Status of new experiment for test of the equivalence principle with UCN

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Neutron experiments

1. A.W. McReynolds, 1951 g =935 ± 70cm/sec^2

2. J.W.Dabbs,J.A.Harvey, D.Pava and H.Horstmann, 1965

   g(002)=973.1 ± 7.4cm/sec^2
   g(100)=975.1 ± 3.1cm/sec^2
   g_{loc} = 979.74cm/sec^2

3. J. Schmiedmayer, NIM A 284, (1989) 59 (Re-estimation of Koster experiment)

$$\gamma = \frac{b_{eff}}{b} = \frac{m^2}{m_i m_g} \frac{g_{loc}}{g_n} = 1.00011 \pm 0.00017$$

4. R.Colella, A,W.Overhauser and S.A. Werner (COW), 1975 accuracy 1%

5. K.S.Litrell, B.E.Allman and S.A.Werner, 1997 discrepancy 1% (all uncertainties on level 0.1%)

6. ILL experiment of G.van der Zouw, et al. (2000) accuracy of about 0.9%

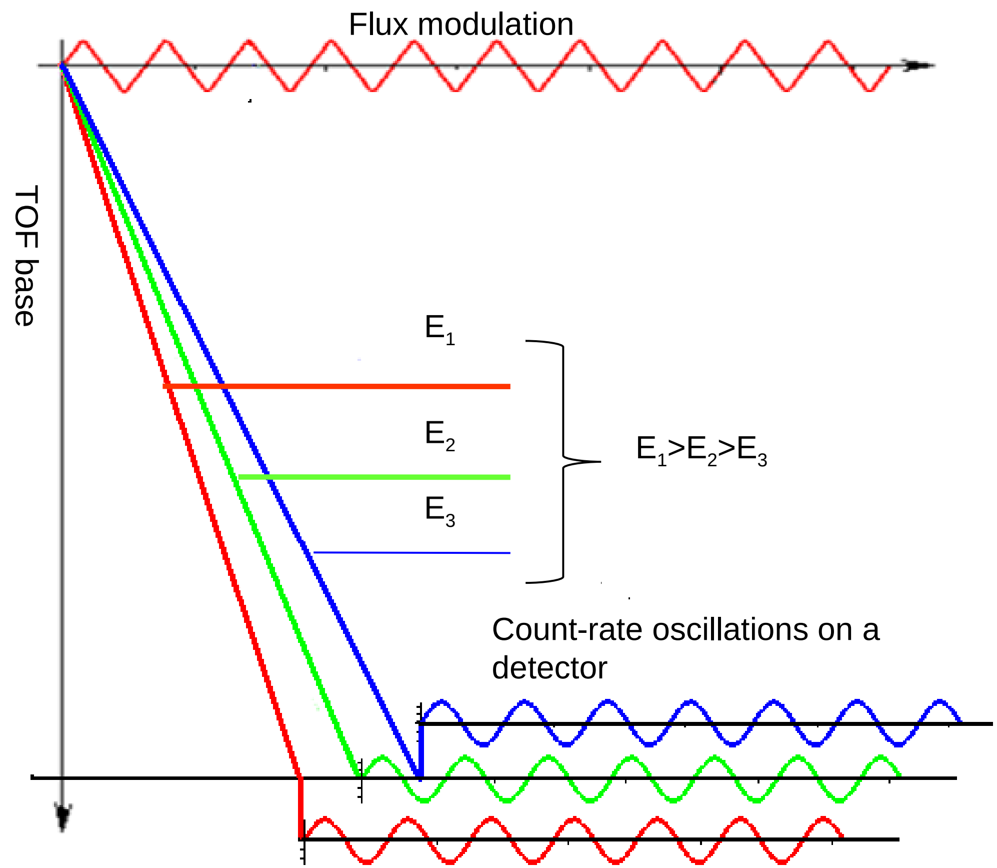
7. A.I. Frank, P. Geltenbort, M. Jentschel,et al. JETP Letters, 86, 225 (2007)

$$1 - \frac{m_g g_n}{m_i g_{loc}} = (1.8 \pm 2.1) \times 10^{-3}$$

New experiment

- The idea is to compare the energy $m_g g_n H$ with energy $\hbar\Omega$
- Peculiar TOF spectrometry

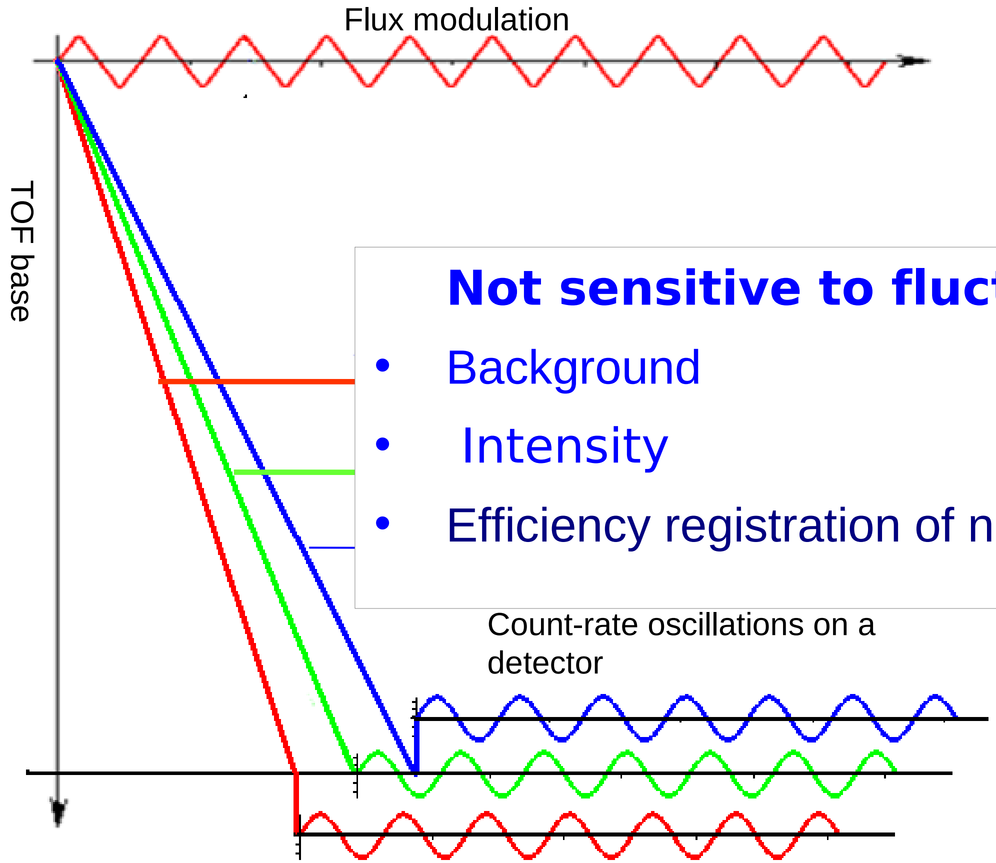
Time of Flight spectroscopy



The measurement of the count rate modulation phase

$$\phi = 2\pi F \tau$$

Time of Flight spectroscopy



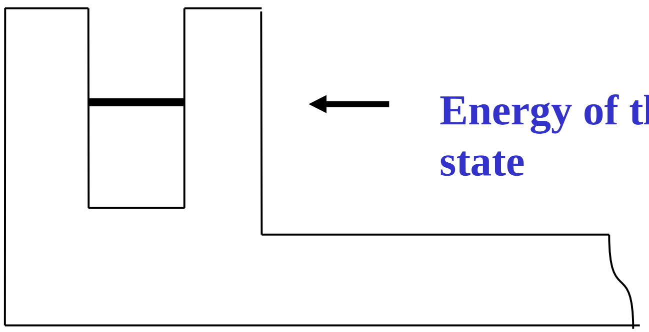
Not sensitive to fluctuations of:

- Background
- Intensity
- Efficiency registration of neutrons

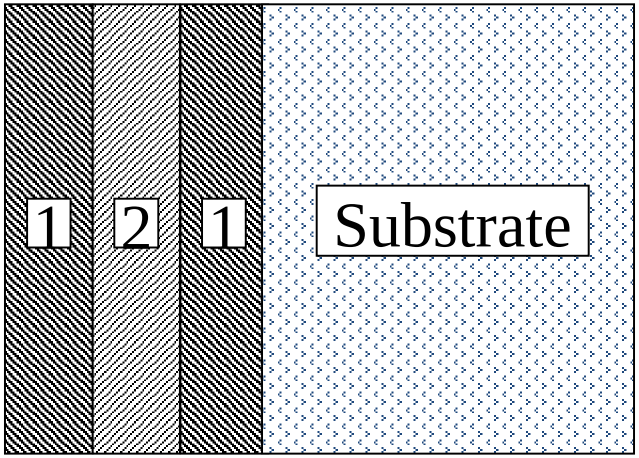
The measurement of the count rate modulation phase

