Test Beam Results of MicroMegas TPC modules

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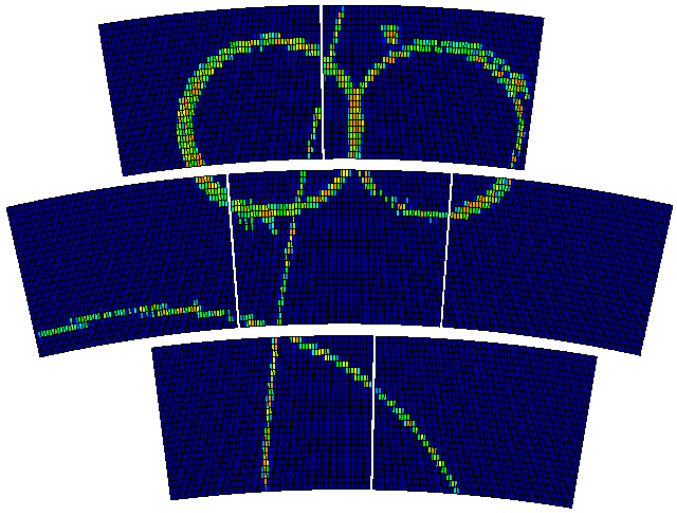

ALCW2015, LCTPC Section
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The EUDET/AIDA test beam facility at DESY provide a 6 GeV electron beam

- Consists of a field cage equipped with an endplate with 7 windows to receive up to 7 fully equipped identical modules

Last beam test of 7 MicroMegas (MM) TPC modules at DESY (Mar. 1– Mar. 14, 2015)

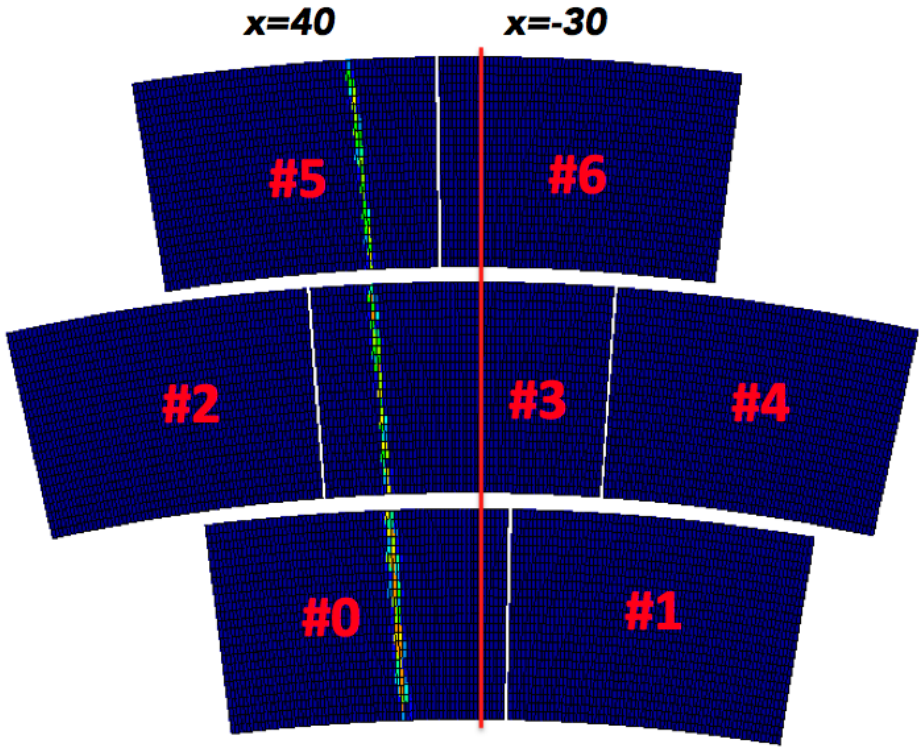
- **Principal goals** of 2015 test beam
  - to test 5 Carbon Loaded Kapton (CLK) and 2 new Black Diamond (BD) MM modules
  - to gather remaining material aimed for publication this year

Prehistory of beam tests with MM modules:

- **Mar 2010:** 1 module, start analysis with FTPC framework; reanalised with MarlinTPC framework
- **May 2011:** cross-talk problem; start using Marlin framework
- **Jul 2012:** multimodule setup with 6 fully operated modules; coherent noise
- **Jan-Feb 2013:** multimodule setup with 7 fully operated modules; many disconnected pads; first complete analysis with MarlinTPC framework
- **Feb 2014:** same as in 2013 with some pads' connection problem; analysis with MarlinTPC framework

- **7 MM modules** with charge dispersion by resistive anode
  - pads of the size 3×7 mm^2
  - 24 rows with 72 pads each
  - 1728 pads per module
- **Beam data taking program:**
  - magnetic field: B=0, 1 T
  - drift field: E=140, 230 V/cm
  - z-scan [5-50]cm every $\Delta z = 5\,\mathrm{cm}$
  - shaping time τ-scan: 100-1000 ns
  - ZS: 4.5σ (baseline) and 3σ
  - beam energy scan [1-5] GeV
  - varying θ angle up to 30°
- **Cosmic data:** cover a whole LP volume

View from inside



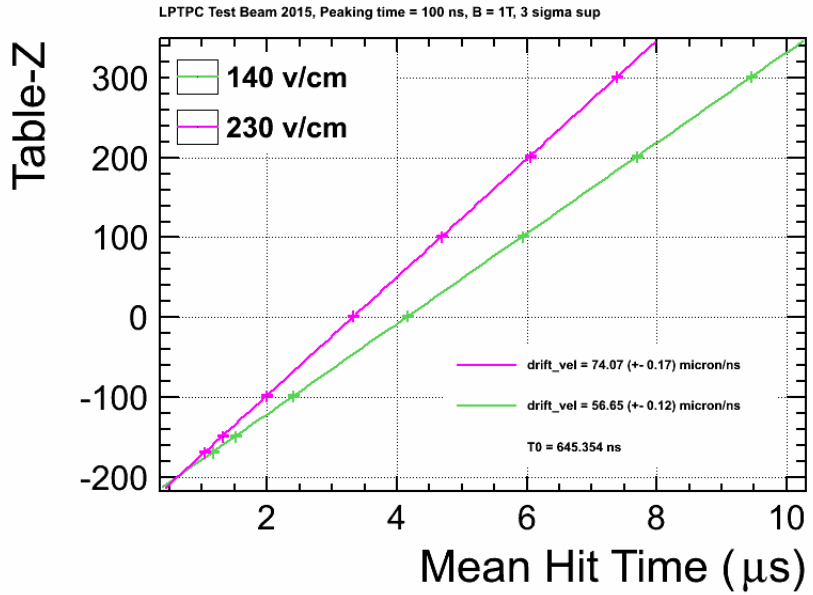
x=40: baseline beam setup
x=-30: complementary beam setup

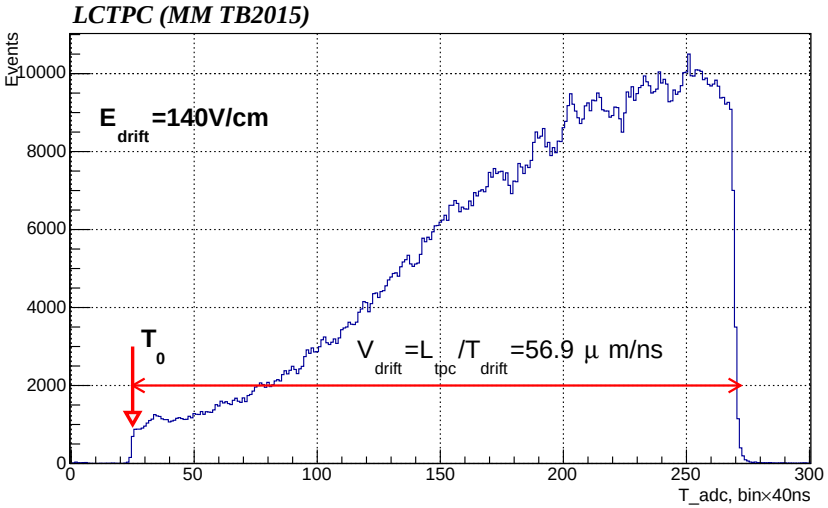
In all plots for TB2015 analysis multi-module track fit is deployed

Gas Property and T_0 Calibration

- Prototype operates with T2K gas
  - Ar(95%), CF_4(3%), iC_4H_{10}(2%)
  - gas purity: 60 ppm O_2, 100 ppm H_2O
  - deploy `Magboltz` calculations
- Absolute T_0 calibration:
  - **beam trigger:** dedicated z-scan at $V_{drift} = 140, 230$ V
    - ➔ $T_0 = 645$ns from fit
  - **cosmic trigger:** accumulate a whole LP volume data events
    - ➔ $T_0 = 22 \times 40\text{ns} = 880\text{ns}$

About 250 ns differnce for T_0 between 2 trigger configurations





	E=140 V/cm	E=230 V/cm
V_d `Data`	$56.7 \pm 0.1 \mu m/ns$	$74.1 \pm 0.2\ \mu m/ns$
V_d `Magboltz`	$57.9 \pm 1.0 \mu m/ns$	$75.5 \pm 1.0 \mu m/ns$
$D_\perp$ `Magboltz`	$74.5 \pm 2.5 \mu m/\sqrt{cm}$	$94.8 \pm 3.1 \mu m/\sqrt{cm}$

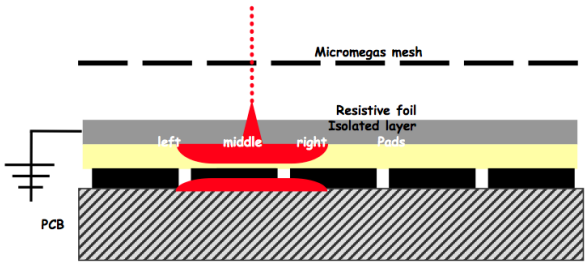
Analysis Dataflow

- **Dataflow has two major steps:**
  - **DAQ** software store data in **raw format** (calib. view, event dispay, slow control)
  - convert raw data in **slcio format**
  - **Analysis** with **MarlinTPC**
    - ➔ pulse finder, calibration
    - ➔ build hits from pulses
    - ➔ reconstruct tracks (track finder and fit)
    - ➔ analysis (corrections, distortion, resolution)
- **First analysis step:** build `TPCTracks`
  - triplet track finder `(RowTripletBasedTrackFinder)`
  - 5-parametric helix fit `(TrackFitterSimpleHelix)`
- **Second analysis step:** deploy `TPCTracks`
  1. correction `(BiasCorrector)`
  2. distortion `(ModuleDistortionCorrection)`
  3. resolution `(ResolutionPerformance)`

Determine resolution from geometric mean of inclusive and exclusive residuals of the whole 3D track fit

Coherent analysis of all data is performed in MarlinTPC framework including legacy 2010

Action on Pad Responce Funciton



☞ Charge density function of time dependent charge dispersion on 2D continuous RC network:

$$\rho(r,t) = \frac{RC}{2t}\exp[-\frac{-r^2RC}{4t}]$$

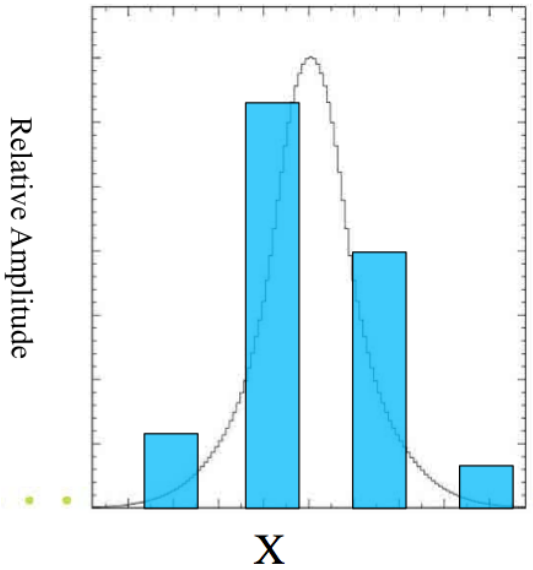
R- surface resistivity
C- capacitance/unit area

