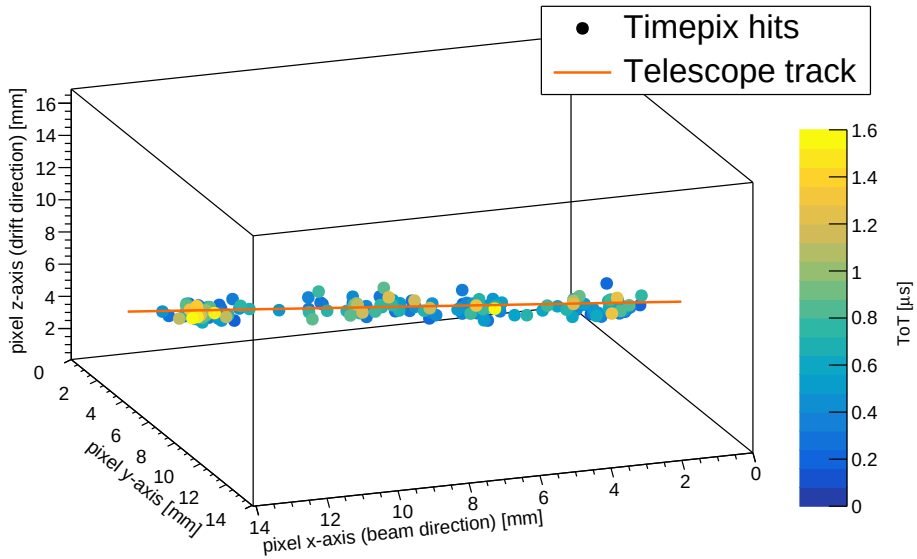

Update on test beam analysis of a single chip Timepix3 Ingrid

Kees Ligtenberg

Lepcol meeting

January 15, 2017

Nikhef

Outline

- Detector setup
- Fit procedure and selection
- time walk corrections **(updated)**
- Cross-talk **(updated)**
- Diffusion coefficients
- Deformations in pixel plane **(updated)**

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Timepix3-based GridPix

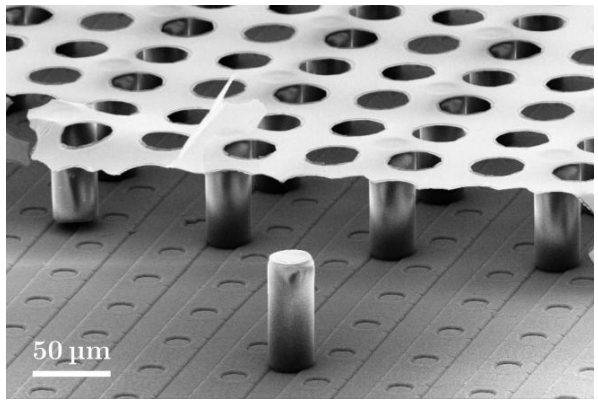
Timepix3-based GridPix:

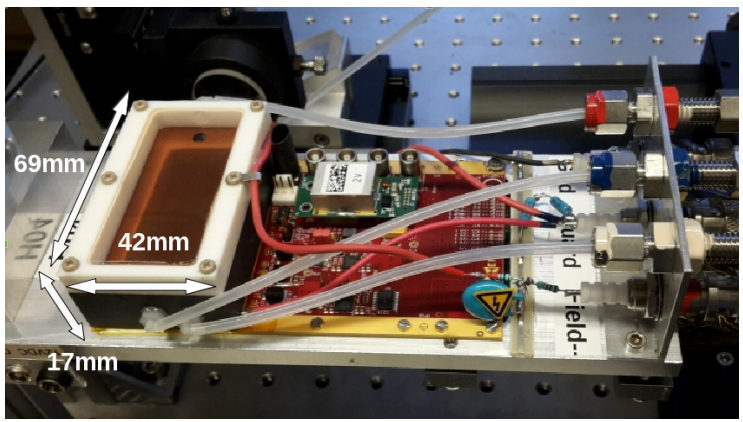
- Micro-pattern gaseous detector with grid aligned to pixels
- 65K 55 µm × 55 µm sized pixels

Timepix3 compared to its predecessor:

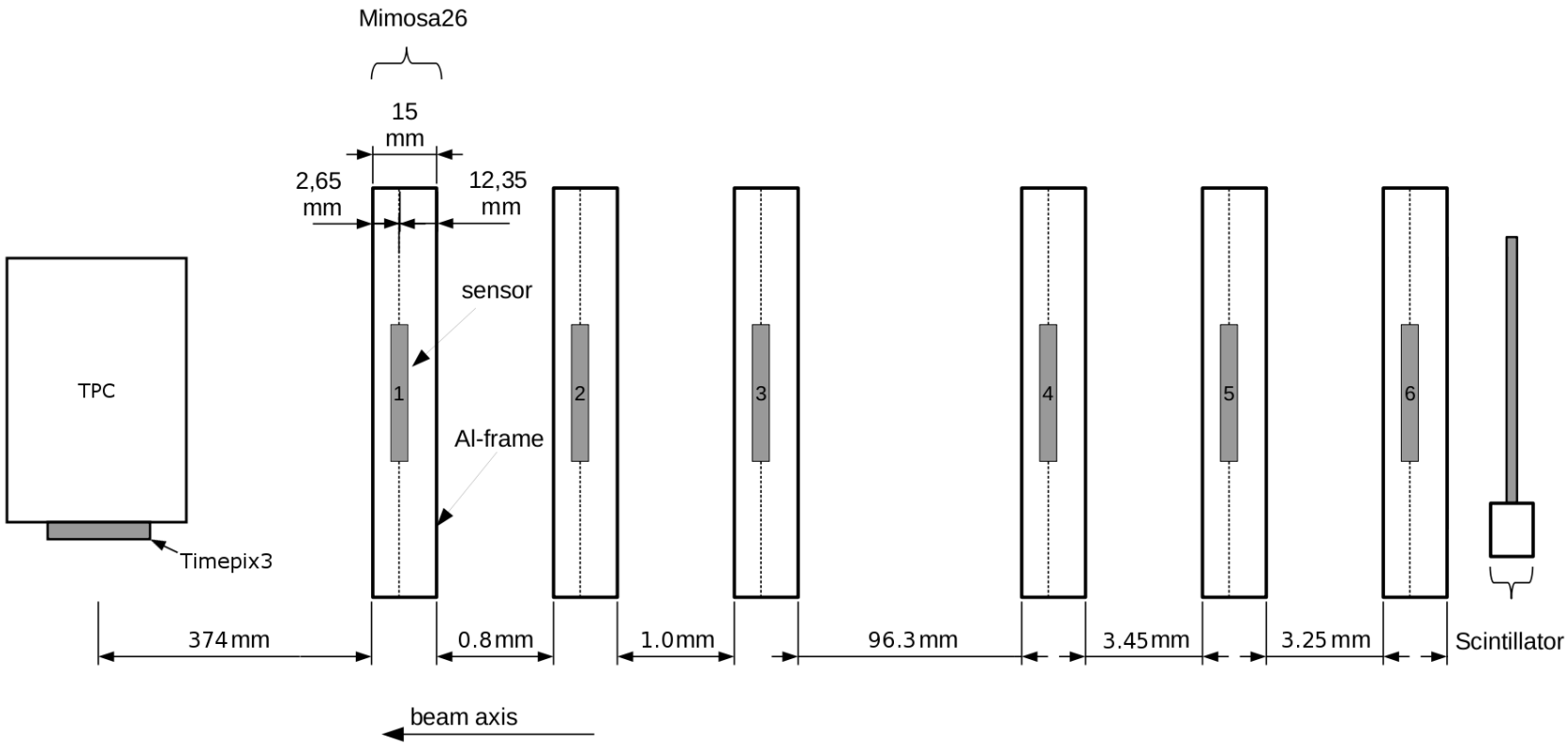
- Improved time resolution of 1.56 ns
- Simultaneous time and charge (ToT) measurement

Single chip Timepix3 detector with field shaping, guard electrode, and
T2K TPC gas (Ar:CF_4:iC_4H_{10} 95:3:2)





Detector setup



Adapted from Thesis Pascal Wolf Bonn, 2016

2.5 GeV electrons delivered by ELSA-facility (Bonn)

Events are triggered by a scintillating plane

Telescope of 6 mimosa planes with 18.4 µm × 18.4 µm sized pixels[1]

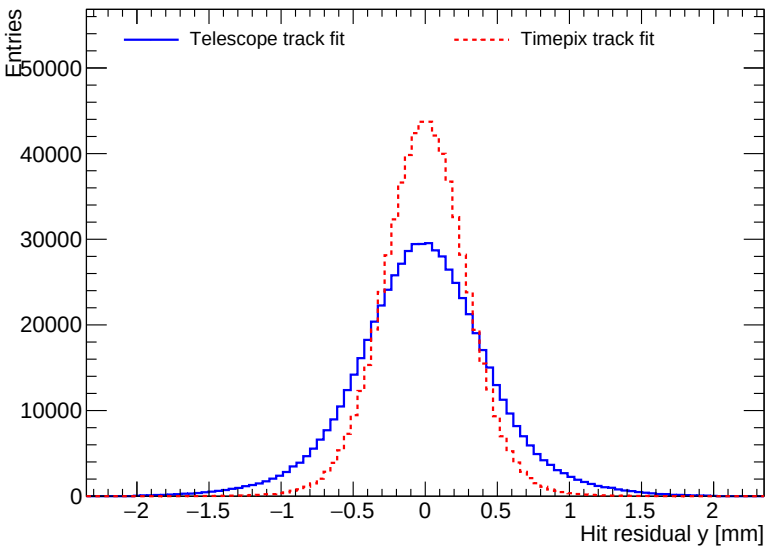
[1] Mimosa telescope provided by Bonn SiLab

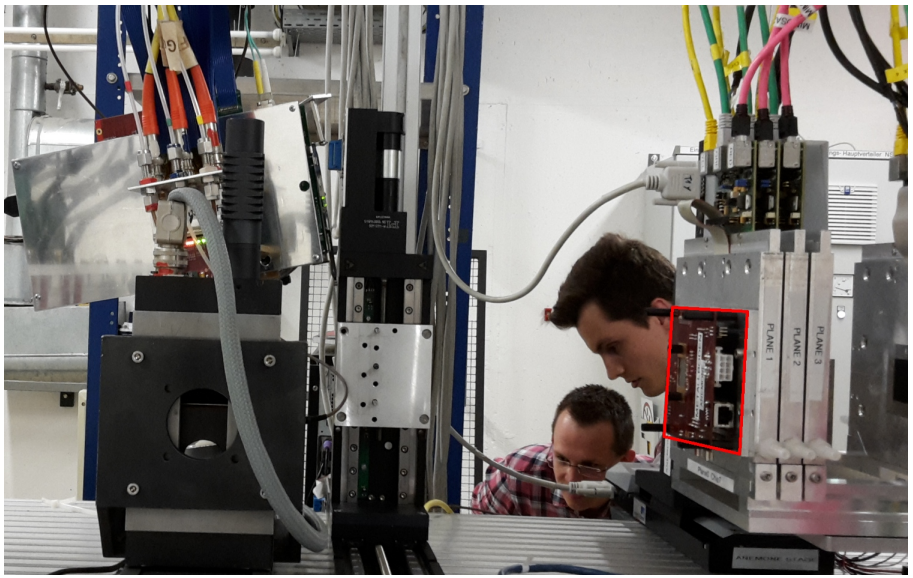
Time matching of telescope and Timepix3

- Timepix3 and telescope are both in data driven mode
- Each telescope frame (115.2 µs) can have a range of triggers
- Decode trigger number in Timepix3 using rising edge only
- Save Timepix3 tracks in a 400 ns window around a trigger (offset 207 µs)

For each frame, attempt to match all events of the Timepix3 with triggers in the range

FEI4 between telescope and TPC





- Telescope track has additional smearing compared to Timepix3 track
- Possibly caused by the FEI4-chip being attached to the telescope (for timing in some other setups)
- Can have caused a scatter of about $\sim$0.7 mRad
- Only use the final telescope plane crossing position in Timepix3 trackfit

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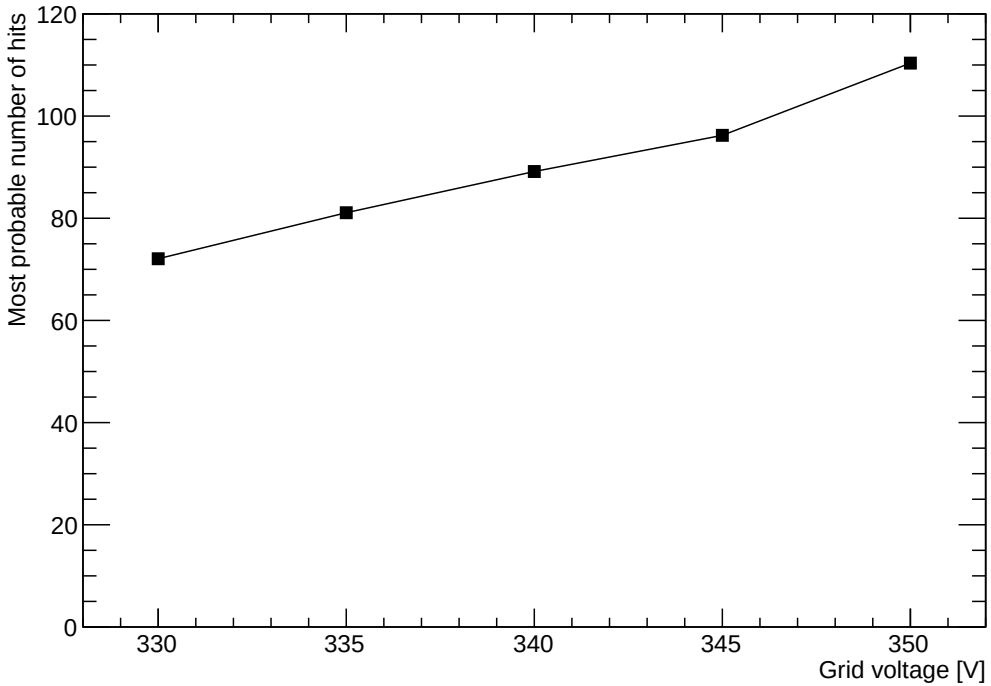
Number of hits for various grid voltages