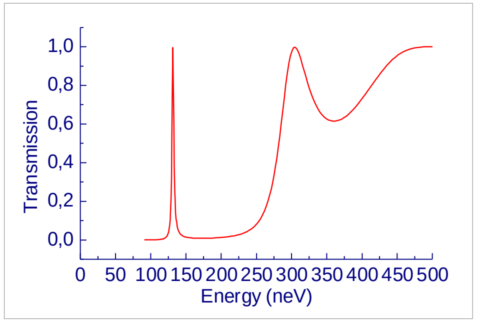
$$\phi = 2\pi F \tau$$

Neutron Interference Filters (NIFs) as Spectrometric device



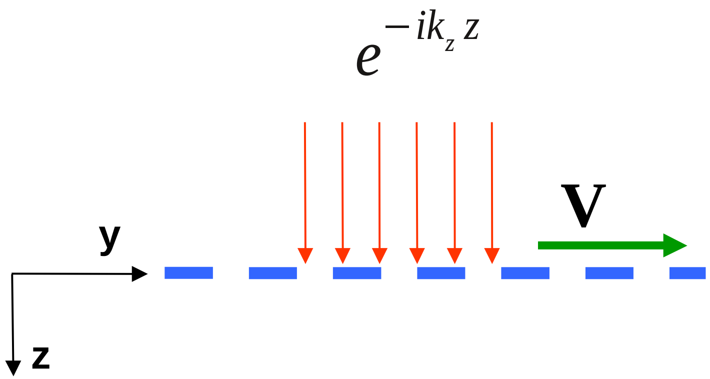
Energy of the state

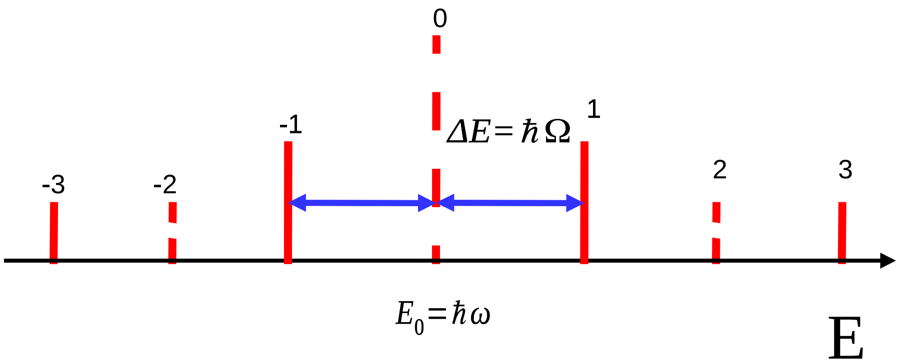




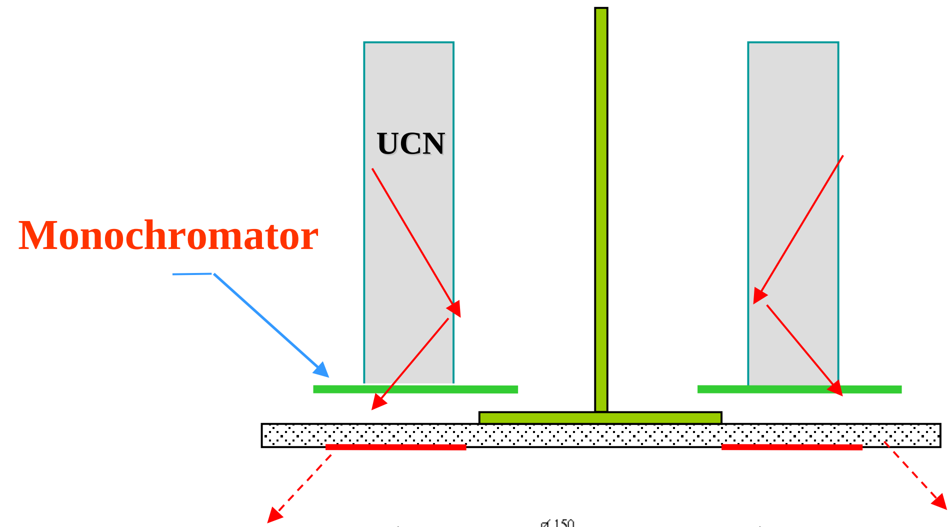
$$U_{1,2} = \frac{2\pi\hbar^2}{m}\left(\rho b_{1,2}\right)$$

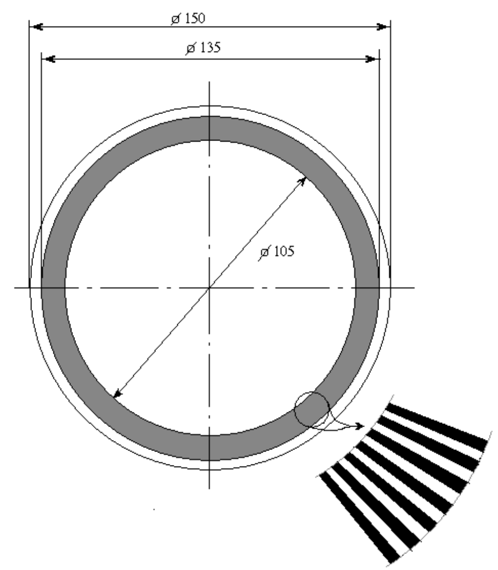
Moving (rotating) diffraction grating for transferring of neutron energy



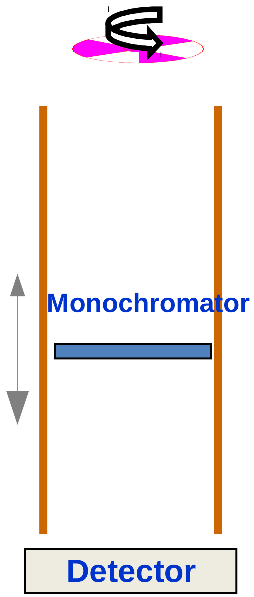


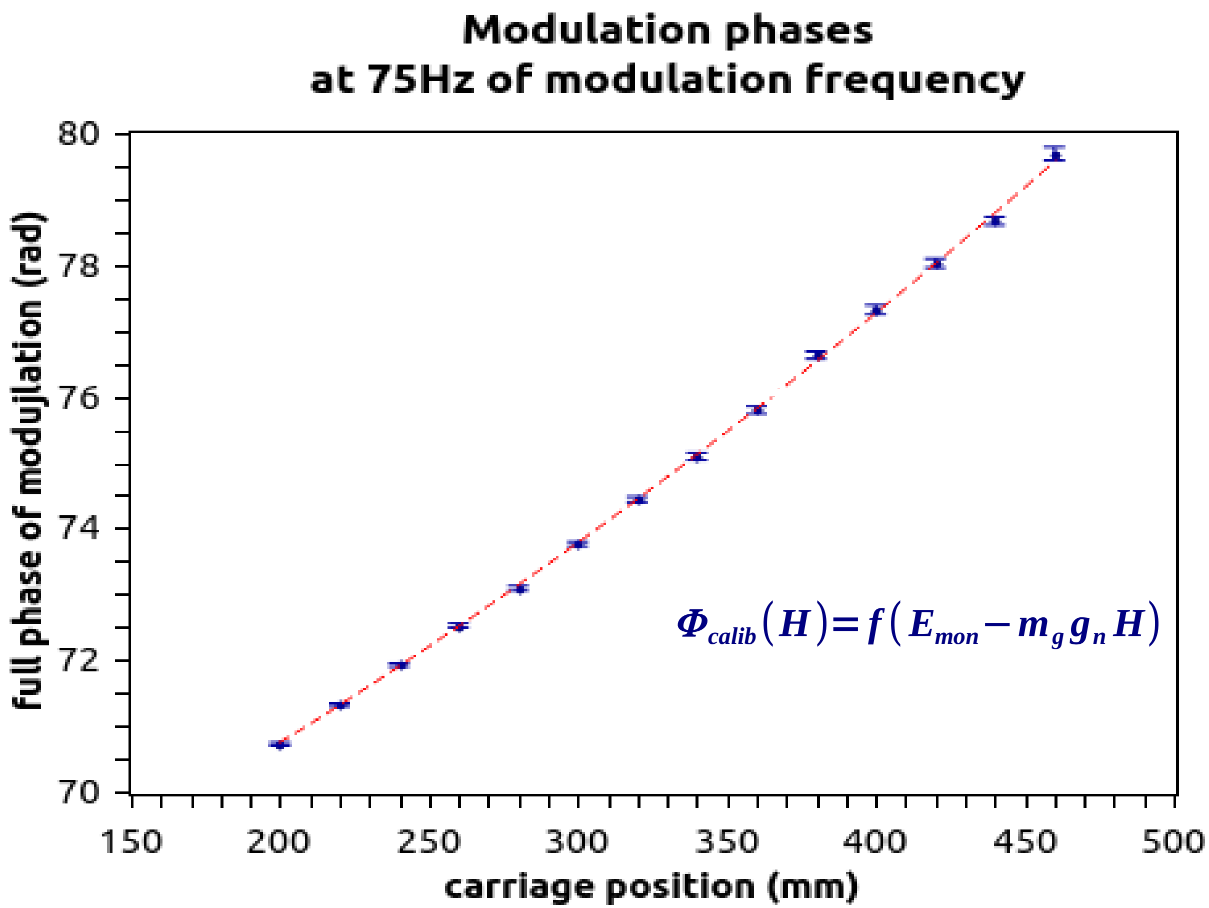
$$\Psi(x,y,z) = \sum a_n \exp[i(k_n z + q_n y - \omega_n t)]$$





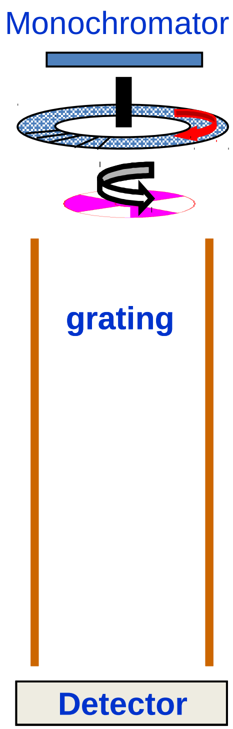
Experiment. Part I - Calibration

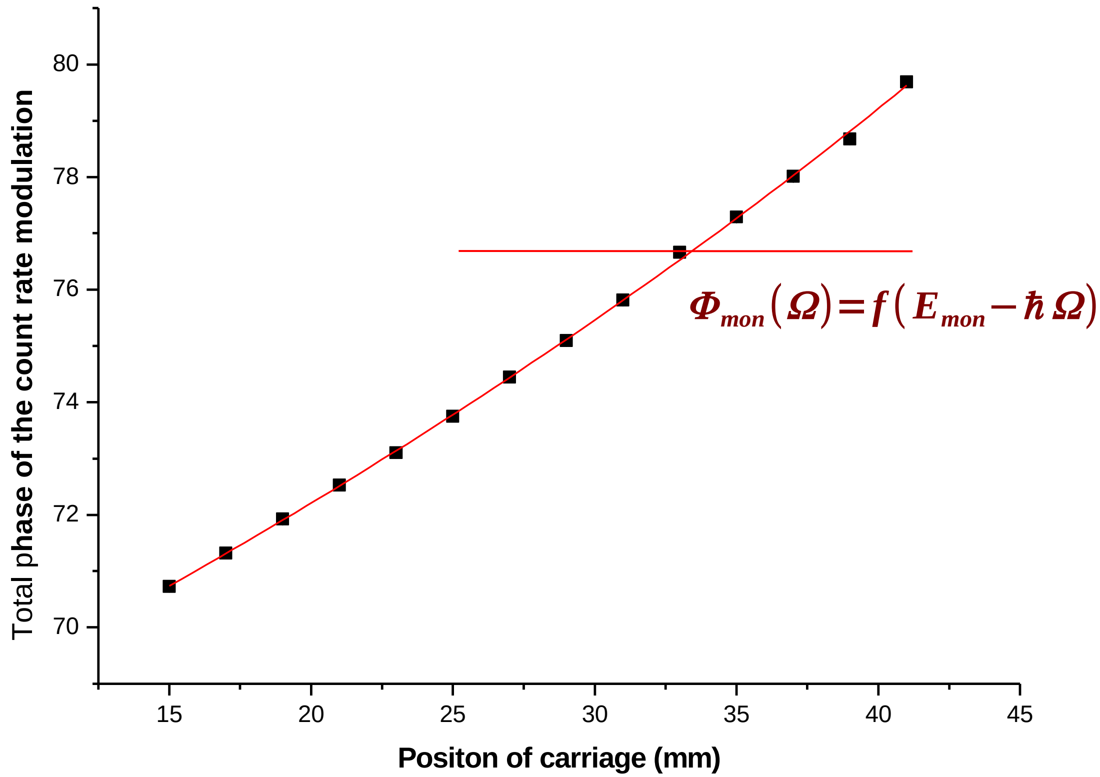




- Changing position of monochromator by height neutrons with different energies at chopper positions are selected

Experiment. Part II (Idea)

