PostDoc: searches for short-range forces with the new GRANIT spectrometer

NEUTRONS FOR SCIENCE

Granit — Gravitational Neutron Induced Transitions

1. **Gravitational and centrifugal quantum states of slow neutrons** (worldwide known experiments («The best work in the world» in 2002 by the Hendrik de Waard foundation, «Event of the Day in the world» by NASA, chapters in major textbooks etc) with numerous applications in solid state physics and quantum optics)
2. **Status of the new GRANIT spectrometer at ILL** (Agreement ILL-LPSC(IN2P3/CNRS-UJF) on the GRANIT instrument is signed in February 2012; the GRANIT spectrometer, in its minimal configuration, has been constructed; first successful cooling of the GRANIT UCN source in February 2012; first neutron tests are in progress)
3. **Scientific motivations** (ultimate sensitivity for spin-dependent and spin-independent fundamental short-range forces; more motivations in a dedicated issue of Compt. Rend. Physique 12 (2011) 703, in materials of a dedicated GRANIT-2010 workshop, and in [P. Brax, G. Pignol, Phys. Rev. Lett. 107 (2011) 111301]
4. **The best time for science at GRANIT: 7 years of development and construction work, several orders of magnitude increase in sensitivity**

Gravitational and centrifugal quantum states of neutrons

Quantum states of neutrons in the Earth's gravitational field

Valery V. Nesvizhevsky*, Hans G. Börner*, Alexander K. Petukhov*, Hartmut Abele†, Stefan Baeßler†, Frank J. Rueß†, Thilo Stöferle†, Alexander Westphal†, Alexei M. Gagarski‡, Guennady A. Petrov‡ & Alexander V. Strelkov§

* *Institute Laue-Langevin, 6 rue Jules Horowitz, Grenoble F-38042, France*
† *University of Heidelberg, 12 Philosophenweg, Heidelberg D-69120, Germa*
‡ *Petersburg Nuclear Physics Institute, Orlova Roscha, Gatchina, Leningrad R-188350, Russia*
§ *Joint Institute for Nuclear Research, Dubna, Moscow reg. R-141980, Russi*

The discrete quantum properties of matter are manifest in a variety of phenomena. Any particle that is trapped in a sufficiently deep and wide potential well is settled in quantum bound states. For example, the existence of quantum states of electrons in an electromagnetic field is responsible for the structure of atoms[16], and quantum states of nucleons in a strong nuclear field give rise to the structure of atomic nuclei[17]. In an analogous way, the gravitational field should lead to the formation of quantum states. But the gravitational force is extremely weak compared to the

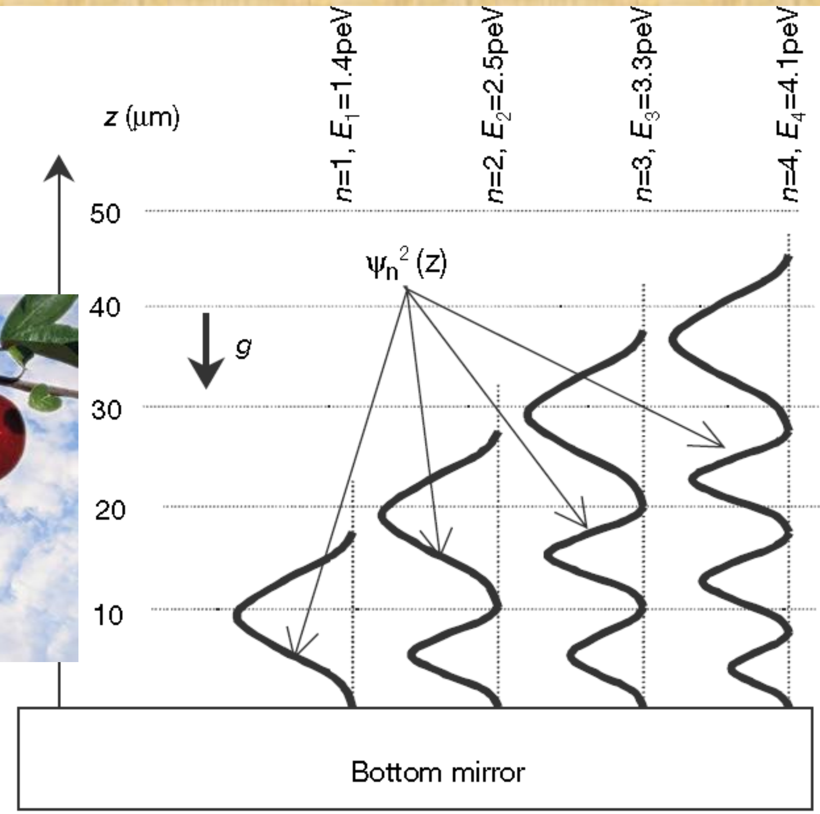

Figure 1 Wavefunctions of the quantum states of neutrons in the potential well formed by the Earth's gravitational field and the horizontal mirror. The probability of finding neutrons at height z, corresponding to the nth quantum state, is proportional to the square of the neutron wavefunction $\psi_n^2(z)$. The vertical axis z provides the length scale for this phenomenon. E_n is the energy of the nth quantum state.

