HERD 2023 PS/SPS Beam Tests - PSD Analysis Updates

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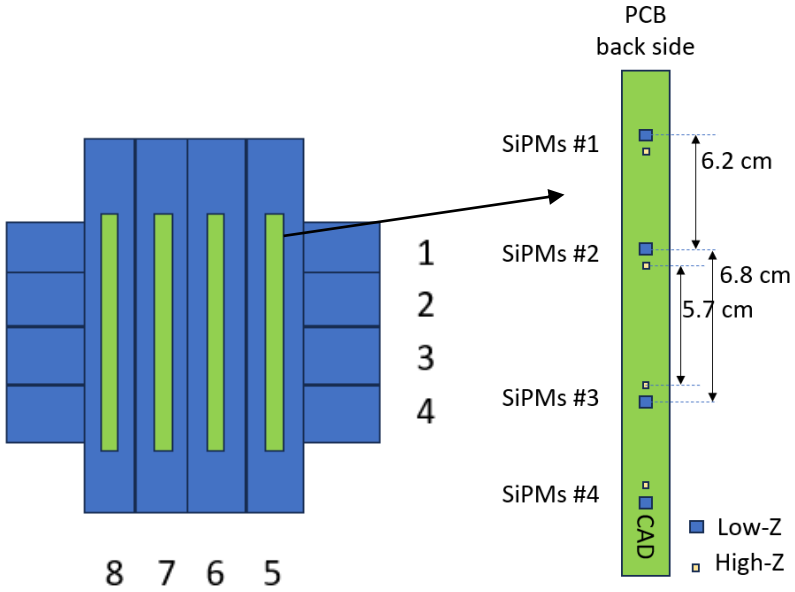
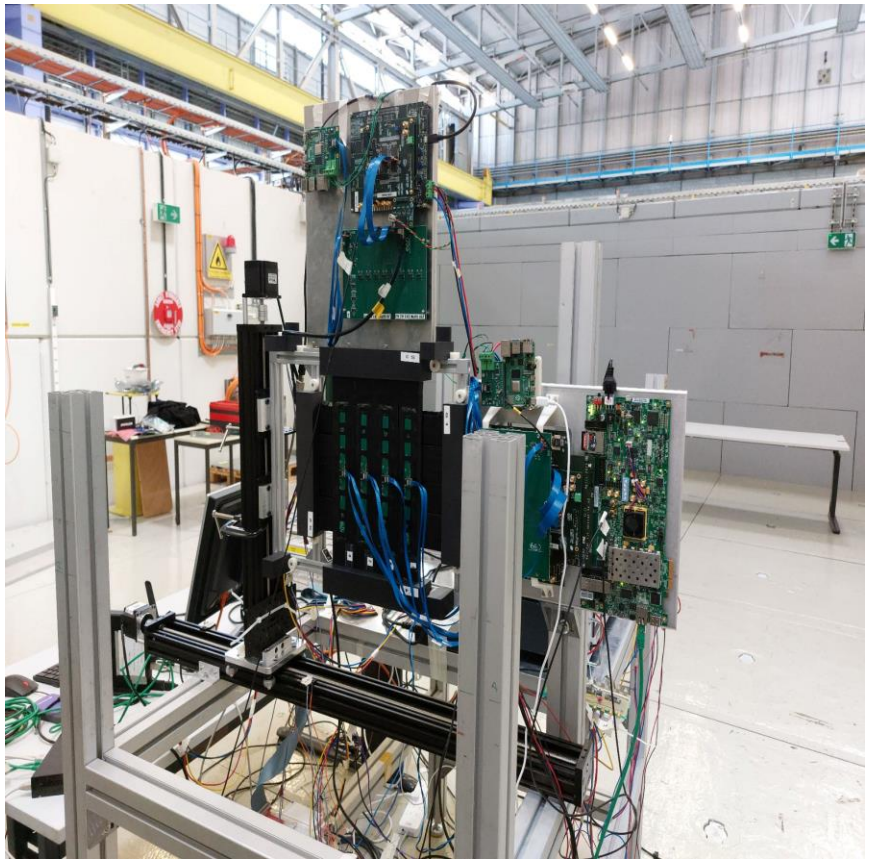
The PSD detector prototype @ PS/SPS BTs

- Within the HERD facility, PSD aims at high efficiency discrimination between photons and charged cosmic rays and charged nuclei identification up to iron
- Prototype PSD_prot0 employed at the CERN PS/SPS 2023 beam tests is composed of 8 plastic scintillator trapezoidal tiles (EJ-204) arranged in 2 layers and coupled to SiPMs
- Each tile is equipped with a PCB housing 8 SiPMs:
  - 4 SiPMs 3x3 mm^2 (Low-Z)
  - 4 SiPMs 1x1 mm^2 (High-Z)
- HERD-BETA chip (by ICCUB-SiUB) as read-out electronics



Sketch of the PSD_prot0 with the PCB housing the low- and high-Z SiPMs

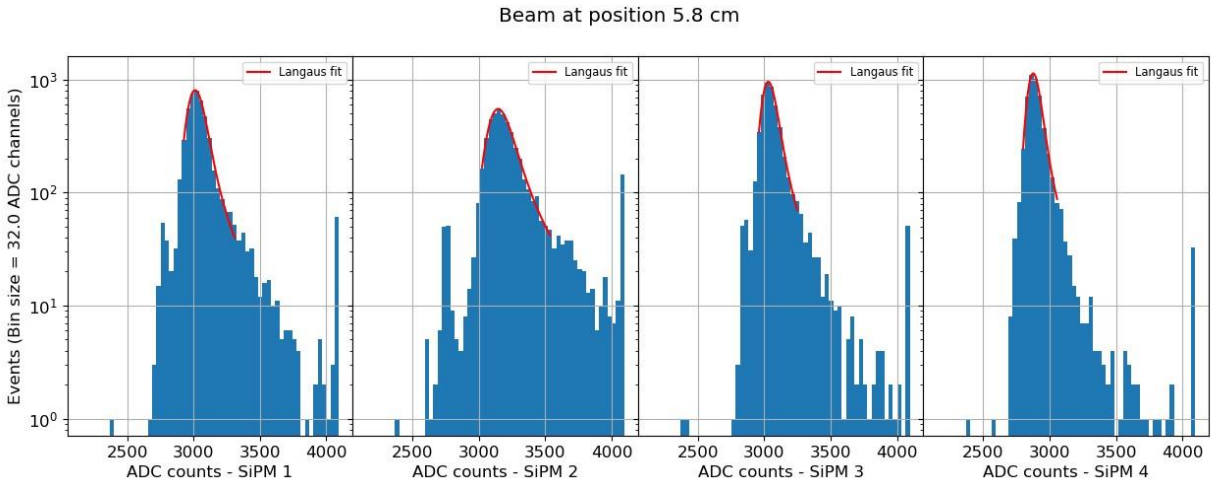
Photograph of the PSD at PS-T9



- Two evaluation boards were employed in the BTs
  1. The BETA evaluation board, by ICCUB-SiUB
  2. Xilinx-zc706-based evaluation board, by IFAE
- The IFAE EB allows for contribution to the L0 trigger providing veto signals for gamma-rays below 10 GeV

PS-T9 analysis: Tile position scan

- Position scan performed on tile #1, with 1cm steps (except for SiPM positions) and with a 1cm beam composed of 10 GeV negative pions
- A Langaus (Landau*Gaussian) fit is applied to the low-Z SiPM ADC distributions, and the MPVs dependence on the incident beam position is considered

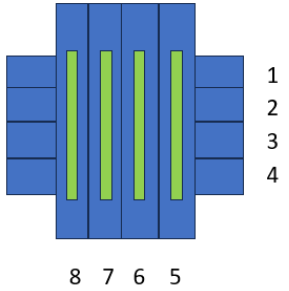


- The **attenuation length** is evaluated through an exponential fit to the MPVs distribution

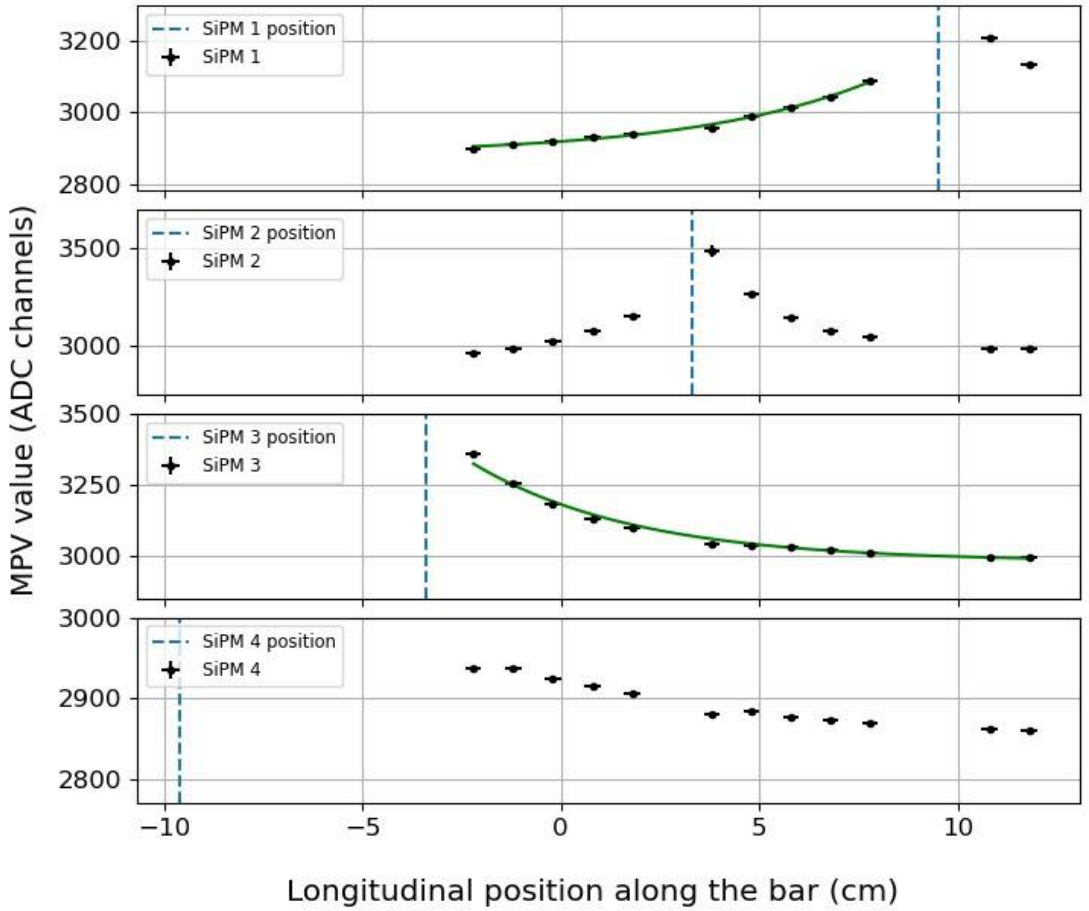
	Attenuation length
SiPM 1	(4.5 ± 0.4) cm
SiPM 3	(4.1 ± 0.3) cm