- Most probable number of hits from gaus-fit
- The increase at 350 V might be an indication of cross-talk to neighbouring pixels
- Results shown from run at $V_{\text{grid}} = 350\,\text{V}$, because highest efficiency

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Tests from run 347

Run 347	
length	60 minutes
triggers	4 733 381
V grid	350 V
E drift	280 V/cm
rotation	17 degree
	0 degree
threshold	800e

- Used first 1 000 000 telescope frames:
  - 461 426 triggers of which 330 925 with matching tracks
- A drift speed of 75 µm/ns was *assumed* ($\sim$ 78 µm/ns calculated[1])

[1] http://www-hep.phys.saga-u.ac.jp/ILC-TPC/gas/index.html

Fit procedure for telescope and Timepix3

- Independently align telescope (5 rotations + 4 $\times$ 2 shifts)
- Rotate and shift Timepix3 to match telescope frame (5 parameters)
- Do ToT and time walk corrections
- Find clusters
- Do a double simple linear regression fit in the telescope frame
  - Errors in directions perpendicular to beam-axis
  - In telescope frame the tracks direction is almost parallel to beam-axis, therefore errors along beam-axis were neglected
- Match Timepix3 and telescope clusters
- Add final plane crossing of telescope as a point with 10 μm errors to Timepix3 fit

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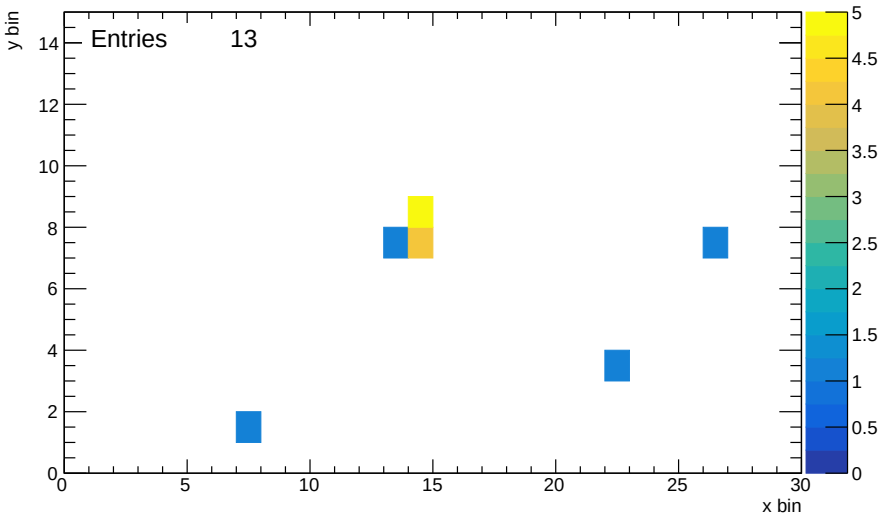
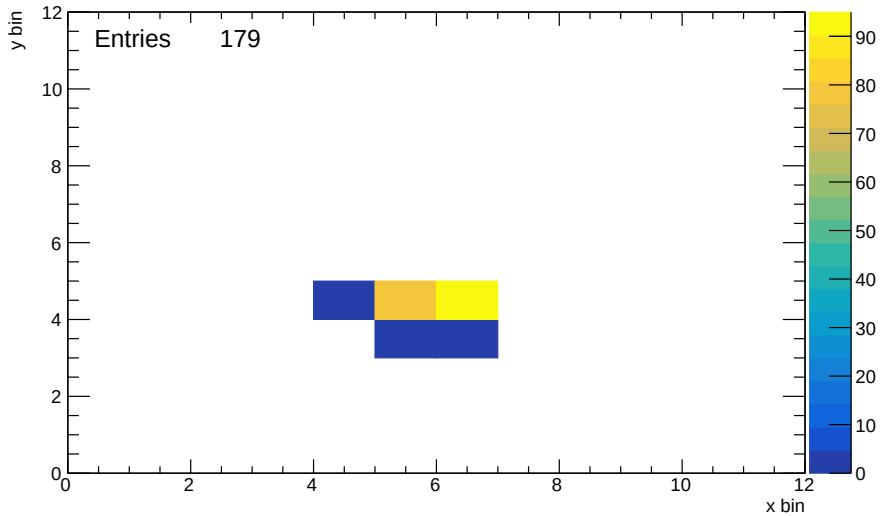
Cluster finding in telescope and Timepix3

Find clusters from hits binned by position for telescope (Timepix3)

- Fill 30×15 (12×12) bins
- If more than 3 (6) hits in one bin, try to merge up to 8 neighbours
- If cluster has more than 10 (5) hits



All telescope planes



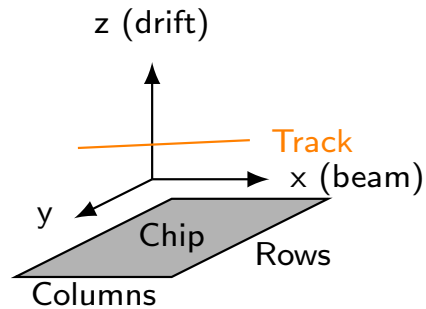
Timepix3

Errors for Timepix3 hits

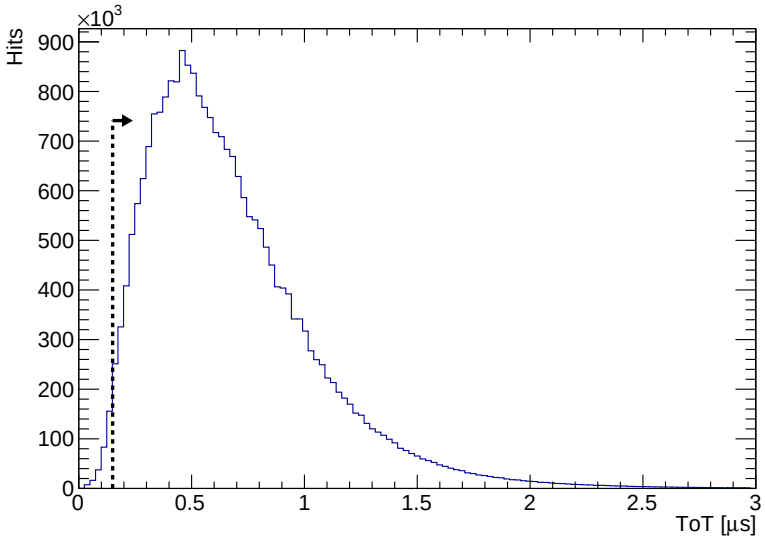
Assign errors to hit:

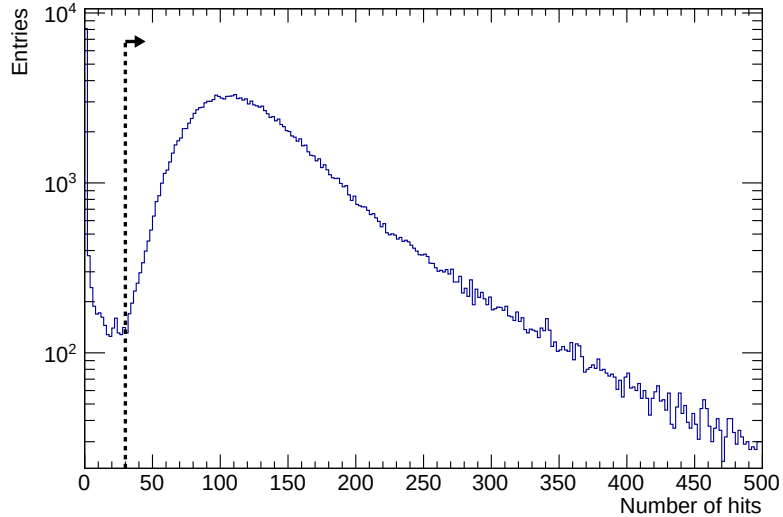
- $\sigma_y^2 = \frac{0.055^2}{12} + D_T^2(z - z_0)$
- $\sigma_z^2 = \frac{(1.56\,\text{ns})^2 v_{\text{drift}}^2}{12} + \sigma_{z0}^2 + D_L^2(z - z_0)$

where D the diffusion coefficient

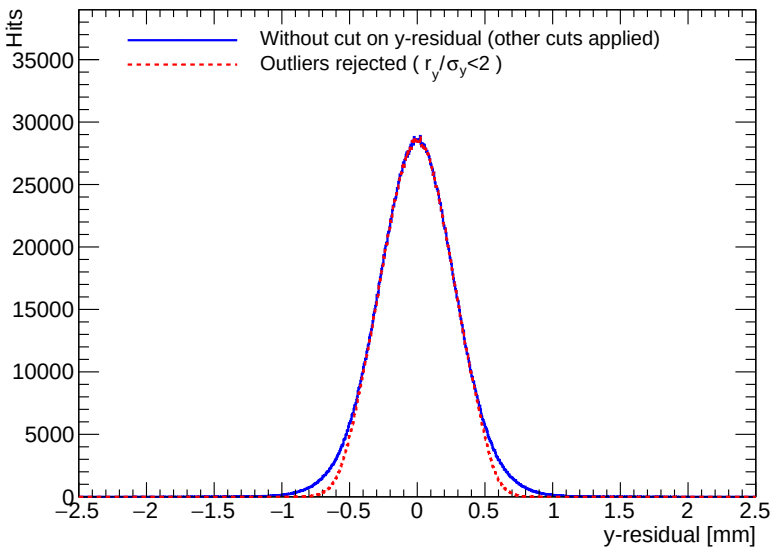


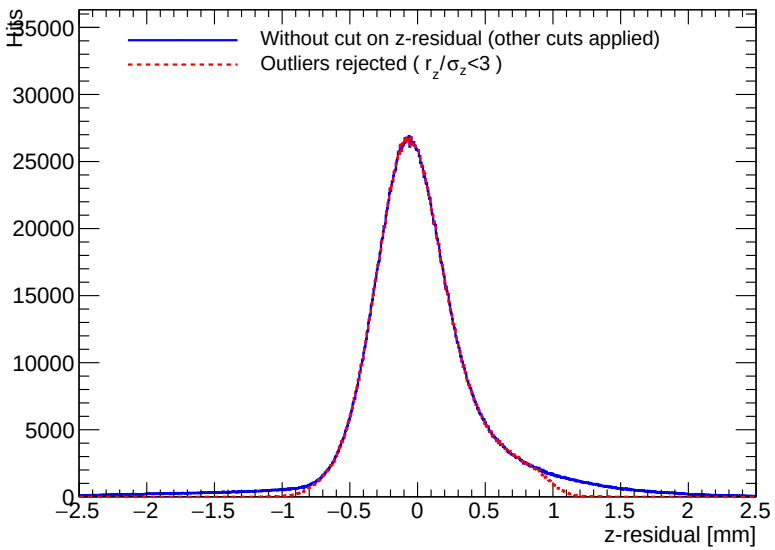
Outlier rejection





Require Time over Threshold ToT $> 0.15\,\mu s$ and more than 30 hits





Require residual $r_y < 2\sigma_y$ and residual $r_z < 3\sigma_z$

Selection cuts

Telescope
At least 4 planes hit
Reject extreme outliers ($> 700\ \mu m$)
Telescope fit goes through tpc
Timepix3
Hit ToT $> 0.15\ \mu s$
At least 30 hits
Exactly one cluster
Cut hit outliers ($> 3\sigma_{drift}$, $> 2\sigma_{plane}$)
Fit goes through front and back (pixel row)
Matching
Fits closer than 1 mm in both x and y at center of tpc
A unique time match
Delta rejection
At least 75% of total number of tpc hits in fit

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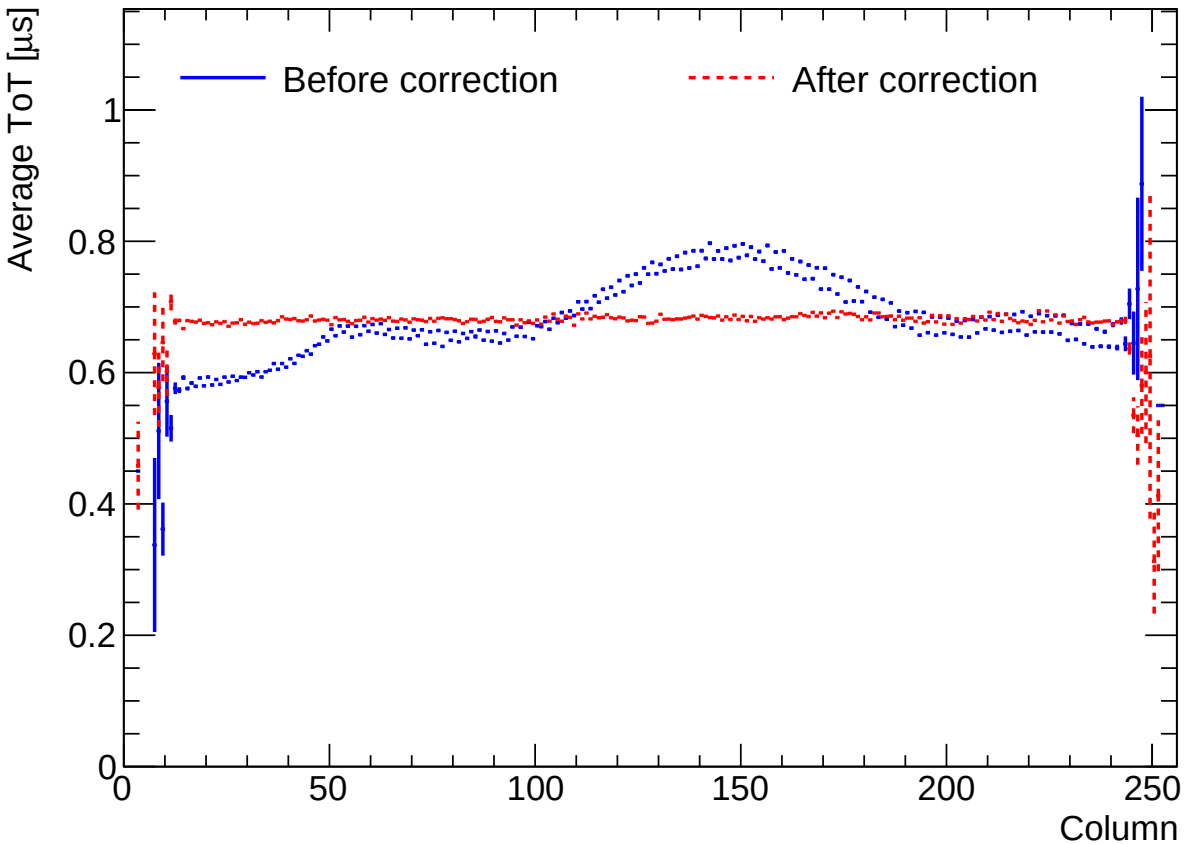
ToT-correction



