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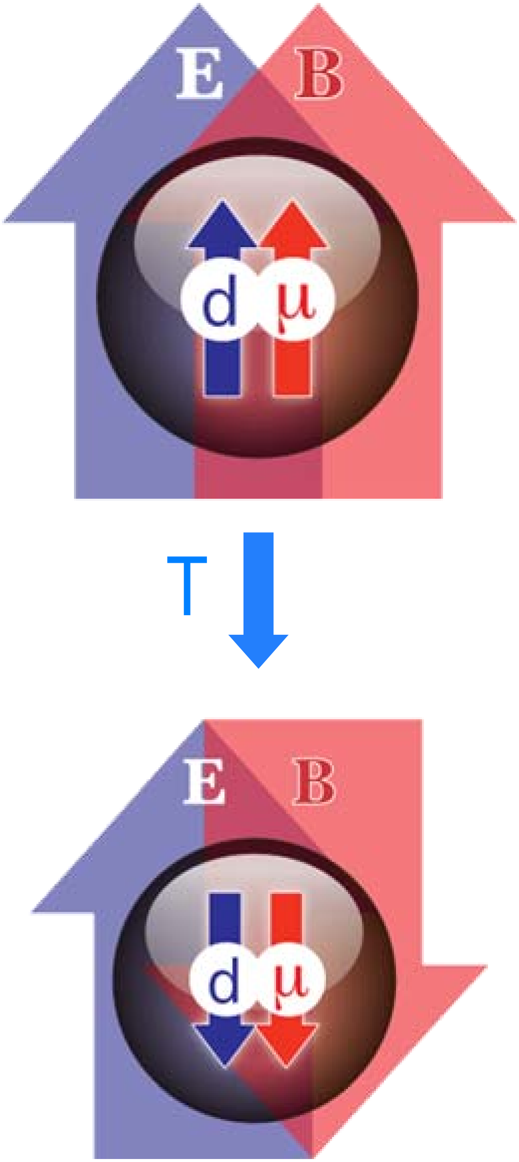
An improved search of the nEDM

Paul Scherrer Institut

Philipp Schmidt-Wellenburg on behalf of the nEDM collaboration

CP violation and EDM



A nonzero particle EDM violates P, T and, assuming CPT conservation, also CP.

→ CP violation so far only in weak decays

→ Might help explain BAU matter/anti-matter problem

→ Excellent probe for physics beyond the Standard Model (complementary to LHC)

→ Creates strong CP problem

nEDM from θ

- nEDM derived from phase transformations

$$d_{\mathrm{n}} \approx \theta \cdot \frac{e}{m_{\mathrm{n}}^{2}} \frac{3 m_{\mathrm{u}} m_{\mathrm{d}} m_{\mathrm{s}}}{m_{\mathrm{u}} m_{\mathrm{d}} + m_{\mathrm{d}} m_{\mathrm{s}} + m_{\mathrm{u}} m_{\mathrm{s}}} \approx \theta \cdot 10^{-16}\, \mathrm{e} \cdot \mathrm{cm}$$

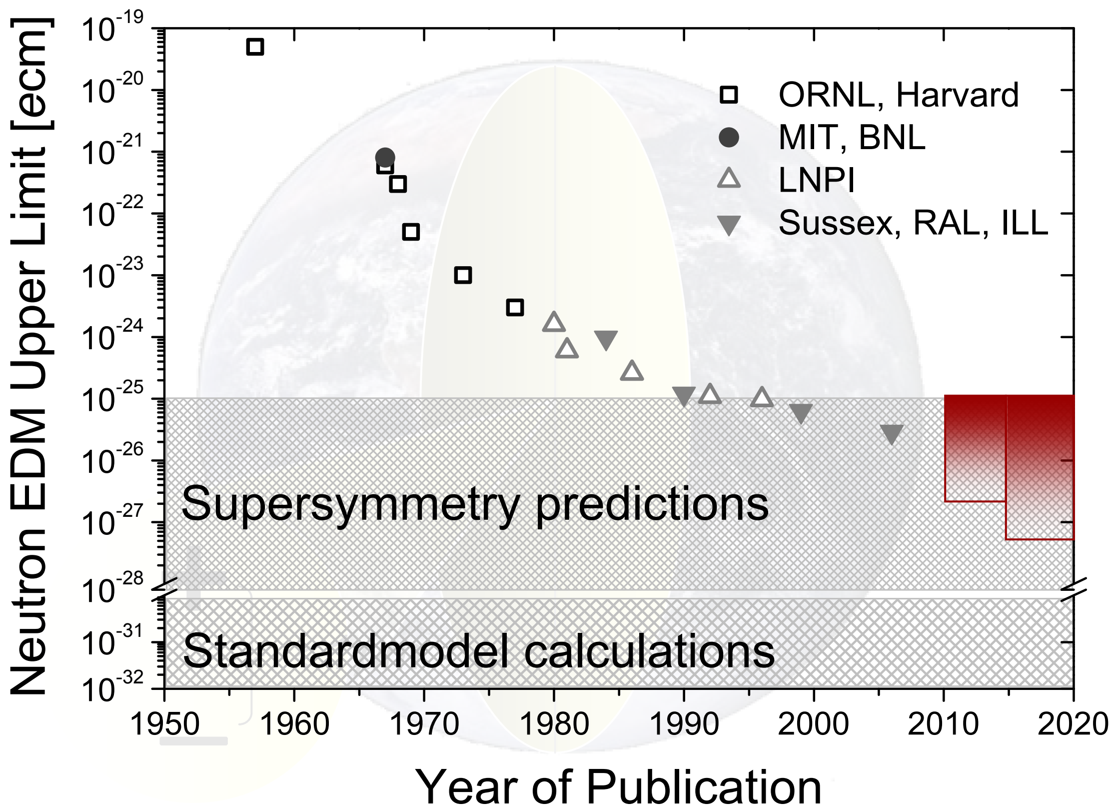
- Latest nEDM upper limit:

$$d_{\mathrm{n}} < 2.9 \times 10^{-26}\, e\ \mathrm{cm}$$

- and hence: $\theta < 10^{-10}$

C.A.Baker et al., PRL 97 (2006) 131801

A brief history of nEDM searches



Aimed at sensitivities at PSI:
Intermediate:
$d_n < 5 \times 10^{-27}$ e cm (95% C.L.)
Final:
$d_n < 5 \times 10^{-28}$ e cm (95% C.L.)

First

Smith, Purcell, Ramsey
$d_n < 5 \times 10^{-20}$ e cm
PR 108 (1957) 120

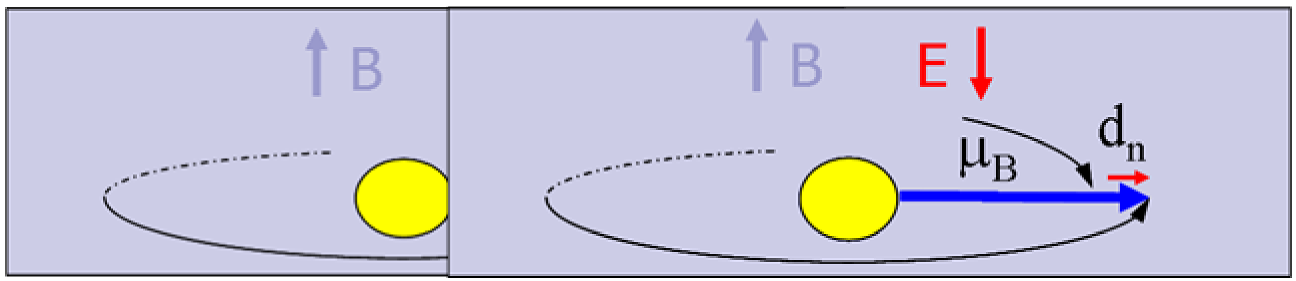
~ 50 years

Last

RAL-Sussex-ILL
$d_n < 2.9 \times 10^{-26}$ e cm
C.A.Baker et al., PRL 97 (2006) 131801

