Offline analysis for CEPC vertex detector test beam at DESY

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Introduction

- Motivation
  - Building a standalone offline analysis framework for CEPC vertex detector TaiChu pixel chip test beam
  - Track reconstruction

    no magnetic

    straight line fit

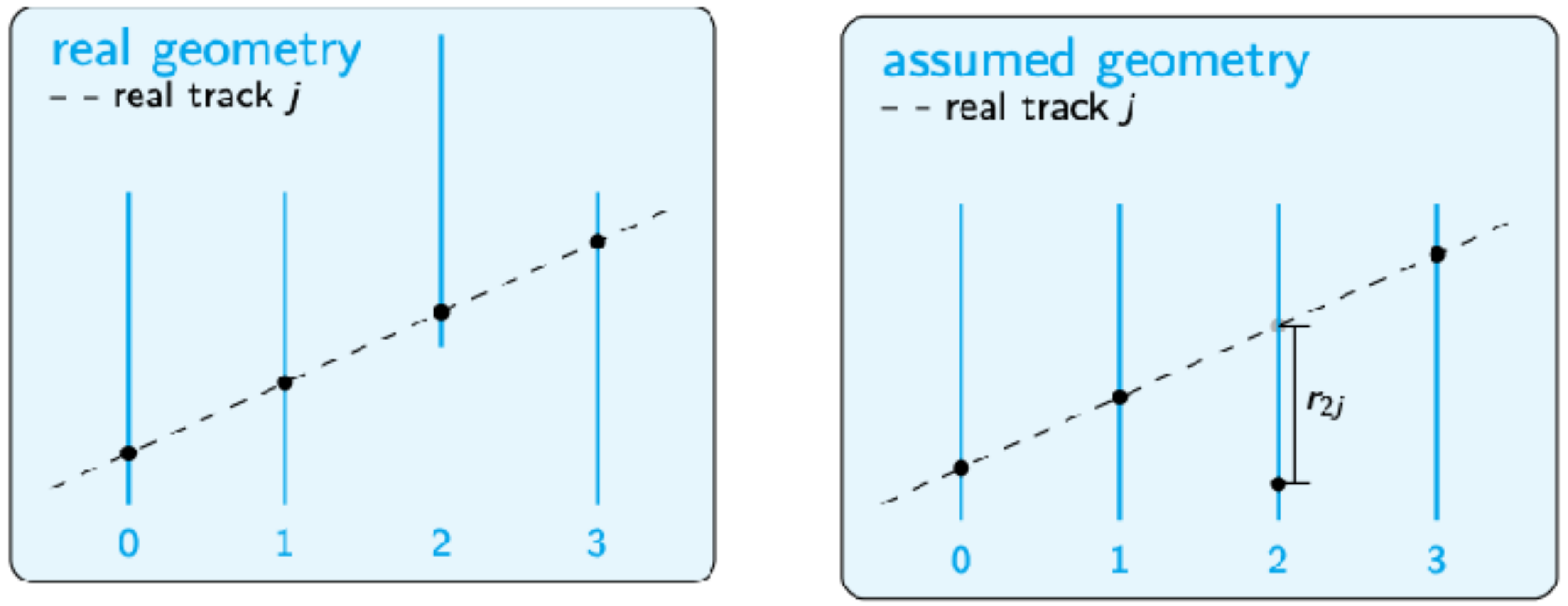
    no considering multi-scattering currently

