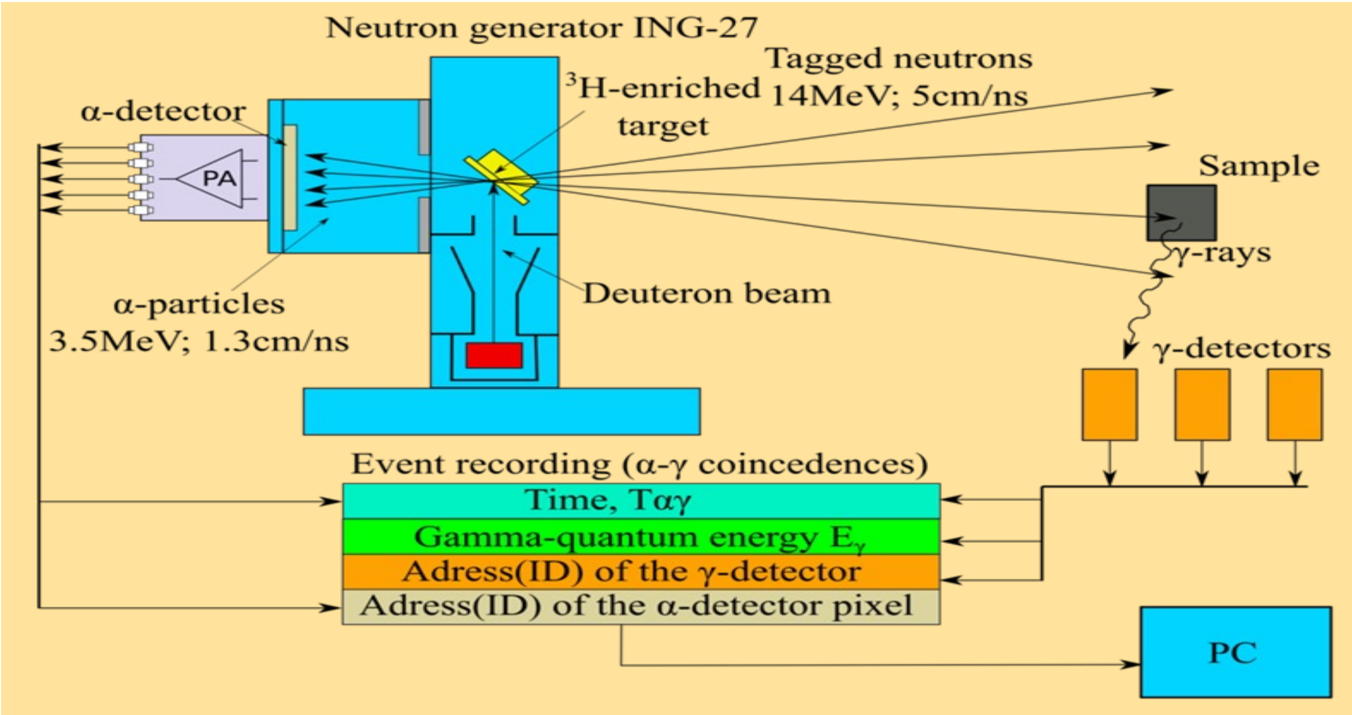
Project TANGRA
TAgged Neutrons & Gamma-Rays

Determination of the Photo-peak Efficiency with Application of Covariance Analysis of γ-Ray Detectors used in TANGRA Project



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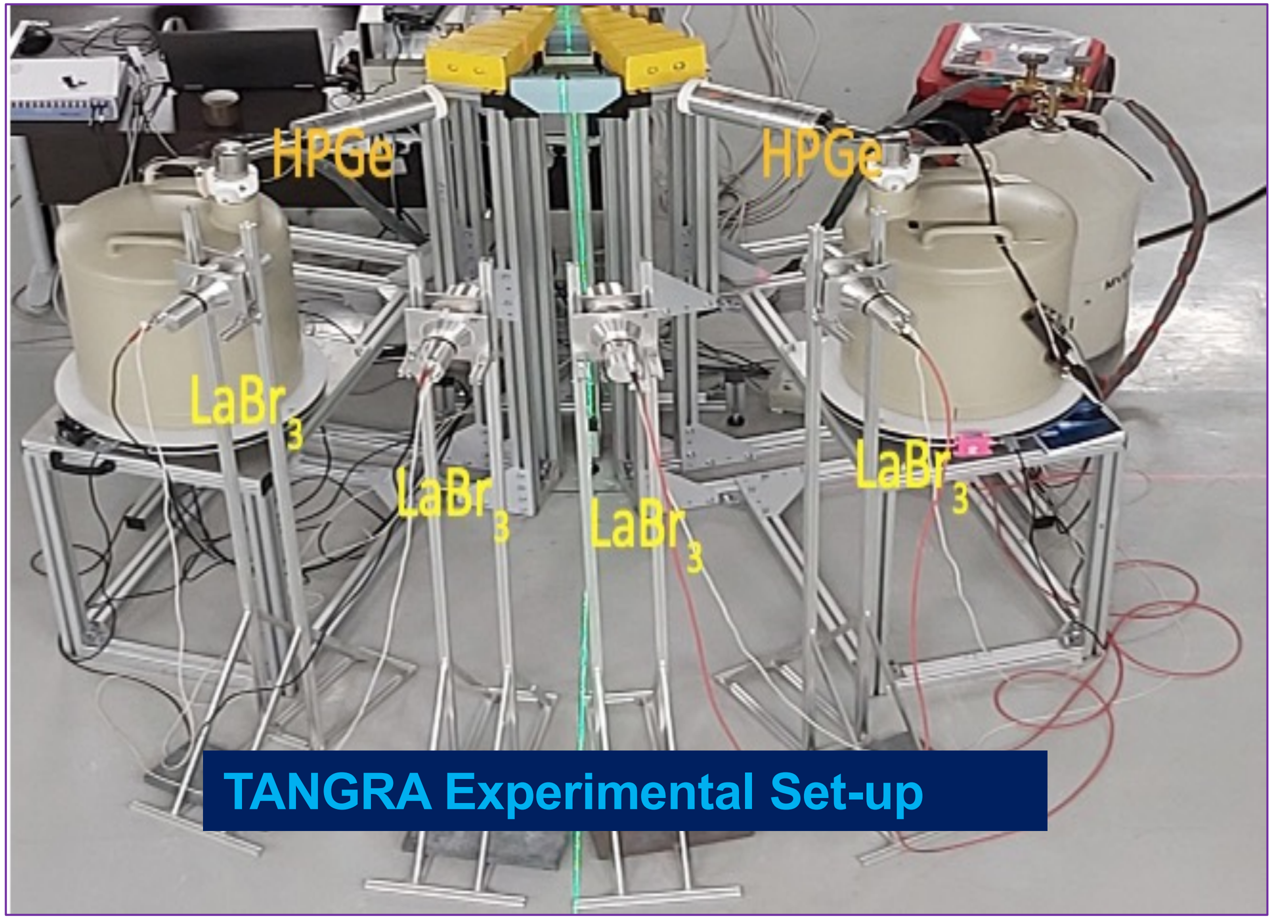
Introduction

Our (n, xγ) reactions using TNM for accurate Data:

- **Available data of (n,xγ) reactions is not accurate.**
- **Angular distributions for low-intense γ-transitions have not been measured before.**
- **Eliminate discrepancies between available experimental and evaluated data.**
- **For some nuclei/gamma transitions the gamma-ray anisotropy hasn't been measured at all.**
- **Investigate possible differences between neutron and proton scattering.**
- **Angular anisotropy of the emitted gamma-rays has to be taken into account if the tagged neutron method is used for elemental analysis.**
- **Possible upgrade of the setup with $LaBr_3$(Ce) and HPGe γ-detectors to measure angular distributions.**
- **To measure cross-section value of (n,xγ) reaction accurately, we need calibrate our LaBr3(Ce) and HPGe γ-detectors.**
- **Analyzed the photo-peak efficiencies of HPGe and $LaBr_3$(Ce) using ^{22}Na, ^{60}Co, ^{133}Ba, ^{137}Cs. ^{152}Eu and ^{228}Th.**
- **Measured the relative photo-peak efficiency using ^{35}Cl(n, γ)^{36}Cl reactions.**
- **Generate Monte Carlo simulation (Geant4) and compared with our data.**
- **Added the covariance matrix analysis in our results to identify the uncertainty accurately.**

Studying of Characteristics of HPGe and $LaBr_3$ Detectors

We have performed the Characteristics Srudies of HPGe and LaBr3 gamma-rays detectors.