Gravitational and centrifugal quantum states of neutrons

nature physics
LETTERS
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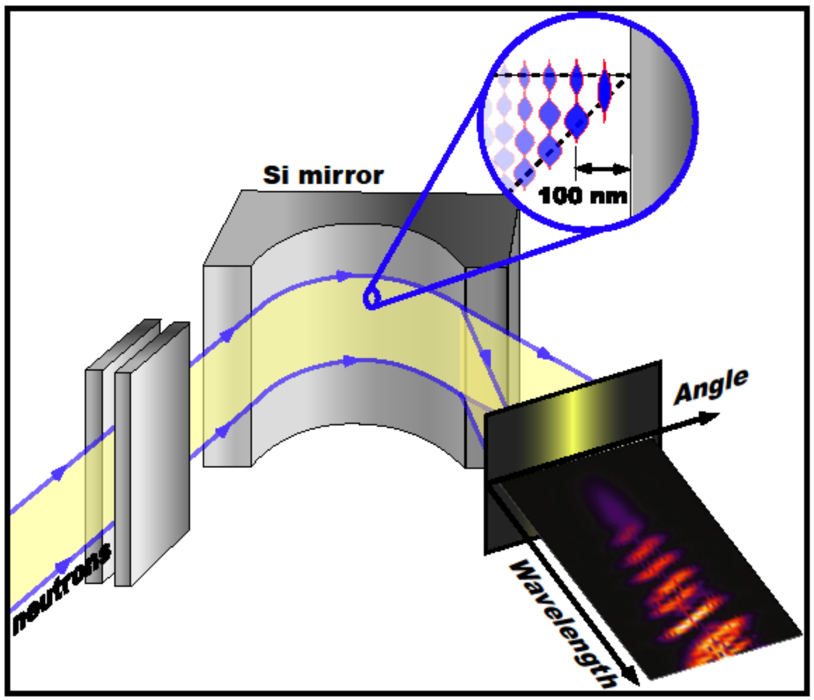
***Nature Physics*, 6,** *114-117 (2010)*

Neutron whispering gallery

Valery V. Nesvizhevsky[1]*, Alexei Yu. Voronin[2], Robert Cubitt[1] and Konstantin V. Protasov[3]



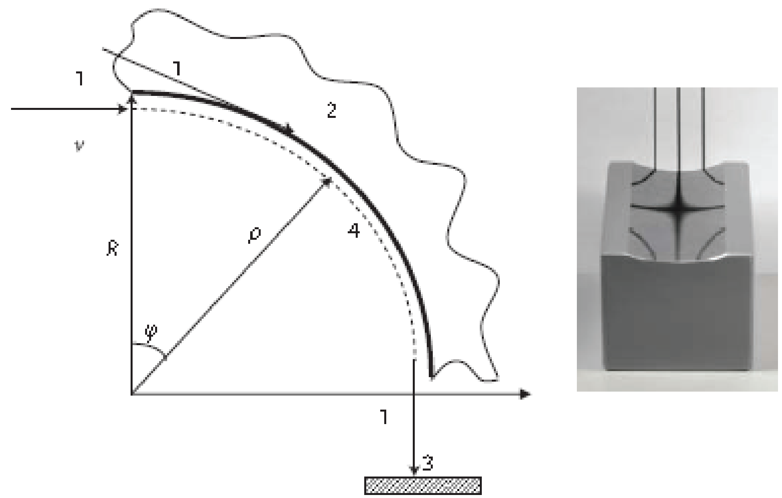


Figure 1 | A scheme of the neutron centrifugal experiment. 1: Classical trajectories of incoming and outgoing neutrons, 2: cylindrical mirror, 3: neutron detector, 4: quantum motion along the mirror surface. Inset: A photo of the single-crystal cylindrical silicon mirror used for the presented experiments, with an optical reflection of black stripes for illustrative purposes.

Gravity / Acceleration

$$E_n \approx \sqrt[3]{\left(\frac{9 \cdot m_n}{8}\right) \cdot \left(\pi \cdot \hbar \cdot g \cdot \left(n - \frac{1}{4}\right)\right)^2}$$

