CAEN

Tools for Discovery

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

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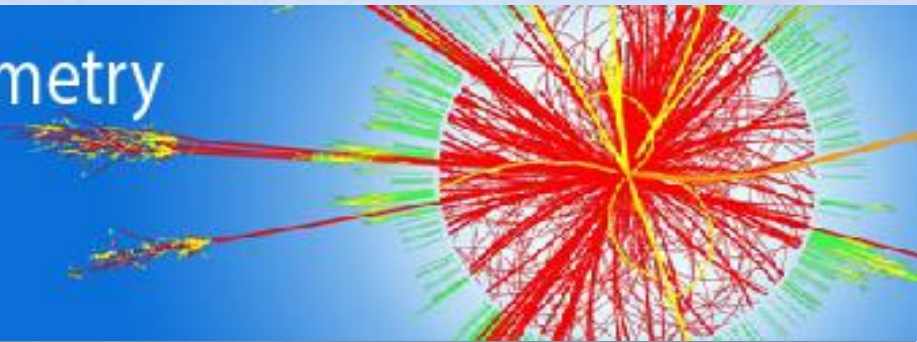
CALOR 2020 – 19th International Conference on Calorimetry in Particle Physics
University of Sussex, UK, 16-20 May, 2022



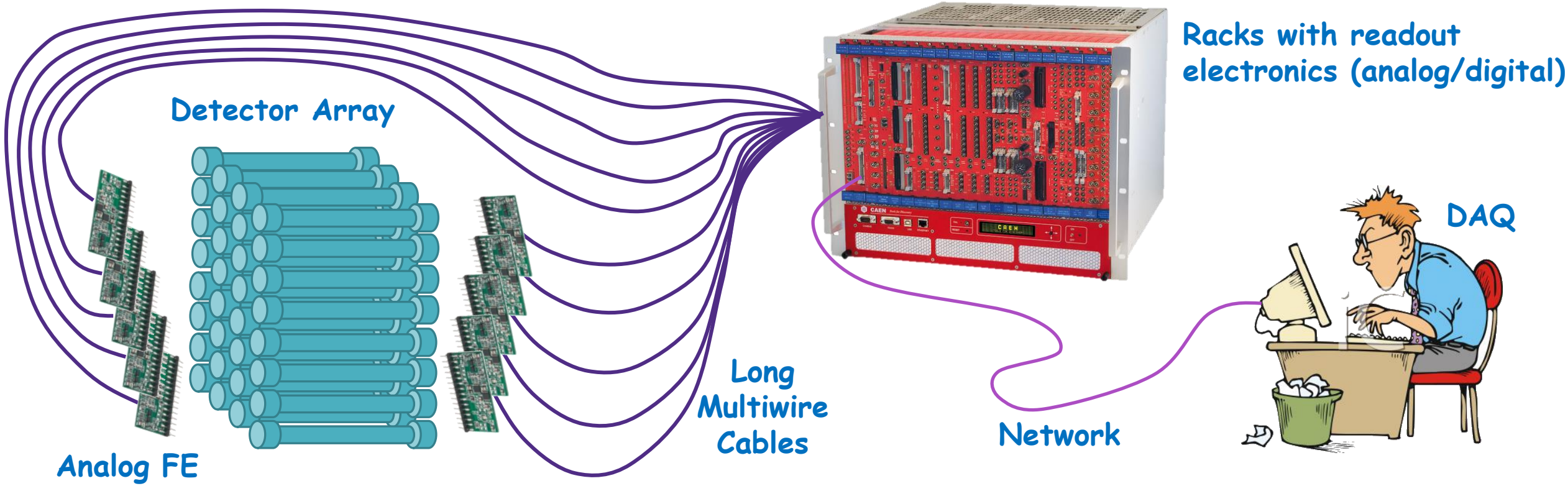
Summary

- FERS-5200 system overview
- Details of the first FERS “flavours”
- Measurements and applications

System overview

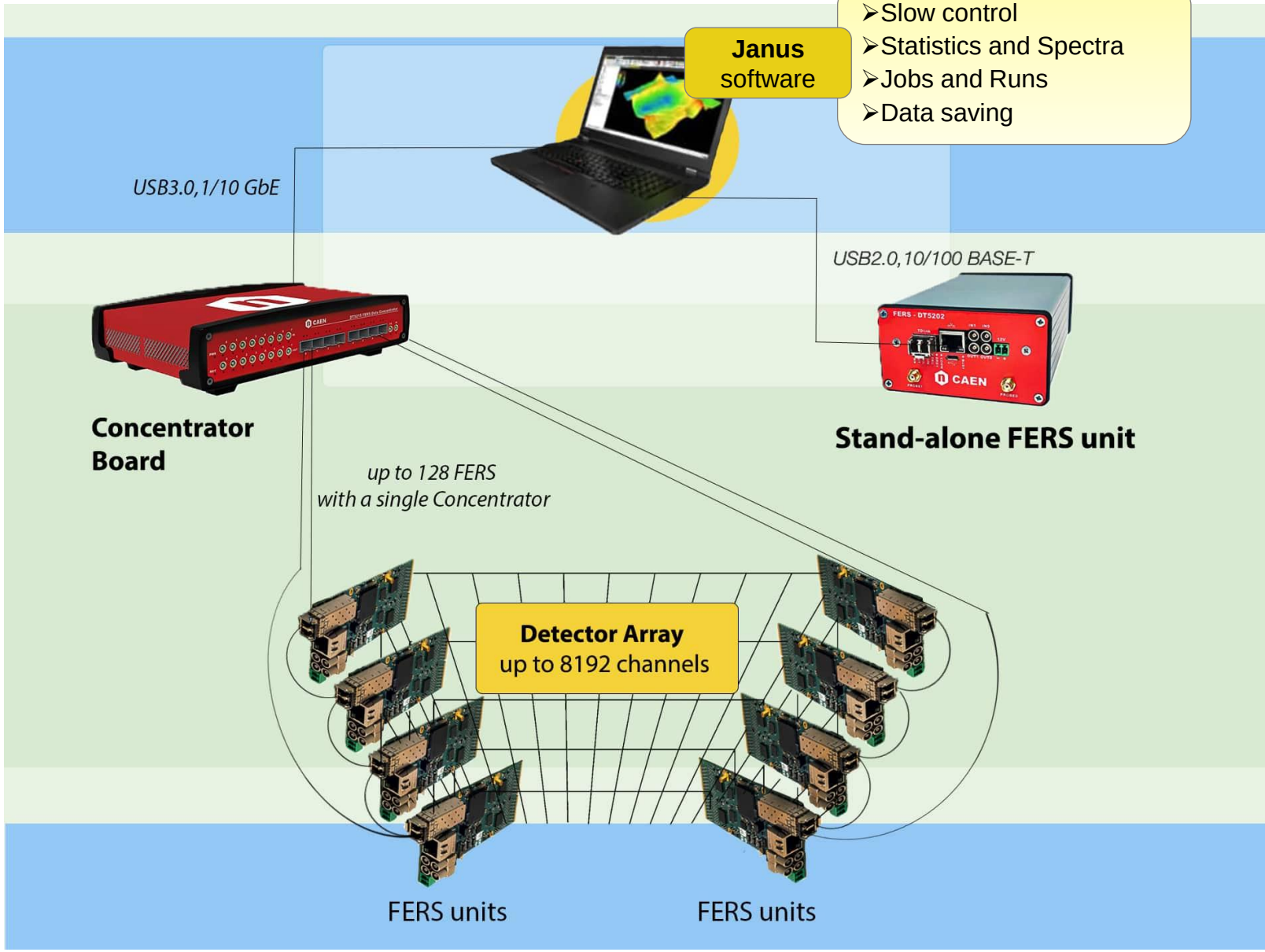
The old way: rack electronics

- Front End Preamplifiers close to the detectors
- Long cables bring analog signals to readout electronics (ADC, TDC, etc.) in racks
- **PROBLEMS**: Signal attenuation, noise pick-up, ground loops, cost of cables, geometry constraints



State of the Art: FERS-5200

- **Modular and Distributed** readout of large arrays of detectors
- **Compact** FERS units based on *ASICs* → front-end + digital
- **Concentrator Board** to manage multiple FERS units
- **TDlink**: 4.25 GB/s Optical link providing Readout, Slow Control, Synchronization → **Easy-scalability**
- **Janus** software to control the whole system and make standard DAQ

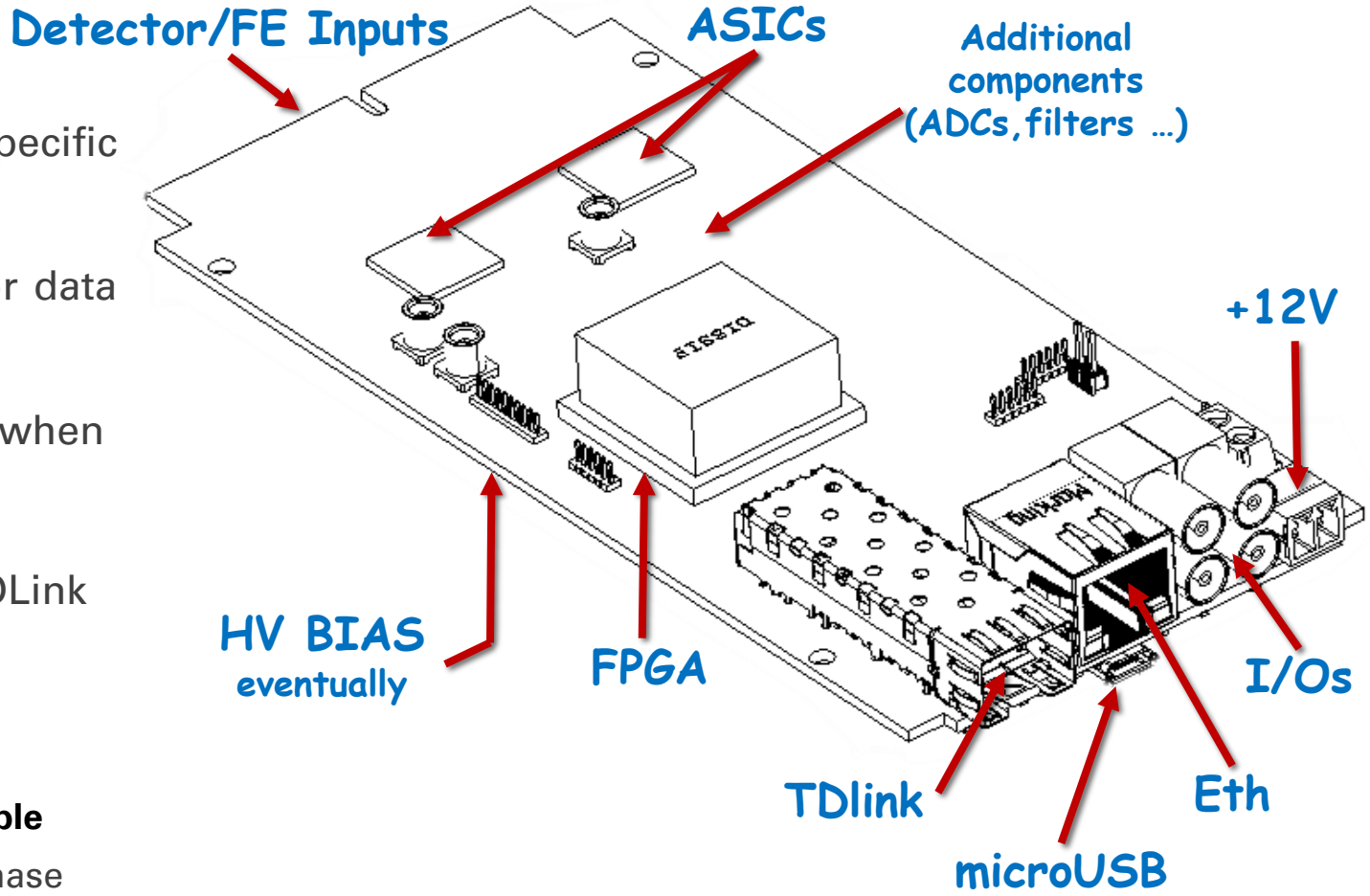


FERS unit – how it is done

- Compact PCB - 17 x 8 cm
- Readout through **ASICs** tailored for specific applications
- FPGA implements the “processing center” for data coming from ASICs
- Embedded **High Voltage** for detector biasing, when requested by the application
- Different readout protocols: USB, Ethernet, TDLink

