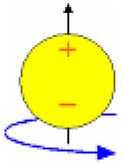


The Search for Neutron Electric Dipole Moment, present experiment at ILL, Grenoble, and future prospects

Plamen IAYDJIEV - INRNE – Sofia,Bulgaria and RAL, UK

nEDM experiment - Rutherford Appleton Laboratory - University of Sussex - ILL

C.A. Baker, K. Green, P. Geltenbort, M.G.D. van der Grinten, P.G. Harris, P.S. Iaydjiev, S.N. Ivanov,

J.M. Pendlebury, D.B. Shiers, D. Wark

CryoEDM experiment - Rutherford Appleton Laboratory - University of Sussex – ILL – University of Kure – University of Oxford

R.A.L. /Sussex/ILL/ - C.A. Baker, K. Green, P. Geltenbort, M.G.D. van der Grinten, P.G. Harris, P.S. Iaydjiev, S.N. Ivanov, J.M. Pendlebury, D.B. Shiers, D.Wark

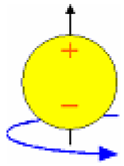
University of Kure (Japan) H. Yoshiki
RAL - M.A.H Tucker, S.N. Balashov, V. Francis
University of Sussex - M. Hardiman, P. Smith, J. Grozier, K. Zuber
University of Oxford H. Kraus, B. Majorovits, N. Jelley, U. Divaker

nEDM experiment

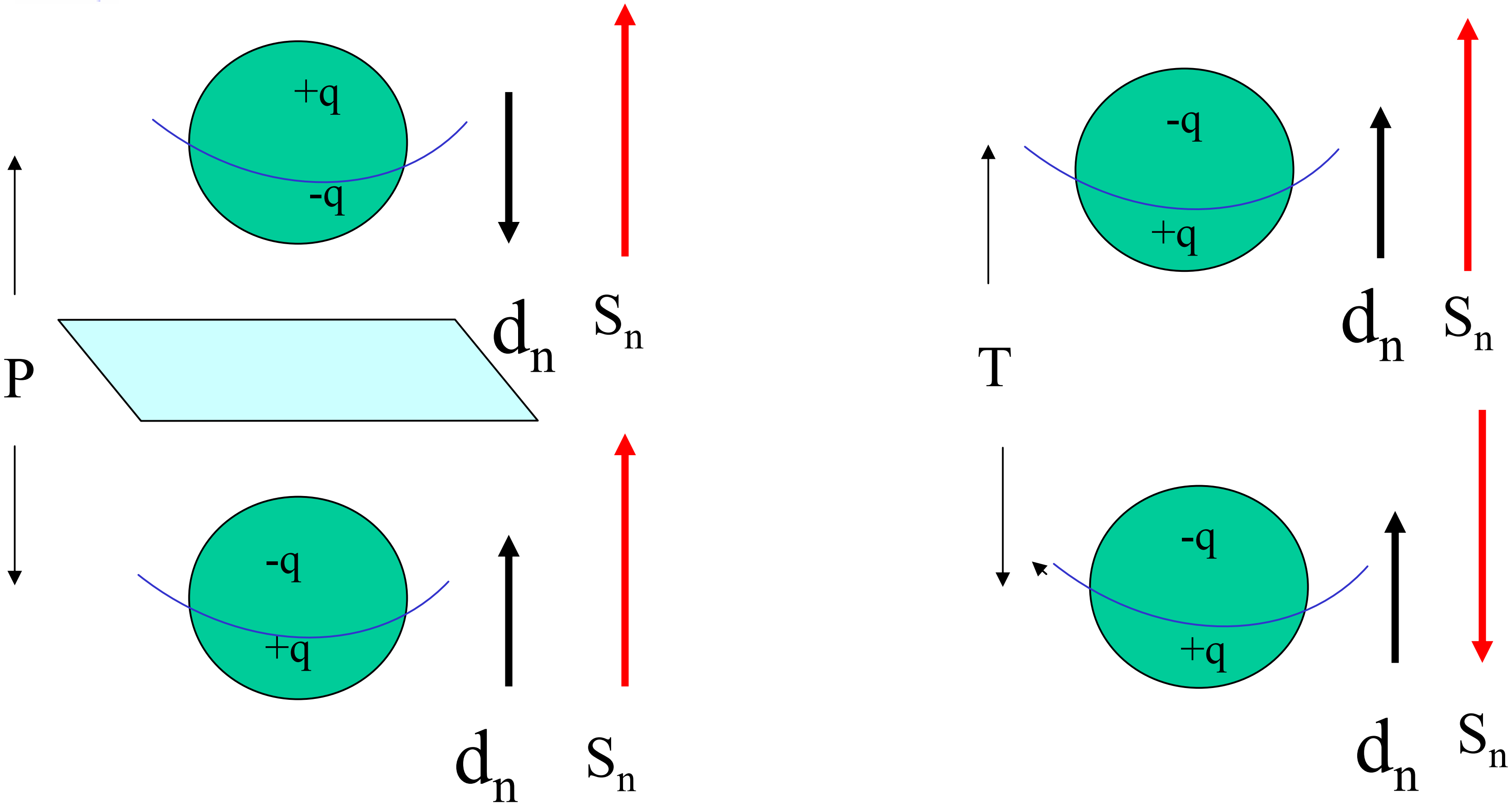
1. Why we need to measure neutron EDM
2. Measurement principle
3. nEDM apparatus
4. Magnetometry – Hg comagnetometer
5. Statistical and systematical errors

CryoEDM experiment

1. Why superfluid Helium
2. UCN source at H53 beam at ILL
3. CryoEDM apparatus
4. Present status and future prospects

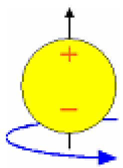


The Search for Neutron Electric Dipole Moment at ILL…



The Neutron Electric Dipole Moment: d_n

$d_n \neq 0 \quad \Rightarrow \quad P$ and T violation

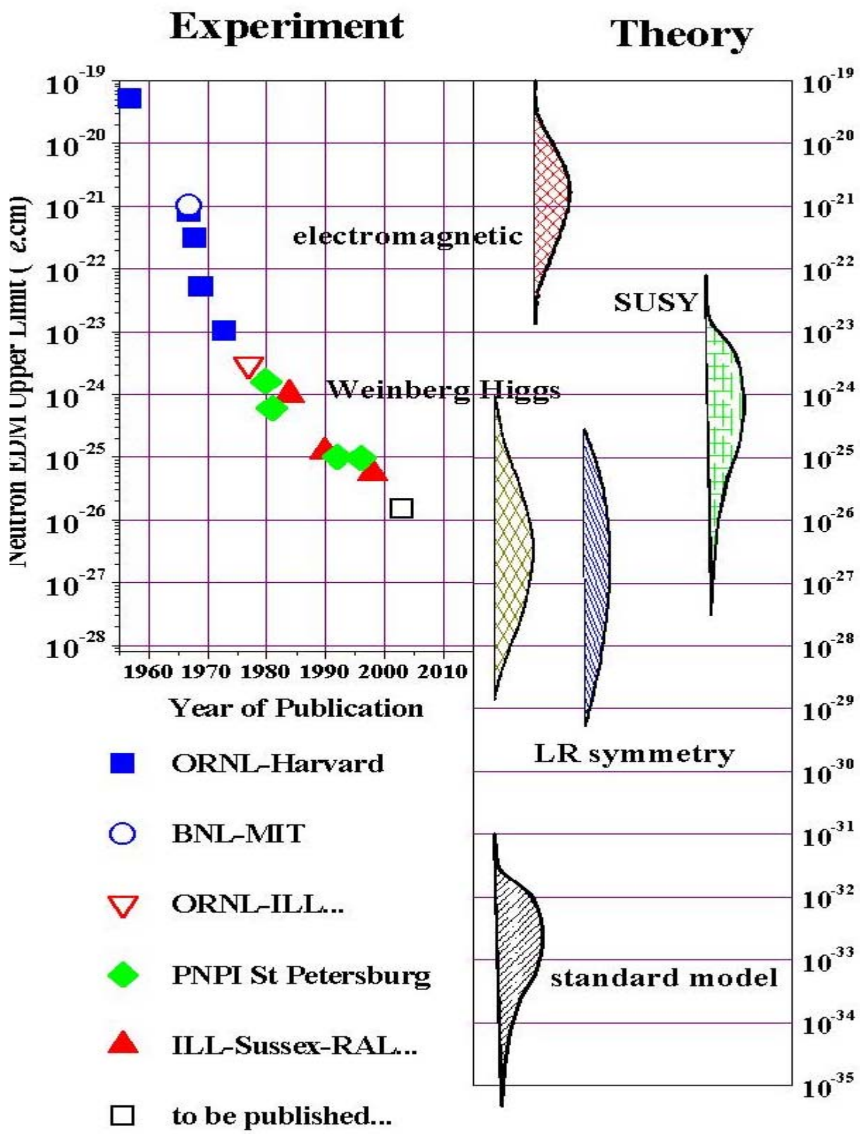


The Search for Neutron Electric Dipole Moment at ILL…

Why we need to measure nEDM

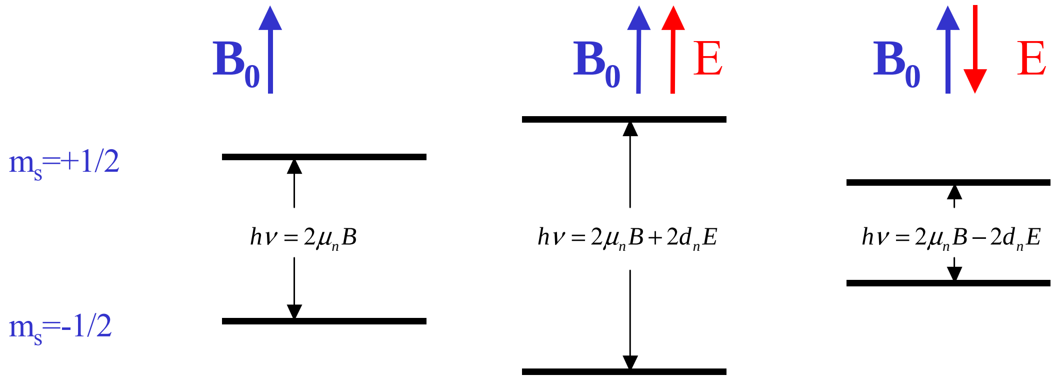
- ..the validity of the parity assumption must rest on experimental evidence..
  - J.M.Smith, E.M.Purcell, N.F.Ramsey, Phys. Rev. 108, 120, (1957)
- CP violation is observed in K and B meson systems.
- CP violation outside of SM is needed to explain observed particle-antiparticle asymmetry in the Universe
- Theoretical predictions

  beyond the SM



The neutron is not as simple as it looks…

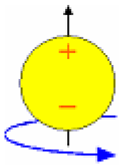
Measurement principle



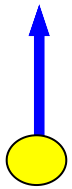
$$H = -\vec{\mu}_n \vec{B} - \vec{d}_n \vec{E}$$

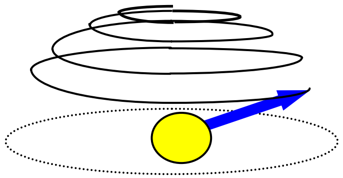
$$\nu(\uparrow\uparrow) - \nu(\uparrow\downarrow) = \Delta\nu = -4\,d\,E\,/\,h$$

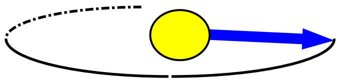
B_0 has to be unchanged when E is reversed

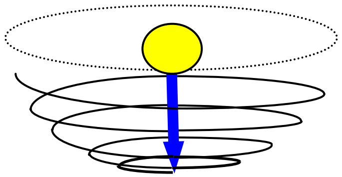


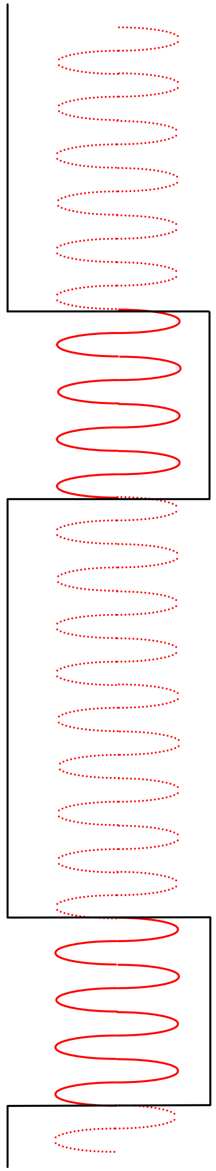
The Search for Neutron Electric Dipole Moment at ILL…

