



Neutron Electric Dipole Moment Search at Paul Scherrer Institute (an update from 2014)

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Outline

Why measuring neutron EDM

Measurement Principle

New value

n2EDM

Conclusion



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Find new sources of CP violation



Electric Dipole Moment d

Similar as magnetic moment μ

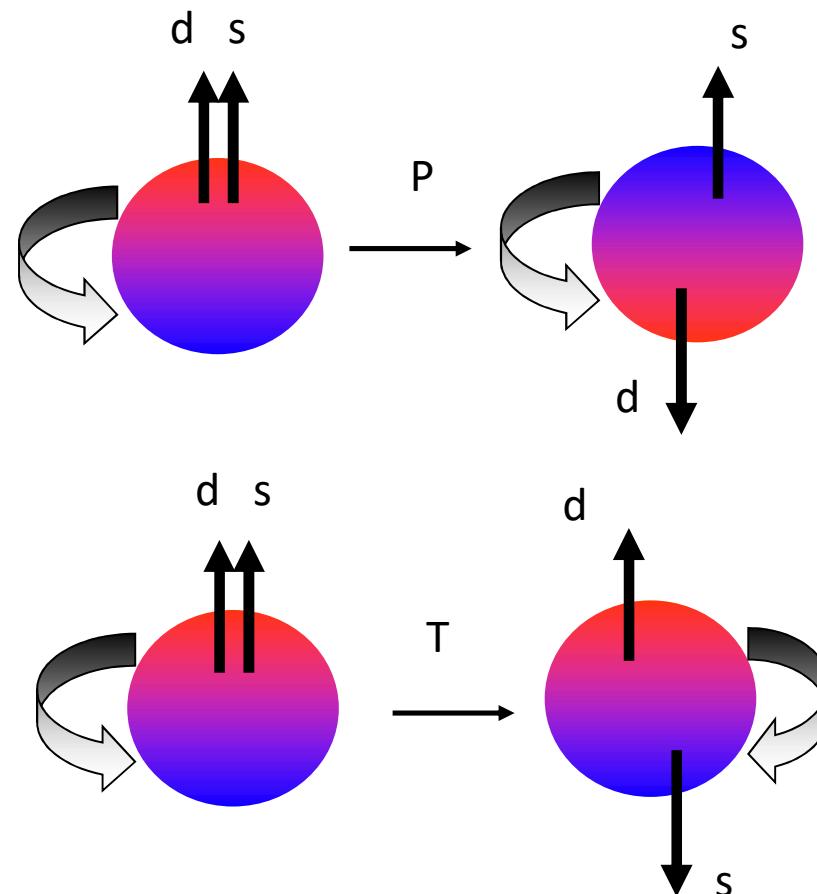
$S = \text{Spin}$

$$\mu = \mu \cdot S \text{ and } d = \delta \cdot S$$

$$H = -(\mu \cdot B + d \cdot E) = -(\mu B + d E)S$$

d is P odd and T odd

Assuming CPT
→ d is CP odd

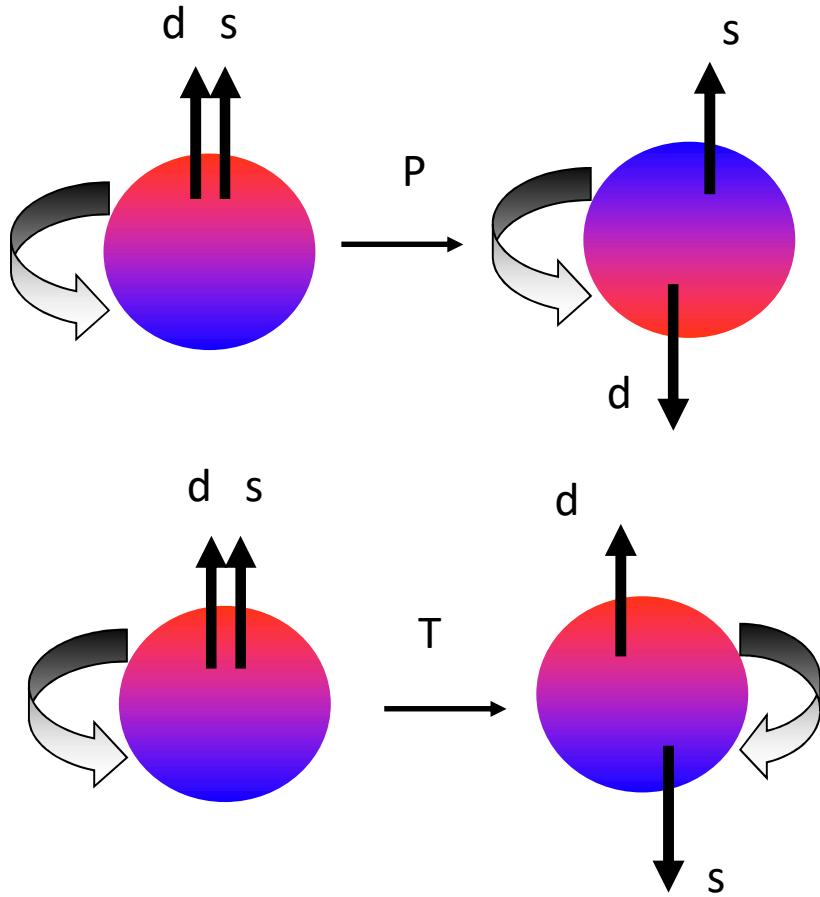


SEARCH for new source of CP violation

Purcell and Ramsey, PR78(1950)807



Can be measure with any particle



Purcell and Ramsey, PR78(1950)807

Neutron
Electrons
Molecules
Atoms...
All of them are part
of the problem

Different techniques...
Laser, Storage rings,
Bottles...





Why looking for EDMs and CPV ?

Baryon Asymmetry

A. Sakharov 1967:

CP-Violation is one of three conditions to enable a universe containing initially equal amounts of matter and antimatter to evolve into a matter-dominated universe, which we see today....

Other requirements B violation, non equilibrium

Other motivations, strong CP, SUSY...

