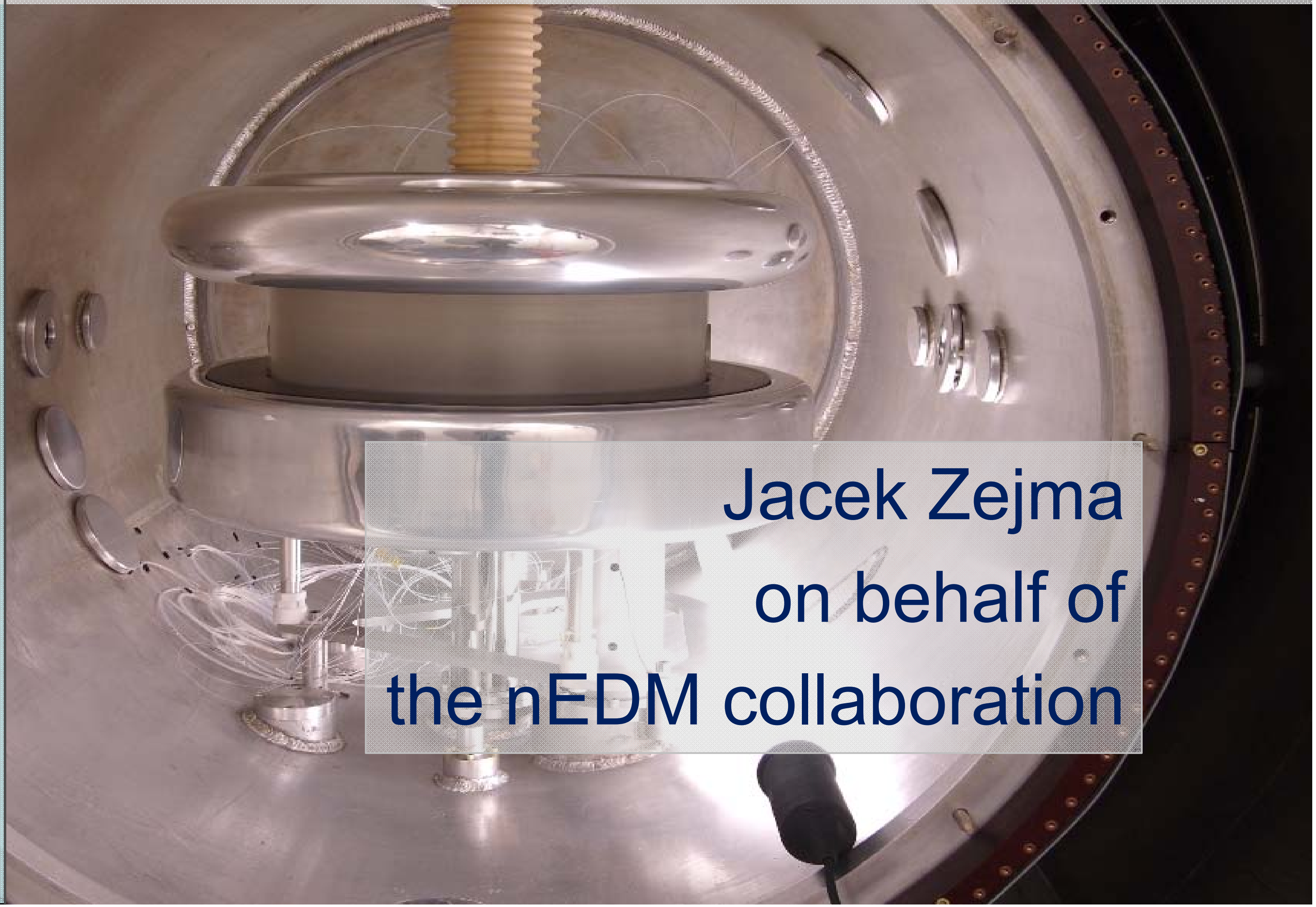
Neutron EDM Experiment at the Paul Scherrer Institute



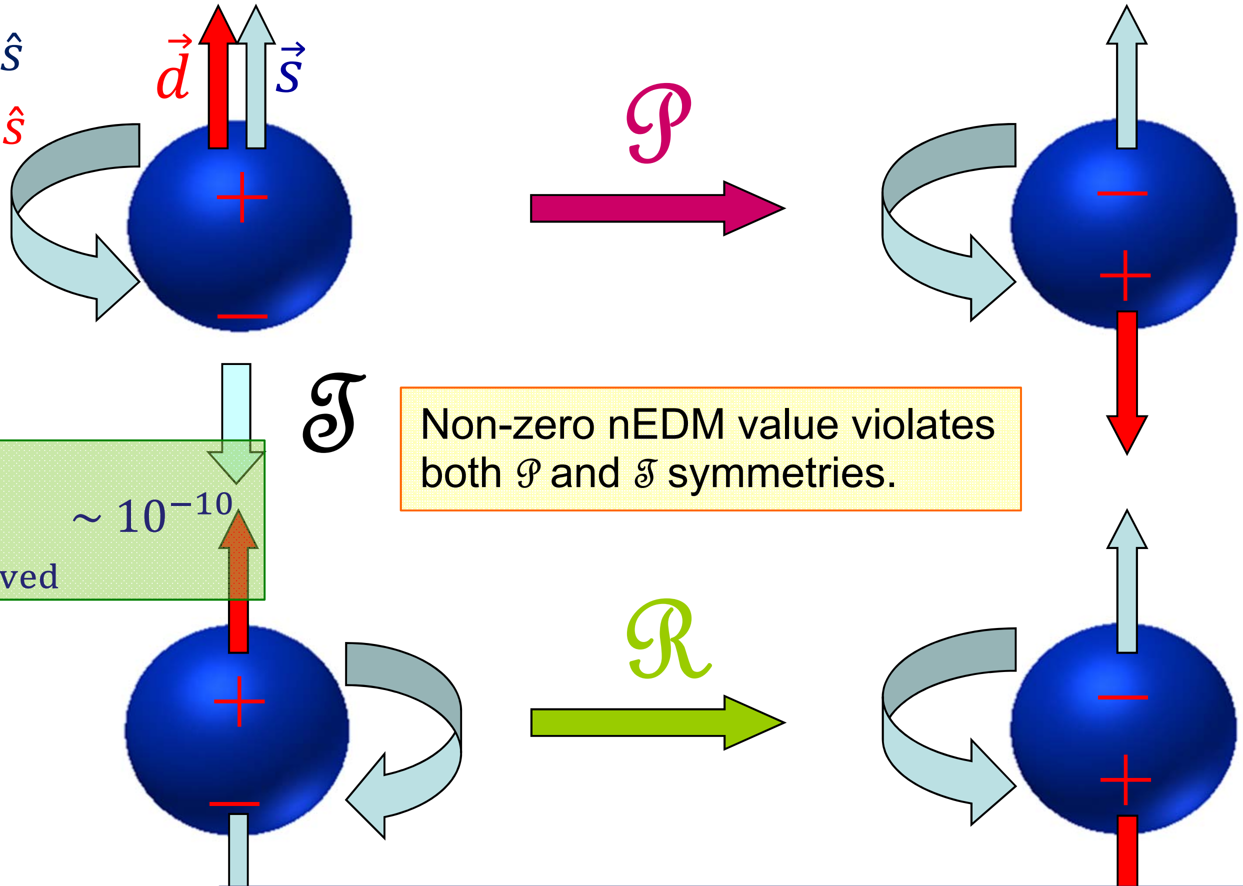
Jacek Zejma
on behalf of
the nEDM collaboration

SSP2012, Groningen
Jacek Zejma
Jagiellonian University
Kraków

Motivation

$\vec{\mu} = \mu \cdot \hat{s}$

$\vec{d} = d \cdot \hat{s}$



$\theta \sim 10^{-10}$

$\left(\frac{n_B}{n_\gamma}\right)_{\text{Observed}} \sim 10^{-10}$

Non-zero nEDM value violates both $\mathcal{P}$ and $\mathfrak{T}$ symmetries.

Motivation of neutron EDM measurements has been already presented in several interesting talks.

Motivation

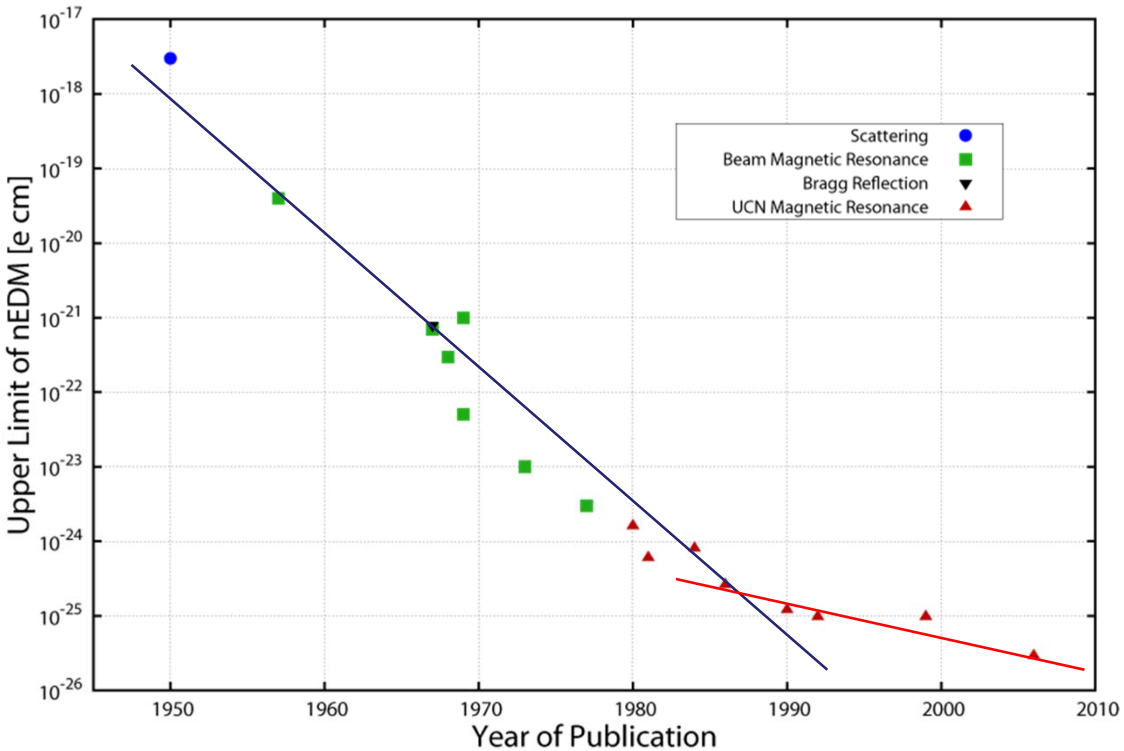
First nEDM experimental estimation:

E. M. Purcell and N. F. Ramsey (1950) $d_n < 3 \cdot 10^{-18}$ e·cm

First dedicated nEDM measurement:

Smith, Purcell, Ramsey (1957) $d_n < 5 \cdot 10^{-20}$ e·cm

Current experimental limitation:
RAL-Sussex-ILL collaboration (2006)
$d_n < 2.9 \cdot 10^{-26}$ e·cm.