Possible upgrade of the setup with HPGe and $LaBr_3$(Ce) γ-detectors to measure angular distributions.

Photo-peak Efficiency

Absolute efficiency can be defined as

$$\epsilon_{abs} = \frac{number\ of\ pulses\ recorded}{number\ of\ radiation\ quanta\ emitted\ by\ source}$$

Photo-peak efficiency,

$$\epsilon_{exp} = \frac{N}{AI_y T_m} \times 100\%$$

Where,
A= Activity of the Radioactive Source.
N=Number of Counts of the Photo-peak.
I_Y= Emission Probability
T_m= Measuring time.
Error in Photo-peak Efficiency,

$$\delta\epsilon_{exp} = \epsilon_{exp}\sqrt{(\frac{\delta N}{N})^2 + (\frac{\delta A}{A})^2 + (\frac{\delta I_Y}{I_Y})^2 + (\frac{\delta T_m}{T_m})^2}$$

Covariance Analysis

- The covariance (correlation) analysis is a mathematical tool that calculates the best estimate of the uncertainty as well as cross-correlations between measured quantities

Photo-peak Efficiency

$$\epsilon_{exp} = \frac{N}{AI_y T_m}$$

There are several sources of uncertainty in the calibration process, which propagate as the uncertainty in the detector's efficiency. This is basically from N, Iγ, A. As a result, the detector's efficiency can be expressed as a function of three attributes,

$$\varepsilon = f(N, I\gamma, A)$$

- If the measurements of a particular attribute are made independently, then the corresponding micro–correlation matrix is a unit matrix.

Let x1, x2, x3 represent the three attributes, namely, γ-ray abundance, γ-ray peak counts, source activity of the radio nuclide respectively.
If Δx_r is the uncertainty in x_r which is used in measuring efficiency ε_i then the partial uncertainty in ε_i due to the attribute x_r is given by

.
$$e_{ir} = \frac{\partial \epsilon_i}{\partial x_r} \Delta x_r, \qquad i = 1, 2, 3, 4 \ldots . 11 \; (for\ 152 - Eu)$$

The covariance matrix for these i-th (11 for Eu-152) measurements is given by

$$(V_\epsilon)_{ij} = \sum_{r=1}^{W} S_{ijr} e_{ir} e_{jr}$$

where S_{ijr} is the micro–correlation between e_{ir} and e_{jr} due to the r-th attribute.

Covariance Matrix Analysis

- For the uncorrelated elements, S_{ijr} can be written as an ($n \times n$) unity matrix and a square matrix of order ($n \times n$) with each element set to "1" for the completely correlated case.
- For partial correlated cases, S_{ijr} can alternatively be an ($n \times n$) matrix with elements $0 < S_{ijr} < 1$.

The micro-correlation matrices for (N, I_γ, A) can be designated as,

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}, \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

With this information of micro–correlations and partial uncertainties, we generate covariance matrix for efficiencies with Complete information of uncertainties. Infact the total uncertainties in measured efficiencies are given by

$$(\sigma_\epsilon)_i = \sqrt{(V_\epsilon)_{ij}}$$

For all i.

Photo-peak Efficiency

Radioactive Source	Energy (keV)	HPGe Ch-16	HPGe Ch-17	LaBr3 Ch-18	LaBr3 Ch-19	LaBr3 Ch-20	LaBr3 Ch-21
^{60}Co	1173.23	0.068±0.002	0.072±0.0024	0.0166±0.005	0.0158±0.004	0.0198±0.004	0.0162±0.006
	1332.49	0.0626±0.002	0.0664±0.0021	0.0145±0.005	0.0131±0.004	0.016±0.005	0.0135±0.005
^{22}Na	511.00	0.1079±0.004	0.1185±0.005	0.0284±0.008	0.0283±0.005	0.031±0.006	0.0284±0.006
	1274.5	0.066±0.002	0.066±0.017	0.014±0.006	0.0123±0.005	0.0206±0.005	0.0112±0.006
^{133}Ba	276.398	0.1937±0.025	0.211±0.083	0.0616±0.009	0.0752±0.0156	0.0712±0.009	0.0625±0.009
	302.853	0.175±0.020	0.1792±0.020	0.0567±0.008	0.0486±0.006	0.0626±0.009	0.0512±0.006
	356.017	0.156±0.007	0.1725±0.009	0.0512±0.008	0.0434±0.005	0.0598±0.009	0.0444±0.005
	383.851	0.152±0.008	0.1652±0.009	0.0395±0.003	0.0395±0.003	0.0485±0.009	0.0383±0.007
^{137}Cs	661.67	0.1043±0.004	0.117±0.005	0.0253±0.009	0.0244±0.008	0.0259±0.007	0.0251±0.005
^{152}Eu	121.7817	0.264±0.017	0.287±0.019	0.0993±0.009	0.0867±0.002	0.094±0.002	0.062±0.007
	244.6975	0.213±0.013	0.227±0.014	0.071±0.0057	0.0778±0.011	0.086±0.005	0.084±0.009
	344.2785	0.147±0.007	0.158±0.008	0.0587±0.005	0.057±0.009	0.059±0.003	0.058±0.007
	411.1163	0.162±0.016	0.156±0.0153	0.0417±0.004	0.0632±0.009	0.042±0.008	0.046±0.007
	443.965	0.148±0.013	0.151±0.029	0.031±0.004	0.046±0.009	0.035±0.009	0.035±0.009
	778.904	0.083±0.003	0.1296±0.0161				
	867.378	0.084±0.0171	0.087±0.003				
	964.079	0.077±0.003	0.083±0.003	0.0253±0.004	0.057±0.009	0.028±0.005	0.023±0.002
	1085.869	0.078±0.003	0.084±0.003	0.025±0.004	0.0632±0.009	0.027±0.009	0.020±0.009
	1112.074	0.061±0.002	0.065±0.002				
	1408.006	0.061±0.006	0.0601±0.005				
^{228}Th	238	0.253±0.016	0.266±0.018	0.0921±0.004	0.092±0.004	0.0831±0.003	0.0842±0.013
	277	0.177±0.014	0.241±0.022	0.0813±0.012	0.077±0.010	0.0701±0.009	0.067±0.01
	509	0.159±0.034	0.1804±0.041	0.0436±0.018	0.0404±0.018	0.0487±0.014	0.021±0.008
	582	0.125±0.006	0.134±0.006	0.0259±0.0005	0.0286±0.007	0.0252±0.0005	0.021±0.008
	726	0.113±0.005	0.122±0.006	0.0186±0.009	0.0212±0.009	0.0217±0.0012	0.020±0.009
	785	0.107±0.007	0.1002±0.005				
	859	0.095±0.004	0.099±0.004				
	1620	0.064±0.003	0.065±0.002				
	2614	0.0478±0.018	0.0695±0.003				

