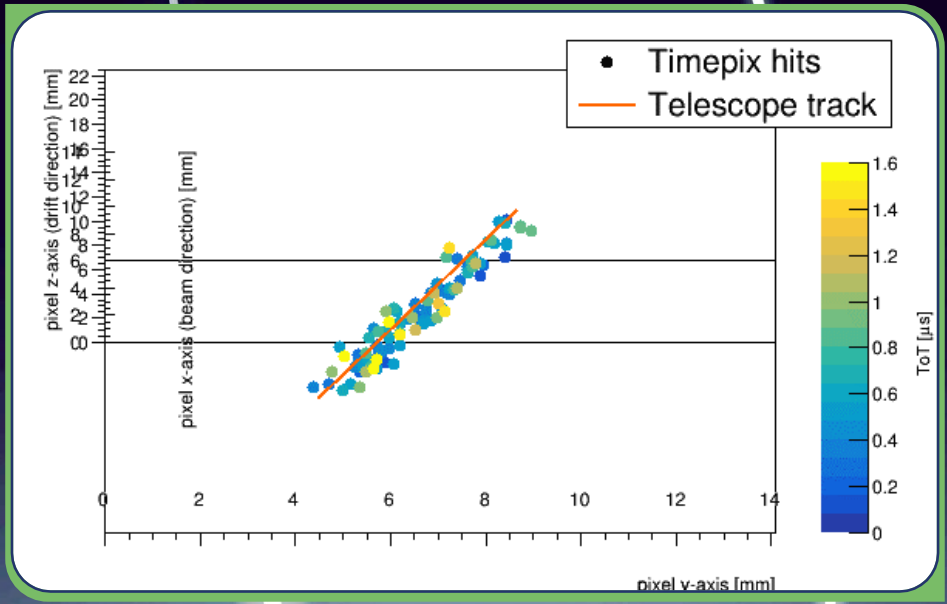


Towards a Gridpix TPC readout at the ILC

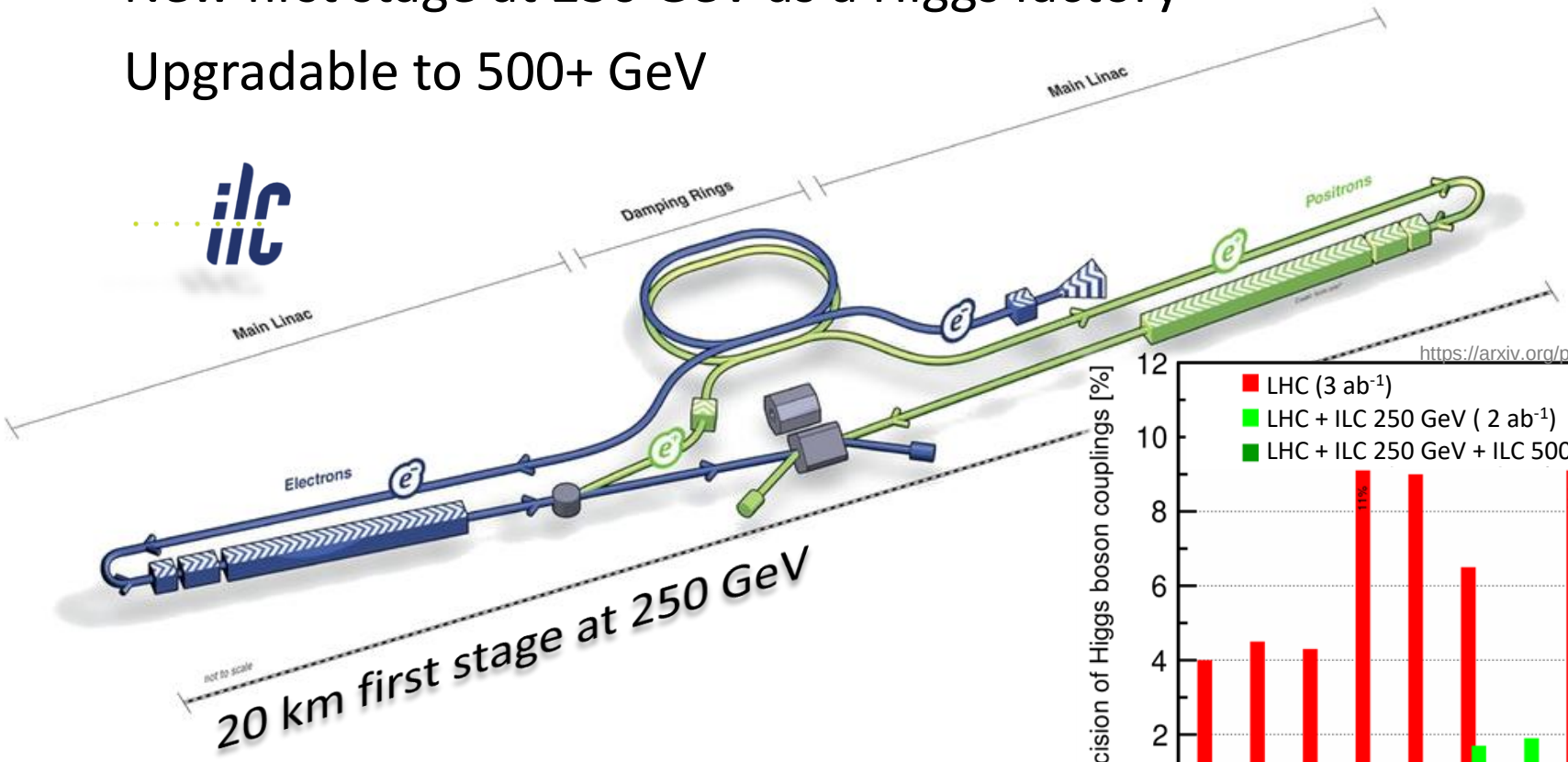
Harry van der Graaf, Fred Hartjes, Kevin Heijhoff,
Peter Kluit, **Kees Ligtenberg**, Gerhard Raven,
Jan Timmermans

