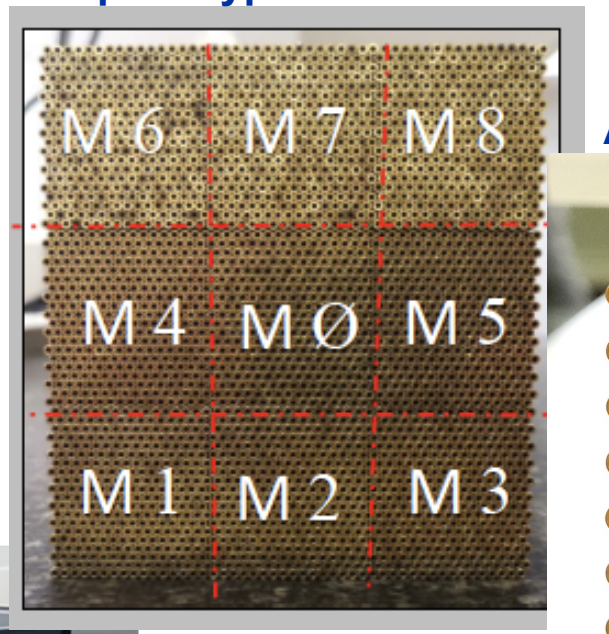
Report on dual-readout calorimeter 2021 beam tests

Lorenzo Pezzotti - CERN
on behalf of the IDEA Dual-Readout Group

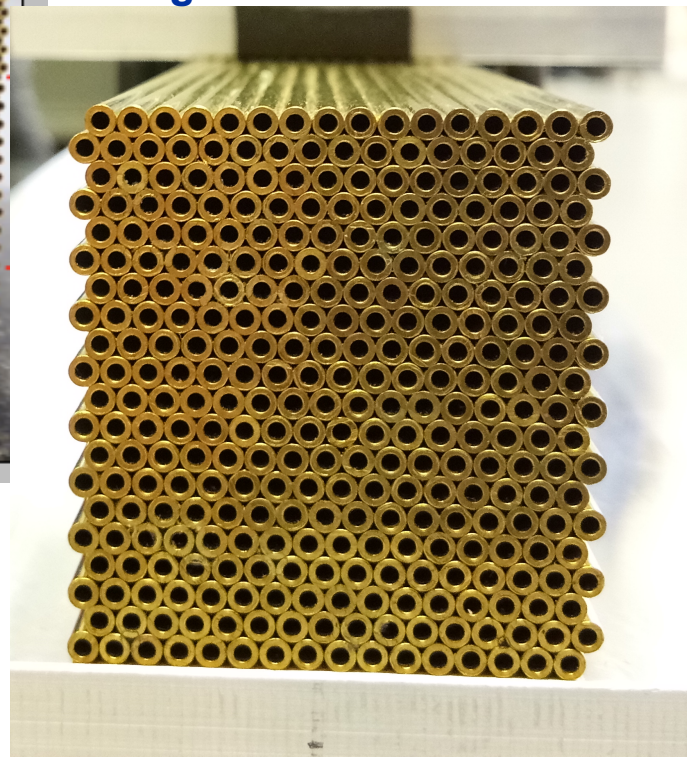
The 2020 dual-readout prototype

- In 2020/2021 we built a new capillary-tube-based dual-readout prototype.
  - Electromagnetic dimensions of 10x10x100 cm^3.
  - 9 towers containing 16x20 capillaries (160 C and 160 S).
  - Capillary tube with outer diameter of 2 mm and inner diameter of 1.1 mm. 1-mm-thick fibers.
- Goal: millimetric 2-dimensional shower-shape reconstruction in dual-readout calorimeters.

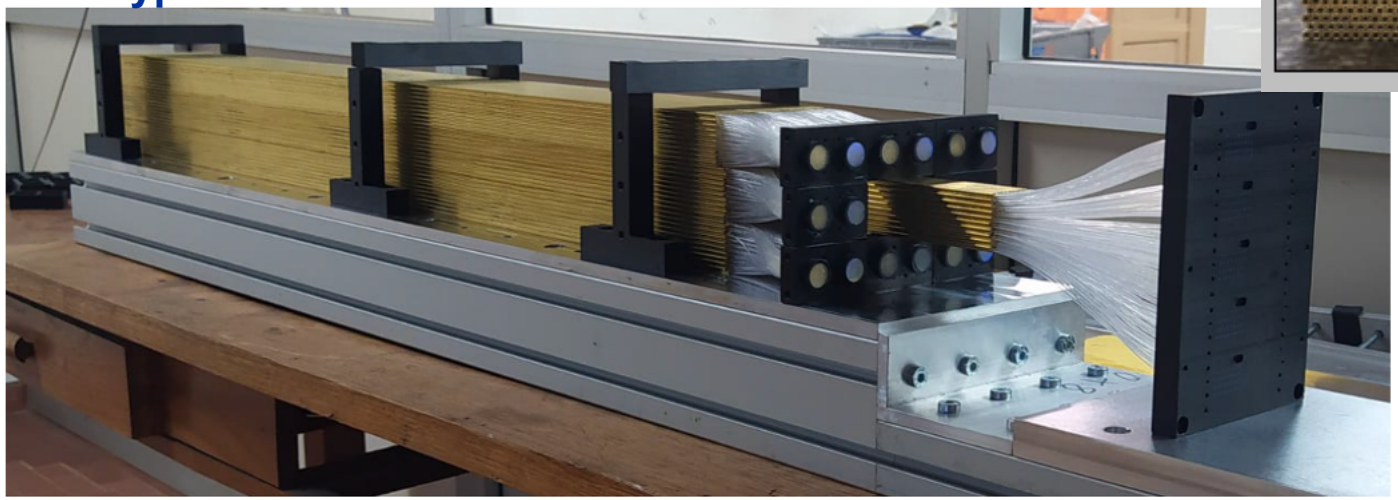
Full prototype - 9 towers



A single tower



Prototype rear end

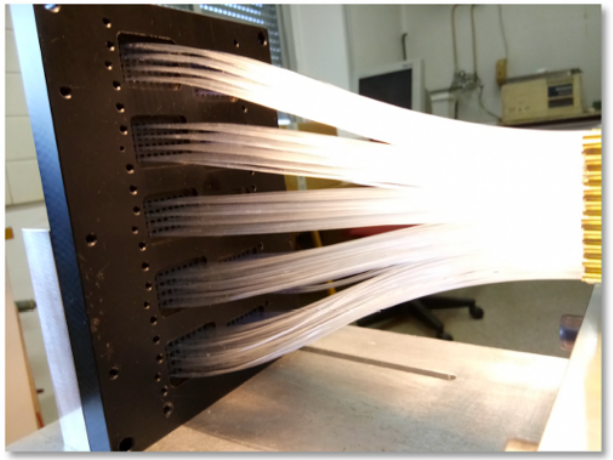


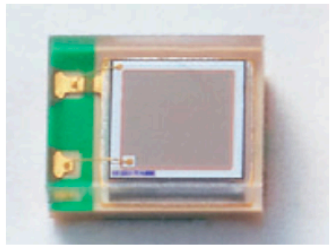
More on mechanics and construction at Gabriella Gaudio's talk at this workshop.

The 2020 dual-readout prototype readout system

- Superior granularity achieved using a hybrid readout system:
  - 320 SiPMs in the central tower independently read-out using
    - 5 FEE readout boards, operated in self-trigger mode.
  - Surrounding 8 towers read-out by two PMTs per tower providing an independent Cherenkov and Scintillation light readout.

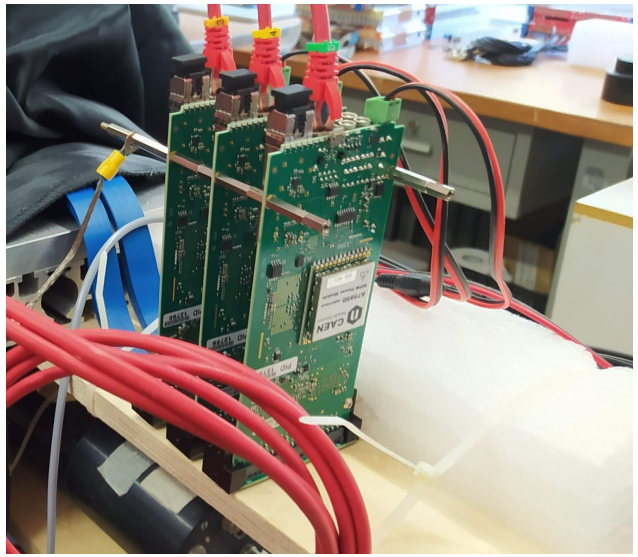
Fiber guiding system





Hamamatsu SiPM: S14160-1315 PS
Cell size: $15\ \mu m$

Front end board housing 64 SiPM



Readout Boards CAEN A5202

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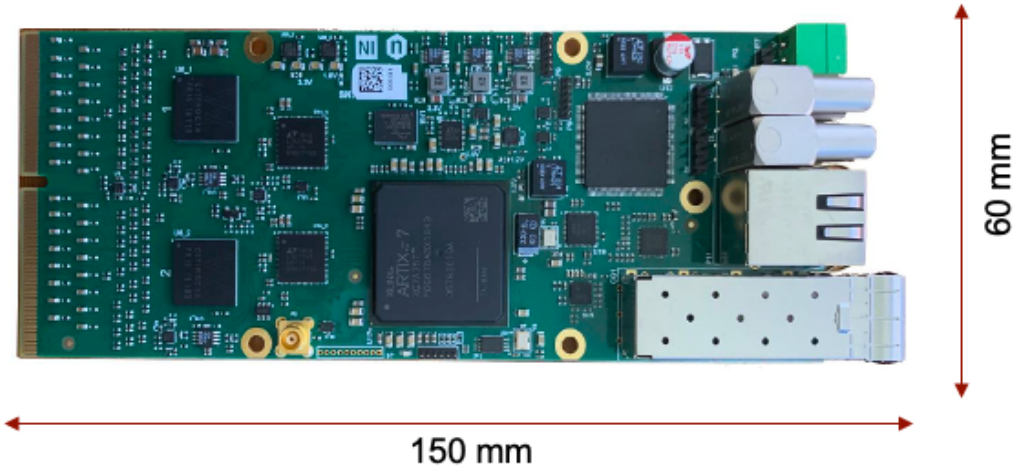
FERS A5202

