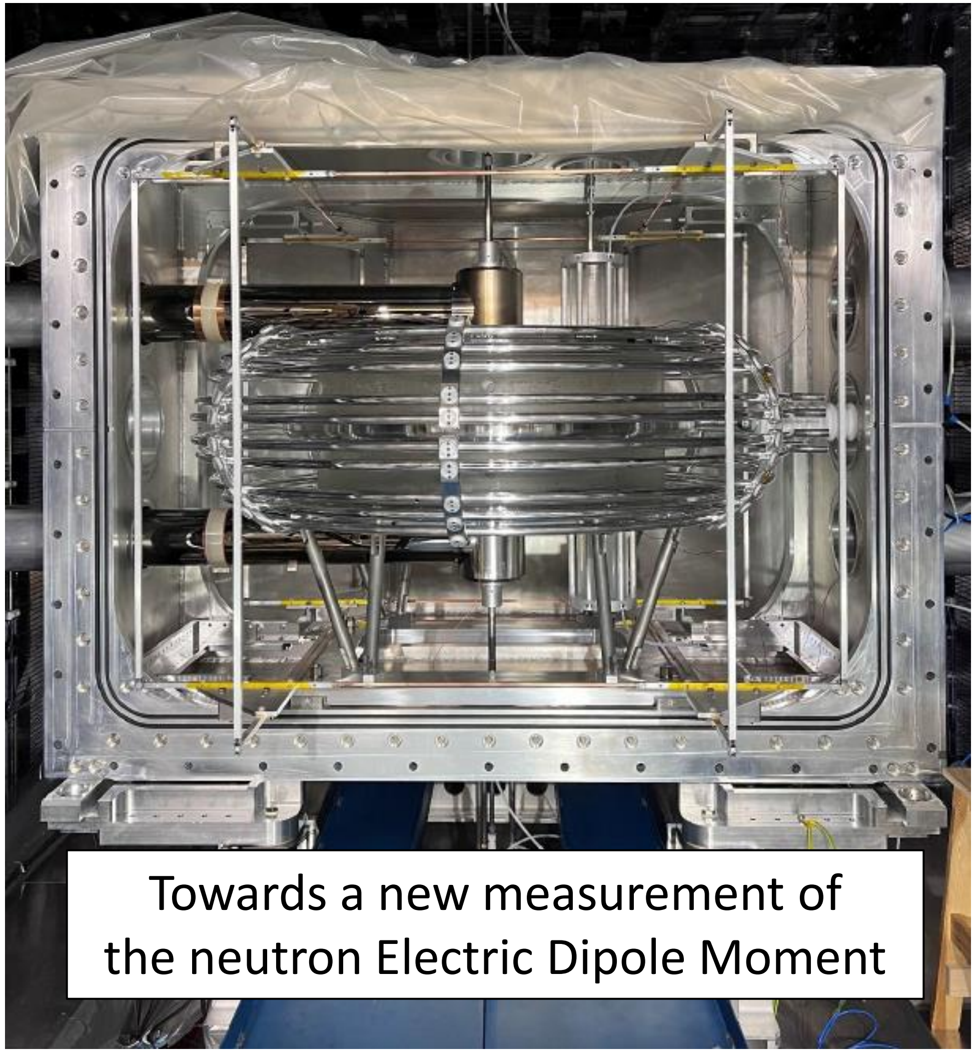
Status of the n2EDM experiment (2024)



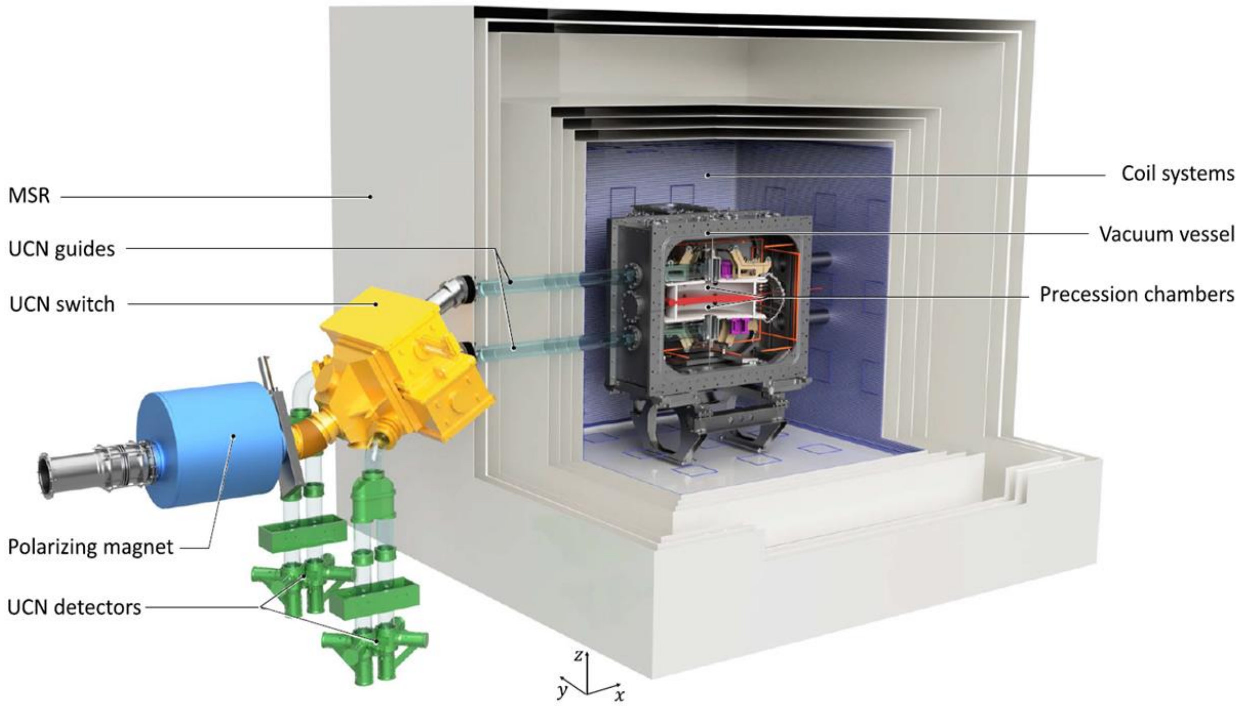
Thomas Lefort on behalf of the nEDM collaboration

