



Neutron Electric Dipole Moment Search at Paul Scherrer Institute

G Ban

On behalf of the nEDM collaboration

LPC Caen-ENSICAEN-CNRS IN2P3

Caen, France





Outline

Why measure nEDM

Measurement Principle

Some developments and Status

n²EDM

Conclusion



Find new sources of CP violation

Electric Dipole Moment

Similar as magnetic moment

$S = \text{Spin}$

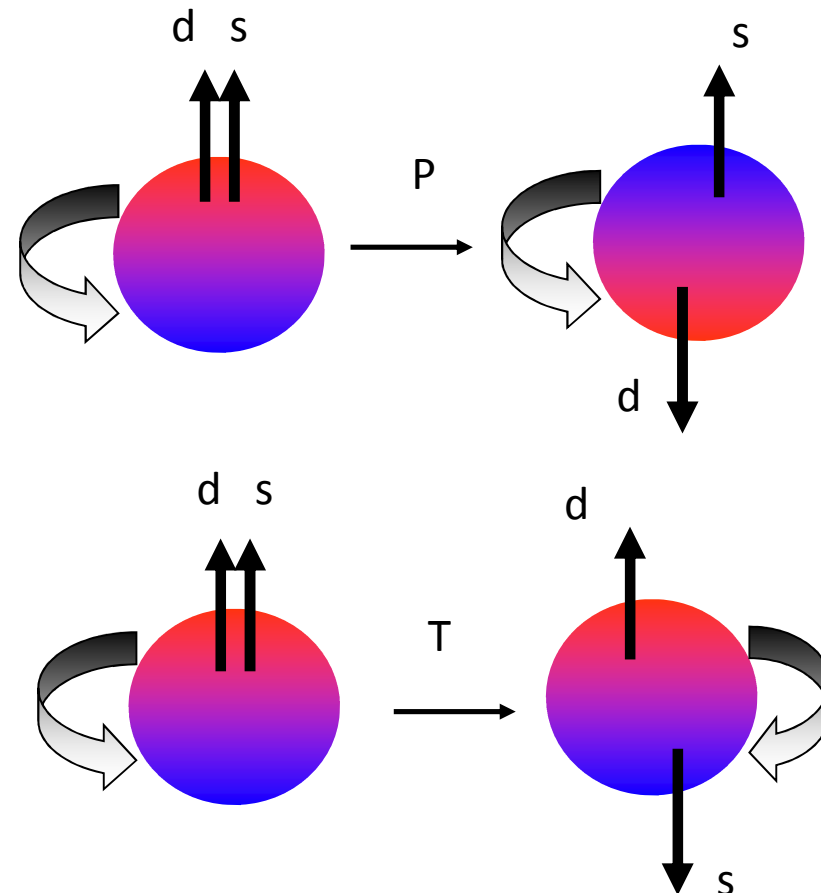
$$\mu = \mu_B S \text{ and } d = \delta S$$

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

d is P odd and T odd

Assuming CPT

$\rightarrow d$ is CP odd



SEARCH for new source of CP violation

Purcell and Ramsey, PR78(1950)807



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:

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

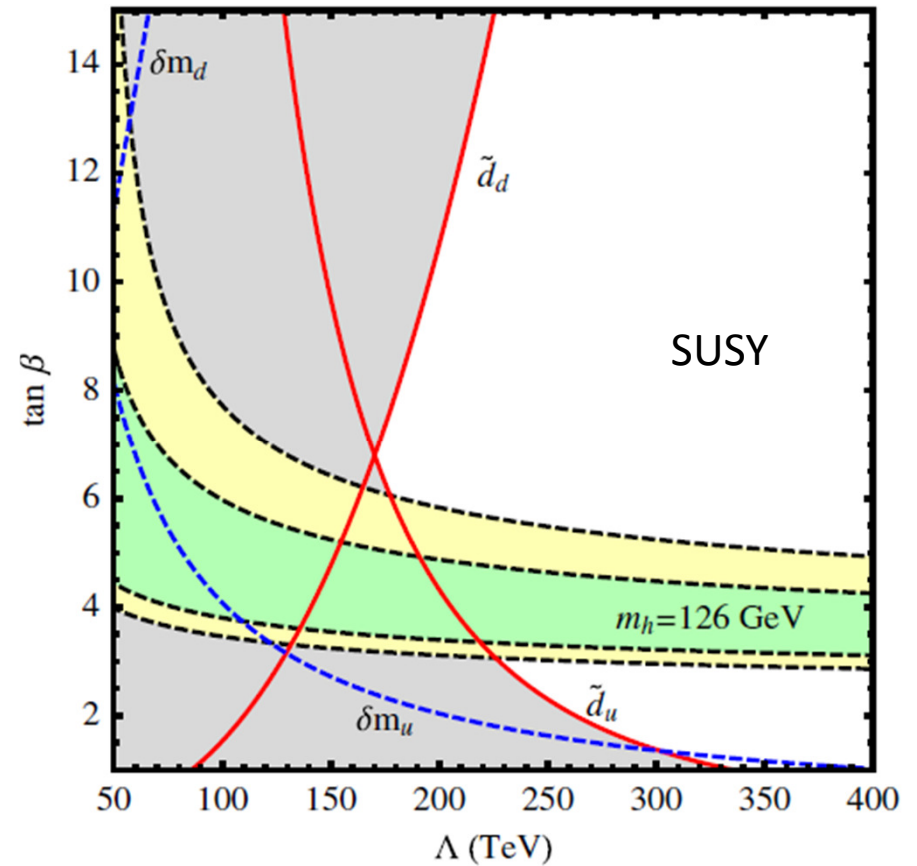
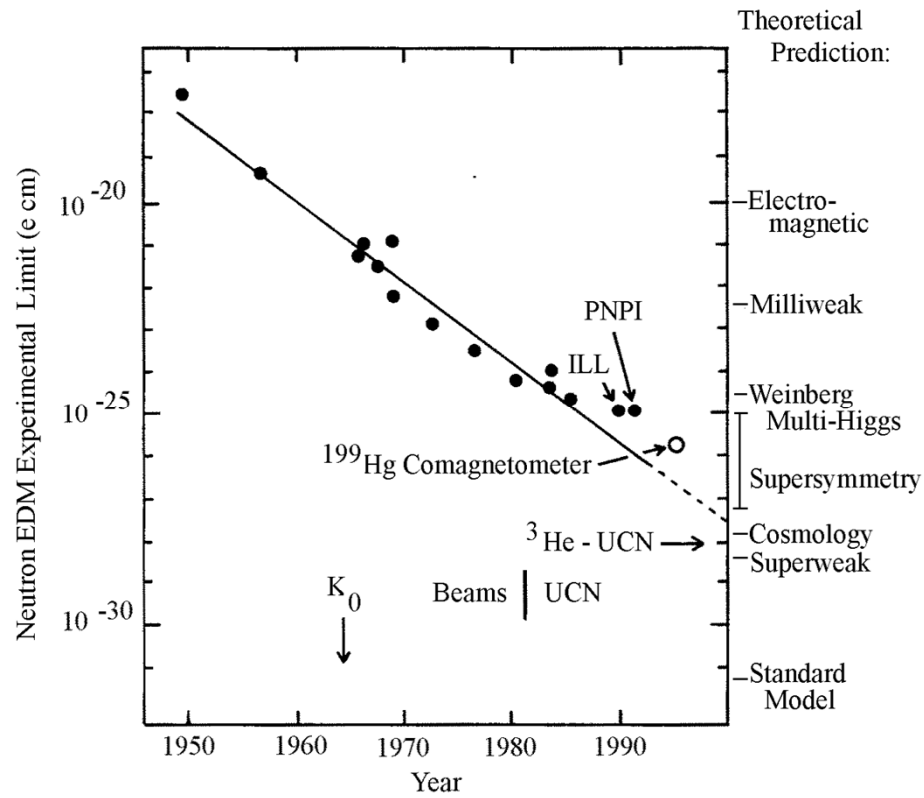
SM expectation:

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





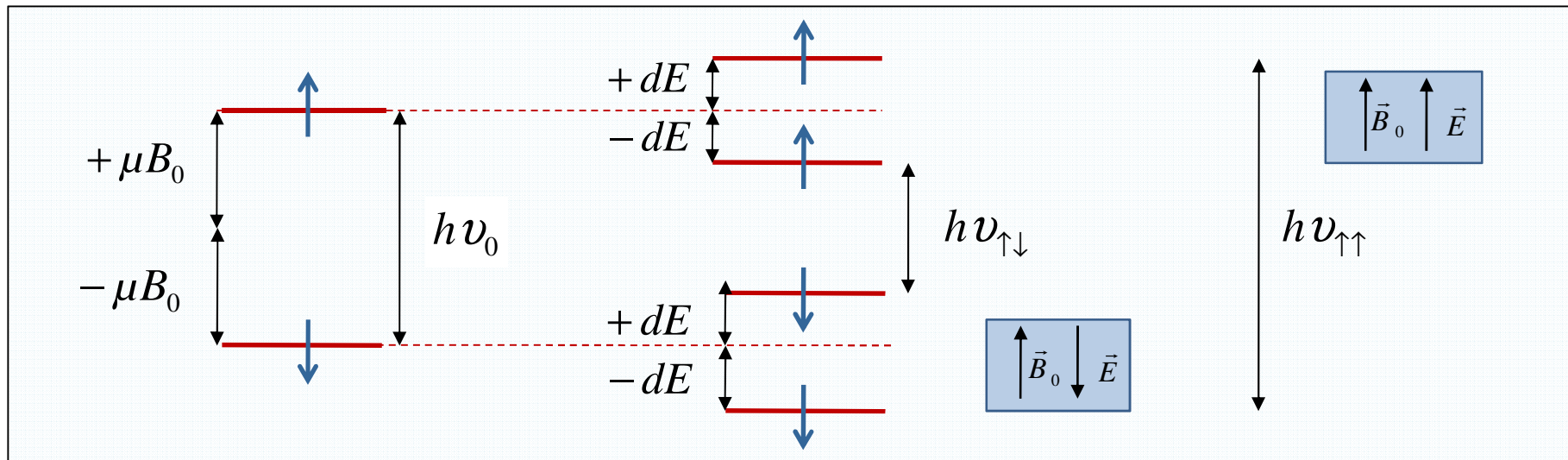
Theories exp tests



McKeen, Pospelov, Ritz
PRD 87 2013



Neutron Larmor frequency shift induced by electric field



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

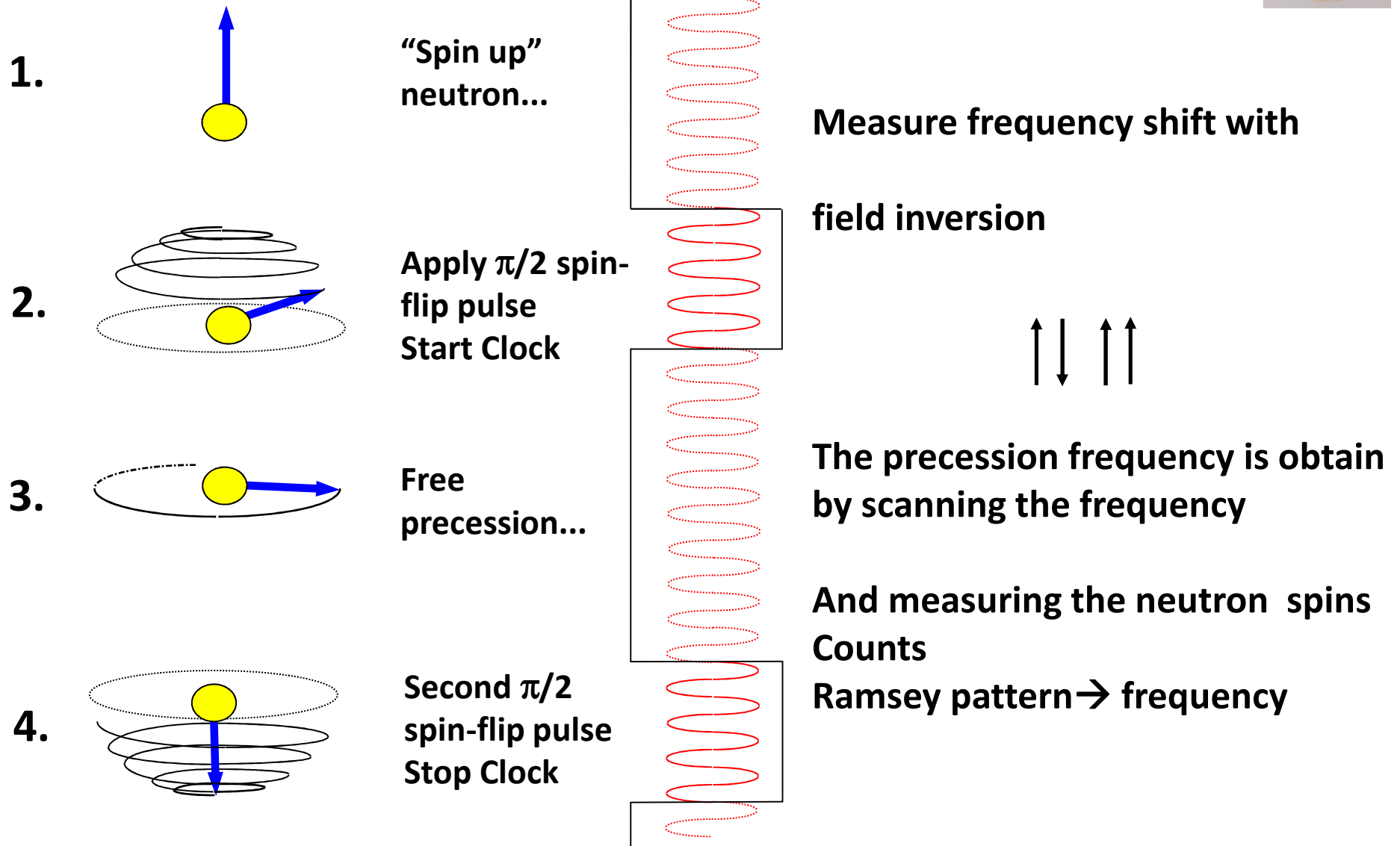
Frequency shift between parallel and anti parallel = EDM

At the present d_n limit 60 nHz difference

→ Control over B and E



Ramsey Method of separated oscillatory Fields





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 100/cm³)

Large polarisation α (90%)

And Systematics...

Present limit

3 10⁻²⁶ e.cm

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

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

SM ~10⁻³¹ e.cm Unreachable

SUSY ~10⁻²⁶ e.cm Right there...





Ultra Cold neutrons or UCNs



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

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

1 m jump in the earth gravity field

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

Or magnetic bottle (60 neV \sim 1T)

Production with fission (ILL) spallation neutrons (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 14 Institutions ~ 50 scientists



M. Burghoff, S. Knappe-Grüneberg, A. Schnabel, **J. Vogt**

Physikalisch Technische Bundesanstalt, Berlin



G. Ban, **V. Hélaïne**¹, T. Lefort, Y. Lemièrre, G. Quéméner, O Navilliat

Laboratoire de Physique Corpusculaire, Caen



K. Bodek, **M. Rawlik**, **G. Wyszynski**³, J. Zejma

Institute of Physics, Jagiellonian University, Cracow



A. Kozela

Henryk Niedwodniczanski Inst. Of Nucl. Physics, Cracow



N. Khomutov

Joint Institute of Nuclear Reasearch, Dubna



M. Kasprzak, **H.C Koch**, A. Weis, Z. Grujic

Département de physique, Université de Fribourg, Fribourg



Y. Kermaïdic, G. Pignol, D. Rebreyend, B. Clément,

Lab. de Physique Subatomique et de Cosmologie, Grenoble



N. Severijns, P. Pataguppi

Katholieke Universiteit, Leuven



W. Heil

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



S. Roccia,

Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse, Paris



S. Afach, G. Bison, Z. Chowdhuri, **M. Ferti**³, B. Lauss, **S. komposch**
D. Ries, P. Schmidt-Wellenburg, G. Zsigmond

Paul Scherrer Institut, Villigen



B. Franke, **K. Kirch**¹, J. Krempel, F. Piegsa, D. Zhu

Eidgenössische Technische Hochschule, Zürich



C Crawford

University of Kentucky



P. Harris, C. Griffith

University of Sussex

also at: ¹Paul Scherrer Institut, ²PNPI Gatchina, ³Eidgenössische Technische Hochschule



