LXXV International conference
«Nucleus – 2025. Nuclear physics and elementary particle physics. Nuclear physics technologies.»

Compton suppressed γ-spectrometer based on $CeBr_3$-NaI(Tl) phoswich detector cluster

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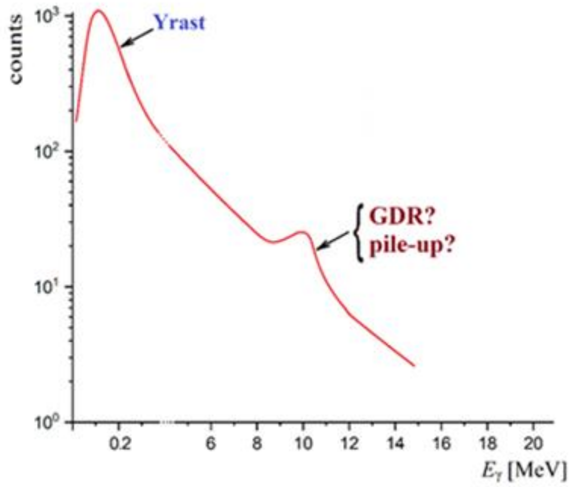
History and preconditions

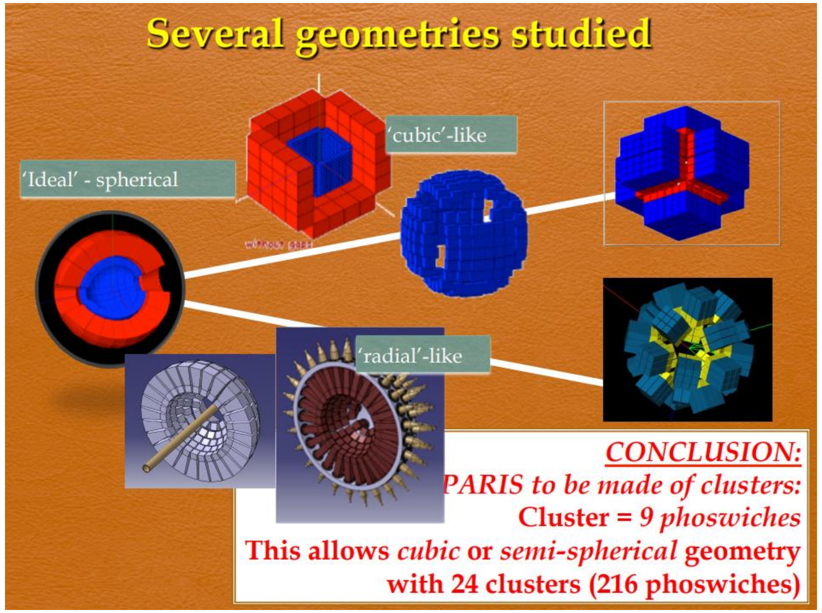


Giant dipole resonance (GDR) is a highly excited state of atomic nuclei involving a large number of nucleons.

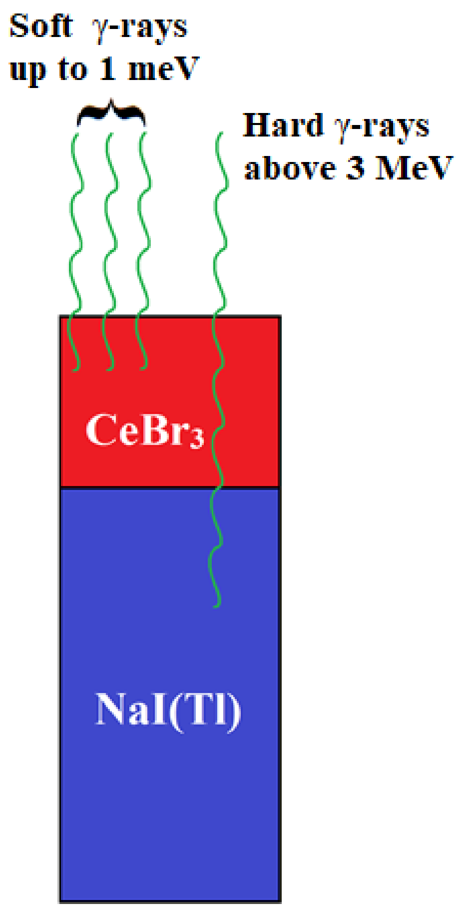
Direct γ-decay of GDR in reactions is accompanied by a γ-cascade with a high multiplicity M_γ value.

