TEST AND IMPROVEMENT OF THE NEW METHOD FOR CHECKING OF THE NEUTRON ELECTRONEUTRALITY BY THE SPIN INTERFEROMETRY TECHNIQUE

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Motivation

- ***Electroneutrality* of the free neutron is commonly accepted.**

- ***Zero neutron electric charge is not a request of Standard Model.***

- ***Overall, only a few hints exist for physics beyond the Standard Model, and the neutrality of neutrons and atoms is such a hint.***

- ***Some models beyond the SM violates boson - lepton (B- L) symmetry could accommodate a nonzero neutron charge $q_n = \varepsilon(B - L) \neq 0$, but the charge of the hydrogen atom (which has B = L) would remain zero.***

- ***Some variants of theories with additional extra dimensions give the possibility to have non-zero neutron electric charge.***

Neutron charge experiment

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

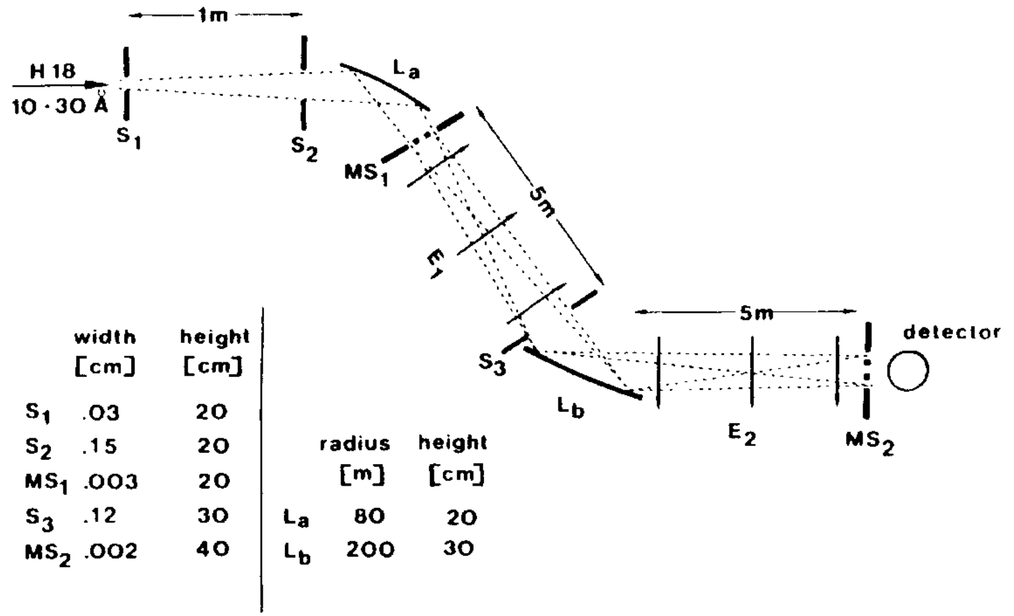
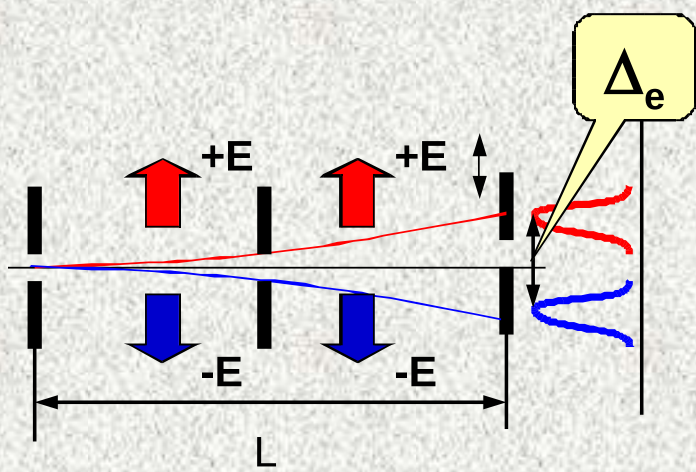


FIG. 1. The design of the deflection apparatus. MS_1 and MS_2 is a multislit system with 31 slits, 30 μm wide, separated by 30-μm-wide absorbing zones. For clarity the dimensions and angles of deflection are not to scale.

