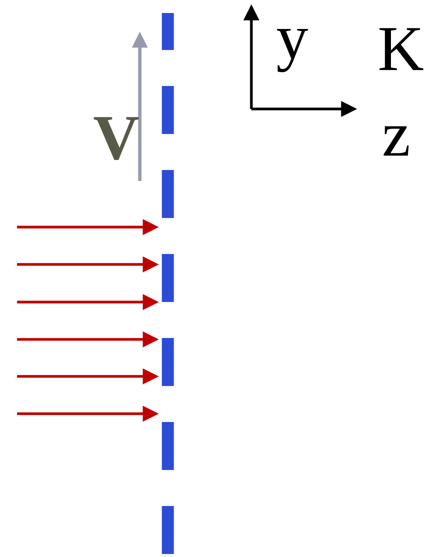
Neutron diffraction on moving grating and systematic effect in the gravity experiment

G.V. Kulin

ISINN-22, 27 may 2014

Moving diffration grating. Elementary theory

A.Frank, V.Nosov, 1994



$$\Psi(z,y,t)=\sum_j a_j \exp[i(k_j z+q_j y-\omega_j t)] \qquad (k_0 L<<1)$$

$$q_j = j\cdot\left(2\pi/L\right)=jq_0$$

$$\omega_j=\omega_0+j\Omega \qquad k_j\cong k_0\left(1+j\frac{\Omega}{\omega_0}\right)^{\frac{1}{2}} \qquad j=0,\ \pm1,\ \pm2....$$

$$\Omega=\frac{2\pi}{T}=2\pi f=2\pi\left(\frac{V}{L}\right)$$

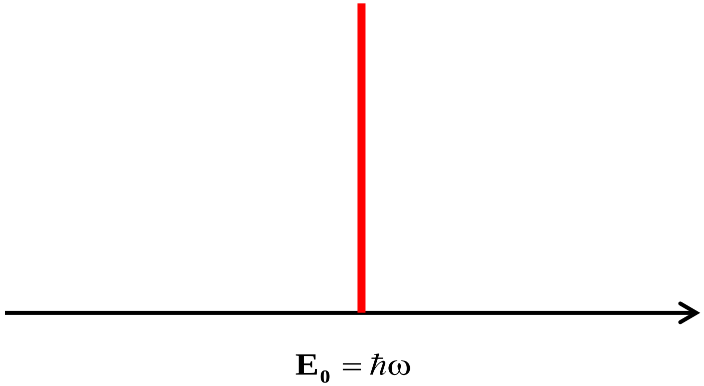
L – space period of grating

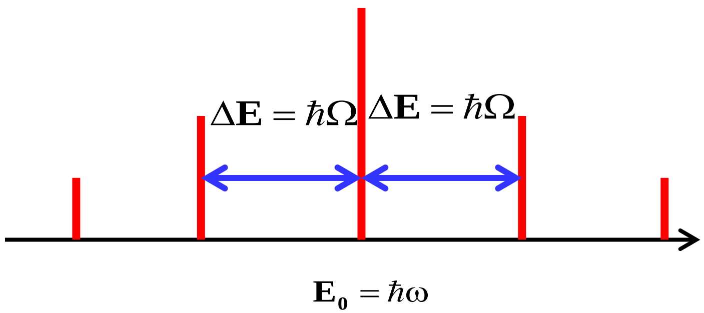
In a limit $L\rightarrow\infty$, $V\rightarrow\infty$, $V/L=f=const$ $\quad q_0\rightarrow 0$

$$a_j=\frac{1}{L}\int_0^L \theta(y)e^{-iq_j y}dy$$

Amplitude or phase modulation of the transmitted wave

Moving diffration grating. Phase π-grating.





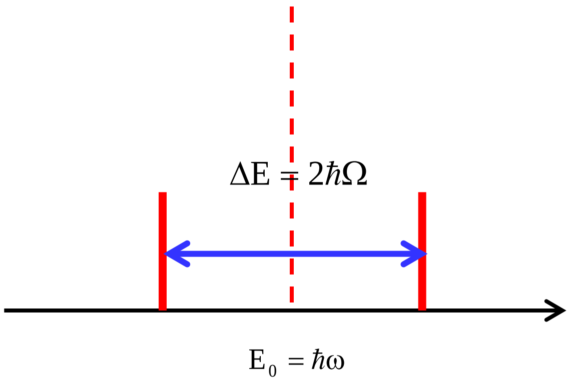
$$\Omega = 2\pi\left(\frac{V}{L}\right)$$

$$\theta(y) = \begin{cases} 1 & \text{if} \quad 0 < y < L/2 \\ \exp(i\pi) & \text{if} \quad L/2 < y < L \end{cases}$$

Phase π - modulation

$$a_j = \frac{2}{i\pi j}, \qquad j = 2s - 1$$ **Only odd orders**

$$|a_{\pm 1}|^2 = \frac{4}{\pi^2} = 0.405 \qquad a_0 = 0\ !$$

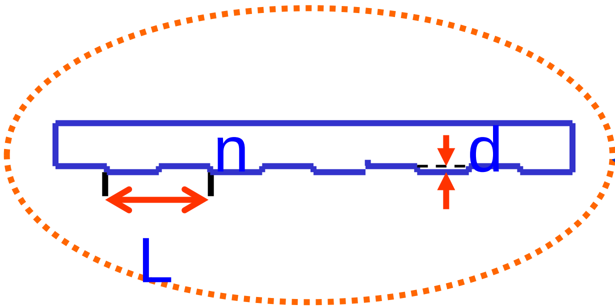


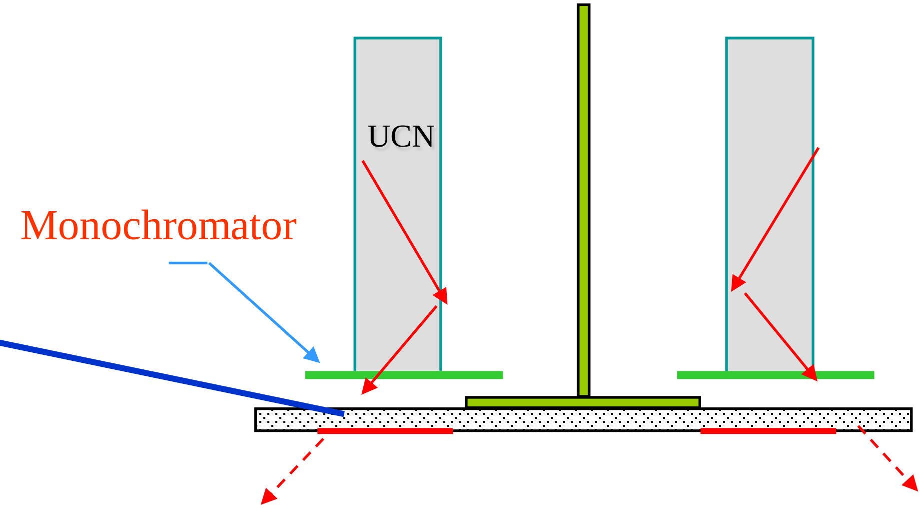
Idea of the gravity experiment

Comparing of the energy $m_g g_n H$ with the energy $\hbar\Omega$ (transferred by the moving grating)