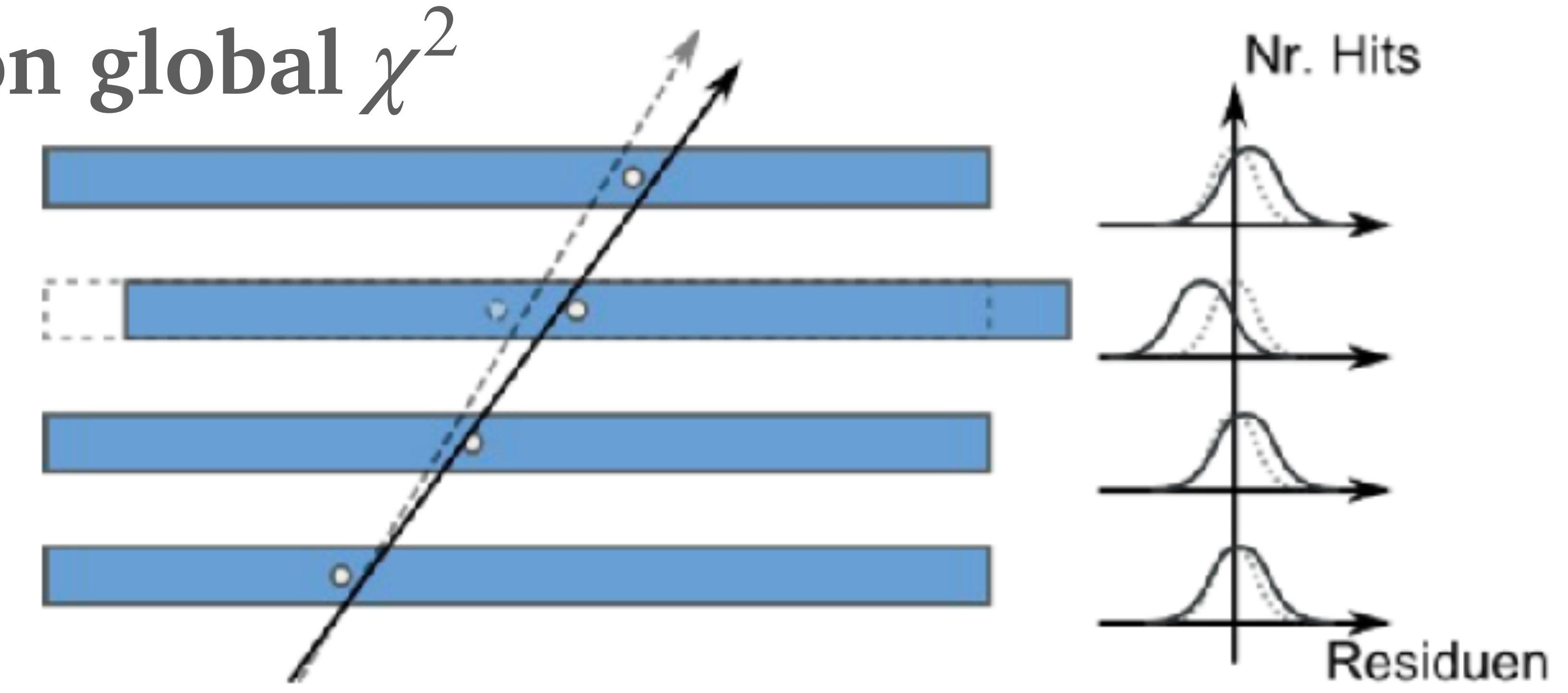
  - alignment

    correction for the misalign chip position

    misalignment effects the resolution of detector

    find the solution of real geometry for global tracks based on global χ^2

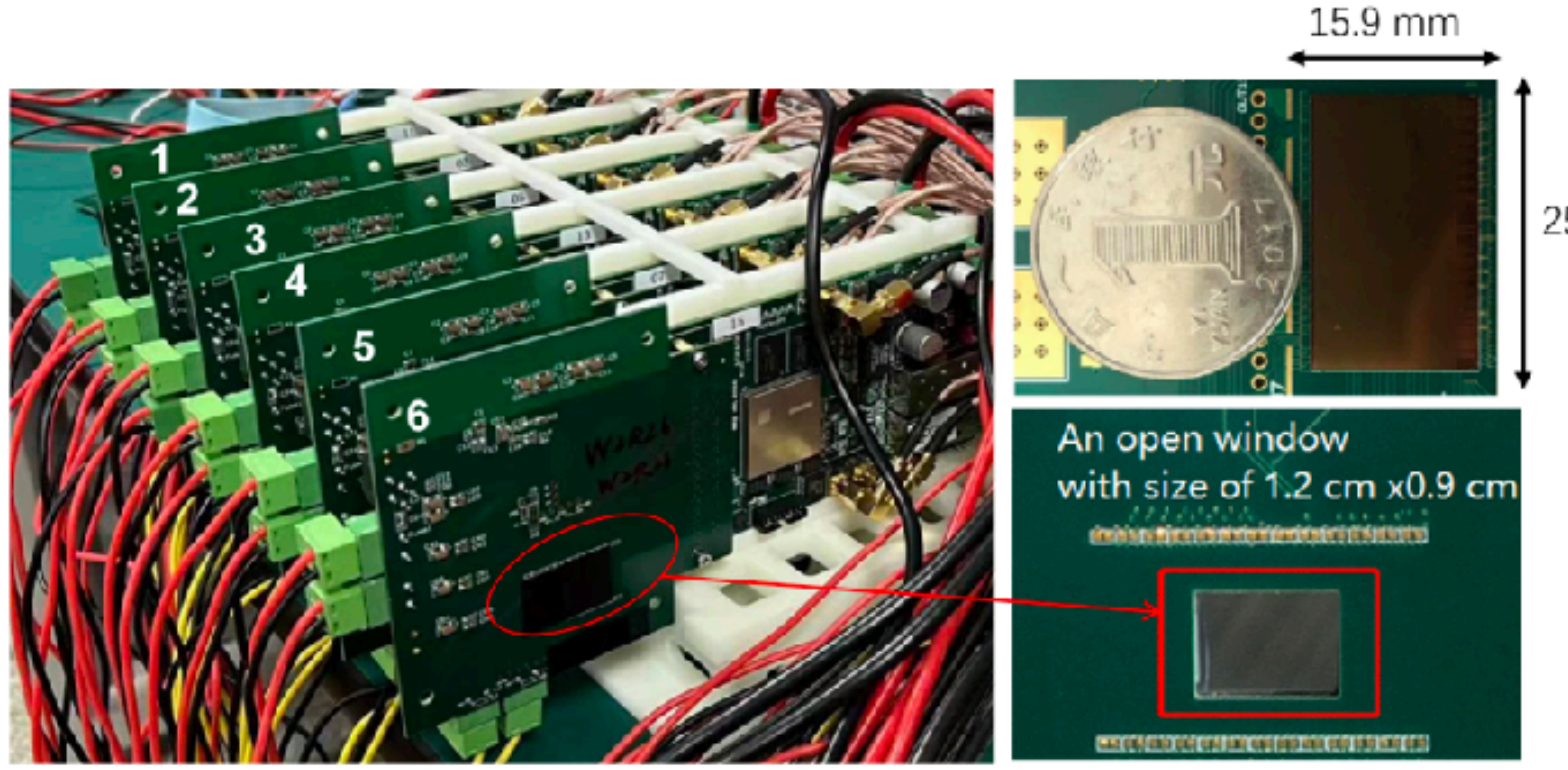




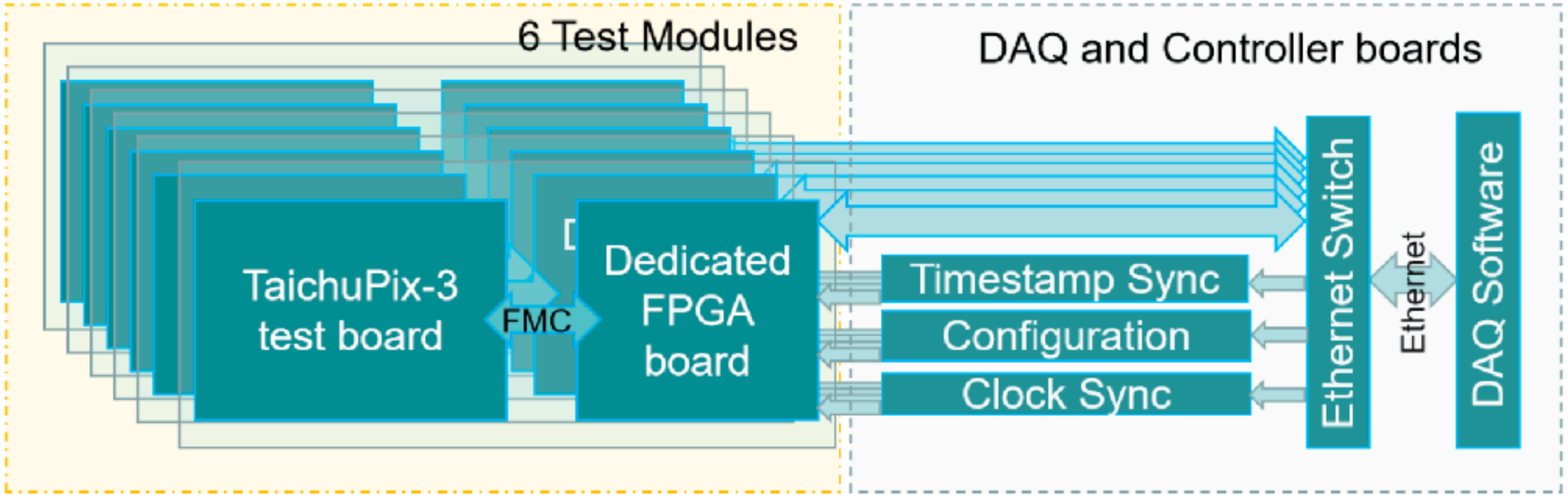
Residual: distance of measured hit with the intersection point of track in the measured chip

- TaiChu silicon pixel detector
  - Pixel size: 25 um
  - Theoretical resolution: 25um/sqrt(12) ~ 7.22 um
  - The experimental resolution should be better than theoretical resolution due to charge sharing

Track reconstruction



- Setup
  - 6 layer, 4cm between each other
  - electron beam energy 3-6 GeV (analysis results based on 4GeV)
  - One of the chips is the detector under test (DUT), the others made up of the telescope
  - 2 DUTs with different process



- Steps for track finding and reconstruction
  - Finding hits in every chip with time coincidence
  - Clustering: geometric centre of gravity of fired neighbouring pixels
- Track fitting
  - least squares line fitting

    x = a1z + b1;

    y = a2z + b2;

    Chi2 definition: $\chi^2(\alpha) = \sum_{i=1}^{n} \frac{f(x_i, \alpha) - e_i)^2}{\sigma_i^2}$, sigmax = sigmay = 25um/sqrt(12)
  - General broken lines method (correction for multiple scattering) is developing

Track alignment

- Method - millepede matrix method

p: alignment parameters, q: track parameters

  - minimize: $\chi^2 = \sum_{i \in tracks} \vec{r}_i^T V_i^{-1} \vec{r}_i$ · is residual $\vec{r}_i(\vec{p}, \vec{q}_i)$, V is the covariance matrix

$$\frac{d\chi^2(\vec{p})}{d\vec{p}} = 0 \longrightarrow \chi^2(\vec{p}) = \chi^2(\vec{p}_0) + \left.\frac{d\chi^2(\vec{p})}{d\vec{p}}\right|_{\vec{p}=\vec{p}_0} (\vec{p} - \vec{p}_0) \longrightarrow \underbrace{(J^T V_i^{-1} J)}_{C} \Delta\vec{p} = \underbrace{J^T V_i^{-1} \vec{r}_i(\vec{p}_0)}_{b}$$

$$C \; \Delta\vec{p} = \vec{b}$$

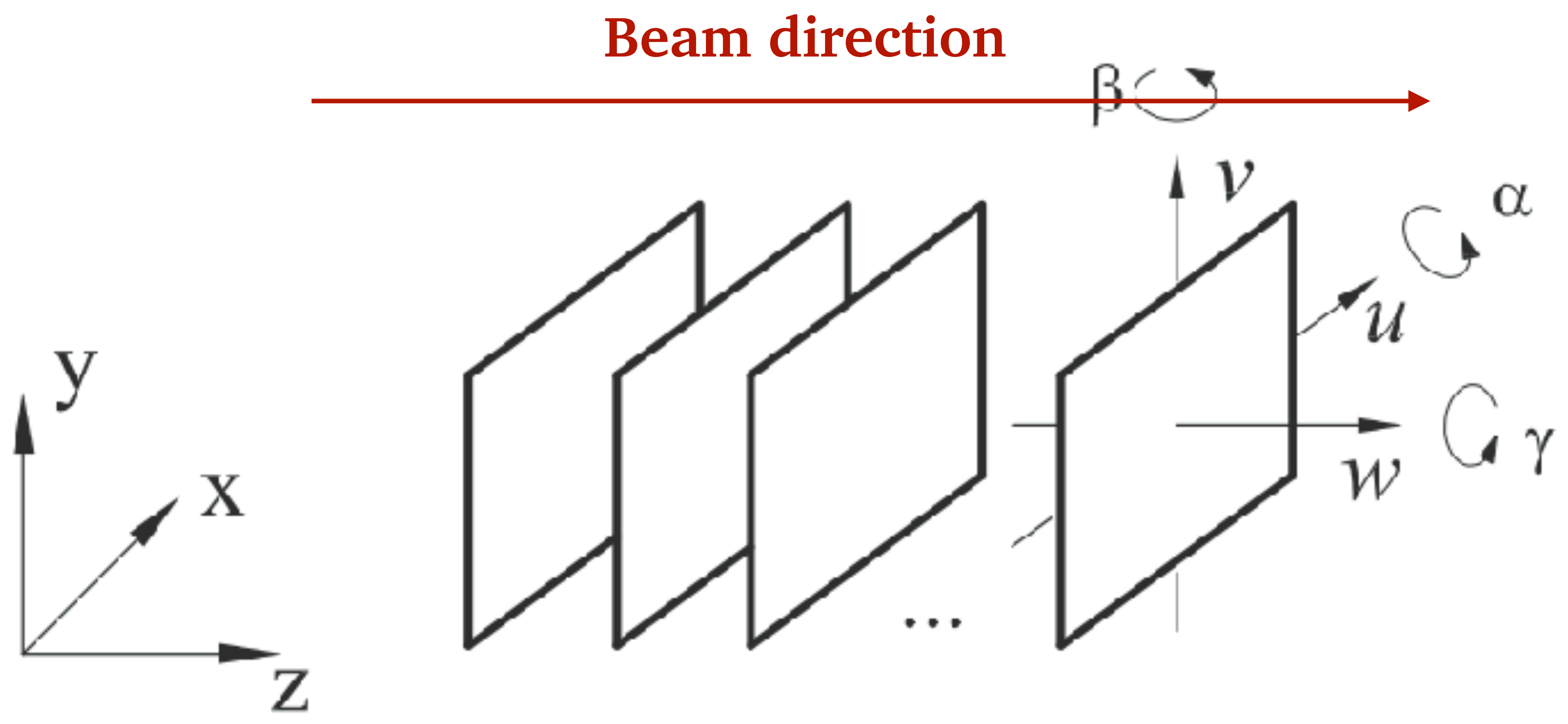
  - invert the Matrix C to find alignment correction Δp
  - reduce matrix C for alignment only

