Position Sensitivity of Large Volume $LaBr_3$:Ce detectors

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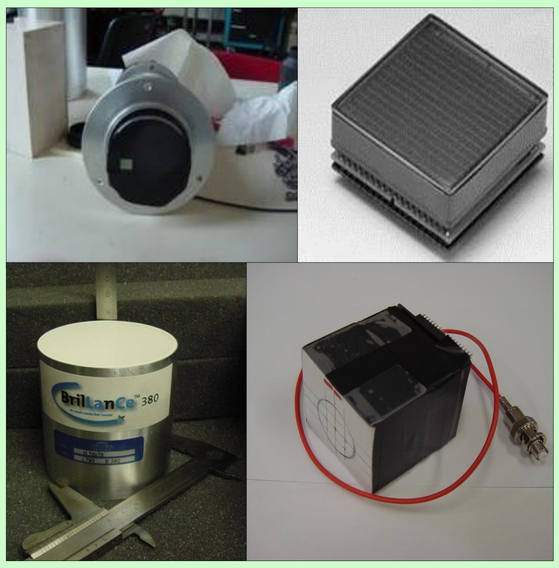
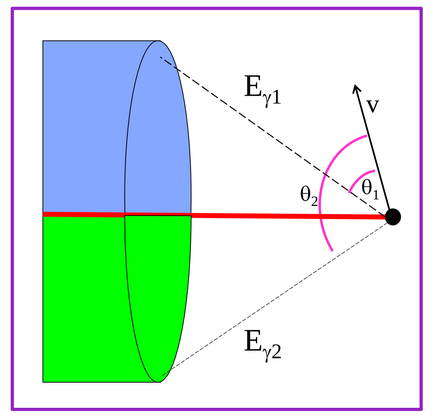
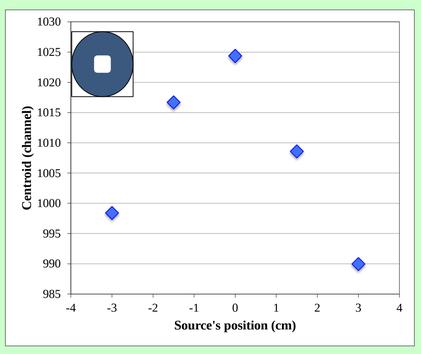


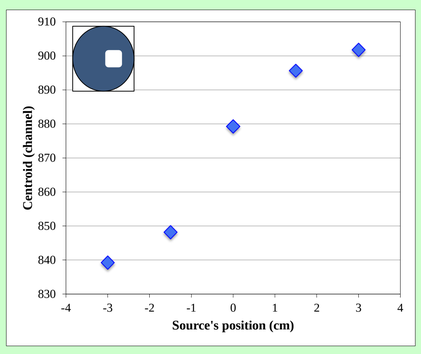
Abstract

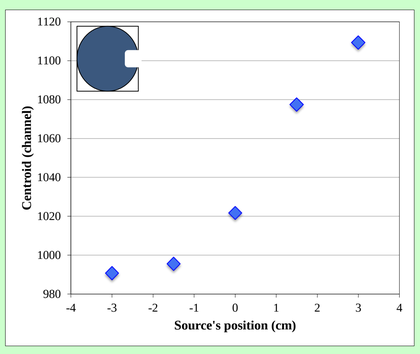
The position sensitivity of two large volume (1" x 1" and 3" x 3") $LaBr_3$:Ce crystals has been measured using collimated beams of 662 keV γ-rays. The crystals have been coupled to a Position Sensitive Photo Multiplier Tube (PSPMT) and/or a shielded phototube.
The results indicate that, in the case of 662 keV γ-rays, in both crystals it should be possible to identify the position of the γ-ray first interaction with a 1-2 cm resolution. Similar tests have been done in the past using 140 keV γ-rays and no sensitivity was found.
Using GEANT4 tracking light routines or GEANT3+SCIDRA simulations it was possible to confirm the results and show that, as expected, the position sensitivity improves as the γ-ray energy increases.
In Nuclear physics basic research and, particularly in gamma spectroscopy, the position sensitivity of a detector is extremely useful to reduce the Doppler Broadening effect in experiments where the γ-ray source moves with high/relativistic velocity. 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 γ-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 finite size of the front face of the detector. 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 γ-ray inside the crystal will reduce or eliminate such effect recovering the intrinsic performances of the detectors.