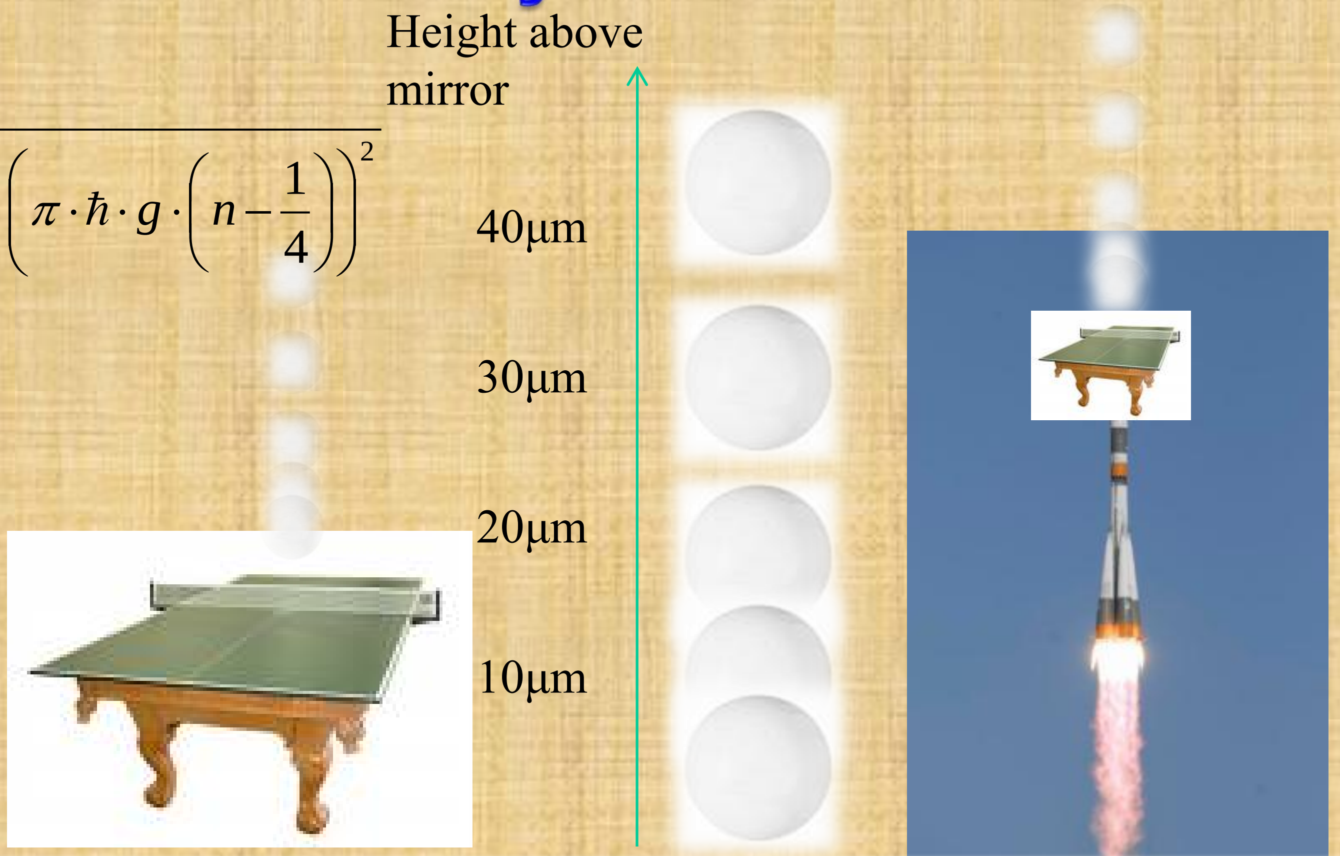


Illustration for quantum motion of an object above a mirror in the gravitational field and that in the accelerating frame. Positions of the ball correspond to the most probable heights of a neutron (or an anti-hydrogen atom) in the 5th quantum state.

Status of the new GRANIT spectrometer at the ILL

Agreement on the GRANIT instrument is signed in February 2012:

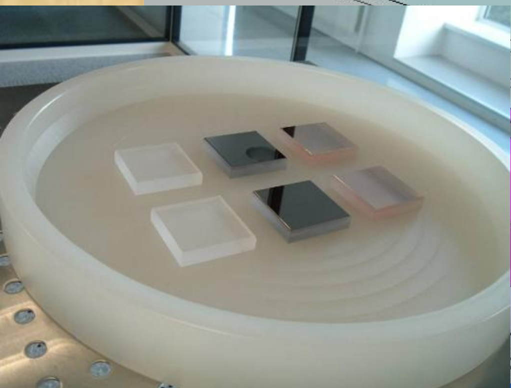
-The Partners are: the ILL , and the CNRS represented by the IN2P3 and the UJF , on behalf of the LPSC, in Grenoble.

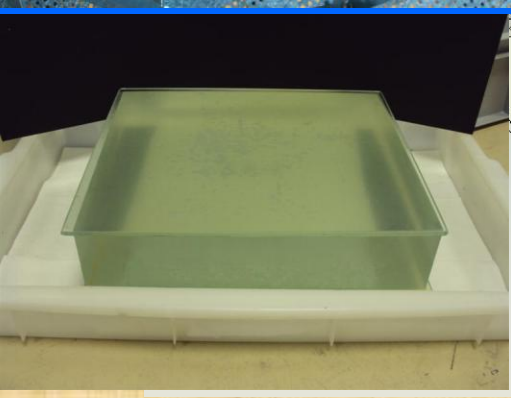
-The key participanting scientists: V.V. Nesvizhevsky, K.V. Protasov, D. Rebreyend, D. Roullier, G. Pignol, and F. Vezzu (+ collaborators from French, USA and Russian laboratories).

