PERFORMANCE STUDY ON HERD SUB-DETECTORS: SILICON CHARGE DETECTOR (SCD) PROTOTYPE

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ABSTRACT

The High Energy cosmic-Radiation Detection (HERD) facility is part of the Cosmic Lighthouse Program onboard China's Space Station. Its purpose is to directly measure high-energy electrons, gamma-rays, and in general all the cosmic ray nuclei. The facility is scheduled to commence operations around 2027 and is expected to remain operational for approximately 10 years.

In this presentation, we present a preliminary analysis of the Silicon Charge Detector (SCD) prototype's performance based on the results obtained from the HERD prototype beam test conducted at CERN SPS in 2022. We will discuss the key performance metrics evaluated, including the Signal-to-Noise ratio, charge resolution, and spatial resolution.

THE SETUP OF BEAM TEST

- There are 8 identical sensors installed in pairs, positioned orthogonally on frames that are mounted on a polymer base.
- The dimensions of each sensor are 96mm × 96mm.
- These sensors enable independent estimation of positions along the X and Y axes, with 4 sensors dedicated to each axis.

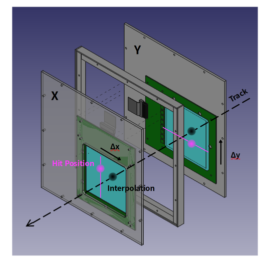
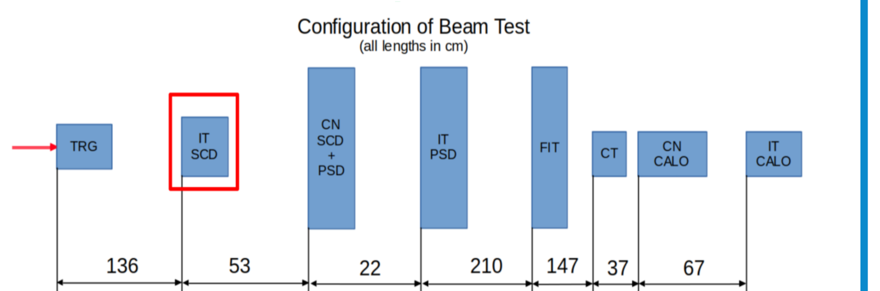
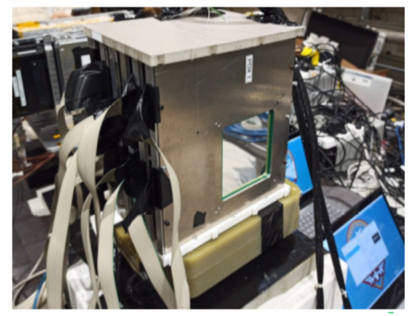


Figure 6





Detector	DE10Nano	Connector	View	ID	Z (mm)
P05	2	J5	-Y	0	0
P06	2	J7	X	1	6.5
P12	3	J5	-X	2	31
L13	3	J7	Y	3	37.5
P01	4	J5	-Y	4	62
P02	4	J7	X	5	68.5
L10	5	J5	-Y	6	93
L09	5	J7	X	7	99.5

Figure 7

THE PROTOTYPE SENSORS OF SCD

- The sensor has a thickness of 150 µm.
- The implantation pitch is 50 µm (2 floating strips).
- The readout pitch is 150 µm.
- 10 64-channel FE ASIC (IDEAS VA)
- It consists of 640 readout strips.
- The ADC resolution is 12 bits.