Experimental realization-rotating gtrating

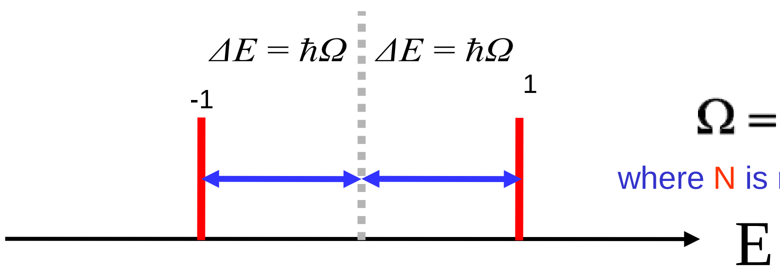
Phase π -grating





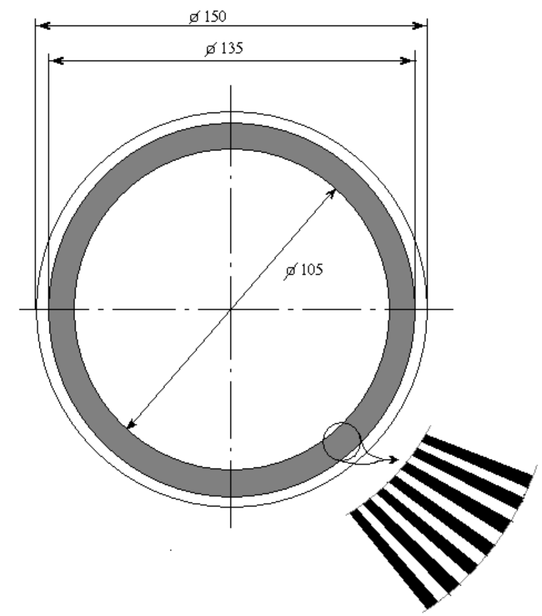
$$\Delta\varphi = \mathbf{k}(\mathbf{n}-1)\mathbf{d} = \pi$$

d = 0.14 μ



$$\Omega = 2\pi f N$$

where N is number of groves



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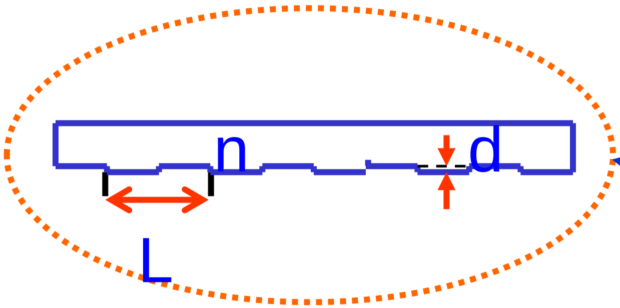

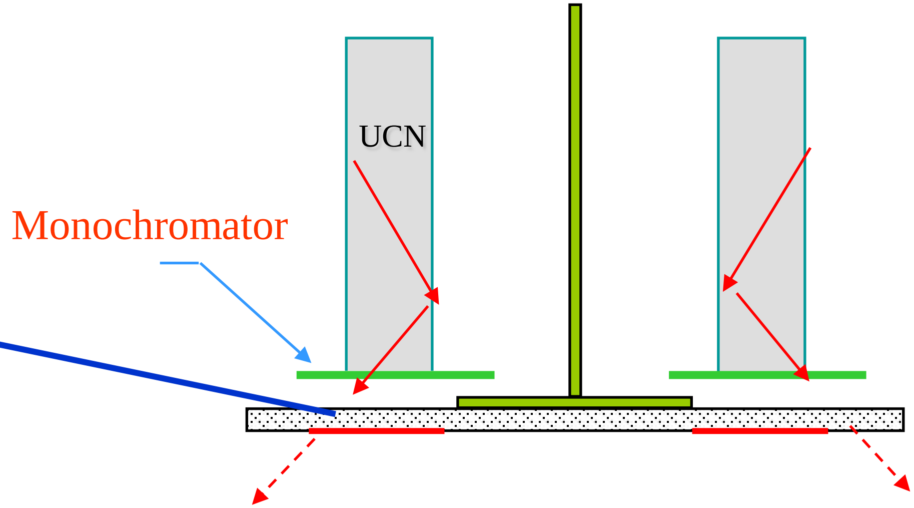

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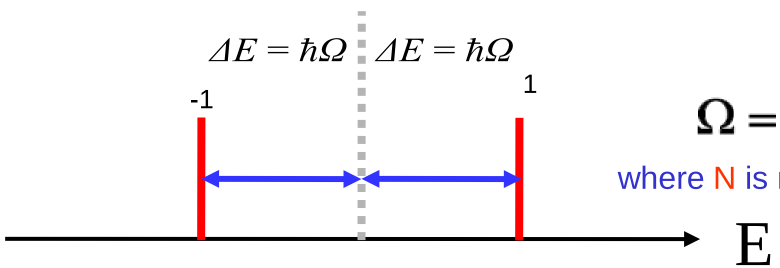

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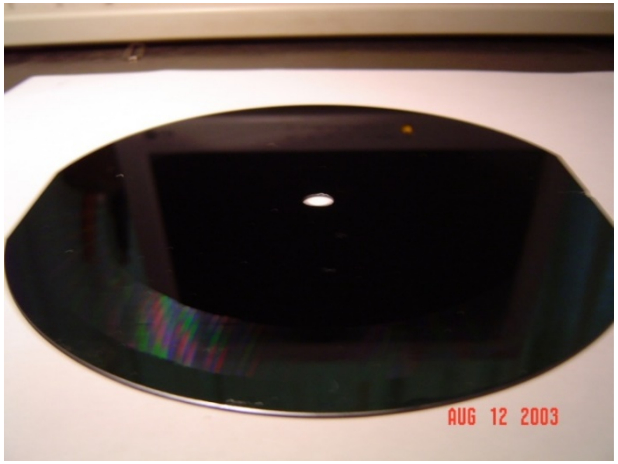
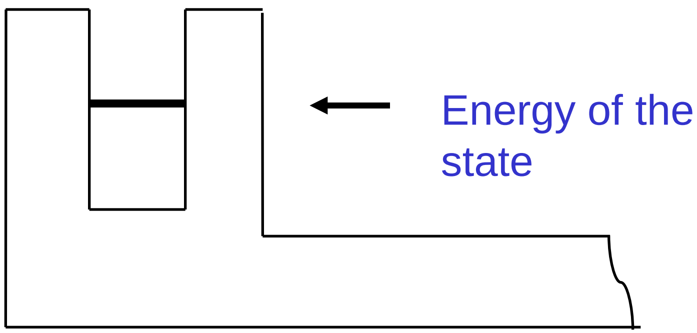
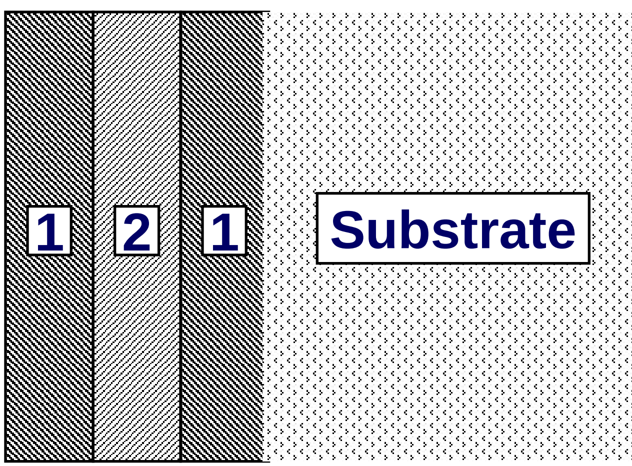
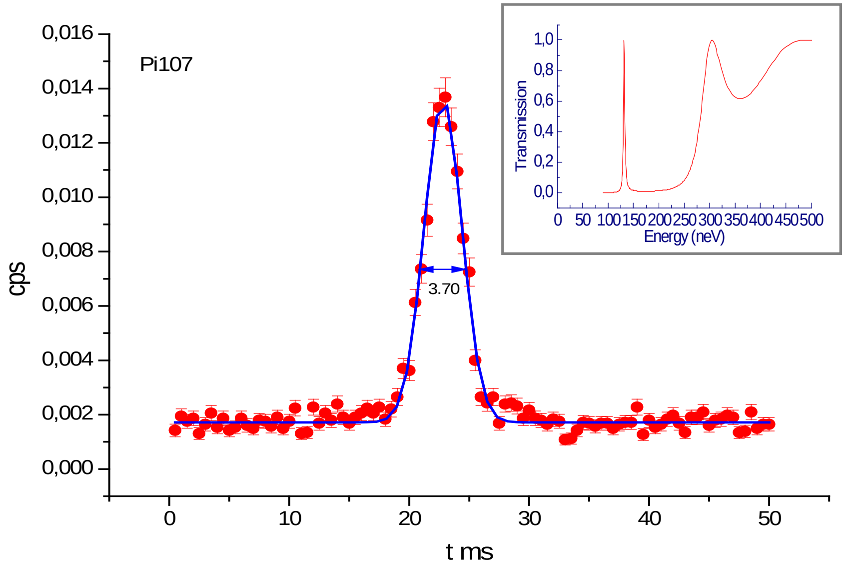


