HERD 2023 PS/SPS Beam Test - PSD Analysis Updates

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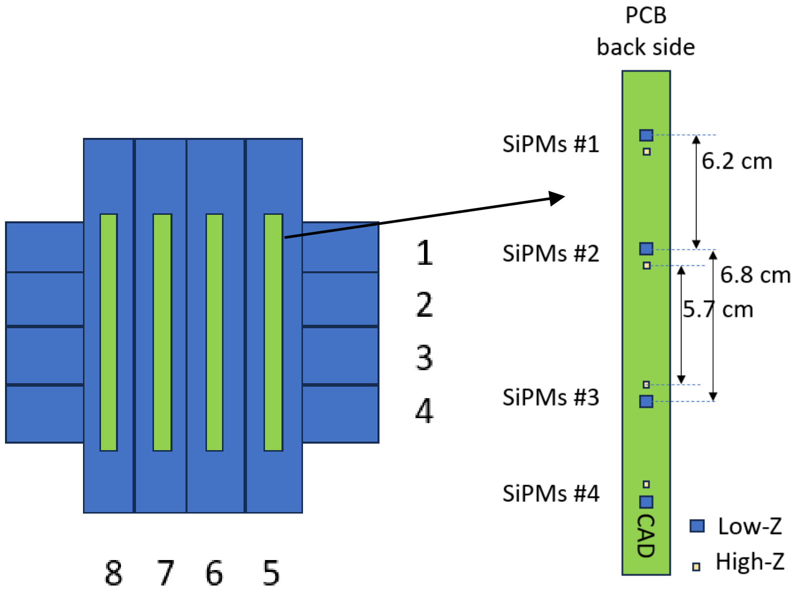
Outline

- The PSD detector prototype @ PS/SPS BTs
- PS-T9 analysis: Tile position scan
- Tile position scan @ CNAO
- PS-T9 analysis: Majority trigger efficiency
- SPS-H4 setup
- SPS-H4 analysis: charge identification capabilities
- SPS-H4 analysis: Birks' law
- Conclusions and to do list

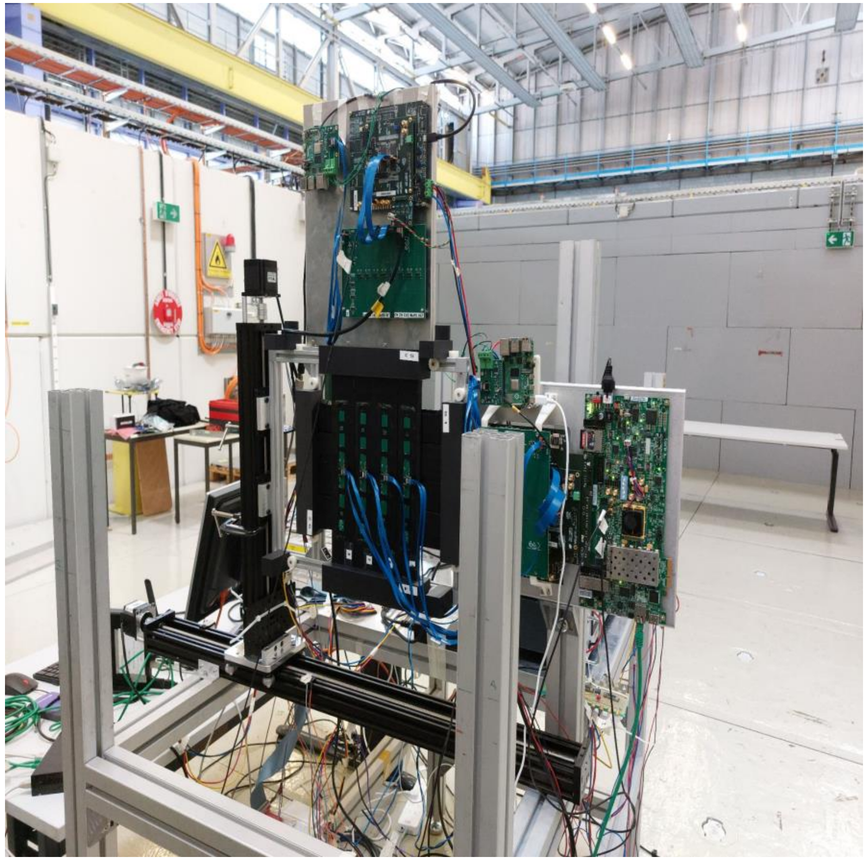
The PSD detector prototype @ PS/SPS BTs

- 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-200) 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