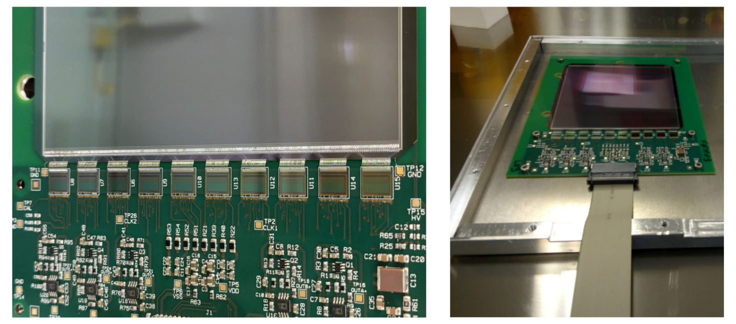


Figure 8: prototype of single sensor HERD

CALIBRATION OF SCD (E.G. P06)

- "Pedestal": the average value measured on each channel in the absence of a physical signal.
- "Sigma raw": the standard deviation around the pedestal value of each channel in the absence of a physical signal.
- "Sigma": The noise level of the channel, is evaluated as the 'Sigma raw' subtracted by the common mode offset in the absence of incident particles.

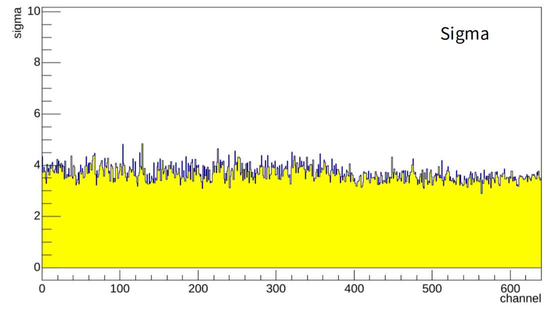


Figure 9: Sigma

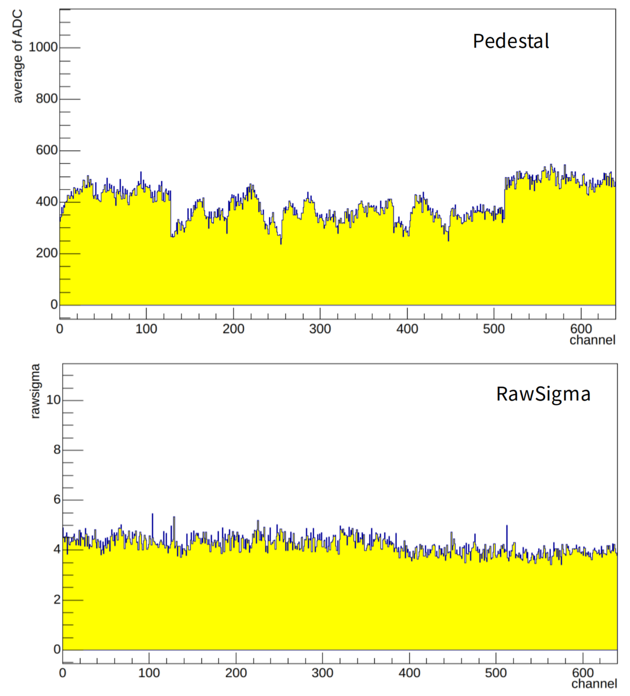


Figure 10: Pedestal and Raw Sigma

INTRODUCTION OF THE BEAM

- The beam test was conducted using a beam of lead nuclei (379 GV/c) directed towards a beryllium target (40 mm).
- The fragmentation products, protons, and nuclei with atomic number Z < 82, are selected based on their rigidity (around 300 GV/c or 150 GeV/nuclei for A/Z = 2) and focused in the experimental area by suitable magnet systems.

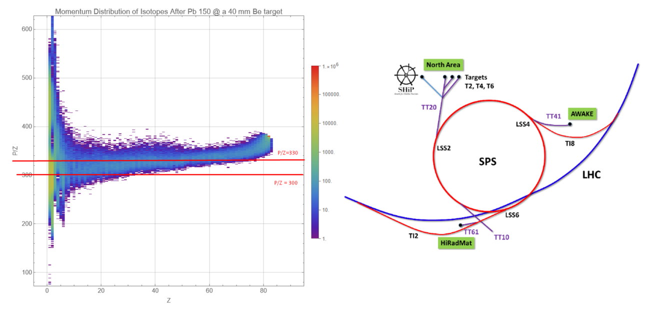


Figure 1: momentum distribution of isotopes

THE ETA-DISTRIBUTION

- To obtain a reliable charge reconstruction and, consequently, a correct reconstruction of the particle track, silicon sensors must have a good capacity to collect the charge induced by particle.
- A useful parameter to evaluate such capacity is the eta function, defined as the ratio between the charge collected on the right strip of the barycenter and the total charge of the cluster.
- $\eta = \frac{Q_{Right}}{(Q_{Left}+Q_{Right})}$.
- As it is defined, the eta varies between 0 and 1, and the value it takes depends on the point at which the particle passes between two readout strips.