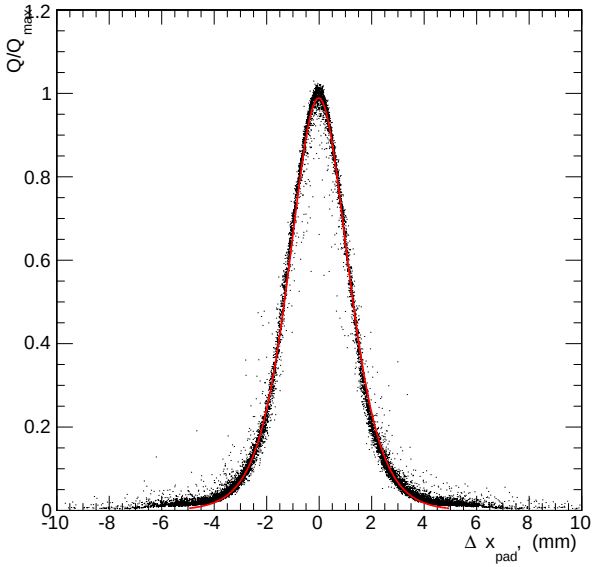
☞ **Hit Finding Procedure**

➠ group adjacent pulses

➠ fit PRF to the pulse amplitudes

Relative fraction of charge seen by pads fitted by Pad Responce Function (PRF)





$$PRF(x) = \frac{4e^{\alpha x}}{(e^{\alpha x}+1)^2}$$

☞ Converged to a single parameter PRF where α

➠ determined per run

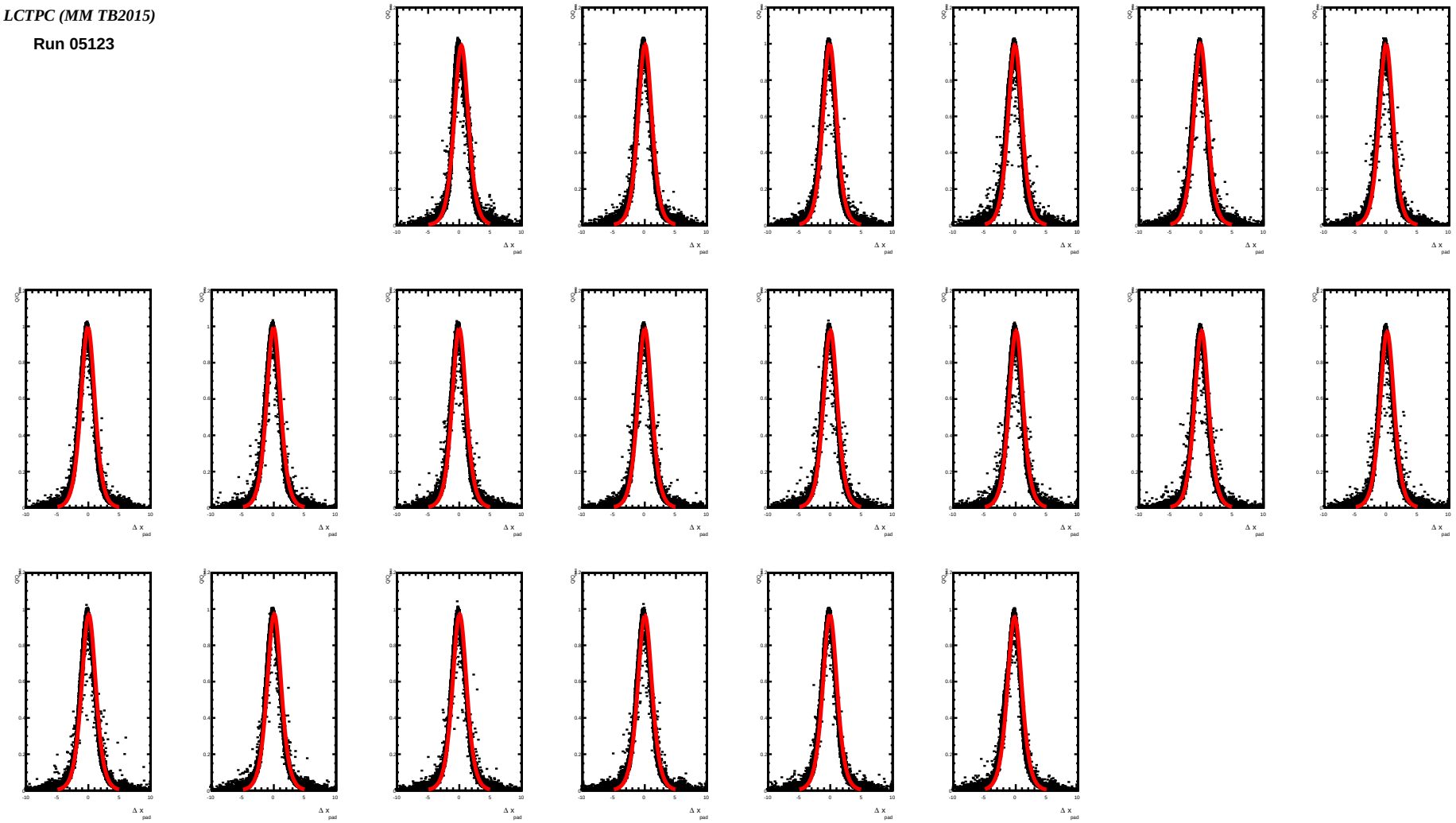
➠ depends on z and τ

➠ varies from 1.15 to 1.3 at $\tau = 200$ ns

Pad Responce Funciton

LCTPC (MM TB2015)

Run 05123



Row-by-row illustrations are for **module#0 (BD2)**

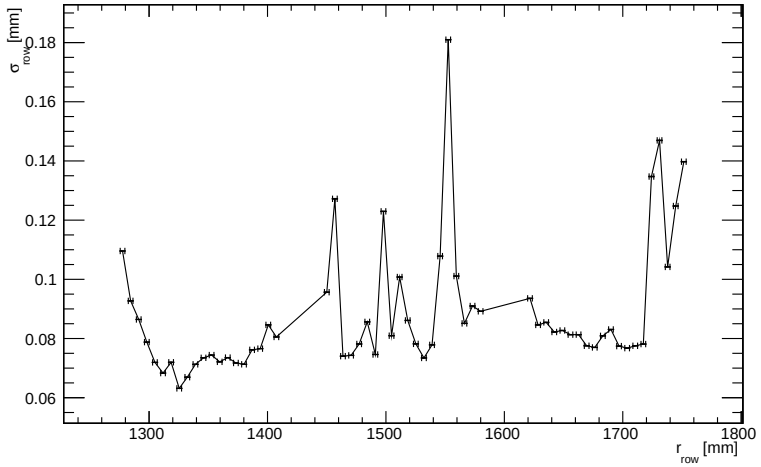
Similar plots for other modules are not shown unless they can generate specific message

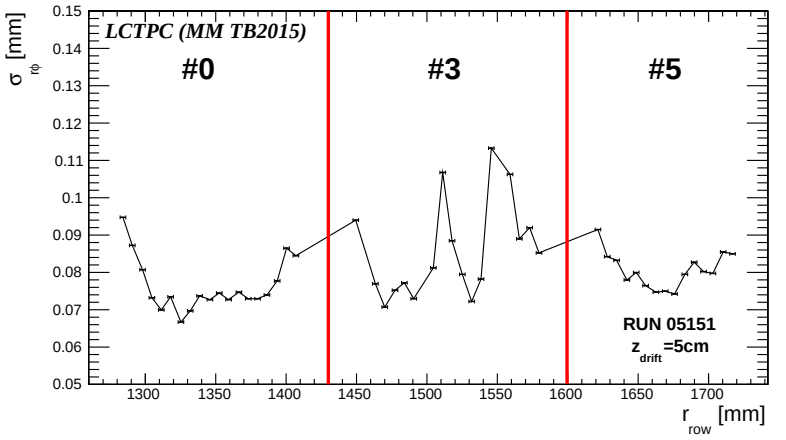
Some connector problems still take place while data taking

- **Dead (hot) channels** ($\leq 5\%$)
  - are well established at pedestal run
  - can be identified with cosmic data
- Mask whole rows before hit finder
  - 2 inner(outer)most rows 0-1,22-23
  - rows with dead chennel(s)
    - ➔ **mod#0:** row 2
    - ➔ **mod#3:** rows 3, 9, 17
    - ➔ **mod#5:** rows 17-21
  - **mod#3:** row 11 is possibly noisy, but is not excluded

Yield **51 rows** *in total for average resolution performance*

Presence of dead pad in a hit degrades row resoluiton





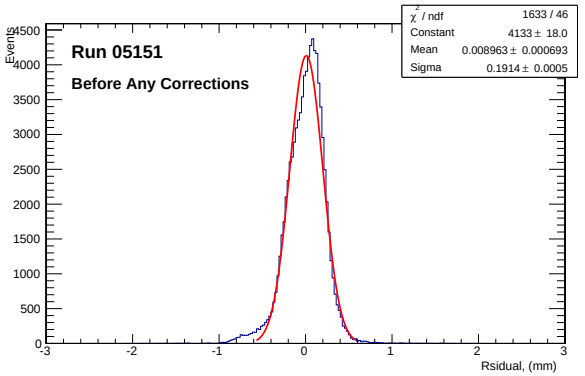
Track fit exploits multi-module setup, i.e. information from all 3 modules

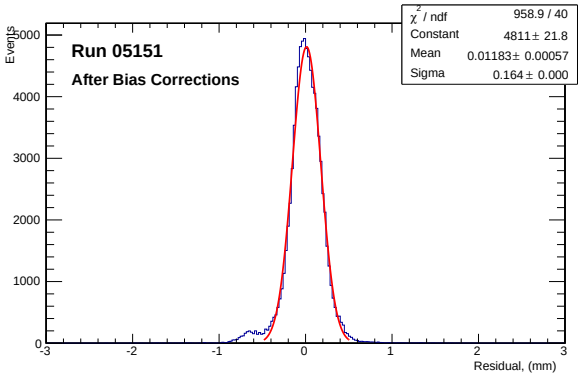
- Resolution is determined from the same statistical sample as those used for the track fit
  - geometric mean of inclusive and exclusive residuals of the whole 3D track fit

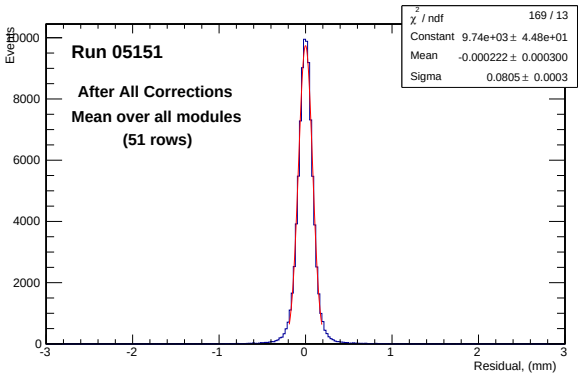
$$\sigma_{\mathrm{i}} = \sqrt{\sigma_{\mathrm{in}} \cdot \sigma^{\mathrm{i}}_{\mathrm{ex}}}$$

offers unbiased resolution estimator
[R.Carnegie, M.Dixit, et.al., NIM **A538** 372 (2005)]

- **Important requirements for σ_{i}:**
  - gaussian-like (low fraction of outliers)
  - zero off-set (systematic error)
- **Corrections** have to be applied
  - **bias:** determined by local RC properties (width)
  - **distortions:** driven by ExB effects at (offset)
  - **alignment:** not for today (offset) ...



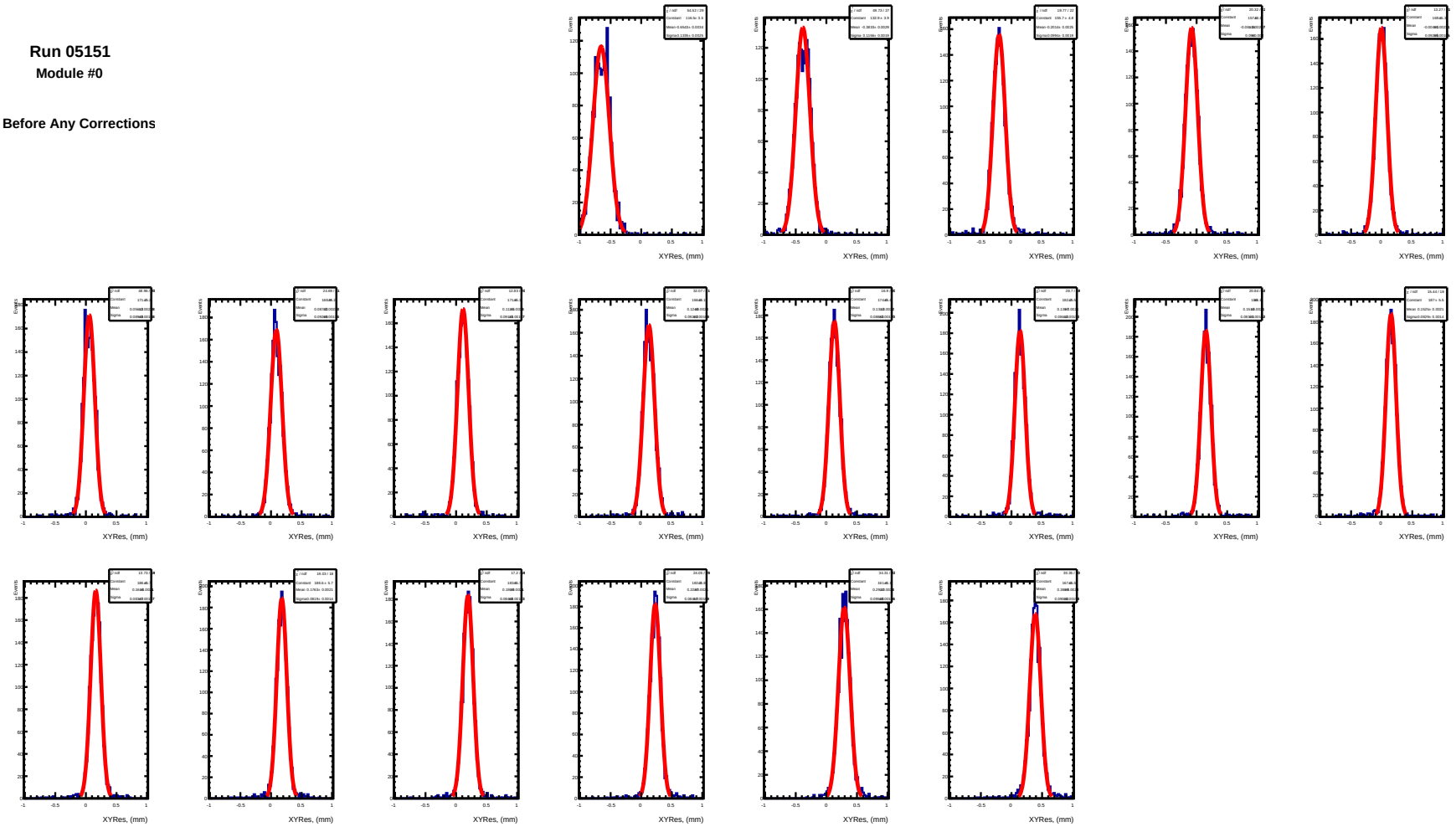




Row-by-Row Residuals

Run 05151
Module #0

Before Any Corrections



Row-by-row illustrations are for **module#0 (BD2)**.

