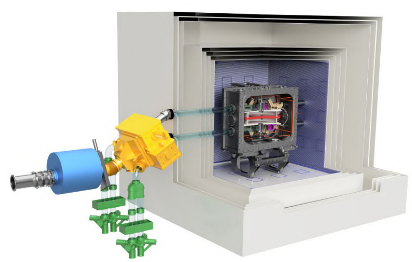


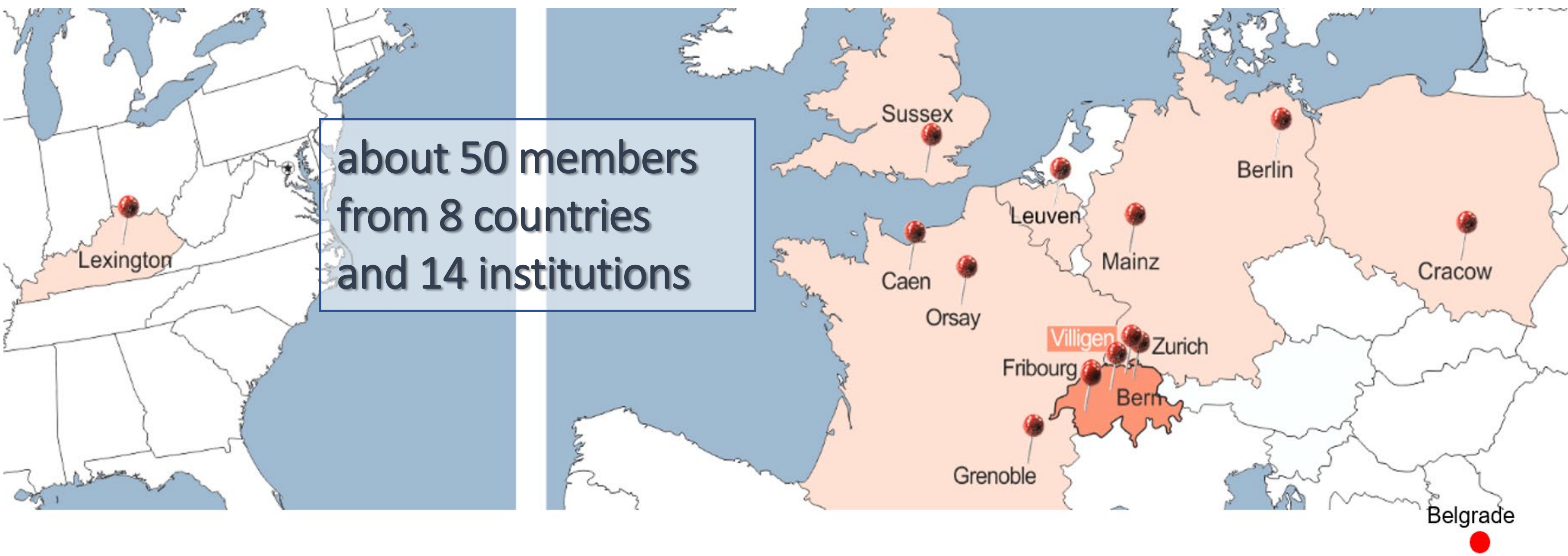
Design of the n2EDM experiment at PSI

Vira Bondar
ETH Zurich

on behalf of the nEDM-Collaboration

Int. Workshop on searches for a Neutron Electric Dipole Moment
15-19 February 2021, Les Houches School of Physics, France