λ = 17.5 Å, L = 9 m, E = 60 kV/cm

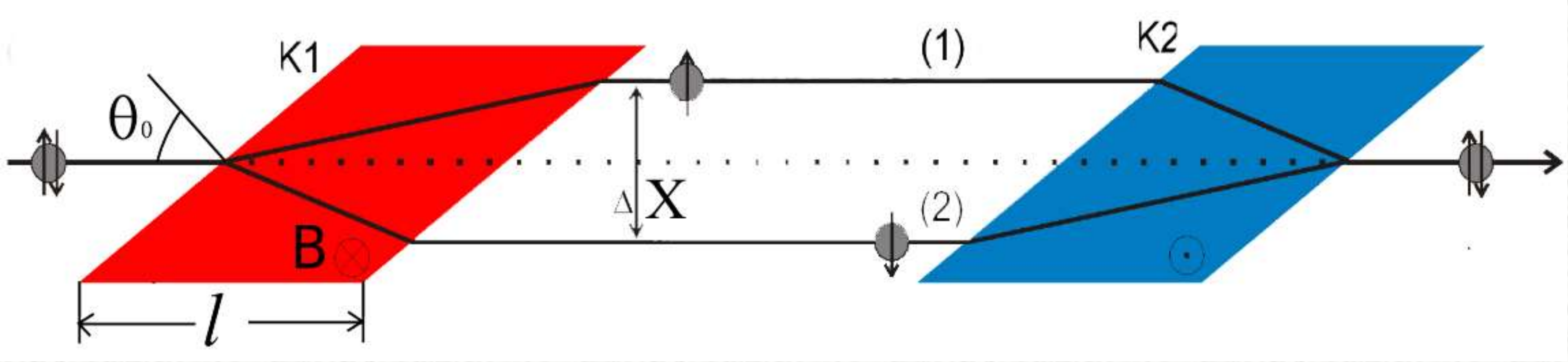


$$\Delta_e = q_n E/2E_n \cdot L^2/2$$

$$\Delta_e[cm] = q_n E \cdot 0.75 \cdot 10^9$$

$$q_n = q_e(-0.4\ \ 1.1)\cdot 10^{-21}$$

SESANS technique

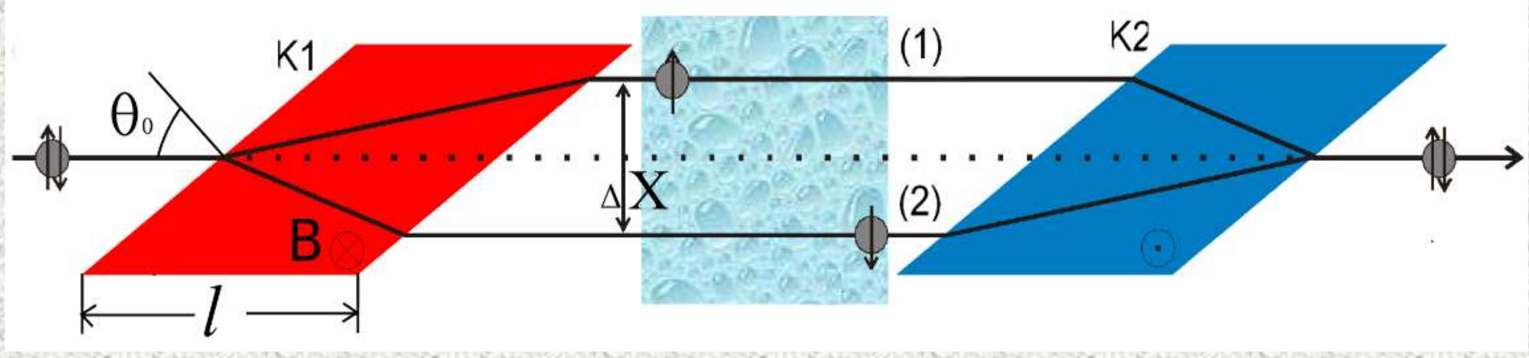


Neutron beam polarization **P** is directed perpendicularly to guiding magnetic field **B**. Neutron wave function can be written in form

$$\psi_i = \frac{1}{\sqrt{2}} \begin{pmatrix} \frac{-i\varphi_0}{2} \\ \frac{i\varphi_0}{2} \end{pmatrix}$$

here φ_0 - neutron spin direction in azimuthally plane. Let's consider **P** parallel to X-axis ($\varphi_0 = 0$)) → **P** = (1; 0; 0)