Systematic offset about 1 mm is observed for residuals in modules#0 and #5.

Systematic effect on position determination in each row

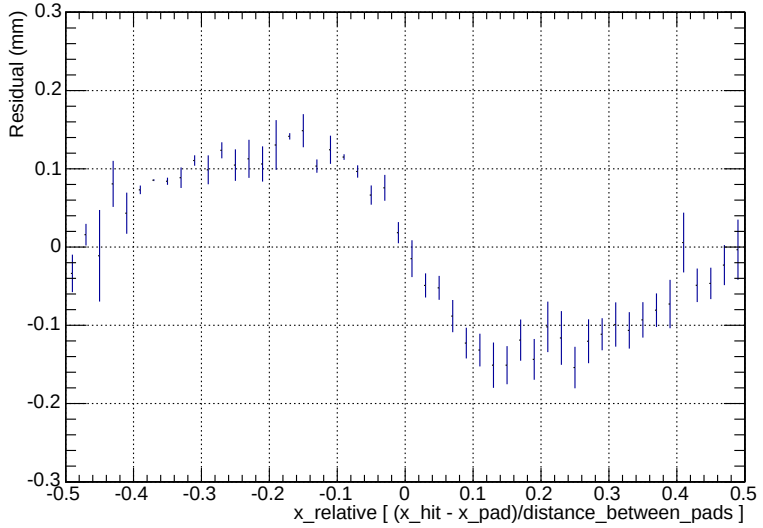
- PRF takes into account real charge distribution and addresses S-curve effect

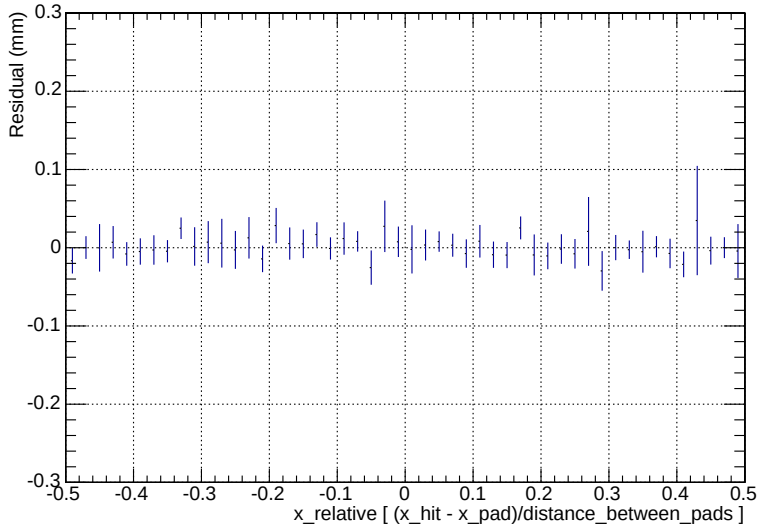
Remnant oscillation about 100 μm occurs periodically if PRF position estimator is used

- Local variations of RC properties lead to a systematic error for track position determination
- Row-by-row corrections are calculated versus a distance from center of leading pad and then applied:

$$\mathbf{x_{rel}} = \frac{\mathbf{x_{hit} - x_{pad}}}{\mathbf{d + \Delta}}, \ [\mathbf{-0.5, 0.5}]$$

Run 05151, Module #3, row 10



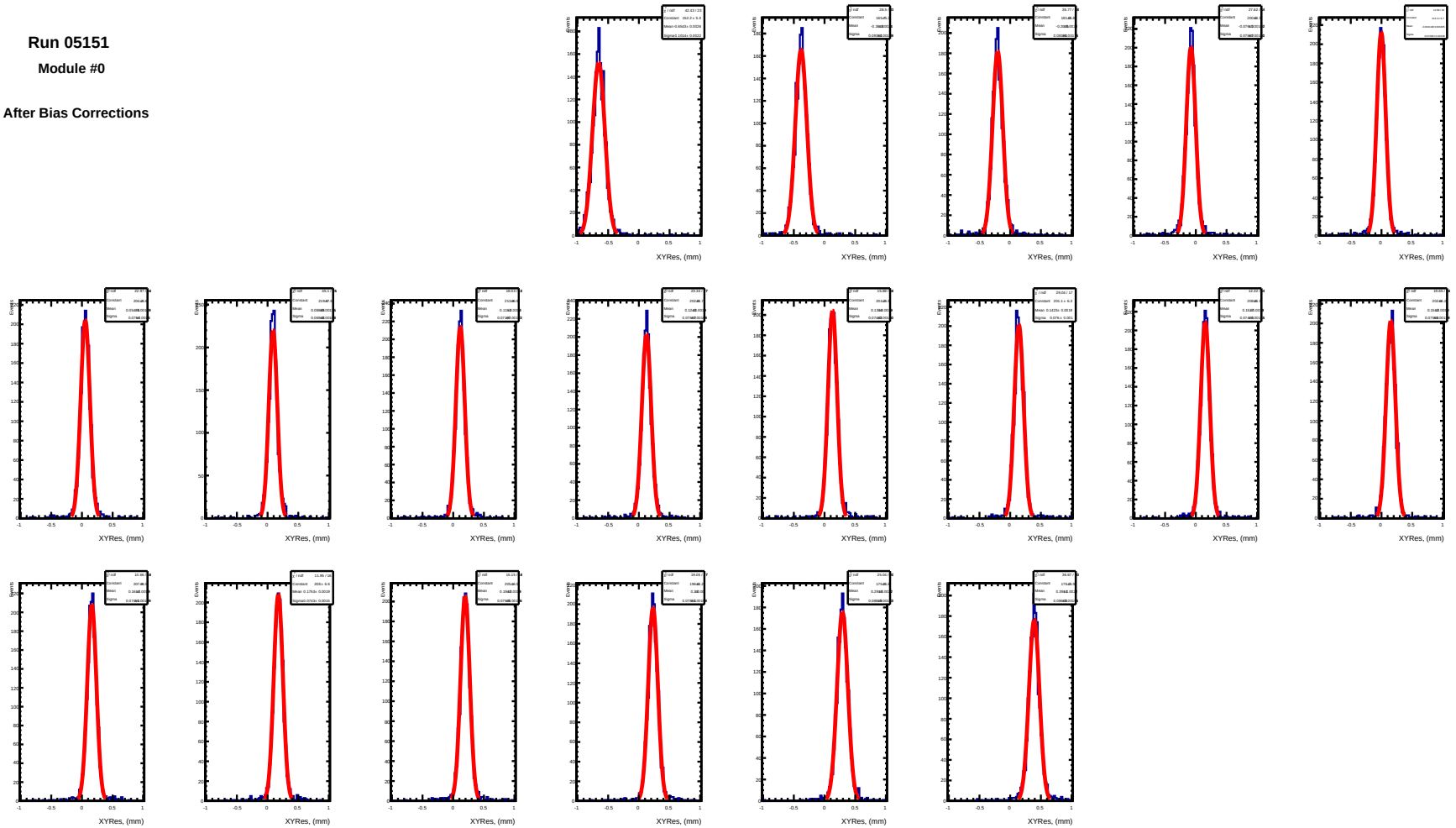


Residuals After Bias Corrections

Run 05151

Module #0

After Bias Corrections

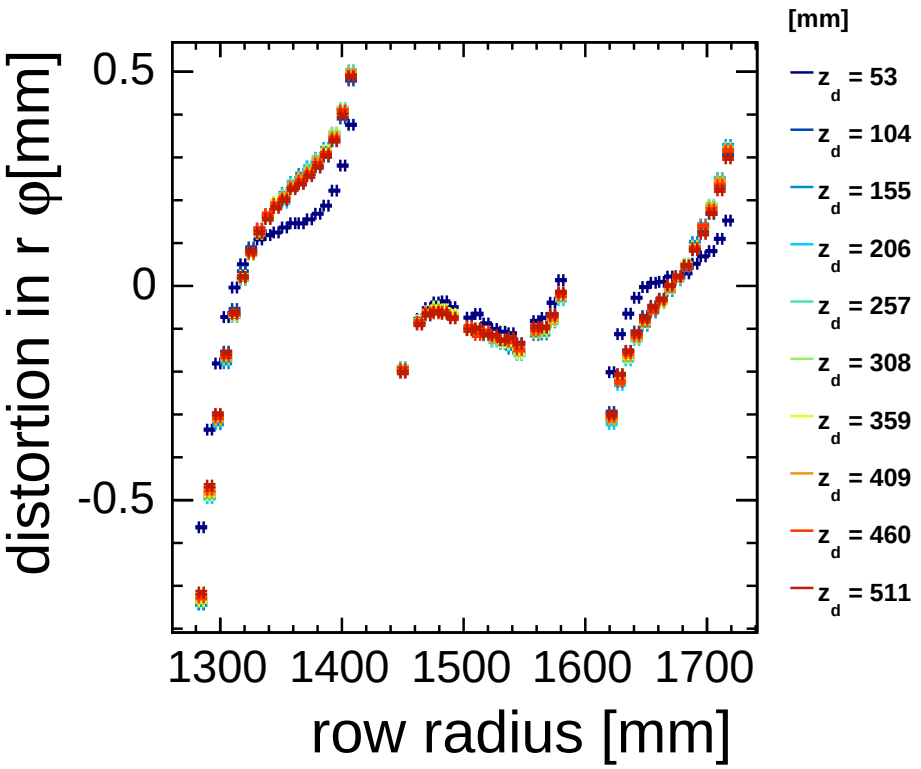


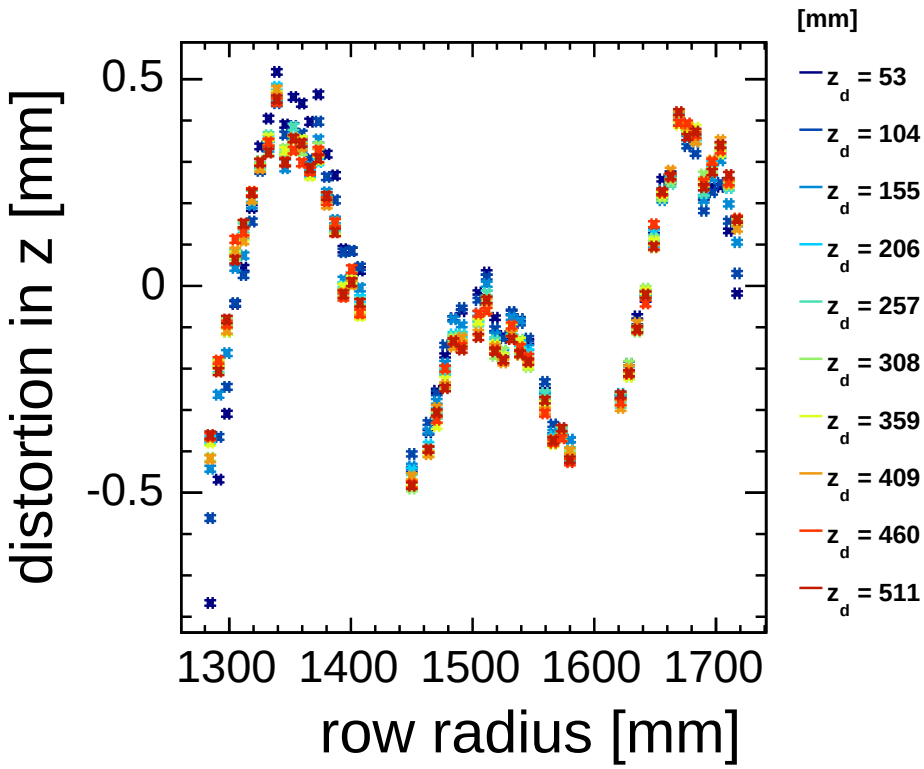
Bias corrections improve dispersion of residulas

Systematic offset about 1 mm remains for residuals in modules#0 and #5.

