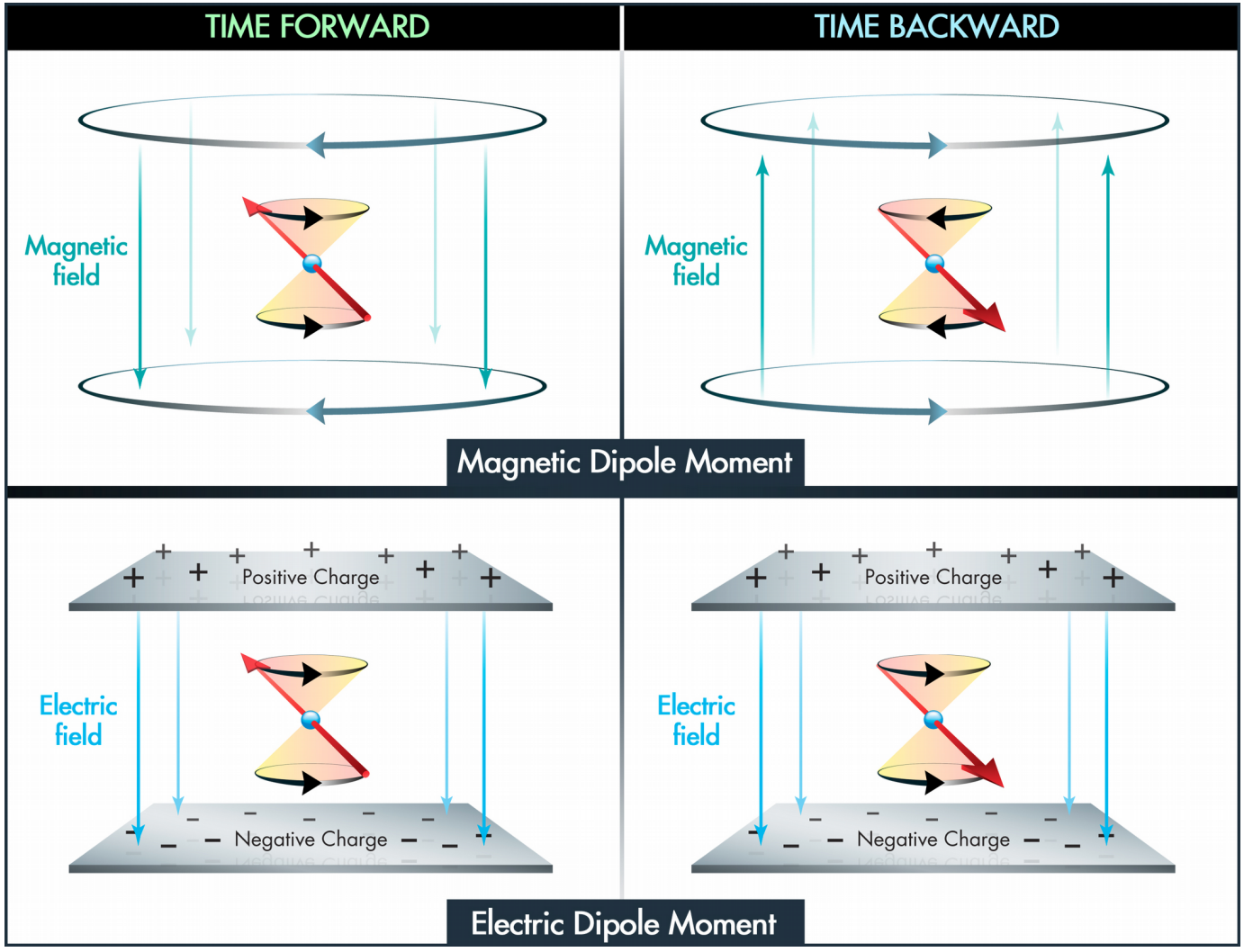
Search for the nEDM at the Paul Scherrer Institute

