

The search for the neutron electric dipole moment at the Paul Scherrer Institut

Guillaume Pignol
For the nEDM collaboration

Osaka, April 9 2010

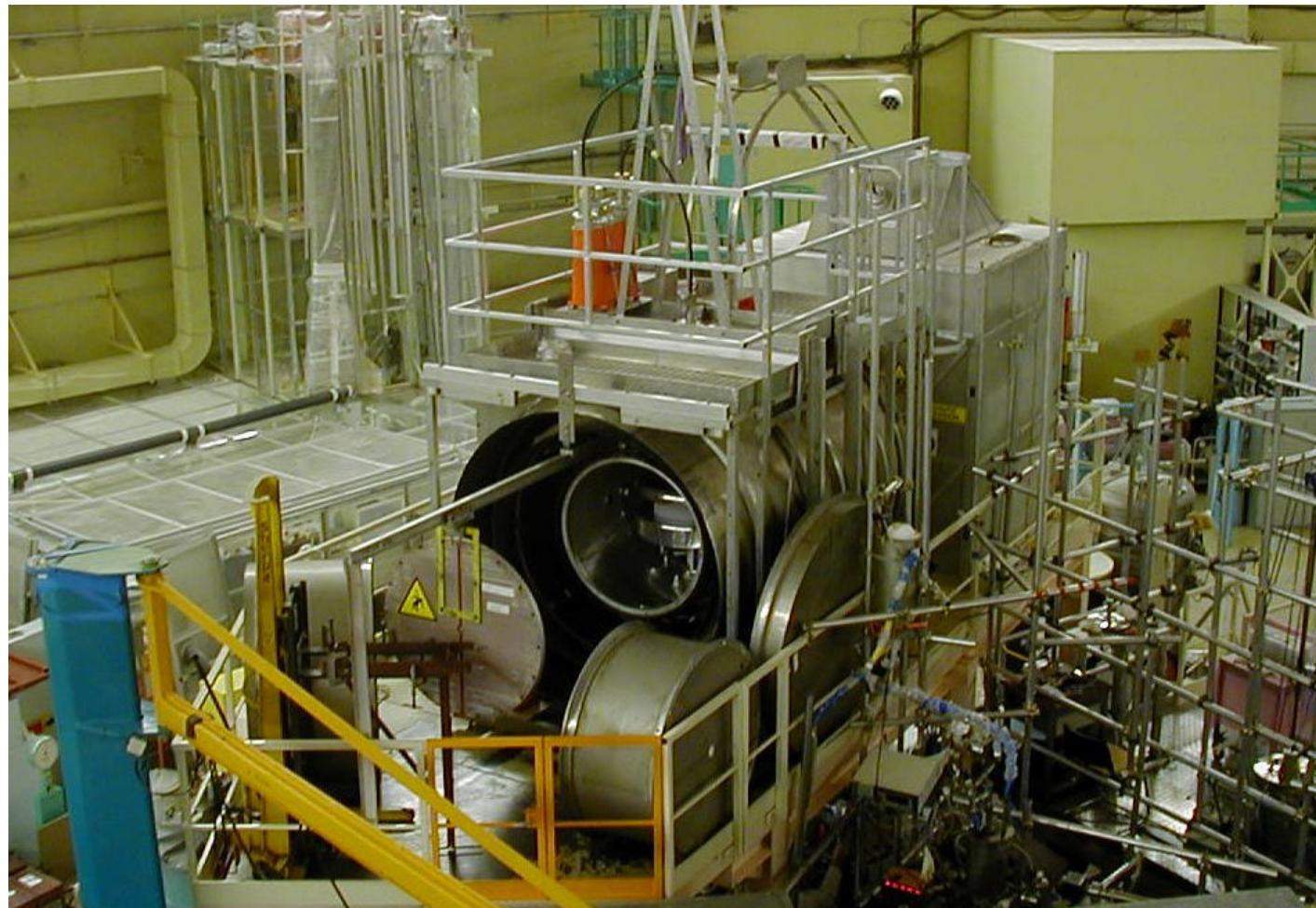
The neutron EDM collaboration

	M. Burghoff, S. Knappe-Grüneberg, A. Schnabel, L. Trahms	<i>Physikalisch Technische Bundesanstalt, Berlin</i>
	G. Ban, Th. Lefort, Y. Lemiere, O. Naviliat-Cuncic, E. Pierre ¹ , G. Quéméner, G. Rogel ²	<i>Laboratoire de Physique Corpusculaire, Caen</i>
	K. Bodek, St. Kistryn, J. Zejma	<i>Institute of Physics, Jagiellonian University, Cracow</i>
	A. Kozela	<i>Henryk Niedwodniczanski Inst. Of Nucl. Physics, Cracow</i>
	N. Khomutov	<i>Joint Institute of Nuclear Research, Dubna</i>
	P. Knowles, A.S. Pazgalev, A. Weis	<i>Département de physique, Université de Fribourg, Fribourg</i>
	<u>P. Fierlinger</u> , B. Franke ¹ , M. Horras ¹ , F. Kuchler, G. Pignol	<i>Excellence Cluster Universe, Garching</i>
	D. Rebreyend	<i>Laboratoire de Physique Subatomique et de Cosmologie, Grenoble</i>
	G. Bison	<i>Biomagnetisches Zentrum, Jena</i>
	S. Roccia, N. Severijns, N.N.	<i>Katholieke Universiteit, Leuven</i>
	G. Hampel, J.V. Kratz, T. Lauer, C. Plonka-Spehr, N. Wiehl, J. Zenner ¹	<i>Inst. für Kernchemie, Johannes-Gutenberg-Universität, Mainz</i>
	W. Heil, A. Kraft, Yu. Sobolev ³	<i>Inst. für Physik, Johannes-Gutenberg-Universität, Mainz</i>
	I. Altarev, E. Gutsmiedl, S. Paul, R. Stoeppler	<i>Technische Universität, München</i>
	Z. Chowdhuri, M. Daum, M. Fertl, R. Henneck, A. Knecht ⁴ , B. Lauss, A. Mtchedlishvili, G. Petzoldt, P. Schmidt-Wellenburg, G. Zsigmond	<i>Paul Scherrer Institut, Villigen</i>
	<u>K. Kirch</u> ¹ , N.N.	<i>Eidgenössische Technische Hochschule, Zürich</i>

also at: ¹Paul Scherrer Institut, ²ILL Grenoble, ³PNPI Gatchina, ⁴University of Zürich