Pile-up effect

Solution



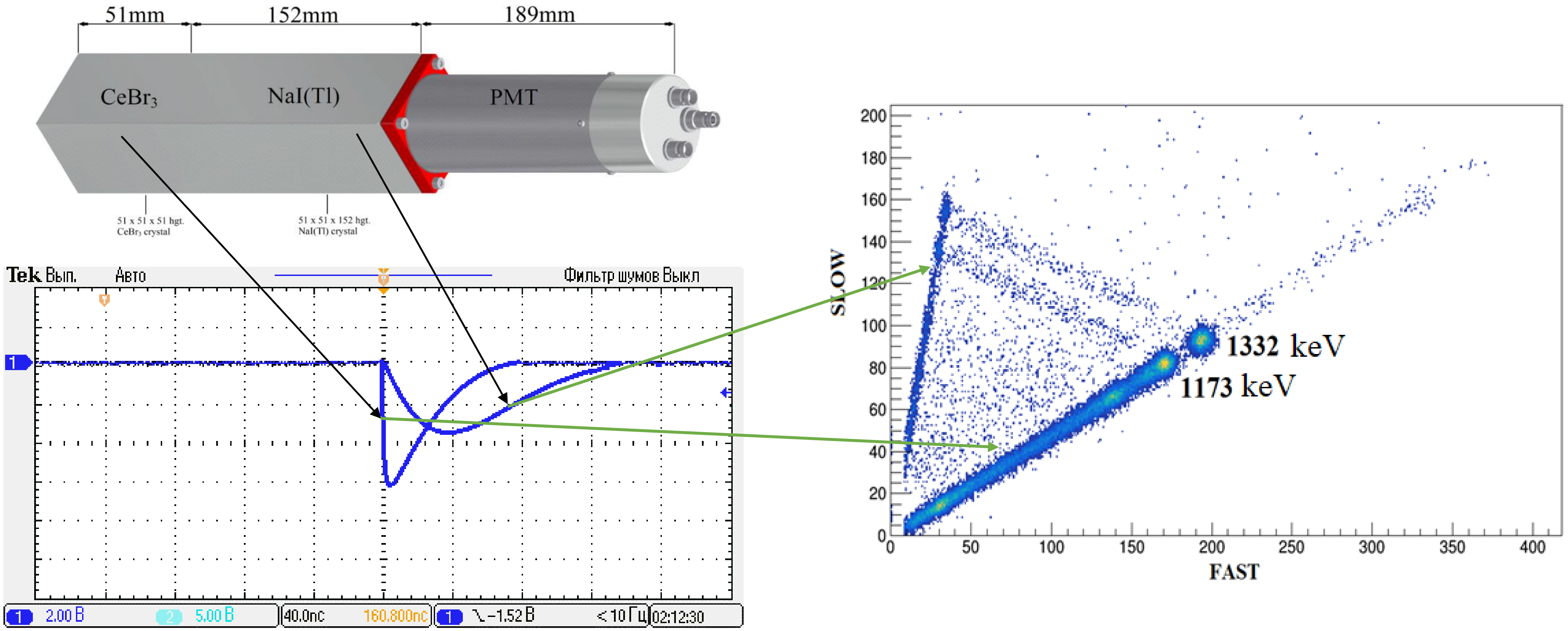
[1]. Maj A. et al. The PARIS project



The phoswich detector technique allows avoiding the pile-up effect by separating the γ-quanta along their absorption length in the detector material.

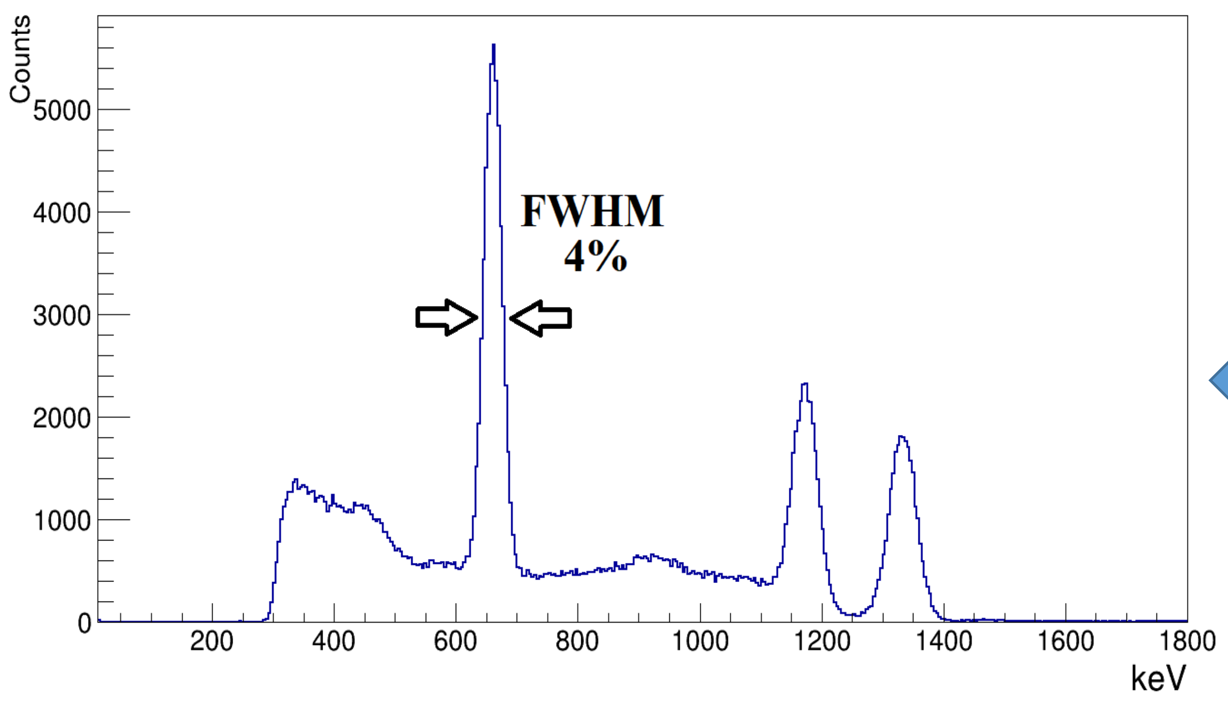
CeBr$_3$-NaI(Tl) phoswich-detector

developed and optimized for high-energy γ-ray (GDR, PDR) detection in the PARIS collaboration[2] as a high-efficiency γ-ray detector

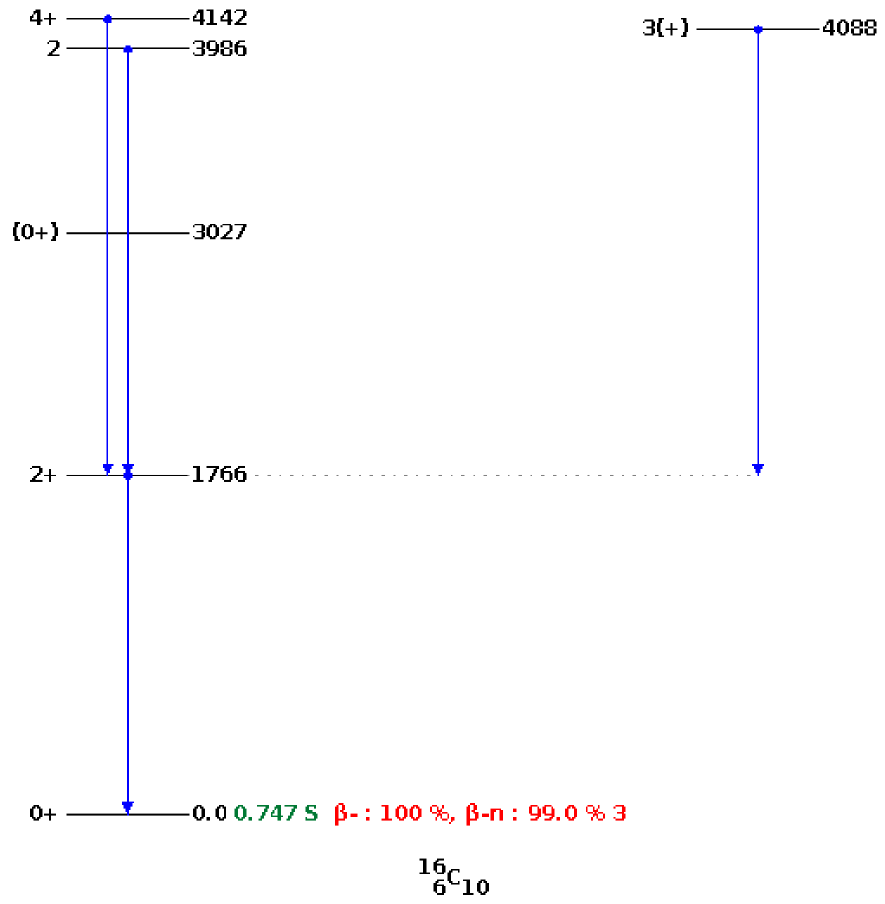


[2]. Maj A. et al. The PARIS project.

