Commissioning of the GRANIT experiment

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NEUTRONS FOR SCIENCE®

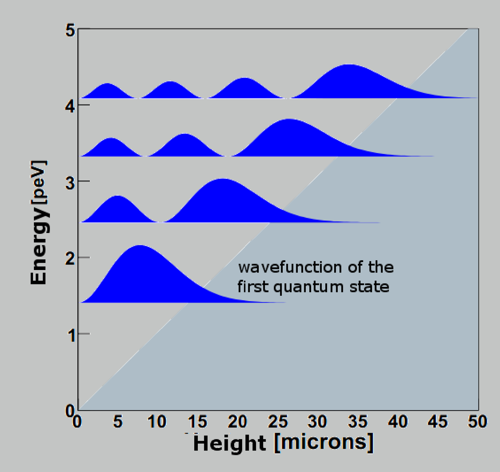
Introduction

The quantification of the energy states of a particle bouncing on a perfect horizontal mirror is predicted by quantum mechanics. These quantum states have been observed for Ultra-Cold Neutrons ($\mathbf{v} < \mathbf{7m/s}$), capable of bouncing on a mirror and non-sensitive to electric fields. (V. V. Nesvizhevsky et al, Nature 415 (2002) 297)

The stationary Schrödinger equation for the vertical motion of a bouncing neutron is

$$-\frac{\hbar^2}{2m_n}\frac{d^2}{dz^2}\psi(z) + (m_n g z + \Phi_{\text{new force}}(z))\,\psi(z) = E\psi(z)$$

The purpose of GRANIT is to use these quantum states, for instance by inducing resonant transitions between quantum states in a flux through mode using an oscillating magnetic field gradient.



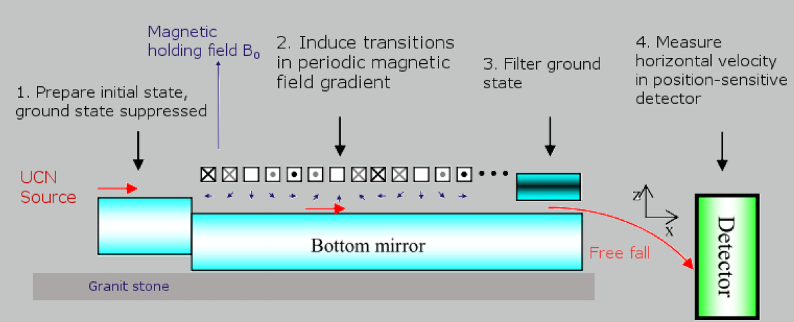
If the only potential is gravity, the solutions of the equation are the Airy functions $\mathbf{Ai}\left(\frac{z}{z_0} - \frac{E}{E_0}\right)$ with

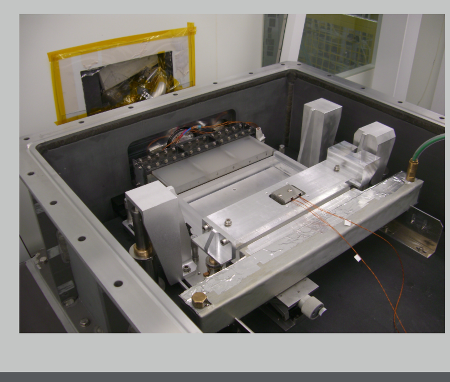
$z_0 = \left(\frac{\hbar^2}{2m_n^2 g}\right)^{\frac{1}{3}} = 5.87\mu$m

and

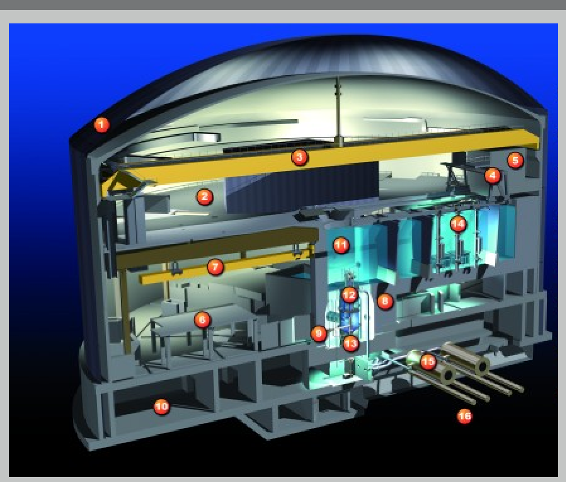
$E_0 = m_n g z_0 = 0.602$peV.

