TESTING OF THE PARIS $LaBr_3$-NaI PHOSWICH DETECTOR WITH HIGH ENERGY GAMMA-RAYS*

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We report on tests of $LaBr_3$:Ce–NaI:Tl phoswich detectors with γ-rays at various γ-ray energies, up to 22.56 MeV, using radioactive sources and nuclear reactions induced by proton beams delivered by accelerators at IFJ PAN Kraków and PLF Mumbai. Two-dimensional analysis of complex waveforms recorded with digital electronics is compared to analog discrimination methods. Both approaches allow to resolve the $LaBr_3$:Ce and NaI:Tl signal components, and to construct clean associated γ-ray spectra. A digital algorithm to be implemented for the PARIS scintillator array is investigated.

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1. Introduction

The Photon Array for the studies with Radioactive Ion and Stable Beams (PARIS) [1] will be a calorimeter for measurements of γ-rays over a wide energy range of 100 keV–50 MeV. The PARIS array will consist of two shells of scintillator detectors. The inner shell will provide fast timing, direction, and γ-ray multiplicity, whereas the total energy of high energy photon shower will be reconstructed in the add-back mode, comprising the information from the outer shell too. The array is being developed using phoswich detectors as a basic component. The PARIS phoswich detector consists of a 2"× 2"× 2" $LaBr_3$:Ce crystal (BriLanCe380^{TM}, see for example [2]), backed by a 2"× 2"× 6" NaI:Tl scintillator, hermetically sealed in a single aluminum can with a glass window to couple to a photomultiplier tube (PMT), as shown in Fig. 1 (a). The light outputs generated in both phoswich components are collected by a single PMT. The present PMT of choice for the PARIS phoswich detector is Hamamatsu R7723-100. The phoswich is being developed and supplied by Saint Gobain Crystals and Detectors [3].

2. Measurements

The main goal of the tests was to investigate the response of the phoswich detectors to high energy γ-radiation. The set-up, consisting of 3 phoswiches and a single $LaBr_3$:Ce detector (Fig. 1 (b)), was exposed to 6.129 MeV γ-rays from a ^{244}Cm–^{13}C source, and 10.763 MeV photons emitted in the ^{27}Al(p,γ)^{28}Si reaction. The in-beam measurement was conducted with a 992 keV proton beam from the Kraków Van de Graaff accelerator.

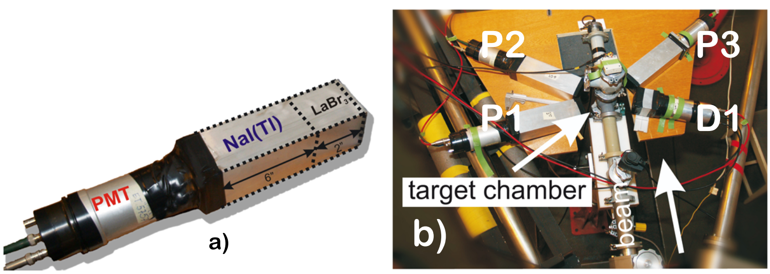

Fig. 1. (a) The $LaBr_3$:Ce–NaI:Tl phoswich detector. (b) An experimental set-up for in-beam tests performed in Kraków; P1, P2, P3 — phoswich detectors, D1 — single $LaBr_3$:Ce detector.

Additional tests were performed in TIFR, Mumbai for two other phoswich detectors where high energy γ- rays were produced in the ^{11}B(p,γ)^{12}C reactions, with the proton beam from an ECR source and the Pelletron accelerator at Mumbai, at the energies of 163 keV and 7.2 MeV, respectively (see Table I).

TABLE I

List of radioactive sources and reactions inducing high energy gammas, used for phoswich tests.

Reaction/Source	E_p	E_γ [MeV]
^{60}Co		1.173, 1.332
^{137}Cs		0.662
^{241}Am–^{9}Be		4.439
^{244}Cm–^{13}C		6.129
^{27}Al$(p,\gamma)^{28}$Si	0.992 MeV (VdG Kraków)	10.763
^{27}Al$(p,p'\gamma)$	7.2 MeV (PLF Mumbai)	3.004
^{12}C$(p,p'\gamma)$	7.2 MeV (PLF Mumbai)	4.439
^{16}O$(p,p'\gamma)$	7.2 MeV (PLF Mumbai)	6.129
^{11}B$(p,\gamma)^{12}$C	7.2 MeV (PLF Mumbai)	5.020, 18.12, 22.56
^{11}B$(p,\gamma)^{12}$C	0.163 MeV (ECR source, TIFR)	4.439, 11.68

In order to assess the contribution of signals from fast — LaBr$_3$ and slow — NaI components, the pulse shape discrimination was applied.