Double column layout of Timepix3 is visible in ToT
Corrected by introducing a factor for each column

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Time walk corrections

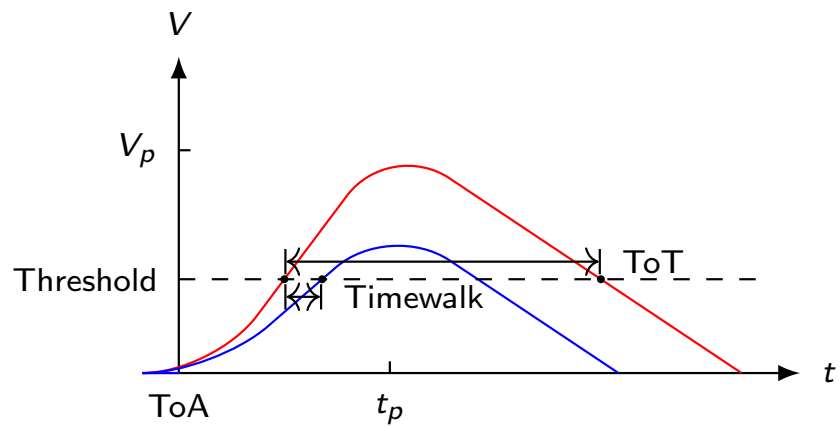
Derived

$$\delta z_{\text{timewalk}} = \frac{c_1}{t_{\text{ToT}} + t_0} + z_0$$

Adding extra terms:

$$\delta z_{\text{timewalk}} = \frac{c_2 t_{\text{ToT}} + c_1}{{t_{\text{ToT}}}^2 + c_3 t_{\text{ToT}} + t_0} + z_0$$

$$\delta z_{\text{timewalk}} = \frac{c_3 {t_{\text{ToT}}}^2 + c_2 t_{\text{ToT}} + c_1}{{t_{\text{ToT}}}^3 + c_4 {t_{\text{ToT}}}^2 + c_5 t_{\text{ToT}} + t_0} + z_0$$



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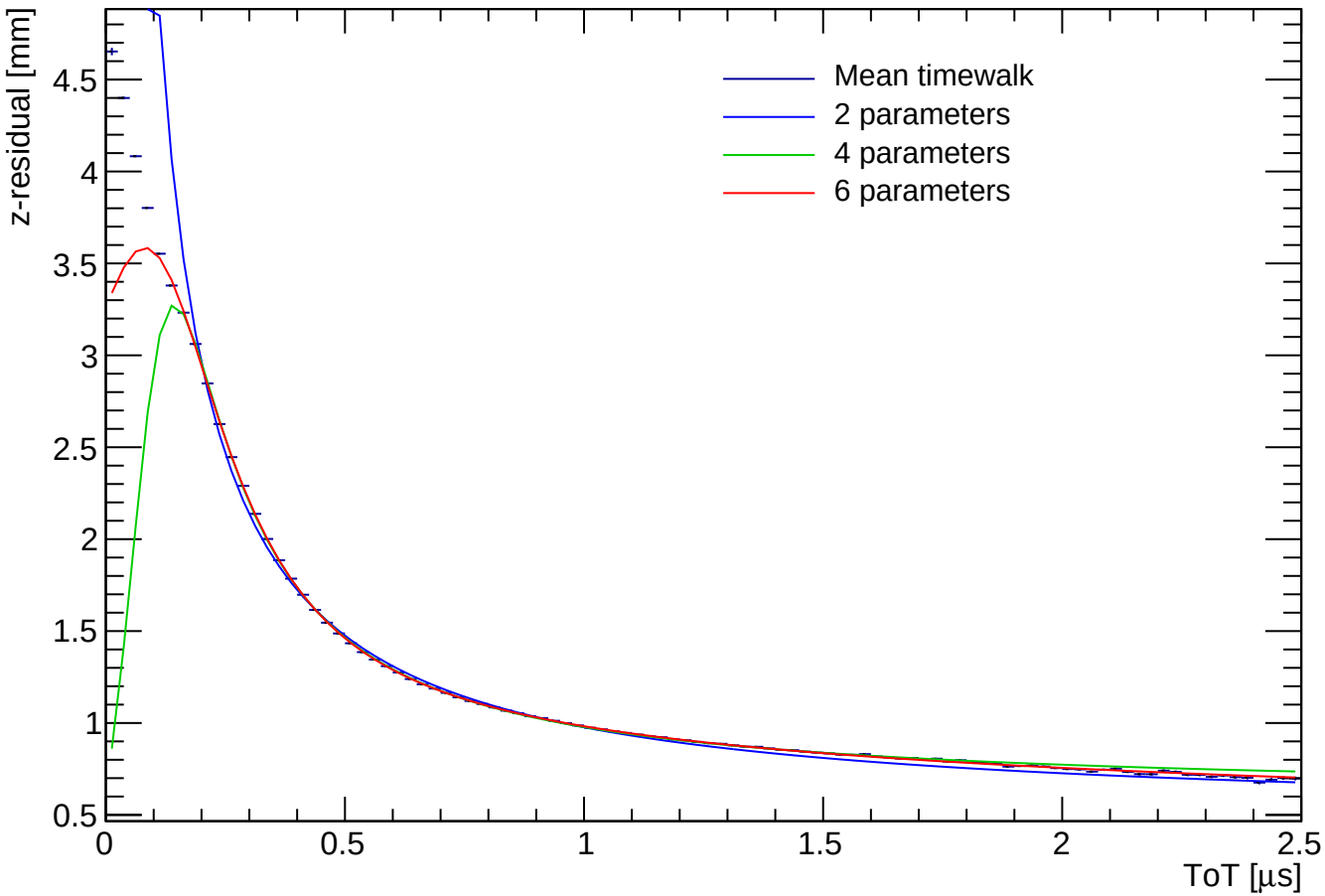
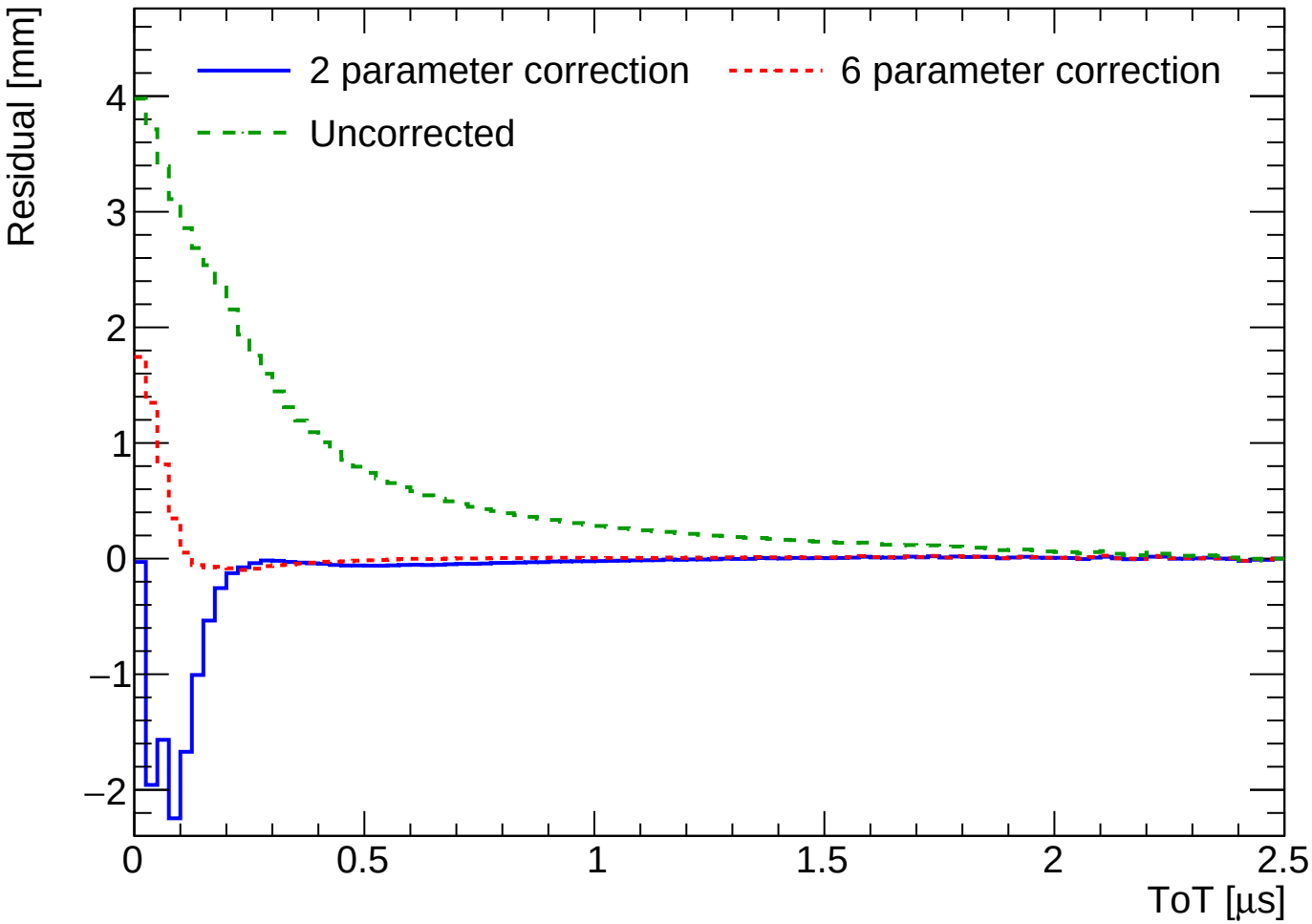
Fit to residual by ToT

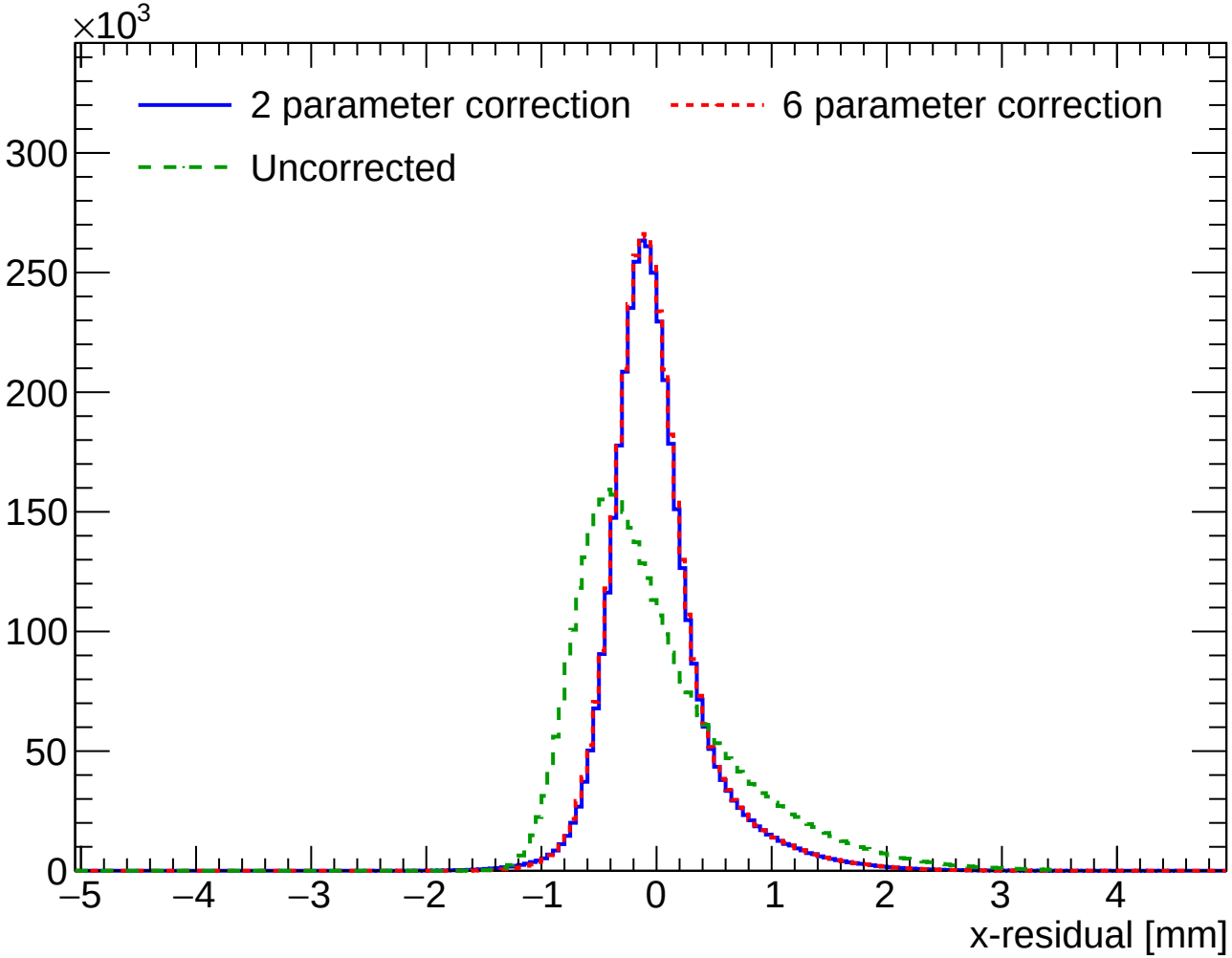


Fit from $t_{\mathrm{ToT}} > 0.15\,\mu\mathrm{s}$

Residuals from fit



Time walk correction using ToT



Crosstalk

If amplification is too strong, the signal can be detected by two neighbouring pixel
Such hit pairs are expected to have low(er) ToT and similar arrival times
This should be observable in distributions

