Position Sensitivity in 3” x 3” $LaBr_3$:Ce scintillators

F. Birocchi[1], N. Blasi[2], F.Camera[1], F. C.L. Crespi[1], C.Boiano[2], S. Brambilla[2], F. Coniglio[1], B.Million[2], S. Riboldi[1], O. Wieland[2]

[1]University of Milano and INFN sez. of Milano, Via Celoria 16, 20133 Milano, Italy

[2] INFN sez. of Milano Via Celoria, 16, 20133 Milano, Italy

Abstract

The position sensitivity in a 3”x3” $LaBr_3$:Ce crystal has been simulated and measured using collimated beams of 662 keV gamma-rays. The simulations have been done using the GEANT4 libraries which allow to follow both the gamma ray interaction in the detector and the scintillation light up to the photocathode. The crystal has been coupled to a PSPMT and/or a shielded PMT. The results indicate that in the 3” x 3” crystal with darkened surfaces it should be possible to localize the first interaction point of a 662 keV gamma ray within 1 cm, in the case of diffusive surfaces the position sensitivity deteriorates but it is not destroyed. As expected, the position sensitivity improves as the gamma ray energy increases. The measurements generally confirm the results given by simulations.

The Lanthanum Bromide material is an inorganic scintillator which, when doped with Cerium, presents excellent scintillation properties. In fact, it has an extremely high light-yield (68 photons/keV), the best energy resolution (2.7% a 662 keV) among scintillators, excellent timing properties (300 ps of time resolution) and a high density (5.1 g/cm^3) [1]. The extremely high scintillation light-yield allows the production of gamma-camera or Small Animal SPET with thin continuous $LaBr_3$:Ce with a sub-millimeter positional resolution [2]. However, at the moment, nothing is known on the imaging properties of position sensitive detectors that use thick (> 2 cm) $LaBr_3$:Ce crystals with medium-high energy gamma-rays (0.5 MeV < E < 20 MeV). The application fields of such kind of devices ranges from fundamental research to astrophysics, homeland security and medical areas. For what it concerns the basic research in nuclear physics and gamma spectroscopy the position sensitivity of a detector is extremely useful to reduce the Doppler Broadening effect in experiments where the gamma-ray source moves with relativistic velocity [3]. These beams are, for example, used in the study of nuclei far from the stability line. In such kind of measurements, the energy of the gamma rays emitted by the moving source (even though monochromatic in the CM system) is Doppler shifted and, in the energy spectra, the full absorption peak is broadened and degraded because of the size of the detector front face. Such effect becomes larger as the v/c of the source increases or the distance source-detector decreases. The localization of the interaction region of the gamma ray inside the crystal will permit a more accurate Doppler correction and will reduce or eliminate such effect recovering the intrinsic performances of the detectors.

The position sensitivity a 3”x3” $LaBr_3$:Ce crystal have been simulated using the GEANT4 libraries. The size of the detector is large enough to provide good full energy peak efficiency, even in the case of high energy gamma rays, and has a still acceptable value of the ratio between the crystal diameter and thickness. The larger is this ratio the better are the “imaging” performances of the detector.

In the simulation a collimated beam of medium-high energy gamma-rays ($0.662 \le E_\gamma \le 5$ MeV) enters into the detector. For each incident gamma ray the positions of the interaction points (IP) and the energy there deposited are extracted. Each IP generates a flash of scintillation light which, photon by photon, is followed up to its absorption or detection by a photosensor. Figure 1 shows the percentage of photons which arrives on the photocathode in the case of incident 662 keV gamma rays which have deposited all the energy in the detector. The value is plotted versus the Z coordinate of the gamma ray first interaction point. The plot in the left panel is relative to a 3”x3” LaBr3:Ce detector with fully absorbing surfaces while the plot in the right panel correspond to a detector with fully diffusive surfaces.

