A Beam Monitor For the AMS Layer0 Tracker Upgrade

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on behalf of the AMS L0 Team

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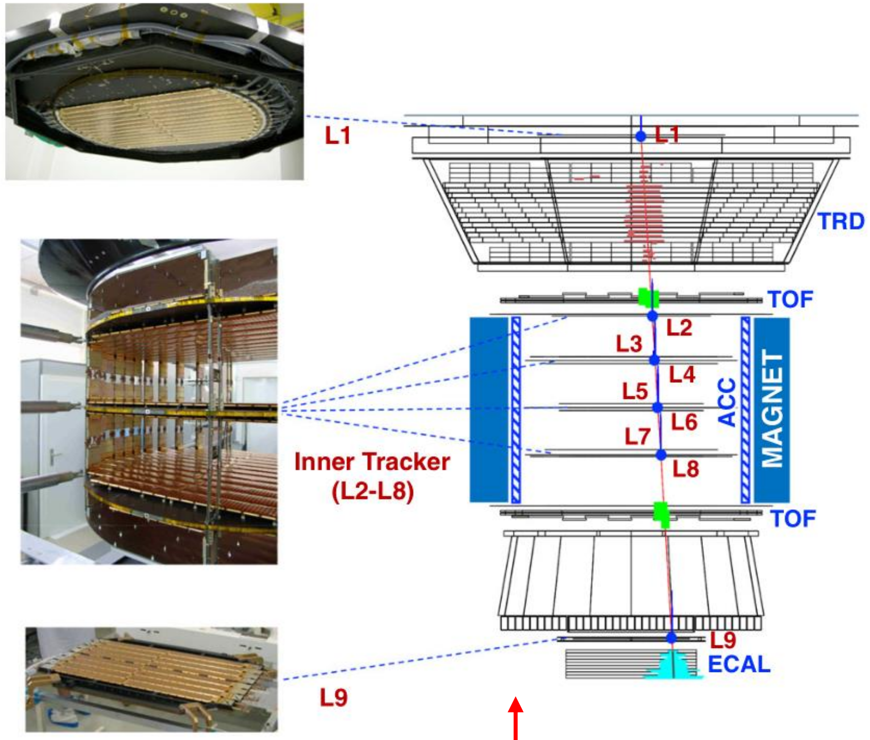
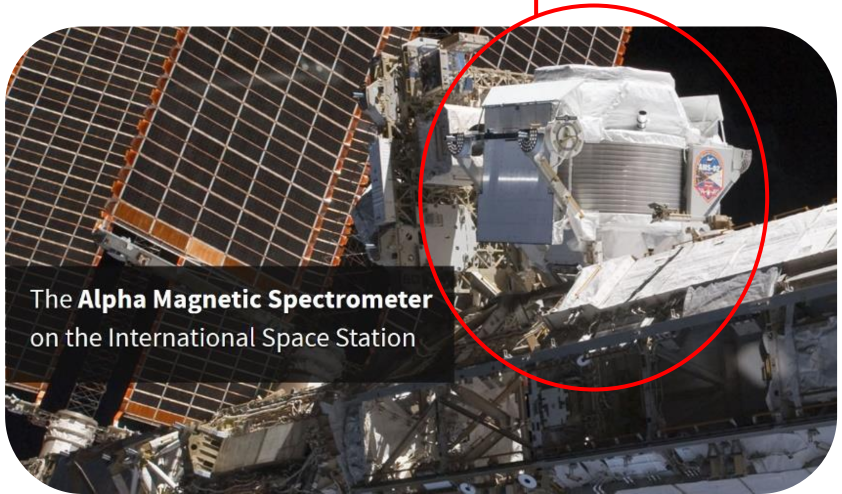
Outline

- Brief introduction of the AMS Layer-0 Tracker upgrade
- Special design of the silicon strip detector
- The telescope for beam tests
- Test beam study on spatial resolution and sensor detection efficiency
- Summary

AMS-02 and the Tracker System

- Launched to the internation space station ISS and installed on May 19, 2011, with total weight **7T**
- Taking data for the whole life of the ISS
- Track deflection within its magnetic field => unique capability of distinguishing matter from anti-matter
- 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
- It contains 9 layers of double side silicon strip trackers
  - Total sensitive area ~6.4m^2

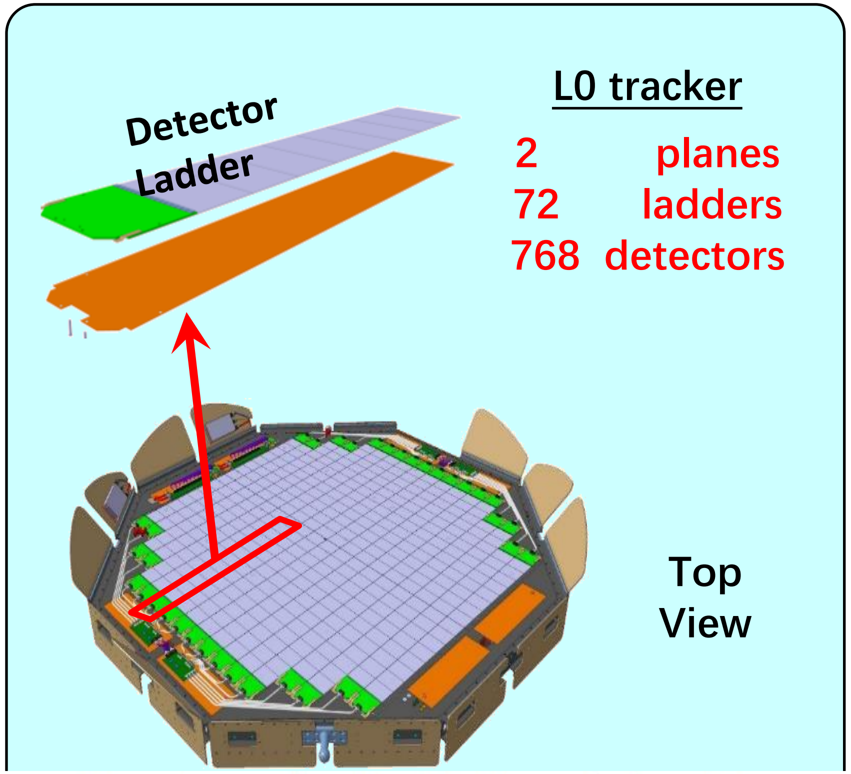




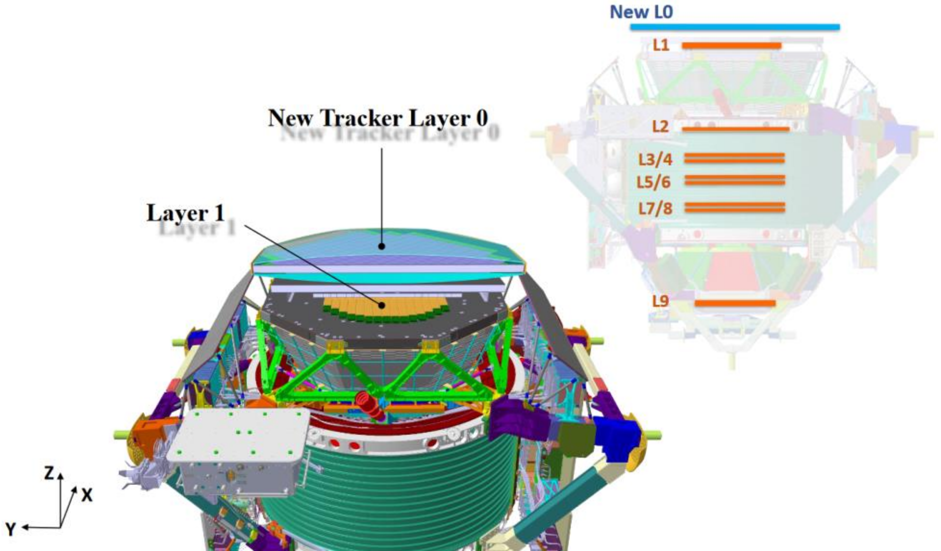
AMS-02 Layer0 Tracker

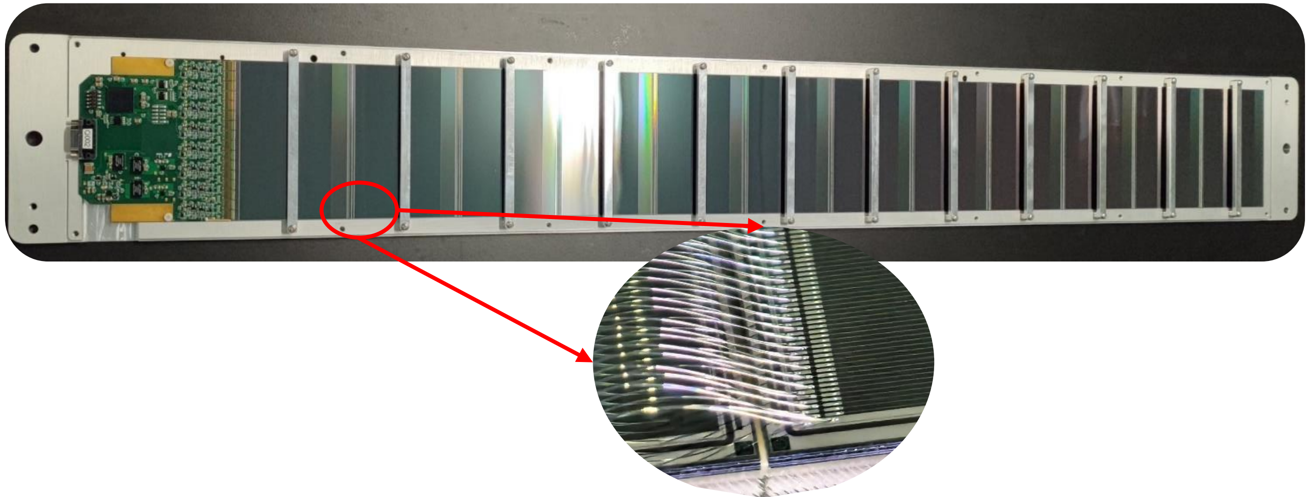
- Will add a new silicon strip tracker(Layer0) on the top of AMS-02
  - Larger sensitive area(~7m^2) to increase cosmic ray acceptance by a factor of 300%
  - Lower material before detectors, better heavy ion detection
  - 2-planes, rotated by 45° with respect to each other, for stereo measurements

- 8/10/12 SSDs are connected in series to form a ladder
  - Large detection area with small electrical power budget
  - Each readout channel corresponds to a very long (~1m) strip
  - Requires high precision placement(<5 um) of the SSDs on the ladder, and precise SSD alignment after assembly with **beam**



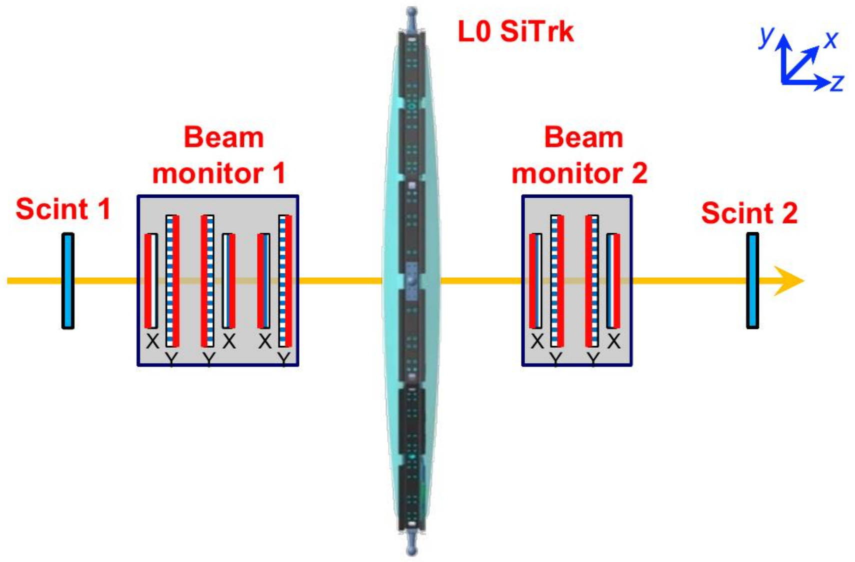
New Layer 0 added to the existing 9 Layers



