Distortion measurements and corrections in Micromegas modules

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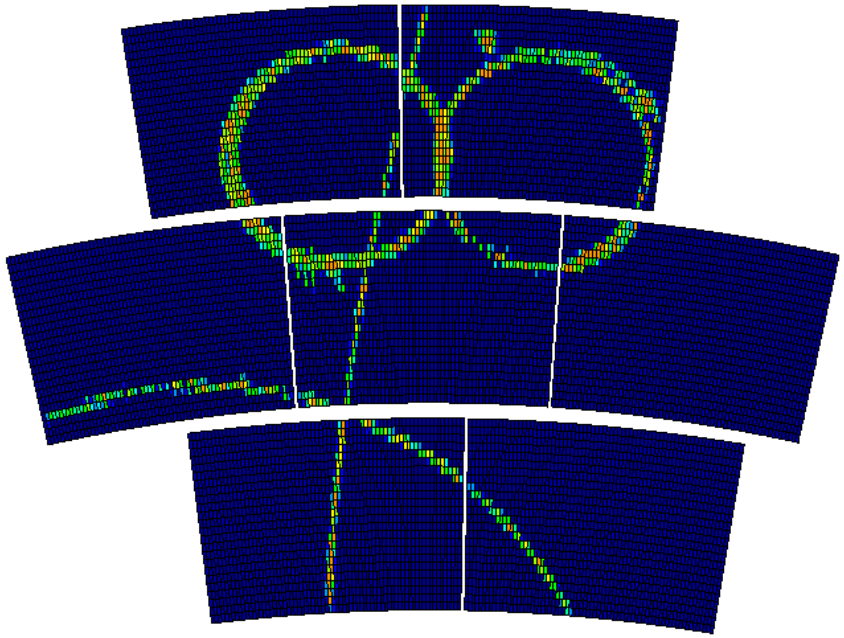
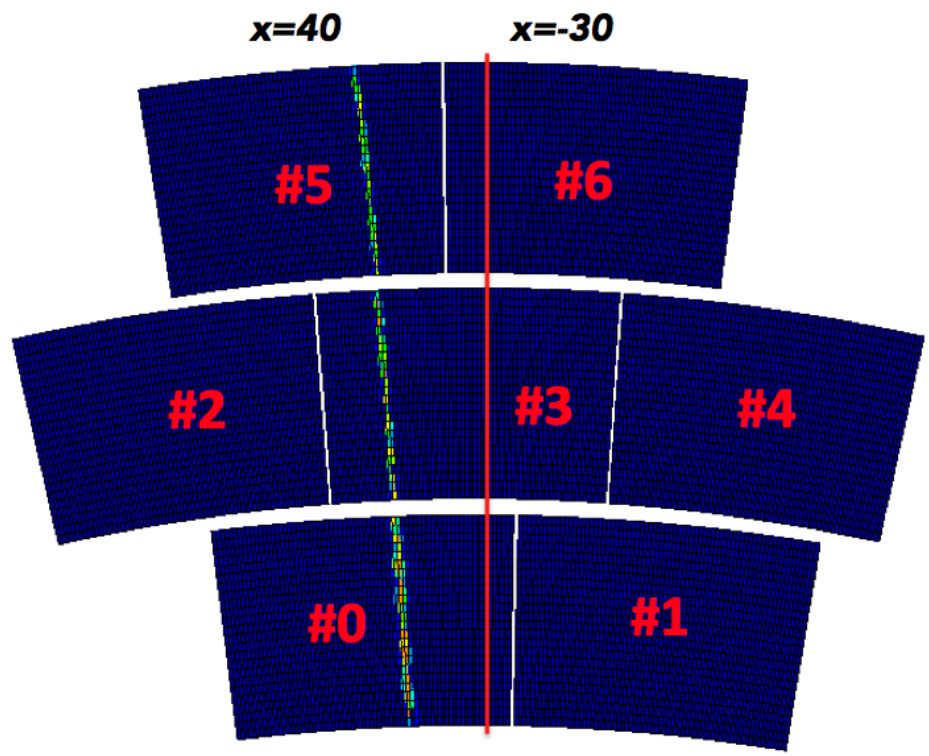


TPC Analysis Meeting
July 6, 2018

Data Taking 2015

- **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

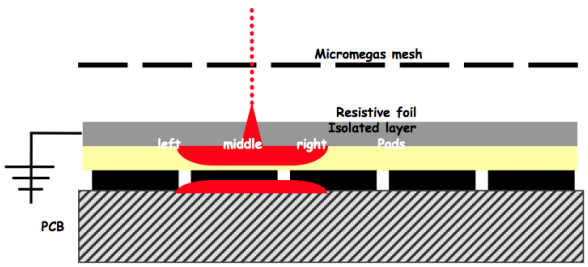
Analysis Dataflow

- **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:

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

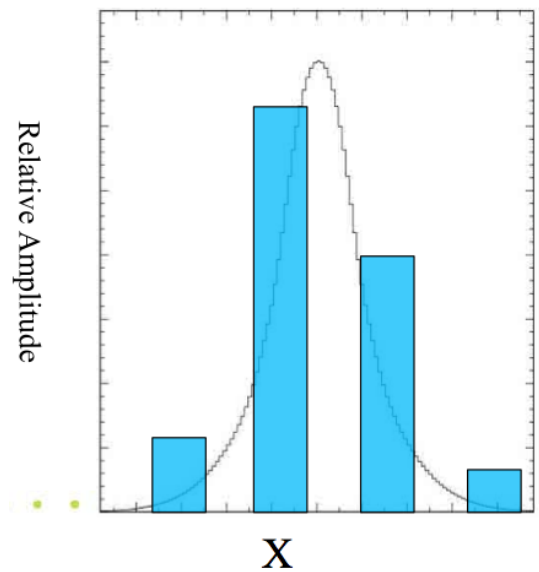
R- surface resistivity
C- capacitance/unit area

