CAEN Electronic Instrumentation
Tools for Discovery

FERS-5200: a distributed Front End Readout System for multi-detector arrays

Carlo Tintori (c.tintori@caen.it)

RTC2024 @ Quy Nhon–Vietnam, 22nd-26th April 2024

Introduction

- Many research groups and spin-off companies develop **ASICs** for the readout of multi-detector systems in NP and HEP applications. Sometimes, they also develop the electronic boards housing the ASICs.
- The same ASICs may become interesting for other applications, but the electronics and the relevant software must be redesigned and adapted.
- **FERS** (Front End Readout System) aims to implement versatile modules facilitating the integration of ASICs, ensuring their adaptability across diverse applications through comprehensive hardware and software provision. **FERS can be used as evaluation board as well as a highly scalable solution.**

CERN weeroc NALU SCIENTIFIC

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

Synergies

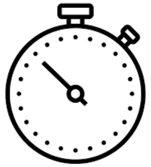
CAEN *Tools for Discovery* NI Nuclear Instruments

Design of Readout Electronics and Power Supply for NP and HEP

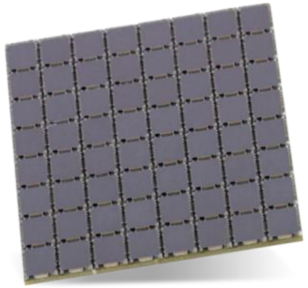
Building electronics around the **ASICs**

make the ASICs ready for the applications!

Multi-board Synchronization



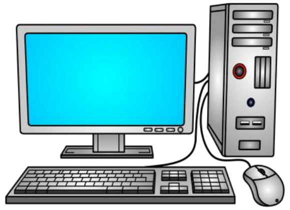
Global Timing



Cabling & Conditioning

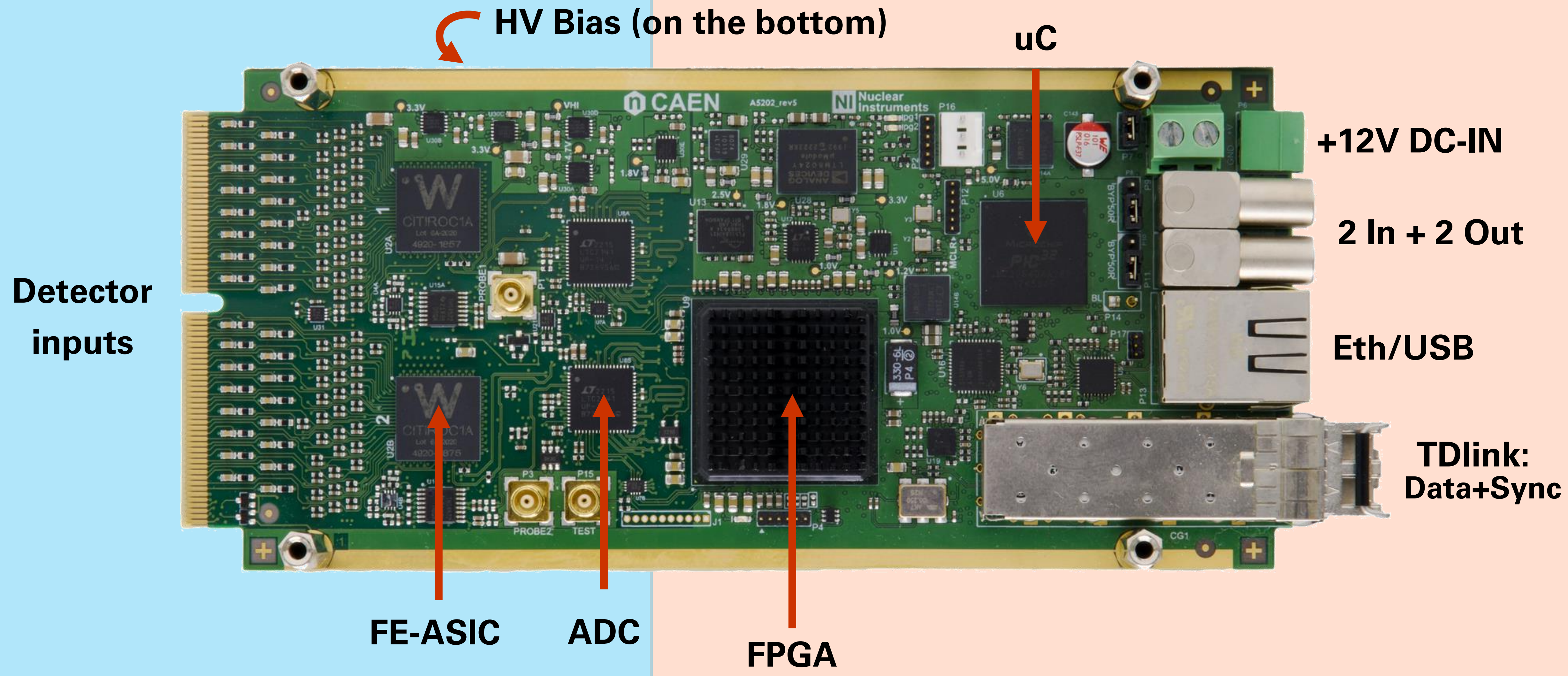
Readout Interfaces

DAQ



Infrastructure (power, clock, configuration…)

FERS A5202: 64 channel SiPM Readout



DETECTOR SPECIFIC FRONT-END

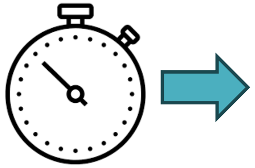
COMMON INFRASTRUCTURE

FERS-5200 architecture

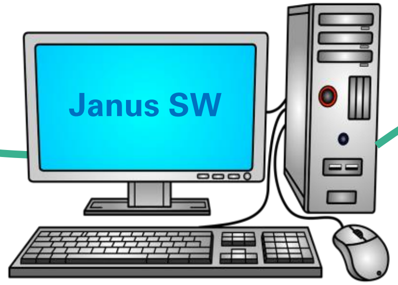
DT5215 Data Concentrator:

- 1 TDlink => up to 16 FERS
- 1 DT5215 => 128 FERS = 8k/16k ch.

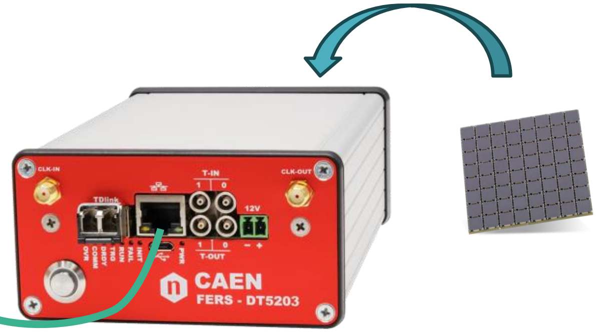
Global Time



1/10G Eth
USB 3.0



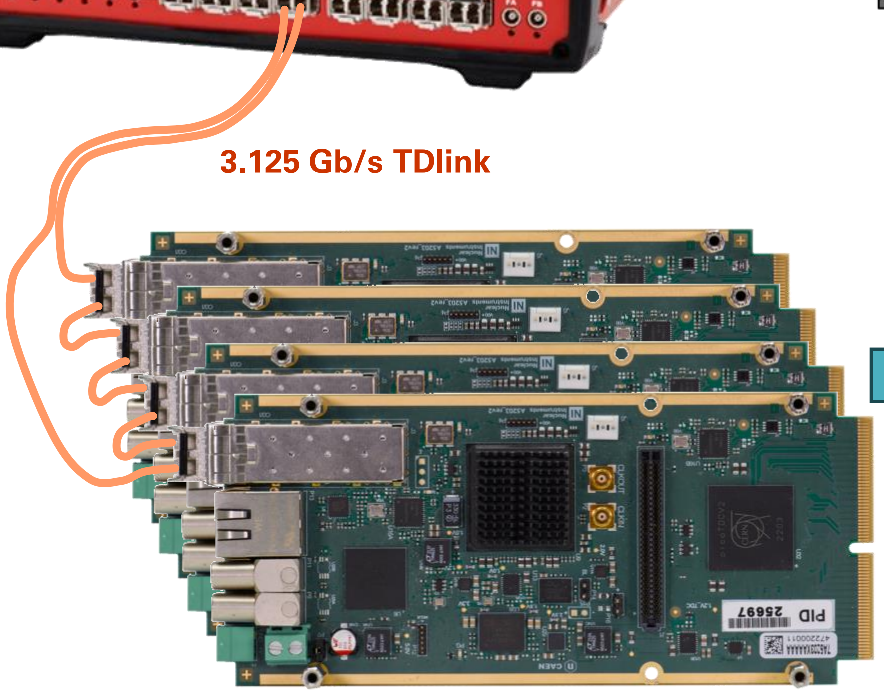
10/100M Eth
USB 2.0



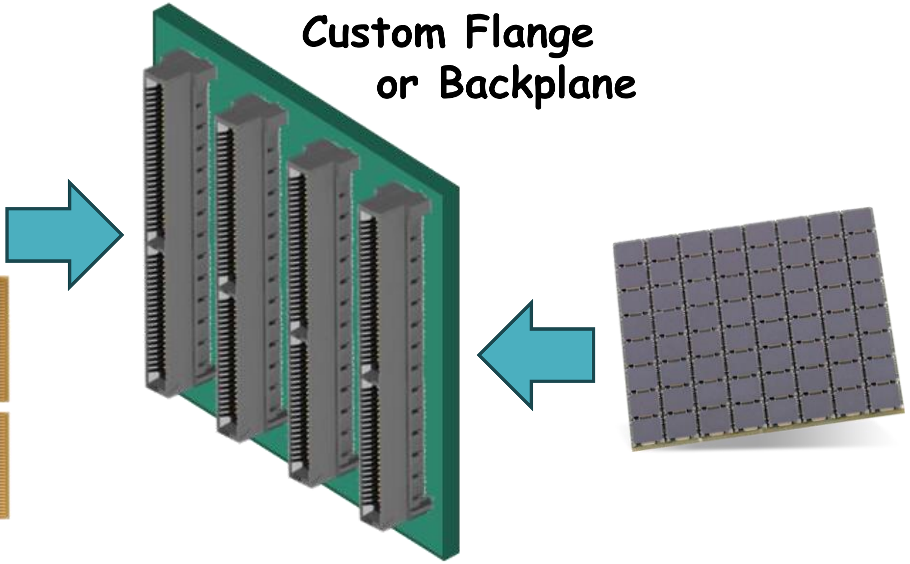
Desktop Evaluation Setup:
Low Cost, Plug & Play