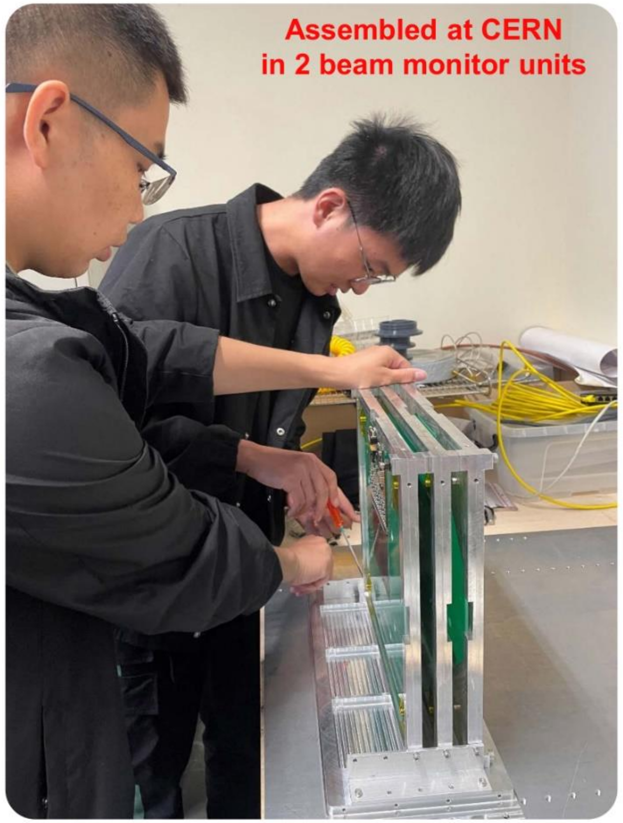


The Beam Monitor for AMS L0 Testbeams

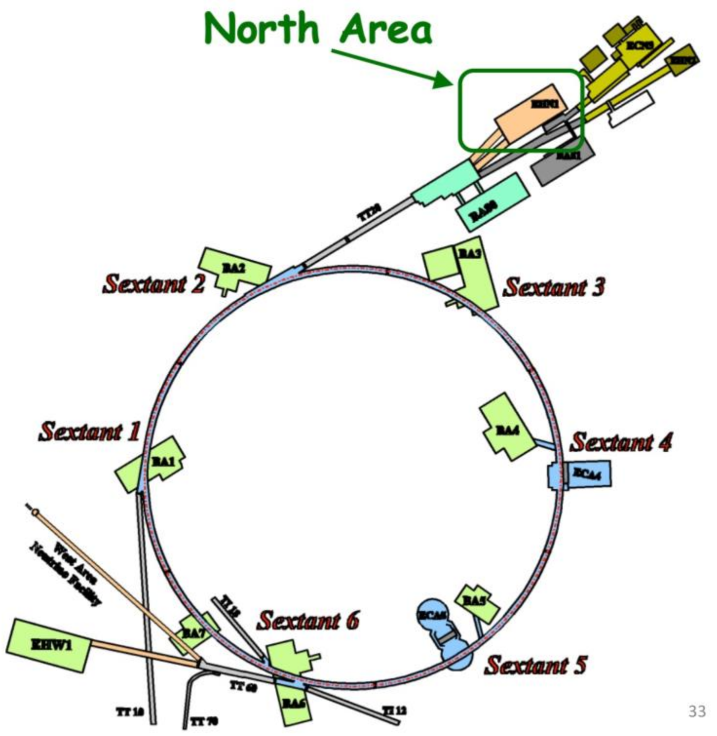
- The AMS L0 needs beam alignment before launching to space
- Produce ≥ 10 beam telescope boards with the same SSD and electronics
- Performed multiple beam tests to study: position resolution, detection efficiency, charge resolution, etc.



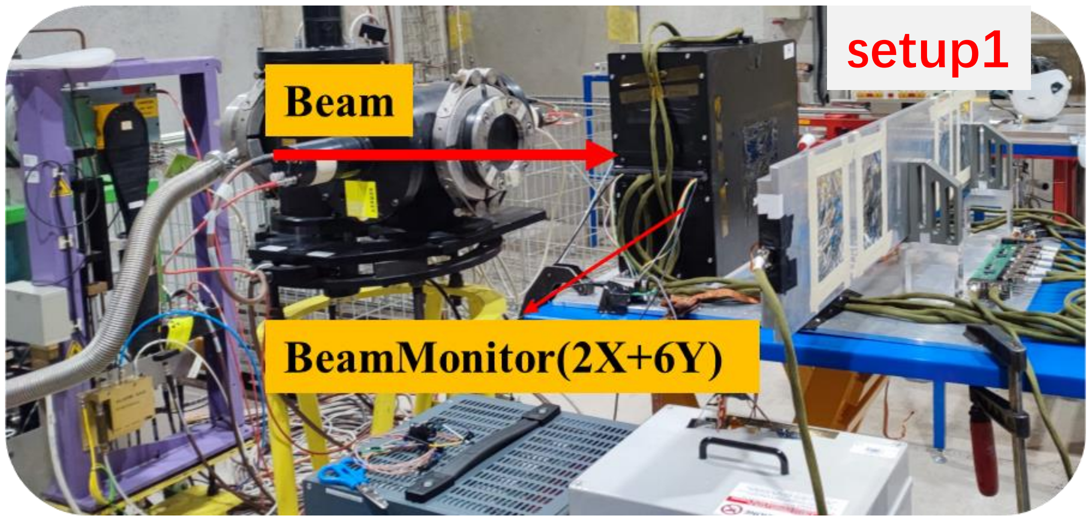
×2 planes in transportation boxes

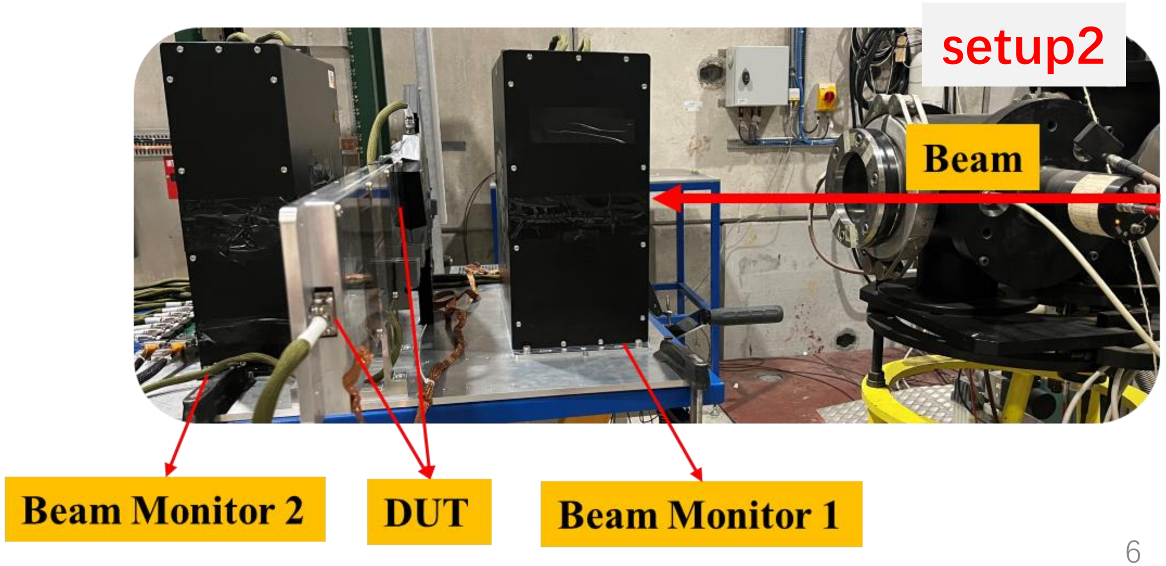


Test Beam @ SPS



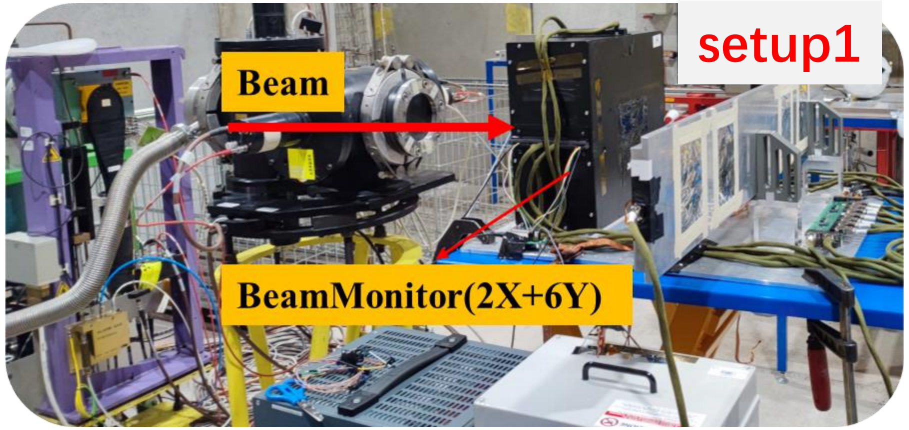
- Performed in Aug 2023 with muon and proton beams to study spatial resolution
- Performed in Oct 2023 with heavy ion beam to study charge resolution
  - Results in the poster presentation by Alessio etc
  - Thanks to the charge tagger detector

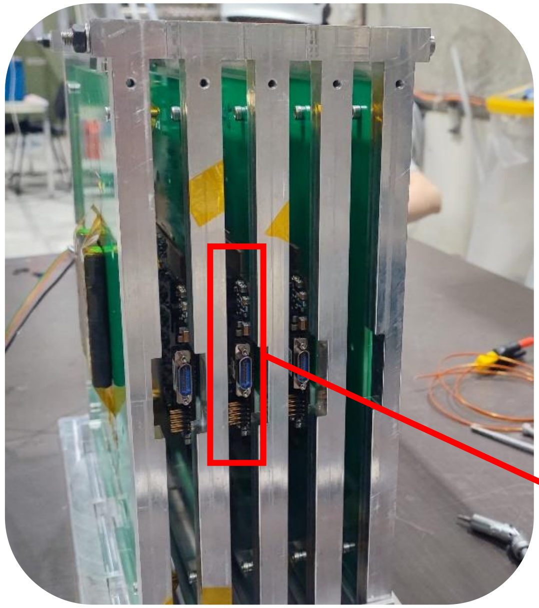


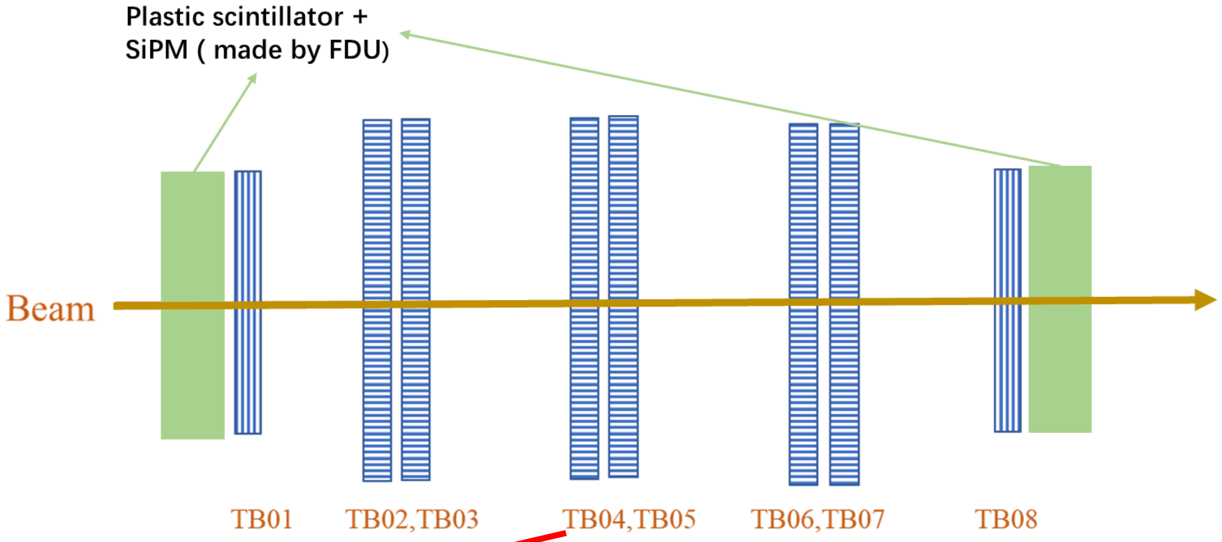


Study of The Beam Monitor

- A setup of 8-plane beam monitor as: X YY YY YY X
  - The 4th plane (Y) as the detector under test (DUT), while others form a telescope
  - Reconstruct 3-D tracks, and fit in the Y-Z plane
- SPS, line H8, ~15 hours beam time
  - Muon Beam @160GeV, ~7M events recorded
  - Proton Beam @180GeV, ~8M events recorded