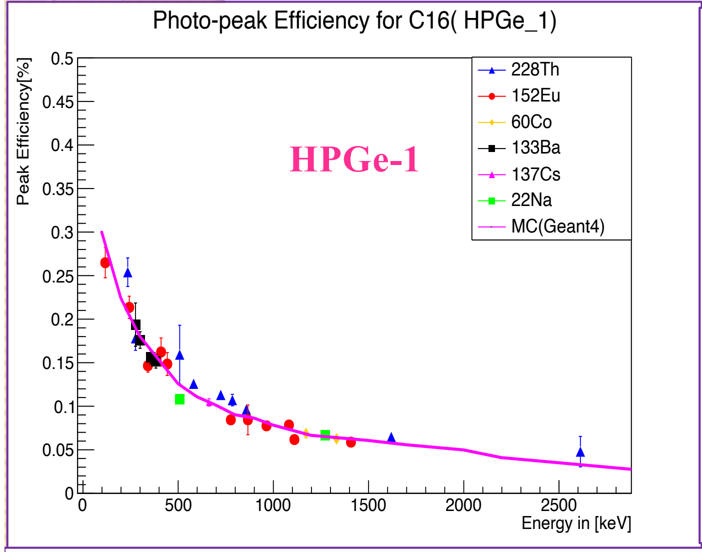
Covariance analysis

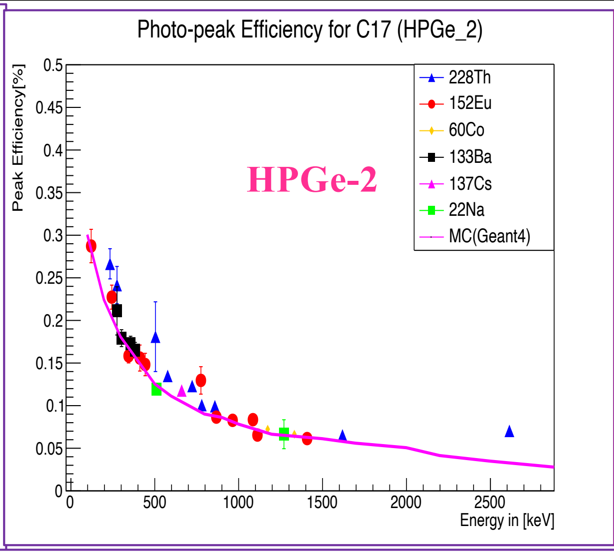
The efficiency calibration of the HPGe detector using the radioactive sources of ^{60}Co, ^{22}Na, 133Ba and ^{137}Cs for the 9 characteristic gamma energies resulting in the 9×9 covariance matrix of efficiencies of HPGe detector Ch16.

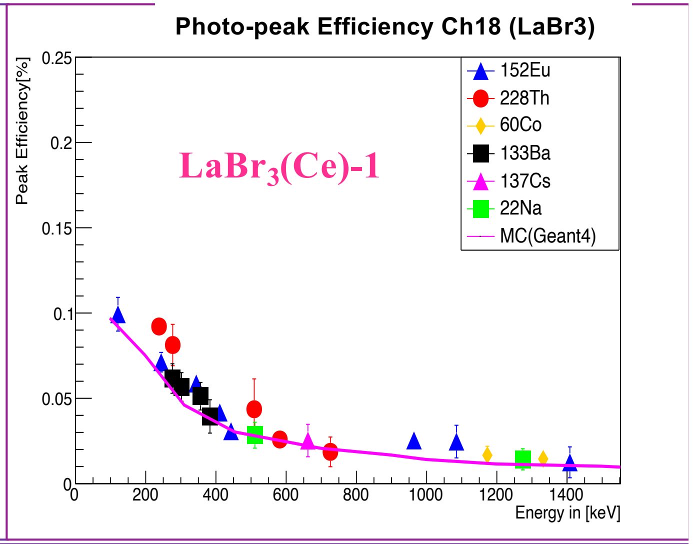
Energy (KeV)	Efficiency [%]	Partial Uncertainties due to attribute for ^{60}Co, ^{22}Na, ^{133}Ba and ^{137}Cs			Total Error (Δ∈)
		$R_1 = \Delta N$	$R_2 = \Delta I_y$	$R_3 = \Delta A$	
276.398	0.0316±0.00166	0.000196269	0.000137448	0.000299637	0.000383661
302.853	0.0467±0.0014	0.000342593	0.00032107	0.00016919	0.00049908
356.017	0.0412±0.0011	0.000173783	2.87356E-05	0.000164547	0.000241044
383.851	0.0294±0.0079	0.000356073	7.53985E-05	0.00015042	0.000393826
511.00	0.1079±0.0044	0.000150843	0.000119853	0.001618015	0.001629445
1274.5	0.0661±0.0021	0.000154266	8.77487E-05	0.000939638	0.000956252
1173.23	0.0683±0.0022	0.000143069	2.05614E-05	0.001026528	0.001036654
1332.49	0.0626±0.002	0.000136715	1.2517E-05	0.000938682	0.000948669
661.67	0.10704±0.0042	0.000310694	0.00024497	0.001563518	0.001612802

Energy (keV)	Covariance Matrix								
276.398	1.4719E-07								
302.853	5.0695E-08	2.4908E-07							
356.017	4.9304E-08	2.7839E-08	5.8102E-08						
383.851	4.5071E-08	2.5449E-08	2.4751E-08	1.5510E-07					
511.00	0	0	0	0	2.6551E-06				
1274.5	0	0	0	0	1.5204E-06	9.1442E-07			
1173.23	0	0	0	0	0	0	1.0747E-06		
1332.49	0	0	0	0	0	0	9.6457E-07	8.999E-07	
661.67	0	0	0	0	0	0	0	0	2.6011E-06

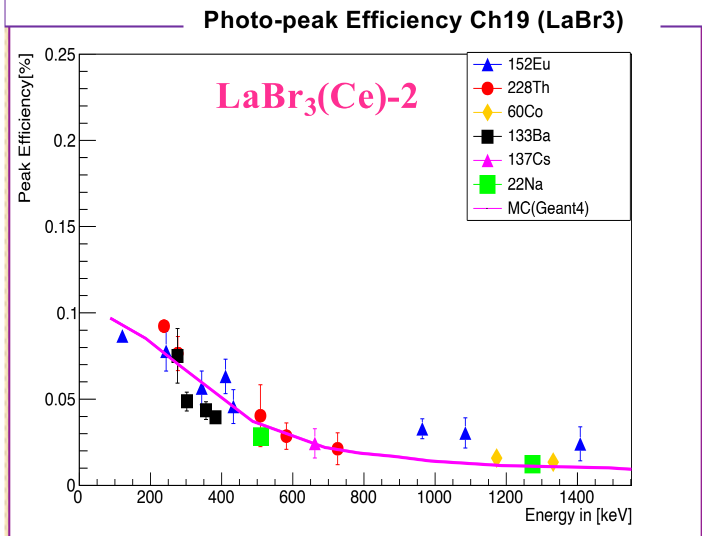
Photo-peak Efficiency of HPGe and LaBr3 Detectors

