Time resolution of a LYSO scintillator PET-like system read out by two fast high quantum-efficient photomultipliers

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The present work [1] has investigated the limits of time resolution obtainable from a system consisting of two small size (3×3×5 mm^3) LYSO scintillator crystals coupled to two fast photomultipliers (PMTs) with high quantum efficiency and exposed to the back-to-back 511 KeV photons resulting from the annihilation of the positron emitted by the radioactive source of Na-22. This measurement was conducted by means of two time pick-off techniques: the Leading Edge Discrimination (LED) and the Constant Fraction Discrimination (CFD).

The measurement was repeated for two different models of photodetectors, with nearly similar quantum efficiency (at the emission peak wavelength of the LYSO, 430 nm), but with different rise time. The two phototubes used are the model R9880U-110 and the model R7600U-200 from Hamamatsu Photonics. The first features a 30% quantum efficiency and 0.57ns risetime. The second model has 40% quantum efficiency and 1.50 ns risetime.

The experimental set up for the determination of the time resolution consists of two sections: the detection apparatus (scintillators+PMTs) and the electronic system for signal processing. The detection system has been realized by mechanically inserting a Na-22 calibration source between two 3×3×5 mm^3 LYSO crystals; each crystal was wrapped with white teflon in order to enhance light collection towards the only 3×5 mm^2 face left open, optically coupled to the PMT. With such an arrangement, the light path to the photocathode was minimized.

The signals (Fig. 1) produced by the photomultipliers are processed (Fig. 2) by a chain of NIM electronics, connected to obtain two process lines: the first provides the trigger and time pick-off for the two signals; the second is for the determination of the signal charge (energy) spectrum. To tag the time of occurring signals and define the trigger (two-fold coincidence) the signals were discriminated at a given threshold by a CAEN N841 LED module or by an ORTEC 935 200-MHz CFD.

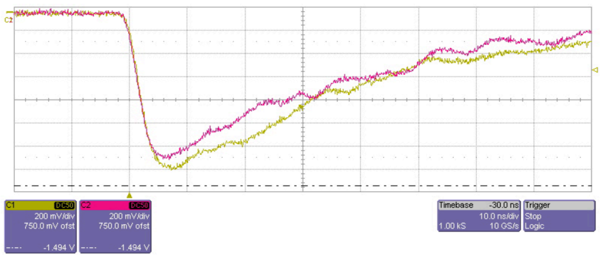

Figure 1. Sample coincident signals for PMT R7600U-200 acquired by a LeCroy WavePro 7300A DSO.

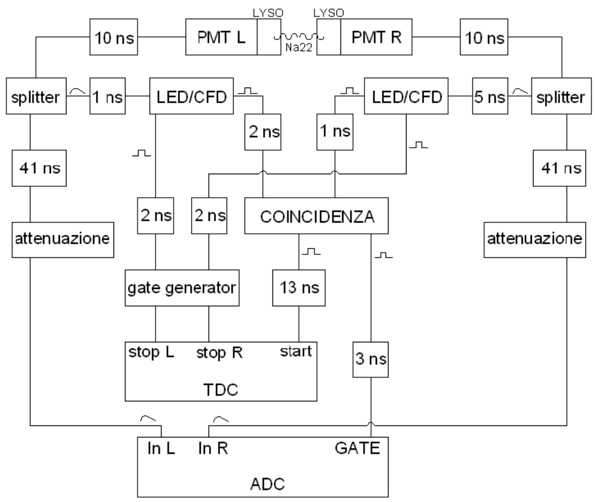

Figure 2. Signal handling and electronics set-up for the performed measurements.

The arrival times of the two signals were measured in Common Start mode by a CAMAC CAEN C414 25 ps Time to Digital Converter (TDC) started by the trigger. The linear signals,

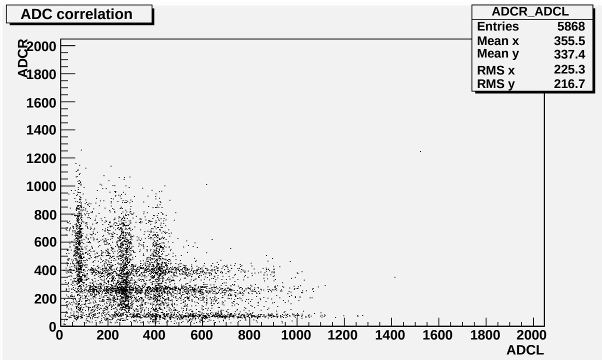

Figure 3. Background measurement for the couple of LYSO crystals (no source, intrinsic radioactivity only).

