Preliminary results on the performance of the new AMS silicon tracking Layer 0 (L0) and the HERD sub-detector SCD

Jiang YaoZu
Università degli Studi e INFN Perugia

Outline:

1. Background

   Cosmic Rays
   HERD experiment
   AMS02 experiment
   Beam test setup

2. Preliminary analysis results

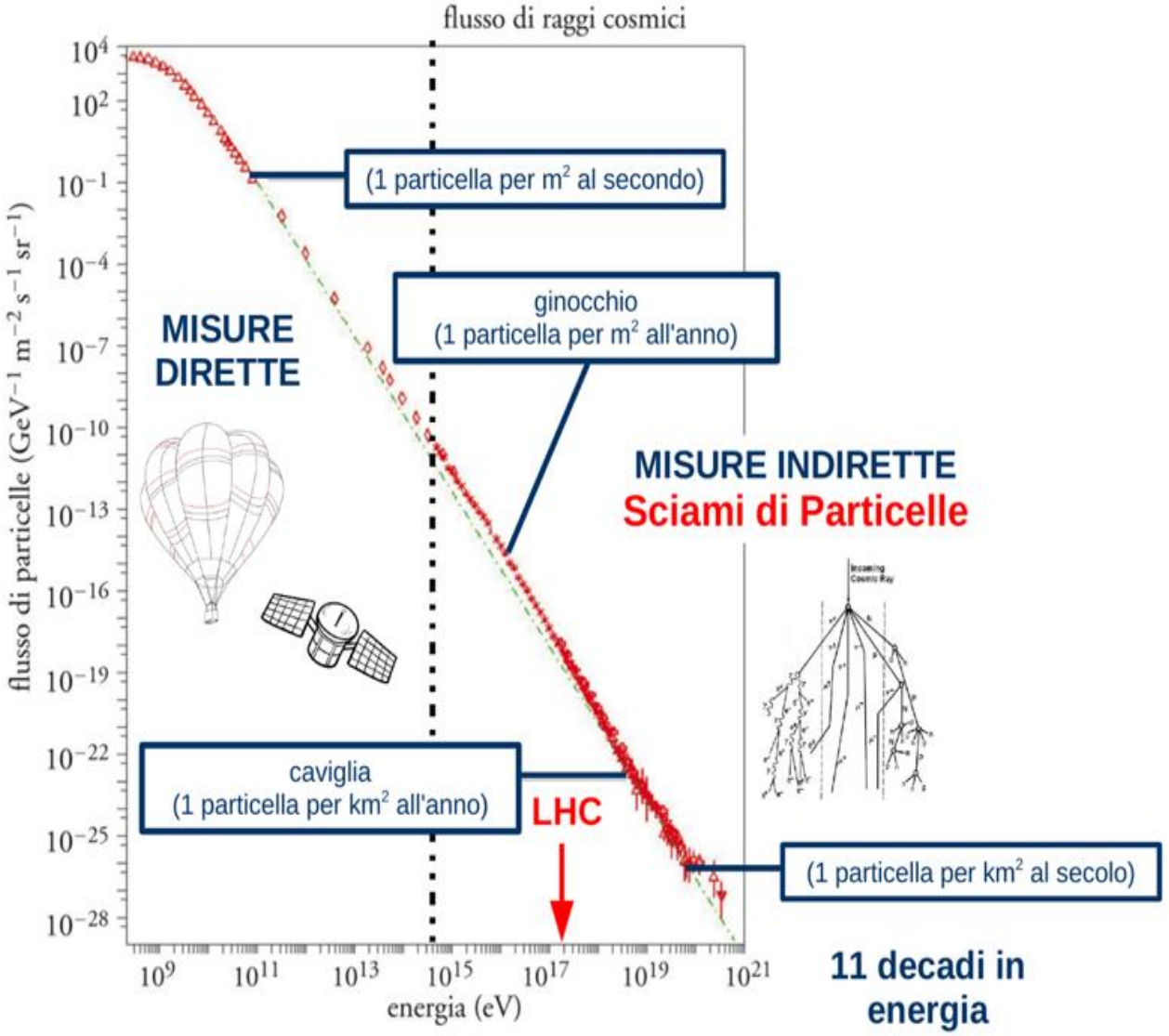
   Calibration
   Charge identification
   Spatial Resolution

Cosmic Ray

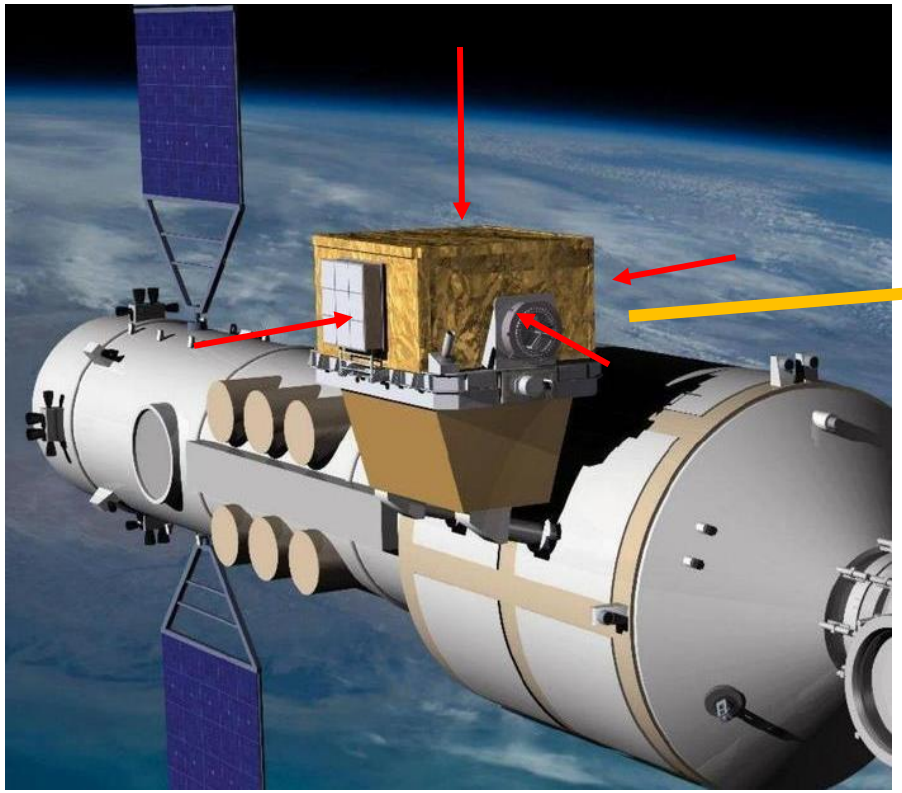
The flux of cosmic rays decreases very rapidly as energy increases:

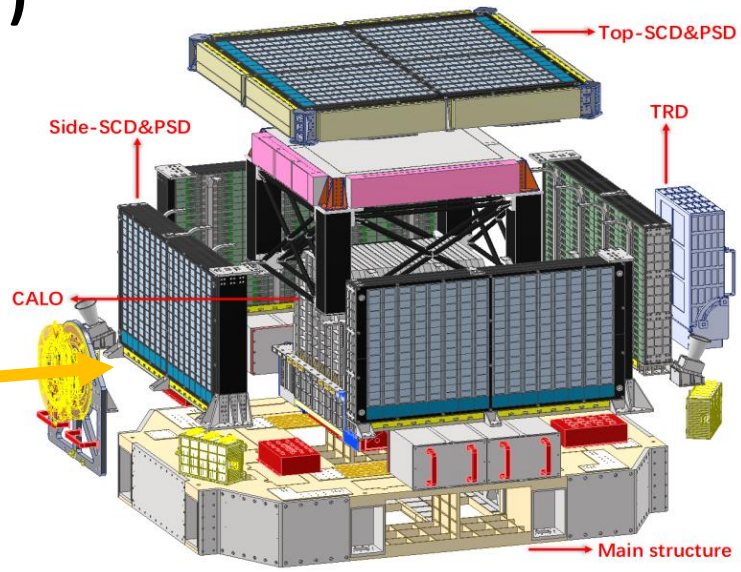
$$\frac{dN}{dE} \propto E^{-x} \qquad x = \begin{cases} 2.7 & E \leqslant 10^{15}\ eV \\ 3.0 & 10^{15} < E < 10^{18}\ eV \end{cases}$$

- E ≈ 10^8 eV → 100 events/m^2/second
- E ≈ 10^{15} eV → 1 event/m^2/year
- E ≈ 10^{19} eV → 1 event/km^2/year
- E > 10^{20} eV → 1 event/km^2/century



HERD (High Energy Radiation Detector)





Composed by:

- SCD (Silicon Charge Detector): charge measurement, tracking
- PSD (Plastic Scintillation Detector): anticoincidence system, charge measurement
- FIT (FIber Tracker): tracking
- CALO (Calorimeter): energy measurement
- TRD (Transition Radiation Detector)

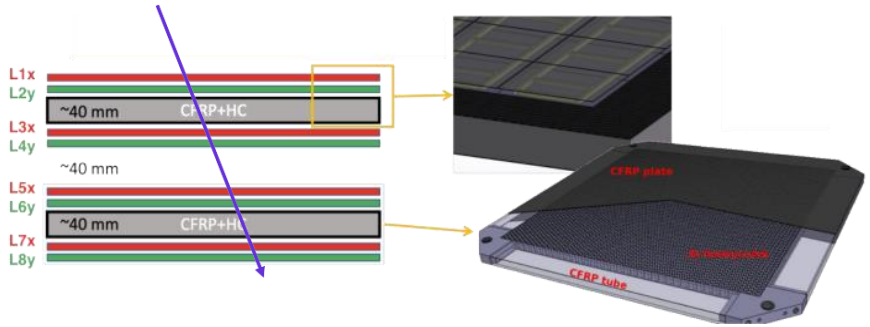
Main objectives:

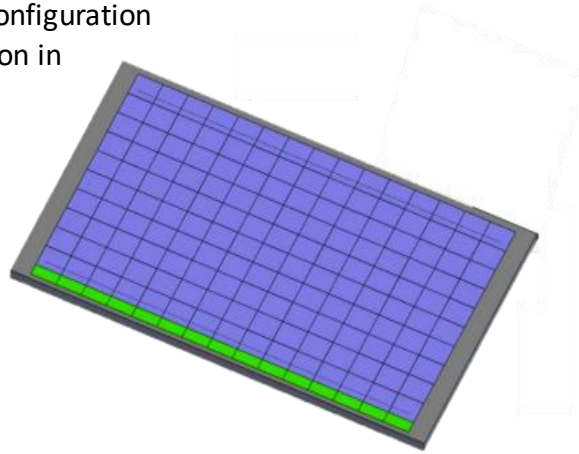
- direct measurement of high energy cosmic rays
- search for dark matter signals
- gamma-ray sky observation

To be installed on the Chinese Space Station in 2027

Silicon Charge Detector:

- placed as the more external detector of the HERD
- 6 or 8 layers of silicon microstrip detectors in hodoscopic (X-Y) configuration
- measure the charge of the charged particles before any interaction in the detector materials

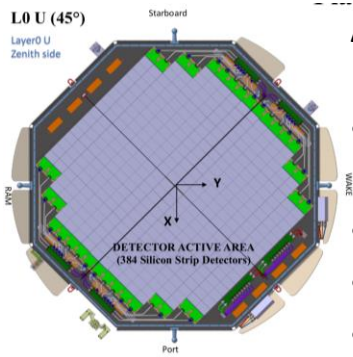


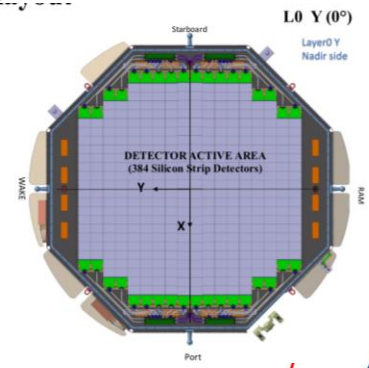


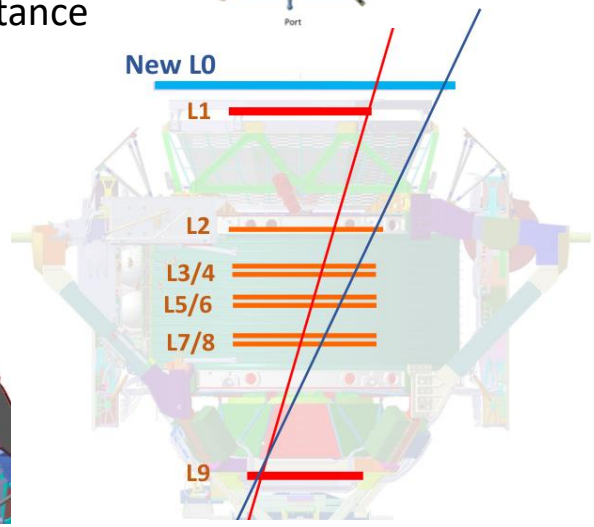
HERD, the first example of the next generation of detectors with five acceptance surfaces.

AMS02-L0 Upgrade

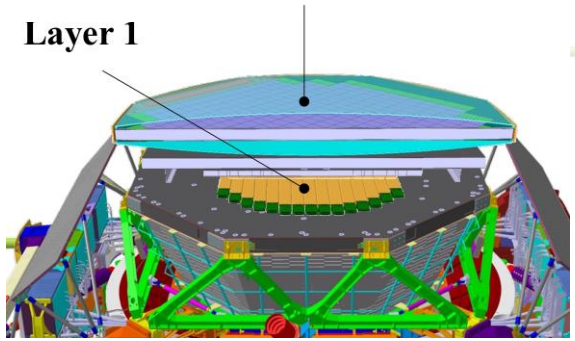
- AMS02-L0, an upgrade which involves adding a new silicon detection layer, called L0, above the existing L1 layer to increase the overall acceptance area
- Composed of two layers of silicon sensors, where one layer is rotate 45 degrees relative to the other.
- The total area of the silicon senso to be installed is ~ 7 m^2. will increase by 300% the acceptance of the experiment.