Measurements at TIFR used charge sensitive ADCs (Silena 4418/Q) with a short gate of 100 ns (for LaBr$_3$:Ce signals) and a long gate of 800 ns (for both LaBr$_3$:Ce and NaI:Tl signals). The PMT anode signal was sent via a passive splitter with variable attenuation factors to the QDC. Events corresponding to full energy deposition in LaBr$_3$:Ce and NaI:Tl were clearly separated in $E_{\rm short}$ *versus* $E_{\rm long}$ 2-dimensional spectra. For events with partial energy deposition in both crystals, the offline summing of individual energy signals (after proper calibration) was performed. For this purpose, data were also recorded with short *versus* delayed (100 to 700 ns) gates, to completely separate the NaI:Tl signal. Source tests using ^{241}Am–^{9}Be, ^{60}Co and ^{137}Cs sources were carried out by placing the source on the detector at different positions. Gate widths were optimised for the LaBr$_3$:Ce resolution (3.5%) at $E_\gamma = 4.4$ MeV. The resolution for NaI:Tl was found to degrade from 5% with the long gate to 5.7% with the delayed long gate at this energy, while LaBr$_3$:Ce resolution remained unaffected. The projected LaBr$_3$:Ce spectra for high-energy γ-rays in the ^{11}B$(p,\gamma)^{12}$C reaction are shown in Fig. 2, using a linear energy calibration extrapolated from a calibration at low γ-ray energies (3–6 MeV). The left panel shows the spectrum obtained at $E_p = 163$ keV, with the full energy absorption peak at $E_\gamma = 11.68$ MeV and escape peaks well resolved. The right panel shows the spectrum measured at $E_p = 7.2$ MeV, corresponding to $E_\gamma = 22.56$ MeV, here a lower PMT bias voltage of -1000 V was applied instead of the earlier used voltage of -1400 V.

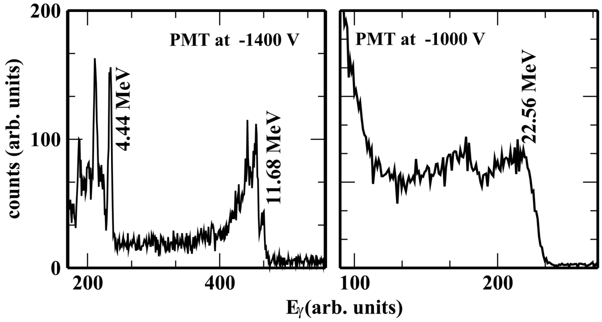

Fig. 2. Parts of gamma ray spectra measured by $LaBr_3$:Ce in the $^{11}B(p,\gamma)^{12}C$ reaction; Gamma lines of 11.68 MeV and 22.56 MeV are indicated.

The discrimination method used in Kraków was provided by an Advanced Pulse Stretcher (APS) module developed in Milano [4]. The APS module supplies two Gaussian signals: "fast" proportional to the amplitude of the rapid signal component only ($LaBr_3$:Ce), and "slow" which is proportional to the energy of the entire signal ($LaBr_3$:Ce and NaI:Tl). Both of the signals were fed to the multichannel CAEN V785 ADC, as shown in the diagram of Fig. 3. The resulting spectra were acquired in the Kmax environment [5]. During the in-beam test in Kraków, a fast active splitter was used to duplicate the PMT signal which was digitized at different frequencies, by the CAEN V1729 (12 bits, 1 GS/s), and the Acqiris DC252 (10 bits, 4 GS/s) digitizers.

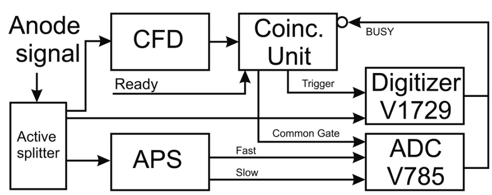

Fig. 3. The block diagram of the Kraków experimental setup.

An example of 2D analysis, similar to the one of TIFR measurements, is shown in Fig. 4. The 2D plot of "Qfast" *versus* "Qslow" amplitudes, registered with the APS module, shows a clear separation between the $LaBr_3$:Ce and NaI:Tl components. The two semi-diagonal stripes contain events corresponding to the energy release in the $LaBr_3$ crystal or in the NaI crystal only. Located between these stripes are events in which the energy deposition was shared between two scintillators. As both crystals had different energy gains, in order to obtain the total energy spectra, we defined a tilted axis that corresponds to gain matched gamma energies (indicated as a dashed line in Fig. 4 (left)). A projection of the matrix points on this axis provides the full add-back spectrum (see Fig. 4 (right)).

