CryoEDM – A Cryogenic Neutron-EDM Experiment

Collaboration:

Sussex University, RAL, ILL, Kure University, Oxford University

Hans Kraus

nEDM Overview

- Theoretical Background
- The Method of Ramsey Resonance
- Room-temperature Experiment
- Ultra-Cold Neutrons
- The Cryogenic Experiment

Fundamental Inversions

C	particle	→	antiparticle	$(Q \rightarrow -Q)$
P	position	→	inverted	$(\mathbf{r} \rightarrow -\mathbf{r})$
T	time	→	reversed	$(t \rightarrow -t)$

Symmetries

Weak interactions are not P or C symmetric.

Normal matter - n, μ, π - readily breaks C / P symmetry.

The combination CP is different:

Normal matter respects CP symmetry to a very high degree.

Time reversal is equivalent to CP (with CPT ok):

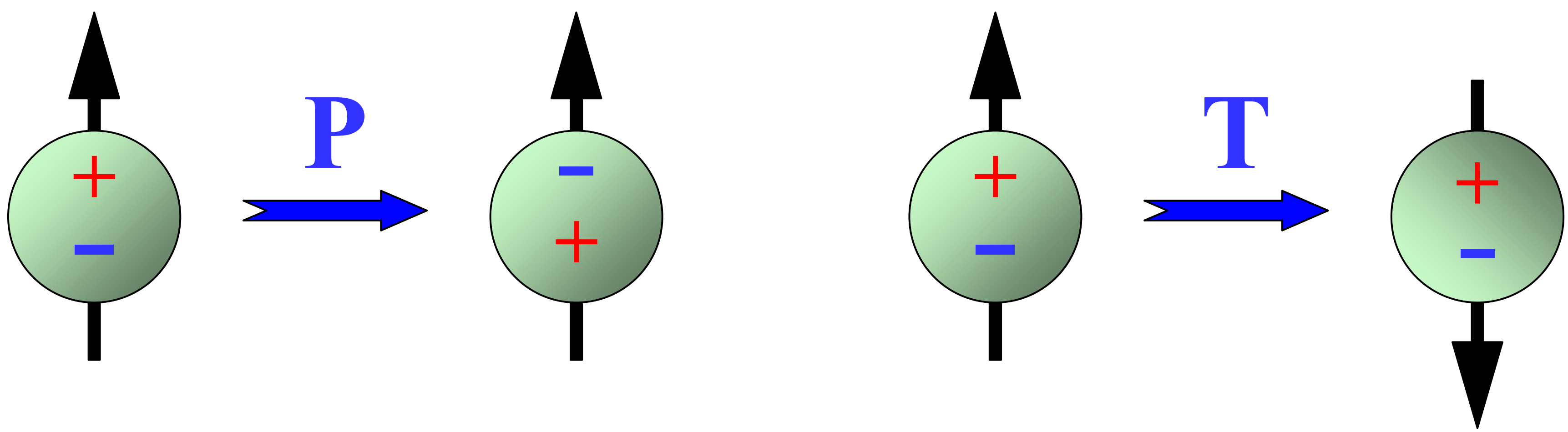
Normal matter respects T symmetry to a very high degree.

EDM breaks P and T Symmetry

neutron EDM: $\mathbf{d}_n = d_n \hat{\mathbf{s}}$

P odd

T odd



($\not{P}$ no big deal)

($\cancel{CP}$ big deal)

(assuming CPT invariance)

Theoretical Overview

- SM contribution is immeasurably small, but...
- most models beyond SM predict values about 10^6 greater than SM. Very low background!
- EDM measurements already constrained SUSY models.
- "Strong CP Problem": Why does QCD not violate CP? Nobody knows.
- Finally, there is the question of baryon – anti-baryon asymmetry in the universe.

Two Motivations to Measure EDM

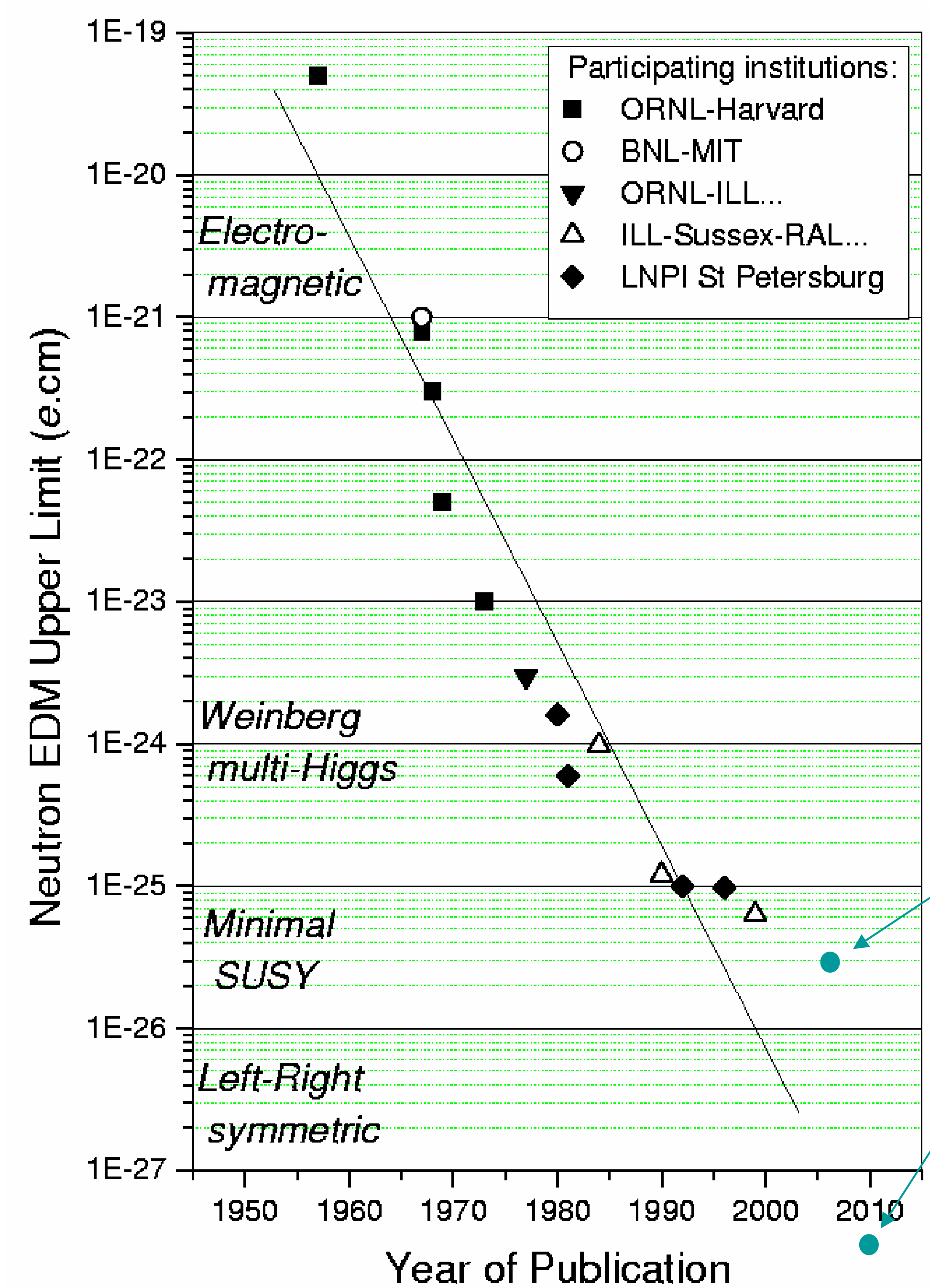
EDM violates T symmetry

Deeply connected to CP violation and the matter-antimatter asymmetry of the Universe

Standard model EDM is effectively zero, but big enough to measure in non-standard models

Direct test of physics beyond the standard model

A Bit of History



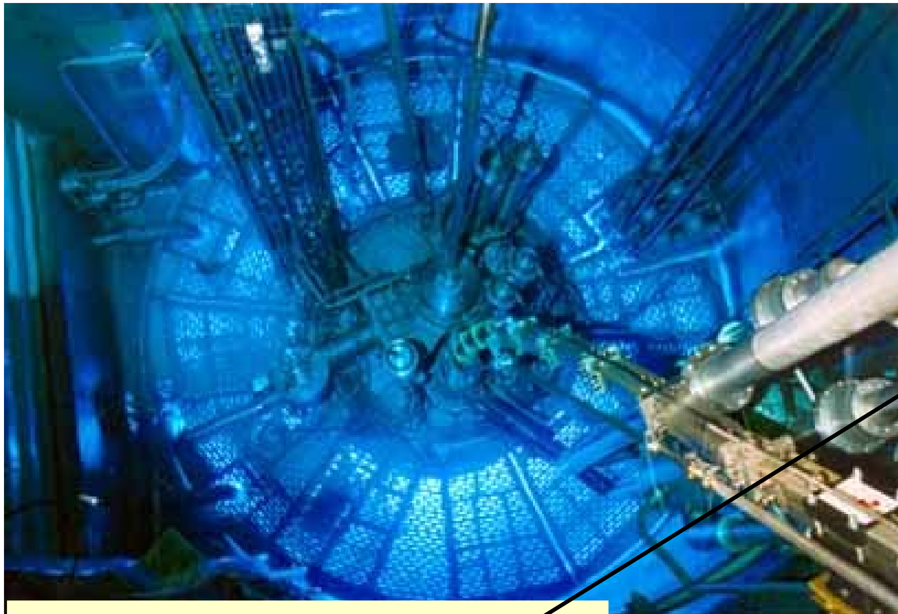
A factor 10 improvement on average every 8 years.

