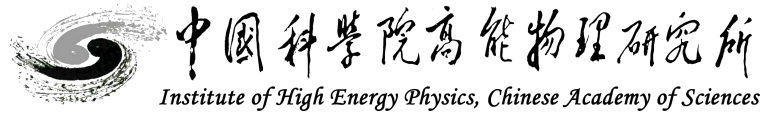




INSTR 2026

October 12–16, 2026 | Hefei China



The upgrades of the new silicon tracker L0 for AMS-02

Qinze Li

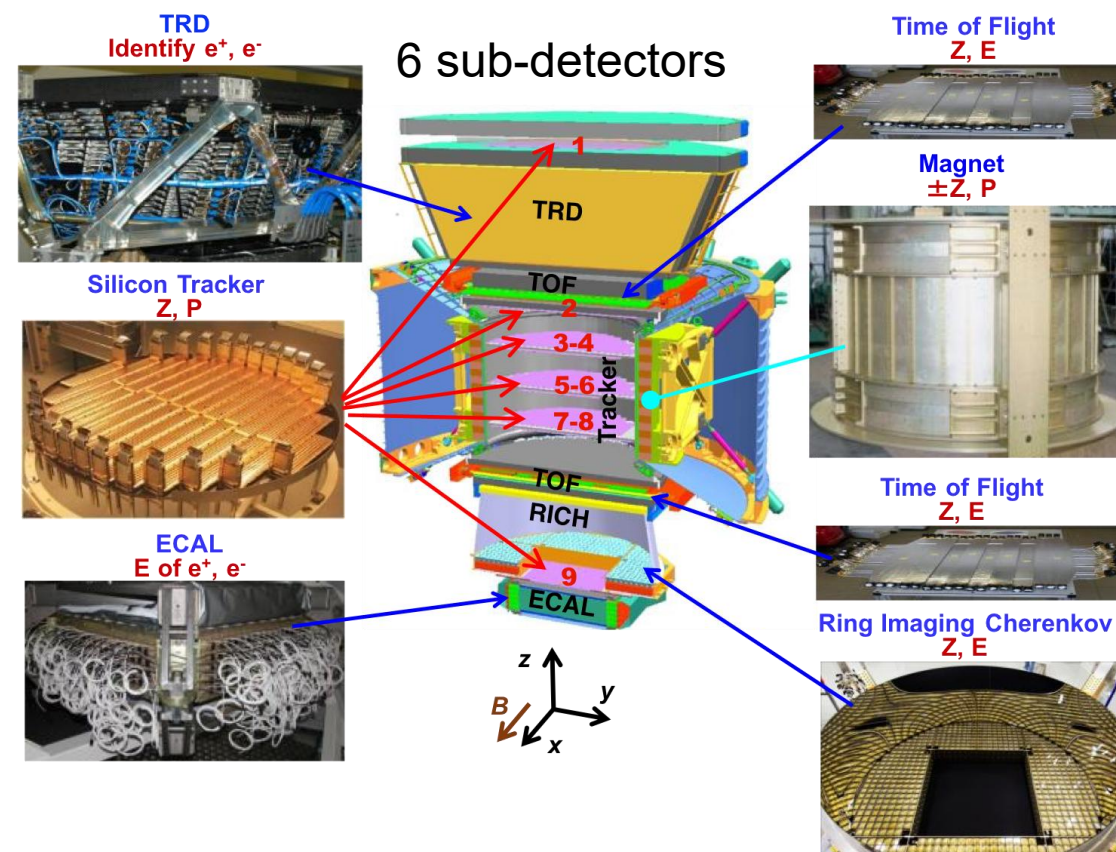
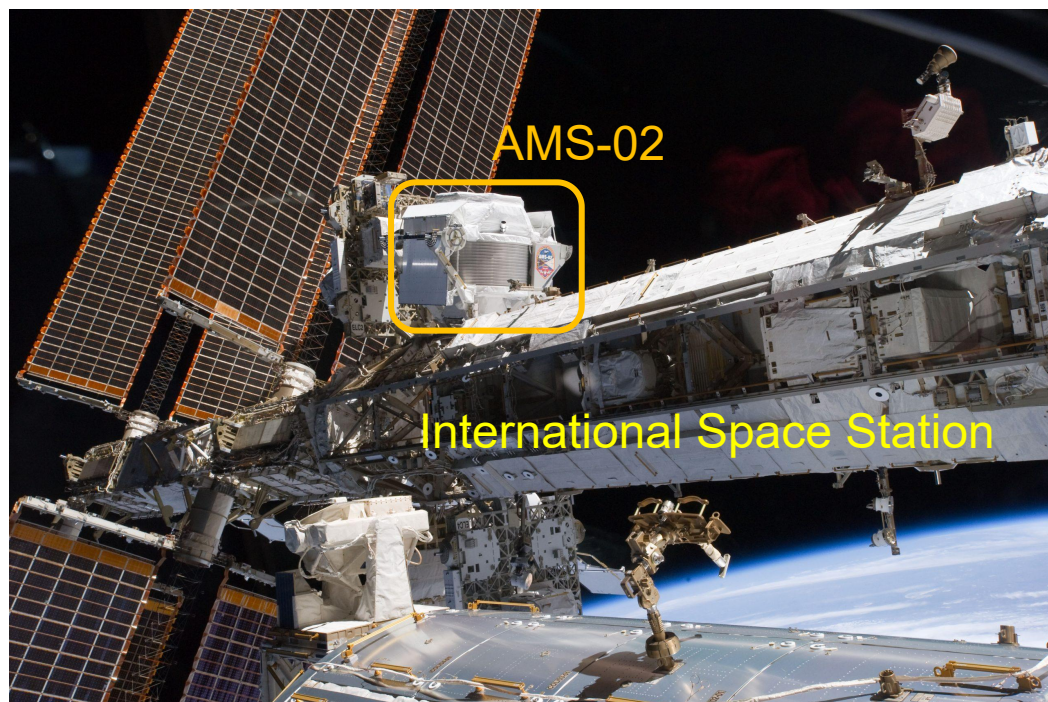
on behalf of L0 assembly group

Oct 12th 2026

Hefei, China



AMS-02 Experiment



The Alpha Magnetic Spectrometer (AMS) is the only magnetic spectrometer in space

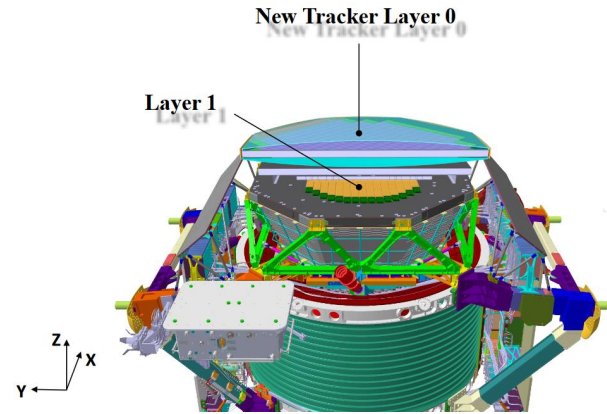
- Dark matter signals
- Primordial antimatter by direct detection of antinuclei
- Production, acceleration and propagation of cosmic rays
- Solar modulation
-

Physics topics

Since its installation in 2011, more than 270 billion cosmic ray events have been collected until now

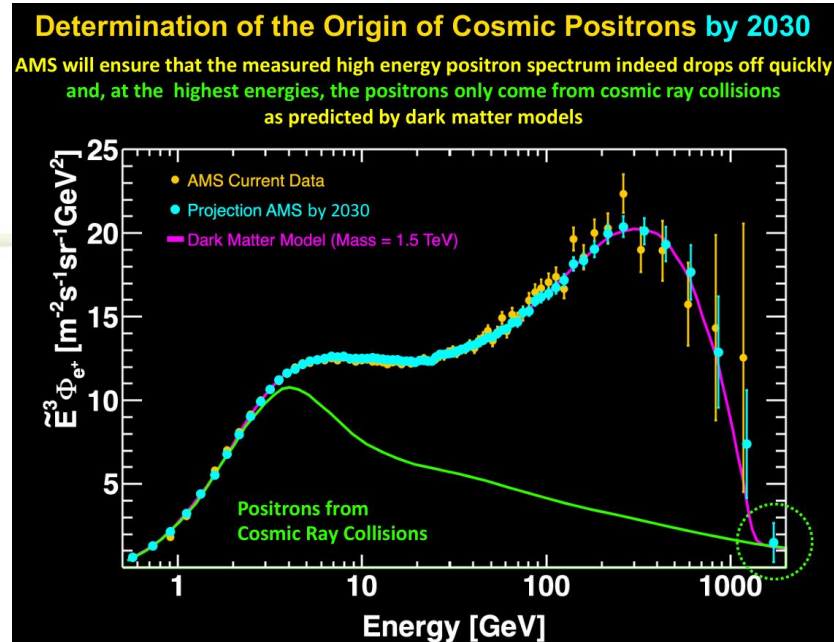
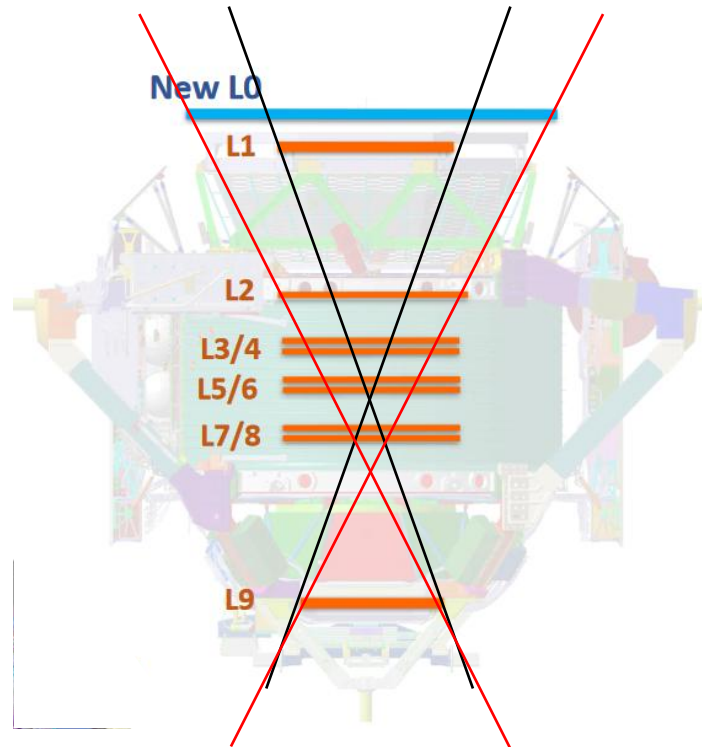


AMS-02 Tracker Upgrade

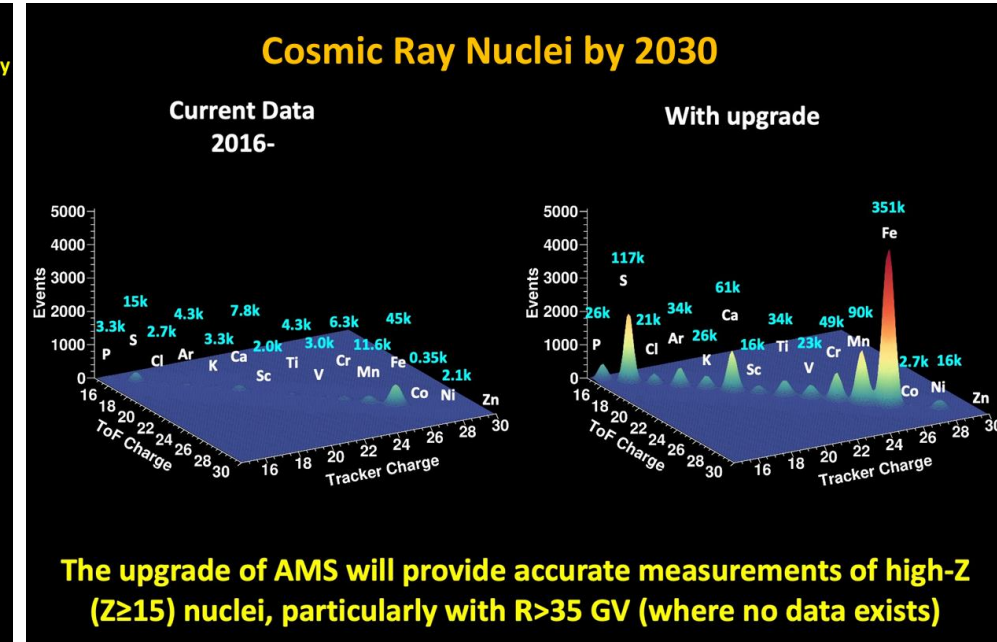


A new silicon strip tracker **Layer-0 (L0)** will be added on the top of AMS, besides the existing 9 layers.