$$S = C_{11} - C_{12} C_{22}^{-1} C_{21}$$

$$\begin{pmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{pmatrix} \begin{pmatrix} \Delta\vec{p}_1 \\ \Delta\vec{p}_2 \end{pmatrix} = \begin{pmatrix} \vec{b}_1 \\ \vec{b}_2 \end{pmatrix} \longrightarrow \begin{pmatrix} \Delta\vec{p}_1 \\ \Delta\vec{p}_2 \end{pmatrix} = \begin{pmatrix} S^{-1} & -S^{-1} C_{21}^T C_{22}^{-1} \\ -C_{22}^{-1} C_{21} S^{-1} & C_{22}^{-1} - C_{22}^{-1} C_{21} S^{-1} C_{21}^T C_{22}^{-1} \end{pmatrix} \begin{pmatrix} \vec{b}_1 \\ \vec{b}_2 \end{pmatrix} \longrightarrow \Delta\vec{p}_1 = S^{-1} \left(\vec{b}_1 - C_{21}^T C_{22}^{-1} \vec{b}_2 \right)$$

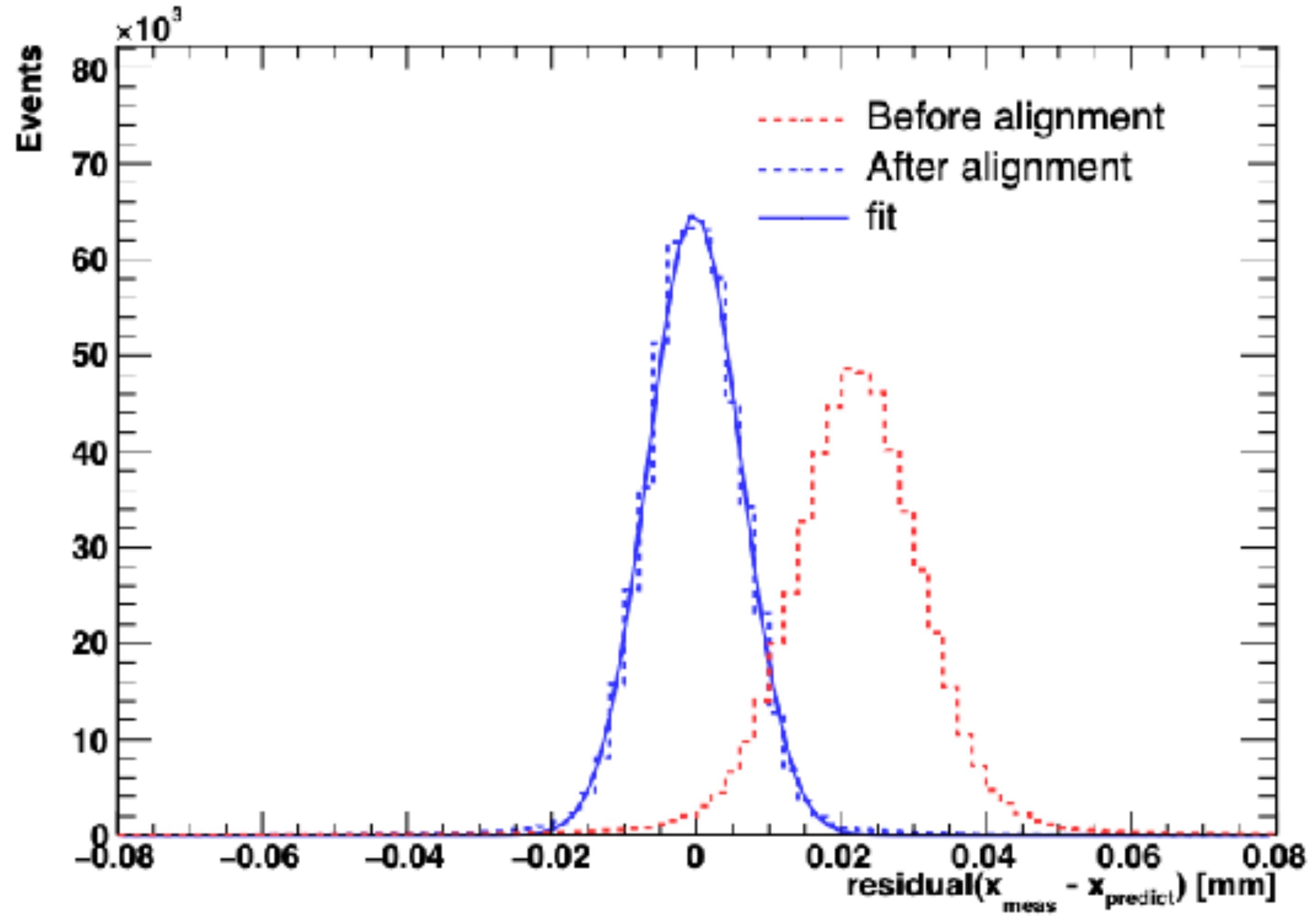
  - Matrix S with smaller size than C, and C_{22} is easy to invert

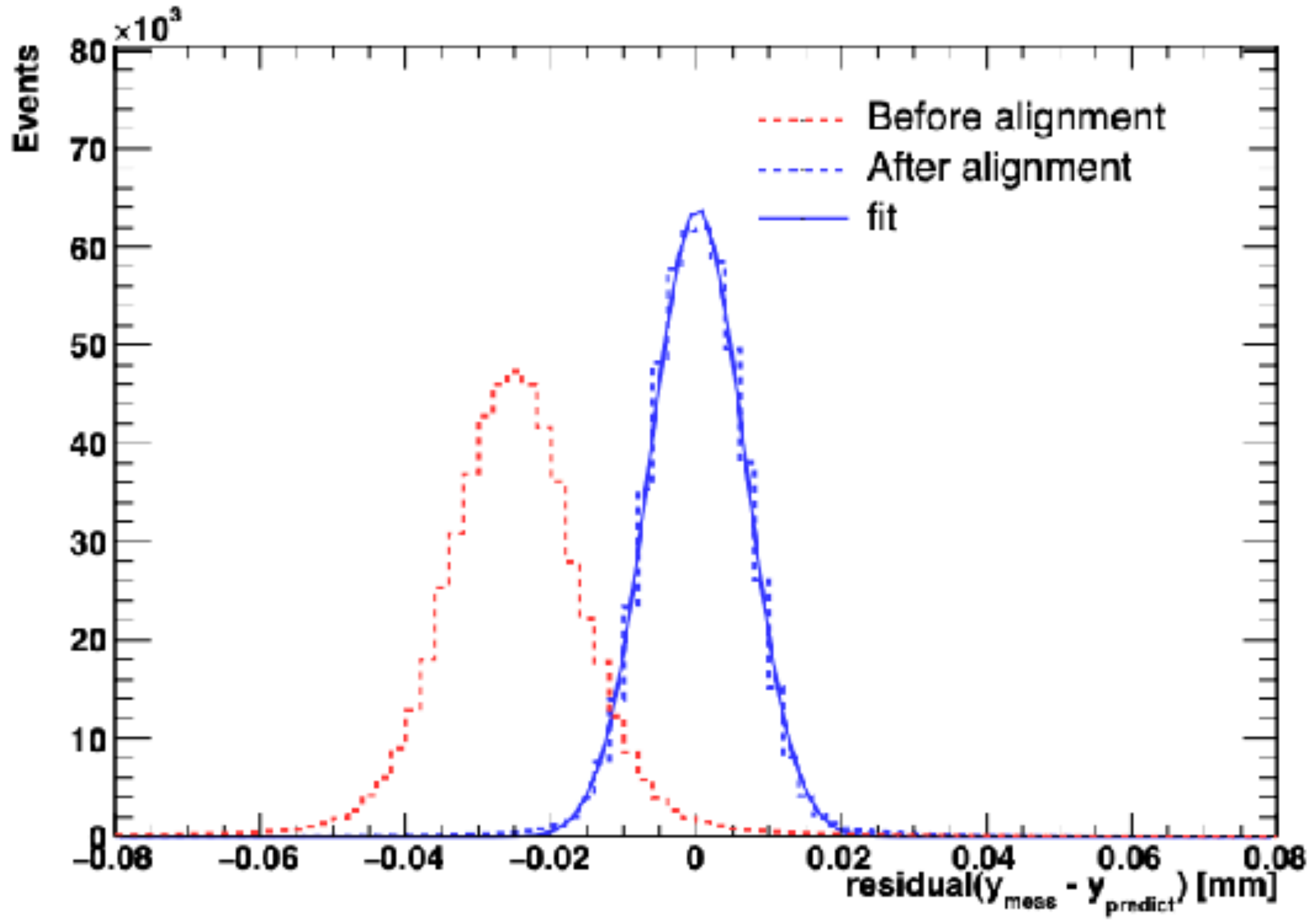
- Six alignment parameters considered
  - Translation along X, Y, Z direction
  - Rotation around X, Y, Z axis

