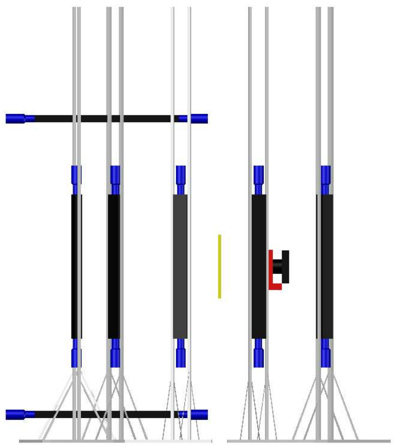
Angular correlation (n', γ) in reaction of neutron's inelastic scattering on ^{12}C

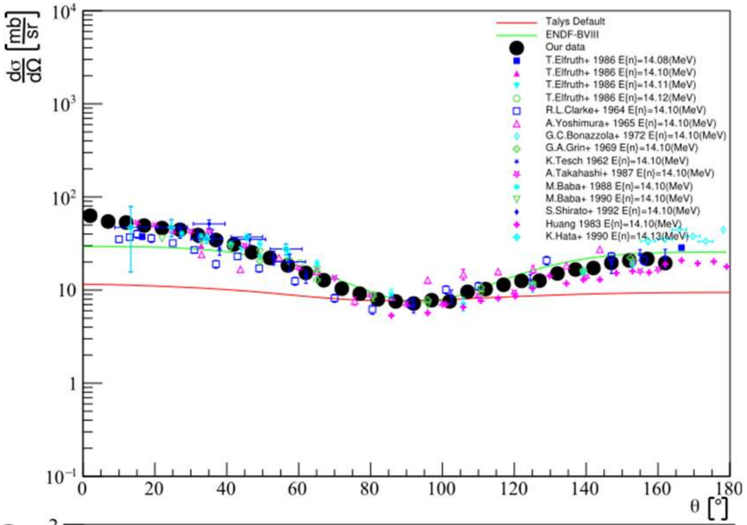


P.G. Filonchik, A.L. Barabanov and TANGRA collaboration

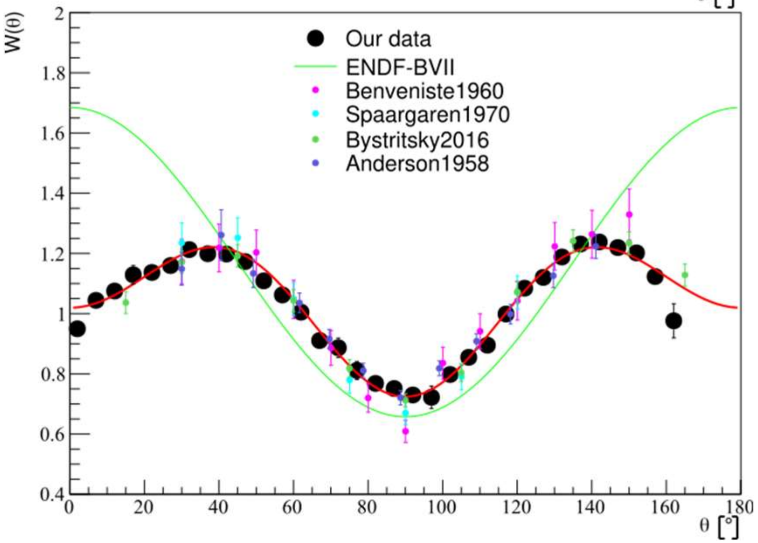
Outline

1. Motivations of studying (n', γ)-correlations
2. Previous experiment
3. New experiment
    1. Setup
    2. Calibration
    3. Experiment
    4. Theory
    5. Comparison with other works
4. Plans

Types of angular correlations



Anysotropy of neutron inelastic scattering from 1st level of ^{12}C.



Anisotropy of γ with energy 4,43 MeV in result of neutron inelastic scattering on ^{12}C

Kelly at al. 2021

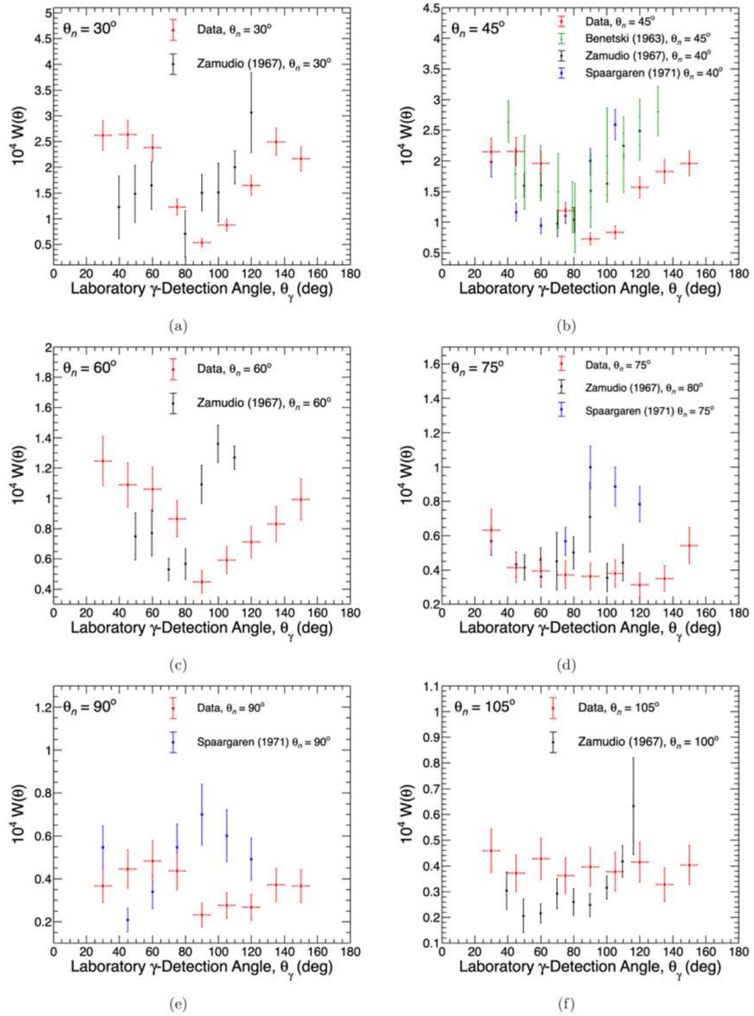
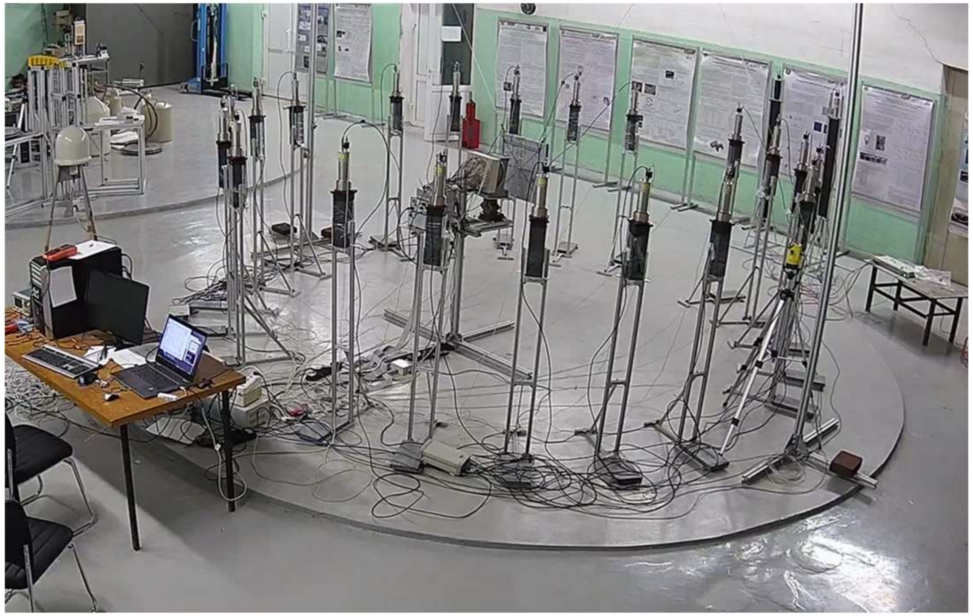


FIG. 12. The results for the normalized correlated n-γ distribution data at $E_\alpha \approx 14$ MeV as γ distributions compared to the available literature data for (a) $\theta_n = 30^\circ$, (b) $\theta_n = 45^\circ$, (c) $\theta_n = 60^\circ$, (d) $\theta_n = 75^\circ$, (e) $\theta_n = 90^\circ$, and (f) $\theta_n = 105^\circ$. The literature data on these plots are scaled to the present results.