Neutron interference filters as spectrometric devices.

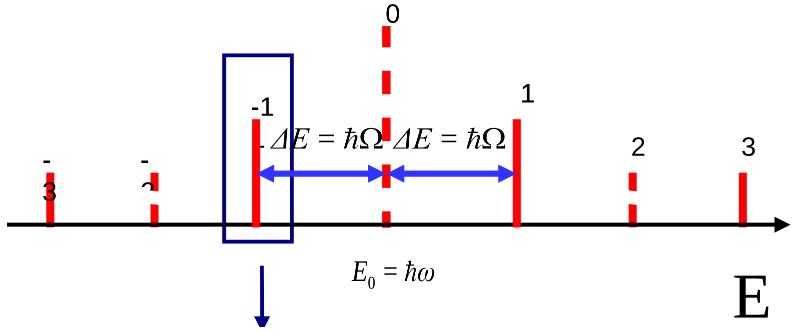


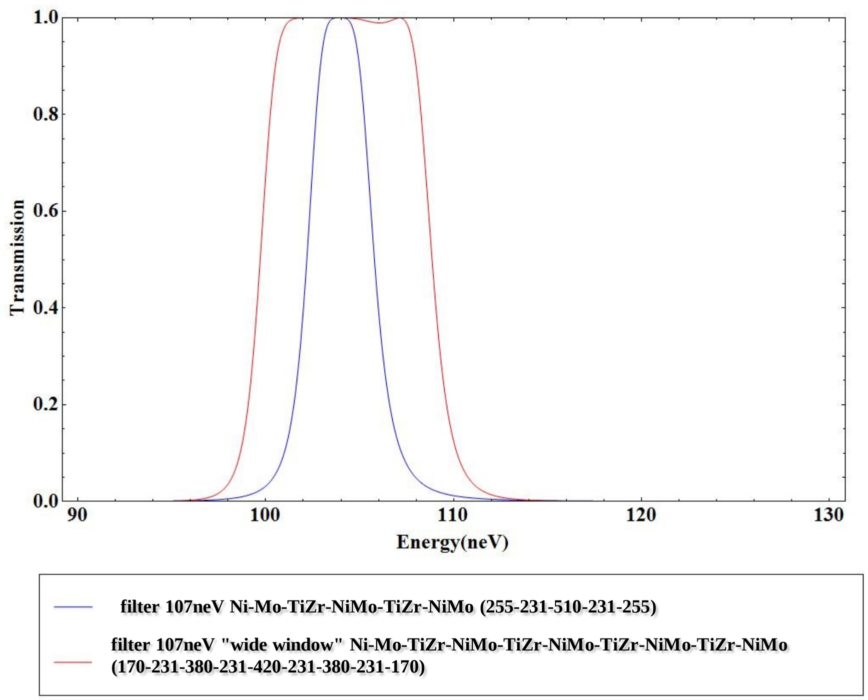




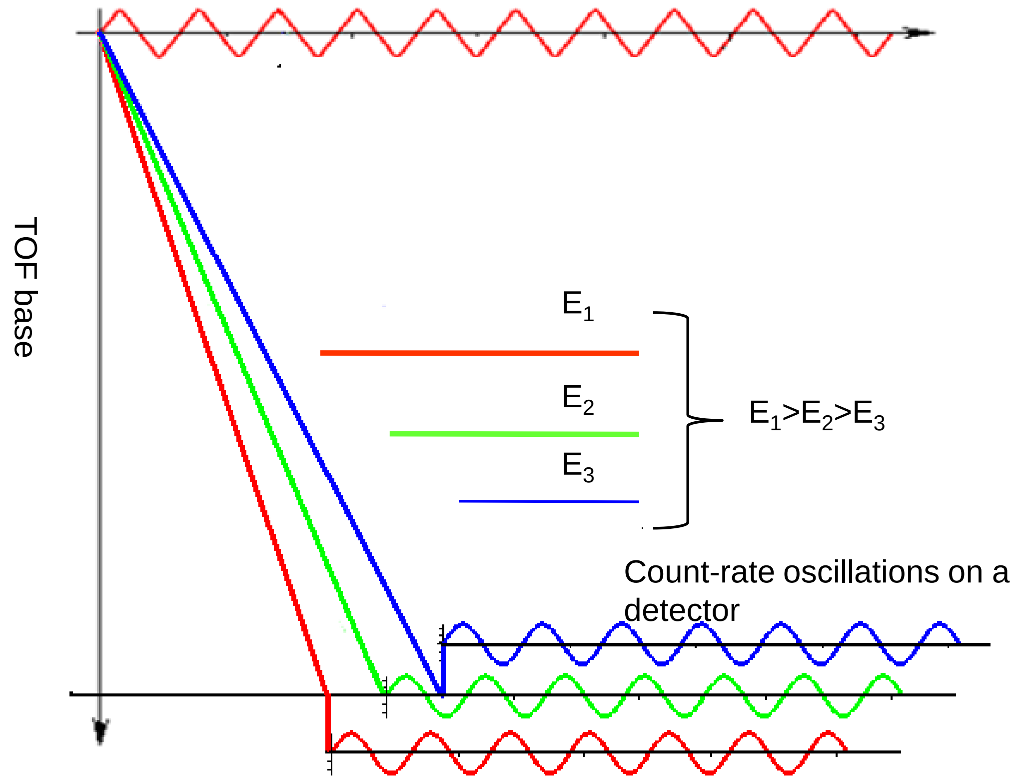
$$U_{1,2} = \frac{2\pi\hbar^2}{m}(\rho b)_{1,2}$$