Desktop version available

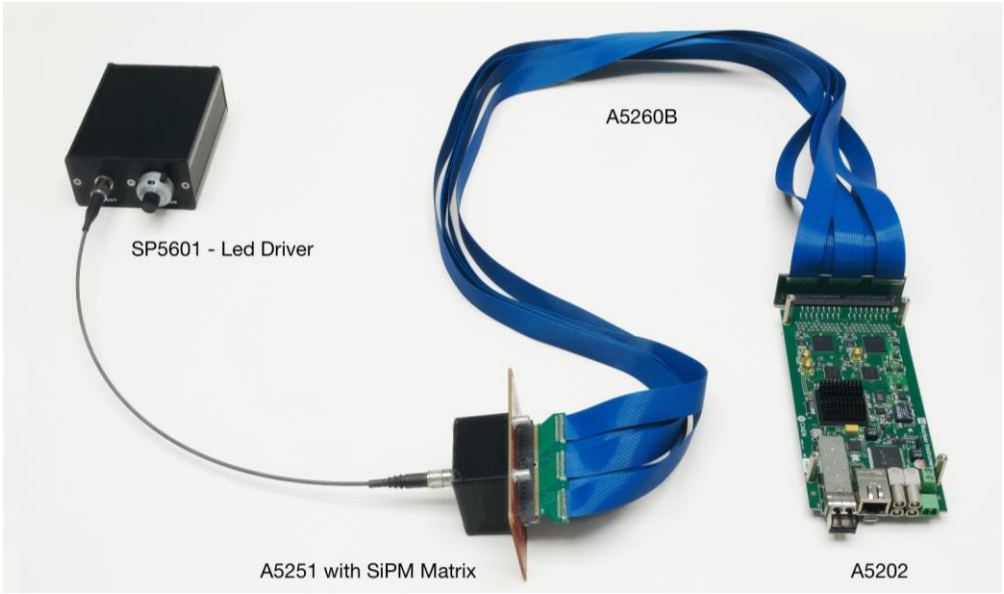
Ideal for prototyping phase

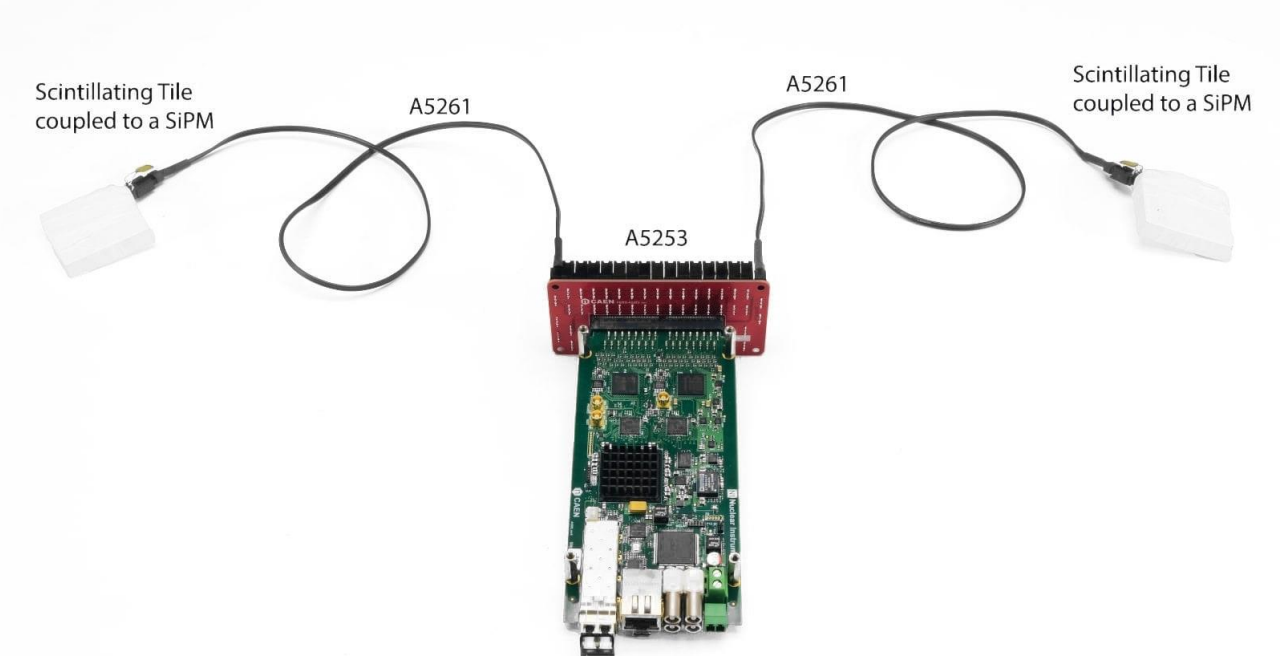


Connectors and Cables

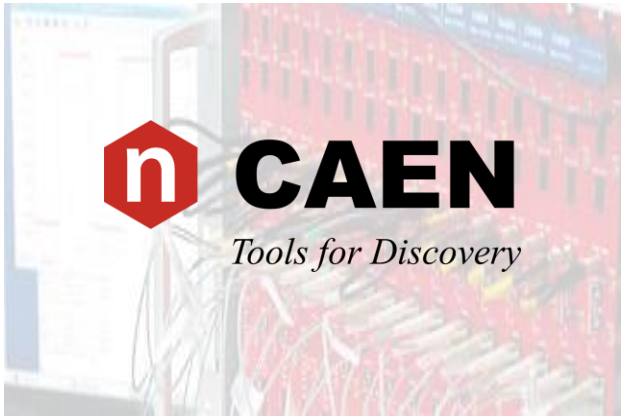
- **Micro-coaxial extension cable** for detector remoting
- Detached electronics simplifies the connection to **cold detectors**
- **Edge connector**: optimal fit for feed-through **flanges**
- Different types of interchangeable end connectors + custom made easily
- Easy fitting of **geometrical constraints**

- 2.54 mm strip
- Hamamatsu footprint
- SensL footprint
- single SiPM footprint
- LEMO with discriminator





Synergies



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

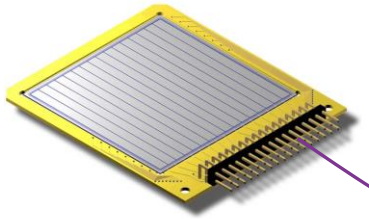
Readout of SiPMs, Si strips, GEMs, PIN diodes, microMegas, MA-PMTs, ... for spectroscopy, PSD, timing applications.

Expertise in **rad-hard** design for HEP

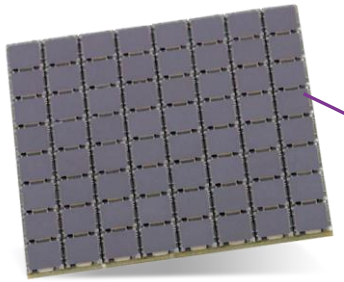
Design of high-end readout electronics and power supply for HEP and NP

Integration expertise → **FERS-5200**

FERS-5200 “flavours”

