Optical Physics of Scintillation Imagers by GEANT4 Simulations

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Abstract

The recent development of the $LaBr_3$:Ce crystals makes their use in a system of gamma imaging for Single Photon Emission Tomography (SPET) applications very attractive, mainly due to their excellent scintillation properties. In this work we use Monte Carlo simulations, in order to model the optical behavior of three crystal configurations. Our goal is to better understand the intrinsic properties of a gamma camera based on $LaBr_3$:Ce crystals, coupled to a position sensitive photomultiplier tube. To this aim, the spatial and energy resolutions, obtainable from optimum photodetection conditions, are investigated.

Keywords: Monte Carlo, GEANT4, $LaBr_3$:Ce crystal, UNIFIED, Penelope, Multi Anode PMT

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1. Introduction

GEANT4 [1] permits an accurate modeling of radiation sources detectors and allows following with great precision the interactions within the different media. The excellent scintillation properties of $LaBr_3$:Ce offer the potential to replace the most widespread scintillation crystal: the NaI:Tl. In form of slab, these crystals are able to provide sub-millimeter spatial resolution values, comparable to scintillation arrays or better then the latter. GEANT4 simulations can model the optical behavior of different crystal configurations. Some intrinsic properties of a $LaBr_3$:Ce gamma camera, as spatial resolution and energy resolution, are therefore studied.

2. Simulation Setup

For the modeling of the electromagnetic interactions, the "Penelope" model of GEANT4 is used. Such a model is better suited for energies ranging from a few hundreds eV to about 1 GeV. To improve the tracking of the electrons, a few parameters [2] have to be tuned up. They control the numerical stability of the results, the electrons step, their stopping power, and the multiple scattering. Furthermore, GEANT4 allows the simulation of the transport and boundary effects for the optical photons generated by the scintillating crystal (Fig. 1). In this way, the whole process can be thoroughly simulated. The simulation starts from the radioactive decay of a ^{99m}Tc source and halts when the optical photons reach the photomultiplier. The simulated scintillation camera reproduces the experimental setup, which consists of a Multi Anodes-PMT (MA-PMT) Hamamatsu Flat Panel H8500 with Quantum Efficiency equal to 27%, (12 stages of metal channel dynodes and 8×8 anode array) [3]. The Flat panel was coupled to a 50×50×4 mm^3 slab of $LaBr_3$:Ce crystal and a 4.5 mm glass window. The crystal is surrounded by a thin layer (0.5 mm) of Aluminium. In the front, the crystal surface is covered by a very small layer of Teflon (0.3 mm), acting as a Lambertian reflector. Crystal edges were black painted in order to reduce reflections. In the simulation, the boundary processes of all crystal surfaces follow the rules of the UNIFIED model [4]. The optical properties of the materials involved in the simulations are gathered from literature. A scintillation light yield equal to 63'000 photons/MeV is assumed for $LaBr_3$:Ce [5]. The scintillation photons are generated as a pure Poisson process. The total Energy Resolution (*ER*) can be parameterized as $ER = \sqrt{ER_{stat}^2 + ER_{\text{int}}^2}$ [6] where: ER_{stat} represents the Poissonian component of *ER* given by the square root of the number of collected photoelectrons; ER_{int} is an additional intrinsic resolution which has been computed in [6] for $LaBr_3$:Ce in a setup similar to the present one and yields (4.5 ± 0.5)% for 140 keV photons. The variance of the electron multiplier gain [6] was not taken into account in the calculation of the total energy resolution. Three different setups are simulated: "Ground", "Polished" and "Air Gap". "Ground" and "Polished" refer to the status of the lateral surfaces of the crystal, while "Air Gap" is the "Ground" model with a thin air interface (0.1 mm) between the crystal and the Photodetector. For every model, the reflectivity of the lateral surfaces and of the front surface was respectively fixed to 0.6 and to 0.95 [7].

