Characteristics of $LaBr_3$ Detector using Geant4 Simulations

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Introduction

Lanthanum Bromide ($LaBr_3$) detectors are widely recognized for their good energy resolution and fast response time, making them ideal for gamma-ray spectroscopy applications [1, 2]. In this study, we simulate the performance of two $LaBr_3$ detectors using `GEANT4` simulation toolkit [3], focusing on energy and timing characteristics when exposed to ^{137}Cs and ^{60}Co radioactive sources. The detectors are positioned face to face with a separation distance of 11 cm, and the results provide insight into the detectors' energy and timing resolution.

Simulation Setup

The cylindrical detectors, each with 2" × 2" crystals enclosed in 0.5 mm thick aluminum casings placed in supporting structure consisting of iron plates and rods (Fig.1), were positioned face to face with an 11 cm separation. The ^{137}Cs source, emitting gamma rays at 661.7 keV, was used to assess the detectors' energy resolution. The simulation incorporated key physical processes such as the photoelectric effect, Compton scattering, and pair production, along with optical processes like light propagation and reflection.
In the simulation, involving around 1 million events, we analyzed the energy spectra, Time-to-Amplitude Converter (TAC) spectra [4], and multiplicity distribution to provide a comprehensive assessment of the detectors' performance in energy accuracy, timing precision, and coincidence detection.

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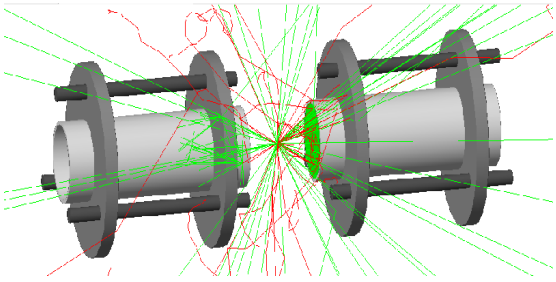

FIG. 1: Visualization of the `GEANT4` simulation geometry with a few representative events. The image illustrates both the detector (Crystals are presented with green colour) setup and the trajectories of gamma rays emitted from a ^{137}Cs source.

Discussion

Fig.2 shows the energy spectra from one of the $LaBr_3$ detectors obtained from simulation, with a prominent peak ≈ 661.7 keV from the ^{137}Cs gamma-ray source. Apart from the low-energy background, the photopeak compares well with the observed data, as evident from the figure. The energy resolution obtained from simulated spectrum is ≈ 3.7% at 662 keV. The measured value is also ≈ 4% [5] at the same energy with an applied -1400 volt bias voltage.
The Time-to-Amplitude Converter (TAC) spectra, which analyze the time difference between events in the two detectors, reveal the timing resolution critical for lifetime measurements and coincidence counting. The results confirm the detectors' typical energy and timing performance and a FWHM ≈ 450 ps is obtained via simulation. The simulated time spectrum closely matches the observed [5] TAC spectrum, as evident from Fig.3. The TAC spectrum was obtained using a radioactive ^{60}Co source.

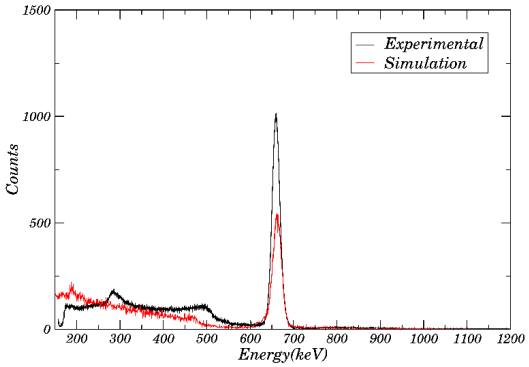

FIG. 2: Energy spectra of $LaBr_3$ detectors exposed to a ^{137}Cs source.

In the simulation, the timing of interactions is recorded by capturing the local time of the energy deposition at first step in each detector. This is managed in the SteppingAction class, which ensures that only the initial interaction time is recorded for each event. The time difference between the two detectors is then calculated and used to generate the Time-to-Amplitude Converter (TAC) spectrum.

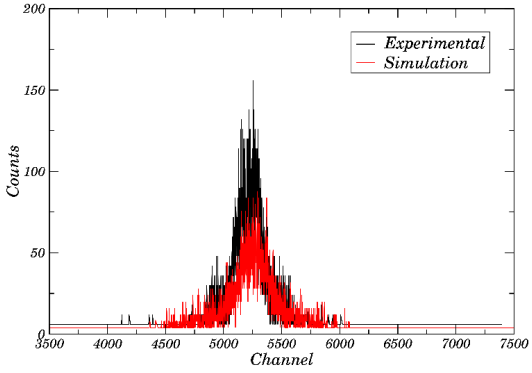

FIG. 3: TAC spectra for $LaBr_3$ detectors placed face to face with a separation of 11 cm. Both the experimental and the simulated TACs are presented here for comparison. Experimental spectrum is taken from Ref.[5]

The multiplicity distribution (Fig.4) shows that 1 and 2-fold events dominate, with minimal 3-fold events, likely due to scattering. The 11 cm separation between detectors minimizes cross-talk, ensuring precise timing measurements.

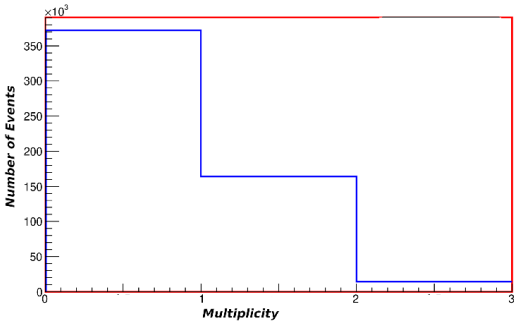

FIG. 4: Multiplicity distribution of events detected by the two $LaBr_3$ detectors with ^{60}Co.

Conclusion

This simulation study highlights the excellent energy and timing resolution of $LaBr_3$ detectors when exposed to ^{137}Cs and ^{60}Co radioactive sources. The results underscore the suitability of $LaBr_3$ detectors for high-resolution gamma-ray spectroscopy and timing applications in nuclear physics experiments. Future work may include simulations with other radioactive sources and varying geometric configurations to further explore the capabilities of $LaBr_3$ detectors in an array of large number of detectors.

References

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