The International Linear Collider

Linear electron-positron collider with polarised beams

New first stage at 250 GeV as a Higgs factory

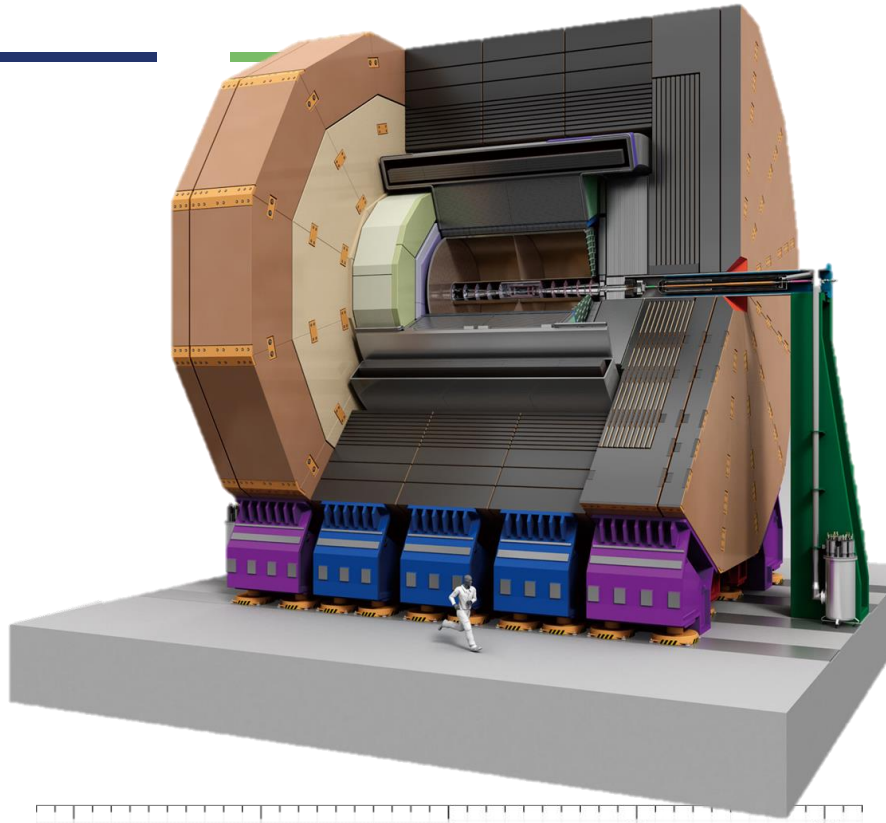
Upgradable to 500+ GeV



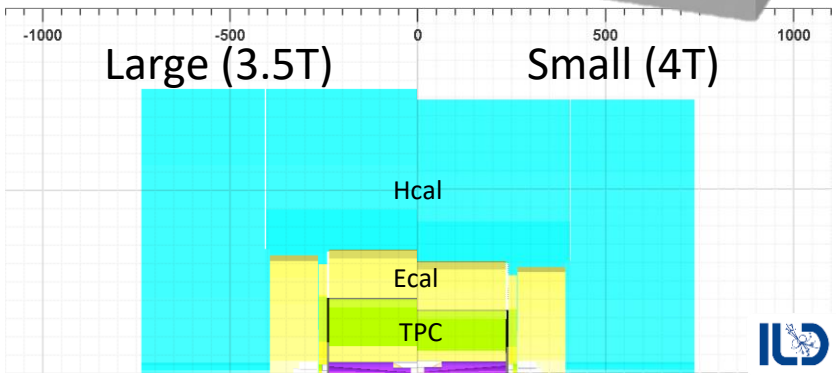
https://arxiv.org/pdf/1710.07621.pdf

The International Large Detector

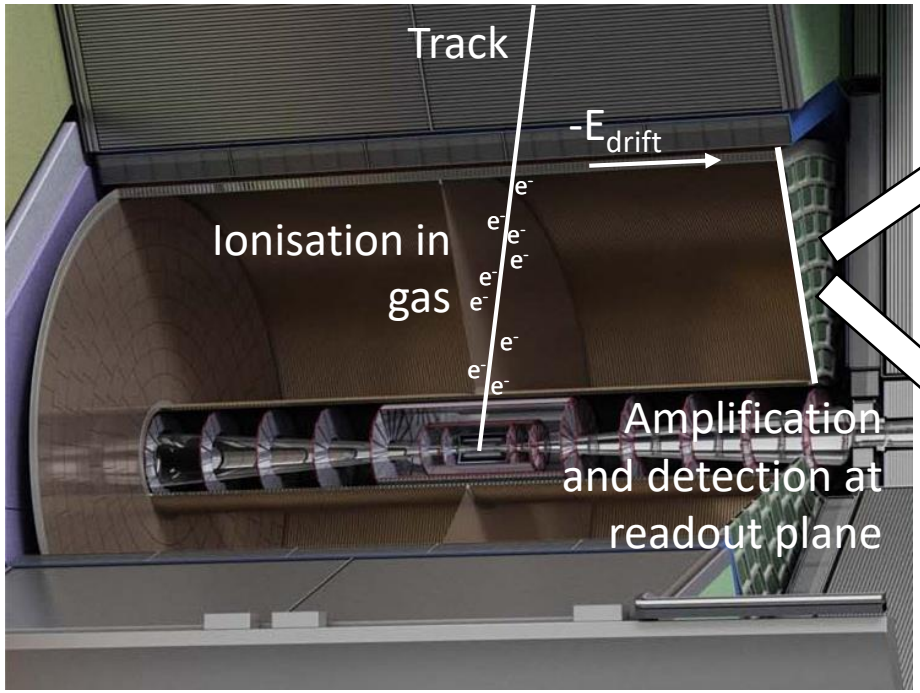
- ILD is a detector concept for ILC with a TPC as the central tracker
- TPC advantages
  - Minimal material budget
  - Many hits per track
  - Particle identification by dE/dx

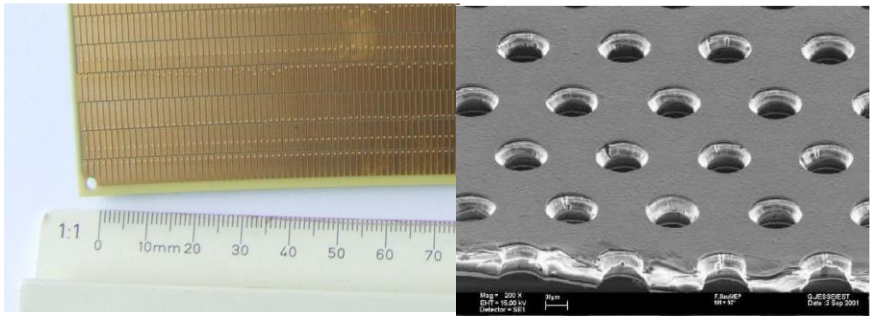


Recently ILD has added an option with smaller radius (R_{TPC}=1.77 m → 1.43 m) and increased magnetic field (B=3.5 T → 4 T)

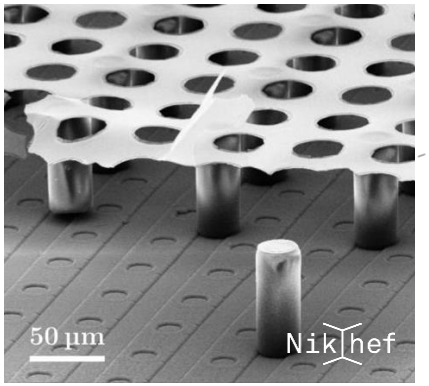


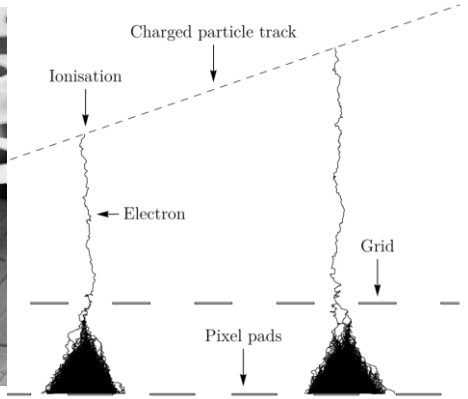
Readout technologies for ILD TPC





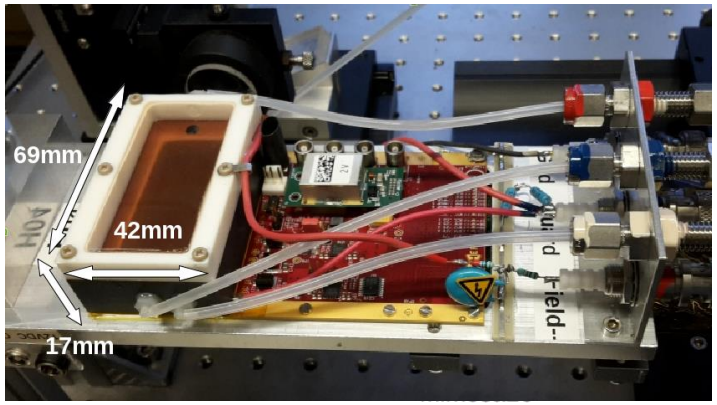
Pads with GEMs or Micromegas for amplification → Detect charge spread





Pixels readout with integrated aligned amplification grid (Gridpix)
→ detect each single electron
Maximal possible information from track

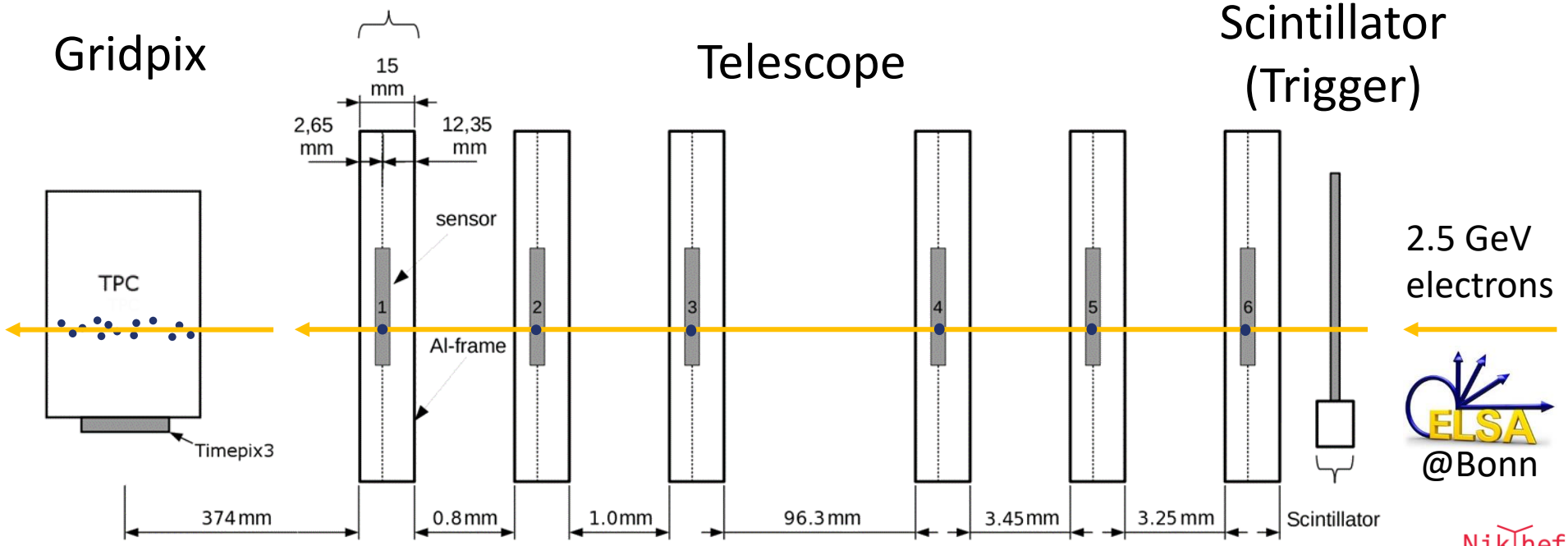
Detector setup at Bonn test beam



First Timepix3 based Gridpix

New!