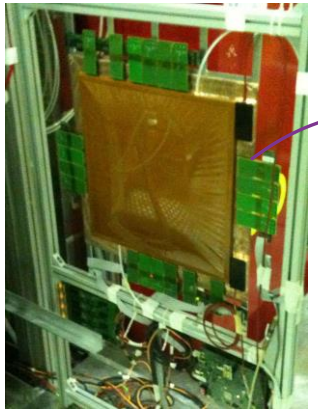


Silicon Strip Detectors

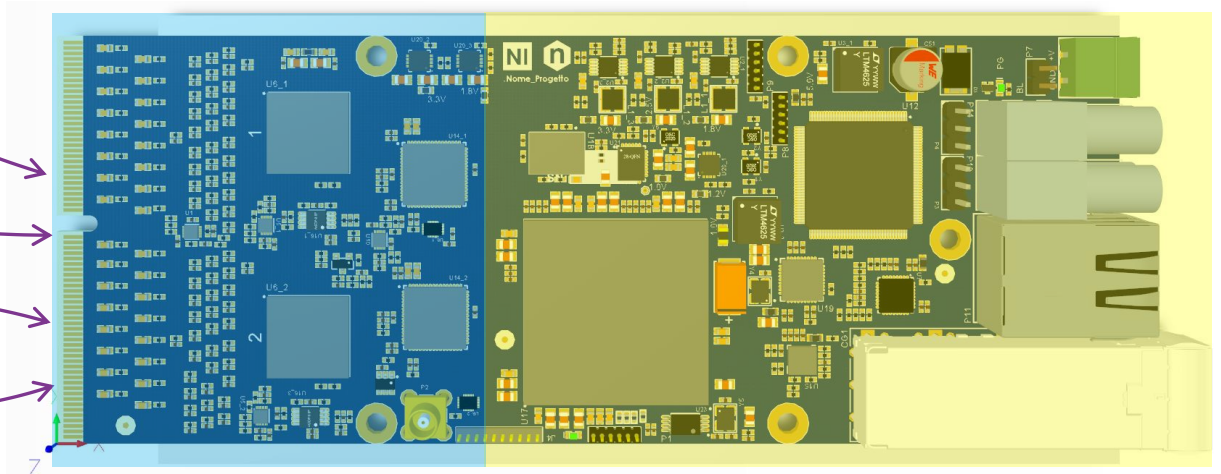


SiPM

Multi- wire chambers



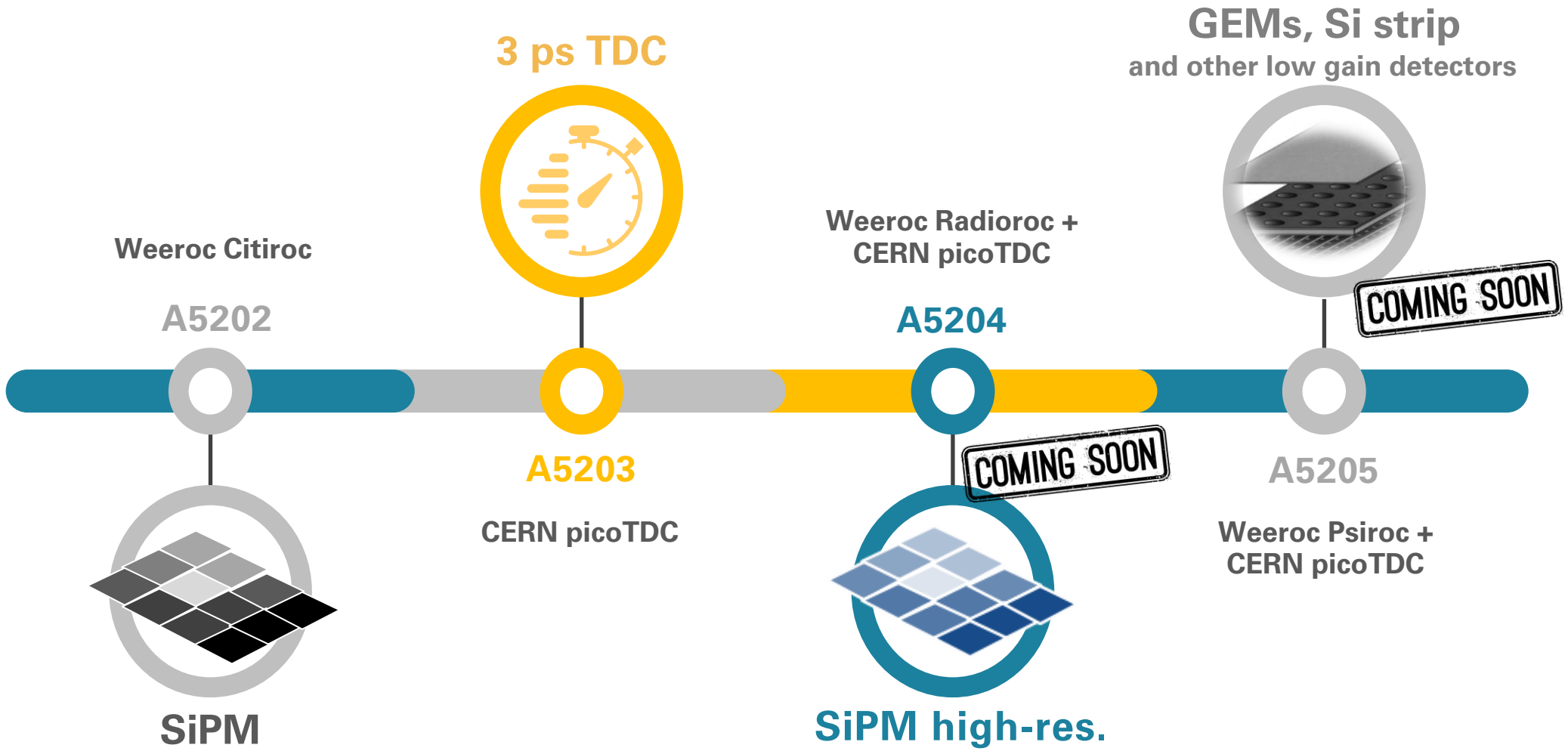
Micromegas, GEMs

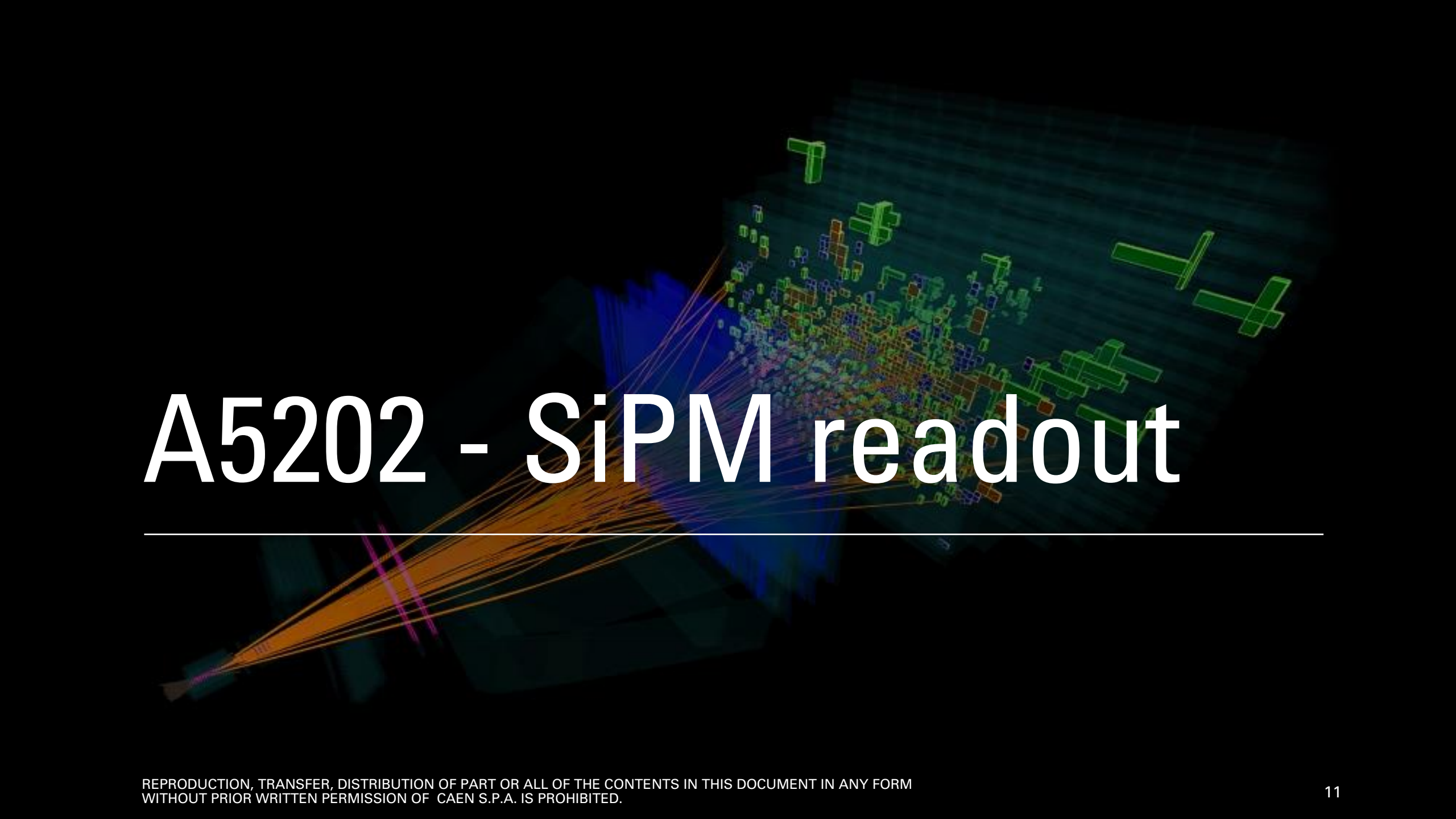


APPLICATION -SPECIFIC COMMON INFRASTRUCTURE

Same infrastructure, different Front-Ends
quick integration of different ASICs

FERS Roadmap

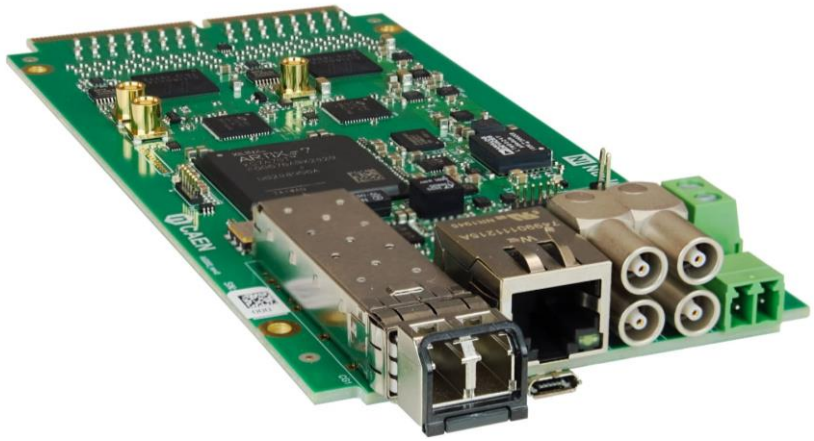


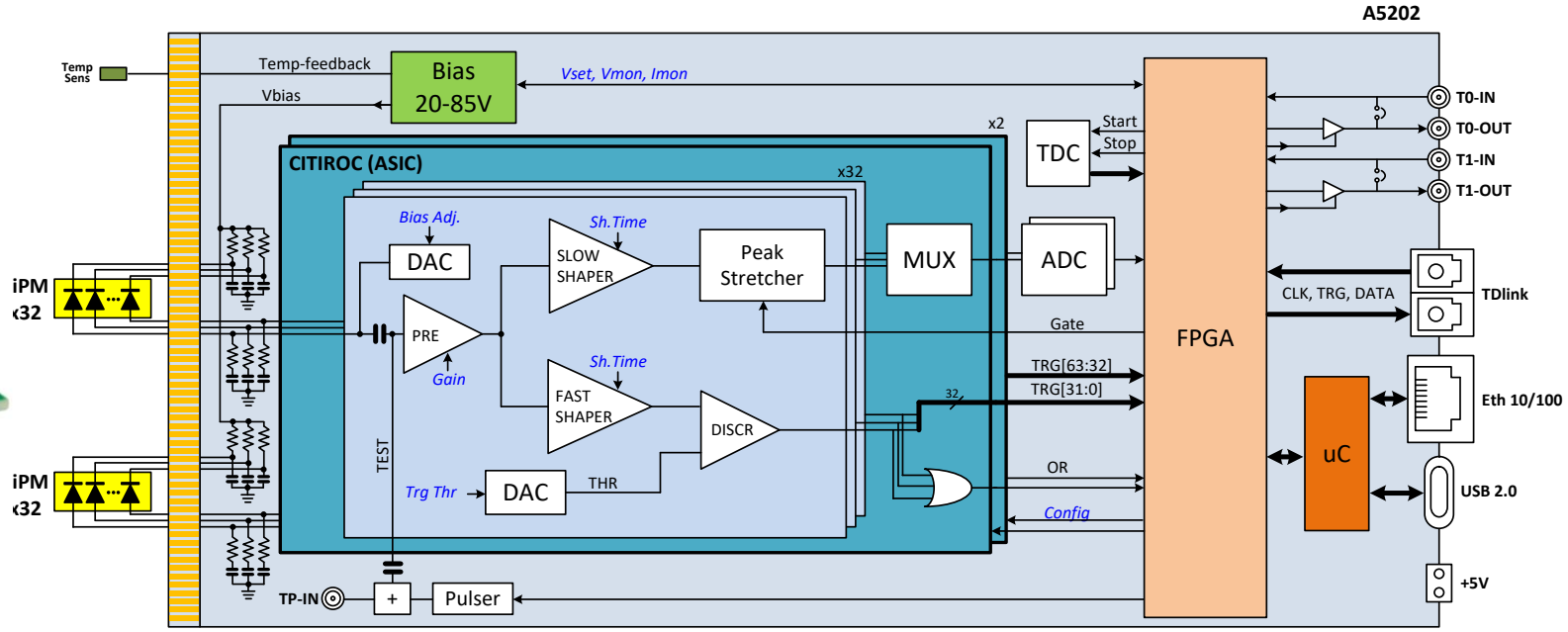


A5202 - SiPM readout

A5202: 64 channel SiPM readout

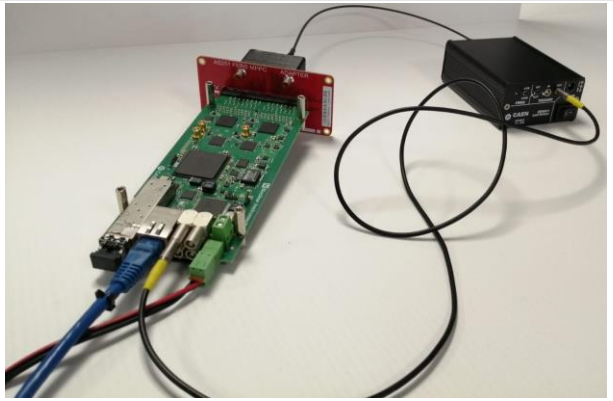
- 64-channels SiPM readout, based on analog chain + **Peak Sensing** strategy (Weeroc **Citiroc-1A**)
- Embedded 20-85 V module for SiPM **bias**
- **Single photoelectron** energy resolution and **0.5 ns** event timestamp resolution
- Readout modes: photon counting, spectroscopy (PHA), event timestamping

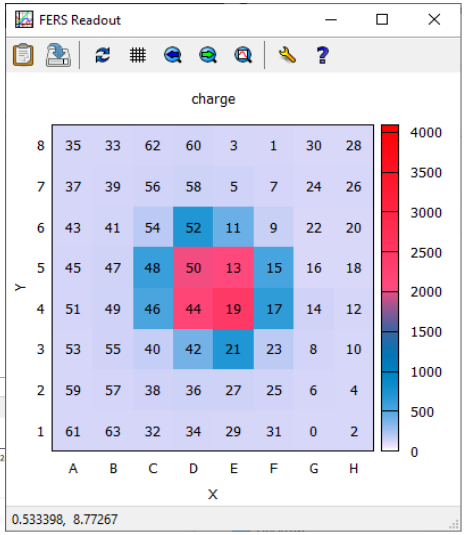




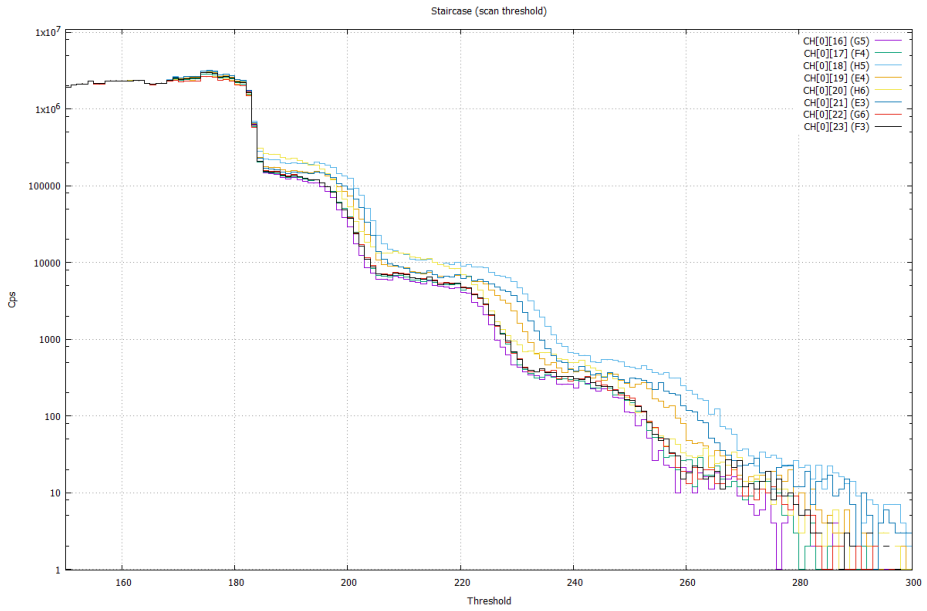
Qualification of A5202

- One A5202 board
- SiPM Matrix Hamamatsu S13361-3050AE-08
- CAEN SP5601 LED Driver

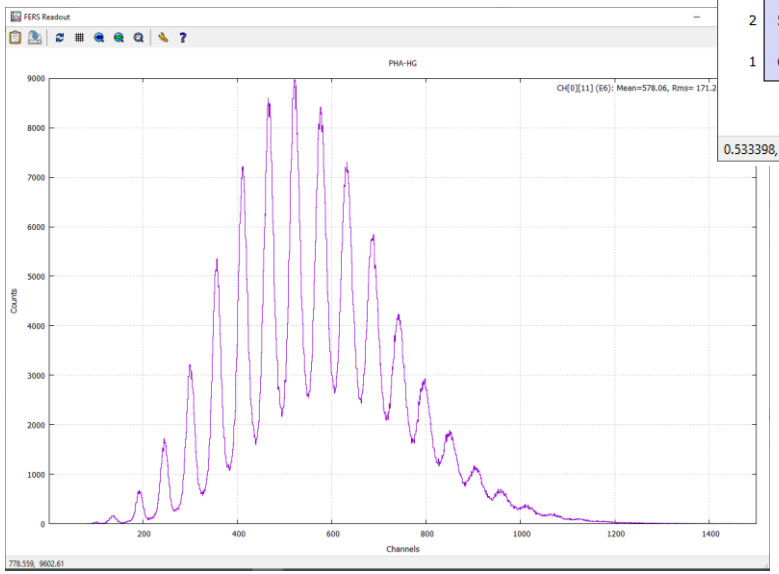




Imaging



Staircase



SiPM spectrum with photopeaks

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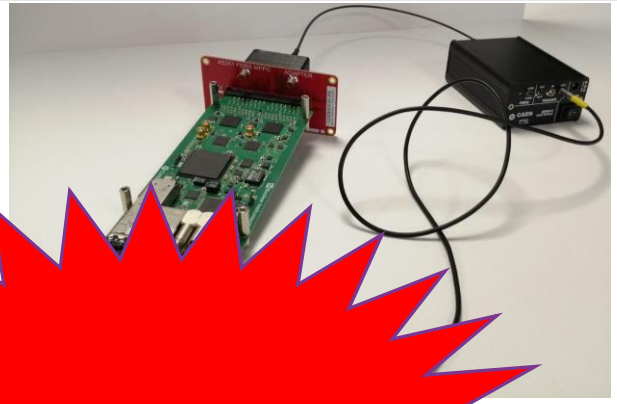
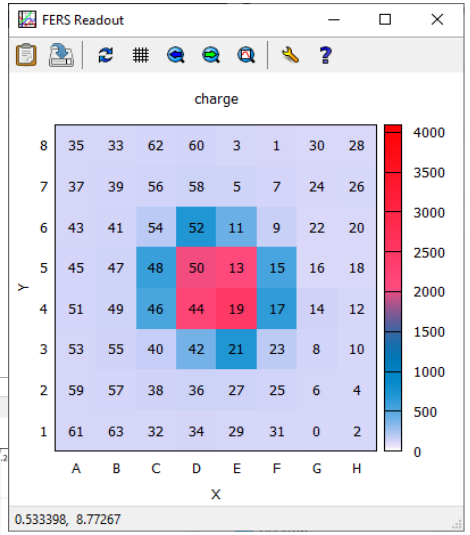
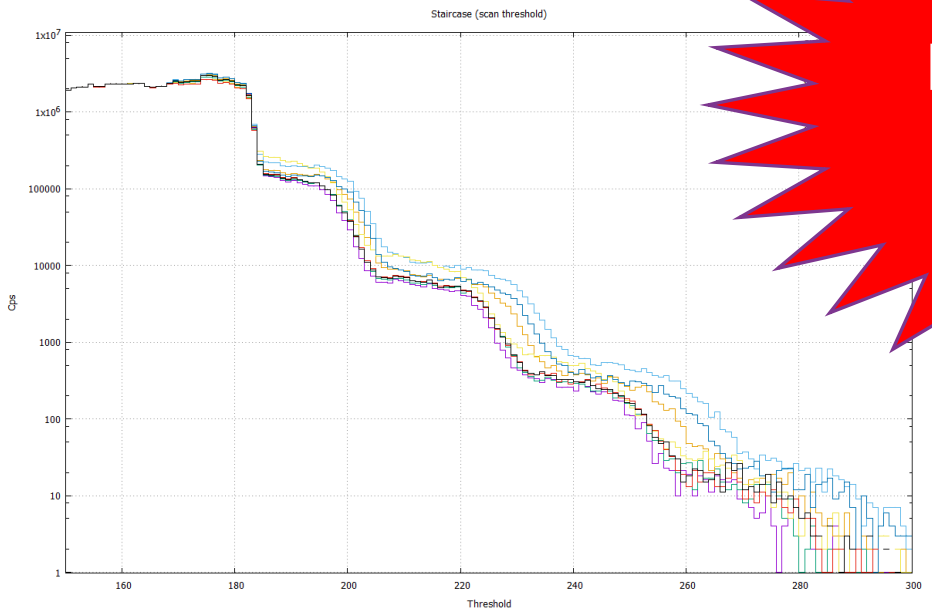


Live Demo at CAEN booth



Imaging



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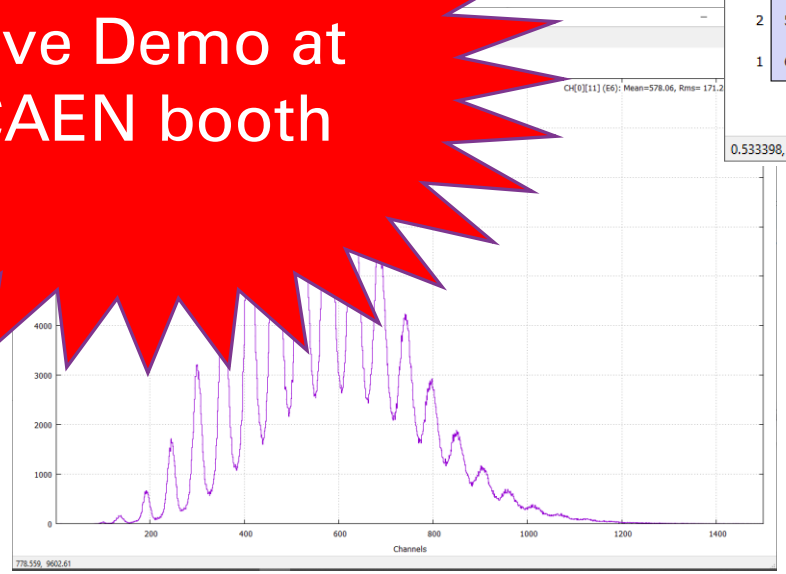
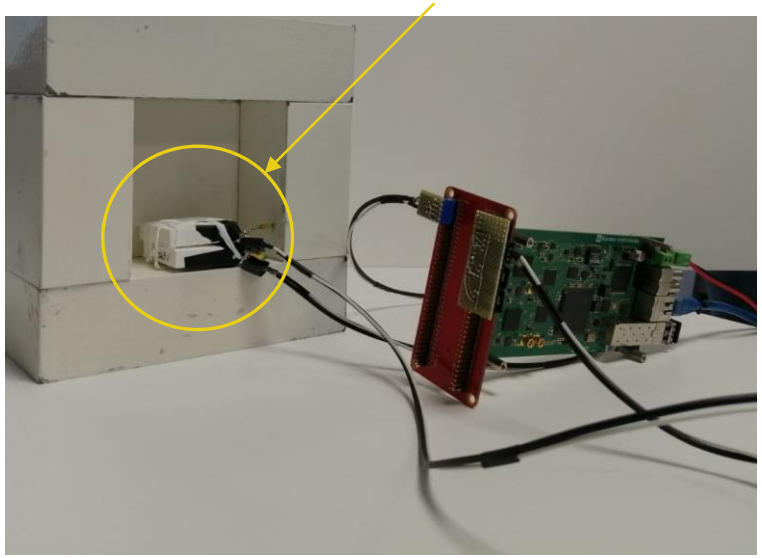