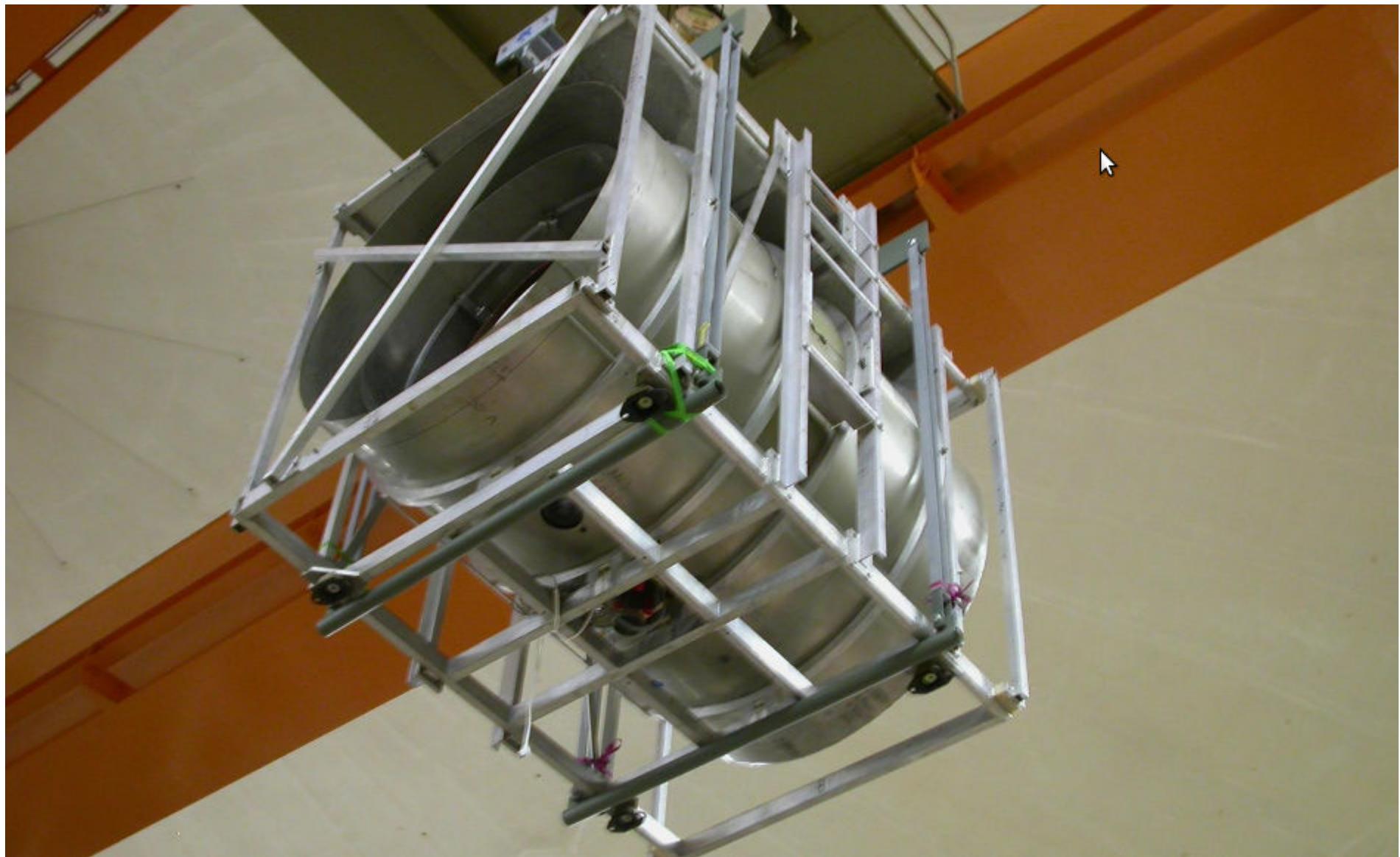


OILL nEDM spectrometer

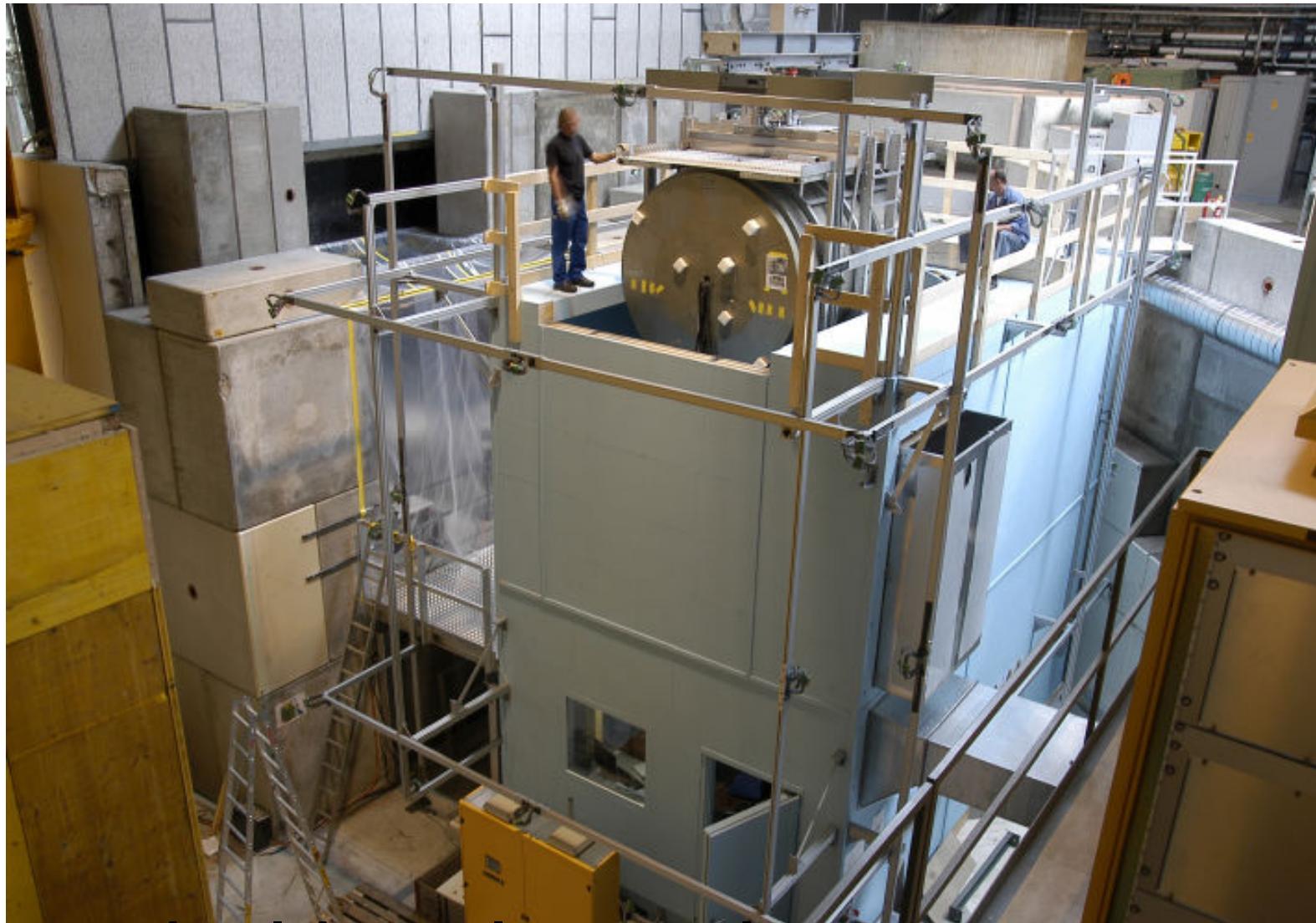


$d_n < 3 \times 10^{-26} \text{ e cm}$ Backer *et al*, Phys. Rev. Lett. **97** (2006)