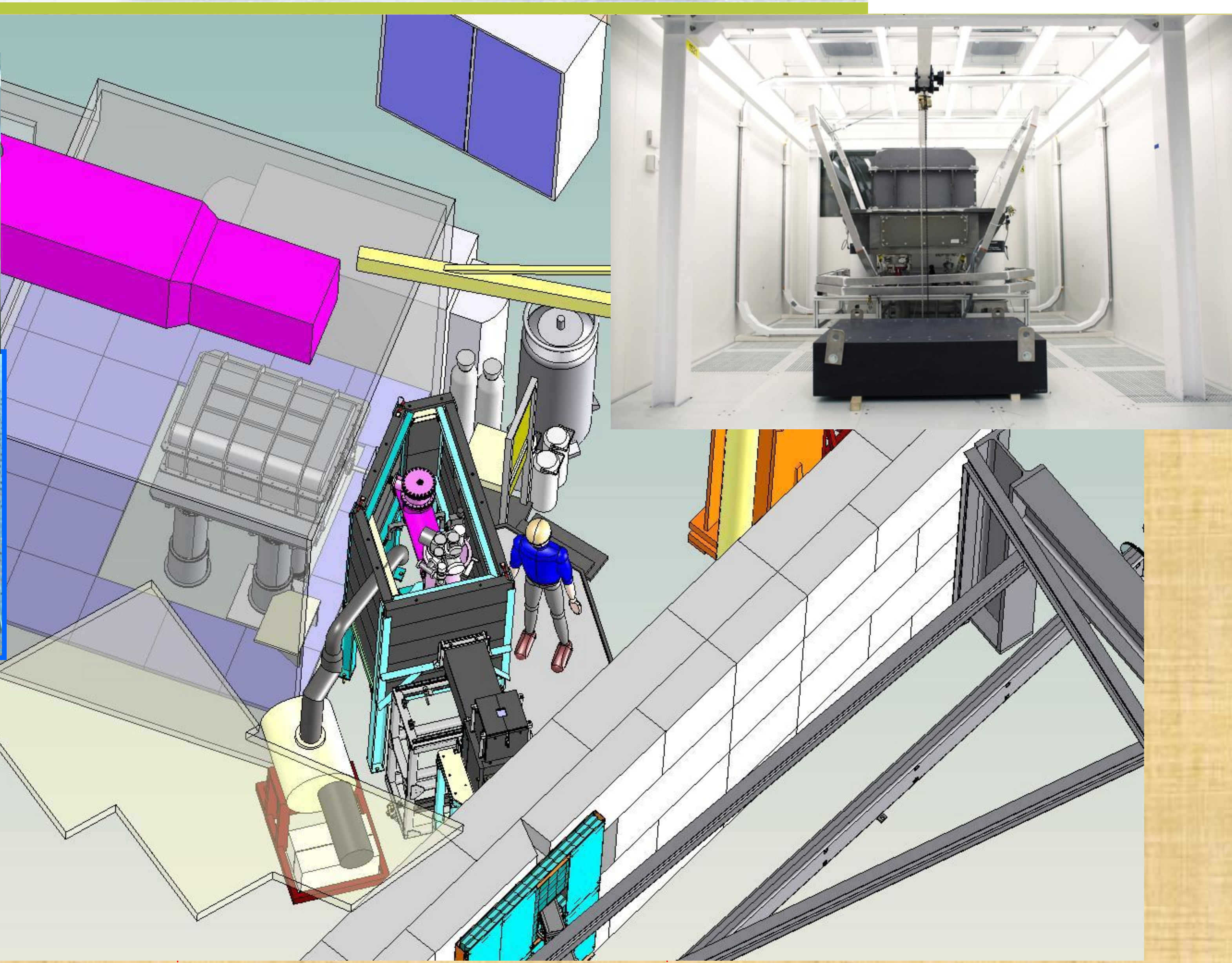
-Location: H172A.

-The share of beam time: 70%: The GRANIT coloboration and 30%: external uses allocated in incordence with ILL standard rules.

