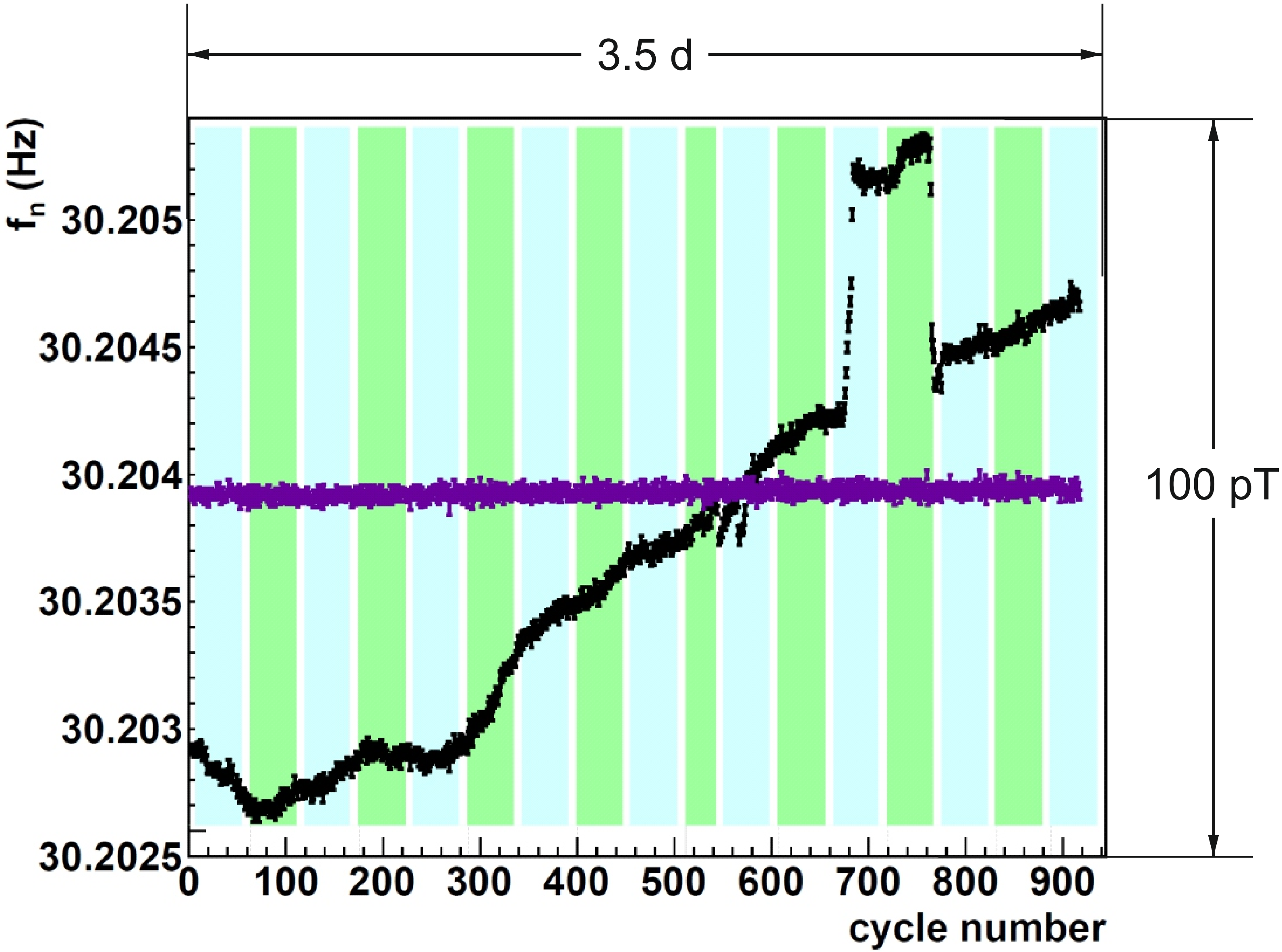
PAUL SCHERRER INSTITUT

Paul Scherrer Institut

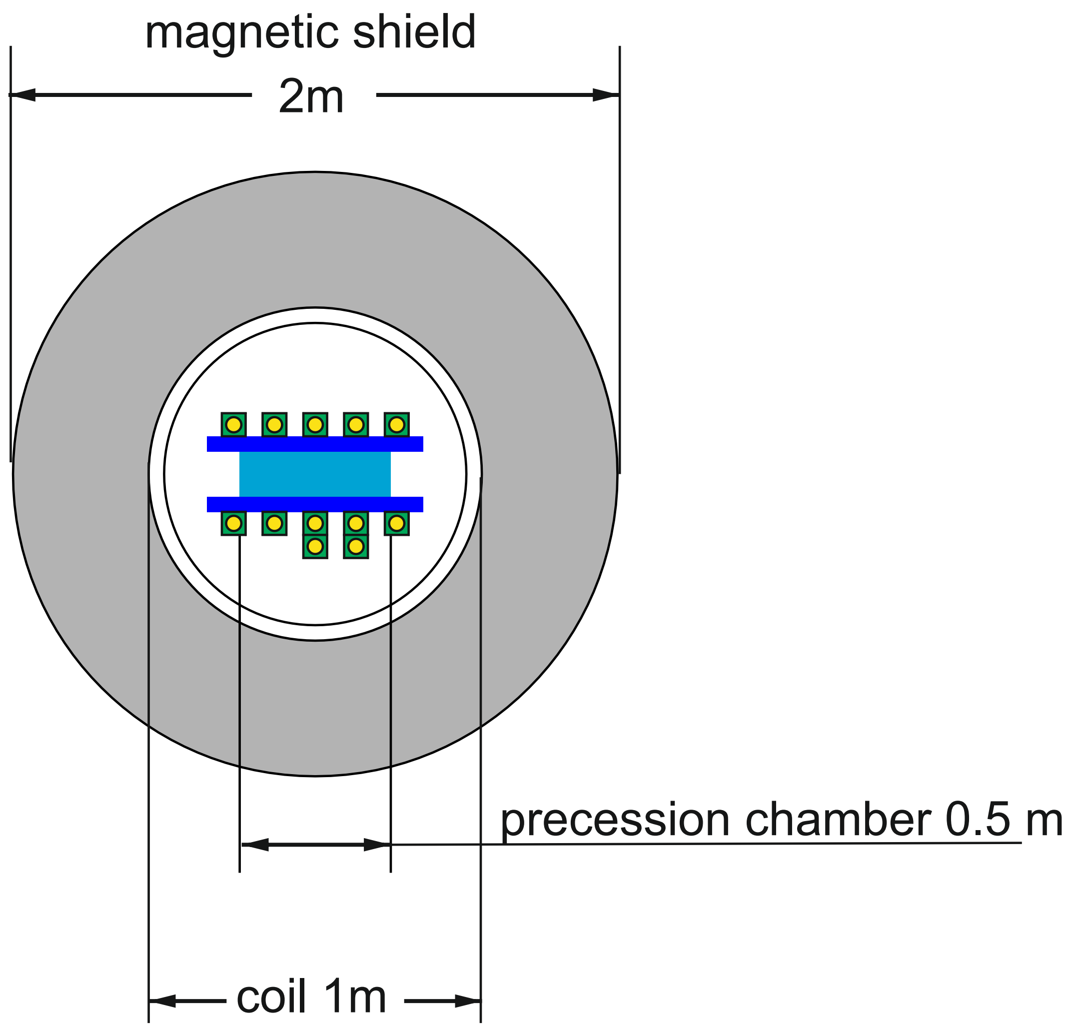
G. Bison for the nEDM collaboration

Magnetometry for next generation neutron EDM experiments

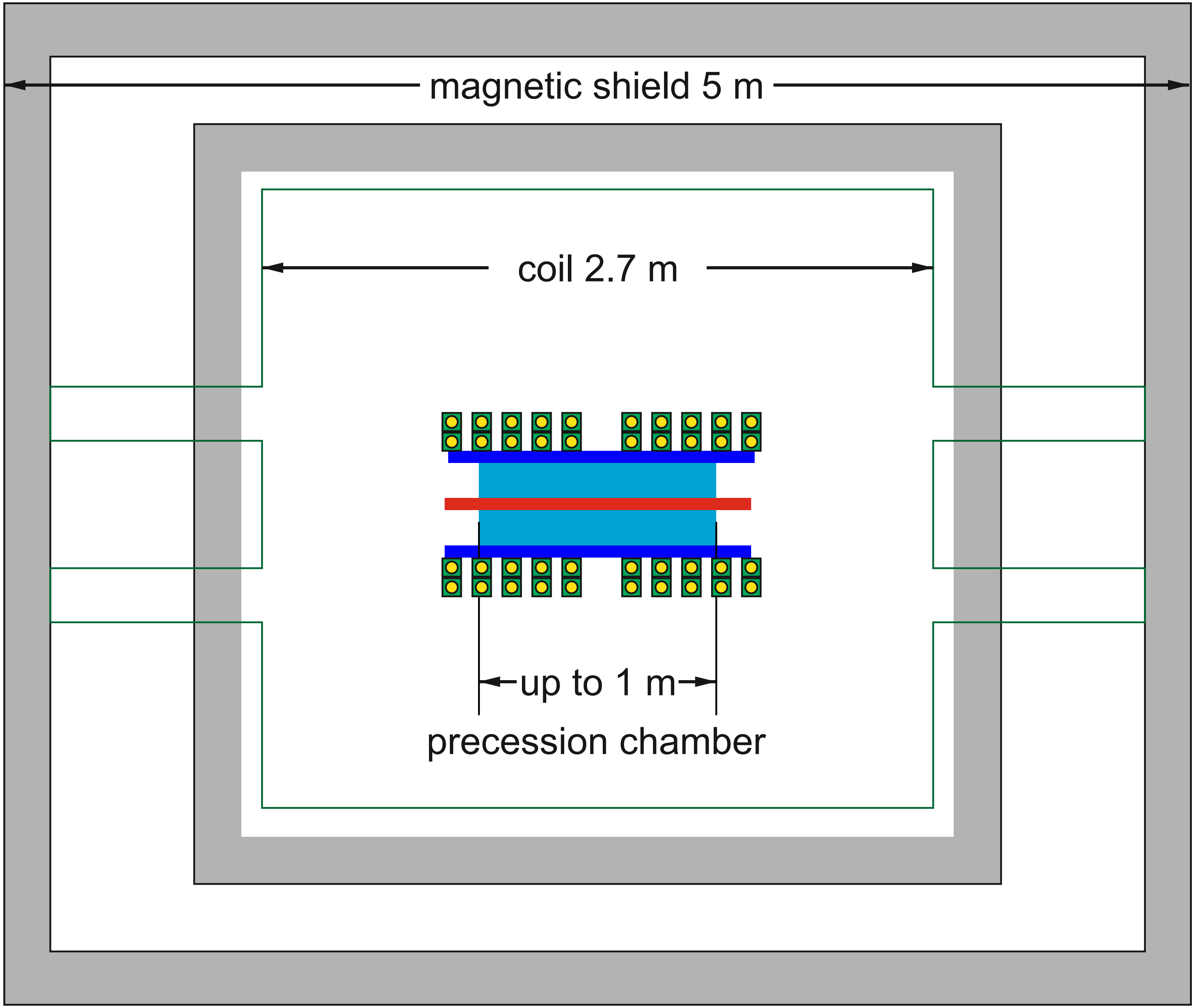
Magnetic field correction



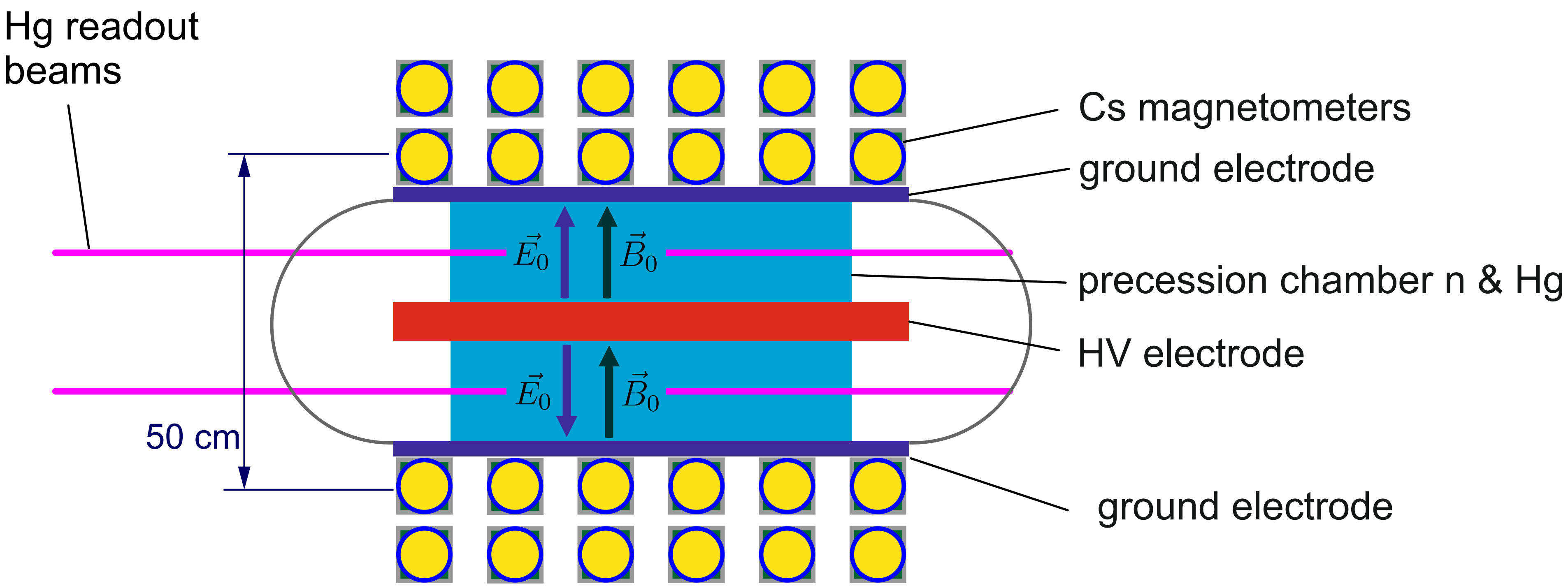
Current nEDM experiment @ PSI



Future n2EDM experiment



Magnetometer Overview

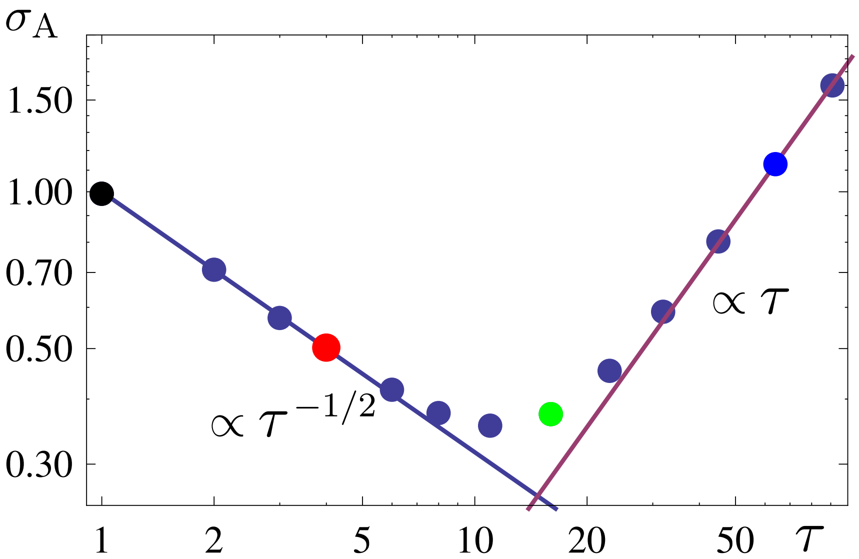


Hg comagnetometer
- Primary magnetic field reference

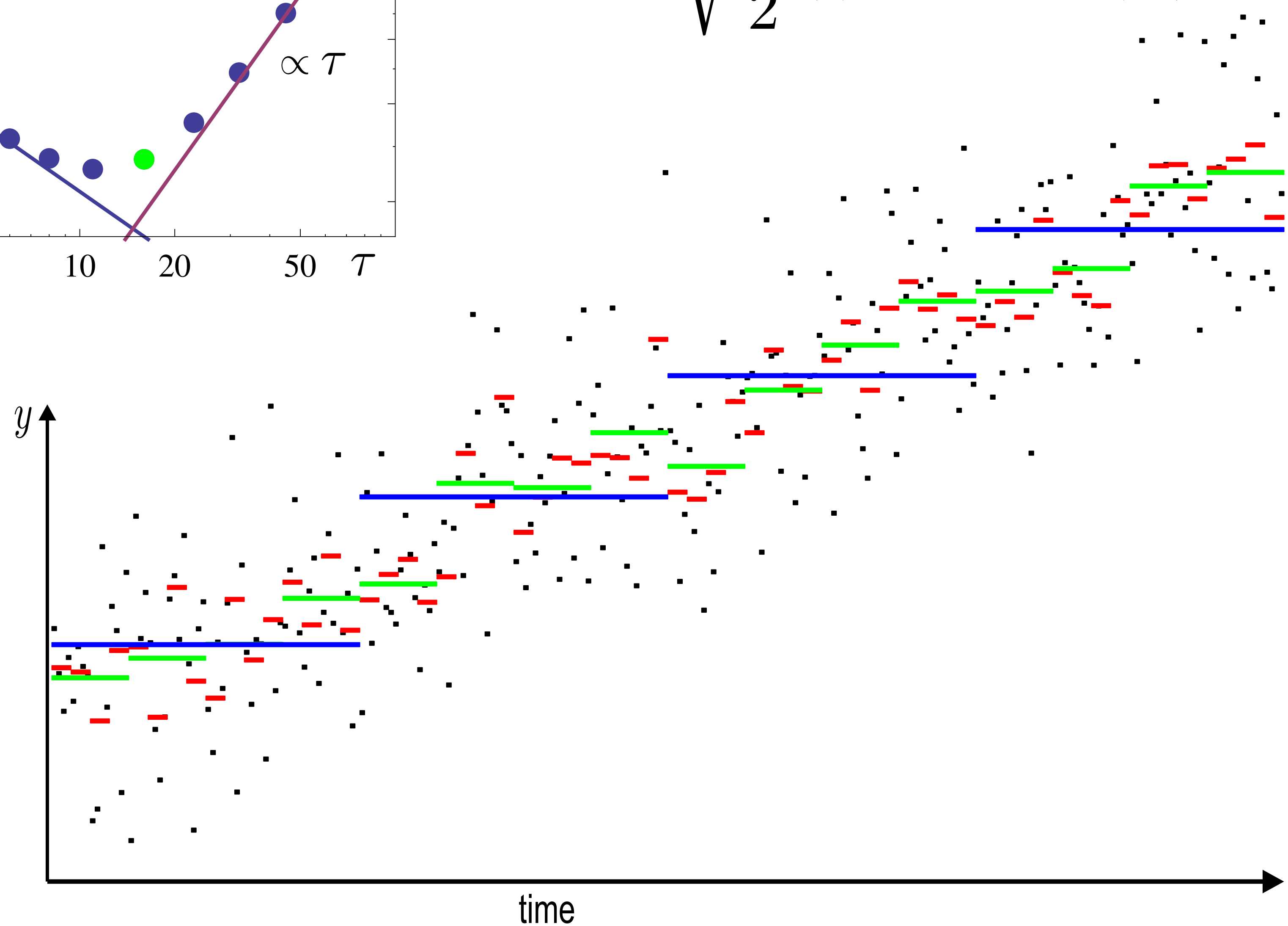
Cs magnetometer array
- Field homogenization
- Secondary magnetic field reference
- Monitor for fast field & gradient changes
- possible upgrade to vector readout

^{3}He magnetometer array (upgrade)
- Absolute magnetometer
- Field homogenization
- Secondary magnetic field reference

