Test of the crystal-diffraction ultra-precise neutron spectrometry. 7-order magnification of the Stern-Gerlach effect

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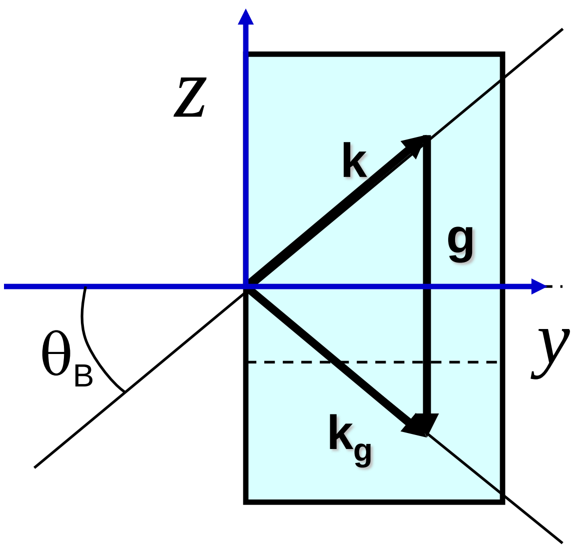
Motivation

To use crystal diffraction effects for neuron in Laue diffraction in perfect crystal to develop an ultraprecise neutron spectrometer with sensitivity to the external force to neutron on a level

$$\sigma(\mathrm{F}_{ext}) \sim (10^{-16} - 10^{-17})eV/cm$$

We consider symmetrical Laue diffraction in the perfect non-absorbing large crystal



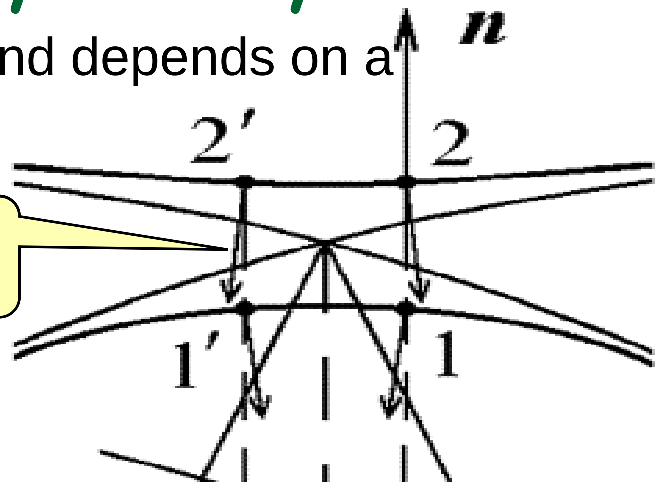
"Perfect" ⇨ Own crystal mosaic << Darwin width of the reflex

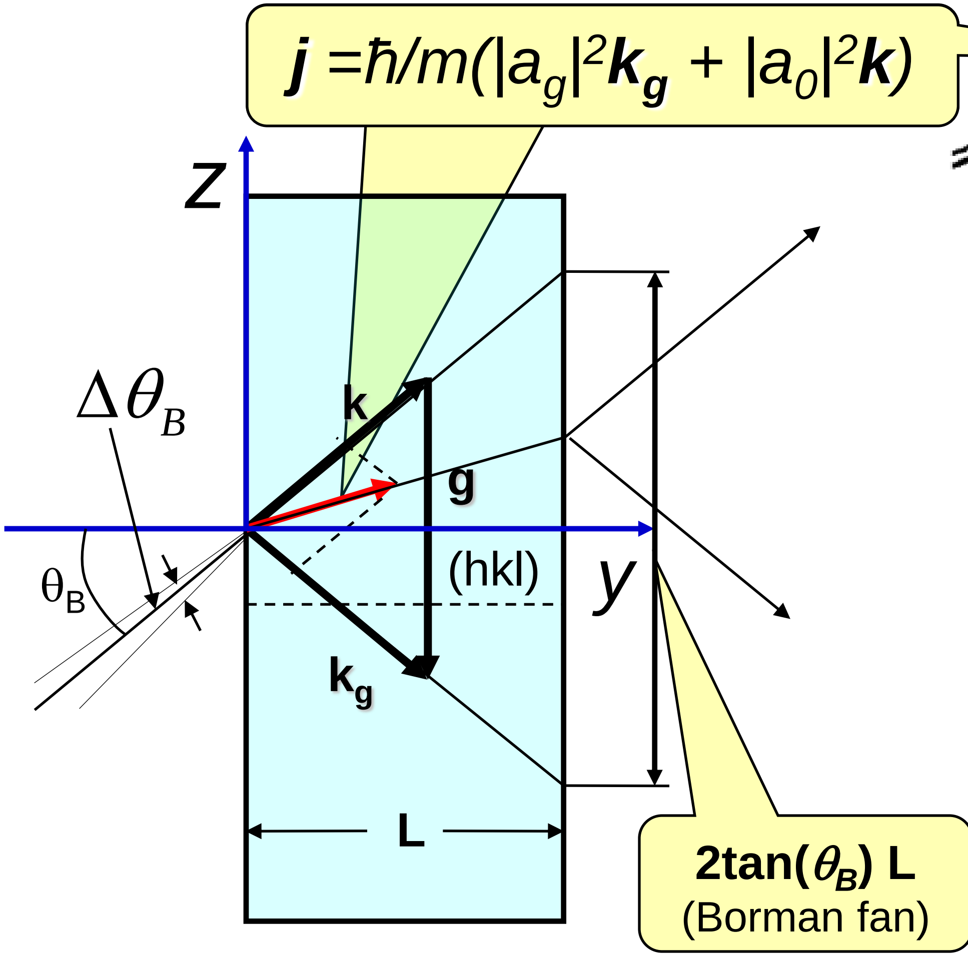
"Large" ⇨ Crystal size >> Extinction length ~ 20 cm in our case