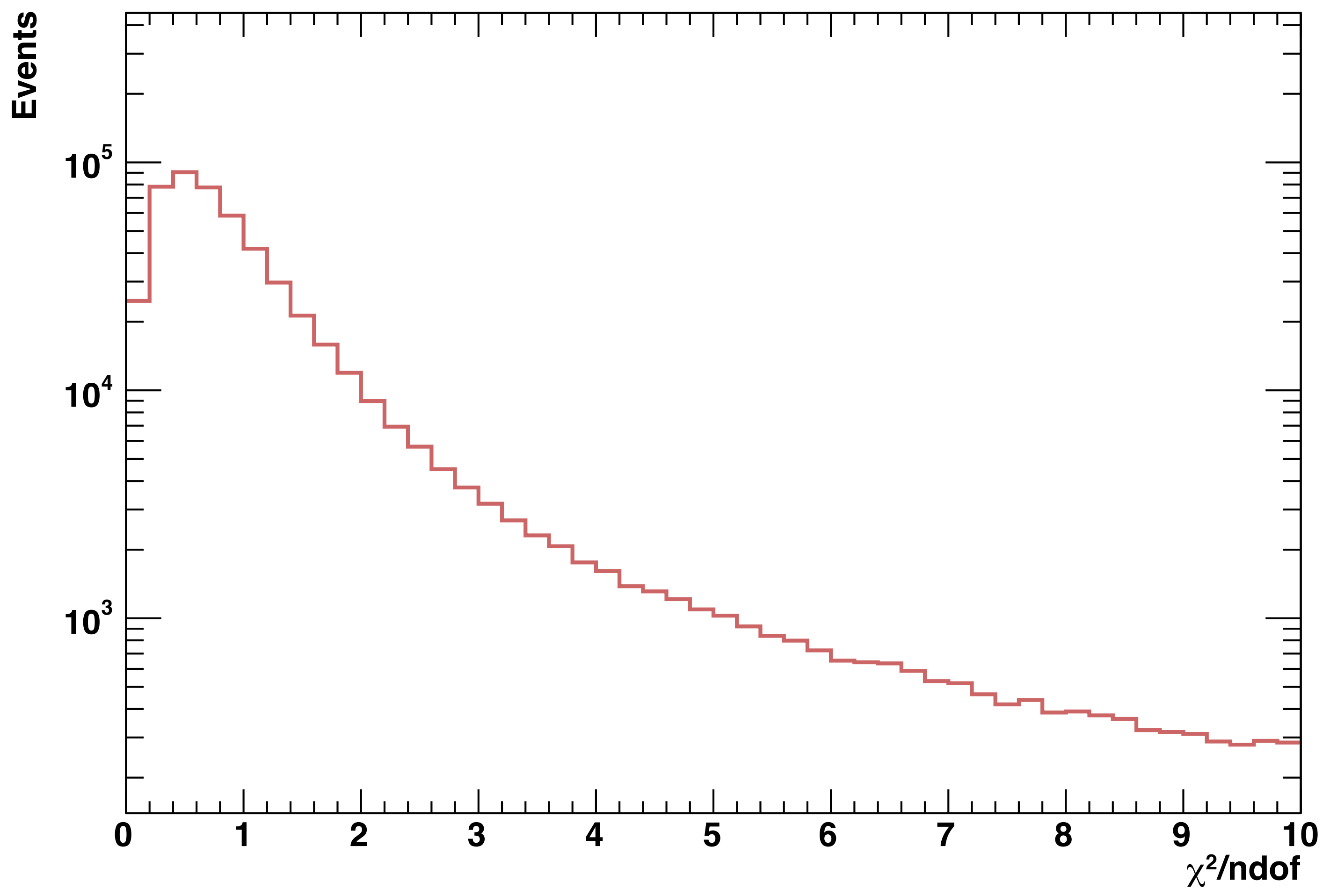


‣ Residual plots before and after alignment (4GeV)

- Residual: the difference between the measured hit position on DUT and the intersection point of track of telescope on the DUT
- straight line fit used for track after alignment correction
- The misalignment can be well corrected by the algorithm

