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Study of the optical properties of continuous and pixelated scintillation crystals

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ABSTRACT: The principal goal of this study is to characterize the width of the light distribution for a given number of initial optical photons and to try to express it as a function of the Depth of Interaction (DOI) in the crystal, where the initial optical photons are produced, the size of the initial volume the optical photons occupy before starting the transmission and the geometrical properties of the optical medium that guides the light to the photomultiplier surface. Monte Carlo runs based on the optical simulation package DETECT2000 have been performed.

The results indicate that in the case of continuous crystal there is an apparent correlation of the DOI and the width of the light distribution. In the case of pixelated crystals the width of the light distribution seems to be independent of the DOI when the source is located deep in the crystal but there is a strong dependence as the source approaches the PSPMT's entrance window. This correlation of the DOI and the light distribution is not affected by the transverse dimensions of the continuous crystal but in the case of pixelated crystals this correlation is strongly depended on the crystal's aspect ratio. Through this study it also became clear that there is no dependence of the light distribution on the shape of the source.

KEYWORDS: Gamma camera, SPECT, PET PET/CT, coronary CT angiography (CTA); Scintillators and scintillating fibres and light guides

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Contents

1 Introduction

Positron Emission Tomography (PET) and Single Photon Emission Tomography (SPECT) have become by now a standard choice for clinical applications. Regardless of the position encoding scheme used, scintillation crystals have to be thick enough to efficiently stop the γ-photons and they usually do not provide information about the Depth of Interaction (DOI). That leads to a non-uniform and non-isotropic spatial resolution [1, 2]. For this reason the measurement of the Depth of Interaction (DOI) and its correlation to the width of the undisturbed light distribution and thus the measured position distribution is the subject of numerous experimental and theoretical investigations [3, 4].

To zero order, the light distribution on the face of the crystal is a Gaussian distribution (in position). The width of this distribution depends mainly on the thickness of the crystal, although it is modified by the surface treatment and edge effects. The use of reflectors, absorbers, special crystal surface finishes, and diffusers can significantly alter the light distribution [5].

The main purpose of this study is the inquiry of the correlation of the DOI and the light distribution in both continuous and pixelated crystals. Following previous experimental investigations on slotted type crystals [6, 7] the width of the light distribution for a given number of initial optical photons is being characterized and expressed as a function of the depth in the crystal, where the initial optical photons are produced, the size of the initial volume the optical photons occupy before starting the transmission and the geometrical properties of the optical medium that guides the light to the photomultiplier surface, such as the size of the pixel in the case of a pixelated crystal.

2 Materials and methods

DETECT 2000 [8] is a Monte Carlo based program dedicated to modeling the optical properties of scintillation crystals. It isotropically generates individual scintillation photons in specified portions of the crystal, follows each photon in its passage through the various components and interactions

