

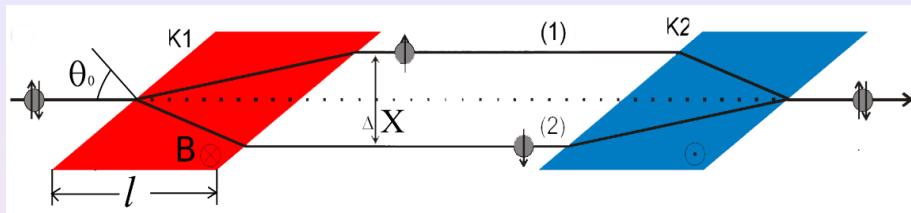
Эксперимент по проверке электронейтральности нейтрона с применением СЭМУРН методики

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SESANS method

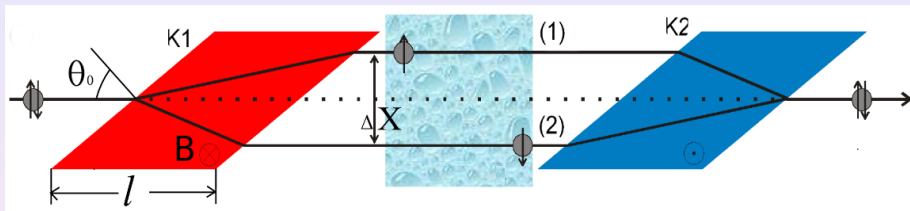


Neutron beam polarization $\mathbf{P}$ is directed perpendicularly to guiding magnetic field B . Neutron wave function can be written in form

$$\psi_{in} = \frac{1}{\sqrt{2}} \begin{pmatrix} e^{-\frac{i\varphi_0}{2}} \\ e^{+\frac{i\varphi_0}{2}} \end{pmatrix},$$

here φ_0 - neutron spin direction in azimuthally plane. Let's consider $\mathbf{P}$ parallel to X-axis ($\varphi_0 = 0$) $\Rightarrow \mathbf{P} = (1, 0, 0)$

SESANS method - II



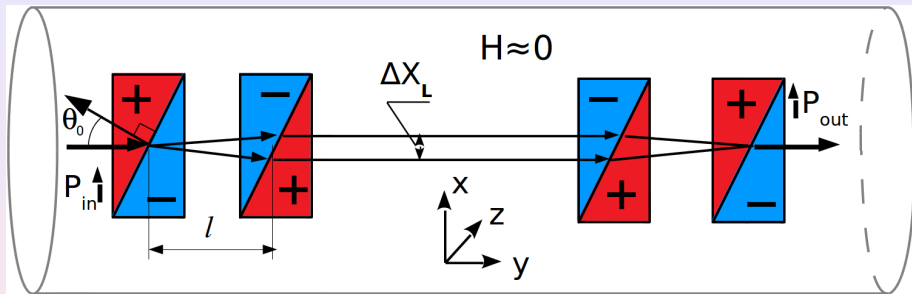
Let's apply $V_{sr}(x)$. The phase difference between these two eigenstates will be

$$\varphi_{sr} = (V_{sr}(x_0) - V_{sr}(x_0 + \Delta x)) / \hbar \cdot \tau,$$

The neutron wave function on the exit of coil K2 will be

$$\psi_{out} = \frac{1}{\sqrt{2}} \begin{pmatrix} e^{-\frac{i\varphi_{sr}}{2}} \\ e^{+\frac{i\varphi_{sr}}{2}} \end{pmatrix} \Rightarrow \mathbf{P} = (\cos \varphi_{sr}, \sin \varphi_{sr}, 0)$$

