Response of $LaBr_3$ scintillation detector on 14.1 MeV neutrons irradiation

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On behalf of the TANGRA collaboration

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Motivation

- Lanthanum(III) bromide ($LaBr_3$) – based detectors became more and more popular:
  - Best energetic resolution for scintillators (~14 keV FWHM for 662 keV)
  - Low light output drift on temperature

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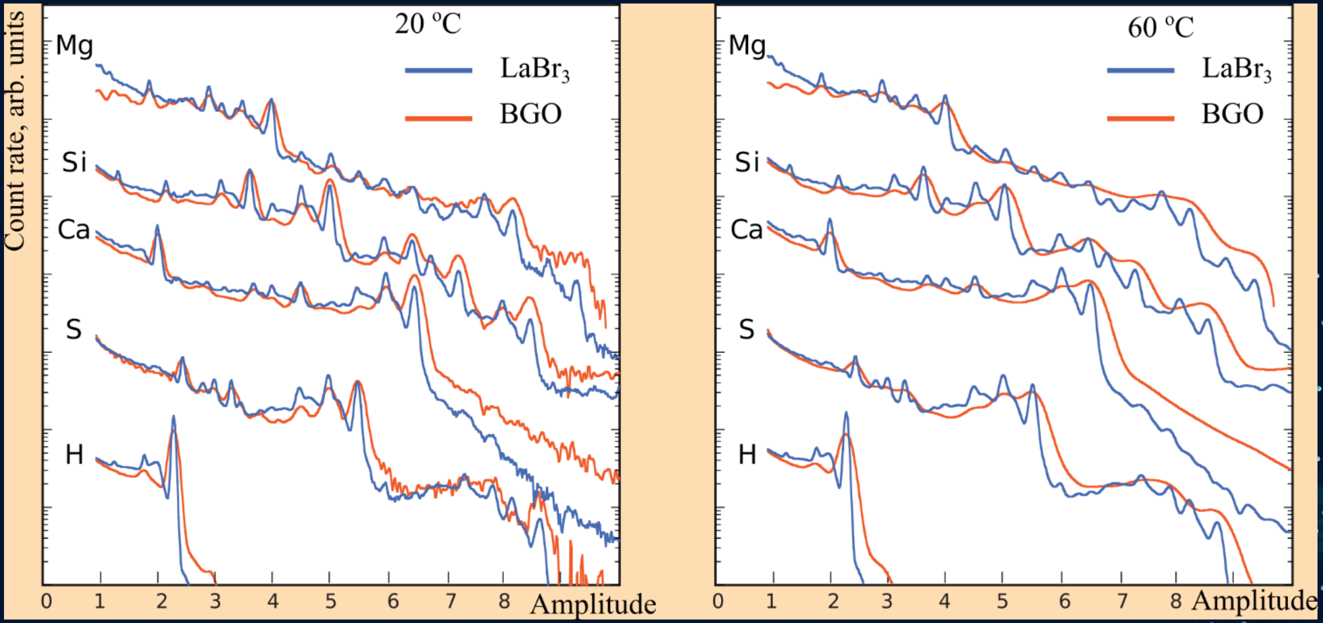
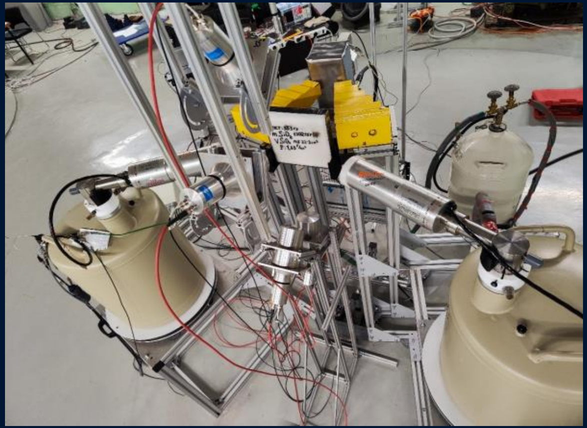


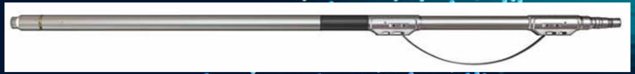
Motivation

- Lanthanum(III) bromide ($LaBr_3$) – based detectors became more and more popular:
  - Best energetic resolution for scintillators (~14 keV FWHM for 662 keV)
  - Low light output drift on temperature
- Used in many nuclear facilities/devices

OSCAR

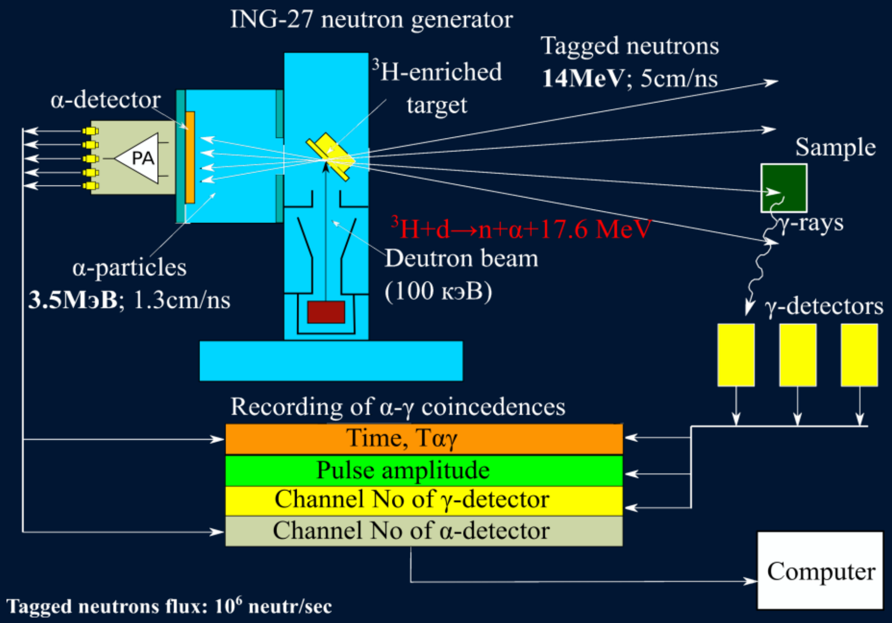


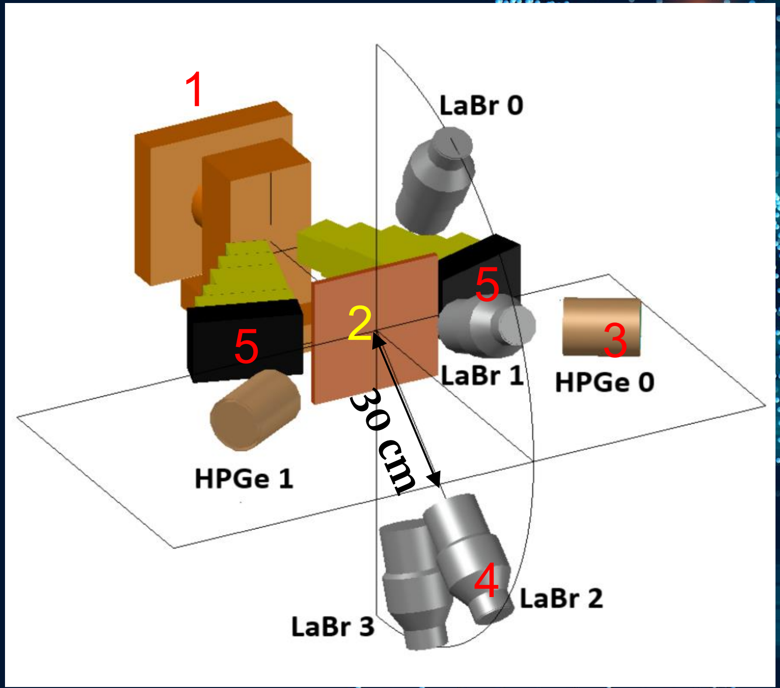
TANGRA



Litho Scanner
(slb.com/ls)