On its way to PSI

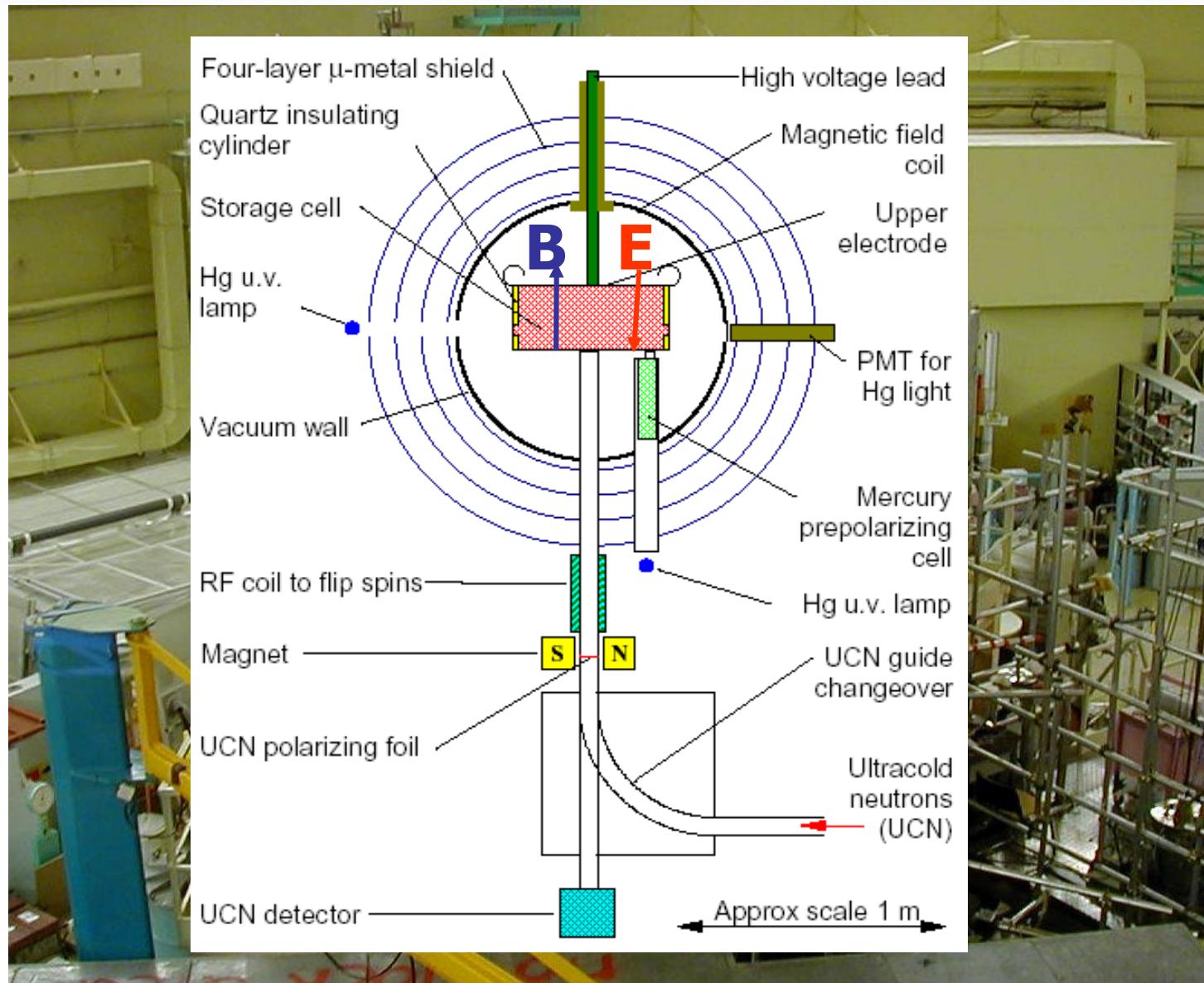


Waiting for the UltraCold neutrons

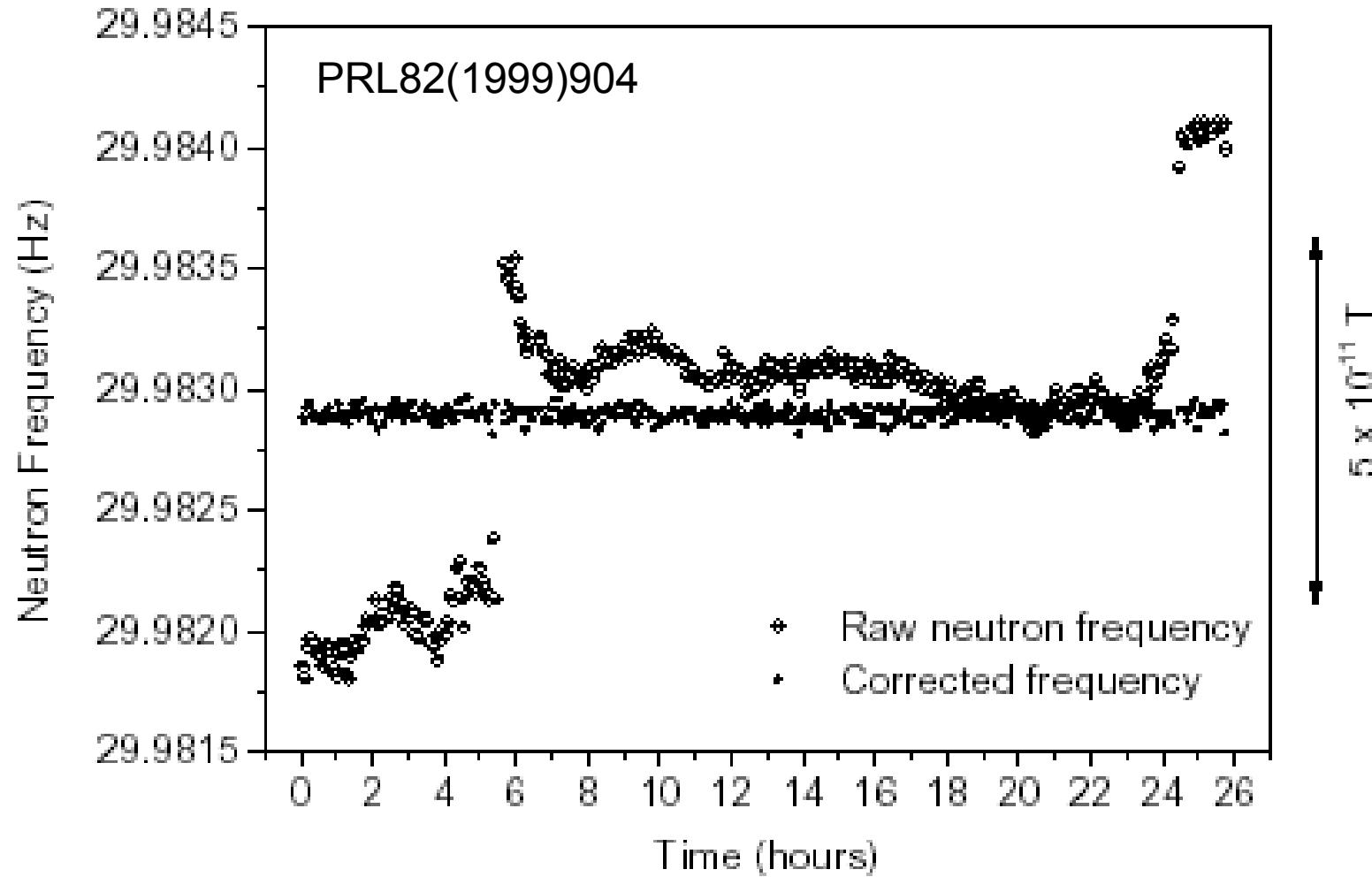


Shield in place, July 2009

OILL nEDM spectrometer



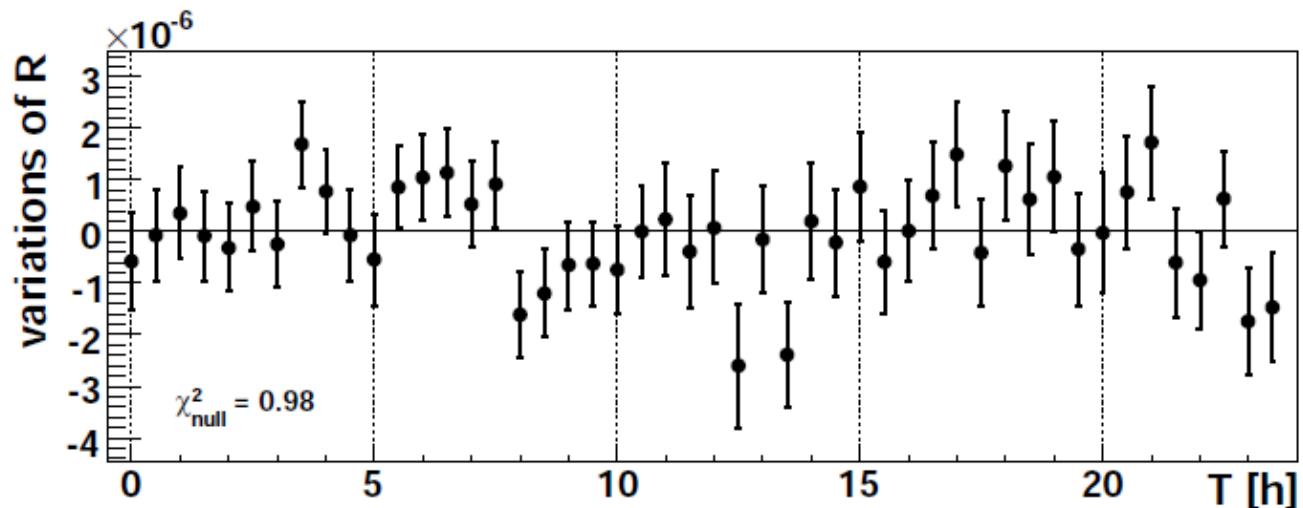
The Mercury comagnetometer



Neutron–mercury clock comparison

April 2008, 5 days of data without E field

$$R = \frac{f_n}{f_{\text{Hg}}} \approx \frac{30 \text{ Hz}}{8 \text{ Hz}}$$



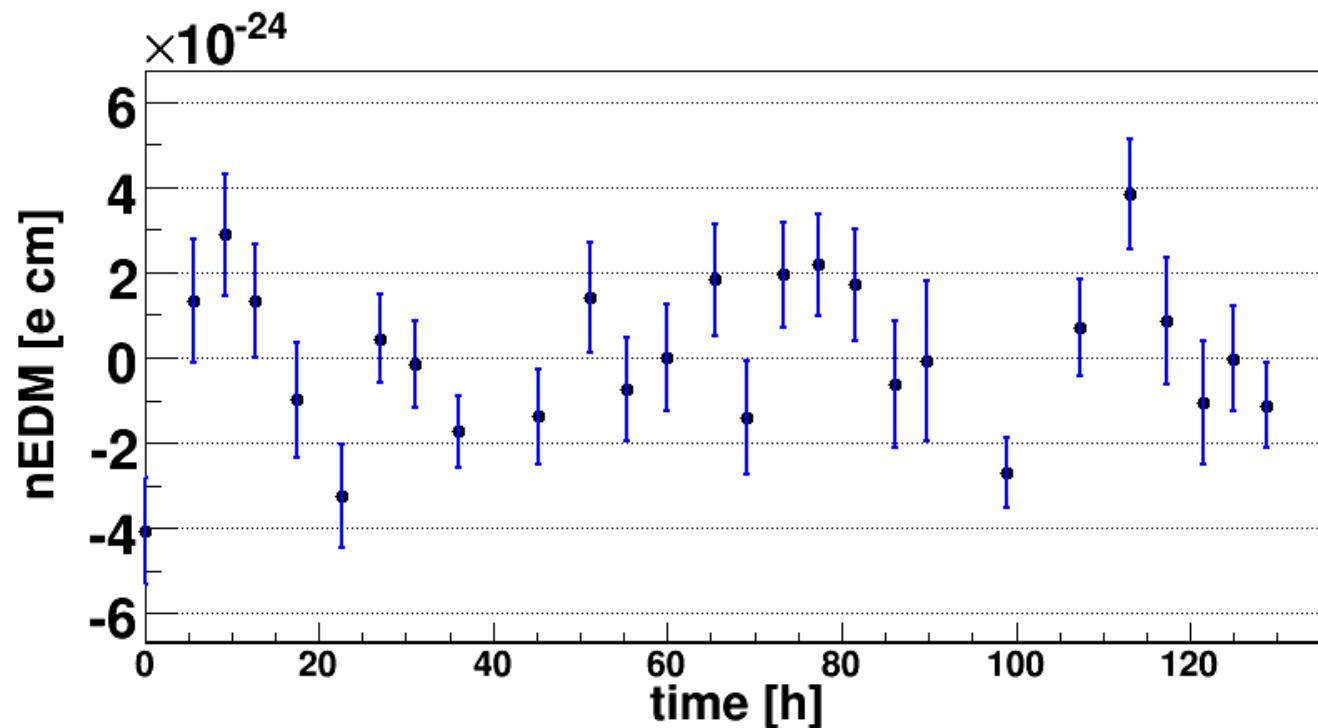
Interpreted as a test of Lorentz invariance

$$b < 2 \times 10^{-20} \text{ eV}$$

Altarev *et al*, Phys. Rev. Lett. **103** (2009)

nEDM runs, december 2008

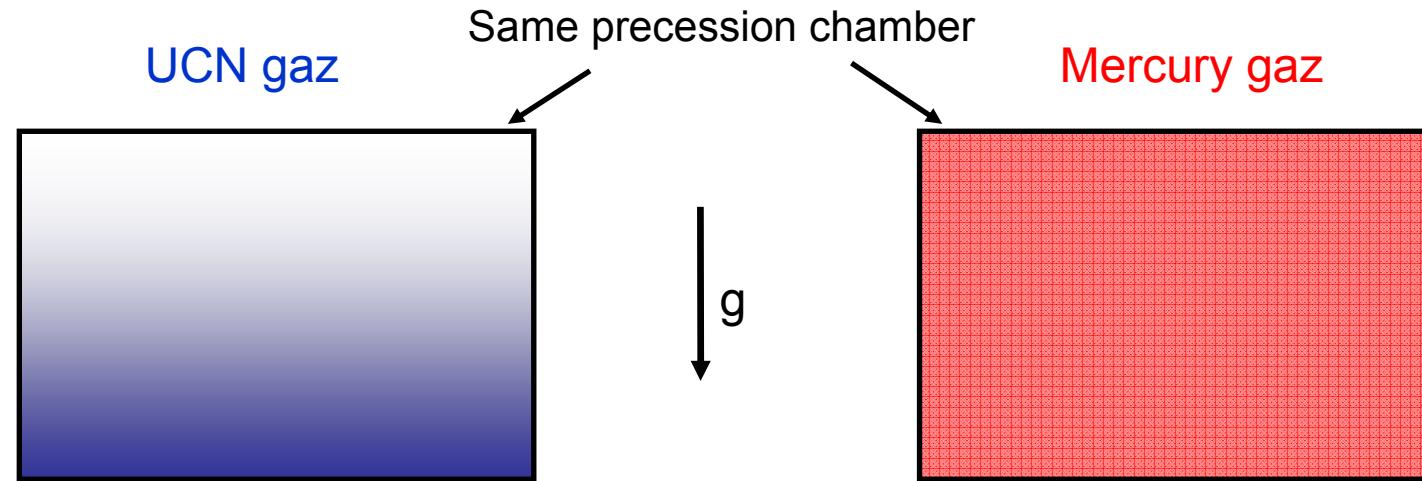
6 days of data, E field reversed every 2 hours



