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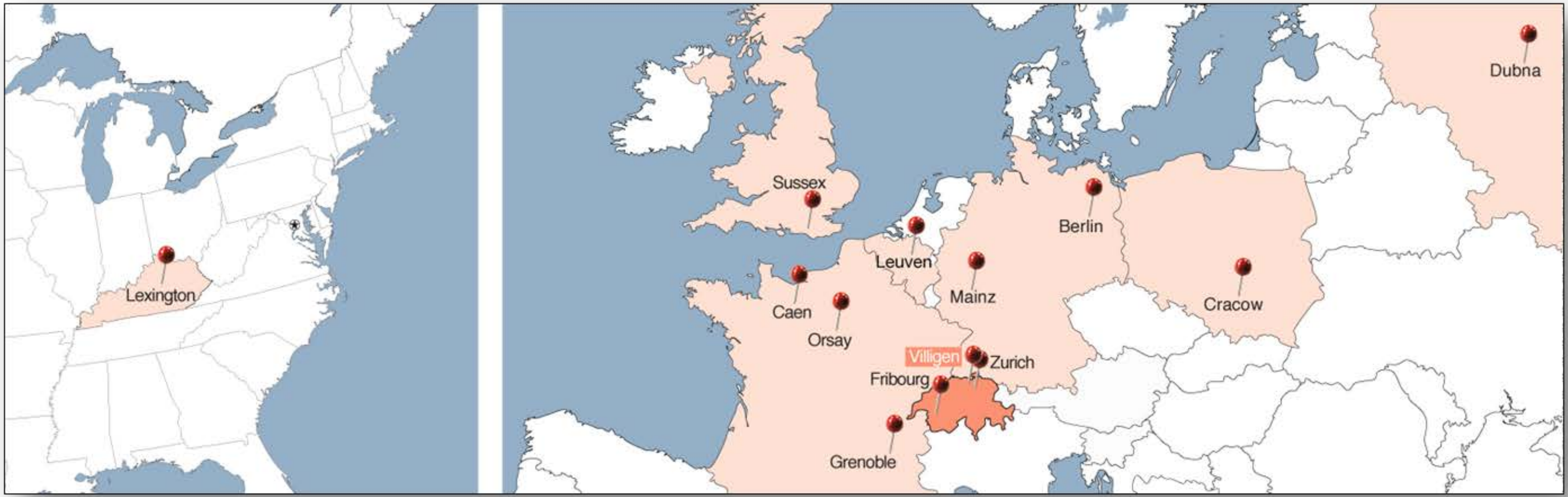
Experimental search for an electric dipole moment of the neutron

Małgorzata Kasprzak
University of Fribourg
Switzerland
on behalf of the nEDM collaboration

PANIC 2014, 25-29.08.2014, Hamburg

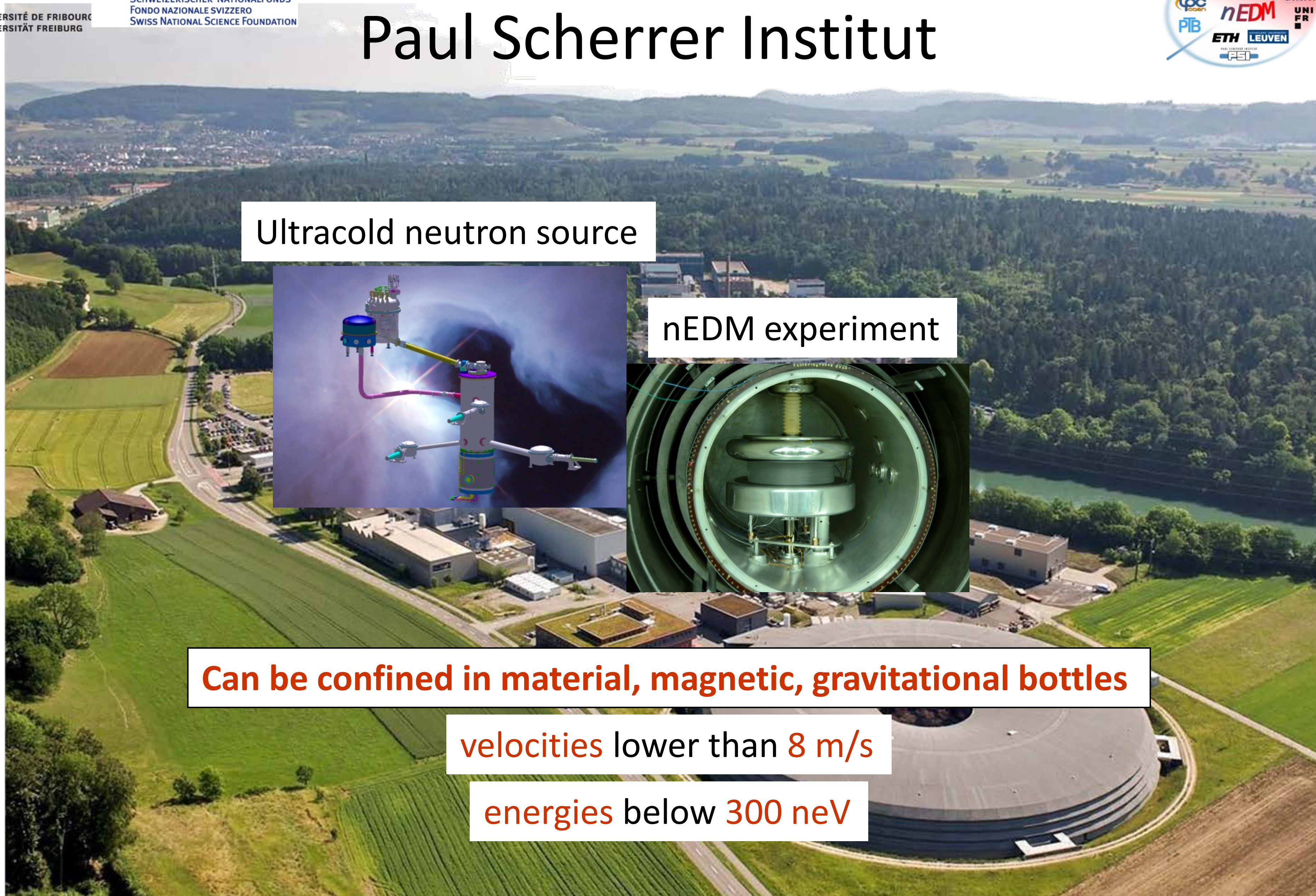
nEDM collaboration

- **About 50 members from 14 institutions**
- **Experiment is performed at the ultracold neutron (UCN) source at the Paul Scherrer Institute in Villigen (Switzerland).**



Paul Scherrer Institut

Paul Scherrer Institut



Ultracold neutron source

nEDM experiment

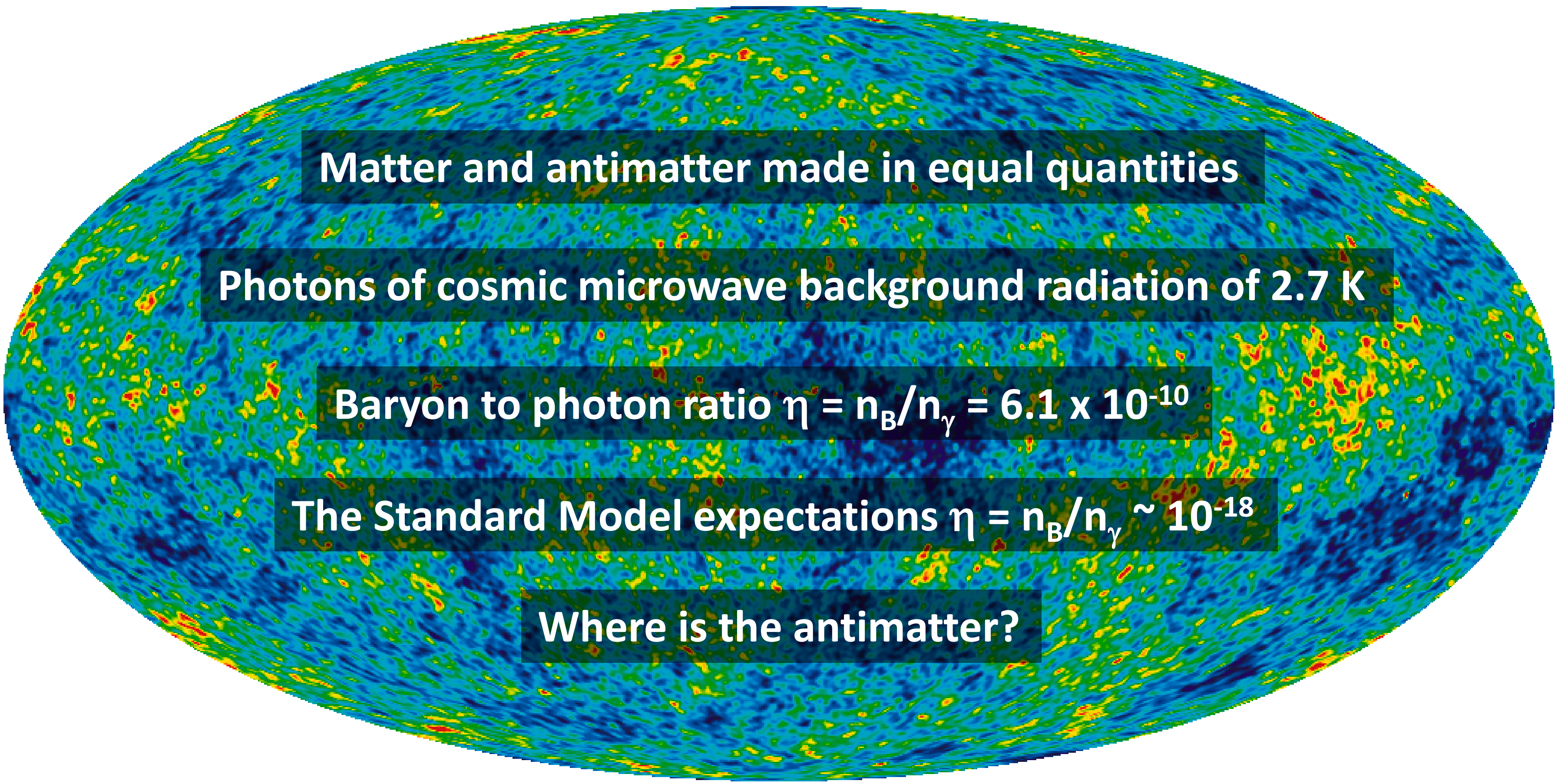
Can be confined in material, magnetic, gravitational bottles

velocities lower than 8 m/s

energies below 300 neV

Big Bang

few hundred thousand years after…



Matter and antimatter made in equal quantities

Photons of cosmic microwave background radiation of 2.7 K

Baryon to photon ratio $\eta = n_B/n_\gamma = 6.1 \times 10^{-10}$

The Standard Model expectations $\eta = n_B/n_\gamma \sim 10^{-18}$

Where is the antimatter?

Picture: NASA / WMAP Science Team

T violation

$$\boxed{\text{EDM} \neq 0 \Rightarrow \text{T violation} \Leftrightarrow \text{CP violation}}$$

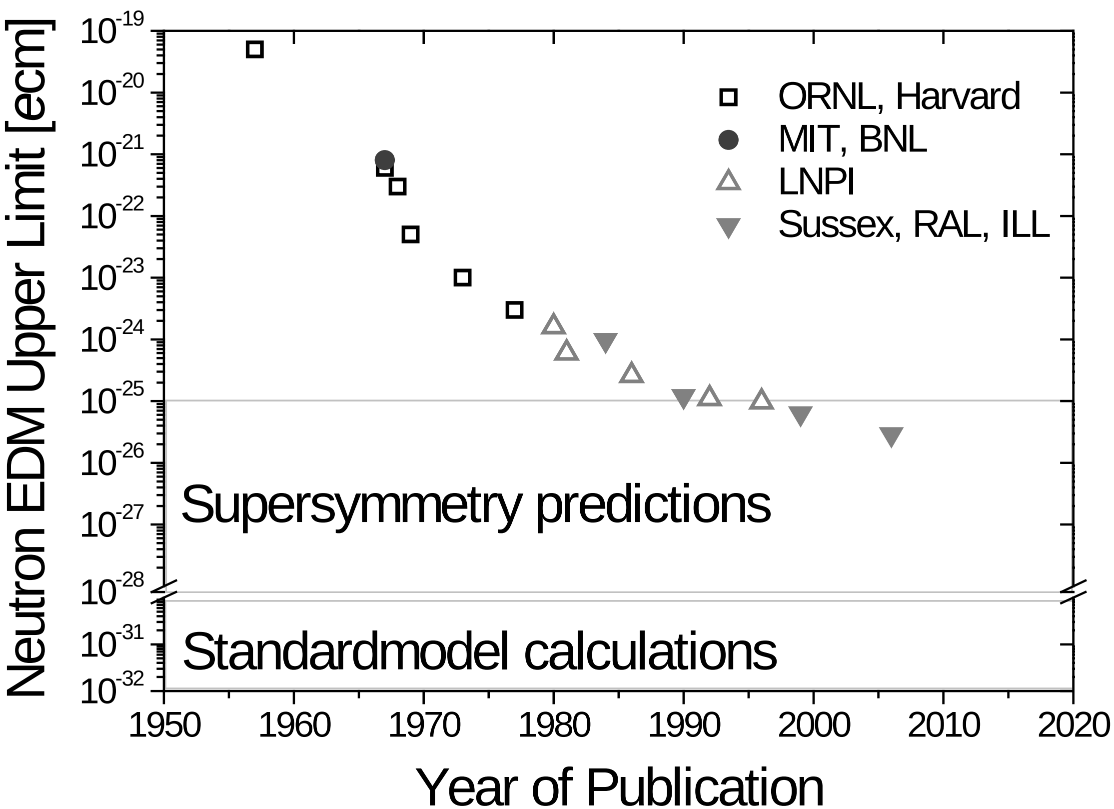
$$H = -d_n \vec{E} \cdot \frac{\vec{S}}{S}$$

$$\vec{S} \underset{}{\overset{T}{\rightleftarrows}} -\vec{S}$$

$$\vec{E} \underset{}{\overset{T}{\rightleftarrows}} \vec{E}$$

$$H = d_n \vec{E} \cdot \frac{\vec{S}}{S}$$

$$d \neq 0 \rightarrow T\ violation$$



Electric dipole moment

$$\boxed{\text{EDM} \neq 0 \Rightarrow \text{T violation} \Leftrightarrow \text{CP violation}}$$