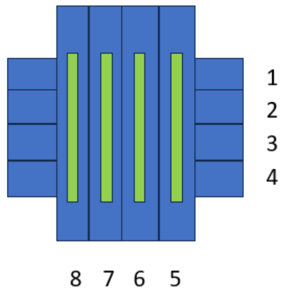
Photograph of the PSD at PS-T9

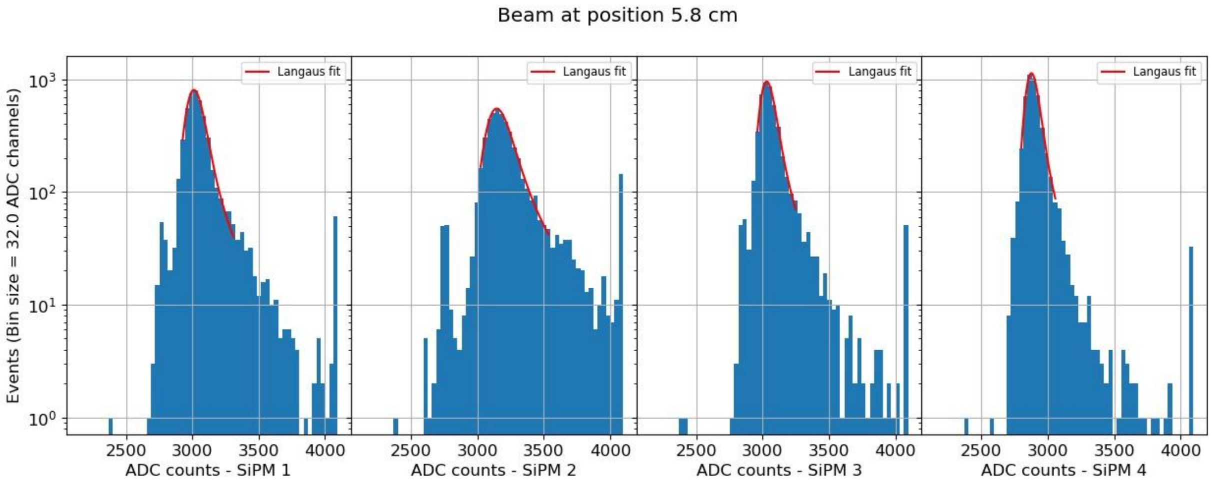


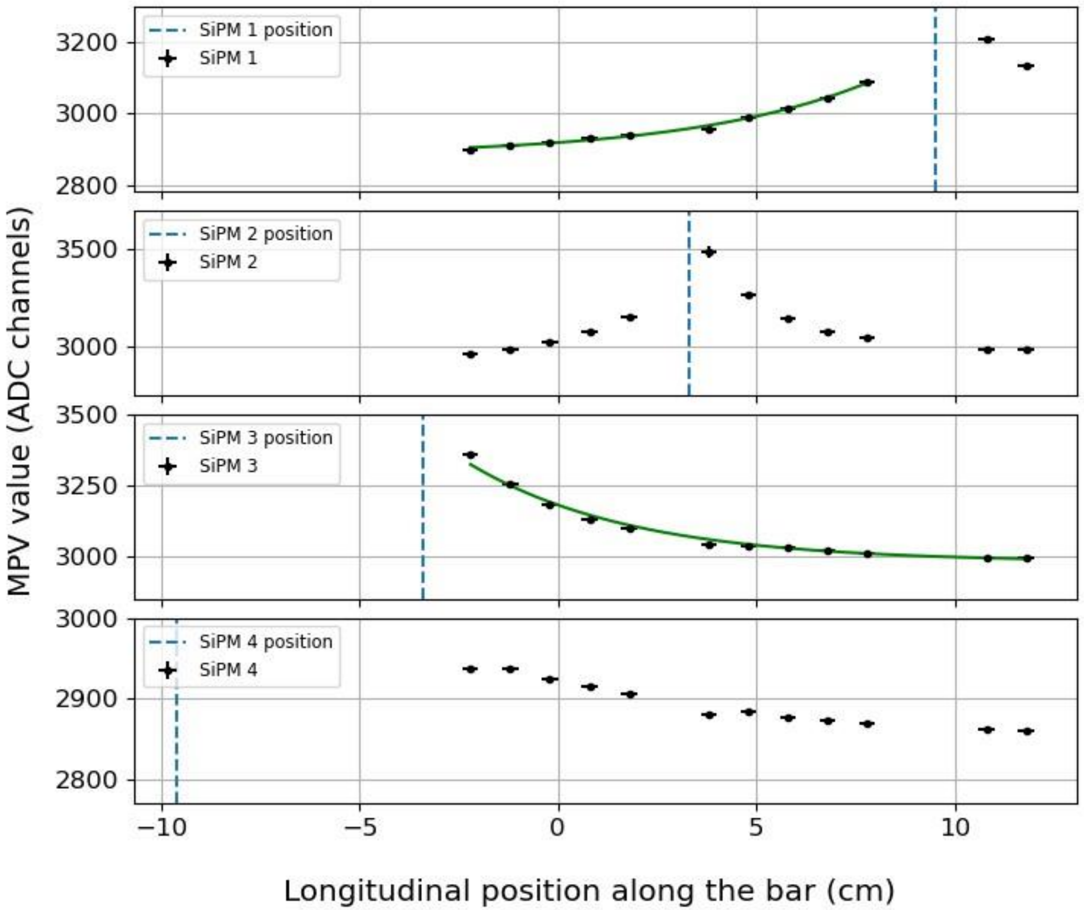
- Two evaluation boards were employed in the BTs
  1. The BETA evaluation board, by ICCUB-SiUB
  2. Xilinx-zc706-based evaluation board, by IFAE
- The IFAE EB allows for contribution to the L0 trigger providing veto signals for gamma-rays below 10 GeV

