Rotation effect of a fissile nucleus (ROT effect) for prompt γ-rays in binary fission of U-235 by polarized neutrons of different energies

D. Berikov, G. Ahmadov, Yu. Kopatch et al.

This presentation summarizes all previous studies on the ROT effects for prompt γ-rays emitted during the binary fission of ^{235}U.

cold polarized neutrons → ITEP group (G. Danilyan et al.)

thermal polarized neutrons → PNPI group (A. Gagarski et al.)

monochromatic polarized neutrons with energies of 62 meV and 270 meV

↓

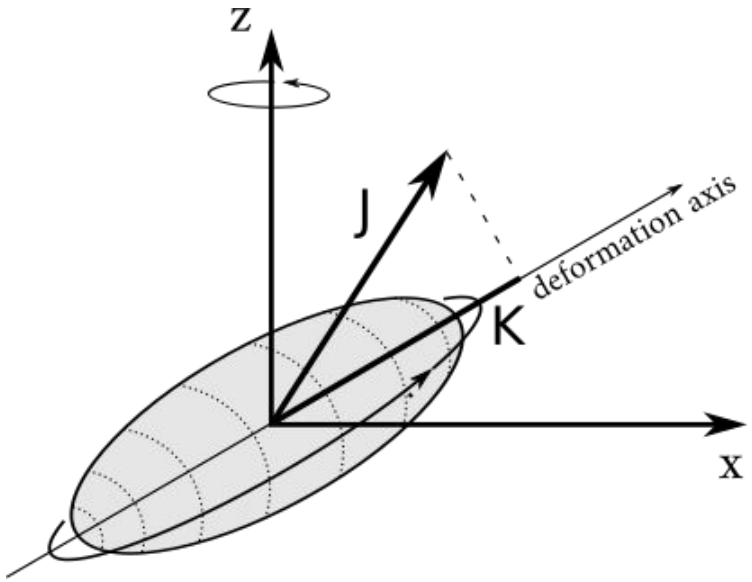
our group

resonance of ^{235}U isotope

Elementary theory of effect

^{235}U

(spin $I = \frac{7}{2}$)

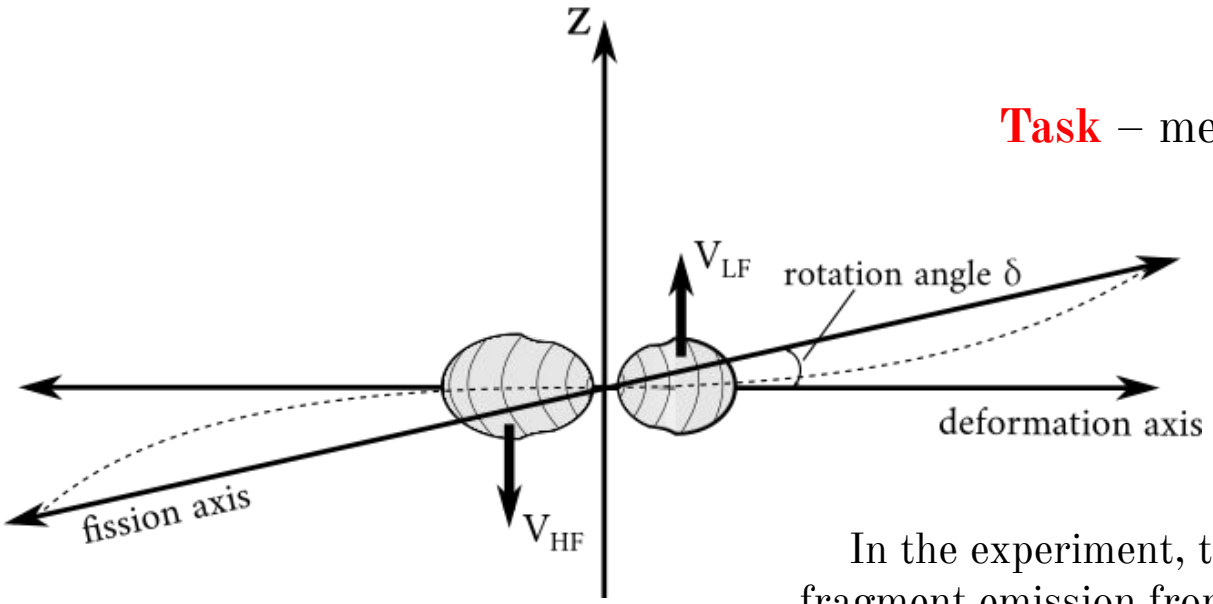


$$J^{\pm} = (I \pm \tfrac{1}{2})$$

$$\omega(J,K) = \begin{cases} \frac{J(J+1)-K^2}{J}\frac{\hbar}{2\Im}p_n \quad for \quad J^+ = 4 \\ -\frac{J(J+1)-K^2}{(J+1)}\frac{\hbar}{2\Im}p_n \quad for \quad J^- = 3 \end{cases}$$