Initial parameter: 140 cm*
*Tabulated value for BC-404

Note: slight differences in bar size and SiPM properties reasonably don't affect the attenuation length estimation significantly.
Indeed, similar results @ CNAO



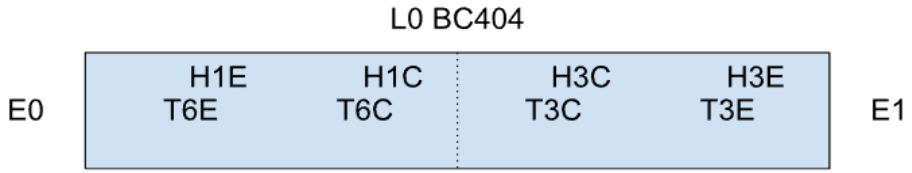
Analyses by E. Casilli



Tile position scan @ CNAO

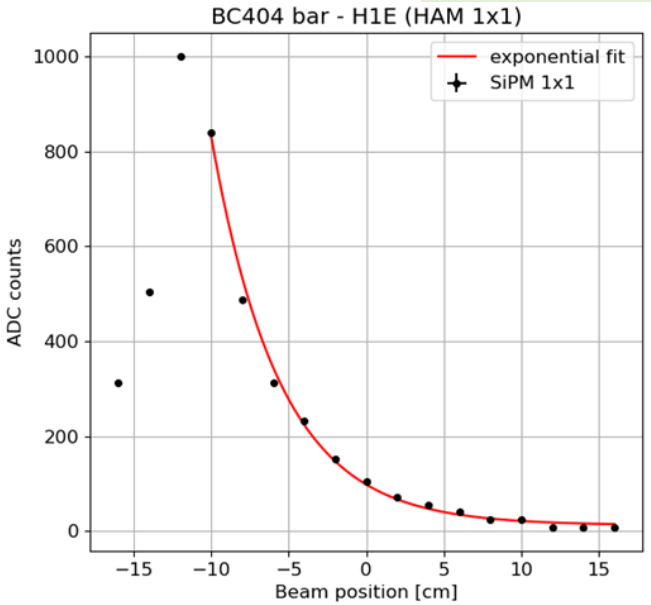
- To study the uniformity of light collection, the tile tested @ CNAO was irradiated with a C beam at 398.84 MeV
- The maximum position is estimated for each beam position, then an exponential fit is employed to evaluate the **attenuation length** of the trapezoidal tile

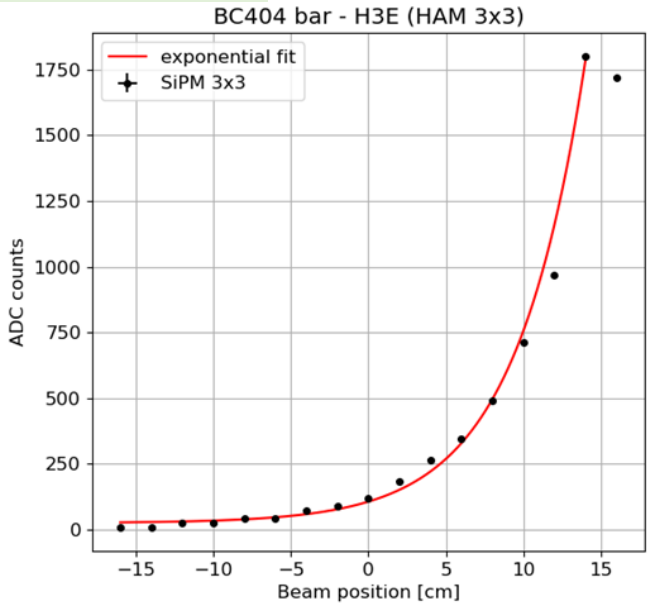
Analyses by E. Casilli



E0, E1 HAM 3x3
H1E, H1C HAM 1x1
T6E, T6C TSV 6x6
H3E, H3C HAM 3x3
T3C, T3E TSV 3x3

Note: slight differences in bar size and SiPM properties reasonably don't affect the attenuation length estimation significantly. Indeed, similar results @ PS





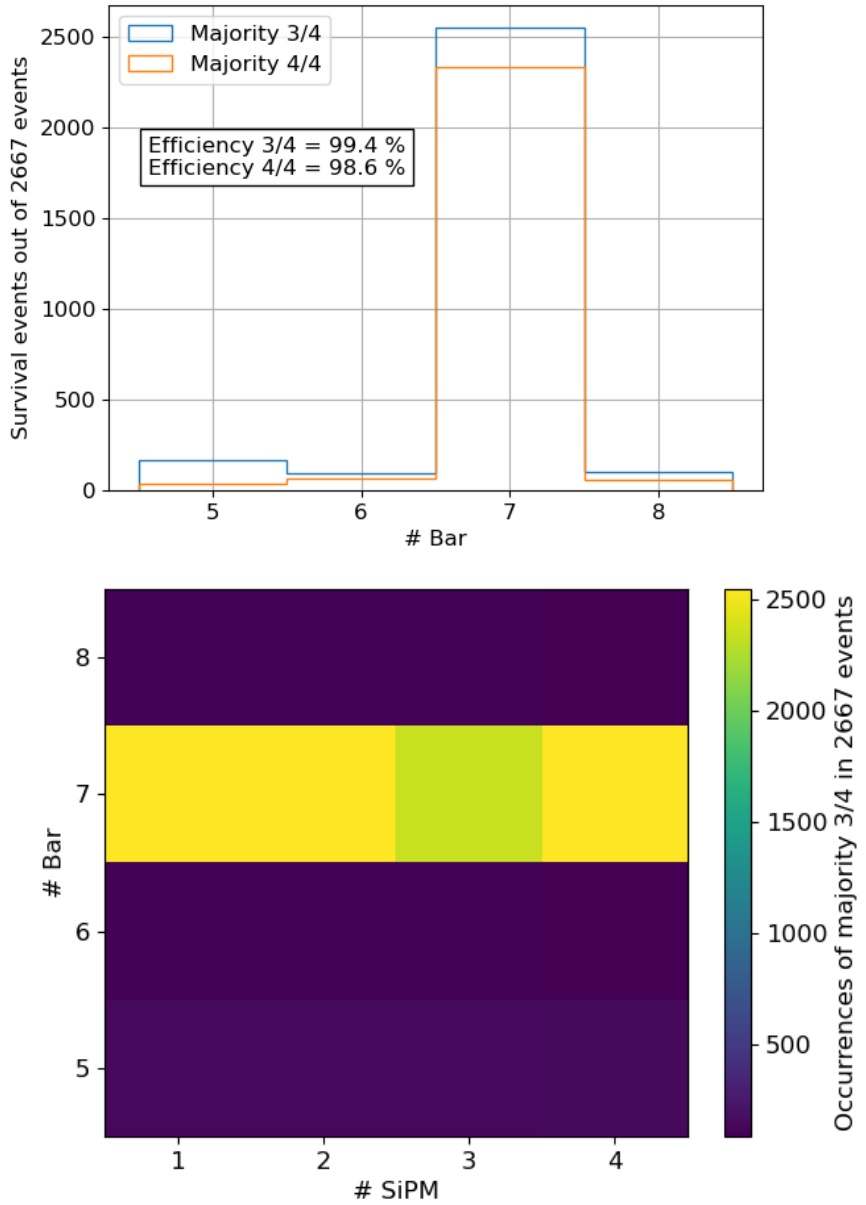
	Attenuation length
H1E	(4.43 ± 0.19) cm
H3E	(4.55 ± 0.14) cm

Initial parameter: 140 cm*
*Tabulated value for BC-404

- Non-uniformity of SiPM signal response due to the different distance between the particle trajectory and SiPM location can be addressed by utilizing a tracking system.
- Information about the particle track can be exploited to estimate the impact point on the PSD, as well as the evaluation and compensation of the non-uniformity

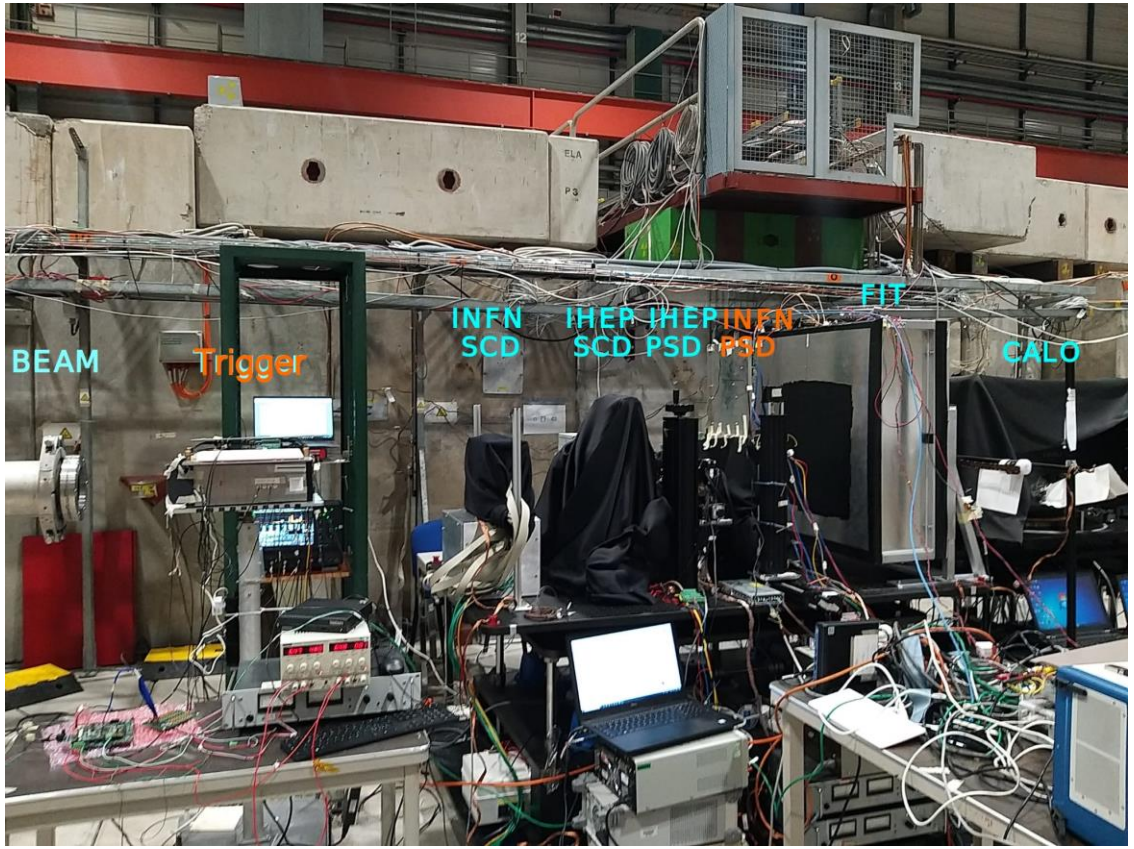
PS-T9: Majority trigger efficiency

- IFAE evaluation board implements internal hardware majority trigger logic to discriminate gamma-rays from charged particles
- Internal trigger logic can be set for low-Z and high-Z SiPMs
- Possibility to digitalize high-gain (HG) or low-gain (LG) signals for richer dynamic range for both low-Z and high-Z particles, but currently the internal trigger can be set only for the HG path
- Tested majority 3/4 and 4/4 @ PS with beam of 10 GeV negative pions
- Trigger efficiencies evaluated as the fraction of events satisfying the internal majority trigger condition over the number of external triggers
- Internal trigger threshold scans were performed at various gains
- **Majority 3/4** (4/4) efficiency values up to **99.0-99.7** % (95-98 %)
- Estimates limited by low statistics, geometrical acceptance...



