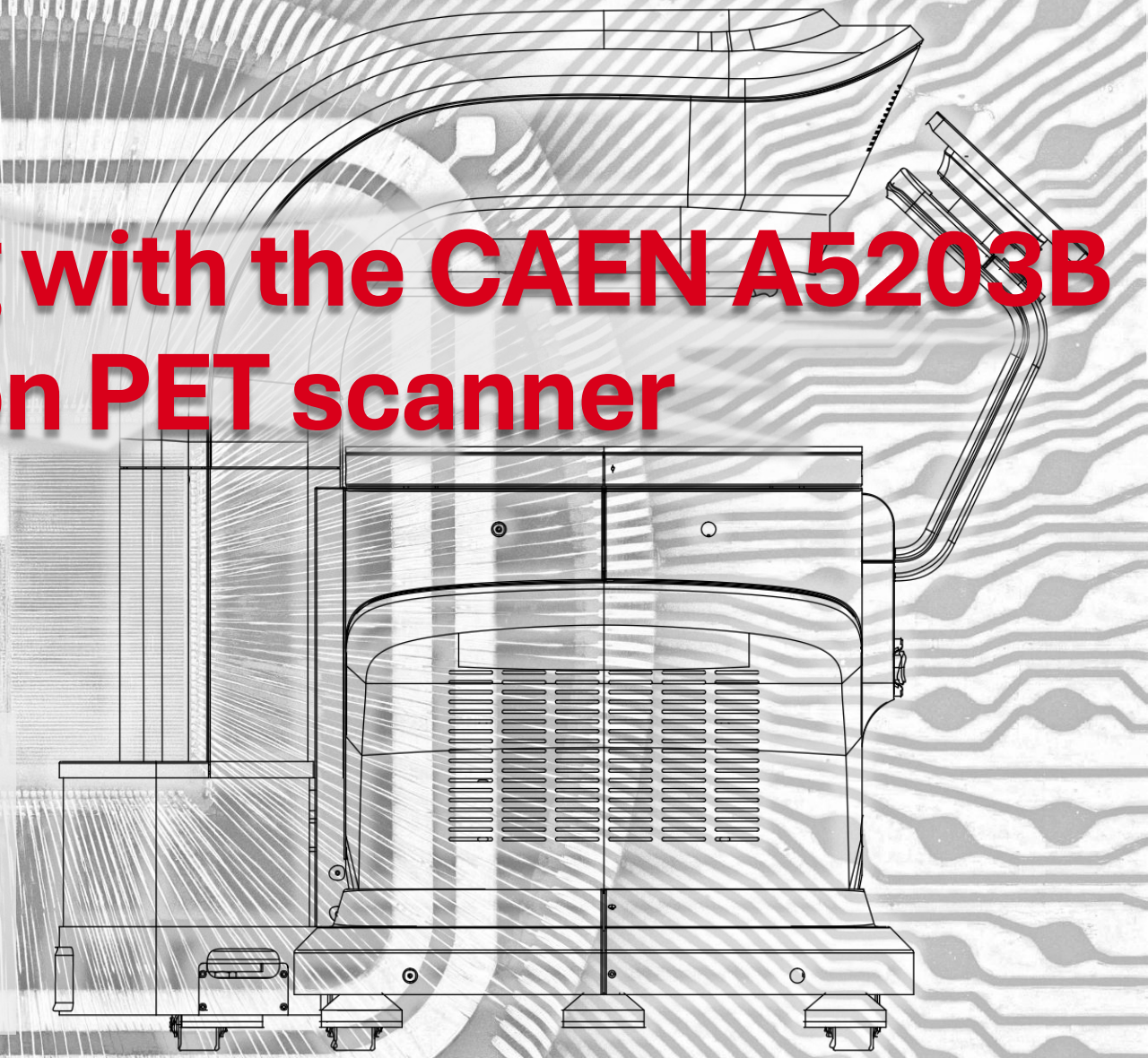
High-Resolution Timing with the CAEN A5203B in the ProVision PET scanner



Camilla Maggio (*c.maggio@caen.it*)

on behalf of

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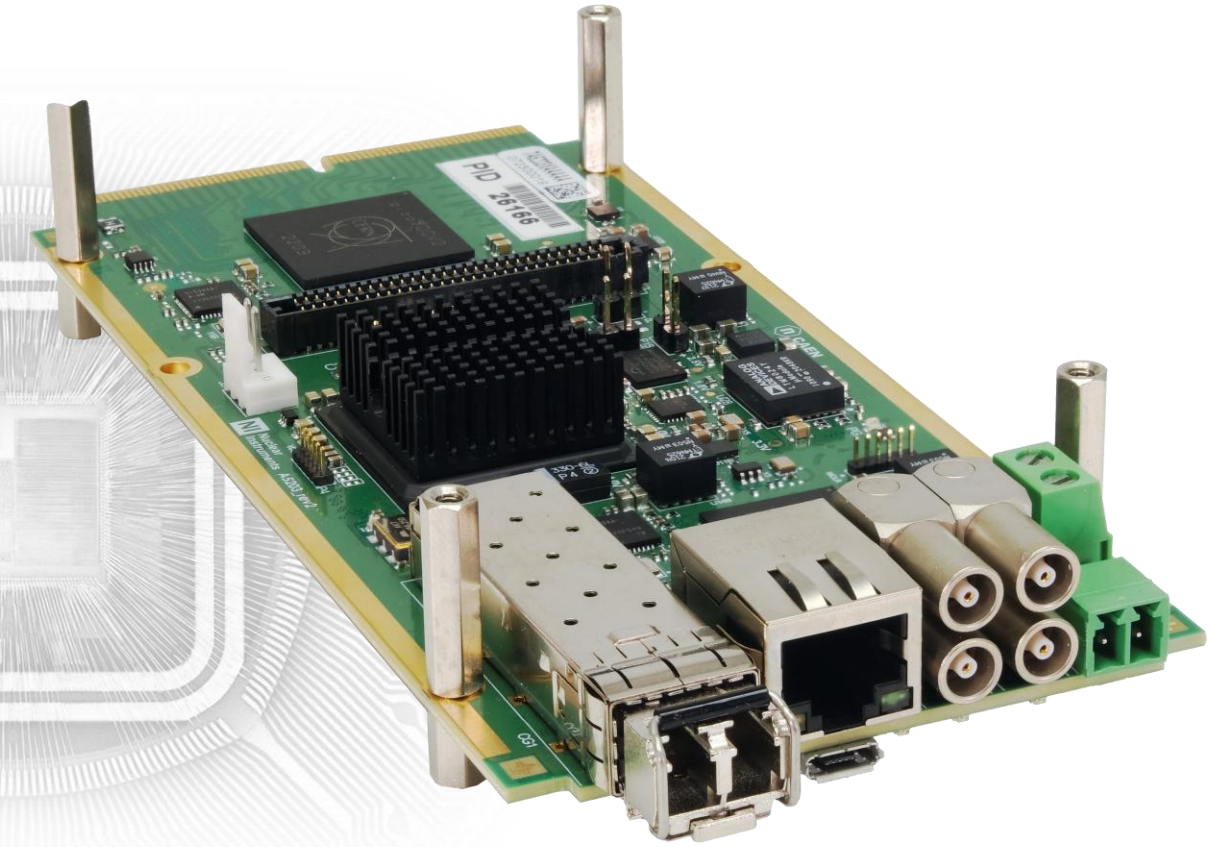
FATA2025 @ Catania – October 9th, 2025