Alternative SESANS layout

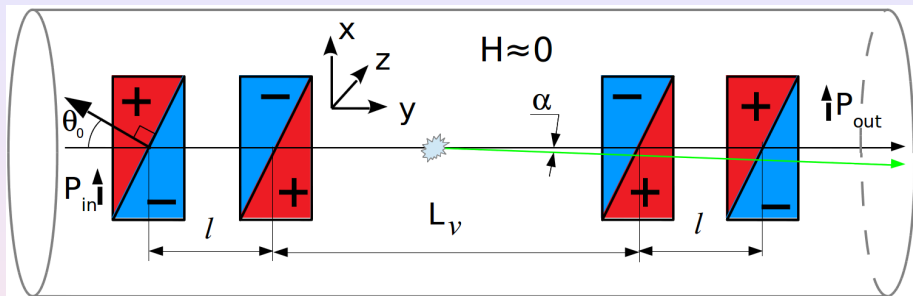


The value of spatial splitting

will be two times more than for the previous scheme

$$\Delta X_L = \frac{2\mu B}{E} \cdot l \cdot \tan \theta_0$$

Classical SESANS interpretation



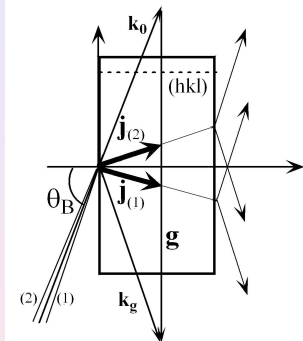
Single coil make a spin modulation in X direction $\phi(x) = 2B\gamma_n \tan(\theta_0) \frac{x}{v}$
 Angle of neutron spin rotation will be

$$\phi = \frac{2B\gamma_n \tan(\theta_0)}{v} (0 - l\alpha_0 - (L_v + l)\alpha_0 + (L_v + 2l)\alpha_0) \equiv 0$$

After the scattering on α angle

$$\phi(\alpha) = \frac{2B\gamma_n \tan(\theta_0)}{v} \cdot l\alpha$$

Laue diffraction in perfect crystal



Symmetrical Laue diffraction.

$\mathbf{j}_{(1)}$ and $\mathbf{j}_{(2)}$ are the neutron fluxes for two direction of incident beam.

Effect of diffraction enhancement

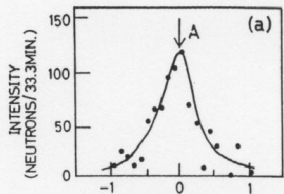
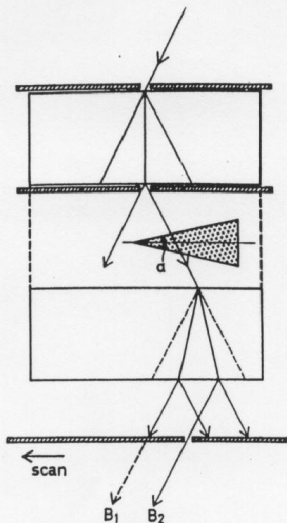
The neutron in the crystal changes the momentum direction by the angle of Ω (by **several tens degrees**) while the incident neutron beam deflects by the Bragg width (**within a few arc seconds**)

$$\Omega = \Delta\theta \cdot \frac{E}{2v_g} \Rightarrow \Delta\theta \cdot 10^5$$

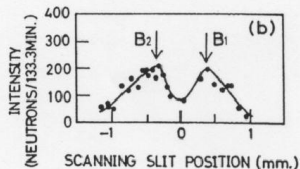
The same phenomenon occurs then not direction but neutron energy is changed according to the

$$\Delta\theta = \frac{\Delta E}{2E} \tan \theta_B$$

Measurement the neutron prism refraction¹



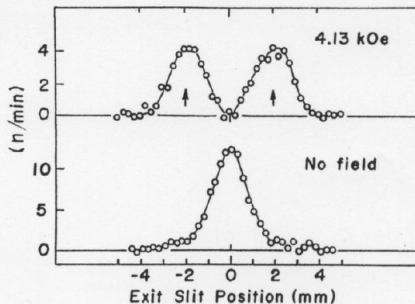
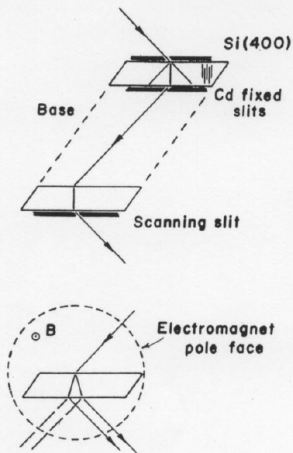
⇐ no refracting prism