Searching for deviations of the expected resonant frequencies we can test the weak equivalence principle in a quantum context and/or probe the existence of a new short-range force such as the Chameleon field, a candidate to explain the Dark Energy.





UCN production



ILL reactor, H172 guide

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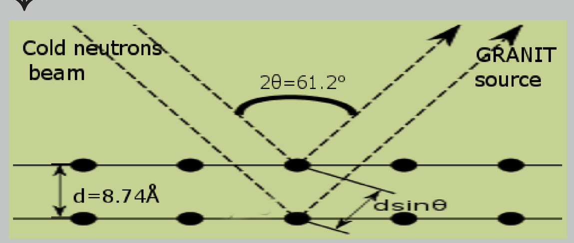

monochromator **8.9Å**

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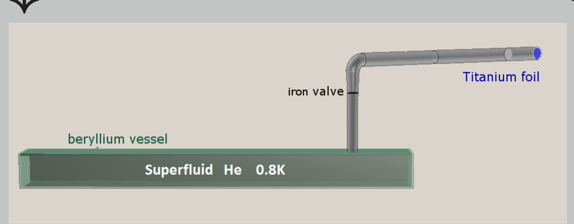

Dedicated source ^{4}He/^{3}He

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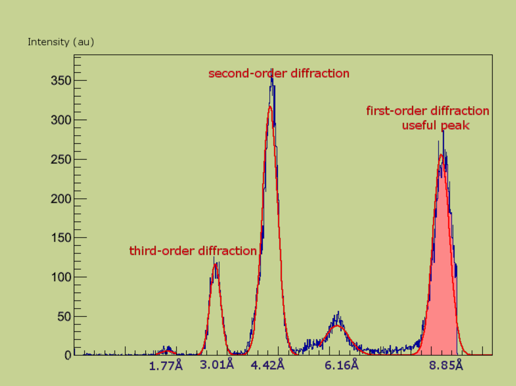
The GRANIT spectrometer inside its cleanroom

Cold beam characterization



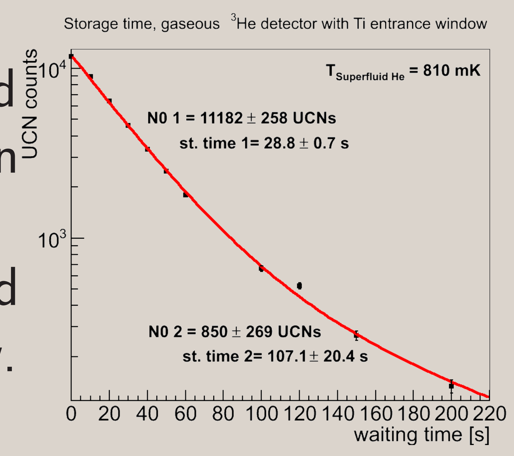
Combining several time of flight measurements (to identify the peaks, their widths and their relative intensities) and a gold foil activation measurement (to have the integral neutron flux), we can deduce the **8.9Å** neutrons flux

$$\Phi_{\text{true}}^{[8.9\text{Å}]} = \Phi_{\text{gold}(1.8\text{Å})} \times \frac{1.8\text{Å}}{8.9\text{Å}} \times \left(\sum_{\lambda \in \text{peaks}} \frac{p_\lambda}{p_{8.9\text{Å}}} \times \frac{\lambda}{8.9\text{Å}}\right)^{-1} \quad (1)$$