A fake crosstalk signal was generated by having a chance to generate a crosstalk hit in a neigbouring pixel

- For crosstalk, the original ToT (charge) is shared between two hits
- The crosstalk hits have the same arrival time

For distributions hits are selected by topology:

0	0	0
0	×	0
0	×	0
0	0	0

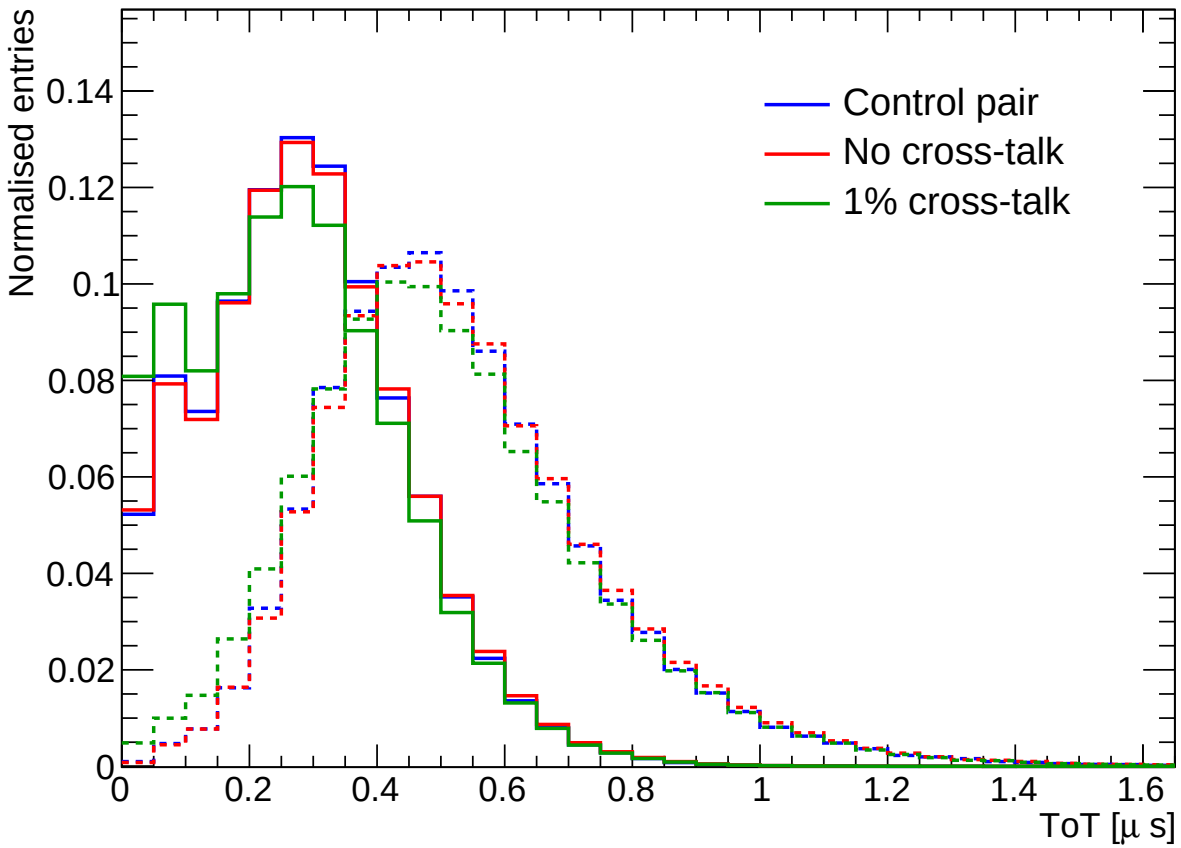
Isolated pair

0	0	0
0	×	0
0	0	0
0	×	0

Control pair

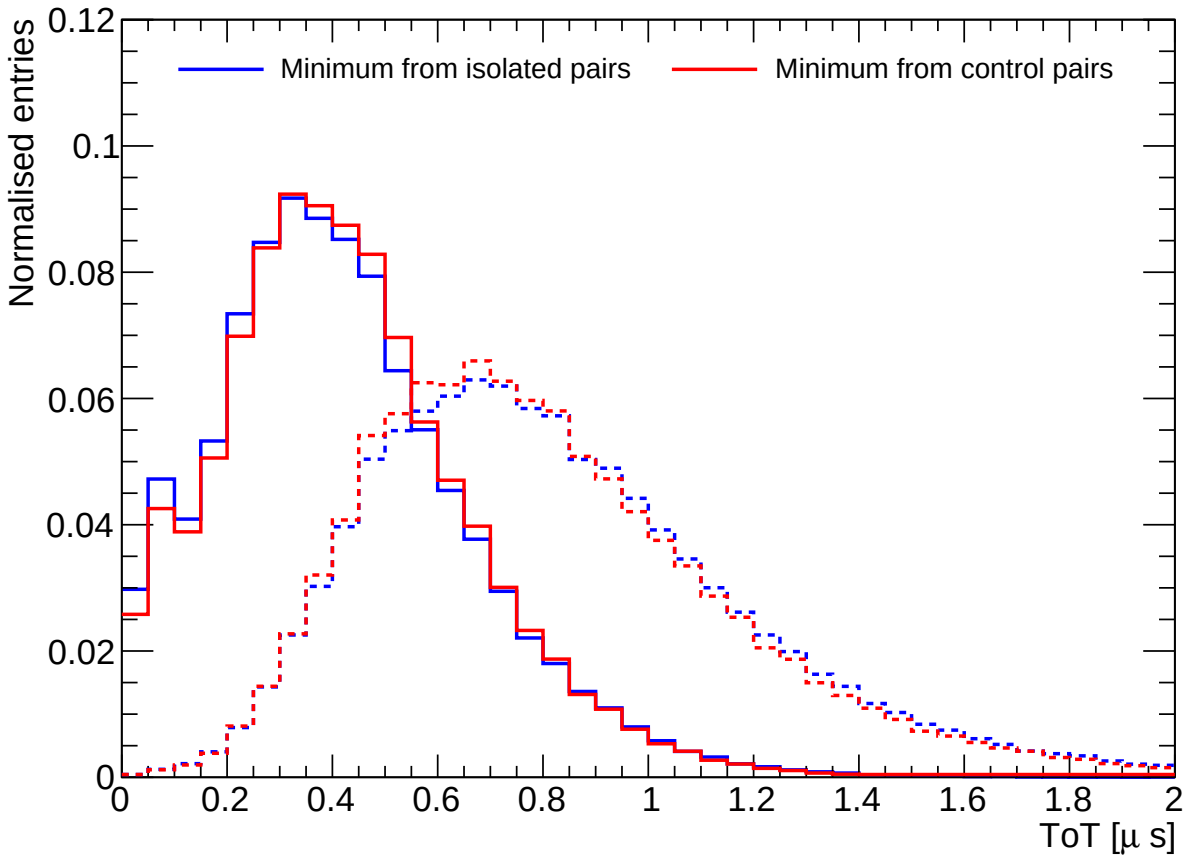
Crosstalk at a grid voltage of 330 V

For a grid voltage of 330 V no crosstalk is expected
The minimum and maximum ToT for each pair is shown:



The control pairs match the isolated pairs at 330 V

Crosstalk at a grid voltage of 350 V



The control pairs do not match the isolated pairs at 350 V
This could indicate a small amount of crosstalk

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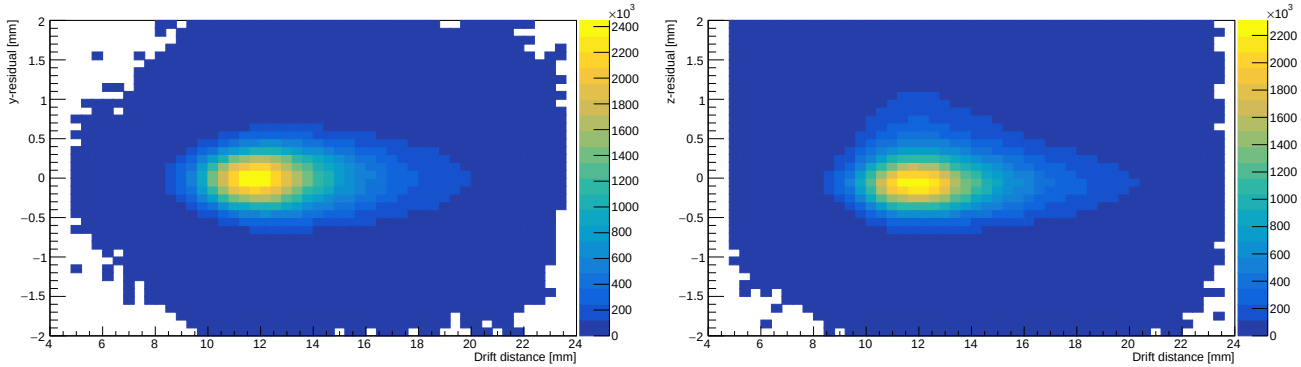
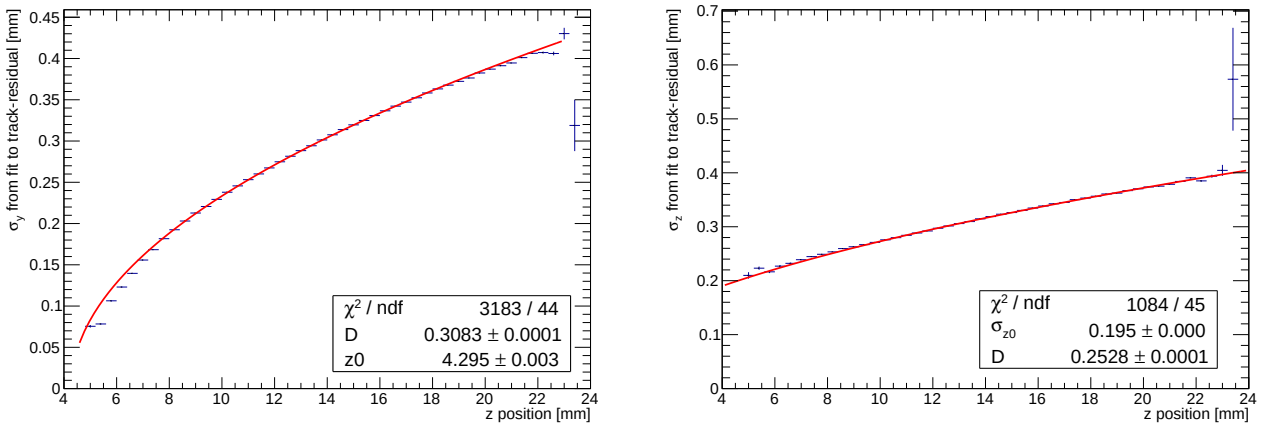
Find diffusion from residuals