Neutron inelastic scattering on ^{12}C

TAgged Neutrons and Gamma Rays (TANGRA)

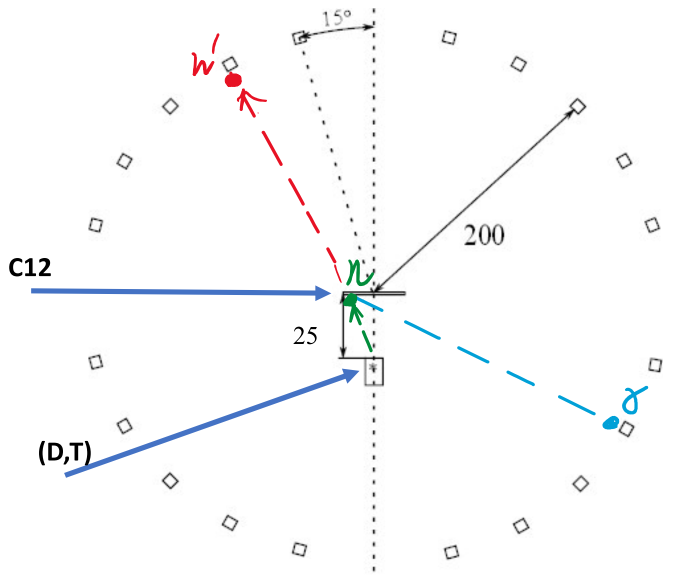
2022-2023

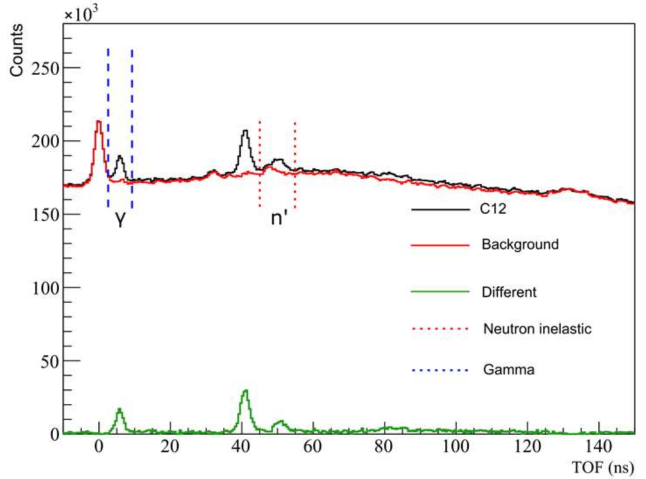


Experimental setup

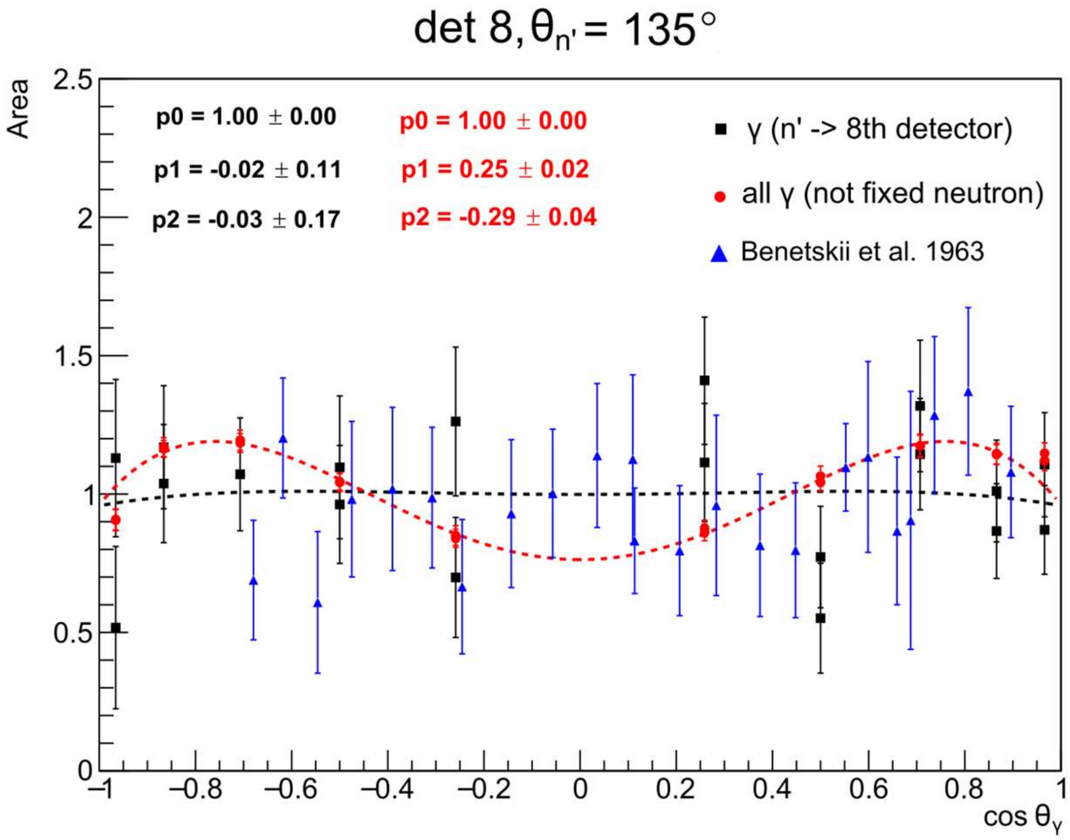
20 detectors around carbon target

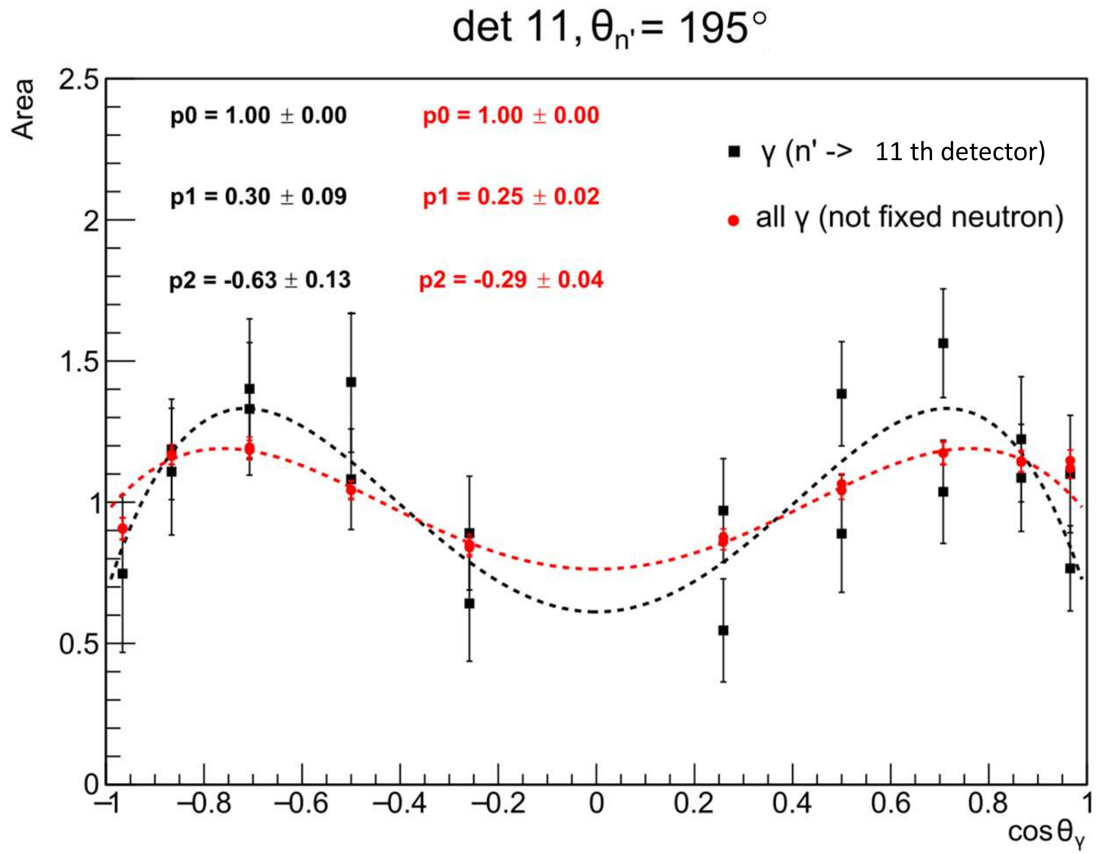
Angular correlations (n', γ)