Step change through new techniques.

The ILL in Grenoble

NEUTRONS
FOR SCIENCE

The Neutron Source



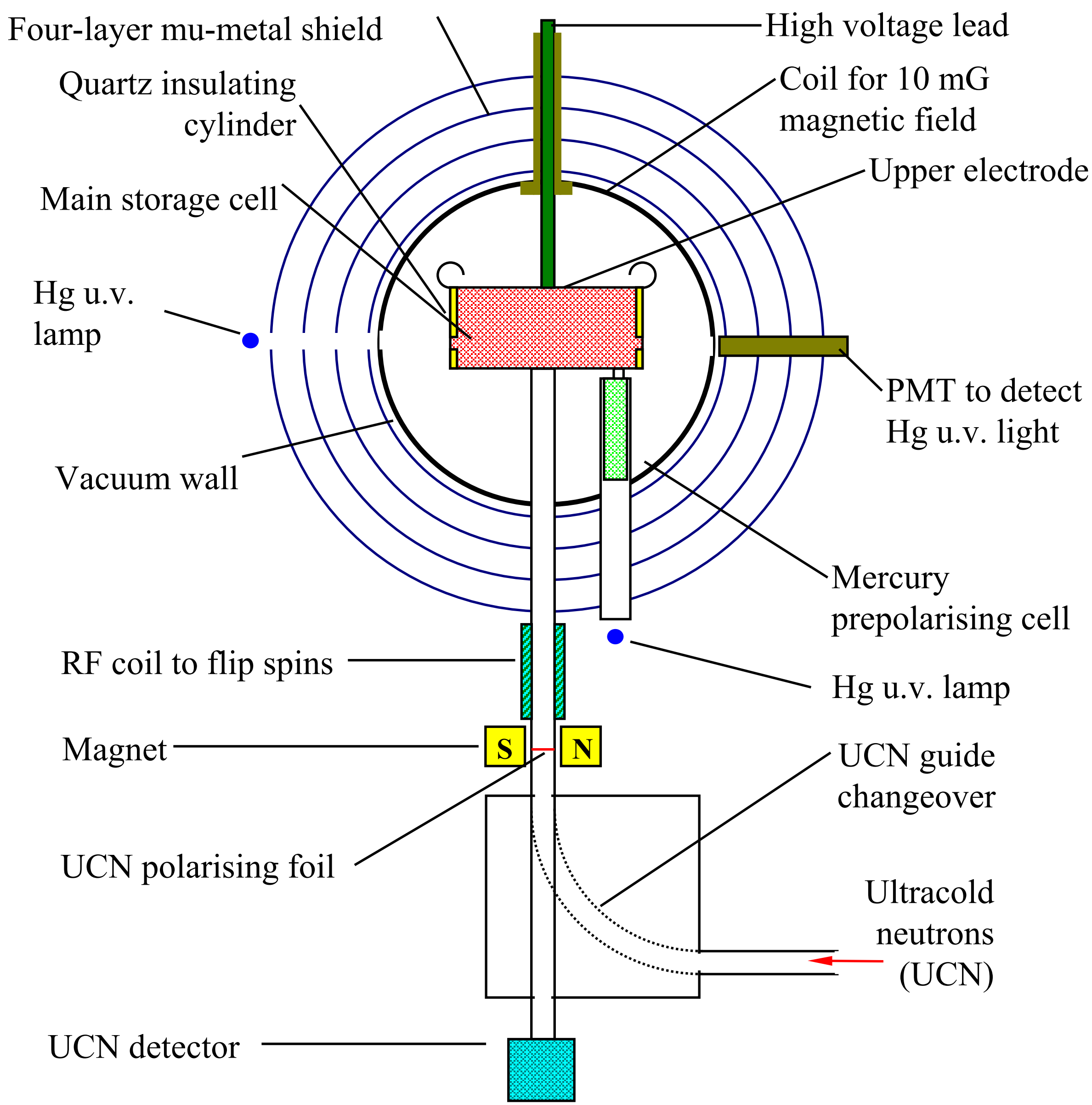
Neutron turbine
A. Steyerl (TUM - 1986)

Vertical guide tube

Cold source

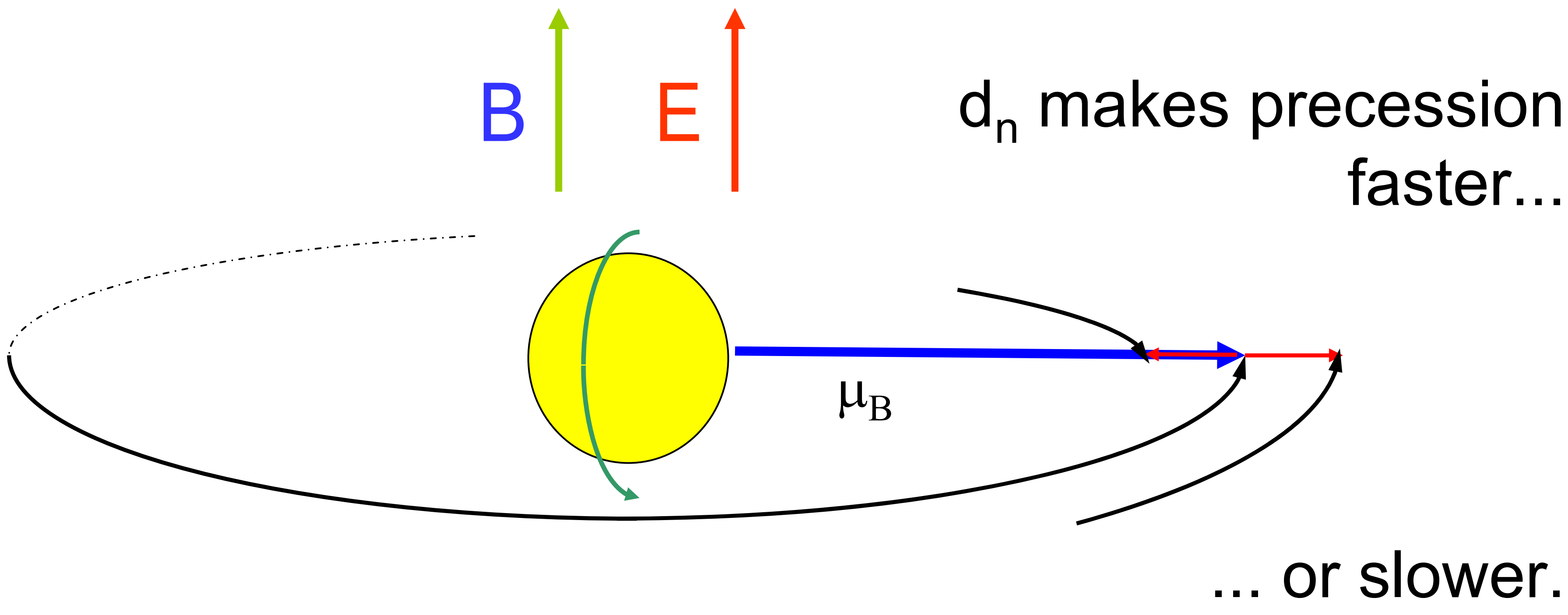
Reactor core

Room Temperature Experiment



Measurement Principle

Measure Larmor spin precession frequency in parallel & antiparallel **B** and **E** fields:



Measurement Principle

Apply const magnetic field, reverse electric field:

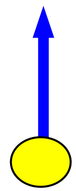
$$\Delta W_{\uparrow\uparrow} = 2\boldsymbol{\mu}_{\mathbf{n}} \cdot \mathbf{B} + 2\mathbf{d}_{\mathbf{n}} \cdot \mathbf{E}$$

$$\Delta W_{\uparrow\downarrow} = 2\boldsymbol{\mu}_{\mathbf{n}} \cdot \mathbf{B} - 2\mathbf{d}_{\mathbf{n}} \cdot \mathbf{E}$$

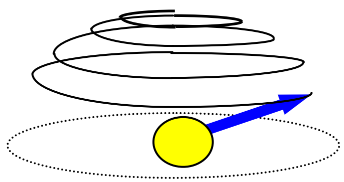
$$\nu_{\uparrow\uparrow} - \nu_{\uparrow\downarrow} = 4\mathbf{d}_{\mathbf{n}} \cdot \mathbf{E} / h$$

Measure difference in precession frequency and find Electric Dipole Moment

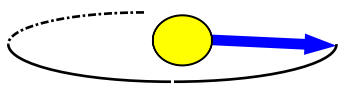
Ramsey's Technique

1. 

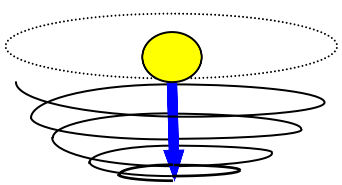
"Spin up" neutron...

2. 

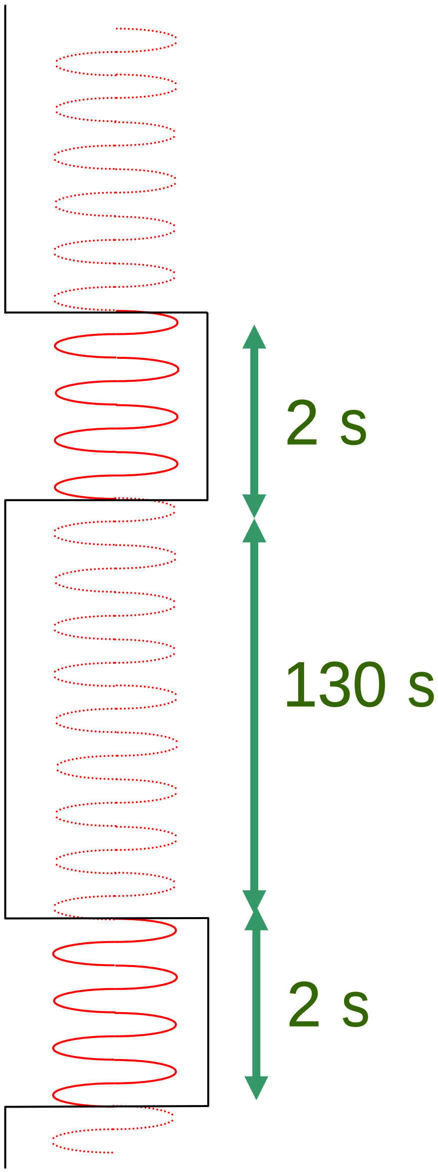
Apply π/2 spin flip pulse...