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

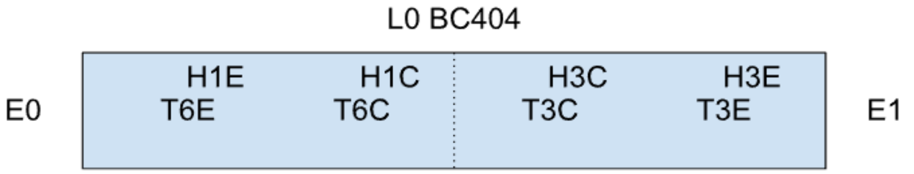
	Attenuation length
SiPM 1	(4.5 ± 0.4) cm
SiPM 3	(4.1 ± 0.3) cm

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

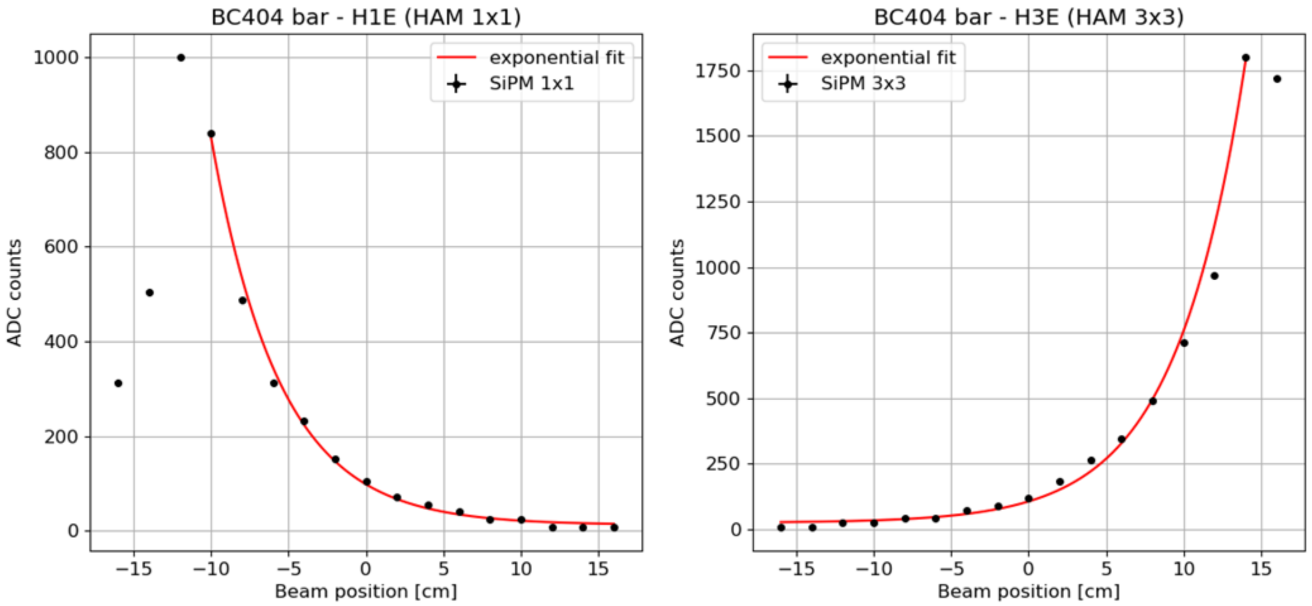
Tile position scan @ CNAO

- 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



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



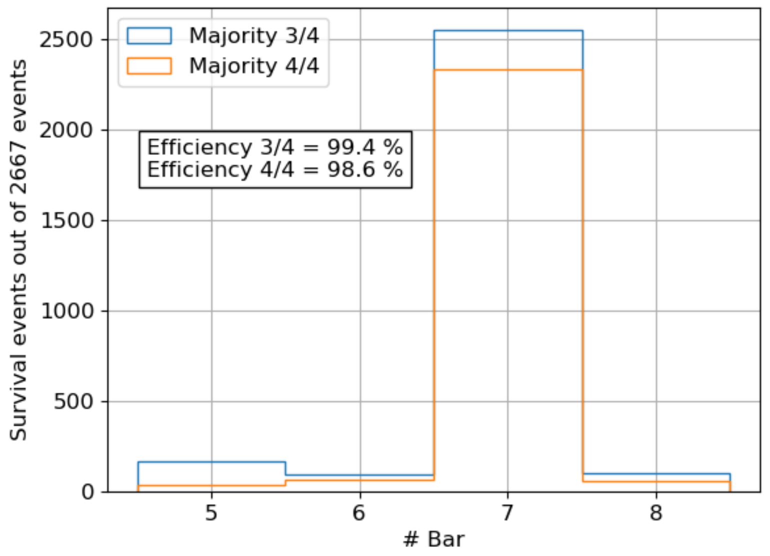
	Attenuation length
H1E	(4.43 ± 0.19) cm
H3E	(4.55 ± 0.14) cm