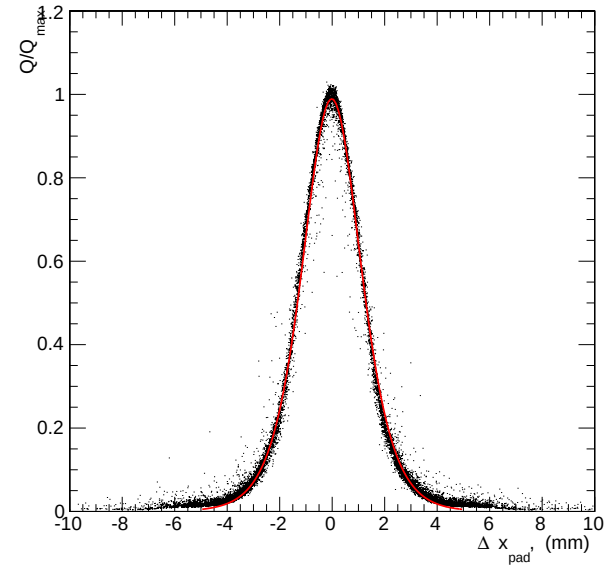
☞ **Hit Finding Procedure**

➠ group adjacent pulses

➠ fit PRF to the pulse amplitudes

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





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

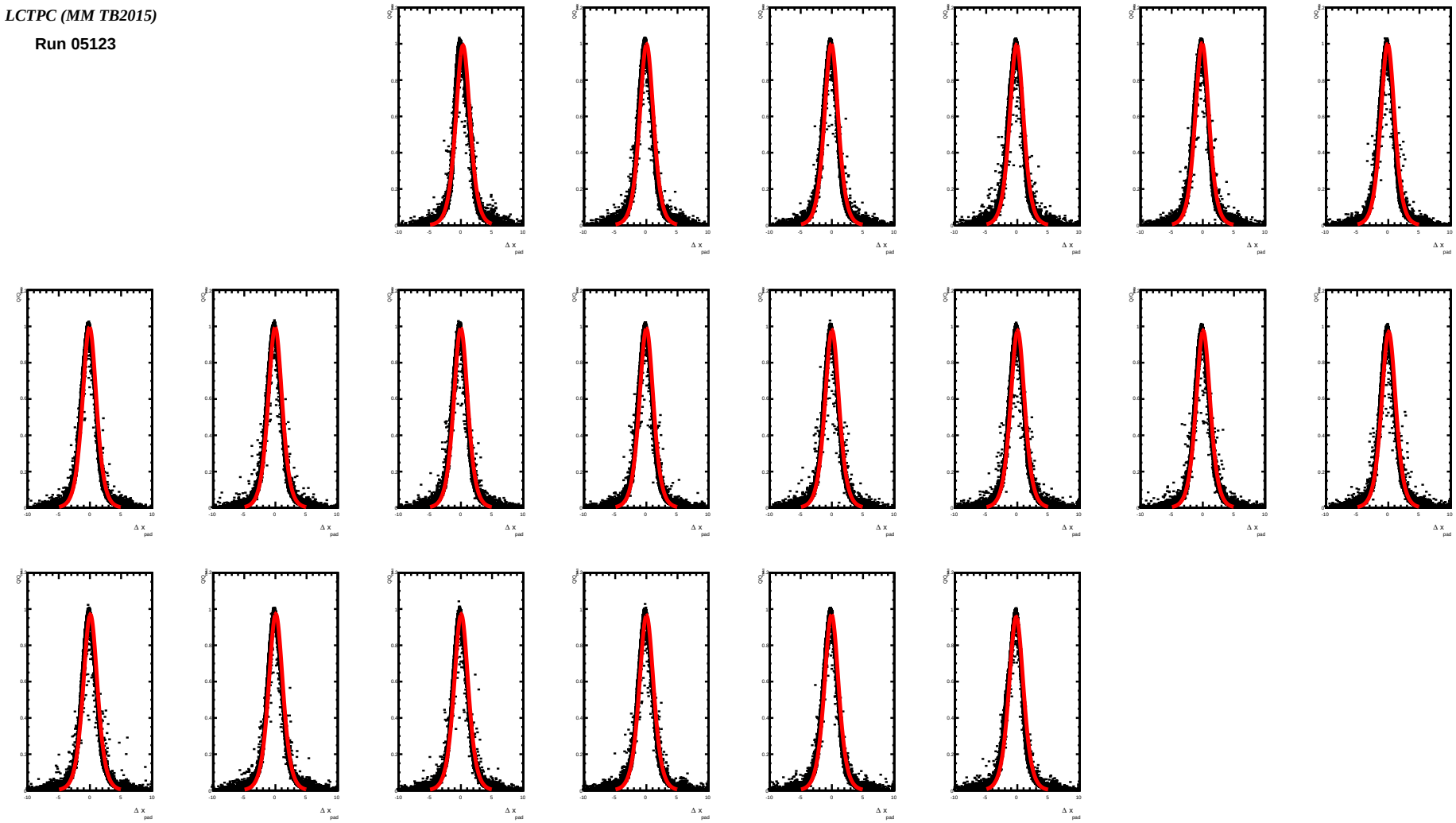
☞ Converged to a single parameter PRF where α