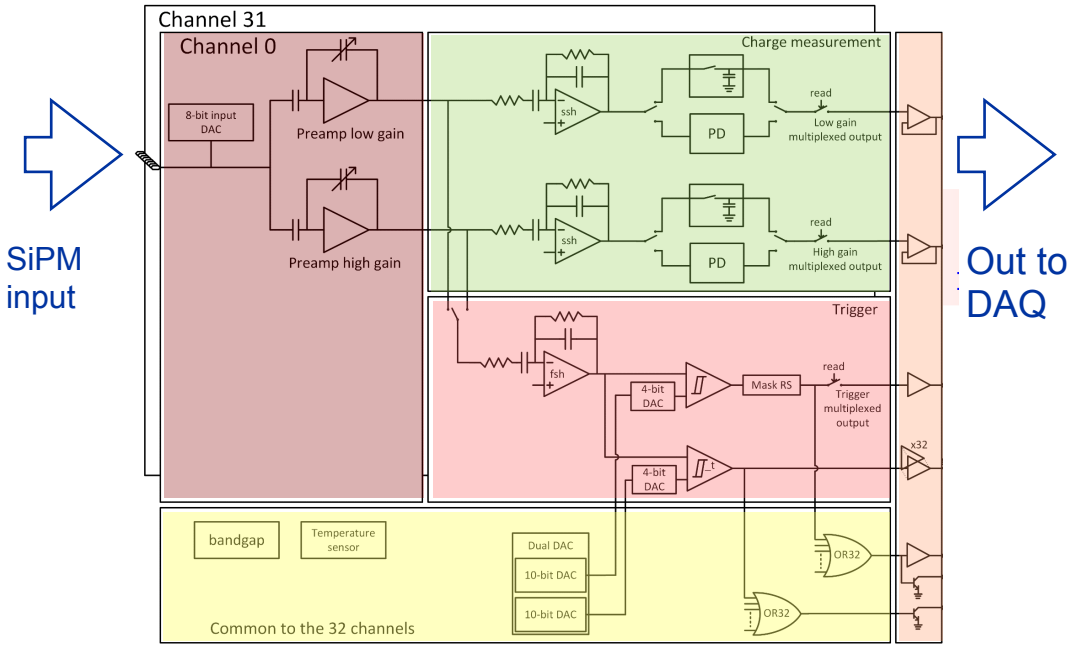


- Two Citiroc1A for reading-out up to 64 SiPMs
- One (20 – 85V) HV power supply with temperature compensation
- Two 12-bit ADCs to measure the charge in all channels
- Timing measured with 64 TDCs implemented on FPGA (LSB = 500 ps)
- 2 High resolution TDCs (LSB = 50 ps)
- Optical link interface for readout (6.25 Gbit/s)

The 2020 dual-readout prototype readout system

- Each SiPM signal split in a Low Gain and a High Gain (x10) charge integrator.
  This configuration allows to calibrate the signal in p.e. in a wide range (from 1 to 4000 p.e.).

CITIROC 1A: block diagram



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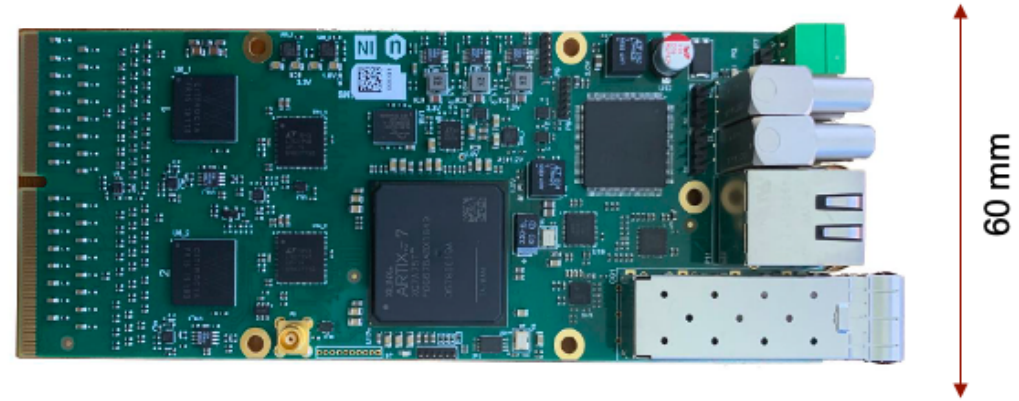

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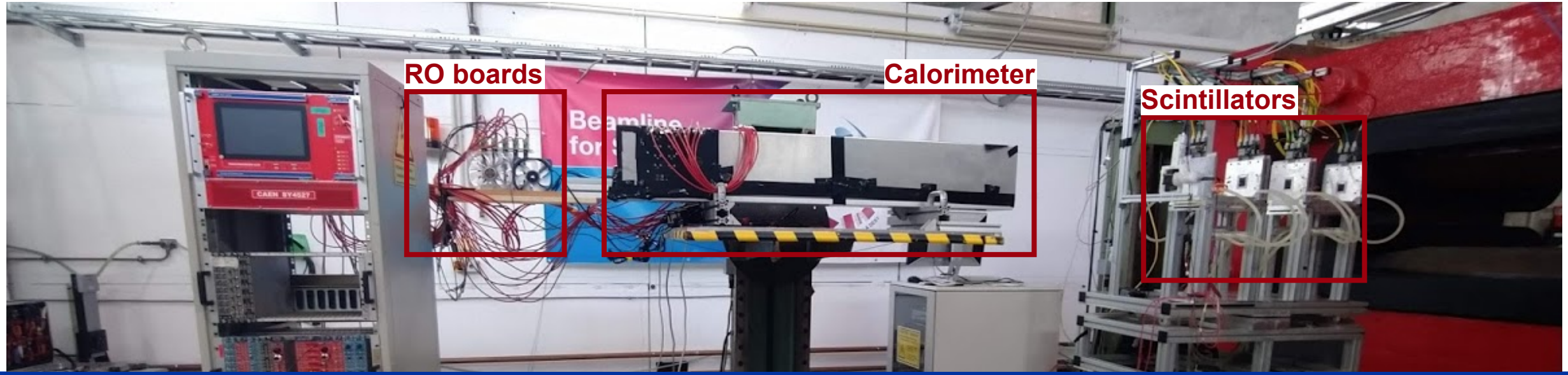
Two beam tests

- At DESY (June 2021)
  - e^- with energy range 1-6 GeV
    - Energy scan both with and without yellow filters on Scintillating fibers.
    - Scan over multiple points at the calo surface to check the dependency of the response on the position.



