



Position sensitivity in large spectroscopic LaBr₃:Ce crystals for Doppler broadening correction



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ABSTRACT

The position sensitivity of a large LaBr₃:Ce crystal was investigated with the aim of correcting for the Doppler broadening in nuclear physics experiments. The crystal was cylindrical, 3 in × 3 in (7.62 cm × 7.62 cm) and with diffusive surfaces as typically used in nuclear physics basic research to measure medium or high energy gamma rays (0.5 MeV < E_γ < 20 MeV). The crystal was coupled to Position Sensitive Photomultipliers (PSPMT). The signals from the 256 segments of the four PSPMTs were acquired grouping them into 16 elements. An event by event analysis was performed and a positron resolution of the order of 2 cm was found. It was verified that this allows an important reduction of the Doppler broadening induced by relativistic beams in Nuclear Physics experiments.

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1. Introduction

The properties of LaBr₃:Ce material are well known: it is an inorganic scintillator characterised by high yield, high density, excellent energy and time resolution [1]. Several groups have been investigating the position sensitivity properties of this material, mostly in medical field (see for example Ref. [2–7]). In this field, the goal is to locate the position of a well known gamma-emitter with a precision as good as possible. Usually, the detected gamma rays are the 140 keV from ^{99m}Tc or the 511 keV from the positron annihilation process. It was found that in gamma-cameras for small animal SPECT a sub-millimetre position resolution can be obtained due to the high light yield of LaBr₃:Ce (see for example Ref. [8–11]). Because of the high position resolution required, the crystals used in this field are rather thin, their thickness being of the order of 1 cm or less. Furthermore, they are provided with absorbing surfaces, so to avoid the reflected scintillation light to reach the photocathode and spoil the position sensitivity. However, this affects the energy resolution.

On the other hand, in nuclear physics basic research, LaBr₃:Ce crystals are employed to study the decay properties of nuclei populated via nuclear reactions. In this case, the position of the emitter is well known, while the energies of the gamma transitions are not known and may range up to several MeV. Therefore, detectors with good energy resolution and high efficiency are needed. These two requirements are fulfilled by diffusive surfaces

in order to collect all the scintillation light, and large thicknesses (> 3 cm). Lately, the availability of exotic beams made possible to study nuclei far from stability via reactions where the nucleus under study is moving, it excites interacting with a target nucleus at rest and de-excites by radiation emission while it is still moving. These exotic beams can reach velocities up to v/c of the order of 0.7 or more [12,13]. In the lab system, the energy of a gamma ray emitted by a moving source depends on the emission angle due to the Doppler effect. Therefore, since the detector covers a non negligible solid angle, the detected energy resolution is deteriorated. To give an example, for a 3"×3" LaBr₃:Ce detector placed at 20 cm distance from the target, the resolution of 1 MeV gamma ray is 25 keV when the emitter is at rest, 70 keV when it moves with v/c=0.3 or 150 keV for v/c=0.7. The problem of Doppler broadening is quite serious in nuclear physics. In fact, it was one of the main reasons for the development of specific arrays made of segmented HPGe crystals [14,15]. With these arrays it is possible to track the gamma ray, to identify its first point of interaction, calculate the emission angle and convert its energy to the centre of mass value [16]. The energy resolution of these arrays is excellent, which is very advantageous in spectroscopy studies below particle threshold, but the system is complex, expensive, hardly transportable from one lab to the other, and the required data analysis is quite sophisticated.

On the other hand, an excellent energy resolution is only needed in spectroscopy studies of high density transitions spectra. In the two opposite cases of low density transition spectra or giant resonances at high excitation energies, 4 or 5% energy resolution

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at ~ 1 MeV would be sufficient [13]. Our purpose is to search for a position sensitive detector with good energy resolution, good efficiency for gamma-rays of energies up to several MeV's, relatively simple to handle and to transport. To this end, $\text{LaBr}_3\text{:Ce}$ crystals are the best candidates, since they have good energy resolution and they are available in large volumes so that they can detect gamma-rays up to tens of MeV. Taking into account the intrinsic energy resolution of the $\text{LaBr}_3\text{:Ce}$, a spatial resolution of the order of the centimetre would be sufficient.

The position sensitivity properties of a $3\text{ in} \times 3\text{ in}$ ($7.62\text{ cm} \times 7.62\text{ cm}$) $\text{LaBr}_3\text{:Ce}$ crystal having diffusive surfaces were already investigated using a statistical approach in [17–20], where it was found that the position sensitivity for such detector was of the order of the centimetre. In the present work we studied the position sensitivity on an event by event basis, as described in Section 2. We applied the results to a simulated case of Doppler broadening built in our laboratory, as discussed in Section 3. In Section 4 conclusions are drawn.

