MEASUREMENT OF T-ODD EFFECTS IN THE NEUTRON INDUCED FISSION OF ^{235}U AT A HOT SOURCE OF POLARIZED RESONANCE NEUTRONS

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Historical background

The T-odd effects in fission of heavy nuclei have been known since more than a decade.

The angular distribution for one of the fission fragments (FF) and ternary particles (TP) at given neutron spin (σ) can be written as:

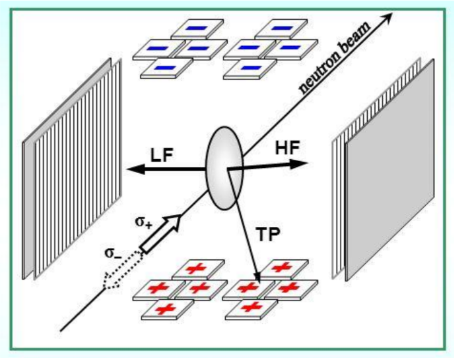
$$W(\theta, \varphi) \sim 1 + < D > \cdot \sigma \cdot [p_f \times p_\alpha]$$

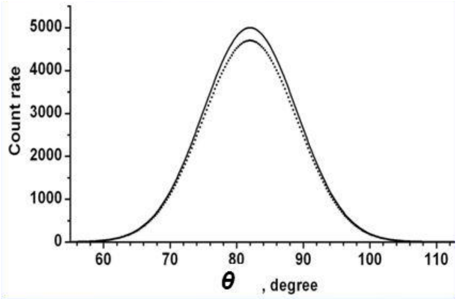
p_f, p_α - momentum of one of the FFs and the TP;
D - coefficient measuring the size of the triple correlation $\sigma \cdot [p_f \times p_\alpha]$;

Experiments at the ILL: TRI-effect

1998 - discovery of the TRI – effect in the ternary fission of ^{233}U

P. Jesinger, A. Kotzle , A.M. Gagarski , F. Gonnenwein , G. Danilyan et al, NIM A 440 (2000), p. 618-625





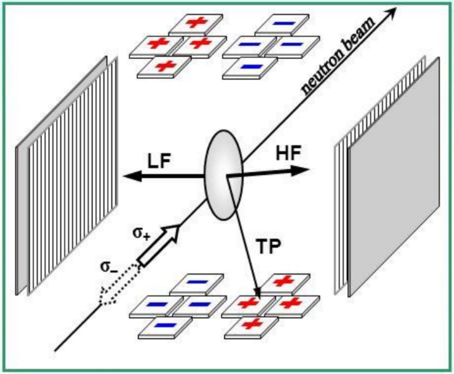
$W = 1 + D_{TRI} \cdot \sigma \cdot [p_{LF} \times p_t]$

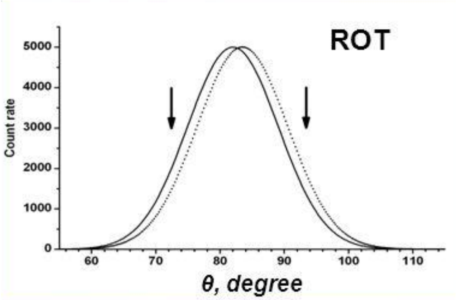
$D_{TRI} = \frac{N^{0}_{up} - N^{1}_{down}}{N^{0}_{up} + N^{1}_{down}}$

Experiments at the ILL: ROT-effect

2005 - discovery of the ROT – effect in the ternary fission of ^{233}U

F. Goennenwein, M. Mutterer, A. Gagarski, I. Guseva, G. Petrov et al, Phys. Lett. B 652 (2007) 13.

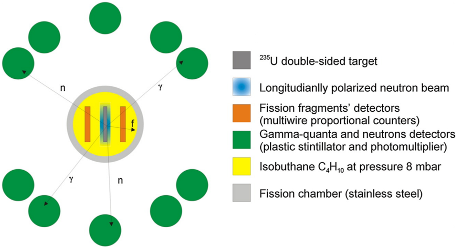




$W = 1 + D_{ROT} \cdot \sigma \cdot [p_{LF} \times p_T](p_{LF} \cdot p_T)$

$A_i = \frac{N_i^+ - N_i^-}{N_i^+ + N_i^-}$

Experiments at the HMI (Berlin): ROT-effect in the γ-ray emission from $^{235}U(n,f)$



