

Measurement of high energy gamma rays with large volume LaBr₃:Ce scintillators

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Abstract

In the last few years, the Lanthanum Bromide scintillators are attracting the scientific community in nuclear spectroscopy because of their “almost ideal” scintillator properties. An array composed of 10 large volume LaBr₃:Ce (3.5” × 8”) detectors, named HECTOR⁺, was developed by the gamma-ray spectroscopy group of University of Milan. A R&D activity was performed on such large detectors and their general performances, especially for high energy gamma rays, have been studied. In fact no information about such large volume crystals is present in literature as they are available since very few years only.

1 Introduction

Recent studies have shown that a LaBr₃:Ce detector gives an optimal energy resolution for scintillators (<3% at 662keV), an excellent time resolution (<1ns), a good efficiency and a negligible variation of the light output with temperature. Furthermore, the study of the signal line-shape allows to discriminate between alpha particle and gamma-rays, using Pulse Shape Analysis techniques [1]. The availability of LaBr₃:Ce crystals in volumes larger than 1000cc could make these scintillators a possible alternative to HPGe detectors for gamma-ray measurements. An array based on LaBr₃:Ce scintillators (eventually coupled with HPGe detectors) will constitute an extremely performing, efficient, cost-effective and easy to handle array for gamma spectroscopy experiments. Indeed the good energy resolution and high efficiency allow the measurement of low and high-energy gamma-rays in nuclear physics experiments in a wide energy range (0-40 MeV), as for example the measurements of the gamma decay of the Giant Dipole Resonance and of the Pygmy Dipole Resonance [6] [7]. The sub-nanosecond time resolution enables an extremely efficient rejection of background radiation not originating from target position. Moreover thanks to the fast time constant (16 ns), these detectors could be used with count rates of hundreds of KHz. Recently these detectors have been used in the AGATA campaign at Legnaro Laboratories while, at the moment, they are located at the PRESPEC setup at GSI coupled again with AGATA.

For these reasons the gamma-ray spectroscopy group of the University of Milan has been working on the development of an array composed of 10 large volume LaBr₃:Ce (3.5” × 8”), named HECTOR⁺. The LaBr₃:Ce have been coupled to a standard SBA PhotoMultiplier Tube (PMT) Hamamatsu R10233-100SEL and a specifically designed active Voltage Divider (VD) developed by the electronic group of INFN Milano [4]. Unfortunately the performances of LaBr₃:Ce (3.5” × 8”) crystals cannot be easily scaled from those of smaller ones [2], because of possible self absorption or possible incomplete reflections of the scintillation light, count rate effects, large PMTs, crystal in-homogeneities and a much higher sensitivity to high energy gamma rays. For these reasons we measured mono-energetic gamma-rays from 1 MeV up to 22.6 MeV at Debrecen ATOMKI Laboratories (Hungary) to investigate the PMT linearity, the detectors energy resolution and their response functions to different count rates.

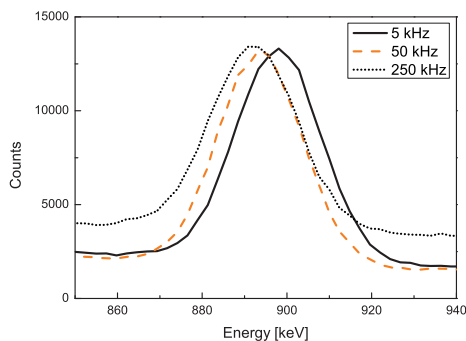


Fig. 1: The 898 keV peak from a ^{88}Y source measured in a $\text{LaBr}_3:\text{Ce}$ ($3.5'' \times 8''$) detector for different count rates.