The tagged neutron method (TNM) & TANGRA setup



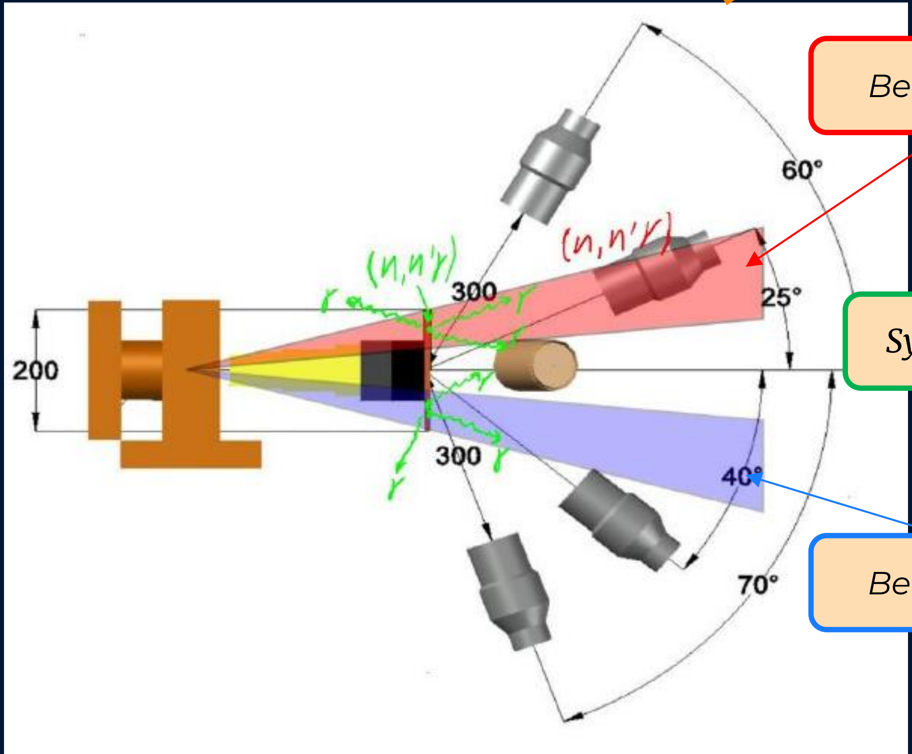


Interesting for nuclear reactions research:

- Angular distributions of *n* and γ
- Correlation between *n* and γ

1) ING-27 neutron generator
2) sample 20×20×X cm
3) HPGe γ-detector (2 pcs, 60% eff)
4) $LaBr_3$ detector (4 pcs)

Idea of experiment

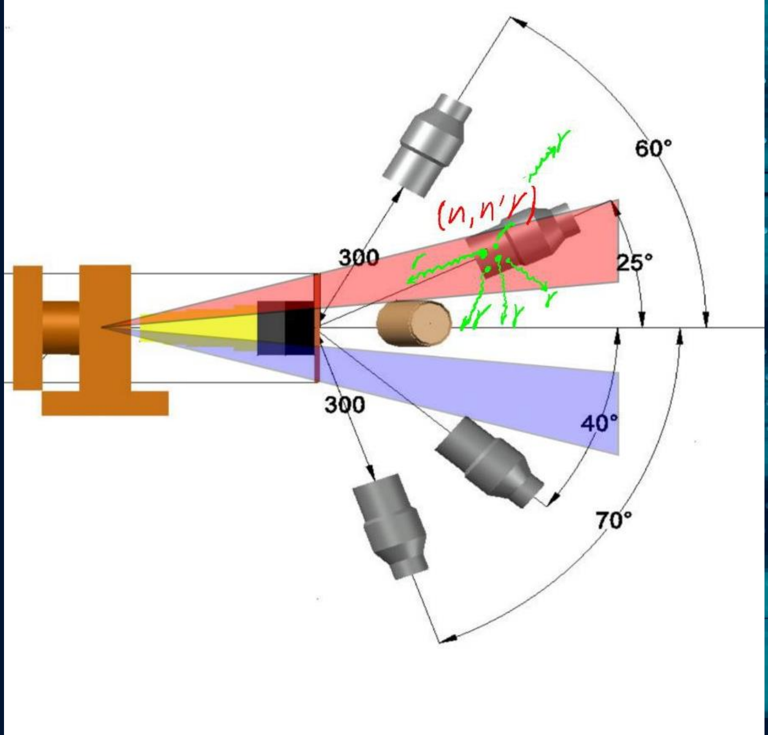


A-B

Beam “A”

Symmetry!

Beam “B”



Idea of experiment

A-B

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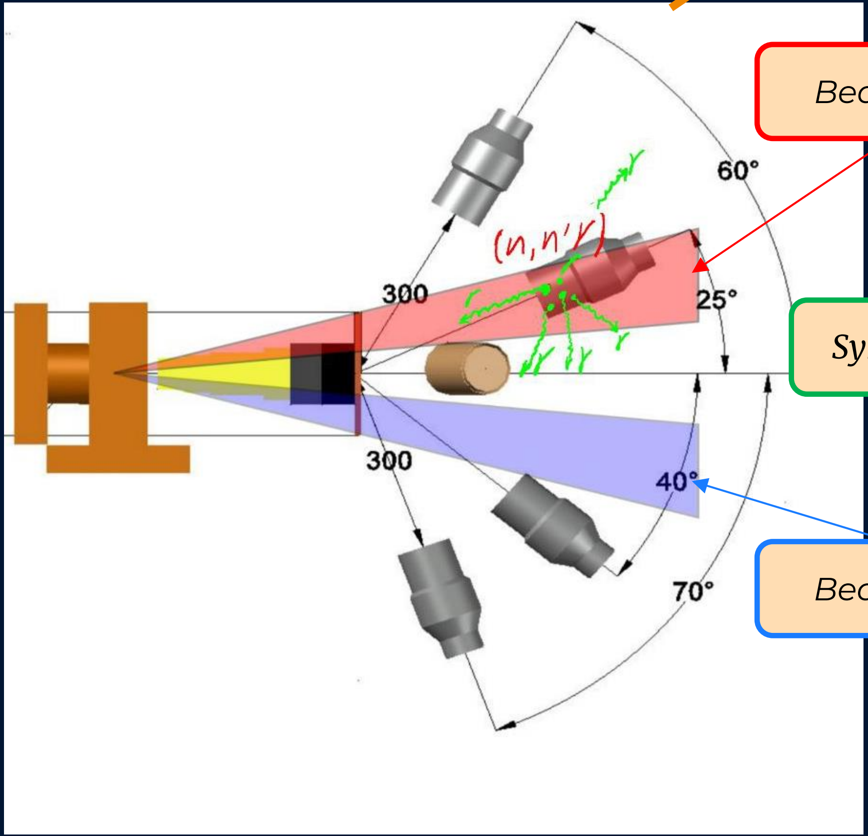
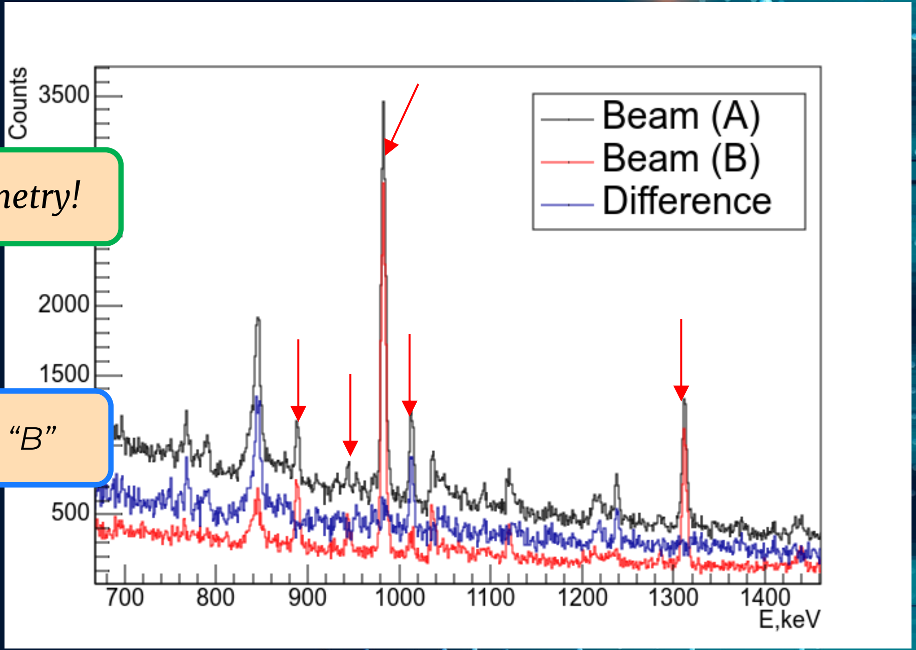




