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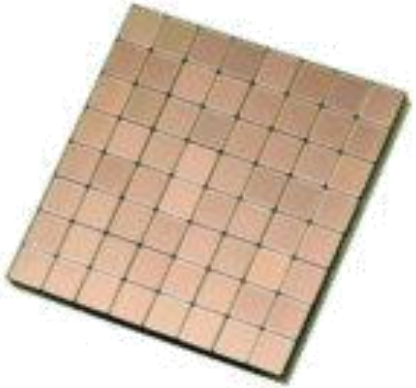
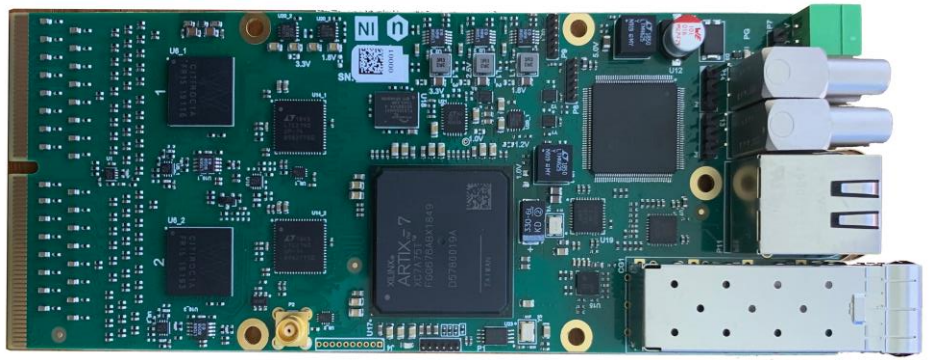
Tools for Discovery

Nuclear Instruments

Electronic Instrumentation





# FERS-5200: Front-End Readout System for large detector arrays

**Massimo Venaruzzo**

*IEEE Real Time 2020*

# Network of Companies

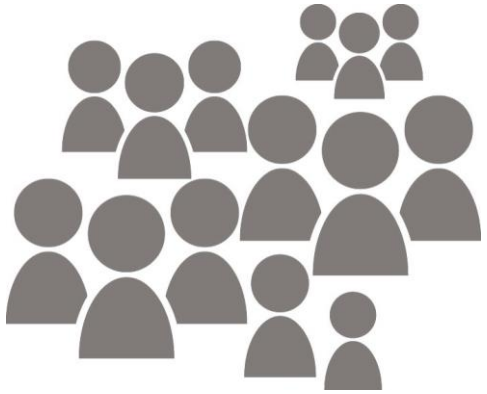
Founded in 1979, CAEN SpA (Costruzioni Appearecchiature Elettroniche Nucleare) as a spin-off of Pisa INFN.

**Core business**: Electronic Instrumentation for physics experiments (world leader)

**Spin-off activities:**

> RFID (2003),
> CAENels (2010),
> CAENqS (2012),
> CAEN SyS (2016)

**Total Employees: ~150**



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# CAEN Market

- For 40 years CAEN has been providing Scientists and Engineers with the most advanced electronic instrumentation for any particle or radiation detectors
- Strong of an extremely close collaboration with the world major research laboratories CAEN is proud to produce the best tools for:
  - High Energy Physics
  - Astrophysics
  - Neutrino Physics
  - Dark Matter Investigation
  - Nuclear Physics
  - Material Science
  - Educational
  - Homeland Security
  - Industrial Applications
- ISO9001 Certified

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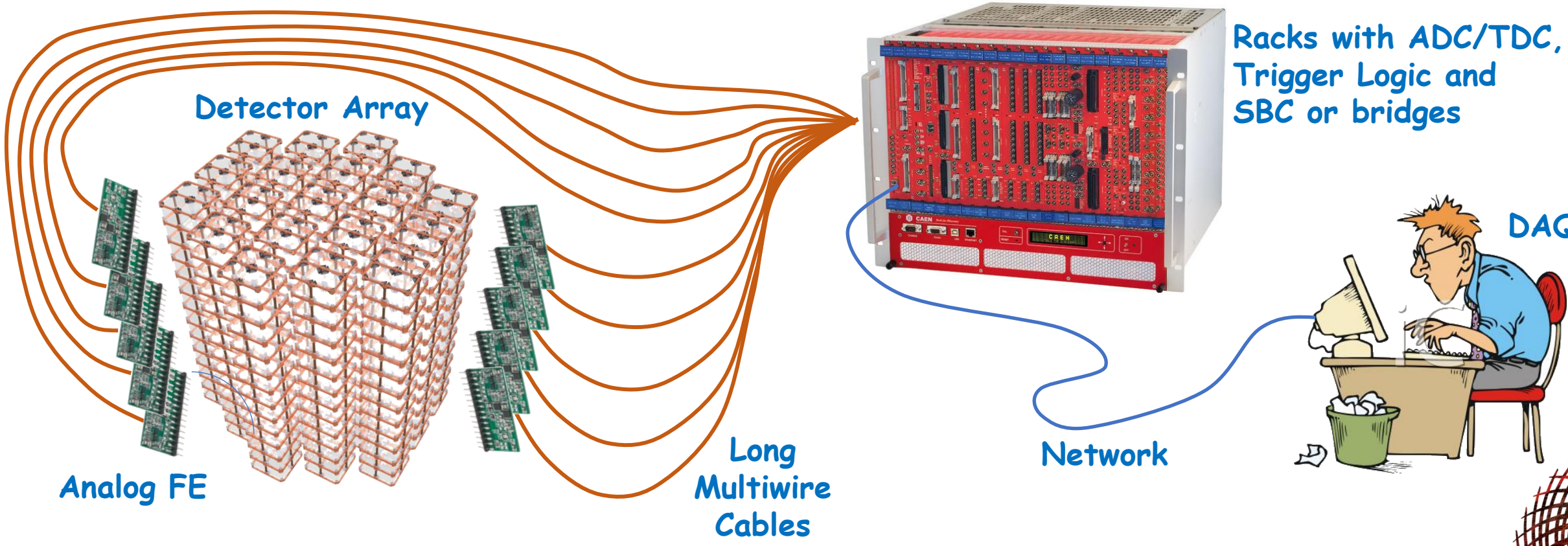
# Rackable Readout Electronics