The measurement technique

Measure the precession frequencies in a magnetic and electric field:

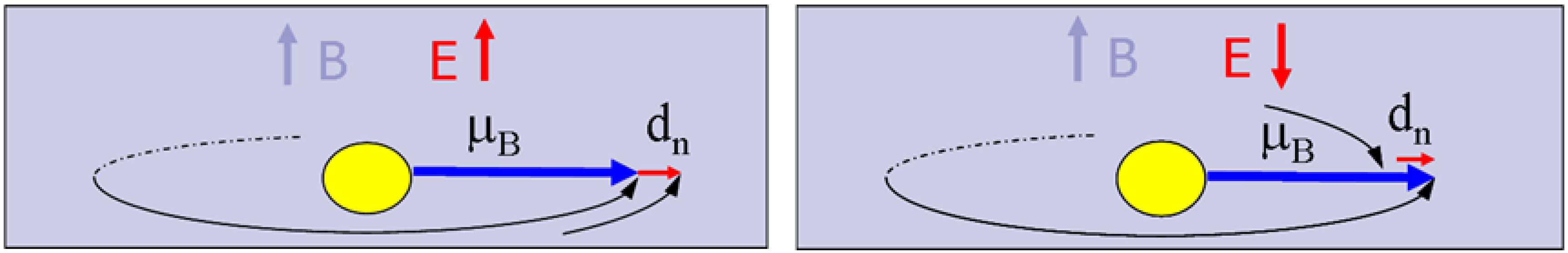


$$\hbar\omega = 2\mu_n B_{\uparrow\uparrow}$$

$$\hbar\omega = 2\mu_n B_{\uparrow\uparrow} + 2d_n E_{\uparrow\uparrow}$$

The measurement technique

Measure the difference of precession frequencies in parallel/anti-parallel fields:



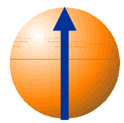
$$\hbar \Delta \omega = 2d_{\mathrm{n}}\left(E_{\uparrow\uparrow} + E_{\uparrow\downarrow}\right) + 2\mu_{\mathrm{n}}\xcancel{\left(B_{\uparrow\uparrow} - B_{\uparrow\downarrow}\right)}$$

for $d_{\mathrm{n}} < 10^{-26}$ → $\Delta\omega/\omega < 2\times10^{-9}$

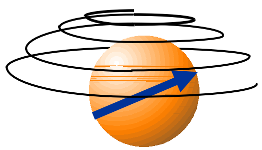
The Ramsey technique

The Ramsey technique of separated oscillating fields

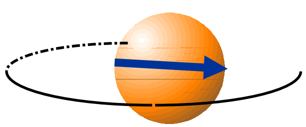
"Spin up" neutron...



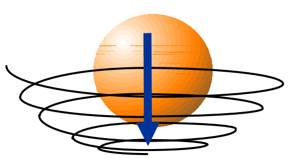
Apply $\pi/2$ spin flip pulse...



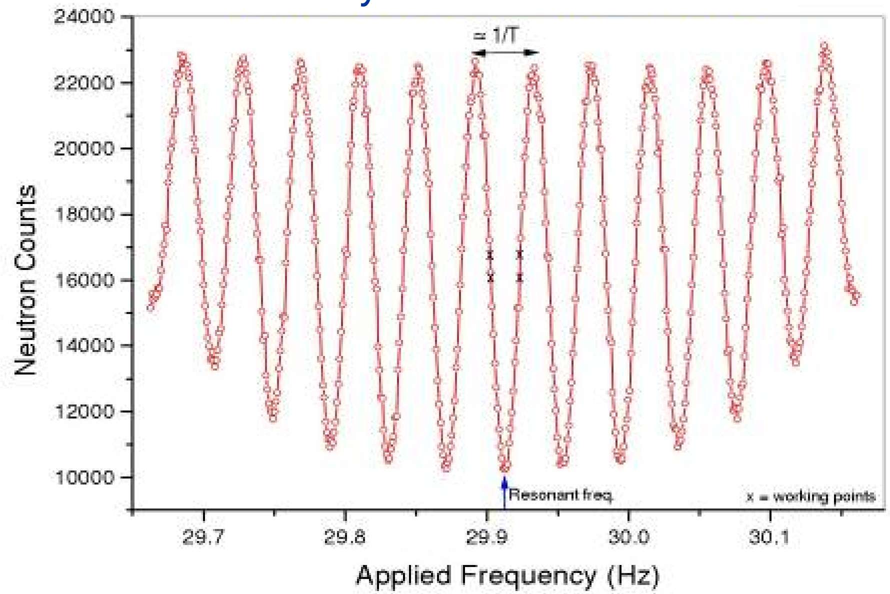
Free precession at ω_L



Second $\pi/2$ spin flip pulse.



Ramsey resonance curve



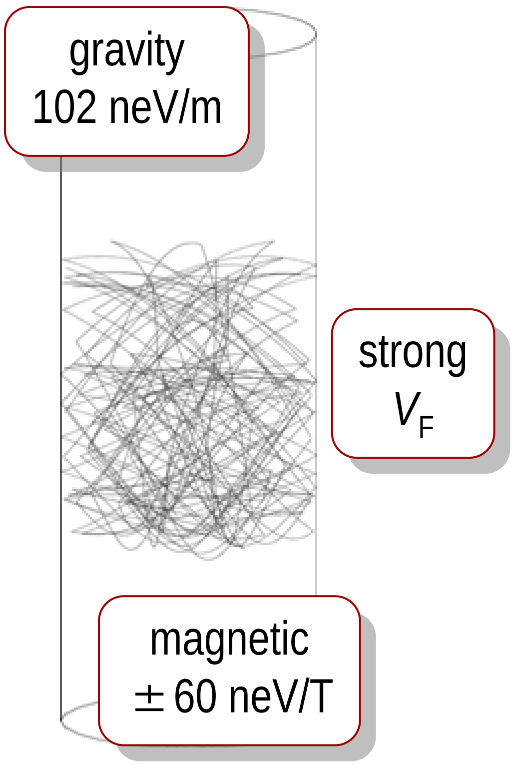
Sensitivity: $$\sigma(d_n) = \frac{\hbar}{2\alpha E T \sqrt{N}}$$

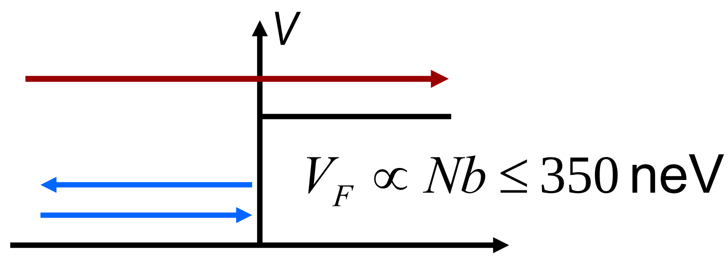
α	Visibility of resonance
E	Electric field strength
T	Time of free precession
N	Number of neutrons

Ultracold neutrons (UCN)

$$\sigma(d_n) \propto \frac{1}{T\sqrt{N}}$$

storable neutrons (UCN)



