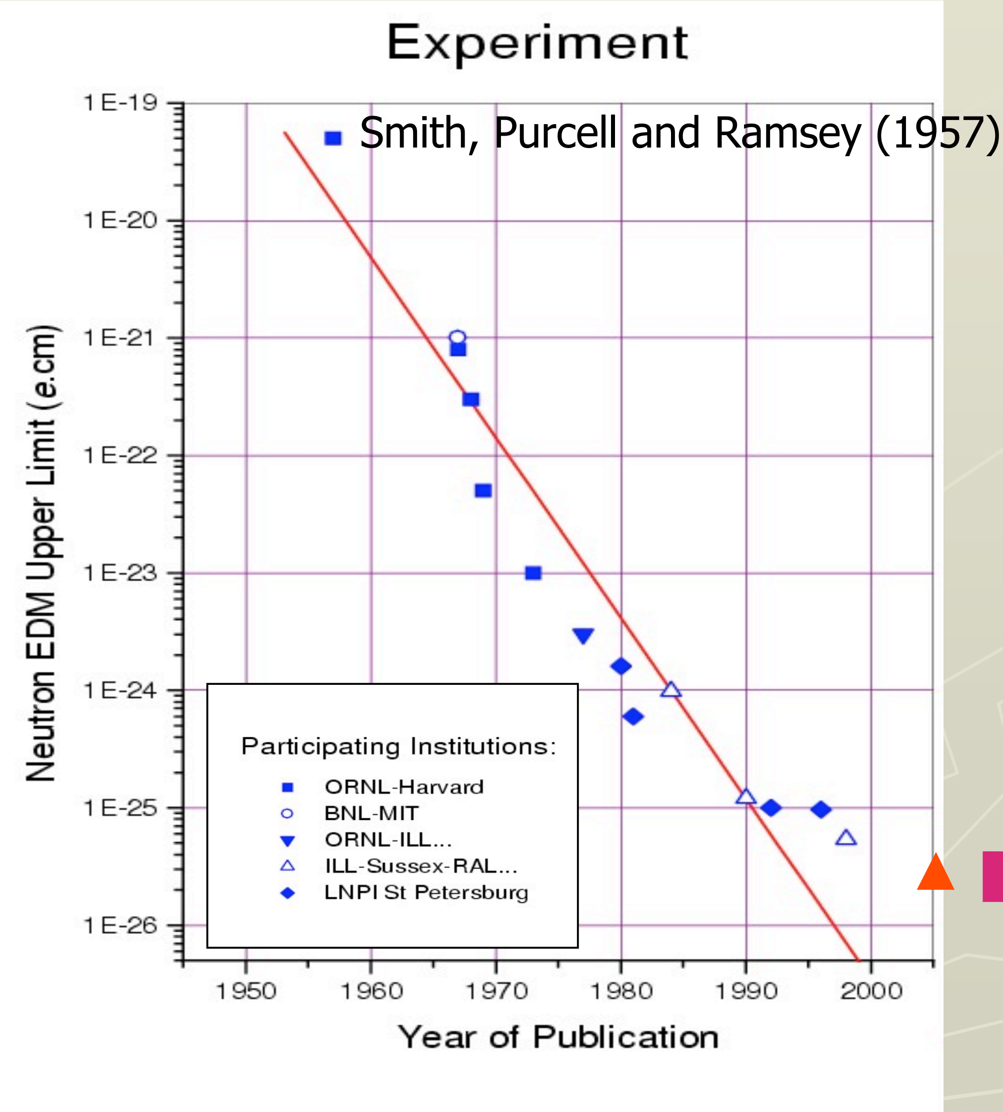
The neutron EDM project at PSI

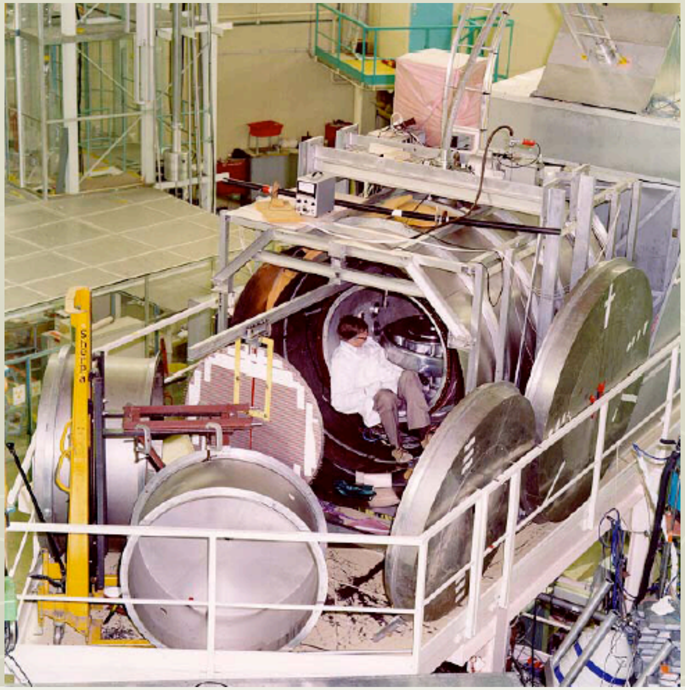
Dominique Rebreyend
(LPSC Grenoble)
for the nEDM-PSI collaboration

Outline

- Physics motivations
- Experimental technique
- Our approach
- Some current R&D activities
- The PSI UCN source

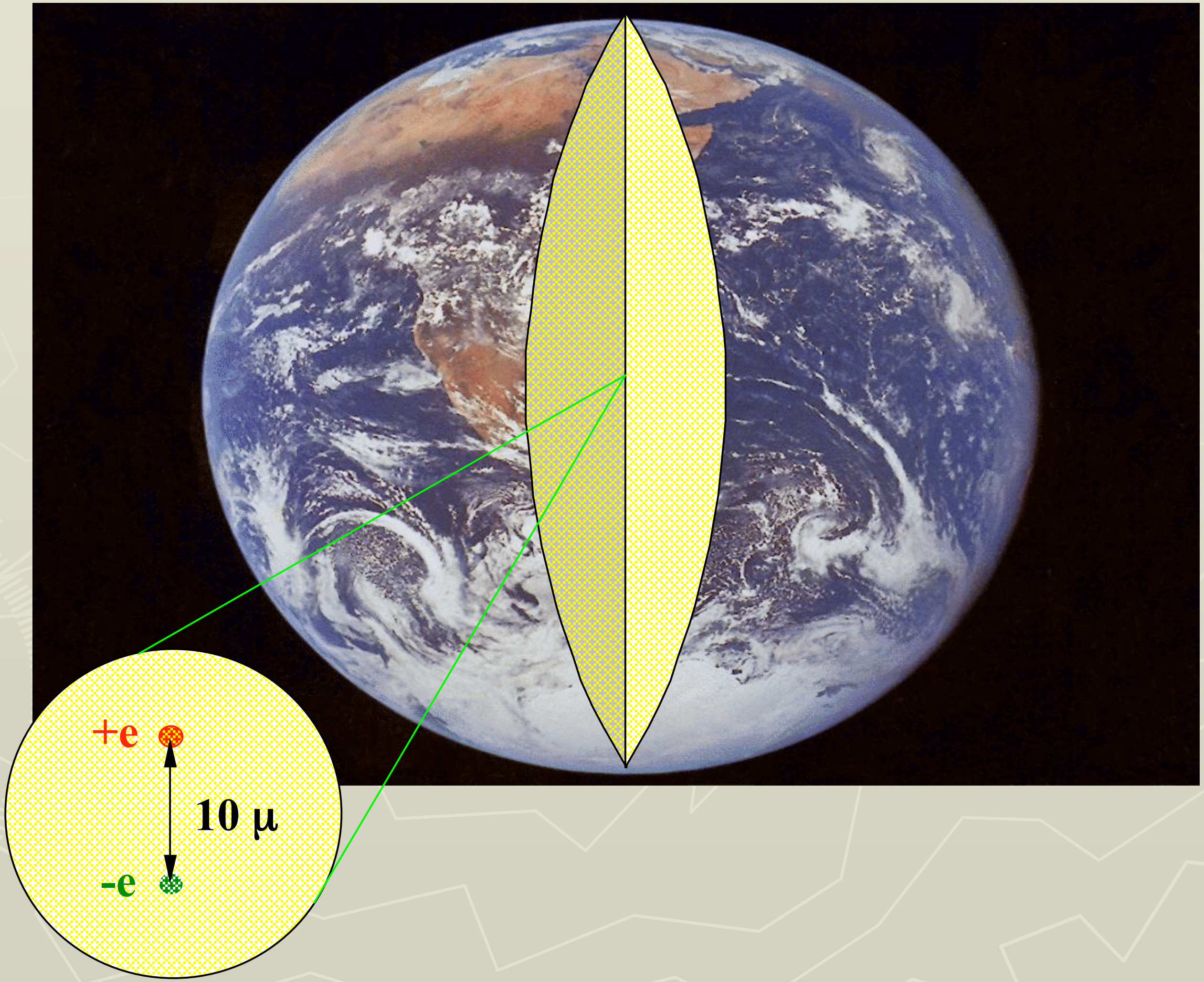
Best upper limit: the RAL-Sussex experiment at ILL