Problem of last experiments:

Limited statistics

$d_n = (+0.2 \pm \mathbf{1.5} \pm 0.7) \cdot 10^{-26}$ e·cm.

Experiment at PSI

General idea:

- continuation of the successful Sussex/RAL/ILL experiment.
- much more intense UCN source
- better control of the systematics

Paul Scherrer Institute:

- new UCN source with intensity of above 1000 cm^{-3} (typical density at ILL is 10 cm^{-3}).

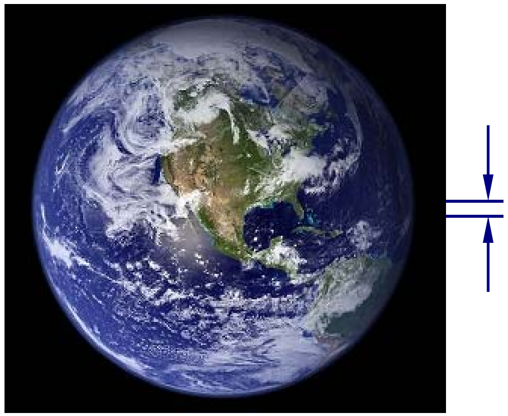
Bernard Lauss's talk on Wednesday (17:20).

Experiment at PSI

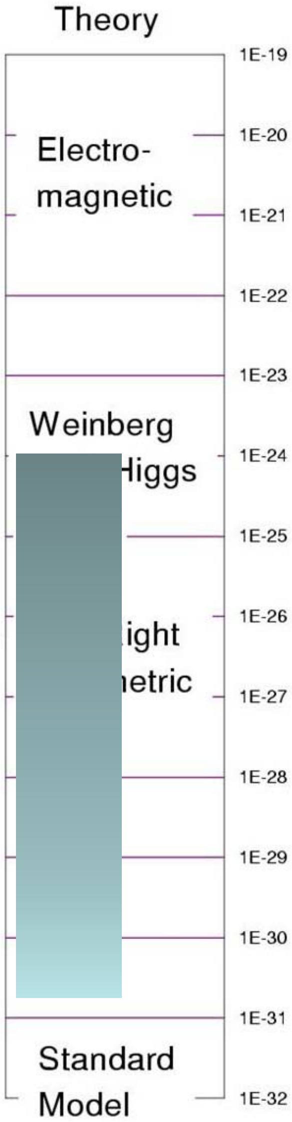
Last result: $d_n < 2.9 \cdot 10^{-26}$ e·cm.

Aim sensitivity of the experiment at Paul Scherrer Institute:

- Intermediate:
  $d_n < 5 \cdot 10^{-27}$ e·cm (95% C.L.)
- Finale:
  $d_n < 5 \cdot 10^{-28}$ e·cm (95% C.L.)



d ≈ 0.7 μm
if neutron is enlarged
to the size of the Earth.

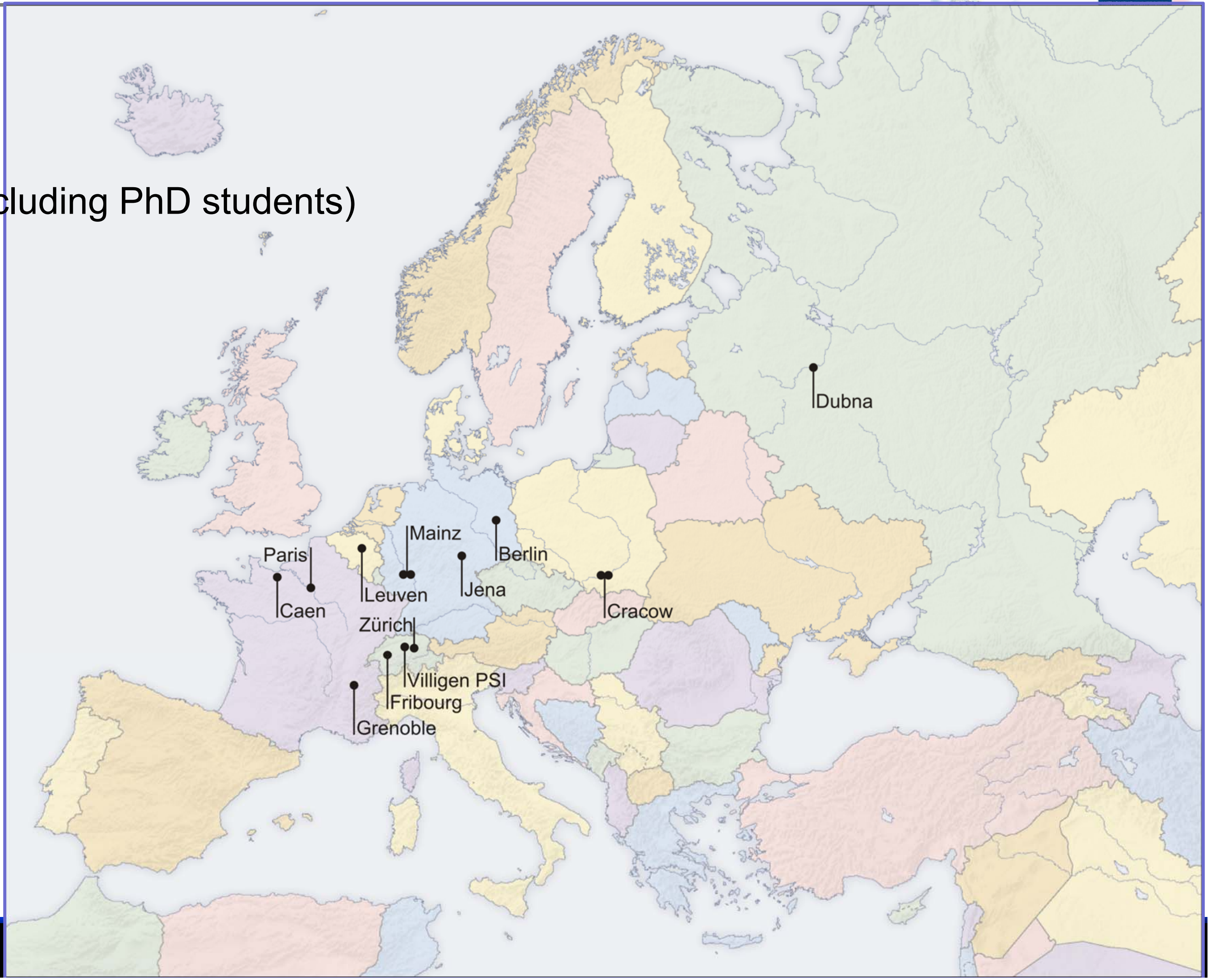


nEDM experiment at PSI

Collaboration of

13 laboratories

51 scientists (including PhD students)



Measurement principle

Larmor precession of the neutron spin

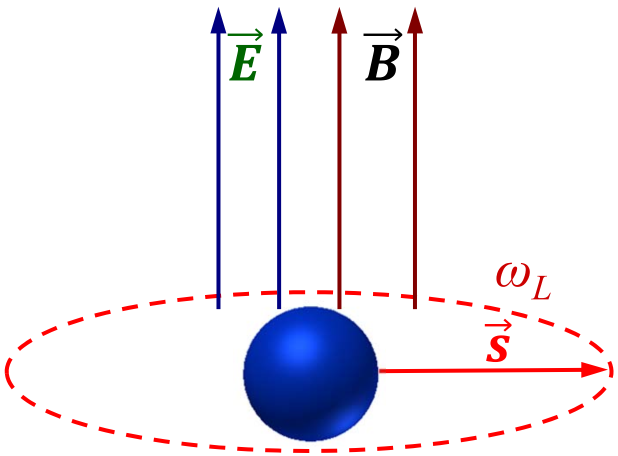
$$\omega_L^+ = \frac{2}{\hbar}(\mu_n B_{\uparrow\uparrow} + d_n E_{\uparrow\uparrow}), \text{ if } \vec{B} \uparrow\uparrow \vec{E}.$$

$$\omega_L^- = \frac{2}{\hbar}(\mu_n B_{\uparrow\downarrow} - d_n E_{\uparrow\downarrow}), \text{ if } \vec{B} \uparrow\downarrow \vec{E}.$$

$$\Delta\omega = \frac{2}{\hbar} d_n (E_{\uparrow\uparrow} + E_{\uparrow\downarrow}) + \frac{2}{\hbar}\mu_n (B_{\uparrow\uparrow} - B_{\uparrow\downarrow})$$