- Simultaneous data-driven detection of time and ToT (charge), allows timewalk corrections
- Higher rates and more precise compared to its predecessor Timepix1

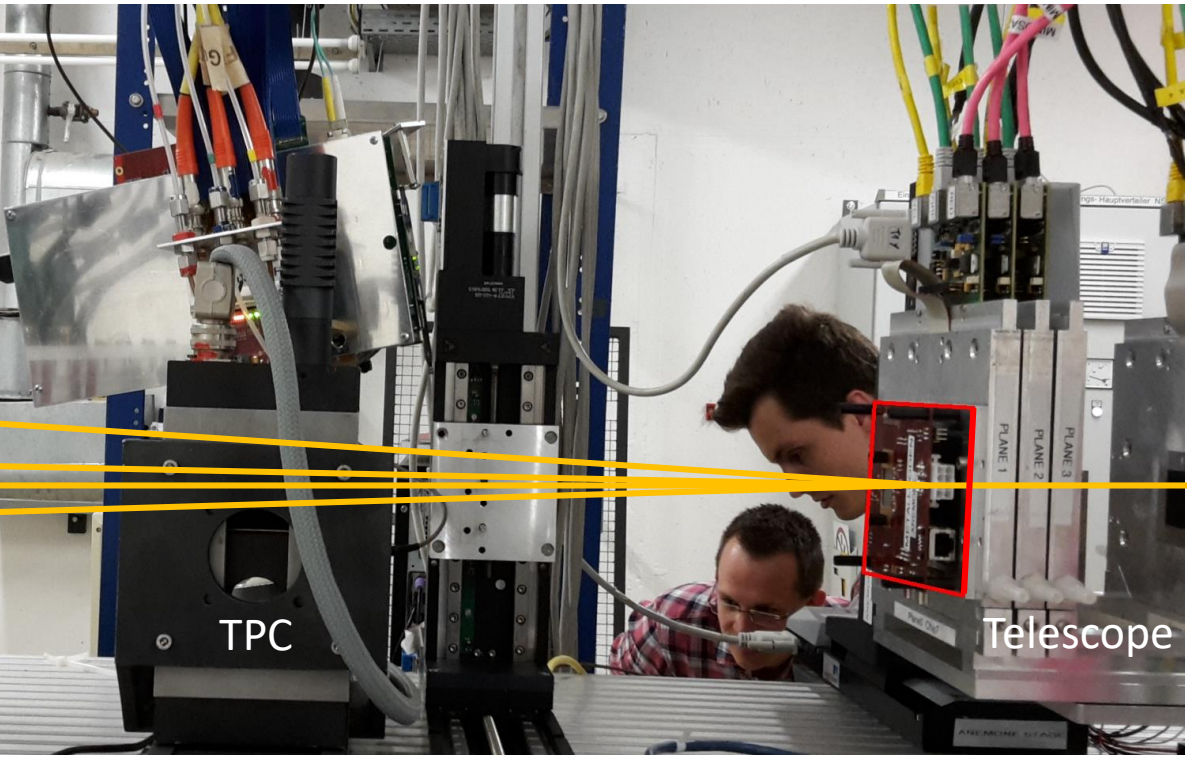


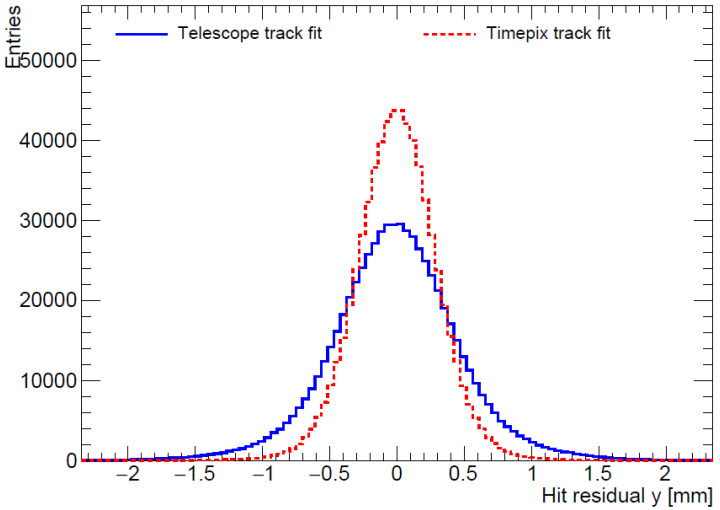
ELSA @Bonn

Image adapted from thesis Pascal Wolf, Bonn 2016

Multiple scattering in setup

Multiple scattering of ~0.7 mrad at last telescope plane





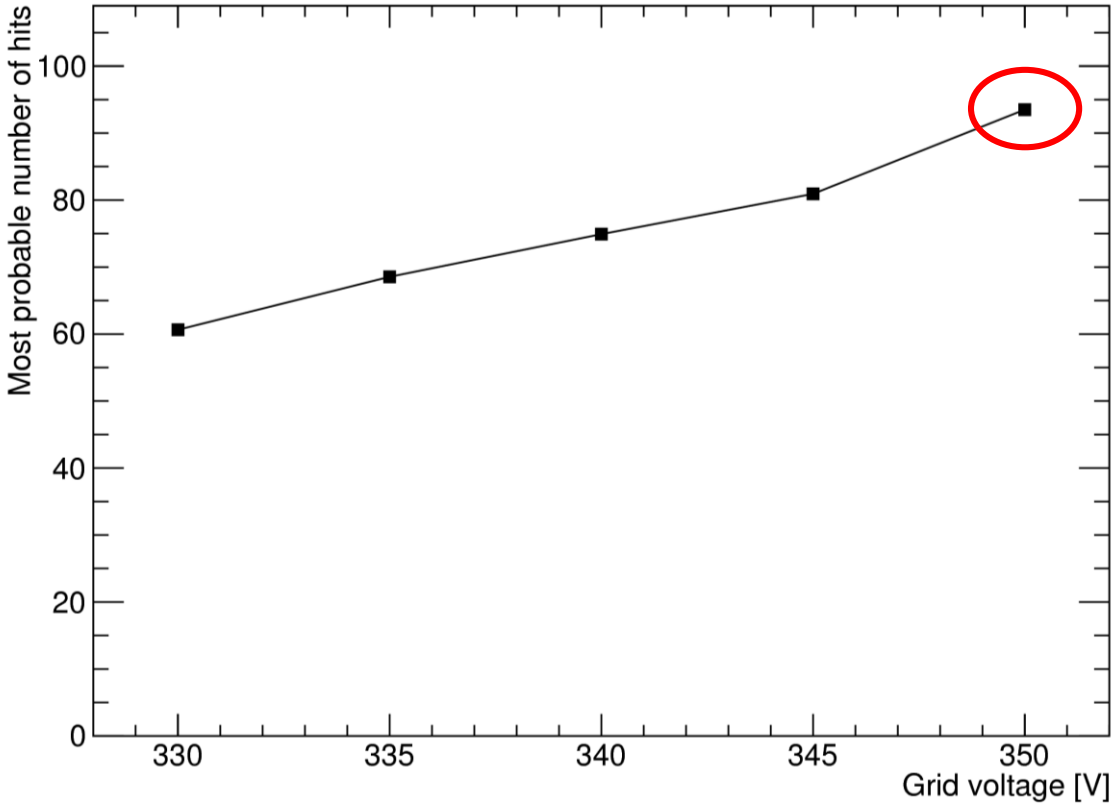
Scatter caused broadening of residual distribution

Use last intercept in track fit for TPC with 10 µm error

Run parameters and selection

Use run with the highest single electron efficiency (close to 1)

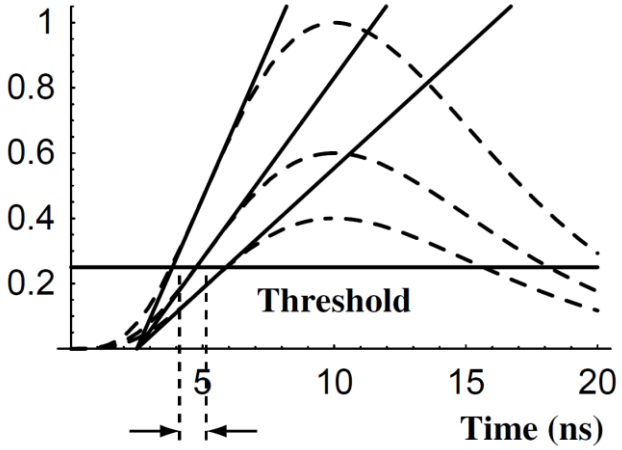
Increase at 350 V can indicate cross-talk to neighboring pixels (small effect if any)