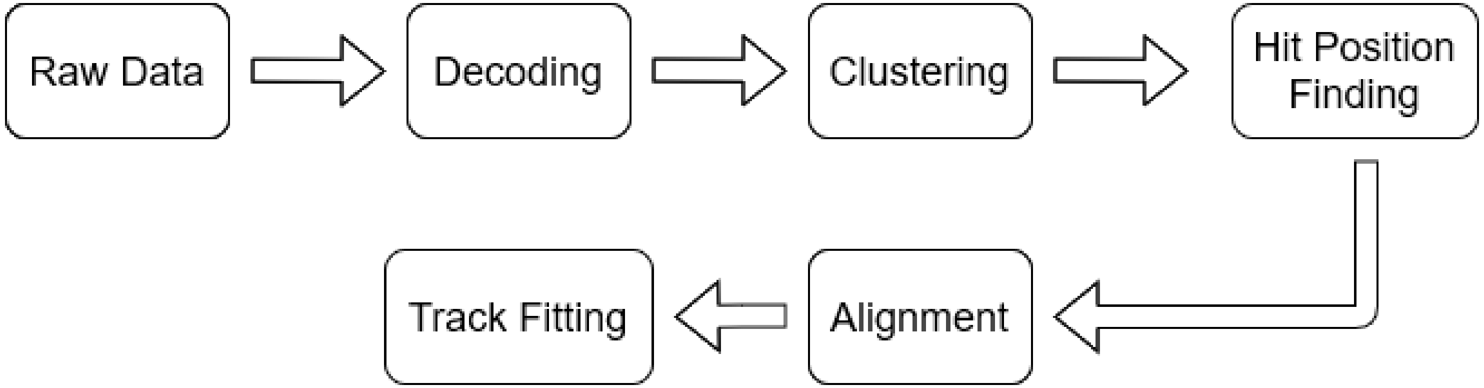






DUT

Beam data analysis process



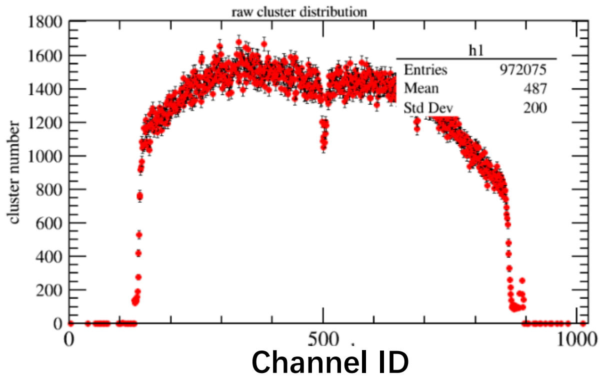
- Decode ADC value from binary raw data
- Form clustering hits after pedestal and common noise subtraction
- Reconstruct hit position with non-linear eta algorithm
- Reconstruct 3-D tracks and fit in the Y-Z plane
- We use MILLEPEDE-II method for detector alignment and GeneralBrokenLines(GBL) package for track fitting

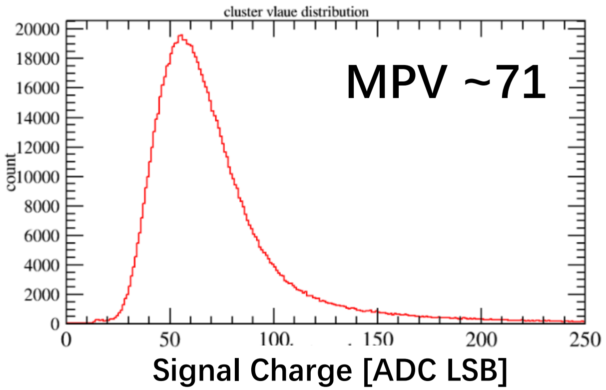
Millepede-II V04-16-00

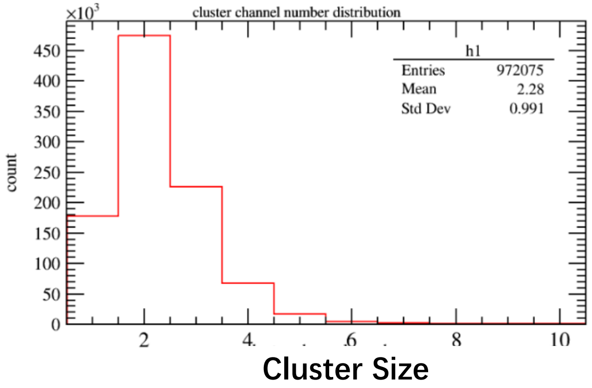
Thanks for the significant development !

Hit Map and Clustering

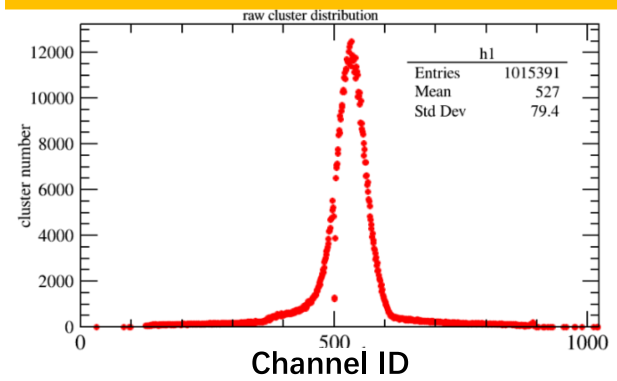
Muon@160 GeV, wide beam

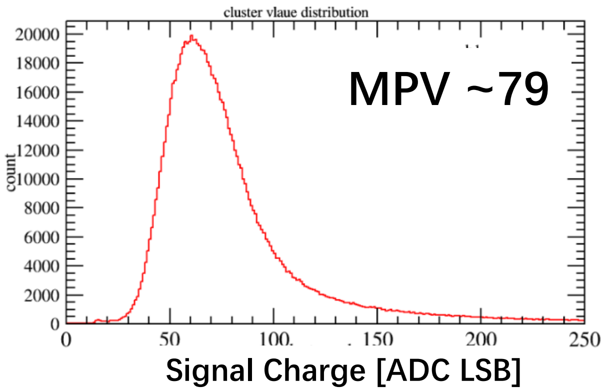


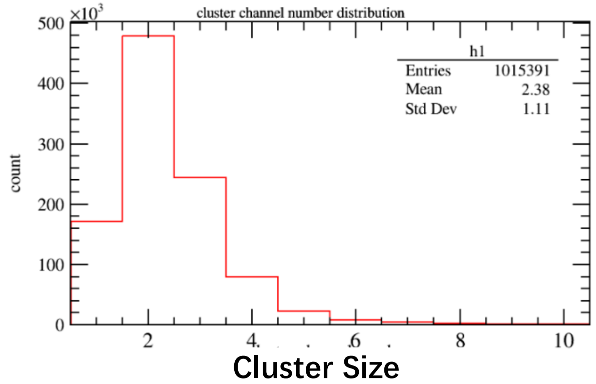




Proton@180 GeV, narrow beam





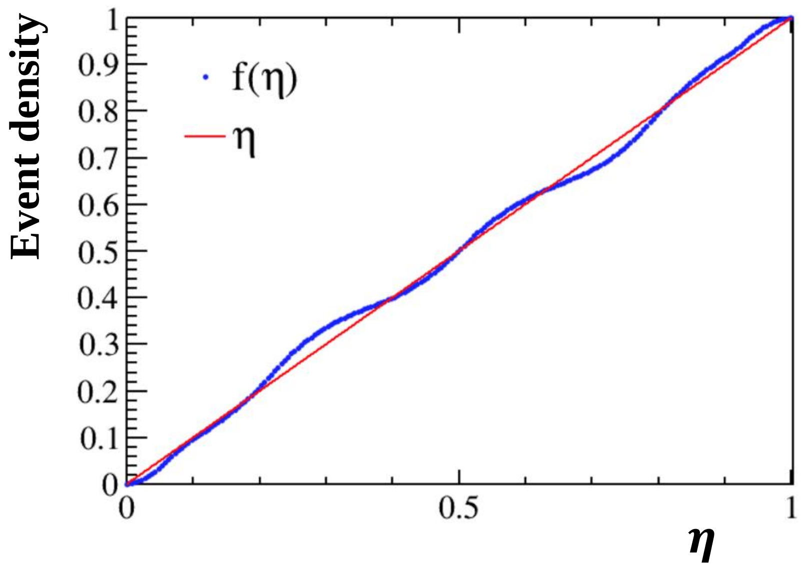


- Form hit clusters with $seed\ threshold = 5\sigma, side\ threshold = 2\sigma$, where the noise σ~3 [ADC LSB]
  - 1 ADC LSB ~ 86 e^-
- MPV is slightly larger from the proton beam, with similar cluster size, peaking at ~ 2 strips

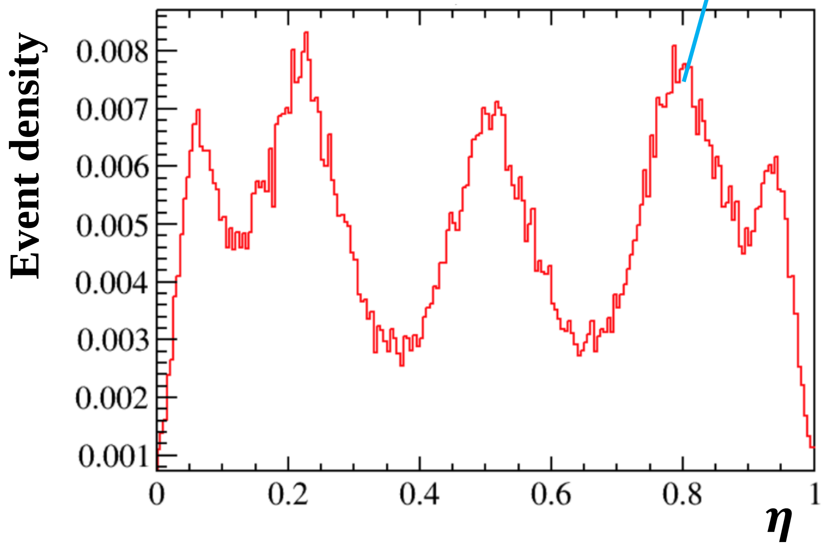
Nonlinear Eta Position Finding

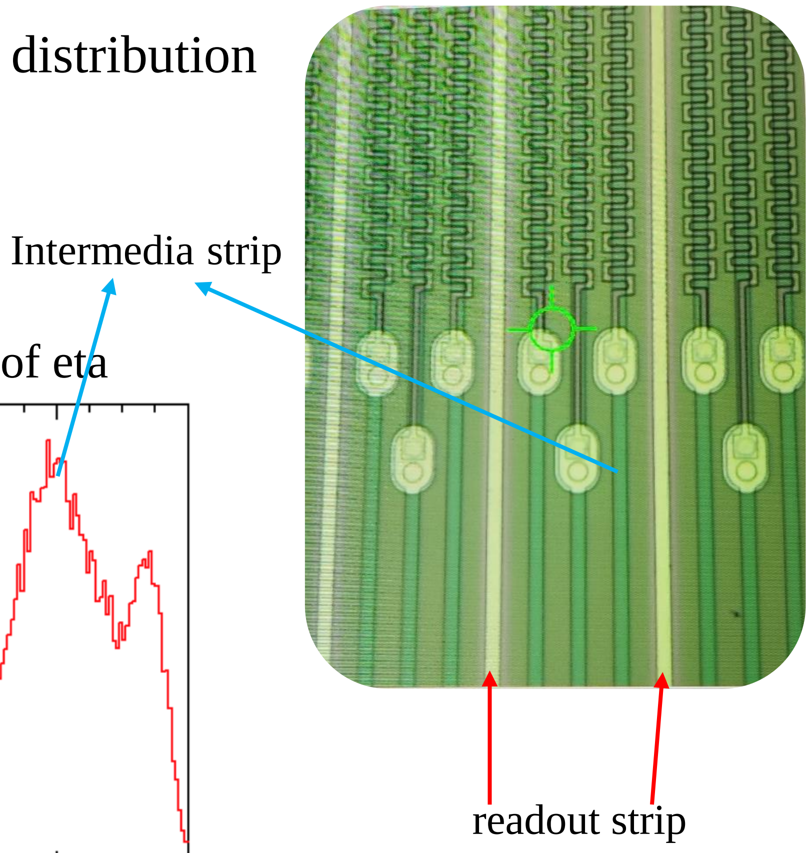
- Eta is defined with 2 adjacent strips of the **highest signals** in a cluster as: $\eta = \frac{A_R}{A_L + A_R}$
- If eta follows a uniform distribution, then the position should be $X_{\mathrm{LIN}} = x_L + P\eta$,P is strip pitch (109um)
- A small correction is applied on the linear calculation, for non-uniform distribution

$$X_\eta = x_L + P f(\eta) \qquad f(\eta) = \int_0^\eta \frac{dN}{d\eta} d\eta \Big/ \int_0^1 \frac{dN}{d\eta} d\eta$$