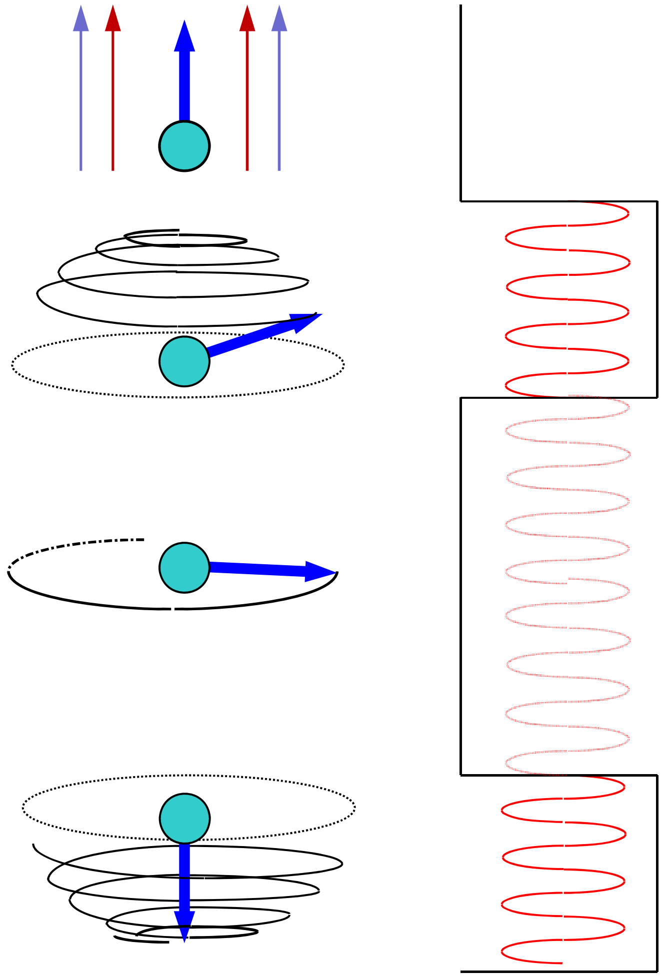
$$\Delta\omega = \frac{4}{\hbar} d_n E, \text{ if } E = E_{\uparrow\uparrow} = E_{\uparrow\downarrow} \text{ and } \boldsymbol{B}_{\uparrow\uparrow} = \boldsymbol{B}_{\uparrow\downarrow}.$$

$$\boldsymbol{d_n \sim 10^{-27}} \Rightarrow \frac{\boldsymbol{\Delta\omega}}{\boldsymbol{\omega}} \boldsymbol{\sim 2 \cdot 10^{-10}}.$$



Measurement principle

The Ramsey method of separated oscillating fields



1. Sample of polarized neutrons with constant $\vec{B}$ (1 μT) i $\vec{E}$ (12 kV/cm) field.

2. RF pulse with $\omega_{RF} = \omega_L$ ($\approx$ 30Hz). Spin rotation by $\pi/2$ to horizontal plane.

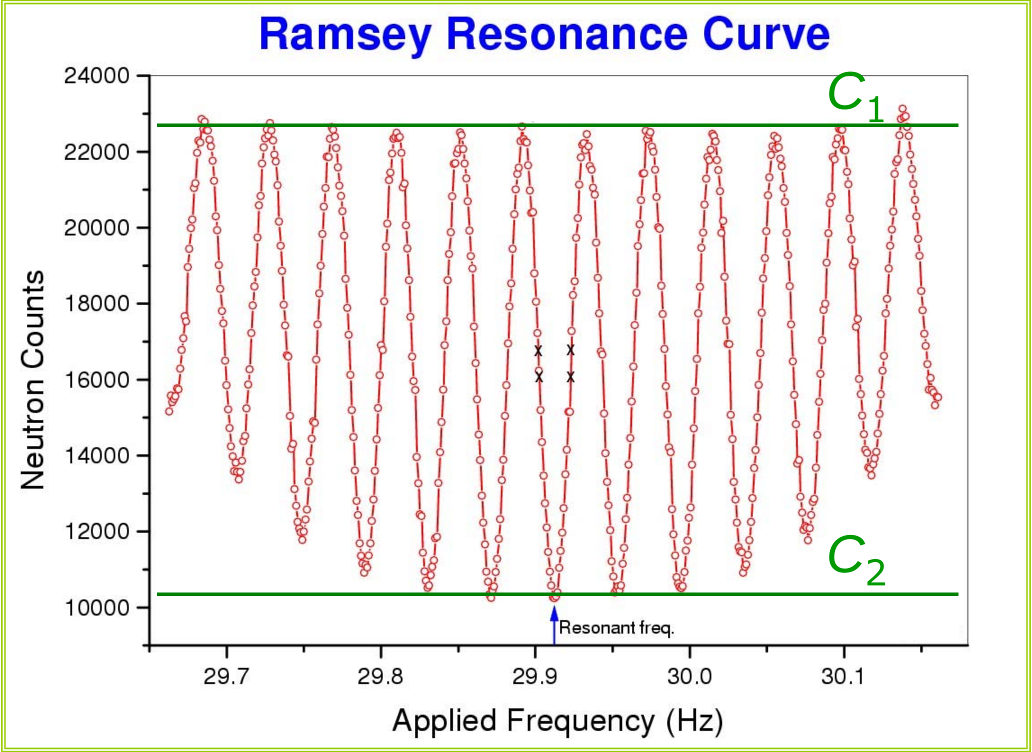
3. Free precession of neutron spin by about 120÷150 s. $\vec{B} \uparrow\uparrow \vec{E}$ **or** $\vec{B} \uparrow\downarrow \vec{E}$.

4. Second 2s long RF pulse. Rotation of spin $\pi/2$ to vertical if d_n=0.

5. **Neutron polarization analysis.**

Measurement principle

The Ramsey method of separated oscillating fields



P.G. Harris et al., PRL 82 (1999) 904

Amount of registered neutrons with polarization equal +1 for E=0.

x – working points

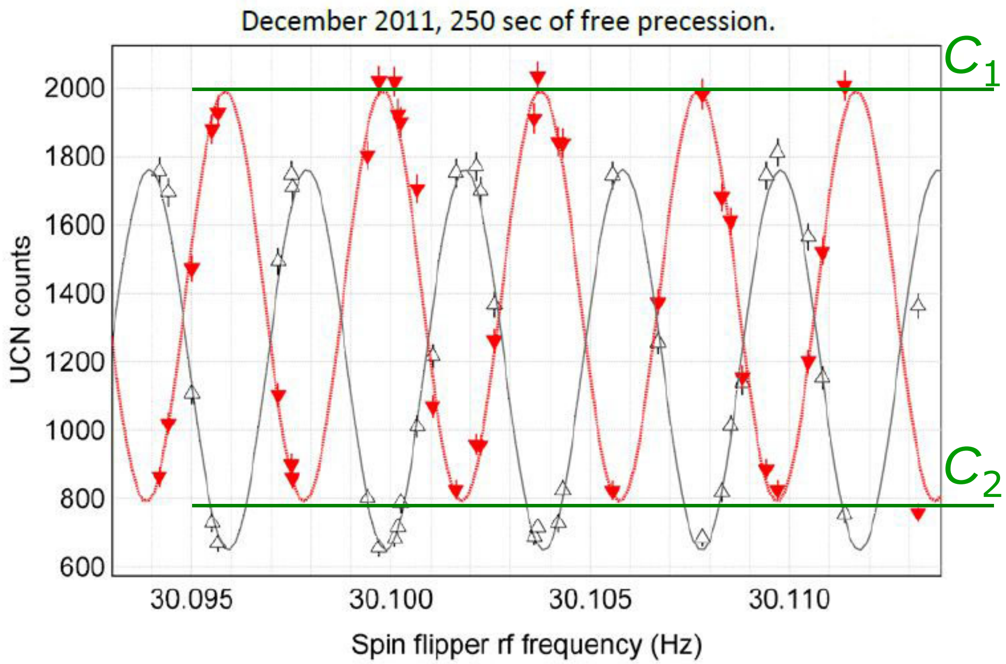
$$\alpha = \frac{C_1 - C_2}{C_1 + C_2}$$

Measurement accuracy:

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

Measurement principle

The Ramsey method of separated oscillating fields



$$\alpha = \frac{C_1 - C_2}{C_1 + C_2}$$

Measurement accuracy:

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nEDM experiment at PSI

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

System components:

- Ultra-cold neutrons:
  - guides, precession chamber, valves.
  - spin polarization and analysis.
  - detection system.
- Magnetic field:
  - μ-metal shield.
  - main and compensation (trim) coils.
  - magnetometers to measure field and its gradients.
- Electric field:
  - power supply and electrodes.
  - leakage current measurement.
  - high-voltage resistant materials
- Data acquisition system:
  - sequence of steps in a measurement cycle.
  - control of all subsystems.
  - collection of data.

nEDM experiment at PSI

Thermo-house

with stabilized temperature.

