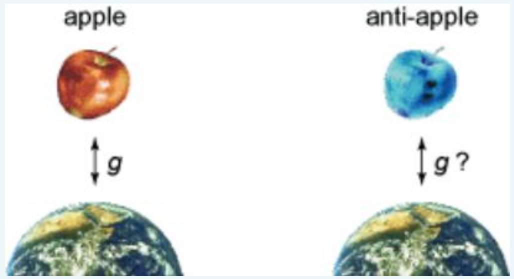
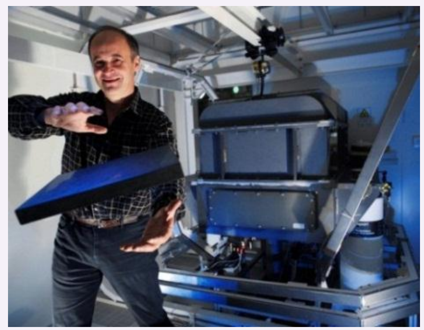
Low energy physics program

AEgIS
GBAR



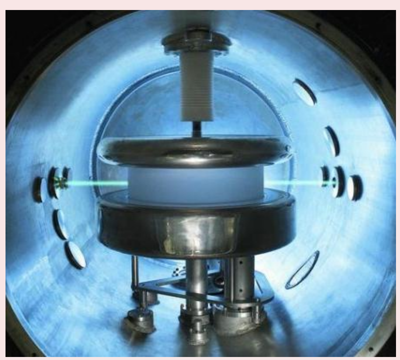
Direct measurement
free fall of antimatter

Gravity
with quantum objects



GRANIT

nEDM



Search for the neutron electric dipole moment to explain the matter-antimatter asymmetry

Gravity

Ultracold neutrons

Guillaume Pignol (LPSC Grenoble)

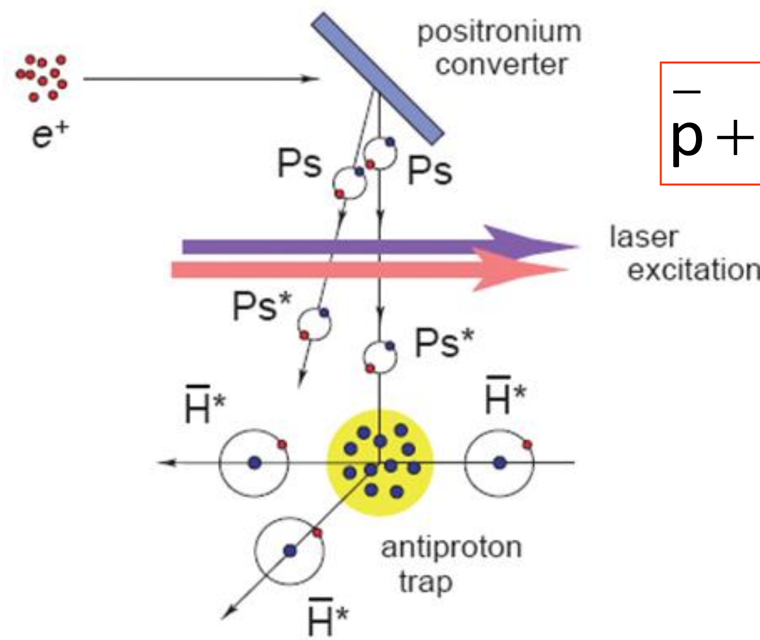
rECFA meeting, Paris, 15 March 2013

Free fall of antihydrogen

Testing the Weak Equivalence Principle

- valid for ordinary macroscopic bodies at the 10^{-12} level
- valid for antimatter at the 10^{-6} level from indirect means: anticlocks, SN1987, $K_0/\overline{K}_0$
- Goal of AEgIS and GBAR: direct free fall measurement of antihydrogen

$\overline{H}$ production at the CERN Antiproton Decelerator (AD)



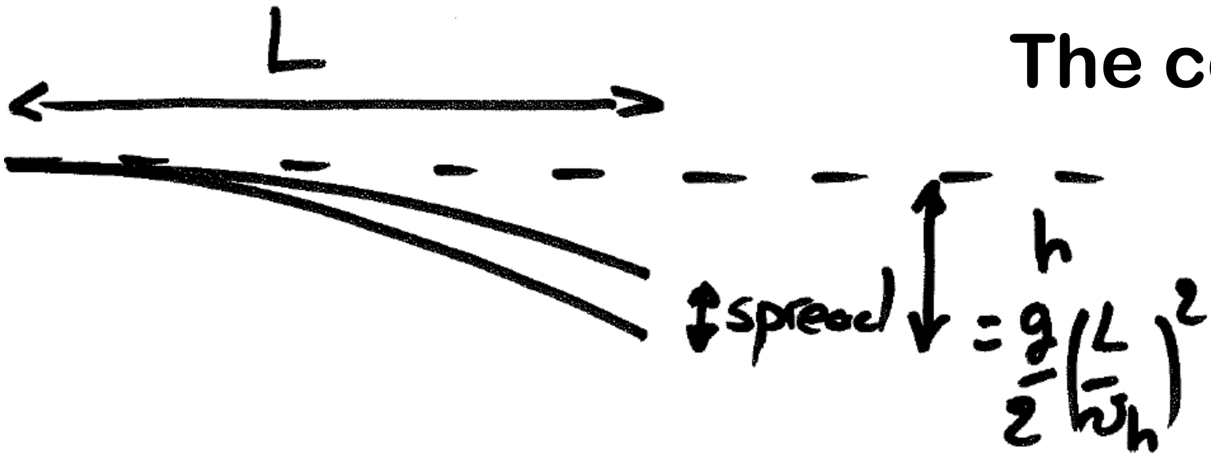
$$\overline{p} + (Ps)^* \rightarrow \overline{H}^* + e^-$$

Pulsed 5 MeV antiprotons

10^7 particles every 100 s

extracted $\overline{H}$
1 per second ?

