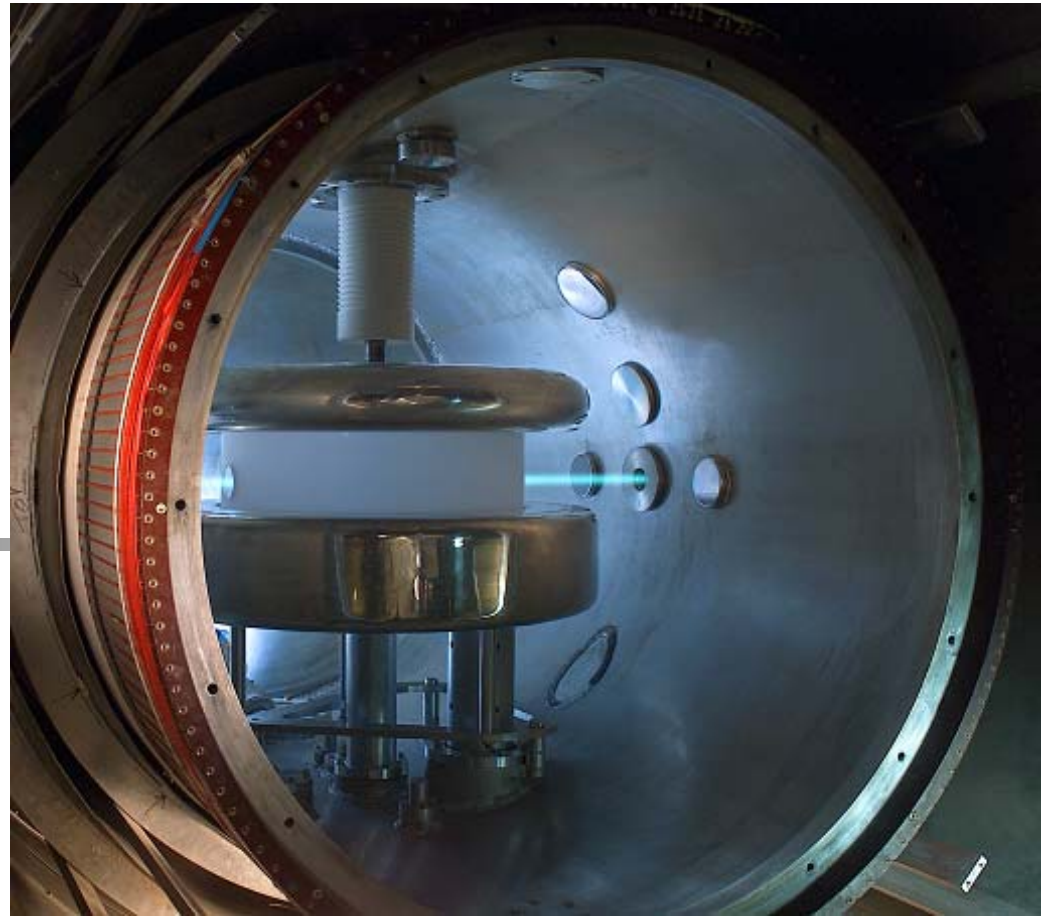
Electric-Dipole Moment * Searches

*(mainly neutron)

Philip Harris

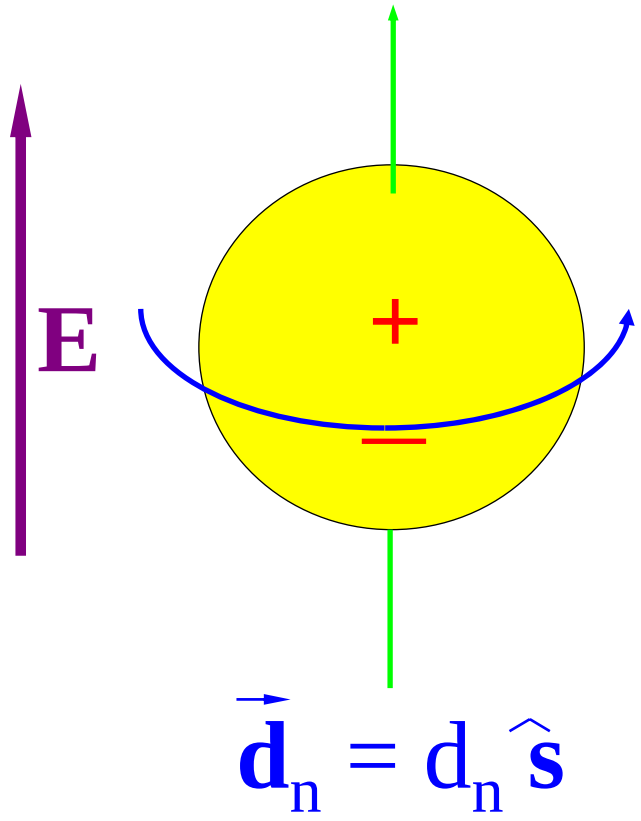
University of Sussex



- Room-temperature nEDM expt: latest results
- CryoEDM: upcoming, 100x sensitivity
- Other EDM expts

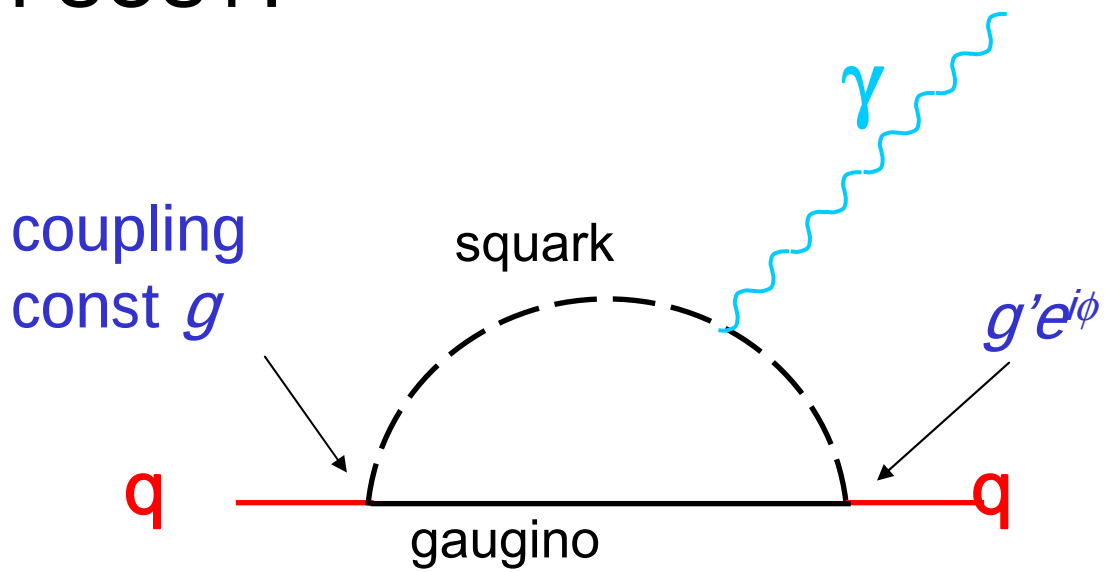
Electric Dipole Moments

- EDMs are
  - P odd
  - T odd
- Complementary approach to study of CPv; probe new physics
- SM predictions v. small; other models typ. 10^6 larger...



Generating EDMs

E.g. in SUSY:



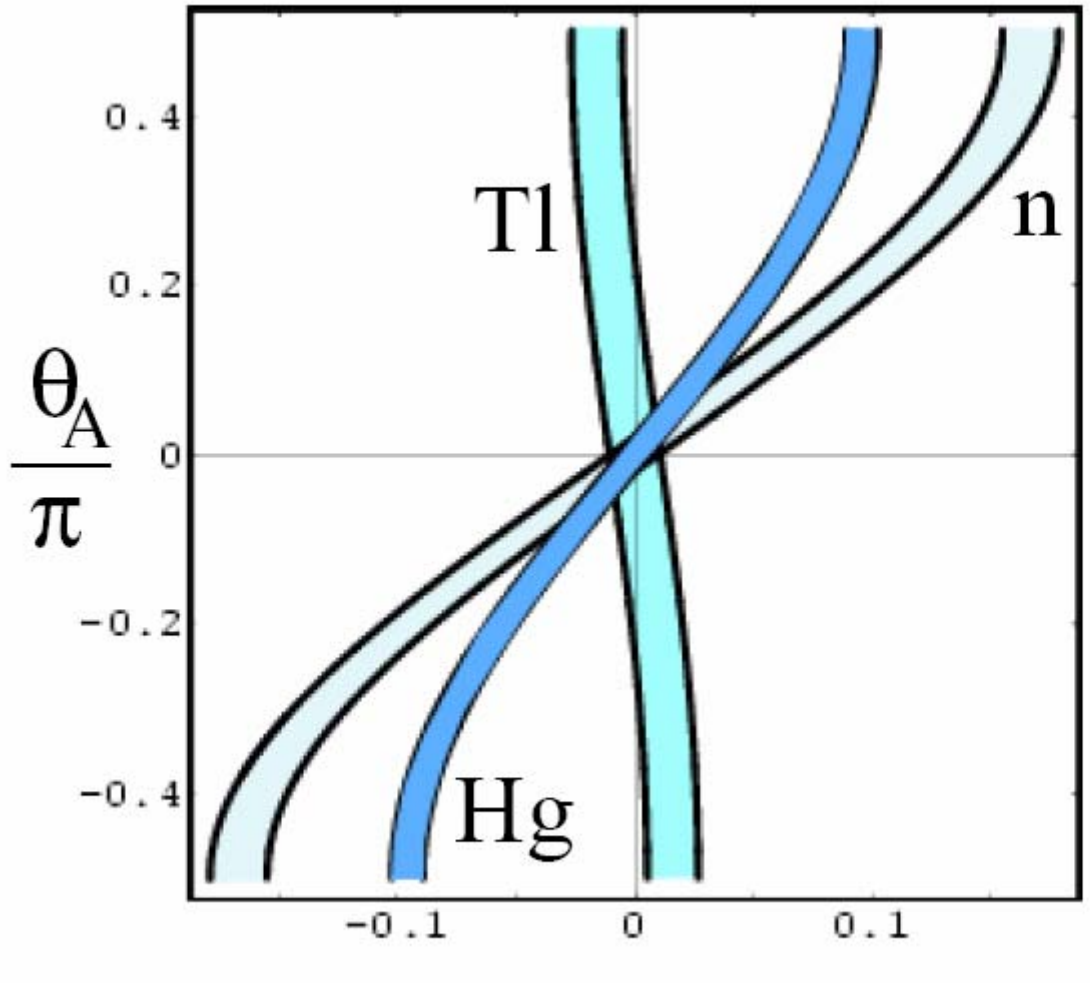
Assumptions: $gg' \approx \alpha$, $\sin(\phi) \approx 1$, $\Lambda \approx 200$ GeV

