Test modelling of a data acquisition system for Time of flight PET

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We are investigating the performances of a data acquisition system for Time of Flight PET, based on LSO crystal slabs and 64 channels Silicon Photomultipliers (SiPMs) matrices (1.2 cm² of active area each). Measurements have been performed to test the timing capability of the detection system (comprehending the SiPM coupled to a LYSO slab and the read-out electronics) with both test signal and radioactive source.

THE DETECTION SYSTEM

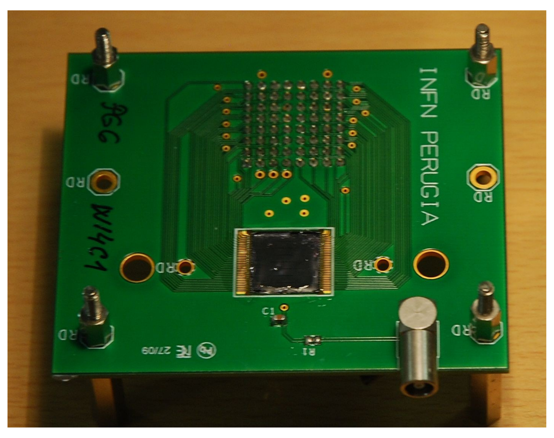


Figure 2: The SiPM Matrix

Detector devices, represented in Figure (2) consists of 8x8 SiPM matrix with 1.5mm pitch. The pixel size is 1.5 mm×1.4 mm for a total of 840 microcells. A common bias voltage is applied to the whole matrix.
Two LYSO slabs, 12x12x5 mm³ each, are coupled to two SiPM matrices in PET configuration. Otical grease is used to improve the optical matching and crystals are wrapped with teflon.

The acquisition system , shown in Figure (1), is composed of a motherboard handling up to 18 DAQ boards. Each DAQ board hosts a custom 8-channels Front-End ASIC [1][2] (named BASIC). The input stage of each BASIC's channel is splitted in two branches: a fast one made of a current buffer connected to a leading edge discriminator for a fast trigger generation; a slow one made of a charge preamplifier connected to a peak detector. The eight outputs are multiplexed and sent to a 10 bits ADC hosted on each DAQ board. Data from all the ADCs are handled by an FPGA located on the motherboard, then sent to a host PC through a USB port.

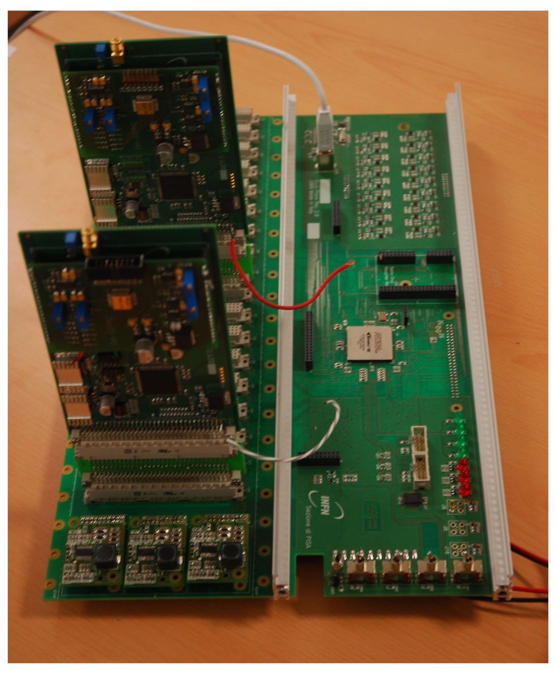


Figure 1: The acquisition system

TIMING PERFORMANCE OF THE SYSTEM
(1) ELECTRONICS TIMING CONTRIBUTION

Preliminary measurements have been performed to estimate the intrinsic time jitter of the Front-End electronics; test signals were used to simulate different charge injections from the SiPMs. To perform this measurement, a synchronous test signal has been sent to the input of two BASICs, and then the time delay of the two fast-OR signals has been acquired. Tests signals consist on square waves of different amplitudes sent to a shaper, whose circuit is represented in Figure (3).

For the charge injection it has been used a capacitance of 390pF and a partition circuit consisting of two resistance to reproduce the right amplitude of the signal. The signal obtained is represented in Figure (4); it has a rise time of the order of the nano-second and a fall time of about 13ns, in good agreement with the SiPM signal shape. For the input impedance of the Front-End circuit a value of 20Ohm was choosen, this value was indicated as the upper limit for the buffer current circuit.

The standard deviation of the time delay distribution as a function of the charge injected is shown in Figure (5). As the charge injected increases, the time jitter decreases and the minimum value achieved is 70 ps sigma, as depicted in Figure (6).