3. 

Free precession...

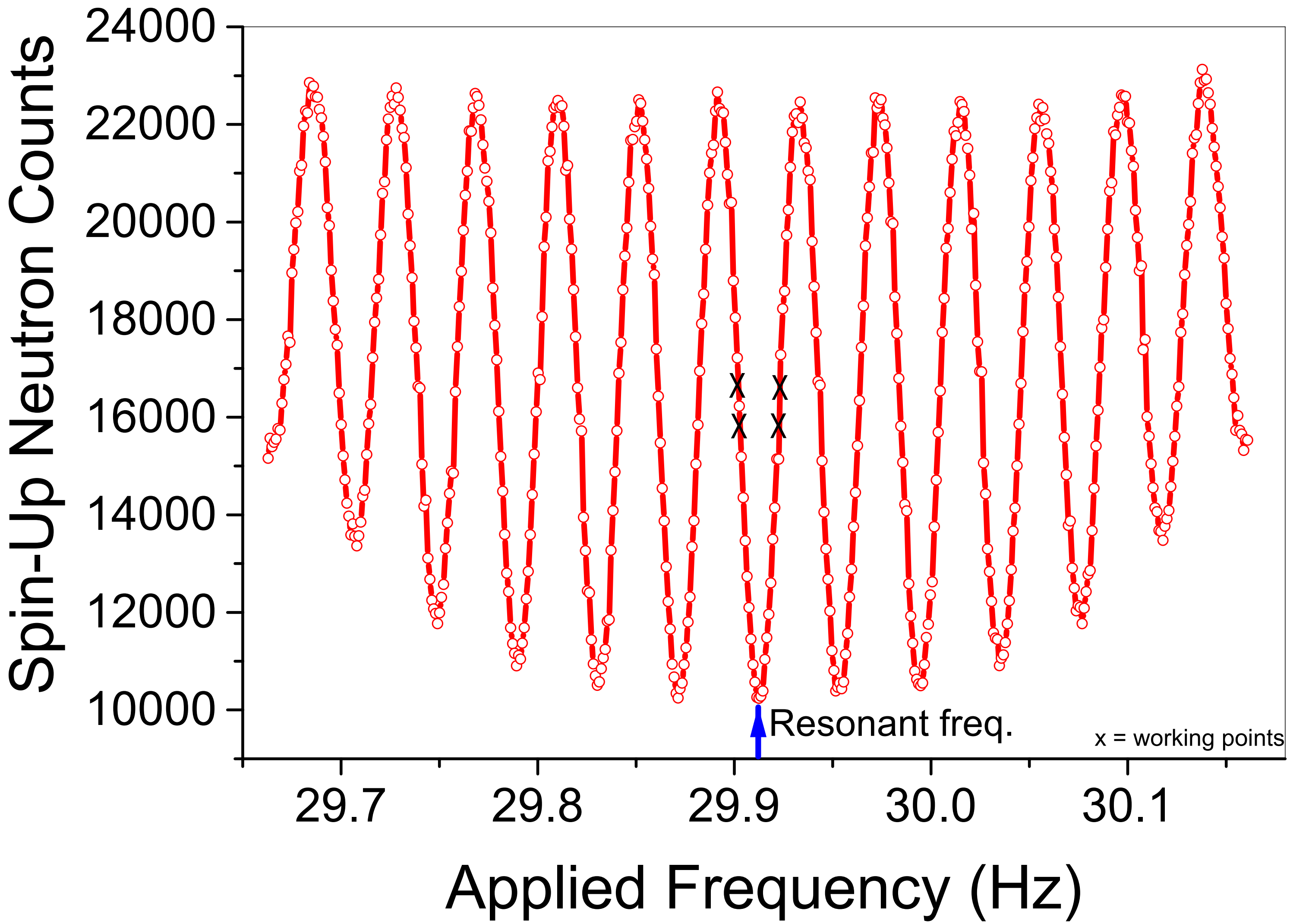
4. 

Second π/2 spin flip pulse.



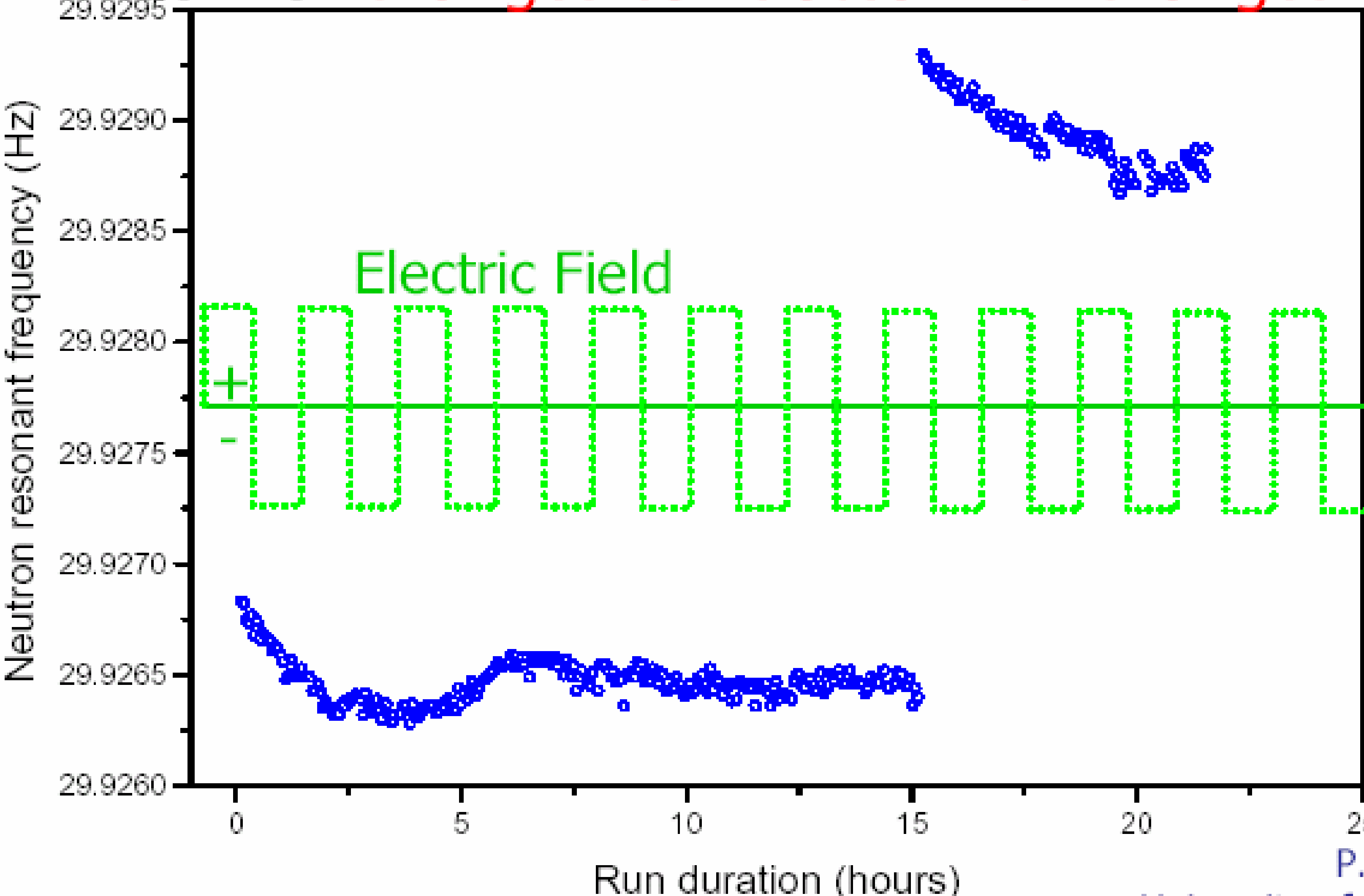
Ramsey Resonance

Phase gives frequency offset from resonance.