Need to correct for distortions to overcome residual offset

Distortions After Bias Corrections

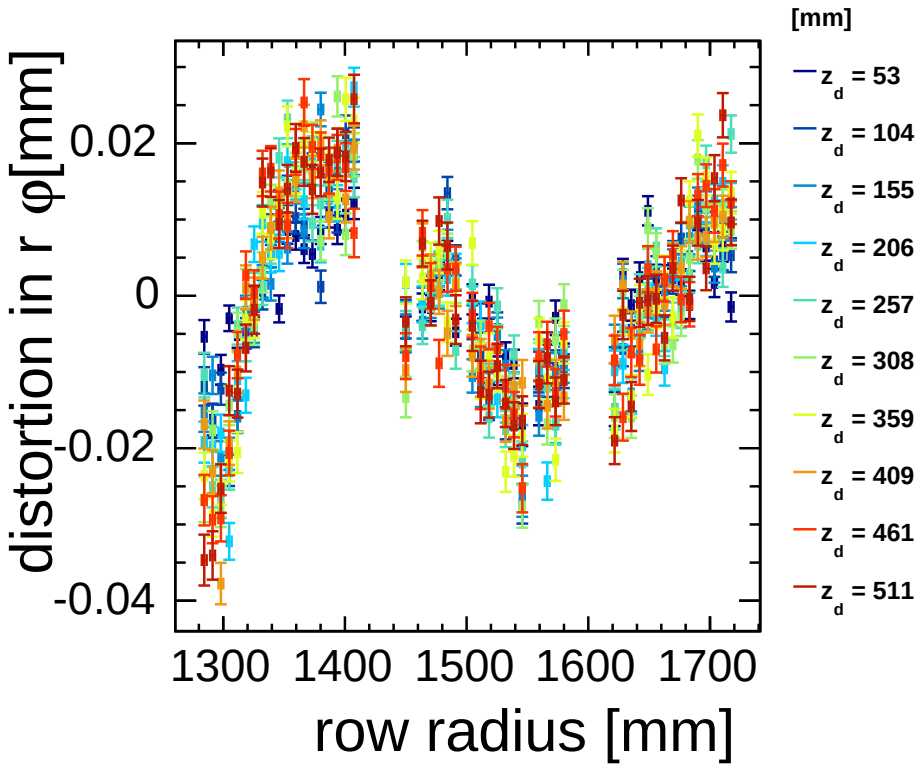


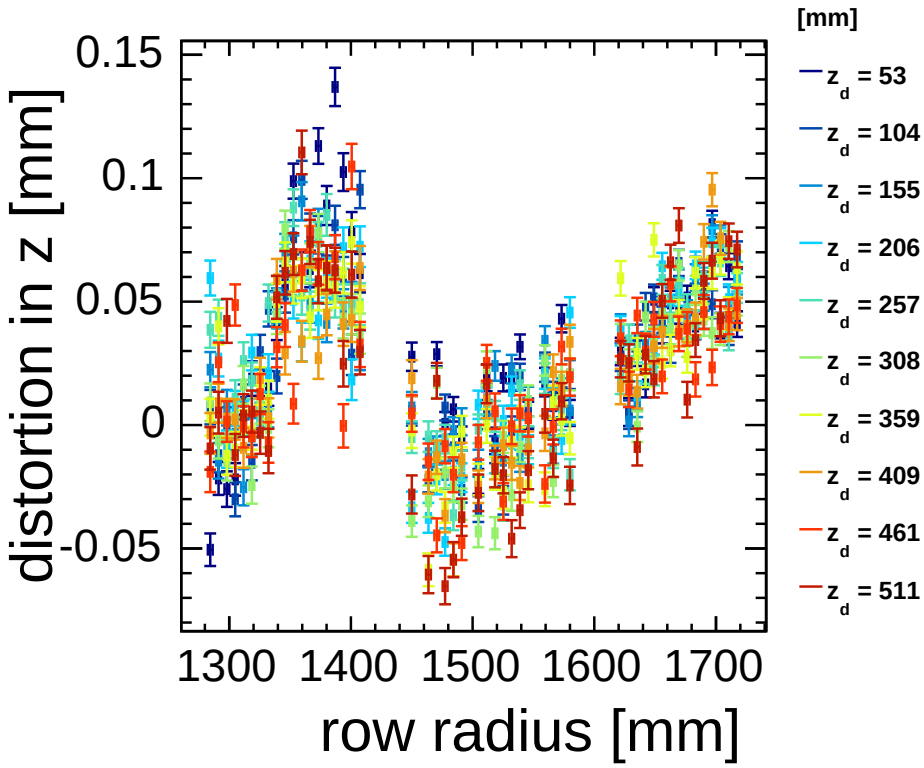


☞ Non-uniform E-field near module boundaries induces ExB effects

- ➠ distortions about 1 mm are observed after bias corrections
- ➠ bias corrections are applied with respect to residual mean

Distortion corrections are necessary on top of bias corrections





☞ Distortion correction pin down resuduals to zero at

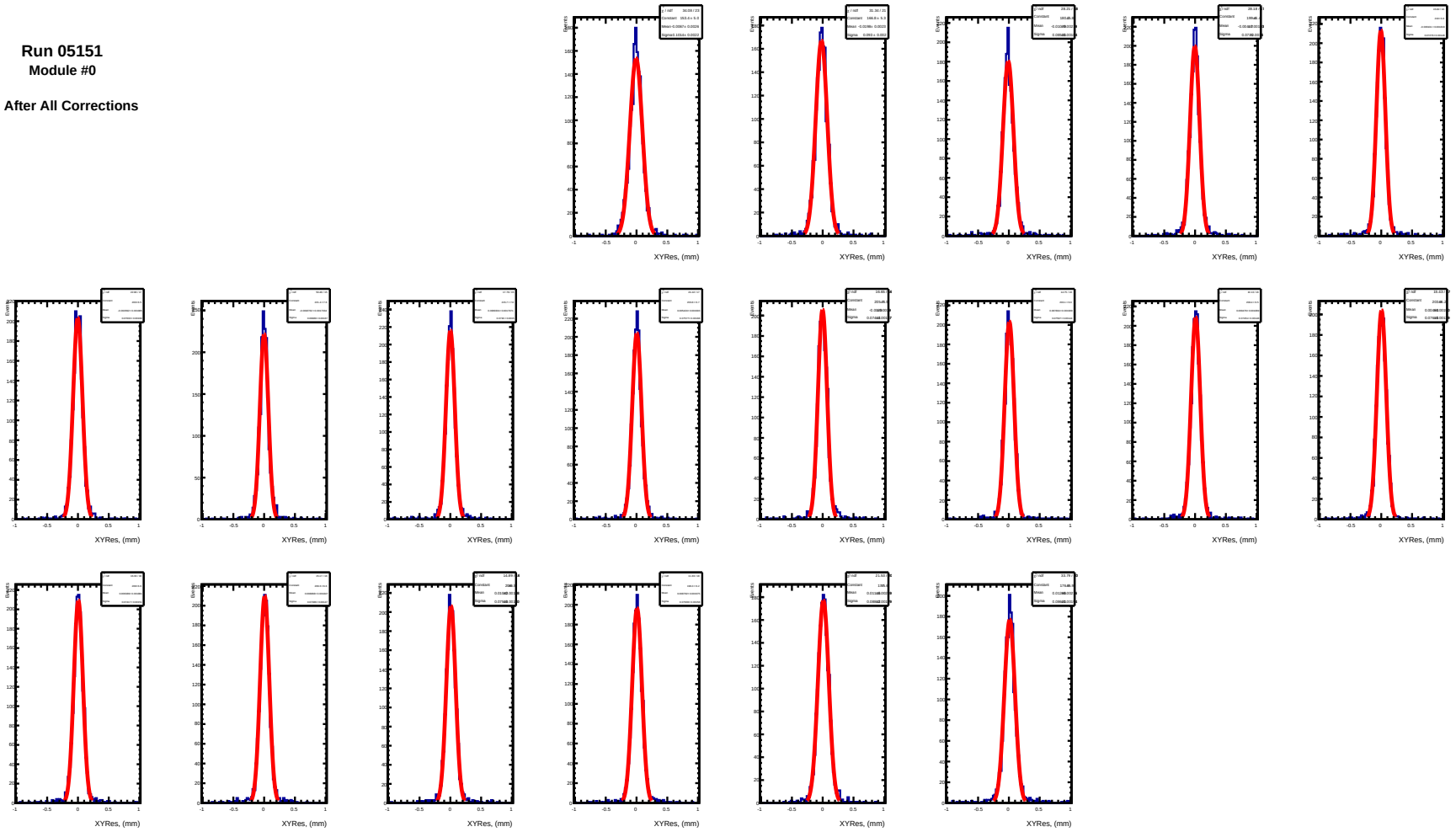
20 μm in $r\phi$ plane and *100 μm in z coordinate* precision

Further improvemnt desirve multi-module alligment and/or track fitter improvement (Kalman)

Residuals

Run 05151
Module #0

After All Corrections

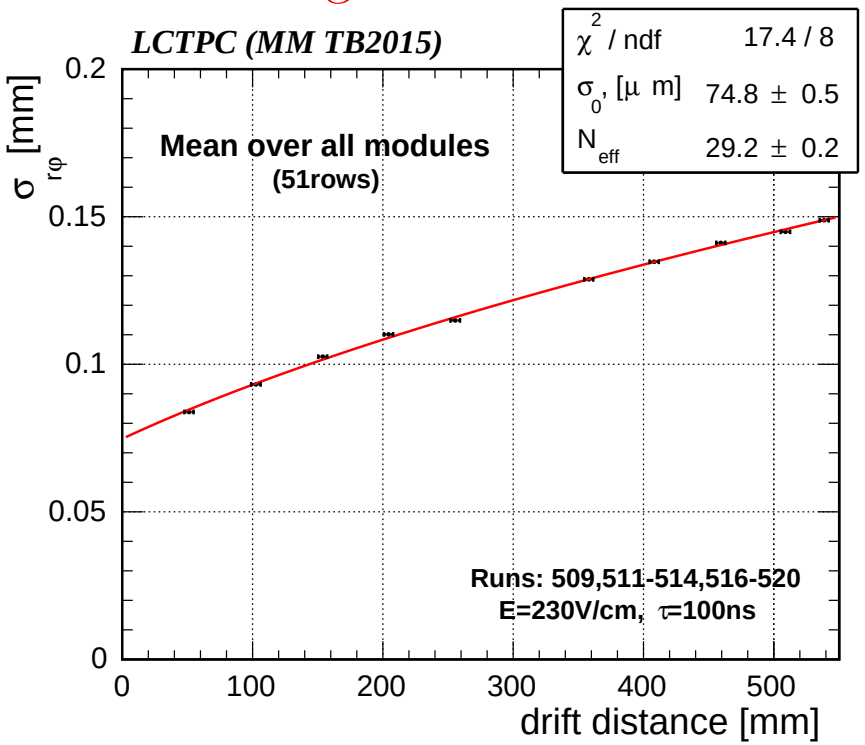


Row-by-row illustrations are for **module#0 (BD2)**.

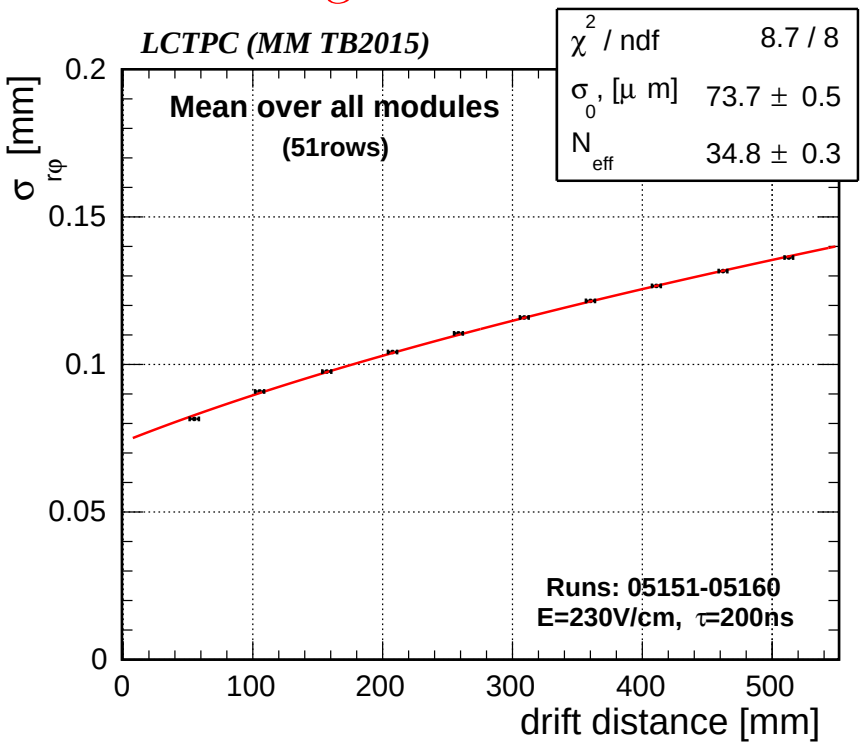
Zero offset for residuals is observed for all modules.