The nEDM collaboration

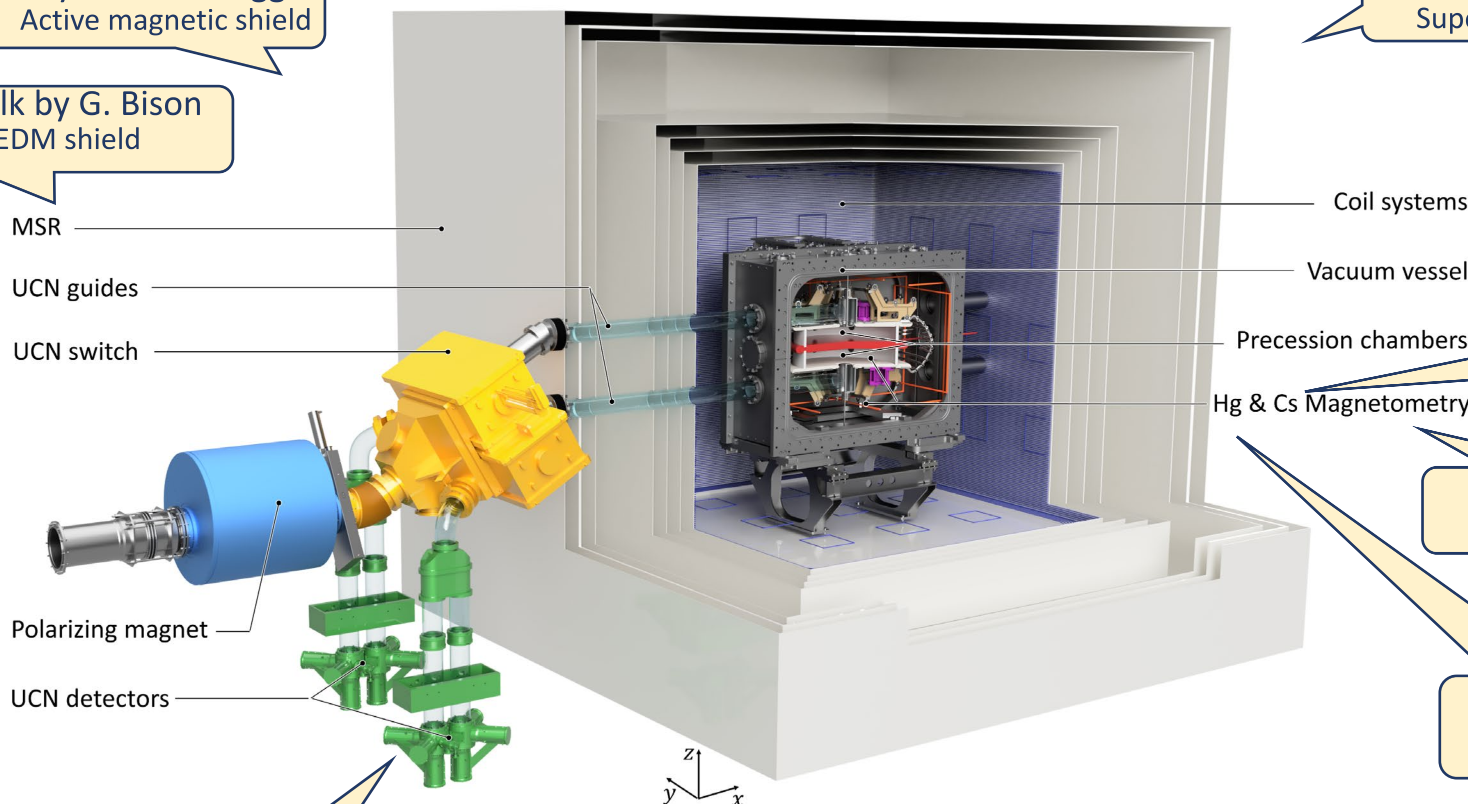


The n2EDM experiment

Talk by S. Emmenegger
Active magnetic shield

Talk by G. Bison
n2EDM shield

Talk by J. Krempel (D. Ries)
Supervisory control & DAQ



Talk by D. Pais
Cs magnetometry

Talk by K. Svirina
Magnetic-field mapping

Talk by S. Touati
Hg magnetometry

Talk by W. Saenz
UCN gaseous detector

Talk by G. Zsigmond
n2EDM simulations

Talk by T. Bouillad
Magic-field option

Talk by P.-J. Chiu
Johnson-Nyquist noise

n2EDM

Talk by I. Rienäcker

Paul Scherrer Institute

Outlines

- n2EDM measurement principle & setup
- Statistical sensitivity
- Main systematic effects
- Towards commissioning

On the way to n2EDM

nEDM

$d_n < 1.8 \times 10^{-26}$ e cm (90%C.L.)

C. Abel *et al.* Phys. Rev. Lett. 124 (2020) 081803

Talk by N. Ayres

Sensitivity improvements:

- Increase in statistics
- Better-controlled systematics

n2EDM

1×10^{-27} e cm

with perspectives of further improvement

N. Ayres *et al.*, submitted to EPJ C (2021)

https://arxiv.org/abs/2101.08730

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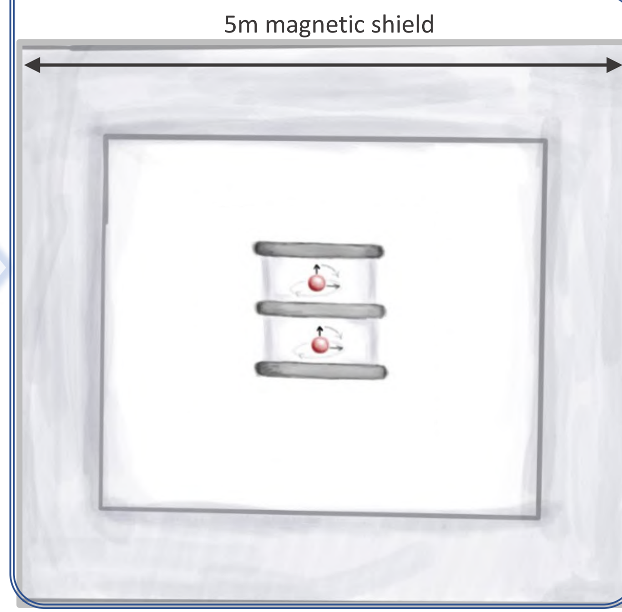
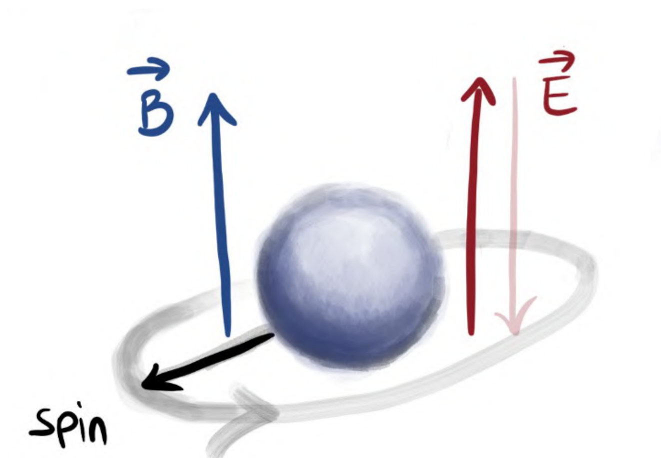
Merge of 2 concepts:
- Large double-chamber setup
- Dual magnetometry



Measuring nEDM

Measure frequency



Picture by I. Belosevic

$$2\pi f = \frac{2\mu}{\hbar}B \pm \frac{2d}{\hbar}|E|$$

$$f(\uparrow\uparrow) - f(\uparrow\downarrow) = -\frac{2}{\pi\hbar}d\,E$$

Control of magnetic field is essential!

