A Dedicated UCN-Source for GRANIT

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Gravitational Levels of Neutrons

Neutrons like all other particles interact with gravity. Thus they can be bound by the earths gravitational field. It is easy to think of a gravitational quantum well for UCN, defined by the earth potential and a mirror consisting of a material with positive Fermi potential. The Schroedinger equation for this system is

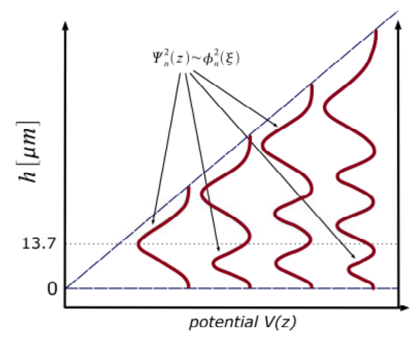
$$-\frac{d_n^2\phi(\xi)}{d\xi^2}+\xi\phi_n(\xi)=\lambda_n\phi(\xi)$$

where ξ is a characteristic variable, connected with z via

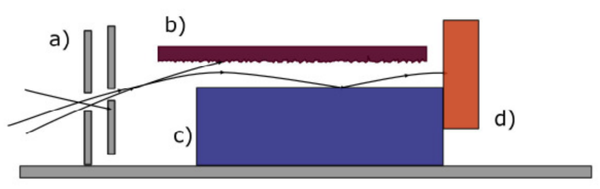
$$\xi=z/\sqrt[3]{1/(2m^2g)}$$

and λ is the quantum number specifing the energy. The eigenfunctions of this system are Airy functions, their square giving the detection probability for a height above the mirror.

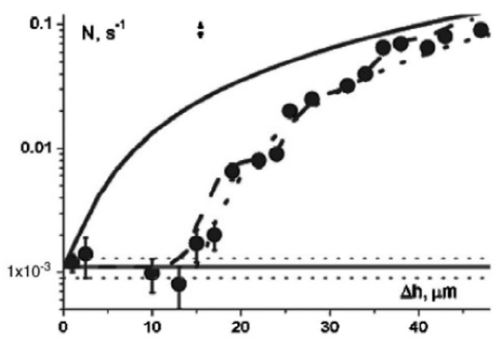
In a recent experiment at the Institute Laue Langevin these first eigenstates have been measured. Though this experiment was limited by the low UCN density, it shows that the principle of detection works and the eigenstates exist. For further research a more powerful UCN-source and a refined experimental setup will be necessary.



The square of the fist four Airy functions which are defining the detection probability for neutrons depending on the height of the absorber.



Experimental scheme of first gravitational level measurement. UCNs enter from the left through several apertures (a), thus selected in energy. The height of the absorber (b) selects the quantum states, whereas the perfectly plane mirror (c) provides the energy barrier at z=0. UCNs passing this setup will be detected with the detector at (d).



The measured transmission of the first gravitational level experiment. The bold line is the expectation for a classical system. The stepwise increase of transmission indicates the quantum character of the states.

The UCN-Source Based on Liquid Helium

Liquid helium at low temperatures is an excellent superthermal converter for ultra-cold neutrons. Excitations of phonons through coherent inelastic scattering by 8.9A neutrons provides a two energy level system. In a cryostat which is actively cooled to temperatures below 0.5K the excitated phonons are immediately destroyed.