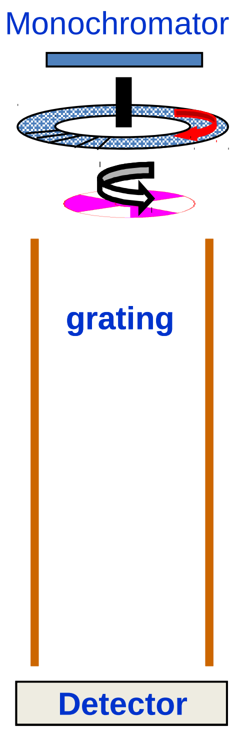


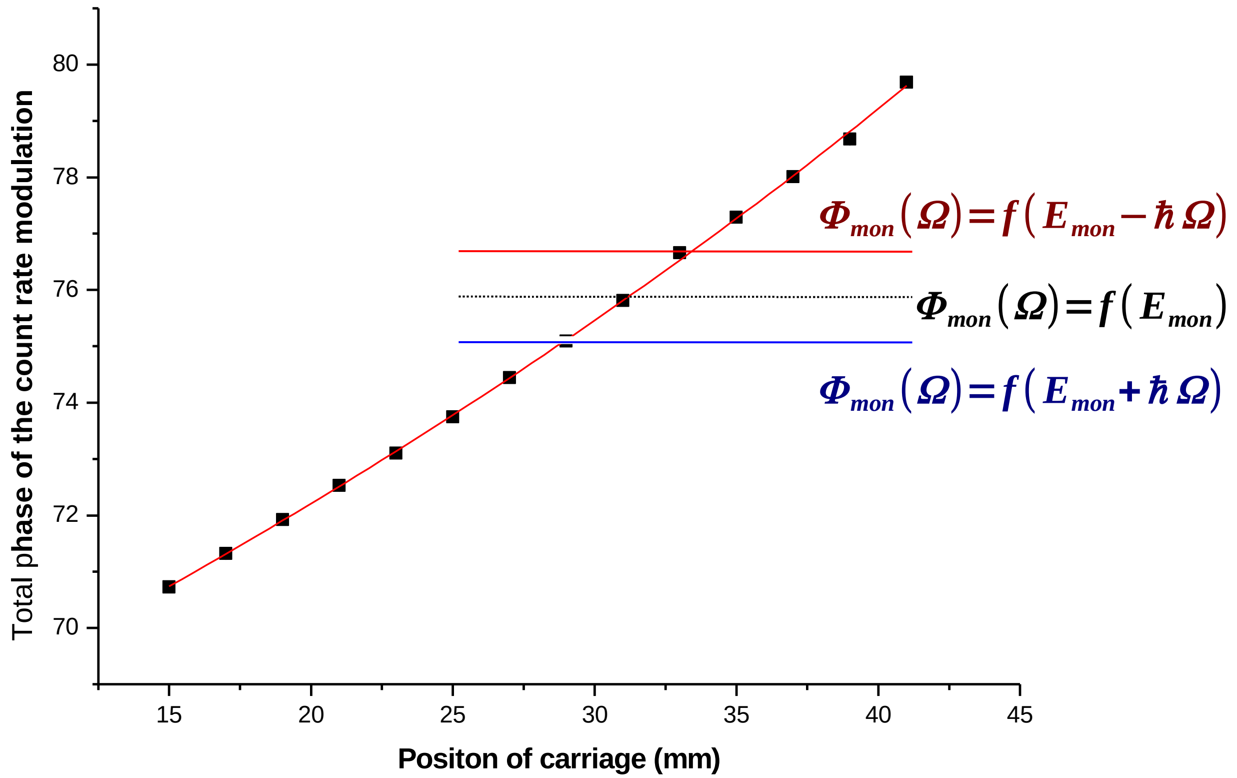


The count rate oscillation phase of the UCN which energy shifted by rotating grating must be compared with the calibration curve

$$\Phi_{mon}(\Omega_i) = \Phi_{mon}(H_i) \text{ means } m_g g_n H_i = \hbar \Omega_i$$

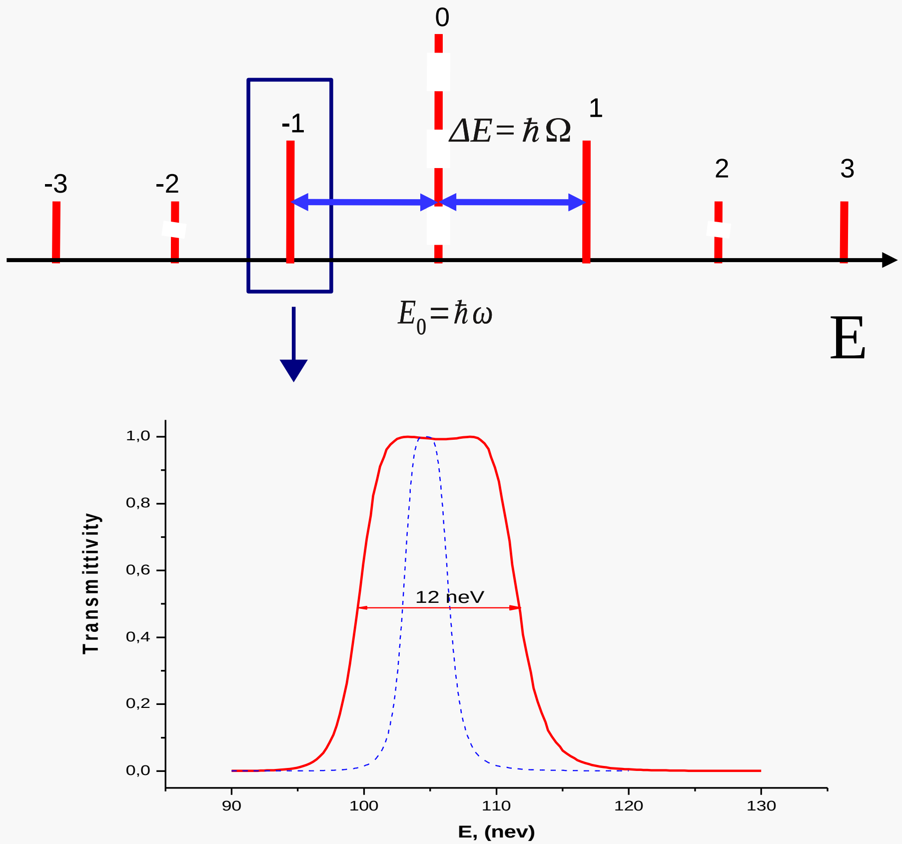
Experiment. Part II (Idea)





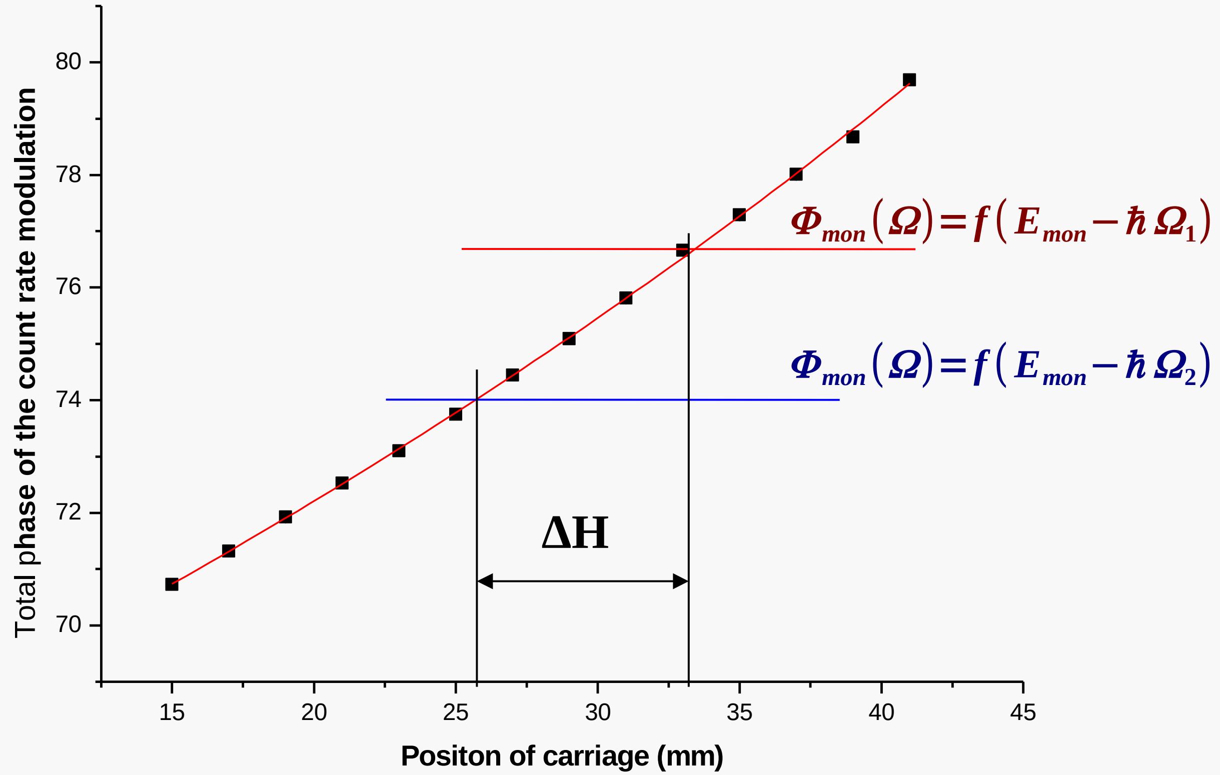
−1 order of diffraction is accompanied by the +1 and higher diffraction orders

Experiment. Part II (Idea)



Special 9-layers filter with wide transmission band to select the UCN of −1 diffraction order