γ from sample marked with red arrows

Results

$$Y_i = \frac{S_i \varepsilon_0}{S_0 \varepsilon_i}$$

- S – area of full energy absorption peak
- ε – correction coefficient (includes efficiency of the HPGe detector, solid angle and self-absorption in LaBr)
- i – investigated peak
- 0 – reference peak

Reference line marked with ***red***
Reactions leads to activation marked with orange

Eγ, keV	Target	Reaction	Yield,%
88,7	^{139}La	(n,2n)	161(11)
165,9	^{139}La	(n,n')	34(7)
217,1	^{79}Br	(n,n')	83(4)
230,4	^{139}La	(n,2n)	42(3)
243,5	^{79}Br	(n,2n)	87(2)
260,8	^{81}Br	(n,n')	29(4)
276	^{81}Br	(n,n')	100
291,4	^{139}La	(n,n')	27(10)
306,5	^{79}Br	(n,n')	34(17)
340,7	^{139}La	(n,2n)	17(4)
381,5	^{79}Br	(n,n')	27(2)
523,1	^{79}Br	(n,n')	20(2)
562,4	^{81}Br	(n,n')	20(3)
613,7	^{79}Br	(n,np)	80(9)
640,6	^{81}Br	(n,n')	19(2)
767	^{81}Br	(n,n')	28(2)
789,4	^{81}Br	(n,n')	22(4)
1043,1	^{139}La	(n,n')	41(8)
1219	^{139}La	(n,n')	41(10)
1237	^{81}Br	(n,n)	26(2)

Identified 47 γ – transitions in total

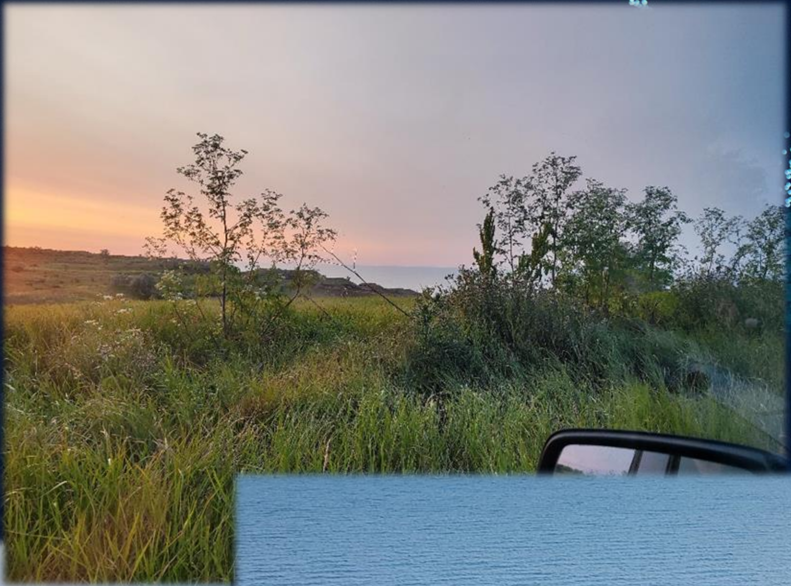
Conclusion & TODO

- Applied technique allowed us to extract γ – yields for reactions in LaBr in "parasite" mode from data obtained in regular measurements
- There are no data for La and Br at 14MeV in EXFOR – probably this data obtained for the first time
- Identified 47 γ – transitions in total

TODO

- Perform regular measurement with La sample and Br-contained sample (planned in 2025) to extract angular distribution of γ – quanta and measure cross-sections
- Create a response function to use it for neutron background subtraction

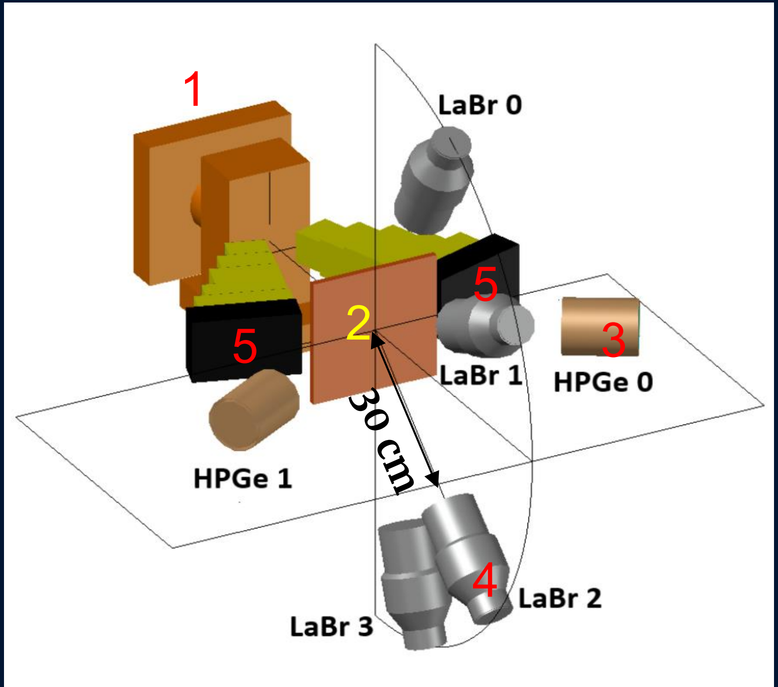
THANKS!

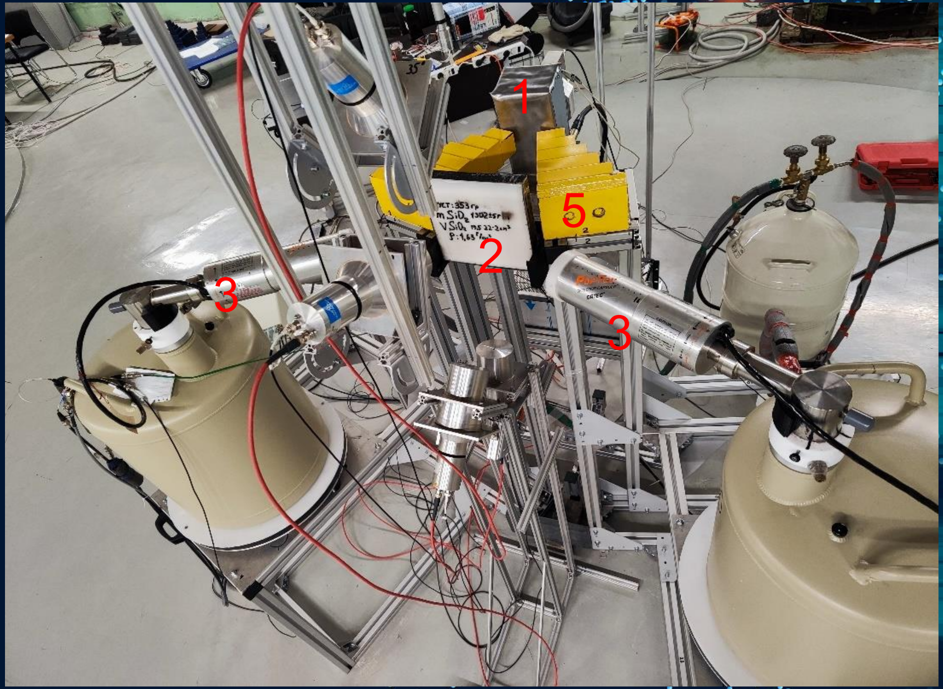


Backup

- Here the important materials about data processing are stored. They were not included in main presentation because of lack of time.
- Don’t hesitate to ask me about that!