ROT asymmetry coefficients in units of 10^{-4}

Angle to the fission axis	^{235}U
0	-0.1 ± 0.3
$\pi/8$	$+0.8 \pm 0.2$
$\pi/4$	$+1.5 \pm 0.2$
$3\pi/8$	$+0.7 \pm 0.3$
$\pi/2$	-0.3 ± 0.3

G.V. Danilyan, P. Granz, V.A. Krakhotin, F. Mezei, V.V. Novitsky, V.S. Pavlov, M. Russina, P.B. Shatalov, T. Wilpert, Phys. Lett. B 679 (2009) 25–29

Experiments at the FRM-II: ROT-effect in γ-ray and neutron emission

G. V. Danilyan, J. Klenke , V. A. Krakhotin, Yu. N. Kopach, V. V. Novitsky, V. S. Pavlov, and P. B. Shatalov, Phys. At. Nucl., 2011, Vol. 74, No. 5, pp. 671–674.

2011 - Search for the TRI- and ROT – effects in the γ-ray and neutron emission from fission of ^{233}U and ^{235}U at the MEPHISTO instrument (FRM-II reactor, Garching).

Summary of results for the polarized cold neutron beam

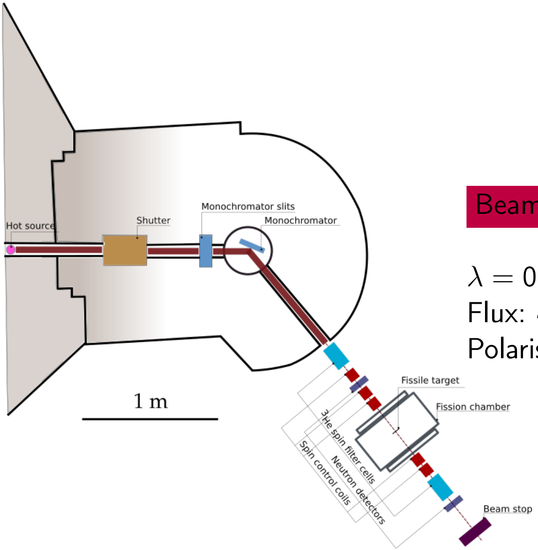
ROT asymmetry coefficients in units of 10^{-5}

Fission product	Angle to the fission axis	^{233}U	^{235}U
γ-rays	22.5	$+2.8 \pm 1.7$	-12.9 ± 2.4
γ-rays	45	$+6.3 \pm 1.6$	-16.6 ± 1.6
γ-rays	67.5	$+6.8 \pm 2.4$	-20.0 ± 1.8
neutrons	22.5	$+4.8 \pm 1.6$	-21.2 ± 2.5

Theoretical models

1. Historically the first attempt to explain the nature of the TRI-effect was based on the statistical model *(V.Bunakov, G. Petrov, F. Goennenwein. 2000, ISINN-8)*.
2. After the ROT-effect discovery the semi-classical model of deformed fissionning system rotation has been proposed*(A. Gagarski, I. Guseva, F.Goennenwein. et al)*.
3. Hypothesis of the "scission γ-emission" for the γ-rays ROT-effect explanation in the ^{235}U binary fission *(G.Danilyan et al. 2008)*.
4. Explanation of the ROT-effect for the γ-rays by the angular anisotropy of the prompt γ-rays, emitted from fission fragments *(V.Novitsky, 2010)*.
5. Calculations of the ROT-effects for the γ-rays and neutrons by Guseva, 2010
6. The quantum mechanical explanations of the T-odd asymmetry effects with taking into account the interference of neutron resonances *(V. Bunakov, S. Kadmensky, 2006 -2009)*.
7. Theoretical approach of spin-orbital interaction for T-odd asymmetry effects explanation *(A. Barabanov, 2011, ISINN-19)*.
8. Comprehensive model description of all experimental data on T-effects in ternary fission *(A.Gagarski et al, Phys. Rev. C 93, 054619, 2016)*.

