A novel approach for mapping of a defective region inside γ-ray detector

Biswajit Das,* A. Kundu, R. Palit, P. Dey, V. Malik,
S. K. Jadav, B. S. Naidu, and A. T. Vazhappilly
Department of Nuclear and Atomic Physics,
Tata Institute of Fundamental Research, Mumbai - 400005, INDIA

Introduction

The advanced nuclear physics experimental studies in γ-ray spectroscopy have been made possible by the research and developments on the technicalities of the efficient and higher resolution γ-ray detectors array [1, 2]. The collection efficiency of the charge carriers and the detection efficiency of the High Purity Germanium (HPGe) detectors, mainly at lower γ-energy reduces over time due to radiation damages such as neutron exposure or due to extended gaps between periods of cooling for aged detectors, often leading to thickening of the inactive dead layer. For the continuance of the performance of large detector facilities, it is very important to monitor the responses of the segmented or single crystal HPGe γ-ray detectors over time. Several groups have carried out the measurements to obtain efficiency variation throughout the crystal by surface scan with collimated low and high energy γ-rays [3]. This method is very time-consuming and needs precise alignments. Alternatively, scanning of a γ-ray detector by projecting the interaction points on a position-sensitive detector in coincidence is a quick method to evaluate the performance throughout the crystal. In this work, we demonstrate through GEANT4 simulation a quick and easy method for identification of a dysfunctional region inside a γ-ray detector. Experimentally, this method can provide a fast and convenient method for inspecting the performance and physical condition of the detectors of interest.

GEANT4 simulation

A scanning setup with a position sensitive photo-multiplier tube coupled to a Ce doped GAGG(Gadolinium Aluminum Gallium Garnet: $Gd_3Al_2Ga_3O_{12}$) crystal has been simulated to image the HPGe detector. A point like ^{22}Na radioactive source has been defined to generate coincidence events, between the HPGe and position sensitive detectors that have been kept co-axially on the two opposite sides of the source. The distances of the source from both the detectors have been defined in order to obtain an optimum size of the image of the HPGe detector reconstructed by the GAGG crystal. The set-up arrangement in GEANT4 simulation has been shown in Fig.1. We have considered all possible physics processes into account. The γ-ray photons, electrons and positrons are expected to be produced during the interaction of γ-rays with detector materials. The considered interaction mechanisms for the γ-rays are photoelectric effect, Compton scattering, and pair production. The electrons and positrons which are produced from photoelectric interaction and Compton scattering can undergo multiple scatterings, ionization and emit Bremsstrahlung radiation, while in addition, the positron can also undergo annihilation.

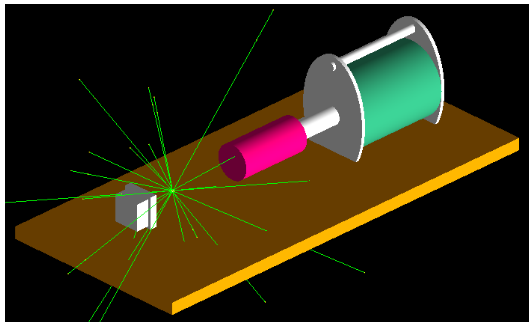

FIG. 1: Coincidence arrangement in GEANT4 simulation with PSPMT-GAGG and single crystal HPGe detector with ^{22}Na source.

Result and discussion

The position resolution of the of the GAGG crystal has been obtained to be about 3 mm.

The 2D image of the front scan of the single HPGe has been obtained in GAGG with an energy gate of 511 keV (Fig.2). This 2D image gives an identification of the cavity hole inside the crystal and the picture of the depleted region. In simulation, the front scan is sensitive to the cavity with diameter above 10 mm and located at 25 mm from the front face. The

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

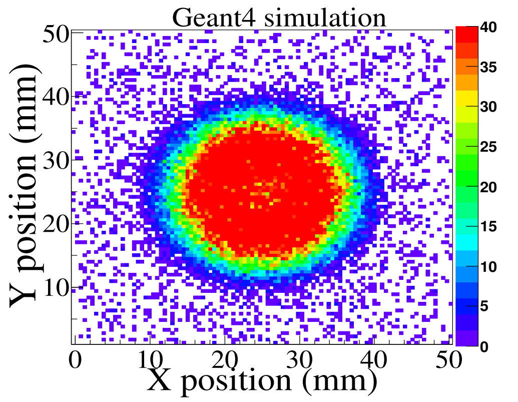

FIG. 2: Simulated scanned image reconstructed on GAGG crystal in energy gate condition on 511 keV on both the detectors.