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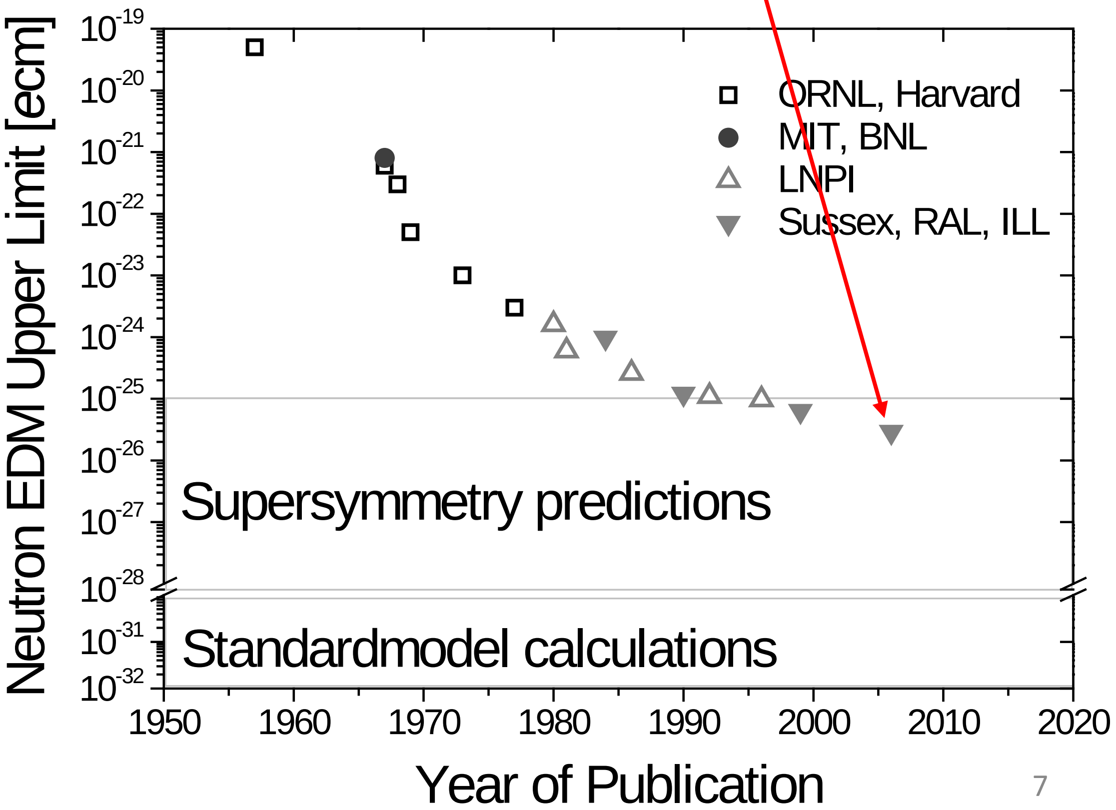
$$H = d_n \vec{E} \cdot \frac{\vec{S}}{S}$$

$$d \neq 0 \rightarrow T\ violation$$

C.A. Baker et al.
Phys. Rev. Lett. 97, 131801, 2006
(RAL/Sussex/ILL)

$$d_n < 2.9 \cdot 10^{-26}\ e \cdot cm$$



Electric dipole moment

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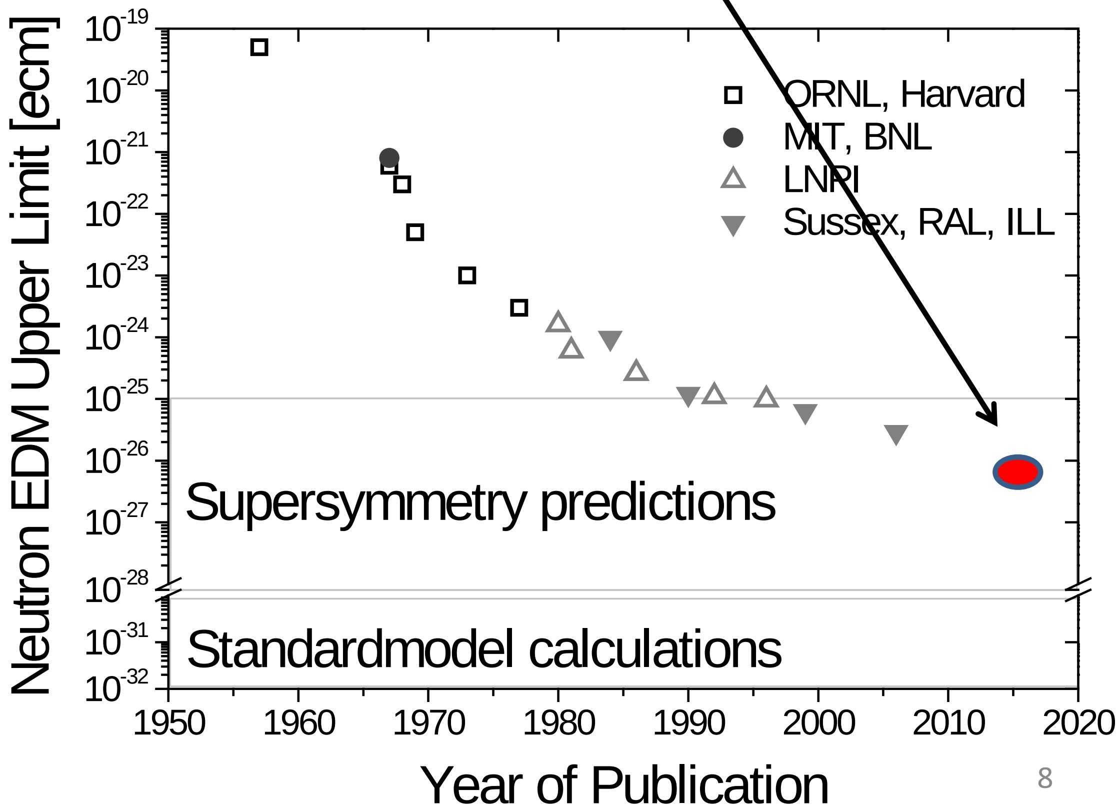
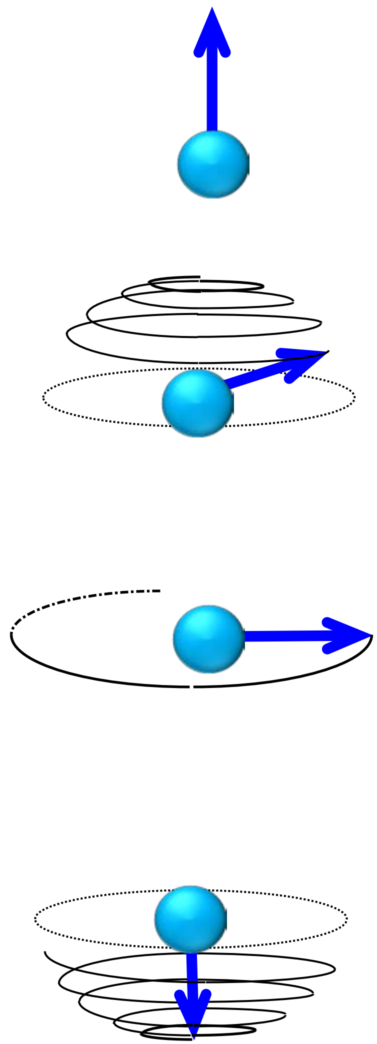
$$H = d_n \vec{E} \cdot \frac{\vec{S}}{S}$$