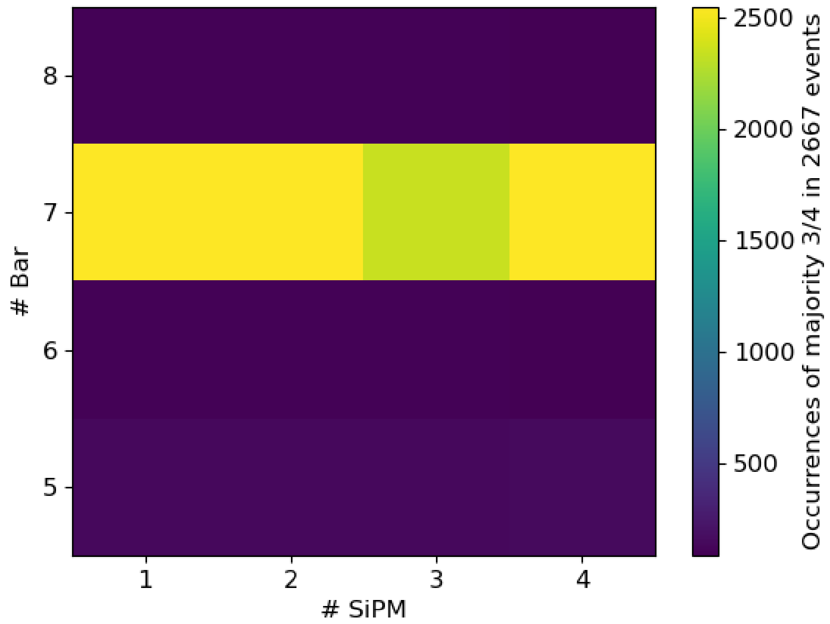
Initial parameter: 140 cm*
*Tabulated value for BC-404

- 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

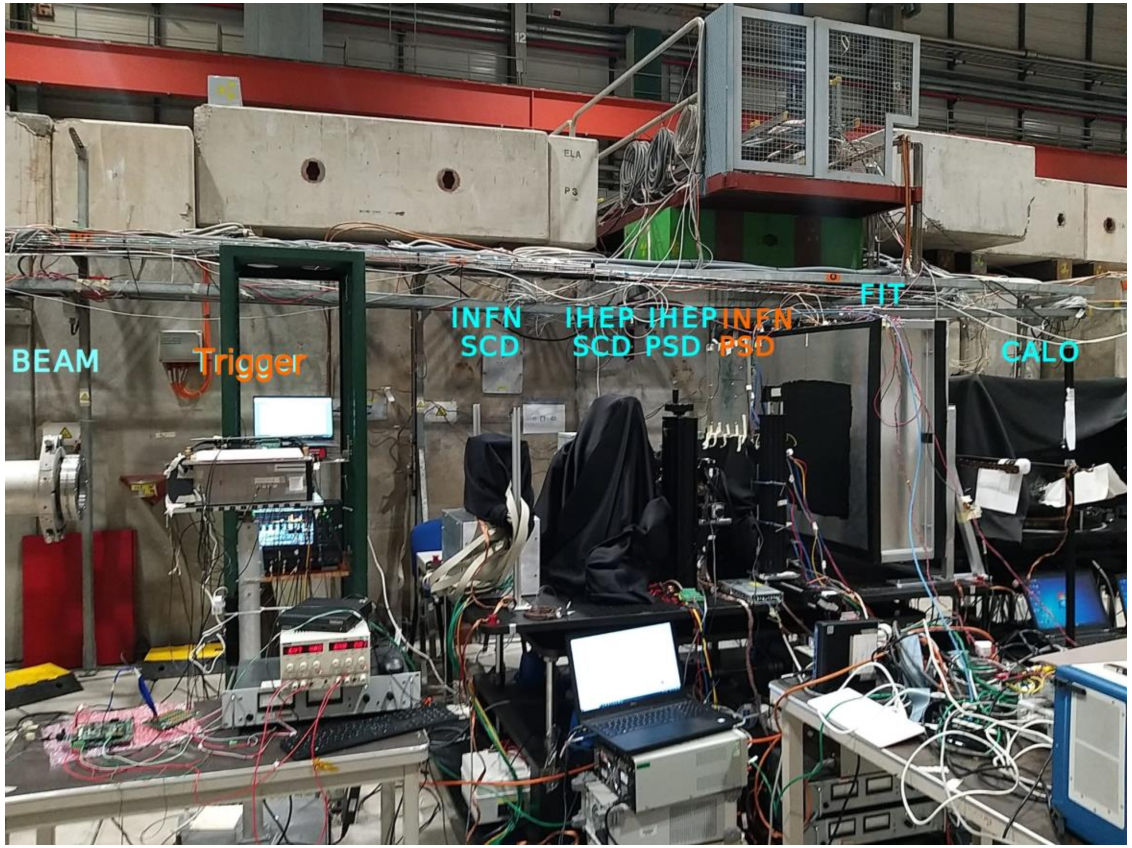
- IFAE evaluation board implements internal hardware majority trigger logic to discriminate gamma-rays from charged particles
- Internal trigger logic can be set for low-Z and high-Z SiPMs
- Possibility to digitalize high-gain (HG) or low-gain (LG) signals for richer dynamic range for both low-Z and 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 hitmap 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