Magnetic-field drifts?

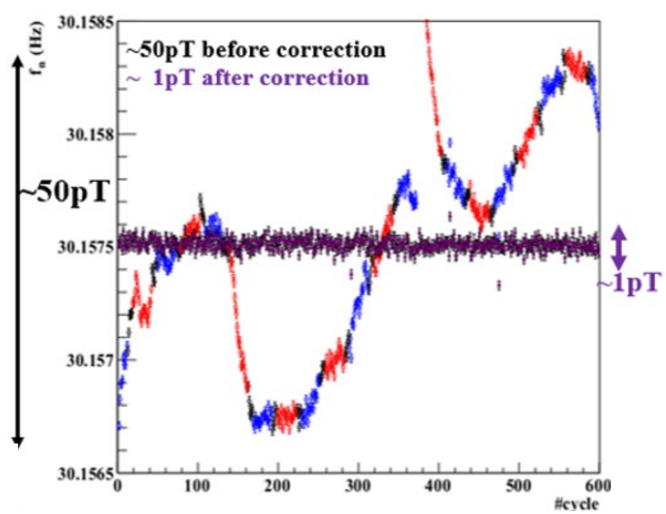
f **-> ratio R**

Mercury co-magnetometer

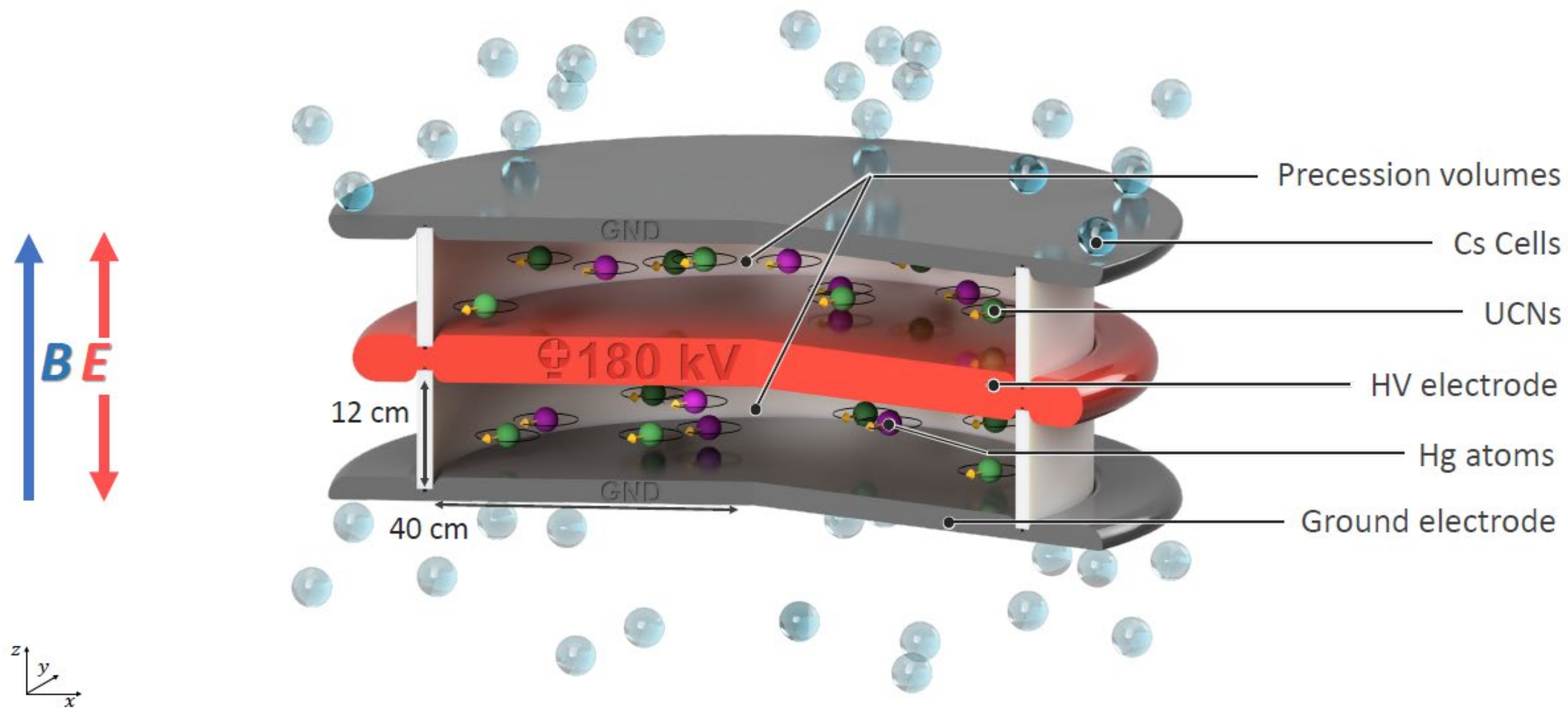
(volume-averaged field)