Status of the new GRANIT spectrometer at the ILL







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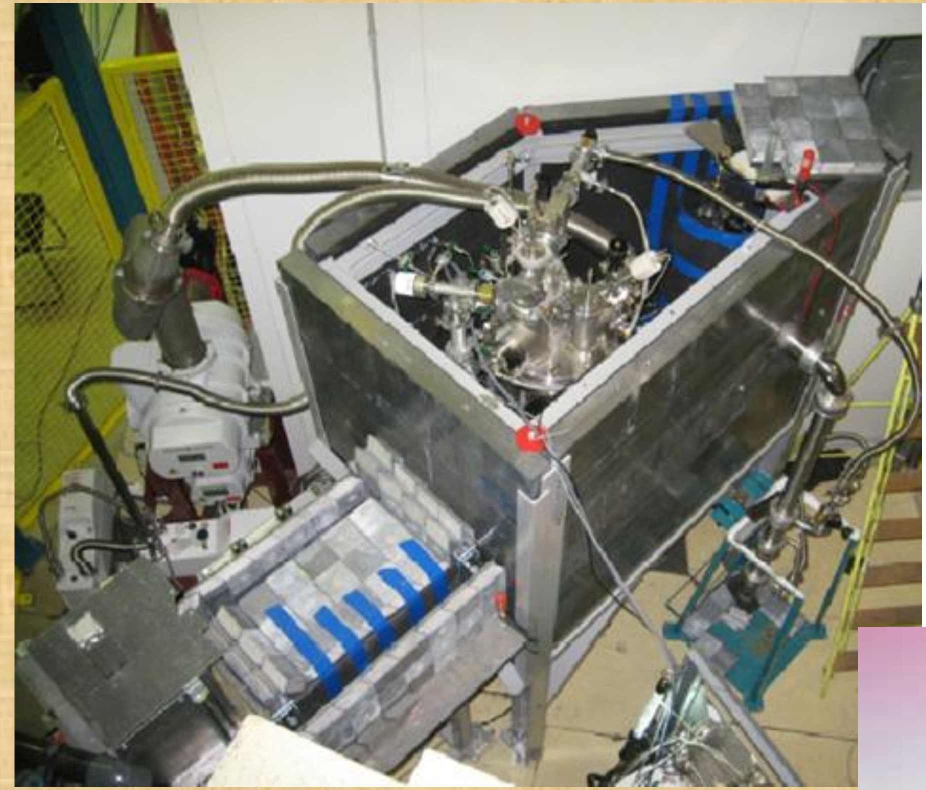
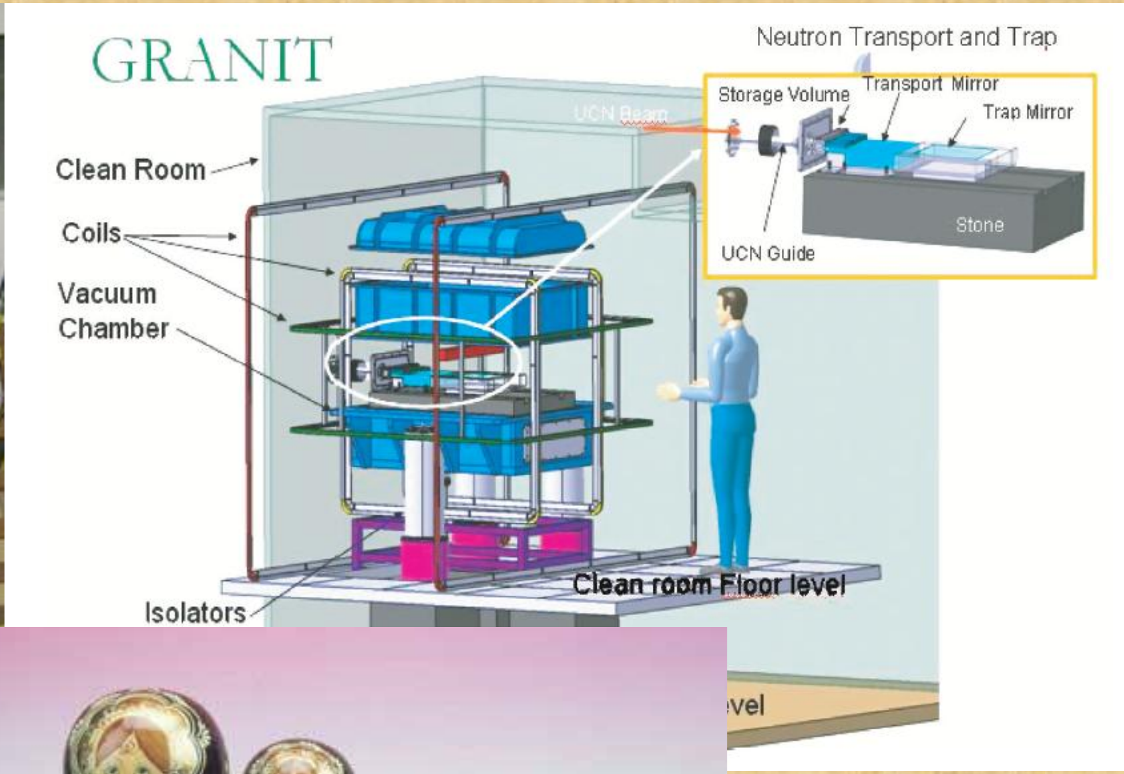




Scientific motivation

GRANIT-2010 Workshop
14-19 February 2010, Les Houches, France

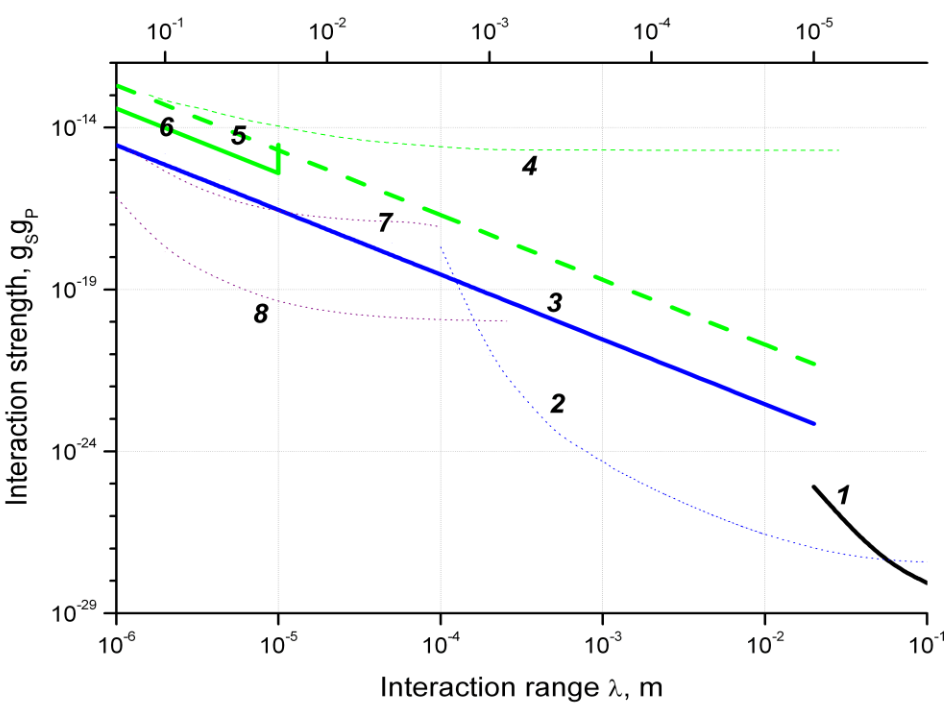
Countries ~12
Europe, Asia, USA, Australia
Proceedings: Compt. Rend. Phys. 12(8) (2011) 703-795