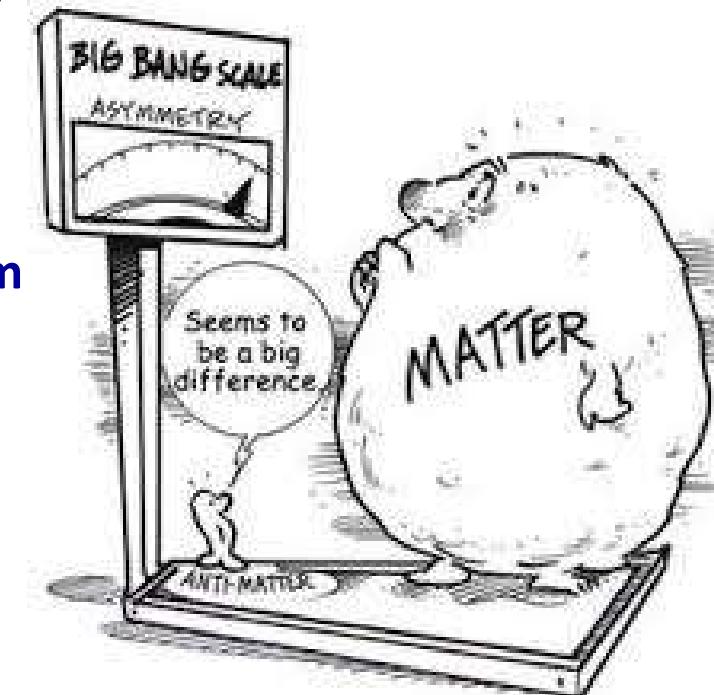
ANY SM extension will be tested by EDMs

Observed:

$$n_B / n_\gamma = 6 \times 10^{-10}$$

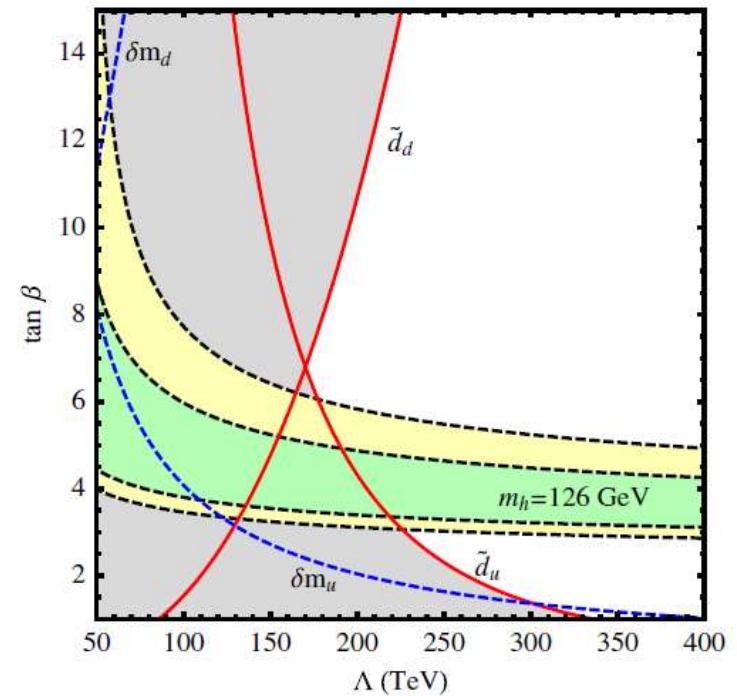
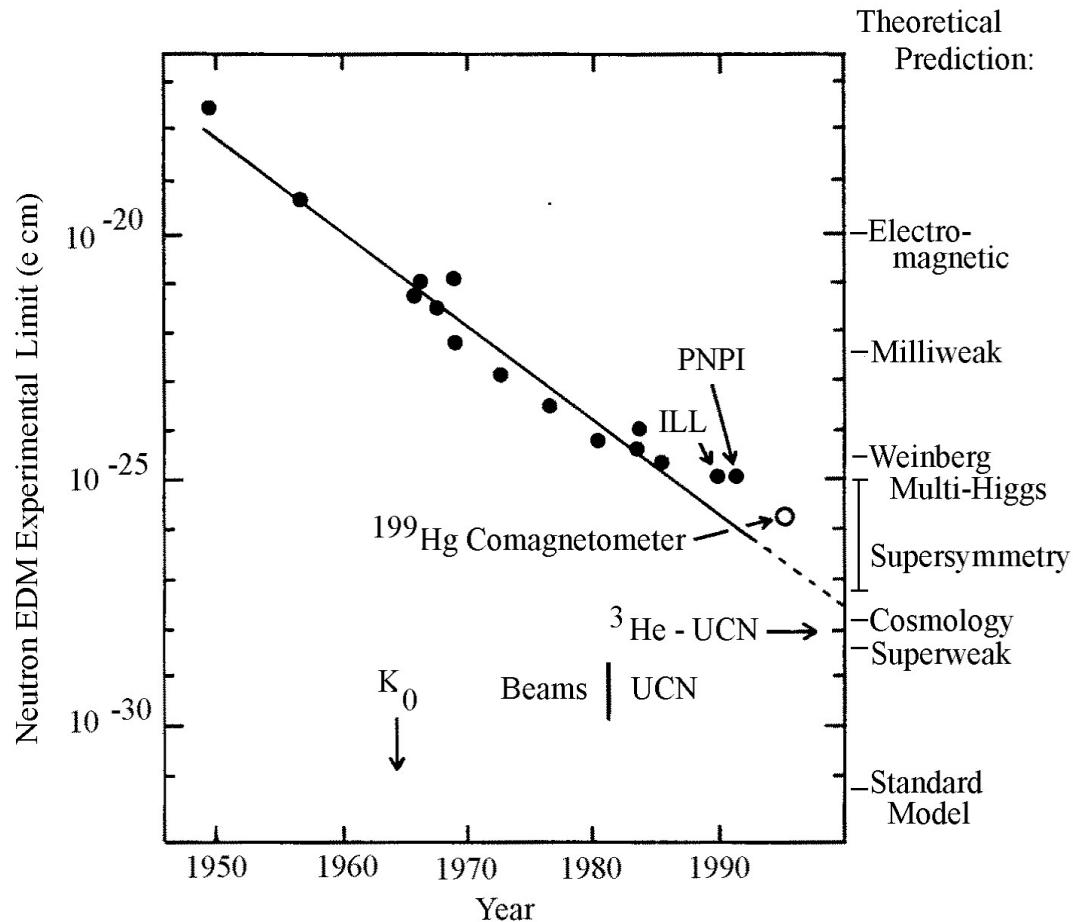
SM expectation:

$$n_B / n_\gamma \sim 10^{-18}$$





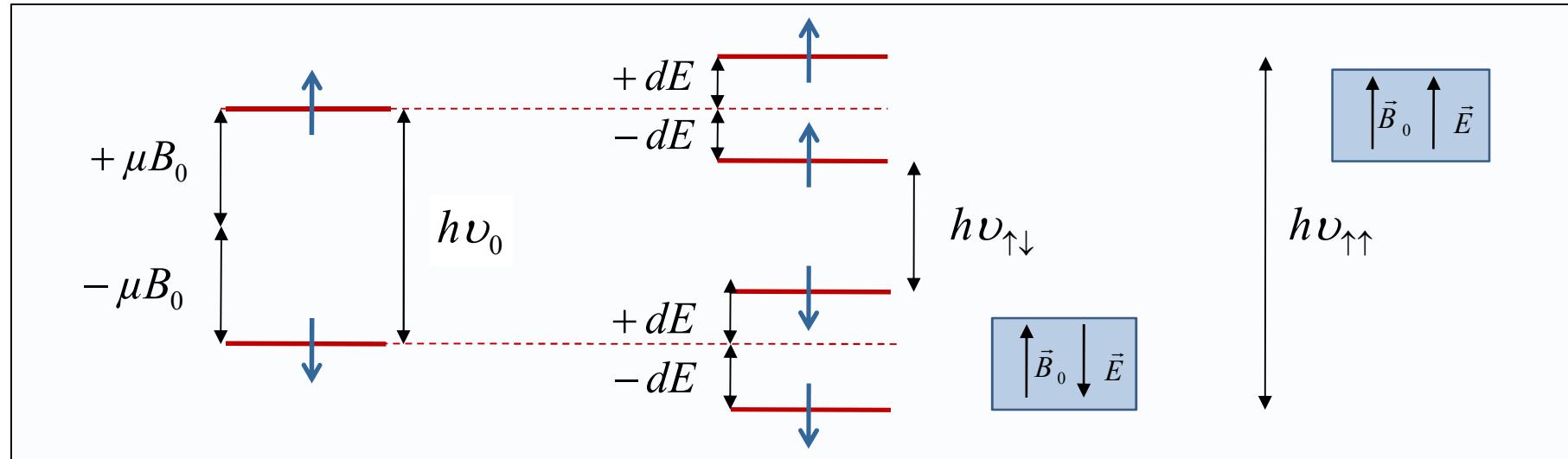
Theories exp tests



McKeen, Pospelov, Ritz
PRD 87 2013



Neutron Larmor frequency shift induced by electric field

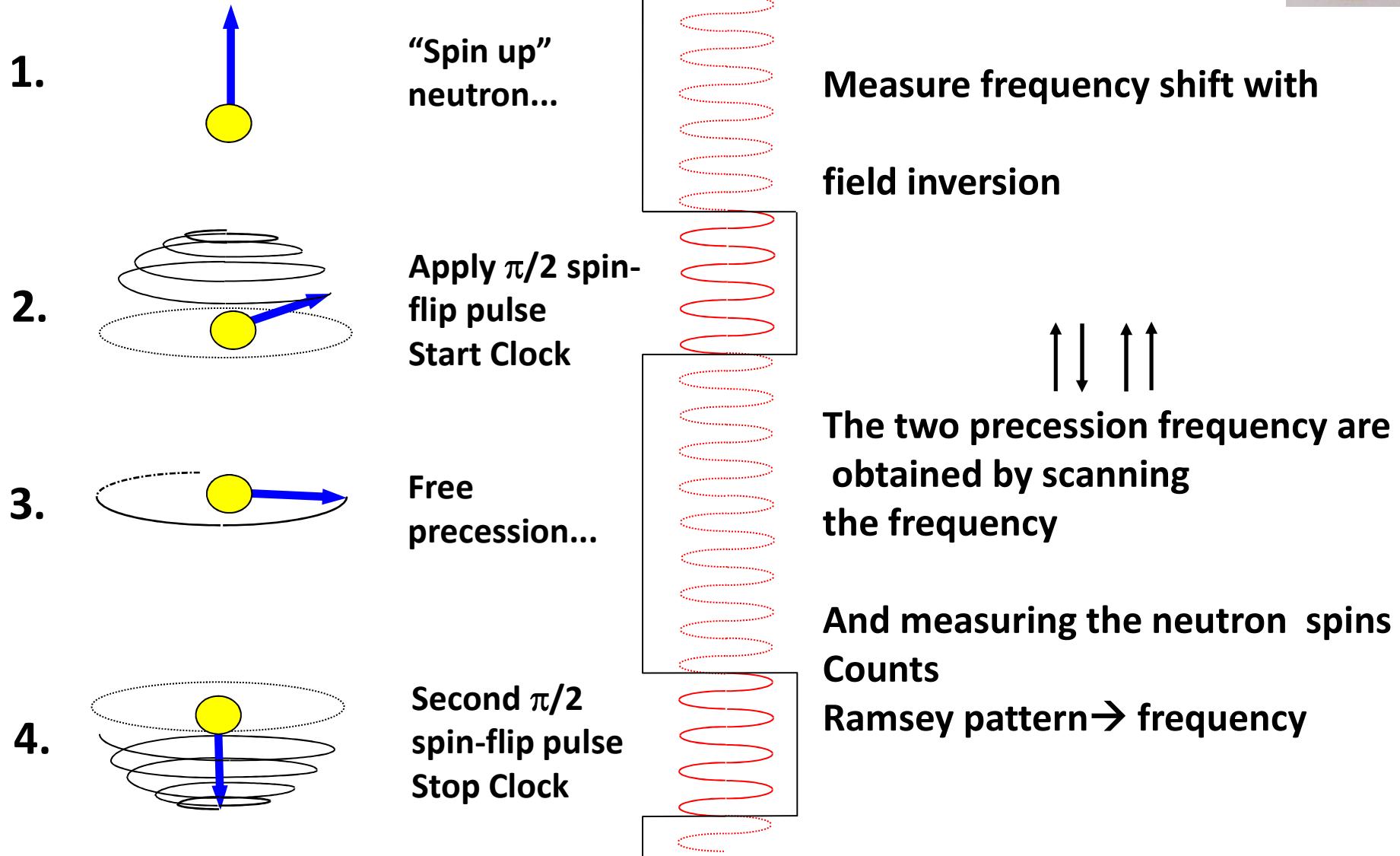


$$h\nu_{\uparrow\uparrow} - h\nu_{\uparrow\downarrow} = 4d_n E$$

Frequency shift between parallel and anti parallel = EDM

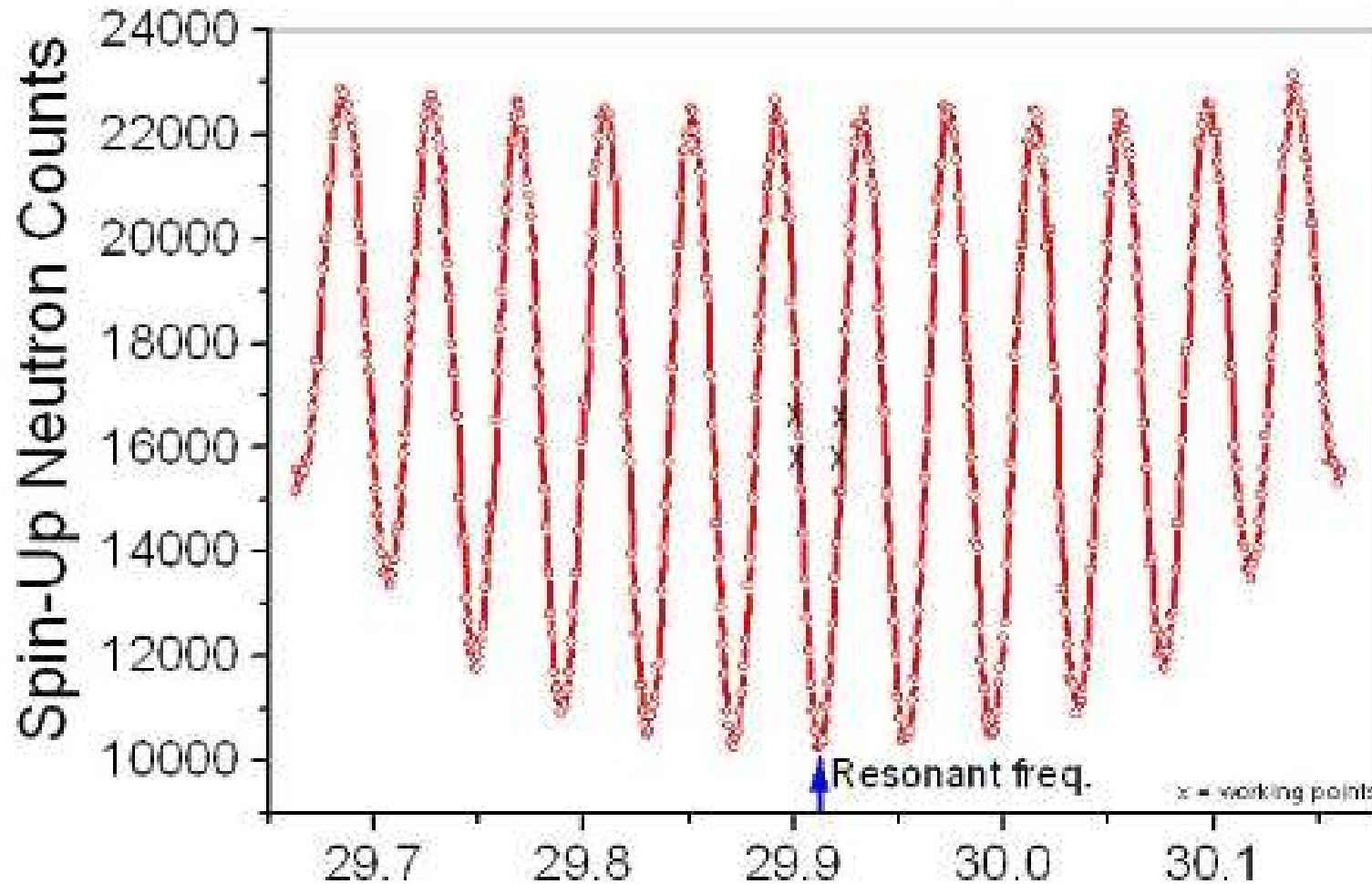
At the present d_n limit 60 nHz difference at
~30 Hz
→ Control over B and E

Ramsey Method of separated oscillatory Fields





Ramsey Pattern





Sensitivity and limits

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

Highest E field (~ 12 kv/cm)

Longest precession time T (> 100 s)

Large neutron number (few $10/\text{cm}^3$)

Large polarisation α (90%)

And Systematics...

Present limit

$< 3 \cdot 10^{-26}$ e.cm

J.M. Pendlebury et al. Phys. Rev. D 92 092003
(2015)

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

SM $\sim 10^{-31}$ e.cm Unreachable

NP BSM $\sim 10^{-27}$ e.cm Right there...