Plot residuals in 2-dimensional histogram

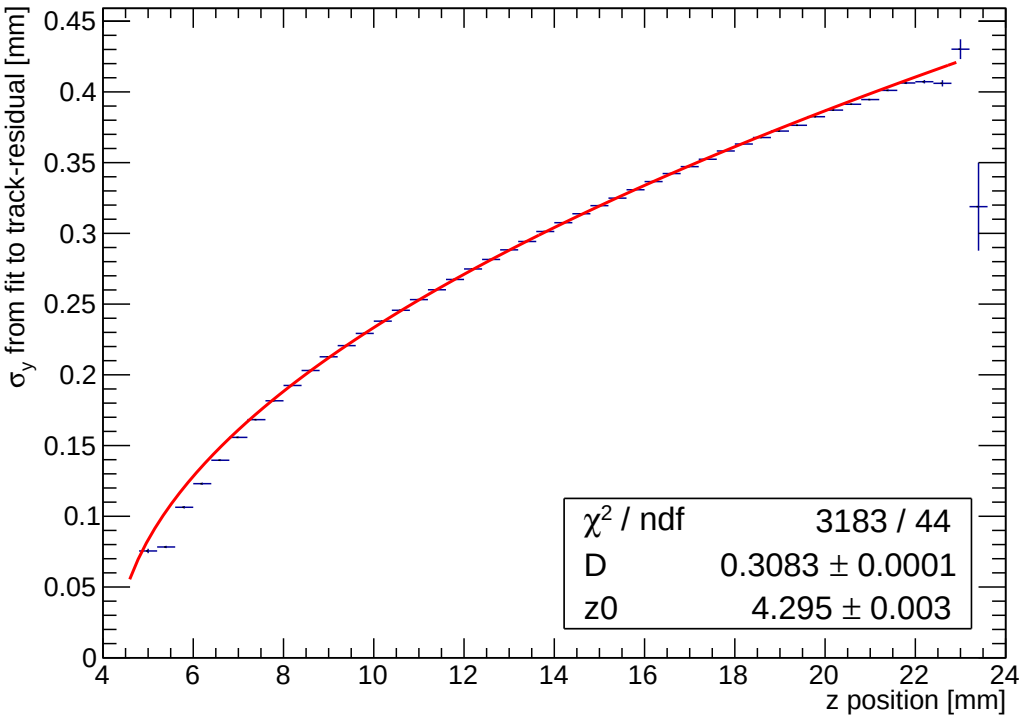


Fit gauss to y-slices and put σ in graph



Fit $\sqrt{\sigma_0^2 + D^2(z - z_0)}$ to graph, and get results $\rightarrow$

Diffusion in pixel plane perpendicular to track



Fix $\sigma_{y0} = 0.055/\sqrt{12} = 0.0159\,\text{mm}$

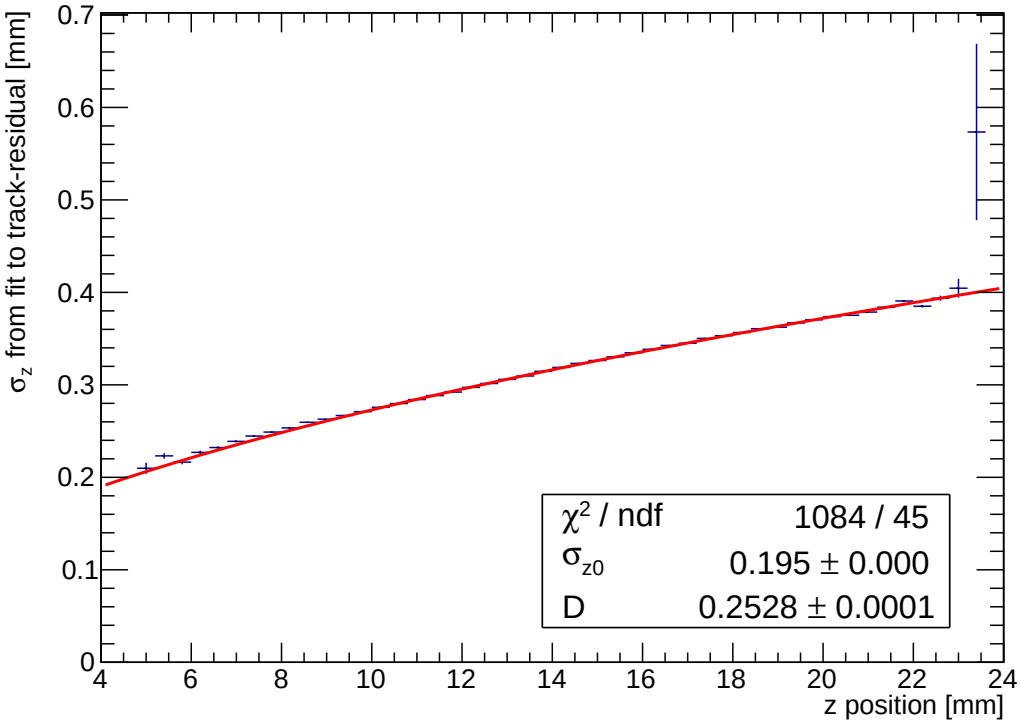
$D_T = 309\,\mu\text{m}/\sqrt{\text{cm}}$ ($\sim 310\,\mu\text{m}/\sqrt{\text{cm}}$ calculated[1])

From laser tests $D_T = 309\,\mu\text{m}/\sqrt{\text{cm}}$ at $V_{\text{grid}} = 330\,\text{V}$, $V_{\text{drift}} = 200\,\text{Vcm}^{-1}$ and $v_{\text{drift}} = 66.4\,\mu\text{m/ns}$ [2]

[1] http://www-hep.phys.saga-u.ac.jp/ILC-TPC/gas/index.html

[2] GridPix detector with Timepix3 ASIC, talk at TIPP17

Diffusion in drift direction



Fix grid position with value from y-fit $z_0 = 4.027\,\text{mm}$
$D_L = 252\,\mu\text{m}/\sqrt{\text{cm}}$ ($\sim 230\,\mu\text{m}/\sqrt{\text{cm}}$ calculated[1])

From laser test without time walk correction $D_L = 254\,\mu\text{m}/\sqrt{\text{cm}}$ at $V_{\text{grid}} = 330\,\text{V}$ and $v_{drift} = 66.4\,\mu\text{m/ns}$ [2]

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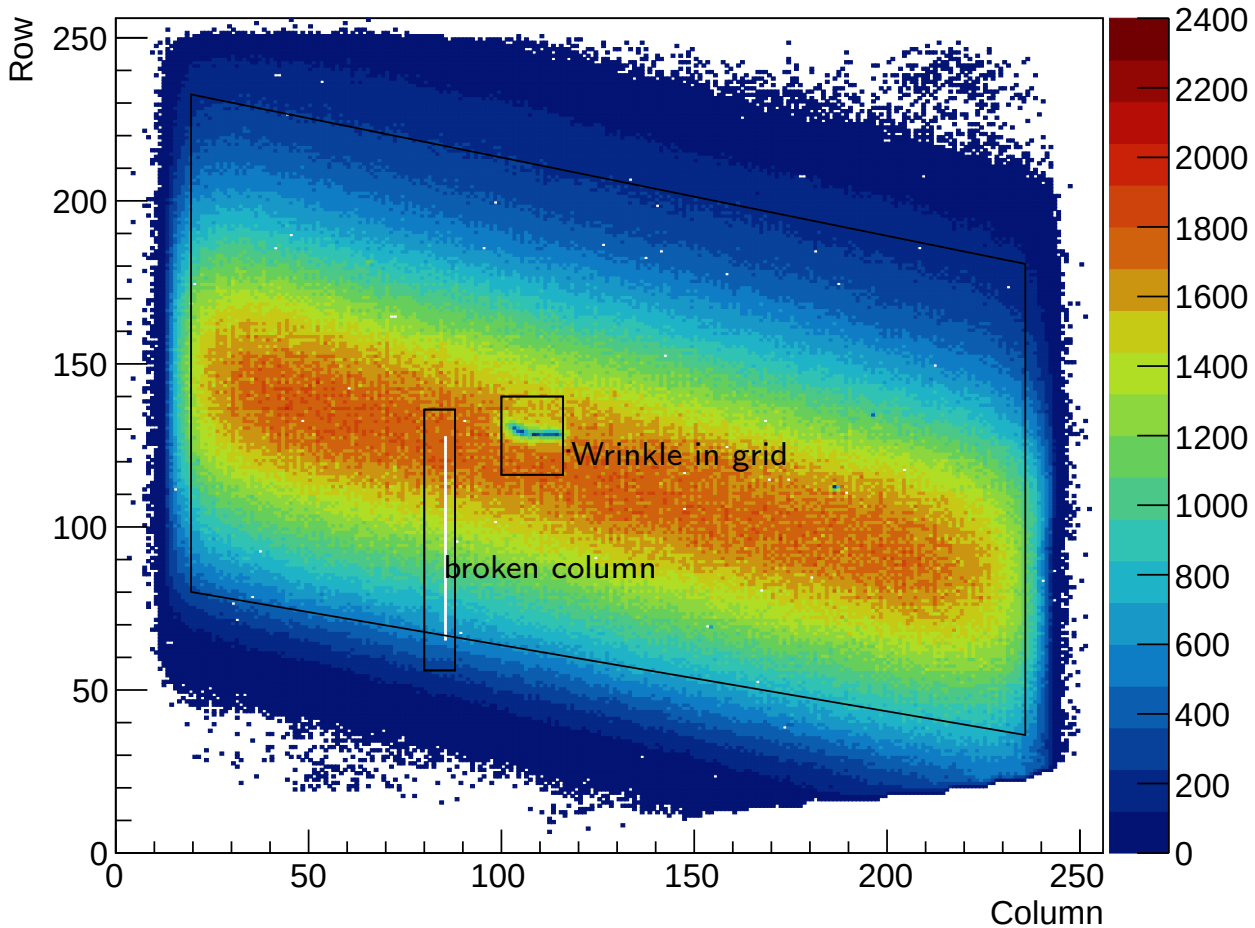
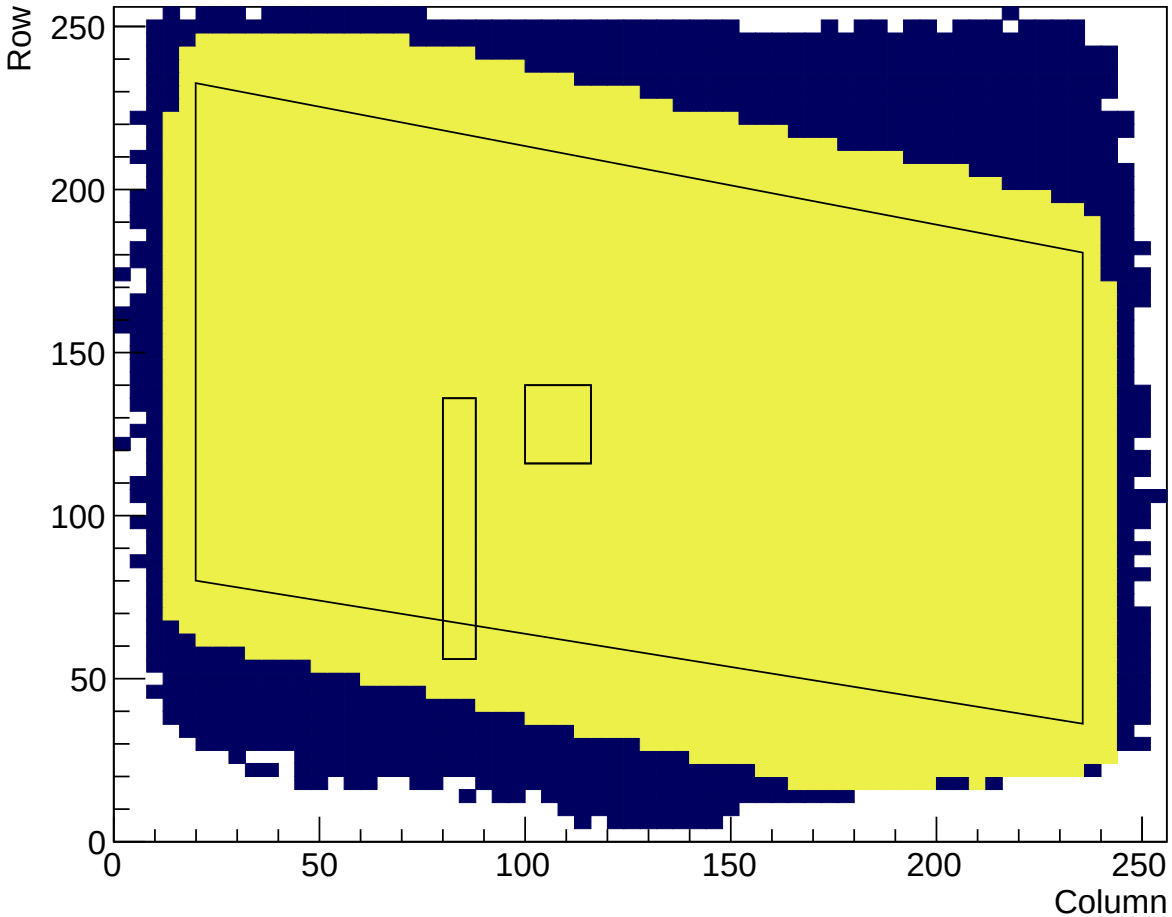
Timepix3 hit map



Note some defects

Define area in center without defect regions

4×4 pixel-bins with more than 1000 hits



Investigate deformations in bins of 4×4 pixels

All bins in defined area have at least 1000 hits

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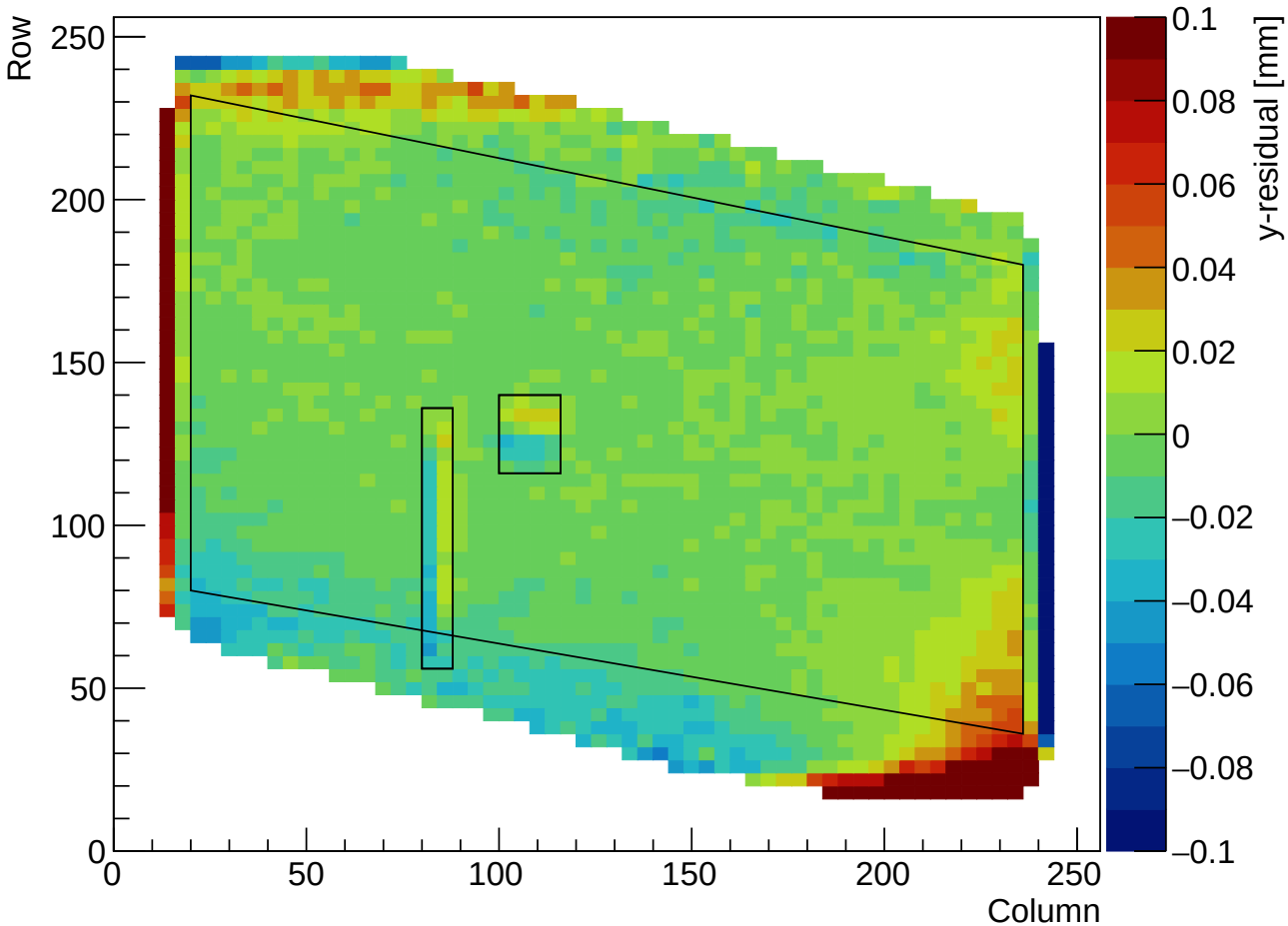
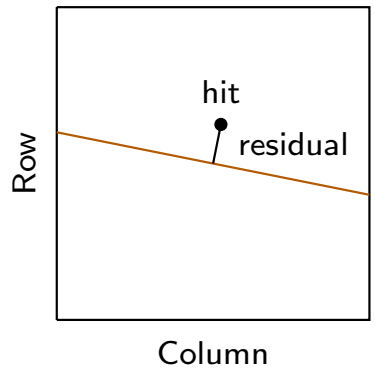
Deformations perpendicular to track in pixel plane