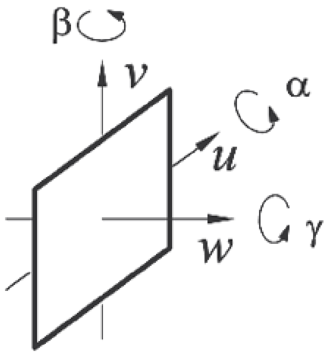


probability density of eta





Detector Alignment



Alignment : Optimize the correction parameters to minimize the chi2

$$\chi^2(\Delta\mathbf{p}, \Delta\mathbf{q}) = \sum_j^{\text{tracks}} \sum_i^{\text{meas.}} \frac{r_{ij}^2}{\sigma_{ij}^2}$$

i:detector
j:track

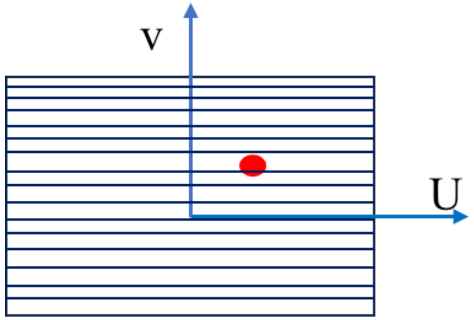
which

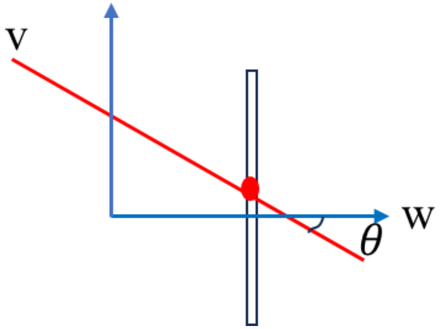
$$r_{ij} = m_{ij} - f_{ij}(\mathbf{p}_0, \mathbf{q}_{j0}) - \boxed{\frac{\partial f_{ij}}{\partial \mathbf{p}}}\Delta\mathbf{p} - \frac{\partial f_{ij}}{\partial \mathbf{q}_j}\Delta\mathbf{q}_j$$

$\vec{p}$: detector correction parameters
$\vec{q}$: track fit parameters

At local system, with 6 correction parameters (Δu,Δv,Δw,α,β,γ):

$$\mathbf{J} = \begin{pmatrix} -1 & 0 \\ 0 & -1 \\ \tan\psi & \tan\vartheta \\ v_x \tan\psi & v_x \tan\vartheta \\ u_x \tan\psi & u_x \tan\vartheta \\ v_x & -u_x \end{pmatrix}$$

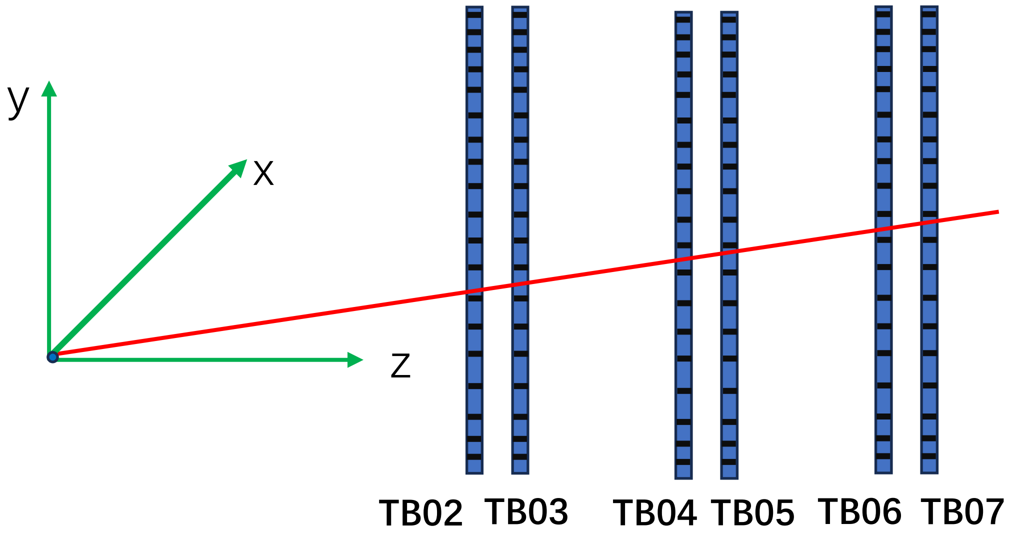


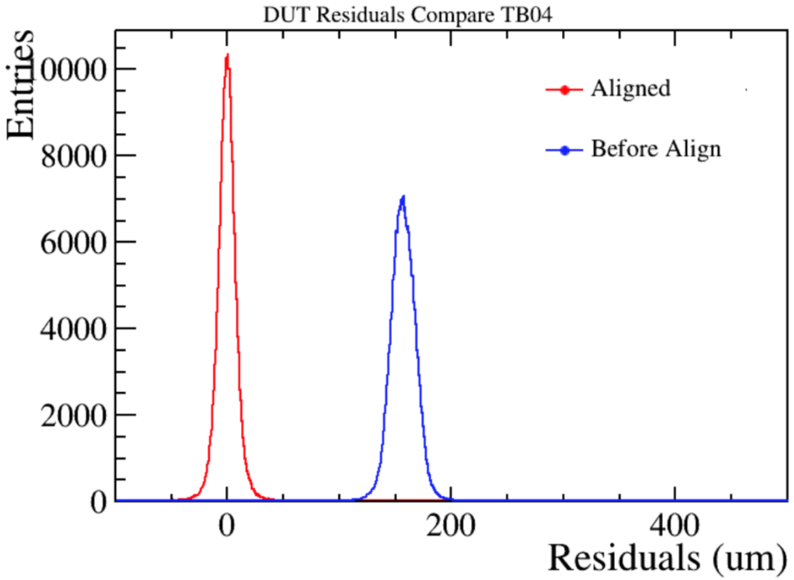


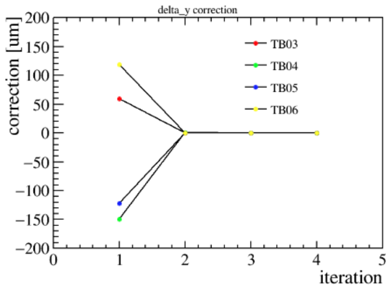
- 3-D track is necessary, even though we have only 1-D detection

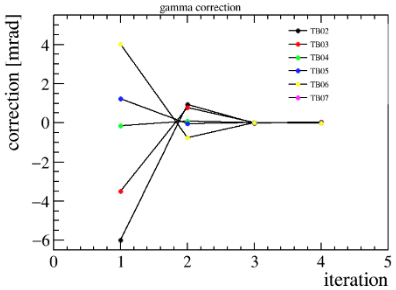
Alignment Results

- Correct 6 y-layers simultaneously
- Checked convergence of correction parameters
- After alignment, mean of residual ~0.5um









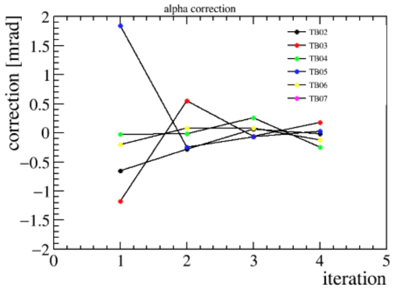
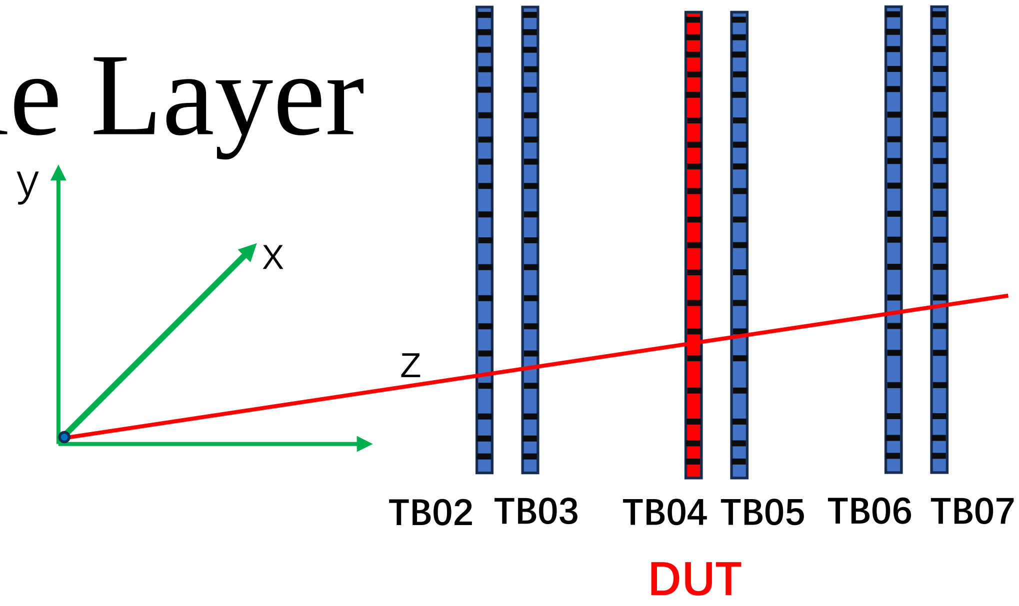


Table1. Final correction values

name	Δy(um)	α(mrad)	β(mrad)	γ(mrad)
TB02	0.00	-0.937	-1.192	-5.060
TB03	59.52	-0.629	-0.112	-2.740
TB04	-149.90	-0.051	0.981	-0.057
TB05	-122.07	1.593	2.222	1.174
TB06	118.70	-0.119	0.450	3.253
TB07	0.00	0.142	-2.350	3.431

Spatial Resolution of A Single Layer



- Unbiased residual of DUT consists of

$$\sigma^2_{\text{meas}} = \sigma^2_{\text{DUT}} + \sigma^2_{\text{tel}}$$

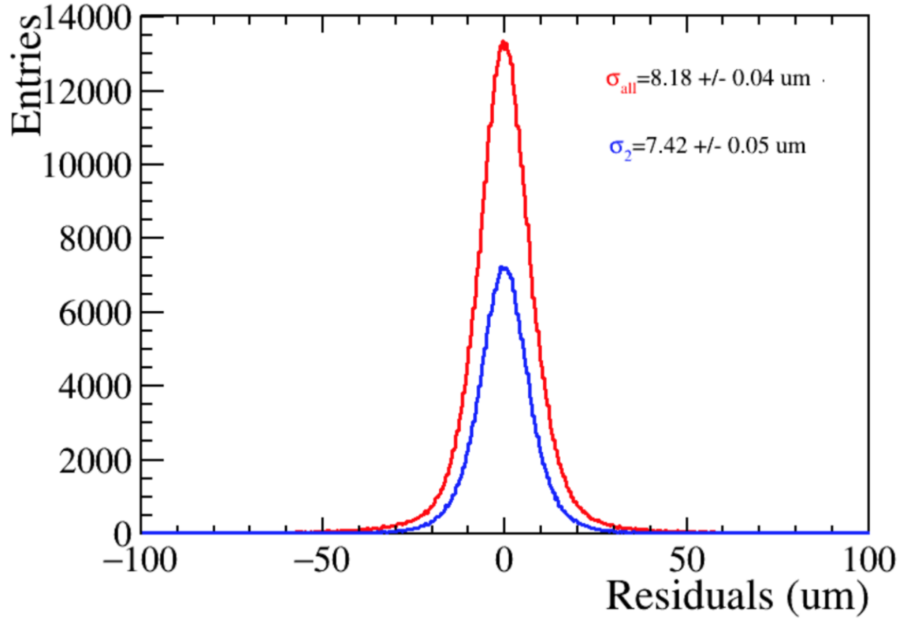
- Since all planes have same configurations, we can assume that they have same intrinsic resolution, thus

$$\sigma^2_{\text{DUT}} = \frac{\sigma^2_{\text{meas}}}{1+k} \qquad k = \frac{\sum_i^N z_i^2}{N\sum_i^N z_i^2 - (\sum_i^N z_i)^2}$$

