Study of enhancement of Photopeak Efficiency of PARIS mini-Cluster

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Introduction

The PARIS (Photon Array for the Studies with Radioactive Ion and Stable Beams) detector array is a high-efficiency detection setup designed for studying high-energy gamma rays to probe the structure of exotic nuclei [1]. The detector utilizes a phoswich design concept, consisting of a $LaBr_3$(Ce)/$CeBr_3$ crystal ($2'' \times 2'' \times 2''$) and a NaI(Tl) crystal ($2'' \times 2'' \times 6''$), both read by a single photomultiplier tube (PMT). As part of the PARIS-INDIA collaboration, it is proposed to integrate PARIS detectors with the INGA setup to explore various aspects of nuclear structure at the BARC-TIFR Pelletron Linac Facility. Some of the proposed physics issues to be investigated include the study of complex high-spin structures in nuclei around ^{90}Zr, shape coexistence in the A $\sim$ 130 region, Jacobi shape transitions in light nuclei, etc. [1].

A detailed characterization of the phoswich detector and its response with NaI energy addback for a single phoswich has been reported earlier [2]. It is envisaged that a few clovers will be replaced with a PARIS mini-cluster in the INGA-PARIS experiment. This paper presents the characterization of a PARIS mini-cluster, comprising four phoswich detectors in a 2x2 arrangement, with emphasis on the improvement in relative photopeak efficiency.

Experimental details

A cluster of four $CeBr_3$-NaI(Tl) PARIS detectors configured in a 2×2 geometry was set up for the present study. Each detector was coupled to an R7723-100 PMT, operated at a typical bias voltage of -1.9 kV. Data was collected using a CAEN V1730 digitizer, customized for the PARIS detector. This digitizer has a 500 MS/s sampling rate, with an input range of 2V_{pp} and 14-bit resolution. Both pulse shape discrimination (PSD) and constant fraction discrimination (CFD) algorithms (for precision coincidence measurements) are inbuilt.

Data analysis was performed using the C++-based ROOT framework. The γ-ray spectra were obtained in list mode ($E_{th} \approx$ 60 keV) using ^{56}Co and ^{241}Am-^{9}Be sources, placed at a distance of 10 cm from the front face of the mini-cluster. The significantly different decay times of $CeBr_3$ and NaI(Tl) scintillation detectors enable effective discrimination of particles interacting exclusively with either detector. The PSD is defined as PSD $= \frac{Q_L - Q_S}{Q_L}$, where Q_S and Q_L are the integrated charge over 200 ns and 1000 ns, respectively.

Data analysis and Results

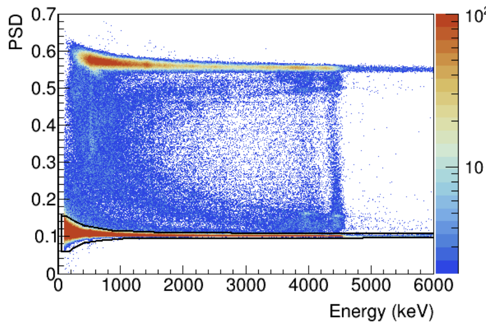

FIG. 1: Energy vs PSD for a single detector together with the gate for CeBr3 events

Detectors were calibrated up to $\sim$ 4.5 MeV using ^{56}Co (847–3254 keV) and ^{241}Am-^{9}Be (4438 keV). The observed non-linearity at 4 MeV is $<$ 0.02 %. This study focuses on primary events in the $CeBr_3$ part of the detector, selected using a PSD gate (black line), as

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TABLE I: Figure of Merit (FOM) for phoswich detectors

Detector	photopeak area (4280-4640 keV)	Escape peak area (3275-4300 keV)	FOM_{exp}	FOM_{sim}
D1	187859	338348	0.555 (2)	0.519 (2)
D2	141166	241059	0.586 (3)	0.526 (2)
D3	182190	304245	0.599 (3)	0.522 (2)
D4	143181	237739	0.602 (3)	0.524 (2)
mini-cluster				
$E_{singles}$	656031	1098310	0.597 (1)	0.534 (1)
E_{total}	956000	990050	0.965 (2)	1.161 (2)

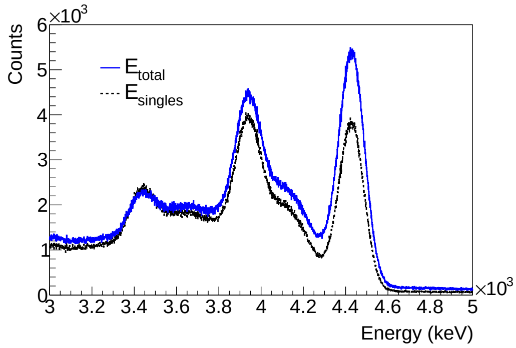

FIG. 2: $E_{singles}$ and E_{total} spectra for 2x2 mini-cluster with ^{241}Am-^{9}Be source.

shown in Figure 1. The mini-cluster configuration offers an opportunity to enhance the photopeak efficiency by employing the add-back technique. For each event in the mini-cluster, the total energy, E_{total}, is calculated as $E_{total} = \sum_{j=1}^{4} E_j$, where E_j is the energy recorded in the $CeBr_3$ part of the j^{th} detector within the coincidence time window of 50 ns.

To make a quantitative comparison between the singles and add-back spectra, a figure of merit (FOM) is defined as the ratio of the photopeak area (4280–4640 keV) to the integral counts under the first and second escape peaks (3275–4300 keV). It should be noted that the latter window also includes Compton scattered events. Figure 2 shows the comparison between the E_{total} (blue solid line) and $E_{singles}$ (black dotted line), where the enhancement in the photopeak intensity compared to that of the first escape peak is clearly evident.

Table I presents the FOM for the singles spectrum of each detector (D1, D2, D3, and D4), along with that for the mini-cluster. The FOM obtained from simulations for the mini-cluster configuration using GEANT4 [3] is also shown for comparison. A reasonable agreement between the data and the simulation is evident. Further improvements can be achieved with NaI energy add-back.

Conclusion

The response of 2x2 PARIS mini-cluster was studied for intended use in INGA-PARIS experiments. The photopeak efficiency shows $\sim$ 60 % enhancement with $CeBr_3$ add-back. Further work will focus on energy dependence of efficiency enhancement due to add-back as well as including the energy deposited in NaI.

Acknowledgments

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