Majority efficiencies and internal trigger hit-map for bars 5-8 in a test run with the beam centered on tile 7.

SPS-H4 setup



Ion beam @ SPS H4 test beam

- Derived from a 150 GeV/A primary Pb beam
- Impinging onto a Beryllium target
- 330 GeV/Z selected beam

T1 Tile (between the beam pipe and the trigger)

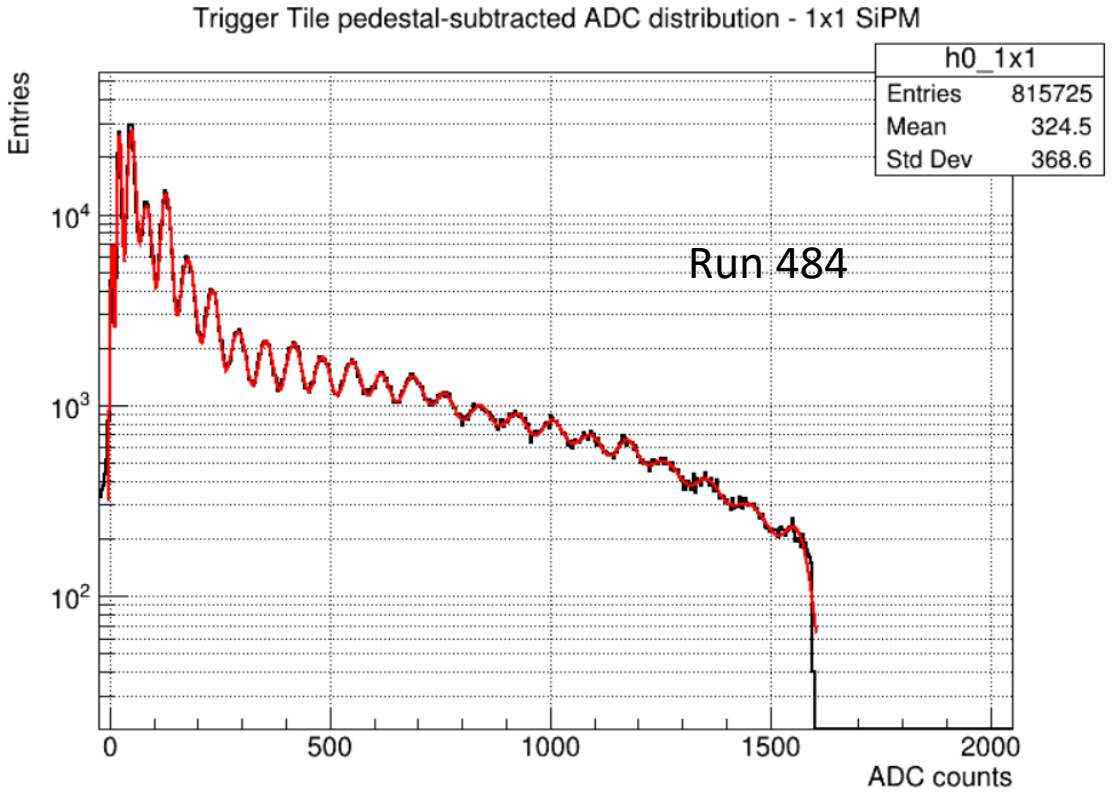
- 10x10x0.5 cm^3 BC-404 plastic scintillator tile
- 3x3 mm^2 and 1x1 mm^2 SiPMs
  (3 SiPMs per type on the small tile side.
  The analog sum of the 3 SiPMs is read-out)
- HERD-BETA as read-out electronics

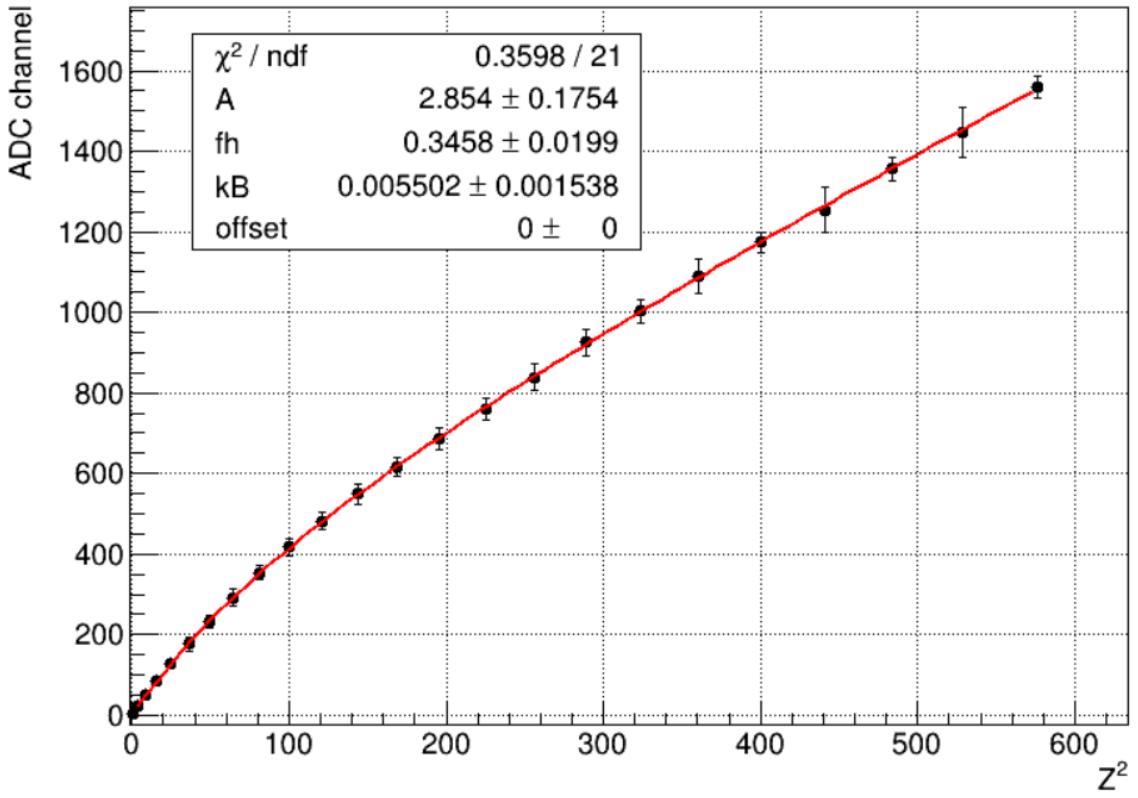
Longitudinal distance of around 90 cm between INFN-SCD and PSD_prot0 prototype

SPS-H4 analysis: Trigger Tile

- Evaluation of the Birks' saturation effect for Trigger Tile response calibration
- Birks' law: $\frac{dL}{dx} = A \cdot \frac{(1 - f_h) \cdot \frac{dE}{dx}}{1 + k_b \cdot \frac{dE}{dx}} + A \cdot f_h \frac{dE}{dx}$
  - $\frac{dL}{dx}$: scintillation light yield
  - $\frac{dE}{dx}$: energy deposited
  - f_h : fraction of energy deposited in the halo
  - k_b : Birks' constant

- Peak positions from the T1 trigger tile ADC distribution estimated with Gaussian fits
- Best-fit value of f_h from the fit with the Birks' function compatible with the reference values in literature
- 57 Trigger Tile I2C runs @ SPS-H4 were converted





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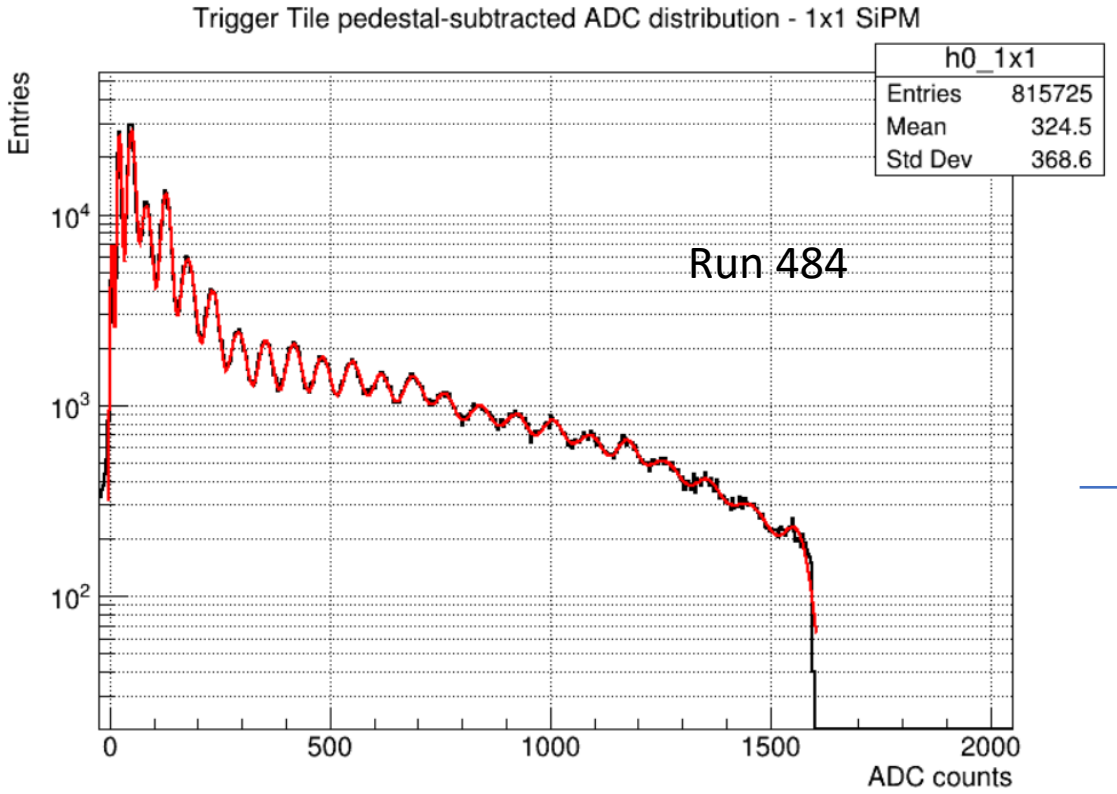