Allan Standard Deviation

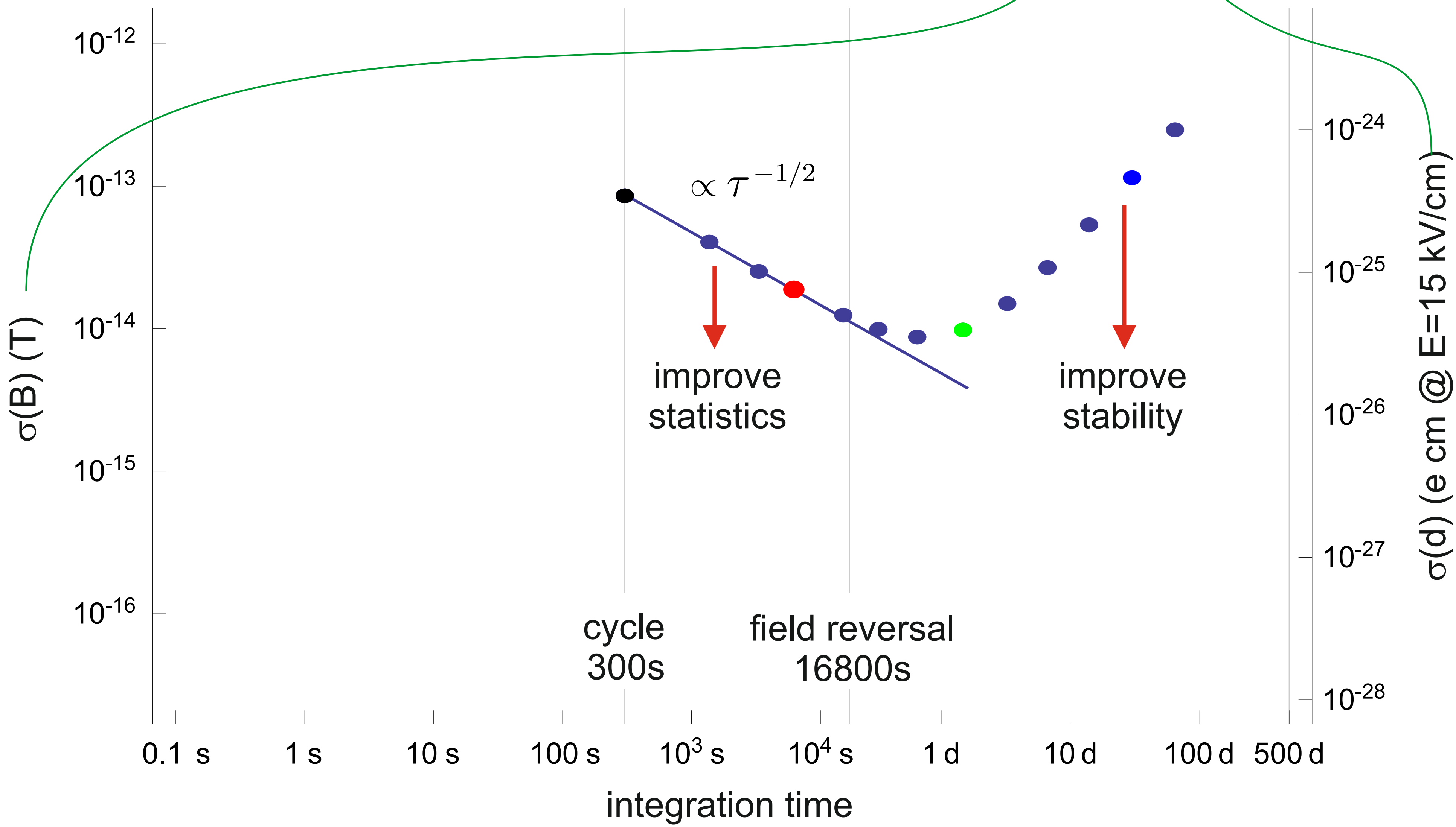


$$\sigma_A = \sqrt{\frac{1}{2}\langle (y_{n+1} - y_n)^2 \rangle}$$



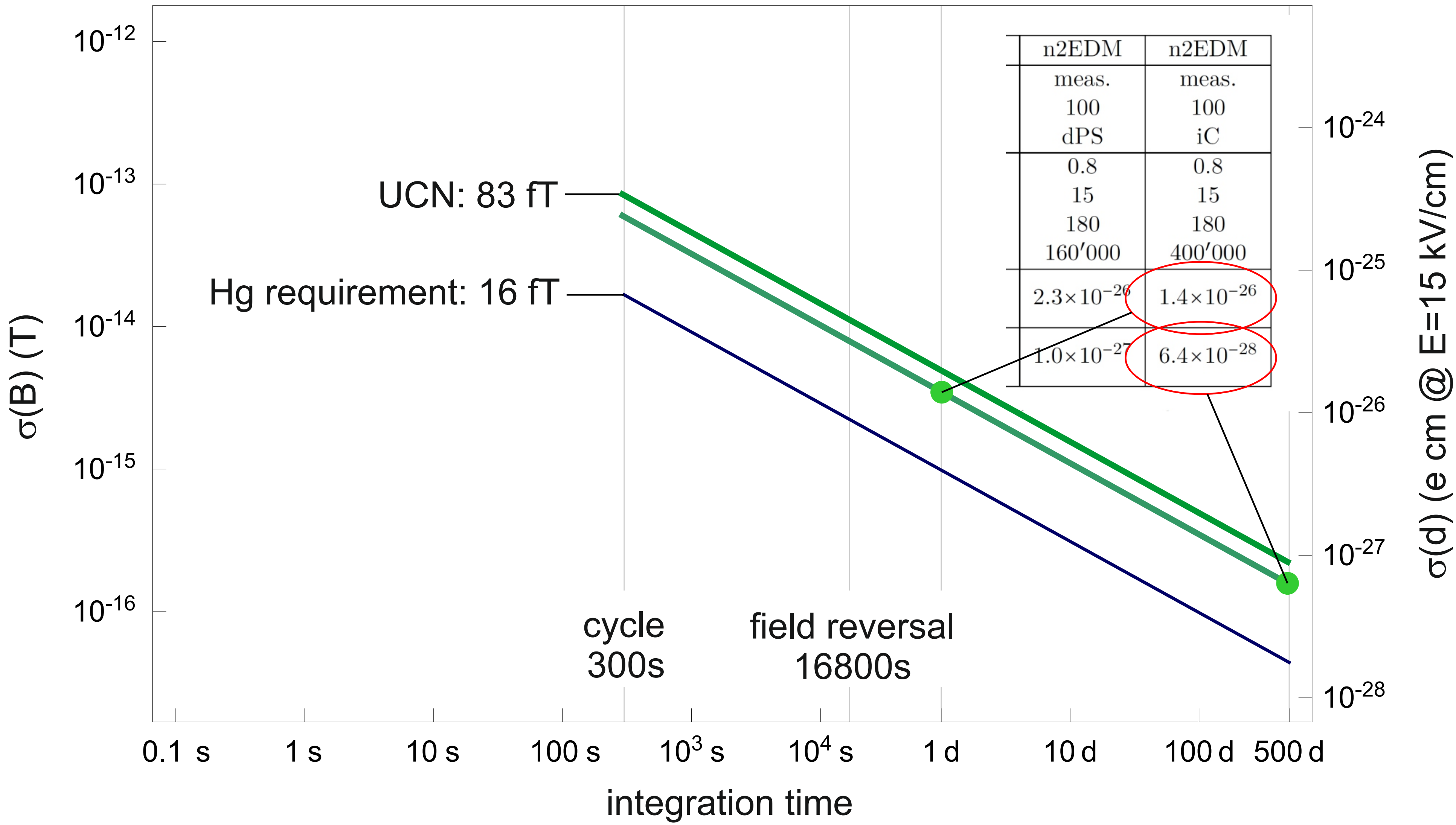
Statistical Magnetometer Performance

Neutron spin precession frequency $h\nu_L = -2\,\mu\,B_0 \pm 2\,d\,E_0$

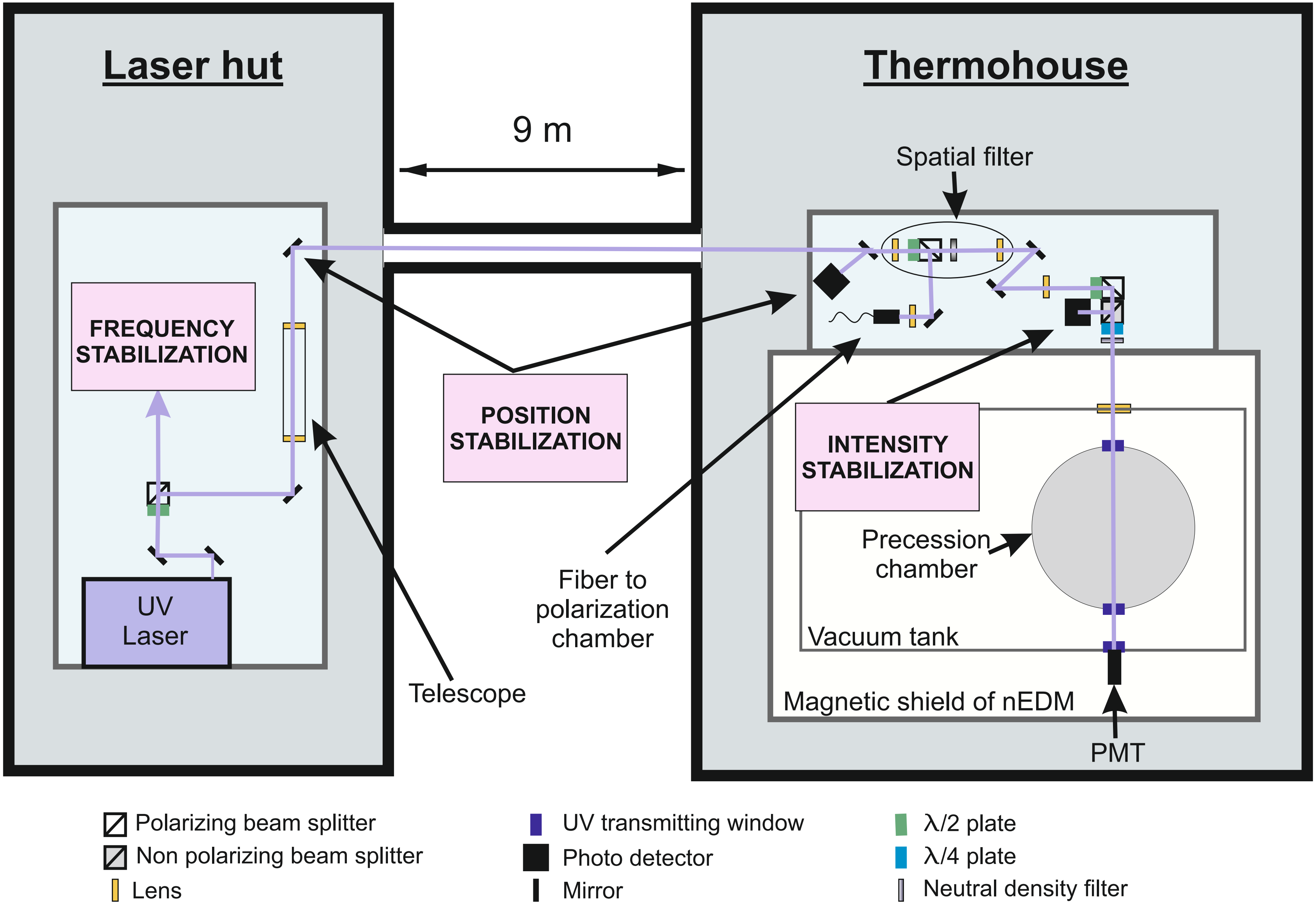


Statistical Magnetometer Performance

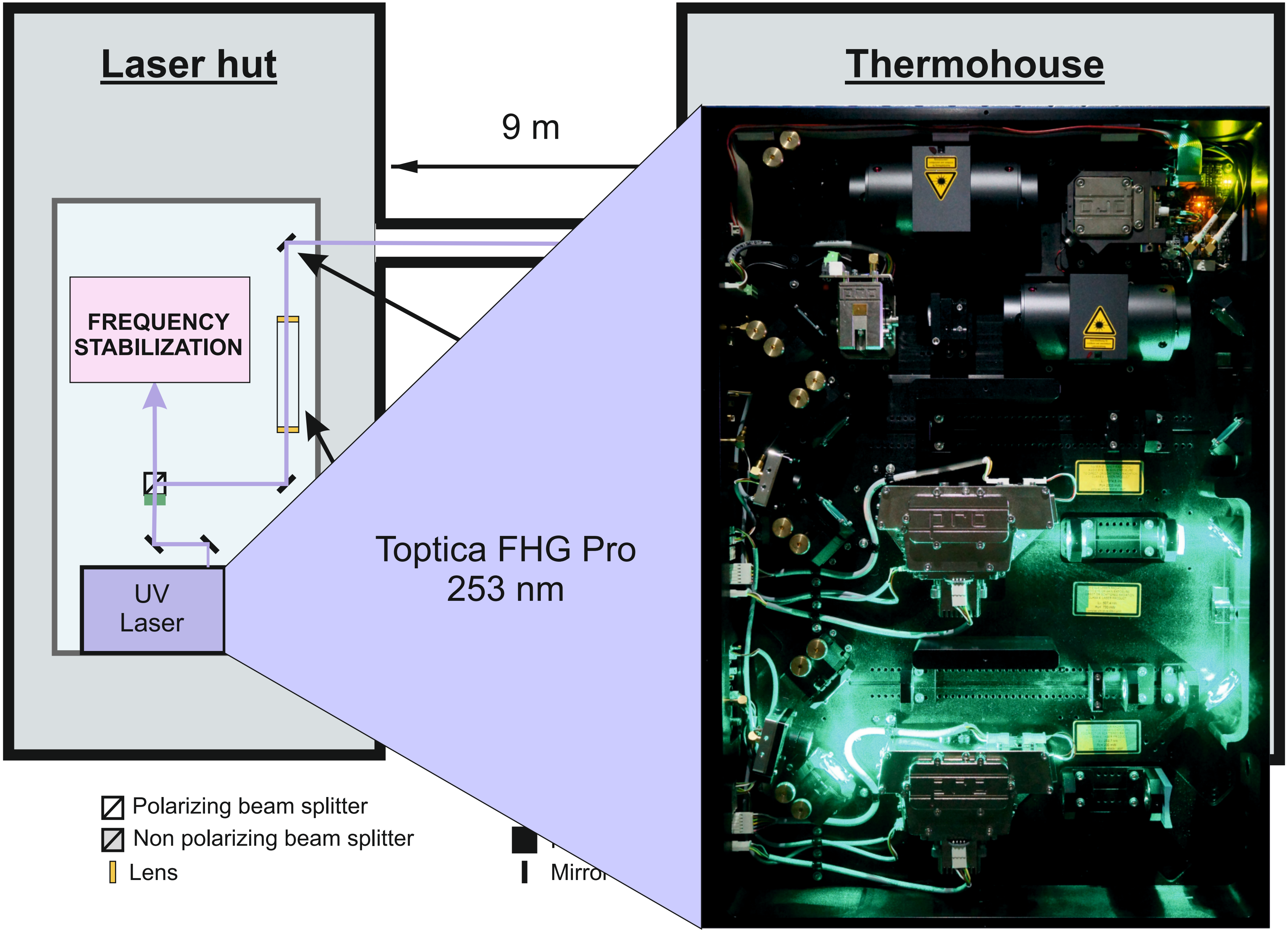
Neutron spin precession frequency $h\nu_L = -2\,\mu\,B_0 \pm 2\,d\,E_0$