➠ determined per run

➠ depends on z and τ

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

Pad Response Funciton



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

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

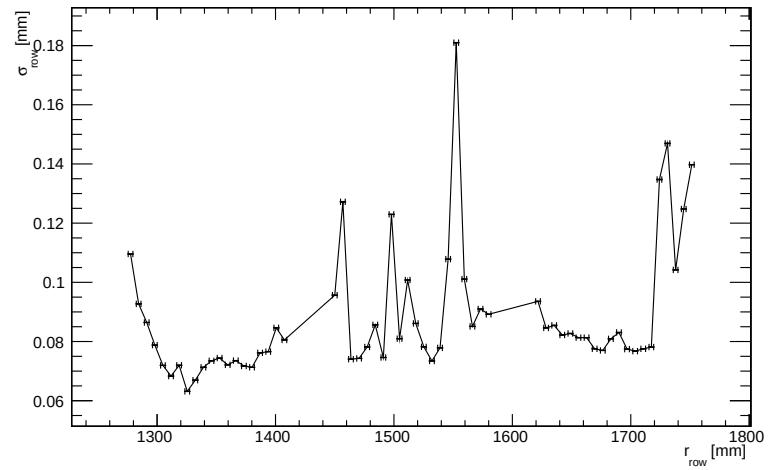
DQM, Bad Channels

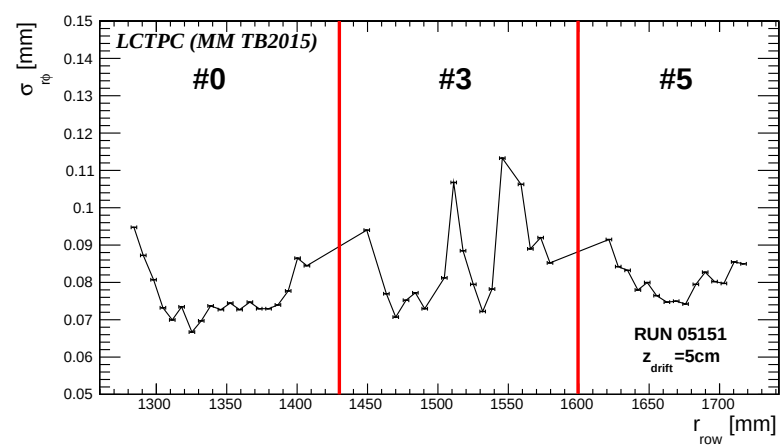
Some connector problems still take place while data taking

- **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 resolution





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

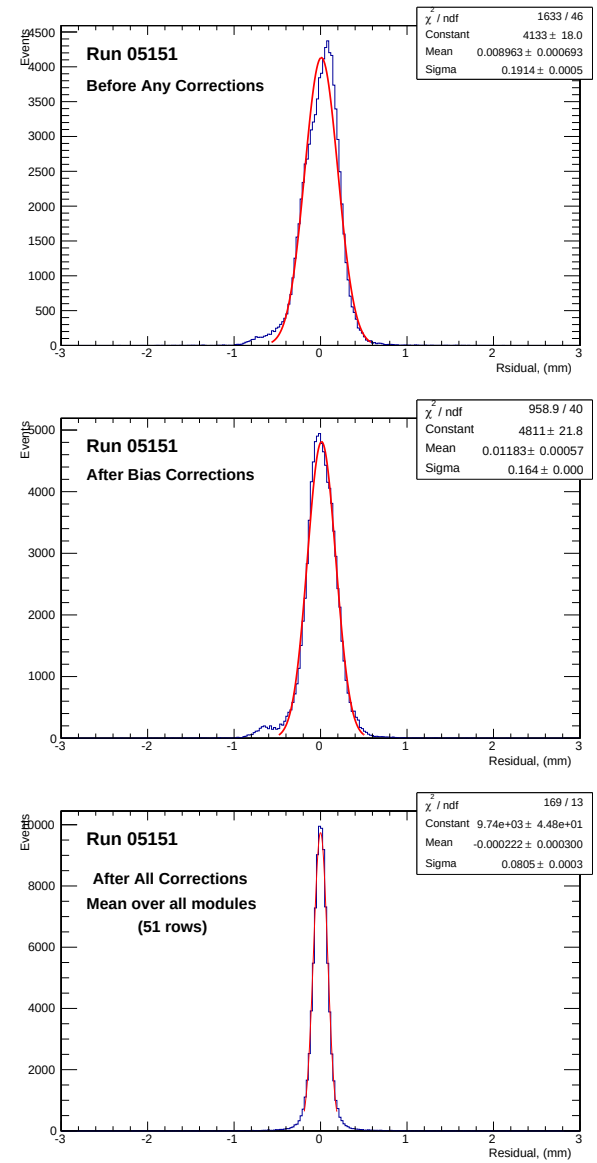
Residual Estimator and Corrections

- 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

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

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

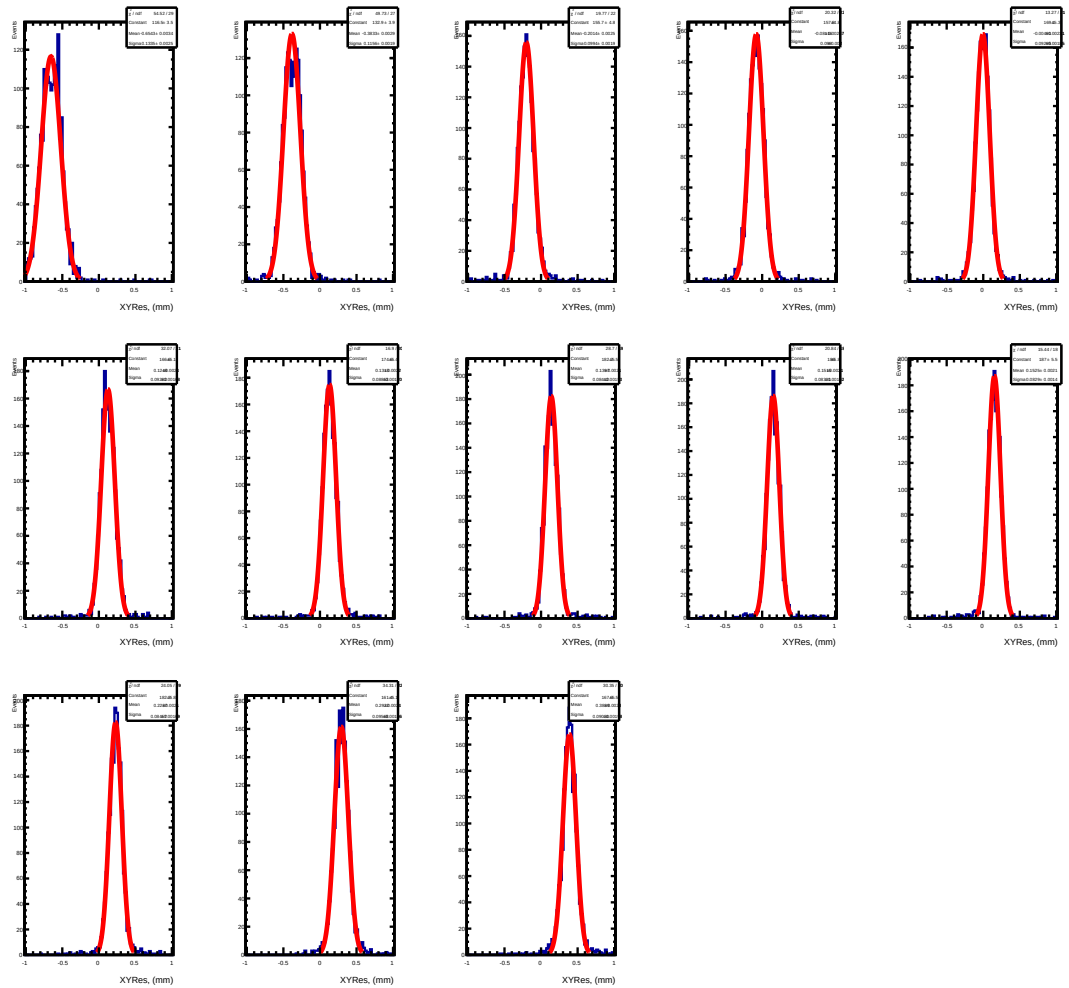
- **Important requirements for σ_{i}:**
  - gaussian-like (low fraction of outliers)
  - zero off-set (systematic error)
- **Corrections** have to be applied
  - **bias:** determined by local RC properties (width)
  - **distortions:** driven by ExB effects at (offset)
  - **alignment:** not for today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