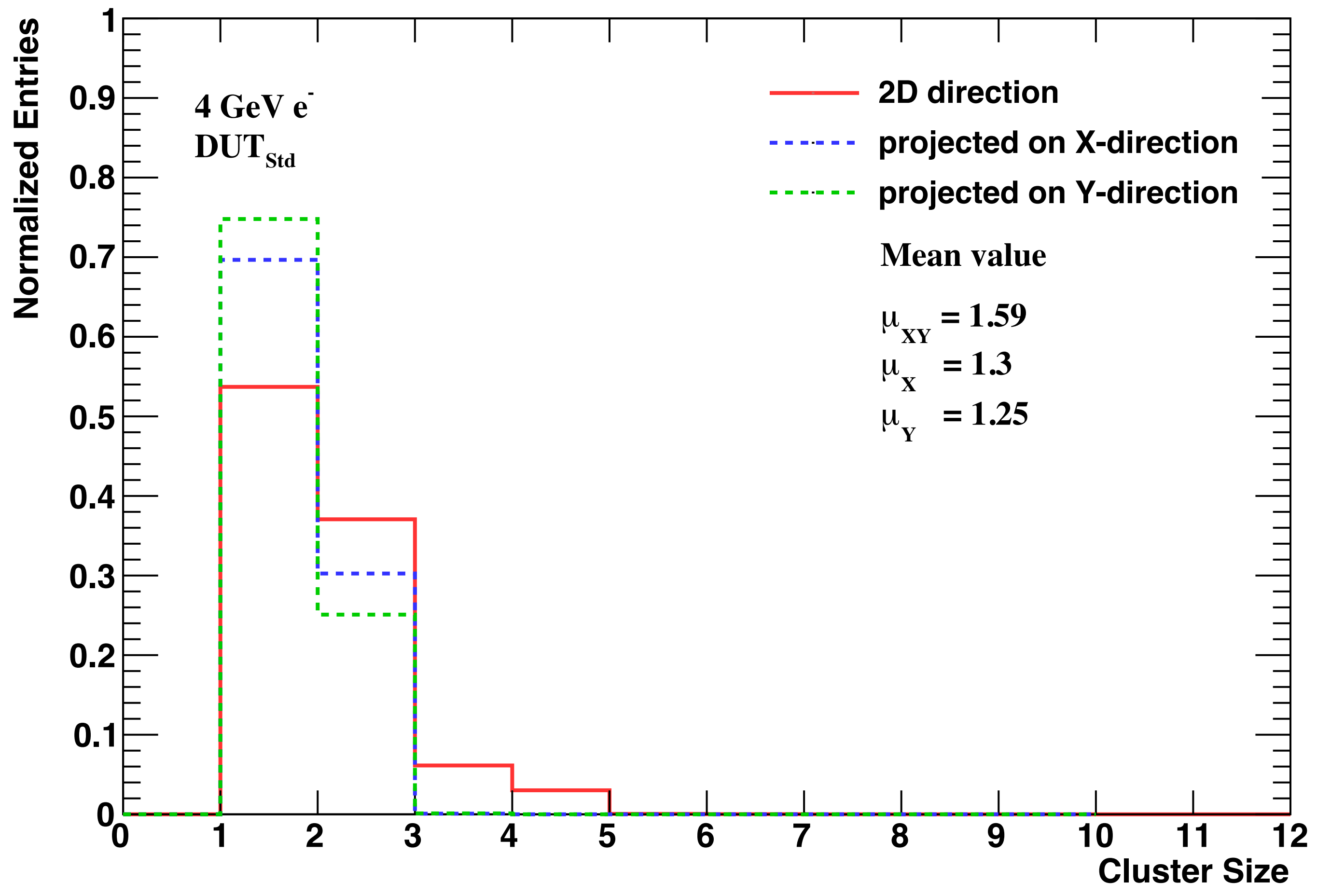


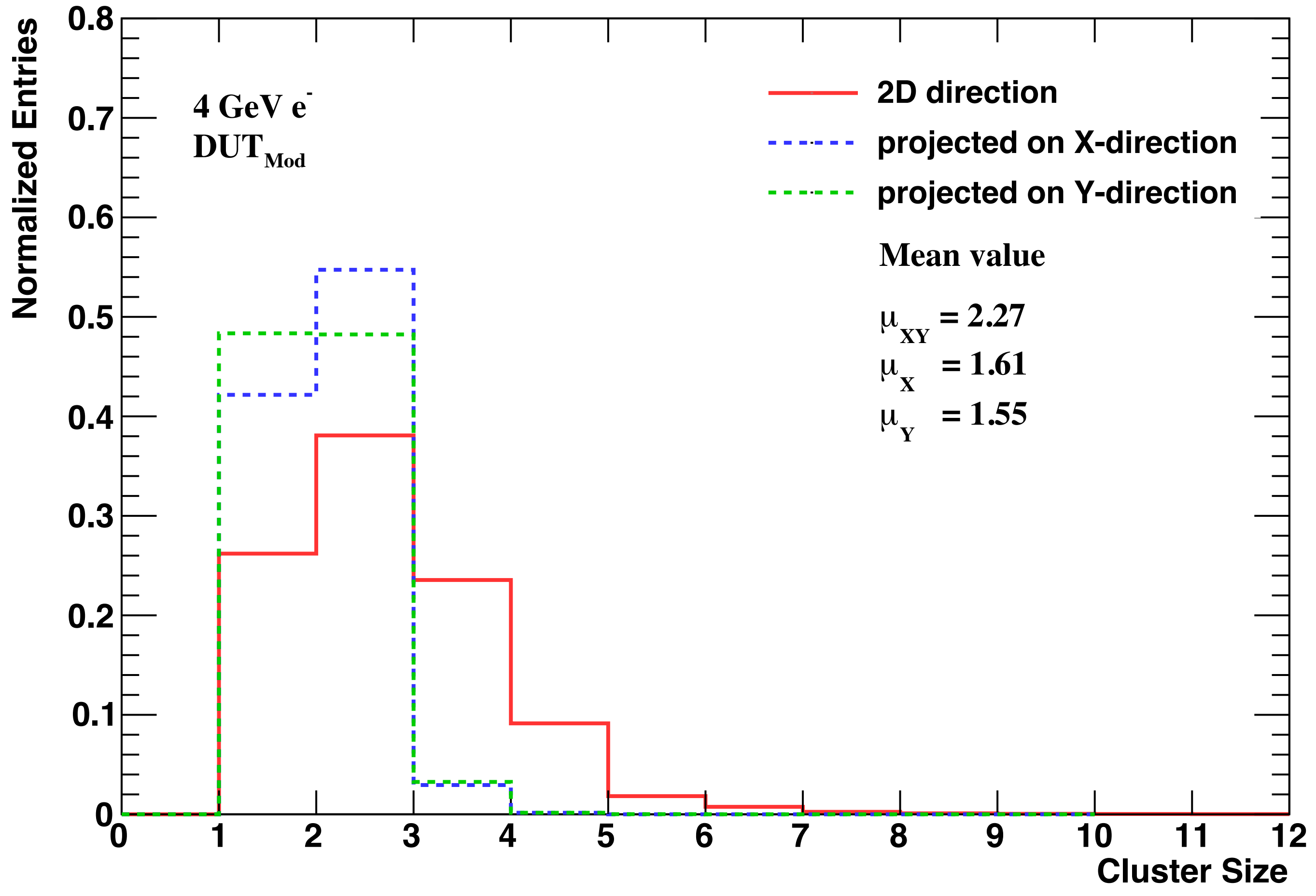




Cluster Size

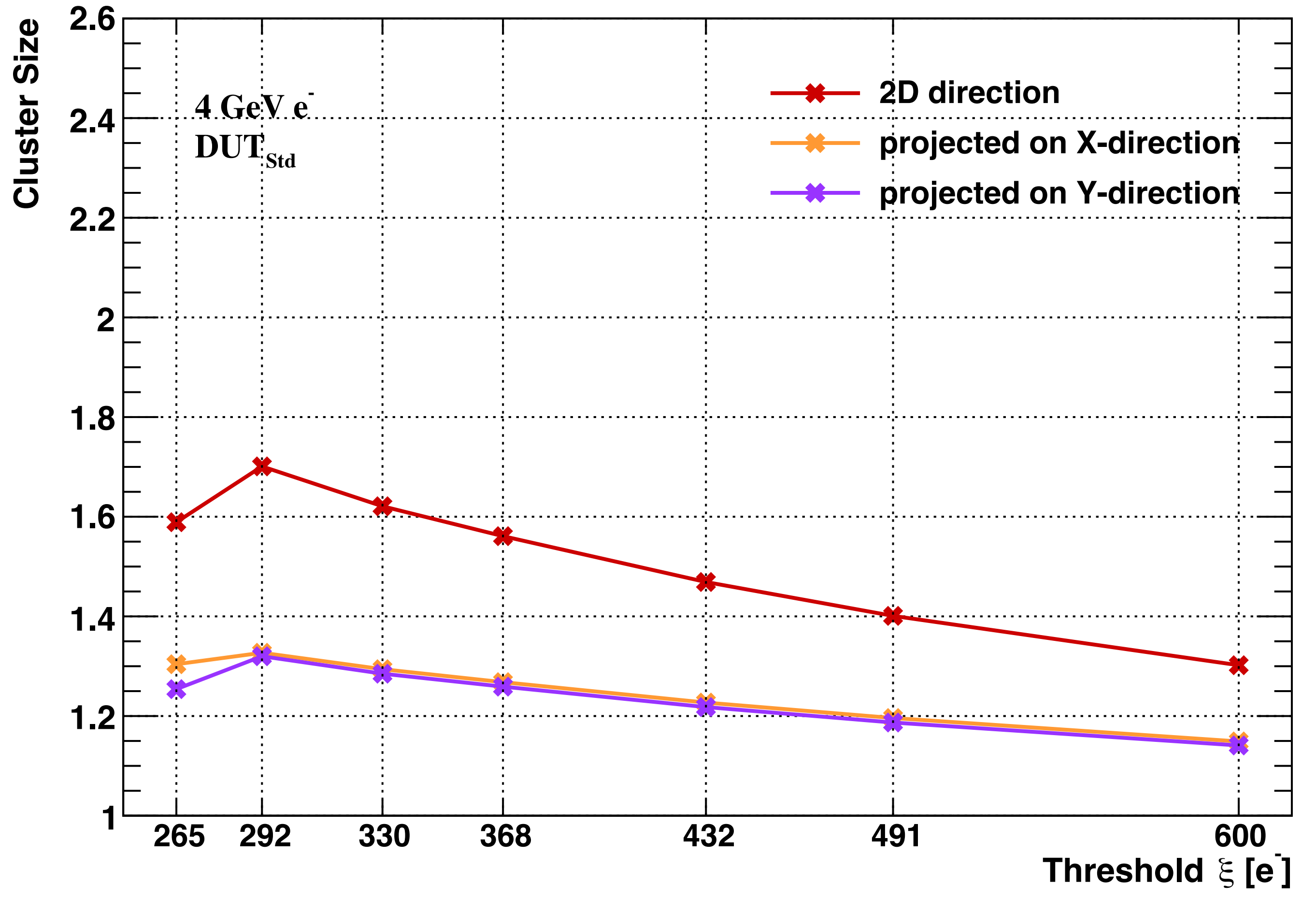
- Cluster size distribution

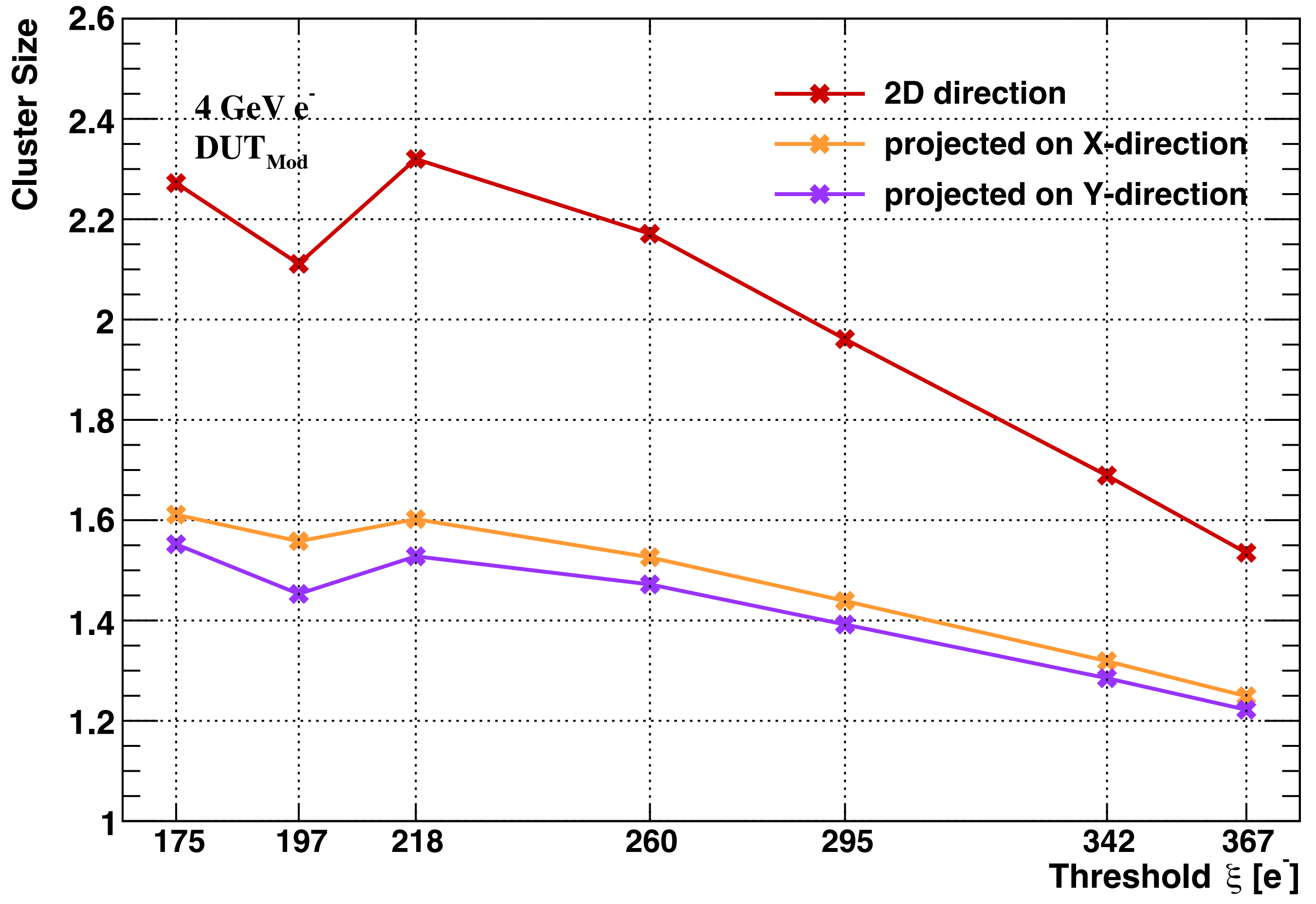




- under threshold $\xi_{std} = 265e^-$, $\xi_{mod} = 175e^-$ (minimum setting threshold)