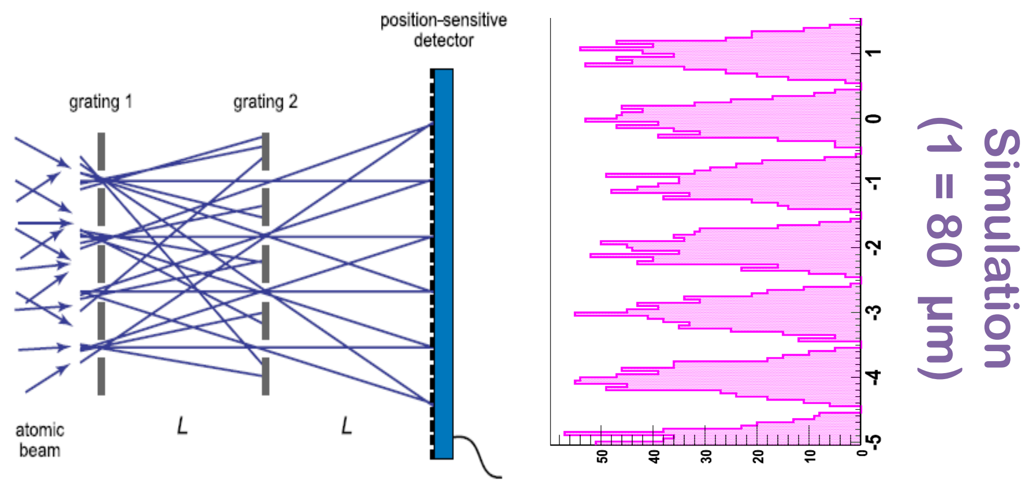
The colder, the better



AEgIS, production of cold antihydrogen out of 100 mK antiprotons

v_T = 50 m/s, v_H = 500 m/s

L = 1 m ➔ h = 20 µm



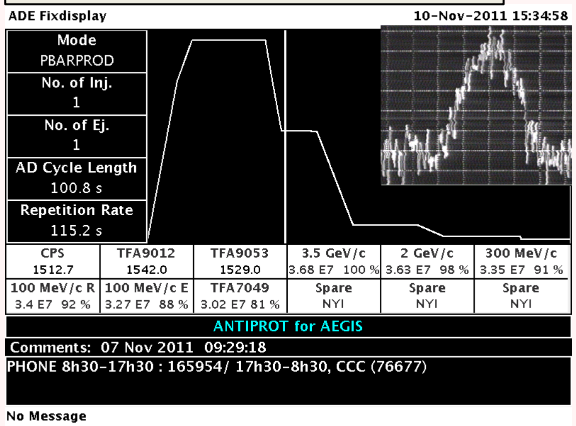
GBAR, cooling trapped Hbar+ to produce ultracold (15 µK) antihydrogen

$v_T = v_H$ = 0.5 m/s

L = 0.1 m ➔ h = 20 cm

Antimatter Experiment – Gravity – Interferometry - Spectroscopy (AEgIS)

First AEGIS pbar signal – 2011



Agenda

2013 (pbar beam off) : oPs, protons

2014 Hbar production at 100 mK

2015 first free fall measurement

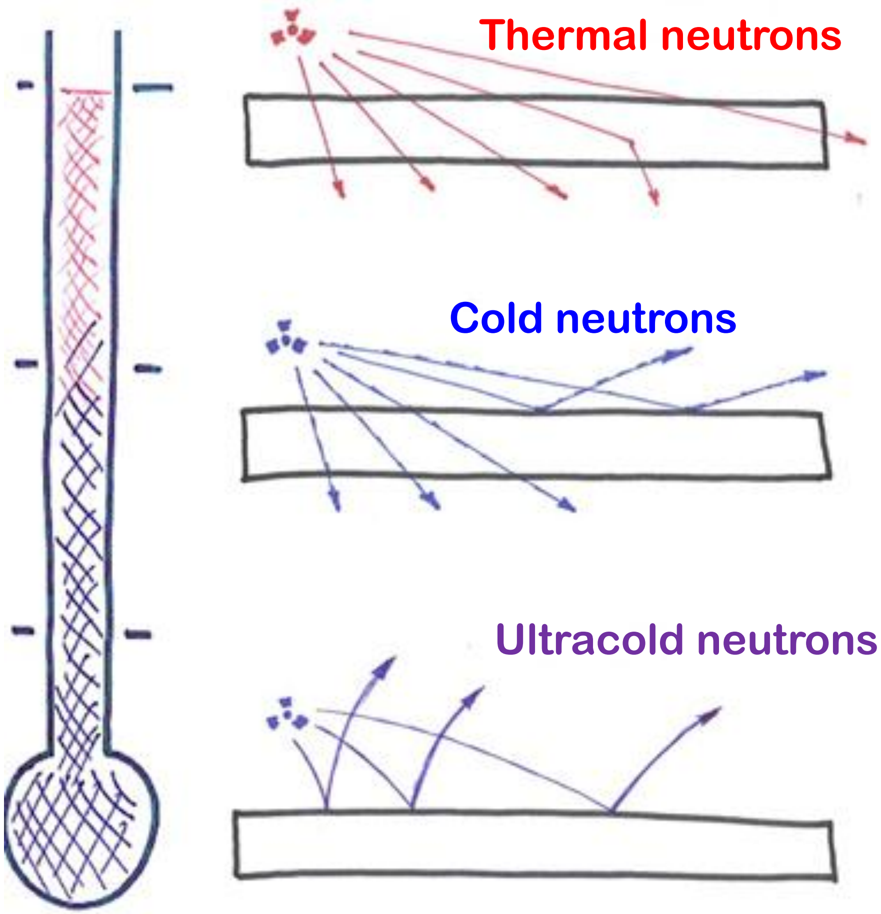
GBAR

2015 installation

2016 ELENA proton commissioning

2017 first antiprotons, measure Hbar+

Ultracold neutrons (UCN)