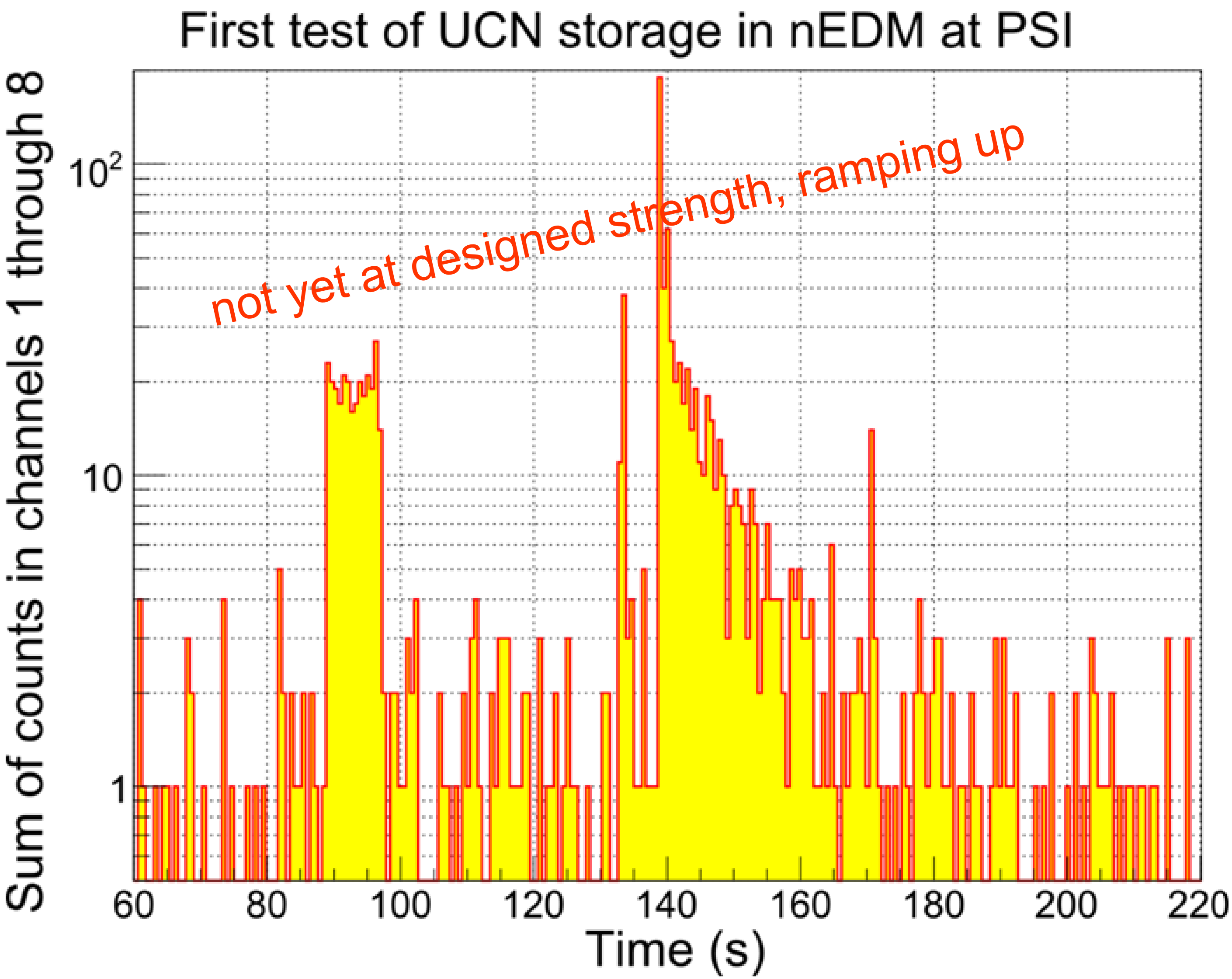


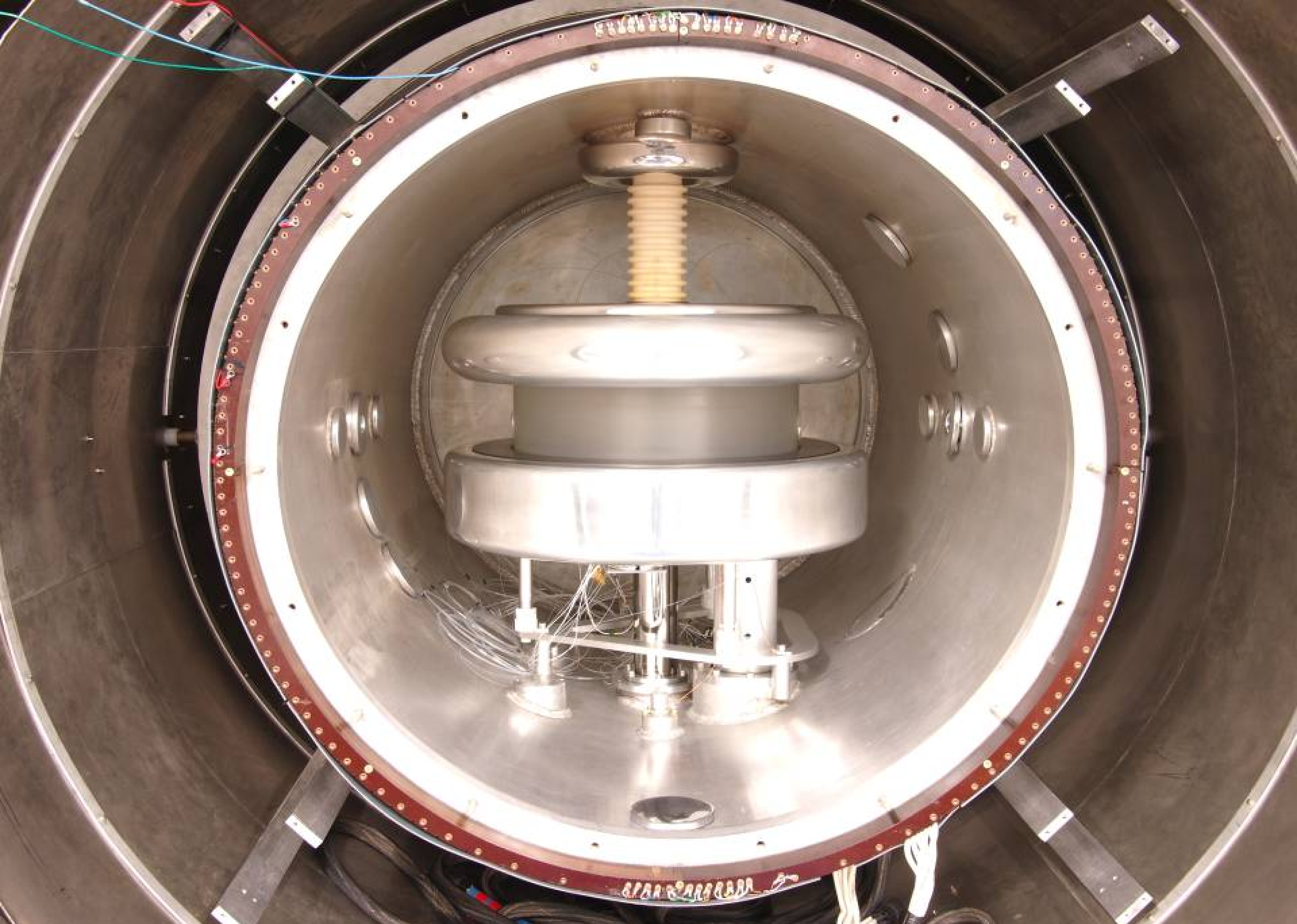
350 neV ↔ 8 m/s ↔ 500 Å ↔ 3 mK