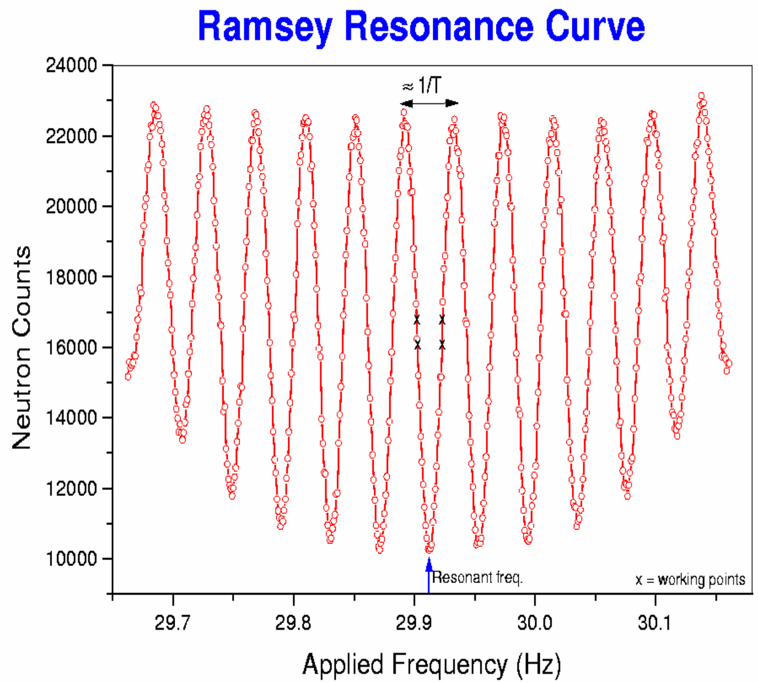
1.  *“Spin up” neutron…*

2.  *Apply $\pi/2$ spin flip pulse…*

3.  *Free precession...*

4.  *Second $\pi/2$ spin flip pulse.*



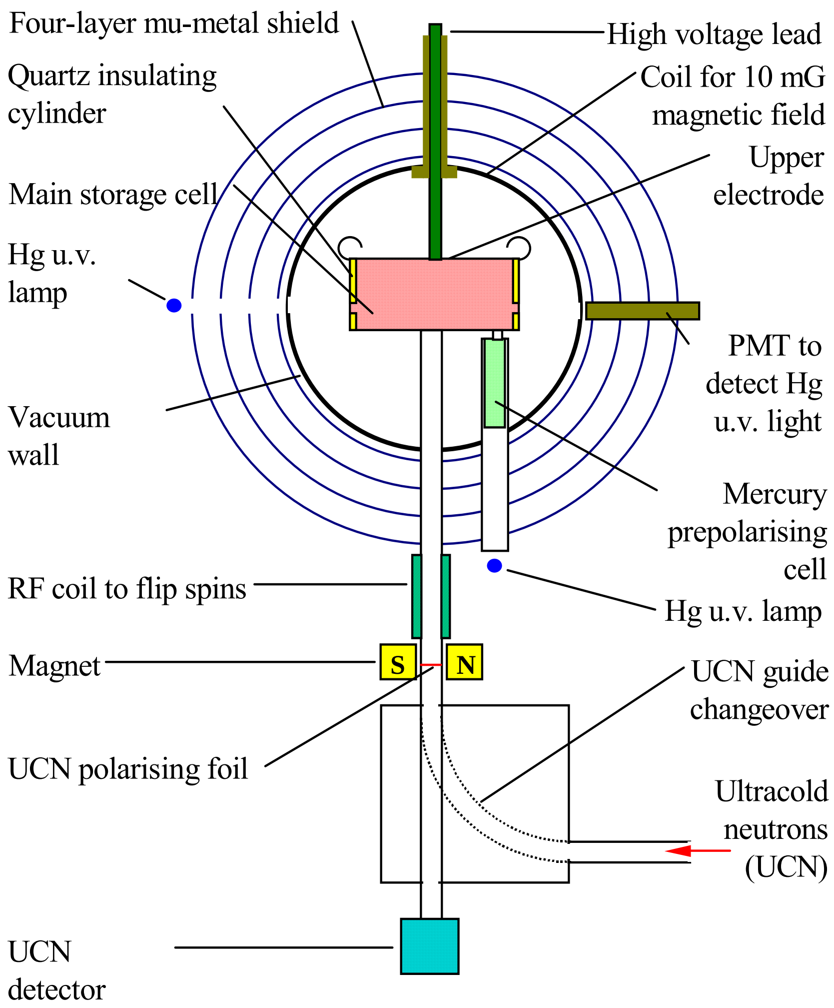


Statistical uncertainty

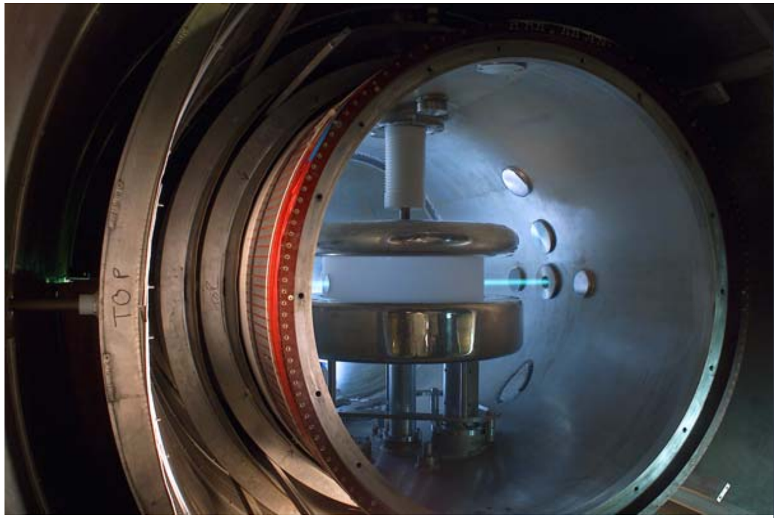
$$\sigma(d_n) = \frac{\hbar / 2}{\alpha E T \sqrt{N}}$$

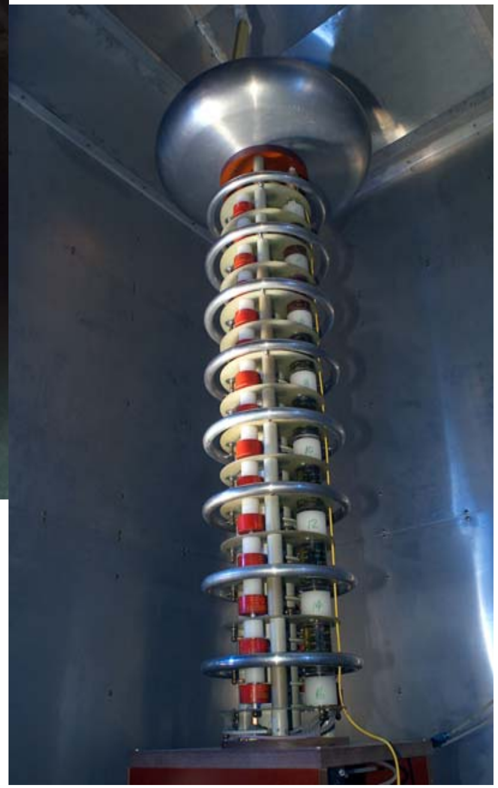
$$\sigma(d_n) = 2 \times 10^{-25} \text{ e.cm/day}$$

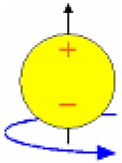
nEDM apparatus



Experimental setup

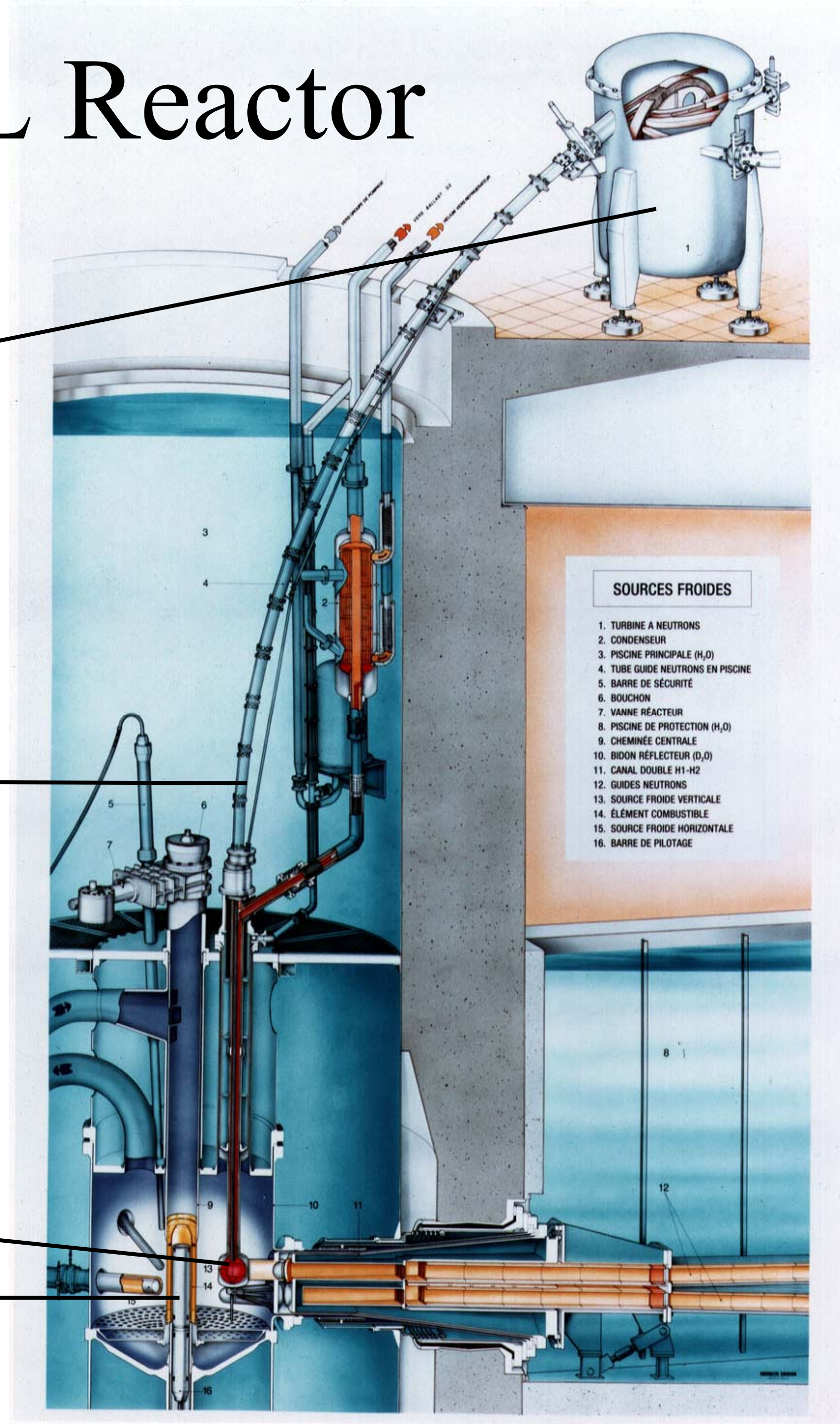






The Search for Neutron Electric Dipole Moment at ILL

The ILL Reactor



The Search for Neutron Electric Dipole Moment at ILL

Grenoble
Institut Laue Langevin
(Alpes)

The Search for Neutron Electric Dipole Moment at ILL

The Search for Neutron Electric Dipole Moment at ILL

Measuring the mercury Larmor precession frequency:

Turn polarised ^{199}Hg by $\pi/2$ rf pulse

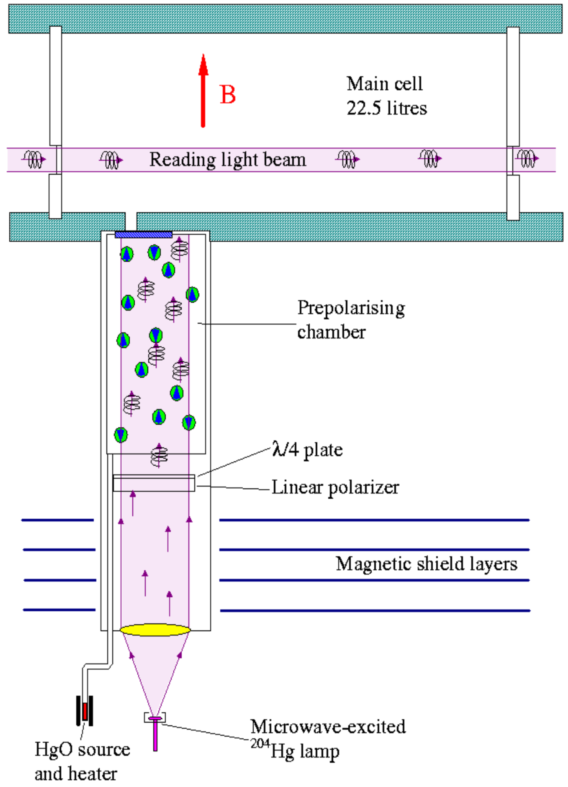
Hg precesses in same volume as neutrons

PMT measures signal of reading bulb

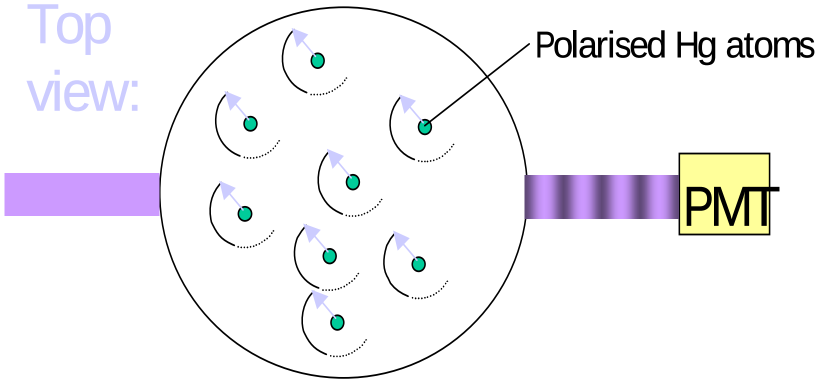
Fit signal to decaying sine curve

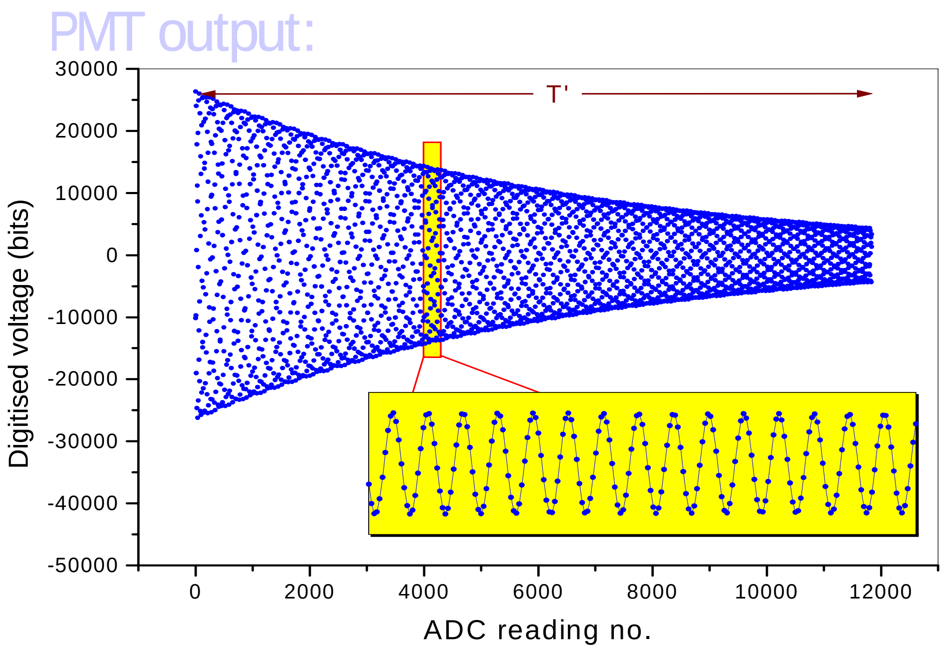
$$d(^{199}Hg) < 2.1 \times 10^{-28}\ e\ cm$$

The Mercury Magnetometer



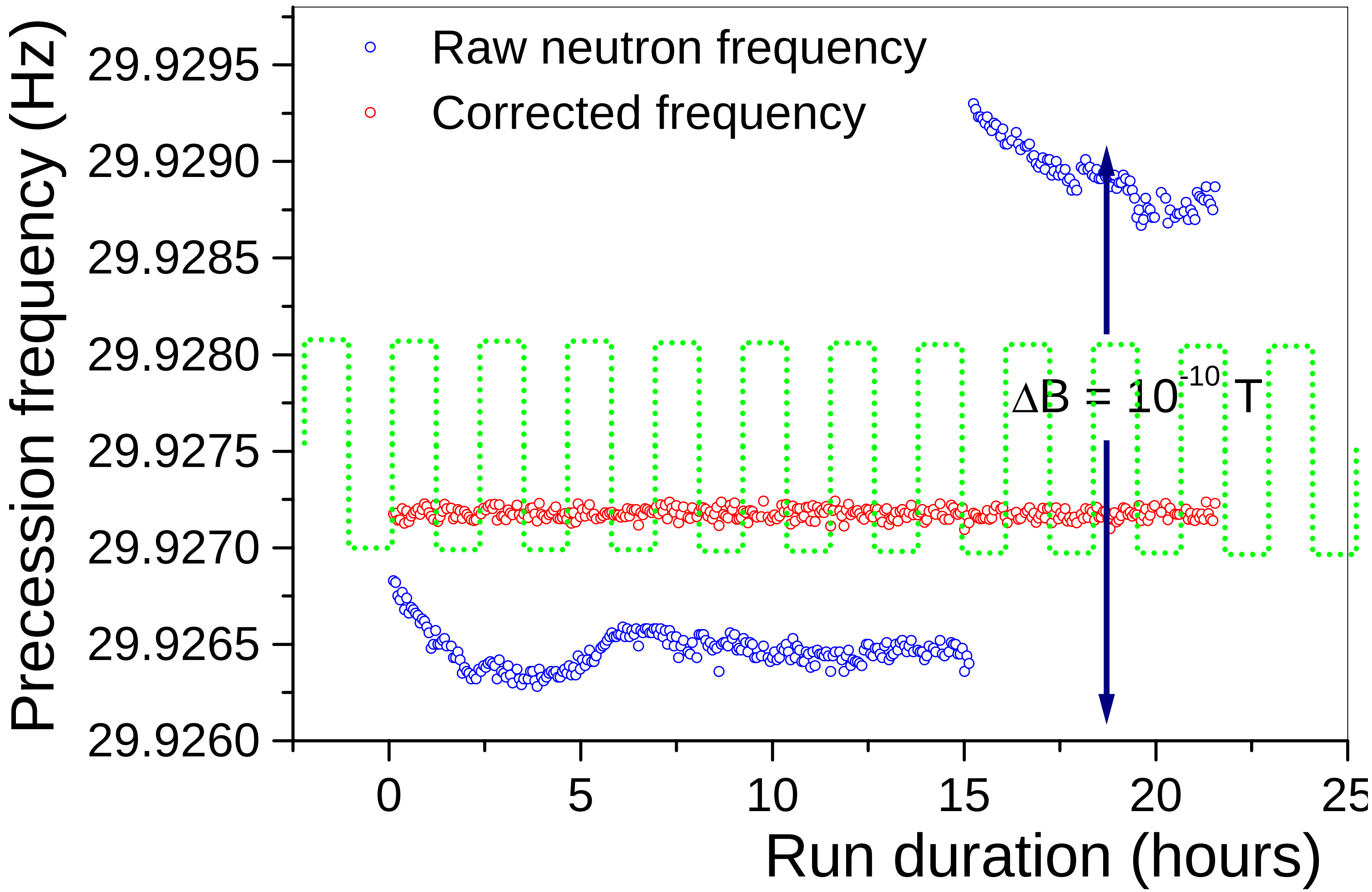
Hg co-magnetometer



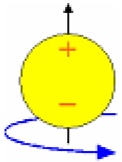


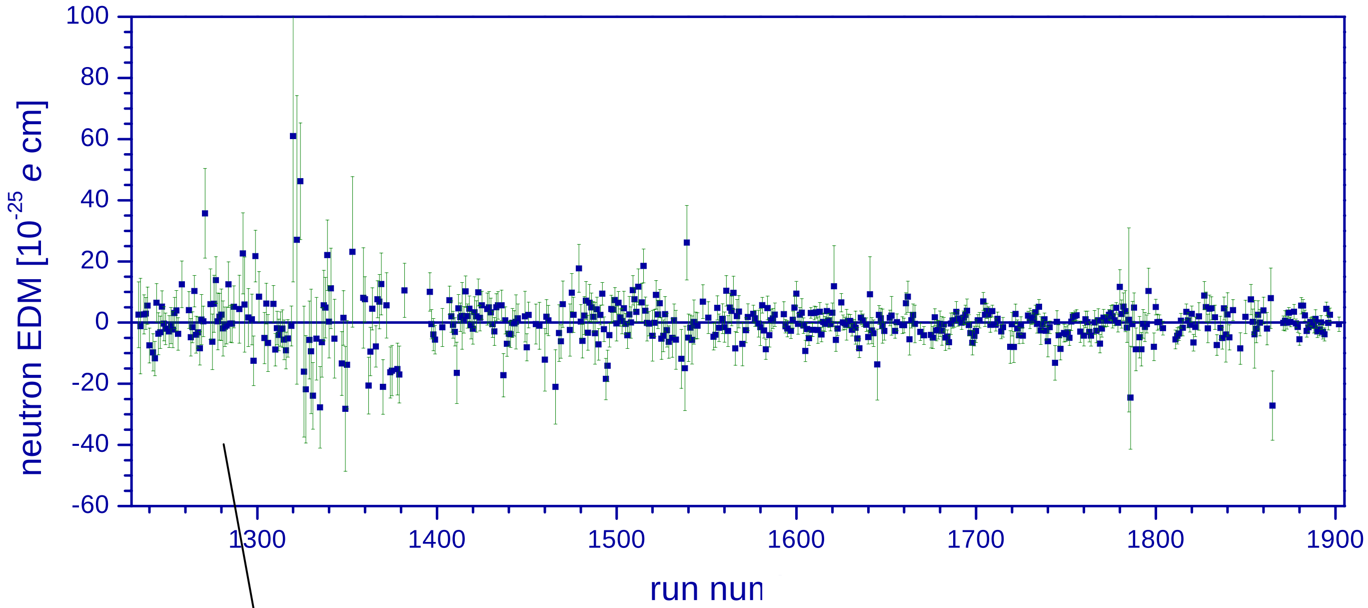
nEDM measurement

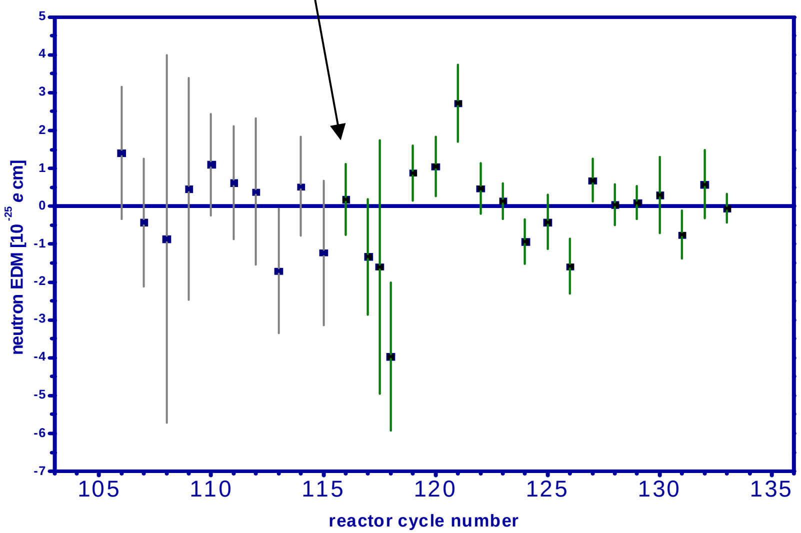
Hg co-magnetometer now compensates B drift