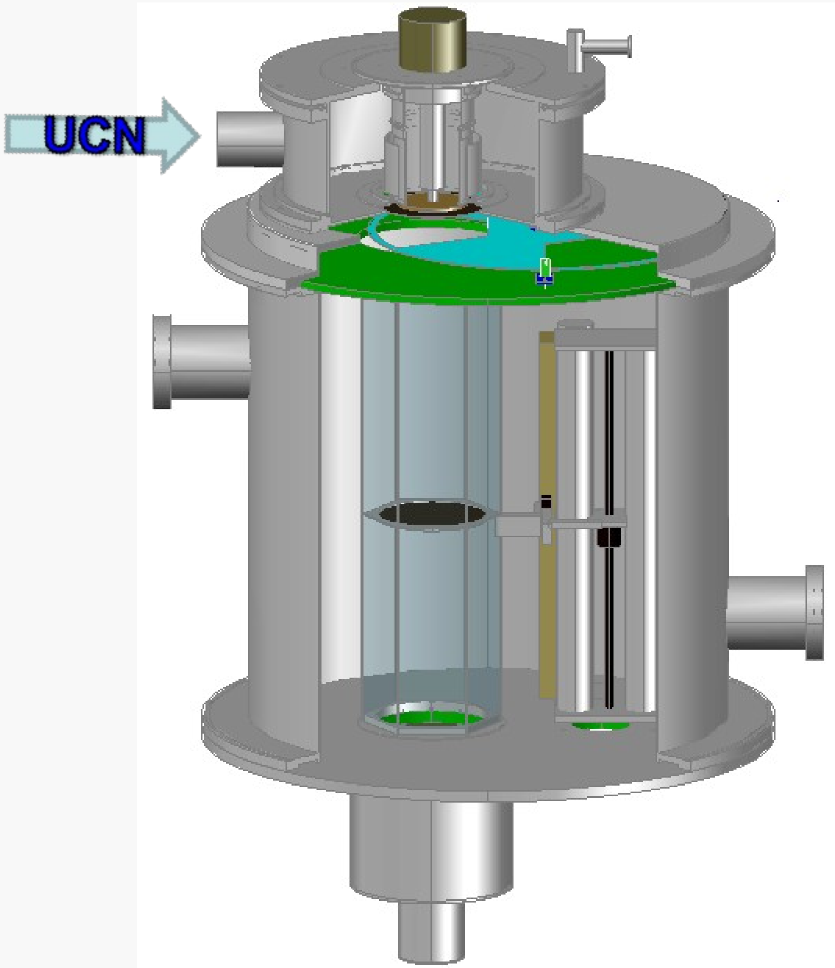
Experiment. Part II (Idea)

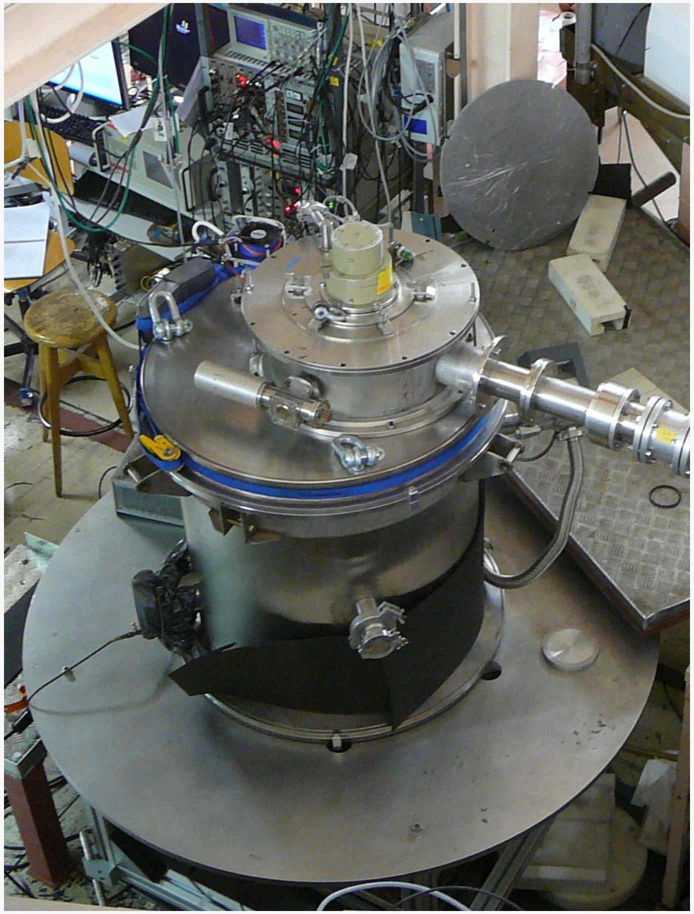


Comparing at same phases for number of frequencies

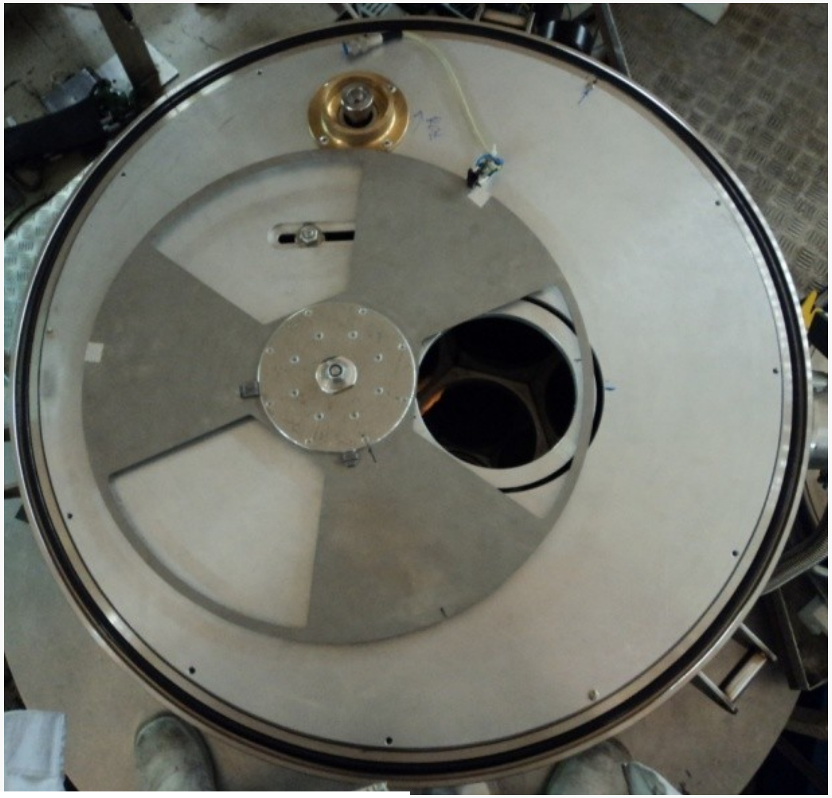
$$m_g g_n = \hbar \frac{\Delta\Omega}{\Delta H}$$

