Position sensitivity in 3”x3” Spectroscopic LaBr3:Ce Crystals

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Abstract. The position sensitivity of a thick, cylindrical and continuous 3” x 3” (7.62 cm x 7.62 cm) LaBr3:Ce crystal with diffusive surfaces was investigated. Nuclear physics basic research uses thick LaBr3:Ce crystals (> 3cm) to measure medium or high energy gamma rays (0.5 MeV < Eγ < 20 MeV). In the first measurement the PMT photocathode entrance window was covered by black absorber except for a small window 1 cm x 1cm wide. A complete scan of the detector over a 0.5 cm step grid was performed. The data show that even in a 3” thick LaBr3:Ce crystal with diffusive surfaces the position of the full energy peak centroid depends on the source position. The position of the full energy peak centroids are sufficient to identify the collimated gamma source position. The crystal was then coupled to four Position Sensitive Photomultipliers (PSPMT). We acquired the signals from the 256 segments of the four PSPMTs grouping them into 16 elements. An event by event analysis shows a position resolution of the order of 2 cm.

1. Introduction
The position sensitivity of a thick, cylindrical and continuous 3” x 3” (7.62 cm x 7.62 cm) LaBr3:Ce crystal with diffusive surfaces was investigated. The LaBr3:Ce material is an inorganic scintillator which presents excellent scintillation properties. Its position sensitivity properties were studied and applied by many groups in several fields, mostly medical. Its high light yield allows a sub-millimeter position resolution in gamma-camera for small animal SPECT. Usually, those gamma cameras are used to detect gamma rays of known energy, mostly the 140 keV from the 99mTc source, or the 511 keV coming from positron annihilation, in order to locate the position and dimension of the emitter with a position resolution as good as possible. Following these requirements, crystals used in this field are mostly continuous, with a maximum thickness of the order of 1 cm, and they have absorbing surfaces, so that only the scintillation light coming directly from the interaction point reaches the photocathode. In nuclear physics basic research, LaBr3:Ce crystals are used to study the decay properties of nuclei populated via nuclear reactions, where an accelerated particle hits a target nucleus. Therefore, the position of the emitter is well known, while the energies of the gamma transitions are unknown a priori, and they could range up to several MeV.

With the availability of exotic beams, nuclei far from stability can be studied via inverse reactions where the nucleus under study is accelerated, excited by the interaction with a target nucleus and de-excited by radiation emission while still moving. These beams can be accelerated to velocities up to v/c = 0.7-0.8. In the lab system, due to the Doppler effect, the energy of a gamma ray emitted by a moving source depends on the angle of emission. Therefore, the energy detected will be degraded
depending on the solid angle covered by the detector. For example, in a 3”x3” LaBr\(_3\):Ce detector placed at 20 cm distance from the target, a 1 MeV gamma ray will be detected with 25 kev resolution if the emitter is at rest, 70 keV resolution if it moves with v/c=0.3 or 230 keV for v/c =0.7. The problem of Doppler broadening is so important in nuclear physics that arrays have been developed [1,2], made of segmented germanium crystal, able to track the detected gamma rays, to identify the interaction point, and correct the gamma energy for the angle of emission [3]. The advantage of these arrays is an excellent energy resolution, but the system is very complicated, hardly transportable from one lab to the other, the setup is complex, and also the data analysis is quite laborious. Last but not least, it is very expensive.

On the other hand, it is not always necessary to have such an excellent energy resolution, for example when studying giant resonances at higher excitation energies, 3 or 4% energy resolution would be sufficient [4]. Our aim is to investigate for a position sensitive detector with a good efficiency, for energies up to several MeV, good energy resolution, simple to handle and to transport, and as cheap as possible. LaBr\(_3\):Ce crystal are ideal candidates, since they are available in large volumes and have good energy resolution when provided with diffusive surfaces, so that all the scintillation light is collected. Since we use imaging to recover energy resolution, considering the intrinsic resolution of the LaBr\(_3\):Ce, a spatial resolution of the order of 1 cm would be sufficient.

2. Statistical measurement

There are two big differences between a nuclear physics spectroscopic detector and the ones usually used for imaging: the first is the thickness. We do not expect to find position sensitivity for one or two hundred keV gamma rays, since they all interact in the first millimeters of the scintillator [5], but for medium or high energies gamma rays position sensitivity might be retained. The second difference is the presence of diffusive surfaces. A 1 MeV gamma ray produces about 60,000 scintillation photons, the largest part of which will undergo several reflections on the surfaces covering a mean path of the order of 1 meter before hitting the photocathode. Therefore the light distribution on the detection surface might be heavily affected.

