Evaluation of Timepix3 Si and CdTe hybrid-pixel detectors spectral performances on X and gamma-rays

Guillaume Amoyal, Yves Menesguen, Vincent Schoepff, Frédérick Carrel, Nicolas Blanc de Lanaute, Jean-Claude Angélique

Evaluation of Timepix3 Si and CdTe hybrid-pixel detectors spectral performances on X and gamma-rays

The Timepix3 [1] is a hybrid-pixel detector readout chip developed, in 2013, in the framework of the Medipix3 international collaboration [2]. It is the successor of the Timepix [3] chip, and can record Time-Of-Arrival (ToA) and Time-Over-Threshold (ToT) simultaneously in each pixel. The chip is designed to work in data driven mode, and can process a throughput of upto 40 Mhits/cm²/s. The Timepix3 hybrid-pixel readout chip consists in a matrix composed of 256 × 256 square-shaped pixels with 55 µm pitch. For each detected event, the Time-of-Arrival (ToA), with a time resolution of 1.5 ns, and the Time-over-Threshold (ToT) that gives access to deposited energy, are recorded. The Timepix3 chip can be hybridized to several semi-conductors, such as silicon (Si) or cadmium telluride (CdTe) with thicknesses up to 5 mm. For this study, a Timepix3 hybridized with a 300 µm thick p-on-n Si sensor, and a Timepix3 hybridized with a 1 mm thick n-on-p CdTe sensor were used. The Timepix3 Si operates in hole collection and a 100 V bias, whereas the Timepix3 CdTe operates in electron collection and a -300 V bias. The chips are controlled by the Katherine readout from RICE [4]. The per pixel energy calibration in Time-over-Threshold calibration mode is obtained following the method proposed by J. Jakubek in [5].

The per pixel energy calibration of Timepix3 Si is obtained with measurements on monochromatic X-ray beams from the SOLEX facility (*SOurce of Low Energy X-rays*) of LNHB (the french national metrology laboratory in the field of ionizing radiation) situated at CEA Paris-Saclay that produces X-ray beams over an energy range from 0.6 keV to 28 keV with a relative energy resolution around 0.1 % [6] and a set of radioactive sources (^{241}Am, ^{57}Co, ^{133}Ba and ^{152}Eu). Figure 1, shows the ToT spectrum and the associated energy-calibrated spectrum of a ^{241}Am source measured with Timepix3 Si. On the energy-calibrated spectrum, characteristic peaks of ^{241}Am are identified.

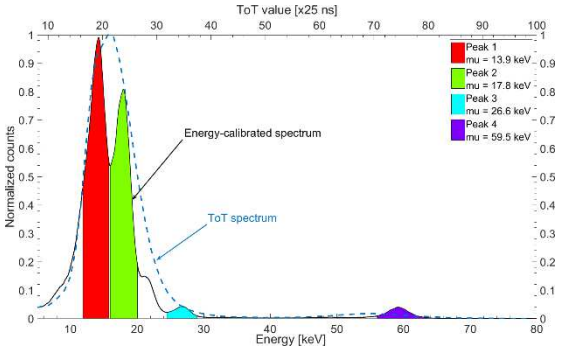

Figure 1 : ToT spectrum (blue dashed line) and energy-calibrated spectrum (black line) of a ^{241}Am source measured with Timepix3 Si.

figure 2 shows, on the left part, the evolution of the relative energy resolution for Timepix3 Si over an energy range going from 6 keV to 122 keV. The relative energy resolution is defined as the ratio of the FWHM with the mean energy of the considered peak. The results on figure 2 are fitted with a commonly used function describing the evolution of relative energy resolution with energy [7]. Results of this calibration allow to determine an energy resolution of 3.97 keV at 59.5 keV for Timepix3 Si, as illustrated on the right part of figure 2.

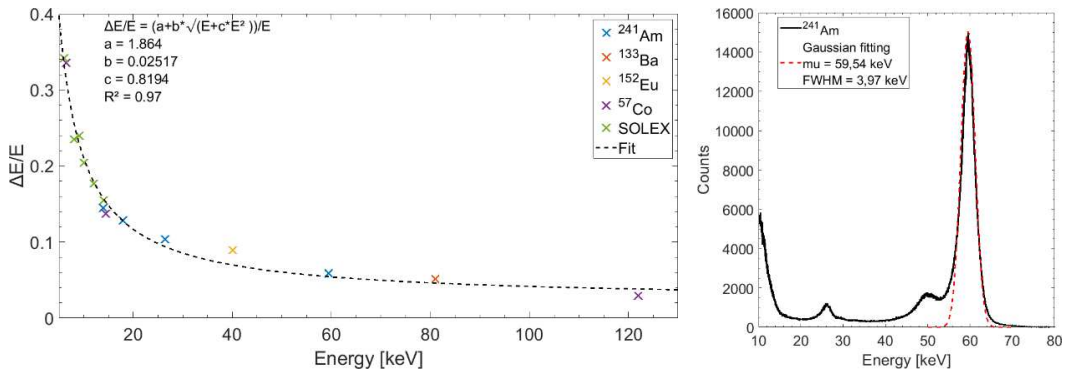

Figure 2 : On the left, evolution of the energy resolution versus the energy for Timepix3 Si. On the right, the measured energy spectrum of a ^{241}Am source with Timepix3 Si.