Neutrons with energy < 100 neV,
or velocity < 5 m/s

are reflected by material walls

UCNs feel gravity

$$mg \times (1\,\mathrm{m}) = 100\ \mathrm{neV}$$

GRANIT to measure the bouncing quantum states

UCNs can be stored in bottles for very long times (1000 s)

precision measurement of the neutron electric dipole moment (nEDM)

UCN sources in Europe

ILL 58 MW high flux reactor

- PF2 instrument, since 1985

UCNs extracted from 20K moderator
2 UCN/cm^3 in EDM experiment

- Superfluid He source for GRANIT

first UCN in 2010,
now 4/cm^3, 100/cm^3 possible

PSI 600 MeV, 2.5 mA proton beam

→lead spallation target

→solid deuterium UCN convertor

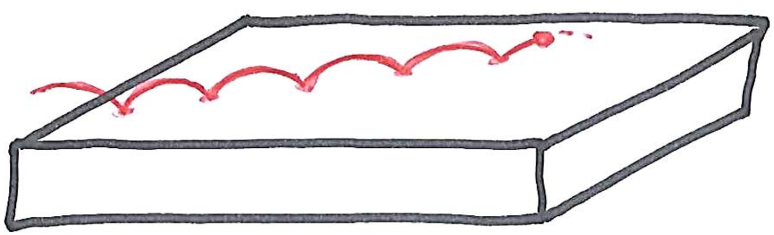
First UCN in 2010

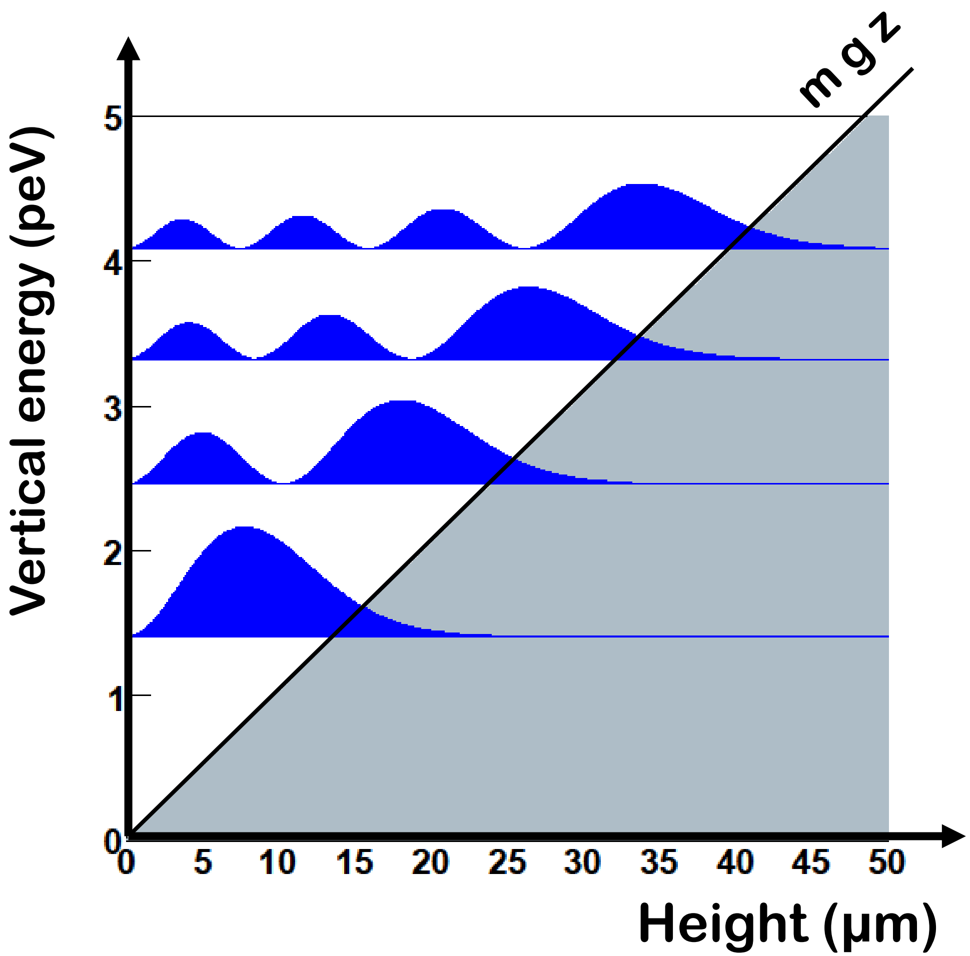
Designed for 50/cm^3 in EDM experiment
Now 2/cm^3

Bouncing neutrons: quantum states

Neutrons with energy < 100 neV

can bounce above a glass mirror.