Peculiarities of γ-ray emission in reactions with light nuclei



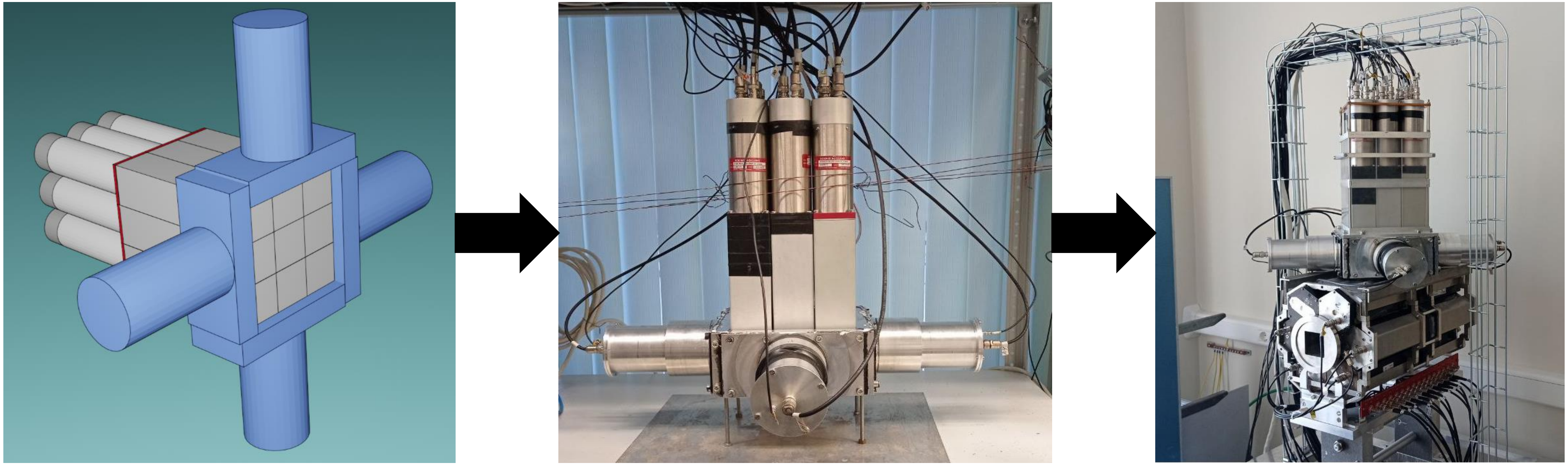
Energy resolution of $CeBr_3$:
~4% for 662 keV (^{137}Cs)



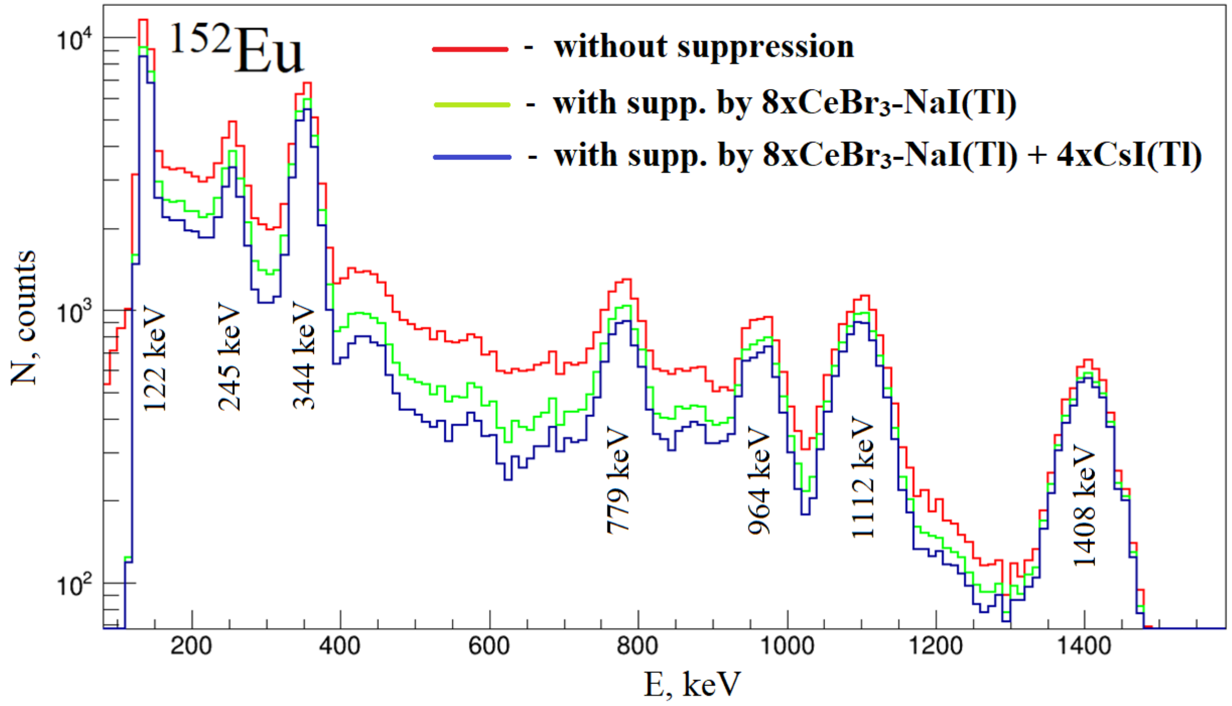
Main idea

The spectrometer must have:

- High registration efficiency of total absorption peak (compared to HPGe) for solving γ-spectrometry problems.
- Energy resolution suitable for γ-spectrometry of reaction with light nuclei products.