3.125 Gb/s TDlink

Readout
+
Slow Control
+
Synchronization

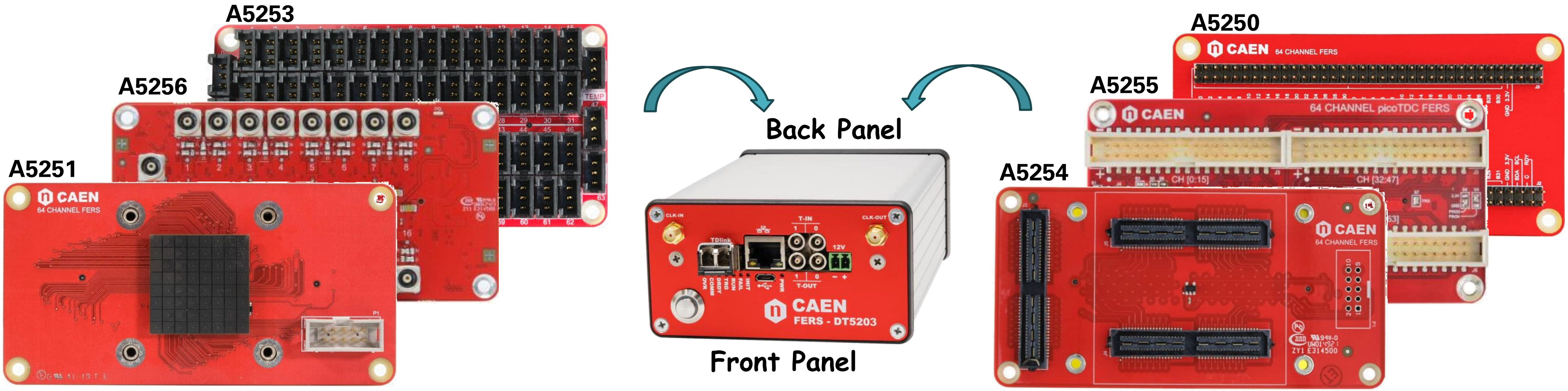


Custom Flange
or Backplane



Easy ASIC integration on FERS

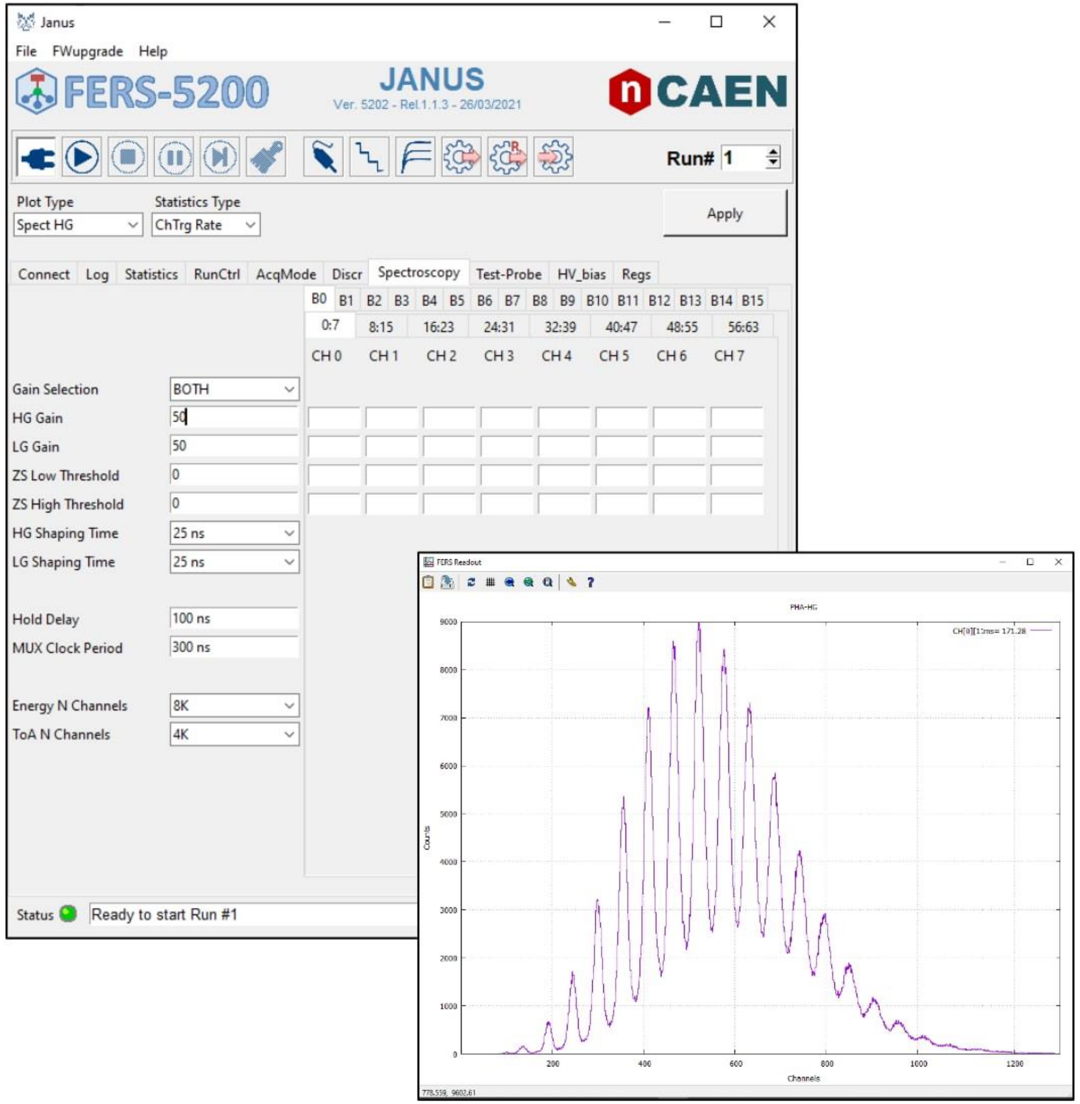
Input Adapters and Front-End



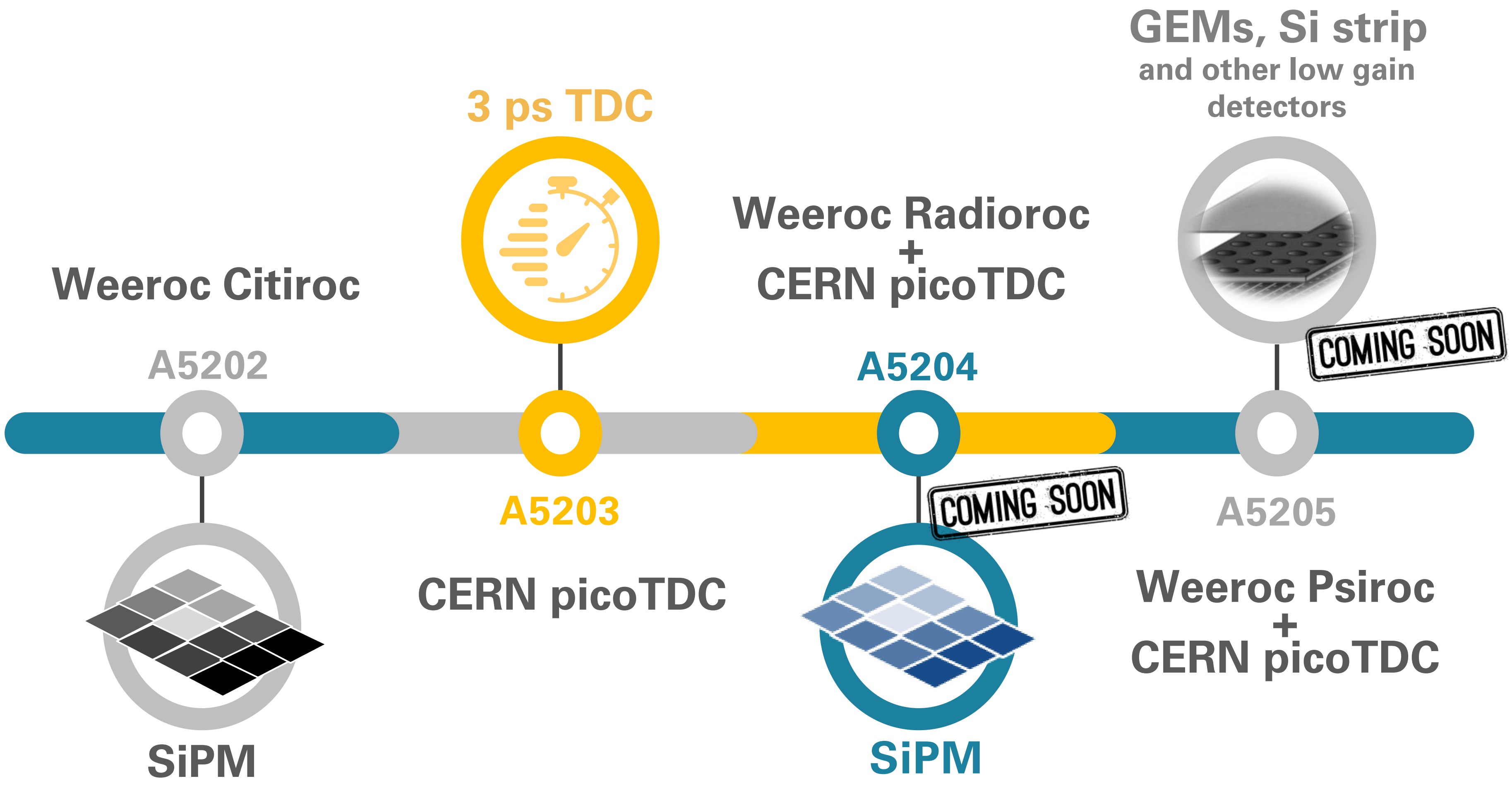
A5260: Remotization cable

Janus Software

- **Open source** software for multi-board configuration and data readout
- Python GUI and C/C++ readout program
- **SDK** for user customization (libs + demo)
- Multi parametric Jobs and Runs with time or counts preset
- Output files: lists in **.bin** or **.csv** 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 10G Eth)



FERS Roadmap



What next?