SiPM spectrum with photopeaks

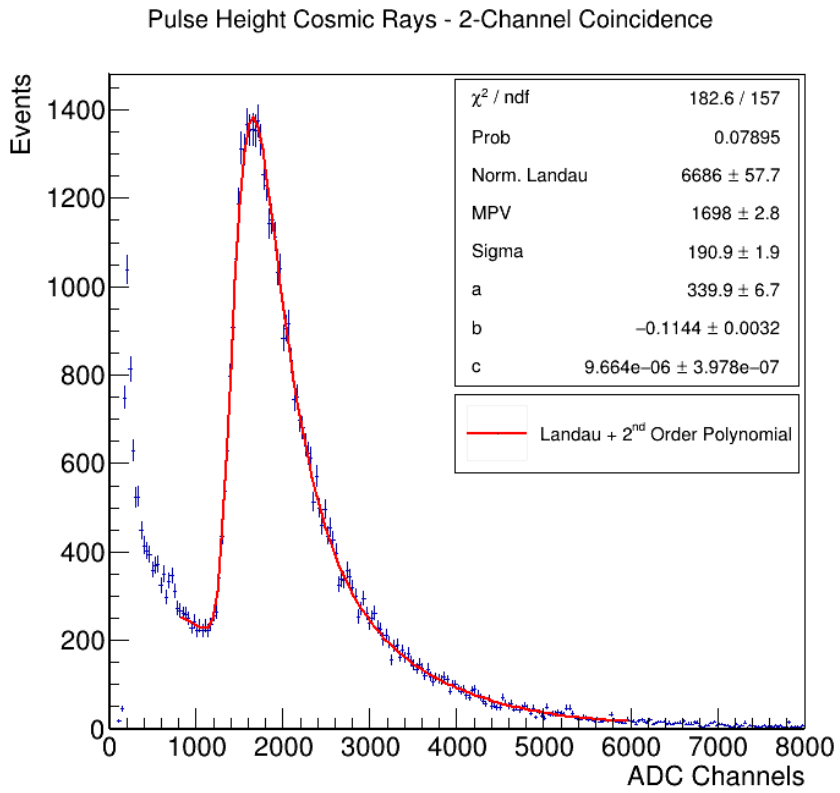
Measurement of Cosmic Ray Energy Loss

Preliminary measurements with one A5202 board. Setup:

- Two 4.8 cm x 4.8 cm x 1 cm plastic scintillators, each one coupled to a Hamamatsu S13360-6050CS SiPM



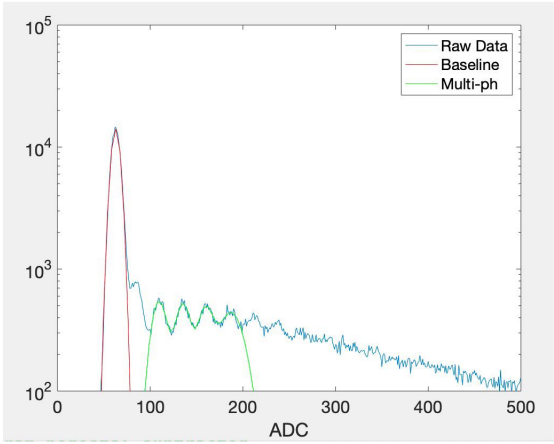
- Two channel coincidence (implemented at firmware level) used as trigger for PHA acquisition

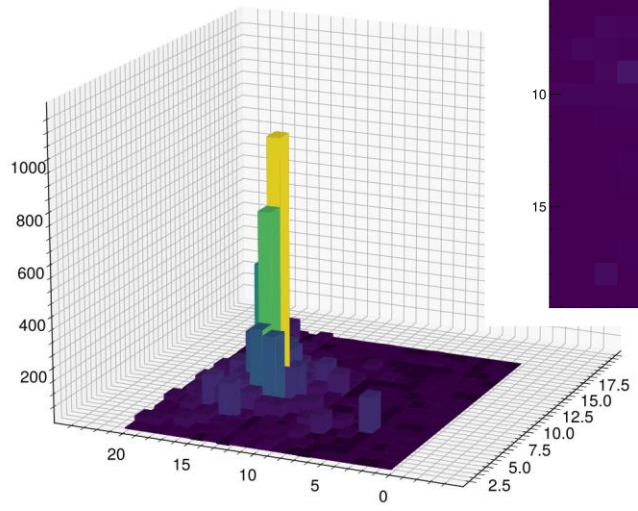


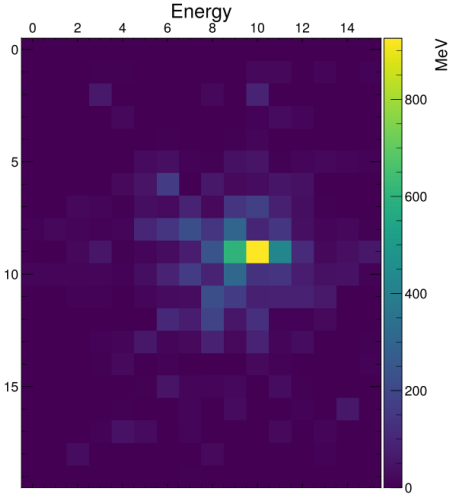
Landau from relativistic muons loss of energy clearly visible

FERS in dual readout calorimetry

- Development and testing of **dual readout highly granular calorimeter**, exploiting SiPM and CAEN A5202
- **320 SiPMs** read out using **five CAEN A5202**
- Successful qualification of a module on beam with EM shower containment – *calibration, EM shower imaging and calorimeter response linearity*
- Plans to **scale-up the system** to handle more SiPMs for hadronic containment





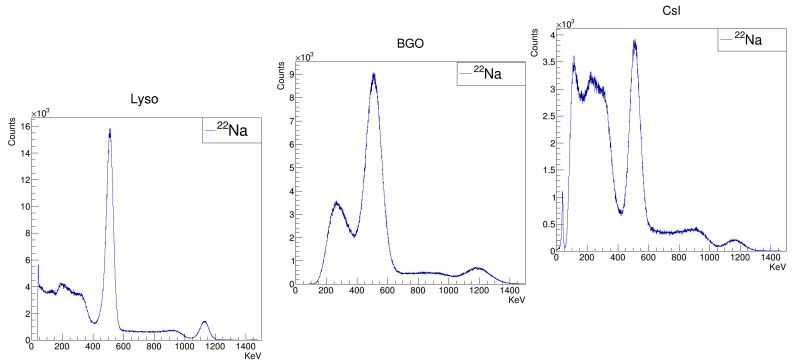


Talk "SiPMs for dual-readout calorimetry"
R.Santoro – Università dell'Insubria
Session 5 - Calorimeter Technologies for Future Colliders 1

More use cases

γ spectroscopy measurements with SiPM and ASIC (Citiroc) front-end electronics

M.Perri *et al*.
Nuclear Inst. and Methods in Physics Research, A - (in press)

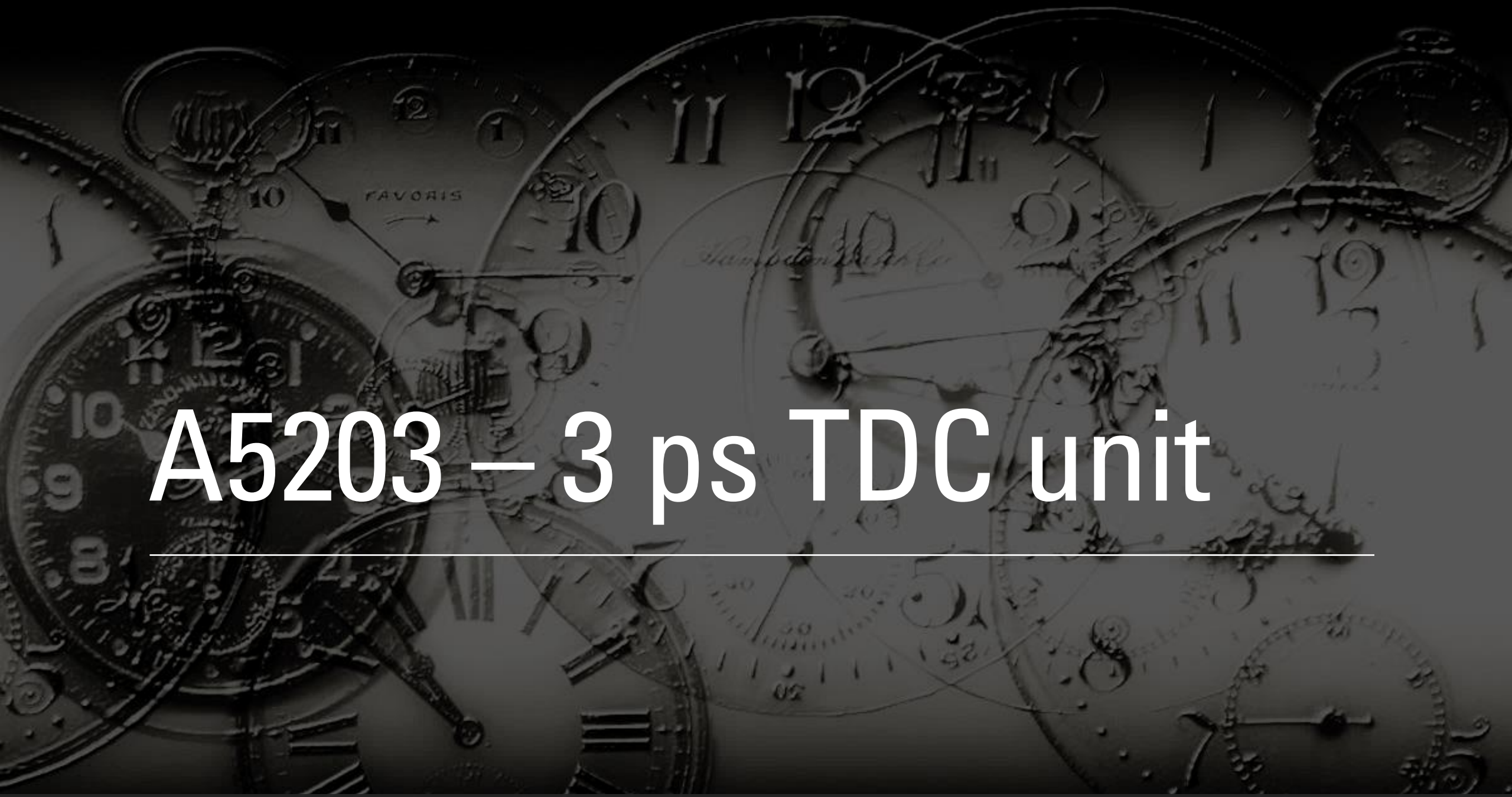


Muon tomography scanner, suitable for **nuclear waste characterization**

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

SiLiF Neutron Counters to Monitor Nuclear Materials in the MICADO Project - https://www.micado-project.eu/

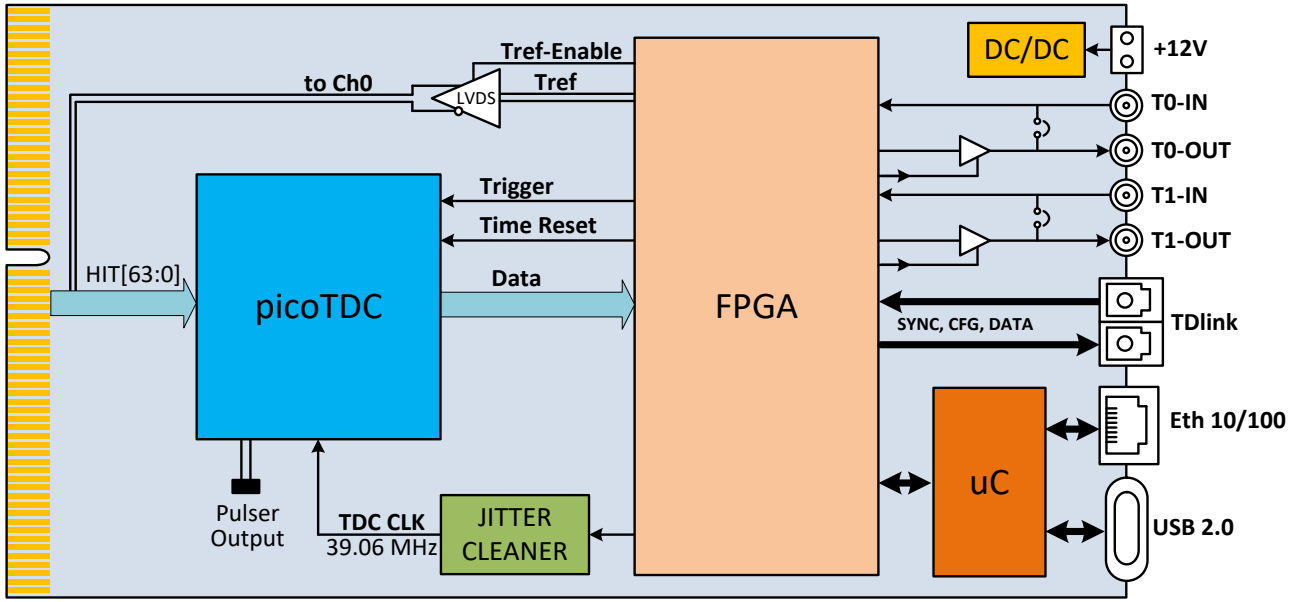
Finocchiaro et al.
Sensors 2021, 21, 2630, https://doi.org/10.3390/s21082630



A5203 – 3 ps TDC unit

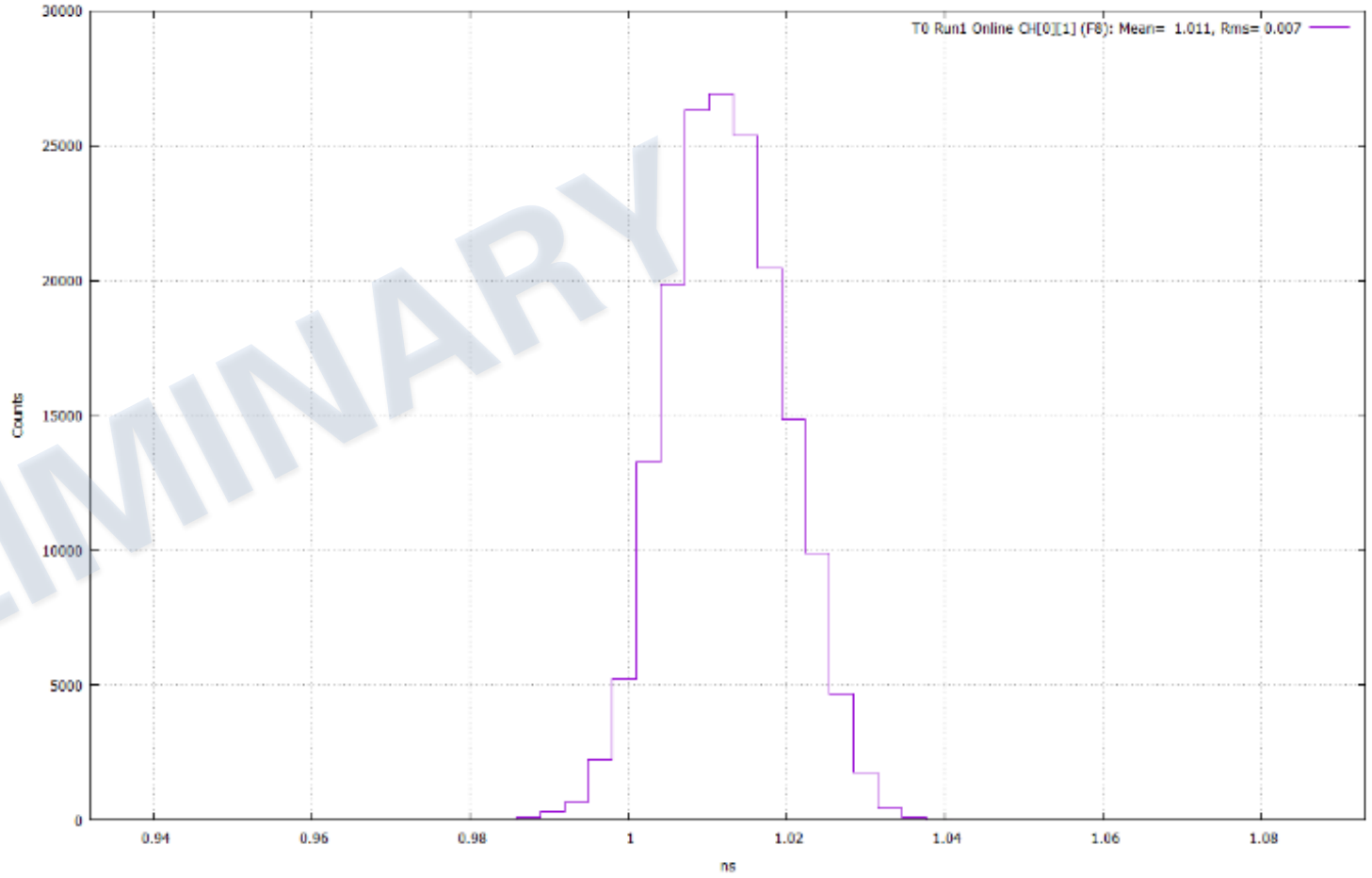
A5203: 64 channel 3 ps TDC

- 64-channels **TDC** unit for extremely high-resolution applications housing CERN **picoTDC** ASIC
- Timing resolution LSB = 3.125 ps, **RMS typ. 7 ps**
- **LVDS**-compliant input → possible coupling with external discriminator output or custom front-end
- Acquisition of rising/falling edge timestamps → **ToA** and **ToT**



Characterization measurements

Spectrum of ΔT between ch1 and ch0 in Common Start Mode, measured with a pulse generator, 1V single-ended pulse, 0.8ns rising edge. The RMS resolution is nearly 7ps.



