PROCEEDINGS OF SCIENCE

Picosecond timing measurements with the FERS-5200 TDC unit

C. Maggio,[a,*] **A. Abba,**[b] **F. Giordano,**[a] **A. Mati,**[a] **D. Ninci,**[a] **A. Picchi,**[a] **C. Tintori**[a] **and Y. Venturini**[a]

[a] *CAEN S.p.A.,*
via della Vetraia 11, Viareggio, Italy
[b] *Nuclear Instruments S.r.l.,*
via Lecco 16, Lambrugo, Italy
E-mail: c.maggio@caen.it, abba@nuclearinstruments.eu, f.giordano@caen.it, a.mati@caen.it, d.ninci@caen.it, a.picchi@caen.it, c.tintori@caen.it, y.venturini@caen.it

Next generation high energy physics experiments will feature high-granularity detectors with thousands of readout channels, thus requiring ASICs (low power and dimension).
CAEN FrontEnd Readout System (FERS) 5200 integrates ASICs on small, synchronizable and distributable systems with Front and Back Ends. The A5203 FERS houses the recently released CERN picoTDC ASIC and provides high-resolution time measurements of Time of Arrival (ToA) and Time over Threshold (ToT).
In this work we will analyze the performances of the A5203 unit: 3.125 ps LSB, ToA measurements down to ~7 ps RMS for signals of fixed amplitude over a single board, and ~20 ps RMS for input signals of variable amplitude (over a 50 dB dynamic range). The walk effect introduced by different amplitudes is corrected using the ToT. Besides walk correction, the ToT is used for signal amplitude reconstruction and background reduction.
The A5203 has been used in various applications, both experimental and industrial. At the end of this work, its application in the ProVision PET scanner will be presented.

42nd International Conference on High Energy Physics (ICHEP2024)
18-24 July 2024
Prague, Czech Republic

*Speaker

PoS(ICHEP2024)1203

1. Introduction

Recent developments in the field of detectors technology move physics experiments and medical tomography systems in the direction of using large arrays of detectors, to be read out with more compact and more cost-effective electronics. CAEN S.p.A [1], in collaboration with Nuclear Instruments S.r.l. [2], has developed the FERS-5200 platform [3] to fit the requirements of this type of application. FERS-5200 is a complete system performing front-end operations in small boards, that can be used individually or combined for larger readout systems. The DT5215 Concentrator board [4] takes care of controlling, reading out and synchronizing up to 128 FERS-5200 units, as if it were a single DAQ system. The data acquisition can be performed via the Janus open-source software, customizable for the user's needs.
The A5203/A5203B unit [5], part of this family, provides high-resolution ToA and ToT measurements for 64/128 channels, thanks to the recently released CERN picoTDC chip [6]. ToAs of the leading edge, or both the leading and trailing edges, of input signals are supplied as an absolute timestamp (Trigger Matching and Streaming acquisition modes) or as a ΔT with respect to a common Tref pulse (Common Start/Stop acquisition modes).
The walk effect on the ToA introduced with the different input pulse amplitudes is corrected via the ToT at software level, avoiding the need of Constant Fraction Discriminator filters. ToT is also used for signal amplitude reconstruction and background reduction (e.g. Dark Count Rate reduction for SiPM-based applications).

2. ToT-Based Analysis: Test Measurements and Results

The relation between ToT and walk is crucial to correct the walk effect that affects ToA measurements. Its estimation implies also the reconstruction of the ToT vs Amplitude curve to evaluate the correct amplitude of the input pulses. The curves of ToT vs Amplitude and Walk vs Amplitude, from which the Walk vs ToT is inferred, are obtained through a sweep of amplitudes of the input pulse (assumed an invariant pulse shape).
Performance tests have been carried out by using a pulse generator and step attenuators, needed for the amplitude scanning, which resulting signal has been fed to an A5203 unit mounting an A5256 discriminator [7] (see **Fig. 1**). The data acquisition has been conducted in Common Start mode, with a Tref signal of fixed amplitude and fixed discriminator threshold (100 mV), and variable amplitude stop signals. Two thresholds have been used to discriminate the stop signals: 5 mV and 300 mV. The choice of the two thresholds has been done as to optimize the resolution in the amplitude reconstruction for signals spread over a 3.8 V amplitude range (see below).

