ANALYSIS OF CHLORINE NEUTRON CAPTURE EXPERIMENT FOR EFFICIENCY CALCULATION VALIDATION

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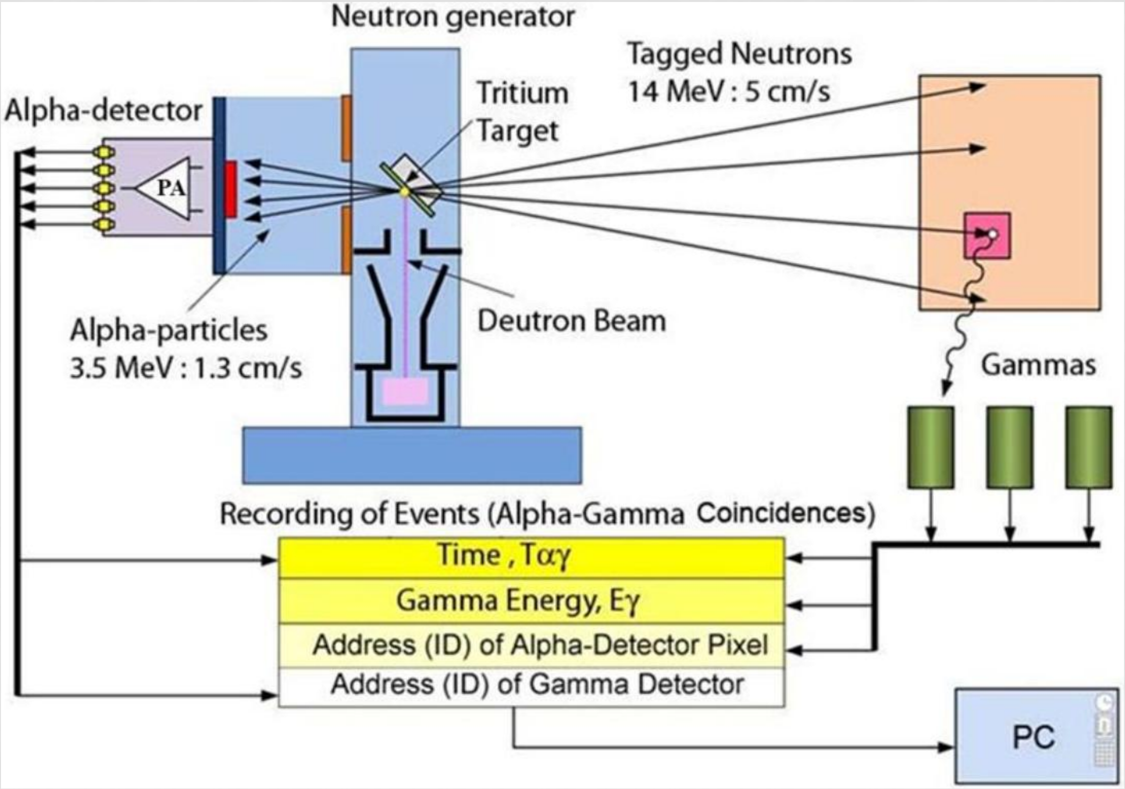
TANGRA – TAgged Neutron & Gamma RAys

The setup is being developed to investigate neutron-induced reactions on different materials, with primary focus on the investigate the inelastic scattering of 14.1MeV neutrons on atomic nuclei using the Tagged Neutron Method (TNM). Gamma emission is detected using scintillators and high-purity germanium detectors. The neutron source is a PuBe mix and the neutron generator is an ING27.

TANGRA – TAgged Neutron & Gamma RAys

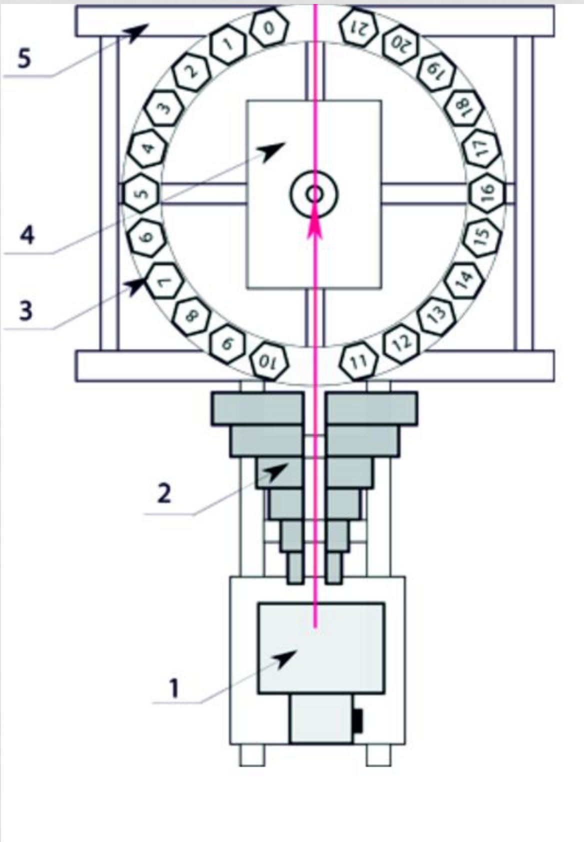


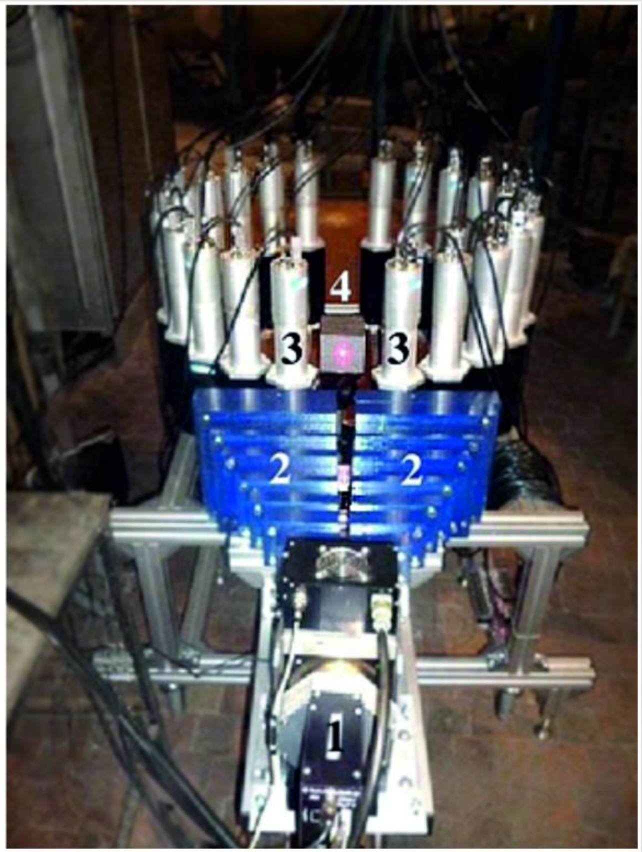
Source of 14.1 MeV neutrons:

$D + T = \alpha + n$

https://flnp.jinr.int/en-us/main/facilities/tangra-project-en

TANGRA – TAgged Neutron & Gamma Rays, beginning





- Number of NaI(Tl) detectors: 22
- NaI(Tl) crystals: hexagonal prism (78 x 90 x 200 mm)
- PMT type: Hamamatsu R1306
- Gamma-ray Energy-resolution ~ 7.2% @ 0.662 MeV
- Gamma-ray Energy-resolution ~ 3.6% @ 4.437 MeV
- Gamma-ray Time-resolution ~ 3.8ns @ 4.437 MeV

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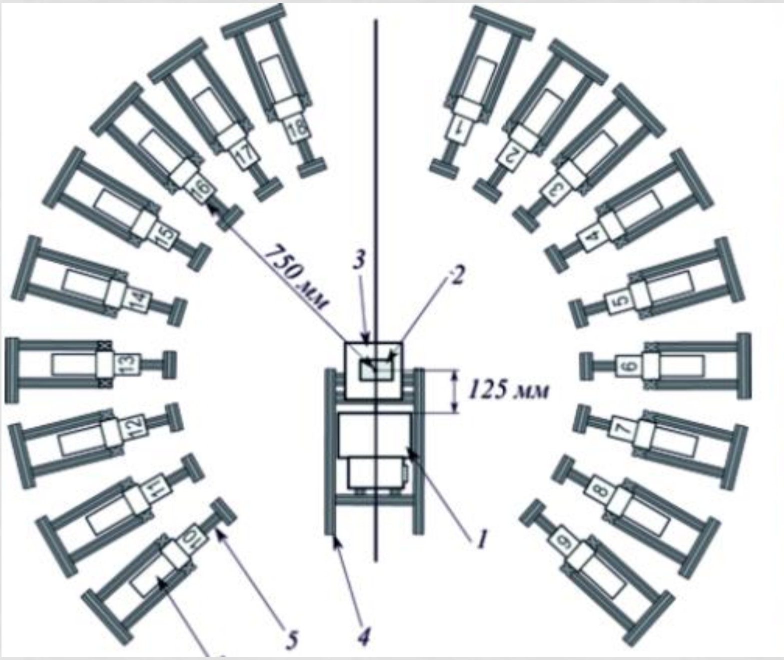
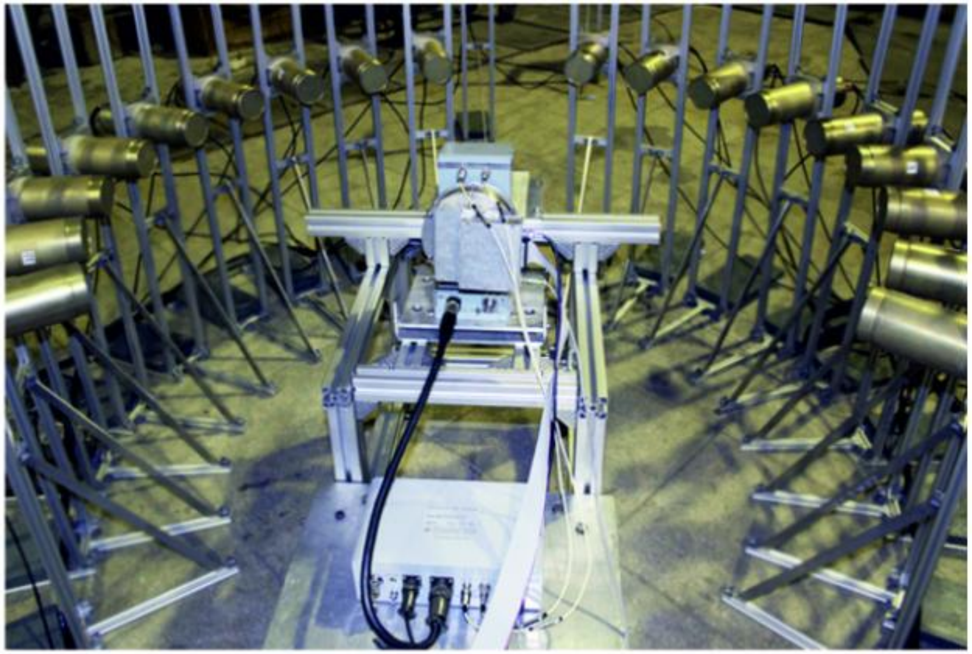
TANGRA – TAgged Neutron & Gamma Rays, modernization

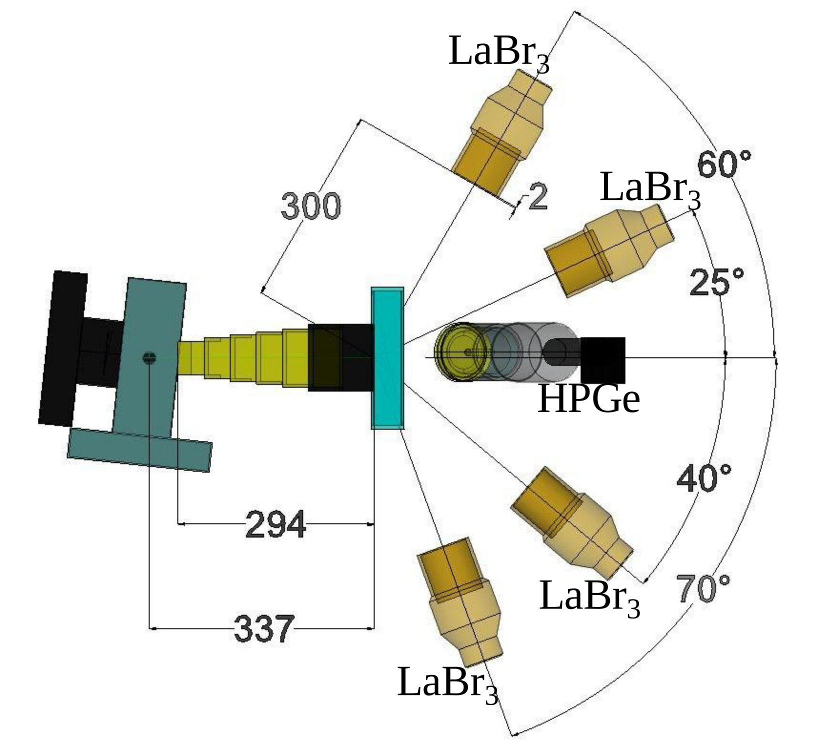


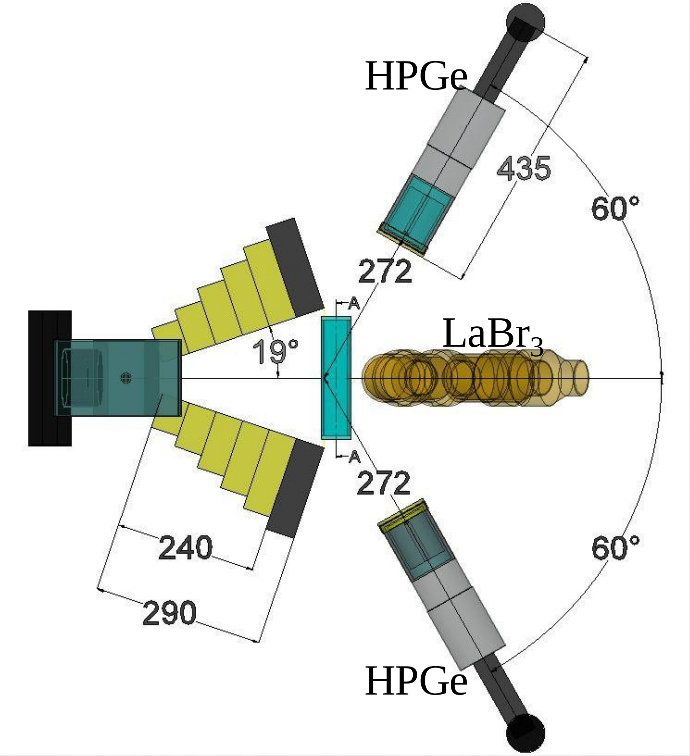


- Number of BGO detectors: 18
- BGO crystals: cylinder (76 x 65 mm)
- PMT type: Hamamatsu R1307
- Gamma-ray Energy-resolution ~ 10.4% @ 0.662 MeV
- Gamma-ray Energy-resolution ~ 4.0% @ 4.437 MeV
- Gamma-ray Time-resolution ~ 4.1ns @ 4.437 MeV

