



Co-funded by  
the European Union



# Performance of the PICOSEC detectors after the CERN testbeam

Riccardo Speziali



ESSnuSB+ collaboration meeting October 2026



# Outline

---

- 01 November test beam: DRD1 setup
- 02 April test beam: hadron dump prototype
- 03 July test beam: high statistics
- 04 Conclusions and future perspectives

# November test beam

## DRD1 test beam

### H4 line

characterization of the detectors with 150-180 GeV muons

## Setup

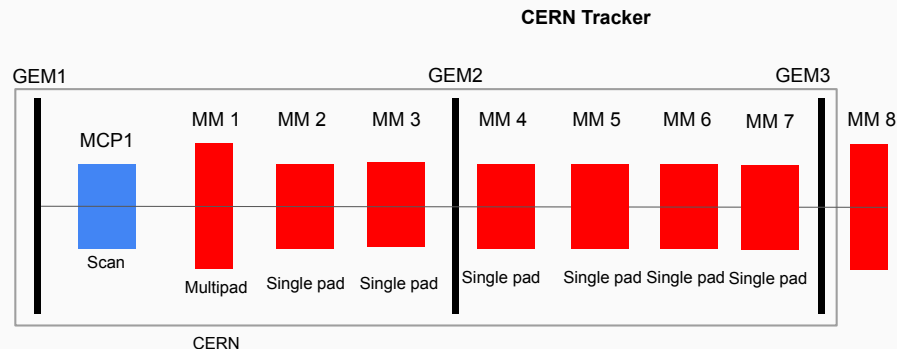
### GEM trackers and reference detector

Three GEMs detector used as trackers coupled with a reference detectors (MCP).

## Data taking

### Scan of the 96 pads

MCP moved all over the active area of the PICOSEC in order to study the time uniformity



# Analysis

01

## Waveform analysis

Signal timing performed by using **constant fraction discrimination (CFD)** at **30%** for both **MCP** and **PICOSEC**.

This time value is w.r.t. **beginning of waveform**.

02

## Time of the first sample

Absolute timing of signals is obtained by summing the time of the **first sample** of the waveform (**Cell0TimeStamp**) to the **CFD**.

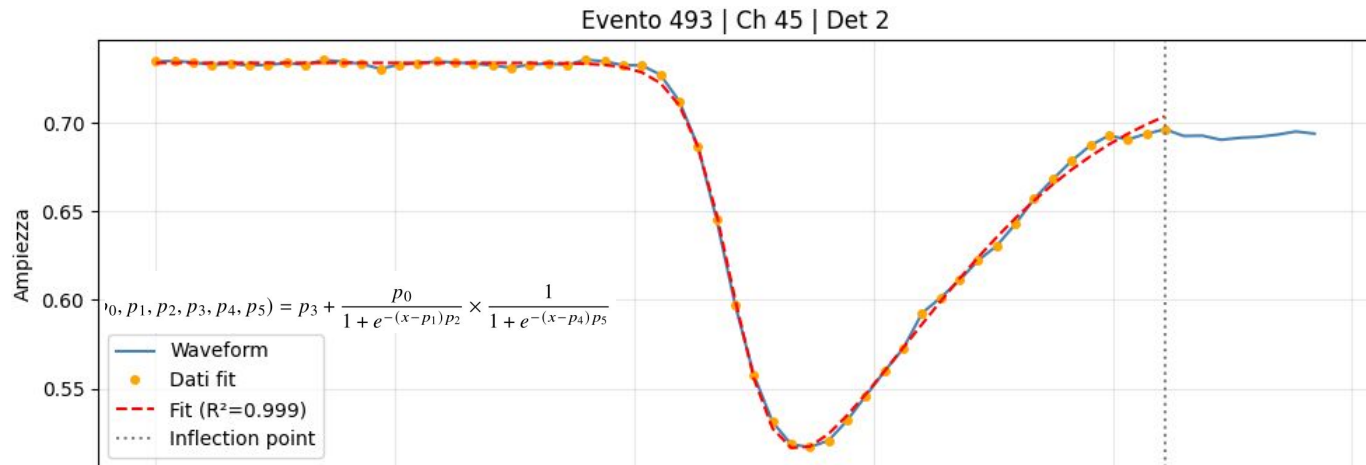
03

## Signal Arrival Time (SAT)

The **signal arrival time (SAT)** at the **PICOSEC** is computed w.r.t. the reference time from **MCP**.

Absolute signal time from **MCP** is subtracted from absolute signal time of the **PICOSEC**.