Ultra Cold neutrons or UCNs



To have the longest precession (observation) time we use ultra cold neutrons UCNs

Energy : $E_n \sim 10^{-7}$ eV ~ 100 neV, $v=4-6$ m/s

1 m jump in the earth gravity field

Can be stored in material bottles (Fermi potential 250 neV)

Or magnetic bottle (60 neV ~ 1 T)

Production from fast neutrons with fission (HFR@ILL) or spallation (PSI, SNS)
through ultra cold moderators (5 K) e.g. Solid D₂





Around the world

■ Operating:

- PNPI, ILL@ILL
(result 2013/14, upgrading)
- nEDM@PSI
(2017 upgrade to n2EDM)

■ R&D and construction

- cryoEDM@ILL
- @RCNP/TRIUMF
- @FRM-2
- @SNS
- @PNPI
- @LANL

■ Possible future projects

- @J-PARC
- @PIK
- @ESS

nEDM collaboration 15 Institutions ~ 50 scientists



Physikalisch Technische Bundesanstalt, Berlin



Laboratoire de Physique Corpusculaire, Caen



Institute of Physics, Jagiellonian University, Cracow



Henryk Niedwodniczanski Inst. Of Nucl. Physics, Cracow



Département de physique, Université de Fribourg, Fribourg



Lab. de Physique Subatomique et de Cosmologie, Grenoble



Katholieke Universiteit, Leuven



Inst. für Kernchemie, Johannes-Gutenberg-Universität, Mainz



Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse, Paris



Paul Scherrer Institut, Villigen



Eidgenössische Technische Hochschule, Zürich



University of Bern



University of Kentucky



University of Sussex



Protons & Muons & Neutrons

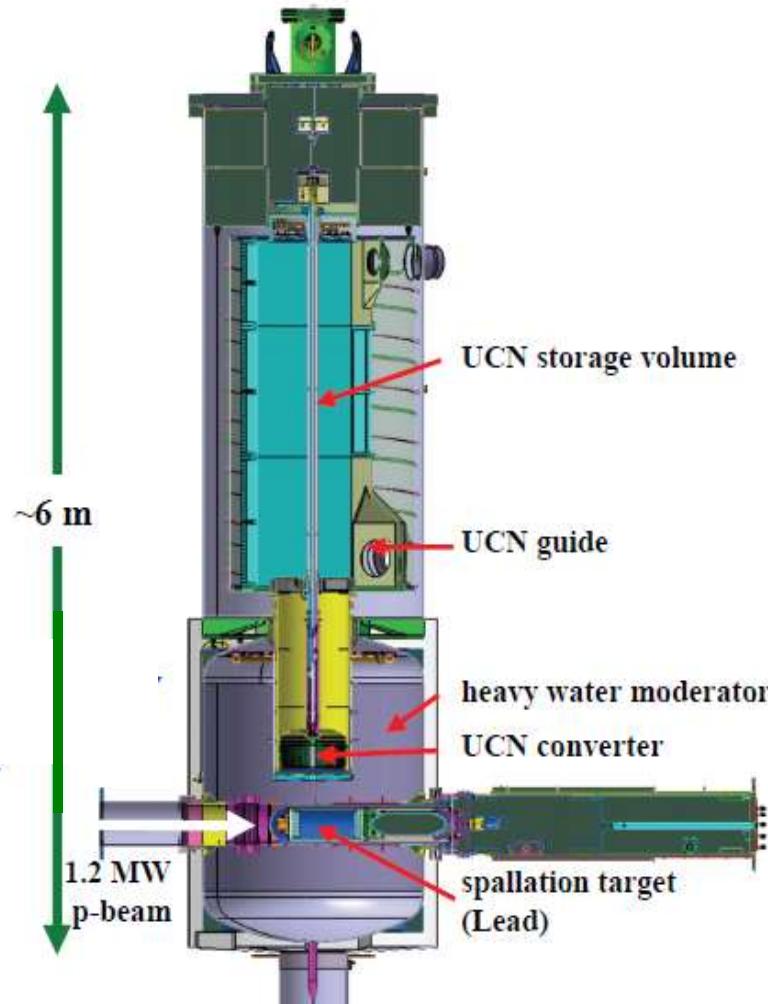


600 MeV P, 2.5 mA

Here



UCN source @ PSI (B. Lauss)