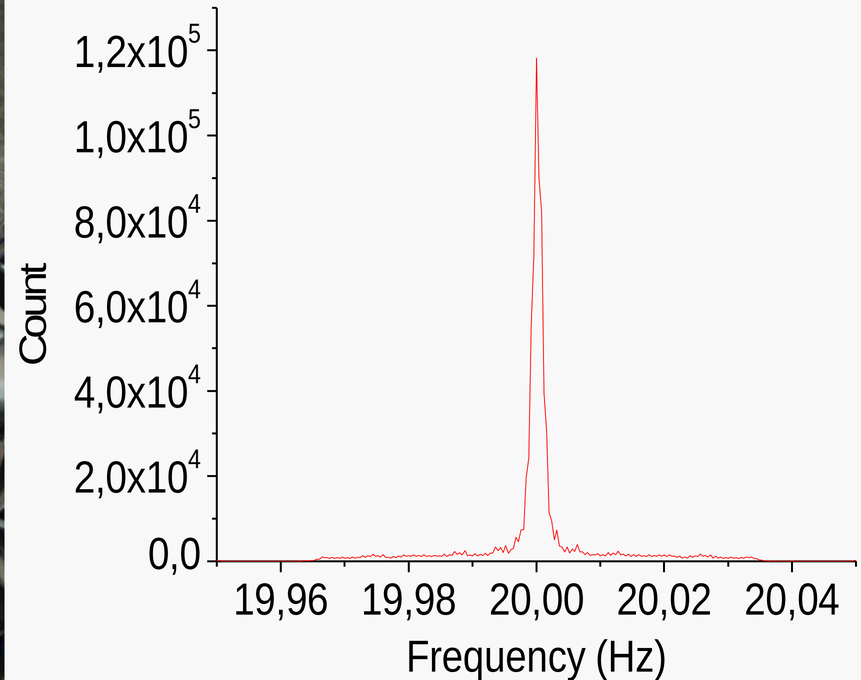
New UCN gravitational spectrometer





Chopper-Modulator

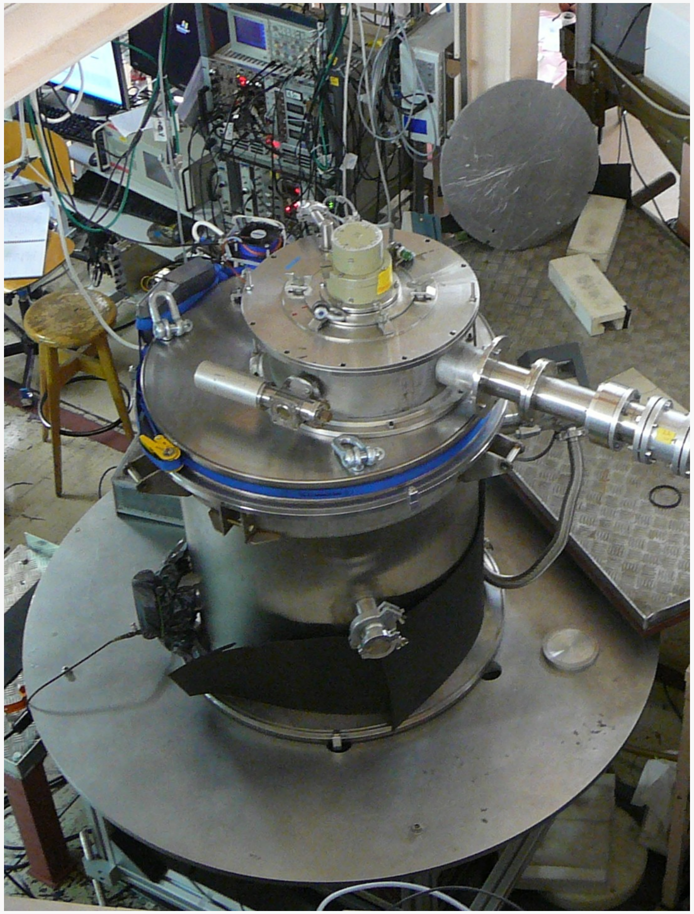




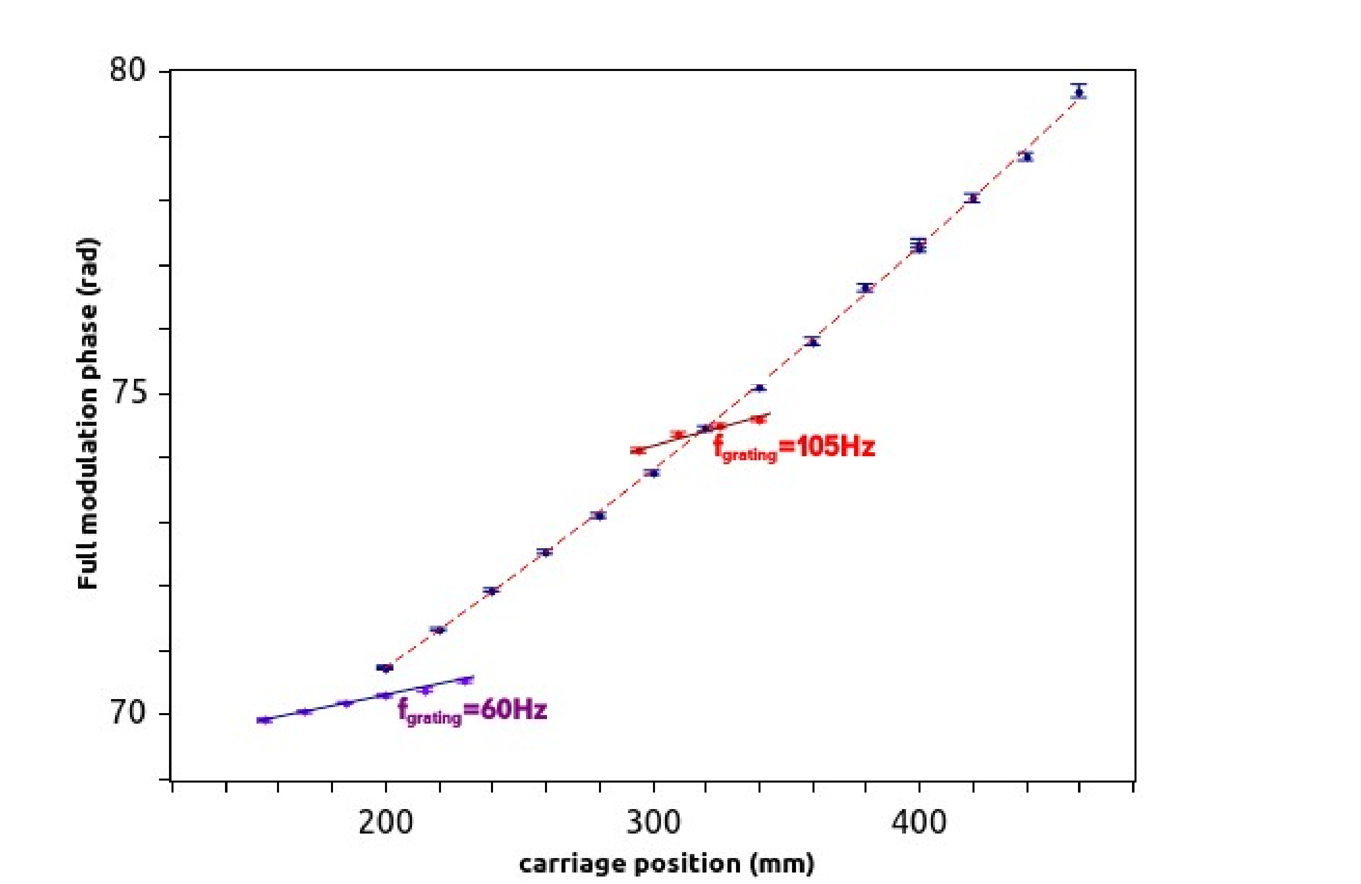
Stability of modulation frequency better then 10^{-4}

New UCN gravitational spectrometer

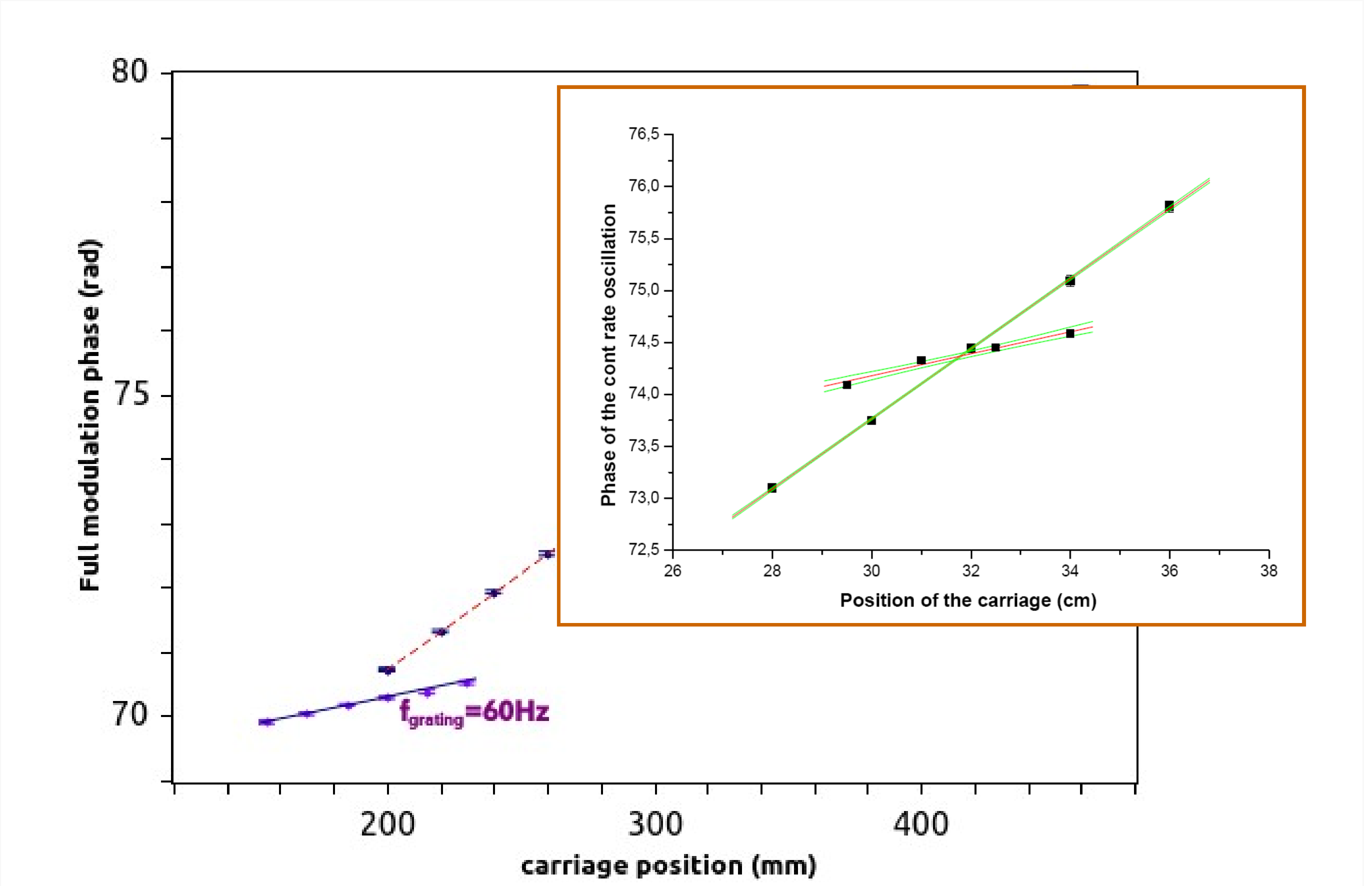
- First tests of main spectrometer elements (2010)
- First full scale test of UCN gravity experiment (2011)



Experiment of 2011



Experiment of 2011

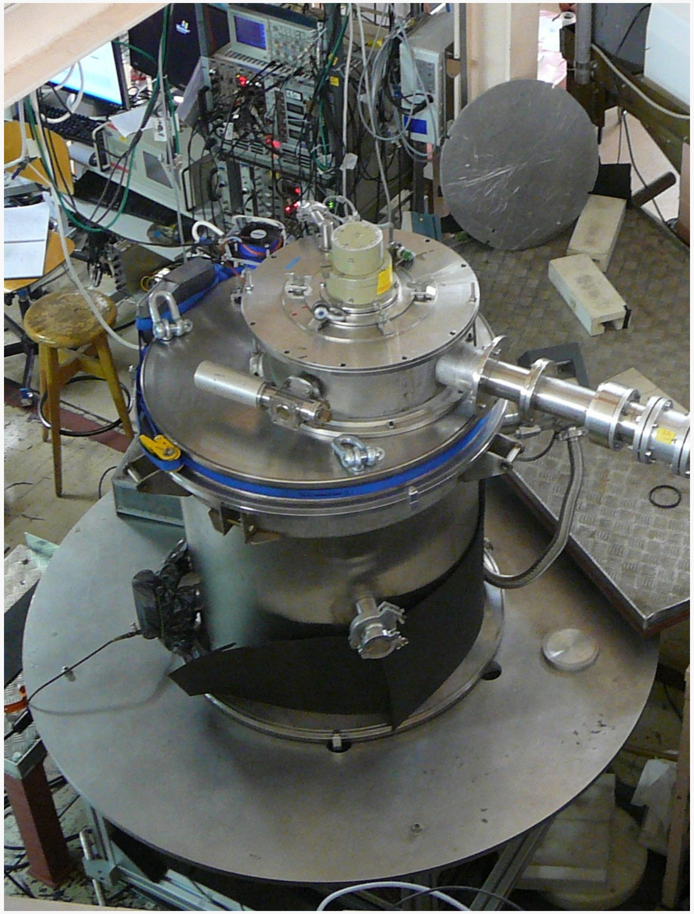


Rate of the collection of accuracy 1.5×10^{-2} per day

For 55 days @ PF2 the statistical accuracy on the level $2\text{x}10^{-3}$ was possible

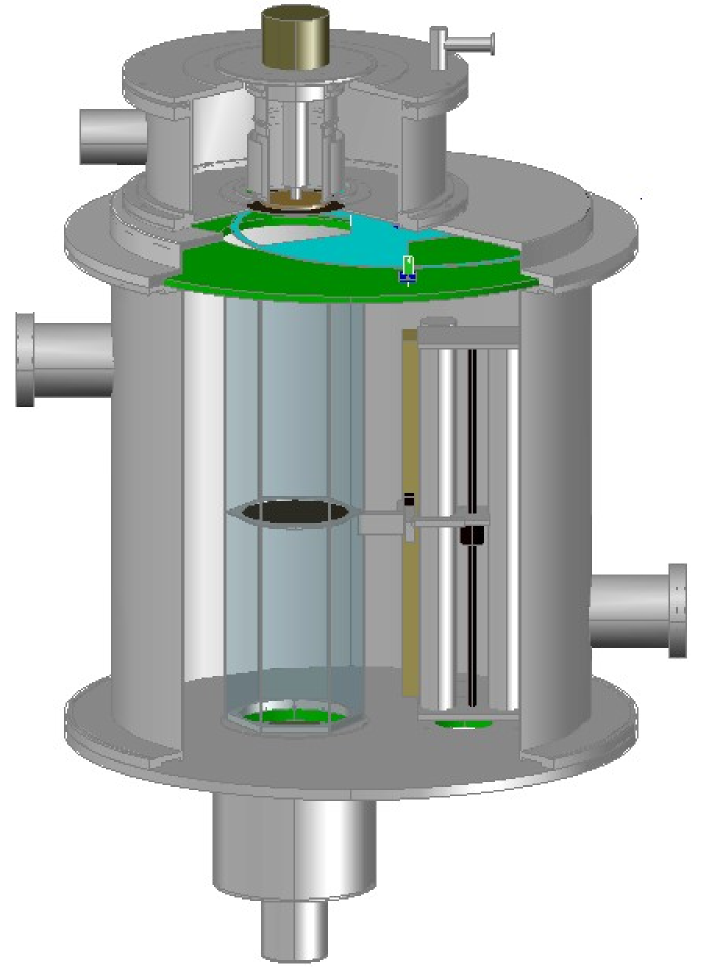
New UCN gravitational spectrometer

- First tests of main spectrometer elements (2010)
- First full scale test of UCN gravity experiment (2011)
- Full scale test of UCN gravity experiment (2012). After some modifications