# Waveforms analysis



## Fit of the fast peak

**Double sigmoid:** used in order to separate the fast peak from the ion tail.

**Ion tail:** not fully recorded by the SAMPIC.

Analysis on the charge regarding only the electrons

## Time properties

**Arrival time:** Constant fraction discrimination at the 30% of the maximum amplitude.

# Time resolution

## SAT analysis

### most hit channel

SAT computed as time difference of absolute signal time from PICOSEC and MCP

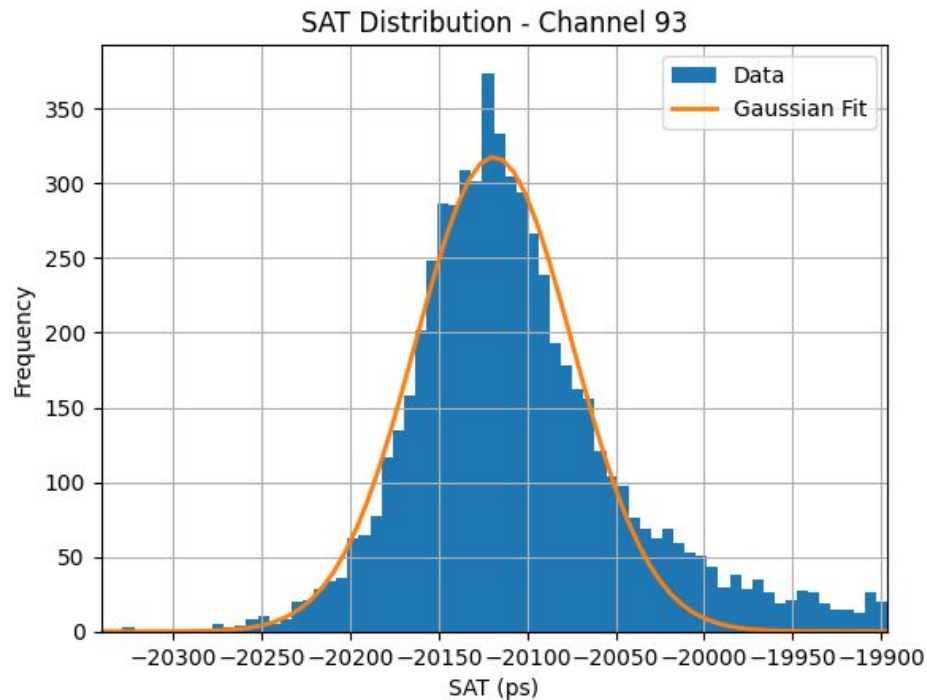
## Gaussian distribution

### standard deviation as time resolution

The standard deviation estimated from gaussian fit gives a conservative estimation of the time resolution for the considered channel

## Results for channel 93

$\mu = -20118.95 \text{ ps}$ ,  $\sigma = 44.42 \text{ ps}$



# Uniformity map

## Single hit events

Only events with 1 hit per pad are selected for this analysis

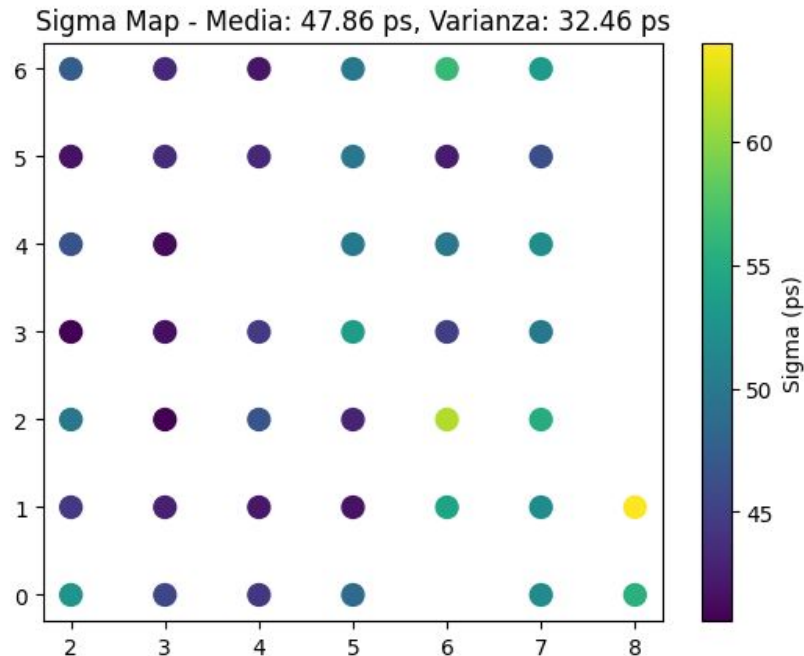
## Alignment

**MCP start from the center of the detector**

If the MCP is not very well aligned with the specific pad the time resolution decrease

## Results for uniformity

Good uniformity in the analysed area and good result regarding the time resolution



# Charge Analysis

## Electron Peak

Analysis of the electron peak area allows for the reliable extrapolation of the mean charge, which represents the number of photons generated by muons.

## Pólya Distribution

The Pólya distribution describes the statistical fluctuation of charge from a single avalanche in a gaseous detector, generalizing Furry's exponential model to account for fluctuations in the Townsend ionization coefficient.

Parameters: mean charge  $\langle Q \rangle$  (detector gain  $G = \langle Q \rangle / (n_{pe} \cdot e)$ ) and shape parameter  $\theta$  (avalanche variance  $\sigma^2/Q^2 = 1/(1+\theta)$ ).

Gain quantifies average signal multiplication, while  $\theta$  describes event-by-event reproducibility (low  $\theta$  = strong fluctuations, high  $\theta$  = stable gain).

## Analytical Formulation & Parameters

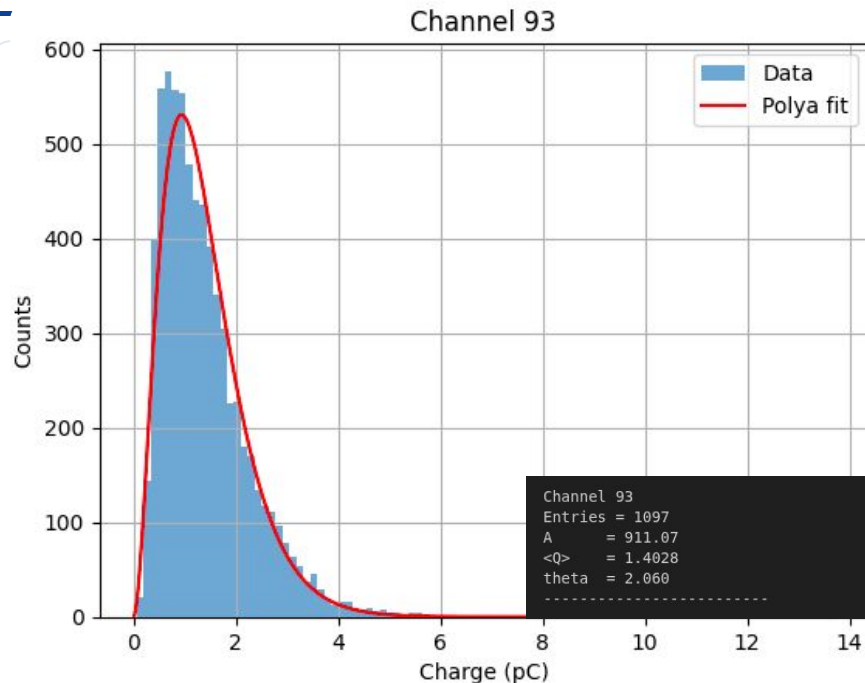
$$f(q) = A \cdot \left( \frac{q}{\langle q \rangle} \right)^\theta \cdot \exp \left[ -(\theta + 1) \frac{q}{\langle q \rangle} \right]$$