"Non-absorbing" ⇨ Length absorption ~ Crystal size >> Extinction length

Neutron trajectory in crystal

j is normal to the dispersion surface and depends on a deviation from exact Bragg condition





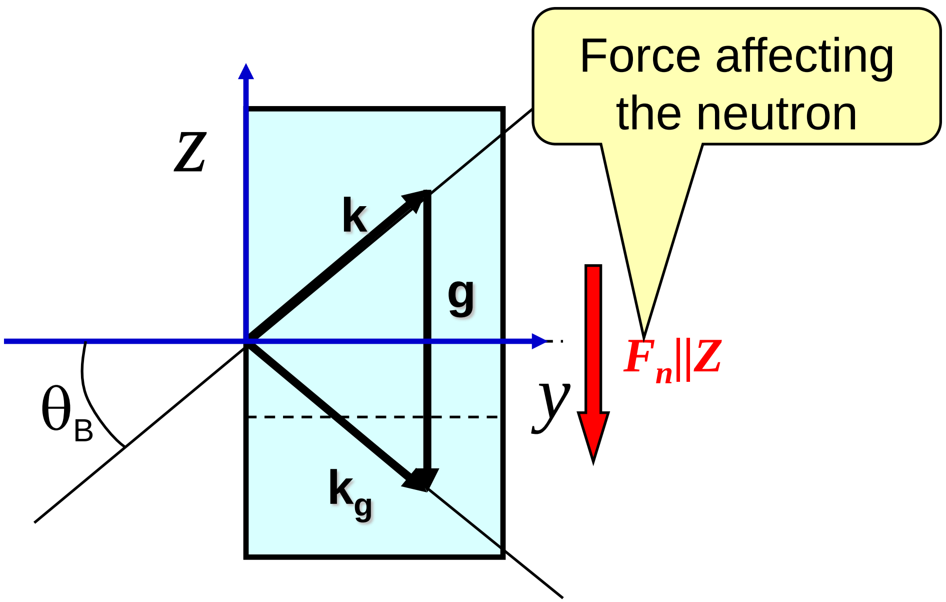
$$\Delta\theta_B \sim (1-5)'' \approx 0.001^0$$

$$\theta_B \sim 45^0$$

Gain factor

$$\frac{2\theta_B}{\Delta\theta_B} \sim \frac{E}{V_g} \sim 10^5$$

Neutron trajectory in the external field



Neutron trajectory equation (Laue diffraction case):

$$\frac{\partial^2 z}{\partial y^2} = \pm \frac{\tan^2(\theta_B)}{m_0} \frac{\pi}{d} \frac{F_n}{2E_n}$$

Equation for free neutron:

$$\frac{\partial^2 z}{\partial y^2} = \frac{F_n}{2E_n}$$

Gain factor for the diffracting neutron

$$K_d = \pm \frac{\tan^2(\theta_B)}{m_0} \frac{\pi}{d}$$

$$m_0 \rightarrow \frac{2F_g d}{V}$$

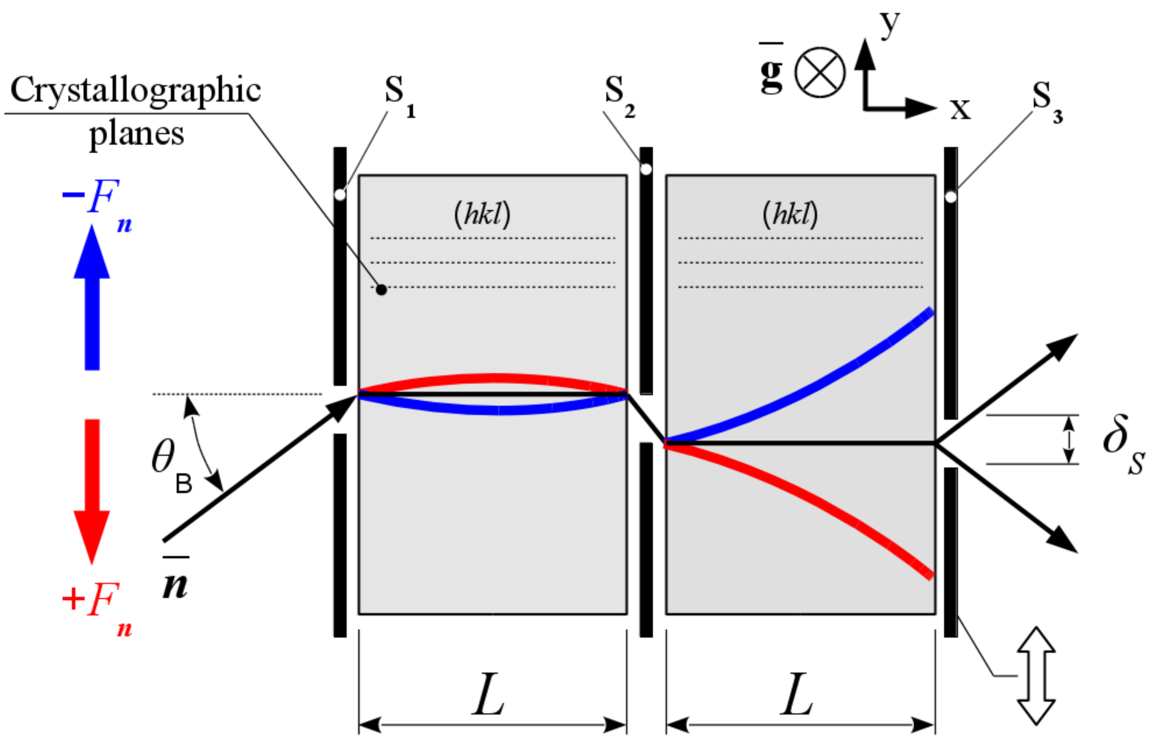
For silicon (220) plane

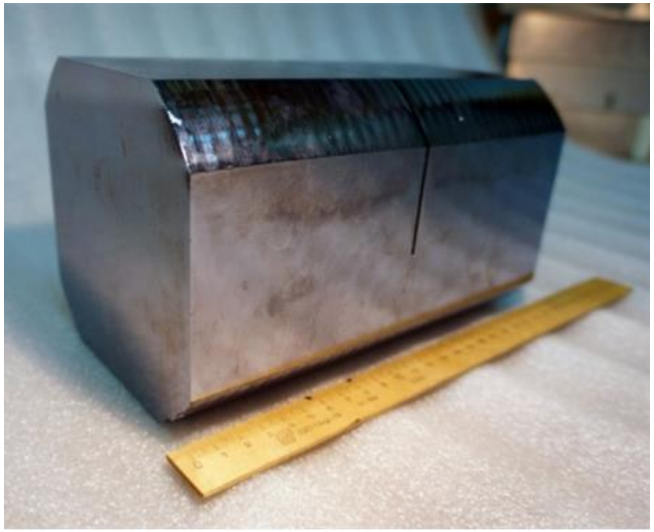
$$K_d = \tan^2(\theta_B) \times 2 \cdot 10^5 \xrightarrow{\theta_B\,(84^0 \div 87^0)} (10^7 \div 10^8)$$

Diffraction in deformed crystal
N.Kato , J. Phys. Soc. Japan (1963) **19**, 971

Experimental measurement of the factor

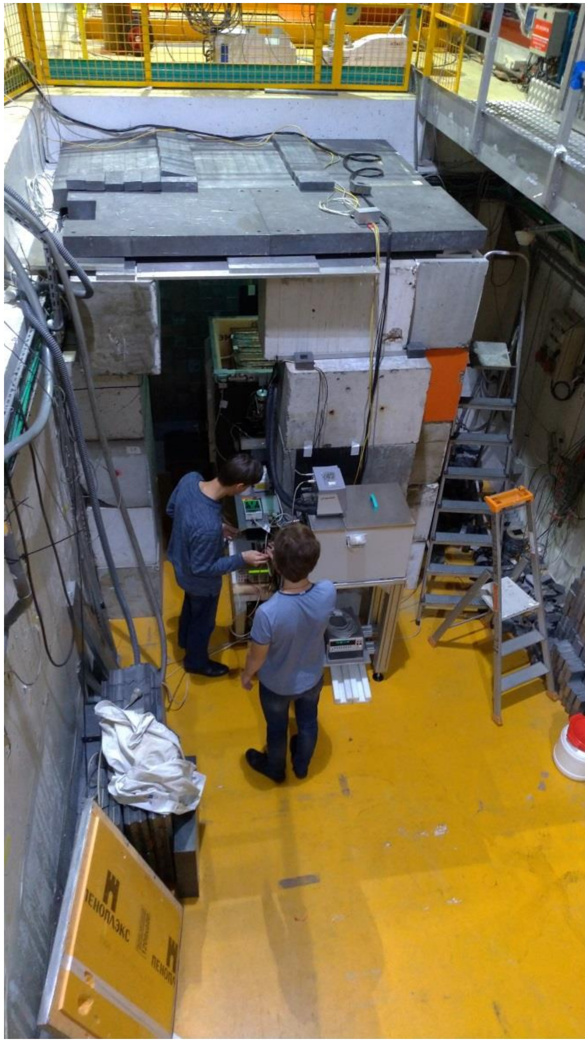
$$K_d = \tan^2(\theta_B)\times 2\cdot 10^5 \xrightarrow{\theta_B(84^0\div 87^0)} (10^7\div 10^8)$$