K. Green *et al.*, Nucl. Instr. Methods Phys. Res., Sect. A **404**, 381 (1998)

$$R = \frac{f_n}{f_{Hg}} = \frac{\gamma_n B_n}{\gamma_{Hg} B_{Hg}}$$



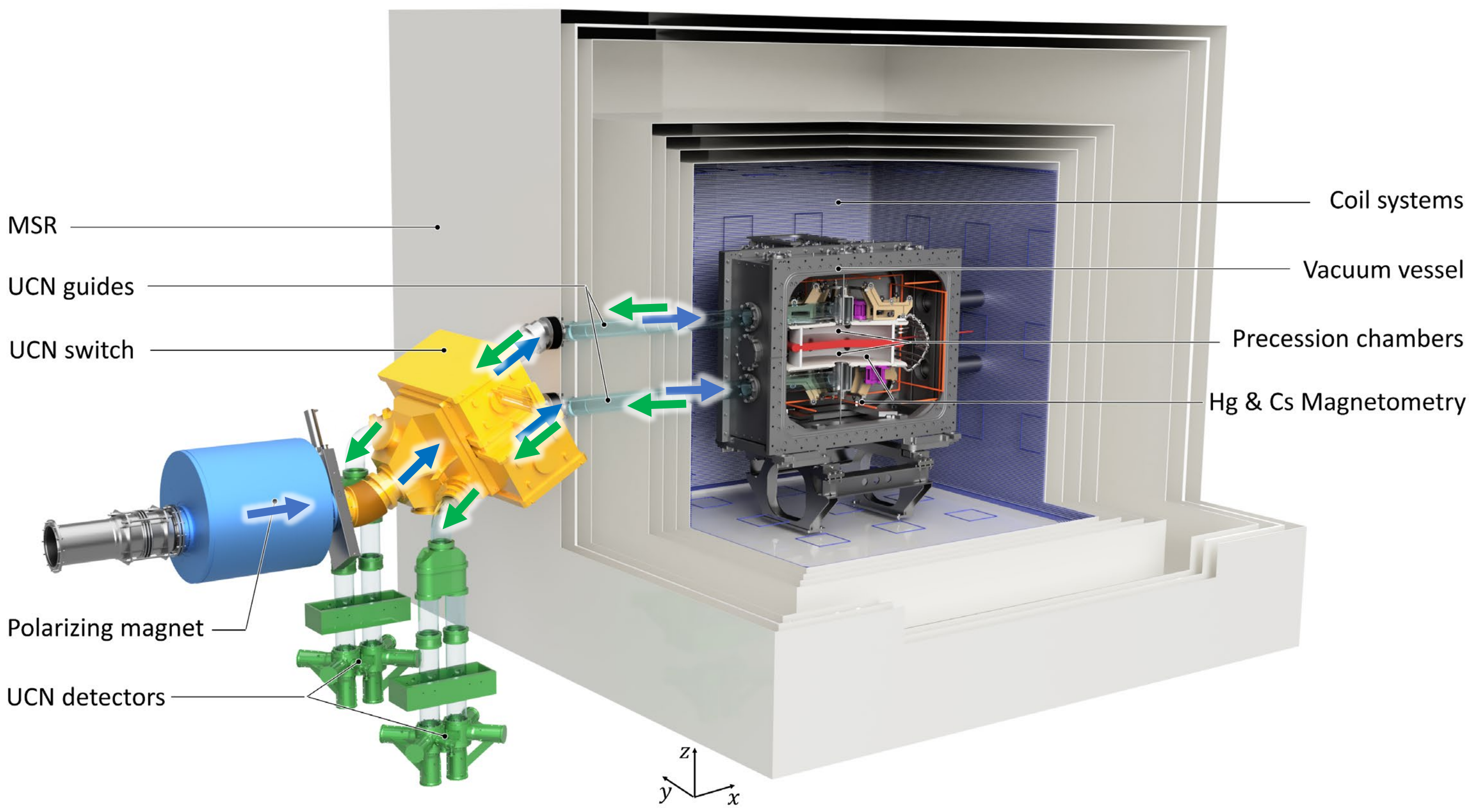
Double-chamber setup



$$d_{\mathrm{n}} = \frac{\pi \hbar f_{\mathrm{Hg}}}{2|E|}\left(\mathcal{R}_{\uparrow\downarrow} - \mathcal{R}_{\uparrow\uparrow}\right)$$

$$d_{\mathrm{n}} = \frac{\pi \hbar f_{\mathrm{Hg}}}{4|E|}\left(\mathcal{R}^{\mathrm{TOP}}_{\uparrow\downarrow} - \mathcal{R}^{\mathrm{TOP}}_{\uparrow\uparrow} + \mathcal{R}^{\mathrm{BOT}}_{\uparrow\downarrow} - \mathcal{R}^{\mathrm{BOT}}_{\uparrow\uparrow}\right)$$