- In our study:

1. fitting tracks using all matching clusters, the spread of unbiased residual at DUT = 8.2 um
2. Subtract Telescope resolution, **spatial resolution of DUT : 7.5 um**

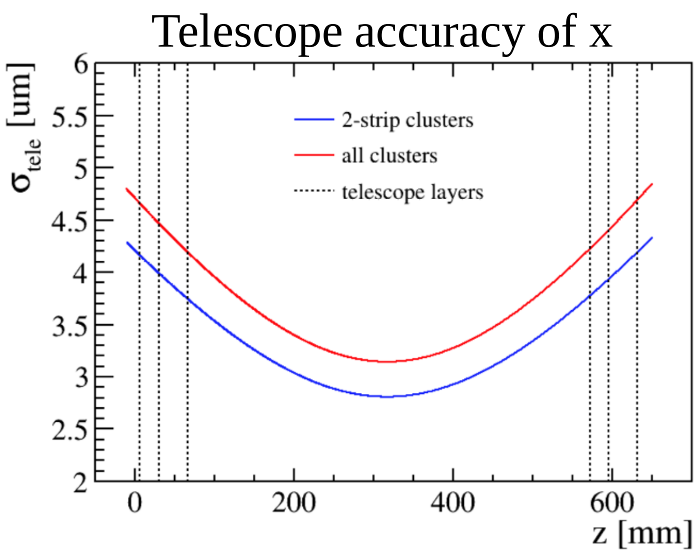
* For better resolution, consider 2-strip clusters of DUT only ,
    * **spatial resolution: 6.6 um**

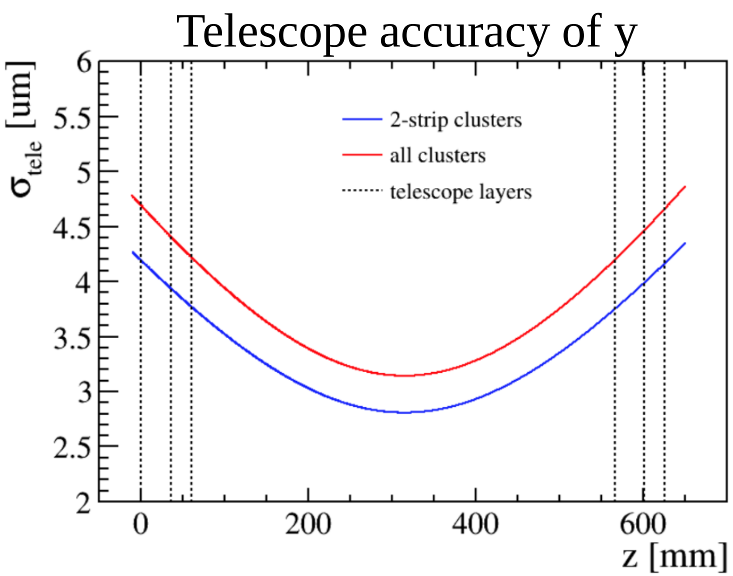


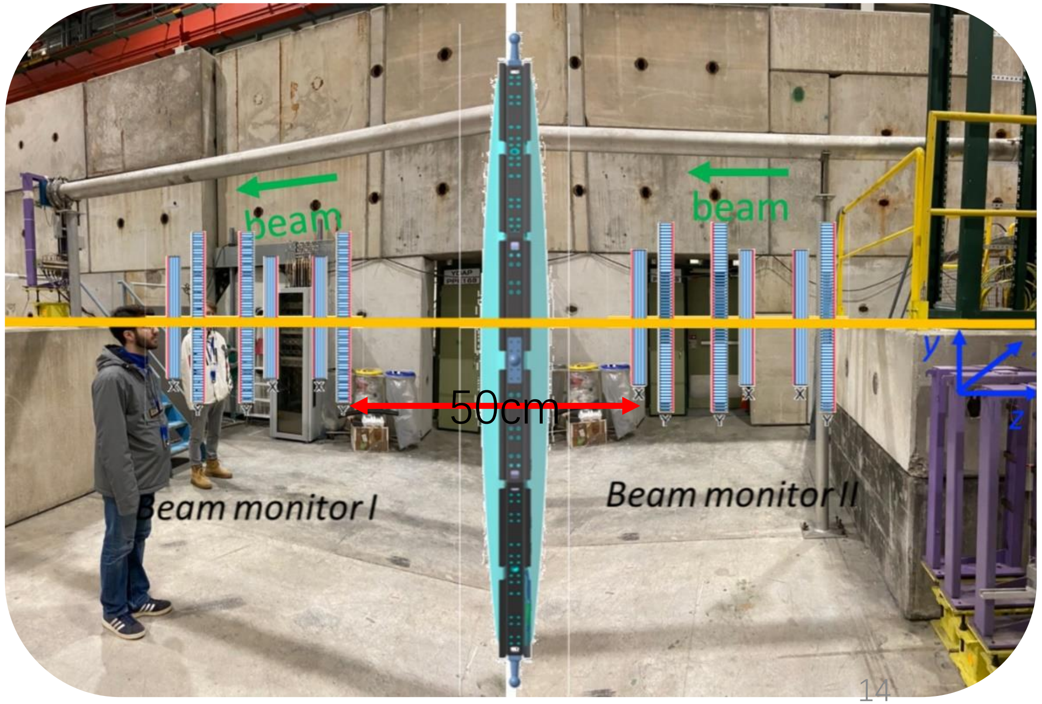
strip pitch: 109um

Estimate Resolution of Beam Monitor

- Use this beam monitor to align the AMS L0 full plane
- Positioning accuracy is simulated in MC according to single board results
  - 12-plane beam monitors set as: YX XY YX DUT YX XY YX
  - Best accuracy of X and Y is 2.7 um

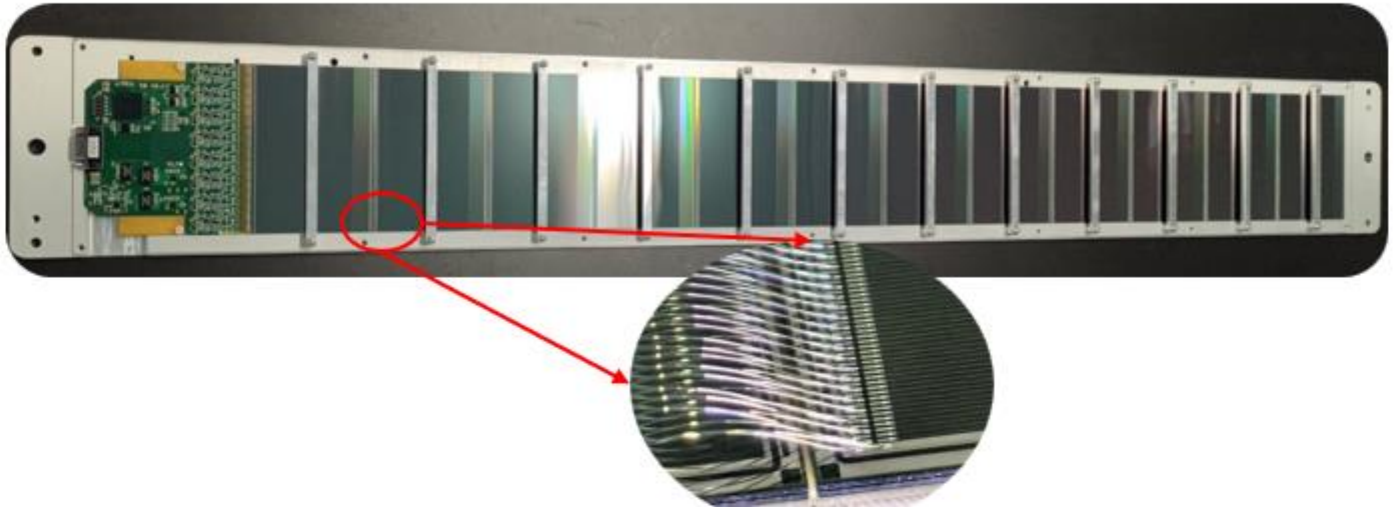






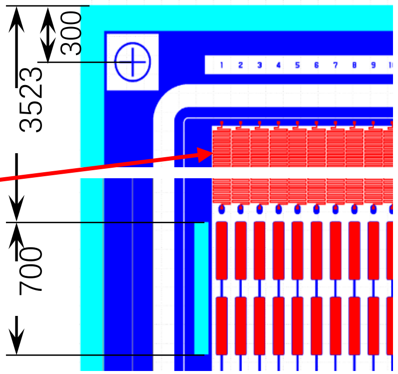
Detector Efficiency Study

- 8/10/12 SSDs are connected in series to form a ladder
  - Large detection area with small electrical power budget
  - Each readout channel corresponds to a very long (~1m) strip
  - Requires high precision placement(<5 um) of the SSDs on the ladder, and precise SSD alignment after assembly with **beam**

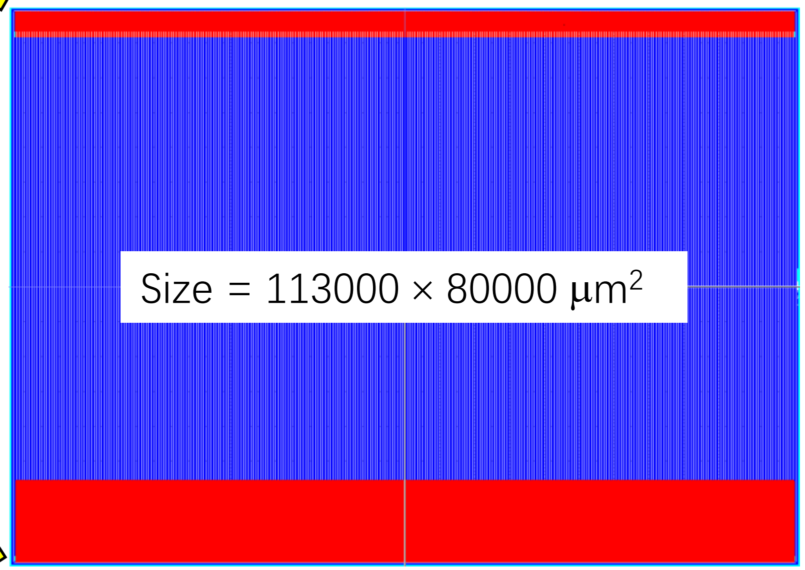


The Design of Silicon Strip Detector

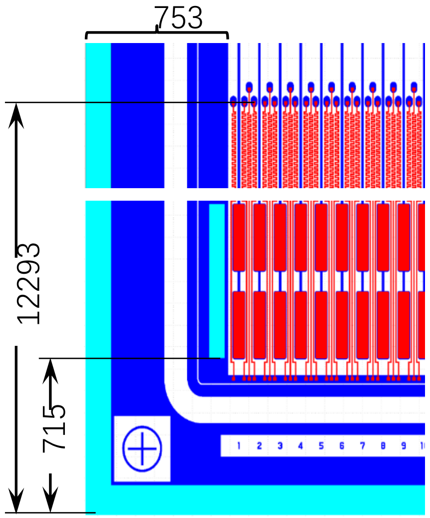
- Special design of bias resistors
  - 8-12 SSDs per ladder, the bias resistor are connected in parallel
  - A large resistance (~100MΩ) is needed to achieve impedance matching
  - The bias resistor and strip located on different layers ⇒largest sensitive area
  - The detection efficiency, especially in region of the bias resistors, was studied at test beam