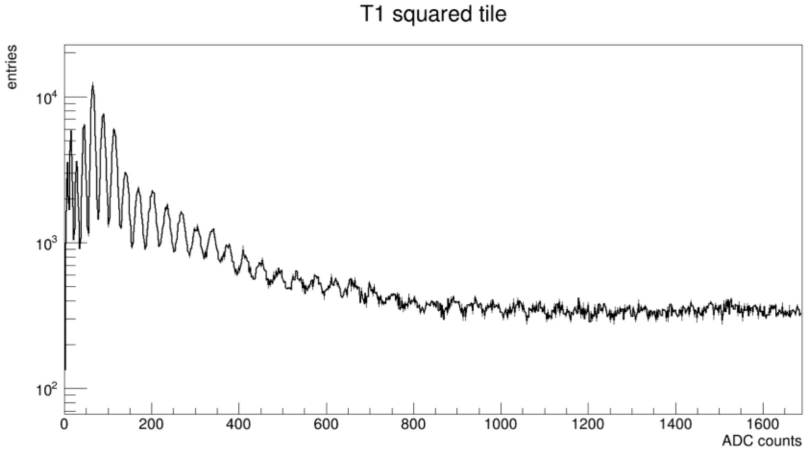
T1 Tile (between the beam pipe and the trigger)

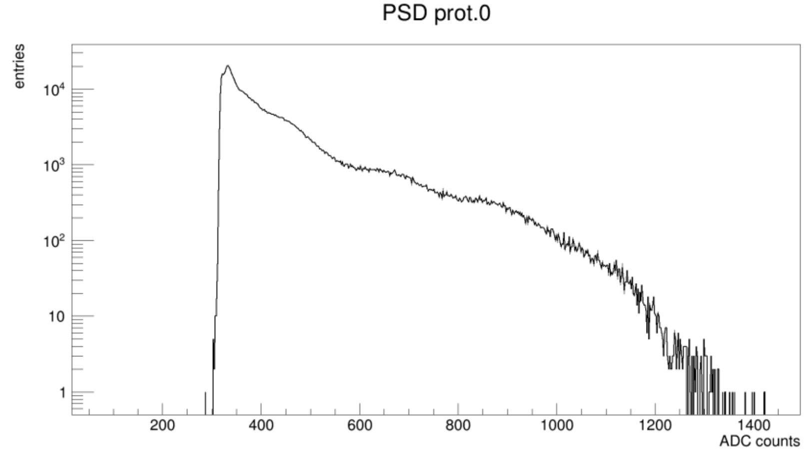
- 10x10x0.5 cm^3 BC-404 plastic scintillator tile
- 3x3 mm^2 and 1x1 mm^2 SiPMs
  (3 SiPMs per type on the small tile side.
  The analog sum of the 3 SiPMs is read-out)
- HERD-BETA as read-out electronics

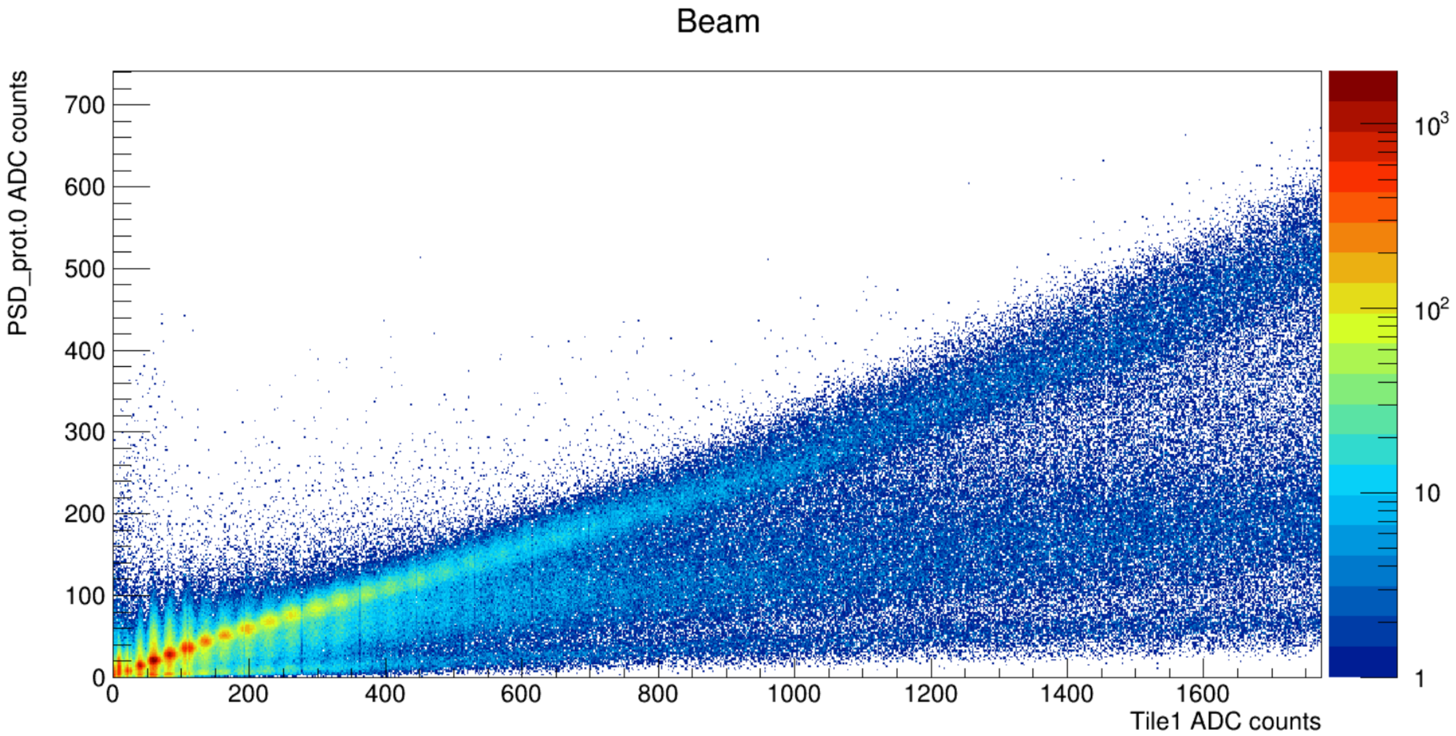
Longitudinal distance of around 90 cm between INFN-SCD and PSD_prot0 prototype