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



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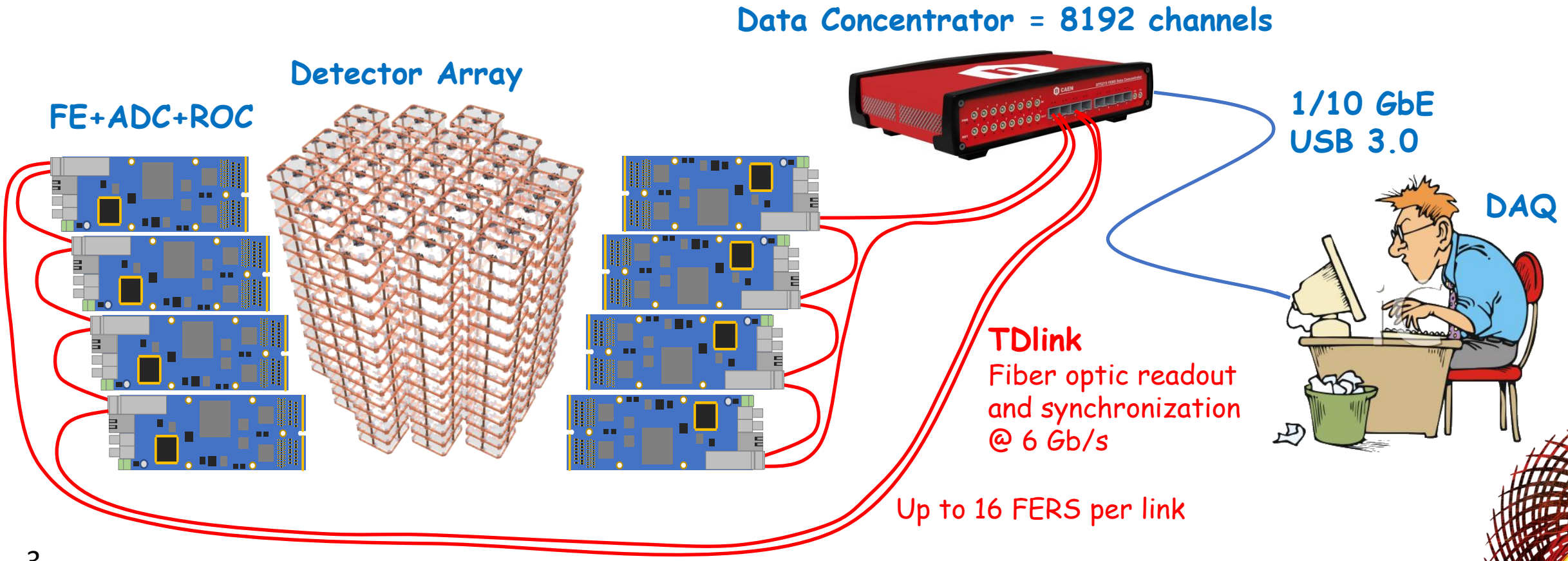
# Distributed Front End Readout System

- Front End Preamplifiers, A/D conversion and data processing/readout in small **FE card**
- **TDlink**: single optical ring connection for synchronization, readout and slow control
- Data Concentrator: provides global synch, trigger logic, event data building and storage
- Easy scalable and deployable: 8192 channels per Data Concentrator



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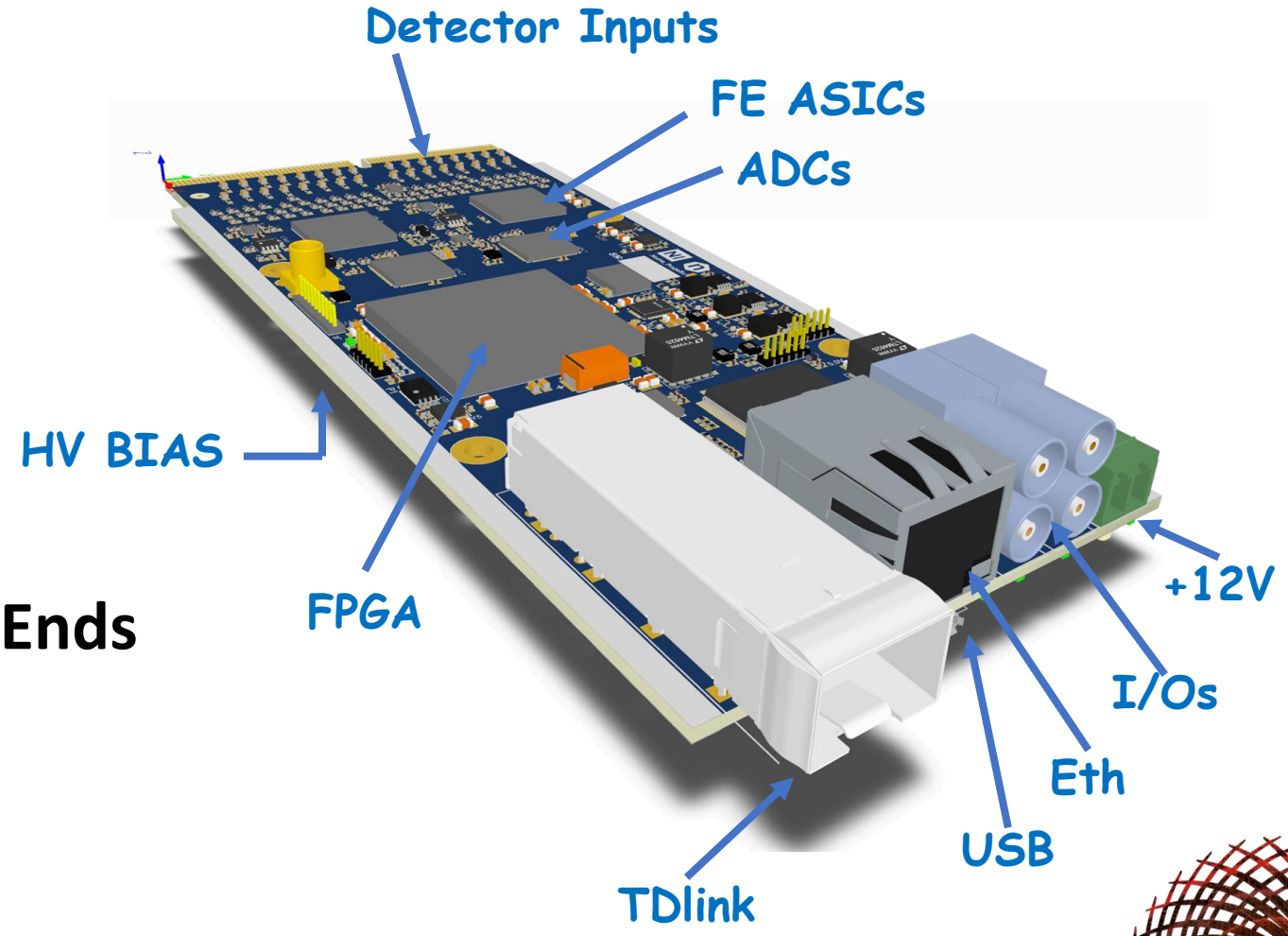
A new line of FE and readout electronics for:

- SiPM
- PMTs and MA-PMTs
- Gas Detector, wire chambers
- GEM
- Micromegas
- Silicon Strip Detectors
- Segmented HPGe detectors




**Same Infrastructure, different Front Ends**

**Quick integration of different ASICs**



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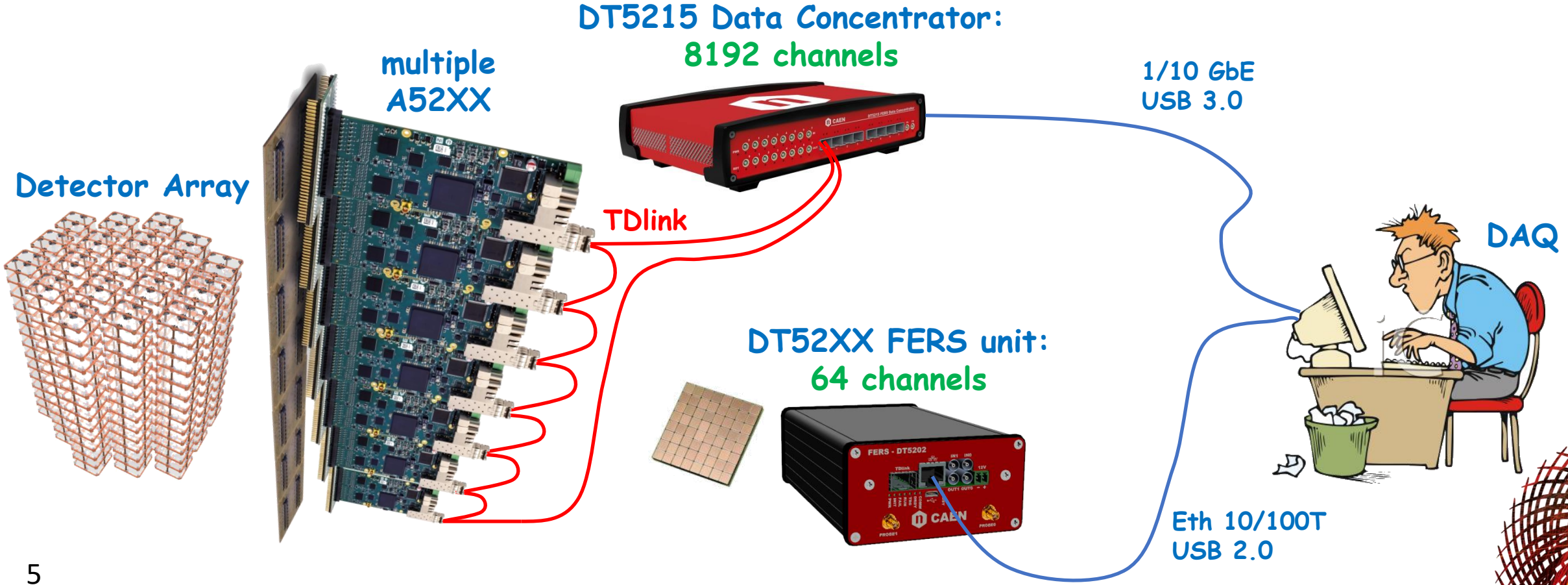
# From evaluation to large experiments

- One FERS unit can be used stand-alone in a desktop form factor, directly connection to PC (USB or Ethernet). No additional hardware required!
- Naked FERS units can be arranged in custom backplanes/mechanics to build large systems, keeping the same user interface (SW, libraries, etc.) and the same electronics



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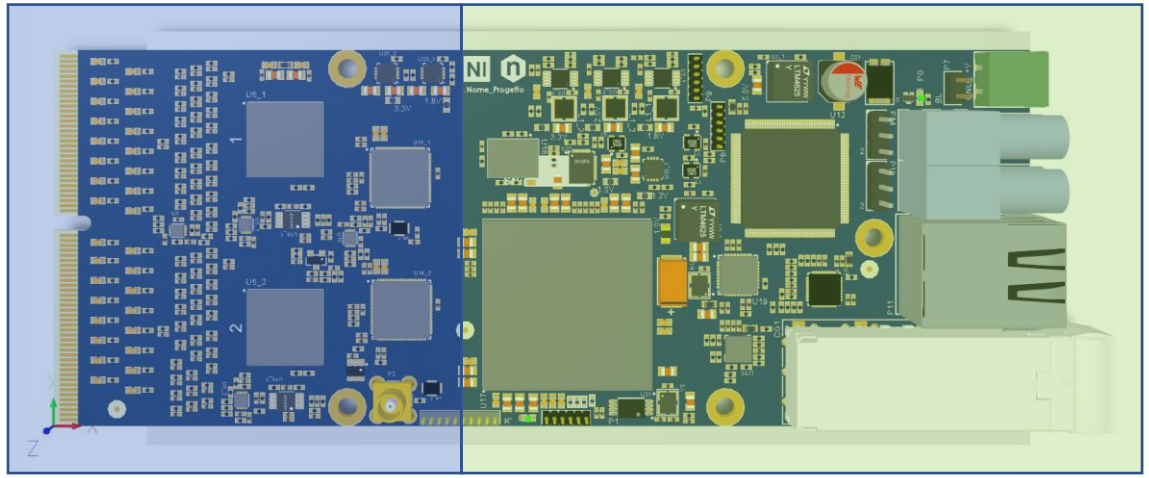
# FERS flavors (possible future implementations)

- **Citiroc:** SiPM Spectroscopy (Weeroc) – Done!
- **picoTDC**: 5 ps TDC (CERN) – almost Done
- **Petiroc:** SiPM timing (Weeroc)
- **Maroc:** MA-PMT (Weeroc)
- **Skiroc:** Silicon Detector (Weeroc)
- **Gemroc:** Gem Detector (Weeroc)



DETECTOR SPECIFIC COMMON INFRASTRUCTURE

- **Sampic:** 10 GS/s SCA waveform digitizer and ps TDC (LaL)
- **AARDVARC / ASOC:** 13 GS/s and 3.2 GS/s SCA waveform digitizer and ps TDC (Nalu Scientific)
- **Hybrid Solutions**: FE in separate box, plug-in FERS with flash ADCs (e.g. 16 channel, 100 MS/s, 14 bit)
  - **A1442:** 16/32 channel preamp for Silicon Strip Detectors
  - **PADIFF**: 32 channel preamp for Neutron Detector
  - Detached FE-ASIC for cryogenic applications