Bias Corrections

Systematic effect on position determination in each row

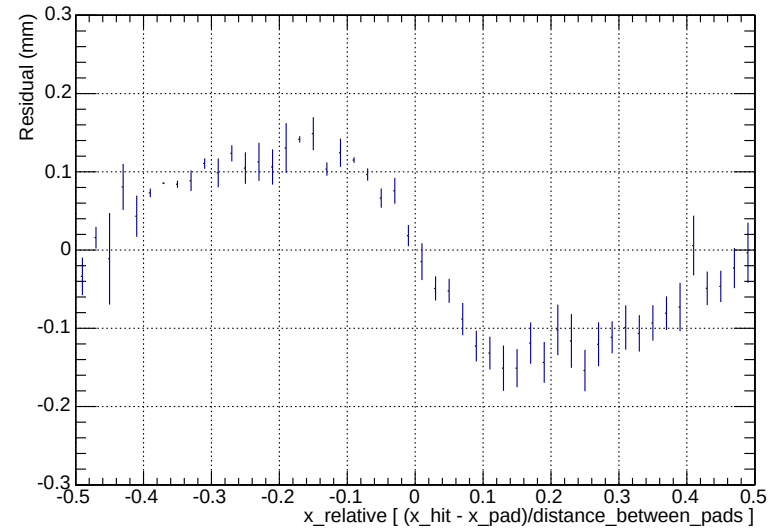
- ☞ PRF takes into account real charge distribution and addresses S-curve effect

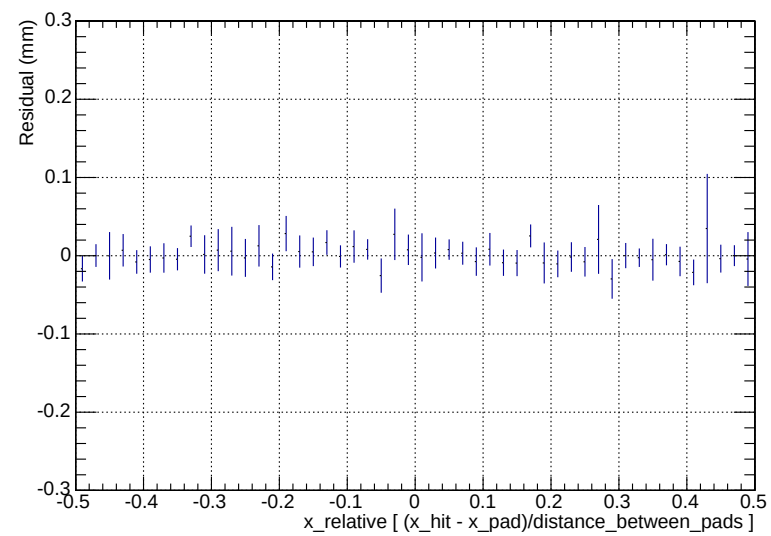
Remnant oscillation about 100 μm occurs periodically if PRF position estimator is used