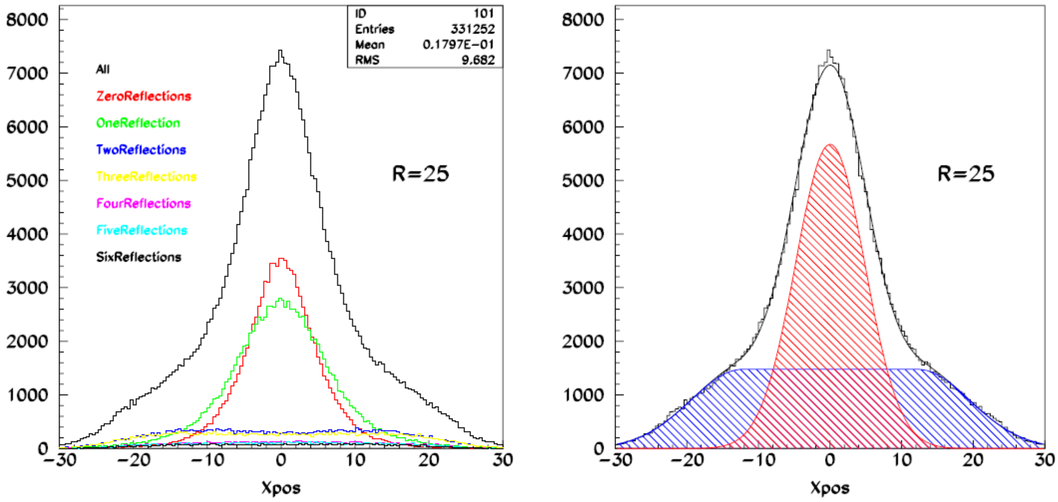

Figure 1. (a) The x-position distribution of the collected light for the case of continuous scintillation crystal of 25 mm radius and for various numbers of reflections. (b) The fitted curve for all possible reflections.

with surfaces and records the fate (absorption, escape or detection) of each. The optical behavior of real surfaces may be specified to simulate possible reflection under polished, ground, painted or metalized conditions, taking into account Snell's law and the optical properties of the various surfaces such as the index of refraction and the reflection coefficient. Both types, homogeneous and pixelated crystal, of a CsI(Tl) scintillation crystal is considered in this study.

2.1 Homogeneous crystal

Initially a continuous CsI(Tl) crystal, 4 mm thick and of 25 mm radius was simulated. The entrance window of the Position Sensitive Photomultiplier Tube (PSPMT) was also taken into account by adding to the simulation 3 mm of pyrex glass before the detective surface. The optical photons were generated isotropically by a point source located on the crystal axis and at various distances from the PSPMT entrance window. A typical x-position distribution of the collected light is given in figure 1a.

In the same figure the distributions of the photons that have been reflected a definite number of times are also given. As can be seen, the photons that have not been reflected follow a Gaussian-like distribution while the photons that have been reflected several times follow a uniform distribution on this axis. This observation led to the construction of a special function (gauss+plateau) that was used to fit the resulting shape of the light distribution. This function is shown in figure 1b. The central Gaussian curve may be thought as the curve that represents the photons that have not been reflected while the blue one, constituted of a constant part (plateau) and two Gaussian edges, is the one that represents the reflected photons.

As a second step, homogenous crystals of different radius were simulated. The results for a crystal of 5 mm radius are given in figure 2.

The position distribution for this case is different as most of the distributions of the photons that have been reflected a definite number of times seem to follow a Gaussian like distribution. For this reason the position distribution for this case has been fitted with two Gaussian curves as shown in figure 2b.

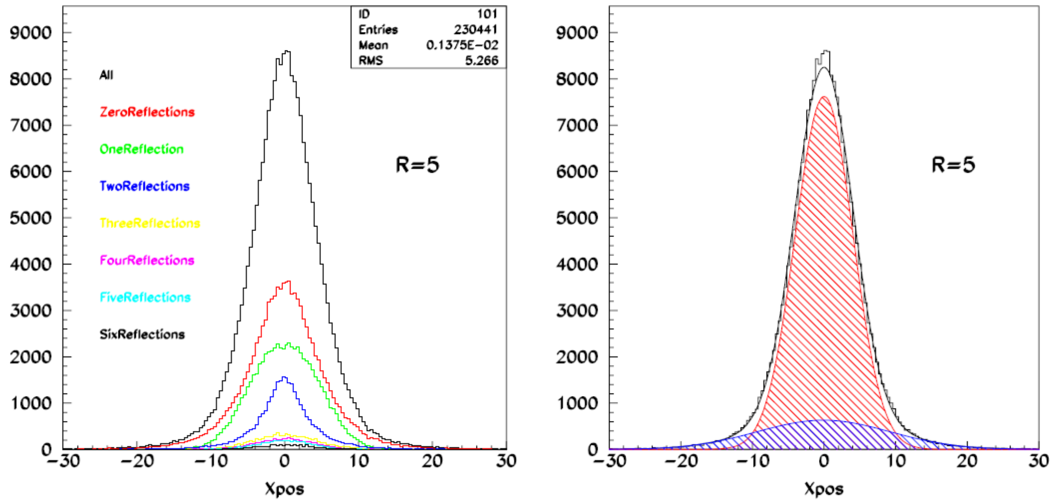

Figure 2. (a) The x-position distribution of the collected light for the case of continuous scintillation crystal of 5 mm radius and for various numbers of reflections. (b) The fitted curve for all possible reflections.