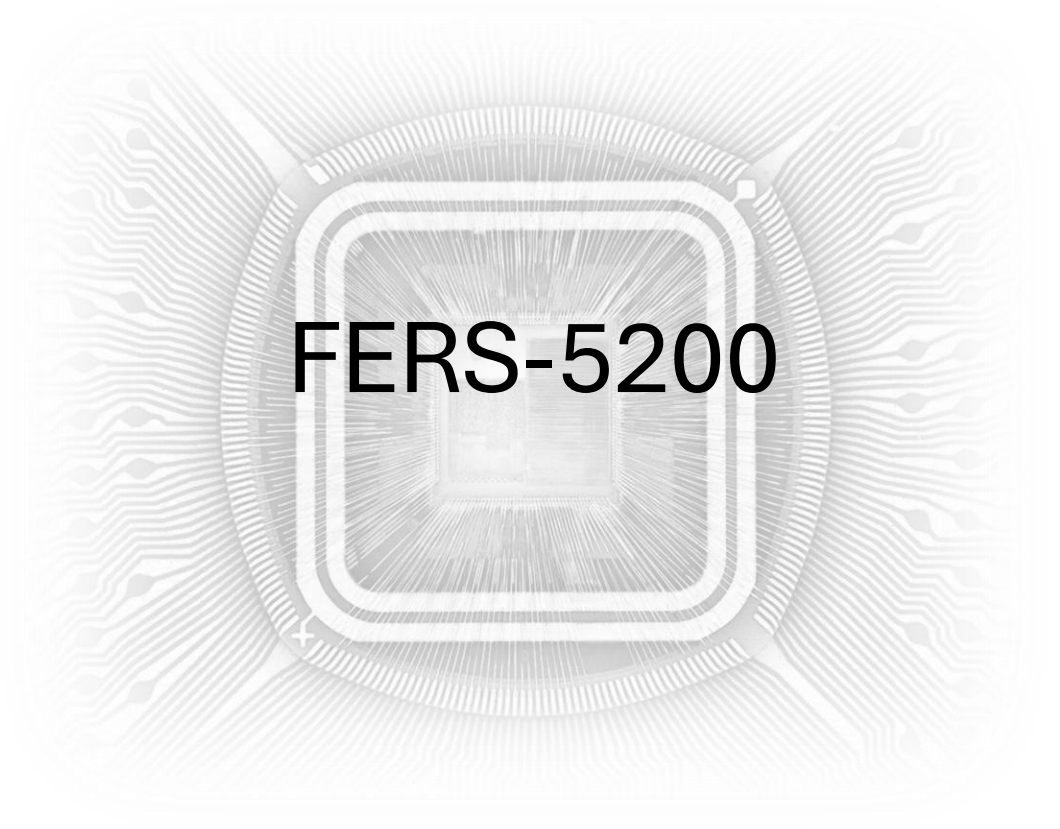
CAEN *Tools for Discovery*

Picotech

Outline

- A5203 and the FERS-5200 Family
- ToT-Based Analysis
- The Provision PET scanner
- Conclusions





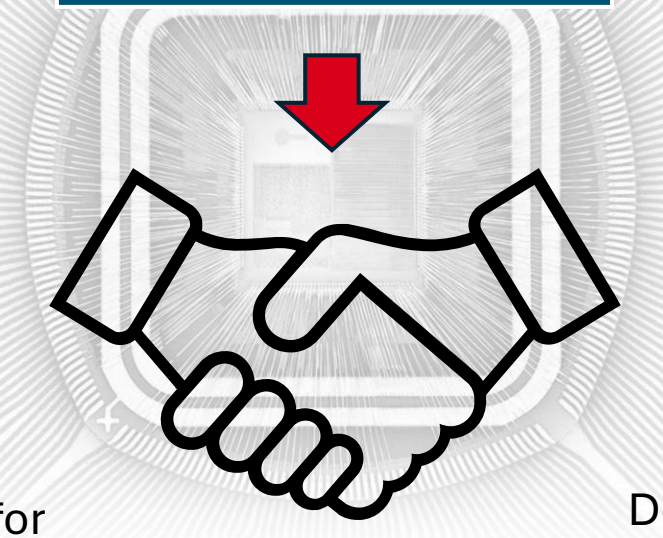
Front End Readout System 5200: The Core Idea

FERS-5200

Compact and Scalable Multi-channel Readout Electronics

High-granularity Detectors with Thousands of Channels

Cost-effective Readout Systems



CERN

weeroc

NALU SCIENTIFIC

Off-the-shelf **front-end ASIC** for scientific instrumentation

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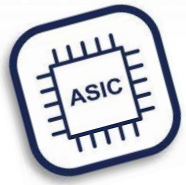
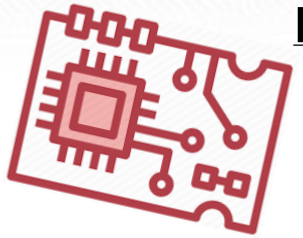
Nuclear Instruments

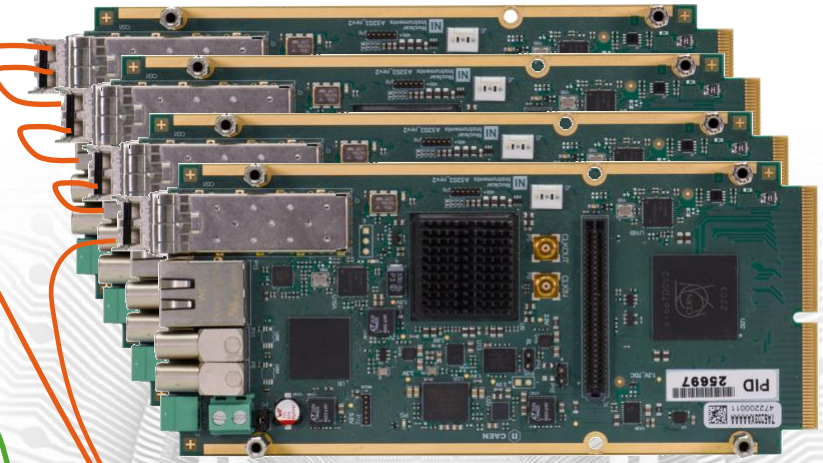
Design of **Readout Electronics and Power Supply** for NP and HEP





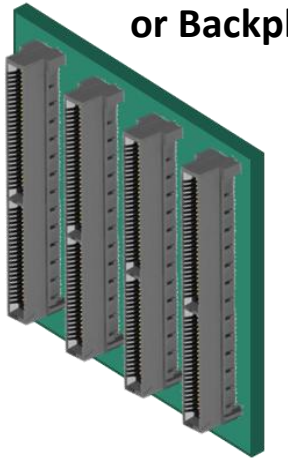
FERS-5200 architecture

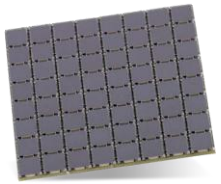
Readout
+
Slow Control
+
Synchronization



