

## Test beam analysis of a single chip Timepix3 Ingrid

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Nikhef and Bonn

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Nikhef

# Outline

- Detector setup
- Fit procedure and selection
- time walk corrections
- Diffusion coefficients
- Deformations in pixel plane

# Timepix3-based GridPix

## Timepix3-based GridPix:

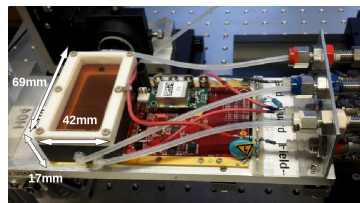
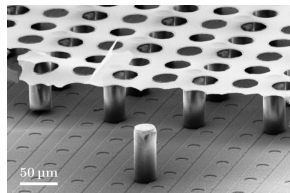
- Micro-pattern gaseous detector with grid aligned to pixels
- 65K  $55\ \mu\text{m} \times 55\ \mu\text{m}$  sized pixels

## Timepix3 compared to its predecessor:

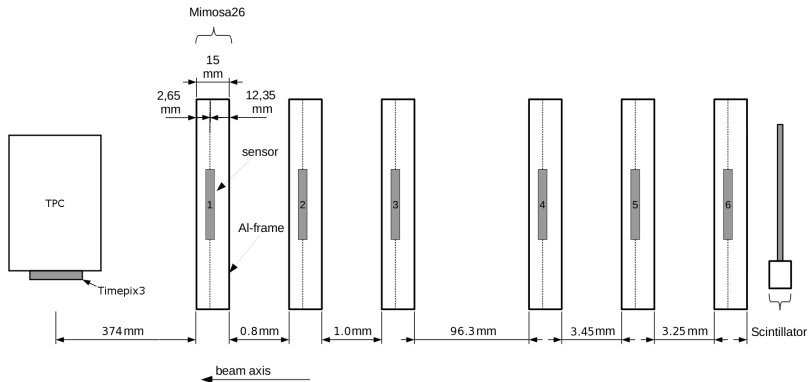
- Improved time resolution of 1.56 ns
- Simultaneous time and charge (ToT) measurement

Single chip Timepix3 detector with field shaping, guard electrode, and T2K TPC gas ( $\text{Ar}:\text{CF}_4:\text{iC}_4\text{H}_{10}$  95:3:2)

See also talk Fred Hartjes



# 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  $18.4 \mu\text{m} \times 18.4 \mu\text{m}$  sized pixels<sup>1</sup>

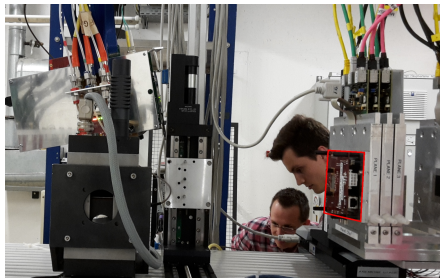
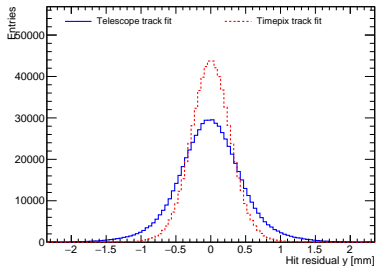
<sup>1</sup>Mimosa telescope provided by Bonn SiLab

# Time matching of telescope and Timepix3

- Timepix3 and telescope are both in data driven mode
- Each telescope frame (115.2  $\mu\text{s}$ ) 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  $\mu\text{s}$ )

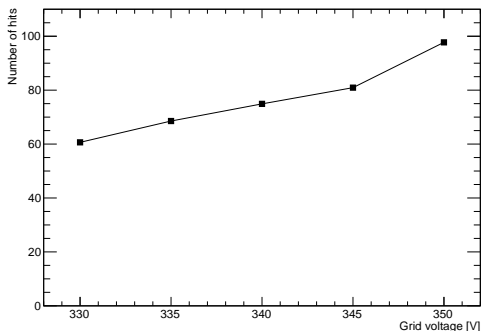
For each frame, attempt to match all events of the Timepix3 with triggers in the range