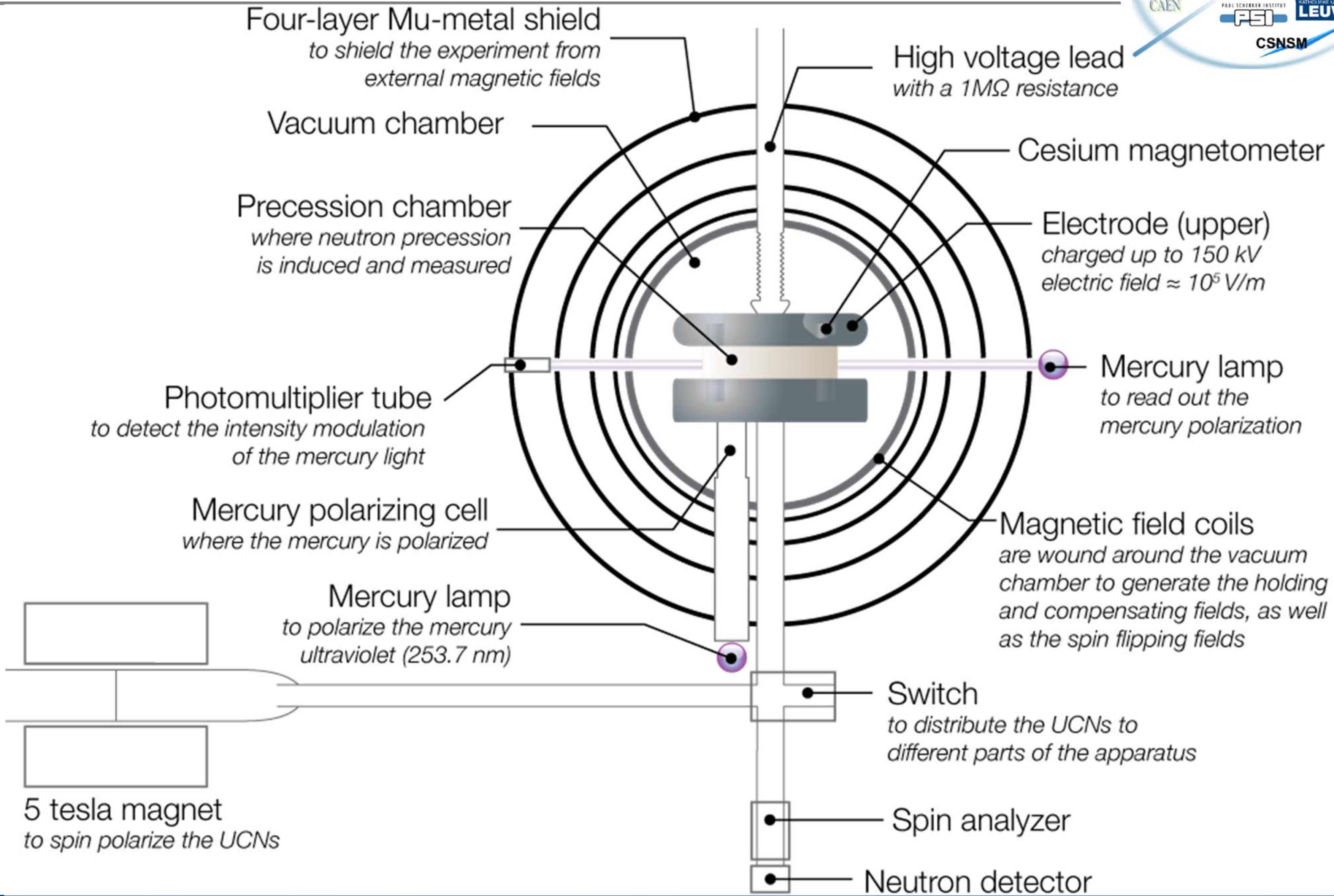
Apparatus with precession chamber

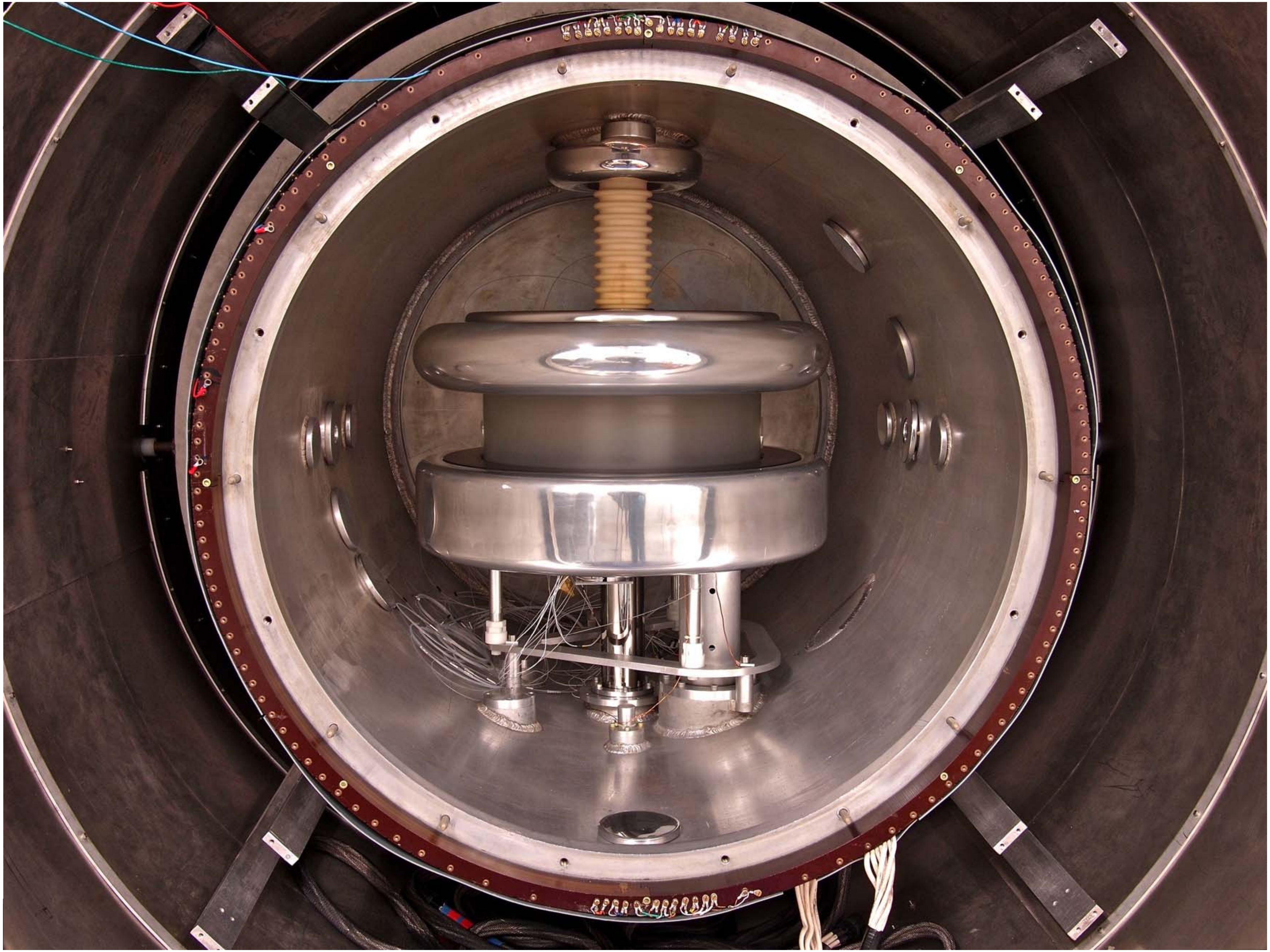
±0.1°C

Control room

±1°C

nEDM experiment at PSI

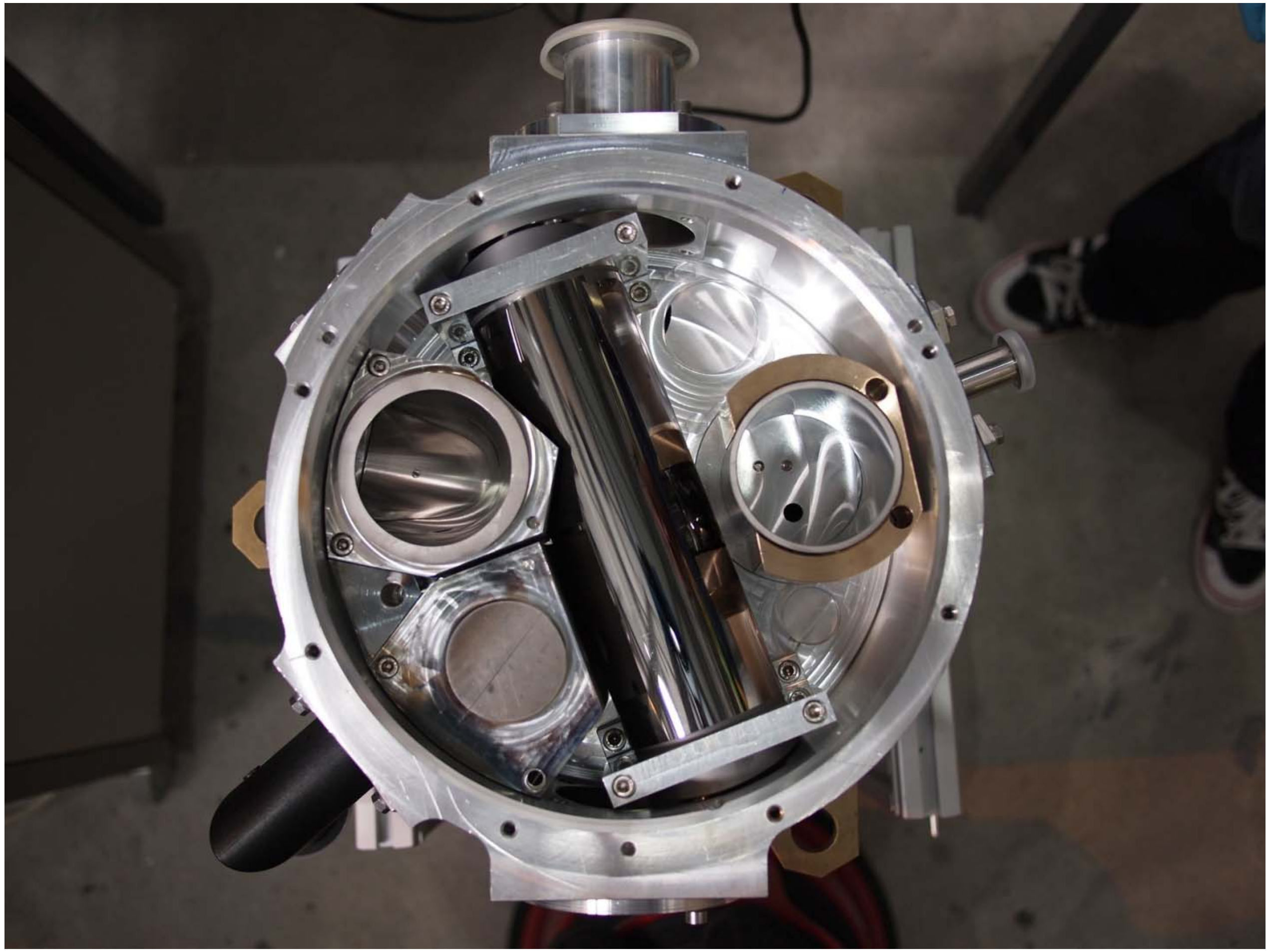




nEDM experiment at PSI

Switch connects UCN storage volume with

- UCN source
- Detection system
- Pumping system
- Pressure gauge