9-layer structure (wide window) to sepate -1 order

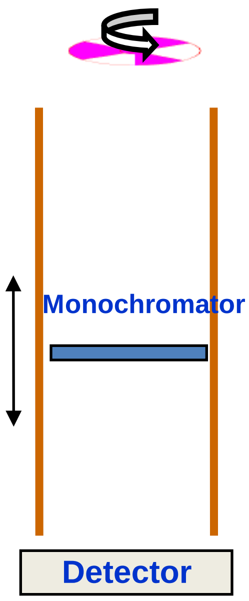


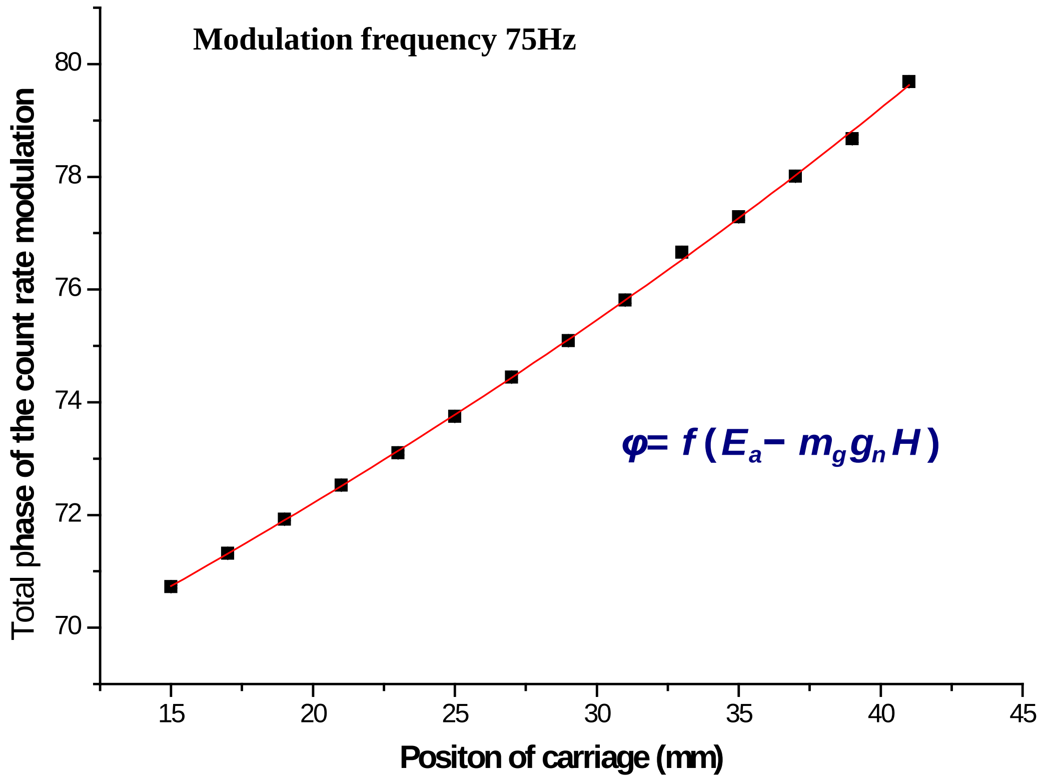


Pecullar TOF spectrometry



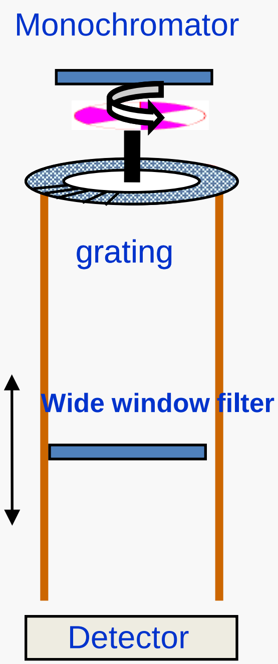
Experiment. Phase I - Calibration

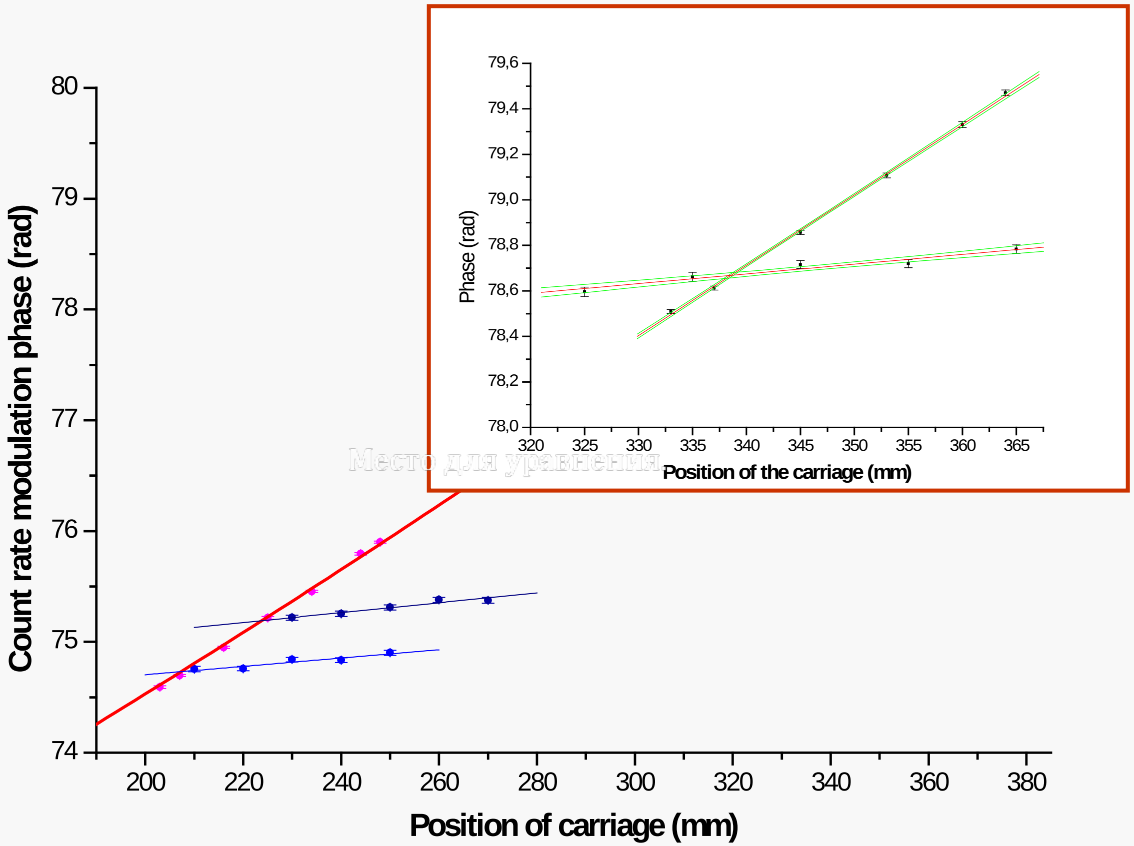




Variation of the monochromator vertical position leads to changing of the UCN energy, time of flight and total phase of the count rate oscillation