D. Berikov et al., Chin. Phys. C Vol. 49, No. 7, P. 074102 (2025)

Elementary theory of effect



Task – measurement of angle δ

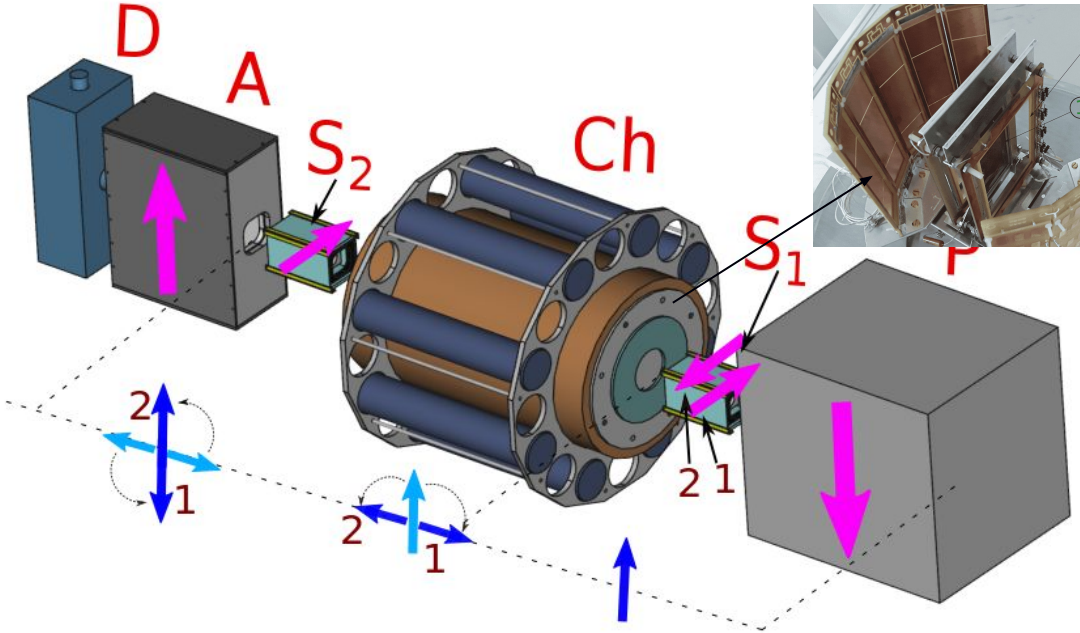
In the experiment, the direction of fission fragment emission from the target is recorded.

How to determine the orientation of the deformation axis at the moment of neck rupture?

D. Berikov et al., Chin. Phys. C Vol. 49, No. 7, P. 074102 (2025)

WE NEED SOME MARK!

Experimental setup

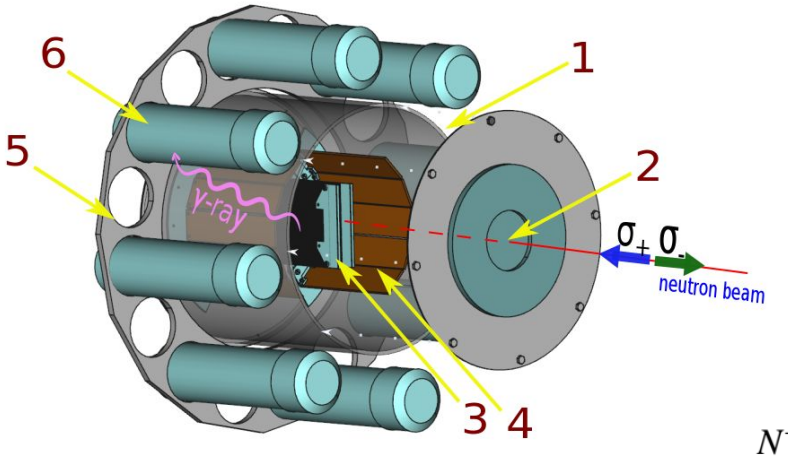


The chamber was filled with CF_4 gas at a pressure of about 10 mbar.