- ☞ 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



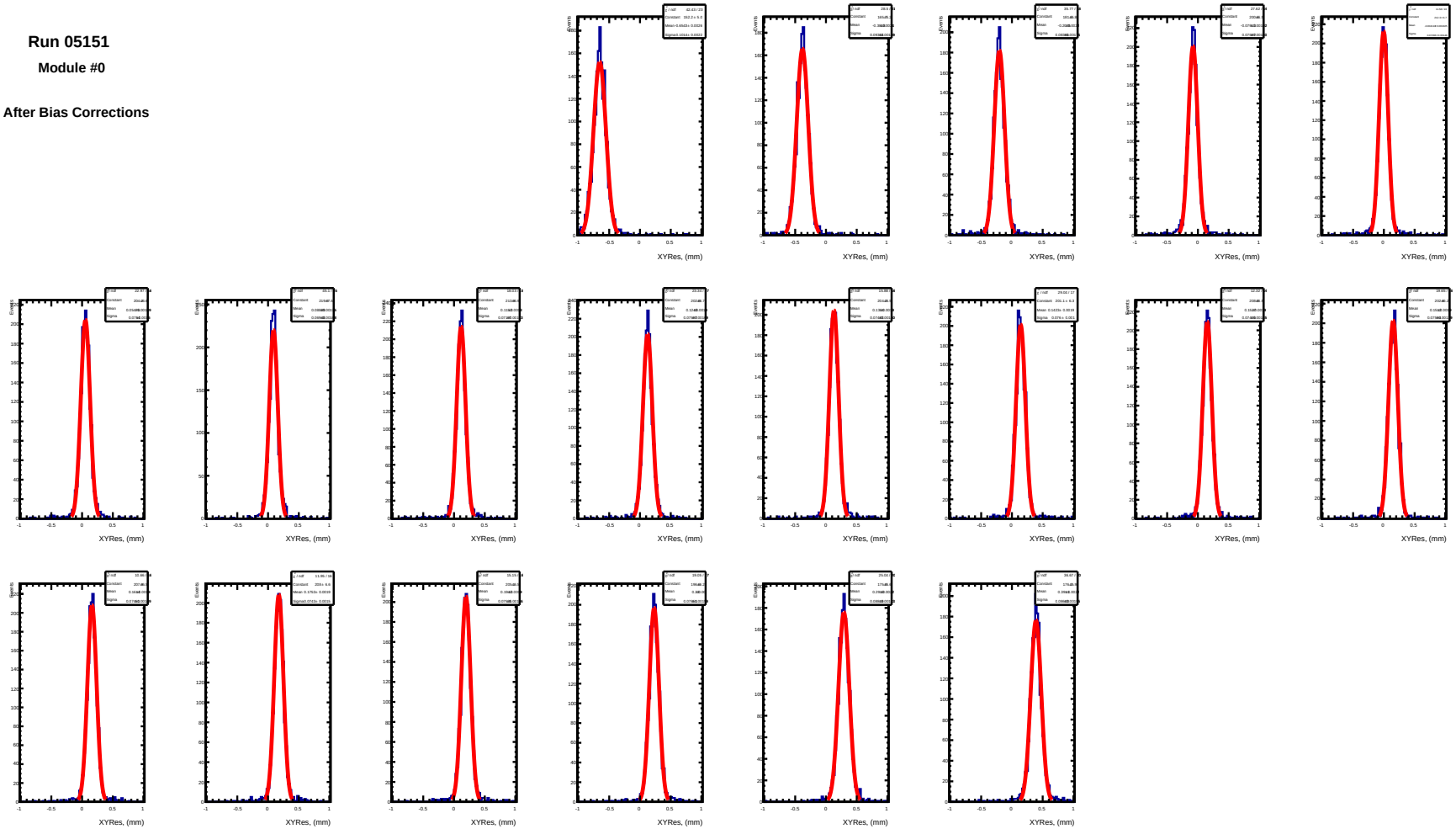


Residuals After Bias Corrections

Run 05151

Module #0

After Bias Corrections

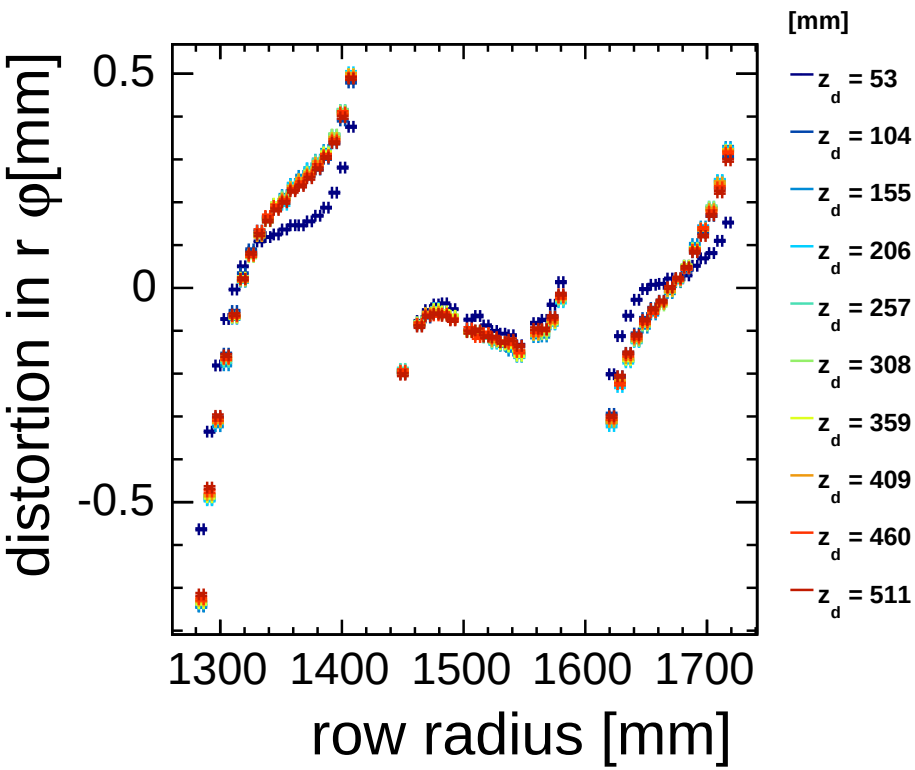


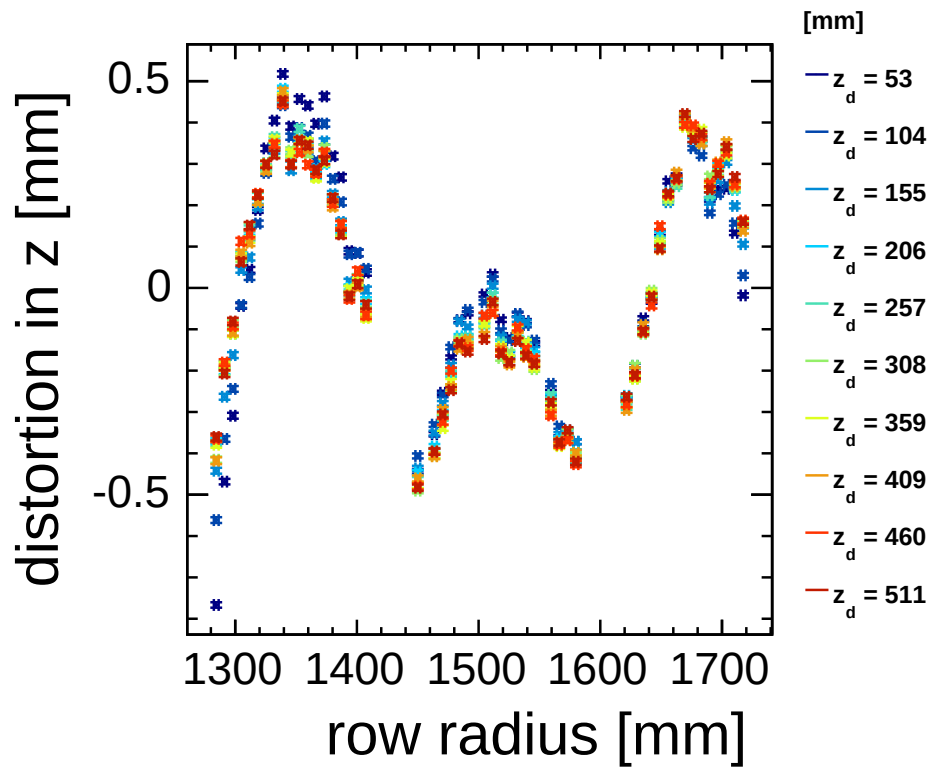