+ Losses only due to collisions with wall material or through imperfections of the production volume

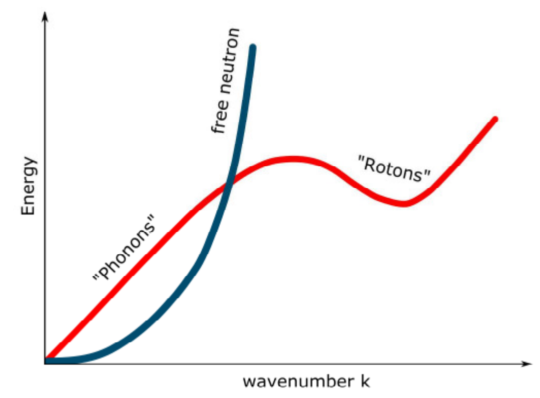
$$\frac{1}{\tau}=\cancel{\frac{1}{\tau_{abs}}}+\frac{1}{\tau_{wall}}+\cancel{\frac{1}{\tau_{up}}}+\frac{1}{\tau_\beta}$$

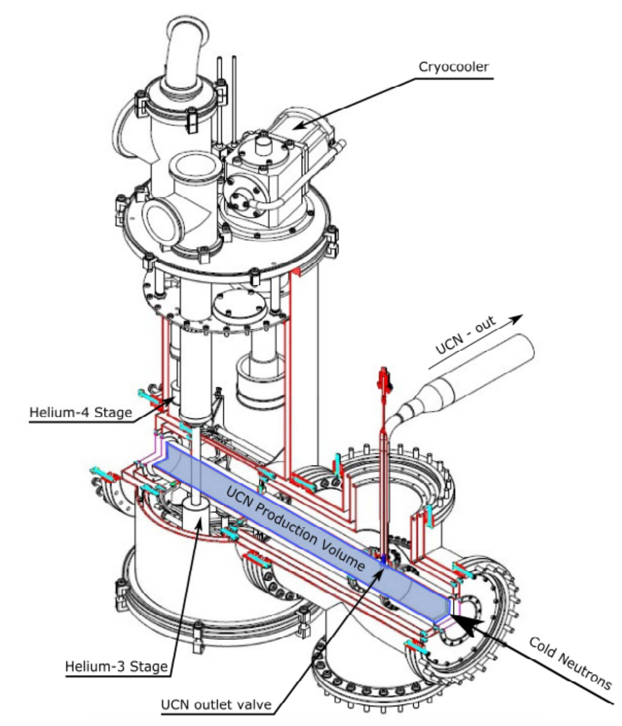
+ Saturated UCN-density inside the production volume is the product of storage time (~100s) and production rate (~10 $cm^{-3}s^{-1}$).

$$\rho_{UCN}=\tau\cdot P(E_{UCN}) \Rightarrow \rho=1000\,cm^{-3}$$

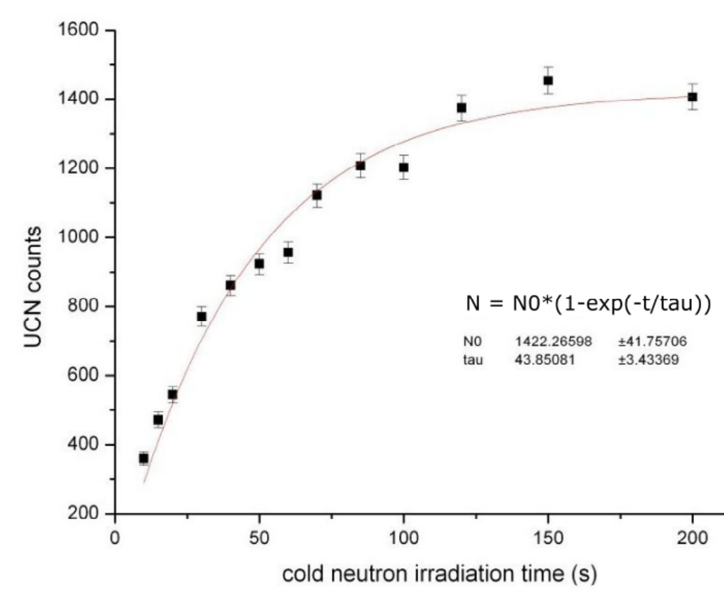
+ Production rate is dependent on CN-flux at 8.9A (~1.5*$10^8 cm^{-2}s^{-1}$@ H172), for high storage time an optimized extraction method will be used.