Target → 82 mg ^{235}U(99.99%)

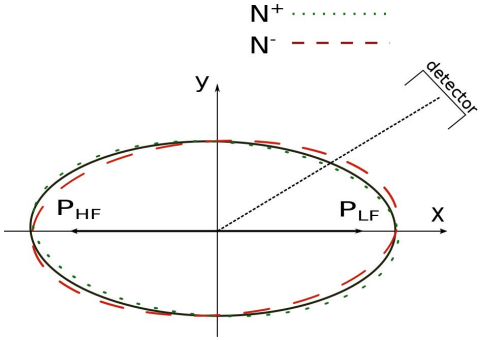
1. D. Berikov, V. Hutanu, Yu. Kopatch et al., JINST **15**, P01014 (2020)
2. D. Berikov, G. Ahmadov, Yu. Kopatch and V. Novitsky, JINST **17**, P08030 (2022)

Experimental technique



$$N(\theta) = N(90^\circ)\cdot(1 + A\cos^2\theta),$$

V. Strutinskii, Zh. Eksp. Teor. Fiz. 37, 861 (1959)



$$\theta' = \theta - \delta \quad \text{if} \quad \sigma > 0$$

$$\theta' = \theta + \delta \quad \text{if} \quad \sigma < 0.$$

$$N^+(\theta') = N(90^\circ)(1 + A\cos^2(\theta' + \delta)) \quad \text{if} \quad \sigma > 0$$

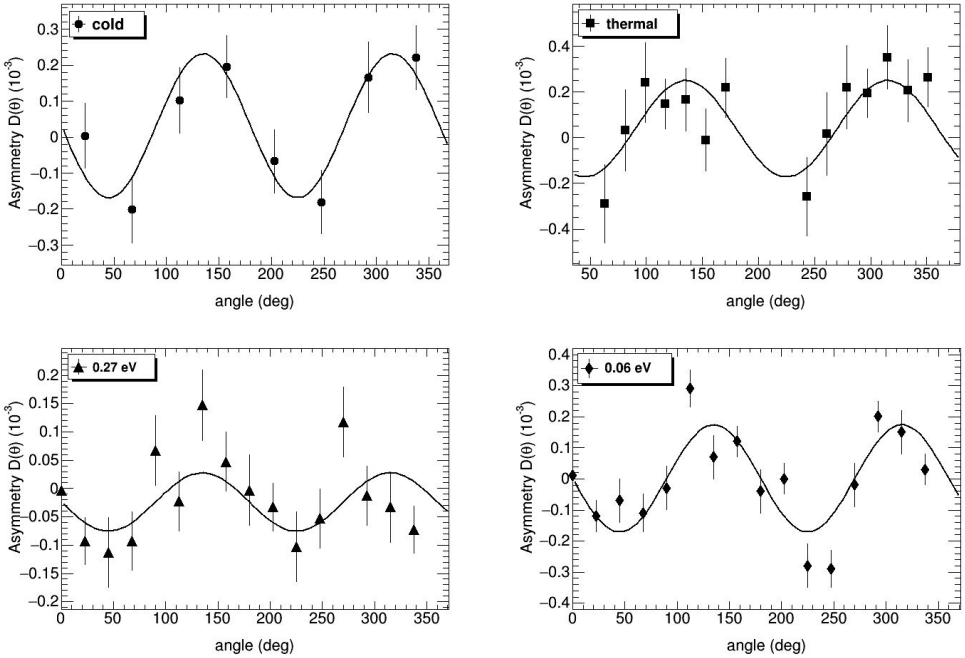
$$N^-(\theta') = N(90^\circ)(1 + A\cos^2(\theta' - \delta)) \quad \text{if} \quad \sigma < 0$$

$$\downarrow$$

$$D(\theta') = \frac{N^+(\theta') - N^-(\theta')}{N^+(\theta') + N^-(\theta')},$$

$$D(\theta') \approx \frac{-A\delta\sin(2\theta')}{1 + A\cos^2\theta'}.$$

Results: ROT asymmetry



Asymmetry ratio $D(\theta')$ as a function of the angle for prompt fission γ-rays. The solid line shows the approximation of the obtained angular dependence $D(\theta')$ by the function $F = R_\gamma \sin(2\theta)$.

Table 1. ROT asymmetry parameters for prompt γ-rays of ^{235}U fission.