$r\phi$ Resolution: 230 V/cm

Peaking time 100 ns



Peaking time 200 ns

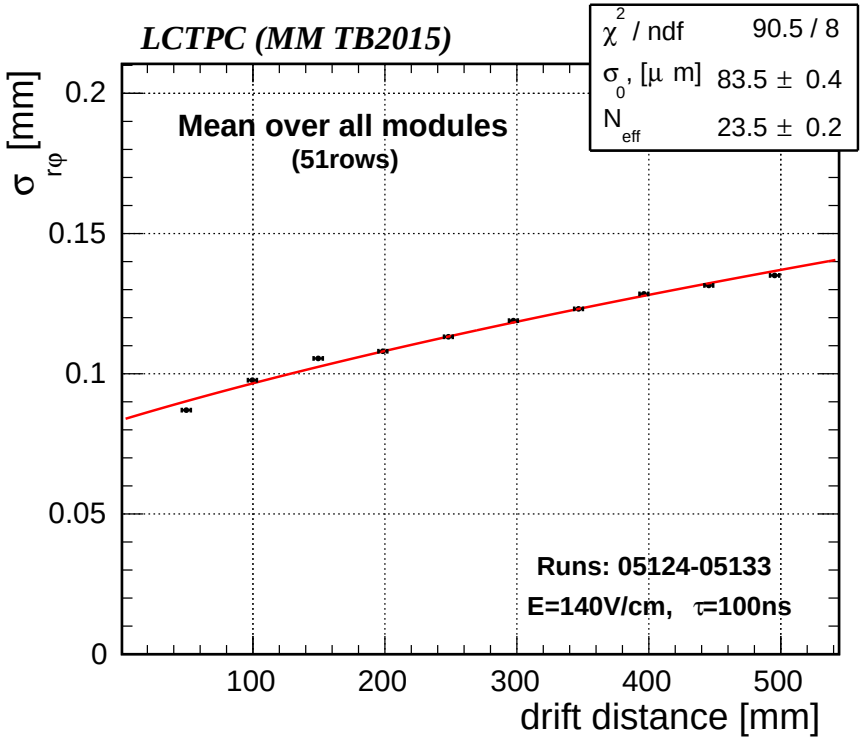


☞ **Fit data with:** $\boldsymbol{\sigma(z) = \sqrt{\sigma_0^2 + \frac{D_\perp^2}{N_{eff}} z},\ \sigma_0^2 = b^2/N_{eff}}$

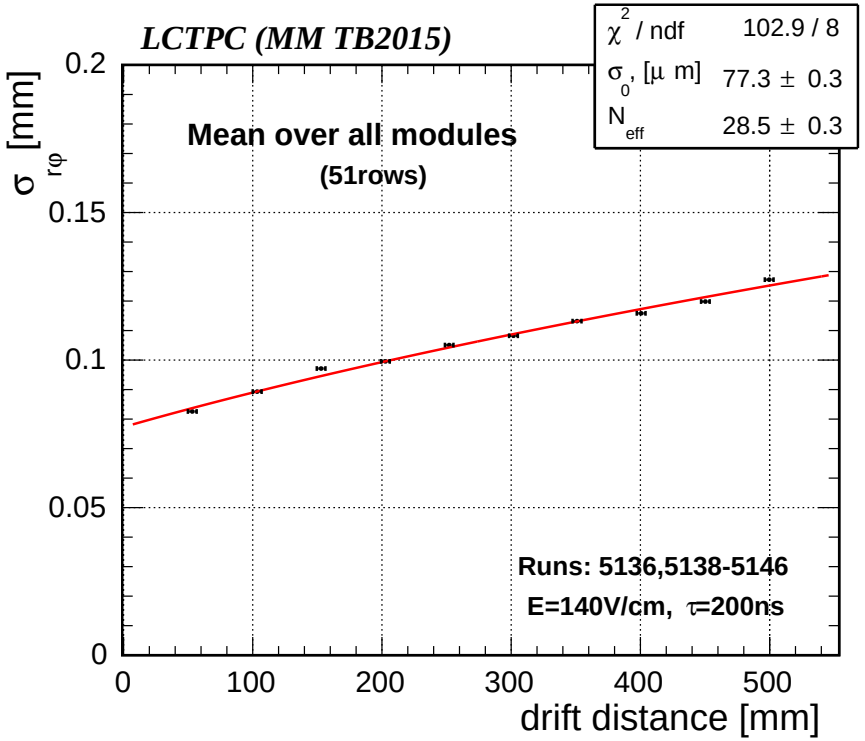
- σ_0 - the resolution at z=0, N_{eff} - the effective number of electrons
- Magboltz calculations of $D_\perp$ at about 3% precision

$r\phi$ Resolution: 140 V/cm

Peaking time 100 ns



Peaking time 200 ns



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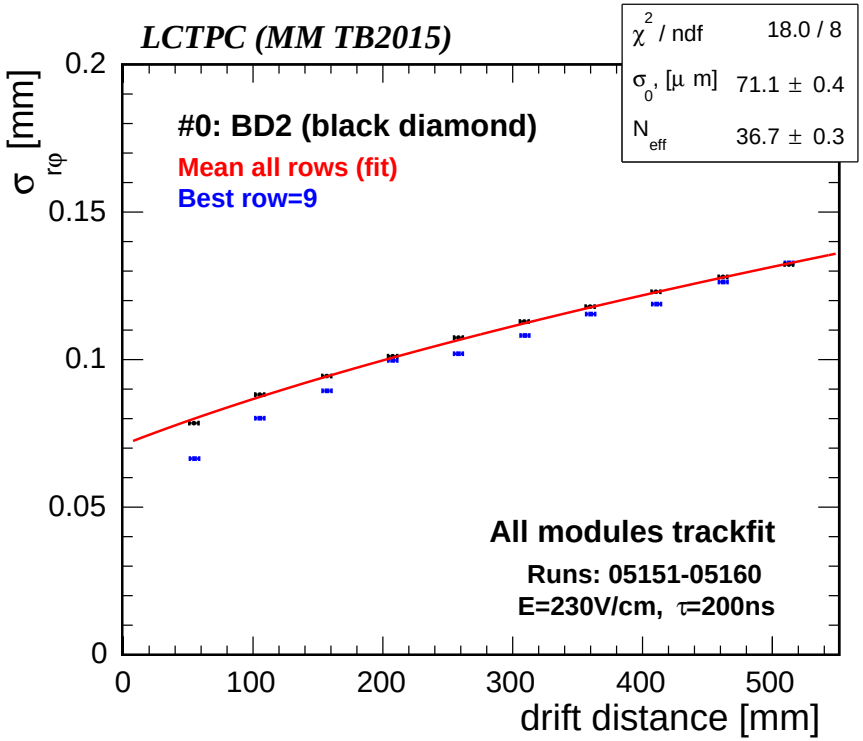
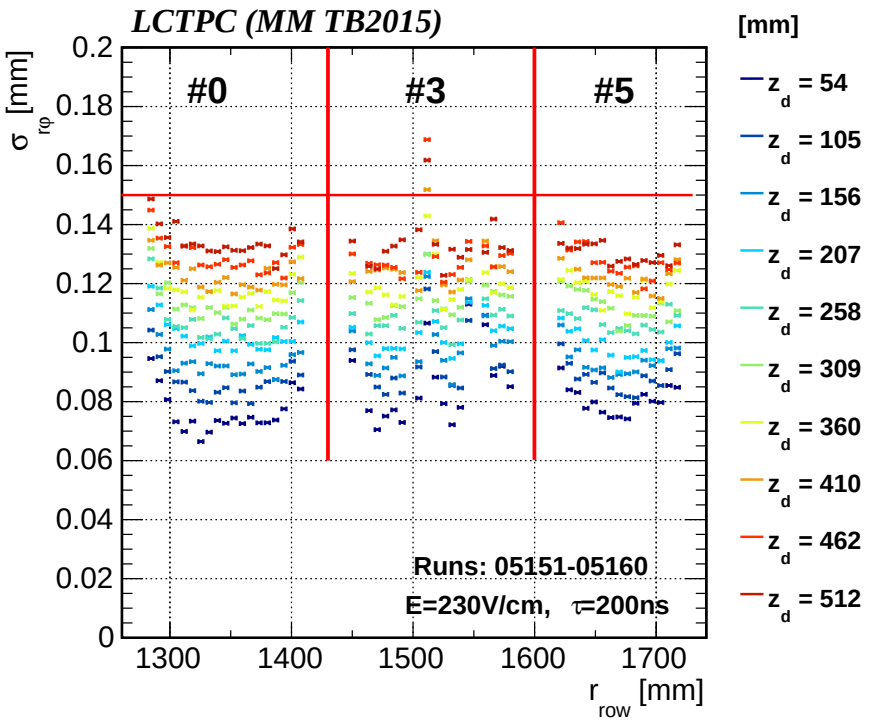




☞ About 10% better transverse resolution observed for BD2 at same $\mathrm{N_{eff}}$ than for overall

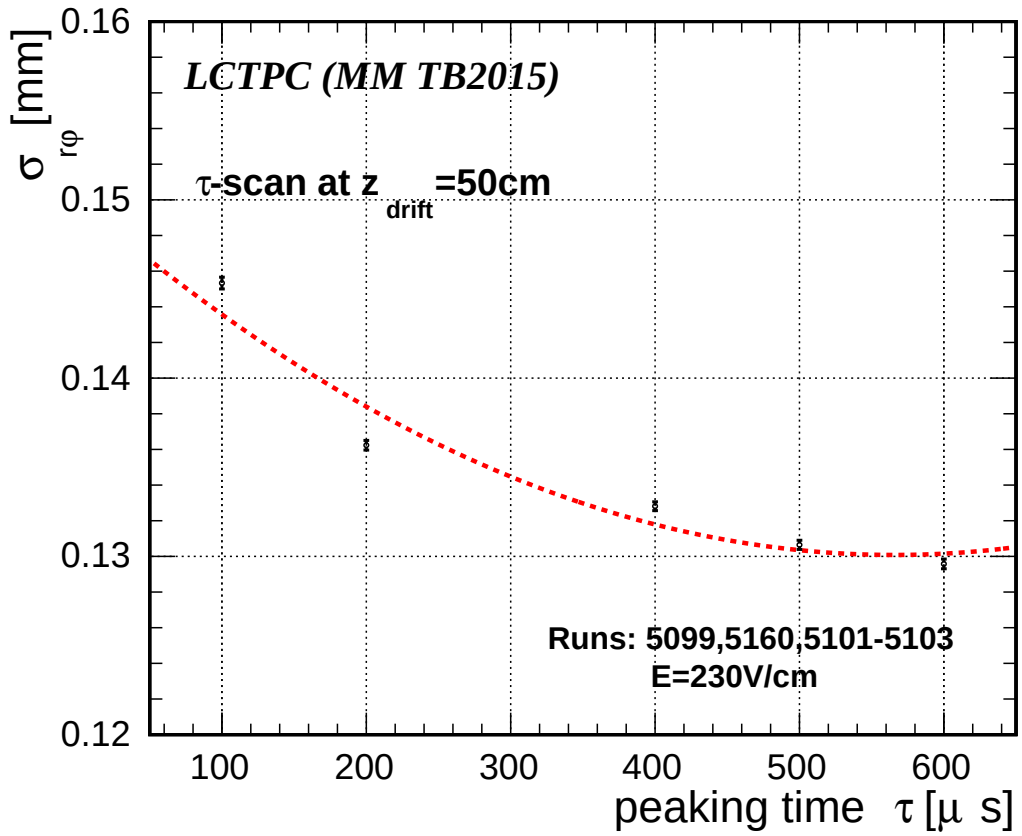
➠ reach $\boldsymbol{\sigma_0 \simeq 70\mu m}$ for multi-module track fit approach

There is a room for further improvement by correcting for misalignment

Peaking Time scan: 230V/cm

- ☞ Have a quick look of the peaking time scan at z=50 cm
  - ➠ consistent with expectation
  - ➠ will be updated adding up to $\tau = 1\mu\mathrm{m}$ data