Measurements of the γ-quanta emission cross-sections & angular distributions





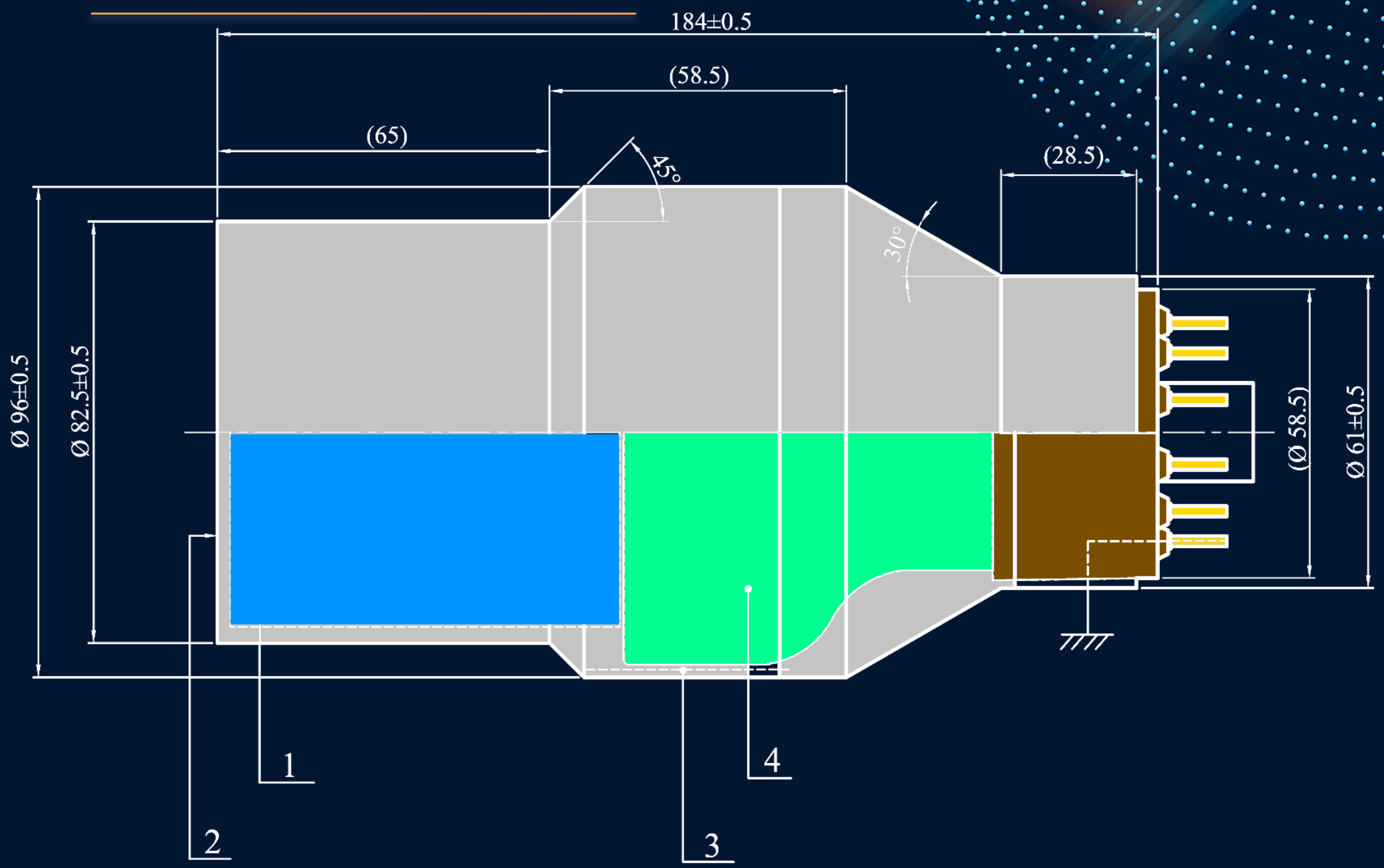
1) ING-27 neutron generator
2) sample 20×20×X cm
3) HPGe γ-detector (2 pcs, 60% eff)

4) $LaBr_3$ γ-detector (4 pcs)

+ Fast measurement

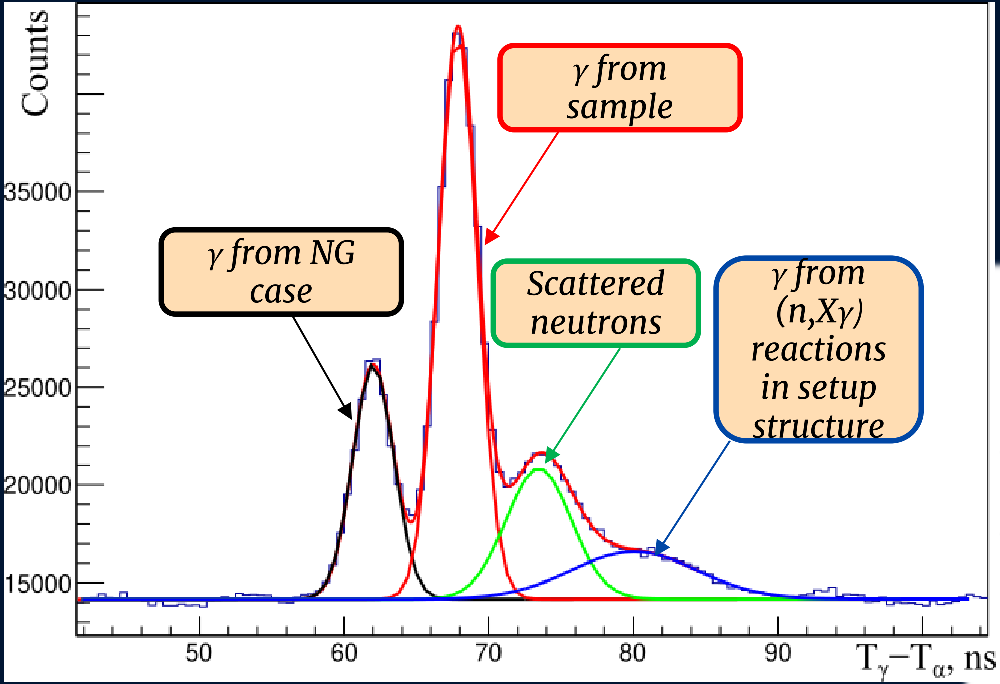
- Extreme detector load (~8×10^4 cps)

