Cross-talk estimation of the hybrid γ-ray detector array through GEANT4 simulation

Biswajit Das[1],* S. Saha[2], R. Palit[1], A. Kundu[1], P. Dey[1], V. Malik[1], S. K. Jadav[1], B. S. Naidu[1], A. T. Vazhappilly[1], and S. Sihotra[3]
[1]*Department of Nuclear and Atomic Physics, Tata Institute of Fundamental Research, Mumbai - 400005, INDIA*
[2]*School of Advanced Sciences, VIT University, Vellore 632014, India, Mumbai - 400005, INDIA and*
[3]*Department of Physics, Panjab University, Chandigarh 160014, India*

Introduction

High Purity Germanium (HPGe) detector remains the best energy-resolving apparatus for nuclear structure studies using discrete γ-ray spectroscopy. On the other way, the $LaBr_3$(Ce) detector can open a new door to investigate the nuclear transition strength by measuring the lifetime of the nuclear state in the range of a few hundred pico-second. A combination of HPGe and $LaBr_3$(Ce) detectors array can extend the lifetime measurement in the range of 100 pico-second to a few nano-second by the triple-fold γ-ray coincidence. A hybrid γ-detector array consisting of maximum 24 Compton suppressed clover HPGe (solid angle $\approx$ 2.58 sr) and 18 $LaBr_3$(Ce) (solid angle $\approx$ 2.16 sr) detectors was setup recently at the BARC-TIFR Pelletron Linac Facility at TIFR, Mumbai and several in-beam experiments have been performed [1]. A detailed simulation work of the Indian National Gamma Array (INGA) with 24 clover detectors has been reported in ref.[2]. Later, 18 $LaBr_3$(Ce) detectors have been added to the simulation code and estimated the absolute photo-peak efficiency of the array and found to be around 9% at 1 MeV [3]. This hybrid array is expected for the study of various nuclear structures and nuclear astrophysics problems. In this work, we have estimated the cross-talk effect, which is amount of erroneously counted interactions of γ-ray photons which have undergone Compton's scattering in neighboring detectors. The estimations have been obtained for 18 $LaBr_3$(Ce) detectors at various γ-ray energy through GEANT4 simulation.

Detector Modeling and Simulation Framework

The GEometry ANd Tracking 4 (G EANT4, version 4.10.05) simulation toolkit has been used for making the geometry and Monte-Carlo calculation. G4Tubs, G4Sphere, G4Trd, G4Box, G4Polycone, G4Polyhedra, G4UnionSolid, and G4SubtractionSolid classes have been used to construct the different parts of the detector and the set-up. The 24 BGO shielded clover HPGe detectors have been arranged at different angles with respect to beamline along with the 18 $LaBr_3$(Ce) detectors (2"x2") to make a 4π γ-detector hybrid array. The GEANT4 geometry of the hybrid INGA setup has been shown in Fig.1. In simulation, we

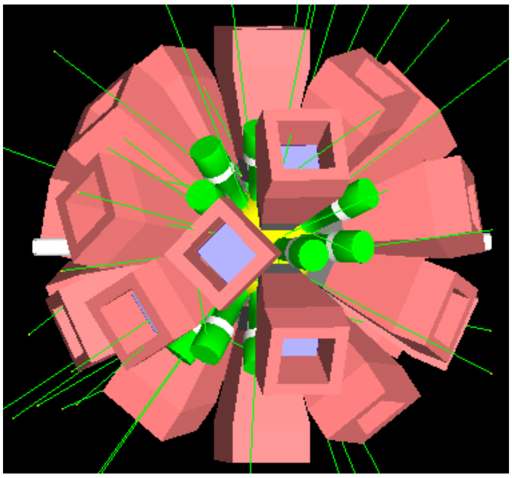

FIG. 1: The hybrid INGA set-up with 24 BGO shielded clover HPGe and 18 $LaBr_3$(Ce) detectors in GEANT4 geometry.

have considered all possible physics processes into account. The γ-ray photons, electrons and positrons are expected to be produced in the trajectory of incident γ-ray while interacting with the matter. The considered interaction mechanisms for the γ-photons are photoelectric effect, Compton scattering, pair production and Rayleigh scattering. The electrons and positrons which produced during interaction can undergo multiple scatterings, ionization and emit Bremsstrahlung radiation. In addition, the positron can undergo annihilation with the material's electrons. For γ-ray interaction with matter, the considered process classes have been used in physics list are G4PhotoElectricEffect, G4ComptonScattering, G4GammaConversion and G4RayleighScattering.