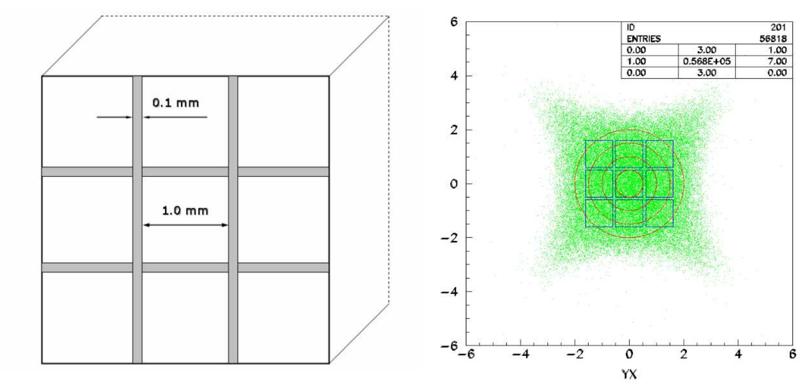

Figure 3. (a) Geometrical profile of the simulated CsI(Tl) pixelated crystal. The shaded area consists of light diffusing material (epoxy). (b) The 2-D light position distribution for the case of pixelated scintillation crystal of 1 mm pixel width.

2.2 Pixelated crystal

The next step was the simulation of a pixelated CsI(Tl) crystal, the profile geometry of which is shown in figure 3. Initially the width of the pixels was 1 mm and the epoxy placed between them was 0.1 mm thick. The source of the optical photons was located inside the central pixel and had the shape of a membrane while the transverse dimensions of the source fitted the ones of the pixel.

The light position distribution for that case is given in figure 4. The position distributions for the photons that have been reflected a definite number of times are also given. It can be seen that these distributions are symmetrical around the center of the pixel but their shape can be easier understood by looking at the two dimensional position distribution of the collected light, given in figure 3b.

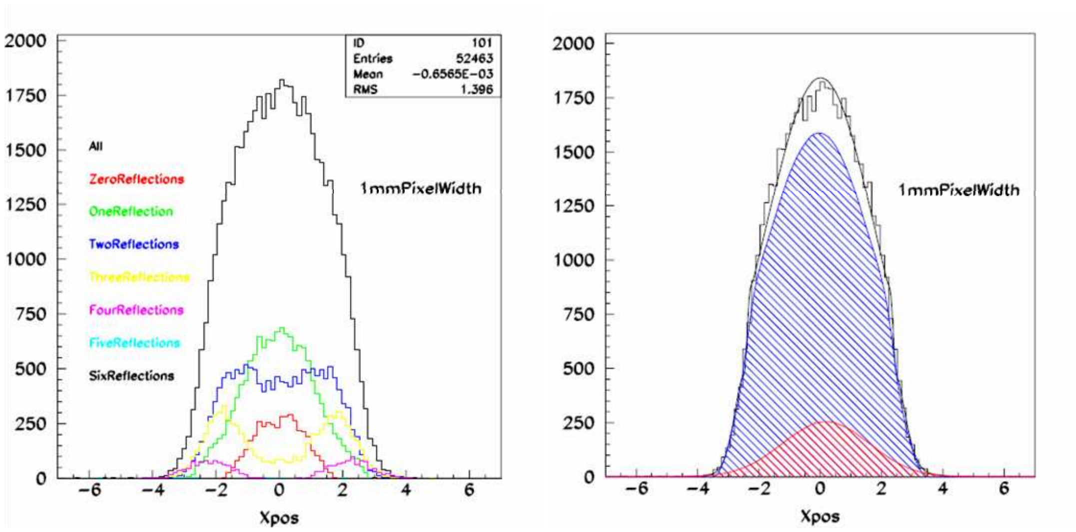

Figure 4. (a) The x-position distribution for the case of pixelated scintillation crystal of 1 mm pixel width and for various numbers of reflections. (b) The fitted curve for all possible reflections.