A first per pixel calibration was obtained for Timepix3 CdTe with the same procedure as Timepix3 Si. However the calibration curve was not satisfactory, as it was not converting ToT values in expected energy values. The per pixel energy calibration of the Timepix3 CdTe is obtained by back side measurements, as illustrated on figure 3. In this configuration, low energy photons are stopped by the wafer which is composed of high Z materials. Therefore, only the linear part of the calibration curve [8] for Timepix3 CdTe is calculated. Figure 4, shows on the left, the evolution of the relative energy resolution versus the energy, and on the right, the measured energy spectrum of a ^{137}Cs (33 MBq) and ^{60}Co (20 MBq) simultaneously placed in front of Timepix3 CdTe at 1 m. **Erreur ! Source du renvoi introuvable.** illustrates the evolution of energy resolution with energy for Timepix3 CdTe on an energy range going from 23 keV to 1.3 MeV. For gamma-rays with an energy higher than 200 keV a relative energy resolution lower than 8 % can be expected with Timepix3 CdTe.

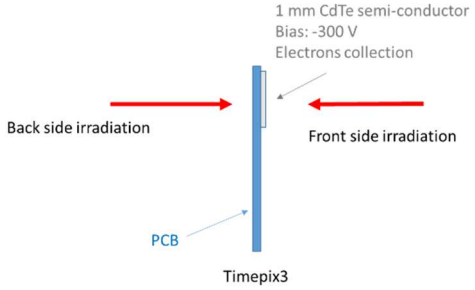

Figure 3 : Illustration of back side and front side irradiations with Timepix3 CdTe.

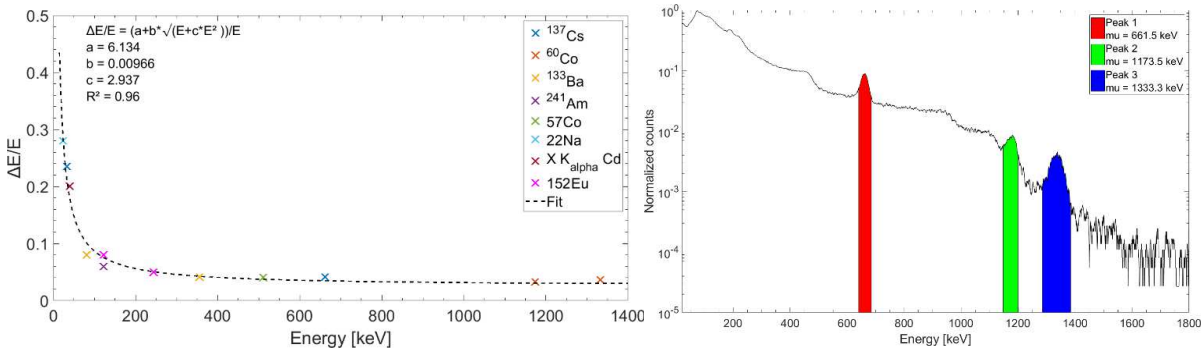

Figure 4 : On the right, Evolution of energy resolution versus energy for Timepix3 CdTe. On the left, the measured energy spectrum of a ^{137}Cs (33 MBq) and ^{60}Co (20 MBq) with Timepix3 CdTe. The distance between sources and Timepix3 CdTe is 1 m.

References

[1] T. Poikela *et al.*, “Timepix3: a 65K channel hybrid pixel readout chip with simultaneous ToA/ToT and sparse readout,” *J. Instrum.*, vol. 9, no. 05, pp. C05013–C05013, 2014.

[2] “Medipix3 Collaboration.” [Online]. Available: https://medipix.web.cern.ch/.

[3] X. Llopart, R. Ballabriga, M. Campbell, L. Tlustos, and W. Wong, “Timepix, a 65k programmable pixel readout chip for arrival time, energy and/or photon counting measurements,” *Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip.*, vol. 581, no. 1–2, pp. 485–494, 2007.

[4] P. Burian, P. Broulím, M. Jára, V. Georgiev, and B. Bergmann, “Katherine: Ethernet Embedded Readout Interface for Timepix3,” *J. Instrum.*, vol. 12, no. 11, pp. C11001–C11001, 2017.

[5] J. Jakubek, “Precise energy calibration of pixel detector working in time-over-threshold mode,” *Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip.*, vol. 633, no. SUPPL. 1, pp. S262–S266, 2011.

[6] C. Bonnelle *et al.*, “SOLEX: a tunable monochromatic X-ray source in the 1–20keV energy range for metrology,” *Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip.*, vol. 516, no. 2, pp. 594–601, 2004.

[7] G. F. Knoll, *Radiation Detection and Measurement*. 2000.

[8] J. Jakubek, “Precise energy calibration of pixel detector working in time-over-threshold mode,” in *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 2011, vol. 633, no. SUPPL. 1, pp. S262–S266.