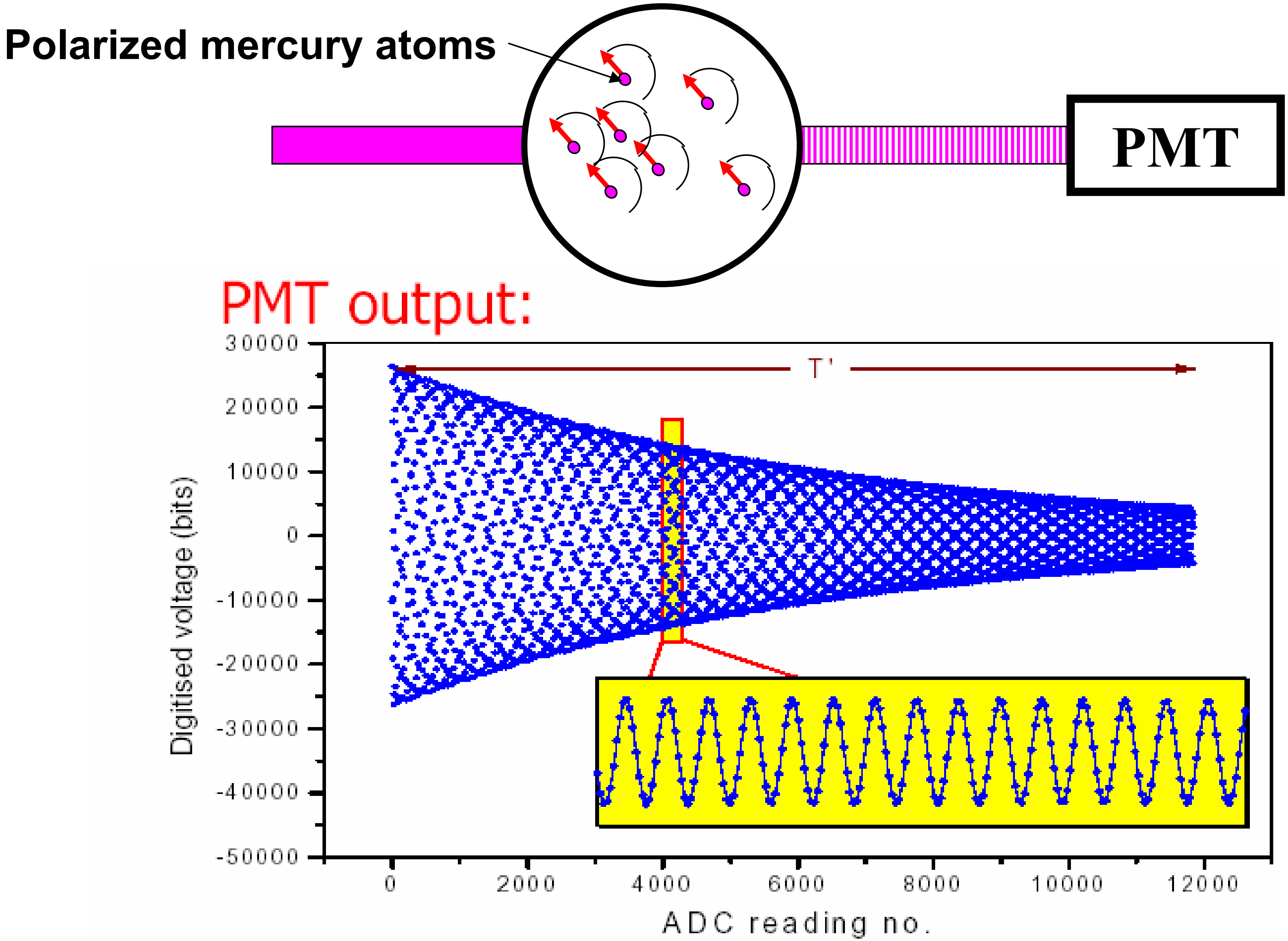
The Measurement

- Look for changes correlated with changes in E

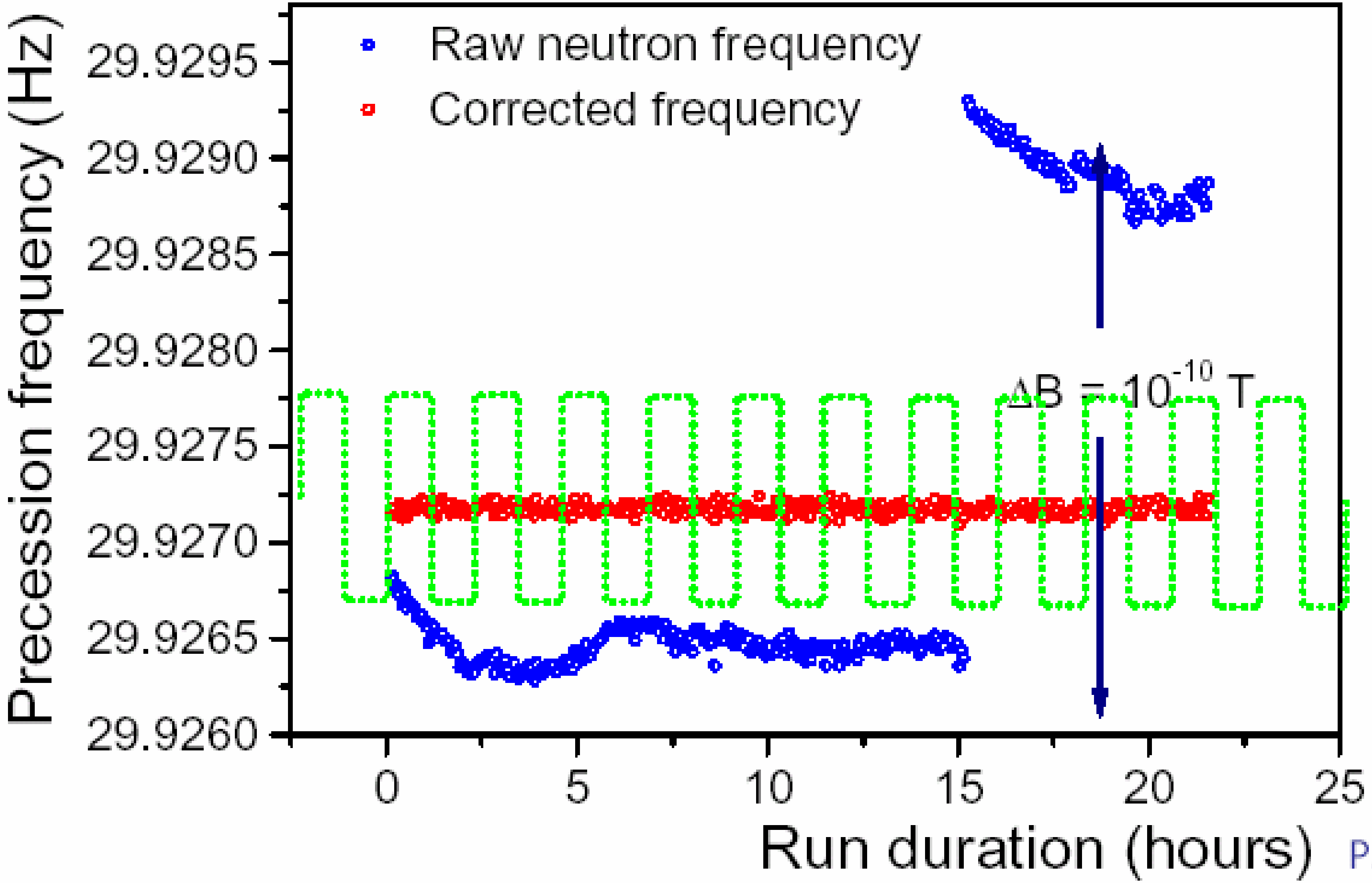


P. Harris
University of Sussex

Mercury Magnetometry



With Magnetometer



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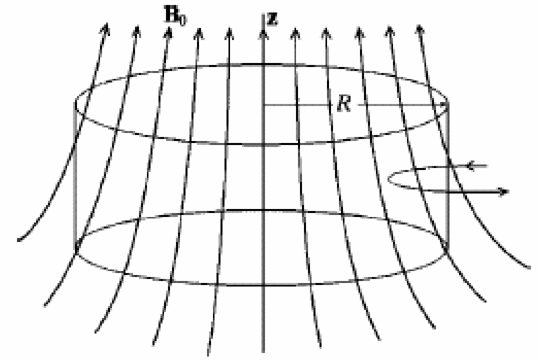
False EDM Signals

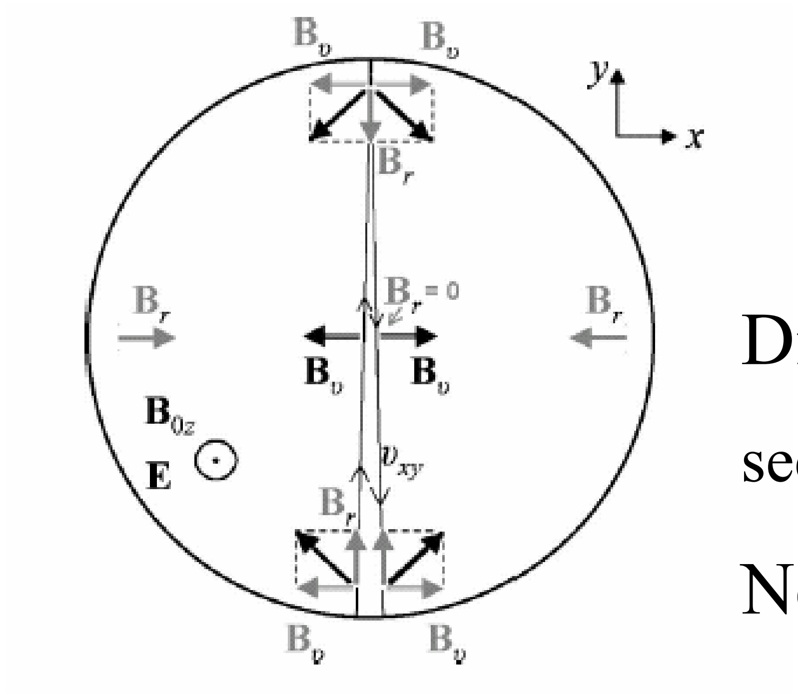
$$\frac{\partial B}{\partial z} \Rightarrow B_r \propto r$$

from div**B** = 0



$$\mathbf{B}' = \frac{1}{\gamma}\frac{\mathbf{v}\times\mathbf{E}}{c^2}$$

from spec. rel.