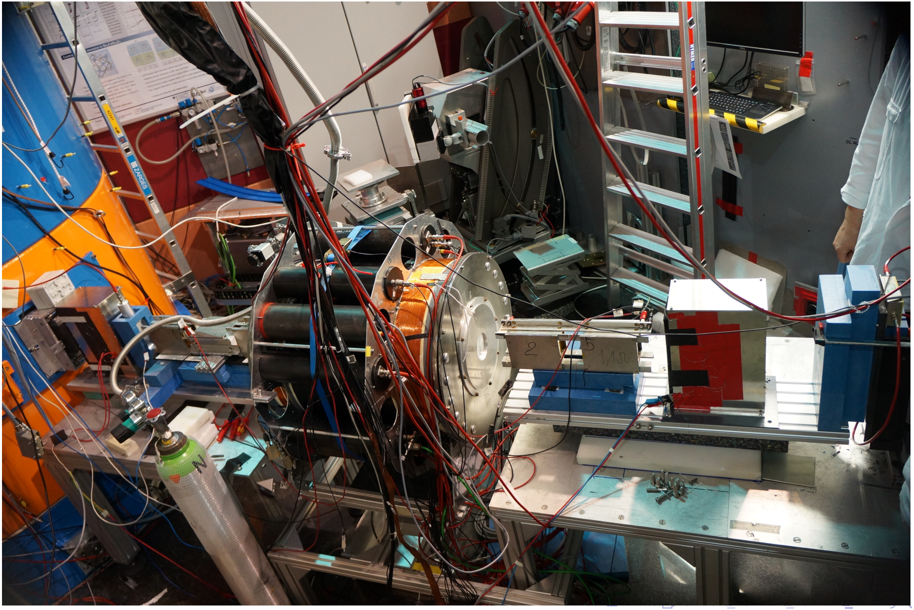
The POLI instrument at the FRM-II reactor



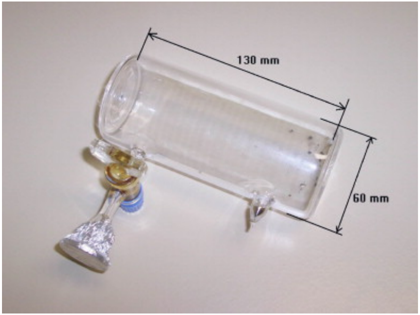
Beam parameters:

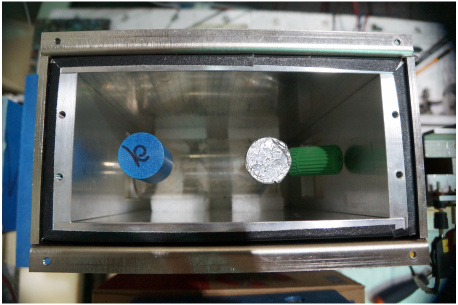
$\lambda = 0.55 (E_n \sim 0.27 eV)$
Flux: $\sim 5 \cdot 10^6 n/cm^2/s$
Polarisation (^3He cell): $\sim 70\%$