$q$ : measured charge

$\langle q \rangle$ : mean charge

$\theta$ : shape parameter

$A$ : amplitude factor



# Charge map

## Single hit events

Only events with 1 hit per pad are selected for this analysis with at least 1000 events

## Mean value from Polya

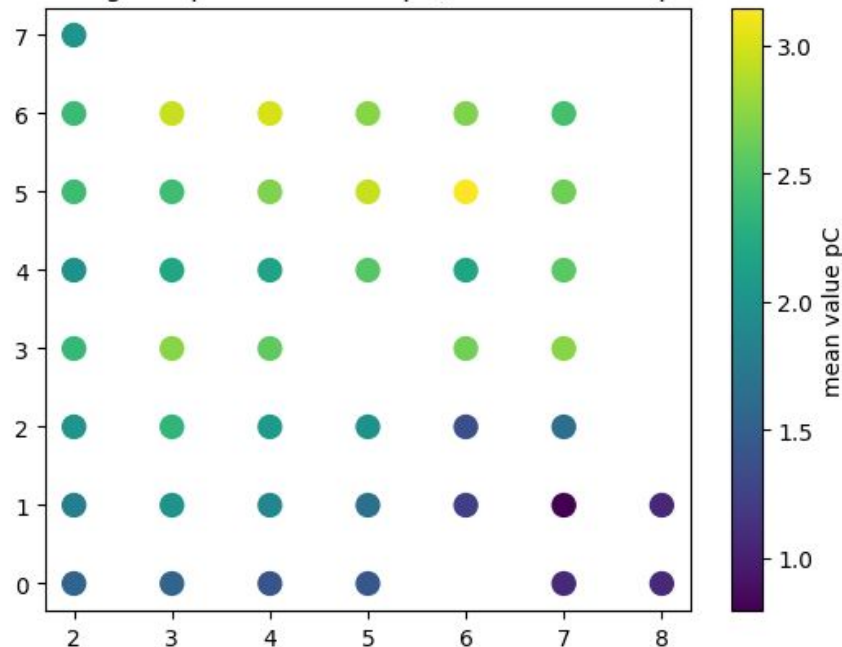
### Detector performance

Gives the overview of the overall performance of the PICOSEC

## Results for uniformity

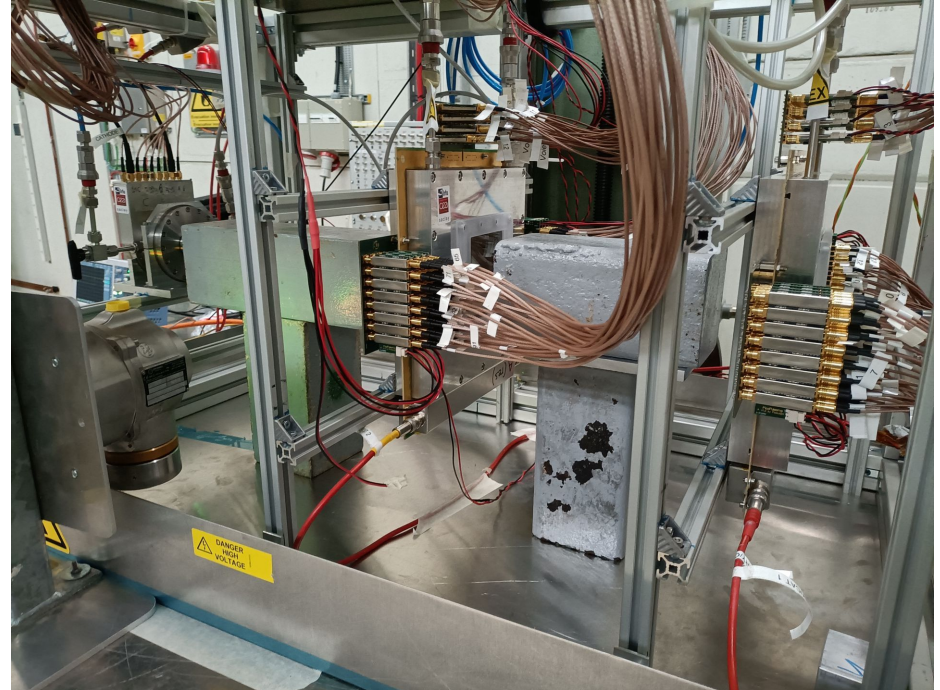
Good multiplication of the charge in the center while near the border becomes low

Charge map - Media: 2.12 pC, Varianza: 0.36 pC



# April: hadron dump prototype

- 3 PICOSEC: 2 96-pad detector and 1 7-pad detector
- **SAMPIC** used as digitation chain
- **Objective:**
  - Get time resolution of the 3 detectors
  - Test detectors under realistic conditions

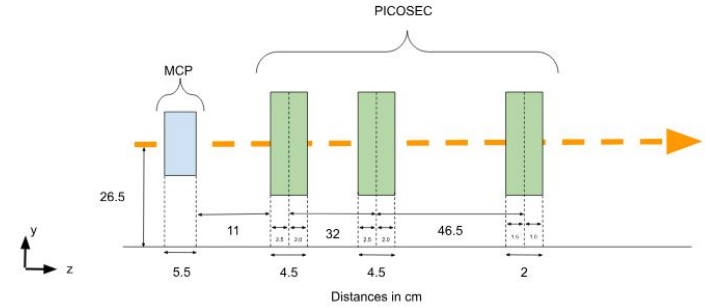


Tried to recover the 3rd 96-pad detector, but unfortunately no signal observed when mounted in the setup