Bias corrections improve dispersion of residuals

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



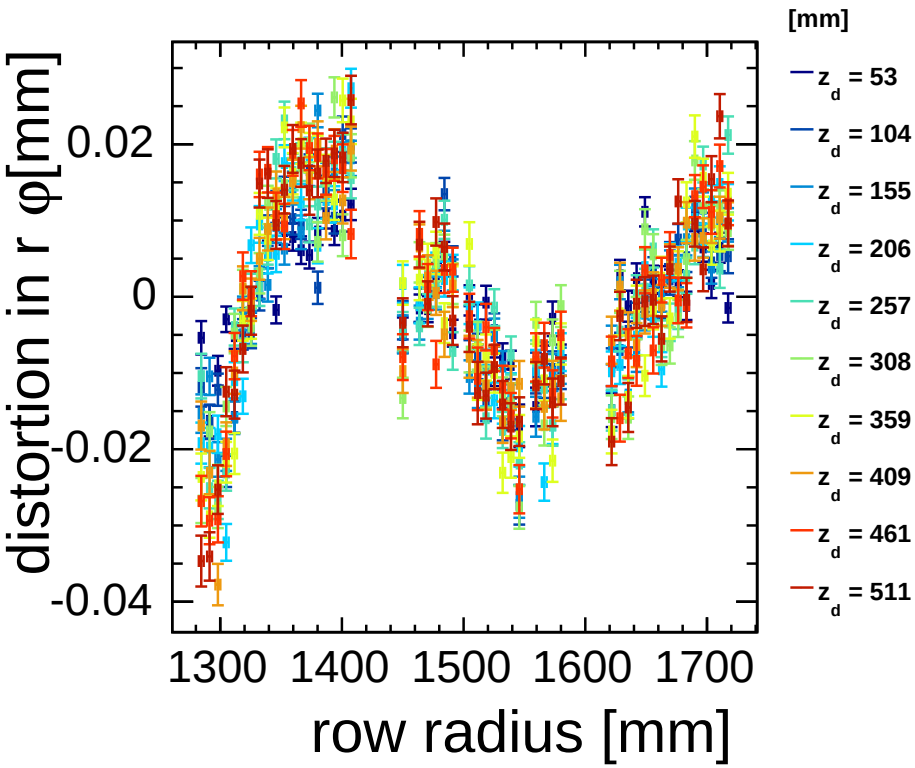


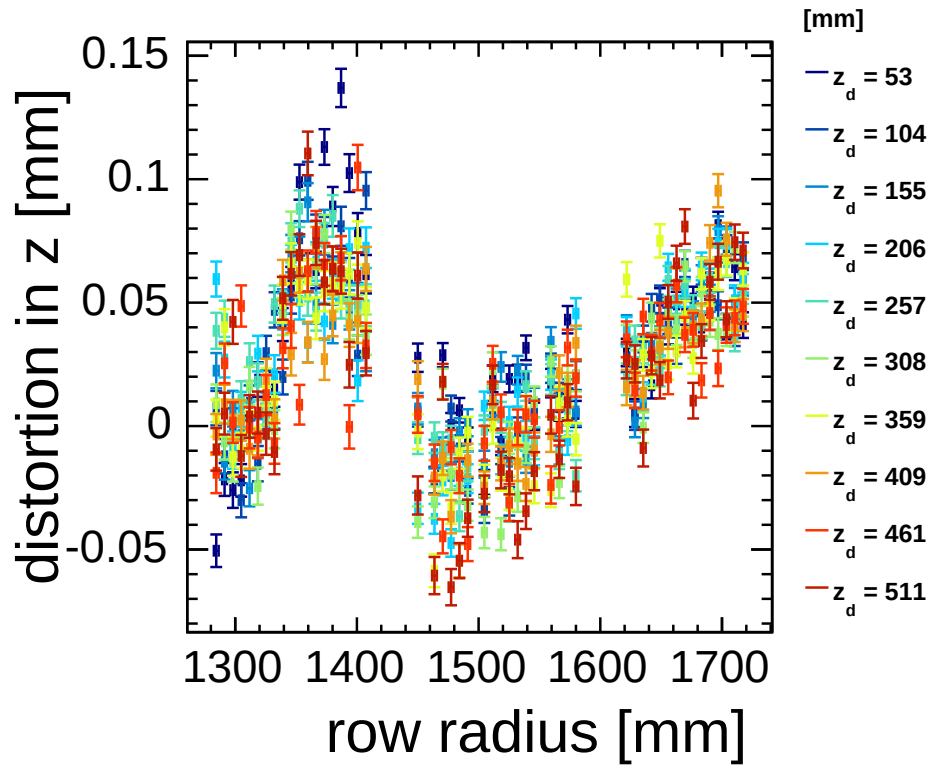
☞ Non-uniform E-field near module boundaries induces ExB effects