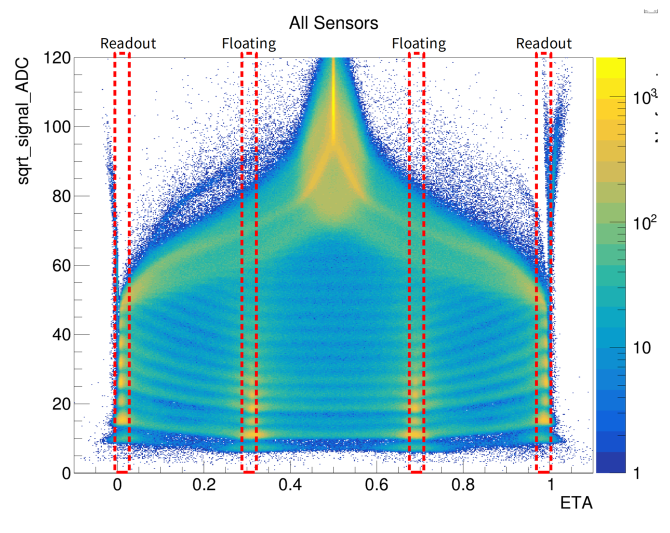


Figure 3: The eta-distribution of all sensors

THE HIGH ENERGY COSMIC-RADIATION DETECTION (HERD) FACILITY

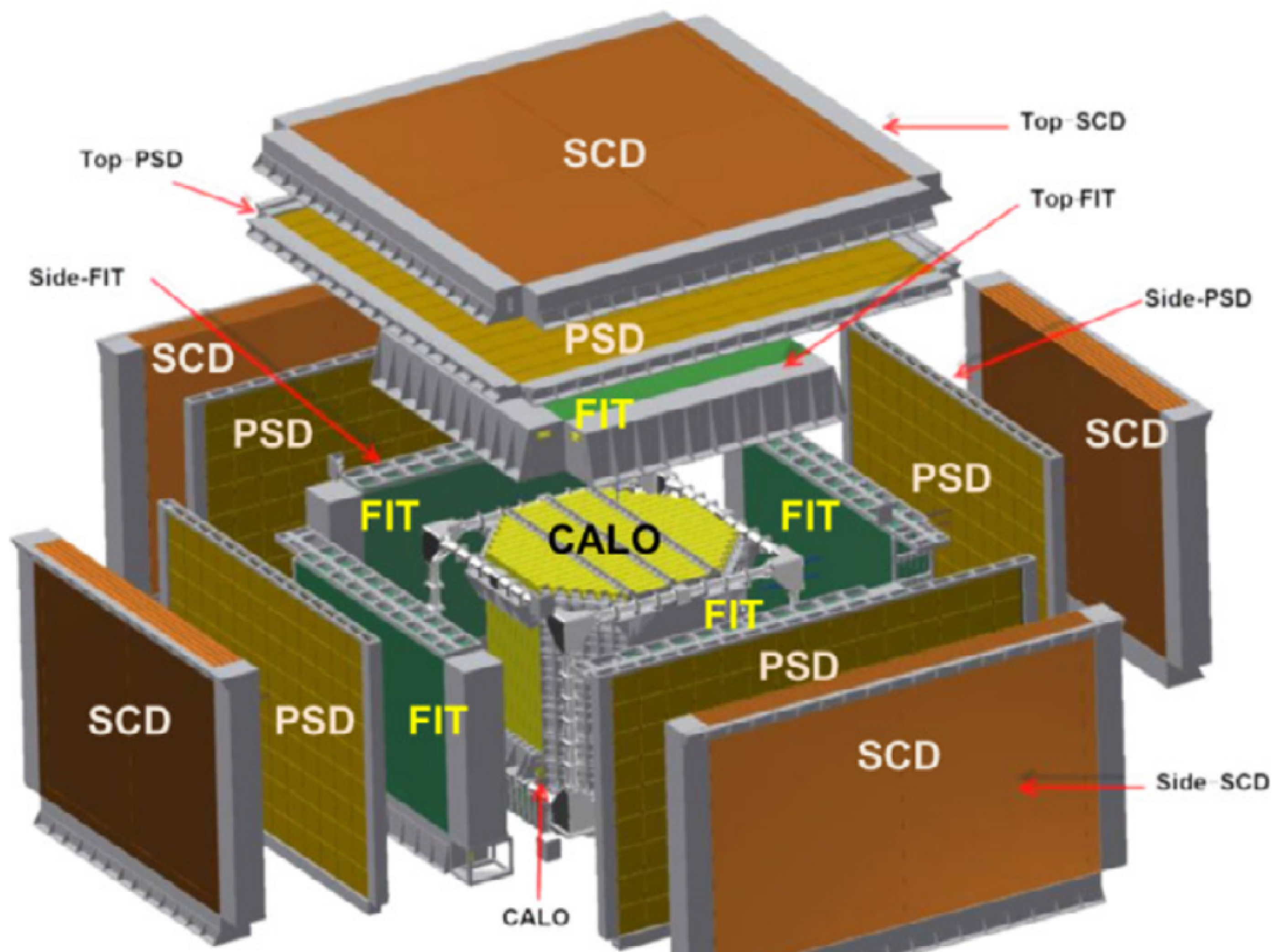


Figure 11: an exploded view of the various sub-detectors

REFERENCES

[1] Dimitrios Kyratzis. Latest advancements of the HERD space mission. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 1048:167970, 2023.

THE CHARGE RESOLUTION

symbol	resolution	error
He	8.9%	0.87%
Li	6.2%	0.23%
Be	6.1%	0.54%
B	4.5%	0.29%
C	4.2%	0.46%
N	3.7%	0.54%
O	3.4%	1%

Table 1: charge resolution of readout strip

symbol	resolution	error
He	9.7%	0.96%
Li	6.3%	0.21%
Be	5.8%	0.49%
B	4.4%	0.29%
C	4.4%	0.42%
N	4.0%	0.79%
O	4.3%	1.6%
F	3.5%	2.0%
Ne	3.5%	2.6%
Na	3.1%	3.9%
Mg	3.4%	5.4%
Al	2.7%	6.0%
Si	3.8%	6.9%