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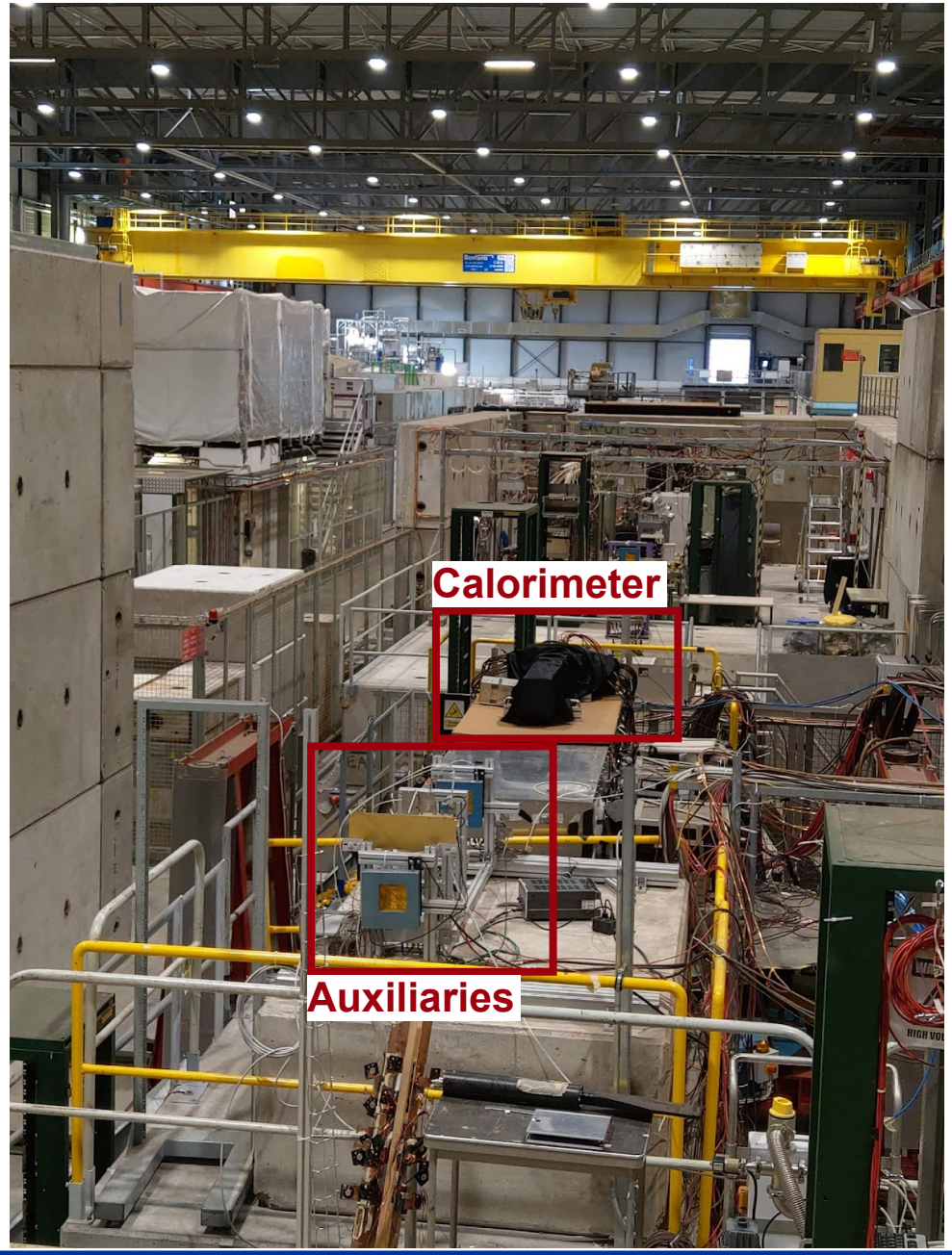
- At CERN-SPS H8 beam line (August 2021)
  - e^+ with energy range 10-125 GeV
    - Energy and position scan.
    - e^+ beams highly affected by π^+ contamination.
  - μ^+ in non-monochromatic beams.



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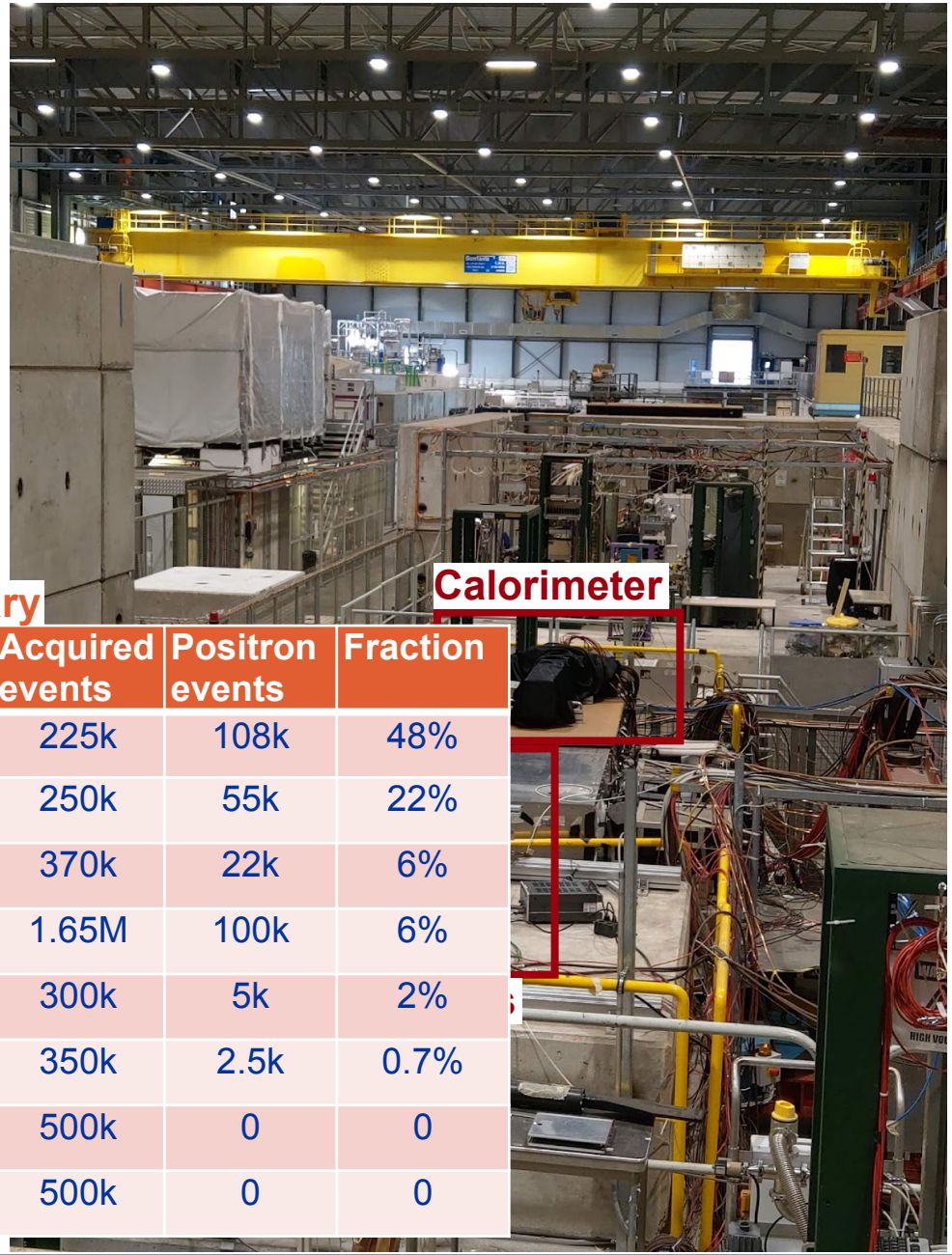
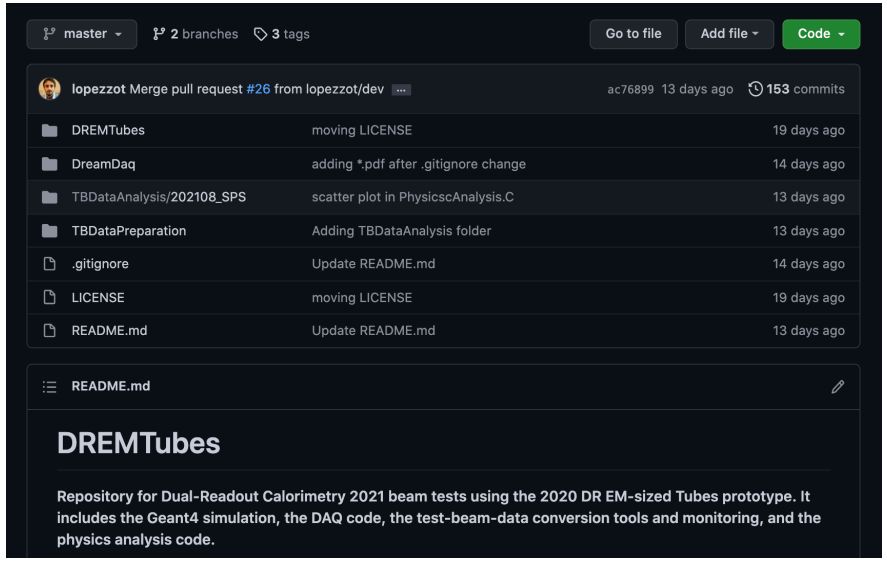


Preliminary

E beam (GeV)	Acquired events	Positron events	Fraction
10	225k	108k	48%
20	250k	55k	22%
30	370k	22k	6%
40	1.65M	100k	6%
60	300k	5k	2%
80	350k	2.5k	0.7%
100	500k	0	0
125	500k	0	0

The 2021 beam test SW

- The 2021 dual-readout calorimeter software is located in a new GitHub repo:
  - [github]
- Divided into four sub-repos:
  - DREAMDaq/ → Test beam data acquisition code
    Contact: Roberto Ferrari
  - TBDataPreparation/ → Converters from raw data to analysis ntuples and raw data monitoring
    Contacts: Lorenzo Pezzotti, Iacopo Vivarelli, Andrea Negri Edoardo Proserpio and Romualdo Santoro
  - TBDataAnalysis/ → Macros for high-level-objects analysis
    Contacts: Lorenzo Pezzotti, Iacopo Vivarelli, Edoardo Proserpio and Romualdo Santoro
  - DREMTubes/ → Geant4 test-beam simulation
    Contact: Lorenzo Pezzotti



Raw data handling and workflow

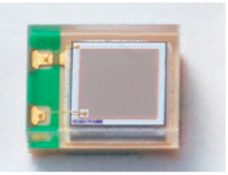
Two independent DAQ systems (SiPMS + (PMT & auxiliaries)) used, therefore the data conversion flow looks like this

Raw Data Handling

Raw ASCII Data as DAQ Output for PMTs and auxiliaries

Rootified raw data output for PMTs and auxiliaries

Rootified raw data output for SiPMs



.dat files as raw data output for SiPMs

Data Merging

Stored events from the two DAQs are synchronized by taking into account the random pedestal events and stored in a dedicated root merged file.