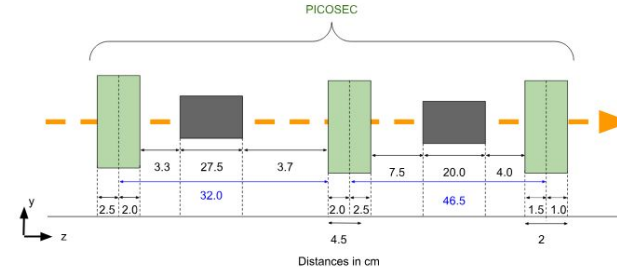
# April: Run performed

- Muon beam
- hadron beam
- high intensity beam 350 kHz/cm<sup>2</sup>
- Run with iron blocks between the detectors
- Run with MCP for time reference

Setup Scheme



Between the first and the second there are 20 cm of iron  
Between the second and the third there are 27.5 cm of iron

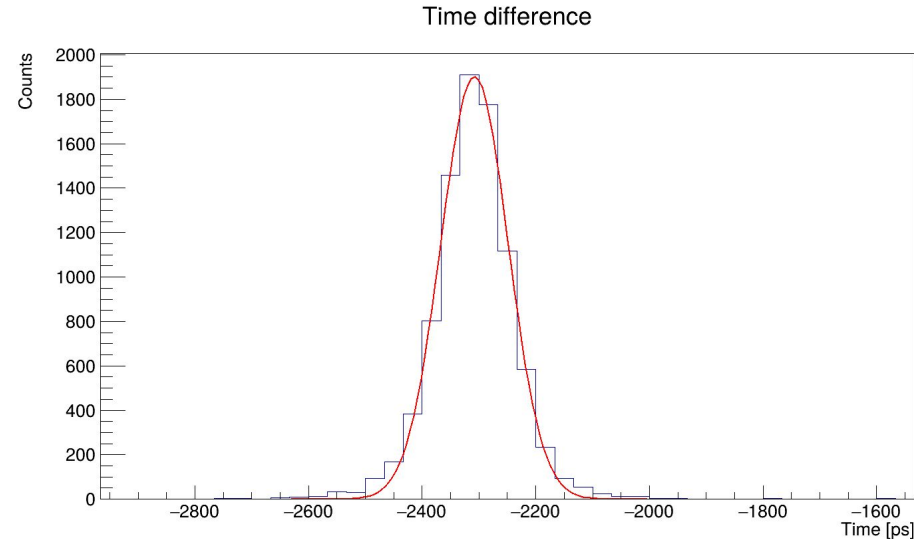


Drawing not to scale

# April: analysis muon run

- Raw analysis on double events
- **Single hit per detector**
- **Evaluated time difference between absolute signal time from DAVIDE and GOLIA detectors**
- **Time resolution: ~42 ps**

```
*****
Minimizer is Minuit2 / Migrad
Chi2          = 24885.5
Ndf           = 16
Edm           = 3.93454e-09
NCalls        = 83
Constant      = 1900.64 +/- 27.7101
Mean          = -2308.03 +/- 0.980319
Sigma         = 59.3361 +/- 1.03516 (limited)
```



# April: muon Brick Run

## Characteristics of the beamline

### 5 GeV muons

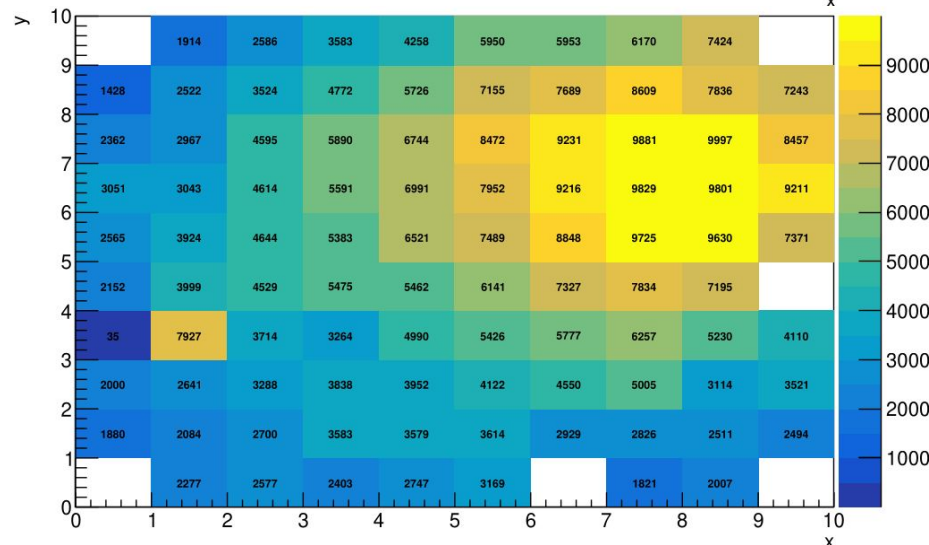
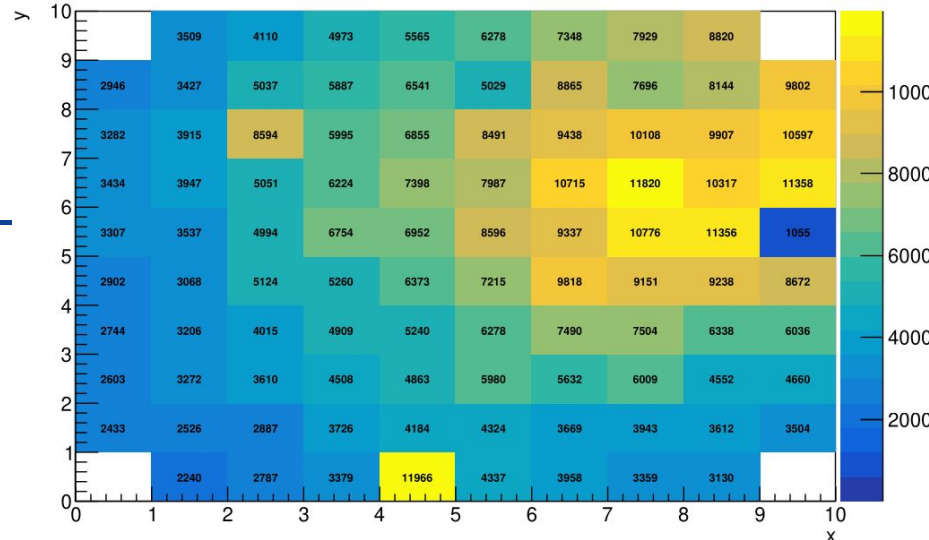
Iron brick placed between the detectors in order to recreate the nuSCOPE hadron dump