Measurement of the suppression coefficient of the Compton part of the γ-spectrum of ^{152}Eu



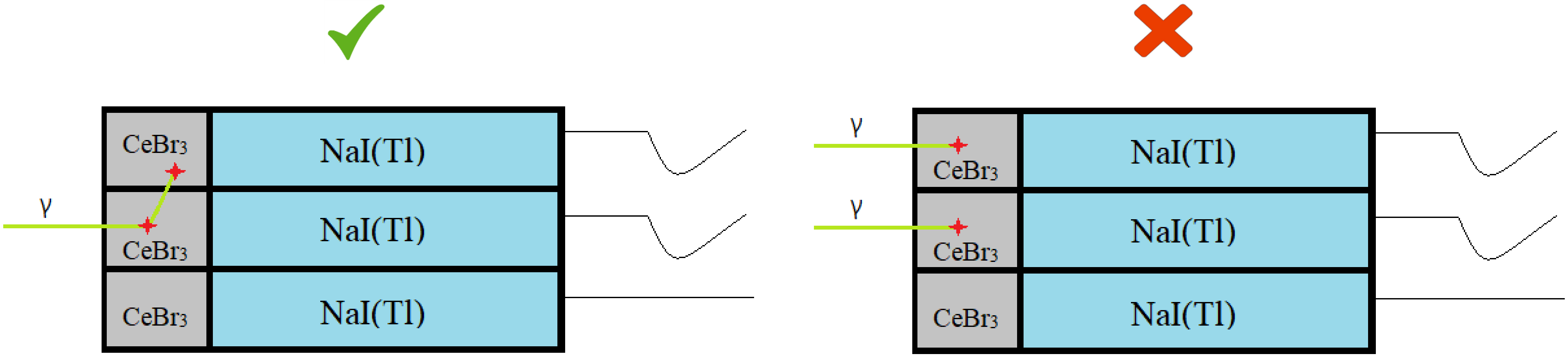
E_γ, keV	$(N_{peak}/N_{total})_{w/o\ AC}$	$(N_{peak}/N_{total})_{AC}$	CSF
245	0.0283	0.0363	1.282
344	0.0899	0.1261	1.402
779	0.0184	0.0256	1.391
964	0.0147	0.0214	1.455
1112	0.0258	0.0359	1.391
1408	0.0211	0.0302	1.431

$$CSF_{total} = \left(\frac{N_{peak}}{N_{total}}\right)_{w/o.AC} \Big/ \left(\frac{N_{peak}}{N_{total}}\right)_{AC},$$

where $\left(\frac{N_{peak}}{N_{total}}\right)_{w/o.AC}$ – the ratio of the number of events in the peak to the total number of events (total) without suppression,

$\left(\frac{N_{peak}}{N_{total}}\right)_{AC}$ – the ratio of the number of events in the peak to the total number of events (total) with suppression.

Chance coincidence loss

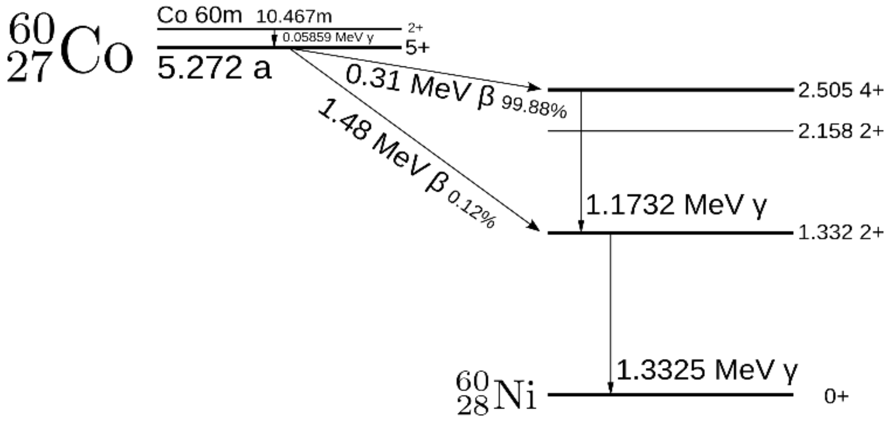


A problem of data (events) loss in the peaks of total absorption[3] due to:

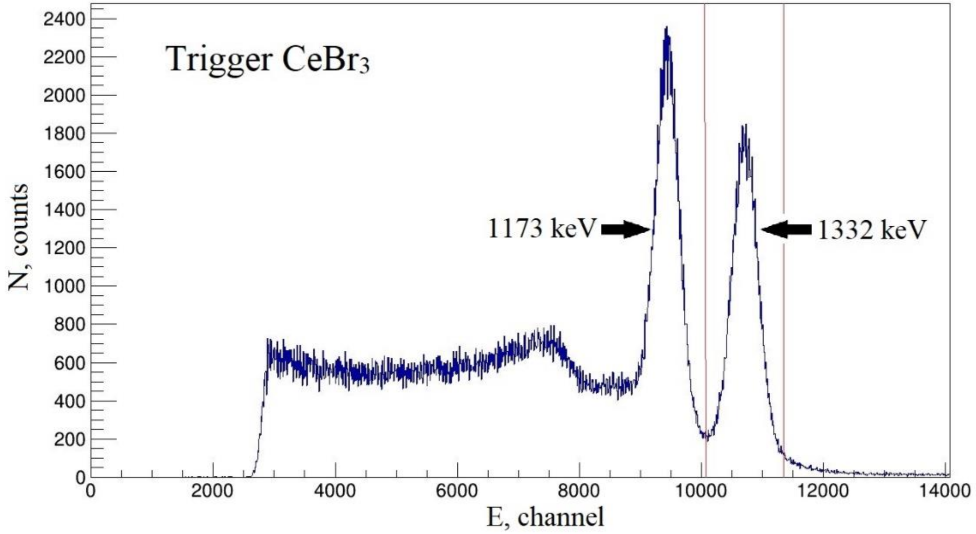
1. The presence of cascade transitions in the source.
2. High intensity of the radiation source.

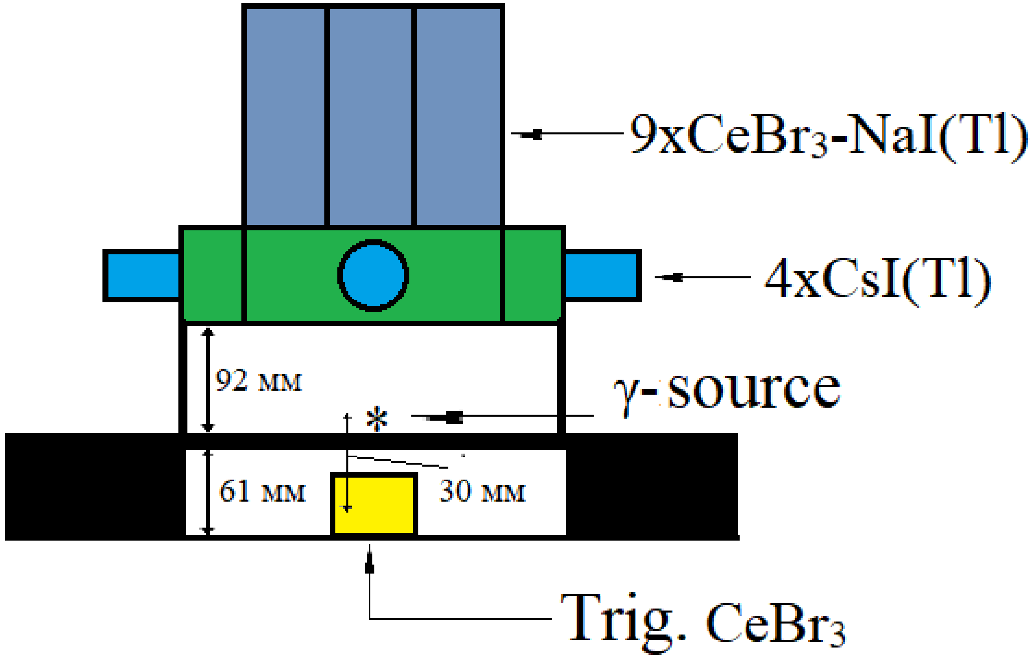
[3]. Westphal G. Journal of Radioanalytical and Nuclear Chemistry. – 1982. – T. 70. – №. 1-2. – C. 387-410.