$$d_n = (-3 \pm 3) \times 10^{-25} \text{ e cm}$$

PhD thesis S. Roccia

Gravitational effect



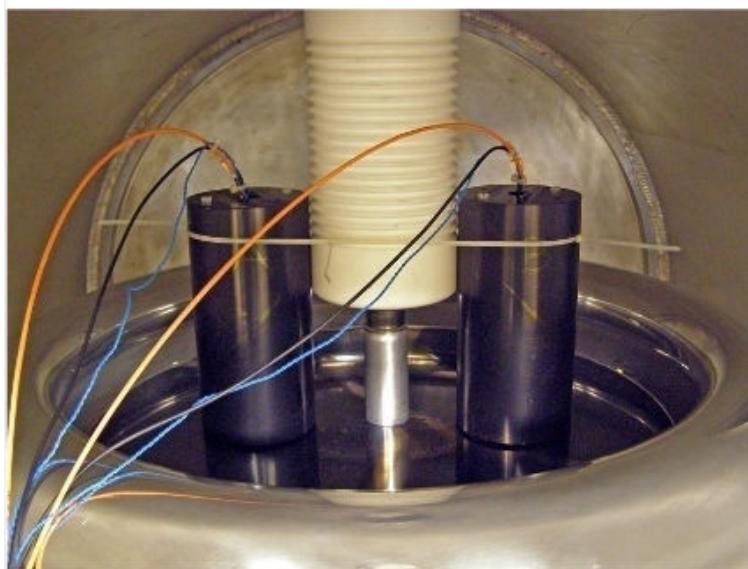
Center of gravity height difference is $h \approx 2 \text{ mm}$

R depends on vertical gradients

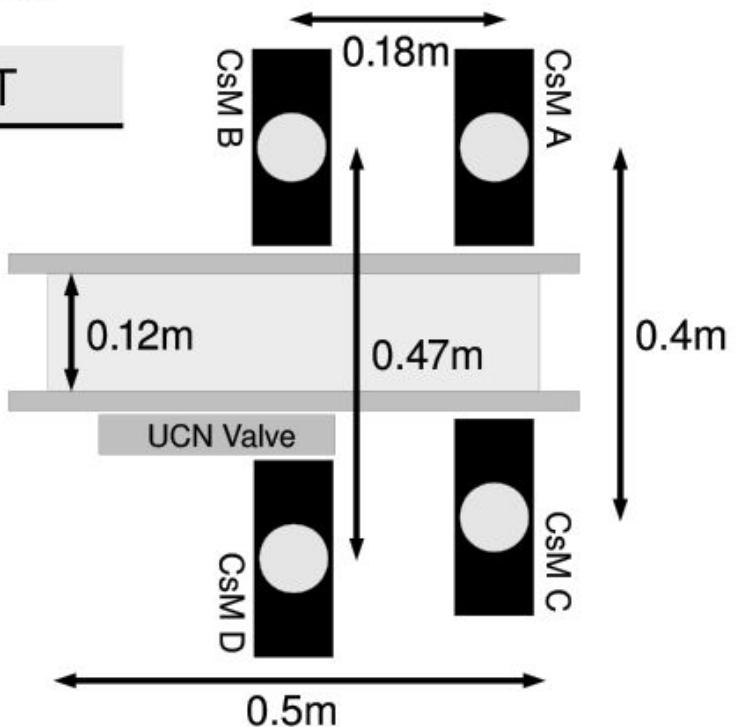
$$R = \frac{\gamma_n}{\gamma_{\text{Hg}}} \left(1 - \frac{(\partial B / \partial z) h}{B} \right)$$

Gradient control: Cs magnetometers

	Neutron	Mercury	Cesium
Polarisation	Nuclear	Nuclear	Electronic
Frequency (B=1 μ T)	30 Hz	8 Hz	3.5 KHz
Accuracy	1 pT	100 fT	10 fT