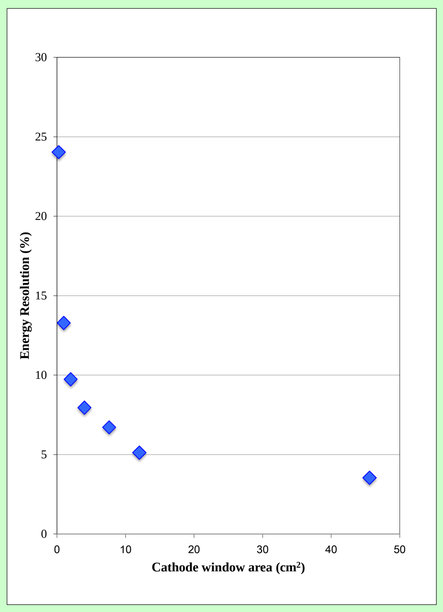
$$E_\gamma = \frac{\sqrt{1-\beta^2}}{1-\beta\cos\theta_\gamma} E_{\gamma 0}$$







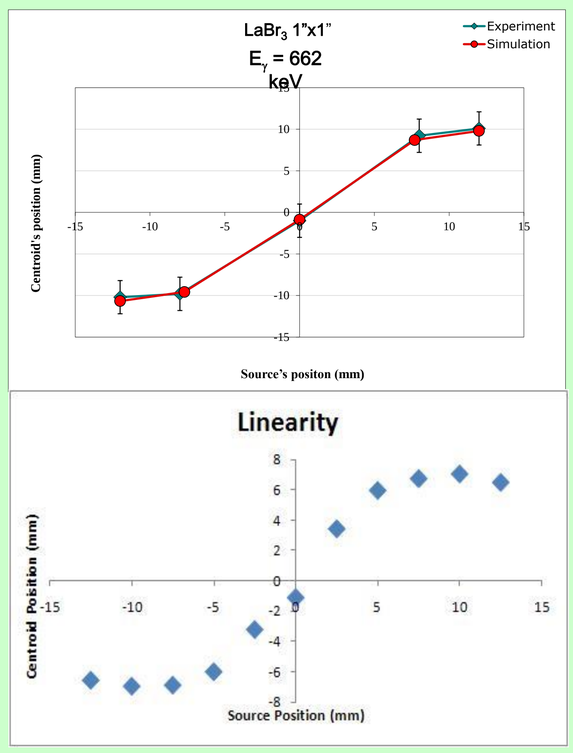




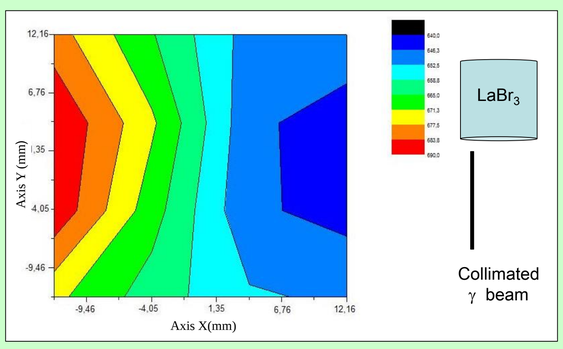
Cylindrical $LaBr_3$:Ce 3"x3" - collimated 662 keV γ–ray source – XP5300 shielded (see upper right picture)

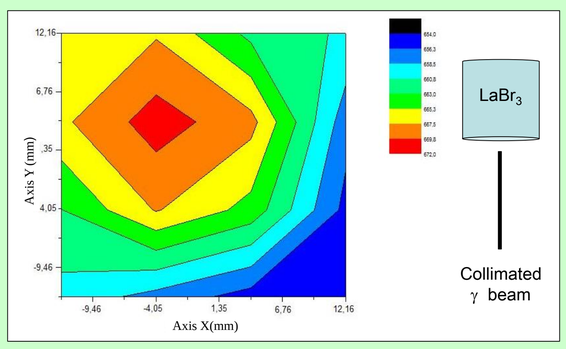
The upper plots show the measured position of the full energy peak, namely the average number of photoelectrons, when 662 keV have been deposited in the detector. In each plot, the position of the window on the PMT is shown in the upper left part and each of the 5 points correspond to the x coordinate of the collimated 662 keV γ-rays beam. It is evident that γ-rays which enter in a different position produce a different intensity pattern on the photocathode .
In the plot on the right the energy resolution at 662 keV has been measured varying the size of the window on the PMT (the photocathode has a surface of 46 cm^2). The setup used for the measurement is the same as for the upper three plots.