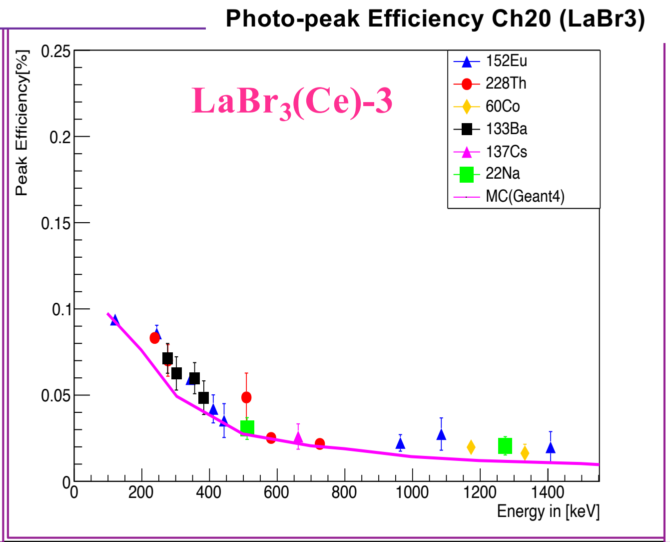


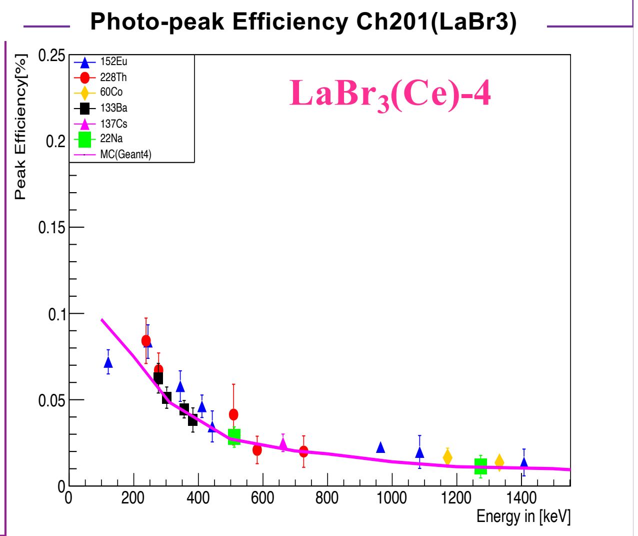




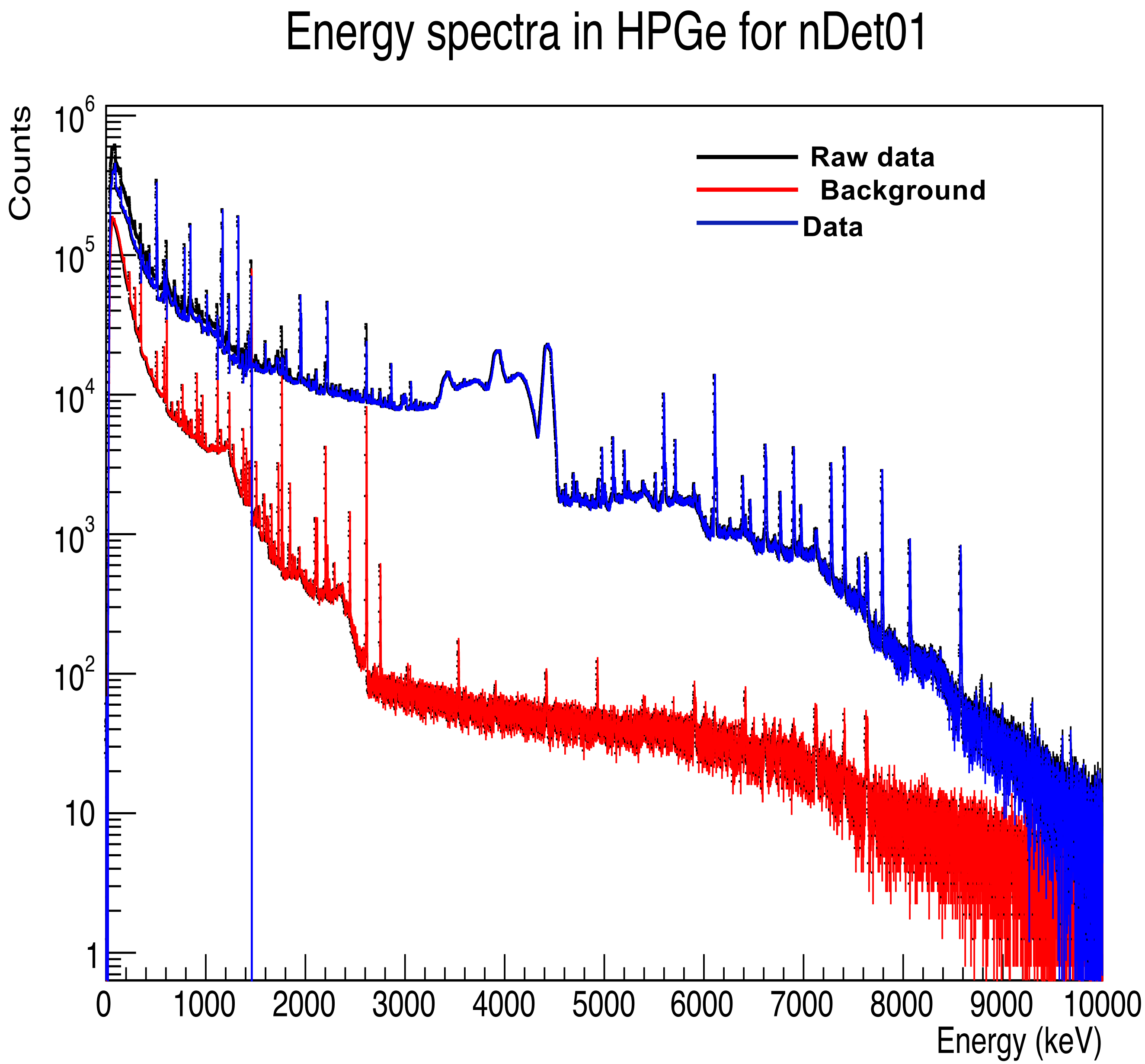
- The agreement between out data and Geant4 (MC) simulation are satisfied.
- But we don't have the efficiency >3MeV. So we did another experiment with ^{35}Cl



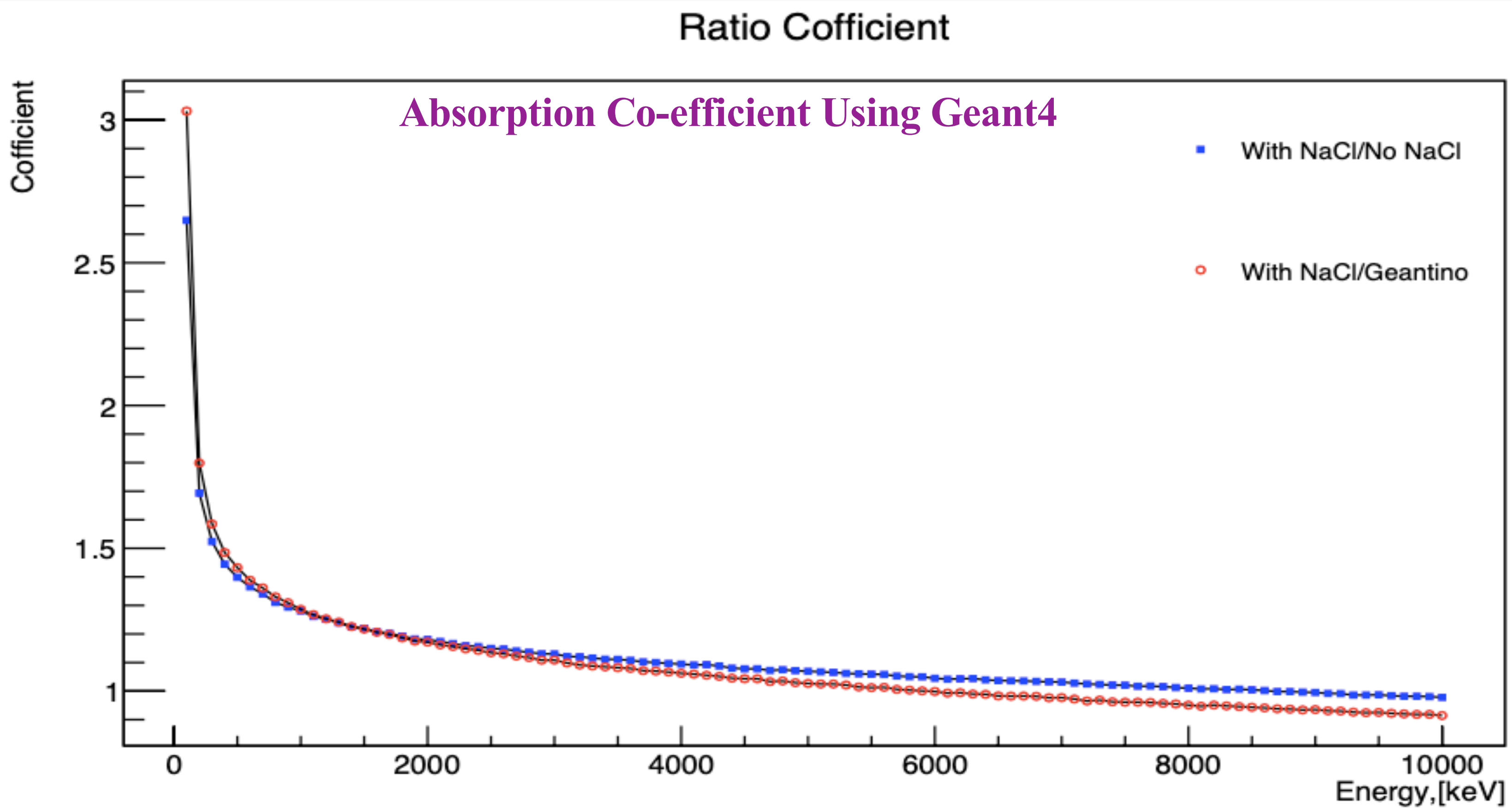




Gamma-Ray Spectrum of n+NaCl, Reaction



Measurement of Photo-peaks



$$N_{corr}=N/C_R$$

Where,
N=number of Events
CR= correction factor (abosrption factor)
Ncorr= Corrected number of events