(n', γ)-correlations



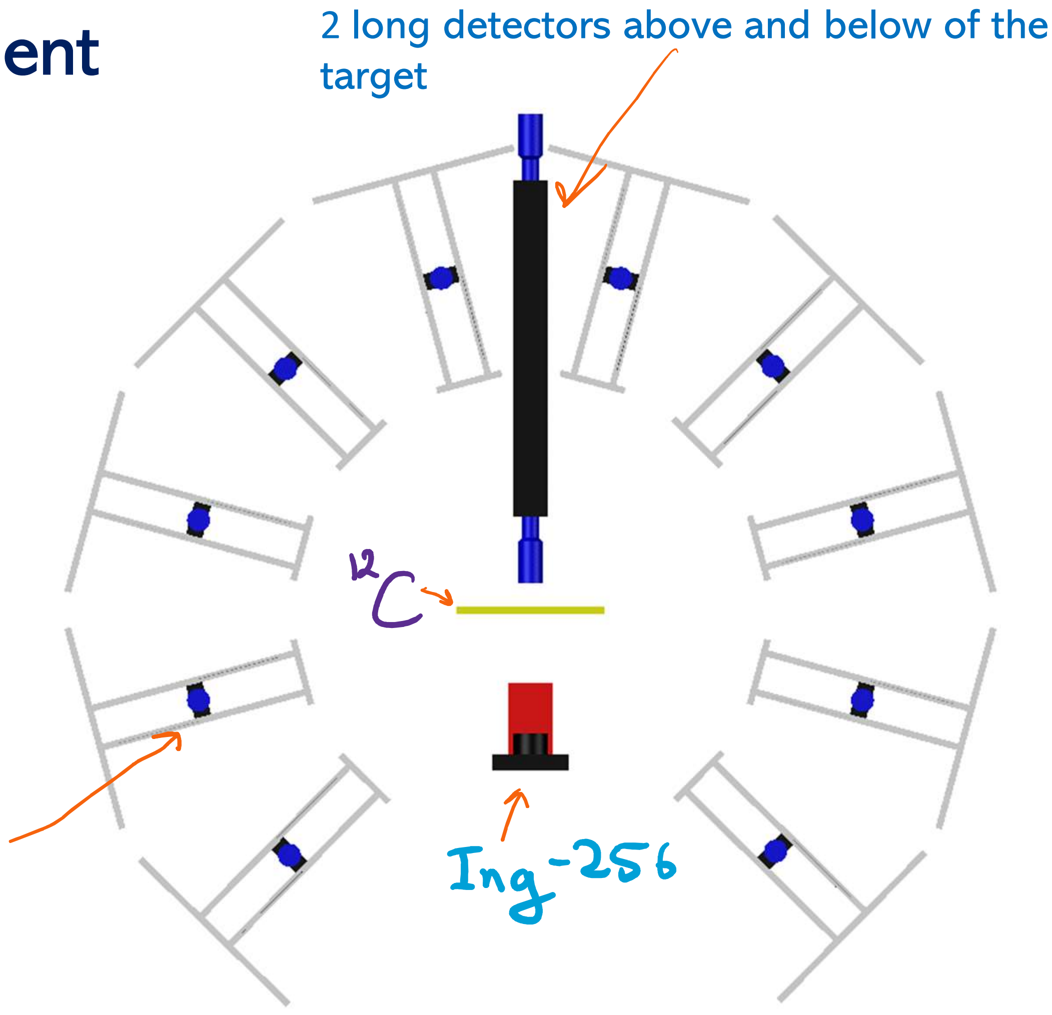


Conclusions from previous experiment

- Received statistics are not enough.
- It needs make new experiment with compacter geometry.

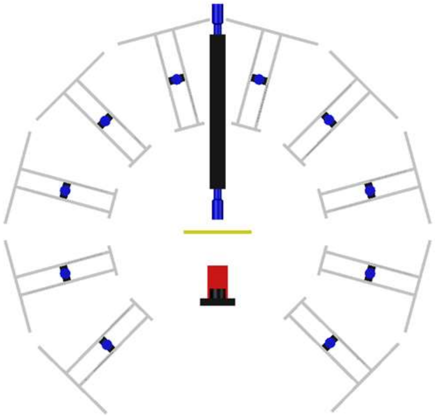
New experiment

- 10 long (1 m) plastic scintillator detectors with 2 PMT made by EPIC CRYSTALL
- Detectors are placed at angles from 15° with step 30° (max 135°)
- **2** long detectors above and below of target

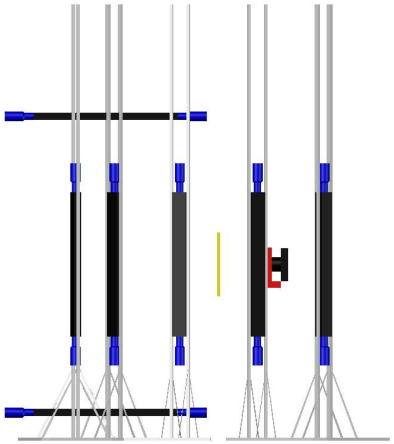


New experimental setup

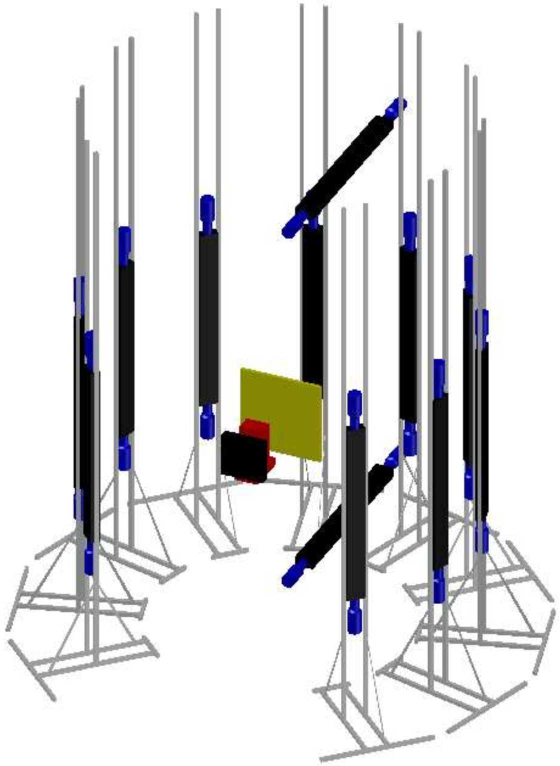
New experimental setup for studying (n', γ)-correlations