SESANS technique II



Let's apply *Vsr (x)* . The phase difference between these two eigenstates will be

φsr =(*Vsr (x)* - *Vsr (x+Δx))/ħ·τ*

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

$$\psi_{out} = \frac{1}{\sqrt{2}} \begin{pmatrix} \frac{-i\varphi_{sr}}{2} \\ \frac{i\varphi_{sr}}{2} \end{pmatrix} \qquad P_{out} = \frac{\langle \psi_{out} | \sigma | \psi_{out} | \rangle}{\langle \psi_{out} | \psi_{out} \rangle}$$

As a result we have

Px = cos φsr ;

Py = sin φsr ;

Pz = 0.

SESANS setup at TU Delft

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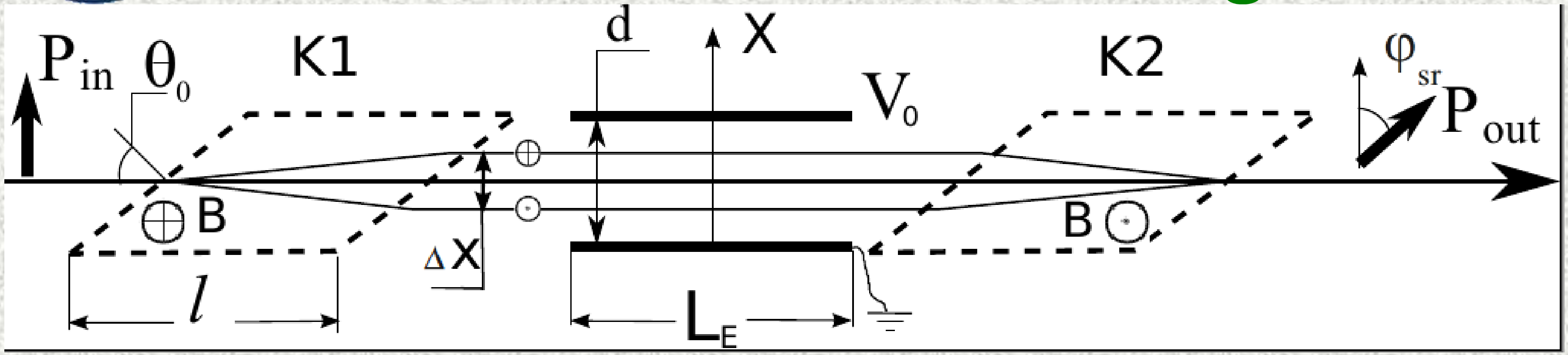
http://tnw.tudelft.nl/index.php?id=33186&L=1

Neutron electric charge



If electric potential $V_E(x)=E_0 \cdot x$ is applied in working area

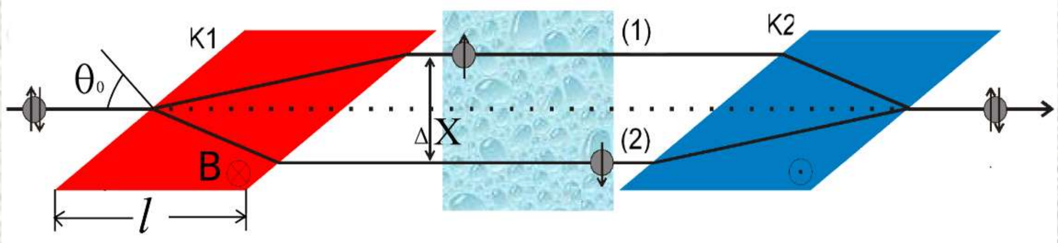
where $E_0=V_0/d$ - the electric field,

then spin rotation angle will be:

$$\phi_e = \frac{E_0 q_n \Delta x}{\hbar} \cdot \tau \qquad \text{where} \qquad \tau = L / \mathrm{v}_n = \frac{L \lambda_n m_n}{\hbar 2\pi}$$

Spatial splitting

$$\Delta x = \frac{\lambda_n^2 l B \tan(\theta_0)\gamma m_n}{4\pi^2\hbar}$$



where l – K1 coil dimention, θ_0 – angle between the neutron velocity and normal to coil edge, B – value of magnetic field inside the coil, γ –gyromagnetic ratio for the neutron.

