
WIR SCHAFFEN WISSEN – HEUTE FÜR MORGEN

Victoria Kletzl :: Paul Scherrer Institute

Minimizing the Magnetic Dipole Contamination in the n2EDM Experiment

LTP Seminar – October 11th 2022

Overview

- The n2EDM experiment @ PSI

- The false EDM effect

- New apparatus: the gradiometer
  - Requirements
  - Caesium magnetometry
  - Design
  - Measurements

- Summary and Outlook

The n2EDM experiment @ PSI

- Looking for the permanent neutron electric dipole moment (nEDM) via

$$f_n = \frac{1}{\pi\hbar}\left|\mu_n \vec{B}_0 \pm d_n \vec{E}\right|$$

- Use ultra cold neutrons (UCN)
- Ramsey method of separated oscillating fields
- Current limit: $d_n < 1.8 \times 10^{-26} e$ cm (90% C.L.) [1]
- Projected sensitivity for n2EDM: $d_n = 1 \times 10^{-27} e$ cm [2]
- Improvements depend on controlling the magnetic field stability and uniformity

[1] C. Abel *et al.* Phys. Rev. Lett. 124, 081803, 2020.

[2] N. J. Ayres *et al.* EPJ C, 2021.

The false EDM

- Special relativity gives a motional magnetic field for particles moving in an electric field :

$$\vec{B}_m = \vec{E} \times \frac{\vec{v}}{c^2}$$

- If $\vec{B}_0 \neq$ uniform → d^{false} for neutrons and Hg comagnetometer
- d^{false} for neutrons and Hg are not the same due to different velocities and precession frequencies!
- This leads to Hg induced false nEDM [3]:

$$d_{n \leftarrow Hg}^{false} = -\left|\frac{\gamma_n}{\gamma_{Hg}}\right| d_{Hg}^{false}$$

- Gradient fields can be monitored and corrected, except if localized (e.g. dipole contaminations)!

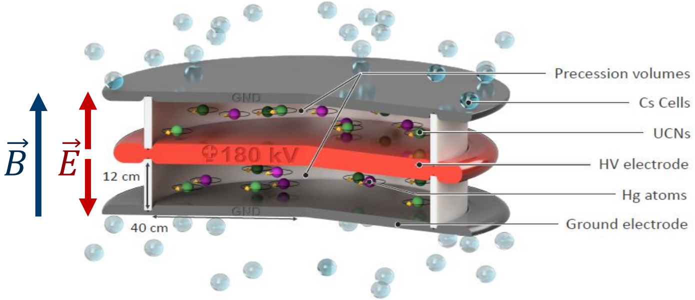
[3] C. Abel *et al.* Phys. Rev. A 99, 042112, 2010.

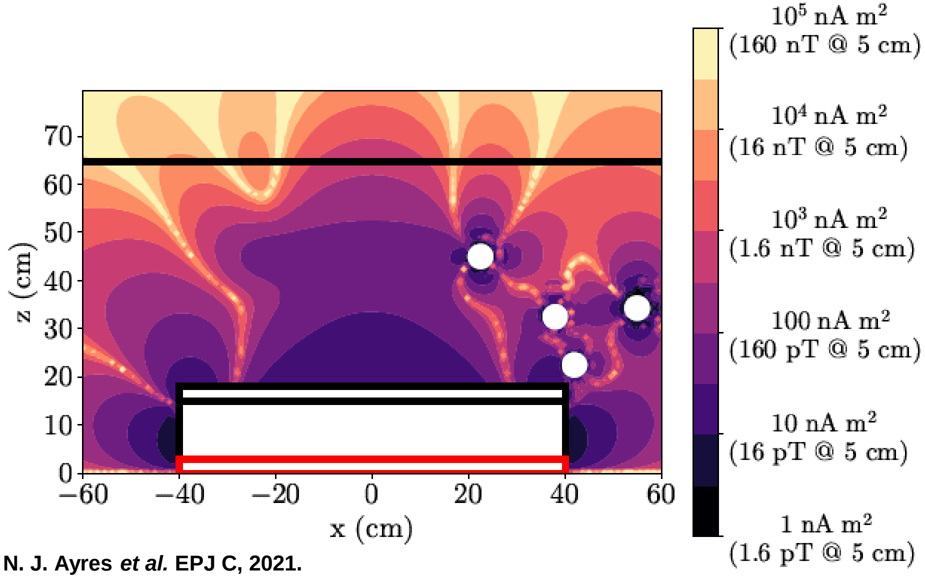
Requirements

- Sensitivity : low pT range
  - ➢ Magnetic shield (shielding factor = 100 000)
  - ➢ Cs magnetometer array
  - ➢ Averaged measurements

- Local to PSI!