- Its large sensitive area ($\sim 7\text{m}^2$) increases the cosmic-ray acceptance to 300%
- Improves charge and track measurement ability
- Ready for flight ~ 2027



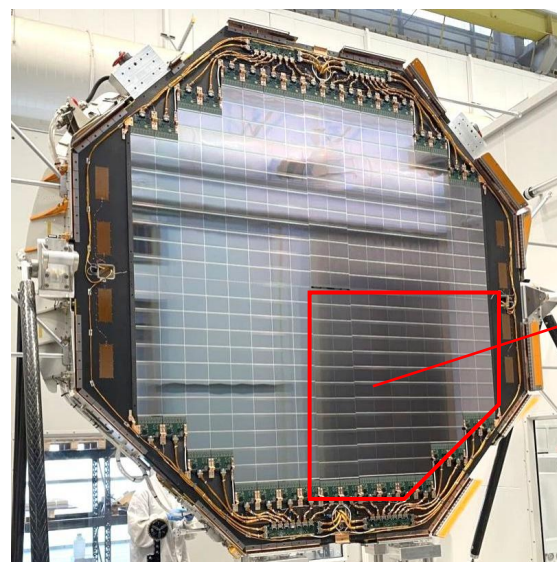
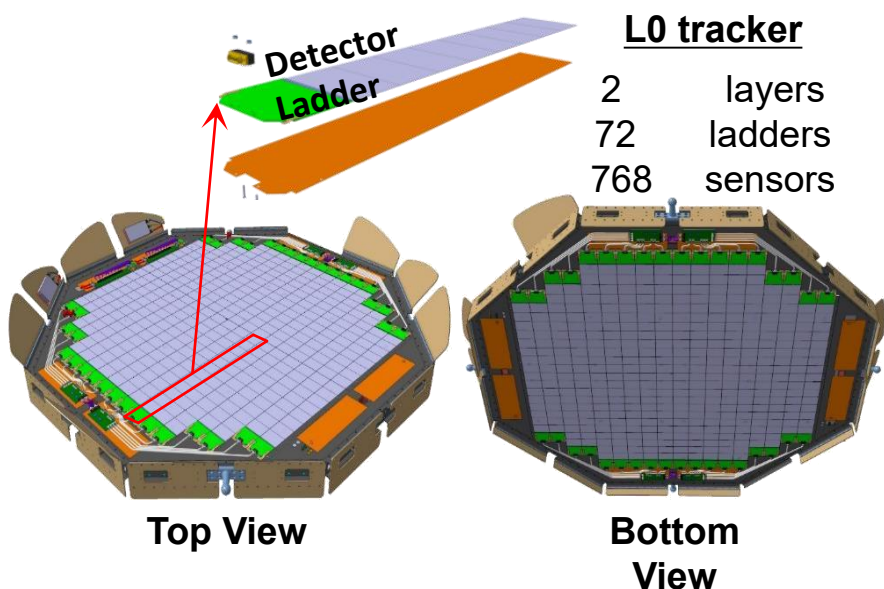
By 2030, more data of high energy cosmic-rays will be obtained



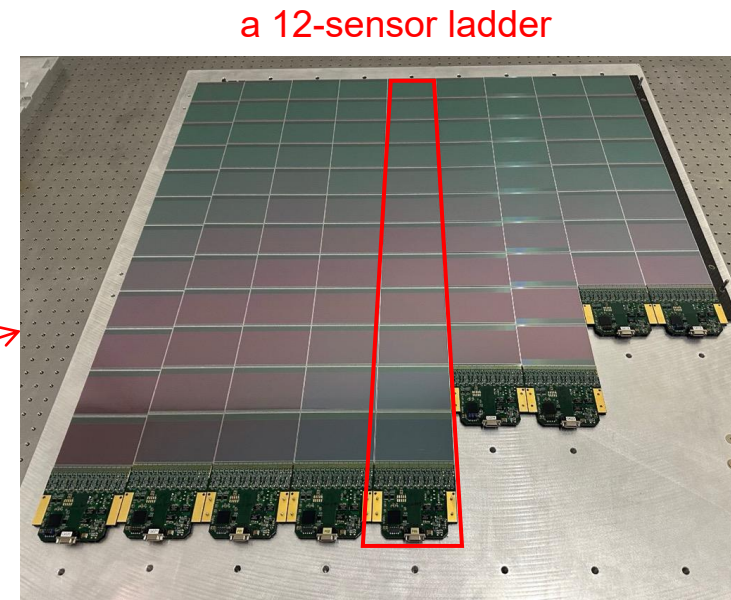
[G. Ambrosi, AMS-L0: upgrade status and prospects @ ASAPP 2023](#)



L0: Silicon Strip Tracker



L0 completed in Sep, 2025



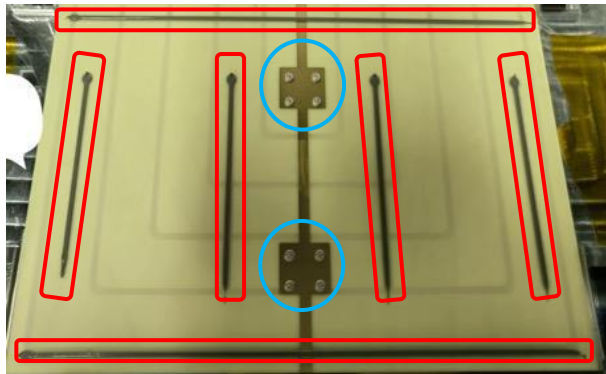
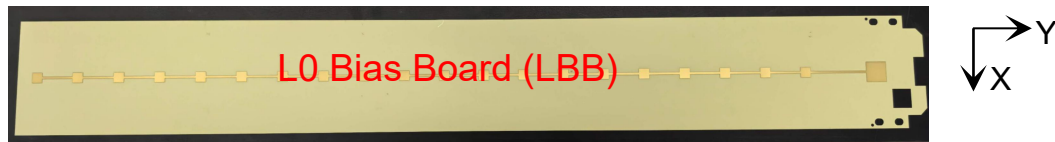
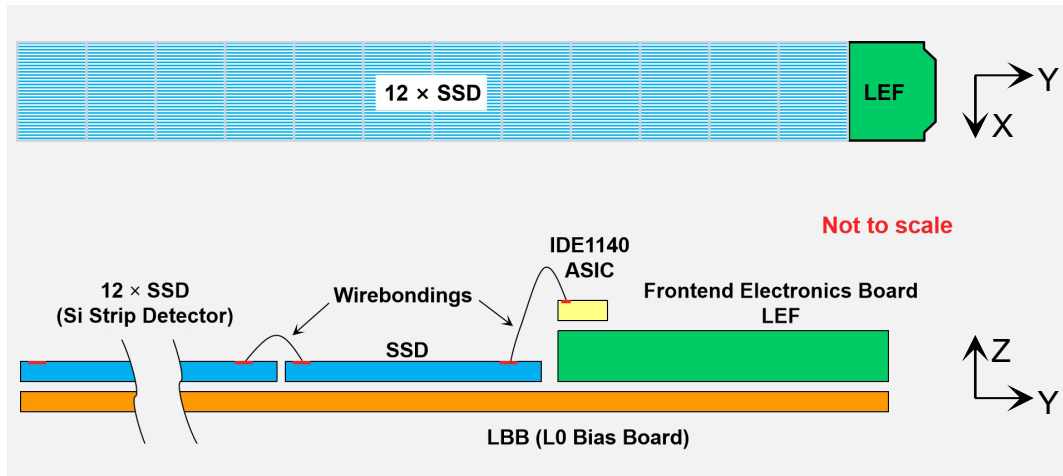
9 ladders on a QL

- L0 is composed of two layers that rotate relative to each other by 45 degrees
- Each layer comprises 4 Quarter Layers (QLs)
- One QL has 9 ladders → totally 72 ladders
- Ladder is the basic readout module of L0

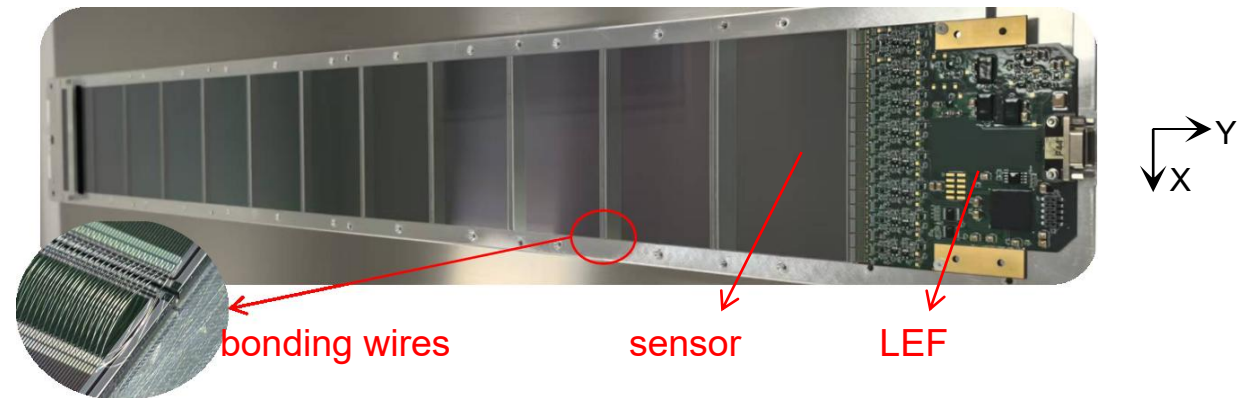
Sensors	Designed by IHEP + Perugia + HPK
Electronics	Produced by IPAS + NCSIST
Ladders	Constructed by IHEP + SDIAT



L0 Ladder



- A ladder includes 8, 10, or 12 silicon strip sensors and an readout board LEF secured on an LBB
- Sensors and LEF are connected by bonding wires (1024 channels + ground), forming a long equalized strip



One readout channel has an equalized strip length of $\sim 1\text{m}$. For a good spatial measurement, precise alignment in X dimension is necessary

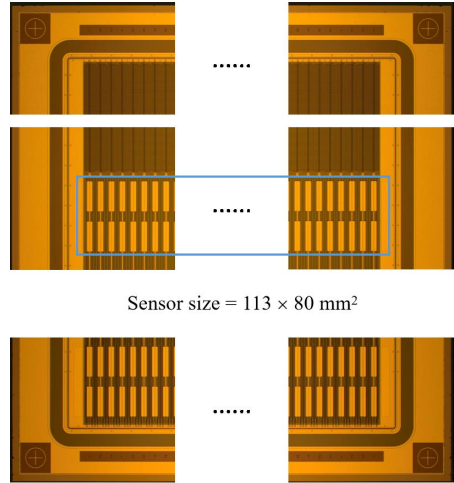
Contents

- AMSL0 ladder production and test results
- AMSL0 single sensor performance study
- AMSL0 ladder performance study



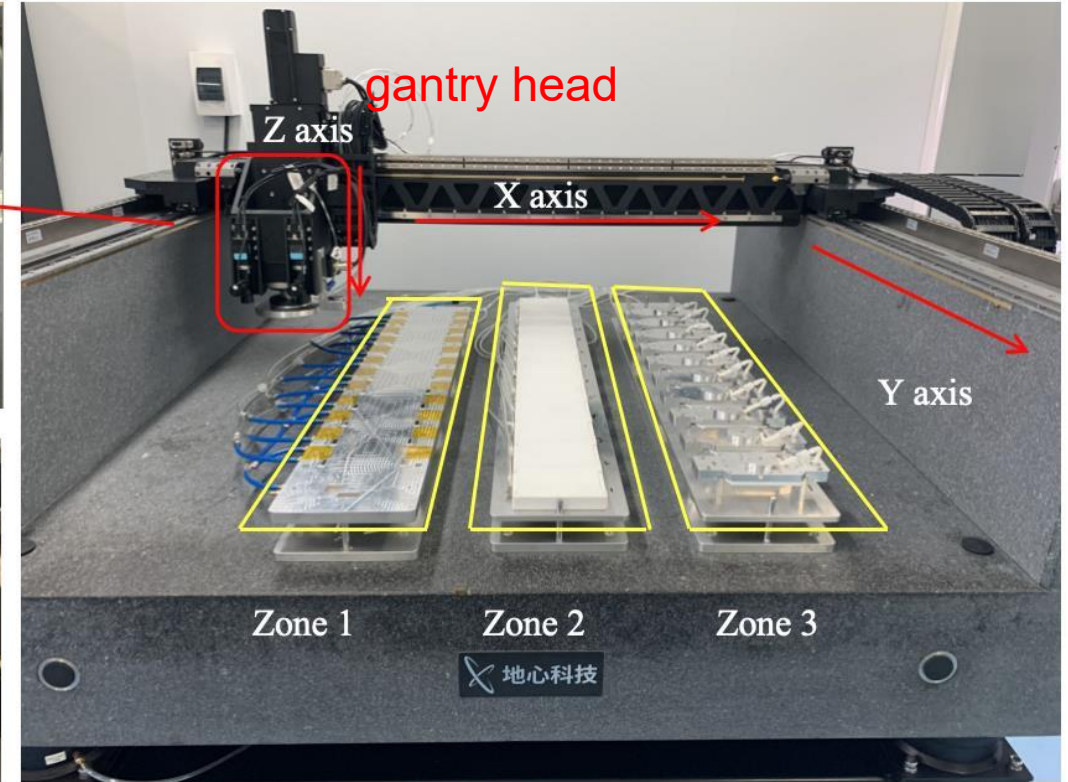
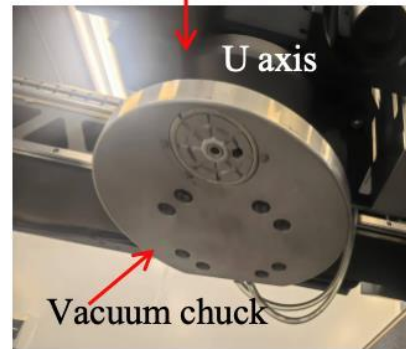
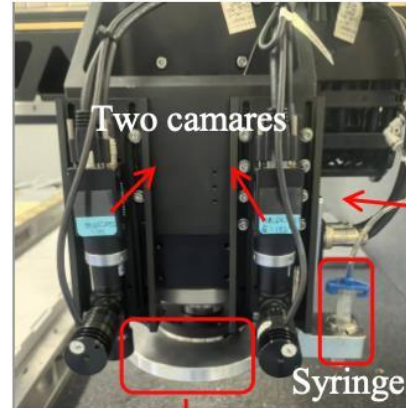
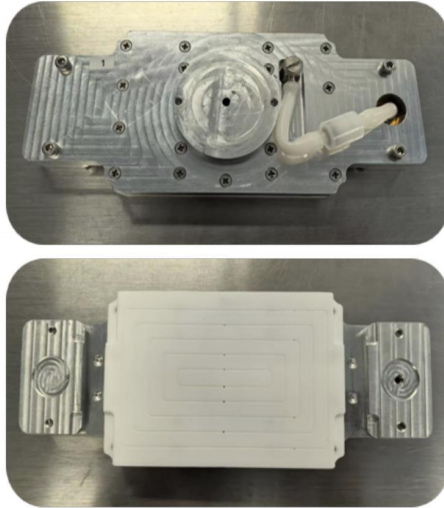
Gantry System for Ladders