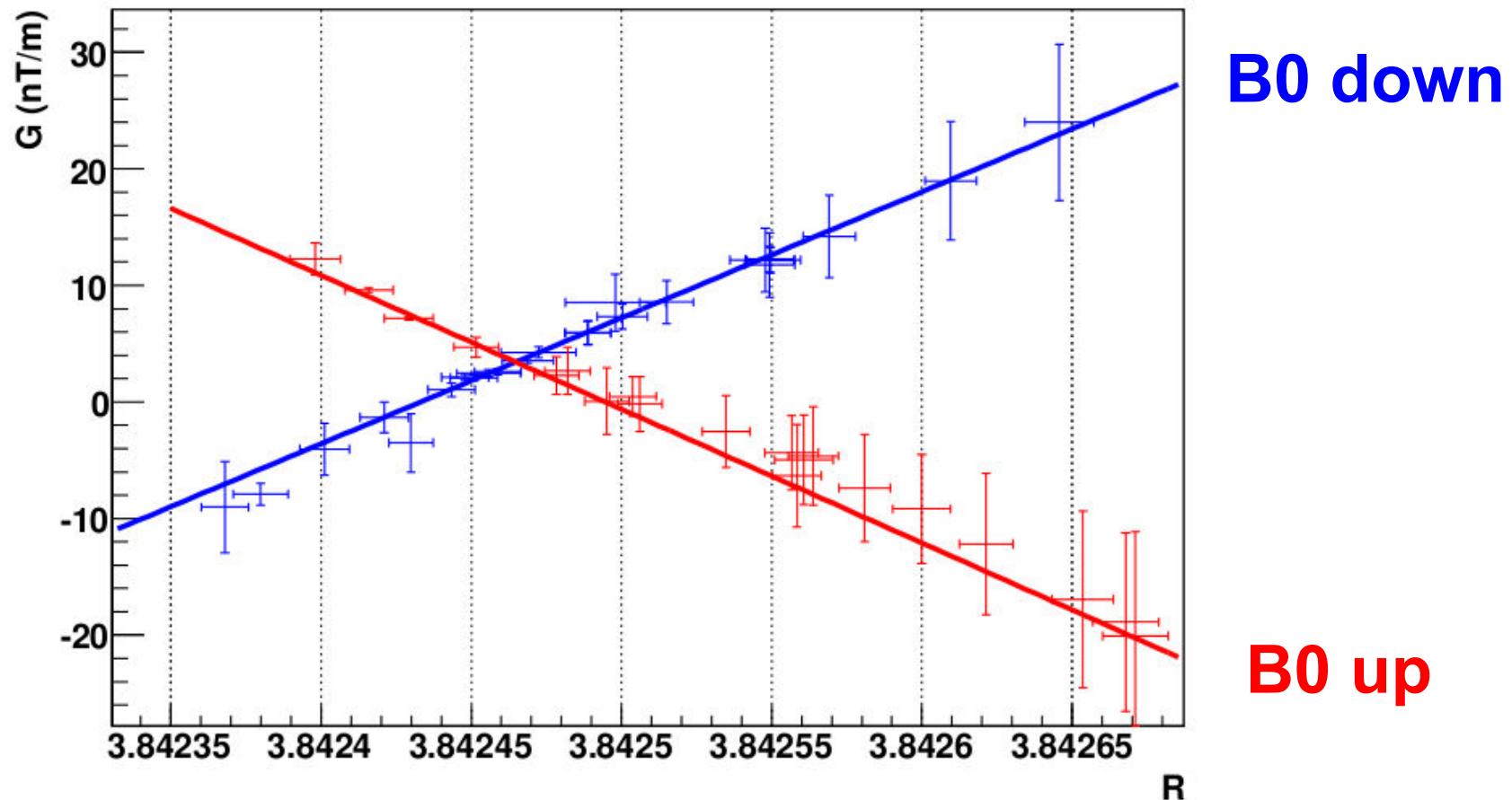
Control of gradients



Gravitational effect measured at ILL

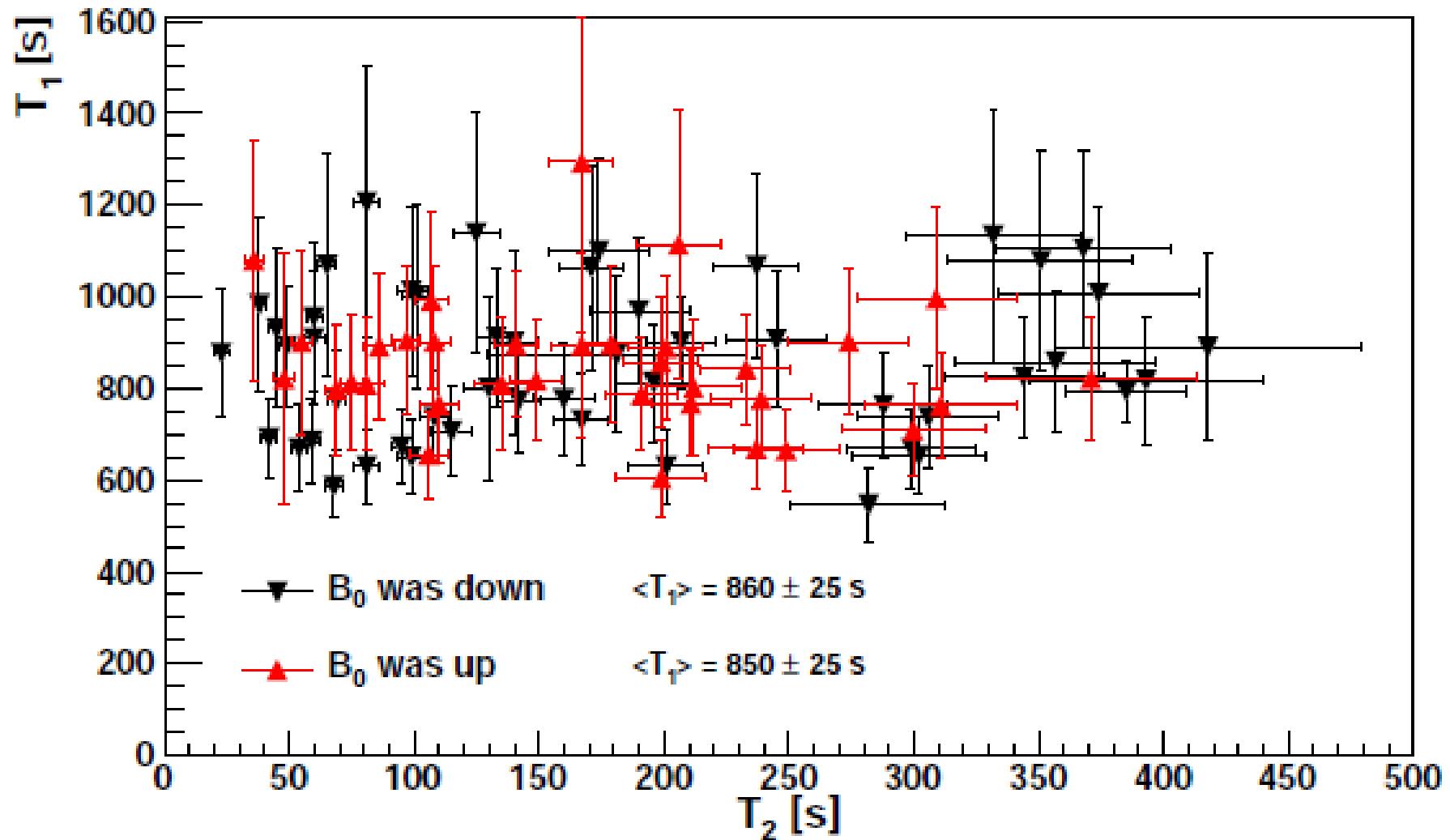
R depends on vertical gradients

$$R = \frac{\gamma_n}{\gamma_{Hg}} \left(1 - \frac{(\partial B / \partial z)h}{B} \right)$$