Table 2: charge resolution of floating strip

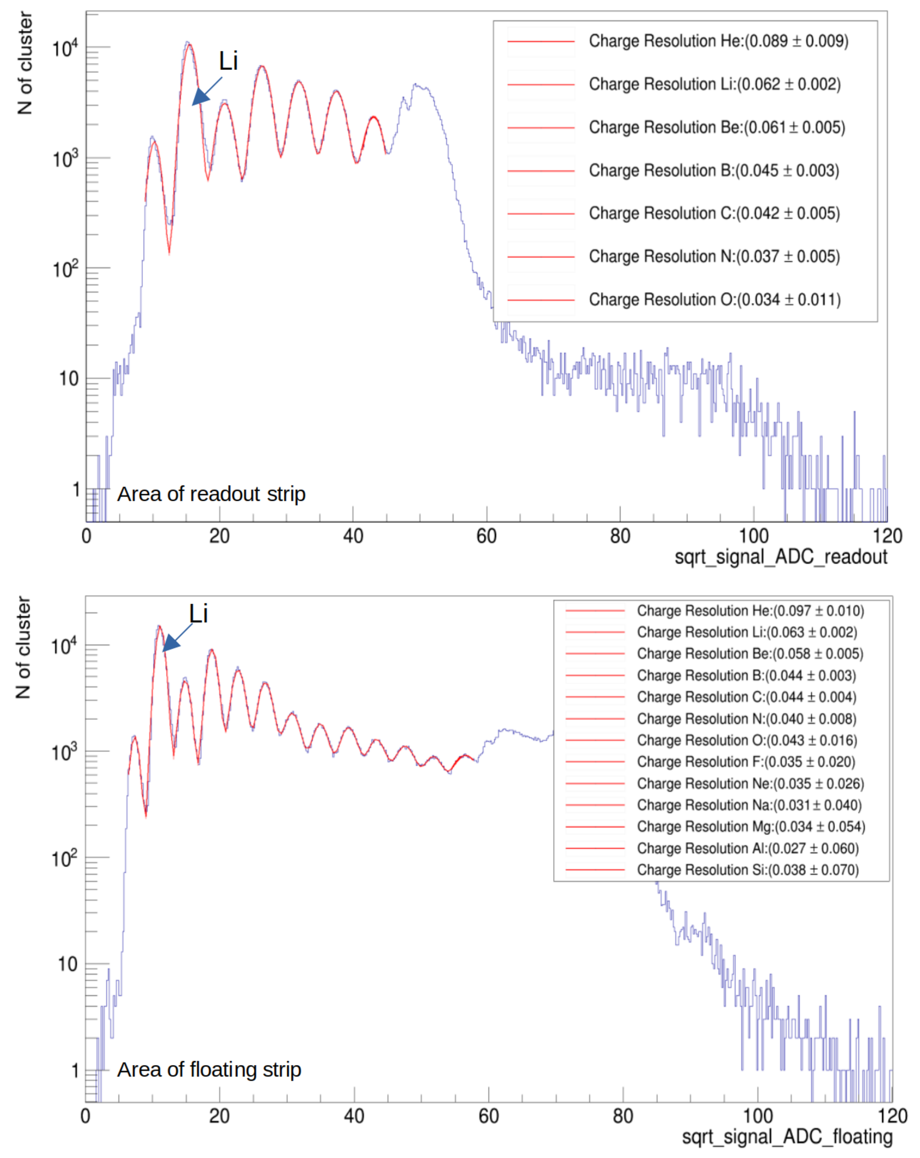


Figure 2: the energy-deposition distribution

THE SPATIAL RESOLUTION

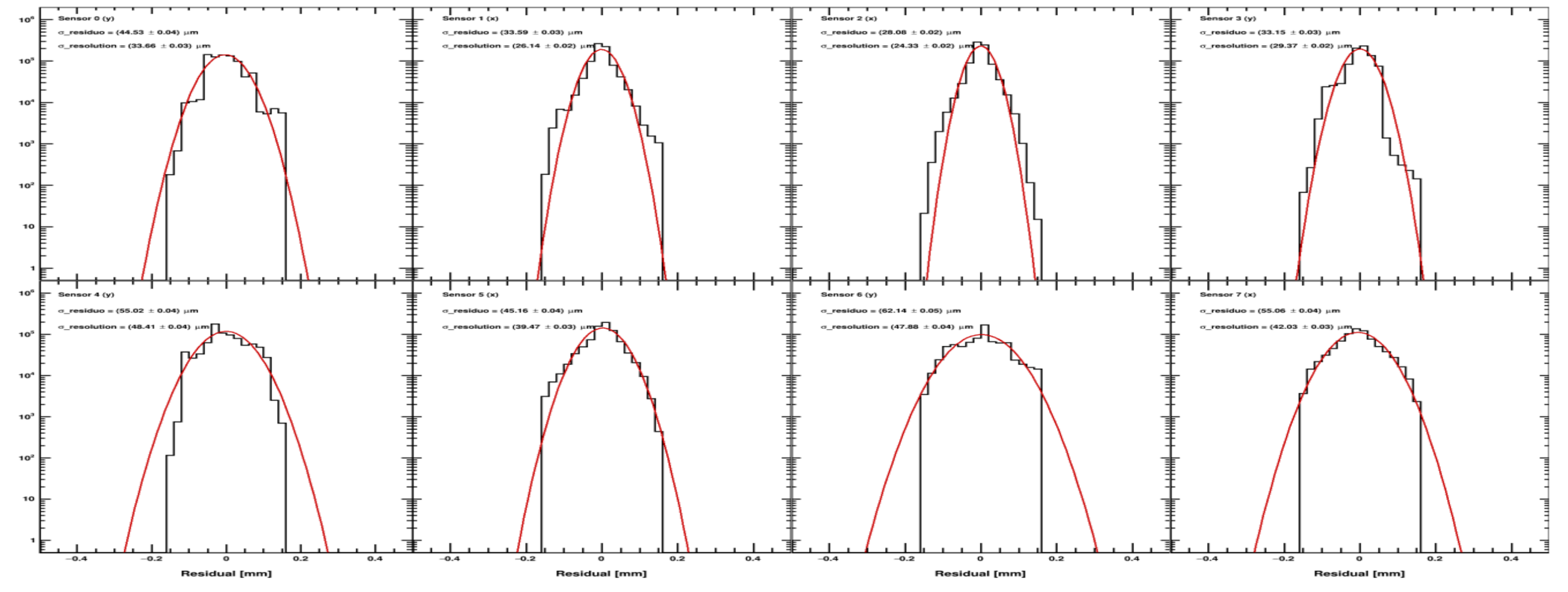


Figure 4: the distribution of residuals of 8 sensors

- 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.
- $\sigma_{RES,i} = \sqrt{\sigma^2_{fit,i} + \sigma^2_{resolu,i}}$.