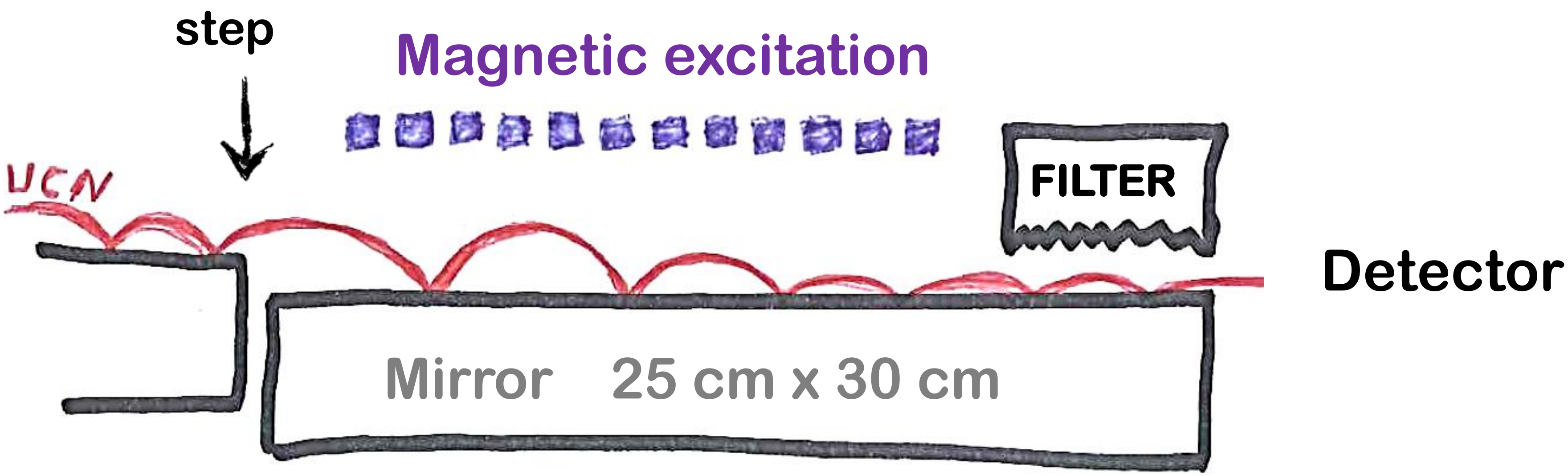


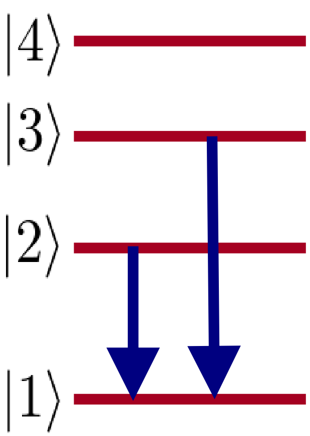


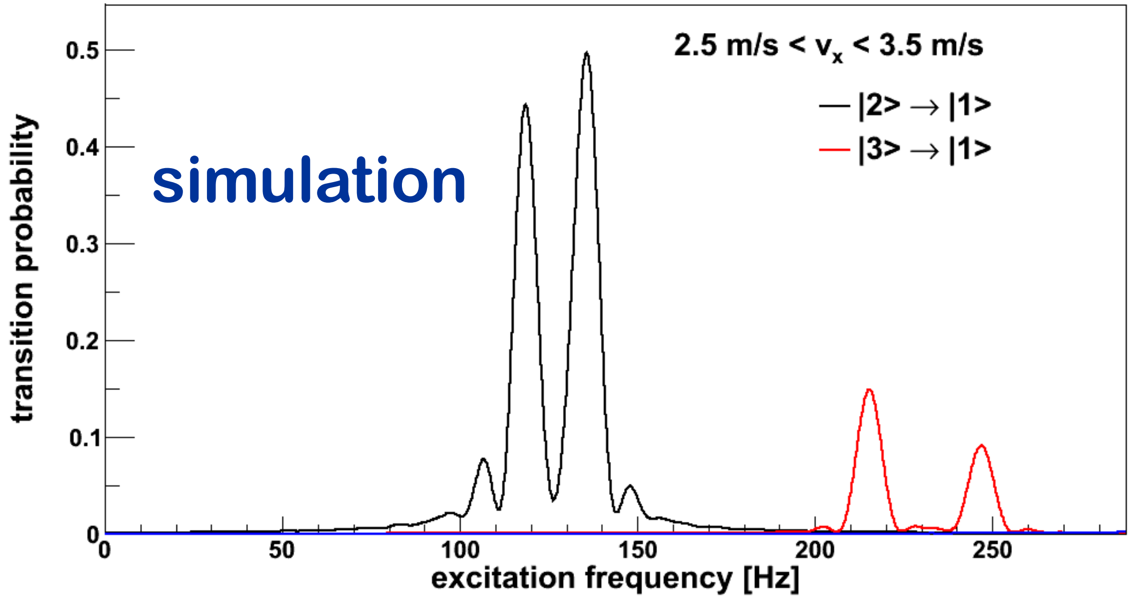
The vertical motion is a simple quantum well problem