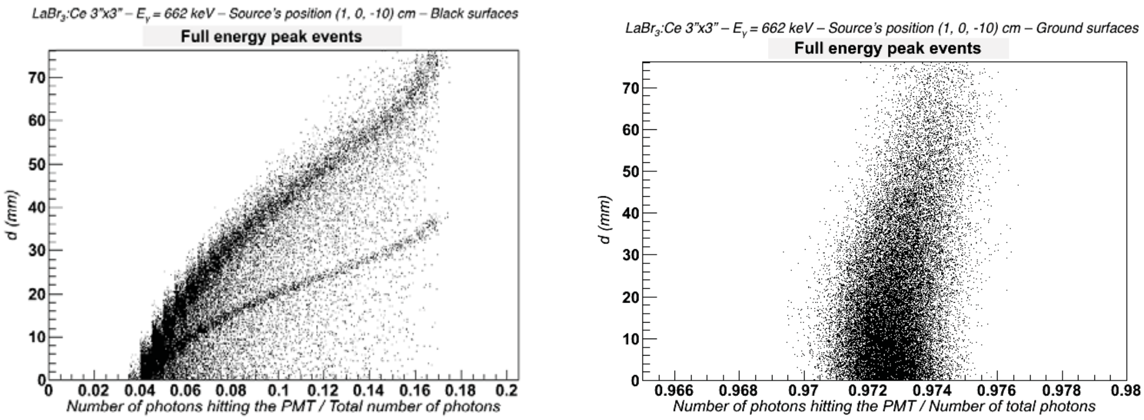

Fig 1: *Left panel: the simulated percentage of scintillation photons which arrive at the photocathode in a cylindrical 3”x3” LaBr3:Ce crystal with dark surfaces. Between the crystal and the photocathode 8 mm of glass has been inserted to take into account the crystal encapsulation and the PMT glass window. Right panel: the same plot as in the left panel but, in this case, the crystal has diffusive fully reflecting surfaces. The quantity d represent the distance from the front face (d=0) along the Z axis of the detector; at d = 73 mm there is the face which is then coupled to the PMT through a 8 mm glass window. In the simulation a collimated beam of 662 keV gamma rays was used. The gamma-rays hit the detector 1 cm away from the crystal center.*

On an event by event basis the image which appears on an ideal segmented photocathode (each segment is 6mm x 6mm) has been recorded. Using an algorithm based on that of ref [4] the incident position of the gamma ray beam was extracted. Figure 2 shows the PSF image extracted for the 3”x3” LaBr3:Ce with dark surfaces in the case the collimated beam of gamma enters in the detector 1 cm and 3 cm away from the center of the front crystal face.

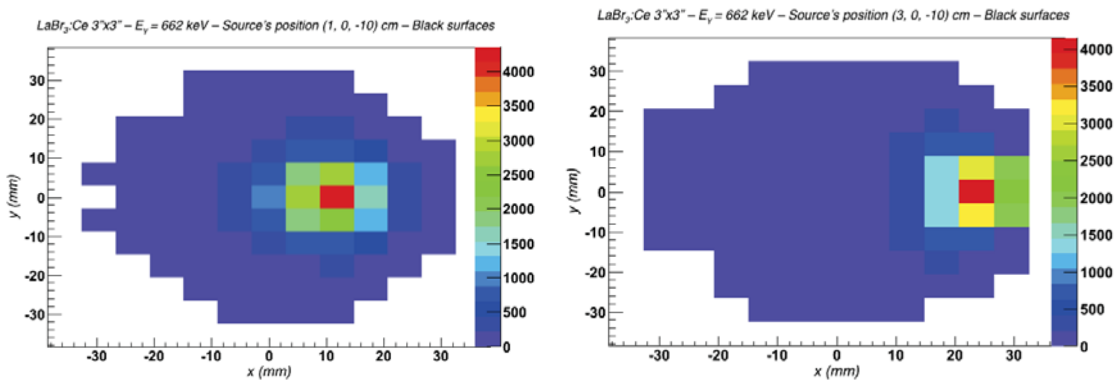

Fig. 2 *The final image achieved, in the simulations, after the analysis of 50000 collimated gamma rays which enters in a cylindrical 3”x3” LaBr3:Ce detector with dark surfaces. Each gamma-ray event produced an image on the photocathode which has been analyzed to extract the ‘estimated’ position on the gamma ray interaction point. The plots shows the extracted position of these interaction points. In the left panel plot the gamma rays enter at x=1 cm and Y=0 cm while, in the right panel, the gamma rays enter at X=3 cm and Y=0 cm.*

In addition simple measurements, using a shielded phototube and a 3”x3” crystal with diffusive reflecting surfaces, shows that at 662 keV there is enough spatial linearity to the crystal in at least three or four slices for Doppler Broadening correction.

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