Fiducial marks for positioning on sensor



Sensor size = $113 \times 80 \text{ mm}^2$

Gripping fixture to pick up sensor



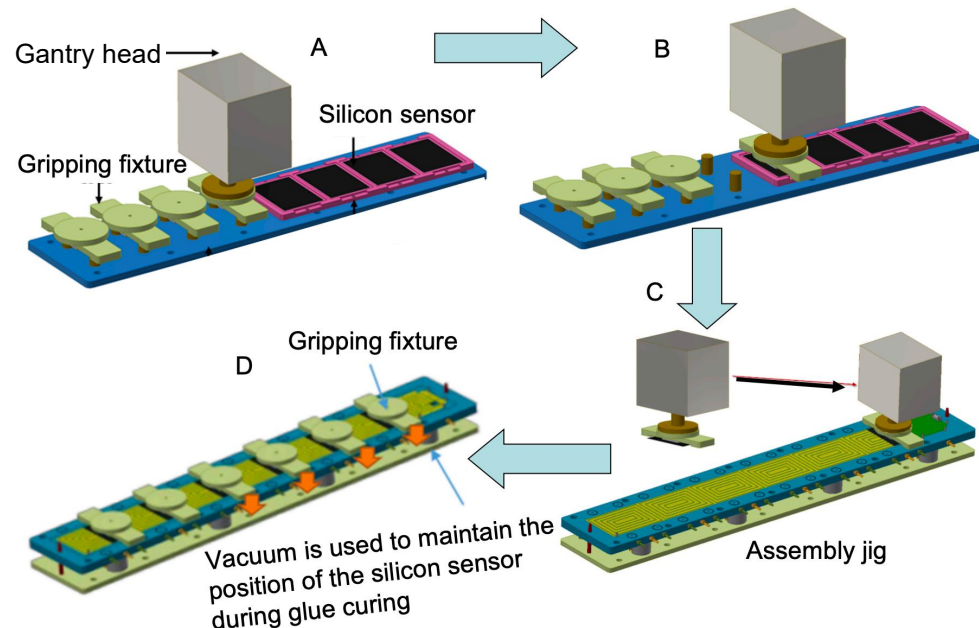
Custom-designed gantry dedicated to AMS L0 ladders for high percision assembly

- Gantry head move in X-Y-Z axis and rotate (U axis) in X-Y plane
- Syringe with an air pump to dispense glue on LBB
- Two cameras to recognize marks on a sensor for positioning in real time
- Head with gripping fixture to pick up, place and fine-tune sensor via vaccum

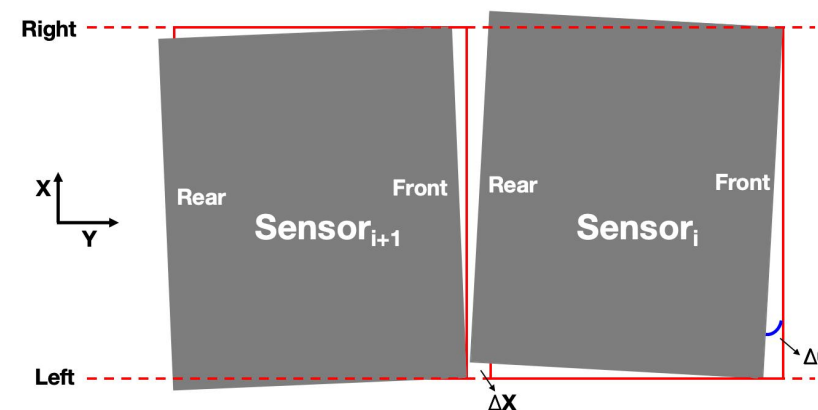
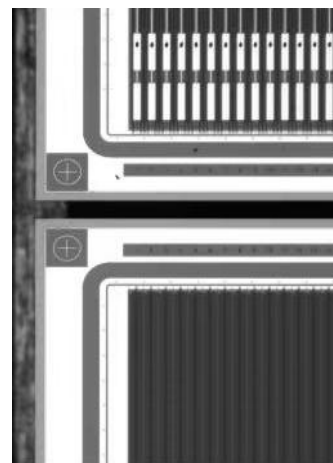
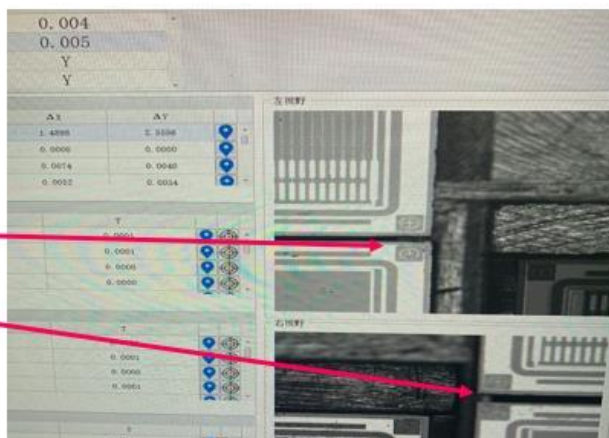
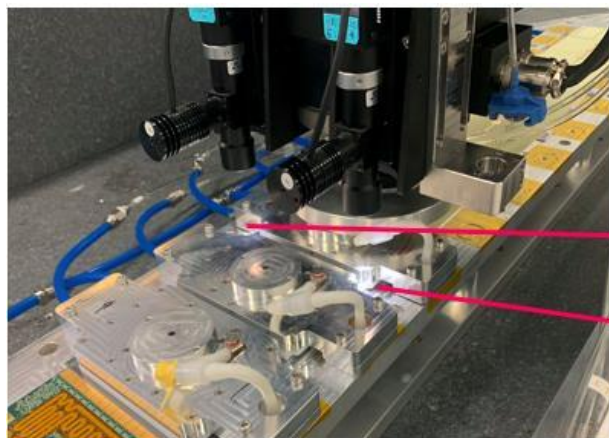
[JINST 21 C01003](#)



L0 ladder assembly steps



- The gantry head picks up a gripping fixture via vacuum
- Picks up a sensor by vacuum
- Places the sensor in the target position on assembly jig
- Align the sensor by **fine tuning** by real-time positioning
- Leave the gripping fixture to clamp the sensor firmly by vacuum at the bottom of jig



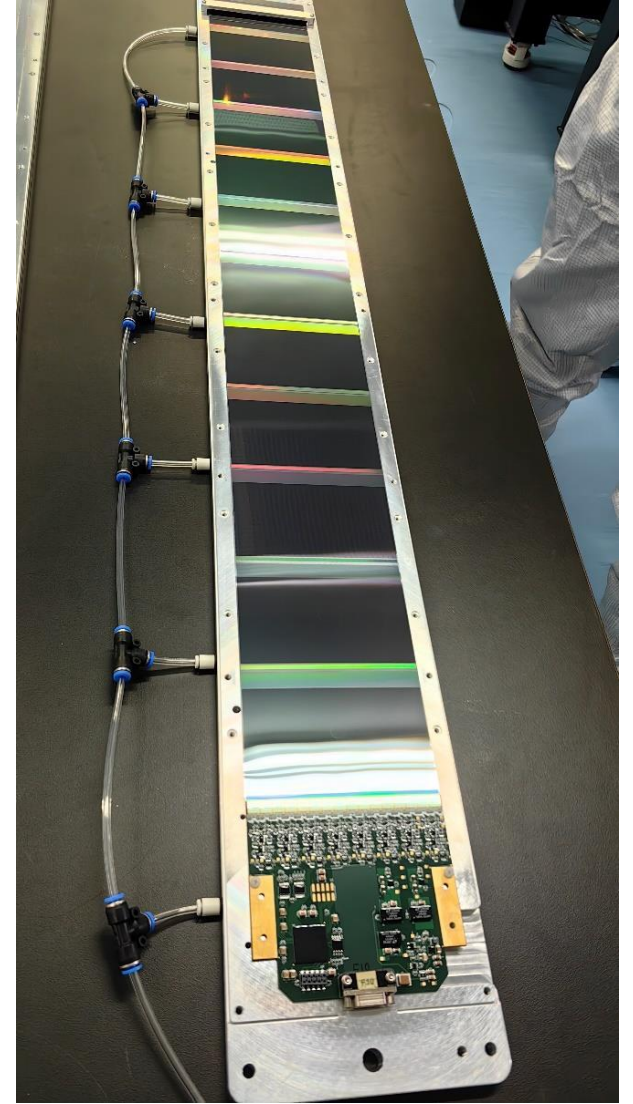
Real-time positioning for fine tuning

L0 ladder assembly steps

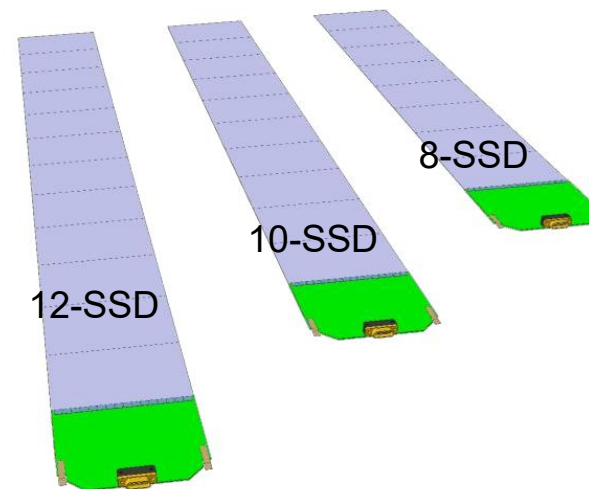
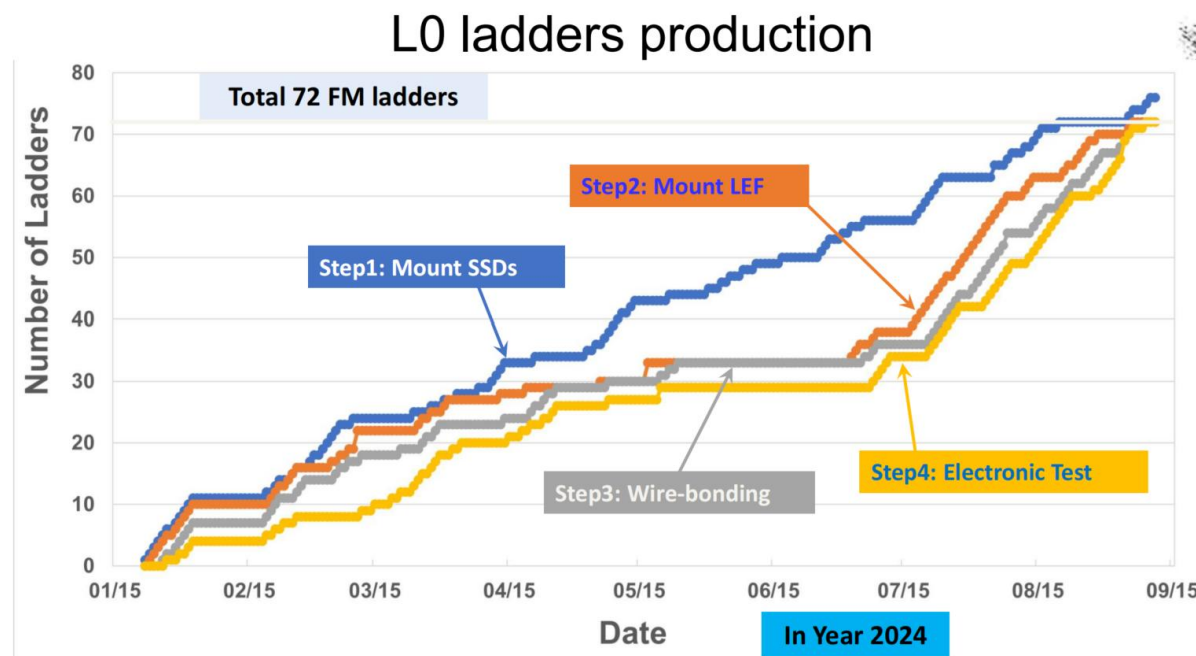


After all sensors assembled and fine-tuned:

- Wait for 24h to let the glue cure
- Remove all gripping fixtures
- Move the ladder by a large-size pickup tool to transportation plate
- Wire bonding



Ladder Assembly Results



By Sep 2024, 76 (4 as spare) ladders have been successfully assembled and tested:

- 42 12-SSD ladders
- 17 10-SSD ladders
- 17 8-SSD ladders

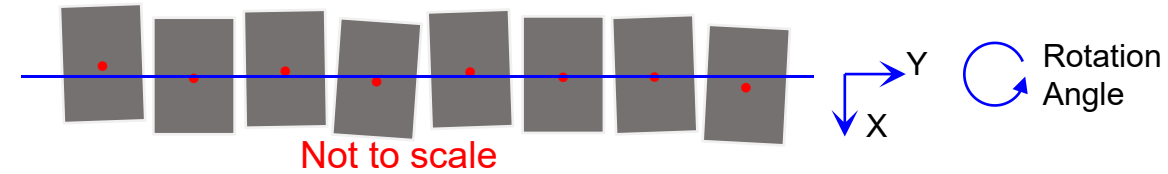
All ladders show good alignment and electrical performance



Ladder Assembly Results

The deviations are denoted as ΔX and $\Delta\theta$

- ΔX : Offset of the center with respect to the fitted line
- $\Delta\theta$: Relative rotation angle with respect to the fitted line



- The overall alignment precision:

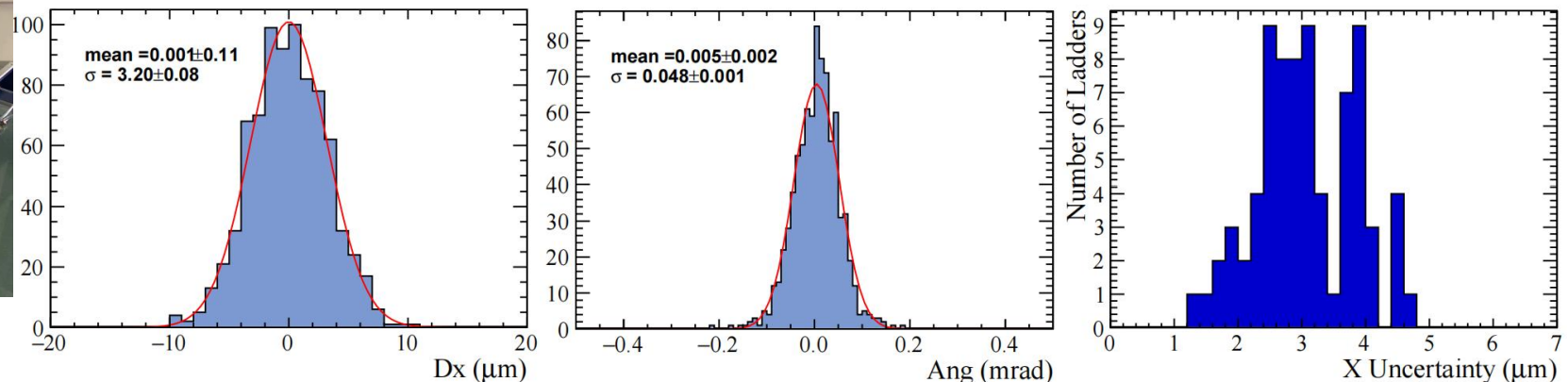
$$\sigma_{\text{tot}} = \sqrt{\sigma_{Dx}^2 + \frac{(L \cdot \sigma_{\theta})^2}{n}} = 3.4 \mu\text{m}$$

- For each ladder, $\sigma < 5 \mu\text{m}$

The results are at
world-leading level



Relative positions of all sensors
are precisely measured by OGP

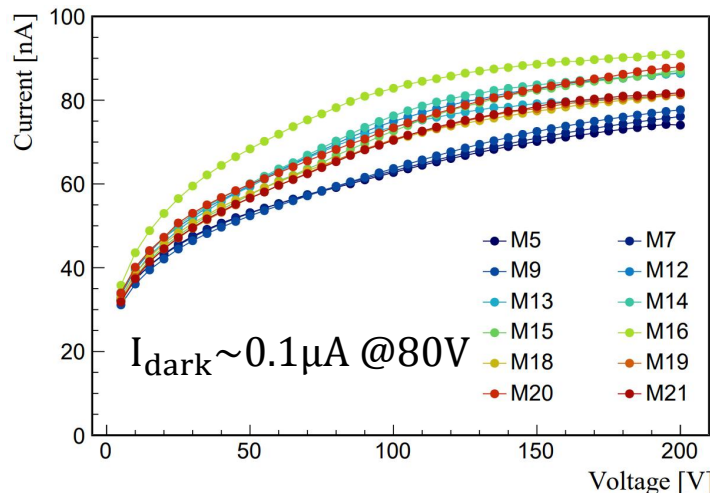
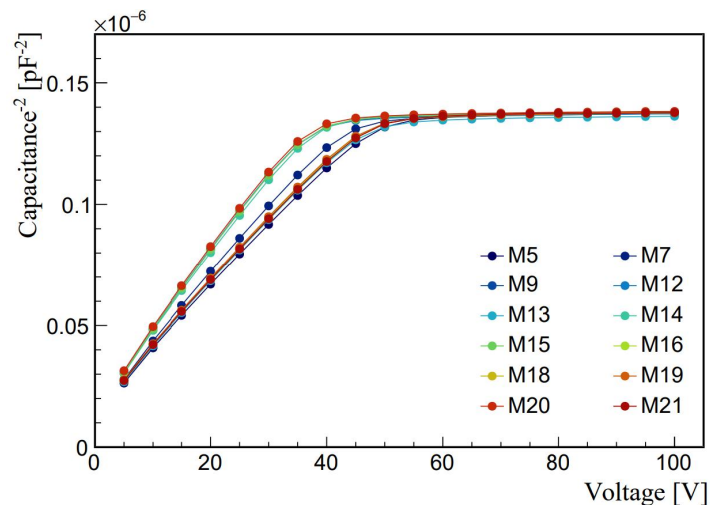


ΔX and $\Delta\theta$ for all sensors

σ for each ladder



Electrical Test (E-Test) Results



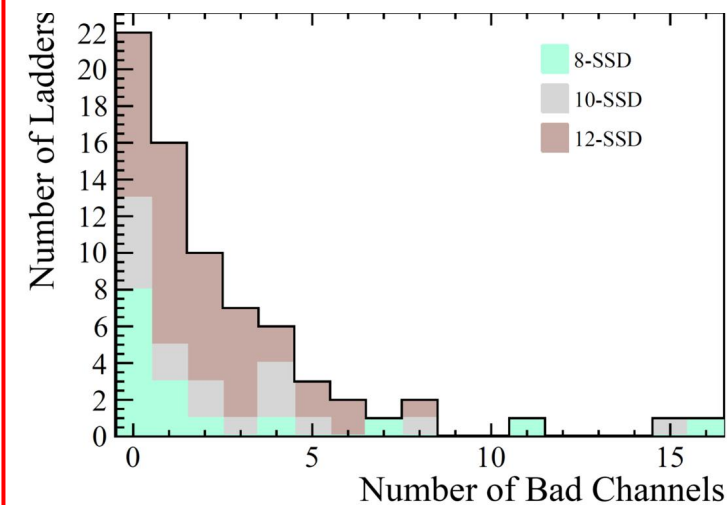
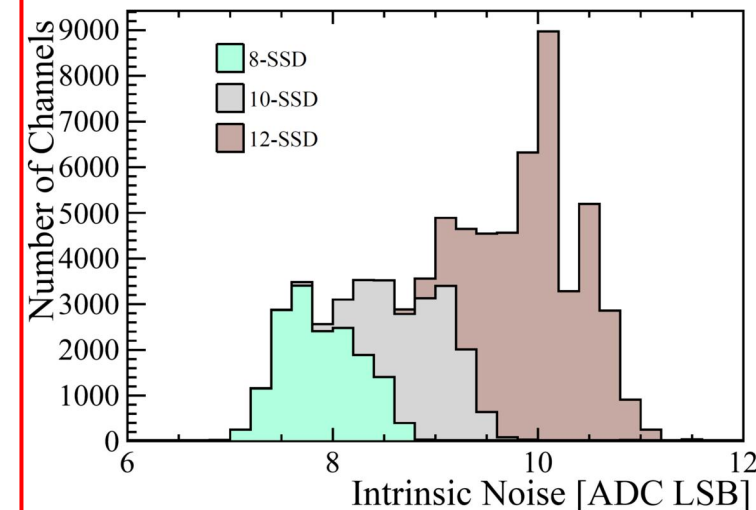
Single sensor CV/IV curve

The maximum expected current of a good ladder at 80V is:

$$I_{dark} = N \times \underset{\text{Sensor}}{0.1} + \underset{\text{LEF}}{0.3} (\mu A)$$

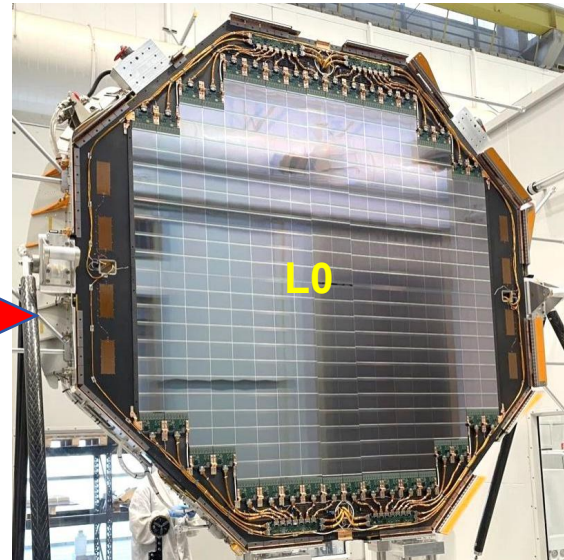
I_{dark} tested of all ladders are below $2 \mu A$

- Average noise for 12-sensor ladder is about 10 LSB, while the MPV of MIP signal spectrum is about 60 LSB
- Only 173 bad channels, accounting for 0.23% of all channels ~78k



Noise and bad channels of all ladders

Process of L0



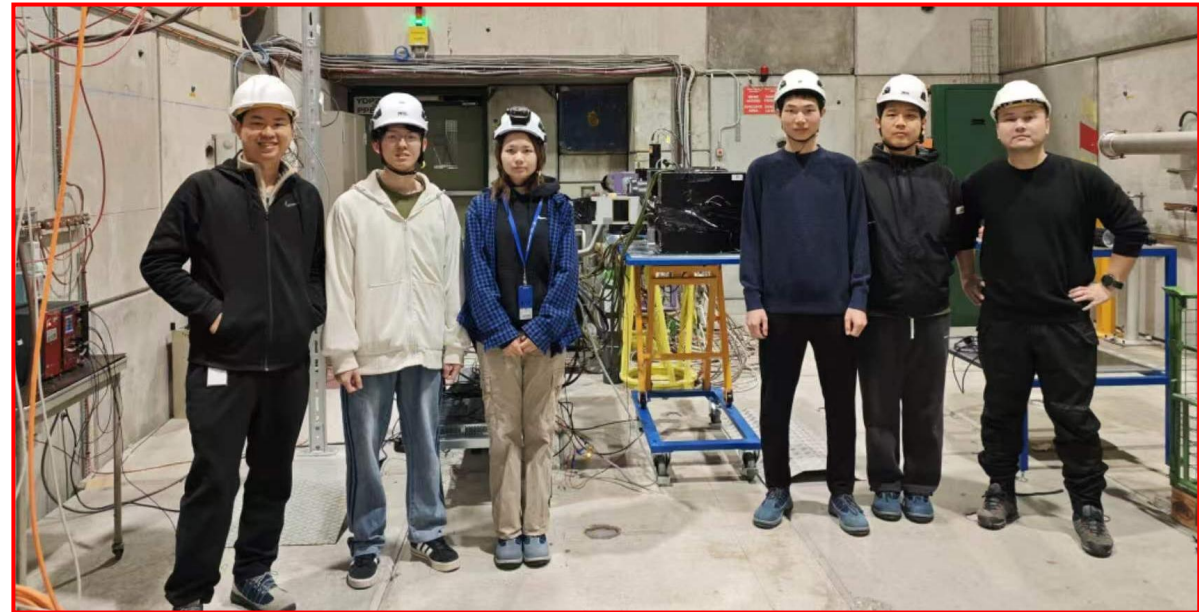
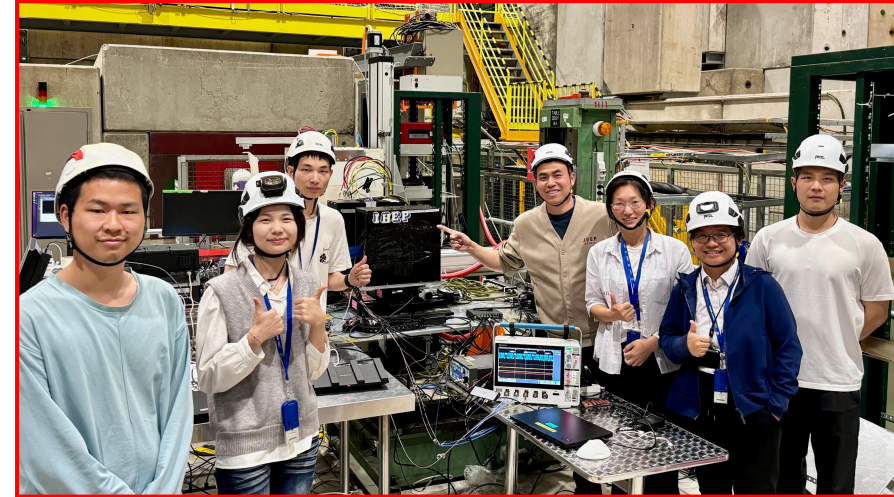
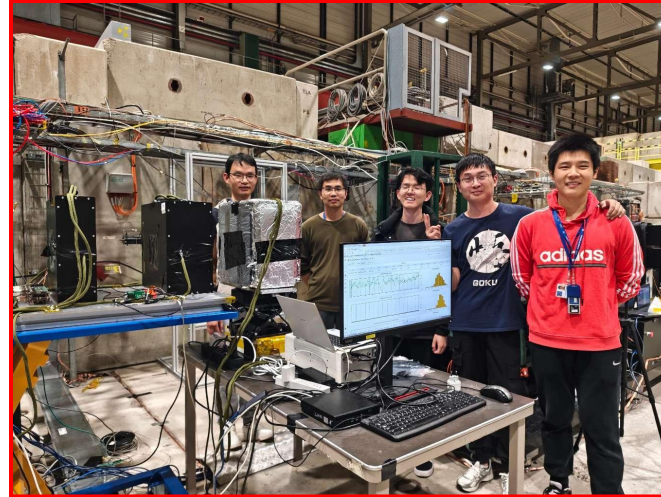
- Jan – Sep 2024:
Construction and E-tests of all ladders
- Sep 2024 – Apr 2025:
Integration and E-tests of 8 QLs
- Sep 2025:
Full-layer integration of L0 completed