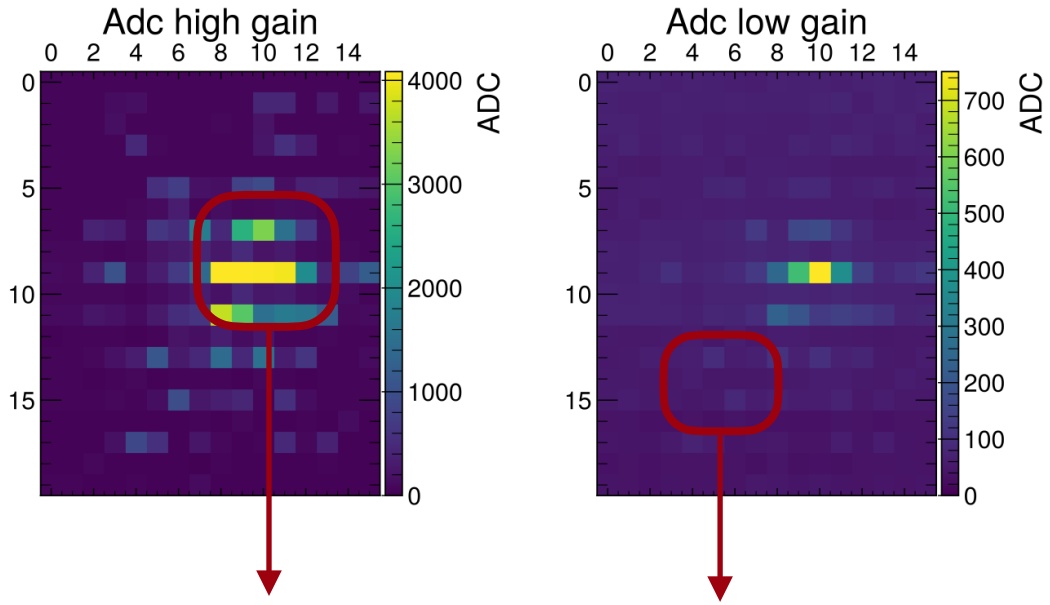
Calibration and High-Level Abstraction

Calibration constants are applied for ADC to GeV conversion, final information is saved in a high-level-object (class) ready for analysis.

SiPM calibration

- Preliminary studies performed to check the possibility of exploiting both the SiPMs High-Gain and Low-Gain configuration.

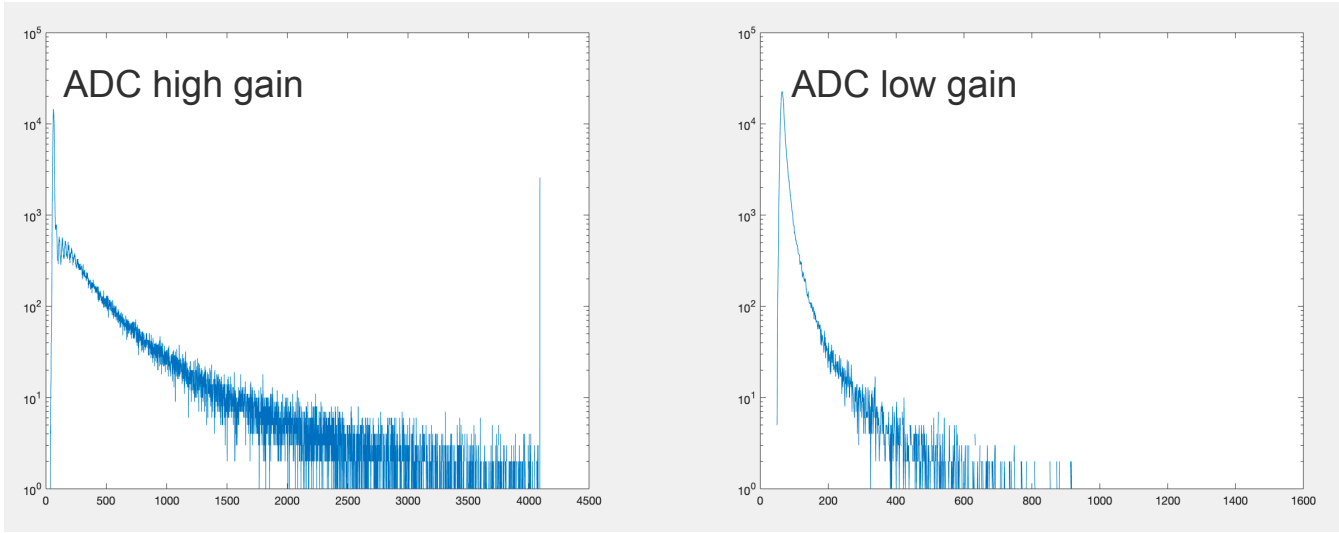
6 GeV e^- - Desy beams



Signal saturation in the region with highest tracks density already at 6 GeV.

Not possible to measure signals at the shower tails.

Multi-photon spectra of scintillating signal



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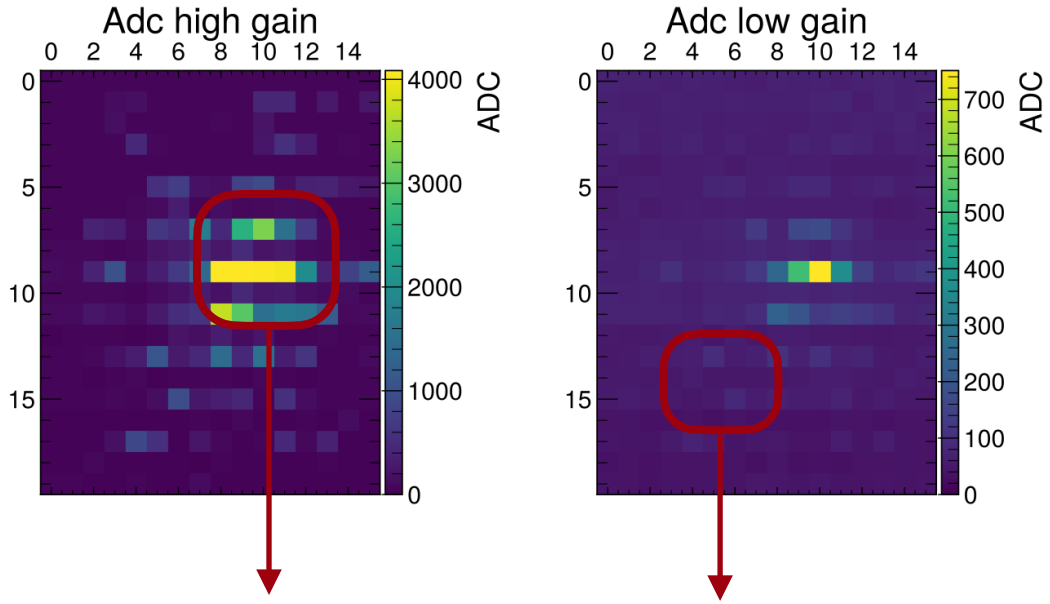