Finally, we have

$$\phi_e = E_o q_n l L B \tan(\theta_0)\gamma \frac{\lambda_n^3 m_n^2}{8\pi^3\hbar^3}$$

and $\phi_e \sim \lambda_n^3$

Numerical estimations

Let's introduce:

B=0.1T, L=1м, l=1м, E_0=100кV/см, $\tan(\theta_0)$=10, λ_n=30Å)

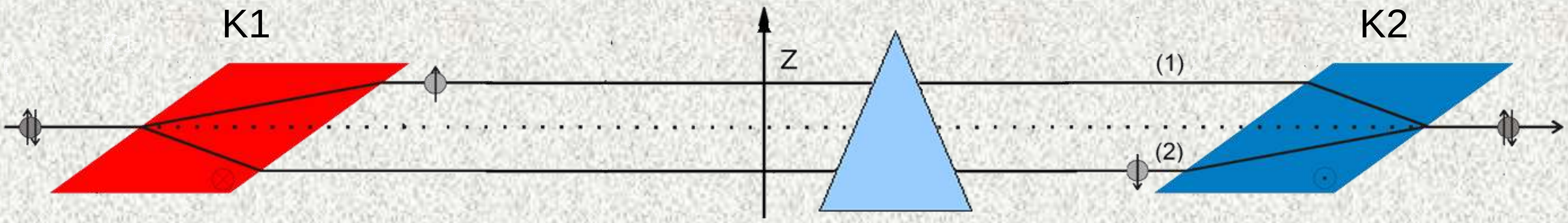
$\Delta x = 0.065$ cm and $\phi_e = 7 \cdot 10^{16} e_n$

where $e_n = q_n/e$ – *neutron electric charge in elementary charge unit*.

Accuracy of $\Delta\varphi_e \sim 10^{-5}$ → **$\sigma(e_n) \sim 1{,}4 \cdot 10^{-22}$**

i.e. order of magnitude better than previous result

Test experiment with the prism



SESANS PNPI characteristics:

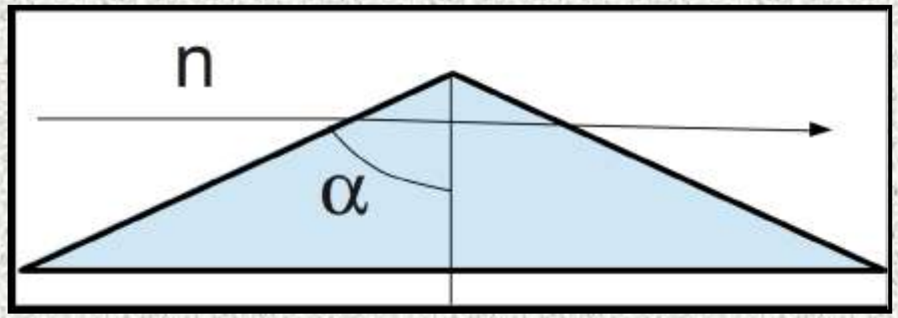
$$\lambda = 0.23nm \qquad l = 0.5m$$

$$\Delta\lambda / \lambda = 0.02 \qquad \theta = 45^{\circ}$$

If B=0.04T → Δx = 200 nm

We use the quartz crystal prism with the vertex angle about 156^0 for neutron beam refraction.