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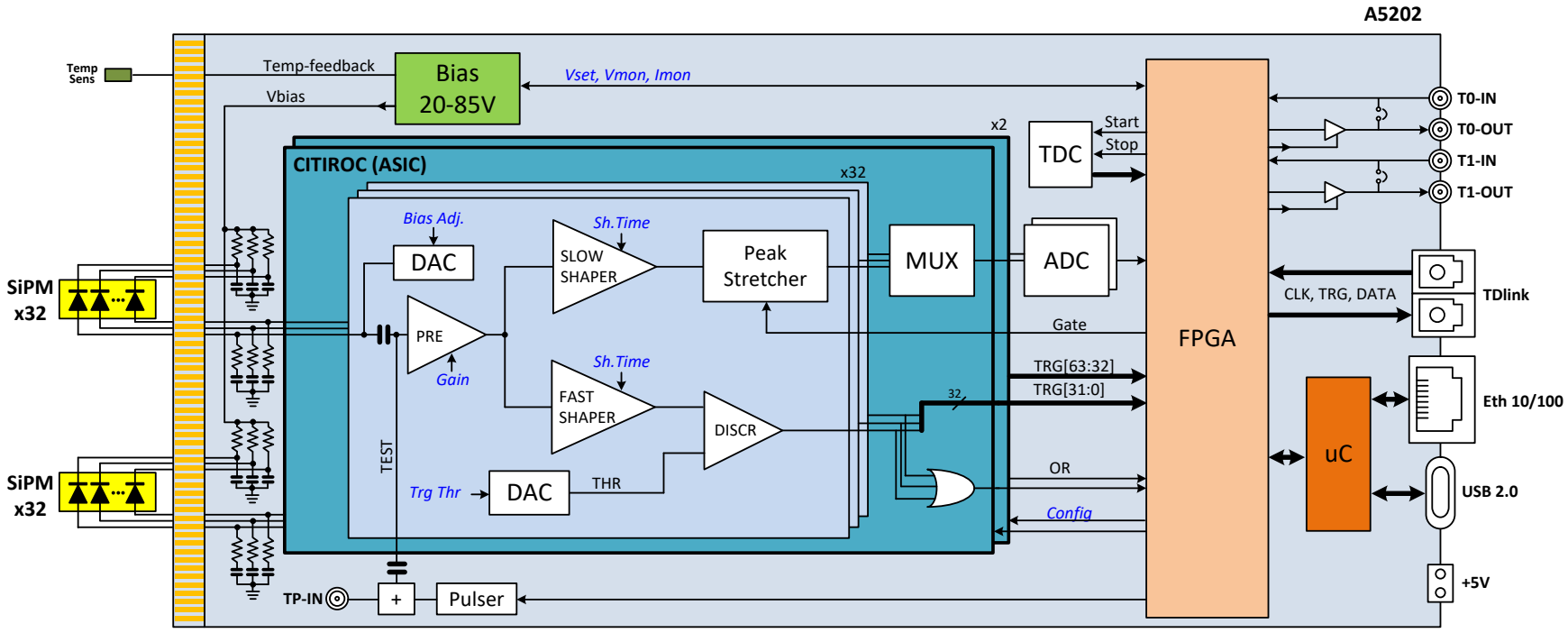
# A5202: 64 channel SiPM readout (Citiroc 1A)

- Based on two ASICs Citiroc 1A (Weeroc): 64 channel SiPM readout
- Embedded HV bias (20-85V) with temperature feedback. Individual HV adjust per channel
- Programmable gain and shaping time for High Res PHA (Multiplexed A/D, max Trg Rate = 100 Kcps)
- Individual discriminator thresholds: down to 1/3 p.e.
- Discriminator outputs for high rate counting (20 Mcps), Time stamping (0.5 ns) and ToT (low res PHA)
- 50 ps TDC for high resolution time stamping of OR trigger (to an external time reference signal)
- Acquisition modes: photon counting, spectroscopy mode (PHA), list mode (channel ID + Tstamp + ToT)



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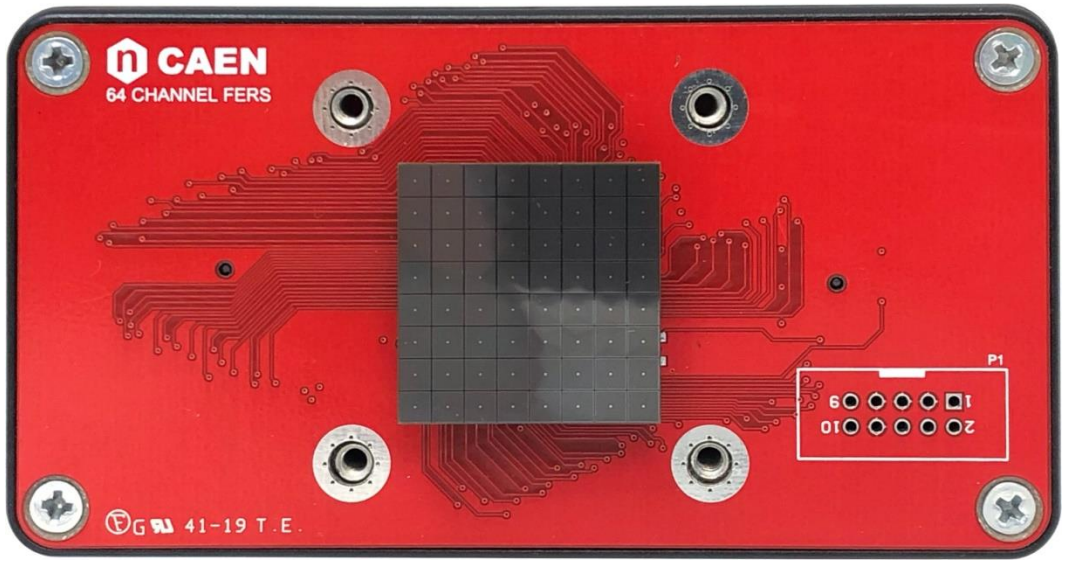
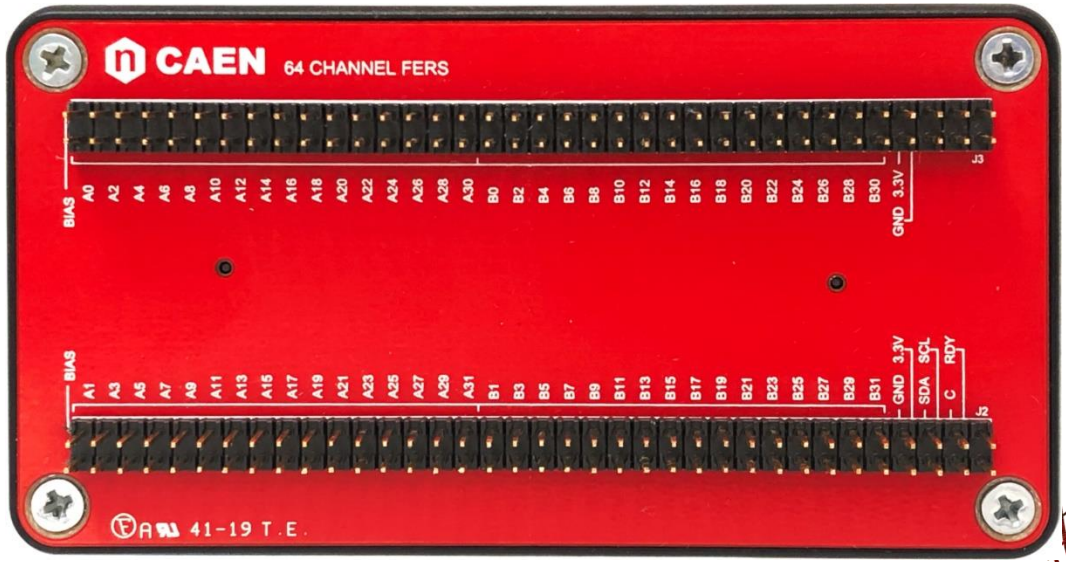
# A5202: 64 channel SiPM readout (Citiroc 1A)