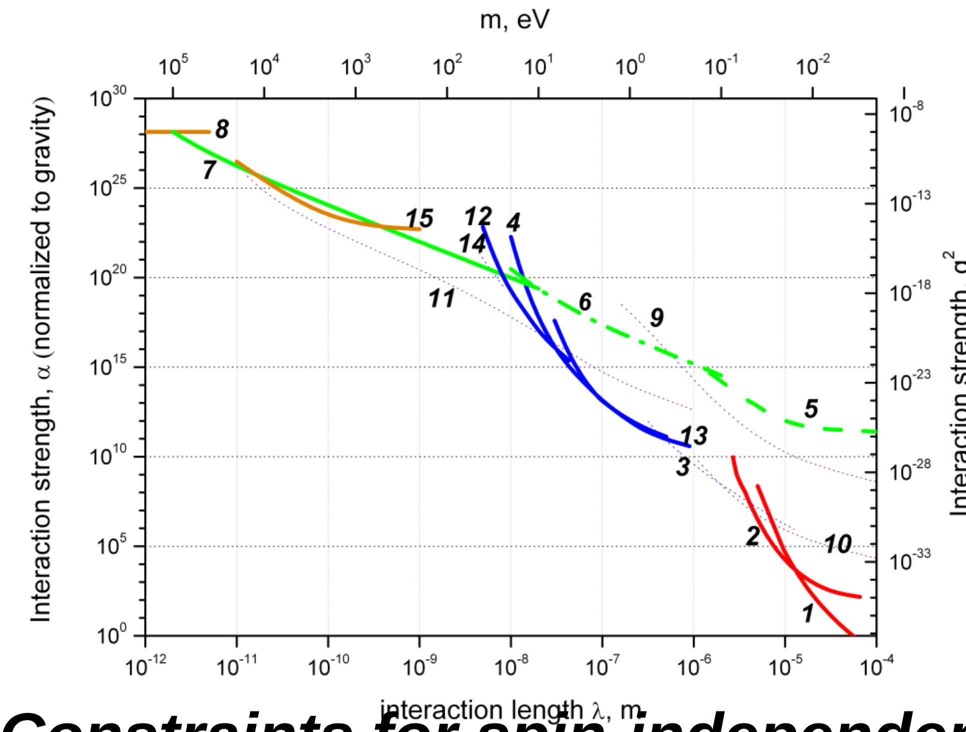
Scientific motivation

The phenomenon of gravitational and centrifugal quantum states of neutrons could be used in various applications, as apriory it provides a very « clean » system with well-defined quantum states.

-***Contraints for short-range forces,***
-***Constrains for axion-like forces,***
-***Constrains for neutron electric charge,***
-***Neutron quantum optics effects,***
-***UCN reflectometry,***
-***Quantum revivals,***
-***Constrains for a logarithmic term in the Schrödinger equation,***
-***Loss of quantum coherence,***
-***UCN extraction, transport, tight valves,***
-Study of thin surface layers.

Constraints for spin-dependent short-range forces





Constraints for spin-independent short-range forces

First experiments

Flow-through mode: modest energy resolution

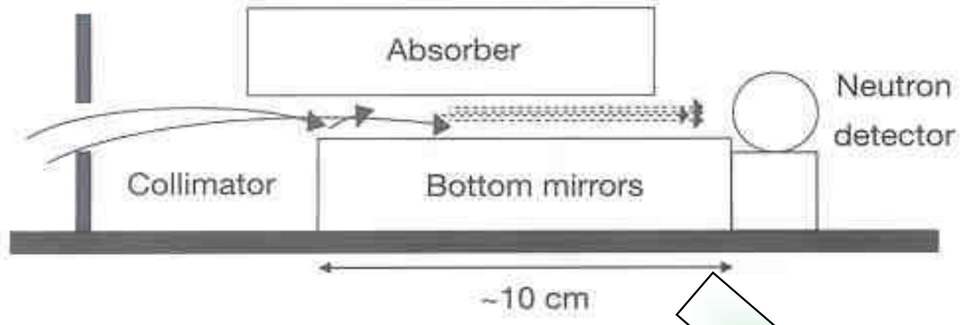
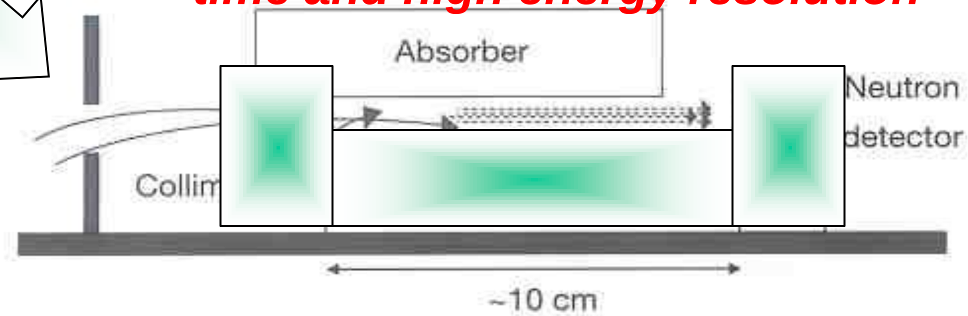


Figure 2 Layout of the experiment. The limitation of the vertical velocity component depends on the relative position of the absorber and mirror. To limit the horizontal velocity component we use an additional entry collimator. The relative height and size of the entry collimator can be adjusted.

Transitions will be excited by periodically varying magnetic field gradient.