Measurement of the suppression factor using the tagged particle method

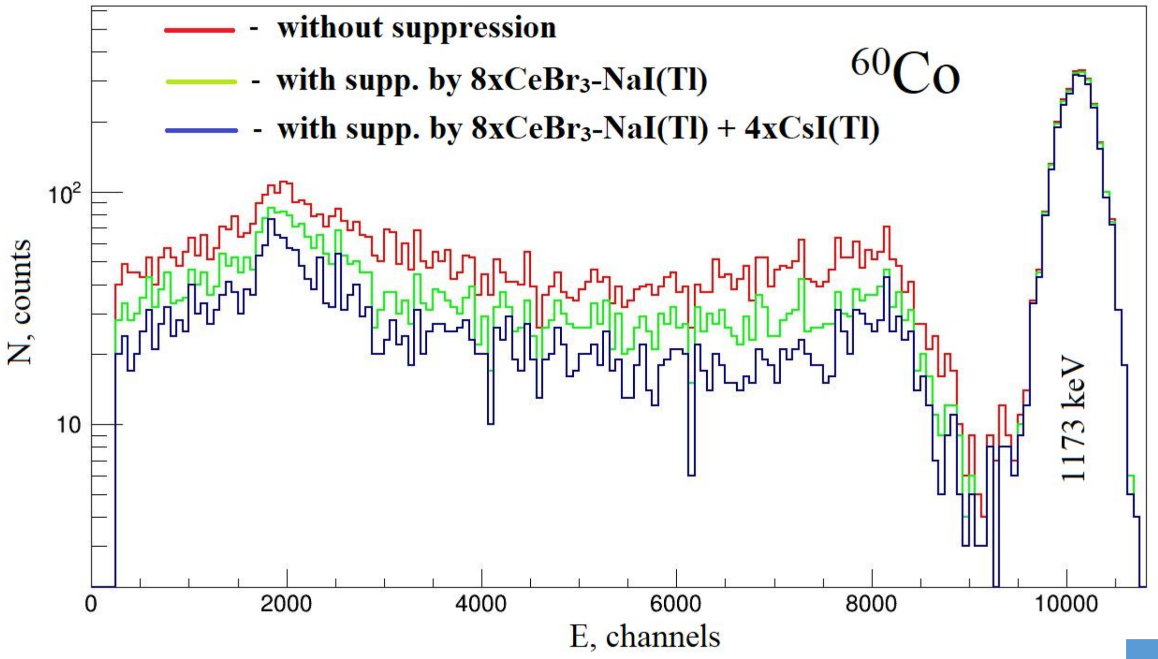


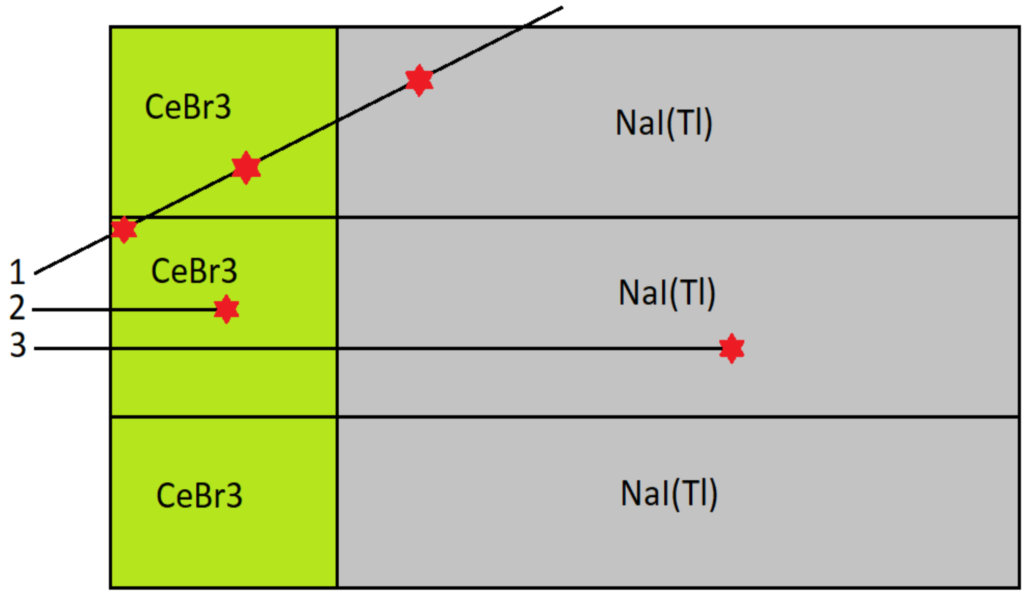
1. Cascade emission of two γ-quanta;
2. The tagged particle method was used to measure the absolute detection efficiency.