Relative Photo-peak Efficiency

N_{Corr} be the corrected number of events of the Photo-peak, N_{norm} be the normalization of the number of events of the photo-peaks.

$$N_{norm} = \frac{N_{Corr}}{N_{max}} \times 100\%$$

Ratio, $$R = \frac{N_{norm}}{I_{\boldsymbol{R}}}$$

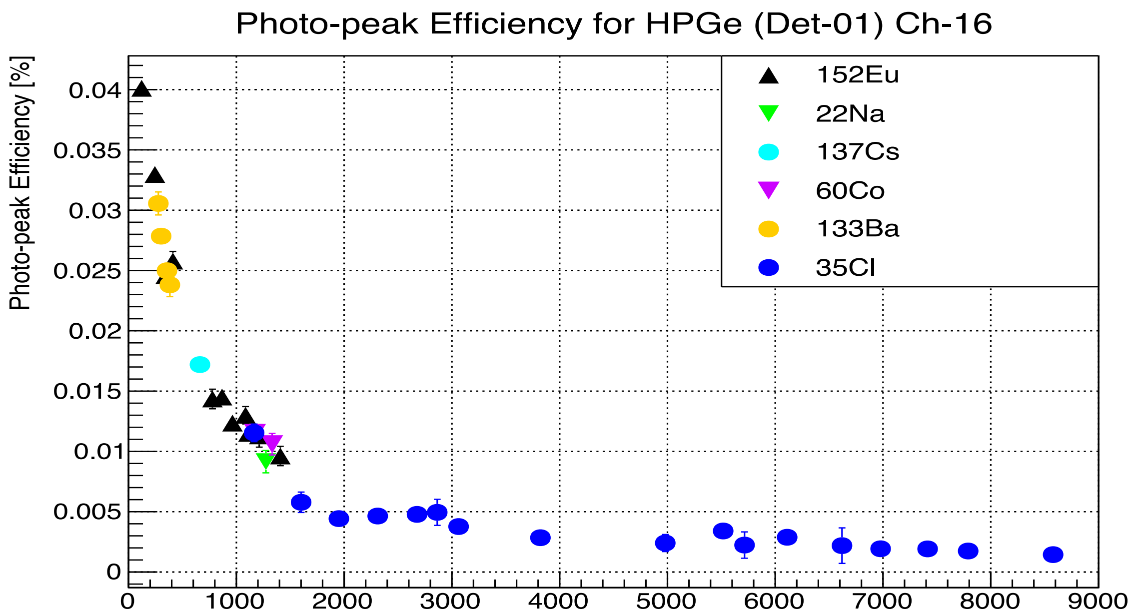
Where, I_R =Relative Intensity.

Relative Photo-peak Efficiency of ^{35}Cl,

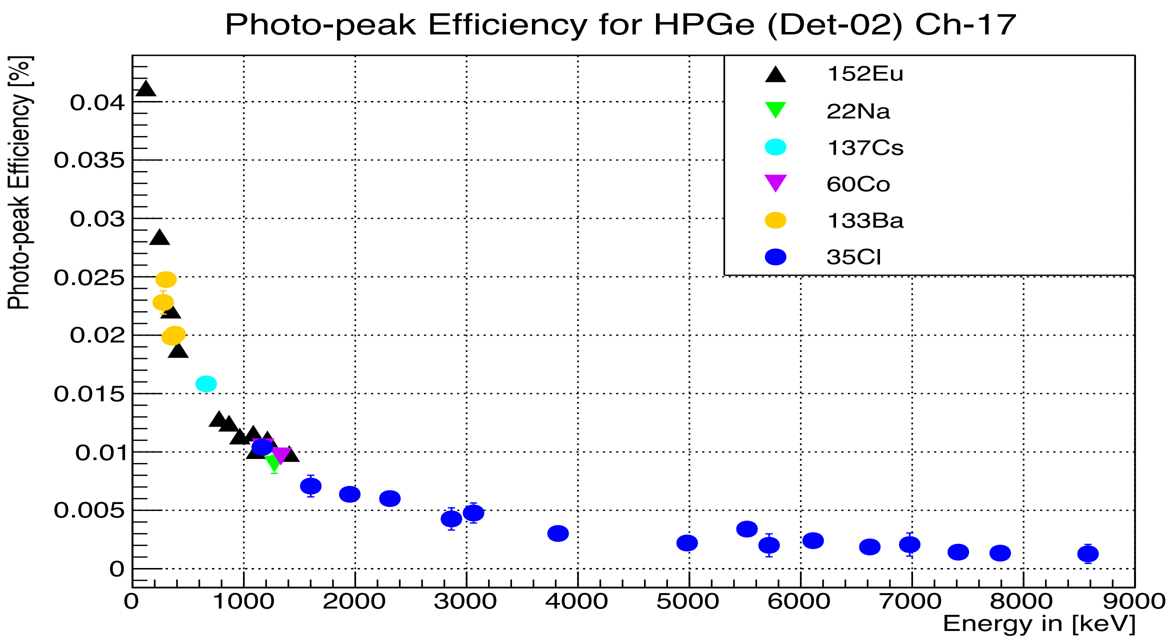
$$\epsilon_{Rel} = R \times \epsilon_p$$

Where, ϵ_p is the calculated photo-peak efficiency of ^{60}Co of our experiment.

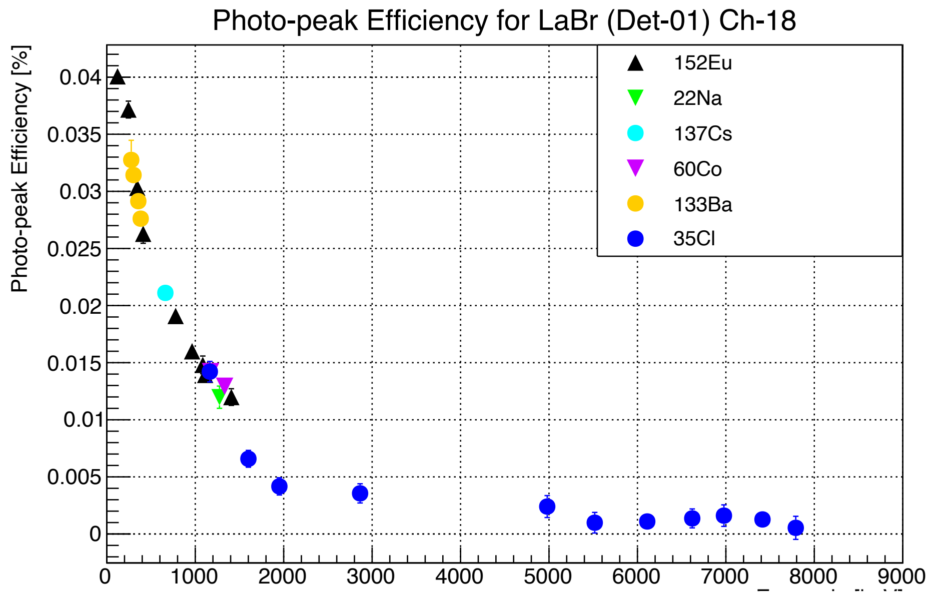
Relative Photo-peak Efficiency for HPGe detector