2. Measurements of the 662 keV gamma-ray from ^{137}Cs

The measurements were performed on an event-by-event basis. The scintillation light was collected by Position Sensitive Photomultipliers (PSPMT). We used Hamamatsu H8500 segmented PSPMT's, which have dimensions $2\text{ in} \times 2\text{ in}$ and consist of 64 segments. Since the crystal surface is larger than each PSPMT, we used four of such tubes in the configuration shown in Fig. 1. The four PMT's we had available were different: two of them were characterised by 10 dynodes and a bialkal photocathode, while the other two had 8 dynodes and SBA photocathodes. The two types of PMT's had different performances, as listed in Table 1: when coupled singularly to the crystal, the 8 dynodes type provided an energy resolution of about 4% at 662 keV, while the 10 dynodes type resulted slightly worse. Note that in this case only about 55% of the crystal surface is covered by the PMT. In Fig. 2, the comparison of the 662 keV peaks of ^{137}Cs obtained with each of the four PSPMT's is shown. When the PSPMT's were used together covering the whole crystal surface, the energy resolution was 4%, corresponding to 26 keV. In this case, 120 segments were active (see the left part of Fig. 3). In order to simplify the setup, we short circuited segments in groups of 16, ending up with 12 macro active segments [19], as shown in the right part of Fig. 3. Note that, since the single segments have in principle different quantum efficiency

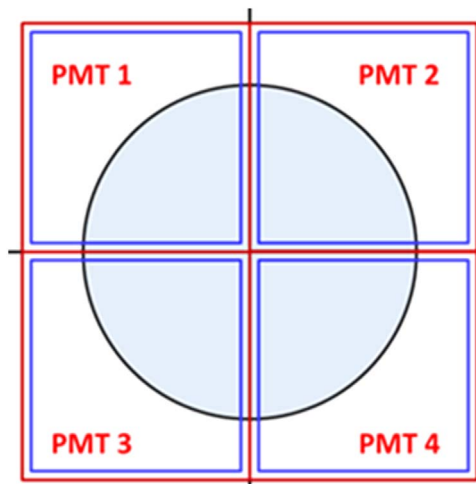


Fig. 1. Four segmented PMT's are coupled to the $\text{LaBr}_3\text{:Ce}$ crystal surface indicated by the blue circle. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1

The properties of the four Hamamatsu H8500 PSPMT's used in this work are listed. In the last column, the energy resolution measured at the 662 keV transition of ^{137}Cs is reported for each PSPMT coupled singularly to the crystal (see inset in Fig. 2), covering about 55% of the crystal surface.

Serial n.	Dynodes	Photocathode	Resolution at 662 keV (%)
ZK0017	8	SBA	4.0
ZK0034	8	SBA	4.2
AA0471	10	Bialkal	5.1
AA0524	10	Bialkal	5.3

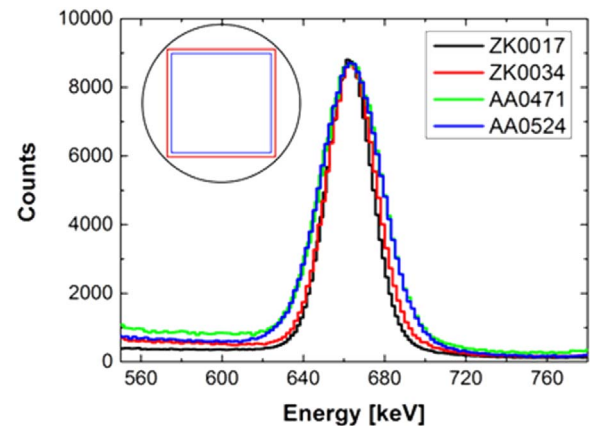


Fig. 2. The measurements of the 662 keV transition of a ^{137}Cs source using the four PSPMT's are compared. The PSPMT's are coupled singularly to the crystal as shown in the inset.

and gain, short circuiting a group of segments reduces the possibility of optimizing the performances of the PSPMT's by adjusting the gain of each single segment.

Measurements were performed with a 400 MBq ^{137}Cs source collimated in a 1 mm diameter beam spot. High voltage of -900 V was applied to the PSPMT's through a CAEN N1470 4 channel HV power supply. Data were taken using two 8 channels amplifier modules especially designed for PSPMT's [20], and a DAQ system based on KMax environment [21]. The source was placed in several (x,y) positions in the front face plane and the measured coordinates of each event were obtained calculating the centre of gravity of the light distribution:

$$x_{\text{pos}} = \sum (x_i \cdot Q_i) / \sum Q_i \quad (1)$$

where x_{pos} is the calculated x-coordinate of the event, x_i are the x-coordinates of the centre of each segment and Q_i are the collected charges in each segment. A similar equation is used for the y-coordinate y_{pos} .

Gating on the 662 keV transition, we obtained Gaussian-like position profile distributions and the FWHM was about 2.3 cm. In Fig. 4, we show the source position profiles in the cathode plane corresponding to two source positions 4 cm apart along the x direction. We defined the origin in the centre of the cathode plane. On the top and on the right the projections on the x-axis and y-axis are shown, respectively. In x-projection the two profiles are well separated. Several measurements with the source placed in different positions between $x = -2\text{ cm}$ and $x = 2\text{ cm}$ and between $y = -2\text{ cm}$ and $y = 2\text{ cm}$ were performed. The upper panel of Fig. 5 shows the centroids of the measured distributions as a function of the source position in the x direction (full dots). The Field of View correction was performed by fitting the data with a 3rd degree polynomial (solid line in the figure). A similar procedure was undertaken for the y direction. With these corrections the source positions were very well reproduced, as can be seen in the bottom

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