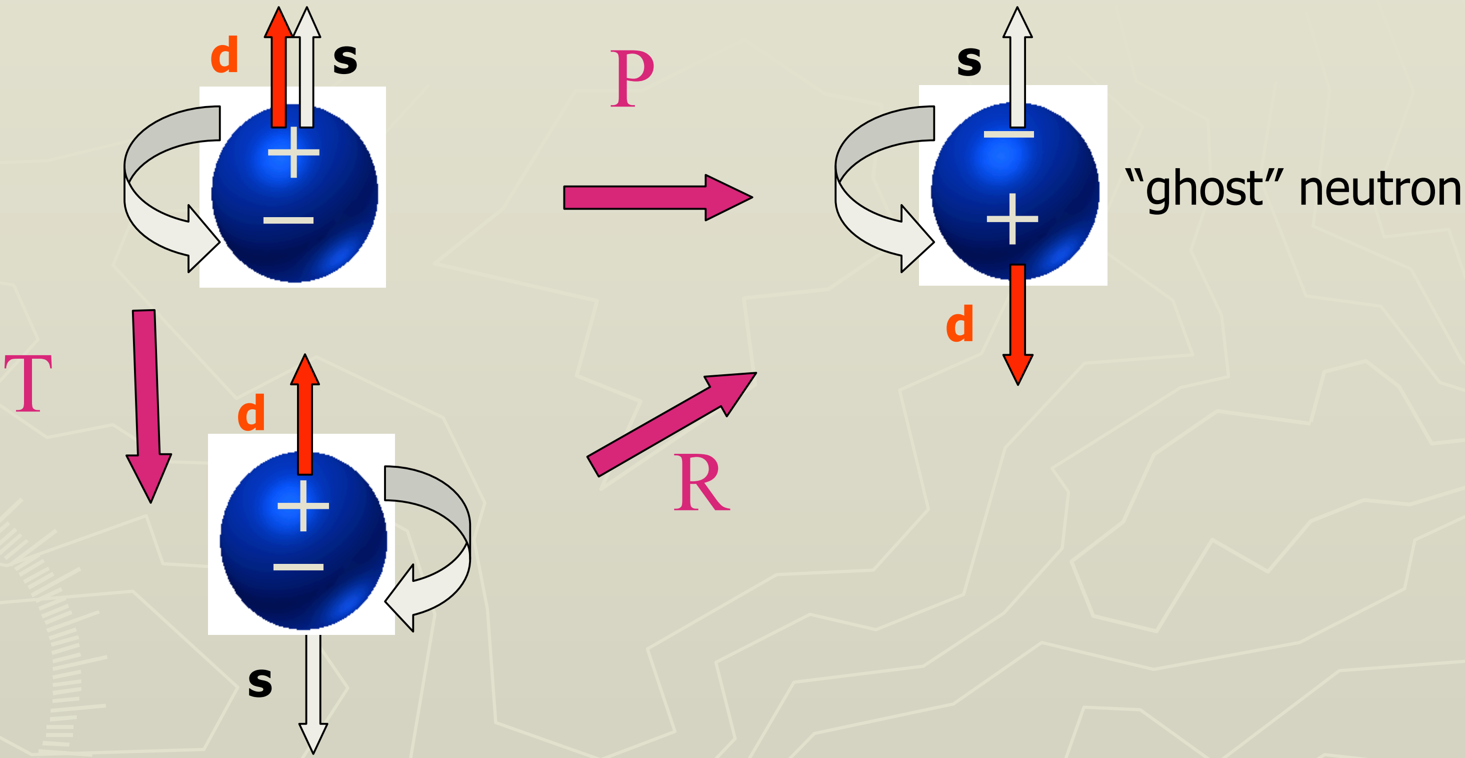


$|d_n| \leq 2.9 \ 10^{-26}$ e cm (90 % CL)
(PRL 97(2006)131801)

A minute quantity...



nEDM and symmetries



nEDM $\neq 0$ → $\not{P}$ and $\not{T}$

+ CPT Theorem → $\not{C}P$

CP violation in SM

- Electroweak sector:

  - CP violation first observed in K_0 decays (1964) and recently in B mesons decays (BABAR at SLAC, BELLE at KEK B).
  - All these CP-odd processes can be interpreted by the introduction of a single phase δ in the CKM matrix.
  - Because of a single phase and no net flavour change, all first-order contributions cancel in the nEDM.

$$\rightarrow \quad d_n \sim 10^{-31}\text{-}10^{-32}\ e\,\text{cm}$$

- QCD:

  - θ term in L_{QCD}

$$d_n \sim \theta \times 10^{-15}\ e\,\text{cm} \quad \rightarrow \quad \theta < 10^{-11}$$

  - Puzzle with no real satisfactory solution so far → *strong CP problem*

Can we explain the disappearance of anti-matter?

- Sakharov's answer (1967): yes if
  - → Off-equilibrium process
  - → Baryon number non-conservation
  - → *CP-odd mechanism*

- Baryon asymmetry of the Universe:
  - $BA^{obs.}$: $3\ 10^{-11} < n_B/n_\gamma < 6\ 10^{-8}$
  - $BA^{SM} \sim 10^{-17}$

CP violation in extensions of SM

- CP-odd phases appear quite generically in extensions of SM, like supersymmetric models.

- → "Natural" predictions of SUSY models:

$$d_n \sim 10^{-23}\text{-}10^{-24}\ e\ \mathrm{cm}$$

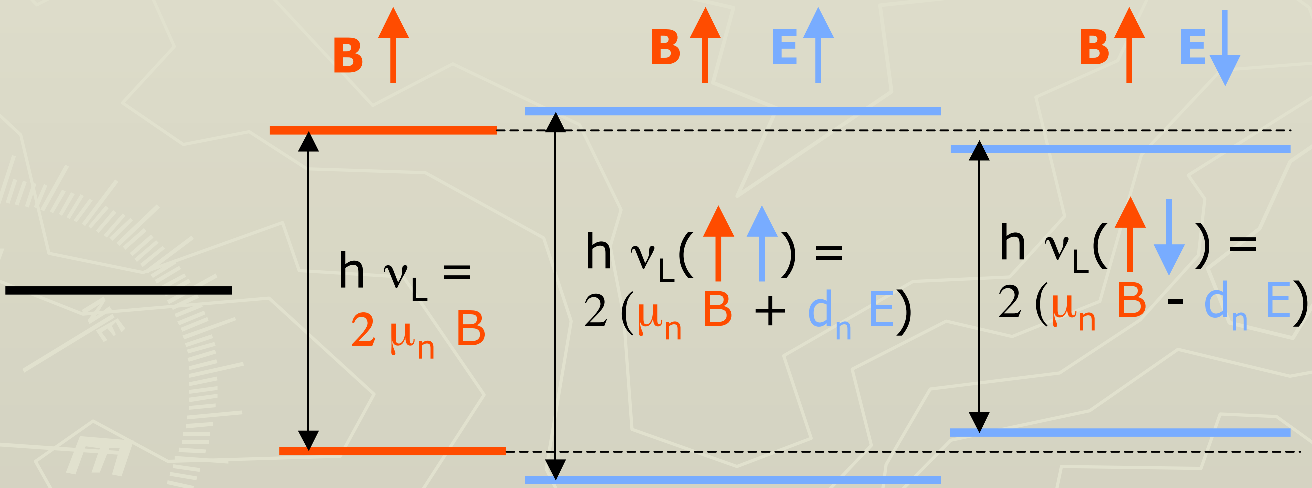
- The current limit on the neutron EDM already provides stringent constraints on SUSY parameters !

→ *SUSY CP problem* !

Experimental technique

Search for electric-field induced changes of the Larmor precession frequency of stored Ultra Cold Neutron (UCN).

$$H = -2\,(\mu_n . B + d_n . E)$$



$$\Delta\nu_L\,(\uparrow\uparrow - \uparrow\downarrow) = 4\,d_n\,E\,/\,h$$

(only if B is unchanged)

The Ultra Cold Neutrons (UCN)

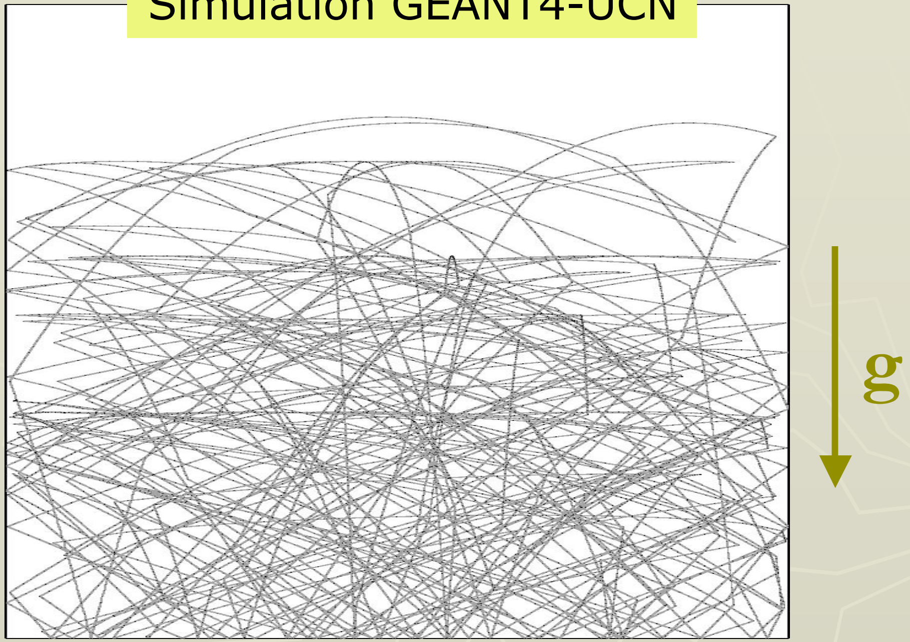
Typical UCN numbers

- E ~ 100 neV (δ z ~ 1 m)
- V ~ 5 m/s
- T ~ mK
- λ ~ 1000 Å

UCN interact with matter via an effective Fermi potential
(V_F= 90 neV for quartz, 270 neV for DLC)

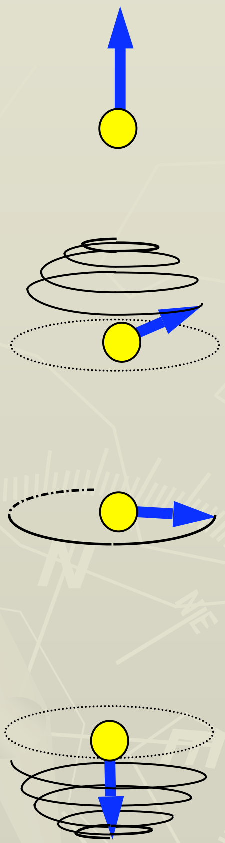
→ Can be stored in vessels!