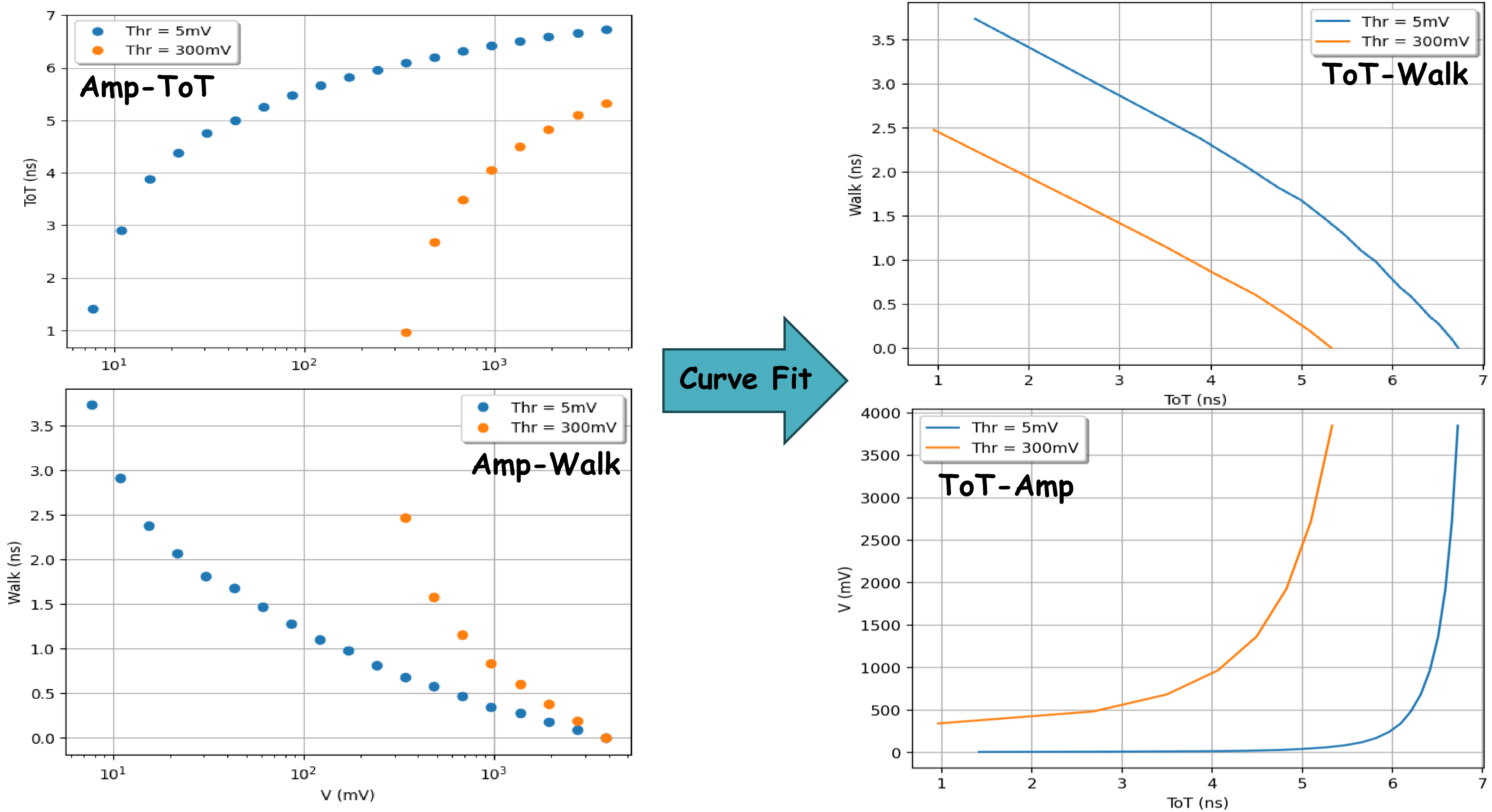
- pin-to-pin compatible Weeroc chips (e.g. MA-PMT…)
- Switched Capacitor Arrays for high speed Waveform Digitizers (Nalu)
- and others…

ToT used for PHA and CFD

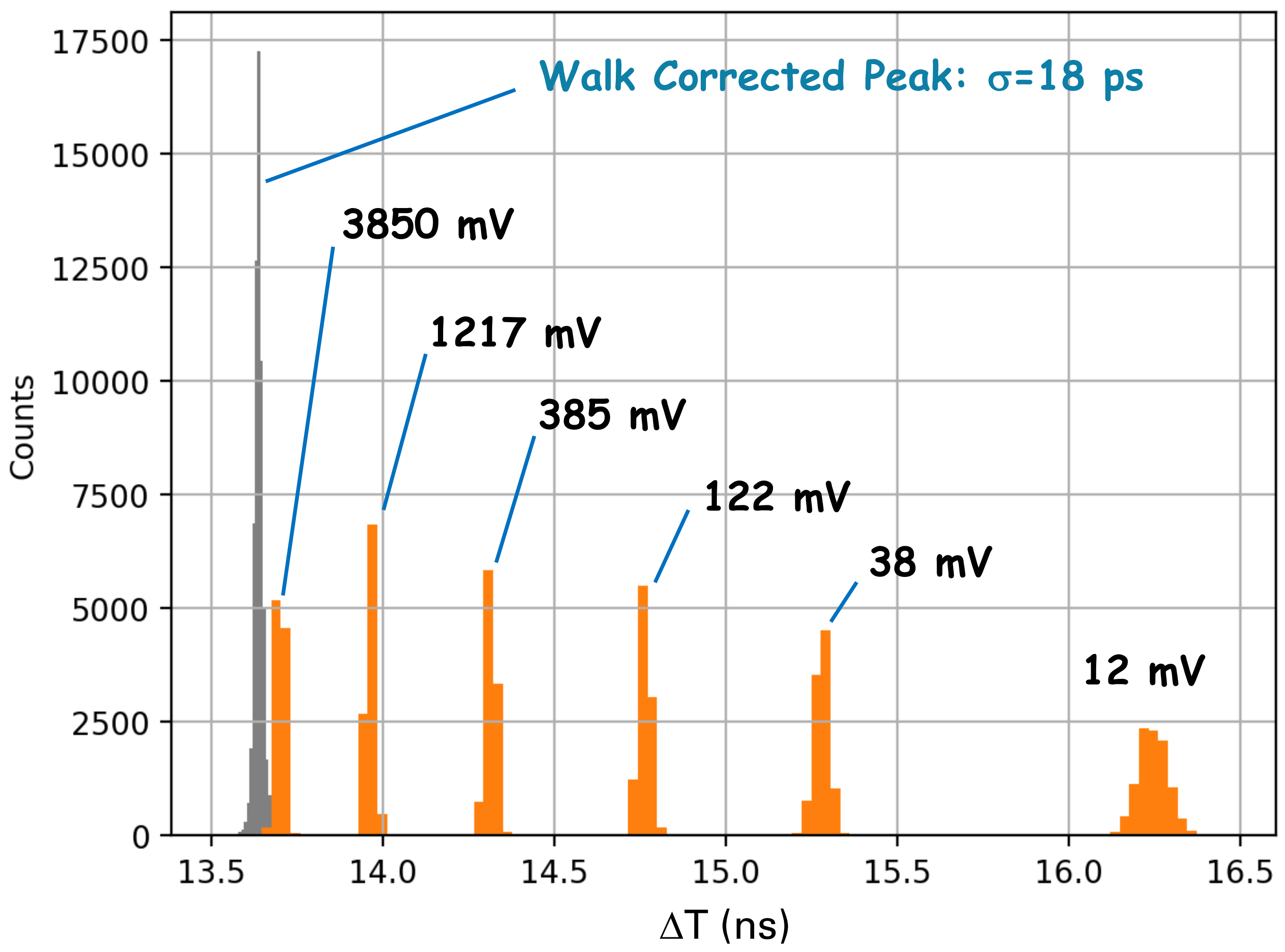
- **picoTDC**: high timing resolution (~ 5 ps), high channel density, almost no dead time
- But...
  - need separate ADC readout chain to acquire energy information (PHA)
  - picoTDC has no Front-End: need external fast discriminator (e.g. CAEN A5256)
- picoTDC provides both Time of Arrival (**ToA**) and Time over Threshold (**ToT**) in one word
- ToT can be used to reconstruct pulse amplitude
- ToT – PHA curve is not linear => need calibration (pulse shape dependent)
- ToT can be used to correct for time walk => no need of Constand Fraction Discriminator in hardware

Ongoing feasibility study of the ToT technique for the readout of 5000 PMTs in SAND (DUNE)

ToT calibration curves (double threshold)



