The estimation of the angle of fission axis rotation in binary fission of ^{235}U induced by polarized neutrons with energies 60 meV and 270 meV

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Abstract. The nuclear rotation effect, the so-called ROT-effect, was first discovered in the angular distributions of α-particles from ternary fission of the ^{235}U nucleus by cold polarized neutrons [1]. This effect consists in the fact that, depending on the spin direction of the fissioning nucleus, the fission axis rotates relative to the angular distribution of α-particles in one or the other direction. However, in the ternary fission, the trajectory of the α-particle also rotates along with the fission axis (its motion is significantly affected by the electric field of the fragments), but due to the fact that the α-particle is lighter than fission fragments, it quickly moves away from the center of rotation, its moment of inertia becomes larger, and the angle of rotation is smaller. That is, the α-particle rotates, but more slowly (by a smaller angle) than the fission axis. To determine the rotation angle of the fission axis (the value of the ROT-effect) in ternary fission, complicated, detailed trajectory calculations are required [2].

It is considered more convenient for analyzing the fission mechanism to study the ROT-effect in the angular distribution of the prompt neutrons and especially γ-quanta. For γ-quanta, the rotation of the fission axis looks different than for α-particles of the ternary fission. According to the model [3, 4], the angular distribution of the γ-quanta is formed at the moment of the nucleus split into two fragments and remains fixed during the escape of the fragments. This is due to the fact that the angular anisotropy of γ-quanta is determined by the alignment of the fragment spins relative to the symmetry axis of the fissile system, and the spins do not rotate in the process of emission due to the law of conservation of angular momentum. It is important to note that for γ-quanta, in contrast to α-particles, the determination of the rotation angle does not depend on complex trajectory calculations and is, in this sense, model-independent.

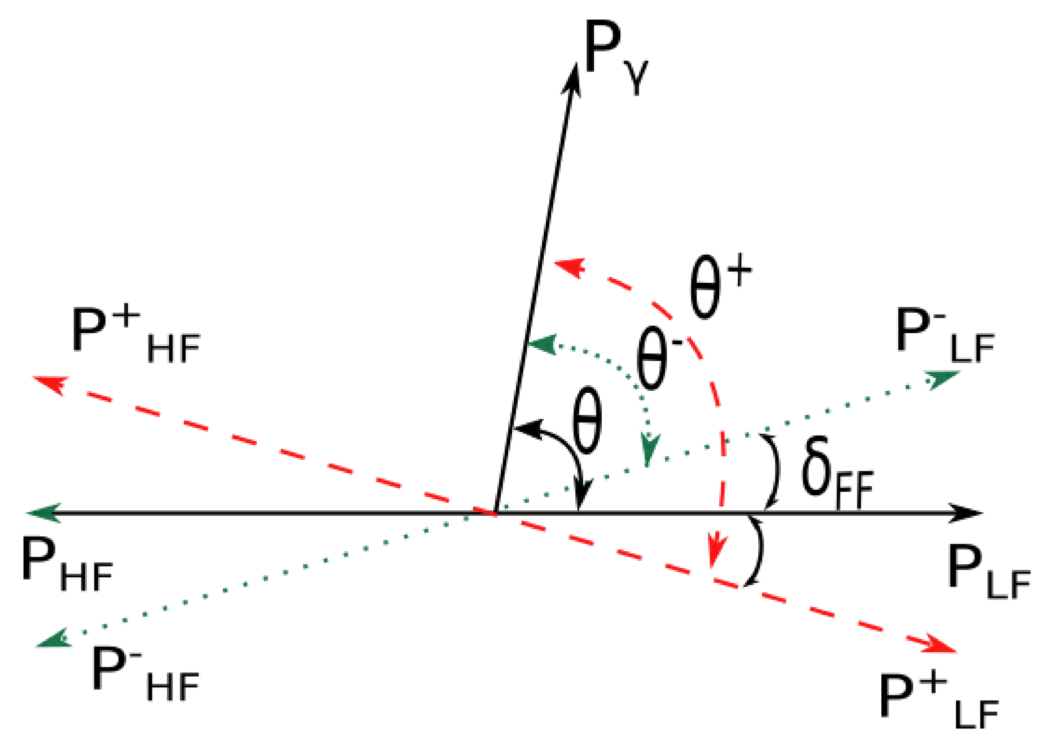

Fig.1. The scheme of the formation of the shift in the angular distribution of γ-rays from fission fragments with respect to their measurement detection; P_{LF}, P_{HF} – initial direction of fragments; P_α – α-particle motion at the moment of scission. By "+" and "-" are labeled the final object directions for opposite directions of the neutron polarization.