# 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

# 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

# Tests from run 347

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## Run 347

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

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- Used first 1 000 000 telescope frames:
  - ▶ 461 426 triggers of which 330 925 with matching tracks
- A drift speed of  $75 \mu\text{m}/\text{ns}$  was *assumed* ( $\sim 78 \mu\text{m}/\text{ns}$  calculated<sup>1</sup>)

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<sup>1</sup><http://www-hep.phys.saga-u.ac.jp/ILC-TPC/gas/index.html>



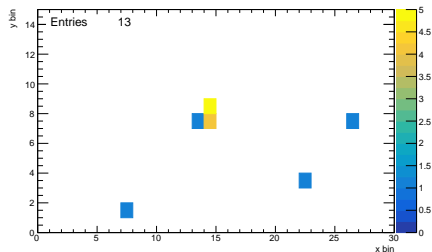
# Fit procedure for telescope and Timepix3

- 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  $10 \mu\text{m}$  errors to Timepix3 fit

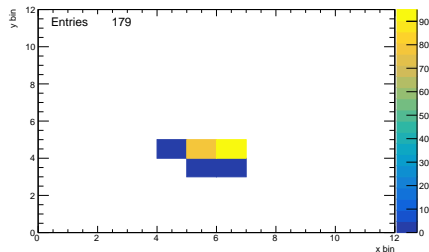
# Cluster finding in telescope and Timepix3

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

- Fill  $30 \times 15$  ( $12 \times 12$ ) 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



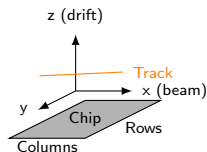
Timepix3

# Errors for Timepix3 hits

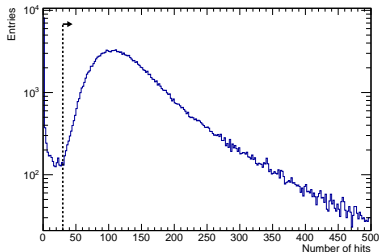
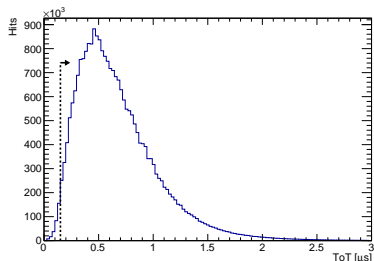
Assign errors to hit:

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

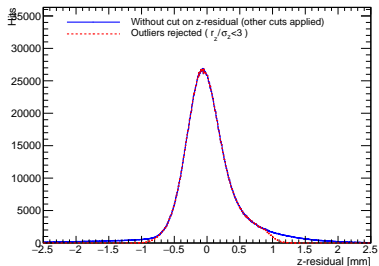
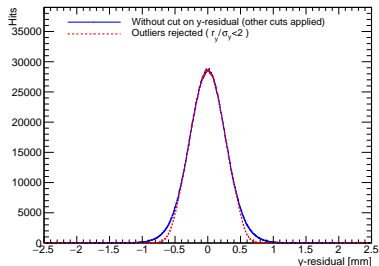
where  $D$  the diffusion coefficient



# Outlier rejection



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



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

# Selection cuts

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## Telescope

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At least 4 planes hit

Reject extreme outliers ( $> 700 \mu\text{m}$ )

Telescope fit goes through tpc

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## Timepix3

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Hit ToT  $> 0.15 \mu\text{s}$

At least 30 hits

Exactly one cluster

Cut hit outliers ( $> 3\sigma_{\text{drift}}$ ,  $> 2\sigma_{\text{plane}}$ )

Fit goes through front and back (pixel row)

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## Matching

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Fits closer than 1 mm in both x and y at center of tpc

A unique time match

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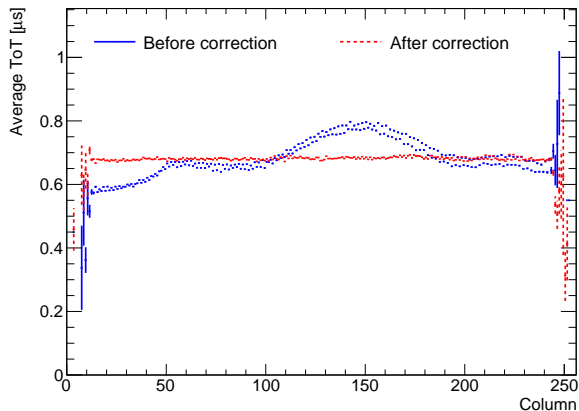
## Delta rejection