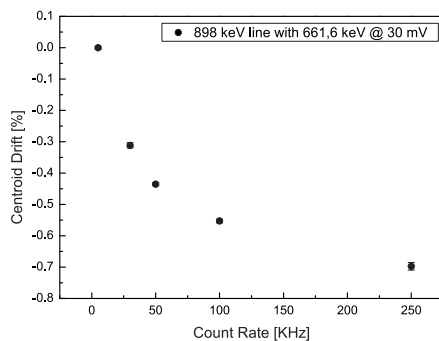


Fig. 2: The centroid drift measured in a $\text{LaBr}_3:\text{Ce}$ ($3.5'' \times 8''$) detector is displayed as a function of the count rate.

2 Studies of the detector properties

The aim of this work is the characterization of the HECTOR⁺ array in term of count rate, pulse distortion and energy resolution.

2.1 Detector response as a function of Count Rate

In principle it is possible to use large volume $\text{LaBr}_3:\text{Ce}$ detectors at very high count rates thanks to their fast pulses (150 ns). However, in such conditions, the average current inside the PMT increases and affects the values of the voltage at the last dinodes. If the count rates is not stable these gain drifts could deteriorate the detector energy resolution. In order to study this behaviour the response of the $\text{LaBr}_3:\text{Ce}$ to different count rates was investigated using as a reference line the gamma-rays emitted by the ^{88}Y source. Different count rates were achieved by placing a 400 MBq ^{137}Cs source at different position relative to the detector. The plots in Fig. 1 shows the centroids drift as a function of count rate (from a few kHz to 250 kHz), obtained using the in house developed active VD [4]. Signals have been digitized at a frequency of 2 GHz and then integrated to produce the energy spectra. As can be seen from the Fig. 2 the centroid drift is smaller than 0.7% at 250 kHz with this VD. In case of stable count rates no significant deterioration of the energy resolution was measured.

2.2 Pulse Distortion

As a consequence of the high light yield of the new Lanthanum Bromide scintillators (63000 ph/MeV), the coupled PMTs generally show saturation effects for high energy gamma rays and such non linearity affects time and energy resolution. Therefore, it is extremely important to account and correct for these effects. An indication of this non ideal behaviour of the PMT+VD is the presence of a distortion in the pulse line-shape [5]. The Fig. 3 shows the pulse line-shape measured in a $\text{LaBr}_3:\text{Ce}$ ($3.5'' \times 8''$) detector coupled to the active VD for monochromatic gamma-rays from 1 MeV up to 17 MeV. As can be observed a very small distortion of the pulse is present. It has to be pointed out that in case one uses a passive VD this distortion becomes relevant. Fig. 4 summarizes the rise time, fall time and FWHM of the pulses displayed in Fig. 3.

2.3 Energy Resolution

The energy resolution was measured using different mono-energetic gamma-rays from 1 MeV up to 22.6 MeV. The monochromatic gamma-rays were obtained using (p, γ) reactions [3]. The $\text{LaBr}_3:\text{Ce}$ ($3.5'' \times 8''$) crystals were coupled to a PMT+activeVD and a in house spectroscopy amplifier (BaFPro) for