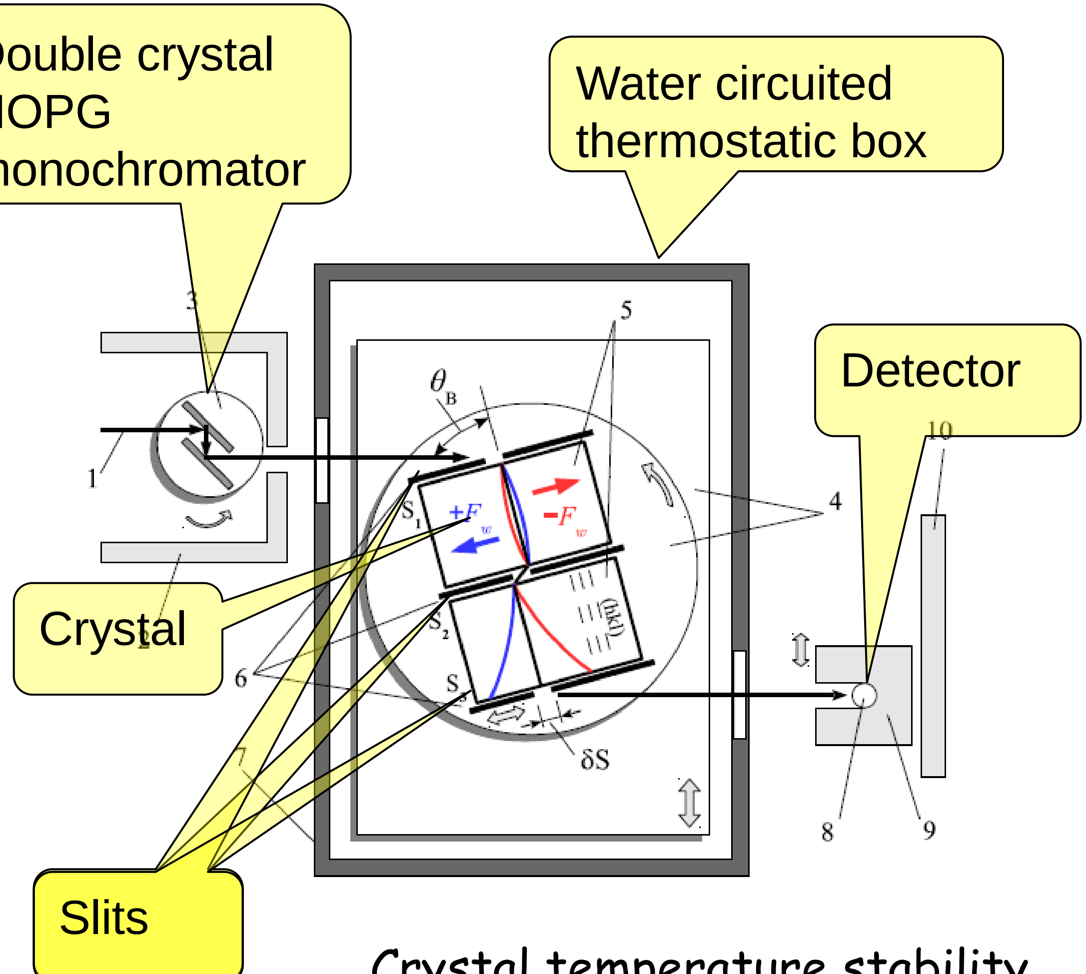




(220) plane of silicon
(d = 1.92 Å).
Crystal size
130x130x220 mm^3

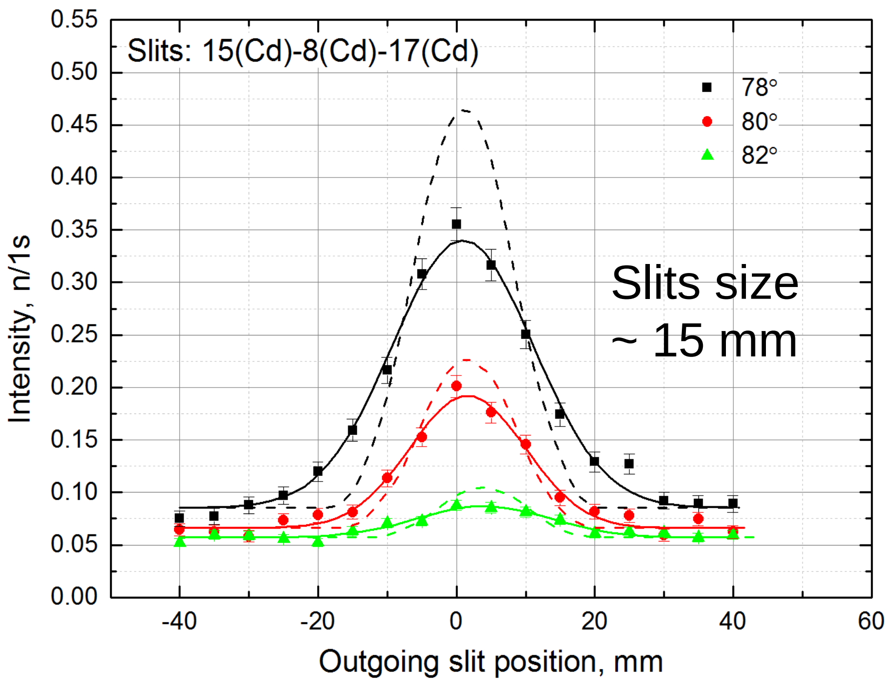
Test experiment (ILL, PF1b beam)

