Monte Carlo simulation for a Broad Energy Germanium (BEGe) detector using Geant4 simulation toolkit

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The experimental γ-ray detection efficiency curve was determined for the a BEGe (Broad Energy Germanium) detector with standard radioactive γ-ray sources placed at 25 cm from the detector face, in the γ-ray energy range 50-1400 keV. A Geant4 simulation was performed to simulate the BEGe detector response for the same source-detector geometry. The simulated efficiency curve was found to well reproduce the experimental γ-ray efficiencies at 25 cm from the face of the detector.

1. Introduction

Reactions at energies far below the Coulomb barrier have small cross-sections $nb - pb$ order, thereby making the cross sections measurement very difficult. During the experiment, the reaction cross section σ is determined as

$$\sigma = \frac{Y}{\epsilon N_B N_T}. \quad (1)$$

where, ϵ is the detector efficiency, Y is the yield of reaction products, N_B is the number of beam particles per unit time and N_T is the number of target nuclei per unit area. To increase the yield Y, we can increase beam current, target thickness and detector efficiency. But the extent of increase of all these quantities are restricted by experimental limitations. In measurements, where cross sections are measured by detecting the γ-rays produced in the reactions, the γ-ray efficiencies can be increased by placing the detector very close to the sample emitting the γ-rays. But such close geometry measurements will involve summing effect due to the cascade emission of γ-rays. This coincidence summing leads us to the reduced counts in the photopeak of a γ-ray of interest which in turn results in reduced γ-ray efficiency. Thus to perform measurements in close geometry we need to do the coincidence summing correction for γ-ray efficiencies and then use these efficiencies in the determination of the reaction cross-sections.

The coincidence summing correction factor (k_{TCS}) [1] can be calculated by

$$k_{TCS} = \frac{1}{1 - \Sigma_{i=1}^{i=n} p_i \epsilon_{ti}}. \quad (2)$$

where, p_i is the probability of coincidence of a γ-ray to the γ-ray of interest and ϵ_{ti} is total efficiency. The probability p_i can be calculated using appropriate parameters from the previously published decay scheme of radioactive nuclei and total efficiency ϵ_{ti} was calculated using Geant4 simulation. In this paper, we were mainly focused on performing Geant4 simulation and recording the detector response for our BEGe detector.

2. Experiment

In this work, the γ-ray efficiency curve was determined for an electrically cooled Falcon 5000 BEGe detector. The Falcon 5000 BEGe detector comes with an inbuilt preamplifier, MCA, Genie-2000 software to collect energy histogram spectrum and a tablet to control all the detector functions. The Falcon 5000 BEGe detector has an inbuilt High Voltage Power Supply (HVPS) to give the bias voltage to the detector. A reverse bias voltage of -3700 V was supplied to the detector from HVPS unit. The standard radioactive sources ^{152}Eu, ^{133}Ba, ^{60}Co, and ^{137}Cs were used for

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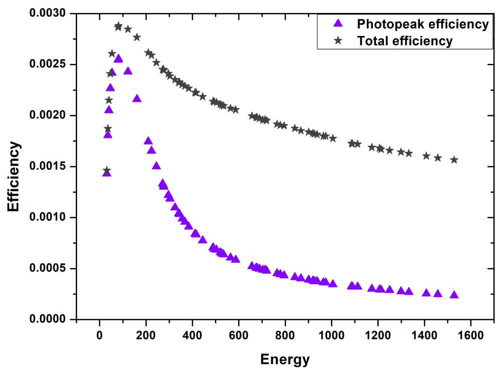

FIG. 1: Geant4 simulated photopeak and total efficiency at 25 cm source-detector distance.

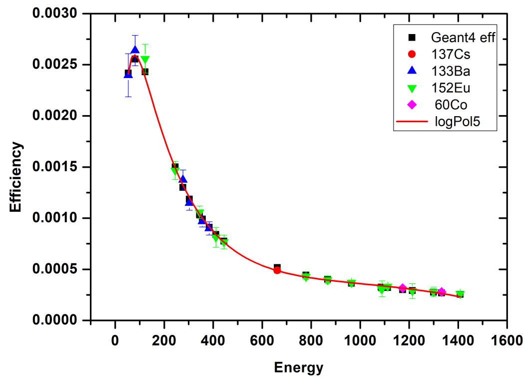

FIG. 2: Experimental and Geant4 simulated efficiency at 25cm source to detector.

data acquisition at different source to detector distances. Initially, data was taken at a distance of 25 cm from the detector surface. This long distance was chosen to avoid any coincidence summing in the spectrum. Data acquisition and preliminary analysis were done using Genie 2000 software. The offline analysis was performed using ROOT software [2].

3. Geant4 Simulation

A Geant4 simulation was performed to obtain the BEGe detector response. Geant4 is a monte carlo simulation toolkit which is consist of a long range of particles, materials, elements, and energy range from 250 eV to TeV. Until now, Geant4 has been proved very useful to perform reliable monte carlo simulation from low to high energy physics. The Geant4 consists of numerous inbuilt classes and we have chosen them as per our requirements. The geometry of the detector was constructed using G4VUserDetectorConstruction class, material and elements were used from the inbuilt NIST library (G4NistManager) class. Information of beam particle (γ-ray) was given using G4VUserPrimaryGeneratorAction classes. These particles were randomly generated by a particle generator (G4particle gun) in a spherically symmetric direction. To define the interactions of γ-ray with the crystal G4EmStandardPhysics class was used as physicslist . This class takes care of all electromagnetic interaction in the detector crystal. The deposited energy by γ-ray in the detector crystal was recorded step by step and added for each event and stored in .root file format. The data was analyzed using ROOT software. The γ-ray spectrum for each energy was simulated for different distances and the efficiencies were calculated. The Geant4 simulated photopeak and total efficiency at 25 cm source to detector distance have been shown in fig. 1.

4. Conclusion

The experimental efficiencies along with Geant4 simulated efficiency have been shown in fig. 2. It is observed that Geant4 simulated efficiencies match the experimental value within the error bar. The log polynomial of 5^{th} order was used to fit the experimental efficiencies. As the effect of coincidence summing is not present for source to detector distance 25 cm measurements, the same detector parameter can be used to obtain the efficiencies for close geometry as well.

References

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