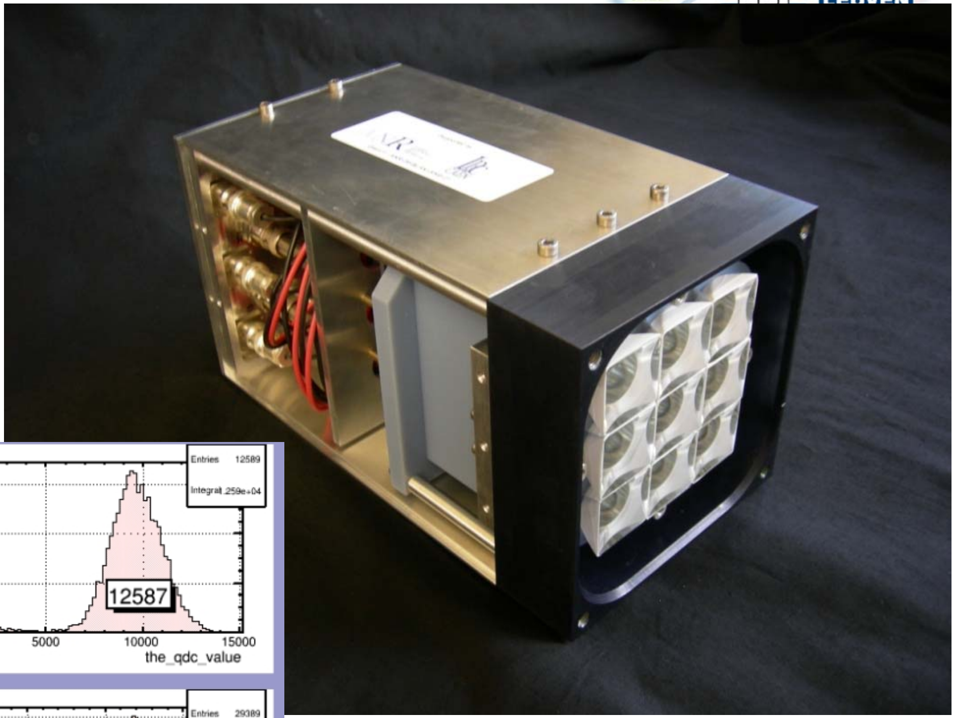


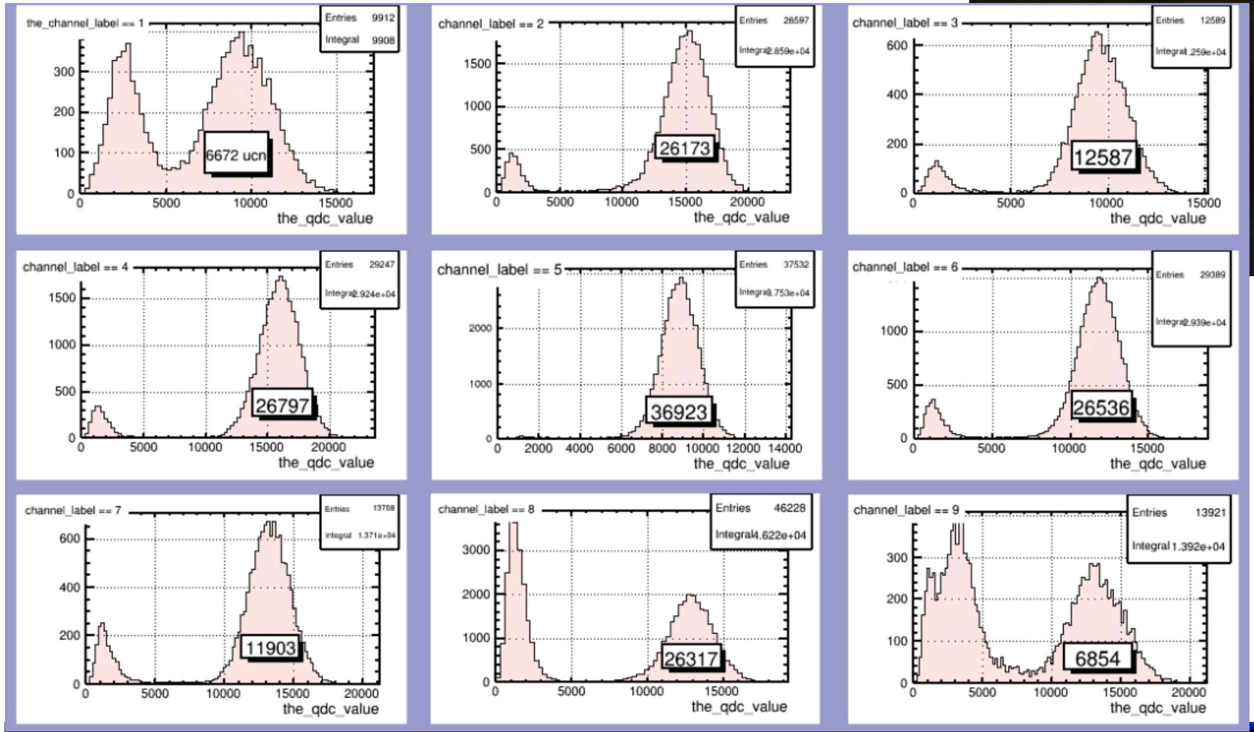
nEDM experiment at PSI

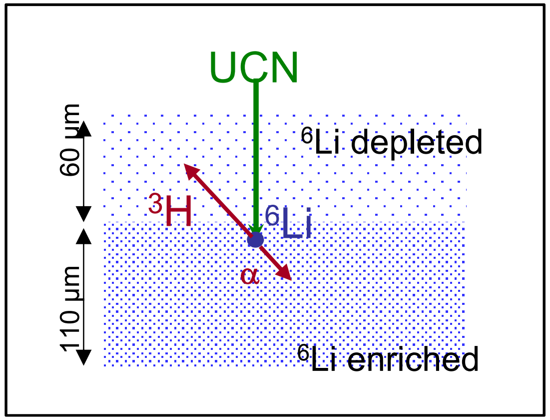
UCN detection system

- ^{6}Li enriched scintillators

$$n + {}^{6}Li \rightarrow {}^{3}H + \alpha$$



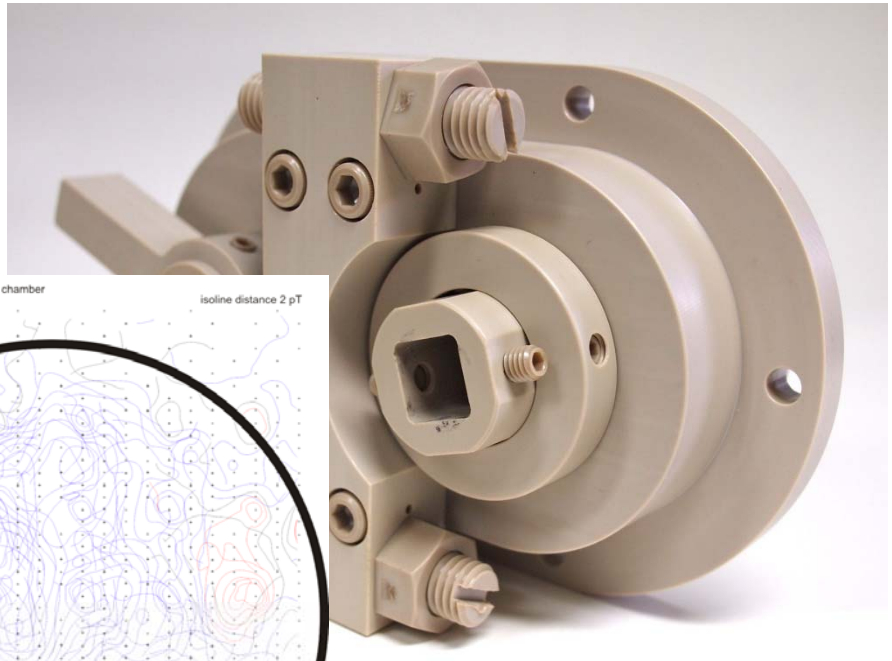


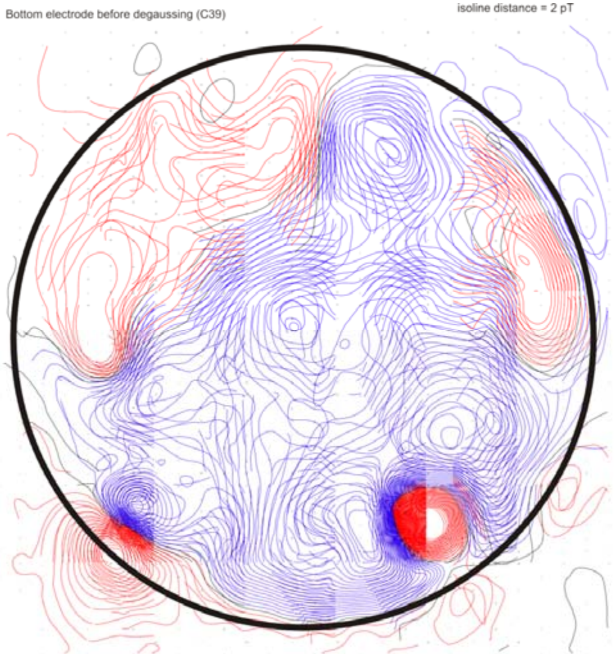