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At least 75% of total number of tpc hits in fit

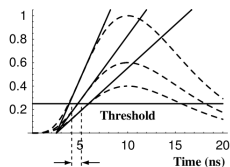
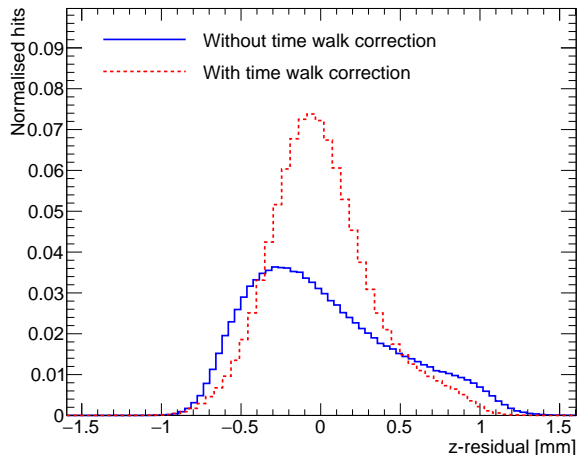
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# ToT-correction



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

# Time walk correction using ToT

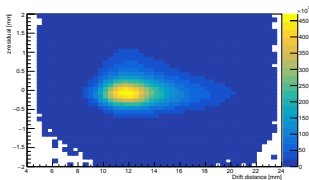
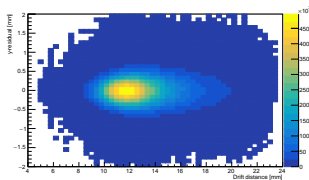


Blum, 2008

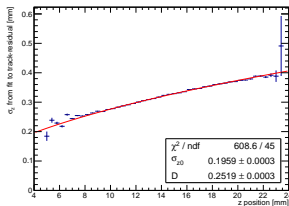
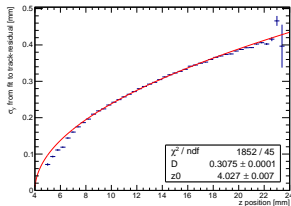
First order timewalk correction by fitting  $\delta z_{\text{timewalk}} = \frac{c_1}{t_{\text{ToT}} + t_0} + z_0$

# Find diffusion from residuals

## Plot residuals in 2-dimensional histogram



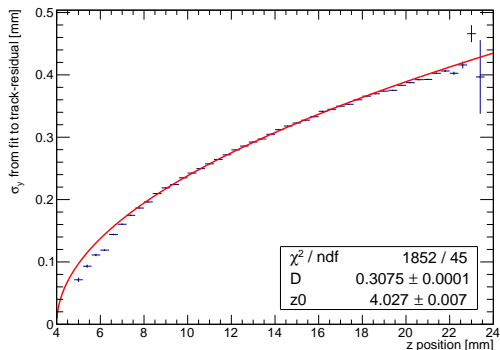
## Fit gauss to y-slices and put $\sigma$ in graph



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



# Diffusion in pixel plane perpendicular to track



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

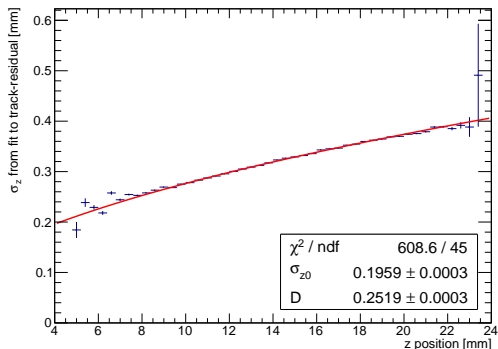
$$D_T = 309 \mu\text{m} / \sqrt{\text{cm}} \quad (\sim 310 \mu\text{m} / \sqrt{\text{cm}} \text{ calculated}^1)$$

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  $v_{\text{drift}} = 66.4 \mu\text{m/ns}^2$