Neutron refraction in quartz prism



Value of phase shift due to refraction in prism

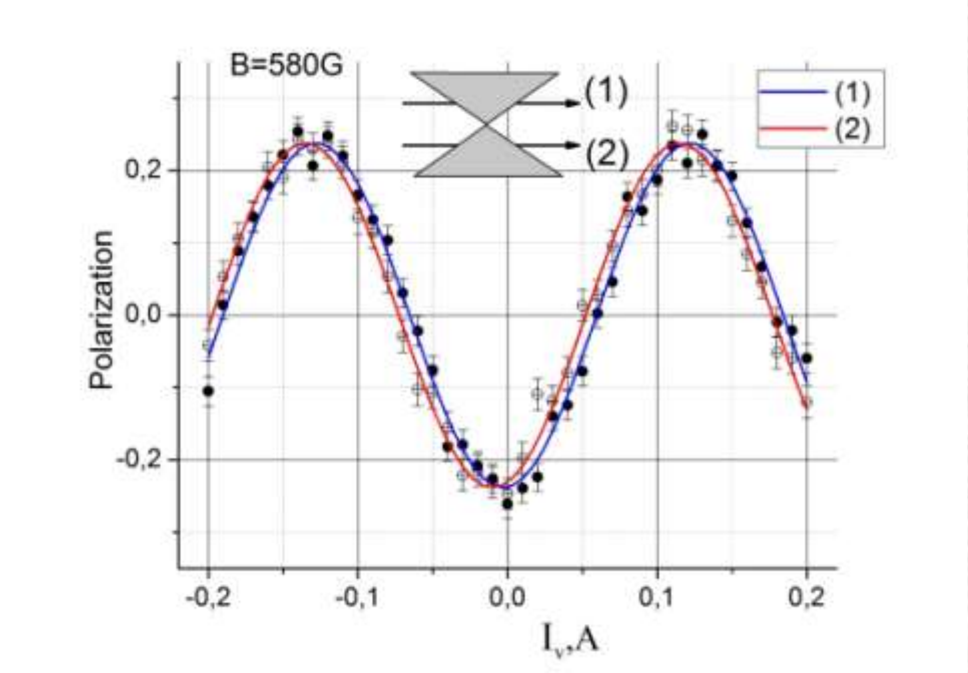
$$\Delta\varphi_r = \frac{V_0}{E}\frac{2\pi}{\lambda}\cdot\Delta x\cdot\tan\alpha$$

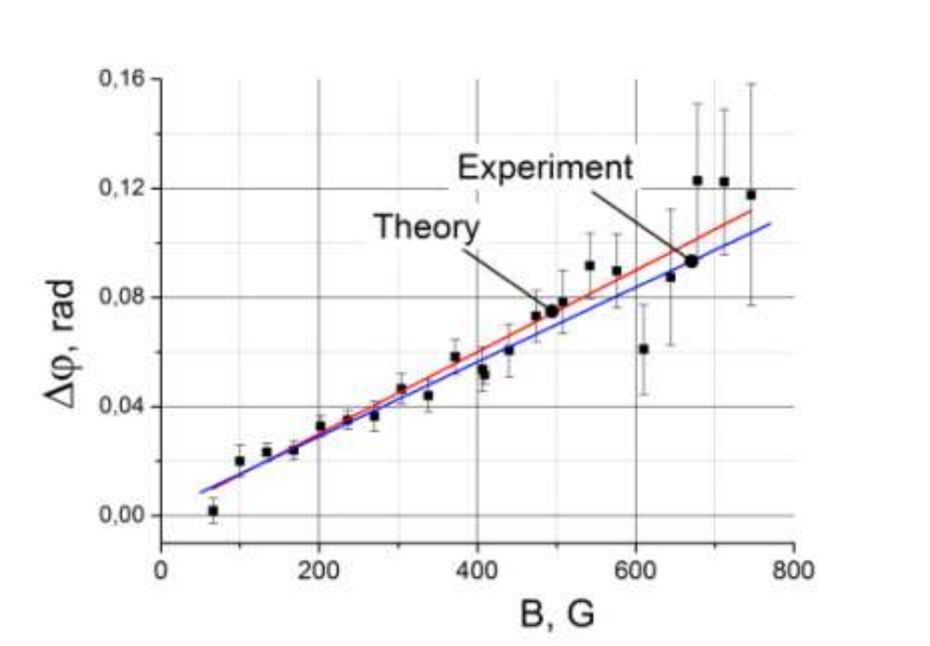
where V_0 – nuclear potential, E – neutron energy,
λ– neutron wavelength, Δx – neutron path difference.