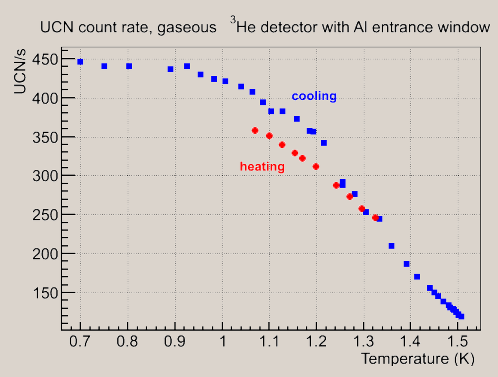
Our TOF results give $\Phi_{\text{true}}^{[8.9\text{Å}]} = (1.2 \pm 0.1) \times 10^8$ neutrons/cm^2/s and $\text{FWHM}_{\text{peak}} < 0.213$Å, so $\frac{d\Phi}{d\lambda}|_{8.9\text{Å}} = (2.3 \pm 0.2) \times 10^8$ neutrons/cm^2/s/Å when the reactor power is **48MW**.

UCN storage time

When the valve is open, the radiation from the extraction tube heats up the superfluid Helium. Since the **emptying time** of the source is **14s**, we get **80%** of the UCNs when we open the valve during **20s**.
A detector with a thin titanium window allows us to see UCNs with $\mathbf{v} < \mathbf{3.2m/s}$ compared to an aluminum window, even if a significant portion of them is absorbed in the Ti window.



UCN flux versus temperature

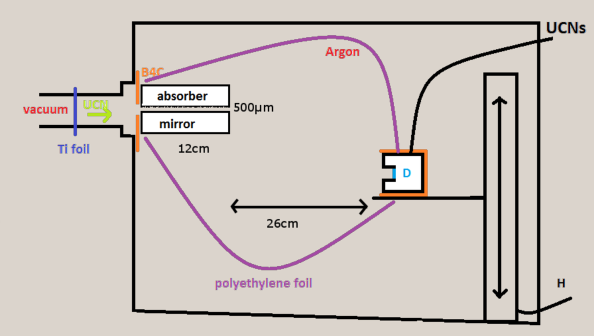


The up-scattering process in superfluid helium is a function of $(\mathbf{T[K]})^7$, and is the main flux-limitation above **1.2**K.
Below **0.9**K, the flux is limited by the losses on the beryllium walls.
Measurements are possible at relatively high temperatures (**1.3K**), where the UCN flux is half of the maximum. Moreover, the superfluid helium is less sensitive to radiative heat when the valve is open, and measurements can last longer.

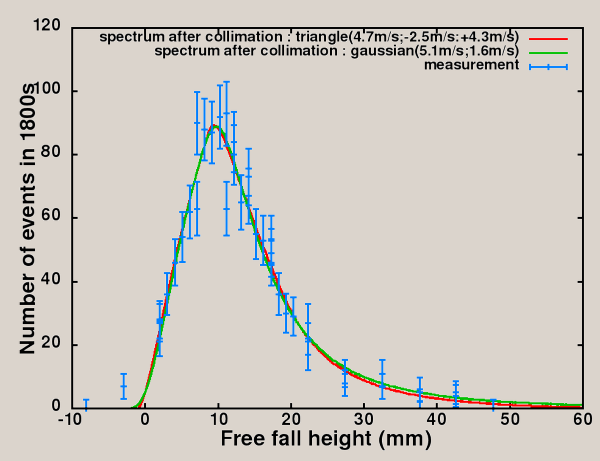
UCNs velocity spectrum

Free fall of the UCNs horizontally collimated :