storage properties are material dependent

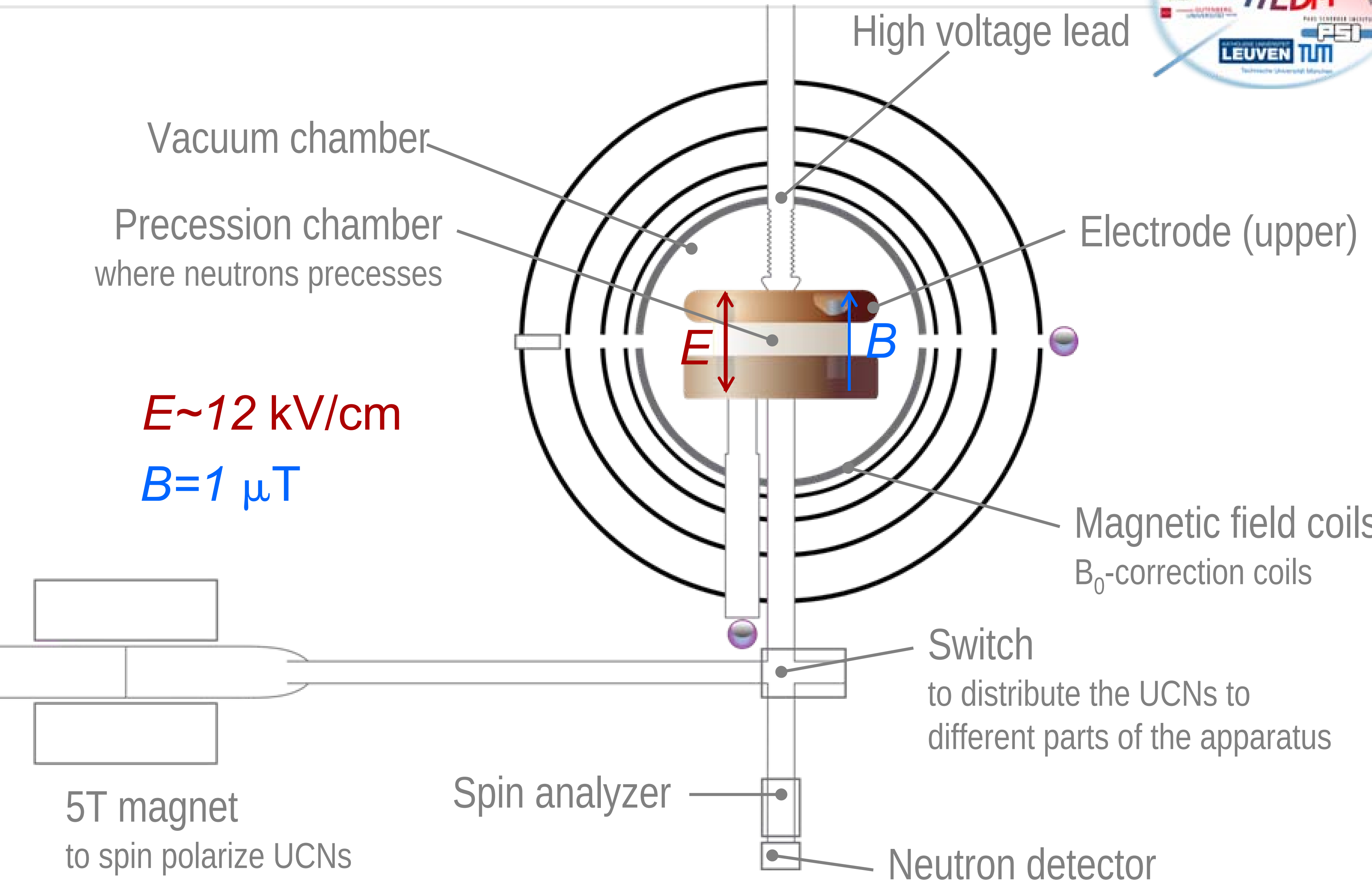
E. Fermi, 1946 , Ya. B. Zeldovich Sov. Phys. JETP 9, 1389 (1959)