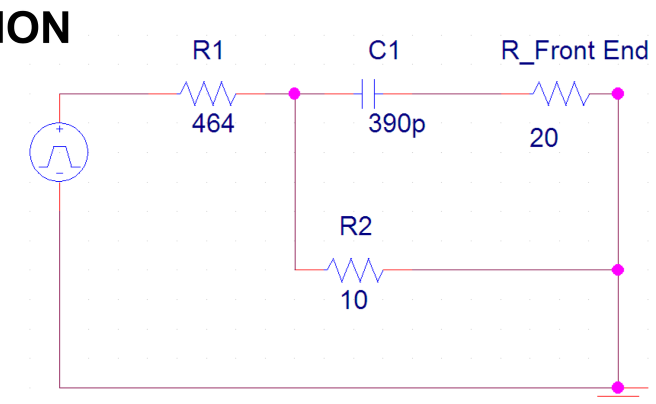


Figure 3: schematic of the charge injection circuit, the 20Ohm impedance symbolizes the Front-End contribution.

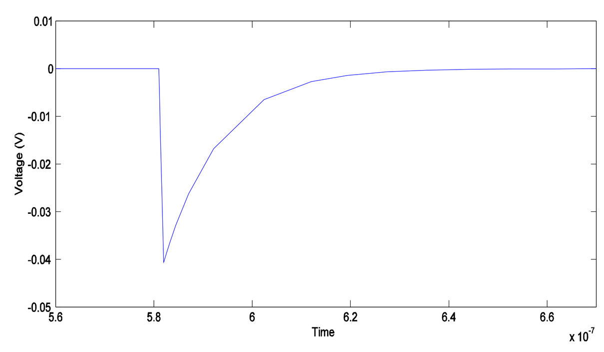
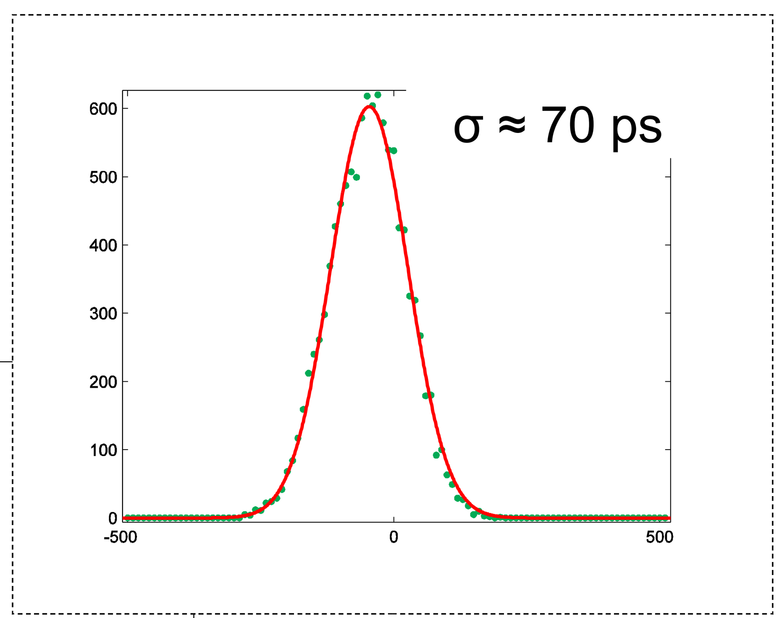


Figure 4: Example of shaping of the used signals.



