CHARACTERIZATION OF A COMPACT TDC UNIT WITH PICOSECOND TIMING CAPABILITIES

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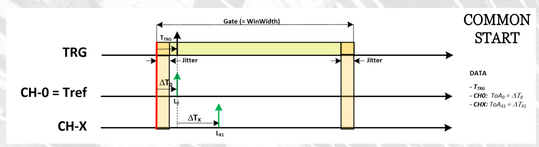
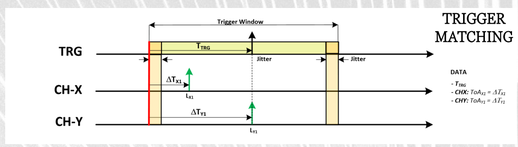
High-precision time measurements are the latest trend for particle physics experiments and medical applications (such as PET). Compactness, scalability and applicability to thousands of channels is required for the readout electronics. CAEN A5203 board, part of a synchronizable and distributable Front-End Readout System (FERS), integrates the CERN picoTDC Application-Specific Integrated Circuit (ASIC) into a small unit for high-resolution time measurements of Time of Arrival (ToA) and Time over Threshold (ToT). The performances of the A5203 unit, in terms of time resolution, walk correction, background reduction and signal amplitude reconstruction will be presented. The reported results come from laboratory tests with a signal generator and the A5256 CAEN Adapter, and from the unit application to the Provision PET scanner.

A5203 PICOTDC UNIT

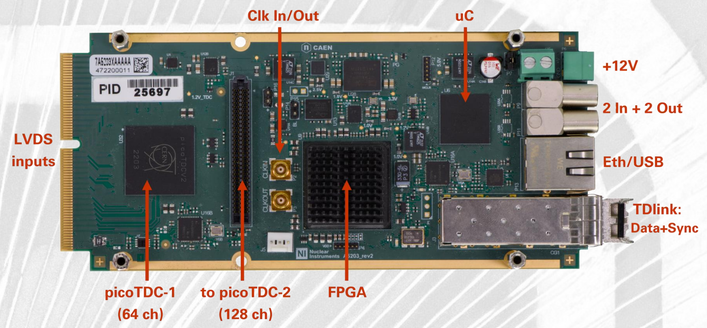
Time-to-Digital Converter: 64/128 channels (1 picoTDC = 64 ch), LSB = 3.125 ps, dynamic range = 56 bit (extended by FPGA)
Inputs: digital, LVDS ⟶ Front-End needed
Output Data: Time of Arrival, Time over Threshold
Data throughput: up to ~**64 Mcps/board** (without filters)
Acquisition modes: Common Start/Stop (Tref=Ch0), Trigger Matching, Streaming





ΔT Resolution (tested with CAEN A5256 edge discriminator and 0.5 Vpp pulses, with 0.8 ns rise time):

- Same board: **typ 5 ps RMS**
- Board to board: **~20 ps RMS**
  synchronized by DT5215 Concentrator Board via TDlink
- Board to board: **~8 ps RMS**
  synchronized by DT5215 Concentrator Board via TDlink , with auxiliary daisy chain/fan out clock cables

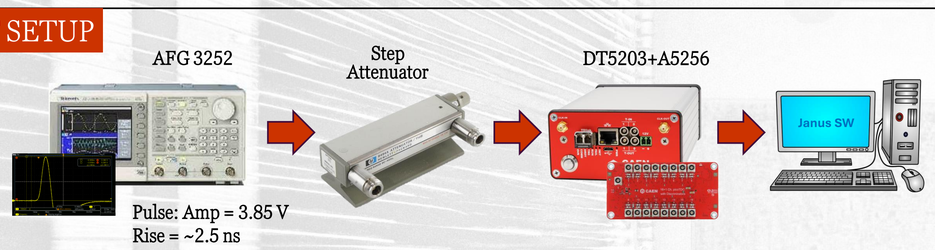


Key Features

- high timing resolution (~ 5 ps), high channel density, almost no dead time
- provides ToA and ToT in one word
- Walk effect on ToA corrected via ToT-based analysis
- PHA energy information obtained through ToT analysis
- Noise and DCR suppression at firmware level via a ToT-based filter

CHARACTERIZATION MEASUREMENTS: ToT-BASED ANALYSIS

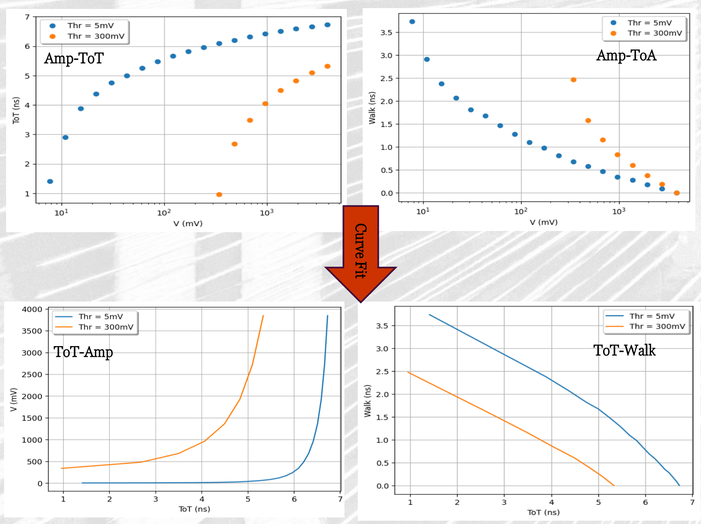
TEST SETUP



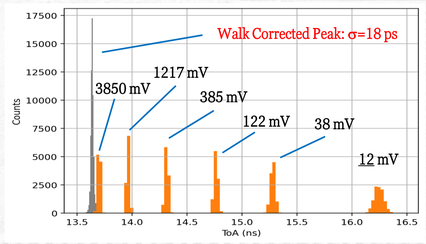
Common Start Acquisition: start on Ch0 with fixed amplitude, stop on Ch1 and Ch2 (dual threshold) with variable amplitude (max = 3.85 V). Delay = 13 ns