Beam Tests

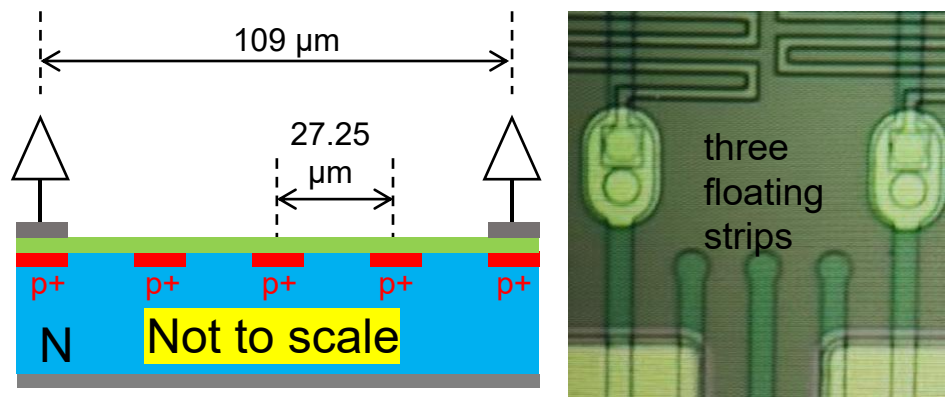
Time			Beam type and site
Jul	11-26	2023	Electron at IHEP
Aug	17-23	2023	Proton and muon at CERN
Oct	24-30	2023	Ion at CERN
Jan	11-25	2024	Electron at IHEP
May	08-29	2024	Muon at CERN
Nov	04-14	2024	Ion at CERN
Aug	15-29	2025	Electron at CERN
Nov	07-25	2025	Ion at CERN
May	08-24	2026	Ion at CERN
Jul	07-26	2026	Ion at CERN

From 2023 to 2026, Many beam tests were performed to study the performance of sensor and ladder





Performance of sensor



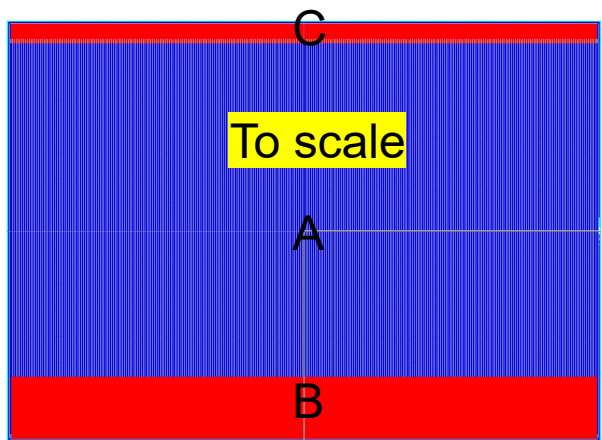
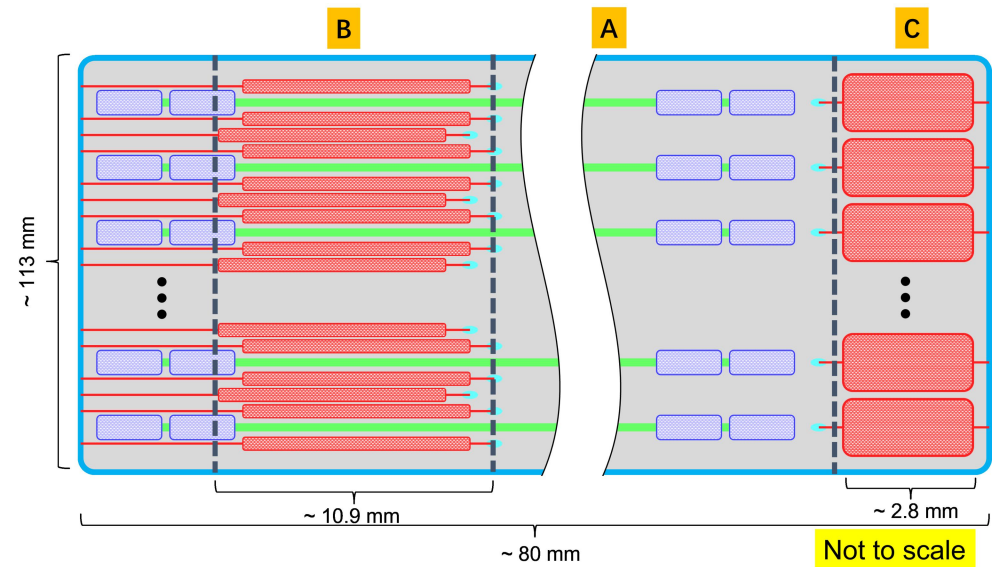
Basic structure of sensor

- p^+ in n type, AC coupled to readout pad
- Pitch of readout channels is 109 μm
- Three floating strips between two adjacent readout channels

Floating strips can enhance charge sharing and thus improve the spatial resolution performance

Three regions of sensor

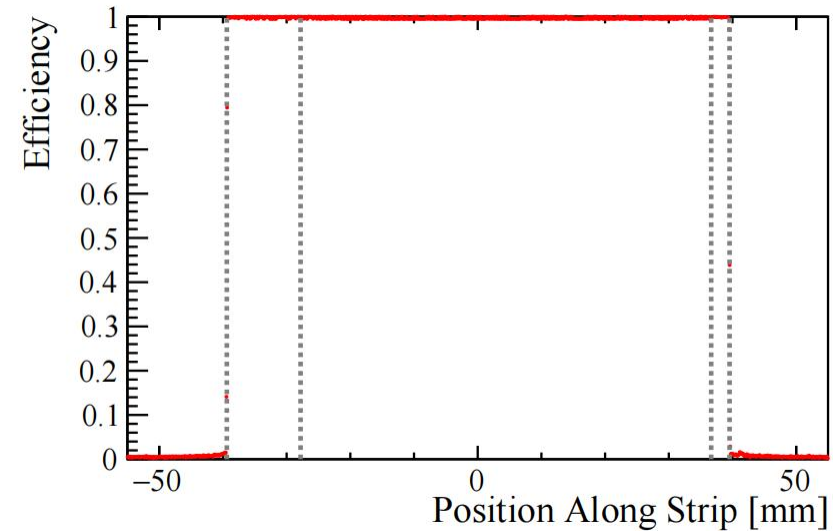
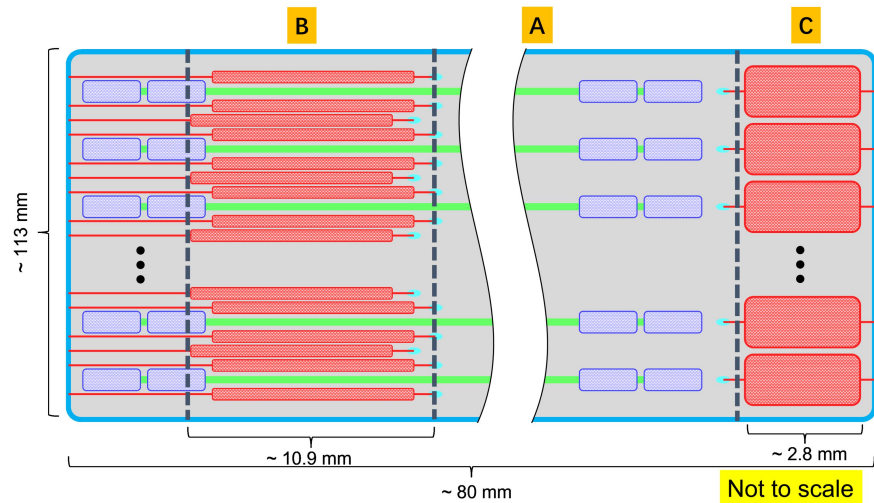
- A: with three floating strips and without bias resistors
- B: with three floating strips and their bias resistors
- C: without floating strips and with bias resistors for readout strips



Region	Bias resistor	Floating strips
A	×	√
B	√	√
C	√	×



Performance of sensor



The detection efficiency of three regions $\sim 99.8\%$

- The bias resistors located between two aluminum read out strips do not affect the efficiency
- The floating strips do not lead to a reduction in detection efficiency

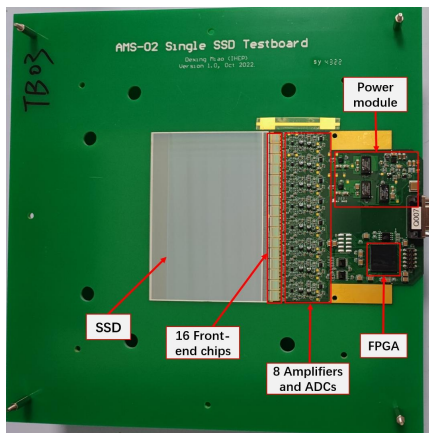
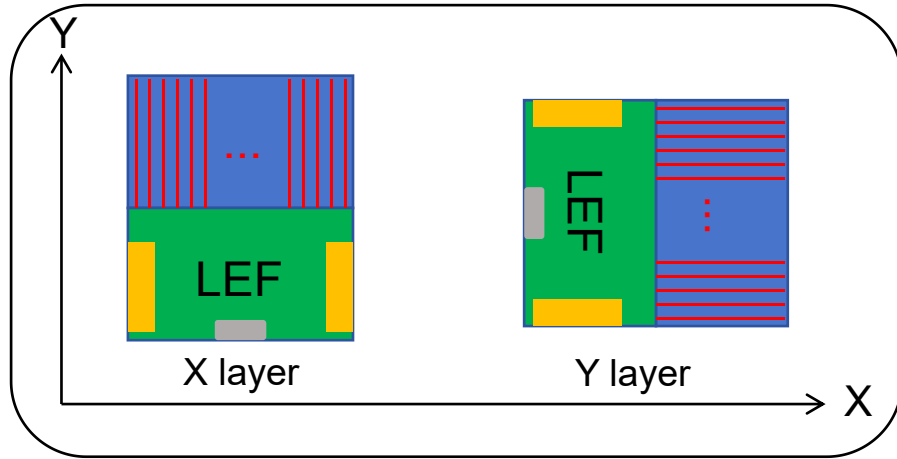
Spatial resolution for A/B $\sim 7.2 \mu\text{m}$, for C $\sim 15.2 \mu\text{m}$