Simulation GEANT4-UCN

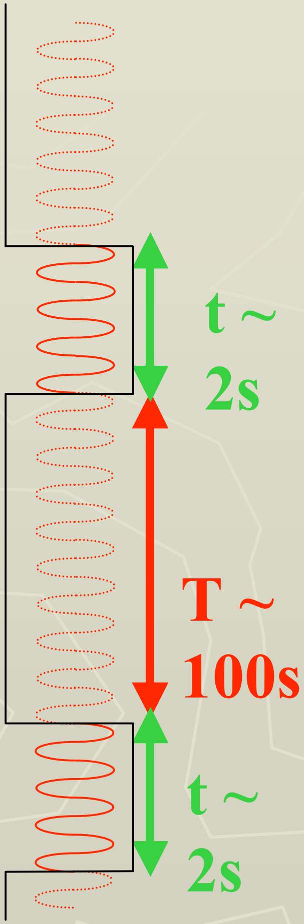


- UCN sources:
  - PF2@ILL (the best to date) : ρ ~ 10 UCN/cm^3 (Fission)
  - UCN@PSI (2009→) : ρ ~ 10^3 UCN/cm^3 (Spallation)
  - + other projets (Munich, Japan…)

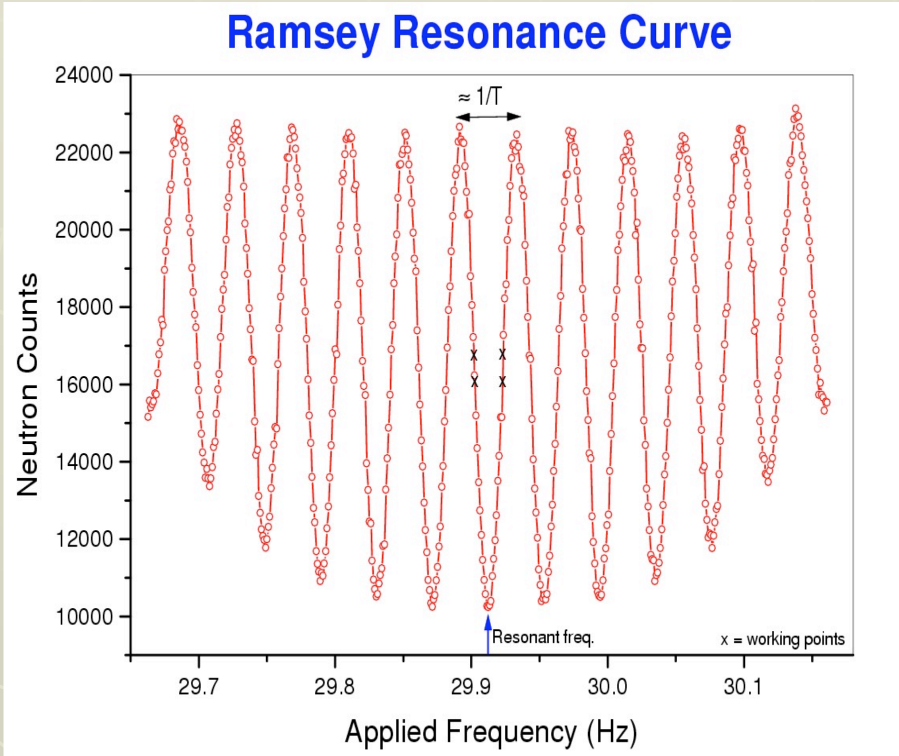
The Ramsey method of separated oscillatory fields



1. *"Spin up" neutron...*
2. *Apply π /2 spin flip pulse...*
3. *Free precession...*
4. *Second π/2 spin flip pulse.*



Ramsey cycle



$\delta\nu_n / \nu_n \sim 10^{-6}$

Statistical error

$$\delta d_n = \frac{h}{4\pi\alpha} \cdot \frac{1}{T \cdot E \cdot \sqrt{N_0}}$$

α : visibility (polarization product)

E : E-field strength

T : storage time

N_0 : number of detected neutrons

RAL-Sussex-ILL experiment:

$\alpha \approx 0.7$, $E \approx 10$ kV/cm, T=130 s, $N \approx 14{,}000$ UCN/cycle

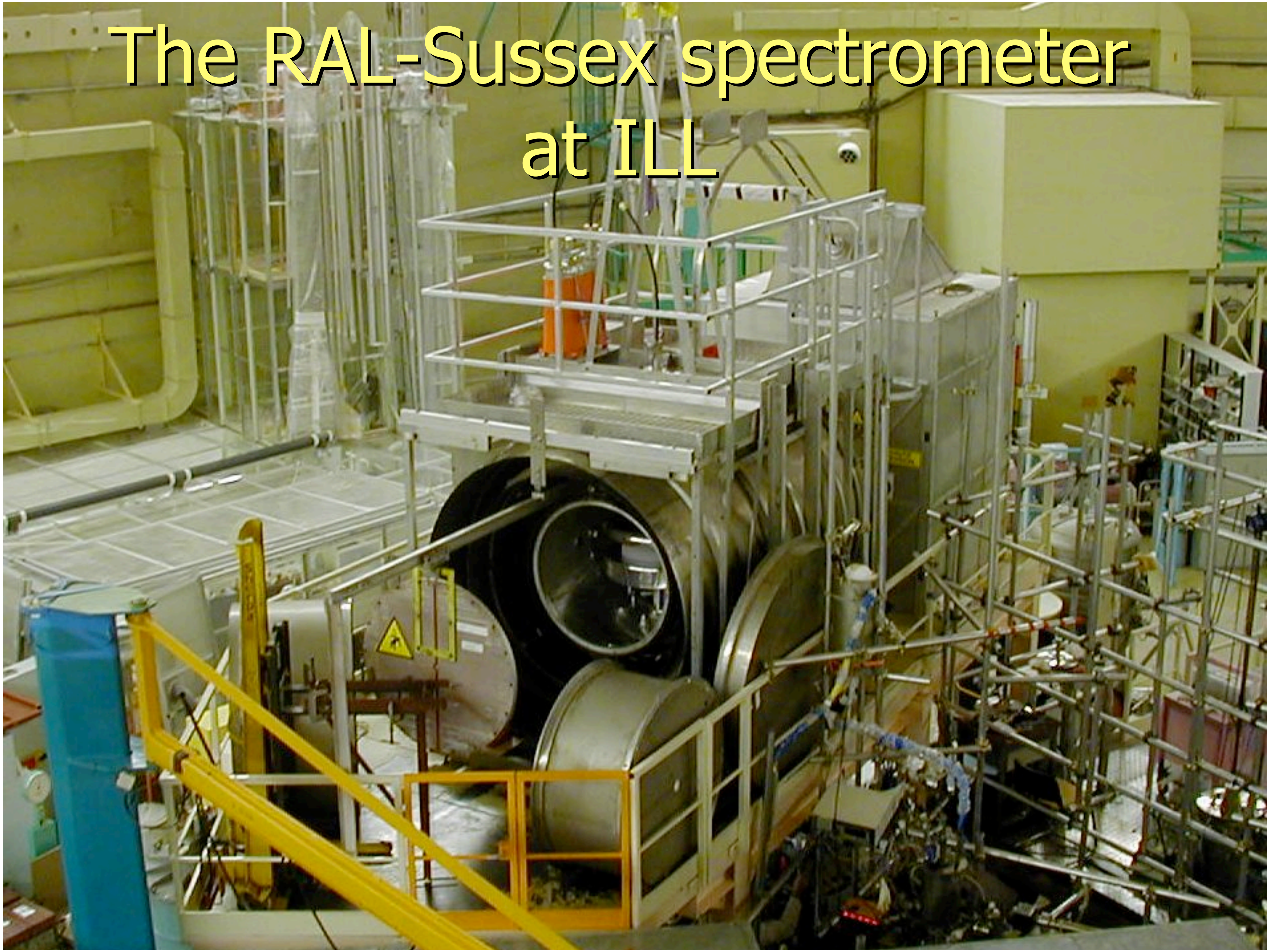
$\delta\, d_n \approx 3 \times 10^{-24}$ *e* cm /cycle or

