The Measurement of Position Resolution of RD53A pixel modules

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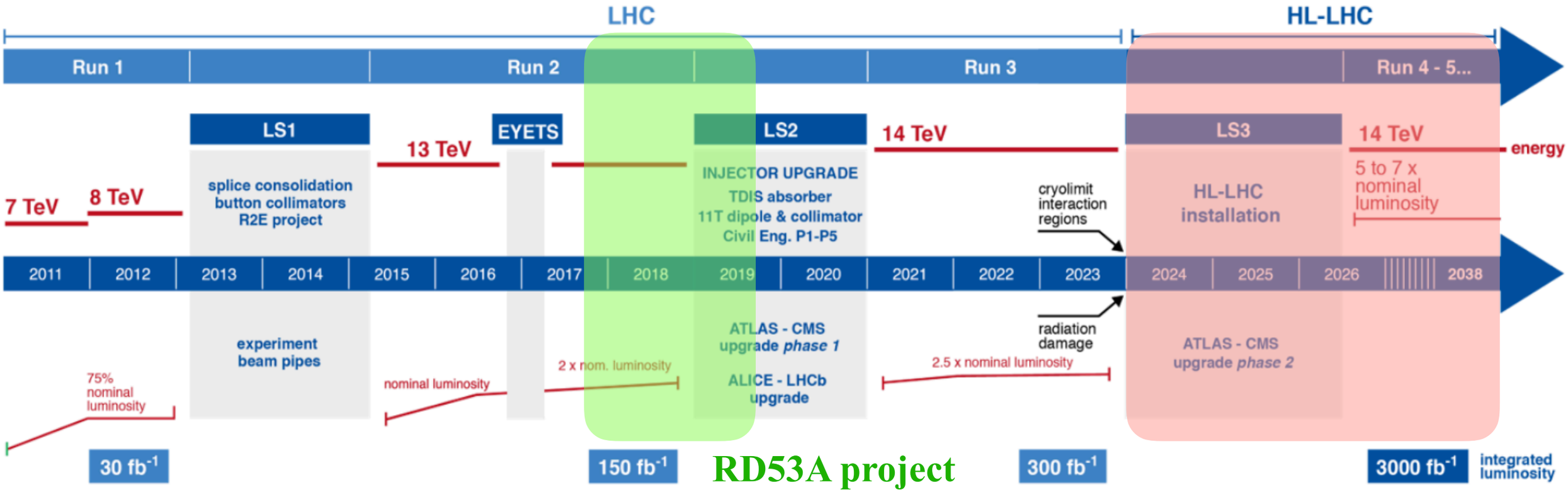
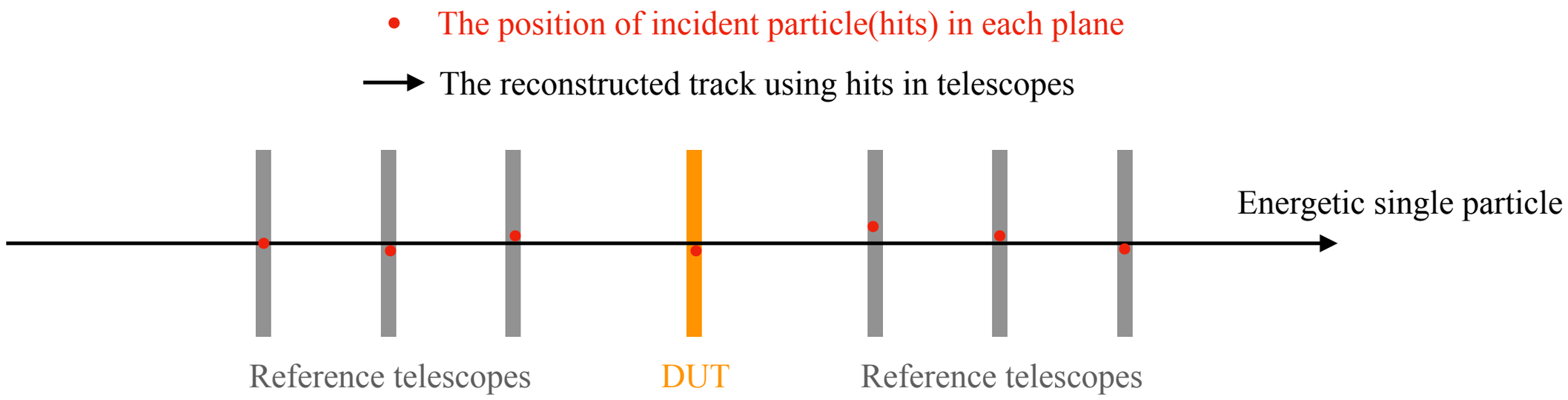
RD53A pixel modules



RD53A project

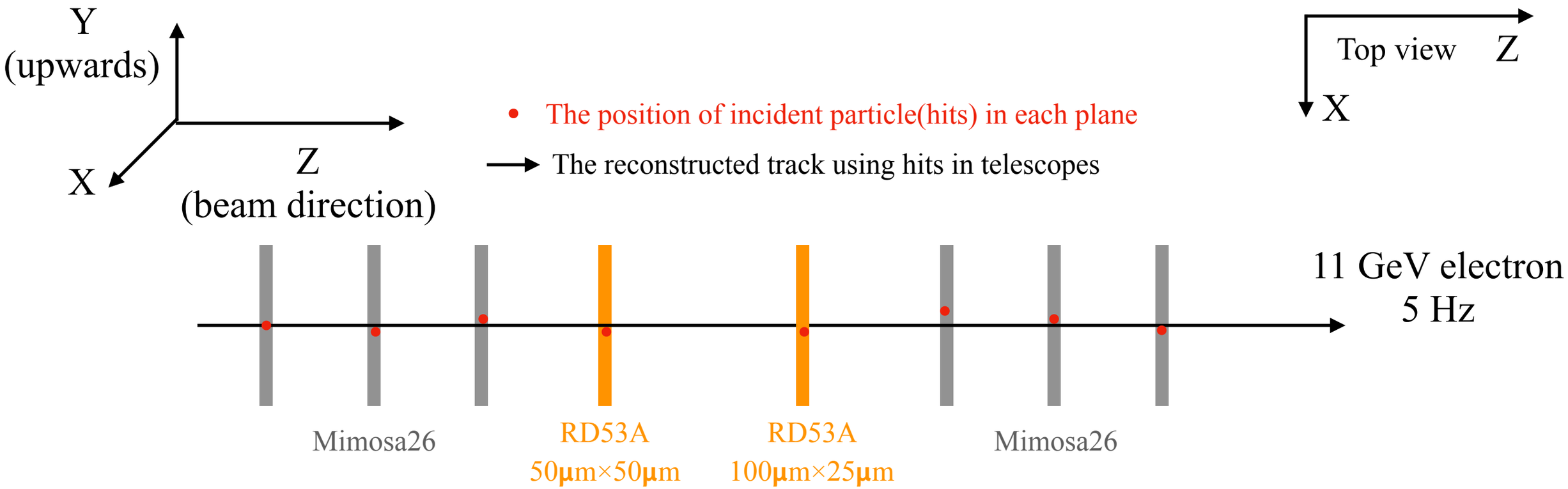
- Pixel detector upgraded for HL-LHC upgrades of ATLAS and CMS
- Demonstrate the suitability of the chosen 65nm CMOS technology
- Only for testing, forms the basis for the production designs

Testbeam setup



- The testbeam determines how devices under test (DUT) respond to a single particle passing through the active area
- Sensors in reference telescopes have better position resolution than DUTs
- Use hits in telescopes to reconstruct the track, and extract position resolution of DUT from the difference between track position and hit position on DUT

Testbeam at SLAC

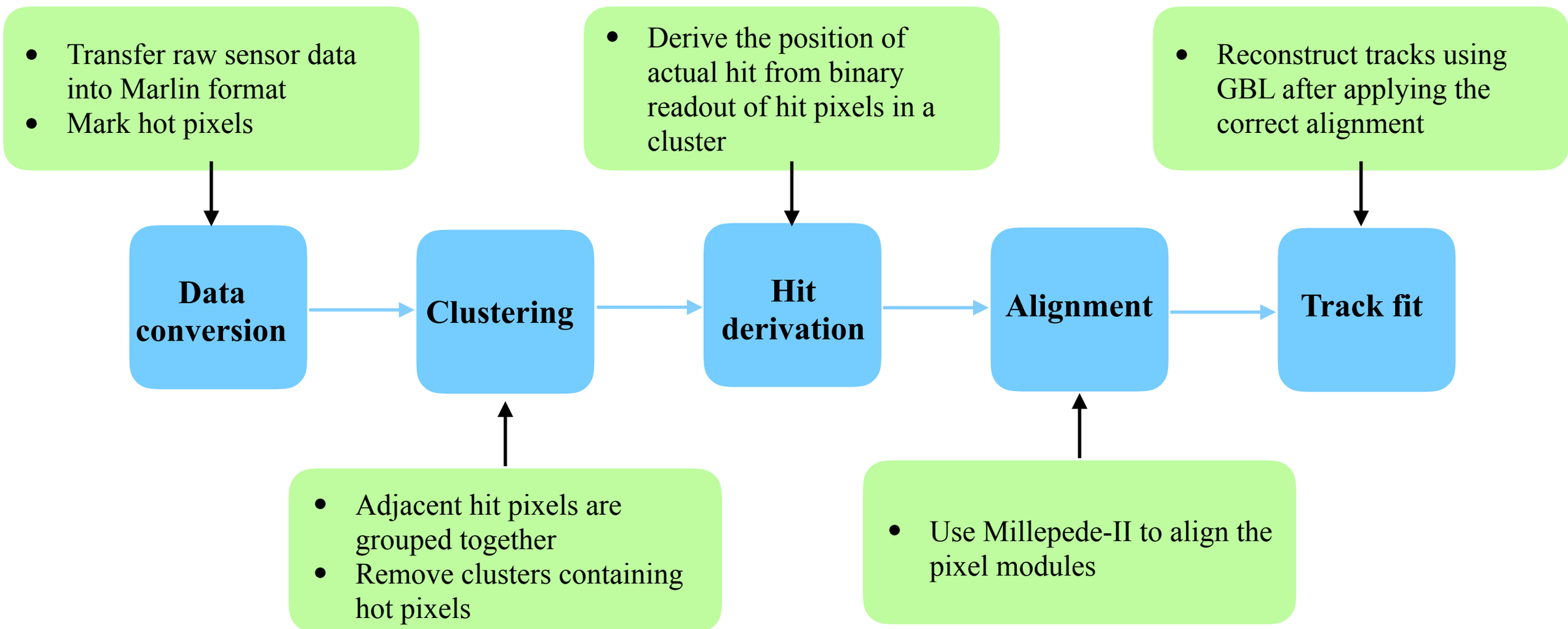


- Testbeam data is collected in November 2018 at SLAC
- Reference telescopes: Mimosa26 with 18.4**μ**m×18.4**μ**m pixel
- Two different device under test (DUTs): RD53A modules
  - ★ 50**μ**m×50**μ**m pixel
  - ★ 100**μ**m×25**μ**m pixel
- Data is collected by YARR (https://github.com/Yarr/Yarr)

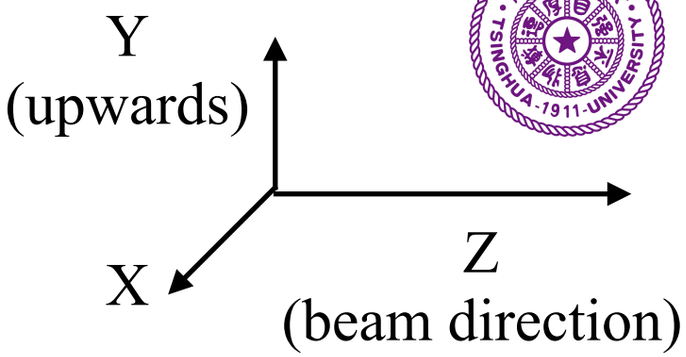
The Offline testbeam analysis

- **EUTelescope v2.0.0** is a very generic and versatile collection of **Marlin(Modular Analysis & Reconstruction for the Linear Collider)** processors, dedicated to processing of testbeam data

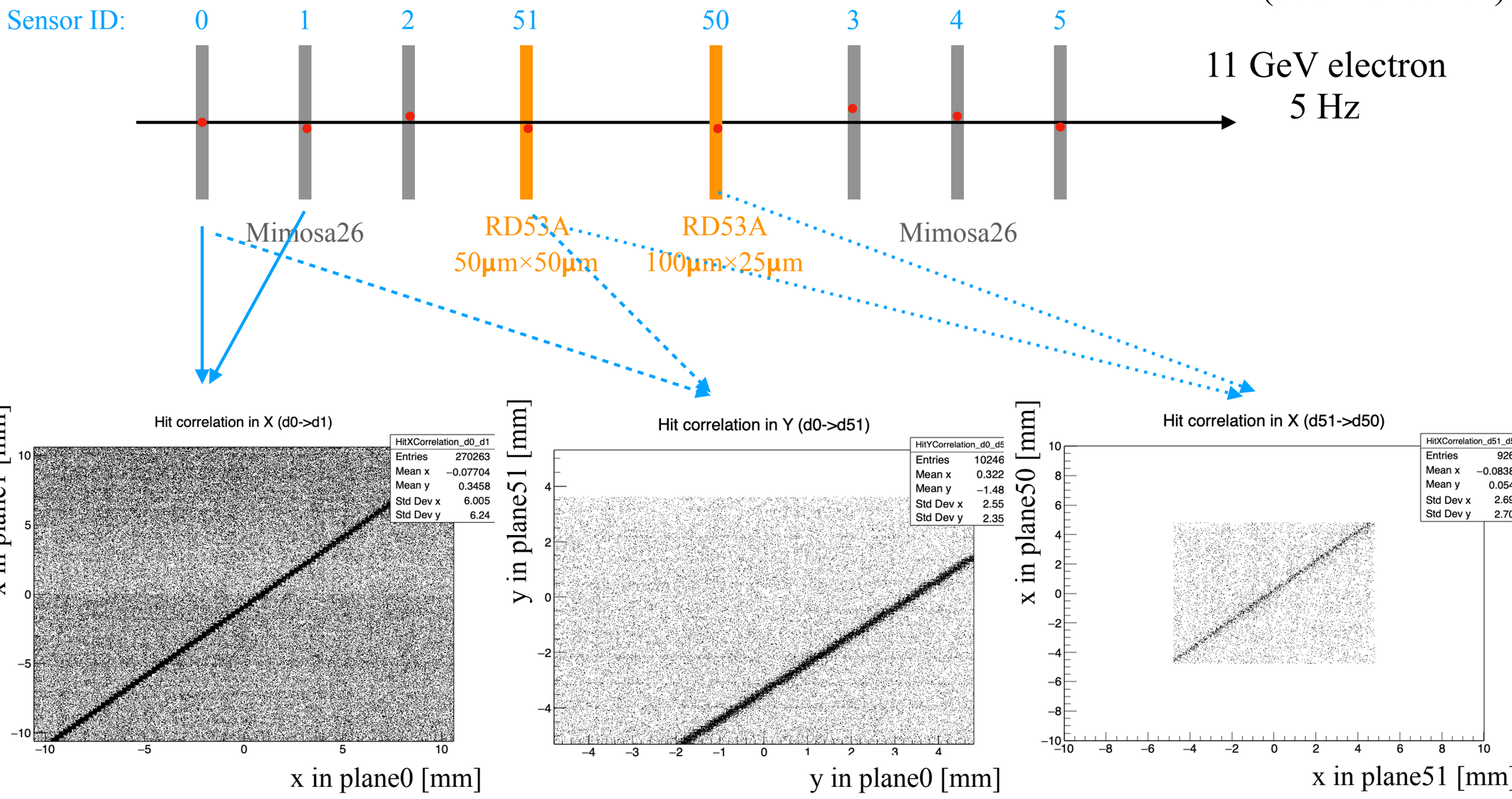
- Track reconstruction algorithm: General Broken Lines(GBL) fitter (https://www.terascale.de/wiki/generalbrokenlines/)



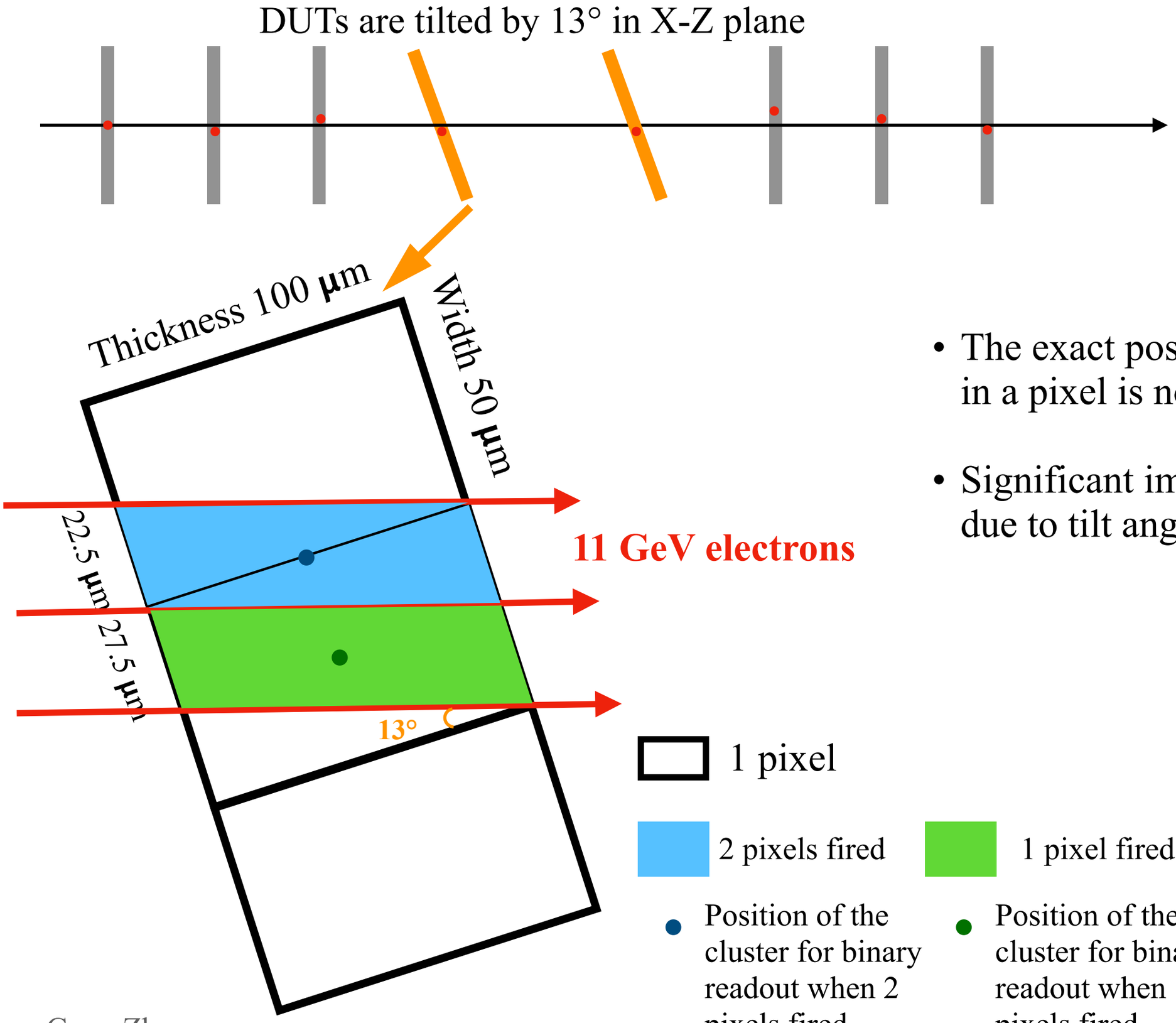
Correlation of hits between 2 planes



- The position of incident particle(hits) in each plane
- The reconstructed track using hits in telescopes

