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The new magnetic field optimisation procedure of the nEDM experiment at PSI

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1. Goal

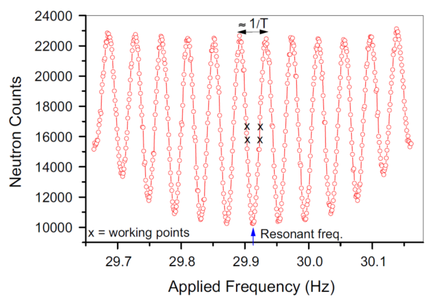
Optimise the magnetic field to:
- improve nEDM **sensitivity**
- reduce **systematic effects**

Combining both offline and online magnetic field information

2. Sensitivity

Statistical uncertainty:

$$\sigma_{d_n} = \frac{\hbar}{2E\alpha T\sqrt{N}}$$



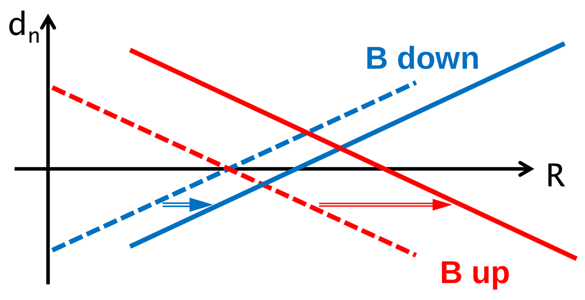
Ramsey visibility α:
- depends on the transverse depolarisation time T_2 of the neutrons
- increases with homogeneity of the longitudinal magnetic field component B_z [1]

3. Systematic effects

Using a co-habiting Hg magnetometer introduces systematic effects:

Density & velocity
- Vertical gradients are sampled differently
- Transverse fields are sampled differently due to difference in adiabaticity

HgM UCN

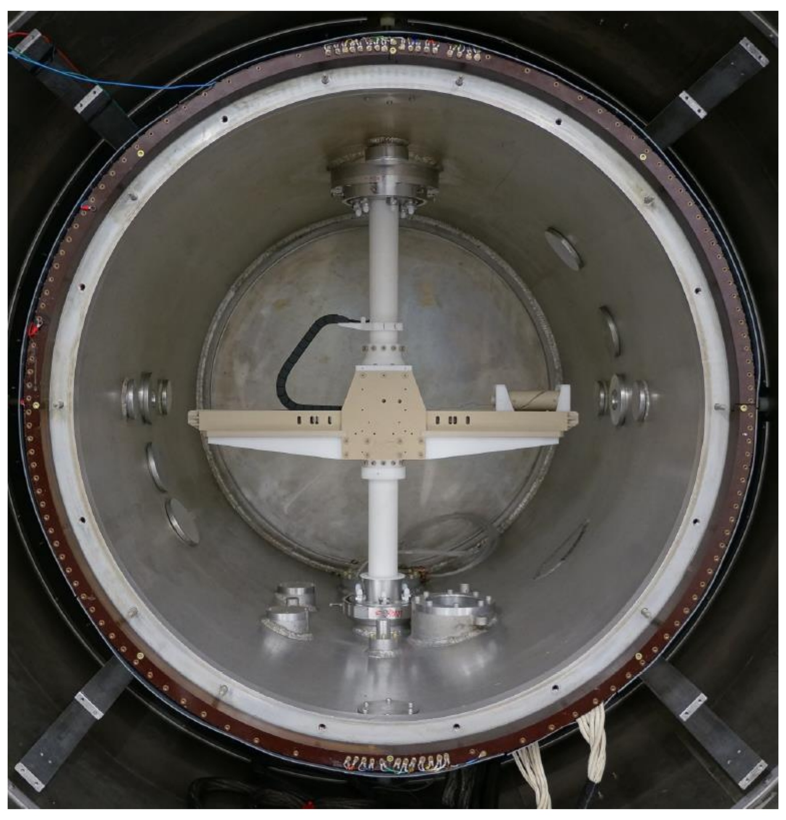


$$R = \frac{f_n}{f_{Hg}} = \frac{\gamma_n}{\gamma_{Hg}}\left(1 \pm \frac{\hbar}{|B|}\frac{\partial B_z}{\partial z} + \frac{\langle B_T^2\rangle}{2B^2}\right)$$

Geometric phase effect
- HgM frequency shift due to interplay of motional magnetic fields (v x E) and magnetic field gradients
- False nEDM proportional to vertical gradient [2]

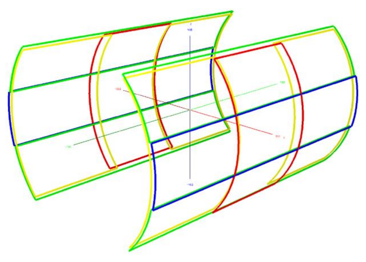
$$d_{n,\mathrm{false}} \propto \frac{\partial B_z}{\partial z}$$

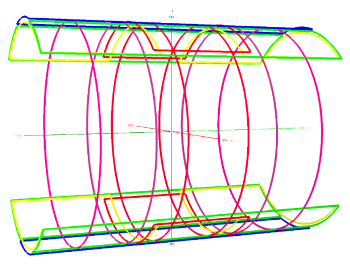
4. Field mapping - offline



Mapping device
- Vector fluxgate sensor mounted on trolley that can move radially on arm
- Arm that can rotate around the vertical axis, and move up and down