S. Roccia, on behalf of the nEDM collaboration at PSI

- nEDM
- n2EDM

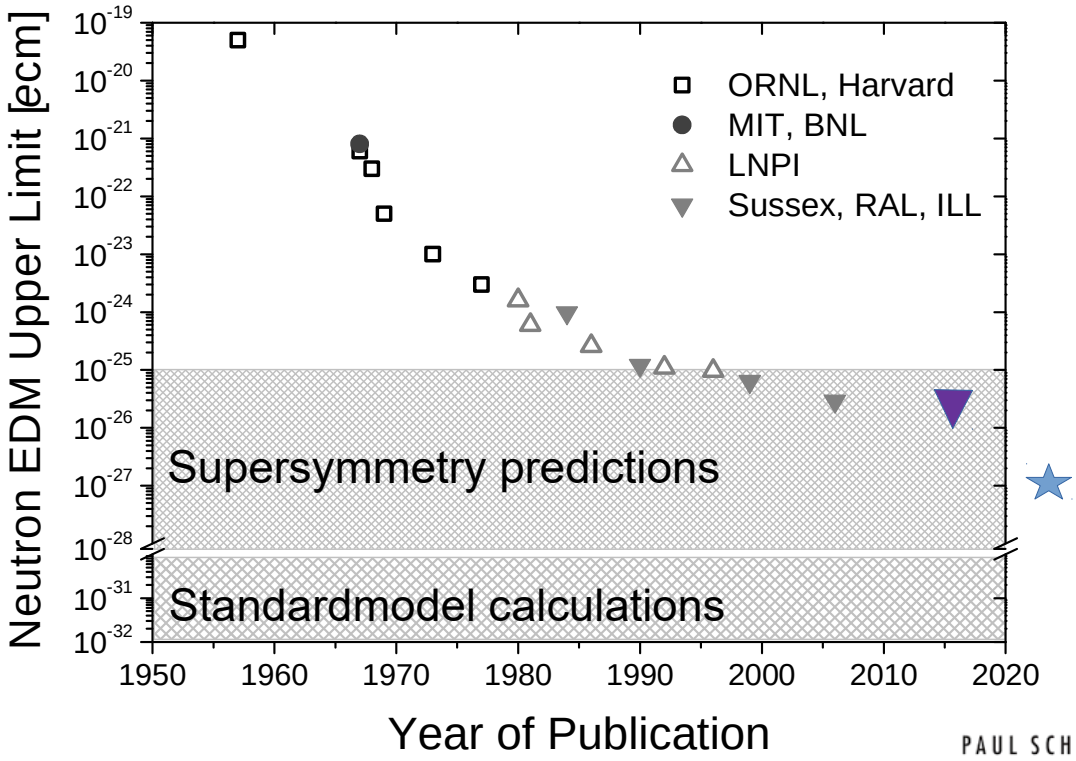
The nEDM collaboration

Welcome University of Bern

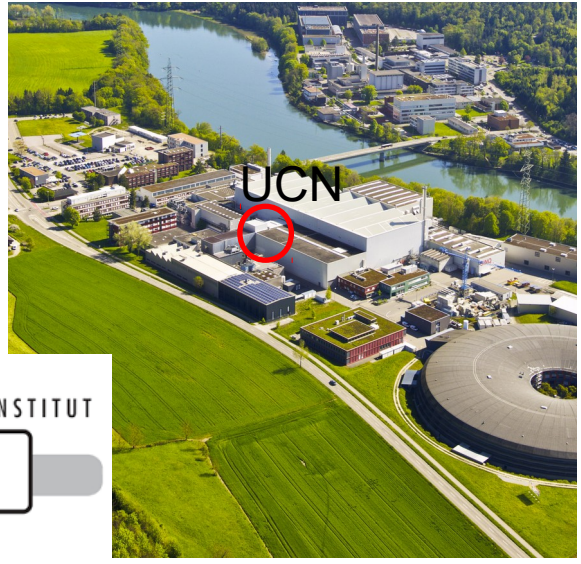


$$H = -\vec{\mu}.\vec{B} - \vec{d}.\vec{E}$$

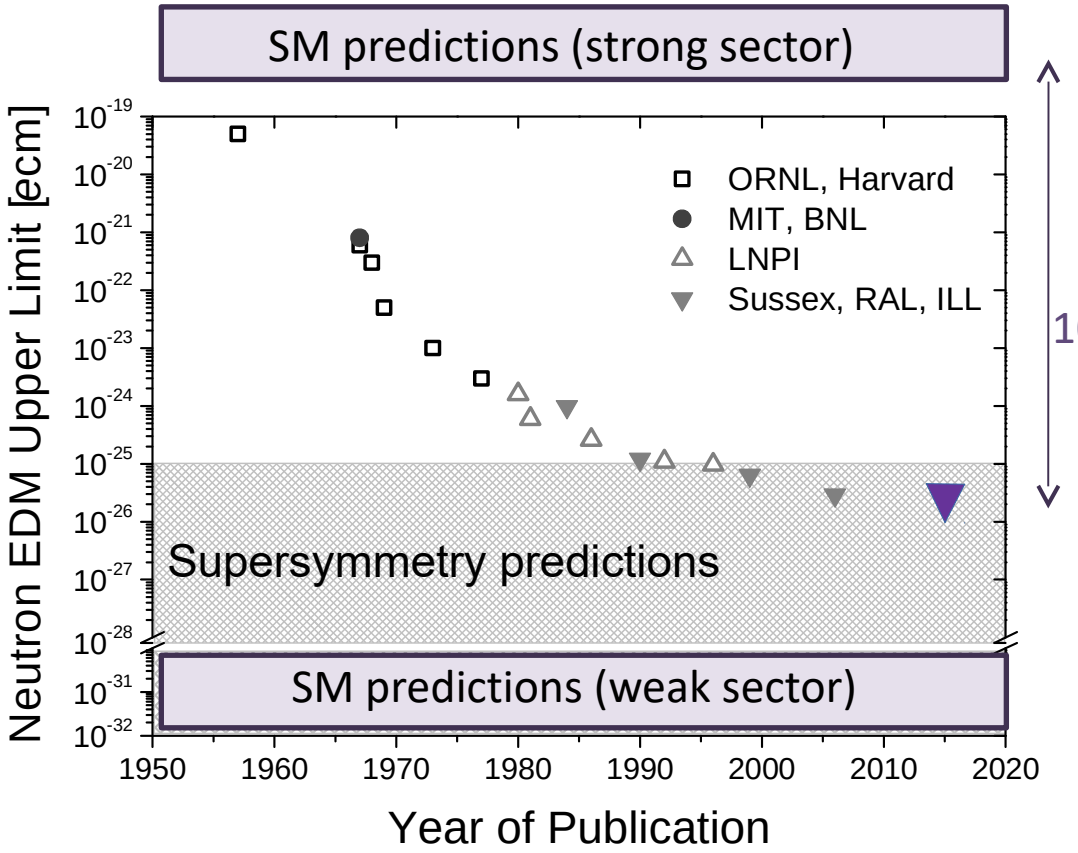
A nonzero particle EDM violates **T, P** and, assuming **CPT** conservation, also **CP**.



NEUTRONS FOR SCIENCE



PAUL SCHERRER INSTITUT
PSI



10 orders of magnitude

Strong CP problem

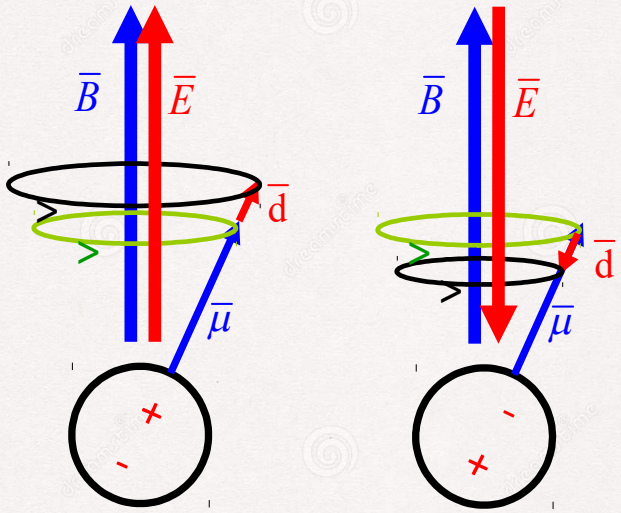
$\theta_{QCD} < 10^{-10}$

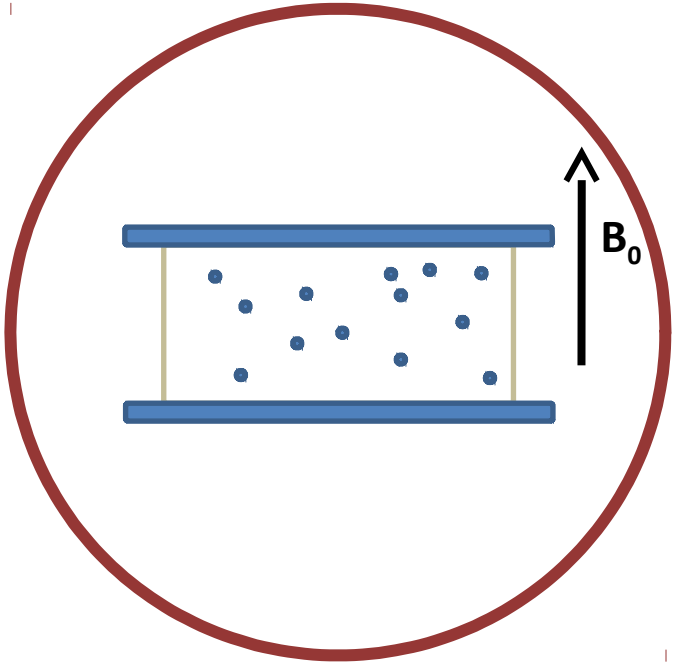
Phase in the CKM matrix

δ_{CKM}

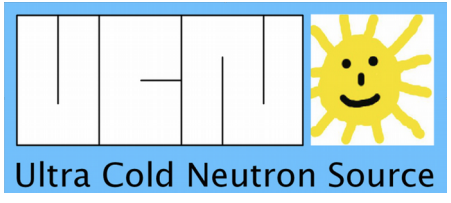
$$H = -\vec{\mu}_n.\vec{B} - \vec{d}_n.\vec{E} = \frac{hf_n}{2}$$

The nEDM





Neutrons reflected for all incidence angles: UCNs



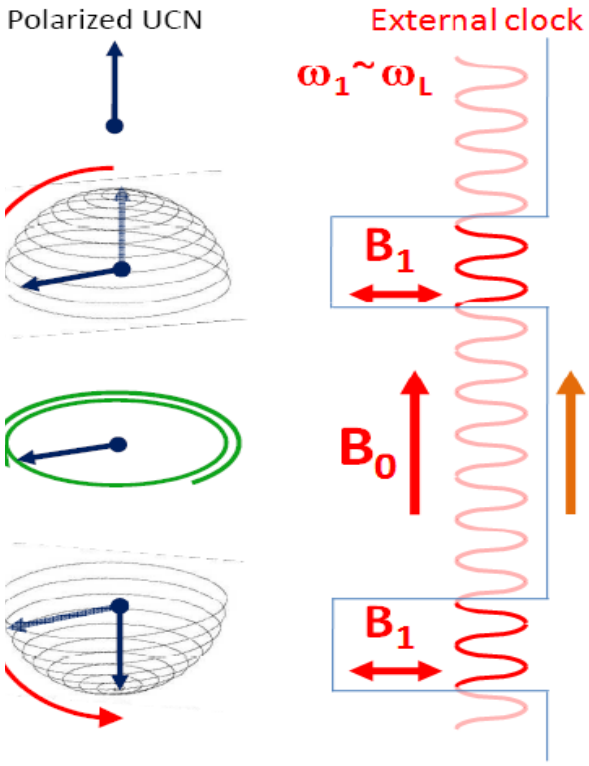
$\lambda_n \approx 800$ Å;