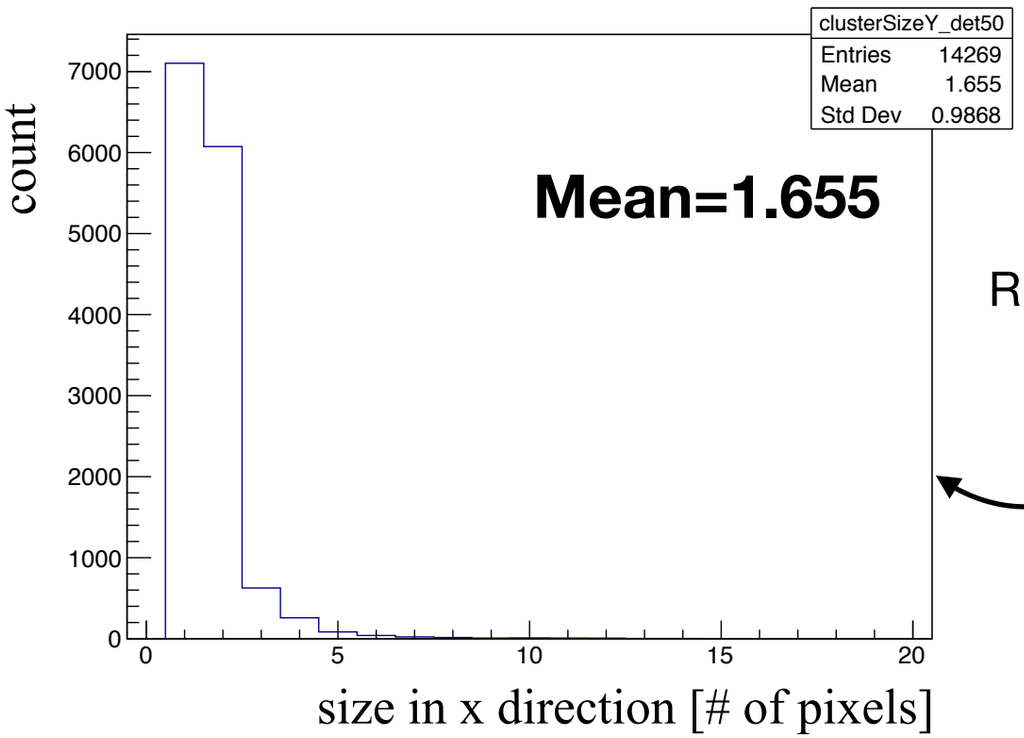


Effect from tilt angle

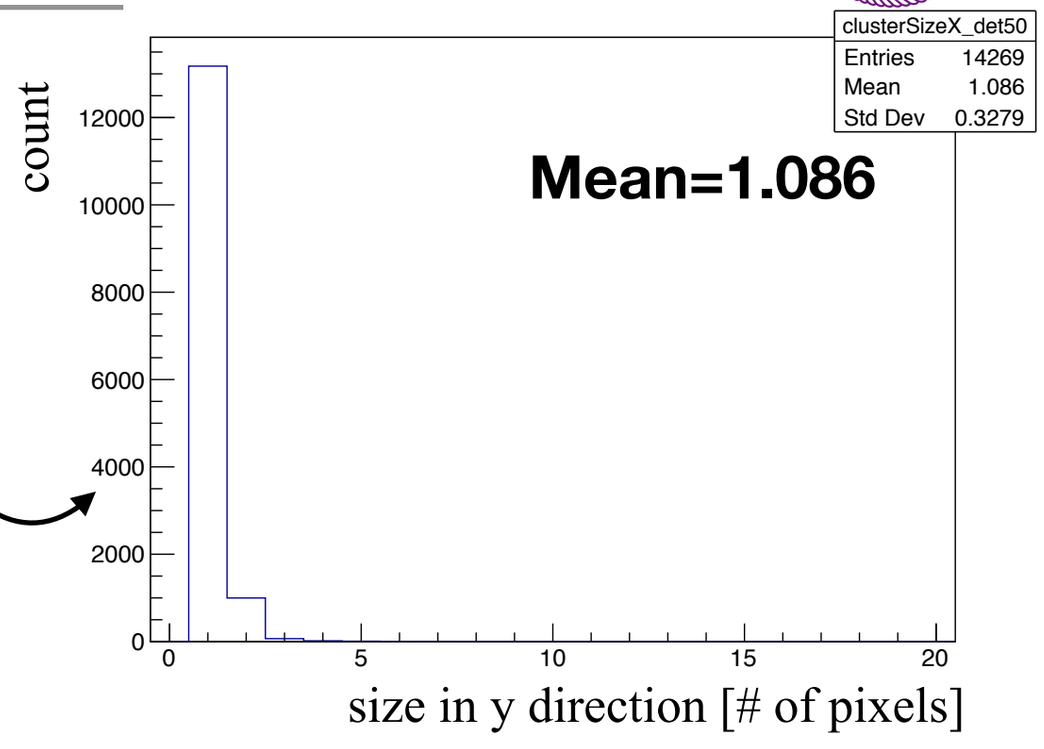


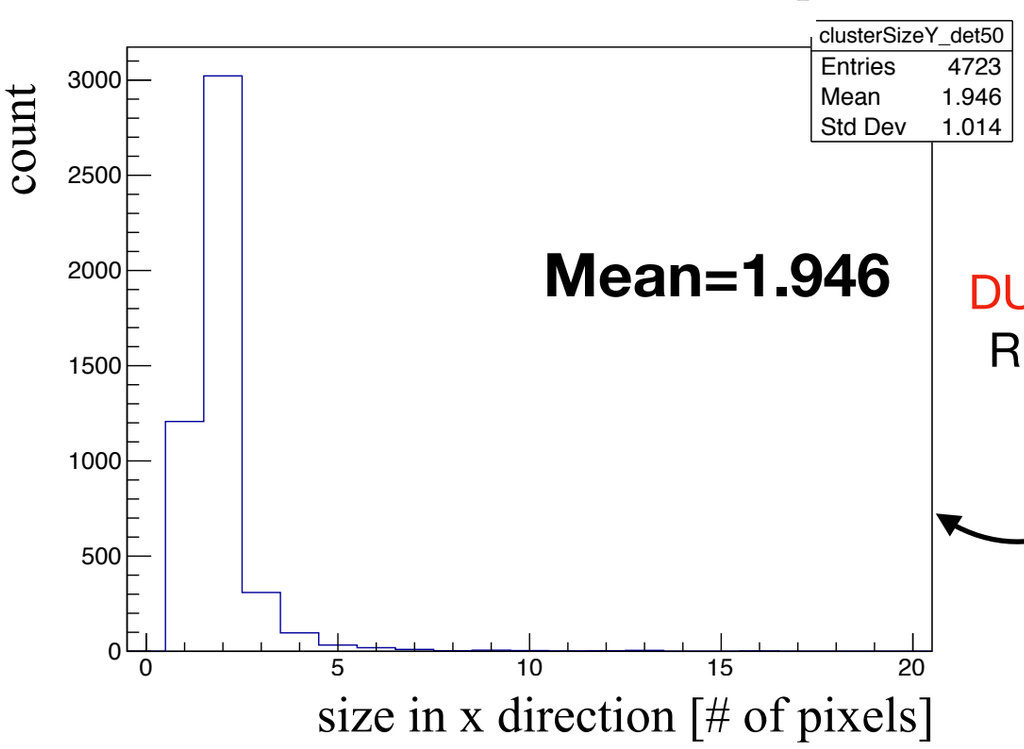
- The exact position of incident particle in a pixel is not resolvable
- Significant improvement in resolution due to tilt angle

Cluster size

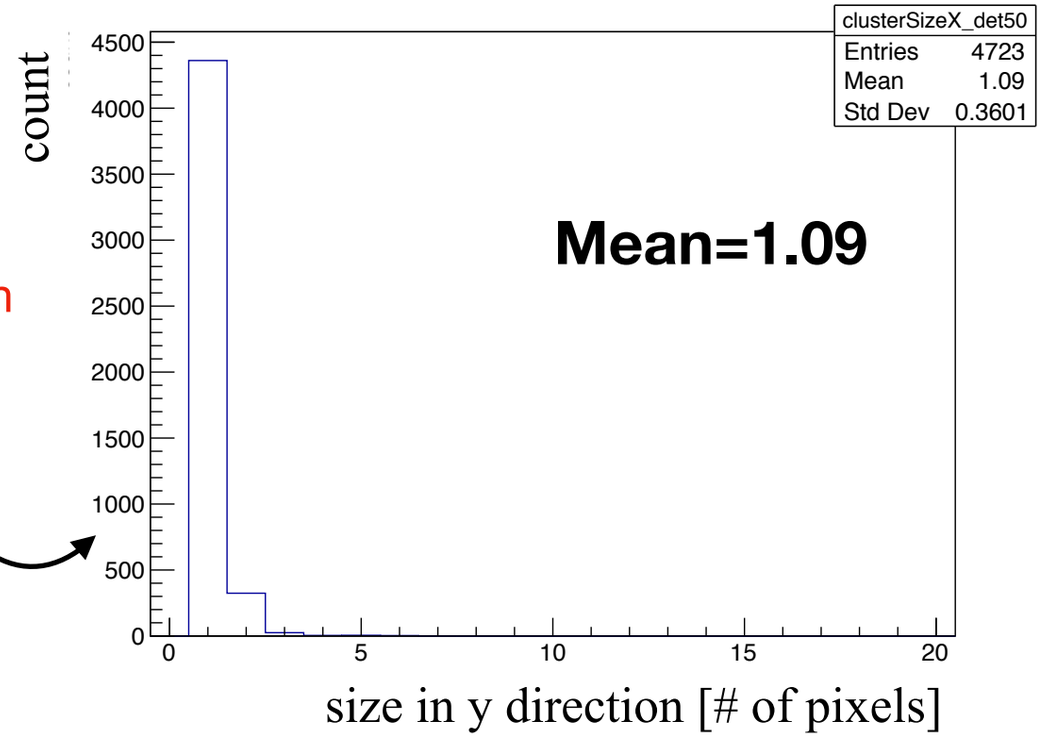


Non-tilted DUT
RD53A 25μm×100μm





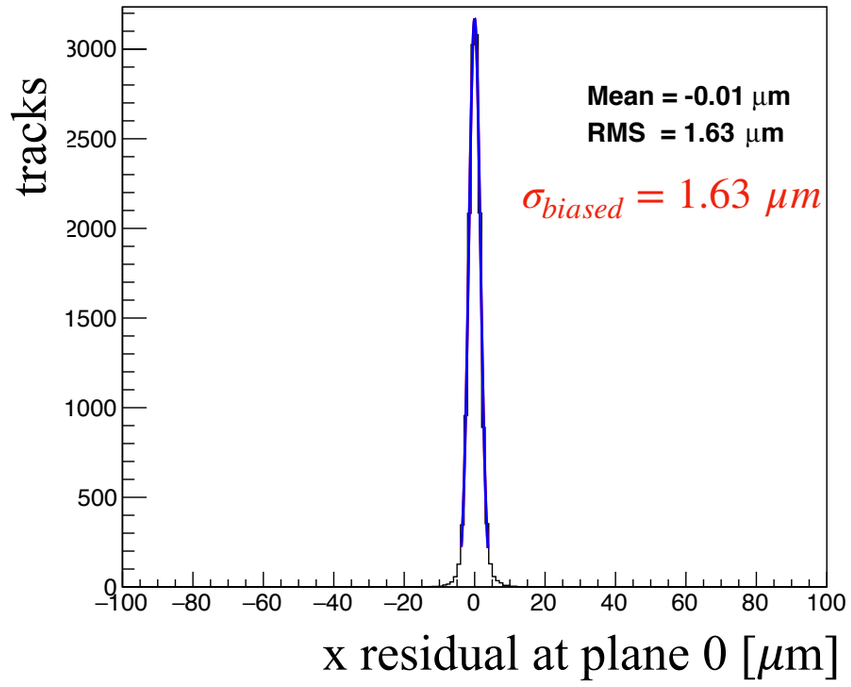
DUT tilted in x direction
RD53A 25μm×100μm

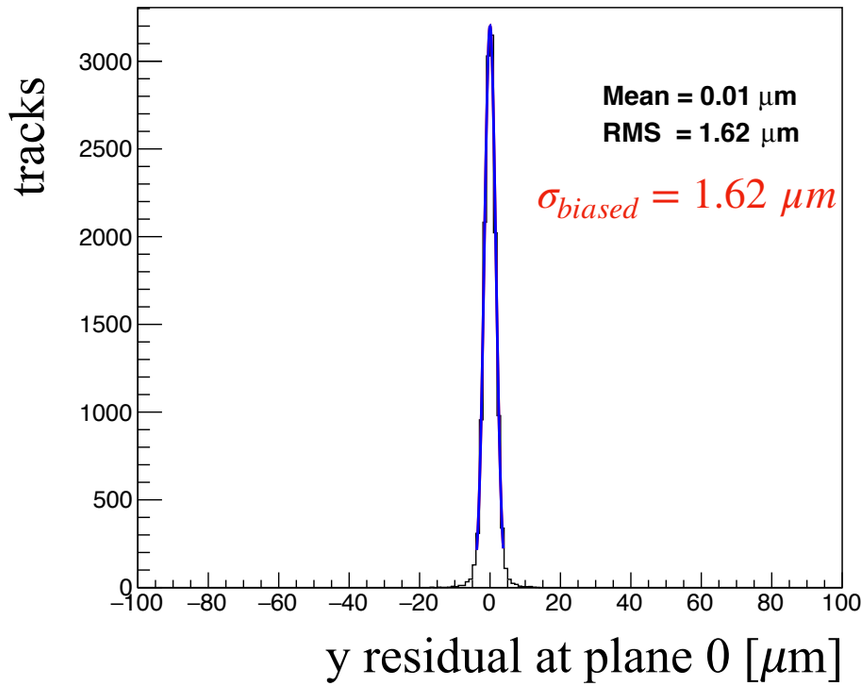


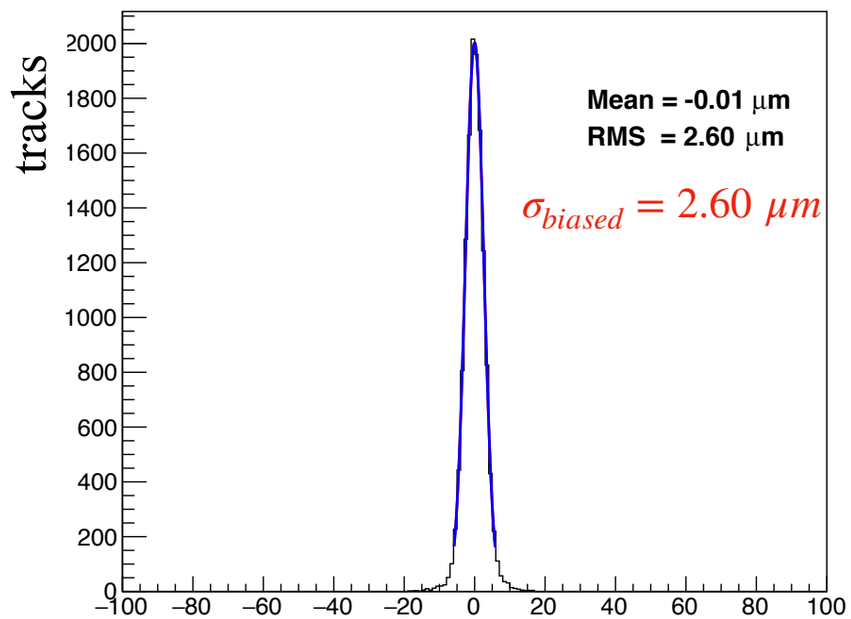
- The larger cluster size in tilted direction demonstrates the smaller equivalent pixel width

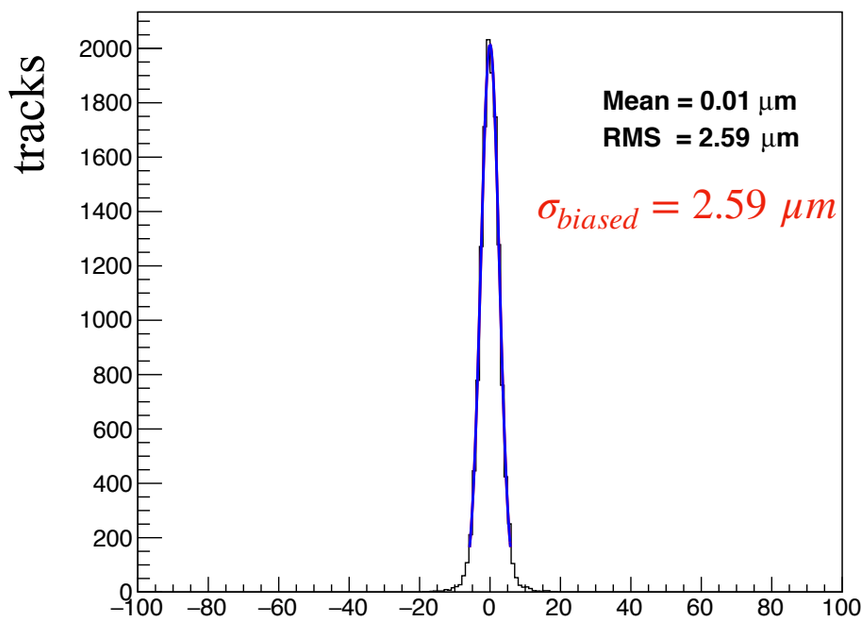
Position resolution (Mimosa26)

- residual = hit position - track position
- Biased residuals as hits on Mimosa26 are used in track fitting
- $\sigma^2_{biased} = \sigma^2_{intrinsic} - \sigma^2_{tracking}$



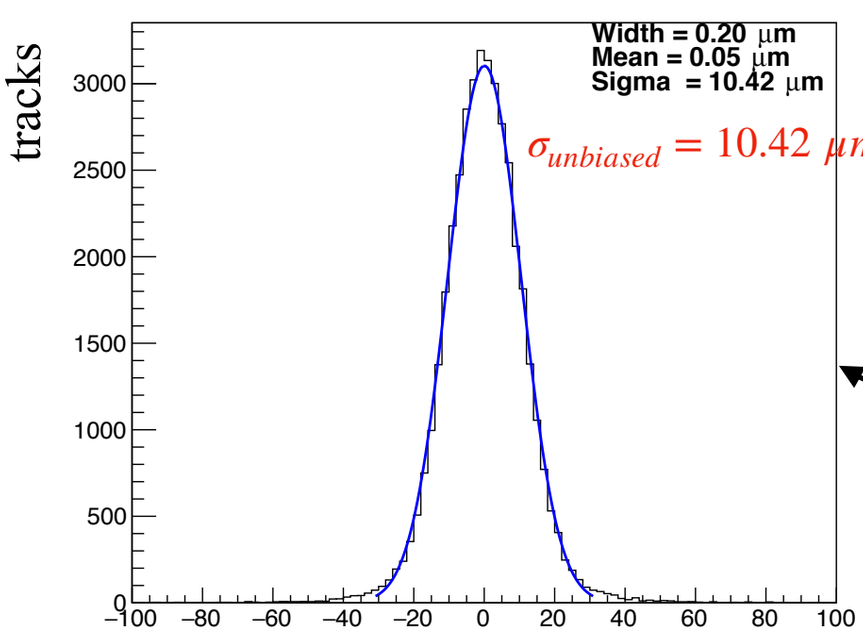




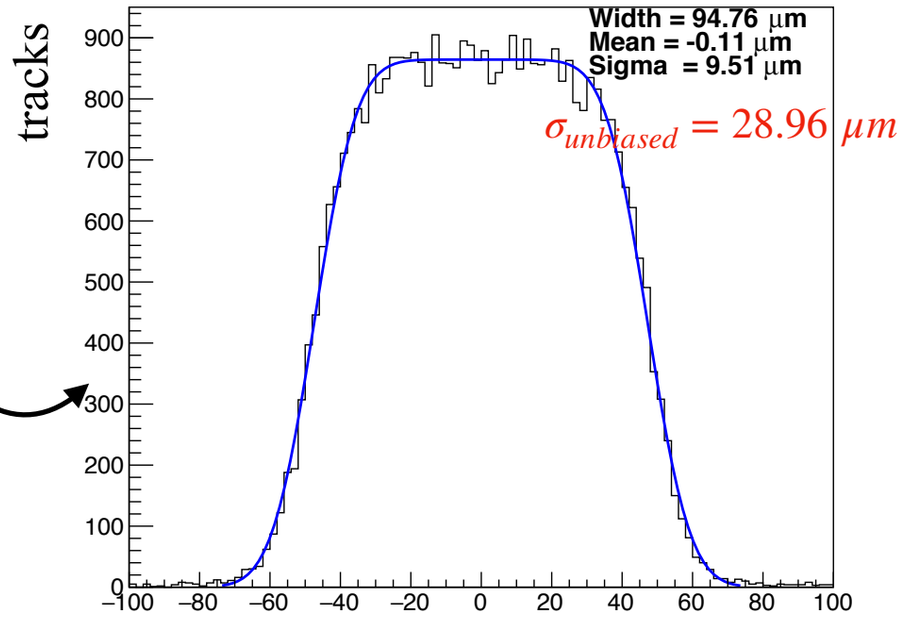


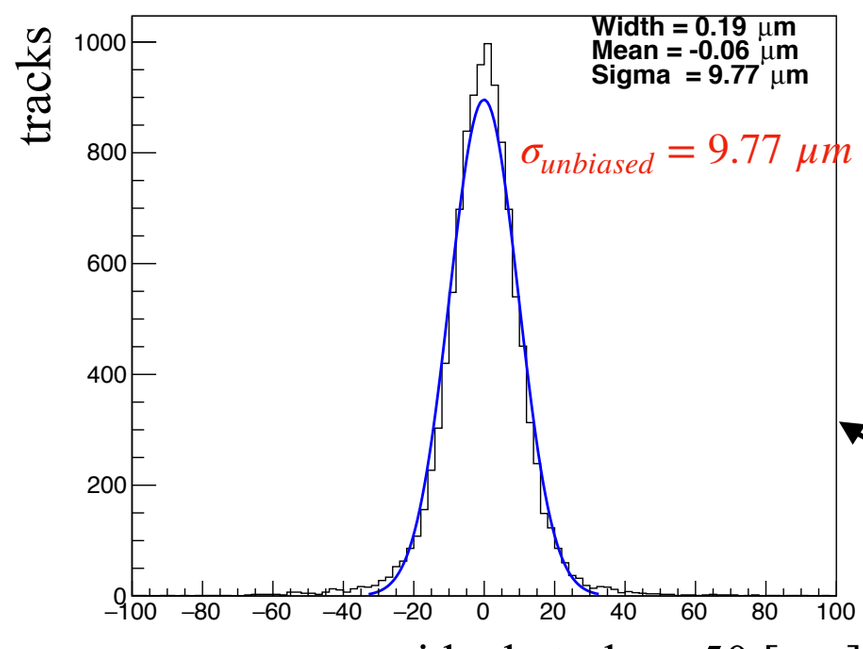
Position resolution (RD53A)