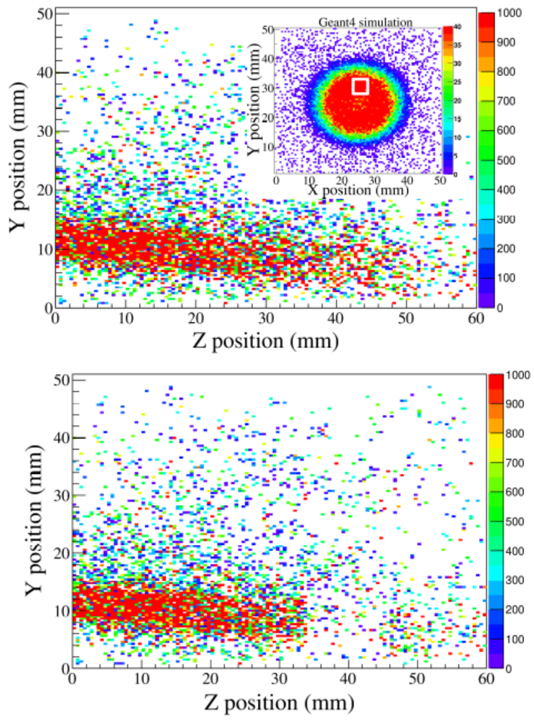

FIG. 3: Up: In inset, GEANT4 simulated 2D image of single HPGe. The γ-ray interaction path in each step of event have been shown in 2D scatter corresponding to sector gate (shown in white rectangle of the inset figure). Down: If any inactive region is present inside the crystal, then that can show up in the 2D trajectory.

cavity beyond 40 mm depth from the front surface, the method is not sensitive to identify the cavity due to the absorption profile of the 511 keV γ-ray. The incident direction of the γ-ray in the HPGe crystal is well defined by a position gate on a sector on the GAGG detector. Along this path length, the 511 keV γ-ray interacts via photoelectric effect or Compton

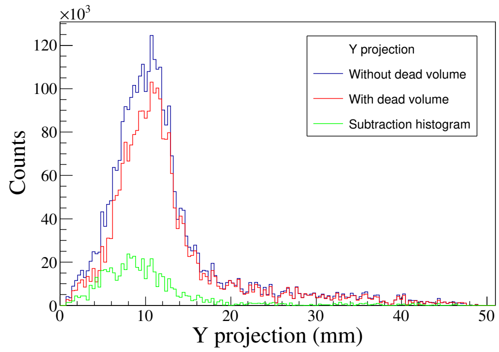

FIG. 4: Y projection histograms with and without presence of dead volume. The peak shift of subtracted histogram can identify the location and depth of the dead volume.

scattering. Irrespective of the nature of the interaction, the first interaction points will lie along this defined path. Depending upon the energy condition in the HPGe detector, the effective depth of the trajectory will be different. The Fig.3 actually shows a 2D projection of the trajectory (Y-Z plane of single HPGe detector) containing the first interaction with and without presence of a defective region on the selected sector gate. From the Y-projection of above two 2D histograms and their subtracted histogram (Fig.4), one can identify the location of the dead volume. The depth from the front face of the dead volume inside the crystal can be determined by the peak shift of the subtracted histogram. However, this approach is sensitive to identify the presence of dead volume inside the crystal volume up to a depth of 40 mm from the surface. A scanning setup has been developed to implement the proposed technique [4]. Systematic measurement has been carried out with the existing single crystal and clover HPGe detectors.

Acknowledgments

We would like to thank Sudipta Saha for useful discussion.

References

[1] R. Palit, Pramana **83** (5) (2014) 719–728.
[2] G. S. Li, et al., Nucl. Instrum. Meth. A **890** (2018) 148–154.
[3] B. De Canditiis, et al., Eur. Phys. J. A **57** (2021) 223.
[4] Biswajit Das, et al., EPJ Web of Conferences **253** (2021) 11005
[5] S. Agostinelli, et al., GEANT4 Collaboration, Nucl. Instrum. Meth. A **506** (2003) 250–303.