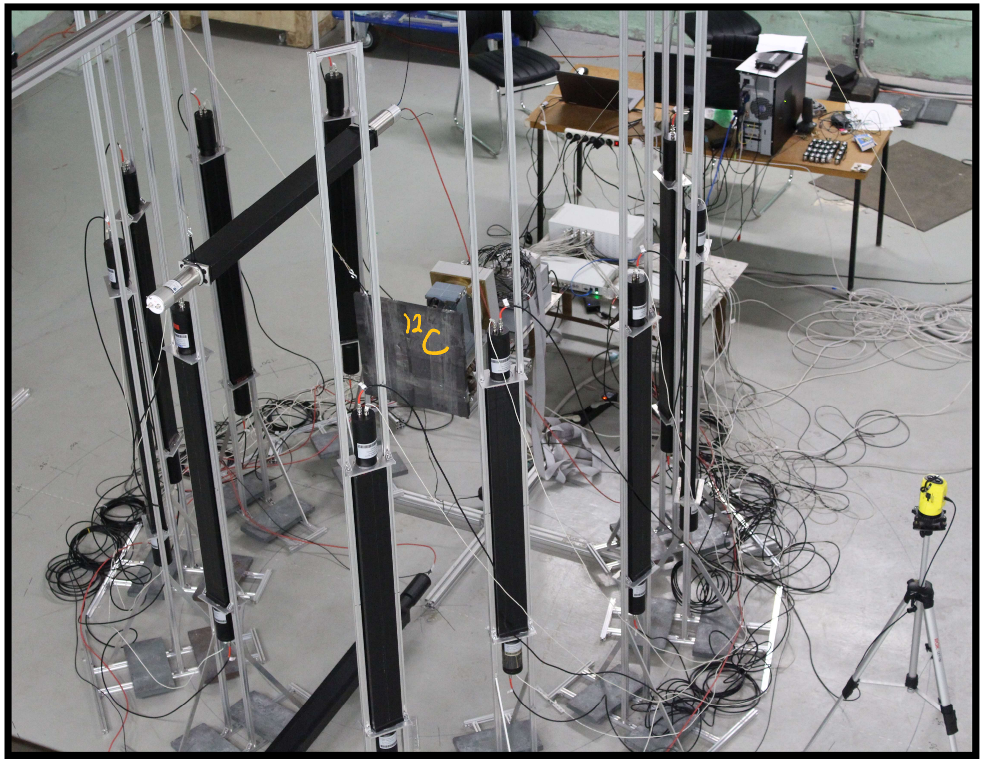


Вид сверху



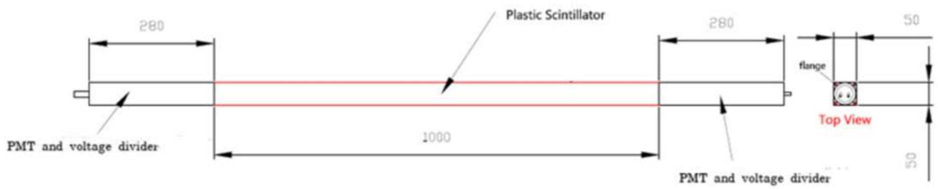
Вид сбоку

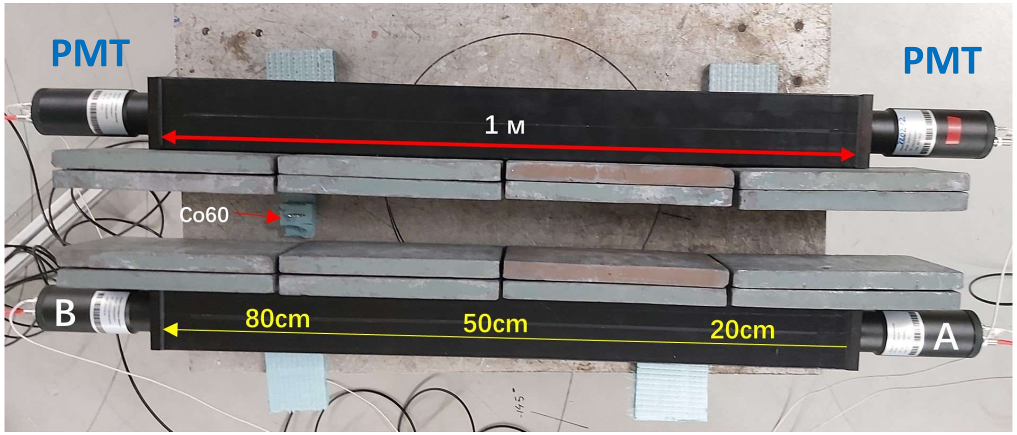


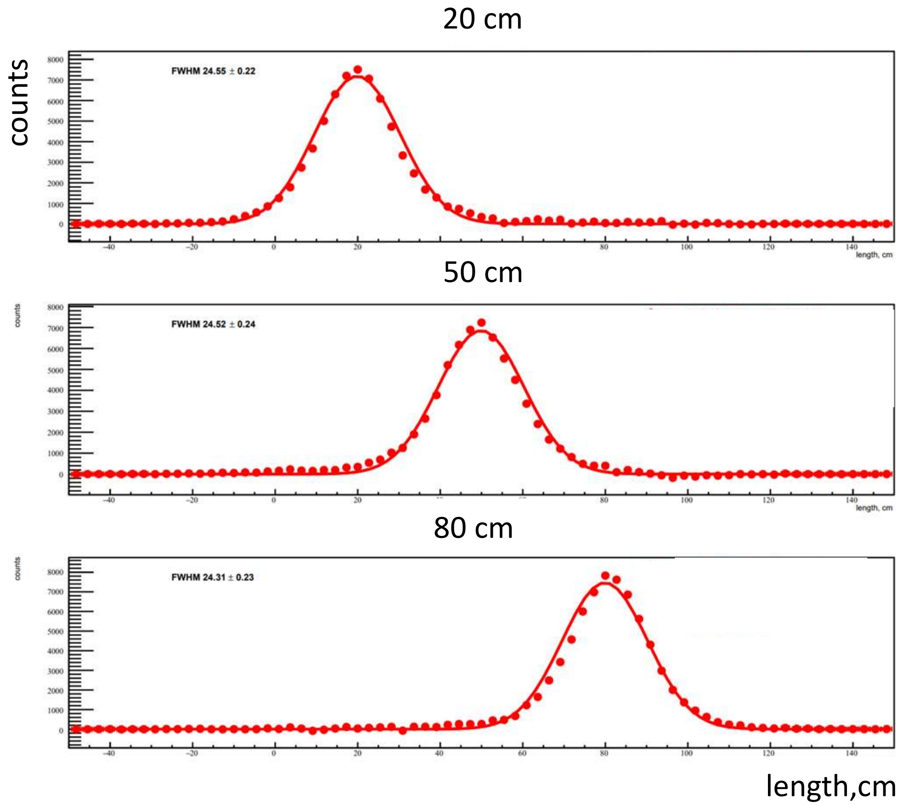


Measurements of detectors' characteristics

Long scintillation detectors Epic CRYSTAL





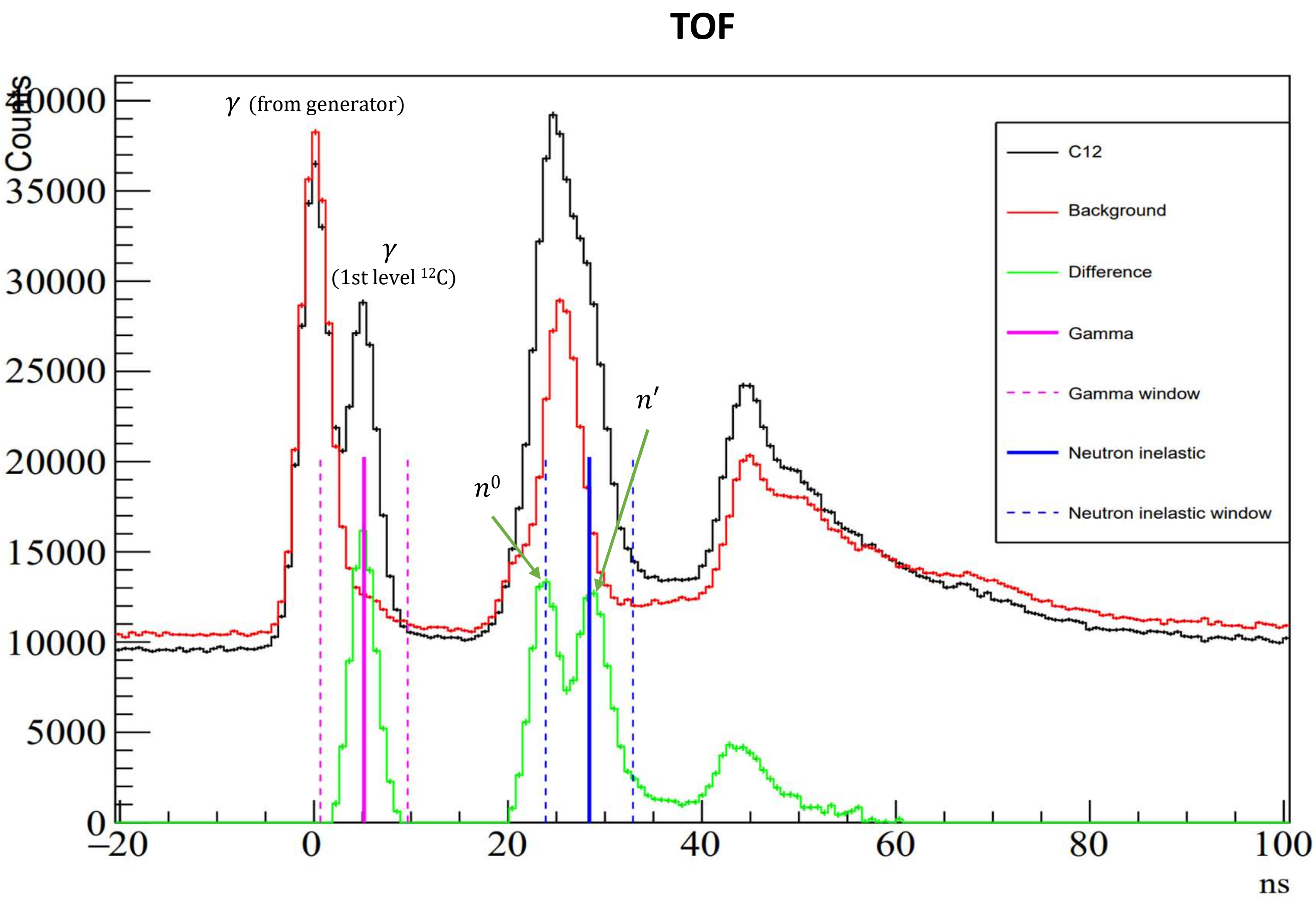


Calibration of detectors

Length resolution – 23,7 cm

Data processing

Around 50 hours of measurements



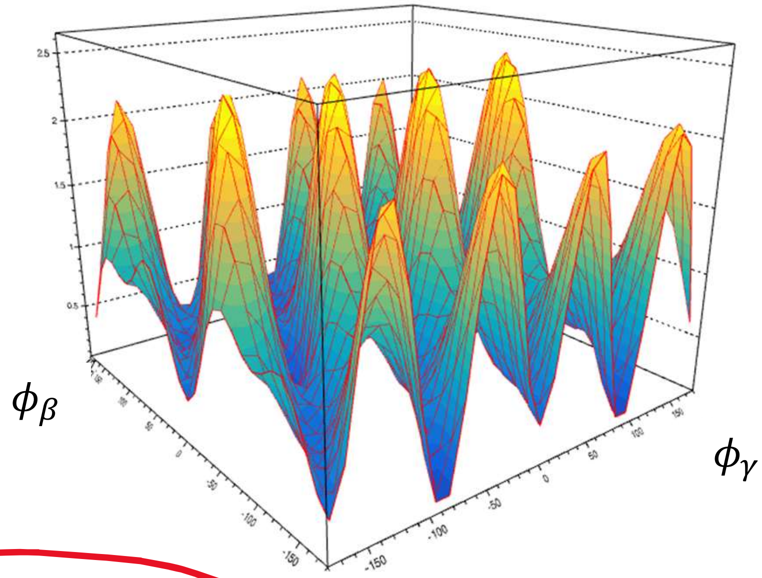
Formula of (n', γ)-correlations

together with Barabanov A.L.

Differential probability of gamma-quanta emission dependence on inelastic scattered neutron direction

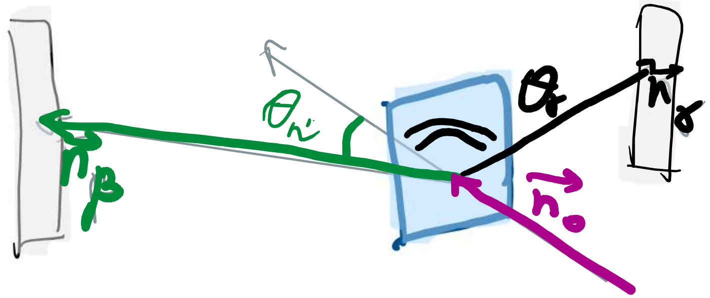
$$dw(\vec{n}_\beta, \vec{n}_\gamma) = A \sum_{Q=0,2,4,\ldots} \sum_{\Lambda\Lambda'} D^{\Lambda}_{\Lambda' Q}\, \phi^{\Lambda}_{\Lambda' Q}(\vec{n}_k, \vec{n}_\beta, \vec{n}_\gamma)\, d\Omega_\beta d\Omega_\gamma$$