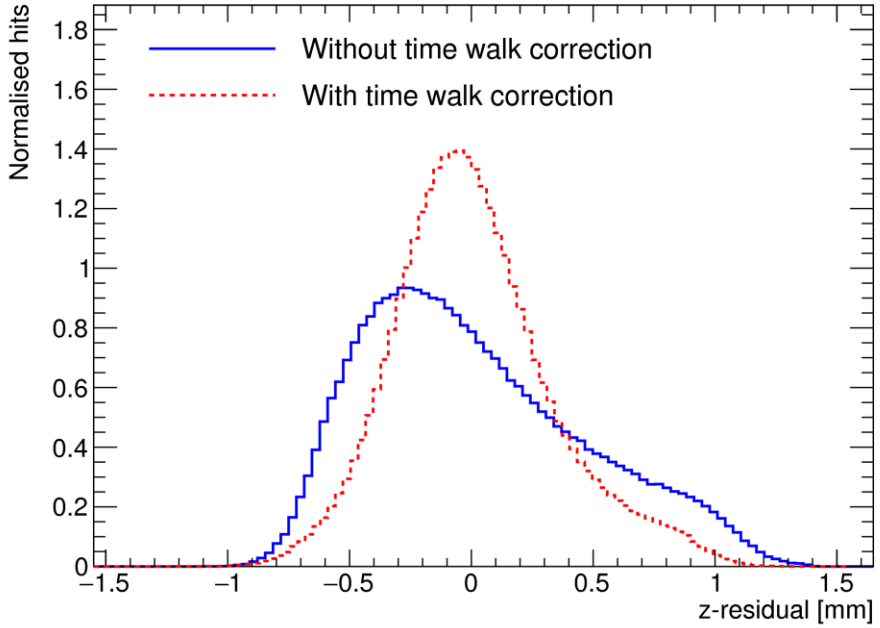
Run 347	
Duration	60 min.
Triggers	4 733 381
V_{grid}	350 V
E_{drift}	280 V/cm
Rotation	17 degr. 0 degr.
Threshold	800 e

Apply basic selection cuts

Timewalk correction



Blum, Particle detection 2008

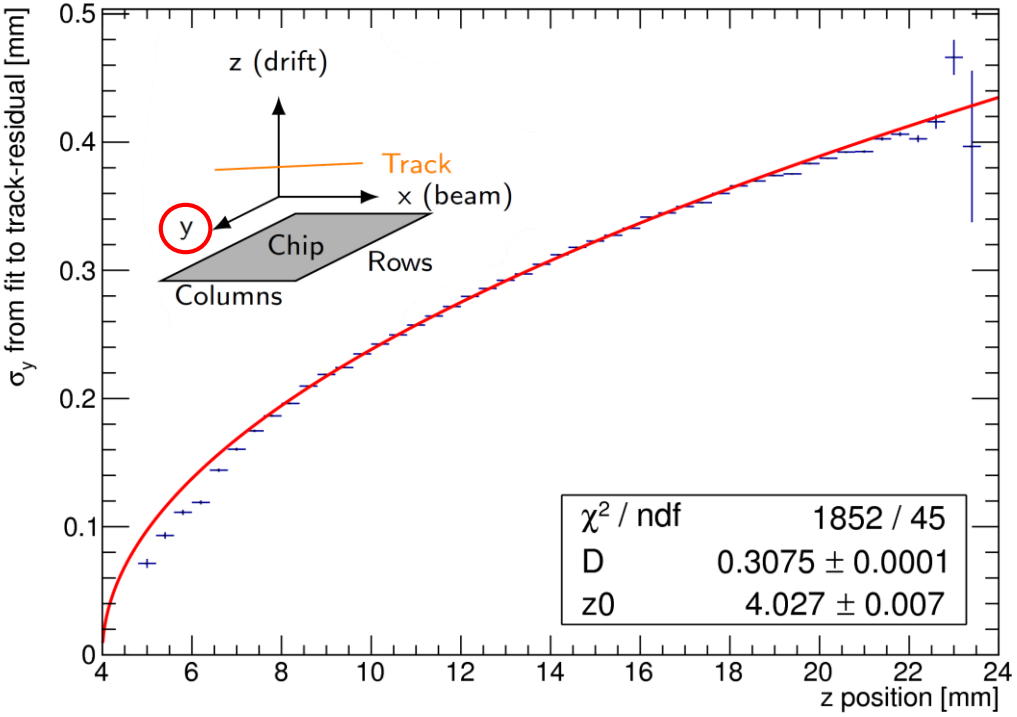


Timewalk error because time of arrival depends on signal amplitude

Timewalk can be corrected using ToT
First order correction applied:

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

Single hit resolution in pixel plane



Measure diffusion and grid position z_0 by fitting

$\sigma_y = \sqrt{\sigma_{y0}^2 + D_T^2(z - z_0)}$, where $\sigma_{y0} = \frac{55}{\sqrt{12}}$ µm

$D_T = 308\ \mu\text{m}/\sqrt{\text{cm}}$ ($310\ \mu\text{m}/\sqrt{\text{cm}}$ calculated)

Note that at $B = 4$ T, $D_T = 25\ \mu\text{m}/\sqrt{\text{cm}}$

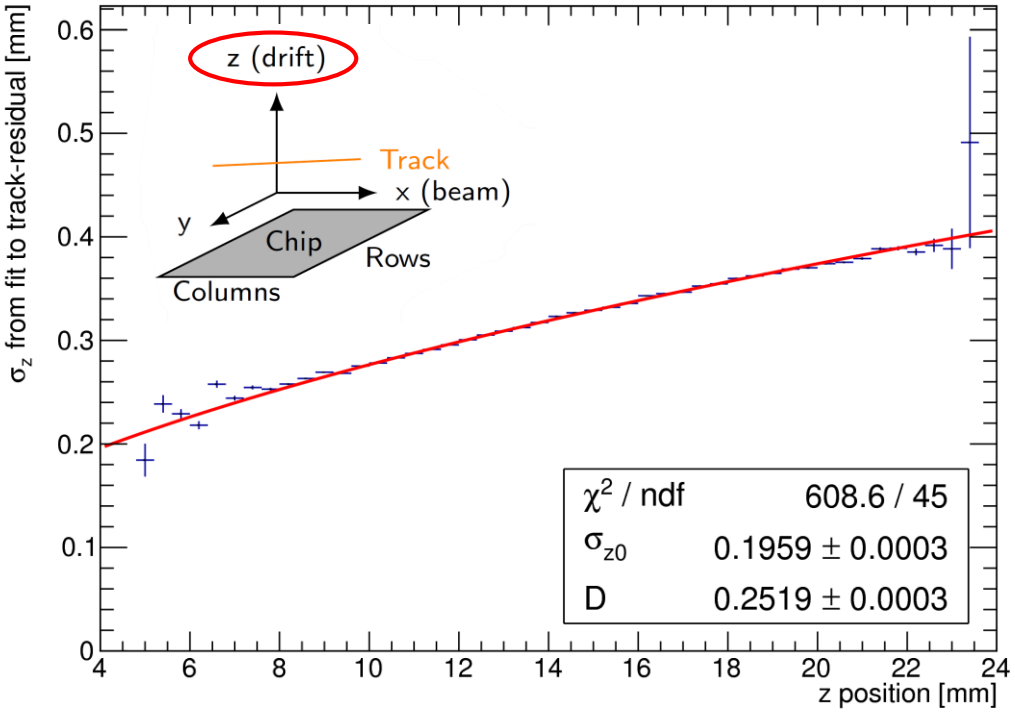
www-hep.phys.saga-u.ac.jp/ILC-TPC/gas/index.html

Single Hit resolution depends on:

- σ_{y0} = pixel size $/\sqrt{12}$
- Diffusion D_T from fit

A hit resolution of ~240 µm is ~24 µm for a 100-hit track (~ 1 cm track length)

Single hit resolution in drift direction



Measure diffusion and σ_{z0} by fitting

$\sigma_z = \sqrt{\sigma_{z0}^2 + D_L^2(z - z_0)}$, where $z_0 = 4.03$ mm

$D_L = 252\ \mu m/\sqrt{cm}$ ($230\ \mu m/\sqrt{cm}$ calculated)