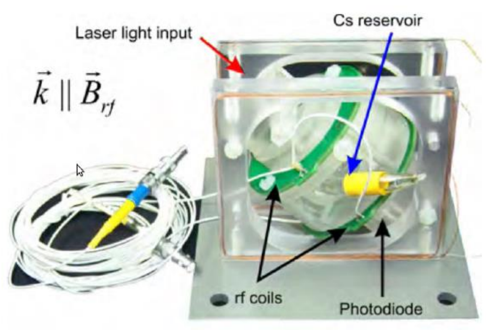
Field maps
- Scan magnetic field at set of positions
- Maps of main field B_0
- Maps of all 30 trimcoils installed around the vacuum tank

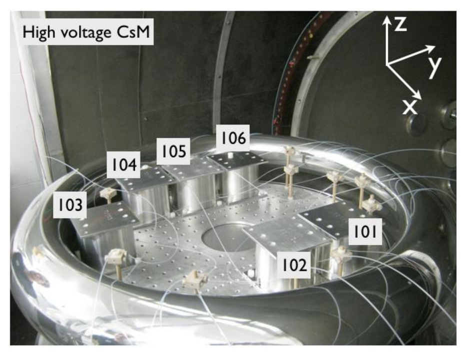




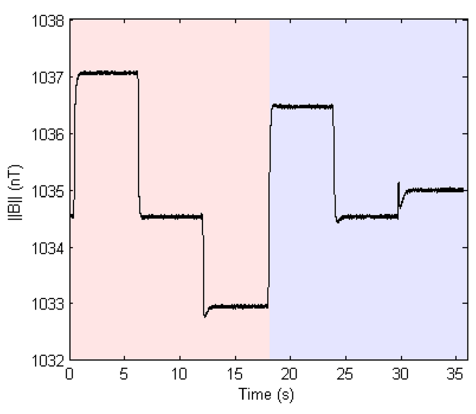
5. CsM variometer mode - online

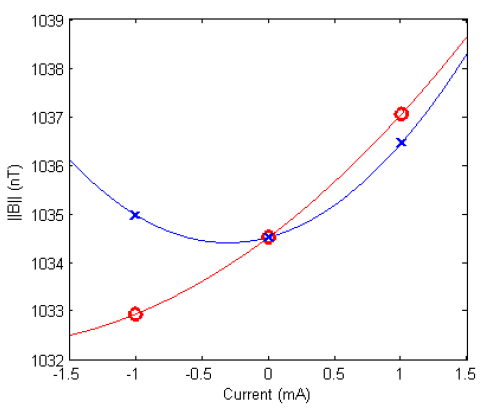
Cs magnetometers:
- 16 CsM around the precession chamber [3]
- Probe the magnitude of the field locally
- Vector information in variometer mode

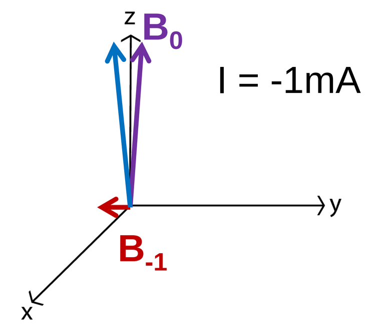


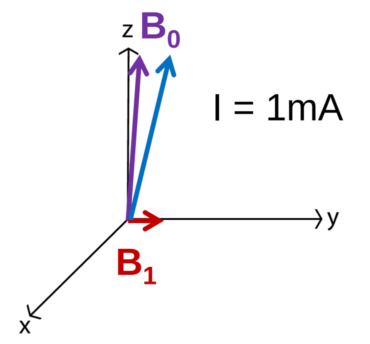


Variometer mode:
1. Measure the magnitude of the main field $\|\vec{B}_0\|$
2. Apply a set of known currents *I* to a mapped transverse coil that generates field $\vec{B}_\perp$
3. Monitor the change in magnitude of the field $\|\vec{B}_0 + I\vec{B}_\perp\|^2 = \|\vec{B}_0\|^2 + 2I\vec{B}_0\cdot\vec{B}_\perp + I^2\|\vec{B}_\perp\|^2$
4. Repeat with a second coil transverse to both B_0 and the first transverse coil









5. The transverse components of B_0 can be extracted from the scalar products

Results
- Absolute accuracy of transverse components is limited by field maps (10nT)
- Relative accuracy is a few percent if the B_0 direction is the same for both measurements
- Precision of 5pT to 50pT can be reached with standard current source

6. Optimisation procedure

Ingredients
- Transverse components of B_0 and all trimcoils from field maps
- Online longitudinal components of B_0 and generated by each trimcoil from the CsMs variometer results

Procedure

Minimise the following function:

$f(I) = a\, S_{longitudinal} + b\, S_{transverse} + c\, S_{current}$

where a, b and c are used to balance the different influences:
- $S_{longitudinal}$ pushes all CsM readings to a certain goal value
- $S_{transverse}$ pushes the volume average $\langle B_T^2\rangle$ to 0
- $S_{current}$ pushes the generated trimcoil fields to 0

7. Results

Before 2015, the typical visibility was 50% - 65%, corresponding to a neutron T_2 time of around 500s. There was a significant difference in visibility for the two B_0 directions.

Since 2015, we successfully reach visibilities of 75% - 80% for both B_0 directions (compared to 86% extrapolated to 0s storage time), corresponding to a neutron T_2 time of a few thousand seconds.

This gain in visibility effectively increased the sensitivity of our experiment by 30%, enabling us to cross the 1×10^{-26} e cm (1σ) mark in 2016, while at the same time keeping systematic effects related to transverse components in check.

8. References

[1] Afach et al., *Gravitational depolarization of ultracold neutrons: Comparison with data*, **Phys. Rev. D 92** (5), 052008

[2] Afach et al., *Measurement of a false electric dipole moment signal from 199Hg atoms exposed to an inhomogeneous magnetic field*, **EPJ D 69** (10),1.

[3] See poster of M. Kasprzak