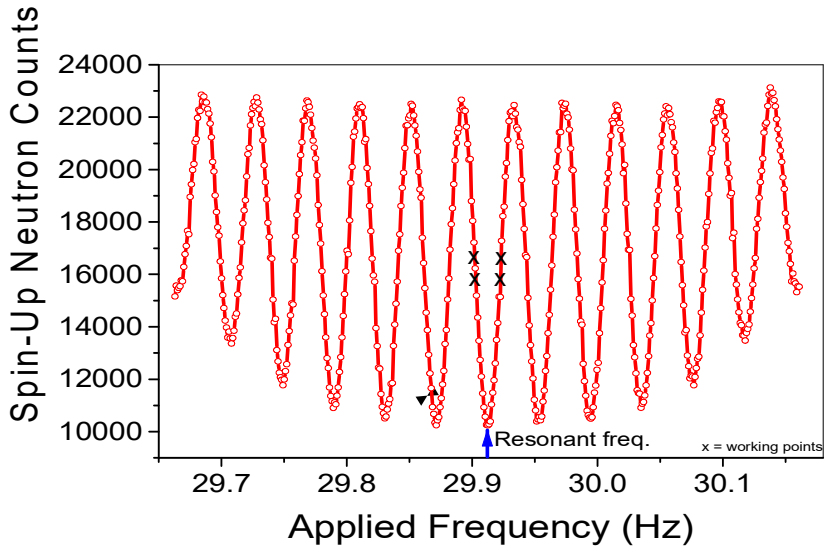
$v_n \approx 5$ m/s;

$T_n \approx 2$ mK ;

$E_n \approx 130$ neV

The Ramsey's method of separated oscillating fields

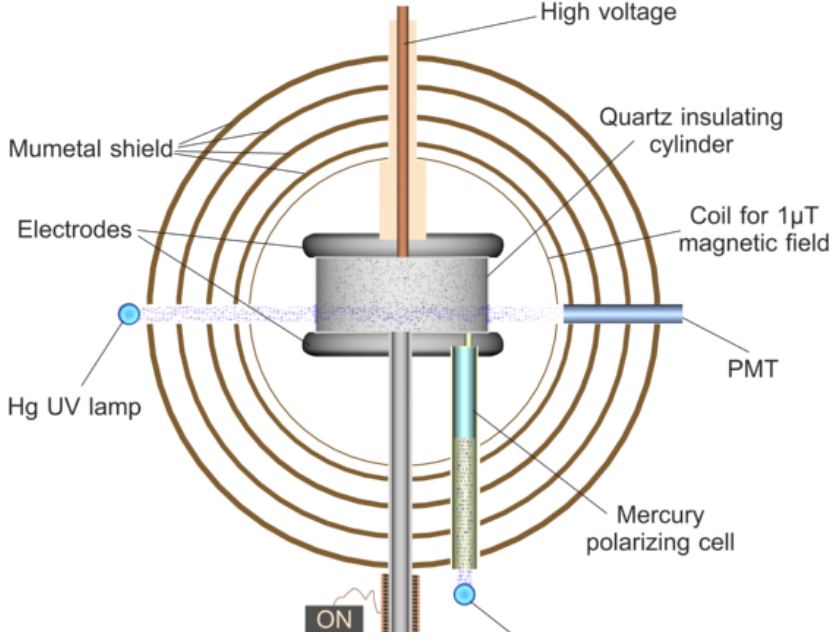




$$\sigma(f_n) = \frac{\Delta\nu}{\alpha\sqrt{N}\pi}$$

First limitation ….. Magnetic field fluctuations

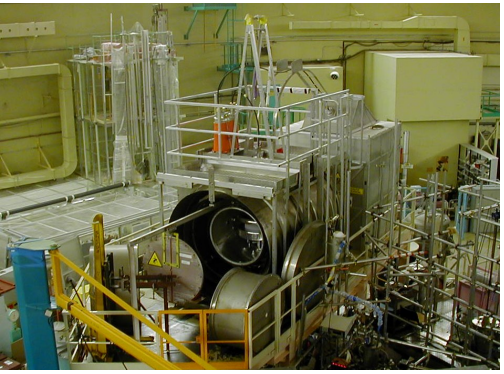
$$
\begin{array}{rcccc}
h\, f_n\,(\uparrow\uparrow) & = & 2\,\vec{\mu}_n.\vec{B}(\uparrow\uparrow) & + & 2\,\vec{d}_n.\vec{E}(\uparrow\uparrow) \\
h\, f_n\,(\uparrow\downarrow) & = & 2\,\vec{\mu}_n.\vec{B}(\uparrow\downarrow) & - & 2\,\vec{d}_n.\vec{E}(\uparrow\downarrow) \\
\hline
h(f_n\,(\uparrow\uparrow) - f_n\,(\uparrow\downarrow)) & = & 2\vec{\mu}_n.(\vec{B}(\uparrow\uparrow) - \vec{B}(\uparrow\downarrow)) & - & 2\vec{d}_n.(\vec{E}(\uparrow\uparrow) + \vec{E}(\uparrow\downarrow))
\end{array}
$$