The n2EDM setup

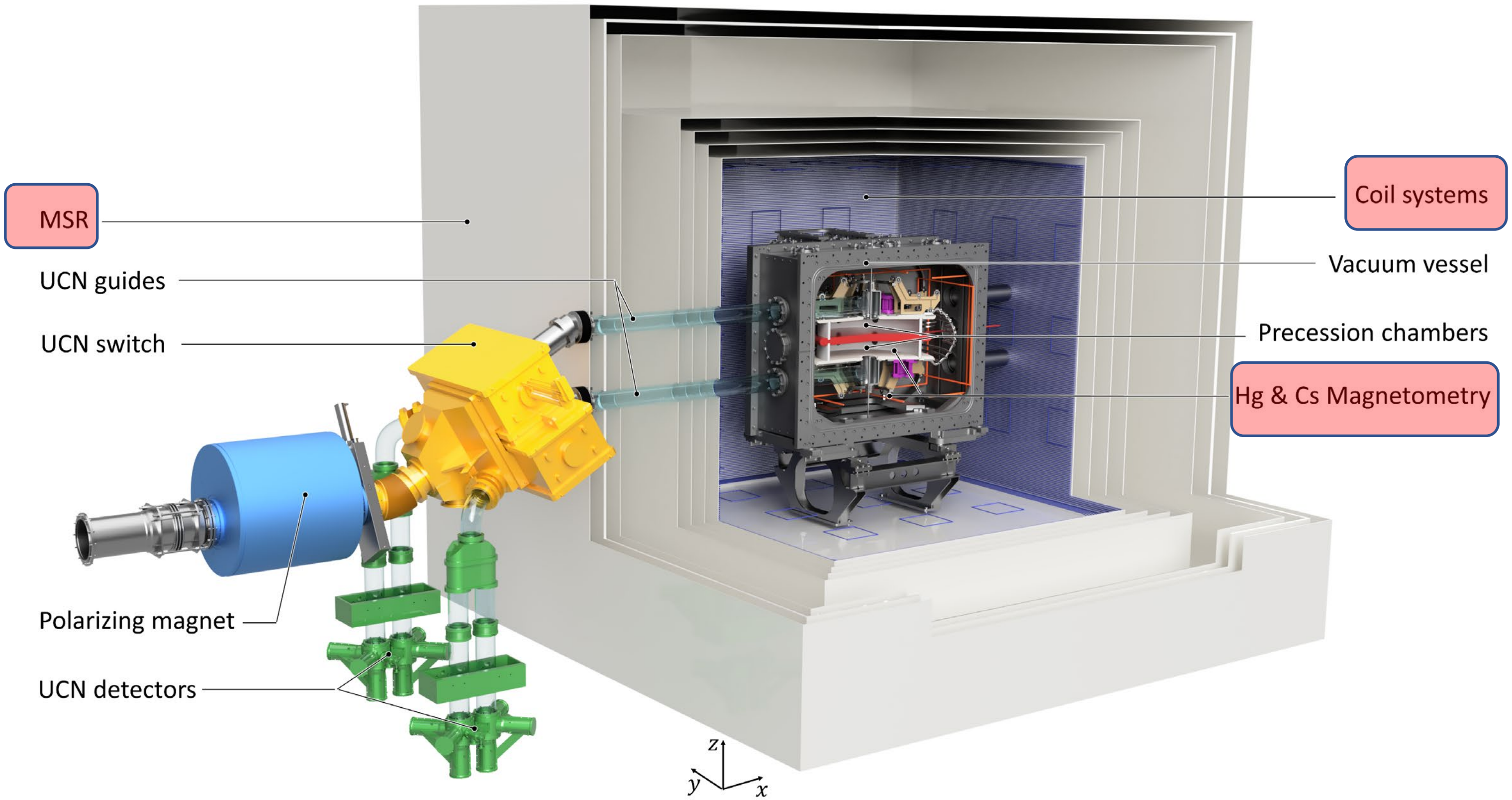


Procedure:

- Polarized UCNs fill the chambers
- Spin-precession in the chambers (Ramsey cycle)
- UCNs are guided towards detectors

Talk by W. Saenz

The n2EDM setup



Larger setup -> more challenges to provide and monitor magnetic field

- Magnetic-field shielding
- Magnetic-field generation
- Magnetic-field measurement

More details later;)

Statistical sensitivity

Sensitivity: $$\sigma(f) = \frac{\hbar}{2\alpha T E \sqrt{N}}$$

- α Visibility of resonance
- T Time of free precession
- N Number of neutrons
- E Electric field strength

Talk by G. Zsigmond
n2EDM simulations

	nEDM	n2EDM
chamber diameter D	DLC & dPS 47 cm	DLC & dPS 80 cm
N (per cycle)	15'000	121'000
T	180 s	180 s
E	11 kV/cm	15 kV/cm
α	0.75	0.8
$\sigma(f_n)$ per cycle	9.6 μHz	3.2 μHz
$\sigma(d_n)$ per day	11×10^{-26} e cm	2.6×10^{-26} e cm
$\sigma(d_n)$ (final)	9.5×10^{-27} e cm	1.1×10^{-27} e cm

Required magnetic-field conditions:
(over measurement cycle)

- Uniformity ~170pT
- Stability ~25fT

Systematics

Main source: Magnetic-field stability and homogeneity

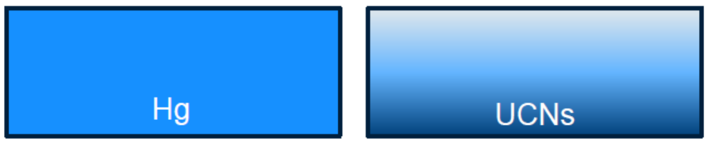
C. Abel *et al.*, Phys.Rev.A 99 (4) (2019) 042112
G. Pignol, Phys. Rev. Lett. B 793, 440 (2019)
C. Abel *et al.,* Phys.Rev. A 101 (5) (2020) 053419
C. Abel *et al.,* Mapping of the magnetic field to correct systematics, in preparation for Phys. Rev. A (2021)

Key contribution: **Mercury co-magnetometer**

UCN & Hg story…

Gravitational shift

- **Different density distribution**



$\overline{v_{\mathrm{Hg}}} \approx 160$ m/s vs. $\overline{v_{\mathrm{UCN}}} \approx$ 4m/s