LaBr structure



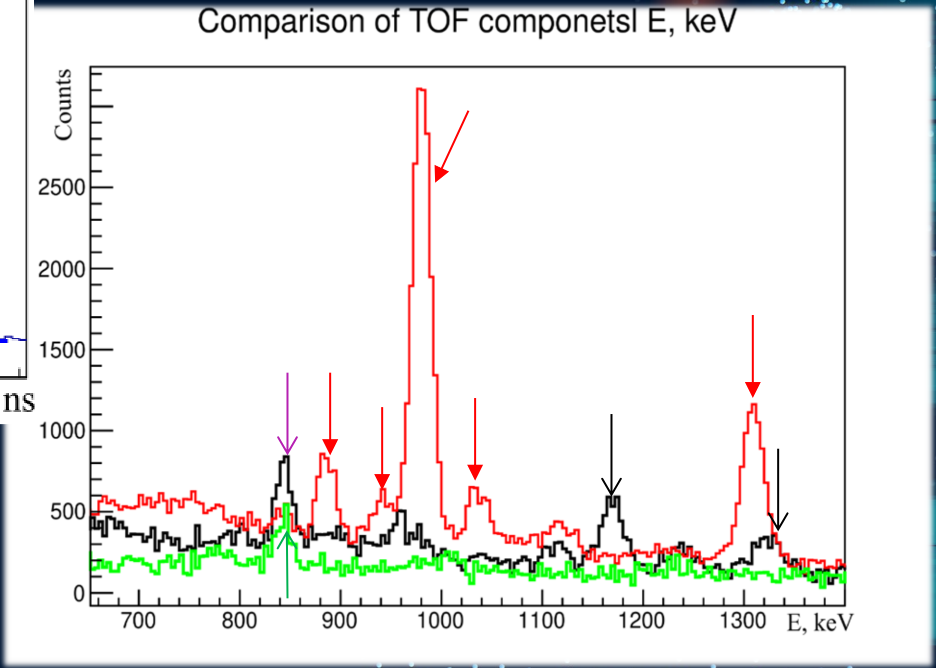
- Sanit-Gobain B380

Data processing with TNM



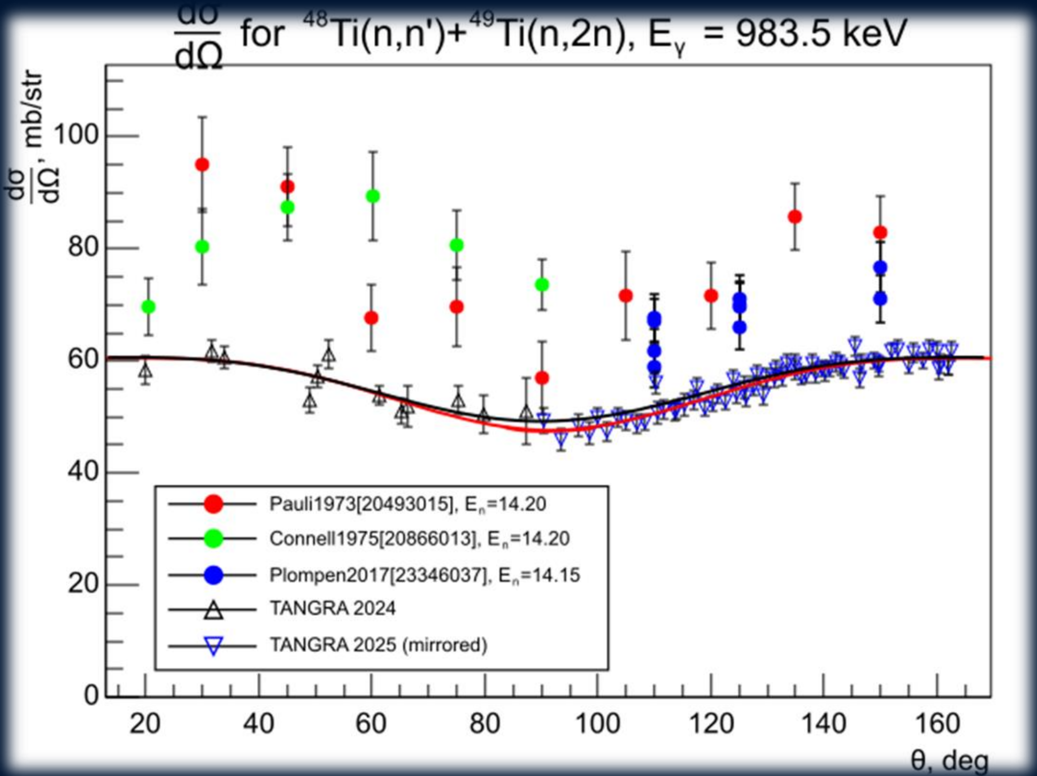
Spectrum below shows impact of different components to sum spectrum.

Peaks from sample marked with red arrows



Main idea – separation of the background events by TOF

Measurements of the γ-quanta emission cross-sections & angular distributions (TiO_2 sample)



Eγ, keV	Reaction	Reference	σ, mb	a_2	a_4
983,5 keV	$^{48}Ti(n,n')$ $^{49}Ti(n,2n)$	Pauli 1973	940 (30)	0,31(8)	-0,1(1)
		Connell 1975	1020 (30)	-0,02(5)	-0.26(9)
		Plompen 2017	842 (15)	0,16(4)	-0,08(7)
		TANGRA 2024	690 (10)	0,16(3)	-0,05(4)
		TANGRA 2025	685 (3)	0,18(1)	-0.06(1)

- And 19 γ-lines more

$$\frac{d\sigma}{d\Omega} = \frac{\sigma}{4\pi} \sum_{l=0,2,4...}^{2J} P_l(\cos(\theta))$$

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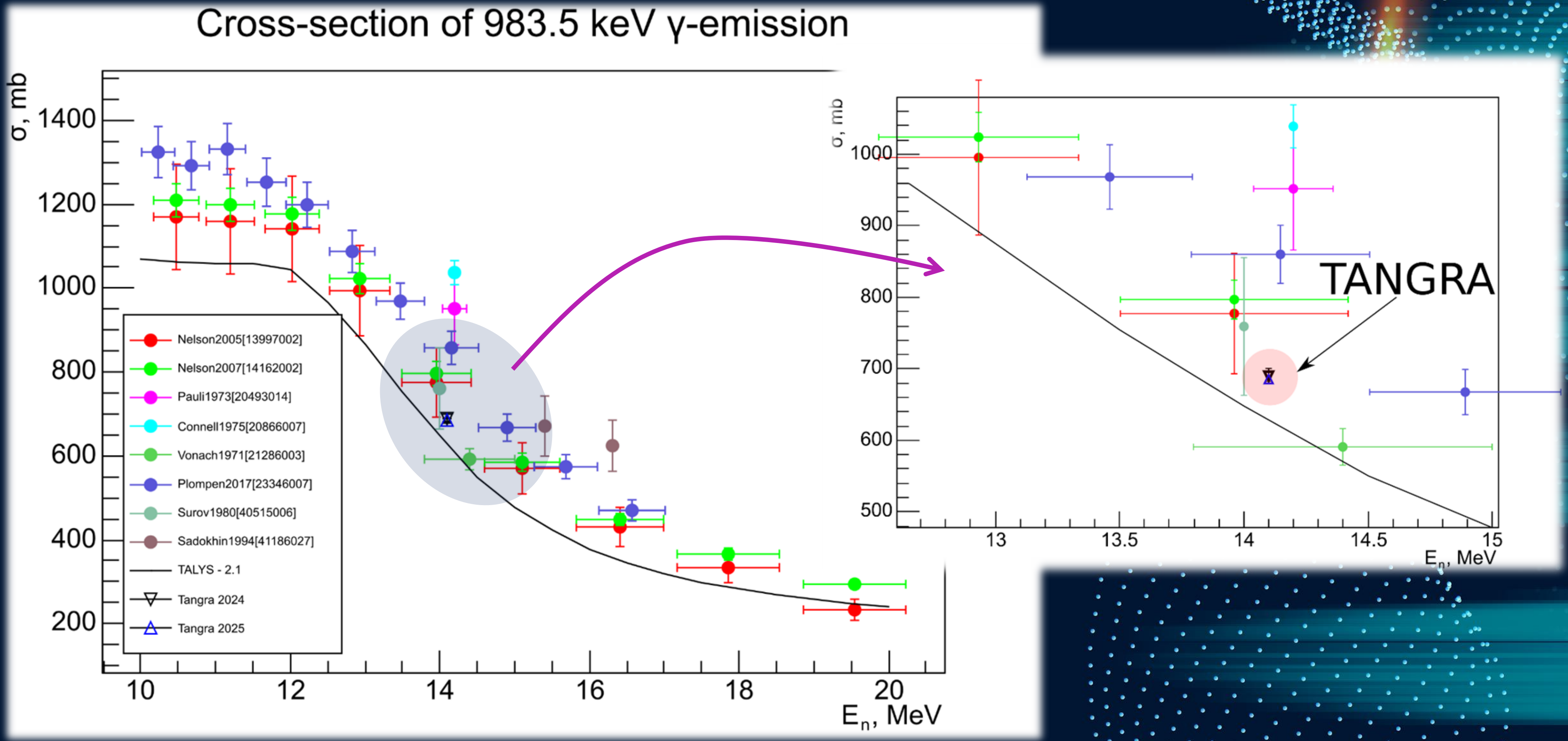
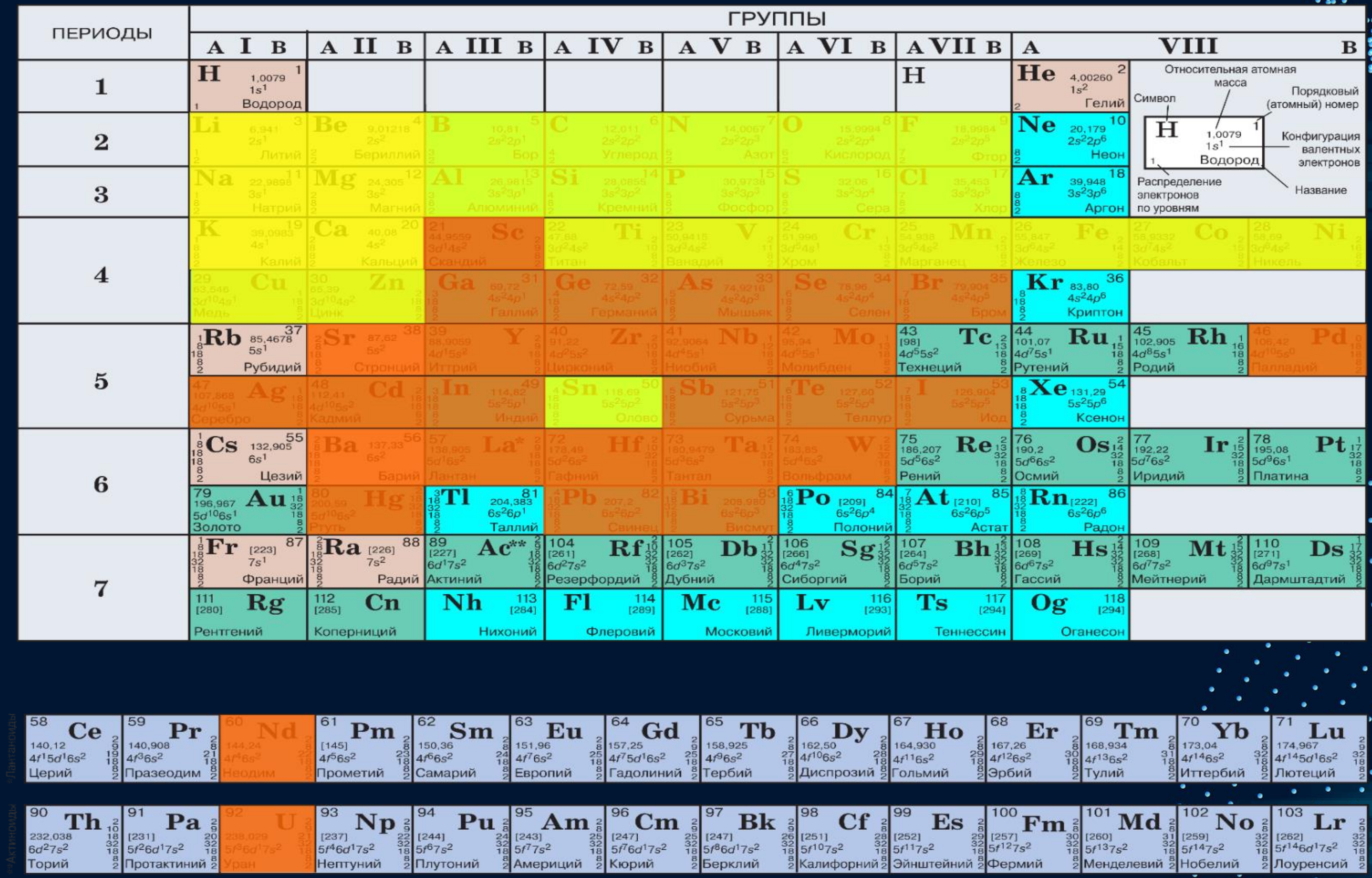