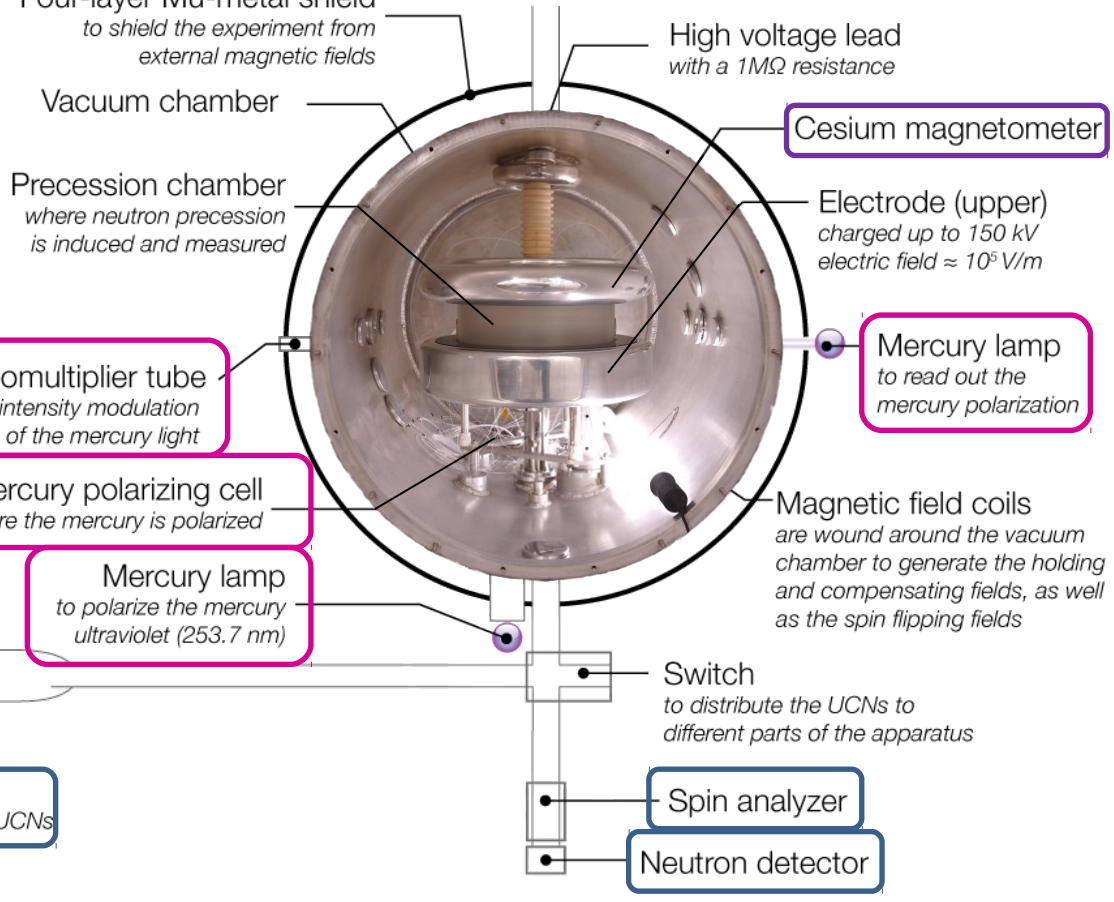


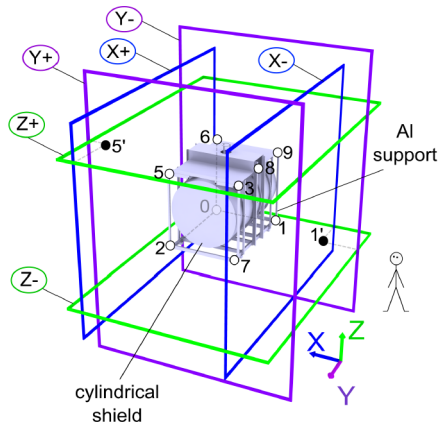
Mercury co-magnetometer (1998)

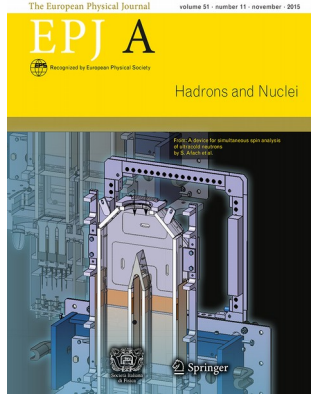
$$R = \frac{f_n}{f_{Hg}} = \frac{\gamma_n B_n}{\gamma_{Hg} B_{Hg}} = \frac{\gamma_n}{\gamma_{Hg}}$$

Cesium magnetometer array (2009)

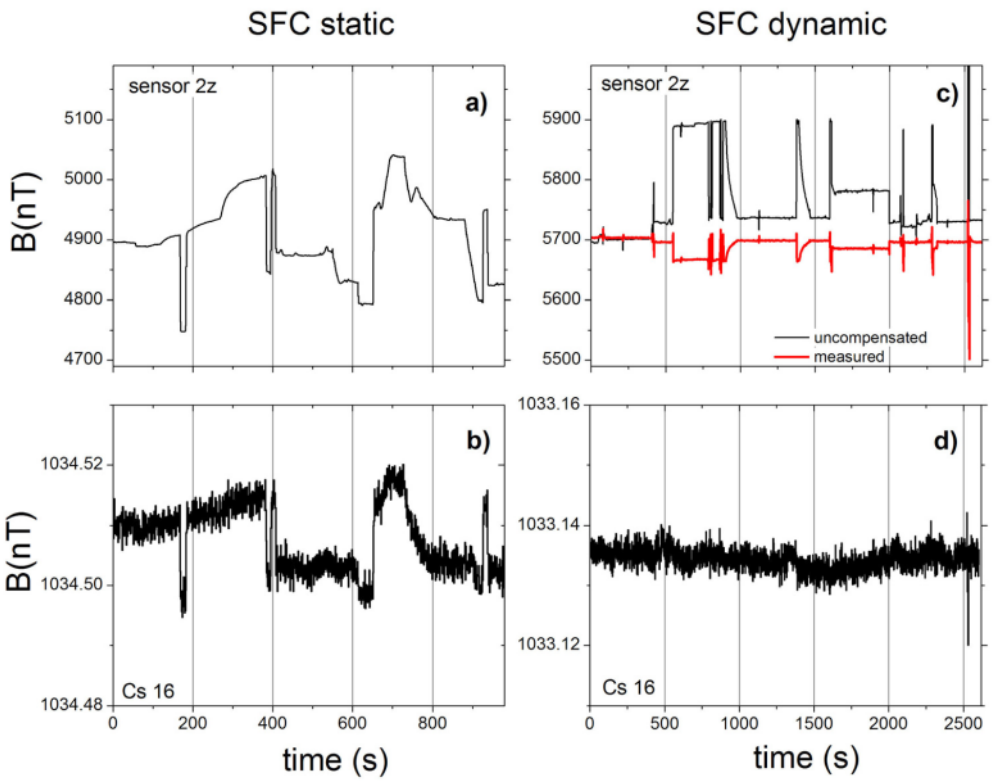


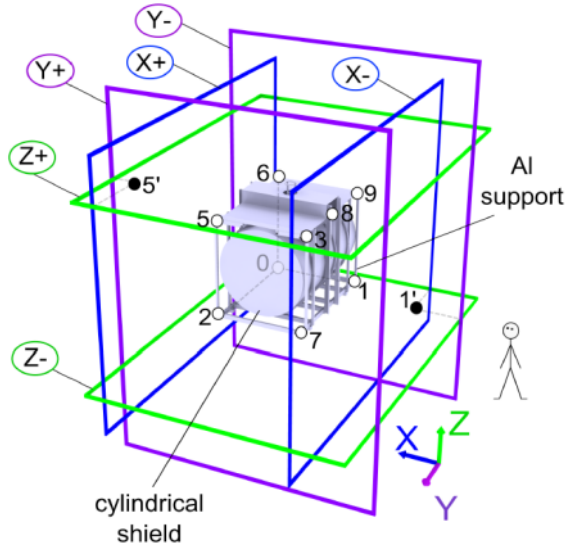

Four-layer Mu-metal shield
to shield the experiment from external magnetic fields
Vacuum chamber
Precession chamber
where neutron precession is induced and measured
High voltage lead
with a 1MΩ resistance
Cesium magnetometer
Electrode (upper)
charged up to 150 kV
electric field ≈ 10⁵ V/m
Mercury lamp
to read out the mercury polarization
Photomultiplier tube
to detect the intensity modulation of the mercury light
Mercury polarizing cell
where the mercury is polarized
Mercury lamp
to polarize the mercury ultraviolet (253.7 nm)
Magnetic field coils
are wound around the vacuum chamber to generate the holding and compensating fields, as well as the spin flipping fields
Switch
to distribute the UCNs to different parts of the apparatus
5 tesla magnet
to spin polarize the UCNs
Spin analyzer
Neutron detector