Neutron spin relaxation times

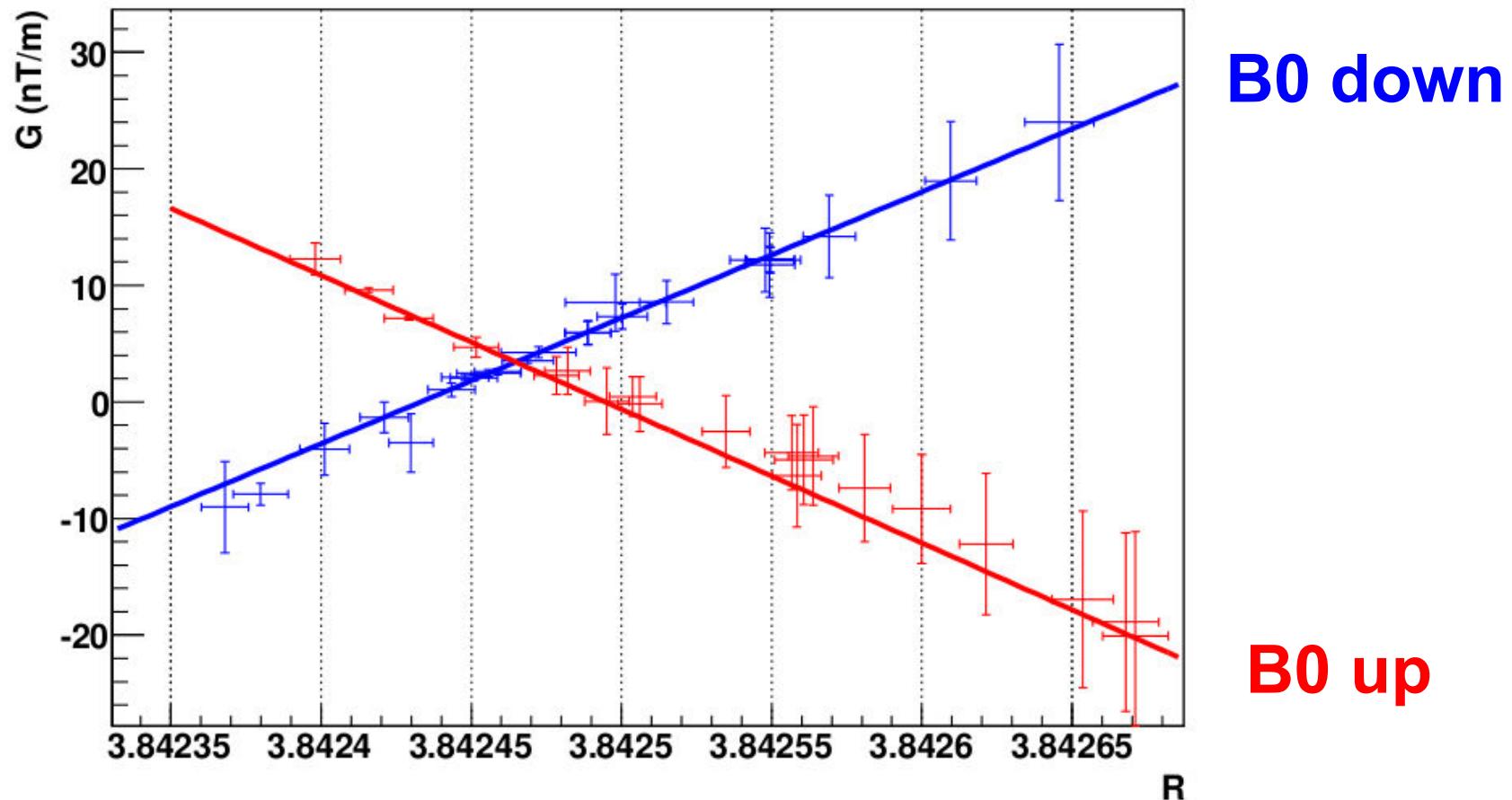
correlation $T_1-T_{2'}$, cycle 153



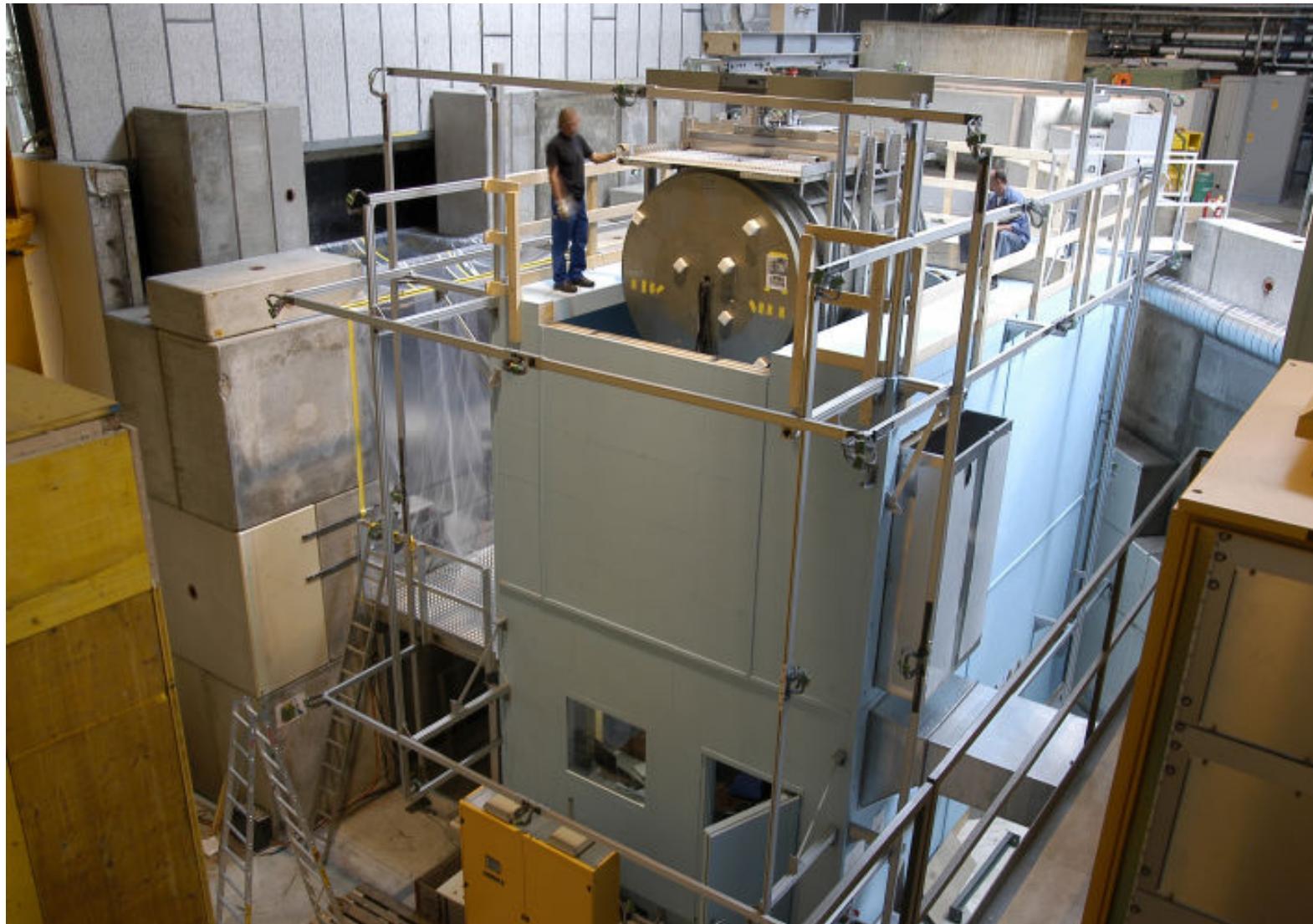
Gravitational effect measured at ILL

R depends on vertical gradients

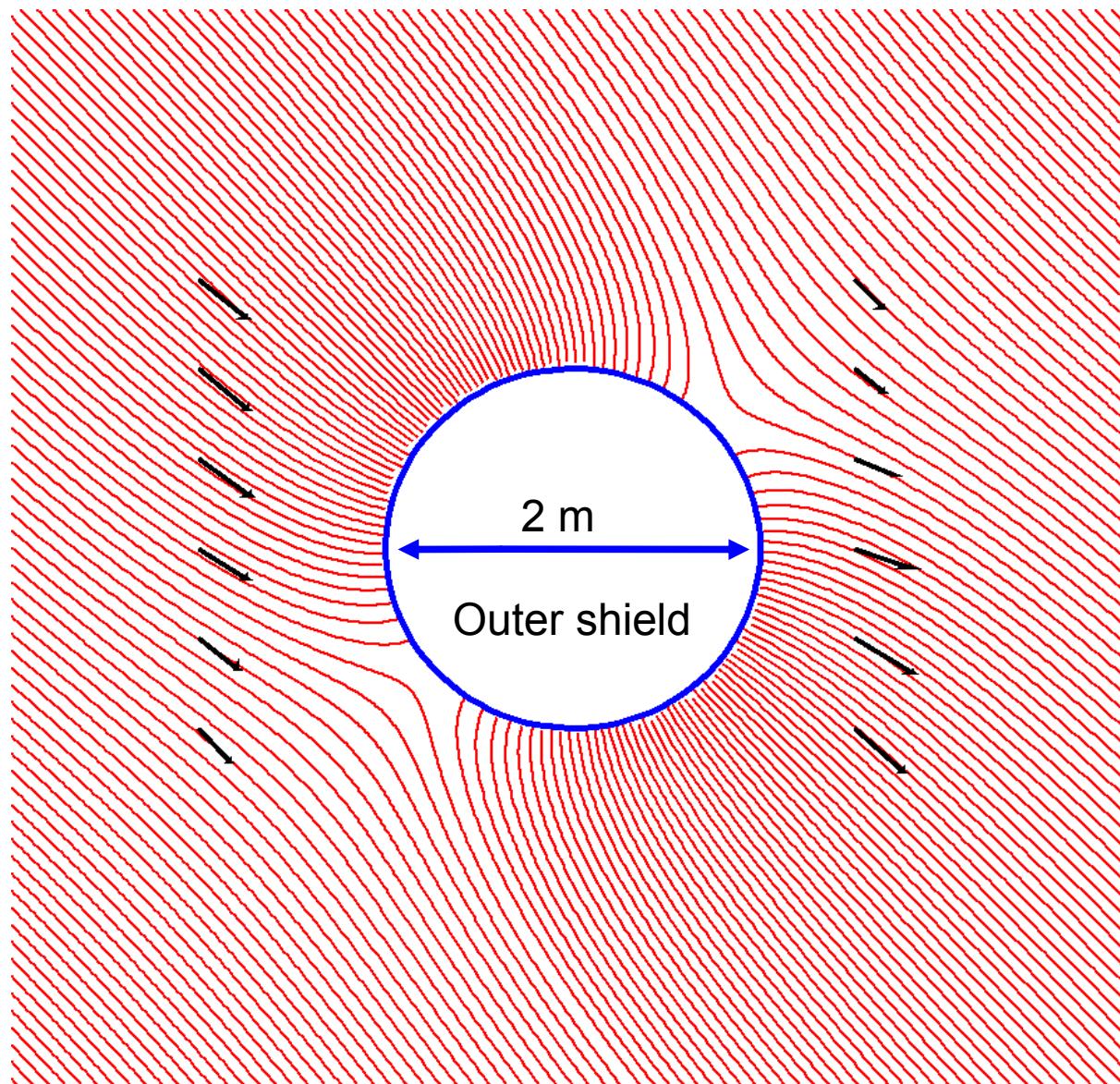
$$R = \frac{\gamma_n}{\gamma_{Hg}} \left(1 - \frac{(\partial B / \partial z)h}{B} \right)$$



PSI, 2009 characterisation of the shield

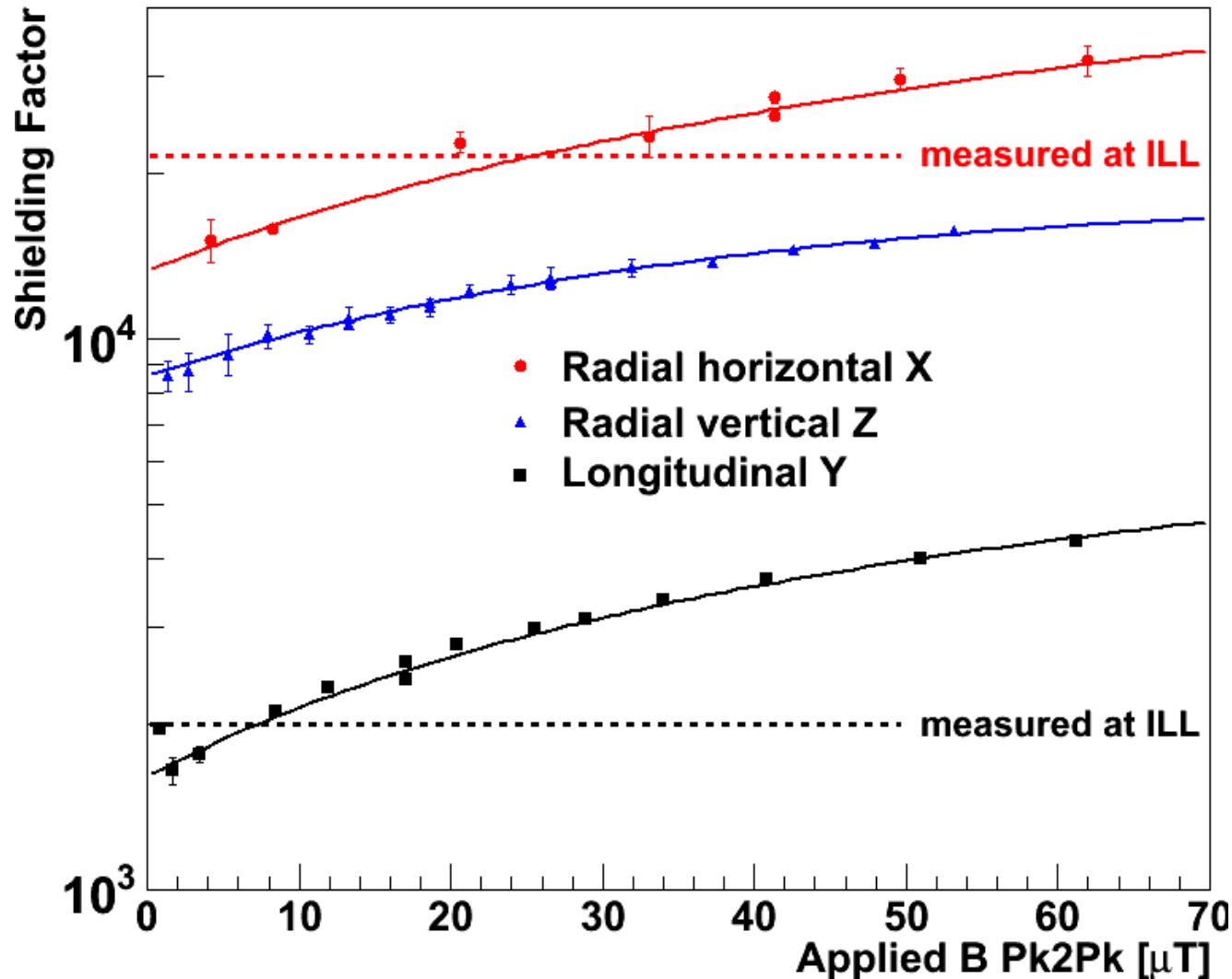


Measurements outside the shield



Magnetic field lines
calculated for
Infinite μ
Infinite cylinder

Investigations on shielding factors



The shield was not damaged during her trip to PSI

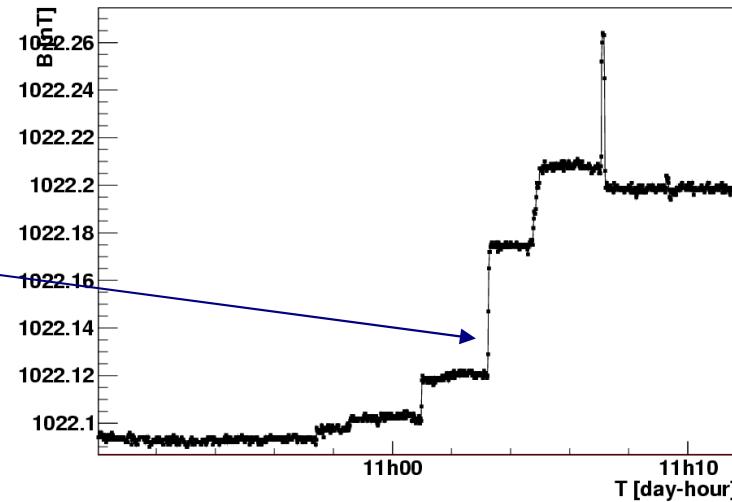
For small perturbations
 $S_X = 13\ 300 \pm 600$
 $S_Y = 1\ 600 \pm 20$
 $S_Z = 8\ 600 \pm 300$