The neutrons were polarized using a ^{3}He neutron spin filter cell. Polarized ^{3}He gas for the polarizer cell was created by SEOP method

Target – 82 mg of ^{235}U (99.99%)

The chamber was filled with CF_4 gas at a pressure of about 10 mbar.

Polarization (^{3}He cell): ~100%

Flux: ~ 1.6*10^7 n/cm^2/s

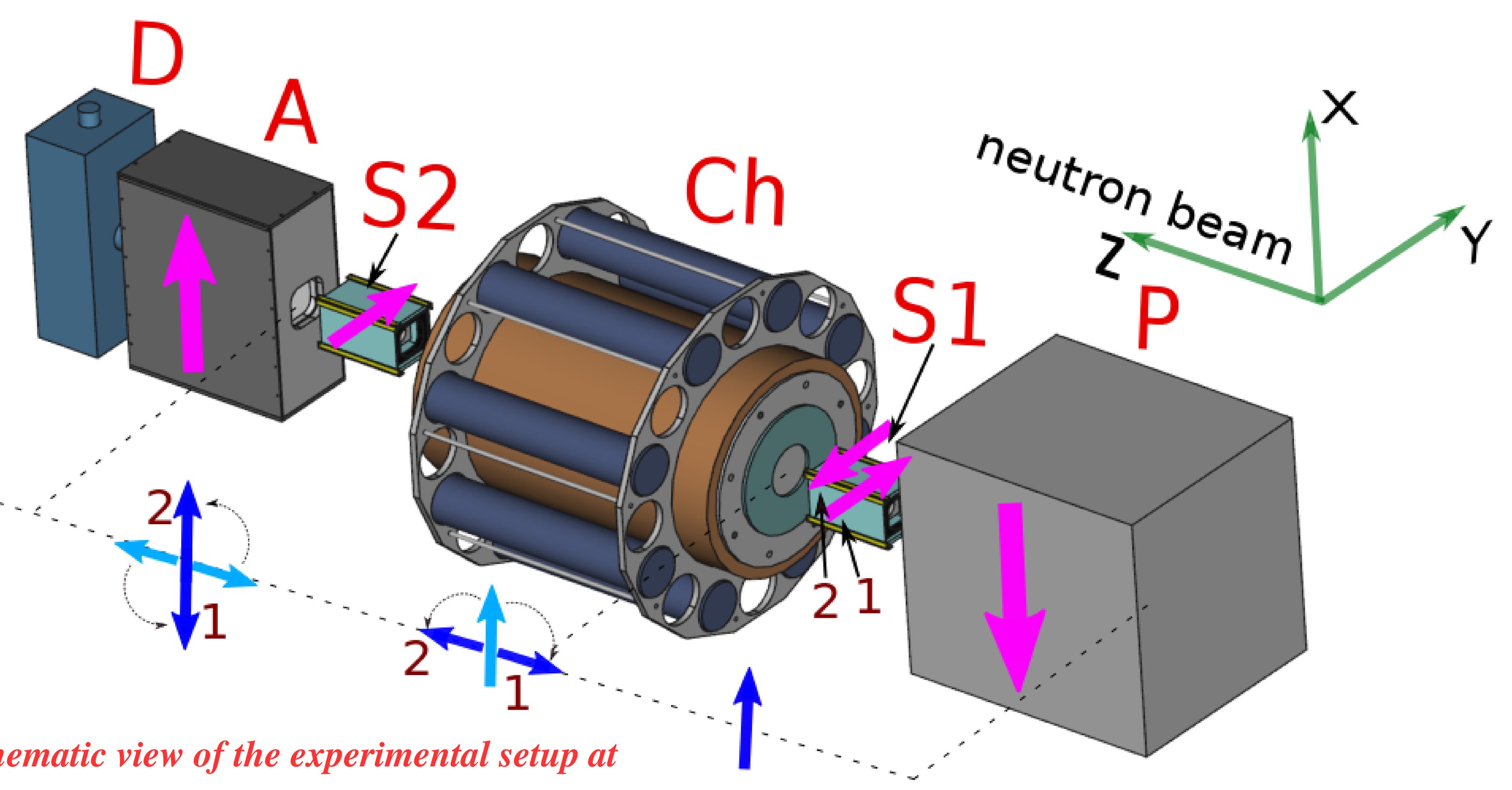

Fig.2. Schematic view of the experimental setup at the POLI facility of FRM-II

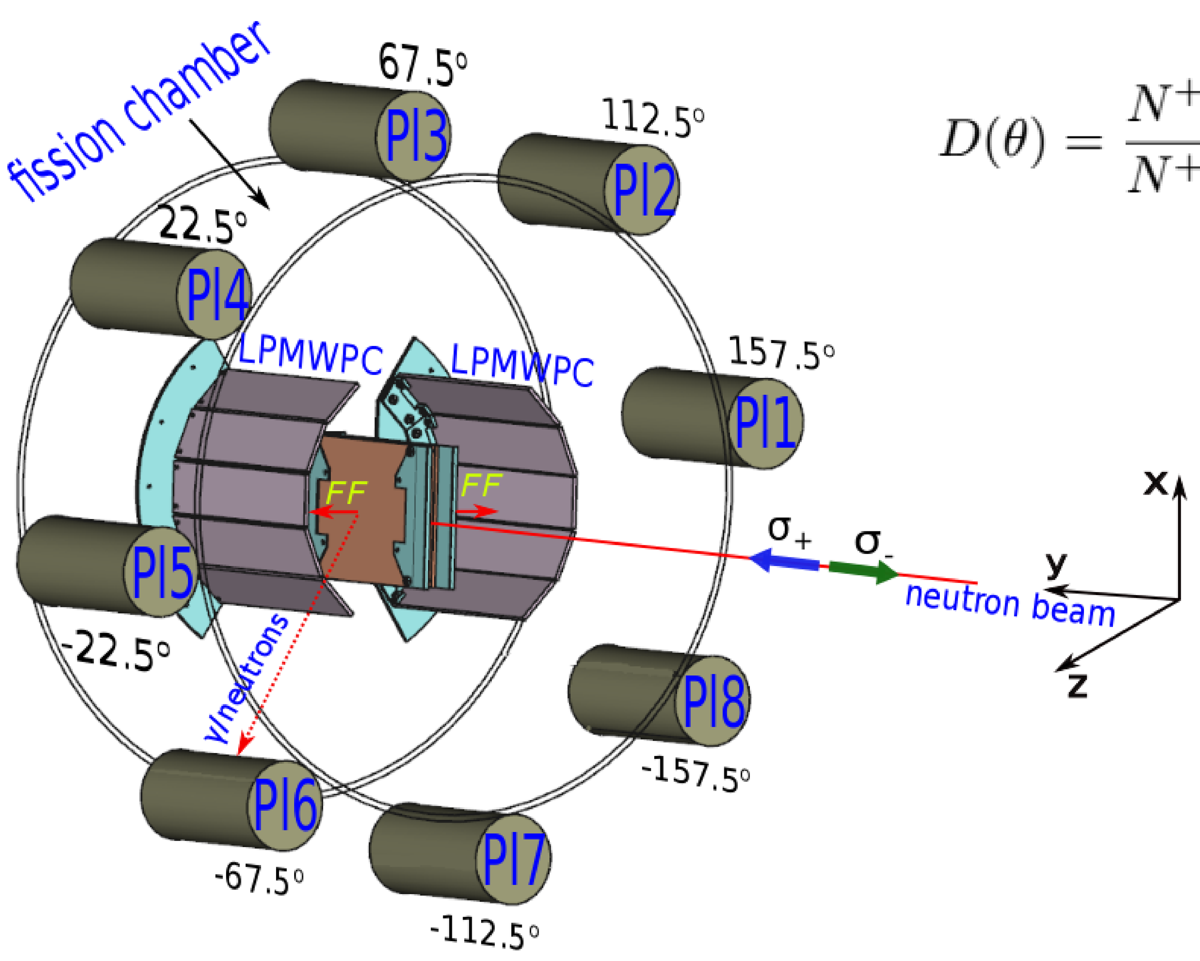

Fig.3. The experimental layout for measuring the ROT-effect in binary fission of ^{235}U induced by polarized, "warm", monochromatic neutrons.