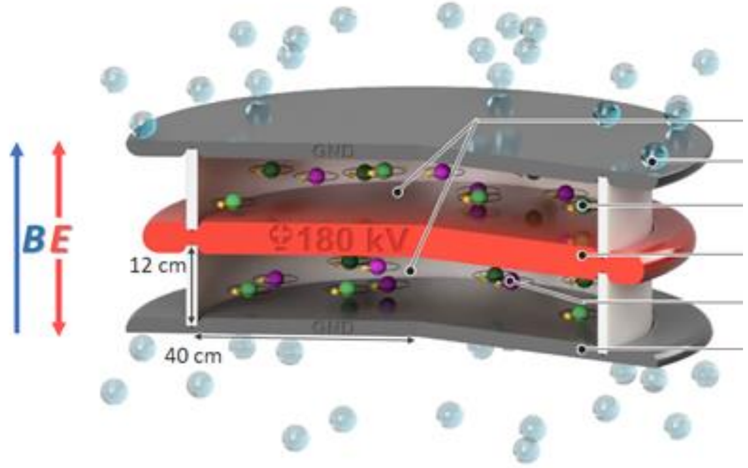
The n2EDM experiment design

From the measurement of two frequencies (parallel and antiparallel fields configurations)

$$d_n = \frac{\pi\hbar}{2|E|}(f_{n,\uparrow\downarrow} - f_{n,\uparrow\uparrow})$$

→ Ramsey's method: required polarized neutrons





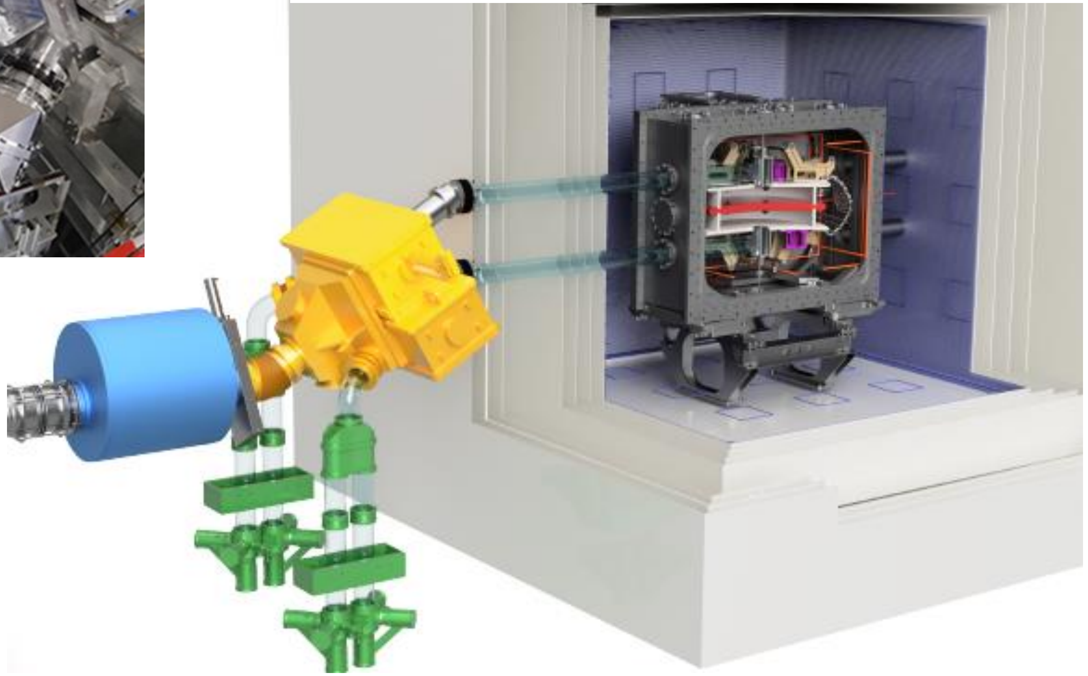
Storage chambers where neutron frequency measurement is performed

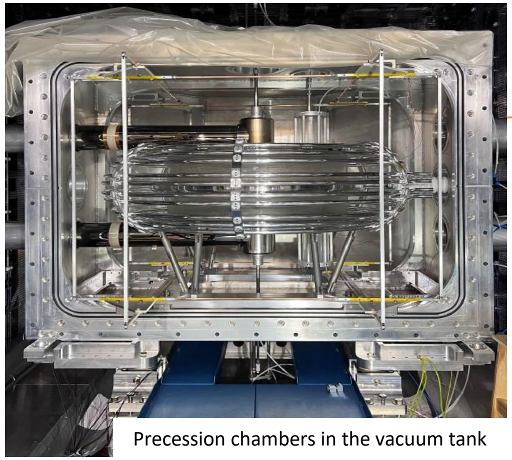
Two main challenges
neutron statistic & magnetic field uniformity and stability

2023: short reminder

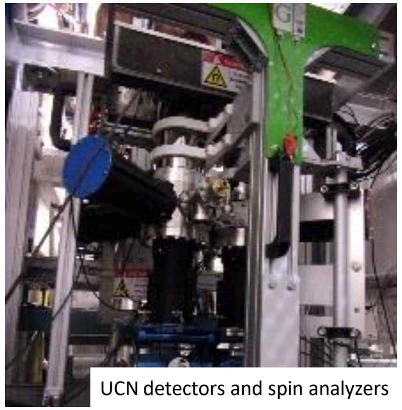
- First UCN in the fully assembled apparatus
- Neutron frequency measured (Ramsey's method)

Switch box





Precession chambers in the vacuum tank



UCN detectors and spin analyzers

Internal coils system

UCN statistic: 10,000 per chamber (factor 6 below design goal)

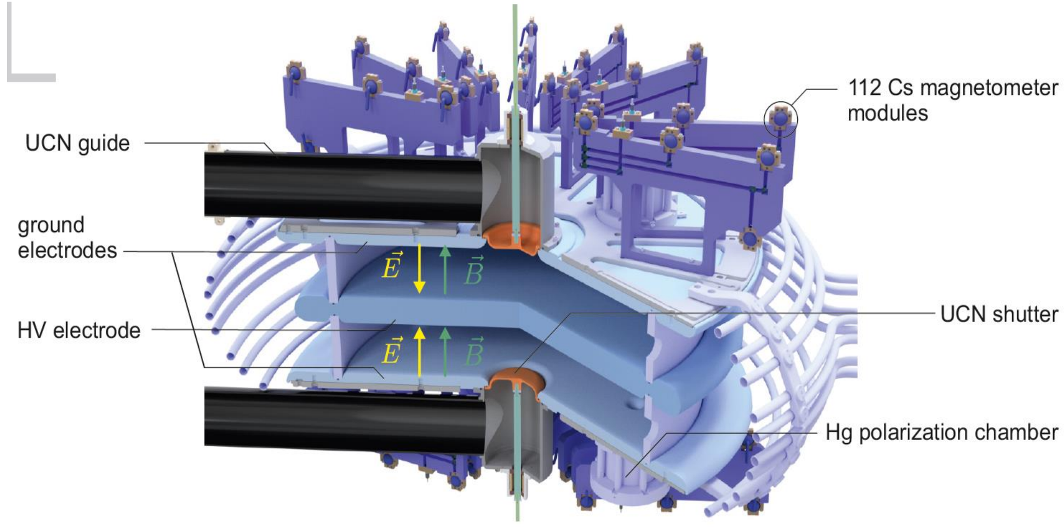
Missing crucial subsystems:

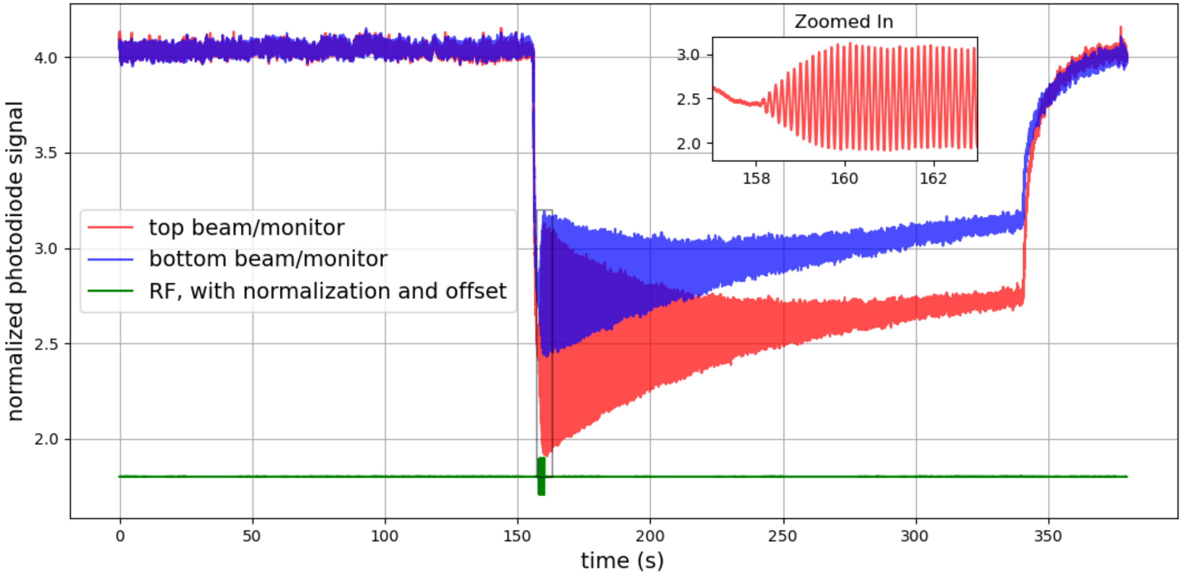
- Magnetometry (Hg, Cs): still under development
- HV: bipolar power supply failed (no electric field) !

2024 goal: first nEDM measurement

2024 achievements: Hg co-magnetometer

Online monitoring of the magnetic field drift in the chambers: mandatory for nEDM measurement ($R = f_n/f_{Hg}$)

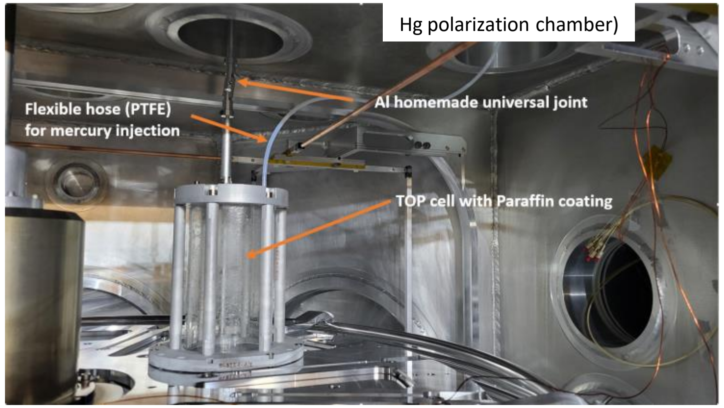




Hg co-magnetomer operational over weeks:

T_2 (TOP) = 50 s ; T_2 (BOT) = 80 s

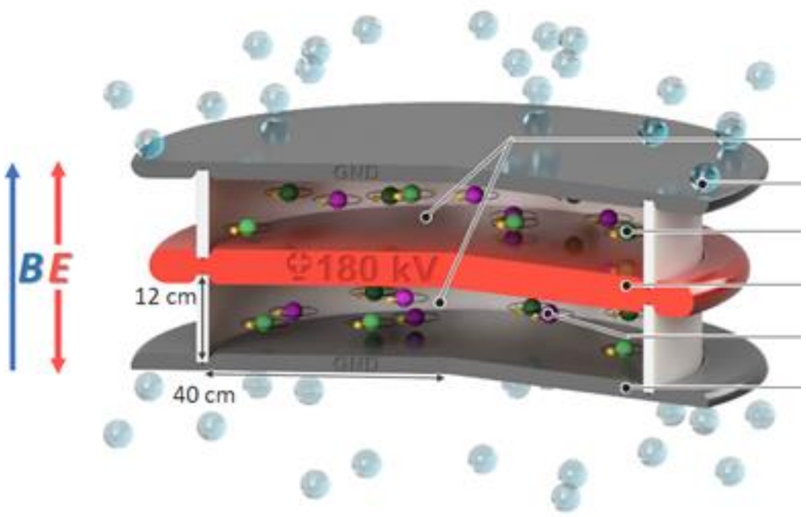
Performance still be improved but nearly at the design goal sensitivity (factor ~ 4 missing)



Operational for nEDM measurement (but sensitivity to improve)

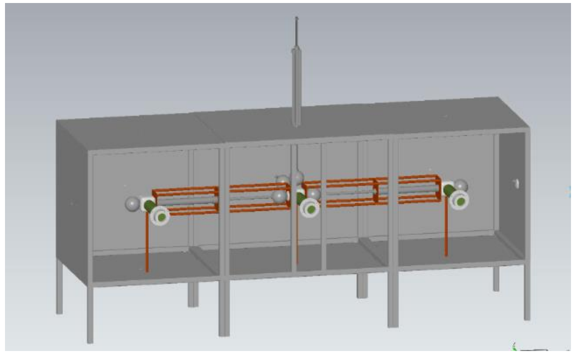
2024 achievements: high voltage

Electric field generation: mandatory for nEDM measurement



Bipolar power supply replaced by two unipolar supplies (300 kV)
Full setup tested for the first time in 2024

Performance:
Stable (sparkless) operation at 150 kV (E= 12.5 kV/cm) : ready for data taking !
Up to 180 kV (design goal) but sparkling (conditioning procedure to improve)



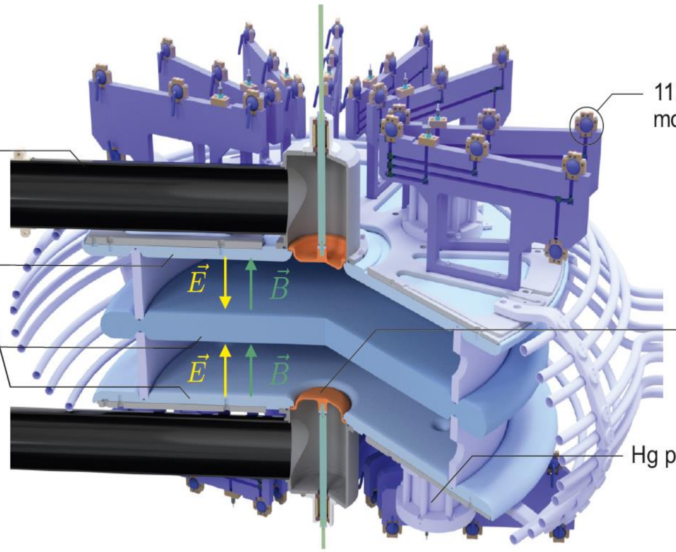
Polarity switcher needed: development started in 2024
Commissioning during 2025 shutdown