New UCN source @PSI





Apparatus

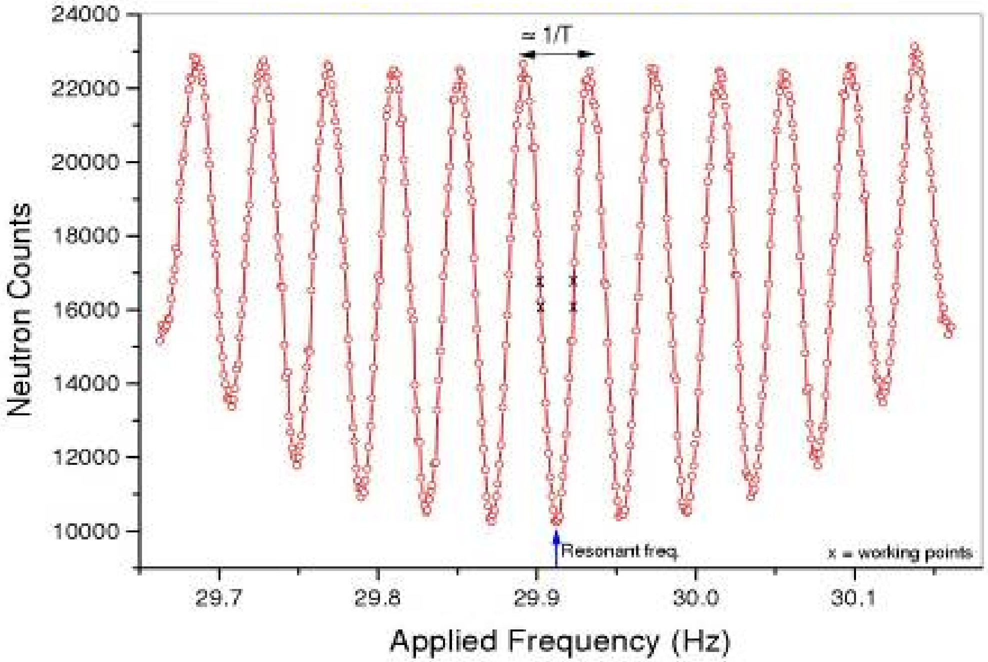


E~12 kV/cm

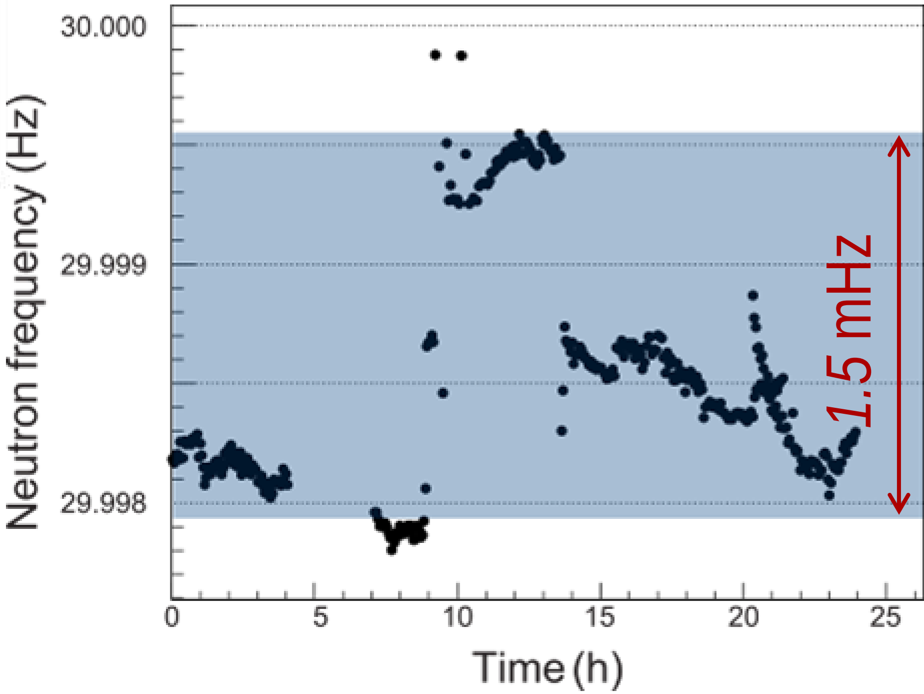
B=1 μT

Measuring frequencies with UCN

Ramsey resonance curve



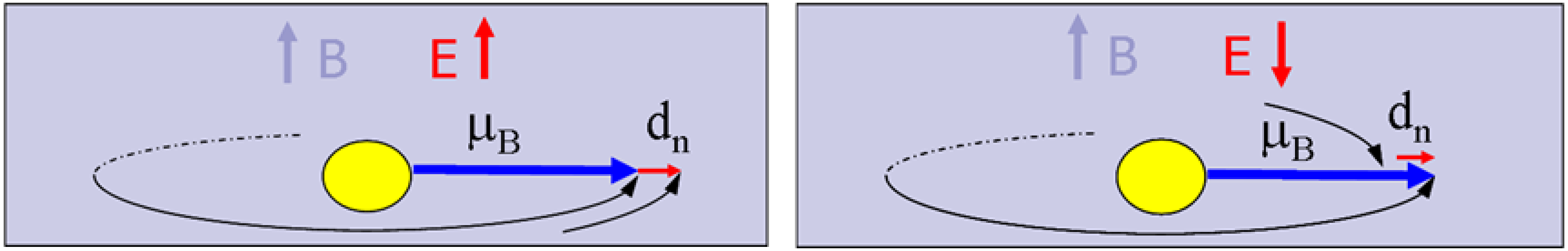
Sensitivity: $\sigma(d_n) = \dfrac{\hbar}{2\alpha E T \sqrt{N}}$



- changing polarity every ~ 1.5h
- comparing frequency +/- polarity
- aimed at sensitivity Δω ≤ 60 nHz

The measurement technique

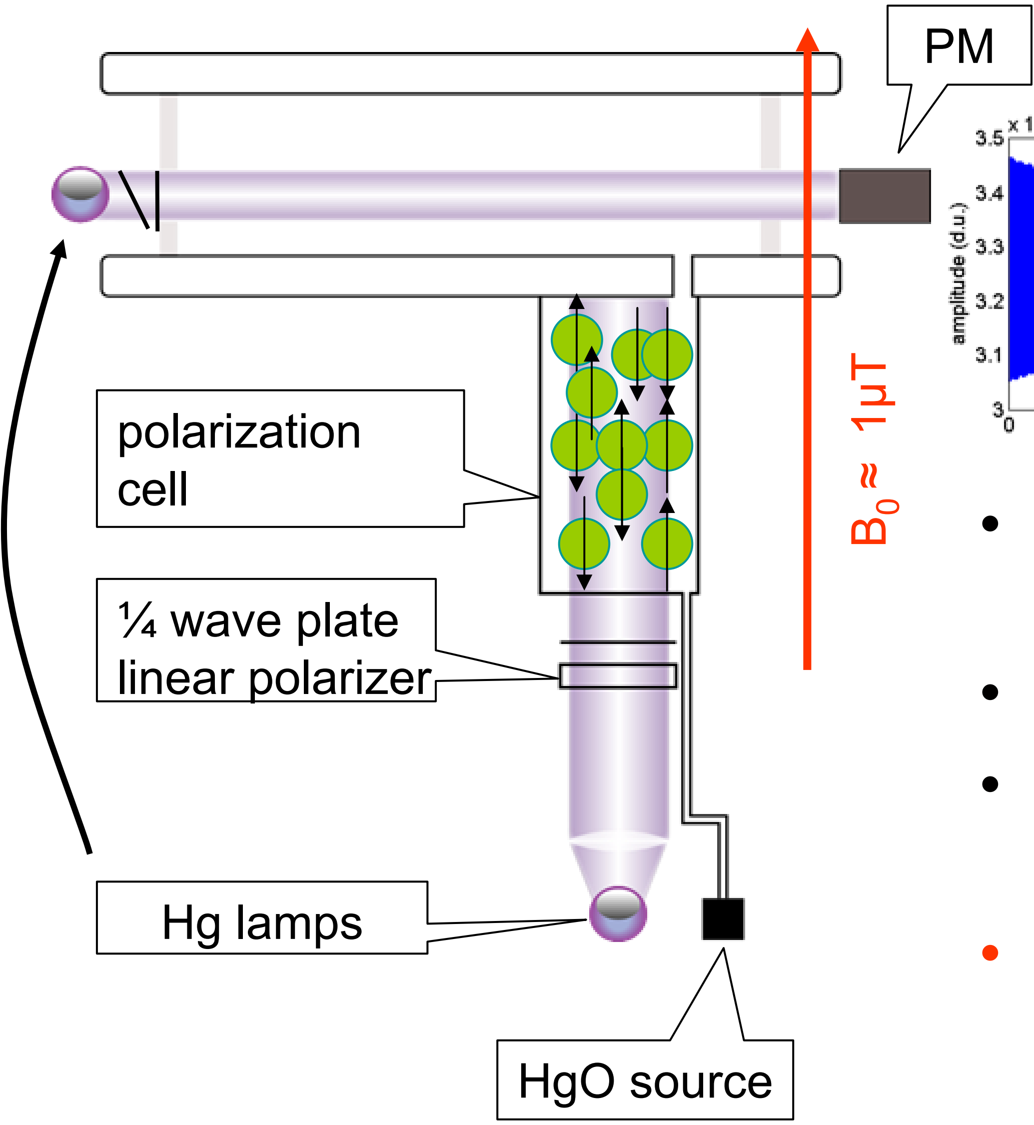
Measure the difference of precession frequencies in parallel/anti-parallel fields:

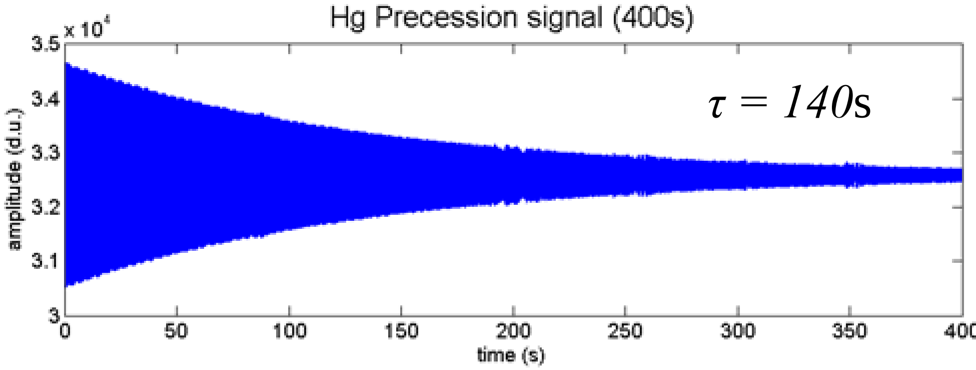


$$\hbar \Delta \omega = 2 d_n \left(E_{\uparrow\uparrow} + E_{\uparrow\downarrow} \right) + 2 \mu_n \left(B_{\uparrow\uparrow} - B_{\uparrow\downarrow} \right)$$