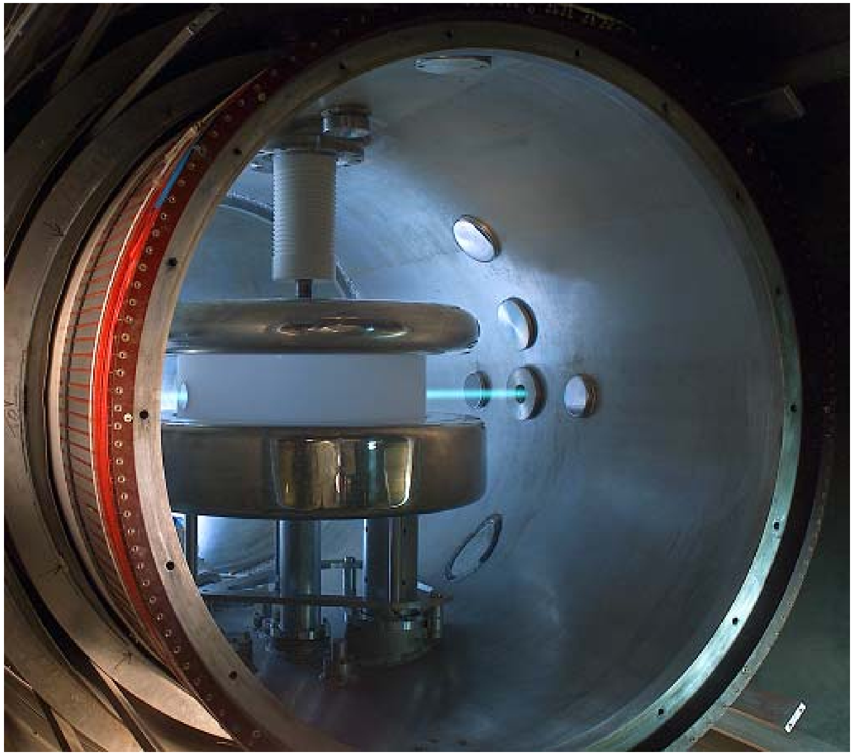


Different for ^{199}Hg and neutrons

see: Phys. Rev. A 70, 032102 (2004)

Need for precise magnetometry

Room Temperature Results



Room temperature neutron EDM result:

C.A. Baker et al., Phys. Rev. Lett. **97,** 131801 (2006) or hep-ex/0602020

$$|d_n| < 2.9\times10^{-26}\ \text{e.cm (90\% C.L.)}$$

CryoEDM – the new generation

University of Sussex

NEUTRONS FOR SCIENCE

Science & Technology Facilities Council

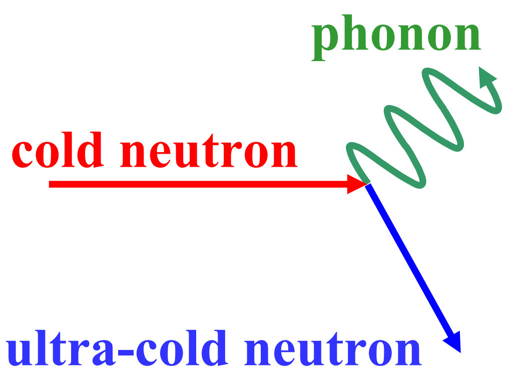
呉大学 KURE UNIVERSITY

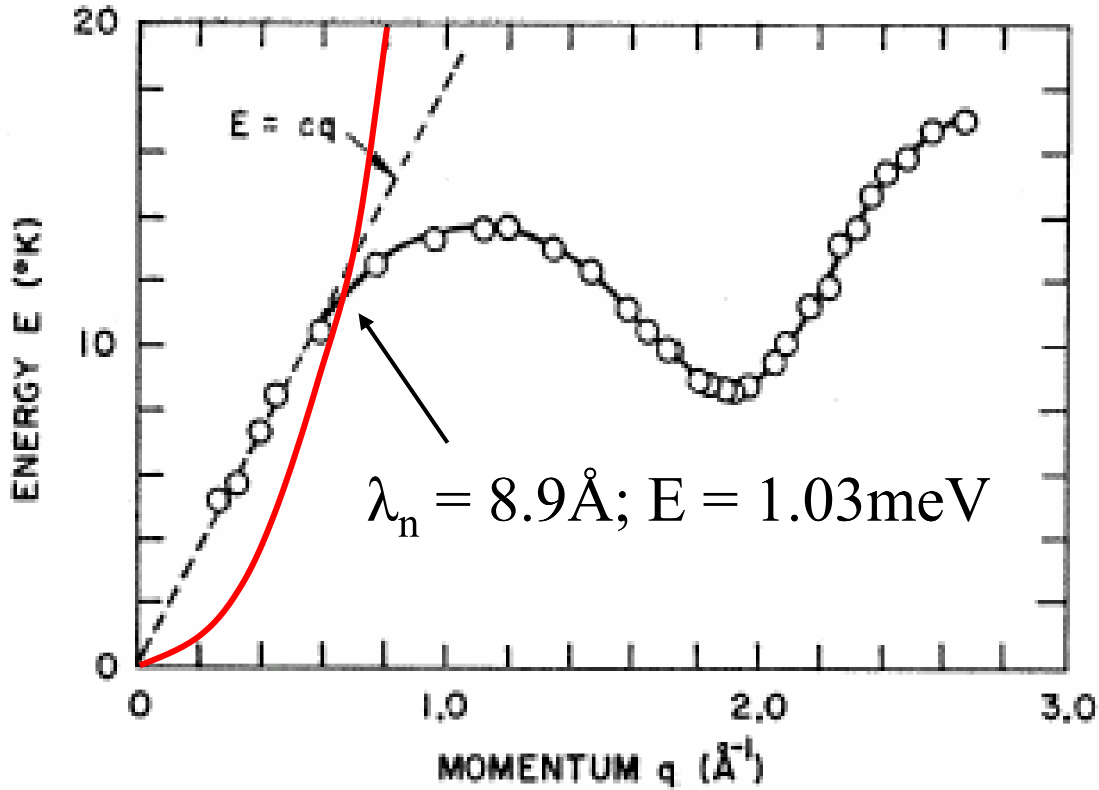
New technology:

- More neutrons
- Higher E field
- Better polarisation
- Longer NMR coherence time

100-fold improvement in sensitivity

Ultra-cold Neutron Production

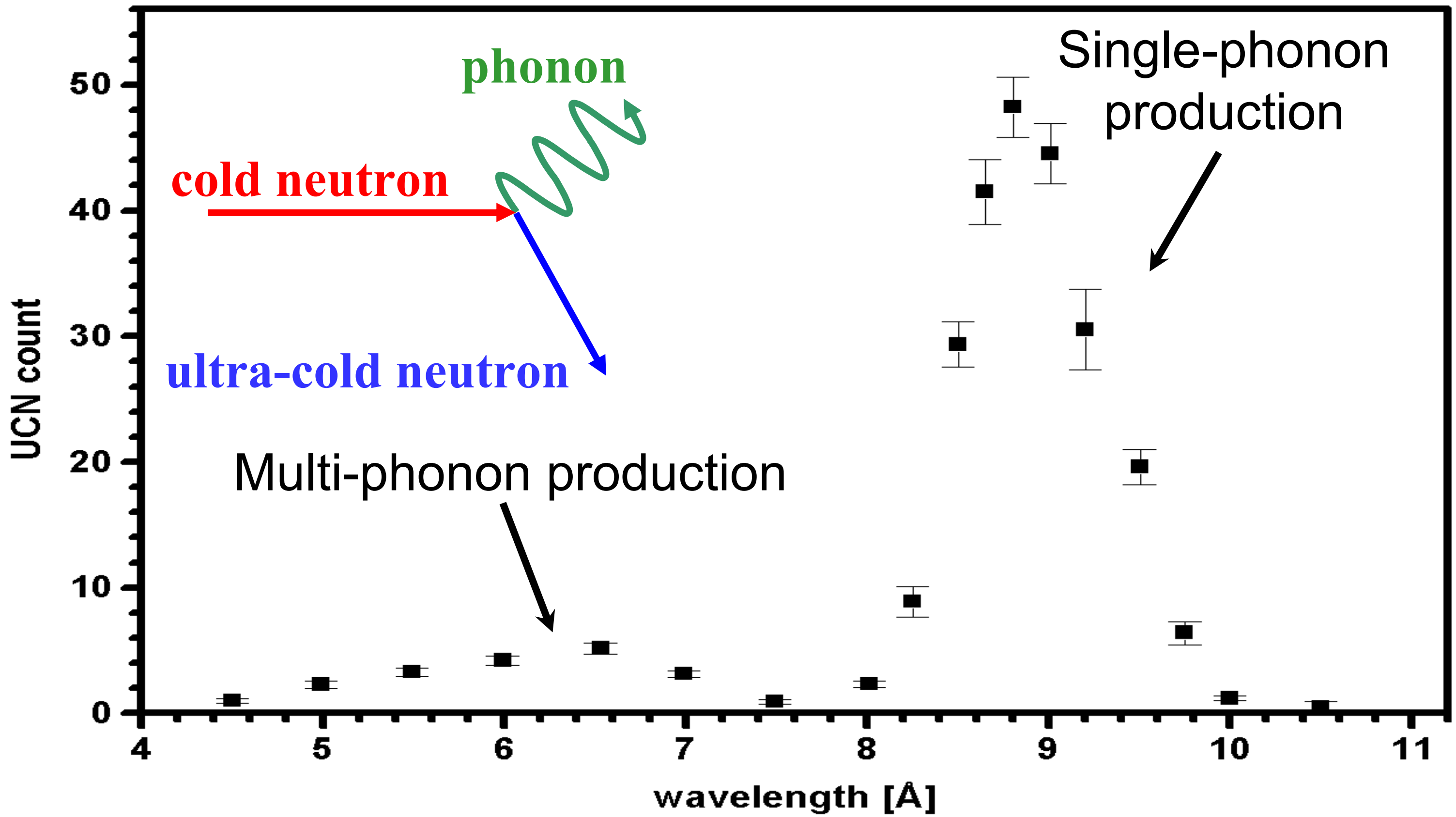




1.03 meV (11K) neutrons down-scatter by emission of phonons in superfluid helium at 0.5K

