Linearity test of PARIS phoswich elements using cosmic muons

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The PARIS (Photon Array for the studies with Radioactive Ion and Stable beams) detector, a γ-ray calorimeter, is under development by an international collaboration for γ-ray measurement with low intensity radioactive ion beams (RIBs) at upcoming RIB facilities [1]. The detector comprises more than 200 PARIS phoswich elements. Each phoswich element is made of a front 2″ cubic $LaBr_3$(Ce) crystal optically coupled to a 2″×2″×6″ NaI(Tl) crystal at the back. Both the crystals are read by a single photomultiplier tube (PMT − Hamamatsu R7723-100) coupled at the rare end. The widely different decay time of the two crystals [16 (250) ns for $LaBr_3$ (NaI)] allows the separation of $LaBr_3$ and NaI signals employing pulse shape discrimination. The advantage of this cost-optimized design is that the timing information could be extracted from the front $LaBr_3$ which has better timing resolution compared to NaI and addback technique could be used to extract the full energy deposition for an event. Further, using these phoswich elements, low energy γ-rays can be measured in a background of high energy γ-rays. Experiments with two PARIS clusters (3×3 matrix of phoswich elements) have demonstrated the capability of the desired phoswich design [2].

The large difference in light yield of the two crystals [63 (38) photons/keV [3] for $LaBr_3$ (NaI)] and the single readout design put limit on the lower operating threshold of the NaI. Moreover, the large light yield of the $LaBr_3$ may saturate the PMT response at high energy and hence introduces non-linearity in the detector response. Recently, a detailed characterization of two phoswich elements including linearity studies over a wide γ-ray energy (0.662–22.6 MeV) has been performed using radioactive sources and radiative proton capture reactions in ^{11}B target [4]. It should be mentioned that the above linearity studies were carried out using a voltage divider specially designed for the phoswich element [4]. For the above energy range, the suggested optimum operating voltage (with non-linearity less than 10%) corresponds 60 mV anode pulse height (A1) for 662 keV energy deposition inside the $LaBr_3$ crystal. Using cosmic ray muons (the minimum ionizing particle–MIP), the linearity studies of the $LaBr_3$ crystal are extended to 34 MeV.

The experimental setup used for the present measurement is shown in Fig. 1. Two phoswich detectors (D1 and D2) and two 2″ cubic $LaBr_3$ detectors (D3 and D4) were placed in a stacked geometry as shown in Fig. 1. Two plastic detectors were placed on the top and bottom of the detectors to select cosmic muons. Coincidence data was

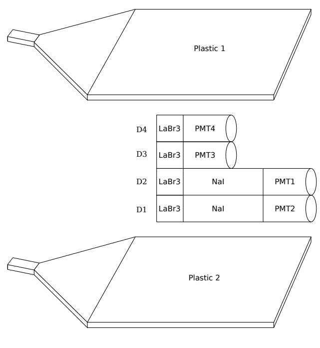

FIG. 1: Schematic setup used for linearity studies with cosmic ray muons. The distance between the plastic and detector is ∼50 cm.

recorded using a CAEN make V1720e digitizer (12 bit ADC, 250 MS/s) with applied voltages corresponding A1=40 mV (V_{D1}=1.27 kV and V_{D2}=1.05 kV) and 60 mV (V_{D1}=1.38 kV and V_{D2}=1.14 kV). The raw anode signals were attenuated suitably using passive attenuators to accommodate the dynamic range of the digitizer. The energy spectra of cosmic ray muon, deposited energy inside the $LaBr_3$ crystal of two phoswich elements, are shown in Fig. 2. This figure clearly shows the characteristic Landau-shape of muon energy deposition. The measured time resolution of the $LaBr_3$ crystals of two phoswich elements (at A1=40 mV) using cosmic muons is found to be 330 ps (see inset of Fig. 2), which is better than the quoted value in Ref. [4]. The mean energy deposition of muons in $LaBr_3$ and NaI was obtained using GEANT4 simulation and they are found to be ∼34 MeV and ∼24 MeV, respectively.

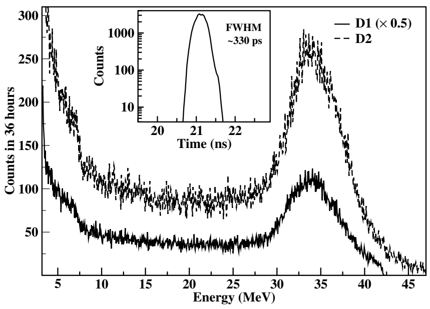

FIG. 2: Cosmic muons spectra of two $LaBr_3$ crystals of phoswich detectors with A1=40 mV, suitably scaled for better viewing. The inset shows the time of flight spectrum of two detectors.

The low energy calibration of the detectors was performed using radioactive sources covering energy range of 0.662–4.439 MeV. For both the operating voltages, the detector ($LaBr_3$) response was found to be linear upto 4.439 MeV. Figure 3 shows the energy response of $LaBr_3$ crystal for two different operating voltages. The symbols represent the peak position of γ-ray and/or cosmic peak whereas the straight lines represent the extrapolated linear calibration upto 4.439 MeV. The percentage deviation of the experimental peak position from the extrapolated linear calibration is defined as the non-linearity (α). The measured non-linearities (at ∼34 MeV) of the two $LaBr_3$ crystal's response for two different applied voltages are tabulated in Table I. It is clear from this table, that for studies upto ∼34 MeV, the optimum voltage (which yields α <10%) would be such that A1=40 mV. For this operating voltage, though the threshold of NaI was ∼2 MeV, it would not affect the energy addback because of the single readout design. Thus, A1=40 mV operating voltage ensures linearity, good time resolution and addback capability of the phoswich elements upto ∼34 MeV.

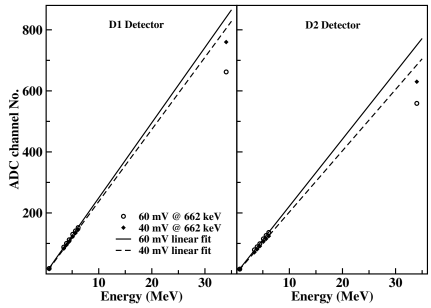

FIG. 3: Energy response linearity of $LaBr_3$ in phoswich detector. The symbols represent the measured data, while the straight lines are the extrapolation of linear calibration using γ-ray energies upto 4.439 MeV.

TABLE I: The non-linearity (α) of the $LaBr_3$(Ce) detector with B3 type voltage divider at E_γ ∼34 MeV for different high voltages (A1) has same meaning as in Table 3.

Detector	**Non-linearity (%)**	
	A1=60 (mV)	A1=40 (mV)
D1	21	6
D2	25	8

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