⇐ 0.032 arc sec =
= $1.5 \cdot 10^{-7}$ rad
refracting prism

¹S.Kikuta et al., J. Phys. Soc. Japan, **39** (1975) 471

Change neutron length wave in magnetic field²

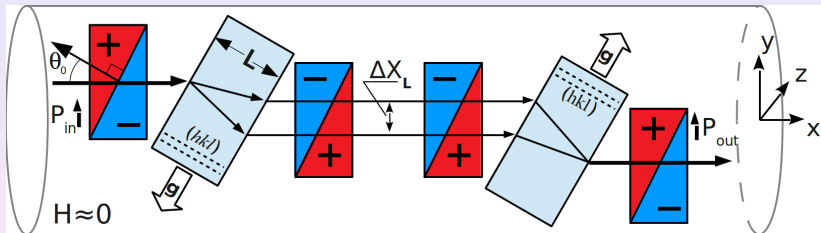


⇐ 4.13 kOe
magnetic field

⇐ no magnetic
field

²A.Zeilinger, C.G.Shull, Phys.Rev.B **19** (1979) 3957

SESANS + Laue diffraction



The values of neutron splitting

Laue diffr.+SESANS

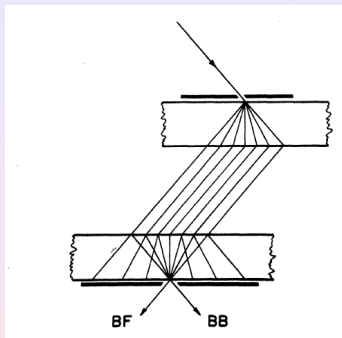
Standard SESANS

$$\Delta X_L = \frac{2\mu B}{v_g} L \sin \theta_B \cdot \tan \theta_0 \iff \Delta X = \frac{2\mu B}{E} \cdot l \cdot \tan \theta_0$$

About $K_g = \frac{E}{v_g} \Rightarrow 10^5$ times more.

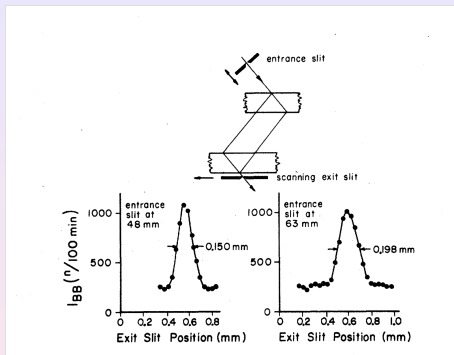
ΔX_L for **silicon (220) and (100) quartz planes**, $L = 10$ cm, $\tan \theta_0 = 1$ and $\theta_B = 65^\circ$ can be **$\sim 40\mu\text{m}$ and $\sim 120\mu\text{m}$** for the **$B = 1$ G**.