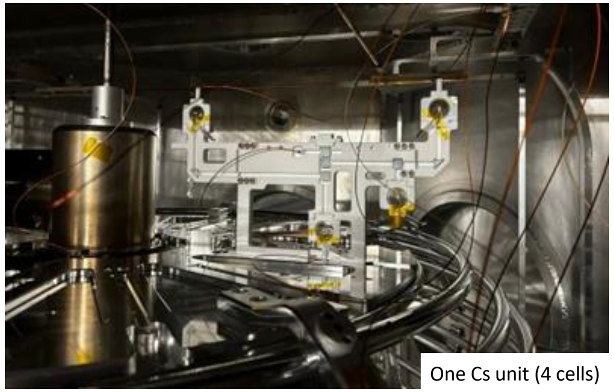
Goal: remote control of polarity changes (switcher) ready before restart of data taking

2024 achievements: Cs magnetometers

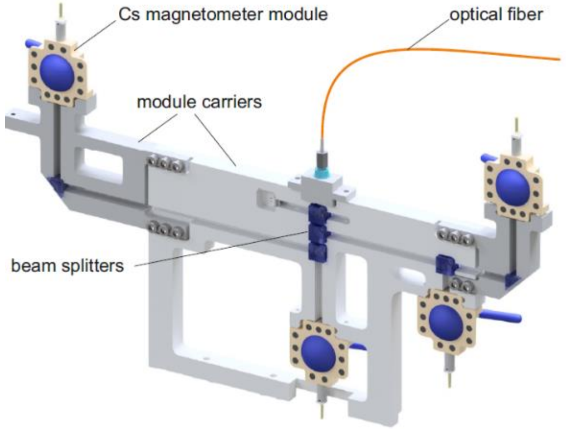
Online monitoring of field non uniformities (G_{30}): systematic assessment

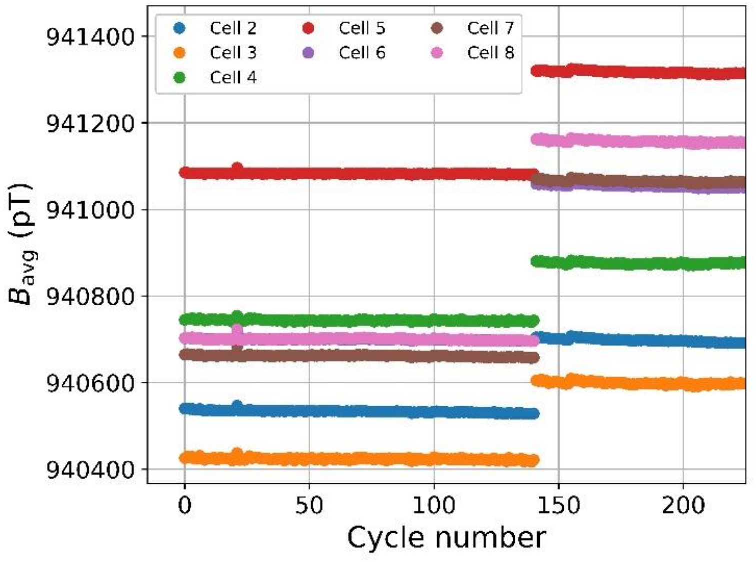
Two Cs units installed in 2024: steady operation over weeks





One Cs unit (4 cells)



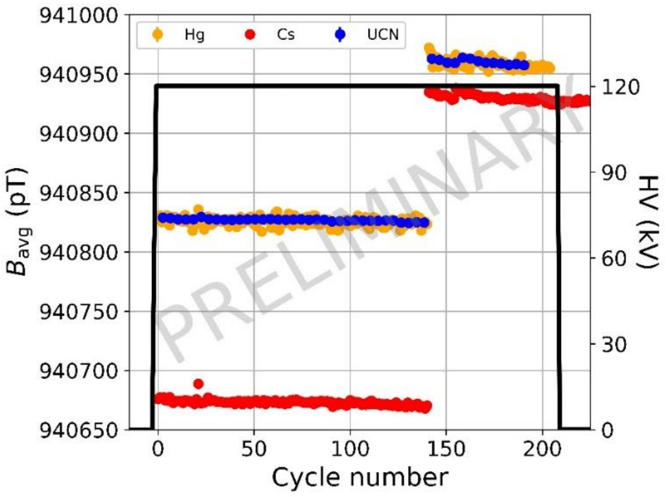


Cs magnetometry planning:

2025: half of Cs setup installed (56 cells) before data taking
2026: full Cs setup installed (112 cells)

First test-EDM run

Four systems (UCN + Hg + Cs + HV) simultaneously operating: → test-EDM run can be performed (~1 day)

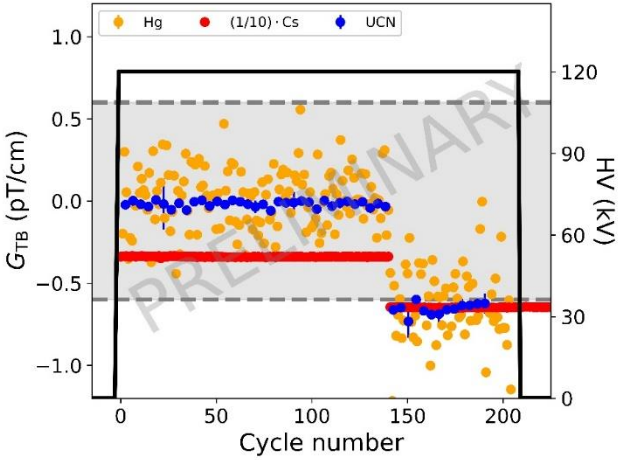


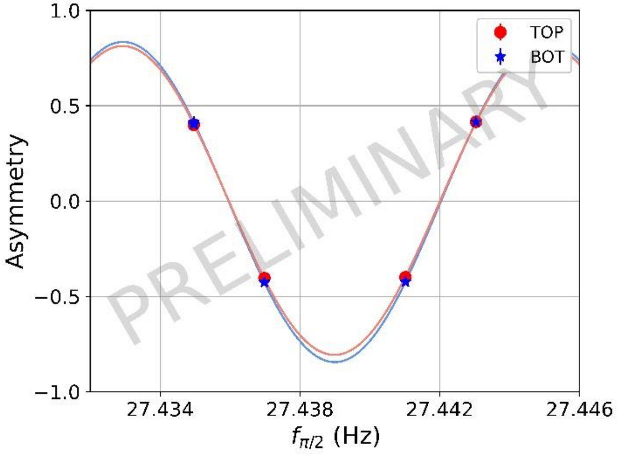
Average magnetic field sampled by neutron, Hg and Cs over a run (~ 1 day):