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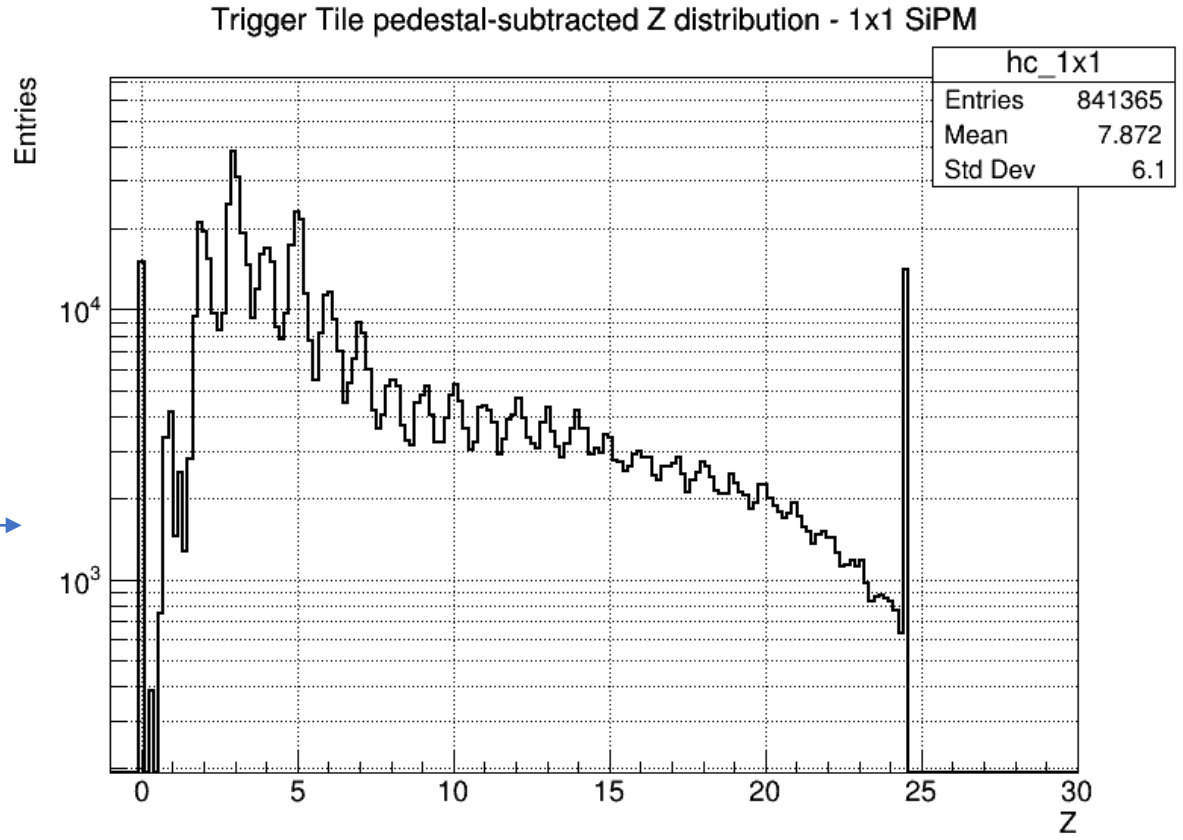
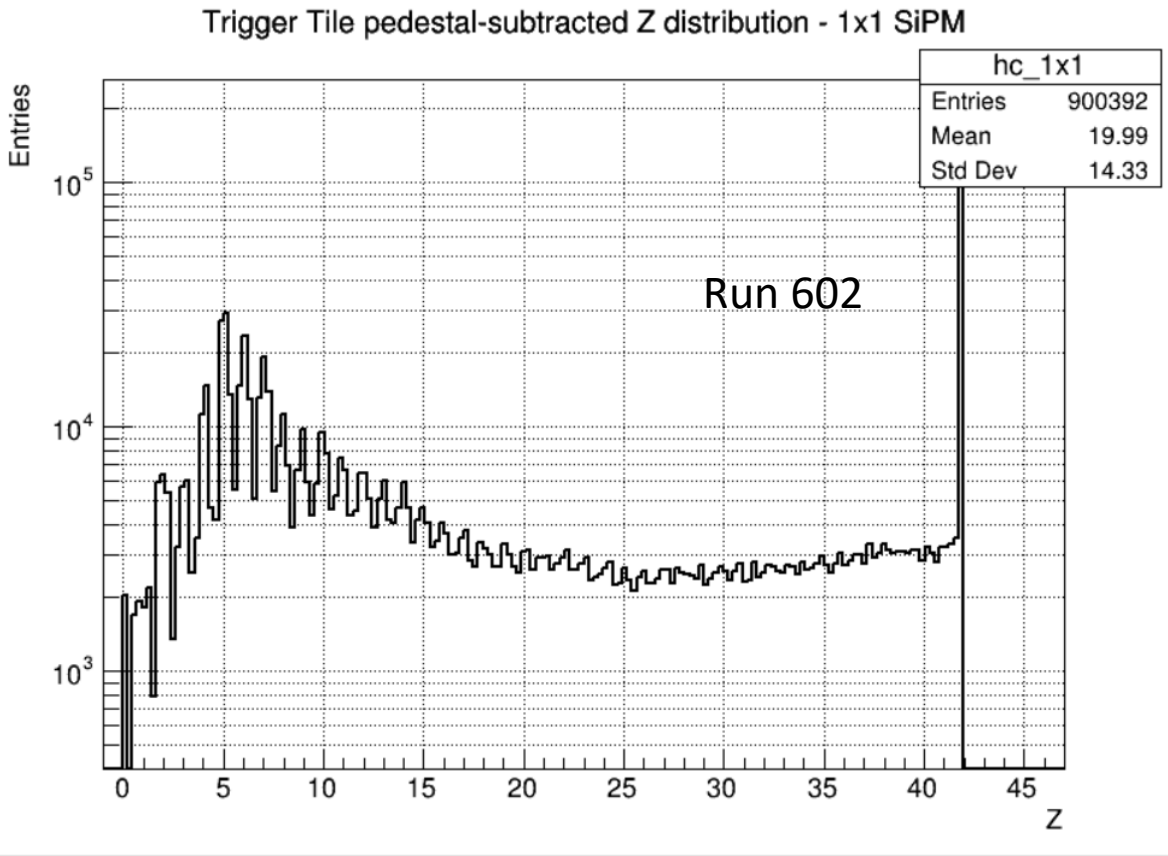
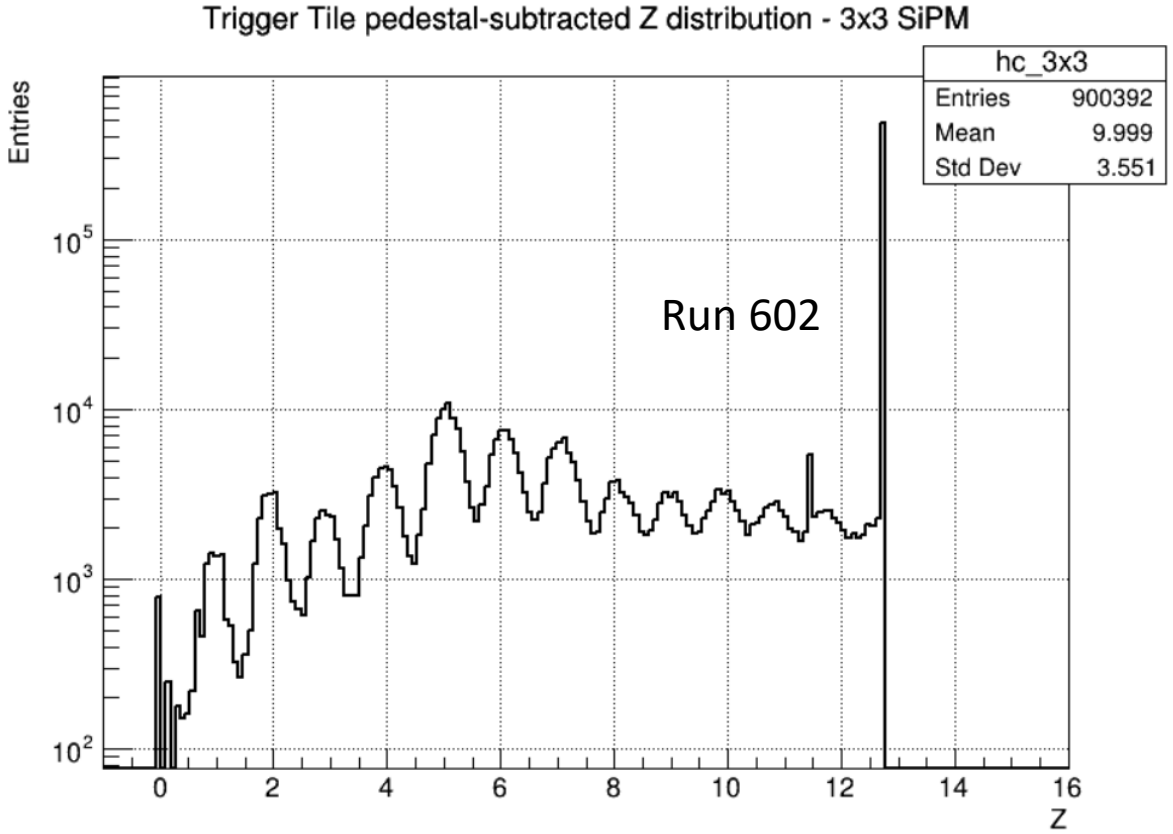


SPS-H4 analysis: Trigger Tile

- T1-trigger (squared) tile shows capability to clearly distinguish signals generated from MIPs to nuclei heavier than iron

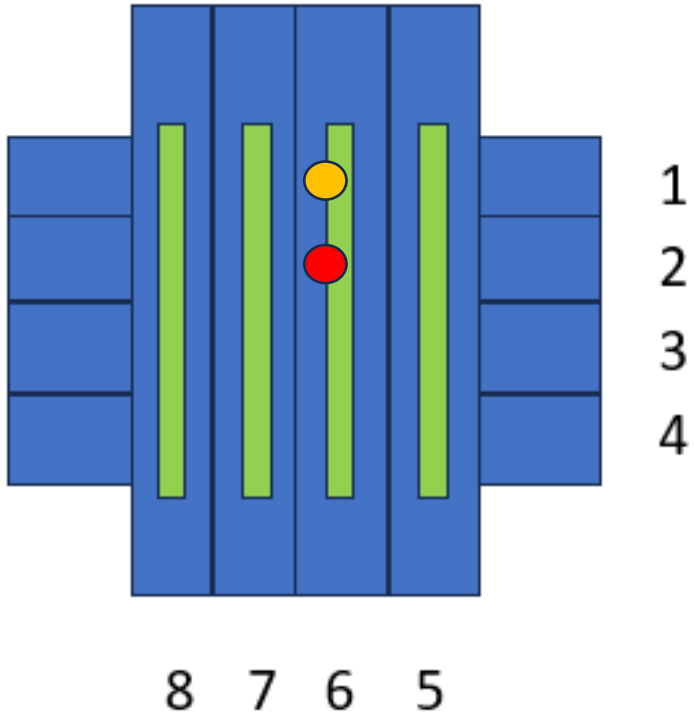
- 57 Trigger Tile I2C runs @ SPS-H4 were Z-converted
- The analysis procedure was applied to both Trigger Tile 1x1 and 3x3 SiPMs