<sup>1</sup> <http://www-hep.phys.saga-u.ac.jp/ILC-TPC/gas/index.html>

<sup>2</sup> GridPix detector with Timepix3 ASIC, talk at TIPP17

# Diffusion in drift direction

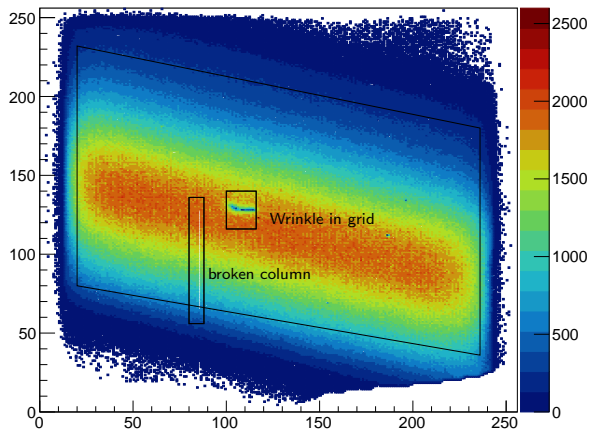


Fix grid position with value from y-fit  $z_0 = 4.027$  mm

$D_L = 252 \mu\text{m}/\sqrt{\text{cm}}$  ( $\sim 230 \mu\text{m}/\sqrt{\text{cm}}$  calculated<sup>1</sup>)

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

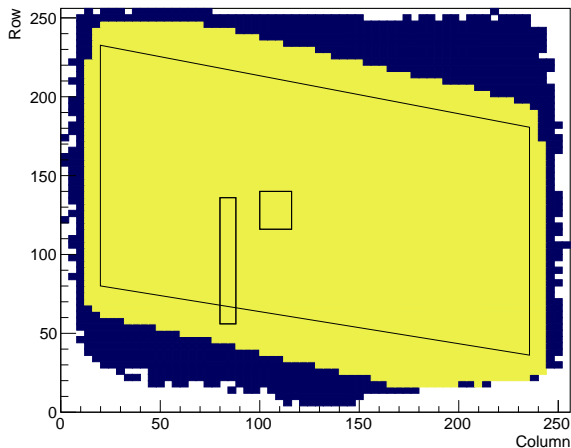
# Timepix3 hit map



Note some defects

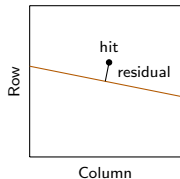
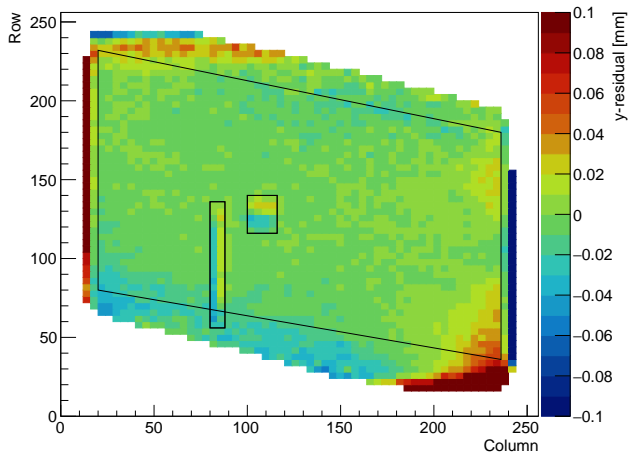
Define area in center without defect regions

## $4 \times 4$ pixel-bins with more than 1000 hits



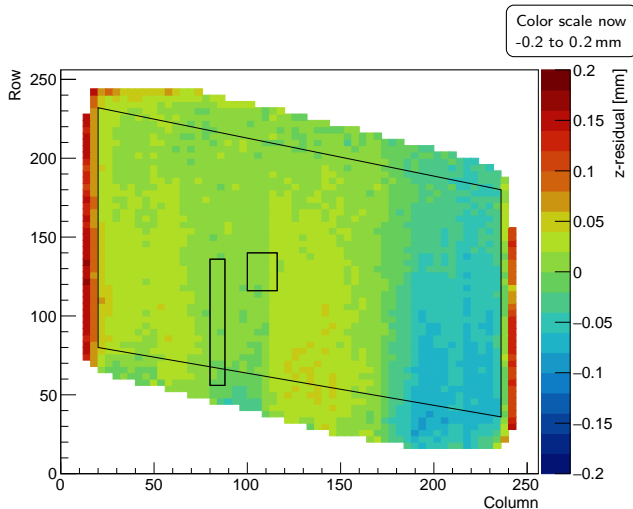
Investigate deformations in bins of  $4 \times 4$  pixels  
All bins in defined area have at least 1000 hits