Measurement of the suppression coefficient of the Compton part of the γ-spectrum of ^{60}Co



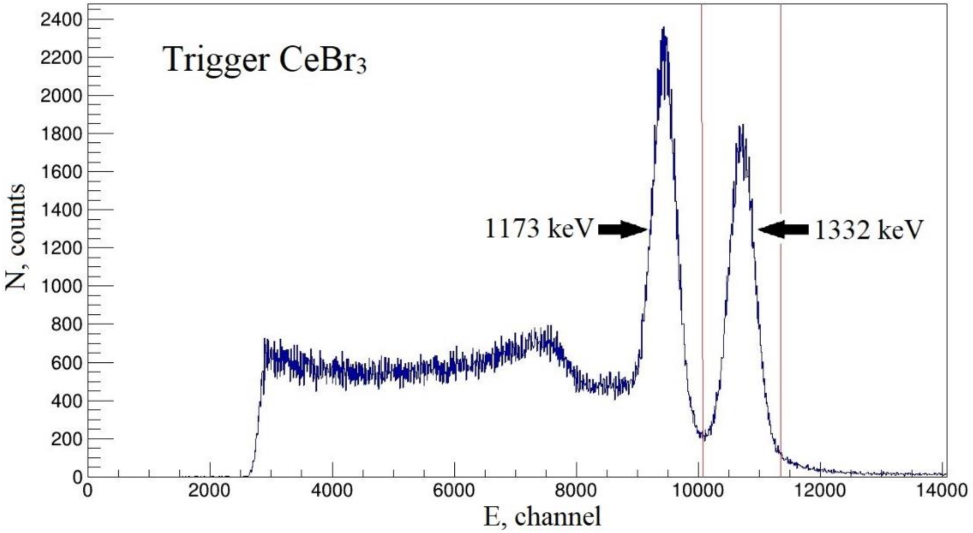


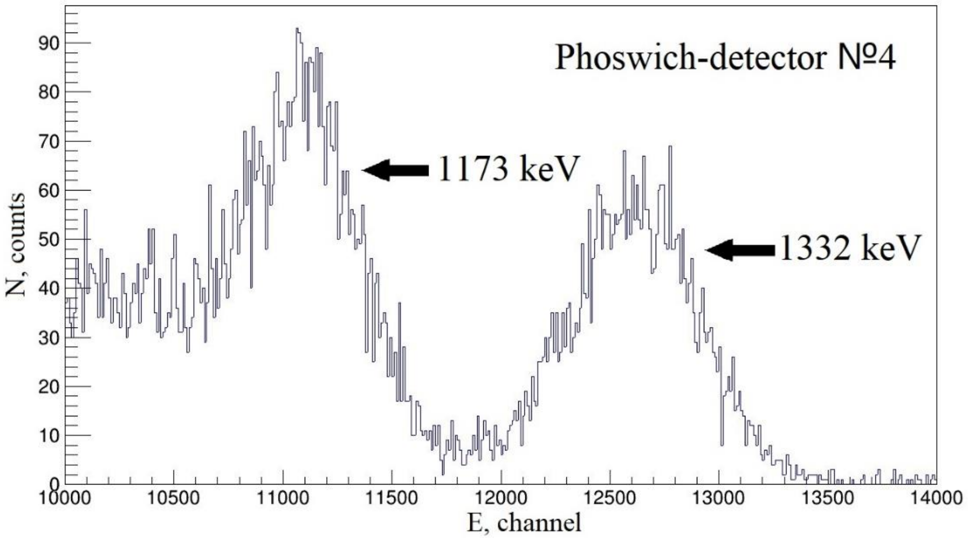
$$AC = \left(1 - \frac{N_{AC}}{N}\right) * 100\%,$$

where N - the number of events in the Compton region of the spectrum without suppression,
and N_{AC} - the number of events in the Compton region of the spectrum with suppression.

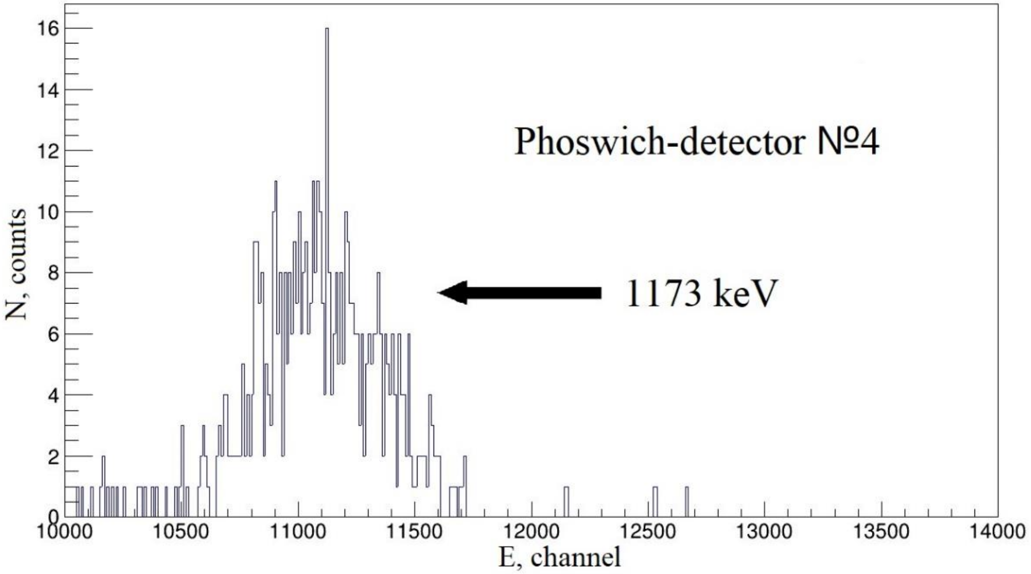
	N, counts	N_{AC}(Phos), counts	N_{AC}(Phos+CsI), counts	AC (Phos),%	AC (Phos+CsI) ,%
Phoswich №1	7774	5365	4123	30,987	46,964

Measurement of absolute γ-peak detection efficiency for E_γ=1173 keV





The tagged particle method was used to measure the absolute detection efficiency.