Rencontres du Vietnam 2014 Flavor Physics





Protons & Muons & Neutrons

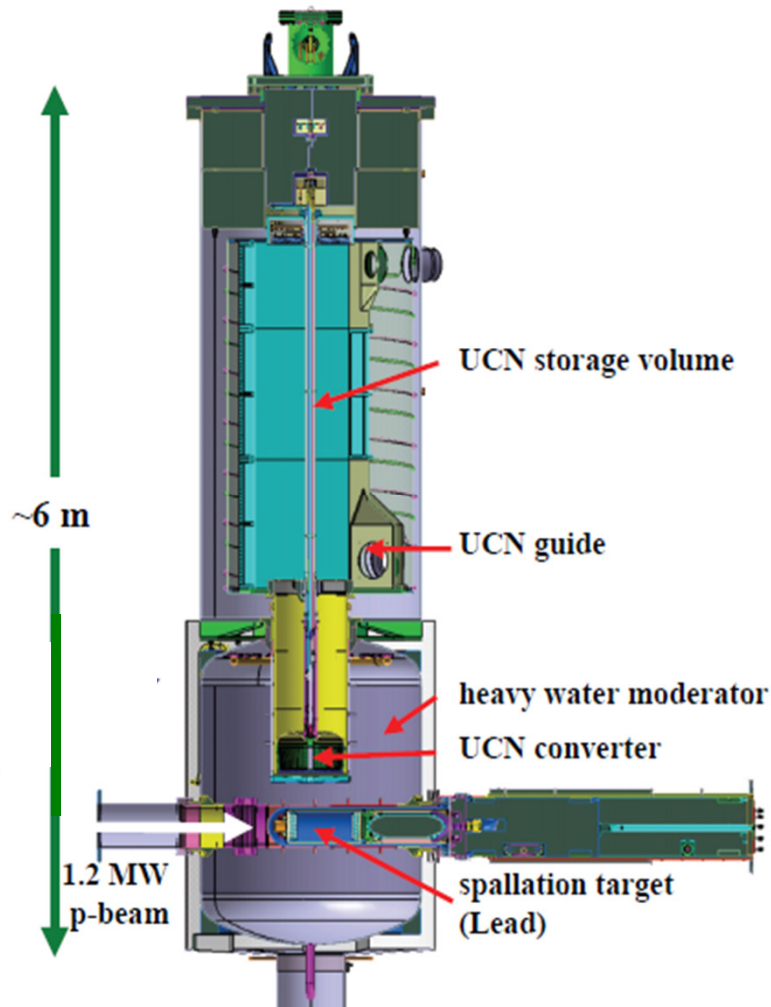


600 MeV P, 2.5 mA

Here



UCN source @ PSI (B. Lauss)