# Deformations perpendicular to track in pixel plane



Each bin displays mean residual from  $4 \times 4$  pixels  
Residuals are filled at expected row and column

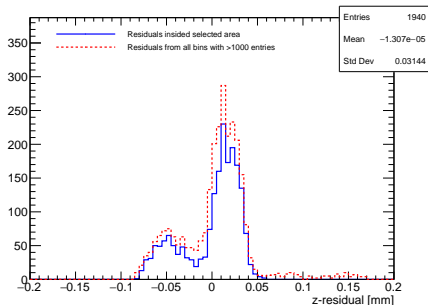
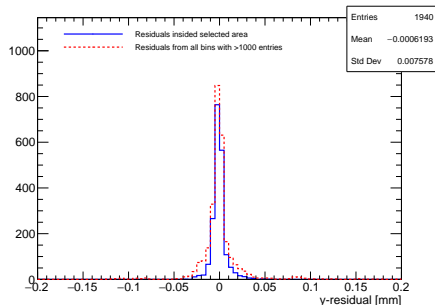
# Deformations in drift direction



Each bin displays mean residual from  $4 \times 4$  pixels  
Residuals are filled at expected row and column

# Histograms of Timepix3 deformations

Fill one entry per bin from previous slide in histogram



RMS in selected area is  $8\ \mu\text{m}$  in plane and  $31\ \mu\text{m}$  ( $0.4\ \text{ns}$ ) in drift direction

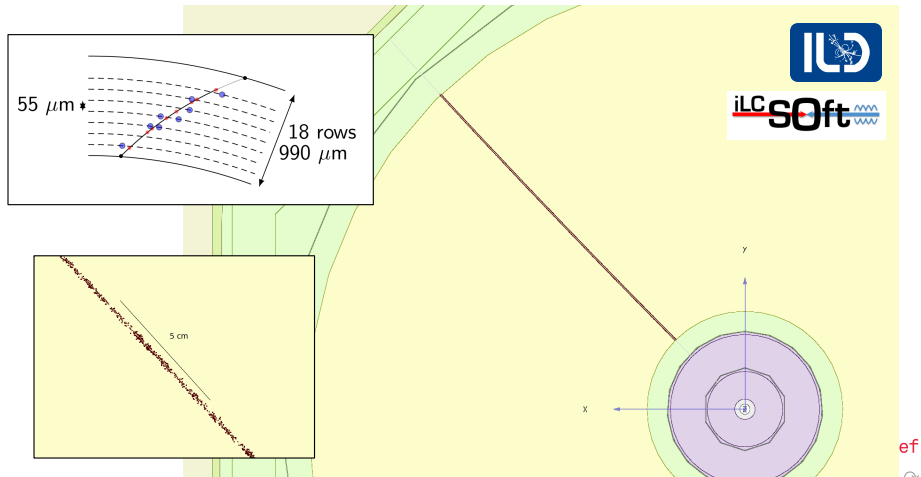
# Conclusions

- Telescope track does not seem to be usable, possibly 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  $D_T = 309 \mu\text{m}/\sqrt{\text{cm}}$  and  $D_L = 257 \mu\text{m}/\sqrt{\text{cm}}$
- Deformations in the pixel plane are found to be  $8 \mu\text{m}$



# Pixel readout implementation in full ILD simulation under development

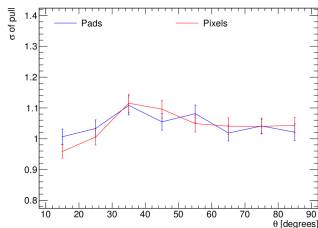
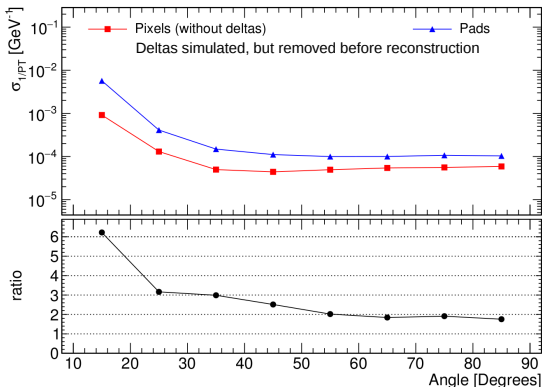
See talk LCTPC-WP meeting 11-5-17