$S_Z < S_X$
Probably due to bottom and top holes

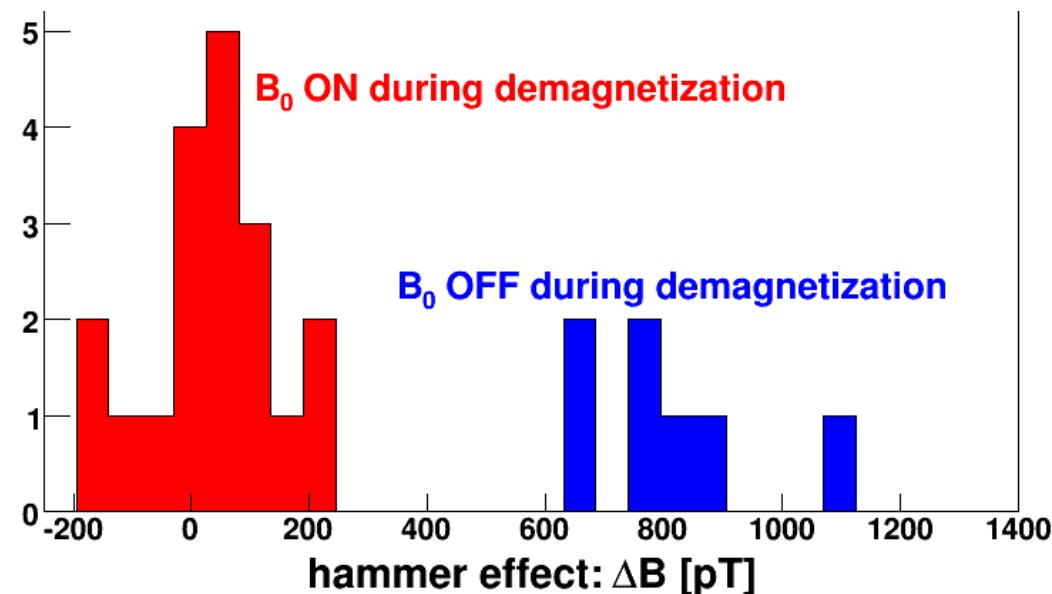
Demagnetization, mechanical stability



cesium 2 in time from Map14112009_104522_P1m.txt

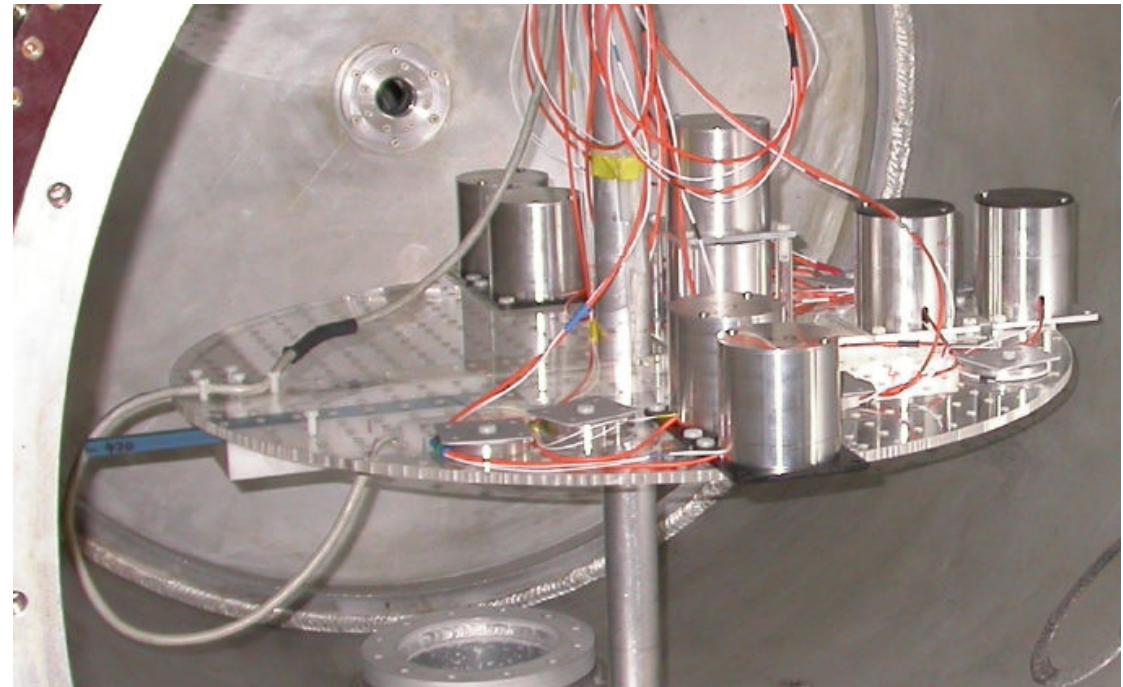


Shocks provoke jumps in the internal B field.
Effect suppressed by 10 by changing the demagnetization procedure