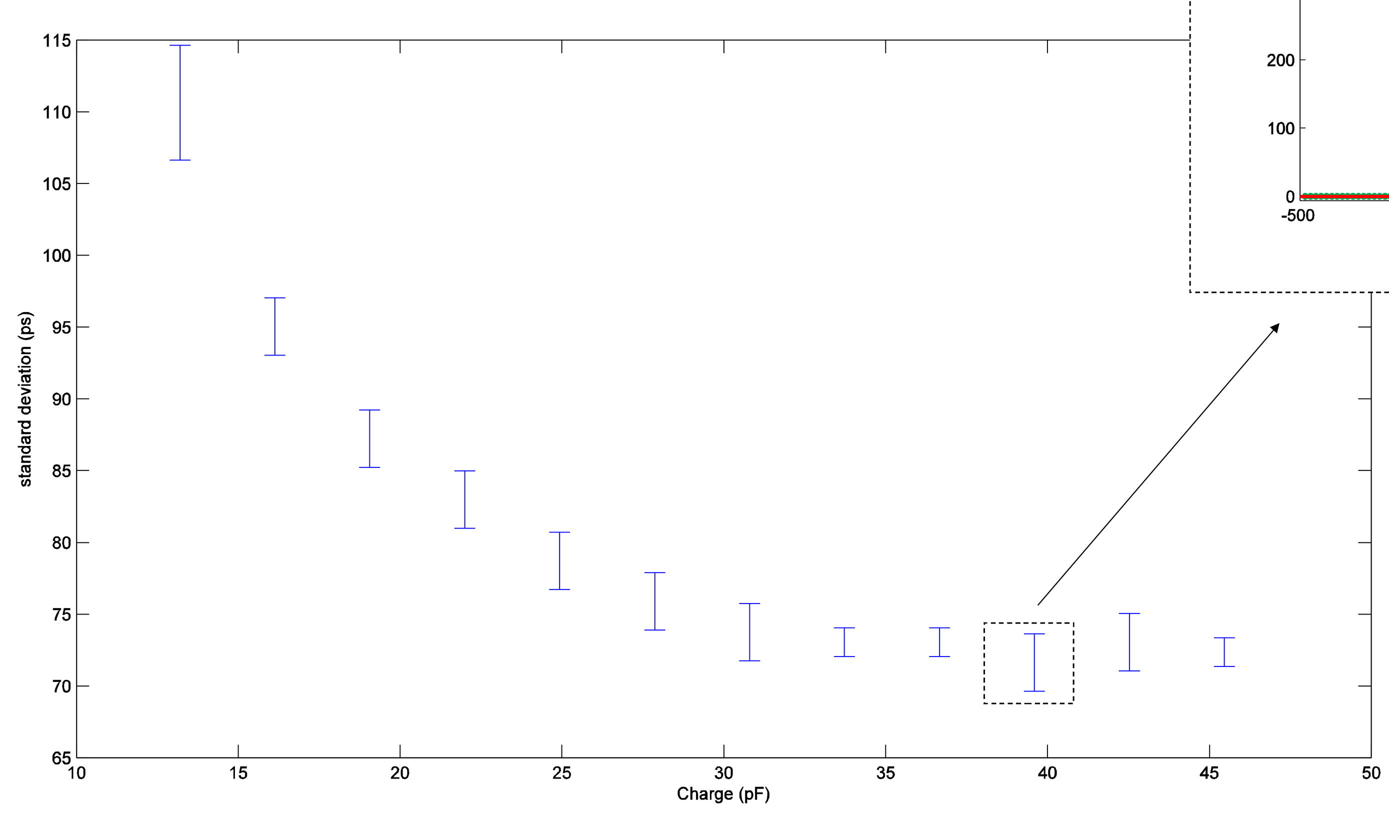


Figure 5 (left): Standard deviation of the time delay distribution as a function of the charge injected

Figure 6 (up): Best time jitter result obtained with a charge loading of 40 pC.

TIMING PERFORMANCE OF THE SYSTEM
(2) TIMING MEASUREMENT

To measure the time jitter of the whole detection system, the two sensors have been mounted one in front of the other and both irradiated with a Na22 source.
The 8 central channels of eachSiPM matrix in a row have been connected to the input channels of the DAQ board and the trigger digital signals (FAST-OR) of both BASIC have been sent to the scope to evaluate the time delay between the two digital signal. The full setting is schematized in Figure (7).
Time measurement was performed using the lower possible treshold and without selecting any energy window for the events, the time delay distribution is shown in Figure (8). The large time jitter of the signals (490 ps sigma) mainly derives from the time walk among signals of different amplitude.
In fact, with the present front-end architecture, only one threshold can be selected for energy selection. An improvement of the Front-End foresees a double discriminator architecture in which one threshold allows the energy selection while a second threshold optimizes the timing performances.

