Temporal Imaging: Observation and Localization of a Compton Effect inside a 20 mm Monolithic LYSO Plate with a Philips Digital Si-PM

Alain Iltis, Hichem Snoussi, Luc Rodrigues de Magalhaes and Christian Morel

***Abstract*—Recently, temporal imaging has been shown to be very promising for enhancing the accuracy of spatio-temporal localization of a scintillation events within a monolithic scintillator [1]. The objective of this communication is to show that, besides scintillation localization performances, Compton events could be efficiently detected and characterized inside a monolithic plate. A time-based robust Compton event reconstruction could lead to the implementation of a cost effective single plate Compton camera based on monolithic scintillating crystals.**

A. *Principles of temporal imaging*

We consider a monolithic scintillator crystal [2] with a layer of segmented Si-PMT glued to the crystal [3]. Figure 1-(a) illustrates the behavior of emitted photons after the scintillation event. Photons emitted inside the cone are detected by the photodetector. All photons emitted outside the cone will be subject to at least one scattering and thus have a longer light path in the crystal and thus will impact later the photo-detectors. At the beginning of the interaction, the image of the un-scattered photons on the detector plane will be a disc $\mathcal{D}$ centered on the 2D location of the interaction and whose diameter linearly related to its depth. On a pixellized SiPM detector, at least two distributions could be obtained: (i) the light distribution and (ii) the time distribution of the first detected photons. Combining the light distribution and the first arrival time distribution will allow to find the center and the diameter of the disc of un-scattered photons. In fact, the critical disc $\mathcal{D}$ is quickly filled by the un-scattered photons. The scattered photons may be later detected outside $\mathcal{D}$, which remains, however, highly dense compared to the whole detection plane. Also, by putting a high statistical weight on the first photons, a ray tracing allows to better constrain the spatial localization and to accurately timing the photo-event.

In this paper, we will demonstrate an additional benefit of temporal imaging, which consists in detecting and characterizing Compton events. Detecting Compton events will certainly allow a much better processing of photon counting data. Localizing and isolating the Compton interaction yield more informative data about the original scintillation event. Furthermore, the localization of the Compton interaction makes the design of a single plate Compton camera possible.

A. Iltis, L. Rodrigues de Magalhaes are with Damavan Imaging, Rosieres Pres Troyes, France

H. Snoussi is with University of Technology of Troyes, UMR CNRS 6281, Troyes, France

C. Morel is with Aix Marseille Université, CNRS/IN2P3, CPPM UMR 7346, Marseille, France

Email: alain.iltis@gmail.com

B. *Single compton scattering*

In the context of temporal imaging, a single compton diffusion can be seen as two photo-electric events that are closely related in time, space and energy. If θ denotes the Compton diffusion angle and θ_c the critical angle, two cases could be considered: (i) $\theta < \theta_c$: The cone of the final photon absorption is located inside the cone of the first compton diffusion. As a consequence, the observed image on the Si-PM will not be very different from a photo-electric event except that the maximum of the light distribution will be skewed with respect to the location of the initial interaction, (ii) $\theta > \theta_c$: Two discs of undiffused photons could be observed on the SiPM. These two discs could be overlapped or completely separated depending on the distance between the final photon absorption and the Compton diffusion.

The single Compton event can be recognized through 3 main characteristics:

- The light distribution shows an axial symmetry along the direction of the diffusion.
- The 2 centers of the bimodal light distribution appear in close coincidence in time: The maximum interval time is of order of 2 to 3 the transit time in the crystal.
- Once the event has been reconstructed, the partition of energy between the 2 centers should follow the following relation: $E = \frac{E_0}{1+\alpha(1-cos(\theta))}$, where E_0 is the total photon energy, E is the final absorbed photon energy and θ the deviation angle.

Experimental acquisition set-up: The Philips Digital Photon Counter [4], the DPC-3200-22 sensor, consists of 16 independent die sensors arranged in a 4×4 array. A die sensor contains four pixels, arranged in a 2×2 array, each consisting of 3200 SPAD cells. A pair of time to digital converters (TDCs) is coupled to each die and generates a single time stamp by die. The timestamp generation is determined by the configured trigger threshold. We choose to use first photon trigger level during our measurements, in order to get the best timing performance. We use a LYSO crystal of size $32\times32\times20$ mm with the polished exit face coupled with optical grease to the Philips Tile. All the other faces are roughened and painted in black. The crystal is $20mm$ distant from a 0,7 MBq Na 22 source.

978-1-5090-1642-6/16/$31.00 ©2016 IEEE

Authorized licensed use limited to: Universite de Technologie de Troyes. Downloaded on January 24,2022 at 10:18:52 UTC from IEEE Xplore. Restrictions apply.

