The mercury co-magnetometer in the n2EDM experiment

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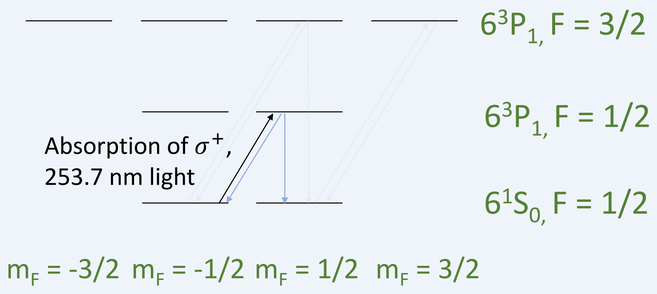
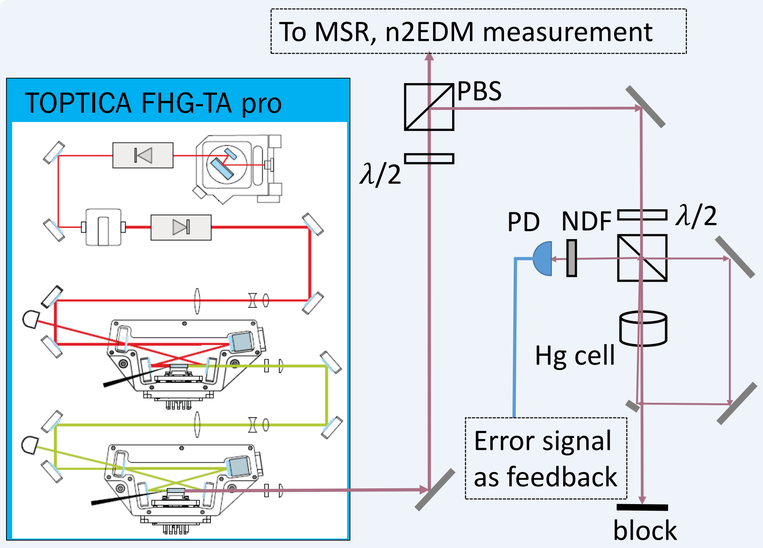
Introduction of a laser-based mercury co-magnetometer

- Aim: correct the neutron frequency for the drifts of the magnetic field
- Optical pumping ^{199}Hg, flip Hg-spin, measure the precession frequency f_{Hg}
- Substitute $f_{\mathrm{Hg}} = \frac{\gamma_{\mathrm{Hg}}}{2\pi} B_0$ into the ratio $R = \frac{f_{\mathrm{n}}}{f_{\mathrm{Hg}}} = \left|\frac{\gamma_{\mathrm{n}}}{\gamma_{\mathrm{Hg}}}\right| \mp \frac{|E|}{\pi\hbar f_{\mathrm{Hg}}} d_{\mathrm{n}}$
- Use R to calculate d_{n}



