A Compact Detector Module for Time of Flight PET and the Associated DAQ system

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Abstract– **A compact Detector Module for Time-Of-Flight PET integrating 128 gamma-ray detection pixels of 3.5x3.5x15 mm^3 LYSO crystals associated to MPPC photosensors has been developed in the framework of the EndoTOFPET-US collaboration. The module has two 64-channel readout ASICs integrating signal conditioning and discrimination circuitry and high-performance TDCs for each channel, featuring 25 ps r.m.s intrinsic resolution and fully digital output (up to 640 Mb/s). The data acquisition system is based on frontend boards, each collecting the data of 1024 channels (8 Detector Modules) and transmitting assembled data frames through an electrical serial link (1.6 Gbps) or two high-speed optical links (2x6.4 Gb/s), and a single DAQ board on the PCIe bus of the acquisition PC. In this work, we present the design and preliminary results of characterization of the Detector Modules and associated DAQ system.**

I. INTRODUCTION

The EndoTOFPET-US system [1,2] is a multi-modal tomograph which includes a 230x230 mm^2 pixelated PET detector.

In this context a compact Detector Module integrating 128 gamma-ray detection pixels of 3.5x3.5x15 mm^3 LYSO:Ce scintillators crystals associated to MPPC photo-sensors was developed. One of the two external plates assembled by the EndoTOFPET-US collaboration uses the TOFPET readout ASIC, a 64 channel mixed-mode chip designed in 130 nm CMOS technology with 25 ps r.m.s intrinsic resolution and low power consumption [3].

The data acquisition of Detector Modules is performed by a dedicated high-rate scalable DAQ system developed in the same context.

II. DETECTOR MODULE

The Detector Module is composed of 8 matrices of 4x4 LYSO scintillating crystals, each with a size of 3.5 x 3.5 x 15 mm^3 produced by CPI Inc. separated by 0.1mm Vikuity Enhanced Specular Reflector foils. These matrices are coupled to 8 arrays of Hamamatsu TSV-MPPCs (S12643-050CN). The photo detector cells have an active area of 3x3mm^2 and are arranged in 4x4 arrays. Both components, the crystal matrix and the MPPC array, have a pitch of 3.6 mm [4].

The crystal matrices and associated MPPCs plug directly in the Front End Board type A (FEB/A) forming a complete Detector Module (DM). Each DM measures 59.4 x 29.5 mm^2 and is four-side buttable such as to form a continuously sensitive area with almost no dead space. The board FEB/A integrates two TOFPET ASICs allowing the readout of eight Hamamatsu S12642-0404PB-50 MPPC 4x4 pixel arrays. A picture of the DM is shown in Figure 1.

The readout architecture is based on a dual-threshold technique. A low-noise front-end amplifier delivers replicas of a fast signal to two voltage mode discriminators, with independently set thresholds (on a per channel basis). The discriminator outputs are fed to a mixed mode dual TDC which provides two time measurements (50 ps binning), allowing the determination of the pulse amplitude from the time-over-threshold.

The FEB/A transmits data in two frames, one per ASIC, each frame consisting of the events captured in a 1024 clock period (6.4 μs frames). Each data link is 8B/10B encoded and a CRC is added at the end of the frame. The maximum rate per channel is 160 k events/s and the maximum FEB/A output rate is 12 M events/s.

The power consumption of the Detector Module is in the range 1-1.5 W depending on certain settings.

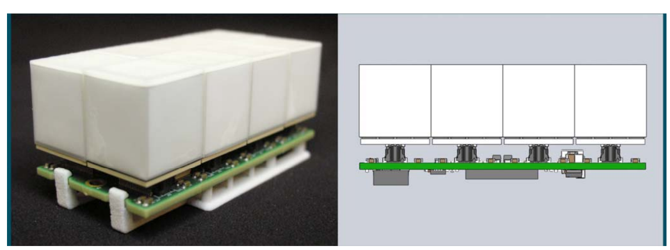

Fig. 1 – Picture of the Detector Module .

III. DATA ACQUISITION

The Front End Board type D (FEB/D) is a carrier of FEB/A readout boards. Up to eight FEB/A boards can be connected to the FEB/D, using either direct board-to-board connectors or flexible cables. Each FEB/D board collects the data of 1024 channels and transmits assembled data frames

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through an electrical serial link (1.6 Gbps) or two high-speed optical links (2x6.4 Gb/s). Using the optical links, the maximum output event rate per FEB/D is 258 M events/s. The FEB/D board is supplied with 24 V. On board DC-DC converters and regulators provide the required low voltages as well as 64 configurable SiPM bias voltage lines.