$$-\frac{\hbar^2}{2m}\frac{d^2\psi}{dz^2} + mgz\,\psi = E\,\psi$$

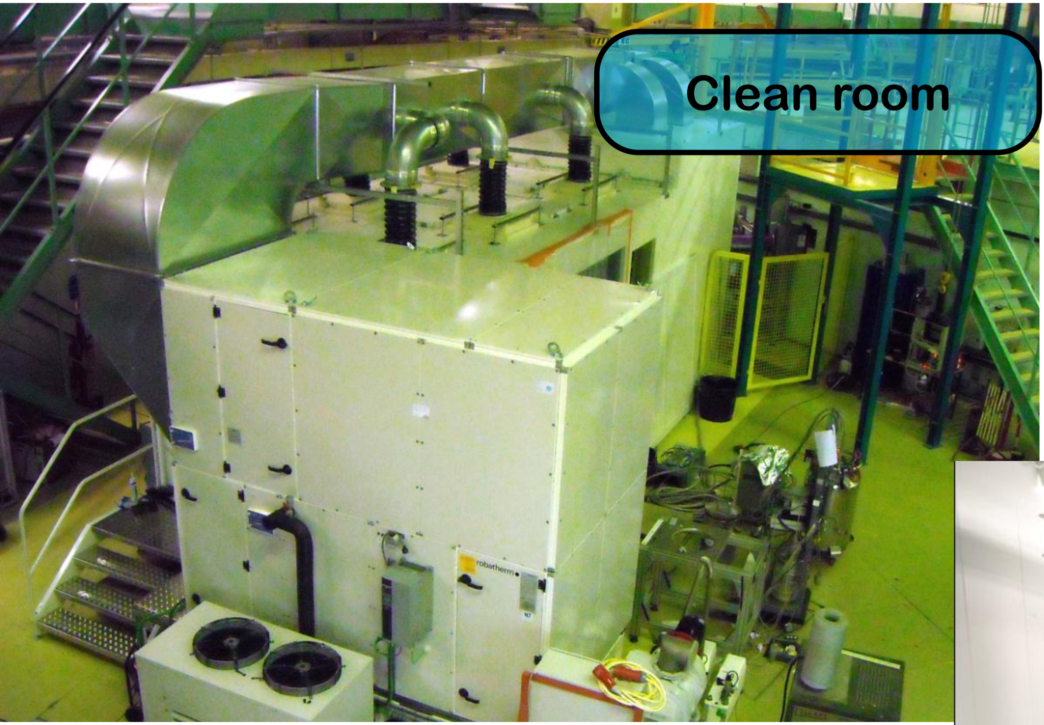
Resonant transitions

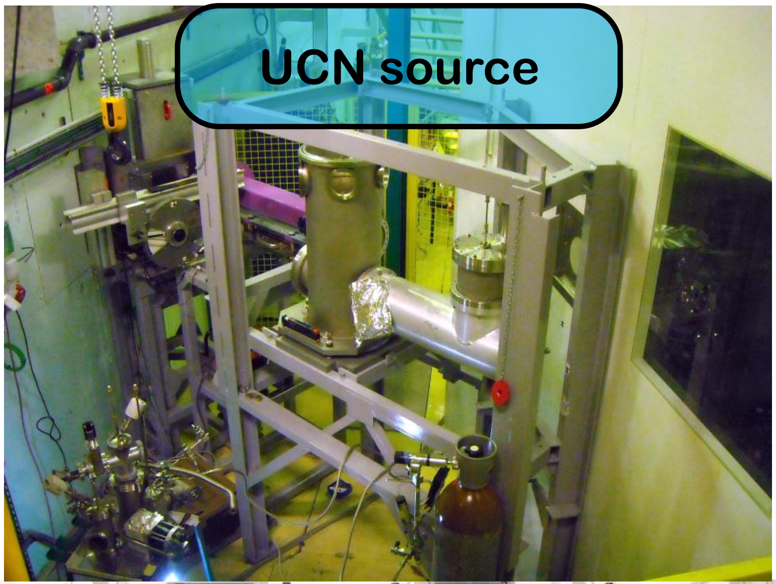


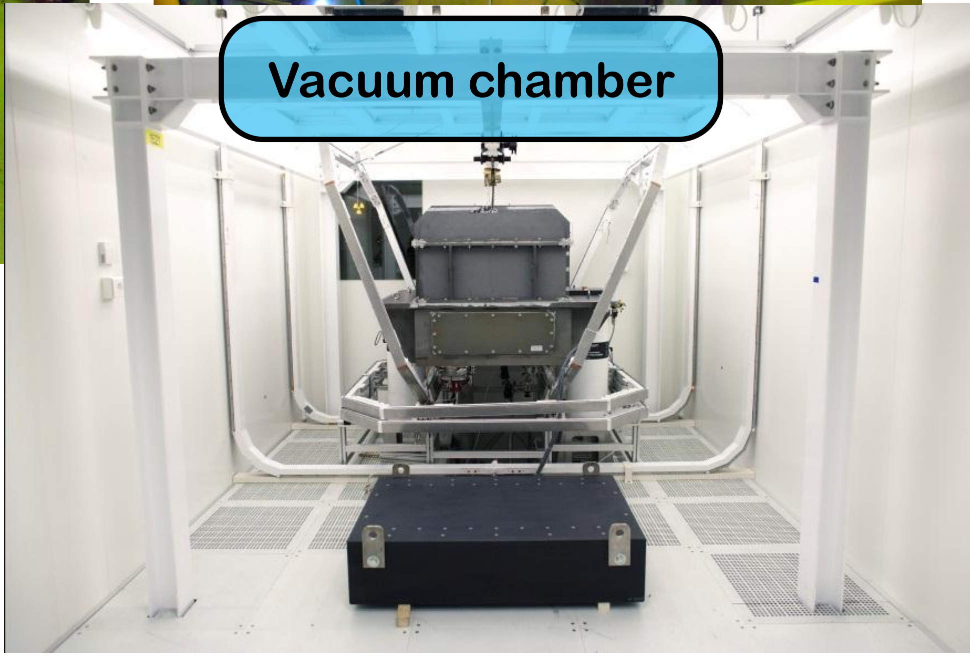




The GRANIT instrument
at the Institut Laue Langevin







Agenda

2012 Commissioning UCN source

2013 Connect source to GRANIT

2014 Physics run

nEDM to probe electroweak baryogenesis

Sakharov conditions
at electroweak phase transition

1 Departure from thermal equilibrium

requires BSM scalar sector
to get a strong first order transition.
May or may not be accessible at the LHC

2 CP violation

requires BSM physics,
accessible by the next generation of EDM experiments

3 Violation of B conservation

SM sphaleron transitions in the symmetric phase

Example: minimal electroweak baryogenesis

Huber, Pospelov, Ritz 2007

$$\mathcal{L}_{\rm dim-6} = \frac{1}{\Lambda^2}(H^\dagger H)^3 + \frac{Z_t}{\Lambda^2}(H^\dagger H)t^c H Q_3,$$