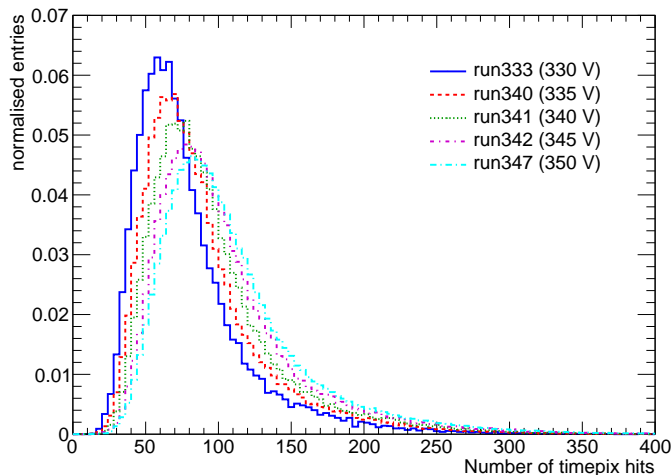
# Update with respect to talk LCTPC-WP Meeting

Resolution from 50 GeV muons

Multiple scattering solves pull issue, resolution slightly decreased

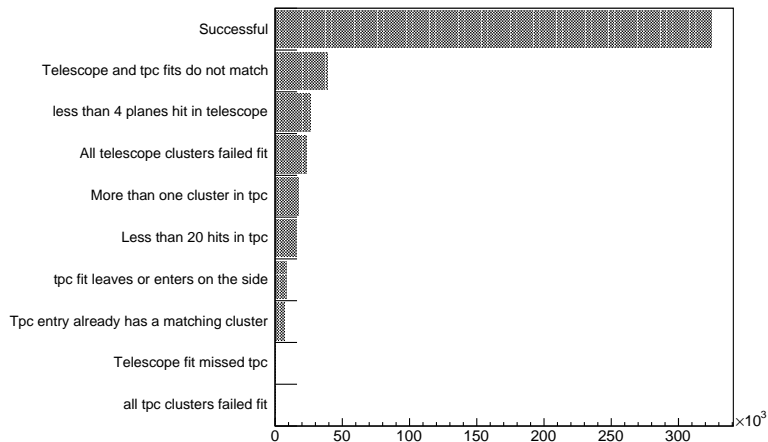


# Number of hits at different grid-voltages



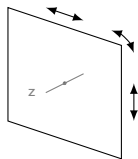
## Number of hits at different grid-voltages

# 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

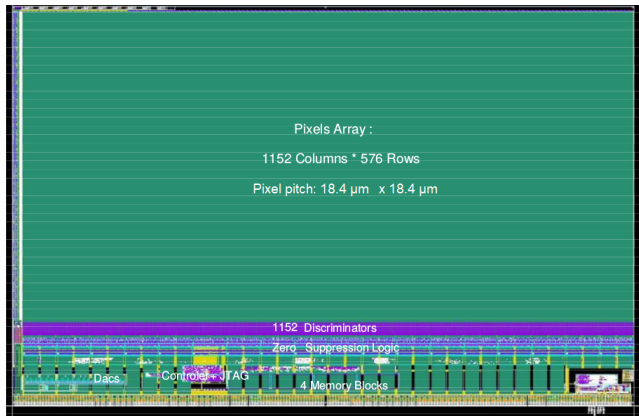
Find corrections from residuals

- Find mean of residuals using gauss 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 position 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