- Measurements must be fast (< 1 min)

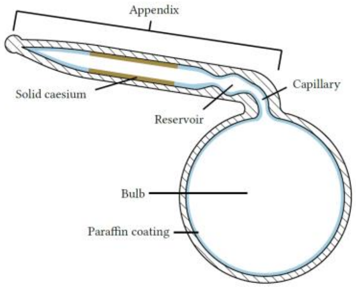




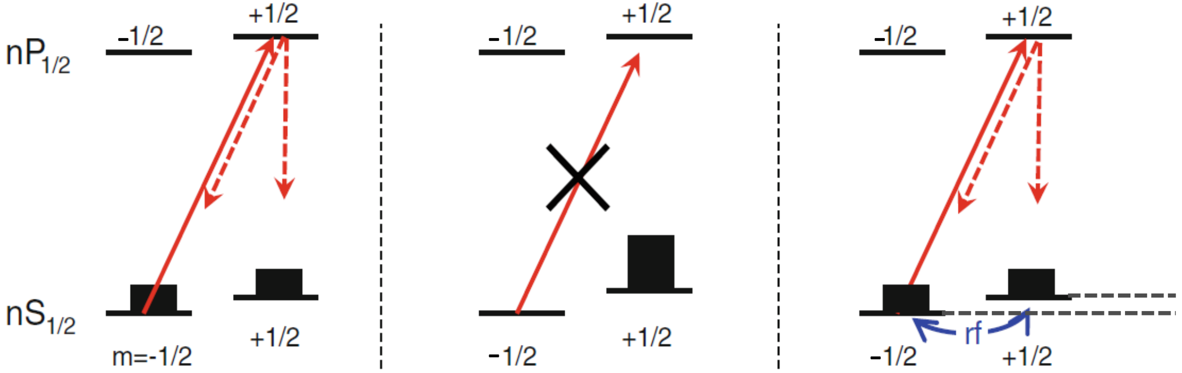
N. J. Ayres *et al.* EPJ C, 2021.

Working Principle of Cs Magnetometers

- Glass bulbs filled with cesium vapor
- Optically pumping on D_1 transition with σ^+
- Read out modulated pumping light



D.A. Pais, Diss. ETH No. 27742, 2021.