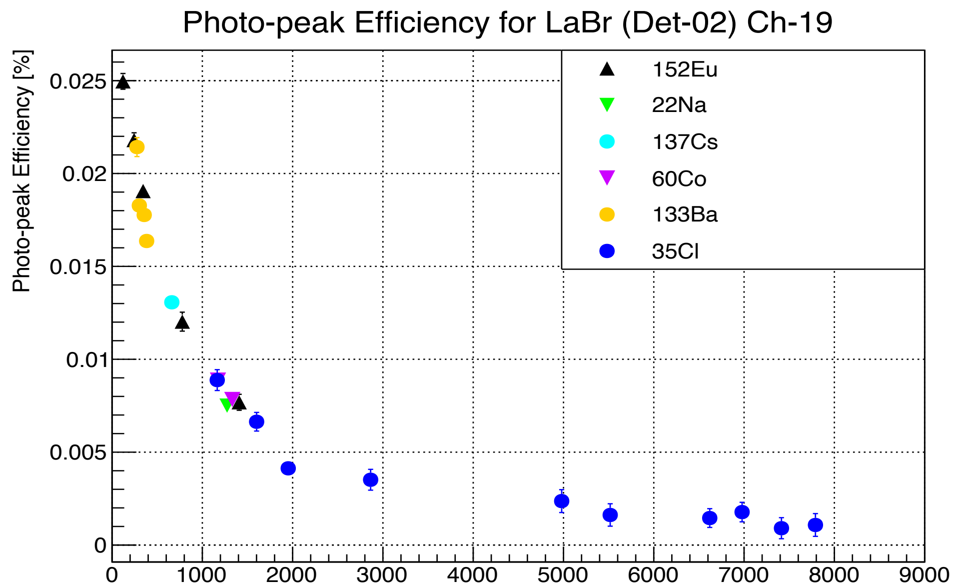


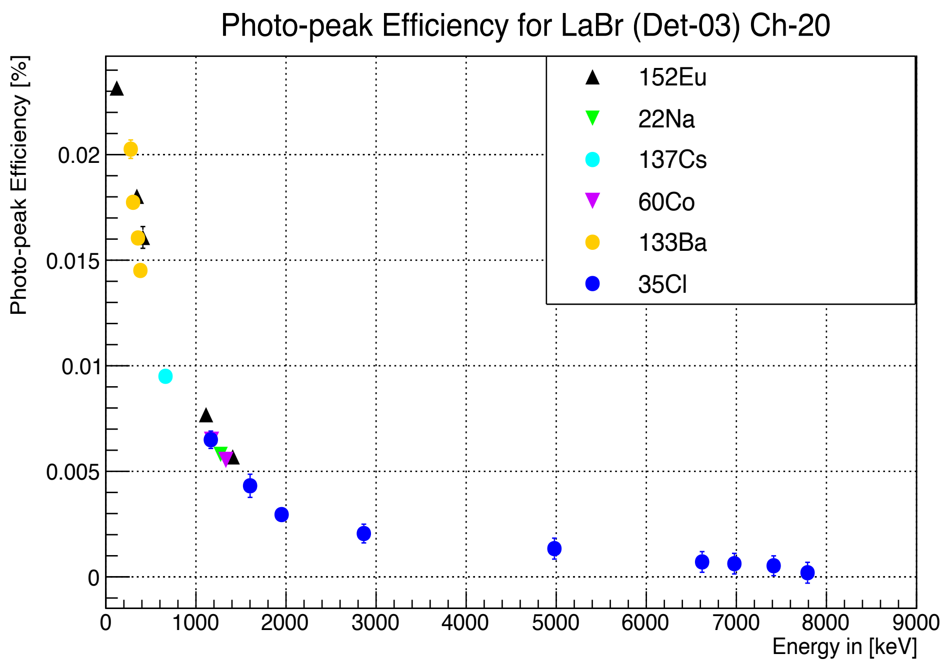
Successfully calculated the detection efficiency of HPGe and LaBr3 detectors up to 9MeV