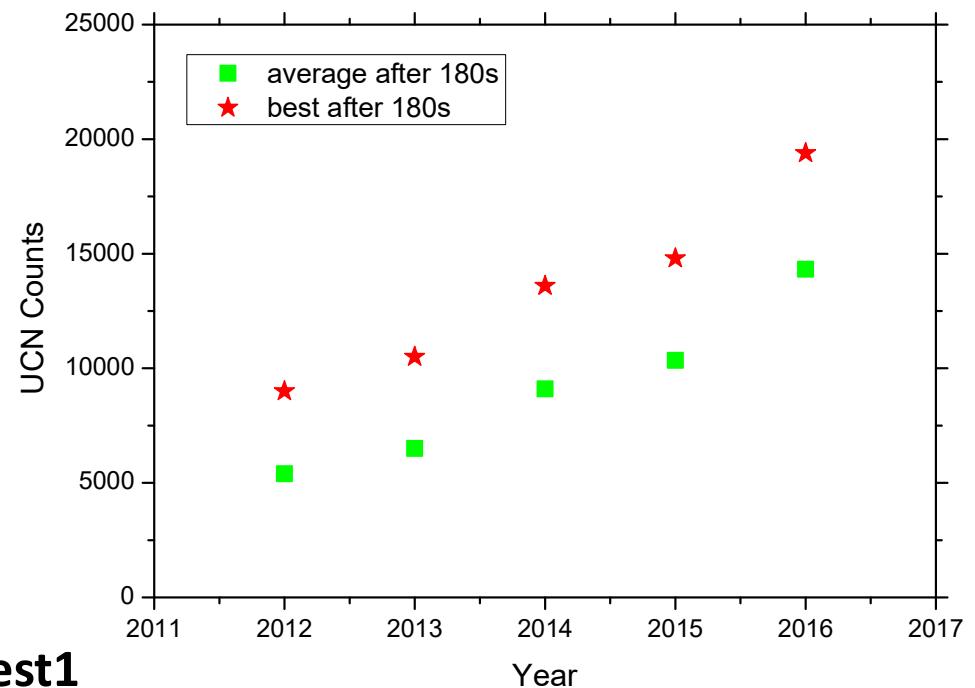


UCN density measured at West1
22 UCN/cm³

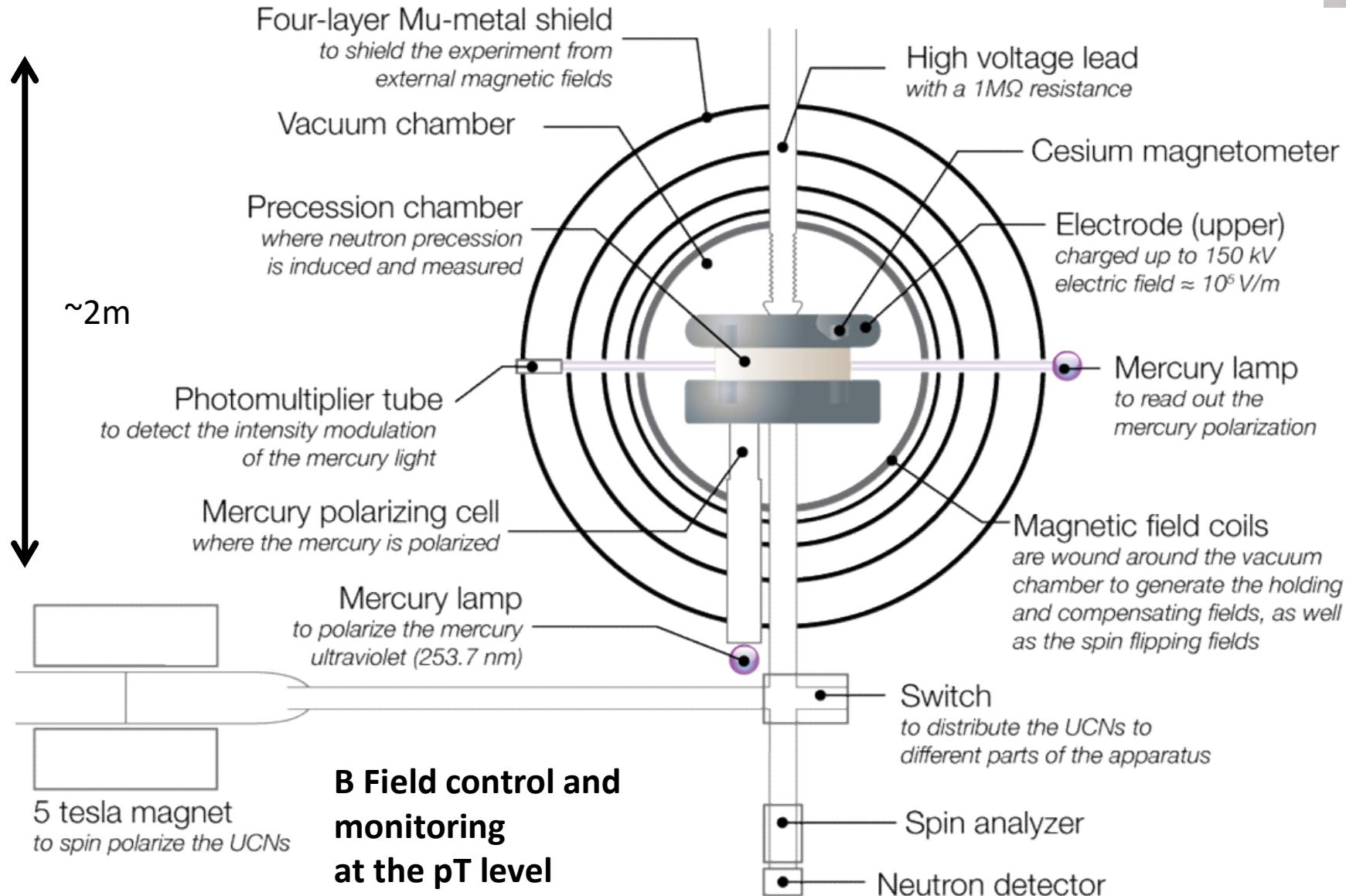
Spallation Source

~2.3 mA protons@600 MeV on lead target

Commissioning at end of 2010
Improving constantly since
a little off the prediction...

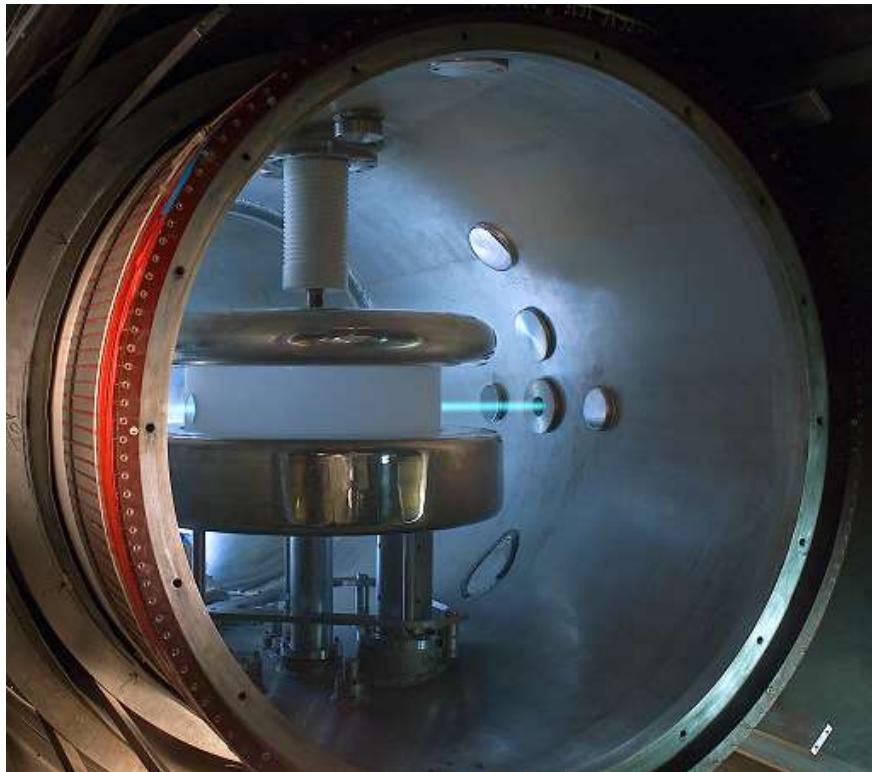


Spectrometer





Pictures





Sensitivity

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

	RAL/Sx/ILL*	PSI 2013	2015		2016	
	avg	avg	best	avg	Best	avg
E-field	8.3	10.3	11	11	11	11
Neutrons	14 300	6 500	14800	10350	19390	14321
T _{free}	130	180	180	180	180	180
T _{duty}	240	340	300	300	300	300
α	0.453	0.57	0.8	0.75	0.82	0.775
$\sigma/d (10^{-25} \text{ ecm})$	3.0	2.8	1.1	1.9	0.96	1.24