Optical pumping process of ^{199}Hg, a fermionic isotope of mercury

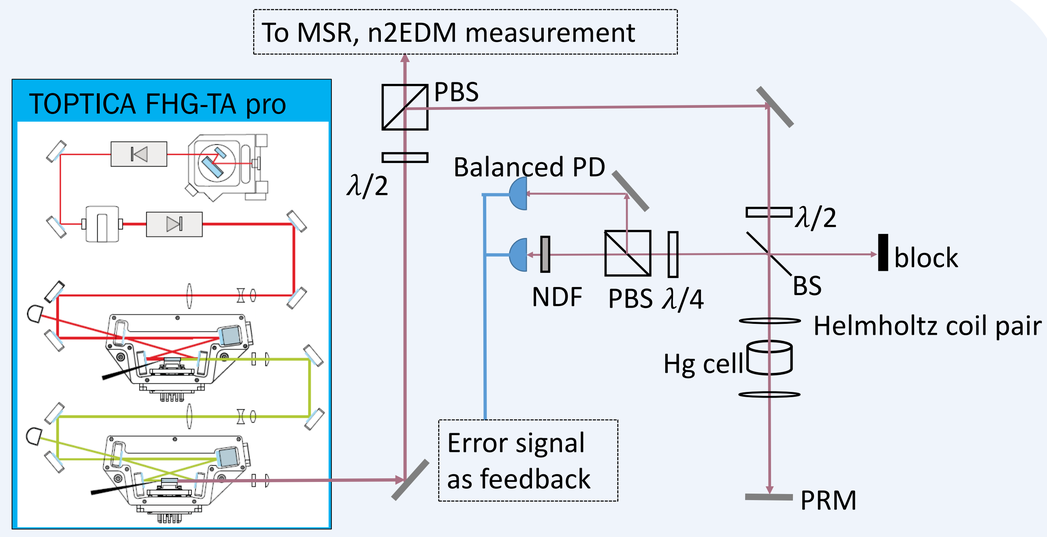


Locking with frequency modulation technique

Laser source: frequency stabilization

Test two locking schemes:

- Doppler-free saturated spectroscopy with frequency modulation
- Sub-Doppler dichroic atomic vapor laser lock



Alternative locking scheme requiring magnetic field

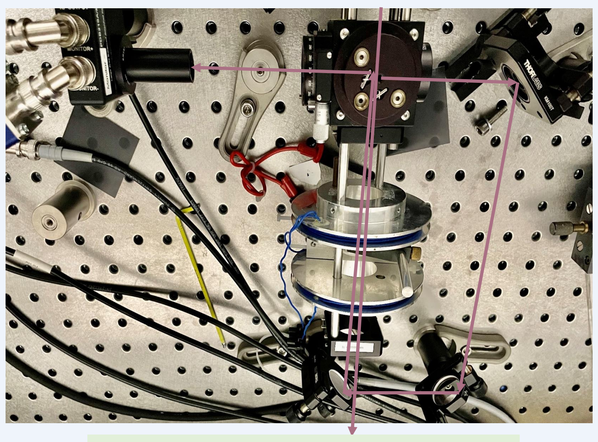
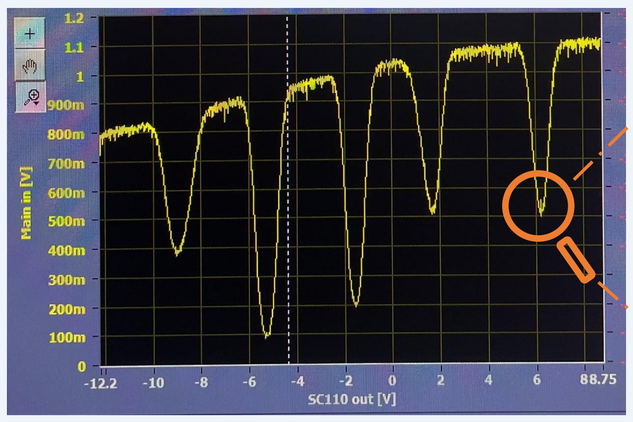
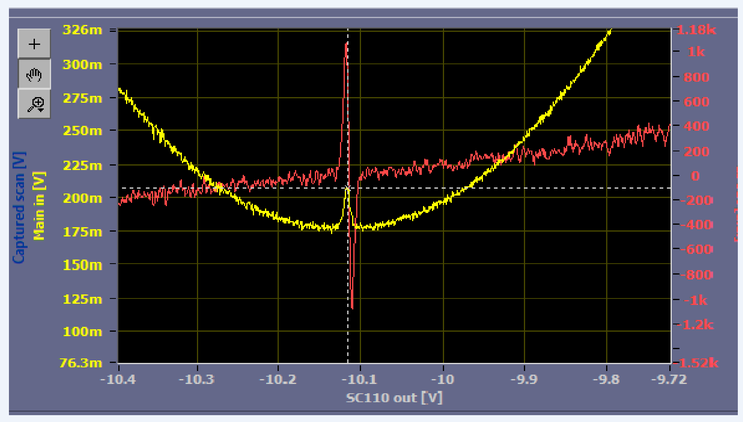