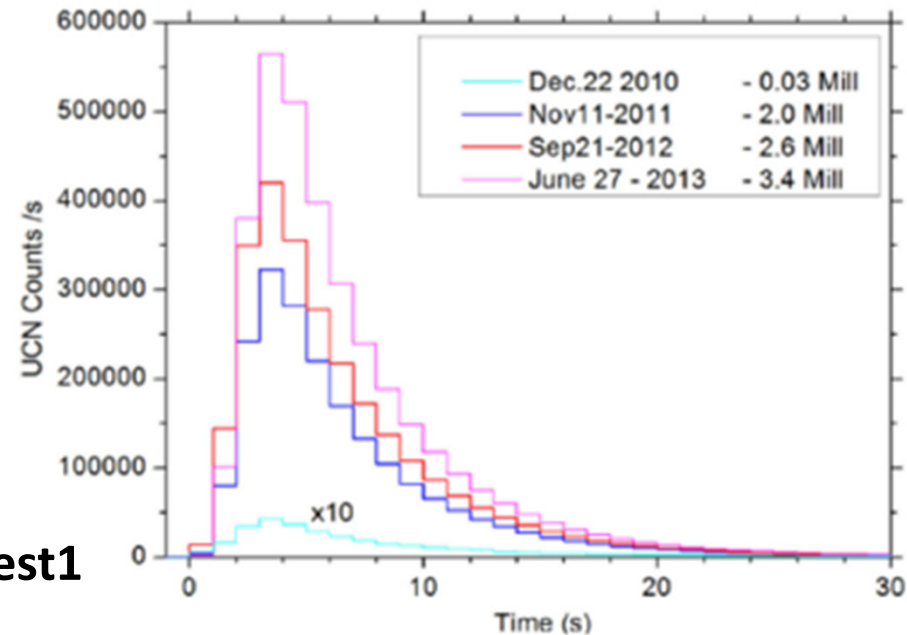
Spallation Source

~2.1 mA protons@600 MeV on lead target

Commissioning at end of 2010

Improving constantly but

Still a factor ~25 out of design



UCN density measured at West1
23 UCN/cm³

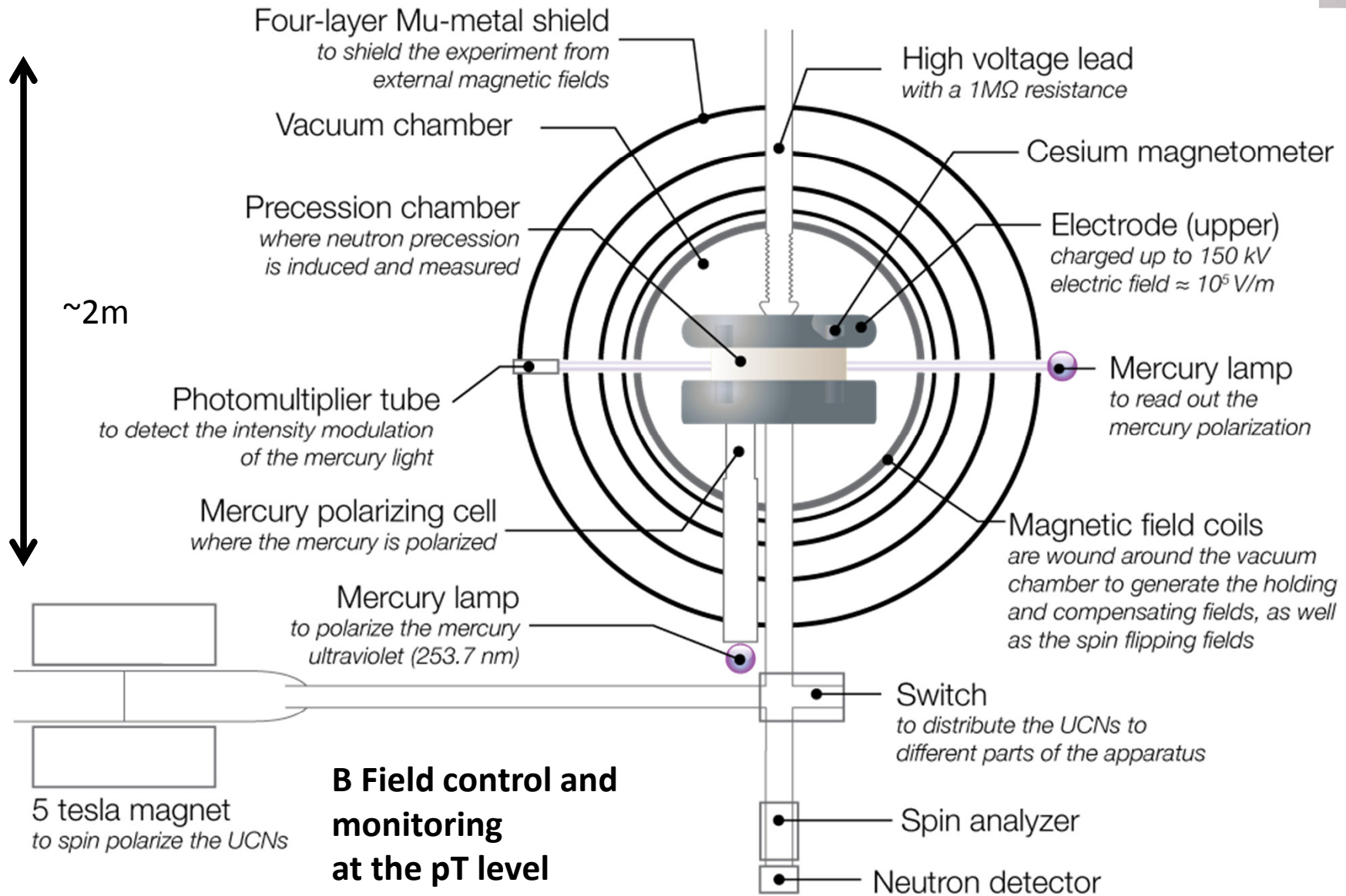
Same vessel used at ILL PF2

4.7 UCN/cm³

Rencontres du Vietnam 2014 Flavor Physics

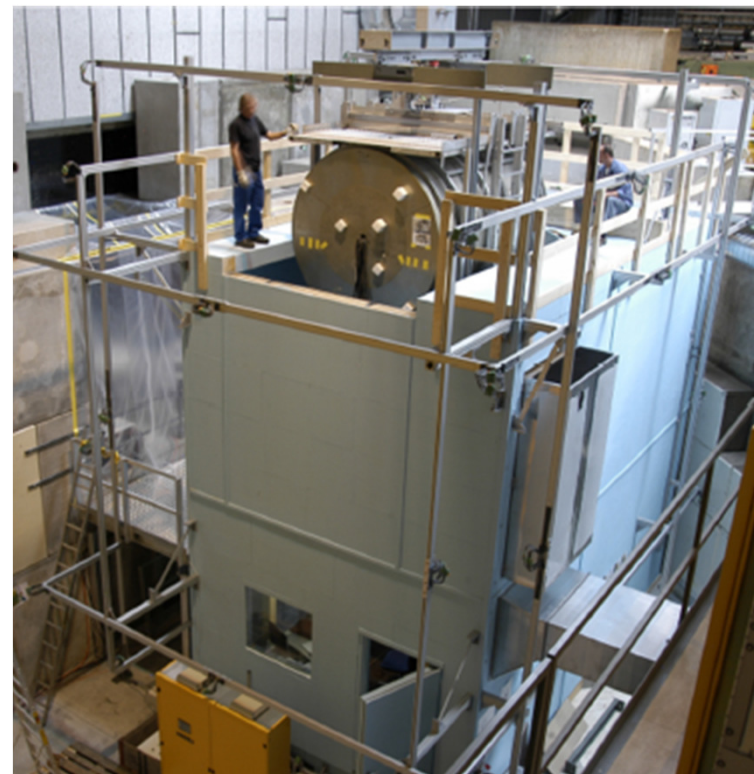
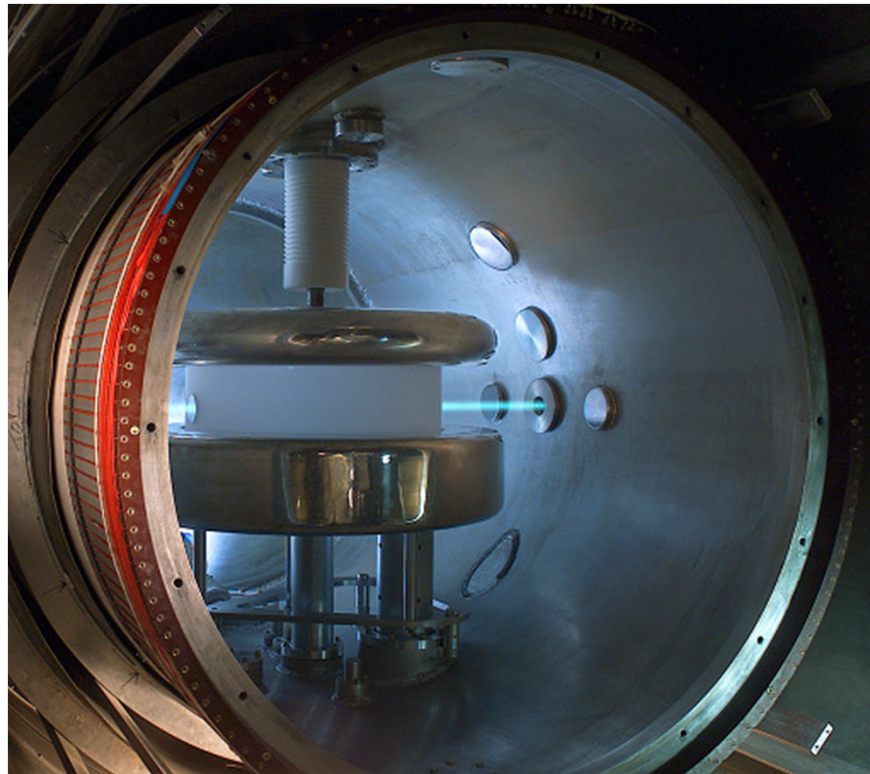


Spectrometer





Pictures





Sensitivity 2013

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

	RAL/Sussex/ILL*		PSI 2013	
	best	avg	best	avg
E-field	8.8	8.3	12	10.3
Neutrons	14 000	14 000	10 500	6 500