Up-scattering suppressed: hardly any 11K phonons

Ultra-cold Neutron Production



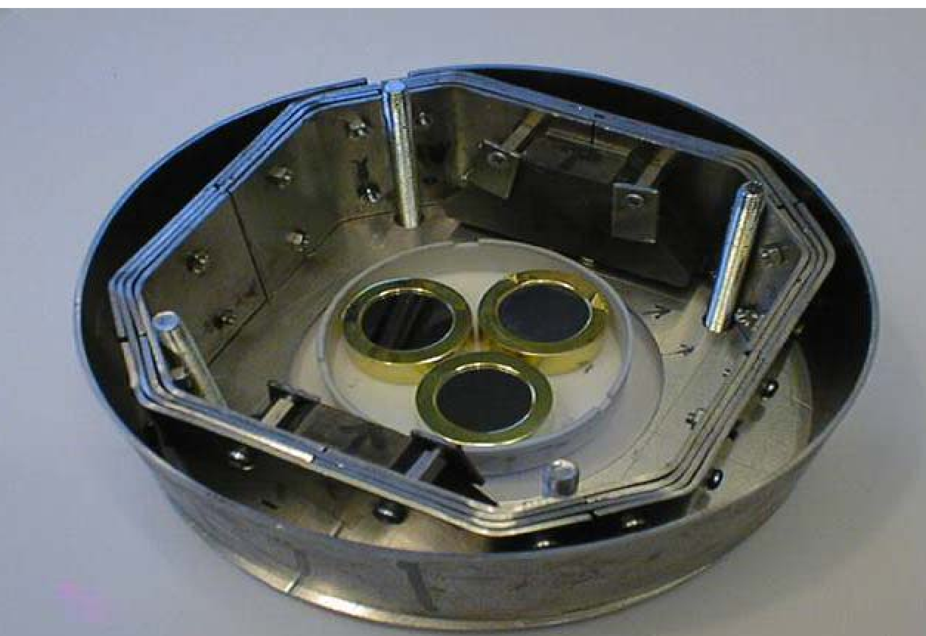
1.19 ± 0.18 UCN cm^{-3} s^{-1} expected

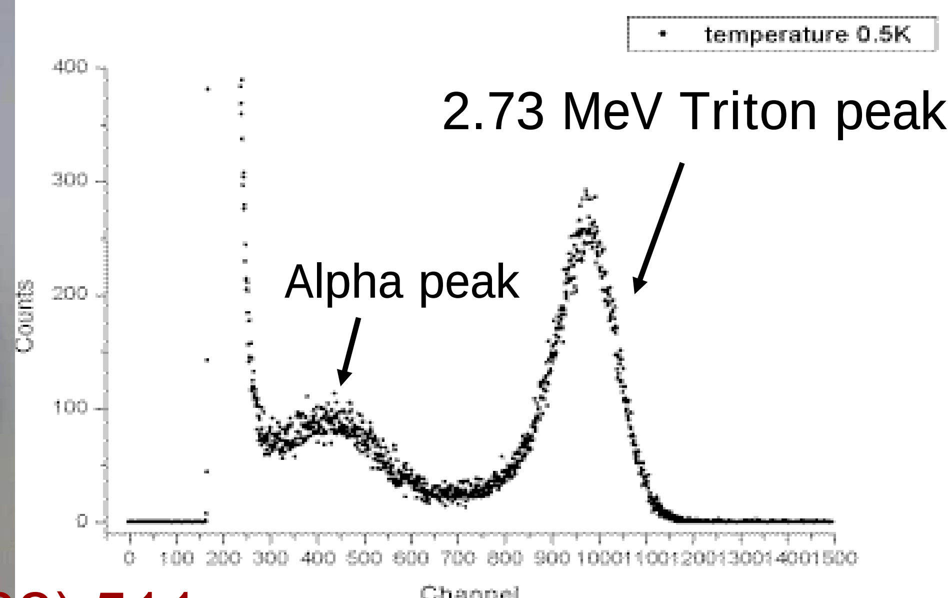
0.91 ± 0.13 UCN cm^{-3} s^{-1} observed

C A Baker et al., Phys. Lett. **A 308** (2002) 67

Ultra-cold Neutron Detection

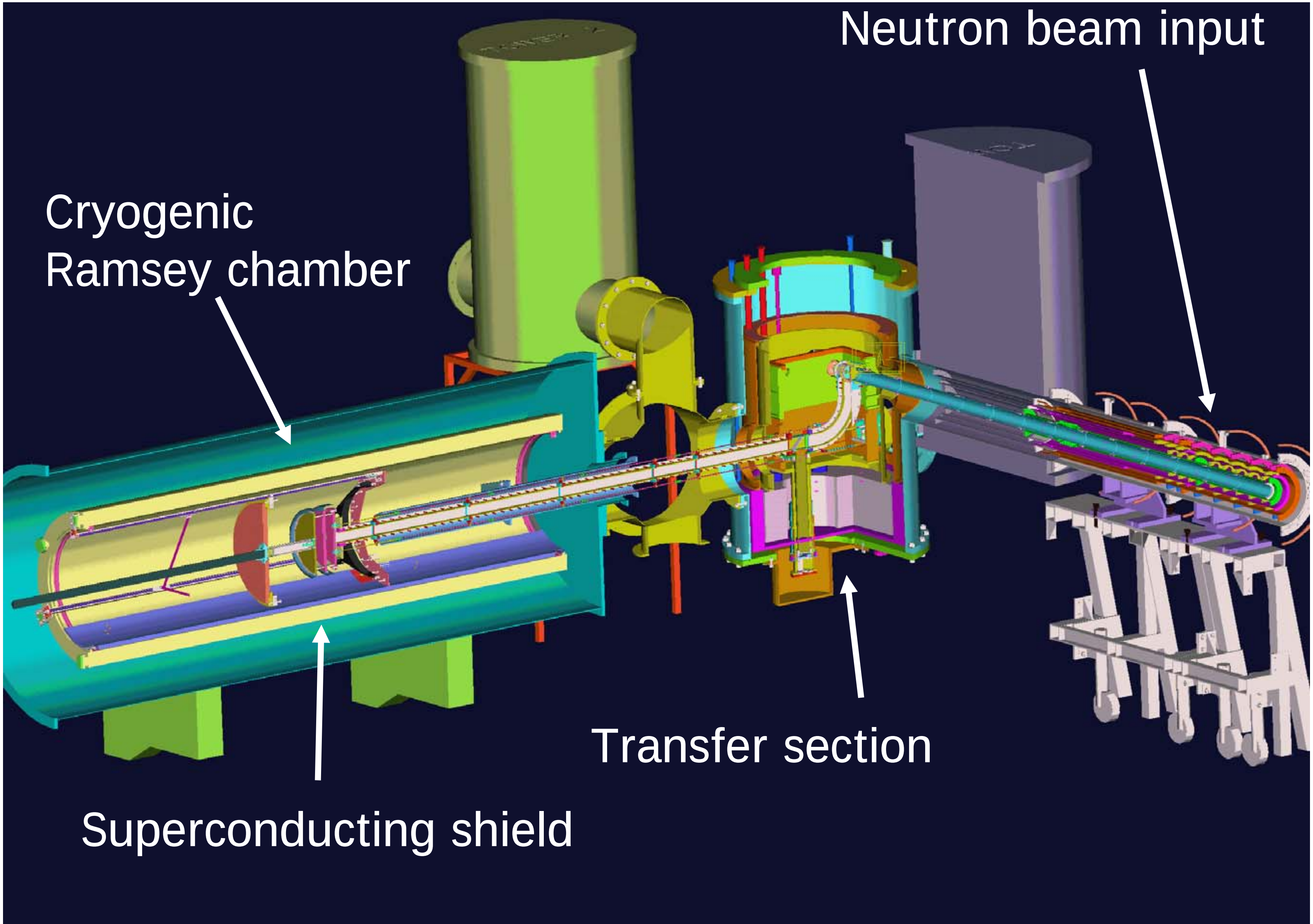
- ORTEC ULTRA at 430mK temperature.
- Equipped with thin surface layer of ^{6}Li.
- Using: $n + {}^{6}Li \rightarrow \alpha + {}^{3}H$