Y-
X+
X-
Y+
Z+
Z-
5'
6
9
8
5
3
0
1
1'
2
7
Al support
cylindrical shield
X
Z
Y

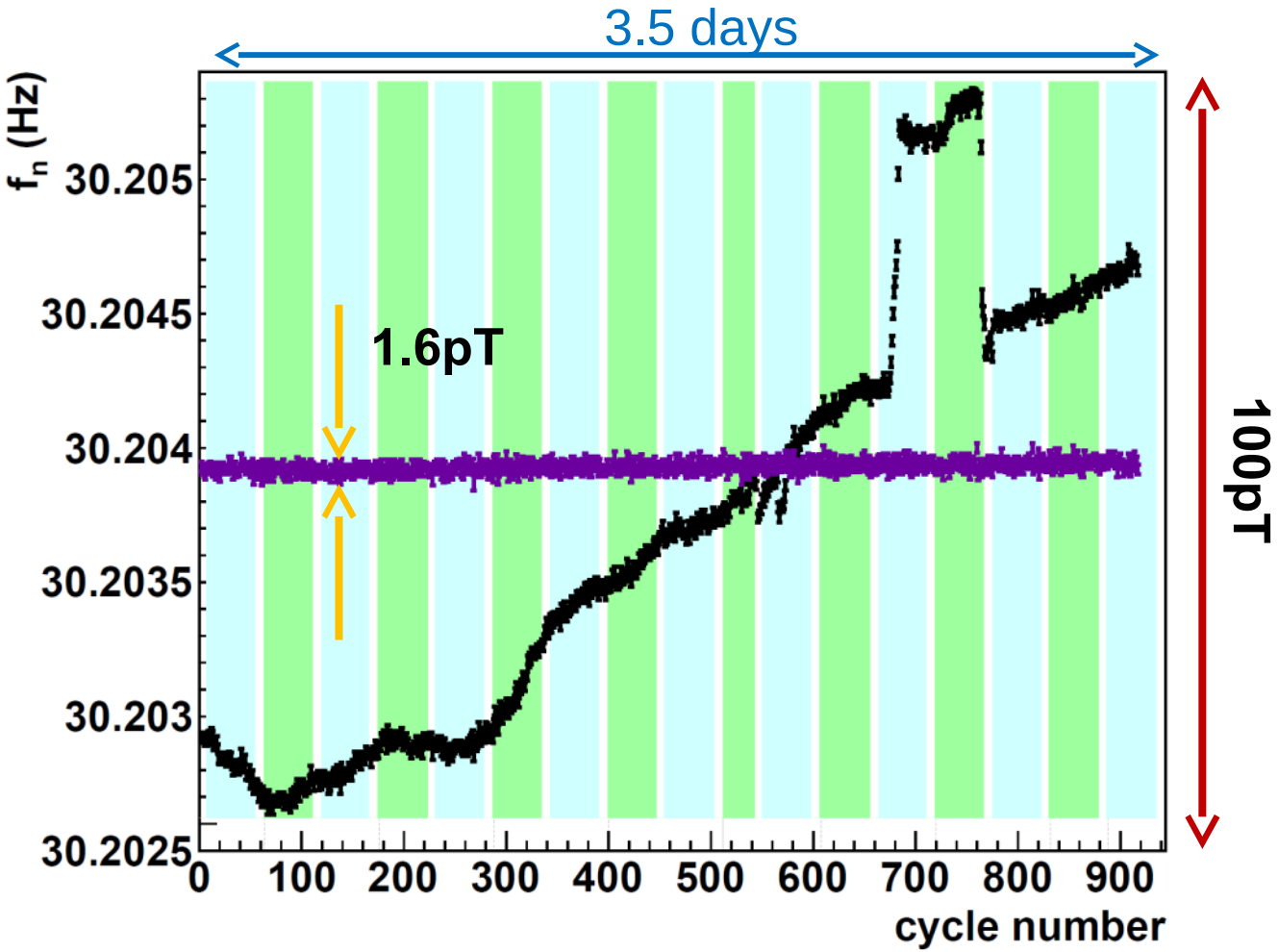

The European Physical Journal
EPJ A
Hadrons and Nuclei
Springer

- Excellent stability
  (dynamic SFC & 4 layer magnetic shield)
- Stability (AD) @400s: ~<400fT

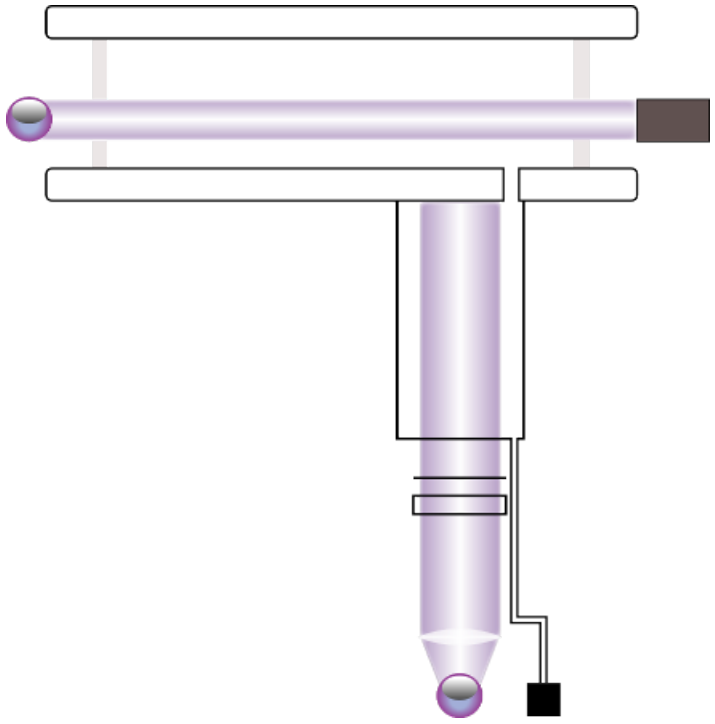




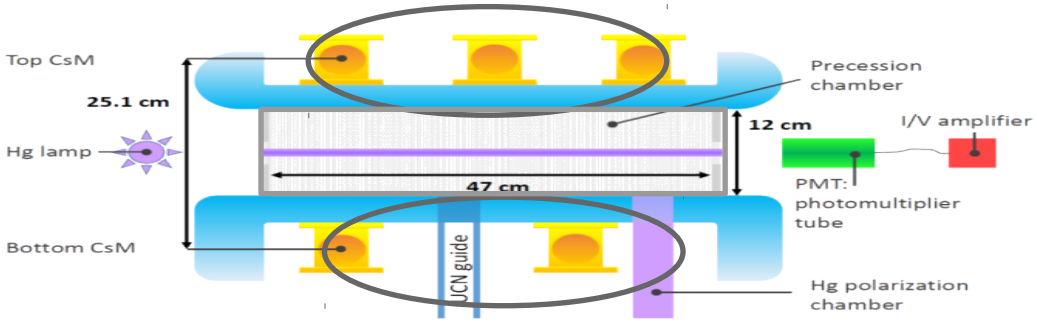
Afach et al., J. Appl. Phys. ***116****, 084510 (2014)*