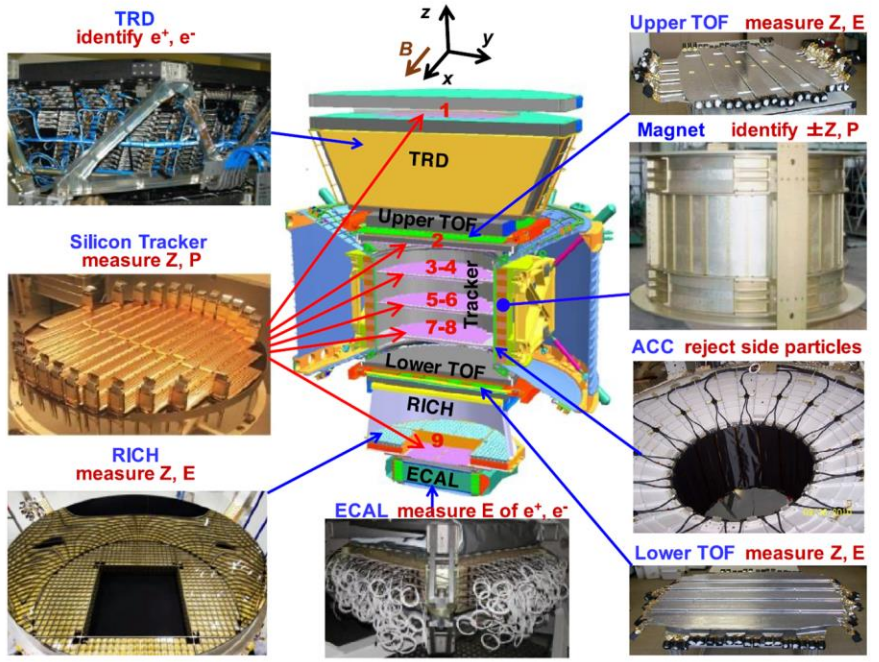
New Tracker Layer 0



Alpha magnetic spectrometer

Composed by:

- TRD (transition radiation detector): distinguish proton /antiproton from electron/ positron
- TOF (Time of Flight Counters): determine the particle time of flight and charge
- Tracker: measure the particle rigidity and charge
- RICH (Ring Imaging Cherenkov counter): measure the particle charge and velocity
- ECAL (Electromagnetic Calorimeter): measure the energy and direction of high energy electrons and photons



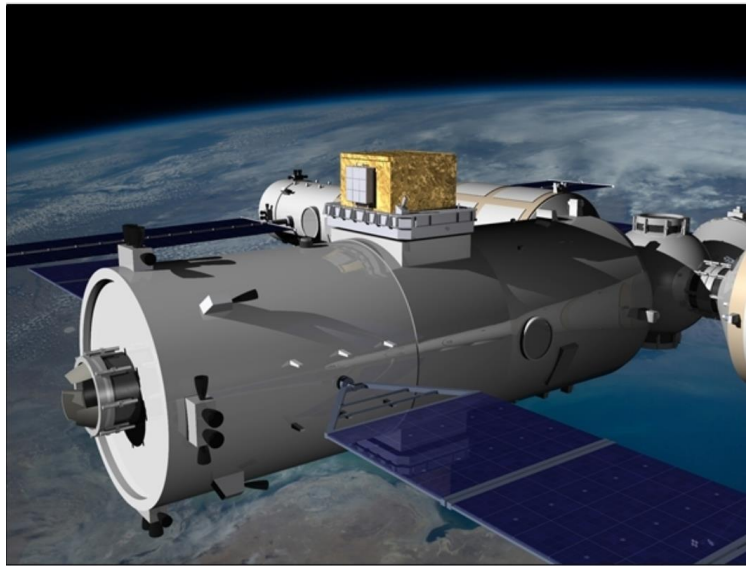
Main objectives:

- search for Primordial Antimatter by direct detection of antinuclei
- search for indirect Dark Matter signals
- study of production, acceleration and propagation of Cosmic-Rays
- study of Solar Modulation

In orbit on the International Space Station since May 2011

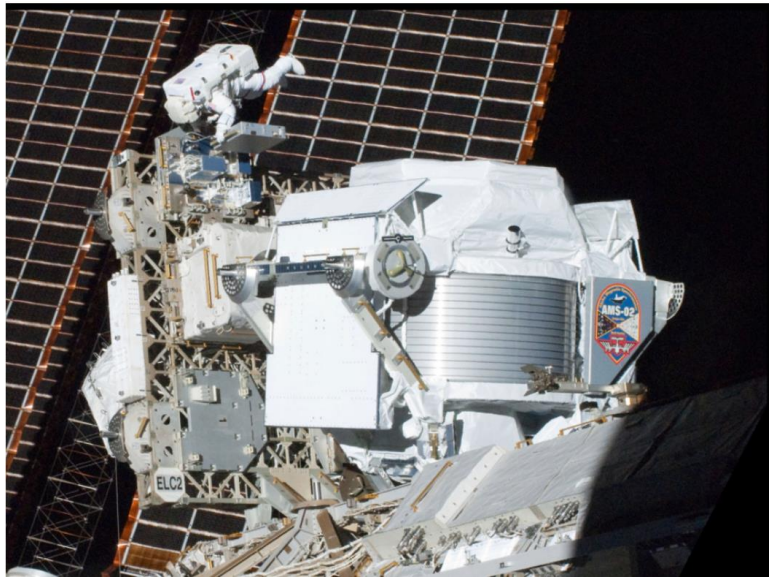
Main constraints imposed

HERD



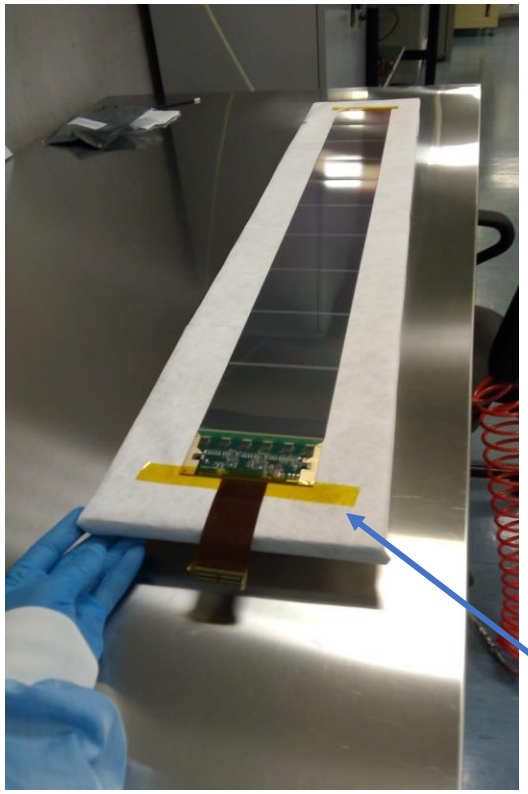
- total weight less than 3 tons
- total power consumption less than 2 kilowatts

AMS-02



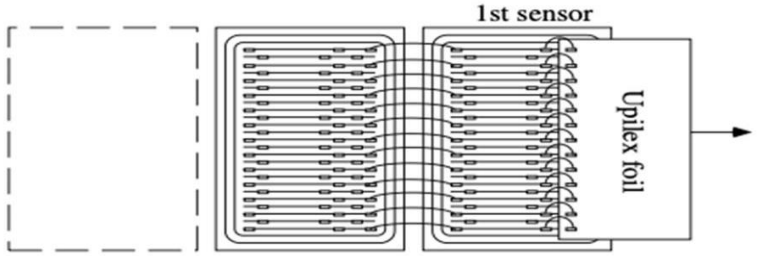
- total weight of around 7 tons
- total power consumption less than 2 kilowatts

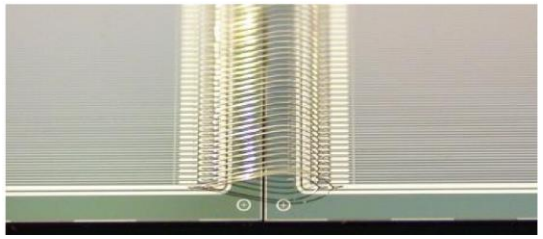
LADDER LUNGHI PER HERD - SCD / AMS - L0

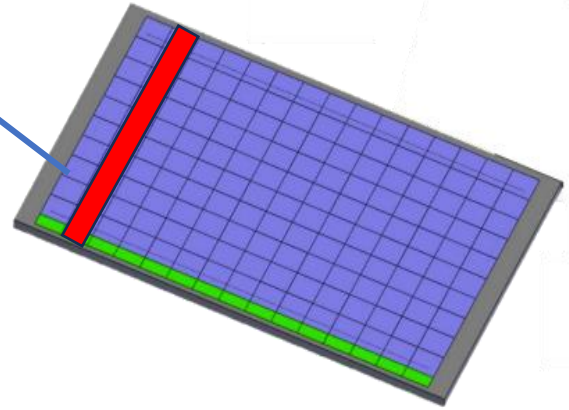


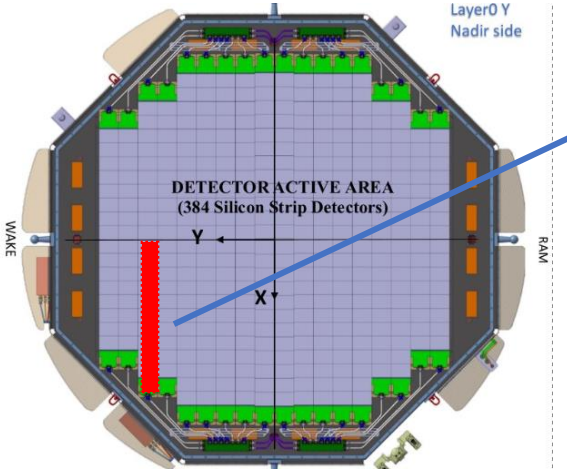
Given the large area to cover and the small electrical power budget, the design must be based on “long” (almost 1 m) silicon sensor modules (i.e. “ladders”), to cover larger areas without increasing the number of channels.

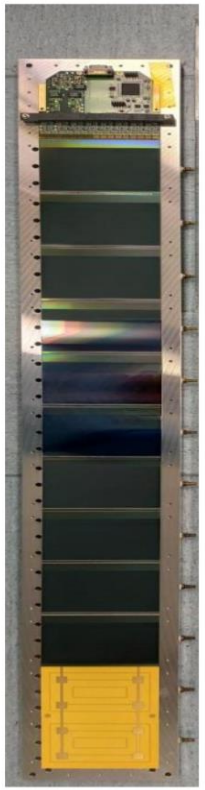
"daisy chain" of 8-12 sensors: the first strip of the first (connected to the readout electronics) sensor has a "bonding" towards the second sensor, and so on…











HERD-SCD:

- Size of a sensors: 10x10 cm^2
- Readout strip pitch 150 um
- Implant Strip pitch 50 um
- 640 readout strips

AMS-L0

- Size of a sensors: 8x11 cm^2
- Readout strip pitch 110 um
- Implant Strip pitch 27.25 um
- 1024 readout strips

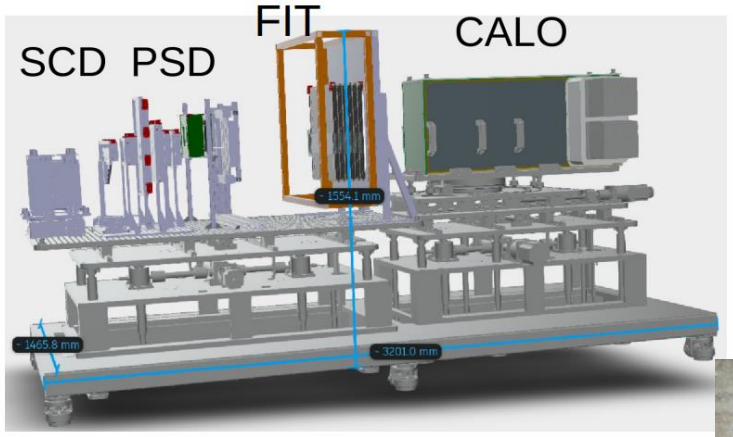
Beam Tests 2023

HERD-SCD

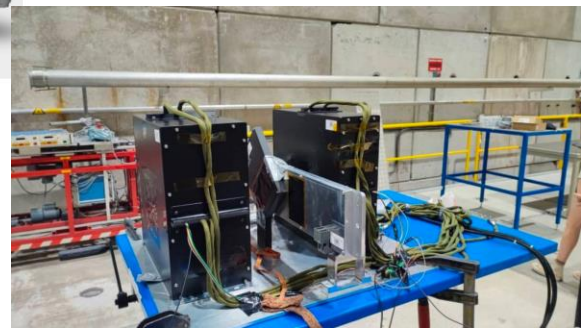
- 2023 September and October at PS and SPS (high energy muons, electrons, hadrons)
- 2023 October at SPS (high energy ions)

