Photon hit response in a LYSO+SiPMs based advanced gamma-imager using GEANT4 simulation

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The γ-spectroscopy community has seen significant advancements with the development of arrays comprising highly segmented position-sensitive HPGe detectors, e.g., Advanced GAmma Tracking Array (AGATA) [1], and the Gamma-Ray Energy Tracking Inbeam Nuclear Array (GRETINA) [2], with key capabilities of γ "tracking" and Pulse Shape Analysis. The capabilities of segmented detectors require thorough characterization of segmented detectors by recording and analyzing the pulses for each individual γ-interaction point inside the detector. In these detectors, γ tracking includes tracking each γ-ray as it passes through the detector, providing information regarding its energy, direction, and interaction points [3, 4]. Therefore, it is crucial to fully comprehend the sensitivity of the detector towards γ-rays hit. To enhance the understanding of detector behavior and performance in different experimental settings, a state-of-art γ-imager is jointly being developed by IIT Ropar and GSI Germany using advanced readout technology to expedite the characterization of detector arrays.

The γ-imager consists of a position-sensitive detector (PSD) featuring a cerium-doped lutetium–yttrium oxyorthosilicate (LYSO) scintillator crystal, coupled with a 96 SiPM matrix readout. An LYSO crystal is chosen for its high scintillation properties and short decay time. A photomultiplier tube is replaced by silicon photomultipliers (SiPMs) due to several advantages which include their compact size, low voltage operation, high gain, and impressive resistance to magnetic fields [7]. The 7 cm diameter gives large field of view (FOV) and its pixelated, narrow design improves position-sensitivity and enables accurate γ-ray interaction determination as it is well-suited for low-energy γ and x-ray investigations [6]. A preliminary qualitative analysis of the test experiments performed at GSI Germany has been carried out by evaluating the amplitude variations in the neighboring channels near the hit location [5].

GEANT4 simulations have been performed to study the PSD response of γ hit, in order to complement the findings of ref. [5], and to evaluate the performance of the PSD. The detector geometry was designed to match the specifications of a novel PSD, which comprises a cylindrical LYSO scintillator crystal with dimensions of 7 cm (diameter) x 3 mm(thickness), refer to ref. [5] for a detailed description of the setup. In order to achieve effective photon detection, the scintillator is optically connected to a 3 mm x 3 mm array of 96 SiPMs using an optical glue layer.

An investigation was carried out comparing the data of a collimated and non-collimated source that was fixed at an 8.5 mm distance from the detector. The collimator had an inner radius of 1 mm and a thickness of 5 mm. In the present work, the photon hits on the SiPM array was evaluated with the use of a 511 keV γ-ray to account for experimental measurements performed using ^{22}Na source. These preliminary studies demonstrate the response of the SiPM array when connected to the LYSO crystal, offering crucial insights into the position-sensitivity and detector performance.

For correct modeling of the light transport within the detector, optical parameters, including absorption length and photon detection efficiency were defined in ac-

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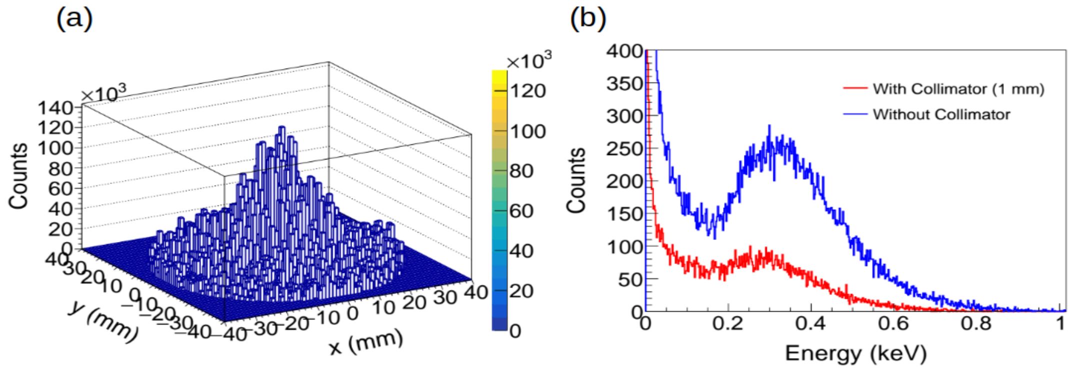

FIG. 1: (a) The distribution of photon hit pattern across the matrix of 96-SiPM array, (b) Energy histogram with and without collimator is overlapped for easy comparison.

cordance with the manufacturer's data sheet for the Silicon. The optical properties of the model are recorded as entries in a G4MaterialPropertiesTable which is connected to the G4Material. The detector volume has also been defined as sensitive.

In Figure 1 (a), the distribution of photon hits on the SiPMs shows how various SiPMs detect the scintillation light from a 511 keV γ. The varying photon hit rates across the array of SiPMs suggest that some SiPMs register higher photon hit counts than others. This variation occurs because the scintillation light produced in the LYSO crystal is not uniformly distributed. The SiPMs positioned closer to the point of scintillation may detect more photons because the light is more effectively directed toward them due to the optical properties of the crystal. Further investigations include the effect of a lead collimator on energy deposition in individual SiPMs. The results show that the total energy recorded across the SiPM array was relatively low when using the collimator. As illustrated in Figure 1(b), the spectrum reflects the γ energy deposition, with the surrounding region representing the Compton background associated with that specific energy.

The source-to-detector distance was maintained at 8.5 mm for both energy spectra measurements, with and without the collimator pointing to the center of the crystal. The lead collimator had an inner radius of 1 mm, a thickness of 5 mm, and was positioned 5 mm away from the center of the crystal. For both studies, 5.10^5 events were provided. The impact of the collimator has been assessed by analyzing both the energy deposited in each individual SiPM and the total energy summed across all SiPMs. This investigation highlights the effective sensitivity of the LYSO+SiPMs-based γ-imager to photon hit. The detailed results of the simulation and their interpretation will be presented during the symposium.

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