Designed by IHEP+Perugia+HPK Swiss



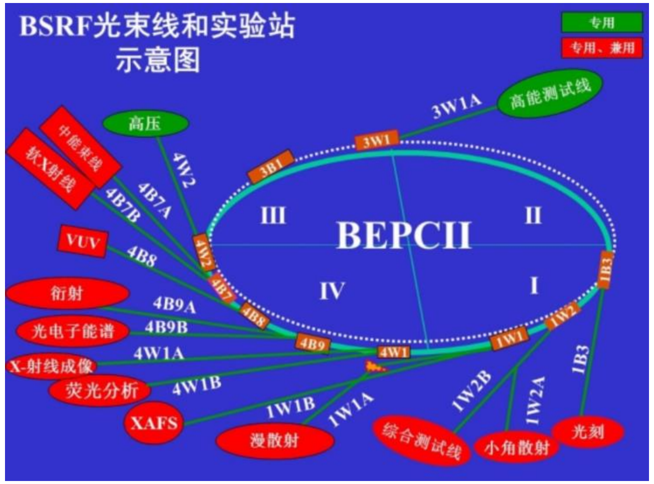
- Alignment marks for precise placement

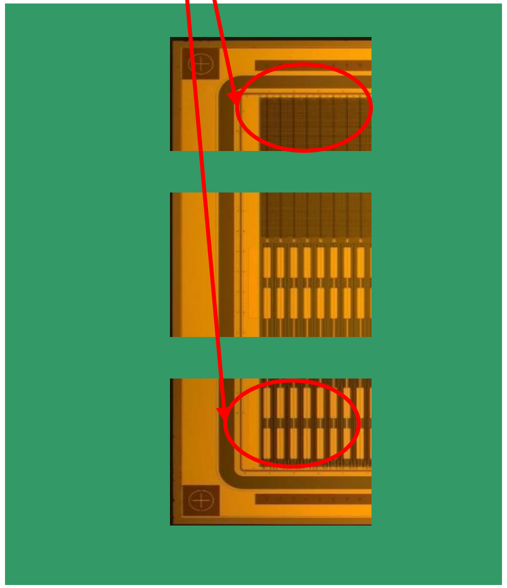


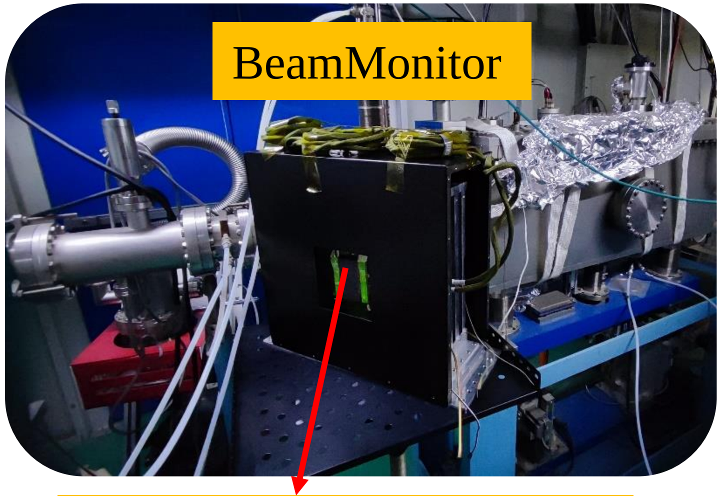
- 1024 readout strips with a pitch of 109 μm
- 3 extra bias strips between adjacent readout strips to improve charge sharing
- AC-coupling readout

Test Beam @ BSRF

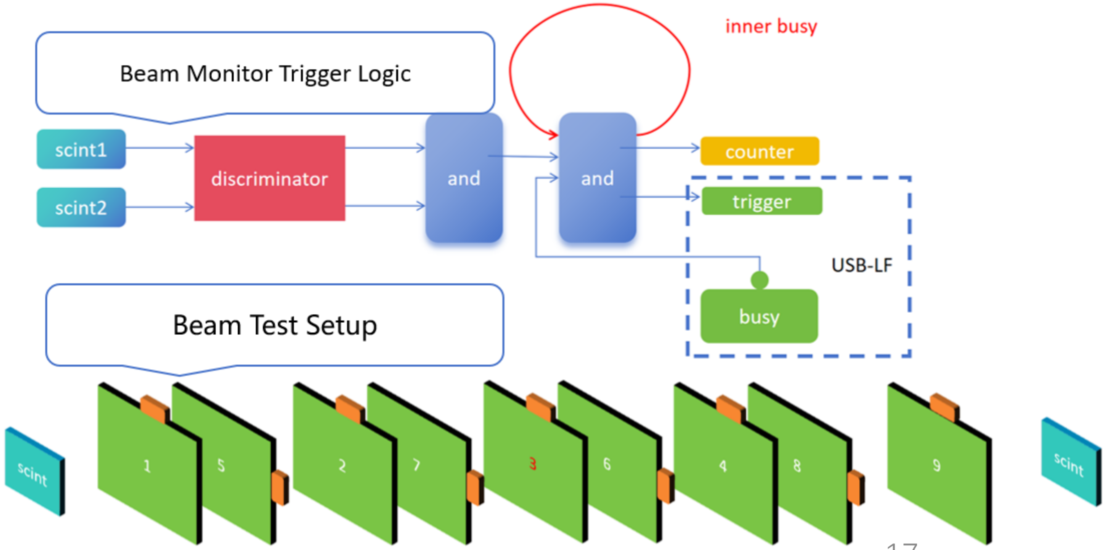
- The beam test was performed in Jan 2024, at Beijing Synchrotron Radiation Facility, BSRF
  - Low energy electron beam < 1GeV
- Study the Detection efficiency, especially in the two **bias resistor region**



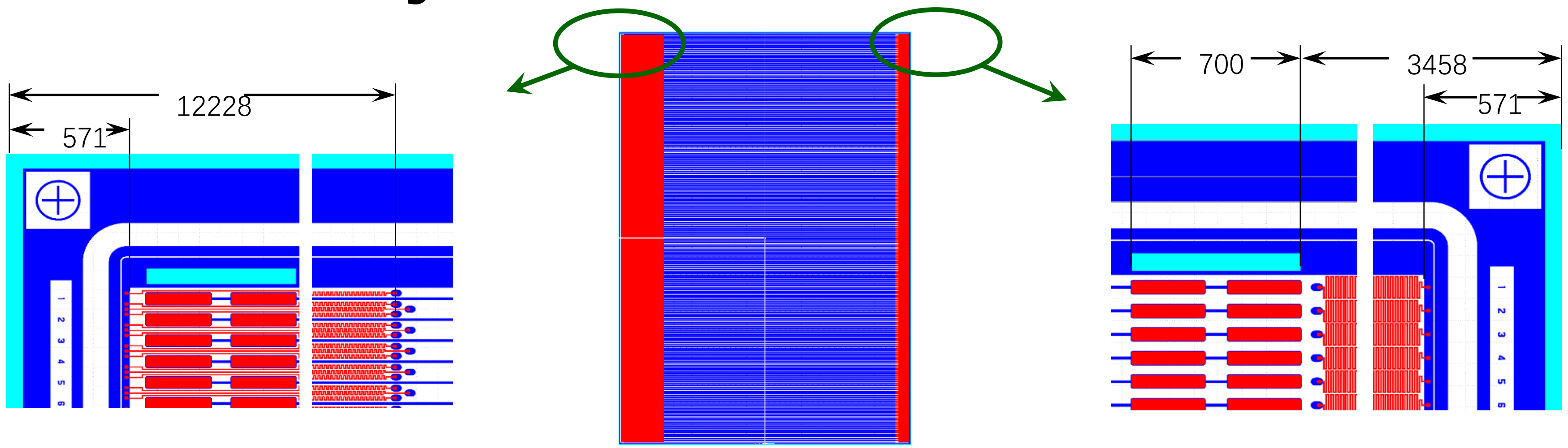




Scintillator(made by FDU)



Detector Efficiency Result

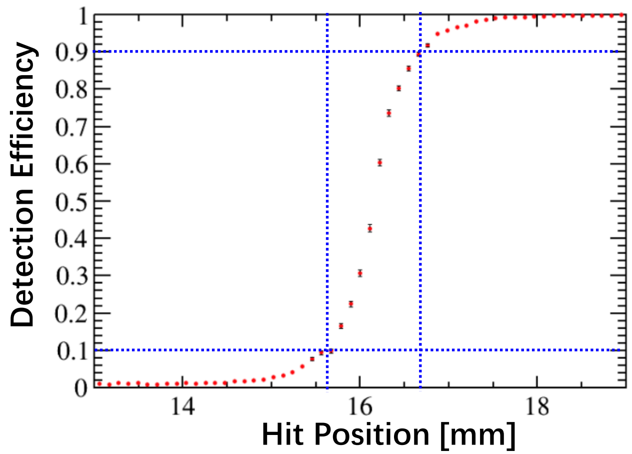


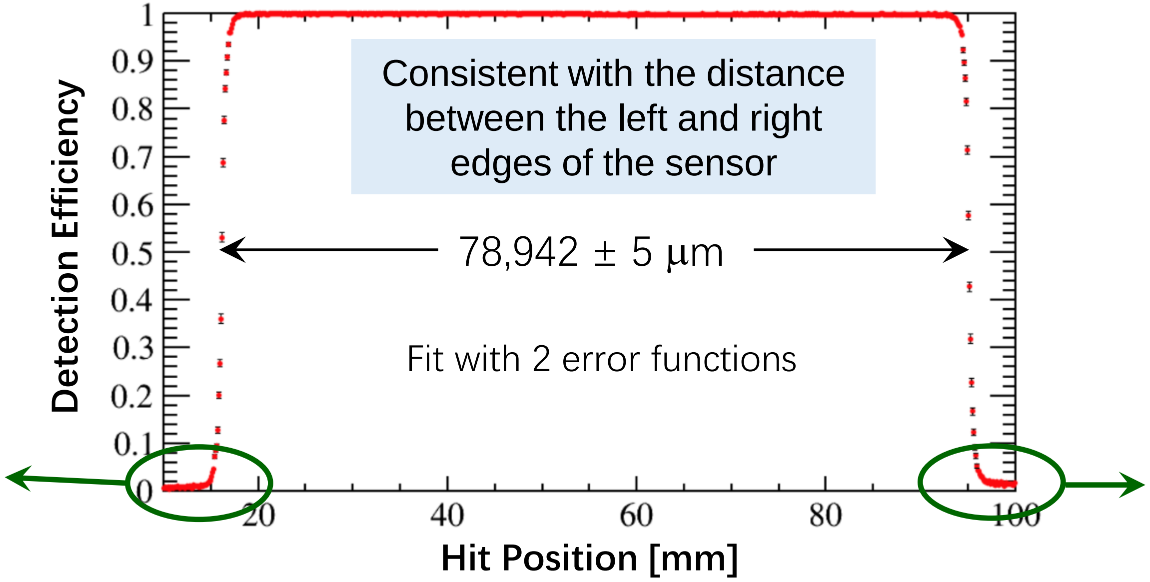
Testbeam@IHEP, Jan 2024

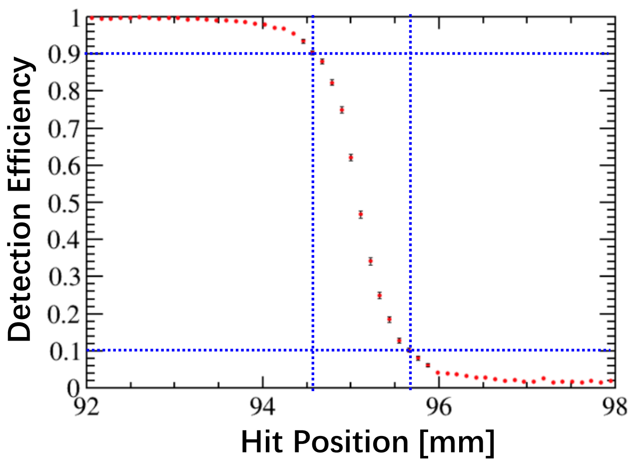
Electron source (< 1GeV)