- Unbiased residuals as hits on DUTs are excluded in track fitting $\sigma^2_{unbiased} = \sigma^2_{intrinsic} + \sigma^2_{tracking}$
- Fit function = Box(width) convolved with Gaussian (Mean,Sigma)
- $\sigma^2_{unbiased}(DUTs) = width^2/12 + sigma^2$

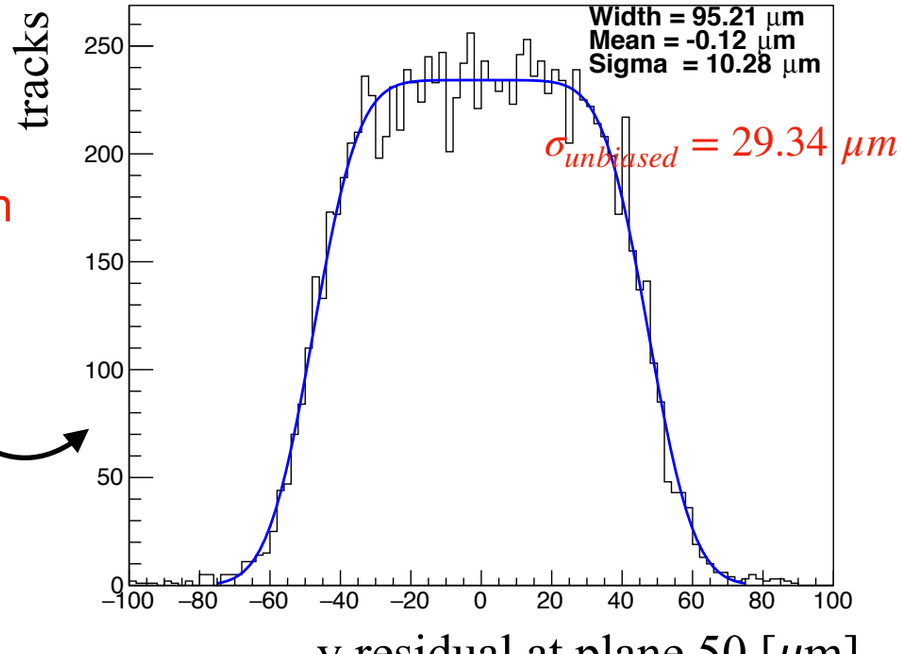


Non-tilted DUT
RD53A 25μm×100μm



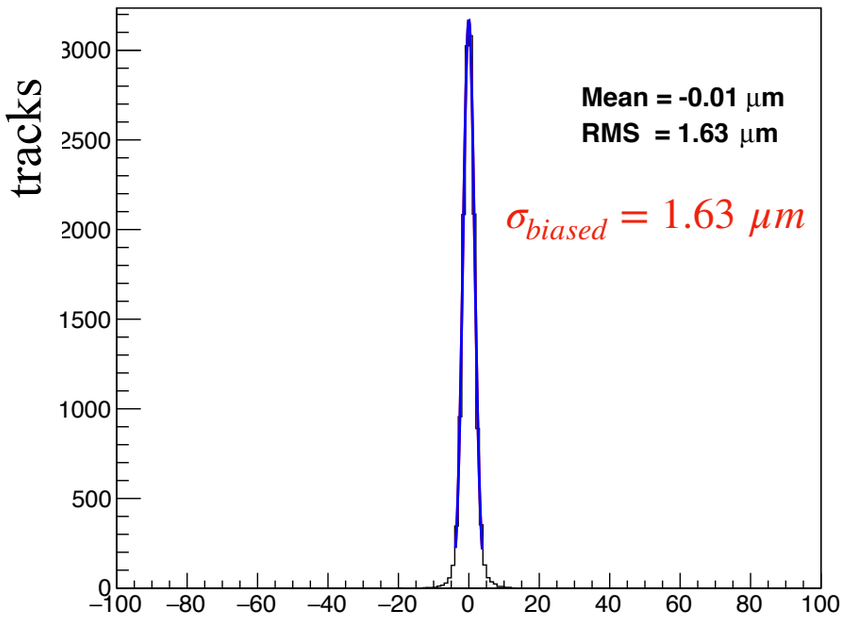


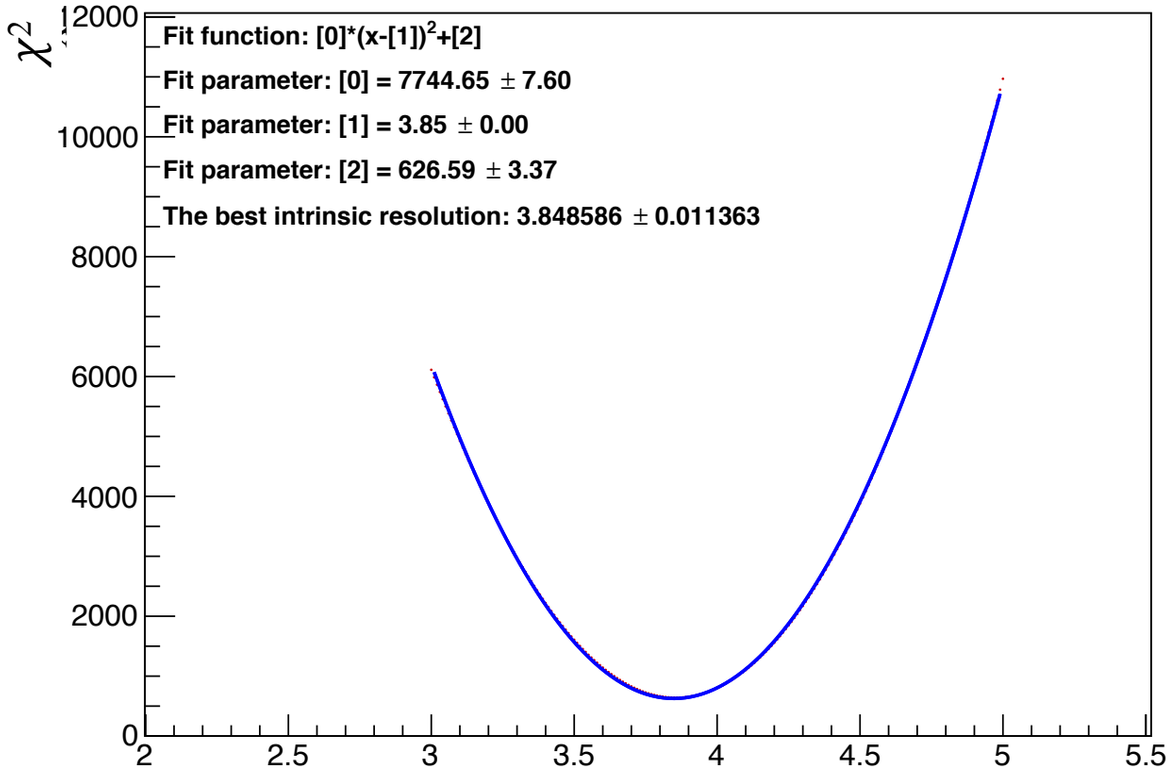
DUT tilted in x direction
RD53A 25μm×100μm



Tracking resolution on DUTs

- Track-resolution-simulator: https://github.com/simonspa/resolution-simulator/tree/master
- The same geometry of SLAC testbeam setup
- Need intrinsic resolution of Mimosa26 as input





Measured

Measured

Scanned

Simulated

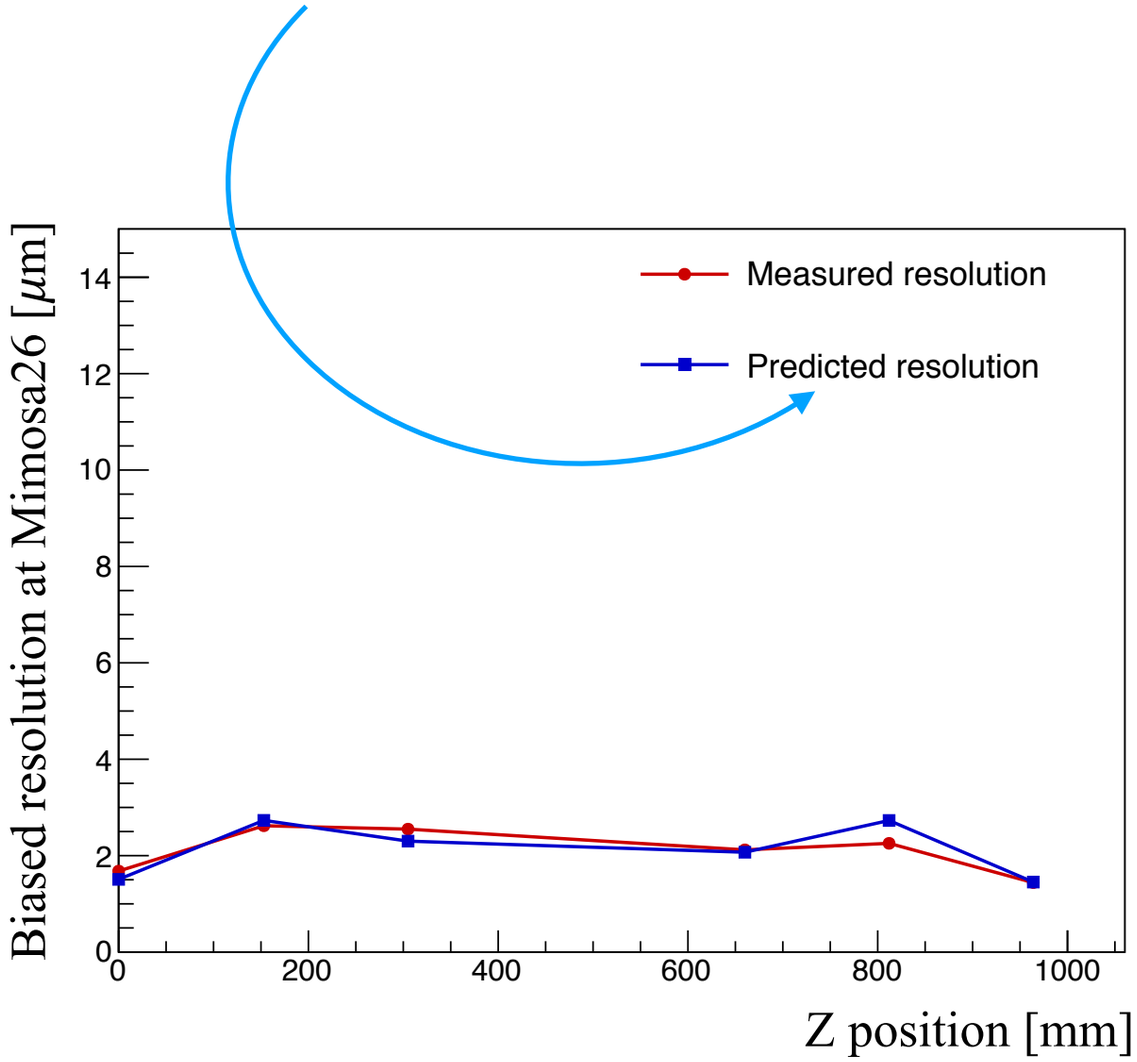
$$\chi^2 = \Sigma_i \frac{(\sigma_{biased,i} - \sqrt{\sigma^2_{intrinsic} - \sigma^2_{track,i}})^2}{V[\sigma_{biased,i}]}$$

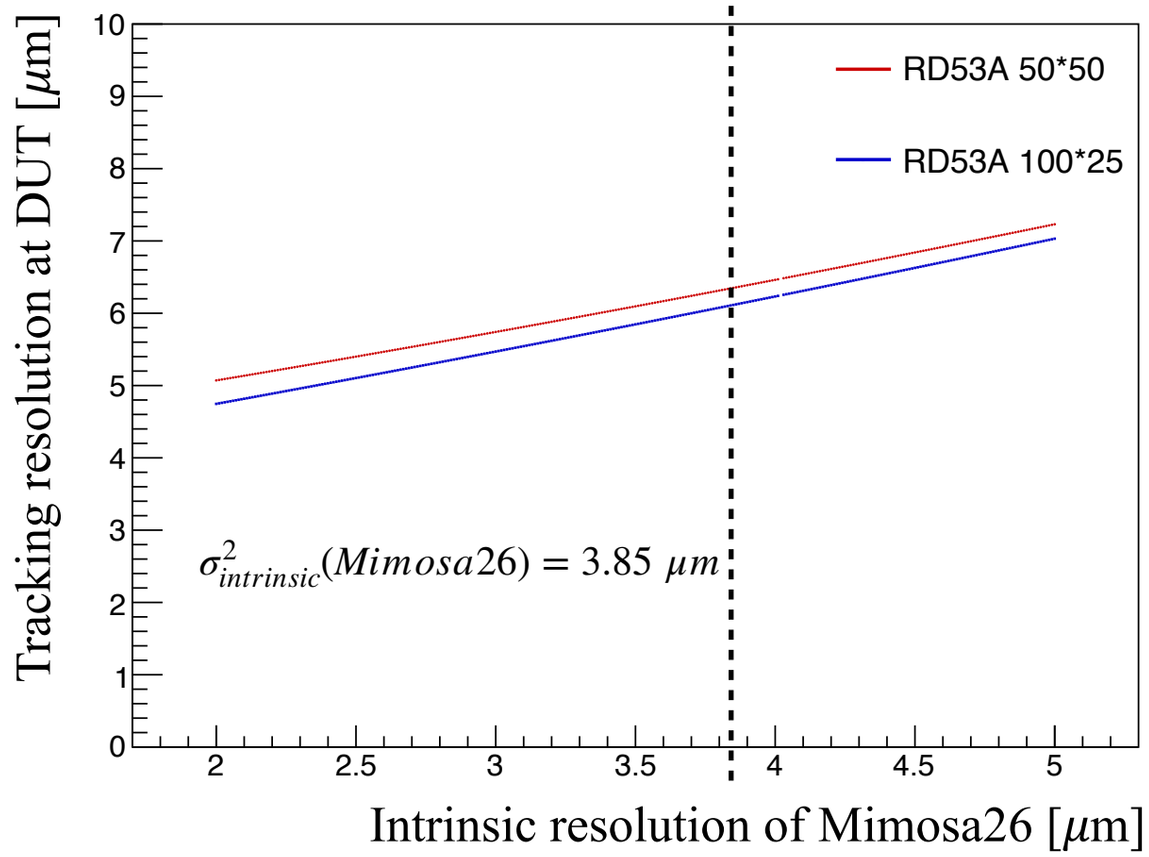
i are the six mimosa26

Tracking resolution on DUTs

- The intrinsic resolution of Mimosa26 is measured as 3.85 **μ**m

$$\sigma^2_{biased}(Mimosa26) = \sigma^2_{intrinsic}(Mimosa26) - \sigma^2_{tracking}(Mimosa26) = 3.85^2 - \sigma^2_{tracking}(Mimosa26)$$





Results

- The position resolutions of non-tilted RD53A modules are both comparable with $pitch/\sqrt{12}$

  pitch: the length or width of a pixel

- RD53A modules with 50×50 **μ**m^2 benefit more from 13° tilt angle

- Systematics include uncertainty of material estimation, beam energy, tracking resolution and Z position of DUTs

	RD53A 50μm×50μm non-tilted side(50μm)	RD53A 50μm×50μm tilted side(50μm)	RD53A 100μm×25μm non-tilted side(100μm)	RD53A 100μm×25μm tilted side(25μm)
$pitch/\sqrt{12}$	14.4	14.4	28.8	7.2
Non-tilted	14.51 ± 1.05	14.58 ± 1.04	28.16 ± 0.67	7.92 ± 1.73
13° tilted	14.04 ± 1.07	10.86 ± 1.09	28.54 ± 0.75	6.81 ± 1.82
$\frac{Non-tilted}{13^\circ\ tilted}$	0.97 ± 0.10	0.74 ± 0.09	1.01 ± 0.04	0.86 ± 0.30

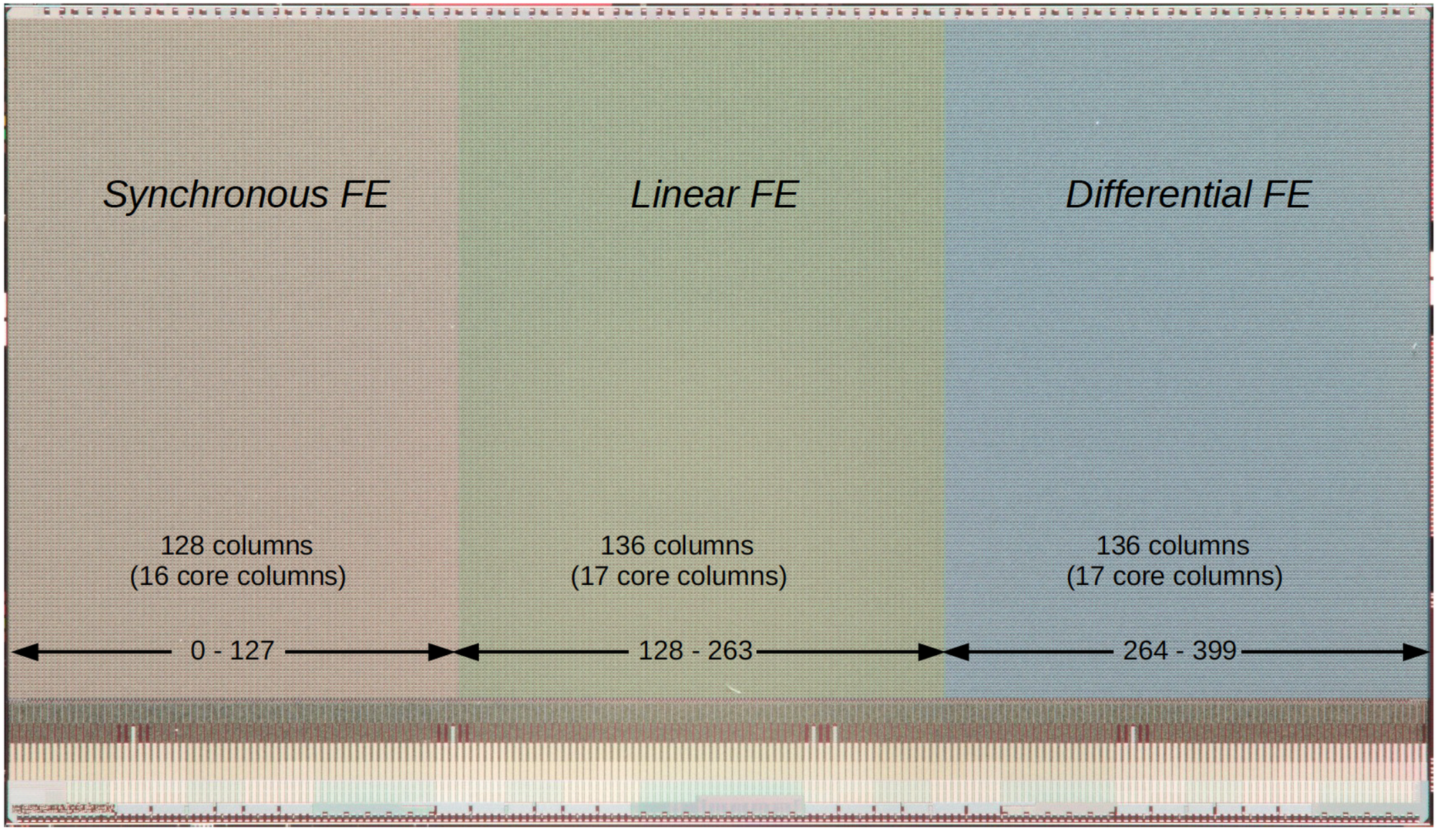
Conclusions

- The intrinsic position resolution of non-tilted and tilted RD53A modules with 50×50 **μ**m^2 and 100×25 **μ**m^2 pitch are measured using 11 GeV electron beam at SLAC
- The position resolution of 50×50 **μ**m^2 RD53A reduces by 26% when tilted by 13°, and 14% for 100×25 **μ**m^2 RD53A
- This information is useful for deciding on the geometry of the pixel layers, which are critical for flavor tagging and other tasks

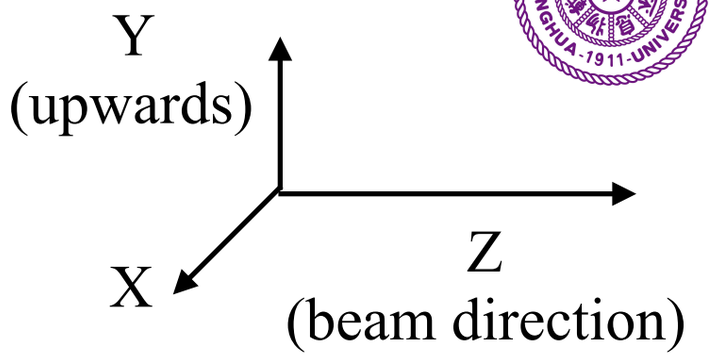
Thank you!