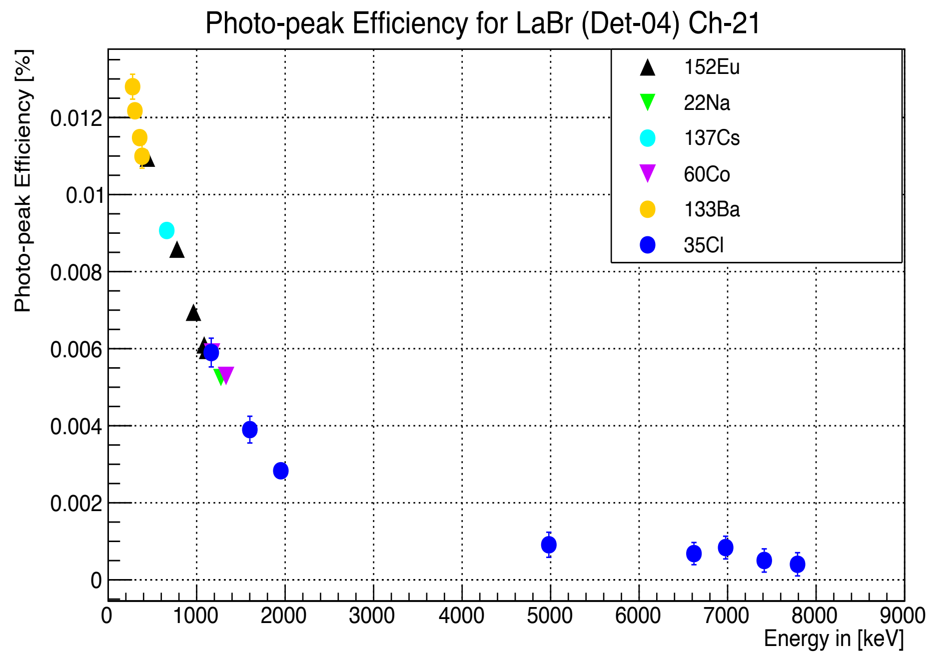


Relative Photo-peak Efficiency for LaBr3 detector









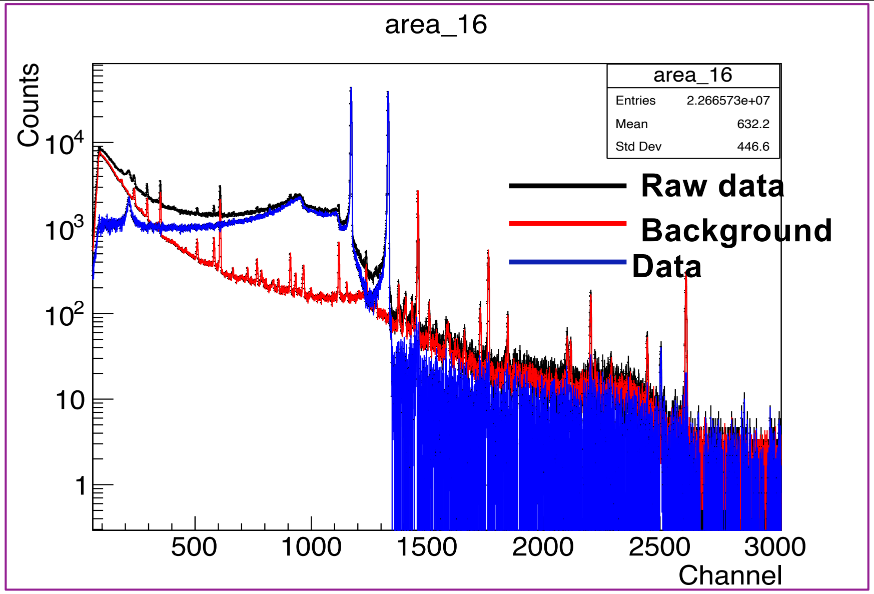
Summary

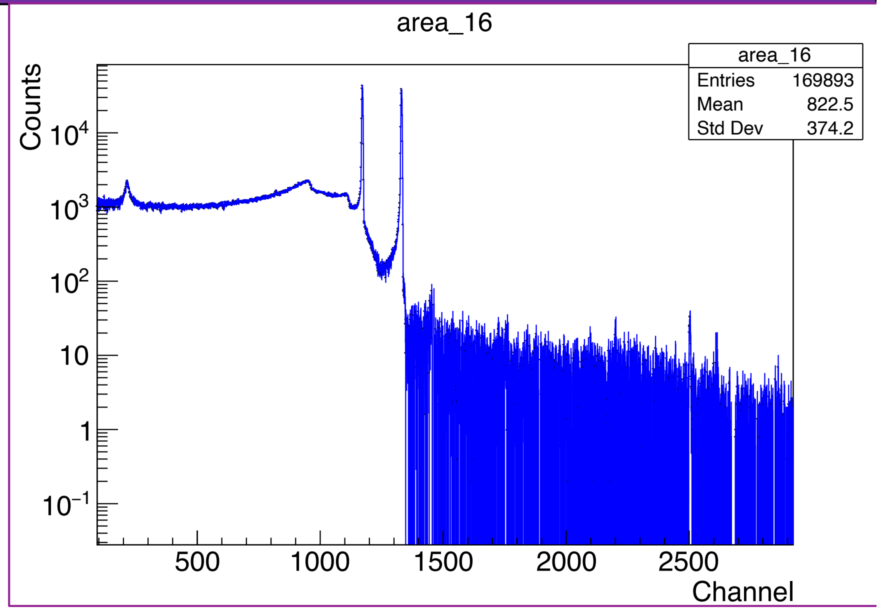
- I've conducted the experiment to study the **characteristics of HPGe and LaBr3 γ-rays detectors used in TANGRA project.**
- As part of this ongoing research program, I've measured the photo-peak efficiencies of the HPGe and $LaBr_3(Ce)$ detectors within a newly constructed experimental facility.
- I've also calculated the relative photo-peak efficiency of HPGe and $LaBr_3(Ce)$ detector using the standard γ-ray point sources including ^{22}Na, ^{60}Co, ^{133}Ba, ^{137}Cs, ^{152}Eu and as well as the $^{35}Cl(n,\gamma)^{36}Cl$ reaction.
- I've generated the monte carlo simulation Geant4 and which is found in comparable agreement with data.
- Now, we know the efficiency of HPGe and LaBr3 γ-rays detectors used in TANGRA project for upto 10MeV range.
- I've added the Covarinace Matrix analysis in our results to calculate the uncertatinty of photo-peak efficiency accurately.

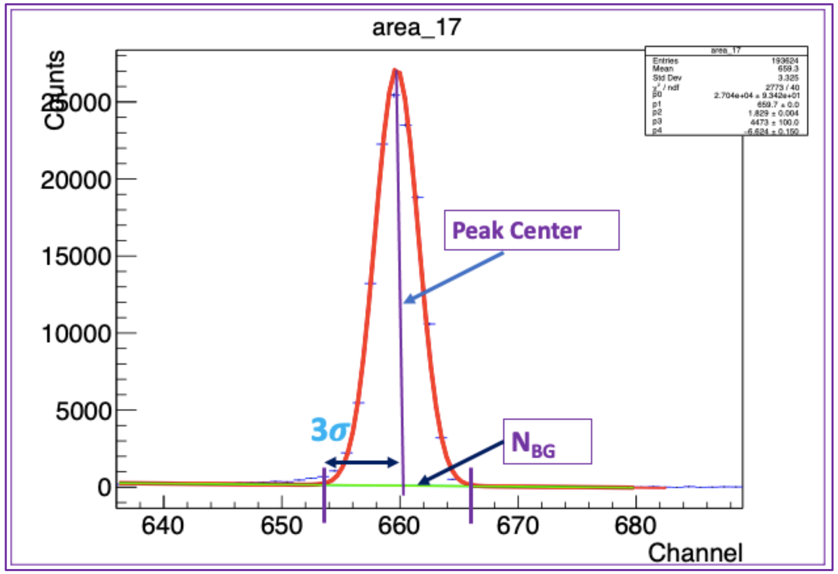
Thank You for Your Attention

Back-Up

Characteristics of Gamma-Sources







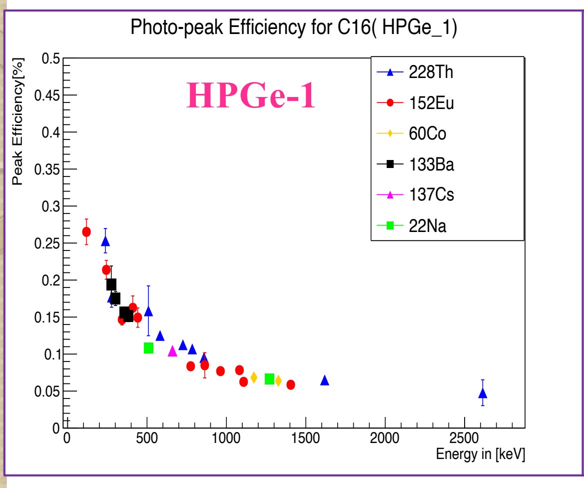
The number of counts of photo peak can be calculated from the below equation:

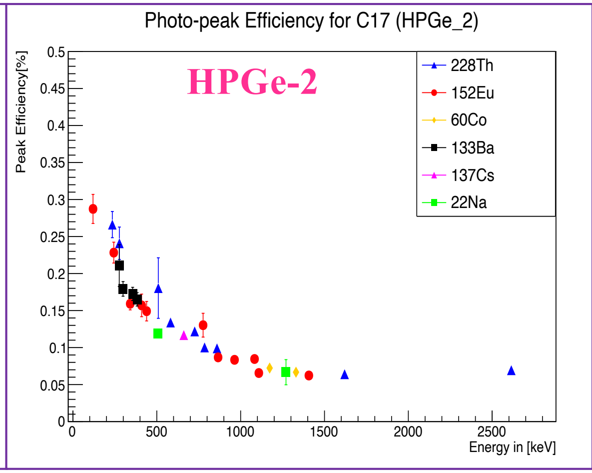
$$N = N_{Raw} - N_{BG}$$

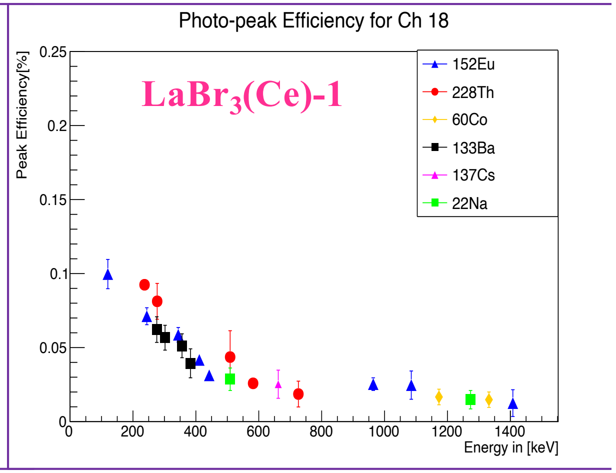
Where N_{Raw} is the raw data and N_{BG} is the background data.

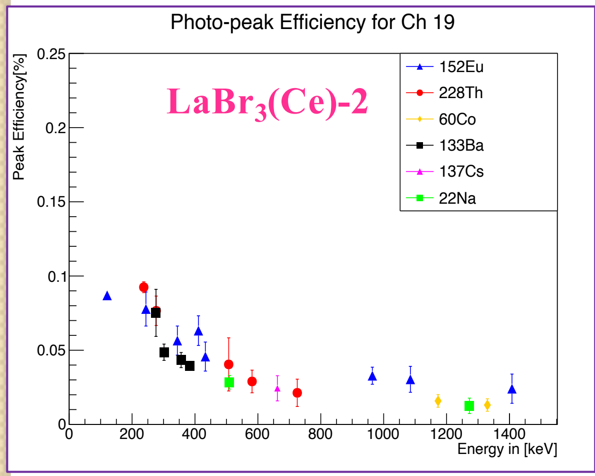
Figure shows the fitting peaks to count the number of events in the photo-peak.