$\approx 2 \times 10^{-25}$ *e* cm /day

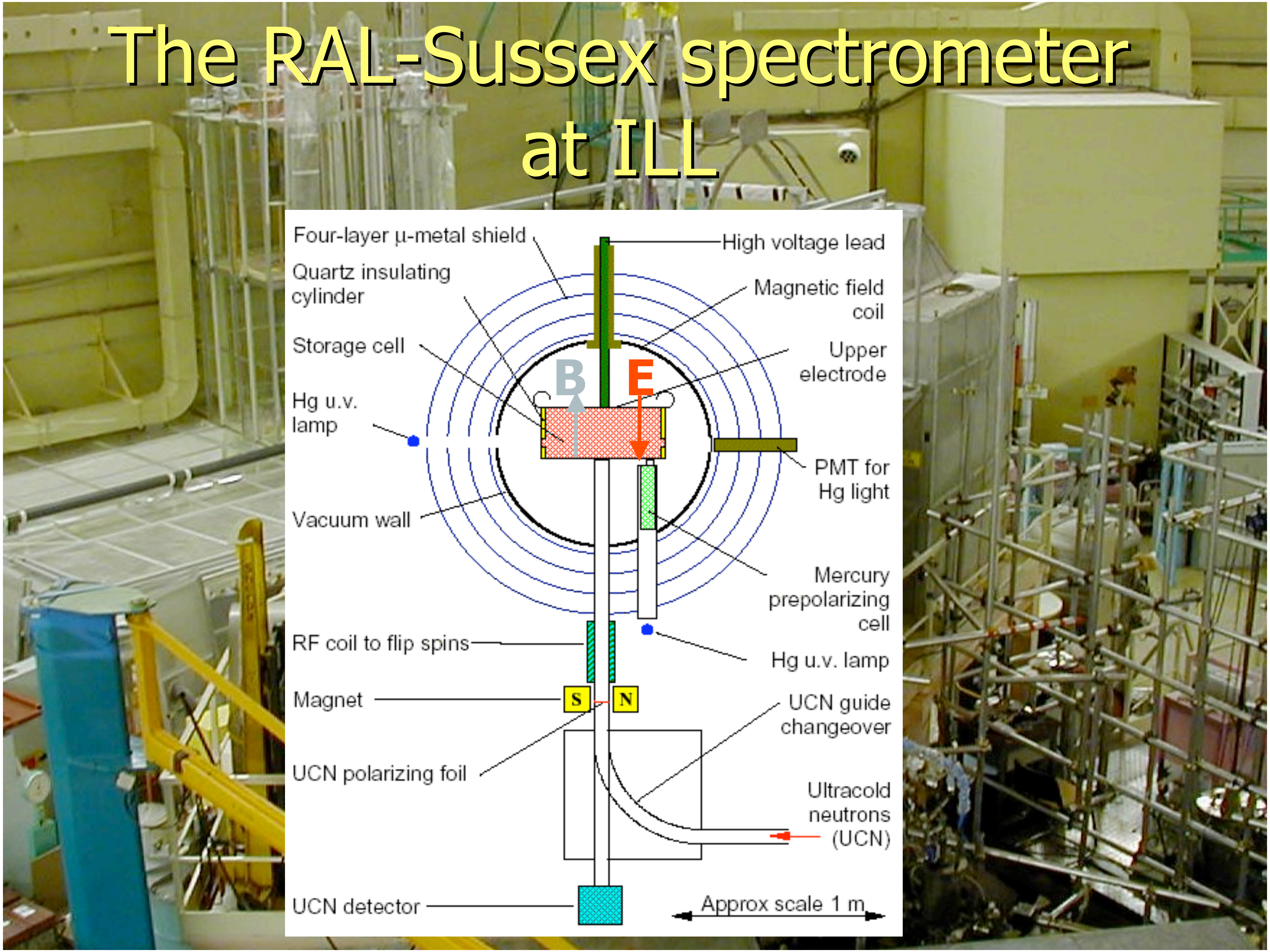
d_n = (+ 0.2 ± 1.5 (stat) ± 0.7 (syst)) x 10^{-26} *e* cm

(PRL 97(2006)131801)

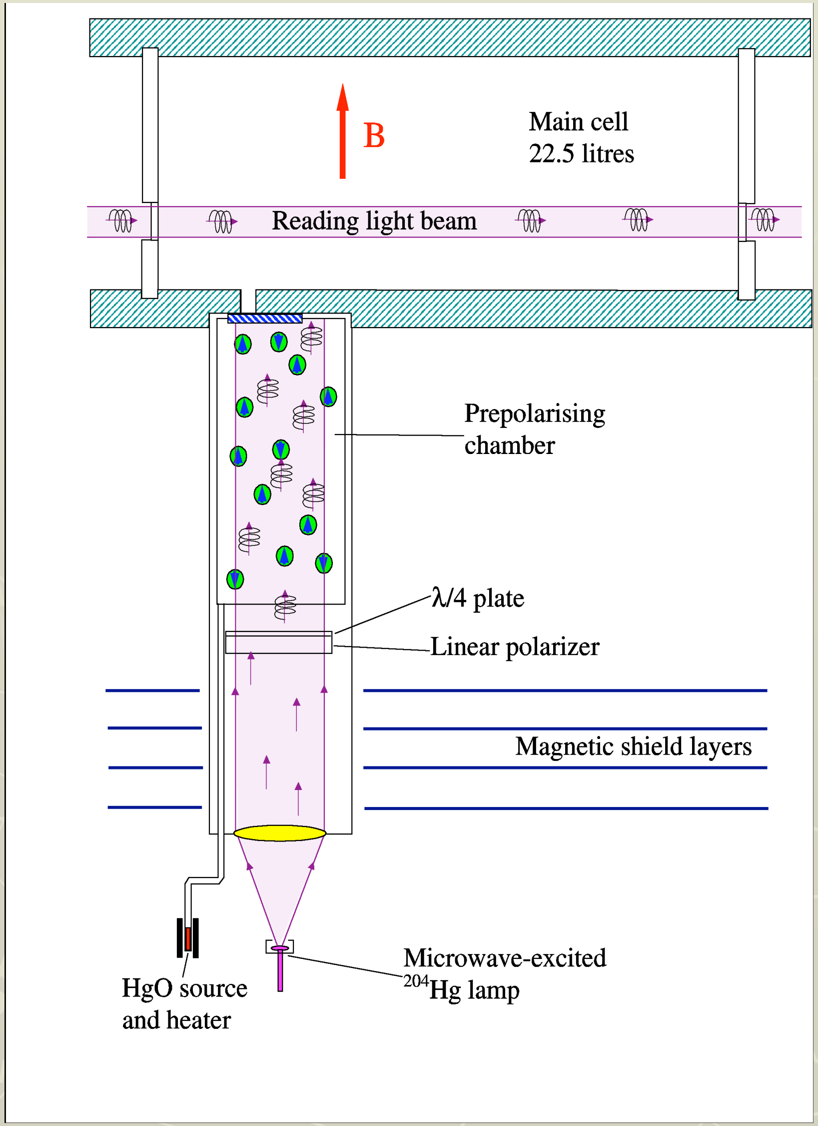
The RAL-Sussex spectrometer at ILL

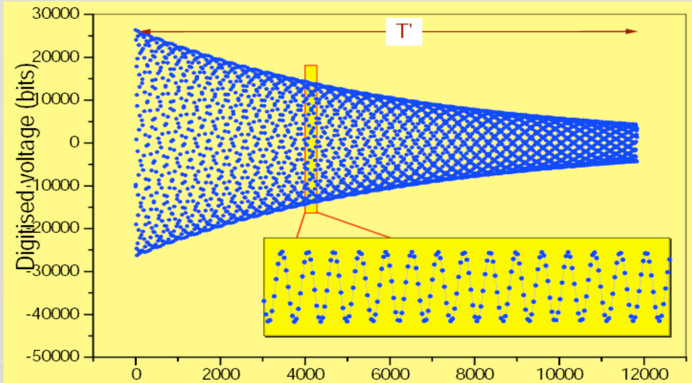


The RAL-Sussex spectrometer at ILL



The Hg co-magnetometer





$\delta\nu \sim 1\ \mu Hz$

$B_0 \approx 1\ \mu T \rightarrow \delta B \sim 100\ fT$

(10 x better than n precision)