Active Stabilization and insitu field monitoring

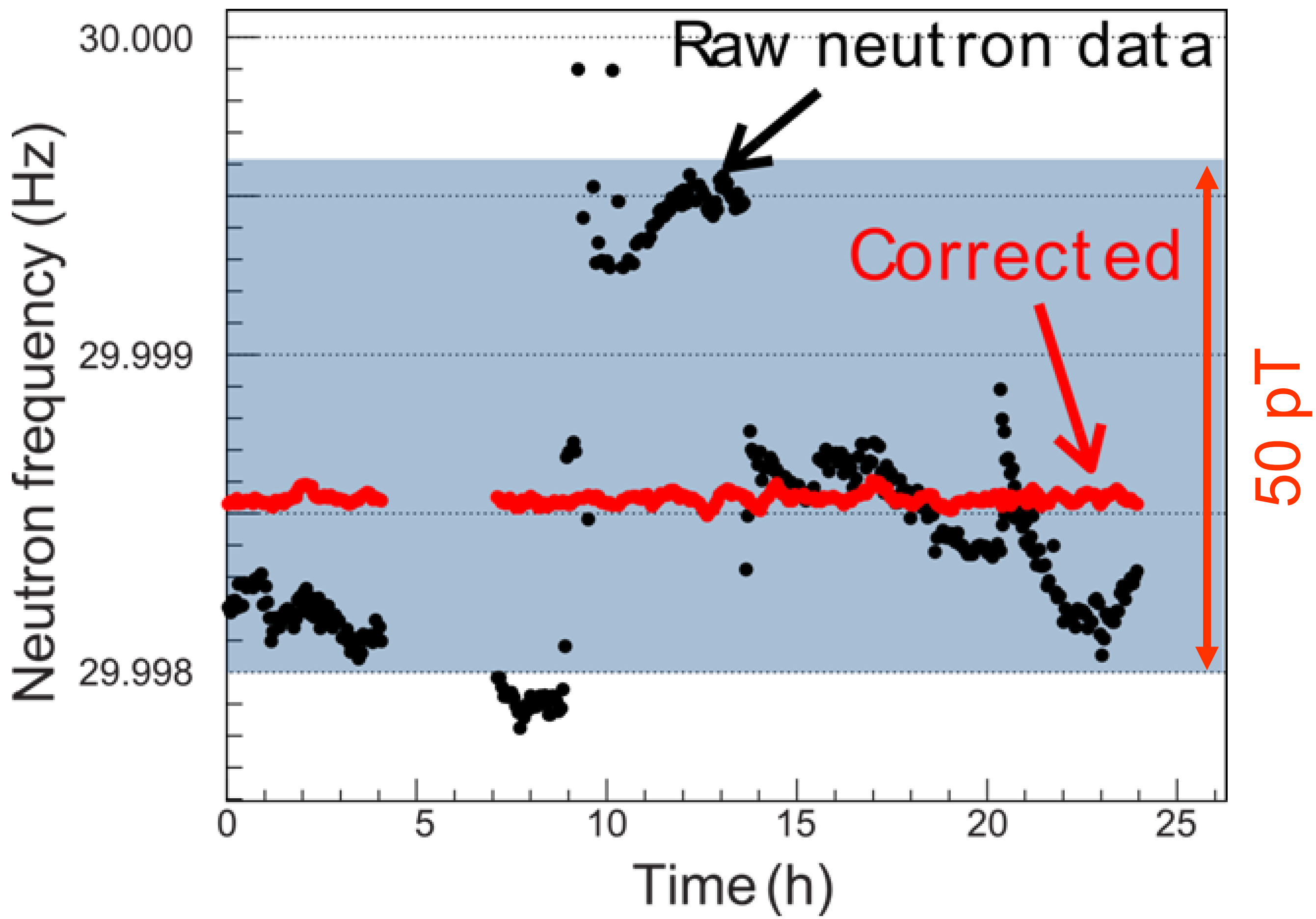
Mercury co-magnetometer





- Average magnetic field (volume and cycle)
- *σ(B) ~ 20 – 50* fT
- Center of mass different than UCN
- Important Systematic effects due to gradient fields

Corrected measurement

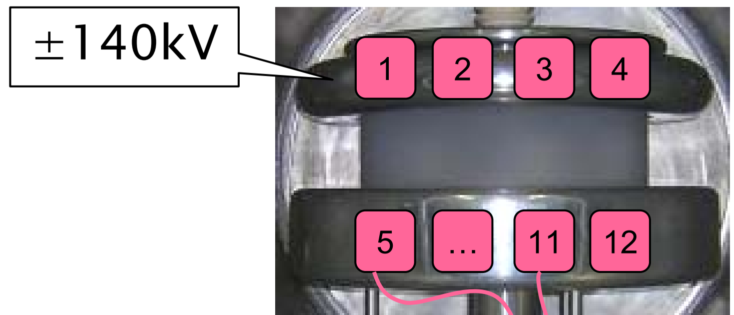


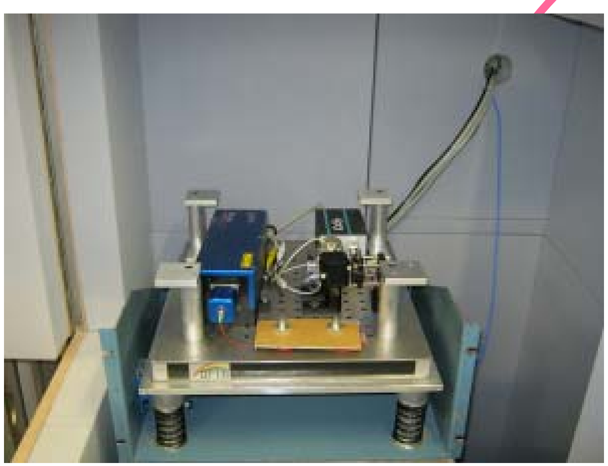
+ 12 Cesium magnetometers for field gradient measurements

