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Development and characterization of a novel single plane Compton gamma camera

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The detection of radiation in the environment is crucial, often requiring compact and portable instruments. One effective method for detecting gamma-ray sources is through the use of a Compton gamma camera. Unlike Anger cameras, Compton gamma cameras employ source localization techniques based on Compton scattering kinematics. Various types of Compton gamma cameras have been developed, including those based on semiconductor detectors, which offer excellent spatial resolution but limited efficiency and high costs, and those based on scintillator detectors, which utilize either photo-multiplier tubes or Silicon photomultipliers. Scintillator-based Compton gamma cameras generally provide lower angular resolution than their semiconductor-based counterparts, but they offer greater efficiency and cost-effectiveness. Most scintillator-based Compton gamma cameras consist of two separate detector readout planes: the scatterer and the absorber, or they implement complex designs to determine the depth-of-interaction of incoming gamma radiation.

In this study, we introduce a novel concept for a Compton gamma camera, utilizing segmented scintillators read out on a single side by silicon photomultipliers. Each detector element comprises two scintillator crystals optically coupled by a light guide. We employed GAGG:Ce scintillators measuring 3 mm x 3 mm x 3 mm and 3 mm x 3 mm x 20 mm plexiglass light guides. These detector elements were arranged in an 8x8 matrix with a 3.2 mm pitch, separated by ESR reflectors. In this configuration, the front scintillator layer acts as the scatterer, and the back scintillator layer acts as the absorber, both read out by the same silicon photomultiplier array coupled to the back side of the matrix. This distinctive feature minimizes the number of read-out channels, essential for a compact and portable device. The length of the 20 mm light guide was chosen based on a compromise between detector intrinsic efficiency and angular resolution, as determined through GEANT4 simulation studies.

Following the design, we constructed the Compton gamma camera and conducted laboratory tests to characterize its performance. The tests involved Cs-137 and Na-22 sources, with the setup temperature maintained between 18-20℃, and the silicon photomultiplier array read out by the TOFPET2 data acquisition system. Energy resolution characterization was performed individually for the front and back detector layers by irradiating the respective layers with the collimated source. The average energy resolution at 662 keV for the front and back GAGG:Ce layers was found to be 8.9 ± 1.9% and 10.8 ± 1.6%, respectively, accounting for variations within the module.

To analyze the Compton events, we applied specific conditions based on kinematic criteria, such as the energy of each detector element and the geometry of the detector (e.g., distance between fired elements). These conditions ensured a clean sample of Compton events. The basic imaging test using a Cs-137 source (diameter ≈ 3 mm) positioned 50 mm in front of the module, employing a back-projection algorithm, revealed a distinct peak corresponding to the source, with a spatial resolution of σ = 5.1 ± 0.2 mm. In this work, we will present detailed results characterizing the detector's performance, including efficiency estimation and imaging capabilities for gamma sources of different energies at varying distances and positions within the field-of-view. Finally, we will discuss the potential of this designed detector for highly compact and portable Compton gamma camera applications in environmental gamma-ray detection and localization.

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