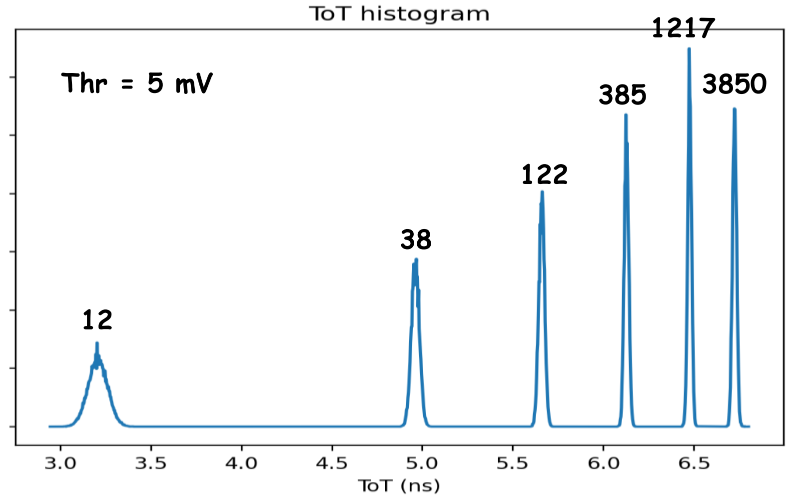
Walk Correction

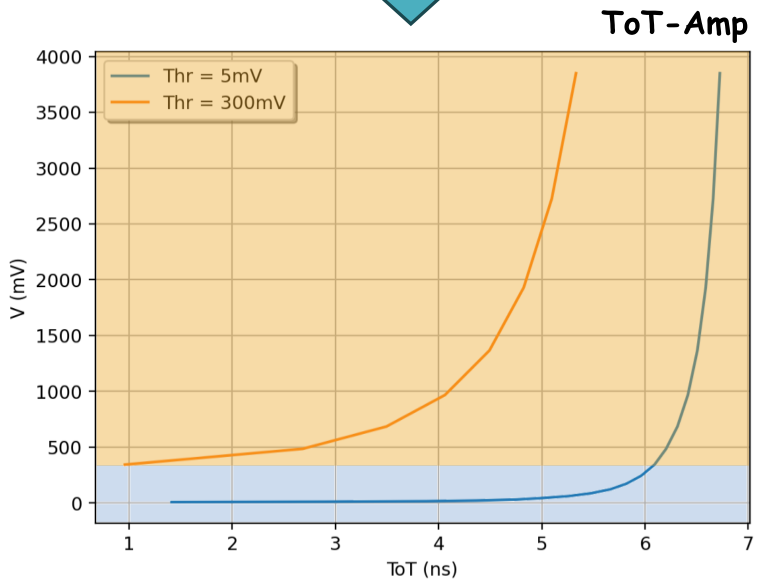


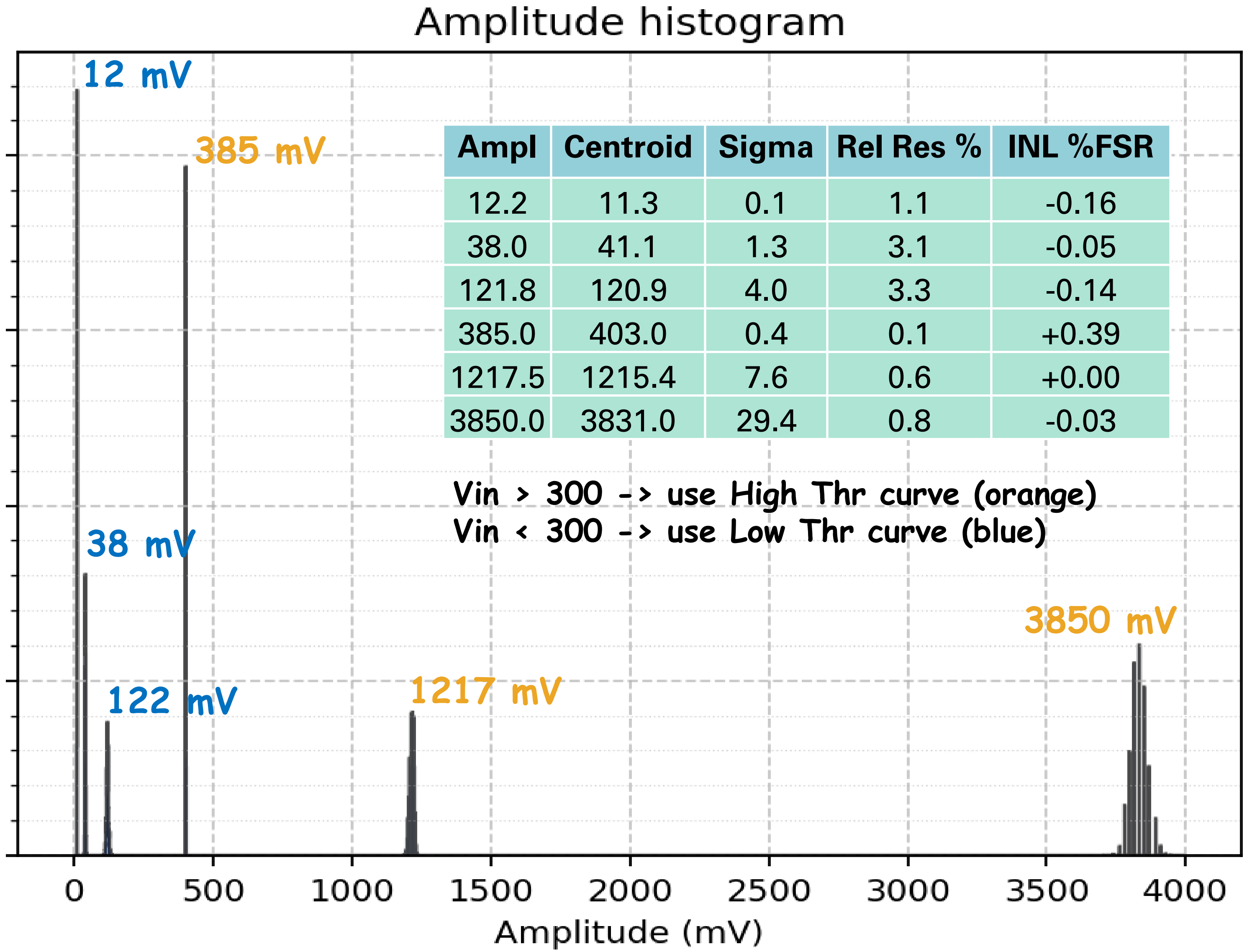
- Acquired pulses at 6 different amplitudes over a 50 dB dynamic range
- The walk causes ~2 ns spread on ΔT:
  6 separate peaks appear on the histogram.
  Timing resolution totally destroyed!
- ΔT corrected by ToT using a 5th order polynomial fit of the **ToT-Walk** points taken at threshold = 5 mV
- Corrected ΔT histogram presents one single peak:

18 ps RMS over 50 dB dynamic range

Amplitude Reconstruction



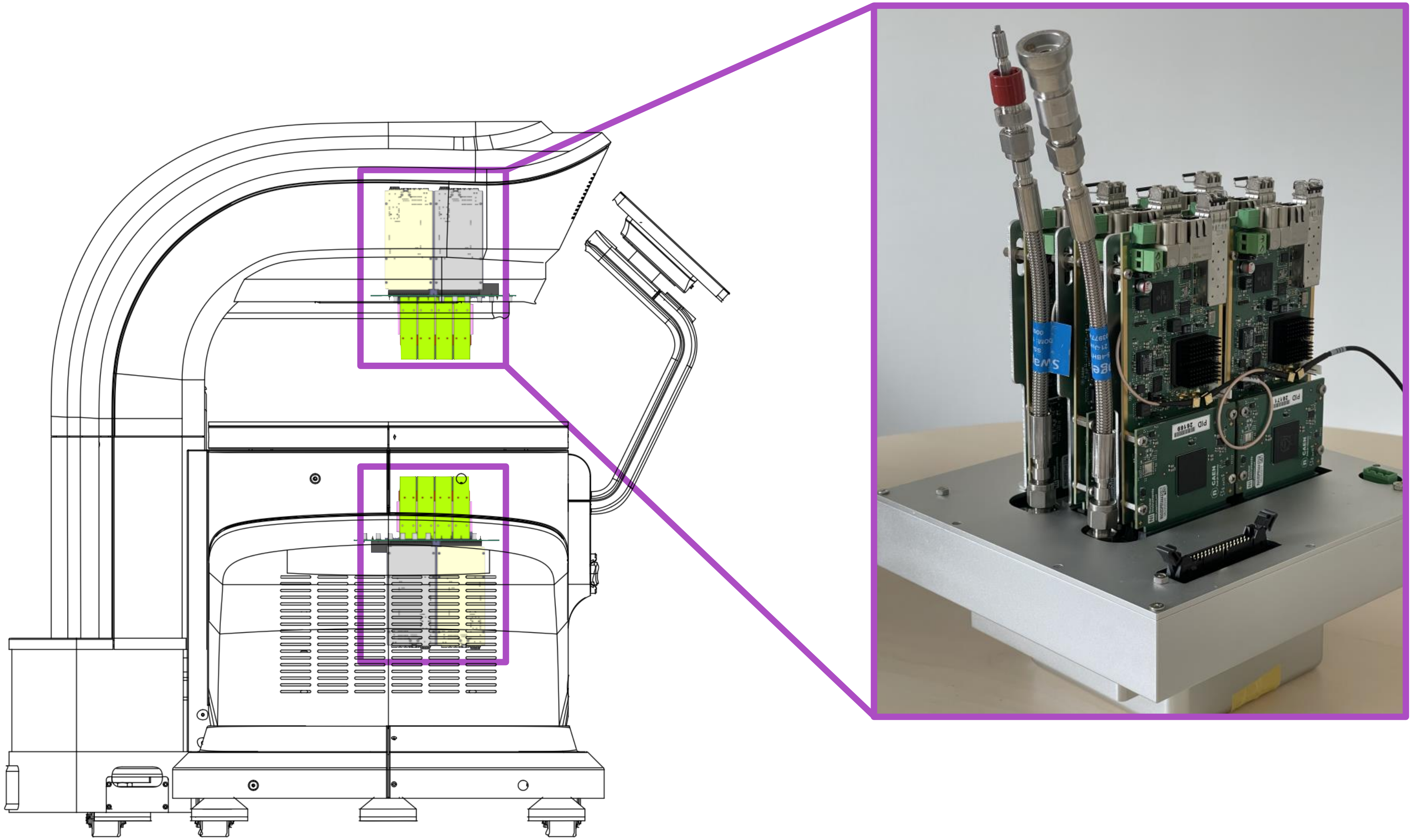




Ampl	Centroid	Sigma	Rel Res %	INL %FSR
12.2	11.3	0.1	1.1	-0.16
38.0	41.1	1.3	3.1	-0.05
121.8	120.9	4.0	3.3	-0.14
385.0	403.0	0.4	0.1	+0.39
1217.5	1215.4	7.6	0.6	+0.00
3850.0	3831.0	29.4	0.8	-0.03