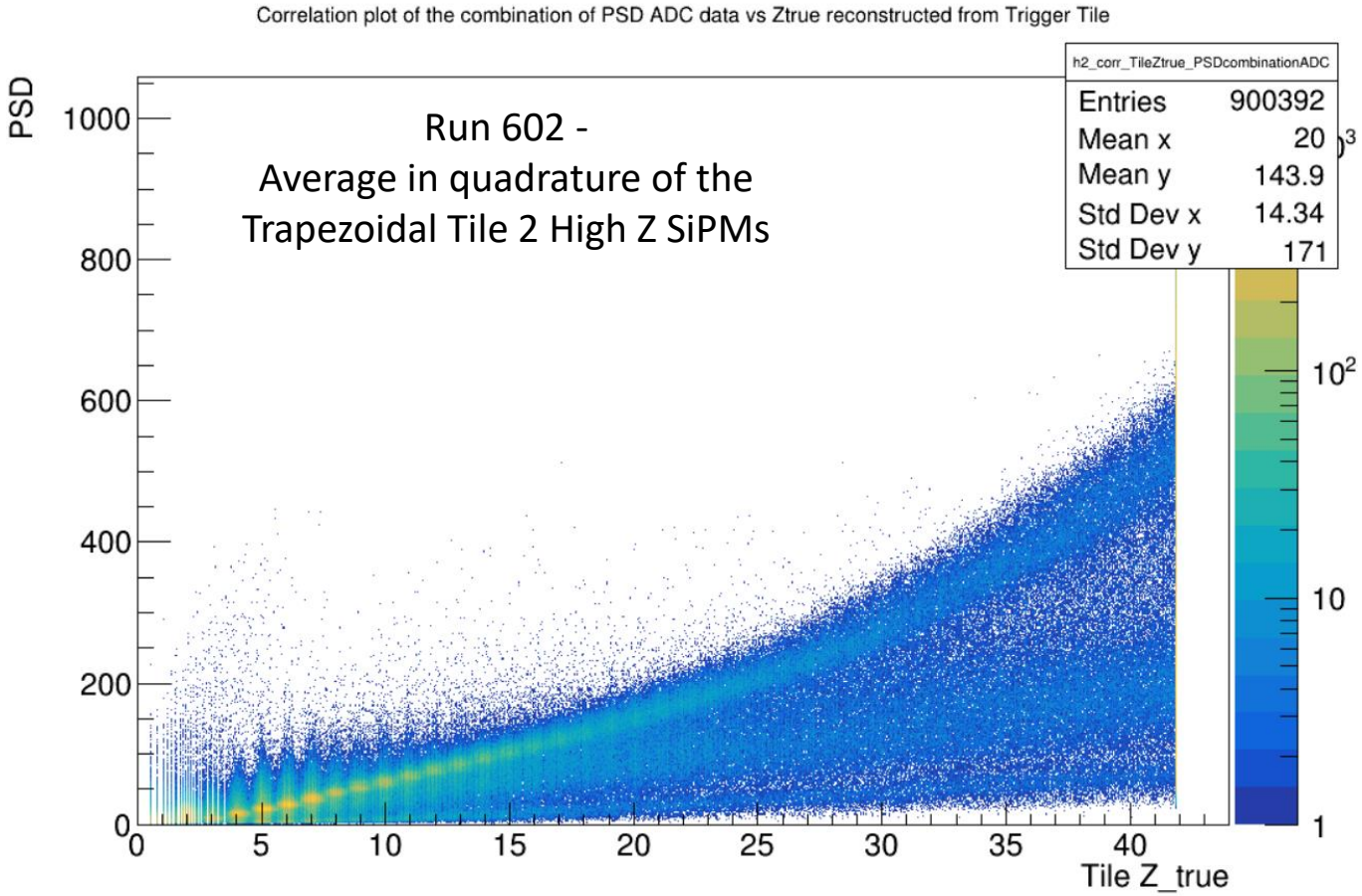




SPS-H4 analysis: PSD

- To perform Z-calibration of the PSD data, we correlated events from T1 trigger tile with those from the PSD_prot0 tile under beam
  - Vertical tiles: **Trapezoidal Tile #6**
  - Horizontal tiles: **Trapezoidal Tile #1 (#2 from run 602)**



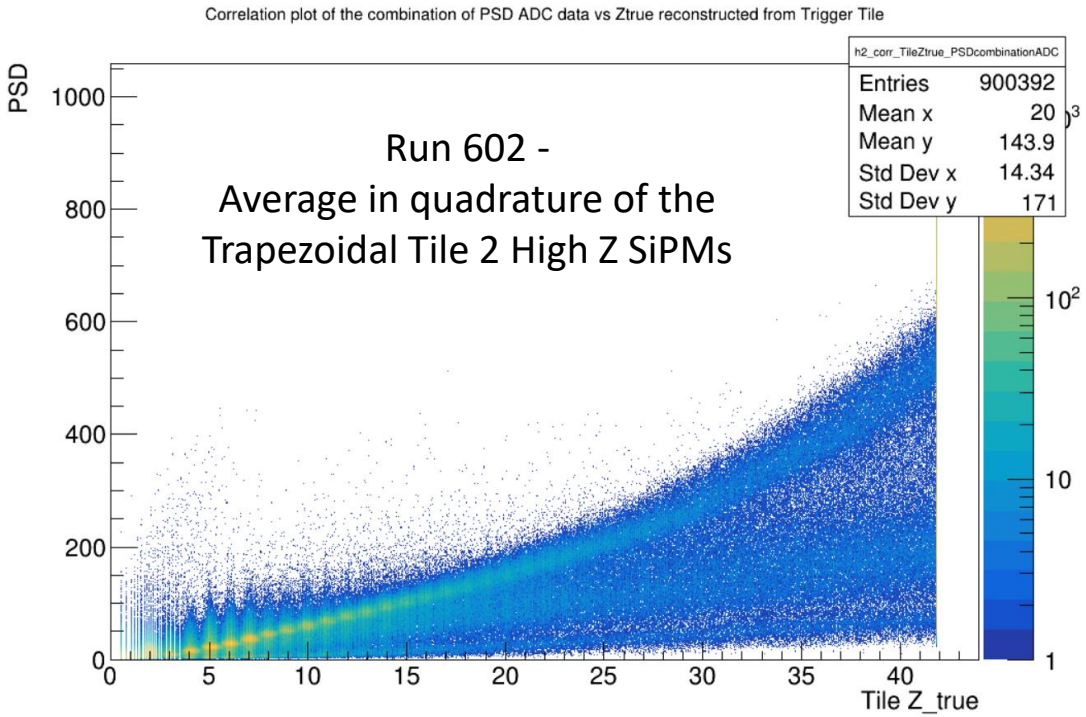


- **Beam position for I2C runs up to run #602**
- **Beam position for I2C runs from run #602**

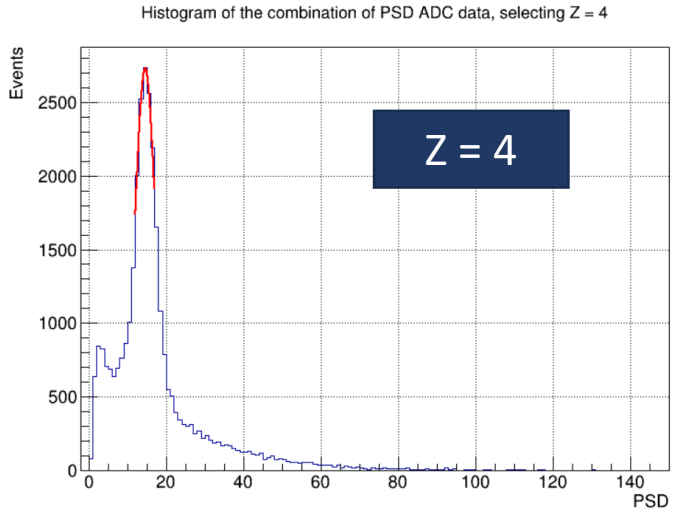
- The analysis strategy consists in calibrating the PSD response based on the Trigger Tile reconstructed Z and accounting for Birks' effects as for the Trigger Tile