SYSTEMATICS

Effects	Status
Direct Effects	
Uncompensated B-Drifts	0.5 ± 1.2
Leakage Current	0.00 ± 0.05
$V \times E$ UCN	0 ± 0.1
Electric Forces	0 ± 0.4
Hg EDM	0.02 ± 0.06
Hg Direct Light Shift	0 ± 0.008
Indirect Effects	
Hg Light Shift	0 ± 0.05
Quadrupole Difference	1.3 ± 2.4
Dipoles	
At the surface	0 ± 0.4
Other Dipoles	0 ± 3
Total	1.8 ± 4.1

J.M. Pendlebury et al. Phys. Rev. D 92
(2015)

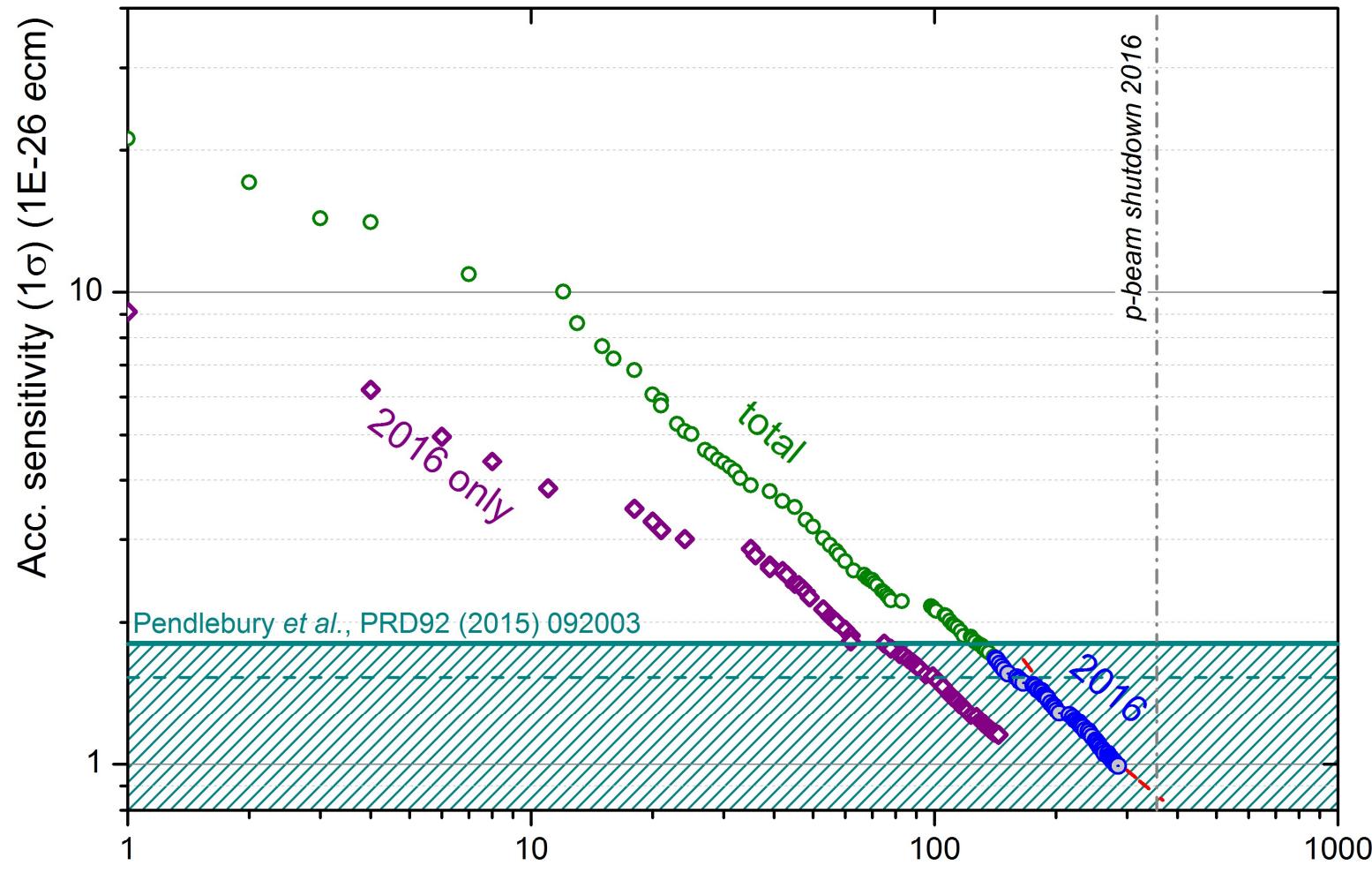
$\text{in } 10^{-27} \text{ ecm}$



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2013-2016 data taking



11/10/16

Final analysis ongoing...