FERS Units

Custom Flange or Backplane

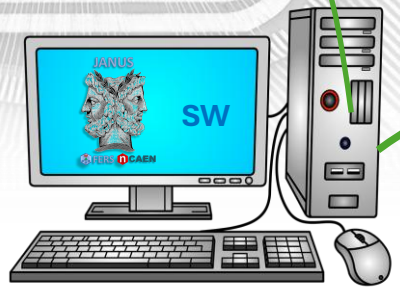




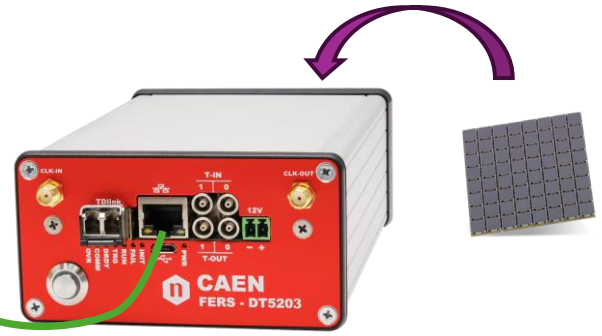
1/10Gb Eth
USB 3.0

USB 3.0

3.125 Gb/s TDlink



10/100Mb Eth
USB 2.0



Desktop Form Factor

DT5215/DT5216 Data Concentrators:

- 1 DT5215 => 16x8 FERS = **8k/16k ch**
- 1 DT5216 => 8 FERS = **512/1024 ch**
- **TDlink** (duplex optical fiber connection) proprietary protocol
- Sync to **GPS** on DT5215 Concentrator Board
- Possibility to sync **multiple DT5125**

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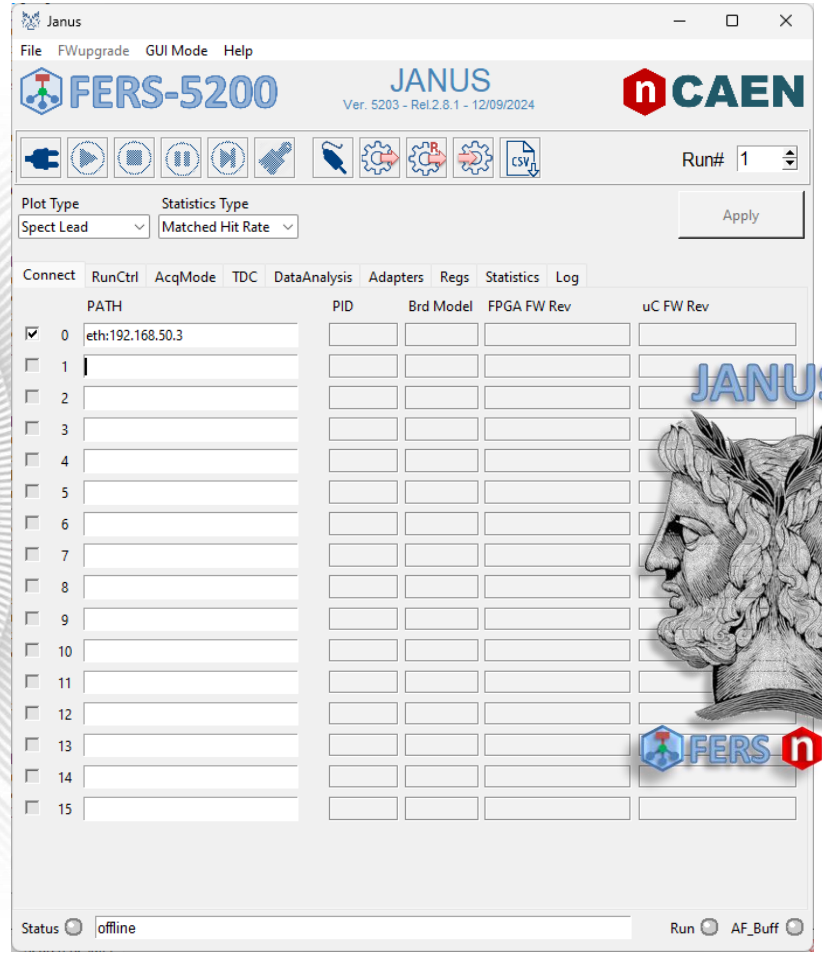
Janus Software & FERSlib Library

- **Open source** software for multi-board configuration and data readout
- available as **GUI (Python) or in console mode** – based on C/C++ readout programs
- Specific Janus version for each FERS unit (Janus 5202, Janus 5203, ...), but with common FERSlib library
- **SDK** for user customization (lib + demo)

HIGHLIGHTS:

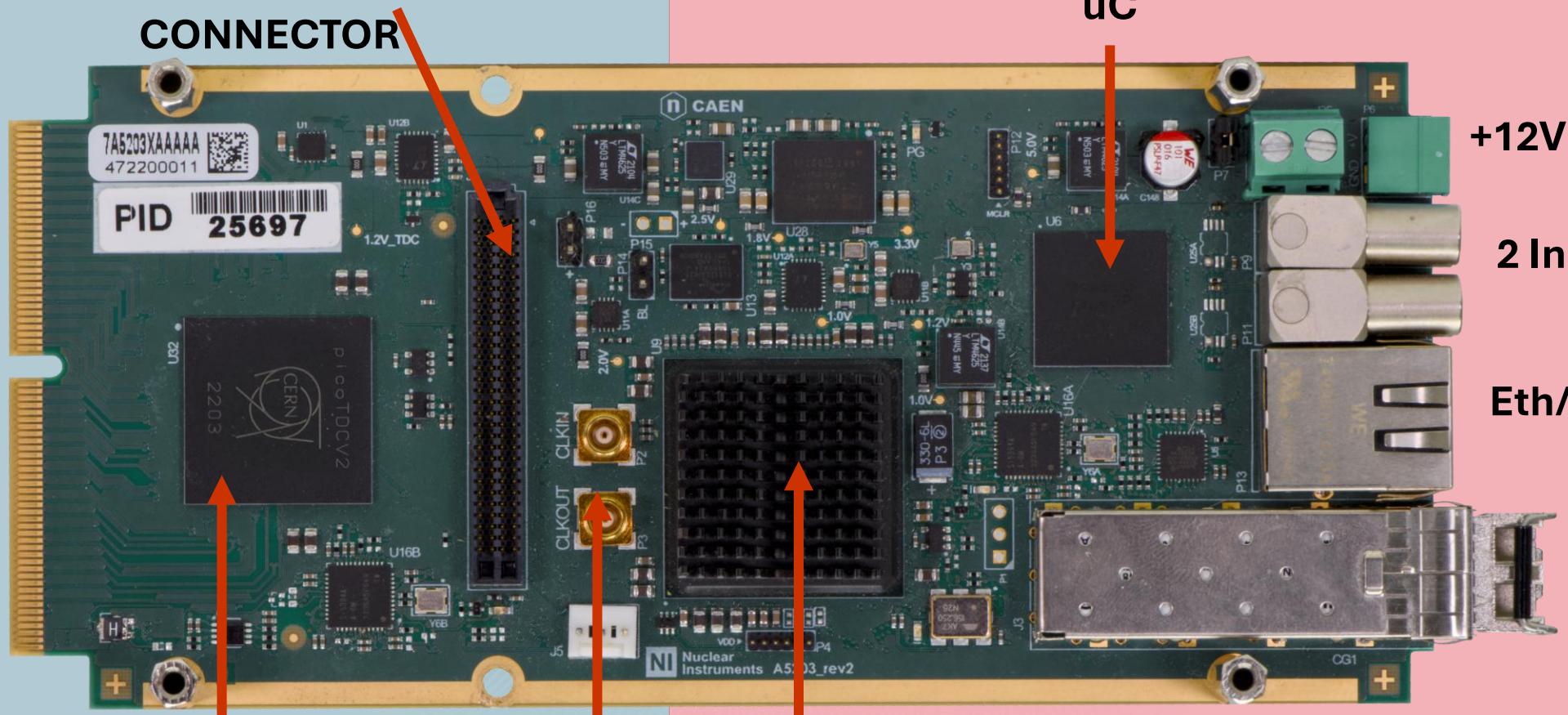
- Multi parametric Jobs and Runs with time or counts preset
- Output files: lists in **.bin**, **.csv** or **ASCII** (.txt) format, spectra, raw data
- Off-line runs for Post-processing and Event Building
- Live plots (with gnuplot) and statistics monitor
- Up to 300 MB/s data throughput (with DT5215 Concentrator via USB 3.0 or 10 Gb Eth)