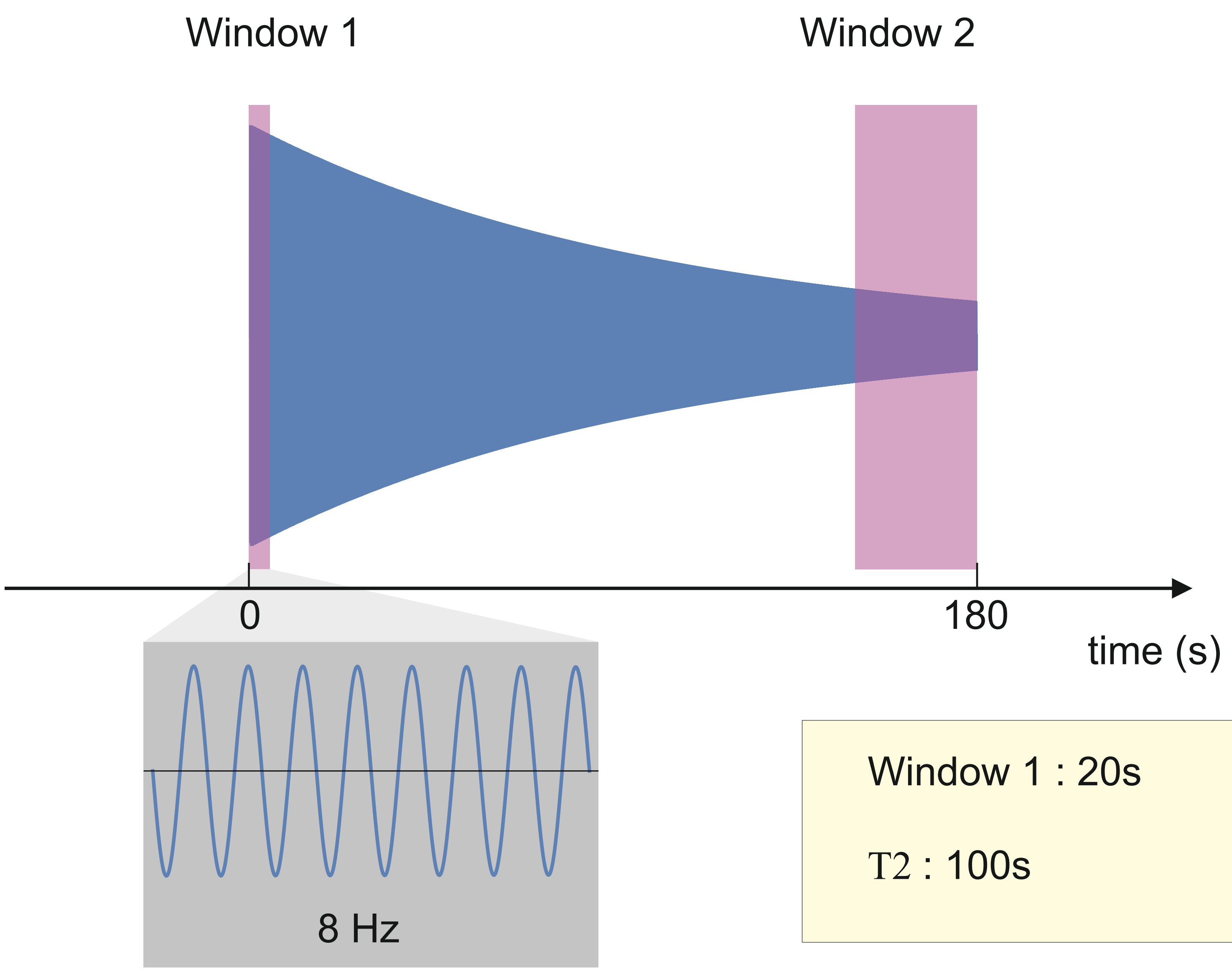
Laser Setup for the Hg Magnetometer



Laser Setup for the Hg Magnetometer



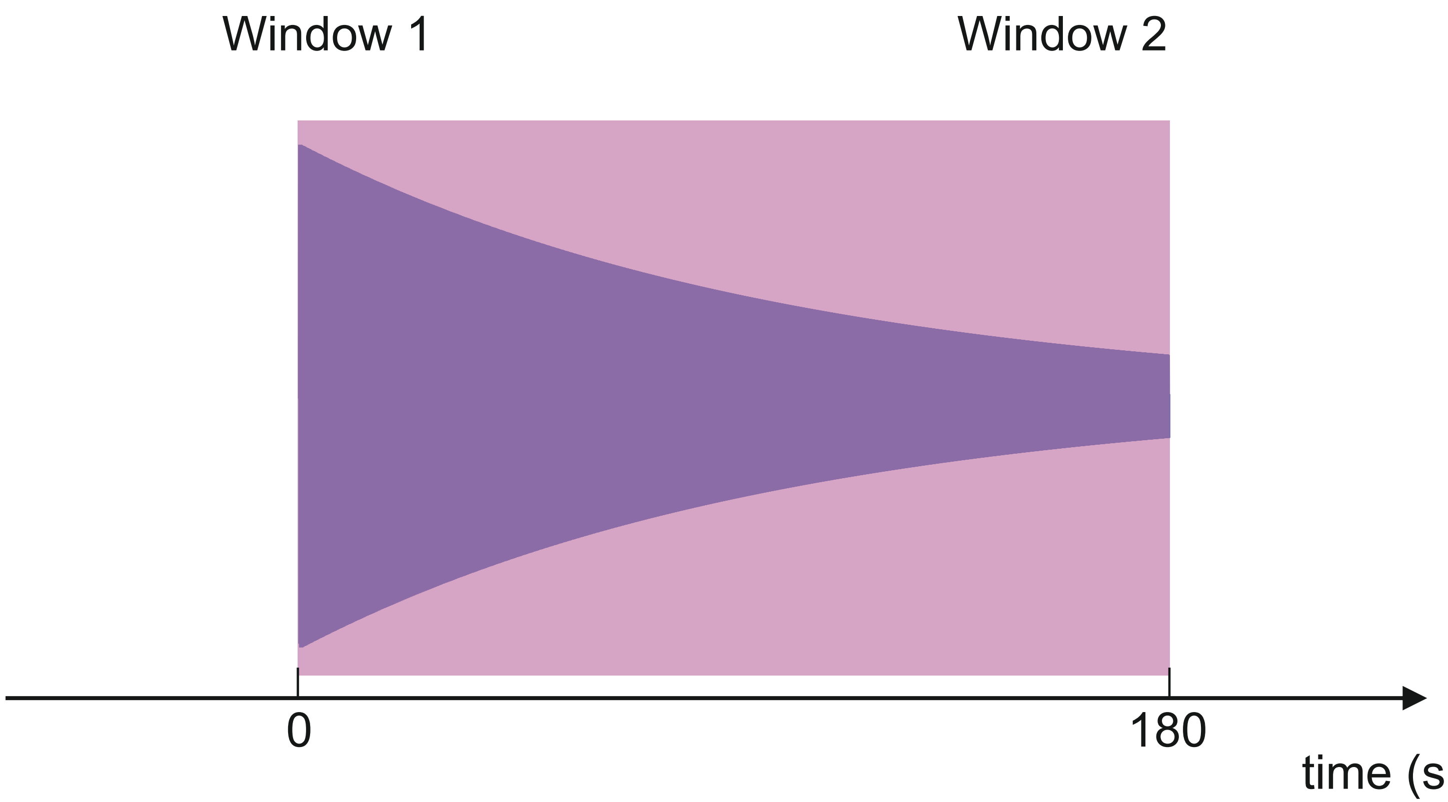
Hg Magnetometer Readout



Window 1 : 20s

T2 : 100s

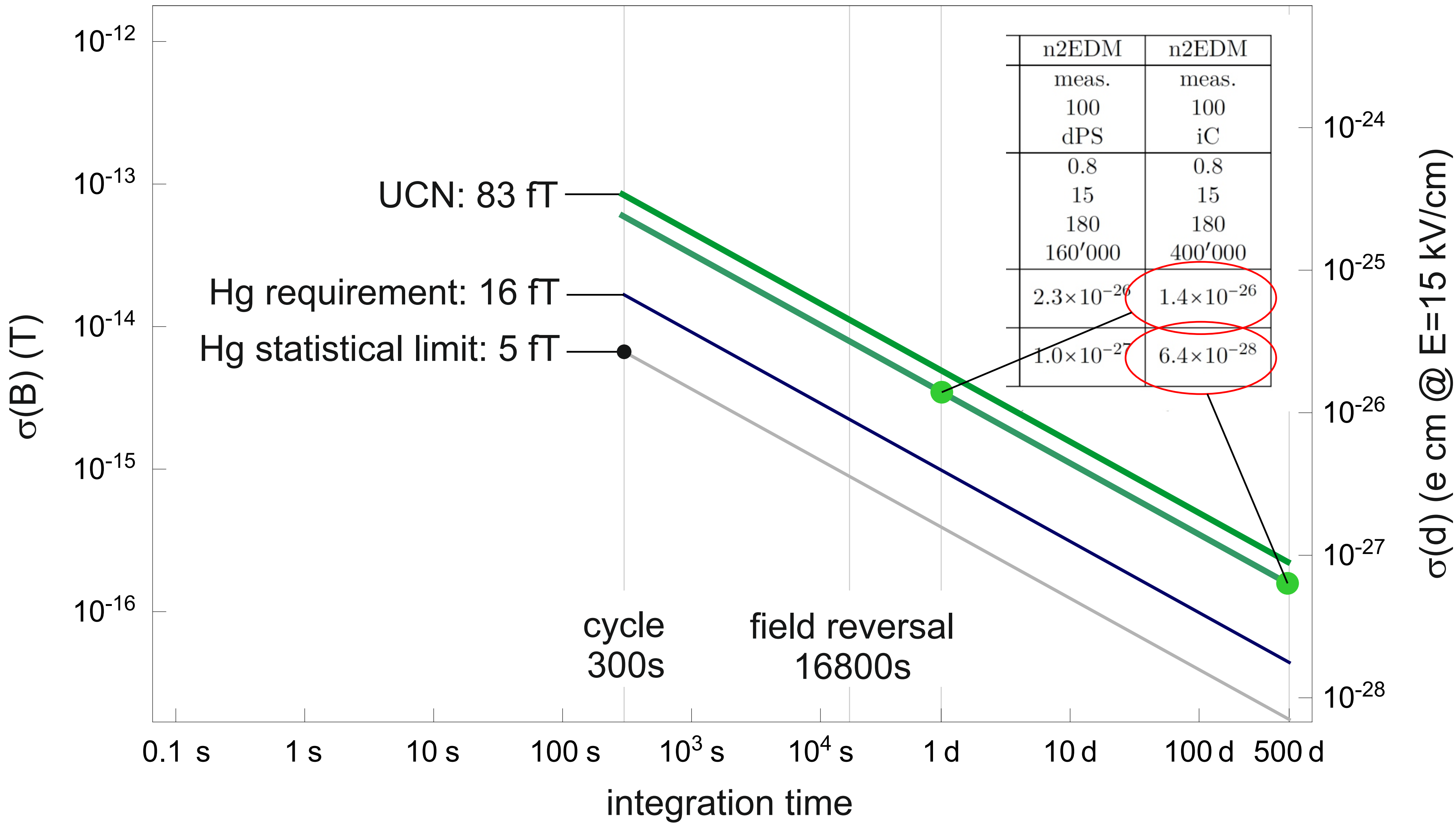
Hg Magnetometer Readout



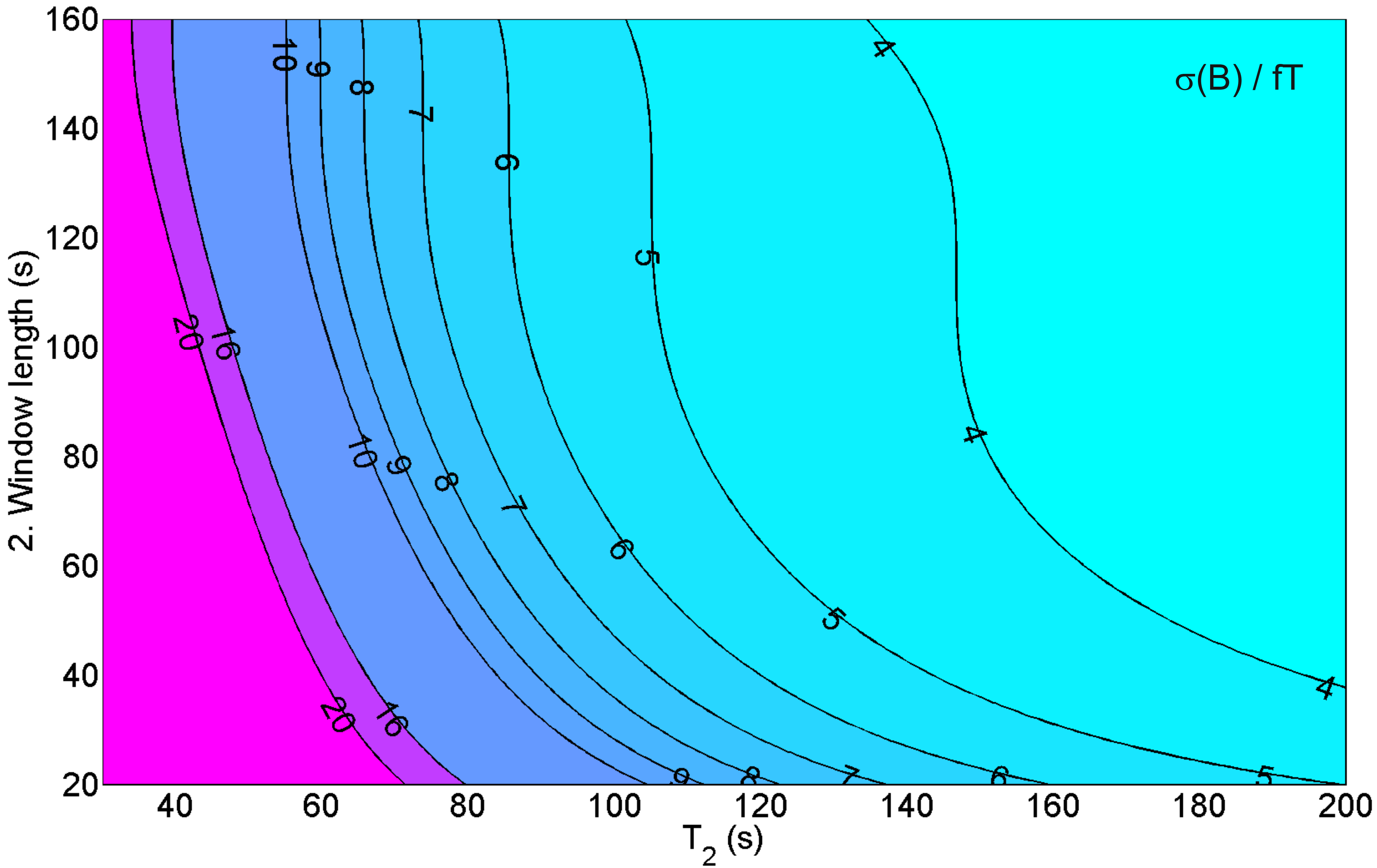
Window 1 : 20s
Window 2 : 160s
T2 : 100s

Statistical Magnetometer Performance

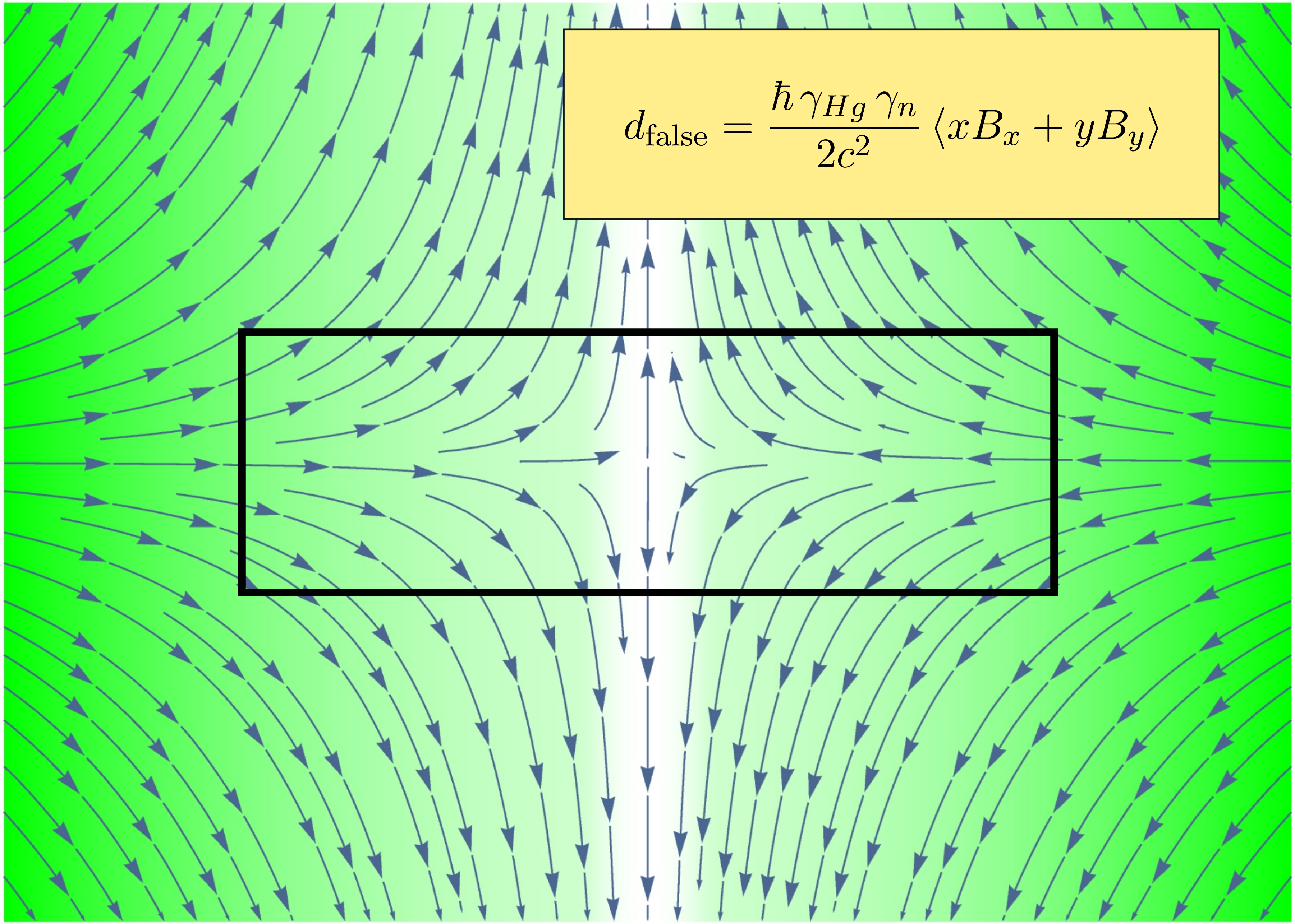
Neutron spin precession frequency $h\nu_L = -2\,\mu\,B_0 \pm 2\,d\,E_0$



Statistical Magnetometer Performance

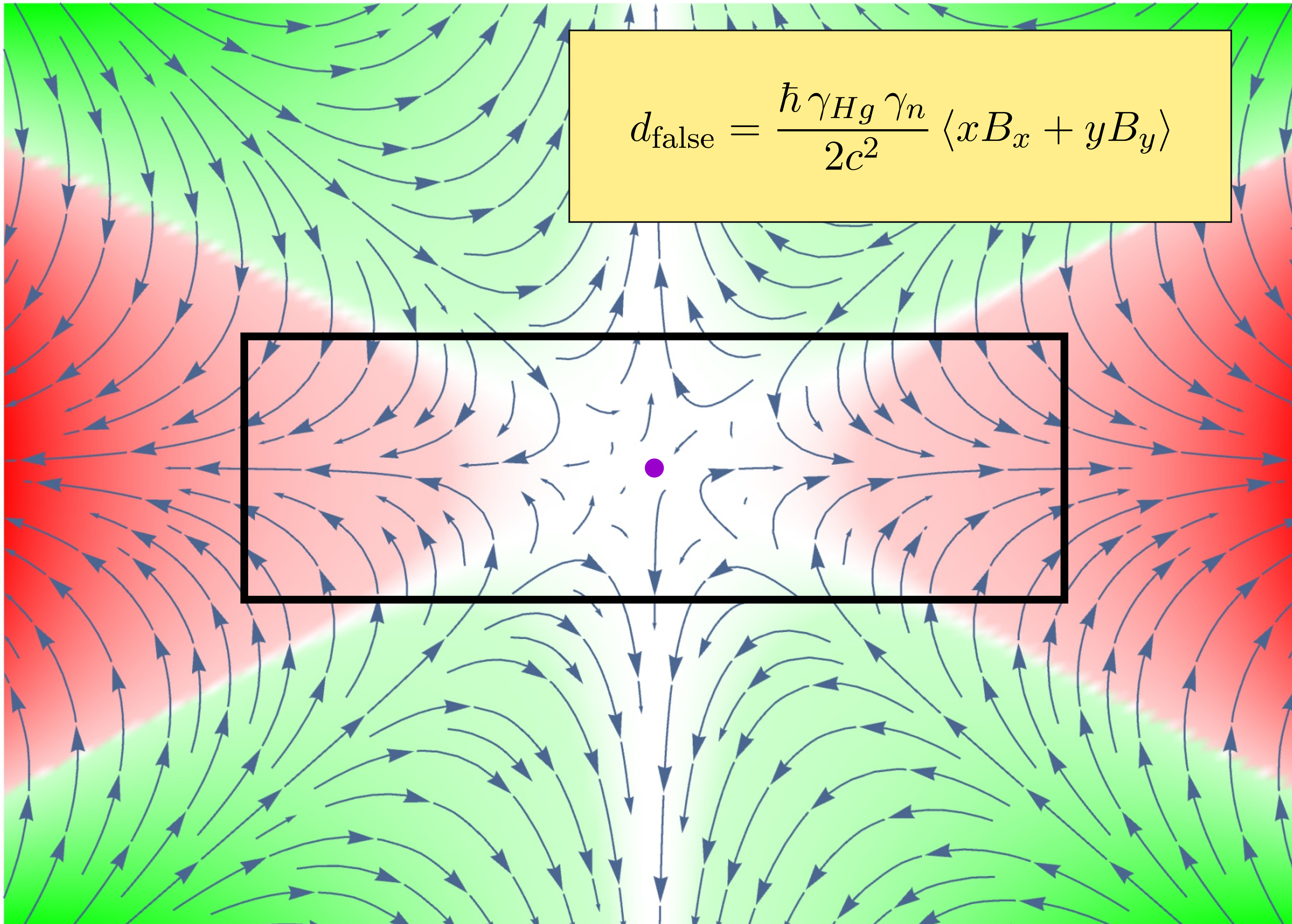


False EDM due to gradient g10



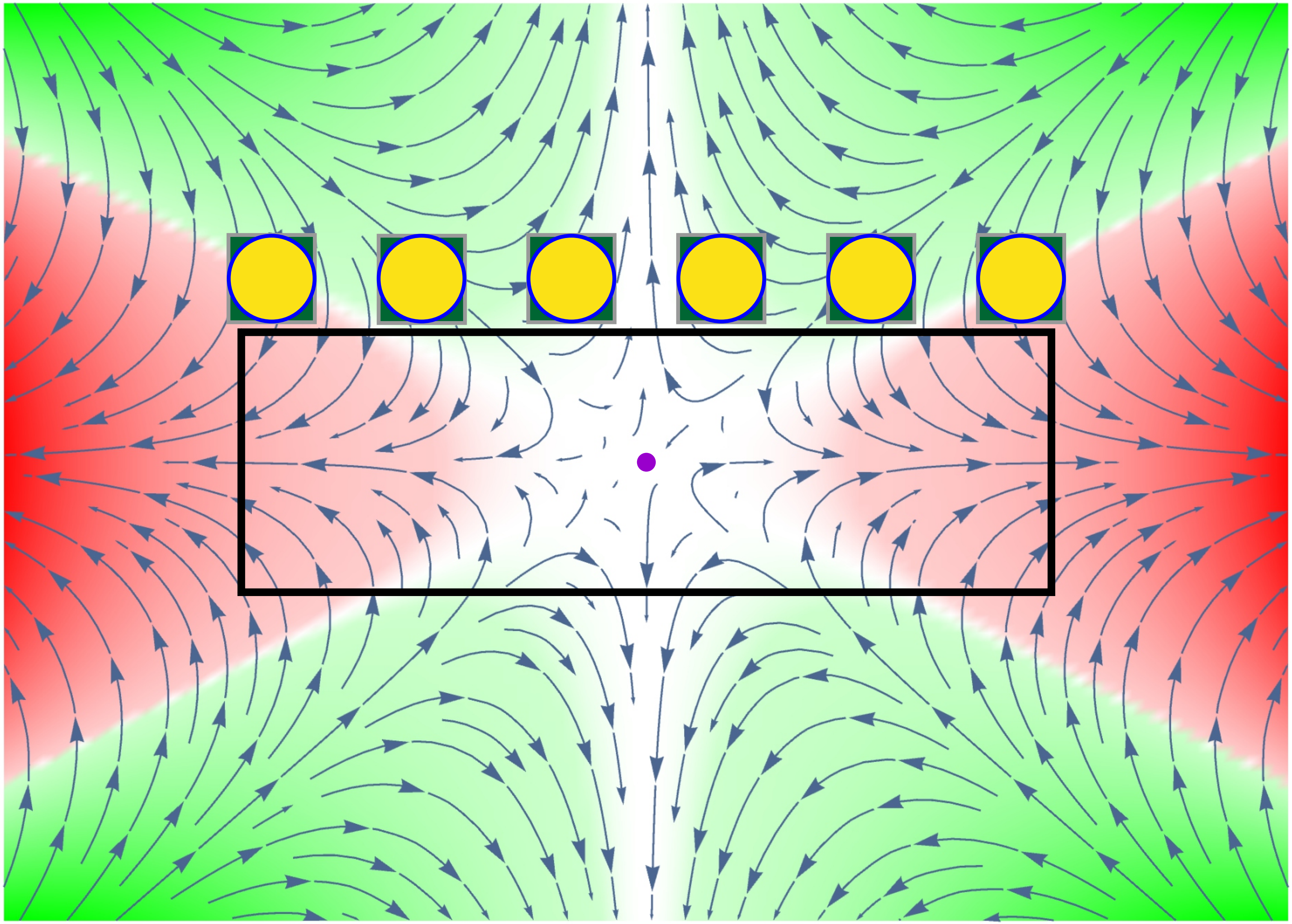
$$d_{\text{false}} = \frac{\hbar \gamma_{Hg} \gamma_n}{2c^2} \langle x B_x + y B_y \rangle$$