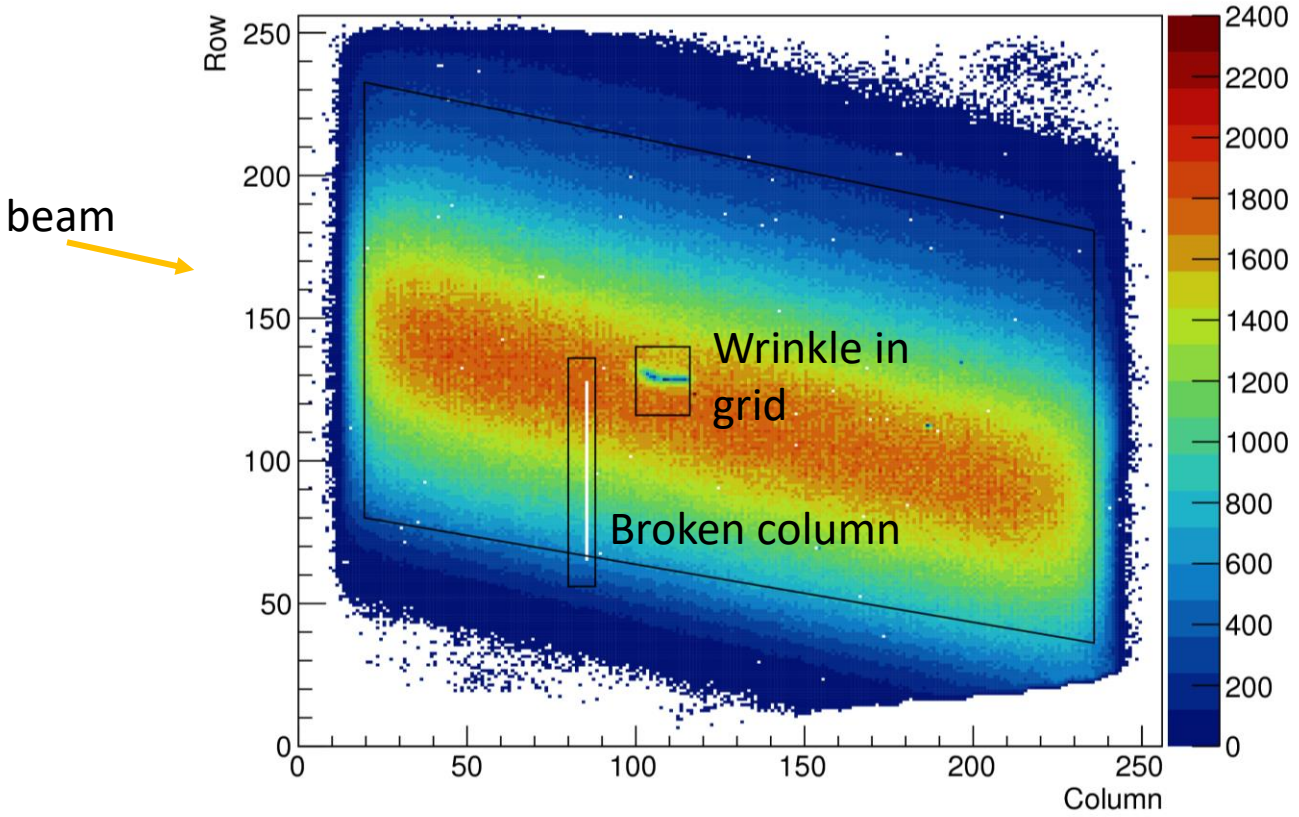
www-hep.phys.saga-u.ac.jp/ILC-TPC/gas/index.html

Single Hit resolution depends on:

- σ_{z0} from fit
- Diffusion D_L from fit

A hit resolution of ~280 µm is ~28 µm for a 100-hit track (~ 1 cm track length)

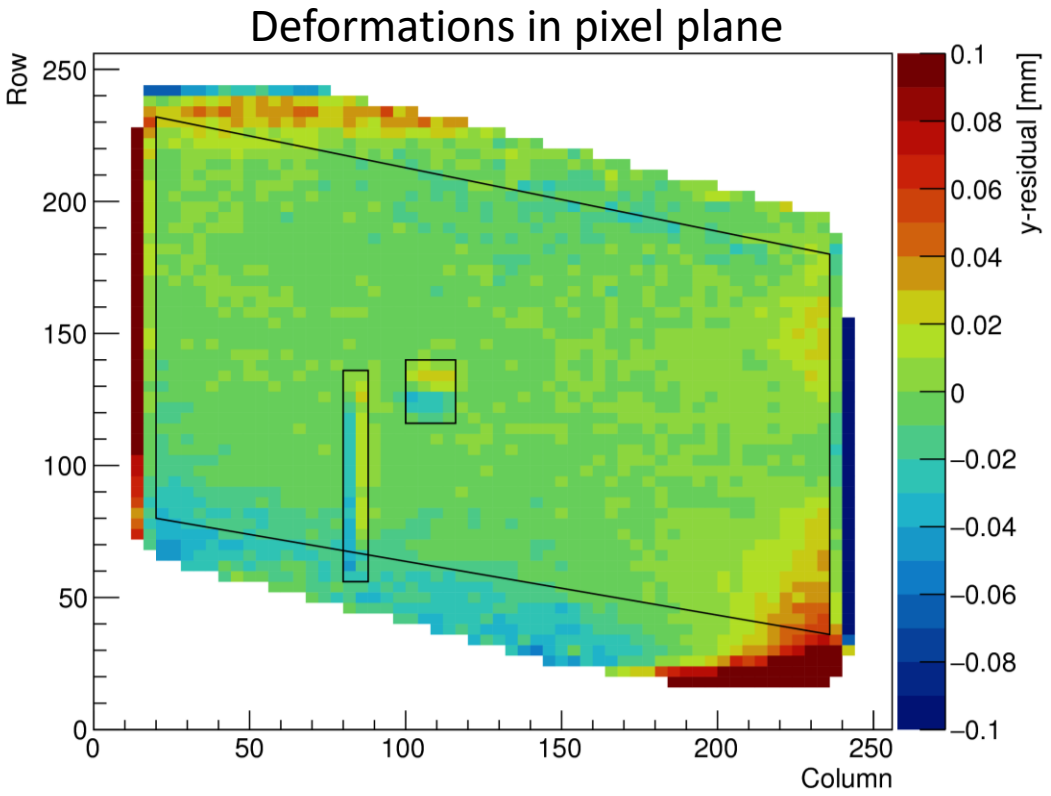
Map of Timepix3 hits

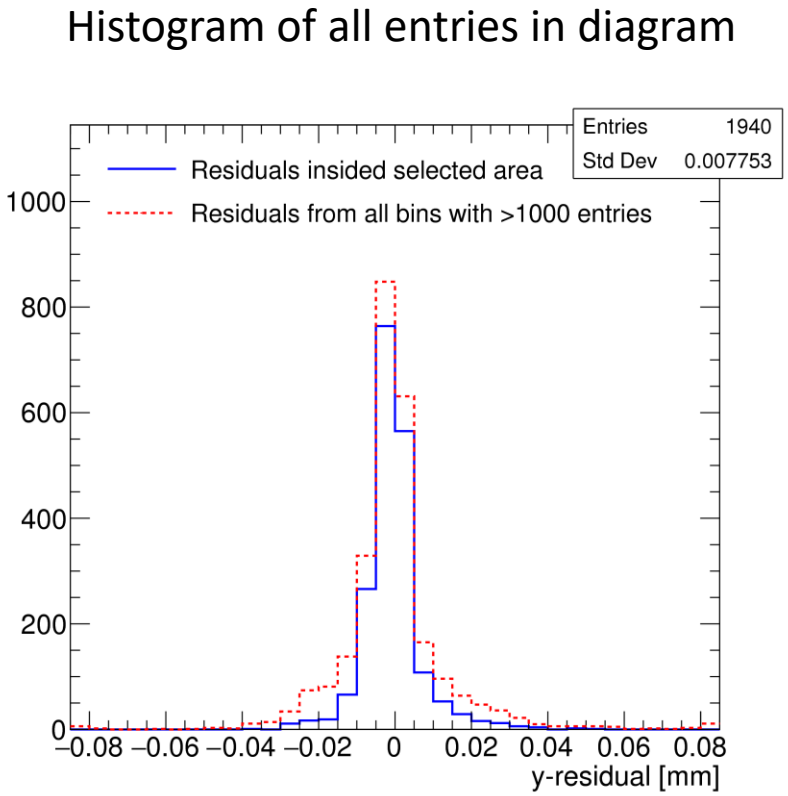


Successfully measured a large number of hits

The chip and grid have some small defects

Deformations in pixel plane





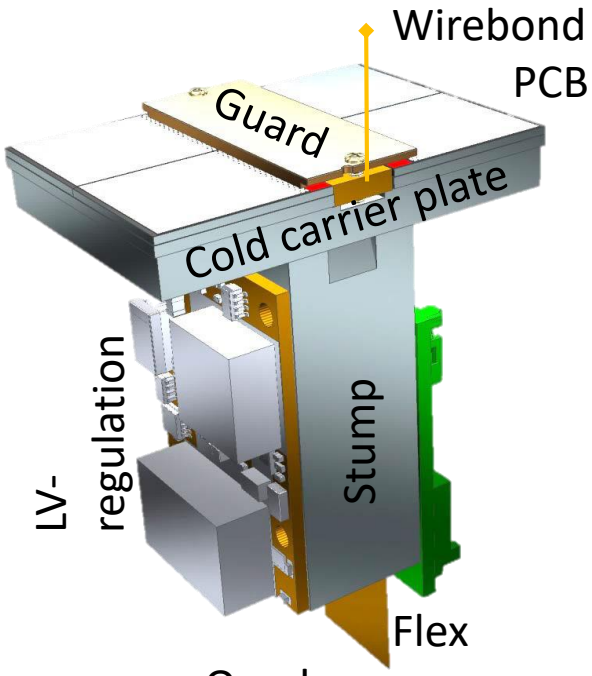
Each bin displays mean of residuals from 4×4 pixels

Residuals are filled at expected row and column

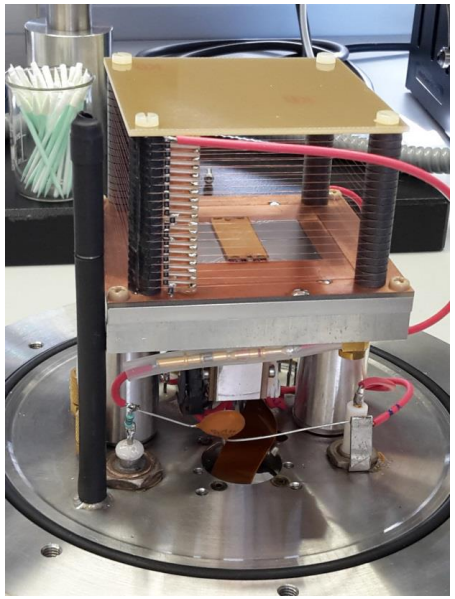
RMS of deviations is 8 µm, enough to meet TPC requirements