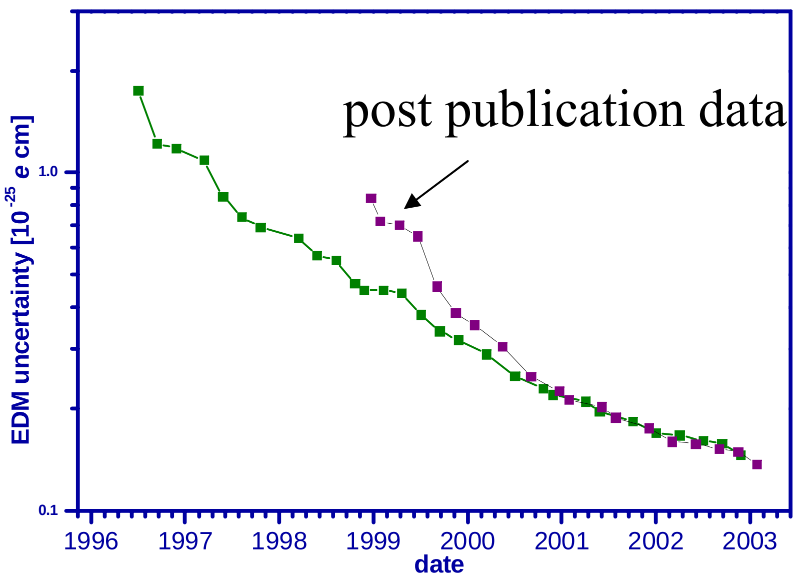


The Search for Neutron Electric Dipole Moment at ILL

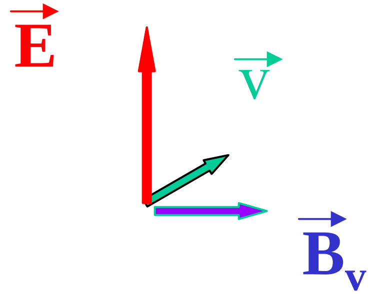








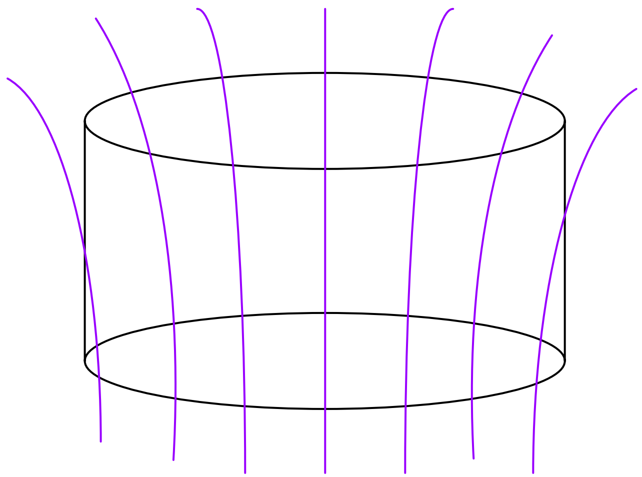
False effects



from Special Relativity, extra motion-induced field

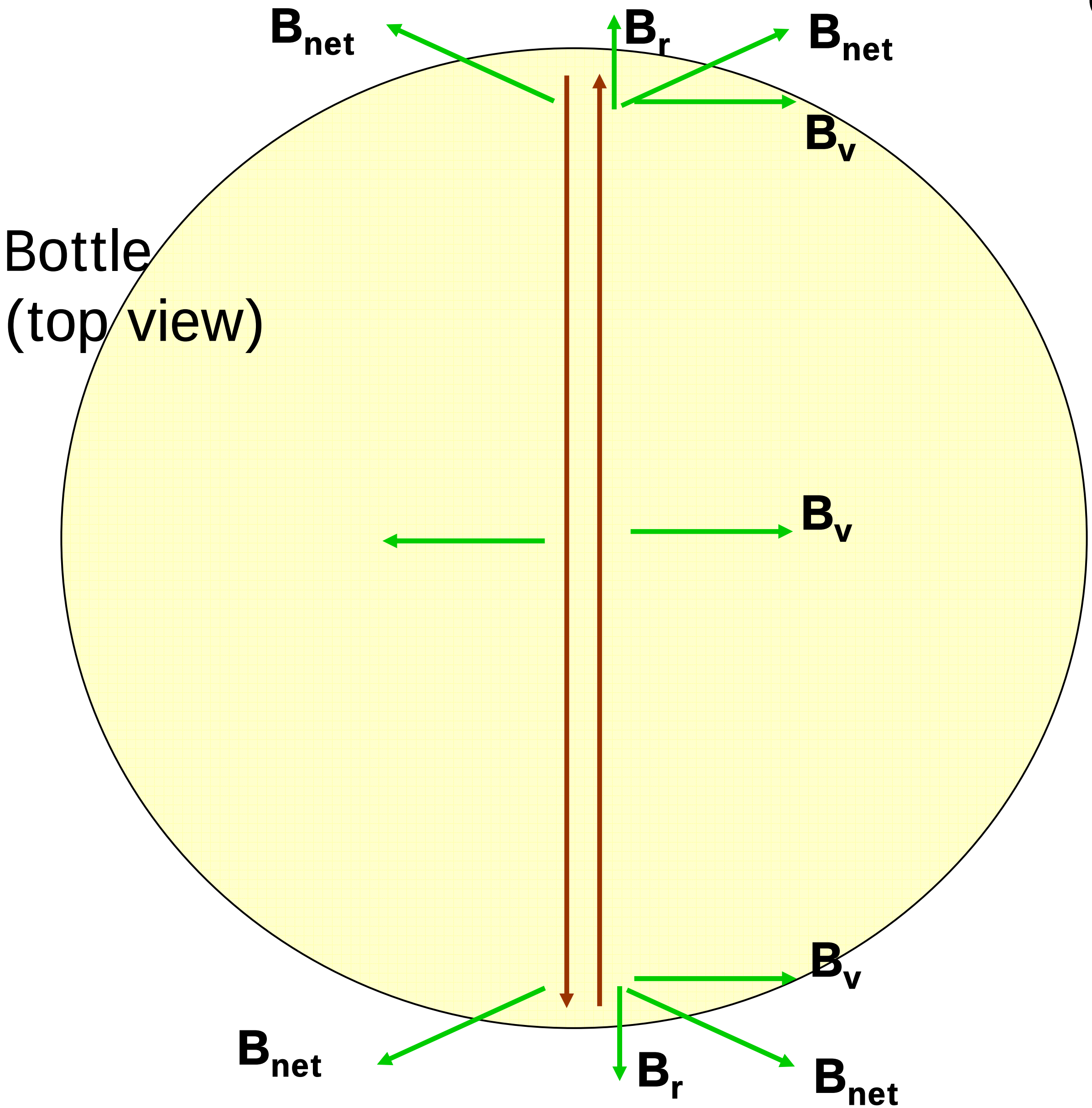
$$\vec{B}_v = \frac{\vec{v}\times\vec{E}}{c^2}$$

If B_0 field has vertical gradient, than



$$B_{0r}\left(\frac{\vec{r}}{r}\right) = -\frac{\partial B_{0z}}{\partial z}\frac{\vec{r}}{2}$$

Geometric phase



… so particle sees additional rotating field

Frequency shift $\propto$ E

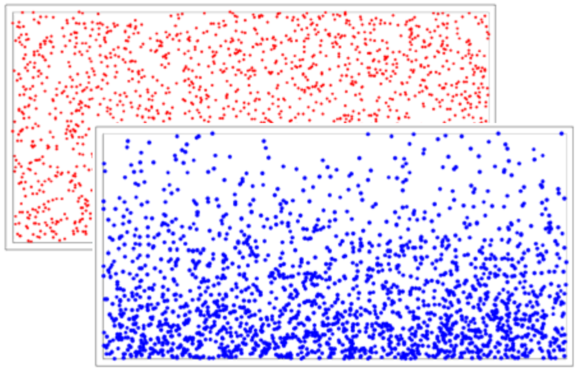
Looks like an EDM

Systematics

- Consider

$$R = \frac{\nu_n}{\nu_{Hg}} \cdot \frac{\gamma_{Hg}}{\gamma_n}$$

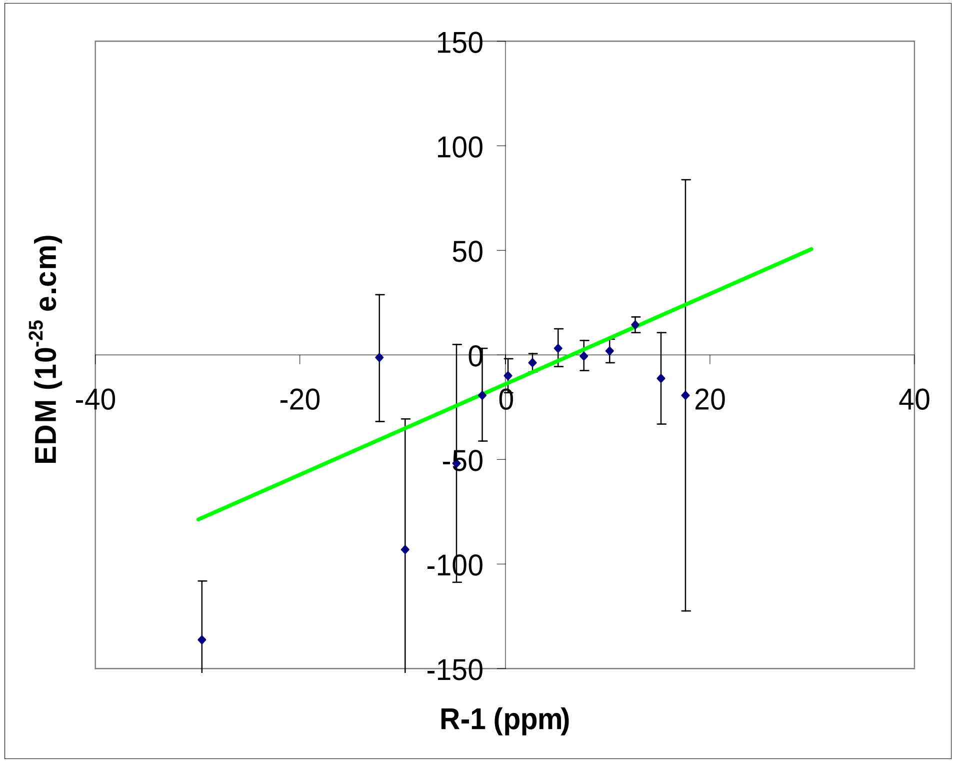
$\Delta \boldsymbol{h}$ = 2.73+/- 0.39 mm