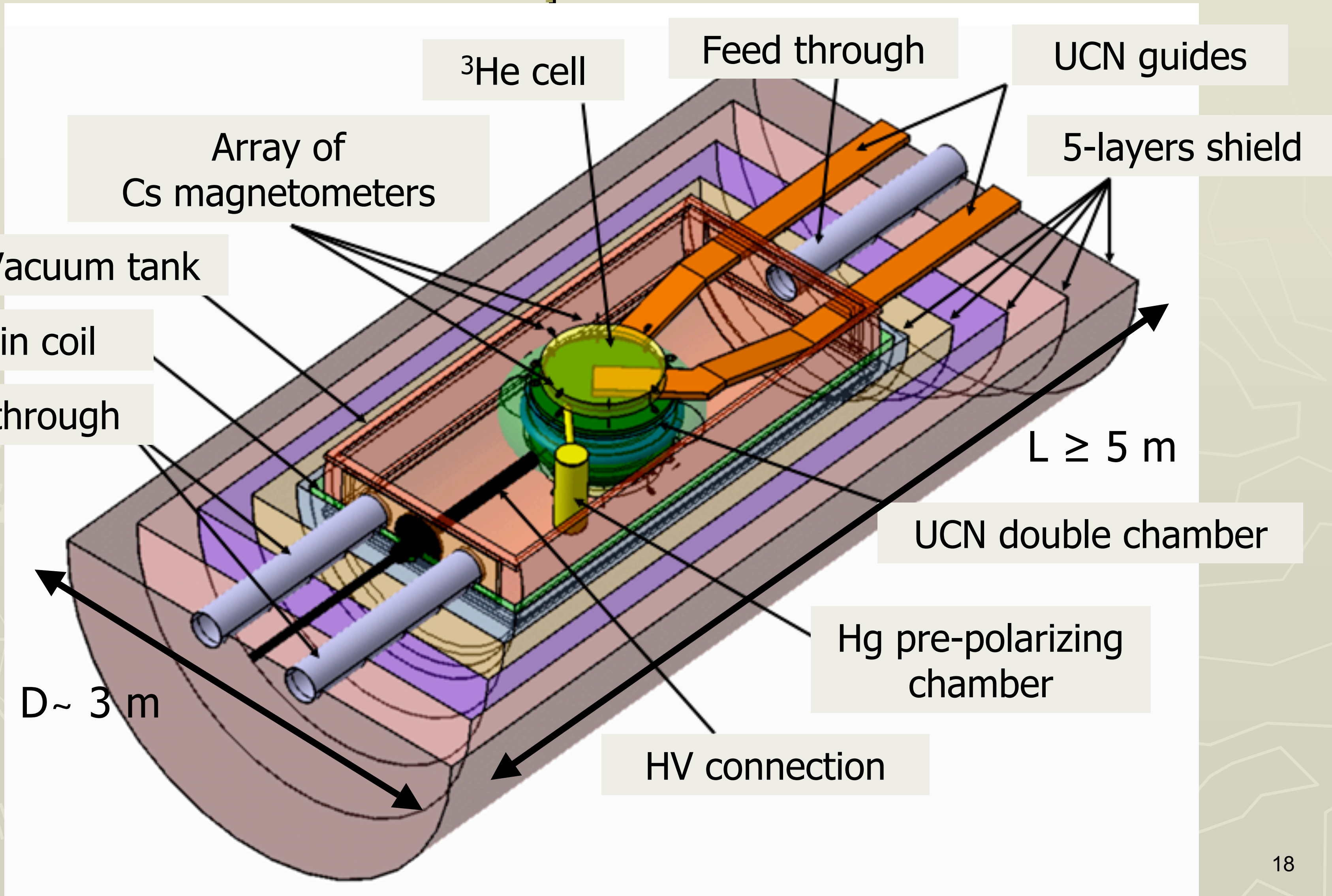
Our approach

- Sensitivity goal : 5×10^{-28} *e* cm
  (SM prediction: $d_n \sim 10^{-31}$ *e* cm)
- In vacuum technique with external UCN source
- Room temperature
  (CRYO-EDM at ILL and SNS-EDM at ORNL are cryogenic)
- Magnetometry:
  - Hg co-magnetometer (R&D on ^{129}Xe and ^{3}He)
  - ^{3}He (sensitivity ~ 1 fT during 200s cycle)
  - External Cs magnetometers for monitoring/stabilization of the field and read-out of ^{3}He precession.

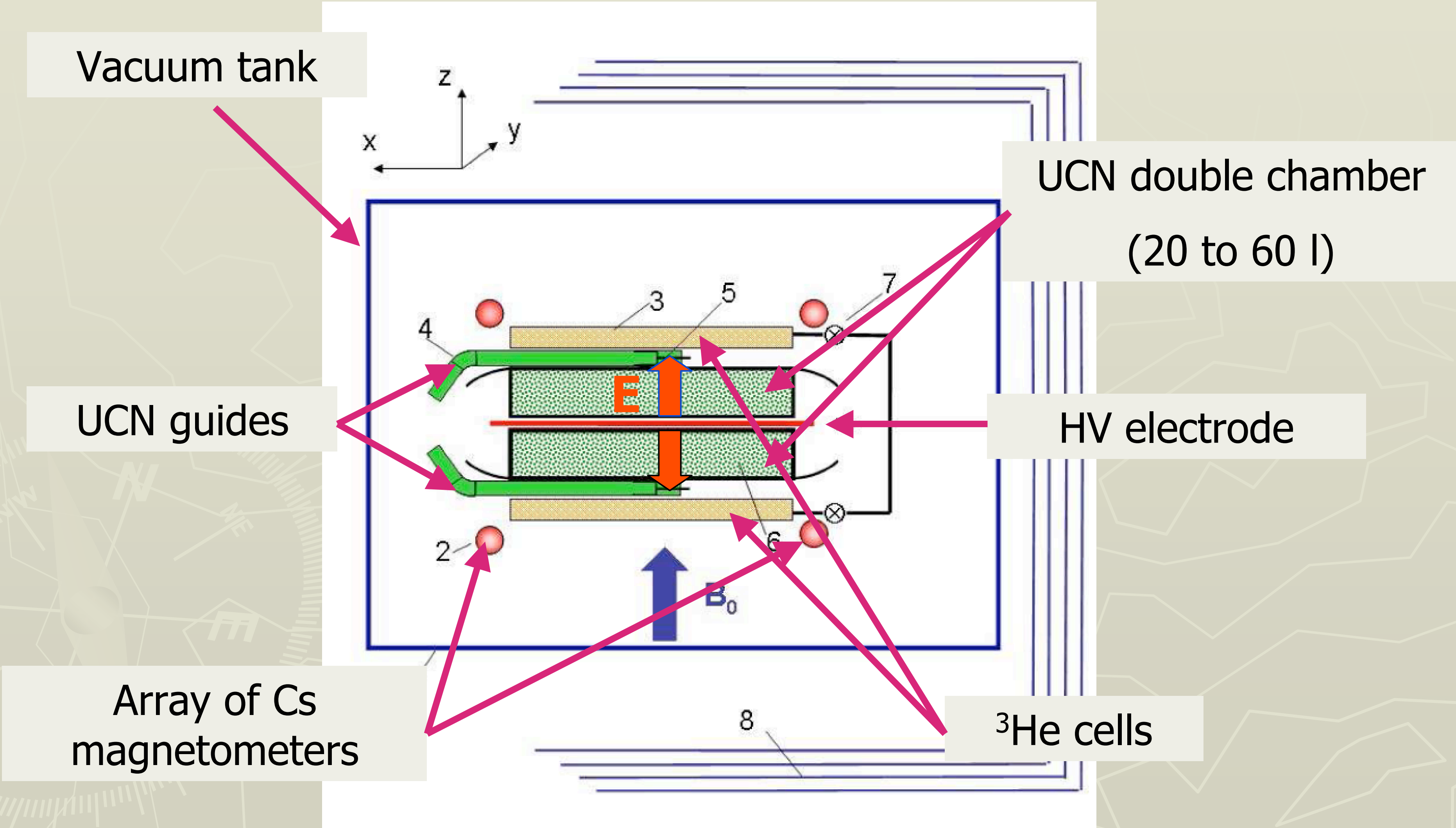
The roadmap

- Phase I (2005-2008)
  - Operation and improvement of the RAL-Sussex spectrometer at ILL
  - R&D on magnetometry, materials, shield calculations, UCN detection...
  - Design of a new spectrometer
- Phase II (2009-2010)
  - Data taking with upgraded version of RAL-Sussex apparatus at PSI
    → sensitivity of 5×10^{-27} *e* cm
  - Construction of the new spectrometer
- Phase III (2011-2015)
  - Data taking with the new spectrometer
    → sensitivity of 5×10^{-28} *e* cm

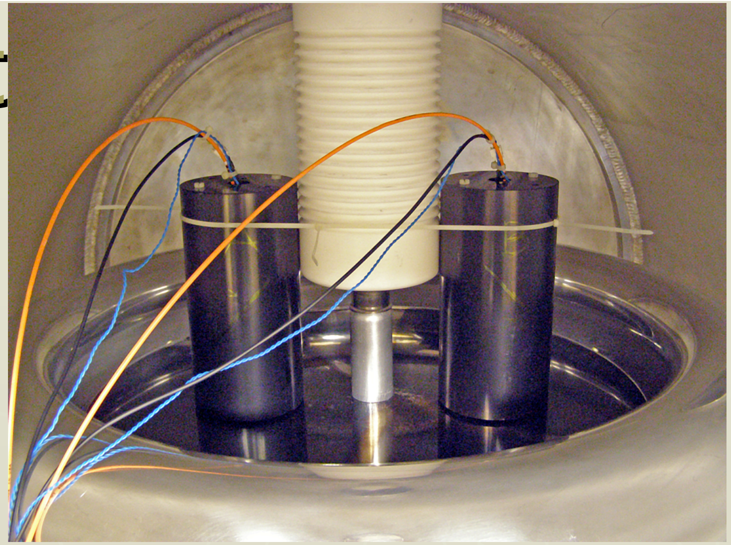
Conceptual design of the future spectrometer