The bias resistor region has efficient detection

Need better beam for a sharp slope to study fine structure

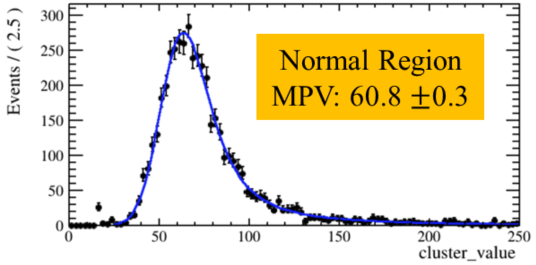


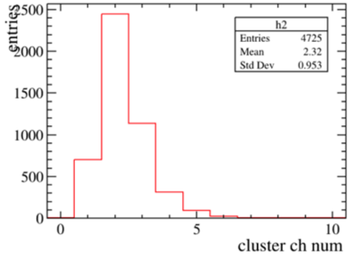


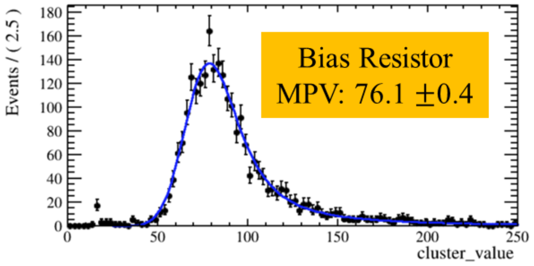


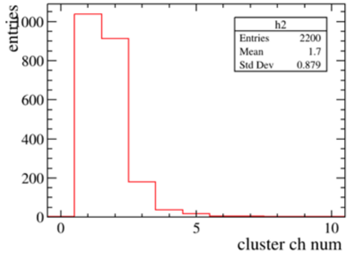
Charge Collection of Bias Resistor Region

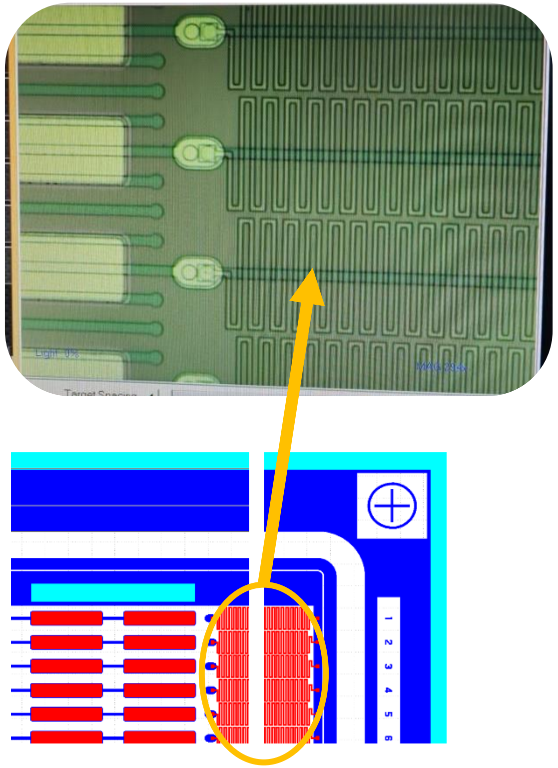
- Fit the cluster charge distribution with a landau ⊗ gaus function to get MPV
- Bias resistor region: larger MPV, but smaller cluster size
- No intermediate bias strips in this region, resulting in less charge sharing

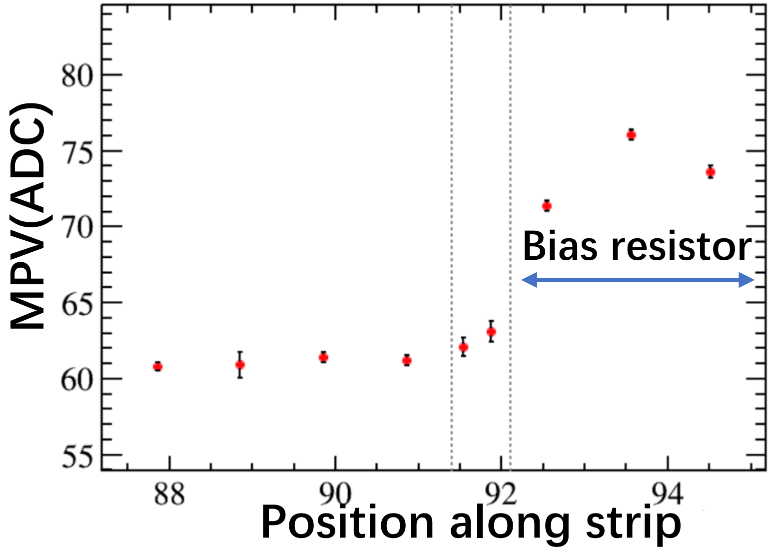


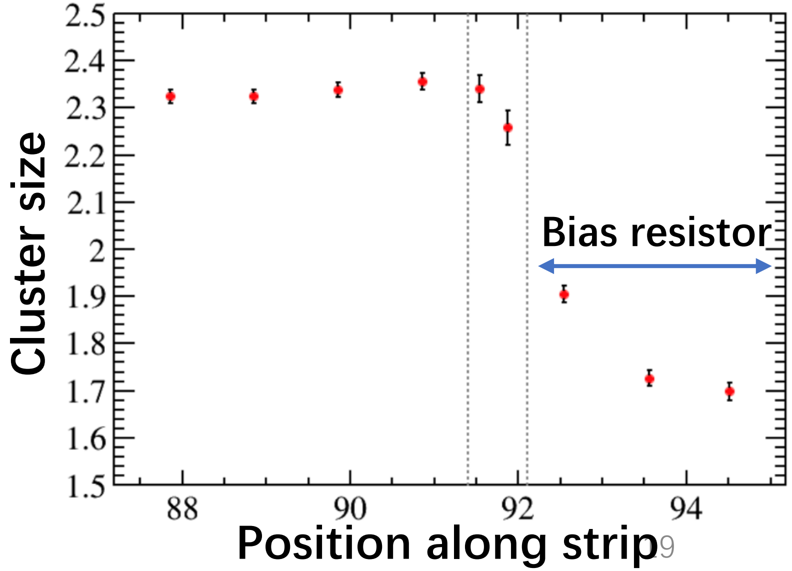






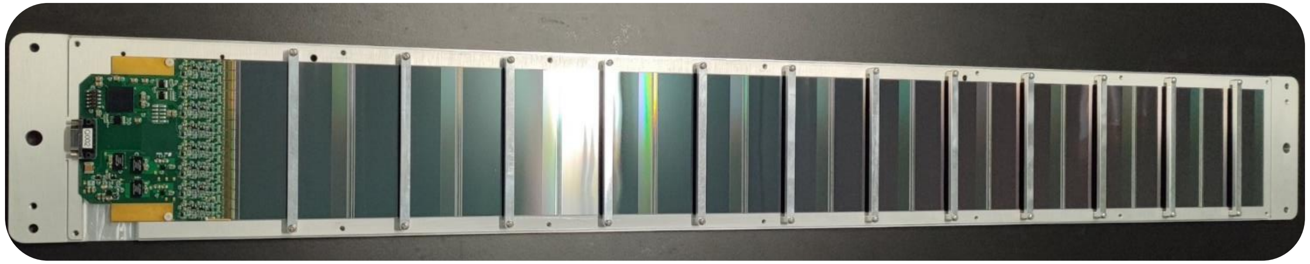


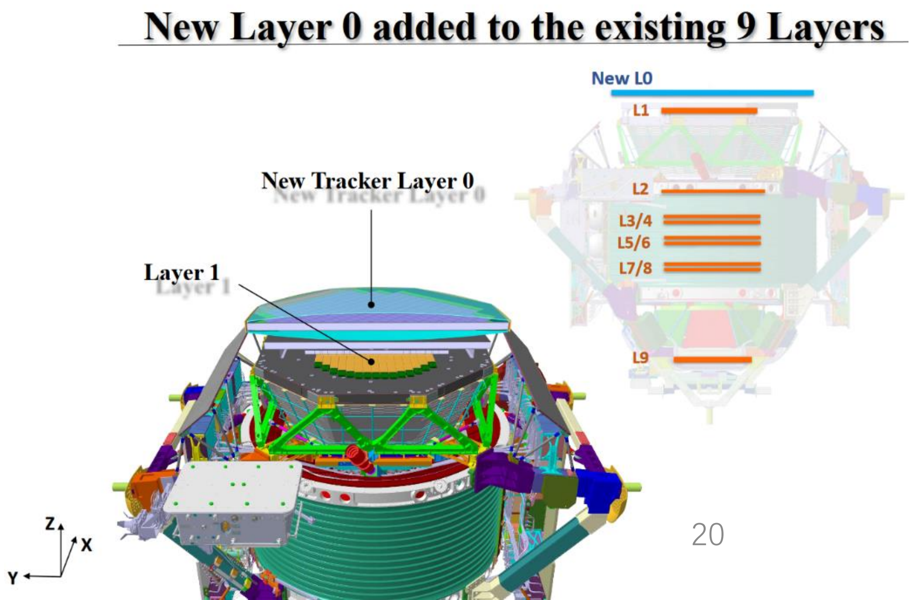




Summary and Plan

- AMS will add a new silicon strip tracker L0, with a total sensitive area of $7m^2$
- A Beam Monitor was produced for AMSL0 alignment and performance study
- Performance of the Beam Monitor was studied in testbeams at SPS
  - Alignment with MILLEPEDE-II and track fitting with GBL
  - Resolution of single layer is 6.6um, and 2.7um for the telescope
- Special bias resistor design of the AMSL0 SSD
  - The bias resistor region has efficient detection
  - Spatial resolution to be further studied





Back up

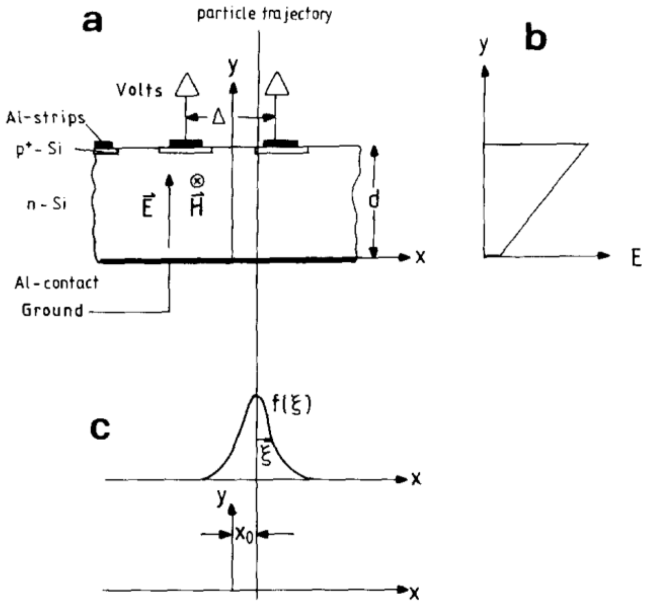
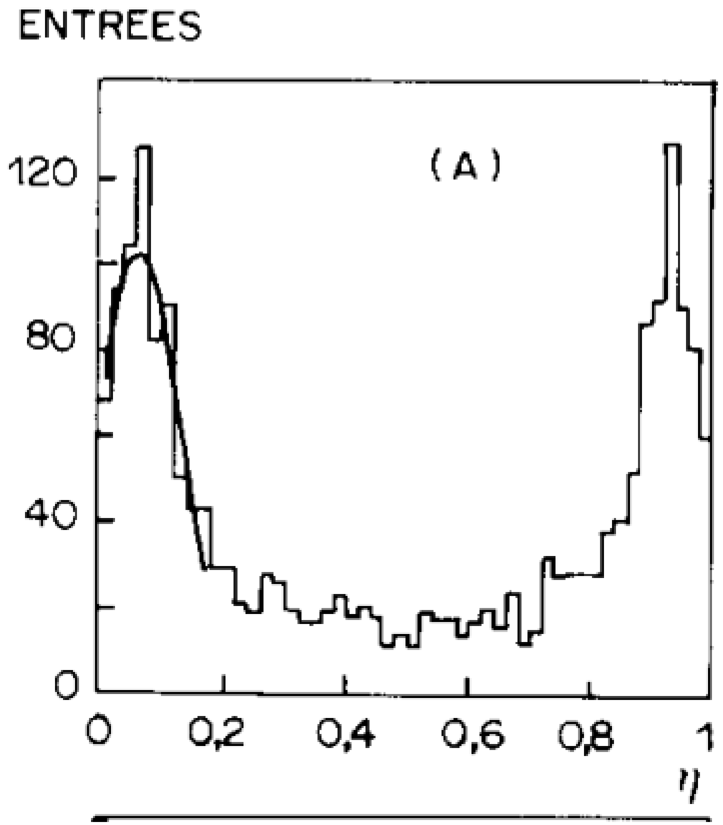


Fig. 2. Layout of the strip detector in the magnetic field; definition of the coordinate system and the parameters used for the measurement of the collected charge distribution. a) Cross-section of strip detector; b) Electric field in detector; c) The distribution of charges.