Photo of the experimental setup



Spin filter cells

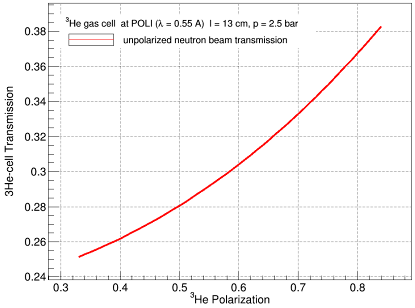


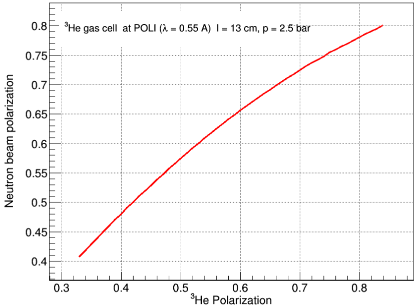


Gas pressure $\sim$ 2.5 bar

Neutron polarization

$$T = T_0 \cdot e^{-\eta} \cdot cosh(\eta P_{He}) \quad P = tanh(\eta P_{He})$$

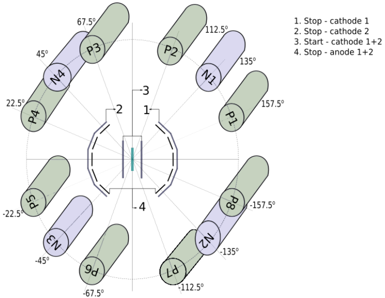




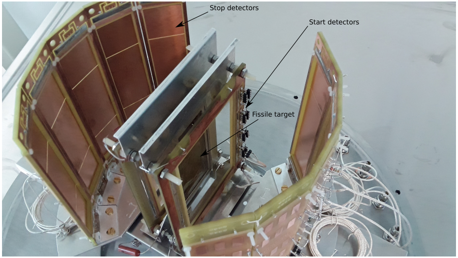
Dependence of the transmission and the degree of polarization of neutrons on the degree of polarization of the ^3He.

Relaxation time was about 40 hours, therefore both cells were replaced every 24 hours.

Fission chamber



Layout of the experimental facility. View from the beam direction.



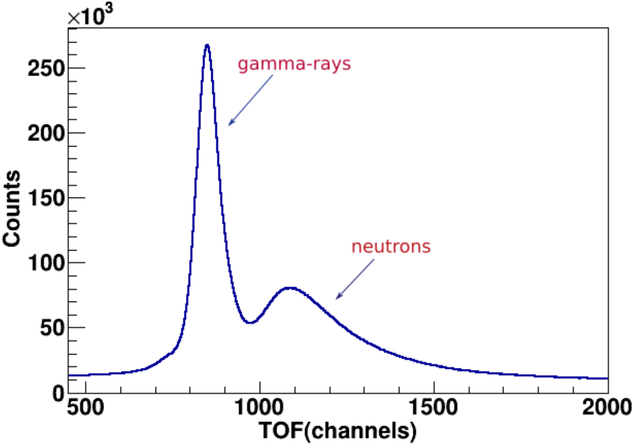
Low-pressure position sensitive multi-wire proportional counters

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

target $\rightarrow$ 82 mg of $^{235}U(99.99\%)$

Detectors of γ-rays and neutrons

- 8 cylindrical plastic scintillators at angles $\pm 22.5, \pm 67.5, \pm 112.5, \pm 157.5$
- 4 NaI scintillators at angles $\pm 45, \pm 135$



Time-of-flight spectrum from one of the plastic detectors.

Results

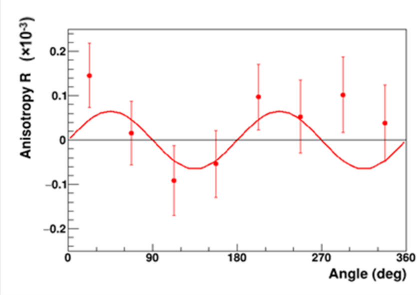
Count rates asymmetry

$$R(\theta) = \frac{N_+(\theta) - N_-(\theta)}{N_+(\theta) + N_-(\theta)}$$

The angular dependence in the first approximation can be fitted by the function

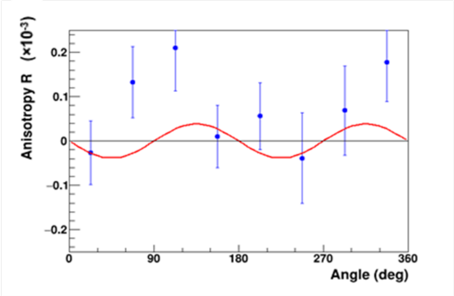
$$F = A \cdot sin(2\theta)$$

$\gamma - rays$



Average value: $(-6.5 \pm 3.9) \cdot 10^{-5}$

neutrons



Average value: $(+3.8 \pm 4.1) \cdot 10^{-5}$

Summary and outlook

- The ROT-effect has been measured for the first time in the lowest resonance of ^{235}U (0.3 eV).
- For gamma-rays, the value of the ROT effect differs from zero at the level of 2σ, for neutrons no statistically significant effect in the limits of errors was observed.
- In this year a new experiment is planned, for the 1.14 eV resonance where the effect should be larger than for cold neutrons and where practically only the J=4 spin state is present.

Thank you for your attention!!!