Current status of measurements



2024

2025

Cross section calculation

Area of γ-peak

Incident angle

$$\frac{d\sigma}{d\Omega}(\theta) = \frac{N_p cos\xi}{4\pi N_\alpha n_{at} k} 10^{27} [\frac{mbarns}{sr}]$$

Number of tagged neutrons

Surface density of atoms in the sample

Total reaction cross section

$$\sigma = 2\pi \int_{-1}^{1} \frac{d\sigma}{d\Omega}(cos\theta)\ dcos\theta$$

Multiple inelastic scattering

Attenuation of incident neutron

Attenuation of γ-rays

Sample thickness

$$k = \int_0^{x_0} \varepsilon(x) k_{ms}(x) k_{satt}(x) k_{iatt}(x) dx$$

The total efficiency

- The features of the experimental approach are the close geometry and the quite large sample
- All corrections changed significantly depending on the target thickness
- We could not consider the various correction independently

Algorithm for determining the correction factor

There are two ways to calculate corrections:

- To calculate them independently in dependence on the sample thickness and take the integral
- **To simulate the total thickness-integrated correction in the GEANT4 using a separate ones as weighting factors**

Correction features:

- Multiple inelastic scattering overstates the number of emitted γ-rays
- Attenuation of incident neutrons and γ-rays understates the number of emitted γ-rays

Simulation features:

- 2 stage - neutron transport and γ-rays transport simulation
- The inelastic multiple scattering is used as a probability factor increasing the number of emitted γ-rays in comparison with its real number
- The inelastic multiple scattering correction calculates taking into account the energy dependence of emission cross section for specific γ-line taken from TALYS for each interaction point
- The correction factor resulted included thickness-integrated multiple scattering, absorption and efficiency coefficients

Simulation of the interaction point and neutron spectra depending on thickness

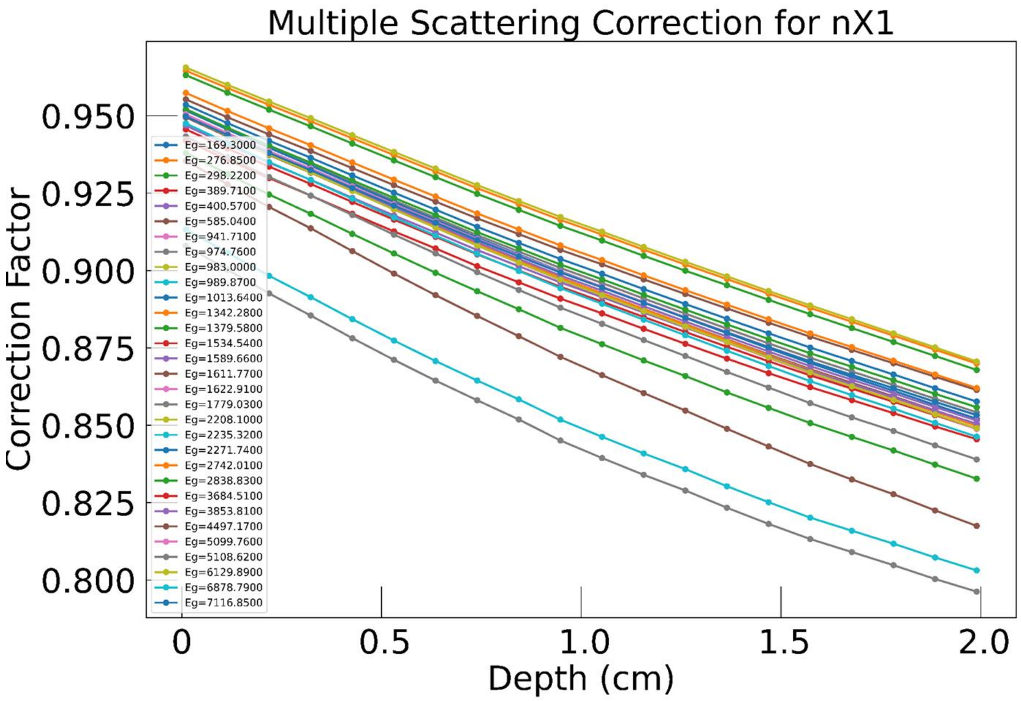
↓

Calculation of the inelastic multiple scattering correction depending on the thickness