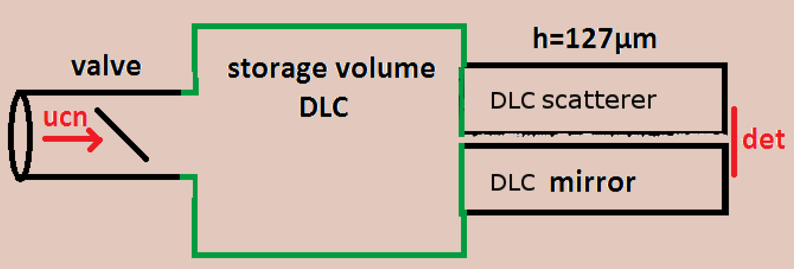
$$h = \frac{g}{2}\left(\frac{d_{\text{freefall}}}{v_{\text{UCN}}}\right)^2$$

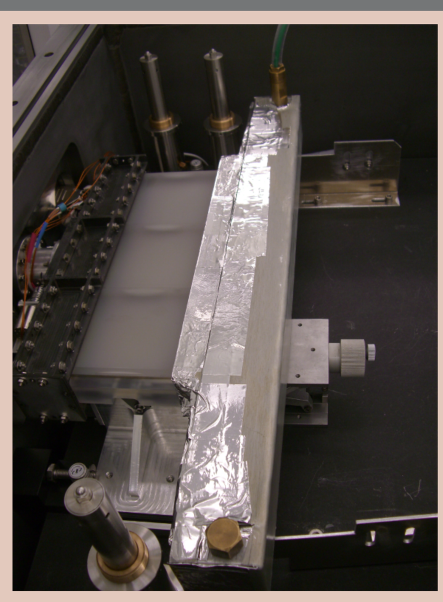


The velocity spectrum is assumed Gaussian or triangular after the collimation, transformed by a simulation of the experiment, then fitted to the measurement.
The **mean velocity** of our UCNs is $\mathbf{5.1 \pm 0.1m/s}$, but the spectrum is quite wide.

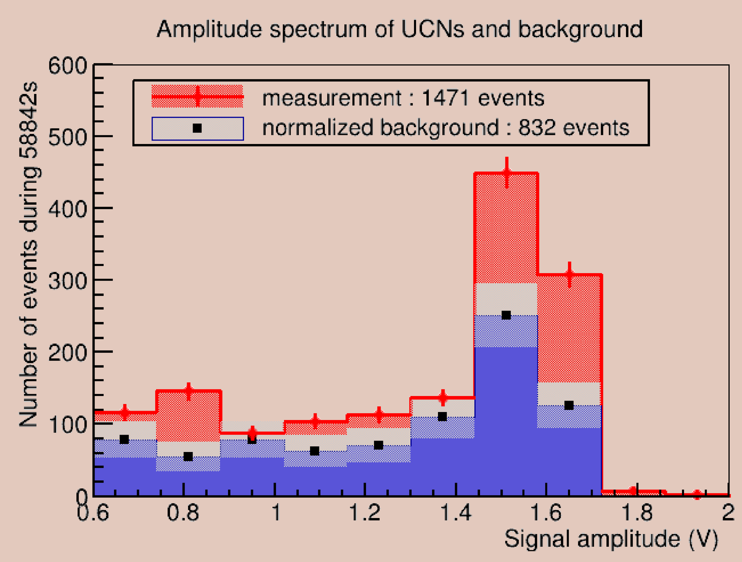


The GRANIT spectrometer : first setup





In this configuration, with the superfluid helium in the production volume at **1.35K**, we measured $(\mathbf{10.9 \pm 1.5}) \times \mathbf{10^{-3}UCN/s}$ at the exit of the extraction slit.
This is lower than expected, partly because a significant portion of our UCNs is too slow to be efficiently detected by our currently used detectors.



Summary and outlines

Commissioning is underway and the very first results have been obtained. Our dedicated UCN source is characterized, but our UCN flux is too low. Several improvements are being discussed in order to improve the number of usable UCNs by more than an order of magnitude (source, extraction, detection), taking advantage of the long reactor shutdown from August 2013 to June 2014. Then, we will be able to induce resonant transitions between quantum states in 2014.