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

picoTech ProVision PET scanner

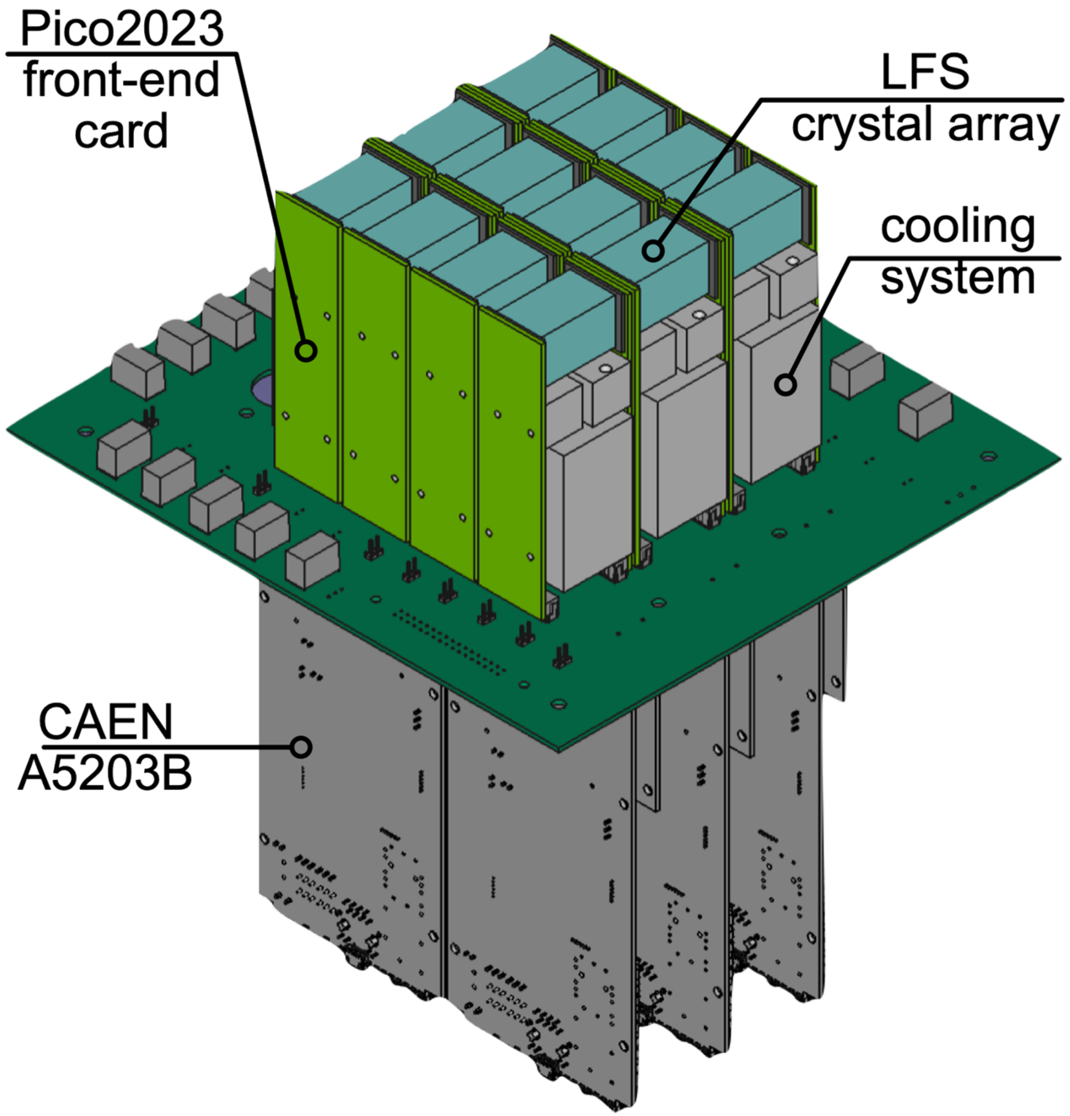


Courtesy of C. Williams

- 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

picoTech ProVision PET scanner (cont.)

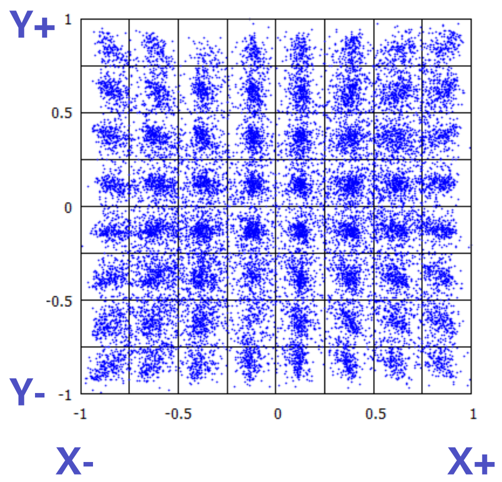
Pico2023:
8 channel differential amplifier-discriminator with amplitude encoded into pulse width

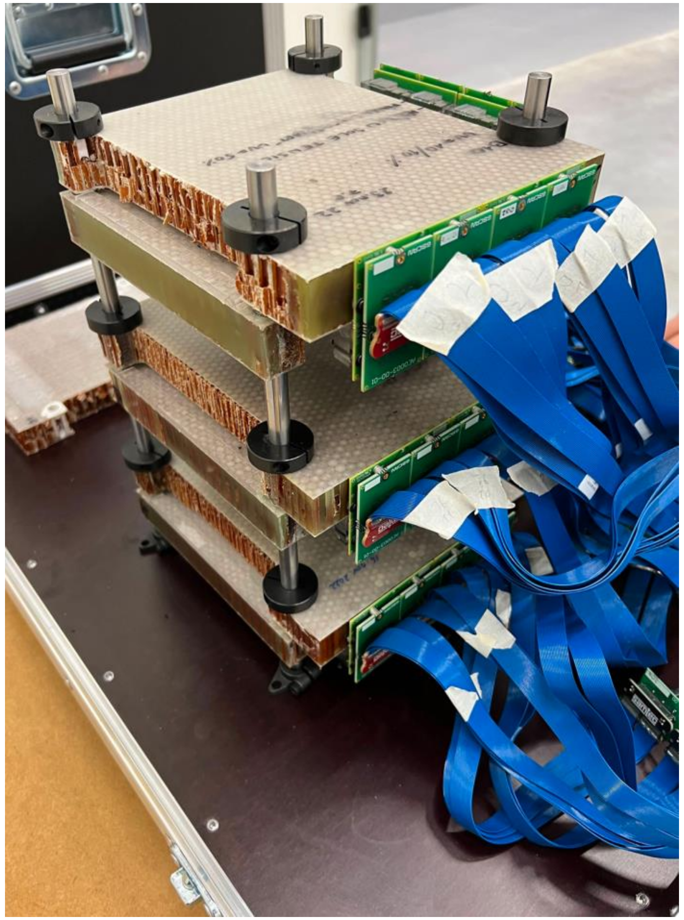


Cosmic Ray Tomograph for identification of hazardous and illegal goods hidden in Trucks and Sea Containers

- 221.184 Fibers + SiPMs
- 1 mux = 64 SiPMs = 4 FERS channels (X+, X-, Y+, Y-)
- 216 A5202 FERS units
- 3 DT5215 (Data Concentrator)