AMS-L0

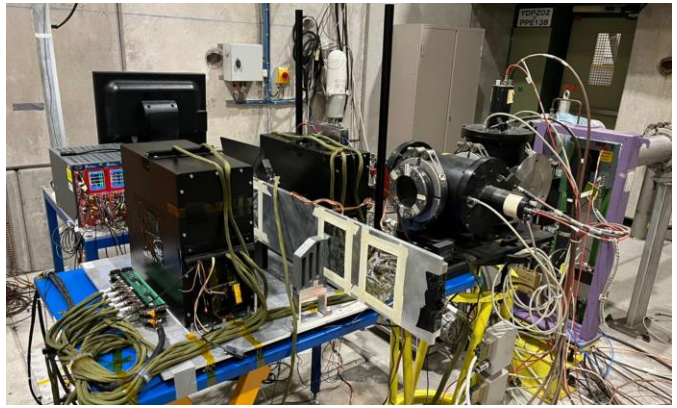
- 2023 August AMS-L0 at SPS (high energy muons, hadrons)
- 2023 October AMS-L0 at SPS (high energy ions)



HERD 2023 September and October at PS and SPS

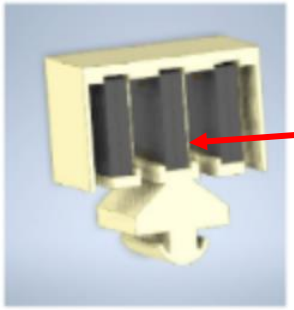


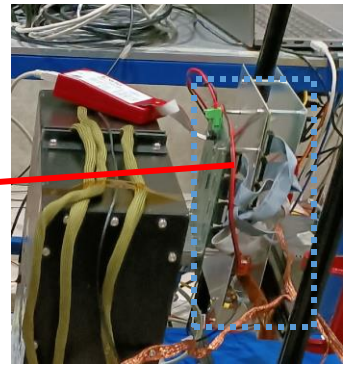
AMS-L0 2023 August at SPS



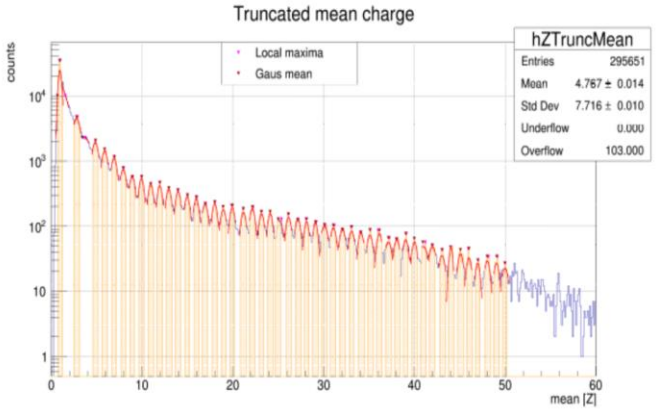
AMS-L0 2023 October at SPS

SETUP (Beam Test 2023 AMS02-L0)

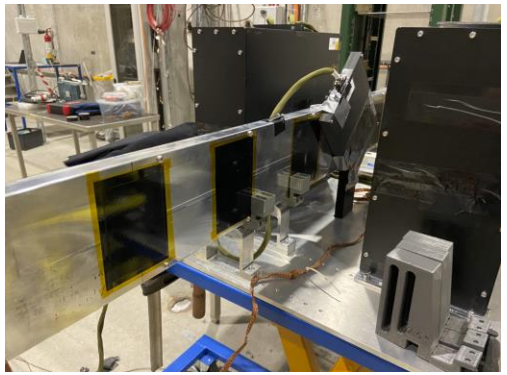




Charge Detector

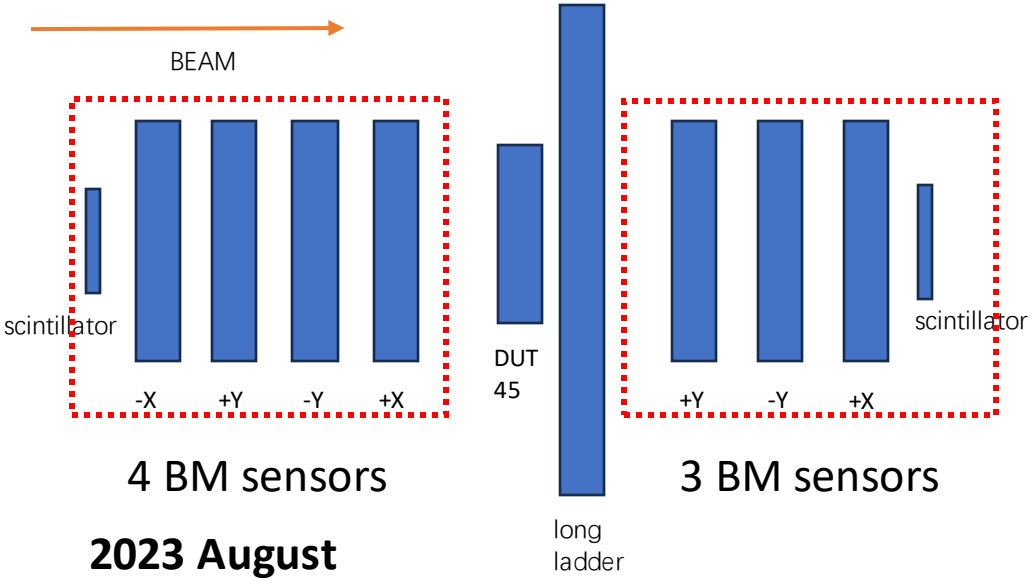


Peak fits of CT



long ladder and single sensor ladder at 45°

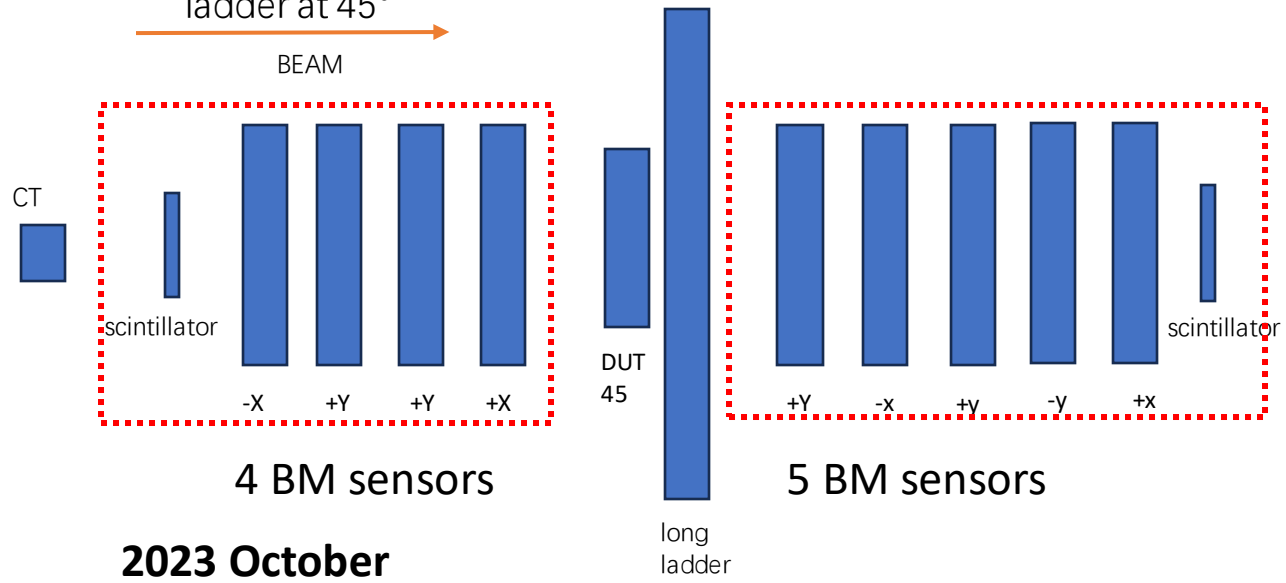
single BM sensor



4 BM sensors

3 BM sensors

2023 August



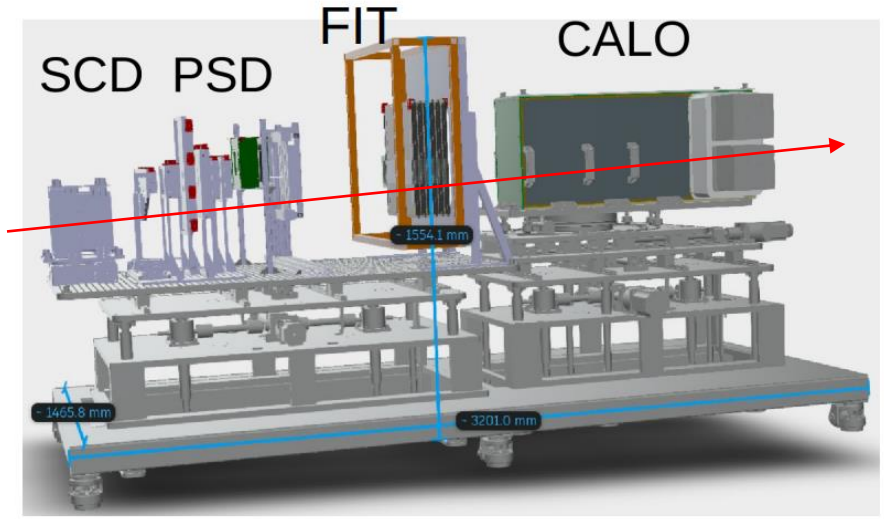
4 BM sensors

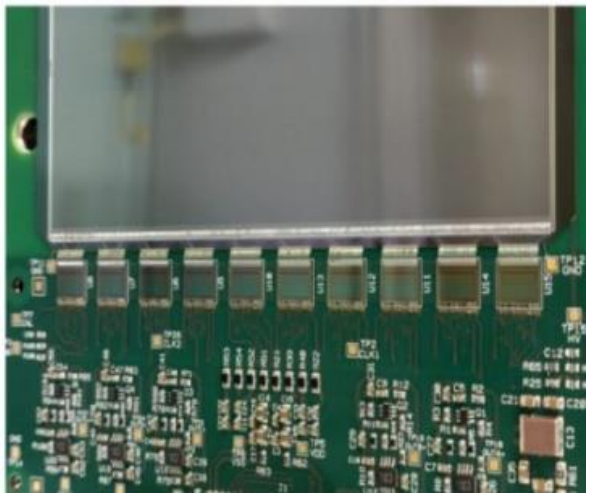
5 BM sensors

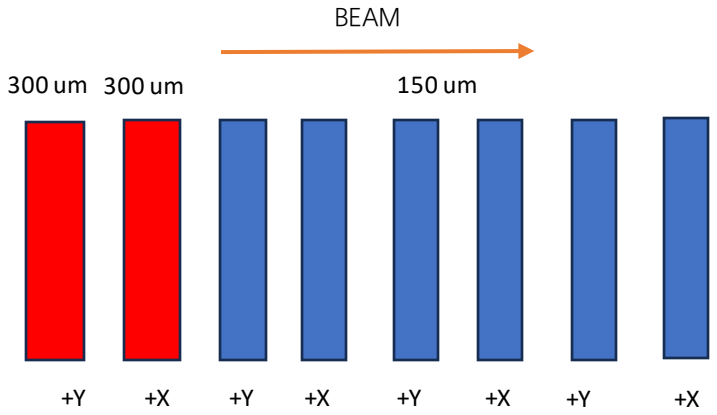
2023 October

SETUP (Beam Test 2023 HERD SCD)

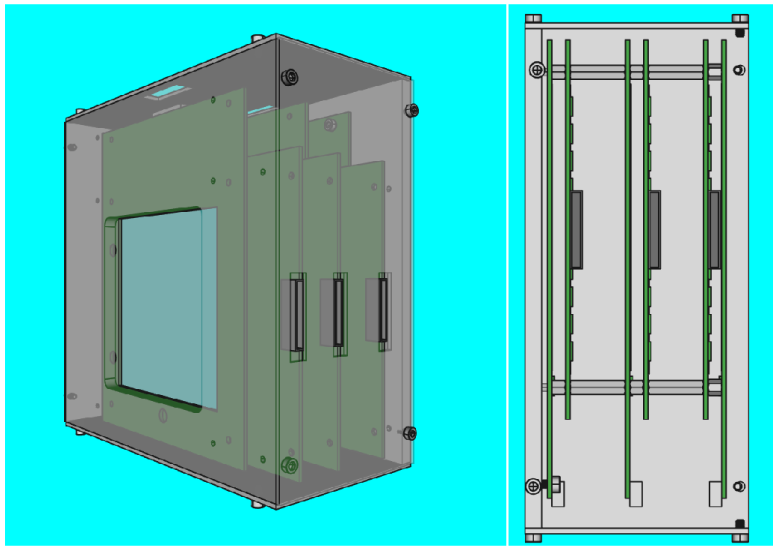
- There are 8 sensors installed in pairs, positioned orthogonally, these sensors enable independent estimation of positions along the X and Y axes, with 4 sensors dedicated to each axis.
- The first 2 sensors have a thickness of 300 µm; the others have a thickness of 150 µm.
- The ADC resolution is 12 bits.