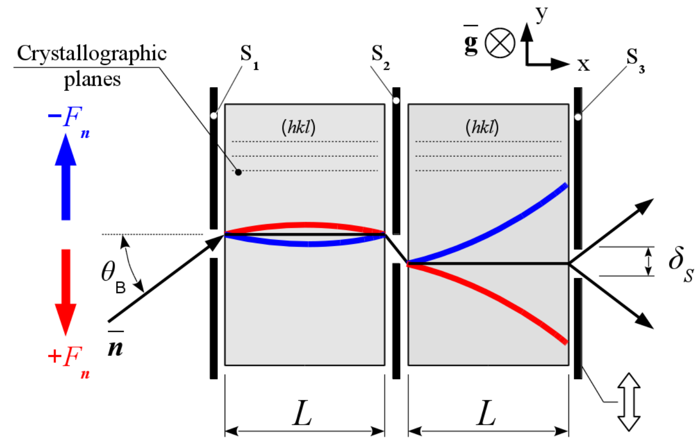


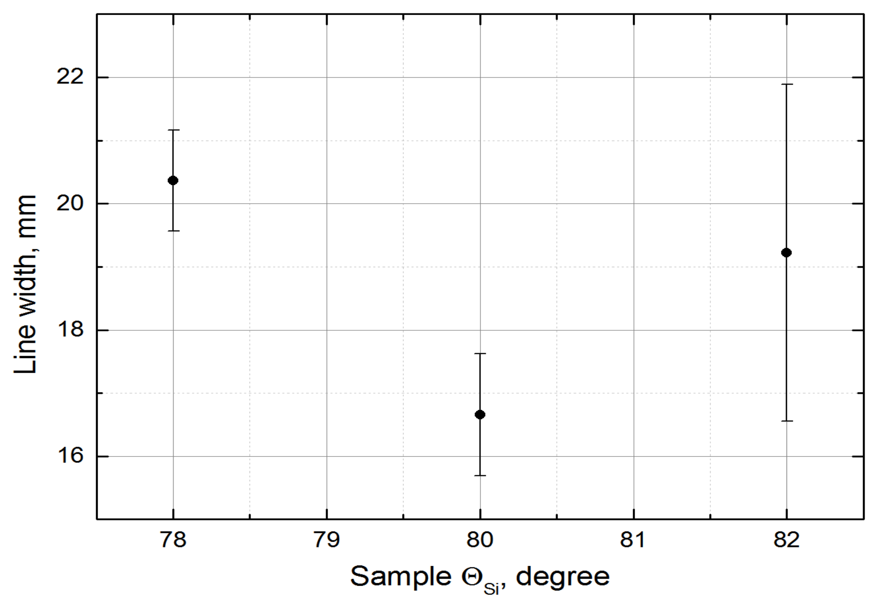


Crystal temperature stability **~2 10^{-2} per day**

No field affecting the neutron







This line width means that crystal homogeneity (Δd/d) is better than 10^{-8} per cm and 10^{-7} for all crystal.