$$D(\theta) = \frac{N^+(\theta) - N^-(\theta)}{N^+(\theta) + N^-(\theta)} \quad (1)$$

Denoting the γ-ray counting rates for the selected angle between the detectors in two opposite directions of neutron polarization through $N^+(\theta)$ and $N^-(\theta)$, respectively, we introduce the asymmetry (1)

Following the works [4, 5] ROT-effect is the direct consequence of the appearance in the rupture process of a strongly deformed fissioning system with large angular momenta of the fission fragments. These momenta, which are oriented perpendicular to the fission fragment axis of symmetry, are conserved up to the time of the γ-quanta emission (≥ 10^{-14} sec) and lead to the well known angular anisotropy of the γ-quanta emission relative to the fission axis:

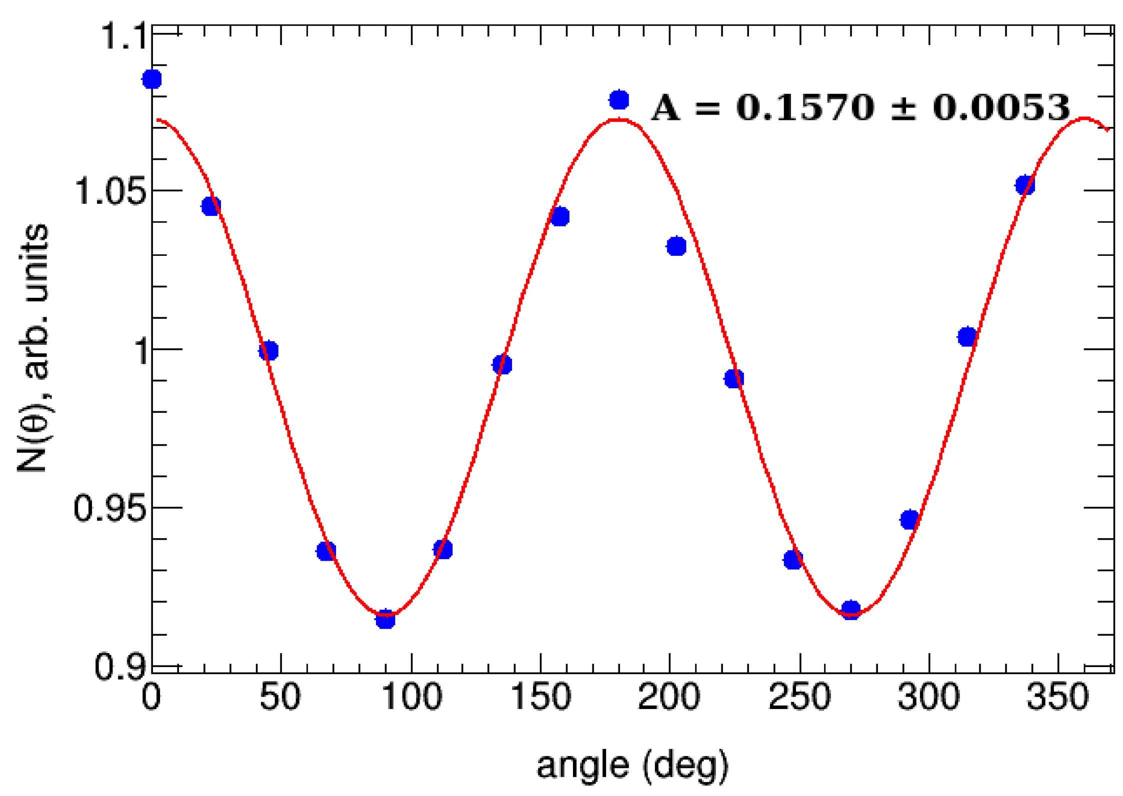

Fig. 4. Angular distribution of γ-rays relative to the fission axis.

$$N(\theta) \sim 1 + A \cdot \cos^2(\theta) \quad (2)$$

A - coefficient of the angular anisotrpy related to the large angular momenta of the fission fragments