Experiment. Phase II

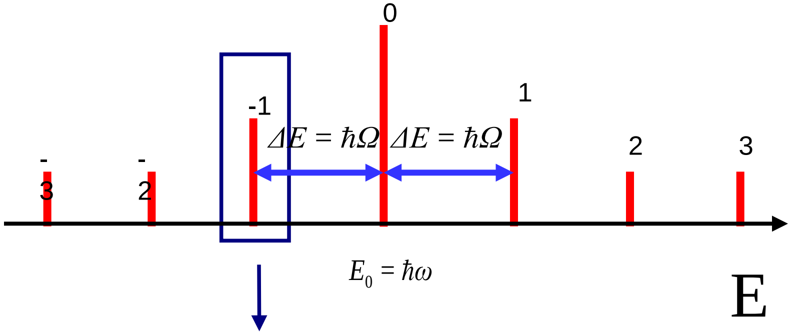


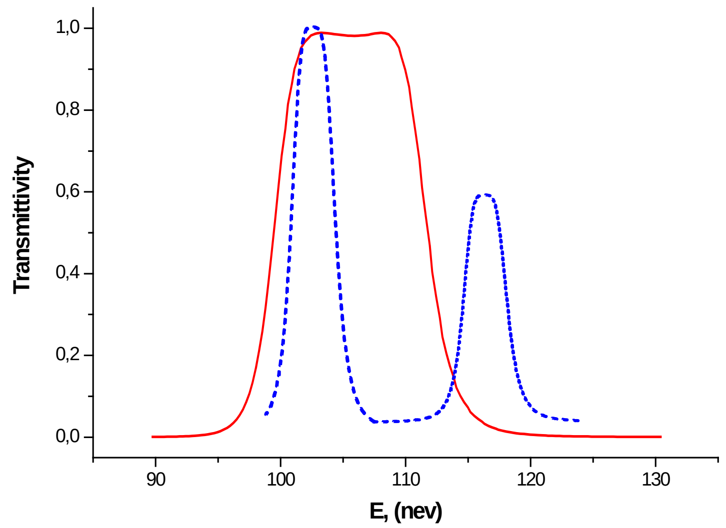


The count rate oscillation phase of the UCN which energy shifted by rotating grating must be compared with the calibration curve

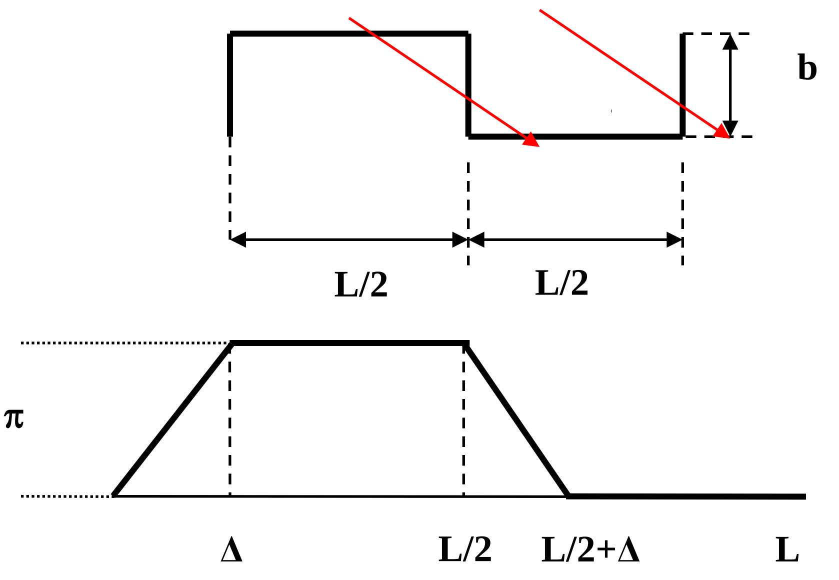
$$\Phi_{mon}(\Omega_i)=\Phi_{mon}(H_i) \; means \; m_g g_n H_i = \hbar\Omega_i$$

Systematic effect





Admixture of zero or other even orders lead to systematic effect



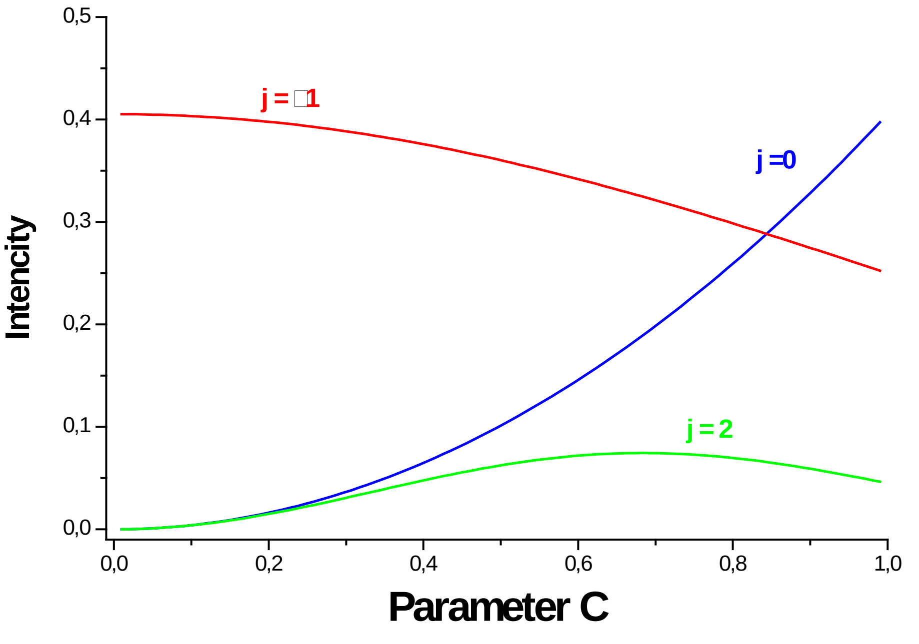
Modulation phase function at angular incidence

$$f(x) = \begin{cases} e^{i\frac{2\pi}{cL}x} & \text{if } 0 < x < \Delta \\ e^{i\pi} & \text{if } \Delta < x < L/2 \\ -e^{i\frac{\pi}{c}\left(1-\frac{2x}{L}\right)} & \text{if } L/2 < x < L/2+\Delta \\ 1 & \text{if } L/2+\Delta < x < L \end{cases}$$