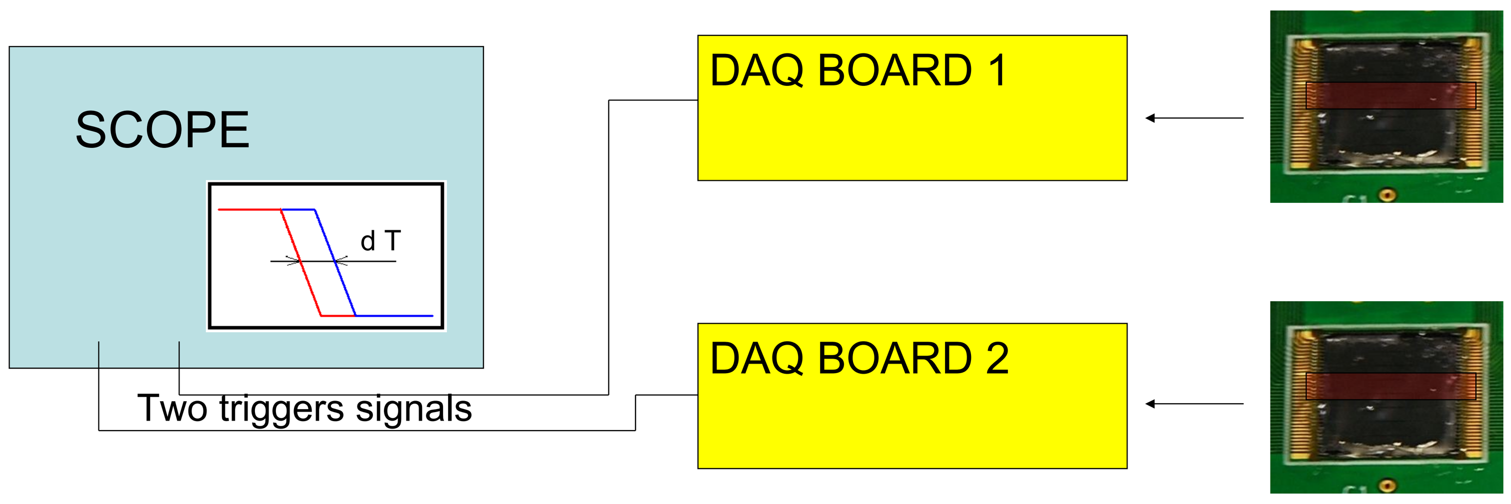


Figure 7: scheme of the set-up used to evaluate time coincidence distribution.

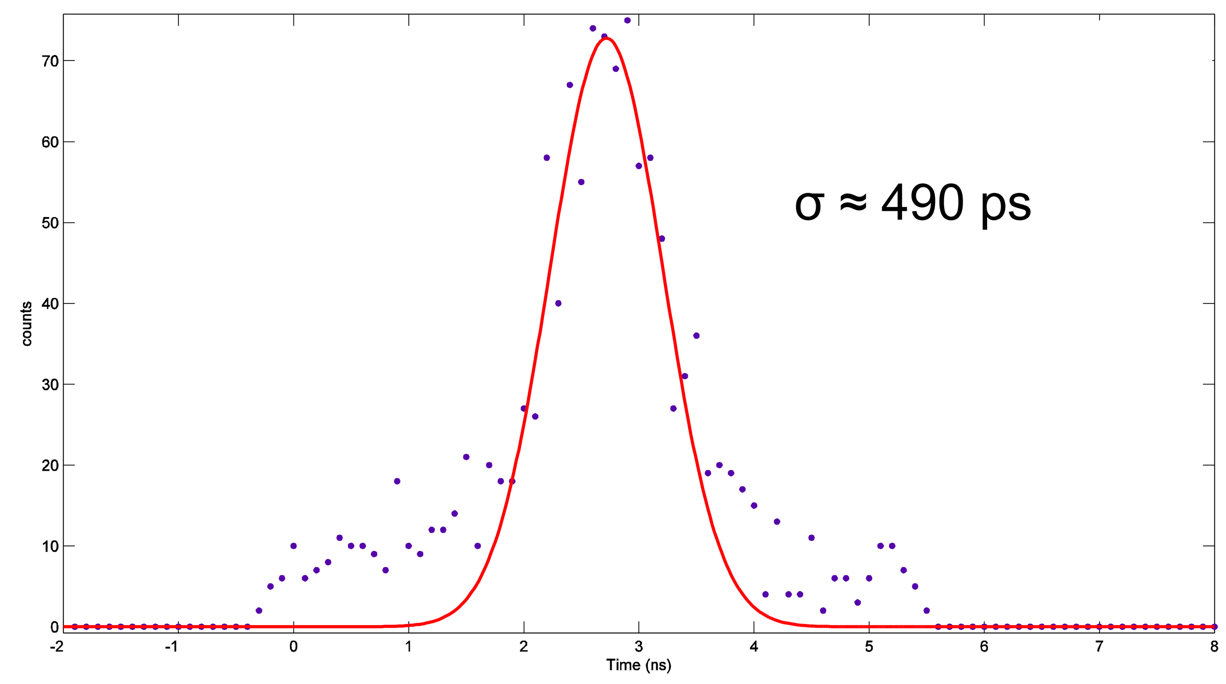


Figure 8: Time delay distribution between two central rows of two different SiPMs matrix with LYSO crystal slabs.

CONCLUSION

The time performance of the electronic acquisition system was tested with promising results for Time Of Flight PET application.
Measurements taken with simulated test signal give 70 ps standard deviation for the intrinsic electronic jitter with high amplitude signals comparable with photo-peak events.
Time distribution obtined with SiPM matrix is dominated by the contribution of the time walk due to signal of different energies. Currently, the single treshold architecture limits the global performance of the system because a low trigger level is necessary to maximize the timing capabilities.
Combining the results for the electronic jitter with previous coincidence measurements obtained at the scope selecting only the photo-peak events with LSO:Ce,Ca crystals [3], we can predict with the double treshold method a standard deviation of less than 200 ps for the total system at 511keV.

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