- high stability observed by the three magnetometers
- neutron in agreement with Hg
- Cs offset due to incomplete array (under investigations)

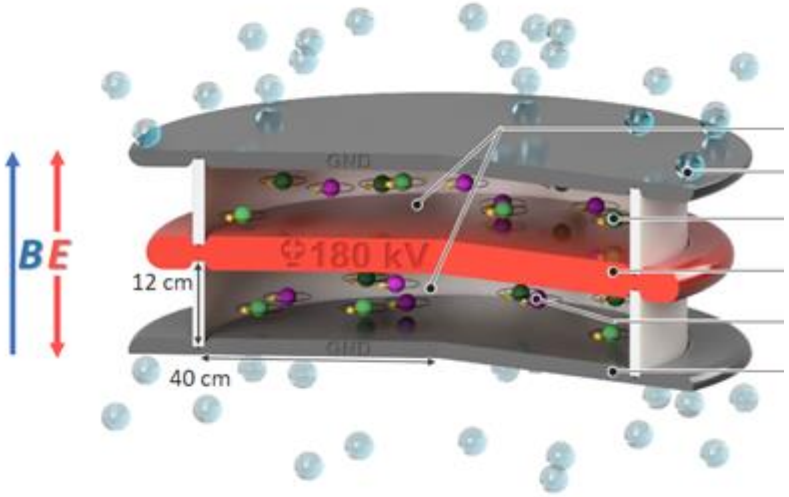
Vertical gradient (G_{TB}): < 0.6 pT/cm (within specifications)

- similar field in both chambers: common RF pulse can be applied





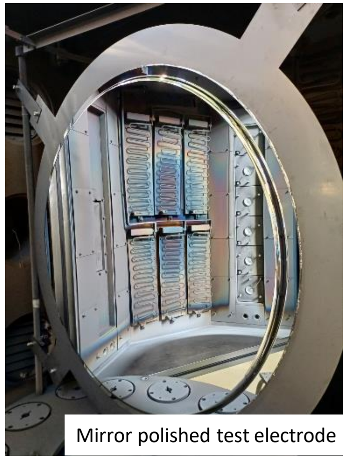
UCN statistic (2024)

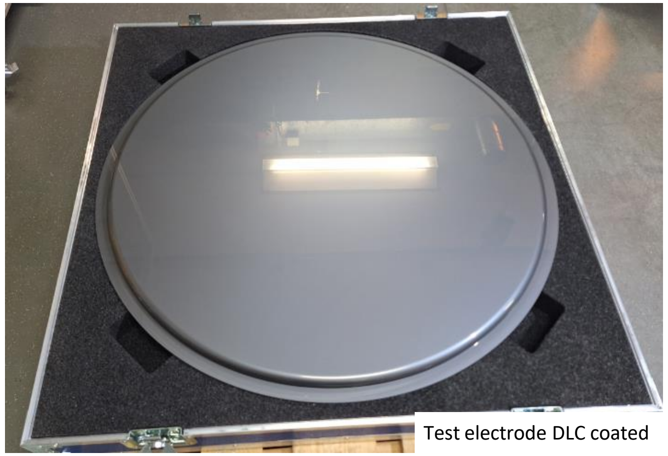


Lot of efforts to improve our storage capability:

- Two culprits (2023): coatings of electrodes (DLC) & insulator ring (DPS)


New insulator ring (quartz)


Mirror polished test electrode

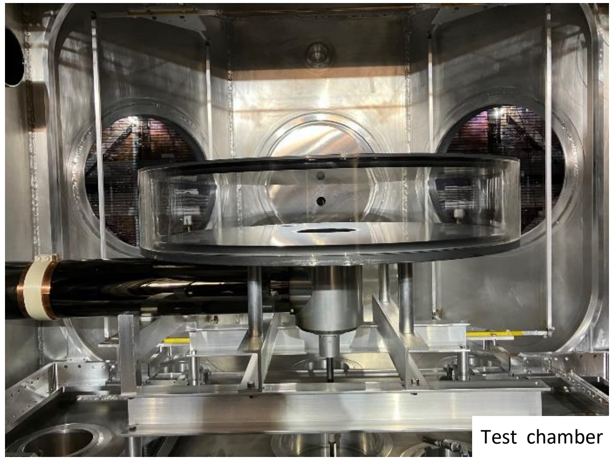

Test electrode DLC coated

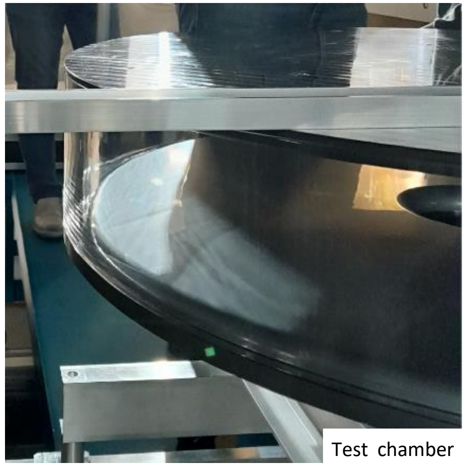
Test of a new UCN storage chamber:

- new insulator rings (quartz instead of Rexolite)
- test electrodes: higher surface quality (polishing) + DLC

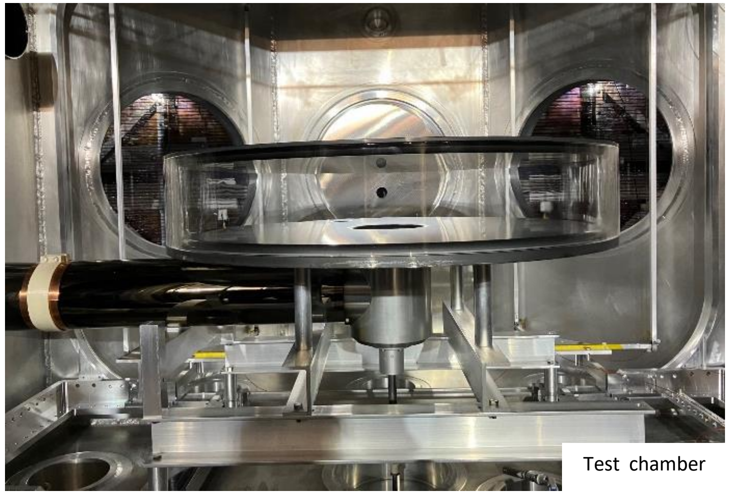
UCN transport: + 40% with new UCN guides

Uncoated quartz ring + test electrodes + new guides
42,000 in the test chamber (x4 / 2023)