Conclusion

- FERS is **modular**
- FERS is **easy-scalable**
- FERS is **flexibile**

Thank you for your attention

Any question/curiosity?

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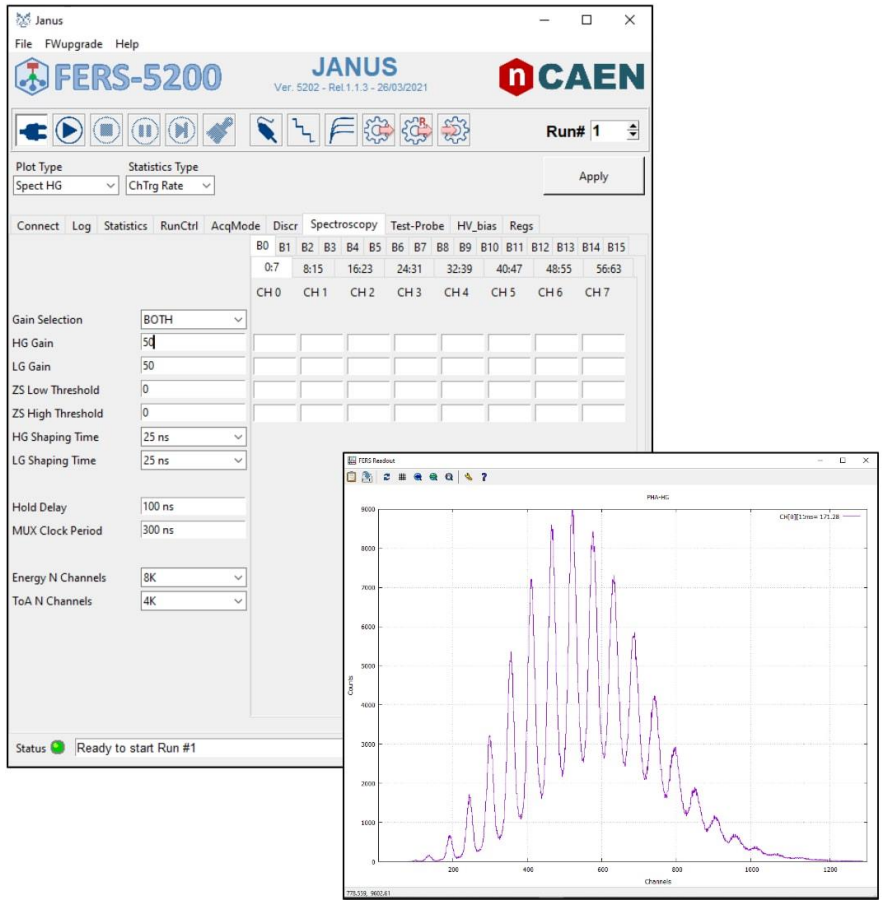
Backup slides

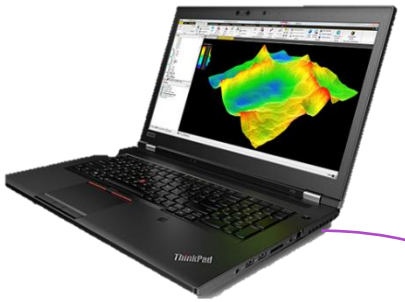
Janus Software

CAEN **Janus software** is free and available for FERS multi-board control and data acquisition:

- Model-dependent GUI for a quick and easy start
- **Open-Source** for user customization
- High Voltage fully controllable by the software
- Management of the acquisition parameters of all connected boards
- Multi parametric Jobs and Runs with time or counts preset
- Data saving of lists in **.bin**, **.txt** format
- Statistics and Spectra visualization



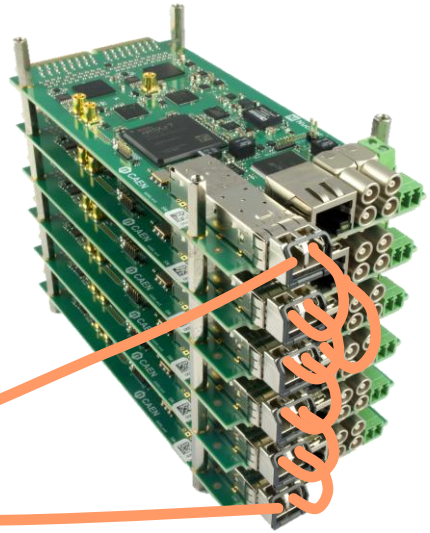
DT5215 – Concentrator Board



Readout Interface
- 1/10 Gbps Ethernet
- USB-3.0

Zynq Ultrascale SoC – FPGA and ARM
- Readout process management
- Event sorting
- Event Building

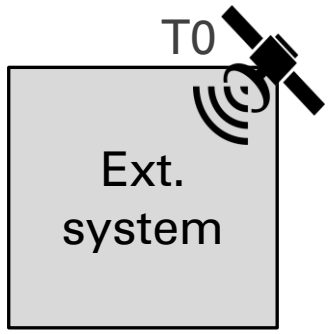
8 x Tdlink @ 4.25 Gbps

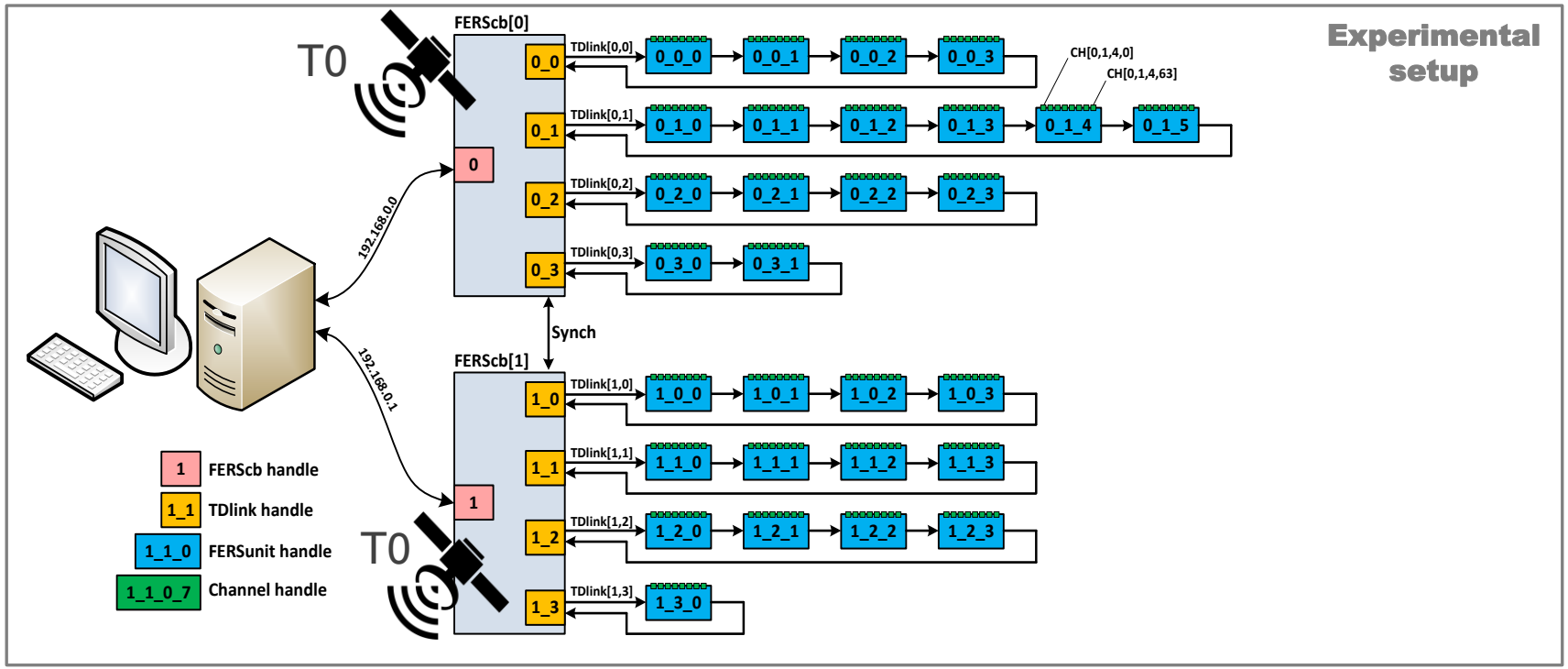


Up to 16 FERS units/link

The key point: TDLink protocol

- **CAEN proprietary protocol TDlink**: 4.25 Gb/s over **optical fiber** providing *Readout*, *Slow Control*, *Sync* and *Clock* at once
- Allows **alignment of the timestamps with external systems** too – for example GPS





x5202: acquisition modes

- **Spectroscopy Mode (PHA)**:
  - A/D conversion of the pulse height (preamp + shaper + peak hold + mux + 14 bit ADC)
  - Common trigger (int. or ext.)
  - Zero suppression with programmable thresholds
  - Max trigger rate = 100 kHz (dead time = ~10 μs per trigger)
- **Counting Mode** (e.g. photon counting in SiPMs):
  - Counters fed by fast discriminator signals
  - Simultaneously latched at programmable time frames and saved to memory (MCS mode)
  - Counting rate up to ~20 Mcps/ch

x5202: acquisition modes

- **Timing Mode** (List of Tstamps and/or Time over Threshold):
  - Independent hit recording: channel ID + timing (0.5 ns resolution)
  - Common start or common stop (int/ext T-ref signal)
  - Gating mode
  - Optionally, **ToT** (0.5 ns resolution) provided for low resolution PHA: Charge Resolution = 1.5%
  - Max total hit rate = ~50 Mcps/board

- **Spectroscopy and Timing mode** (List of PHA + Tstamps and/or ToT)

COMING SOON

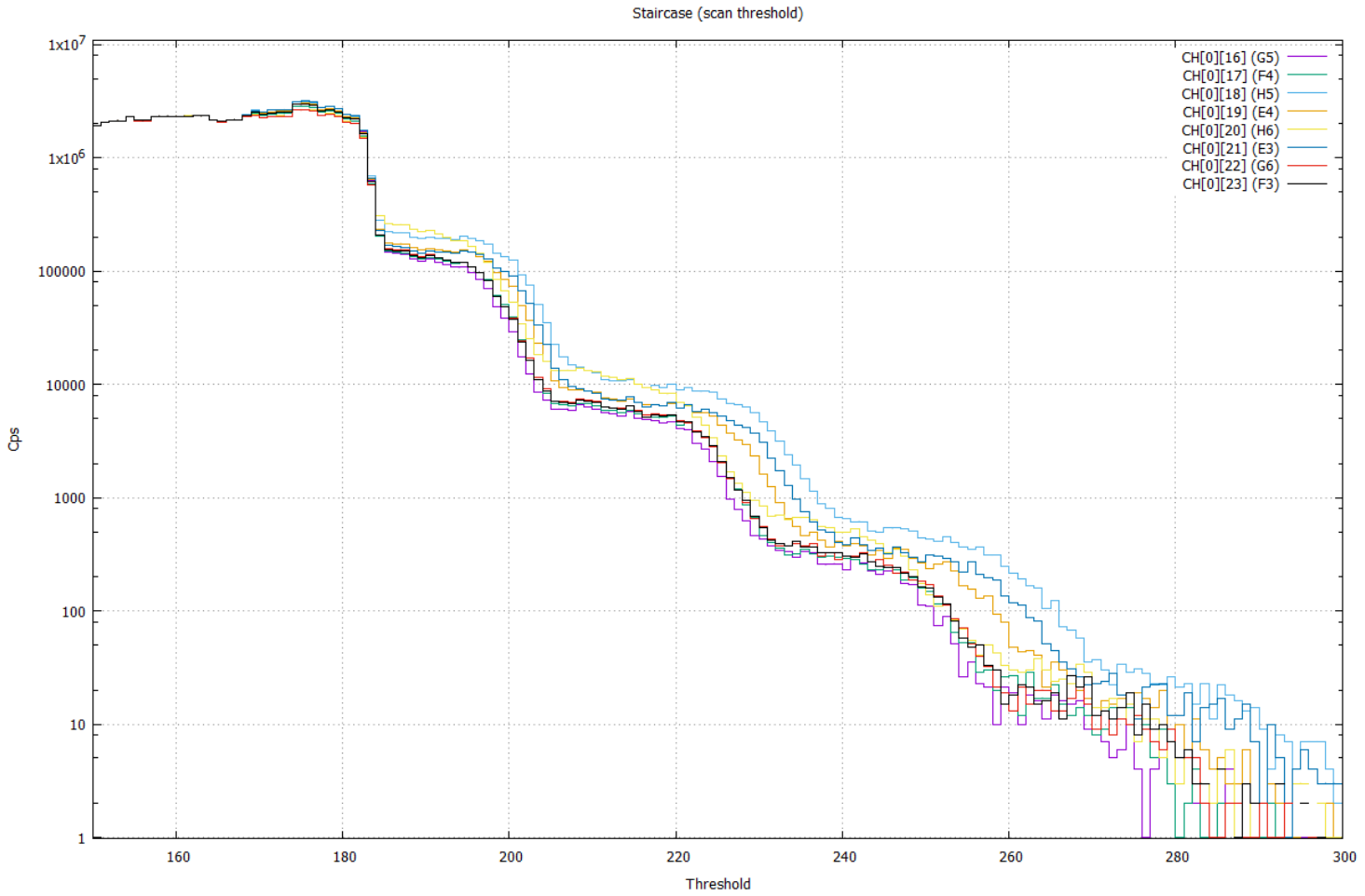
A5202: readout modes

- **Common Trigger Mode**
  - **FERS units**: generate a trigger request (typically OR of channel discriminators)
  - **Data Concentrators**: receive and combine requests from all units and generate the **Global Trigger**
  - **Event Building** and data reduction takes place in the ARM processor of the Data Concentrator
- **Trigger-less Mode (independent channel acquisition)**
  - **FERS units**: each channel pushes data asynchronously, typically at different rates
  - No trigger and data correlation in HW. Events reconstruction in DAQ.
- ARM processor running **Linux** and local DDR memory available in Data Concentrator
- High throughput data transfer to host computers via 10 GbE or USB 3.0
- Users can run custom routines for data handling in the embedded ARM