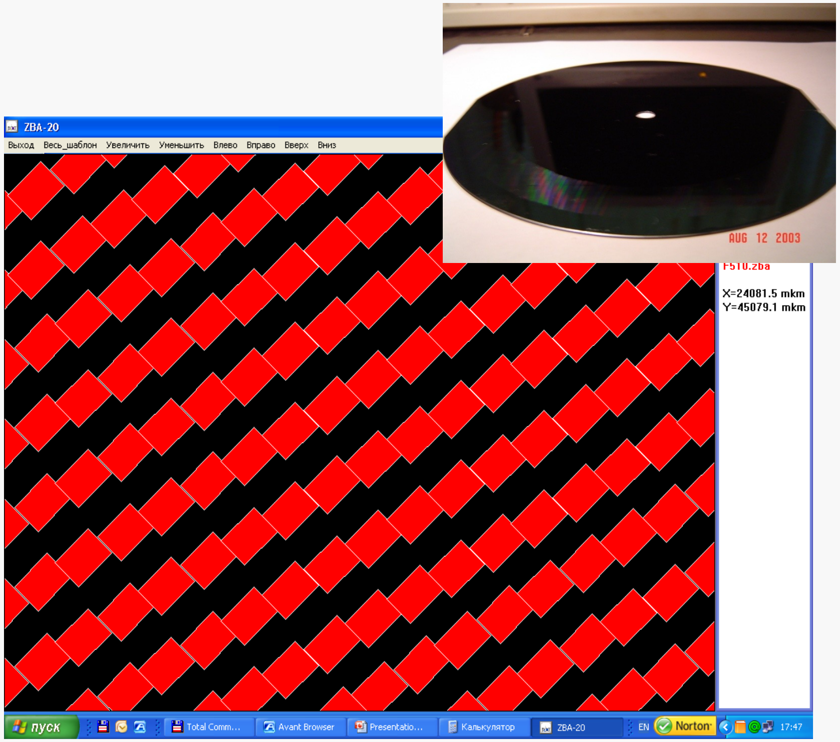


Experiment 2012 (upgrade)

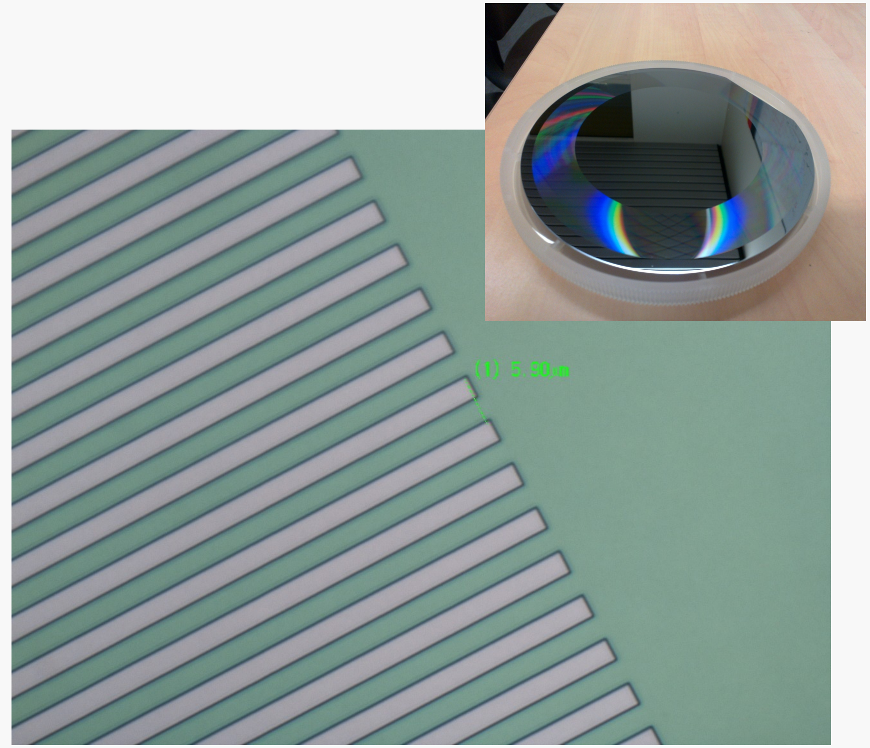
- Diameter of entrance guide was changed from 70 to 80 mm
- New carriage (less shading of glass guide)
- New NIFs with more thin Si support 0.3mm instead 0.6mm before
- New NIF– monochromator with more narrow transmission spectrum (84Hz modulation frequency instead of 75Hz in 2011)
- New phase diffraction grating



Phase diffraction graing

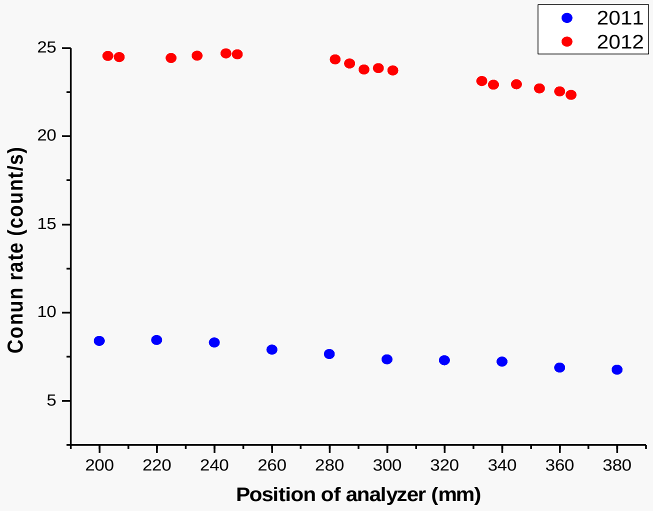


Grating (2011)

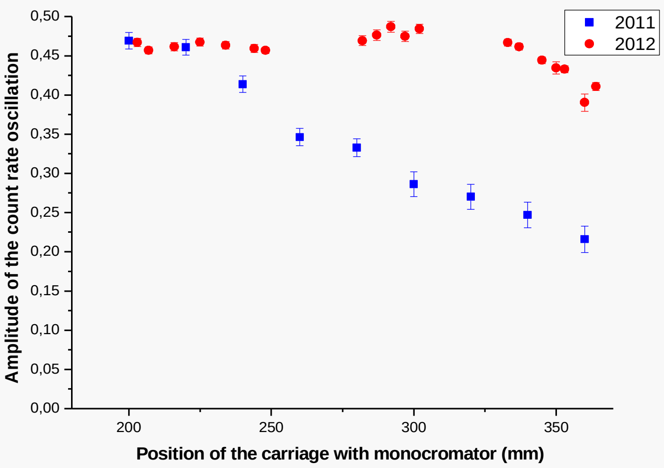


Grating manufactured by the QUDOS technology LTD (2012)

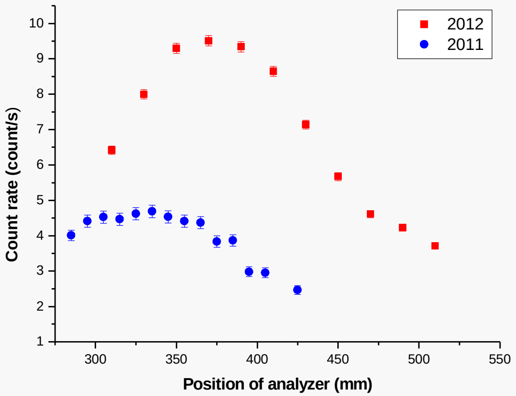
Experiment 2012



Count rate in the geometry of calibration with rotating chopper– modulator

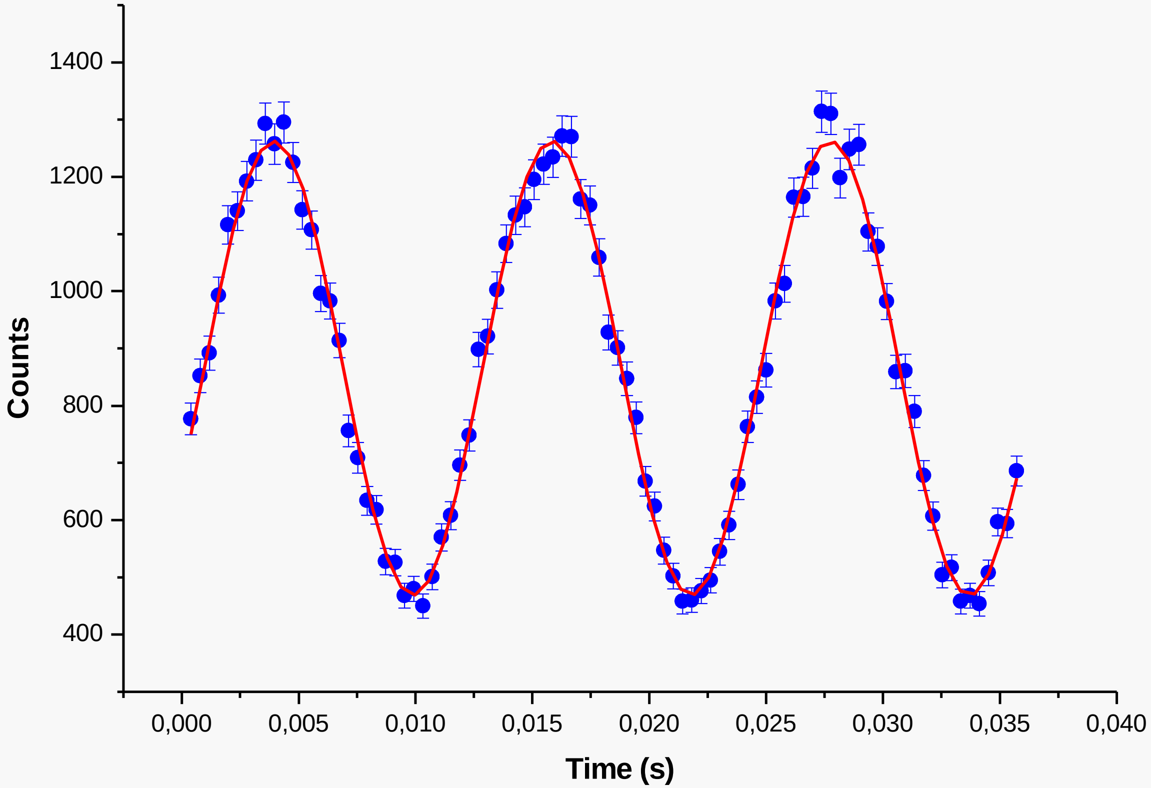


Amplitude of the count rate oscillation in dependence of position of analyzer. Geometry of calibration.