https://flnp.jinr.int/en-us/main/facilities/tangra-project-en

TANGRA – TAgged Neutron & Gamma Rays, more upgrades

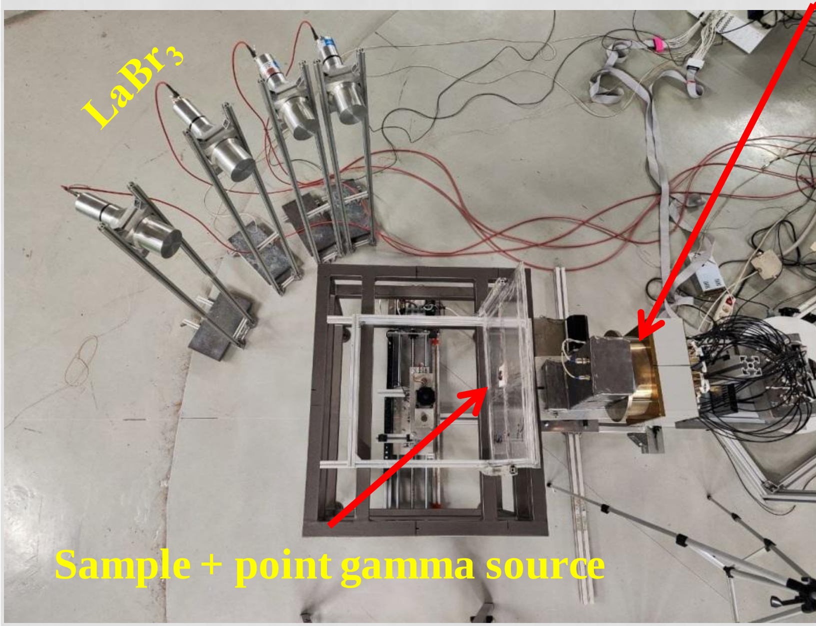


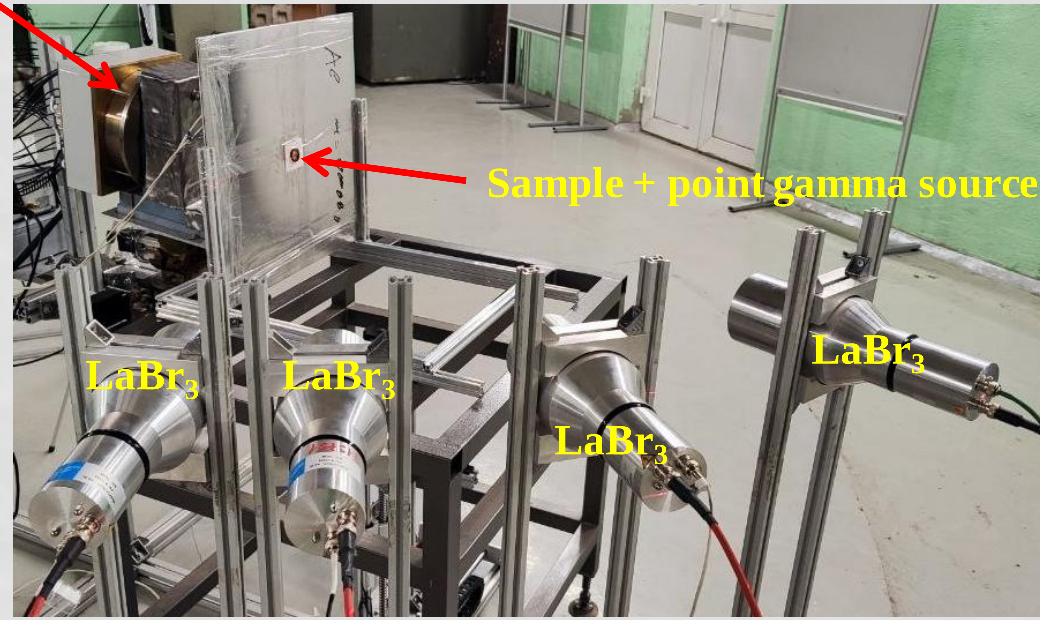


2D scheme of the recently upgraded TANGRA setup,
left: side view, right: top view

TANGRA – TAgged Neutron & Gamma Rays, more upgrades

Neutron generator ING27





Picture of the last configuration of the experimental setup

TANGRA – TAgged Neutron & Gamma Rays, DAQ

Fast digitizer CRS-6/32 DAQ (32-channel, 200 MHz, 11-bit, USB-3 connection; approximately 10^5 events/s/channel)

Photo-peak counting efficiency

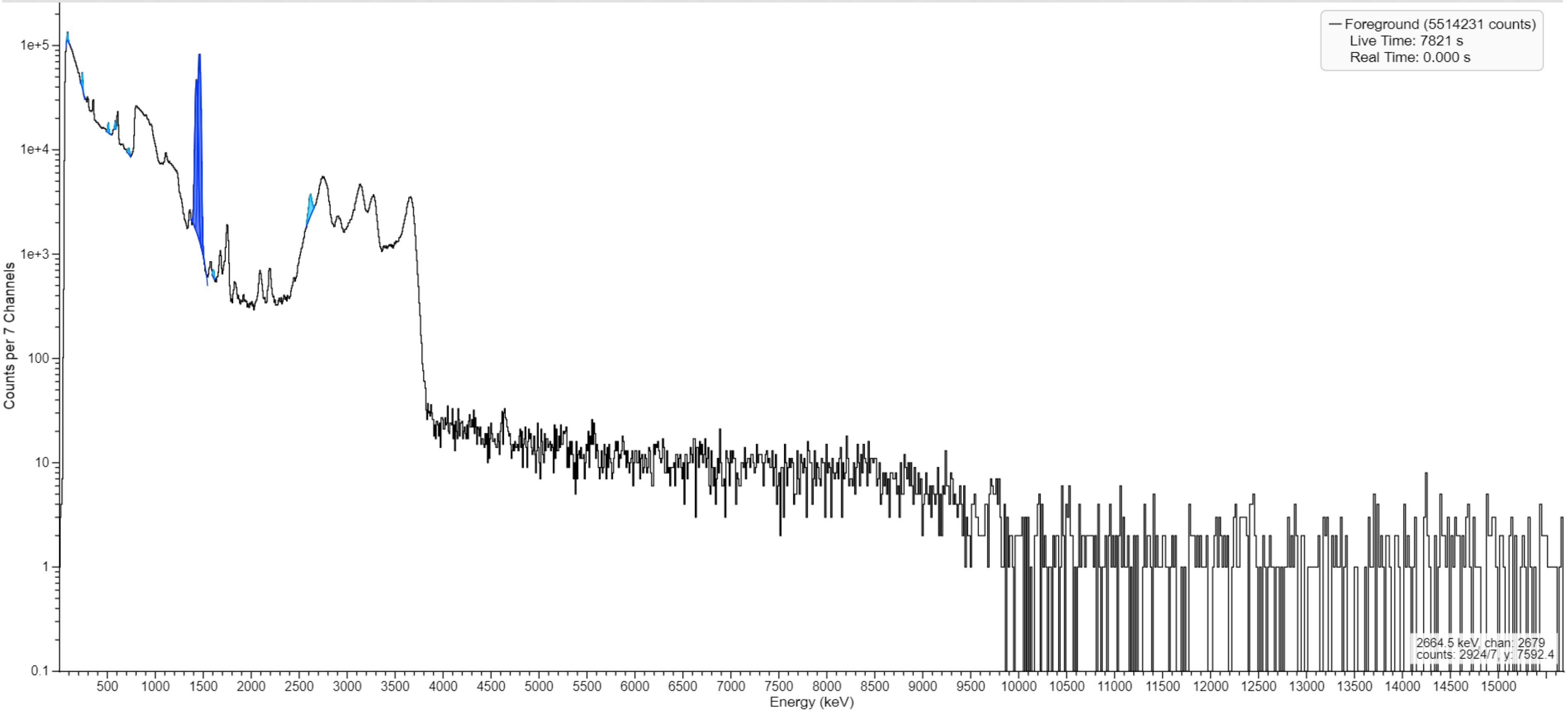
$$\varepsilon_\gamma = \frac{N_\gamma}{A \cdot I_\gamma \cdot t_{meas}}$$

ε – counting efficiency, N – energy peak counts, A – isotope activity at the time of measurement, I – intensity of gamma emission, tmeas – time of measurement,
γ – the interested gamma energy

$$A = A_0 \cdot e^{-\lambda \cdot t}$$

A_0 – certified activity of the used point gamma source, λ – decay constant, t – elapsed time between the certifying of the point gamma source and time of experimental measurements