- The peak value of cluster size of DUT_{std} is 1 pixel, ~2 pixel for DUT_{mod}

- Cluster size vs. threshold

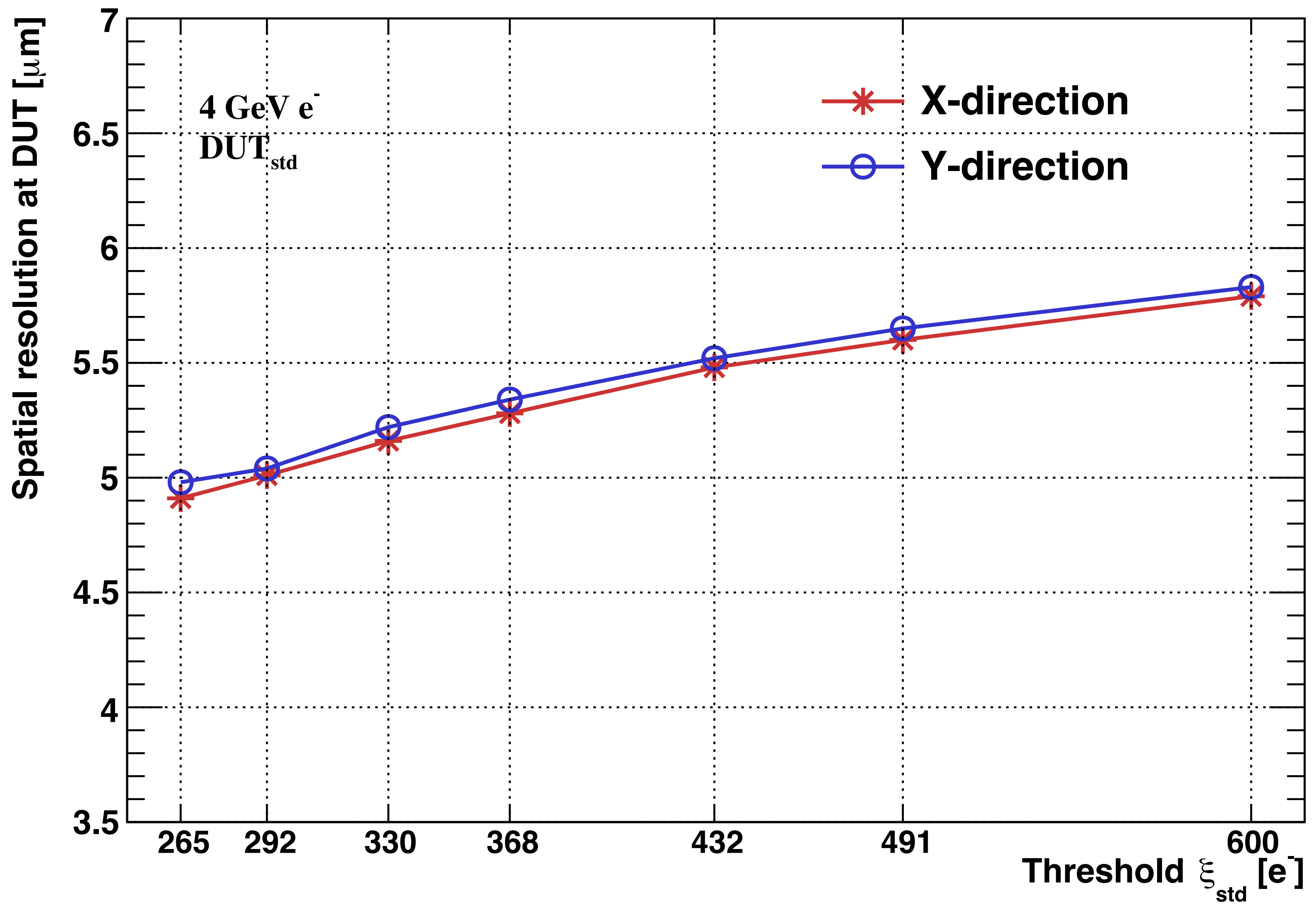


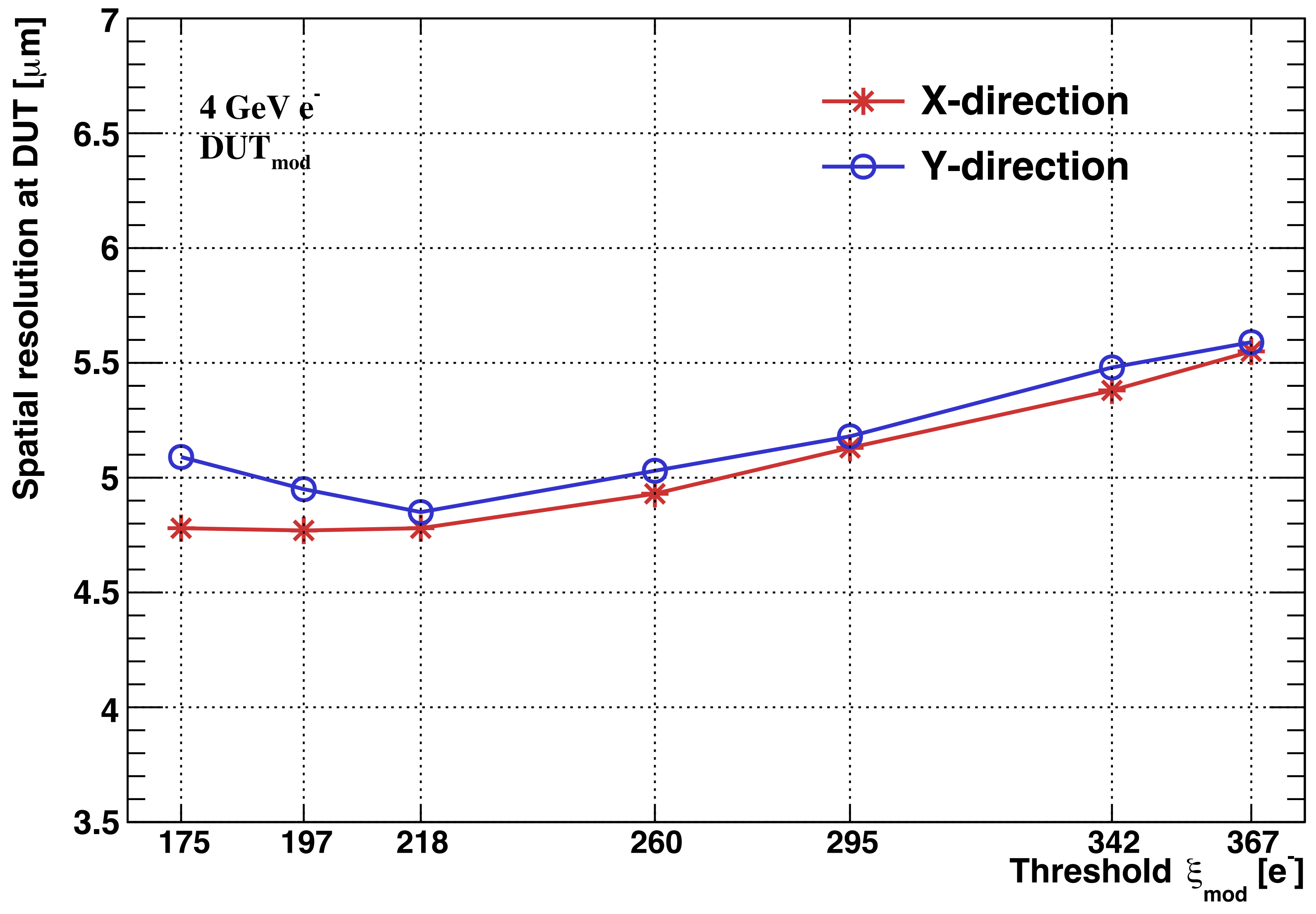


- DUT_{mod} with modified technology has a larger depletion layer than DUT_{std} with standard technology
- In general, the higher the threshold, the smaller the cluster size