Scanning curve of –1 diffraction order with the grating spinning at 6300 rpm

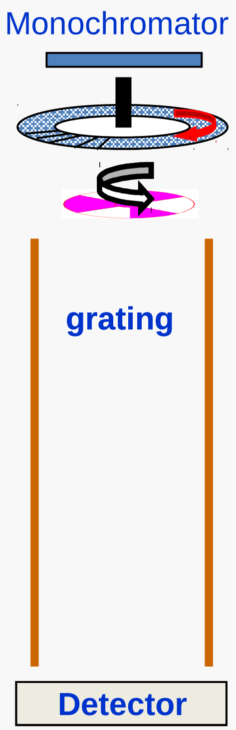
Experiment 2012

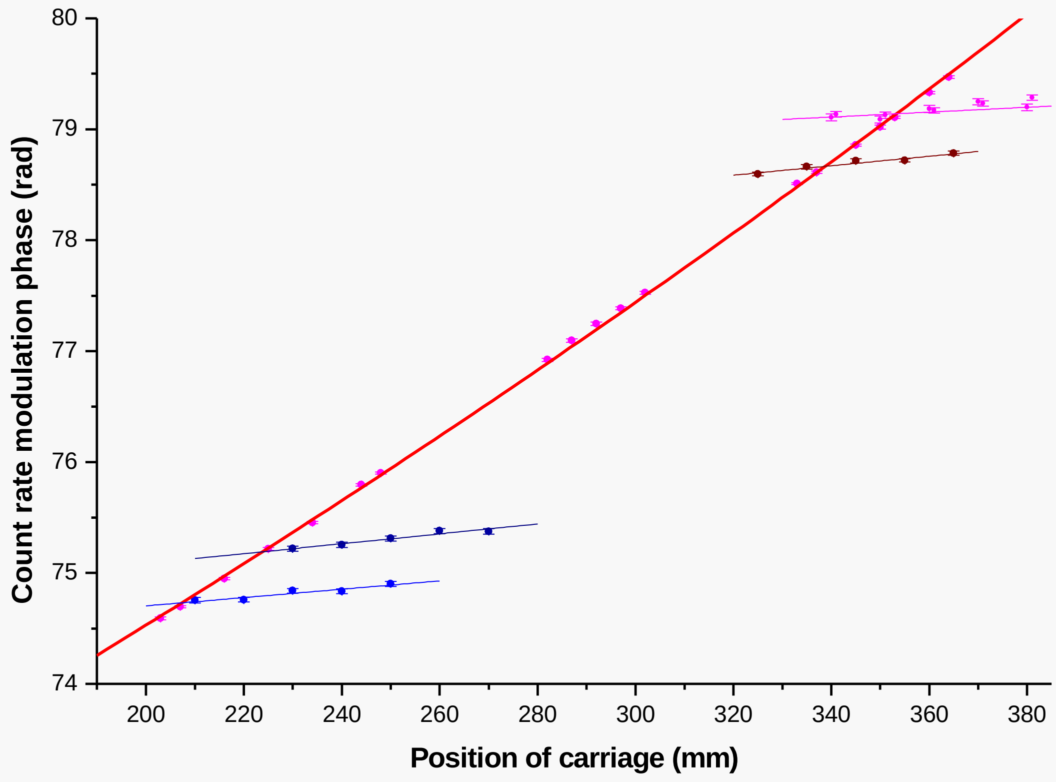


Geometry of calibration

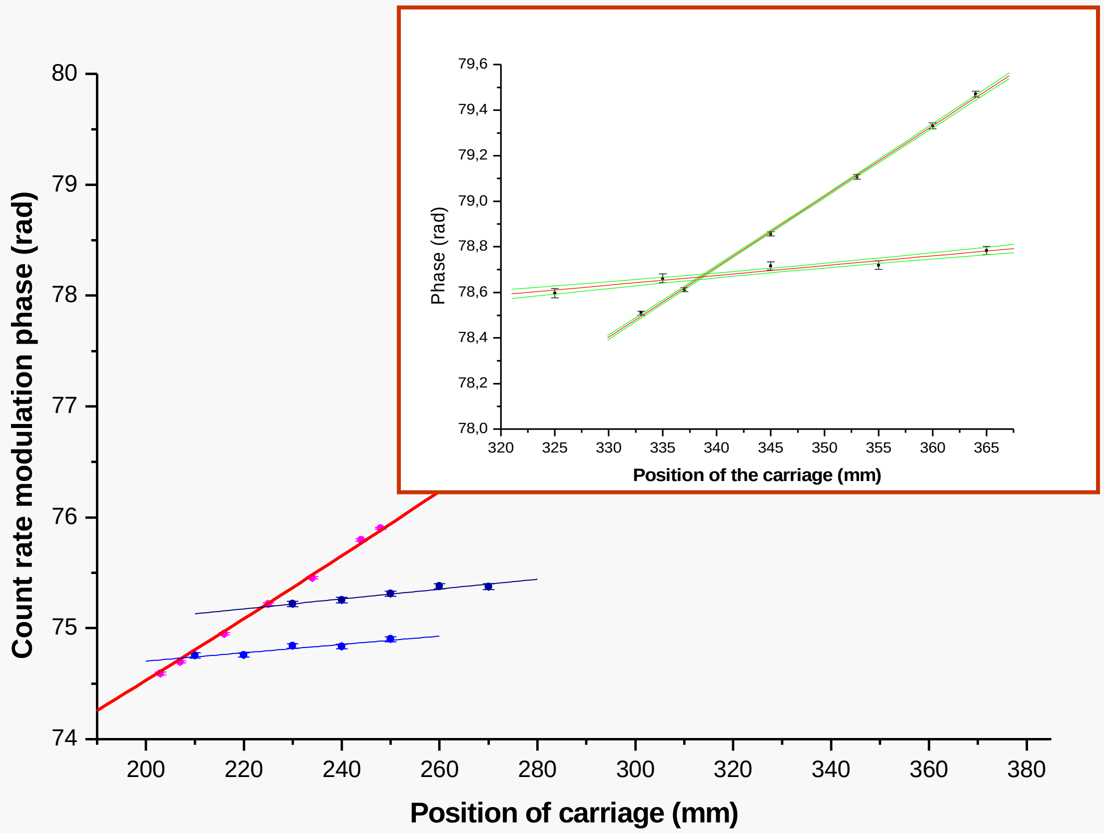
Oscillation of the count rate. Modulation frequency 84Hz, statistic collection time 3200 s, error for the phase measurement 0.01rad, total phase about 80 radian

Experiment 2012





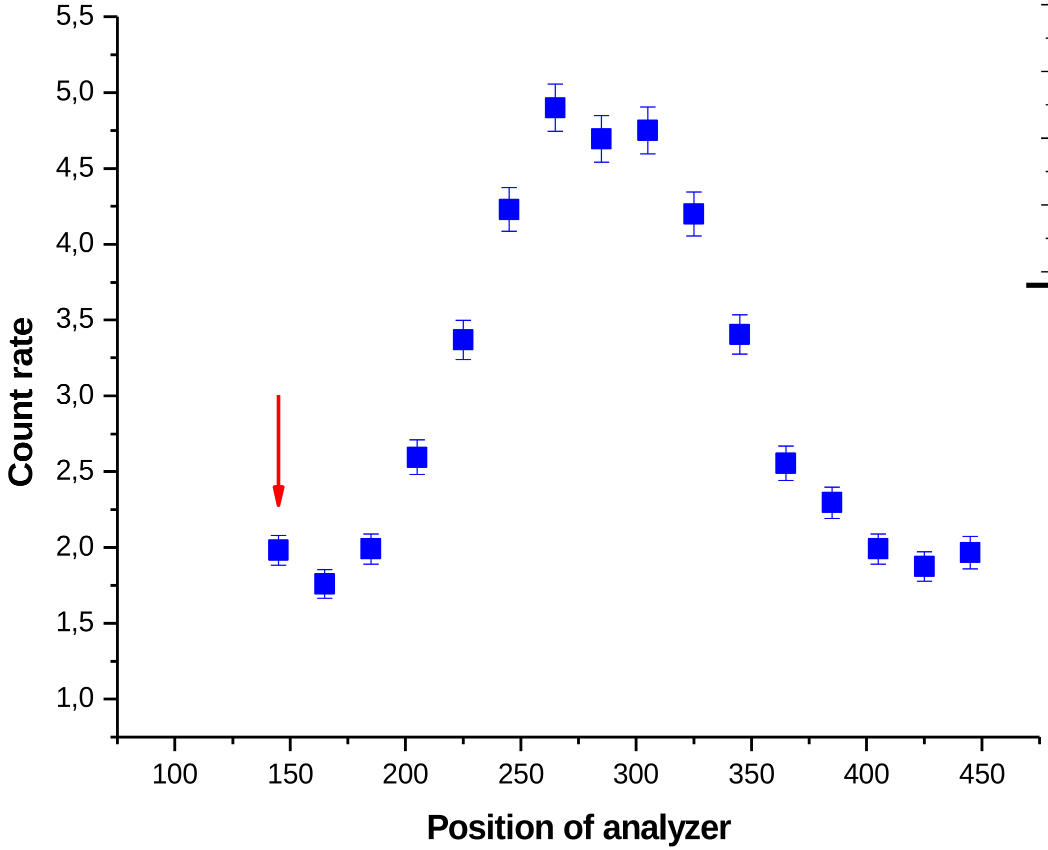
Experiment 2012

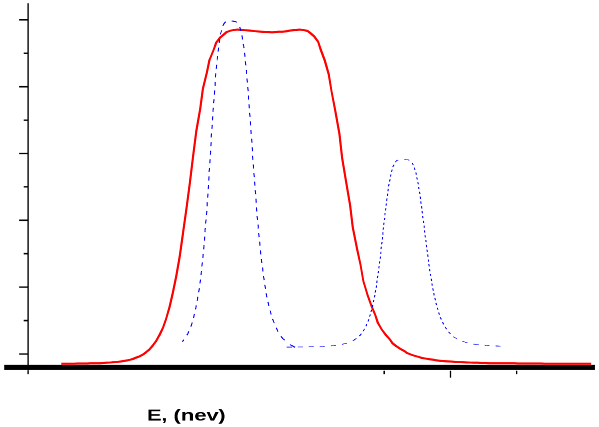


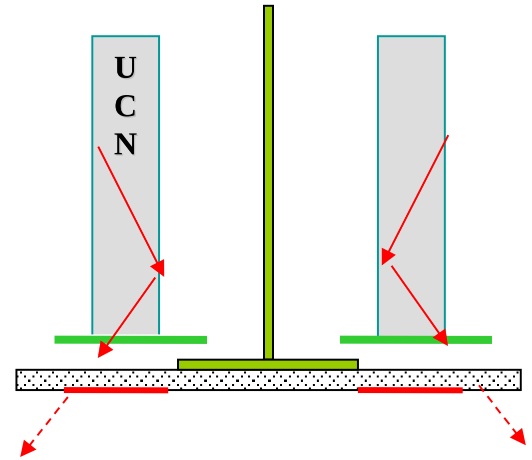
Rate of the collection of accuracy 5×10^{-3} per day (1.5×10⁻² per day in 2011)

Statistical accuracy of the order of 5×10^{-4} during two cycles @ PF2

The systematic effect due to admixture of zero order







Scanning curve of −1 diffraction order measured with wide 9-layers analyzer at grating rotation frequency 75 Hz (4500rpm)

Main results of Experiment 2012

1. The full scale test measurements with new spectrometer was performed.

2. The rate of the collection of statistical accuracy, was obtained as 5×10^{-3} per day. That is enough to collect statistical accuracy of the order of 5×10^{-4} during two cycle of statistic collection at PF2 source.