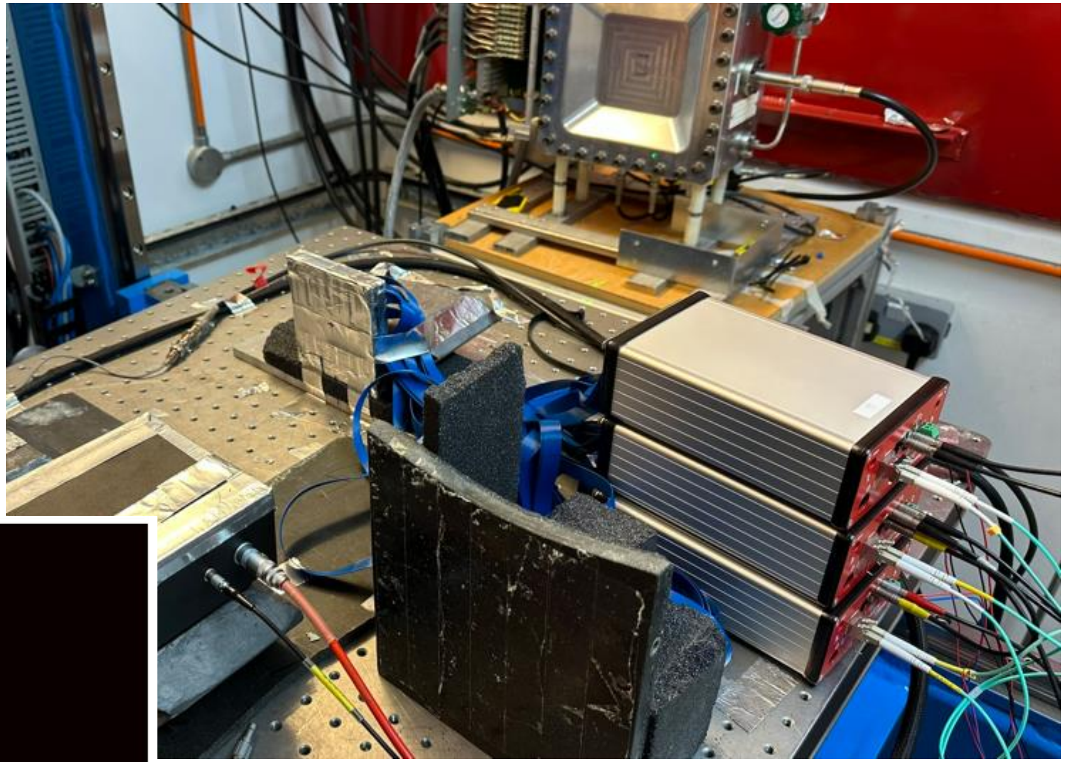
Mux Constellation

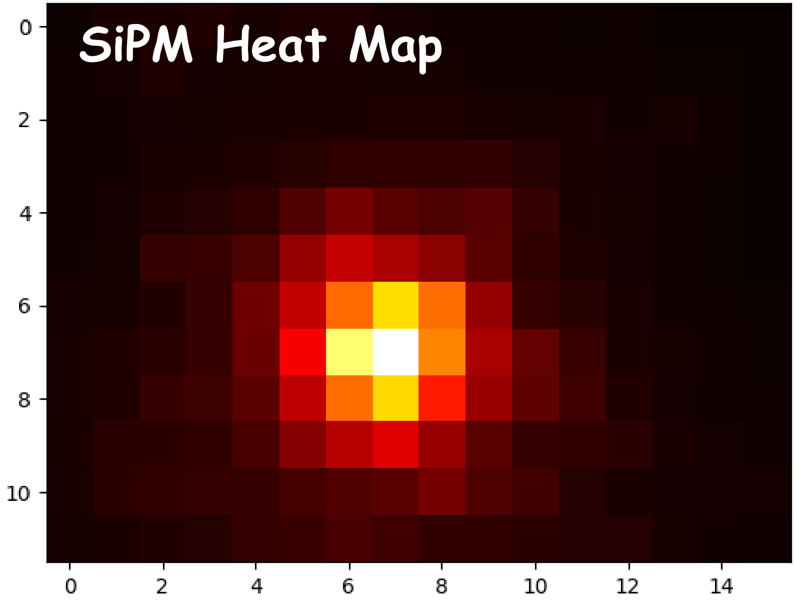


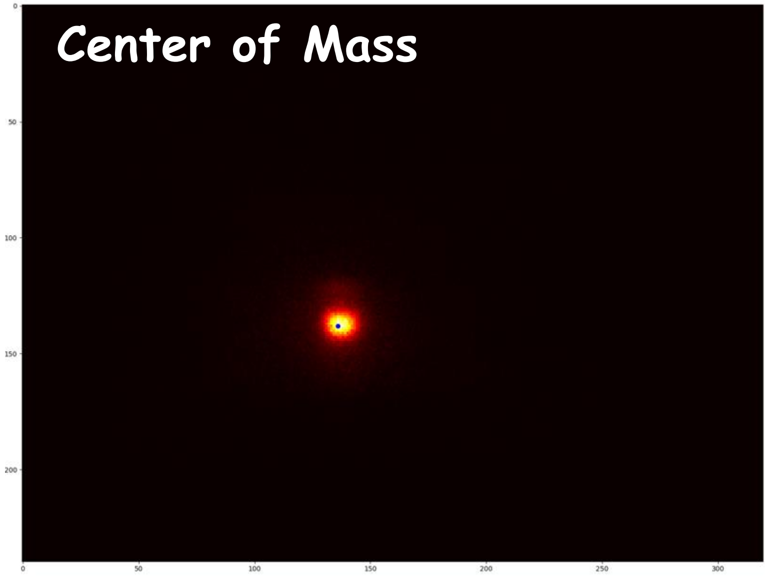


Neutron anger camera

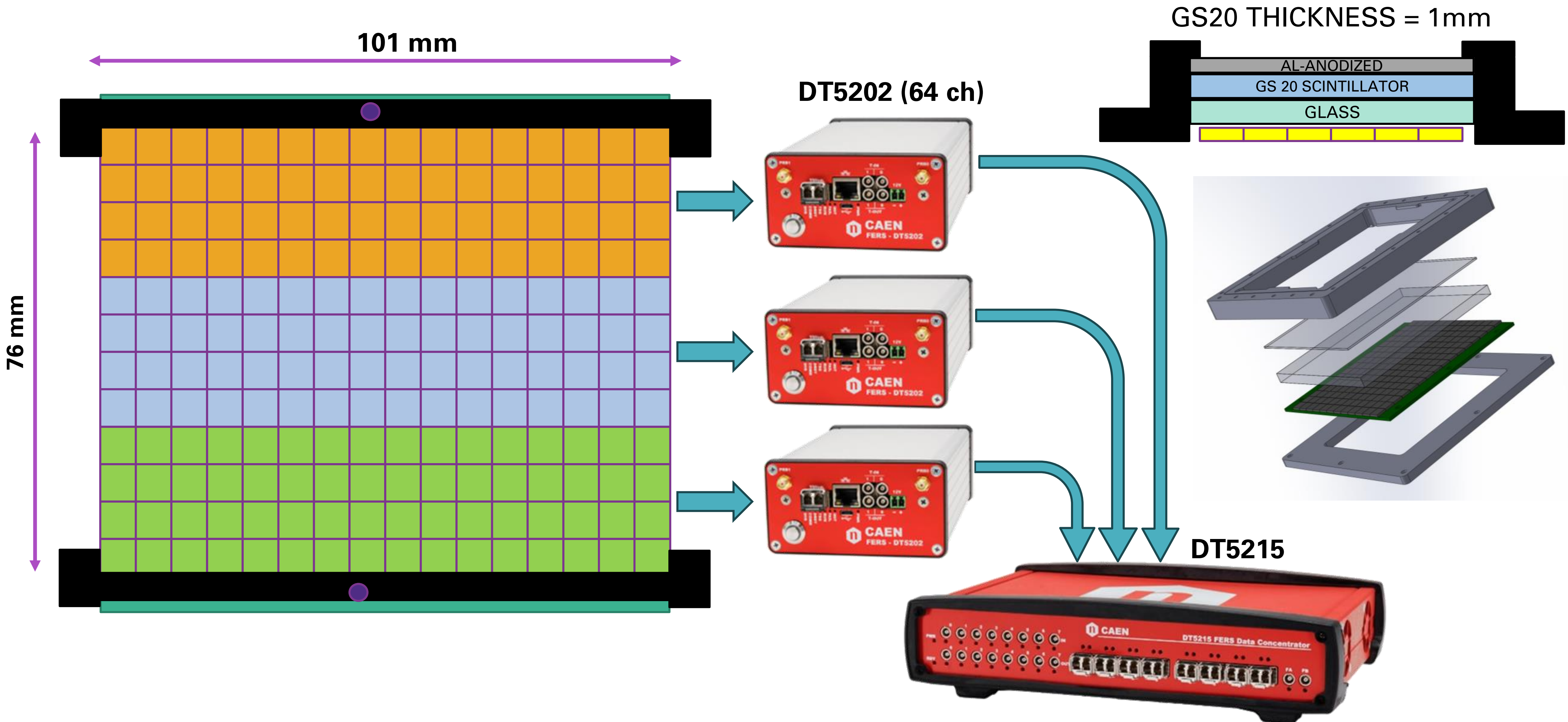
- Based on GS20 scintillators
- 6x6 mm SiPMs, 16x12 array (192 channels)
- 3 DT5203 + 1 DT5215 Concentrator
- Majority trigger implemented in FERS cards
- Gamma discrimination based on Energy Cut
- < 1 mm spatial resolution







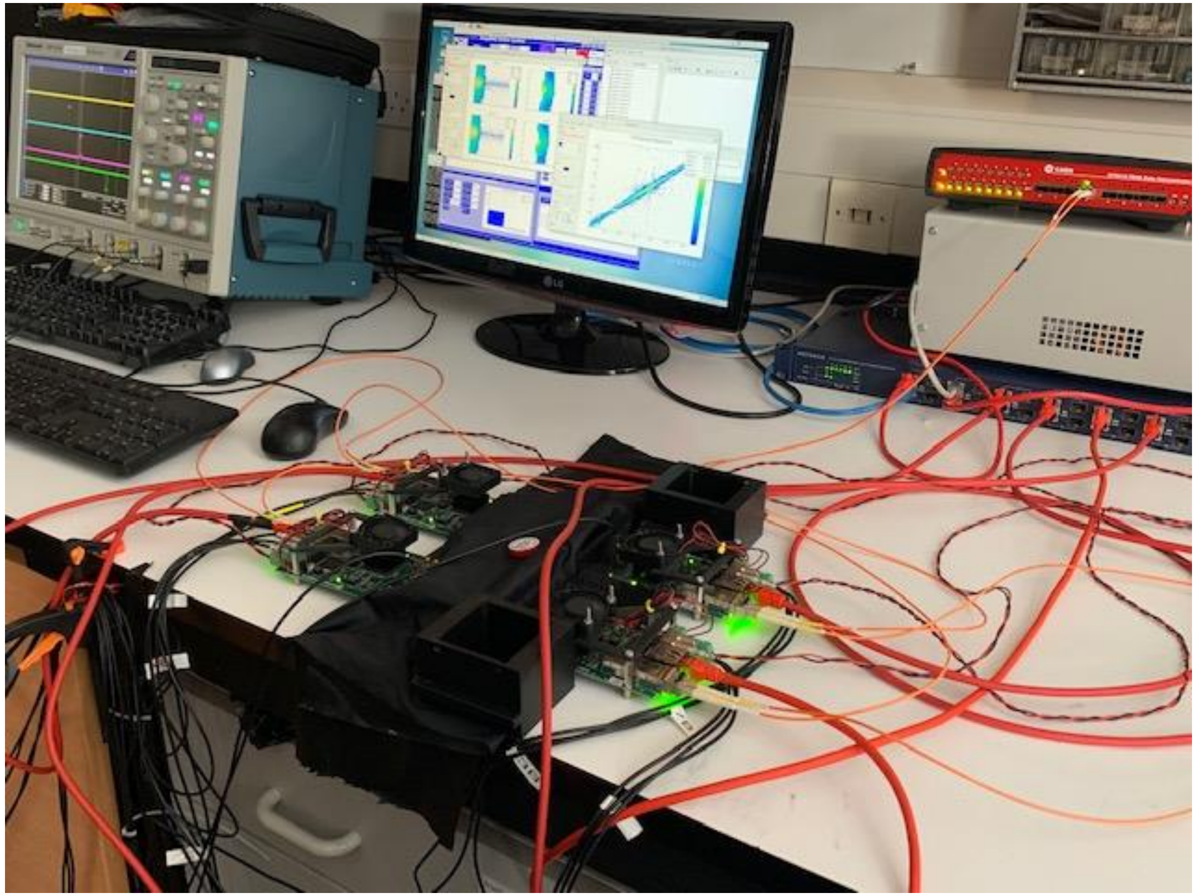
Neutron anger camera (cont.)



Muon tomography - nuclear waste

- **Muon tomography scanner**, suitable for **nuclear waste characterization,** by Lynkeos Technology (Scotland)
- First design with MA-PMTs and MAROC chip readout
- Device successfully deployed at Sellafield site (UK)
- Upgrading to **SiPMs** detectors in 2021 – readout electronics based on FERS A5202 (CITIROC)