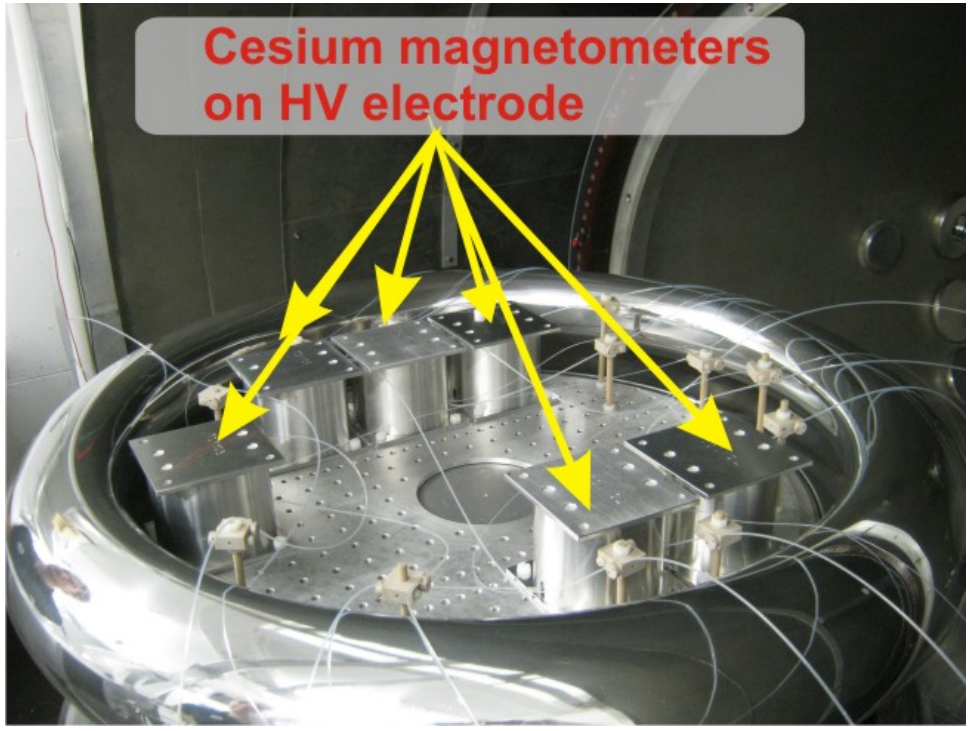


The Hg co-magnetometer



Monitoring of the vertical gradient
Homogenisation of the magnetic field





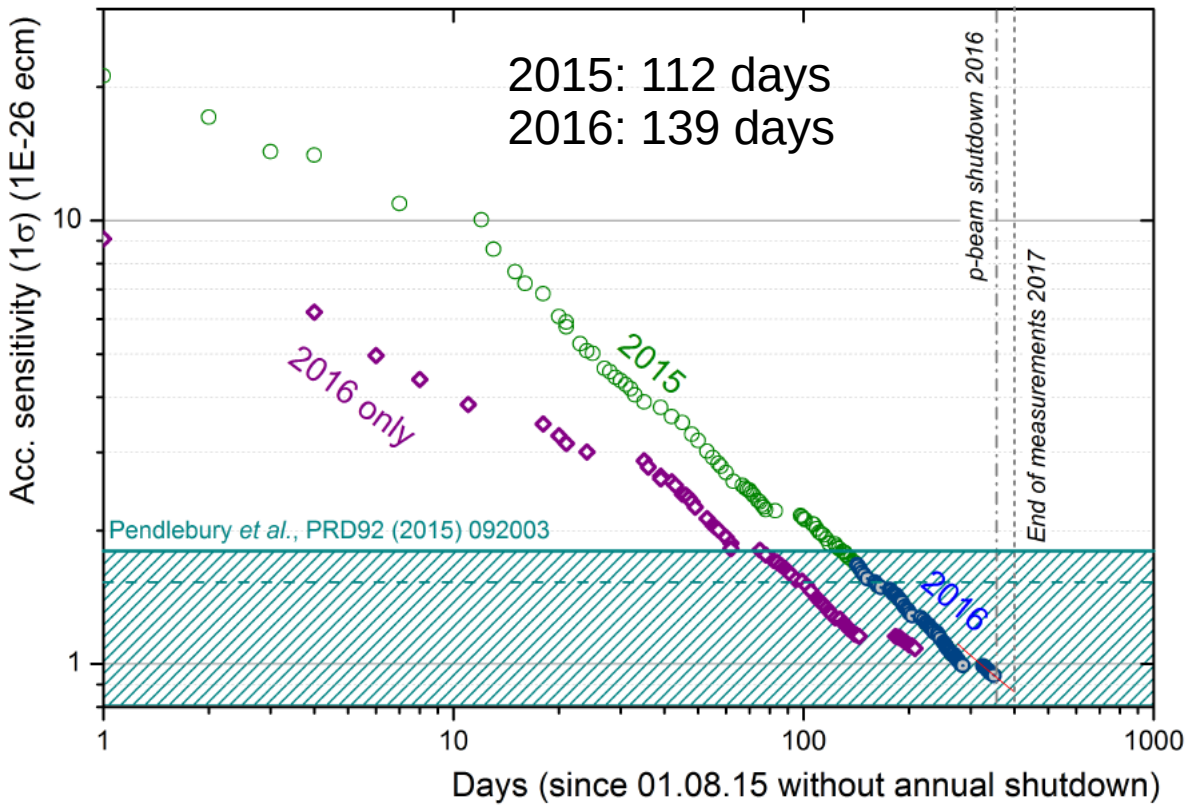
	nEDM@ILL 2006	nEDM@PSI 2016
Chamber	1	1
Diameter (cm)	47	47
Neutron/cycle	14 000	15 000
E(kV/cm)	8.3	11 (15)
T(s)	130	180
α	0.45 (0.6)	0.75 (0.80)
Sens/day(e.cm)	$30*10^{-26}$	$11*10^{-26}$

World record for sensitivity

Statistical sensitivity

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

Pushing the limit of the technique at room temperature



Accumulated raw sensitivity

2015: 1.7×10^{-26} ecm

2016: 1.1×10^{-26} ecm

Total: 0.94×10^{-26} ecm

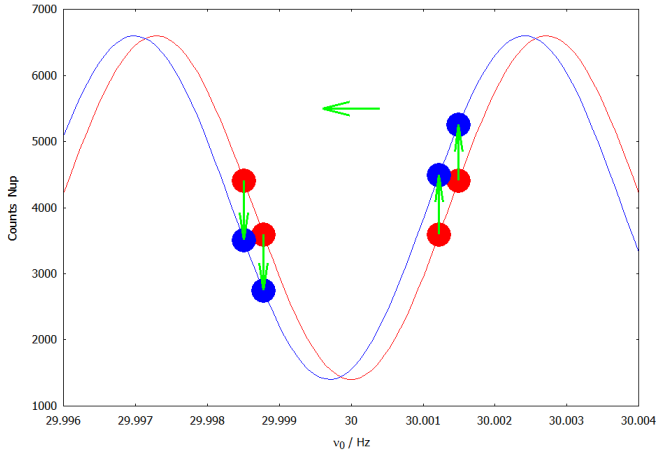
(values from simple fit)

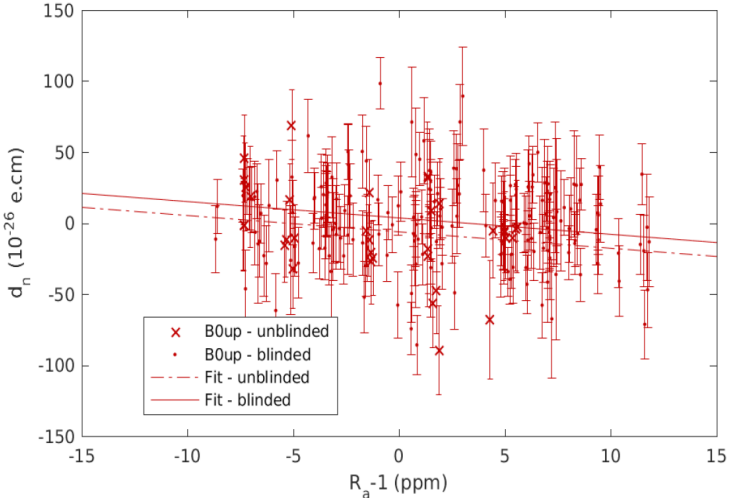
2016 : 1.5 % of available pulses missed

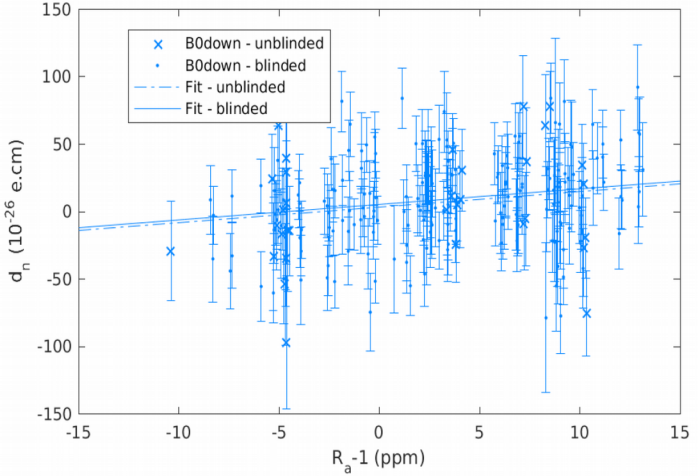
On-going analysis (preliminary)
- Blinded data
- 2 analysis teams (East/West)