	Asymmetry parameter R_γ, in units of 10^{-5}	
E_n/eV	Preliminary results	Corrected results
cold	20.9 ± 2.4 (for 67.5°) [6]	−20.0 ± 4.5
thermal		−21.1 ± 6.8 [21]
0.06	−12.5 ± 3.1 [13]	−17.3 ± 2.8 [14]
0.27	3.8 ± 2.8 [12]	−5.4 ± 2.5

[6] G. V. Danilyan, J. Klenke, V. A. Krakhotin *et al.*, Phys. At. Nucl. **74**, 671 (2011)

[12] Yu. Kopatch, V. Novitsky, G. Ahmadov, A. Gagarski, D. Berikov, K. Zhumadilov, G. Danilyan, V. Hutanu, J. Klenke, and S. Masalovich, in *Proceedings of the XXVII International Seminar on Interaction of Neutrons with Nuclei*, Dubna, Russia, June 10-14, 2019 (JINR, Dubna, 2020), p. 235.

[13] Yu. Kopatch, D. Berikov, G. Ahmadov *et al.*, in *Proceedings of the XXV II International Seminar on Interaction of Neutrons with Nuclei*, Dubna, Russia, June 10-14, 2019 (JINR, Dubna, 2020), p. 242

[14] D. Berikov, G. Ahmadov, Yu. Kopatch *et al.*, Phys. Rev. C **104**, 024607 (2021)

[21] G. V. Valsky, A. M. Gagarski, I. S. Guseva *et al.*, Bull. Russ. Acad. Sci. Phys. **74**, 767 (2010)

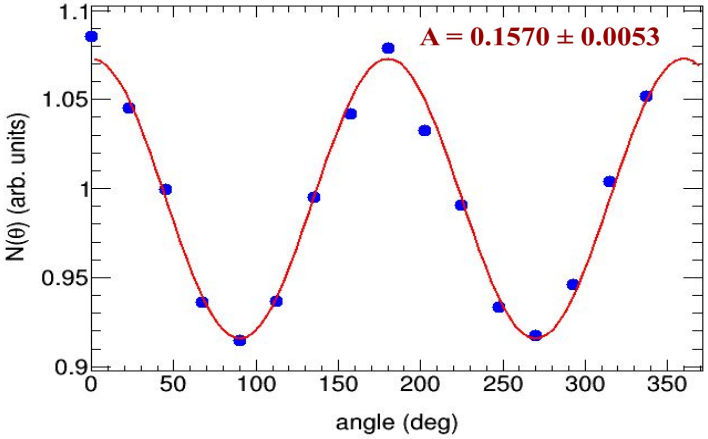
Results: rotation angle

Table 2. Experimental results.

	cold	thermal [21]	0.06 eV [14]	0.27 eV
A	0.159 ± 0.014	0.146 ± 0.002	0.157 ± 0.005	0.163 ± 0.013
δ	0.078 ± 0.017	0.103 ± 0.028	0.069 ± 0.008	0.021 ± 0.009

[14] D. Berikov, G. Ahmadov, Yu. Kopatch *et al.*, Phys. Rev. C **104**, 024607 (2021)

[21] G. V. Valsky, A. M. Gagarski, I. S. Guseva *et al.*, Bull. Russ. Acad. Sci. Phys. **74**, 767 (2010)