REAR PANEL: COMMON INFRASTRUCTURE

FRONT PANEL : EXCHANGABLE AND CUSTOMIZABLE



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# Acquisition Modes (for A5202)

- **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 (read fired channels only)
  - 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
  - Simultaneous latched at programmable time frames and saved to memory (MCS mode)
  - Counting rate up to ~20 Mcps/ch
- **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 (T-ref signal from LEMO input)
  - Gating mode (coincidence with external gate)
  - Optionally, **ToT** (0.5 ns) provided for low resolution PHA: Charge Resolution = 1.5%
  - Max total hit rate = ~50 Mcps/board
- **Waveform Mode**:
  - Signal inspection: mux output waveform and control signals



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# 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**
  - Triggers produce formatted data packets in the FERS units. Little local data buffering.
  - Data Concentrator reads data fragments belonging to the same event from FERS units (using Tstamp or Trigger-ID)
  - **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
  - Data aggregated in small packets in FERS units, then bigger packets in Data Concentrator
  - 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



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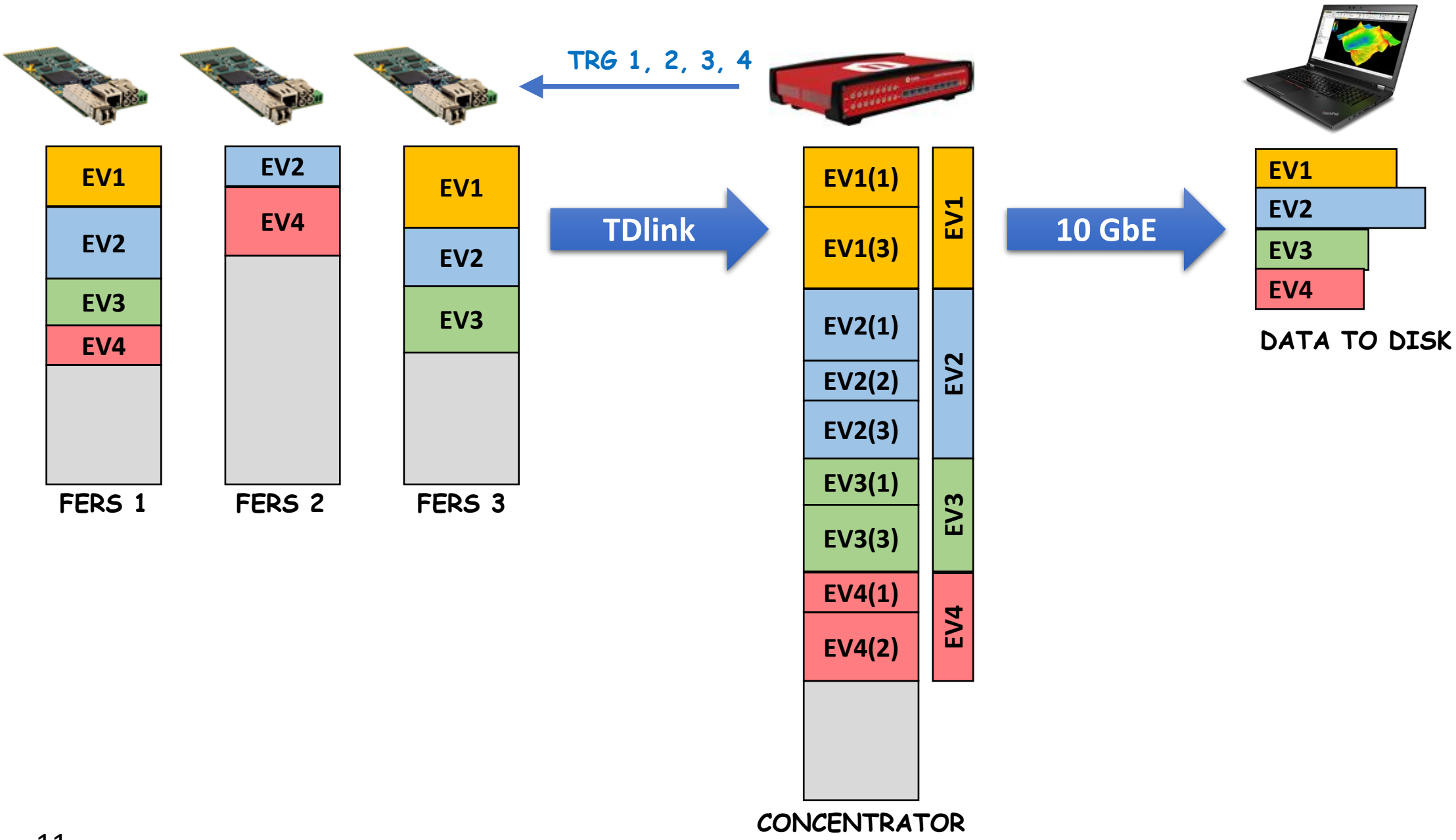
# In-built sparse event readout