SiPM readout with A5202 – Staircase

Example for the trend of the number of events triggered as a function of the threshold:

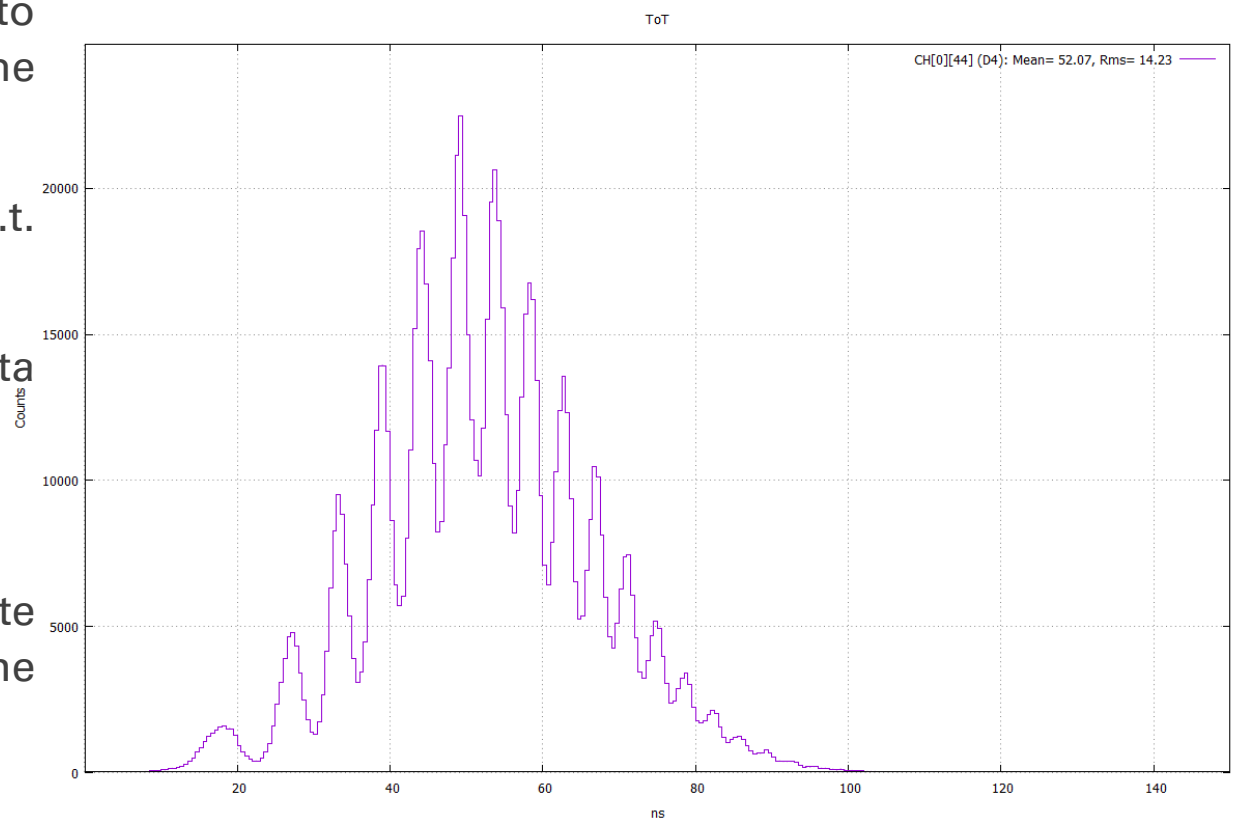
- No LED Driver used → Dark Count Rate only
- Each stair correspond to a different number of photoelectrons triggered



SiPM readout with A5202 – ToT

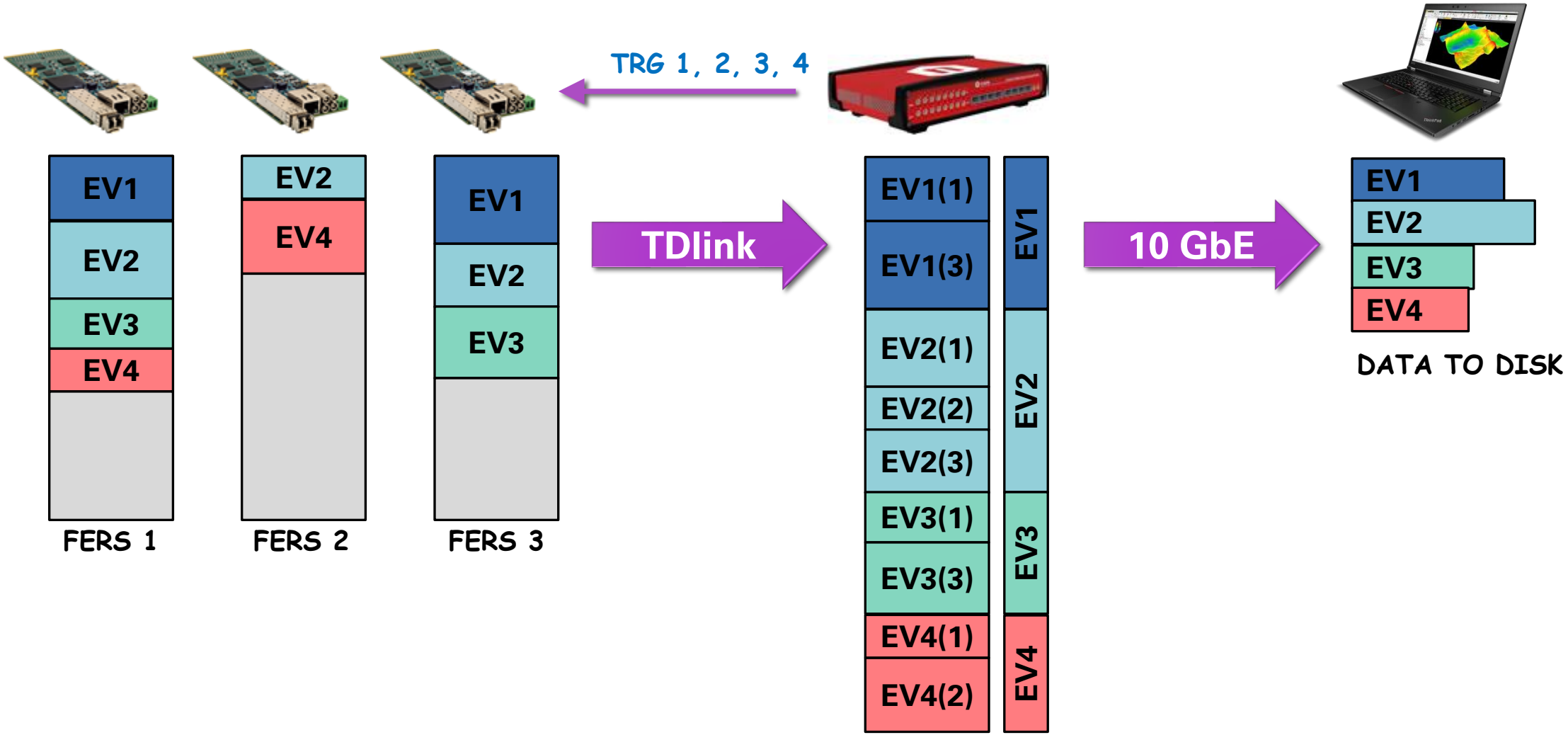
The Time over Threshold (ToT) of the pulse allows to reconstruct the energy information as well with some advantages:

- Greater dynamics to higher amplitude signals w.r.t. PHA
- Independent channel acquisition (trigger-less data streaming)
- Lower dead time ⟶ Higher acquisition Rate
- Photopeaks clearly visible and well resolved despite the lower resolution (~ 1/3) w.r.t. PHA using the same setup



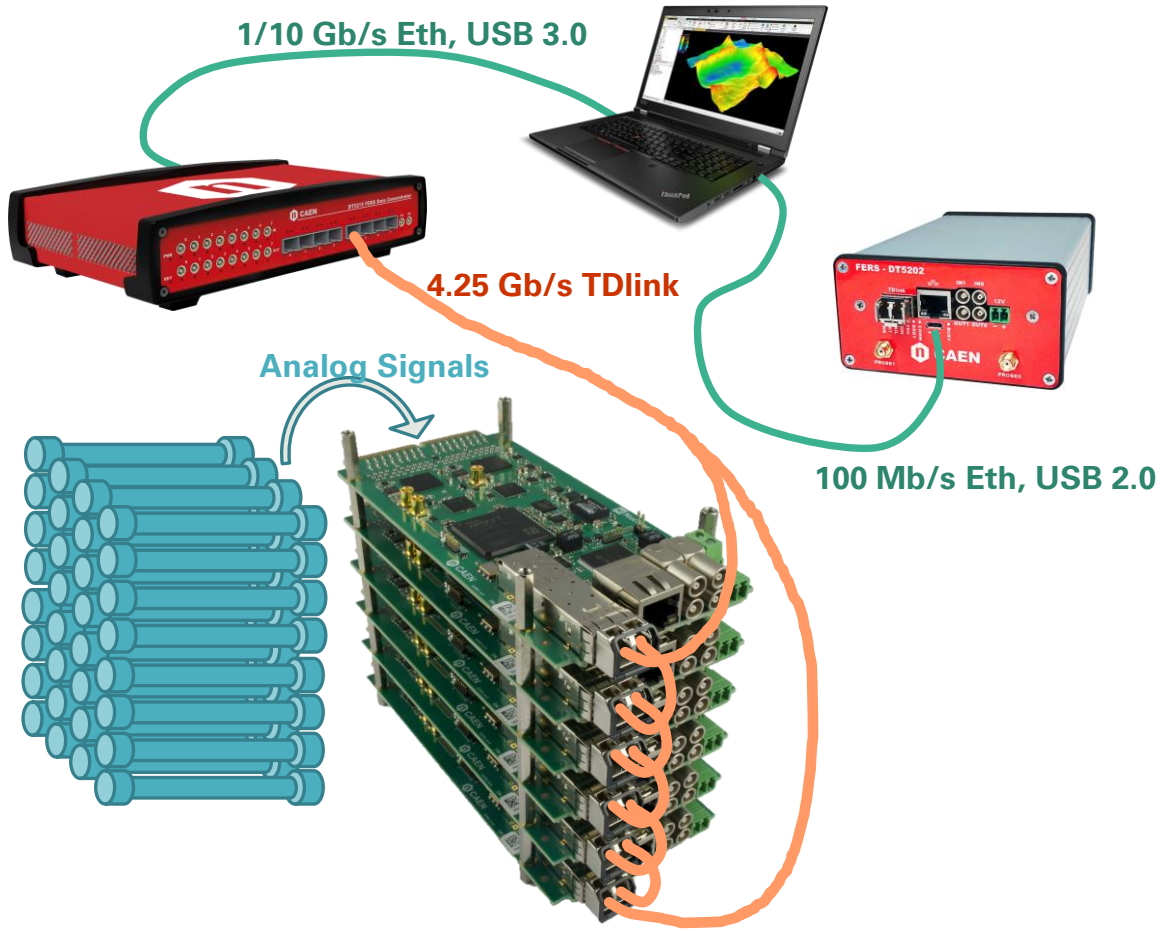
SiPM ToT spectrum with the clearly visible photopeaks

In-built sparse event readout

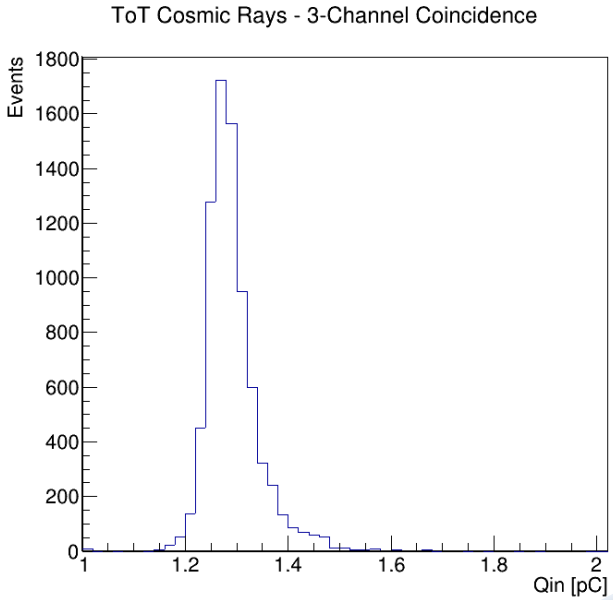


FERS-5200

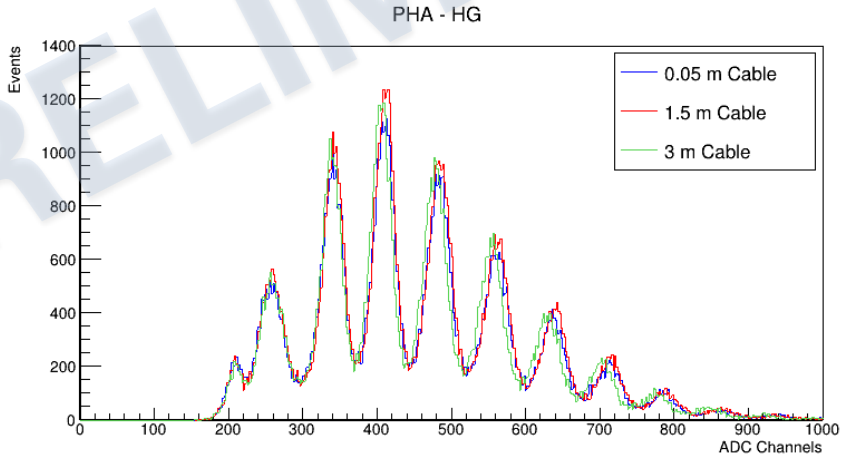
- **Modular** readout of large arrays of detectors
- **Compact** and **dense** FERS units based on **ASICs**: front-end + digital
- Dedicated protocol developed for **distributed systems**
- **Easy-scalability** of systems through daisy-chain of **fibers**
  1 FERS unit = 64/128 ch
  1 Concentrator = 8k/16k channels
- Stand Alone version for **Evaluation** => scale up to 10k/100k channels with same electronics