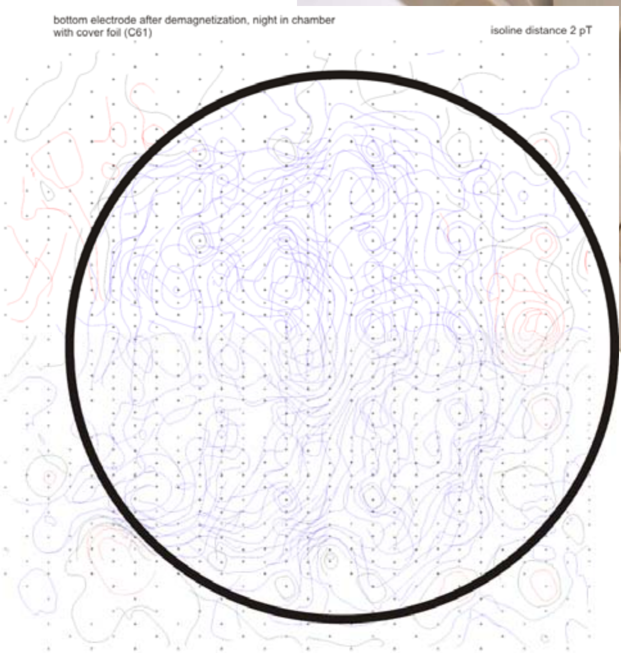
nEDM experiment at PSI

Using nonmagnetic materials

- Tests at PTB Berlin



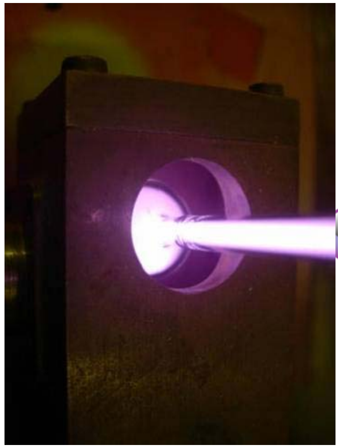


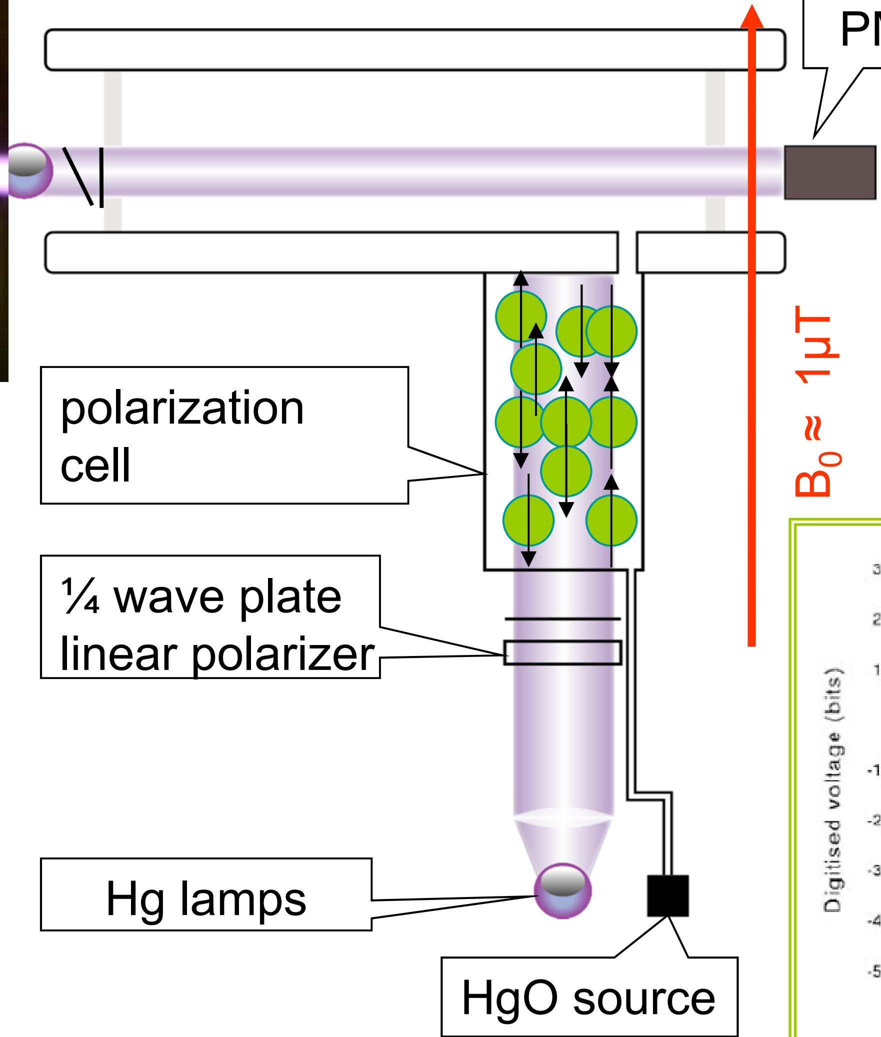


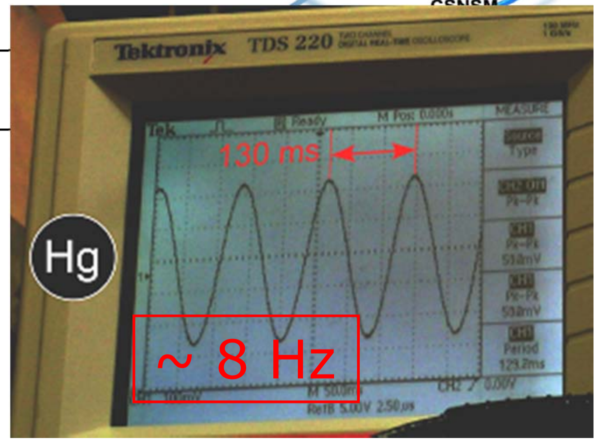
$\Delta B_{pp} \approx 200$ pT After demagnetization $\Delta B_{pp} \approx 20$ pT

