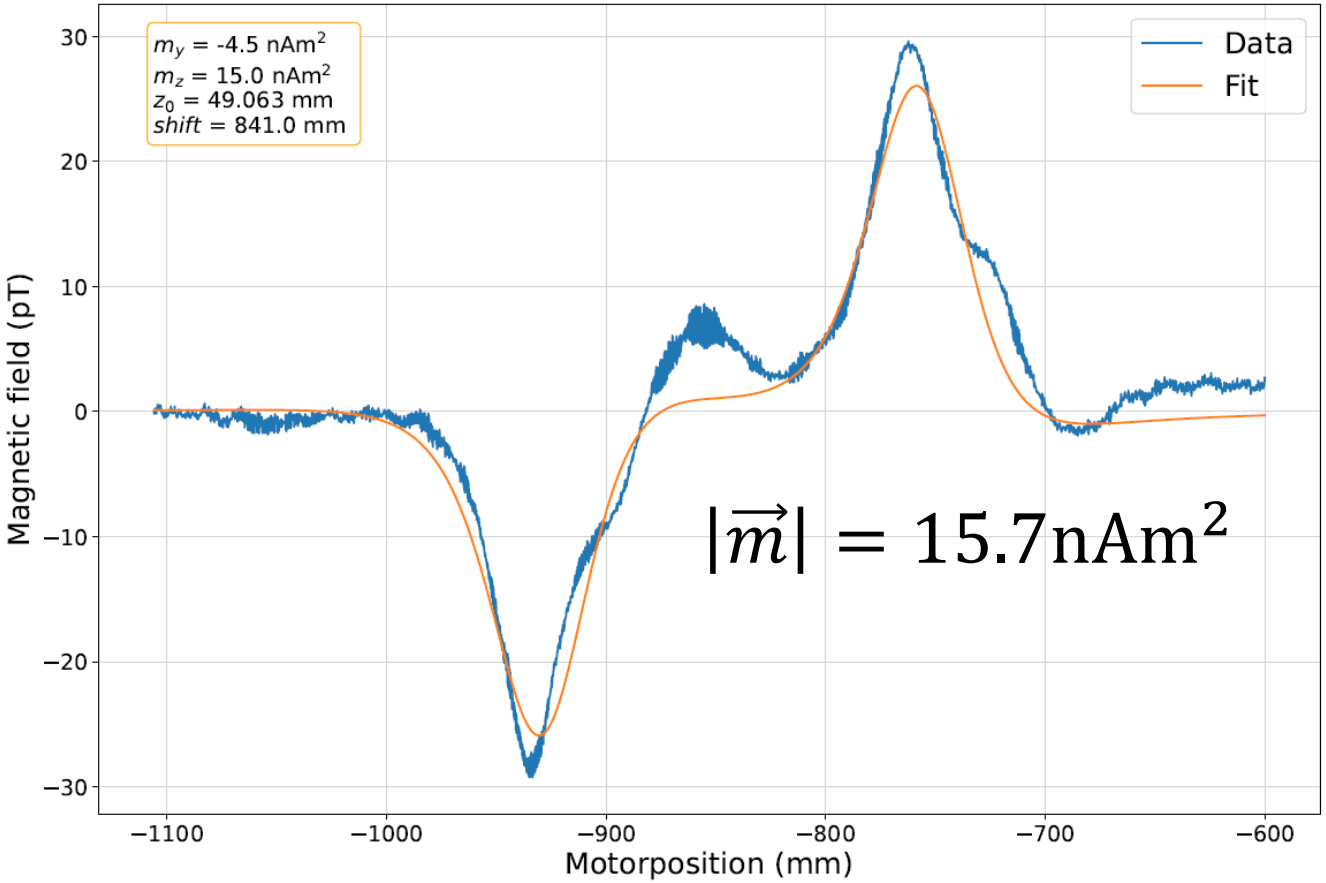


Measure 1000s of macroscopic parts (cm-big)

nA m^2 sensitivity (10 μm iron dust at saturation)

$\tau_{\mathrm{summer-student}}$

Difficult to find *minimally*-magnetic materials



PEEK holder for Cs cell (most sensitive part for $\vec{B}$ reconstruction)

Tolerance for this piece is $0.7\mathrm{nAm}^2$!

Summary

Thanks!