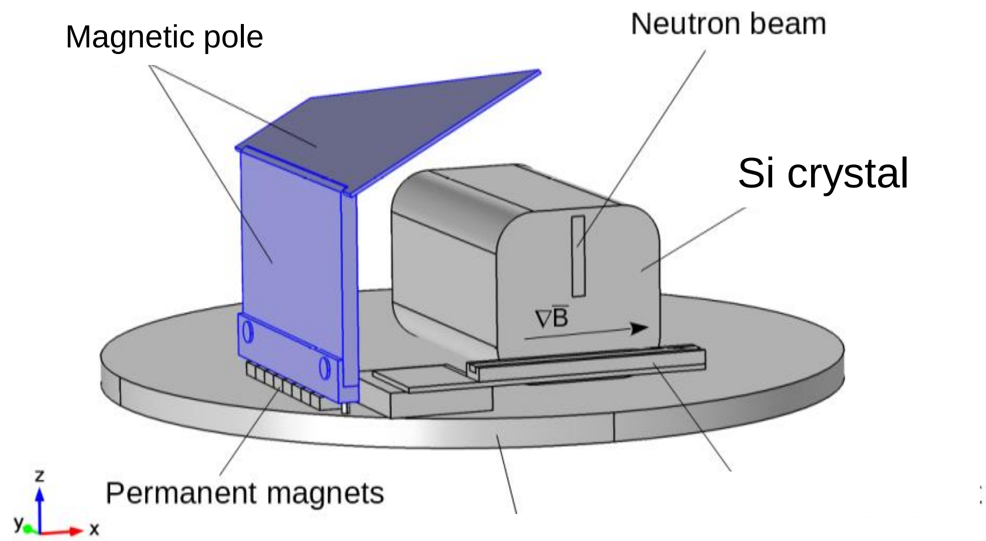
Gradient of magnetic field

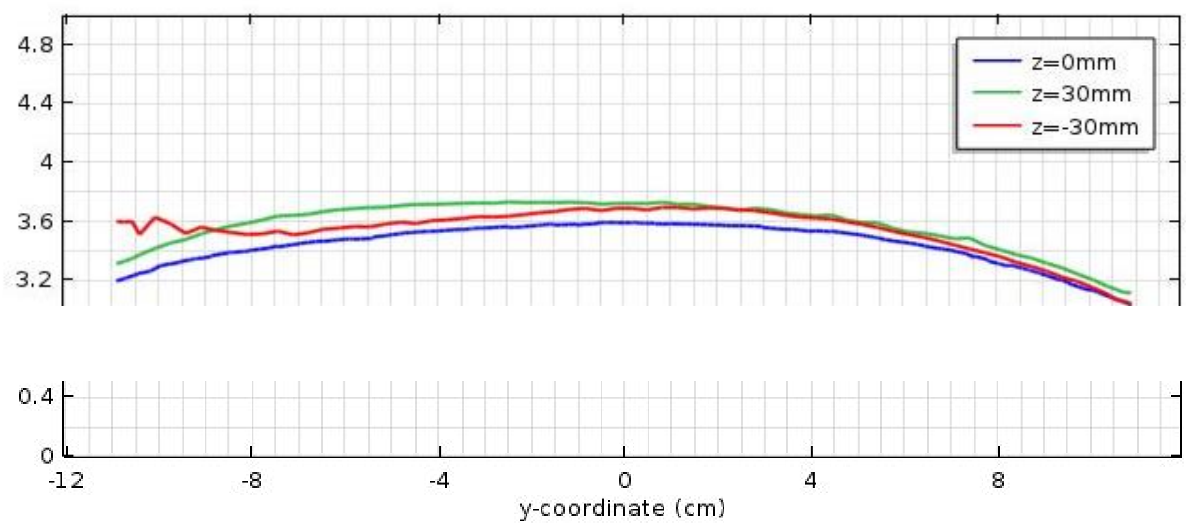
Magnetic field gradient

$$grad\left(|\overrightarrow{B}|\right) = 1.5\ G/cm$$

$$F_M = 10^{-11}\ eV/cm$$

Gravity 10^{-9} eV/cm
but different direction

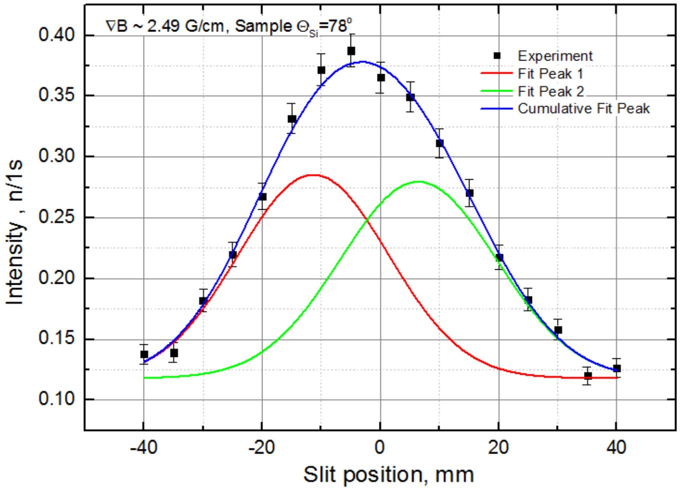


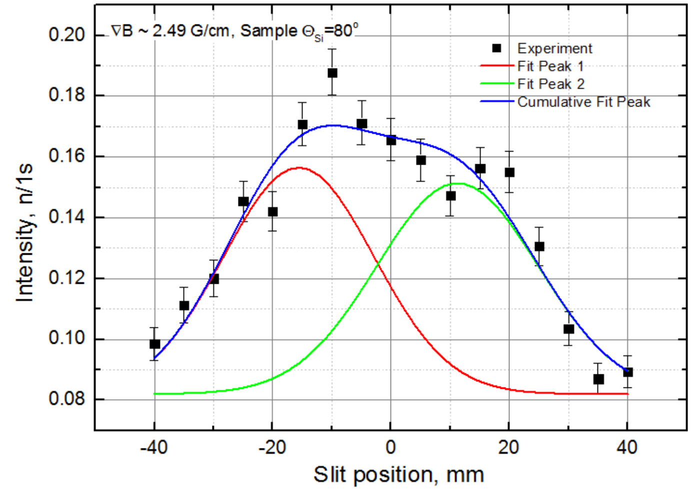


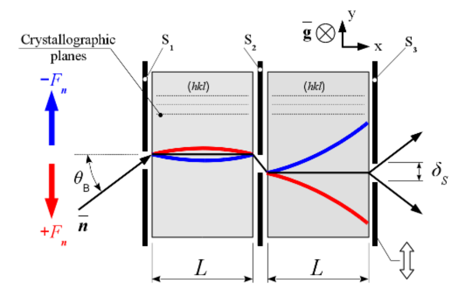
Homogeneous magnetic field gradient is ~ 20%