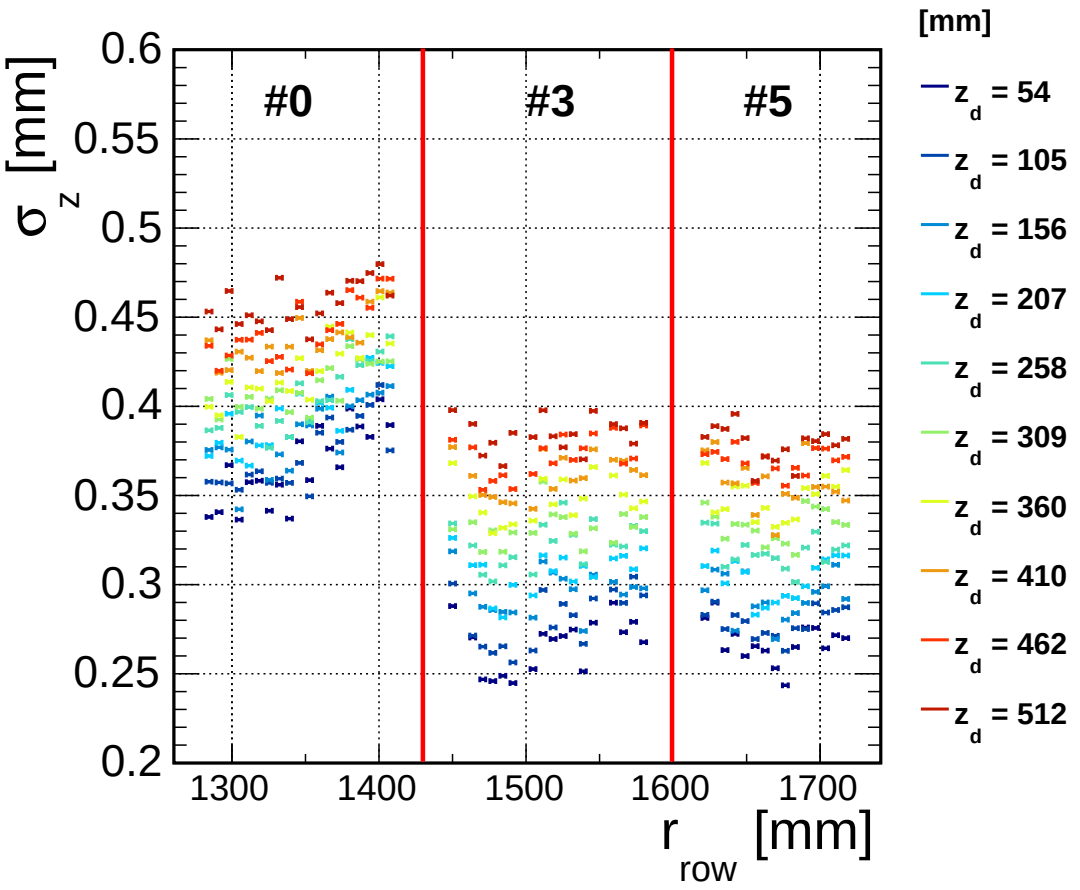
Consistent with TB2010 reanalysed data at z=50 cm: $\sigma_{r\phi} = 130\mu m!$



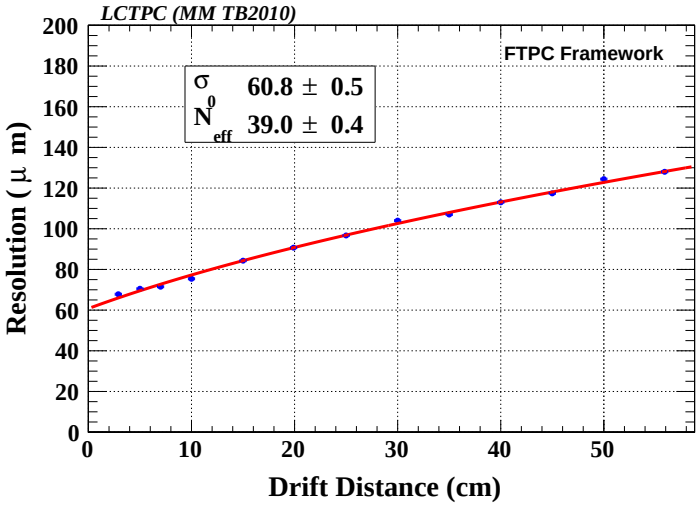
Remarks on z-Resolution

- Have a quick look of z-resolution with Gaussian inflection point method
  - difference between BD2 and CLK modules is noticible
  - worse longitudinal resolution is observed for BD2

Need to verify the pulse shape for BD2

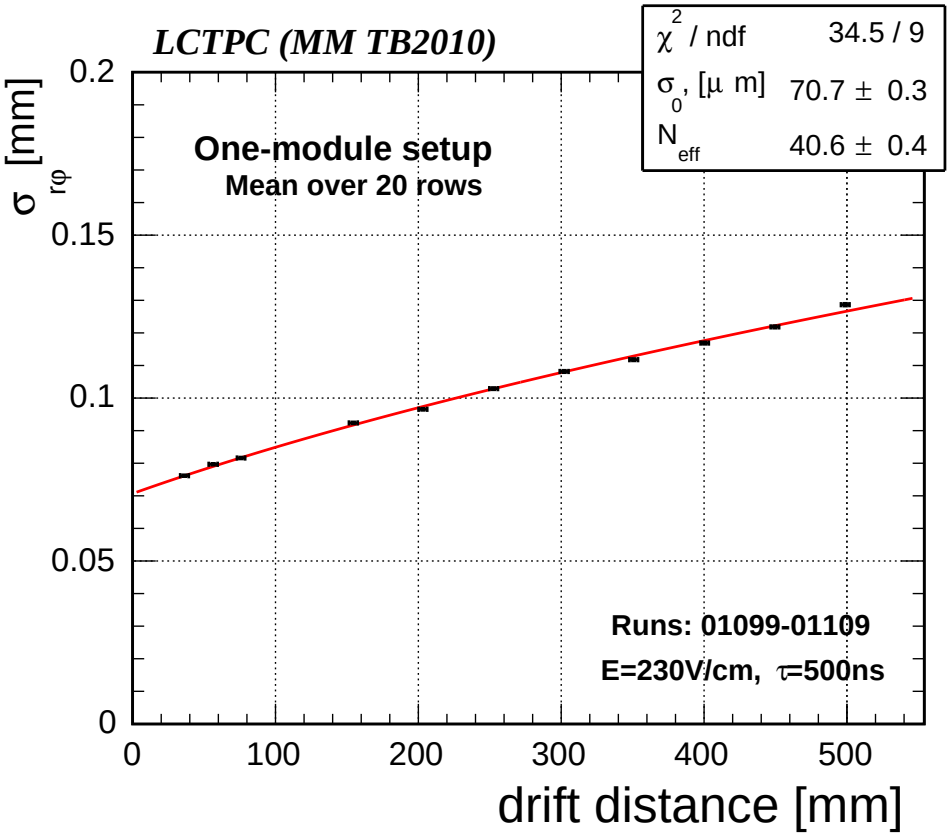


Single-Module setup analyzed with both **FTPC and MarlinTPC frameworks**
(Unaffected by misallignment!)

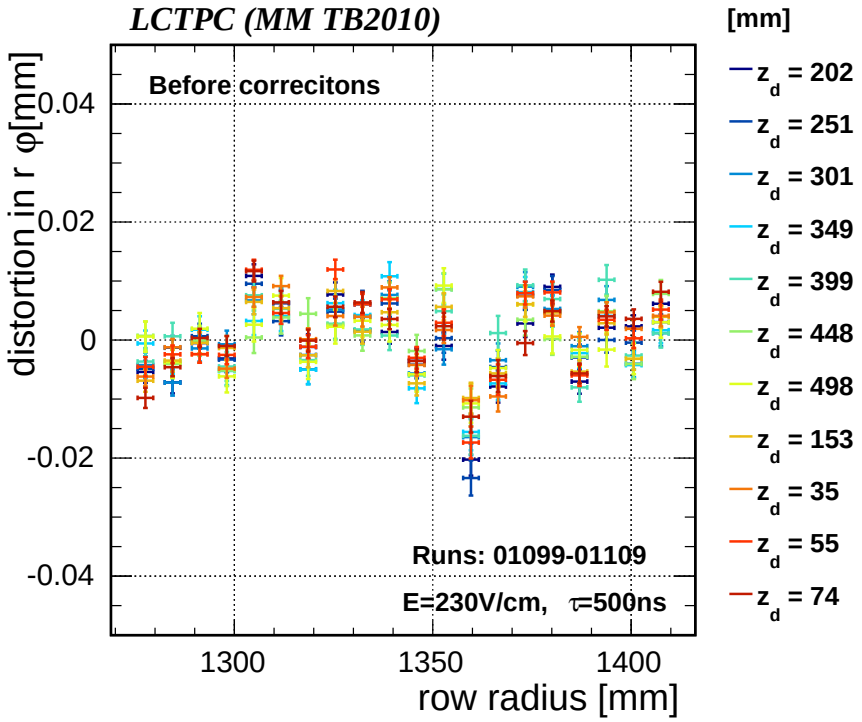


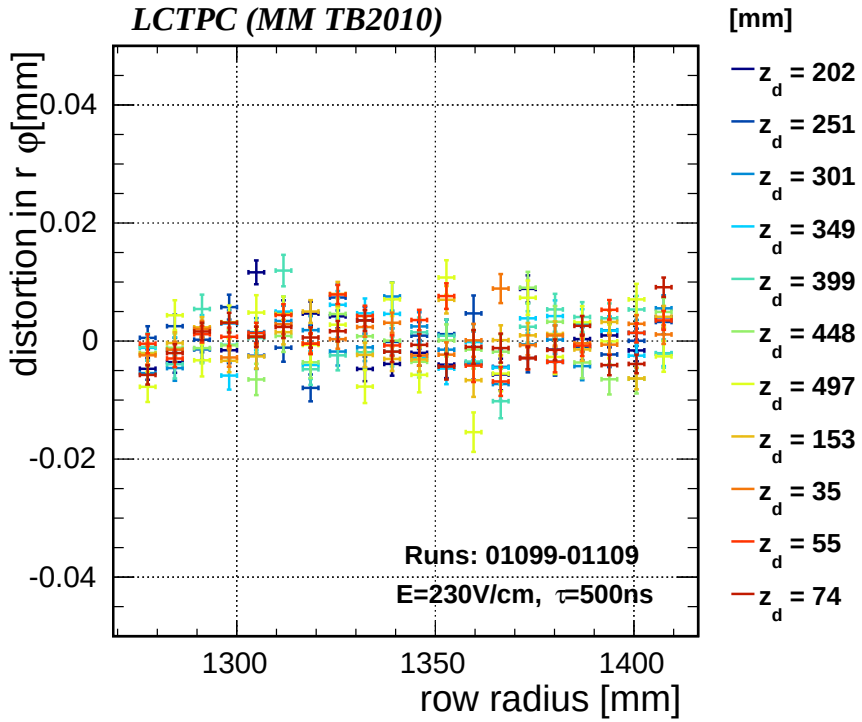
☞ Deployed simple selections to enrich "**single track**" event content

- reject multiple-track events
- require less than 5 hits with more than 40 ADC counts outside 10 central pad lines