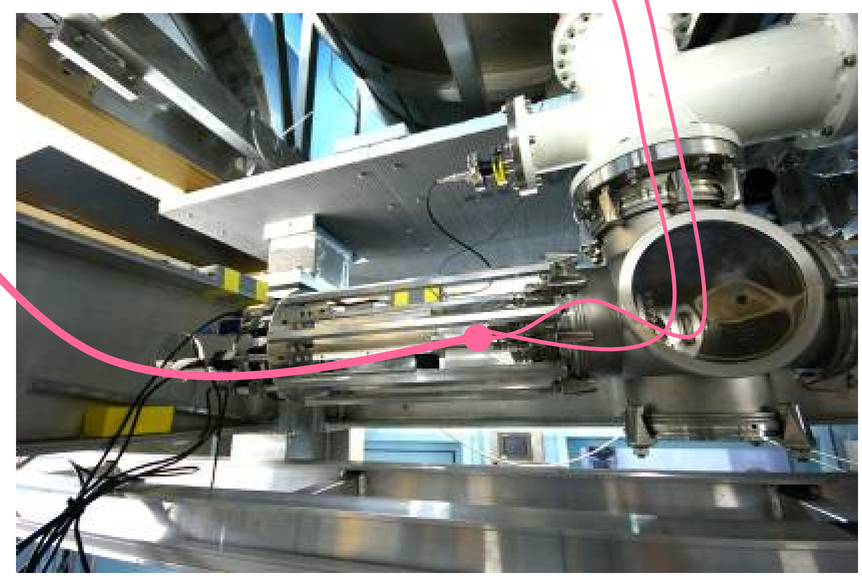
Cesium magnetometers

Monitoring of vertical magnetic gradients

- Two cesium magnetometer arrays
- Stabilized laser
- PID phase locked DAQ







Systematic effects

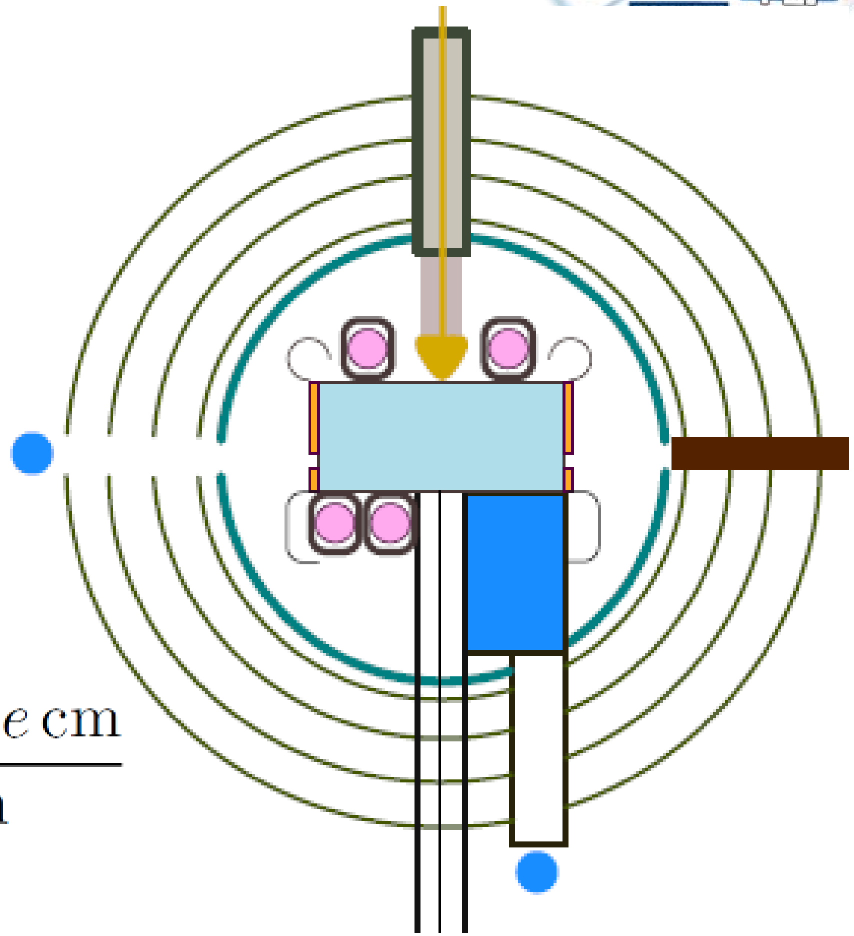
Effect	Shift (see Ref.) [10^{-27} *e* cm]	σ (see Ref.) [10^{-27} *e* cm]	σ (at PSI) [10^{-27} *e* cm]
Door cavity dipole	-5.6	2.00	**0.10**
Other dipole fields	0.0	6.00	**0.40**
Quadrupole difference	-1.3	2.00	**0.60**
v×**E** translational	0.0	0.03	0.03
v×E rotational	0.0	1.00	**0.10**
Second-order v×E	0.0	0.02	0.02
νHg light shift (geo phase)	3.5	0.80	**0.40**
νHg light shift (direct)	0.0	0.20	0.20
Uncompensated B drift	0.0	2.40	**0.90**
Hg atom EDM	-0.4	0.30	**0.06**
Electric forces	0.0	0.40	0.40
Leakage currents	0.0	0.10	0.10
ac fields	0.0	0.01	0.01
Total	-3.8	7.19	**1.37**

Uncompensated field drift

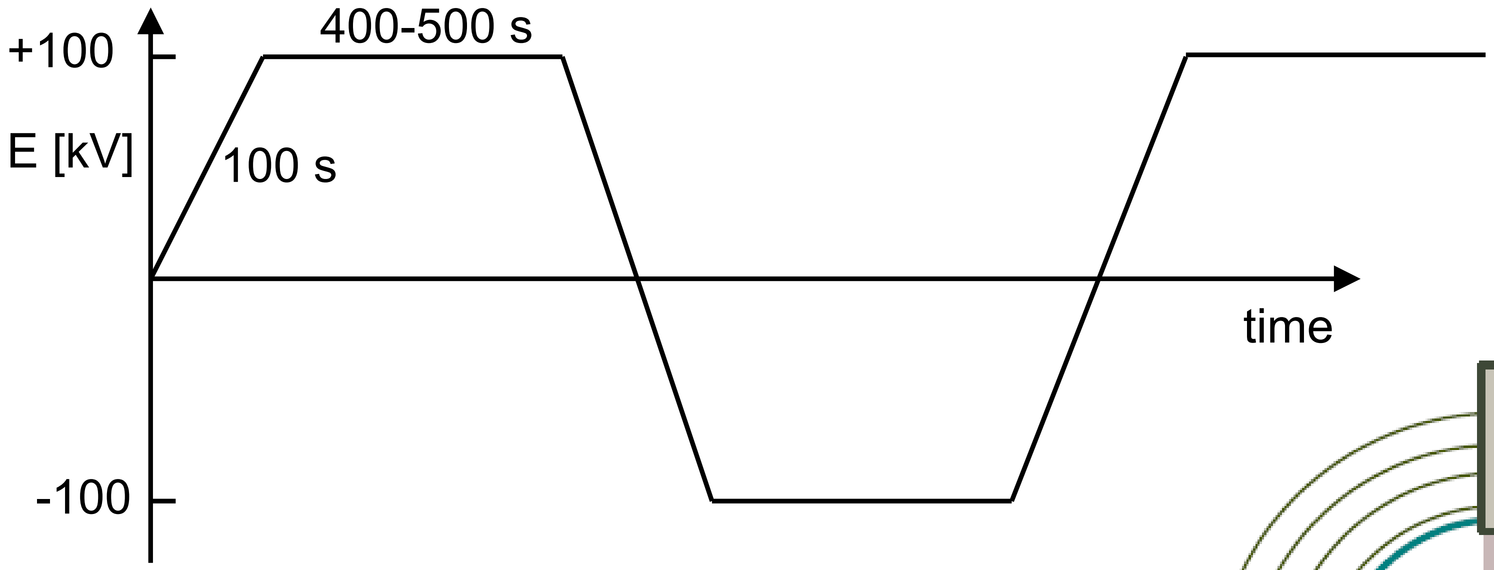
Magnetization through changing polarity

$$\sigma(d_n) = \frac{\hbar \gamma_n}{2E} \Delta h \, \delta G$$

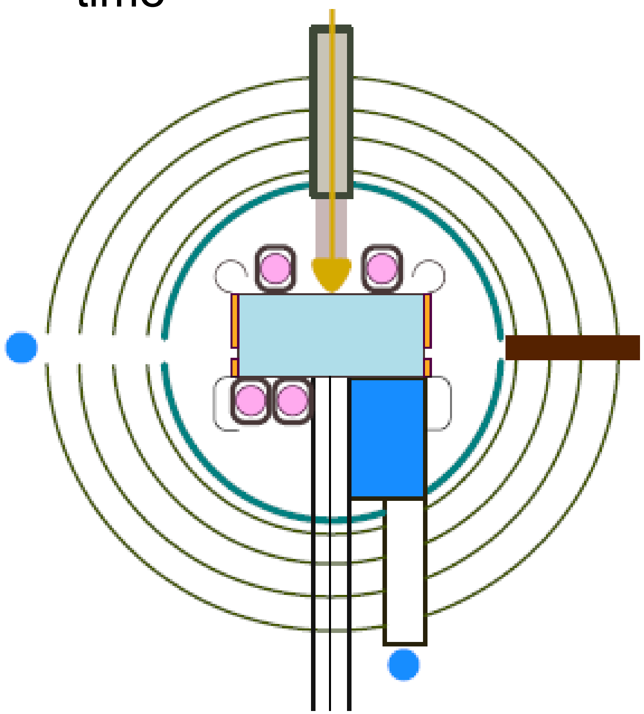
$$\frac{1.8 \times 10^{-27}\, e\,\mathrm{cm}}{1\,\mathrm{fT/cm}}$$