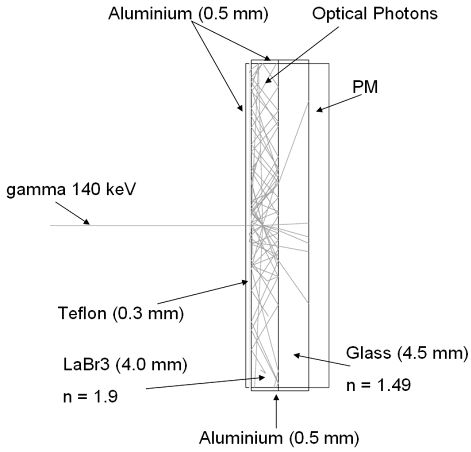

Figure 1: Sketch of the optical photons distribution inside the $LaBr_3$:Ce crystal, as simulated with GEANT4.

3. Results

The values of spatial, energy resolution and the average number of photoelectrons reaching the anode are summarized in Table 1, where experimental values are obtained using a crystal with polished lateral surfaces

	Ground	Air Gap	Polished	Exp
<Nphe>	1603 ± 1	1137 ± 1	1047 ± 1	-
ER %	7.4 ± 0.4	8.3 ± 0.4	8.6 ± 0.4	9.0± 0.1
SR (mm)	0.75 ± 0.04	0.8 ± 0.1	0.77 ± 0.02	1.1± 0.1

Table 1: Values obtained as a function of the three different setup.

The output of the Monte Carlo simulations is arranged to reproduce the segmentation of the 8×8 anodic array of the MA-PMT, in order to analyze the sampling of the charge spread. Considering a coordinate system *(x,y)* with the origin in the centre of anodic plane, Fig. 2 shows the charge projection along the *x*-direction, as simulated for the three different setups with the same source position. Monte Carlo shows in all configurations a very large light spread through the whole crystal.

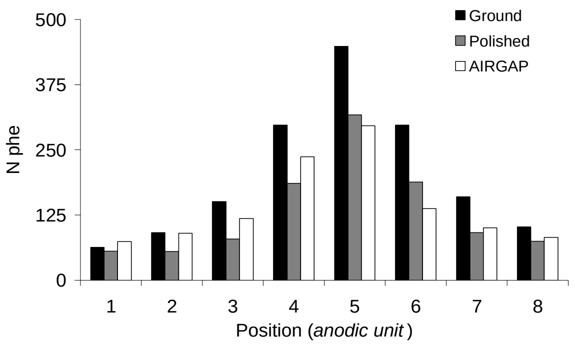

Figure 2: Average spread of number of photoelectrons in the anodic plane for different setup configurations.

The simulation results ("Polished", which corresponds to the real crystal surface treatment) show a reasonable agreement with experimental data in terms of ER. For the spatial resolution, the comparison between the experiment and the simulations is shown in Fig. 3. All results are obtained using a compact gamma camera scanned with 0.4 mm collimated ^{99m}Tc spot source at 2 mm step distance.
The Monte Carlo confirms the better performance of a ground crystal lateral surface both in terms of energy resolution and spatial resolution.

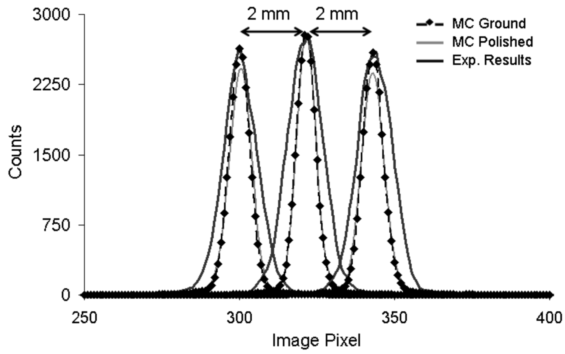

Figure 3: Spatial Resolution comparison between Monte Carlo and experimental results: image profiles of three collimated irradiation are shown.

4. Conclusion

The Monte Carlo simulations helps collecting important information about imaging potentials of $LaBr_3$:Ce. Energy resolution at 140 keV agrees reasonably with the experimental data. Monte Carlo predictions allow to conclude that $LaBr_3$:Ce crystals with a ground treatment of lateral surfaces could pave the way to submillimeter spatial resolution, with high detection efficiency and energy resolution.

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