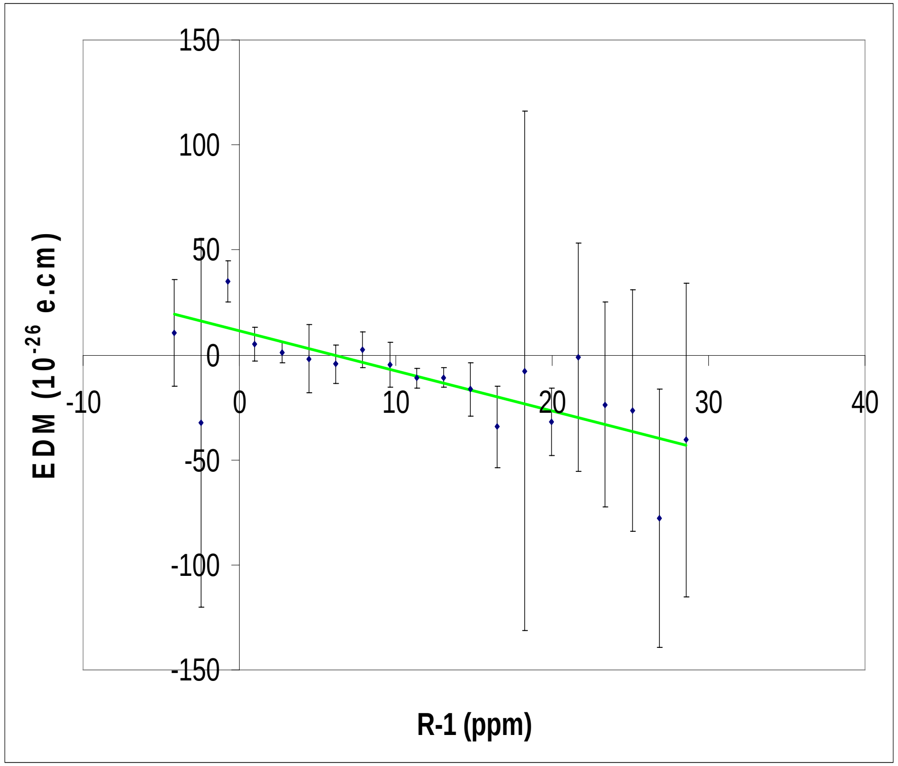
- Should have value 1
- R is shifted by magnetic field gradients
- Plot EDM vs measured R-1:

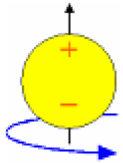
The Search for Neutron Electric Dipole Moment at ILL

B field Down



B field Up



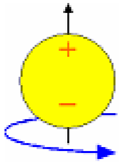


Statistical and systematical errors

d_n = -0.31 ± 1.54 x 10^{-26} e.cm preliminary

Systematical errors

Dipole & quadrupole shifts
Enhanced GP dipole shifts
(**E** x **v**)/c^2 from translation
(**E** x **v**)/c^2 from rotation
Light shift: direct
B fluctuations
Light shift: GP effects
E forces – distortion of bottle
Tangential leakage currents
AC B fields from HV ripple
Others ……..



CryoEDM experiment

Statistical uncertainty

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

$\sigma(d_n) = 2 \times 10^{-25}$ e.cm/day

for "room temperature" nEDM experiment

New UCN source

Superthermal UCN source:

a) a medium has a very small neutron absorption;

b) the medium has a critical energy for total reflection which is much smaller than that of vessel's walls

c) the medium behaves as if there were only one excited state with excitation energy $E >> T >> E_u$

T-temperature of the medium, E_u – the UCN energy

R.Golub and J.M.Pendlebury Phys. Let. 62A, 337, (1977)

Isotopically pure HeII

a) $\sigma_{absorption}=0$

b) $V_{crit}=21$ neV

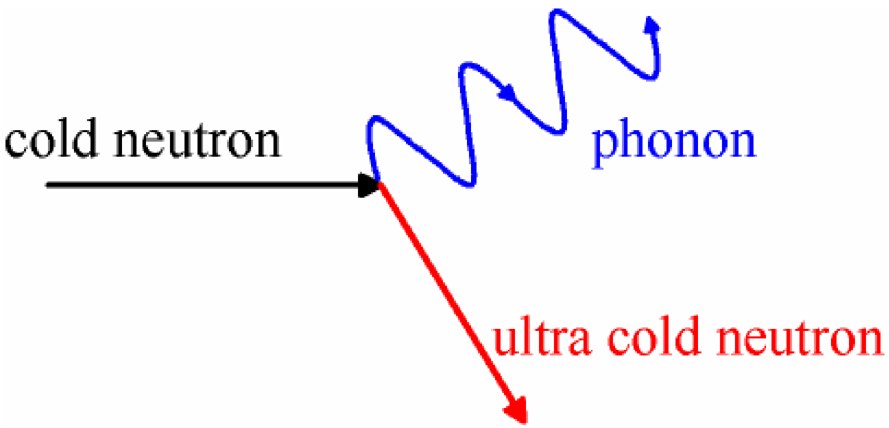
c) Pure coherent scattering $E_{phonon}=11K$,

$T_{He}=0.5K$, $E_{UCN}=1$ mK

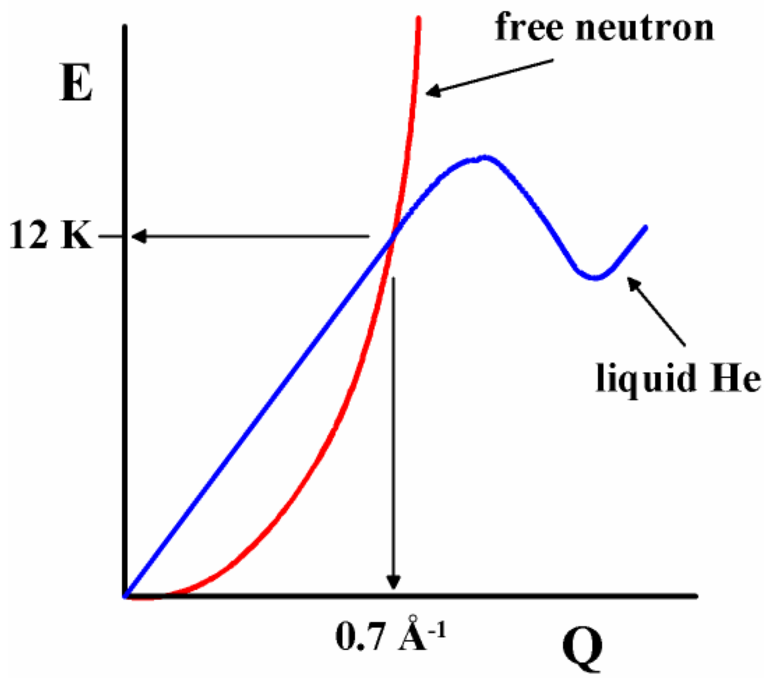
Production rate one-phonon interaction:

$$R_I = 4.1 \times 10^{-8} \left.\frac{d\Phi}{d\lambda}\right|_{\lambda^*} \text{cm}^{-3}\text{s}^{-1}$$

main process: one phonon downscattering



Energy momentum dispersion curve



Storing superthermal UCN

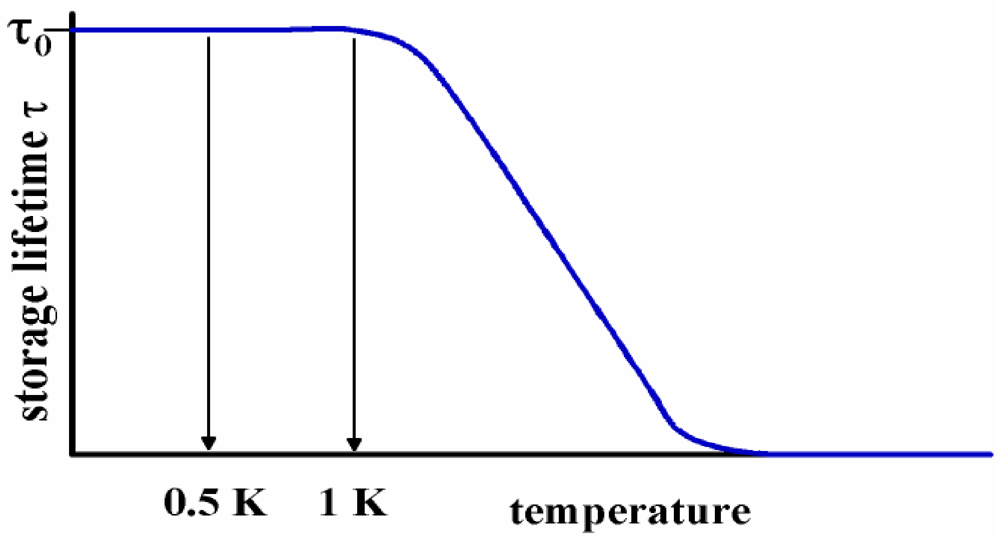
τ - storage time, one phonon scattering only

$$\frac{1}{\tau} = A \exp\left[-\frac{11.9}{T}\right] + \frac{1}{\tau_0}$$

limited by:

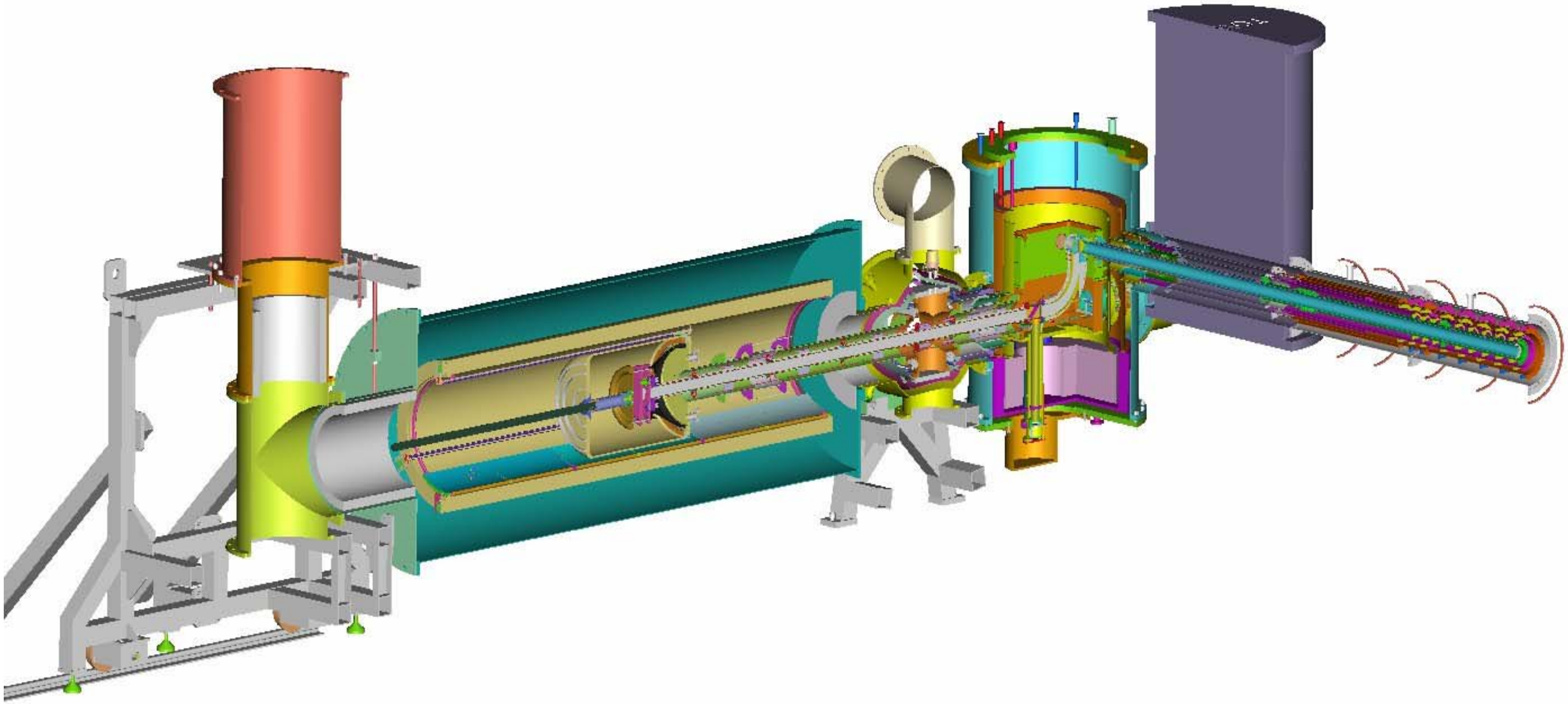
- **neutron lifetime**
- **^{4}He purity**
- **storage volume wall absorption cross section**
- **upscattering**

storage time vs helium temperature:



The Search for Neutron Electric Dipole Moment at ILL

CryoEDM overview



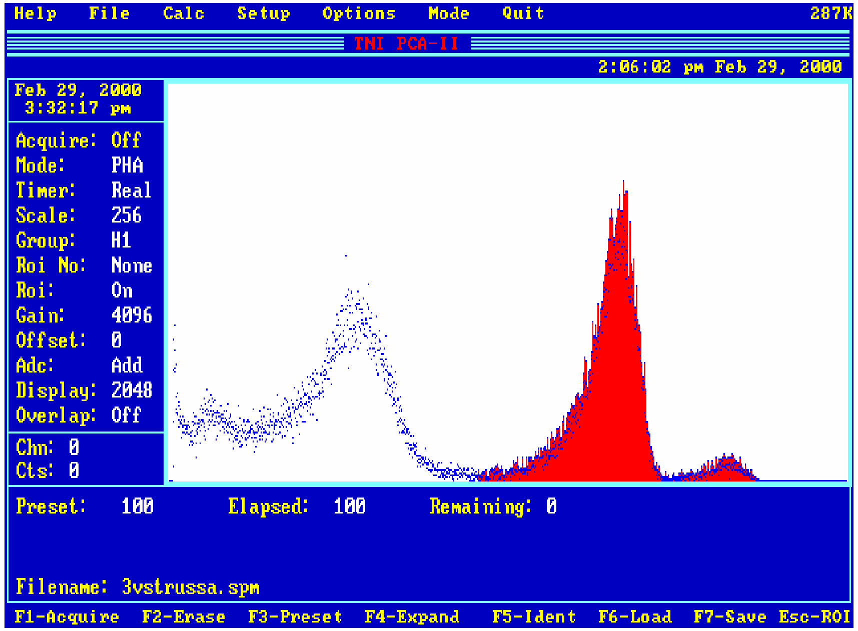
Neutron detection

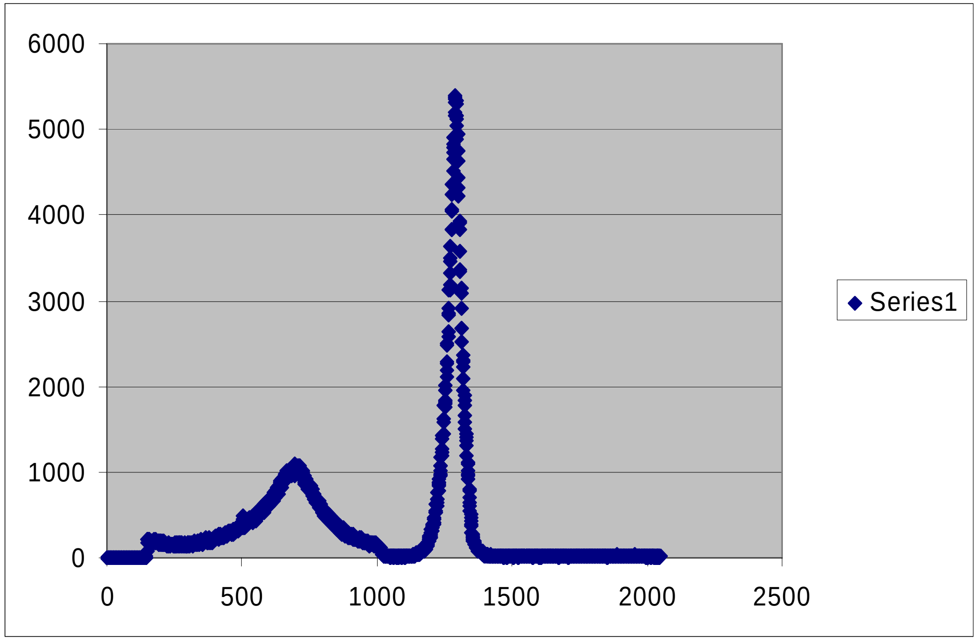
Ion-implanted Si with neutron to charged particles converter

$$n + {}^{10}B \rightarrow \alpha(1.78 MeV) + {}^{7}Li(1.01)$$

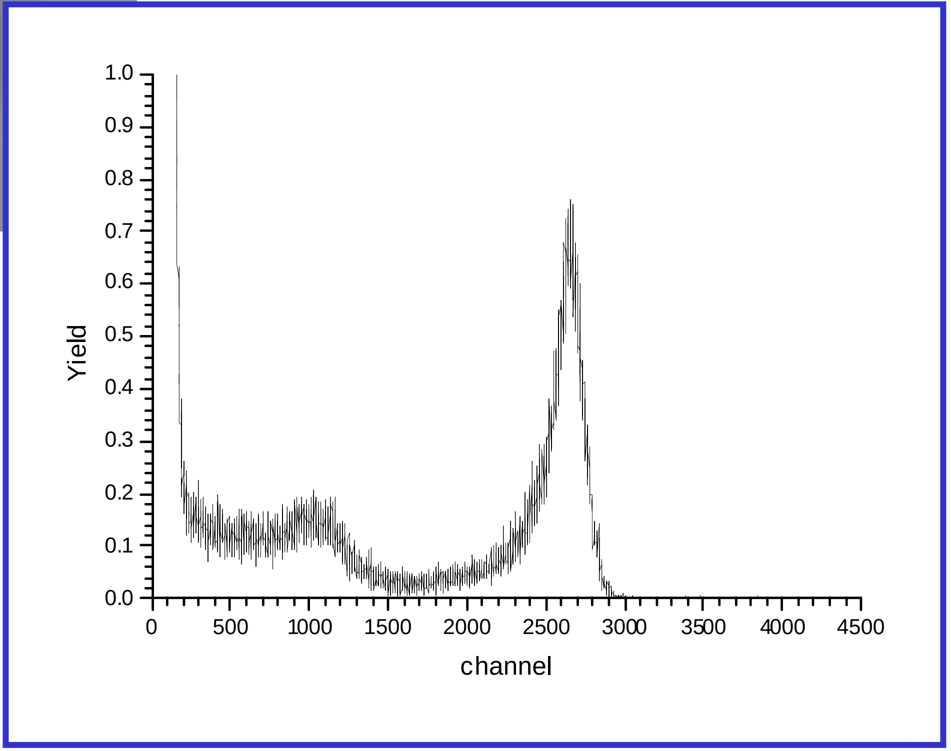
$$n + {}^{10}B \rightarrow \alpha(1.47 MeV) + {}^{7}Li(0.83 MeV) + \gamma(0.48 MeV)$$

$$n + {}^{6}Li \rightarrow \alpha(2.05\ MeV) + {}^{3}H(2.74\ MeV)$$

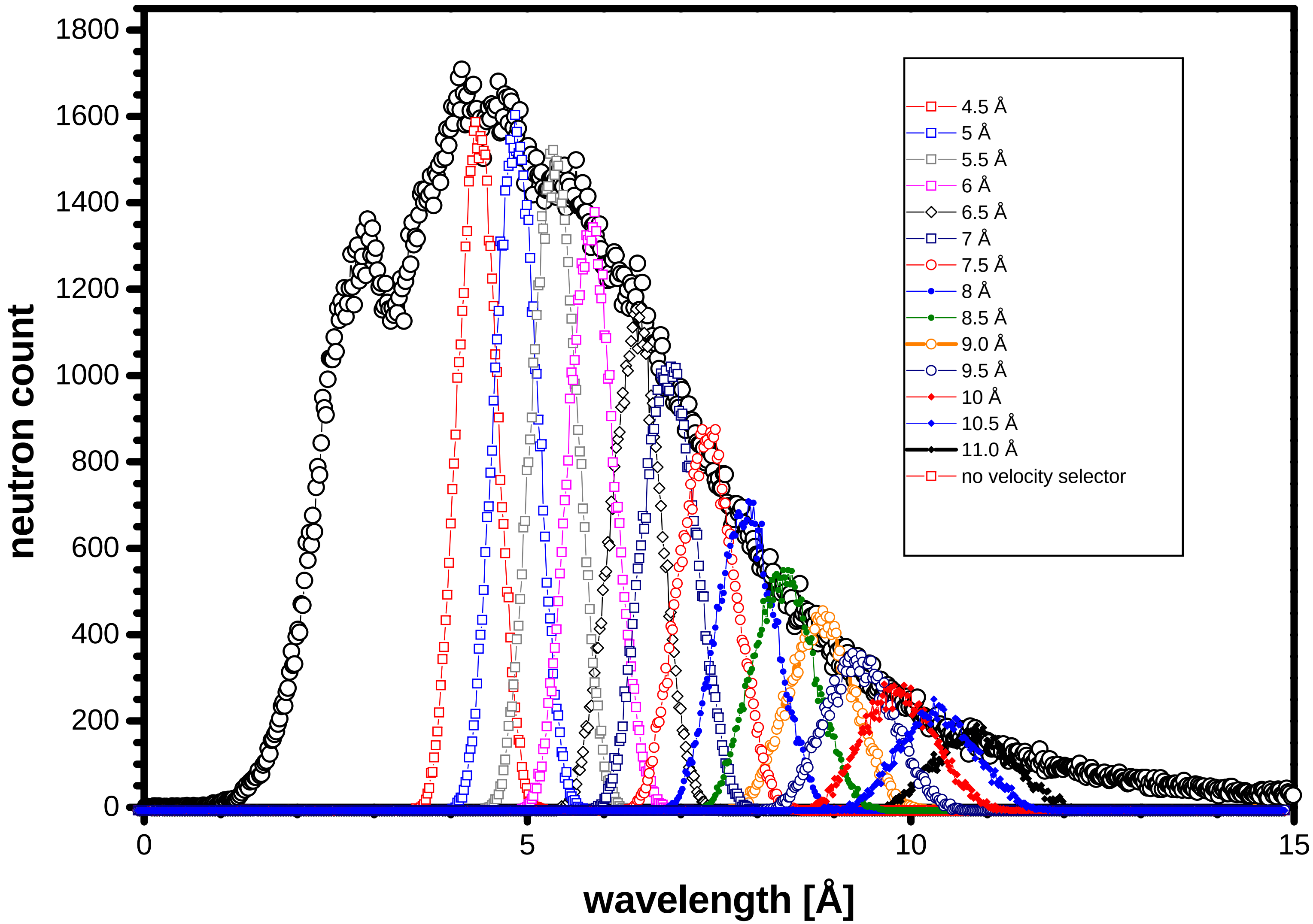




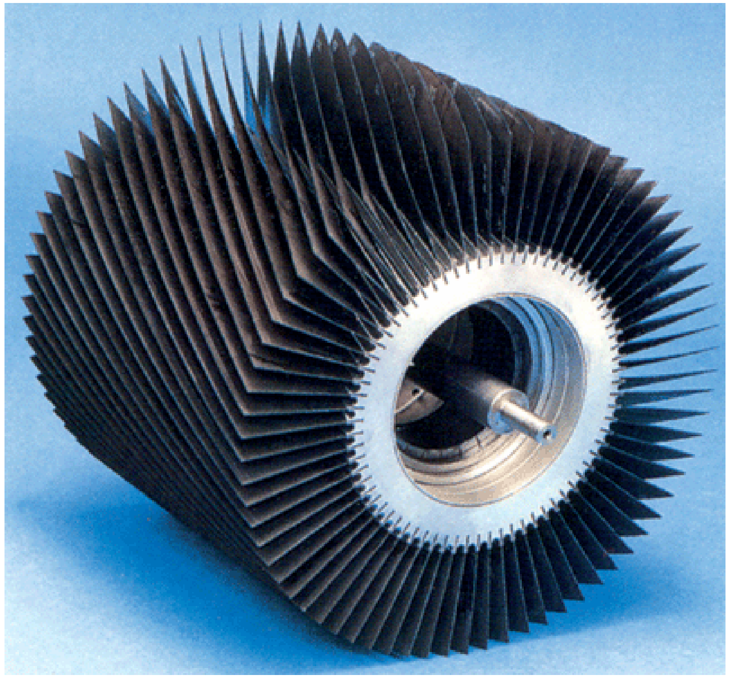
Pulse Height Analysis of cryogenic UCN detectors