The double chamber arrangement



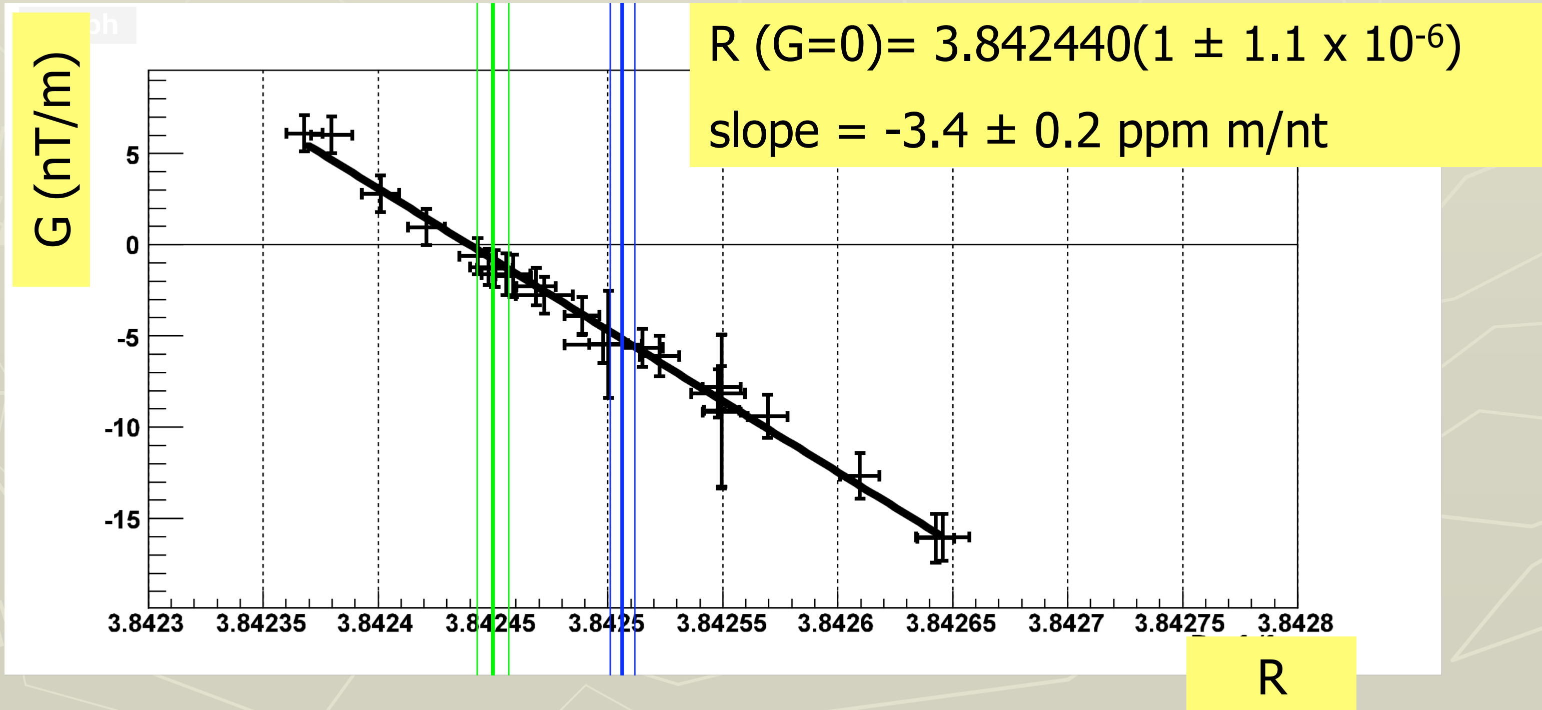
Simultaneous measurement with n/Hg/Cs



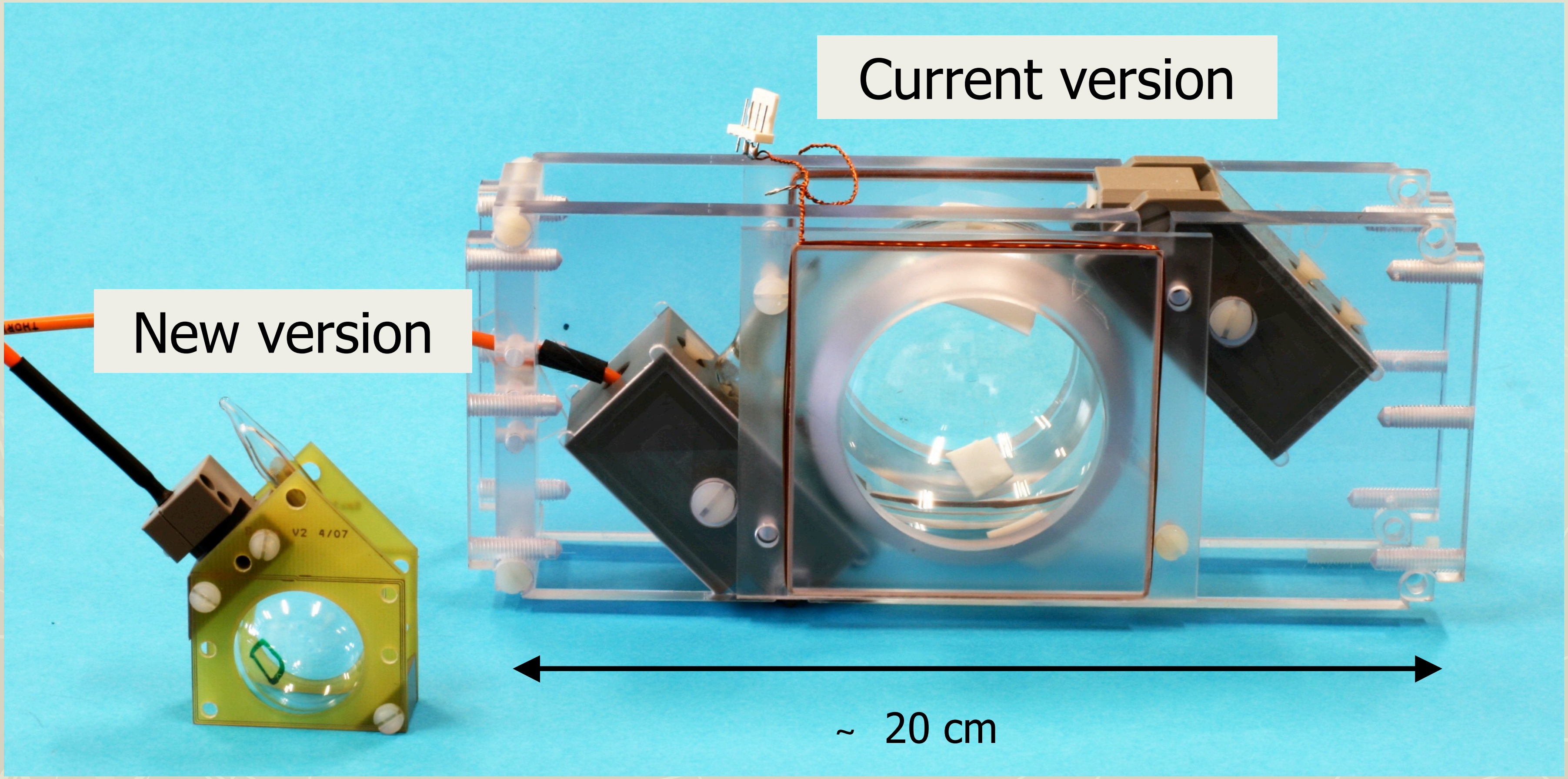
Ratio of n/Hg precession frequencies:

$$R = \nu_n/\nu_{Hg} = (\gamma_n/\gamma_{Hg})\,(1 + G\,\Delta h/B)$$

- G = vertical gradient (← Cs magnetometers)
- Δh = distance between n and Hg center-of-gravity (estimated via simulation)