The acquired spectrum from ^{228}Th point source with $LaBr_3$



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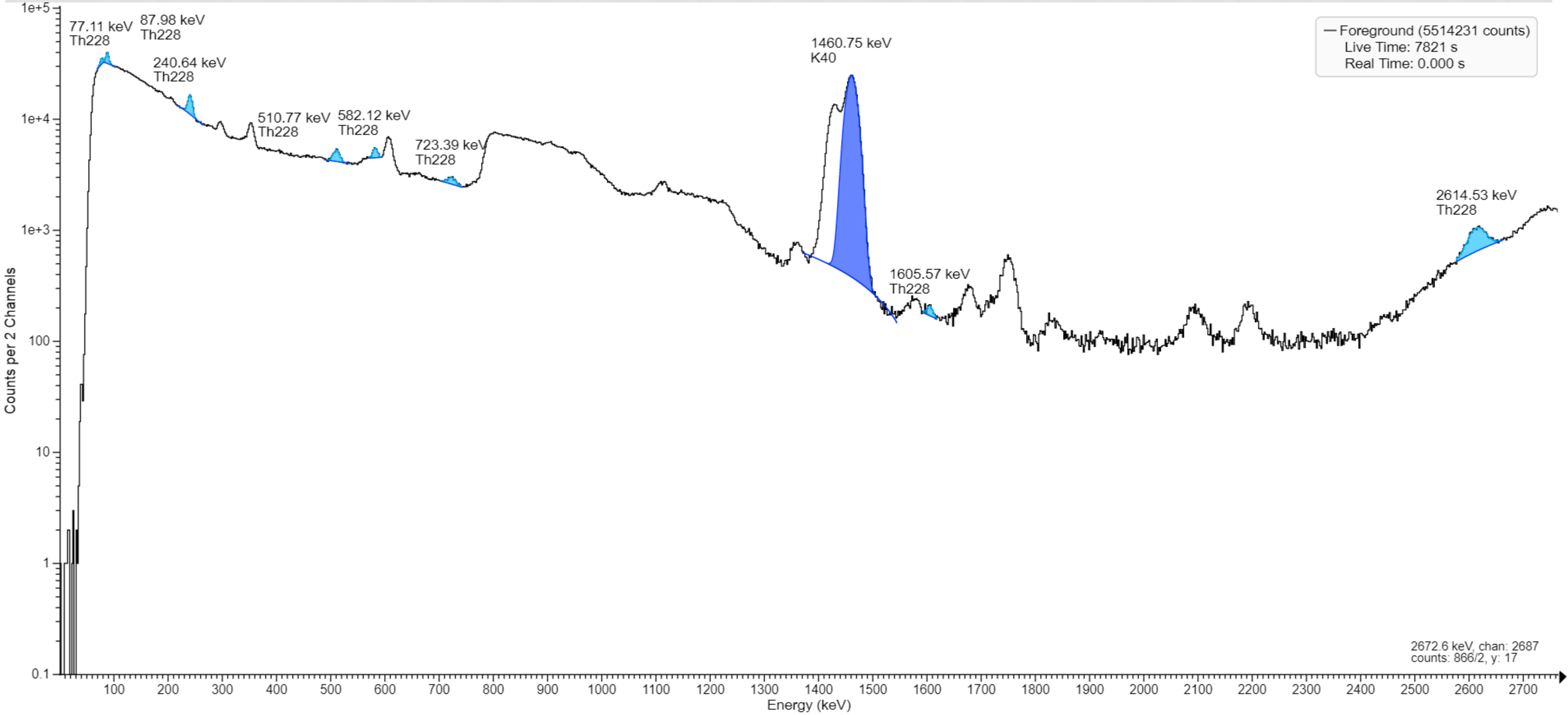
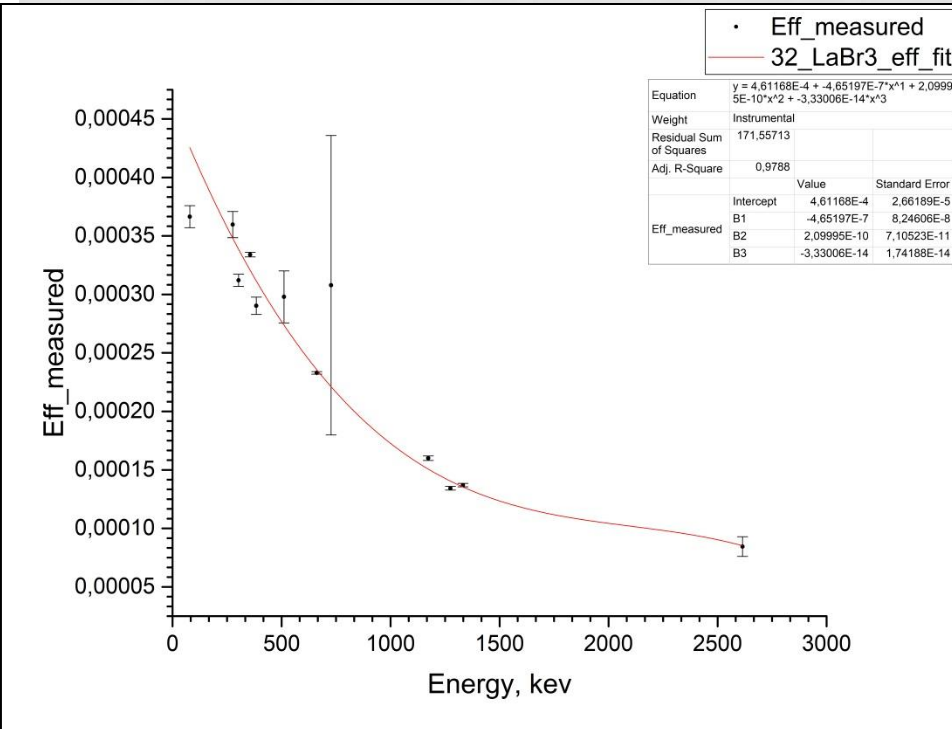
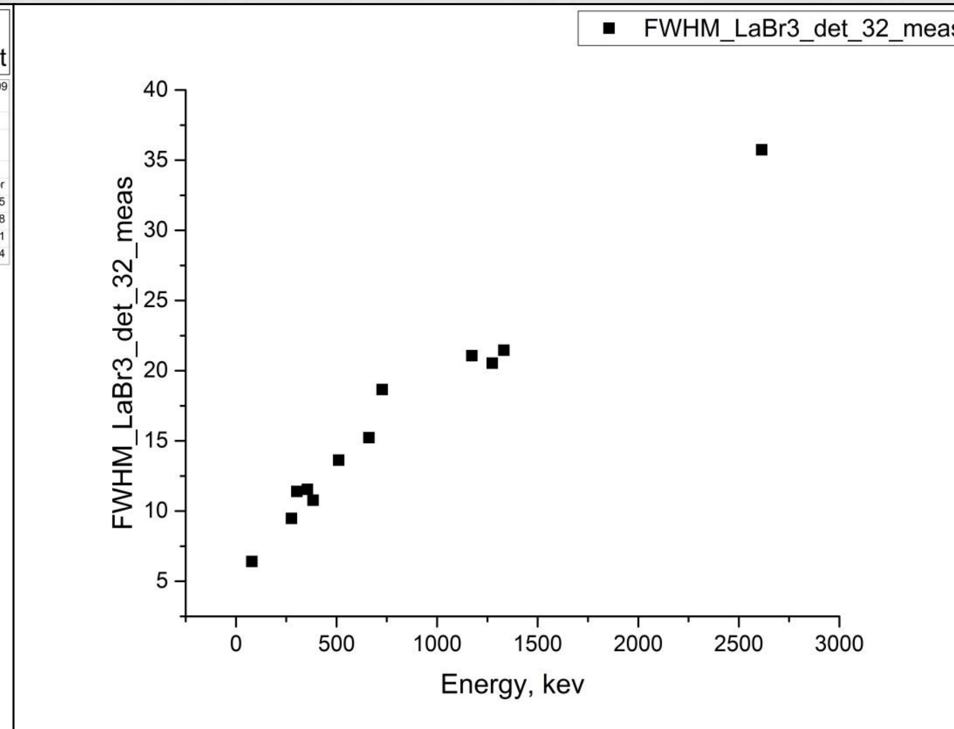


Measured characteristics for the energy range up to 2614 keV for $LaBr_3$ detectors



Equation	y = 4,61168E-4 + -4,65197E-7*x^1 + 2,09995E-10*x^2 + -3,33006E-14*x^3		
Weight	Instrumental		
Residual Sum of Squares	171,55713		
Adj. R-Square	0,9788		
		Value	Standard Error
Eff_measured	Intercept	4,61168E-4	2,66189E-5
	B1	-4,65197E-7	8,24606E-8
	B2	2,09995E-10	7,10523E-11
	B3	-3,33006E-14	1,74188E-14



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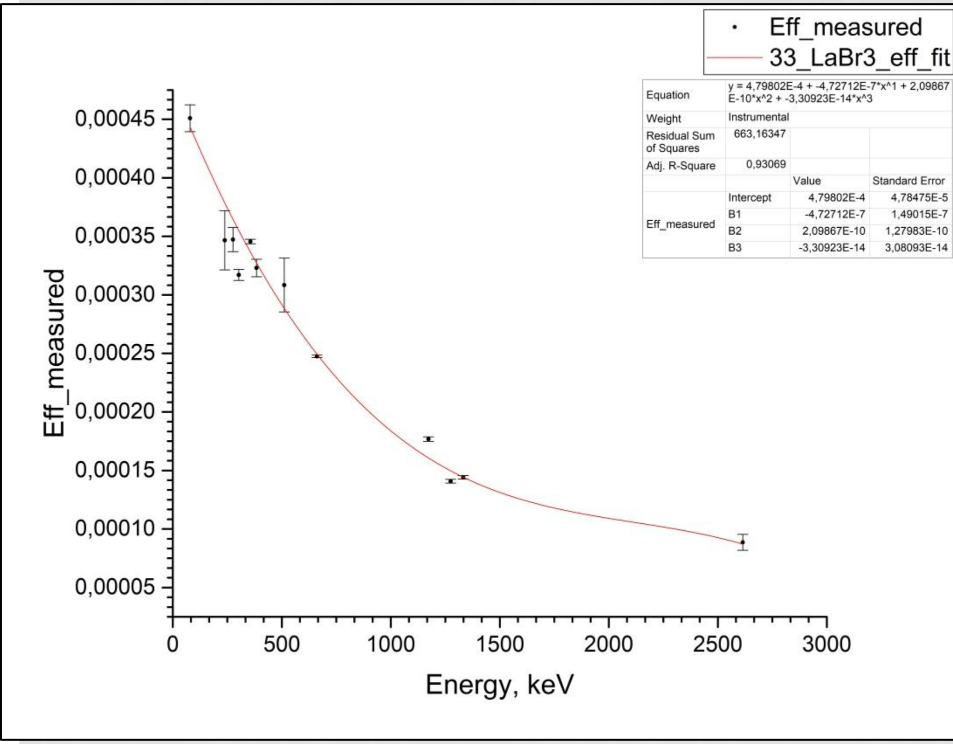
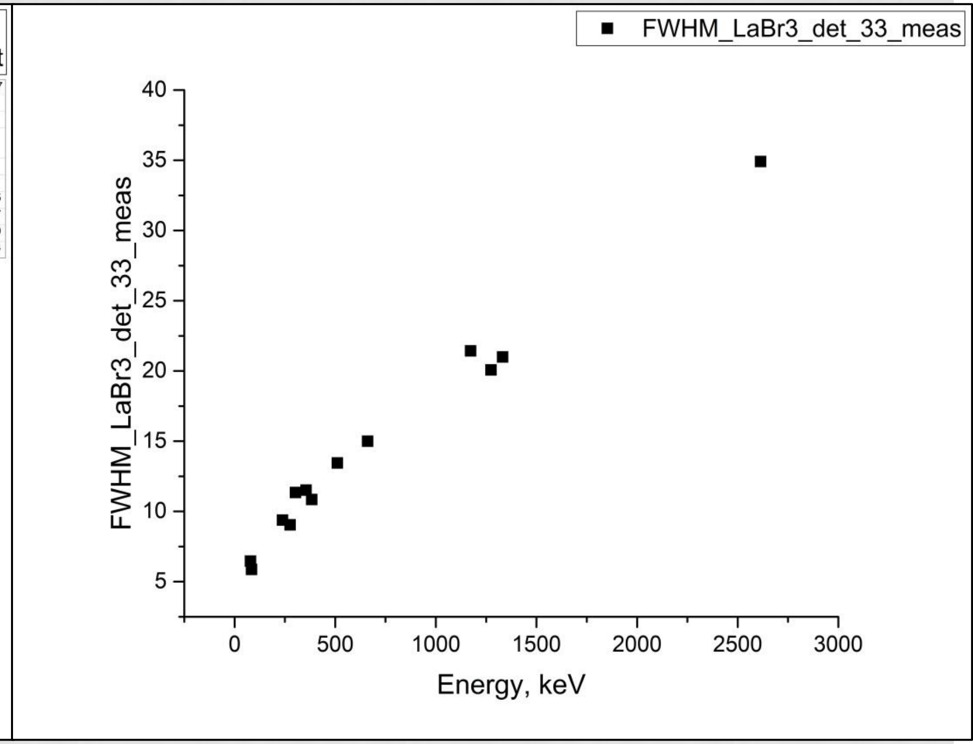


Equation	y = 4,79802E-4 + -4,72712E-7*x^1 + 2,09867E-10*x^2 + -3,30923E-14*x^3		
Weight	Instrumental		
Residual Sum of Squares	663,16347		
Adj. R-Square	0,93069		
		Value	Standard Error
Eff_measured	Intercept	4,79802E-4	4,78475E-5
	B1	-4,72712E-7	1,49015E-7
	B2	2,09867E-10	1,27983E-10
	B3	-3,30923E-14	3,08093E-14



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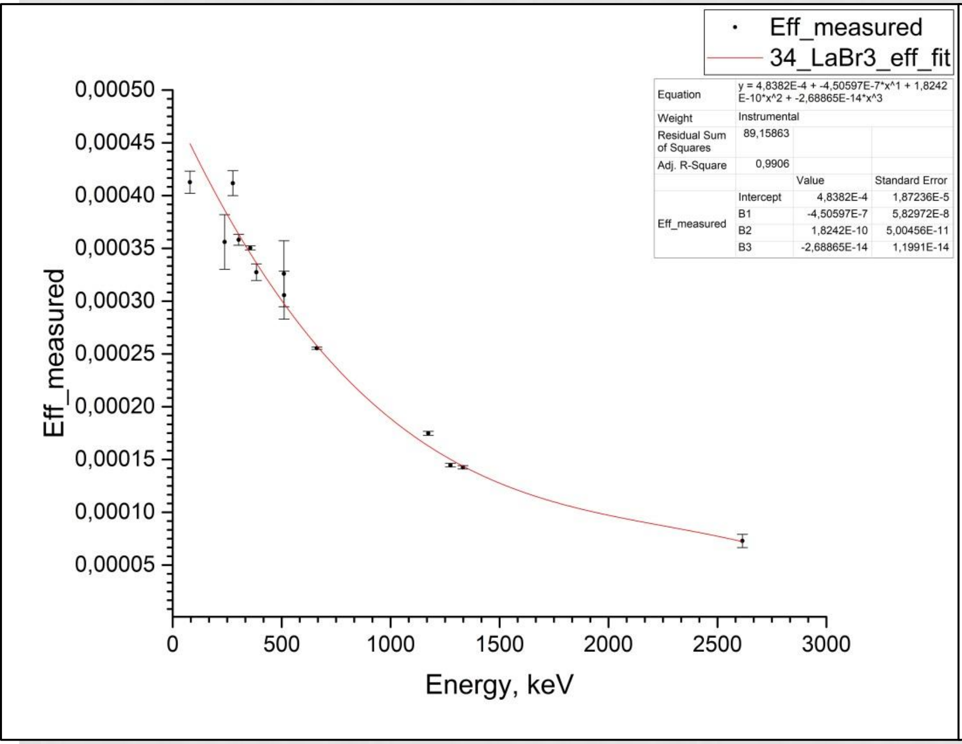