C. Single Compton event observation and characterization

Once an event is validated, the Philips system records the time when the first photon is detected and the energy deposited on each pixel of the die during the integration. This gives an event matrix with the following information:

- The number of photons detected by each pixel during the integration time (see Figure 1-(b)).
- The time stamp when the first photon is detected on each die. The arrival time of the first detected photon for each event is taken as a reference time (0 ps). We thus keep only the difference (in units of $19,5$ ps) between the remaining dies and this reference die. The spatial distribution of these timestamp differences will be a key component in the Compton characterization. See Figure 1-(b) where these values are written at the intersection of the 4 pixels composing a die. One has then for each event a joint 2D visualisation of the light distribution and also of the time distribution.

The transfer time, denoted TT and defined as the time taken by an UV photon to cross the thickness of the scintillator, plays an important role in the temporal characterization of the Gamma ray interaction with the crystal. In our setting, the value of the TT is about 122 ps. Compton events typically imply some lateral propagation of the Gamma ray before the second emission. Thus, a simple criterion for recognizing a Compton event is the second the time window between the first and the second interactions which has to be less than $2TT$, i.e 12 timestamp units in our setting. For instance, the event shown in Figure 1-(b) has the following features corroborating the Compton event: (i) 2 light distribution maxima, (ii) the light distribution has an axial symmetry and (iii) the 2 maxima are spaced by only 9 timestamp units. An instance of Compton characterization is given on the event reported in Figure 1-(b). We aim to localize the first and the second photon interactions in space, time and energy. In our set-up the overall energy of the event is difficult to calibrate as the loss of photons on black painted absorbing faces depends on the position of the interaction. It is worth noted that, without identifying the Compton effect, the localization of the first photo-electric event is wrong (red circle in in Figure 1-(b)). However, combining the light and the relative timestamp distribution yields the following 3D positions estimations: $X1 = 18$ mm, $Y1 = 18$ mm, $Z1 = 4$ mm for the first event (in a blue circle in Figure 1-(b)) and $X2 = 20$ mm, $Y2 = 12$ mm, $Z2 = 2$ mm for the second event (in a dashed red circle).

ACKNOWLEDGMENT

This work is supported by the French ANDRA TEMPORAL Investissement d'avenir GRANT.

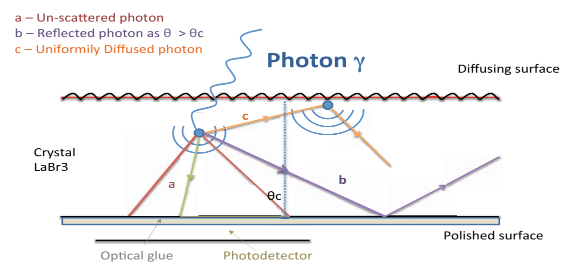
REFERENCES

[1] Alain Iltis and Hichem Snoussi , The Temporal PET Camera: A New Concept With High Spatial and Timing Resolution for PET Imaging,J. Imaging 2015, 1(1), 45-59; doi:10.3390/jimaging1010045

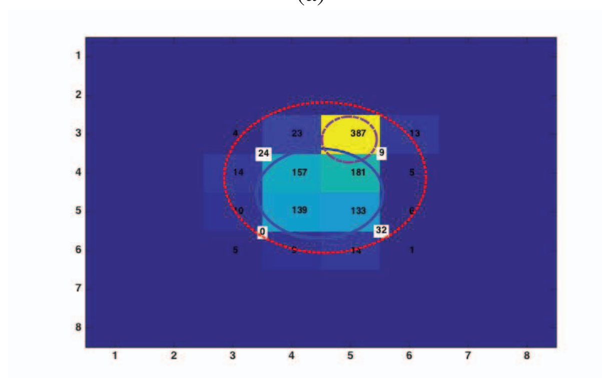
[2] Iltis, A., Mayhugh, M. R., Menge, P., Rozsa, C. M., Selles, O., and Solovyev. Lanthanum halide scintillators: Properties and applications. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 563(2), 359-363, 2006

[3] Stefan Seifert, Herman T van Dam, Jan Huizenga, Ruud Vinke, Peter Dendooven, Herbert Lohner and Dennis R Schaart , Monolithic LaBr3:Ce crystals on silicon photomultiplier arrays for time-of-flight positron emission tomography, Phys. Med. Biol 57 (2012) 2219-2233.

[4] Thomas Frach, Gordian Prescher, Carsten Degenhardt, Rik de Gruyter, Anja Schmitz, and Rob Ballizany , The Digital Silicon Photomultiplier Principle of Operation and Intrinsic Detector Performance, 2009 IEEE Nuclear Science Symposium Conference Record (NSS/MIC)



(a)



(b)

Fig. 1. (a) Illustration of emitted photons behaviors before detection on the Si-PM, (b) An instance of a Compton event detection: we report the number of detected photons per pixel and the first arrival time per die (a group of 4 pixels).

Authorized licensed use limited to: Universite de Technologie de Troyes. Downloaded on January 24,2022 at 10:18:52 UTC from IEEE Xplore. Restrictions apply.