$$d \neq 0 \rightarrow T \text{ violation}$$

Aim : $d_n < 5 \cdot 10^{-27} e \cdot cm$



Measurement



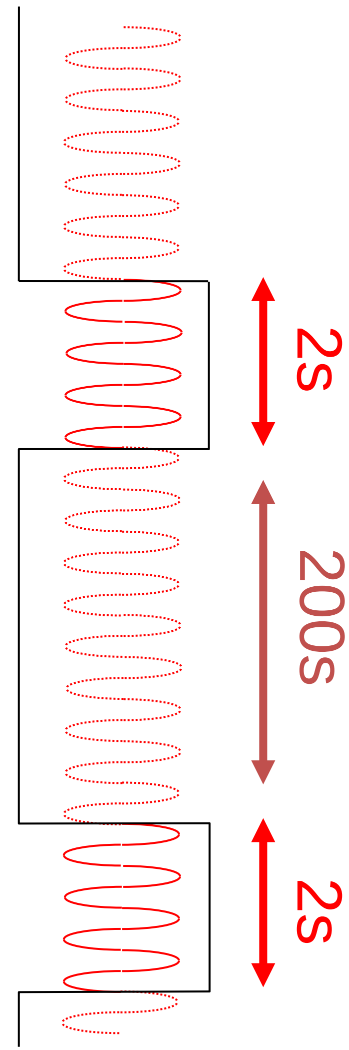
“Spin up” neutron

Apply $\pi/2$ spin flip

Free precession

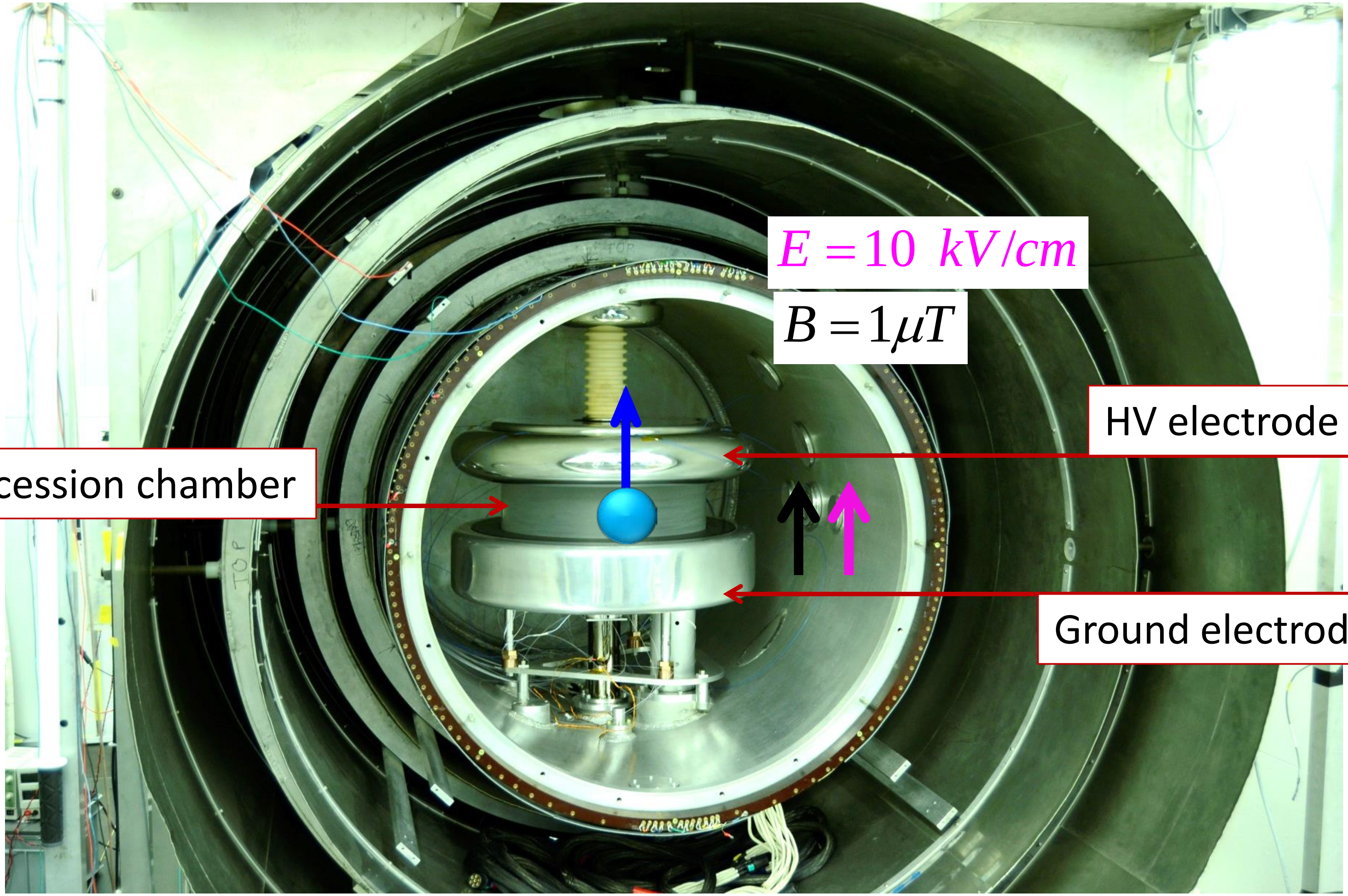
$$h\nu = 2\mu_n B \pm 2d_n E$$

Second $\pi/2$ spin flip

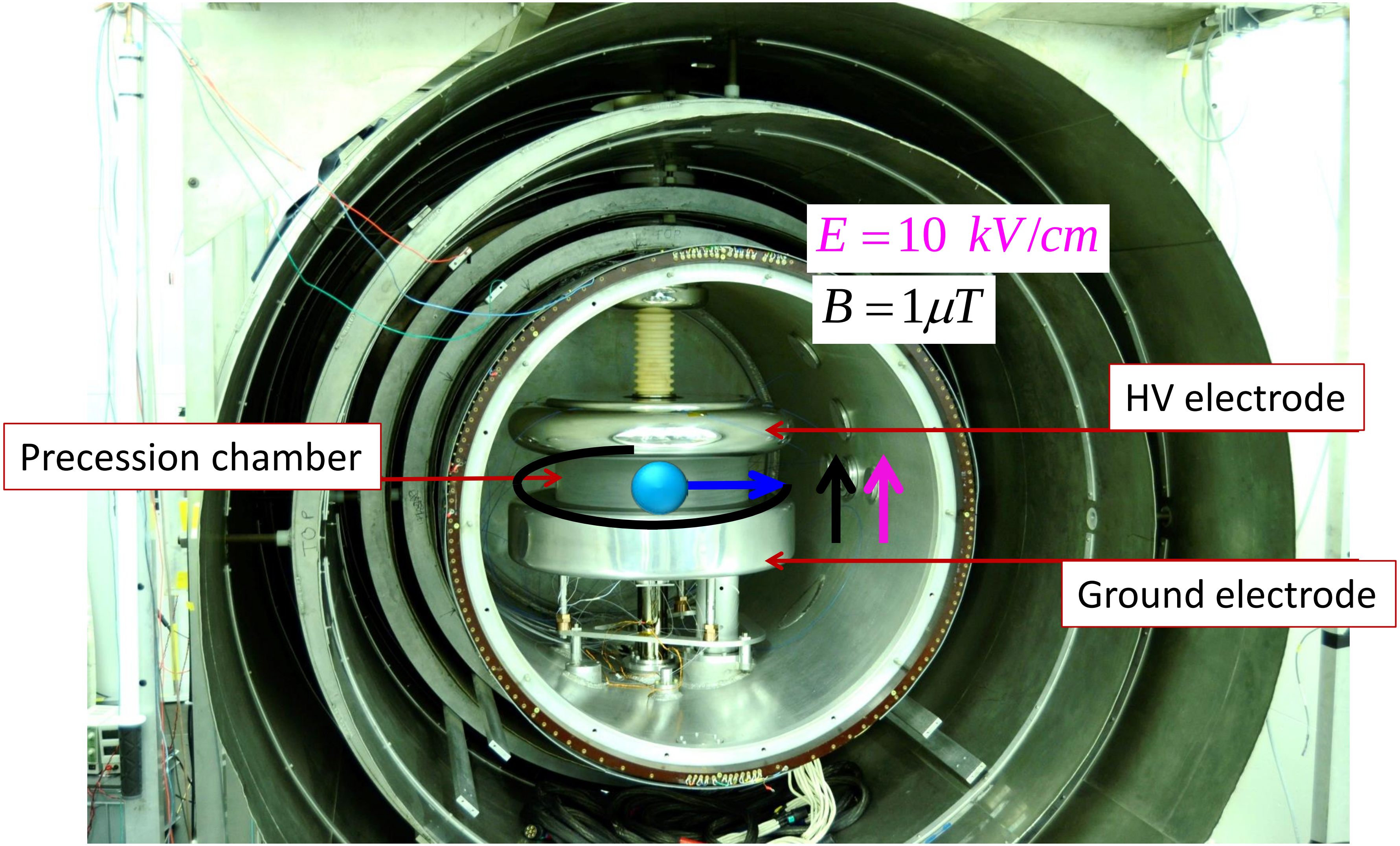


to the spin analyser and neutron detector

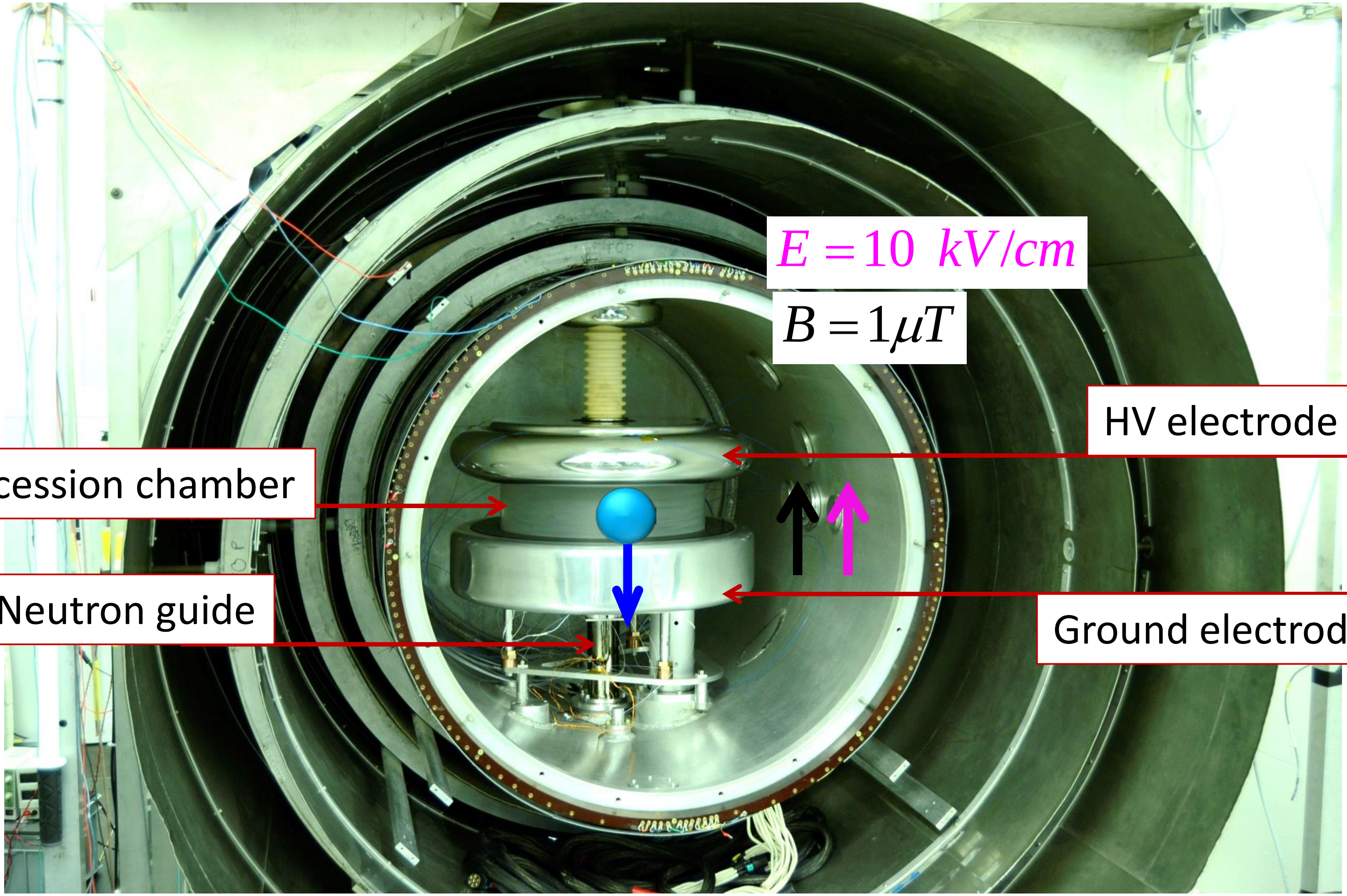
nEDM experiment



nEDM experiment

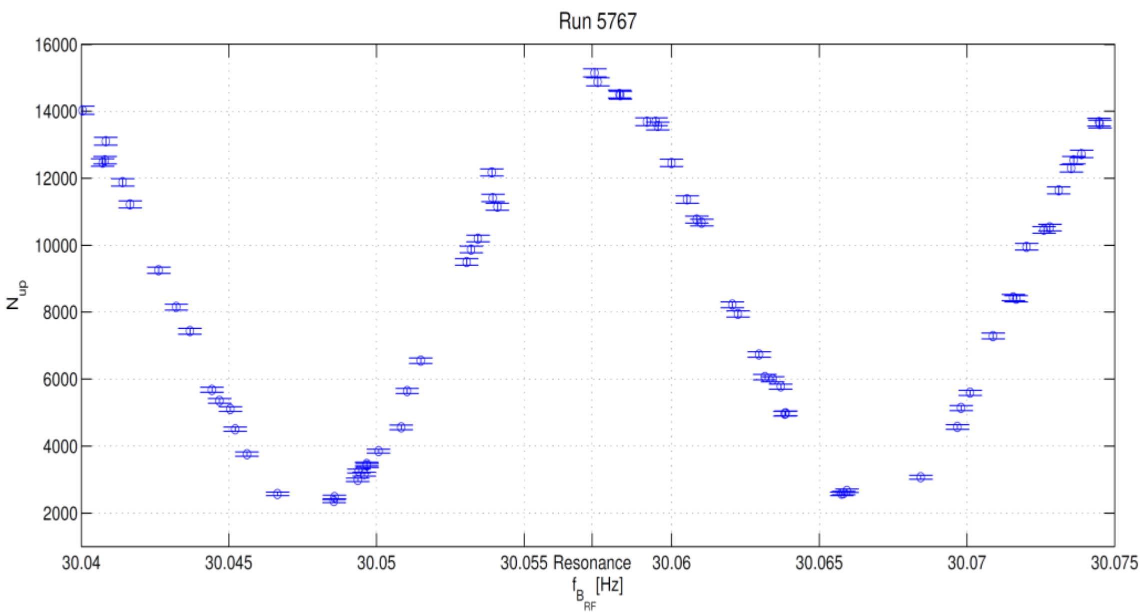


nEDM experiment



Measurement

Detector counts as a function of spin flip frequency



Statistical sensitivity:

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

Integrated sensitivity 2012 & 2013:

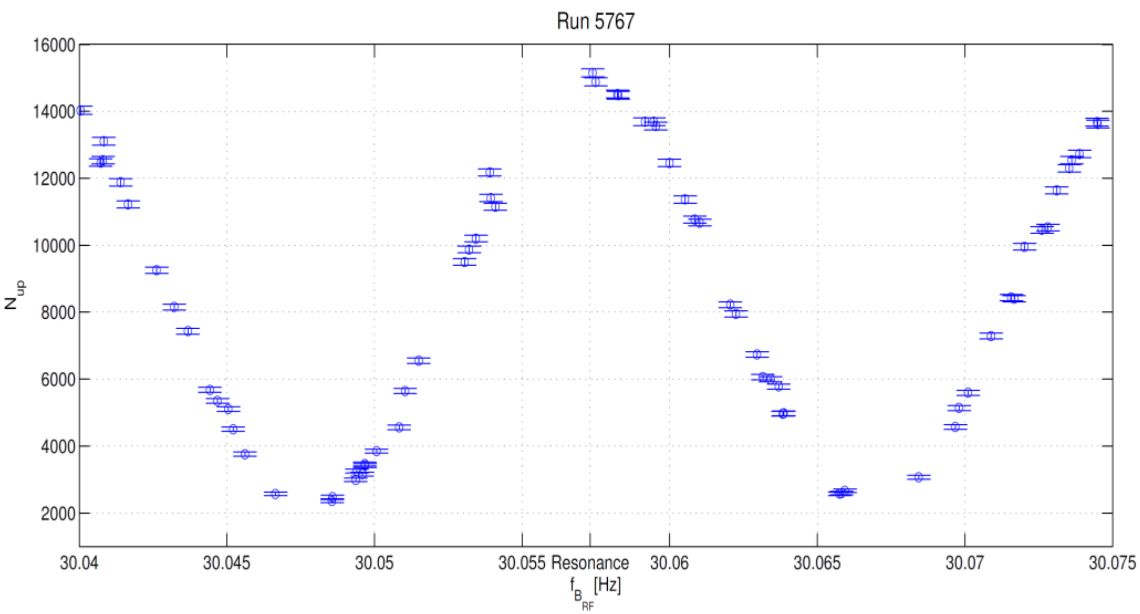
$$\sigma(d_n) = 5.6 \cdot 10^{-26}\mathrm{e}\cdot cm$$

T	Time of free precession (180 s)
N	Number of neutrons at half resonance (6500)
E	Electric field strength (10.3 kV/cm)
m	Number of single measurements
α	Visibility of resonance (0.57)

$$\alpha = \frac{N_{max} - N_{min}}{N_{max} + N_{min}}$$

Measurement

Detector counts as a function of spin flip frequency



Statistical sensitivity:

$$\sigma(d_n) = \frac{\hbar}{2\alpha TE\sqrt{Nm}}$$

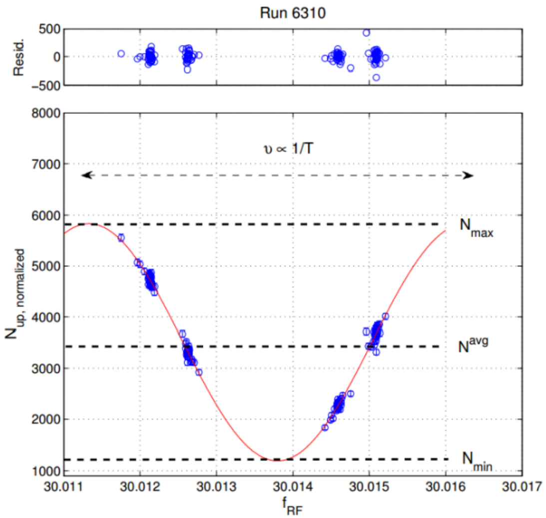
$$for\ m = 36000\ (150\ days)$$

$$\sigma(d_n) = 1.4 \cdot 10^{-26} e \cdot cm$$

$$d_n < 2.9 \cdot 10^{-26} e \cdot cm$$

T	Time of free precession (180 s)
N	Number of neutrons at half resonance (7500) (new UCN guides – coating facility at PSI)
E	Electric field strength (10.3 kV/cm)
m	Number of single measurements
α	Visibility of resonance (0.75) (improved guiding field and spin analysis)

nEDM experiment



$$N^{i}_{\uparrow\downarrow} = \bar{N}_{\uparrow\downarrow} \mp \alpha \bar{N}_{\uparrow\downarrow} \cos\left(\frac{\pi\left(\nu_n - \nu^{i}_{RF}\right)}{\Delta\nu}\right)$$