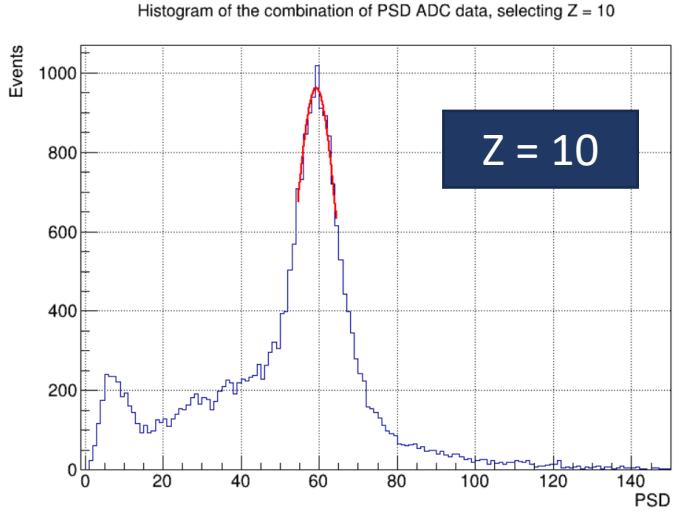
SPS-H4 analysis: PSD

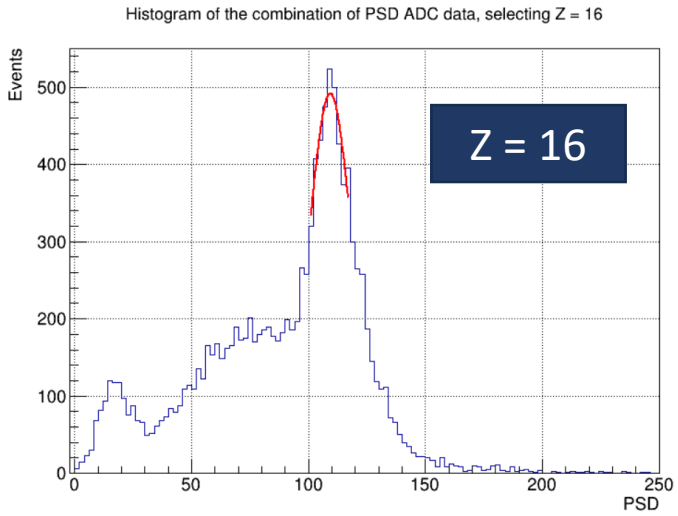
High-Z SiPM: Tile under beam

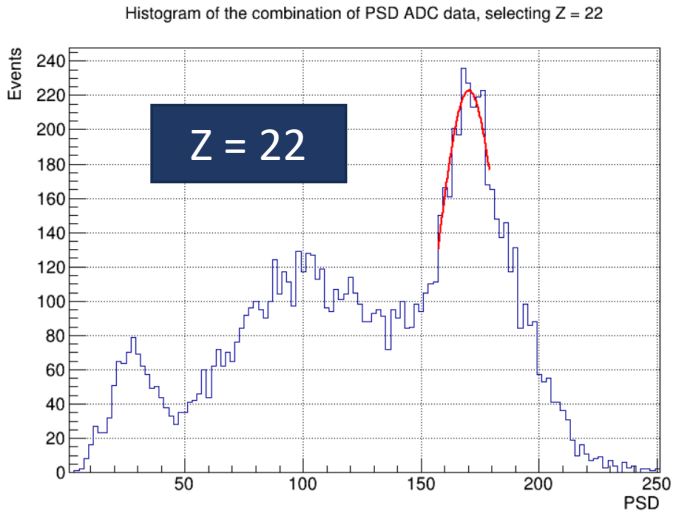


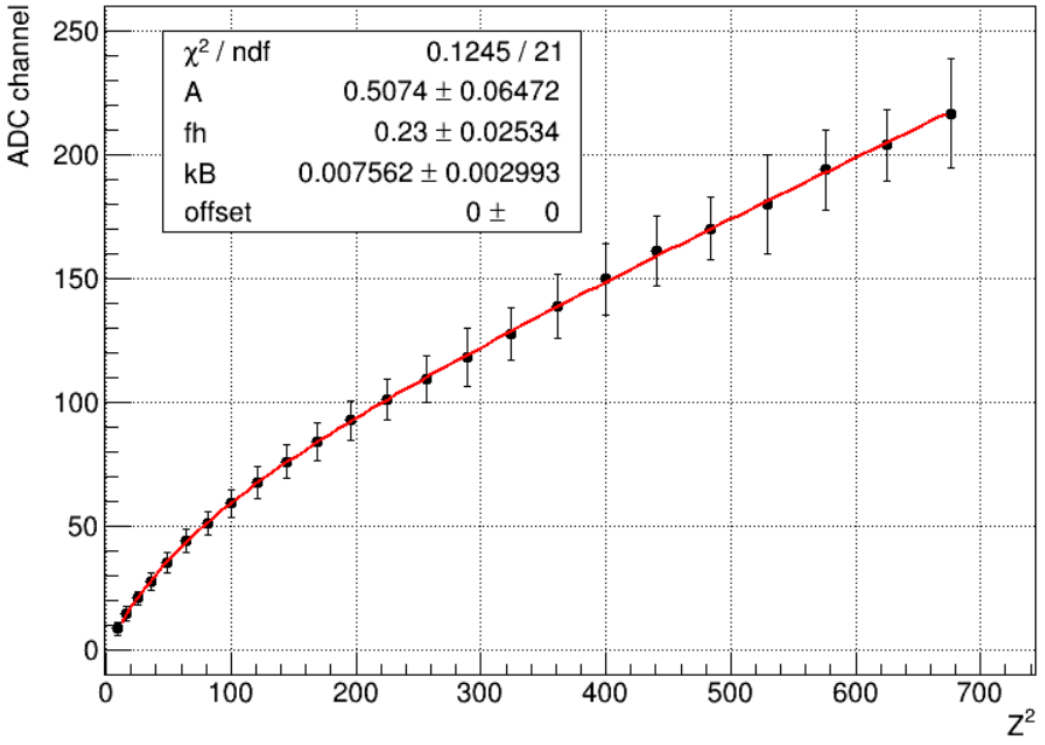
Run 602 -
Average in quadrature of the
Trapezoidal Tile 2 High Z SiPMs