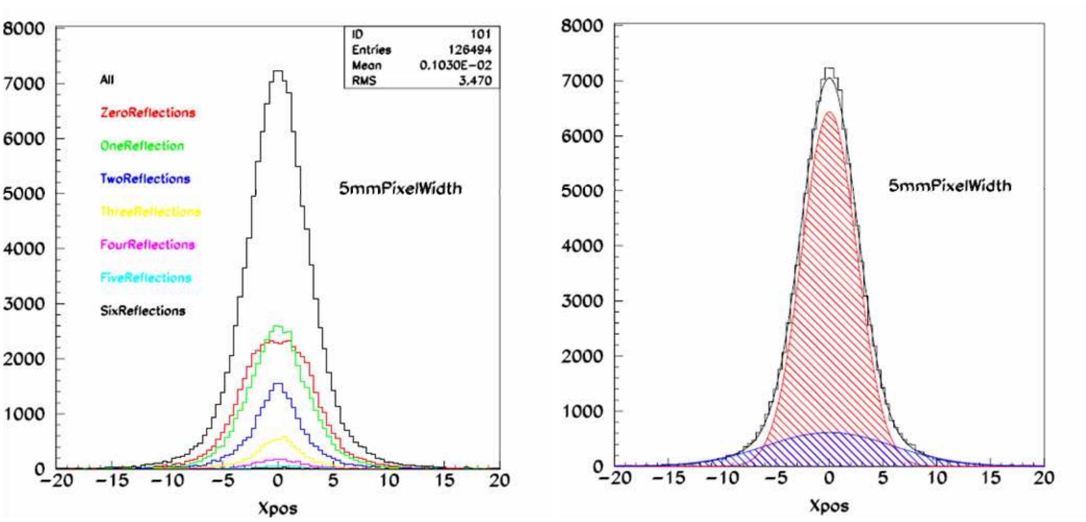

Figure 5. (a) The x-position distribution for the case of pixelated scintillation crystal of 5 mm pixel width and for various numbers of reflections. (b) The fitted curve for all possible reflections.

The position distribution for this case was fitted with a phenomenological curve that was constructed and is shown in figure 4b. The red Gaussian curve can be thought to represent the detected photons that have not been reflected inside the crystal, while the blue curve represents the photons that have been reflected several times.

Finally, in figure 5 the results for the case of a pixelated crystal of 5 mm width of pixel are being presented. The epoxy placed between the pixels was again 0.1 mm thick and the source of the optical photons was located inside the central pixel, had the shape of a membrane transverse dimensions that fitted the ones of the pixel. In all the above cases of the pixelated crystal, only the central pixel was illuminated.

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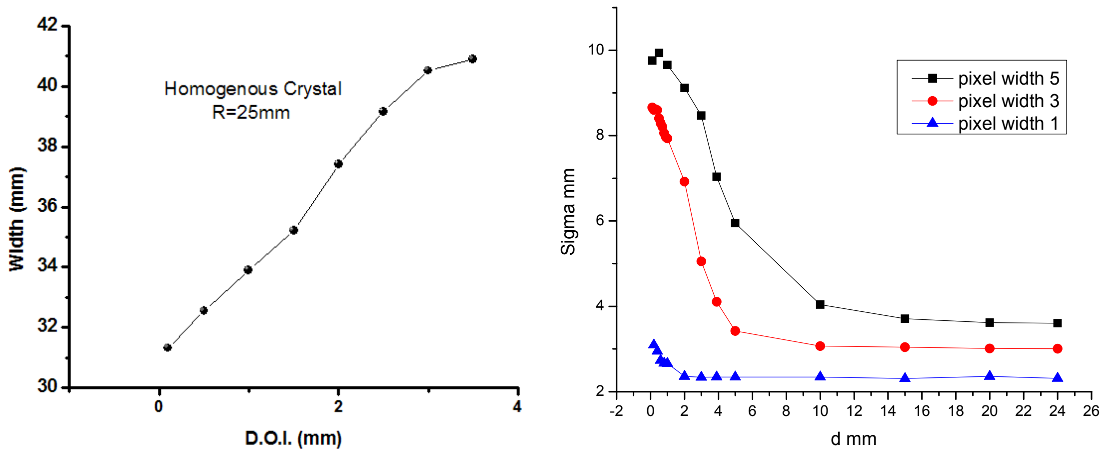