- ➠ 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 Corrections





☞ Distortion correction pin down resuduals to zero at

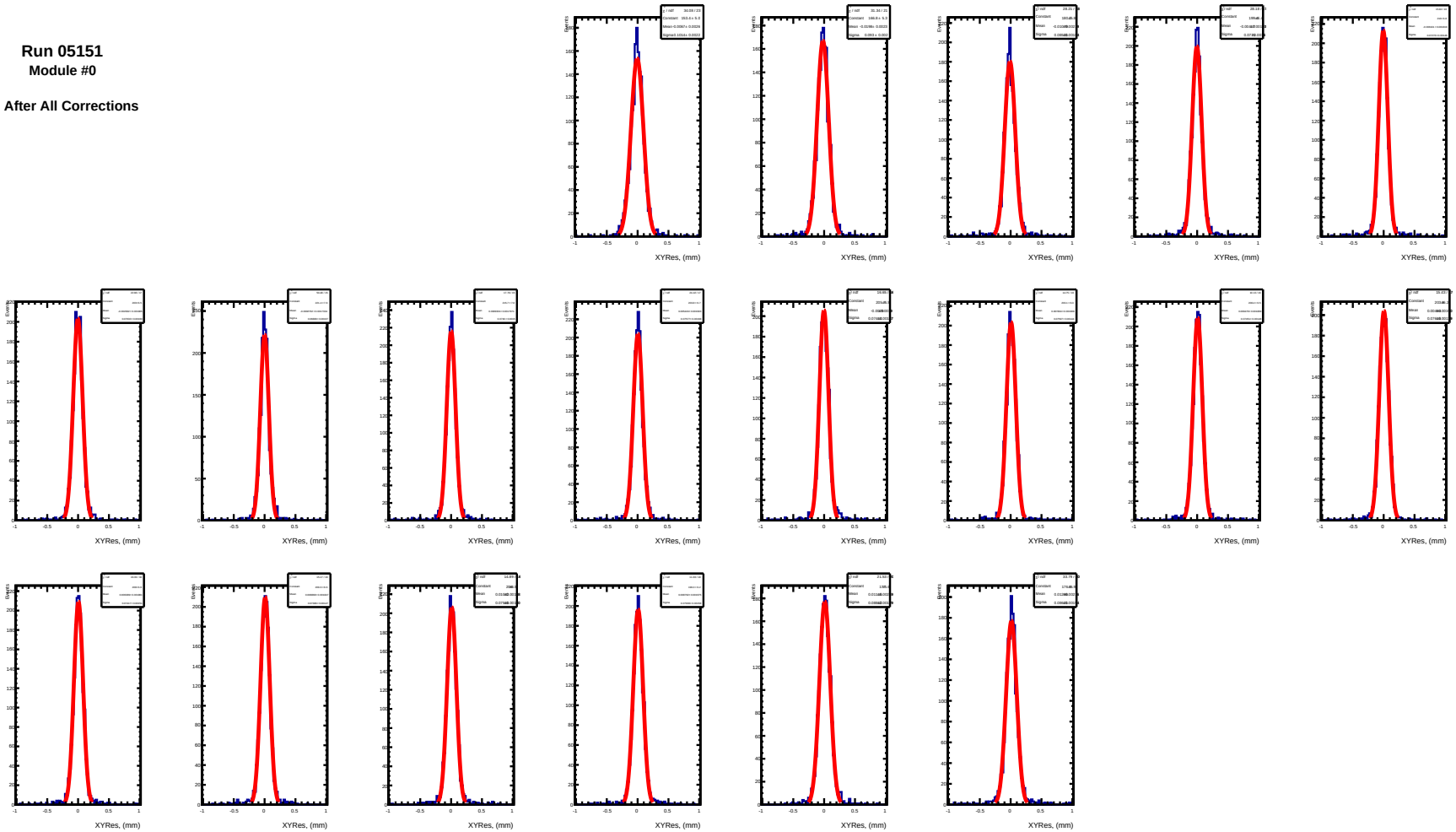
20 μm in $r\phi$ plane and *100 μm in z coordinate* precision

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

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.