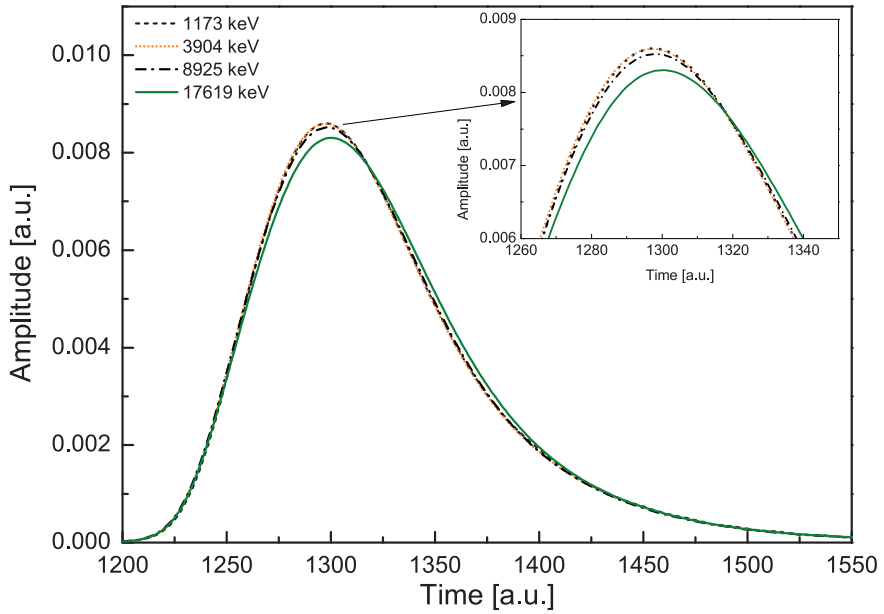


Fig. 3: The pulse line-shape measured in a $\text{LaBr}_3(\text{Ce})$ ($3.5'' \times 8''$) detector with the active VD for different gamma-ray energies.

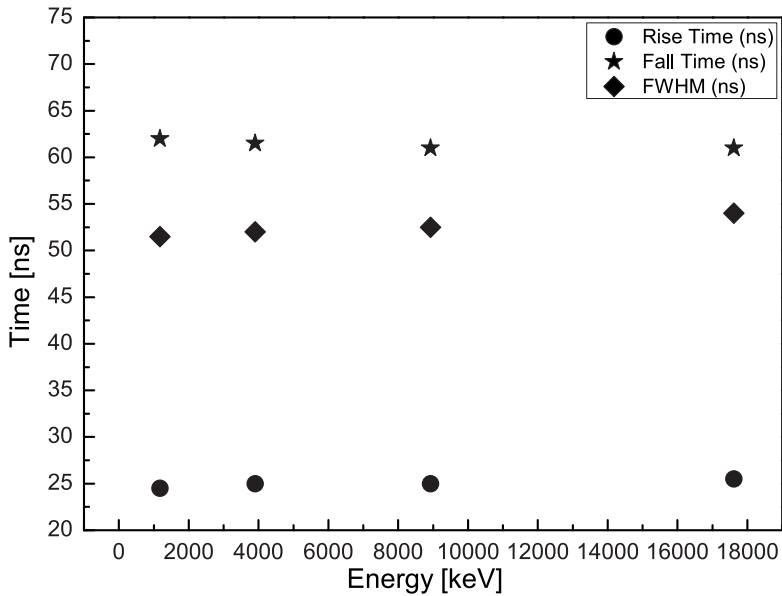


Fig. 4: The pulse line-shape parameters extracted from Fig. 3 .

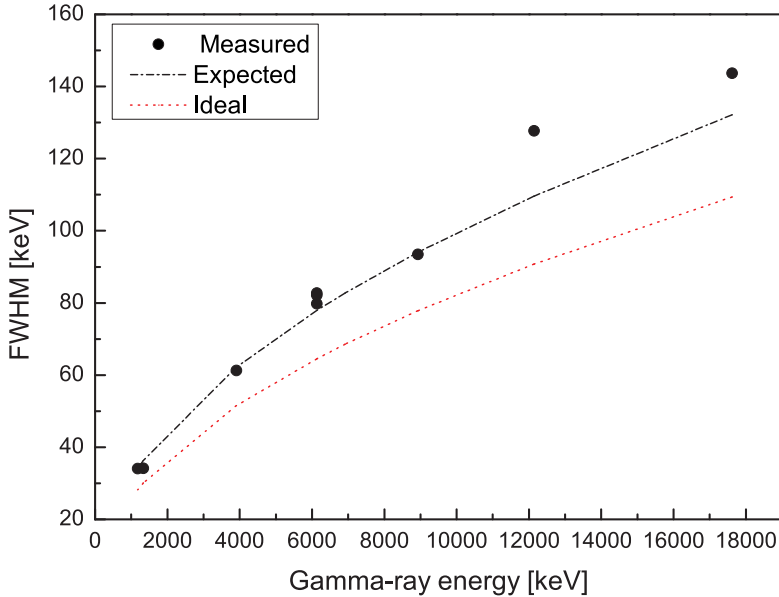


Fig. 5: The measured energy resolution for a $\text{LaBr}_3:\text{Ce}$ ($3.5'' \times 8''$) detector with the active VD. The filled points are the results obtained at ATOMKI Debrecen Laboratory using an analog electronics (BaFPro modul). The dashed black line indicates the expected $1/\sqrt{E}$ trend. The dashed red line indicates the values obtained at University of Milan from digitalized pulses