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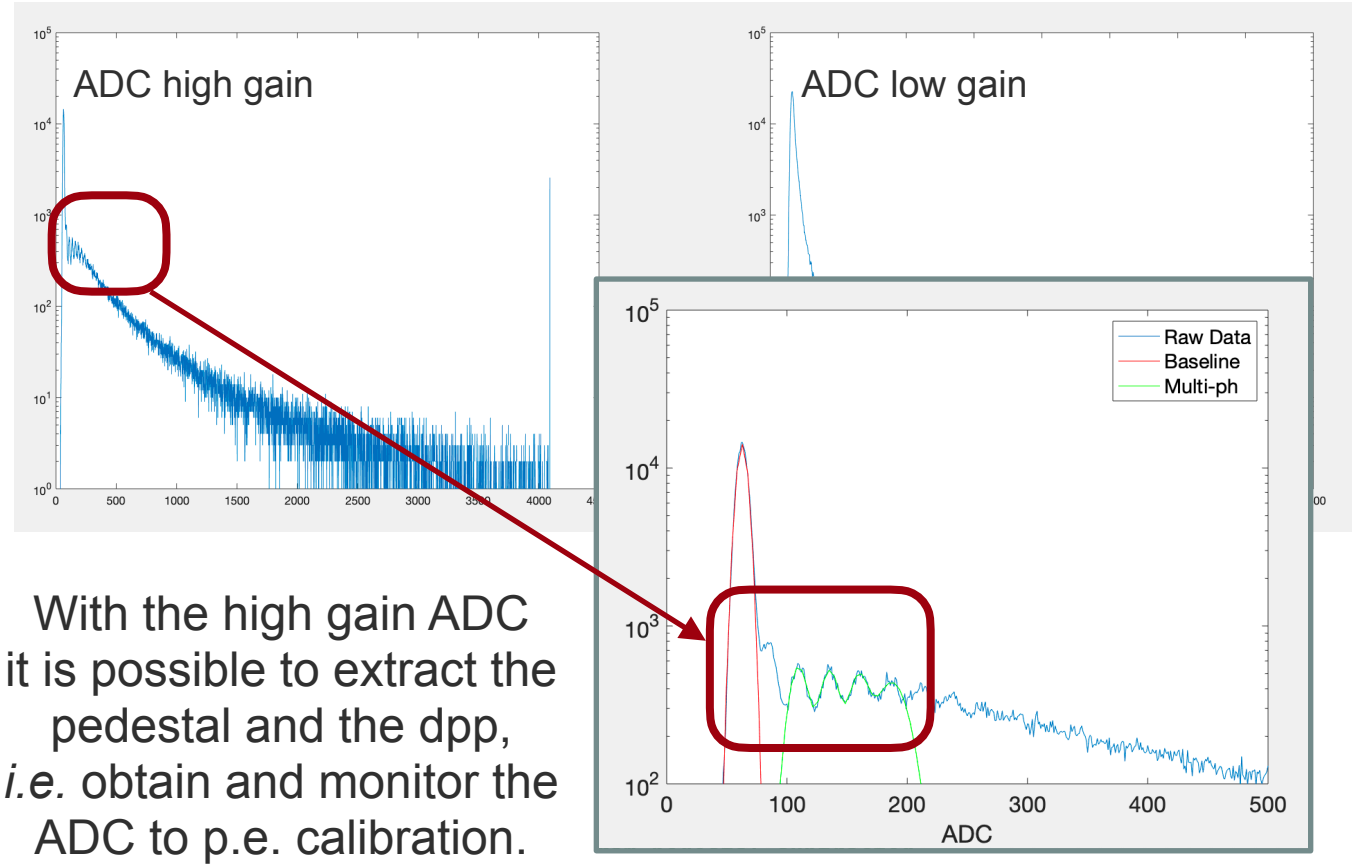
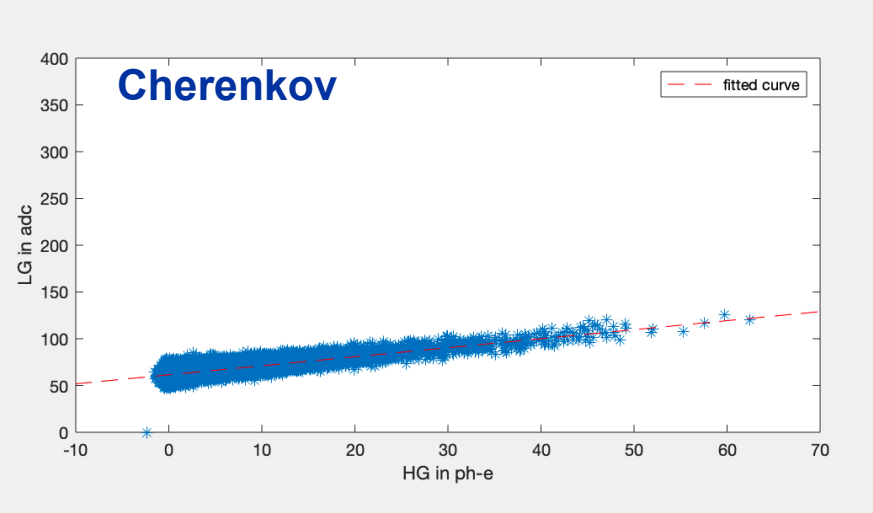
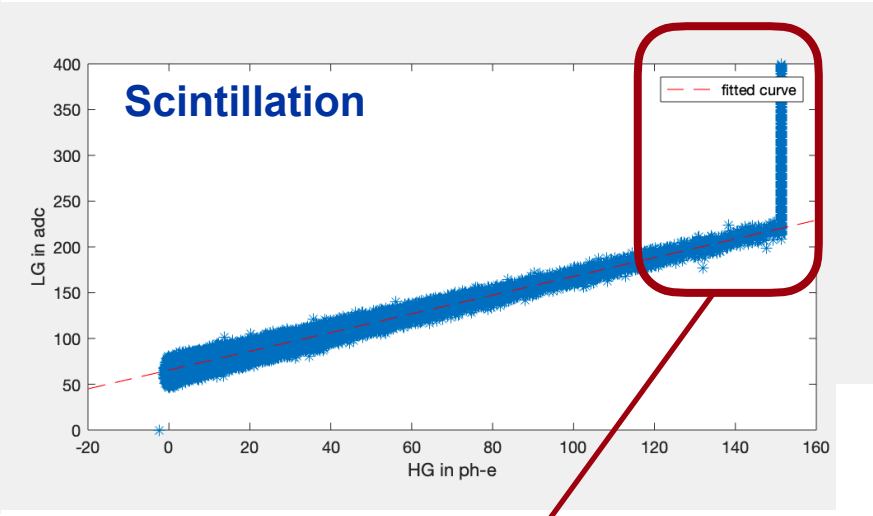


With the high gain ADC it is possible to extract the pedestal and the dpp, *i.e.* obtain and monitor the ADC to p.e. calibration.

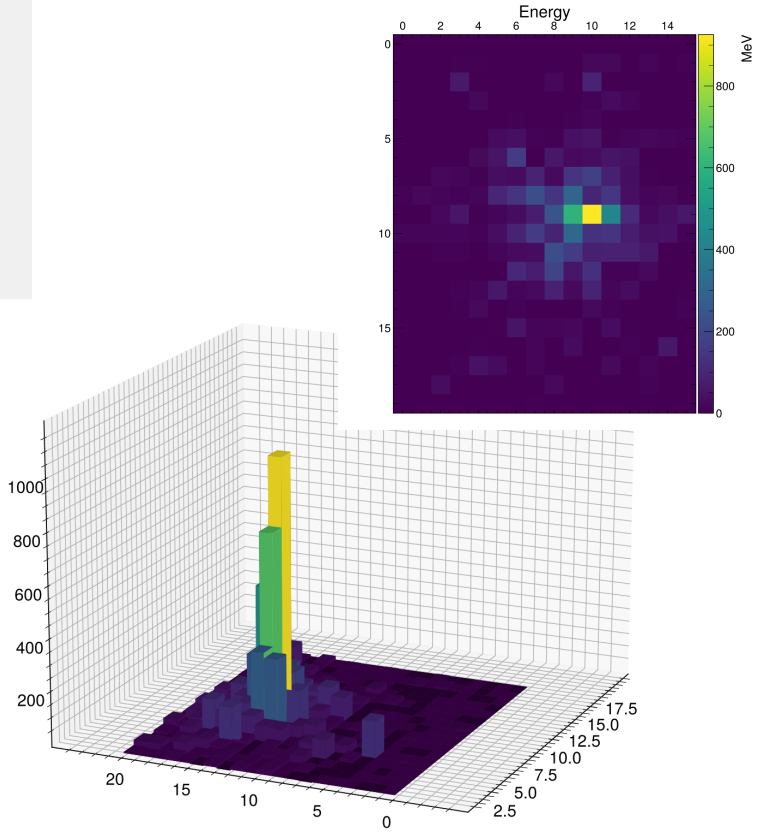
SiPM calibration

- Low Gain calibration (ADC/p.e.) obtained with a correlation plot between LG ADC and measured HG p.e.





Reconstructed energy deposits for every SiPM obtained by combining the HG and LG signals.

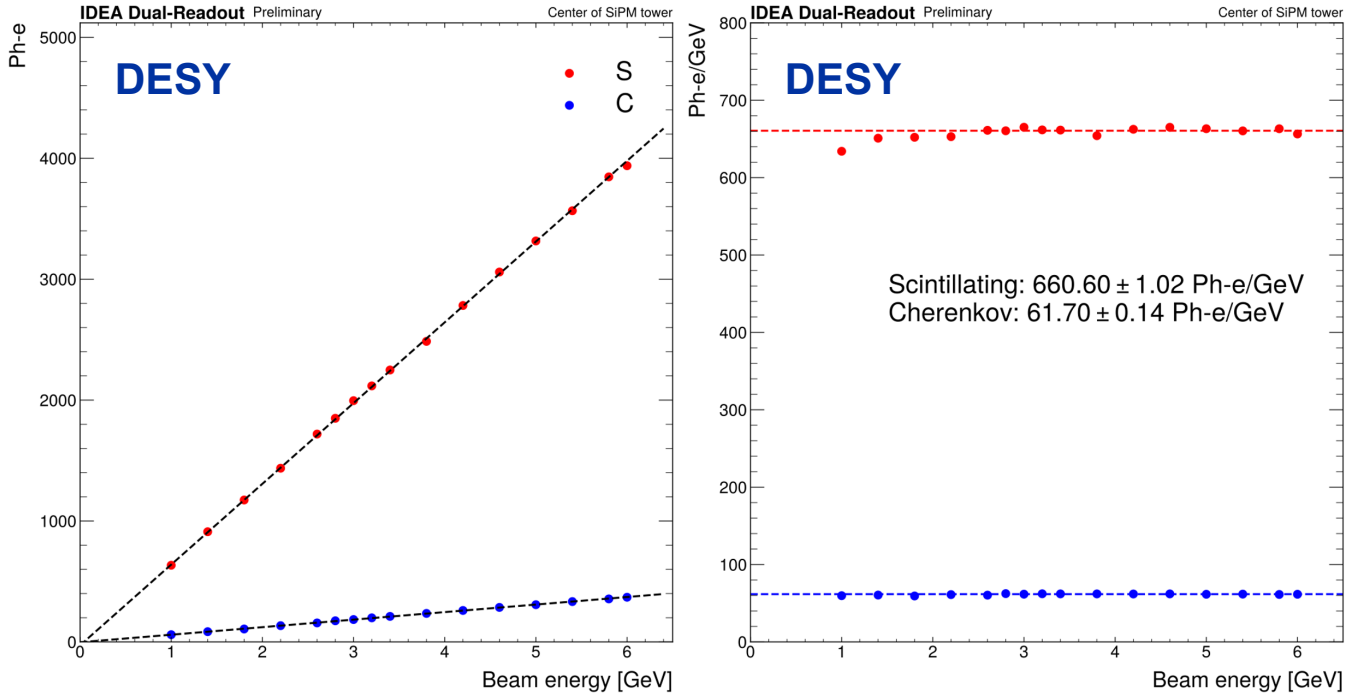


Possible to extract and monitor the low gain ADC/p.e. calibration for each run and each SiPM.