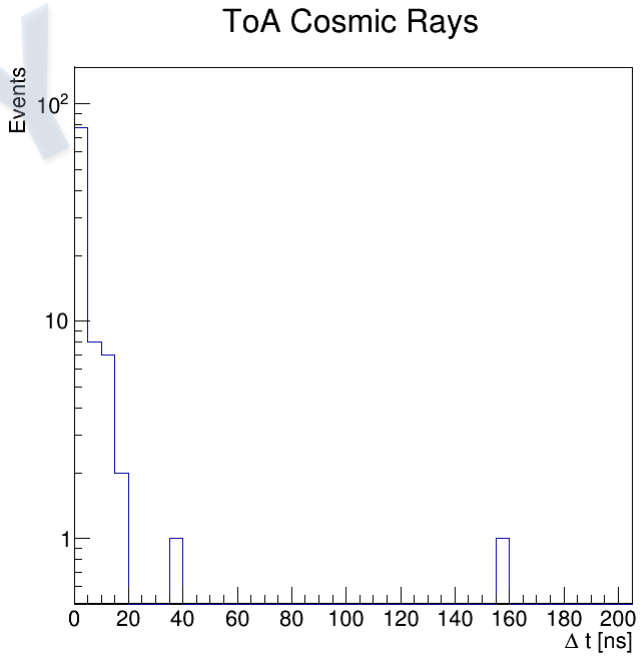
Work in progress



Landau distribution of
Cosmic Rays in ToT mode

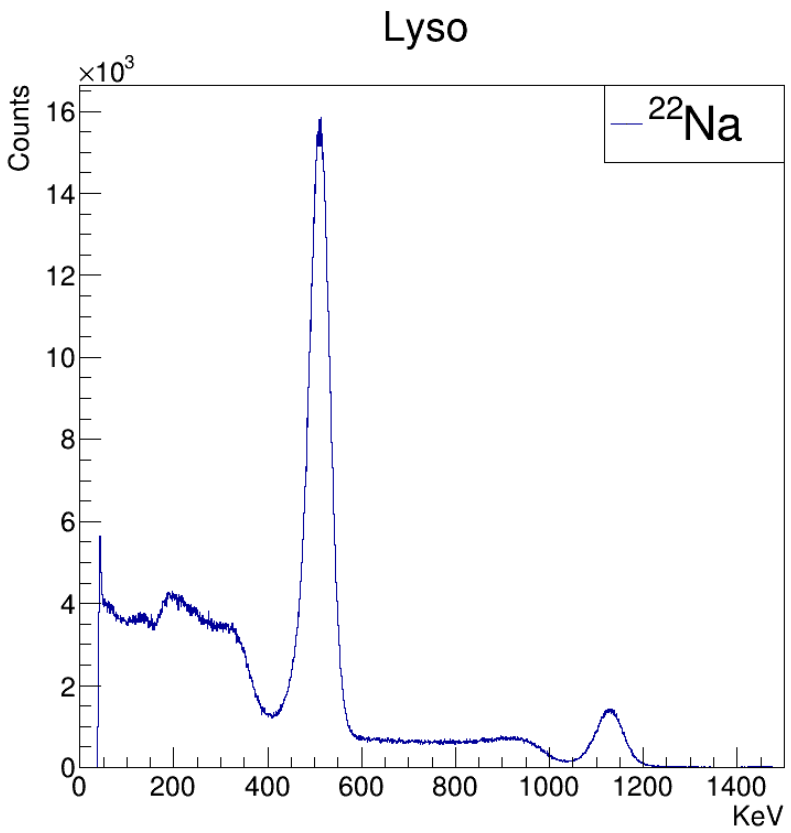


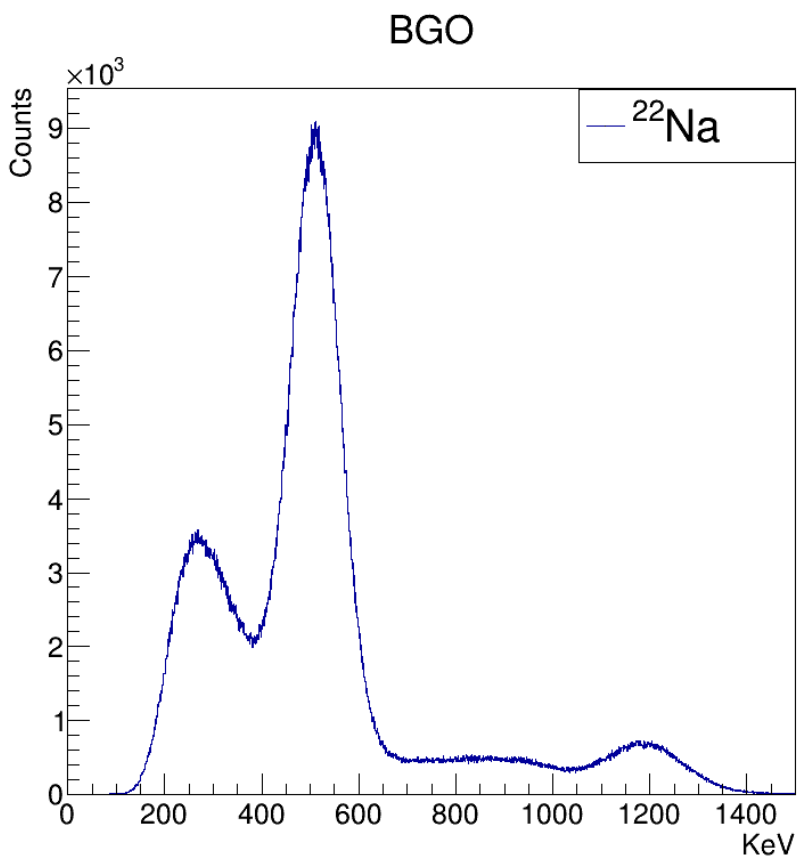
Energy loss along a cable with remote SiPM

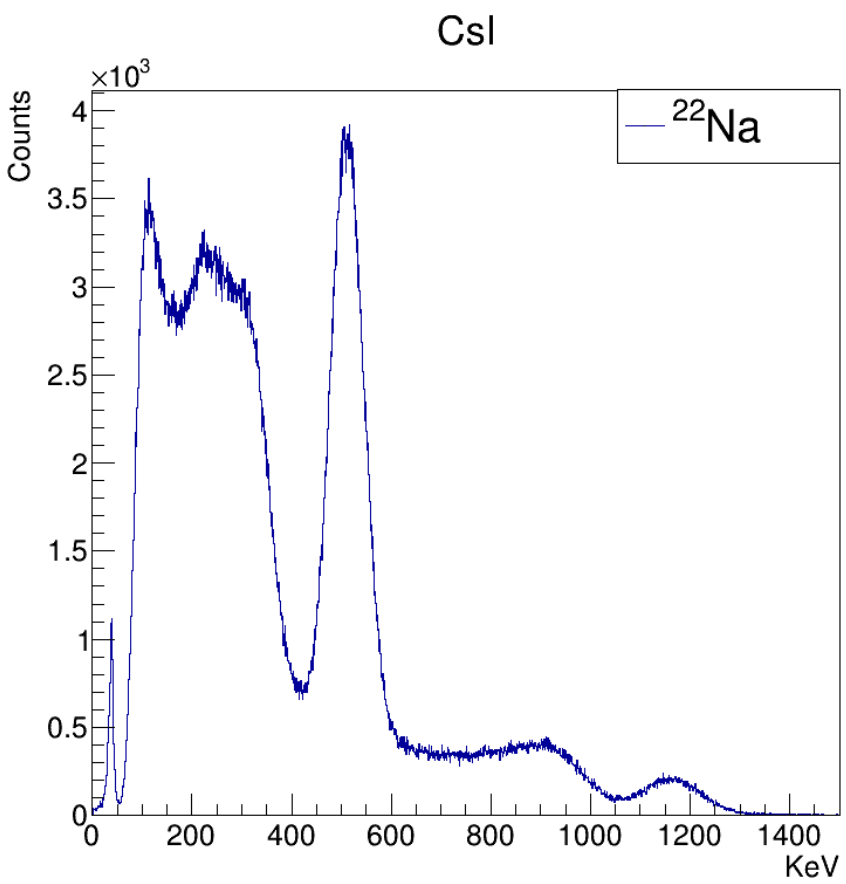


Muon lifetime with plastic scintillators

Spectroscopy



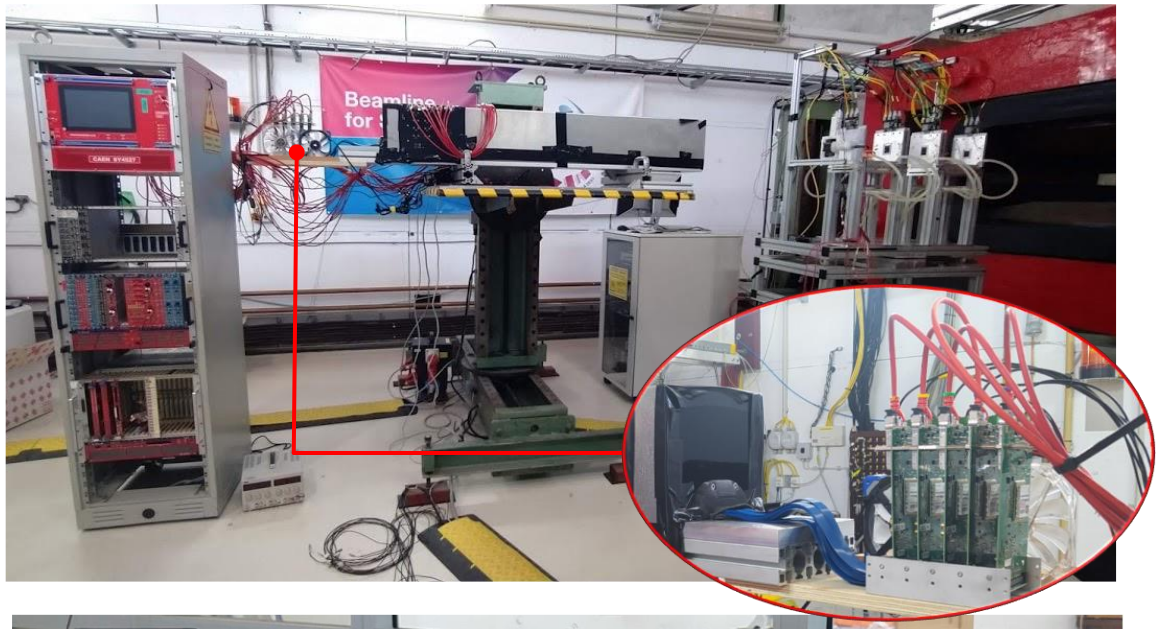


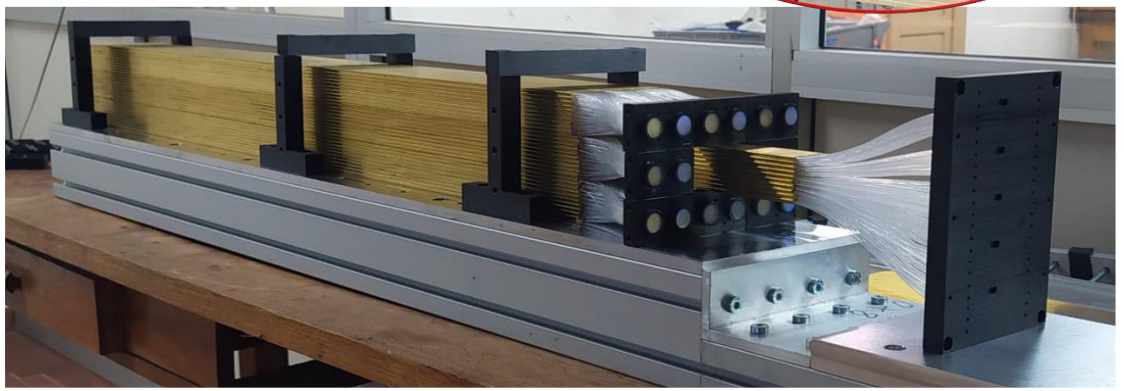


Case history

FERS in dual readout calorimetry

- Development and testing of **dual readout highly granular calorimeter**, exploiting SiPM technology and CAEN A5202 board.
- **320 SiPMs** read out using **five CAEN A5202**
- 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



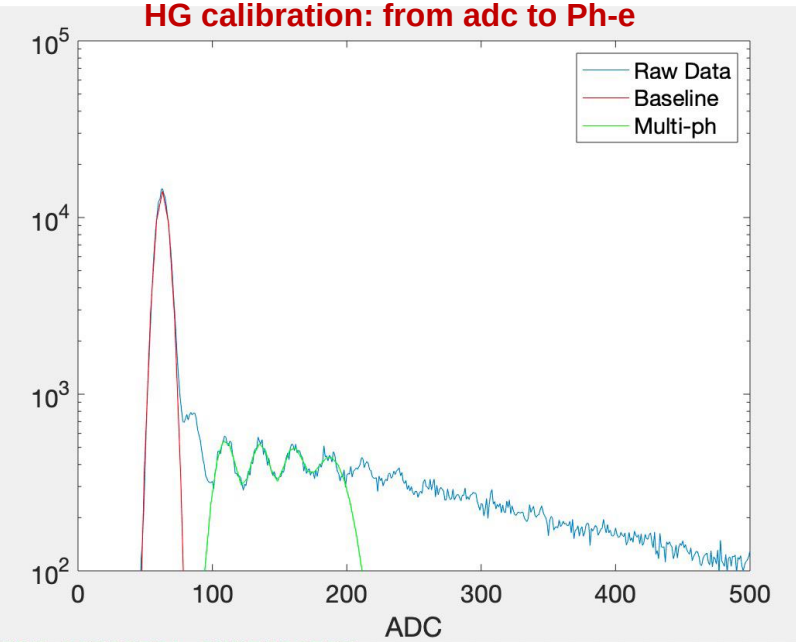


Talk "SiPMs for dual-readout calorimetry"
R.Santoro – Università dell'Insubria
Session 5 - Calorimeter Technologies for Future Colliders 1

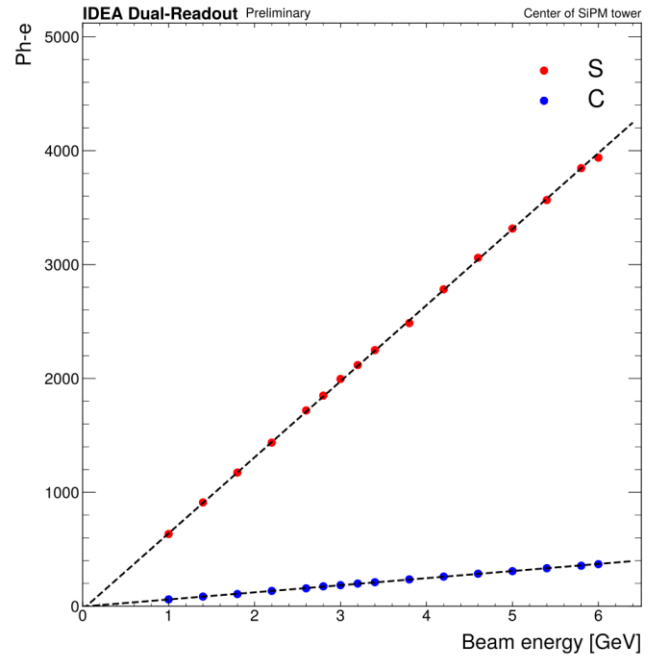
FERS in dual readout calorimetry

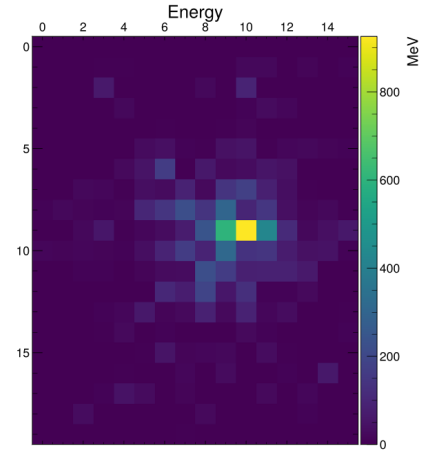
CAEN A5202 demonstrated to work for SiPM calibration and lead to excellent results in the linearity of the calorimeter response and EM shower containment