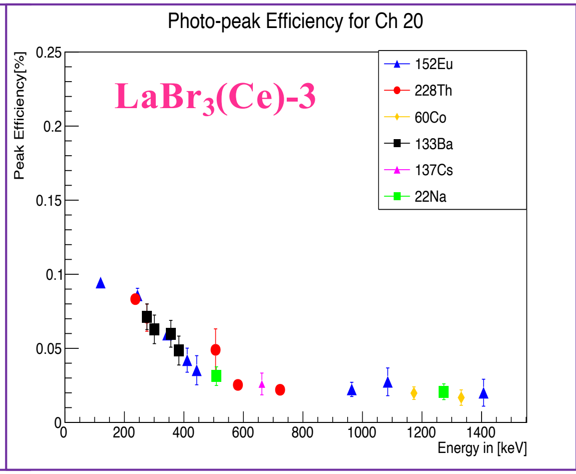
Photo-peak Efficiency

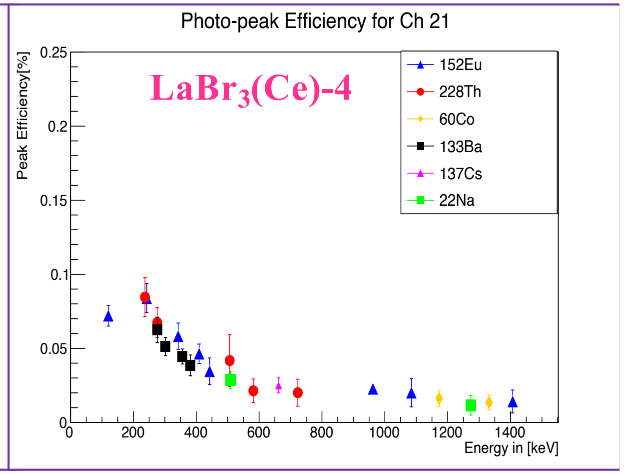












GEANT4 Simulation

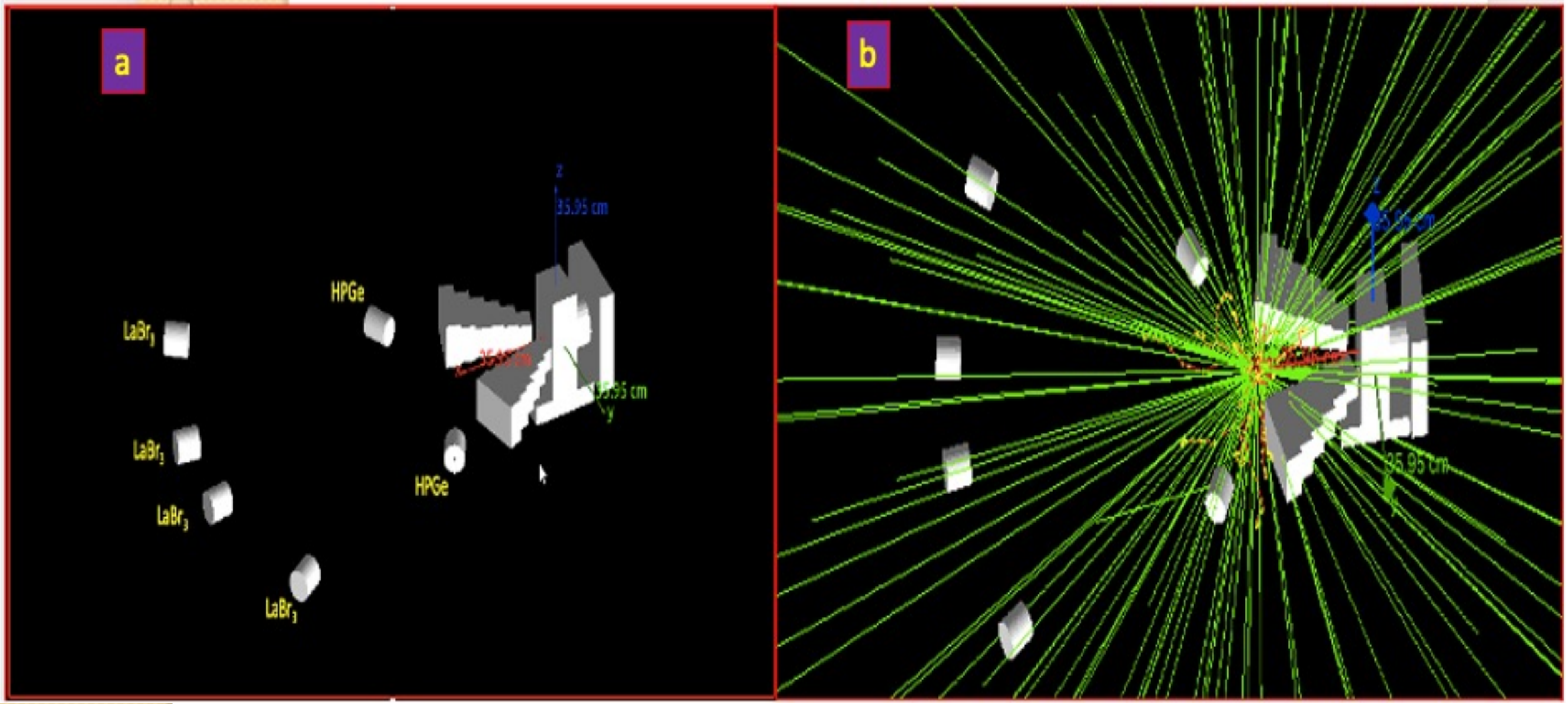
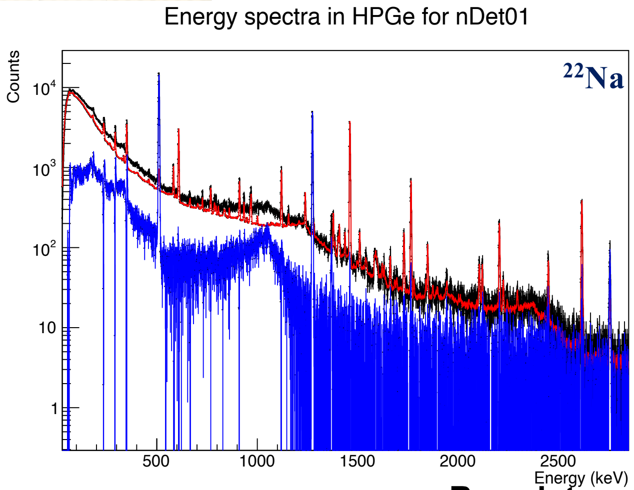


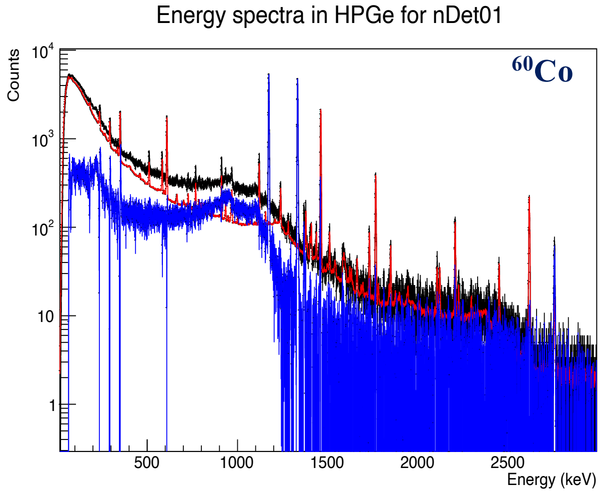
Figure (a) Experimental Set-up of TANGRA project in Geant4 Simulation (b) Simulated experimental set-up with gamma rays (green line).

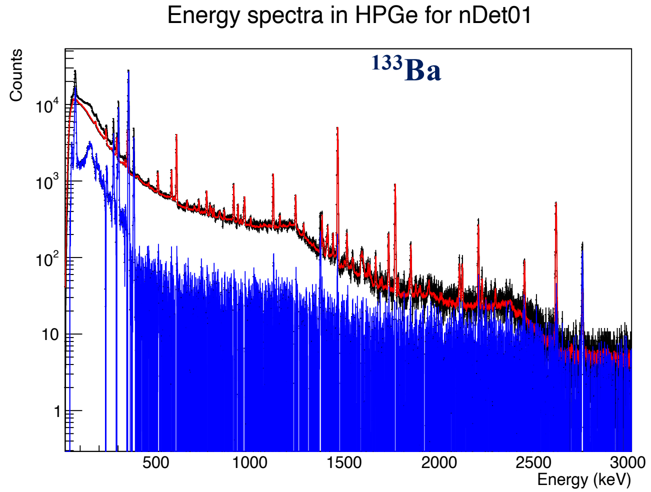
Measurement of Relative Photo-peak Efficiency

Possible upgrade of the setup with HPGe and $LaBr_3$(Ce) γ-detectors to measure angular distributions.

Measurement of Relative Photo-peak Efficiency







Raw data
Background
Data