THE A5203 FERS-5200 UNIT

FERS A5203: 64/128 channel Readout

FERS-5200



128 CH CONNECTOR

uC

+12V DC-IN

2 In + 2 Out

Eth/USB

TDlink: Data+Sync

Detector inputs

ASIC

Auxiliary Clock

FPGA

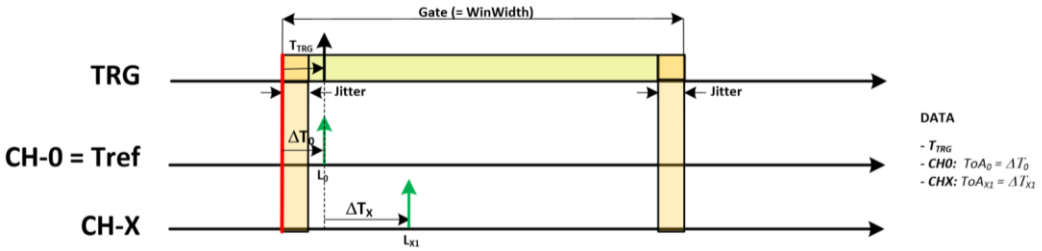
DETECTOR SPECIFIC FRONT-END

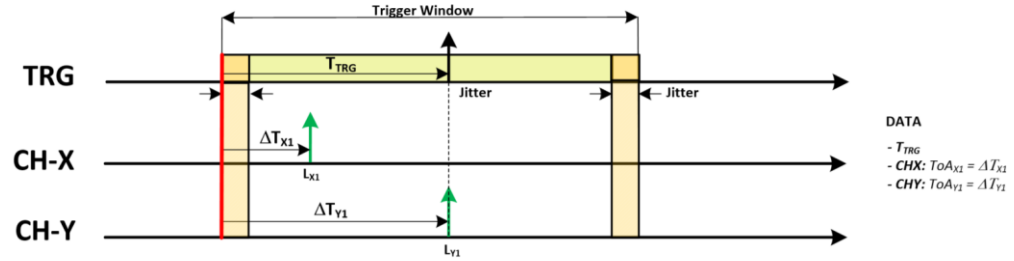
COMMON INFRASTRUCTURE

CAEN Tools for Discovery

X5203 Specifications

- **TDC**: 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 (ToA), Time over Threshold (ToT)
- **Data throughput:** up to **~64 Mcps/board** (without filters)
- **Acquisition modes**: Common Start/Stop (Tref=Ch0), Trigger Matching, Streaming





- **DeltaT Resolution** (*) :
  - 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

(*) Tested with A5256 discriminator. Pulse: 0.5 Vpp, 0.8 ns rise time

X5203 Specifications

x5203 Pros	x5203 Cons
• high timing resolution (~ 5 ps), high channel density, almost no dead time • provides ToA and ToT in one word	• ToA affected by walk effect • No energy information (PHA) acquired -> need for a separate ADC readout chain

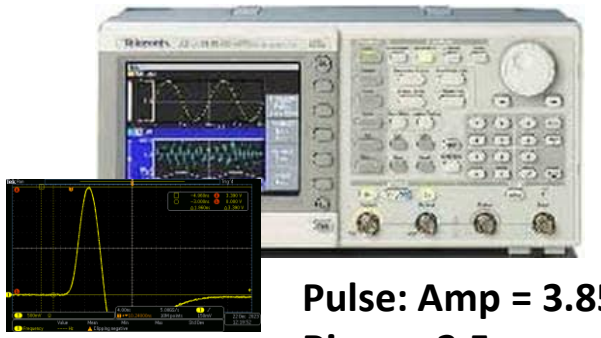
-> ToT-Based Analysis: Walk correction and PHA

- **ToT** can be used **to correct for time walk** => no need of Constant Fraction Discriminator in hardware
- **ToT** can be used **to reconstruct pulse amplitude**: ToT – PHA curve is not linear => need calibration (pulse shape dependent)
- **FPGA ToT filter**: rejects pulses if **ToT < LowCut** or **ToT > HighCut** (remove noise, DCR, saturation…)