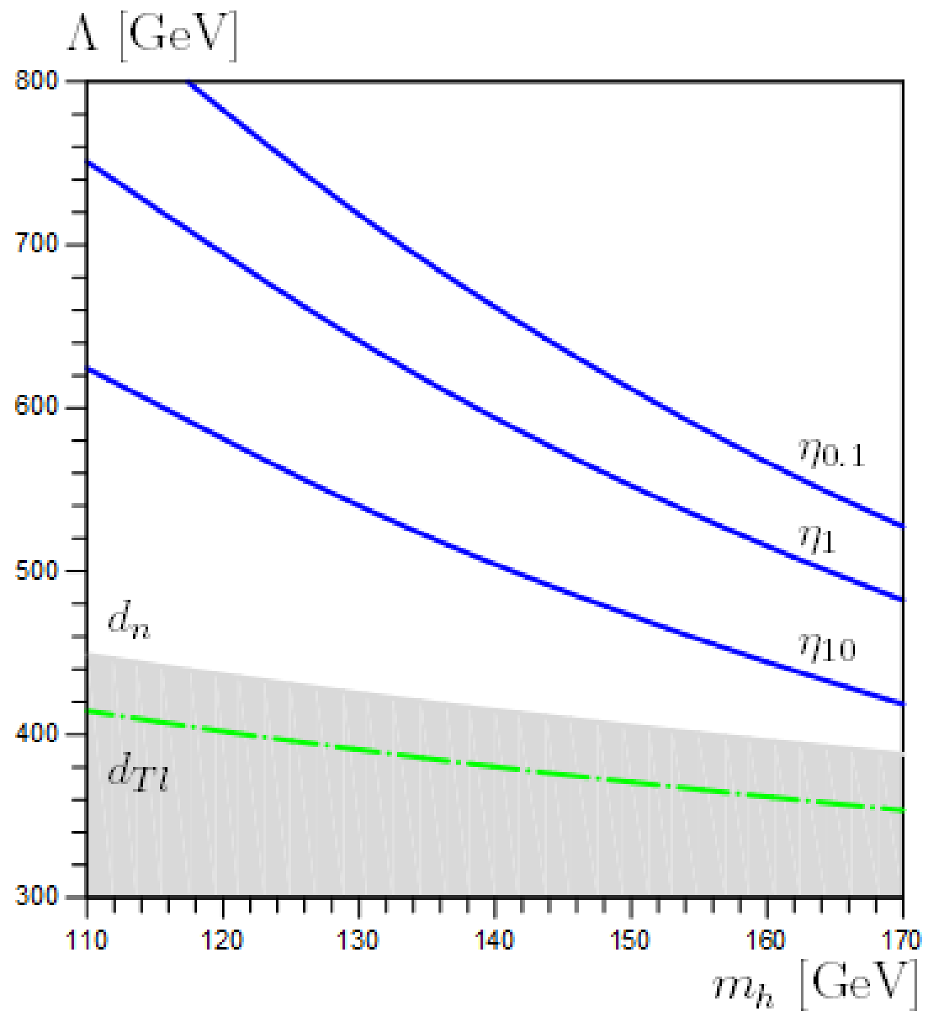
Makes the phase transition strongly first order

CP violation

Prediction for 126 GeV Higgs

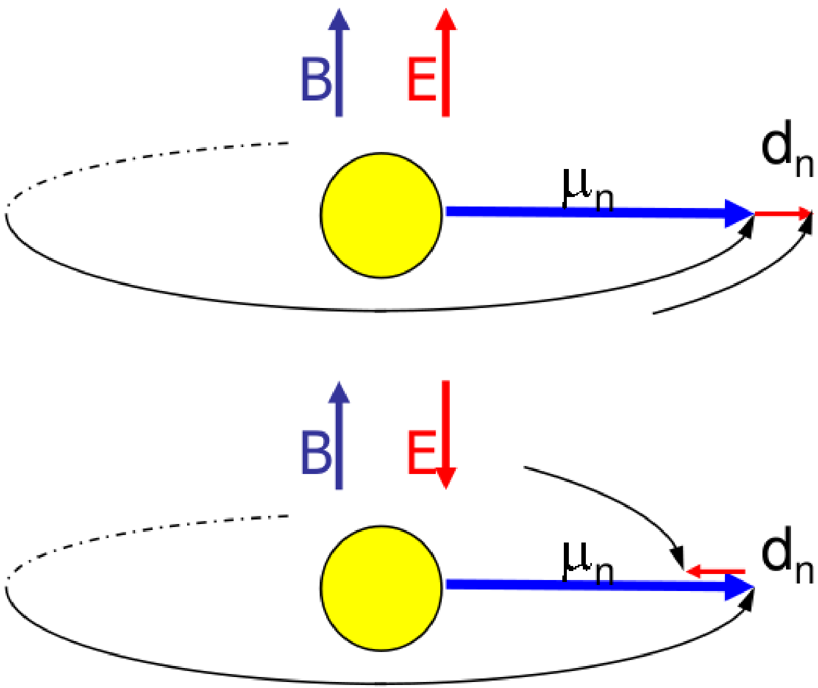
nEDM = 1.3 x 10^{-26} e cm

(Current limit at 3 x 10^{-26} e cm)



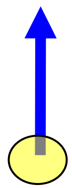
Principle of the nEDM measurement

$$H = -\vec{\mu_n} \cdot \vec{B} - \vec{d_n} \cdot \vec{E} = h\nu_L/2$$

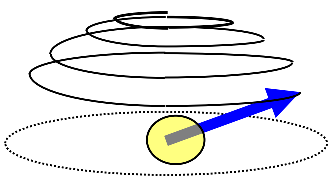


$$\nu_L(\uparrow\uparrow) - \nu_L(\uparrow\downarrow) = -\frac{4d_n}{h}E$$

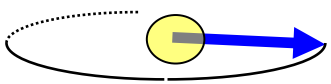
The Ramsey method



"Spin up" neutron...

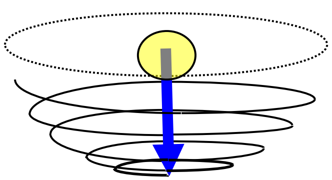


Apply $\pi/2$ spin-flip pulse...