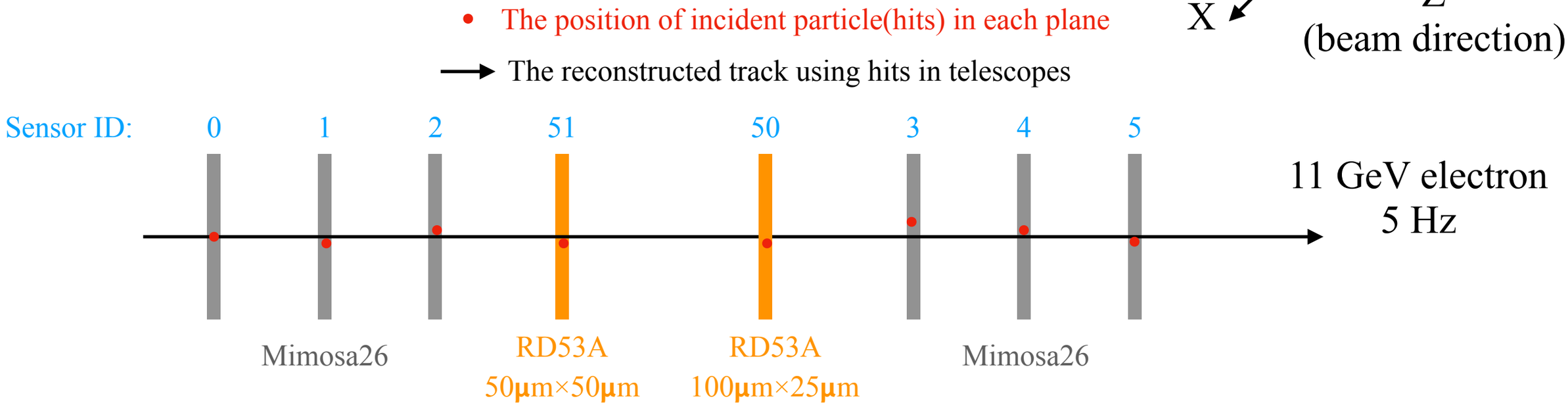
Backup

There front-ends on RD53A



Testbeam at SLAC

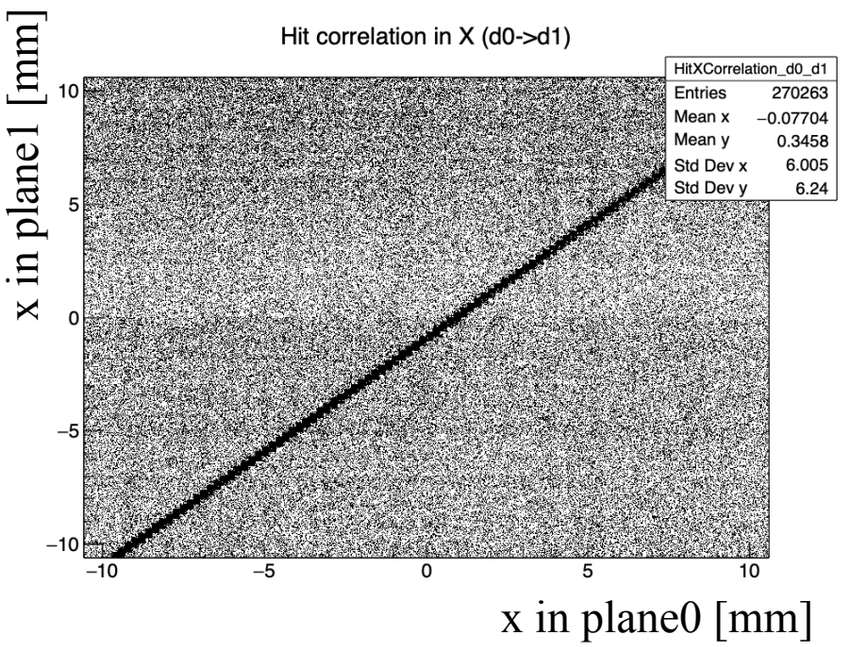


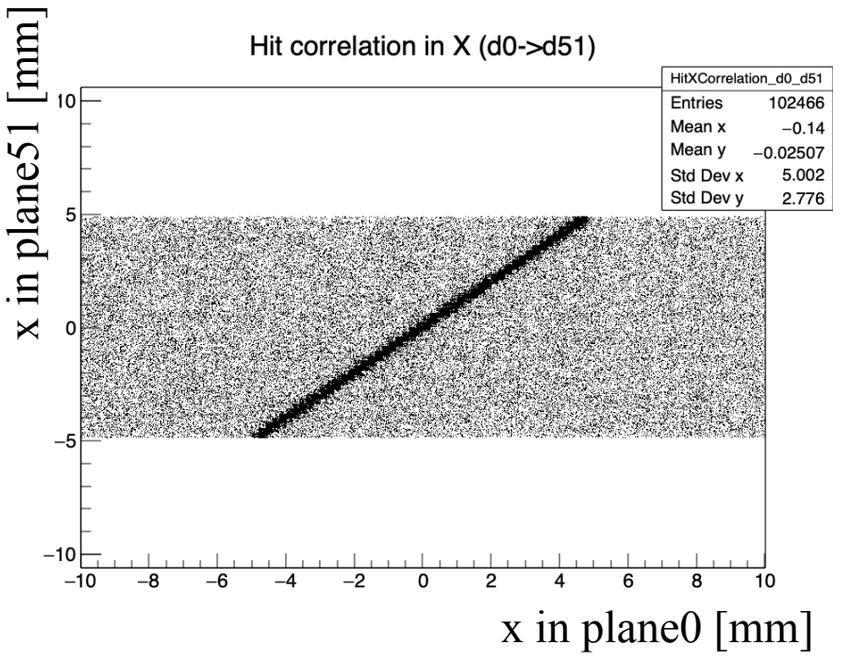


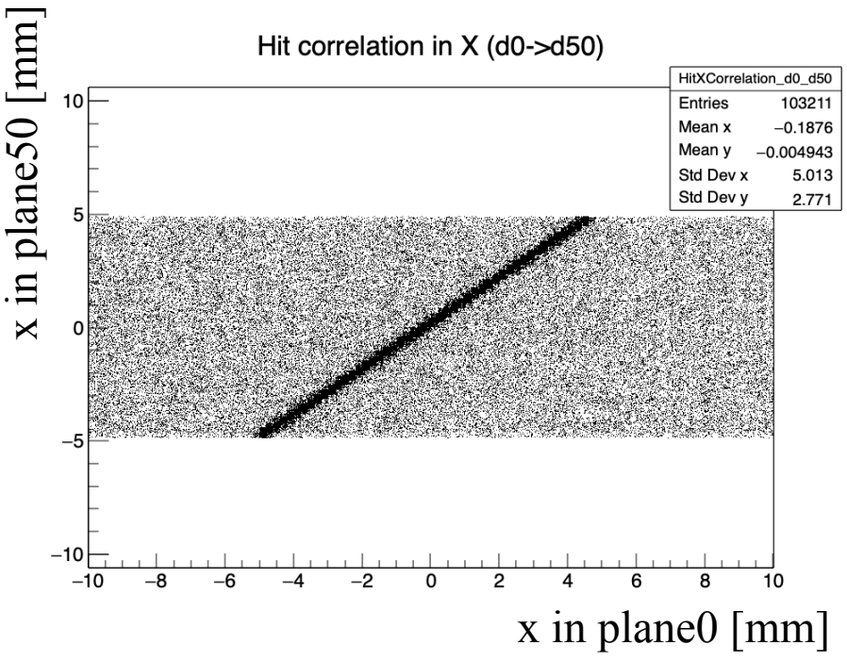
- Reference telescopes: Mimosa26 with 18.4**μ**m×18.4**μ**m pixels, 1152 pixels in x direction, 576 pixels in y direction, 21.2mm×10.6mm

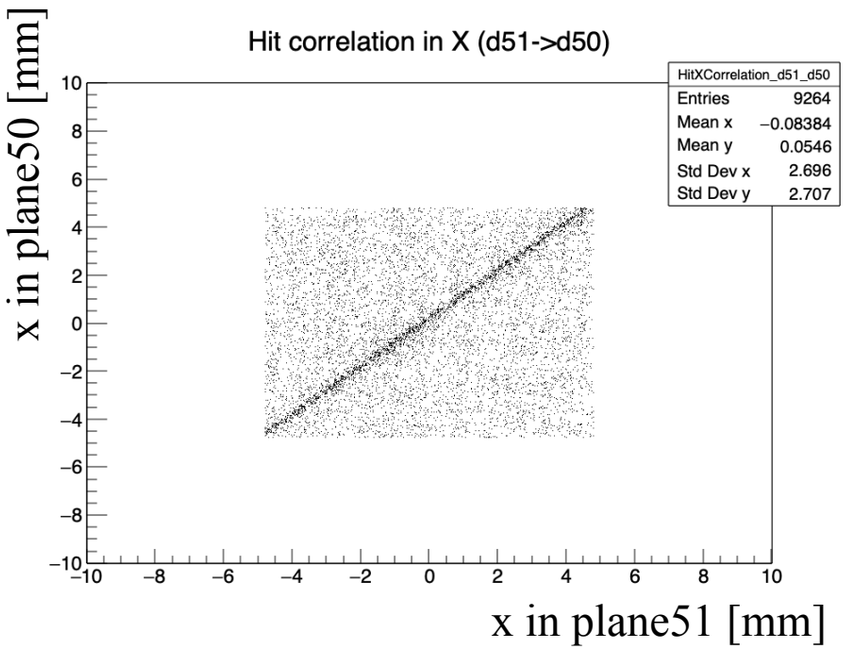
- Two different device under test (DUTs) rotated by 90° in X-Y plane: RD53A modules, 20.0mm×9.6mm
  - ★ 50**μ**m×50**μ**m sensor: 400 pixels in x direction, 192 pixels in y direction
  - ★ 100**μ**m×25**μ**m sensor: 200 pixels in x direction, 384 pixels in y direction

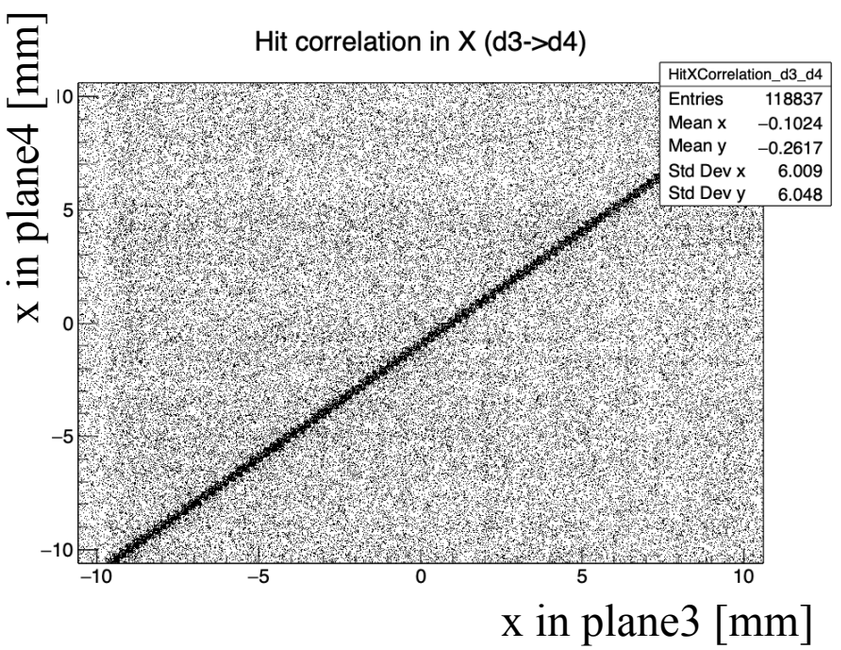
Correlation in x direction

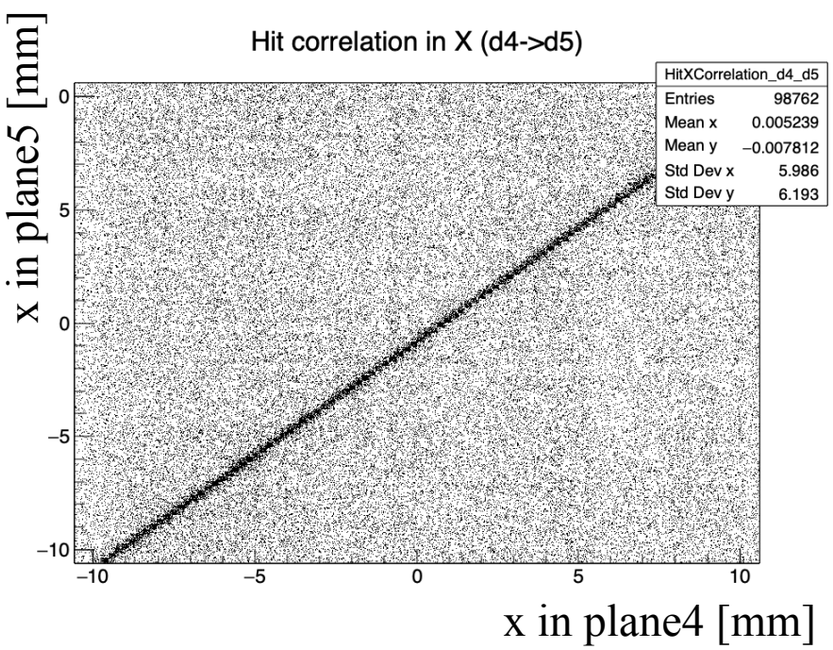






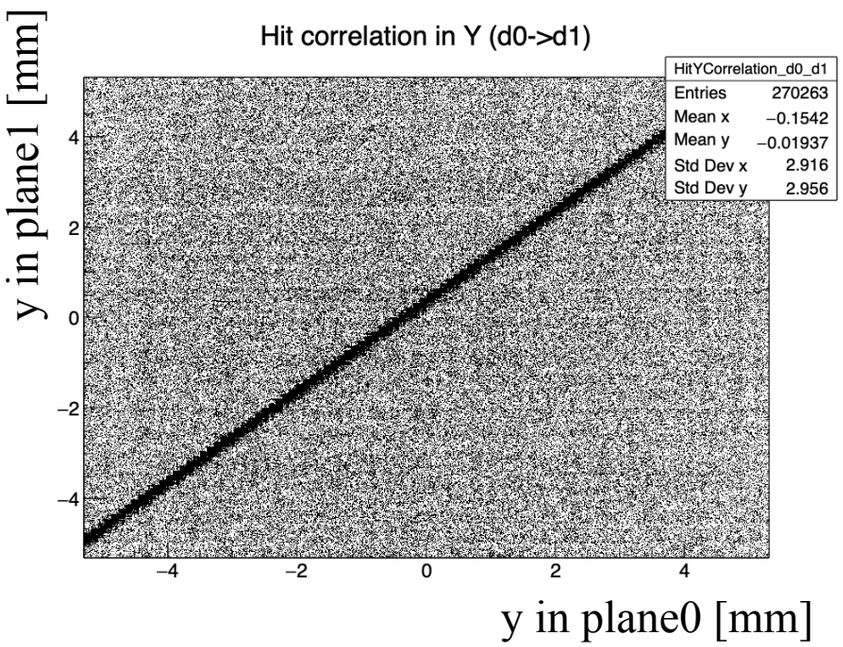


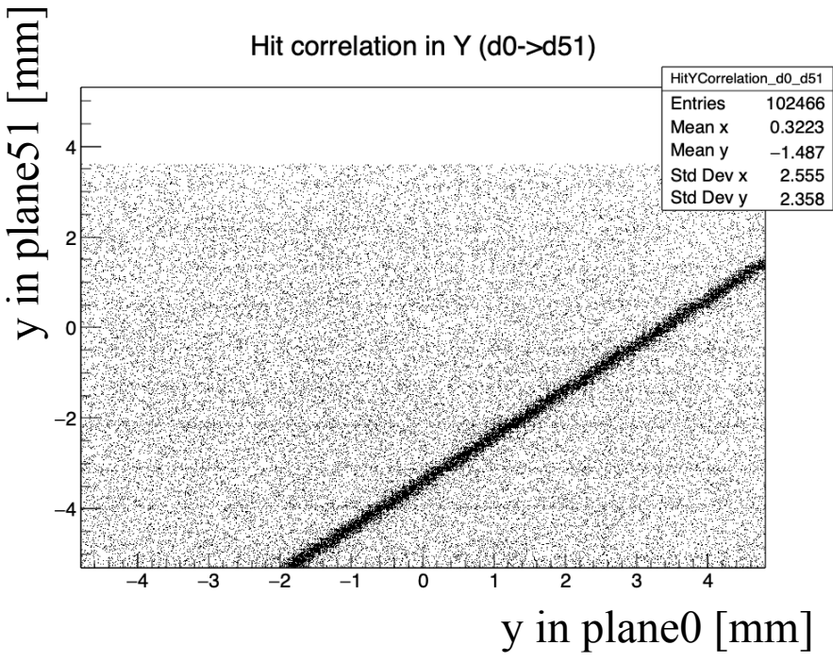


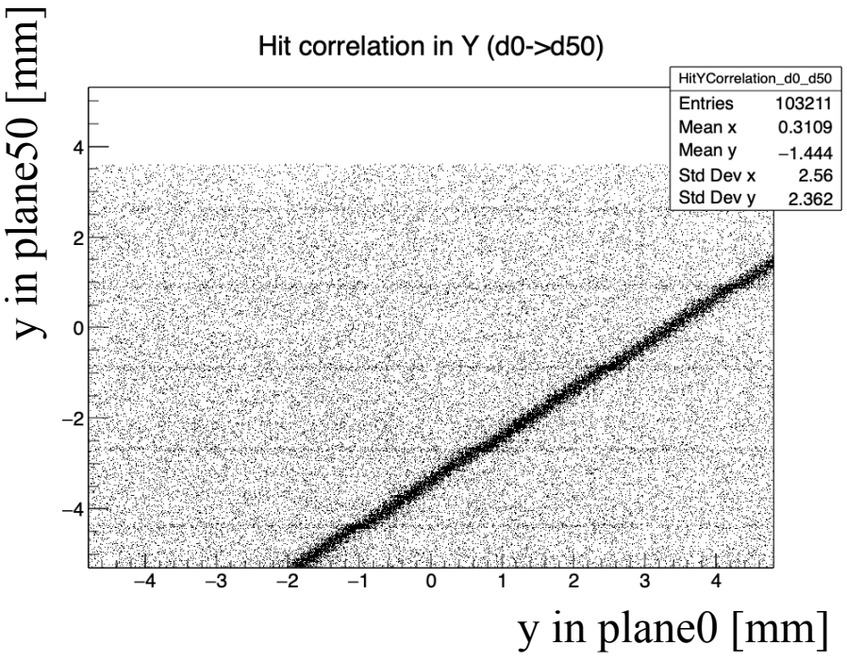


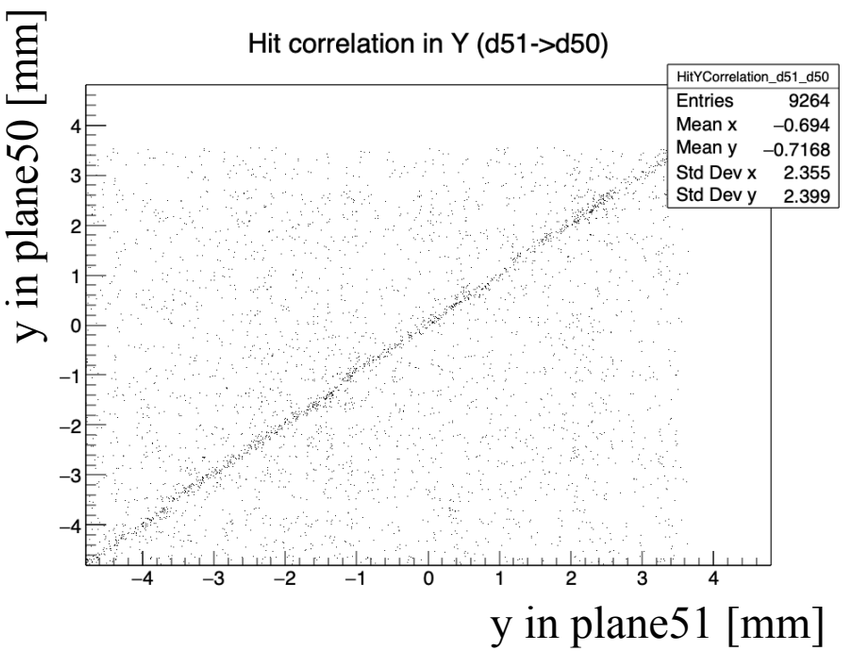
Telescopes: plane0~5, RD53A 50μm×50μm: plane51, RD53A 100μm×25μm: plane50