False EDM due to gradient g30

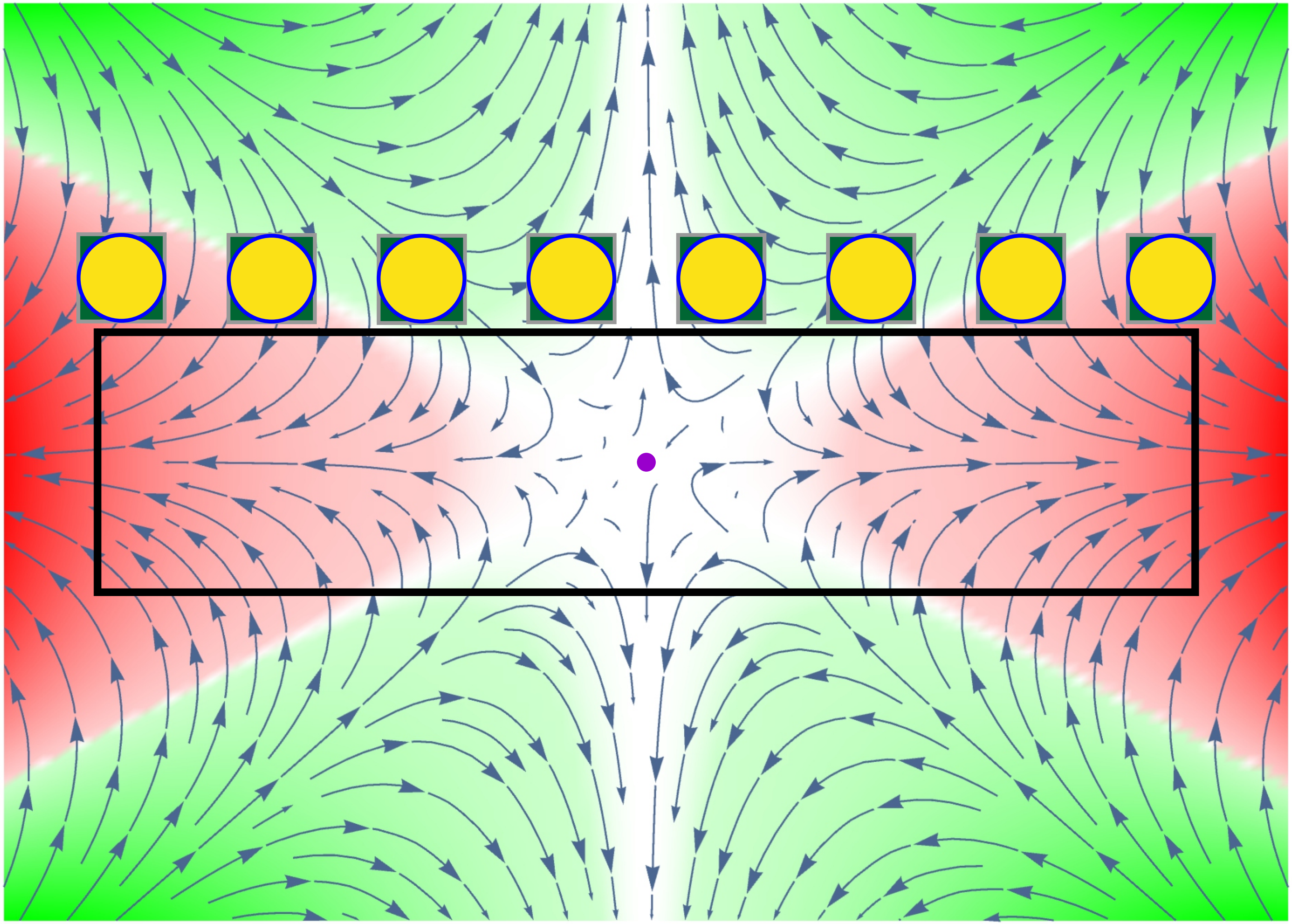


$$d_{\text{false}} = \frac{\hbar \, \gamma_{Hg} \, \gamma_n}{2c^2} \langle x B_x + y B_y \rangle$$

False EDM due to gradient g30

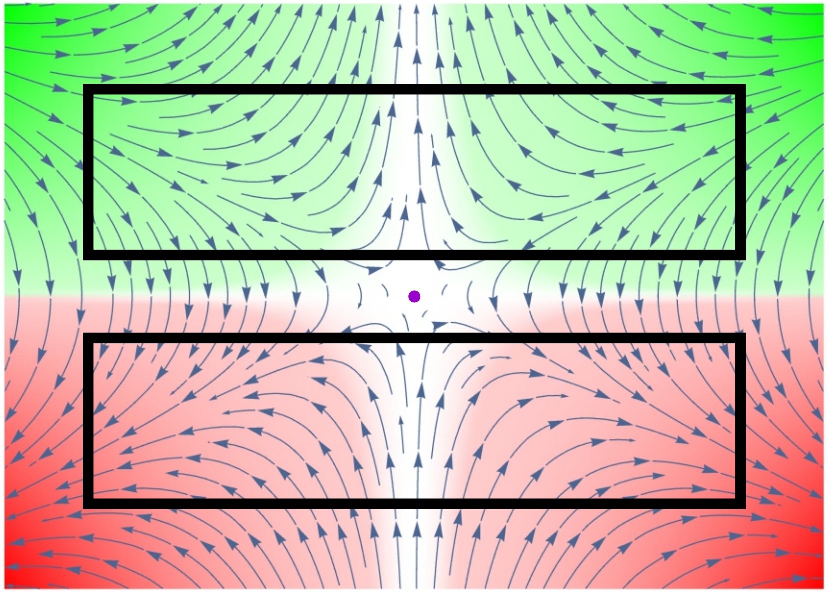


False EDM due to gradient g30



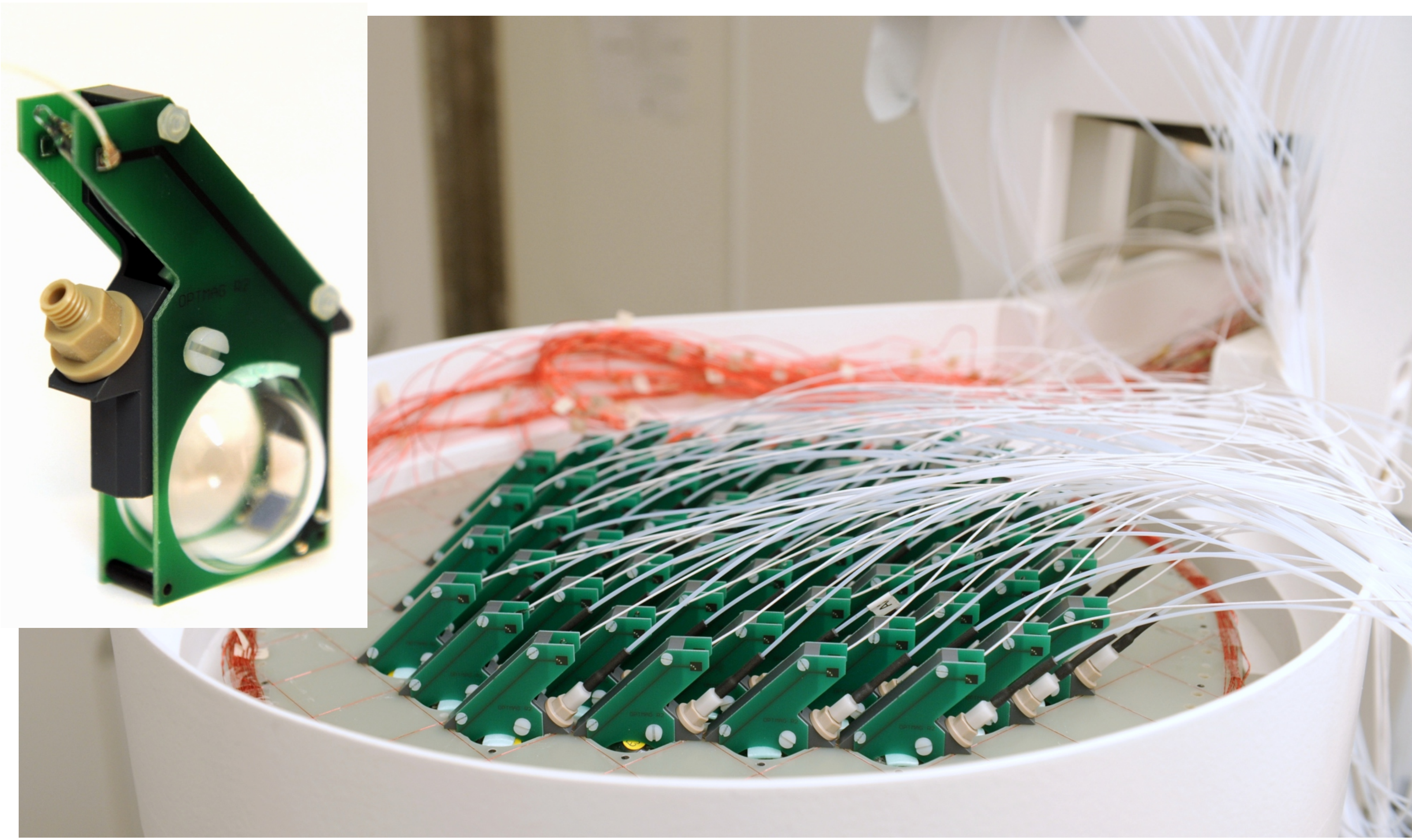
False EDM through higher order gradients

$$
\begin{aligned}
d_{\mathrm{n,f}} = \frac{\hbar \gamma_{\mathrm{Hg}} \gamma_{\mathrm{n}}}{2c^2} \Bigg[& - g_{1,0} \frac{r^2}{4} \\
& - g_{2,0} \frac{r^2\, 3H}{8} \\
& - g_{3,0} \frac{r^2 \left(31H^2 - 8r^2\right)}{64} \\
& - g_{4,0} \frac{r^2\, 3H \left(13H^2 - 8r^2\right)}{64} \\
& - g_{5,0} \frac{r^2 \left(2343H^4 - 2480H^2 r^2 + 240r^4\right)}{3072} \\
& - g_{6,0} \frac{r^2\, 3H \left(651H^4 - 1040H^2 r^2 + 240r^4\right)}{2048} \\
& - g_{7,0} \frac{r^2 \left(19531H^6 - 43736H^4 r^2 + 17360H^2 r^4 - 896r^6\right)}{16384} \\
& - g_{8,0} \frac{r^2\, 3H \left(4069H^6 - 12152H^4 r^2 + 7280H^2 r^4 - 896r^6\right)}{8192} \\
& - g_{9,0} \frac{r^2 \left(488281H^8 - 1874976H^6 r^2 + 1574496H^4 r^4 - 333312H^2 r^6 + 10752r^8\right)}{262144} \Bigg]
\end{aligned}
$$



Gradient extraction: Order 5: 48 DOF, Order 7: 80 DOF, Order 9: 120DOF

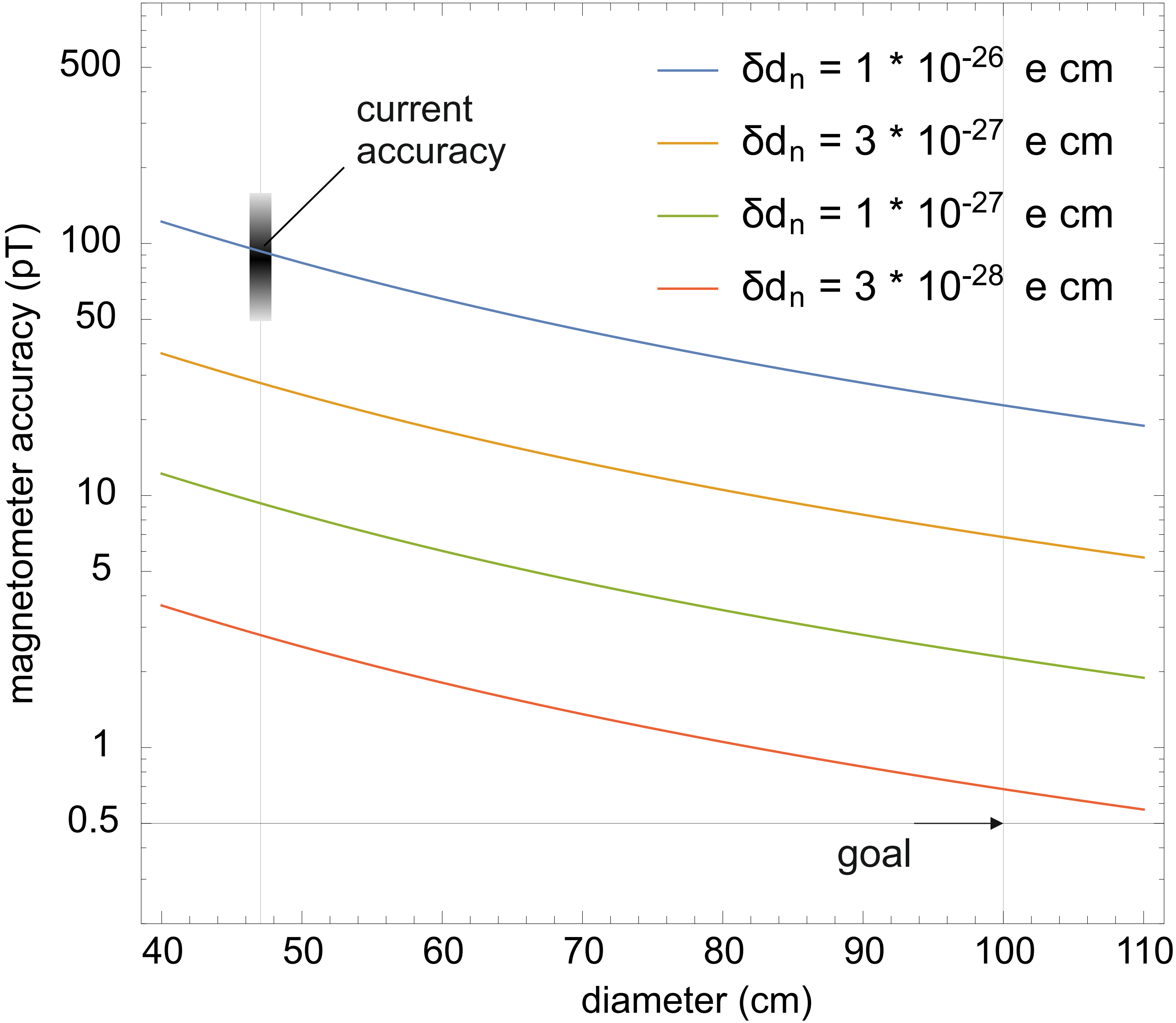
57 Channel Cs Magnetometer Array



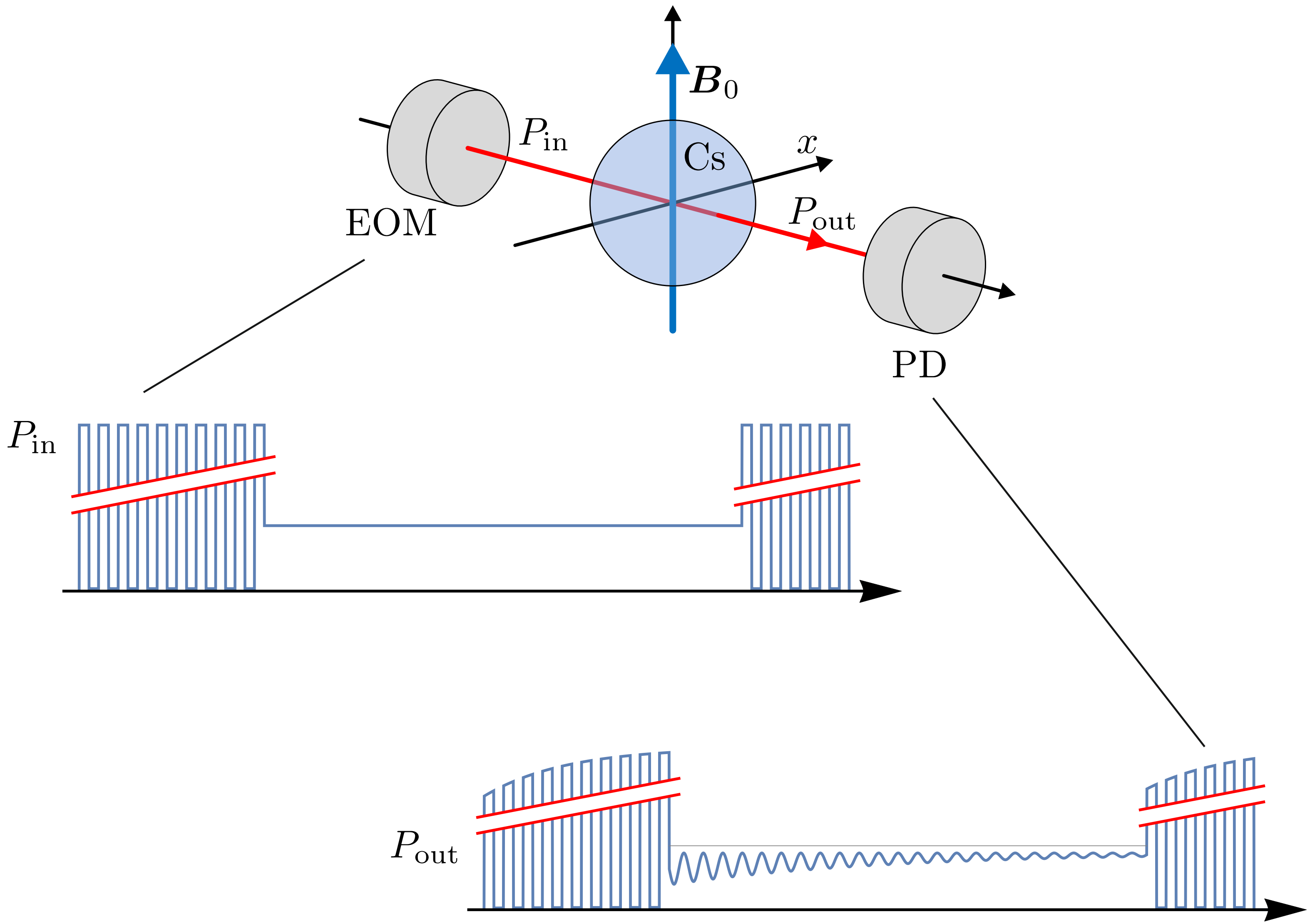
Optical multichannel room temperature magnetic field imaging system for clinical application

G. Lembke, S. N. Erné, H. Nowak, B. Menhorn, A. Pasquarelli, and G. B. Biomed. Opt. Express, 5(3):62–65, 2014.

False EDM through cubic gradients

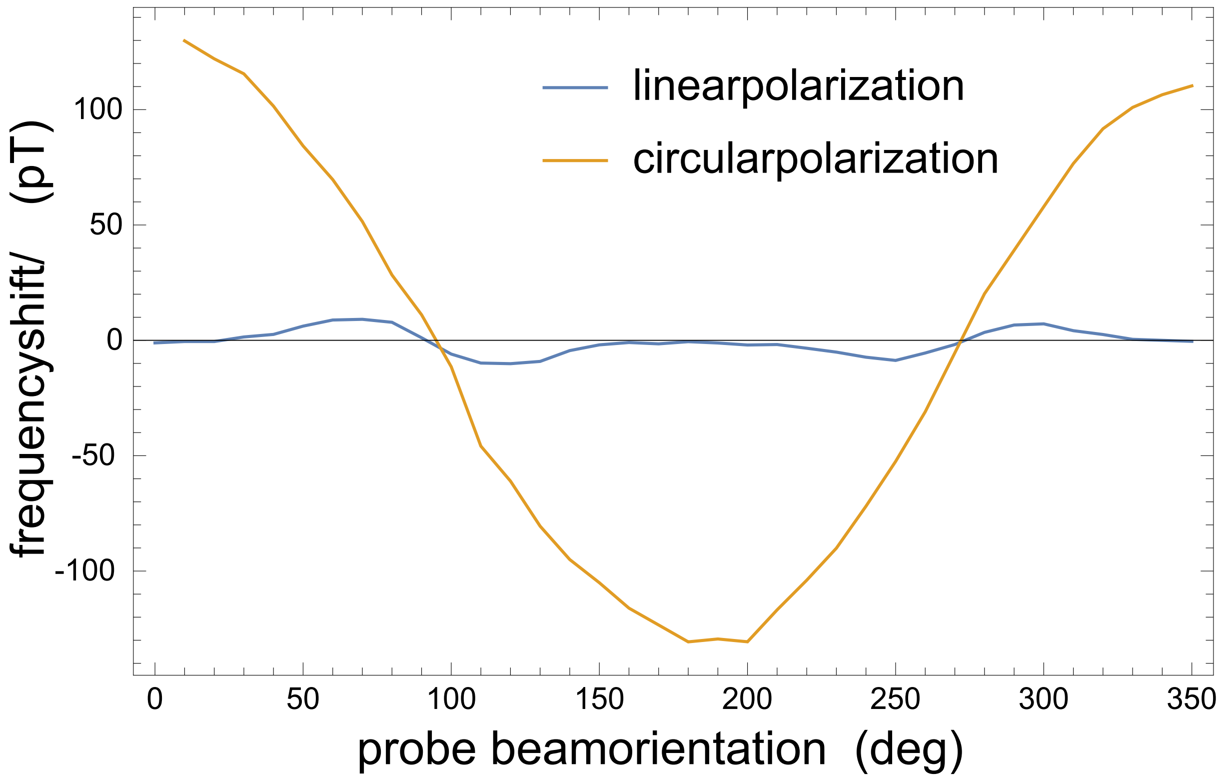


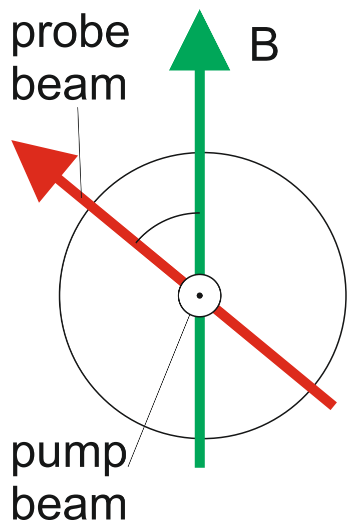
All optical Cs Magnetometer



A sensitive and accurate atomic magnetometer based on free spin precession.
Z. D. Grujic, P. A. Koss, G. B., and A. Weis. Eur. Phys. J. D, 69(5), 2015.