Gives *u, d* quark EDMs $\approx 3 \times 10^{-24}$ *e*cm

≈100 x current limit

"SUSY CP" problem

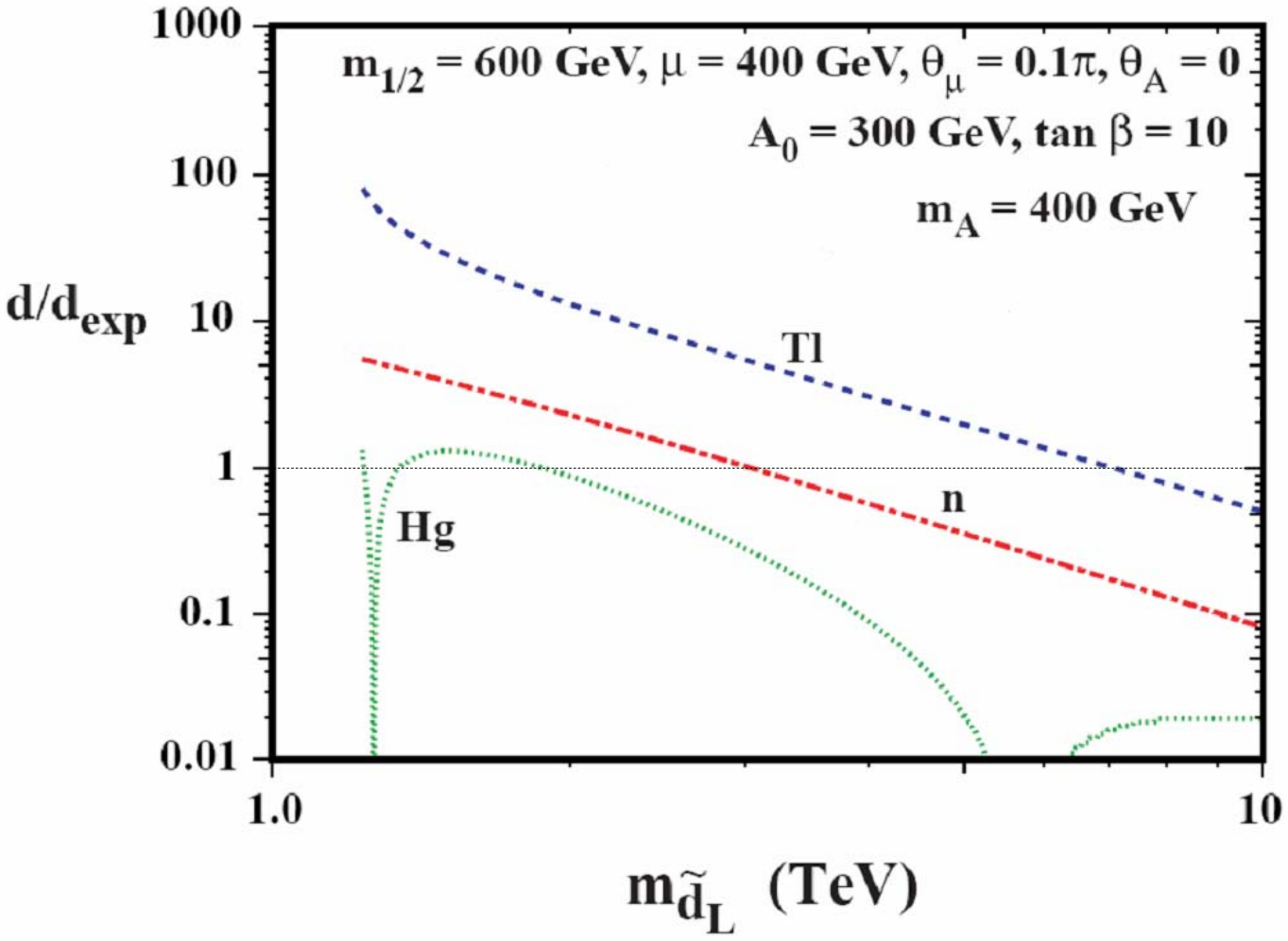
Constraints on SUSY parameters



M_{SUSY} = 500 GeV
tan β = 3

Pospelov & Ritz, hep-ph/0504231

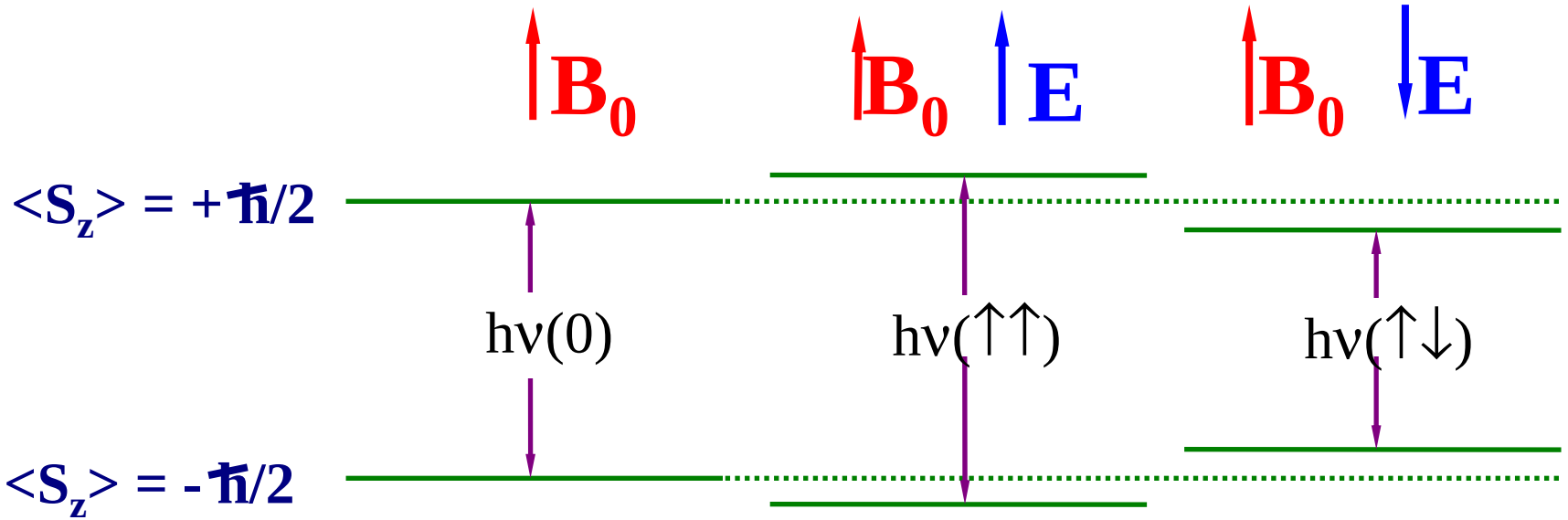
SUSY, cont'd



Lebedev et al., hep-ph/0402023

Measurement principle

Use (Ramsey) NMR on ultracold neutrons in **B, E** fields

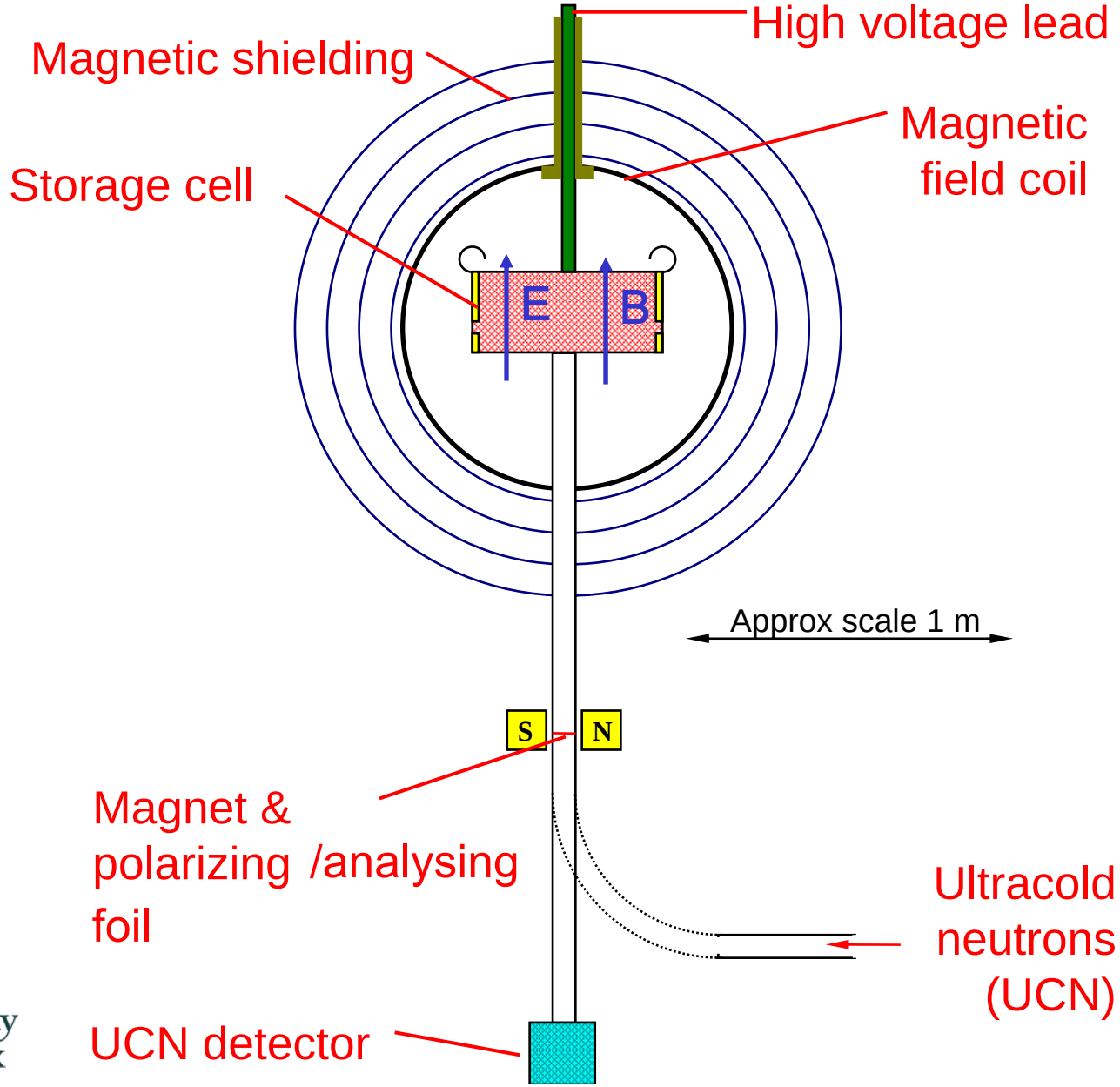


$$\nu(\uparrow\uparrow) - \nu(\uparrow\downarrow) = -4\,E\,d/\,h$$

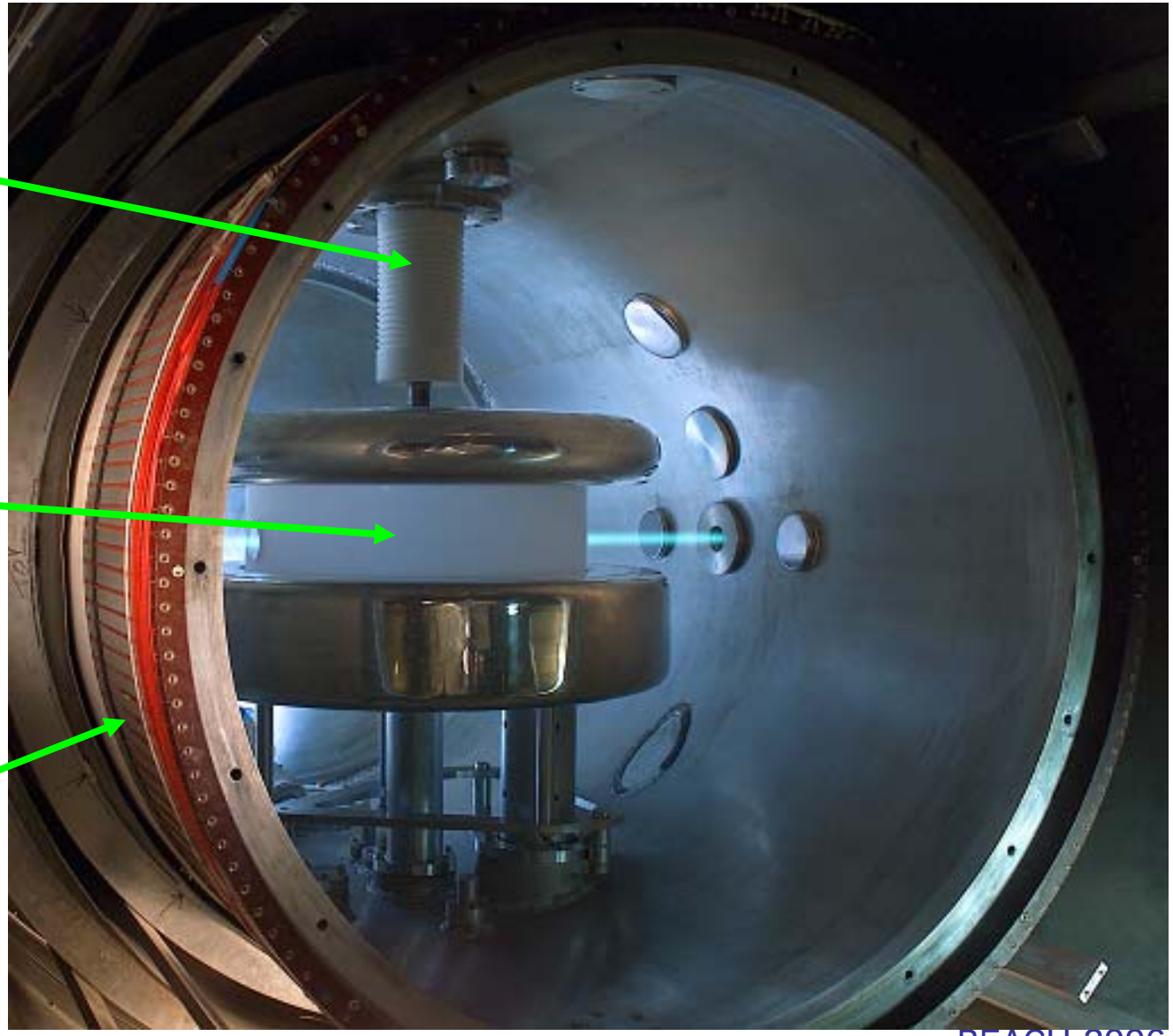
assuming **B** unchanged when **E** is reversed.

Level splitting we can resolve: $<10^{-21}$ eV

Apparatus


High voltage lead
Magnetic shielding
Magnetic field coil
Storage cell
E
B
Approx scale 1 m
S
N
Magnet & polarizing /analysing foil
Ultracold neutrons (UCN)
UCN detector

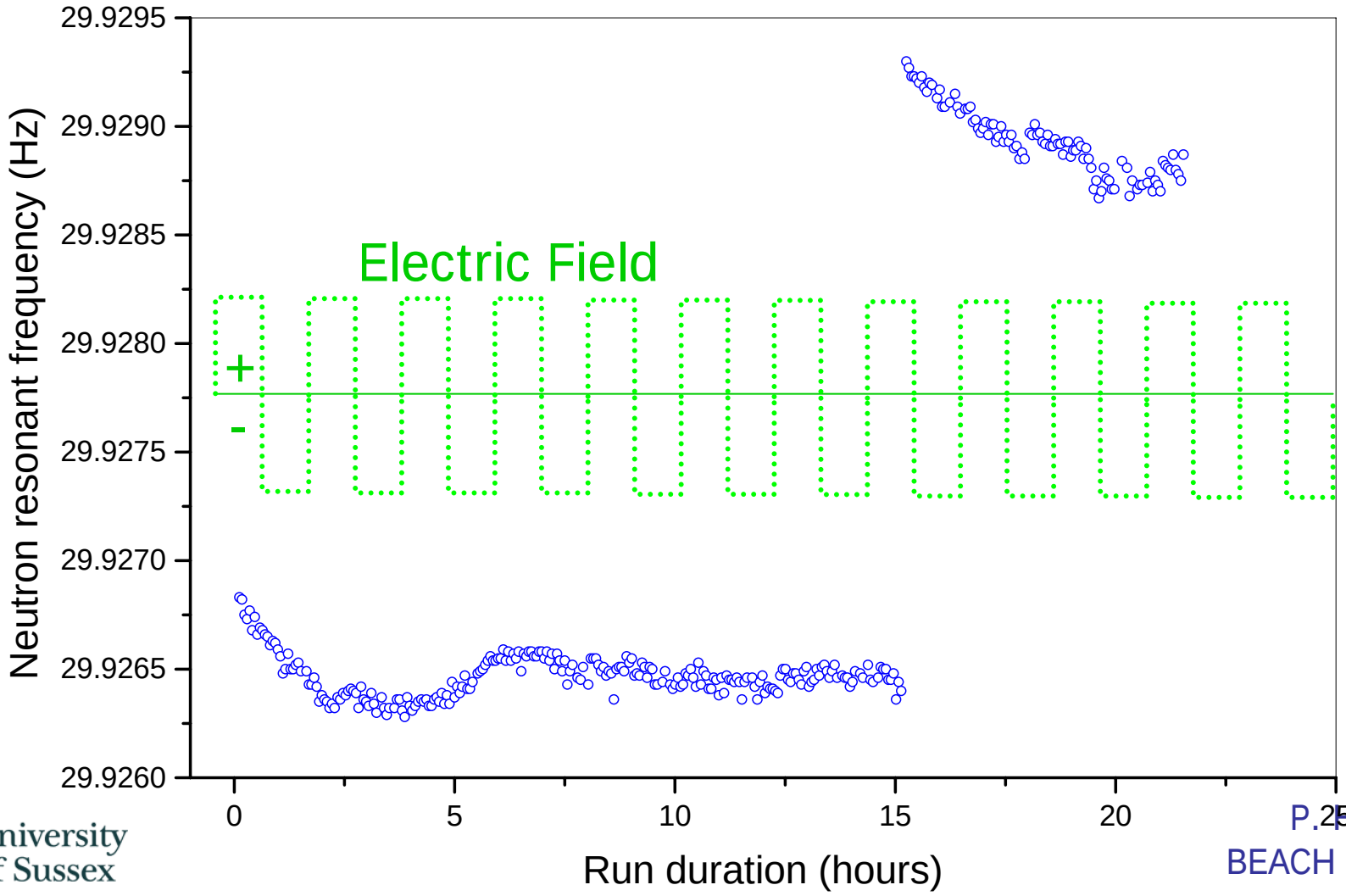
Apparatus



nEDM measurement

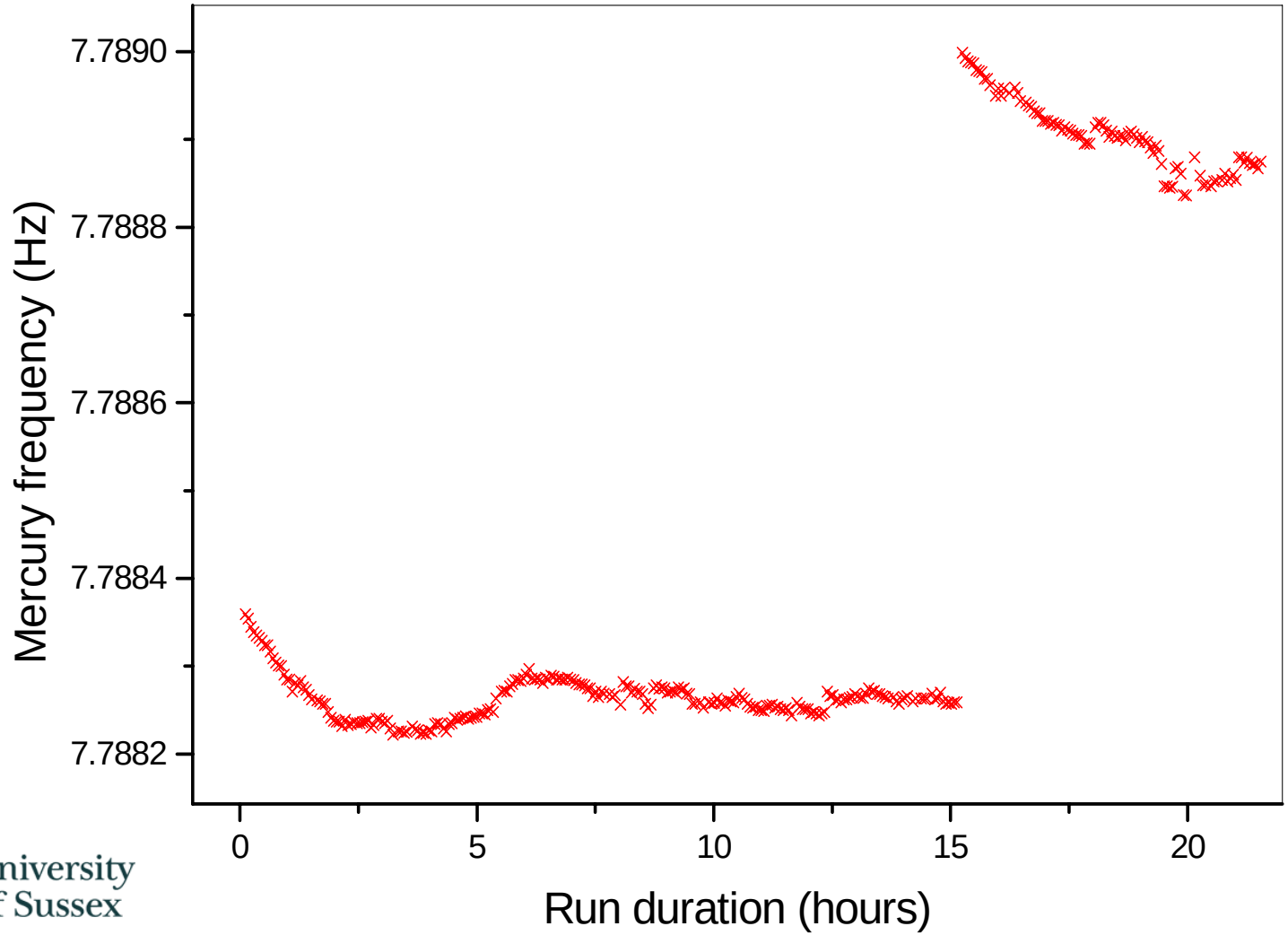
$$d_n \propto \frac{\Delta\nu}{\Delta E}$$

- Keep track of neutron resonant frequency
- Look for n freq changes correlated with changes in E



Mercury co-magnetometer

Compensates B drift...