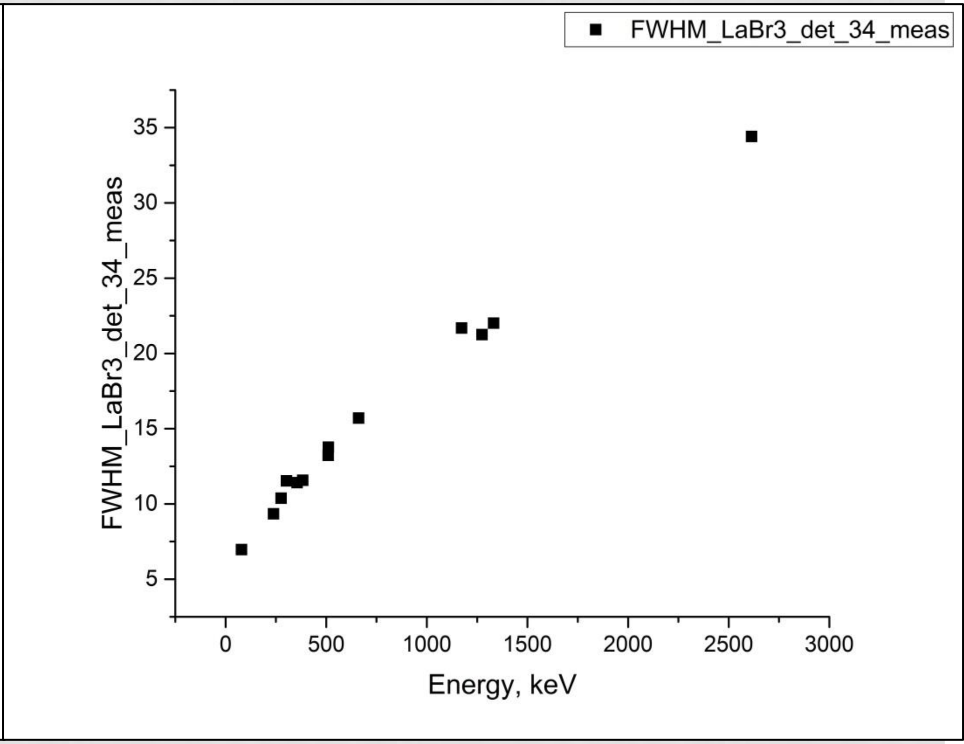

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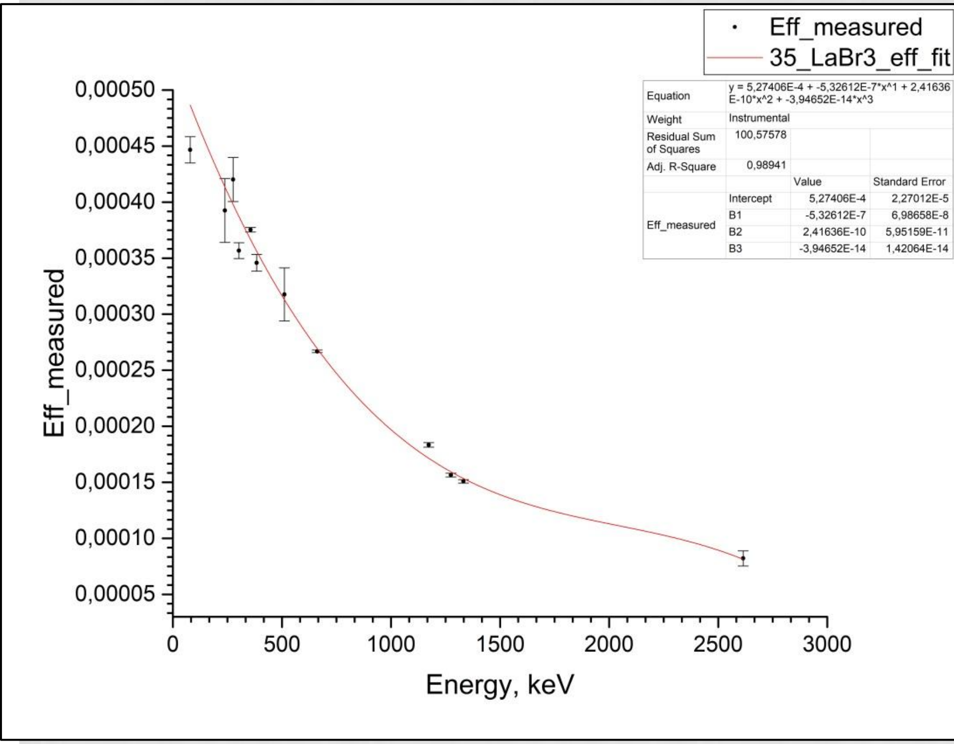
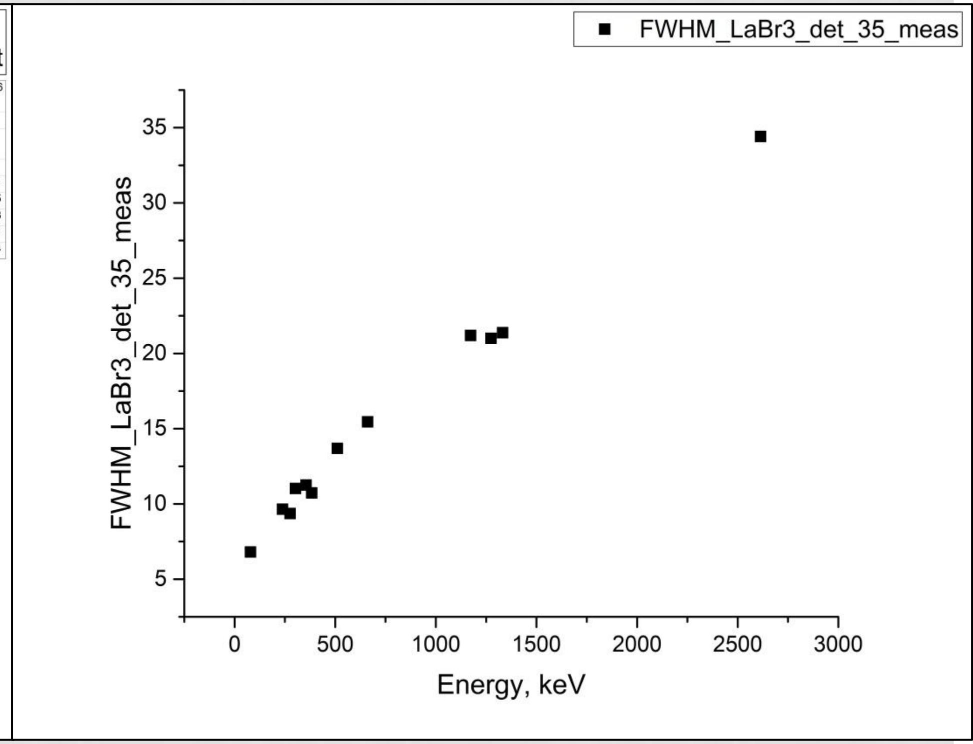
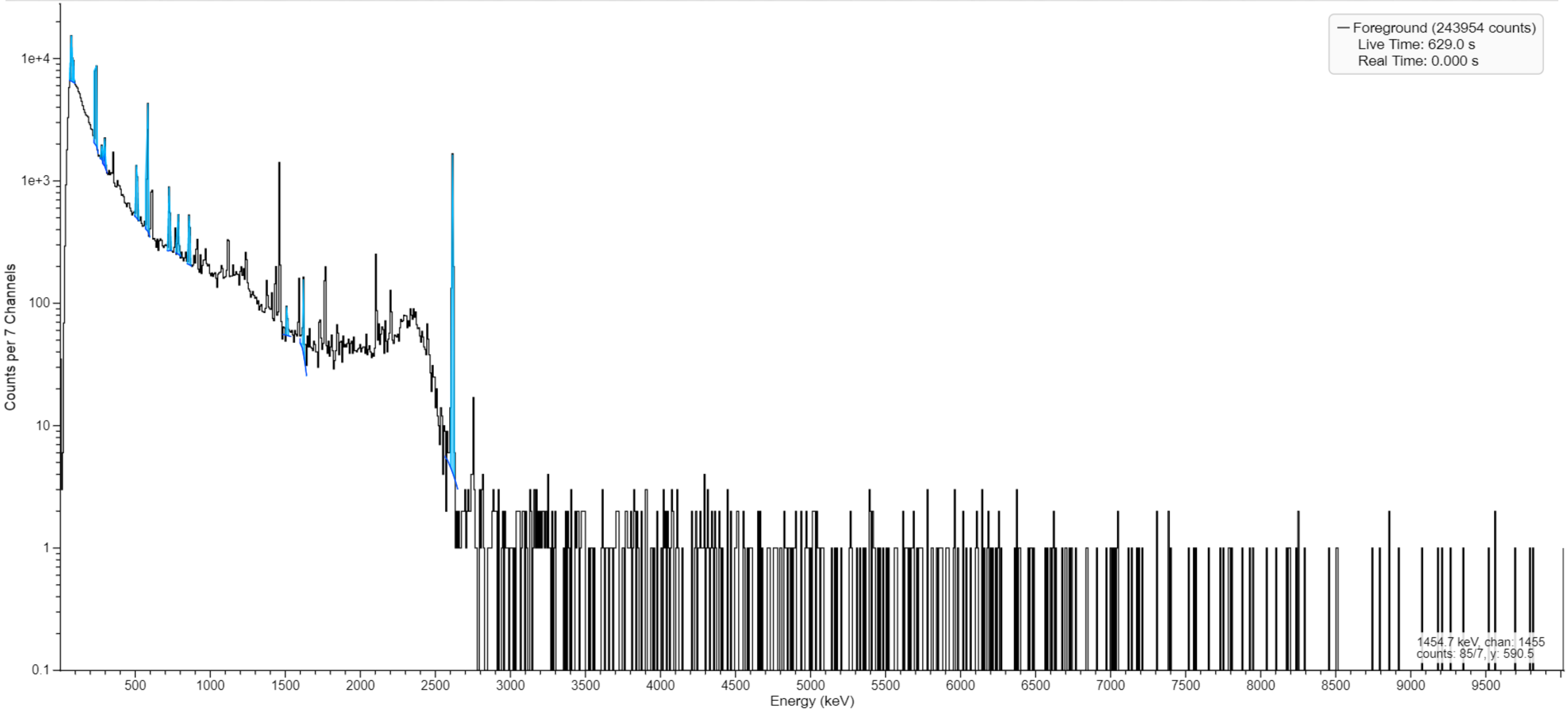