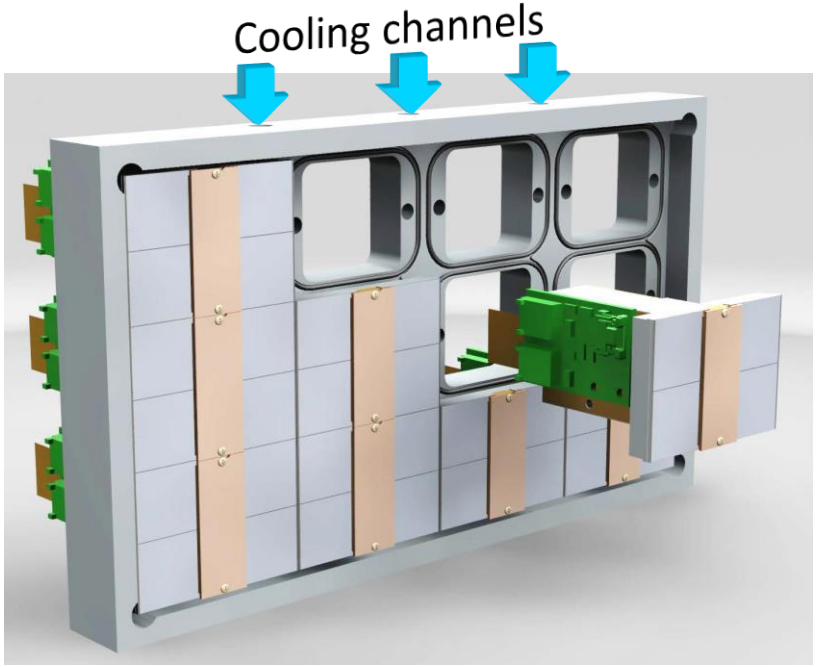
Quad development

- 4 GridPix chips on one mechanical support (40×28 mm^2)
- All services under large active surface (68.9% coverage)
- First electrical Quads assembled and functional



Quad


Test Box



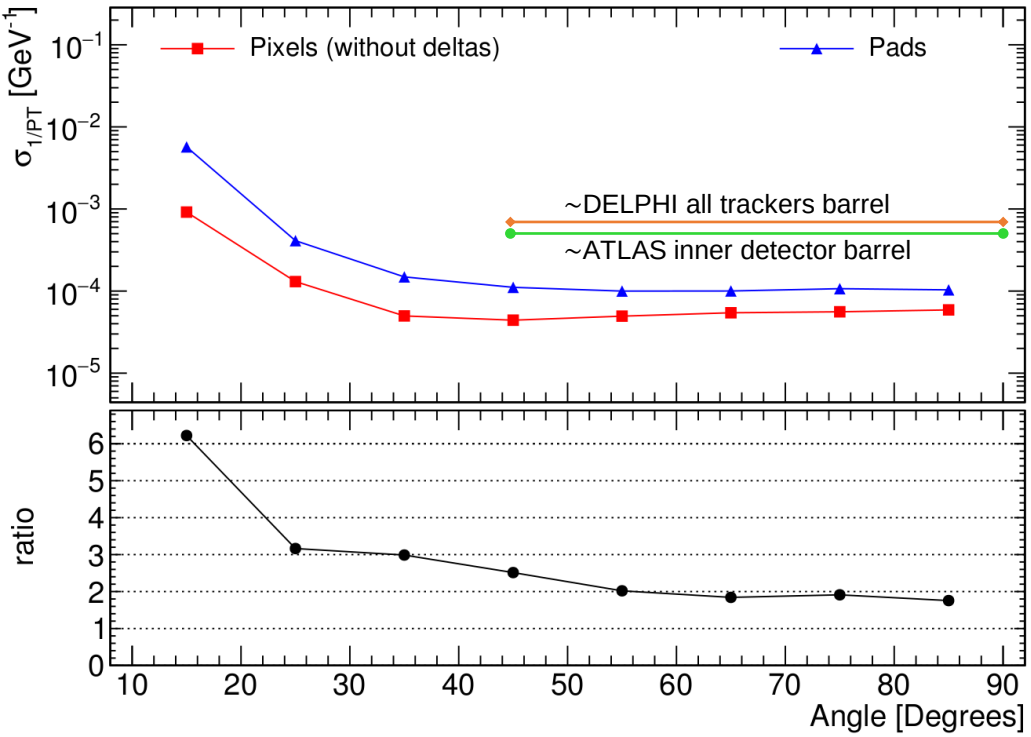
Quad base plate

+Bas van der Heijden, Charles Ietswaard, Auke Korporaal, Oscar van Petten, Joop Rövekamp

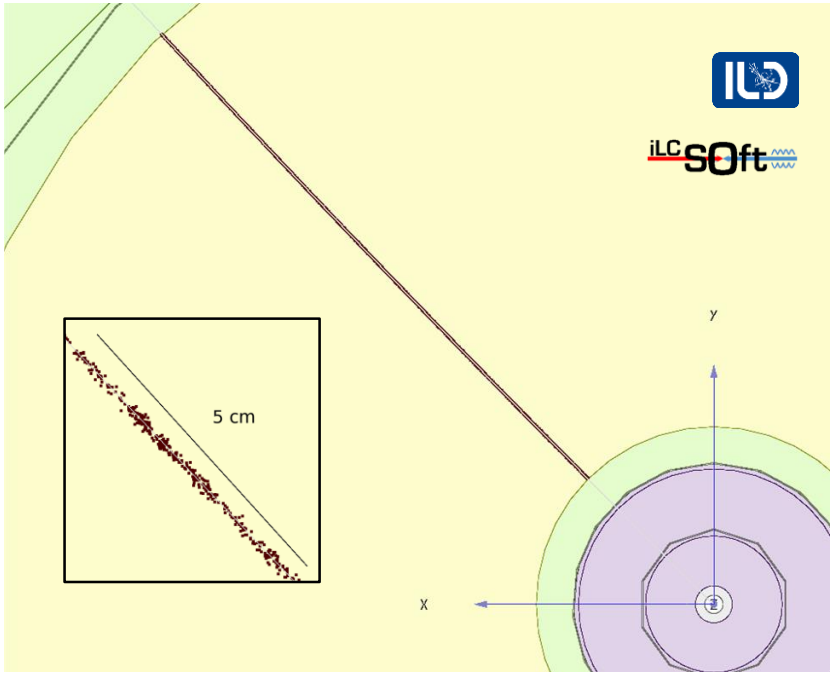
Resolution of ILD TPC with Gridpix

- Pixel TPC in full ILD DD4HEP simulation
- Momentum resolution is a factor 1.8-6 better than pads (for 100% coverage)

Momentum resolution for 50 GeV muon

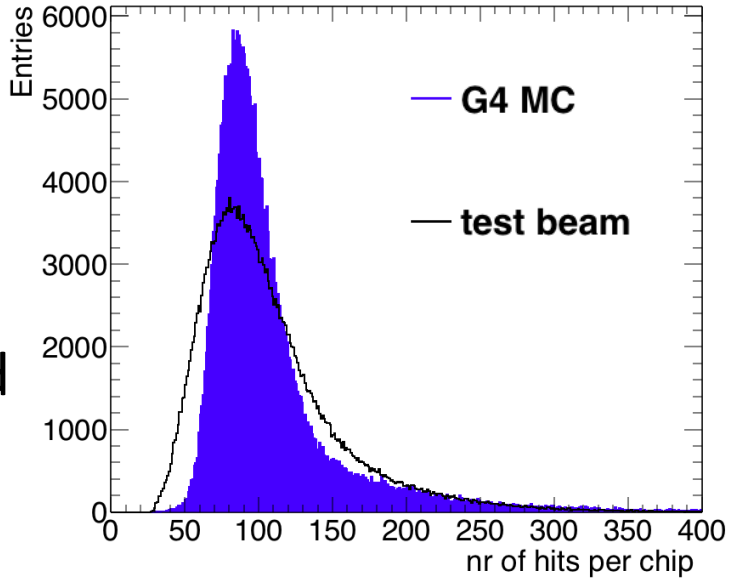


50 GeV muon track with pixel readout



dE/dx measurements

- dE/dx by charge is sensitive to long Landau tail
- A pixel readout resolves primary clusters allowing cluster counting
- Clustering algorithms were developed and extrapolated to ILD TPC with realistic coverage



Method	e/K separation at 2 GeV	G4 MC	Data	dE/dx
Truncated hits (charge like)		8.6 σ	5.7 σ	5.3%
Clusterz (cluster neighbours along track)		11.0 σ	5.7 σ	
Cluster1 (count hits at same track position as one)		9.1 σ	7.4 σ	
Distance (fit distribution of hit distance)		13.3 σ	9.5 σ	3.1%

Pad perfomance is approximately 4.6% dE/dx (ALICE TPC has 5.5% for pp collisions)