Figure 6. The correlation between the DOI and the width of the light distribution. (a) The case of a homogenous crystal with 25 mm radius. (b) Pixelated crystals with various pixel sizes. The parameter d measures the distance from the photomultiplier entrance.

3 Results

Using the curves presented in the previous section we fitted the position distributions of the accumulated light in the case of homogenous crystals and for various positions of the source of the optical photons. The results given in figure 6a present a clear correlation of the DOI to the width of the position distribution for a cylindrical, homogeneous crystal with 25 mm radius.

In order to investigate whether the same correlation appears or not in the case of pixelated crystals, the light distributions taken from the simulations were fitted with the curves presented earlier and the width of the distribution for the various DOI values was plotted. The parameter d measures the distance from the photomultiplier entrance. The results for pixelated crystals with various pixel sizes are presented in figure 6b.

Finally, the simulations were repeated for the case of pixelated crystal and a volume source of optical photons the transverse dimensions of which fitted the pixel while the source was 1 mm height. The results for the crystals with 5 mm and 1 mm pixel width are presented in figure 7.

4 Discussion

The characterization of the light distribution presented in this paper indicates that it is strongly correlated to both the depth inside the crystal (DOI), where the initial optical photons are produced and to the crystal's geometrical properties. The results of this study have shown that the DOI affects the width of the distribution while the crystal's shape seems to affect both the shape and the width. It is also clear that the initial volume the photons occupy does not affect the final shape and width of the light distribution. The goal of the future work will be the experimental confirmation of the results of the simulations presented here. The experimental setup will be based on a Position Sensitive Photomultiplier Tube with 32 anode wires (16 wires at each axis) that will allow us to study the measured position distribution of the scintillation light. Several types of crystals, including continuous, pixelated and slotted ones, will be used in order to obtain a complete set of results.

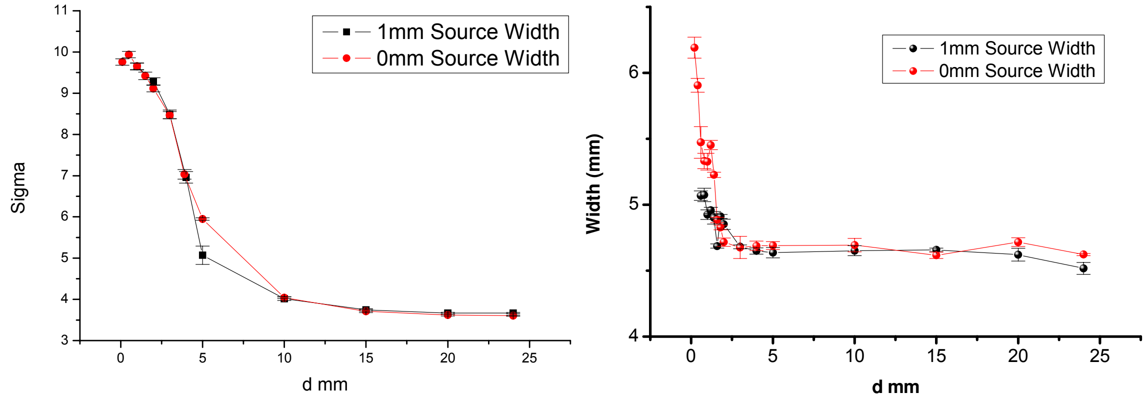

Figure 7. The correlation between the DOI (d measures the distance from the photomultiplier entrance) and the width of the light distribution in the case of pixelated crystals for the two cases of the initial volume the photons occupy before starting the transmission. (a) The pixel width is 5 mm. (b) As in the previous case but for 1 mm pixel width.

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