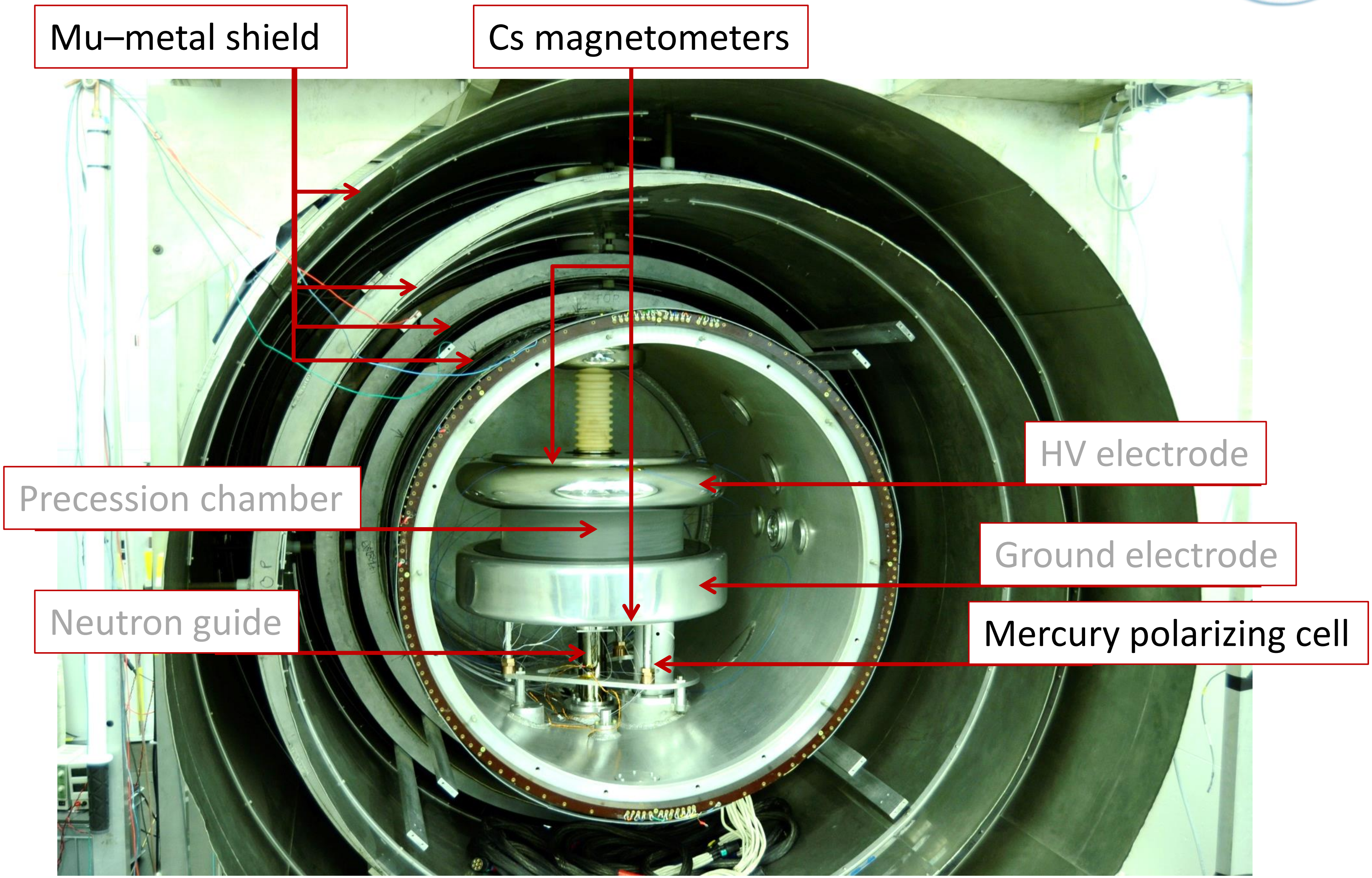
$$\frac{h(\nu_{\uparrow\uparrow} - \nu_{\downarrow\uparrow})}{4E} = d_{meas} = d_n + \frac{\mu_n}{2E}\left(|B|_{\uparrow\uparrow} - |B|_{\uparrow\downarrow}\right)$$

$$Aim: \quad d_n < 5\cdot 10^{-27}\, e\cdot cm$$

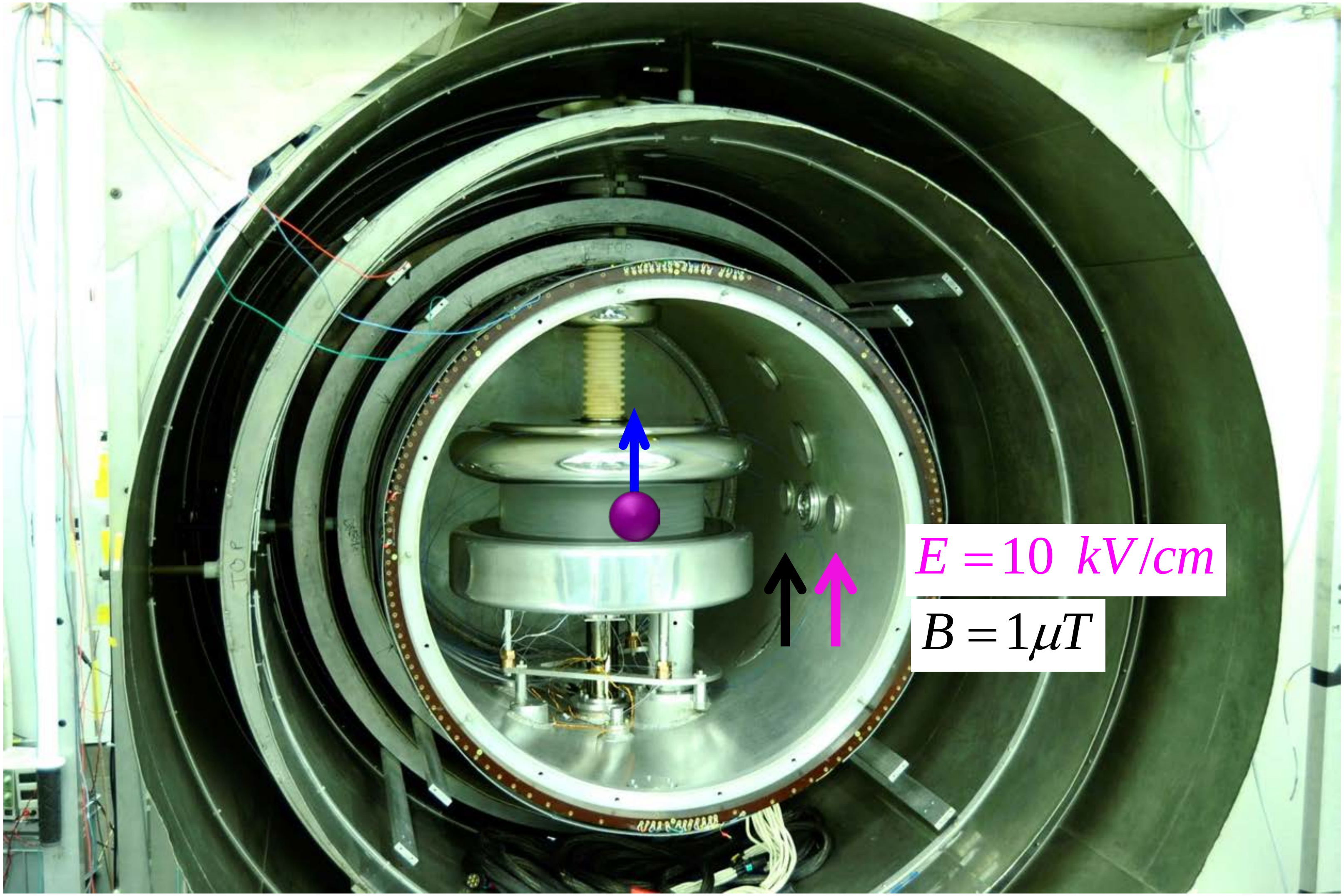
$$\delta B = \sigma(d_n)\frac{2E}{\mu_n}\sqrt{m}; \sigma(d_n) = 2.6\cdot 10^{-27}\, e\cdot cm$$

$$m = 3.6\cdot 10^{4} \Rightarrow \delta B < 170\, fT$$

nEDM experiment



Hg co-magnetometer



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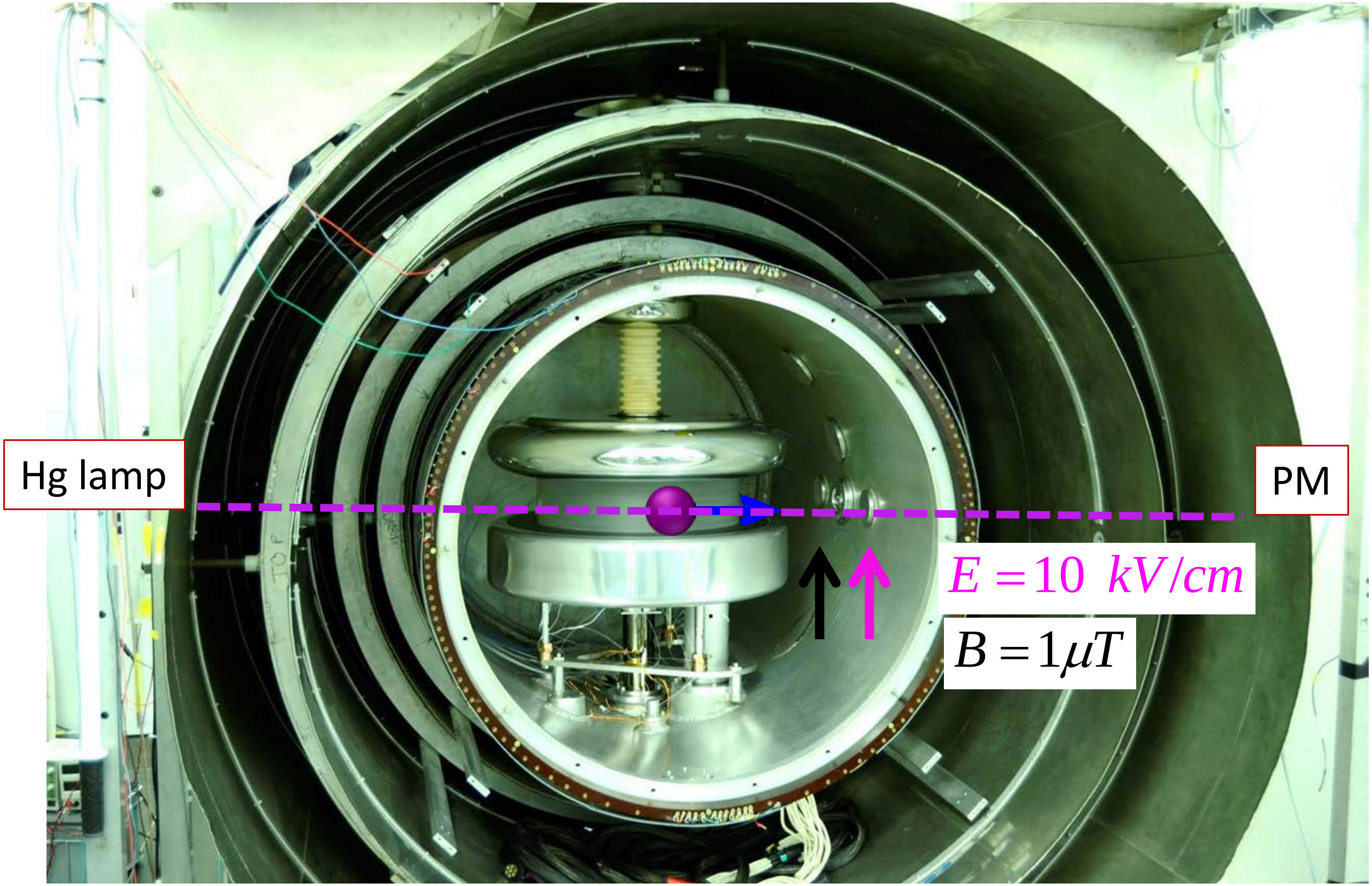

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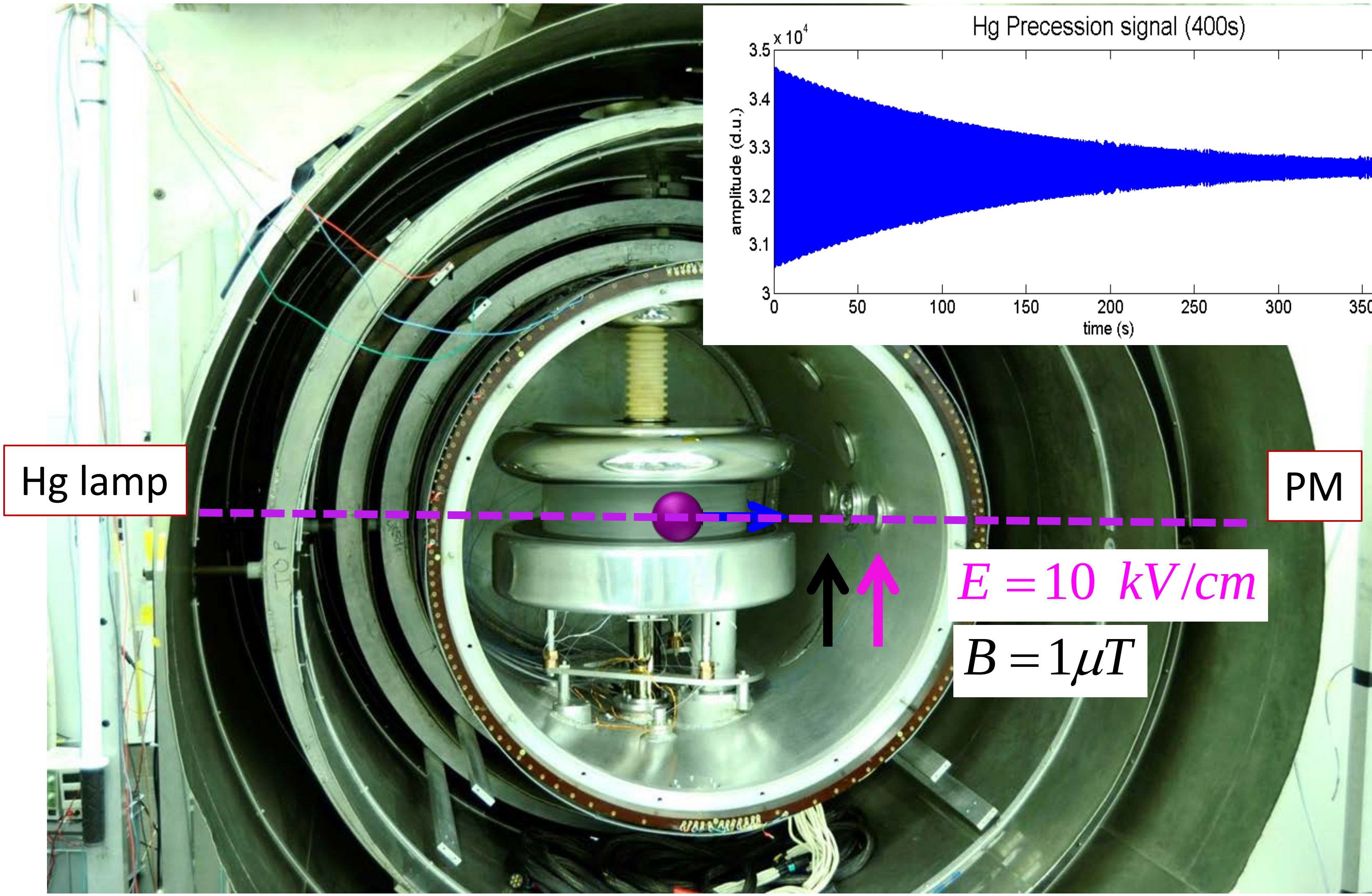