- The floating strips improve the spatial resolution performance

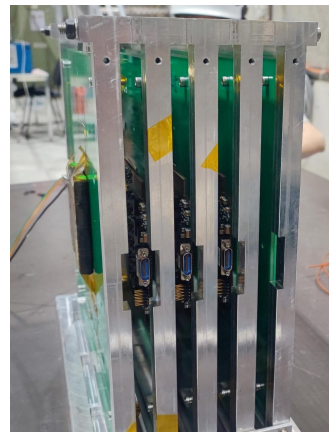


Application: Beam Monitor

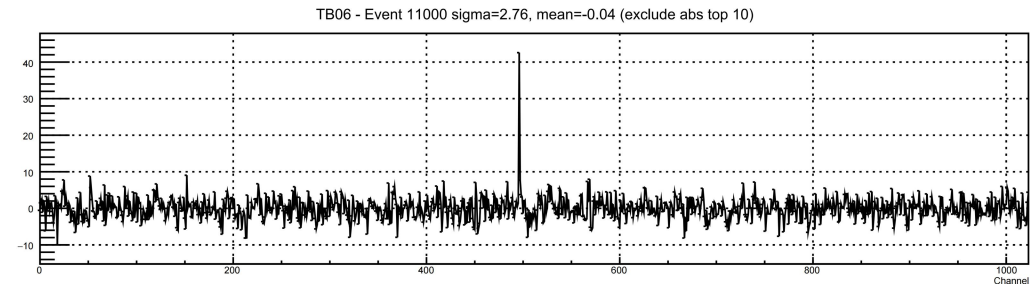
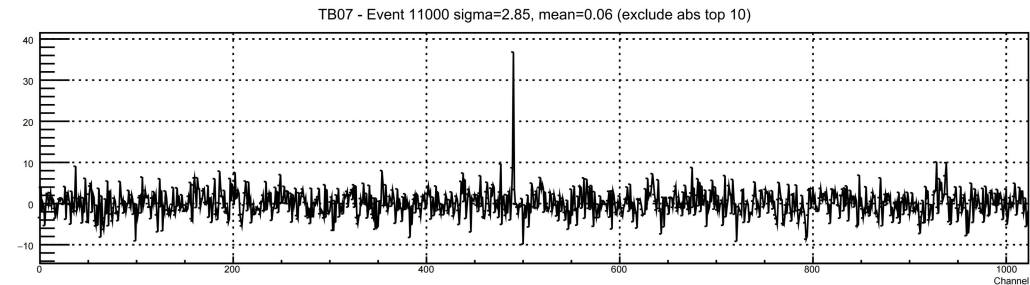
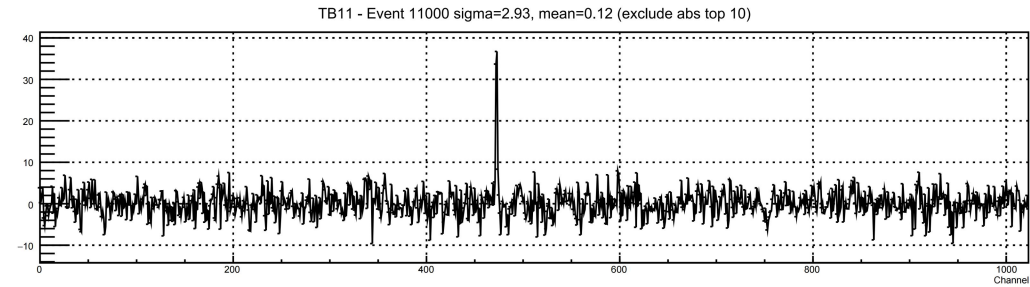
- An SSD sensor and an LEF form a TB, several TBs in X/Y direction form a BM
- BM can reconstruct 3D tracks



A Test Board (TB)



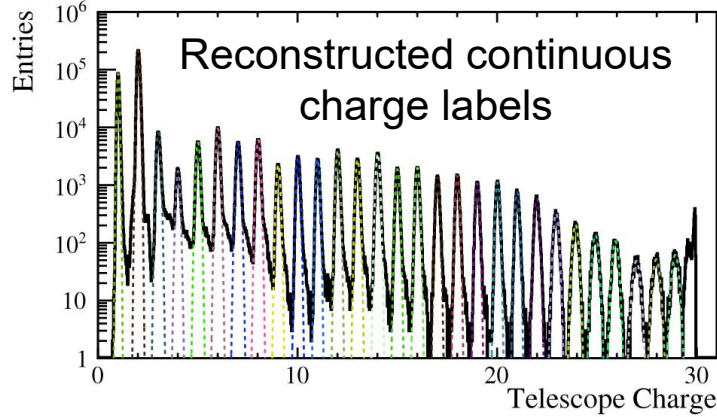
Beam Monitor (BM) of
3X+3Y layers



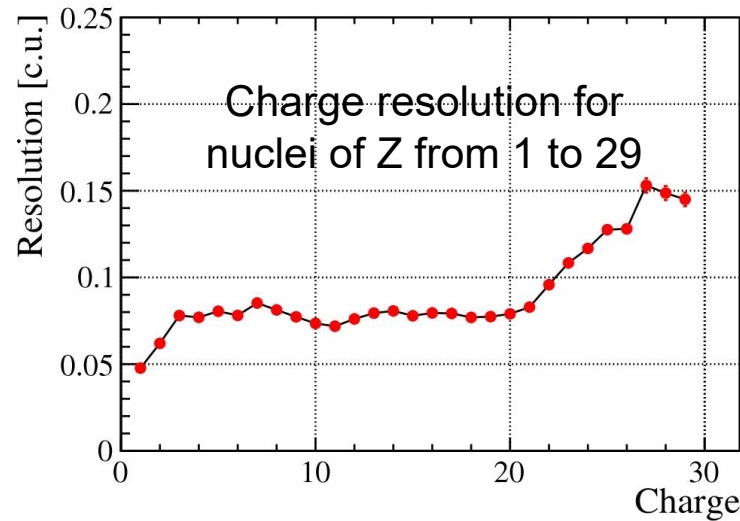
A typical minimum ionizing particle (MIP) event response for 3 layers. The horizontal axis represents the 1024 channels of a TB, and the vertical axis shows the signal amplitude in ADC LSB



Charge Reconstruction for Heavy Nuclei



(a)

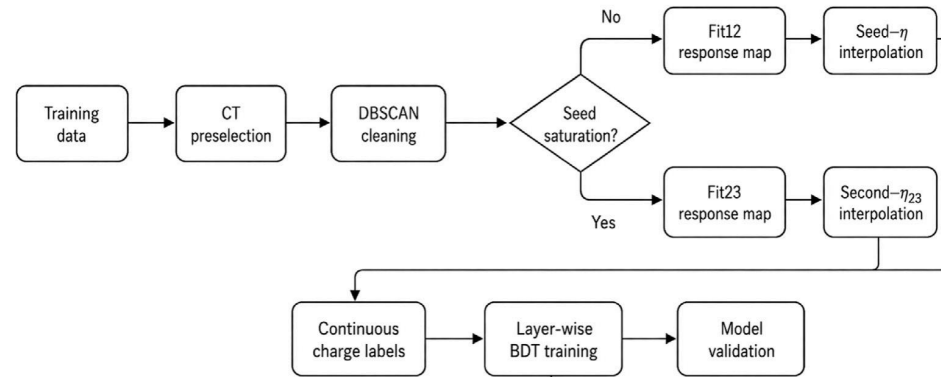


*We thank INFN, Florence for providing Charge
Tagger data used for event pre-selection*

In addition to track reconstruction for MIPs, BM can reconstruct charge for heavy nuclei, thus performing PID

- Use BDT as a core algorithm, a charge resolution better than **0.16** charge units is achieved for heavy nuclei with Z from 1 to 29, by a $5X+4Y$ BM

Training-label construction

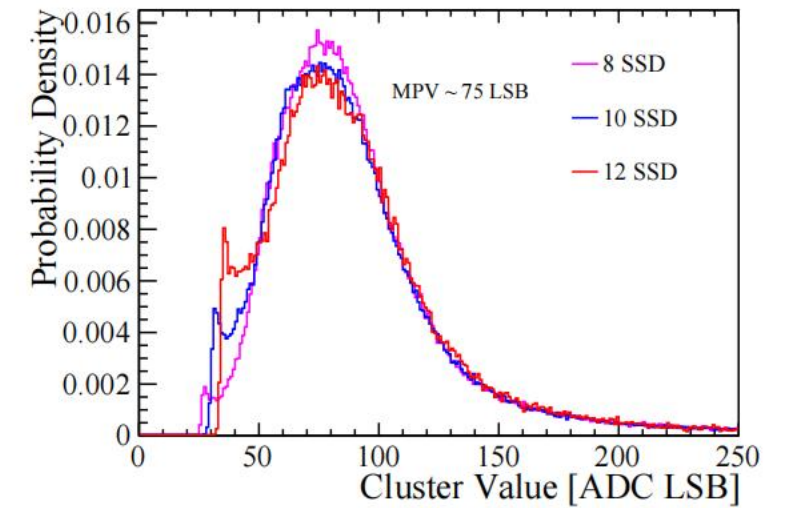
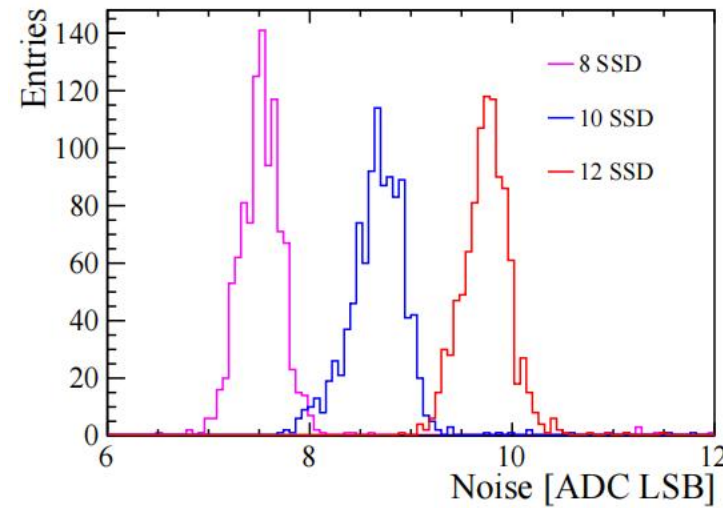
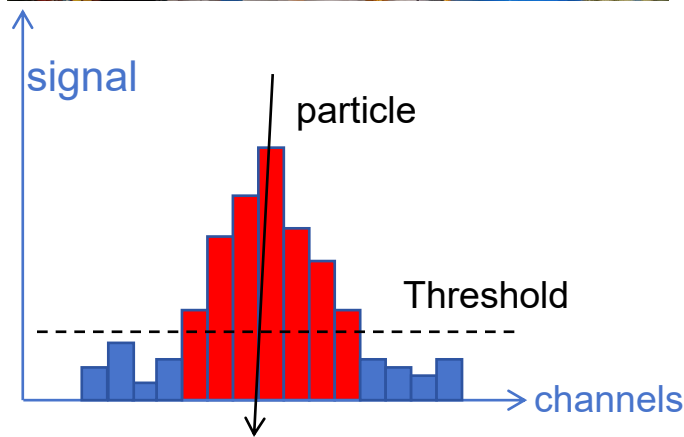
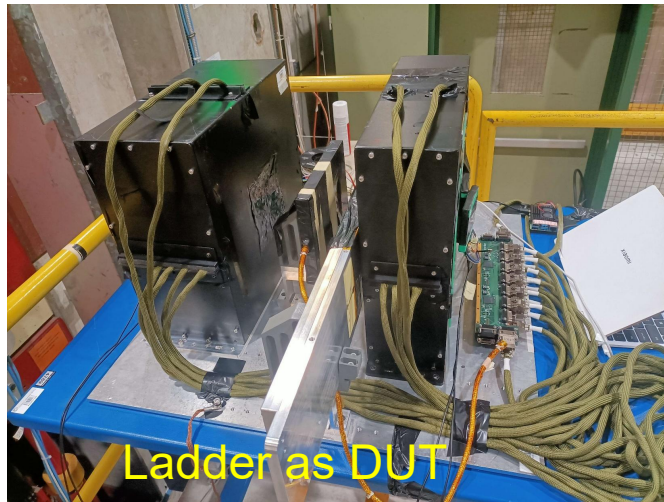


Application to full data





Performance of ladder

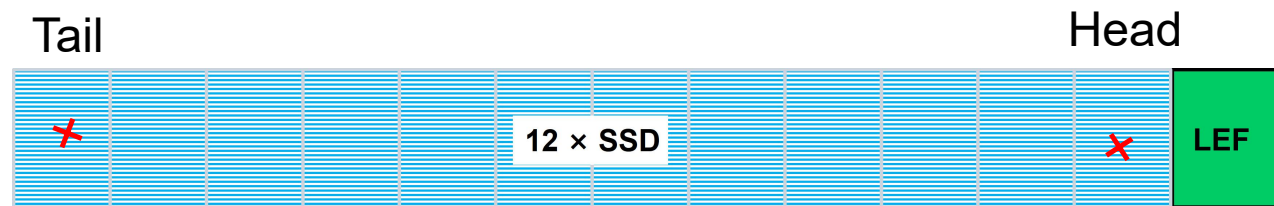


For a ladder with 8/10/12 sensors, the average noise is 7.6/8.7/9.7 LSB respectively

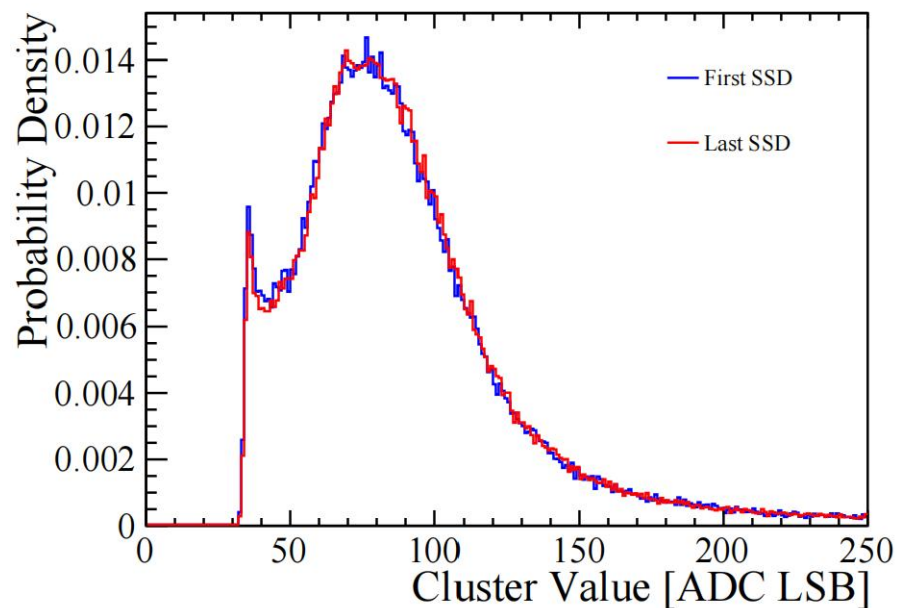
- The MPV of MIPs cluster value is about 75 LSB
- The corresponding spatial resolution for normal incident is 9.5/10.6/11.4 μm respectively



Performance of ladder



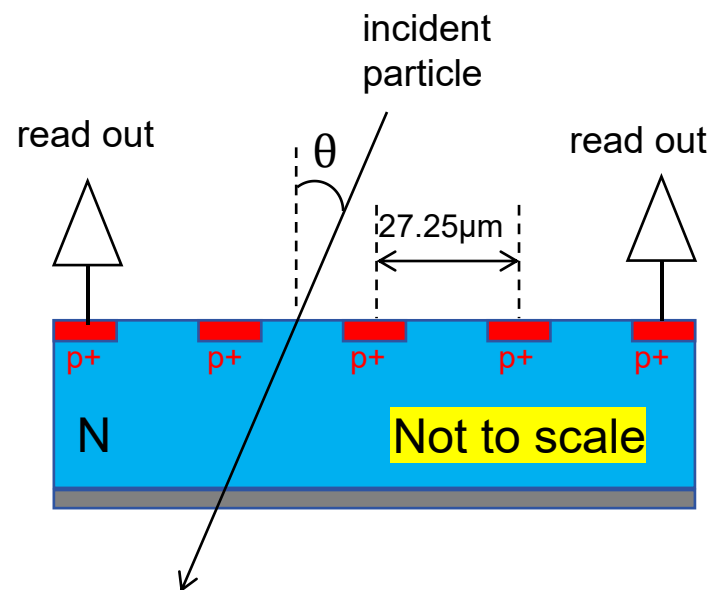
Degrade of performance in the tail ?