The acquired spectrum from ^{228}Th point source with HPGe



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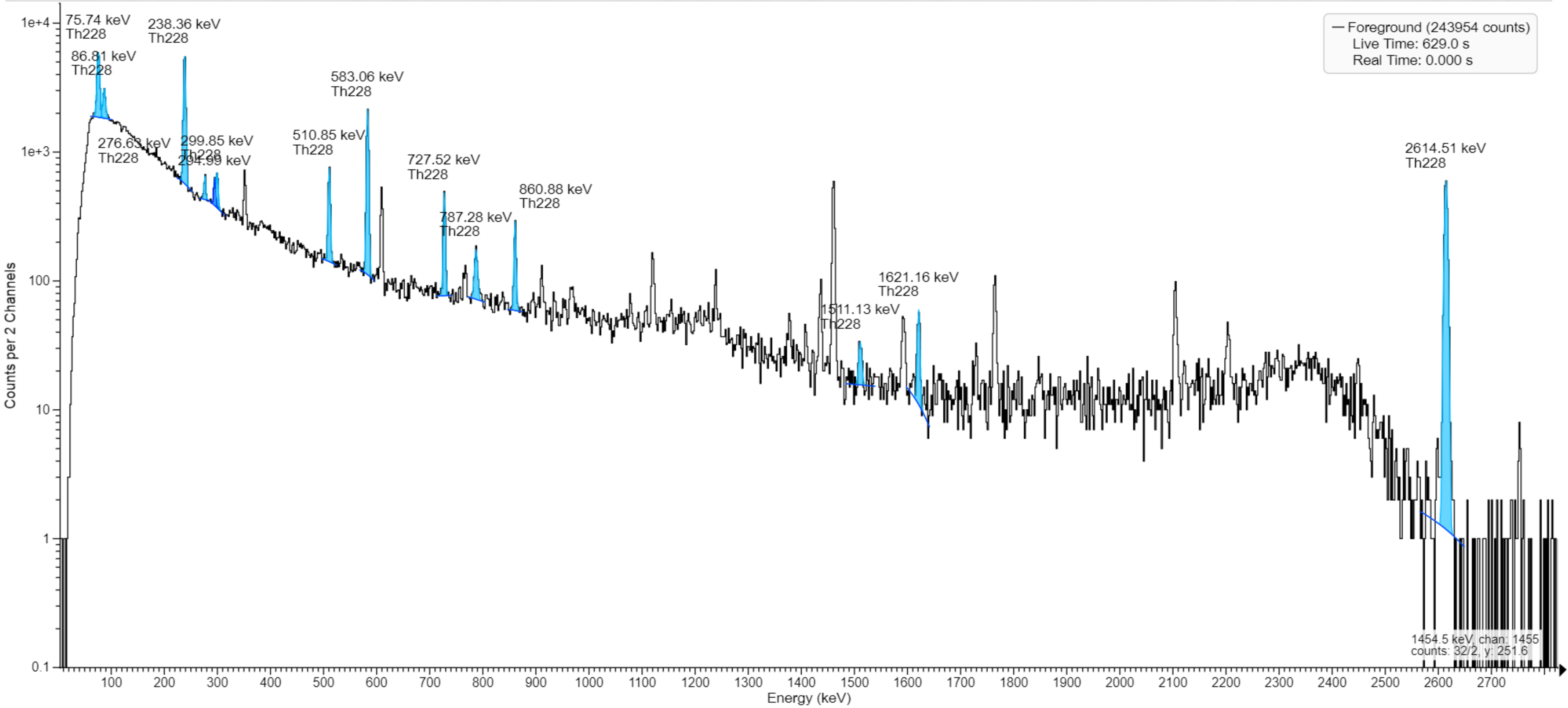
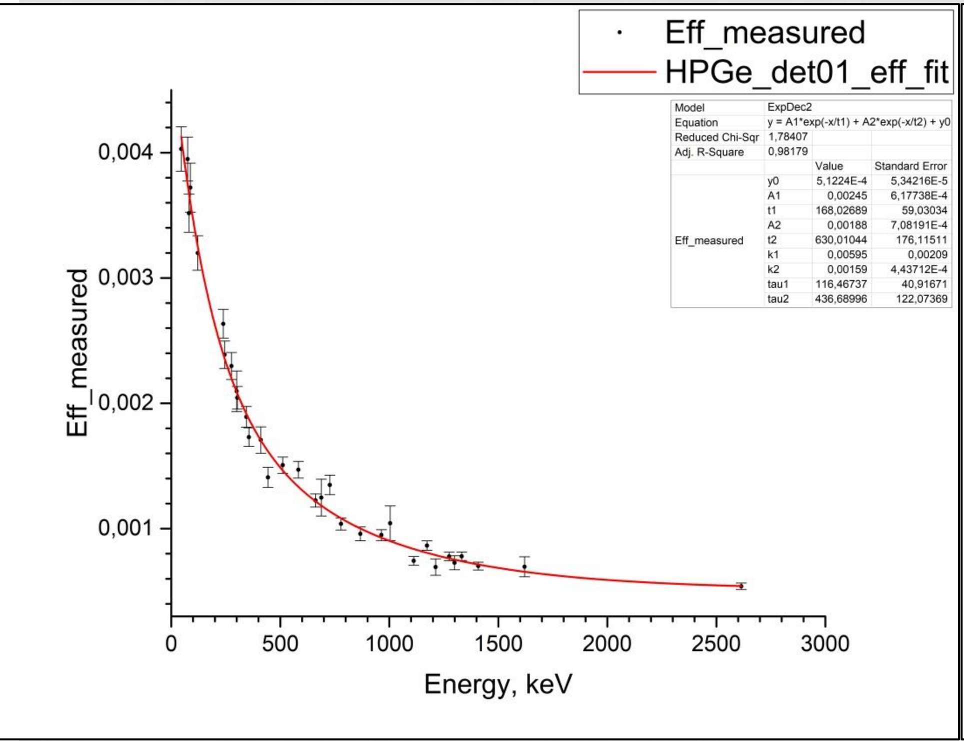
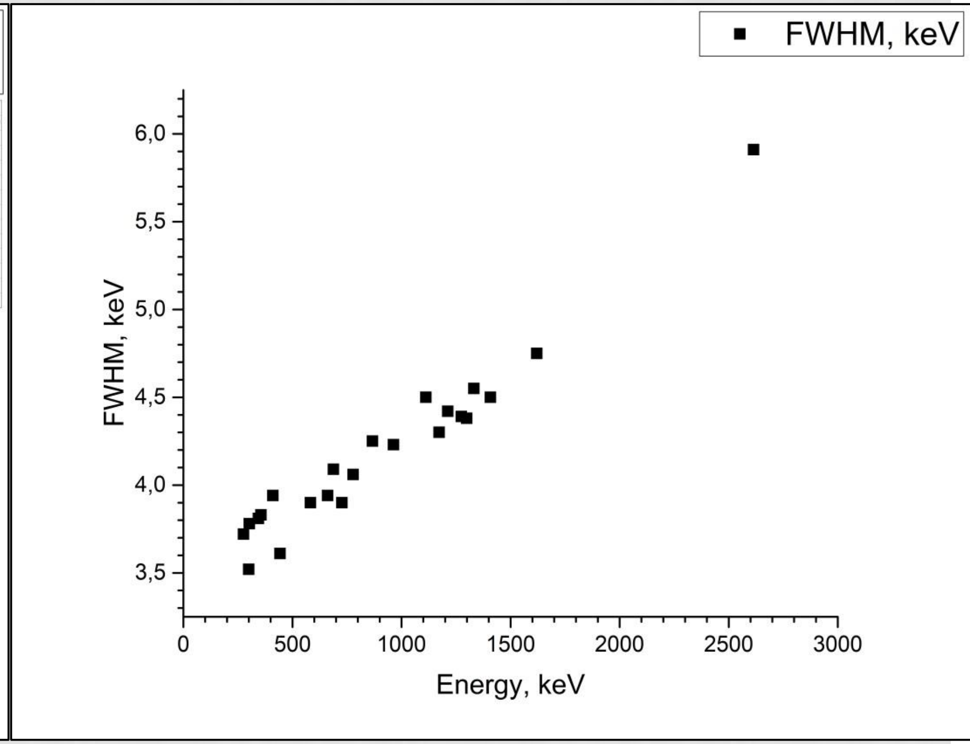


Measured characteristics for the energy range up to 2614 keV for HPGe detectors



Model	ExpDec2		
Equation	y = A1*exp(-x/t1) + A2*exp(-x/t2) + y0		
Reduced Chi-Sqr	1,78407		
Adj. R-Square	0,98179		
		Value	Standard Error
Eff_measured	y0	5,1224E-4	5,34216E-5
	A1	0,00245	6,17738E-4
	t1	168,02689	59,03034
	A2	0,00188	7,08191E-4
	t2	630,01044	176,11511
	k1	0,00595	0,00209
	k2	0,00159	4,43712E-4
	tau1	116,46737	40,91671
	tau2	436,68996	122,07369



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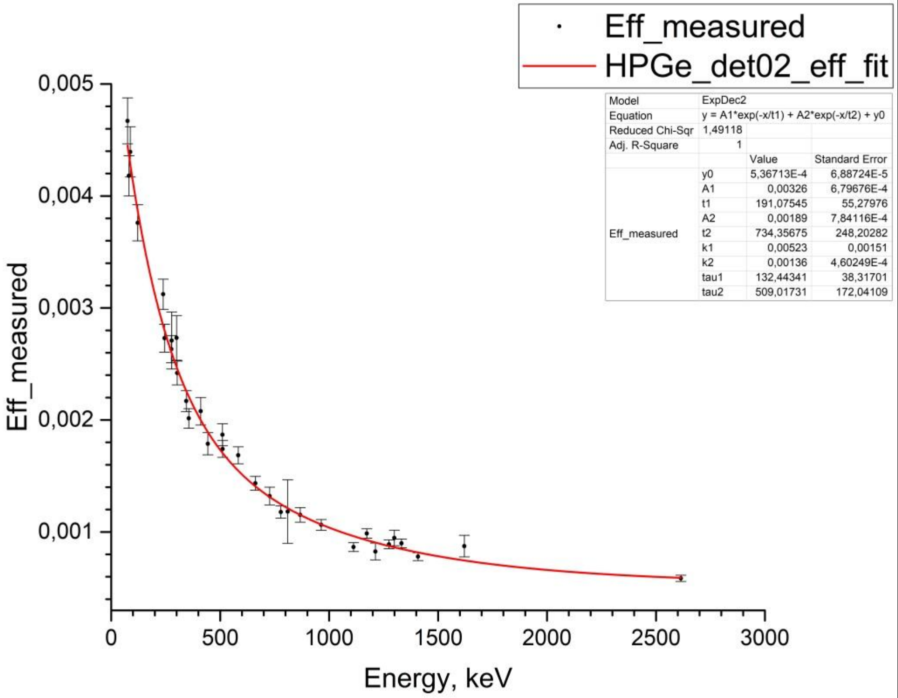
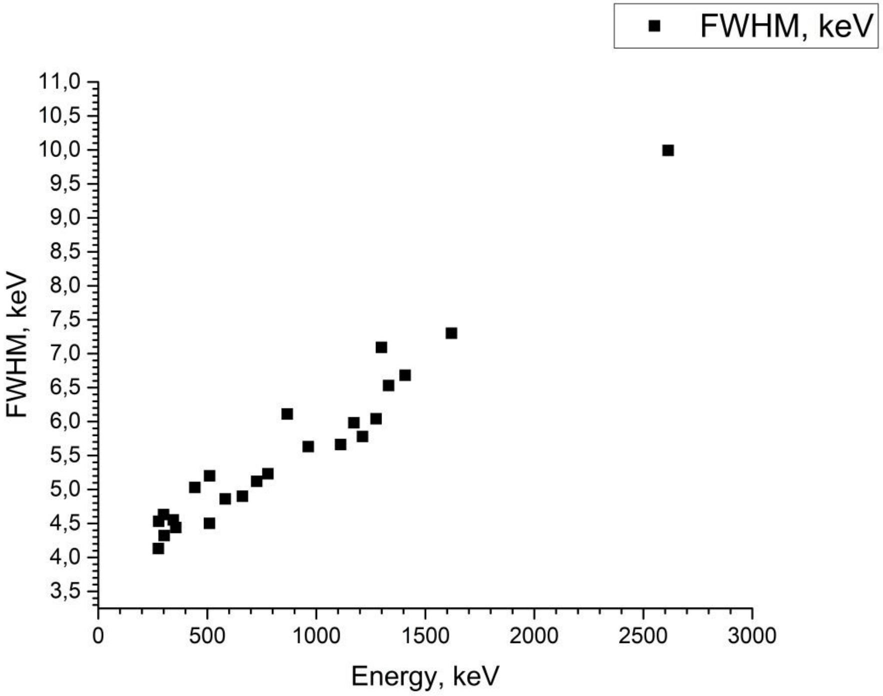
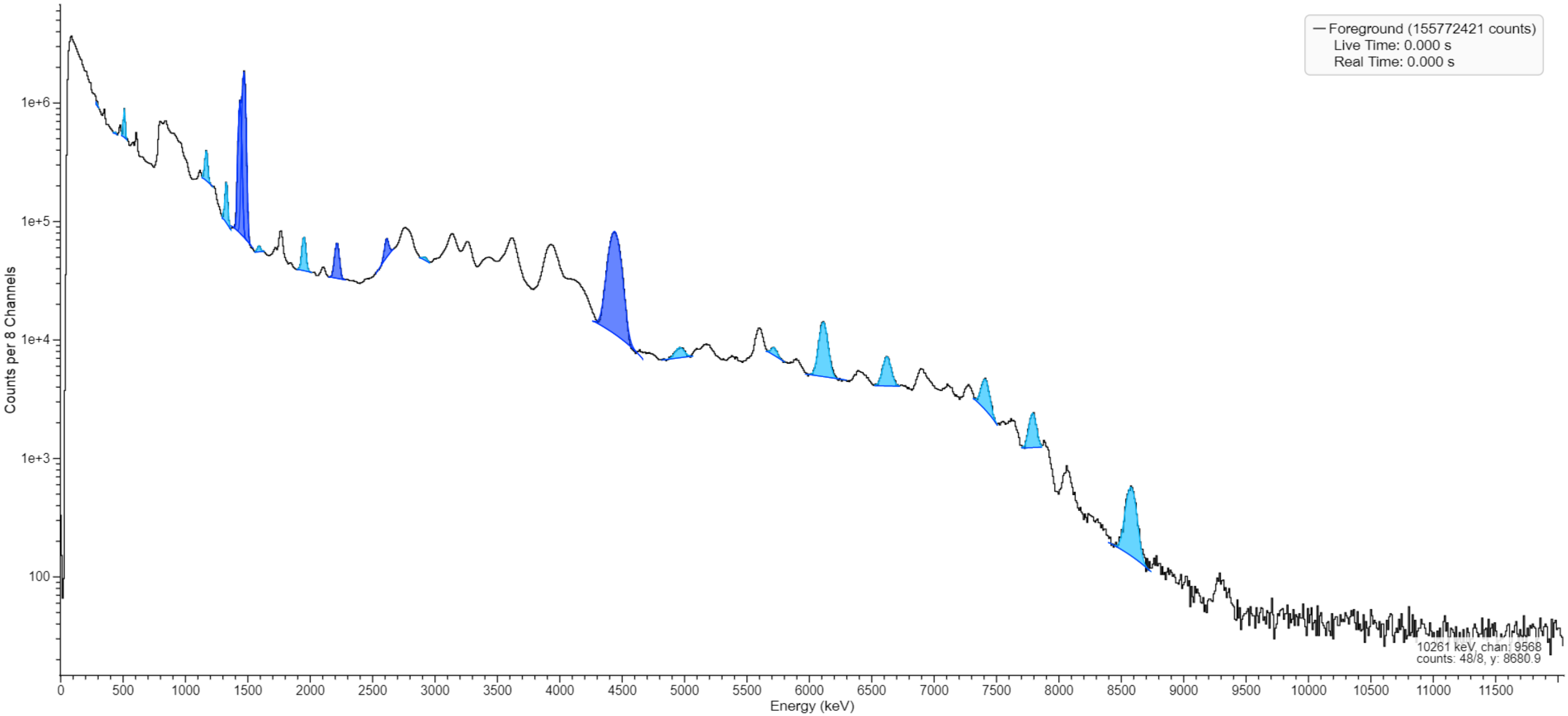


Model	ExpDec2		
Equation	y = A1*exp(-x/t1) + A2*exp(-x/t2) + y0		
Reduced Chi-Sqr	1,49118		
Adj. R-Square	1		
		Value	Standard Error
Eff_measured	y0	5,36713E-4	6,88724E-5
	A1	0,00326	6,79676E-4
	t1	191,07545	55,27976
	A2	0,00189	7,84116E-4
	t2	734,35675	248,20282
	k1	0,00523	0,00151
	k2	0,00136	4,60249E-4
	tau1	132,44341	38,31701
	tau2	509,01731	172,04109