-> Center-of-mass offset $\langle z \rangle$

- **Frequency shift:**

$$\delta_{\mathrm{grav}}^{\mathrm{TOP}} = G_{1,0} \frac{\langle z \rangle_{\mathrm{TOP}}}{B_0}$$

$$\delta_{\mathrm{grav}}^{\mathrm{BOT}} = G_{1,0} \frac{\langle z \rangle_{\mathrm{BOT}}}{B_0}$$

$$\langle z \rangle_{TOP} = 0.9mm$$

$$\langle z \rangle_{BOT} = 1.2mm$$

- **False EDM:**

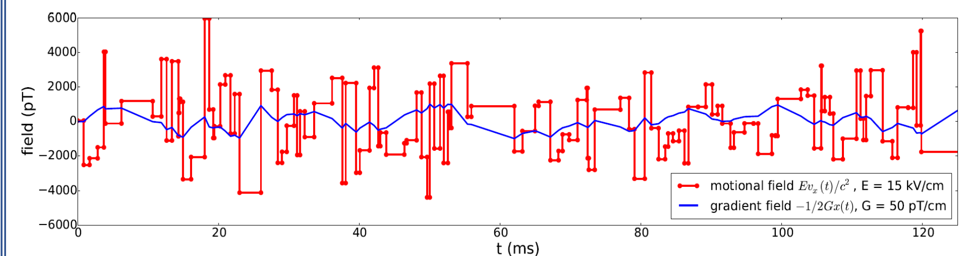
$$\delta d_{\mathrm{n}} = \frac{\hbar \gamma_{\mathrm{n}}}{4E} (\langle z \rangle_{\mathrm{BOT}} - \langle z \rangle_{\mathrm{TOP}}) \delta G(V)$$

False EDM due to "vxE" effect

Leading systematics

$$\mathbf{B}_m = \mathbf{E} \times \mathbf{v} / c^2$$

Interplay between motional magnetic field and magnetic-field gradients



$$d_{n \leftarrow \mathrm{Hg}}^{\mathrm{false}} = -\frac{\hbar |\gamma_n \gamma_{\mathrm{Hg}}|}{2c^2} \langle x B_x + y B_y \rangle$$

$$d_{n \leftarrow \mathrm{Hg}}^{\mathrm{false}} = \frac{G_{1,0}}{1\,\mathrm{pT/cm}} \times 1.28 \times 10^{-26}\ e\ \mathrm{cm}$$

Talk by T. Bouillad

Control of gradients is important!

We expect to control systematics on the level of $\sim 5 \times 10^{-28}$

Magnetic-field requirements

- Magnetic-field shielding
- Magnetic-field generation
- Magnetic-field measurement

(over measurement cycle)

Related to statistical errors

Uniformity < 170pT

Stability < 25fT

Related to systematical errors

Co-magnetometer accuracy < 100fT

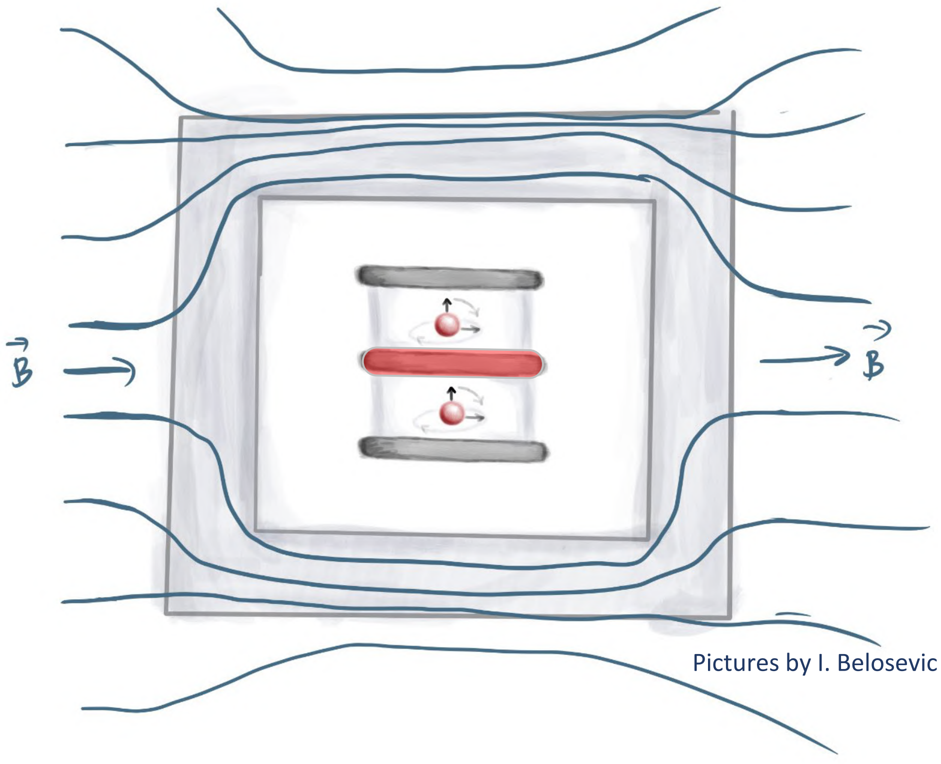
Accuracy of the degree 3 mode: δG_3 < 20fT/cm

Accuracy of the degree 5 mode: δG_5 < 20fT/cm

Dipoles close to electrode < 20pT at 5cm

So how to fulfill these requirements in practice?