T _{free}	130	130	200	180
T _{duty}	240	240	340	340
α	0.6	0.453	0.62	0.57
σ/d (10^{-25} ecm)	2.3	3.0	1.5	2.8

2013 data taking:

3266 cycles

25 days (**→ aim at 100 days in 2014**)

2013 accumulated sensitivity 6×10^{-26} e.cm





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

**With present apparatus
Goal $\sim 10^{-26}$ ecm in 3 years**

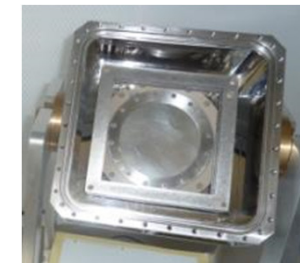
In 10^{-27} ecm



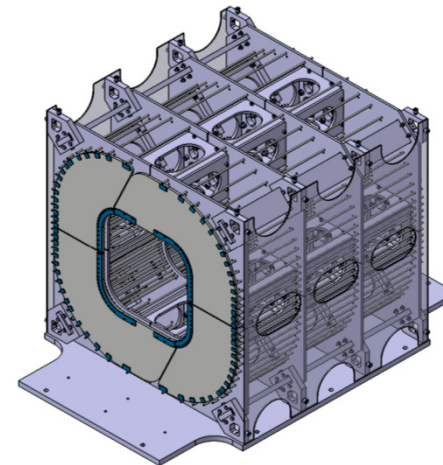


Developments for nedm and n2edm

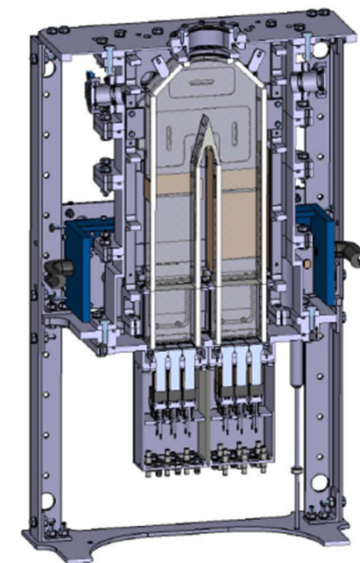
- Detection Fast UCN detectors (Scintillation)
- CS HV vector magnetometers
- Laser Hg co magnetometry
- Double spin analysis
- Coil design