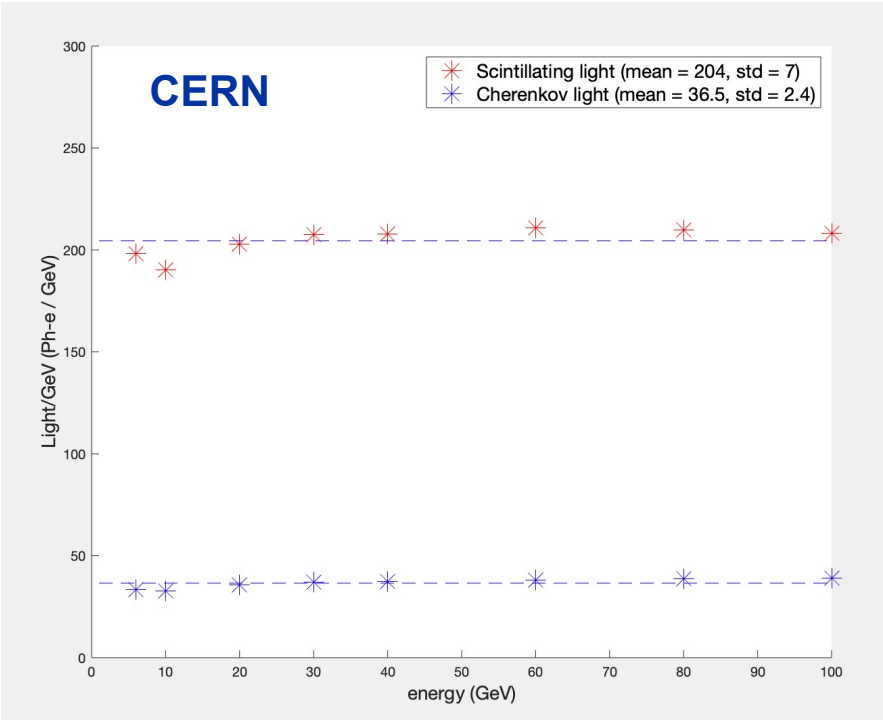
Clearly visible how the high gain saturation can be recovered.

SiPM linearity studies

- By exploiting the HG and LG signals and their cross-calibration, preliminary results were obtained for the response of the SiPM-readout tower.



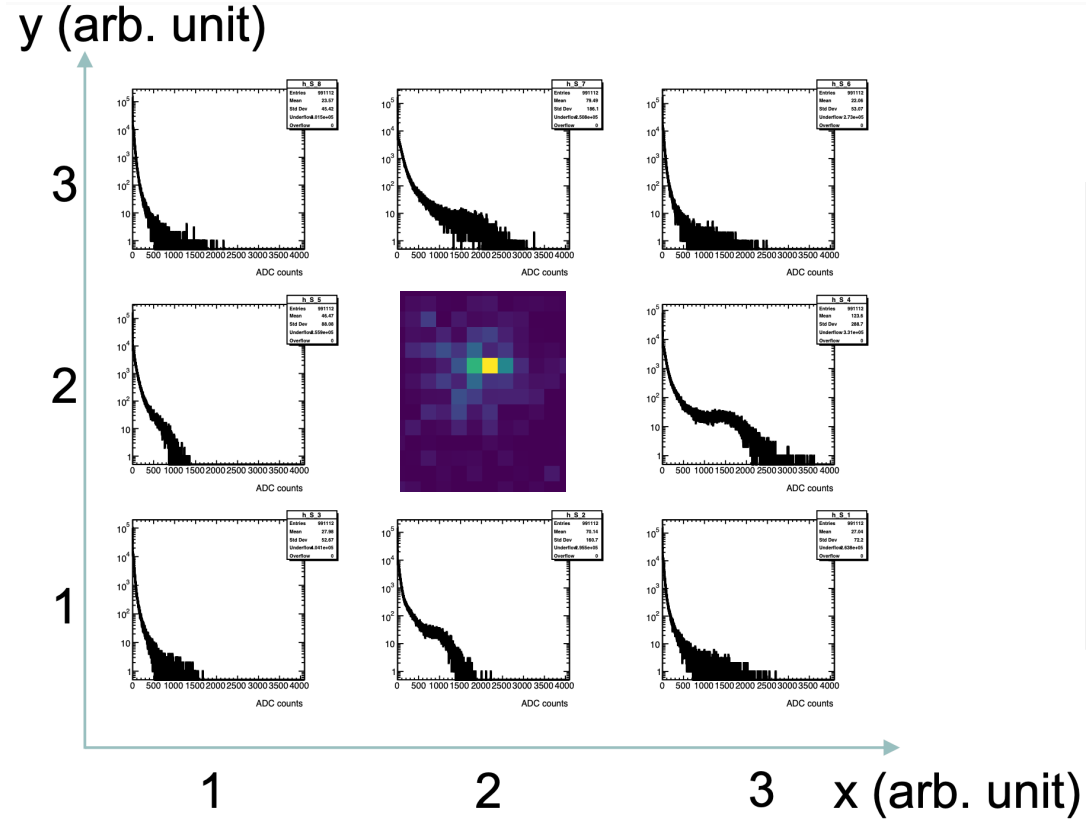
Preliminary - no filters used.



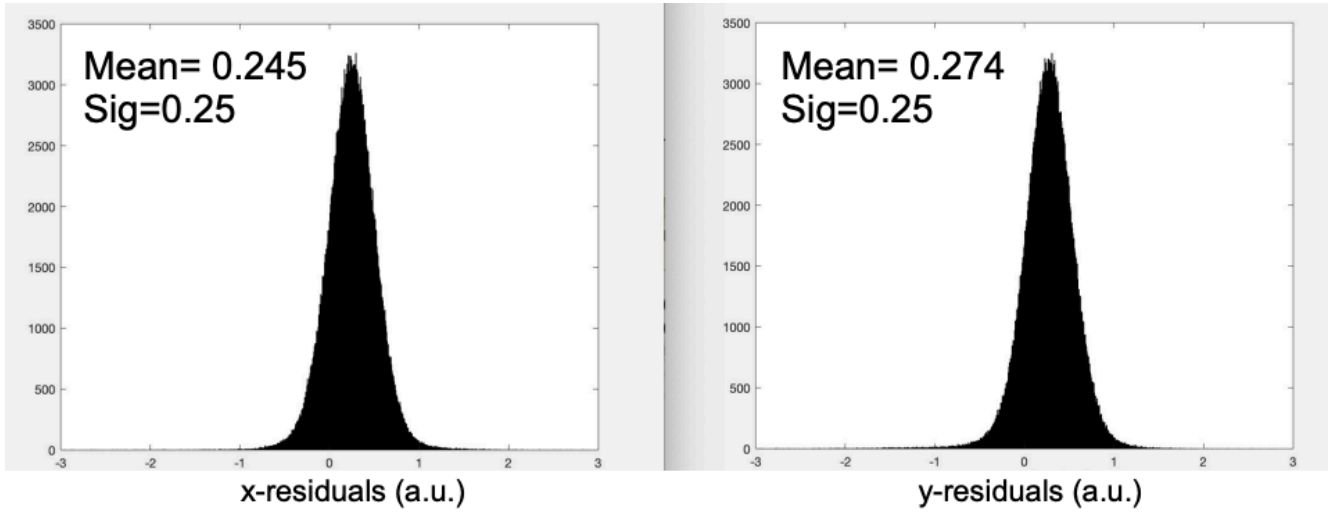
Preliminary -
yellow filters used over scintillating fibers,
neutral filters used over clear fibers.

PMT/SiPM synchronization

- The PMTs and SiPMs signals can be used to extract the shower barycenter position per event. Information useful to validate the data synchronization.