The dispersion curves of the free neutron and the excitations of liquid helium. Neutrons are downscattered from the point of intersection to the UCN-energy regime, obeying momentum and energy conservation.





Helimephisto: the prototye source at the Mephisto Guideline at FRMII Munich



First measurements with Helimephisto have been performed at the Munich Research Reactor in December, 2006. The data show the build up of UCN-density, with a cold neutron beam reduced to modest intensity and the cold source not completely filled. The attenuation had been necessary to reduce heating effects and radiation. Extrapolating this data to full flux with a filled cold source at a converter temperature of 0.5K will yield densities of 1000 UCN/cm3.

The Experimental Setup of UCN-Source and GRANIT

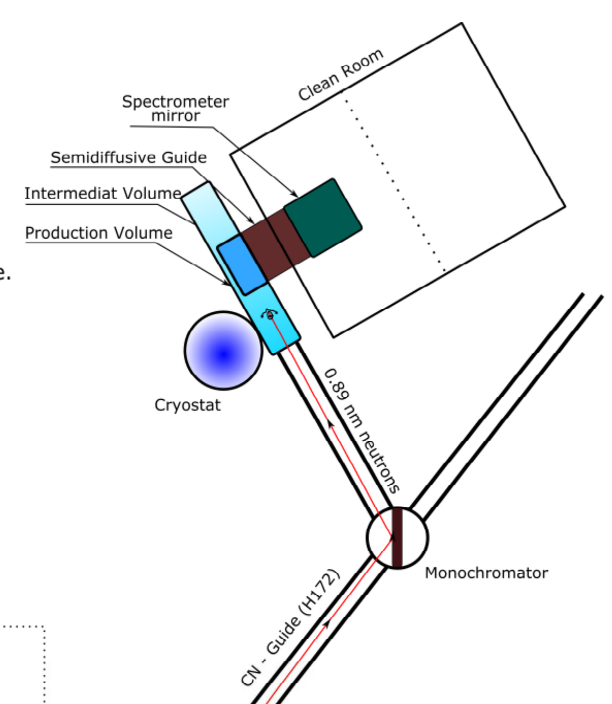
+ The experiment will be set up on the H172 neutron guide in level C of the ILL Research Reactor.

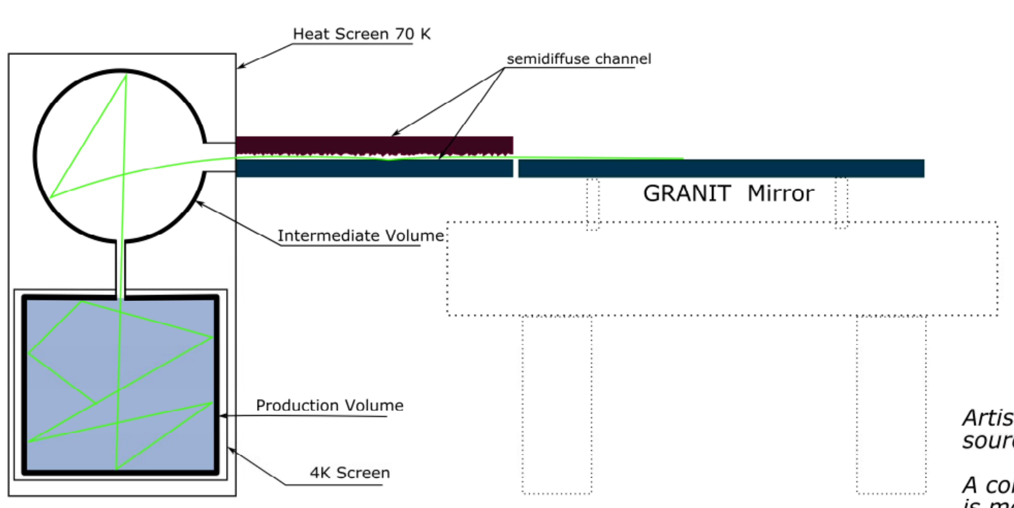
+ A potassium intercalated graphite monochromator will be used to reflect out 0.89nm neutrons under a take-off angle of ~60 degree. Optional a second iHOPG monochromator can be placed at the same position for a 0.89nm beam under ~112 degree. This will allow to place a second experiment requiring 0.89nm neutrons on the same CN beam.