*Electronic address: `biswajit.das@tifr.res.in`

Results and Discussion

The simulated and measured γ-ray energy spectra of ^{60}Co have been shown in Fig. 2. The

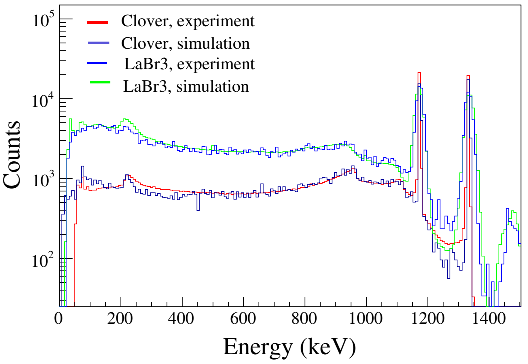

FIG. 2: Simulated and measured γ-ray energy spectrum of ^{60}Co.

cross-talk events between the LaBr$_3$(Ce) detectors have been obtained at 0.5, 1, 1.5 and 2 MeV γ-ray energy with multiplicity greater than one and a energy threshold of 40 keV in individual detector. In the table-I, the percentage of cross-talk events out of total events generated from the target position is reported. Less cross-talk

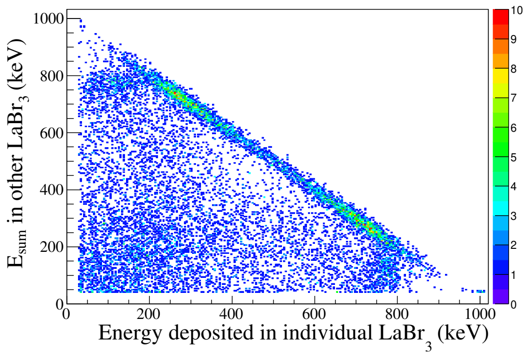

FIG. 3: Simulated Compton cross-talk between the LaBr$_3$(Ce) detectors of 1 MeV γ-ray.

TABLE I: Percentage of cross-talk events in various γ-ray energy

γ-ray energy (MeV)	Percentage of cross-talk
0.5	0.122
1.0	0.168
1.5	0.184
2.0	0.209

events are expected in clover HPGe detectors because of the BGO shield. But for LaBr$_3$(Ce) detectors, the effect of cross-talk is more as they are close enough without any shielding. The cross-talk events will contribute the gamma background and will affect the lifetime measurements when we used two closed LaBr$_3$(Ce) detectors. In order to reduced this background,

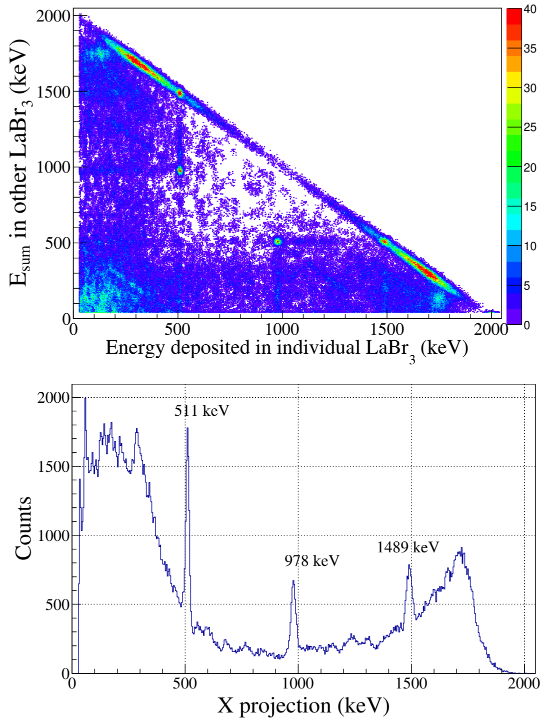

FIG. 4: Up: Simulated Compton cross-talk between the LaBr$_3$(Ce) detectors of 2 MeV γ-ray. Down: X projection of the above plot.

the design of shielded LaBr$_3$(Ce) detectors are in progress. The cross-talk events have been shown for 1 MeV (Fig.3) and 2 MeV (Fig.4(top)) in 2D scatter plot. The single-escape, double-escape events and their Compton background are also present in the cross-talk for 2 MeV γ-ray (Fig.4(bottom)). One can eliminate the cross-talk background with proper choice of energy and time coincidence window. The main advantage of coupling these two types of detectors in an array is to clean the background of the time difference spectrum of LaBr$_3$(Ce) for lifetime measurement of nuclear state with energy gate on the clover HPGe detector.

Acknowledgments

We would like to thank the funding agency, DAE and DST, Government of India, under project no. 12-RD-TFR-5.02-0200, and IR/S2/PF-03/2003-II, respectively.

References

[1] Md S. R. Laskar, et al., Phys. Rev. C **104**, L011301 (2021).

[2] S. Saha, R. Palit, et al., JINST **11**, P03030 (2016).

[3] Biswajit Das, et al., Jl. of the Instrum. Soc. of India, **51**, 1-4 (2021)