TOT-BASED ANALYSIS

ToT Analysis Setup

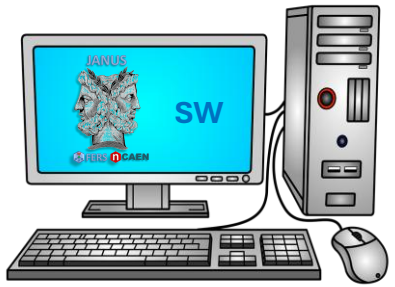
AFG 3252



Pulse: Amp = 3.85 V
Rise = ~2.5 ns

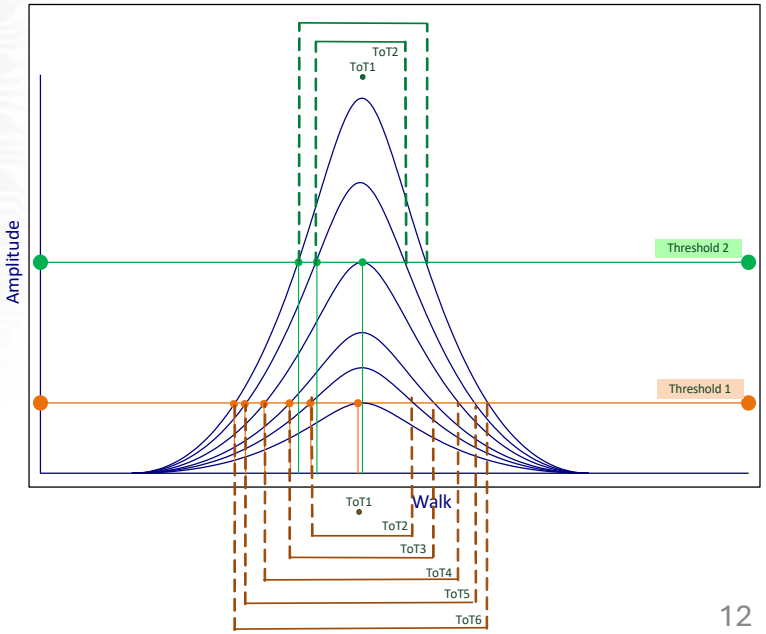
Step Attenuator

DT5203+A5256

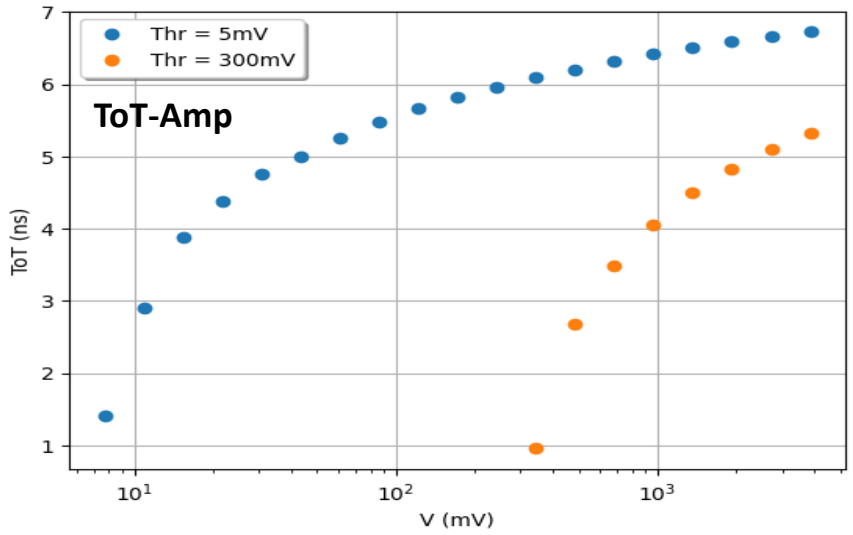


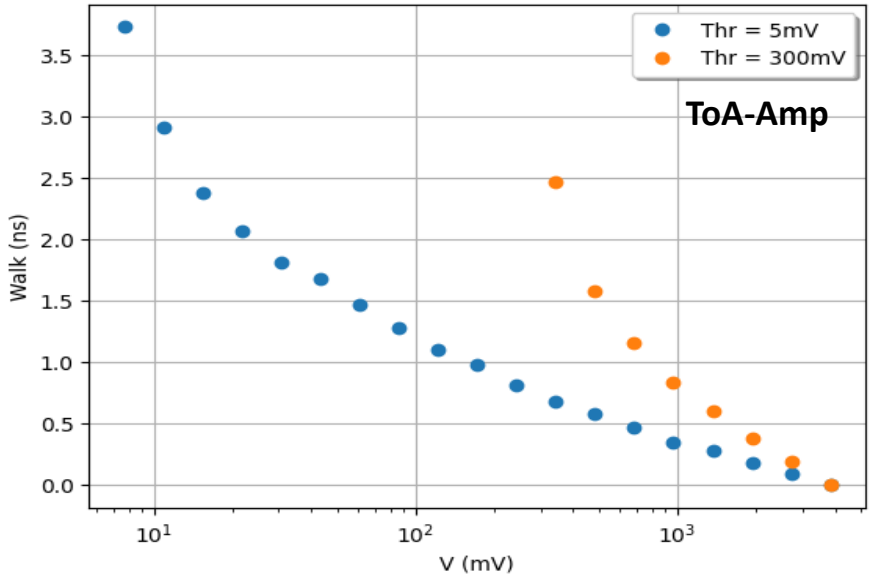
Common Start Acquisition: start on Ch0 with fixed amplitude, stop on Ch1 and Ch2 (dual threshold) with variable amplitude (max = 3.85 V). Delay = 13 ns

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)

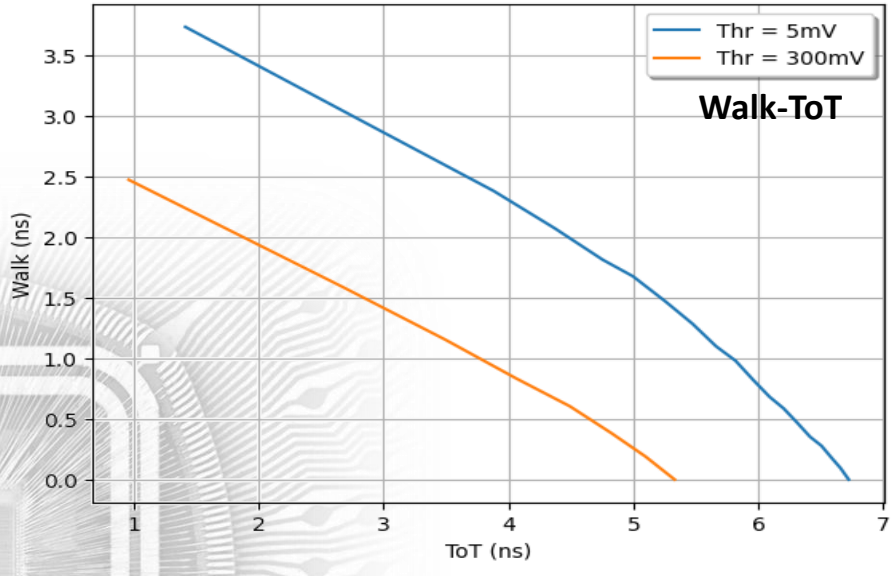


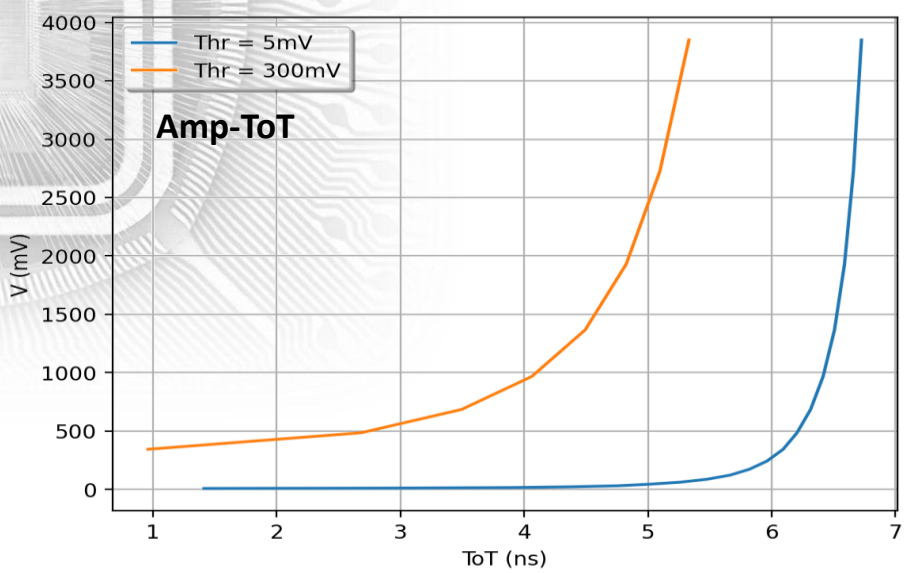
ToT calibration curves (double threshold)