$$c = 2\frac{b}{L}\frac{V}{v_n}$$

Orders intensity transformation

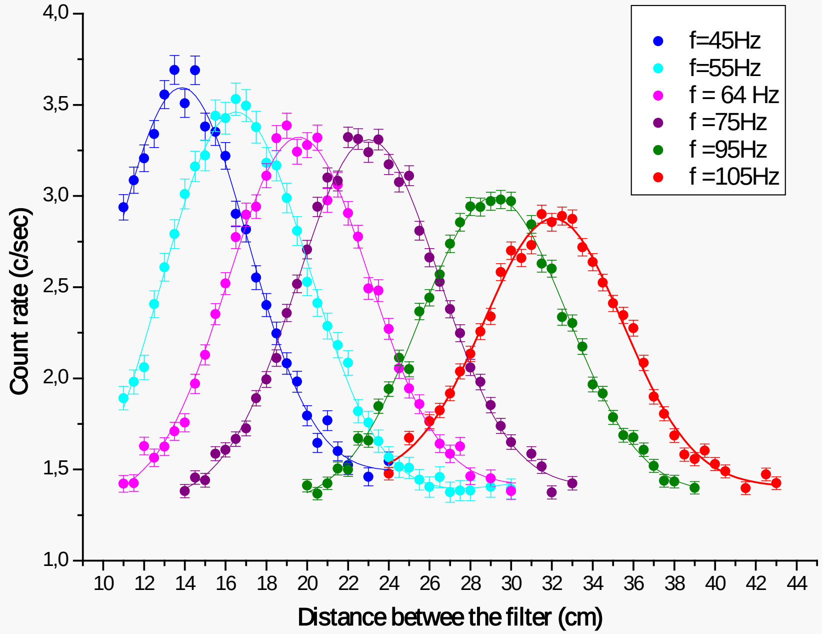
$$a_j = \frac{1}{2d} \int_0^{2d} f(x) \exp(j \frac{\pi}{d} x) dx$$

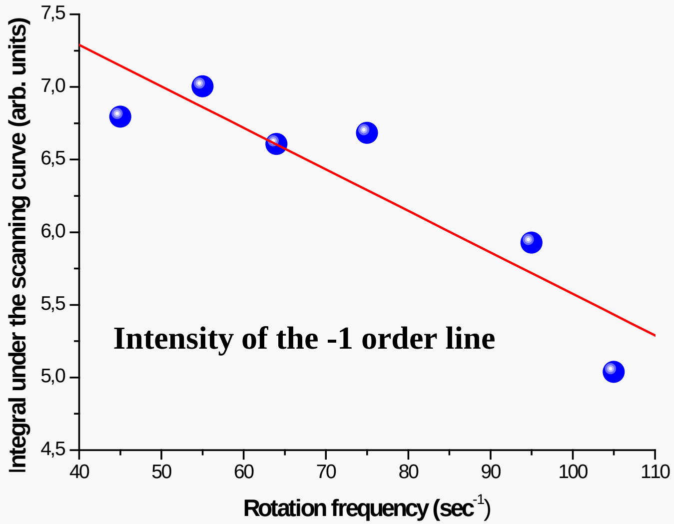


Zero, firsts and second orders intencity dependence from parameter c.

Edge effect

Angular period of grating 0.0831 mrad (5μ at the middle diameter)

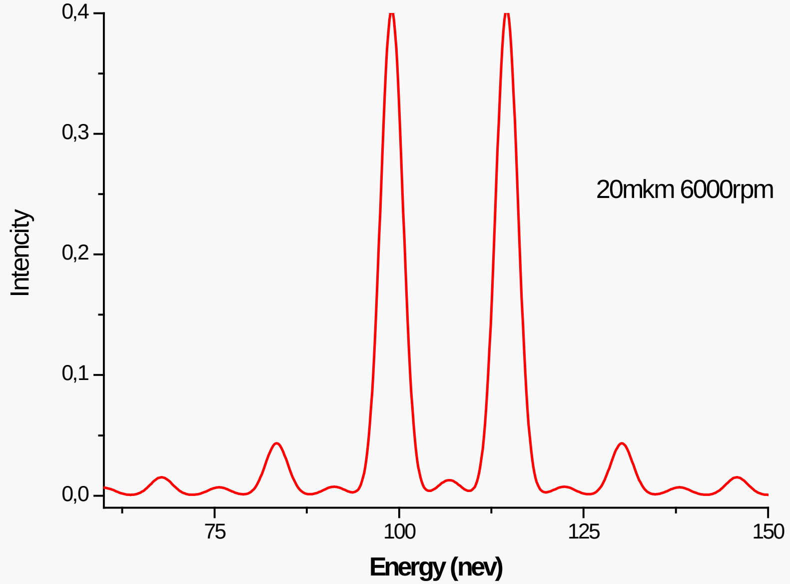




-1st order dependence from grating frequency rotation (2006)

Diffraction on moving grating (more rigorous theory)

Angular grating period 0.3324 mrad (20 μ at the middle diameter)



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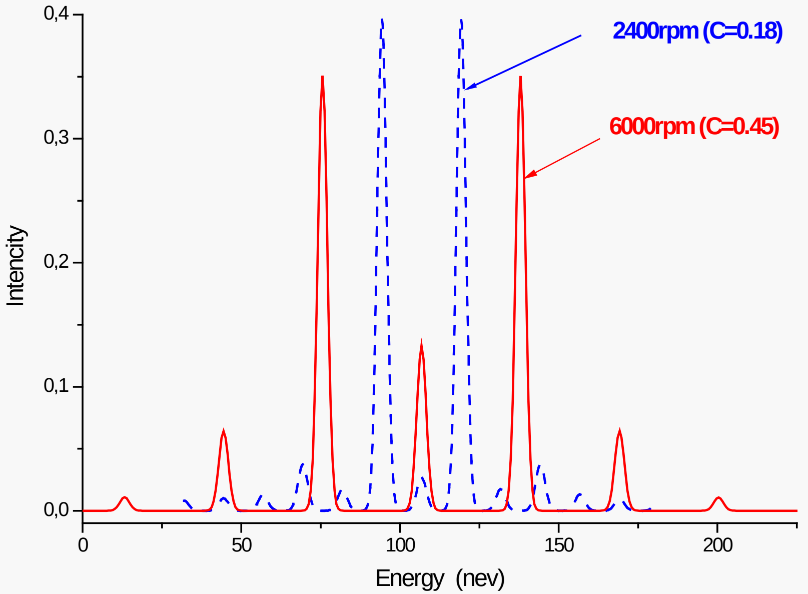


V.A. Bushuev, A.I. Frank, G.V. Kulin - to be published

Measurement of spectra after moving grating at the end of 2014 is planed by Fourier spectrometry method.

Fourier spectrometry method

Count rate oscillation at the detector

J.F. Colwell at al. NIM (1969)

$$Z(t) = \int_0^\infty I(t')\cos\left(\omega(t-t')\right)dt'$$

Initial spectrum can be restored by measuring of count rate oscillation aplitudes and phases at different modulation frequencies

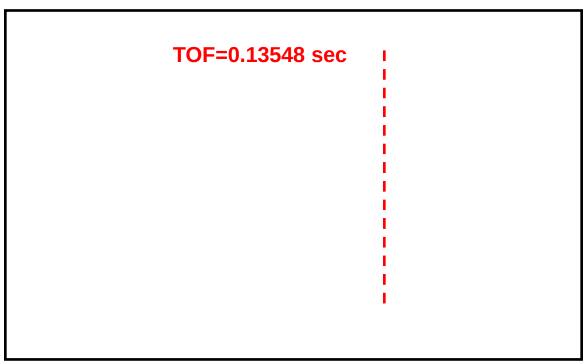
$$I(t) = \int_0^\infty C(\omega)\cos(\omega t)d\omega + \int_0^\infty S(\omega)\sin(\omega t)d\omega$$