Detector

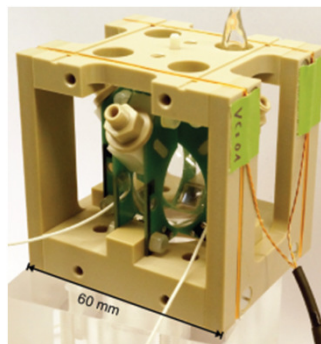


Coils



Spin analysis

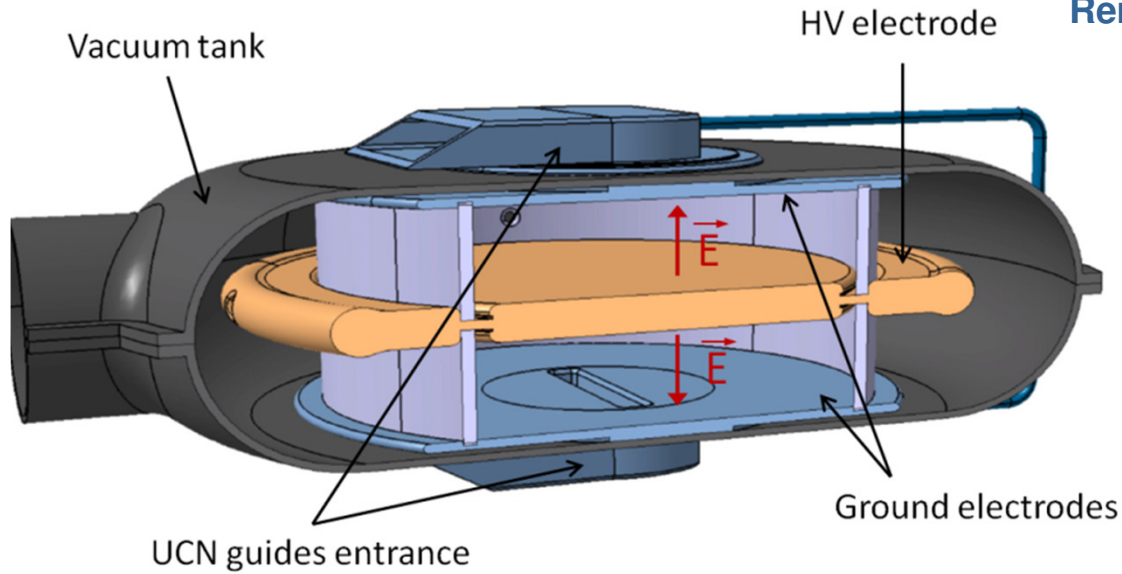
CS vector magnetometer



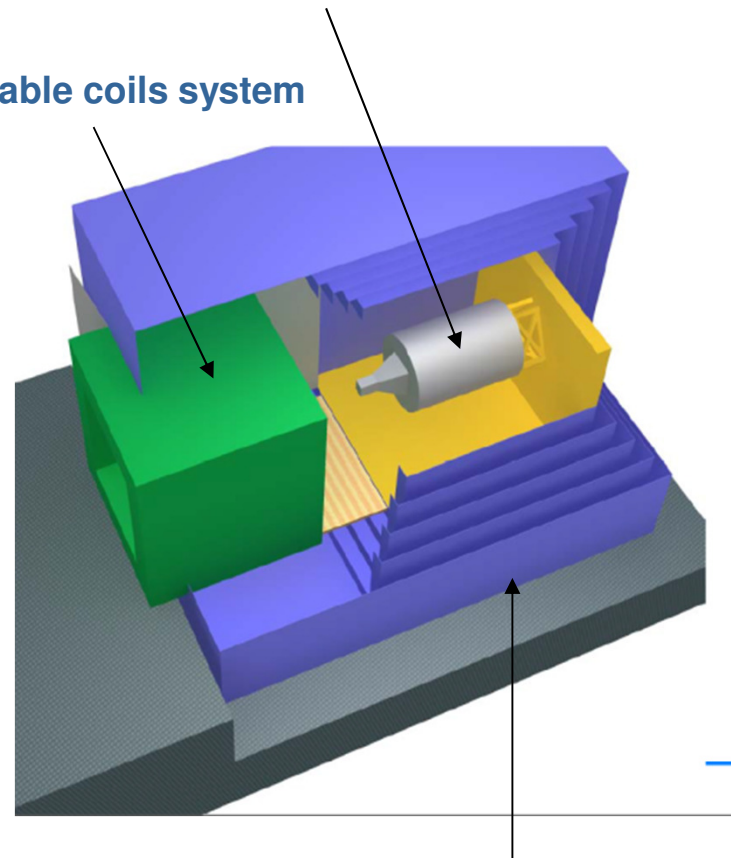
n2EDM



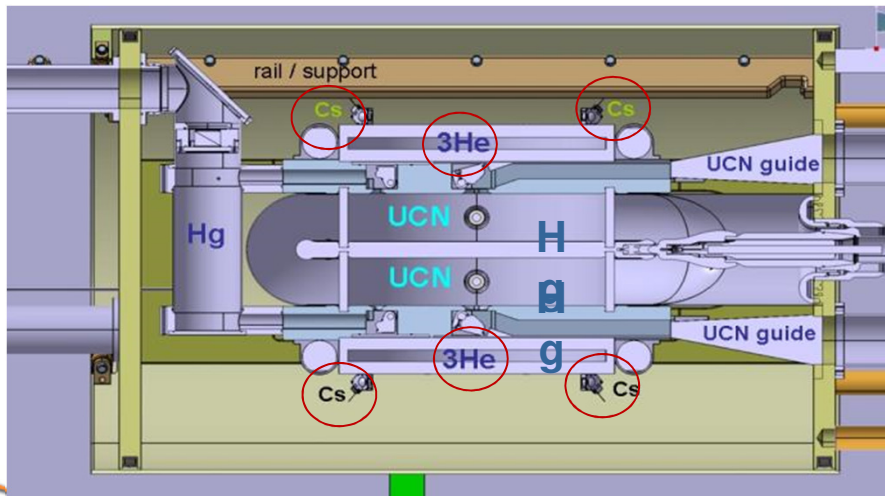
Double chamber



Removable coils system



Fixed multilayer passive magnetic shield



Goal
 10^{-27} e cm
 in ~2020





Conclusion

EDM are a powerful probe to tests BSM theories (SUSY others ?...)