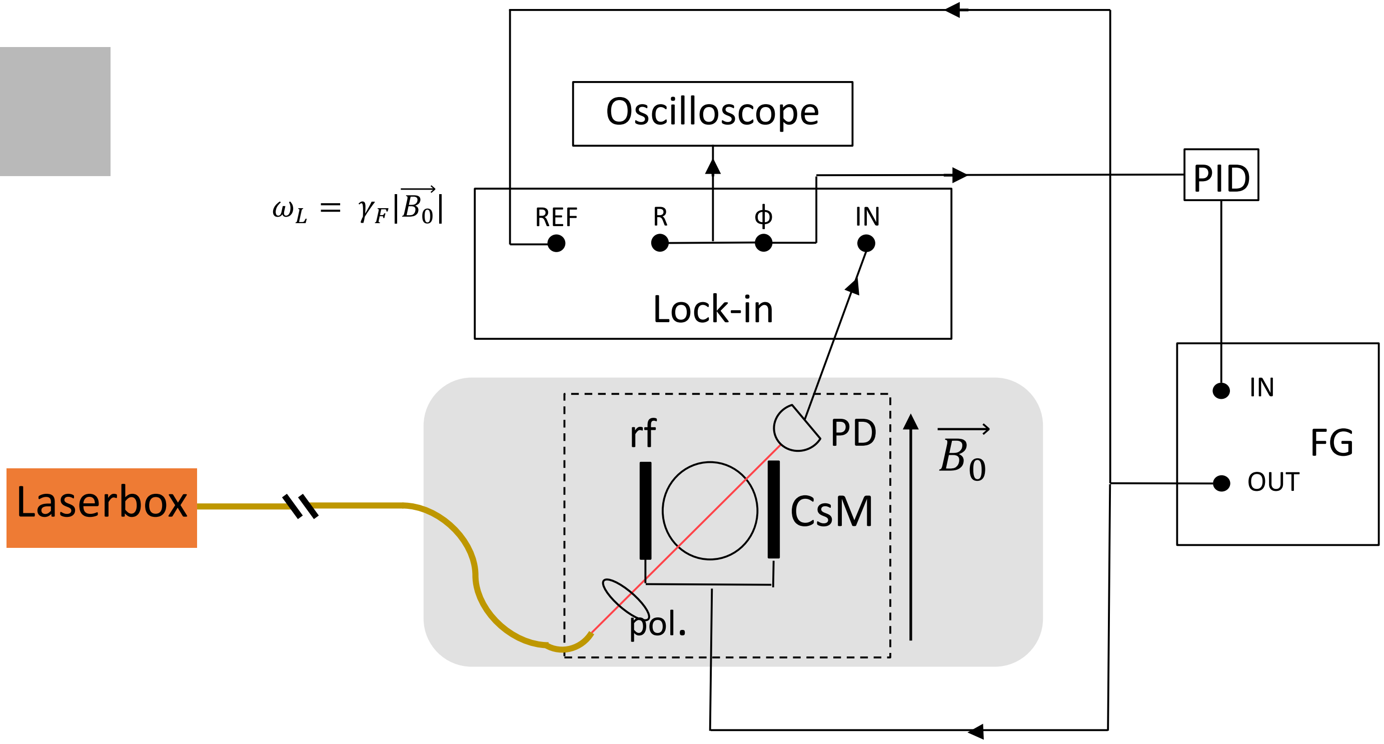


$$\Delta E = |\gamma_F||\overrightarrow{B_0}|\hbar$$

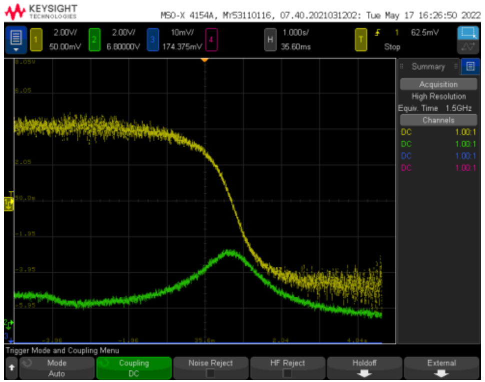
$$\omega_L = \gamma_F|\overrightarrow{B_0}|$$

Adapted from A. Weis, G. Bison, Z.D. Grujic
in *High Sensitivity Magnetometers*, Springer 2017.