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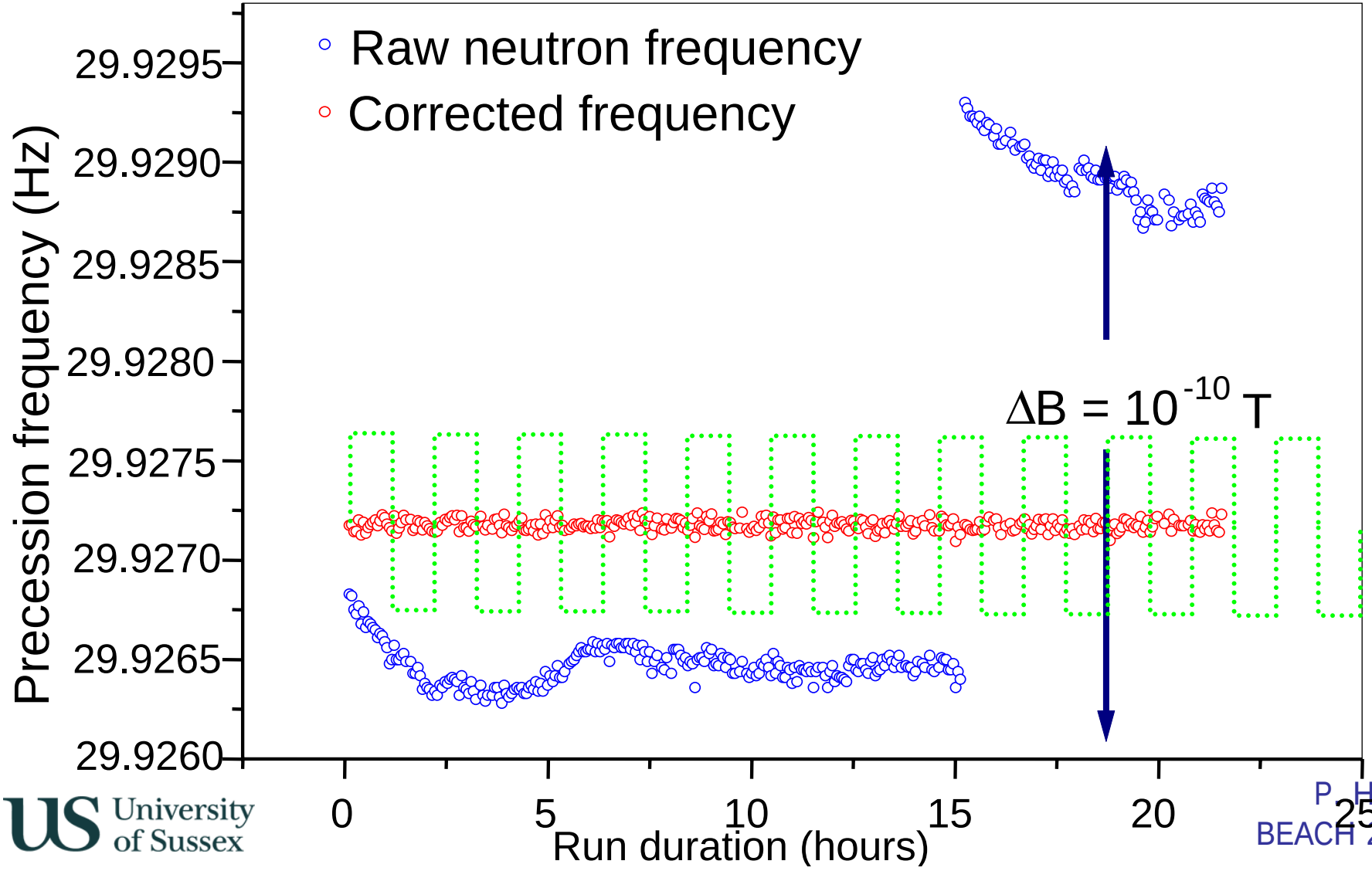
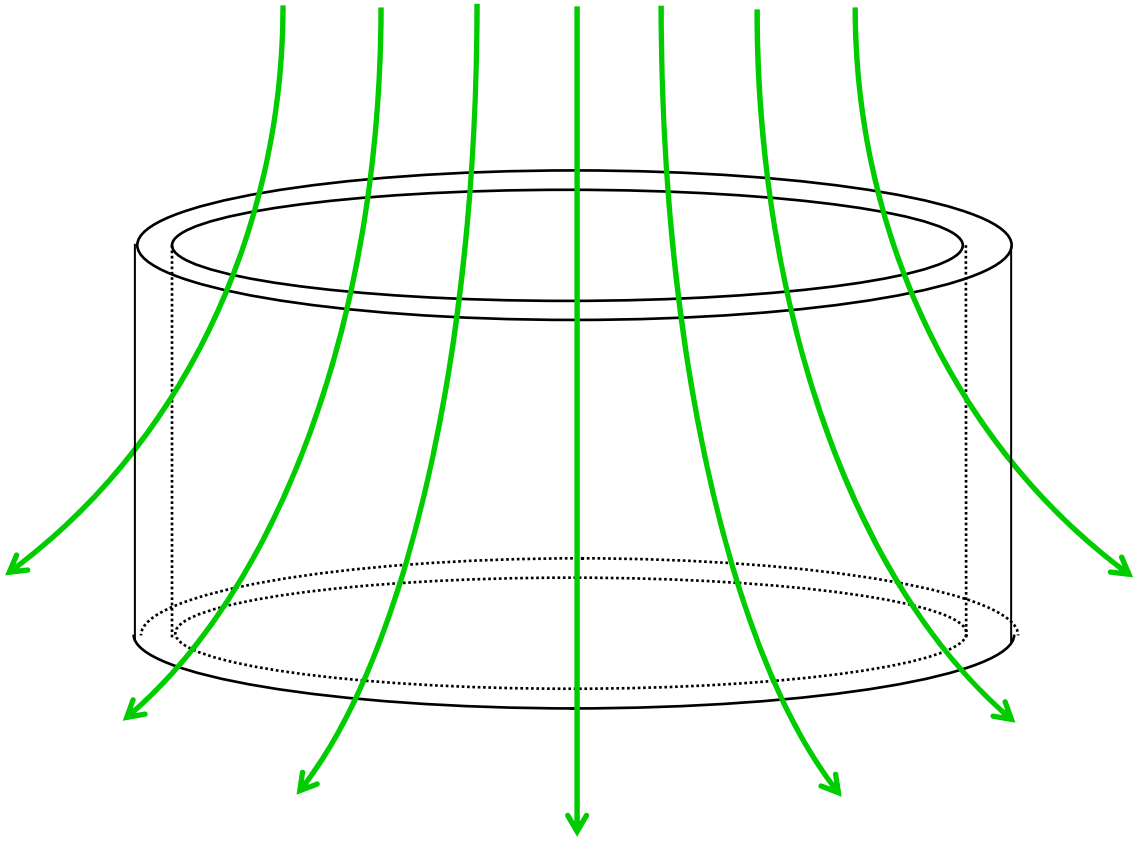
nEDM measurement



New systematic

Two effects:

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

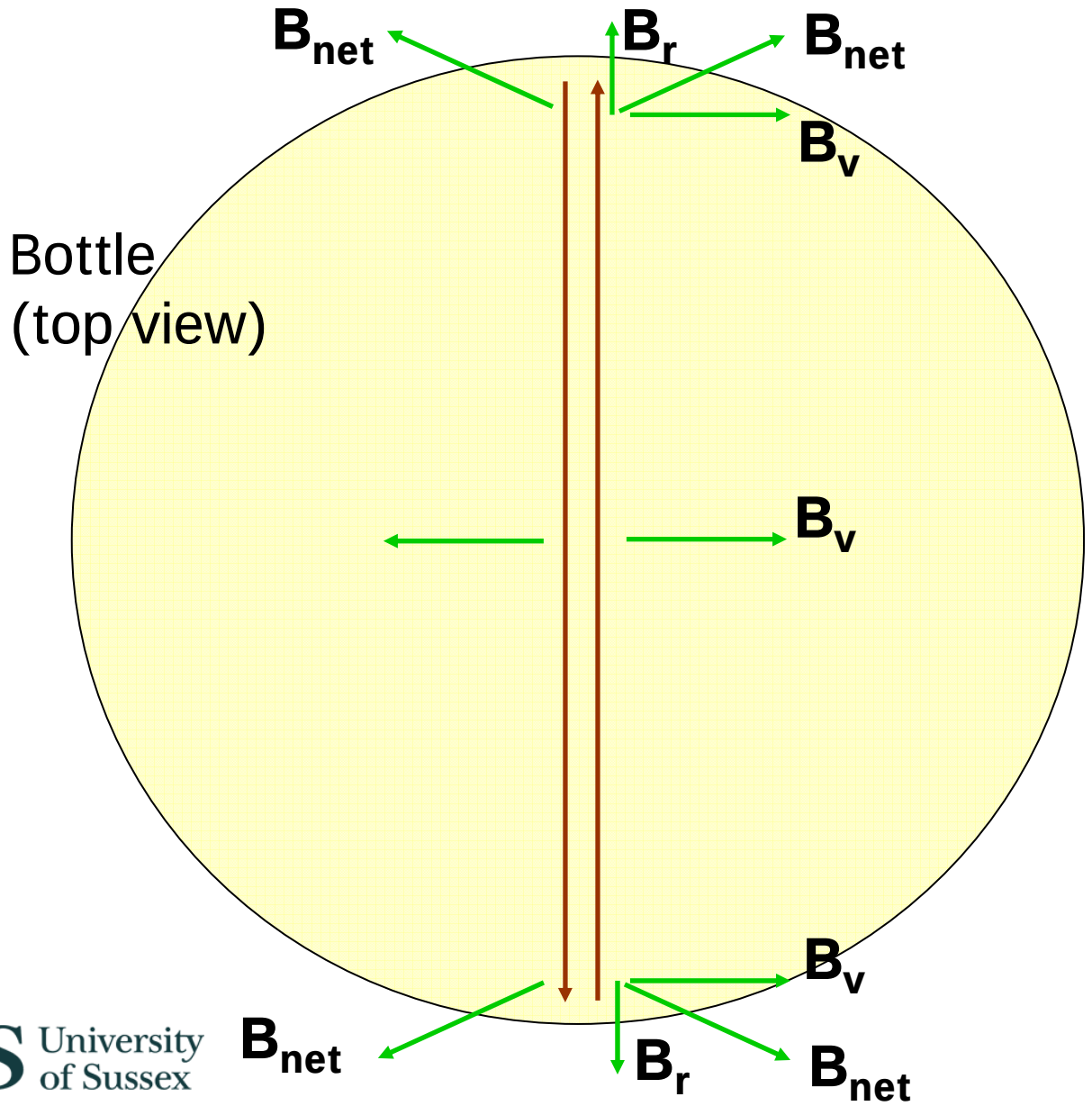


and, from Special Relativity, extra motion-induced field

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

Geometric Phase

J. Pendlebury et al., PRA 70 032102 (2004)
P. Harris, J. Pendlebury, PRA 73 014101 (2006)



... so particle sees additional rotating field

Frequency shift $\propto E$

Looks like an EDM

Unique signature: can eliminate it

Error budget (10^{-26} *e*.cm)

Effect	Shift	Uncertainty
Statistical	0	1.51
Door cavity dipole; quadrupole fields	-1.10	0.45
Other GP dipole shifts	0	0.60
(**E** x **v**)/c^2 from translation	0	0.05
(**E** x **v**)/c^2 from rotation	0	0.10
Light shift: direct & GP	0.35	0.08
B fluctuations	0	0.24
E forces – distortion of bottle	0	0.04
Tangential leakage currents	0	0.01
AC B fields from HV ripple	0	0.001
Hg atom EDM	0	0.05
2^{nd} order **Exv**	0	0.002
Total	–0.75	1.51 stat, 0.80 sys

Final Result

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CCLRC

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New limit:

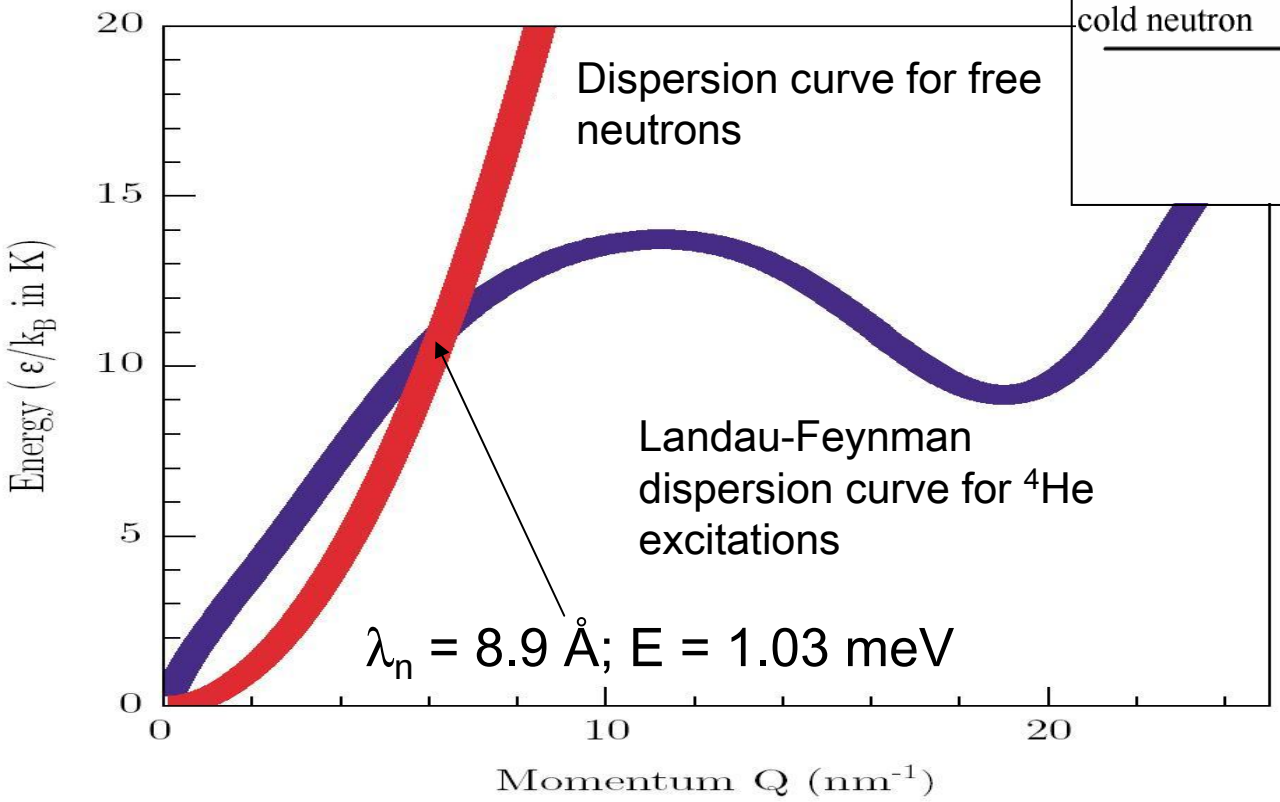
$|d_n| < 3.0 \times 10^{-26}$ e.cm (90% CL)

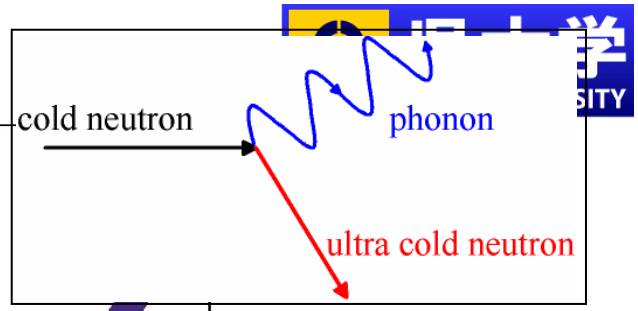
(prev. limit 6.3×10^{-26} e.cm, PRL 82, 904 (1999))