It might explain Baryon asymmetry

Our effort at PSI aims to reach 10^{-26} ecm at first

Then in 2018-20 the 10^{-27} ecm range

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



THANK YOU For Your ATTENTION !!



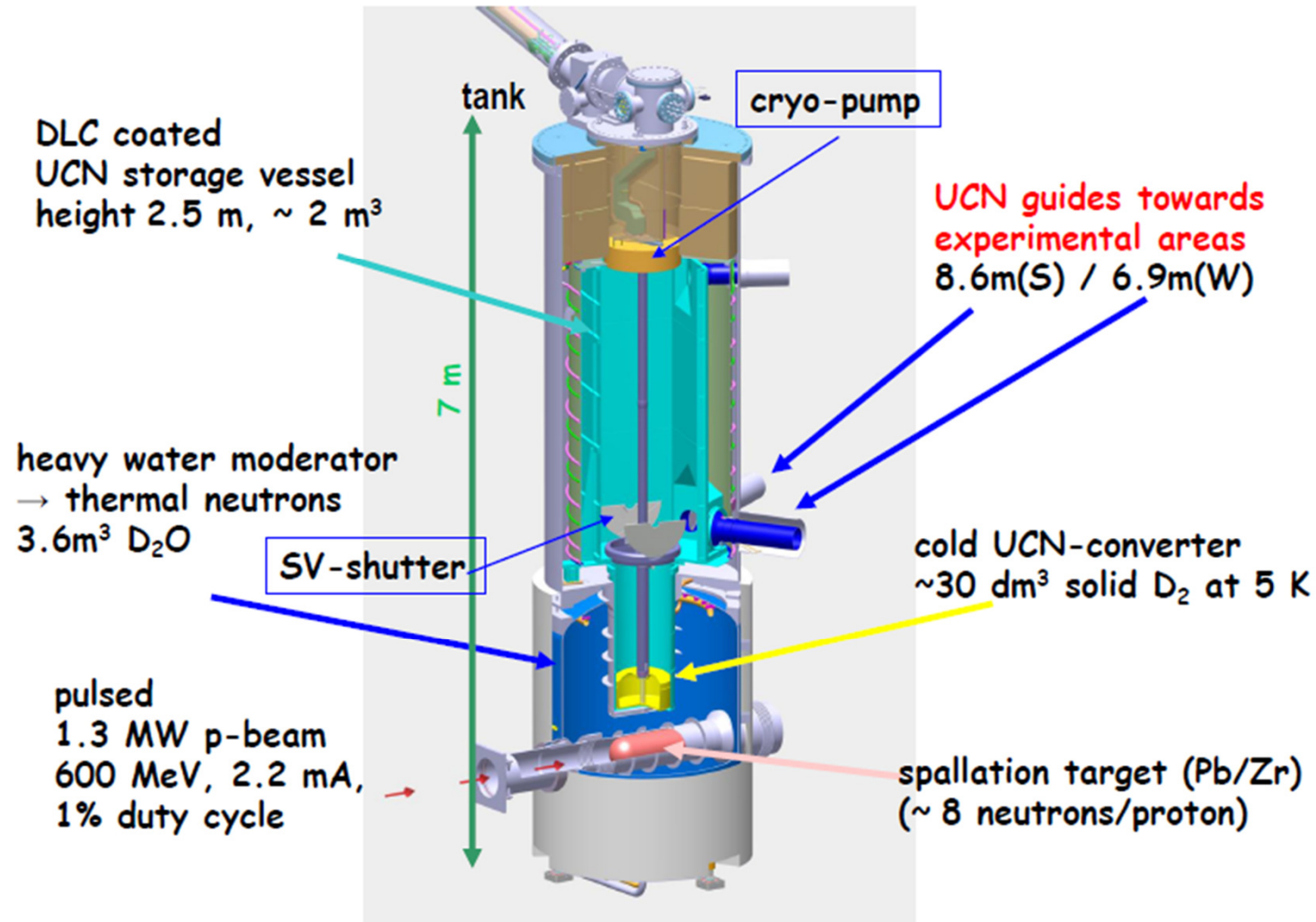
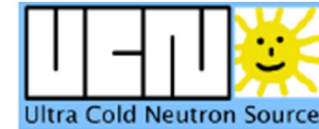
Blue hill
Brewery



Rencontres du Vietnam 2014 Flavor Physics



The PSI UCN source



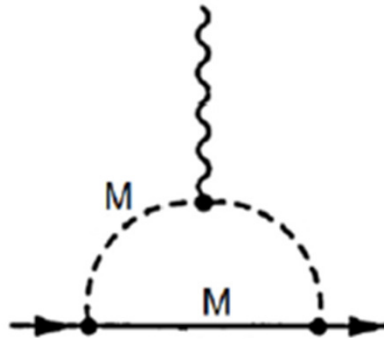


Rencontres du Vietnam 2014 Flavor Physics





Theories exp tests


$$d_n \approx \left(\frac{1 \text{ TeV}}{M} \right)^2 \times \sin(\phi) \times 10^{-25} \text{ e cm}$$