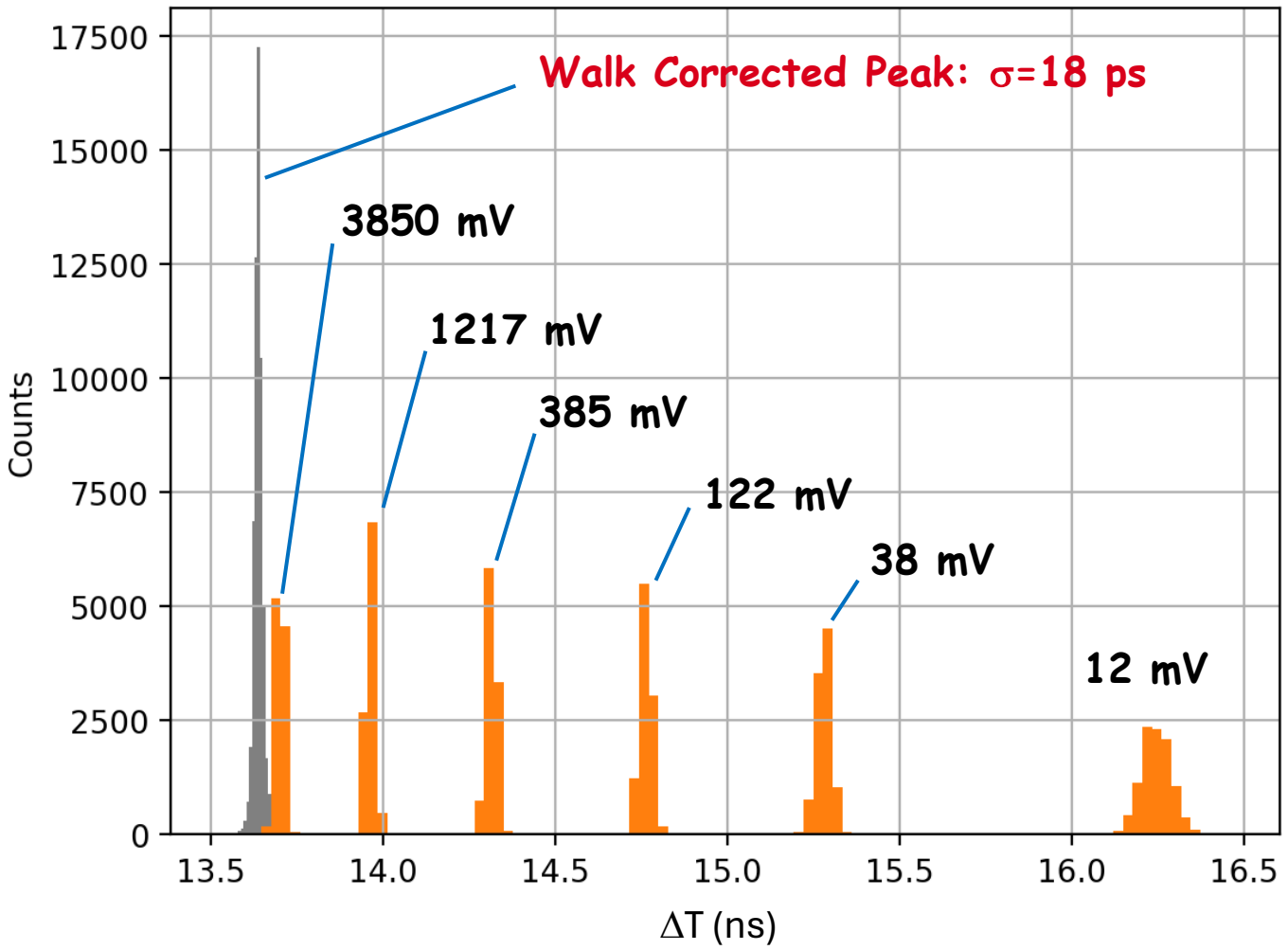


Curve Fit





Walk Correction

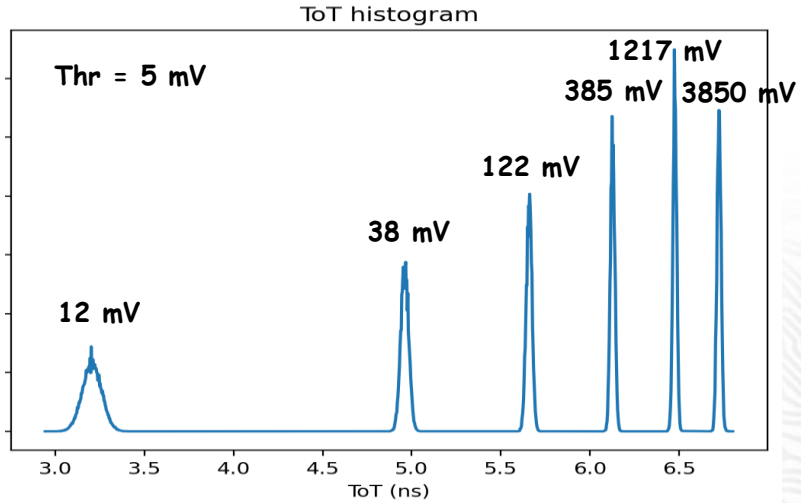


- Pulses at 6 different amplitudes over a 50 dB dynamic range
- ~2 ns spread on ΔT (ToA) caused by the walk effect: 6 separate peaks !!

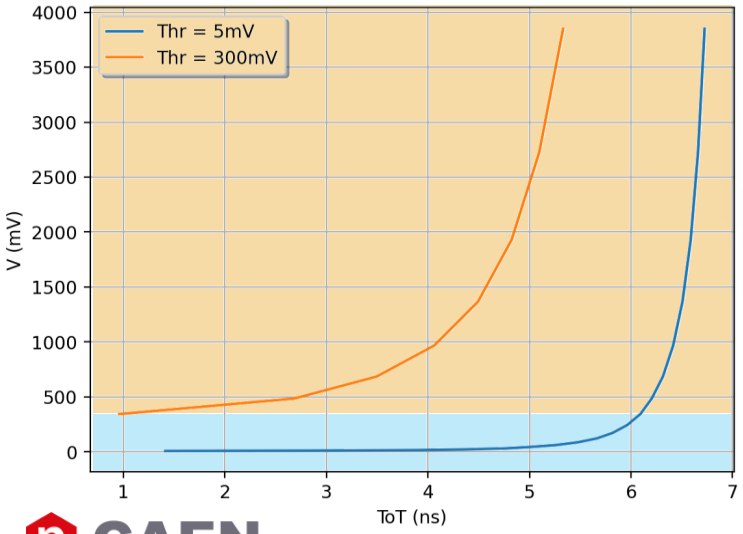
  ➔ timing resolution totally destroyed
- ΔT corrected by ToT using a 5th order polynomial fit of the **ToT-Walk** points taken at threshold = 5 mV
- Corrected ΔT histogram presents one single peak:

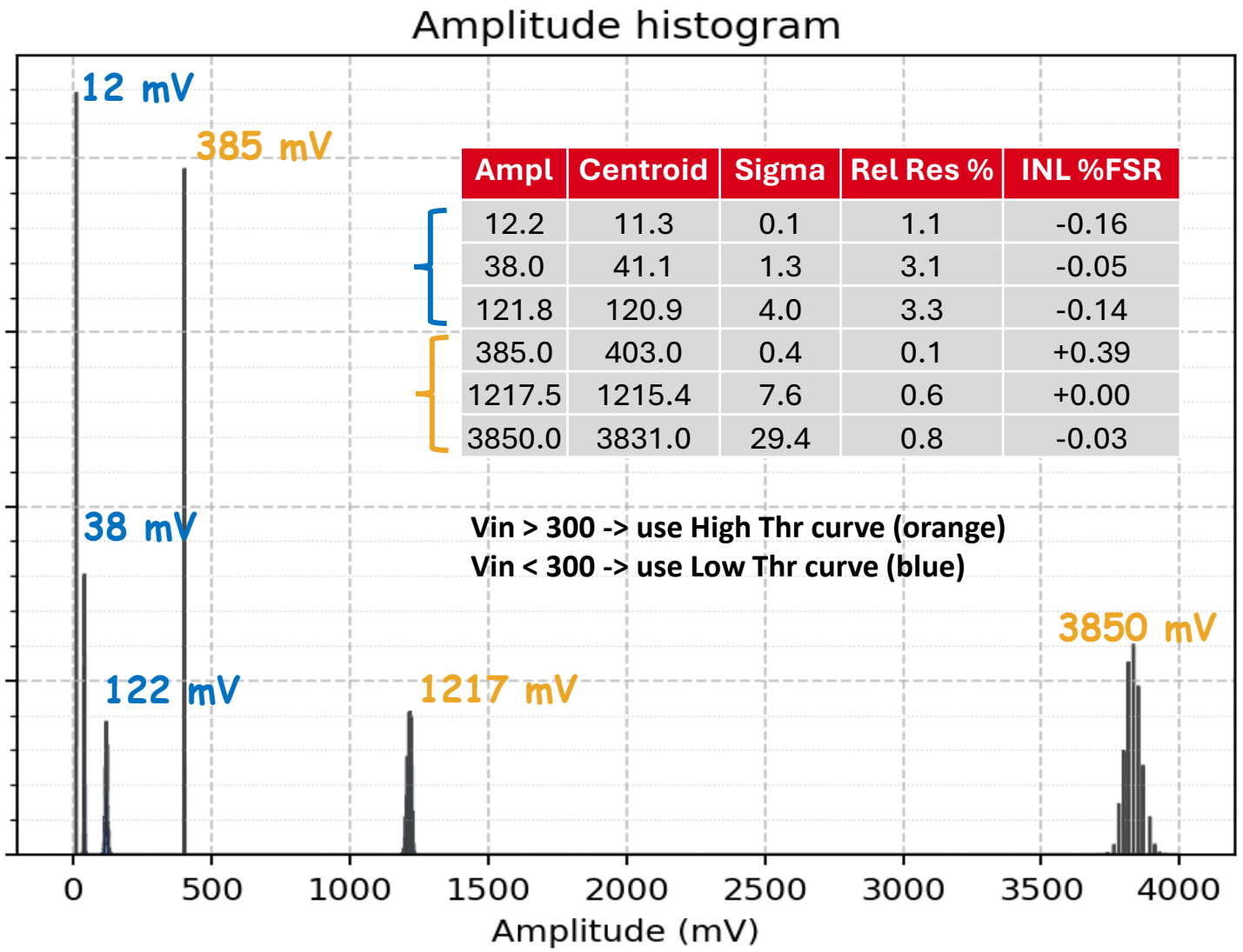
  18 ps RMS over 50 dB dynamic range

Amplitude Reconstruction



ToT-Amp





Ampl	Centroid	Sigma	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

Vin > 300 -> use High Thr curve (orange)
Vin < 300 -> use Low Thr curve (blue)

THE PROVISION PET SCANNER

The ProVision PET Scanner

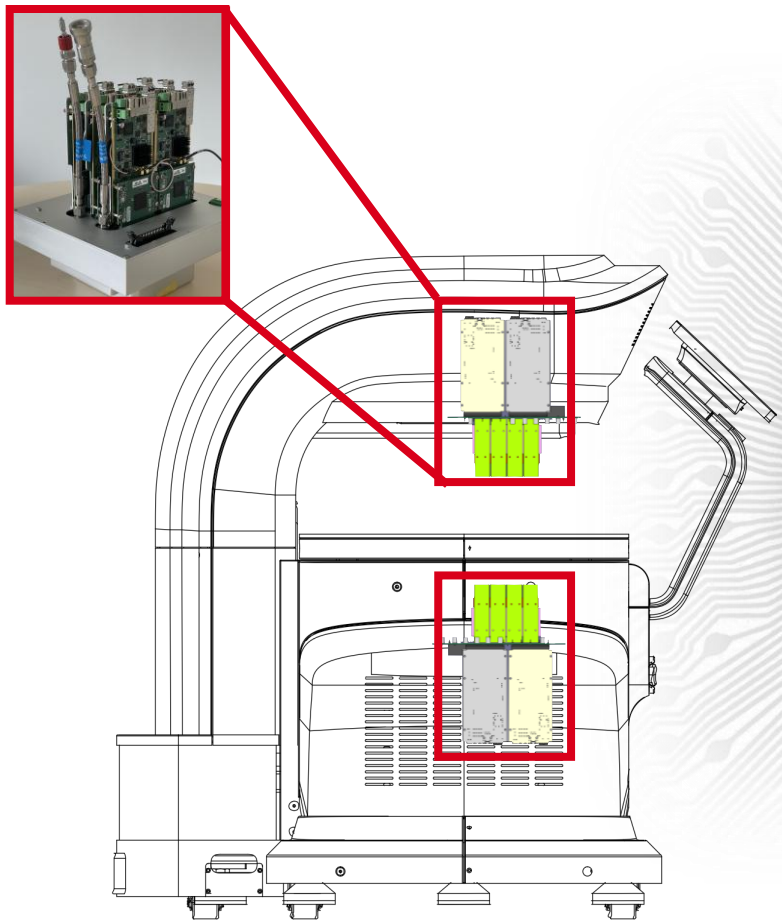
FERS-5200

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.