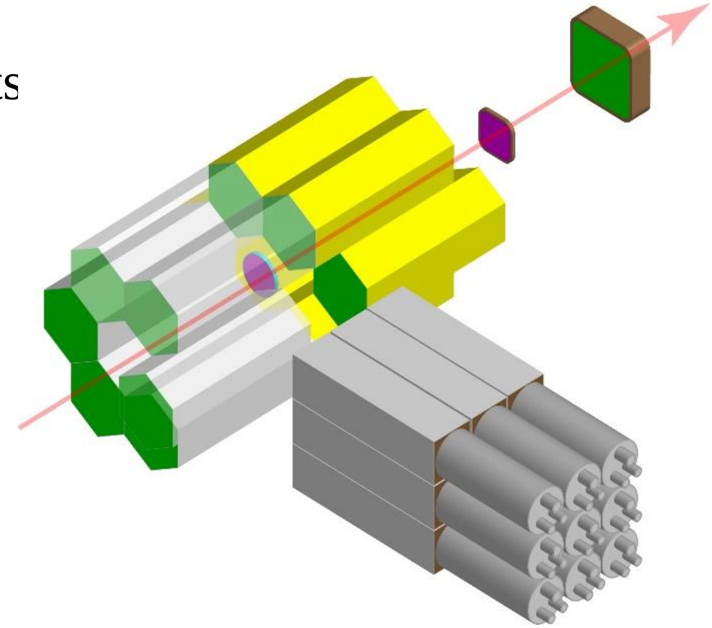
Σ_ε~ 21.9%

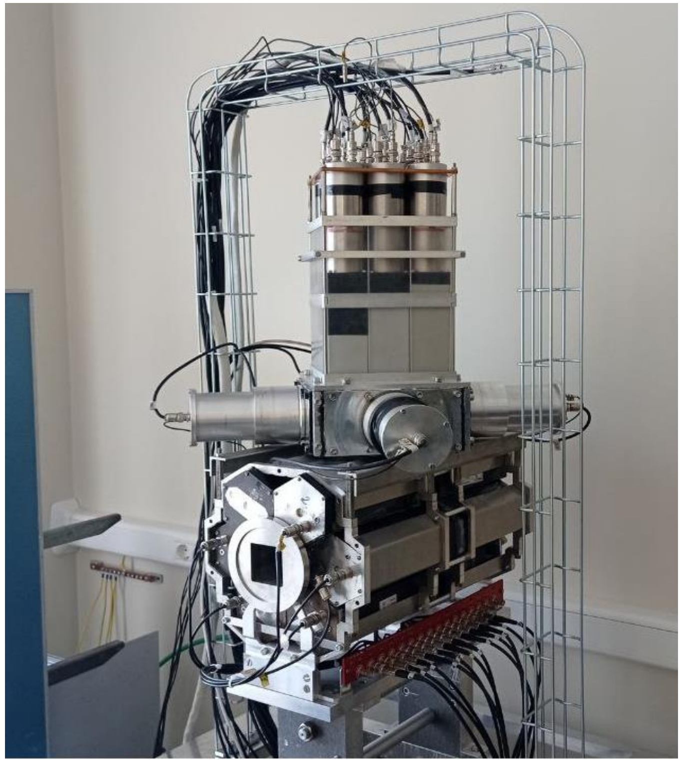
Future Applications

The developed spectrometer will be integrated into the MULTI setup[4], enabling the detection of reaction products involving light neutron-rich nuclei.

Key Objectives of the Anti-Compton Spectrometer:

- Detection of low-energy γ-rays (from nuclear de-excitation).
- Suppression of Compton scattered events from γ-rays.
- The registration of fast neutrons with energies comparable to the beam energy, measured using the time-of-flight (ToF) method.





[4]. Siváček I. et al. //Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. – 2020. – T. 976. – C. 164255

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Thank you for your attention!

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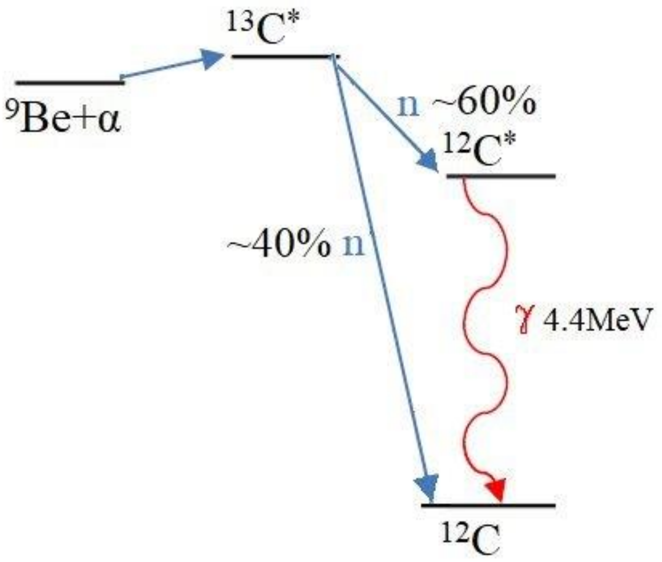
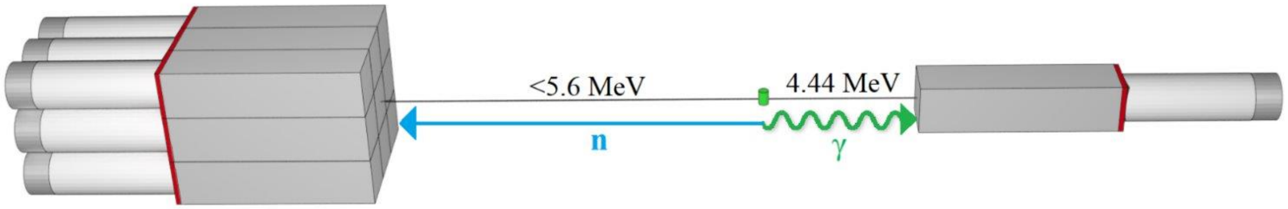
Tagged Neutron Method

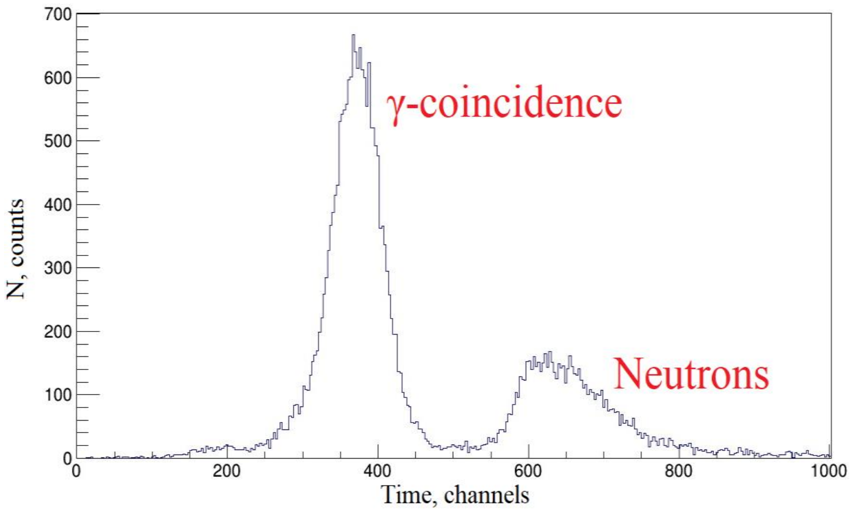
- Since the detector lacks pulse-shape discrimination (PSD) capability for n-γ separation, the Time-of-Flight (TOF) method was employed.
- The detection efficiency $\varepsilon(E_n)$ for phoswich scintillation detectors was measured using the tagged neutron method with a $^{239}Pu/^{9}Be$ neutron-gamma source and a trigger detector.
- The trigger detector was used to register gamma rays with E_γ = 4.44 MeV emitted from the $^{239}Pu/^{9}Be$ source.