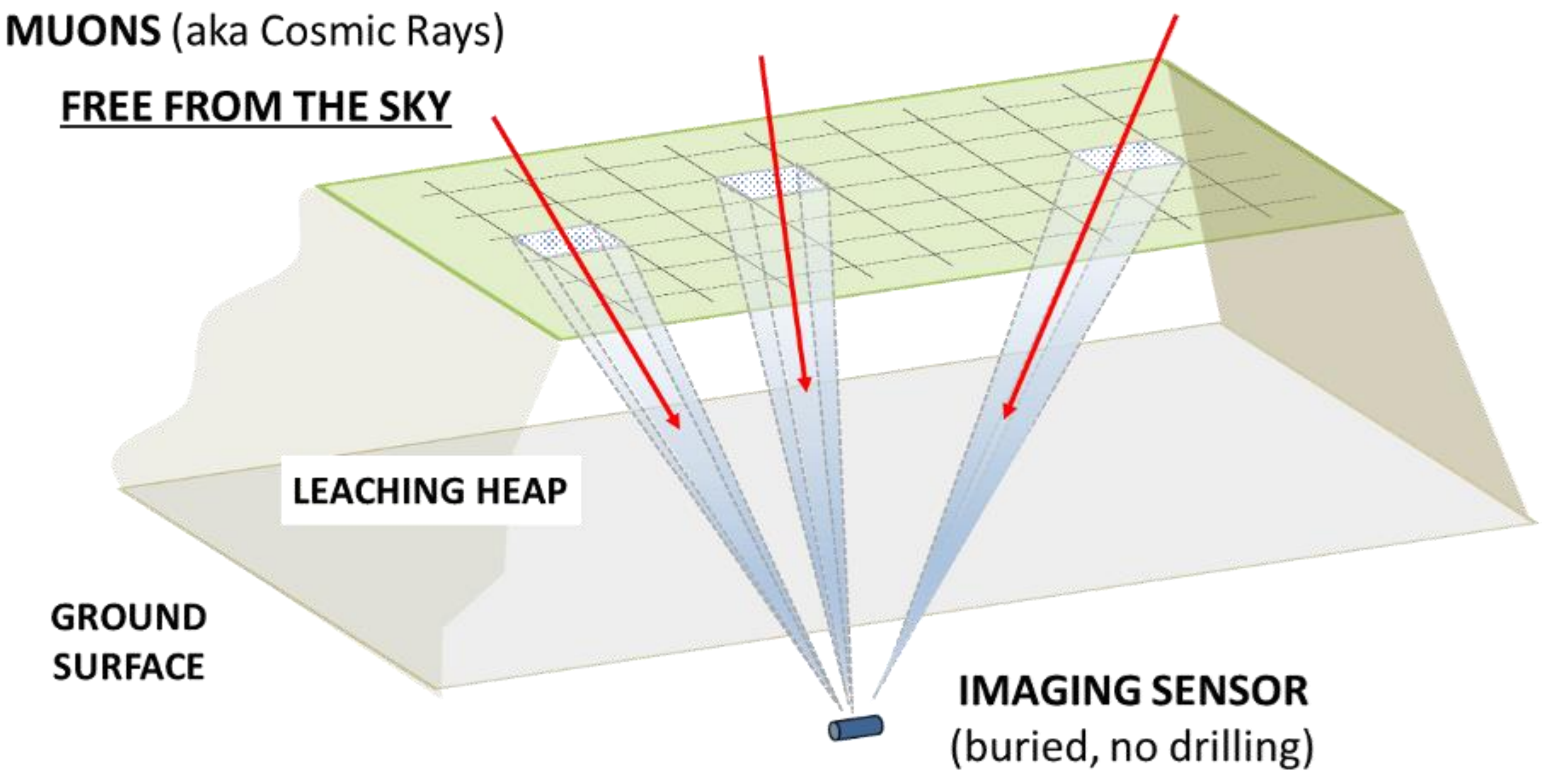
- 1024 fibers + SiPMs
- 16 A5202s + 1 DT5215
- ~ 1m x 1m active area



First-of-a-kind muography for nuclear waste characterization
D. Mahon *et al.*
Philos. Trans. R. Soc. A, 377 (2018), p. 0048,
10.1098/rsta.2018.0048

Muon tomography - geophysics

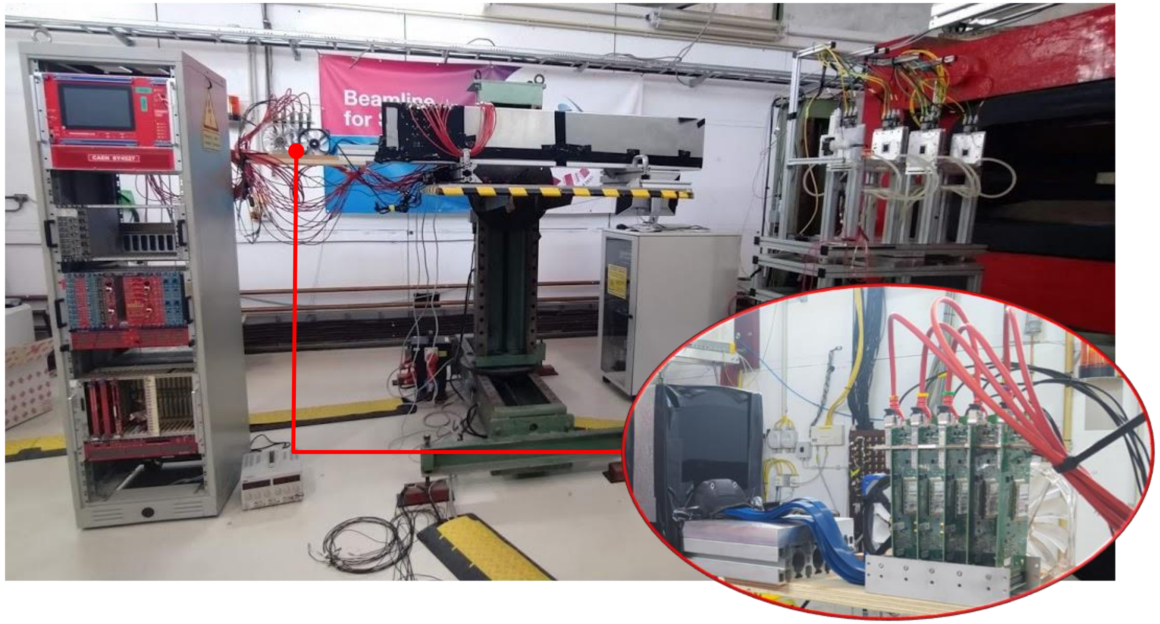
- **Imaging sensor** for mining, Oil&Gas
- Two A5202 reading SiPM in the buried sensor
- One DT5215 with 300 m optical fiber on the ground surface
- Installed in Atacama Desert



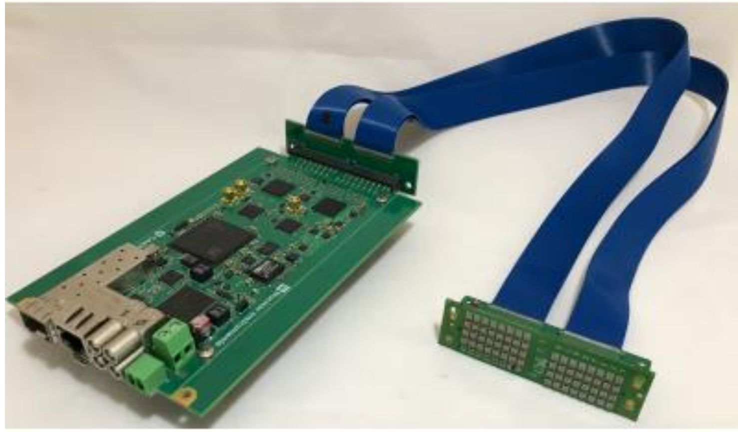
https://muonvision.com/technology-how-does-muon-vision-work/

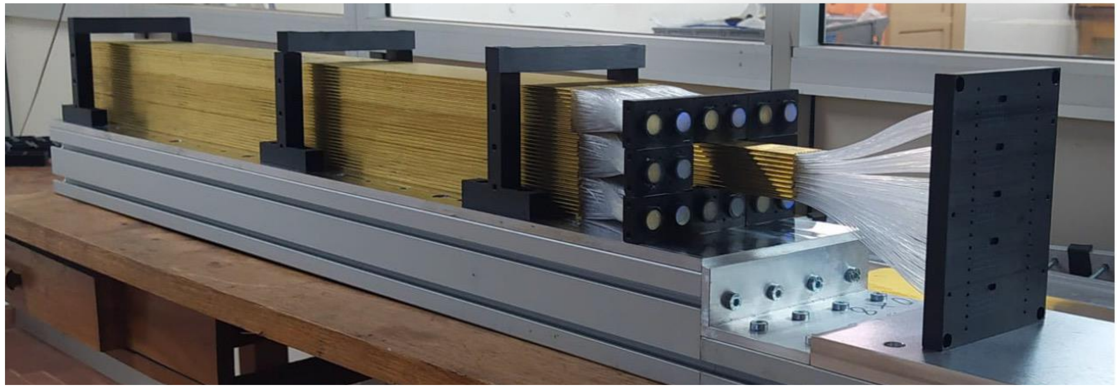
IDEA – dual-readout calorimeter

- Development and testing of **dual readout highly granular calorimeter**, exploiting SiPM technology and CAEN A5202 board.
- Successful qualification of a module on beam with EM shower containment @Desy (June 2021) and @CERN (August 2021)
- Plans to **scale-up the system** to handle more SiPMs for hadronic containment



- **320 SiPM = 5 A5202s**
- **No Concentrator**
- **Sync via LEMO cable**
- **Custom SiPM holder with remotization cable**





Courtesy of R. Santoro

https://indico.ihep.ac.cn/event/14967/contribution/1/material/slides/0.pdf

Conclusion

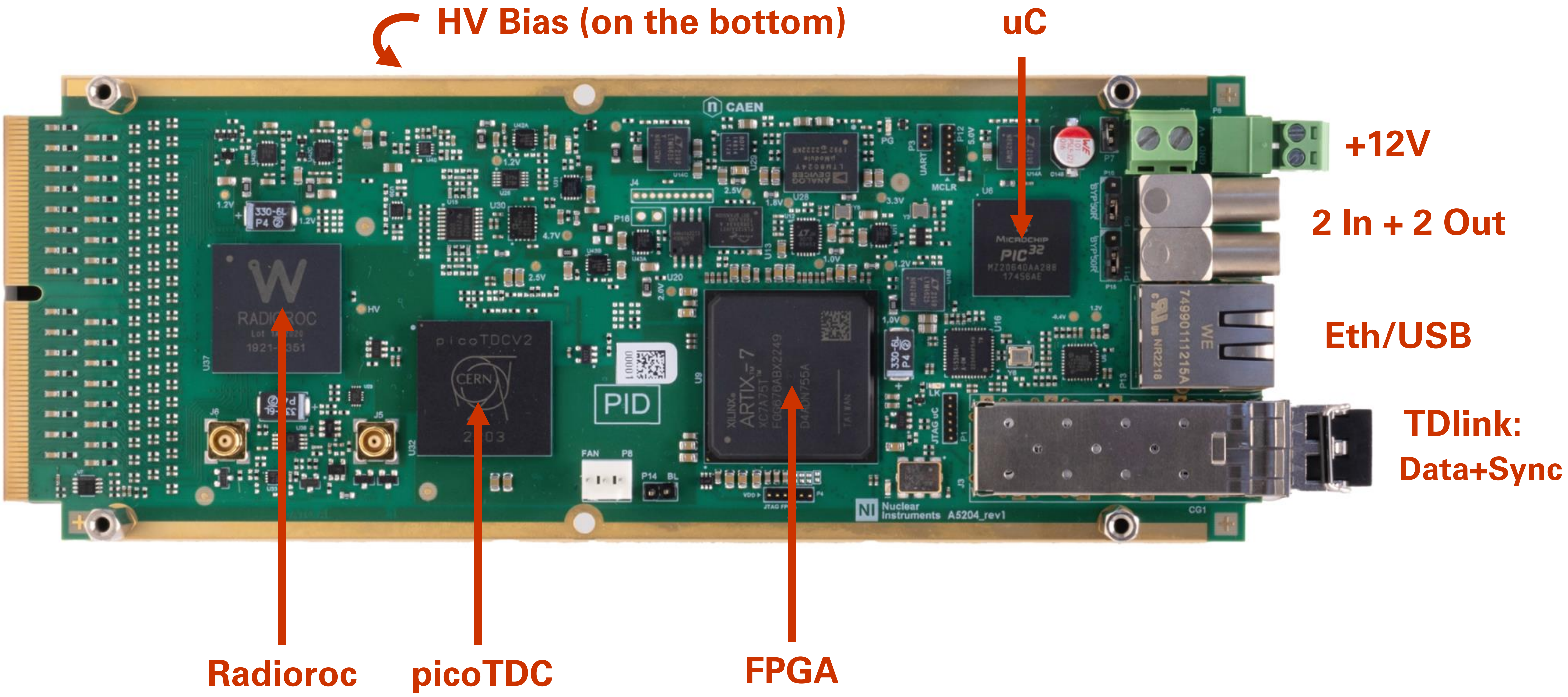
- **FERS** is **modular, easy-scalable and flexible**
- FERS allows for a quick and easy integration of ASICs developed for nuclear physics applications
- Two models already designed:
  - A5202 for SiPM readout, mainly used in scintillating fibers readout
  - A5203 ultra high resolution TDC, mainly used for PET systems
- The ToT can be successfully used for pulse amplitude reconstruction and time walk correction (no CFD required)
- Many applications in HEP/NP, Muon Tomography and Medical Imaging are using FERS modules for the detector readout
- New models being designed…