ALICE-TDR-016

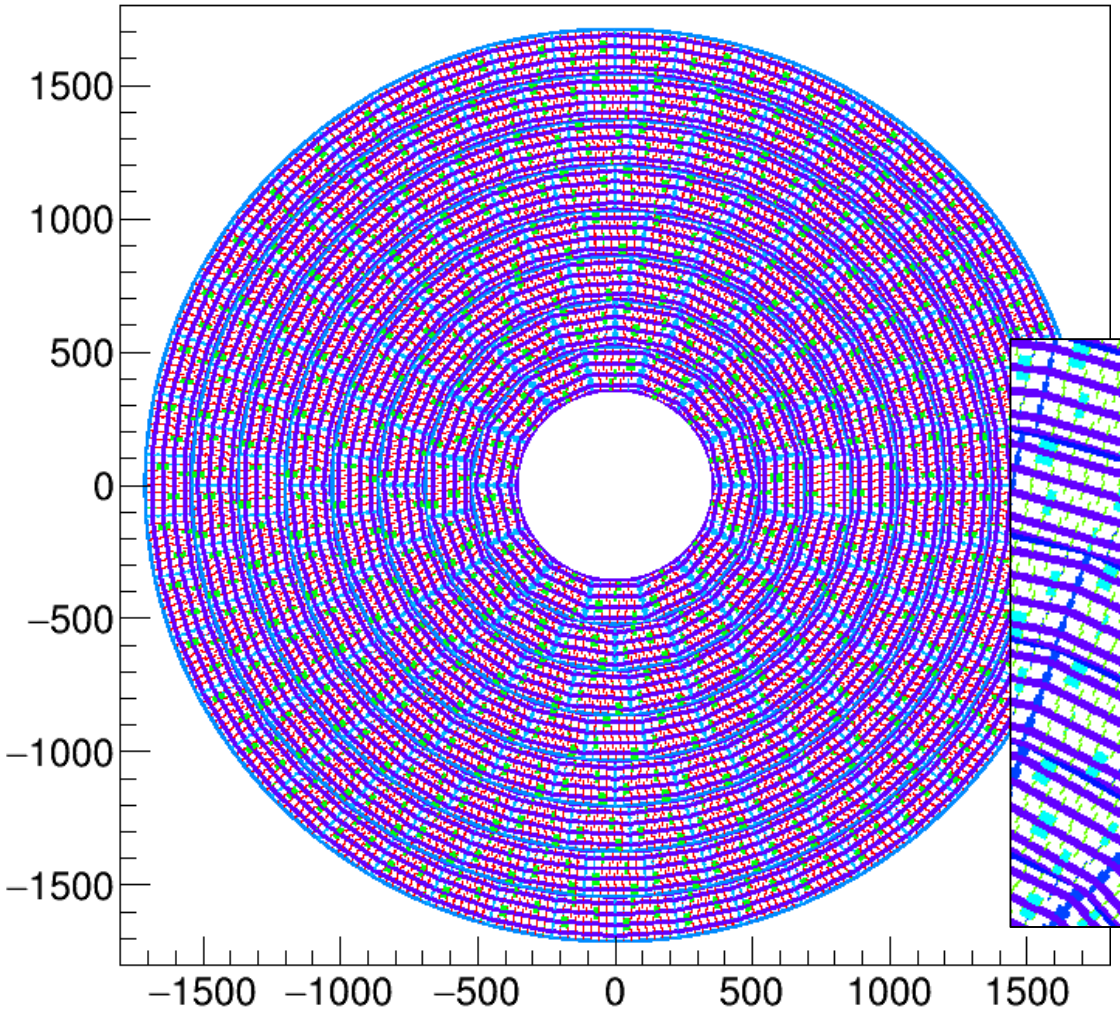
Nikhef

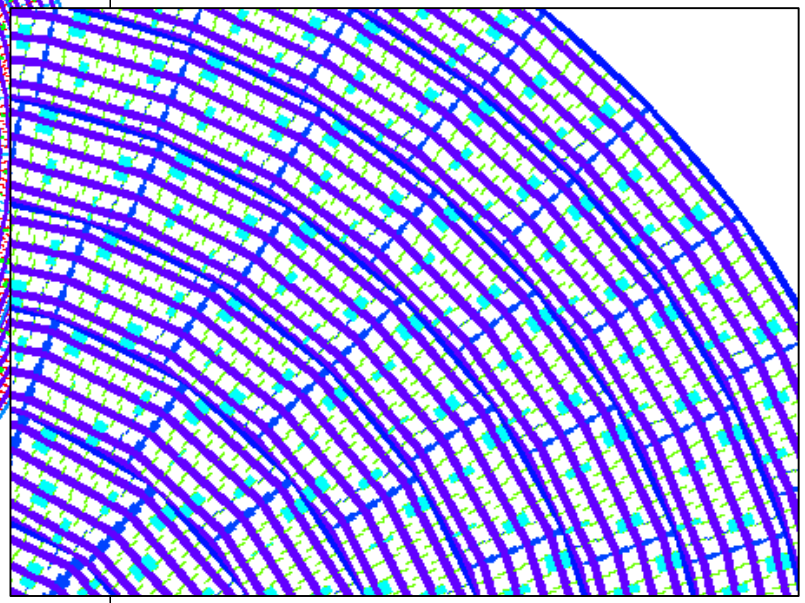
Summary

- A Gridpix detector with Timepix3 was successfully built and demonstrated
  - Timewalk correction was applied
  - Diffusion was calculated
  - Deformations were measured
- Quad development is progressing rapidly
  - First electric Quads are built and working
- Gridpix is a promising technology choice for ILD TPC readout
  - Factor 1.8-6 Improvement in momentum resolution
  - Factor ~2 Improvement in dE/dx resolution