$$A = \frac{\omega\, a_L(e)^2}{2\hbar c^3 k_\alpha k_\beta r_\beta^2} \frac{m_\beta}{m_\alpha},$$

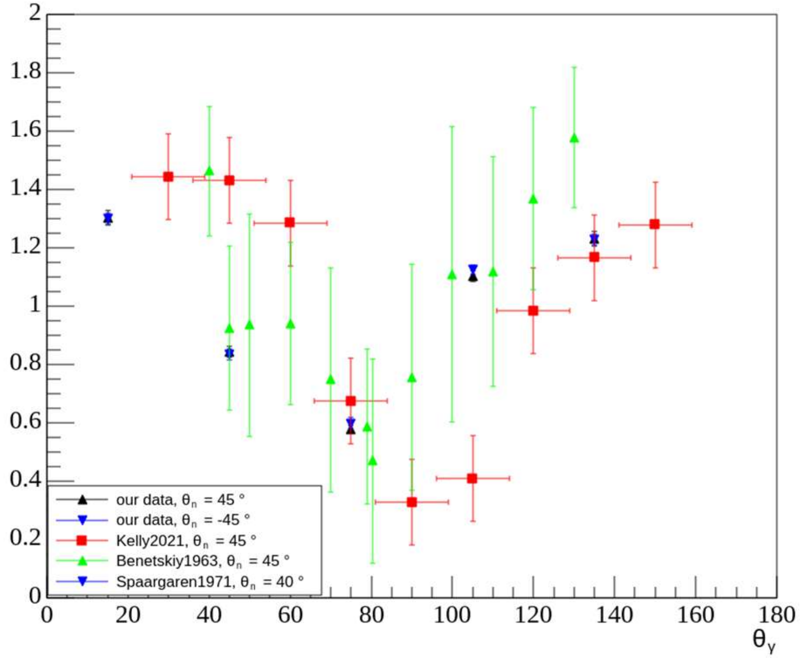


$$D^{\Lambda}_{\Lambda' Q} = \sqrt{2Q+1}\, C^{L1}_{L1Q0}\, U(I_f I_i L Q, L I_i) \sqrt{(2I_i+1)(2\Lambda'+1)} \times$$
$$\sum_{JJ'} g_{J'} \sum_{l_\alpha l'_\alpha j_\alpha j'_\alpha l_\beta l'_\beta j_\beta j'_\beta} S_J(l_\alpha j_\alpha \to l_\beta j_\beta)\, S^*_{J'}(l'_\alpha j'_\alpha \to l'_\beta j'_\beta) \sqrt{(2J+1)(2j'_\beta+1)} \times$$
$$C^{l_\alpha 0}_{l'_\alpha 0 \Lambda 0} C^{l_\beta 0}_{l'_\beta 0 \Lambda' 0}\, U(s j'_\alpha l_\alpha \Lambda, l'_\alpha j_\alpha)\, U(I_\alpha J' j_\alpha \Lambda, j'_\alpha J)\, U(s j'_\beta l_\beta \Lambda', l'_\beta j_\beta) \begin{Bmatrix} J & j_\beta & I_i \\ J' & j'_\beta & I_i \\ \Lambda & \Lambda' & Q \end{Bmatrix}.$$