V.V. N., K.V. Protasov, « Quantum states of neutrons in the Earth's gravitational field : state of the art, applications, perspectives », Ed. Book on Trends in Quantum Gravity Research (NOVA science publishers, New York, 2006).

Now: storage mode, long observation time and high energy resolution



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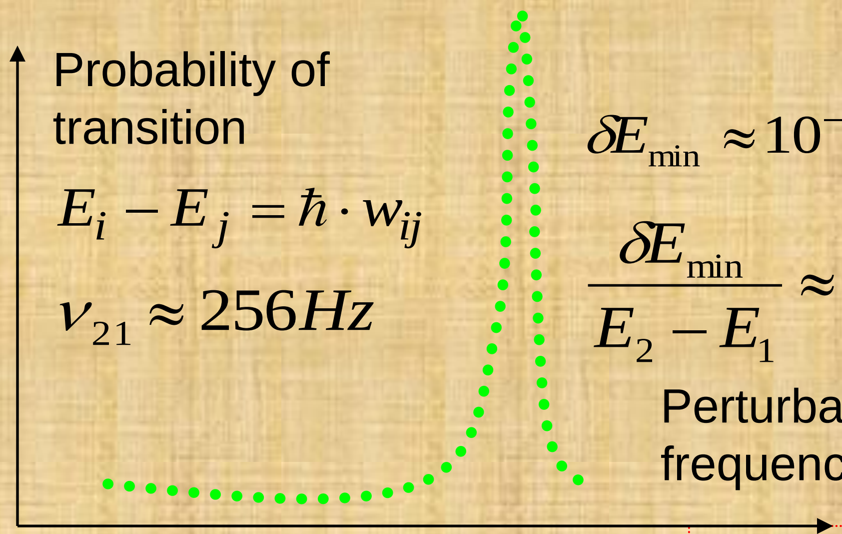