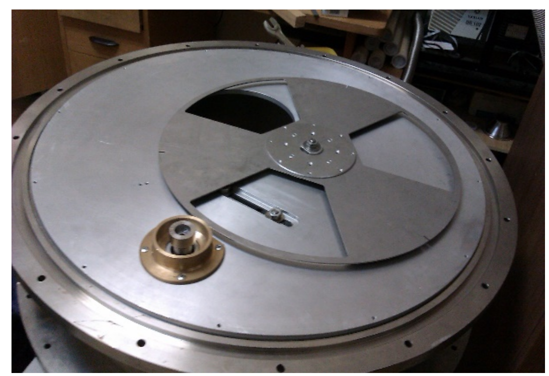
where

$$C(\omega) = \frac{2}{\pi}\int_0^\infty I(t')\cos\left(\omega t'\right)dt'$$

$$S(\omega) = \frac{2}{\pi}\int_0^\infty I(t')\sin\left(\omega t'\right)dt'$$

Spectrum from NIF, measured by Fourier spectrometry method (2011)





Fourier spectrometry method

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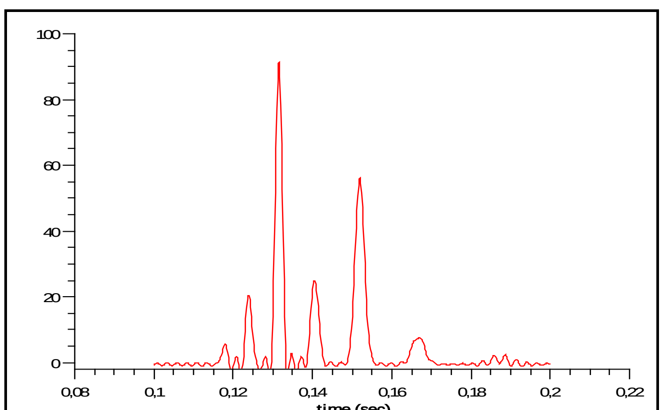
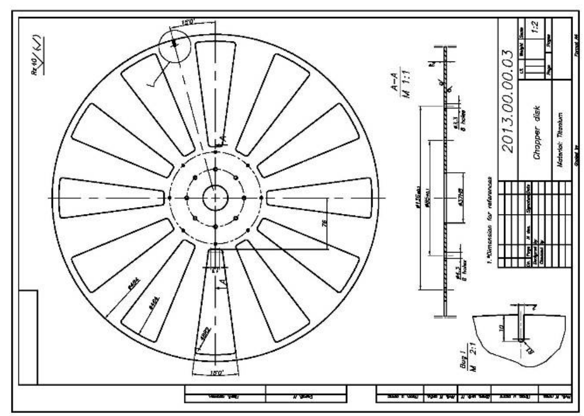
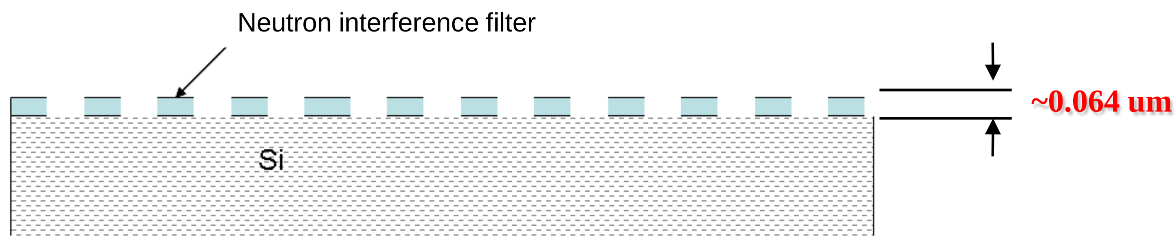
Using of new chopper allow to measure in wide frequency range (up to 400Hz)



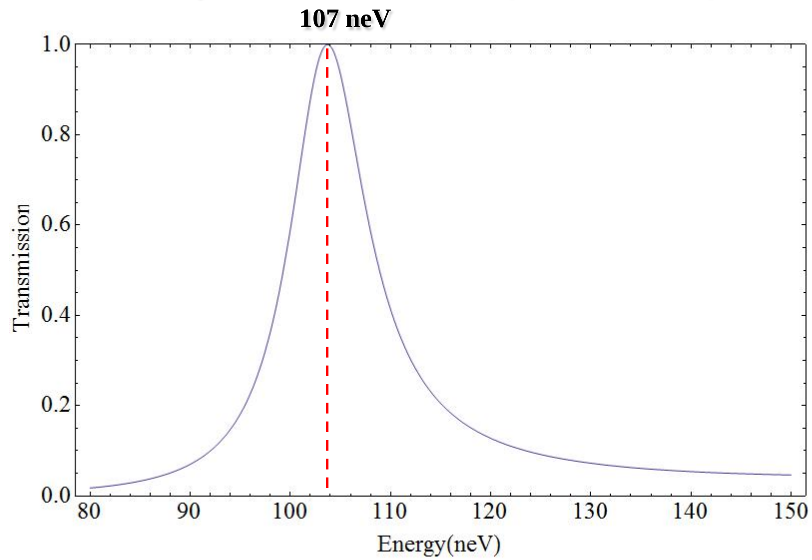


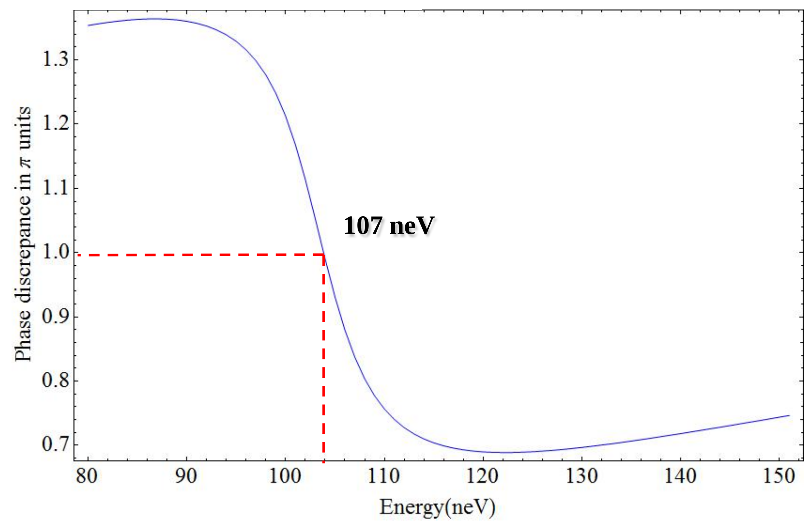
Multilayer structure, neutron interference filter (calculations)

How to decrease parameter C ?