Demonstrated sensitivity after analysis (2015-2016)

$$\bar{1.15\times10^{-26}}\, e\cdot\mathrm{cm}$$







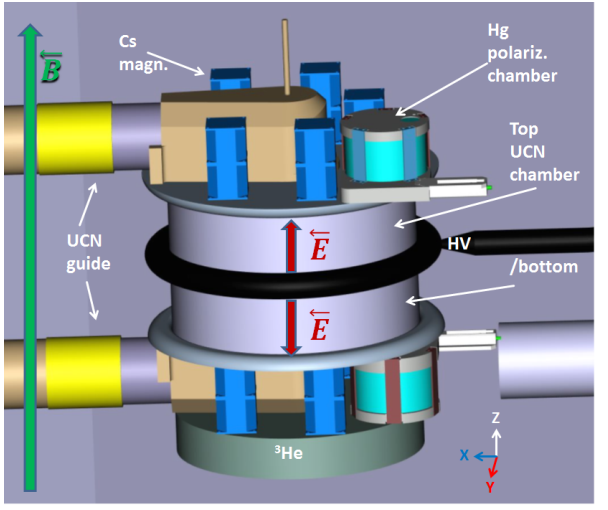
Unblinded d_n: -1.28 +- 3.85 x 10^{-26} e cm

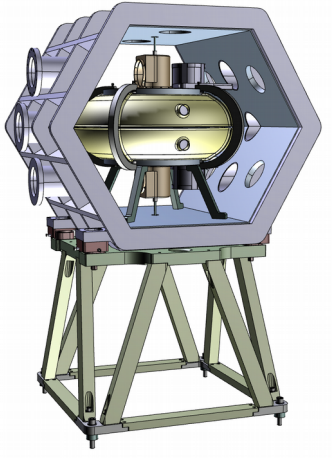
Blinded d_n: 4.63 +- 1.22 x 10^{-26} e cm

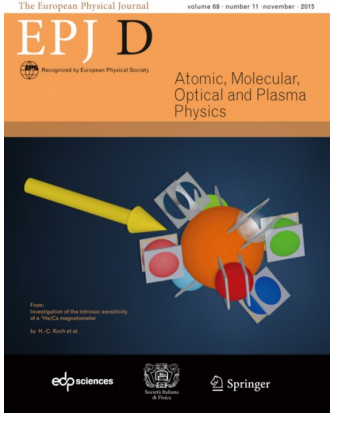
h: 0.40 +- 0.07 cm

Chi^2/DoF: 708/464, p-value: 2.02e-12

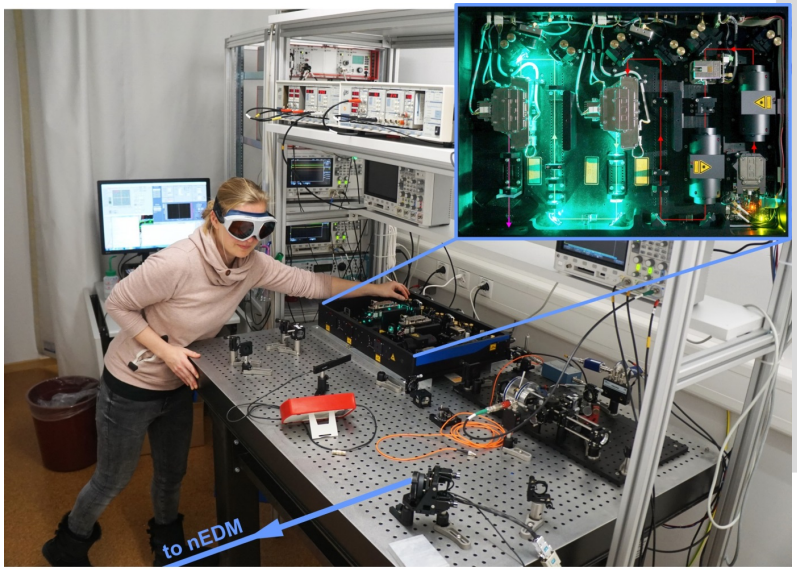
	nEDM@ILL 2006	nEDM@PSI 2016	n2EDM@PSI 2020
Chamber	1	1	2
Diameter (cm)	47	47	100
Neutron/cycle	14 000	15 000	400 000
E(kV/cm)	8.3	11 (15)	15
T(s)	130	180	180
α	0.45 (0.6)	0.75 (0.80)	0.8
Sens/day(e.cm)	$30*10^{-26}$	$11*10^{-26}$	$1.4*10^{-26}$
Sens (500 days)	$1.3*10^{-26}$	$5.0*10^{-27}$	$6.4*10^{-28}$