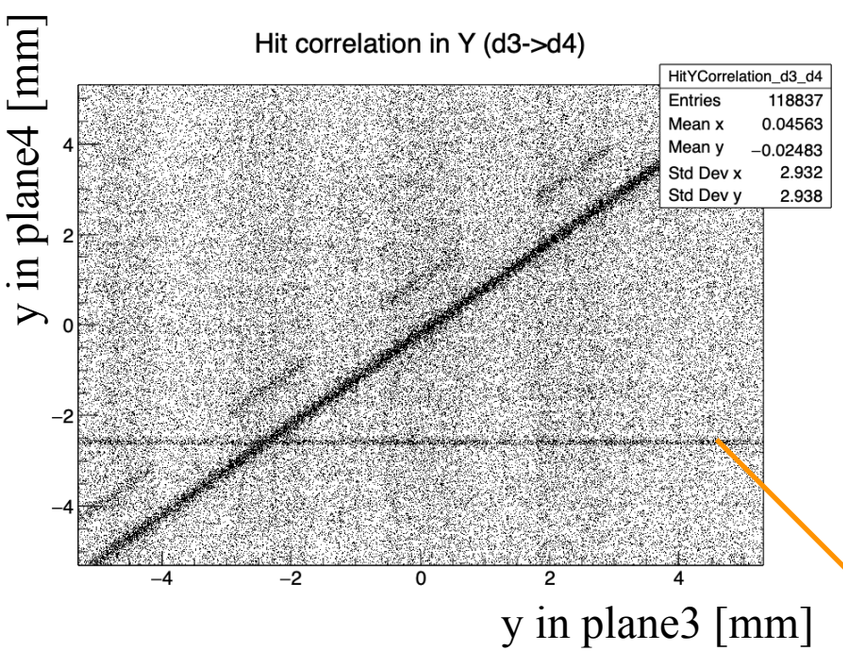
Correlation in y direction

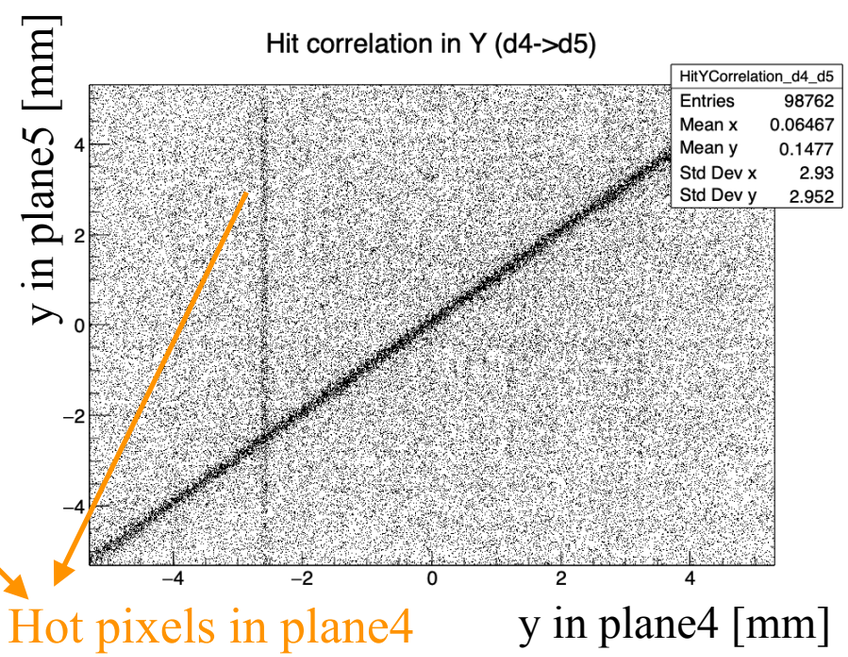






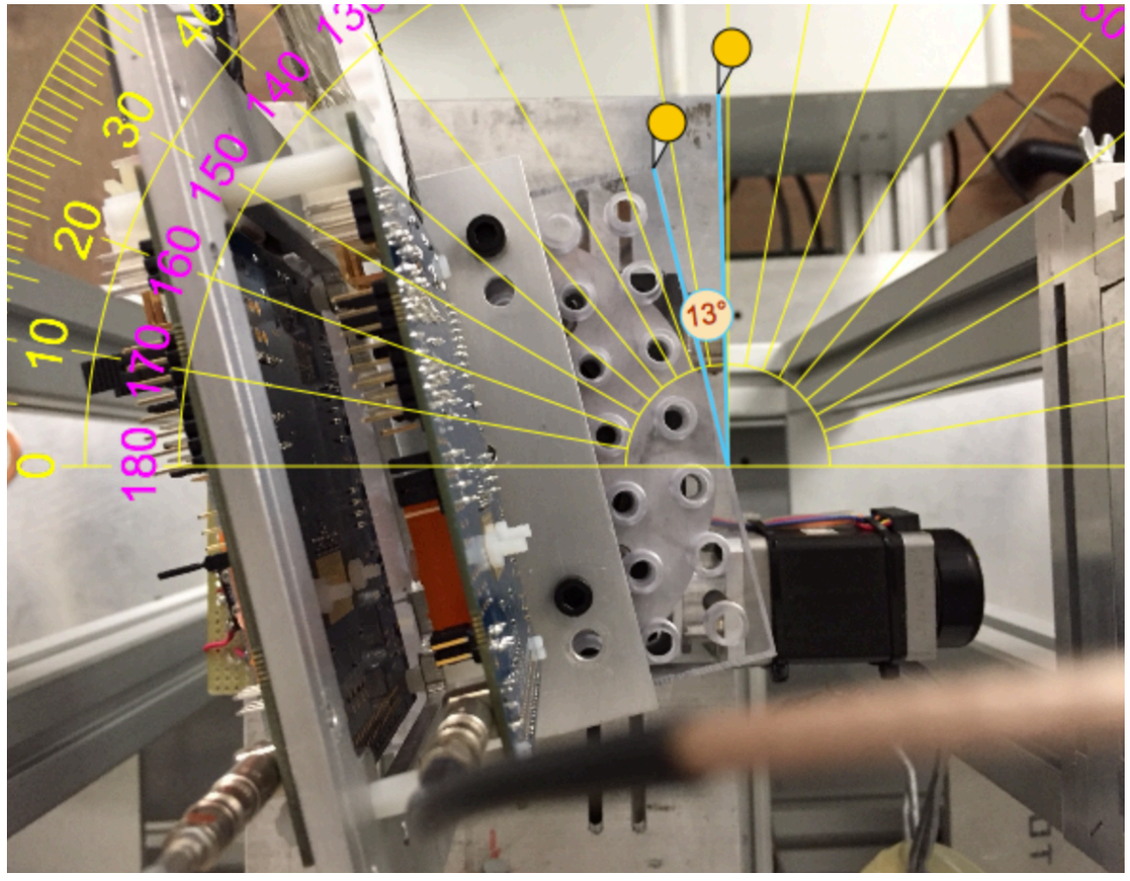






Telescopes: plane0~5, RD53A 50μm×50μm: plane51, RD53A 100μm×25μm: plane50

Tilted DUTs



Tilt angle: 13° in XZ plane

After 3 iterations of GBL alignment

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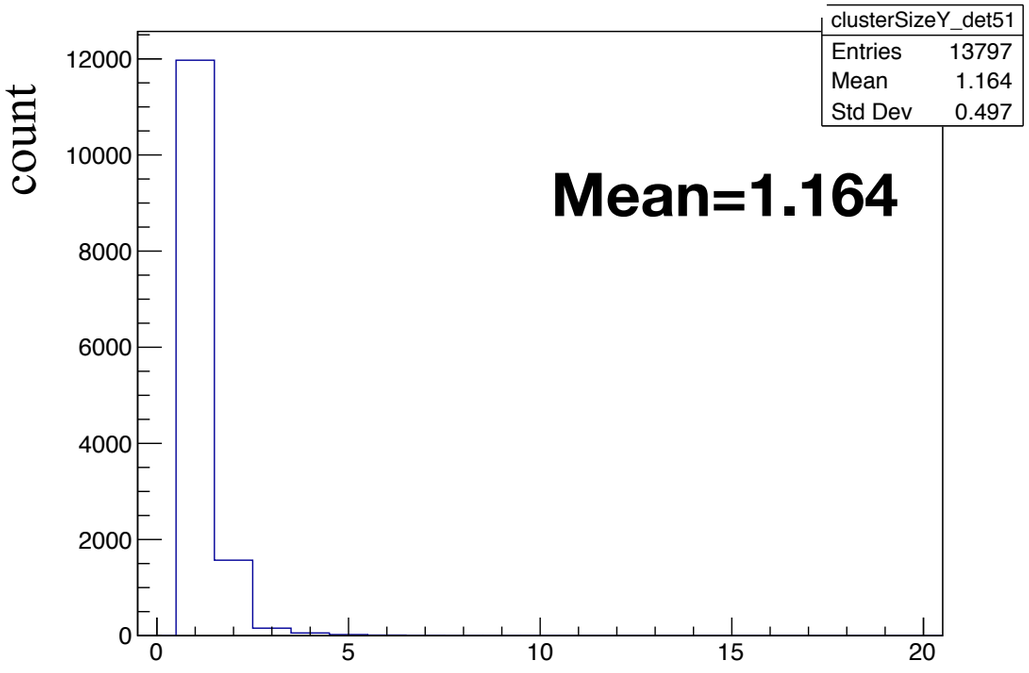
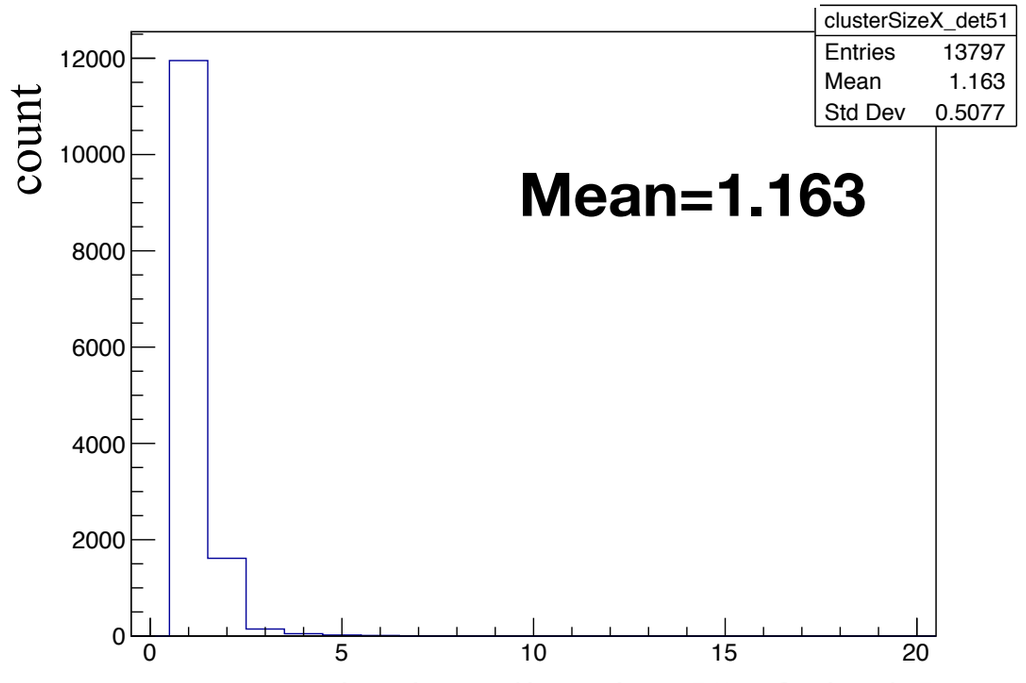
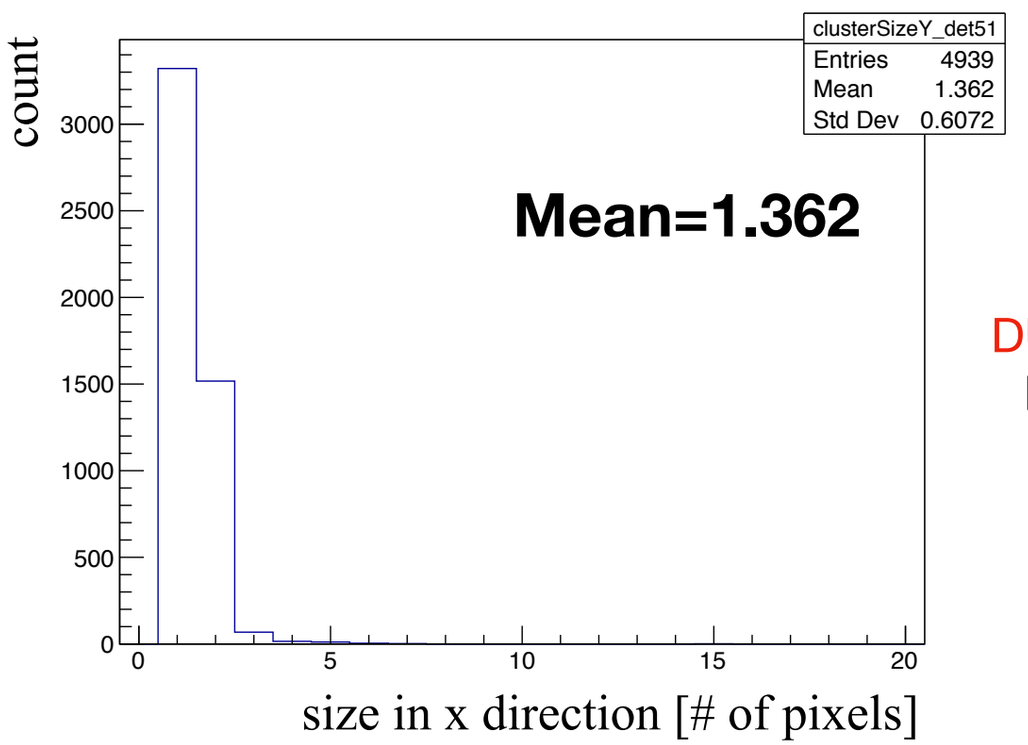
Cluster size

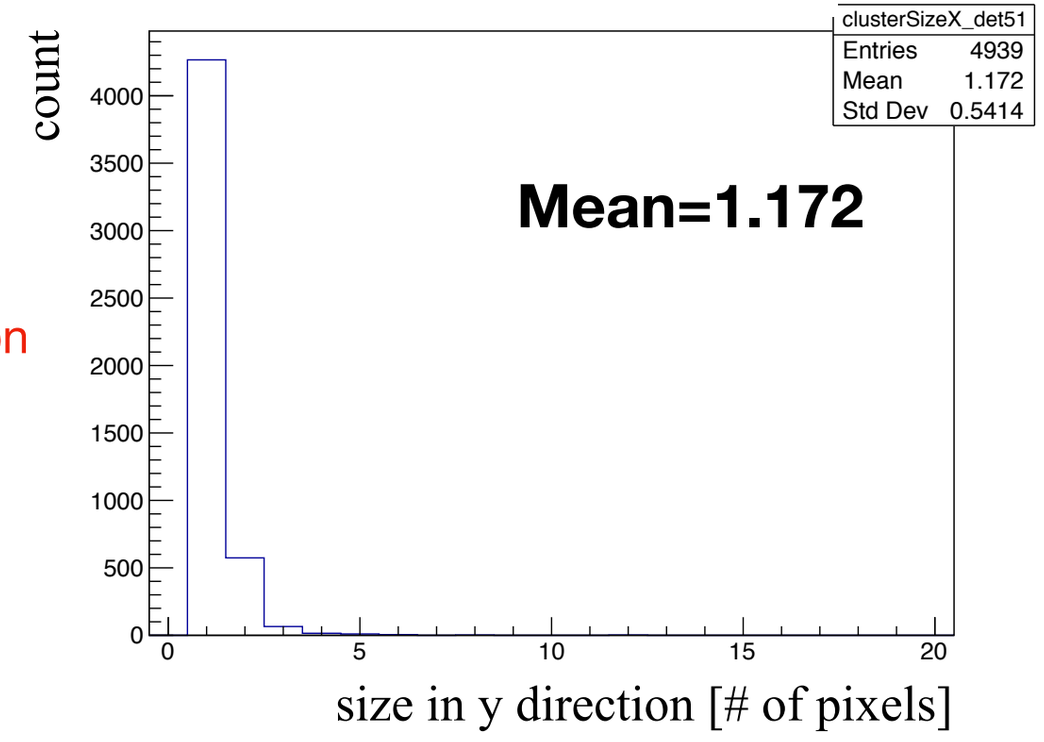


Non-tilted DUT
RD53A 50μm×50μm



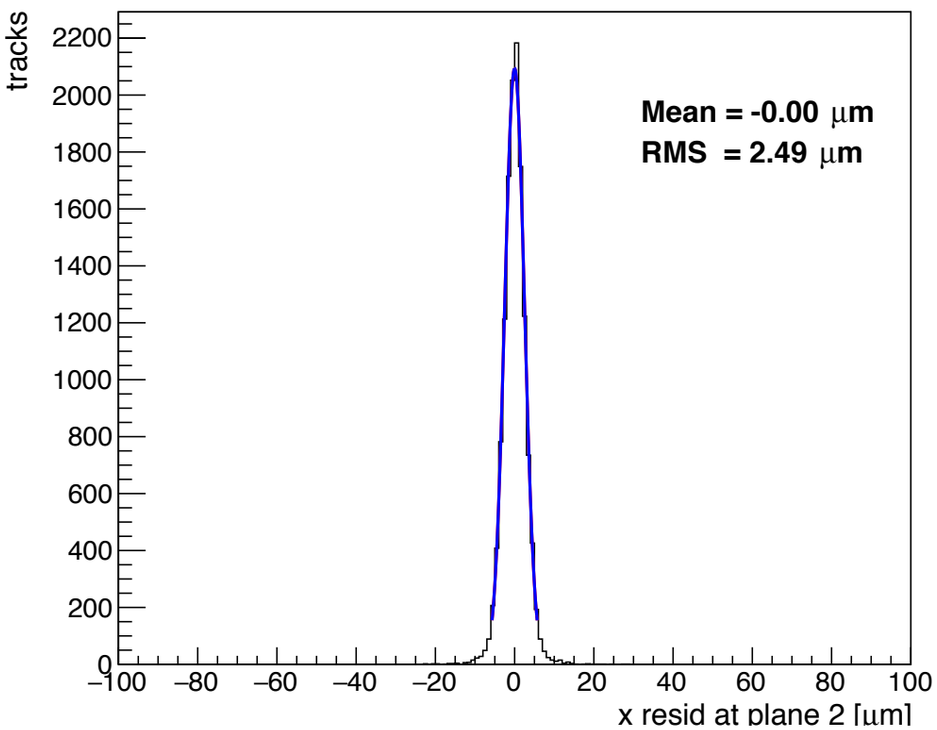


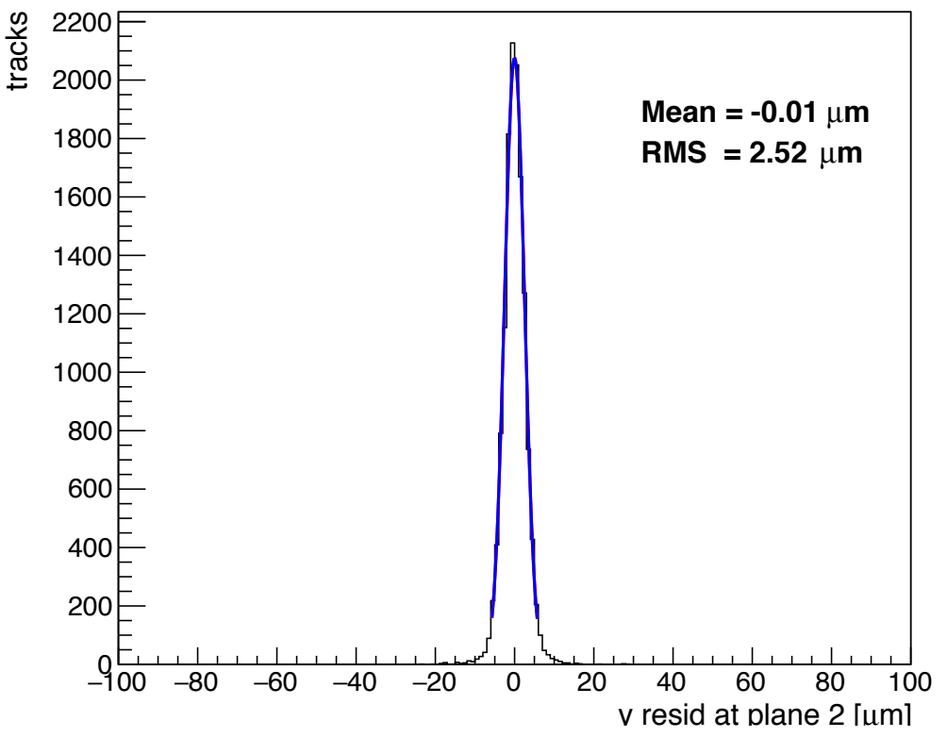
DUT tilted in x direction
RD53A 50μm×50μm