eurostars
ProVision

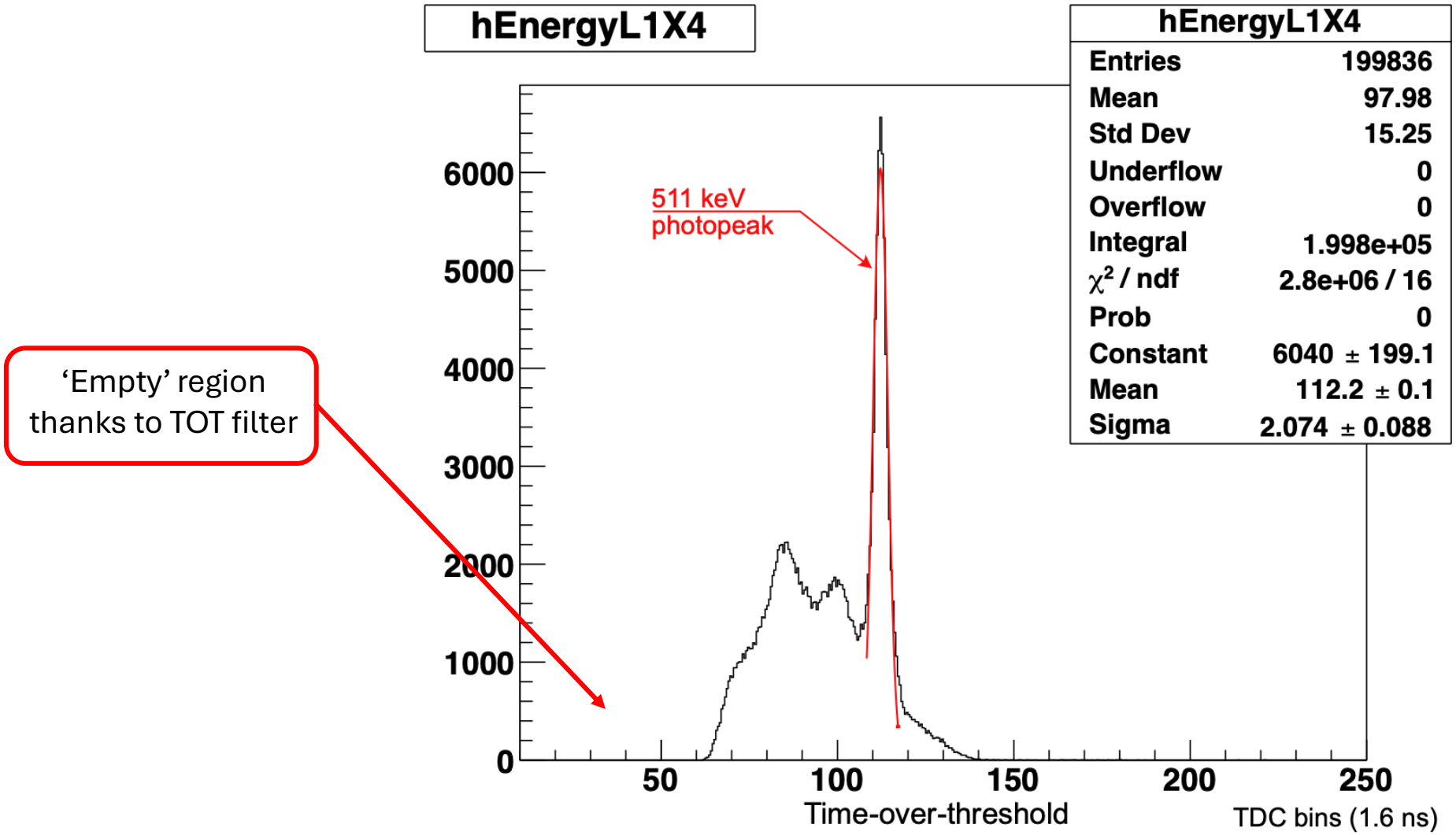
CAEN Tools for Discovery
Picotech

The PET Scanner & the A5203

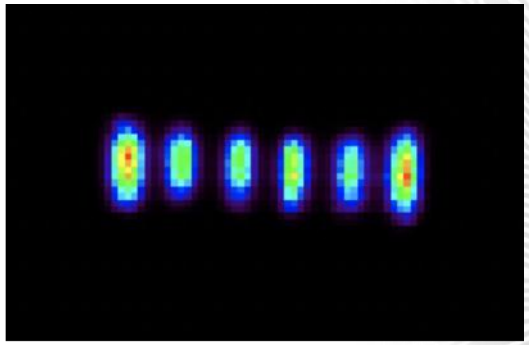


- 2x768 SiPM channels
- 2x6 A5203Bs (128 ch TDC)
- 1 DT5215 Concentrator
- Precise timing and TOT measurement
- High throughput – almost zero deadtime
- ToT cut for Dark Count and noise suppression

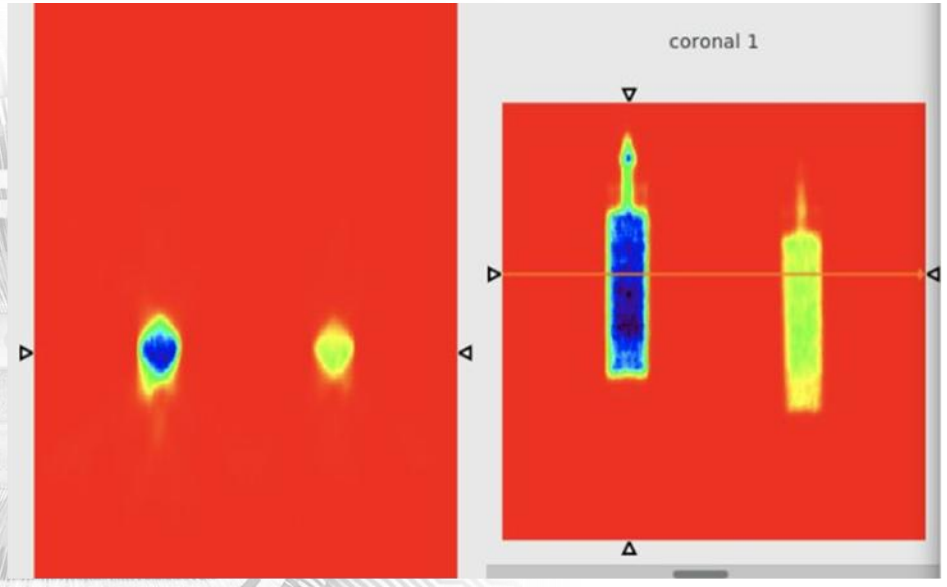
ToT Filter



PET Results (1)

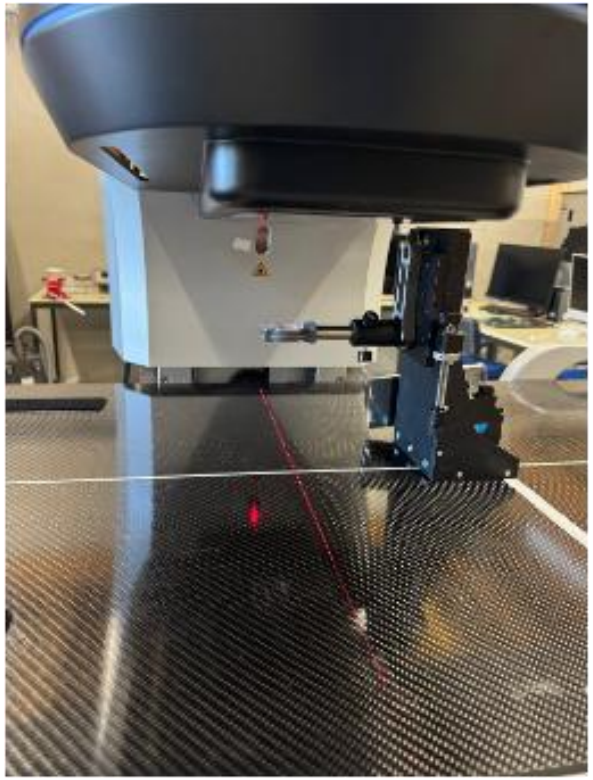


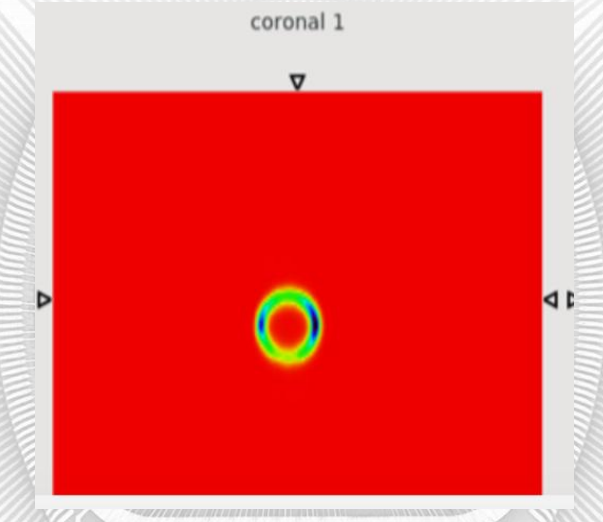
4mm thick Sodium disks separated by 4mm gaps



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

PET Results (2)





10 mm diameter Na-22 ring source (300 kBq)

➔ *analyzed and reconstructed with list-mode Maximum-A-Posteriori (One-Step-Late) algorithm*

➔ *spatial resolution of 1.8 mm based on a TOF timing resolution of 170 ps*

Conclusions

FERS-5200

- **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 **ToA**VS**ToT** calibration curves in a real data acquisition case

  ➔ Machine learning ???
- New FERS Units embedding the picoTDC + → Radioroc chip: **A5204**
  → Psiroc chip: **A5205**

CAEN Tools for Discovery

THANK YOU!