Preprint hep-ex/0602020
provisional acceptance PRL

www.neutronedm.org

2. CryoEDM



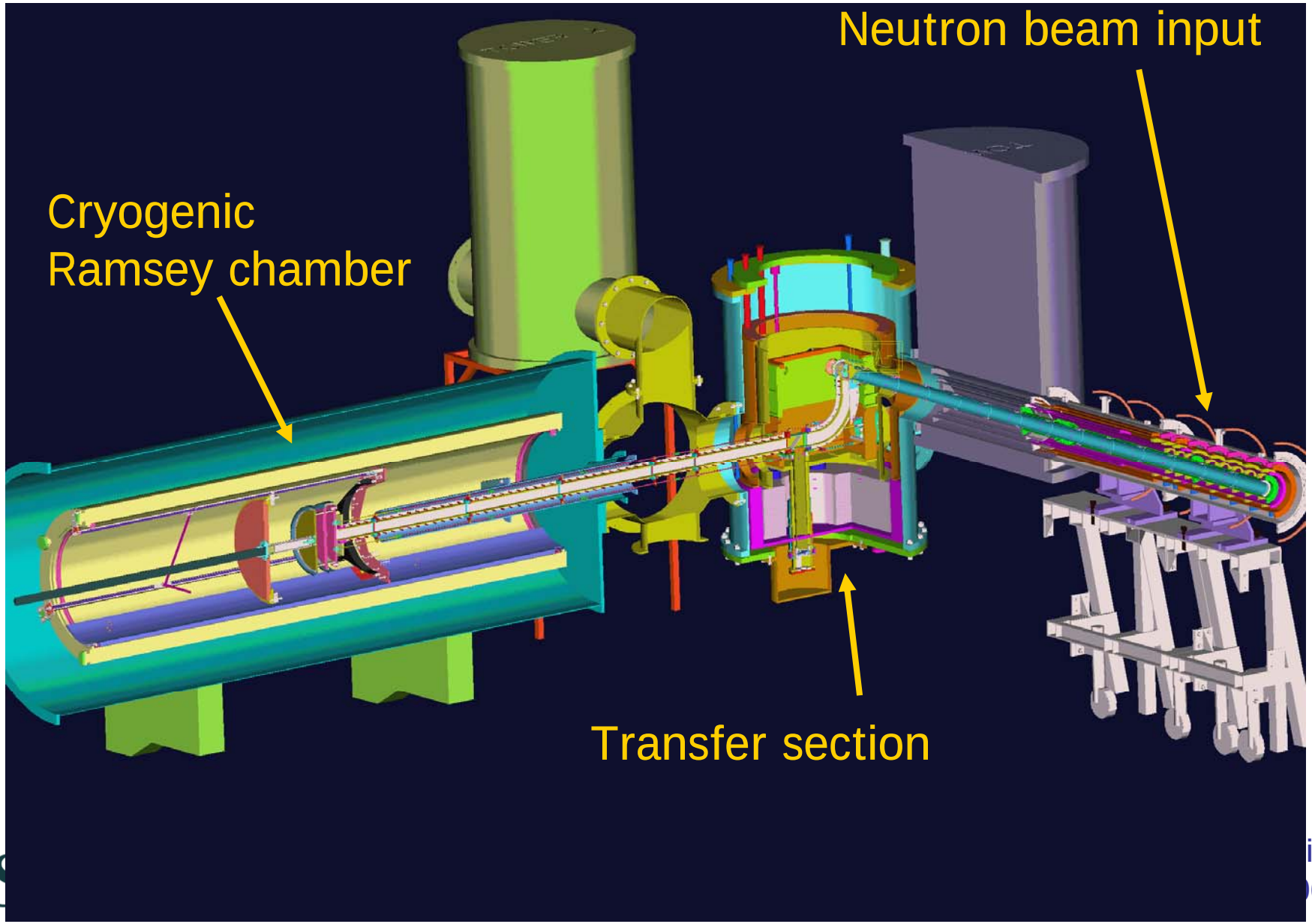


R. Golub and J.M. Pendlebury
Phys. Lett. **53A** (1975),
Phys. Lett. **62A** (1977)

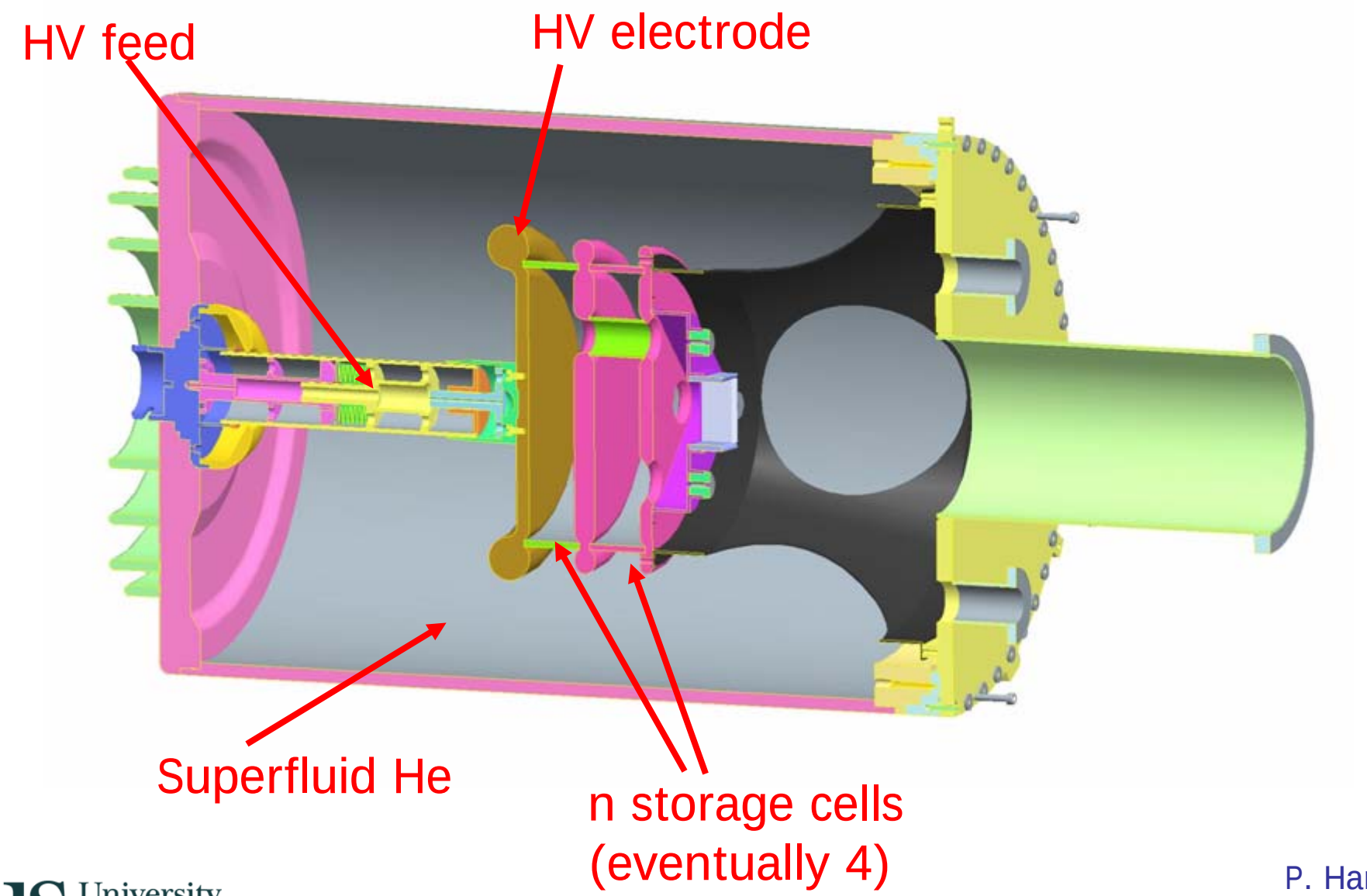
- More neutrons
- Higher E field
- Better polarisation
- Longer coherence time

100-fold improvement in sensitivity!

CryoEDM overview



Cryogenic Ramsey chamber



CryoEDM

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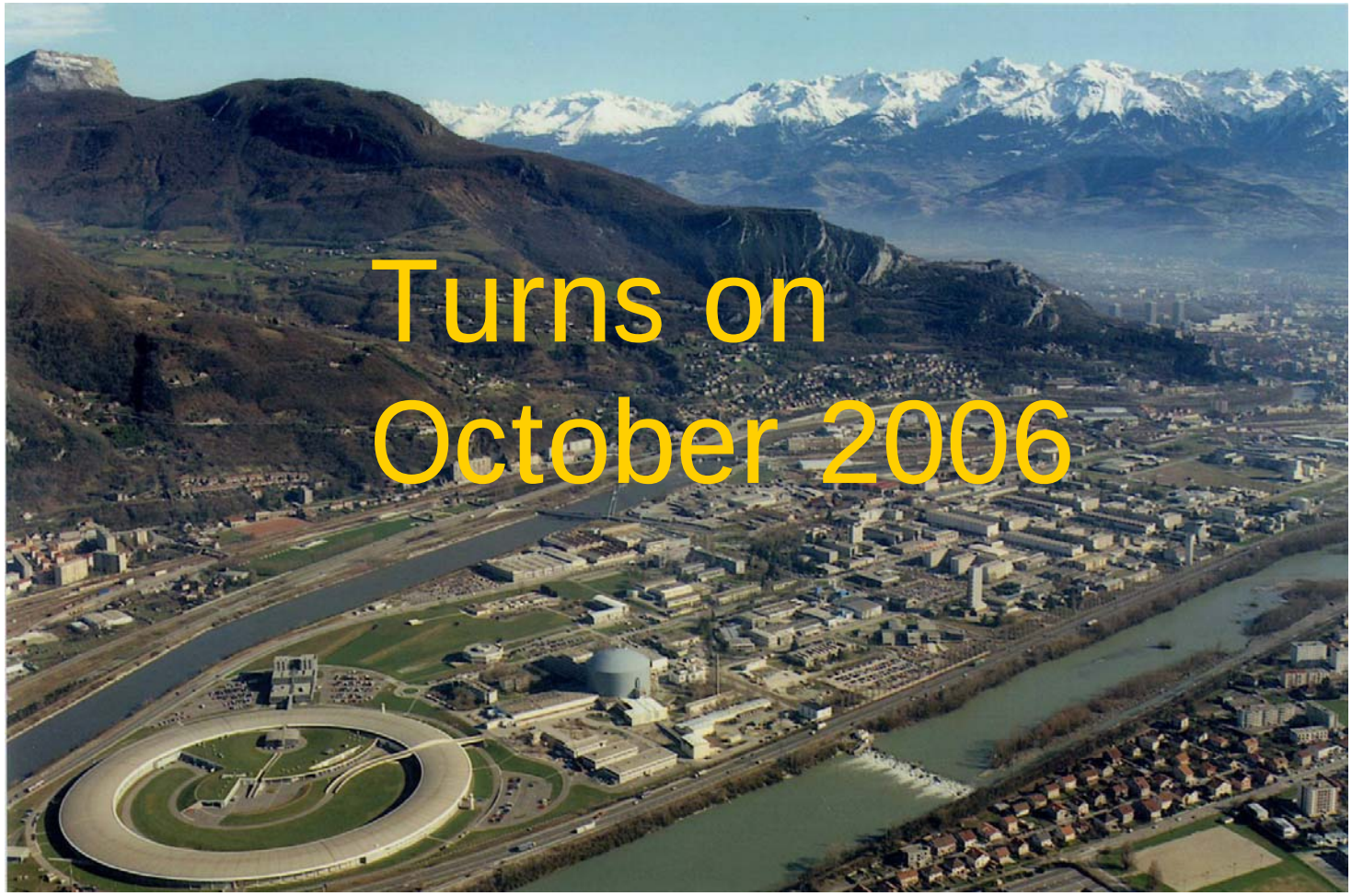
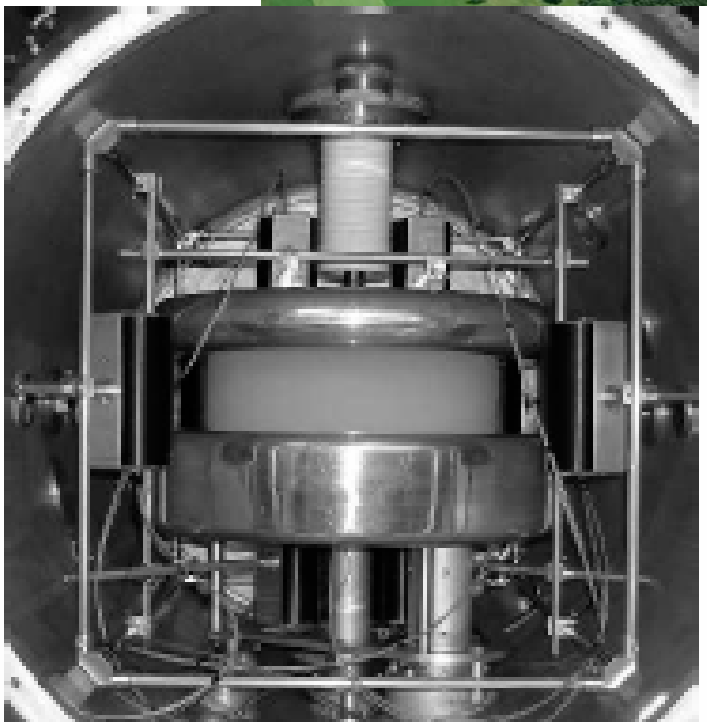
KURE UNIVERSITY



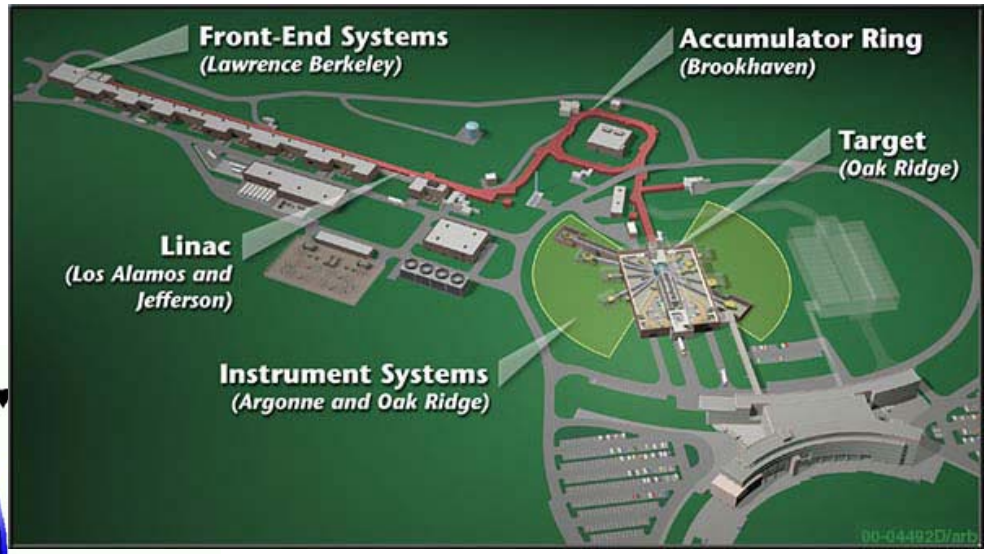
3. Other EDM experiments: PSI

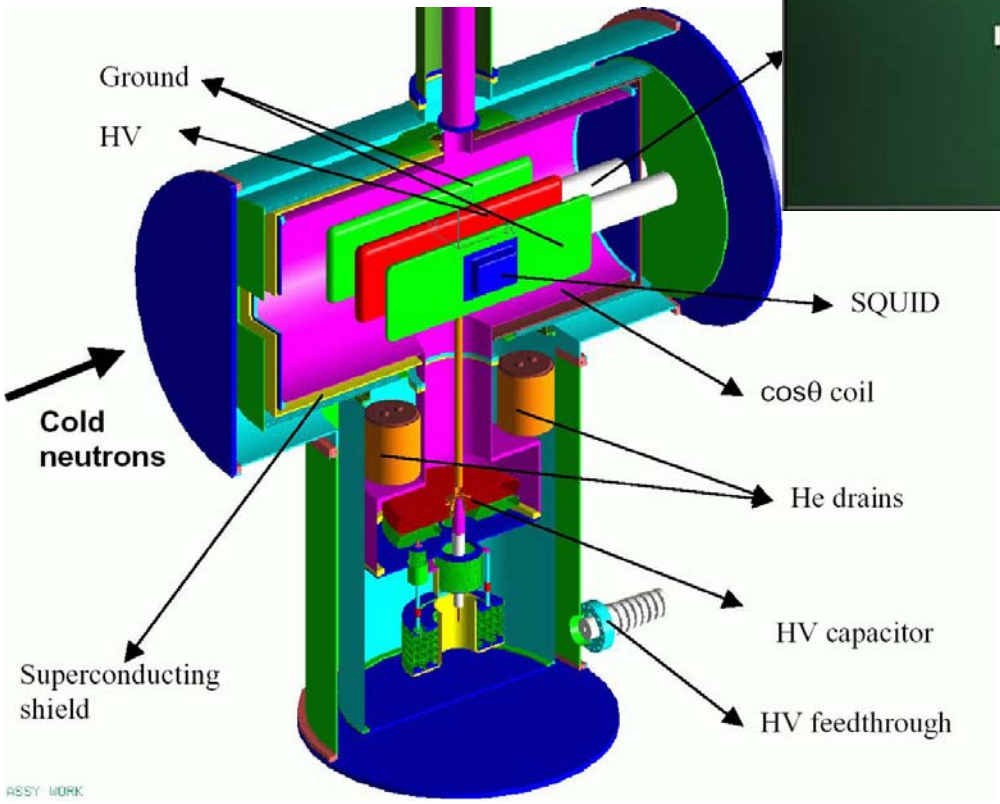
- spallation target
- D_2O moderator
- currently testing apparatus from ILL