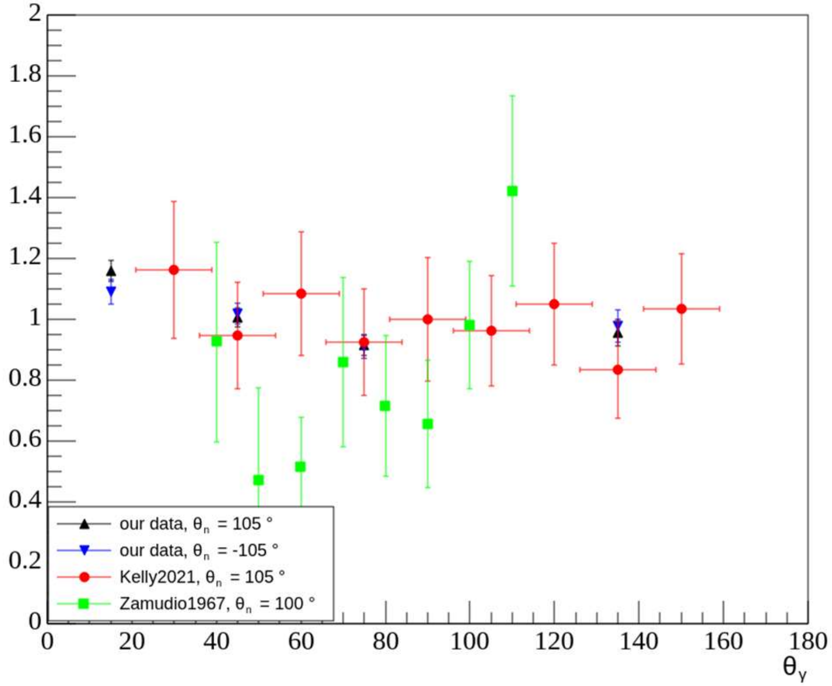
S-matrix coefficients from TALYS



Comparison (n', γ) - correlations with other data



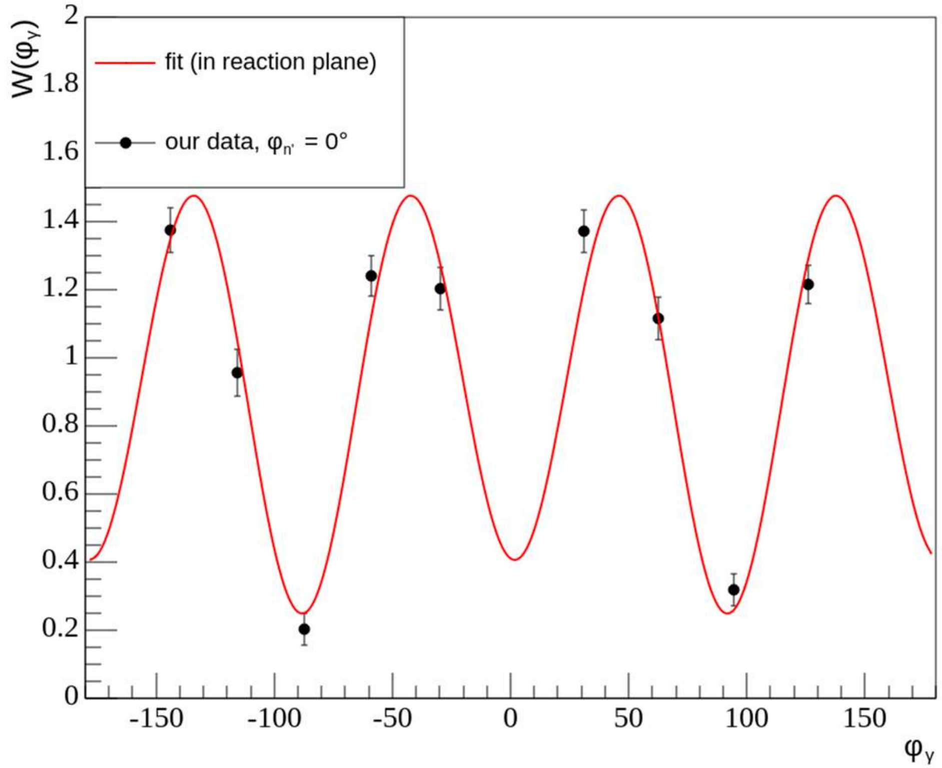
$\theta_{n'} = 45°$

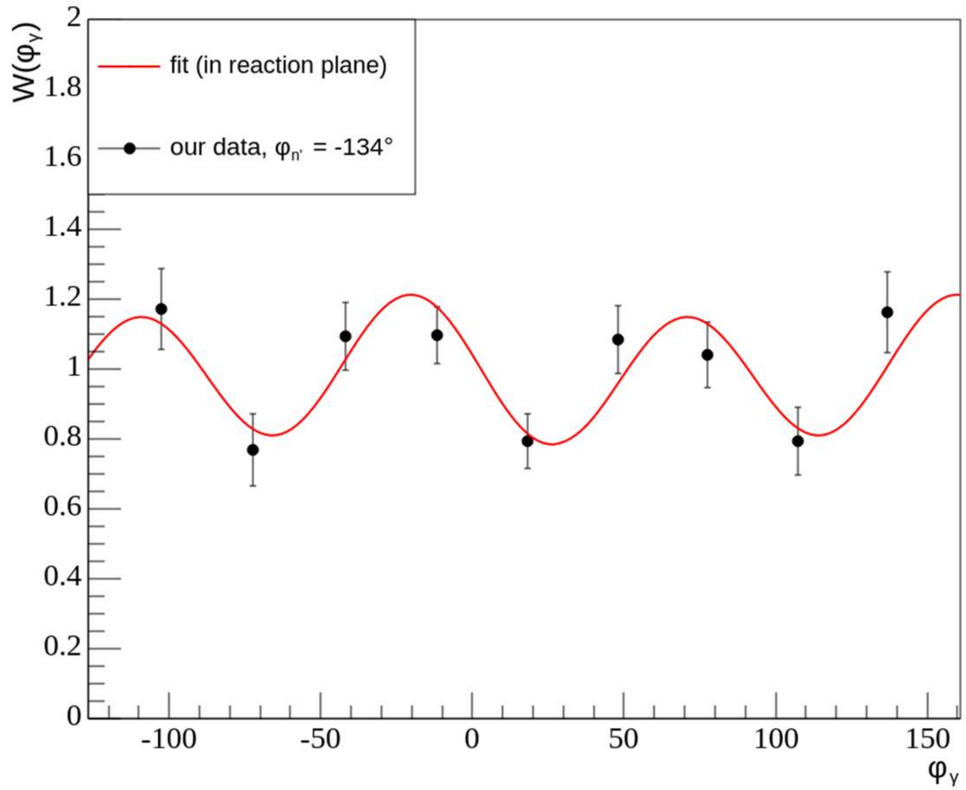


$\theta_{n'} = 105°$

Comparison with theoretical calculations

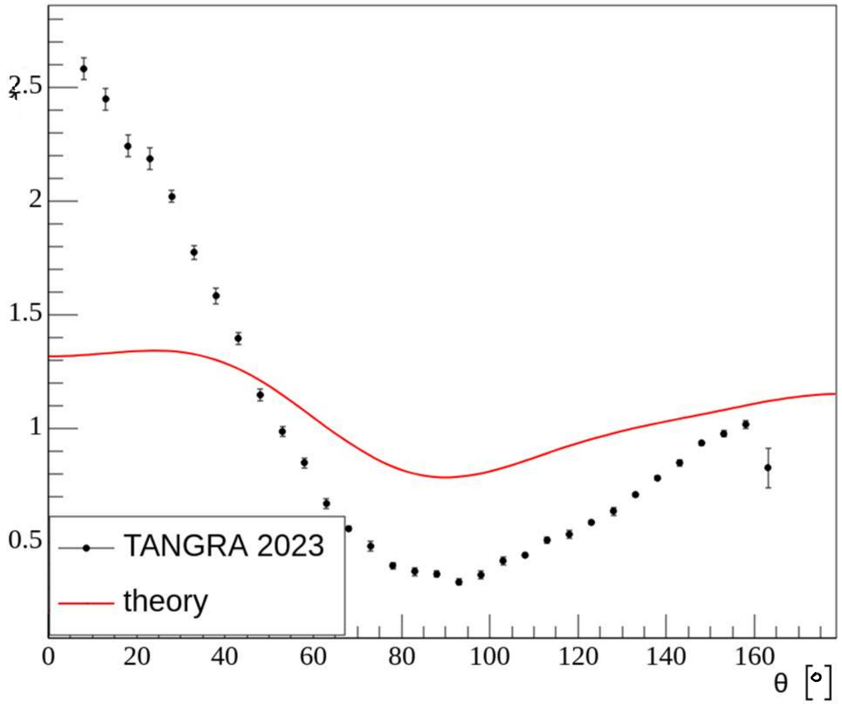
$$dw(\vec{n}_\beta, \vec{n}_\gamma) = A \sum_{Q=0,2,4,\dots} \sum_{\Lambda\Lambda'} D^{\Lambda}_{\Lambda' Q}\, \phi^{\Lambda}_{\Lambda' Q}(\vec{n}_k, \vec{n}_\beta, \vec{n}_\gamma)\, d\Omega_\beta d\Omega_\gamma$$