Uncompensated field drift

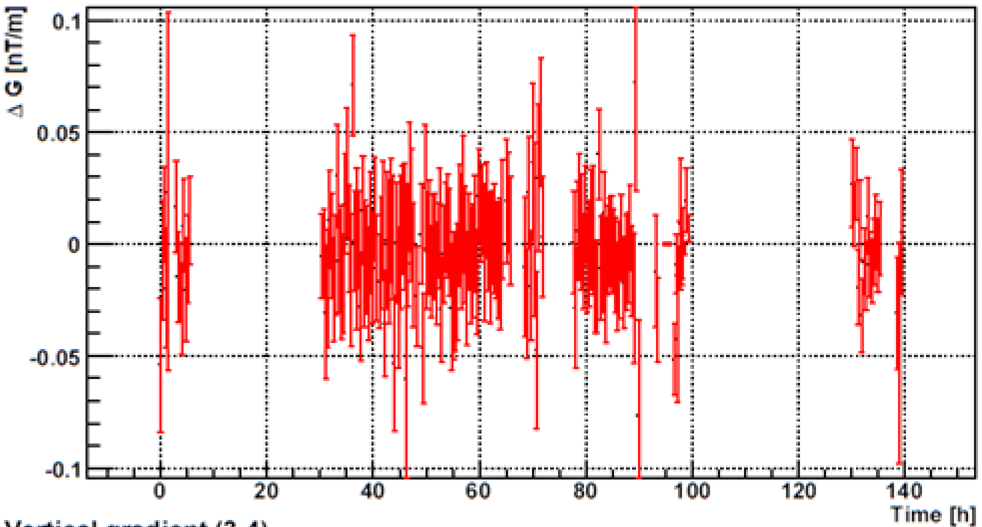


Ramping speed = 1 kV/s
Charging current = 35 nA

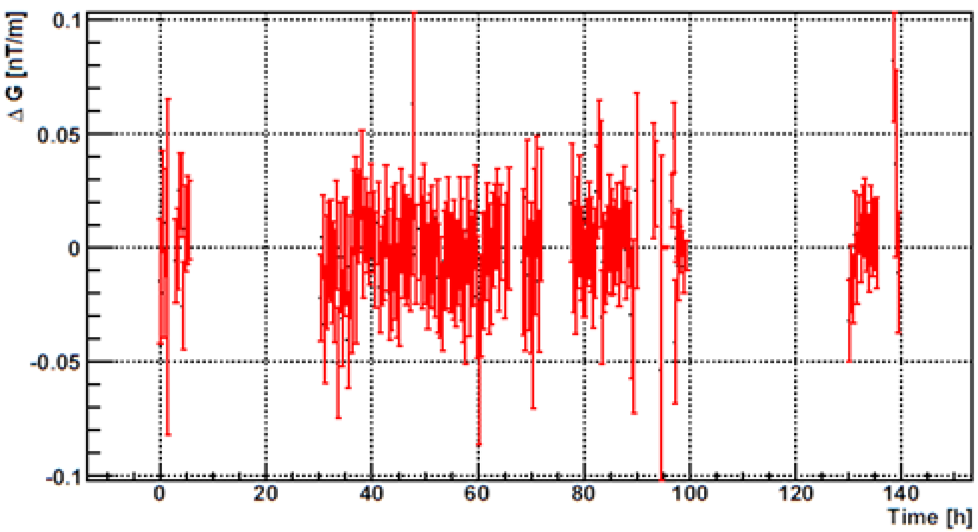


Uncompensated field drift

Vertical gradient (1-2)



Vertical gradient (3-4)



No effect is observed at the level of 2.8 fT/cm

Translates into

$$d_n^{\text{false}} = (-0.5 \pm 2.5)\times 10^{-27} \quad e\cdot\text{cm}$$

No effect is o rved at the level of 2. cm

200 nights + weekends

$$\sigma\left(d_n^{\text{false}}\right) < 0.9\times 10^{-27} \quad e\cdot\text{cm}$$

Conclusion

- UCN source is ramping up
  → first data this year (50 nights)
- Reduction of main systematic effects

$$d_n = (\,?\pm 6_{\text{stat}} \pm\ 4_{\text{sys}})\times 10^{-27}\ \text{e}\cdot\text{cm}$$

- Further improvements on systematic effects winter shut-down 2011-2012
- 200 nights of data in 2012-2013

$$d_n = (\,?\pm 3_{\text{stat}} \pm\ 2_{\text{sys}})\times 10^{-27}\ \text{e}\cdot\text{cm}$$

The Neutron EDM Collaboration

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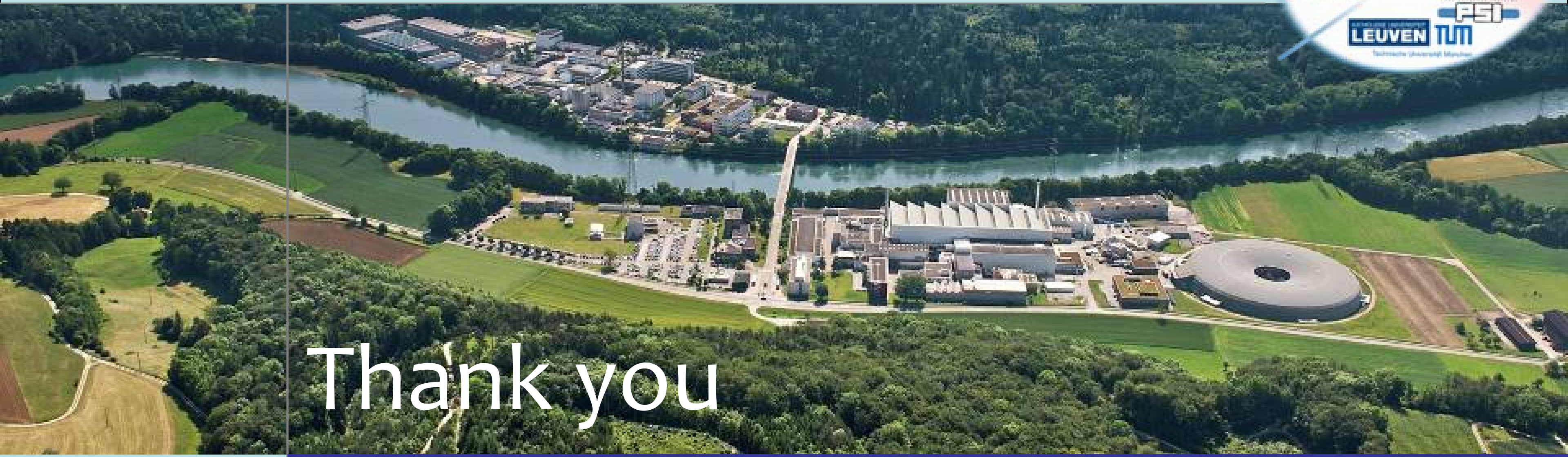

Thank you

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