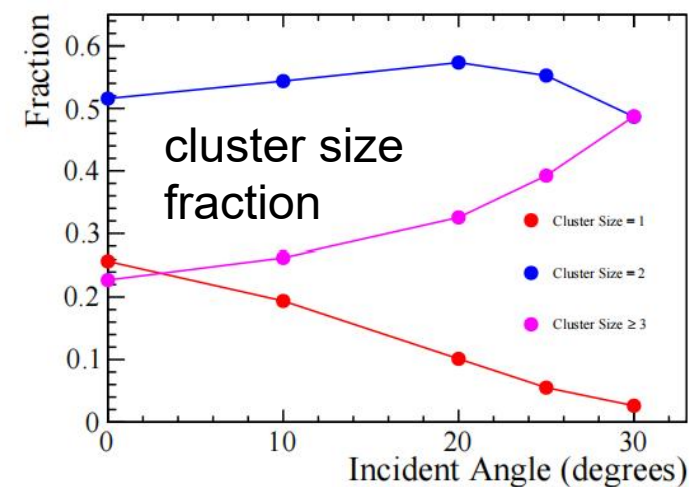
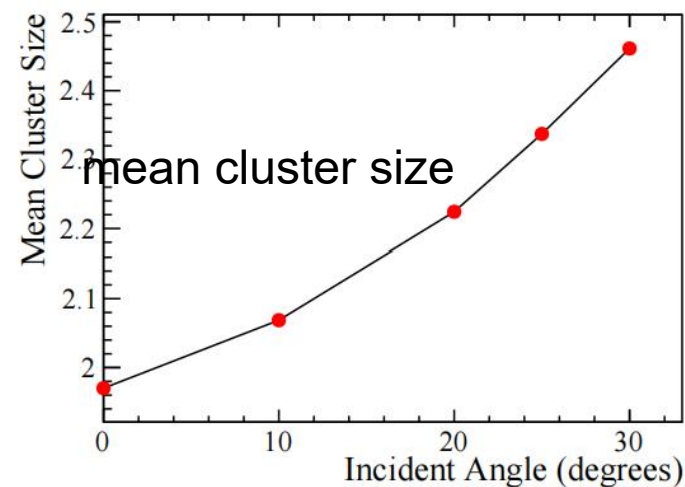
- Cluster value distributions for head-end and tail-end sensors are nearly identical, indicating there is no appreciable signal loss during the transportation to LEF



Performance of ladder

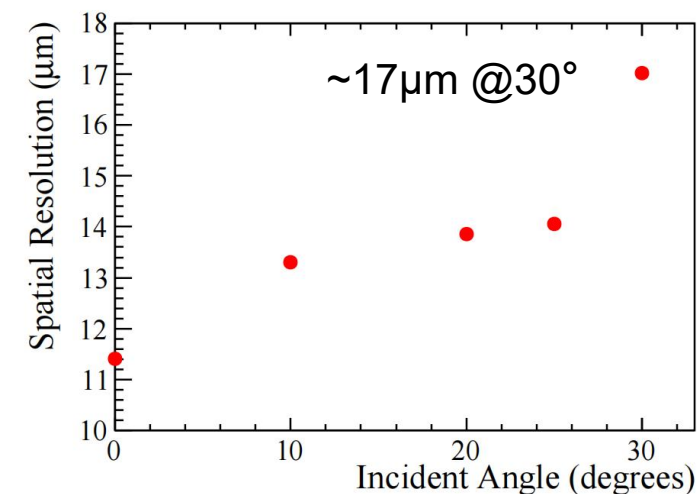


In practice, cosmic rays arrive from all directions, performance when particle impacting at different angles is important

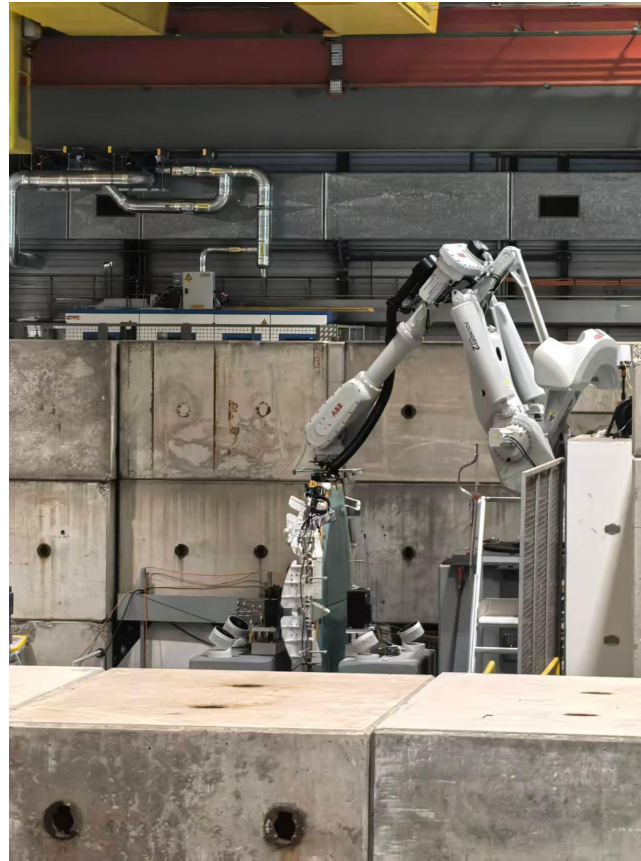
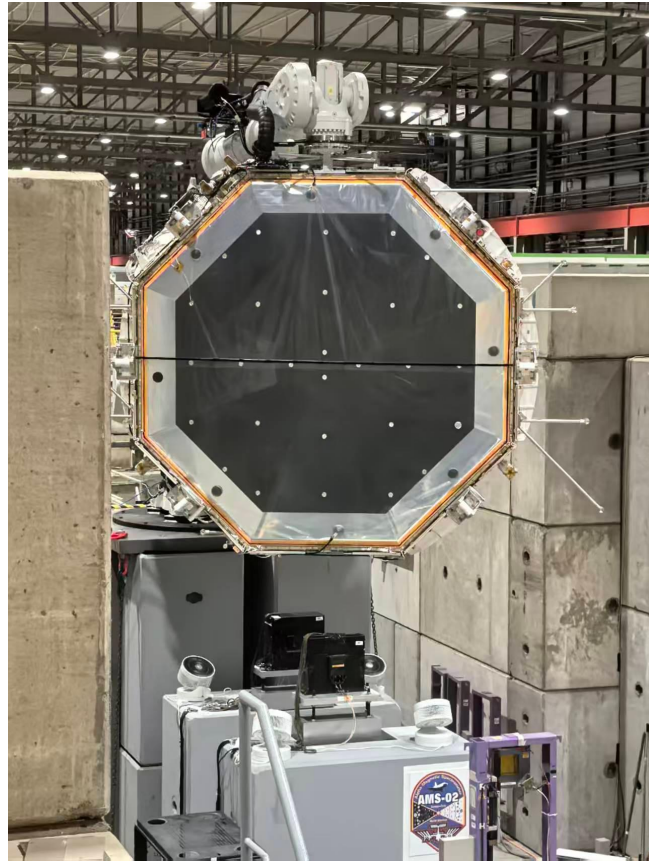


The resolution increases as the incident angle increases

- Mainly due to the larger fraction of clusters whose sizes are > 2
- Clusters whose sizes is > 2 have worse hit reconstruction precision than those whose sizes = 2



Beam Test of L0



The L0 alignment beam test was completed at the end of July, 2026

- Two BMs (3X+3Y) provided tracking information for L0
- Data analysis is ongoing

Summary



All ladders assembled and tested:

- Overall assembly precision: $3.4\ \mu\text{m}$
- Leakage current $< 2\ \mu\text{A}$

Sensor performance

- Sensitive area detection efficiency $\sim 99.8\%$
- Main region spatial resolution: $7.2\ \mu\text{m}$
- Charge resolution $< 0.16\ \text{c.u.}$ ($Z = 1-29$)

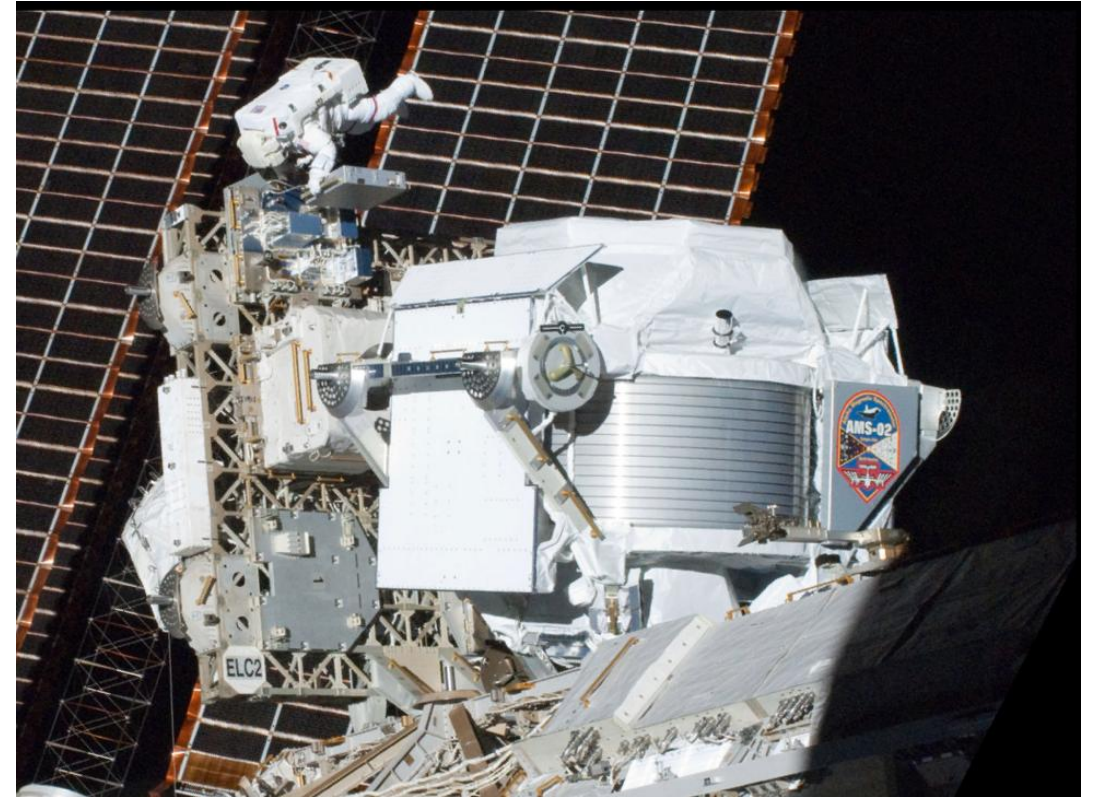
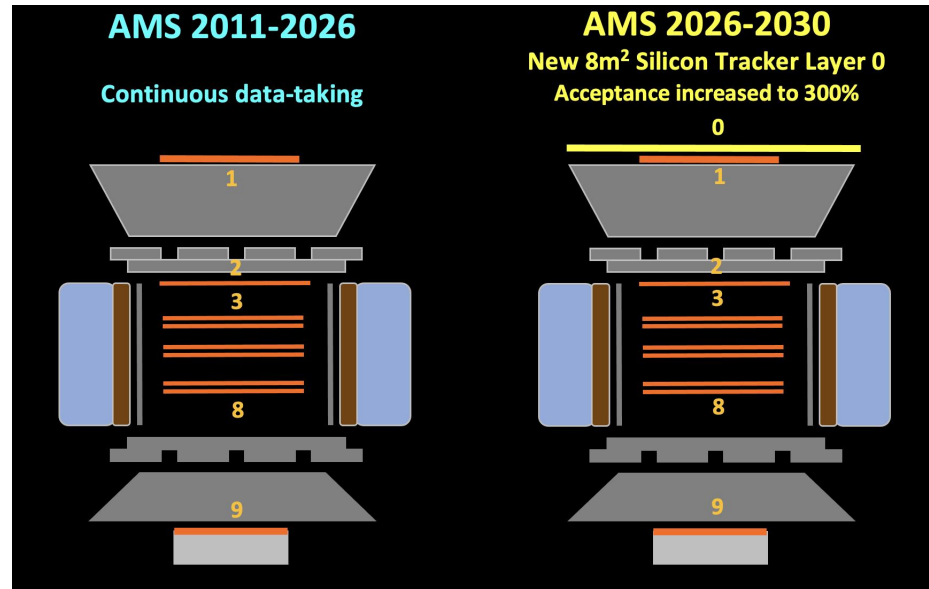
Ladder performance