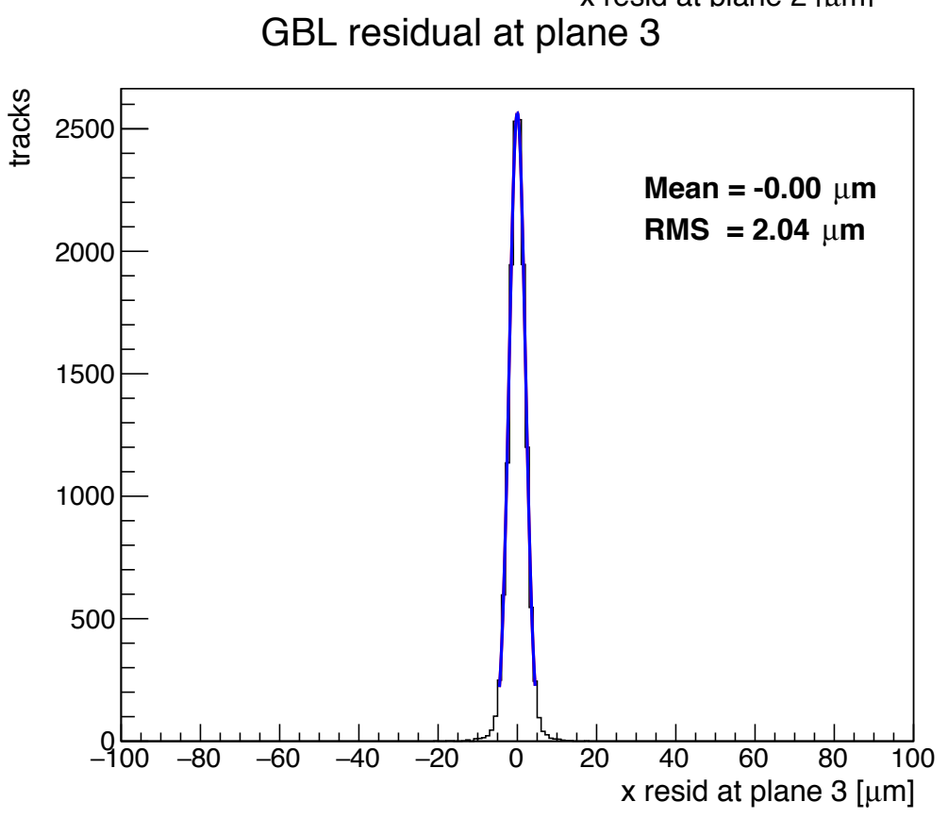


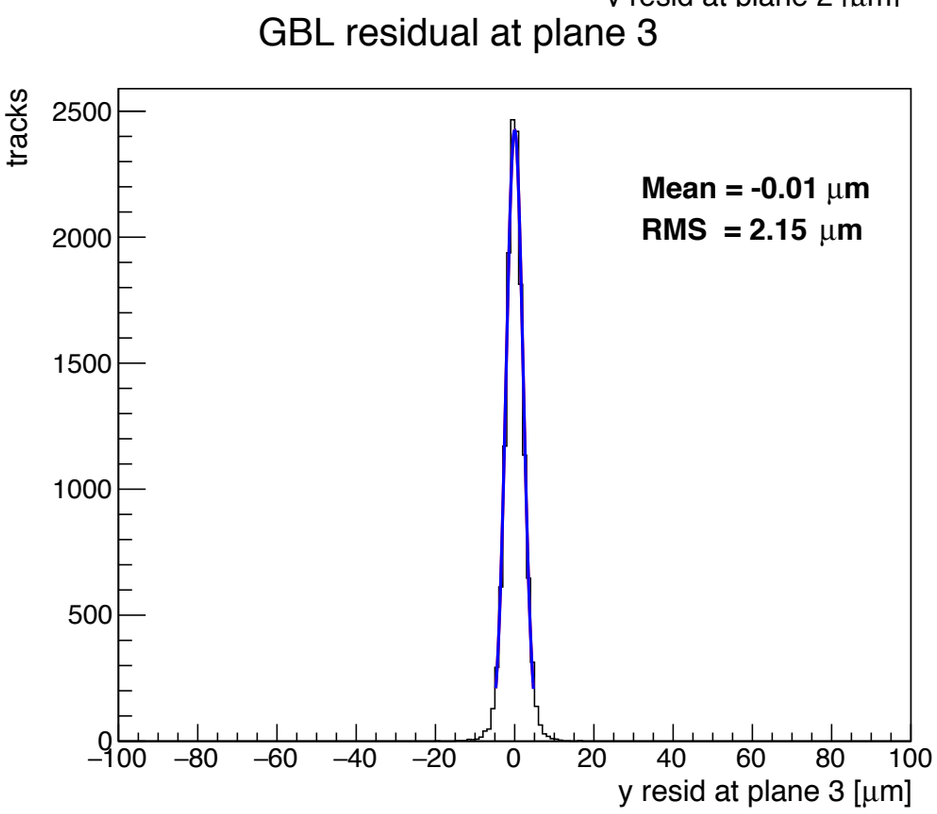
- Cluster size in tilted direction increase

Position resolution (Mimosa26)

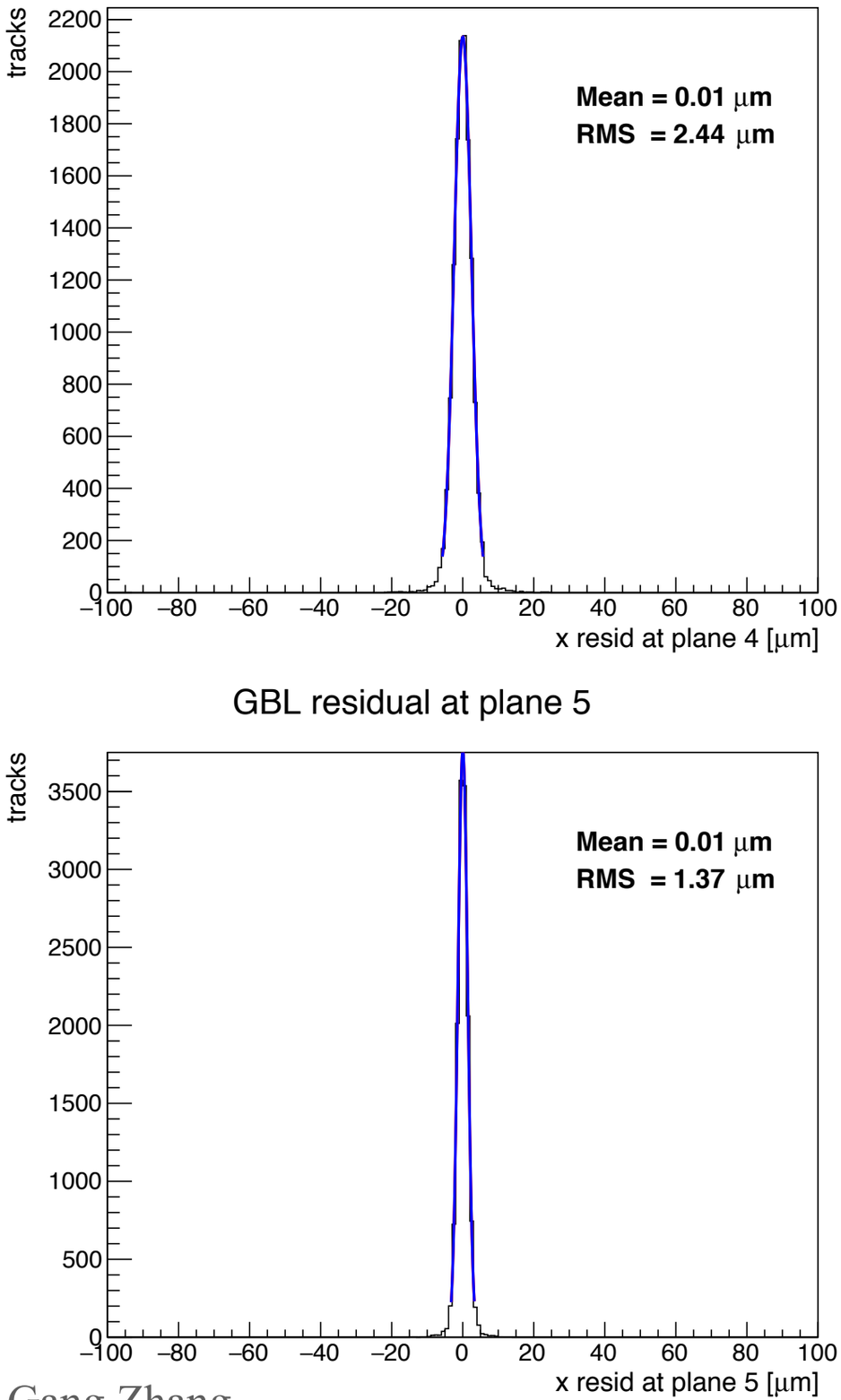


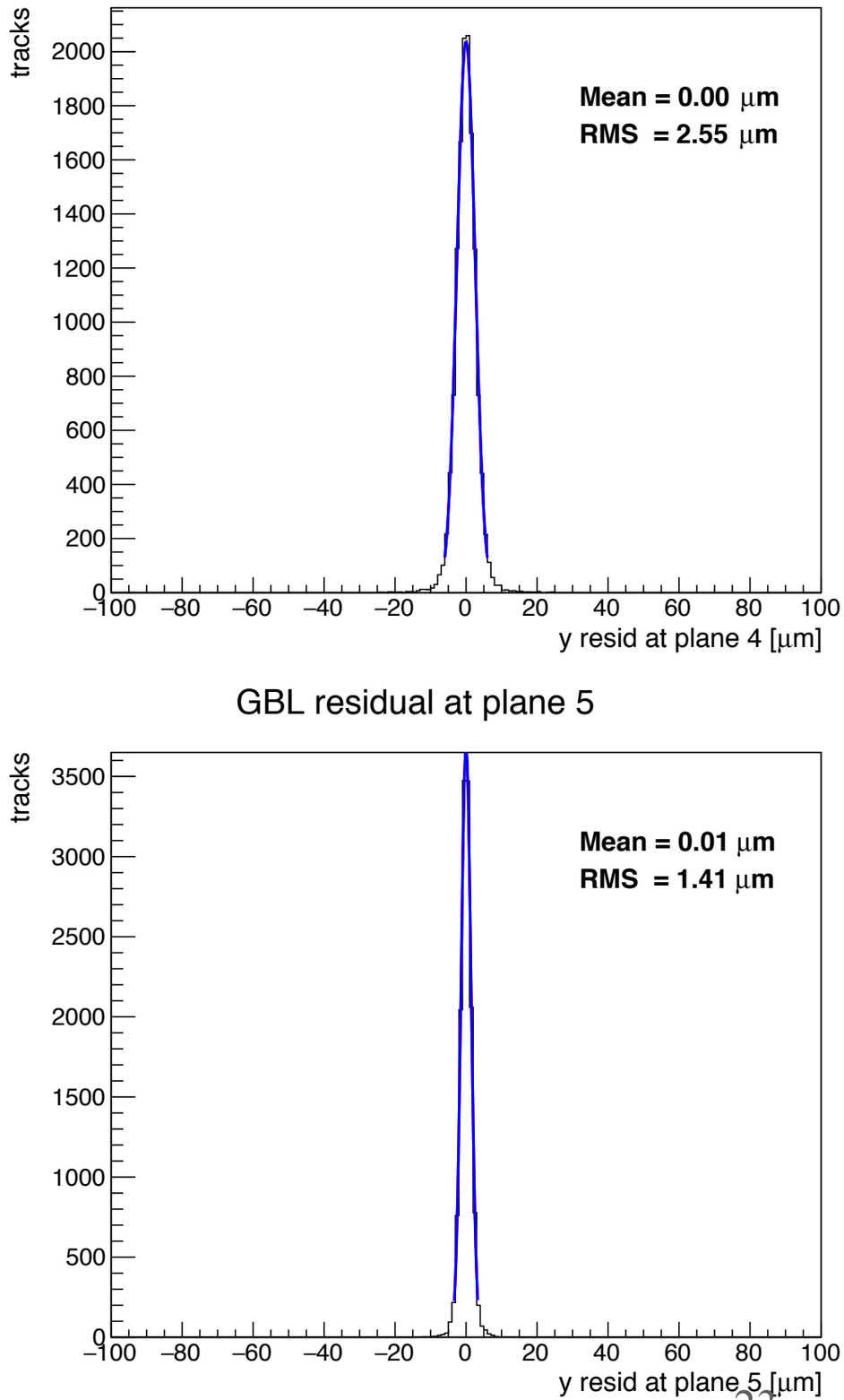






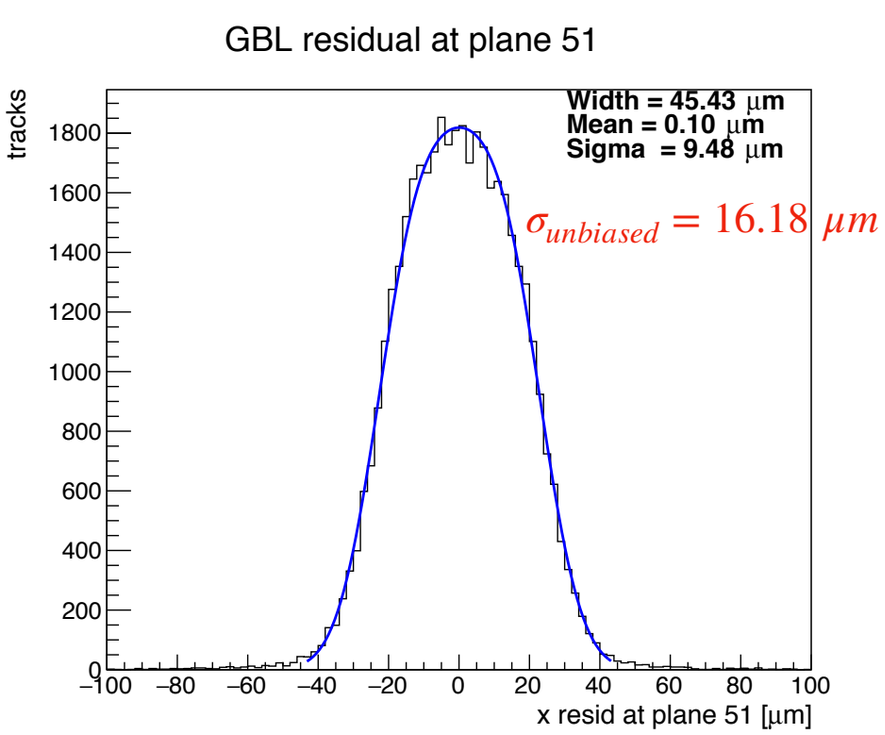
Position resolution (Mimosa26)





position resolution (RD53A)

fit function = Box(width) convolved with Gaussian (Mean,Sigma)