## Mapping

### 96 pad hit of this run

**Top image:** first detector on the line

**Bottom image:** second detector in the line



# April: hadron Brick Run

## Characteristics of the beamline

### 15 GeV hadrons

Iron brick placed between the detectors in order to recreate the nuSCOPE hadron dump

## Mapping

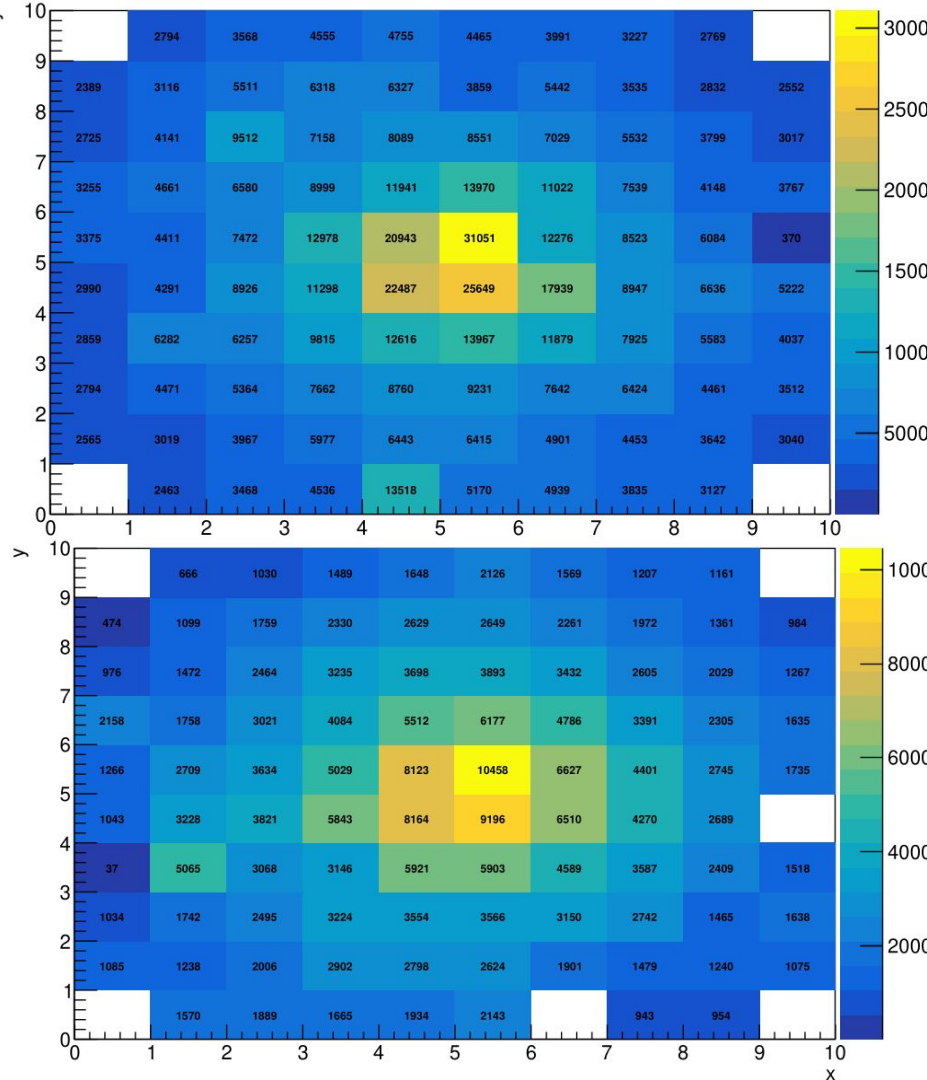
### 96 pad hit of this run

**Top image:** first detector on the line

**Bottom image:** second detector in the line

## Result

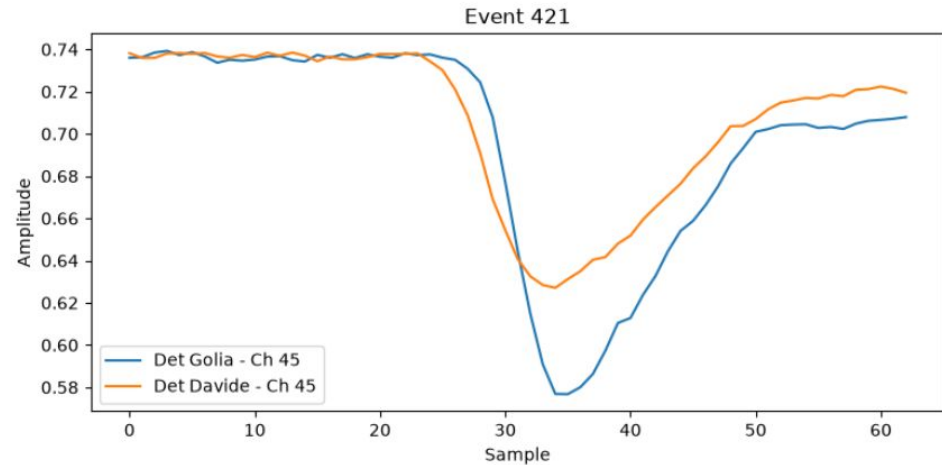
- Good work for the digitization chain
- Good response of the detectors
- Further analysis on amplitude and charge for reconstruction of the events



# April: brick runs analysis

Next steps:

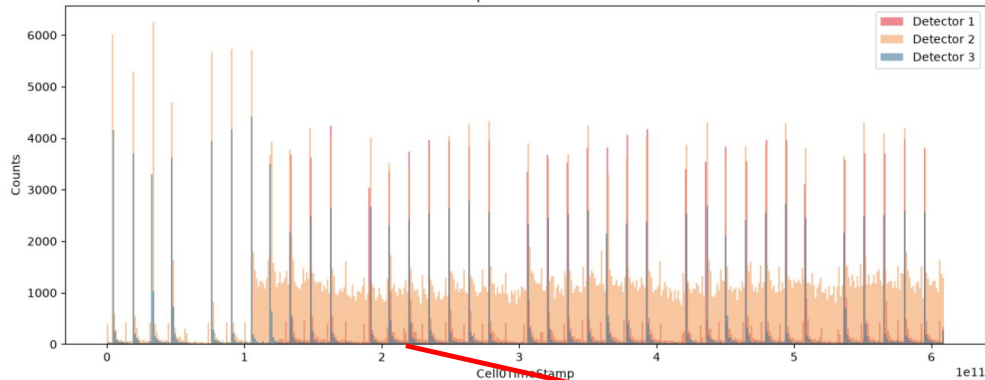
- Analysis on the charge with the Polya function on single hit events per detector
- Reconstruction of the lost energy of the incoming particle



# April: hadron run 375kHz/cm<sup>2</sup>

Figure

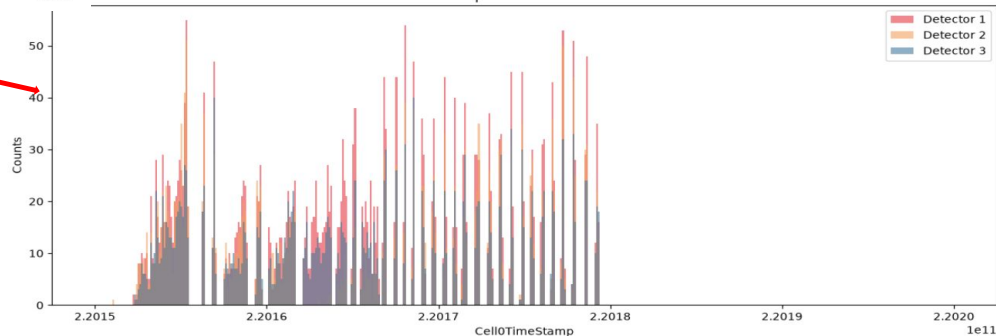
Cell0TimeStamp distribution — all detectors



- Zoom of a single spill
- Not a full collection of the spill
- In the next slide waveforms of this particular spill...

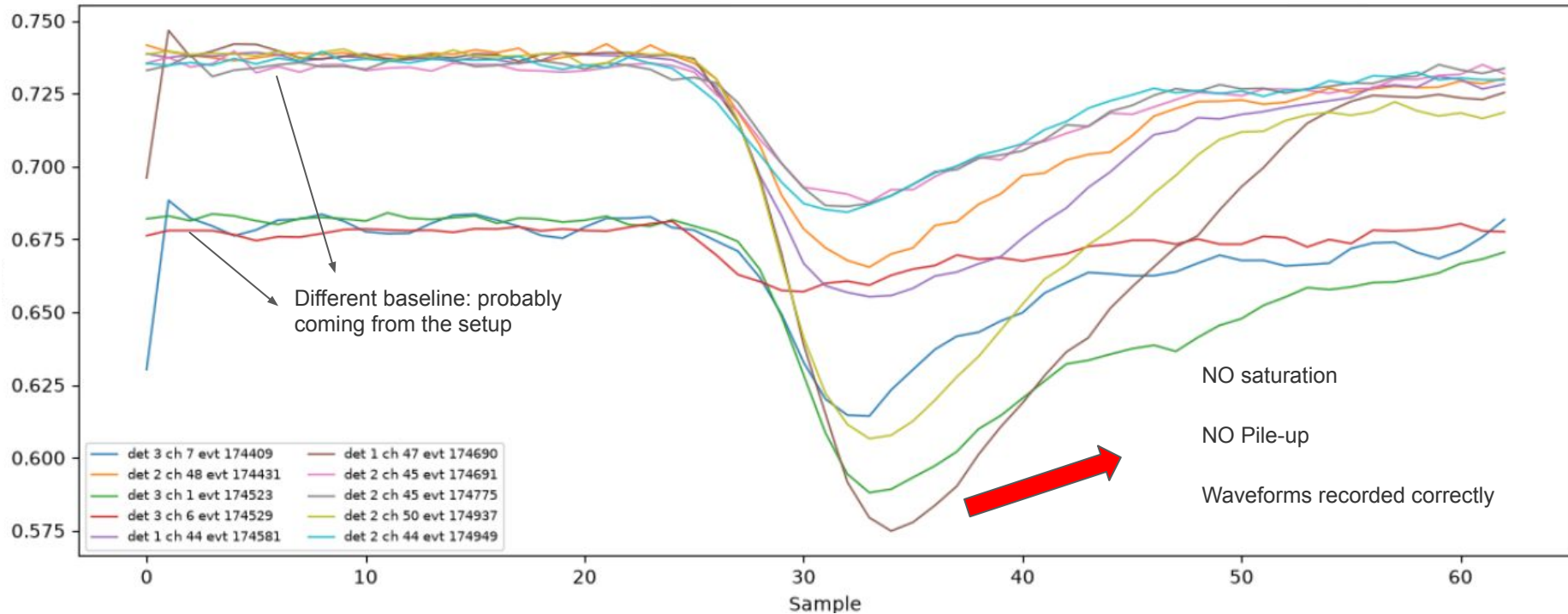
- Distribution in time of the number of events
- Noise from the beginning
- only 10 minutes data