- 8-/10-/12-sensor ladder resolution: $9.5 / 10.6 / 11.4\ \mu\text{m}$
- Spatial resolution degrades at large incident angles: $\sim 17\ \mu\text{m}$ @ 30°
- Long distance signal loss on ladders is negligible

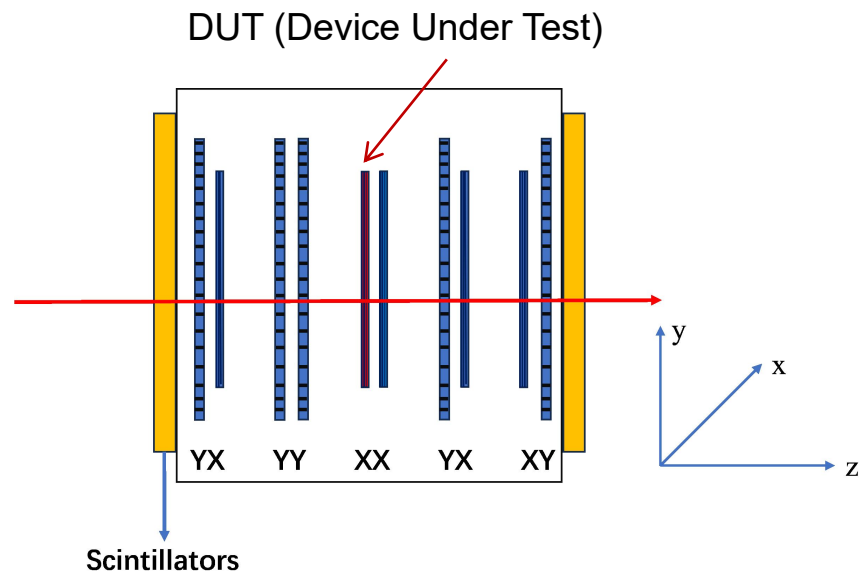


Thank you for your attention

BACK UP



Tracking Performance of sensor



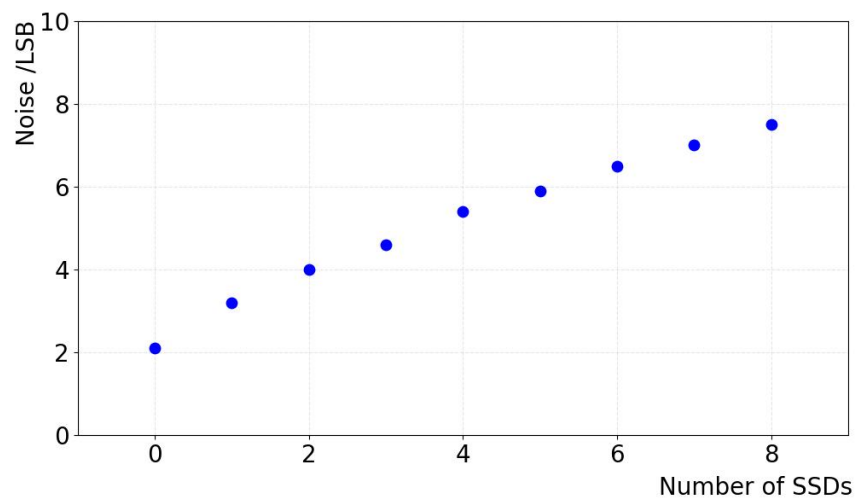
Use one X-layer as DUT, other X-layers act as a BM, the relation:

$$\sigma_{\text{meas}} = \sqrt{\sigma_{\text{BM}}^2 + \sigma_{\text{DUT}}^2}$$

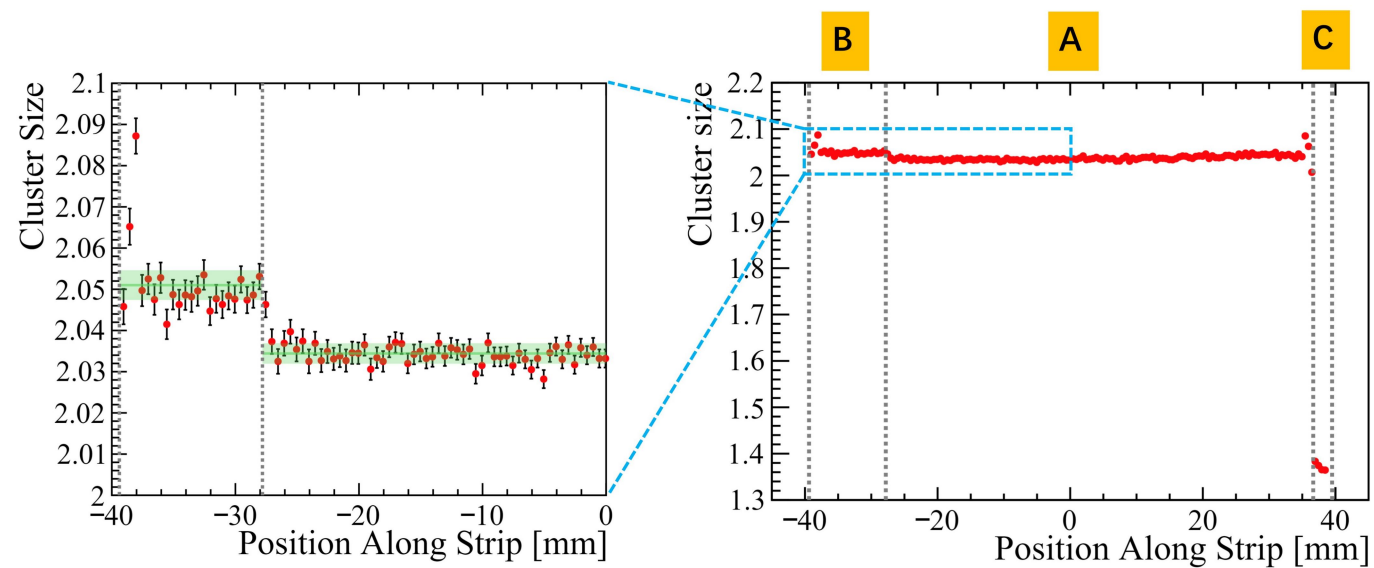
For the setup, $\sigma_{\text{BM}} = 0.5 \times \sigma_{\text{DUT}}$

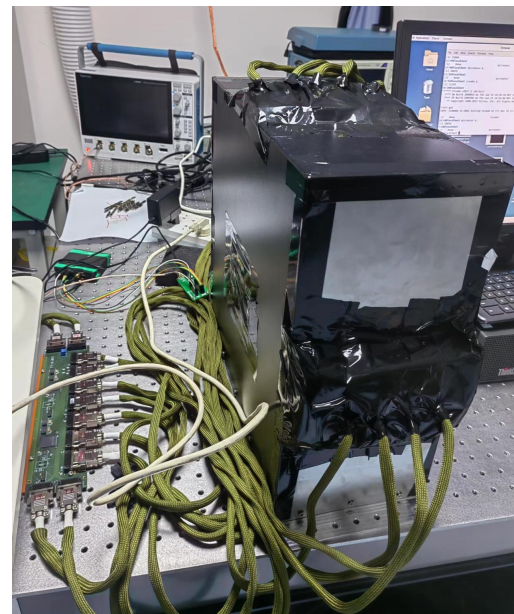


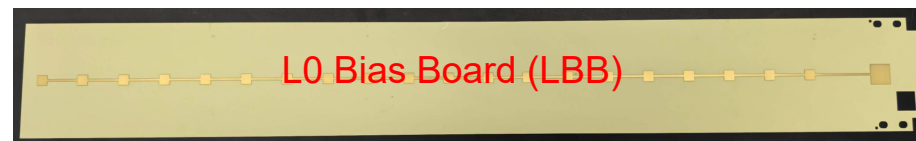
- Gantry head moves in X, Y and Z directions, and the rotary table at the end rotates in X-Y plane
- Linear axis positioning accuracy better than 1 μm over 1 meter, and rotational accuracy better than 0.001°



Noise increases as sensor numbers increase



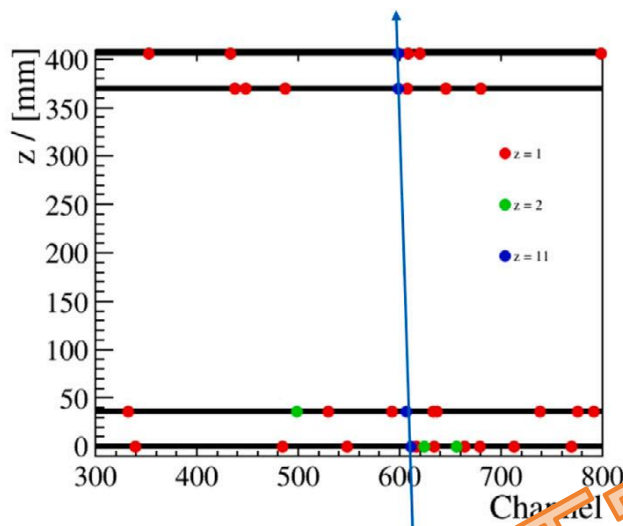
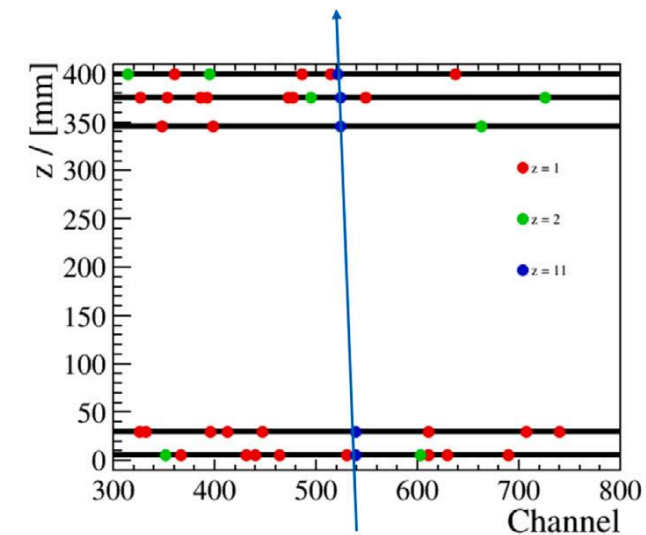




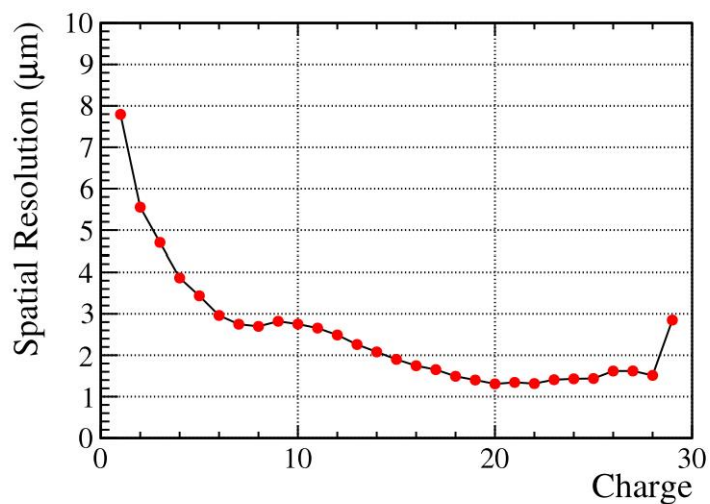
glass-reinforced epoxy laminate material (FR-4)



Tracking Performance for Heavy Nuclei



Based on charge reconstruction, the spatial resolution for heavy nuclei of different Z can be investigated



As Z increases, the deposited energy rises, leading to an overall improvement in resolution

Excessive signal induces saturation in readout channels, so the resolution degrades for $Z > 20$



Title: The upgrade of the silicon tracking detector at AMS-02

Abstract:

The Alpha Magnetic Spectrometer (AMS-02) is currently the only magnetic spectrometer operating in space and has provided unique opportunities to explore fundamental questions, including the origin of antimatter and the nature of dark matter. Motivated by its outstanding physics performance and scientific potential, AMS is expected to continue operation to 2030s with a major detector upgrade. The upgrade of the AMS silicon tracker introduces an additional layer of silicon micro-strip detectors outside the existing tracking system, requiring ultra-large-area, high-precision, and low-mass detector modules suitable for long-term space operation.

This project aims to develop 96 cm-long silicon micro-strip detector modules with an alignment accuracy better than 10 μm . To address the challenges associated with the assembly of large-scale precision silicon detectors, a dedicated high-precision gantry-based assembly system and corresponding alignment techniques have been developed. The project has successfully realized space-qualified silicon micro-strip detector modules featuring unprecedented scale and micron-level assembly precision. This report will present the latest progress and key technologies in the design, precision assembly, integration, and performance validation of the silicon micro-strip tracker upgrade for the AMS experiment.