HG calibration: from adc to Ph-e

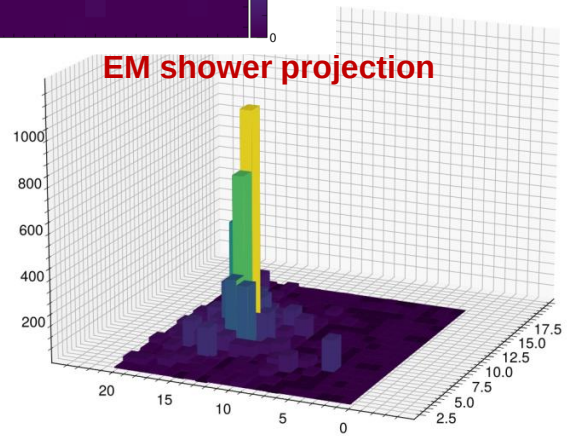


Calorimeter linearity up to 6 GeV





EM shower projection

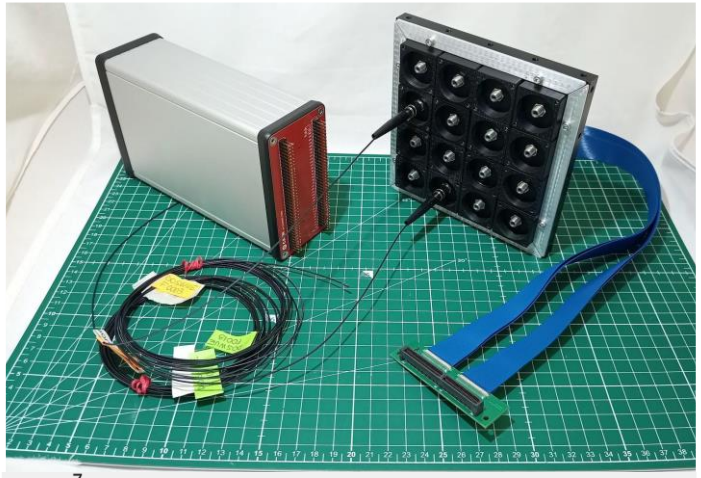


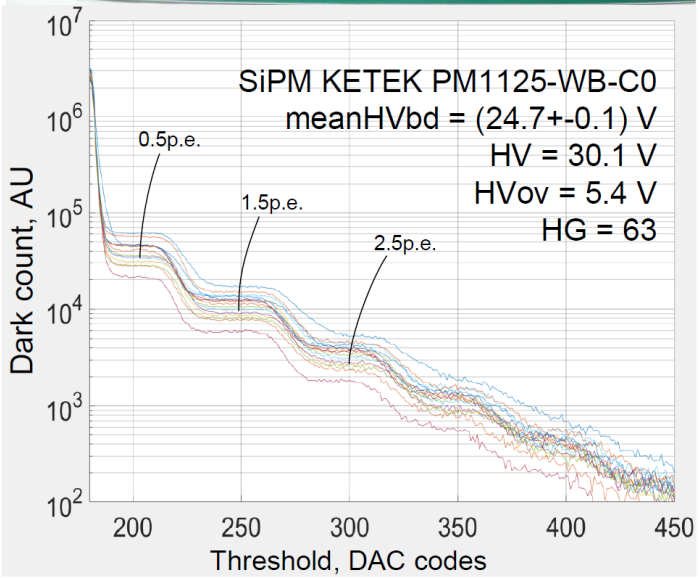
Courtesy of R. Santoro

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

FERS in ORIGIN project

- **Biomedical application:** real-time, in-vivo dosimeter imaging for oncological brachytherapy treatment
- **Standalone** desktop version DT5202 used to readout 16/32 PMMA fibers with scintillators in their tip
- CAEN DT5202 demonstrated to have a good imaging resolution and uniformity among channels
- Close staircases, clearly-resoluted p.e. and negligible noise

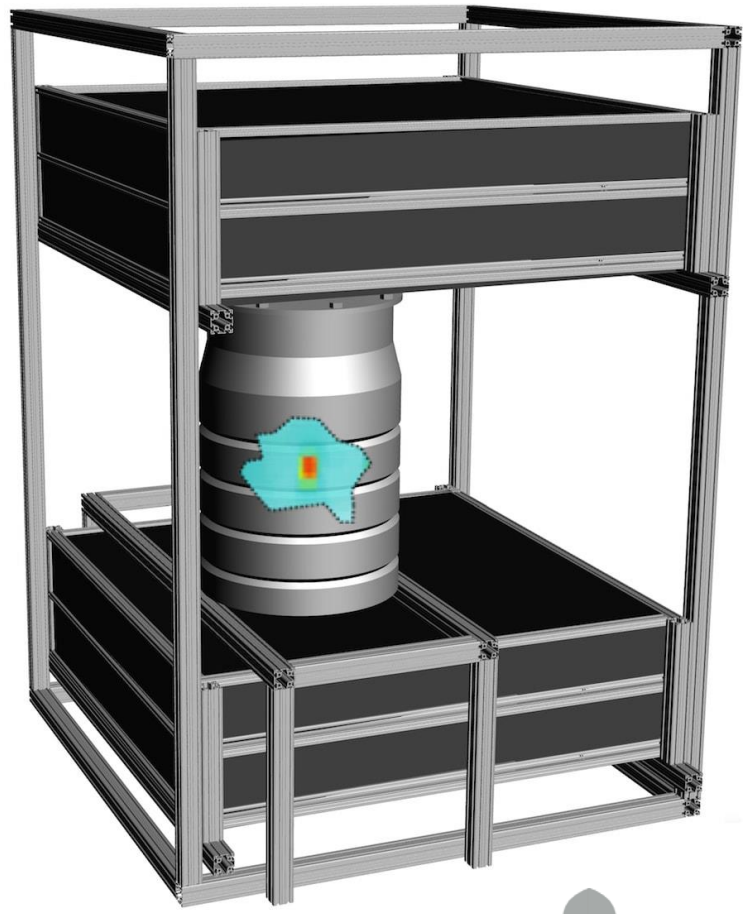




[See NSS-MIC 2021 poster "Qualification of a Silicon Photomultiplier scalable readout system" (#912)]

FERS in cosmic ray tomography

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

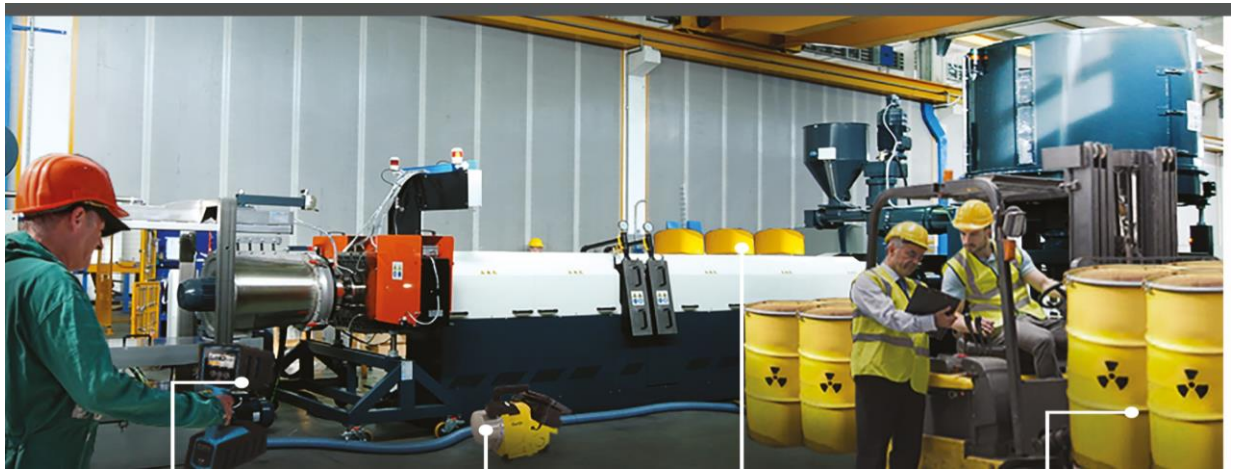


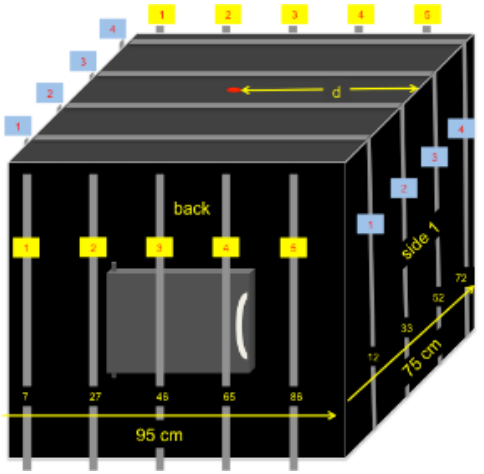
First-of-a-kind muography for nuclear waste characterization
D. Mahon *et al.*
Philos. Trans. R. Soc. A, 377 (2018), p. 0048, 10.1098/rsta.2018.0048

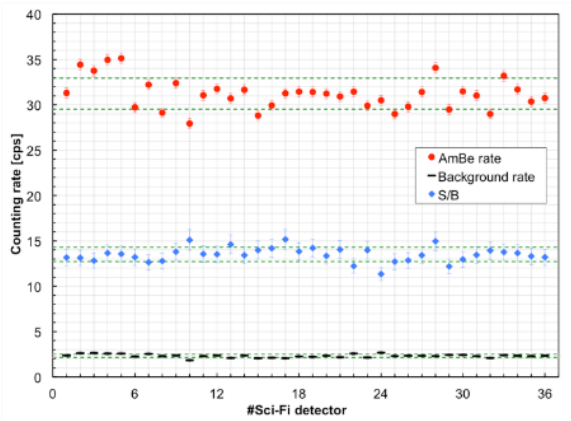
LYNKEOS TECHNOLOGY LTD

FERS in D&D operations

- **CAEN** is the coordinator of the **MICADO** project, aiming at developing reference processes and instrumentation for cleaning and decommissioning operations in nuclear power plants
- Detection system for gammas and neutrons, based on SciFi & SiLiF detectors
- **SciFi** readout with **FERS** electronics (SiLiF with CAEN V2740)
- Thanks to the **modular** structure, the instrument can be used for the radiological monitoring of the waste during storage

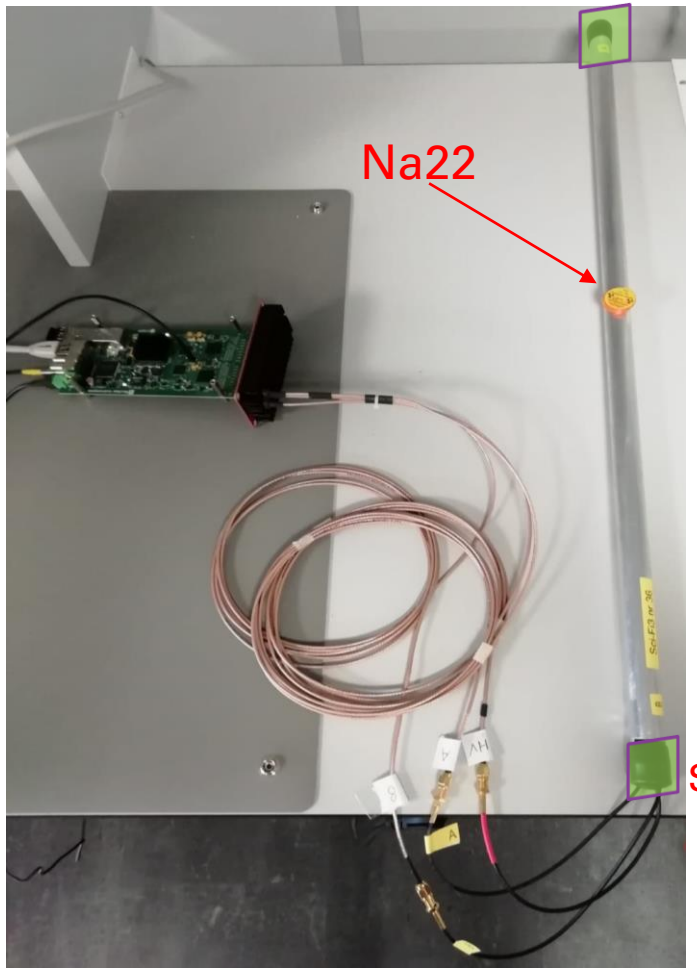




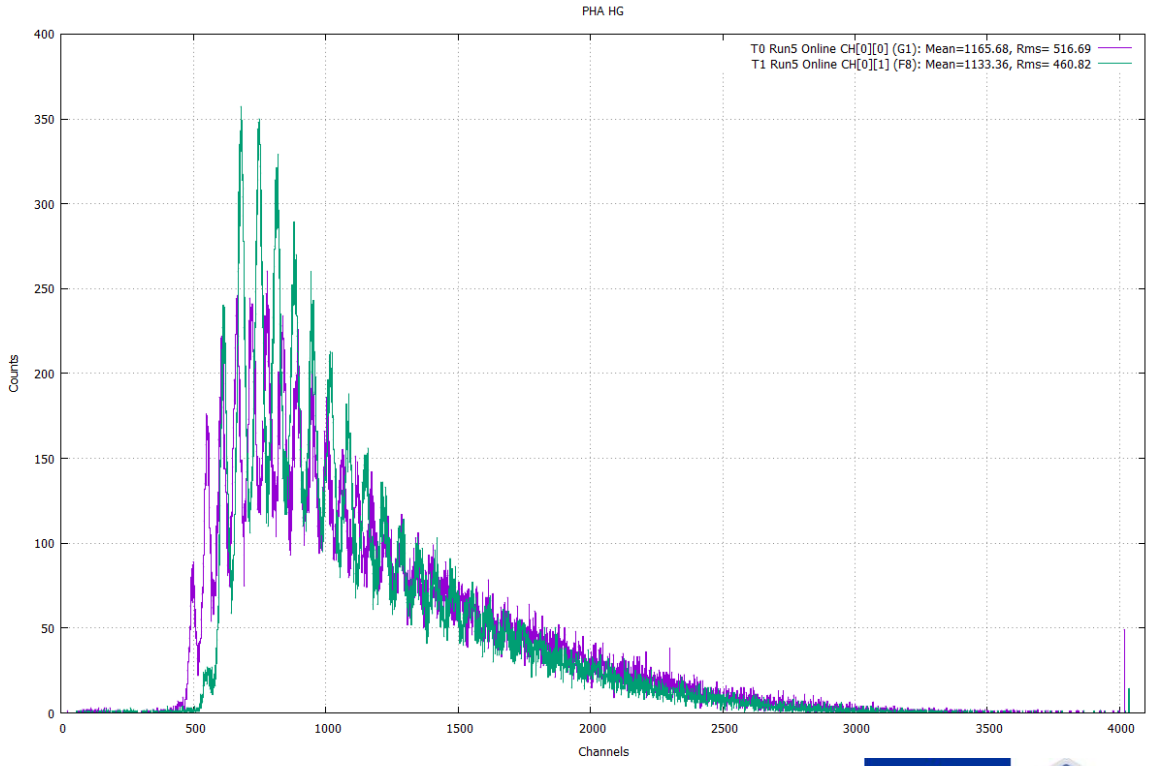


https://www.micado-project.eu/

FERS in D&D operations



- Readout of **SiPM-coupled SciFiGamma bar** using A5253 adapter
- Coincidence trigger



https://www.micado-project.eu/