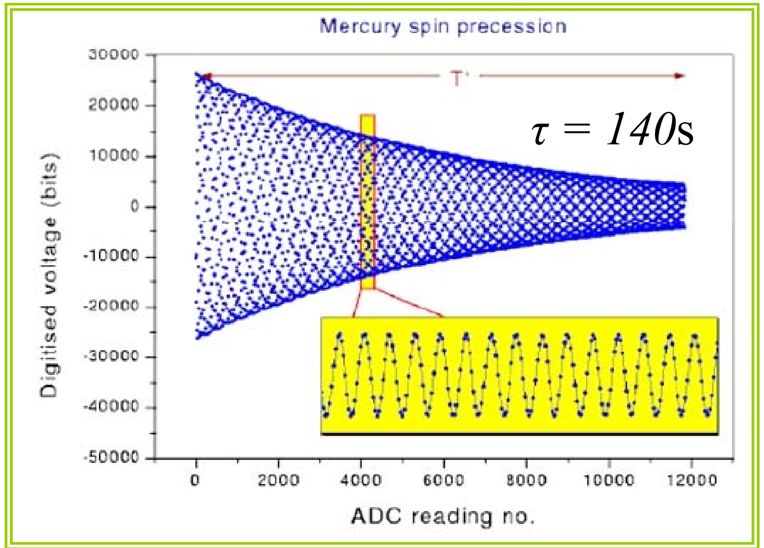
nEDM experiment at PSI

^{199}Hg co-magnetometer





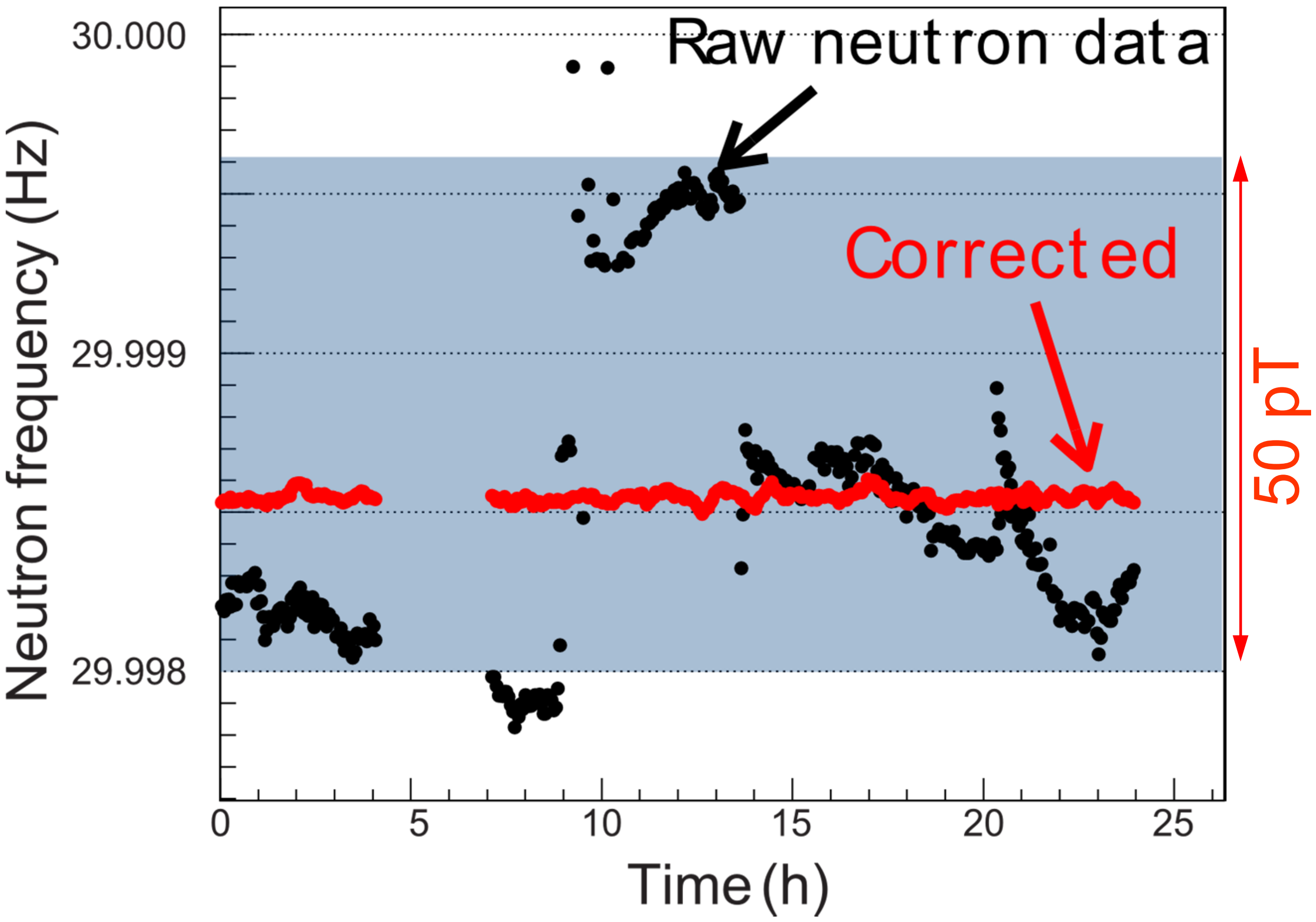




50 fT/100s

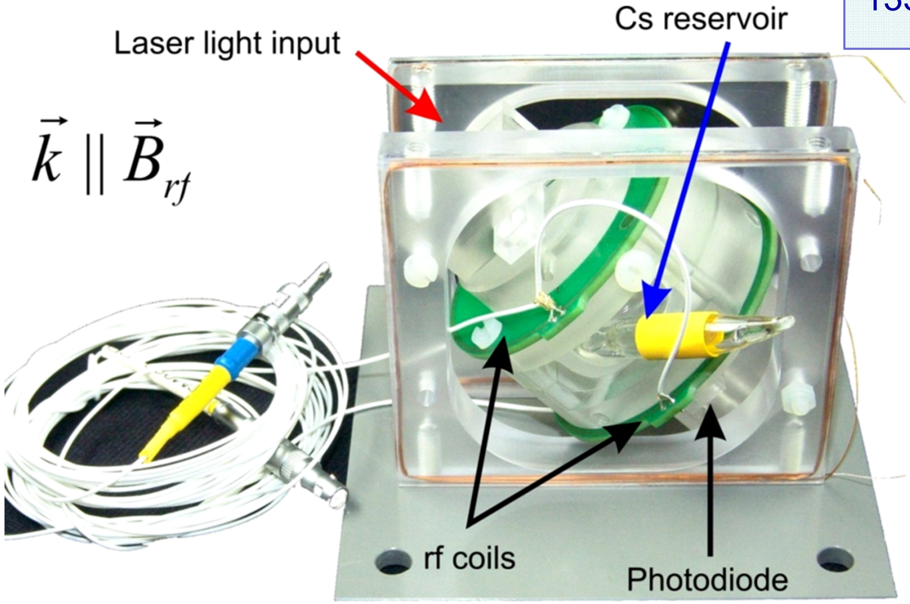
nEDM experiment at PSI

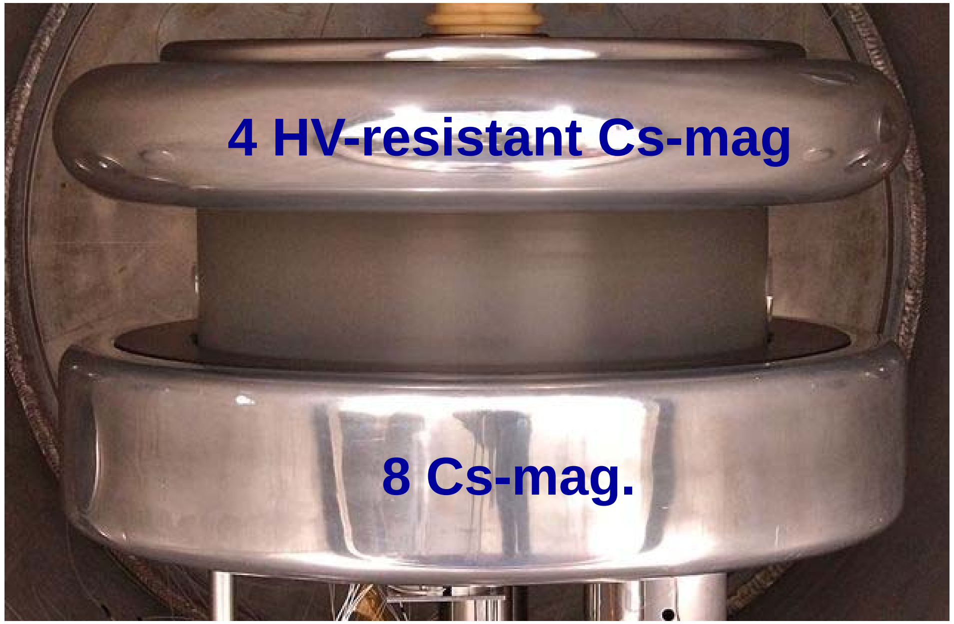
^{199}Hg co-magnetometer

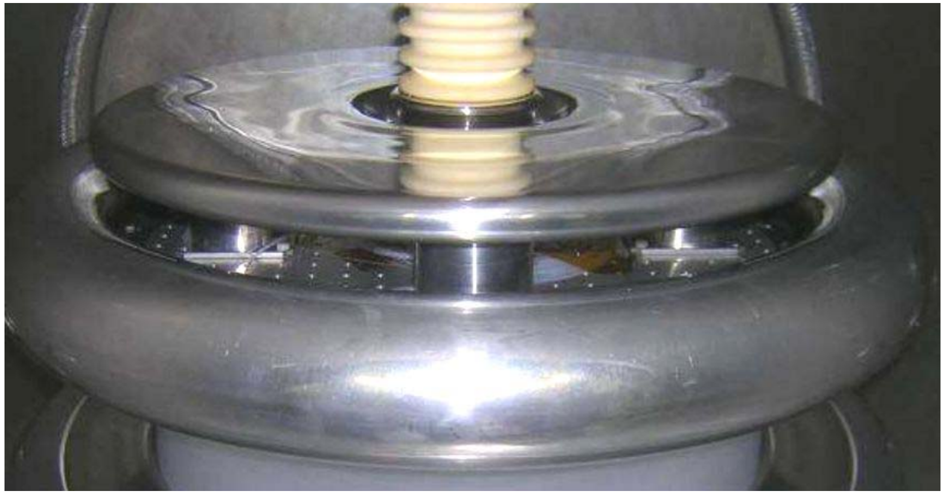


nEDM experiment at PSI

^{133}Cs magnetometers







Measurement of
- field gradients,
- rapid field changes.

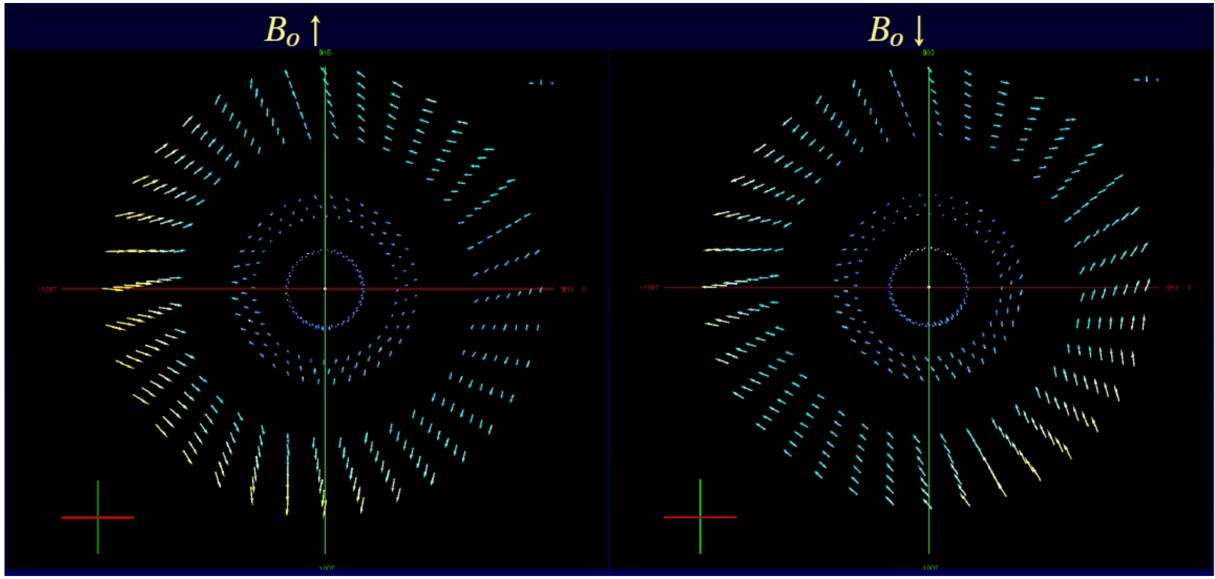
100 fT/1s

nEDM experiment at PSI

Magnetic field shielding

- Passive:
  - 4 layers of μ-metal
- Active:
  - Surrounding field compensation (6 coils)
  - 30 trim coils

Field mapping.