Mx Magnetometer Mode

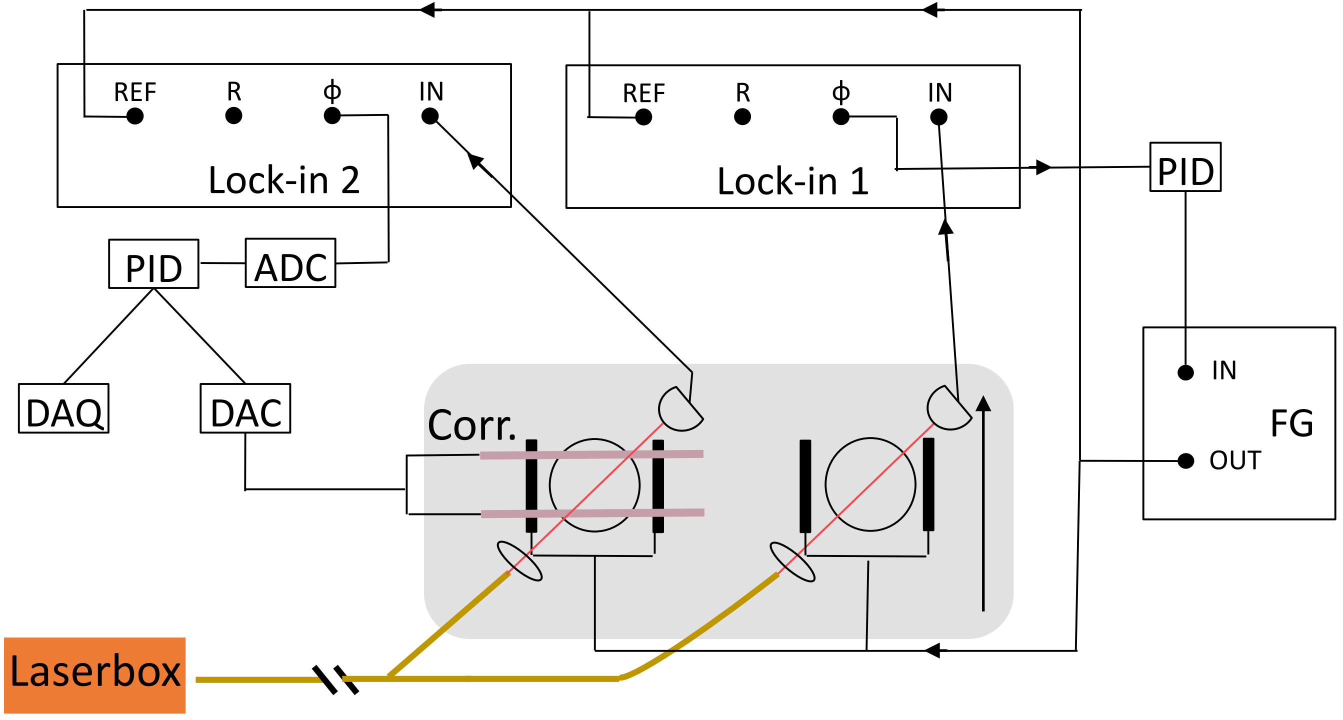


$$\omega_L = \gamma_F |\overrightarrow{B_0}|$$

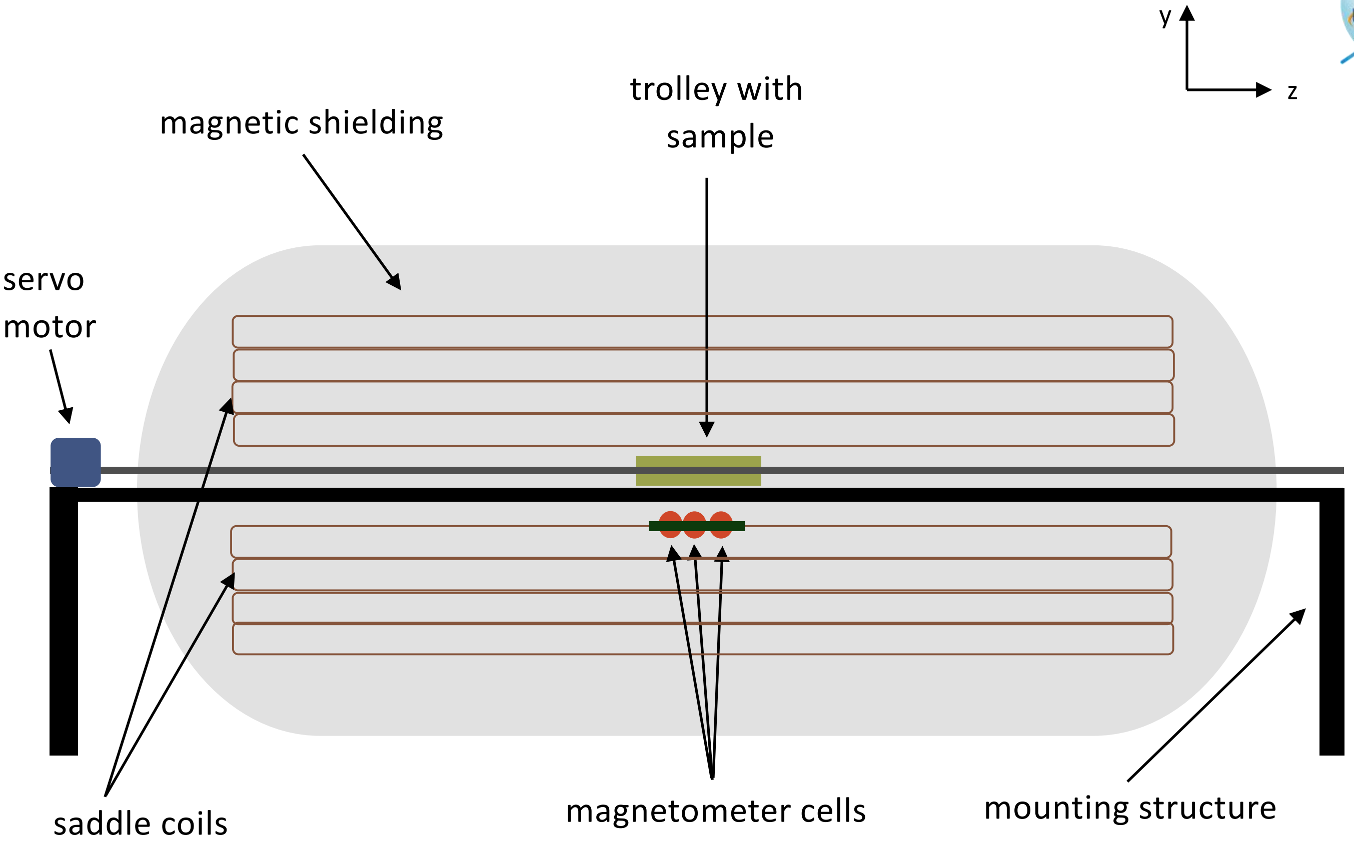