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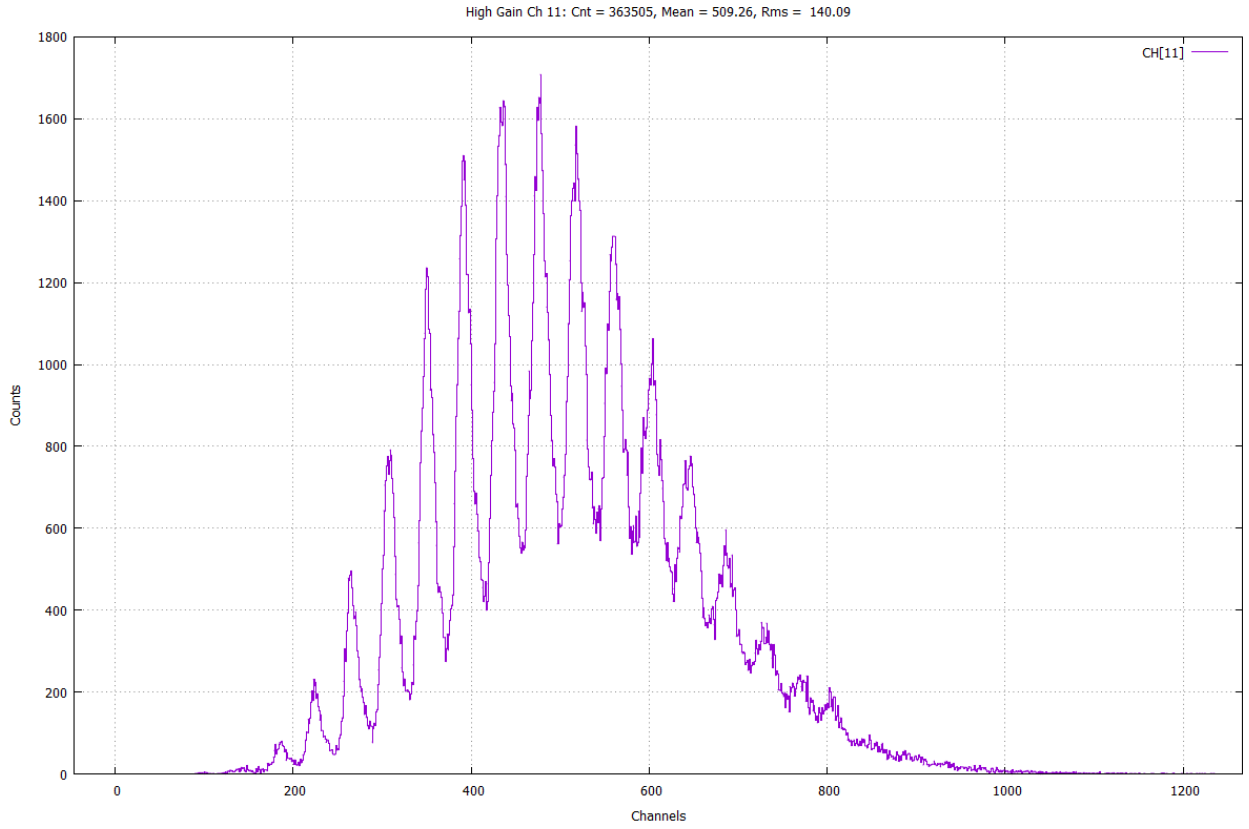
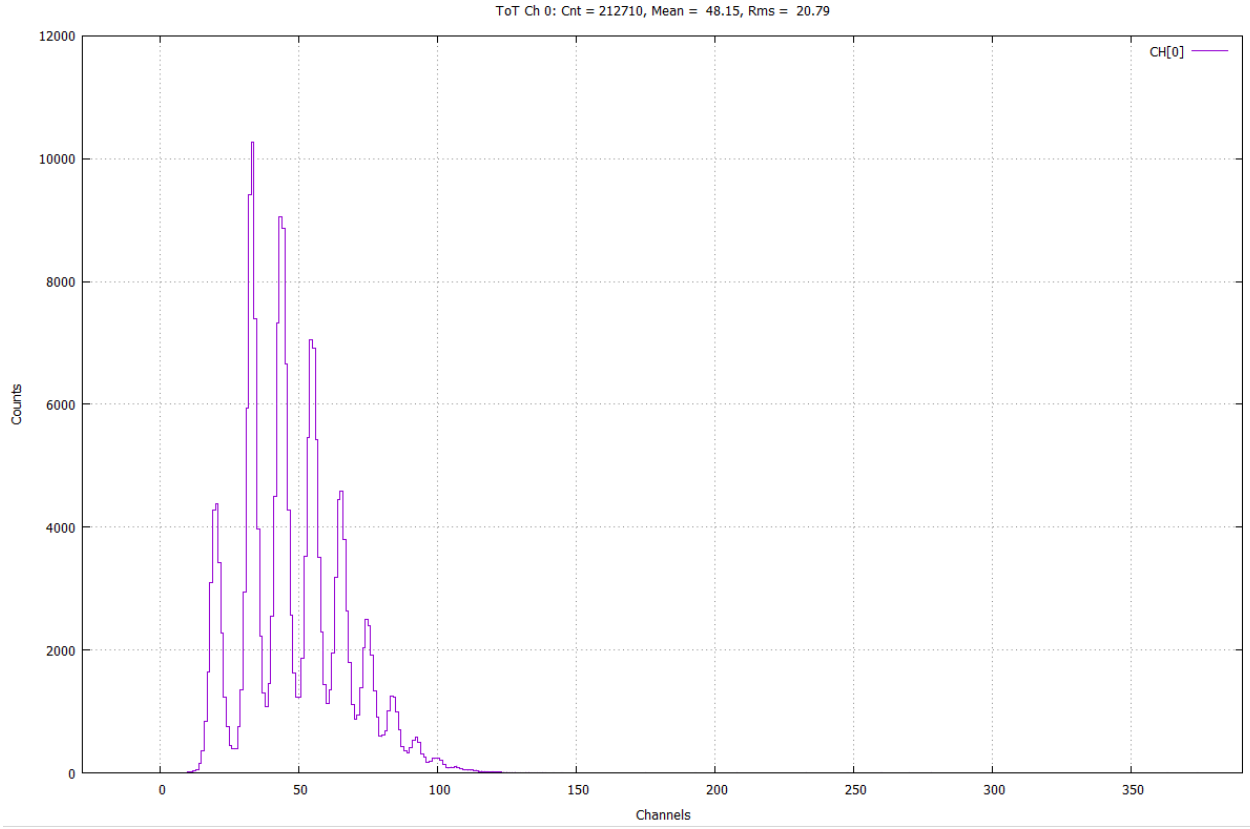
# First preliminary results (Multiphoton peak)