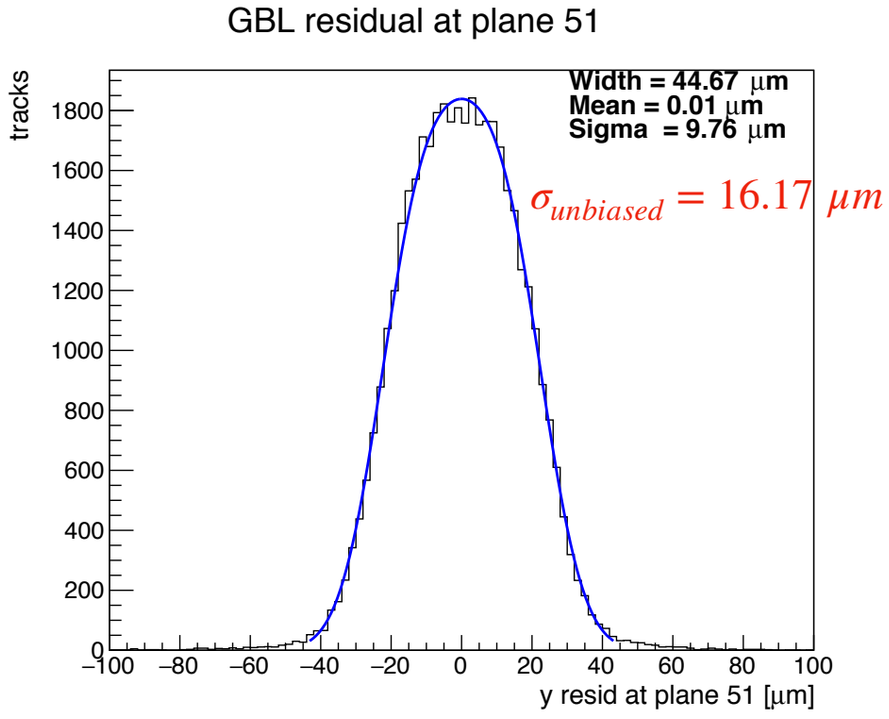


Non-tilted DUT

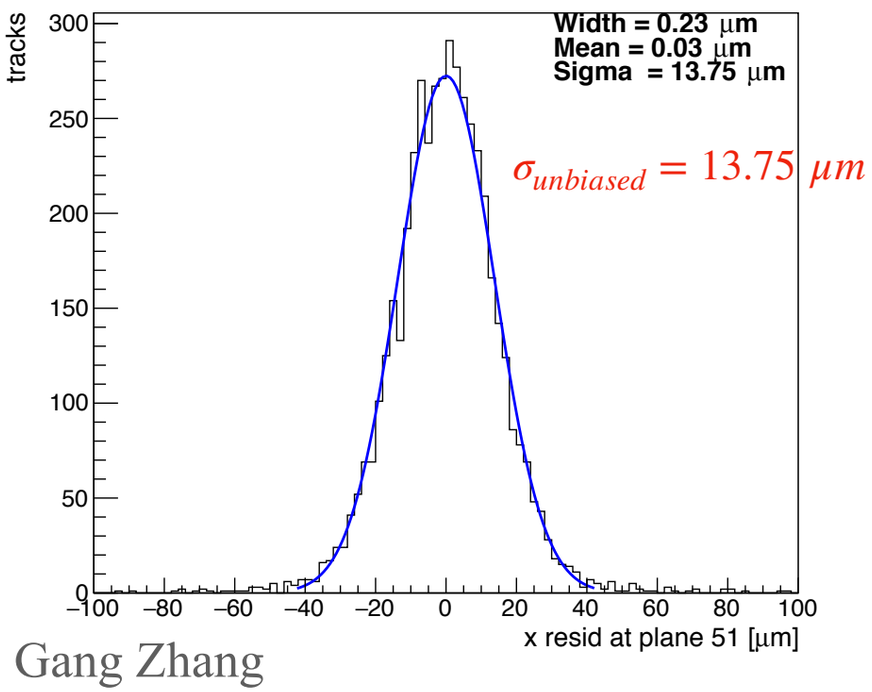
RD53A 50μm×50μm

$$\frac{pitch_x}{\sqrt{12}} = 14.4\ \mu m$$

$$\frac{pitch_y}{\sqrt{12}} = 14.4\ \mu m$$

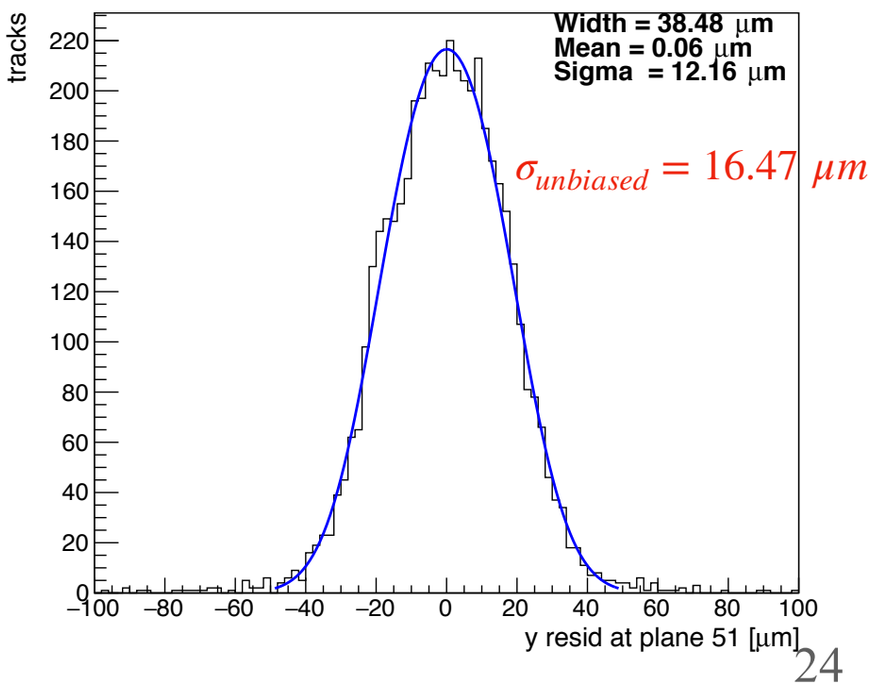


$$\sigma^2_{unbiased} = \sigma^2_{intrinsic} + \sigma^2_{tracking}$$

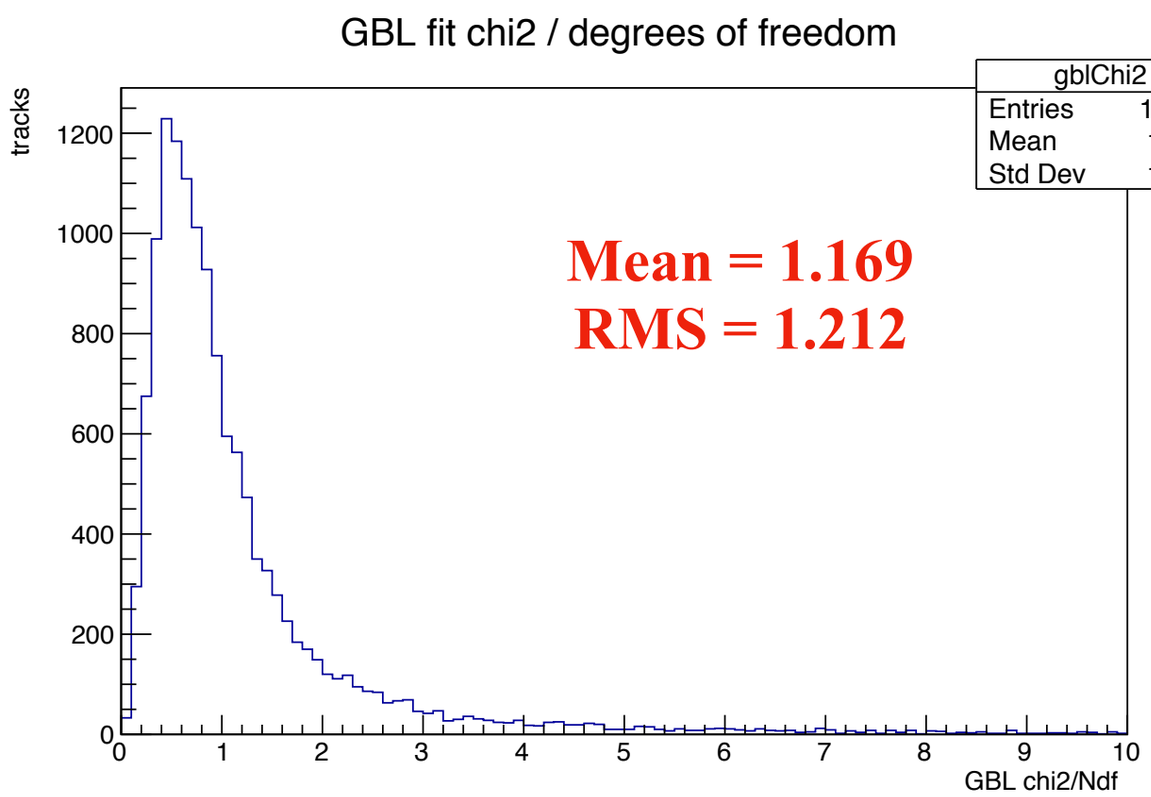


DUT tilted in x direction

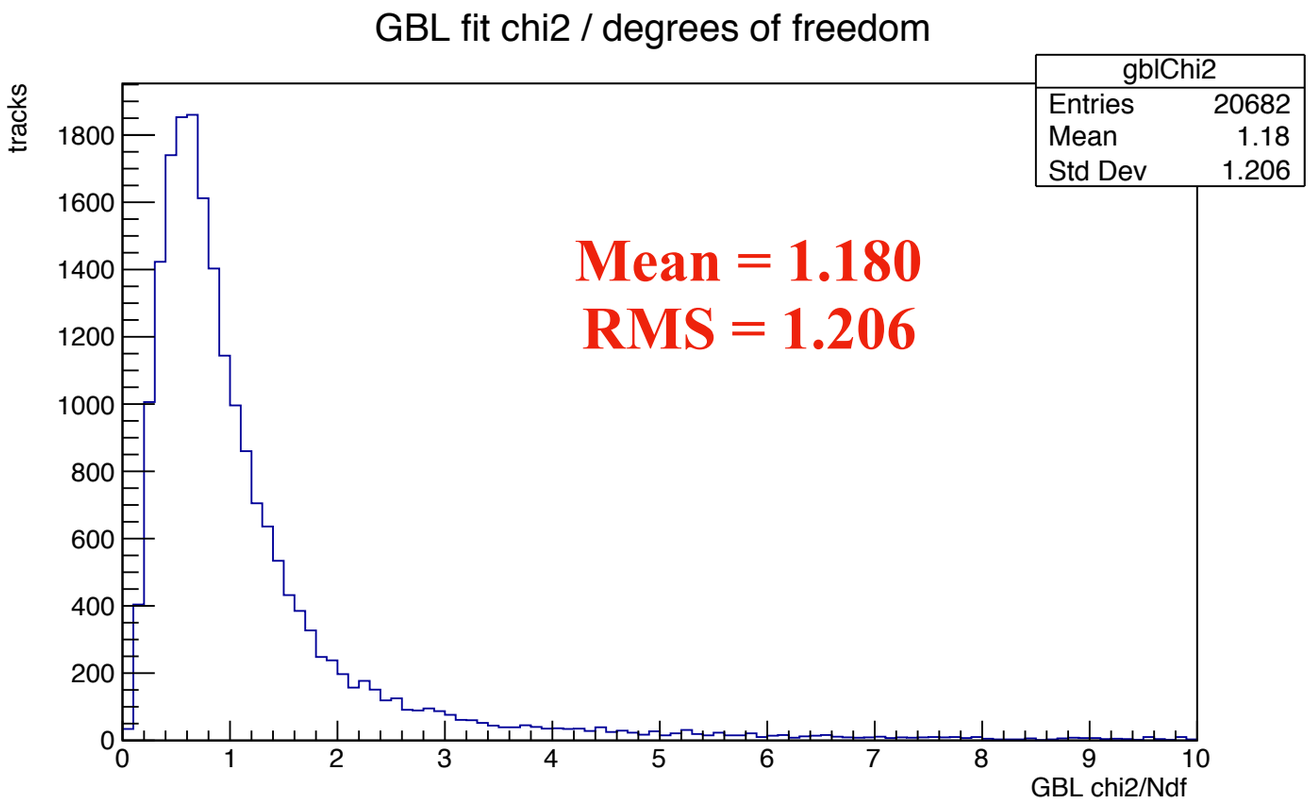
RD53A 50μm×50μm



Chi^2/d.o.f. comparison

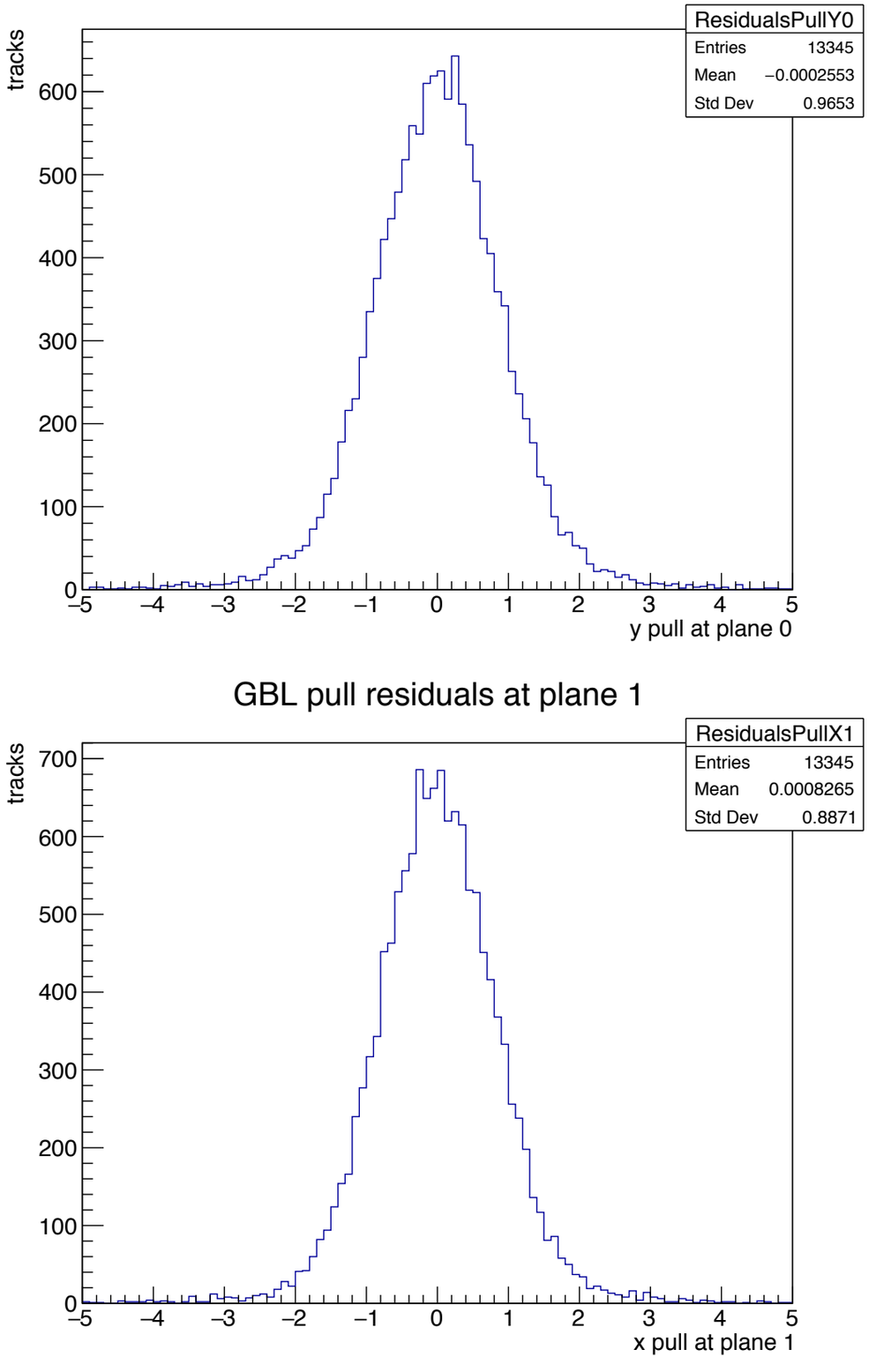


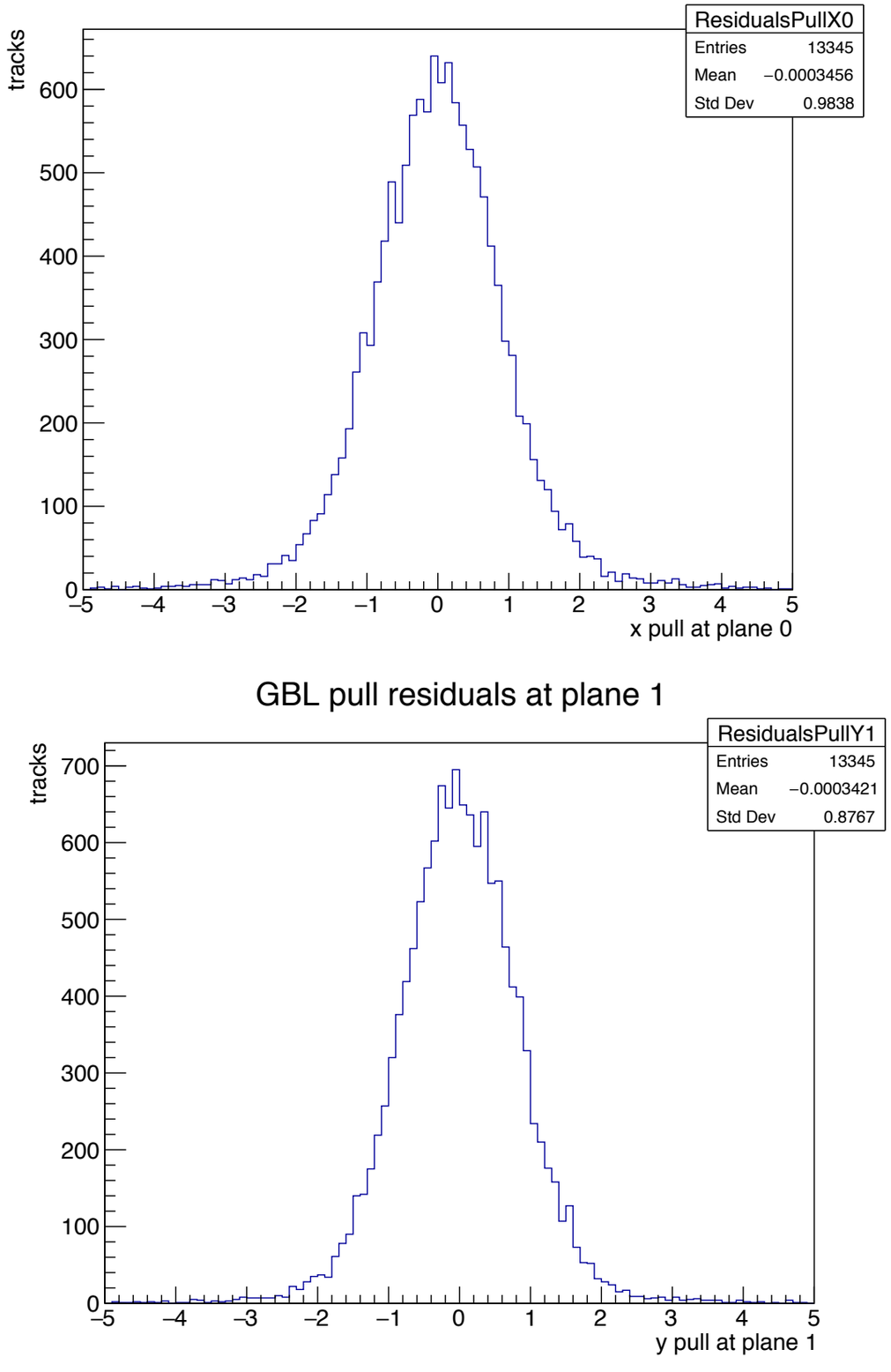
No tilt angle



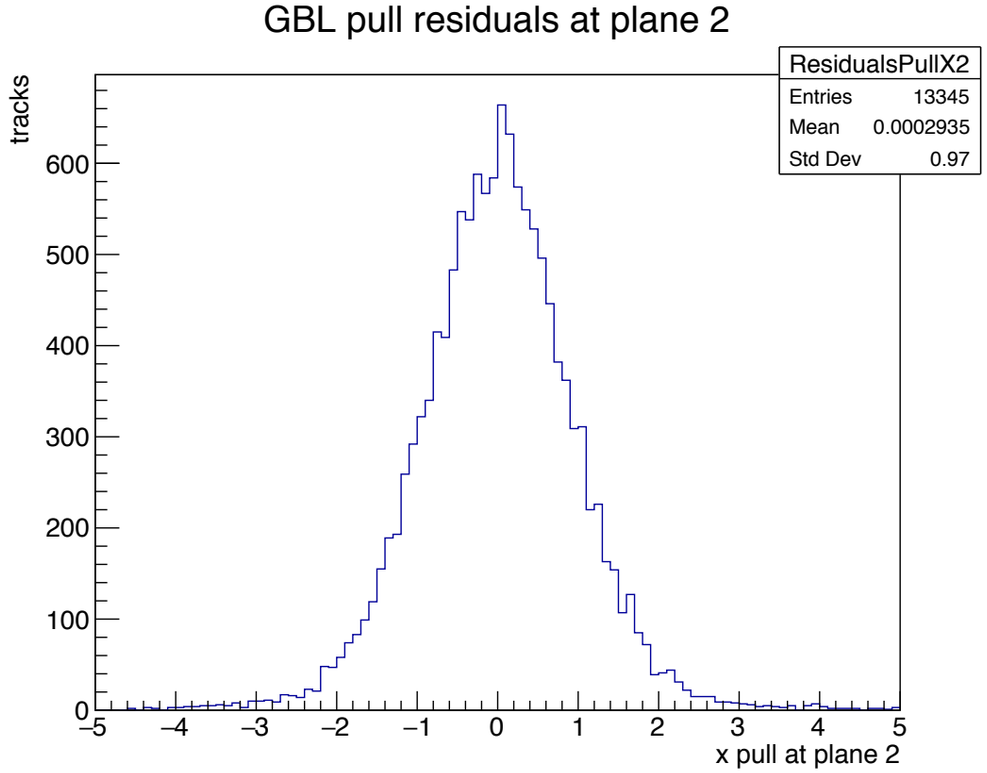
13° tilt angle

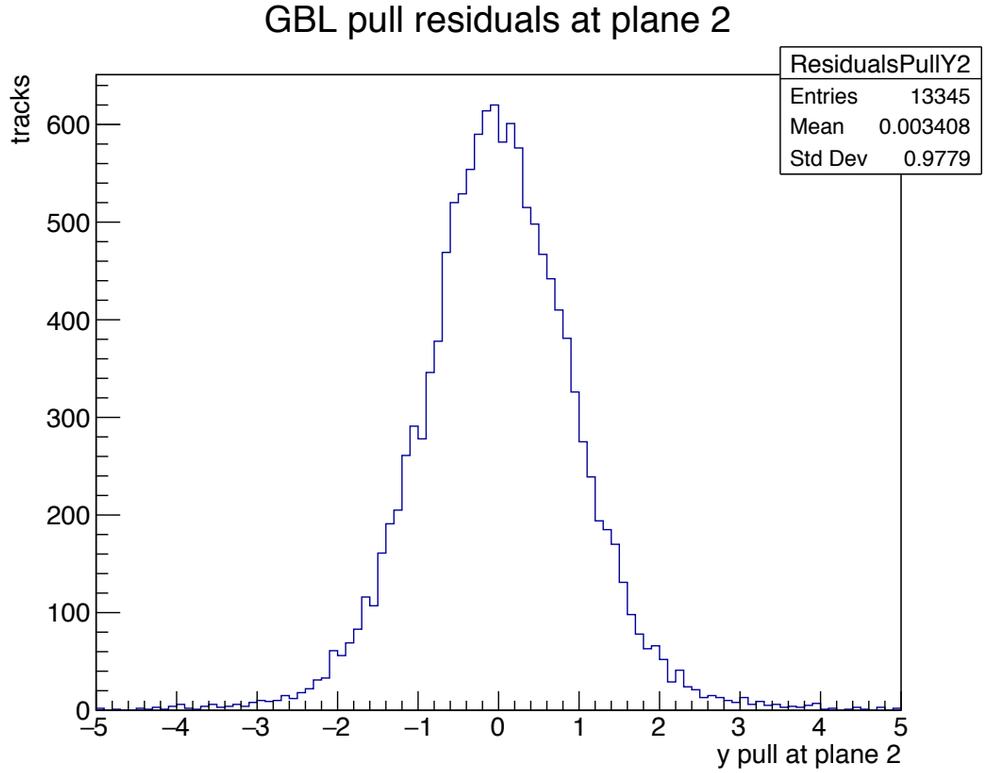
Pull distribution

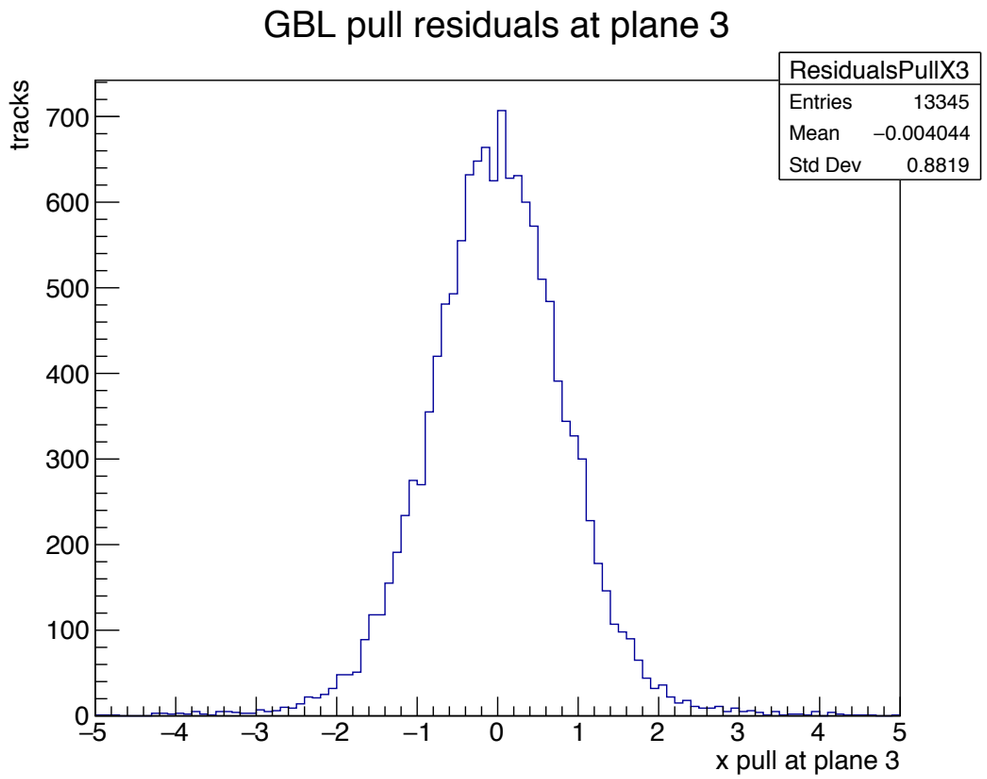


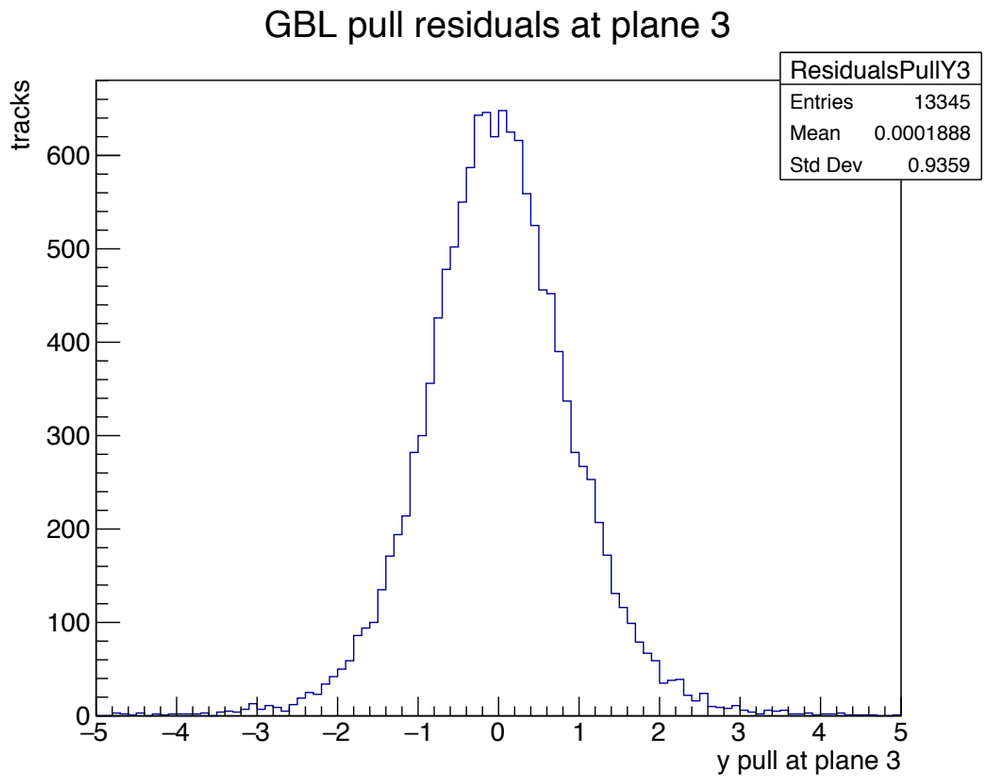


Pull distribution

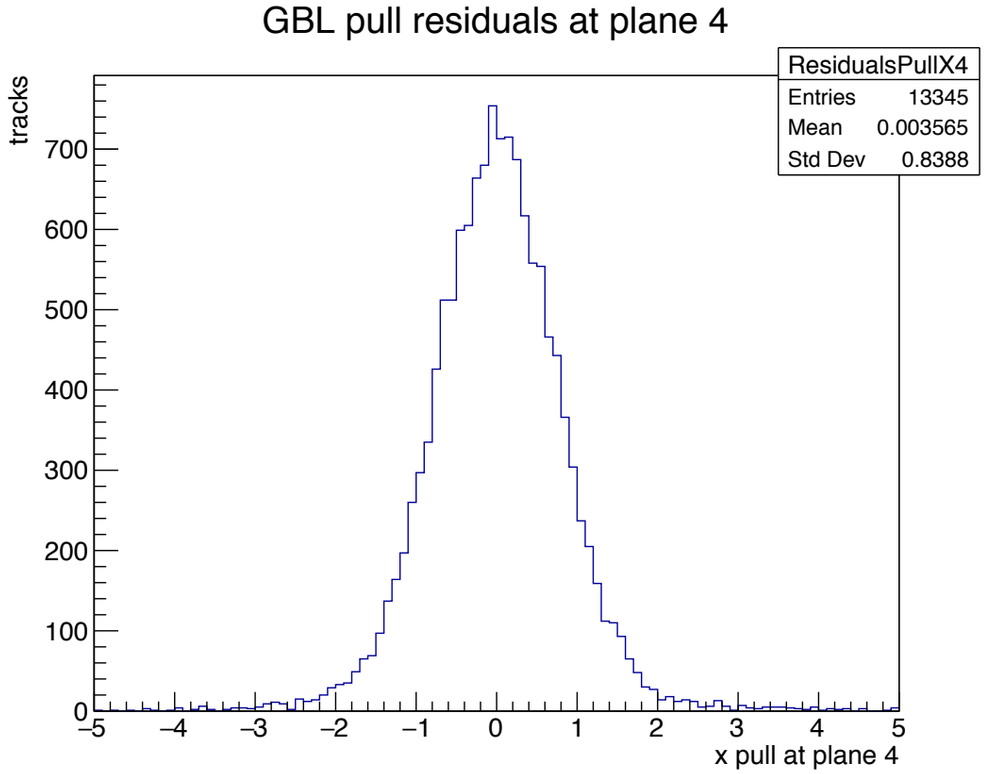


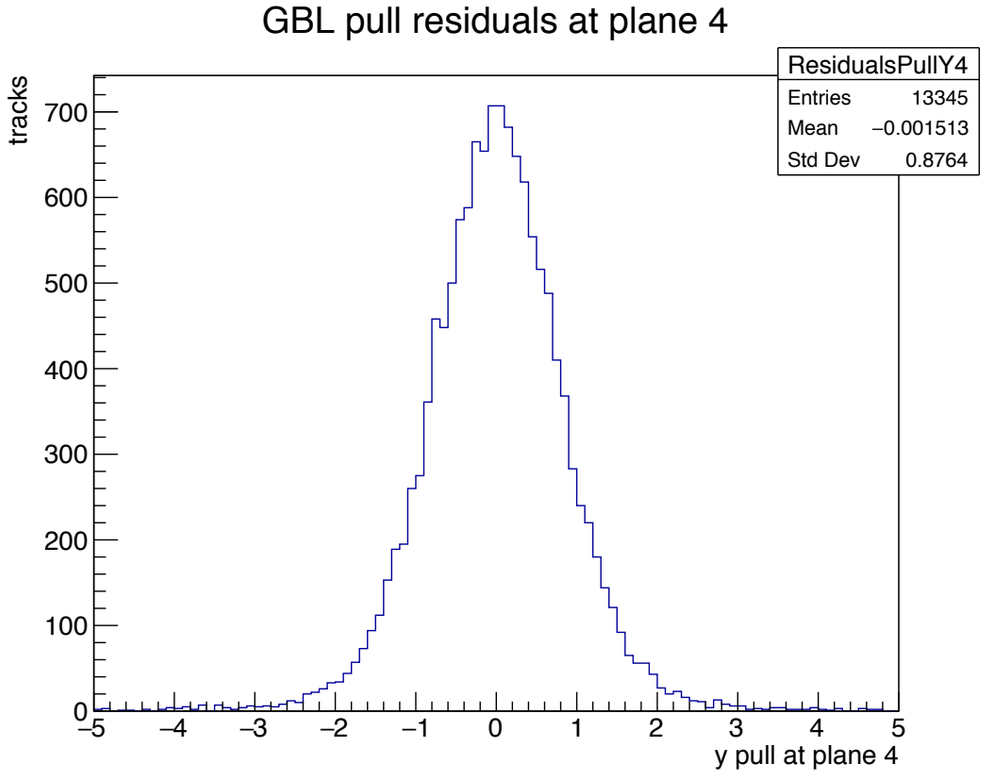


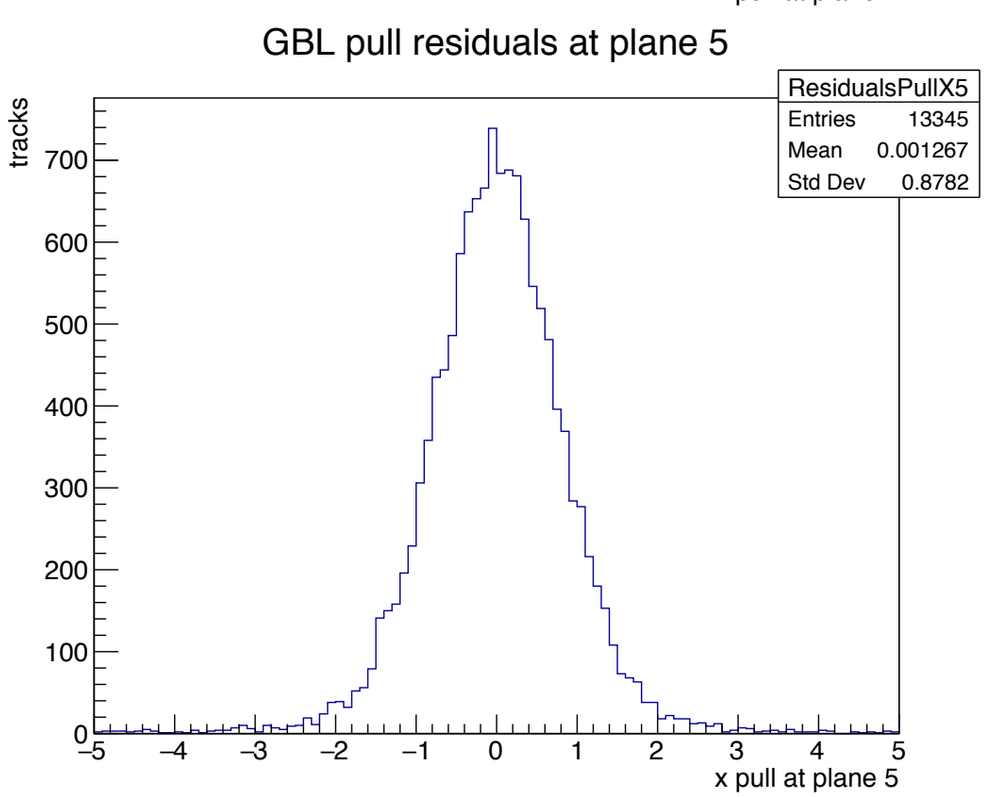


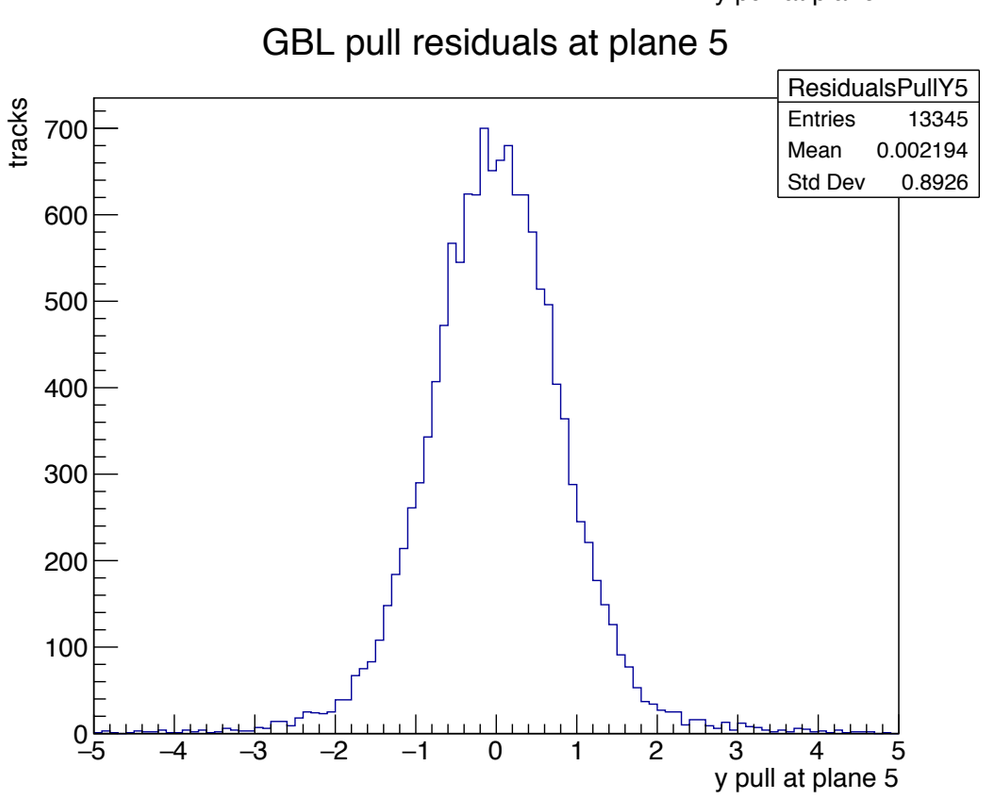


Pull distribution



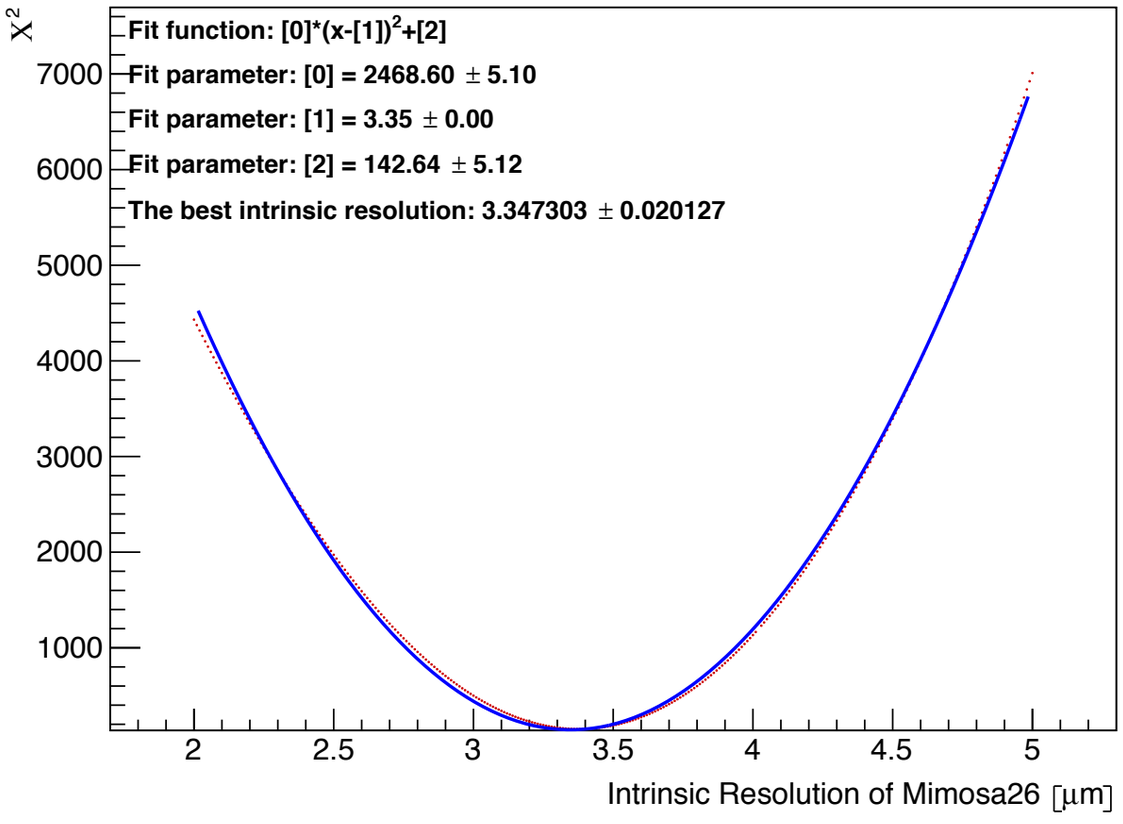






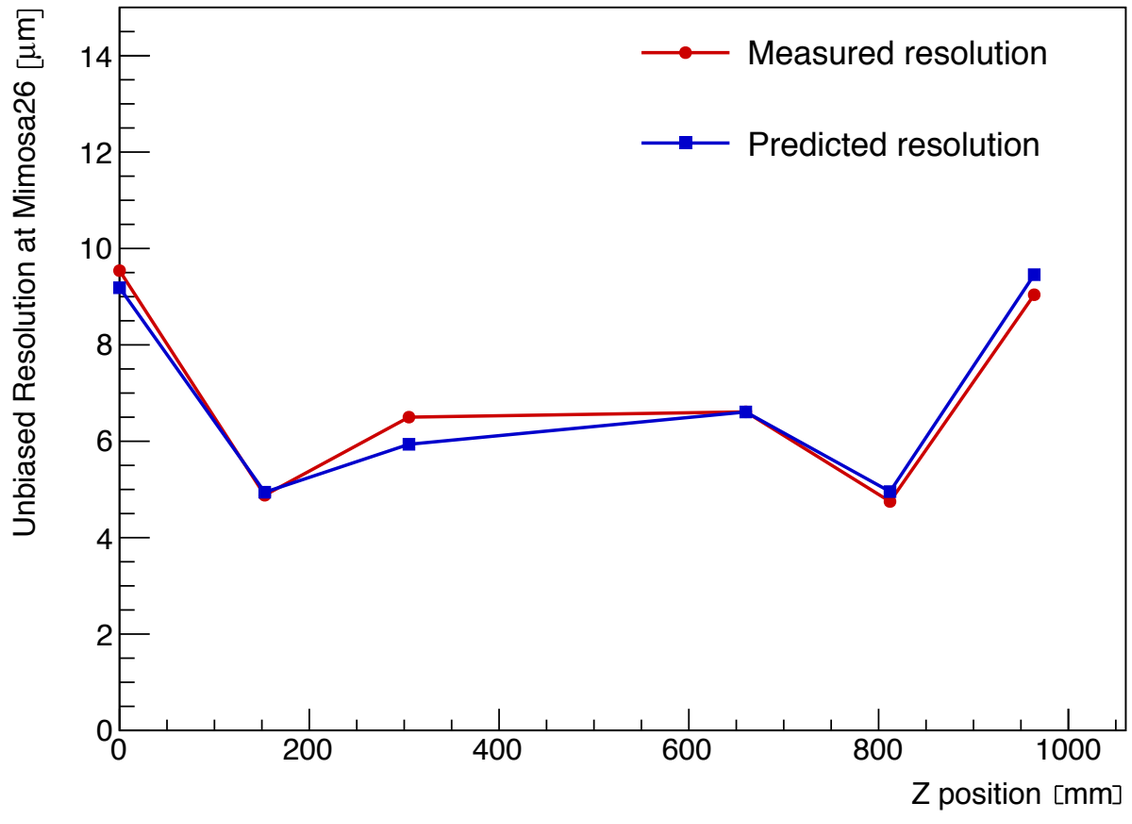
Tracking resolution based on simulator

- Scan intrinsic resolution of Mimosa26