MSO-X 4154A, MY53110116, 07.40.2021031202: Tue May 17 16:26:50 2022

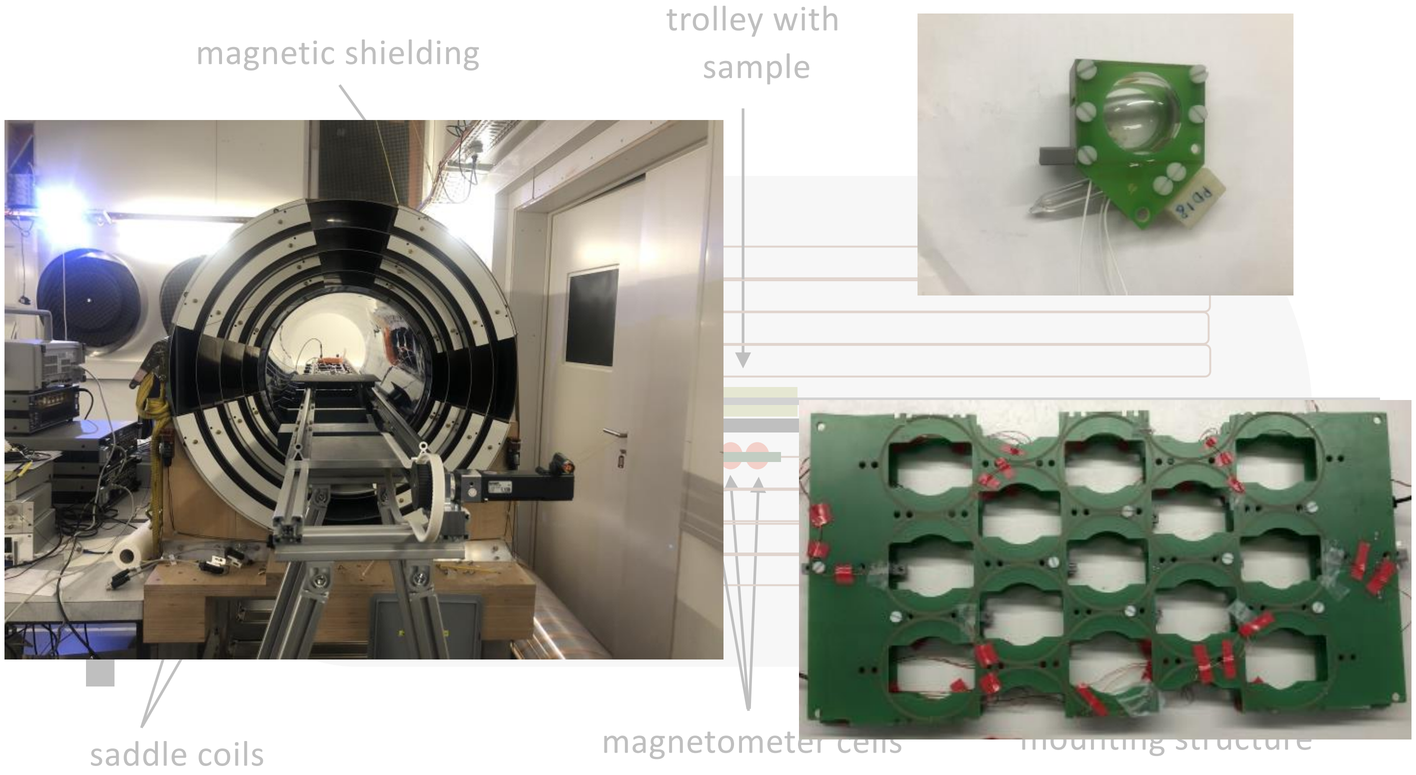
Cs Magnetometer Array



The Gradiometer - Design

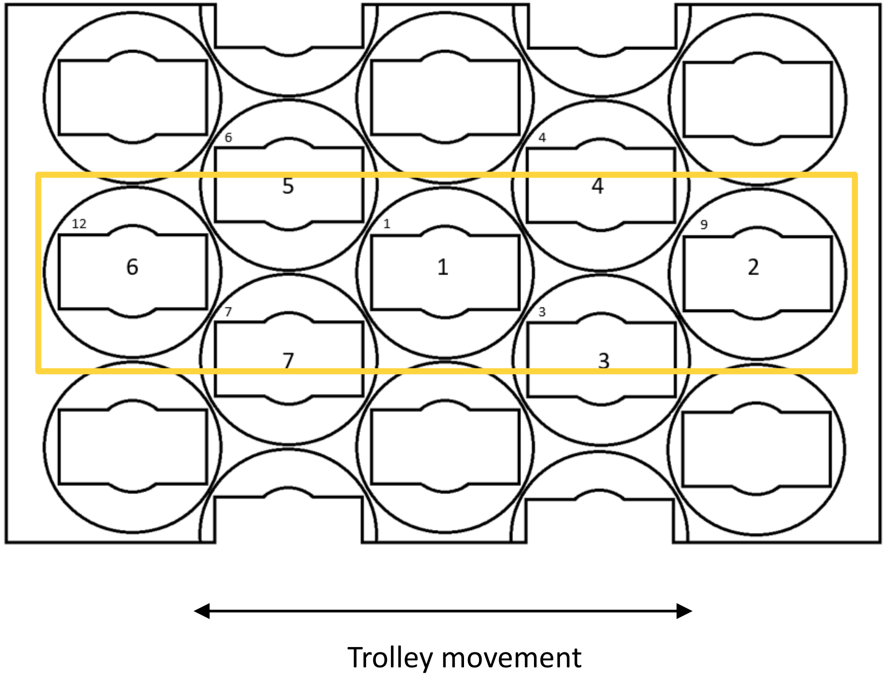