Beam splitting at different Bragg angle

$$grad(|\vec{B}|) = 1.5\ G/cm$$

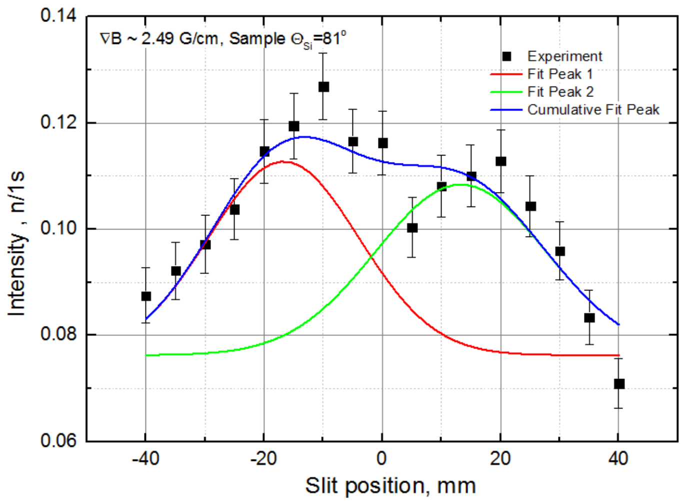


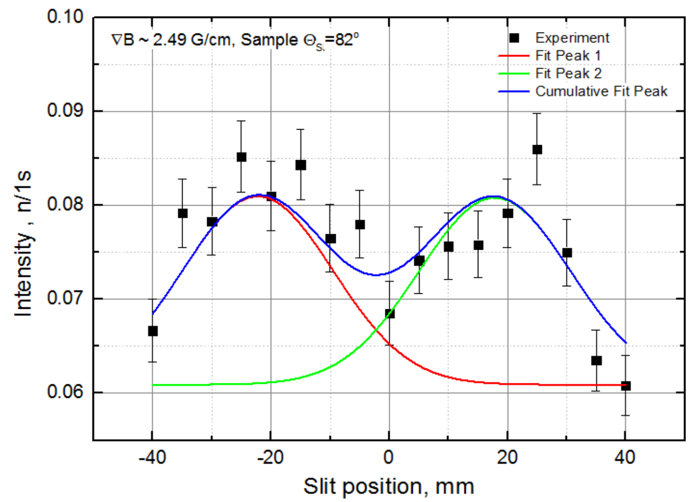




Low statistics due to strong beam monochromatization

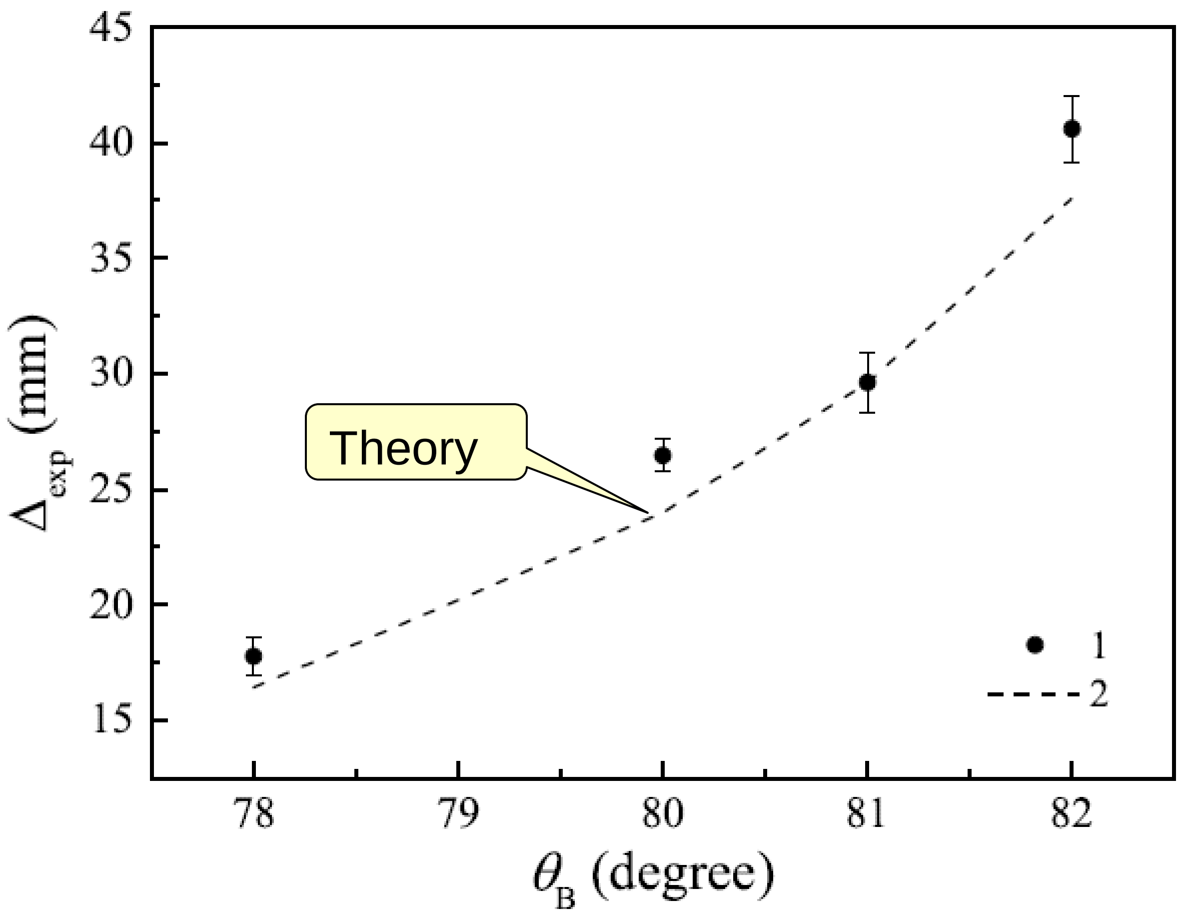
$\Delta\lambda/\lambda \sim 10^{-7}$

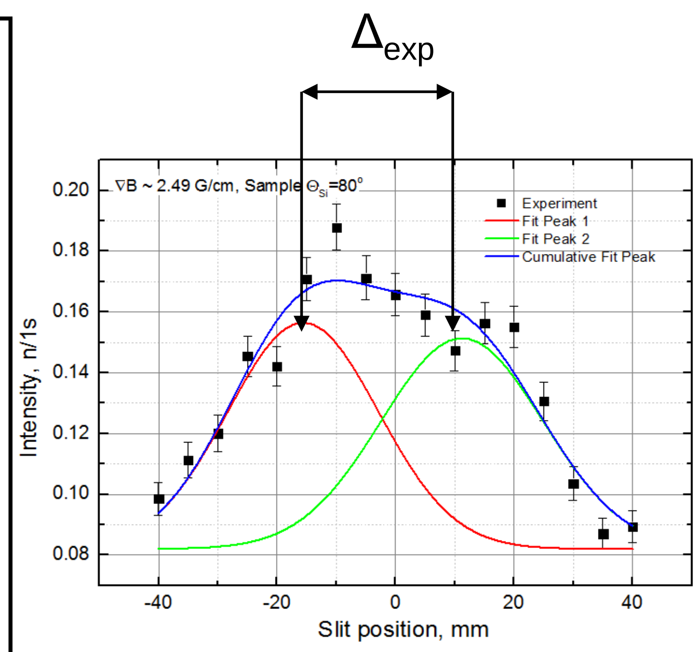




Statistics can be increased at least on one order

The beam splitting on Bragg angle





Beam splitting for free neutron with λ = 3.8 Å, flight base 220 mm(crystal size) and MF gradient 1.5 G/cm will be **about 6 nm.**

Test experiment conclusion

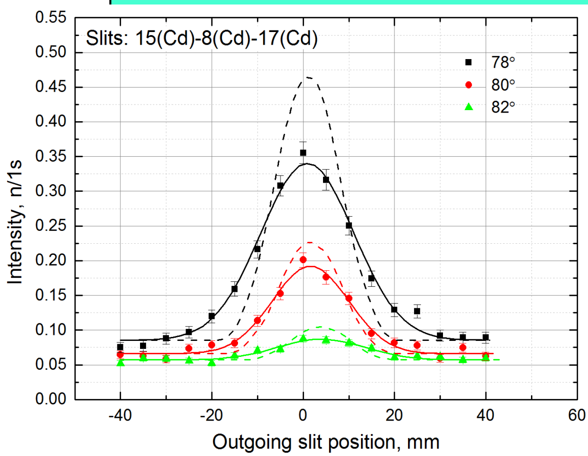
The diffraction gain factor for neutron inclination in the external field was measured first for Bragg angle close to π/2. It coincide with the theory.

$$\boxed{K_{\mathrm{exp}} = (1.2 \pm 0.2) \cdot 10^5 \cdot \tan^2(\theta_{\mathrm{B}})} \Leftrightarrow \boxed{K_{\mathrm{t}} = 1.14 \cdot 10^5 \cdot \tan^2(\theta_{\mathrm{B}})}$$

$$\theta_{\mathrm{B}} = 82^\circ$$

$$\boxed{K_{\mathrm{exp}} = (6.1 \pm 1.0) \cdot 10^6}$$

For (220) Silicon plane



Corresponds to the external force resolution