Other nEDM experiments: USA

- SNS at ORNL





- LANL-led
- testing underway
- not yet funded

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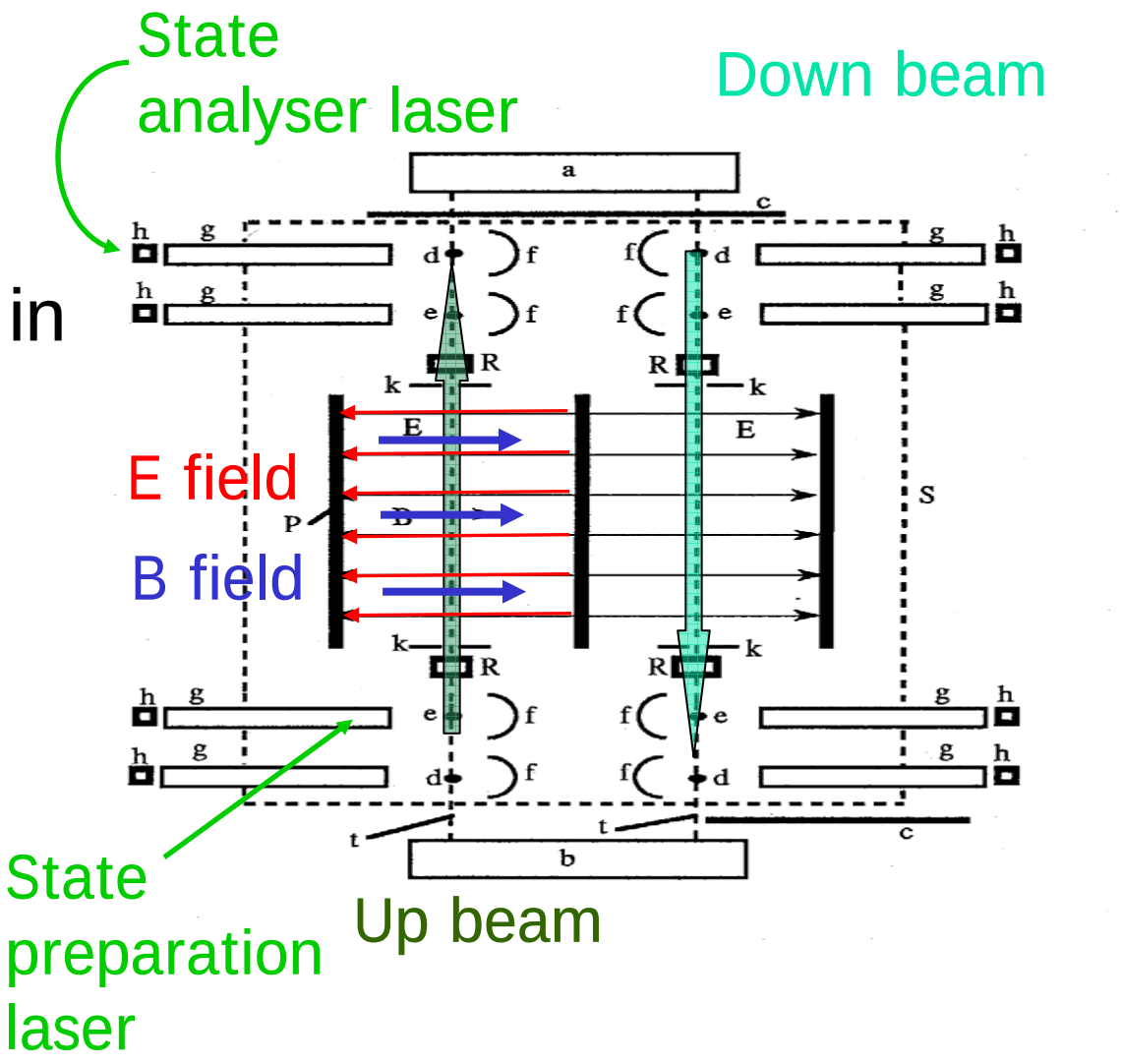
Electron EDM: Berkeley

- Use unpaired e^- in paramagnetic atom
- Pairs of Tl beams in opposite E fields
- Na beams as comagnetometer

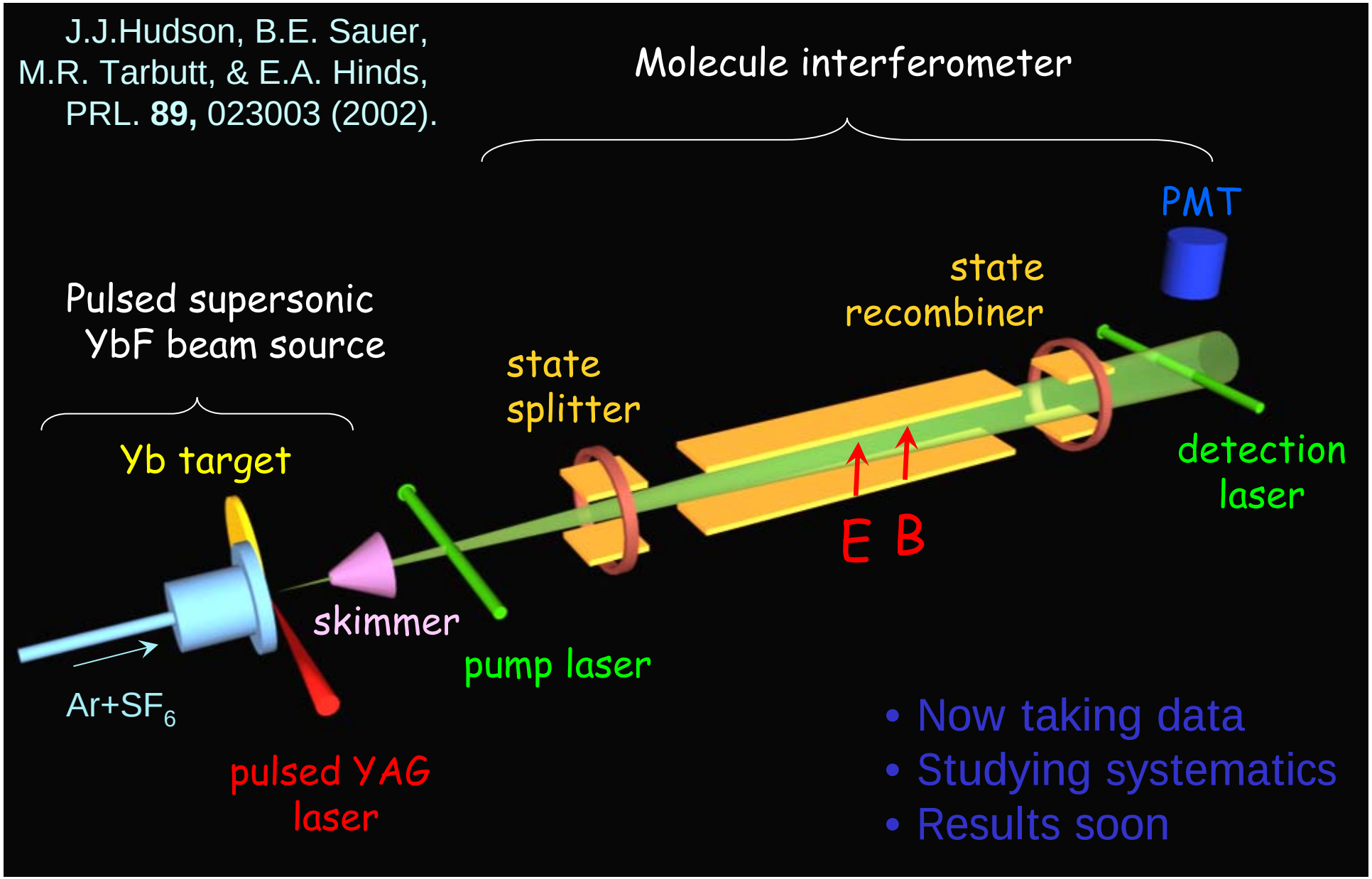
Final result:
$d_e < 1.6 \times 10^{-27}$ e.cm
(systematics limited)



Electron EDM measurements

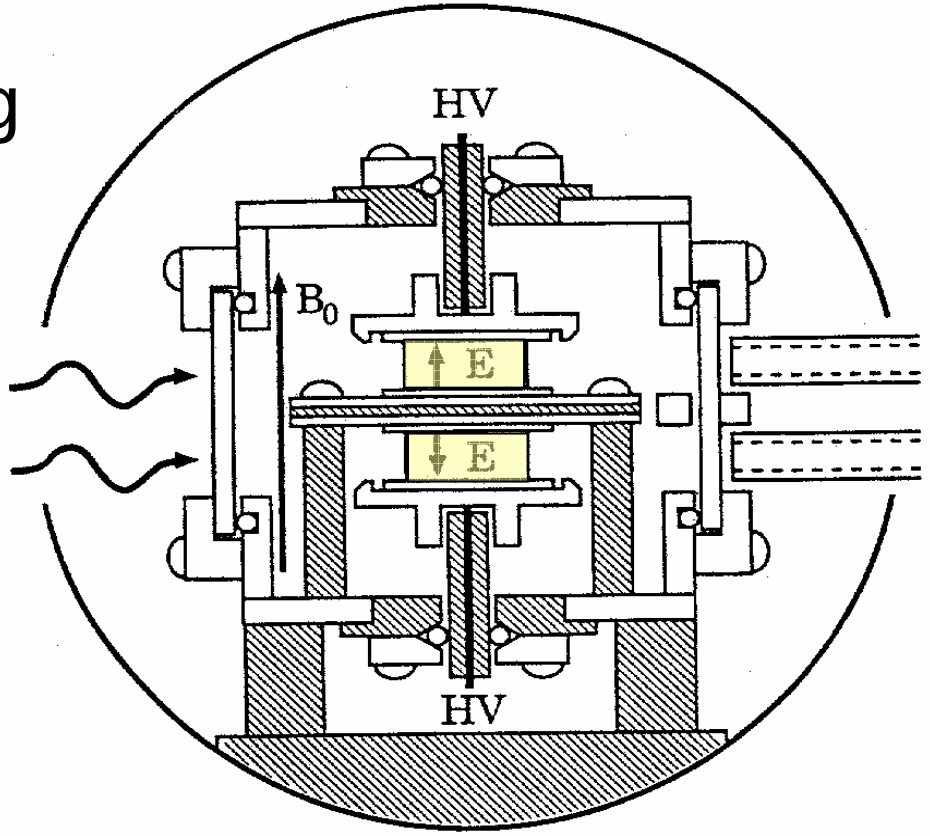
Group	System	Advantages	Projected gain
D. Weiss (Penn St.)	Trapped Cs	Long coherence	~100!
D. Heinzen (Texas)	Trapped Cs	Long coherence	~100!
H. Gould (LBL)	Cs fountain	Long coherence	?
L. Hunter (Amherst)	GdIG solid	Huge S/N	100?
S. Lamoreaux (LANL) C.-Y. Liu (Indiana)	GGG solid	Huge S/N	100?-100,000?
E. Hinds (Imperial)	YbF beam	Large Internal E	3, then 30
D. DeMille (Yale)	**PbO* cell**	**Int.E+good S/N**	**30-1,000?**
E. Cornell (JILA)	trapped HBr^+	Int. E + long T	??
N. Shafer-Ray (Okla.)	trapped PbF	Int. E + long T	??

Imperial College Electron EDM experiment



^{199}Hg EDM

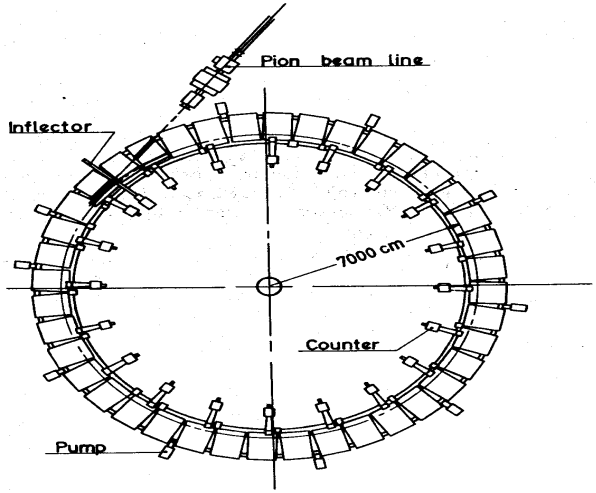
- Optically pumped ^{199}Hg atoms precess in B, E fields, modulating absorption signal
  - Dual cells remove effect of drifts in B



- Result:
  $d(^{199}Hg) < 2.1 \times 10^{-28}$ e cm
- Provides good limit on CPv effects in nuclear forces, inc. θ_{QCD}

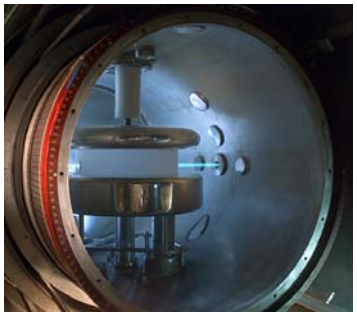
… and more!

- Muon EDM: from g-2
  (7E-19; proposal at JPARC for ~10^{-24})
- Deuterium EDM: similar principle (may reach ~10^{-29} e.cm)
- Tau weak dipole moment – look for CP-odd observables in diff. x-sec at Z res.
  (6E-18 e.cm from LEP data)

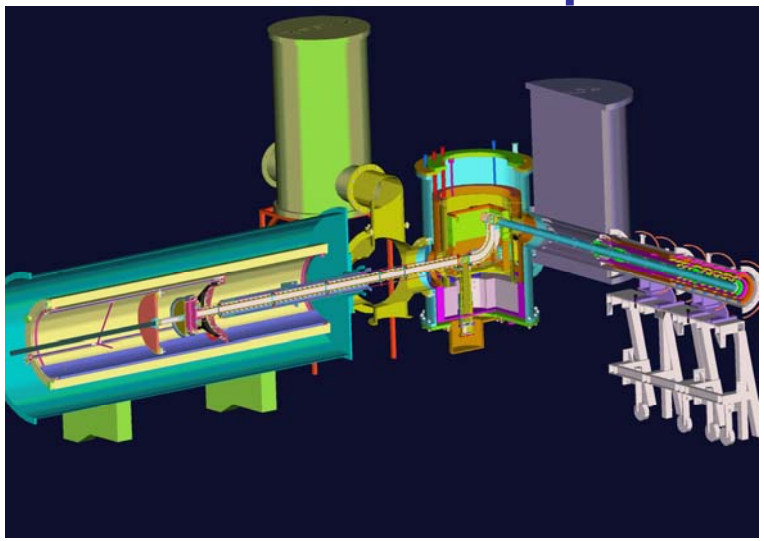


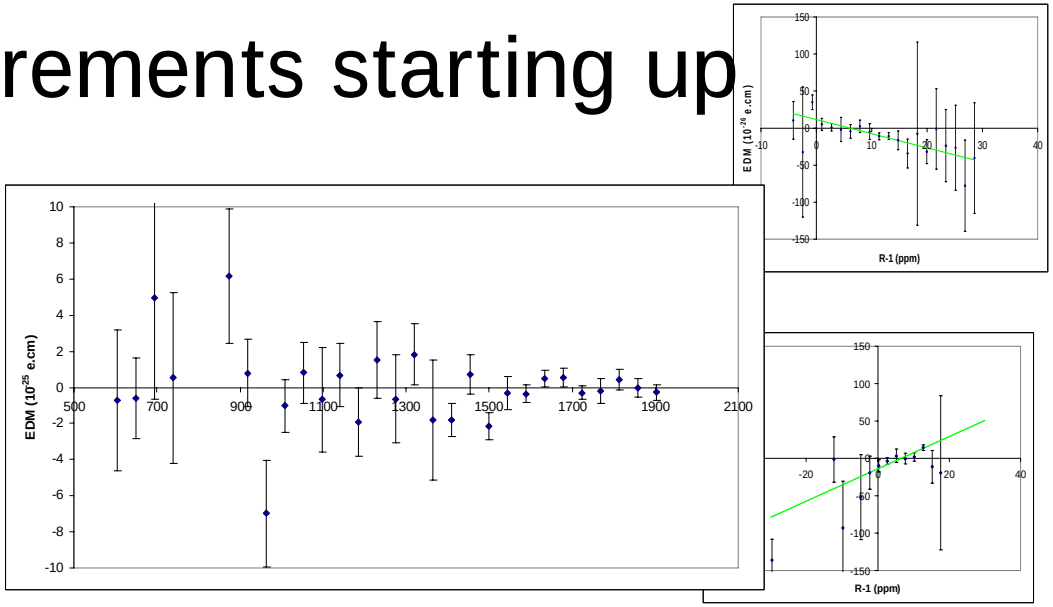
Sensitivity to physics BSM depends on source of CPv

Conclusions



- New nEDM limit, 3.0 x 10^{-26} e.cm
  - Tightens the constraints on beyond-SM CPv
- Systematics understood as never before
- CryoEDM coming soon – 100x more sensitive
- Several new measurements starting up
- Watch this space!