↓

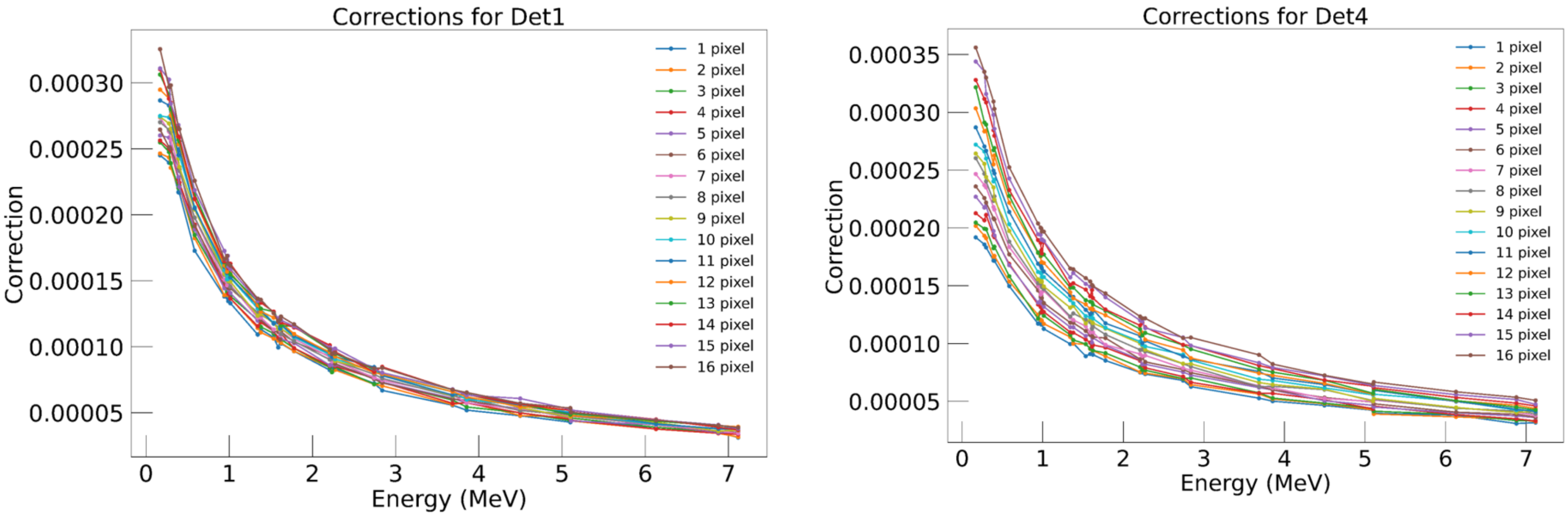
Simulation of γ-rays detection efficiency emitting them from the interaction points

Example of the multiple scattering correction



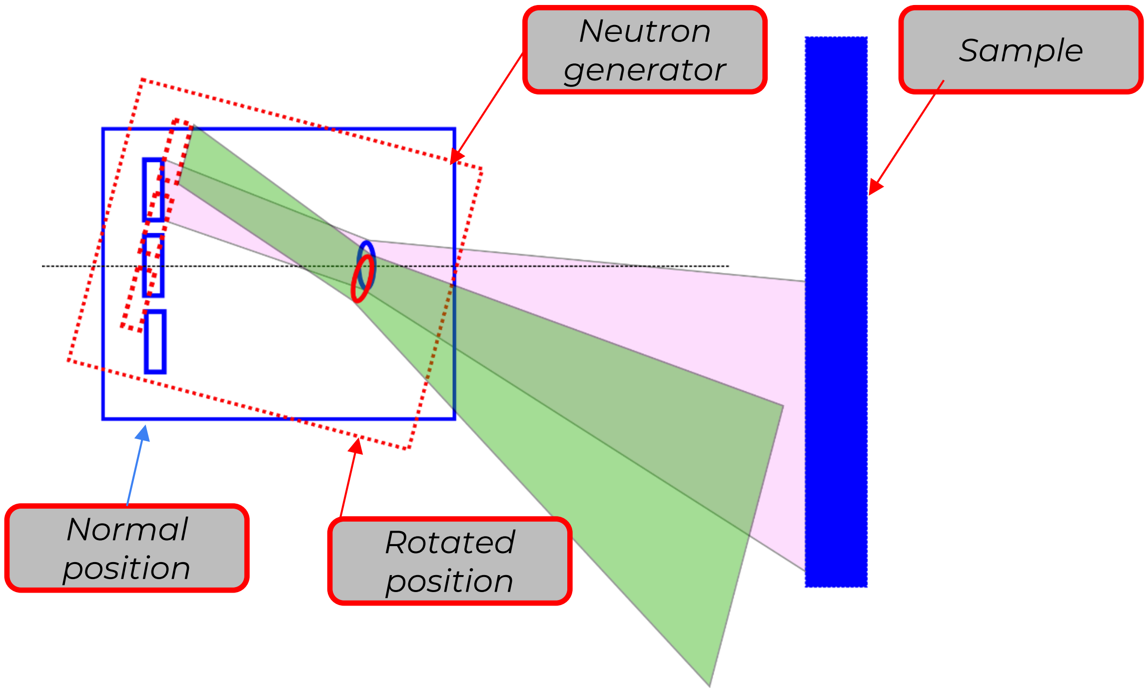
Multiple scattering correction factor depending on the sample thickness. The example corresponding to the SiO_2 sample and first vertical strip

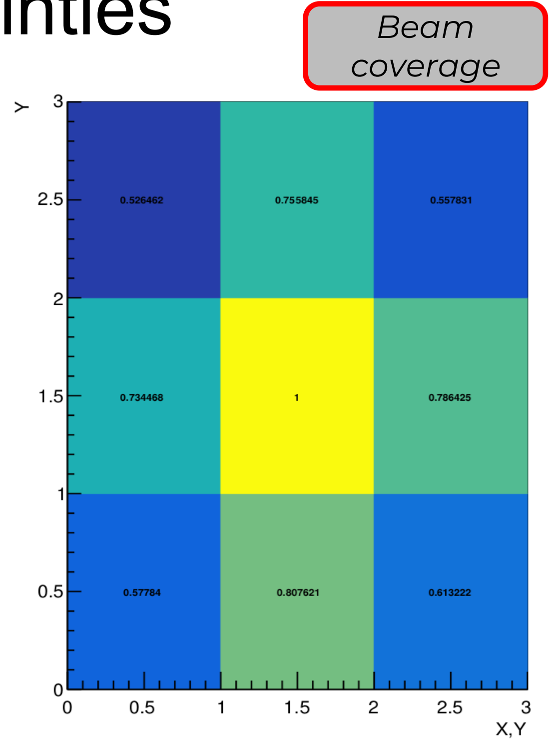
Integrated correction factors using the example of the SiO_2 sample



The correction factors including the attenuation correction, total efficiency and multiple inelastic scattering corresponding to the various $LaBr_3$ detectors