The DAQ Board is a PCIe data acquisition board that collects data from frontend FEB/D boards. The card performs a coarse event selection of coincidence candidates using a 12.5 ns wide coincidence window. Up to four master FEB/D boards can be connected to the DAQ board using HDMI cables. A master FED/D can be daisy chained with several slave FEB/D boards. Therefore the DAQ board can be integrated with several FEB/D boards forming a complete scalable data acquisition system with tens of thousand channels.

Experimental tests making use of the four present links transmitting simultaneously from the on-detector to the off-detector electronics, demonstrate that 1.6 Gb/s can be used on each link maintaining an error free data transmission during 24 hours continuous acquisitions. The interface PC-DAQ board is based on a PCIe motherboard interconnection and was shown to provide error free data transmission at 4Gb/s.

IV. Results

The Single Photon Time Resolution was measured by setting the time threshold at the lowest level and exciting the SiPM with an attenuated and synchronized picosecond laser pulse. The ToT distribution of events within ±0.5 ns of the expected laser pulse time show a distribution corresponding to 1 to a few photons (Figure 1). The time distribution of events with ToT corresponding to 1 photon provides a measurement of the Single Photon Time Resolution. A value of 200 ps (FWHM) is obtained (Figure 3).

Figure 4 shows results of the Coincidence Time Resolution (CTR) between two detector modules obtained with multi-photon laser pulses and beam splitting. A value of 100 ps (FWHM) is obtained.

The Coincidence Time Resolution was also measured with two detector modules facing each other and a Na22 source in between. The measurement was performed with SiPM bias voltage of 67.5 V. Events were selected within 1 sigma of the photopeak. The result is shown in Figure 5. The measured CTR is 355 ps FWHM. It should be noted that in the present prototype the matching factor between the SiPM and crystal pixels is 70%. Extrapolating to a matching factor of 100% a CTR~300ps is expected.

The TOFPET chip uses Time-over-Threshold for measurements of energy, which is a non-linear function. Internal calibration circuitry allows this non-linearity to be measured (Figure 6). After correction, an energy resolution of the 511 keV photopeak of 20% FWHM is measured (Figure 7).

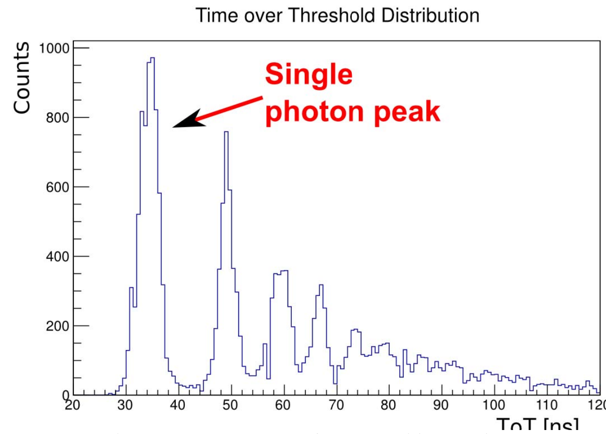

Fig. 2 – ToT spectrum of attenuated laser pulses.

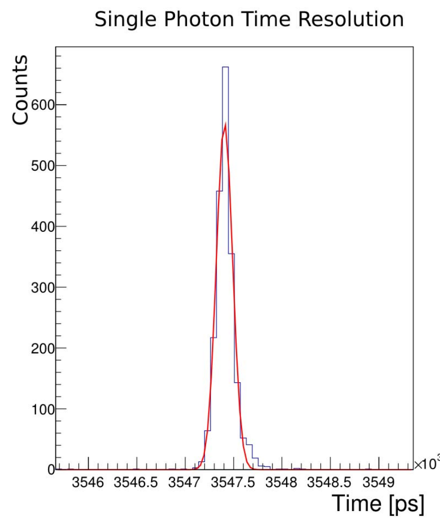

Fig. 3 - Single Photon Time Resolution (200 ps FWHM)

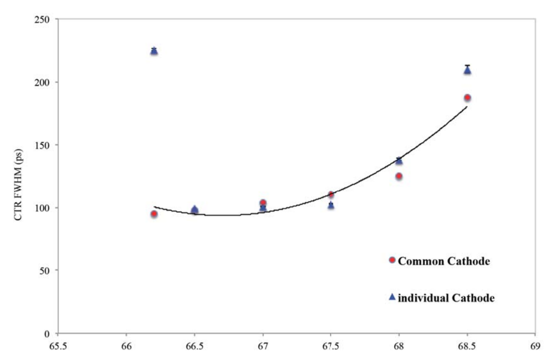

Fig. 4 – CTR between detector modules measured with multi-photon laser pulses as a function of SiPM bias voltage.