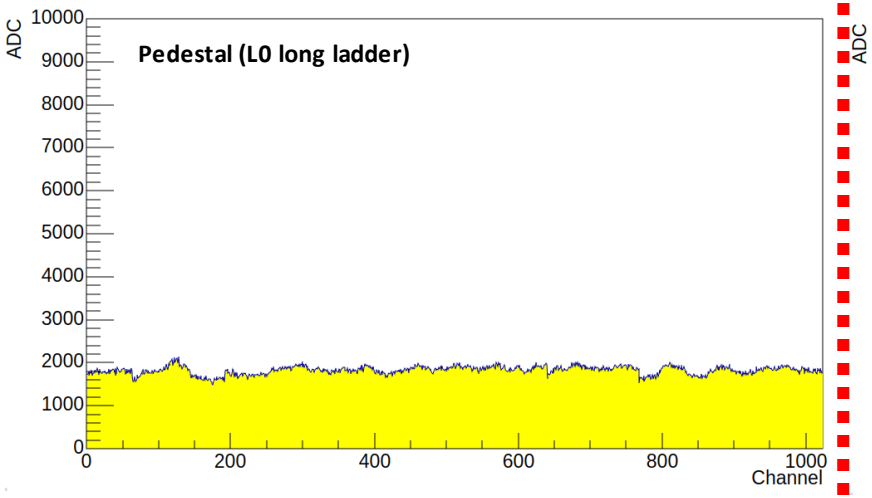


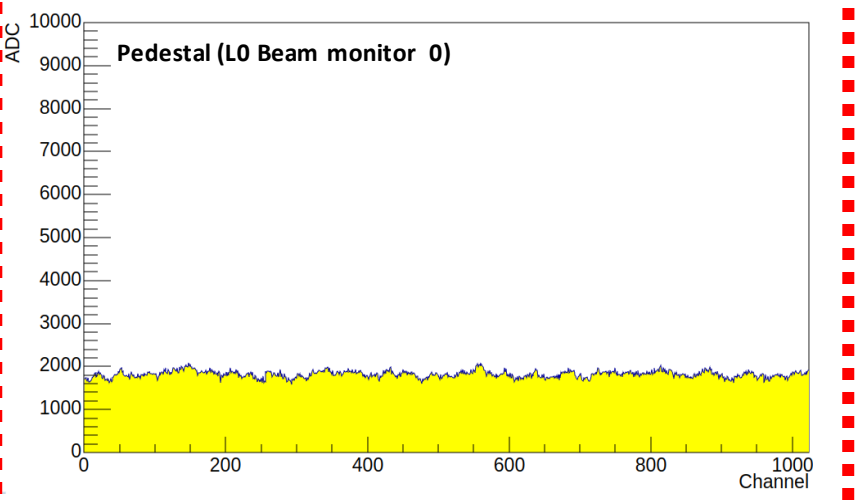
Detector ID	Thickness (um)	Z (mm)
0	300	0
1	300	4.4
2	150	37.75
3	150	42.45
4	150	65.8
5	150	70.47
6	150	93.85
7	150	98.55

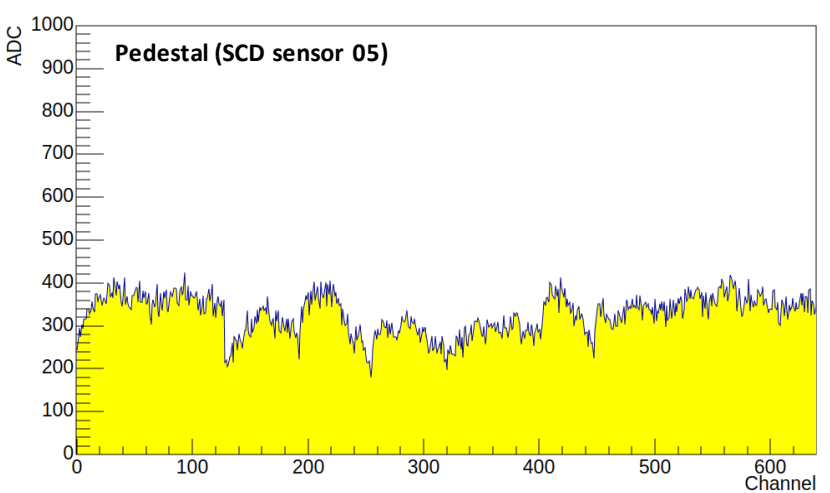


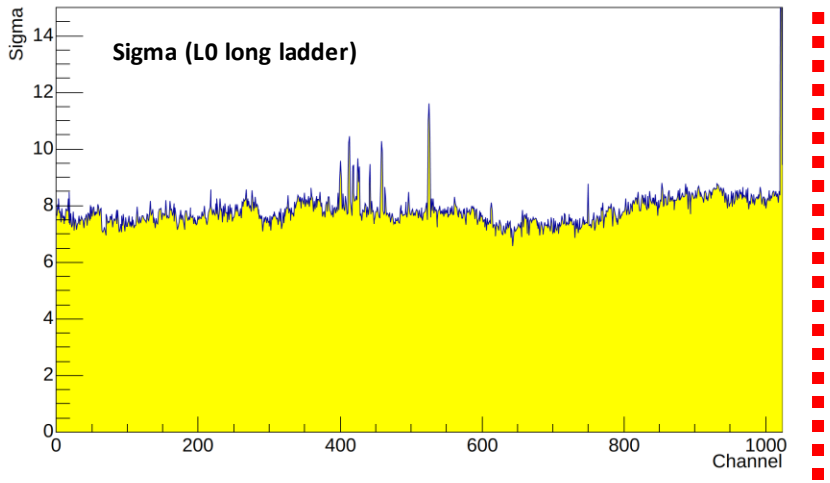
2023 October

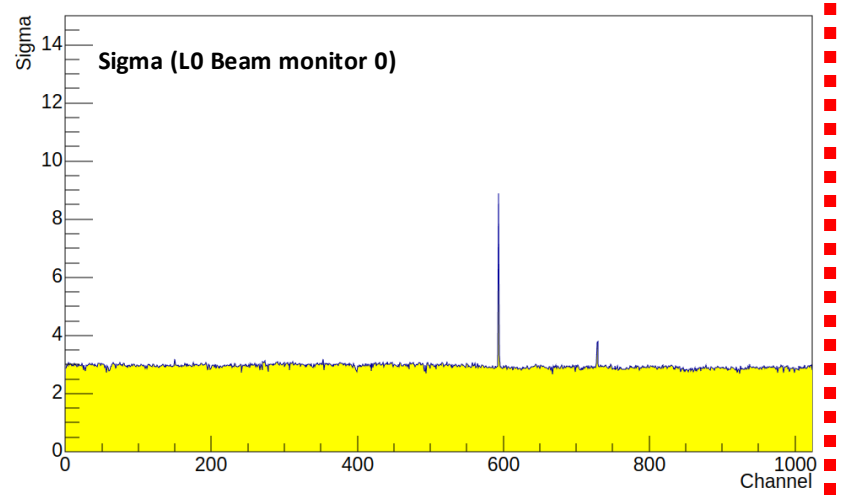
Calibration: Pedestal and Noise

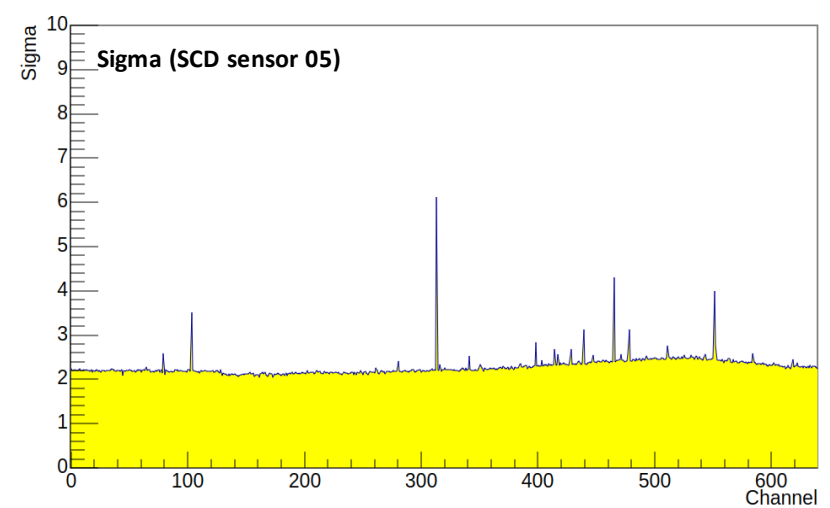










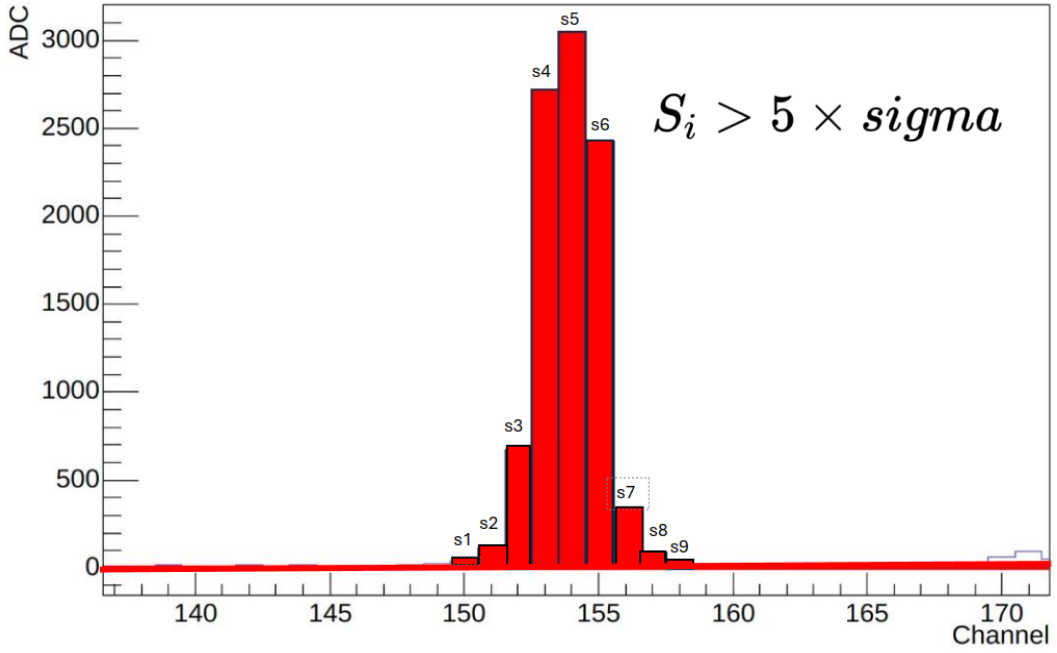


* "Pedestal" is the average signal of each readout strip when no particles pass through the detector

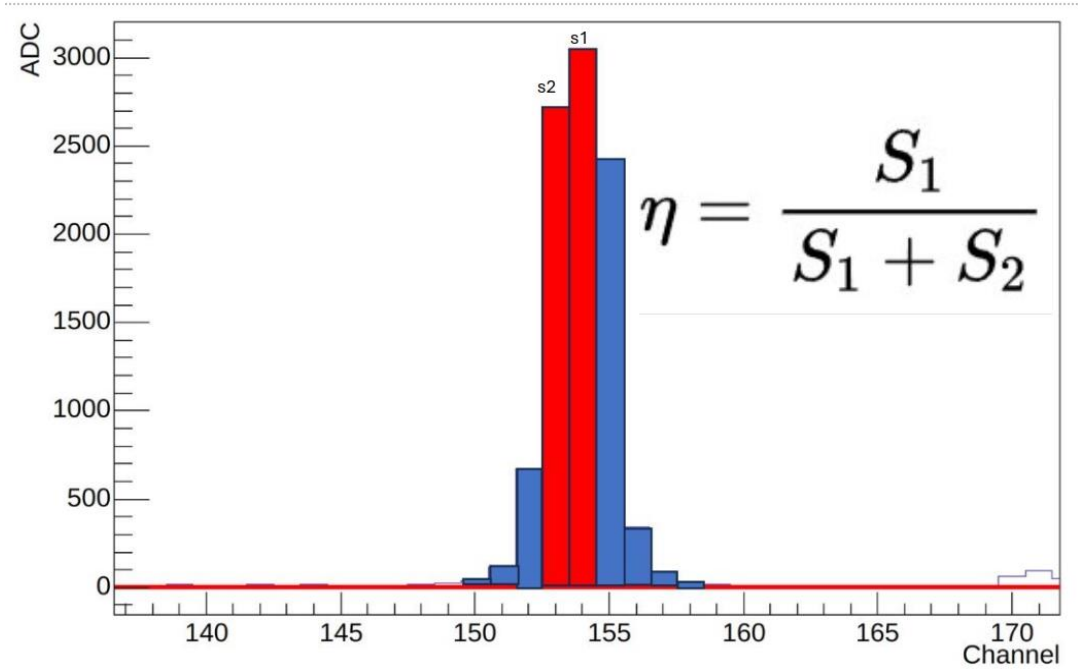
* "Sigma" represents the fluctuation of the signal of each readout strip around the pedestal when no particles pass through the detector.

Charge identification

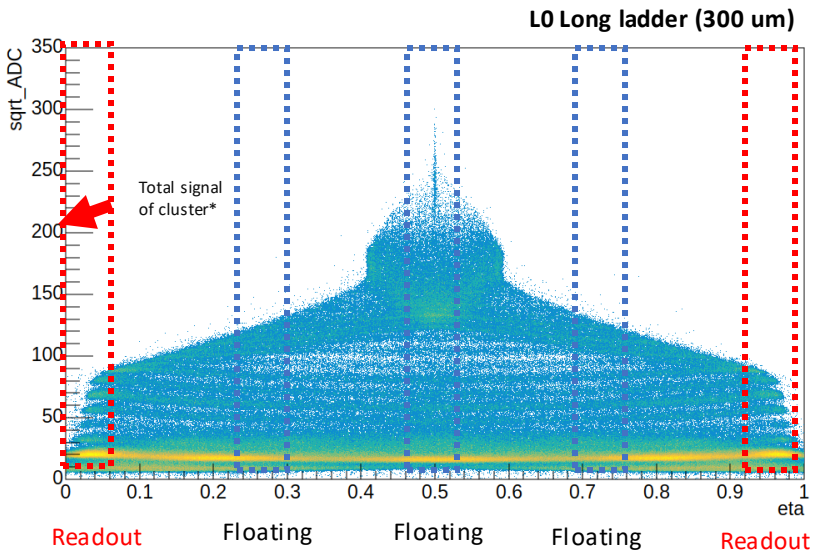
- The cluster is a collection of strips with signal magnitudes exceeding a certain threshold near the particle hit position.