Cs magnetometers with linear polarization





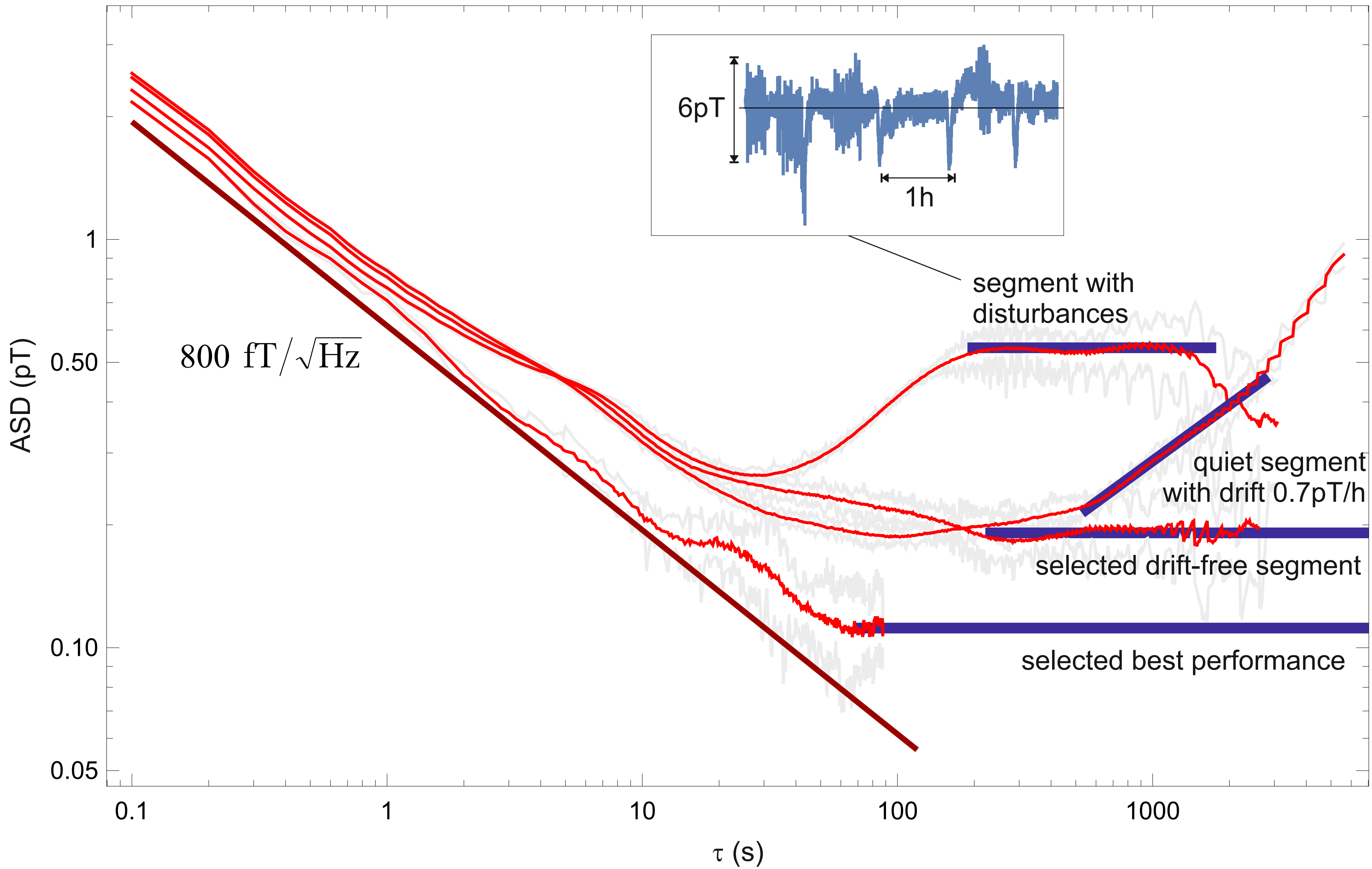
no light shift (?)

no magnetic cross-talk

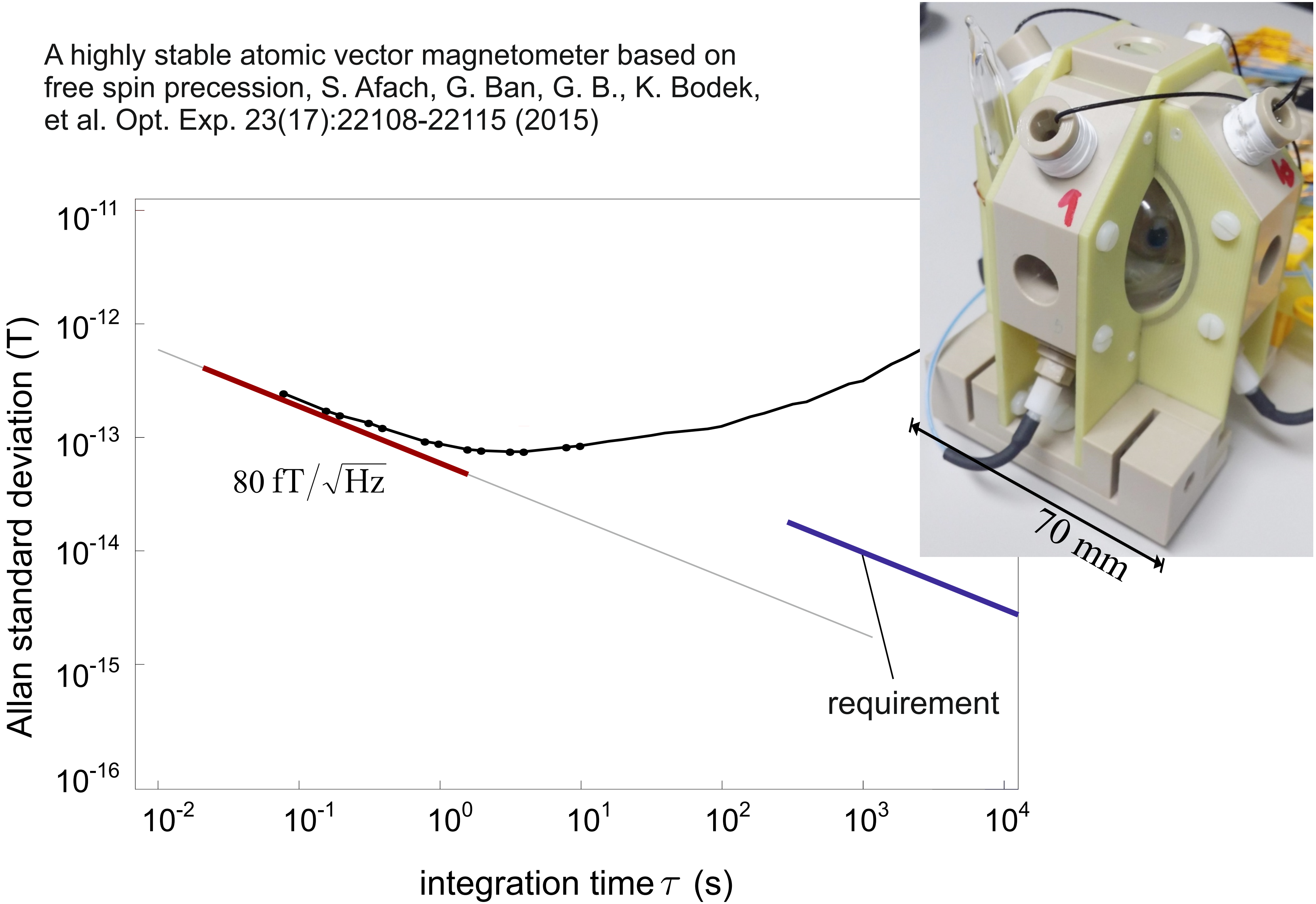
much less offset effect

less sensitive

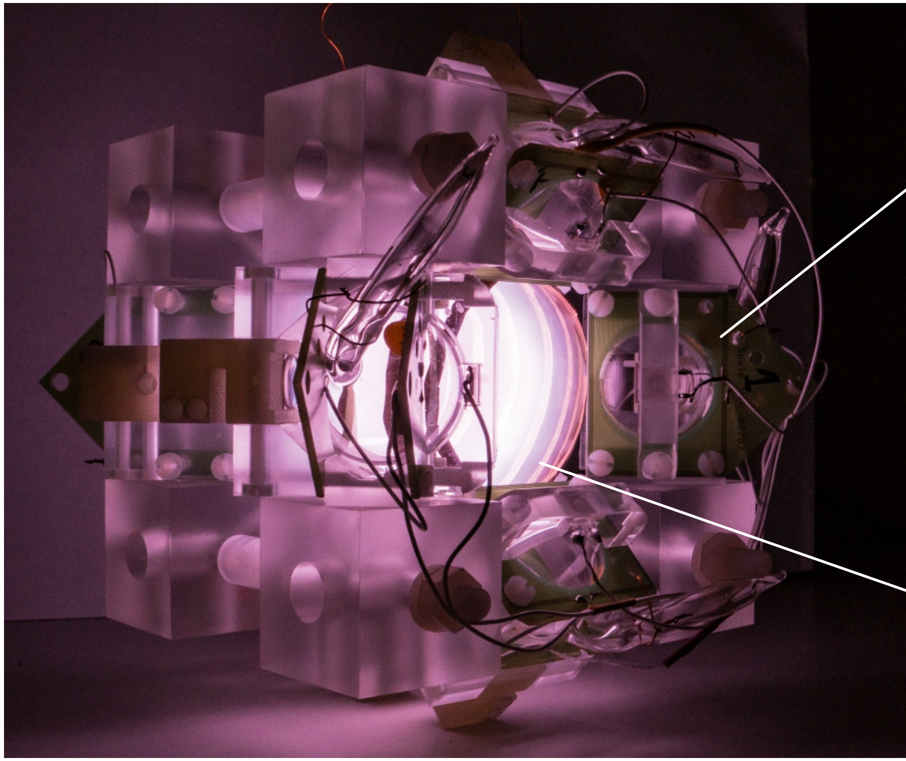
ASD with linear polarized light



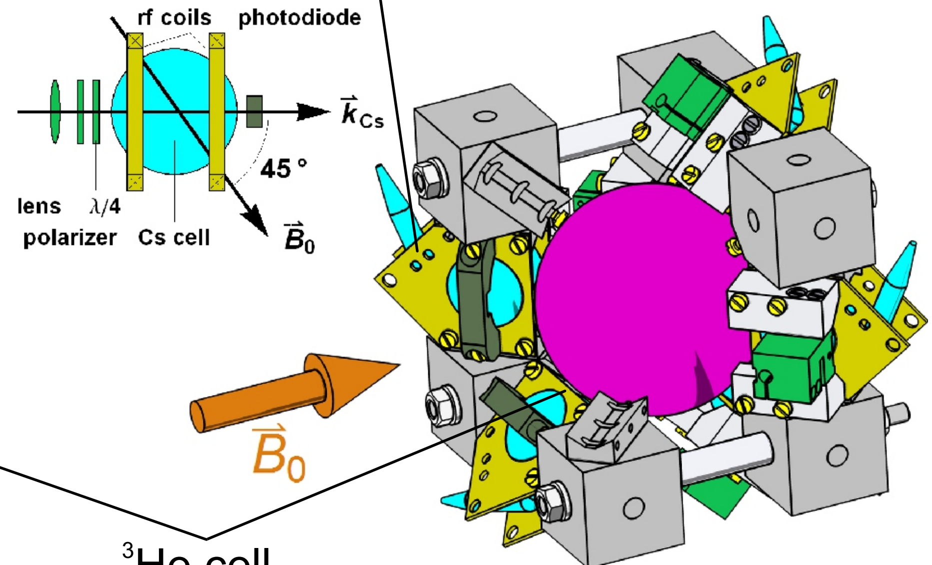
A highly stable atomic vector magnetometer based on free spin precession, S. Afach, G. Ban, G. B., K. Bodek, et al. Opt. Exp. 23(17):22108-22115 (2015)



He Magnetometer



eight Cs magnetometers



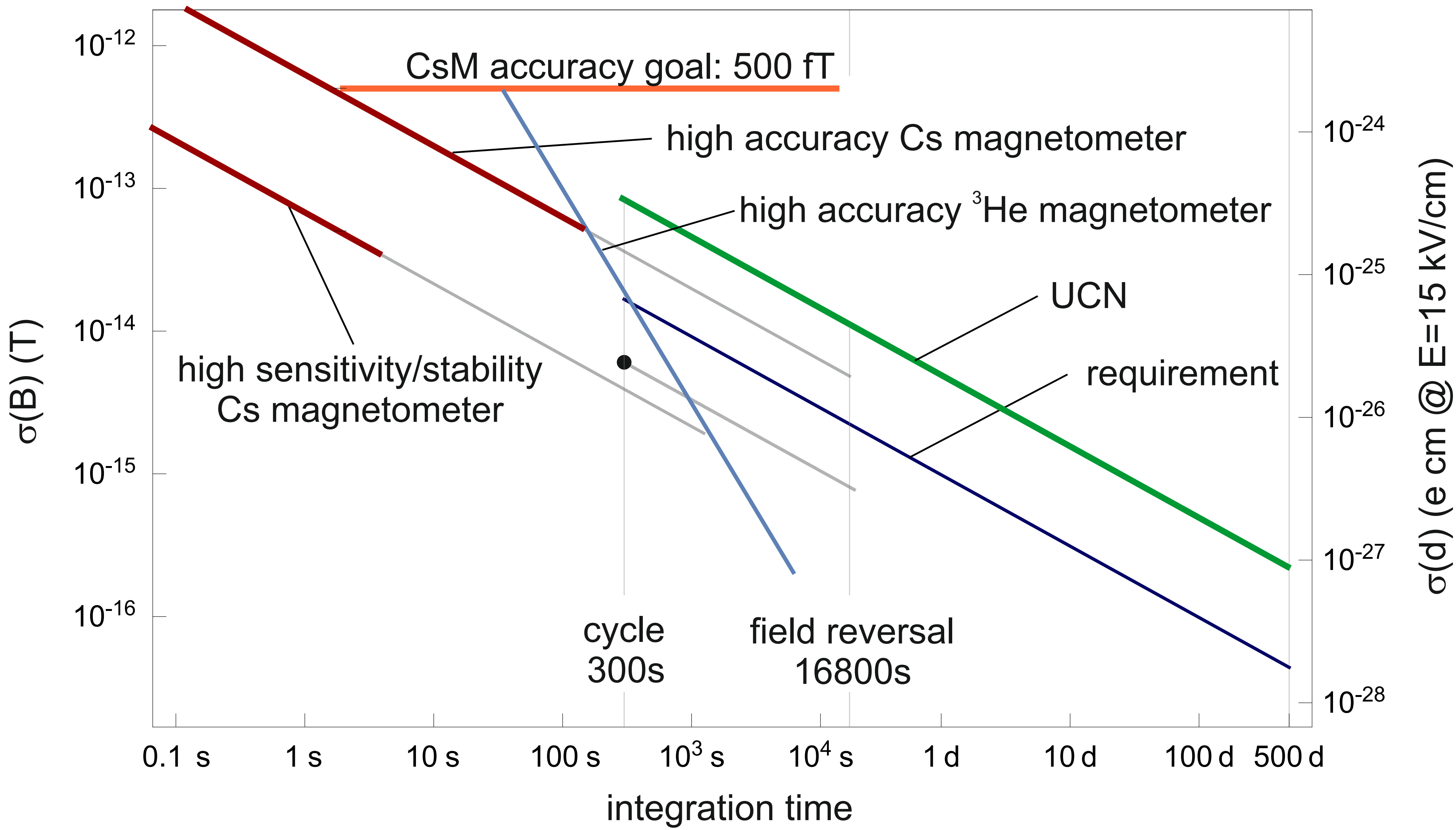
^{3}He cell

metastable exchange optical pumping

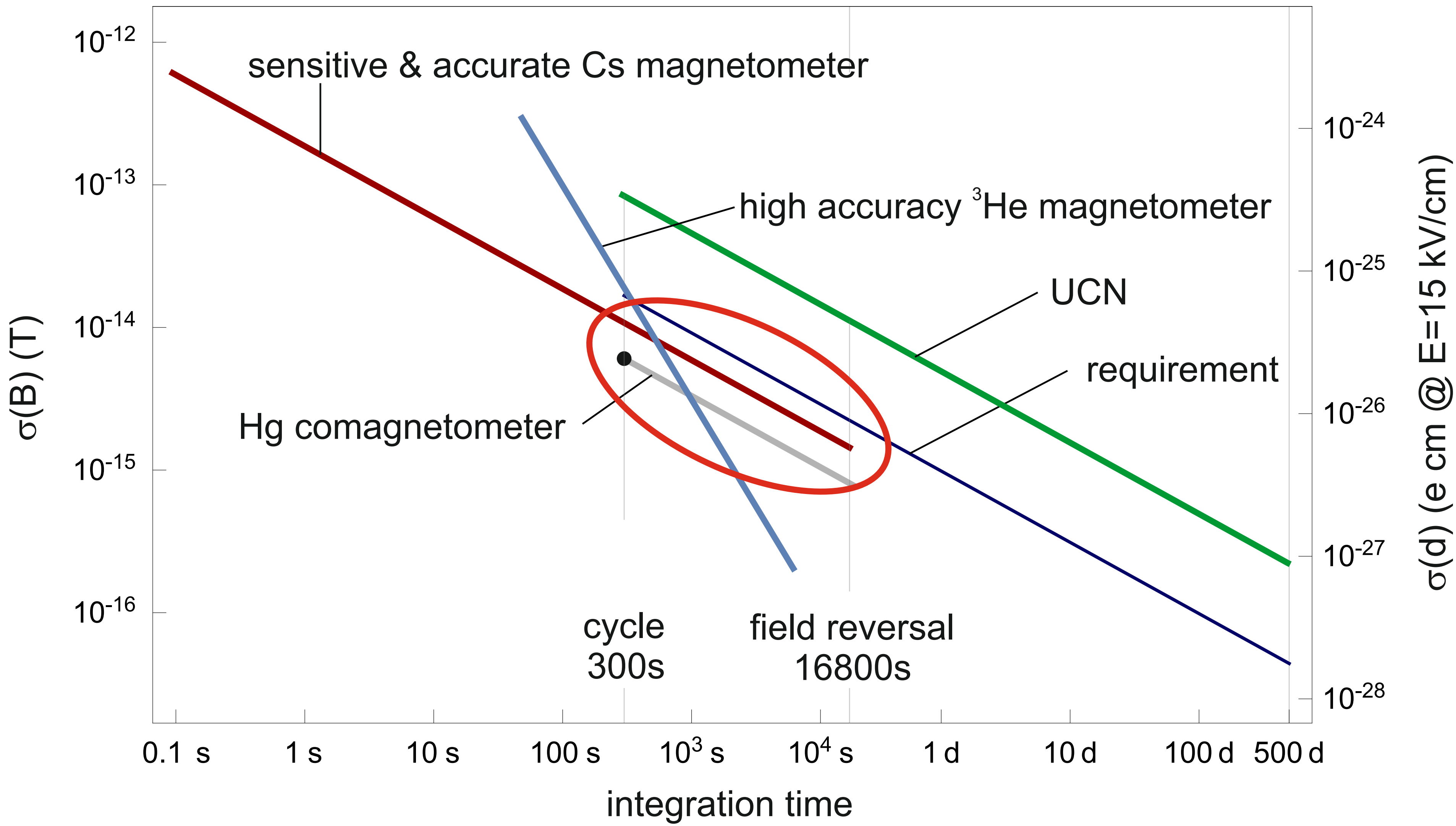
Design and performance of an absolute ^{3}He/Cs magnetometer H.-C. Koch, G. Bison, Z. D. Grujić, W. Heil, M. Kasprzak, P. Knowles, A. Kraft, A. Pazgalev, A. Schnabel, J. Voigt, A. Weis. Eur. Phys. J. D 69:202 (2015)

Investigation of the intrinsic sensitivity of a ^{3}He/Cs magnetometer. H.-C. Koch, G. Bison, Z. D. Grujić, W. Heil, M. Kasprzak, P. Knowles, A. Kraft, A. Pazgalev, A. Schnabel, J. Voigt, A. Weis Eur. Phys. J. D 69: 262 (2015).