The Gradiometer - Design

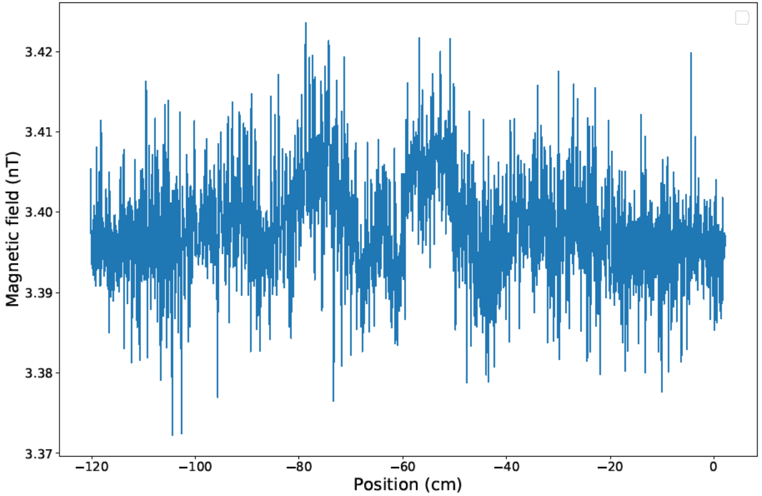


First Measurements: Configuration

- Select cells 6, 1 and 2
- Cell 1 as reference
- Cells 6 and 2 are connected to DAQ