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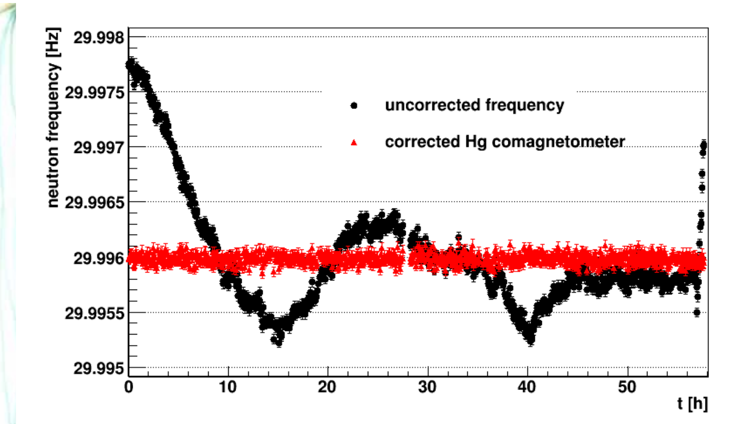
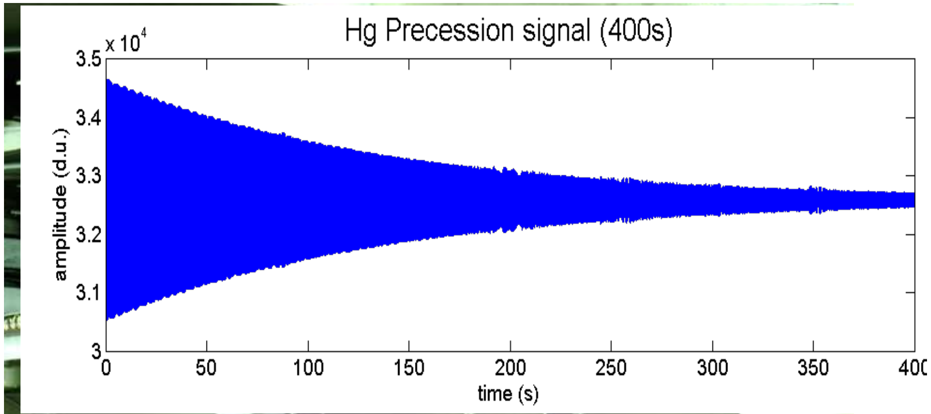
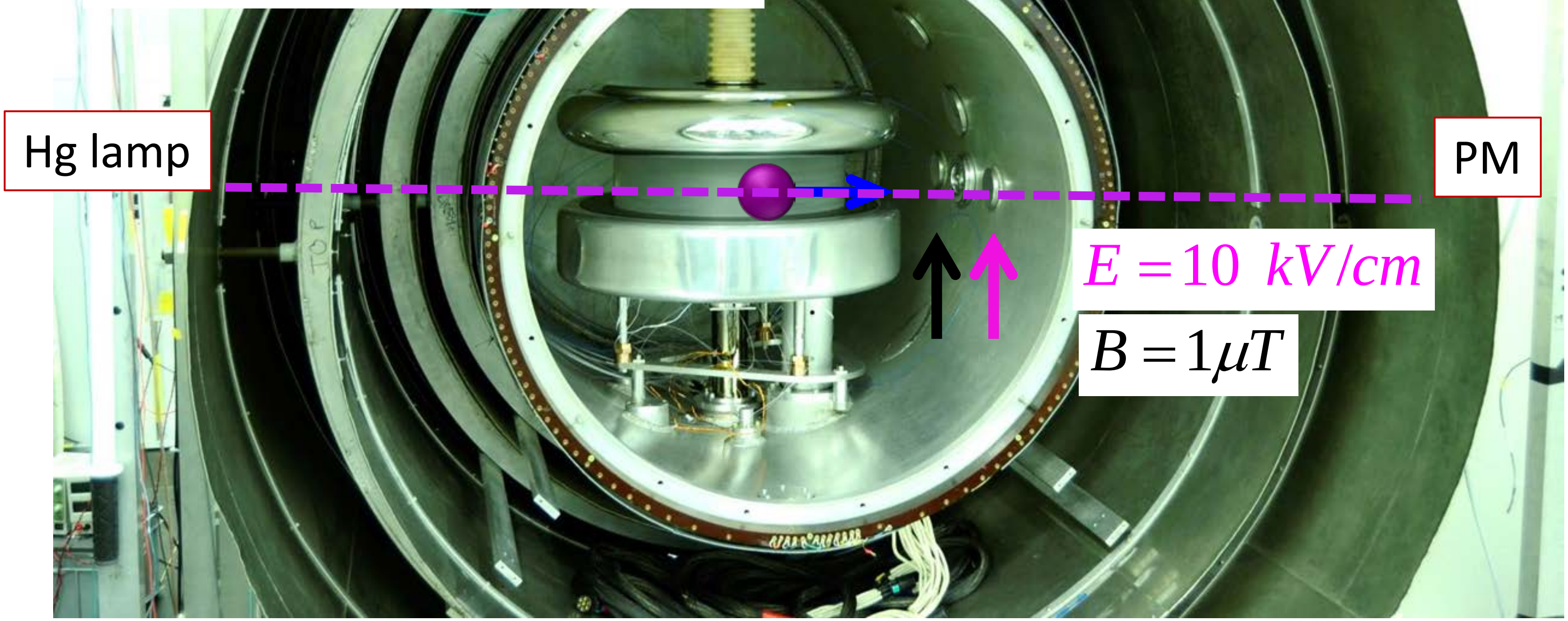
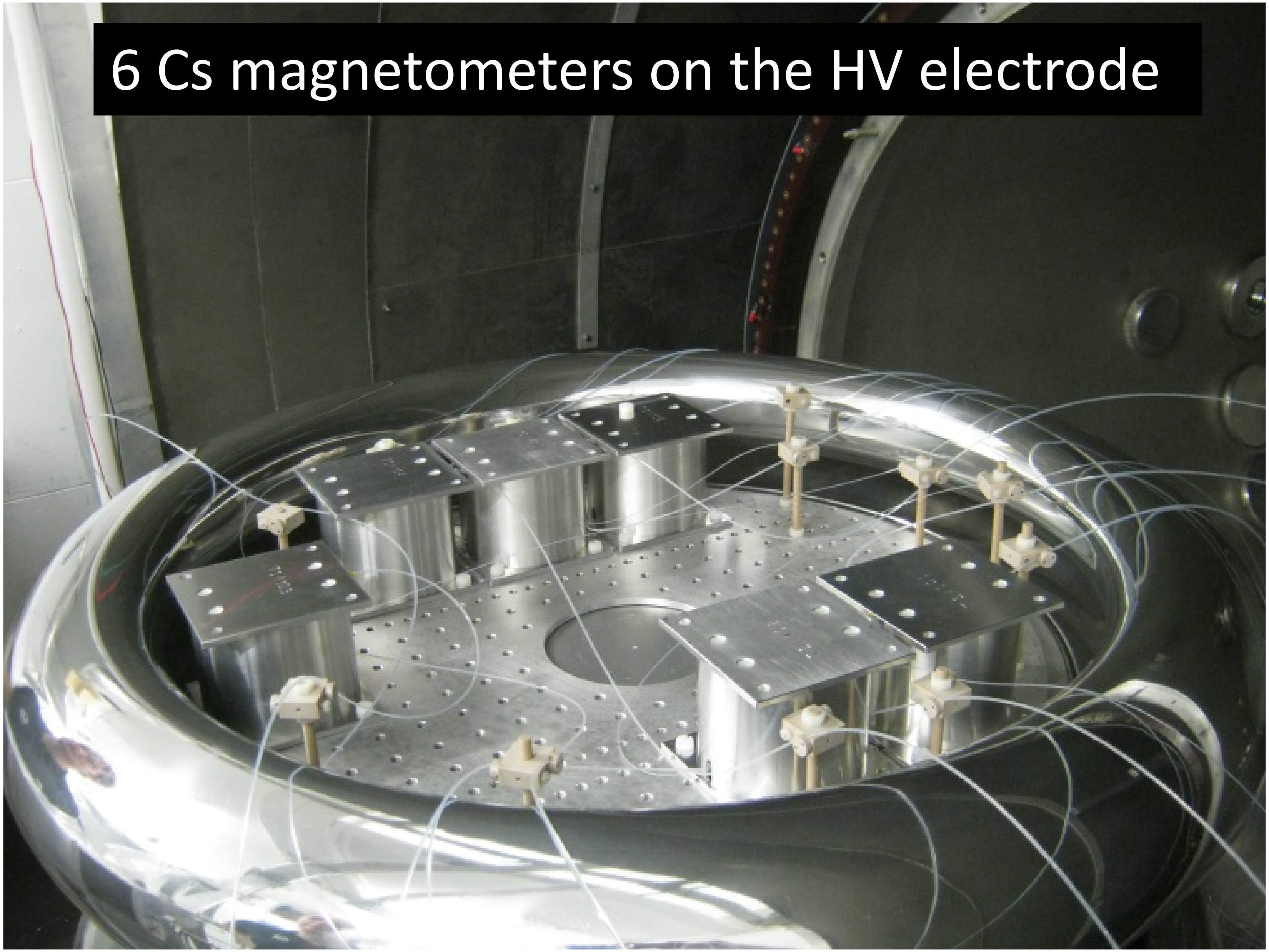