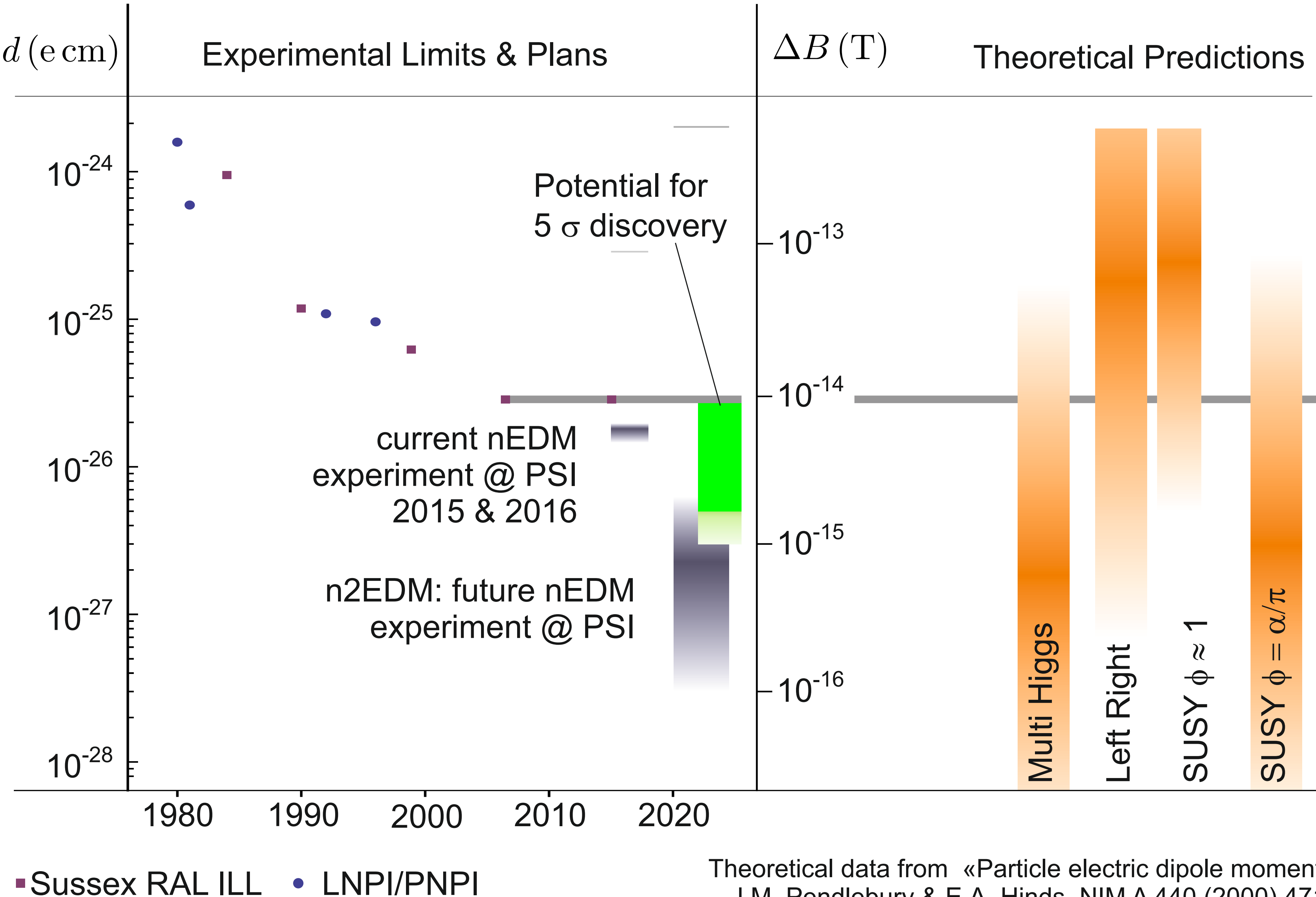
Statistical Magnetometer Performance



Goals for n2EDM

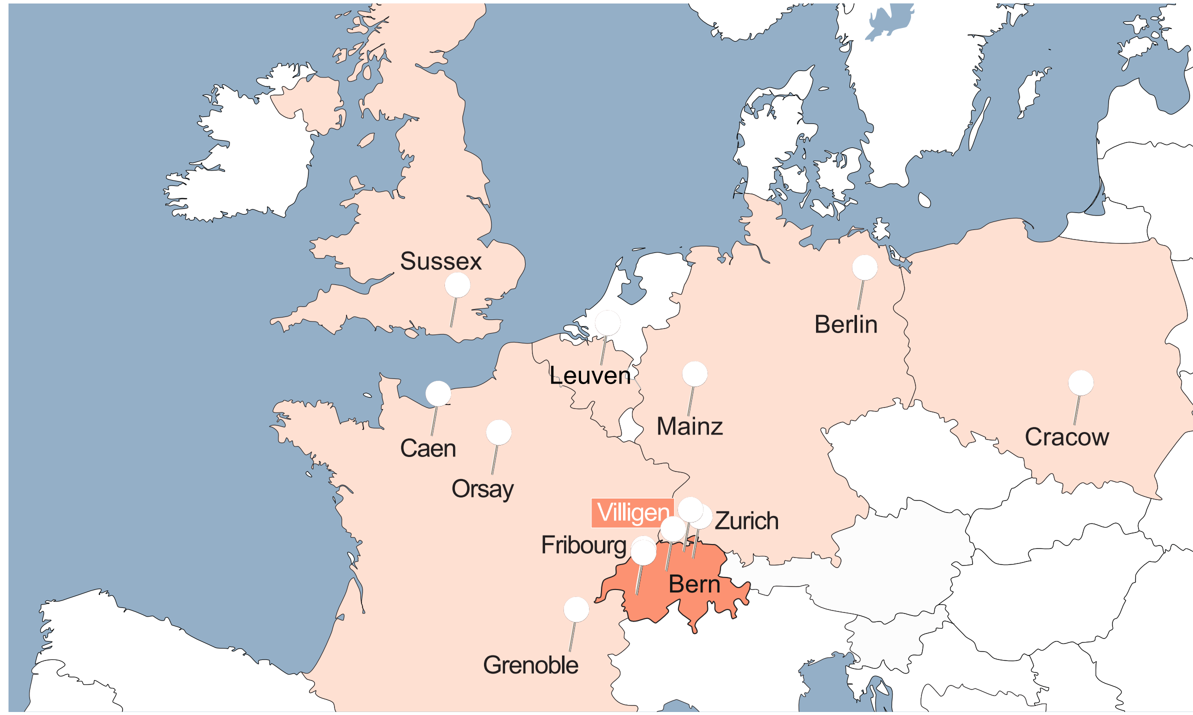


Outlook



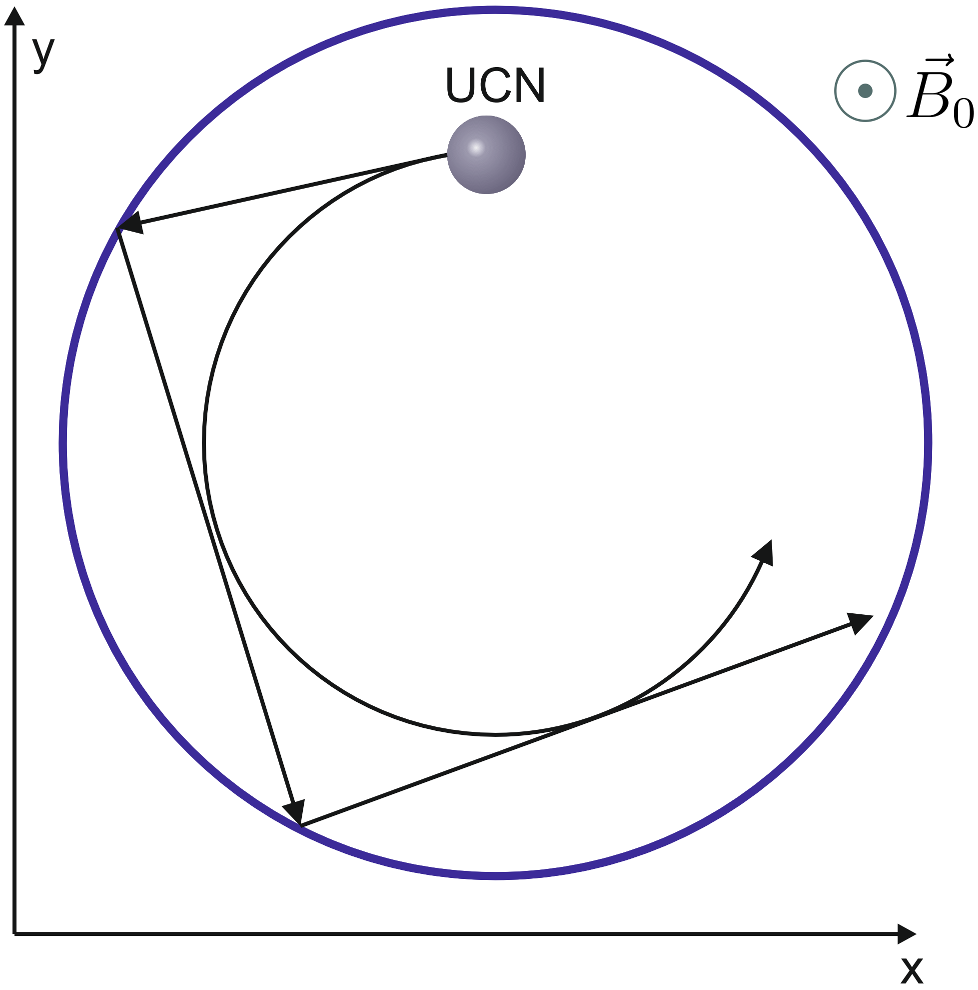
Theoretical data from «Particle electric dipole moments»
J.M. Pendlebury & E.A. Hinds, NIM A 440 (2000) 471