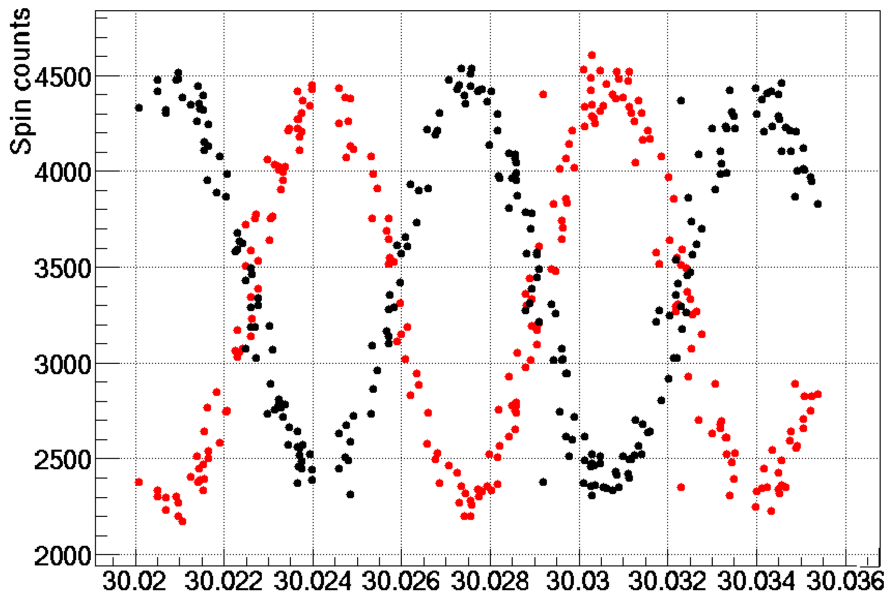


Free precession...

T ~ 200 s



Second $\pi/2$ spin-flip pulse



Applied pulse frequency [Hz]

$$\sigma d_n = \frac{\hbar}{2\,\alpha\,E\,T\,\sqrt{N}}$$

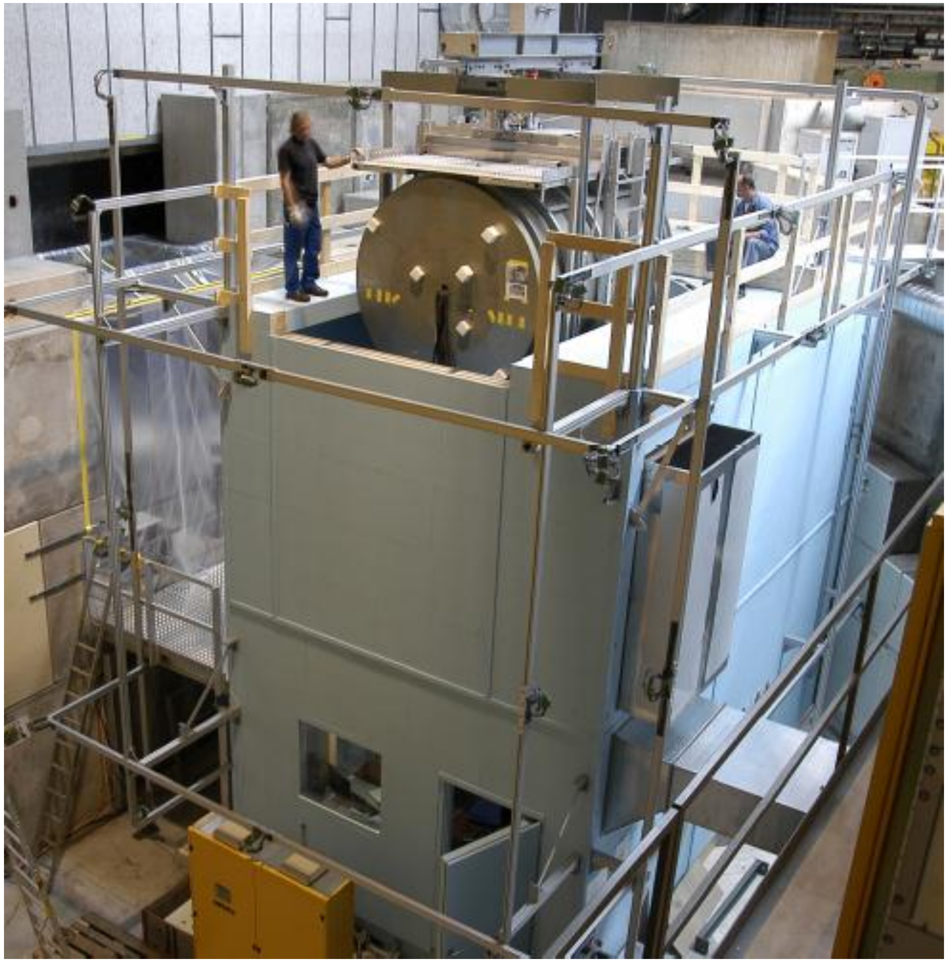
polarization (→ α)

electric field (→ E)

precession time (→ T)

counts (→ N)

Current nEDM apparatus at PSI



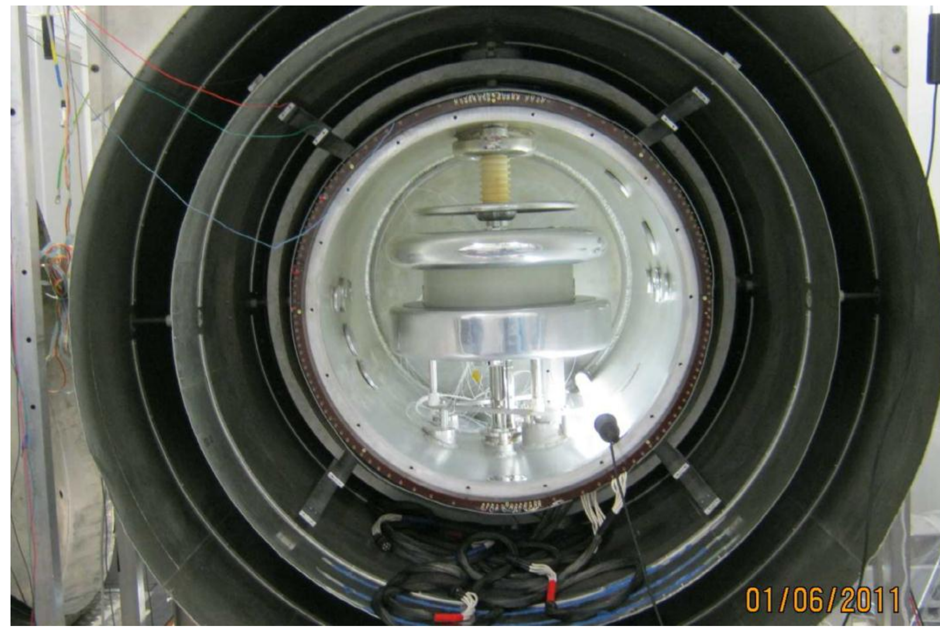
OILL apparatus moved from ILL to PSI in 2009