Consistent result for both frameworks



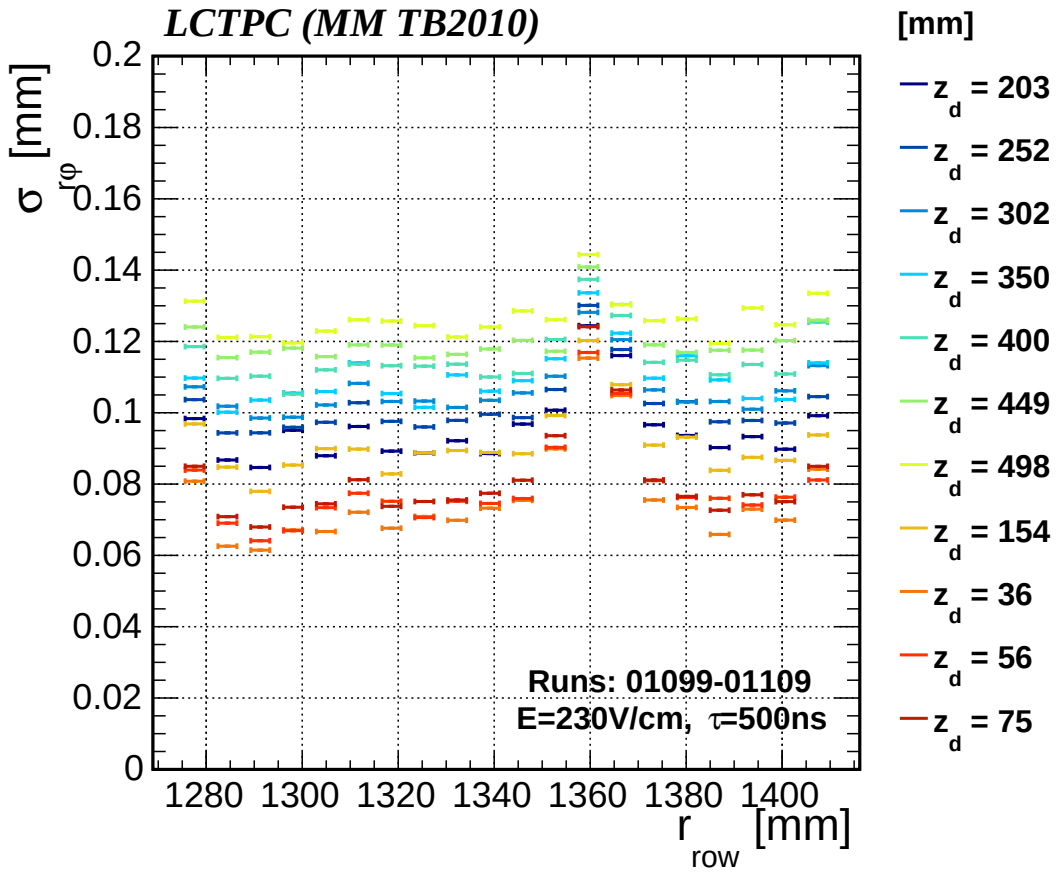


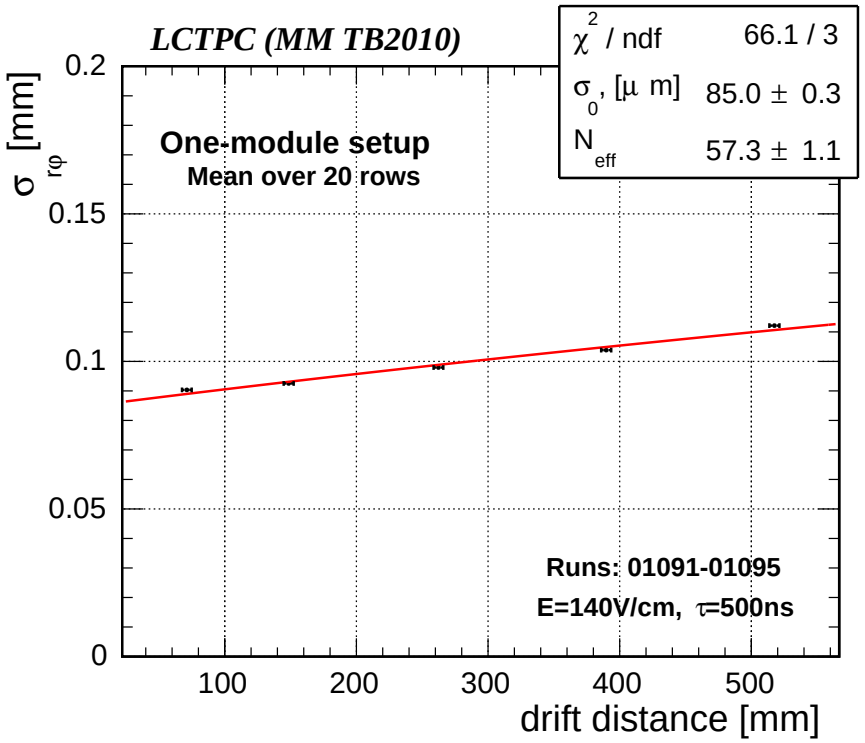
☞ Small distortions are observed in a **single-module setup**

- possibly compensated by track curvature
- oddly spike takes place in row 14
  (possibly missing pad)

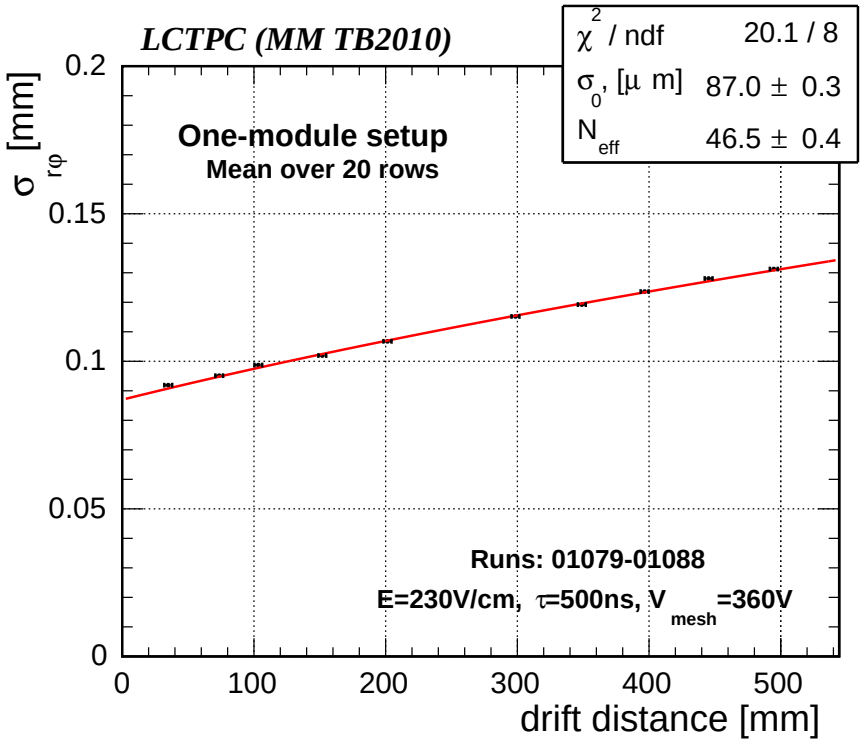
- **General uniformity is satisfactory**

  Worse resoliution in rows 14 and 15





Reach about $\sigma_{r\phi} = 110\mu m$ at large drift distance (very high N_{eff})



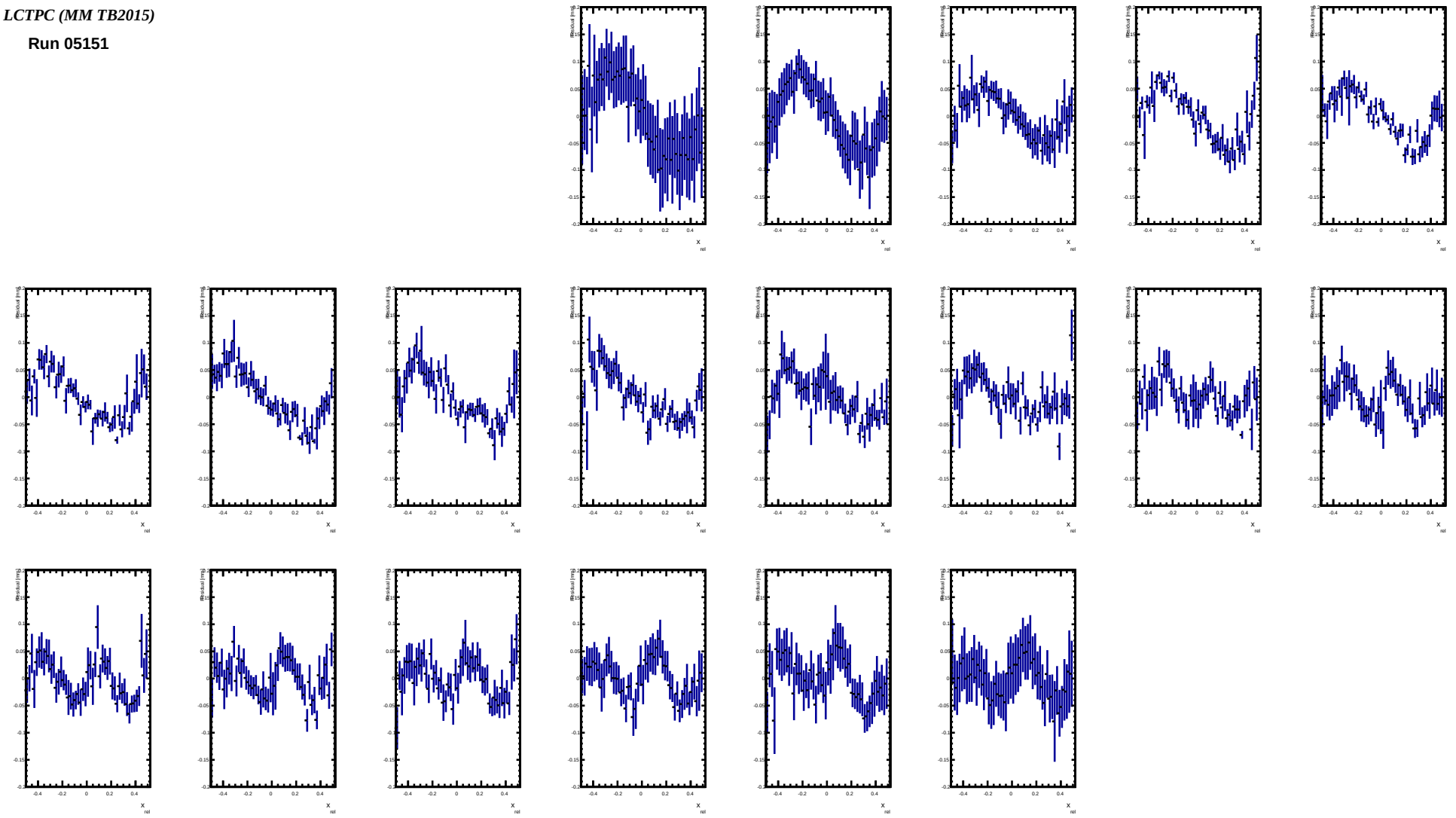
Lower gain degrades resolution at small drift distance

- **Preliminary analysis of resolution carried out for TB2015 data**
  - generic strategy for the analysis data flow is undertood
  - current result is based on **multi-module** triplet track finder and helix track fit
  - general correction sequence has been investigated by controlling residual distributions
    - ➔ **bias corrections** improve a variation from the distance of a pad center (RC inhomogeneities)
    - ➔ **distortion corrections** overcome a systematic offset in residuals (ExB effect)
- **Further fine-tuning is warranted**
  - study of **track finding and fitting** algorithms impact on corrections
  - **alignment corrections** (impact from $\mathrm{B} = 0$ T data)
- **Legacy analysis of TB2010 data carried out using MarlinTPC**
  - reasonable agreement achieved with TB2015 and FTPC public result
  - smaller corrections are observed for one-module setup
  - 2 rows are a bit problematic
  - needs to determine the publication strategy

Backup

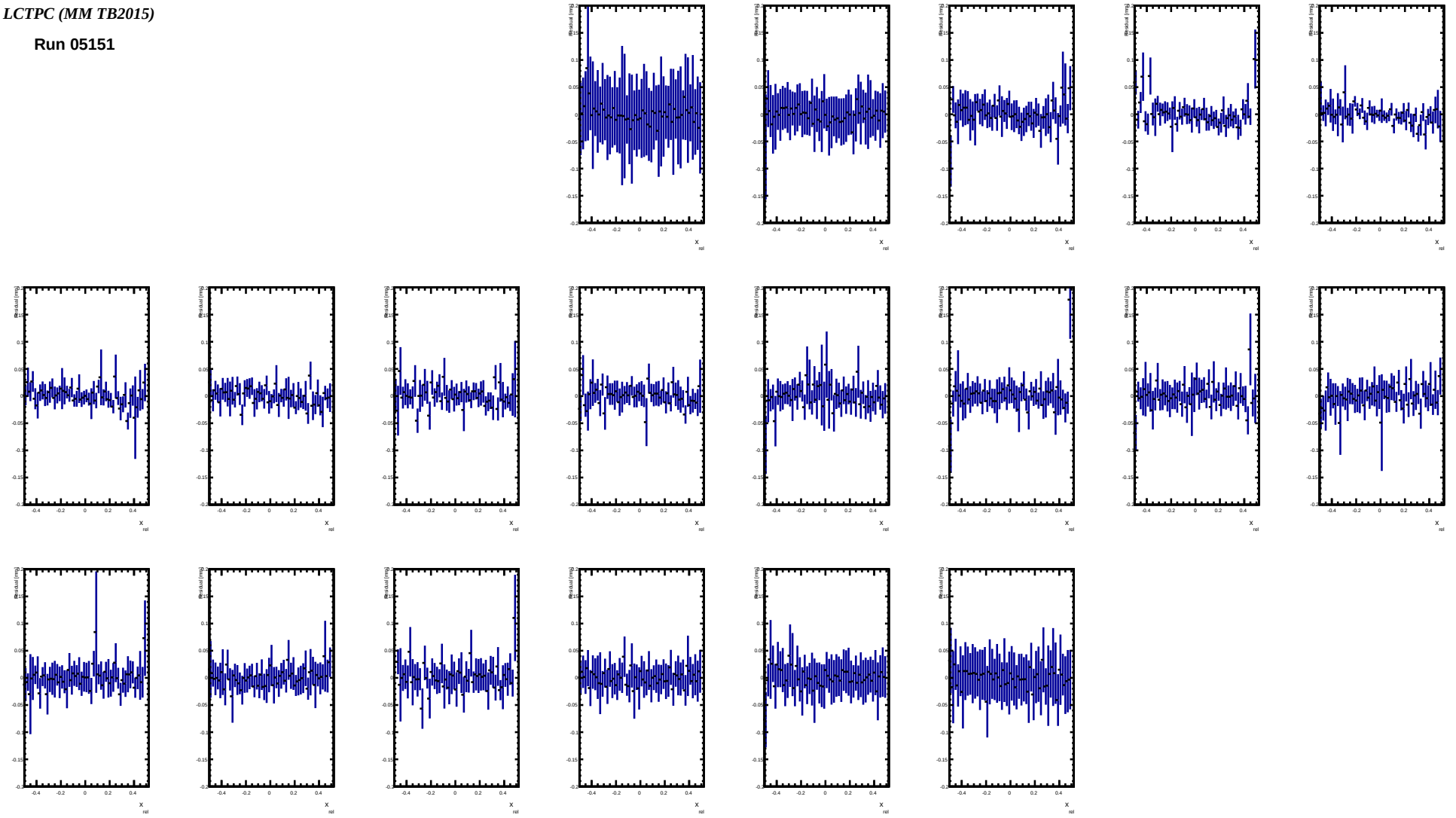
LCTPC (MM TB2015)