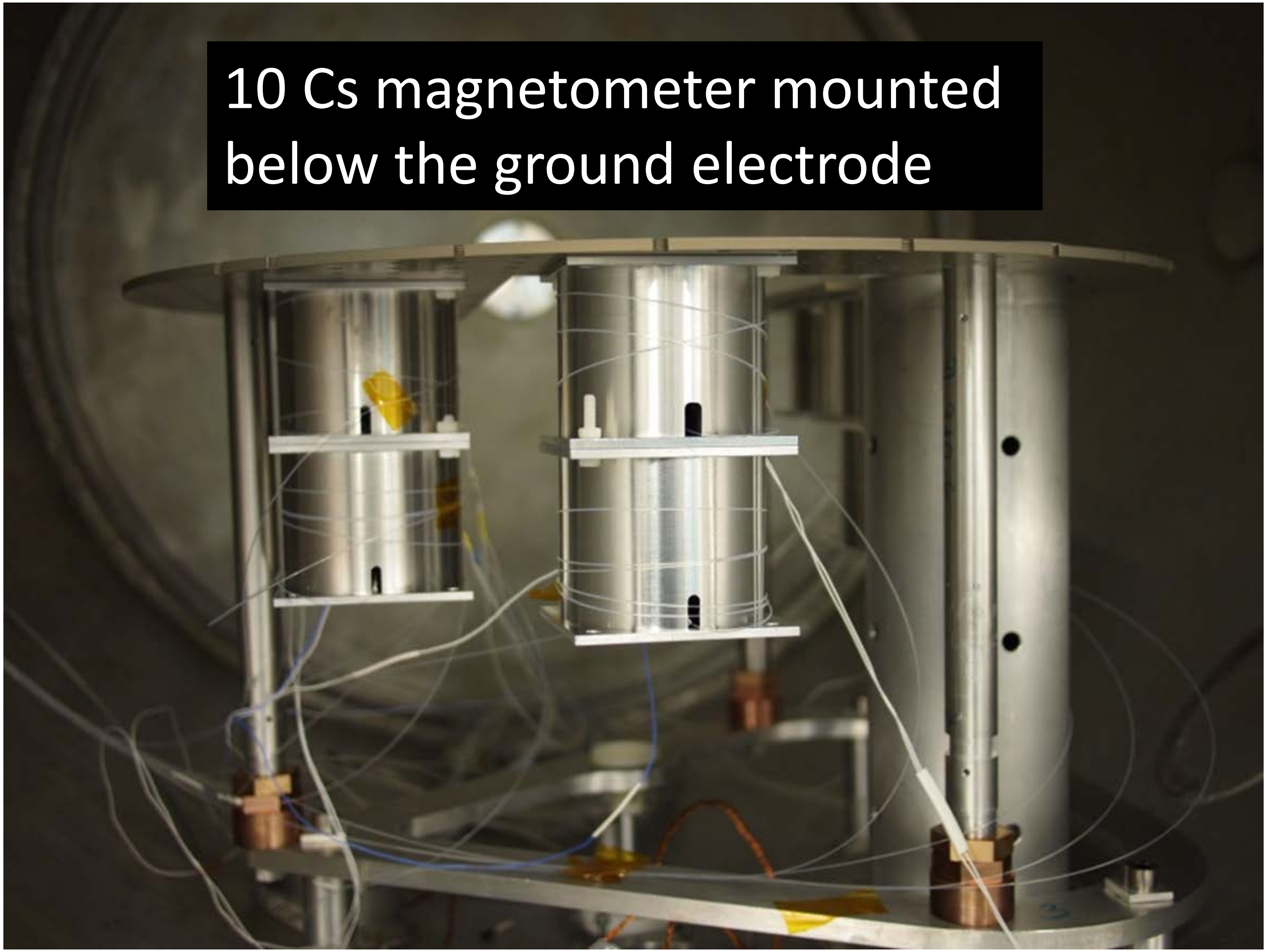




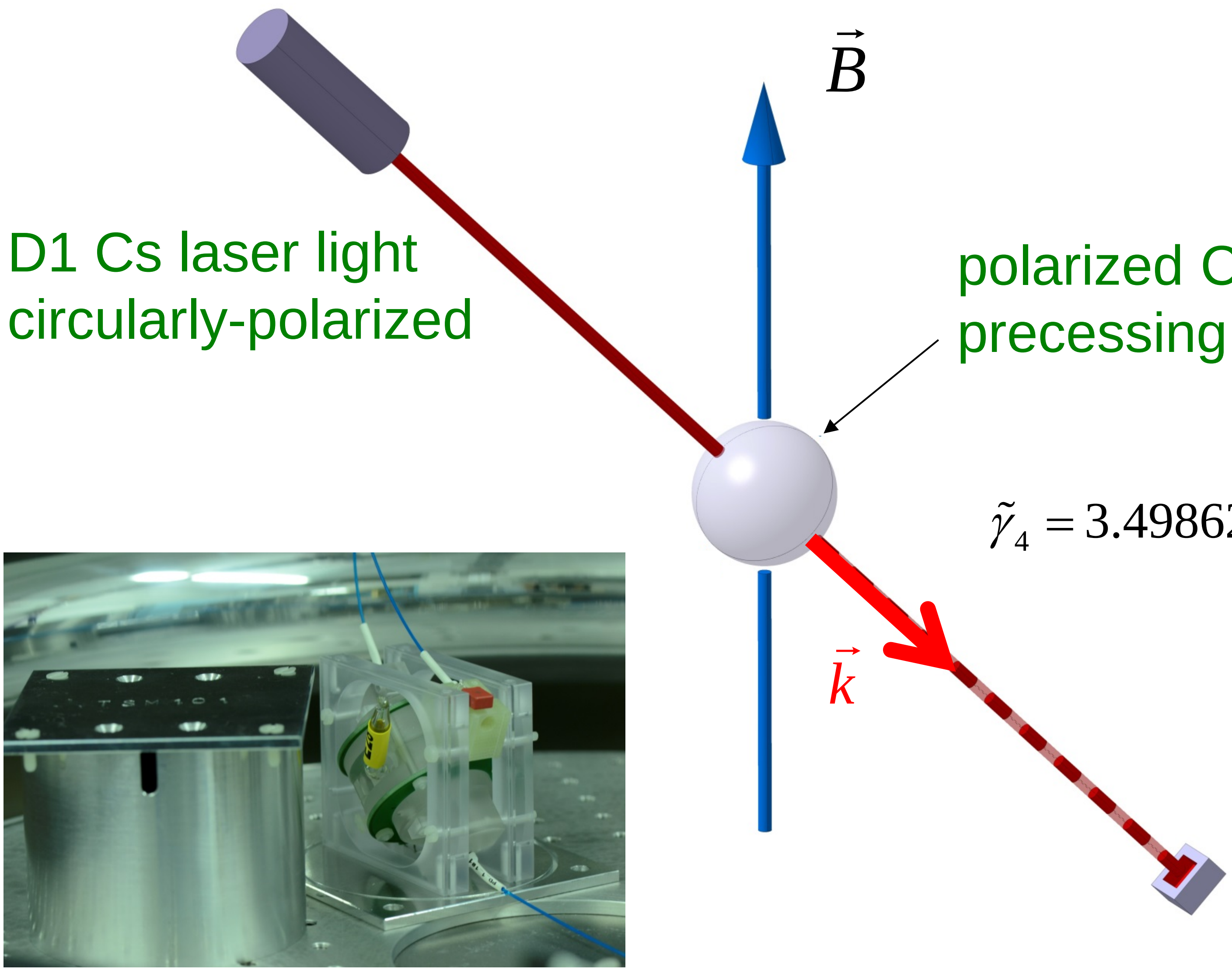
Cs magnetometer array



Cs magnetometer array



Cs sensor operation



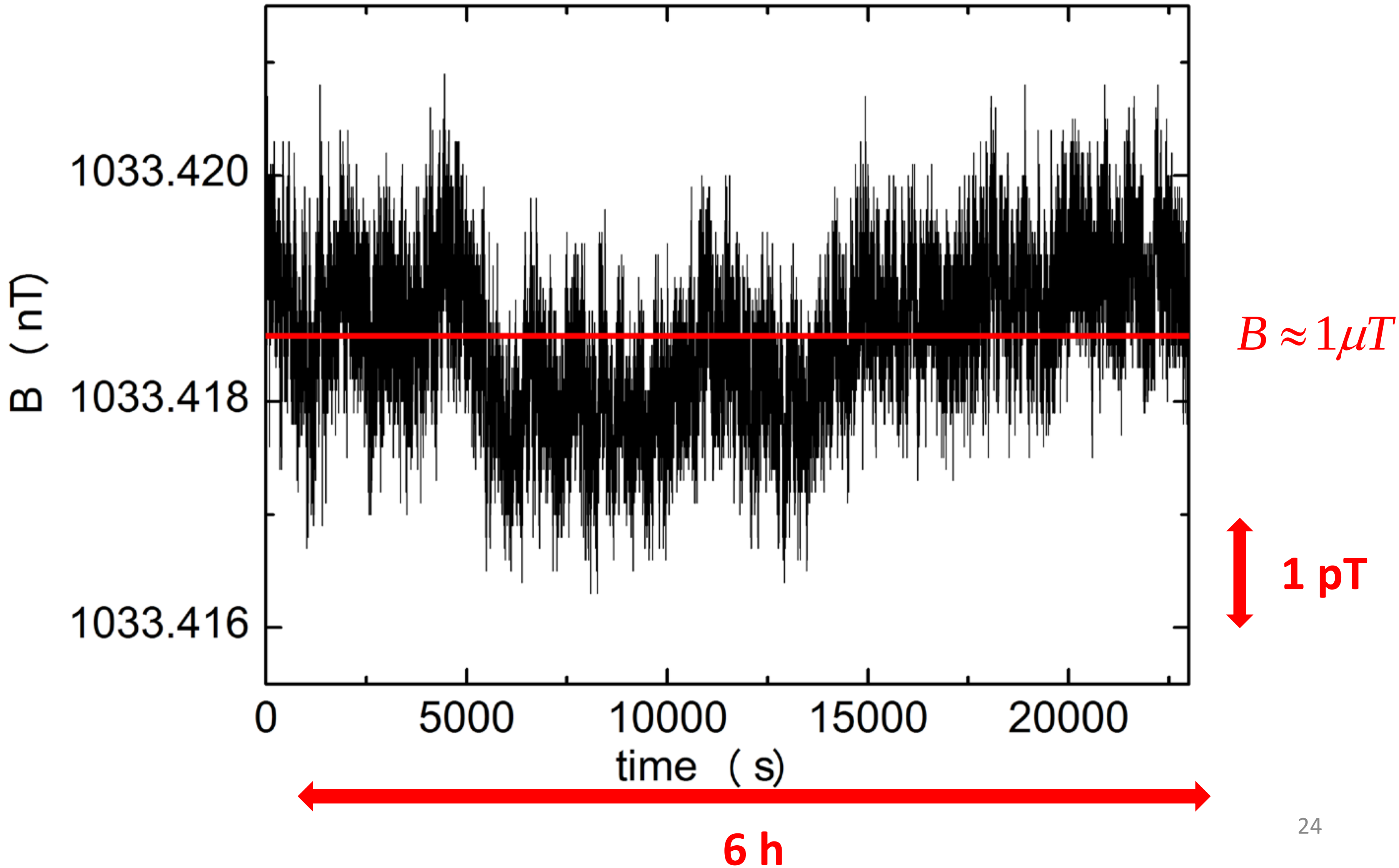
D1 Cs laser light
circularly-polarized

polarized Cs atoms
precessing at $\nu_L = \tilde{\gamma}_4 \left|\vec{B}\right|$

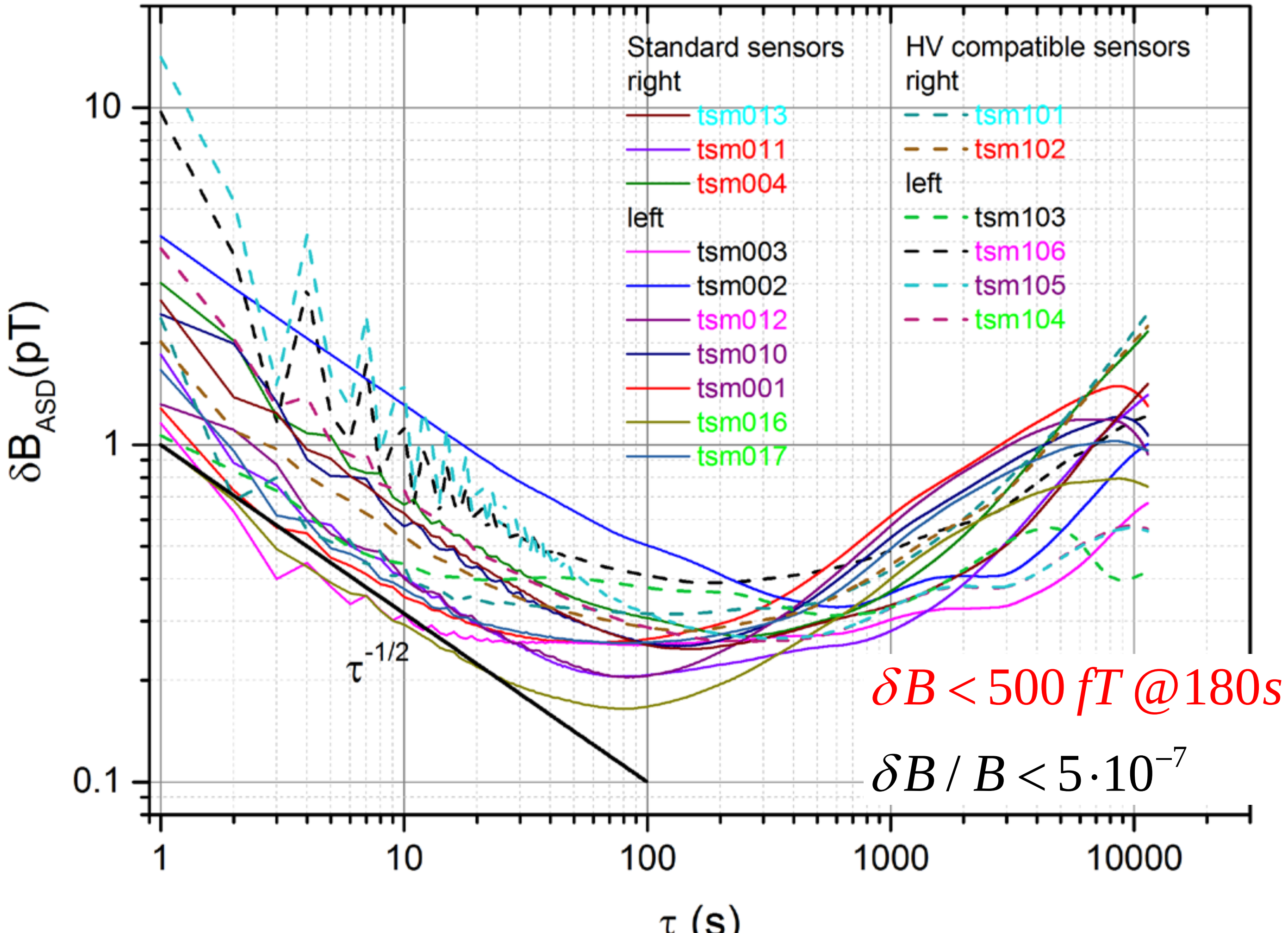
$\tilde{\gamma}_4 = 3.49862110(36)$ Hz/nT

photodiode

B field variations in time



B field stability



Systematic effects

Effect	Status (10^{-27} e cm)
Leakage Current	0.00±0.05
vxE UCN	0±0.1
Electric Forces	0 ±0.0
Uncompensated B Drift	-0.7±1.1
Hg EDM	0.02±0.06
Hg Light Shift	0±0.05
Quadrupole Difference	1.3±2.4
Dipoles	0±3.03
Total	**0.58±4.0**

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Outlook

- Experiment is ready to take data and can reach (or improve) the current nEDM limit in 150 days
- The systematic effect are well controled (e.g. magnetometers)
- The final sensitivity depends on the improvements in the UCN density and transport

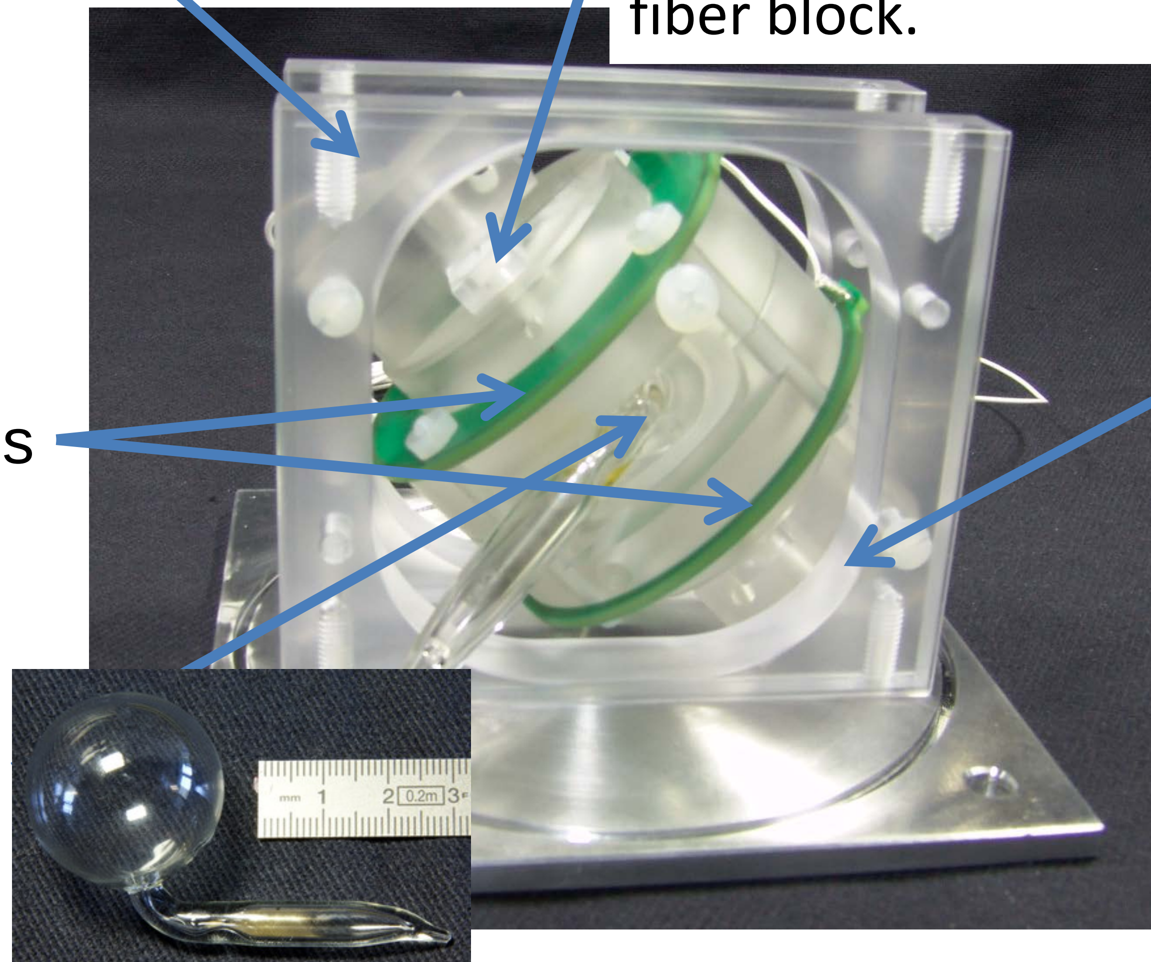
Thank you

Backup

Cs sensor in nEDM experiment

A lens, polarizer and quarter-wave plate creating collimated circularly-polarized light are mounted in the fiber block.