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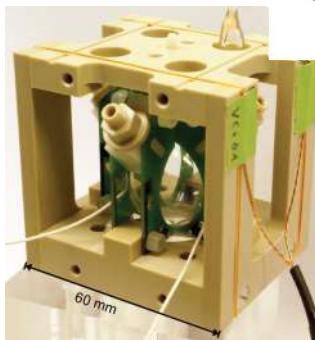
n2edm → 2020

**Room temperature spectrometer
Double chamber, Larger volume**

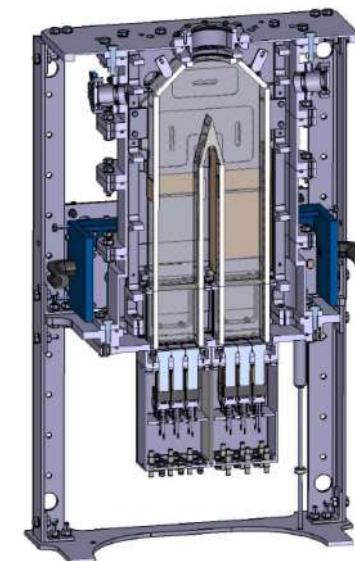
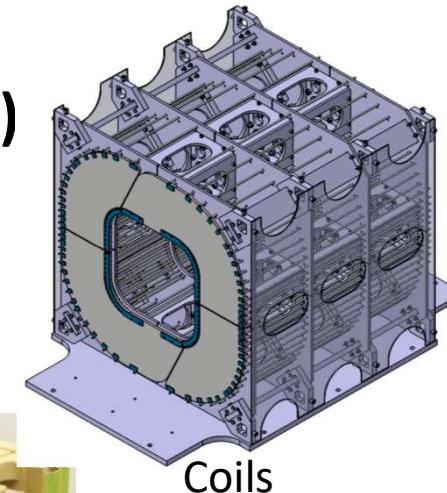


Detector

- Detection UCN Fast detectors (Gas Scintillation)
- CS HV vector magnetometers (pT)
- Laser Hg co magnetometry
- Double spin analysis
- Coil design...



CS vector magnetometer



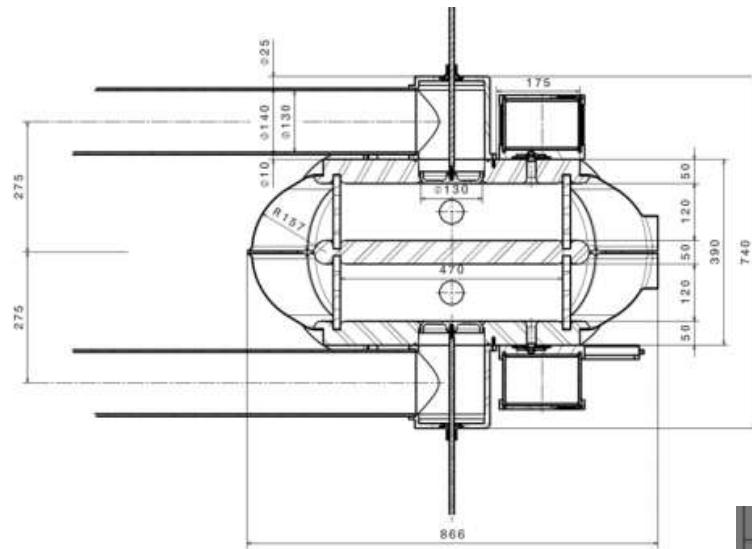
Spin analysis





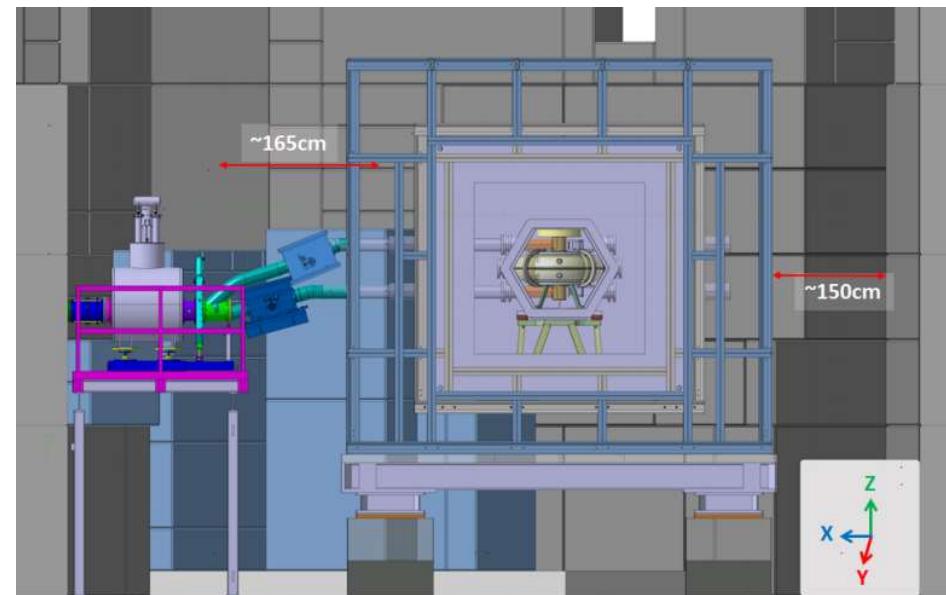
n2EDM

Double chamber



New shielding
New guides
New vacuum vessel

General Layout





Expected sensitivity

	Current	n2EDM	n2EDM	n2EDM	n2EDM	n2EDM	n2EDM
phase	2016 average	comm.	comm.	meas.	meas.	meas.	meas.
ID (cm)	47	47	47	80	80	100	100
coating	dPS	dPS	iC	dPS	iC	dPS	iC
α	0.75	0.8	0.8	0.8	0.8	0.8	0.8
E (kV/cm)	11	15	15	15	15	15	15
T (s)	180	180	180	180	180	180	180
N	15'000	50'000	100'300	121'000	292'000	160'000	400'000
$\sigma(d_n)$ (e·cm) per day	11×10^{-26}	4.1×10^{-26}	2.8×10^{-26}	2.6×10^{-26}	1.7×10^{-26}	2.3×10^{-26}	1.4×10^{-26}
$\sigma(d_n)$ (e·cm) 500 data days	5.0×10^{-27}	1.8×10^{-27}	1.3×10^{-27}	1.2×10^{-27}	7.5×10^{-28}	1.0×10^{-27}	6.4×10^{-28}



Conclusion

EDM are a powerful probe to search for new CPV source

It might explain Baryon asymmetry

**For the neutron a new limit in the 10^{-26} e.cm range
will be publish (2017-2018)**

**Work has been going on for the UCN source improvements and
n2EDM spectrometer design**

Goal a non zero EDM or a limit 10^{-27} e.cm in 2023-25



THANK YOU For Your ATTENTION !!



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