New Cs magnetometer prototype

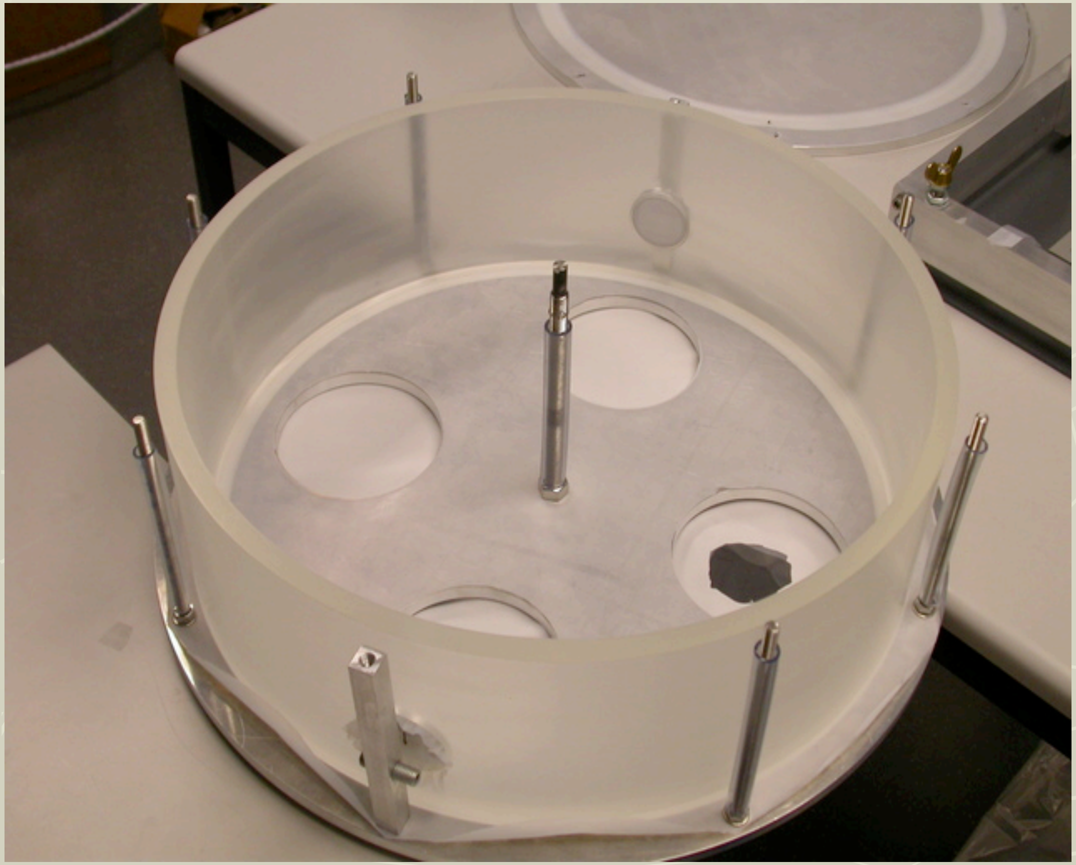


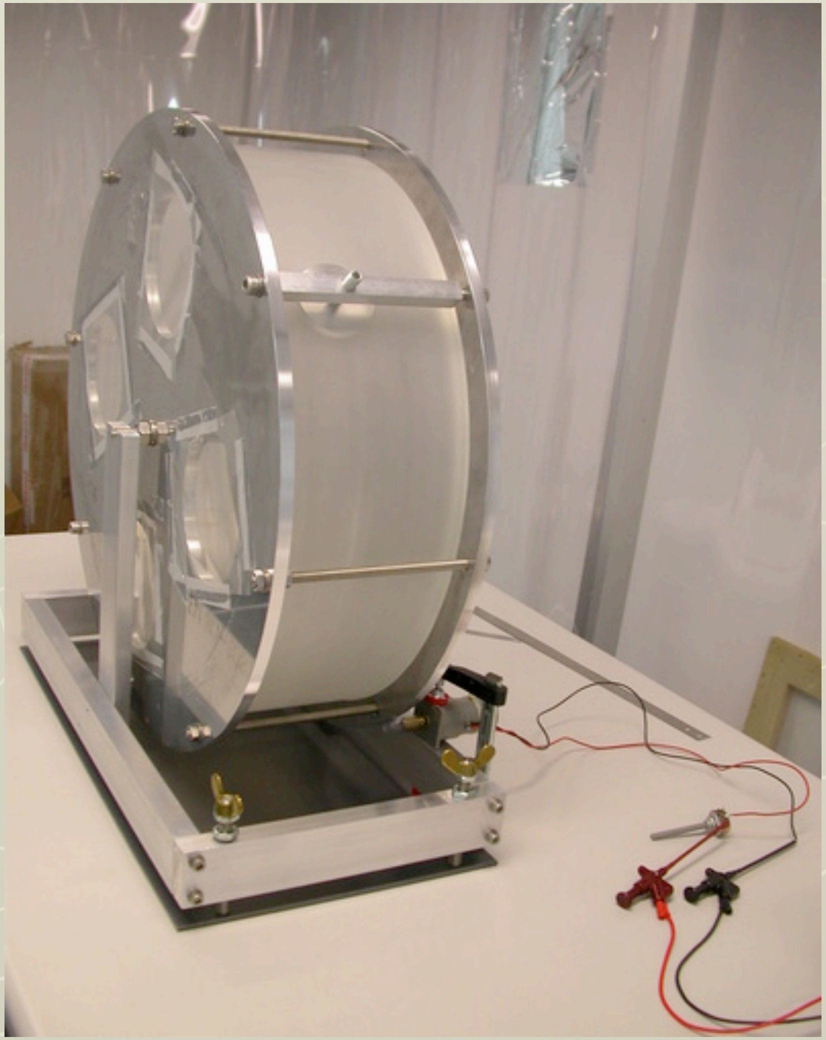
→ Allows a much larger number of magnetometers

DPS coated ring

Materials:

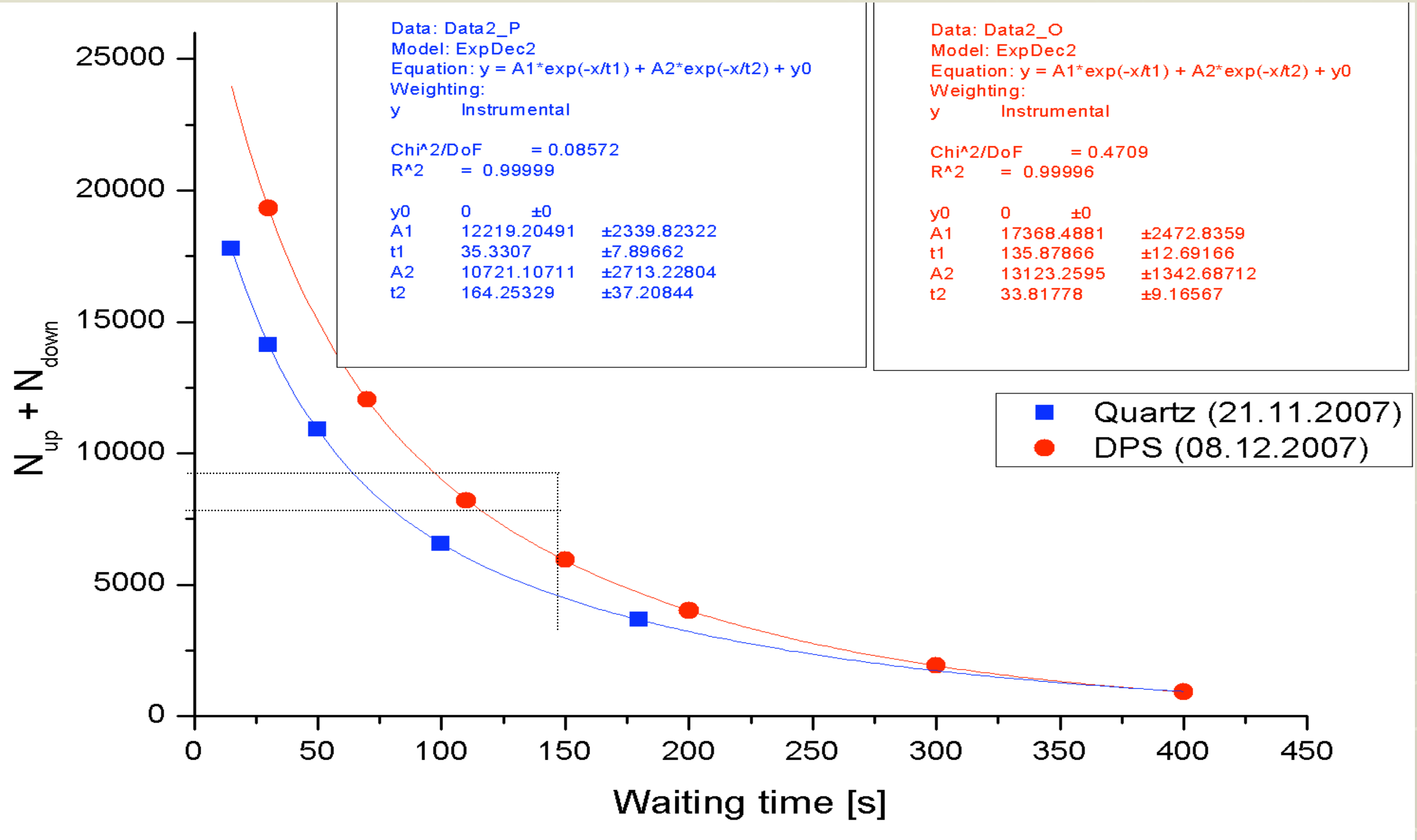
- Rexolite (cross-linked polystyrene) ring
- Deuterated PS solved in d-toluene
- Fermi potential: 162 ± 10 neV



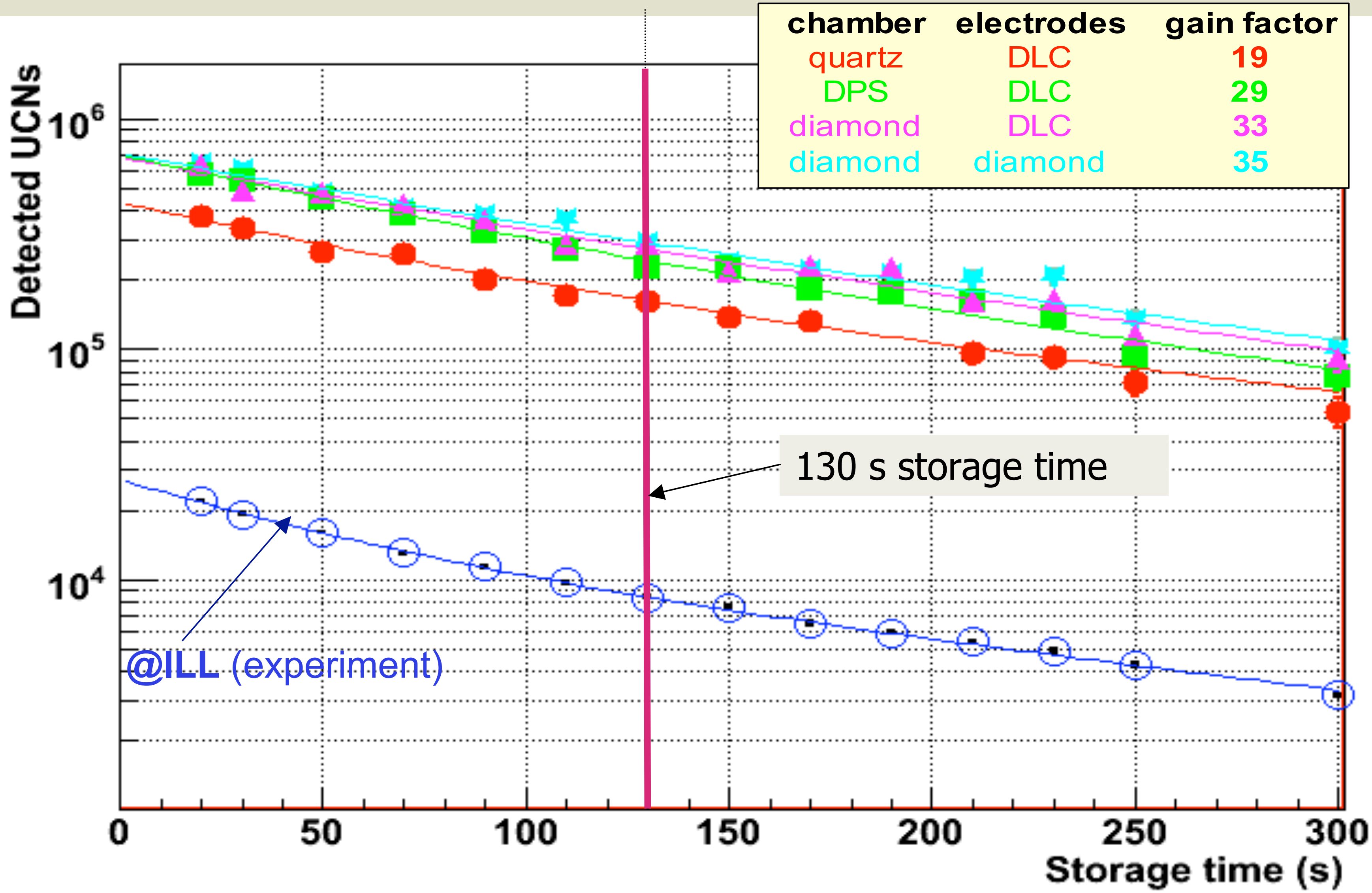


Recent tests at ILL

~30% gain in number of UCNs after 150 sec storage time



UCN Storage time vs coating (simulation at the PSI source)