Magnetic shielding



Pictures by I. Belosevic

Magnetic shielding: passive & active

Talk by G. Bison

Talk by S. Emmenegger

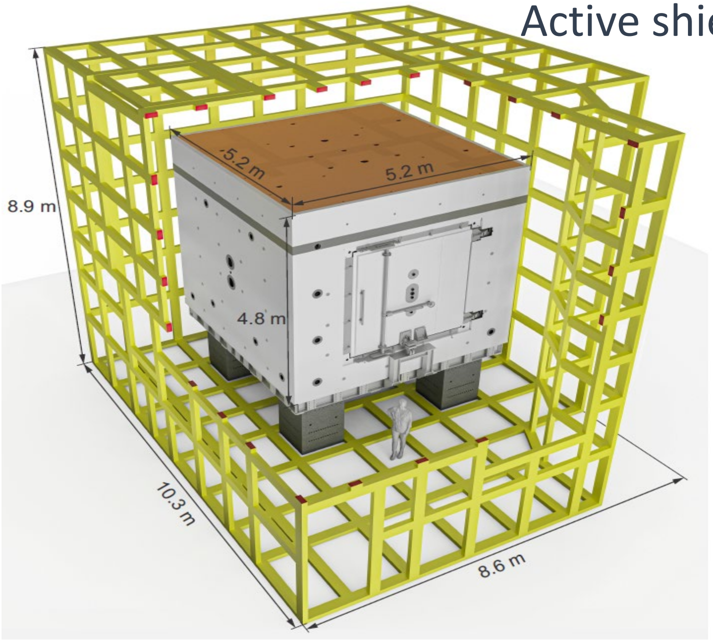
Magnetically-shielded room (MSR)

Passive shielding

- 6 mu-metal layers
- Inner dimensions 2.93m x 2.93m x 2.93m
- Quasi-static shielding factor 100’000
- Residual fields < 150 pT (in central volume)

AMS

Active shielding

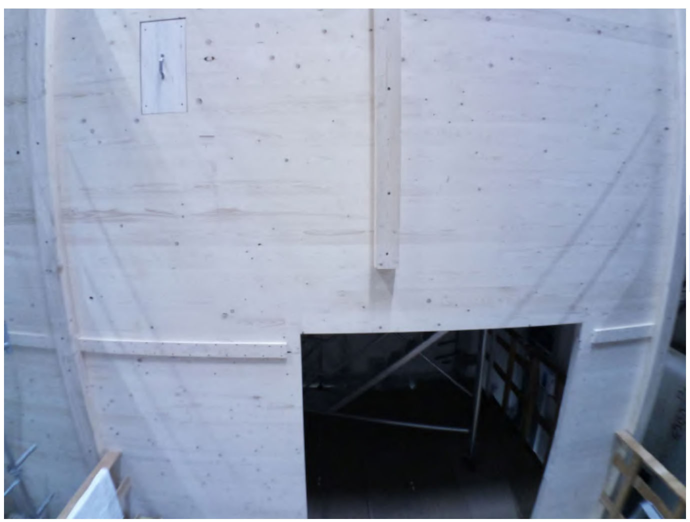


M. Rawlik *et al.*, Am. J. Physics 86(8), 602 (2018)

- 8 actively-controlled coils
- Spanning a volume of ~1000m^3
- Compensates field disturbances from outside
- Stable and uniform magnetic field around MSR