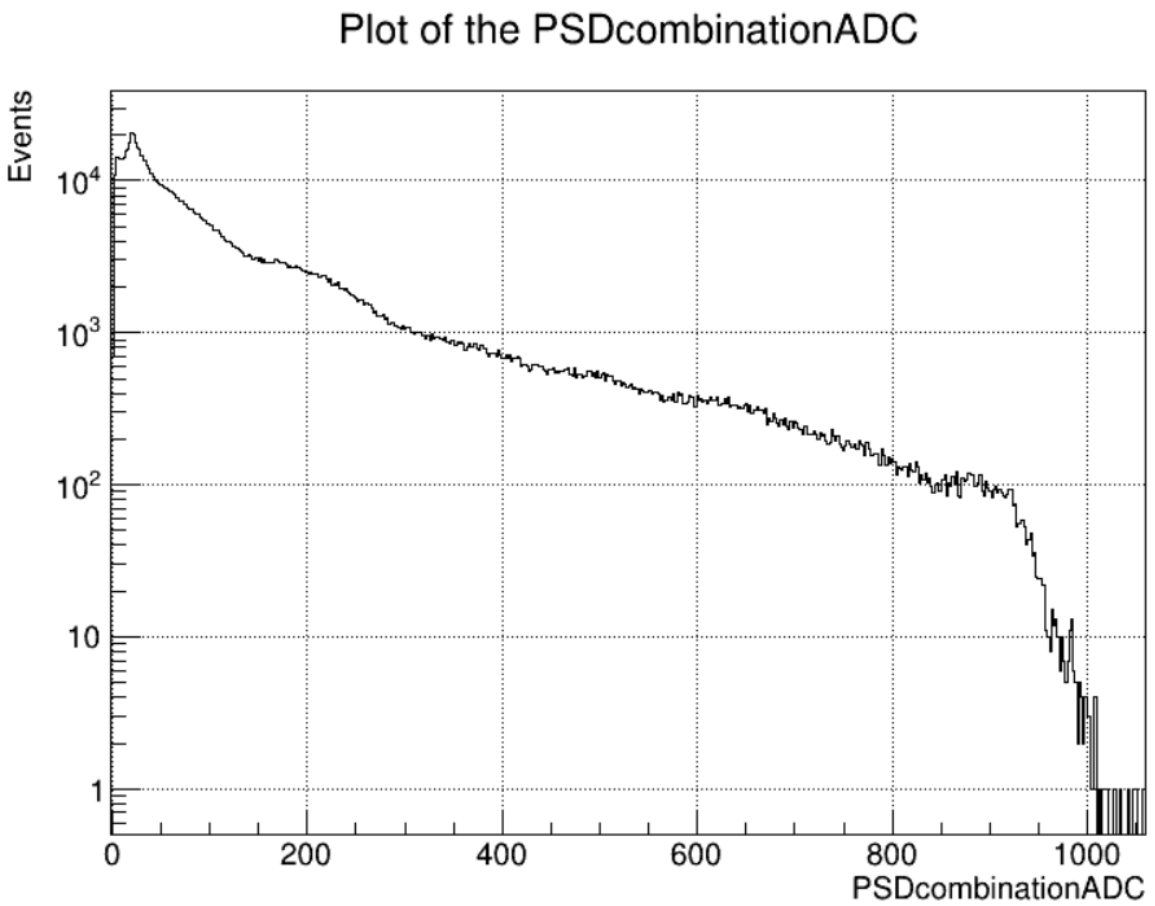


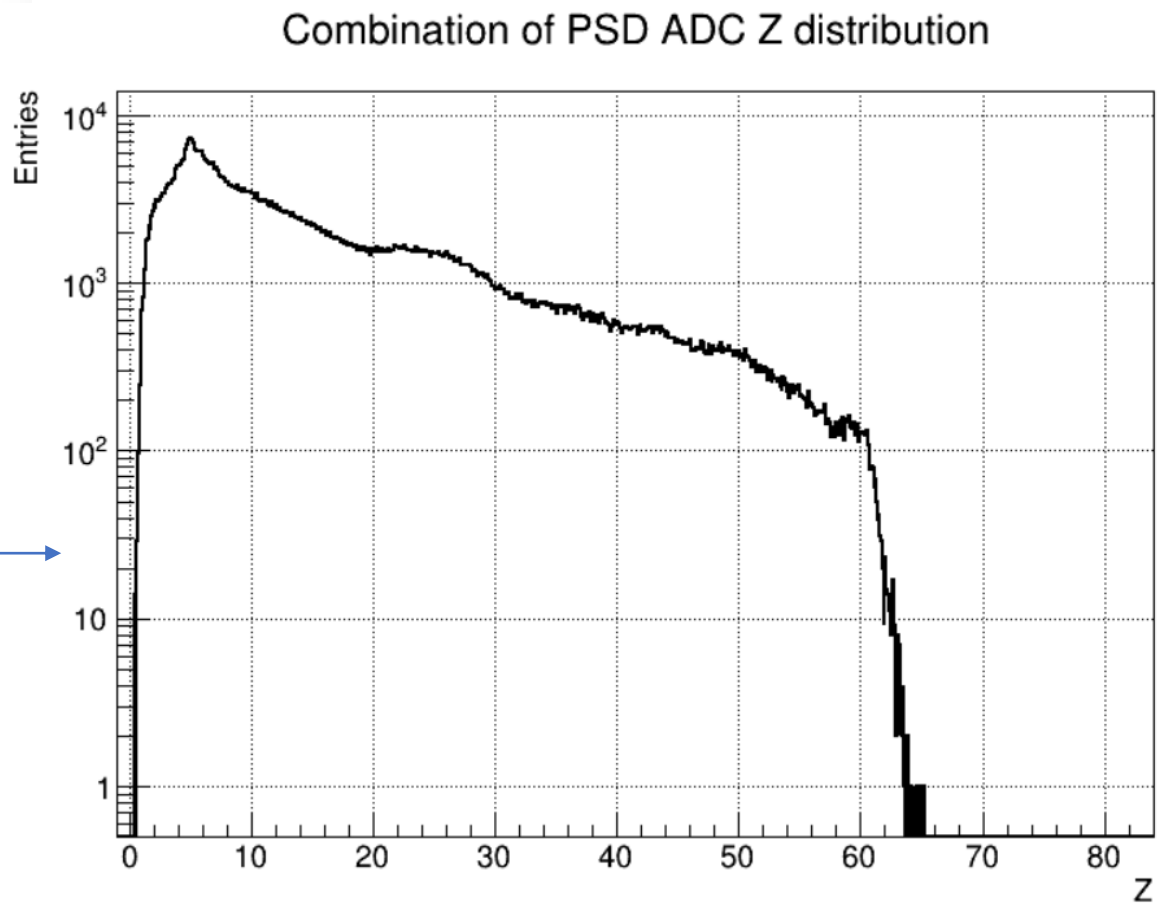




SPS-H4 analysis: PSD

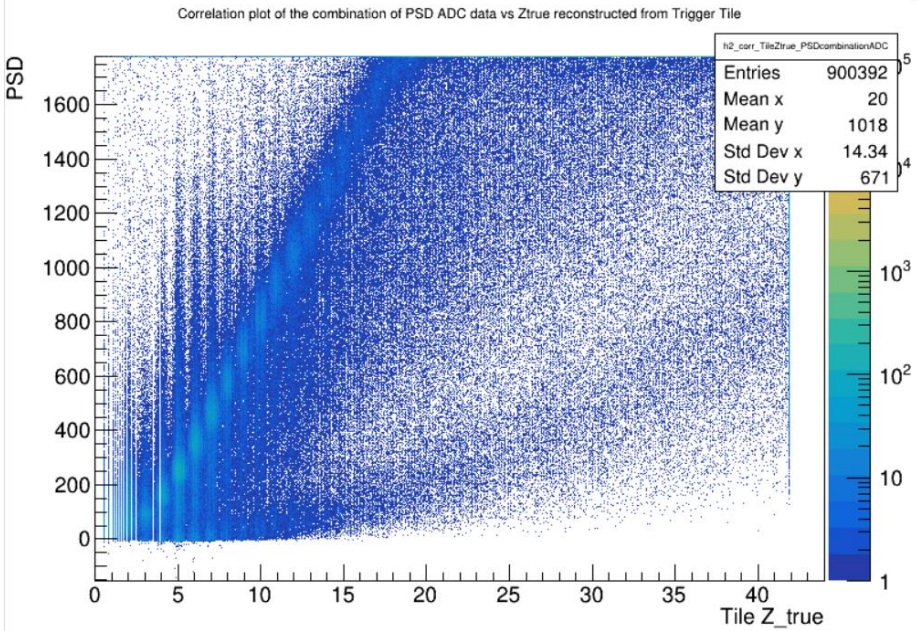
- From the Birks' law fit, the ADC spectrum can be converted to a Z one, as done for the Trigger Tile
- A similar approach was used to convert Low-Z SiPM spectra of the trapezoidal tiles mainly hit by the beam





SPS-H4 analysis: PSD

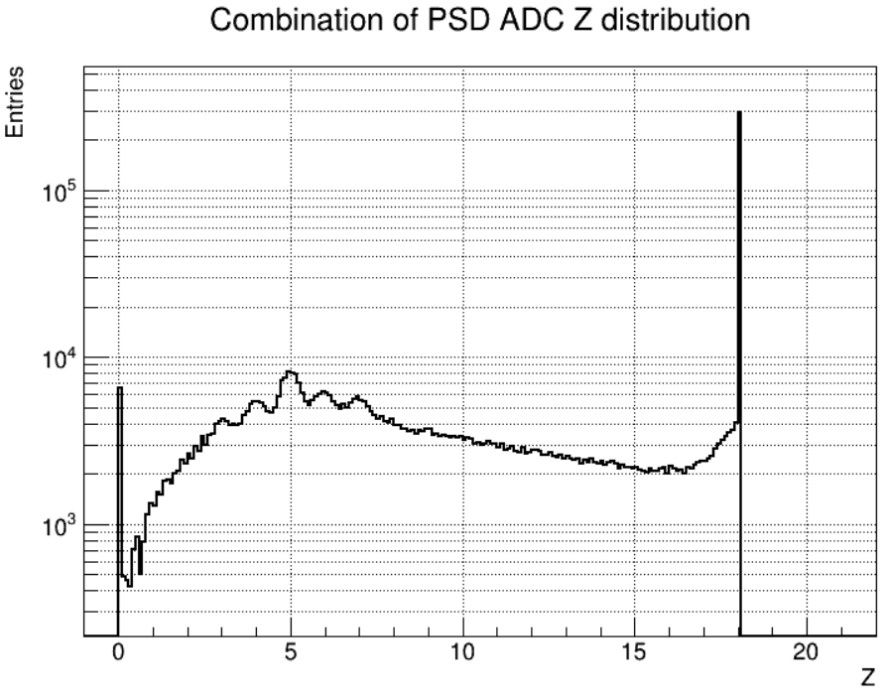
Low-Z SiPM: Tile under beam

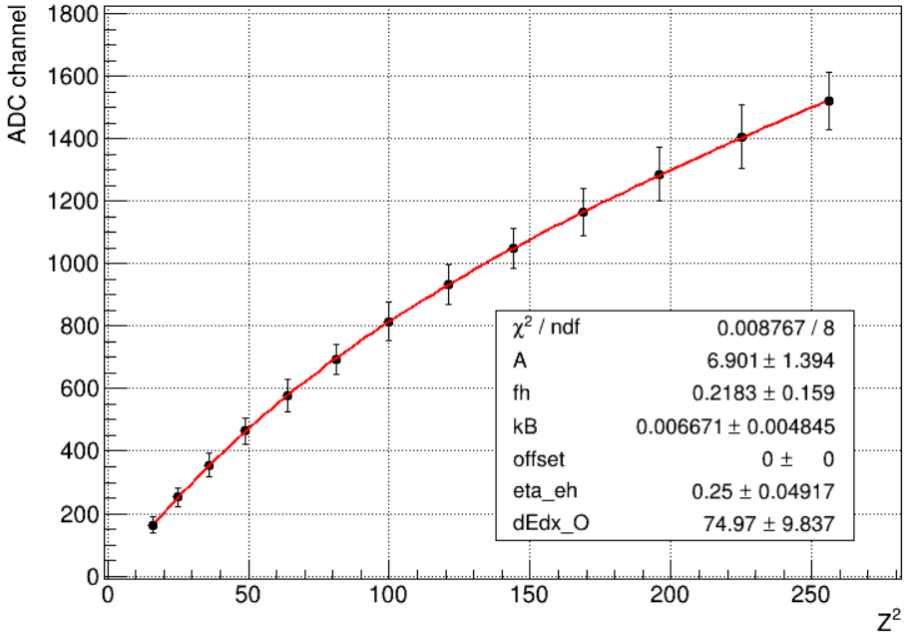


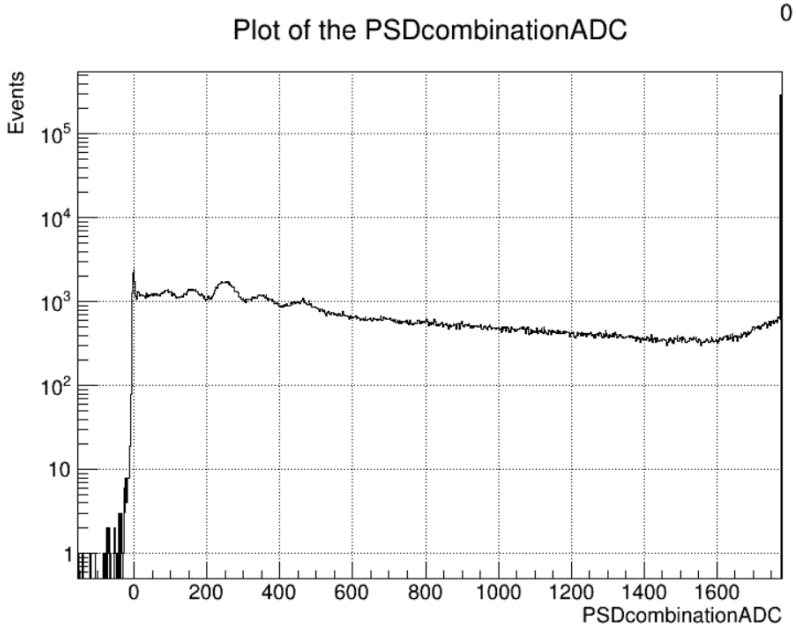
This analysis strategy was applied to both Low- and High-Z SiPMs of the trapezoidal tiles mainly hit by the beam:

- Vertical: **Tr. Tile #6**
- Horizontal: **Tr. Tile #1**

(#2 from run 602)