Spatial resolution studies

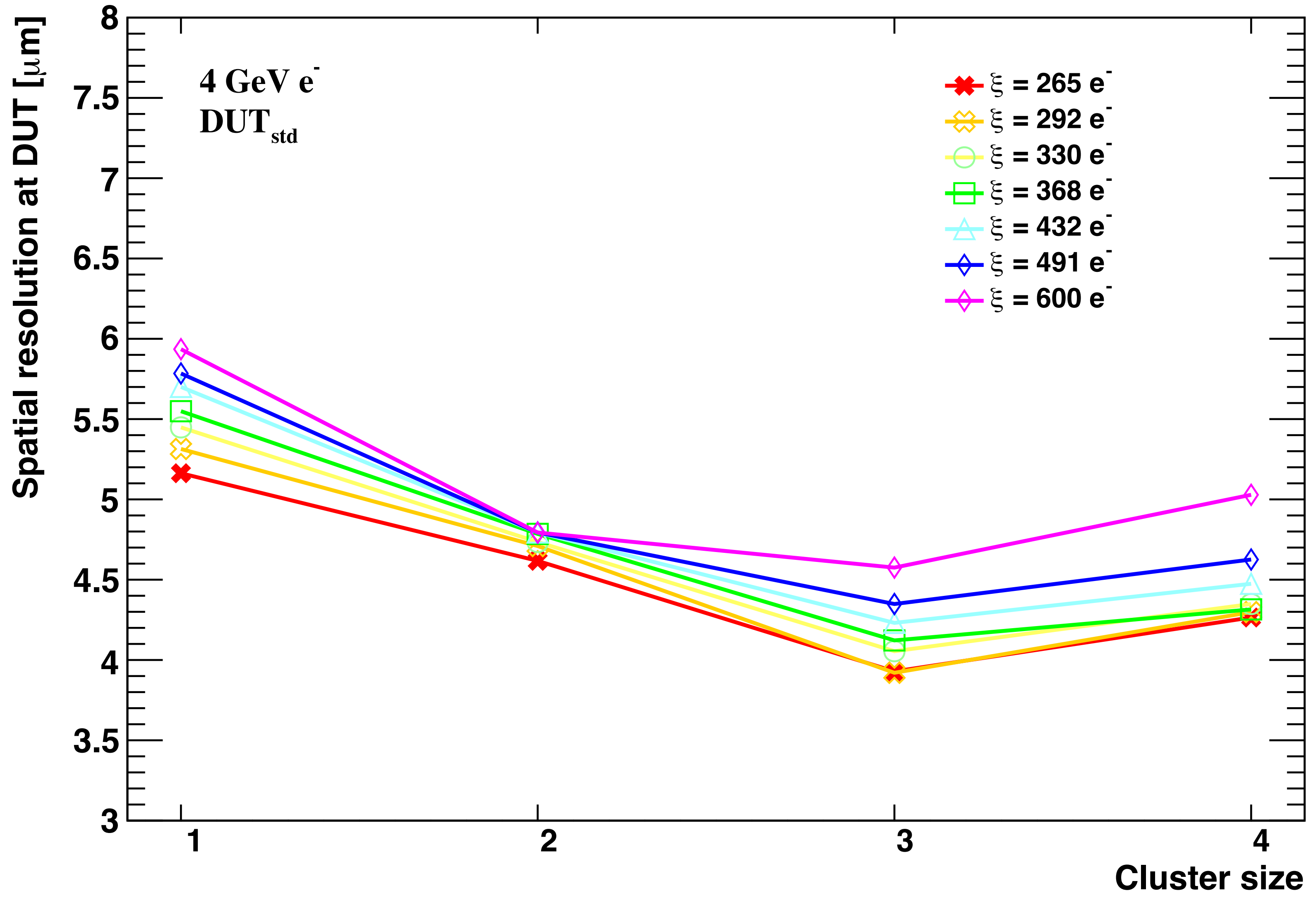
- Spatial resolution vs. threshold (4GeV)

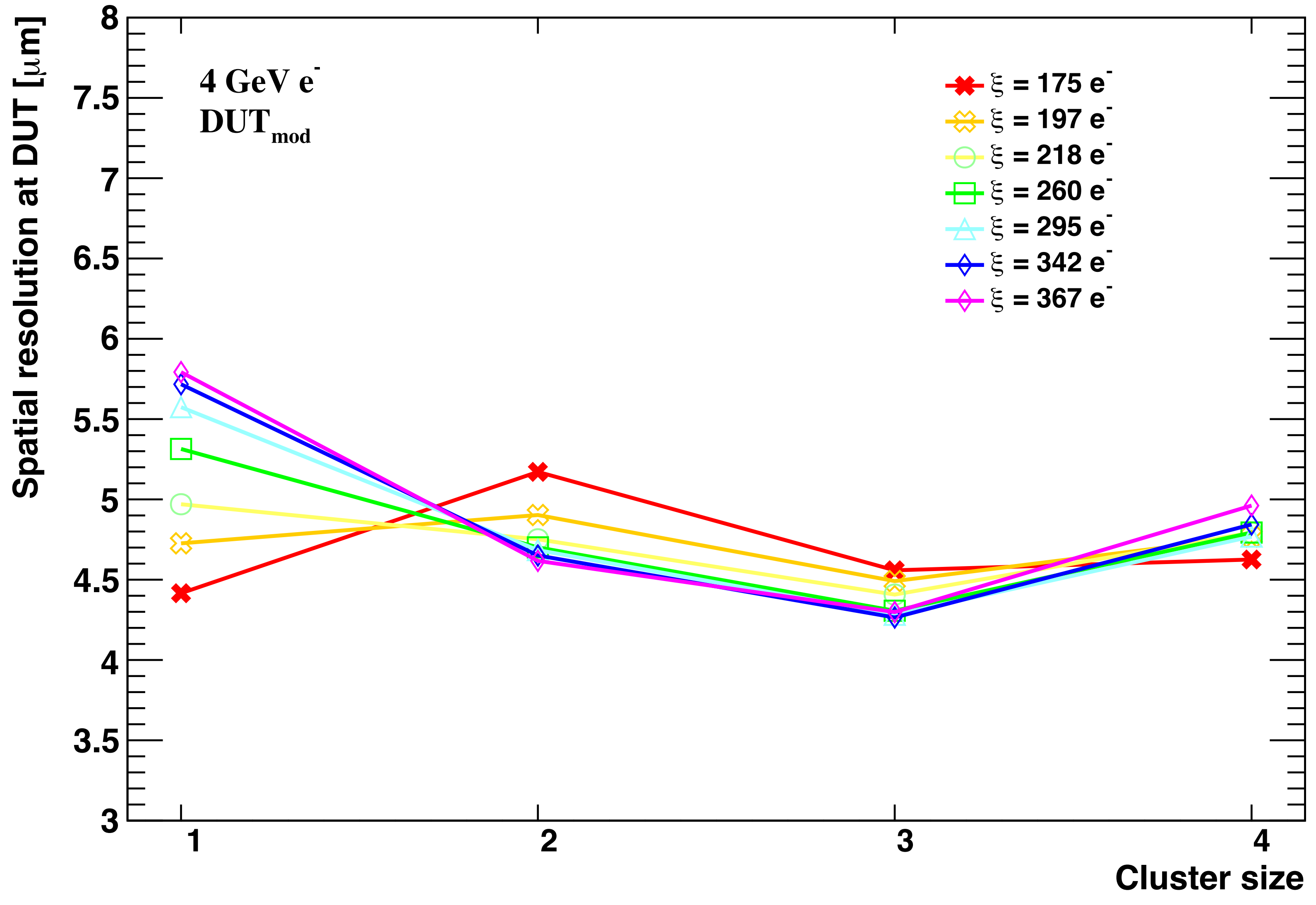




- $\sigma_{res}^{unbiased} = \sqrt{(\sigma_{DUT})^2 + k(\sigma_{tel})^2}$, k depends on the relative distance between the DUT and the telescope planes
- A track quality cut $\chi^2/ndf < 1$ applied
- With an increased threshold old, the spatial resolution gets worse
- For DUT_{mod}, a worse resolution also occurs when the threshold is lower than $\xi_{mod} = 218e^-$, which can be explained by the increased number of noise at lower threshold

‣ Spatial resolution vs. cluster size (4GeV)





resolution only in x-direction

- For most case, the resolution is best when cluster size = 3
- But, for DUT_{mod} with $\xi = 175e^-$ (minimum setting threshold), the best resolution when cluster size = 1, may due to the increasing noise on minimum threshold.
- For DUT_{std}, the resolution worse with the threshold increases in any case of cluster size
- For DUT_{mod}, the resolution better with the threshold increases in case of cluster size = 2 Or 3; the resolution worse with the threshold increases in case of cluster size = 1 Or 4

Preliminary results after correction for multi-scattering

- Using General broken lines package
  - refit correction for multi-scattering, equal to Kalman fitter in math
  - adding the silicon scatter (X/X0 = 150 um / 93.663 mm)
  - adding the possible scattering angle

$$\theta_0 = \frac{13.6MeV}{\beta cp} Z \sqrt{\frac{x}{X_0}} (1 + 0.038 ln(\frac{x}{X_0}))$$