- Simulate track resolution at each Mimosa26 plane
- Minimize the different between measured and calculated unbiased resolution



$$\chi^2 = \Sigma_i \frac{(\sigma_{unbiased,i} - \sqrt{\sigma^2_{intrinsic} + \sigma^2_{track,i}})^2}{V[\sigma_{unbiased,i}]}$$

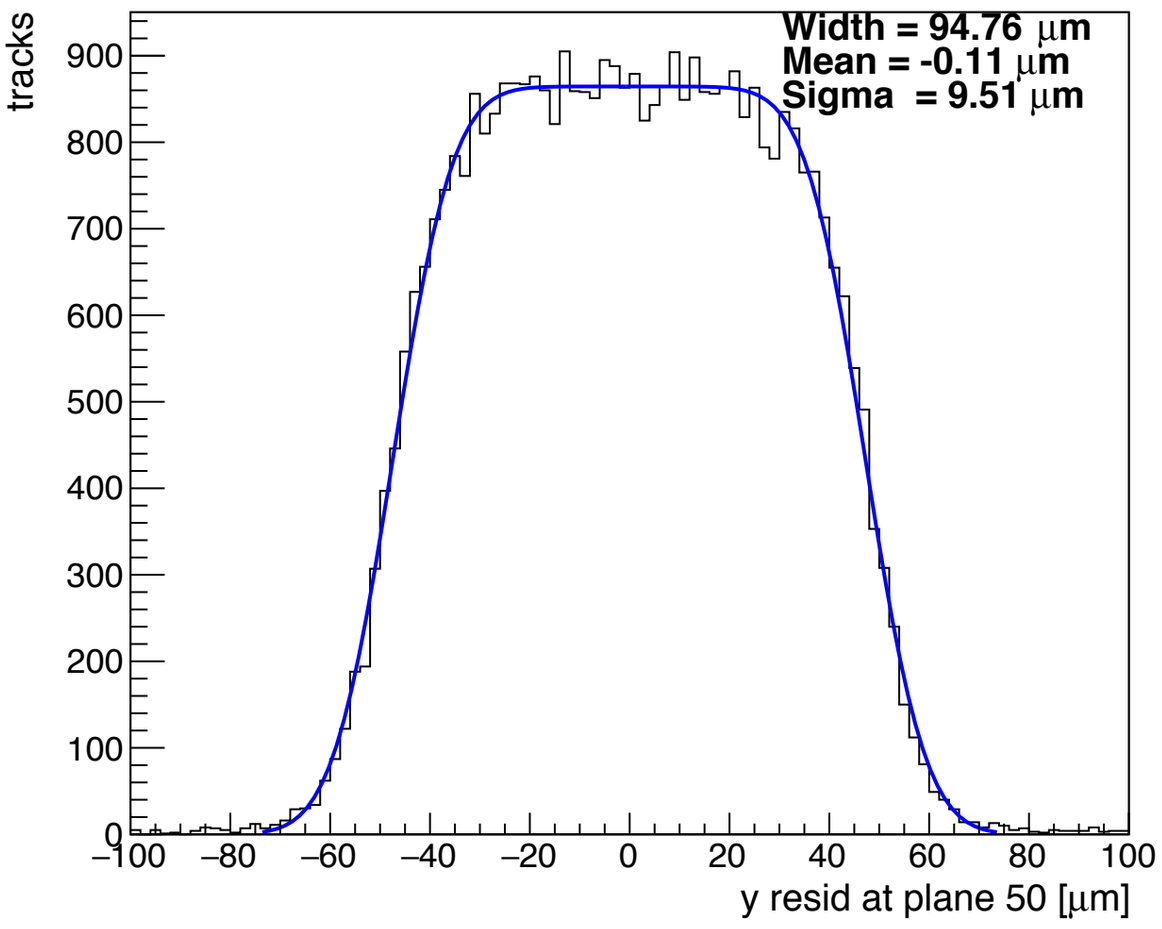
i are the six mimosa26



Use 3.35 micron as intrinsic resolution of Mimosa26 for predicted resolution

Intrinsic resolution

- With pitch of pixels increasing, the residuals should be fit by convolution of box and gaussian function



$$R_{unbiased} = R_{track} + R_{intrinsic}$$

$$\sigma^2(unbiased) = \sigma^2(track) + \sigma^2(intrinsic)$$

$$R_{unbiased} \approx Box(width) + Gauss(sigma)$$

$$\sigma^2(unbiased) = width^2/12 + sigma^2$$

$$\sigma^2(intrinsic) = width^2/12 + sigma^2 - \sigma^2(track)$$

Systematics

	RD53A 50μm×50μm non-tilted side(50μm)	RD53A 50μm×50μm tilted side(50μm)	RD53A 100μm×25μm non-tilted side(100μm)	RD53A 100μm×25μm tilted side(25μm)
10% variation of material on DUTs	0.13	0.12	0.03	0.07
track resolution	0.15	0.15	0.3	0.3
10% variation of beam energy	0.02	0.11	0.03	0.07
Z position+/-10 mm	1.03	1.02	0.6	1.7
total	1.05	1.04	0.67	1.73