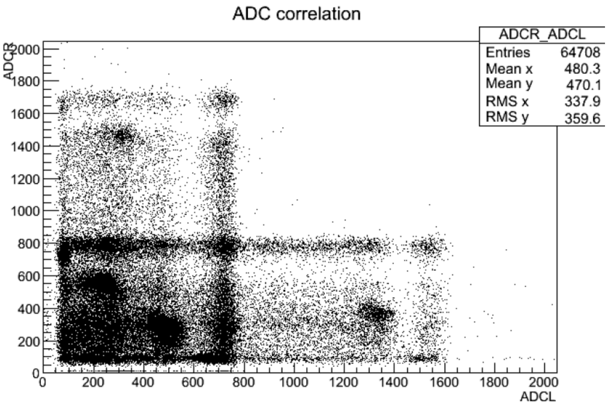

Figure 4. Na-22 source measurement for the couple of LYSO crystals. Correlated events for the coincident detection of 511 KeV gammas are centered at about (500,800) ADC-channel. All other structures are due to Compton scattering, accompanying gammas and intrinsic radioactivity of LYSO.

through splitters and attenuators, were charge integrated by a LeCroy 2249W Analog-to-Digital Converter (ADC), gated by the same event trigger. The time and charge parameters were saved event-by-event to a disk file by a National Instruments LabVIEW based data acquisition (DAQ) code. The data for every run were processed with a program written in Cern ROOT framework.

The charge measurement was very useful to understand the background (Fig. 3) due to the intrinsic radioactivity of the LYSO crystals, emitting X-rays and soft gammas.

In addition, it provided an efficient way to select the 511 KeV coincident events (Fig. 4, 5) from the Compton scattering, higher energy accompanying gammas and intrinsic background.

Time of flight (time difference) spectra (Fig. 6)

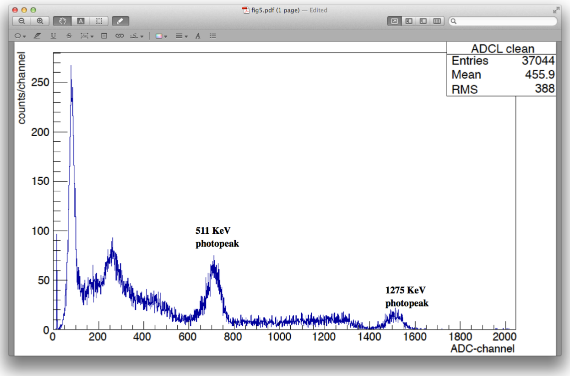

Figure 5. Na-22 source spectrum measured by detector left in coincidence with 511 KeV gammas tagged by detector right.

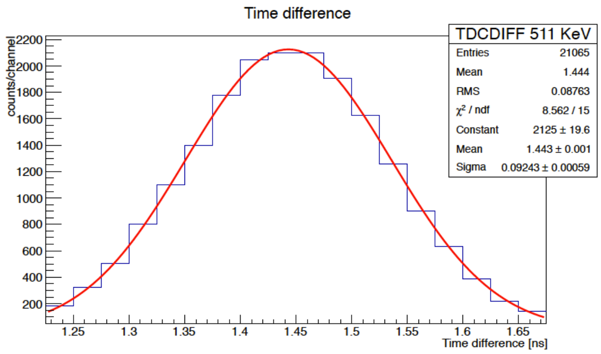

Figure 6. Sample time difference spectrum for coincident 511 KeV gammas in both detector arms with gaussian fit. In this run a time resolution of σ=92 ps is quoted.

were obtained by selecting all events corresponding to the coincident detection of the two 511 KeV gammas and calculating the difference of times measured by the TDC with respect to the common zero of the trigger.

In the reported measurements, the LED time pick-off technique has shown a better resolution (σ_t =70 ps for R9880U-110, σ_t =60 ps for R7600U-200) at the lowest measurable thresholds. The better performance of the second PMT despite of its longer rise time, is probably determined by the higher quantum efficiency. The measurements with CFD gave us a slightly worse values of about 90 ps with optimized threshold and delay parameters.

REFERENCES

1. G. Masiello, Timing di scintillatori inorganici, Tesi di Laurea in Fisica (quadriennale), Bari, 2012 and references therein.