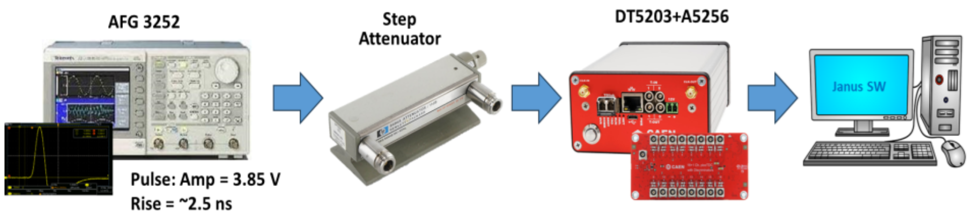

Figure 1: Components of the setup used for the performance measurements of the 5203 FERS unit.

Obtained data are presented in **Fig. 2**. On the left, the ToT with respect to the amplitude for the two thresholds is shown. On the right, the walk effect with respect to the amplitude for the two thresholds is shown.

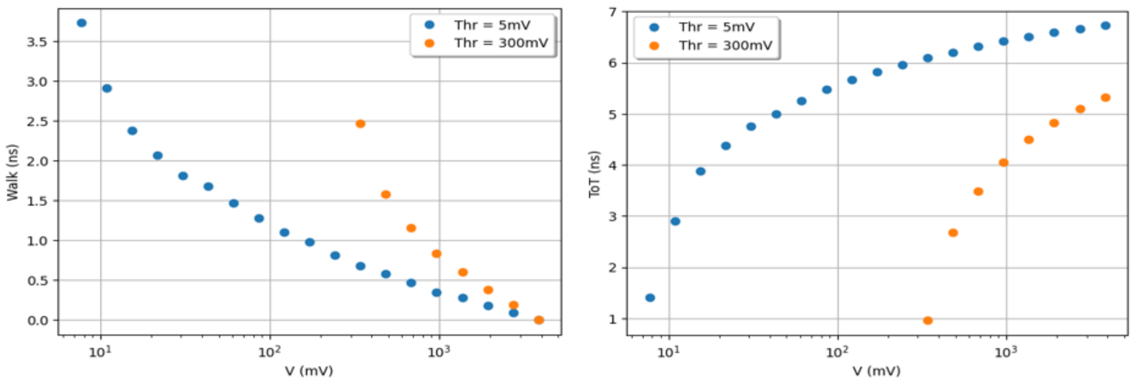

Figure 2: Walk vs amplitude data points (*left*) and ToT vs amplitude data points (*right*) for two discrimination thresholds. Data related to the 5 mV threshold are represented in light blue, data related to the 300 mV threshold are represented in orange.

Data points have then been used to reconstruct the walk with respect to the ToT and the Amplitude with respect to the ToT (see **Fig. 3**).

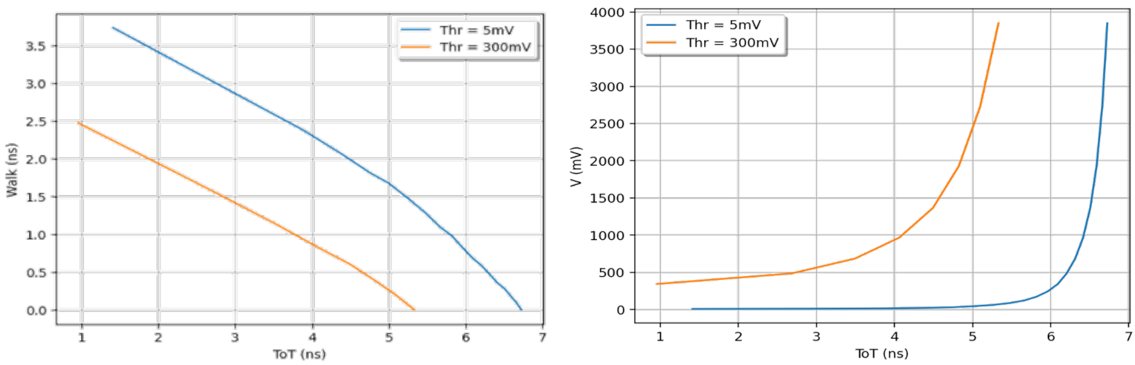

Figure 3: Walk vs ToT curve (*left*) and amplitude vs ToT curve (*right*) for two discrimination thresholds. The curve related to the 5 mV threshold is represented in light blue, the one related to the 300 mV threshold is represented in orange.