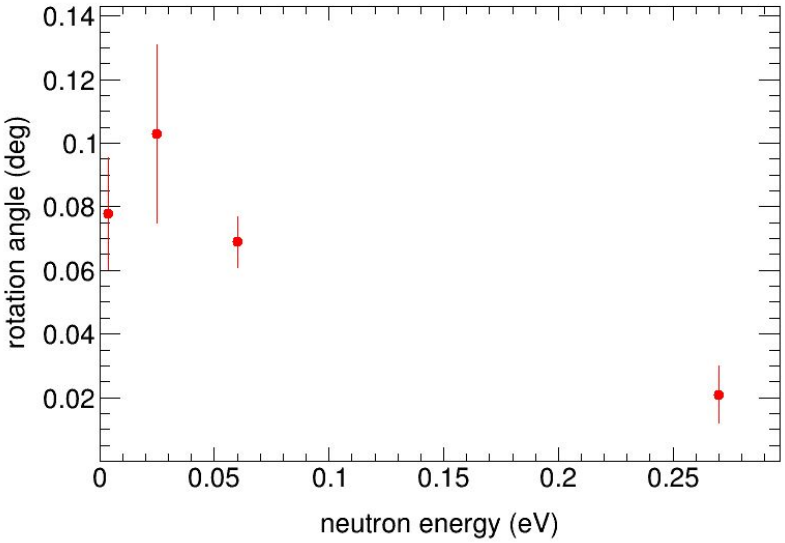


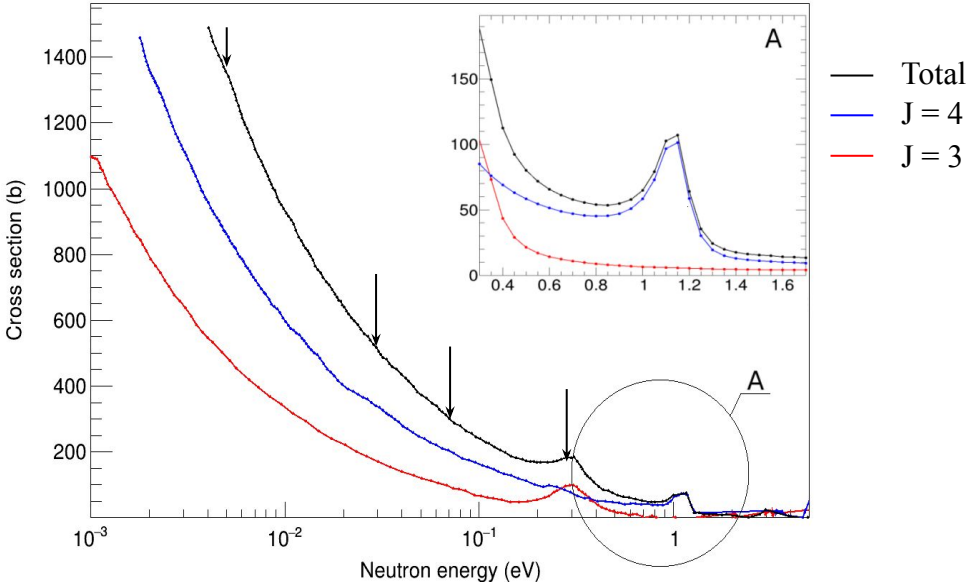
$$N(\theta) = N(90^\circ)\cdot(1 + A\cos^2\theta),$$

$$D(\theta') \approx \frac{-A\delta\sin(2\theta')}{1 + A\cos^2\theta'}.$$

G. Ahmadov, D. Berikov, Yu. Kopatch, Romanian Reports in Physics **75**, 202 (2023)

Results: dependence of the ROT effect on the neutron energy





$$\omega(J,K) = \begin{cases} \frac{J(J+1)-K^2}{J}\frac{\hbar}{2\Im}p_n \quad for \quad J^+ = 4 \\ -\frac{J(J+1)-K^2}{(J+1)}\frac{\hbar}{2\Im}p_n \quad for \quad J^- = 3 \end{cases}$$

A. Gagarski, F. Goennenwein, I. Guseva et al., Phys.Rev.C 93, 054619 (2016)

I. Guseva, A. Gagarski, F. Goennenwein et al., EPJ Web Conf. 256, 00006 (2021)

Conclusion

The conducted studies on ROT effects for prompt γ-rays from the fission of ^{235}U using polarized neutrons provide important experimental data that are significant for understanding the theory of nuclear fission and the study of the dynamics of the fission process, especially near the break point. The work consolidates the results of measurements of ROT asymmetry and the rotation angles of the fissile nucleus of ^{235}U for various neutron energies, including data from our group (for energies of 0.06 and 0.27 eV) and results from other research teams. It should be highlighted that this work first demonstrates the rotation angle of the nucleus for cold neutrons and for the first isolated resonance of 235U (0.27 eV). To calculate the rotation angle of the nucleus for cold neutrons, data from the authors of ITEP were reprocessed.

Moreover, the obtained ROT-asymmetry values for the first isolated resonance indicate that the effect is significantly smaller compared to cold neutrons. Nevertheless, this result is important for testing the proposed theoretical models and understanding the fission process as a whole. The theoretical calculations predicted such a reduction in the anisotropy coefficient for the isolated resonance at 0.27 eV for ^{235}U based on known contributions from J = 3 and J = 4 partial cross-sections for these nuclei and from the values of the most probable K-channel for these spins obtained in the corresponding studies.

Thank you for your attention!