The nEDM Collaboration

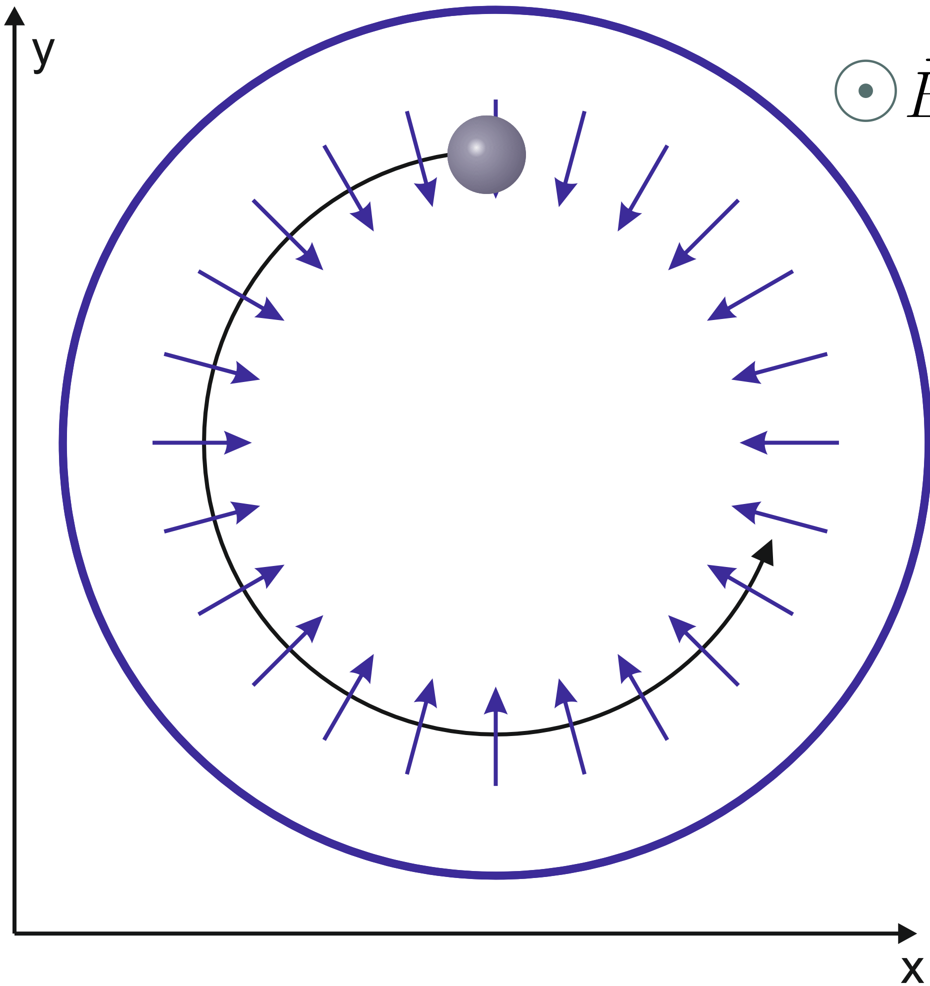


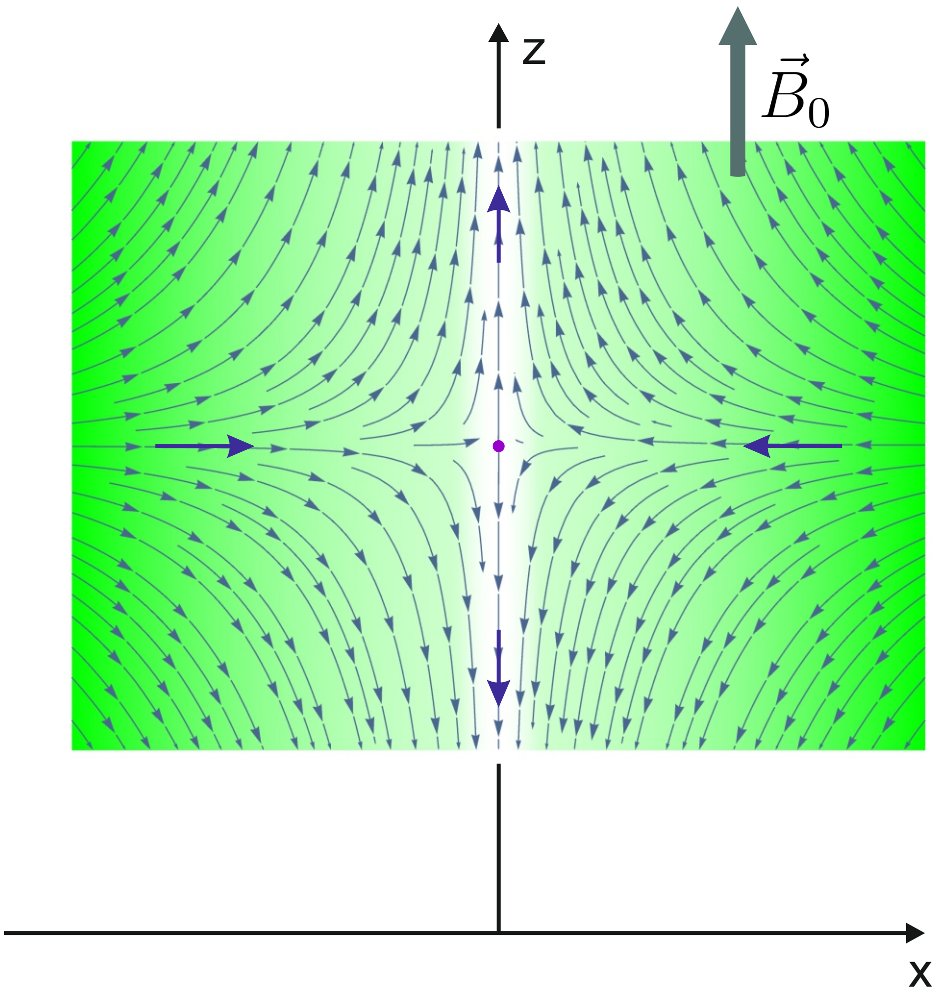
Backup

Ramsey Bloch Siegert shift



Ramsey Bloch Siegert shift due to magnetic gradients

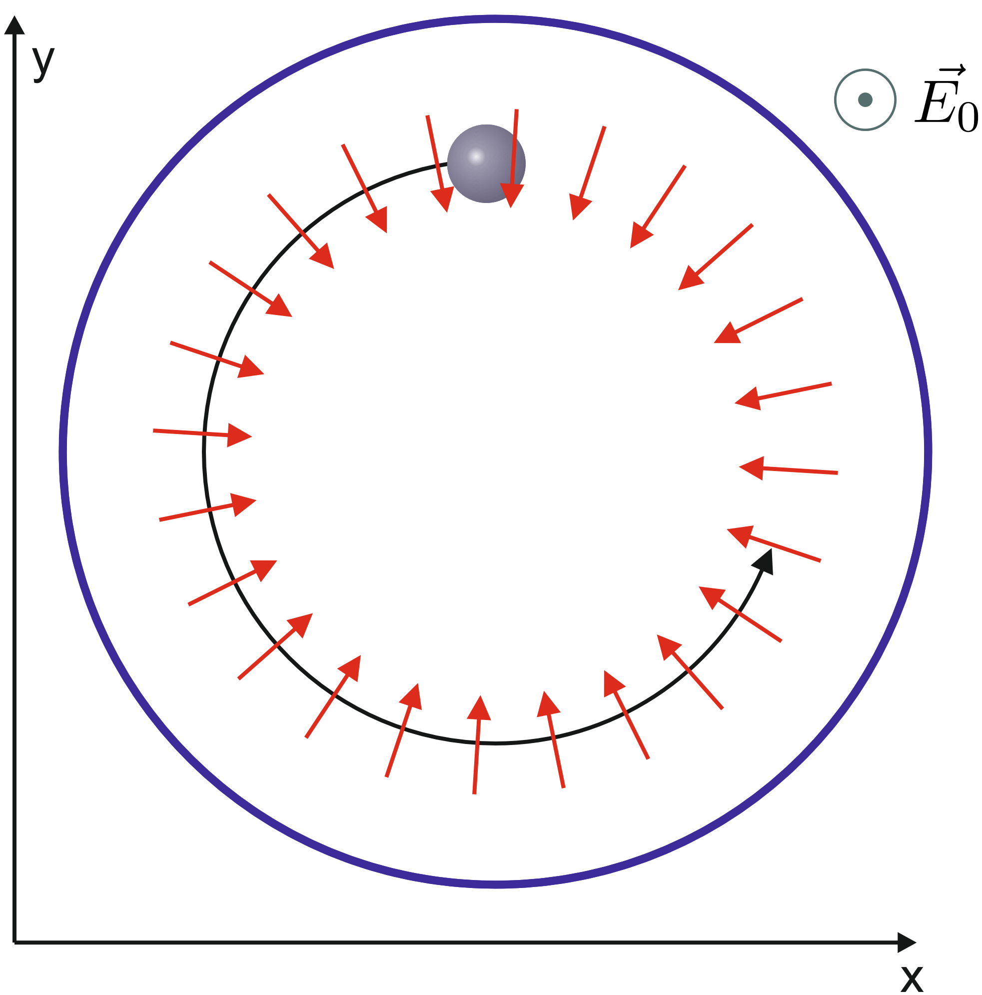


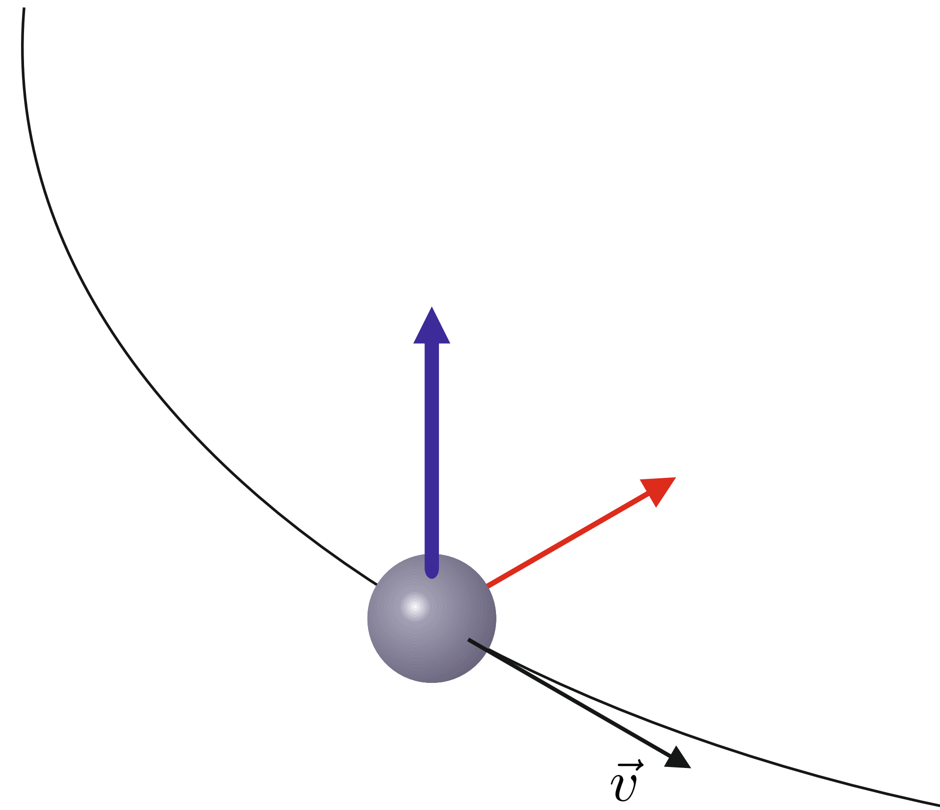


$$\Delta\omega = \frac{\gamma^2 B_{xy}^2}{2(\omega_L \pm \omega_r)}$$

$$\vec{B}_G = \frac{\partial B_z}{\partial z}\frac{\vec{r}}{2}$$

Ramsey Bloch Siegert shift due to motional B-fields

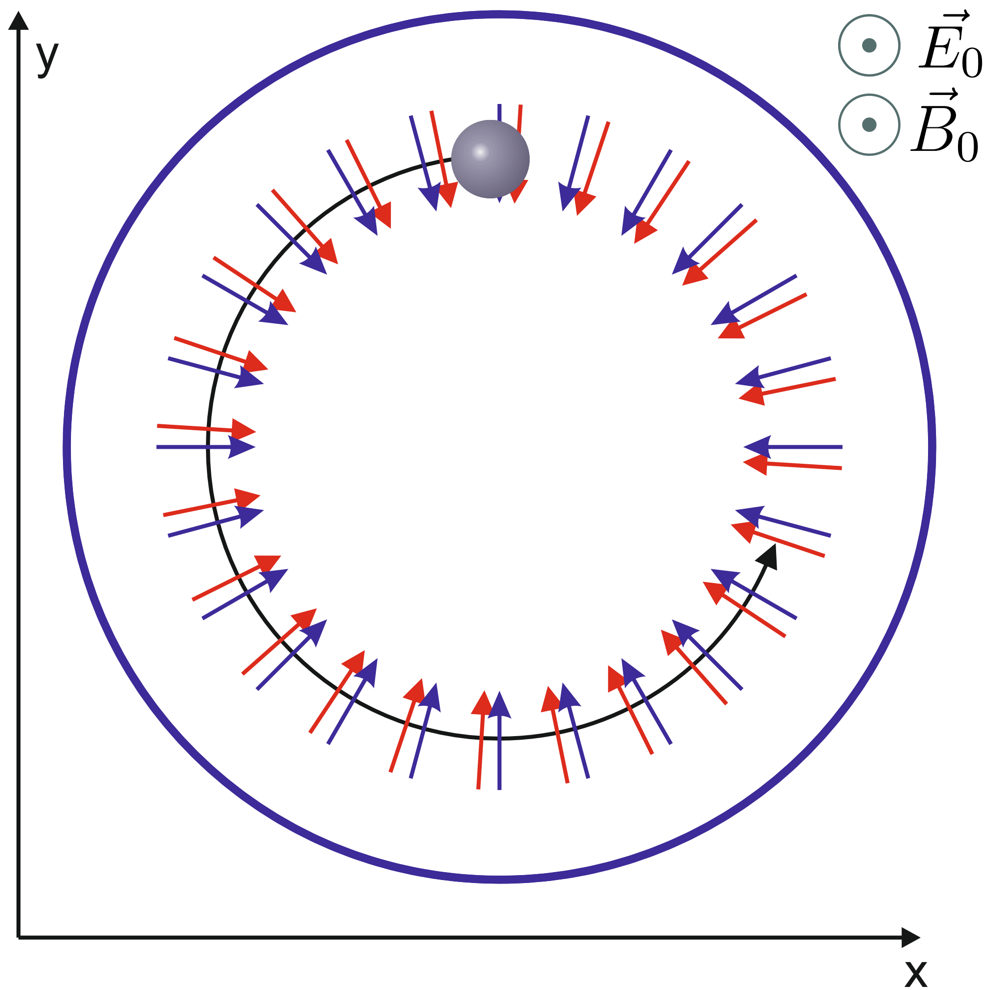




$$\Delta\omega = \frac{\gamma^2 B_{xy}^2}{2(\omega_L \pm \omega_r)}$$

$$\vec{B}_E = \frac{\vec{E}_0 \times \vec{v}}{c^2}$$

False EDM



$\vec{B}_G$ $\vec{B}_E$

$$\Delta\omega = \frac{\gamma^2 B_{xy}^2}{2(\omega_L \pm \omega_r)}$$

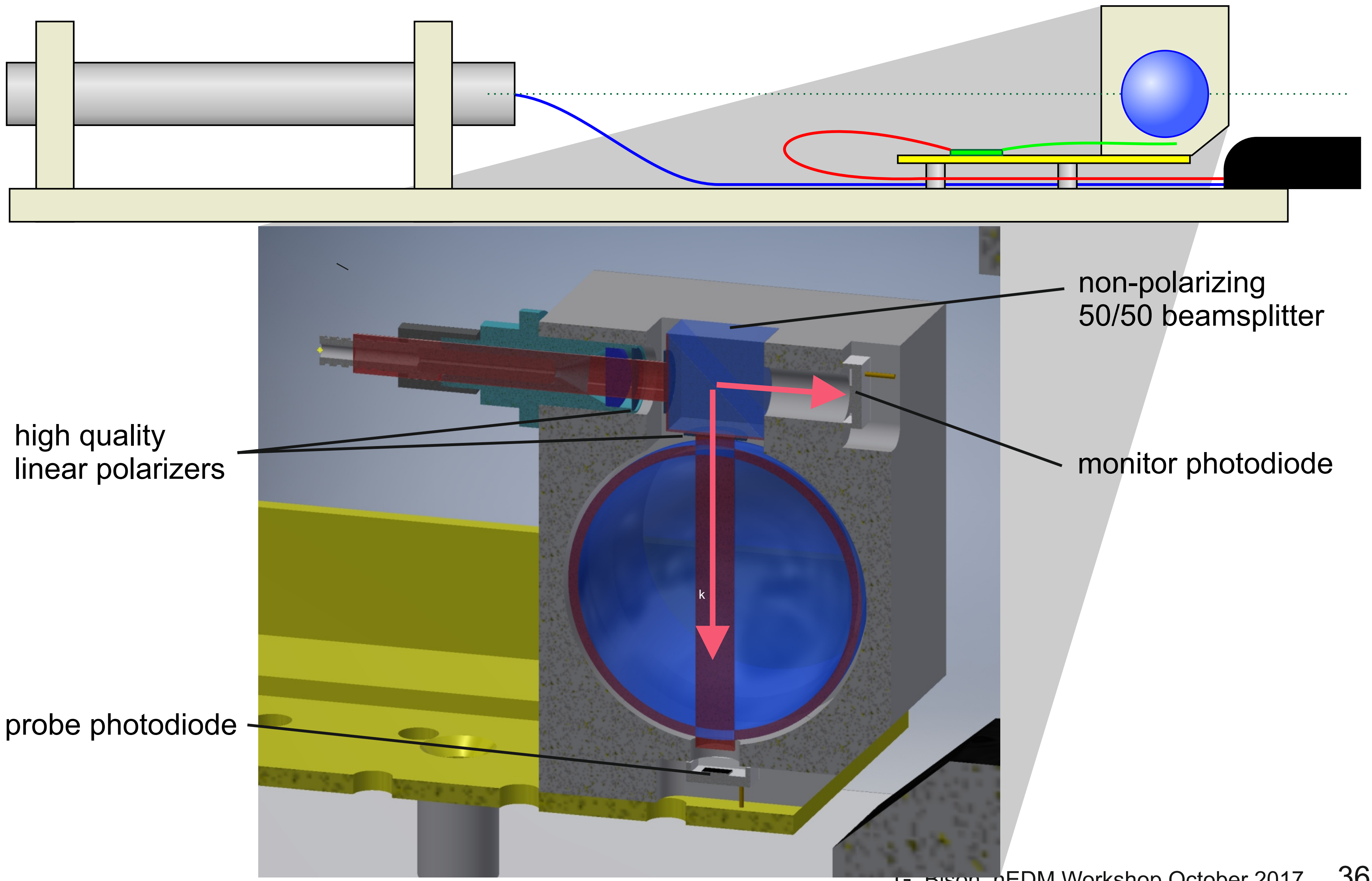
$$= \Delta\omega_{EE} + \Delta\omega_{GG} + \Delta\omega_{EG}$$

EDM-like signal: proportional to the E-field and the B-field gradient

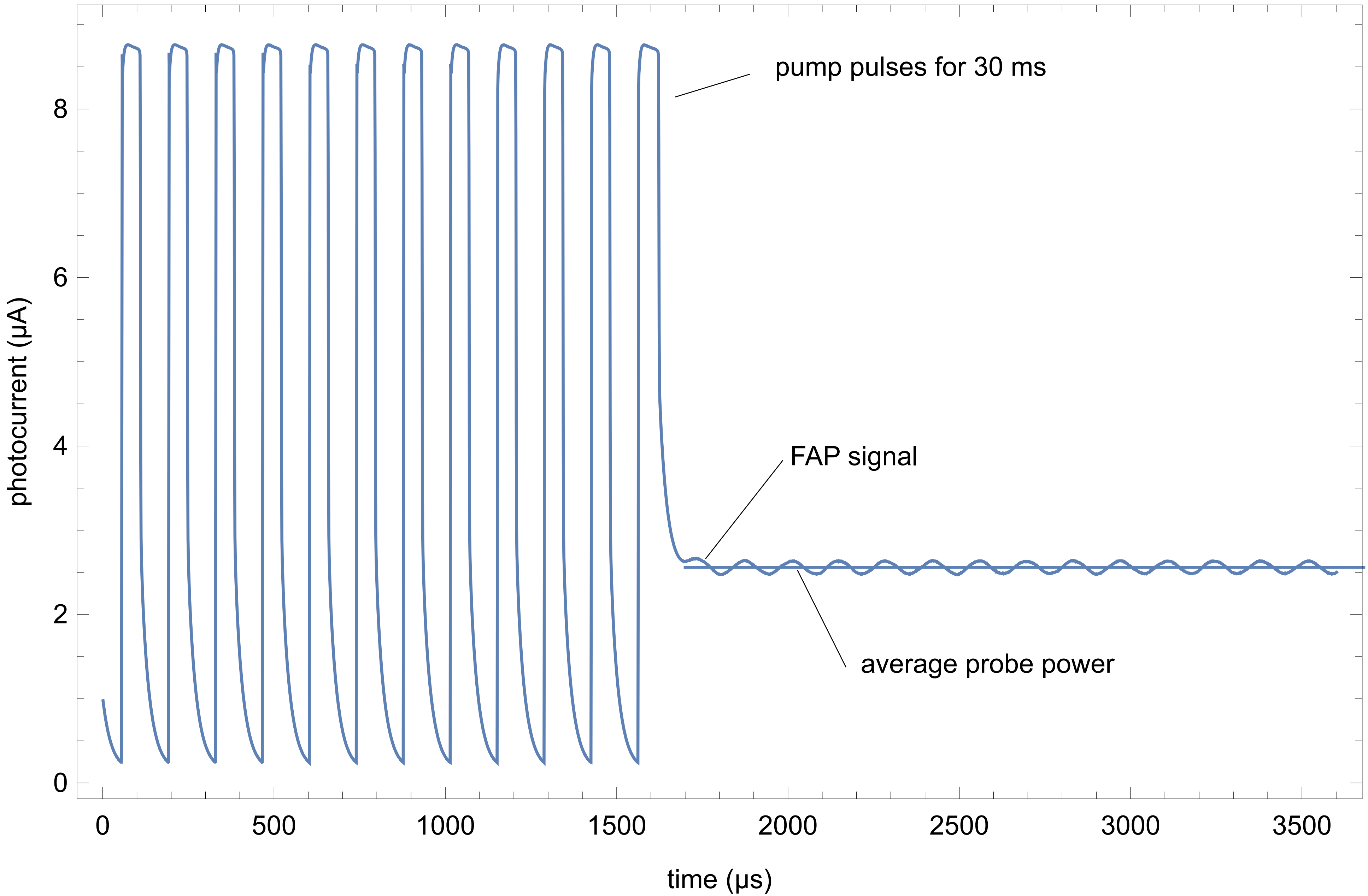
$$d_{\text{false}} = \frac{\hbar\,\gamma_{Hg}\,\gamma_n}{2c^2}\langle xB_x + yB_y\rangle$$

Pignol & Roccia, Phys. Rev. A 85, 042105 (2012)

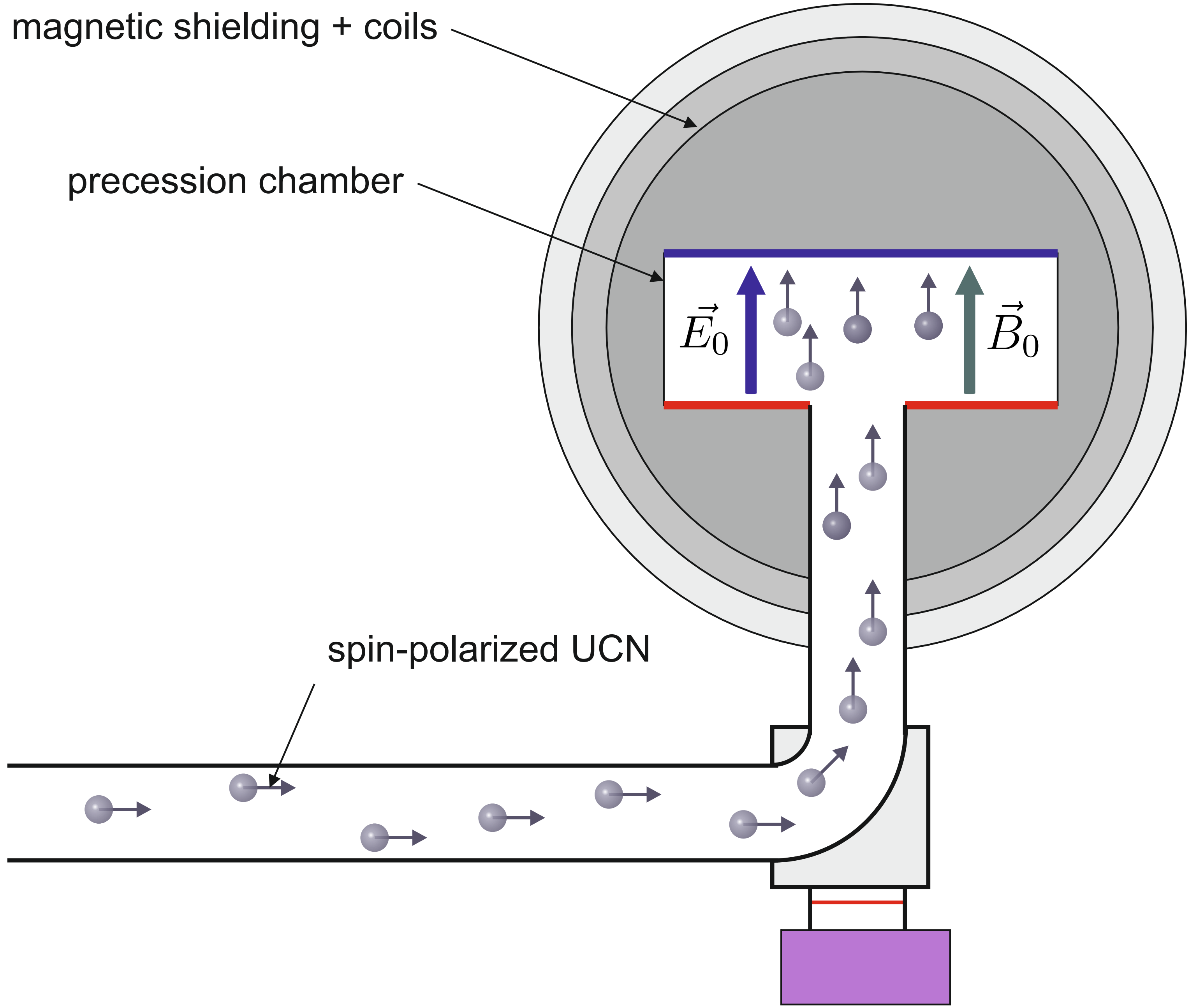
Detail: scalar Cs magnetometer



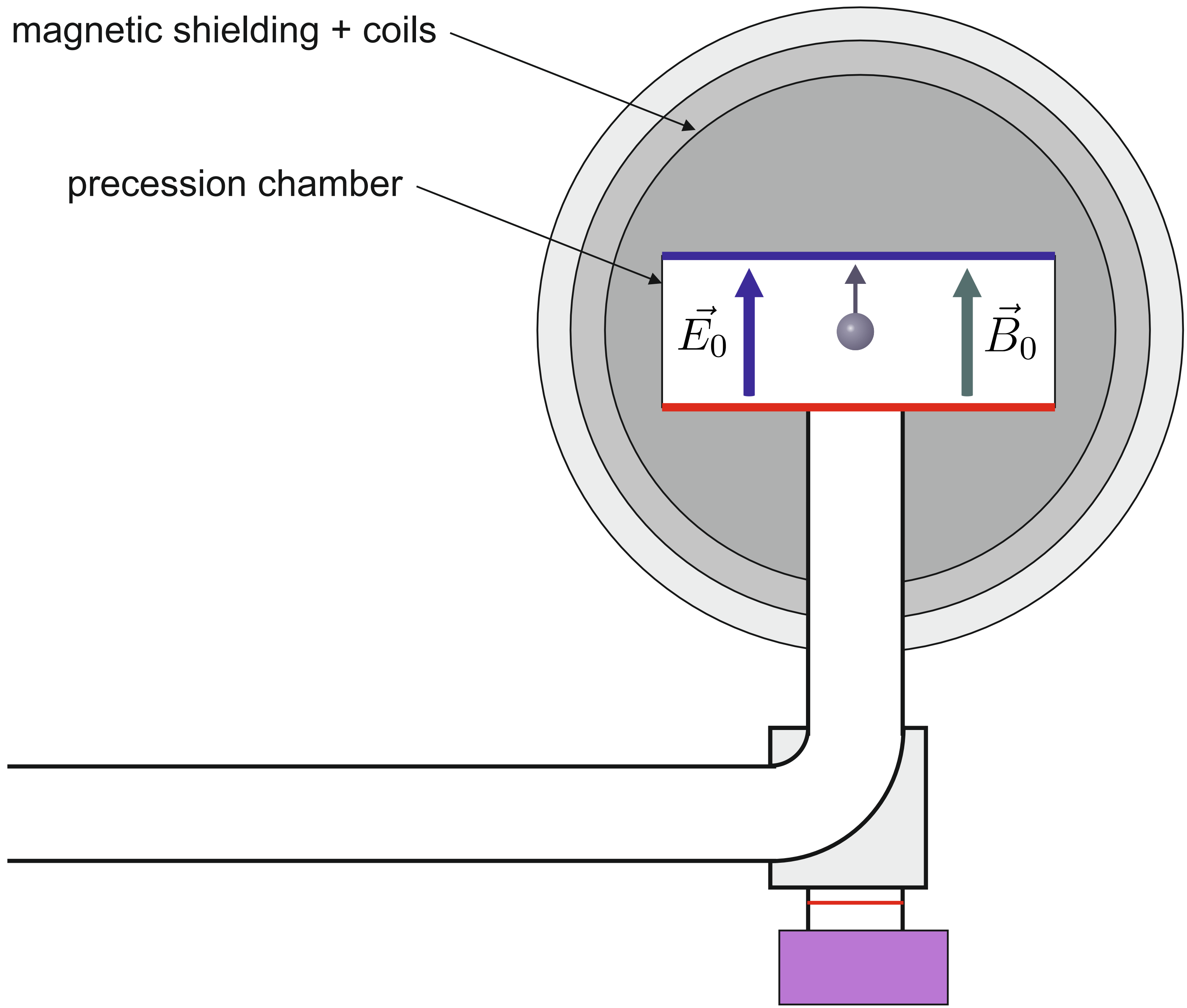
Detail: Free Alignment Precession (FAP)