SiPM Matrix Hamamatsu S13361-3050AE-08




Multiphoton peak (PHA mode)




Multiphoton peak (ToT mode)

Some optimization about the noise still to be done



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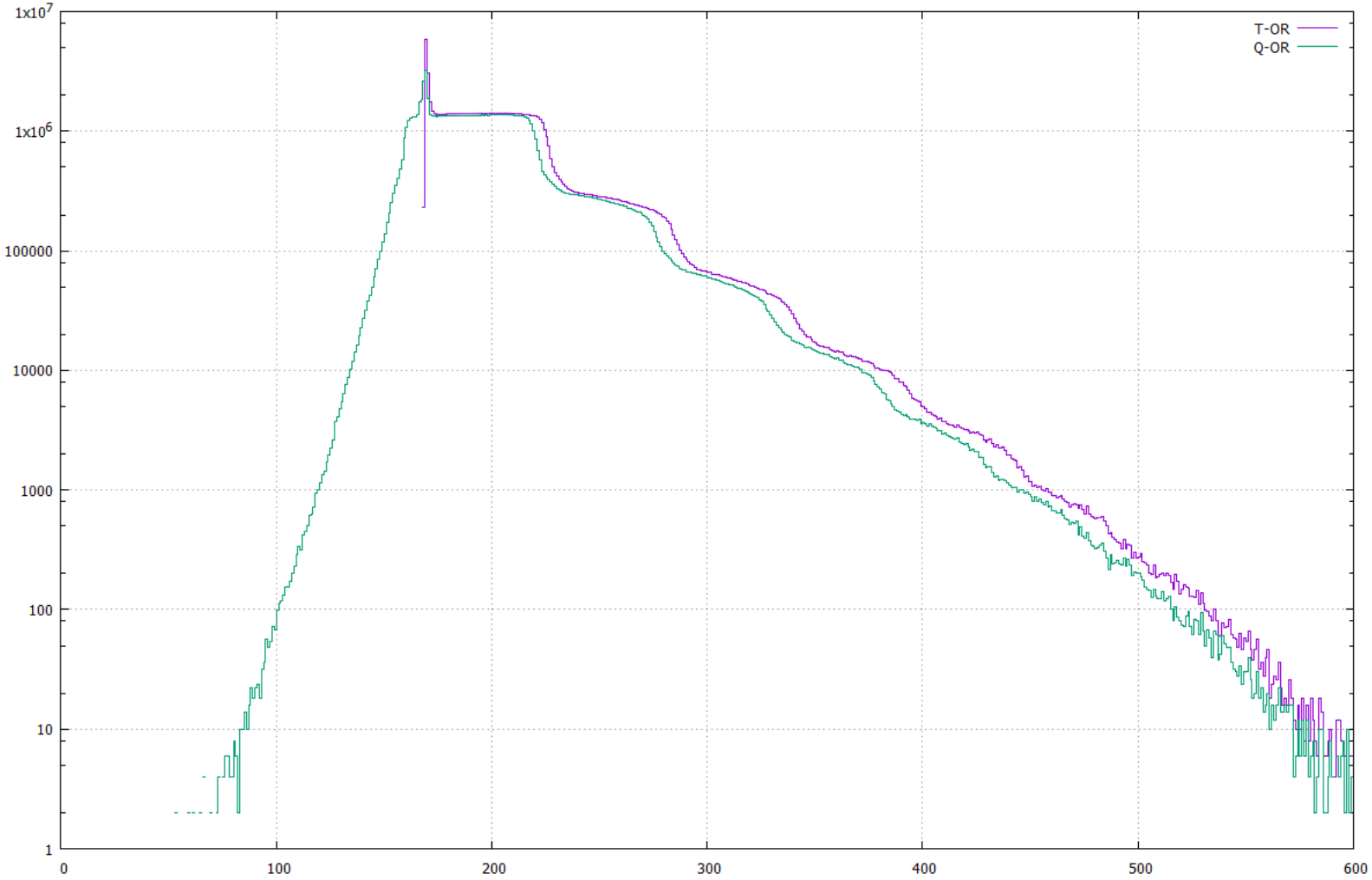
# First preliminary results (Staircase)

SiPM Matrix Hamamatsu S13361-3050AE-08




Green line: Slow discriminator

Magenta line: Fast discriminator

Counts vs Threshold (Staircase) – OR of the SiPM matrix pixels



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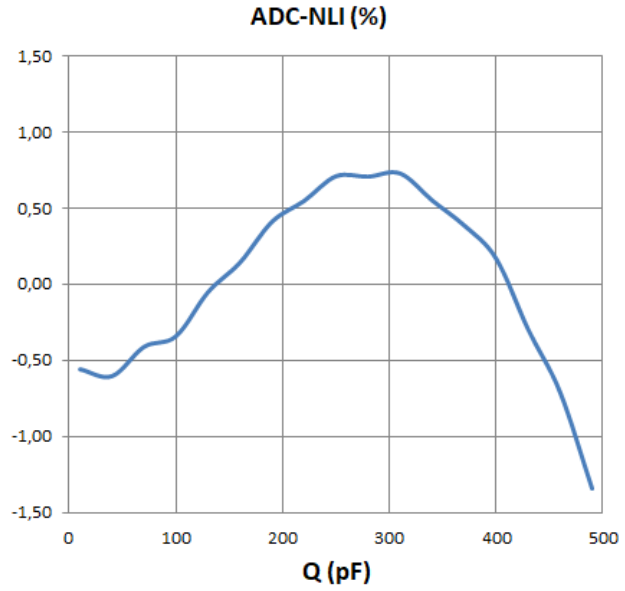
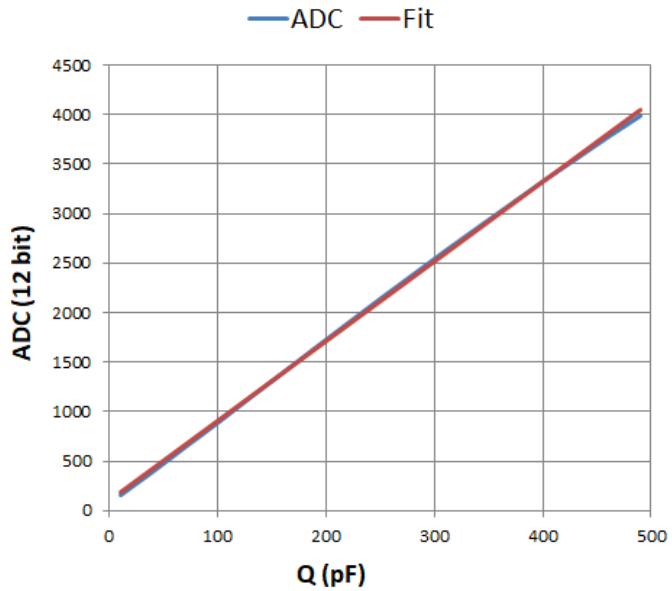
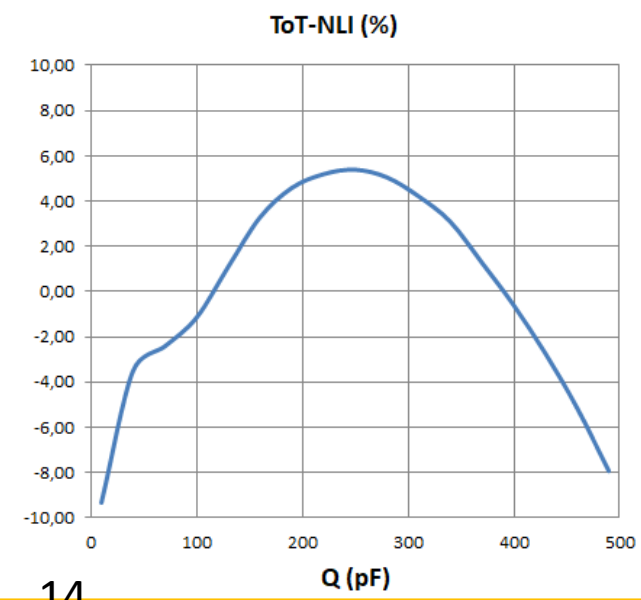
# First preliminary results (Linearity – Low Gain Case)