- By knowing the value of the error in the fit prediction for each sensor, it is possible to obtain an estimate of the intrinsic resolution of the sensors.
- $\sigma_{fit,i} \approx \sqrt{\frac{1}{D}\left[\sum_{j=1}^{4}\frac{z_j^2}{\sigma_j^2} - 2z_i\sum_{j=1}^{4}\frac{z_j^2}{\sigma_j^2} + z_i^2\sum_{j=1}^{4}\frac{1}{\sigma_j^2}\right]}$.

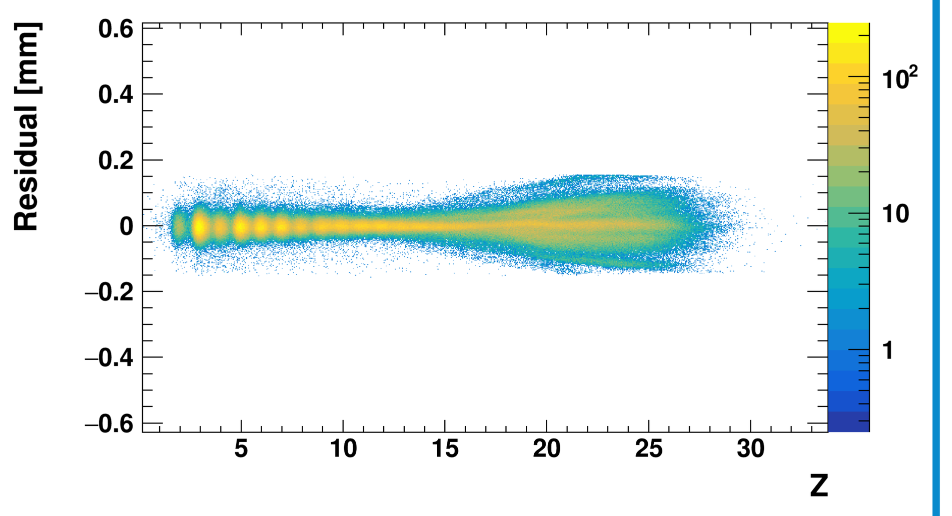


Figure 5: the distribution of residuals vs charge (2nd sensor)