Performance testing of a Compton-suppressed $LaBr_3$(Ce)-NaI(Tl) Phoswich detector using BaF_2 as an anti-Compton shield

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Introduction

In an ideal γ-ray spectrum, full-energy peak indicates the complete absorption of the γ-ray's energy by the detector. However, a real γ-ray spectrum consists of photopeaks from fully absorbed γ-rays and those from the surrounding and cosmic background, along with the Compton scattered γ-rays from the main detector. Due to this Compton continuum, the photo-peaks in the low energy region may be suppressed. Reduction of this Compton continuum can be achieved by using a primary detector surrounded by a set of secondary detectors, acting as Anti-Compton Shield. To reduce the Compton background efficiently, the secondary detectors are generally chosen from high density scintillators for increased efficiency. The combined detector system is operated in anti-coincidence mode. However, at γ-ray energies beyond the particle emission threshold, like those observed in the Giant Dipole Resonance (GDR) [1] and Pygmy Dipole Resonance (PDR) [2] regions, reduction of Compton background is necessary to obtain distinct and clear spectral patterns.

In this work, a γ-ray spectrometer with Compton suppression is being developed, using a PARIS [3] phoswich detector as the primary component and a 12 element BaF_2 (3.5cm×3.5cm×35.0cm) [4] detectors for detection of Compton scattered γ-rays. The phoswich consists of a frontal component of 2″×2″×2″ $LaBr_3$(Ce) and a rear component of a 2″×2″×6″ NaI(Tl), coupled to a single photomultiplier tube (PMT- Hamamatsu R7723-100) to collect the light output generated from both the detectors. The linearity, energy resolution, time resolution and addback technique of this phoswich has been reported earlier [5,6]. The schematic diagram of detectors system used for the present experiment is shown in Fig. 1. This paper reports the study of the Compton suppression in the PARIS phoswich detector and compares the results with simulations using GEANT4.

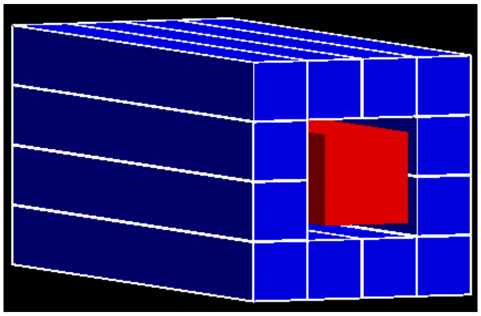

Fig. 1: The schematic diagram of the experimental set-up.

Experimental setup and GEANT4 simulation

The standard laboratory source ^{137}Cs is placed in front of $LaBr_3$(Ce), a part of phoswich detector where most of the incident energy is deposited because of its high density (5.06 g/cm^3). All the 12-BaF_2 detectors are covered with lead block which is an excellent attenuator to γ-photons, such that, they are not triggered directly by the γ-rays emitted from the source. A VME based data acquisition system is used to register energy in event-by-event mode. The signal coming from all the 13 PMTs are first fed to a fixed gain 8-channel fast amplifier (CAEN N412). The linear signals from 12-BaF_2 detectors are sent to an attenuator box to introduce a delay and then connected to a VME QDC (CEAN V792). The logic parts of the same are fed to Leading Edge Discriminator (LED). The 'OR' output of LED is connected to discriminator and then acts as one of the inputs of Anti-Coincidence module. For phoswich detector, the signal from fast amplifier is first fed to discriminator for setting threshold and then send to a Gate and Delay Generator (GDG) to generate logic gate which acts as another inputs of Anti-Coincidence module. Finally, the output of the Anti-coincidence module is used as a master gate for charge integration.

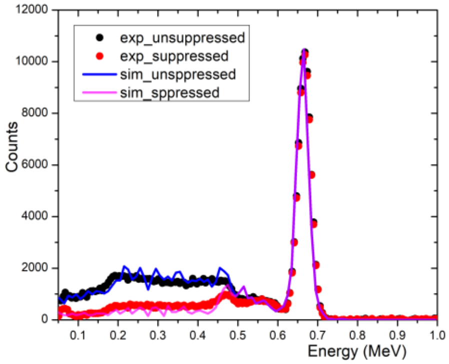

Fig. 2: The Compton suppressed and unsuppressed energy spectrum of the phoswich detector in comparison with the simulated spectrum for 662 keV incident γ-rays from ^{137}Cs source.

The GEANT4 (version 10.5.1) simulation toolkit has been used to construct the geometry and perform Monte Carlo calculations. G4Box class has been used to construct the geometry. The distance between the isotropic γ-ray source (^{137}Cs) and the spectrometer front-surface is kept at 10 cm. 10^6 events are generated in each run from the source position. The simulation incorporates all potential interaction mechanisms for γ-photons, electrons (e^-), and positrons (e^+) by utilizing the appropriate classes.

Results and Discussion

Typically, the performance of Compton suppression is assessed using the P/T ratio, which is defined as the ratio of the area under the photopeak to the total area of the spectrum. The Compton suppressed and unsuppressed spectra obtained from both the experiment and GEANT4 simulation is shown in Fig. 2. The simulated spectra have been found to closely match the experimental results. The values of P/T as obtained from both experiment and simulation are listed in Table 1. It is observed that P/T ratio of ^{137}Cs is improved by greater than 50% after Compton suppression.

To assess the performance of the BaF$_2$ shields at high energies, the simulated spectra of γ-radiation with energy E_γ = 10 MeV are presented in Fig. 3. It has been observed that the background is reduced by nearly 85%.

Table 1: The measured and simulated P/T ratio for unsuppressed and suppressed configurations.

Conditions	P/T ratio	
	Experiment	**Simulation**
Unsuppressed	0.38	0.36
Suppressed	0.58	0.61

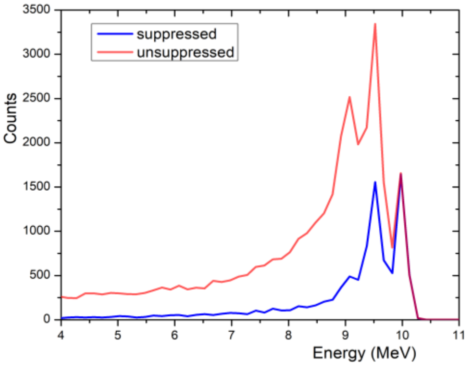

Fig. 3: The Compton suppressed and unsuppressed energy spectrum of the phoswich detector at 10 MeV γ-ray obtained from GEANT4 simulation.

Thus, this setup is suitable for gamma spectroscopy applications, GDR and PDR studies where high levels of background may arise either from external radiation or from the Compton continuum generated by the scattered γ-rays from the source. Due to high granularity, this detector system can also be used in actual in-beam experiment to suppress the cosmic muons.

References

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