+ A standalone cryostat similar in design to the prototype Helimephisto will provide the cooling power necessary to cool down to 0.5K. It includes also a facility to clean the remaining helium-3 from the liquid helium-4.

+ A saturated density of first 400 UCN/cm3 will be further improved through low loss coating of the volume.

+ Calculations with simple diffusion equation yield a density of 200 UCN/cm3 in the intermediate volume. With a semidiffusive channel for extraction we anticipate a neutron flux of 350 UCN/s for GRANIT.





Artist view of the complete spectrometer with source.

A cold white beam from the vertical cold source is monochromated by the potassium intercalated graphite crystal. It enters the production volume through two aluminum heat screens and a diamond like carbon coated thin stainless steel window. Inside the volume the neutrons are downscattered into the UCN energy regime.

Potassium Intercalated Graphite as a Long Wavelength Monochromator

First experiments with Helimephisto have shown that with a full white cold neutron beam there is a significant heating effect. Furthermore, neutrons outside the 0.89 nm production band are scattered arbitrarly and cause a huge background. These two effects along with the wish of being able to use the provided beam for further experiments downstream make the developement of a monochromator necessary.

+ Crystals act as monochromator via Bragg scattering.

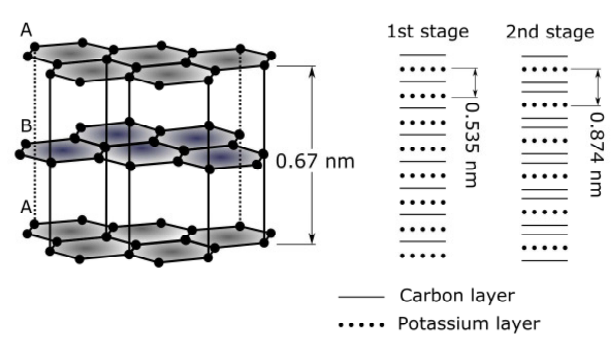
$$n\lambda=2d\sin(\theta)$$

+ Potassium intercalated crystals of HOPG (highly oriented pyrolytic graphite) exist with several d-spacings and have the desired mosaicity.

+ Experiments at NIST have shown a reflectivity of 85% for 0.89nm neutrons.

+ These advantages justify the trade-off in intensity, which is also due to not using multiphonon production rate.

$$\Rightarrow \Phi_{CN\,8.9}\approx 1.3\cdot 10^8 cm^{-2}s^{-1}$$

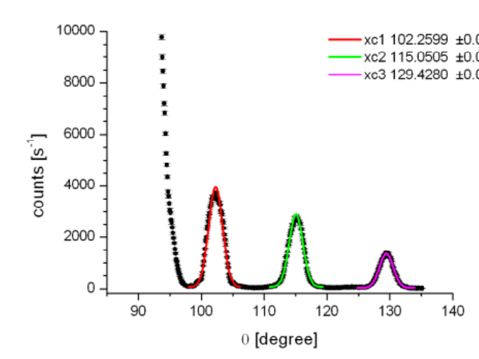


Carbon lattice and d-spacing of the first two stages of potassium GiCs (Graphite intecalated Crystal).