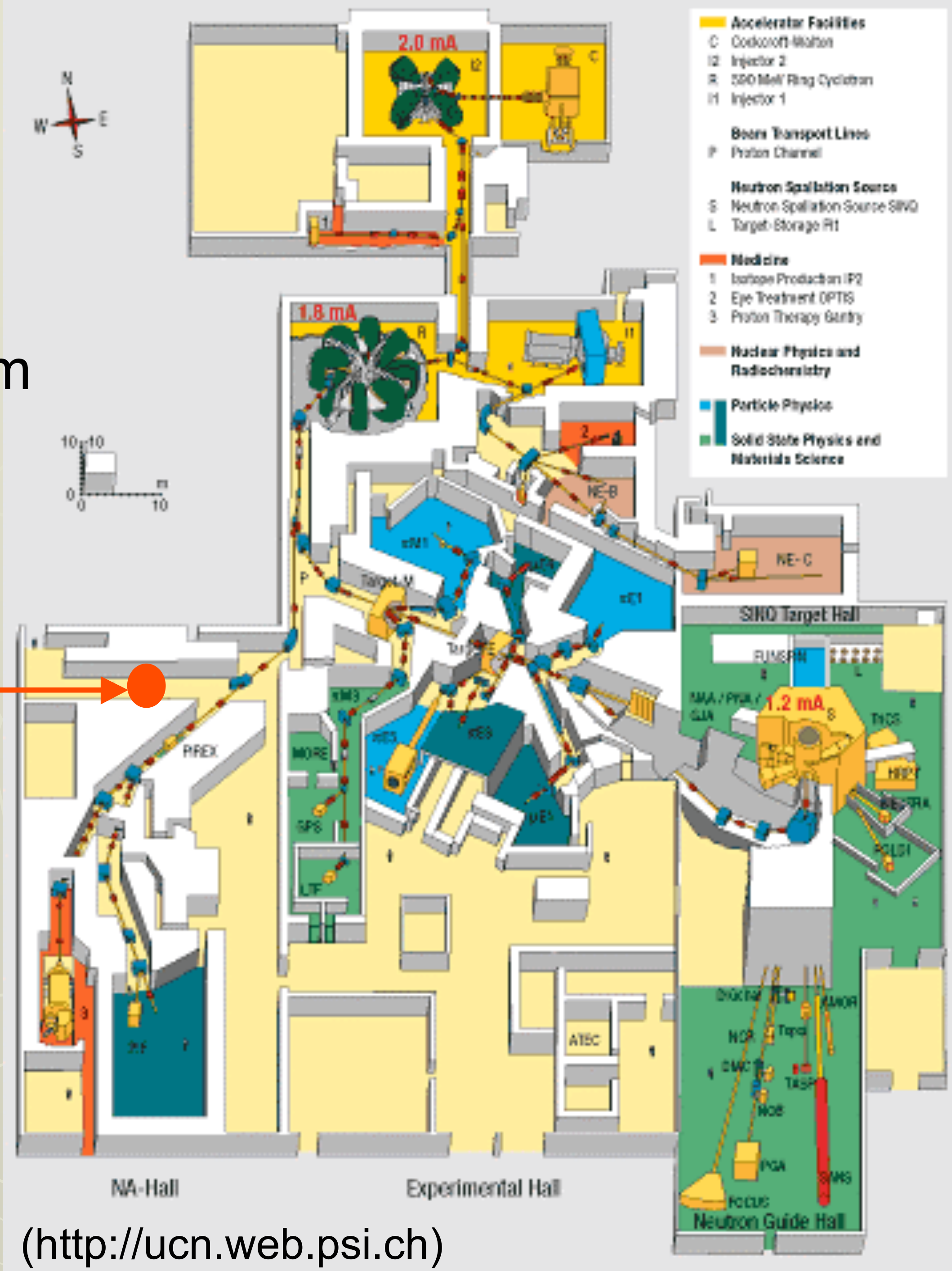


The UCN source at PSI

Spallation source with
600 MeV, 2 mA proton beam

First UCN : mid 2009

UCN source



(http://ucn.web.psi.ch)

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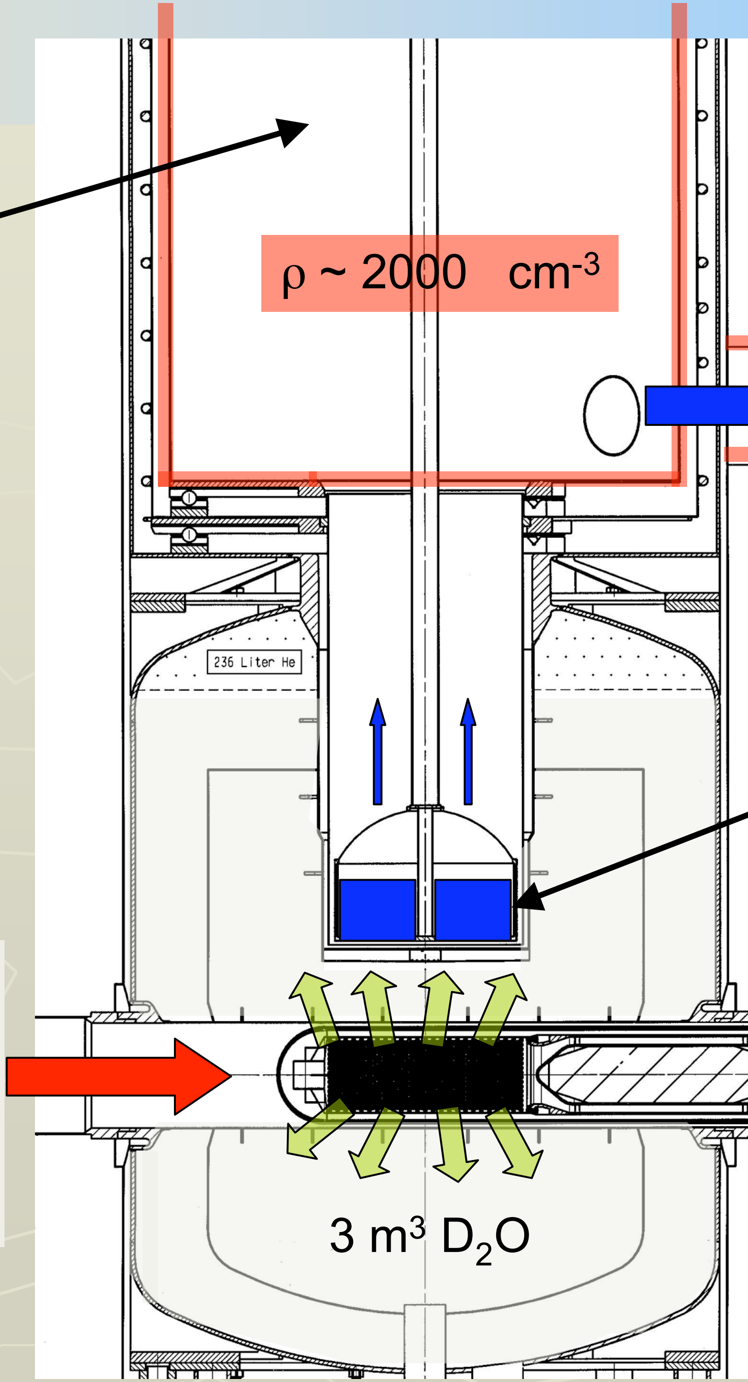
UCN Ultra Cold Neutron Source

2 m^3 volume storage trap



UCN guide

$\rho_{exp} > 1000\ cm^{-3}$

30 liters solid D_2

2 mA, 600 MeV proton beam
(more than 1 MW !)
1% duty cycle

OILL in UCN south area at PSI

Active preparation of the move to PSI
(planned for early 2009)

The Neutron EDM Collaboration

M. Burghoff, S. Knappe-Grueneberg, T. Sander-Thoemmes, A. Schnabel, L. Trahms
*PTB, **Berlin**, Germany*

G. Ban, Th. Lefort, O. Naviliat-Cuncic
*LPC, **Caen,** France*

K. Bodek, St. Kistryn, M. Kuzniak[2], J. Zejma
*Jagiellonian University, **Cracow,** Poland*

N. Khomutov
*JINR, **Dubna,** Russia*

P. Knowles, A. Weis
*Université de Fribourg, **Fribourg,** Switzerland*

G. Rogel[1]
*ILL, **Grenoble,** France*

G. Quéméner, D. Rebreyend, S. Roccia
*LPSC, **Grenoble,** France*

N. Severijns
*Catholic University, **Leuven**, Belgium*

G. Hampel, W. Heil, J.V. Kratz, T. Lauer, C. Plonka-Spehr, Y. Sobolev, N. Wiehl
*Johannes-Gutenberg-Universität, **Mainz,** Germany*

I. Altarev, P. Fierlinger, E. Gutsmiedl, S. Paul, R. Stoepler
*TUM, **Münich**, Germany*

M. Daum, R. Henneck, S. Heule[3], M. Kasprzak[4], K. Kirch, A. Knecht[3], A. Mchedlishvili, A. Pichlmaier, G. Zsigmond
*Paul Scherrer Institut, **Villigen,** Switzerland*

also at: [1]*LPC Caen,* [2]*Paul Scherrer Institut,* [3]*University of Zürich,* [4]*SMI Vienna*