3. The systematic effect due to admixture of zero order to the spectrum of minus first order was found. This problem may be probably solved by manufacturing of the grating with

   a) smaller inner diameter, that as we hope will decrease the intensity of UCN bypasses the grating

   b) with larger space frequency that will increase separation between the zero (if it will be) and minus first orders.

Possible impruvements

1. The grating with larger number of groves (94 500 instead of 75398) will be used. That will increase the energy transform

2. The monochromator with position of transmission line at 95nev will be used instead of monochromator with 105 nev line.

3. The TOF base will be increased from to 70 to 90 cm

All that will double the collection rate of the statistical accuracy.

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Thank you for your attention!

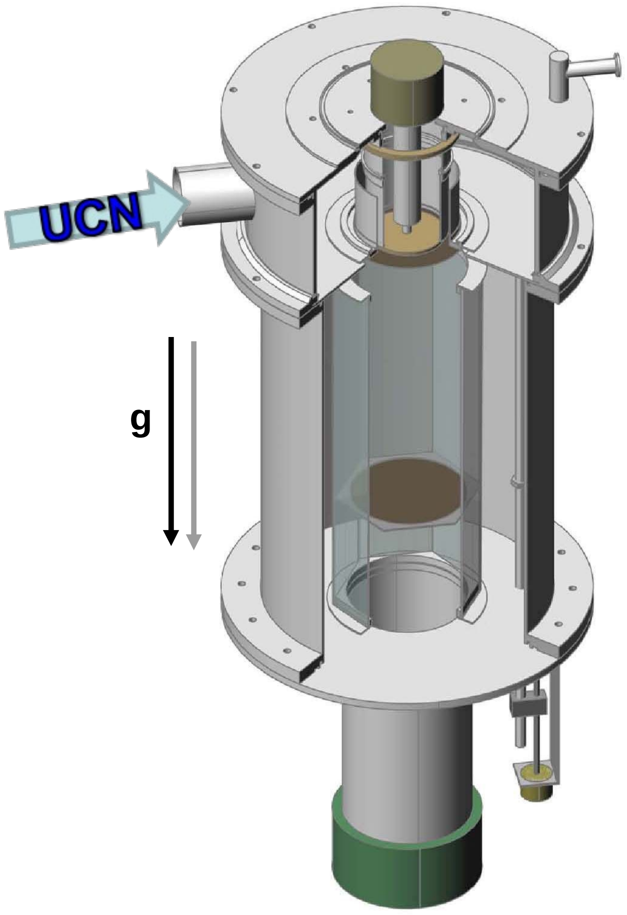
Free Fall Universality tests (short review)

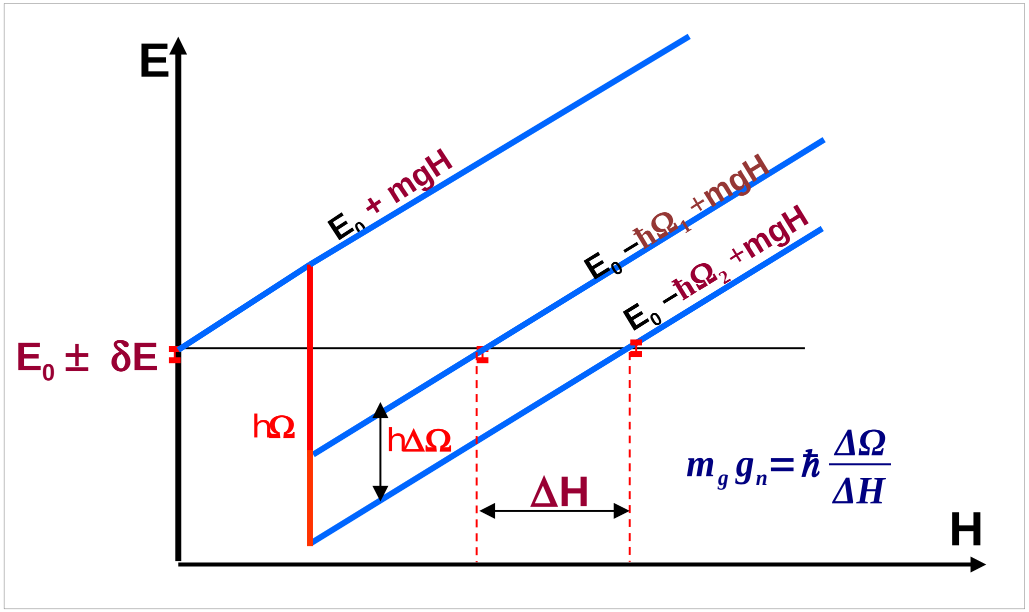
Test body	Attractor (distance)	Result	Reference
Al и Au (30g)	Sun	$\eta(\mathbf{Au},\mathbf{Al}) = (1.3 \pm 1.0)\times 10^{-11}$	1
Al и Cu (350g)	Galileo Type experiment (Earth)	$\Delta g/g = (2.9 \pm 7.2)\times 10^{-10}$	2
Be и Ti (5 g)	Earth	$\eta_{\mathbf{Earth,Be-Ti}} = (0.3 \pm 1.8)\times 10^{-13}$	3
Atoms ^{85}Rb/^{87}Rb	Earth	$\Delta g/g = (1.2 \pm 1.7)\times 10^{-7}$	4
(Lunar laser ranging)	Sun	$\left\| (\mathbf{M_g}/\mathbf{M_i})_{\mathbf{Earth}} - (\mathbf{M_g}/\mathbf{M_i})_{\mathbf{Moon}} \right\| = (-1.0 \pm 1.4)\times 10^{-13}$	5
Cu and Pb (10g)	Attractor ^{238}U, (2.6T) 20cm	$\dfrac{\Delta \mathbf{a}_{(\mathbf{Cu-Pb})} = (1.0 \pm 2.8)\times 10^{-13}\,\mathbf{cm/s^2}}{\mathbf{a} = 9.8\times 10^{-5}\,\mathbf{cm/s^2}}$	6

$$\eta(A,B) = \frac{\Delta a}{a} = 2\frac{(M_g/m_1)_A - (M_g/m_1)_B}{(M_g/m_1)_A + (M_g/m_1)_B}$$

1. P.G. Roll, R. Krotkov, and R.H. Dicke, Ann. Phys. (N.Y.) 26, 442 (1964)
2. S.Carusotto, V.Cavassinni, A.Mordacci et. al. Phys.Rev Lett. 69, 1722 (1992)
3. S. Schlamminger, K.-Y. Choi, T. A. Wagner, et al. Phys.Rev Lett 100, 041101 (2008)
4. S. Fray, C. A. Diez, T. W. Hänsch, and M. Weitz. arXiv:physics/0411052 v.2 (2005)
5. J. G. Williams, S.G. Turyshev, and D. H. Boggs, Int.J.Mod.Phys.D18:1129-1175, (2009)
6. G. L. Smith, C. D. Hoyle, J. H. Gundlach, E. G. Adelberger, B. R. Heckel, and H. E. Swanson. Phys. Rev. Rev. D 61, (1999) 022001

Previous experiment. 2006





Result:

$$1-\frac{m_g g_n}{m_i g_{loc}}=(1.8\pm 2.1)\times 10^{-3}$$

A.I. Frank, P. Geltenbort, M. Jentschel,et al. JETP Letters, 86, 225 (2007)

Some possible sources of systematic errors (analysis is continuing)

- Non-verticality of the axis of the spectrometer.
- Thermal extension
- Accuracy of measurement of the filter-analyzer position
- Frequency stability
- Gradient of a magnetic field
- Re-reflection between some elements of spectrometer
- Insufficient separation of +1 and -1 orders (some overlapping)

L.Koester, 1976

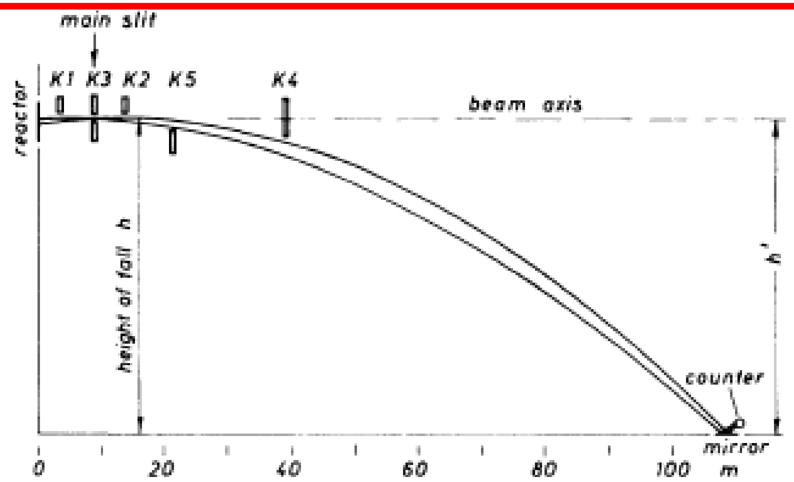


FIG. 1. Principle of the neutron gravity refractometer.
K1, ... , K5: slits and stopper for the neutron beam

$$\mathbf{mgh_0} \text{ € } \mathbf{U_{eff}} = \frac{2\pi h^2}{\mathbf{m}}\rho \mathbf{b}$$

Knowing the neutron mass **m** and local free fall acceleration g_{loc} one can obtain the effective scattering length b_{eff}

$$b_{eff} = \frac{m^2 g_{loc} h_0}{2\pi h^2 \rho}$$

Coherence length **b** was measured also in the neutron scattering experiment with **Pb** and **Bi**. Thus the equivalence factor γ was found

$$m_g g_n h_0 = \frac{2\pi h^2}{m_i}\rho b \qquad \gamma = \frac{b_{eff}}{b} = \frac{m^2}{m_i m_g}\frac{g_{loc}}{g_n}$$

$1-\gamma = (3 \pm 3) \times 10^{-4}$ V.F.Sears,1982

J. Schmiedmayer, NIM A 284, (1989) 59

$\gamma = 1.00011 \pm 0.00017$

Koester's experiment and the problem of n-e scattering

When the value of b_{coh} extracts from the total cross section data it is necessary to take into account n-e scattering. For the case of Pb and Bi correspondent corrections are of the order 1%. Consequently, if one aim to reach 10^{-4} in precision of b_{coh} the amplitude of n-e scattering must be known with precision of 1%.

It is not evident that b_{ne} is known with such precision even now