Test chamber

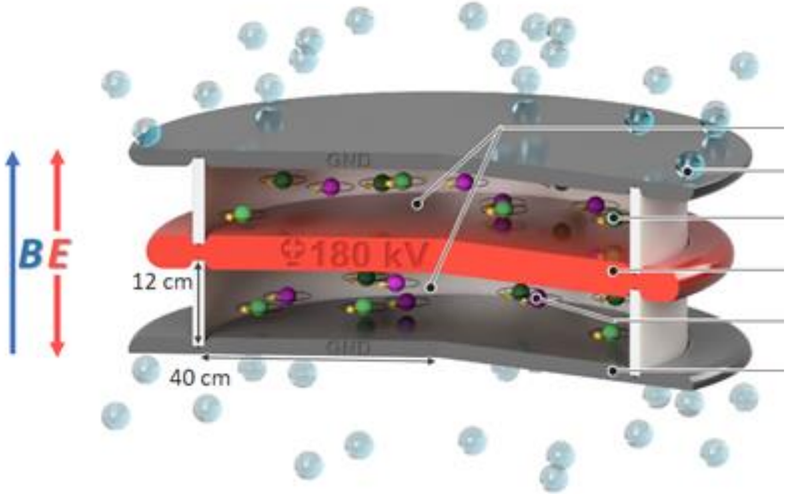

Test chamber

UCN statistic in 2025-2026



Test chamber

Manufacturing (x2) in 2025 →



Manufacturing of new electrodes: (improved) design done

- goal: ready for summer

Uncoated quartz ring + new DLC coated electrodes

84,000 for two chambers (66 % of design goal)

Still room for improvements in 2025:

- Insulator ring: coating with deuterated paraffin (V_F = 90 neV → 160 neV)
  ongoing development (ready in 2025 ?)
- A few new UCN guides towards detectors

New UCN guides

Main actions in 2025

Still a lot of work …. before restart of data taking

Field mapping during winter: field reproducibility (offline corrections of systematic effects)

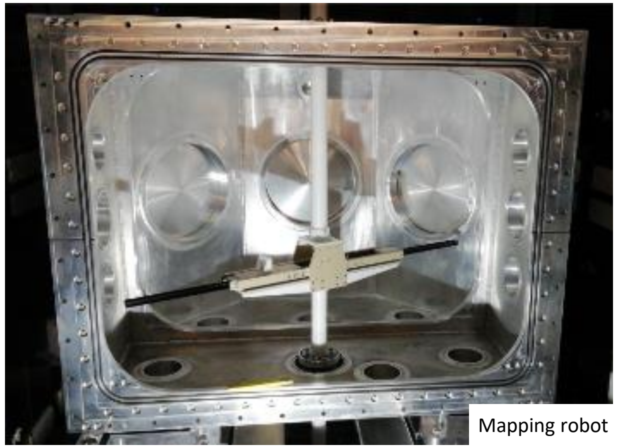
Implementation of the blinding procedure: directly in the DAQ system

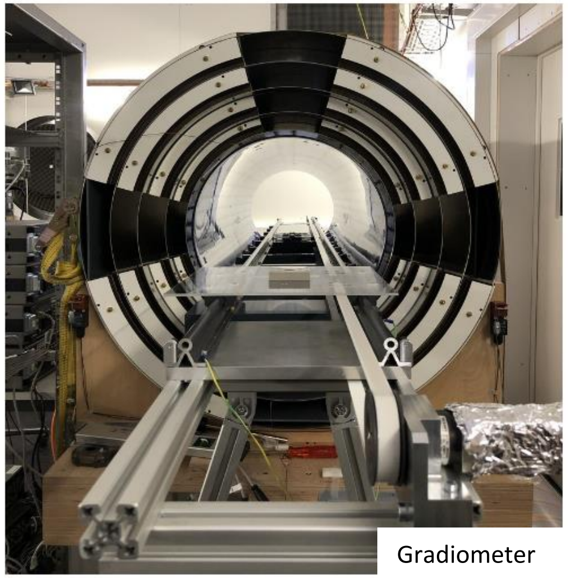
Installation of half of the Cs array (56 cells): online assessment of higher order gradients

Improvements of the Hg co-magnetometer sensitivity: ongoing study

Substantial effort to get a magnetically clean environment:
- Small pieces scanned with PSI gradiometer (cleaned or replaced)
- Large pieces (i.e. electrodes): scanned at PTB (cleaned)

and many others tasks …


Mapping robot


Gradiometer

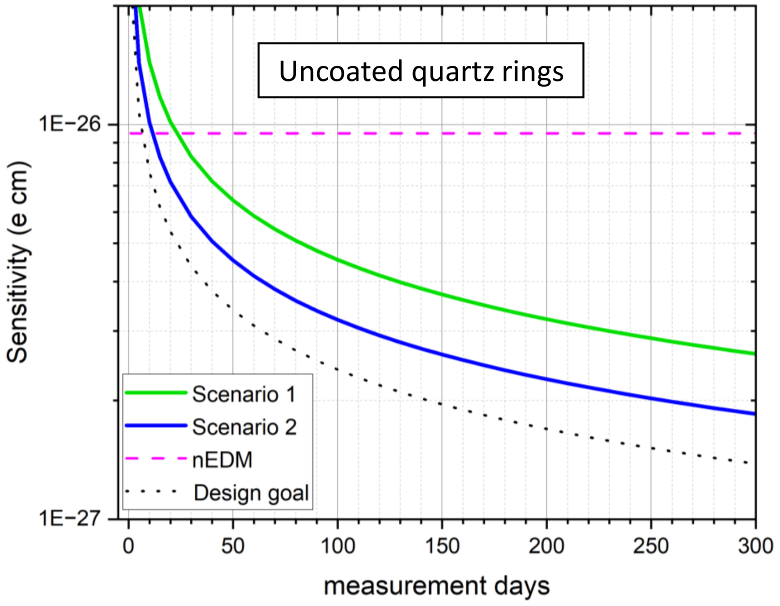
Current n2EDM sensitivity

Experiment sensitivity $\sigma(d_n)$ $\sigma(d_n) = \frac{\hbar}{2\alpha E T \sqrt{N}}$

Current sensitivity: improved by a factor 2.4 / nEDM experiment
~ 30 days required to reach previous experiment sensitivity

Components	nEDM (2016)	n2EDM (2024)	Design goal
Precession time (T)	180 s	180 s	180 s
Neutrons statistic (N)	15,000	64,000 *	120,000
High Voltage (E)	± 11 KV/cm	± 12.5 KV/cm	± 15 KV/cm
Polarisation (α)	0.75	0.82 - 0.85	0.80
Daily sensitivity (σ)	11. 10^{-26} ecm	4.5 10^{-26} ecm	2.6 10^{-26} ecm

* Former electrodes



Room for improvement: UCN statistic (ring coating) + High Voltage (conditioning)
→ towards the design goal sensitivity

2025: first measurement in the 10^{-27} e cm range ?