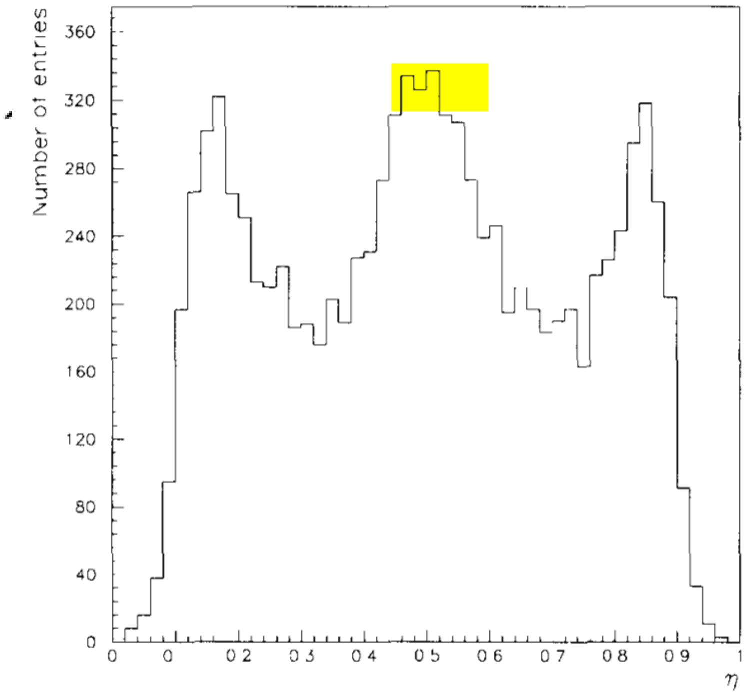
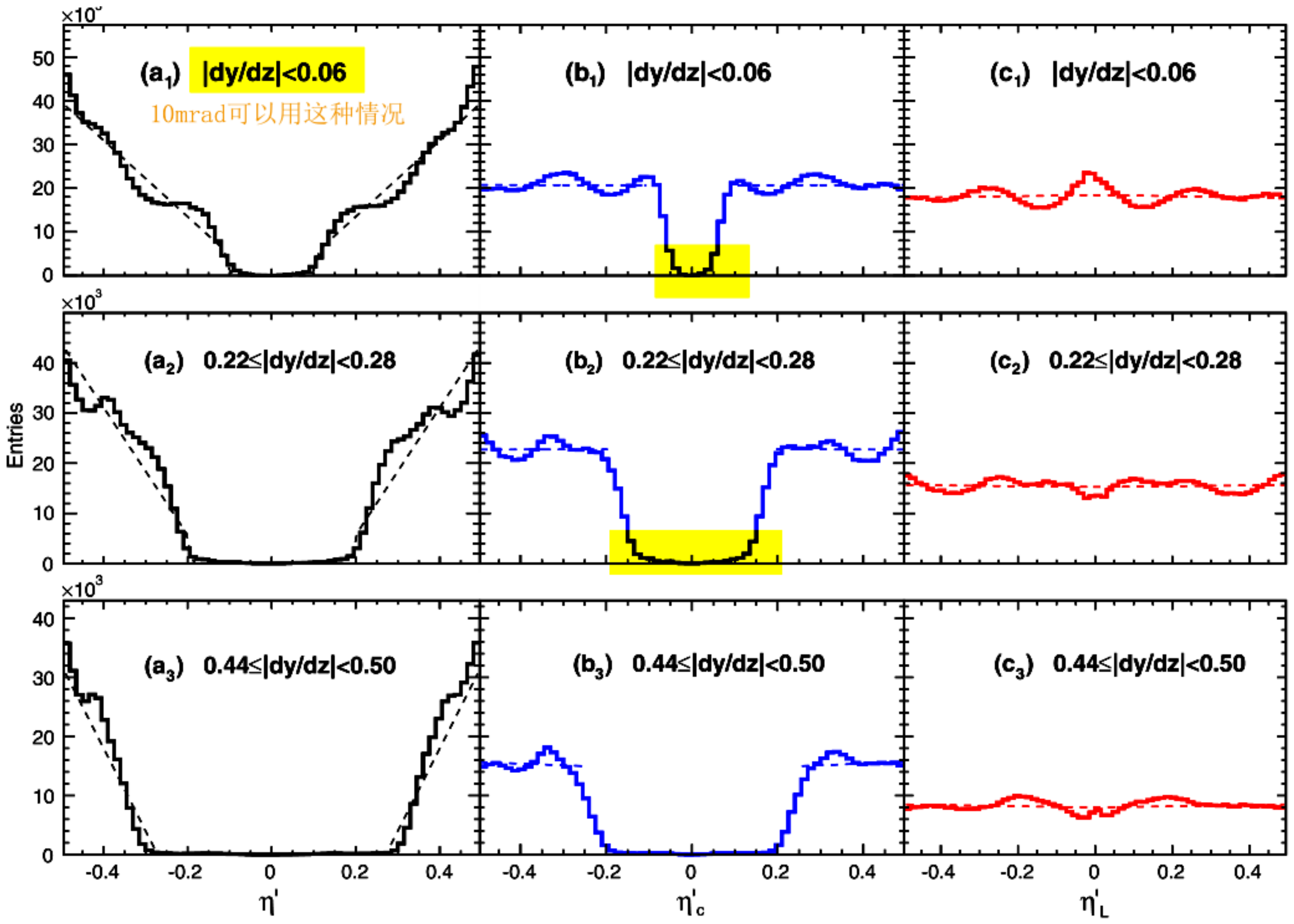


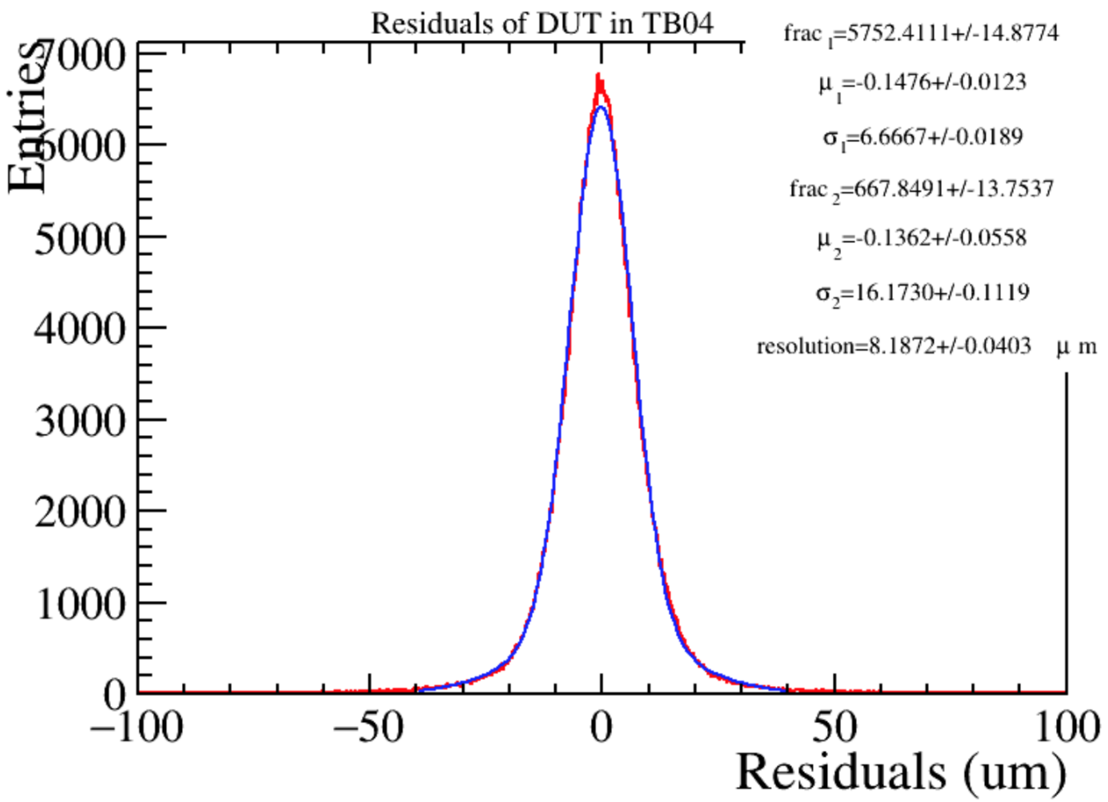
Fig. 6. The simulated distribution of the variable η for a detector with one intermediate strip, $P = 50\ \mu m$ and $S/N = 20$.

[1]CHARGE COLLECTION IN SILICON STRIP DETECTORS

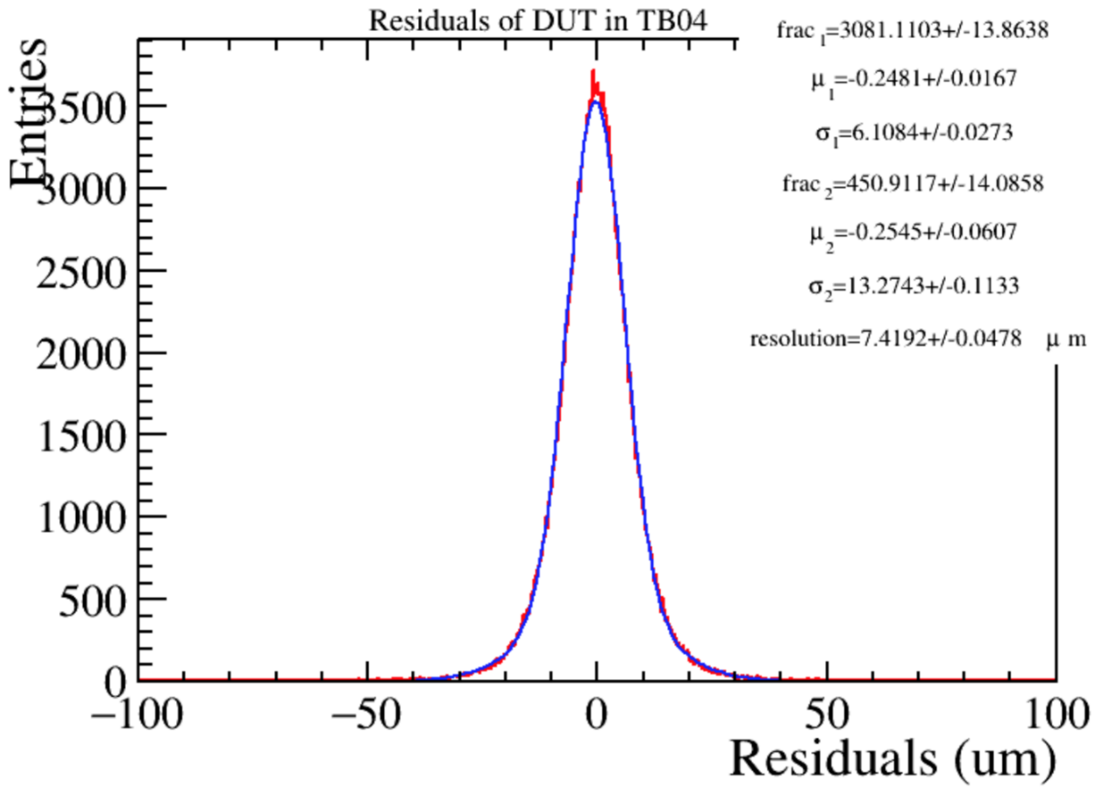
[2]Spatial resolution of silicon microstrip detectors


×10³
(a1) |dy/dz|<0.06
10mrad可以用这种情况
(b1) |dy/dz|<0.06
(c1) |dy/dz|<0.06
(a2) 0.22≤|dy/dz|<0.28
(b2) 0.22≤|dy/dz|<0.28
(c2) 0.22≤|dy/dz|<0.28
(a3) 0.44≤|dy/dz|<0.50
(b3) 0.44≤|dy/dz|<0.50
(c3) 0.44≤|dy/dz|<0.50
Entries
η'
η'c
η'L

Fit of residual



All match cluster



2-strip cluster