Two crystal focusing³



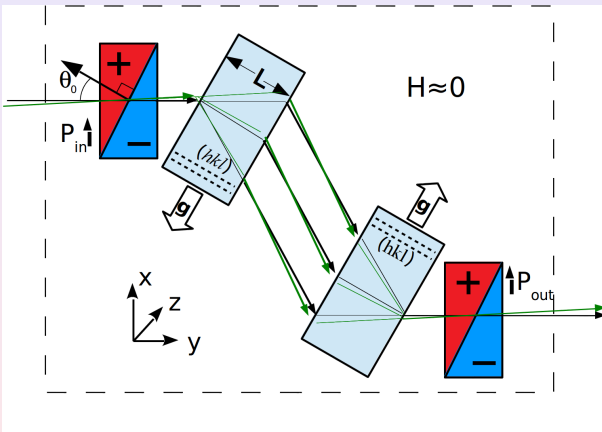
Spatial resolution

$$x_w = \frac{\lambda \tan(\theta_B)}{2\pi} \sim (10 - 50) \mu m$$



³ x-rays - Инденбом ВЛ., Слободецкий И.Ш., Труни К.Г. ЖЭТФ (1974) 66 1110
neutron - J. Arthur, C. G. Shull, A. Zeilinger, Phys. Rev. B, 32 5753 (1985)

New layout of SESANS + Laue diffraction



Advantages -

- More luminosity
- Only two coils
- More space in research area.

Disadvantage -

- Nobody saw the two crystal diffraction focusing effect in separated crystals

Sensitivity of SESANS + Laue

Angle of spin rotation

$$\varphi_v = \frac{dV}{dx} \Delta X_L \cdot \frac{L_v}{\hbar v_n} \simeq 5 \cdot 10^{12} \cdot \frac{dV}{dx} [eV/cm]$$

For the (100) quartz plane ($d=4.255\text{\AA}$, $v_g = 1.8 \cdot 10^{-8}\text{eV}$),
 $\theta_B = 65^0, L = 10\text{cm}, \tan \theta_0 = 3, B = 100\text{G}, L_v = 100\text{cm}$

Statistical sensitivity

Accuracy of spin rotation measurement can be about 10^{-4} rad, so

$$\sigma \left(\frac{dV}{dx} \right) \simeq 2 \cdot 10^{-17} [eV/cm] \simeq 2 \cdot 10^{-8} m_n g$$

$$\sigma(\alpha) \simeq 10^{-12} \text{rad}$$

Possible applications

- Test of a neutron electro-neutrality $\frac{dV}{dx} = E_e q_n$.

$$\sigma(\varphi) = 10^{-4} \implies \underline{\sigma(q_n) \simeq 2 \cdot 10^{-22} e}$$

about one orders better present accuracy*.

* J.Baumann, R.Gahler, J.Kalus, W.Mampe, PR D37, 3107 (1988)

- Study the neutron gravity in the Earth with the sensitivity

$$\underline{\sigma(m_n g) \sim 10^{-8} m_n g}$$

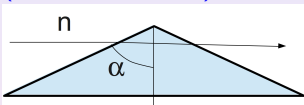
- Search for the new fundamental interaction of a neutron with the matter (5-th force) at the range distance about 0.01 – 1 cm
- Measurement of a matter refracting index $\implies$ amplitude of neutron scattering with stat. accuracy

$$\underline{\sigma(a_n) \sim (10^{-5} - 10^{-6})} \text{ for condensed matter}$$

$$\underline{\sigma(a_n) \sim (10^{-3} - 10^{-4})} \text{ for gas (There are some questions.)}$$

Neutron refraction in quartz prism⁴

SESANS at WWR-M reactor
(PNPI, Gatchina)



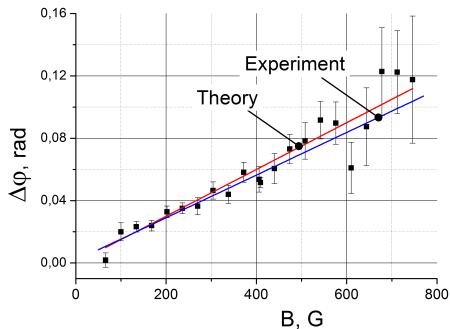
Value of phase shift due to refraction in prism

$$\Delta\varphi_r = \frac{V_0}{E} \frac{2\pi}{\lambda} \Delta x \tan \alpha$$

We used quartz prism

$$V_0 \simeq 10^{-7} \text{ eV}, \alpha = 78^0$$

The phase shift dependence on a value of magnetic field in main coils.