Using the expressions (1) and (2) after some simple transformations one can get the following formula for the ROT asymmetry coefficient value:

$$D(\theta) \approx \frac{-A \cdot \delta_{FF} \cdot \sin(2\theta)}{1 + A \cdot \cos^2\theta} \quad (3)$$

$$D(\theta) = R_\gamma \cdot \sin(2\theta) \quad (4)$$

Rotation angle of the fission axis

Comparing (3) and (4) one can write:

$$\delta_{FF} = \frac{-R_\gamma \cdot (1 + A \cdot \cos^2\theta)}{A} \quad (5)$$

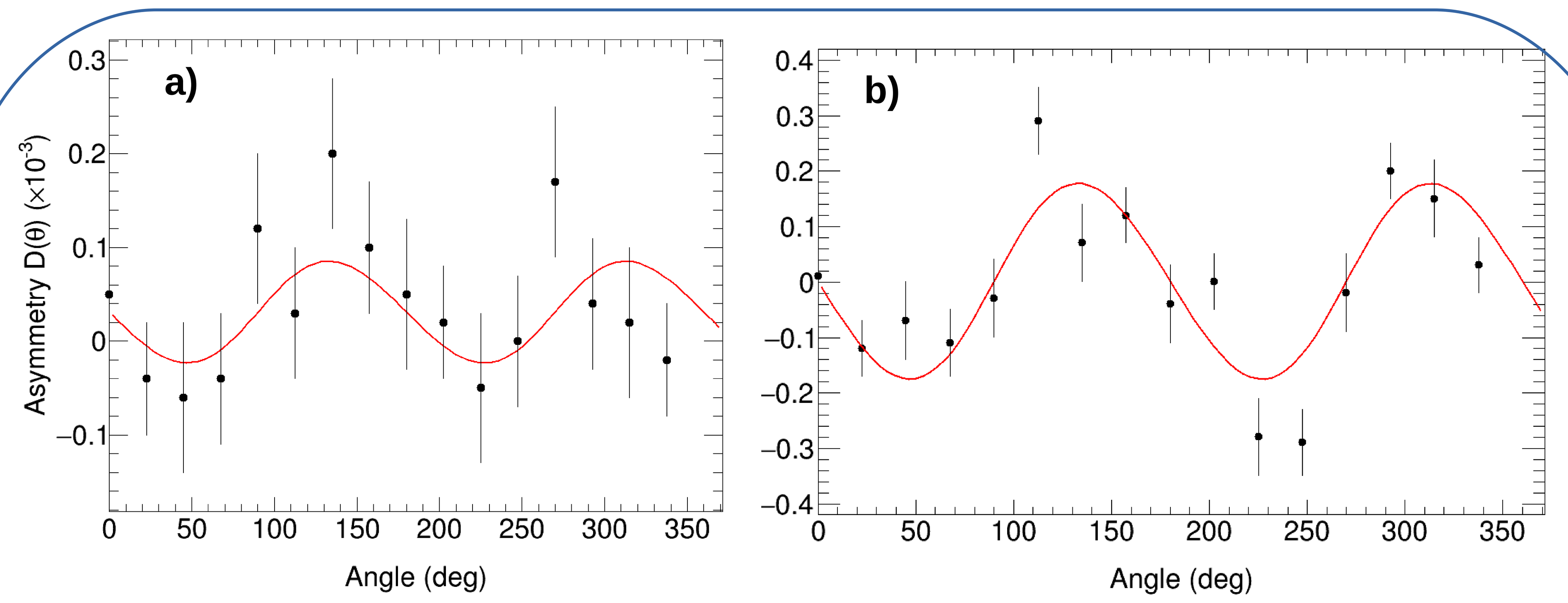

Fig. 5. Asymmetry ratio D as a function of angle for the gamma-rays. a) for 270 meV; b) for 60 meV

Obtained angular dependence approximated by the function (4), where R_γ is the asymmetry parameter.

$R_\gamma = -(5.37 \pm 2.53) \times 10^{-5}$ ***for 270 meV***

$R_\gamma = -(17.3 \pm 2.8) \times 10^{-5}$ ***for 60 meV***

The rotation angle of the fission axis was determined by fitting the angular distribution of the γ-rays emitted in binary fission by farmula (5).

$\delta_{FF} = 0.0205 \pm 0.0097$ deg ***for 270 meV***

$\delta_{FF} = 0.069 \pm 0.008$ deg ***for 60 meV***

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