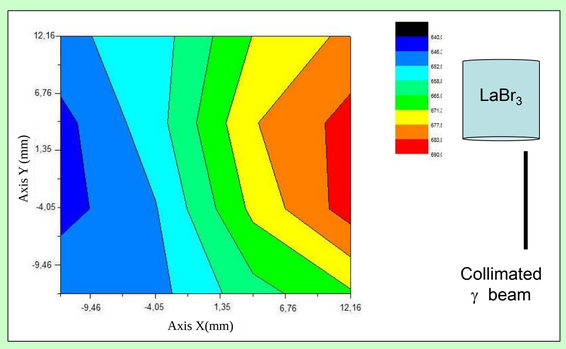
Spatial Linearity



The upper plot displays the measured spatial linearity as was extracted form the experimental data for the 1" x 1" $LaBr_3$:Ce crystal and the segmented phototube, together with a simulation obtained with GEANT3+SCIDRA. The lower plot shows the linearity for the GEANT4 simulation (error bars are not plotted since they are smaller than the size of the symbols). It is evident that there is position sensitivity in the central part of the crystal. Saturation appears in the region near the lateral surface.

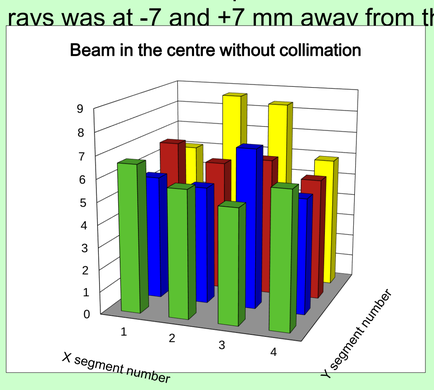


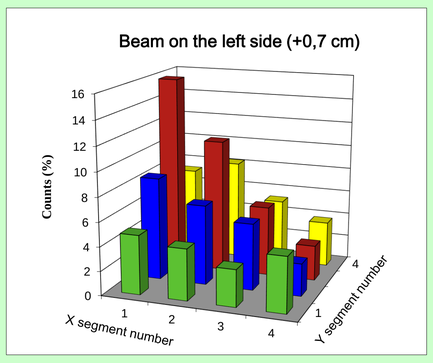


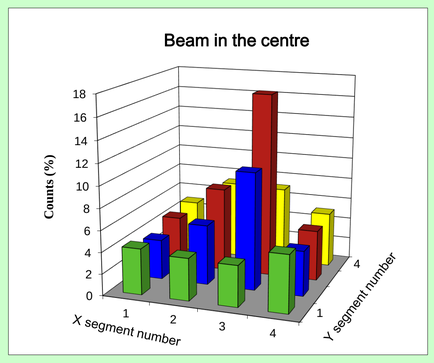


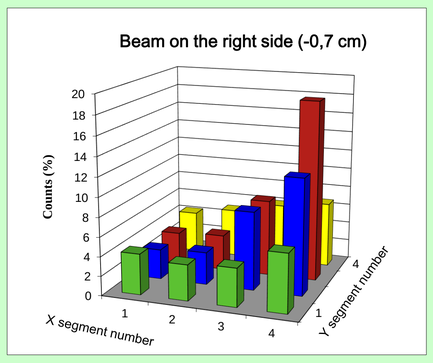
Cylindrical $LaBr_3$:Ce 1"x1" - collimated 662 keV γ-ray source – H8500C-100 Mod 8

The upper plots show the image produced in a 1" x 1" $LaBr_3$:Ce scintillator with a collimated 662 keV γ-ray beam was measured on the segmented anode of a H8500C-100 Mod 8 phototube. In the central plot the collimation pointed approximately at the central position, in the left and right plots the collimated beam of γ-rays was at -7 and +7 mm away from the centre. The values on the Z axis represent the position of the centroid of the full 662 keV energy peak.