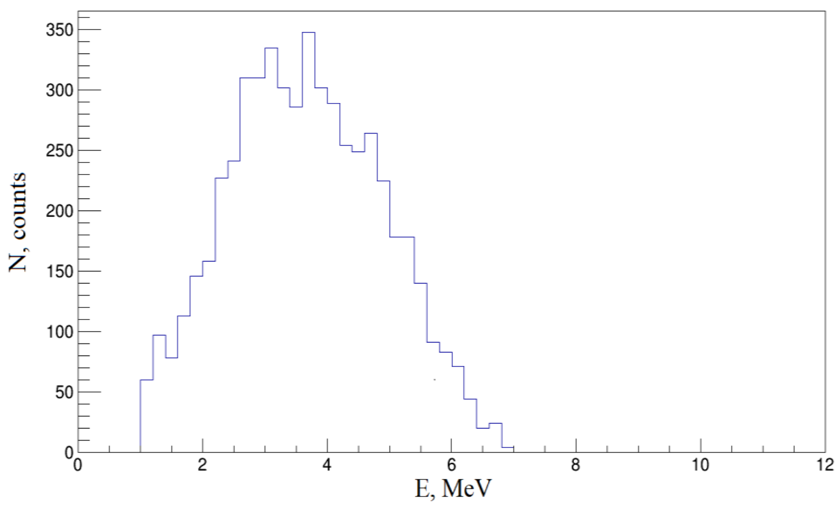




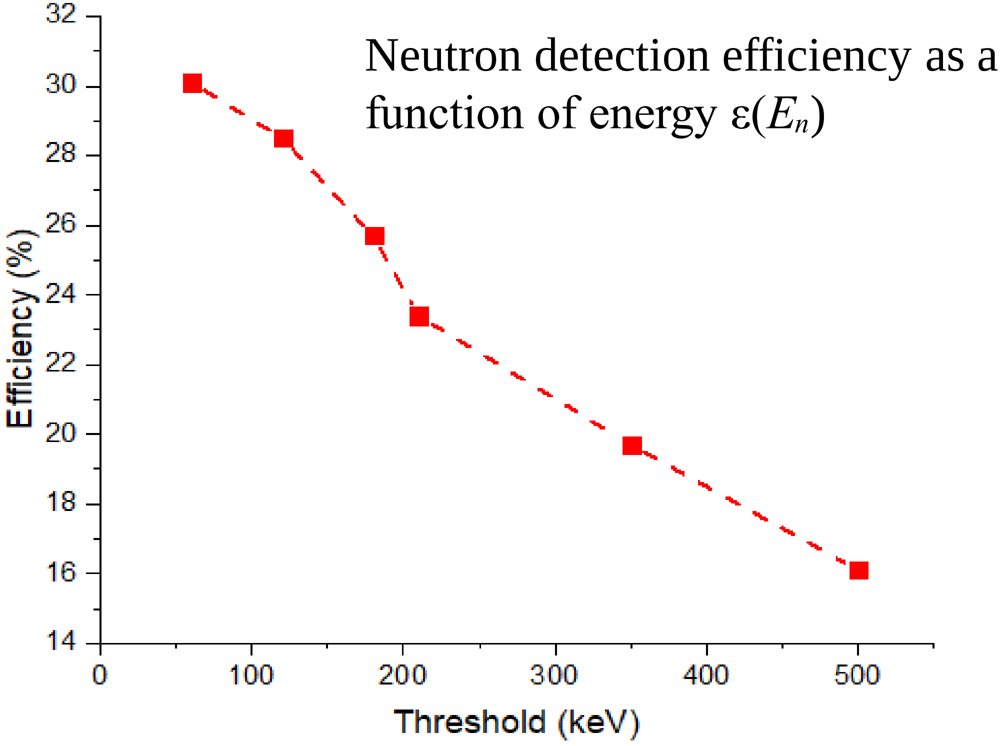
Data processing

For absolute time calibration relative to physical start of every event we used the TOF method. γ-coincidence peak was used to calculate the start of event. That information further was used to calculate neutron energy.

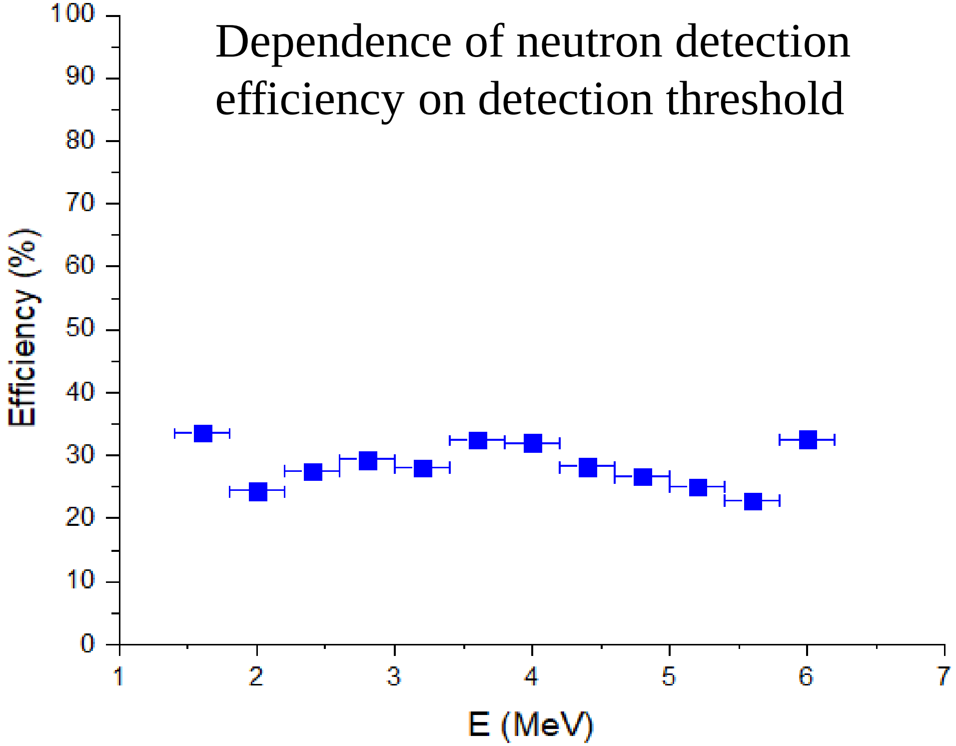




Results



Neutron detection efficiency as a function of energy ε(E_n)



Dependence of neutron detection efficiency on detection threshold

- The results in the left graph demonstrate the main advantage of the $CeBr_3$-based scintillation detector - the flat dependence of detection efficiency on neutron energy with an average value of <ε>~29%.
- The efficiency versus threshold dependence, shows the importance of minimizing this parameter.