The Search for Neutron Electric Dipole Moment at ILL



Neutron velocity selector



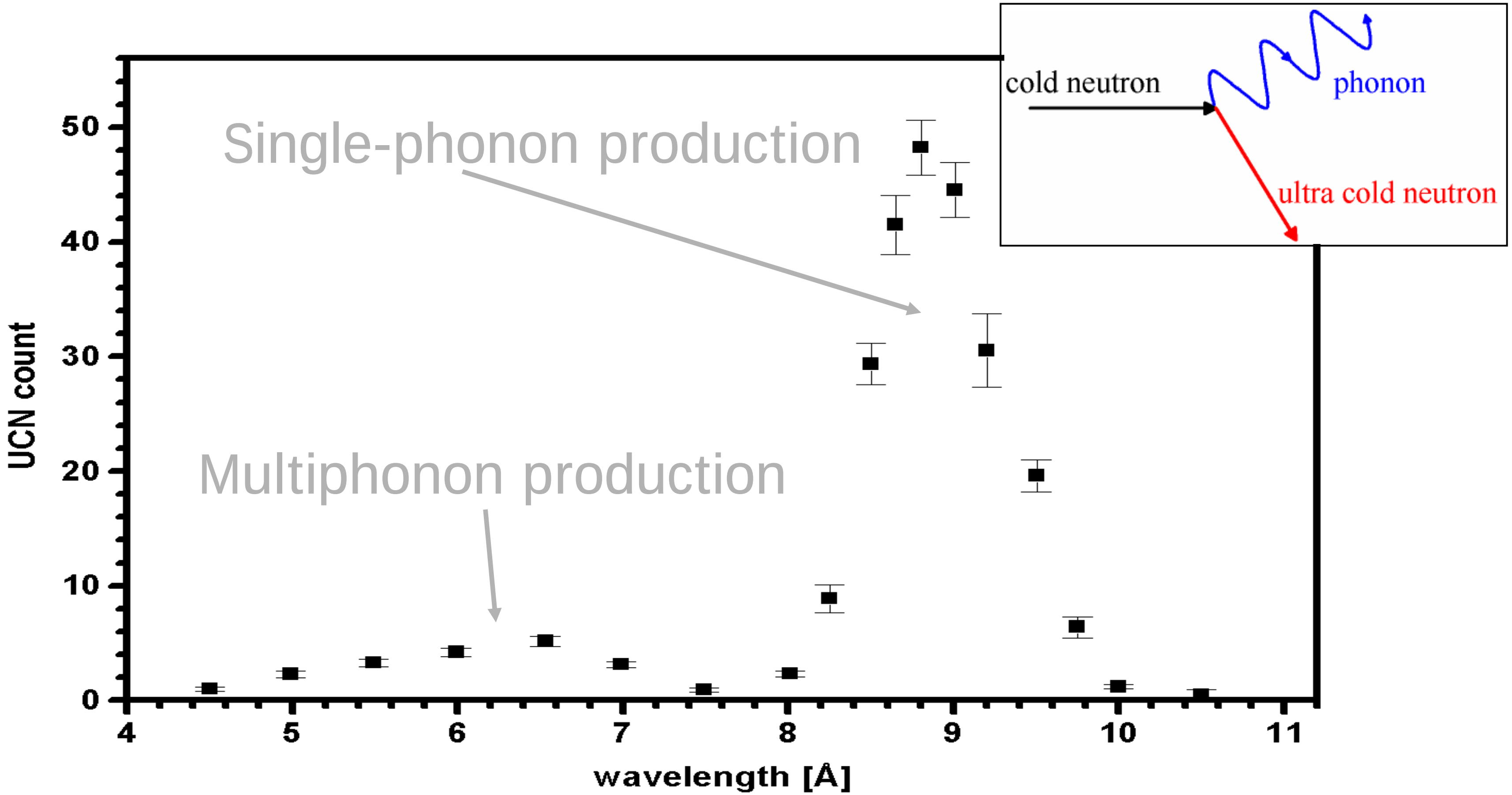
Daimler-Benz Aerospace

Dornier

Wavelength λ 0.45 to 4.3 nm

α(′)	T(%)	R(%)
60	79.4	11.4

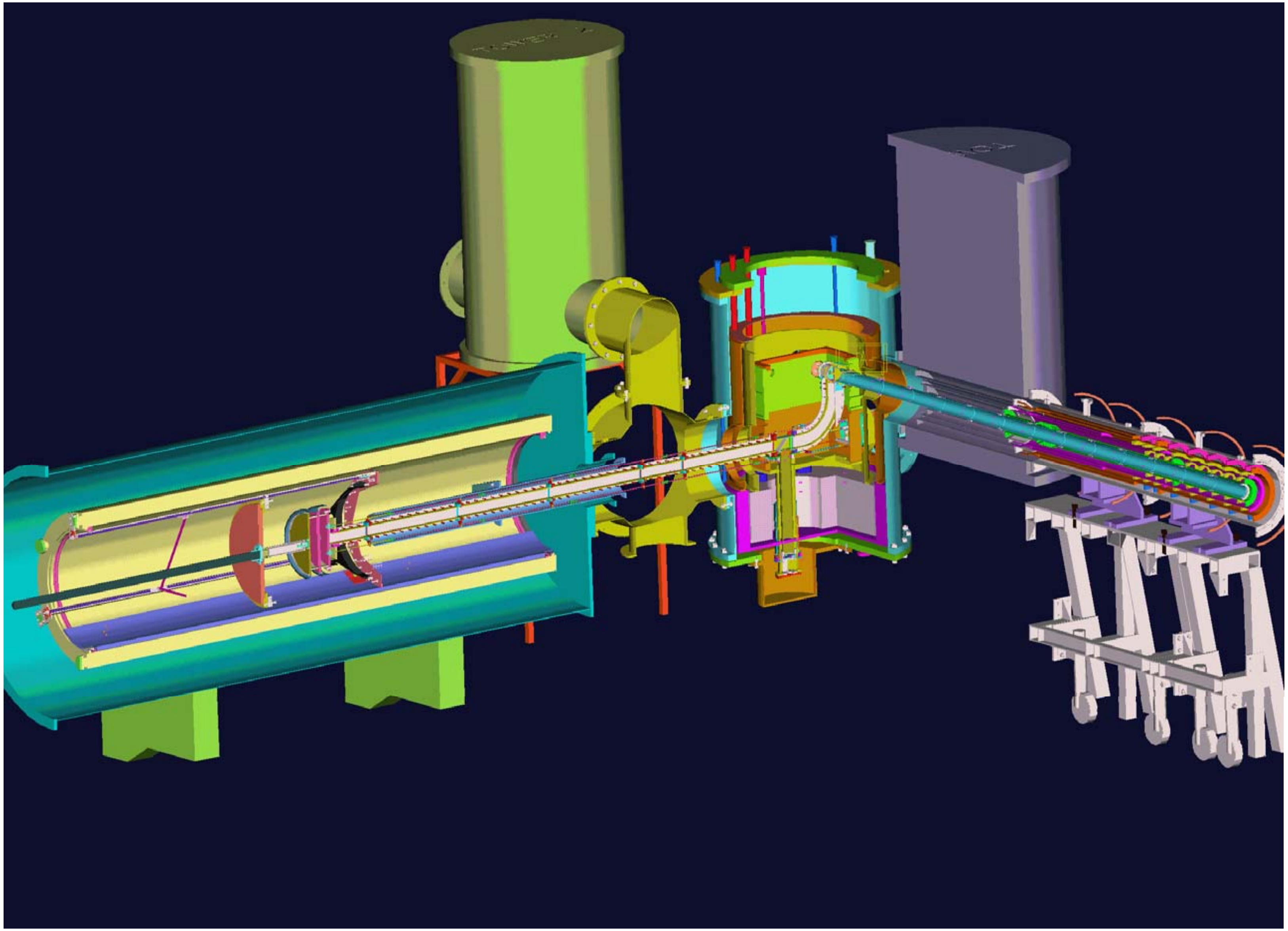
UCN production rate vs λ_n



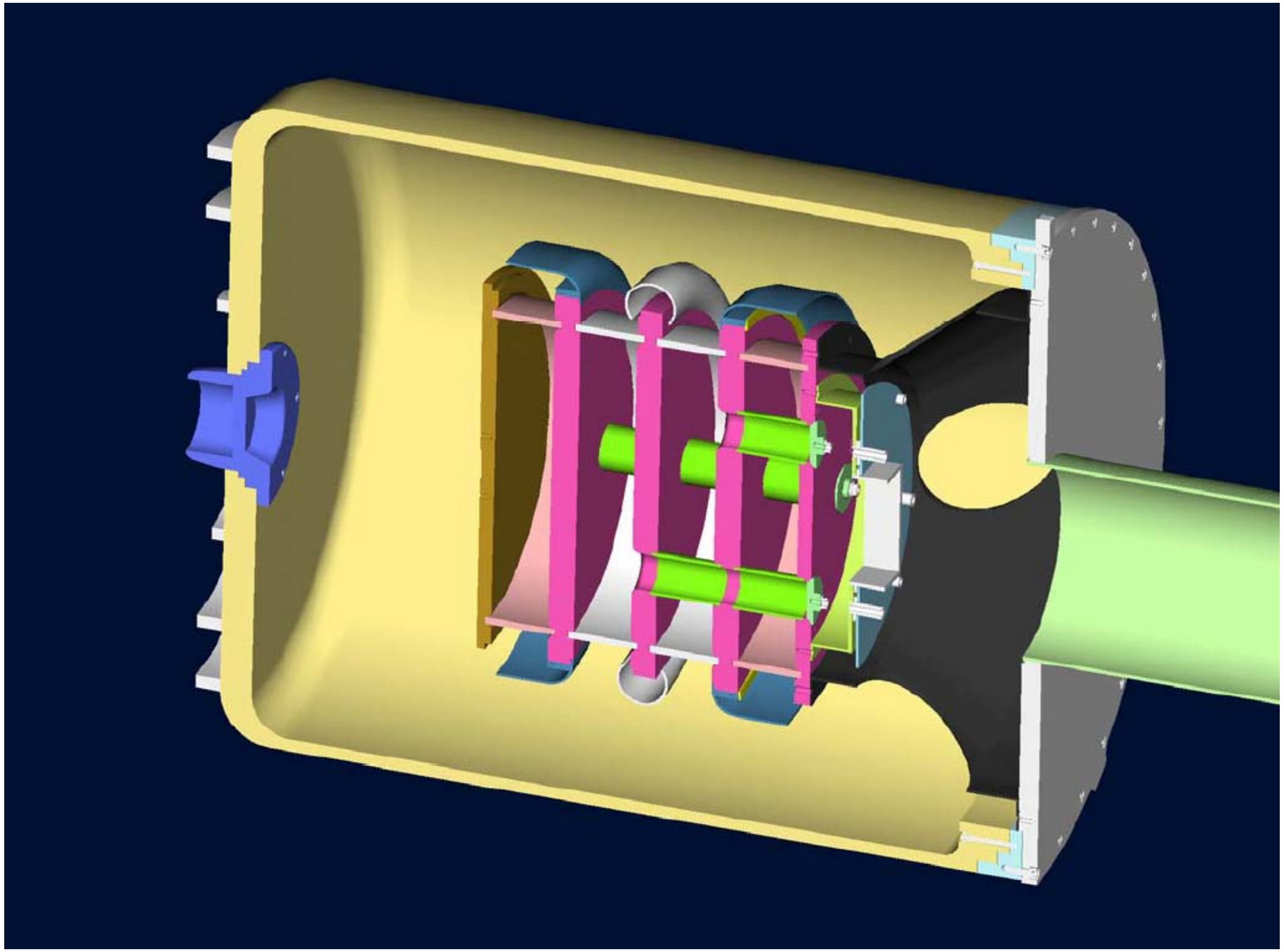
1.19±0.18 UCN cm^{-3} s^{-1} expected, 0.91± 0.13 observed

See C.A.Baker *et al.*, Phys.Lett. **A308** 67-74 (2002)