To verify if position sensitivity is still present, we performed a simple test, taking a Hamamatsu R6233-100SEL spectroscopic PMT 3”X3” which, coupled to a Hamamatsu E1198-26 voltage divider usually gives 20 keV resolution at 662 keV. We shielded the tube with black tape, leaving a square window with 1 cm side (see Fig. 1). We then collimated an intense \(^{137}\)Cs source into a beam spot with

![Figure 1. Lower panel: the shielded PMT together with the 3”x3” LaBr\(_3\):Ce crystal is shown. Upper panel: the position of the three windows in the PMT shielding are indicated: from the left: position A (0cm,0cm); position B (1.5cm,0cm); position C (3cm,0cm)
a diameter of 1 mm and performed a set of measurements moving the source on a half a centimeter grid. The measurements were repeated for three window positions: in the center, at 1.5 and 3 cm from the center. As a result, by plotting the centroids of the 662 keV peak as a function of the source position, we find a correlation between the window position and the source position [6] (see Fig. 2).

**Figure 2.** Centroids of the 662 keV peak are plotted as a function of the source position for the three window positions, as indicated in the insets.

**Figure 3.** The positions of the full energy peak centroid obtained in the measurements with the source in the “unknown” position (black lines) are compared with the tabulated centroids as a function of the source position along the x axis for the three window positions, as indicated in the insets. The error bars of the “blind” measurements are represented by the dashed black lines.

We can conclude that some position sensitivity is still present. In order to extrapolate the source position from the data, we tabulated the centroid values corresponding to the grid source positions for each window. An additional table relative to a fourth window position was deduced by applying a 90° rotation to the window at 3 cm from the center. We then placed the source in an “unknown” position and performed four measurements with the four window positions in the shield.
The measured centroids were compared to the tabulated ones and the source coordinates corresponding to the centroids overlapping with the data were selected (see Fig. 3). They were plotted on a plane, representing the crystal front face, as shown in Fig. 4. The overlap of the selected coordinates corresponds to the source position and we find a good agreement within 1 cm, which is the grid step dimension. These results are very promising.

3. Event by event measurement

For practical application, we need an event by event analysis. This requires the use of segmented position sensitive photo tubes. We used the Hamamatsu H8500, which is the largest available, it has dimensions 2”x2” and 64 segments. In order to cover the whole crystal surface, we used four of such tubes. They were not equal: two of them had 10 dynodes and a bialkal photocathode, while the other two had 8 dynods and SBA photocathodes. The performances of the two types of PMT’s were different: the energy resolution of each single PMT coupled to the crystal was about 5% for the first type and about 4% for the other. When used together, the energy resolution of the four PMT’s was 4% at 662 keV. The complete cover of the detector surface implies the use of 120 segments. In order to have a simpler setup, we short circuited segments in groups of 16, so that we ended up with 12 macro segments, as shown in fig. 5.

Data were taken with the collimated $^{137}$Cs source in several positions, which are indicated by open squares in fig. 6. The coordinates of each event were obtained calculating the center of gravity of the light distribution. Gating on the 662 keV transition, the position profiles are Gaussian distributions with a FWHM of about 2.3 cm. If we plot the centroids of the distributions as a function of the source position, we see a deviation from linearity as found in all imaging studies (Fig.7). By correcting for
this non linearity performing a fit with a 3\textsuperscript{rd} degree polynomial (solid line in Fig. 7), the source position is very well reproduced, as can be seen in Fig. 6.

![Figure 6](image1.png) ![Figure 7](image2.png)

**Figure 6.** The calculated source positions (triangles) are compared to true position of the source (open squares).

**Figure 7.** The graph shows the measured linearity along the x-axis. The line is a polynomial fit.

4. Conclusions

The position sensitivity of a spectroscopic 3”x3” LaBr3:Ce detector was investigated through measurements using an intense $^{137}$Cs collimated beam of 1 mm diameter. A simple test using a Hamamatsu R6233-100SEL spectroscopic PMT shielded so that only a 1 cm$^2$ is left shows a correlation between source and window positions. The event by event analysis, performed with Position Sensitive PMT’s, demonstrates a position sensitivity with a resolution of the order of 2 cm for 662 keV gamma rays. Such resolution would be sufficient to correct for Doppler broadening in nuclear physics experiments with exotic beams.

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