Run 05151



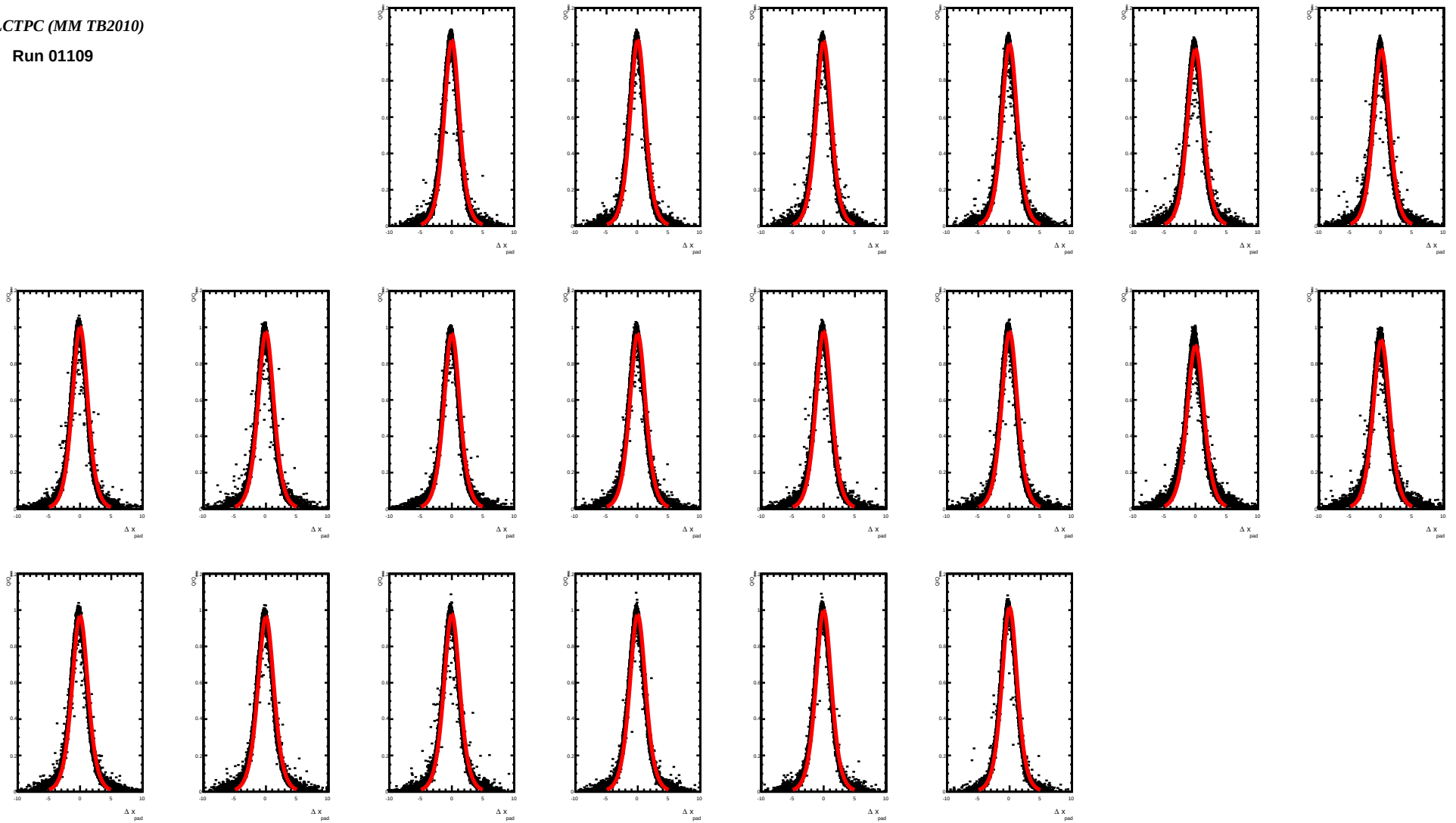
LCTPC (MM TB2015)

Run 05151

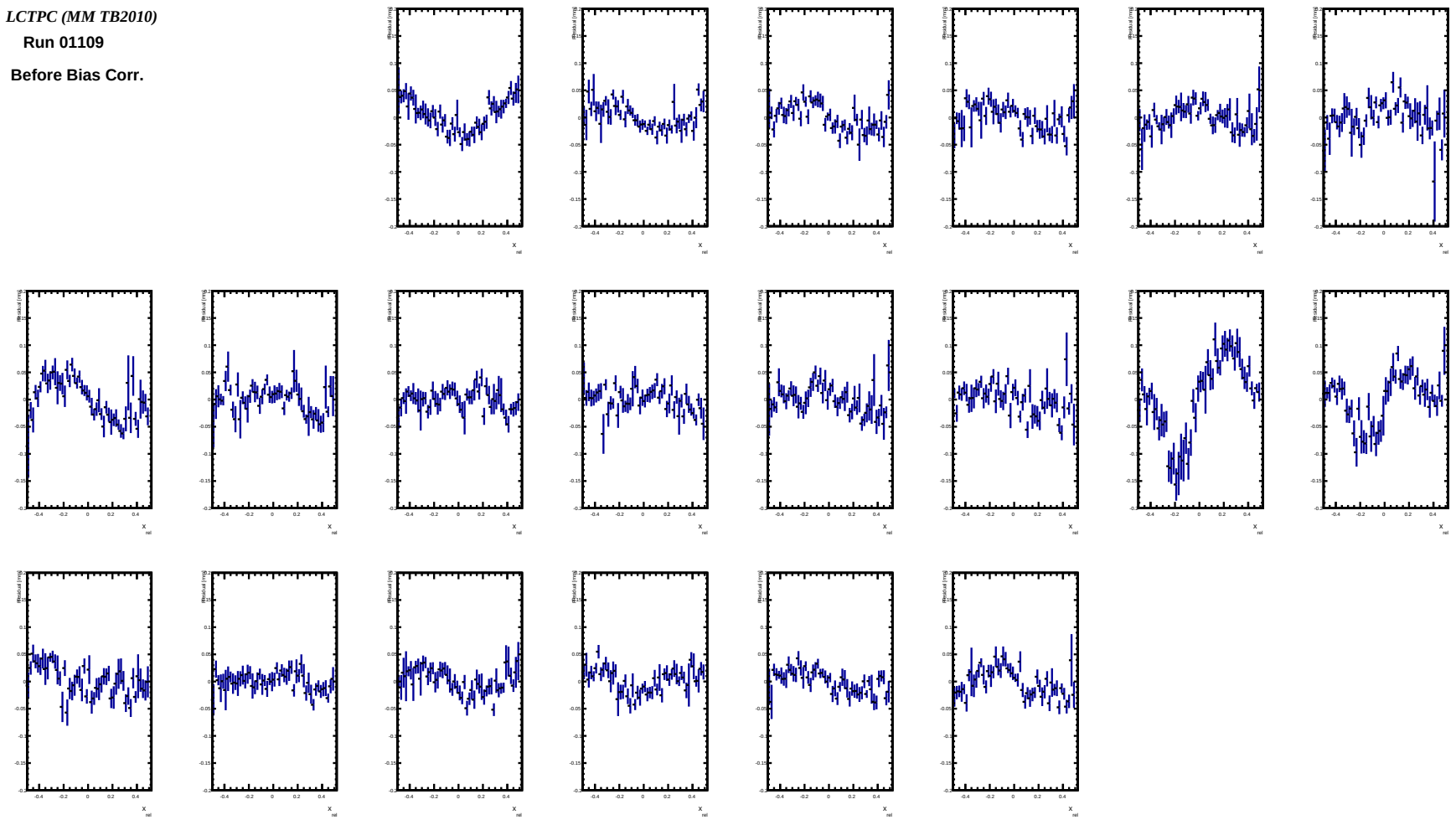


LCTPC (MM TB2010)

Run 01109

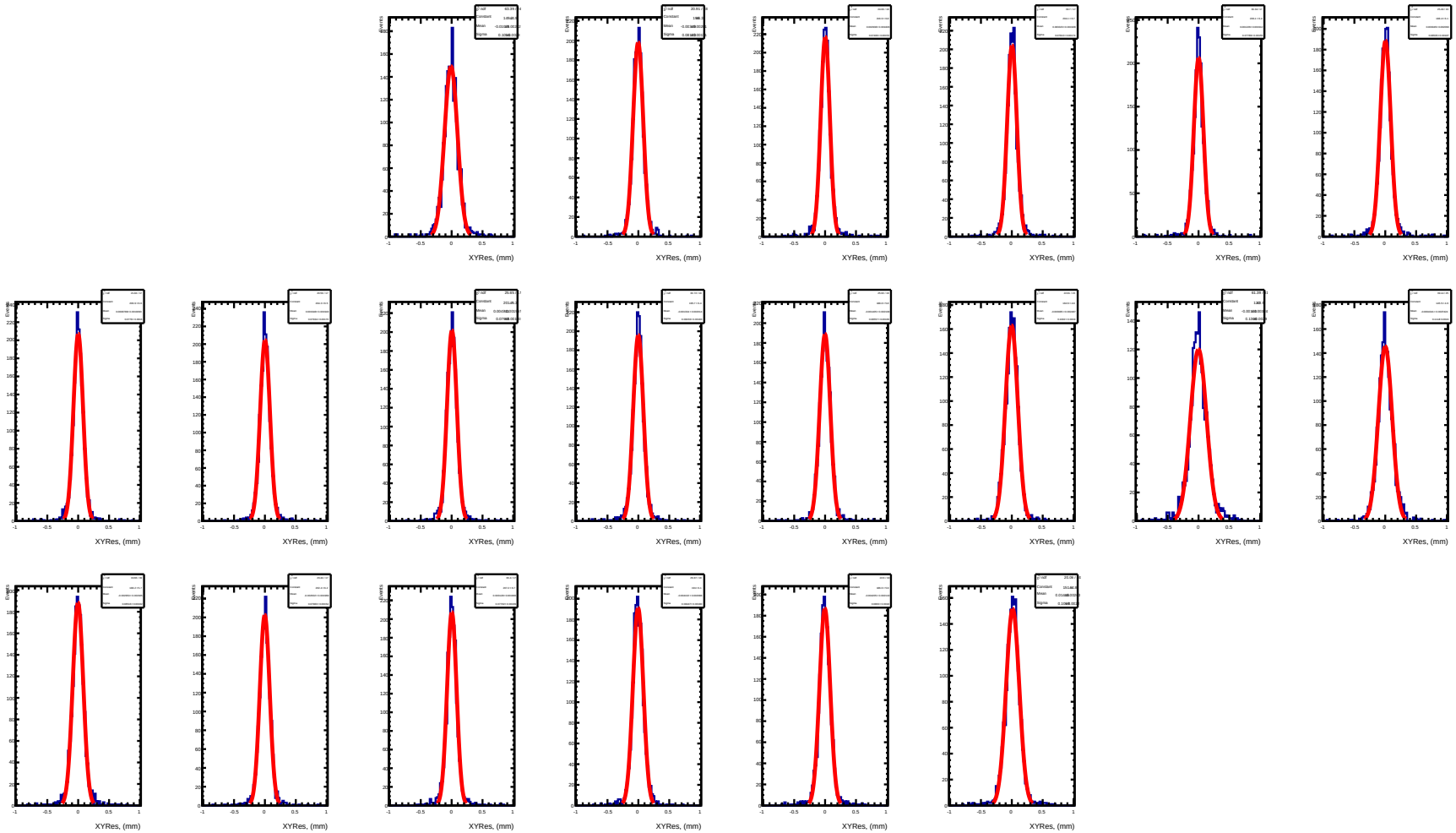


Bias TB2010



☞ Smaller bias is observed in a single-module setup

➠ significantly enhanced in rows 14 and 15 (dead/noisy channel?)



☞ Worse resolution in rows 14 and 15 (dead/noisy channel?)