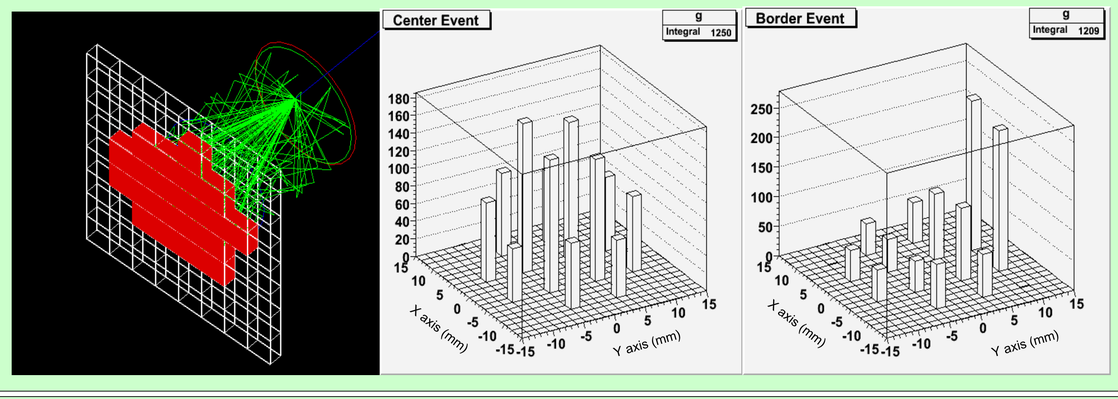
Cylindrical $LaBr_3$:Ce 1"x1" - 4π and collimated 662 keV γ-ray source – H8500C-100 Mod 8

The upper plots show the distributions of the position of the segment which, event by event, has measured the highest number of photoelectrons. The plot have been extracted sorting, on an event by event basis, the same data set from which the contour plots of the upper panel have been extracted. The left plot shows a dataset in which a non collimated 662 keV γ-rays source was used. The plots on the central left, central right and right show the case in which the collimated beam of γ-rays was at -7 mm, approximately in the central position and at +7 mm respectively.

The two plots show the calculated spatial linearity as was extracted from GEANT3+SCIDRA calculations. The simulated detectors were $LaBr_3$:Ce with a size of 1"x1" and 3" x 3" and 2 MeV γ-rays.
In the simulation the back surface of the crystal was covered with a segmented phototube with 6 mm square segments.
In both cases, as expected, the spatial resolution and linearity improve, as compared to the 662 keV case, because of the large number of scintillation photons produced in the interaction event.
The error bar of the plots indicate the FWHM of the measured full energy peak

GEANT4 Simulations

The plots on the right show the results of GEANT4 simulations of the previous measurements. In the simulations the scintillation light produced in the interaction of the γ-rays has been trasported up to the photocathode. A visualization of the light transport is shown on the left.. The central and right plots show the distribution of the position of the segment which, event by event, has measured the highest number of photoelectrons. The optical properties of the lateral surfaces of the detector follow the "UNIFIED" model's 'groundbackpainted' surface with a reflectivity of 0.99, a σ_α of 1.0 rad, and a spectral lobe constant of 0.6.



Conclusions

The Monte Carlo simulations have shown that the energy deposit of a γ-ray in large volume $LaBr_3$:Ce crystal maintains spatial information independent of the energy of the interacting γ-ray. The simulations show that the FWHM of the spatial distribution in the x-y plane of the energy deposit in the crystal never exceeds 2.5 mm for gamma-rays up to 20 MeV. The positional information is, however, degraded in the process of the collection of the scintillation light at the photocathode. In fact, the used and simulated crystals have the surfaces treated to reflect/diffuse the incident light. This guarantees the almost complete collection of the scintillation light at the photocathode and consequently an optimal energy resolution, but it degrades the positional information of the gamma-ray interaction point. However measurements using 1"x1" and 3"x3" $LaBr_3$:Ce detectors show that it is possible, with a simple algorithm, to identify, within 1-2 cm, the position of the interaction of the majority of the γ-rays which have interacted the crystals. More accurate techniques are under development to improve the positional resolution and to increase the number of 'identified' γ-rays. Simulations still do not perfectly match the measured data as the reflective/diffusive properties of $LaBr_3$:Ce surfaces are not known in detail.