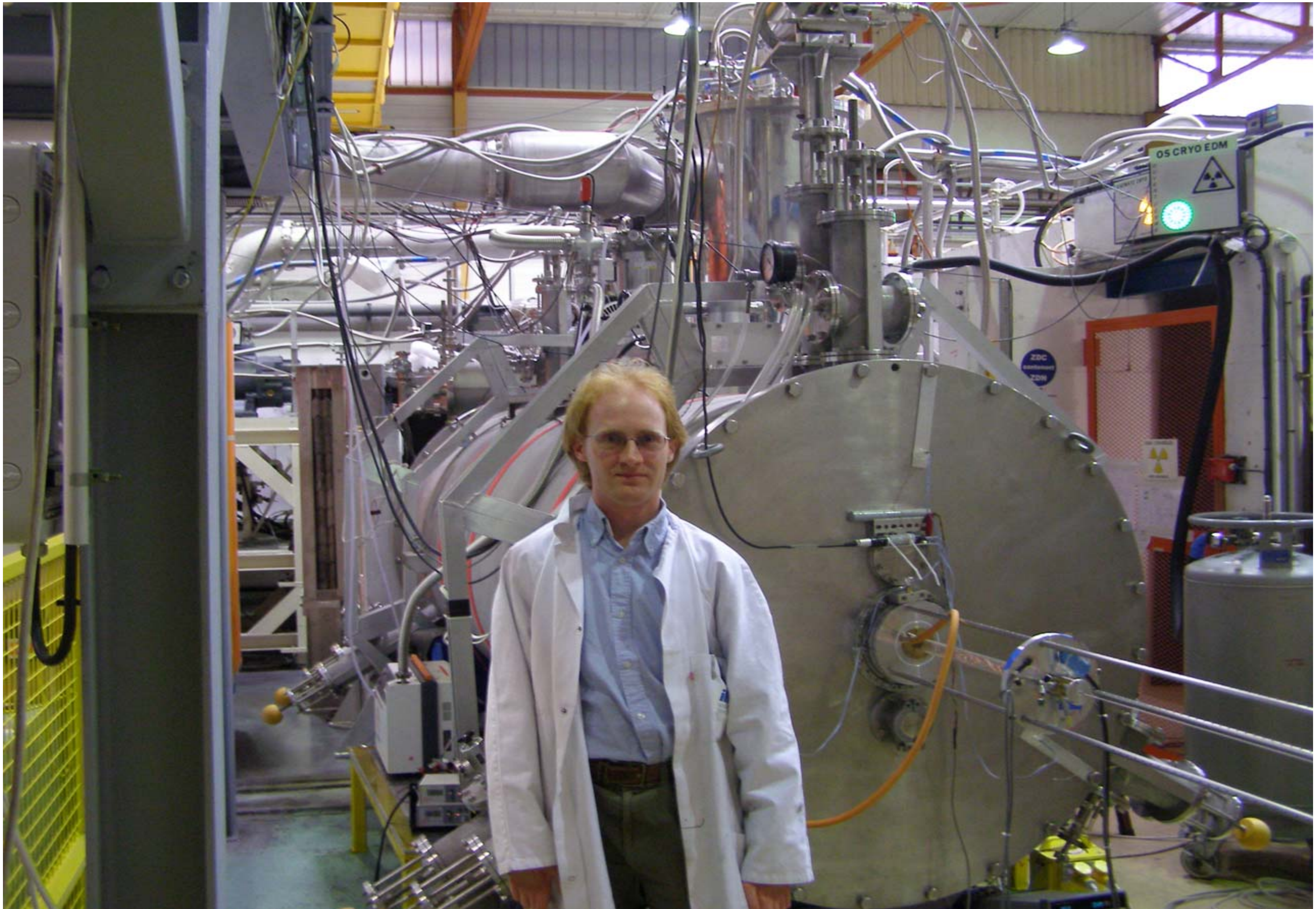


C.A.Baker *et al.*, NIM **A487** (2002) 511

The Cryogenic Setup



Superconducting Shield



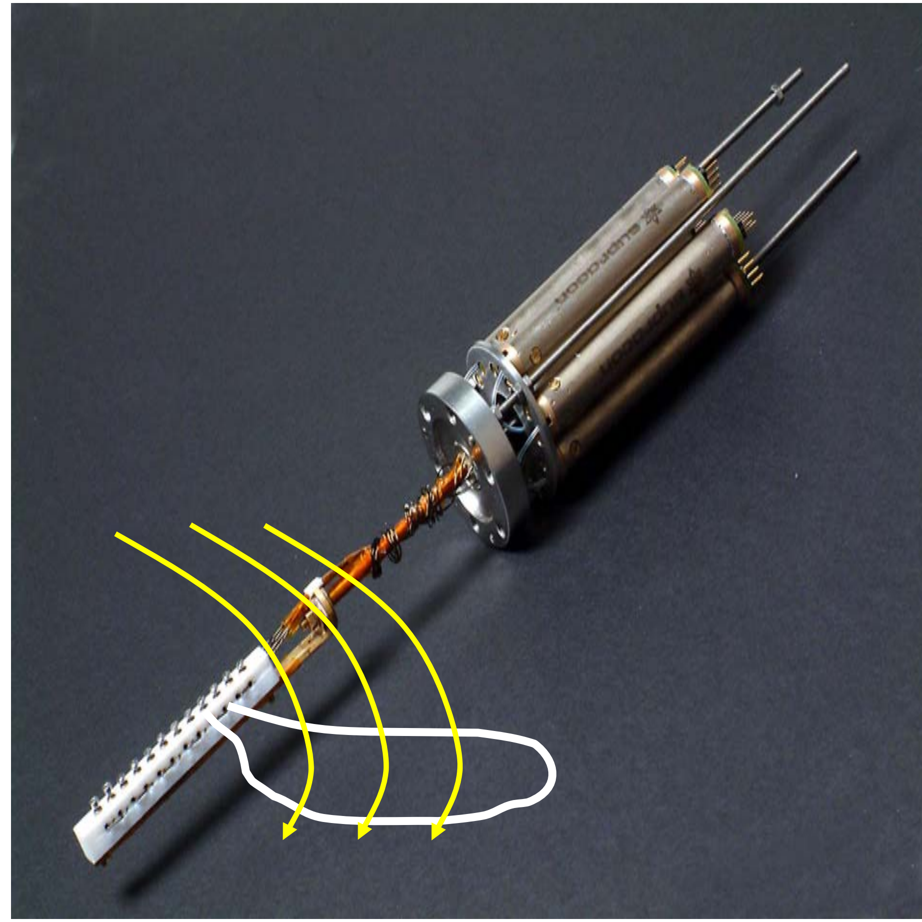
Improvements on Statistics

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

Parameter	RT Expt	Sensitivity
• Polarisation+detection	α = 0.75	x 1.2
• Electric field:	E = 10^6 V/m	x 4
• Precession period:	T = 130 s	x 2
• Neutrons counted:	N = 6 x 10^6 /day	x 4.5
(with new beamline)		x 2.6