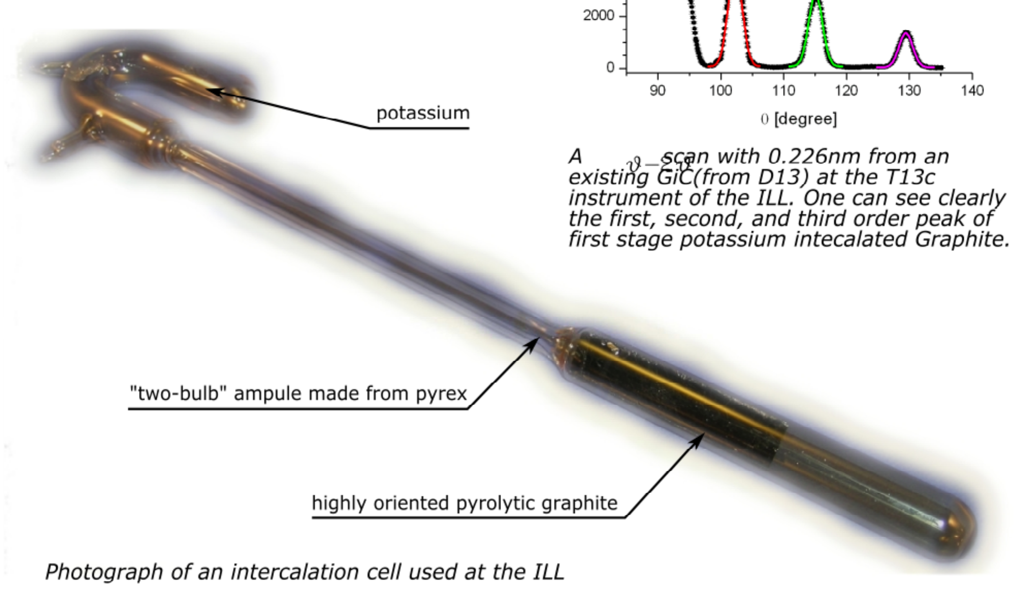
+ At the ILL together with the support of the NIST, iHOPG crystals are grown employing the "two-bulb" technique. The two bulbs of the cell (see picture) are heated to the desired temperature, where the temperature of the potassium side is approximately 250 C.

+ The staging (number of carbon layers between two layers of intercalant) is defined by the temperature difference between carbon temperature and potassium temperature. For the first stage no heat gradient ist necessary, for the second one of 112 K.

+ A $\vartheta-2\vartheta$-scan with 0.24 nm or 0.35 nm is used for determination of the quality of the stage grown.



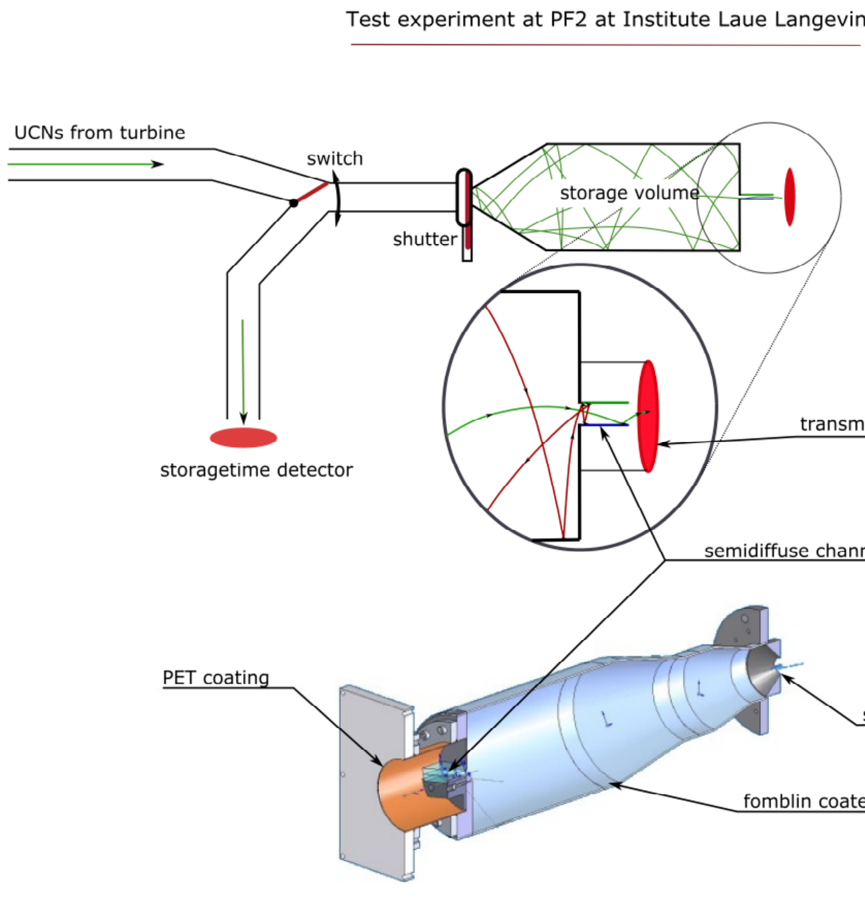
A $\vartheta-2\vartheta$-scan with 0.226nm from an existing GiC(from D13) at the T13c instrument of the ILL. One can see clearly the first, second, and third order peak of first stage potassium intecalated Graphite.