CryoEDM overview

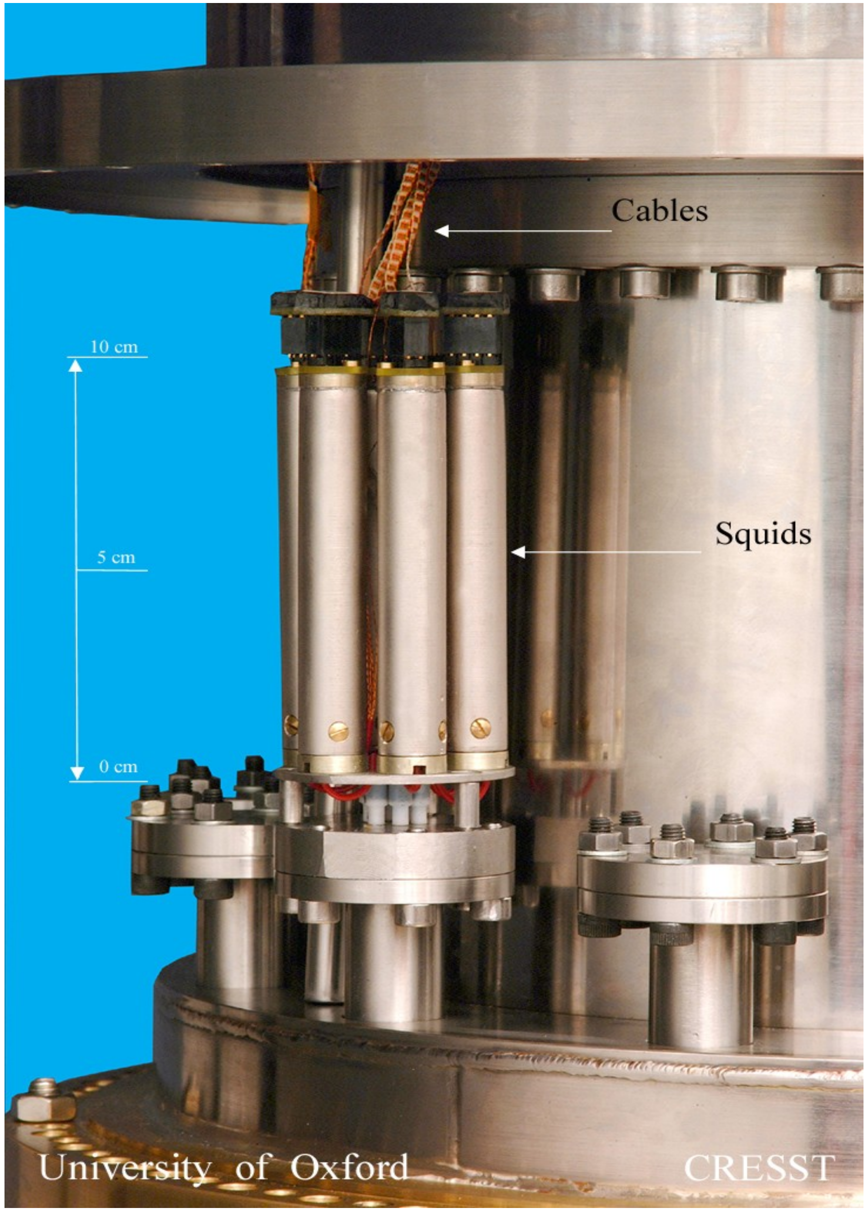


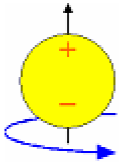
Cryogenic Ramsey chamber



Magnetometry

- SQUID Magnetometers
  - Developed at Oxford for CRESST
  - Highly sensitive: adequate to monitor field fluctuations
- Also: Neutron Magnetometers...





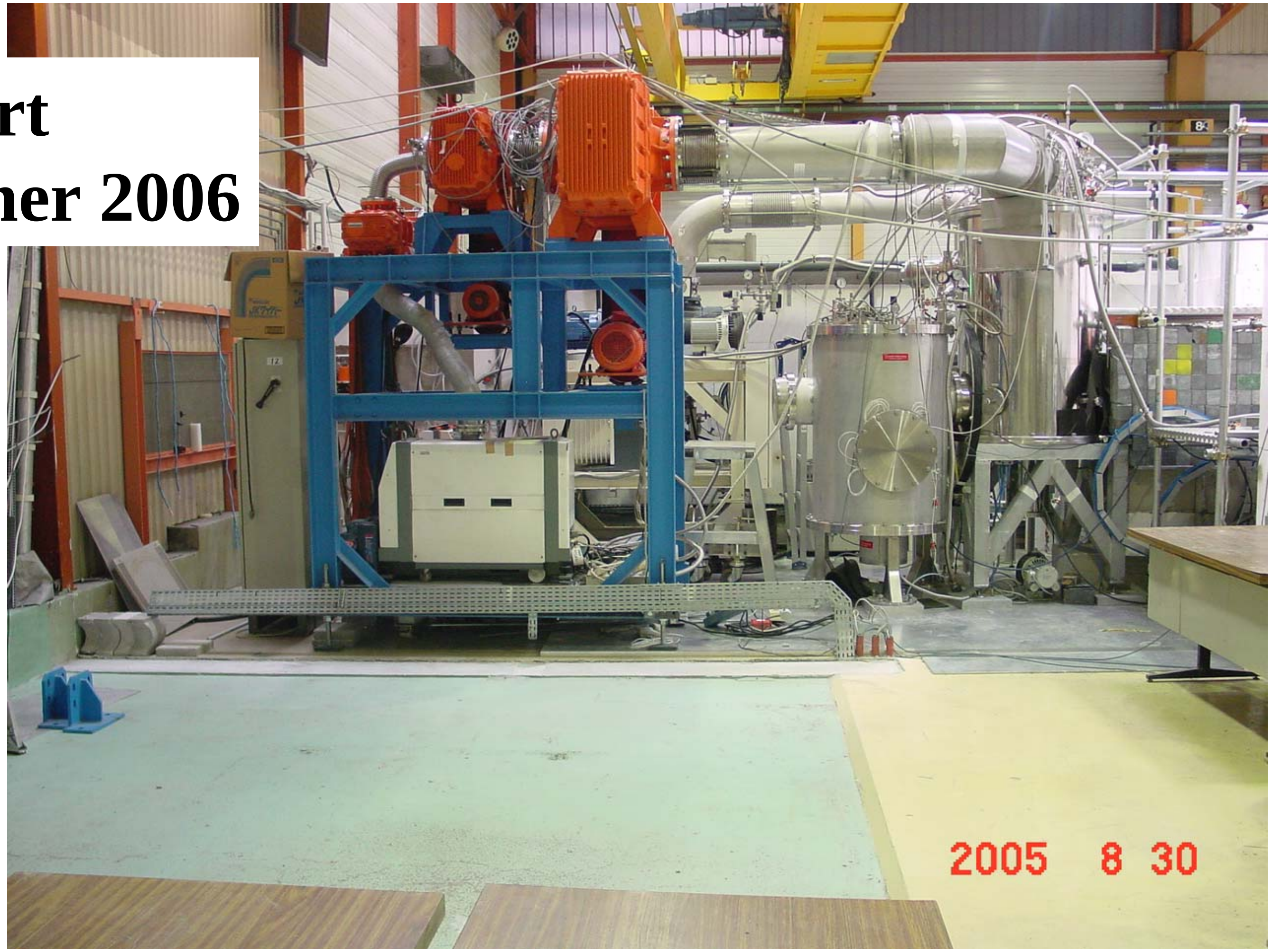
Statistical limits

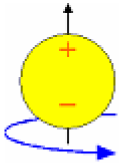
$$\sigma_d = \frac{\hbar / 2}{\alpha\, E\, T \sqrt{N}}$$

Factor	Current	Increase
• Polarisation+detection	$\alpha = 0.75$	x 1.5
• Electric field:	$E = 10^6$ V/m	x 2.0
• Precession period:	$T = 130$ s	x 1.8
• Neutrons counted:	$N = 6 \times 10^6$ /day	x 14.9
(with new beamline)		x 2.6

Total increase = x 80 (x200 with new beamline)

CryoEDM to start running in summer 2006





The Search for Neutron Electric Dipole Moment, present experiment at ILL, Grenoble, and future prospects

Plamen IAYDJIEV - INRNE – Sofia,Bulgaria and RAL, UK

nEDM experiment - Rutherford Appleton Laboratory - University of Sussex - ILL

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CryoEDM experiment - Rutherford Appleton Laboratory - University of Sussex – ILL – University of Kure – University of Oxford

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University of Kure (Japan) H. Yoshiki
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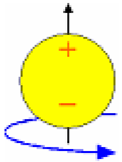
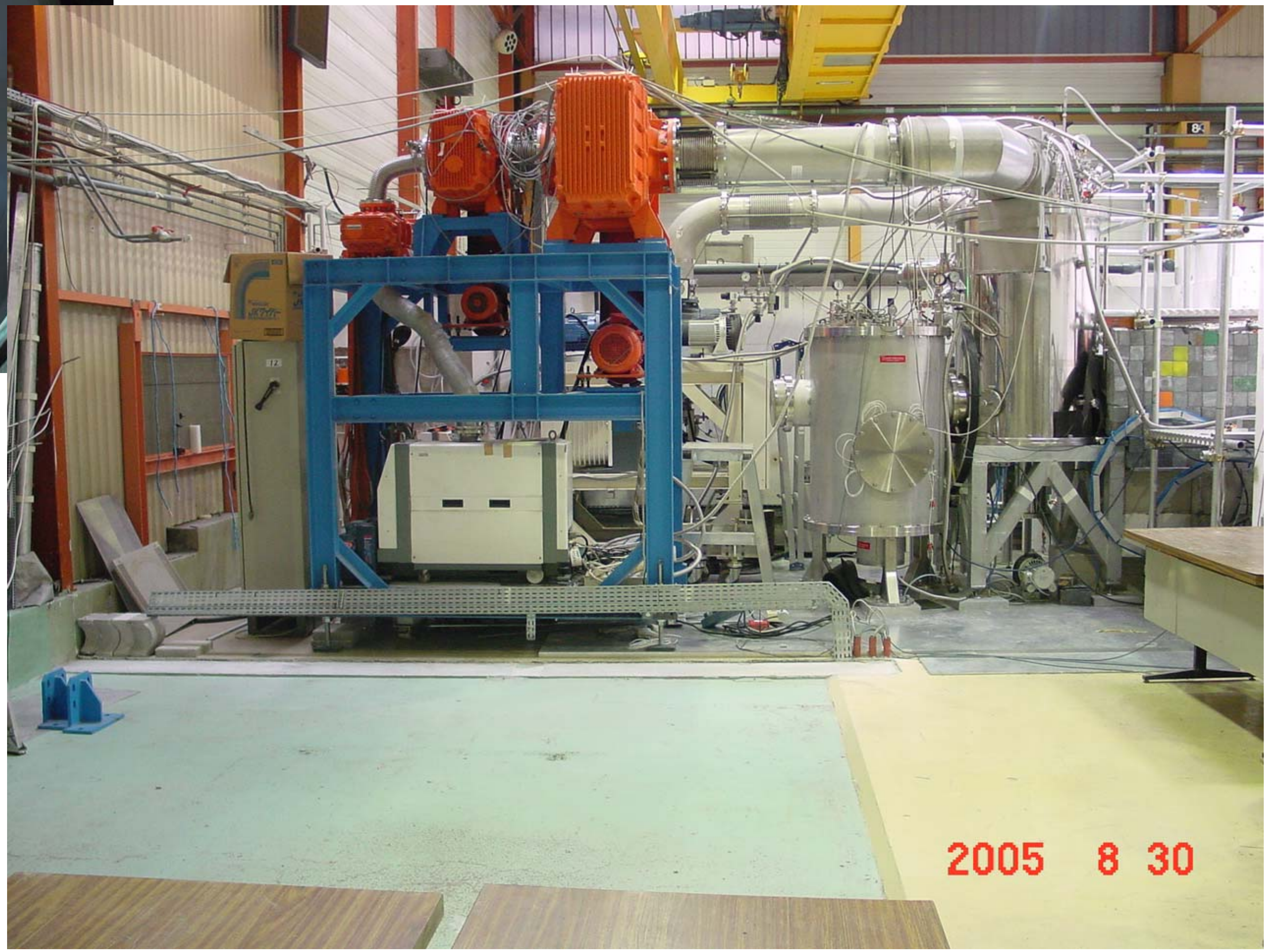


The Search for Neutron Electric Dipole Moment at ILL

CryoEDM

10^{-27} e.cm 2006/8

10^{-28} e.cm 2008/9



nEDM

dn = $-0.31 \pm 1.54 \times 10^{-26}$ e.cm
preliminary