The acquired spectrum from ^{35}Cl (n, γ) ^{36}Cl reaction with $LaBr_3$



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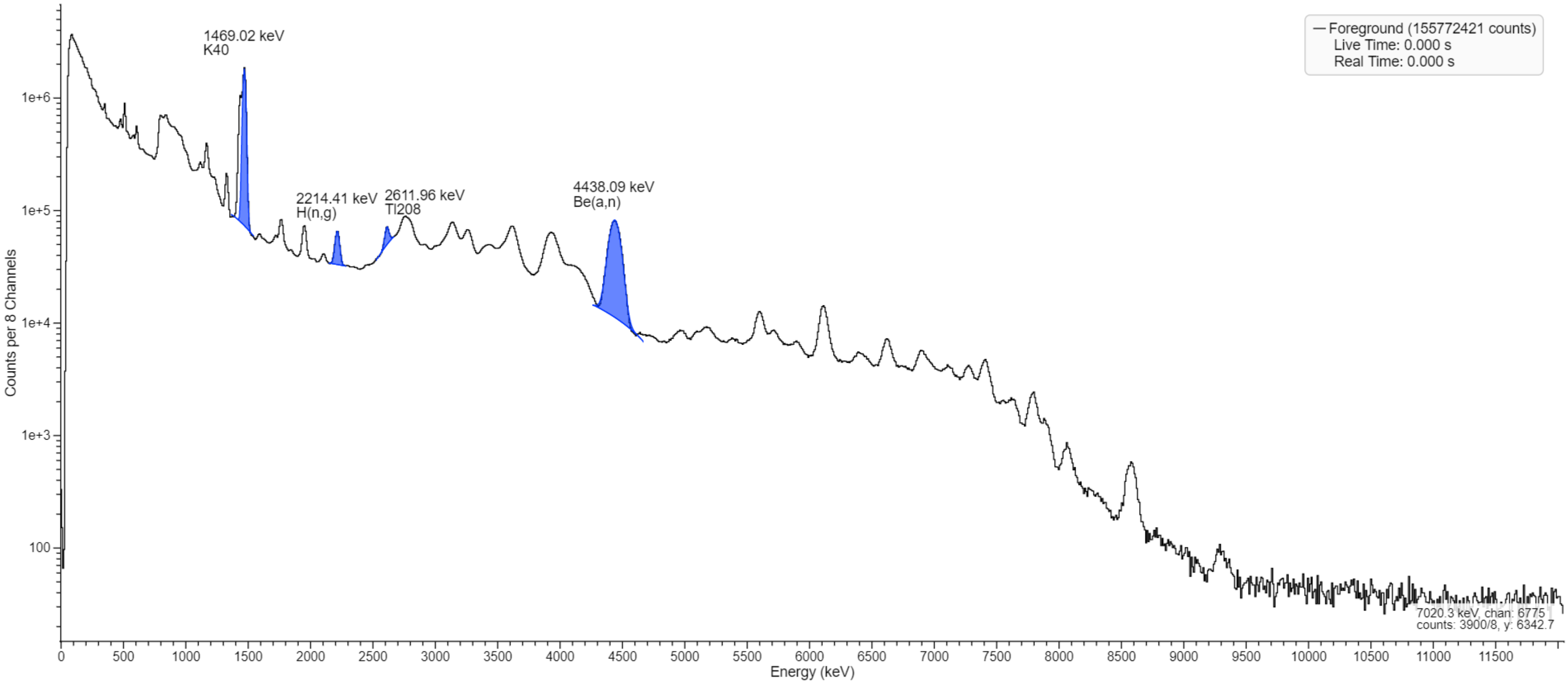

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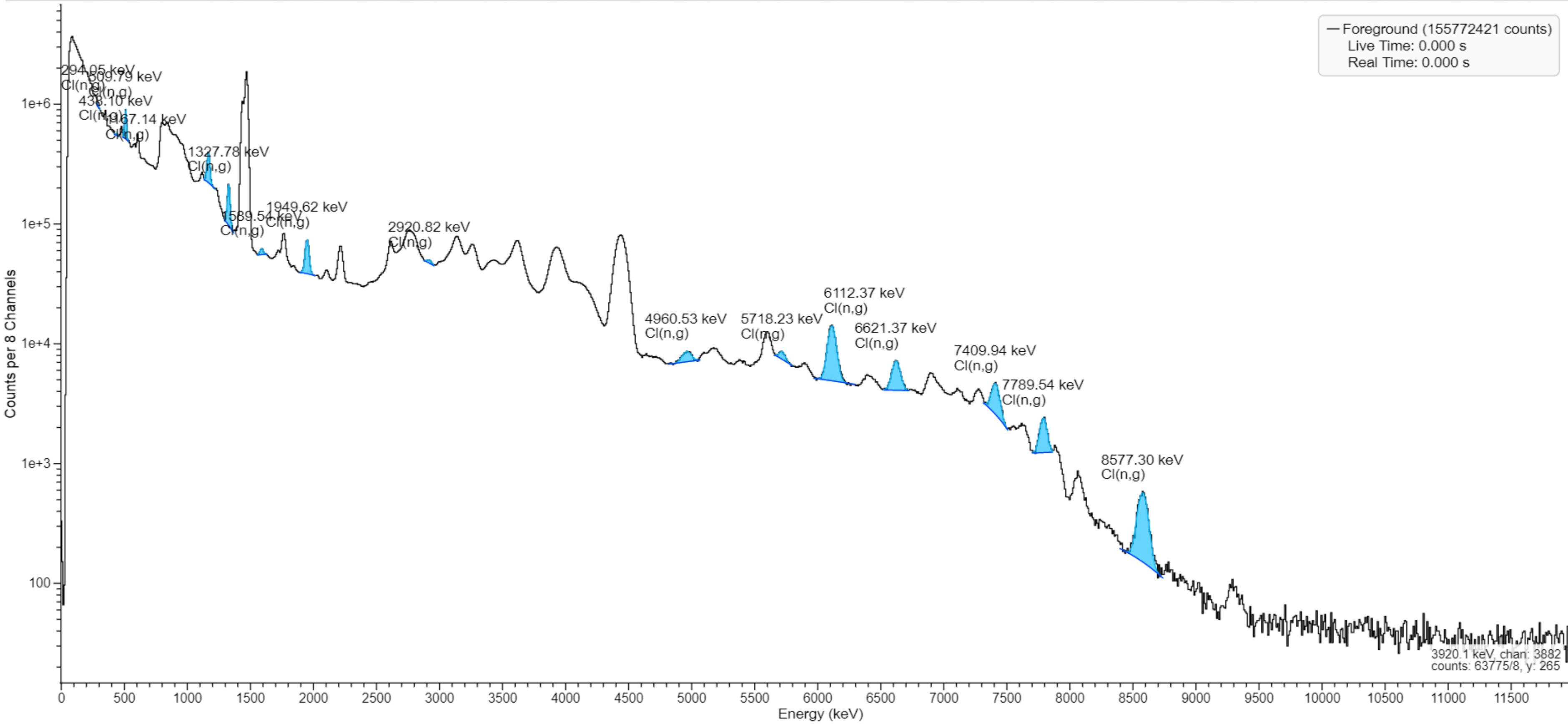
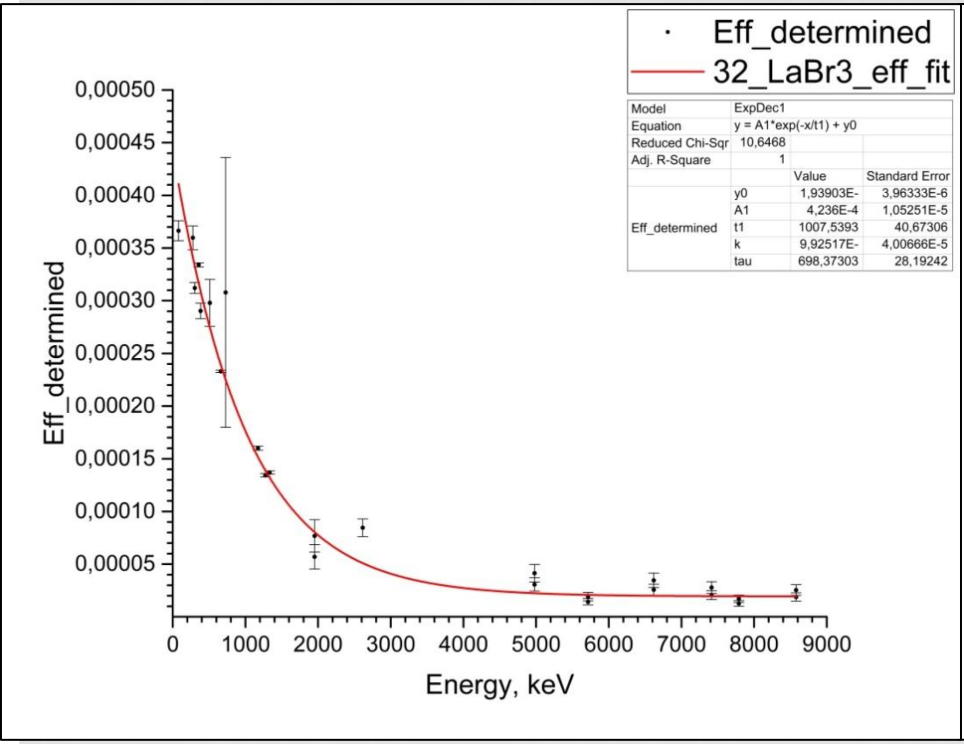


Efficiency calculation for energy range of gamma above 2614 keV

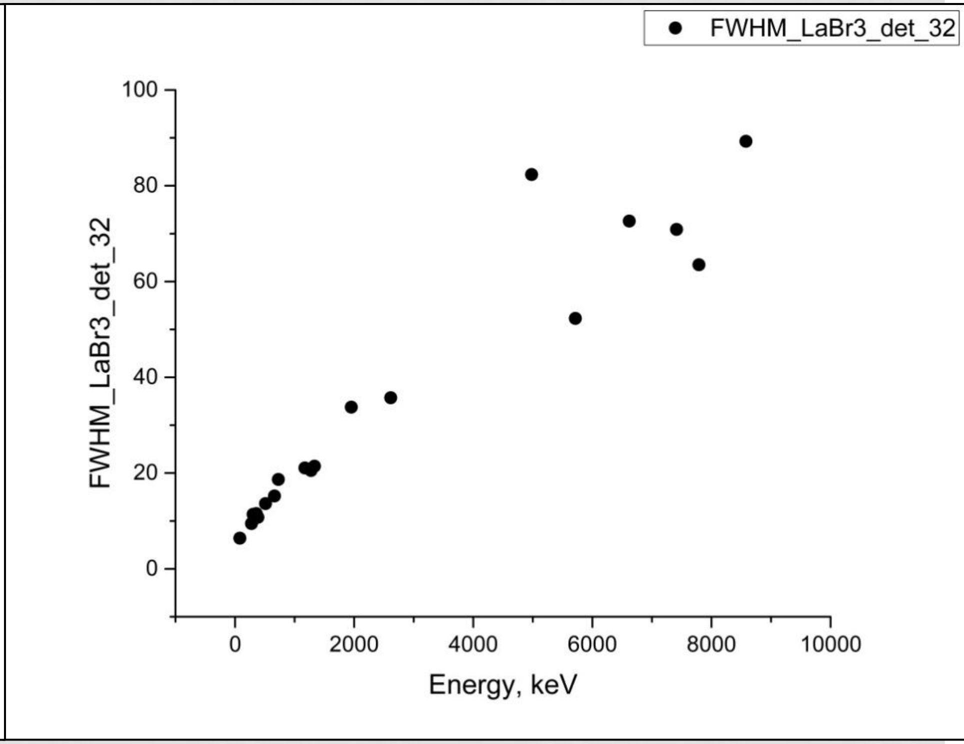
$$\varepsilon(E_{\gamma i}) = \frac{N_{\gamma}(E_{\gamma i}) \cdot I(E_{\gamma 0})}{I(E_{\gamma i}) \cdot N_{\gamma}(E_{\gamma 0})} \cdot \varepsilon(E_{\gamma 0})$$

ε – counting efficiency, N – energy peak counts, I – intensity of gamma emission,
γi – interested gamma energy, γ0 – reference gamma energy

Determined characteristics for wide energy range for $LaBr_3$ detectors



Model	ExpDec1		
Equation	y = A1*exp(-x/t1) + y0		
Reduced Chi-Sqr	10,6468		
Adj. R-Square	1		
		Value	Standard Error
Eff_determined	y0	1,93903E-	3,96333E-6
	A1	4,236E-4	1,05251E-5
	t1	1007,5393	40,67306
	k	9,92517E-	4,00666E-5
	tau	698,37303	28,19242



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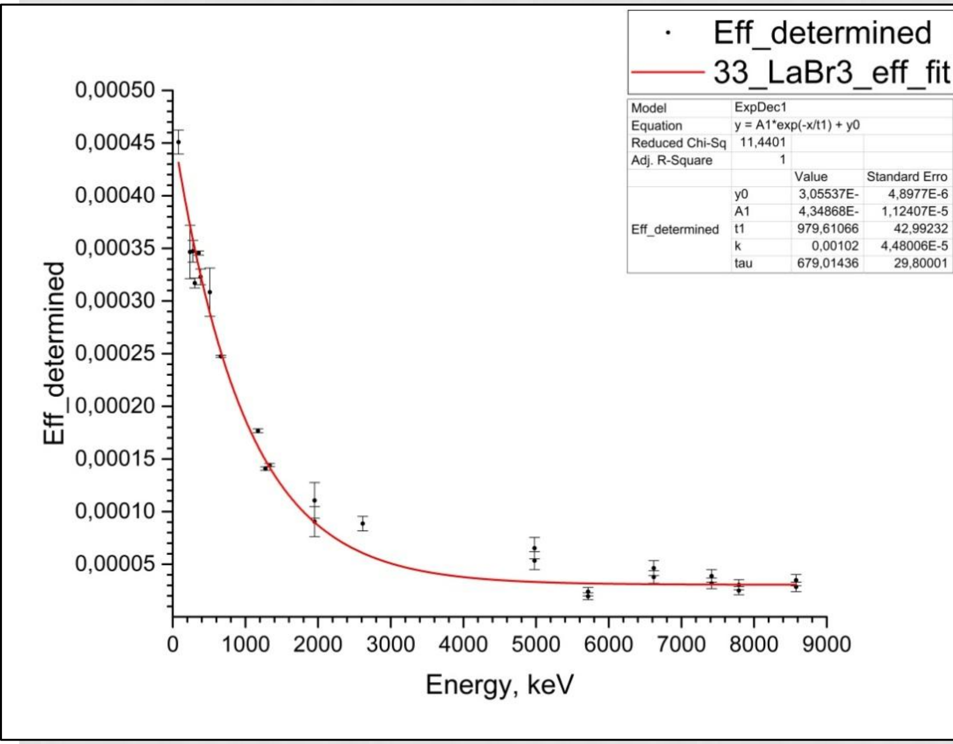