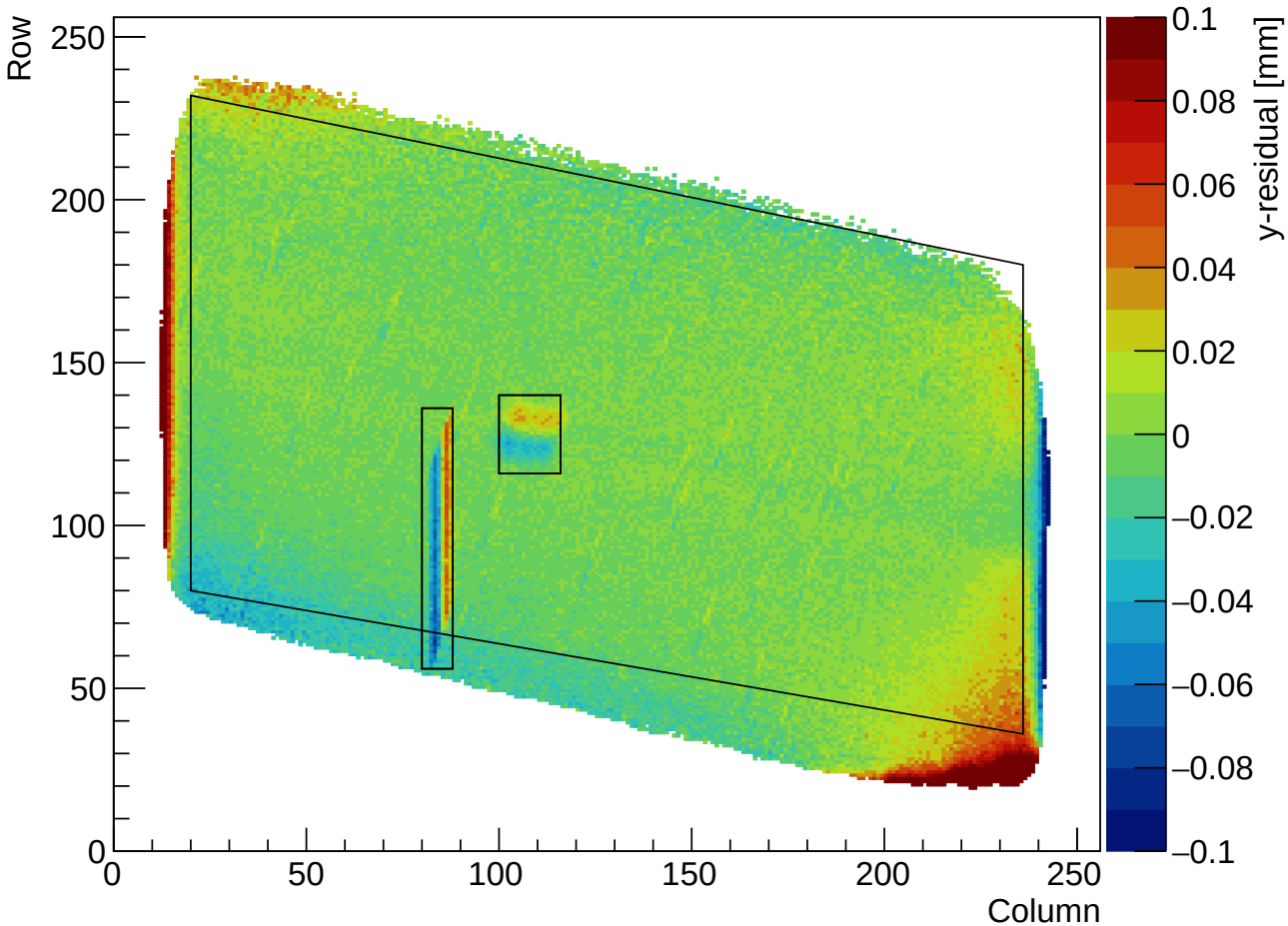


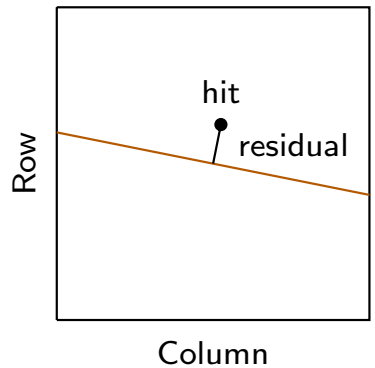


Each bin displays mean residual from 4×4 pixels

Residuals are filled at expected row and column

Deformations perpendicular to track in pixel plane



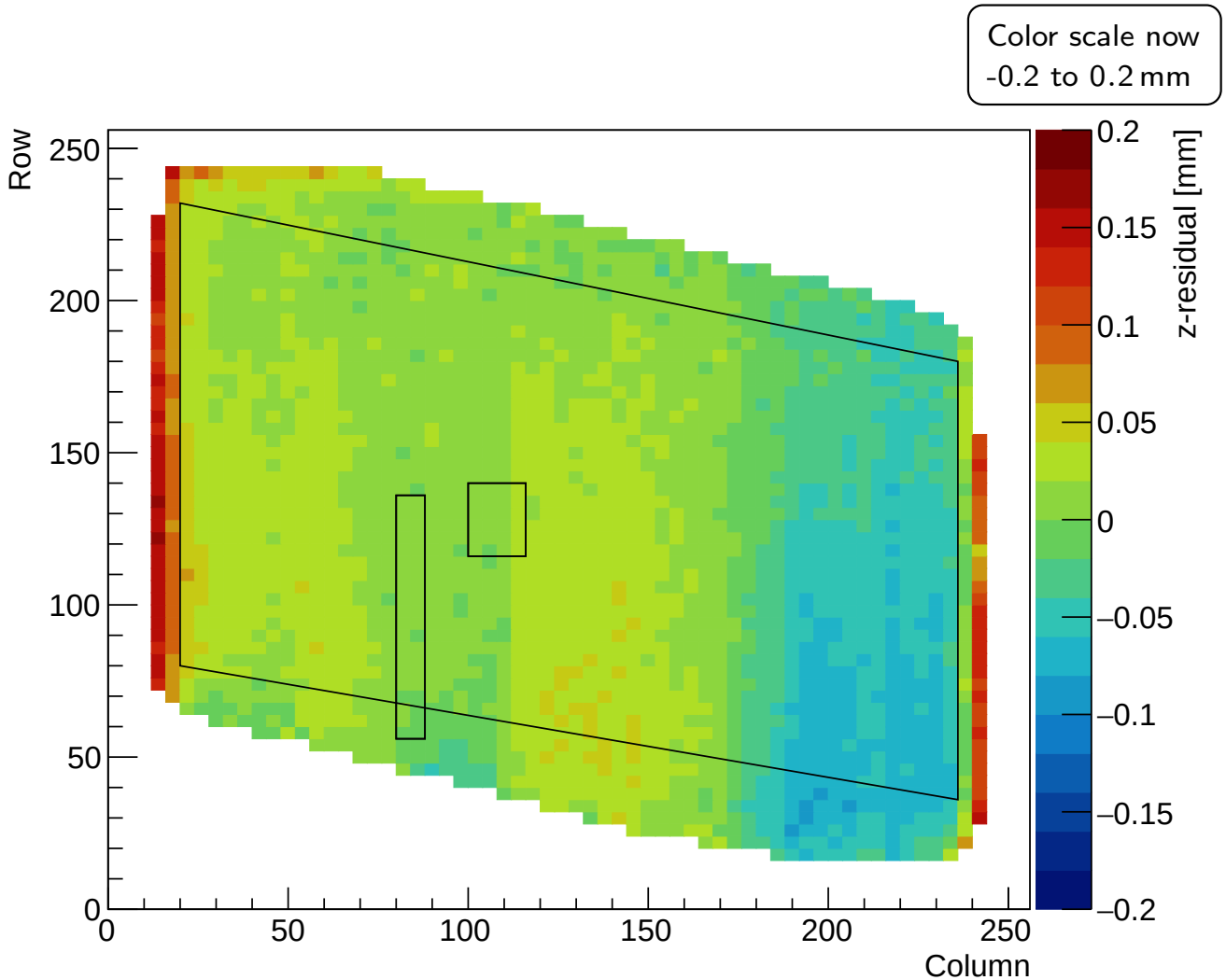


Each bin displays mean residual from 1×1 pixels

Area is not a good match anymore

Residuals are filled at expected row and column

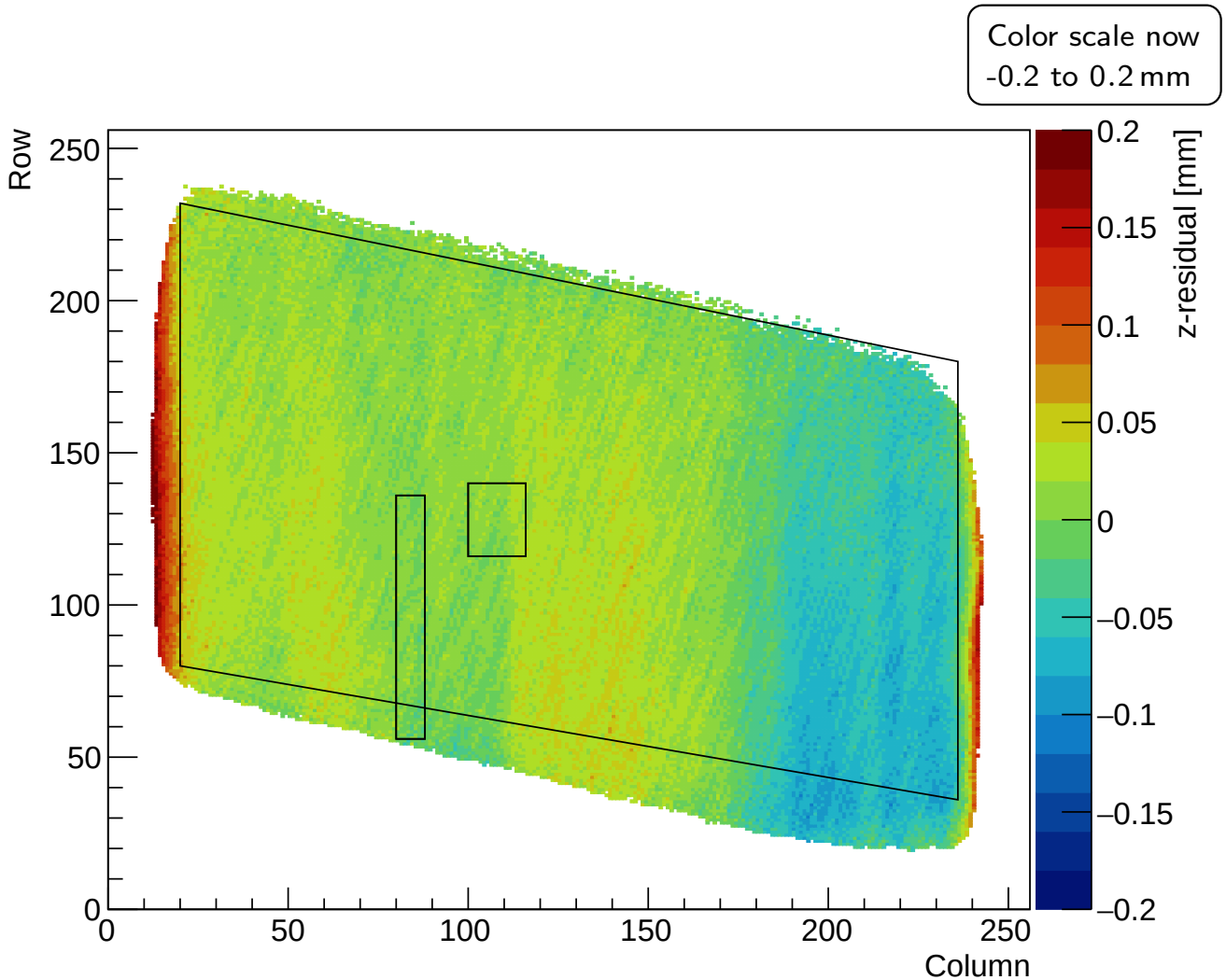
Deformations in drift direction



Each bin displays mean residual from 4×4 pixels

Residuals are filled at expected row and column

Deformations in drift direction



Each bin displays mean residual from 1×1 pixels

Area is not a good match anymore, and chip structure is visible

Residuals are filled at expected row and column

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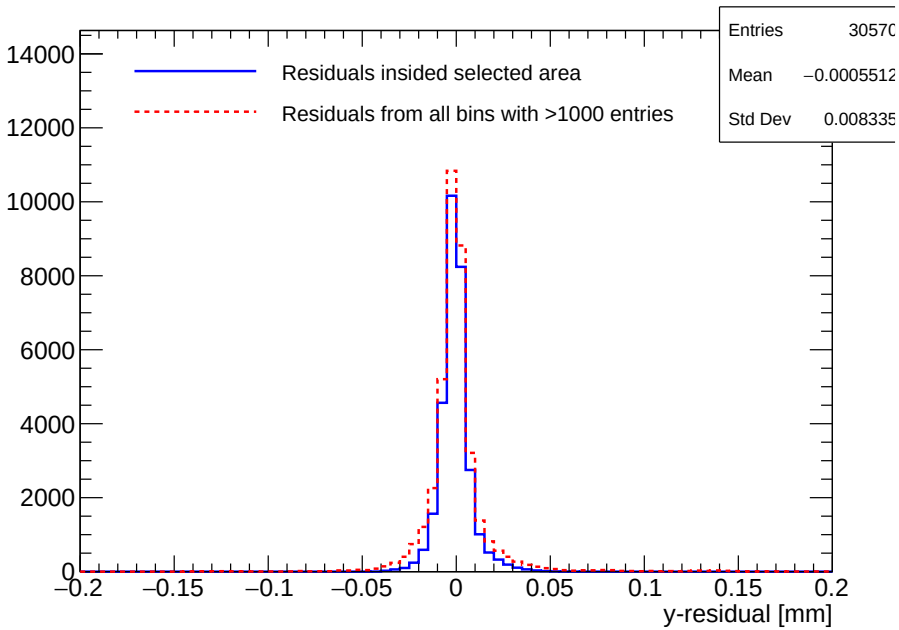
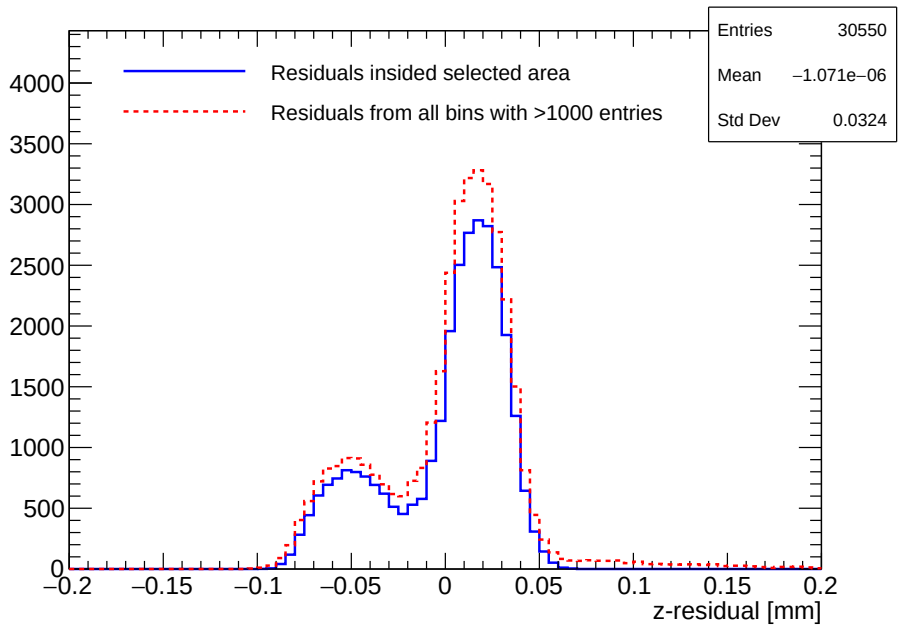
Histograms of Timepix3 deformations

Fill one entry per bin (pixel) from previous slide in histogram





RMS in selected area is 8 µm in plane and 31 µm (0.4 ns) in drift direction

Conclusions

- Telescope track does not seem te be usable, possible due to material between telescope and Timepix3. Instead, a single point was used