The used quartz prism

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

Experimental results



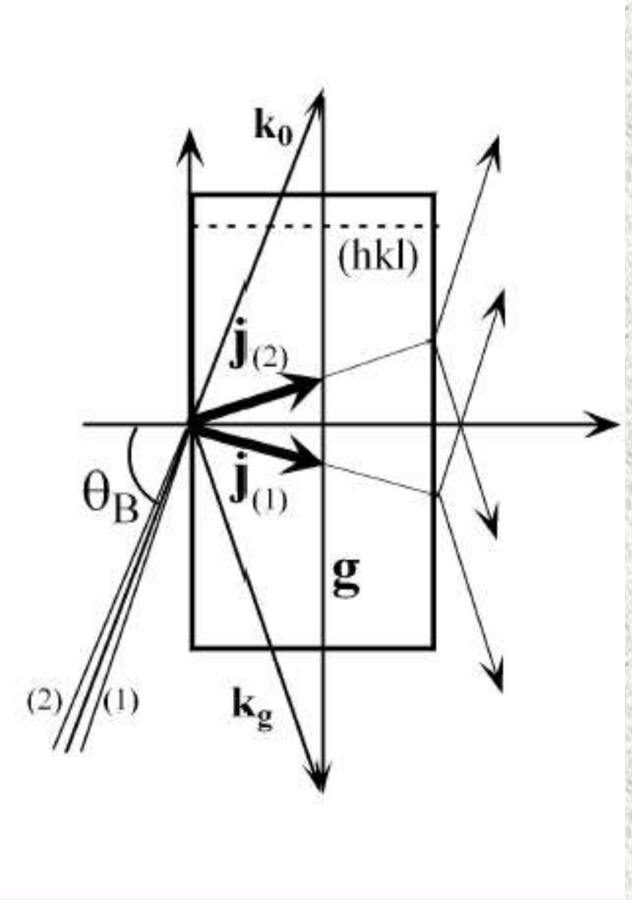


Example of experimental curves

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

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

Laue diraction in perfect crystal



Symmetrical Laue diraction. j(1) and j(2) are the neutron fluxes for two direction of incident beam.

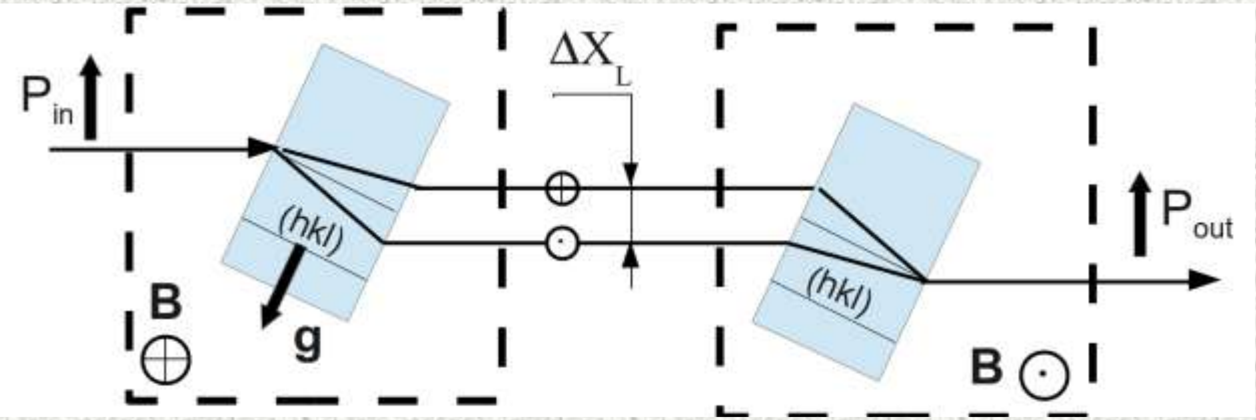
Effect of diffraction enhancement
The neutron in the crystal changes the momentum direction by the angle of (by several tens degrees) while the incident neutron beam deflects by the Bragg width (within a few arc seconds)