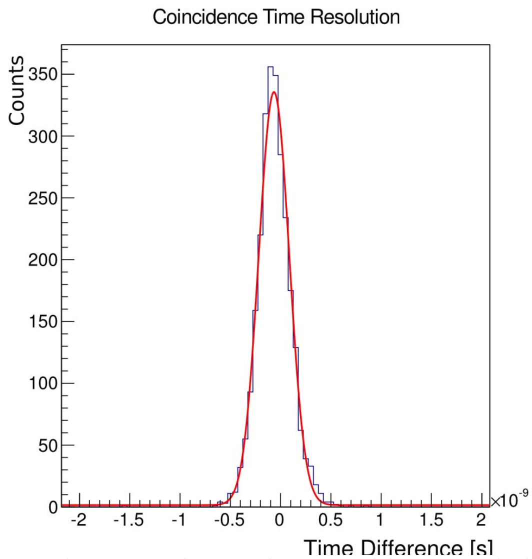

Fig 5 – Fig. 3 – CTR between detector modules measured with a Na22 source (355 ps FWHM).

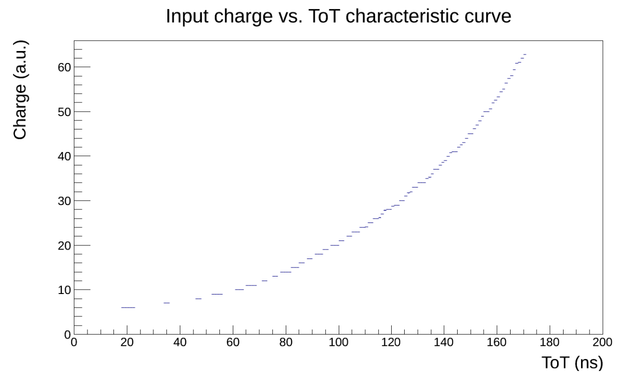

Fig. 6 – Example of calibration curve: input charge as a function of ToT measured in one detector channel.

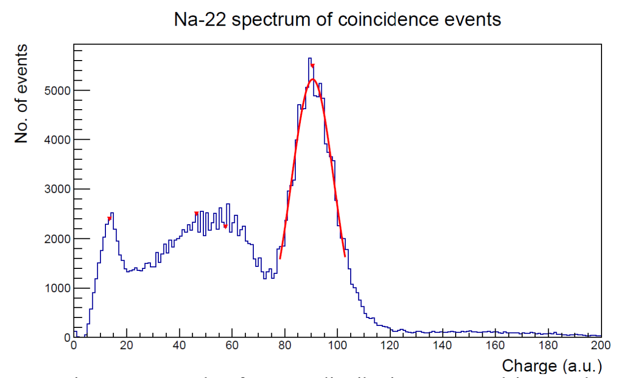

Fig. 7 – Example of energy distribution measured in one detector channel. The fit to the 511 keV peak yield a resolution of 20% (FWHM).

V. Conclusions

The development of the frontend electronics and data acquisition system of the EndoTOFPET-US external plate was a complex task. In this paper we have presented one of the two solutions that have been pursued by the Collaboration. Very good results have already been achieved in the design and characterization of the sensors, readout electronics and data acquisition.

References

[1] N. Aubry et al. EndoTOFPET-US: a novel multimodal tool for endoscopy and positron emission tomography, 2013 JINST 8 C04002.

[2] J. Varela et al., EndoTOFPET-US: Commissioning of a Multi-Modal Endoscope for Ultrasound and Time of Flight PET, submitted to this Conference.

[3] M.D. Rolo, R. Bugalho, F. Goncalves, G. Mazza, A. Rivetti, J.C. Silva, R. Silva, and J. Varela. TOFPET ASIC for PET applications. Journal of Instrumentation, 8(02):C02050, 2013.

[4] F. Hadj et al., Quality control of the LYSO crystal matrices, MPPC arrays, and the assembled MPPC-crystal modules for the external plate of the EndoTOFPET-US system, submitted to this Conference.