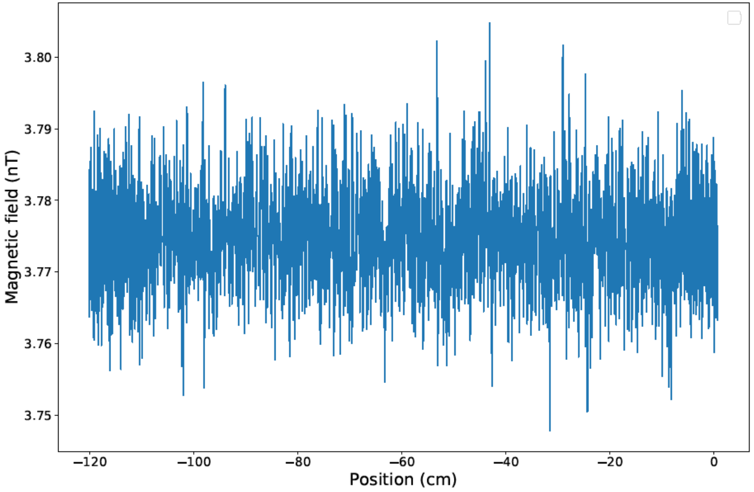


Example Measurements



Noise is too high for ~ pT measurement

20pT structures are clearly visible



Summary and Outlook

Summary

- Systematic error induced by magnetic contaminations
- Building local apparatus
- Based on Cesium magnetometry
- Goal: ~pT sensitivity

Outlook

- Reduce noise
- Implement fitting function for automatic magnetic dipole moment readout

Wir schaffen Wissen – heute für morgen

Thank you for you attention!

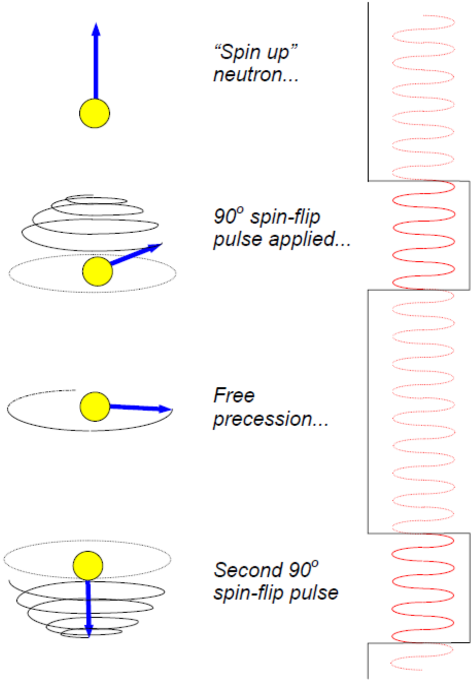
The Ramsey Method

1. System is polarised along main field axis

2. Linear oscillating field with frequency ω induces spin-flip

3. Particle precesses freely in plane perpendicular to field axis

4. Second linear oscillating field with frequency ω induces second spin-flip



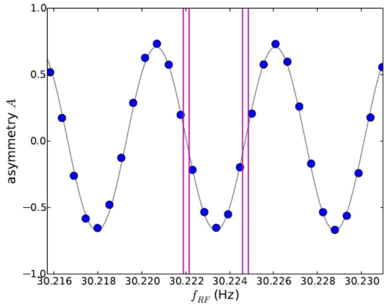
"Spin up" neutron...

90^o spin-flip pulse applied...

Free precession...

Second 90^o spin-flip pulse

S P. Harris, *The Neutron EDM Experiment*, arXiv:0709.3100v3 (2007) .



N. J. Ayres *et al.* EPJ C, 2021.

Magnetometer systems

Mercury co-magnetometer

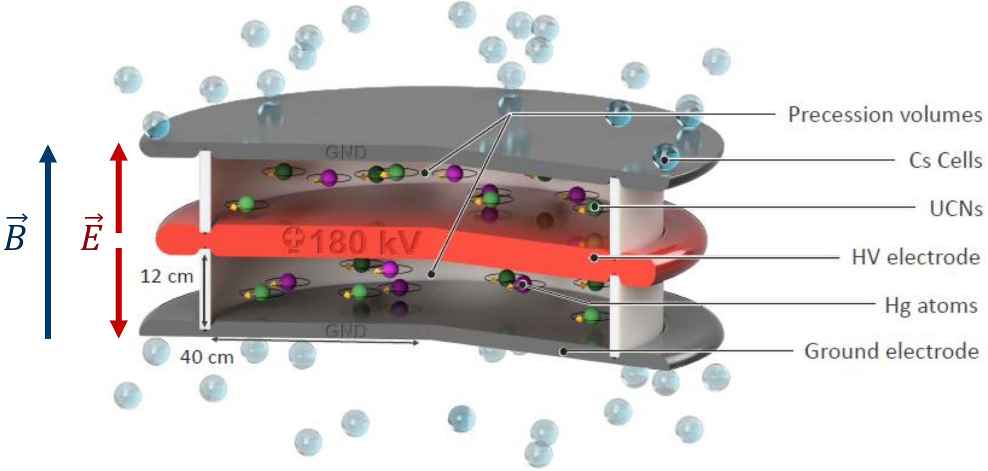
- Inside the precession chambers
- Optical readout of spin precession
- Corrects for field drifts, linear gradients
- Sensitivity of 25fT was already demonstrated