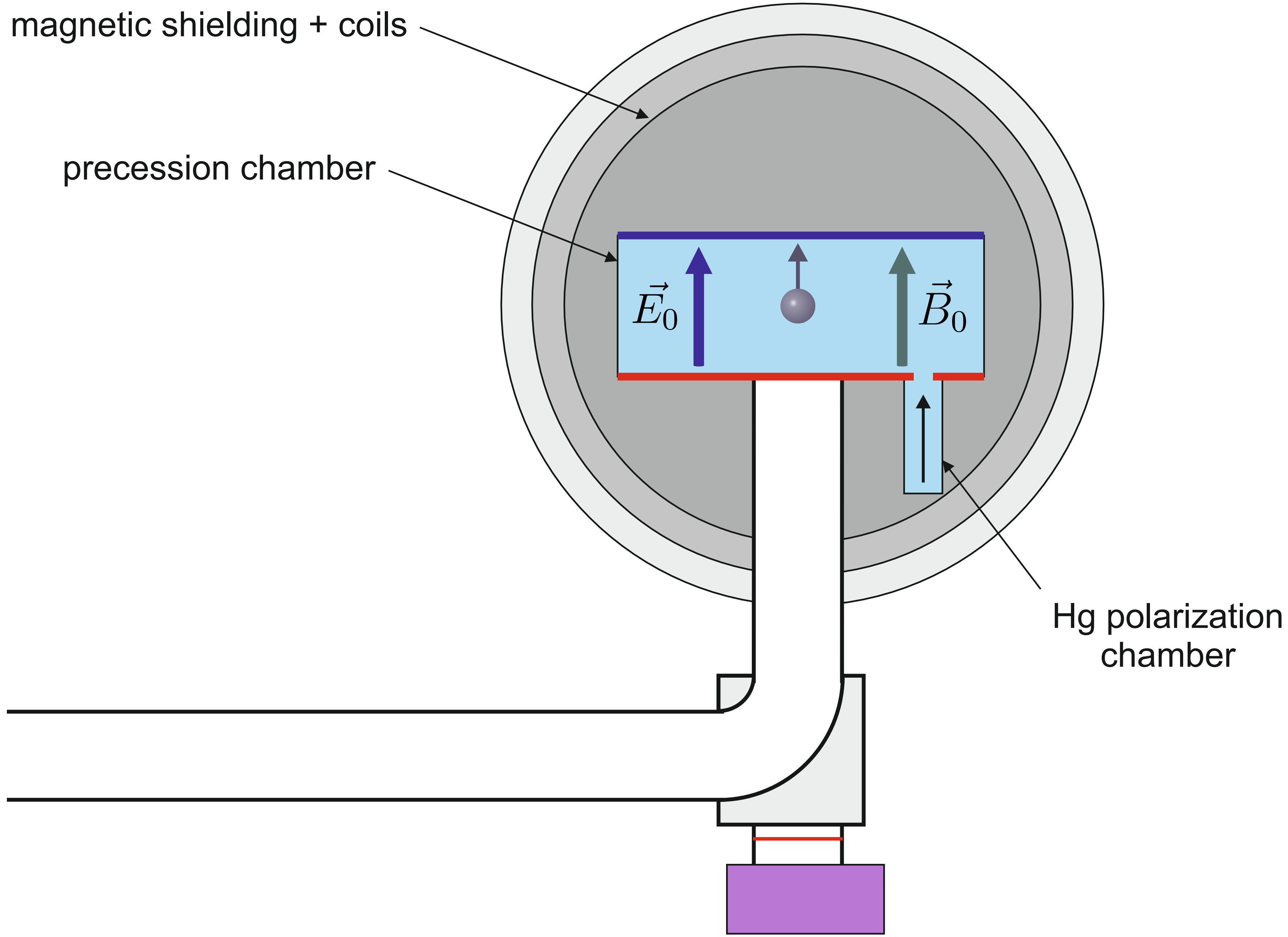
Filling the Precession Chamber



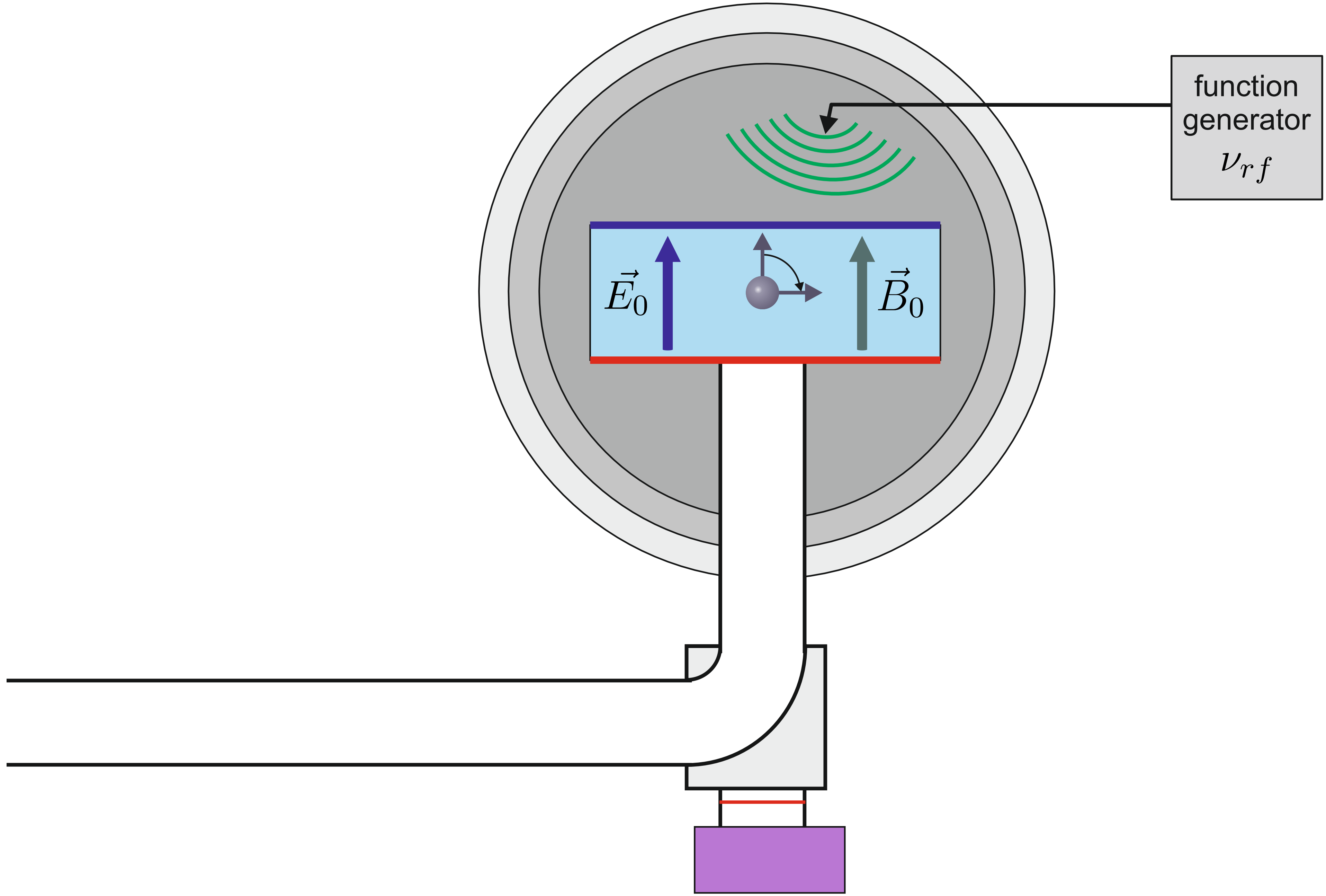
Filling the Precession Chamber



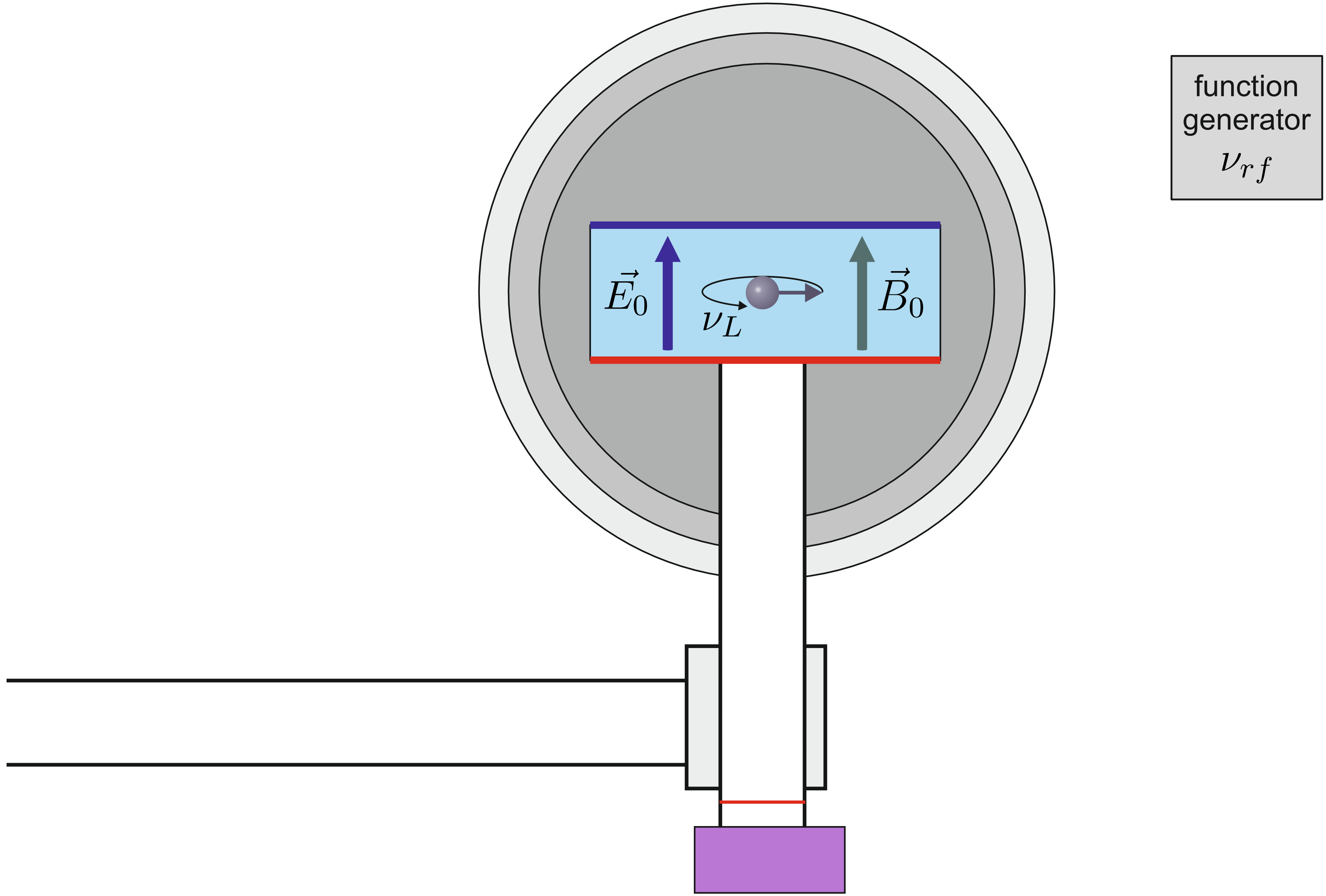
Filling the Precession Chamber



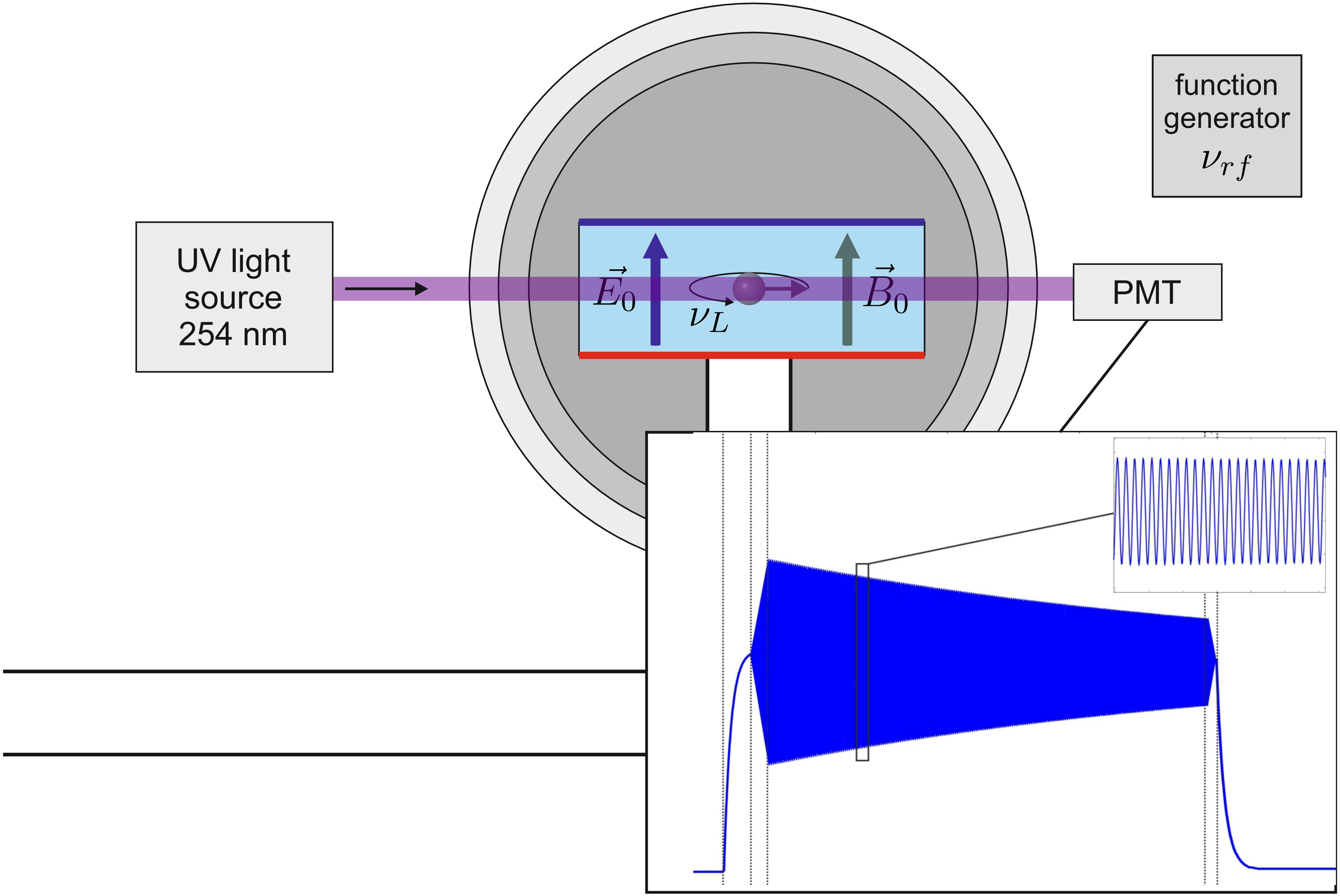
Ramsey Cycle



Ramsey Cycle

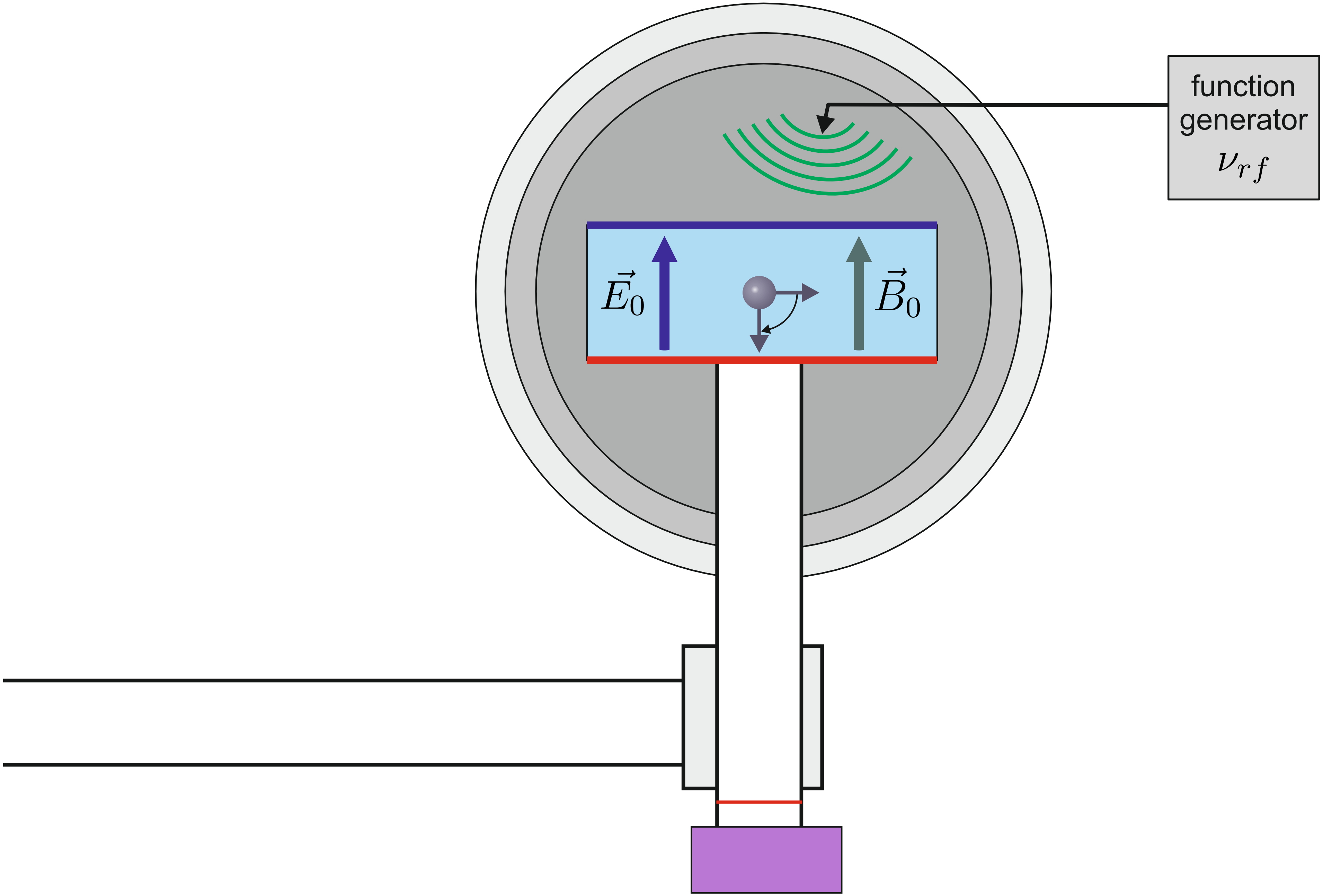


Hg readout

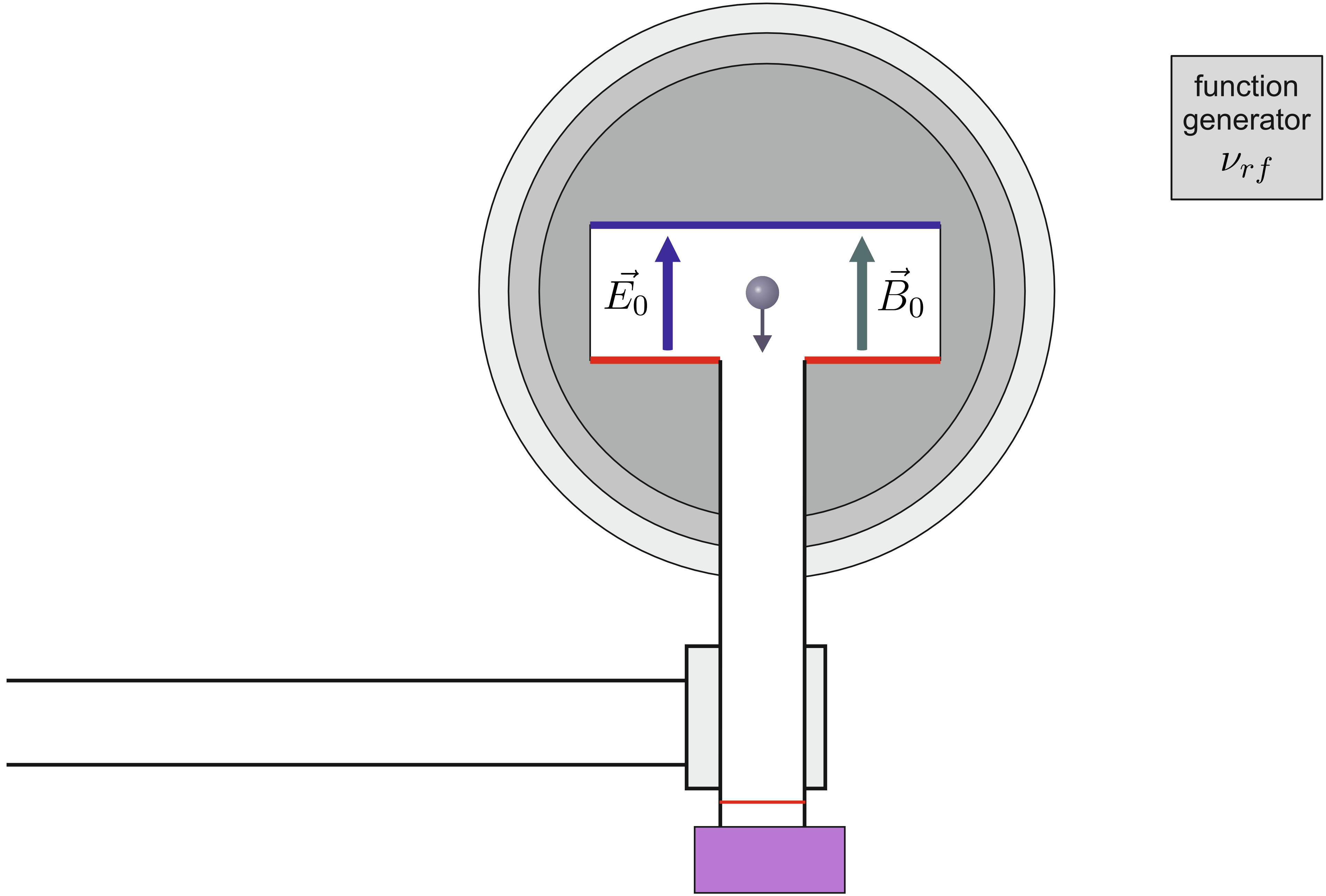


UV light
source
254 nm
$\vec{E}_0$
ν_L
$\vec{B}_0$
PMT
function
generator
ν_{rf}

Ramsey Cycle



Emptying the Precession Chamber



Neutron Detection