Input for a fiber carrying the frequency-stabilized laser light.

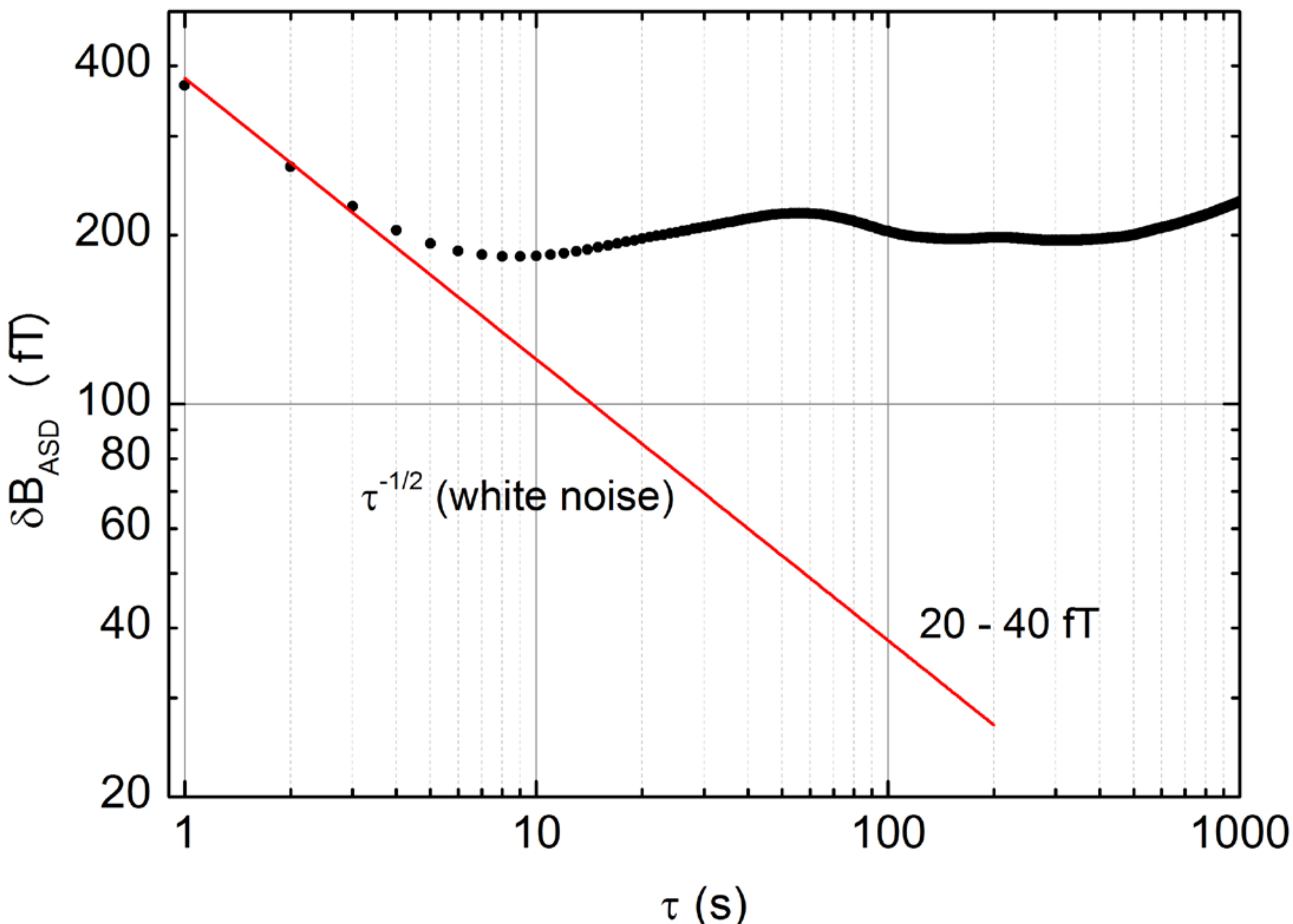


Photodiode

rf coils

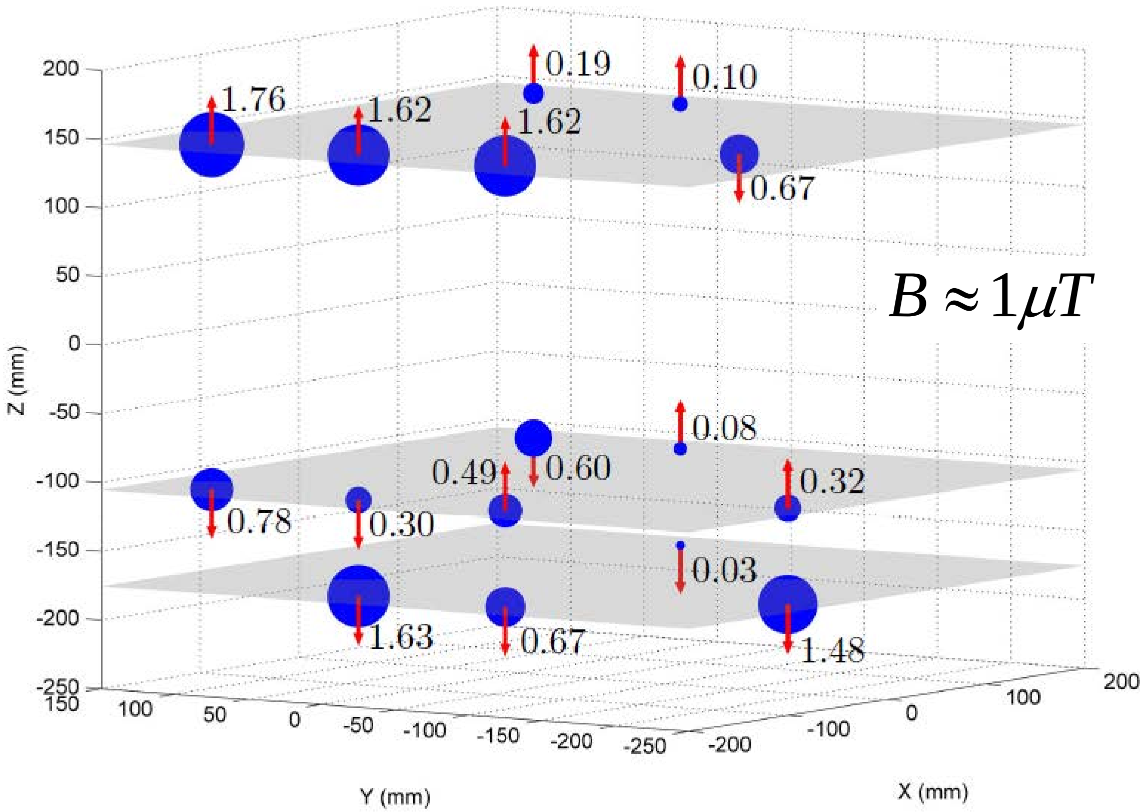
Glass cell filled with Cs vapour

Allan standard deviation as a measure of magnetic field stability



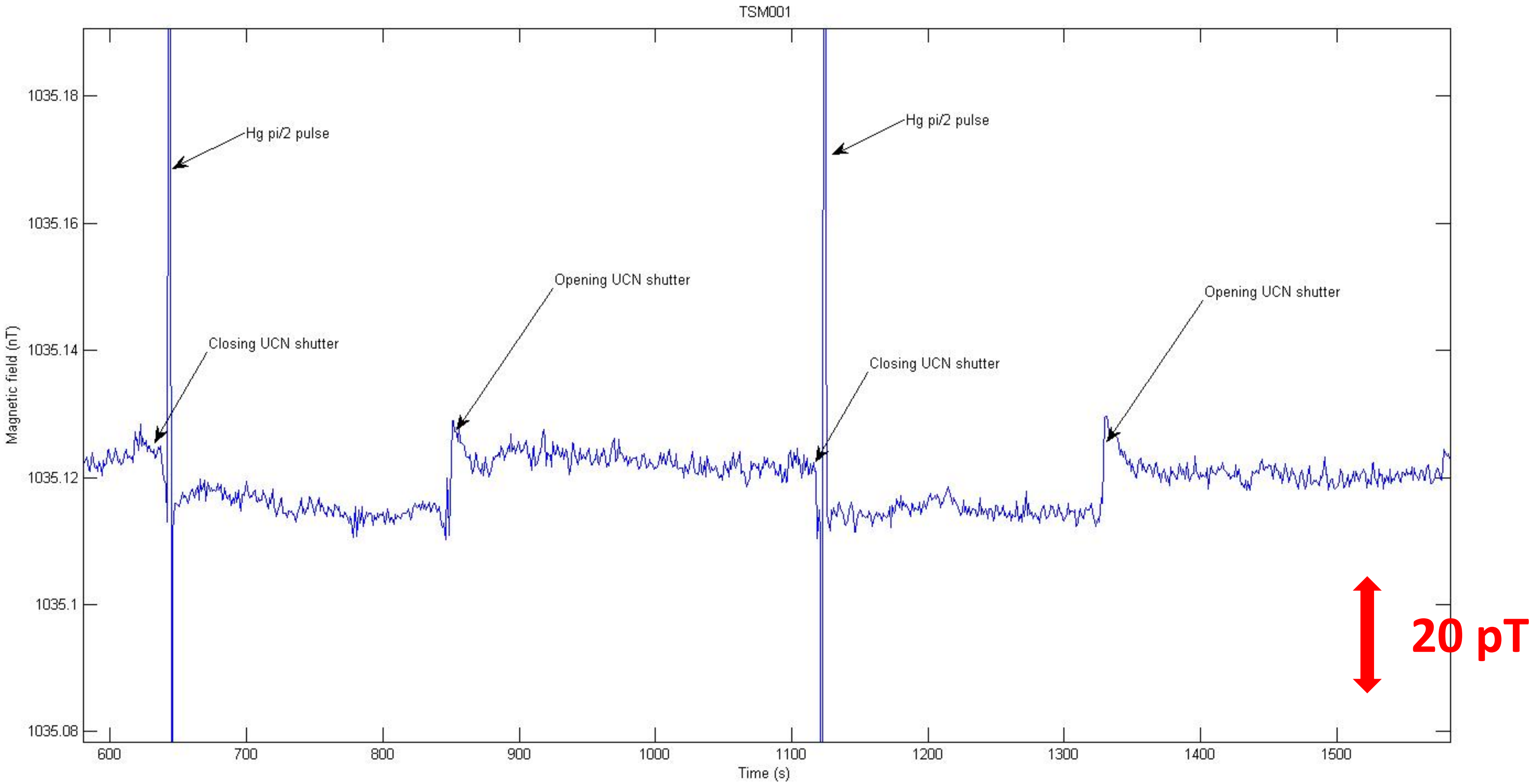
The spatial distribution of the magnetic field

Deviations of the individual sensors' readings (in nT) from the average reading of all sensors, main field on, correction coils off.

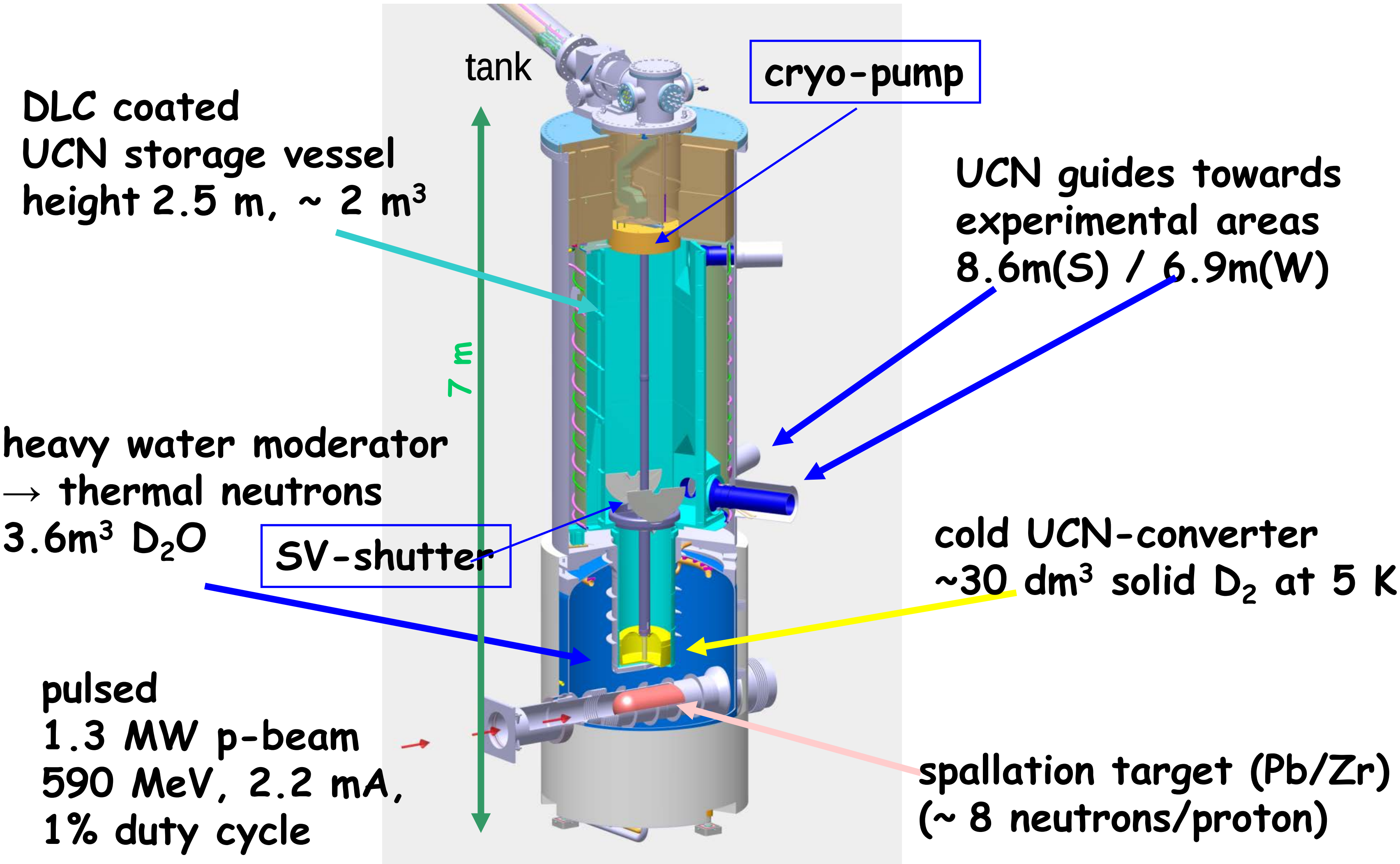


$B \approx 1\mu T$

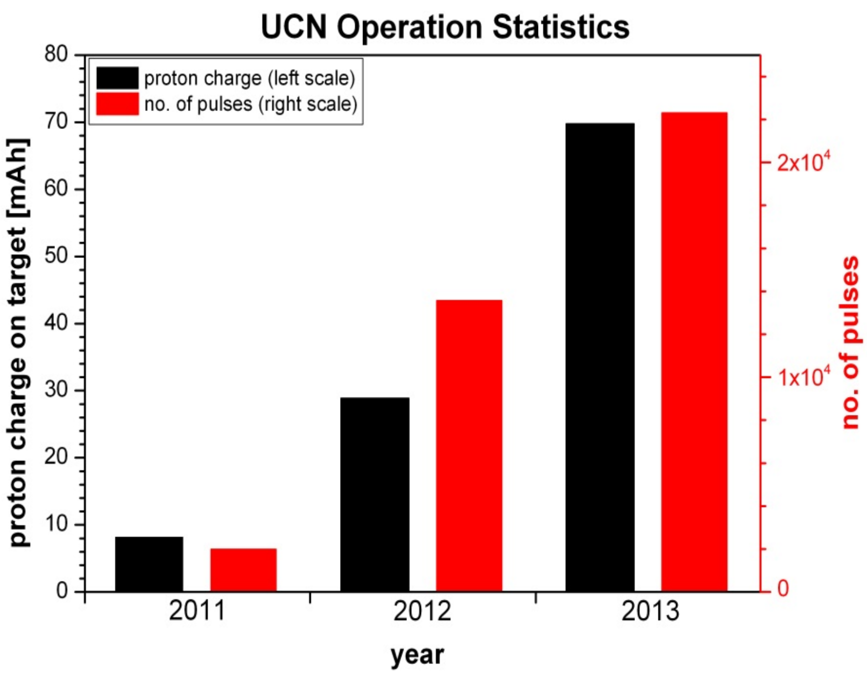
Magnetic field during nEDM runs seen by Cs