In **Fig. 4** we present ToA measurements, with and without walk correction, performed with a Tref signal of 1.0 V amplitude (100 mV fixed discriminator threshold) and stop signals at 6 different amplitudes. For a total dynamic of 3.8 V (50 dB) with a 5 mV discriminator threshold, the spread of ToA measurements over more than 2 ns is reduced to a single peak of 18 ps RMS after walk correction. The latter is achieved via a 5th degree polynomial fit, using the curves in **Fig. 3**, but similar results can be obtained with a 3rd degree fit.

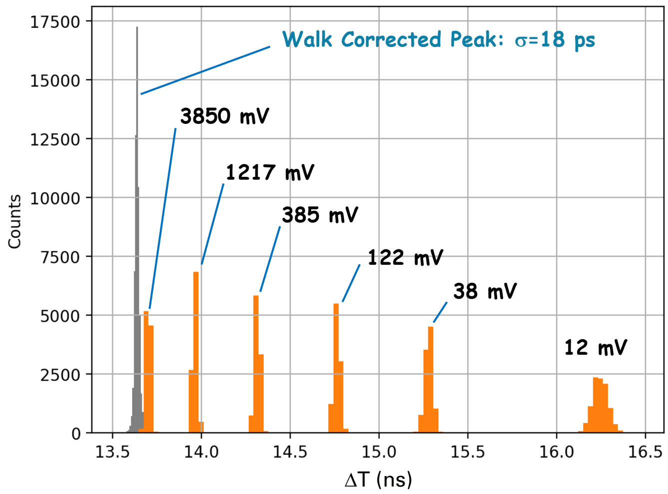

Figure 4: ToA measurements of input signals at different amplitudes before (orange) and after (grey) walk correction.

The amplitude reconstruction of the 6 stop signals has been performed by using both the 5 mV and 300 mV threshold curves. The former was considered for input signals of amplitudes (set via the attenuators) going from 12.2 mV to 121.8 mV, the latter for the ones of amplitudes going from 385.0 mV to 3850.0 mV. In **Tab. 1**, in reference to the amplitudes set via the attenuators, the reconstructed amplitudes, the uncertainty, the relative resolution and the integral non-linearity (INL) are presented. As visible, the amplitude reconstruction resolution depends on the proximity of the signal amplitude to the discrimination threshold, given the difficulty in the ToT estimation.

Ampl. Set [mV]	Ampl. Rec. [mV]	σ [mV]	Rel. Res. %	INL %FSR
12.2	11.3	0.1	1.1	-0.16
38.0	41.1	1.3	3.1	-0.05
121.8	120.9	4.0	3.3	-0.14
385.0	403.0	0.4	0.1	+0.39
1217.5	1215.4	7.6	0.6	+0.00
3850.0	3831.0	29.4	0.8	-0.03

Table 1: Reconstructed amplitudes for the 5 mV discrimination threshold (first three rows), and for the 300 mV discrimination threshold (last three rows). The columns present: the input signal amplitude as taken from the pulser+attenuators, the reconstructed signal amplitudes, the uncertainty, the percentage of the relative resolution, and the integral non-linearity in percentage of the full scale range (FSR).

3. PET Application

The ProVision PET scanner [8] consists of two planar detectors. Each detector has 768 channels and is readout with six A5203B cards (see **Fig. 5**). Precise timing is required for an accurate coincidence time resolution. The energy deposited in the crystals is derived from the ToT measurements. An example of a Na22 spectrum measured during the ProVision PET commissioning phase is shown in **Fig.** 6. Worth noting the fact that the noise (ToT<50 bins) has been subtracted thanks to the ToT suppression based on threshold that is implemented in the A5203 firmware.