Main source of systematic uncertainties

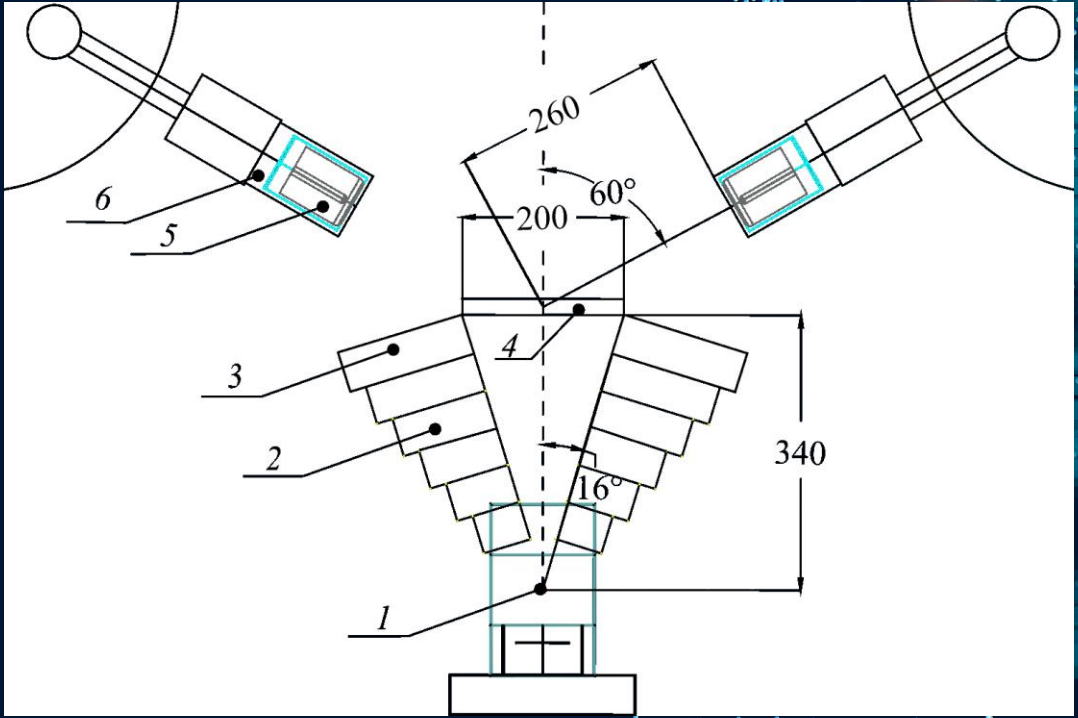




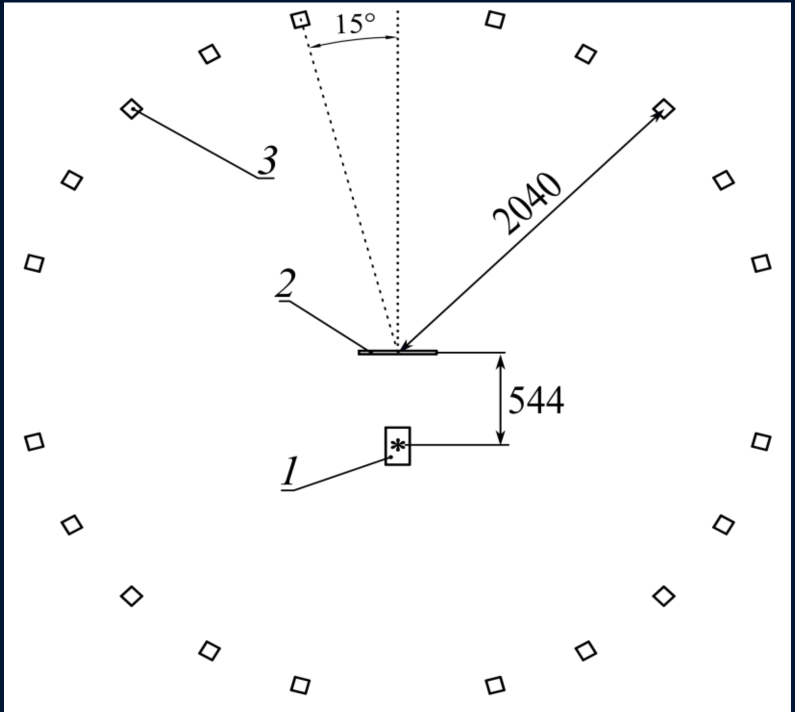
Small rotation of the NG could lead to dramatic change of target coverage. It could be corrected by relative calibration to central pixel and rotation angle could be adjusted to minimize CS difference between pix-det combinations with small difference in angle

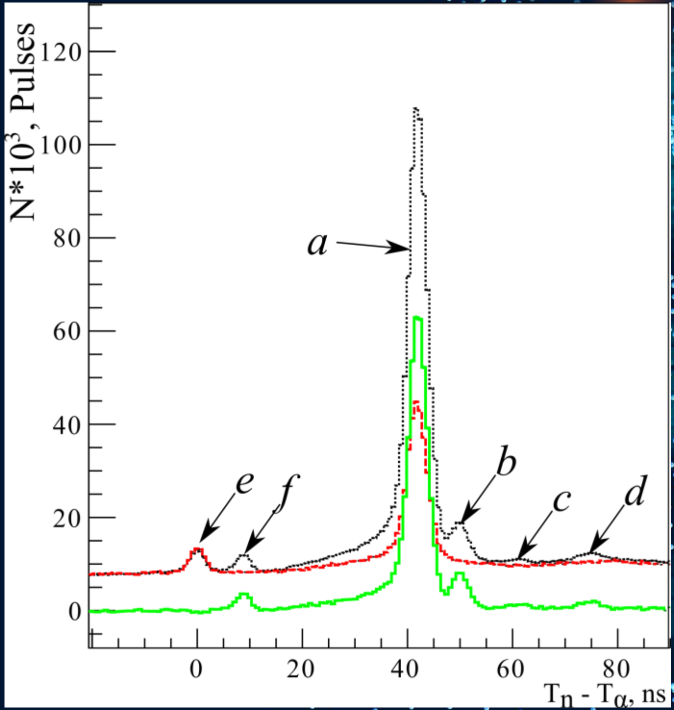
Configuration for γ-quanta emission CS measurement

- 1-ING-27, 2-iron-, 3-lead parts of the collimator, 4-sample, 5-HPGe crystal, 6-case of the detector.
- Updated “HPGe” setup contains two ORTEC-made spectrometers with relative efficiency of 60%
- Set of LaBr detectors will be used to measure the γ-angular distribution



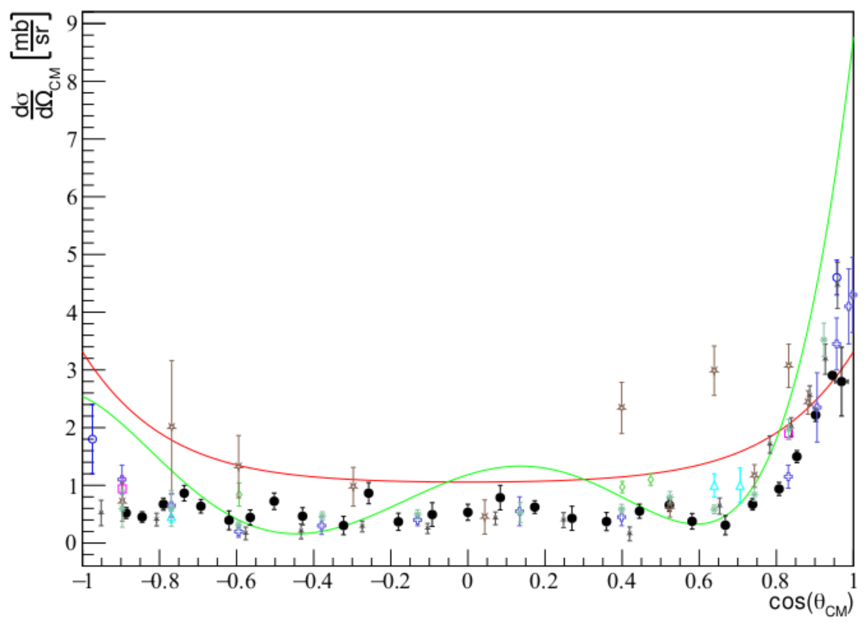
Measurement of *n'* angular distributions and n' γ correlations

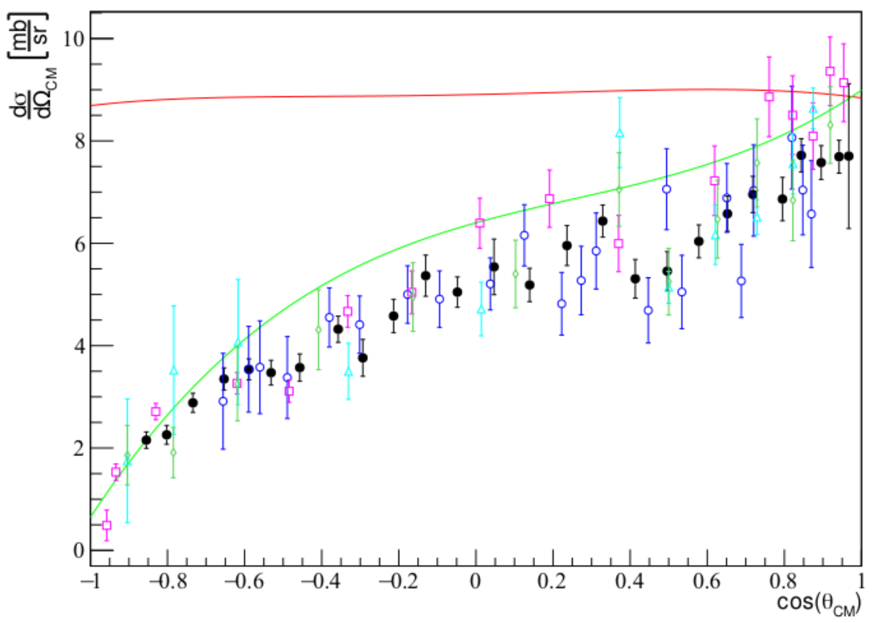




- 1-ING-27 neutron generator, 2-sample, 3-PFT n−detector

a -direct and elastically scattered neutrons, *b*-4.4 MeV, *c*-7.6 MeV, *d*-9.6 MeV excited states, *e* -γ−quanta emitted from case of the ING-27, *f*- γ from sample





- 7.6 MeV state (Hoyle state)
- Green line – ENDF-B-VIII
- Red line - TALYS

- 9.6+9.8+9.9 MeV states