Photo of the locking scheme



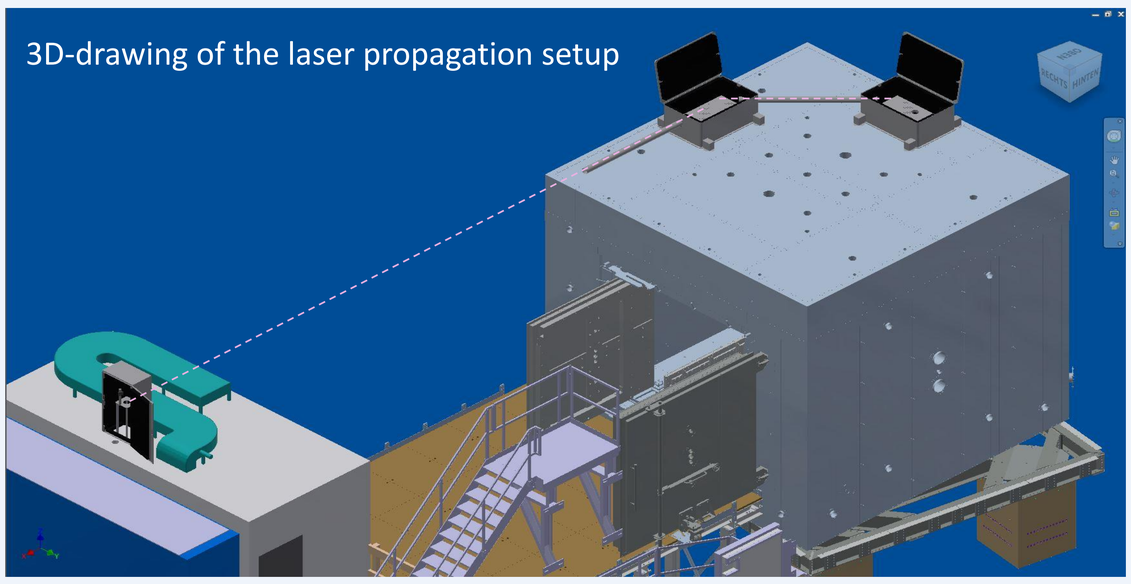
Mercury absorption lines



Zoom-in view of the Doppler-free peak

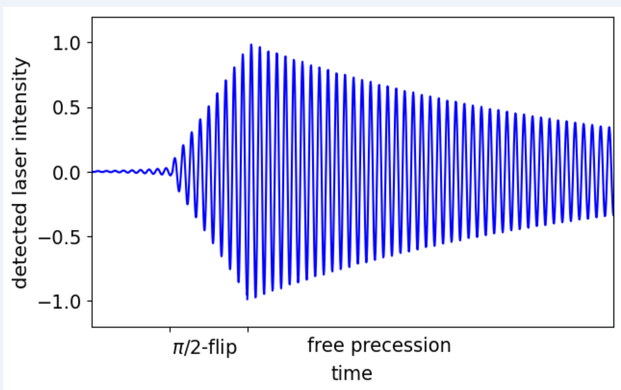
Laser path to the experimental area

- Challenge: Free-space propagation > 10 m
- Transit points: Boxes with foam protecting optics from acoustic waves
- In future: Fibre test for the pump beam; guiding laser to chambers