Thank you for your attention

Visit us at our booth for a live demo of the FERS reading a SiPM matrix

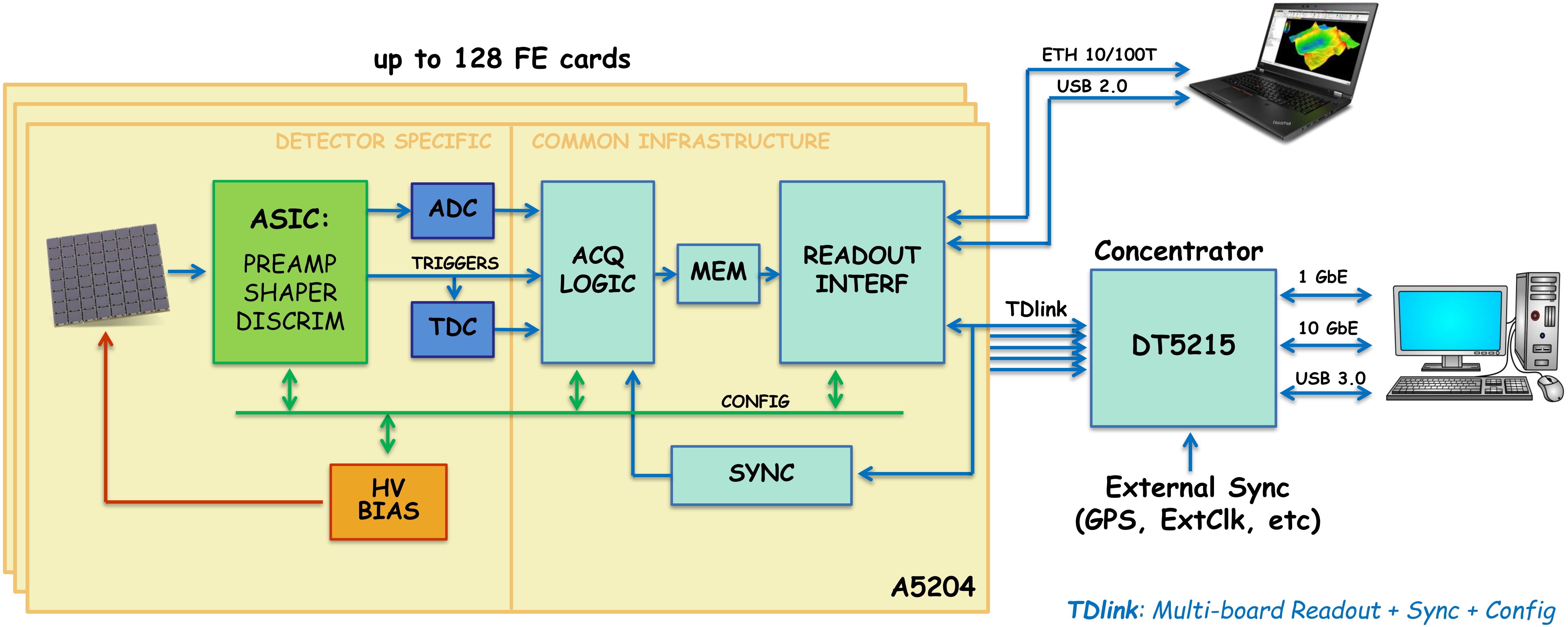
Backup slides

FERS A5204: 64 channel SiPM Readout



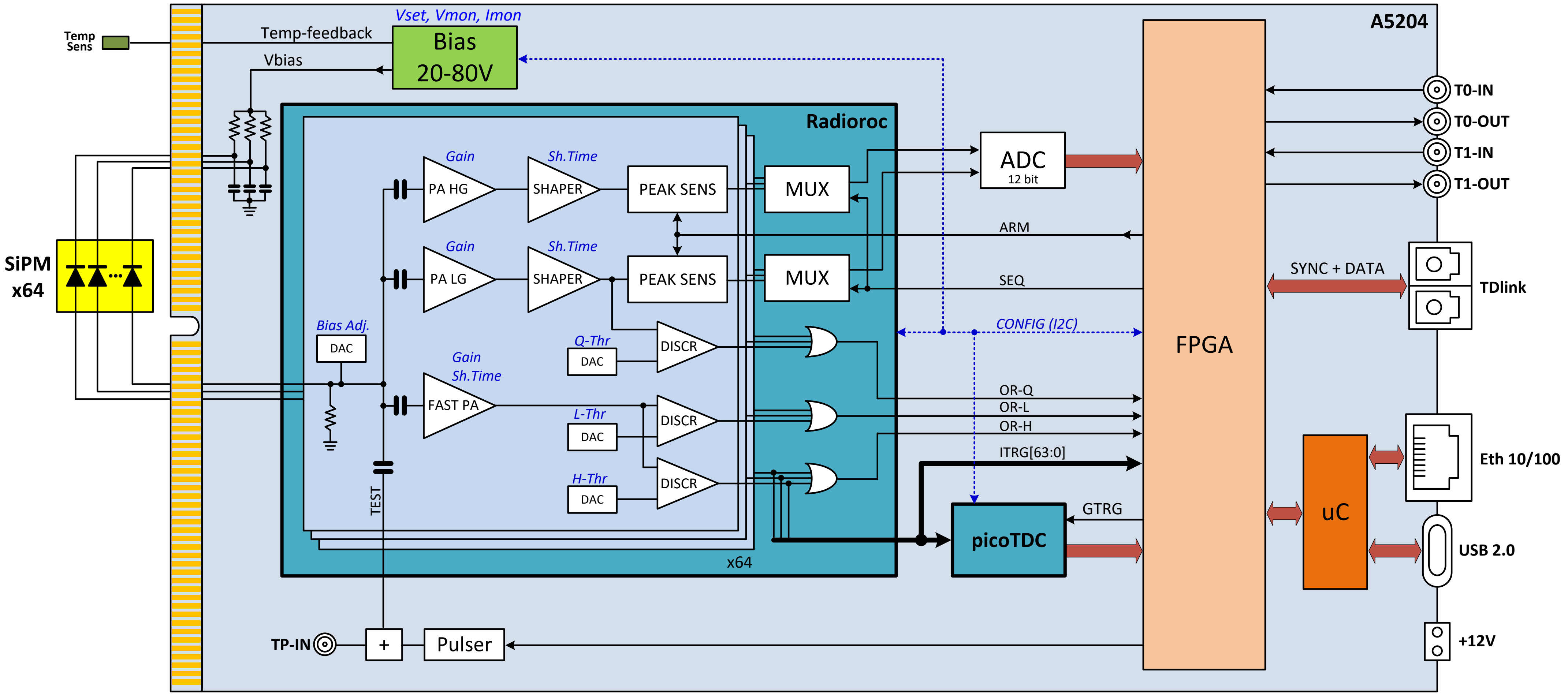
FERS-5200: generic block diagram

Direct Connect: easy but slow (~2 MB/s)



TDlink: Multi-board Readout + Sync + Config
Up to 300 MB/s

A5204: block diagram



Technical Specifications

- **A5202/A5204**: 64 channel SiPM Readout based on Citiroc/Radioroc+picoTDC
  - All-in-one readout: Preamp + Shaper + Discr + ADC + TDC + HV Bias (20-80 V)
  - Dynamic Range: 1 to 2500 p.e.
  - Single photon detection (threshold at 1/3 p.e.)
  - Timing resolution = 55 ps FWHM (A5203 only)
  - Acquisition Modes
    - Counting (20 Mcps and more)
    - Spectroscopy (PHA) => Common Trigger => Max Trg rate = 100 KHz
    - Timing (ToA + ToT) => Individual Self Trigger => Max Hit rate = 1 Mcps/ch (depending on Model)
    - Mixed (PHA + ToA)

Technical Specifications (cont.)

- **A5203**: 64/128 channel picoTDC
  - LSB = 3.125 ps, dynamic range = 56 bit (extended by FPGA)
  - Acquisition modes: Common Start, Common Stop, Trigger Matching, Streaming
  - ΔT Resolution (*) :
    - Same board: typ 5 ps RMS
    - Board to board (with clock cables): ~8 ps RMS
    - Board to board (without clock cables): ~20 ps RMS

- **A5205**: 64 channel SSD, GEM, PIN diode readout based on Psiroc + picoTDC
  - Pos/Neg inputs. Dynamic range up to 5 pC with PHA, 100 pC with ToT
  - Programmable gain: 125 mV/pC up to 4 V/pC. Min trigger threshold = 0,5 fC
  - Linearized ToT

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