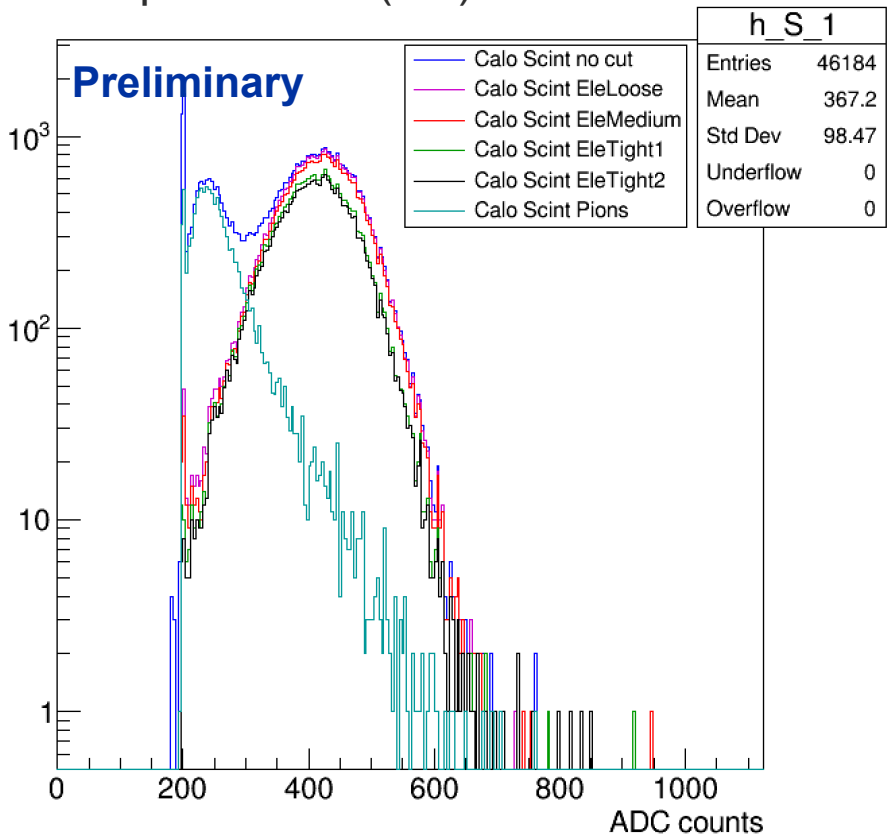
Residual barycenter coordinates



Possible to synchronize and merge PMTs and SiPMs data for every further analysis.

Events selection

- High π^+ contamination in e^+ beams at the CERN-SPS.
- Ongoing studies to effectively identify e^+ in the SPS beams combining two Cherenkov counters (C1, C2) and the preshower (PS).

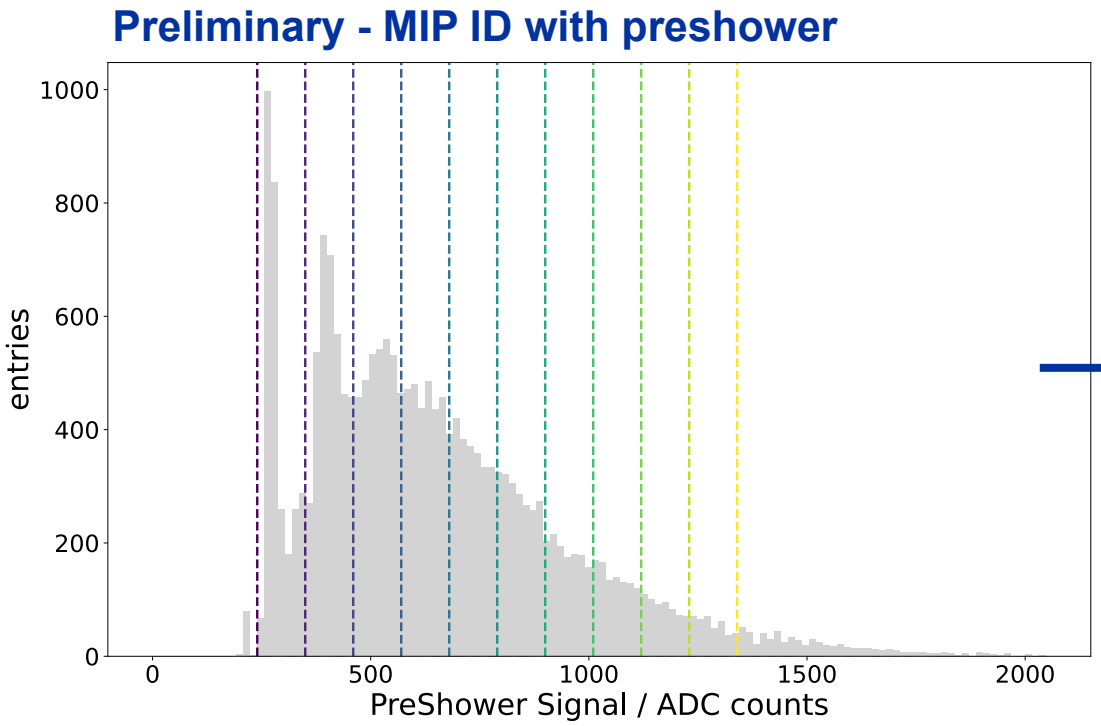


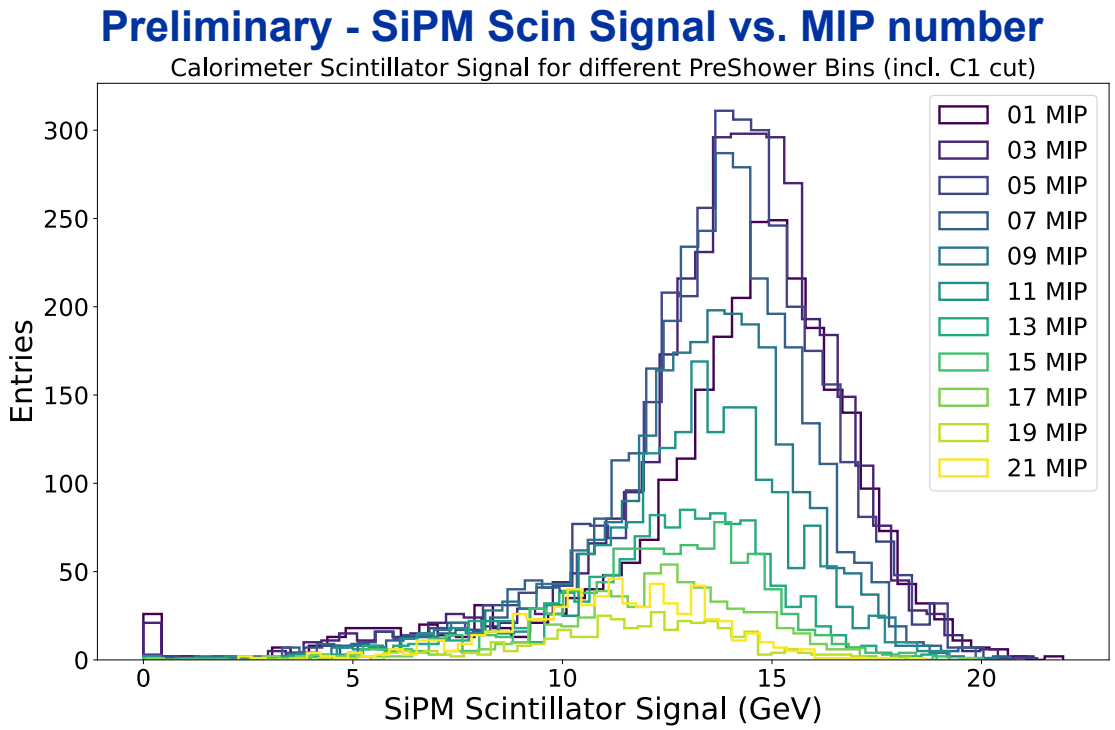
- Example of PMTs scintillation signal, for 10 GeV beams, as a function of the selecting cuts:
  - No cuts
  - e^+ identification:
    - Cherenkov only: C1 || C2
    - Cherenkov only: C1 && C2
    - Cherenkov + Preshower: (C1 || C2) && PS
    - Cherenkov + Preshower: (C1 && C2) && PS
  - π^+ identification:
    - Cherenkov only: !(C1 || C2)

Events selection

- High signal dependence over the preshower selecting cuts.

Example: SiPM scintillation signal distribution for 20 GeV e^+ as a function of the preshower selection.