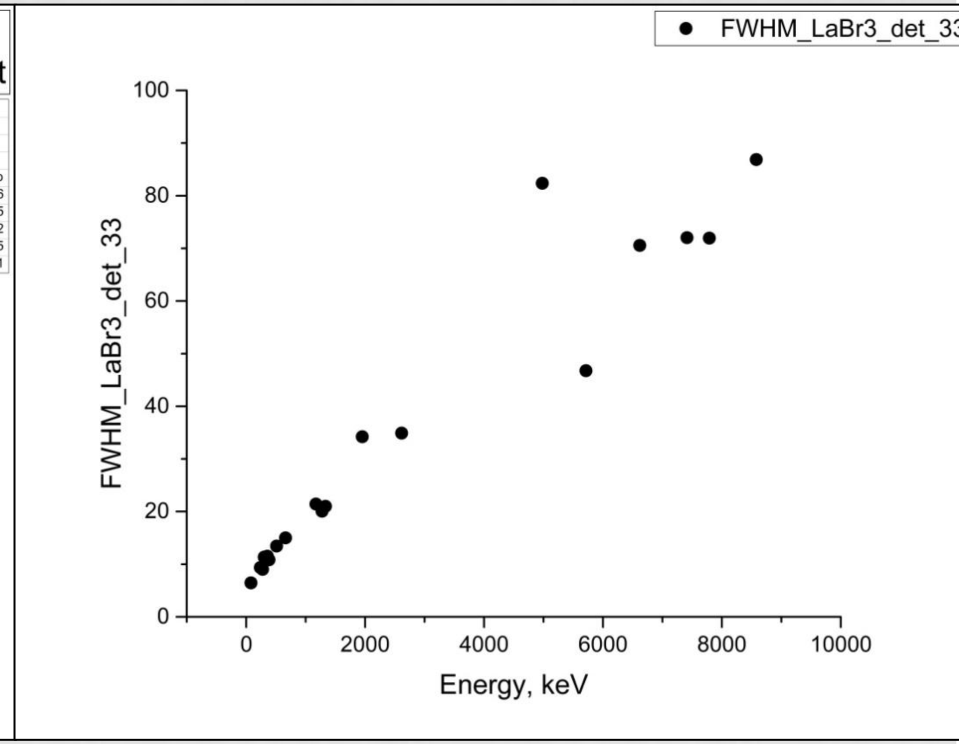

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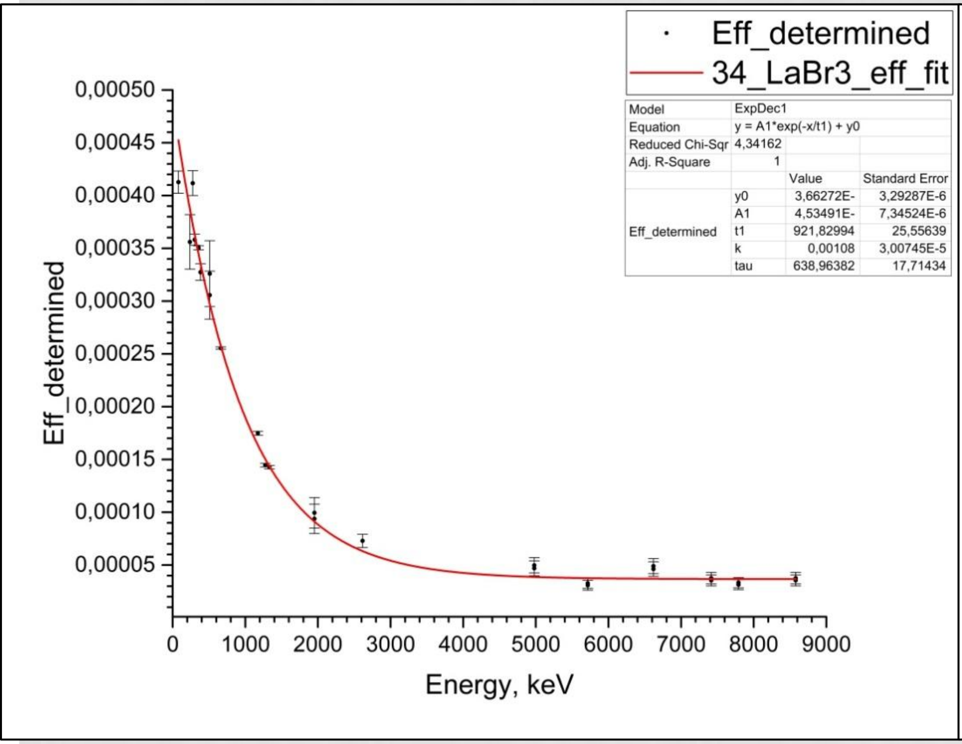

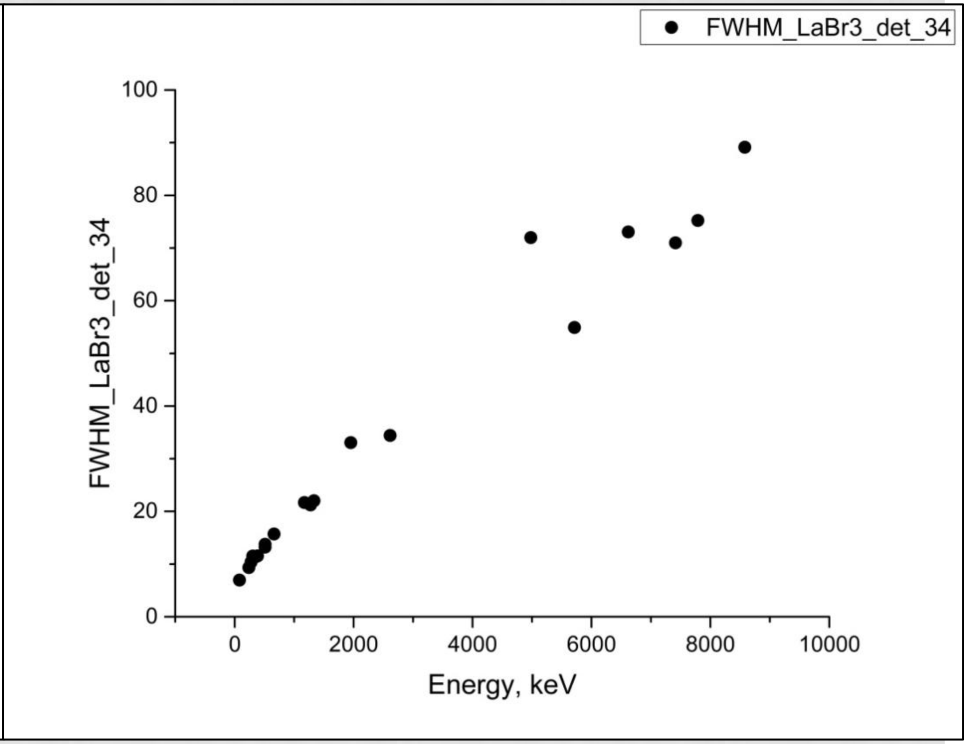

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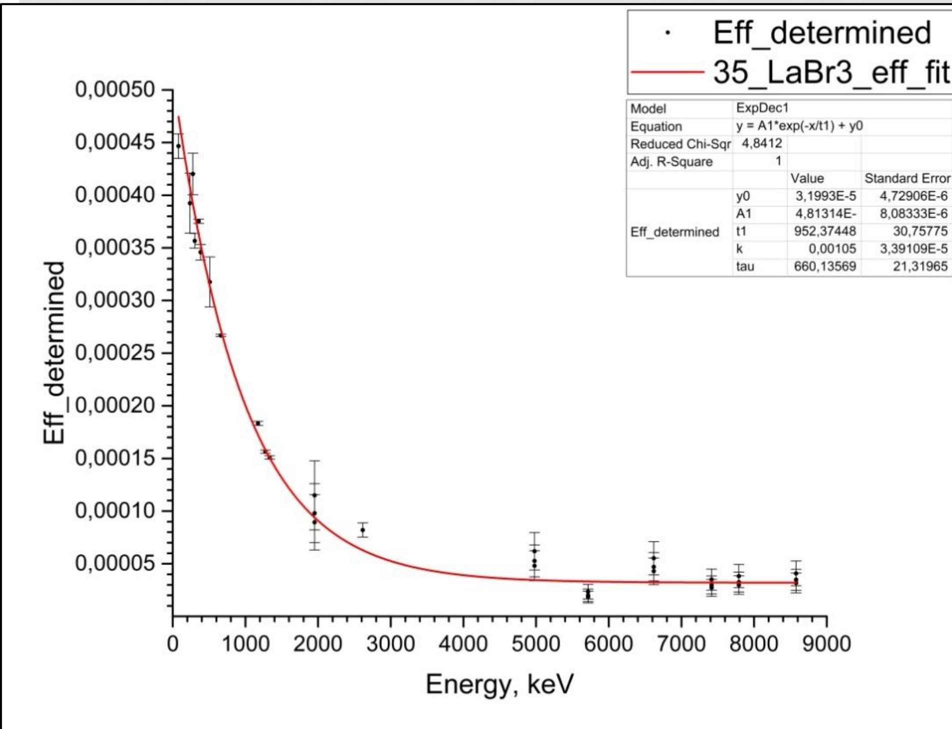
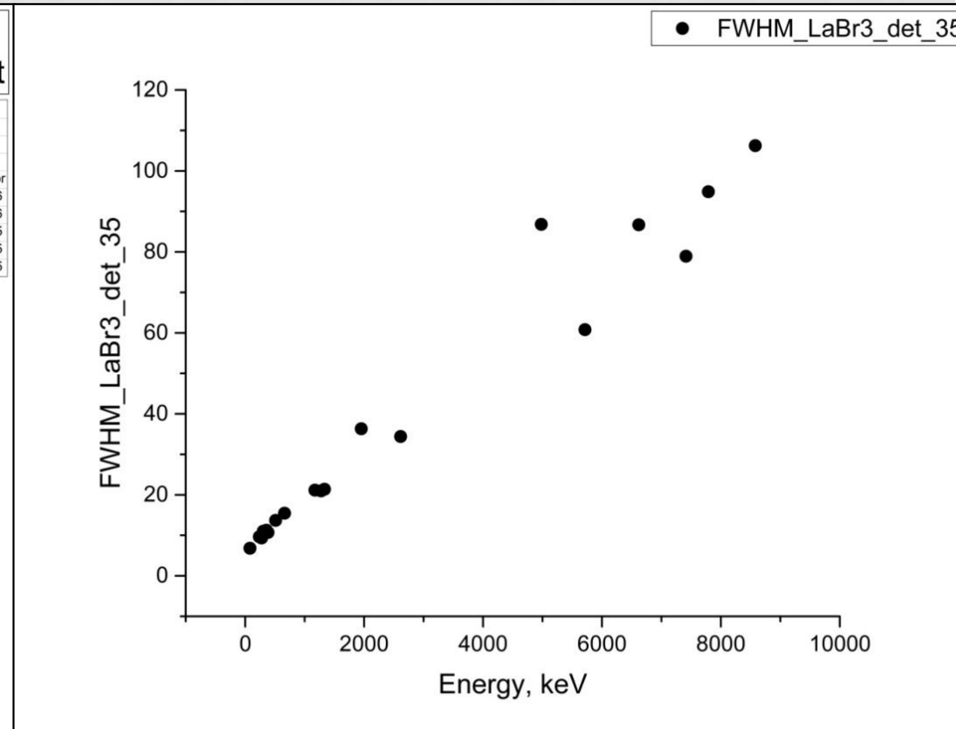
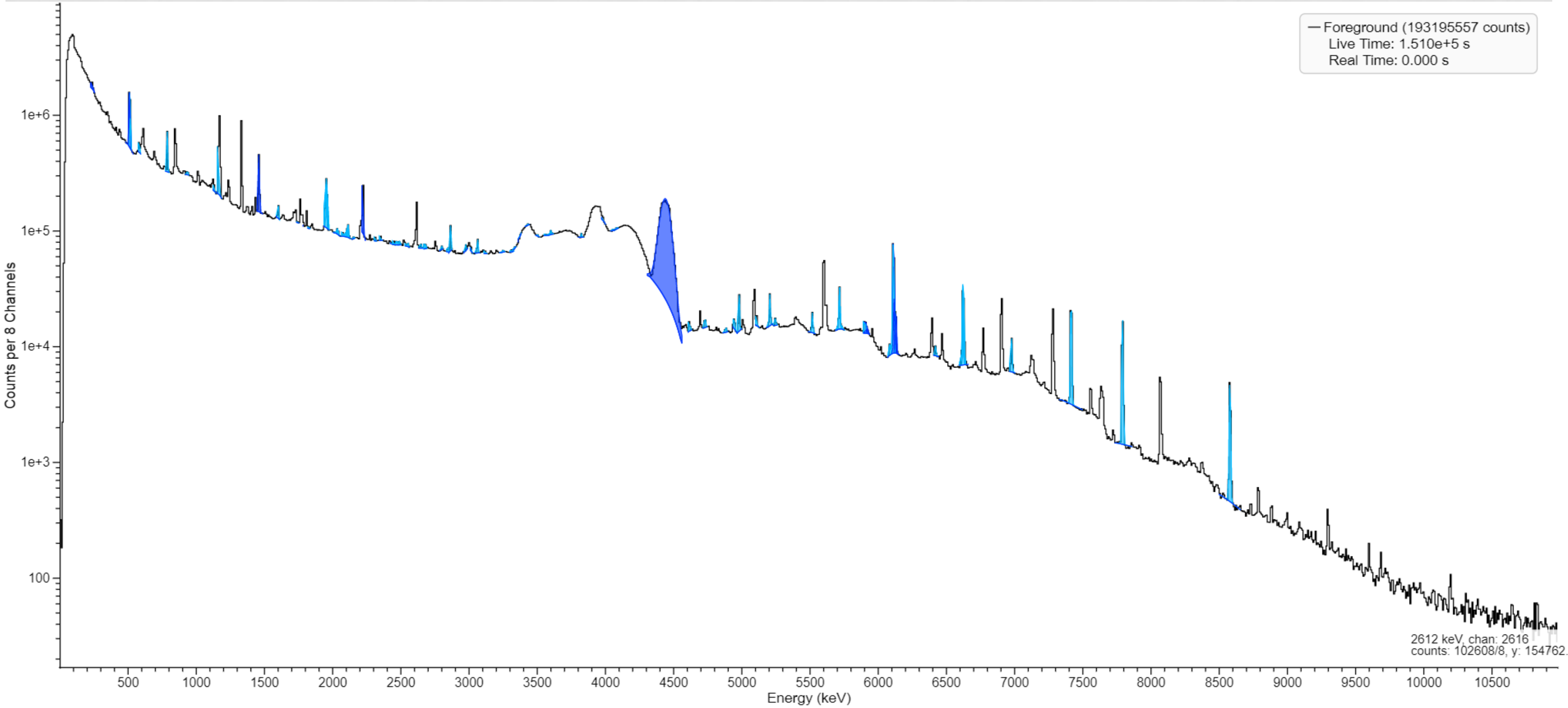
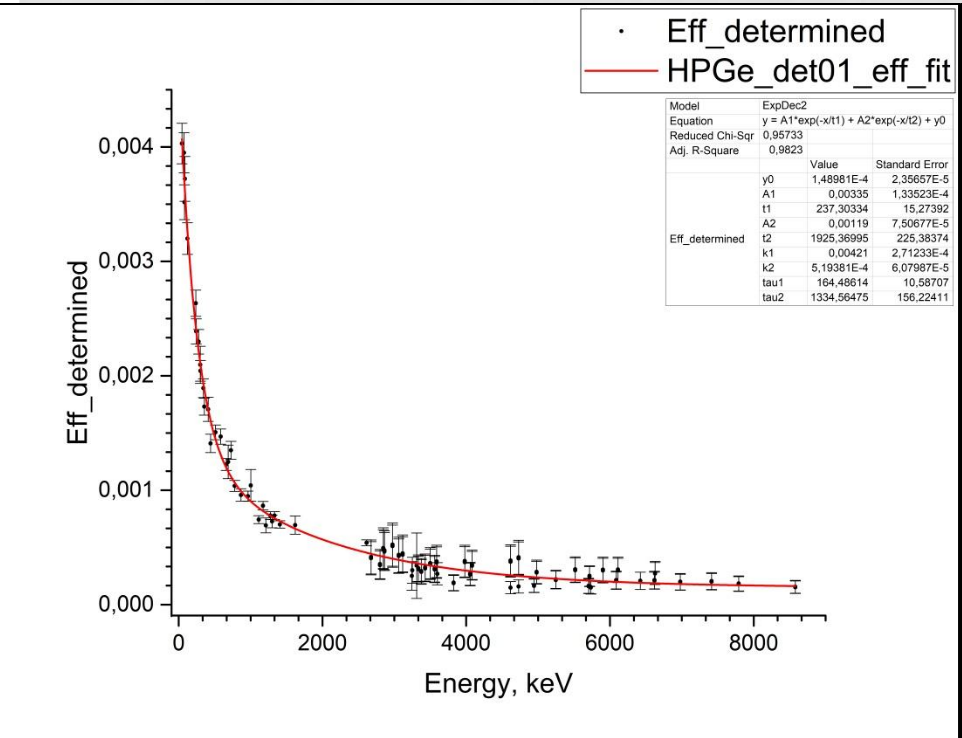