Longitudinal neutron spin relaxation T_1 = 3600 s, Transverse relaxation T_2 = 560 s.

nEDM experiment at PSI

Mean $\langle z \rangle$ values of Hg atoms and UCNs in the precession chamber differ by $\Delta h \approx 2.3$ mm – this is a source of uncompensated field drifts:

$$f_n + f_n^{false} = f_{Hg} \frac{\gamma_n}{\gamma_{Hg}} \left(1 + \frac{\partial B}{\partial z} \cdot \frac{1}{B} \cdot \Delta h\right)$$

Measurement of gradient:

< 2.8 fT/cm

What corresponds to

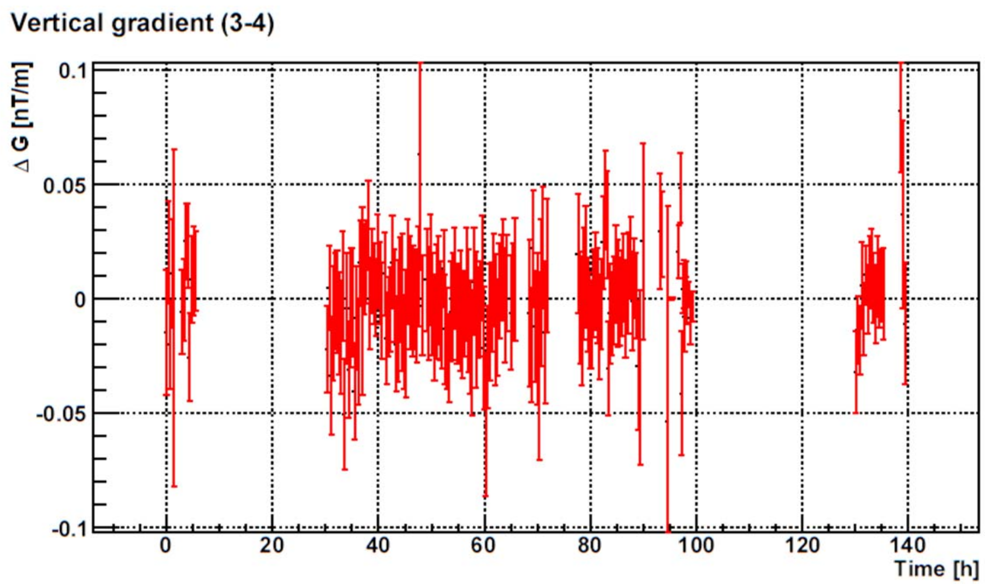
systematic effect

$2.5 \cdot 10^{-27}$e·cm

With CS magnetometers we can

obtain accuracy

$\sigma(d_n^{false}) < 0.9 \cdot 10^{-27}$e·cm



nEDM experiment at PSI

Towards n2EDM

1. Better magnetometry system.
2. Active magnetic shielding
3. Simultaneous measurement with **E** parallel and anti-parallel to **B** in the symmetric double-chamber system.
4. Simultaneous neutron “up” and “down” spin measurement.

nEDM experiment at PSI

Summary

1. UCN source is ready for delivering neutrons.
2. All sub-systems tested and ready to work.
   - some improvements and tests are still being prepared.
3. Expected accuracy obtained in the measurement 2012-2013

$$d_n = (\ldots \pm 2 \ \pm 2) \cdot 10^{-27} \mathrm{e \cdot cm}.$$

4. Investigations regarding next step are in progress.

nEDM experiment at PSI

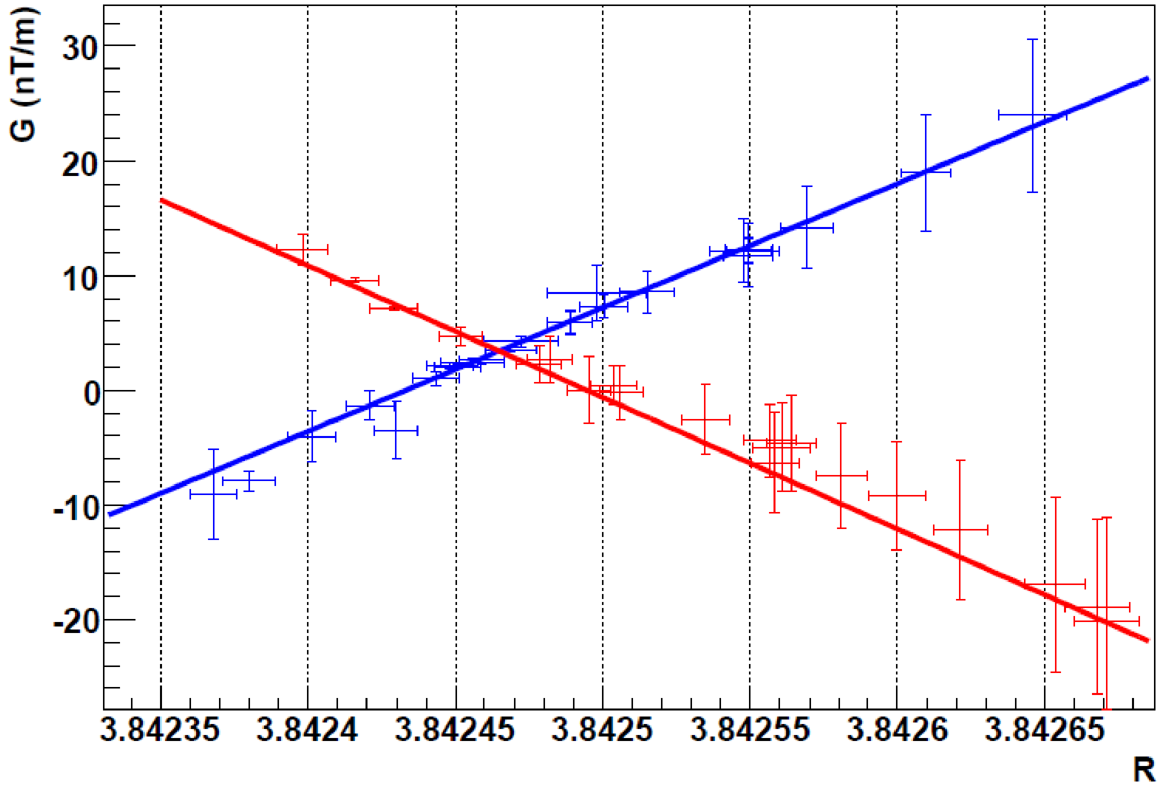
Thank you

nEDM experiment at PSI

Dedicated measurement for estimation of Δh

$$R = \frac{f_n}{f_{Hg}} = \frac{\gamma_n}{\gamma_{Hg}}\left(1 + \frac{\partial B}{\partial z}\cdot\frac{1}{B}\cdot\Delta h\right)$$

Δh = 2.3 ± 0.1 mm

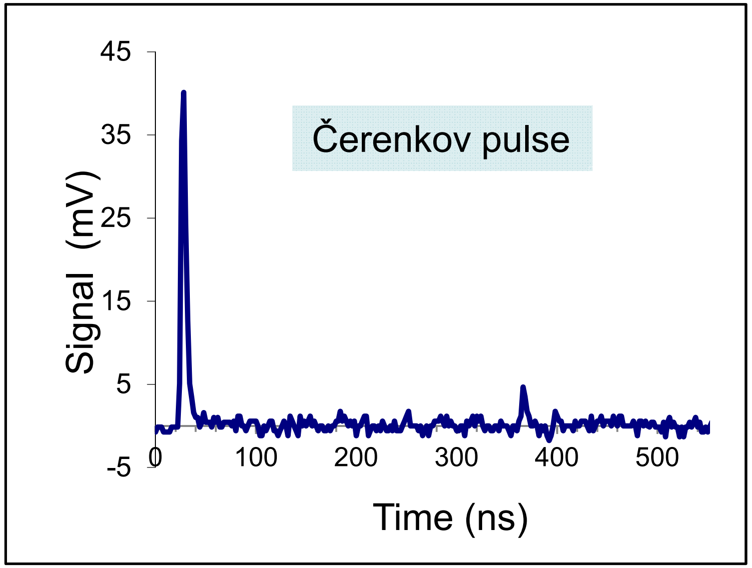


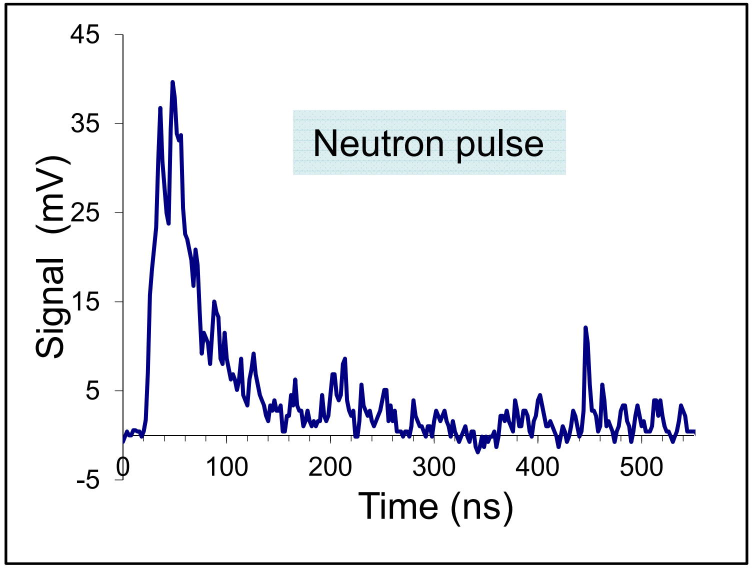
nEDM experiment at PSI

Effect	Status ($\cdot 10^{-27}$ ecm) (Feb. 2012)
Leakage Current	0.00 ± 0.05
Uncompensated B drift	2.9 ± 8.6
vxE UCN	0 ± 0.1
Electric Forces	0. ± 0.4
Hg EDM	0.02 ± 0.06
Hg Light Shift	0.00 ± 0.05
Quadrupole Difference	1.3 ± 2.4
Dipoles	0 ± 3
Total	**4.2 ± 9.4**

nEDM experiment at PSI

Signals from a UCN detector





nEDM experiment at PSI

Long term magnetic field drifts measured with both Hg and Cs magnetometers