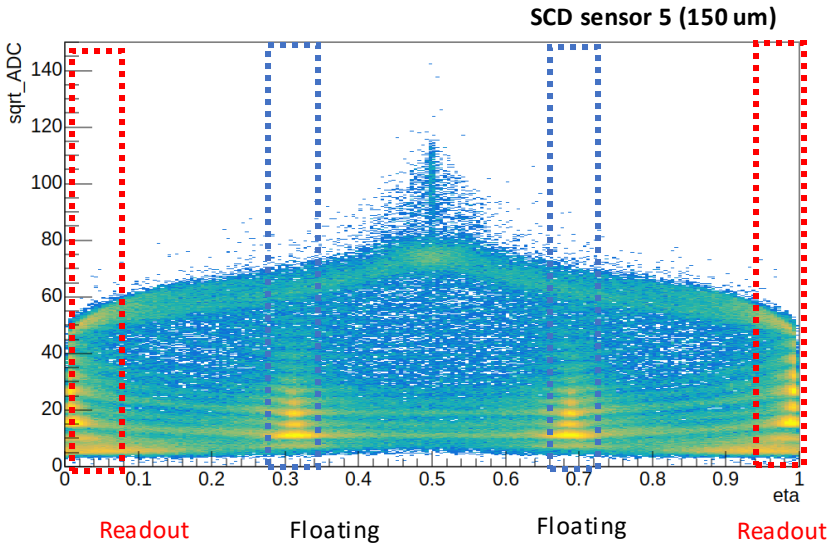


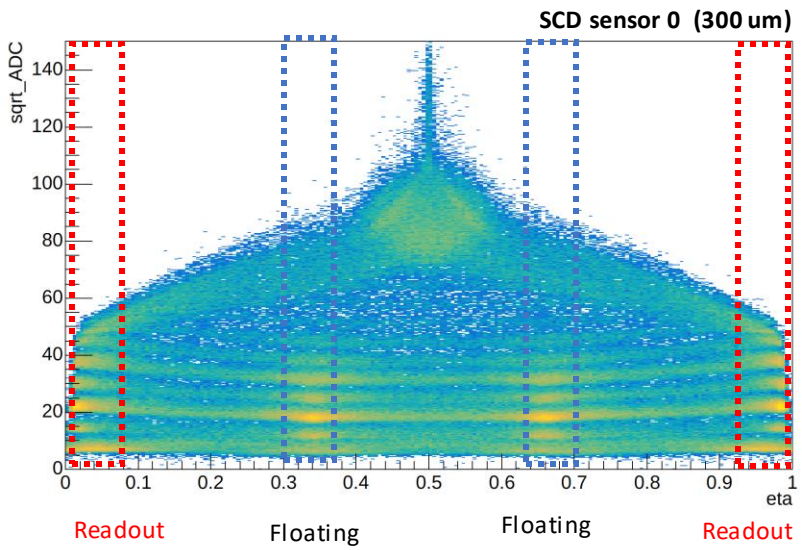
- The "eta" is defined as the ratio between the charge collected on the right strip of the two largest signal strips and the total charge collected by both the strips.

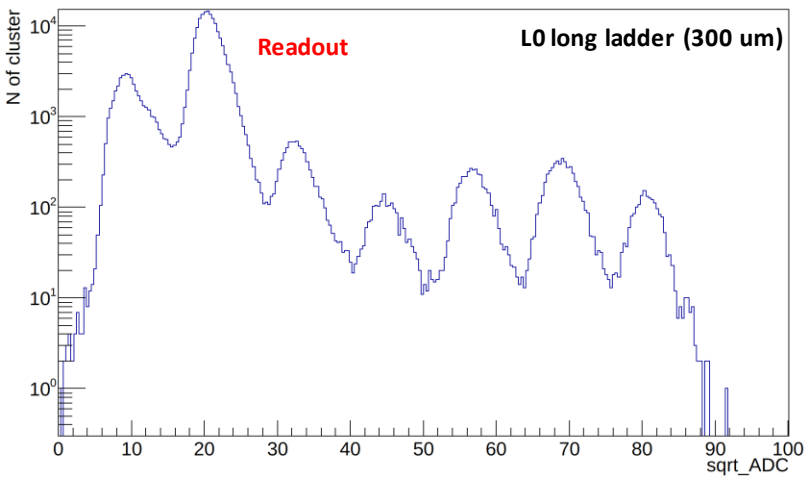


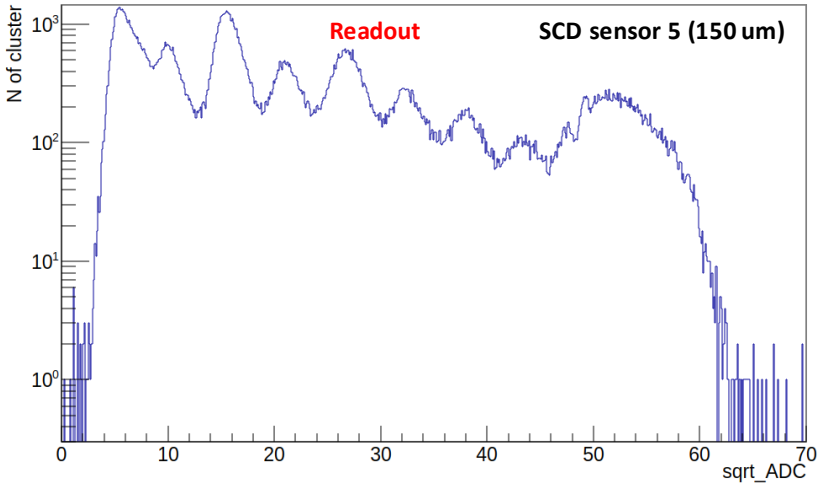
Charge identification – Total signal

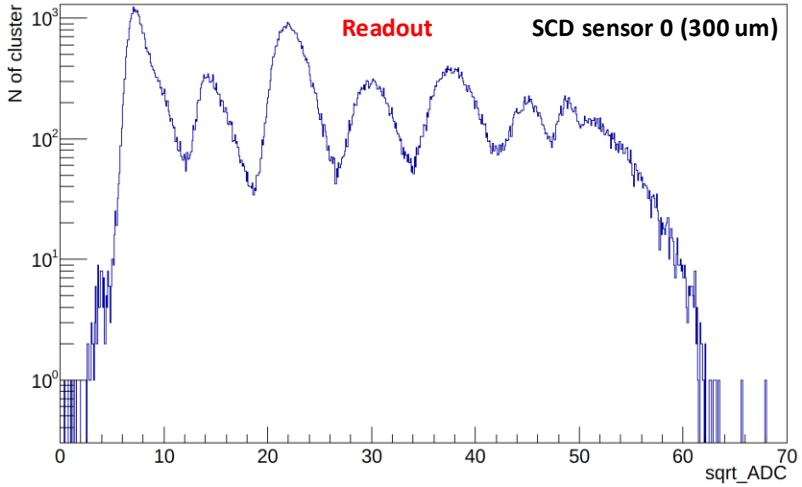






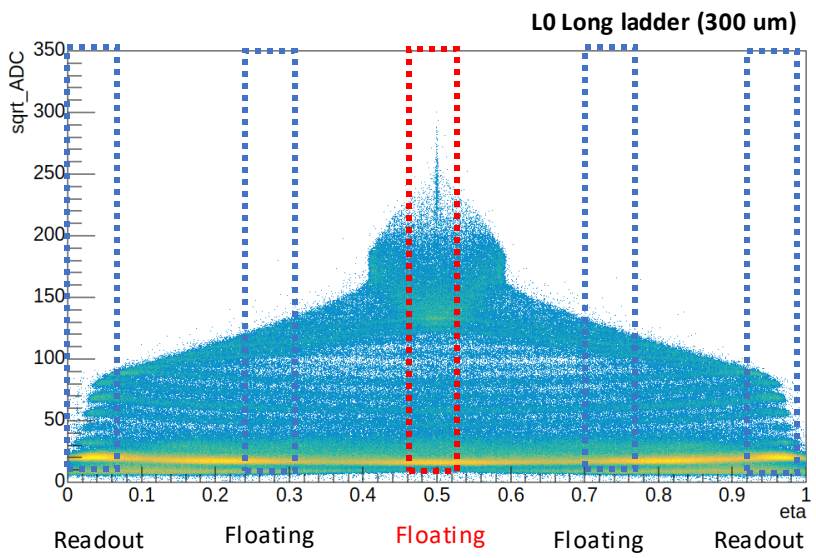


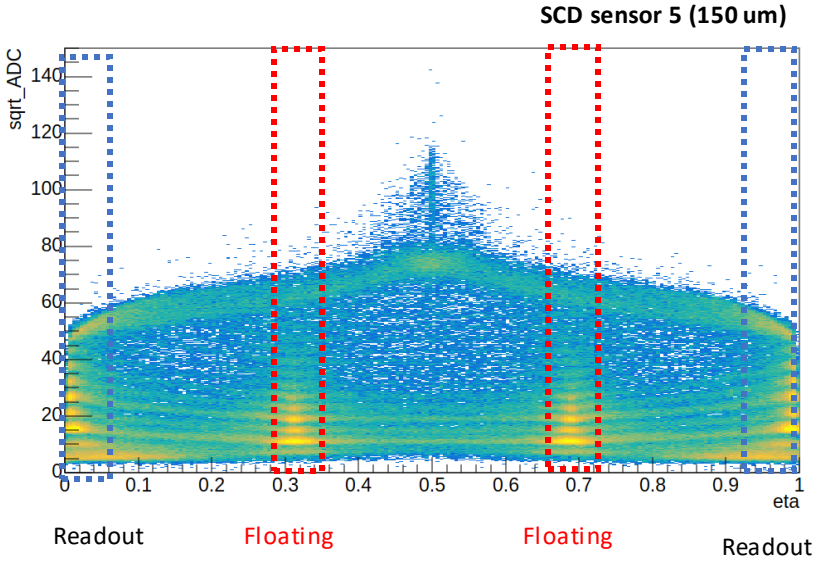


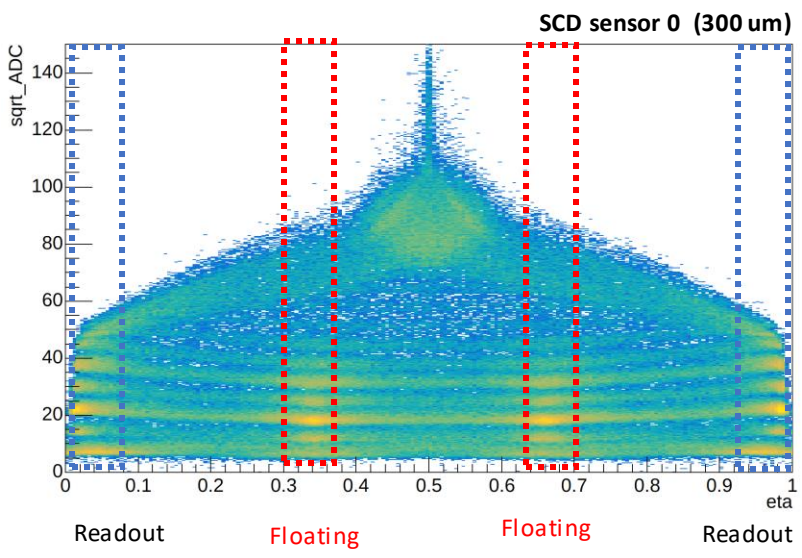


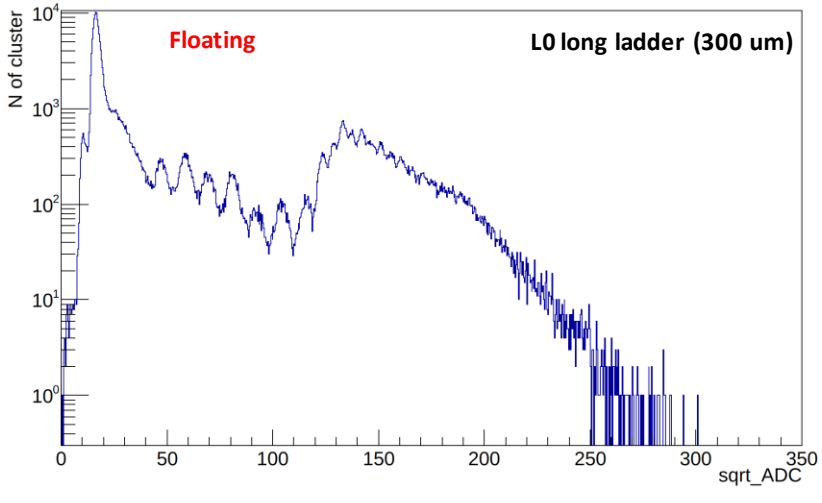
* The total signal is defined as the sum of signals on all strips within the cluster.