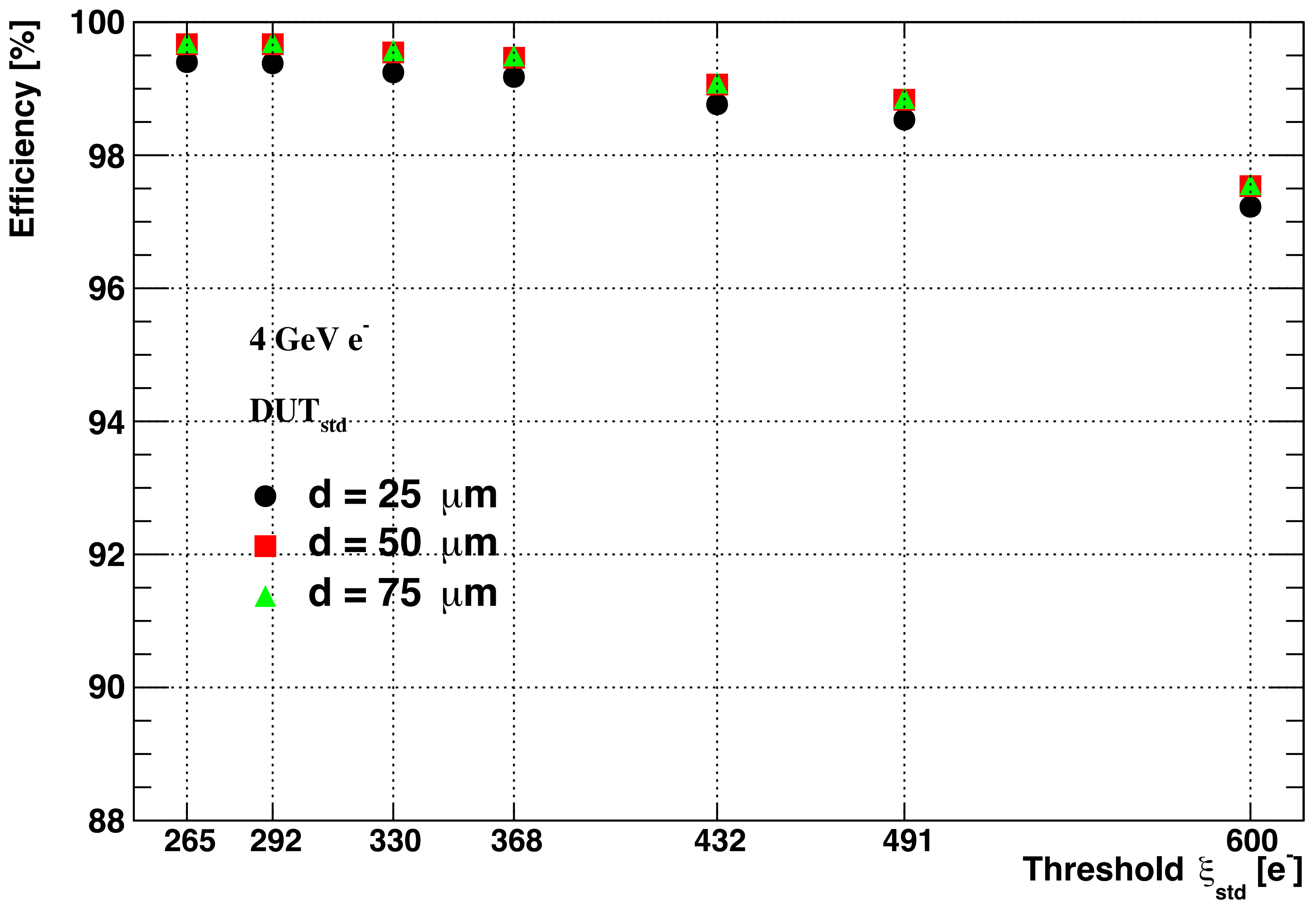
- std: standard process chip, mod: modified process
- SL: straight line fit, GBL: correction for multi-scattering
- No adding any cuts on tracks
- only list the residual width on x direction
- preliminary results, I still have several things need to be checked and understood …

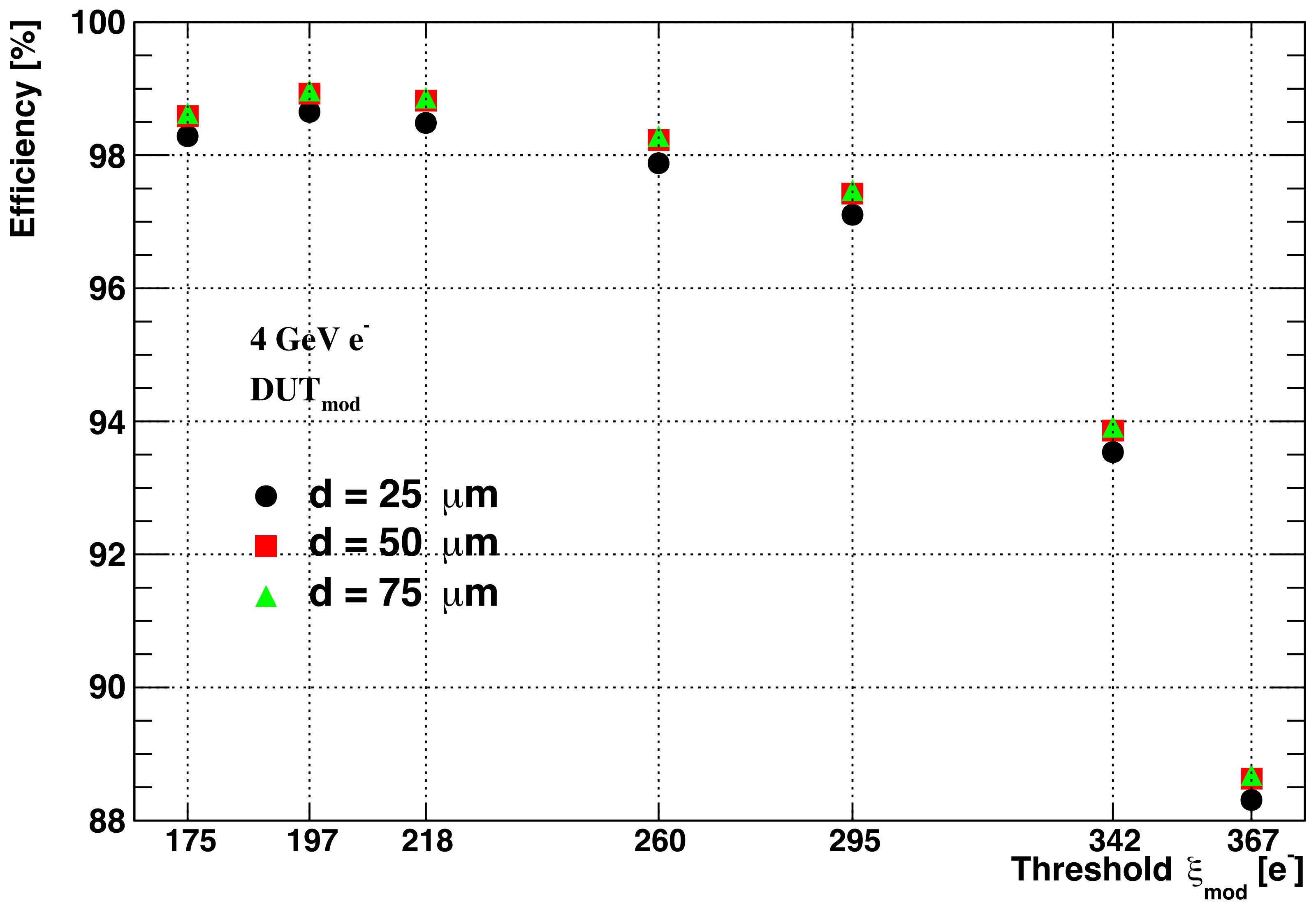
planeID	0 (std) thr = 16	1 (mod) thr = 64	2 (std) thr = 16	3 (mod) thr = 32	4 (std) thr = 96	5 (std) thr = 16
SL (biased)	5.87	4.71	6.13	6.23	5.42	5.99
GBL (biased)	3.52	4.33	4.53	4.6	4.96	3.69
SL (unbiased)	12.1	6.67	7.48	7.59	7.68	12.62
GBL (unbiased)	10.97	6.62	6.69	6.81	7.62	11.84

Efficiency

- Efficiency is the ratio of tracks that match the hit on the DUT within a distance d dddd around the predicted hit rom the telescope to all tracks of the telescope
- With increasing threshold, the efficiency decrease
- minimum eff. for DUT_{std} is 97%, minimum eff. for DUT_{mod} is 89%

$$\epsilon = \frac{N^{matched\ Tracks}_{|x_{meas},y_{meas} - x_{pre},y_{pre}|<d}}{N^{Tracks}_{tel}}$$





Summary

- The offline analysis for CEPC vertex detector testbeam data
- Next to do:
    - correct for multi-scattering
    - look at the kink angle

Backup