Photograph of an intercalation cell used at the ILL

Density Maintaining Semidiffuse Extraction Channel

Test experiment at PF2 at Institute Laue Langevin



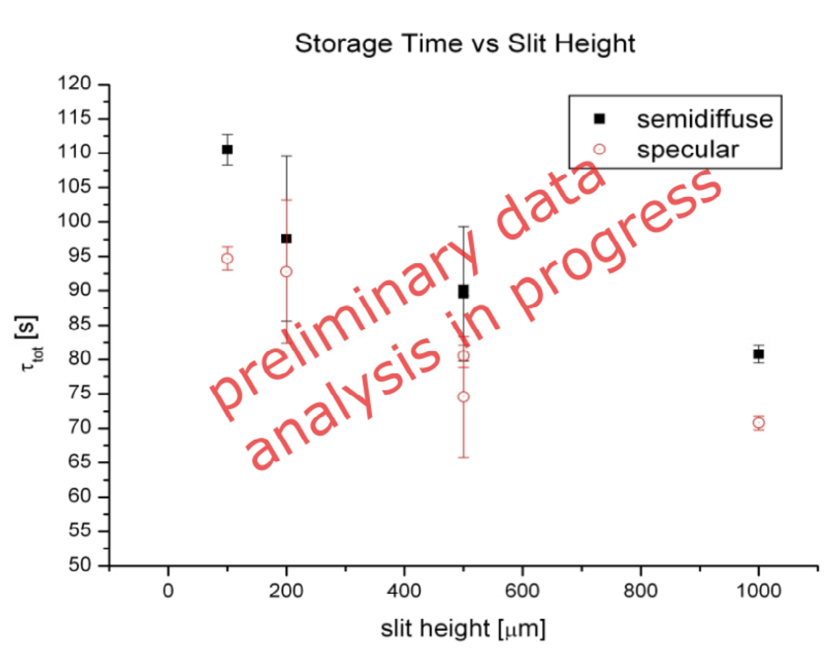
UCN from the turbine at PF2 enter through the switch and the UCN shutter into the storage volume. Here they are stored for t=50,100,...,300s. Thereafter the shutter is closed while the switch is in the emptying position and all remaining neutrons are counted in the storagetime detector. UCN penetrating through the channel are detected by the transmission detecter, which is divided in four horizontal strips to detect a vertical resolution.

+ All surfaces are made from a high fermipotential material (diamond like carbon coatings), thus storing a broad energy spectrum.

+ Only neutrons with vertical energies smaller than the channel height will pass (the ones needed for GRANIT).

+ All other neutrons will be reflected back into the volume maintaining a high UCN-density. Nevertheless a small fraction will be absorbed or decay inside the channel.

+ An experiment with a channel made from sapphire has been perfomed and shows that the principle works.



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