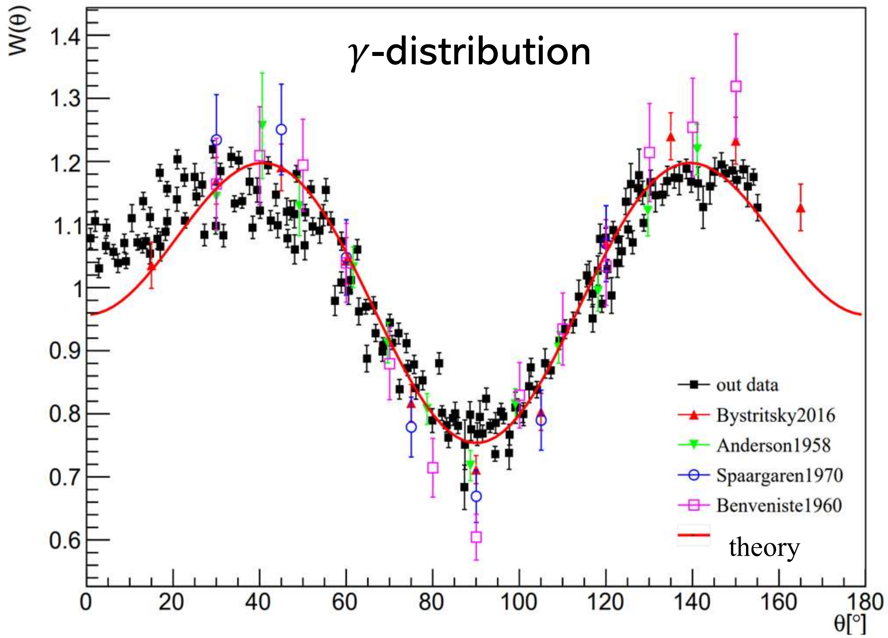




Comparison of experimental angular distribution with theoretical calculations

Angular distribution of inelastic scattered neutron from En = 4,44MeV





$$W(\theta) = 1 + \sum_{l=2,4,\ldots}^{2J} a_l P_l(\cos\theta)$$

Work	a_2	a_4
Theory	$0,26$	$-0,30$
Bystritsky	$0,34 \pm 0,02$	$-0,33 \pm -0,02$
Anderson	$0,29 \pm 0,02$	$-0,28 \pm 0,02$
Benvensite	$0,37 \pm 0,05$	$-0,39 \pm 0,07$
Spaargaren	$0,39 \pm 0,01$	$-0,37 \pm 0,01$

Plans

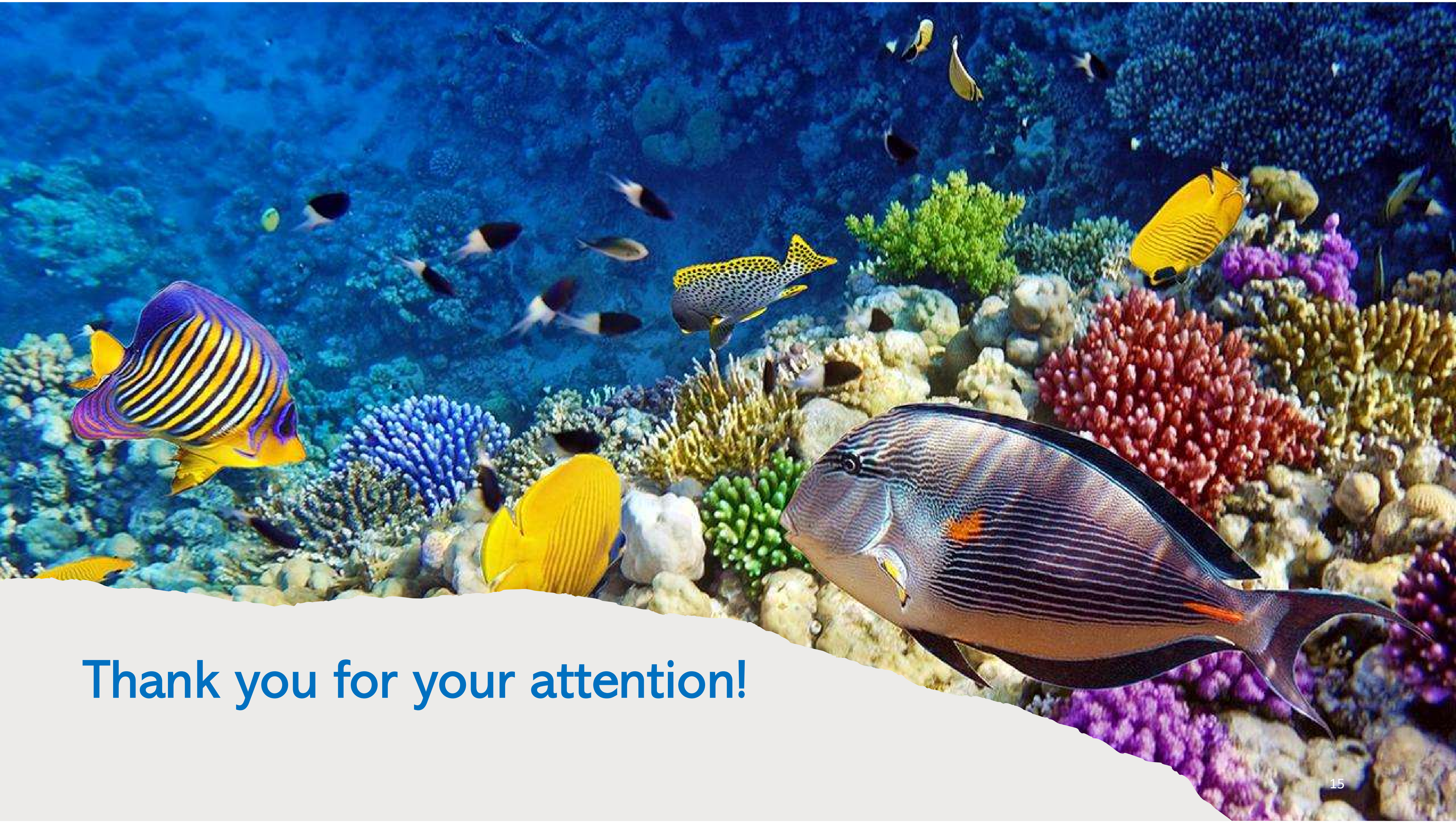
Use of spatial resolution of detectors.