1. Sweep: acquire **ToT** and **ΔT (ToA)** at different amplitudes (from 0 to 54 dB, 3 dB step)
2. Fit points and build **ToT-Walk (ToA)** and **ToT-Ampl** curves
3. Use curves to **correct Walk** from ToT (replace CFD)
4. Use curves to **get Amplitude** from ToT (make ADC from TDC)

CALIBRATION

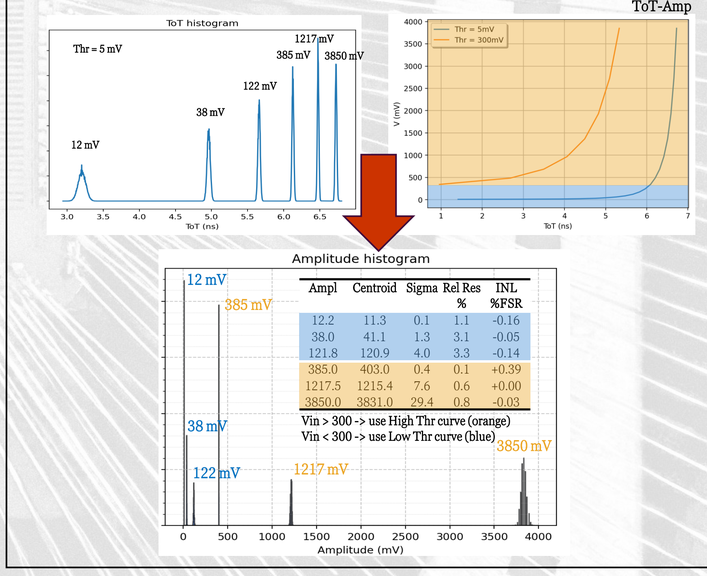


WALK CORRECTION



- Pulses at 6 different amplitudes over a 50 dB dynamic range
- ~2 ns spread on ΔT (ToA) caused by the walk effect: 6 separate peaks !!
  ➔ timing resolution totally destroyed
- ΔT corrected by ToT using a 5th order polynomial fit of the **ToT-Walk** points taken at threshold = 5 mV
- Corrected ΔT histogram presents one single peak:
  18 ps RMS over 50 dB dynamic range

AMPLITUDE RECONSTRUCTION

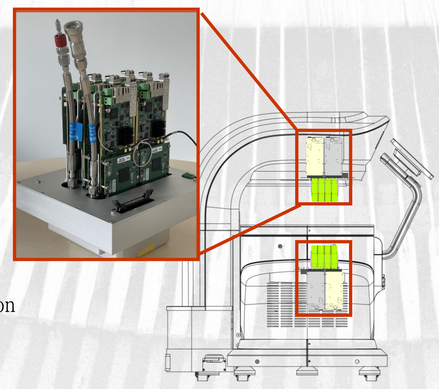


PROVISION PET SCANNER

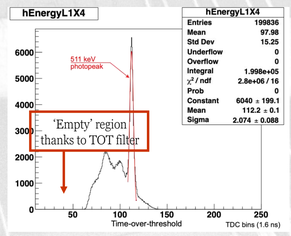
PET SYSTEM

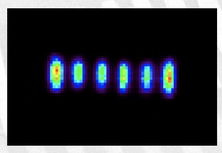
ProVision PET Scanner (a Eureka Eurostars project) is a PET scanner specialized in imaging aggressive prostate cancer at an early-stage. It is a high precision compact machine with reduced dose exposure constituted of two planar detectors that are placed on either side of the lying patient.

- 2x768 SiPM channels
- 2x6 A5203Bs (128 ch TDC)
- 1 DT5215 Concentrator Board for A5203B units synchronization
- Precise timing and TOT measurement
- High throughput – almost zero deadtime
- ToT cut for Dark Count and noise suppression
- 170ps Coincidence Time Resolution

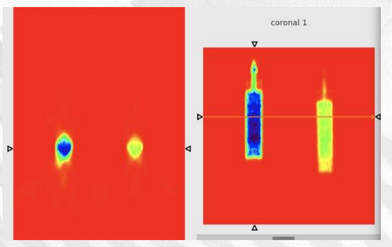


IMAGING RESULTS





4mm thick Sodium disks separated by 4mm gaps



Transverse view and coronal view of 2 syringes filled with FDG radiotracer, with activities at 3:1 ratio

- **ToA and ToT** measurements with a resolution of **5 ps RMS**
- **Walk correction** (mimic CFD) possible with single or double threshold: **18 ps RMS on a 50 dB dynamic range**
- **Amplitude reconstruction** (mimic ADC) requires at least 2 thresholds (2 TDC channels).
  Linearity = ~0.4%. Resolution = ~3%. Possible improvement with a more accurate threshold setting
- Optimal results in the Provision PET scanner: **few mm size radioactive sources easily detectable thanks to the x5203 high-time resolution**
- Challenge: build ToAVSToT calibration curves in a real data acquisition case -> Machine learning /Neural Networks
- New FERS Units embedding the picoTDC + ⟶ Radioroc chip: **A5204**
  Psiroc chip: **A5205**