Cell0TimeStamp distribution — all detectors



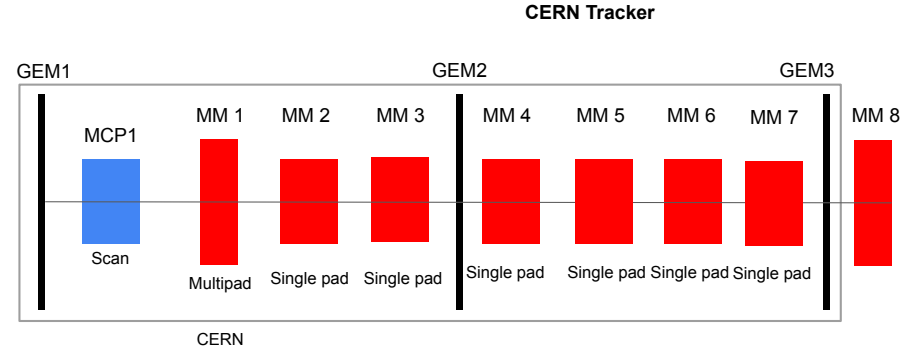
# April: hadron run 375kHz/cm<sup>2</sup>

Waveforms con Cell0TimeStamp in [2.202e+11, 2.202e+11]



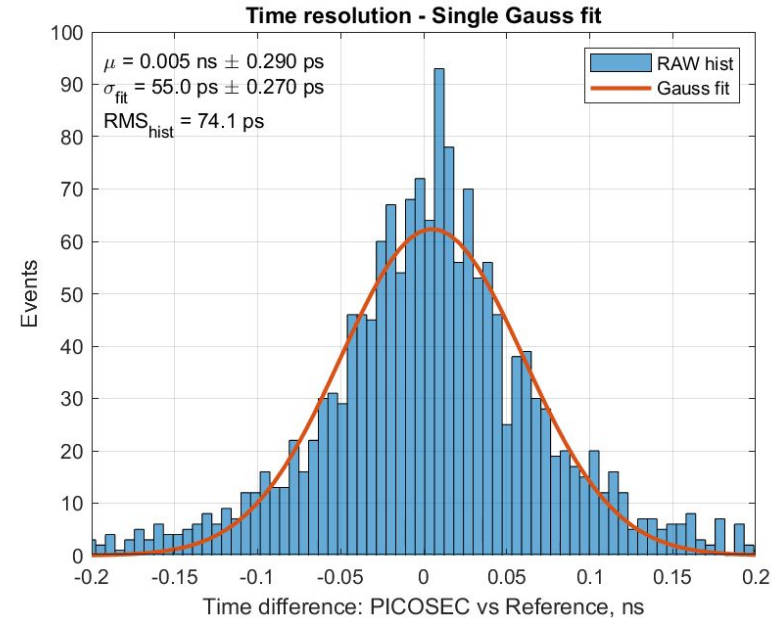
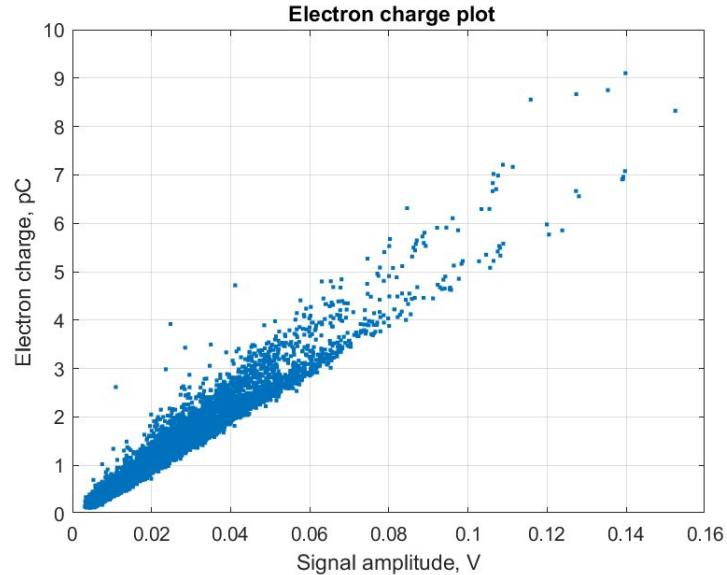
# July: test beam

- Single channel run for looking at the performance
- High statistics runs covering the center of the PICOSEC
- High intensity pion run without the reference (only counting mode) for april comparison