the shaping of signals was used. The detector HV was chosen in order to have an anode signal of 30 mV for an event which deposit 661.6 keV inside the crystal. The results are showed in Fig. 5. The energy resolution reflects the expected trend up to 10 MeV. Due to the crystal in-homogeneities or, alternatively, to small gain drift of the PMT gain down to temperature or voltage a deterioration of the energy resolution from the $1/\sqrt{E}$ trend was observed for the two highest gamma-ray energies. The dotted red line shows the energy resolution measured (up to 9 MeV) and expected (for $E_\gamma > 9$ MeV) in our R&D laboratory using digitized pulses. Fig. 6 shows a comparison between energy spectra measured with a $\text{LaBr}_3:\text{Ce}$ ($3.5'' \times 8''$) detector and a HPGe detector. The used source is a AmBe-Ni source. In such a source, a core of ^9Be and alpha-unstable ^{241}Am is surrounded by a thick layer of paraffin; some metal discs of natural Nickel are also placed inside the paraffin layer. The radiative capture of thermal neutrons in natural Nickel produces several gamma rays of which those at 8.997 MeV is the strongest one. The AmBe-Ni source is very useful because the $^{58}\text{Ni}(n, \gamma)$ neutron capture reaction produces gamma-rays up to 9 MeV of energy, and this is one of the few ways to have such high energy gammas without using an accelerator. The 9 MeV gamma-ray is resolved in both spectra.

3 Conclusions

We studied the performances of large volume $\text{LaBr}_3:\text{Ce}$ ($3.5'' \times 8''$) detector in terms of the PMT+VD response, the detectors energy resolution and their response functions to different count rates. The characteristics of these detectors were investigated in a wide energy range, from 1 MeV up to 22.6 MeV. These tests were performed in preparation to the experimental campaign at GSI Laboratories (Germany) where the HECTOR⁺ array will be used in the PRESPEC-AGATA setup.

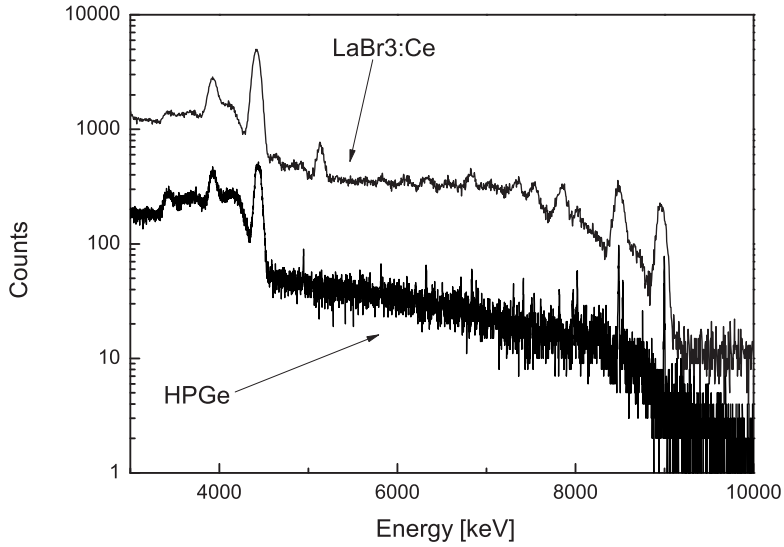


Fig. 6: The energy spectra measured using a $\text{LaBr}_3:\text{Ce}$ ($3.5'' \times 8''$) detector with the active VD in black and a HPGe in red. An AmBe-Ni source was used.

References

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