Thank you

n2EDM sensitivity

Current sensitivity $\sigma(d_n)$

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

Components	nEDM (2016)	n2EDM (2024)	Design goal
Precession time (T)	180 s	180 s	180 s
Neutrons statistic (N)	15,000	60,000	120,000
High Voltage (E)	± 11 KV/cm	± 12.5 KV/cm	± 15 KV/cm
Polarisation (α)	0.75	0.82 - 0.85	0.80
Daily sensitivity (σ)	11. 10^{-26} ecm	5. 10^{-26} ecm	2.6 10^{-26} ecm

Magnetometry:

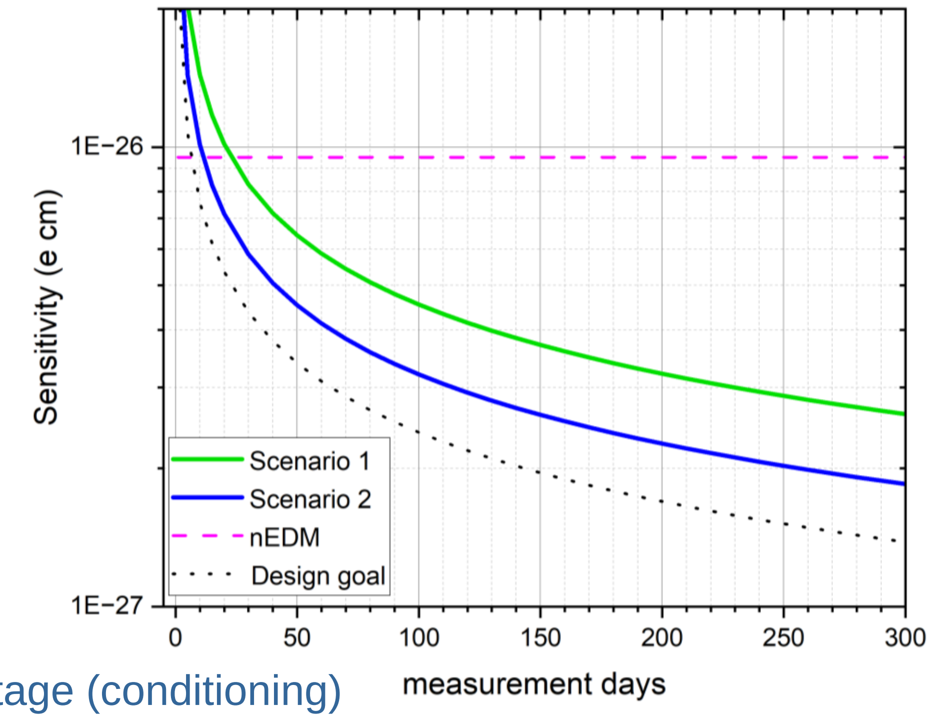
Components	2024	Design goal
Hg Comagnetometer	T_2 = 50 - 70 s	T_2 = 100 s
Cs magnetometers	8 cells	112 cells
Magnetic field [1]	$\sigma(B_z) = 35$ pT	$\sigma(B_z) = 170$ pT

Current sensitivity:

- improved by a factor 2 / nEDM experiment
- missing a factor 2 / design goal

With current sensitivity:

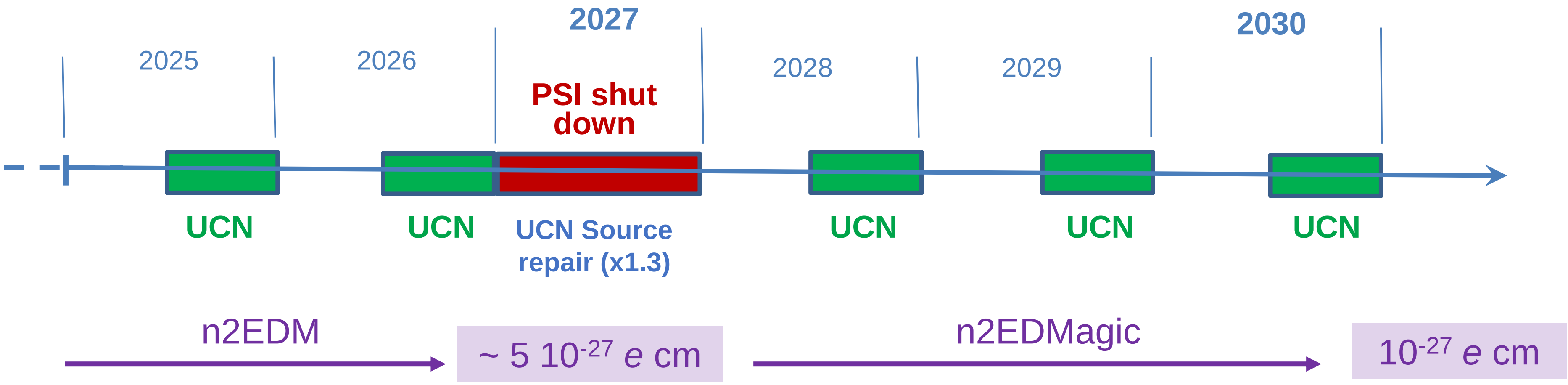
15 to 30 days required to reach previous experiment sensitivity



Room for improvement: UCN statistic (ring coating) + High Voltage (conditioning)

[1] “Generating a highly uniform magnetic field inside the magnetically shielded room of the n2EDM experiment” accepted in EPJC (2025)

The n2EDM experiment in the coming years



Measuring the energy spectrum of stored UCN

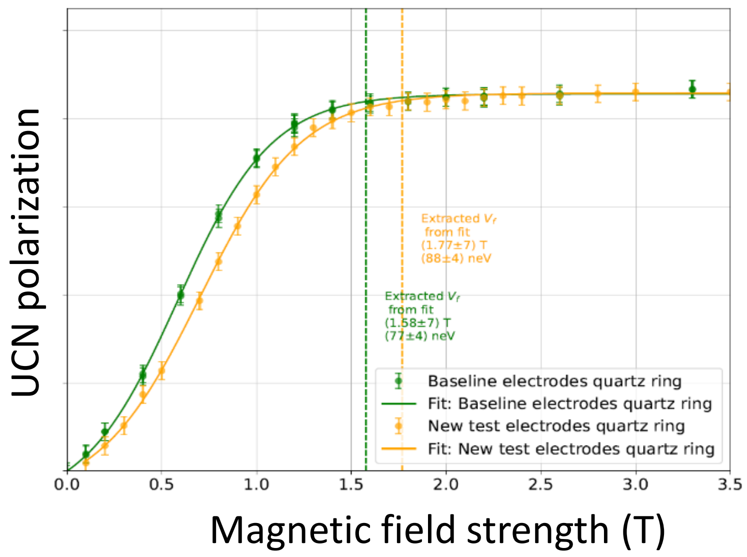
Super Conducting Magnet (SCM) scan:

UCN polarized up to a given energy E_{max} (a given SCM field strength)
- Polarized UCN: $E < E_{max}$; unpolarized UCN: $E > E_{max}$

UCN polarization measured at the end of the storage period
- low polarization → high energy (unpolarized) UCN are stored
- large polarization → high energy (unpolarized) UCN are lost during storage

E_{max} is a measurement of the lowest Fermi potential in the chambers

Results confirm that coating of electrodes and rings were not performant

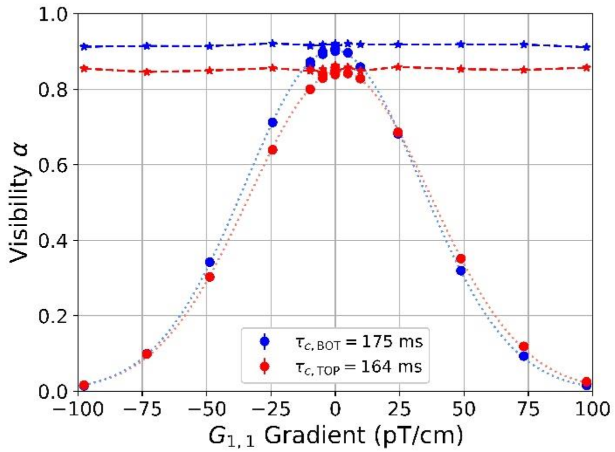


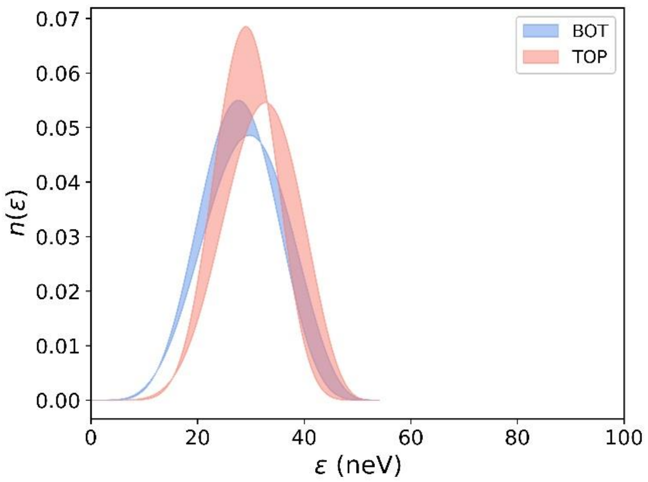
Magnetic field gradient scan:

Depolarization rate depends on:
- UCN energy spectrum & field non uniformities

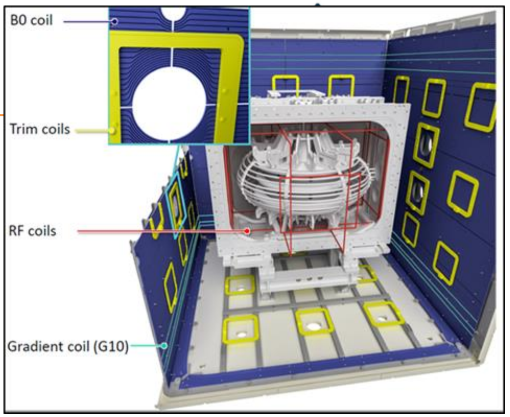
$$\alpha(T) = \alpha_0 \int n(\epsilon) \exp\left(-\frac{T}{T_{2,\mathrm{mag}}(\epsilon)}\right) d\epsilon,$$

Method:
apply different field gradients and measure UCN polarization
Depolarization give access to UCN energy spectrum

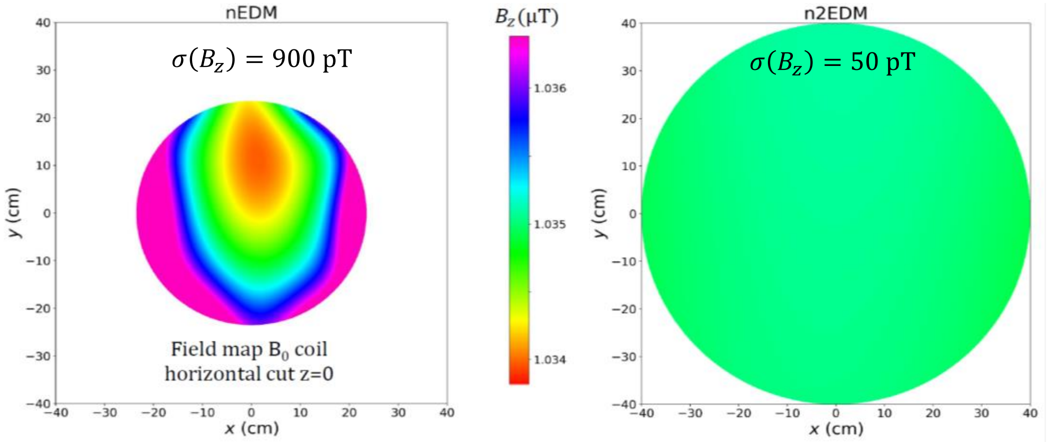


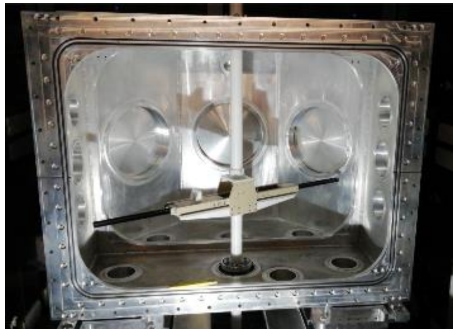


Magnetic field commissioning



Magnetic field characterization (2021-2022): close collaboration between LPC and LPSC
- internal coils system simulated, built and installed by LPC
- field characterization performed by LPSC





	Required	w/o optim.	w/ optim.
Statistical requirements			
Vertical uniformity $\sigma(B_z)$ (pT)	< 170	49.1 ± 1.5	34.7 ± 1.5
Systematical requirements			
$d^{\text{false}}_{\text{n}\leftarrow\text{Hg}}(\acute{G}_{30}\acute{H}_{30})$ ($10^{-28}\,e\,$cm)	< 3	81.7 ± 2.9	2.3 ± 2.9
$d^{\text{false}}_{\text{n}\leftarrow\text{Hg}}(\acute{G}_{50}\acute{H}_{50})$ ($10^{-28}\,e\,$cm)	< 3	9.2 ± 0.7	0.7 ± 0.7
$d^{\text{false}}_{\text{n}\leftarrow\text{Hg}}(\acute{G}_{70}\acute{H}_{70})$ ($10^{-28}\,e\,$cm)	< 3	0.3 ± 0.1	0.2 ± 0.1

Performances are excellent

Part of the systematics already below requirements

T. Bouillaud, P. Flaux, "An exceptionally uniform magnetic field for the n2EDM experiment" (LPC-LPSC); internal review.