SPS-H4 analysis: charge identification capabilities

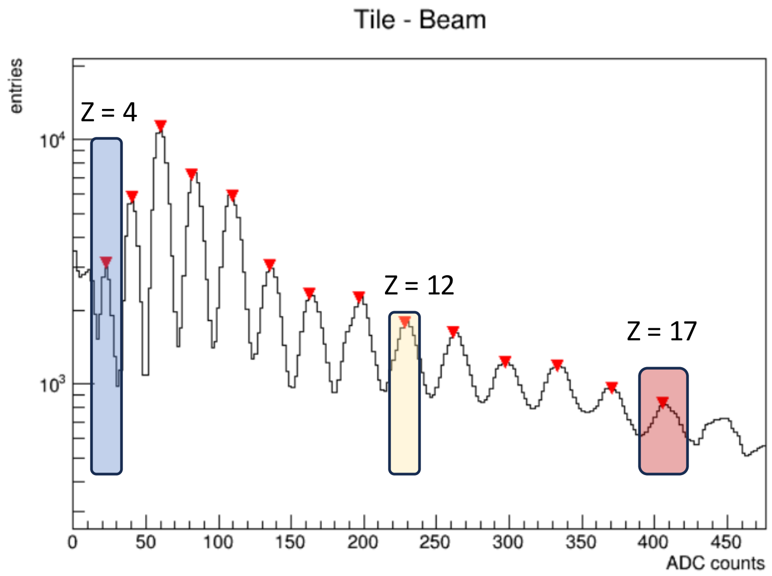
- T1-trigger (squared) tile show a capability to clearly distinguish signals generated from nuclei up to Z=26 and over, while the PSD_prot.0 spectrum do not show such a high charge resolution.
  - This different behavior is due to the particle fragmentation along the beam line that does not allow to resolve peaks for primary nuclei.
- To infer the signals due to the primary particles, we correlated events from T1 trigger tile with those from the PSD_prot0 tile under beam