- ToT was corrected and used for a simple time walk correction
- The diffusion coefficient fitted from data is $D_T = 309\,\mu m/\sqrt{cm}$ and $D_L = 257\,\mu m/\sqrt{cm}$
- Deformations in the pixel plane are found to be 8 µm

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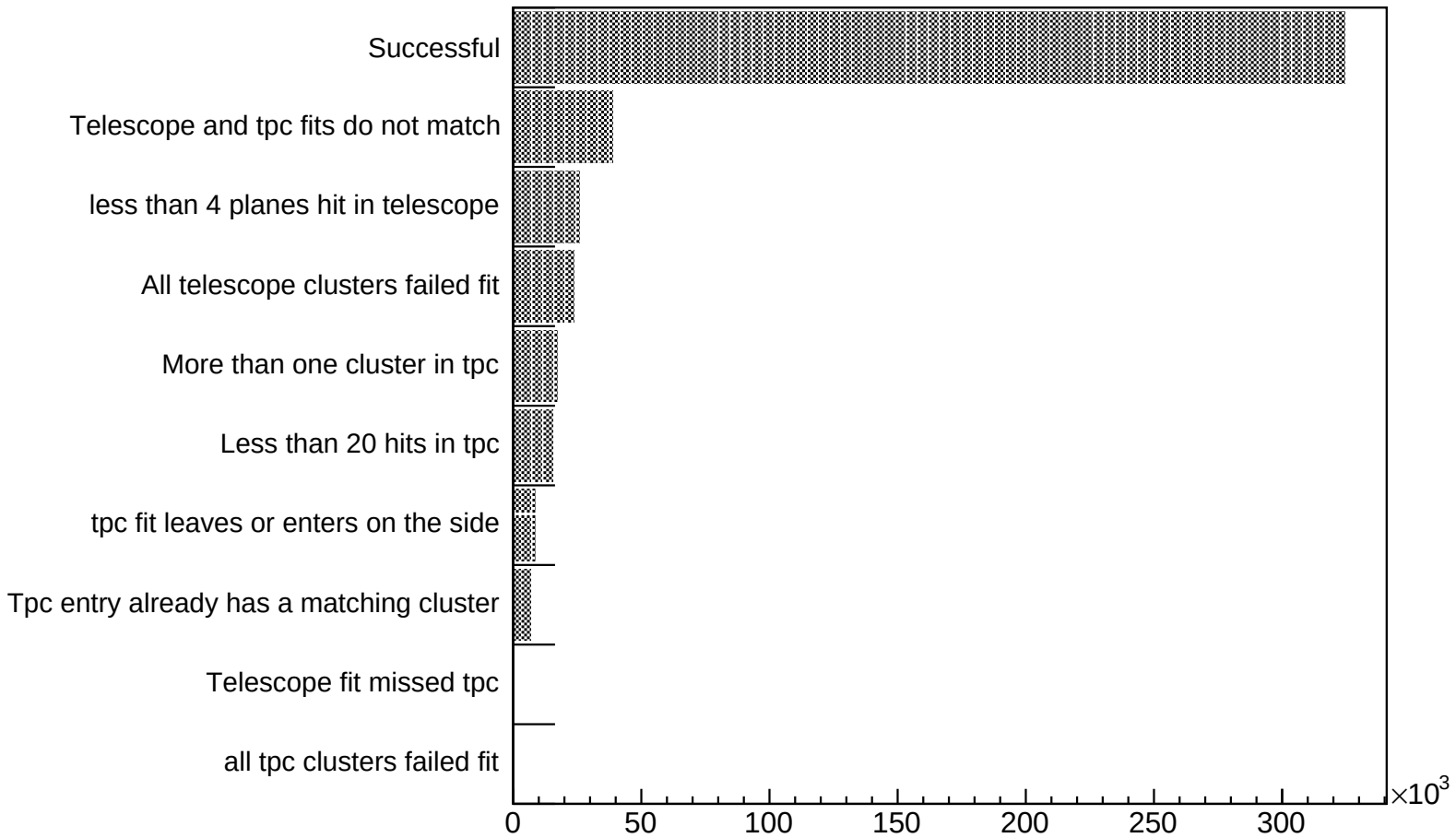
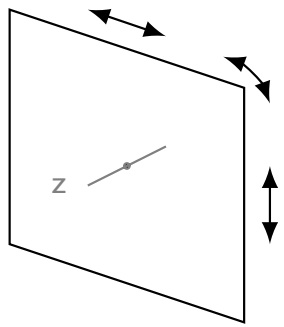
Indication of cut effects



Cuts are roughly in order presented before

Align telescope planes



Align with 3 degrees of freedom: x, y shifts and rotation around z
Fix z position and assume all detectors perpendicular to the z-axis

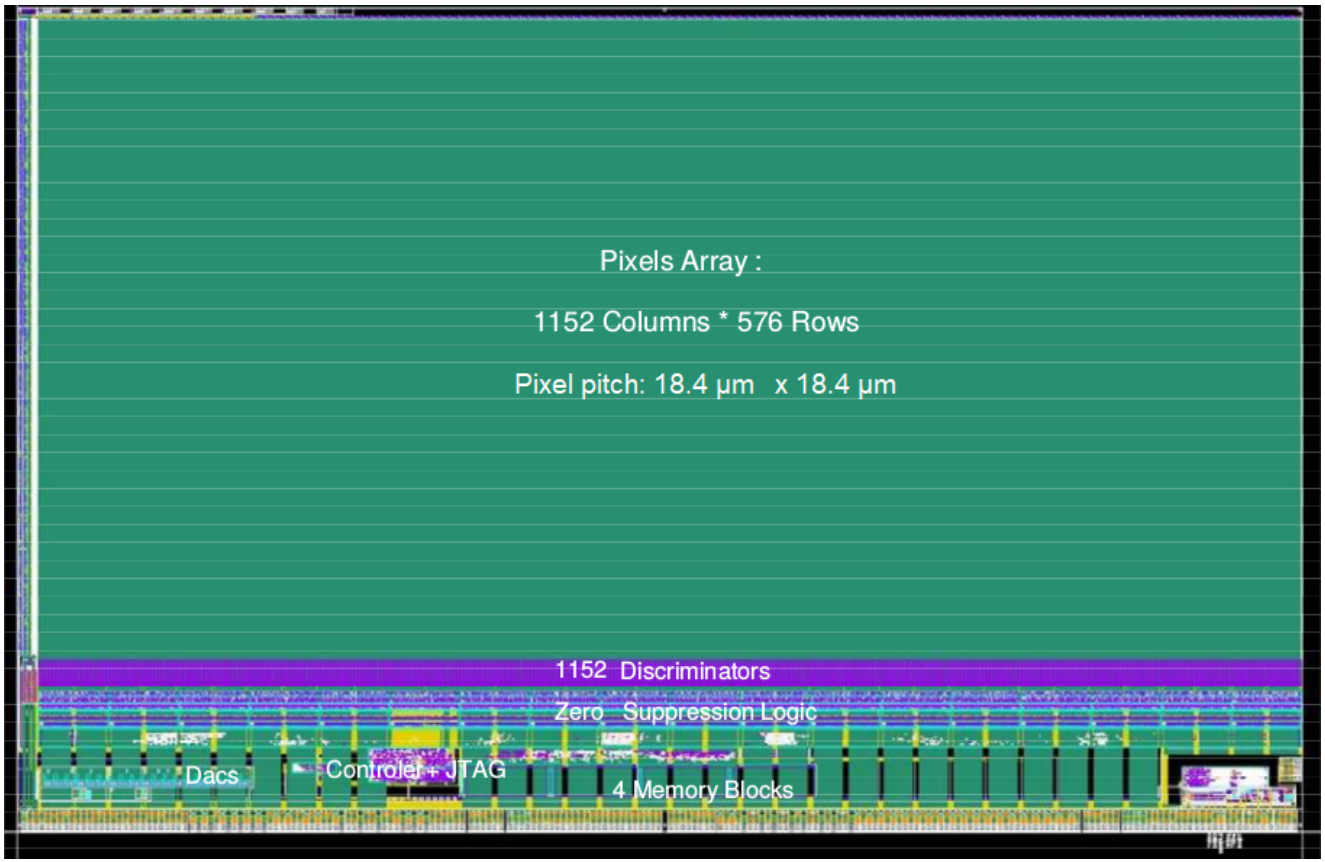
Find corrections from residuals

- Find mean of residuals using gaus fit
- Find rotation using histogram of $\Delta\phi = (yr_x - xr_y)/(x^2 + y^2)$, where x, y are the hit coordinates with respect to the average hit position and r is the residual, histogram is weighted by $\sqrt{x^2 + y^2}$

Telescope alignment procedure

1. Fit through points in plane 2 and 5
   shift planes 1,3,4,5,6 in x and y
2. Fit through points in plane 2 and 5
   rotate plane 5 around its average hit postition to match plane 2
3. Fit through points in plane 2 and 5
   rotate all planes around their average hit position
4. Fit through points in all planes
   check if converged.