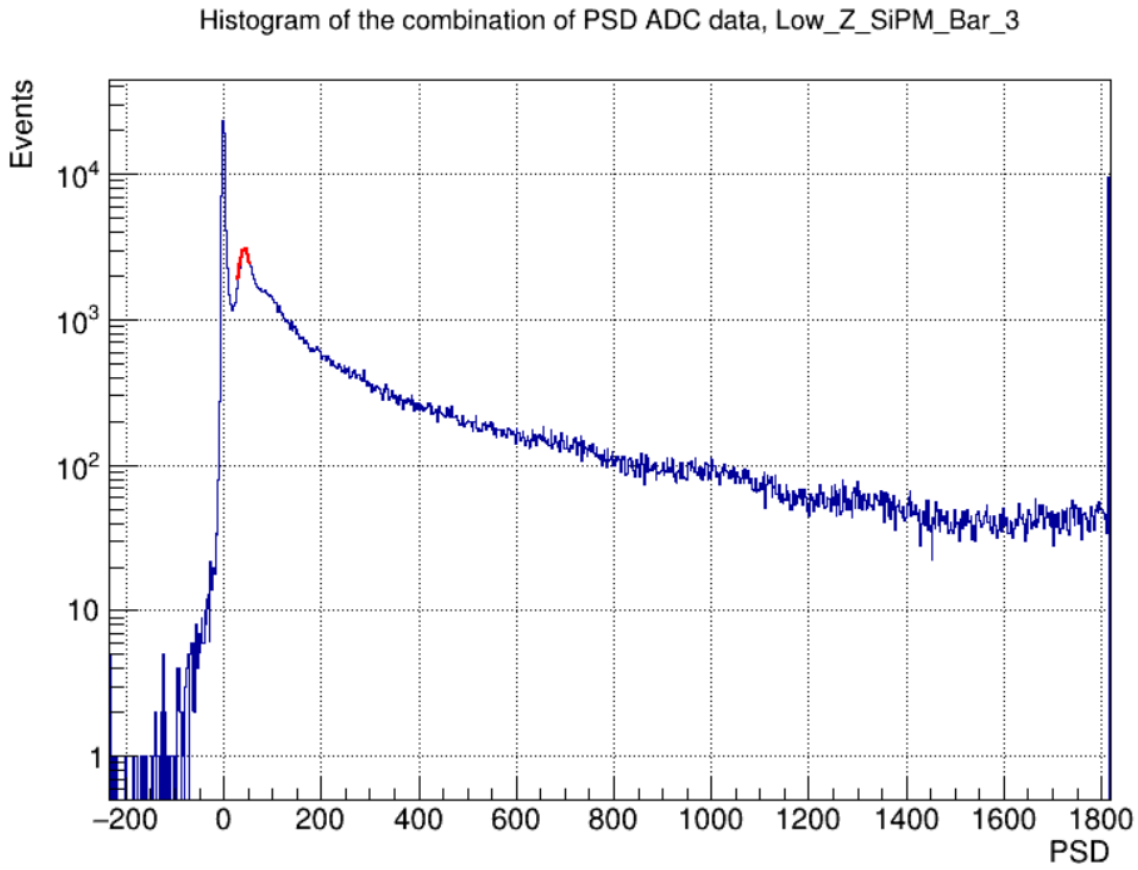


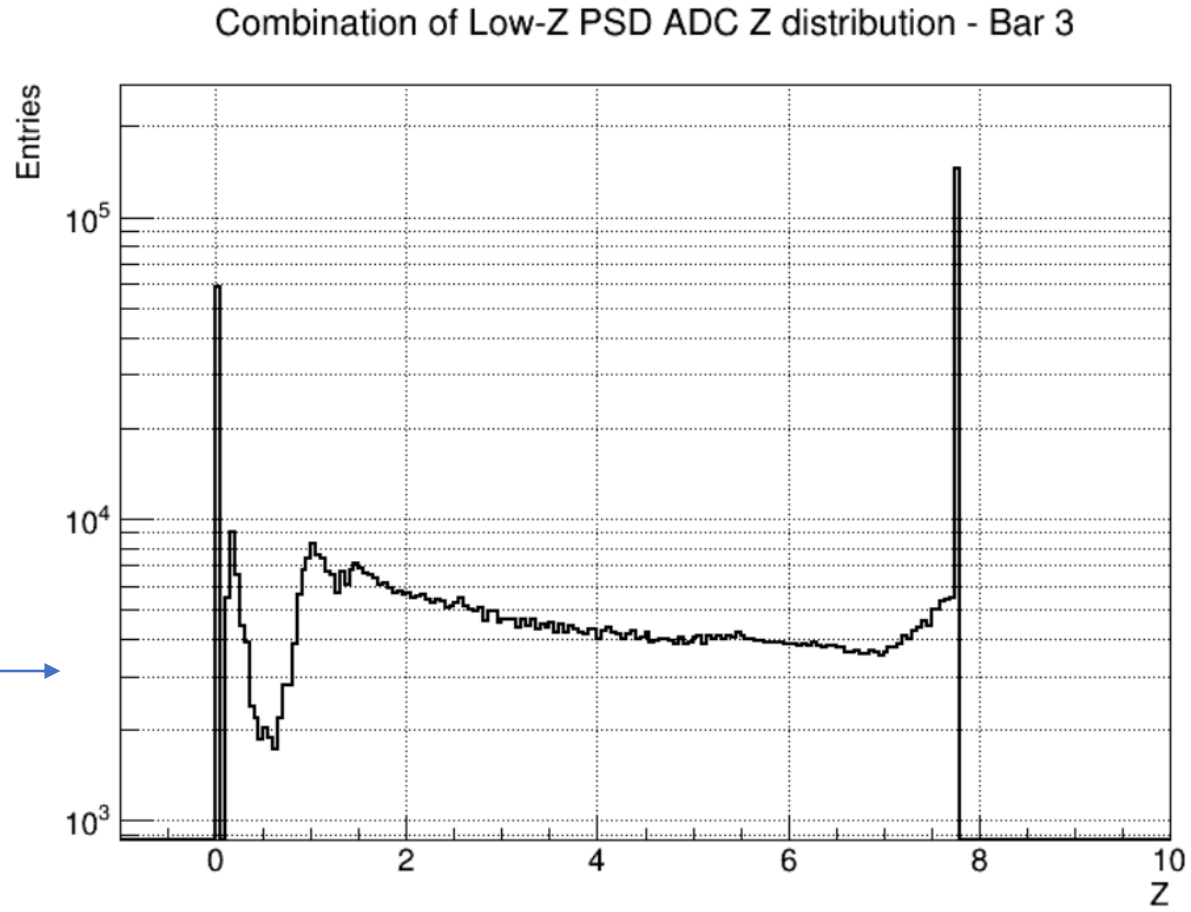


SPS-H4 analysis: PSD

Low-Z SiPM: Tiles far from beam

- The PSD prototype tiles that are not directly hit by the beam are hit by fragments
- At any PSD gain, one peak in the Low-Z ADC spectra can be resolved, which is reasonable to be associated to MIP signals, from which an approximate calibration can be performed



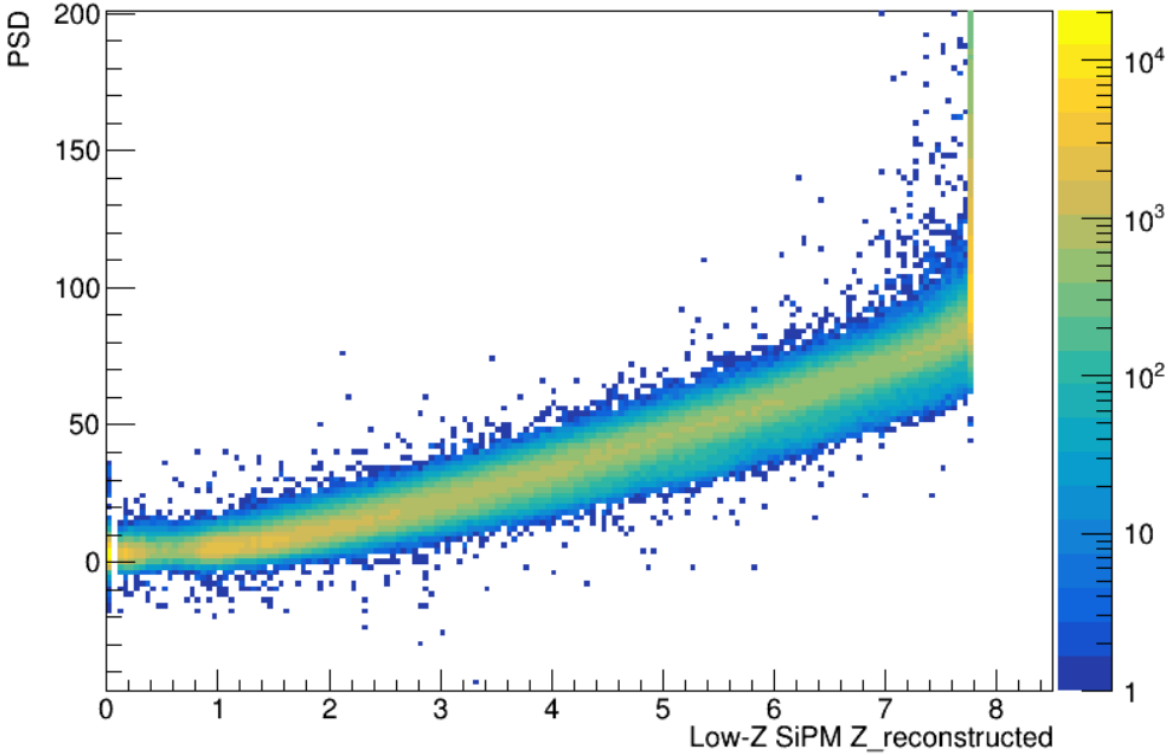


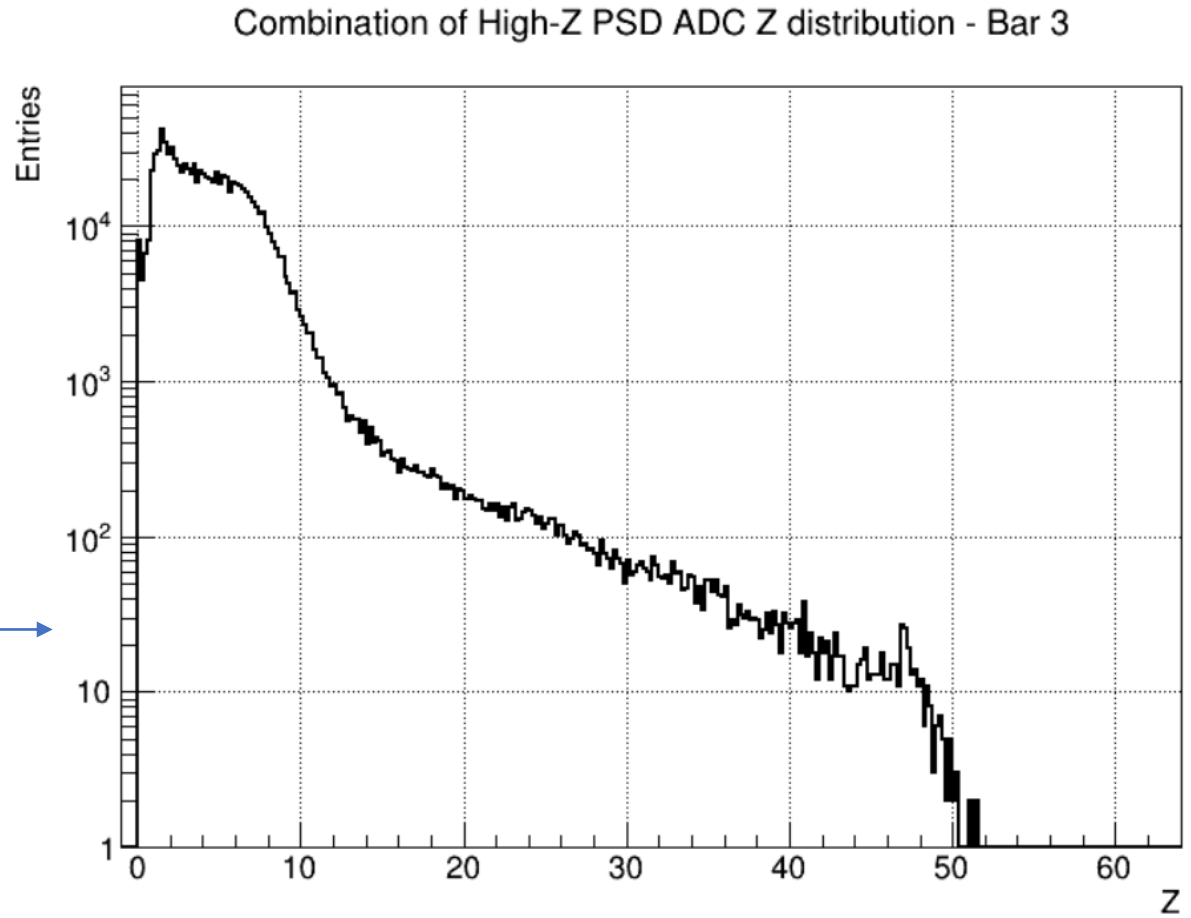
SPS-H4 analysis: PSD

Low-Z SiPM: Tiles far from beam

- From the Low-Z calibration, by taking advantage of the correlation between the Low-Z and High-Z SiPMs for each tile, it is possible to calibrate also the High-Z SiPMs of the PSD tiles that are not mainly hit by the beam
- This analysis pipeline allowed us to estimate, for each tile, 2 values of Z (High-Z/Low-Z) for each event

In the very next few days, we're about to complete the conversion of 53 SPS-H4 PSD runs, for a total of 13.5 M physics events





Issues with IFAE board

- Events corrupted after 20k events
- Shifts in the ADC and I2C info occurring in a non-predictable way

Conclusions

- Z-calibration of the high- and low-Z SiPMs of the PSD prototype tiles during the SPS-H4 beam test shows the capabilities of the detector in charged nuclei identification performances

- The SCD tracks can be employed to improve the accuracy of the trapezoidal tile calibration, by accounting properly for the non-uniformity of light collection along the tile observed @ CNAO and @ PS beam test

Backup