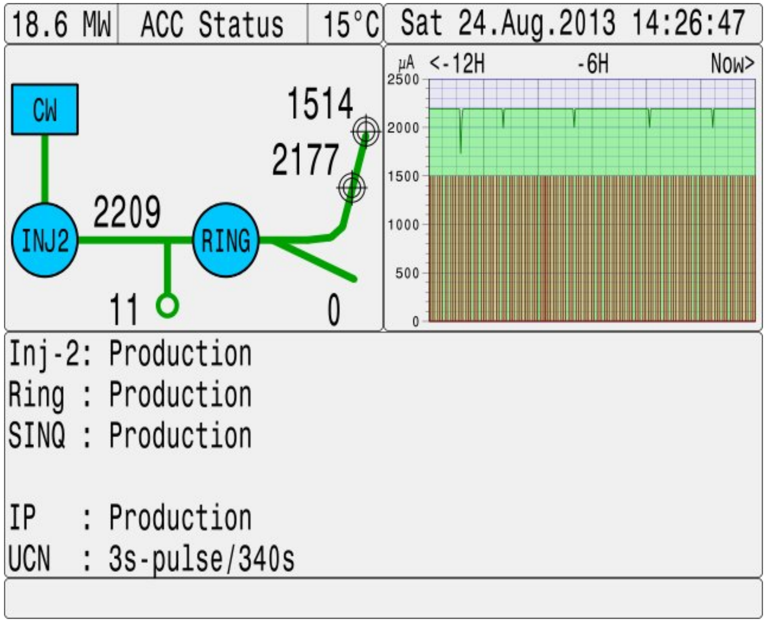


Sketch of the PSI UCN source



UCN Operation



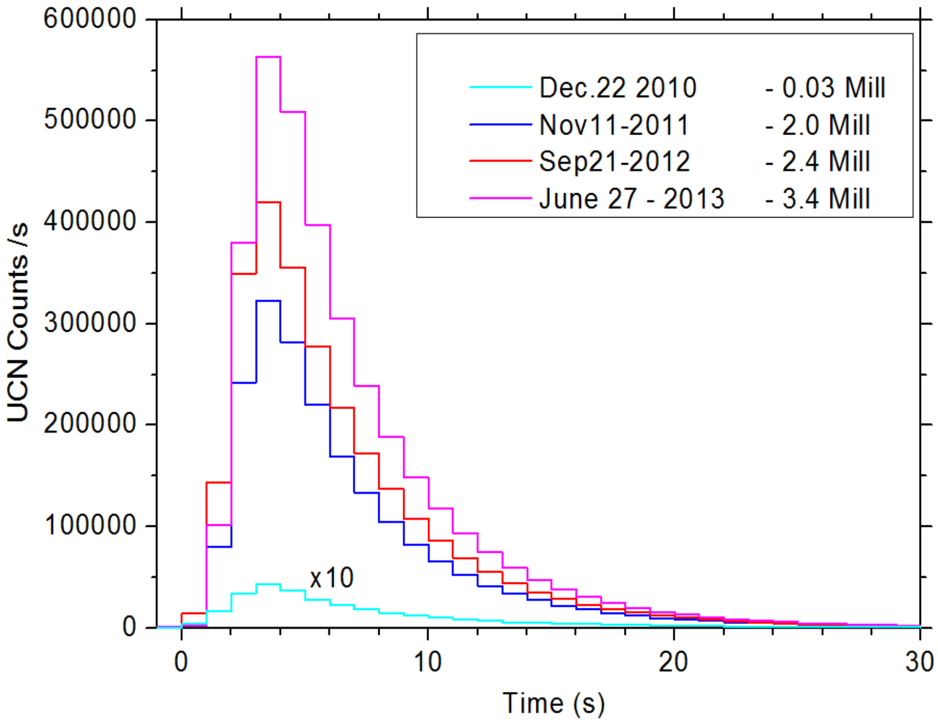


UCN production period May 23 - Dec. 23

69 full days where nEDM could make use of UCN

data taking mode:
- 240 pulses per day
- 7200 pulses per month

UCN source – status end of 2013



best norm pulse performance in

preliminary

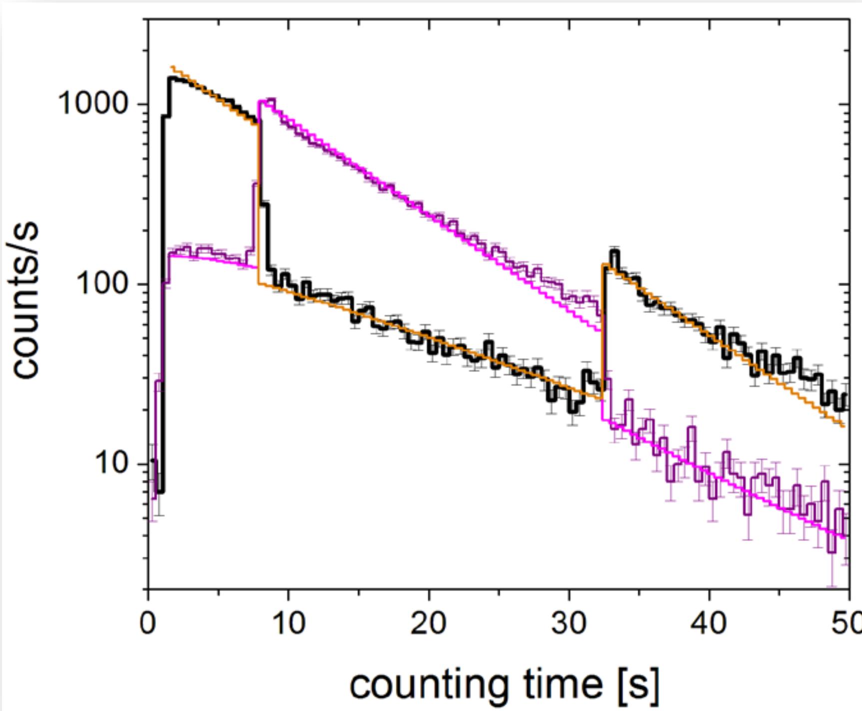
2010: 30'000

2011: 2'020'000 (Nov. 2011)

2012: 2'400'000 (Sept.2012)

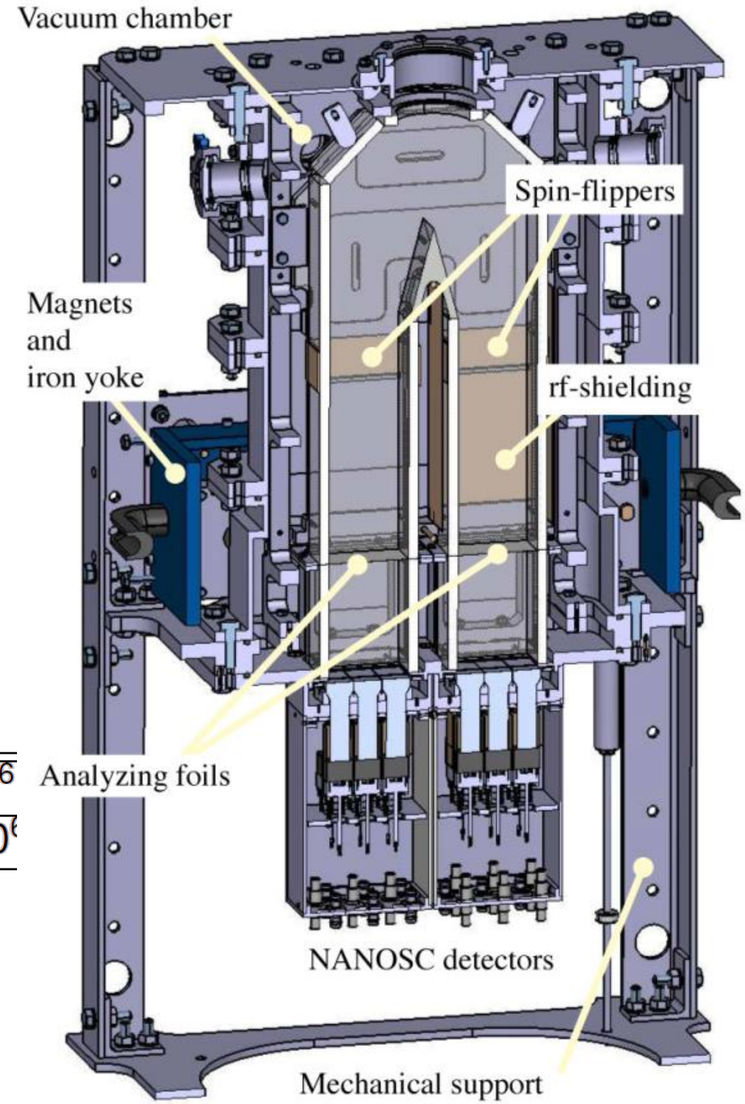
2013: 3'450'000 (June 2013)

Simultaneous spin detection



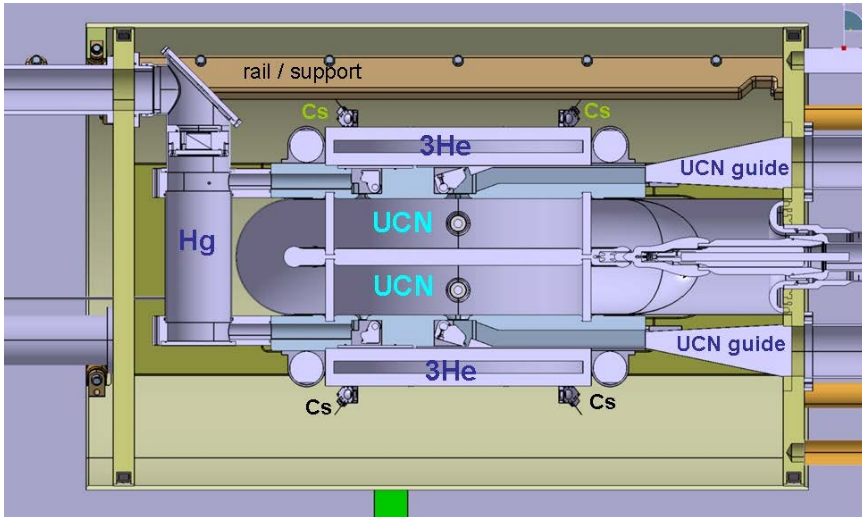
	Visibility α [%]	N_{tot}	$N_{West\text{-}1}$
USSA	63.4 ± 1.8	3791(14)	$1.878(5) \times 10^6$
Sequential	59.7 ± 2.2	2692(15)	$1.651(16) \times 10^6$
Ratio	1.062(49)	1.238(10)	

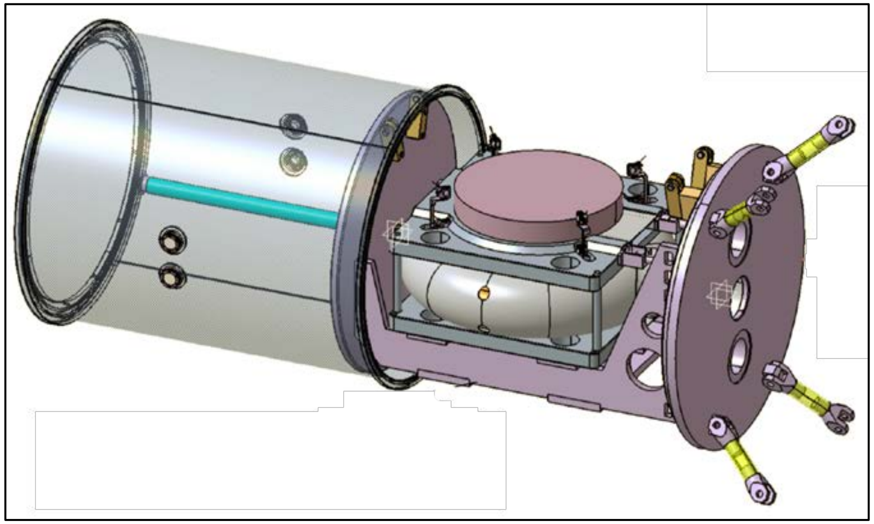
~20% increase in sensitivity (for 2014)



n2EDM

Present design status of the n2EDM apparatus:





New features/improvements:

- **Two UCN precession chambers with opposite electric field directions**
- **Improved magnetic enviornment due to better shielding & compensation**
- **Higher neutron statistics due to better adaption to UCN source**
- **Improved magnetometry (Hg, Cs, 3He) – laser read out of Hg-FID to avoid light shift**