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

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

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

SESANS + Laue diffraction



The values of neutron splitting

Laue diffr. +SESANS

$$\Delta X_L = \frac{\mu B}{2v_g} L \sin\theta_B$$

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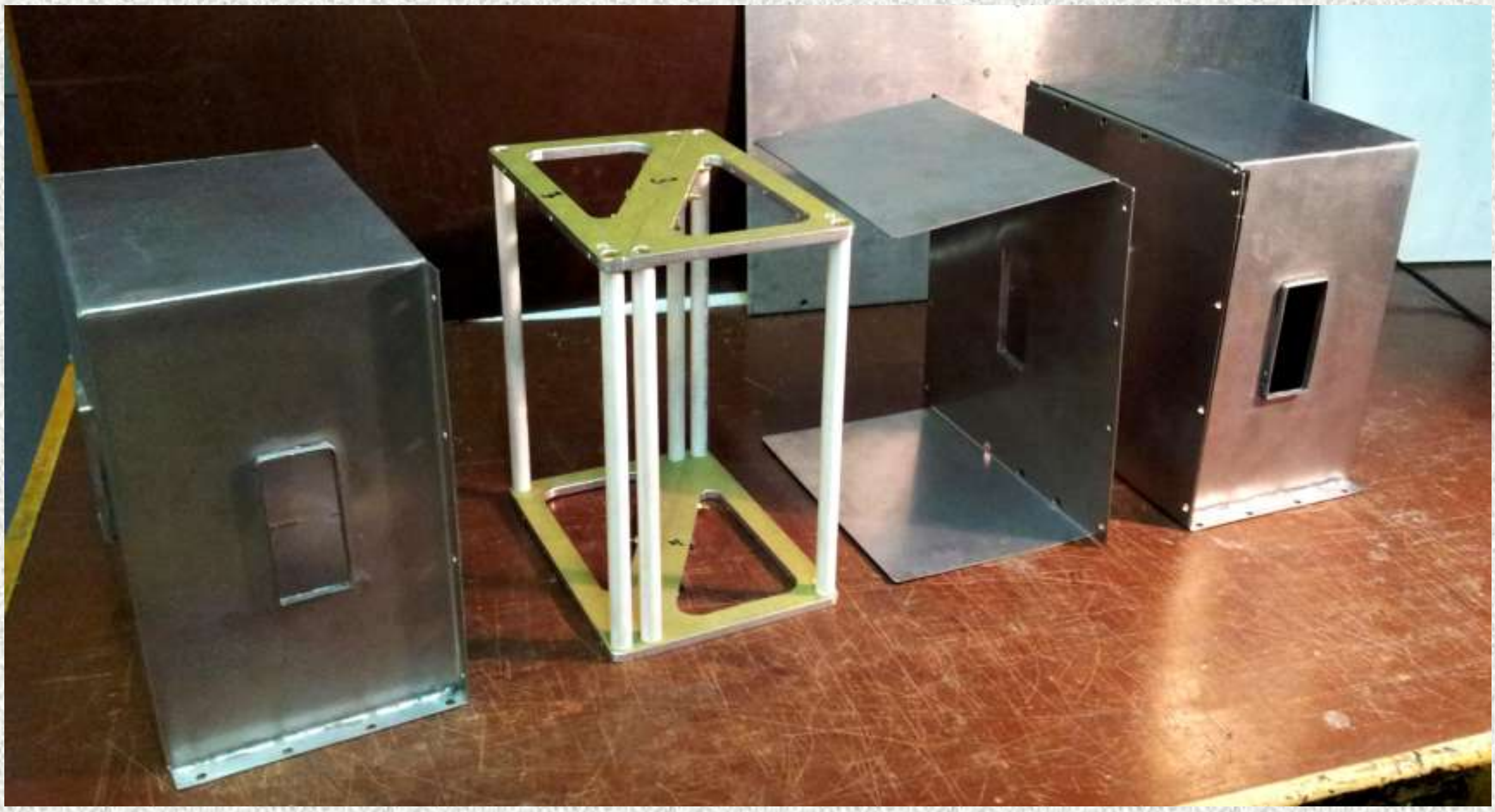
SESANS

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

About $K_g = \frac{E}{2v_g} \Rightarrow 10^5$ **times more**

ΔX_L *for (220) plane of silicon and (100) plane of quartz crystalls, L=10 cm and θ_B =65 degree can be ~ 10μm and ~ 25μm correspondingly for*

B = 1 G



Summary

New approach to test a neutron electroneutrality is proposed.

It is based on using spin interferometer technique realised in the SESANS apparatuses

The sensitivity of the proposed technique can be a few 10^{-22} e, i.e. order of magnitude better than previous result

The demonstration experiment to test the possibility to measure phase shift caused by neutron refraction in media was done. The results fully coincide with the theoretical expectation.

There is a possibility to improve the method accuracy on a few orders based on a neutron Laue diffraction in a perfect crystal

Thank You