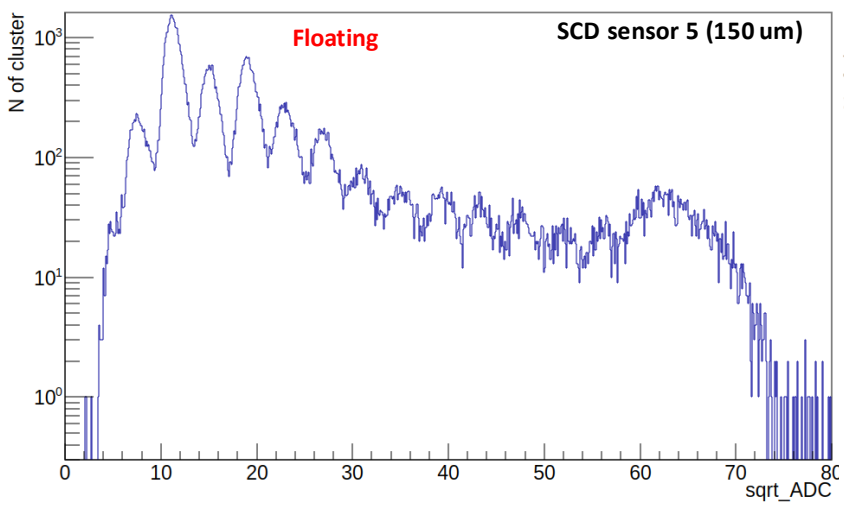
Charge identification – Total signal

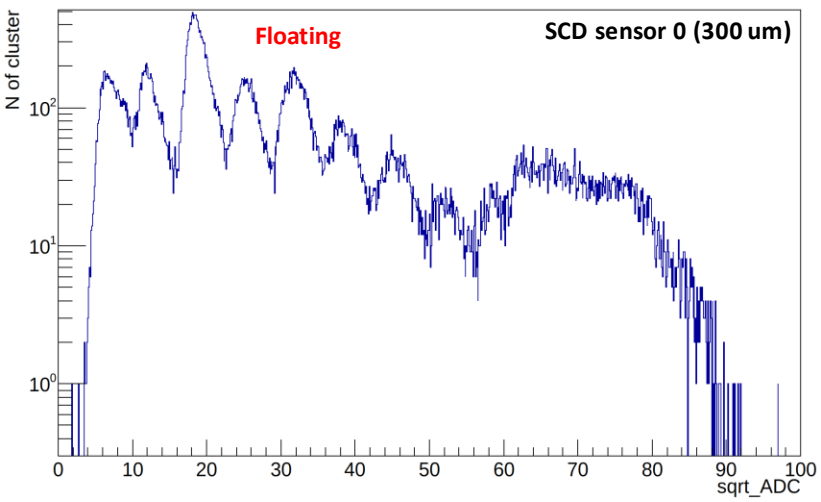




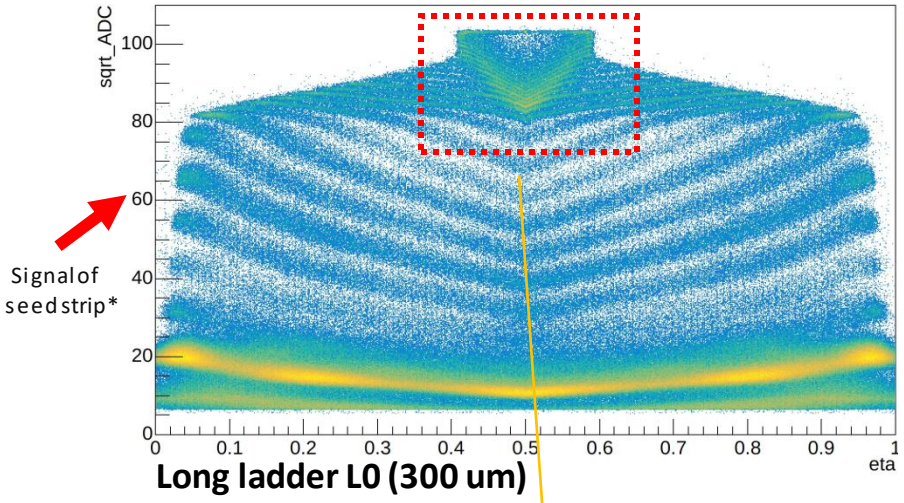


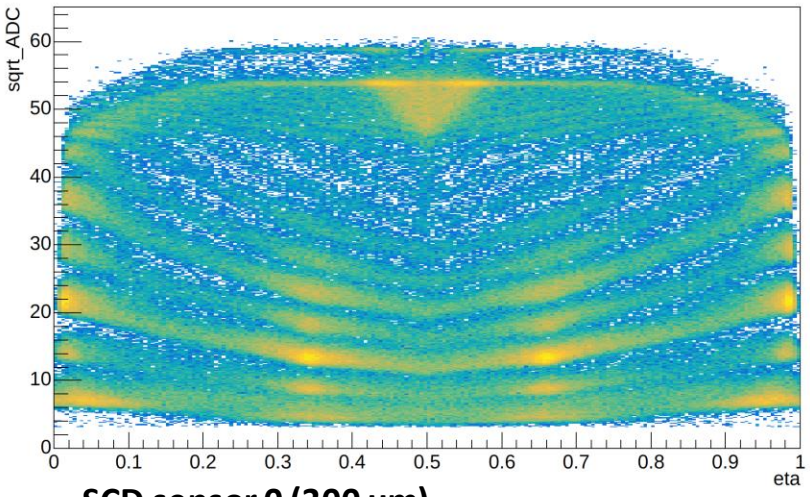


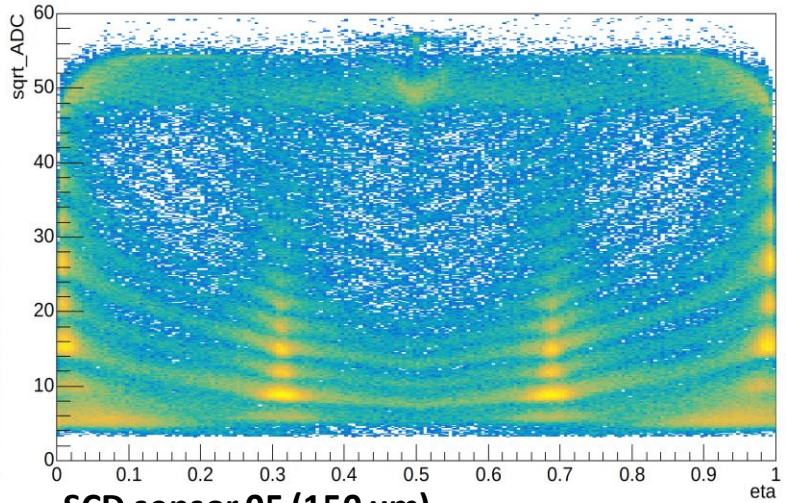


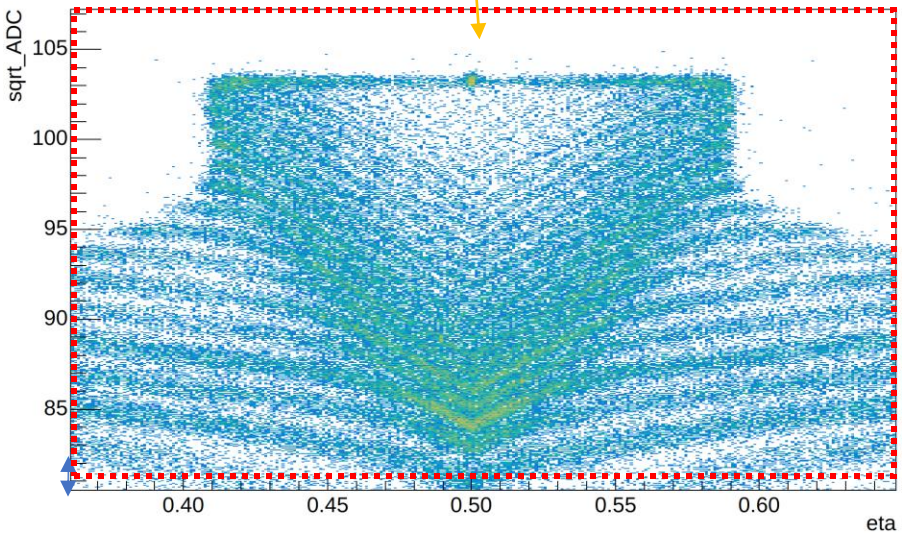


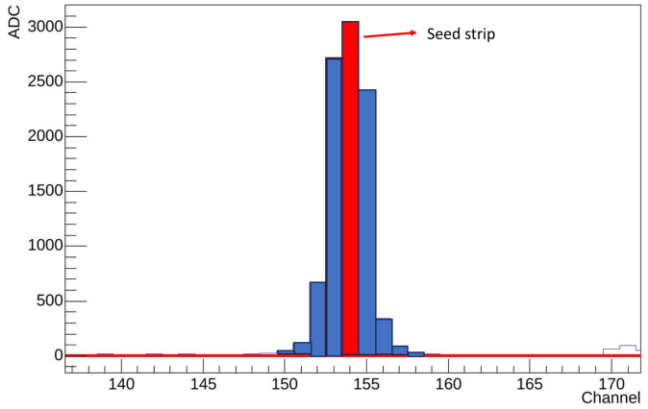
Charge identification – Maximum strip signal









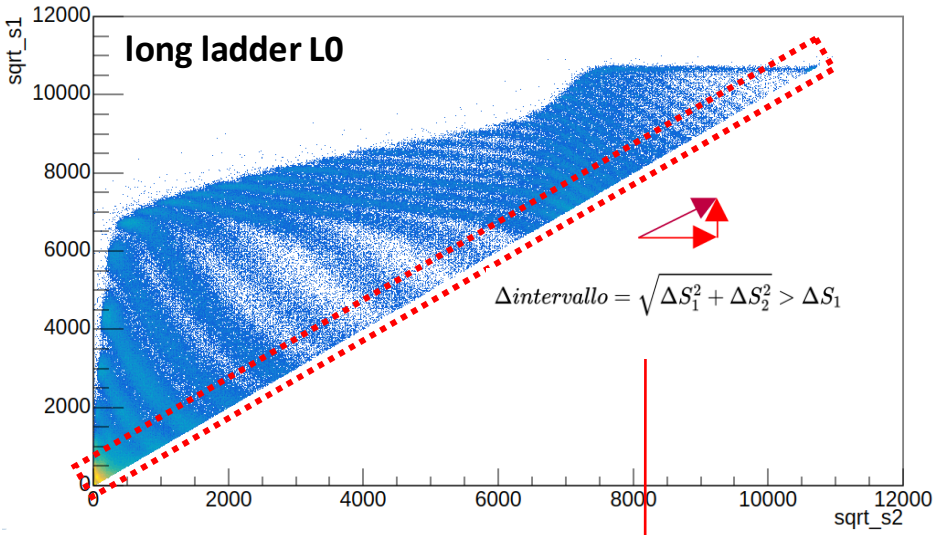


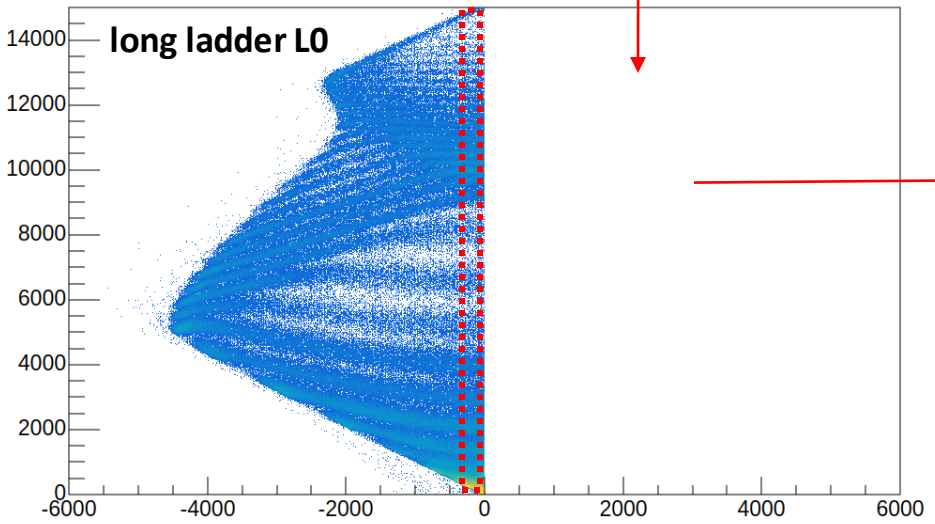
In the HERD case we don't see a so good resolution for high Z's:

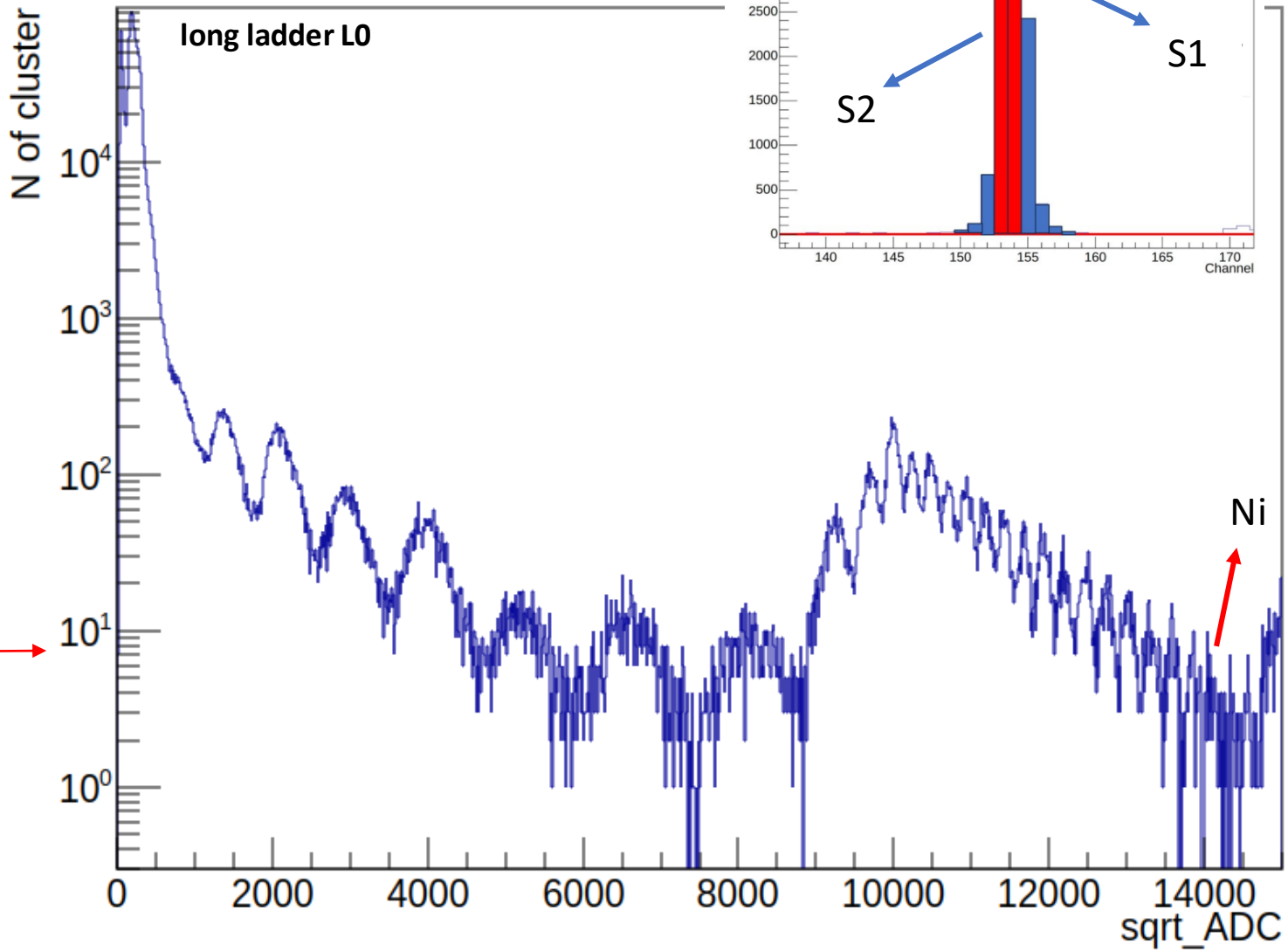
the ADC of L0 is 4 times finer than that of SCD. It can be observed that the spacing between peaks is less than 4 ADC units: the SCD ADC is not sufficient to detect this fine structure

* "Seed strip" is the strip with the maximum signal in a cluster, typically the one closest to the particle impact position

Charge identification – Alternative method

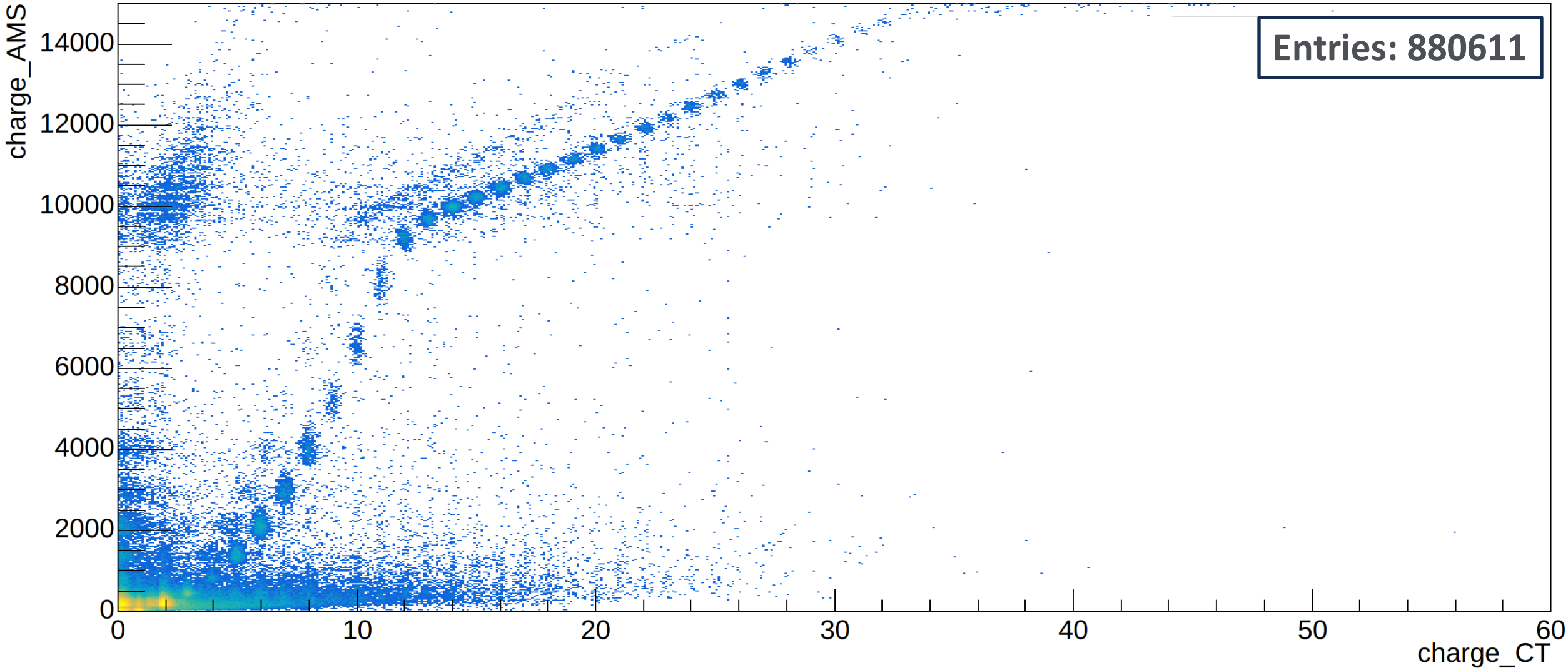




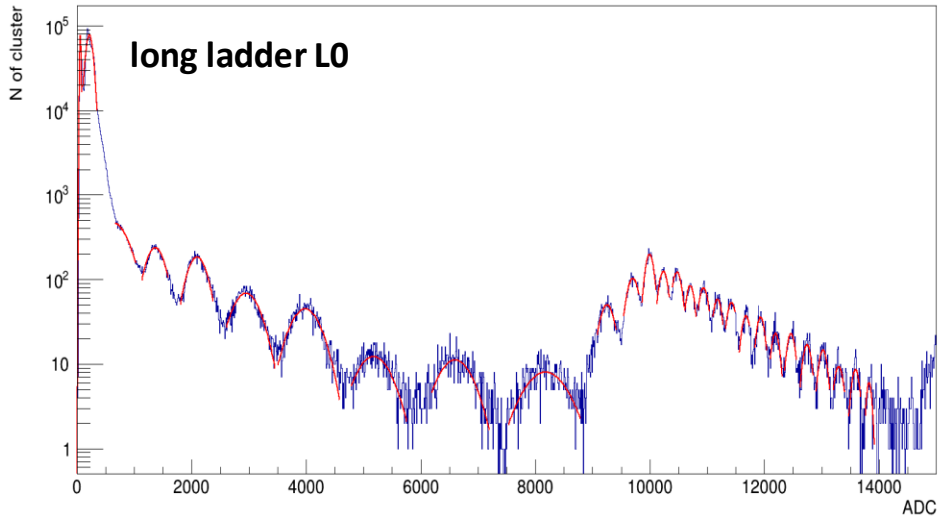


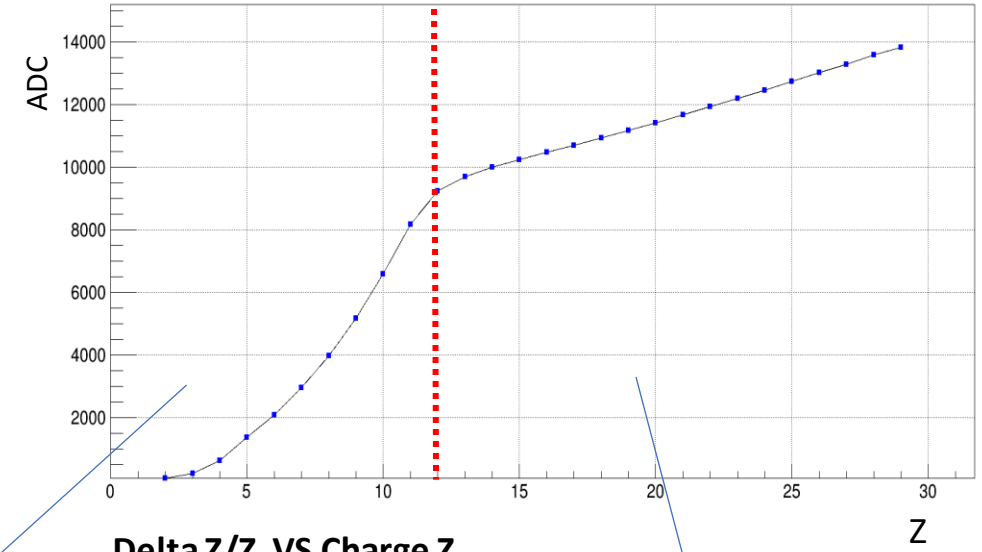
* S1 is the strip with the maximum signal in a cluster, typically the one closest to the particle impact position
* S2 is the strip with second largest signal in a cluster.

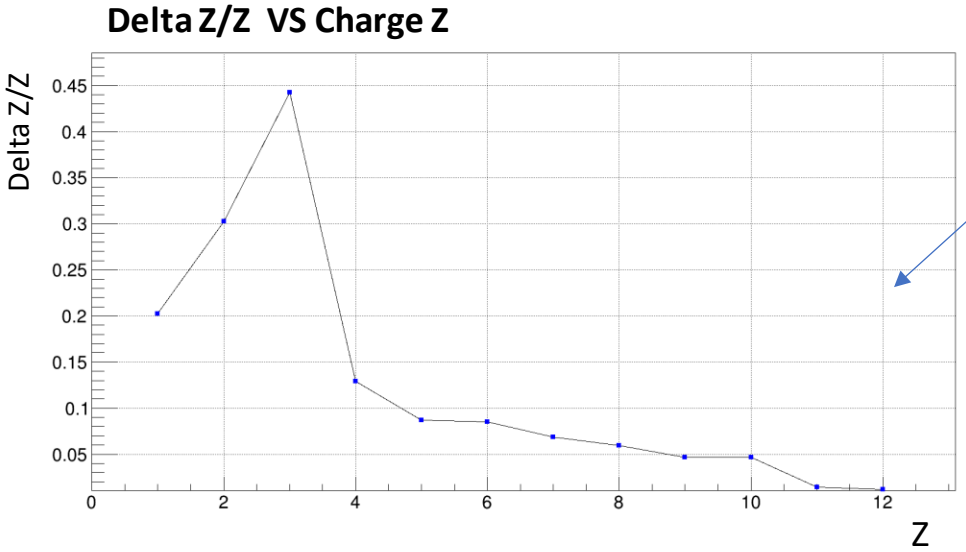
Charge identification – Alternative method