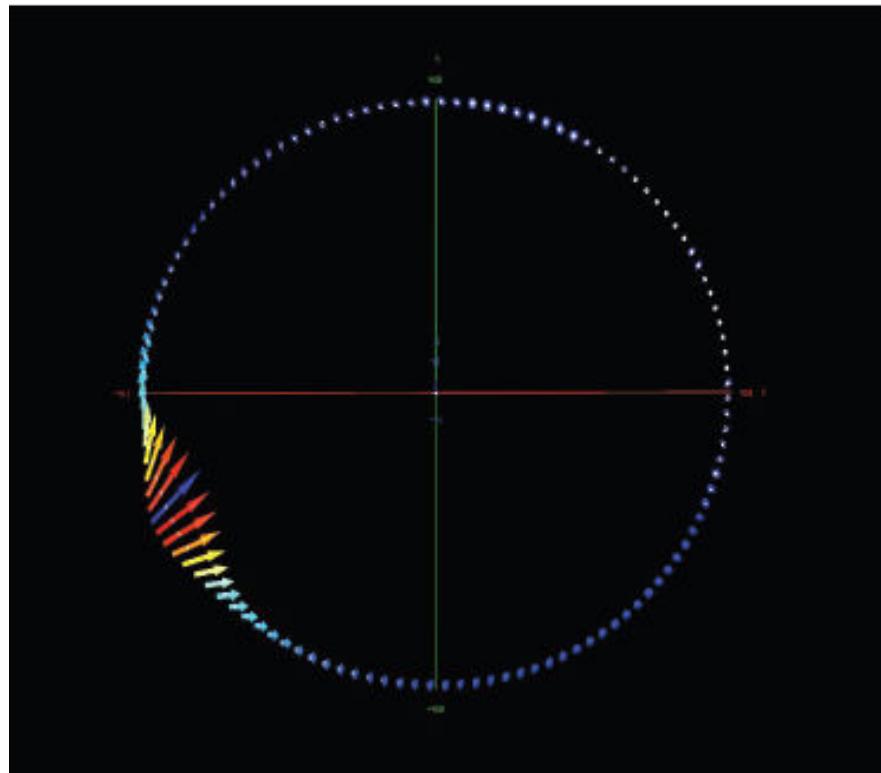
Field mapping inside the shield

Vectorial fluxgate

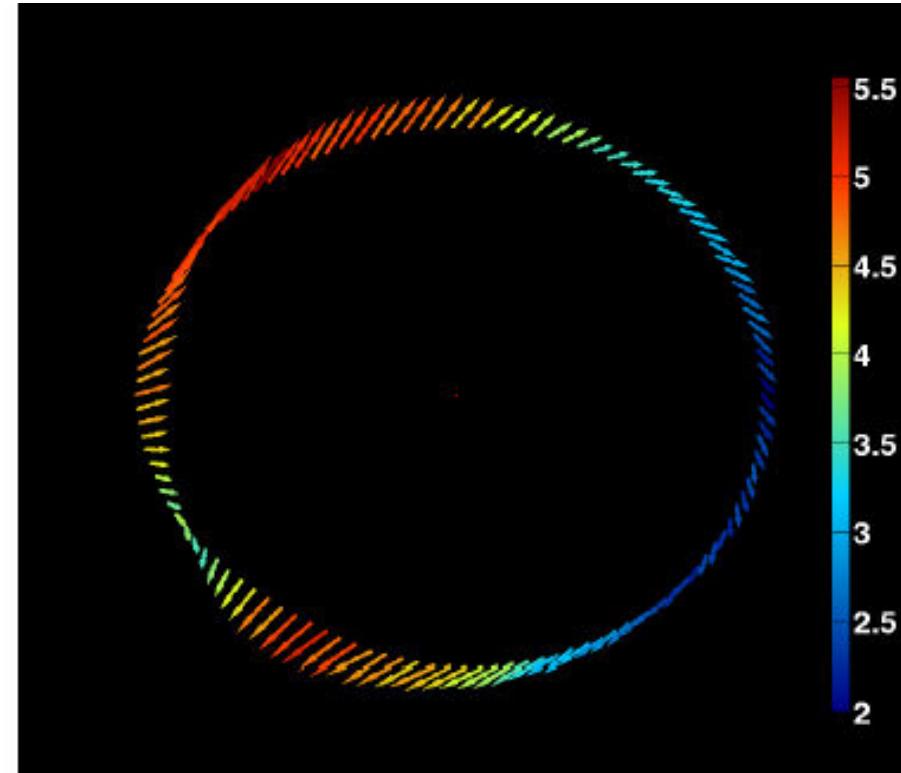


8 Scalar Cesium
magnetometers

Field mapping with the fluxgate

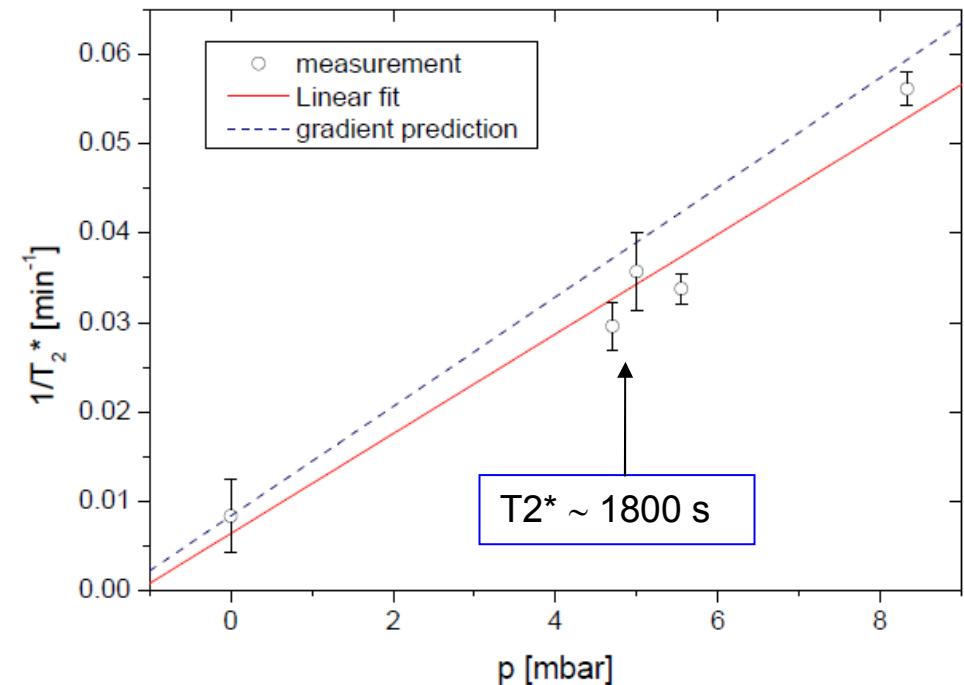
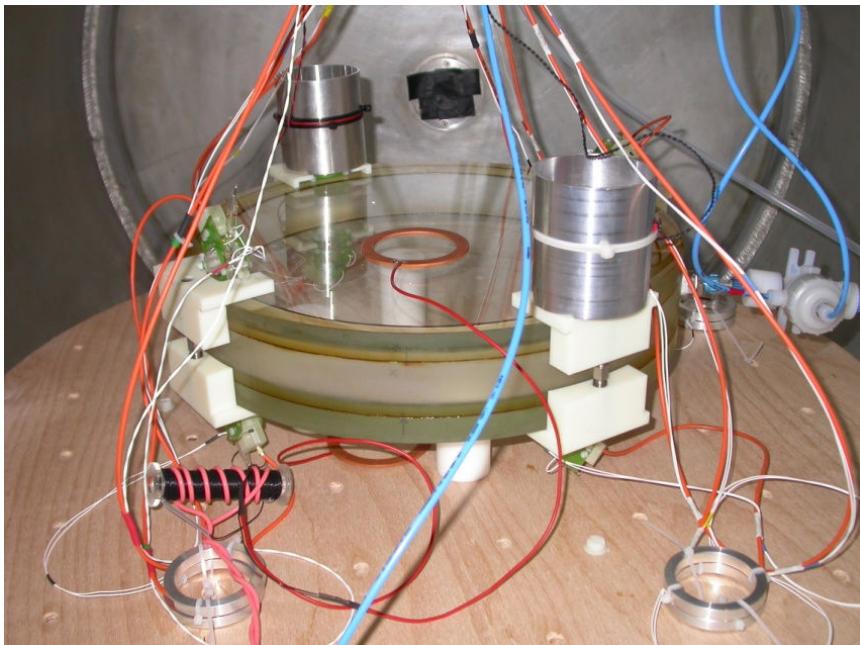


Before removing a
magnetic nut
 $B_{max} = 60$ nT
At radius 40 cm



After removing the
magnetic nut
 $B_{max} = 5$ nT
At radius 40 cm

3He depolarization measurement

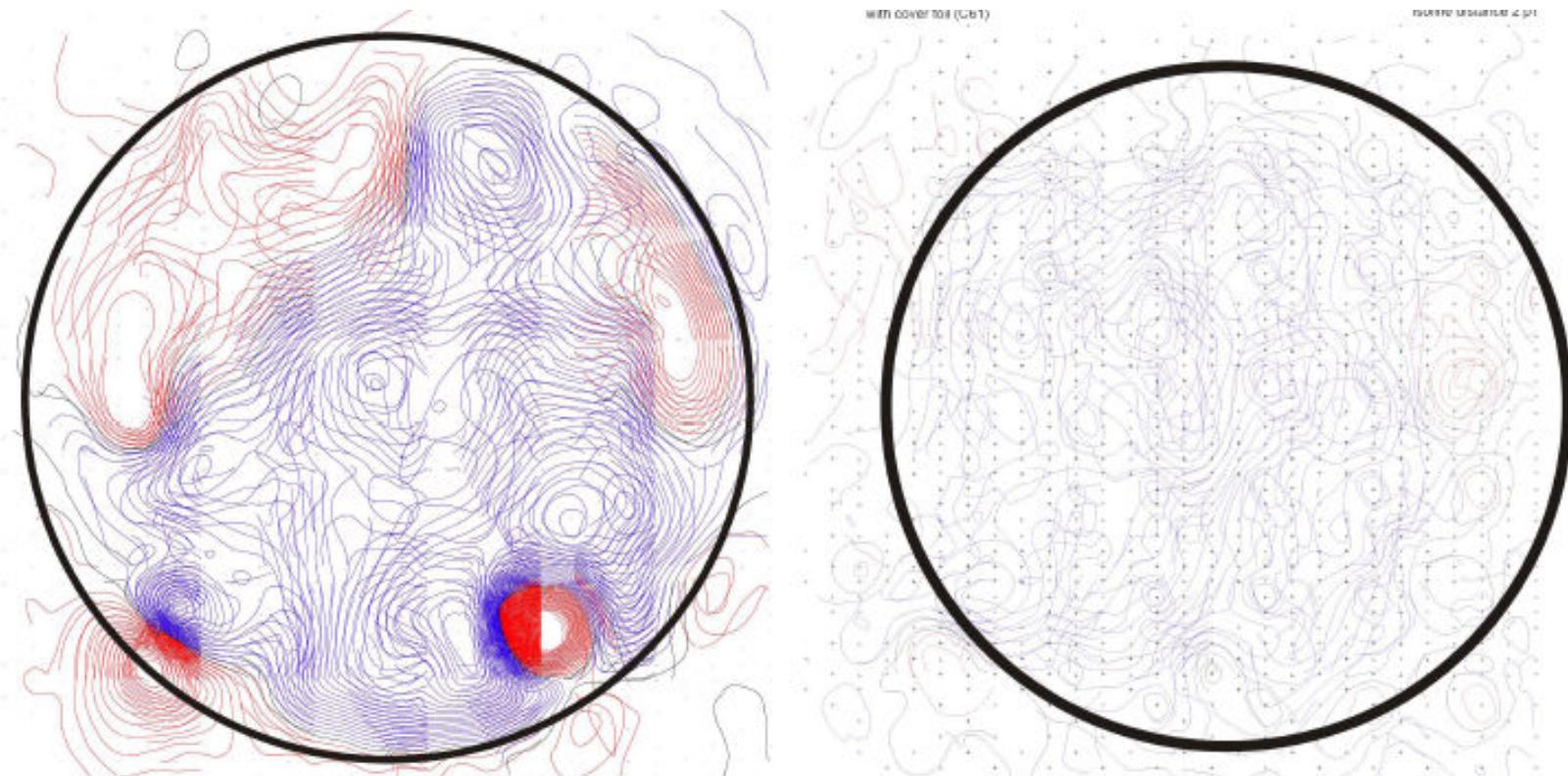


$$\frac{1}{T_2^*} = \frac{1}{T_1^{\text{wall}}} + \frac{\gamma^2 h^4}{120D} \left(\frac{\partial B_{0z}}{\partial z} \right)^2 + \frac{7\gamma^2 R^4}{96D} \left[\left(\frac{\partial B_{0z}}{\partial x} \right)^2 + \left(\frac{\partial B_{0z}}{\partial y} \right)^2 \right]$$

B0 = 1 μT is homogeneous at the level of 0.5 nT over the storage volume

Magnetism removal in BMRS2 Berlin

Bottom electrode field map at 3 cm distance



Before demagnetization
 $B_{\text{max}} = 200 \text{ pT}$

After demagnetization
 $B_{\text{max}} = 20 \text{ pT}$

OILL is upgraded

OLD

Concept
Magnetic shield

PARTIALLY NEW

Storage chamber
B0 coil and correction coils
Hg comagnetometer

BRAND NEW

UCN detectors
Spin polarization & analysis
Demagnetization stuff
HV stuff
Electronics & software
Vacuum system
Surrounding field compensation huge coils

Conclusions, our project

Phase I: OILL at ILL

OILL is working again.

EDM runs for 6 days

$$d_n = (-3 \pm 3) \times 10^{-25} \text{ e cm}$$

Test of Lorentz invariance

$$b < 2 \times 10^{-20} \text{ eV}$$

Phase II: OILL at PSI (2009-2012)

Statistics x100

Goal:

$$d_n < 5 \times 10^{-27} \text{ e cm}$$

Phase III: build a new nEDM spectrometer

Shield funded.

Goal:

$$d_n < 5 \times 10^{-28} \text{ e cm}$$