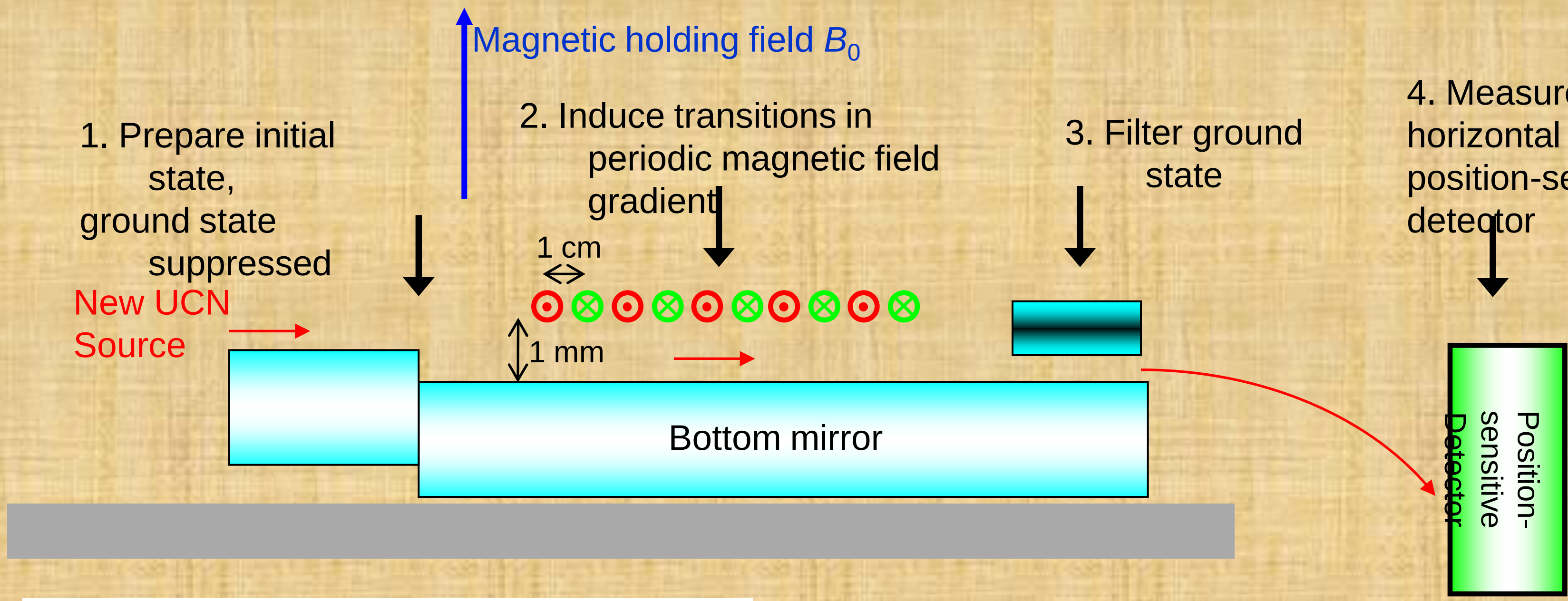
$$E_i - E_j = \hbar \cdot w_{ij}$$

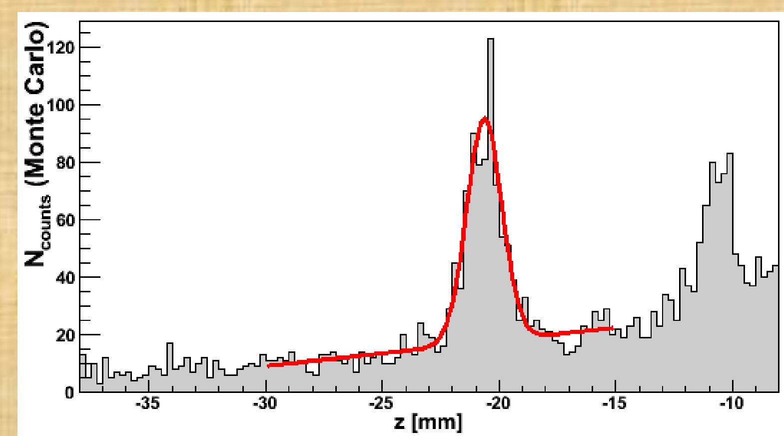
$$\nu_{21} \approx 256 Hz$$

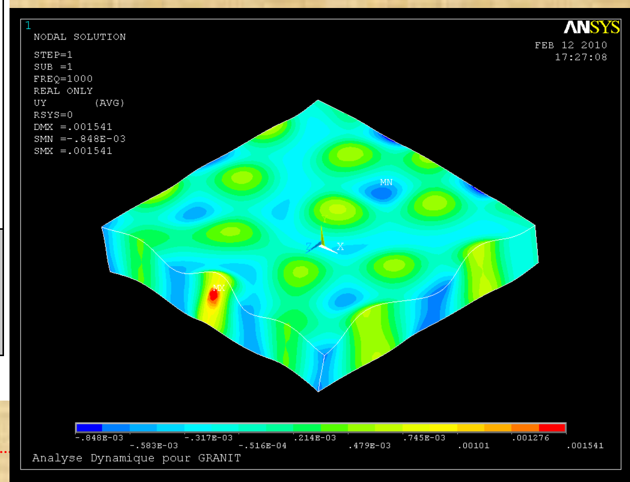
$$\delta E_{\min} \approx 10^{-18} eV$$

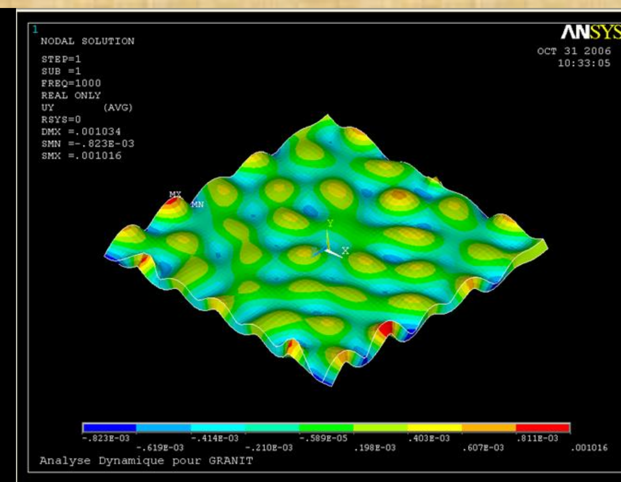
$$\frac{\delta E_{\min}}{E_2 - E_1} \approx 10^{-6}$$

First experiments









Numerous follow-up projects and technical developments to study and use gravitational quantum states of neutrons

T. Sanuki, S. Komamiya, S. Kawasaki, S. Sonoda, « Proposal for measuring the quantum states of neutrons in the gravitational field with a CCD-based pixel sensor », NIM A 600 (2009) 657.

J. Jakubek, Ph. Schmidt-Wellenburg, P. Geltenbort, M. Platkevic, Ch. Plonka-Spehr, J. Solc, T. Soldner, « A coated pixel device TimPix with micron spatial resolution for UCN detection », NIM A 600 (2009) 651.

J. Jakubek, M. Platkevic, Ph. Schmidt-Wellenburg, P. Geltenbort, Ch. Plonka-Spehr, M. Daum, « Position-sensitive spectroscopy of ultra-cold neutrons with Timepix pixel detector », NIM A 607 (2009) 45.

H. Abele, T. Jenke, D. Stadler, P. Geltenbort, « QuBounce: the dynamics of ultracold neutrons falling in the gravity potential of the Earth », Nucl. Phys. A 827 (2009) 593.

T. Jenke, T. Stadler, H. Abele, P. Geltenbort, « Q-Bounce-experiments with quantum bouncing ultracold neutrons », NIM A 611 (2009) 318.

S. Kawasaki, G. Ichikawa, M. Hino, Y. Kamiya, M. Kitaguchi, S. Komamiya, T. Sanuki, S. Sonoda, « Development of a pixel detector for ultracold neutrons », NIM A 615 (2010) 42.

T. Jenke, P. Geltenbort, H. Lemmel, H. Abele, « Realization of a gravity-resonance-spectroscopy technique », Nature Phys. 7 (2011) 468.

Important details

-UCN (ultracold neutrons group) at LPSC has appeared due to common activity with ILL on GRANIT project; very strong and fruitfull collaboration between these laboratories is the key of success;

-Even at the level of construction of the spectrometer and during related methodical developments we have had enormously high scientific output (over 40 publications in high-ranking scientific journals for quite a small group of several people) – to be even higher in the measurements phase!;

-We have had preliminary discussions with two excellent candidates, deeply involved in UCN activity, who are interested to join our group if such a position is open;

-Very high visibility of this PostDoc position, as many of the GRANIT collaborators (V.V. Nesvizhevsky, K.V. Protasov, G. Pignol, D. Rebreyend…) have also other duties, and only our PhD student Damien Roullier is 100 % of time at the instrument. We NEED to have another person 100 % of time involved in the GRANIT activity.