**Test conditions:**

- Input Signal:
  - Square Wave
  - Freq=100Hz
  - RiseTime=10ns
  - FallTime=100us
- Variable amplitude (Vin) from 100mV to 4900mV in steps of 300mV
- C-inject = 100 pF
- 1 pe = $10^6$ electrons = 160 fC (assuming SiPM Gain = $10^6$)
- Citiroc Configuration:
  - Shaping Time = 0 (87.5ns)
  - Coarse_Thr_T = 175
  - Fine_Thr_T = 0
  - Low Gain = 36
  - Trg_HoldTime = 100 ns

**Fit results:**

| | |
|---|---|
| RMS | 8,69 |
| RMS in pC | 1,08 |
| RMS in p.e. | 6,76 |

| | |
|---|---|
| RMS | 0,50 |
| RMS in pC | 7,55 |
| RMS in p.e. | 47,19 |



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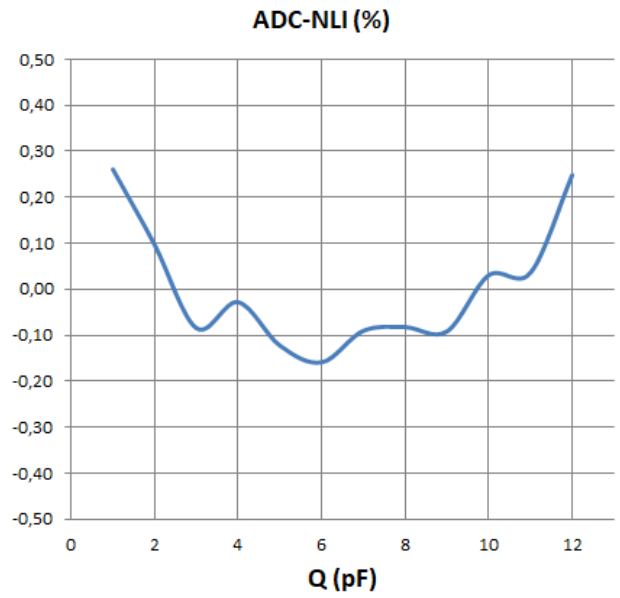
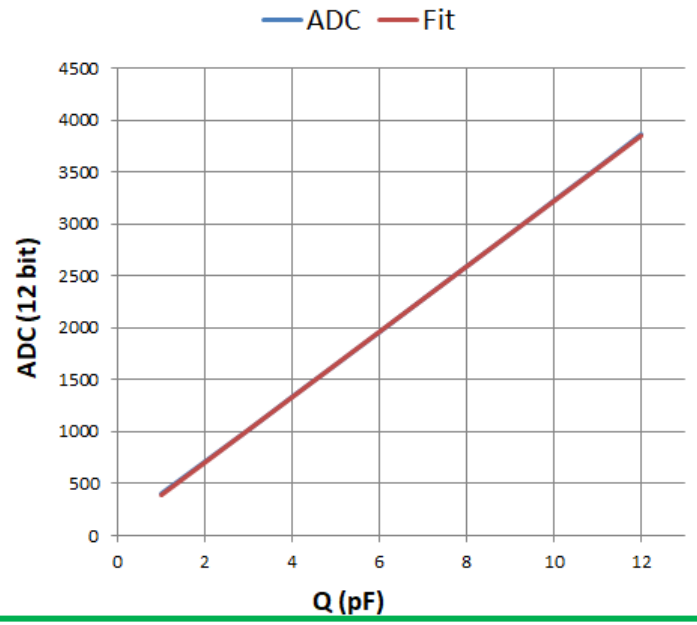
# First preliminary results (Linearity – High Gain Case)




ToT NLI Test in High Gain condition

To Be Done

**Test conditions:**

- Input Signal:
  - Square Wave
  - Freq=100Hz
  - RiseTime=10ns
  - FallTime=100us
- Variable amplitude (Vin) from 10mV to 120mV in steps of 10mV
- C-inject = 100 pF
- 1 pe = $10^6$ electrons = 160 fC (assuming SiPM Gain = $10^6$)
- Citiroc Configuration:
  - Shaping Time = 5 (25ns)
  - Coarse_Thr_T = 185
  - Fine_Thr_T = 0
  - Low Gain = 51
  - Trg_HoldTime = 200 ns

**Fit results:**

| | |
|---|---|
| RMS | 17,08 |
| RMS in pC | 0,054 |
| RMS in p.e. | 0,34 |

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# Conclusion

- FERS5200 Platform designed to be a solution for large detectors arrays in which the approach with old-fashioned analog electronics but also the digital approach based on digitizer becomes not affordable
- SiPM is the first supported detector but more to come (picoTDC is the next to come)
- Some development and testing steps still to be done to optimize some capabilities and test the platform
- Available in 2021

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# Thank You