Shielded magnetic environment

$B_0 = 1\ \mu T$

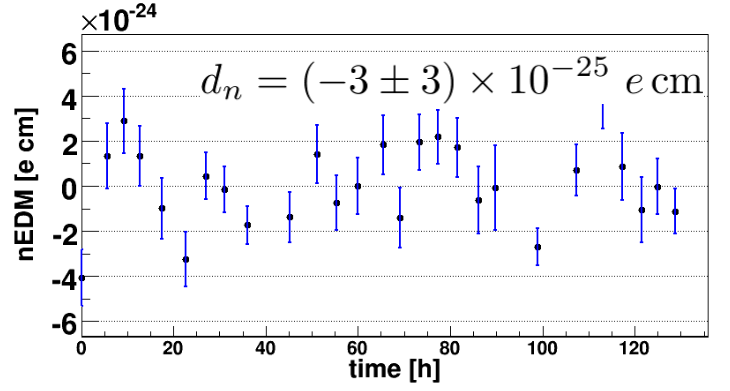
Homogeneity < 10^{-3}

Time stability < 10^{-6}



Electric field 150 kV / 12 cm

nEDM@PSI project



Phase I (2005-2009)
Upgrade the apparatus at ILL

Phase II (2009-2015)
Apparatus installed at PSI
Start datataking 2013

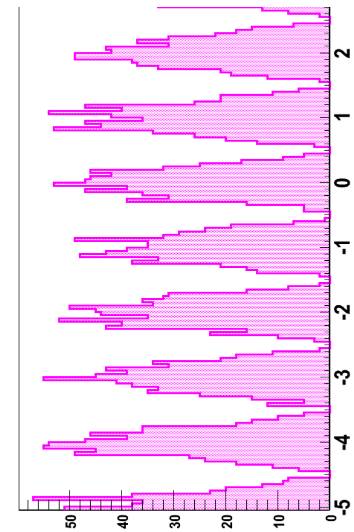
Sensitivity goal
1×10^{-26} e cm

Phase III (2015-2022)
Build new apparatus

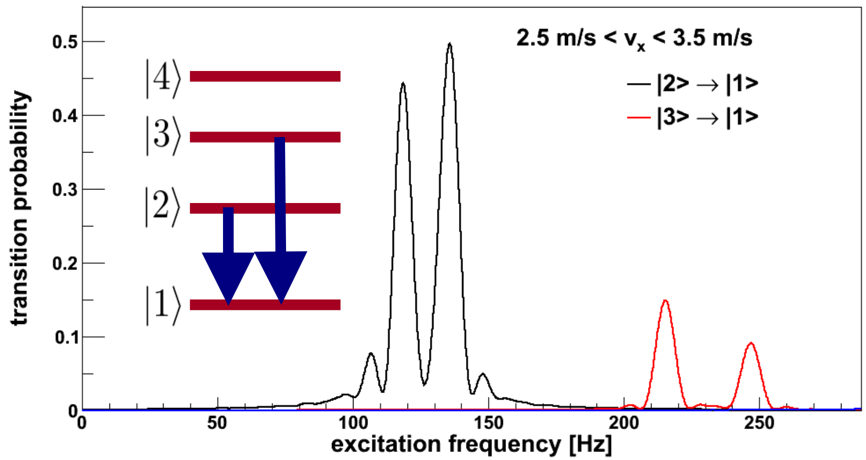
- **double chamber**
- **Increase E field**
- **larger magnetic shield**

Sensitivity goal
1×10^{-27} e cm

Conclusion: by the next rECFA meeting we should

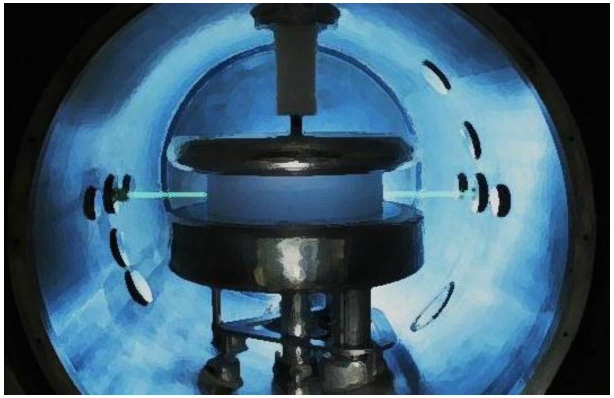


1 Have seen the free fall of antihydrogen



2 observe transition frequencies of the neutron bouncer with GRANIT

3 measure nonzero nEDM or exclude simple scenarios for EW baryogenesis



Laboratories / Experiments

Experiments	French Laboratories
AEgIS	Université Claude Bernard, Lyon Laboratoire Aimé Cotton, Orsay
GBAR	Laboratoire Kastler Brossel, Paris CSNSM, Orsay CEA IRFU, Saclay ILL, Grenoble
GRANIT	ILL, Grenoble LPSC, Grenoble LMA, Lyon
nEDM	LPC, Caen LPSC, Grenoble CSNSM, Orsay
Cern Axion Solar Telescope	CEA IRFU, Saclay
Neutron lifetime	LPC, Caen
Vacuum Magnetic Birefringence	LNCMI, Toulouse