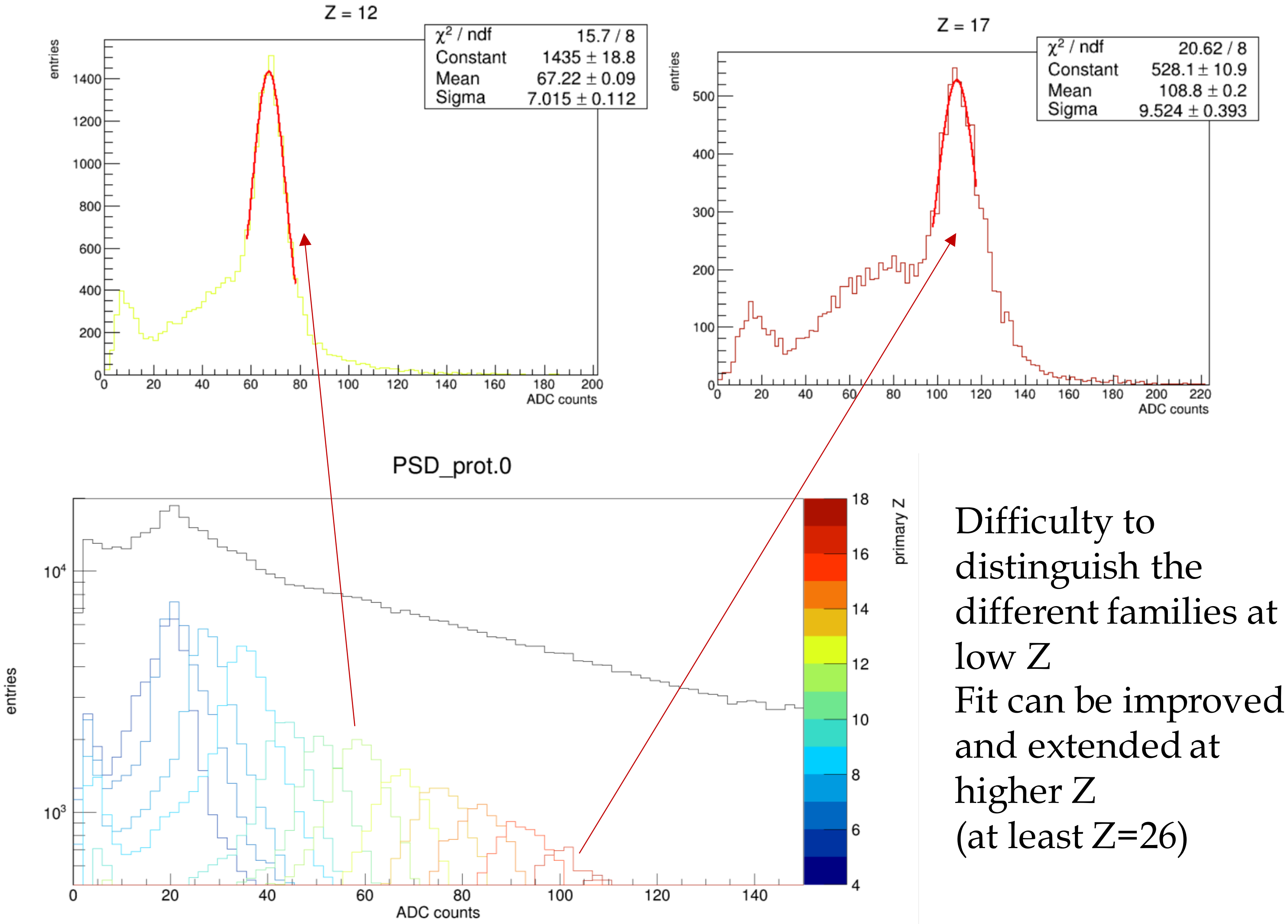


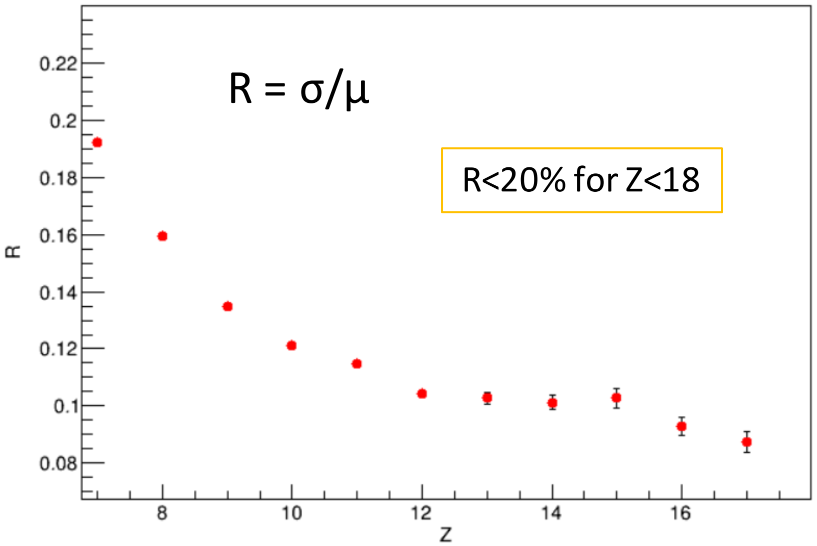




SPS-H4 analysis: charge identification capabilities





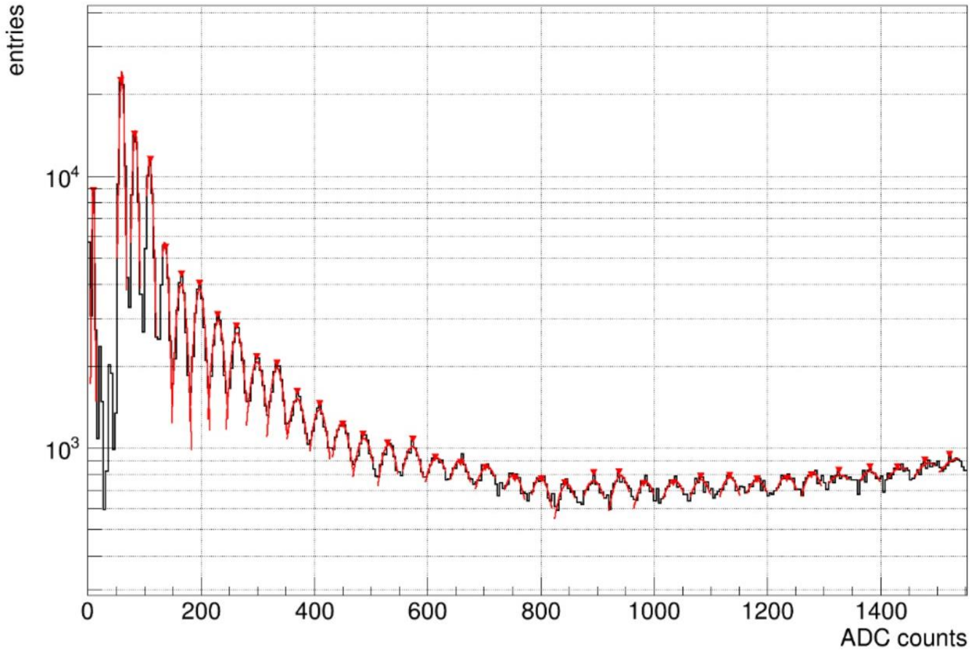


Difficulty to distinguish the different families at low Z

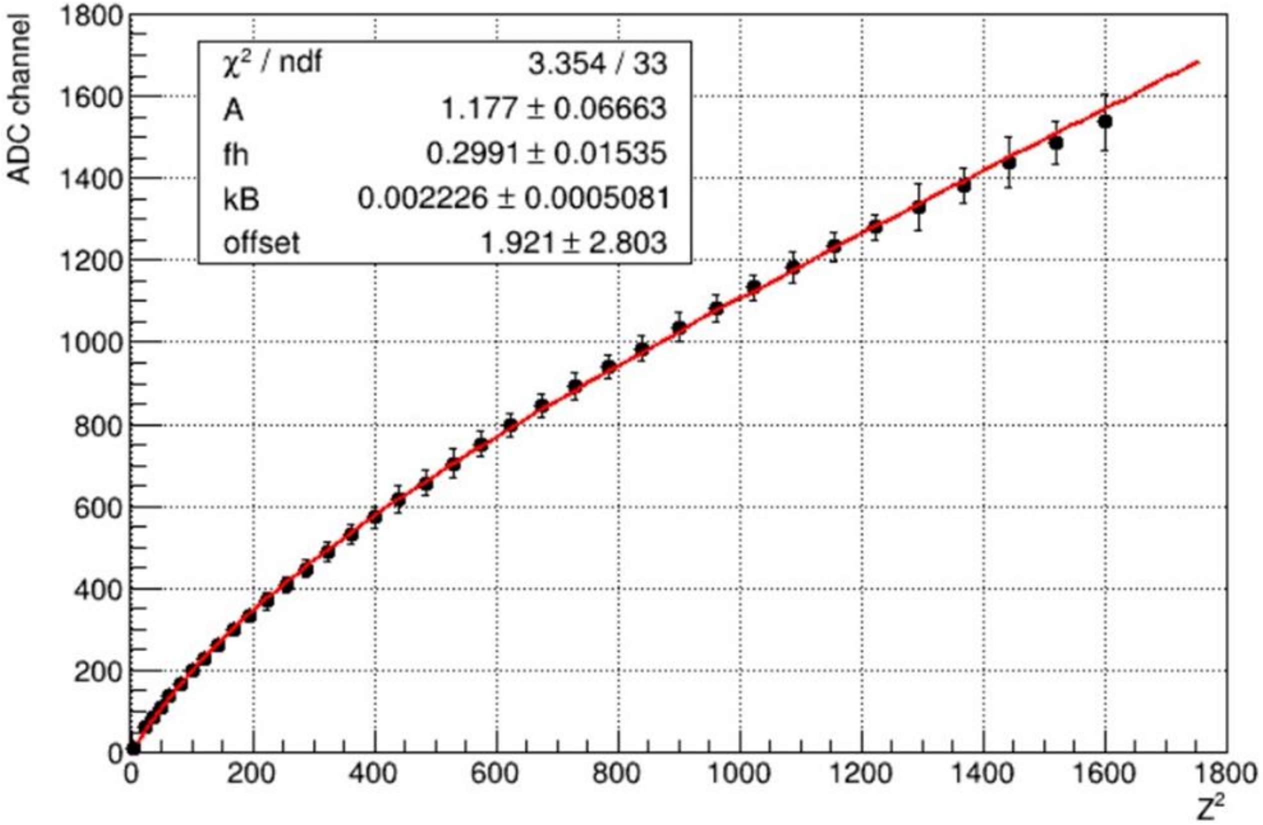
Fit can be improved and extended at higher Z (at least Z=26)

SPS-H4 analysis: Birks’ law

- Evaluation of the Birks’ saturation effect for PSD 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 is compatible with the reference values in literature



Conclusions and to-do list

- First characterization @ CERN PS/SPS 2023 BTs of PSD_prot0 in terms of discrimination efficiency and charged nuclei identification capabilities
  - Position scans @ PS and CNAO were employed to quantify non-uniformity of detector response with the incident particle position
  - Majority trigger efficiency tests with MIPs
  - Charged nuclei identification capabilities investigated through charge-tagging T1 trigger tile

- Evaluation and compensation of the non-uniformity in light collection
  - Further studies using SCD tracks
- Assessment of the final charge identification capability of the PSD_prot.0 improving and/or removing the fragmentation
  - further studies using SCD data to better “weight” the signals from all SiPMs using the hit position of the beam

Backup