F_{ext}~5 10^{-12} eV/cm =5 10^{-3} mg

Next step

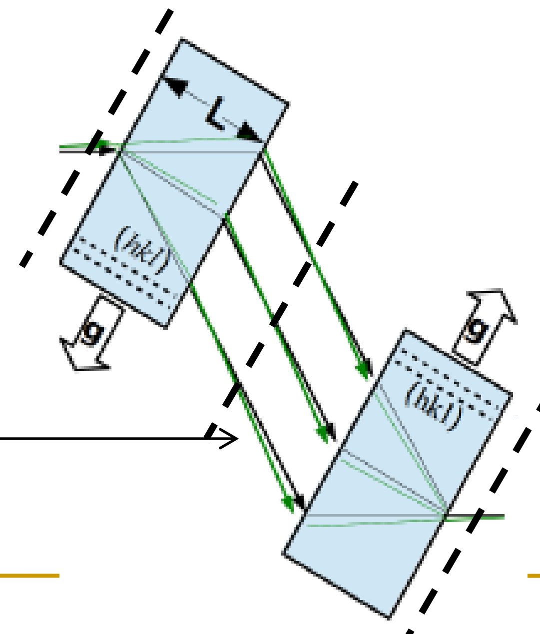
1. Setup optimization to increase statistics and reach **Bragg angle about $(84\ -86)^0$ and slit size ~1-2 mm**

Improve the current resolution in 10-30 times

External force resolution

F_{ext}~$(2\text{-}5)\ 10^{-13}$ eV/cm =$(2\text{-}5)\ 10^{-4}$ mg

2. Design and build the setup with crystals spaced ~ 1 meter apart from each other and multislit collimation.



Possible applications

1. The sensitivity to the **neutron electric charge** can be improved by **an order of magnitude** compared with the current experimental limit;
2. **The equivalence of the inertial and gravitational mass of the neutron** can be verified with an **accuracy of 10^{-5}** (compare with the current experimental value **$1.7\ 10^{-4}$**);
3. **Neutron scattering amplitudes** can be measured with higher accuracy for both solids and gases;
4. Neutron diffraction in perfect crystals and **crystal properties** on the inter-planar **distance homogeneity of $\Delta d/d \sim (10^{-7} - 10^{-8})$** can be studied.

Thank you for attention