3 layer NIF NiMo-TiZr-NiMo (205Å-231Å-205Å)

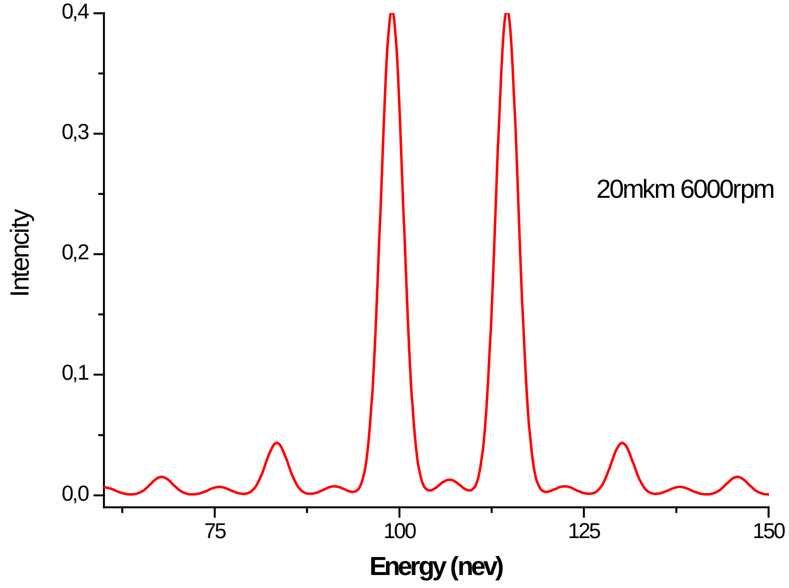




Phase π-grating with interference filter on Si support allow to decrease parameter C in ~2 times (0.064um instead of 0.14um for Si- phase grating)

Diffraction on moving grating (more rigorous theory)

Angular grating period 0.3324 mrad (20 μ at the middle diameter)



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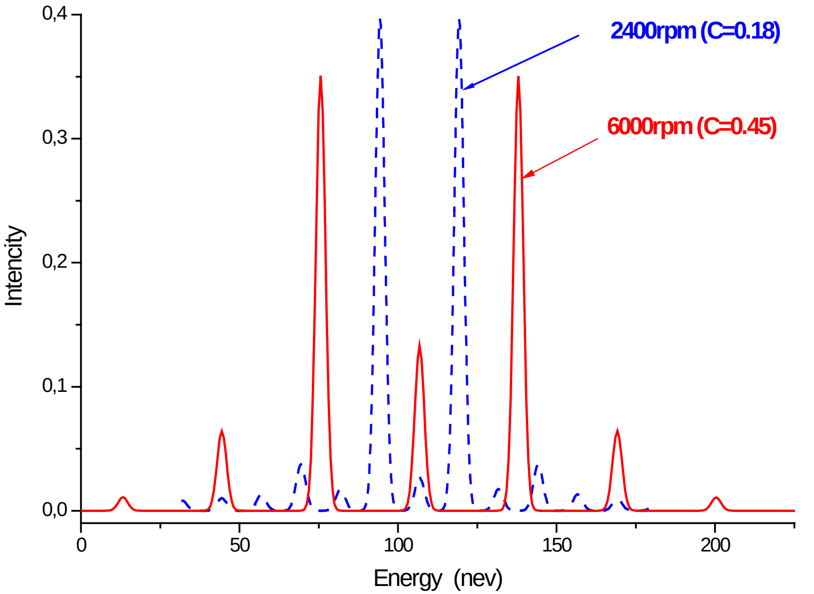


V.A. Bushuev, A.I. Frank, G.V. Kulin - to be published

Measurement of spectra after moving grating at the end of 2014 is planed by Fourier spectrometry method.

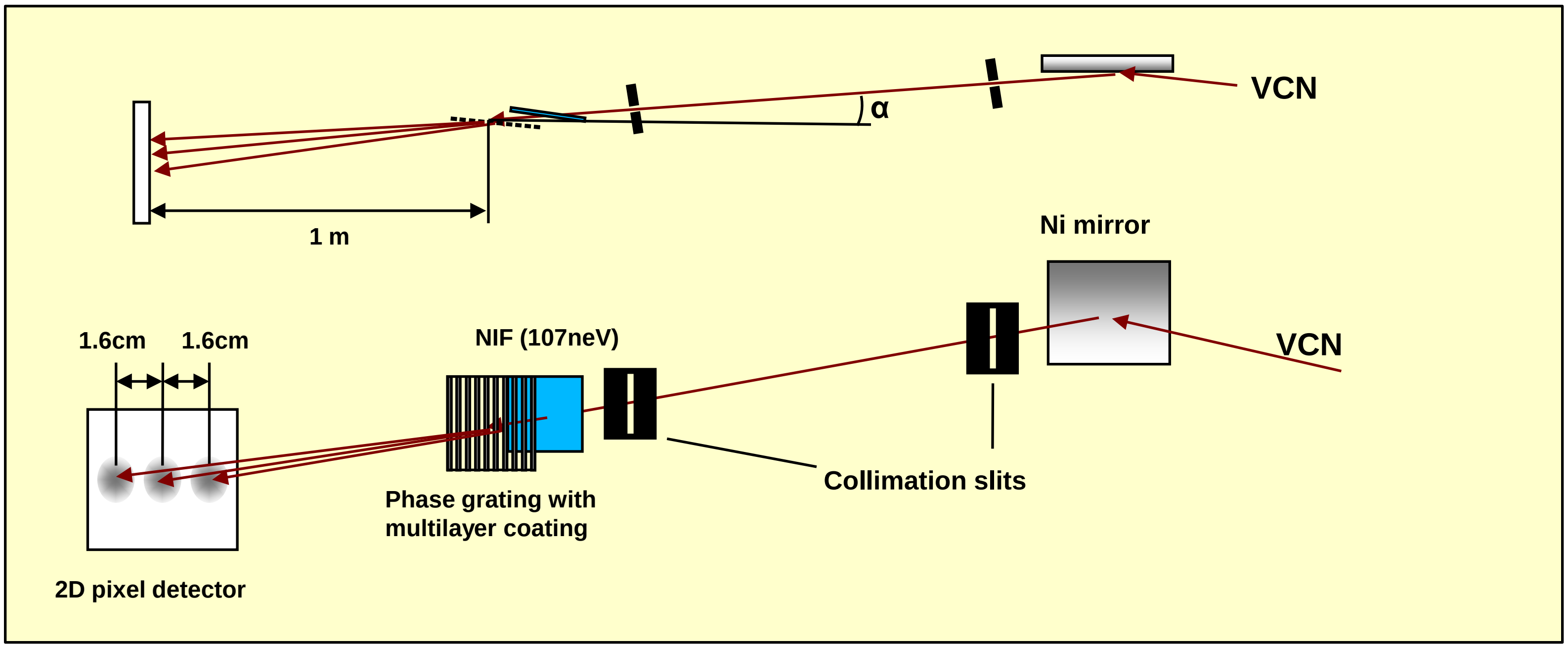
Test measurements with grating at rest and VCN beam

UCN v=4.5m/s and grating rotating at frequency 100Hz (V=38m/s at middle of diameter)

in frame of moving grating

λ~100 Å, incidence angle α ~ 0.12 rad

Idea of VCN experiment



Period of the grating ~ 5μ

Diffraction angle λ/(αL) ~ 1.6x10^{-2} rad

Summary

1. **Angular incidence on phase π grating lead to apearence of even orders. Admixture of other difraction orders lead to systematic in experiment on test of equivalence plinciple for free neutron**

2. **At the end of 2014 year experiment on investigation of Indencity of diffraction orders at different frequencies of grating rotation will performed.**

3. **Investigation of way to decrease role of even orders in main experiment.**

4. **VCN experiment for test of the new type grating is planed.**

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Thanks for your the attention!