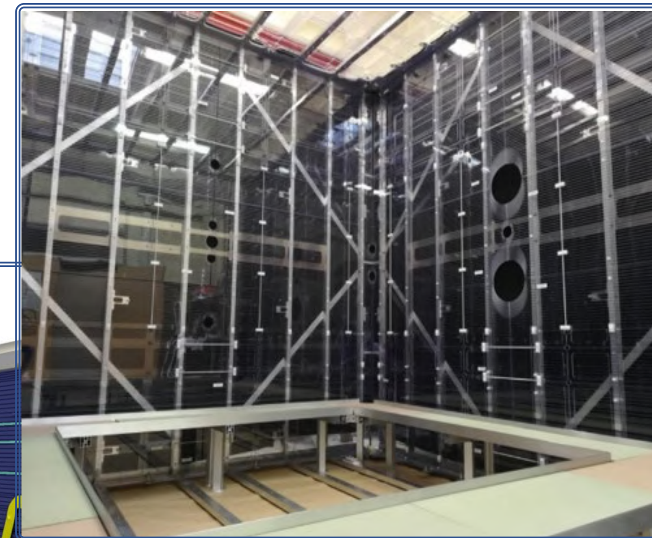
Thermohouse

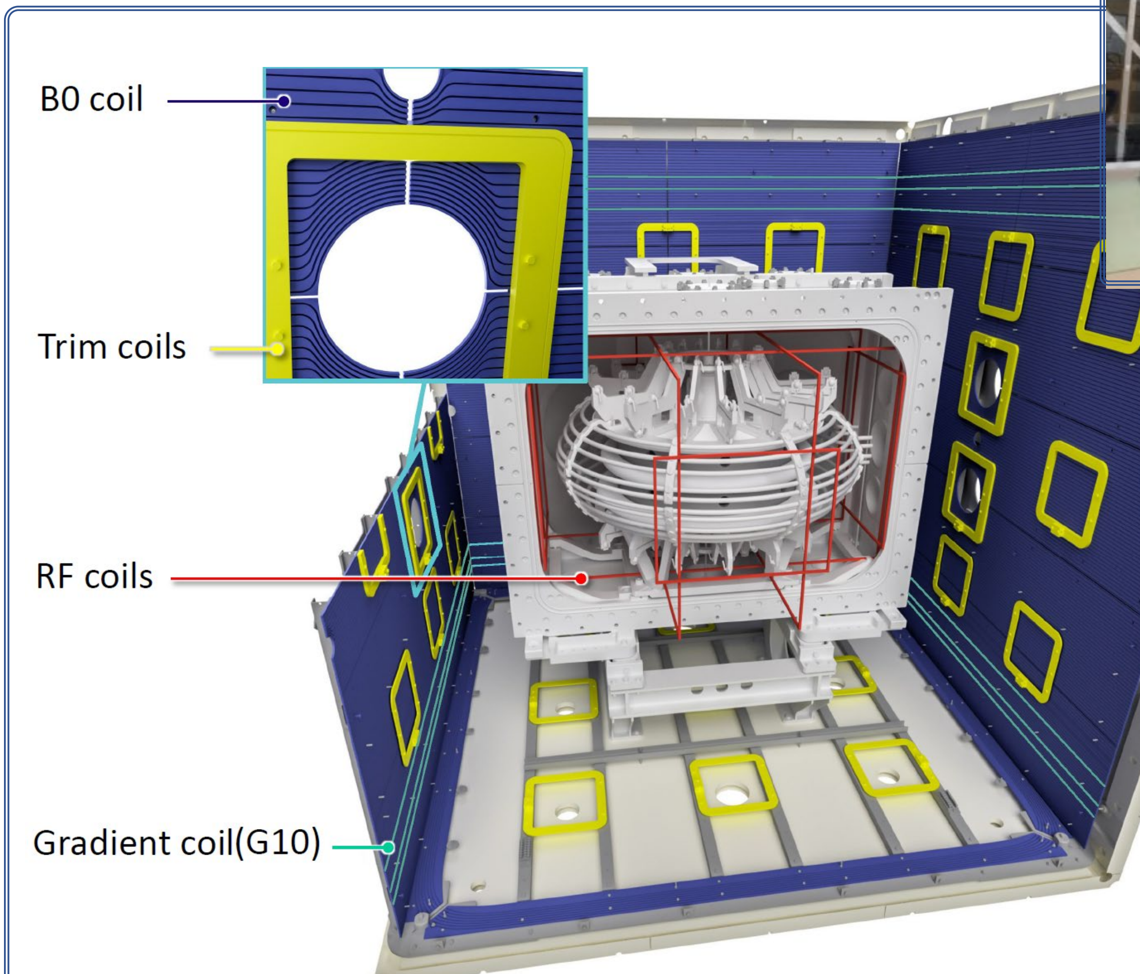
Thermohouse



Magnetic-field generation: coil systems

- Produce a very uniform B0 field (1µT)
- Produce specific gradients
- Hold the UCN polarisation
- Neutron spin manipulation





Talk by C. Crawford

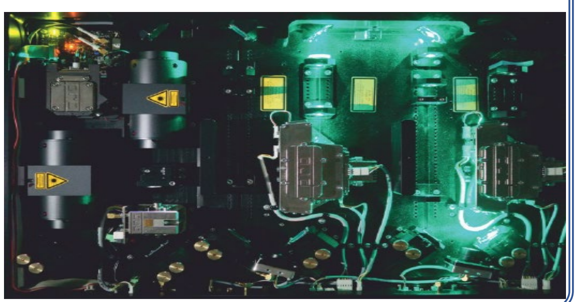
Magnetic-field measurement

Talk by S. Touati

Hg magnetometry

Polarized Hg atoms
(laser readout)

Function:
-Correction field drifts
-Compensation of systematics related to first-order gradients

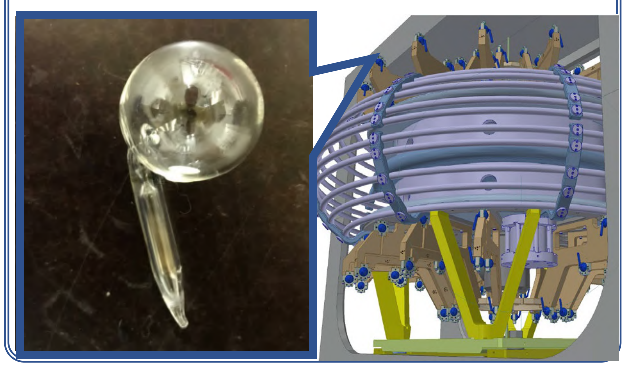


Talk by D. Pais

Cs magnetometry

Array of 112 Cs sensors

Function:
Instantaneous measurement of magnetic-field uniformity

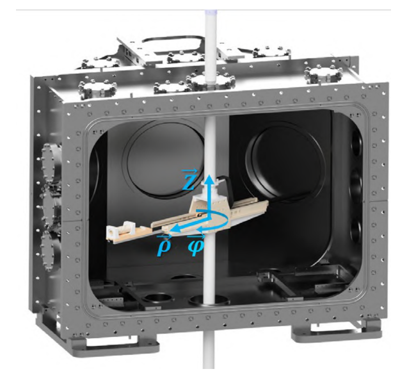


Talk by K. Svirina

Mapping

Based on fluxgate sensor

Function (Offline):
-Coil's cartography
-Control high-order gradients



G. Ban *et al.,* Nucl. Instrum. Methods A 896, 129 (2018)
C. Abel *et al.,* Phys.Rev. A 101 (5) (2020) 053419
C. Abel *et al.,* Mapping of the magnetic field to correct systematics, in preparation for Phys. Rev. A (2021)

Towards commissioning

- MSR with record performance is commissioned
- AMS installation ongoing

Next:

Installation of coil system (ready)
Vacuum tank (ready)
Precession chambers

- 2022 Commissioning of full apparatus and start data taking