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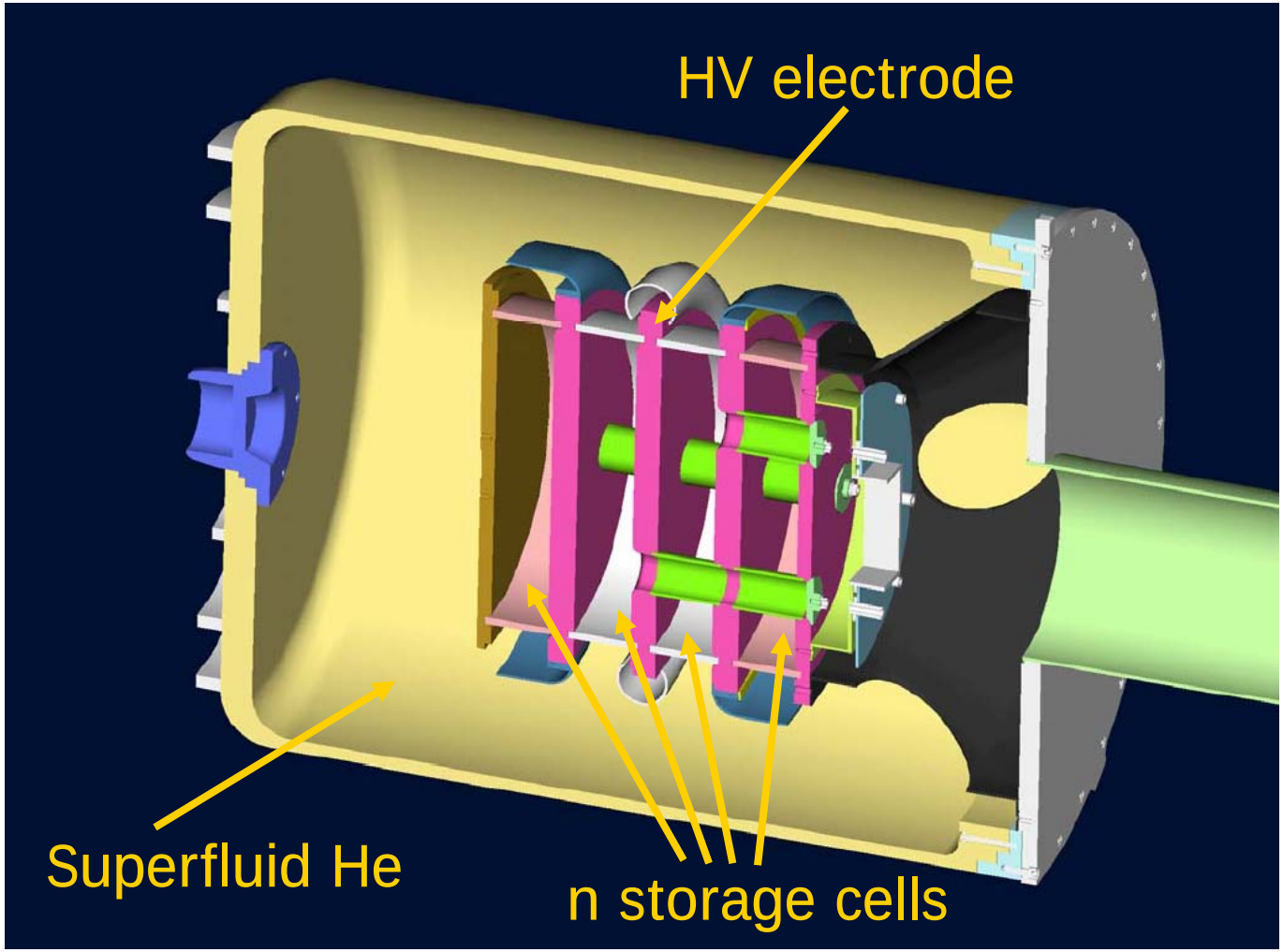
spare slides

Cryogenic Ramsey chamber



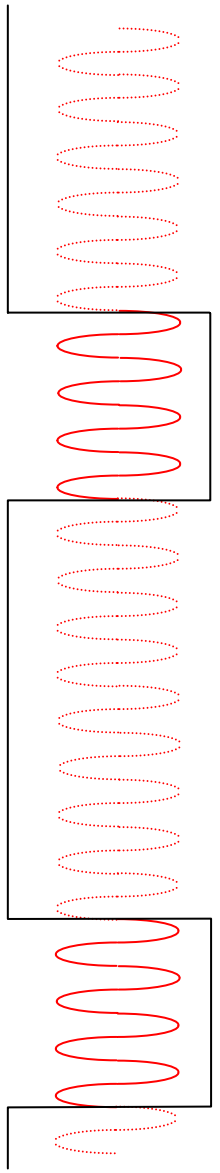
Ramsey method of Separated Oscillating Fields

1. *"Spin up" neutron...*

2. *Apply π/2 spin flip pulse...*

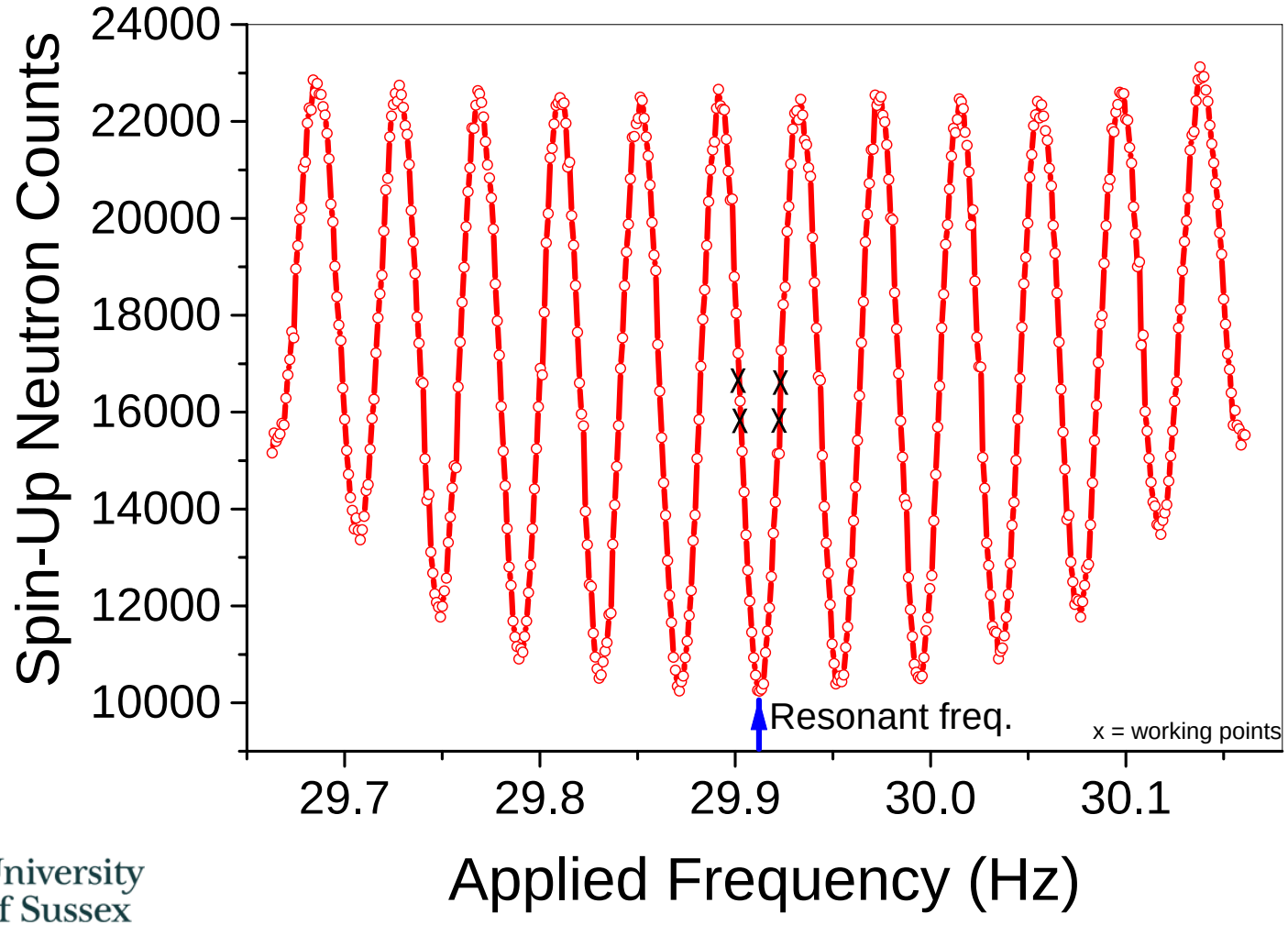
3. *Free precession. ..*

4. *Second π/2 spin flip pulse.*

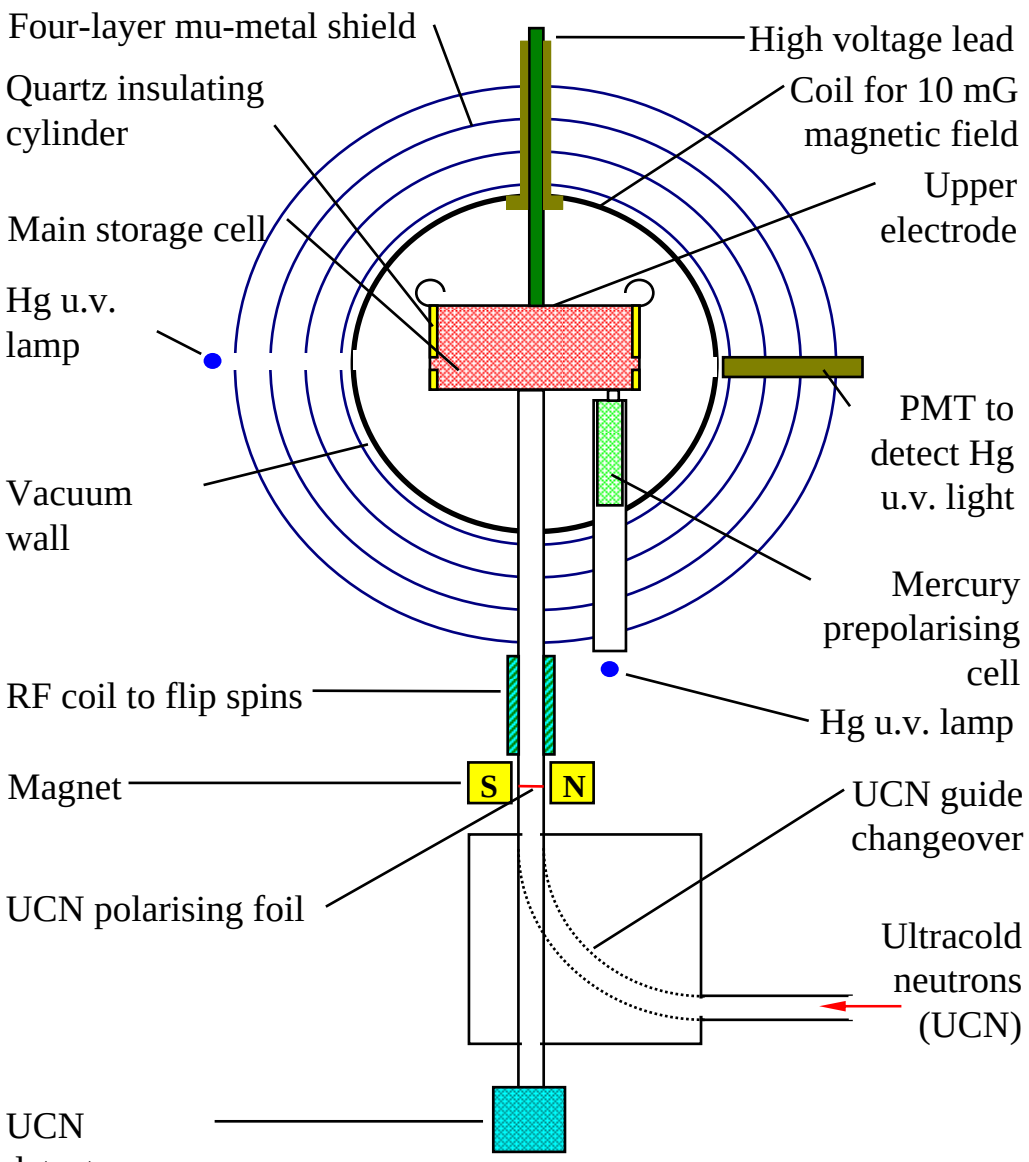


Ramsey resonance

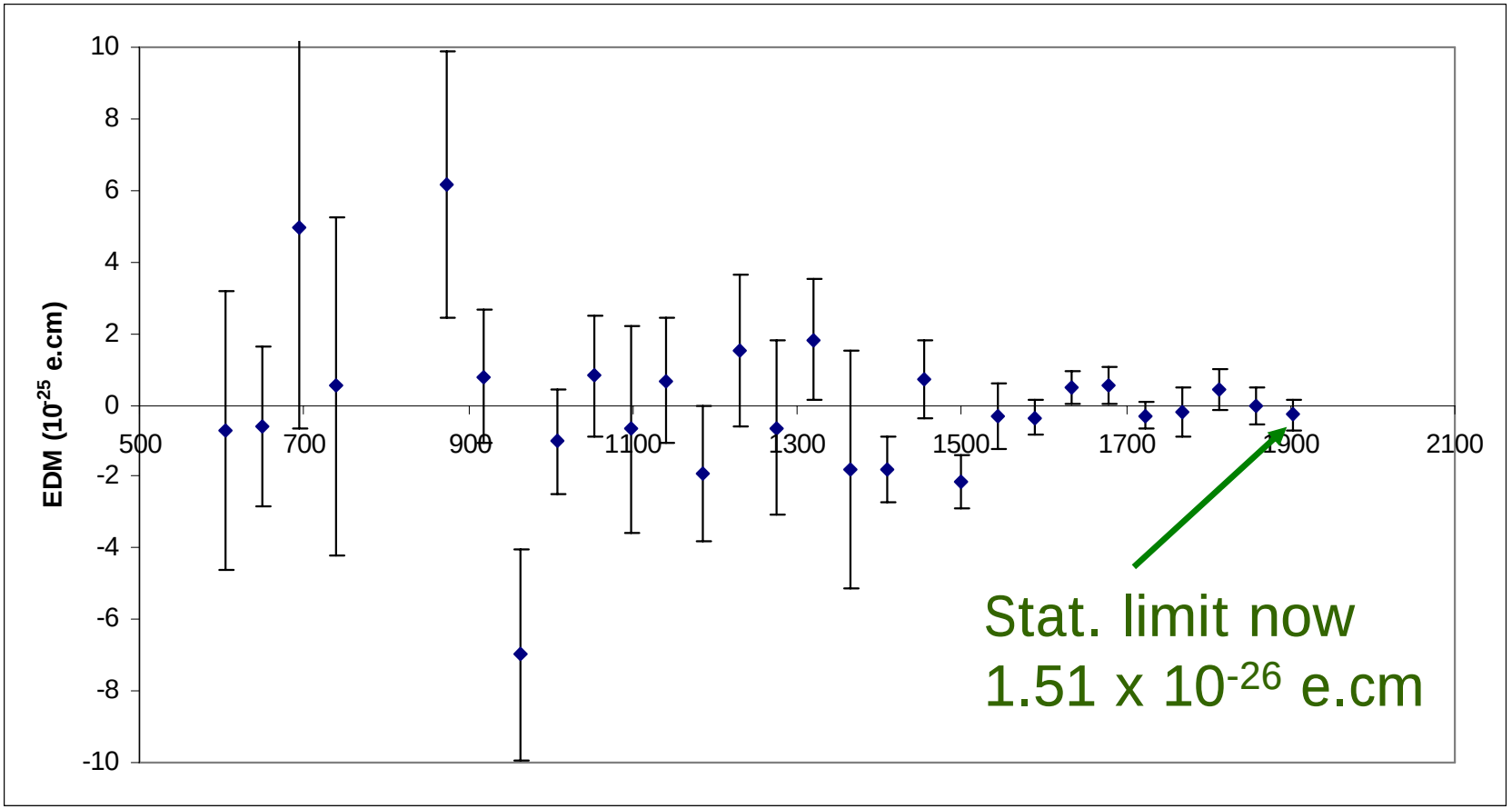
- "2-slit" interference pattern
- Phase gives freq offset from resonance