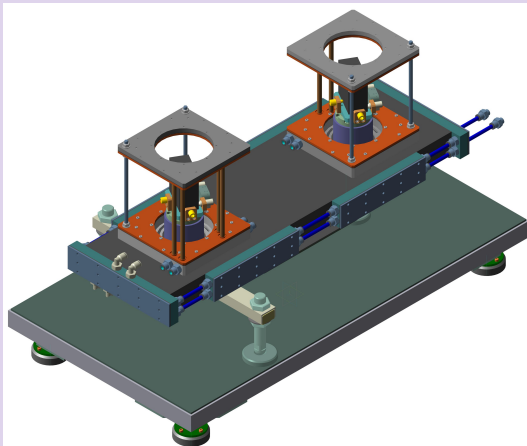


⁴Thanks to Axelrod L.A. and Zabenkin V.N.

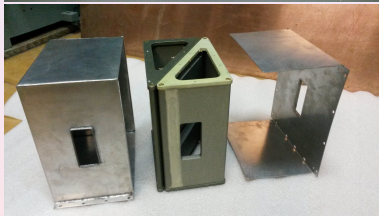
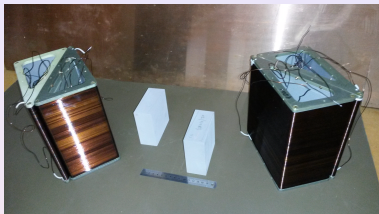
Full scale setup construction is now under construction

Crystal diffraction unit of the setup

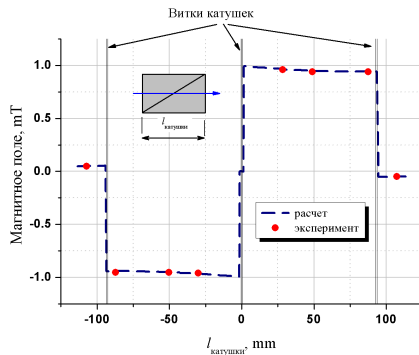
- SiO_2 crystals -
 $100 \times 100 \times 50 \text{ mm}^3$, (100)
plane, $d=4.255 \text{ \AA}$ or
Si crystal, (220)
plane, $d=3.313 \text{ \AA}$
- Accuracy of crystal
rotation - $0.3''$
- Table - glassceramics with
 $\alpha \sim 10^{-8}/\text{K}$
- Temperature stability -
 0.01 K per day



Magnetic field coils



Field in the coils

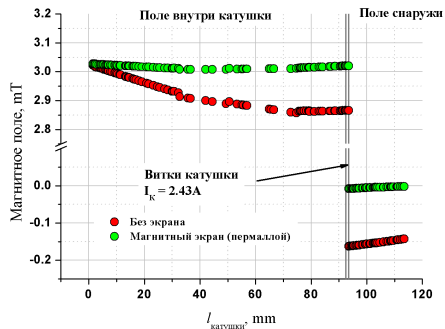


Simulation of magnetic field

For 1 mm μ -metal screen

- Homogeneity of the inside field improved by 15 times
- Value of outside field decrease by 30 times
- The ratio of field integral inside and outside the coil becomes $\sim 2 \cdot 10^3$.

Field in the triangle coils



Summary

New approach for precise neutron spectrometry is proposed.

It is based on two principle

- spin interferometer technique **SESANS**
- effects in perfect crystal **Laue diffraction**

A method sensitivity can reach

$$\sigma \left(\frac{dV}{dx} \right) \simeq 10^{-17} [eV/cm] \Rightarrow \underline{\sigma(E_n) \sim 10^{-15} eV}$$

This approach can be applied for

- Test of a neutron electro-neutrality with the best accuracy
- Study the neutron gravity in the Earth with the sensitivity
- Search for the new fundamental interaction
- Precise measurement of an amplitude of neutron scattering