Backup

Tiling of ILD TPC with Quads



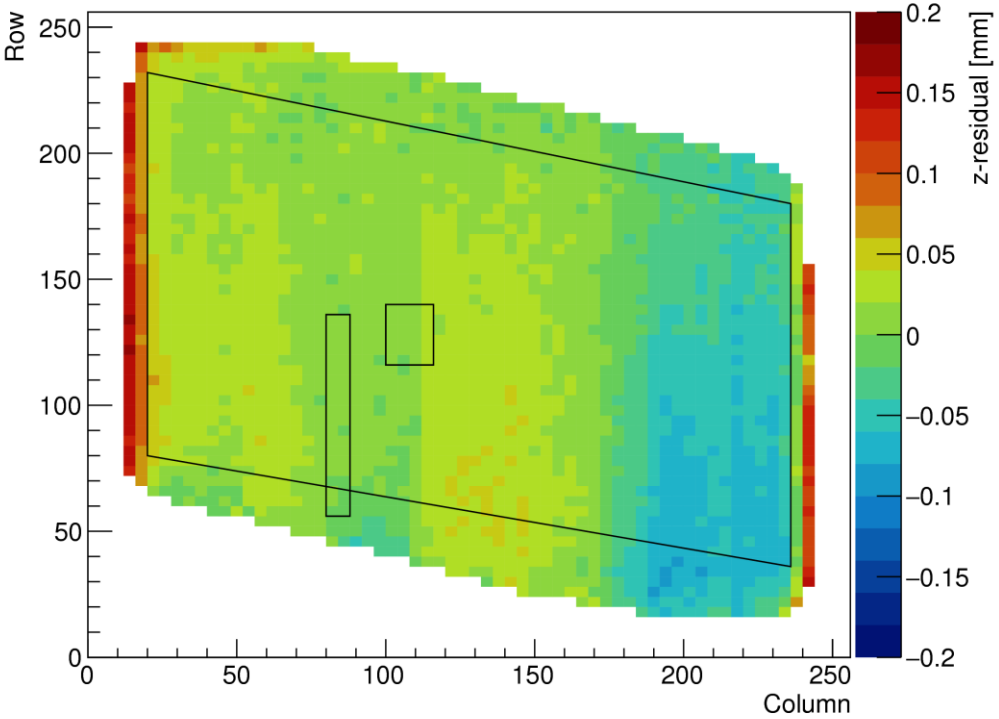


Quads positioned tiled inside ILD TPC modules

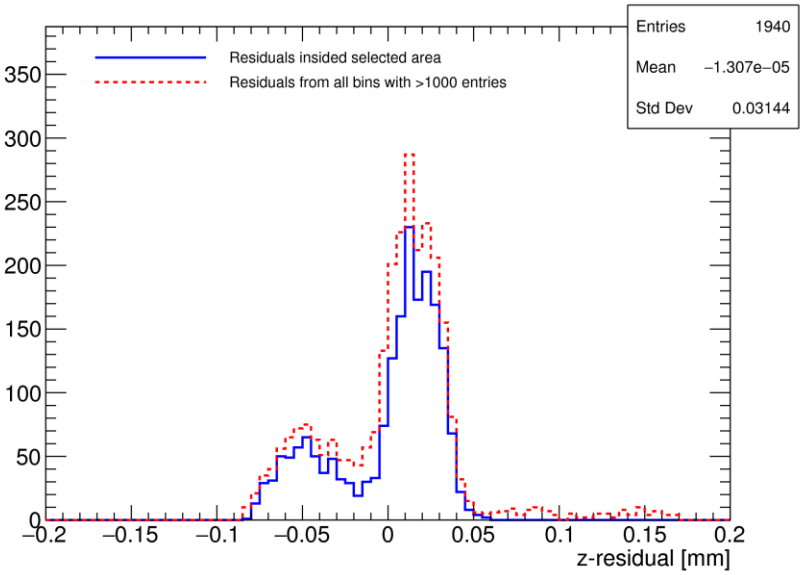
58.7% coverage

Deformations in drift direction

Deformations in drift direction



Histogram of all entries in diagram

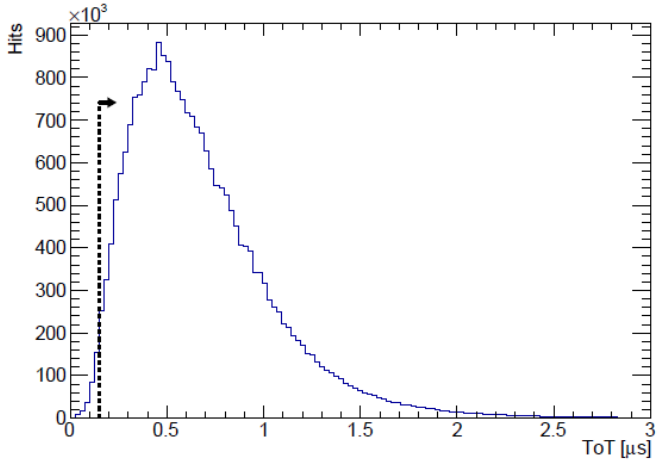


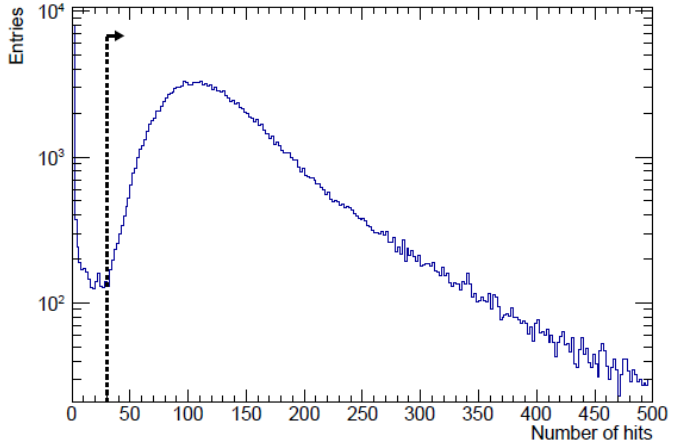
Each bin displays mean of residuals from 4×4 pixels

Residuals are filled at expected row and column

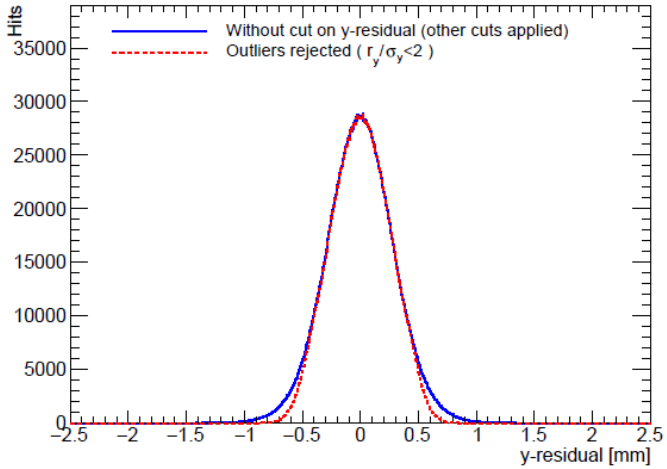
RMS of deviations is 31 µm

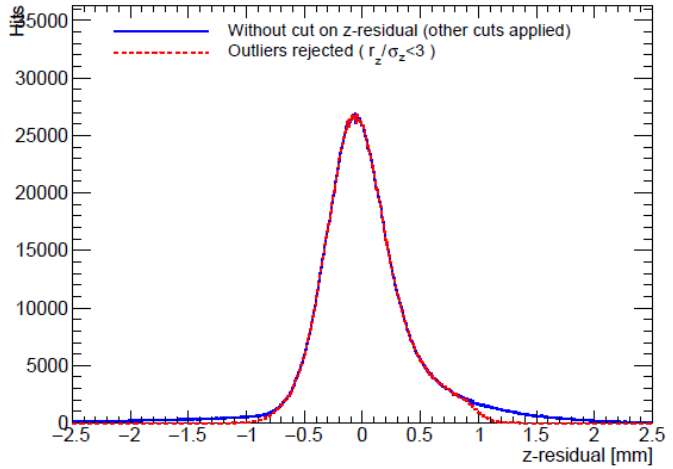
Outlier rejection





Require Time over Threshold ToT $>$ 0.15 µs and more than 30 hits

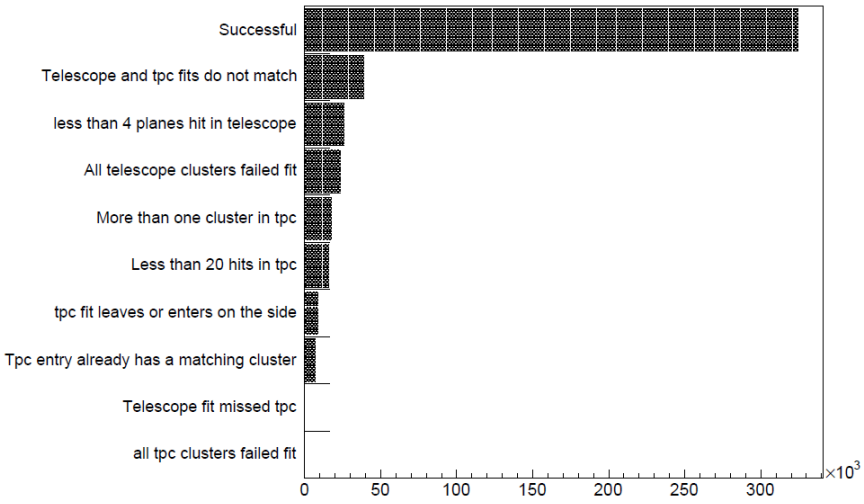




Require residual $r_y < 2\sigma_y$ and residual $r_z < 3\sigma_z$

Selection

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

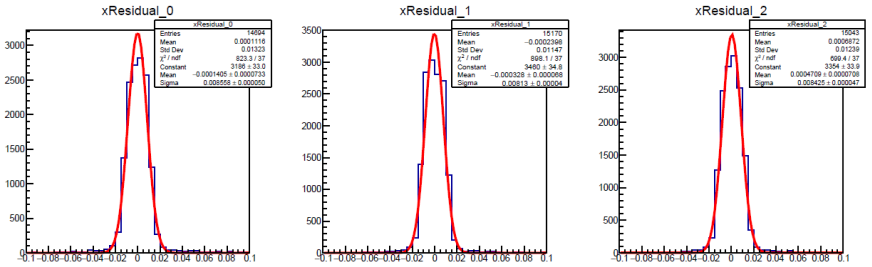


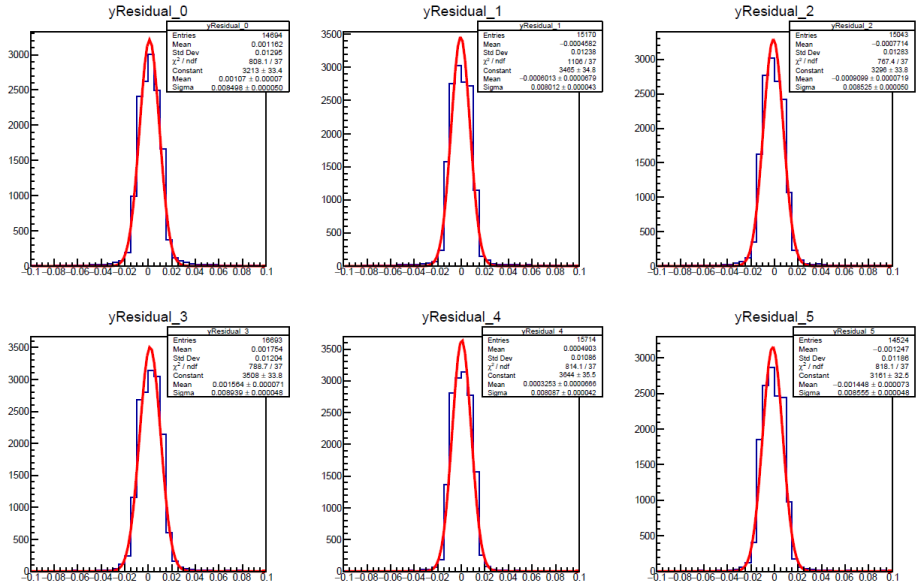
Run 347	
length	60 minutes
triggers	4 733 381
V grid	350 V
E drift	280 V/cm
rotation	17 degree
	0 degree
threshold	800e

Time matching

- 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

Telescope residuals





RMS is approximately 10 µm