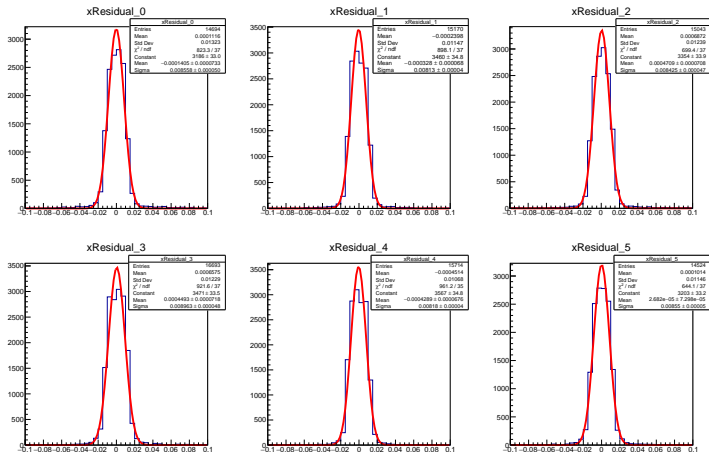


MIMOSA26 User Manual, 2011

Detector with digital silicon pixels

Rolling shutter readout with 115.2  $\mu\text{s}$  per frame

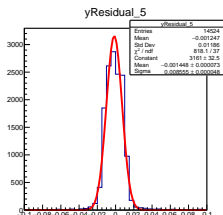
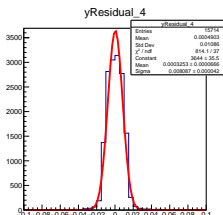
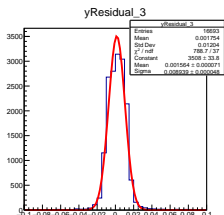
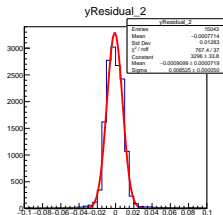
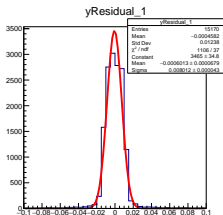
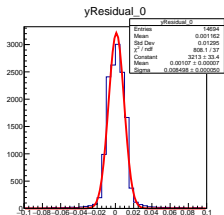
# Telescope residuals



Residuals are  $\sim 8 \mu\text{m}$

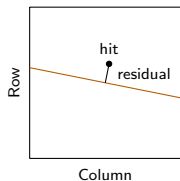
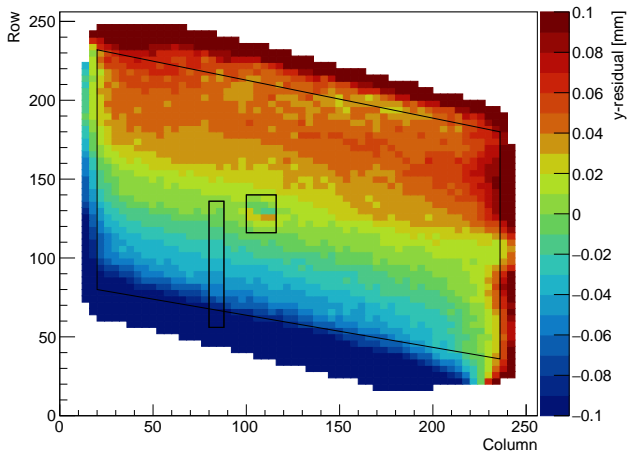


# Telescope residuals



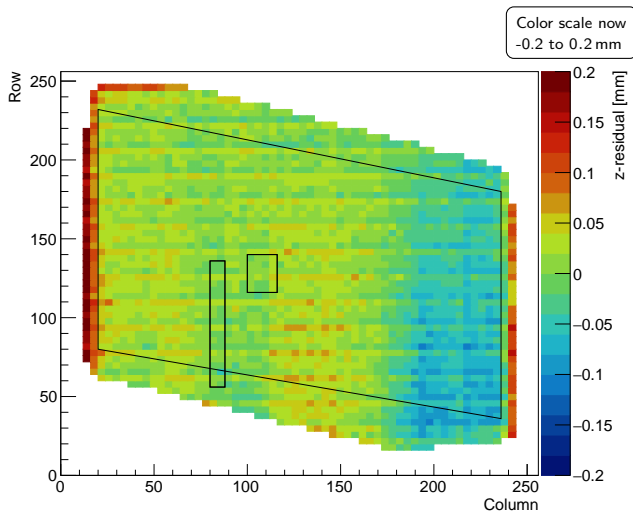
Residuals are  $\sim 8 \mu\text{m}$

# 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