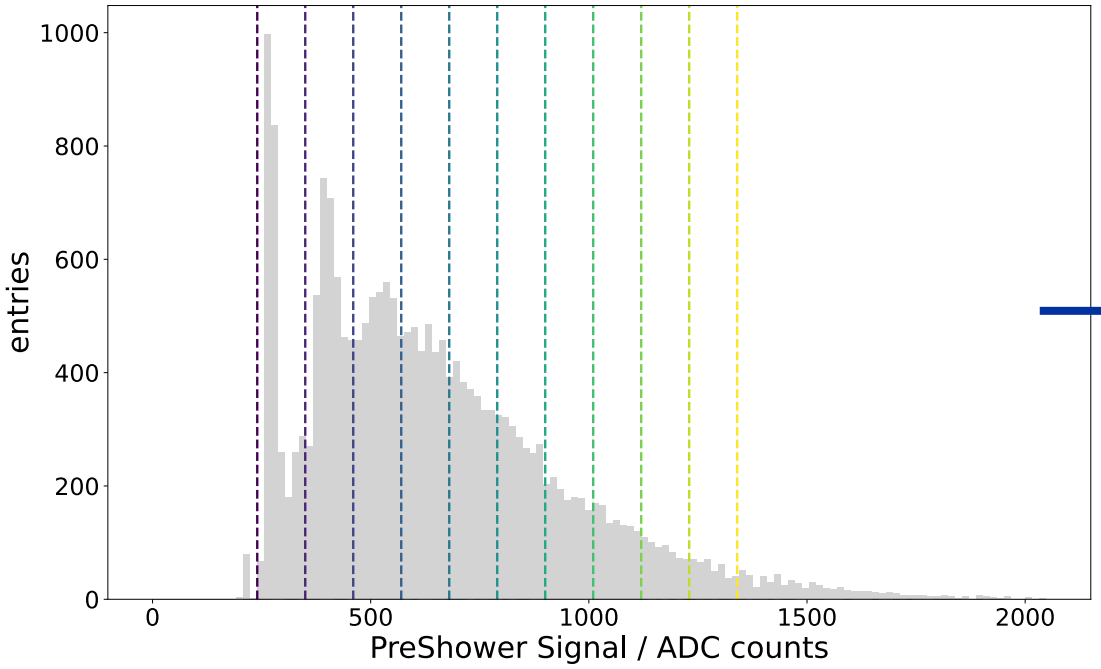


Events selection

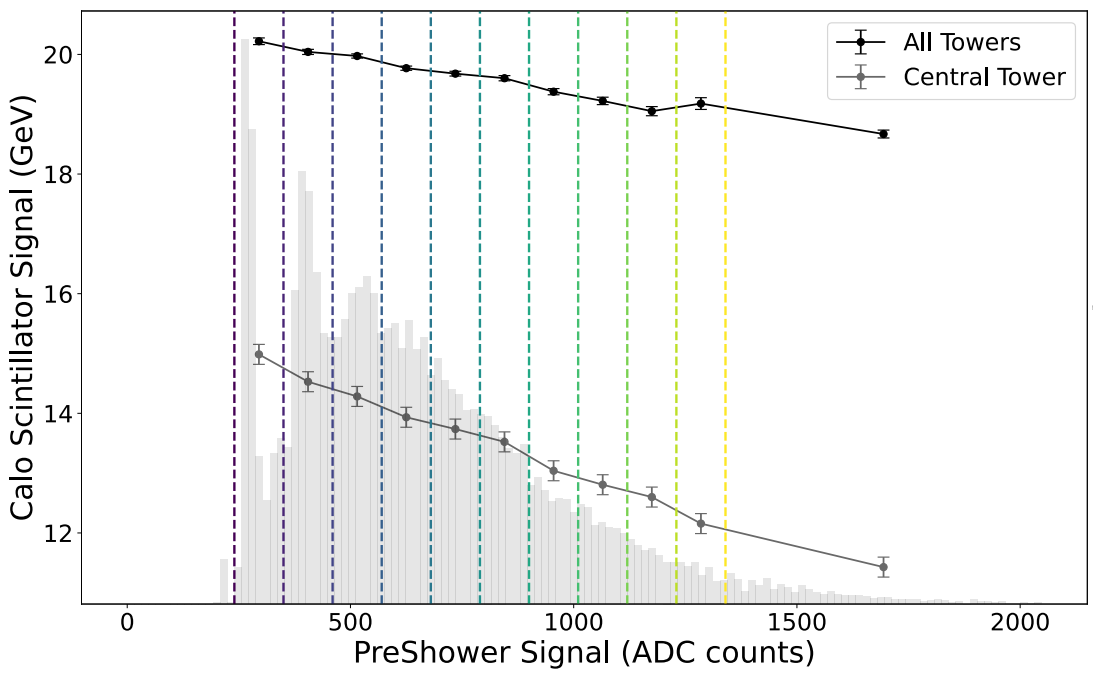
- High signal dependence over the preshower selecting cuts.
- Partially possible to recover some missing energy from tracks impinging the PMTs surrounding towers.

Example: mean scintillation signal for 20 GeV e^+ as a function of the preshower selection.

Preliminary - MIP ID with preshower



Preliminary - Scintillation signal



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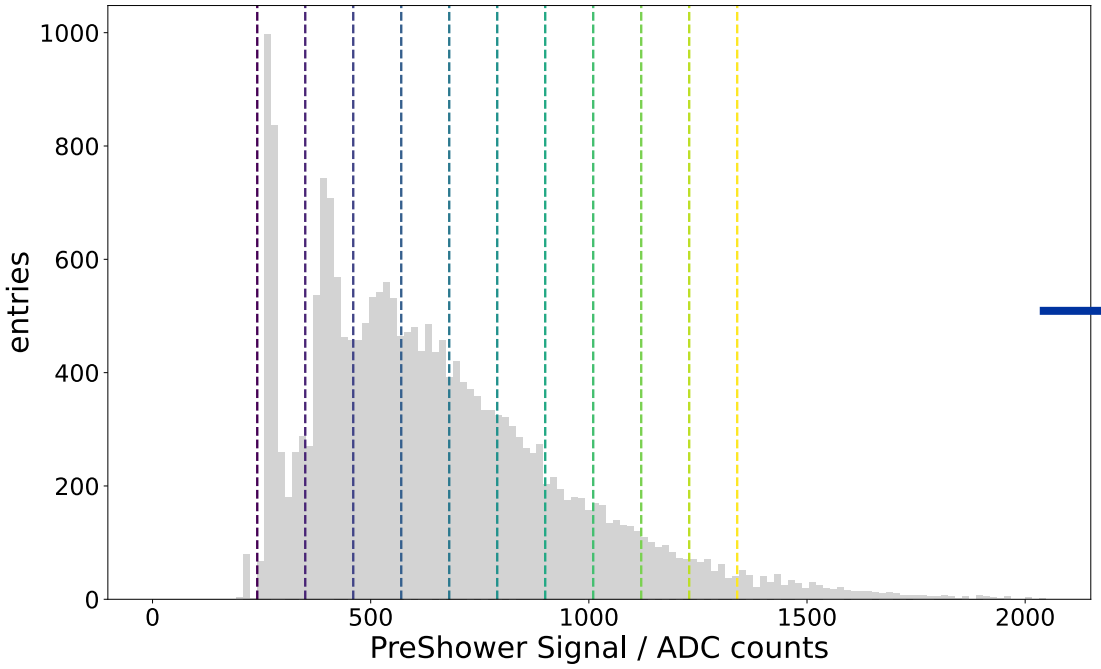
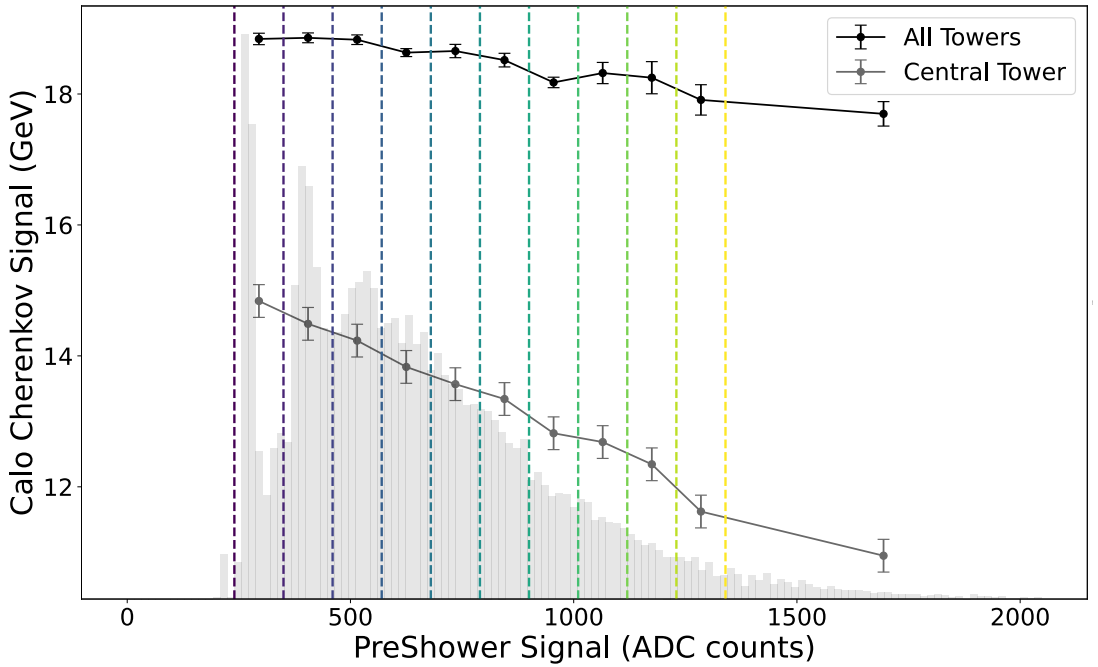


Preliminary - Cherenkov signal



Take home & conclusions

- A new dual-readout prototype based on the capillary tubes technique was built in 2020 and tested with beams in 2021.
- We collected:
  - 1-6 GeV e^- events @ DESY
    first dual-readout calorimeter ever tested at DESY
  - 10-125 GeV e^+ events @ CERN-SPS
- At present, several studies are ongoing in order to:
  - Extract e^+ events in the SPS data.
  - Check the two DAQs synchronization.
  - Calibrate the detector and evaluate its performance.
  - Reproduce results with Geant4.