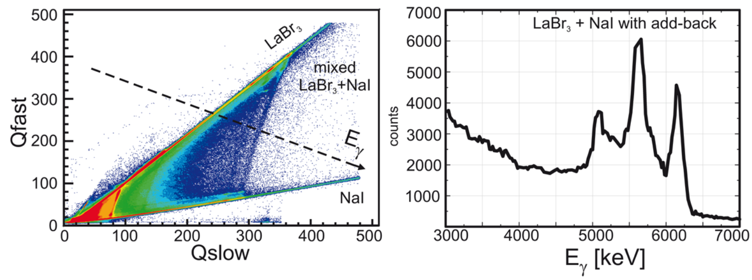

Fig. 4. Left: the 2D plot of charges collected in fast (Qfast) and slow (Qslow) gates by a phoswich detector for 6.13 MeV γ-rays. Right: the corresponding add-back γ spectrum, obtained as the projection on the energy axis E_γ, indicated by the dashed line.

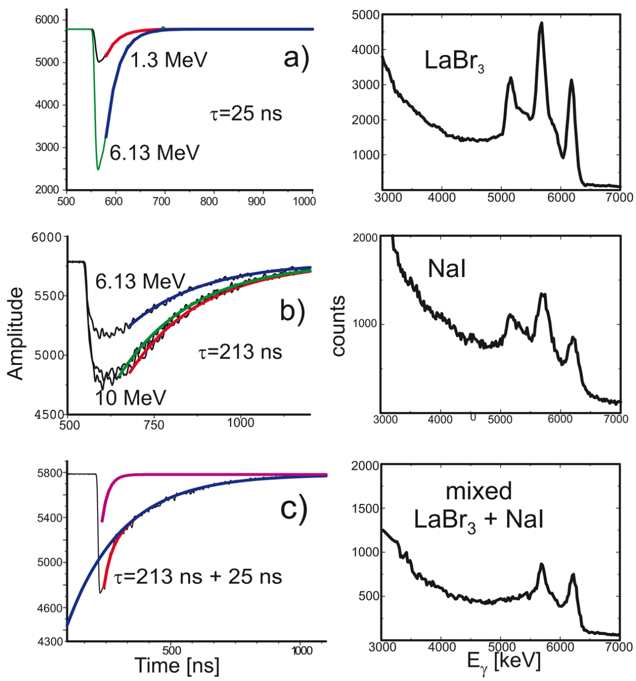

Fig. 5. Left: the analytical function fit to signal shapes associated with different regions of the Qfast–Qslow matrix, as indicated in Fig. 4 (left). Calculated decay times τ are shown. Right: the 6.13 MeV gamma line and the escape peaks reconstructed by charge integration of the filtered detector pulses.

Typical PMT signals, corresponding to $LaBr_3$:Ce and NaI:Tl for 6.13 MeV full absorption peaks, selected by two-dimensional conditions on the "Qfast"–"Qslow" matrix, are shown in Figs. 5 (a) and 5 (b). An exponential fit provided decay times τ describing the waveforms of reference. These parameters were observed to be valid also for signals induced by photons of $E_\gamma = 1.3$ MeV and $E_\gamma = 10.76$ MeV. In Fig. 5 (c) an example of a complex signal produced by a 6.13 MeV photon interacting in both parts of the phoswich is shown. It turned out that a multi-component fit of the signal amplitudes (at fixed decay times deduced from the signals of reference) accurately reproduced the registered waveforms. The γ-ray energy spectra corresponding to the $LaBr_3$-like, NaI-like, and mixed events are shown along with the representative phoswich signals. It is worth noting that in the spectrum of scattered photons (Fig. 5 (c)) the double escape peak is significantly reduced, what illustrates an increase of efficiency of the phoswich with respect to the individual scintillators.

3. Conclusions

The phoswich $LaBr_3$:Ce–NaI:Tl detector response to γ-rays has been studied over a wide energy range. Both analog (APS based) and digital signal analysis provided good separation between $LaBr_3$:Ce (fast) and NaI:Tl (slow) components of the phoswich signal. The obtained waveform parameters were found to be valid for a wide range of the γ-ray energies. The total energy deposited in the detector, measured using the add-back mode, produced clean γ-ray spectra with a good energy resolution. An experimental test with a suitable analysis algorithm has yet to be devised to investigate the effect of γ-ray multiplicity on measurements of high energy γ-rays.

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