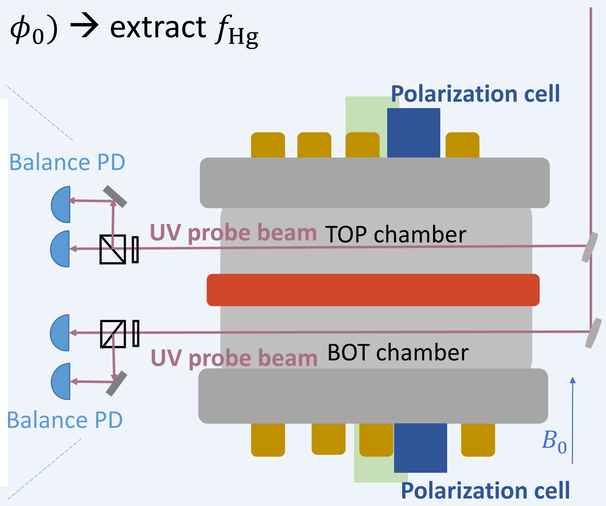


Detection scheme + Measurement

- Spin polarize ^{199}Hg atoms
- Release Hg into precession chambers → Hg "cohabits" with UCNs
- Apply $f_{\mathrm{RF}} \approx 8$ Hz → Flip the Hg spin by $\pi/2$
- Hg free precession → UV beams traversing two chambers
- PD signal: $A(t) = a\, e^{-\frac{t}{T_2}} \sin(2\pi f_{\mathrm{Hg}} t + \phi_0)$ → extract f_{Hg}



Differential PD signal



Sketch of measurement scheme

Hg related systematic effect in the n2EDM experiment

Dominant effect from the motional field $\overrightarrow{B_{\mathrm{m}}} = \vec{v} \times \vec{E}/c^2$

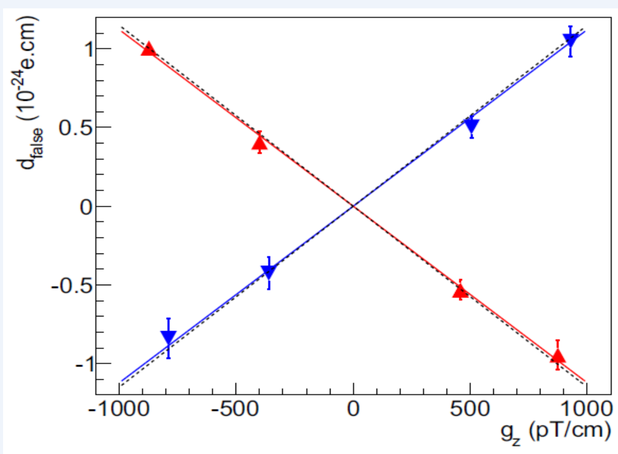
According to the Spin relaxation theory: $\delta\omega = \delta\omega_{B^2} + \delta\omega_{BE} + \delta\omega_{E^2}$

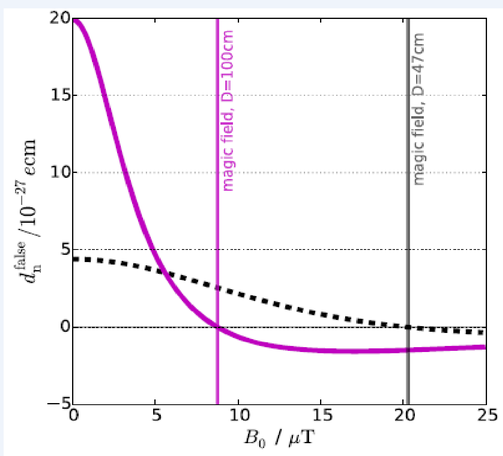
– quadratic terms can be mostly canceled with the double chamber design.

– $\delta\omega_{BE} \propto \frac{\partial B_0}{\partial z} E \;\Rightarrow\; d^{\mathrm{false}}_{\mathrm{n\leftarrow Hg}} = \left|\frac{\gamma_{\mathrm{n}}}{\gamma_{\mathrm{Hg}}}\right| d^{\mathrm{false}}_{\mathrm{Hg}} = \left|\frac{\gamma_{\mathrm{n}}}{\gamma_{\mathrm{Hg}}}\right| \frac{h}{4\pi E} \delta\omega$

→Study the relationship between $d^{\mathrm{false}}_{\mathrm{n\leftarrow Hg}}$ and the magnetic field gradient

Alternative solution: tune the B_0 field to a "magic" value to cancel $d^{\mathrm{false}}_{\mathrm{n\leftarrow Hg}}$ out





Left: False Hg EDM measured in the nEDM experiment in 2015 Eur. Phys. J. D (2015) 69: 225
Right: Choose a magic field value to cancel the false EDM out Physics Letters B 793 (2019) 440–444