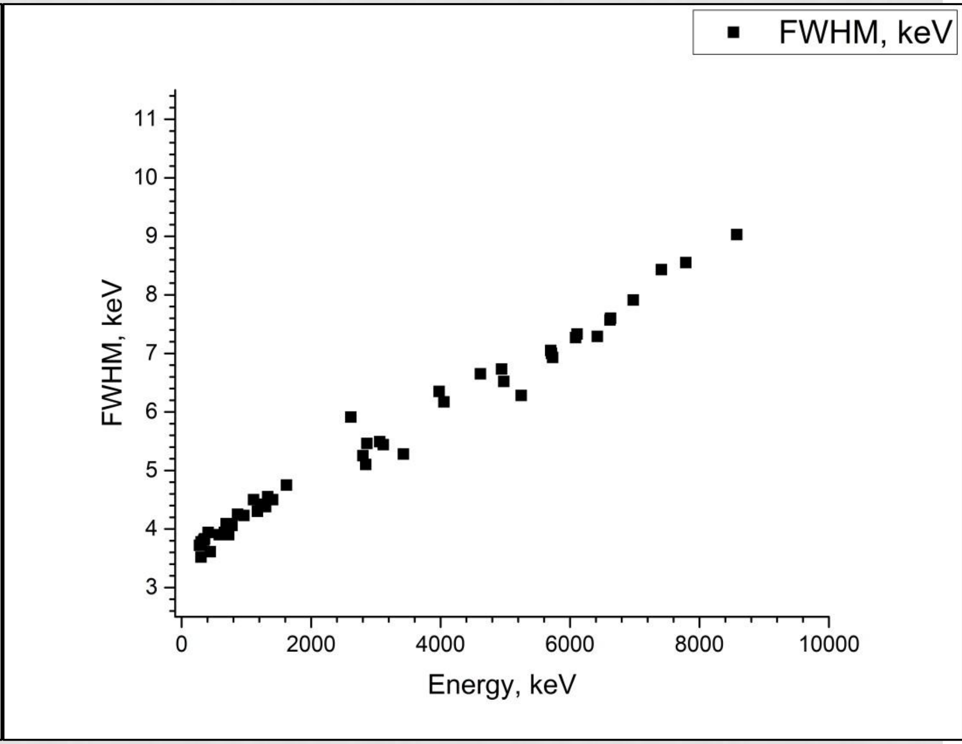
The acquired spectrum from $^{35}Cl\ (n, \gamma)\ ^{36}Cl$ reaction with HPGe



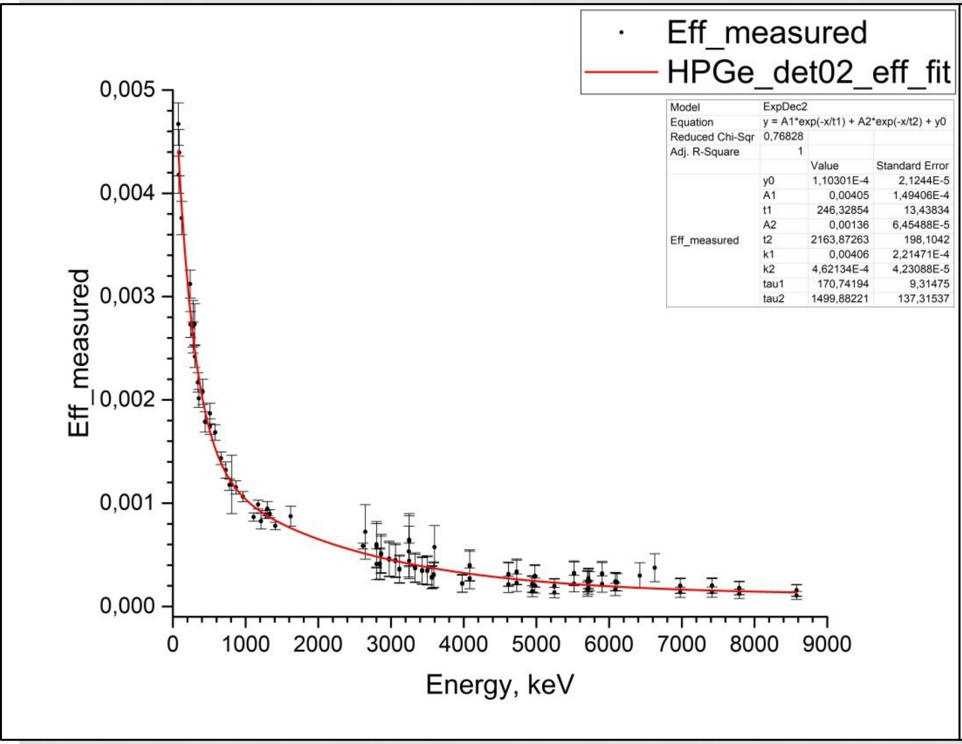
Determined characteristics for wide energy range for HPGe detectors



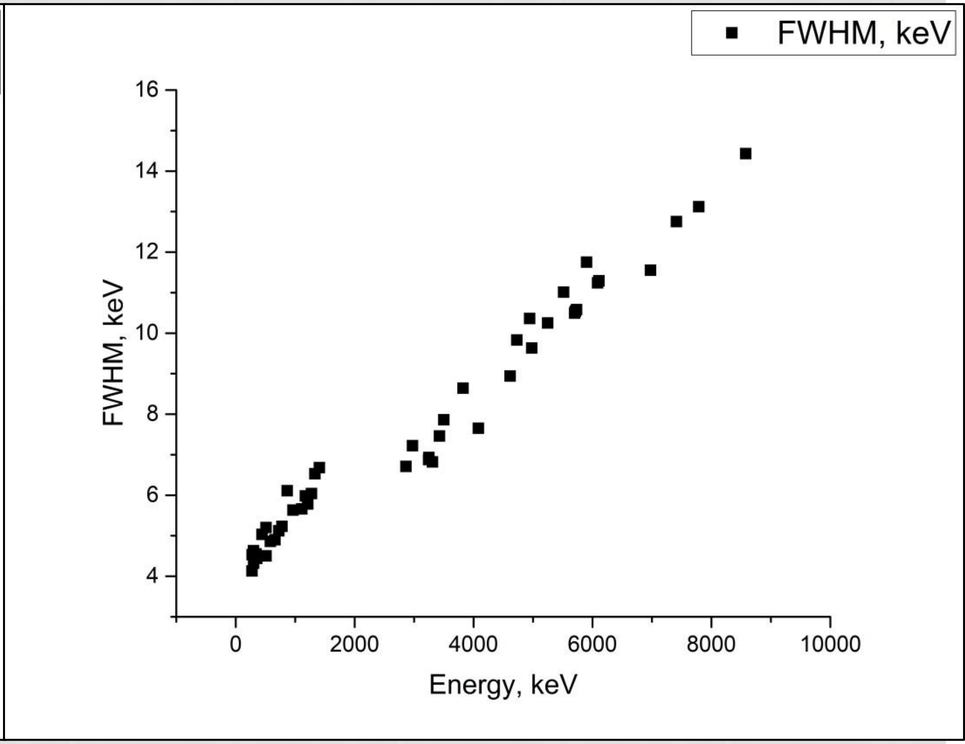
Model	ExpDec2		
Equation	y = A1*exp(-x/t1) + A2*exp(-x/t2) + y0		
Reduced Chi-Sqr	0,95733		
Adj. R-Square	0,9823		
		Value	Standard Error
Eff_determined	y0	1,48981E-4	2,35657E-5
	A1	0,00335	1,33523E-4
	t1	237,30334	15,27392
	A2	0,00119	7,50677E-5
	t2	1925,36995	225,38374
	k1	0,00421	2,71233E-4
	k2	5,19381E-4	6,07987E-5
	tau1	164,48614	10,58707
	tau2	1334,56475	156,22411



Determined characteristics for wide energy range for HPGe detectors



Model	ExpDec2		
Equation	y = A1*exp(-x/t1) + A2*exp(-x/t2) + y0		
Reduced Chi-Sqr	0,76828		
Adj. R-Square	1		
		Value	Standard Error
Eff_measured	y0	1,10301E-4	2,1244E-5
	A1	0,00405	1,49406E-4
	t1	246,32854	13,43834
	A2	0,00136	6,45488E-5
	t2	2163,87263	198,1042
	k1	0,00406	2,21471E-4
	k2	4,62134E-4	4,23088E-5
	tau1	170,74194	9,31475
	tau2	1499,88221	137,31537



Summary

- ✓ Within the TANGRA project at JINR-FLNP, a new experimental setup was built to precisely measure the yields (probabilities, cross-sections) of (n, x n’ γ) nuclear reactions;
- ✓ The acquired data from the HPGe and $LaBr_3$ detectors were successfully decoded and processed;
- ✓ The counting efficiencies in the wide energy range for the HPGe and $LaBr_3$ detectors were calculated using measurements of a set of standard radioactive point gamma sources (^{22}Na, ^{60}Co, ^{133}Ba, ^{137}Cs, ^{228}Th) and the radioactive capture reaction of the neutrons on the ^{35}Cl nucleus.