To calculate errors of angles.

To calculate differential cross-section of (n, γ)-correlations.

To find correct parameters for calculation of reaction by TALYS program.

Make correct comparison of our experimental data with other experiments and theoretical approach.



Thank you for your attention!

Literature

B.A. Benetskii, I.M. Frank. **Angular correlation between gamma rays and 14-MeV neutrons scattered inelastically by carbon.** Soviet Physics JETP, vol. 17, n. 2 (1963) p. 309

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N.A. Fedorov. **Studying of 14.1 MeV neutrons scattering on light nuclei. Master thesis.** MSU, Moscow, 2017.

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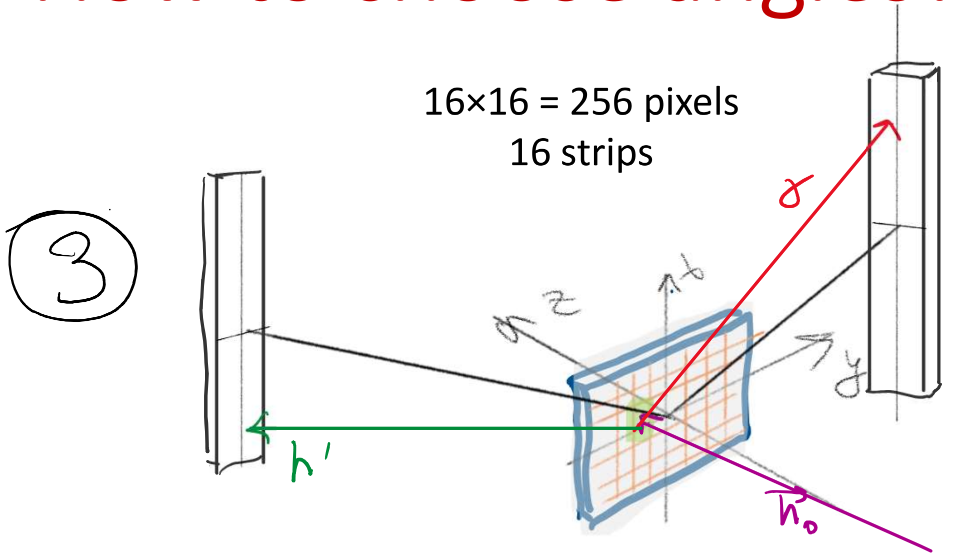
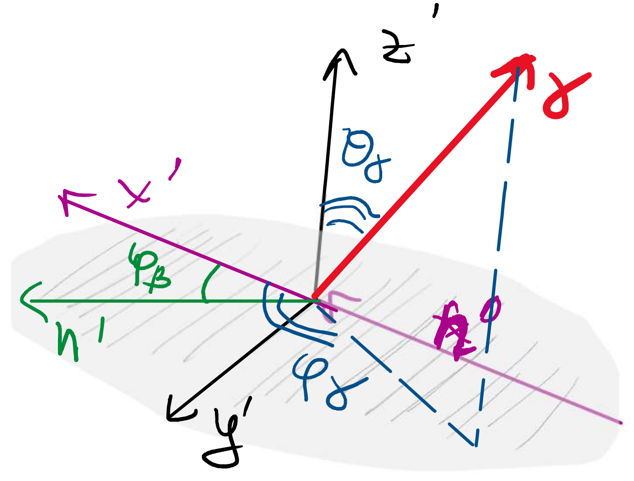
Kelly, K. J., Devlin, M., O’Donnell, J. M., & Bennett, E. A. (2021). Correlated n−γ angular distributions from the Q=4.4398 MeV C12(n,n′γ) reaction for incident neutron energies from 6.5 MeV to 16.5 MeV. *Physical Review. C, 104*(6).

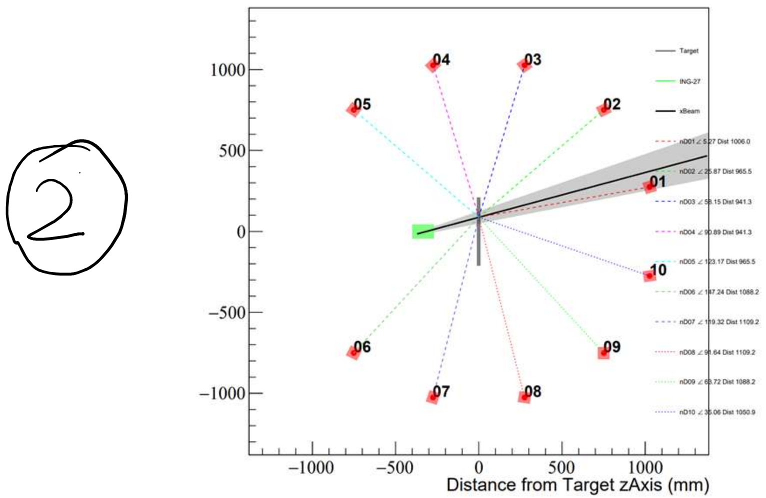
How to choose angles?

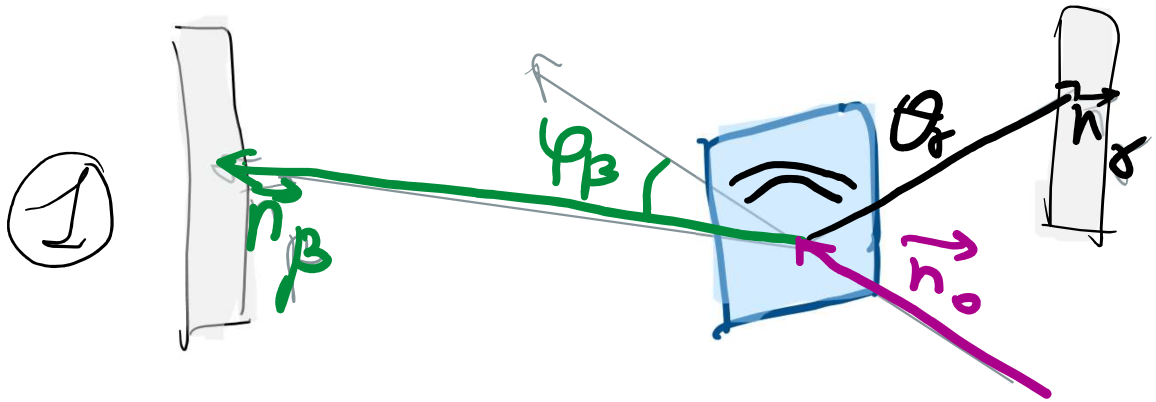




Plane of reaction

Top view of beams nX04





Comparison with theoretical calculations

$$dw(\vec{n}_\beta, \vec{n}_\gamma) = A \sum_{Q=0,2,4,\ldots} \sum_{\Lambda\Lambda'} D^{\Lambda}_{\Lambda' Q}\, \phi^{\Lambda}_{\Lambda' Q}(\vec{n}_k, \vec{n}_\beta, \vec{n}_\gamma)\, d\Omega_\beta d\Omega_\gamma$$