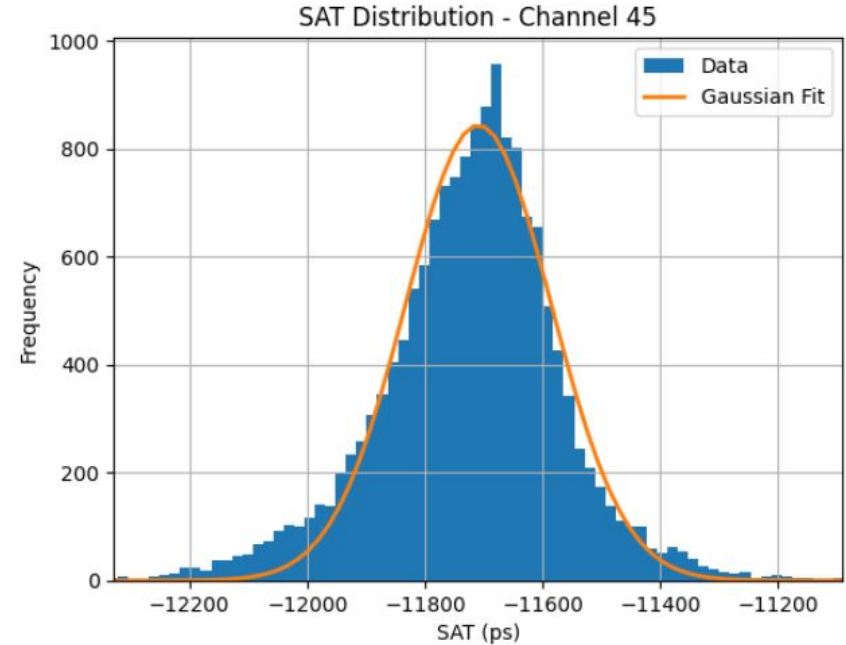
# July: Single channel run

BEAM 2026 July RUN 284 Pool2 DUT:C4 REF:C1 96-pad Piment nuSCOPE



# July: High statistics

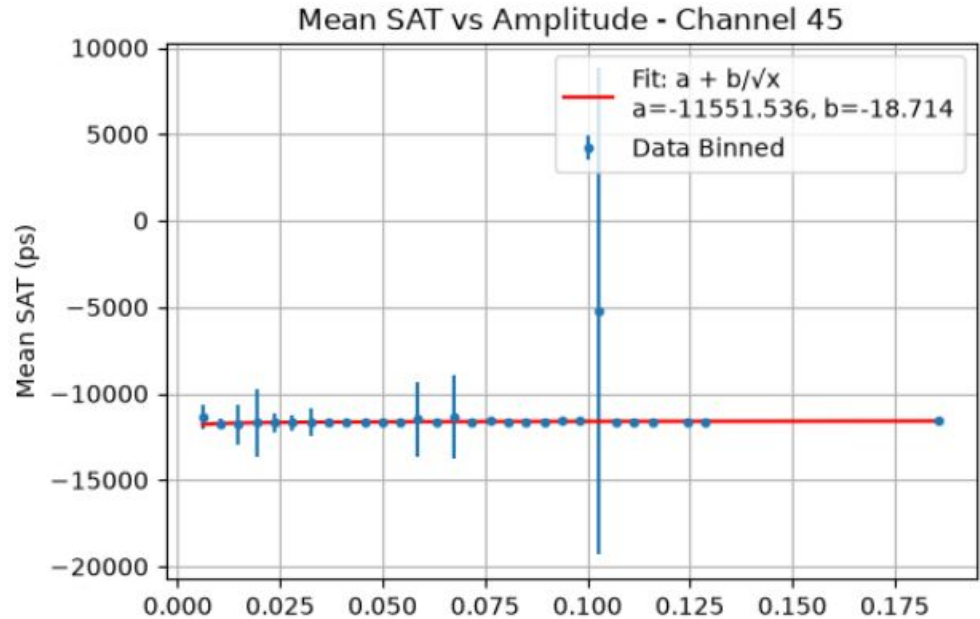
- Time resolution obtained from the gaussian fit
- Higher than the one obtained from the single channel run
- How to fix it: working on the calibration curve for this data



$\mu = -11709.10 \text{ ps}$ ,  $\sigma = 123.80 \text{ ps}$

# July: Calibration curves

- Dividing the Amplitude values in bin and taking the mean value from them
- Using an empirical equation to fit the data
- Then making the corrections of the raw data using the calibration curve
- Working in progress: not every channel behave the same

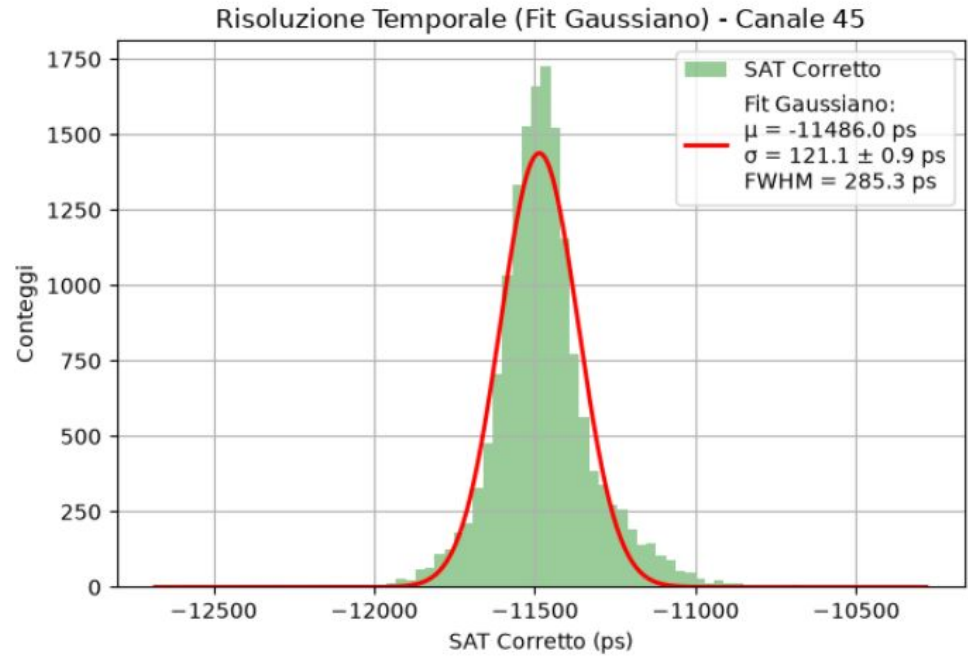


# July: Data correction

- Low value of the time resolution
- Not the one expected comparing to previous test beam and single channel run
- Simplest conclusion: not a very well alignment between MCP and PAD ->try to look double or triple hits events

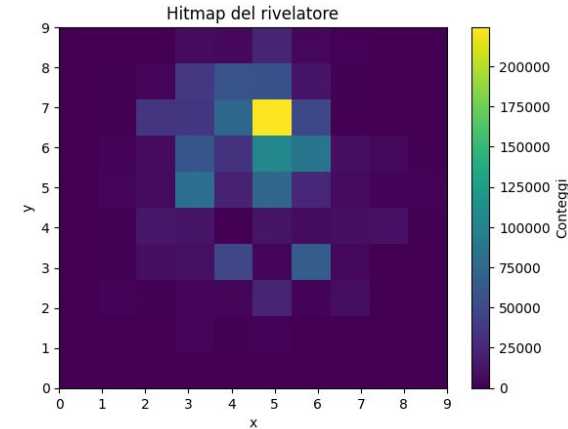
Next step:

- meeting with A.Kallitsopoulou and T.Papaevangelou regarding the calibration



# July: high intensity pion run

- 1MHz/cm2 pion beam
- DAQ set on counting mode without MCP and trackers
- no trigger in the SAMPIC
- Set the SAMPIC to the maximum power of sampling
- Still the same problem of April tb: not able to collect all the events coming from a single spill



# Thank you for your attention

Questions & Discussion