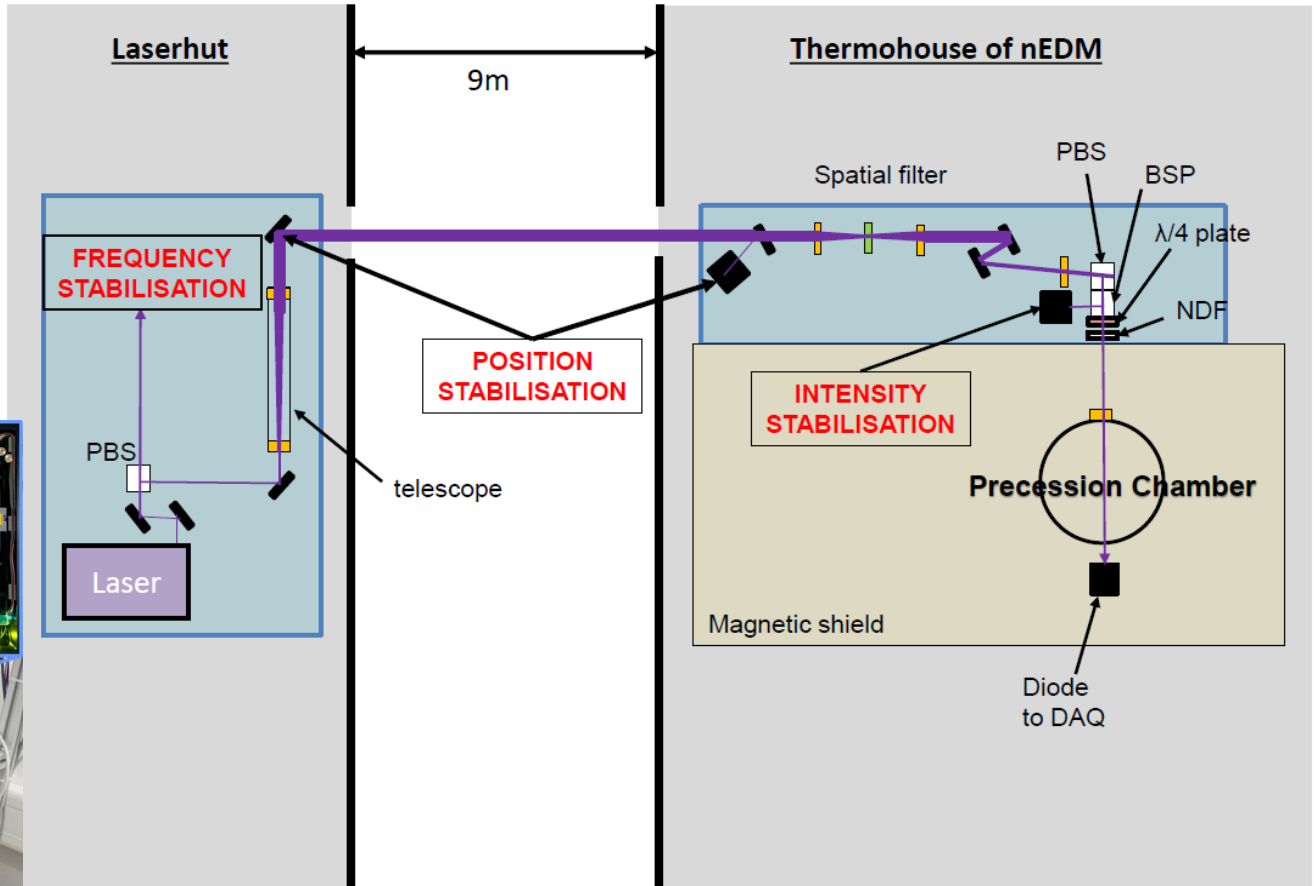






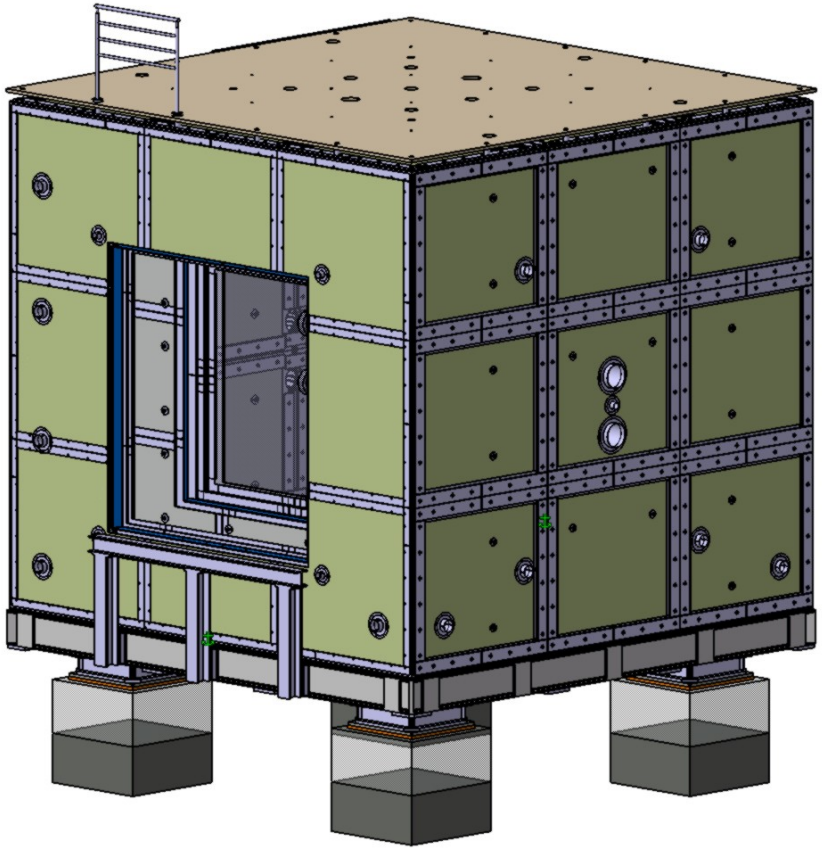
Hg co-magnetometer
nEDM sensitivity: 50-70 fT (35 fT)
n2EDM requirements: 26 fT





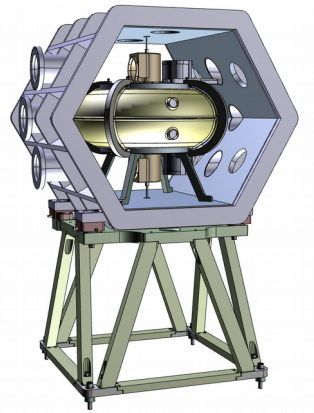
Demonstrated sensitivity: 8 fT
Used for nEDM data taking in 2017

July 2009 & October 2017 ??



December 2017 installation of the shielded room

- n2EDM R&D efforts merged into one concept design
- Highly based on demonstrated techniques
- Shielded room expected in 2017



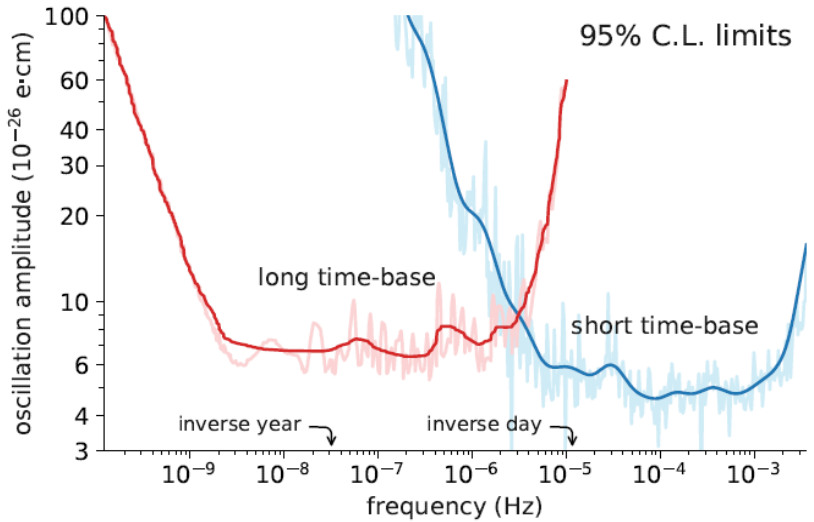
- nEDM operated with high efficiency and world-record sensitivity
- Systematic effect studies reanalysis of 2006 data
- More data in 2017 for by products

Thanks
Merci

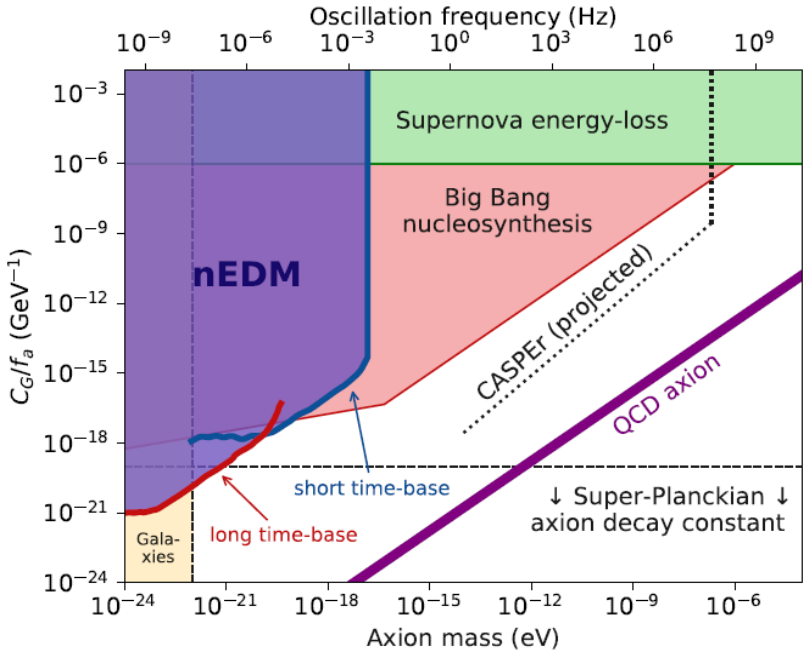
Search for axion-like dark matter through nuclear spin precession in electric and magnetic fields

C. Abel et al. (RAL-Sussex_ILL collab. + PSI collab + King's College London) → Arxiv

$$d_n(t) \approx +2.4 \times 10^{-16} \frac{C_G a_0}{f_a} \cos(m_a t)\ e \cdot \mathrm{cm}\,.$$



ILL data: long data taking



PSI data: high sensitivity
Still blinded