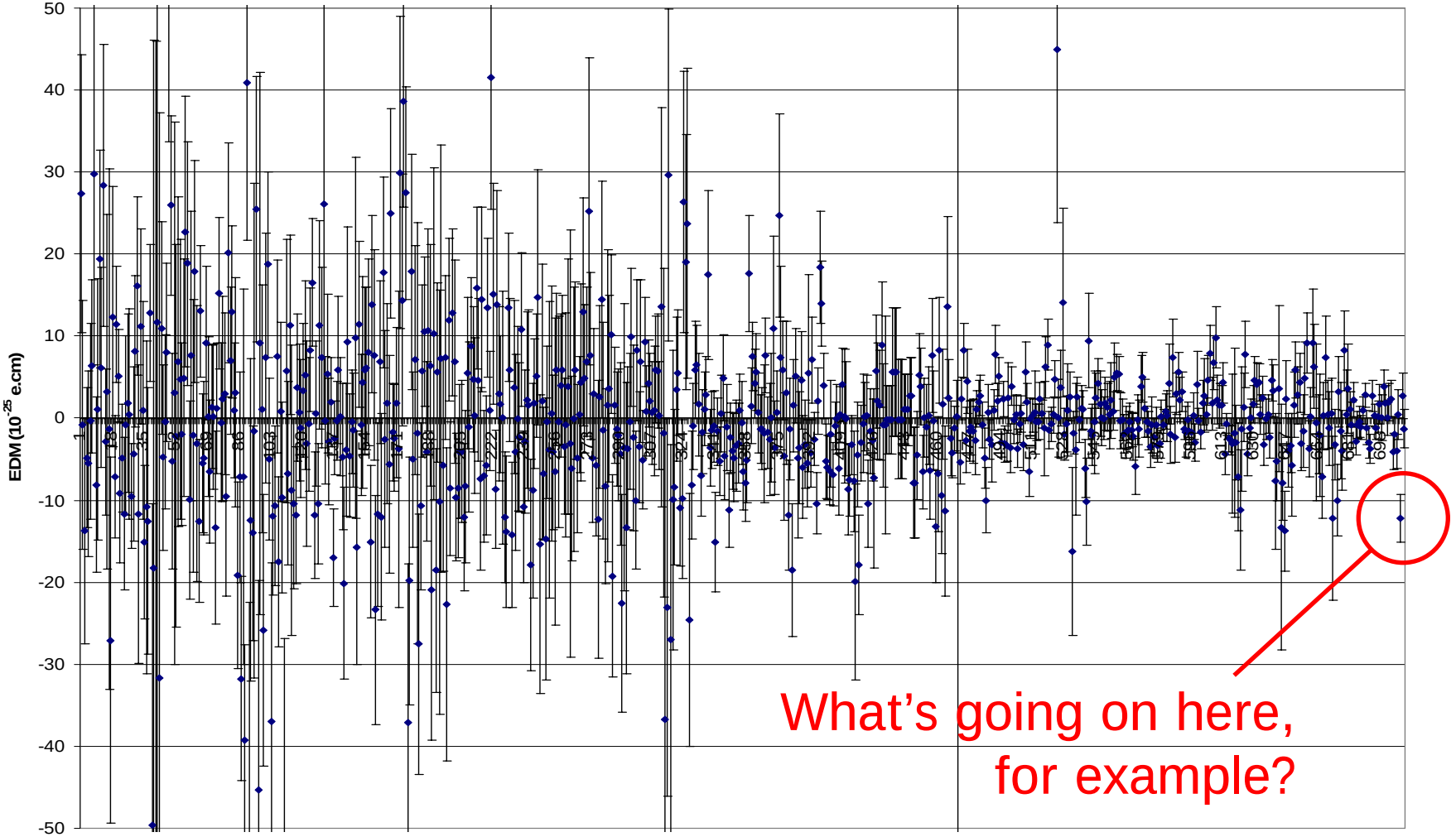
nEDM apparatus



Neutron EDM results (binned)



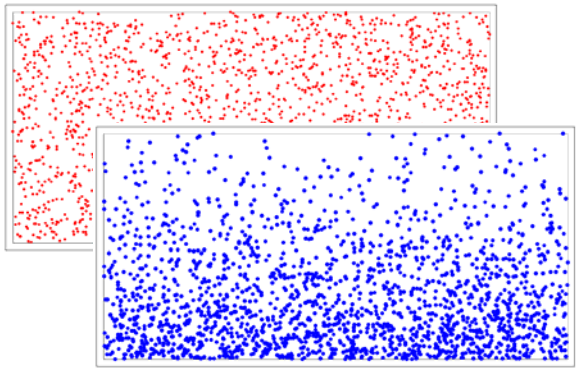
Neutron EDM results (individual runs)



Geometric Phase How to measure it

- Consider

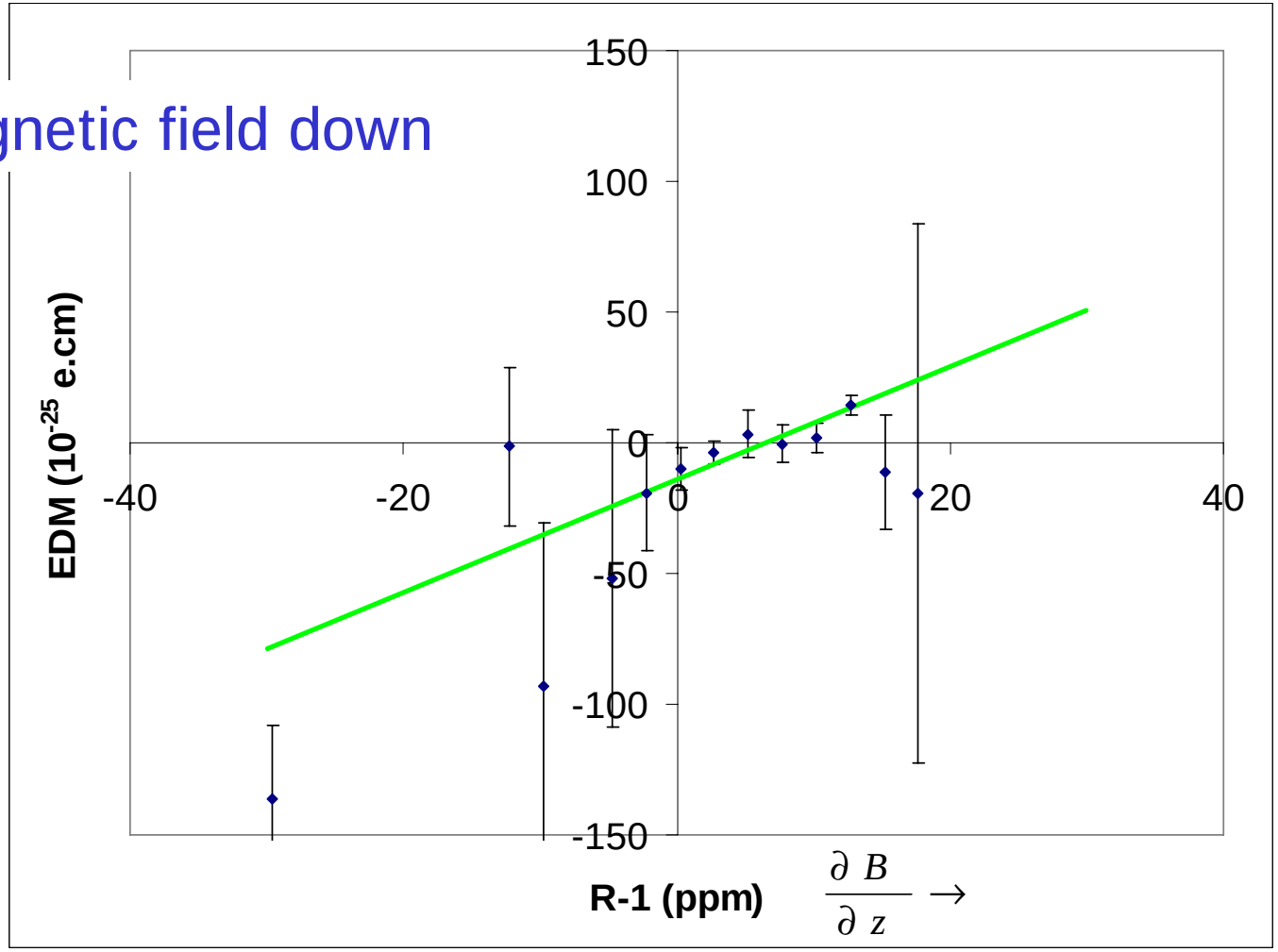
$$R = \frac{\nu_n}{\nu_{Hg}} \cdot \frac{\gamma_{Hg}}{\gamma_n}$$



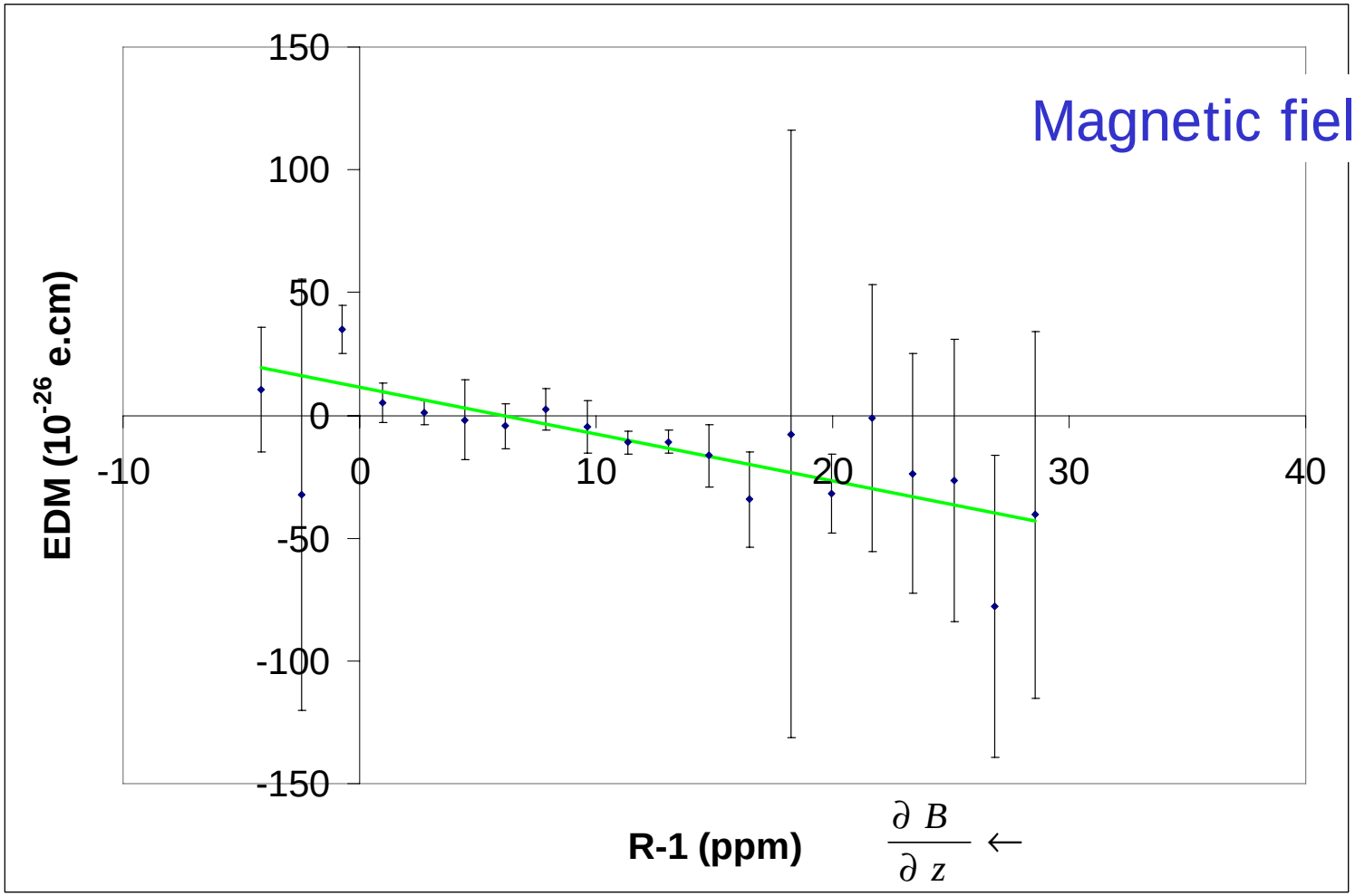
- Should have value 1
- R is shifted by magnetic field gradients
- Plot EDM vs measured R-1:

Geometric Phase

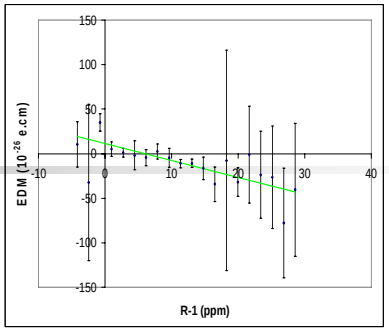
Magnetic field down

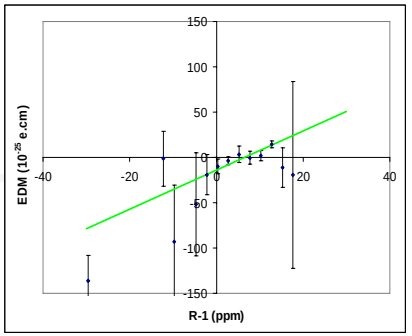


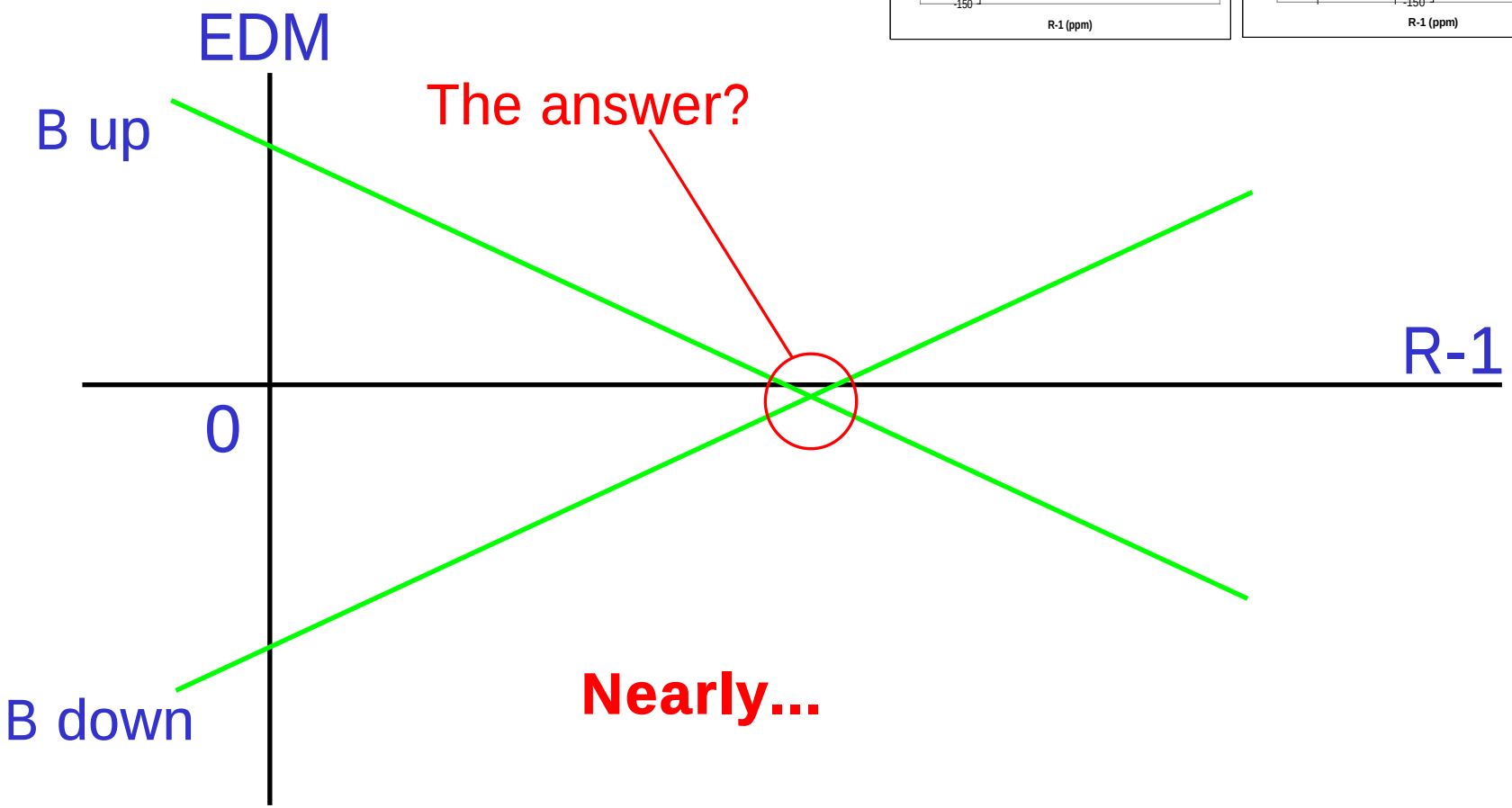
Geometric Phase



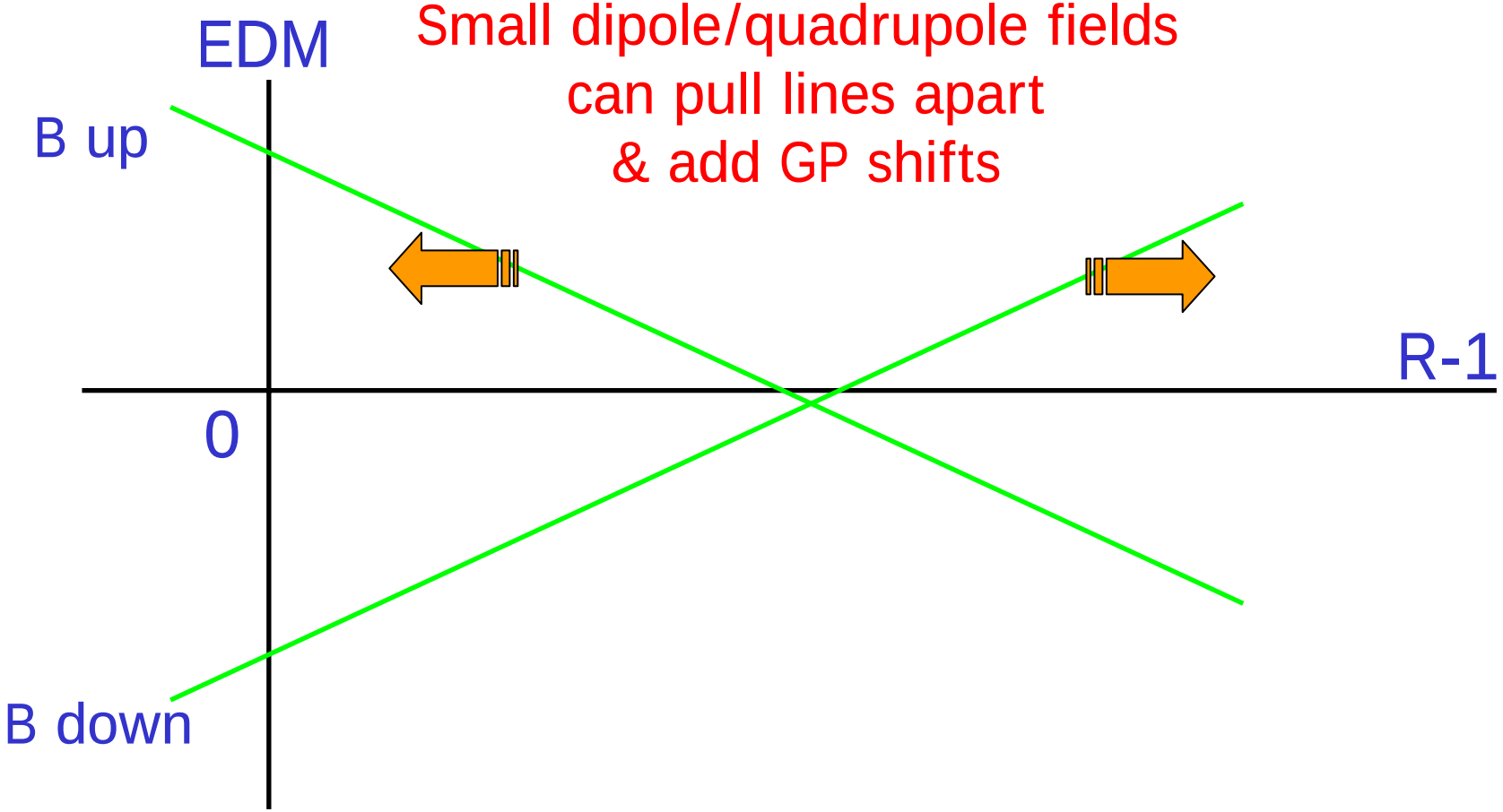
Results


EDM (10^-25 e.cm)
R-1 (ppm)

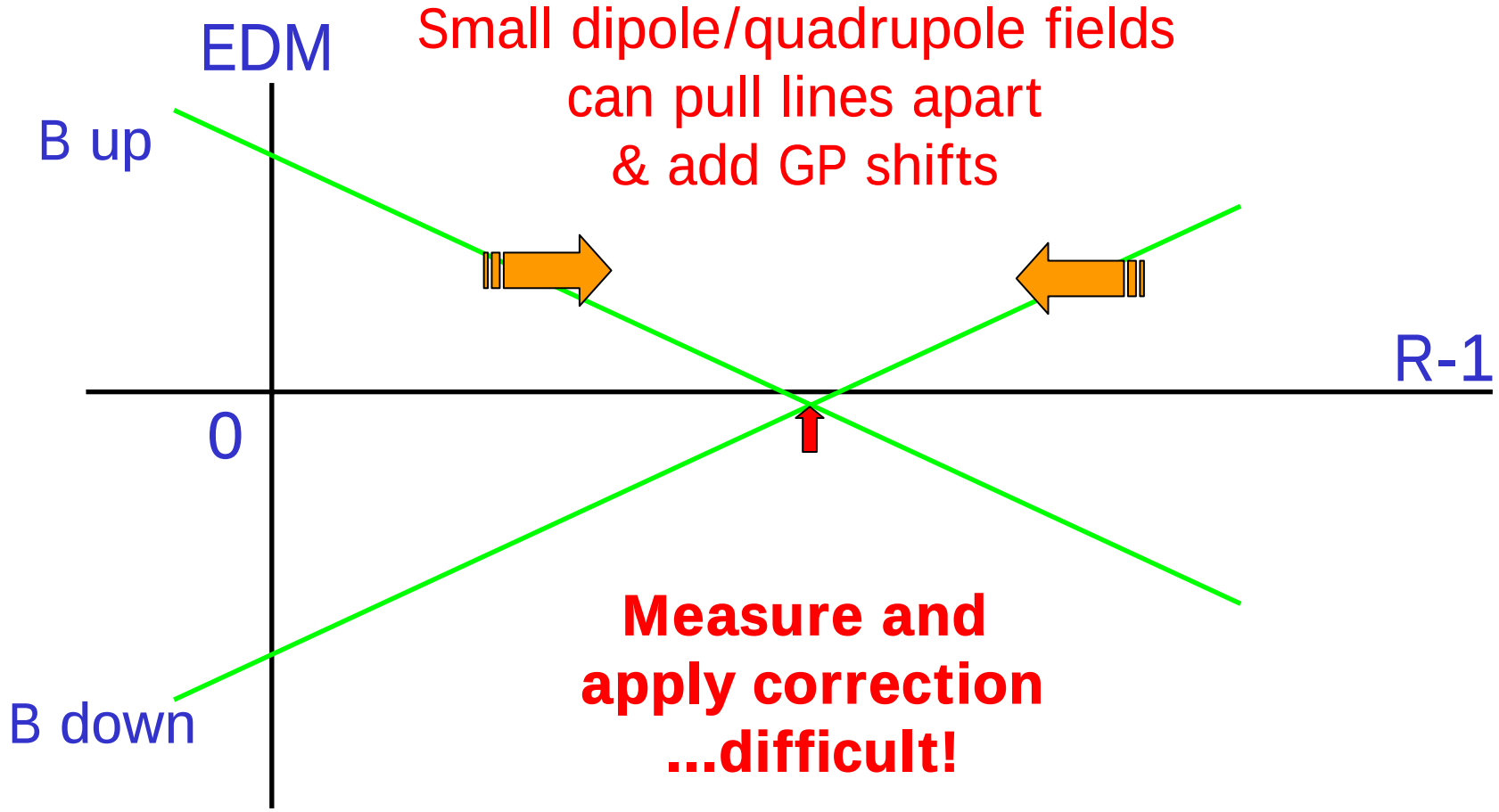

EDM (10^-25 e.cm)
R-1 (ppm)


EDM
B up
The answer?
R-1
0
B down
Nearly...

Results

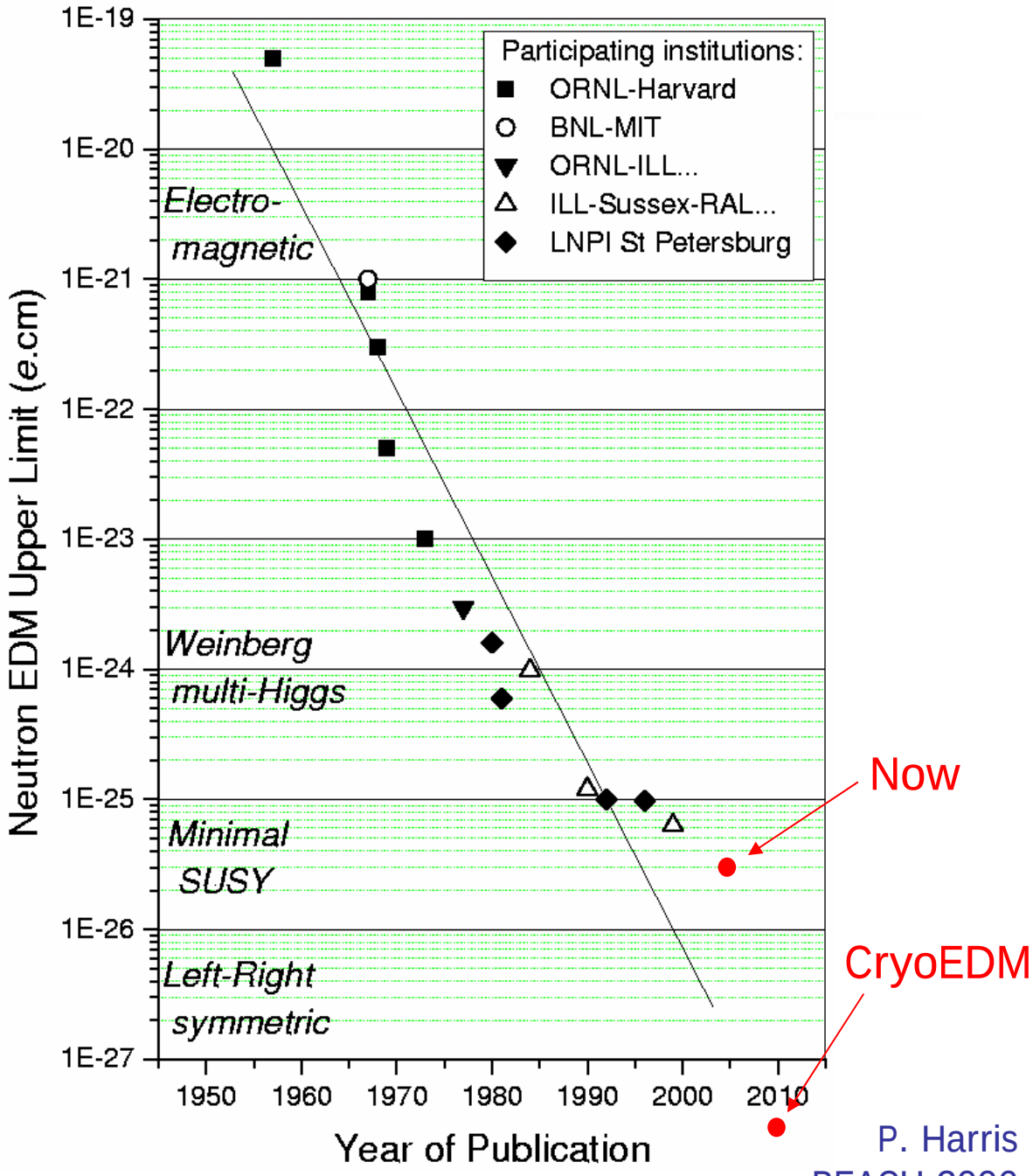

EDM
Small dipole/quadrupole fields
can pull lines apart
& add GP shifts
B up
R-1
0
B down

Results


EDM
B up
B down
0
R-1
Small dipole/quadrupole fields
can pull lines apart
& add GP shifts
Measure and
apply correction
...difficult!

History

Factor 10
every 8 years
on average



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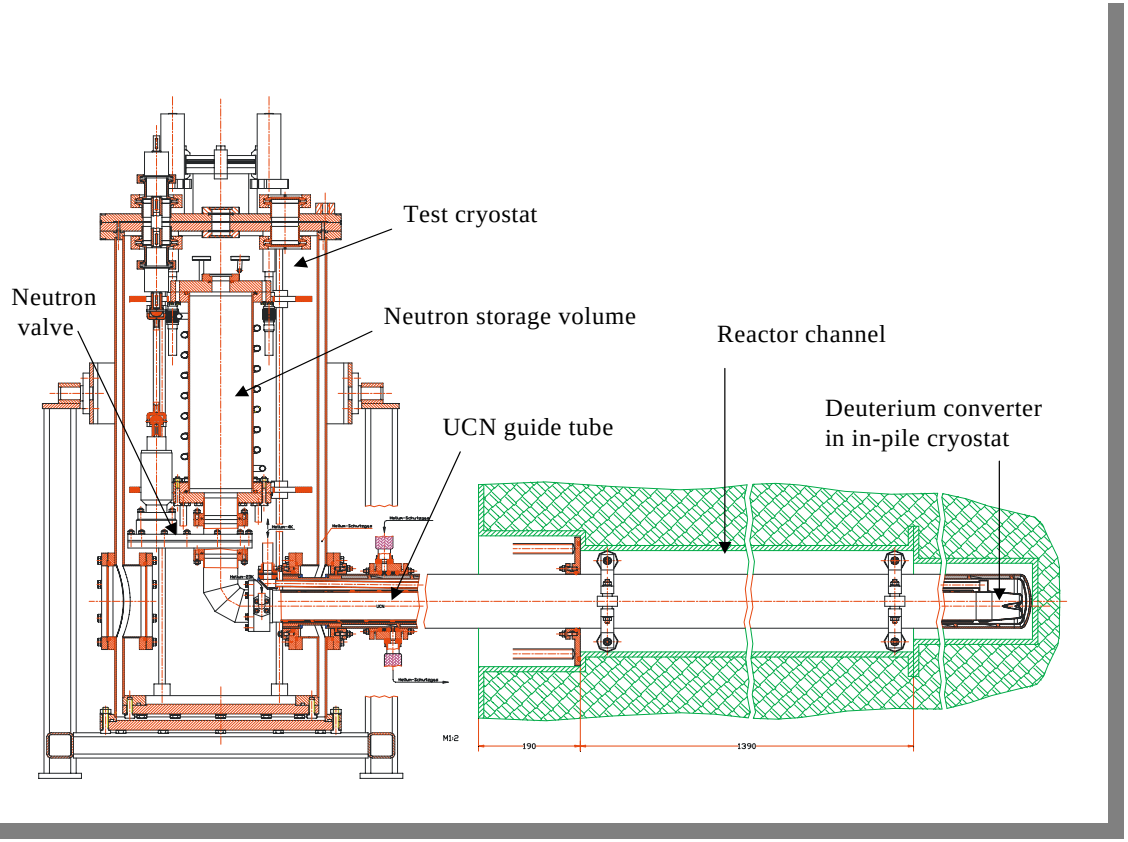
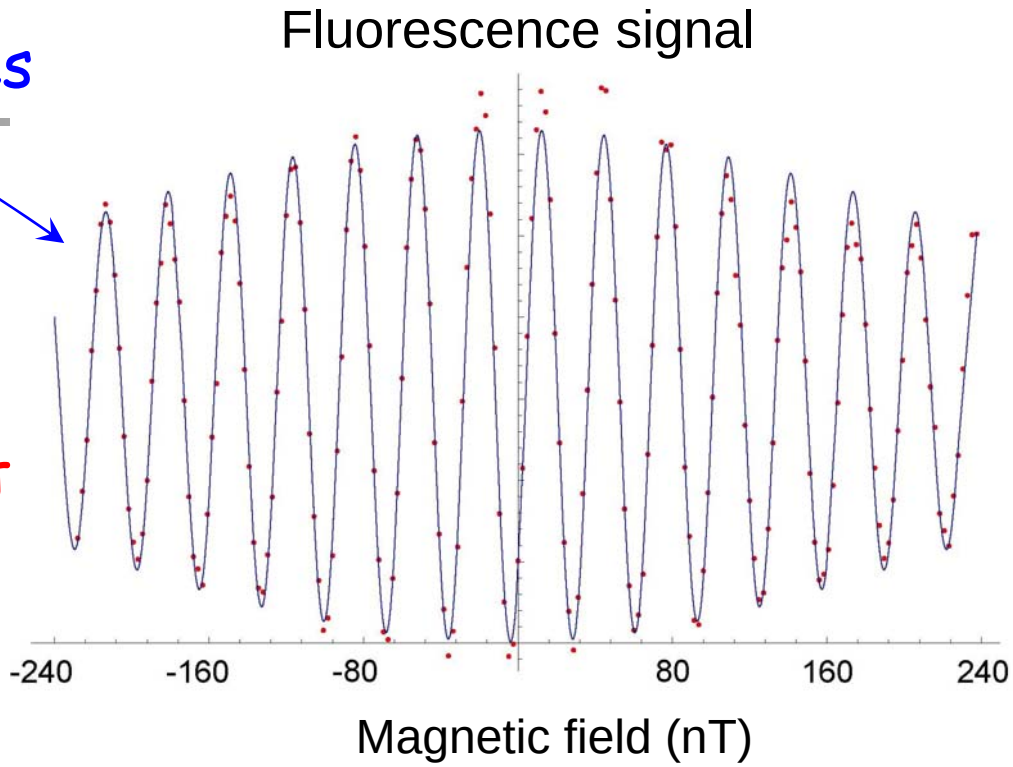
Other nEDM experiments: Mainz

- Testing UCN source at TRIGA, Mainz for later installation at FRM, Munich



The interference fringes



EDM given by fringe shift with reversal of E or B

Data being taken now. Systematics being studied.

Current status: $d_e = \_ \pm 5 \times 10^{-28}$ e.cm

Expected 2010: $d_e = \_ \pm 5 \times 10^{-29}$ e.cm