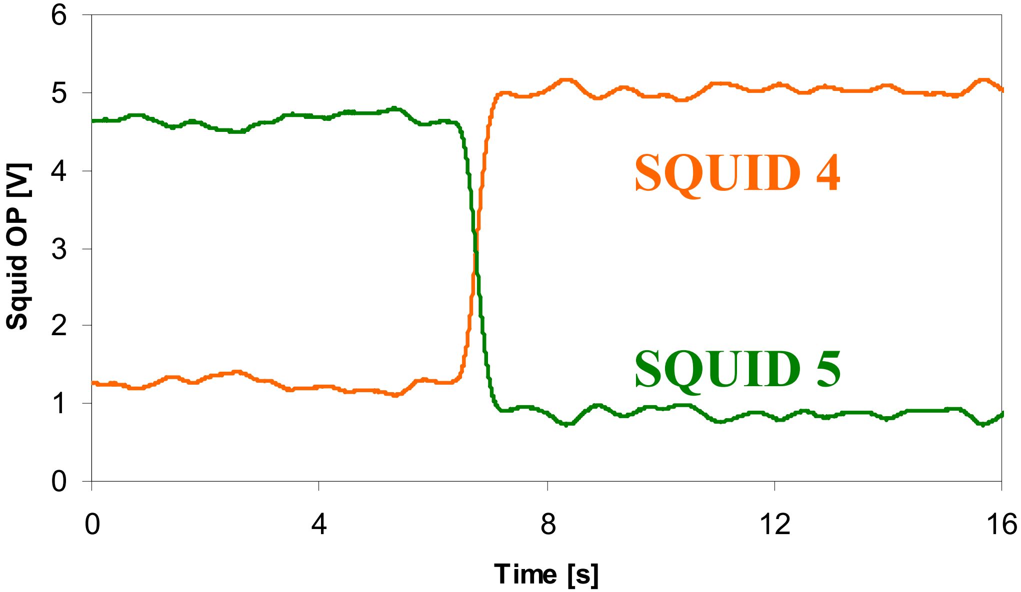
Total improvement: appr. x 100

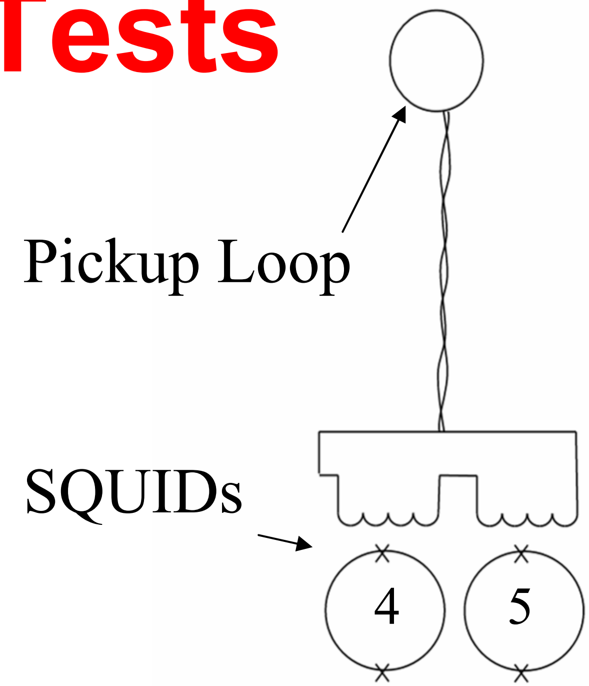
SQUIDS from CRESST

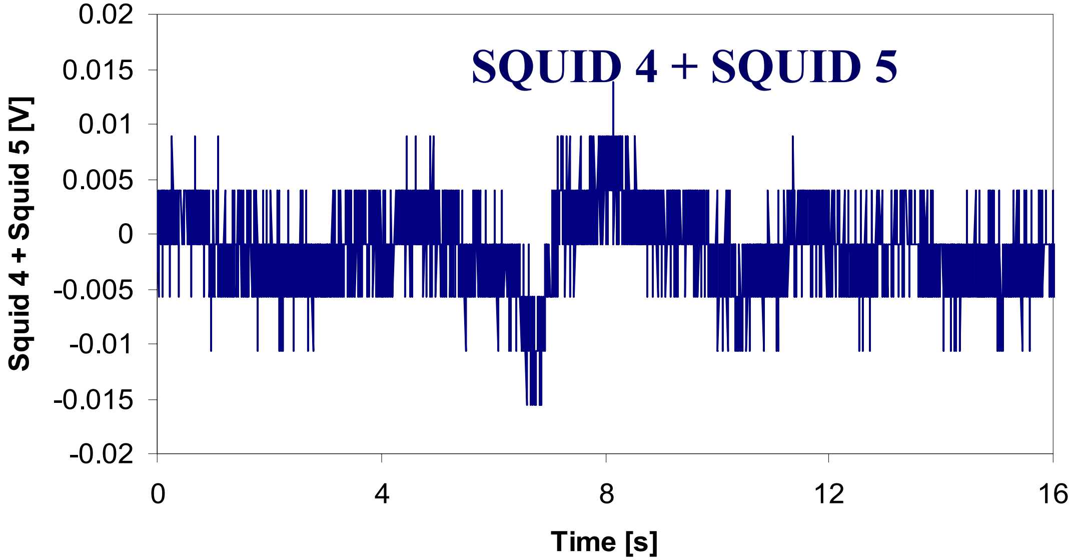


SQUIDs for Magnetometry

Magnetometry Tests

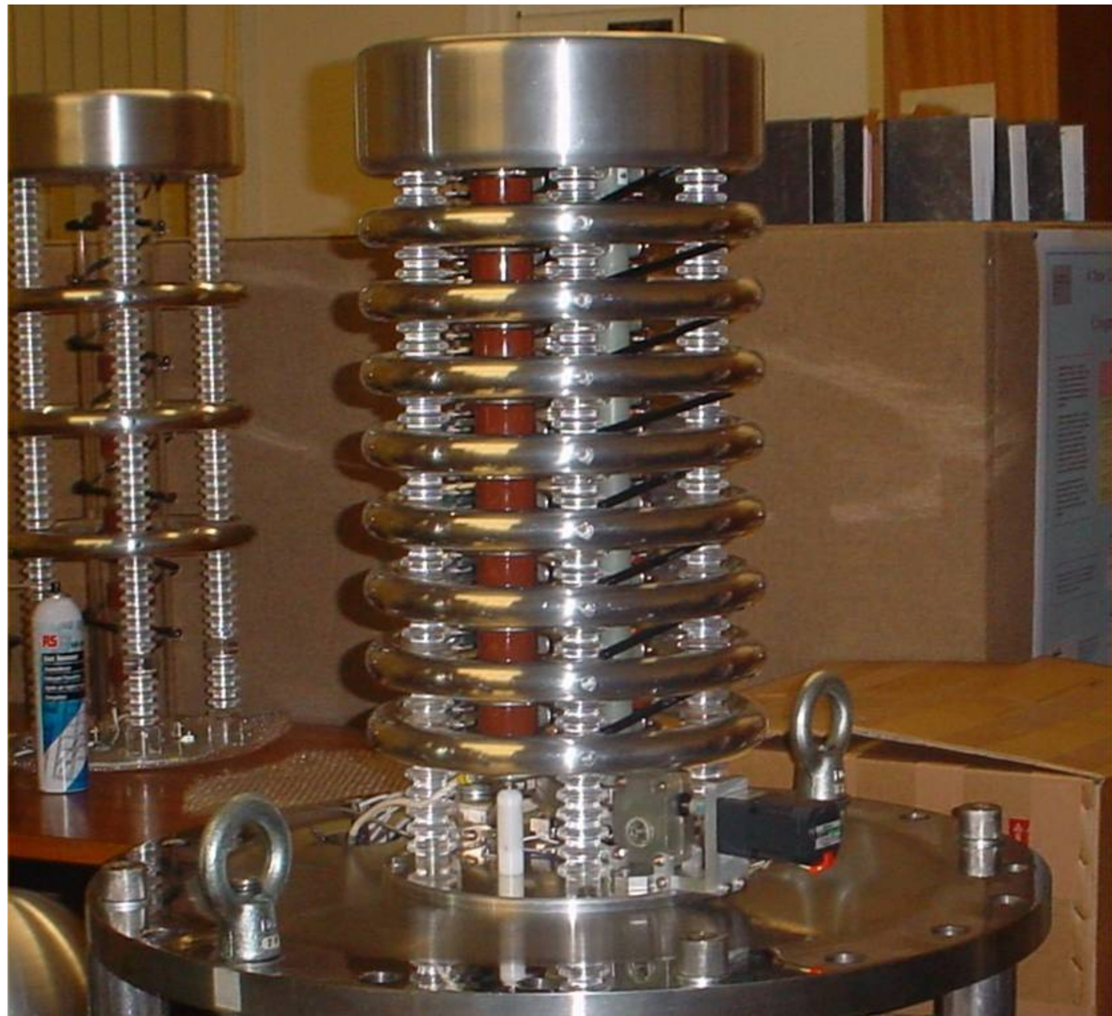






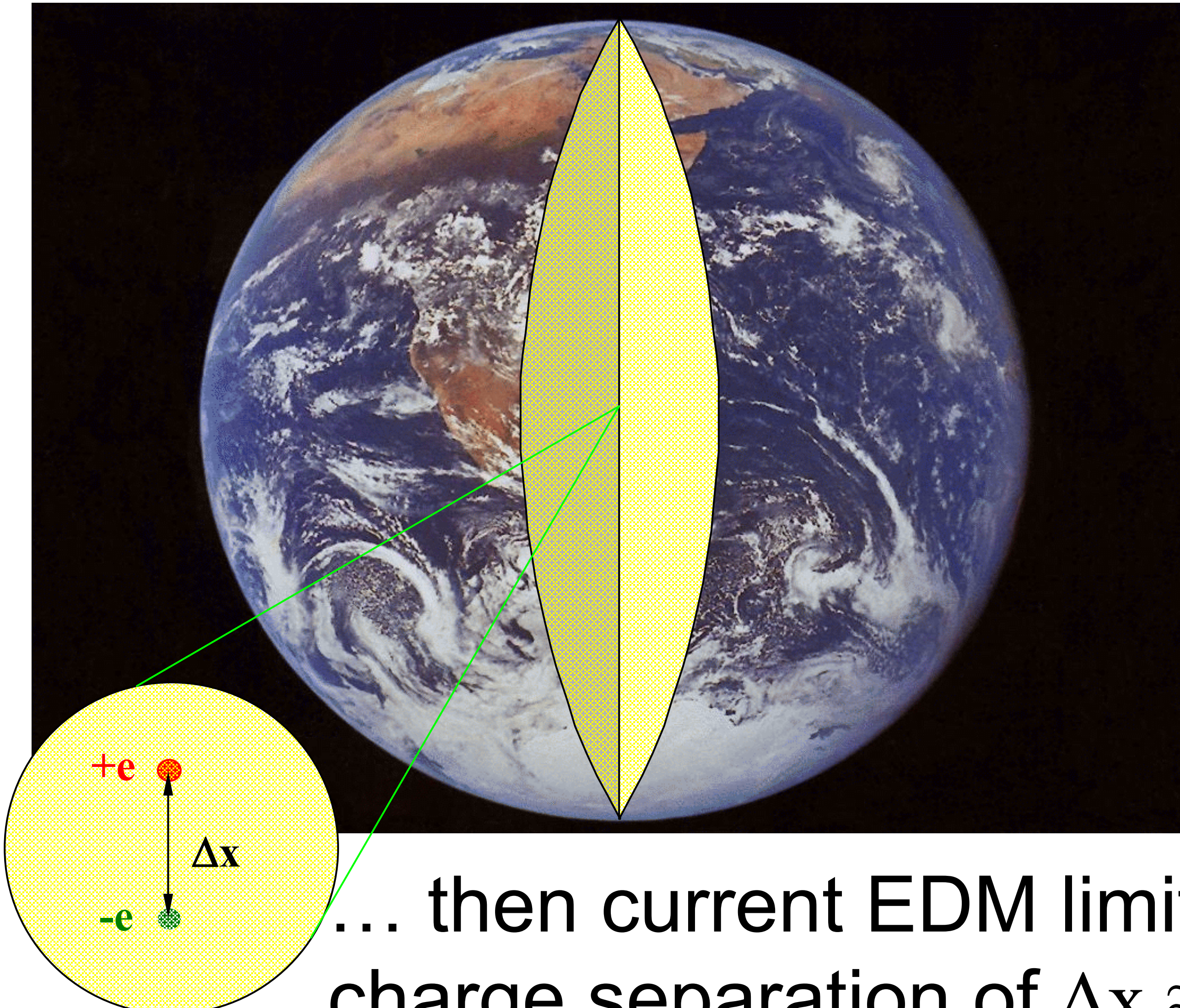
Resolution 0.16 pT (1.6nG) @ 1Hz

Ramsey Cell and HV Stack



Reality Check

If neutrons were the size of the Earth …



… then current EDM limit means charge separation of $\Delta x \approx 1.5\mu m$

Summary

- After half a century, no sign of an EDM …
- SUSY being squeezed. Ever-tighter limits continue to constrain physics beyond SM.
- Room-temperature experiment finished.
- CryoEDM: under way with aim of ~100 improvement in sensitivity.