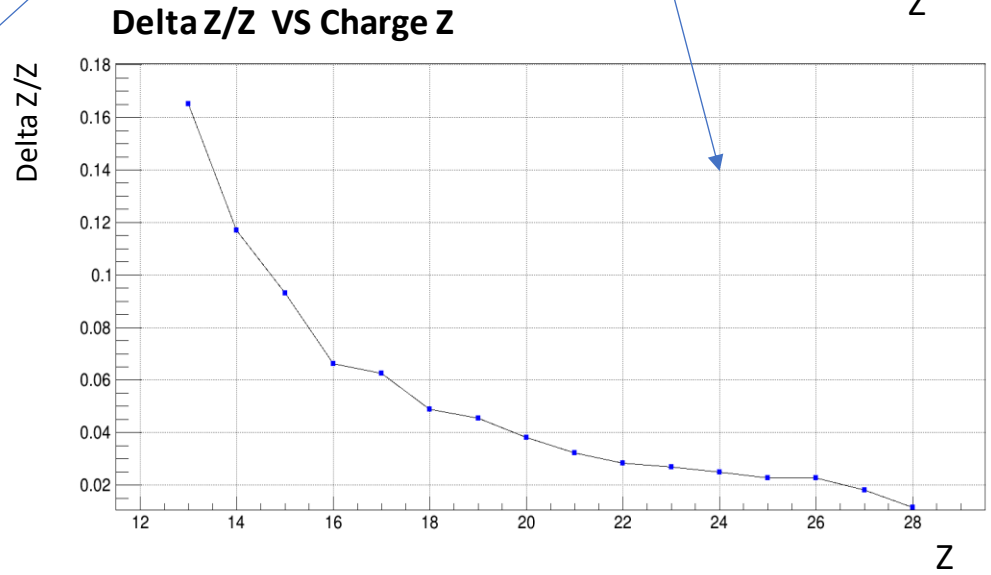


Charge identification – Alternative method

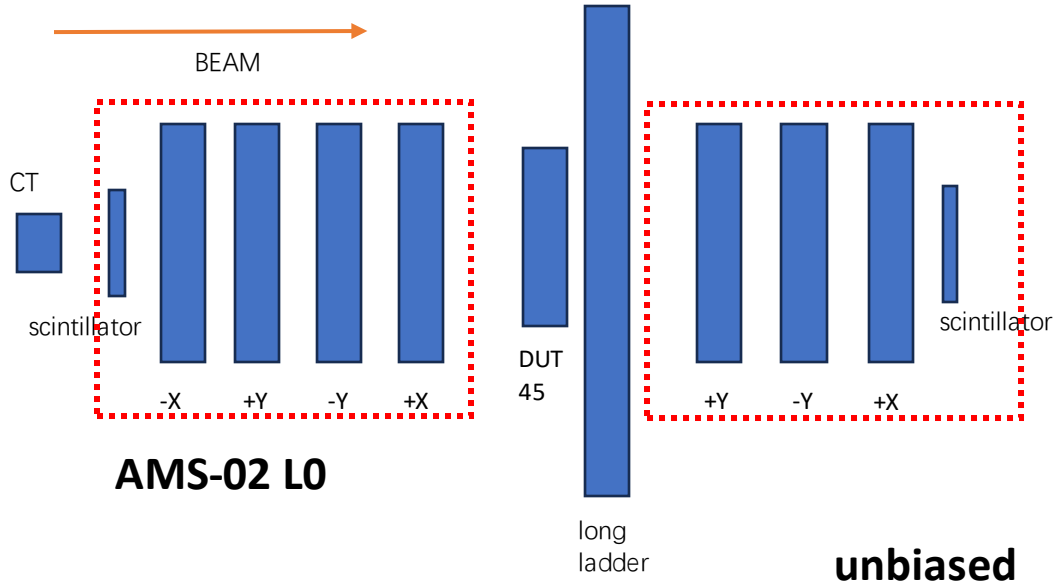




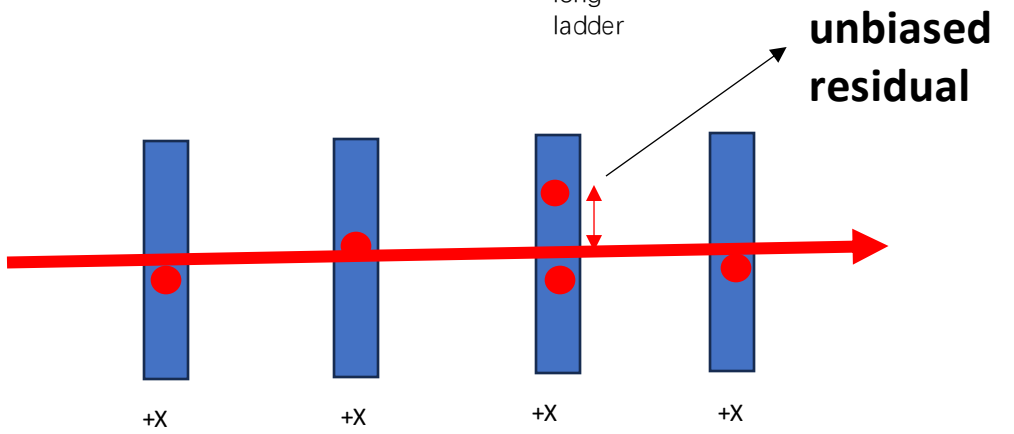


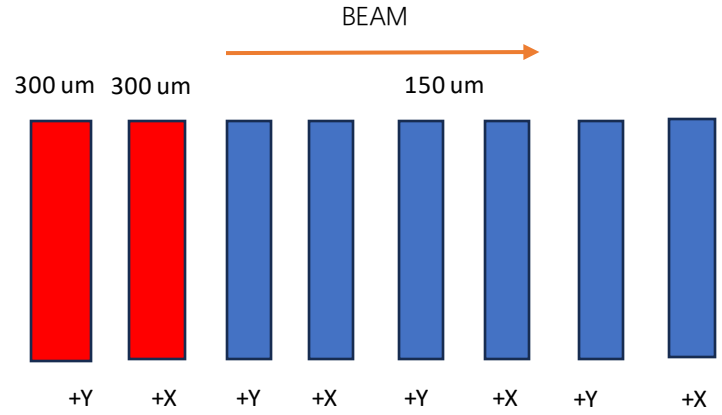


Spatial Resolution



AMS-02 L0



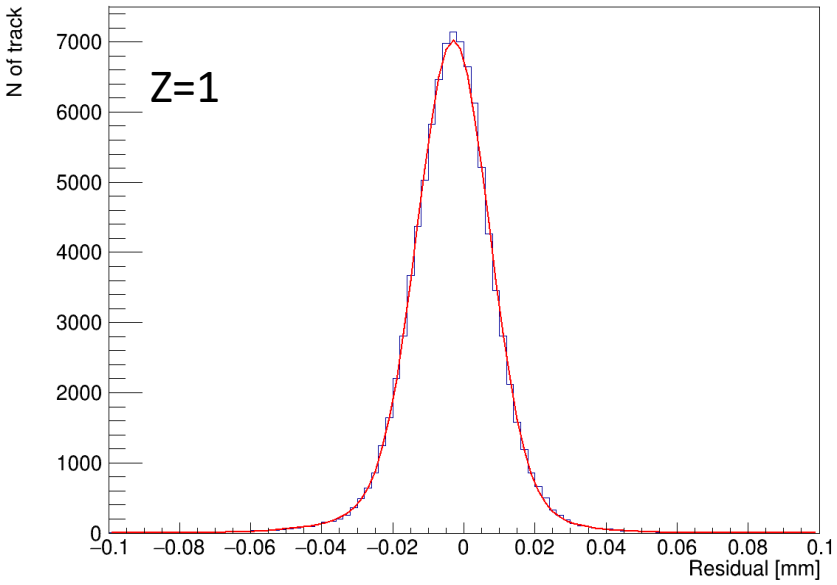


HERD SCD

- The width (sigma) of the residual distribution can be expressed as the sum of two contributions, the intrinsic resolution of the sensor and the error in the fit prediction.

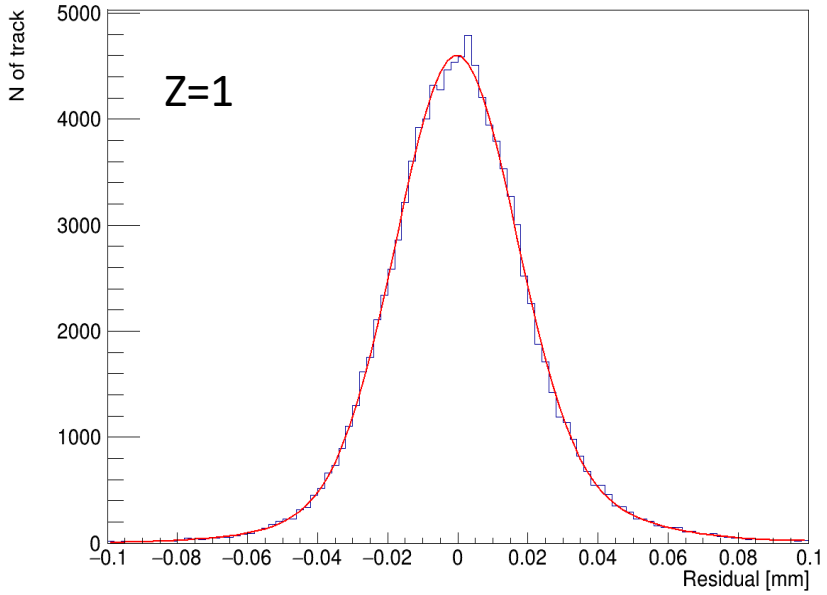
- $\sigma_{RES,i} = \sqrt{\sigma^2_{fit,i} + \sigma^2_{resolu,i}}$.

Spatial Resolution



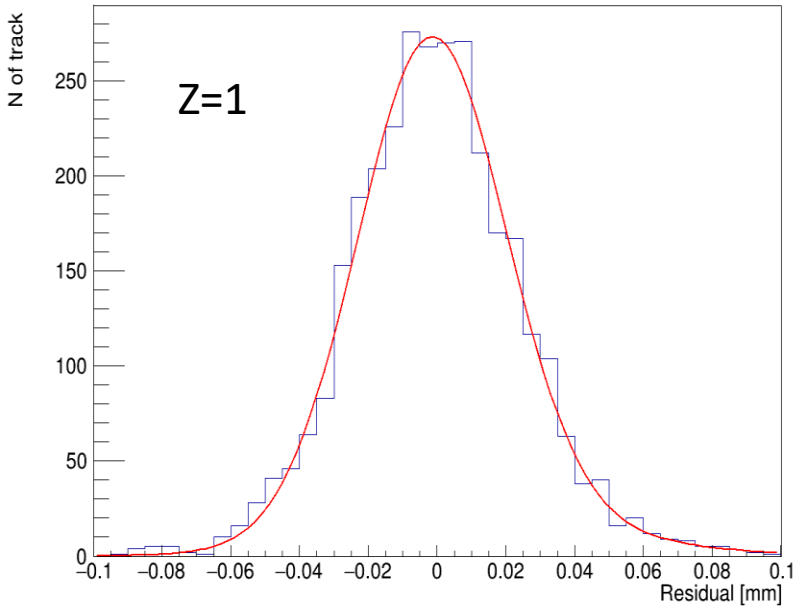
L0 Beam monitor 05

- Sigma residual (unbiased): 10.04±0.05 µm
- Resolution: 7.45±0.05 µm



L0 long ladder

- Sigma residual (unbiased): 16.89±0.11 µm
- Resolution: 16.53±0.11 µm



SCD sensor 05

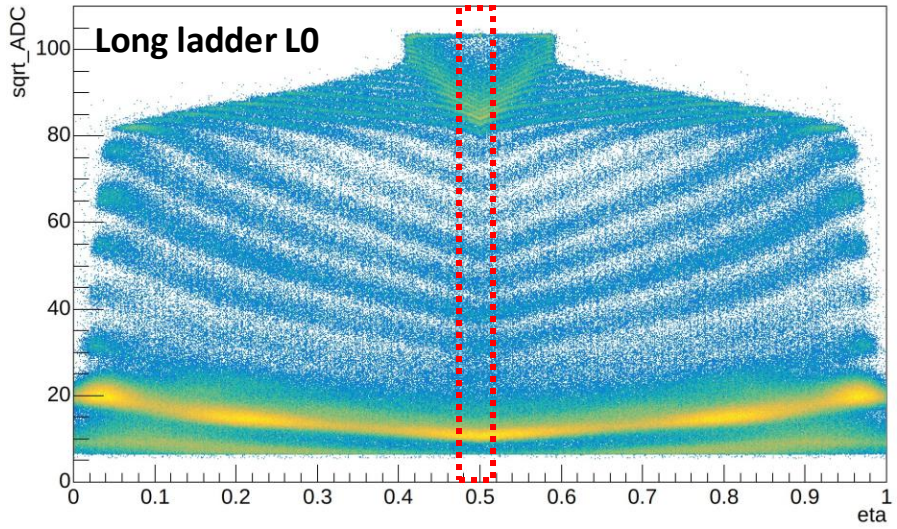
- Sigma residual (unbiased): 21.50±0.57 µm
- Resolution: 21.06±0.57 µm

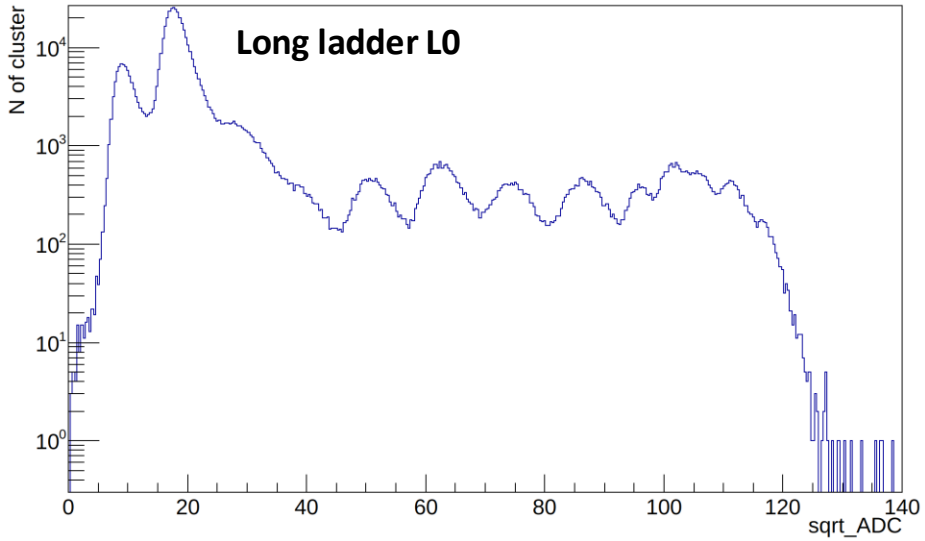
Conclusion

- The AMS-L0 long ladder can identify peaks up to Nickel
- The HERD-SCD sensor is able to identify peaks up to Sulfur
- The spatial resolution of the AMS-L0 long ladder is around 16 µm
- The spatial resolution of the HERD-SCD sensor is around 21 µm

Backup

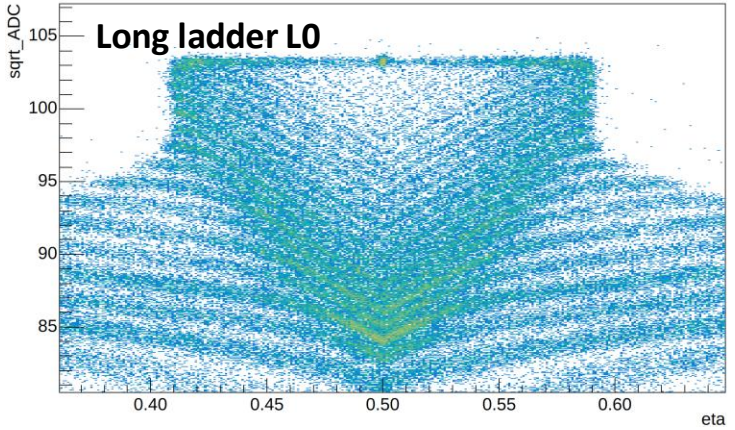
Charge identification





Why still can't we see fine structures?

- Because based on the trend of the curve, if the selected bin interval is wide, it will cause overlap between peaks. If the selected bin interval is very narrow, it will result in very few statistics.
- Therefore, it is necessary to increase the spacing between peaks as much as possible.



Charge identification – Alternative method