Cs magnetometer array

- Surrounds the precession chambers
- Optical readout of spin precession
- Corrects higher order gradients
- Accuracy goal: 5pT

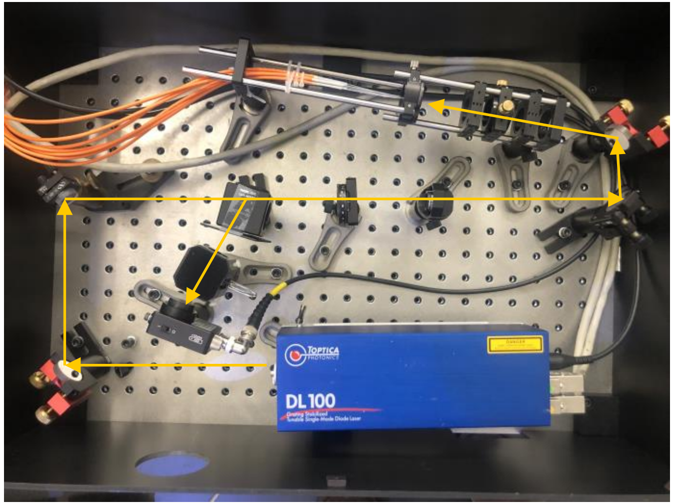
Dipole contamination scanners

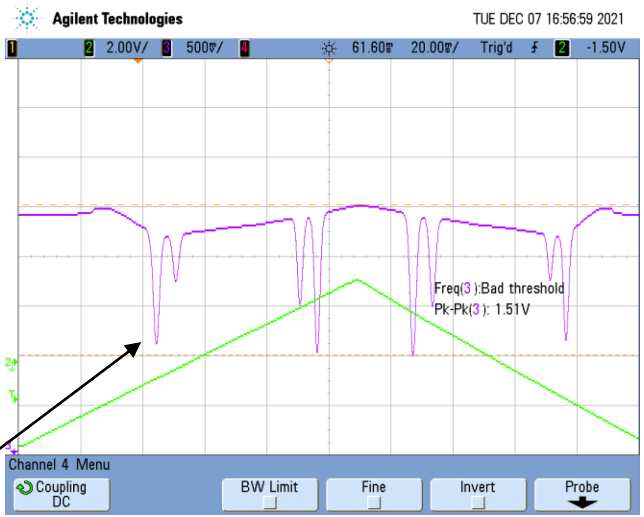
- SQUID array @ PTB Berlin (660 km)
- Gradiometer @ PSI (100m)



N. J. Ayres *et al.* EPJ C, 2021.

Laserbox



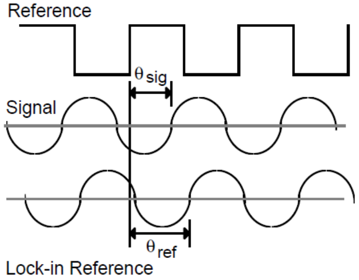

Freq(3):Bad threshold
Pk-Pk(3): 1.51V

F = 4 → F‘=3

PAUL SCHERRER INSTITUT

Lock-in amplifier: Principle

- Reads in the signal and amplifies $V_{sig}\sin(\omega_r t + \theta_{sig})$
- Signal is multiplied with reference signal $V_L\sin(\omega_L t + \theta_{ref})$
- Product is difference between two AC signals with frequencies $(\omega_r - \omega_L)$ and $(\omega_r + \omega_L)$
- Add low pass filer → AC signals are filtered out
- If $(\omega_r = \omega_L)$ → DC signal $1/2 V_{sig} V_L \cos(\theta_{sig} - \theta_{ref})$
- Add 90° shifted reference signal and multiply → $1/2 V_{sig} V_L \sin(\theta_{sig} - \theta_{ref})$



Stanford Research Instruments: SR830 manual

Lock-in amplifier: Signals

- $X = V_{sig} \cos\theta$ (in phase component)
- $Y = V_{sig} \sin\theta$ (quadrature component)
- $R = \sqrt{X^2 + Y^2} = V_{sig}$ (Amplitude of the signal)
- $\theta = \tan^{-1}(\frac{Y}{X})$ (Phase shift)