Mimosa telescope



MIMOSA26 User Manual, 2011

Detector with digital silicon pixels

Rolling shutter readout with 115.2 µs per frame

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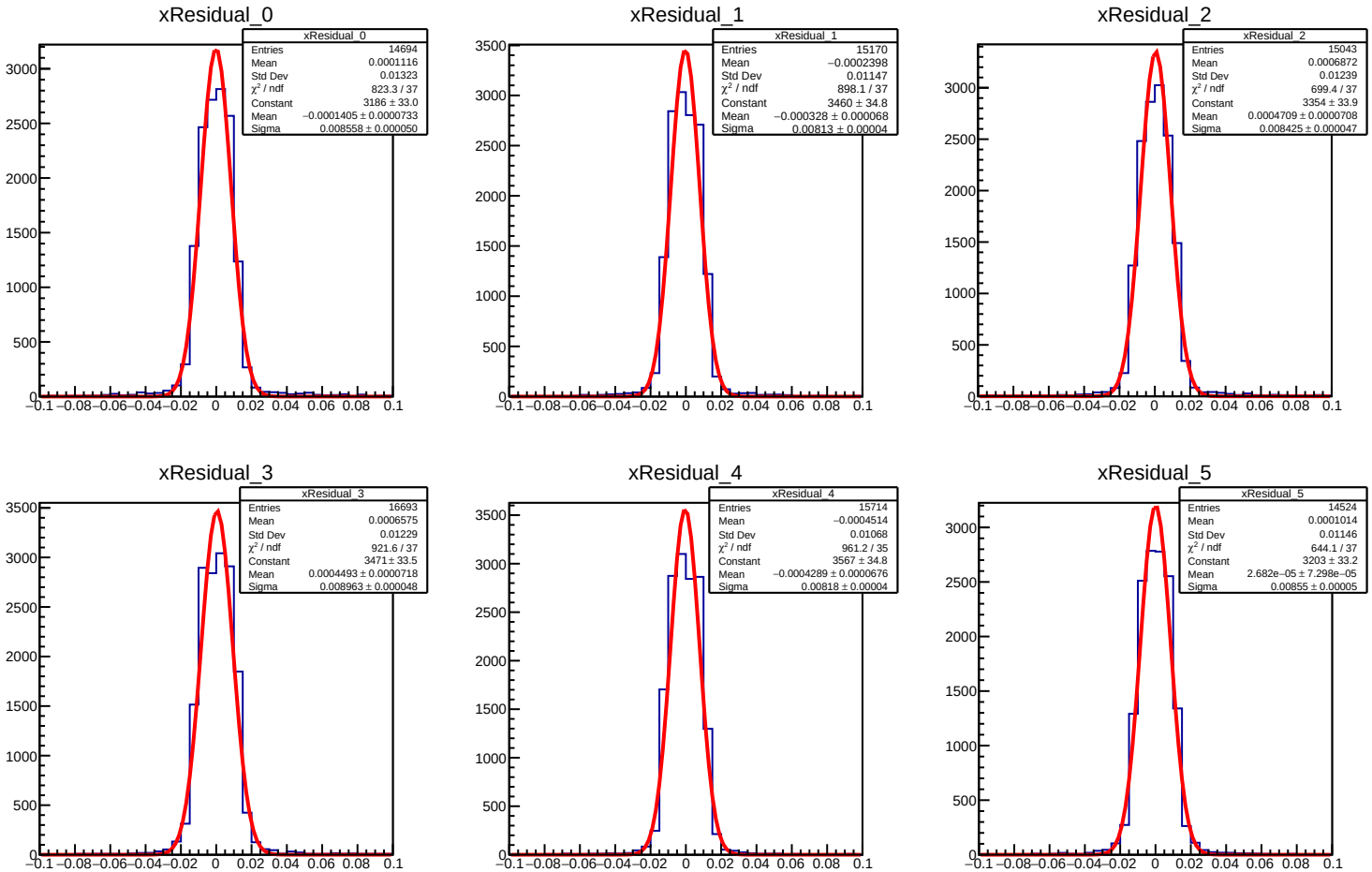
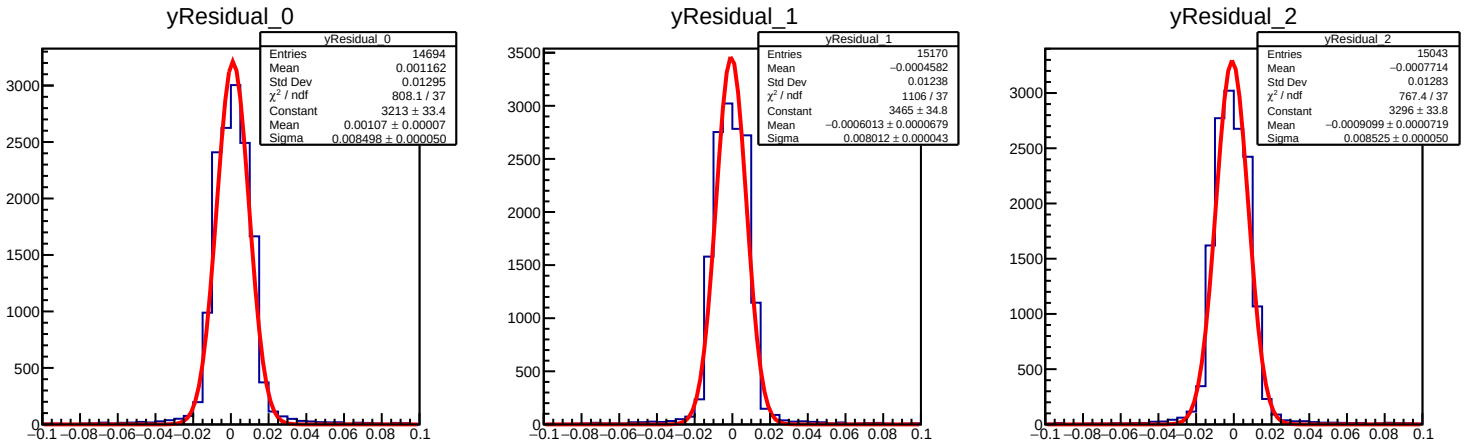
Telescope residuals



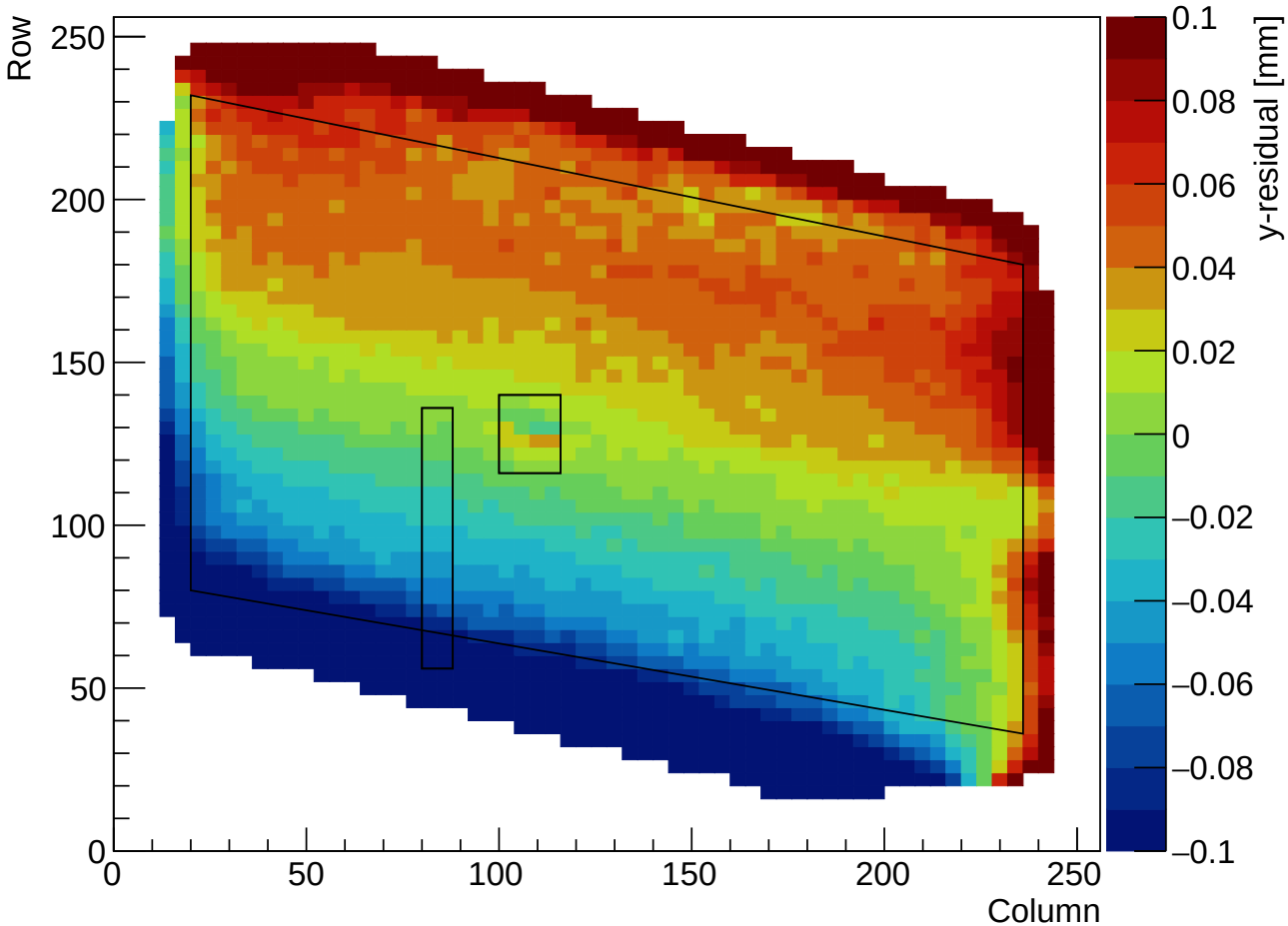
Residuals are $\sim 8\,\mu m$

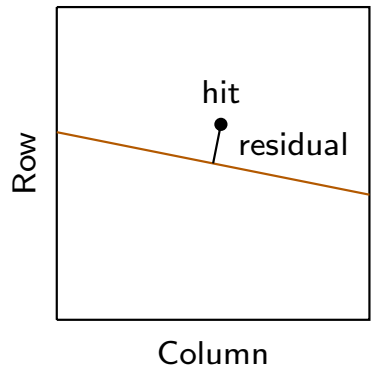
Telescope residuals



Residuals are $\sim 8\,\mu m$

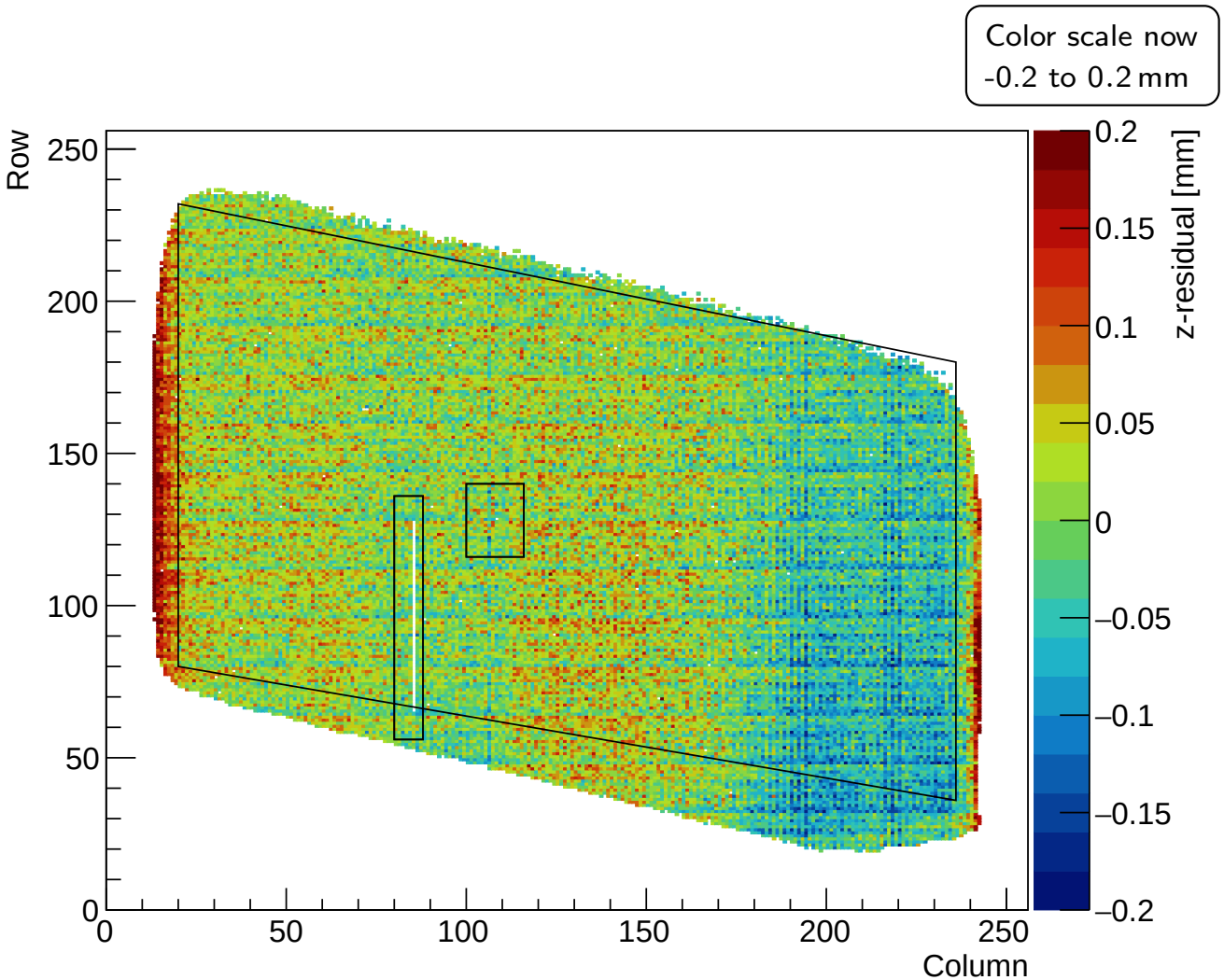
Deformations perpendicular to track in pixel plane





Residuals are filled at detecting row and column

Deformations in drift direction



Residuals are filled at detecting row and column