Characterisation of a $LaBr_3$(Ce)-NaI(Tl) Phoswich detector for high energy gamma rays

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Introduction

In recent days the $LaBr_3$(Ce) scintillator has attracted much attention due to its excellent energy and time resolution. Many advanced detector arrays demanding high resolution and high efficiency for gamma ray detection are planned at upcoming accelerator facilities using these detectors. The PARIS detector [1] comprising clusters of $LaBr_3$-NaI phoswich elements, is designed for high energy gamma ray studies with Radioactive ion beams and a prototype cluster of 3 x 3 detectors is under development. Each phoswich detector consists of 2"x 2"x 2" $LaBr_3$(Ce) (Brilliance 380, Saint Gobain make) optically coupled to 2"x 2"x 6" NaI(Tl) [2]. We have characterised two phoswich detectors for the PARIS prototype with radioactive sources and using the ^{11}B(p,γ) reaction. The energy resolution and linearity of the phoswich detectors have been studied over a wide range upto 22 MeV, for the first time.

Experimental Details and Analysis

Each $LaBr_3$-NaI detector assembly is housed in an aluminium casing with a light guide provided at the rear window. The detector is optically coupled to a 10 stage, 2" Hamamatsu photomultiplier tube (PMT) R7723-100, having a E5859-15 voltage divider circuit. This PMT (-1800 V maximum) with a borosilicate glass window has a maximum sensitivity at 420 nm. It is well suited for both $LaBr_3$ and NaI and also yields good time resolution. Due to the high light yield of $LaBr_3$ (63000 photons/MeV) non-linear effects in PMT response are expected to be significant at higher energies. Hence the performance of the detector in terms of linearity, energy and time resolution was studied over a wide range of PMT voltages, namely 1000-1800V. It was found that the anode pulse height of one detector (D1) is ∼3 times smaller as compared to that of the other detector (D2). The light output from $LaBr_3$(Ce) and NaI(Tl) can be separated by their widely different decay times, 16 ns and 250 ns, respectively. The anode pulse was given to a linear FanIn/FanOut unit and conventional analog electronics has been used for pulse processing. In the energy spectra recorded with a spectroscopic amplifier, the relative positions of spectral peaks from NaI and $LaBr_3$ strongly depend on shaping times and separation of two components cannot be achieved in an unambiguous manner. Hence charge sensitive ADCs (Silena 4418/Q) were used with a short gate for $LaBr_3$ (100 ns) and long gate for NaI (800 ns). Data were also recorded with short vs. delayed (100-700 ns) gates, to completely separate the NaI signal. Source tests using ^{241}Am-^{9}Be, ^{60}Co and ^{137}Cs were carried out at different positions on the detector. Gate widths were optimised for the resolution at E_γ=4.4 MeV. The resolution for NaI was found to worsen from 5% with long gate to 5.7% with the delayed long gate at this energy.

To study the detector response at high energies, an in-beam experiment was done using the 7.2 MeV proton beam from the Pelletron Linac facility, Mumbai. Both the detectors were kept at a distance of 8 cm from the target at +45°(D1) and -135°(D2) w.r.t. the beam direction. In addition a BaF_2 detector was also mounted at -45° for reference. For each detector E_{short}, $E_{long}/E_{delayed}$ and timing between two phoswich detectors were recorded using the CAMAC based acquisition system LAMPS [3]. Data were also recorded

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with D1 and D2 arranged to get an effective 4" thick $LaBr_3$ and also in a geometry with detectors stacked one above the other. The cosmic ray data were also collected in the stacked geometry. Table I gives the list of reactions and targets used.

TABLE I: List of targets and reactions.

Target	Reaction	E_γ (MeV)
Al foil, 0.95mg/cm^2	^{27}Al(p,p')γ[4]	3.004
Mylar, 11mg/cm^2	^{12}C(p,p')γ[4] ^{16}O (p,p')γ	4.439 6.129
^{nat}B, 1mg/cm^2 (on 5mil Ta backing)	^{11}B(p,γ)^{12}C [5]	5.0,22.5,18.1

Fig. 1(a) shows a 2-D plot of E_{short} vs. E_{long} for ^{241}Am-^{9}Be source in front of D2, where total energy events in $LaBr_3$ and NaI are clearly separated. The short gate projection of the $LaBr_3$

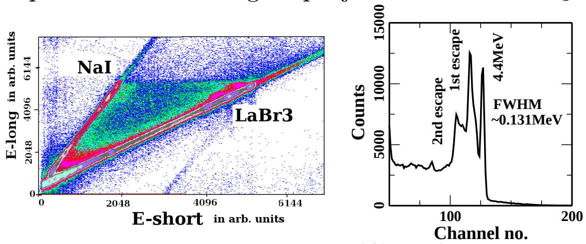

FIG. 1: (a)Energy spectra with ^{241}Am-^{9}Be with D2 at -1500 V, (b) E_{short} projection for ($LaBr_3$) band

band in Fig. 1(b) clearly shows both escape peaks. At 4.4 MeV, the energy resolution obtained is 3.7% for D1 and 2.9% for D2. During the in-beam measurement resolution was slightly worse, namely, 4% and 3% for D1 and D2, respectively.

Results

Fig. 2 shows the energy calibration curve for D2 at -1500 V, which is fairly linear upto 6.13 MeV. Better linearity is obtained at lower voltages but energy resolution worsens from 3% at -1500 V to 5.8% at -1000 V. The projected $LaBr_3$ spectra for high-energy γ rays are shown in Fig. 3, using a linear energy calibration obtained from low energy gamma rays (3-6 MeV). The Monte Carlo simulations using Geant4 [6] incorporating Doppler correction are also shown in the same figure with suitable scaling for comparison. Even at -1200 V, $\sim$15% non-linearity is observed at $\sim$20 MeV for D2. This non-linearity reduces to $\sim$3% at -1000 V. The non-linearity in D1 is very small compared to D2, namely, $\sim$2% at -1400 V and negligible at

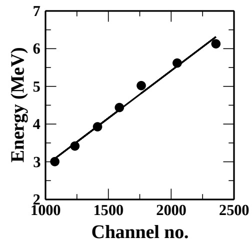

FIG. 2: Linearity curve for D2 at -1500 V

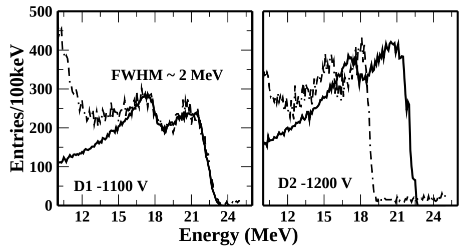

FIG. 3: Projected high energy gamma ray spectra in (dashed line) together with simulations (solid line)

lower voltages. The overall agreement between data and simulation is very good after corrections for energy calibration. Further analysis to study improvement in peak shape after add-back of NaI energy is in progress. It should be mentioned that no significant improvement was observed for peak shape with D1-D2 combination giving 4" $LaBr_3$ thickness.

The time resolution for each phoswich detector was measured to be σ $\sim$160 ps with a ^{60}Co source at -1800 V and σ $\sim$250 ps with cosmic ray muons at lower PMT voltages (-1000 V).

The present results indicate that in order to preserve linearity upto $\sim$30MeV, the operating voltage needs to be around -1000 to -1200 V. This substantially lower operating voltage leads to poorer energy and time resolution even in $LaBr_3$(Ce).

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