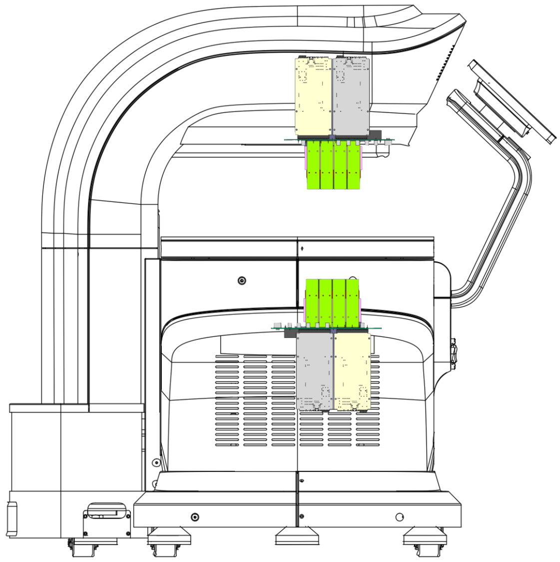

Figure 5: Sketch of the ProVision PET scanner. A5203B units are highlighted in green on the image.

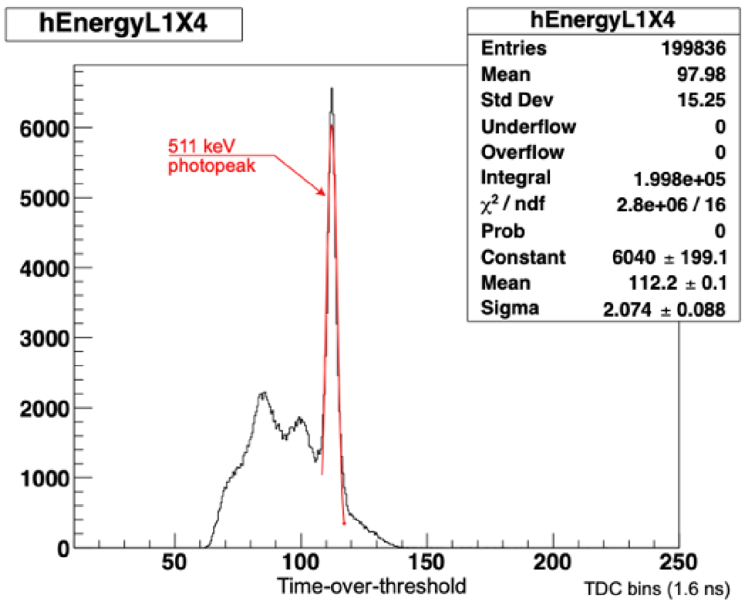

Figure 6: Na-22 spectrum obtained via A5203 ToT measurements (ToT resolution of 1.6 ns). Noise reduction thanks to event suppression based on ToT threshold.

Fig. 7 shows imaging results of a coronal view of a stack of six 4 mm thick Na-22 disks, separated by a 4 mm gap between them.

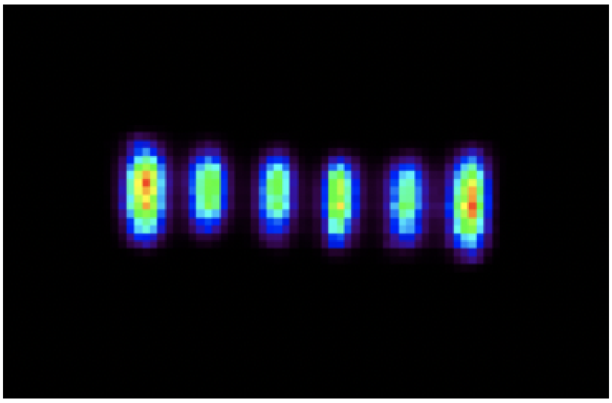

Figure 7: Coronal view of 4mm thick Na-22 disks separated by 4mm gaps, obtained during tests of the ProVision PET scanner.

4. Discussion and Conclusions

Optimal time resolution of the order of tens of picoseconds can be obtained with the A5203 unit thanks to walk correction via ToT. The latter is used with excellent results also for signal amplitude reconstruction and background reduction, in the particular case of PET medical systems. Nevertheless, in real acquisition systems, the walk curve estimation is difficult to achieve, given the difficulty in controlling signal amplitudes. New methods that include neural networks are under study and development.

References

[1] https://www.caen.it/

[2] https://www.nuclearinstruments.eu/

[3] https://www.caen.it/subfamilies/fers-5200/

[4] https://www.caen.it/products/dt5215/

[5] https://www.caen.it/products/a5203/

[6] https://kt.cern/technologies/picotdc

[7] https://www.caen.it/products/a5256/

[8] https://provision-eurostars.com/