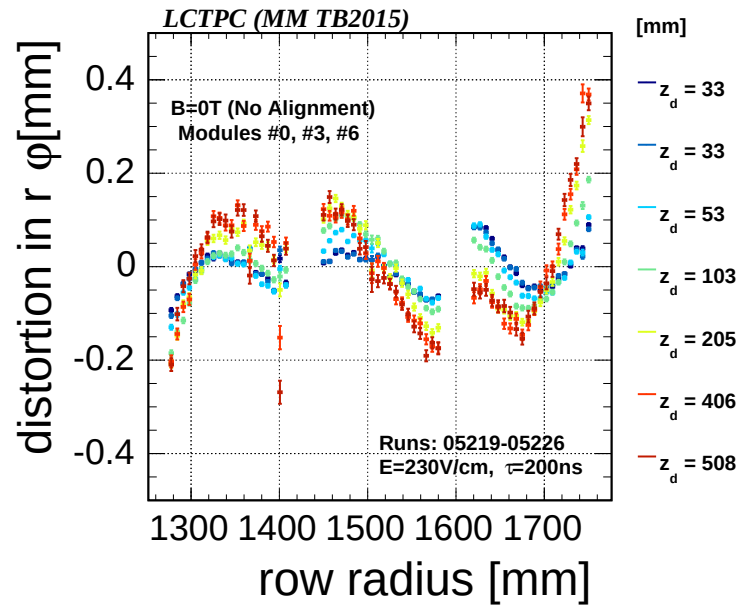
Module Alignment

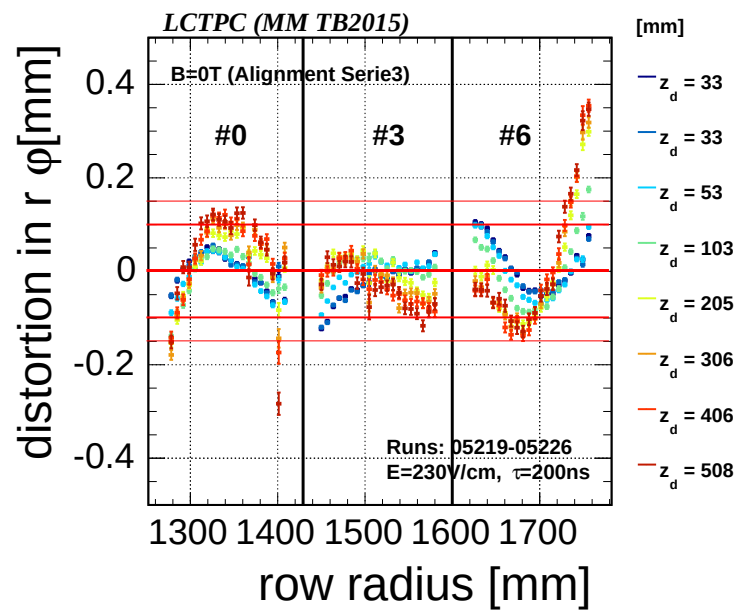
Residual offsets are due to distortions (ExB) and misalignment (multi-module setup)

☞ **Alignment is accounted as overall rotations (θ) and shifts (x and y)**

- uses all data at B=0T to exclude ExB effects
- corrections are obtained in an iterative procedure unless they are within errors (**3 serie**)
- determined in module-by-module basis
- uses multi-dimensional χ^2 minimization with **Millipede II** interfaced to **GBL tracks**

Available TB data allowed us to study the whole set of systematic effects relevant to the multi-module setup





Conclusions

- **Major systematic effects relevant to multi-mudule setup were measured and corrected using TB2015 data**
  - generic strategy for the analysis data flow is straightforward
  - result is based on **multi-module** triplet track finder and helix track fit
  - general correction sequence has been developed 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)
    - → **alignment corrections** fine tune remnant offset due to imperfect alignment
- **After all the corrections, maximum distortions are**
  - **20 μm in $r\phi$ plane**
  - **100 μm in z coordinate**

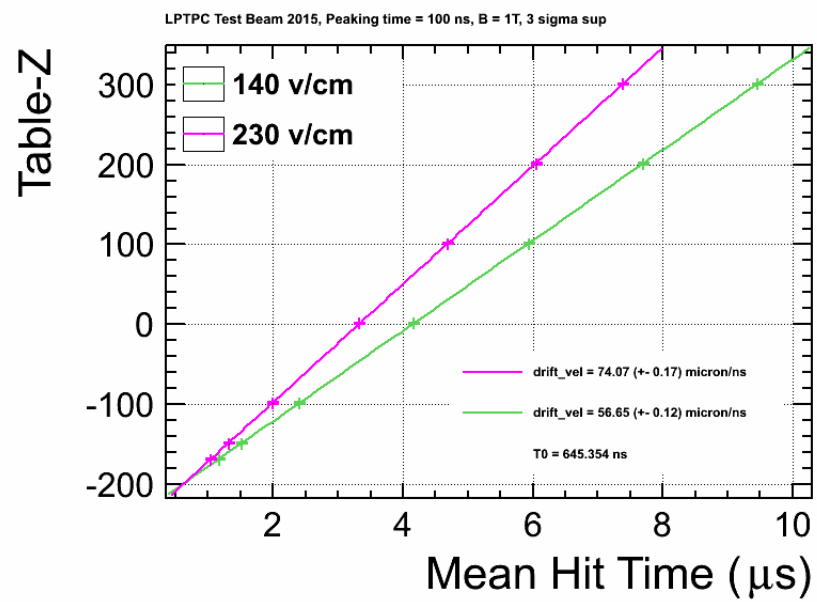
Backup

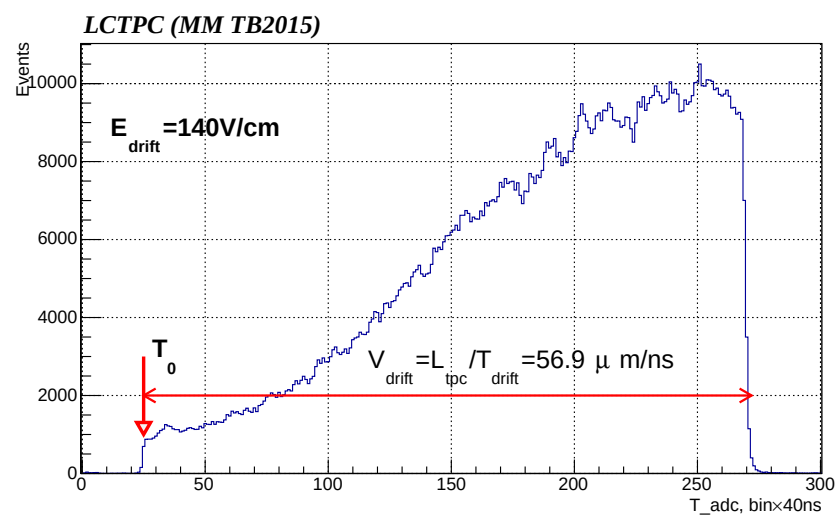
Gas Property and T_0 Calibration

- 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
    ➔ $T_0 = 22 \times 40\text{ns} = 880\text{ns}$

	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`	$74.5 \pm 2.5\mu m/\sqrt{cm}$	$94.8 \pm 3.1\mu m/\sqrt{cm}$

About 250 ns differnce for T_0 between 2 trigger configurations

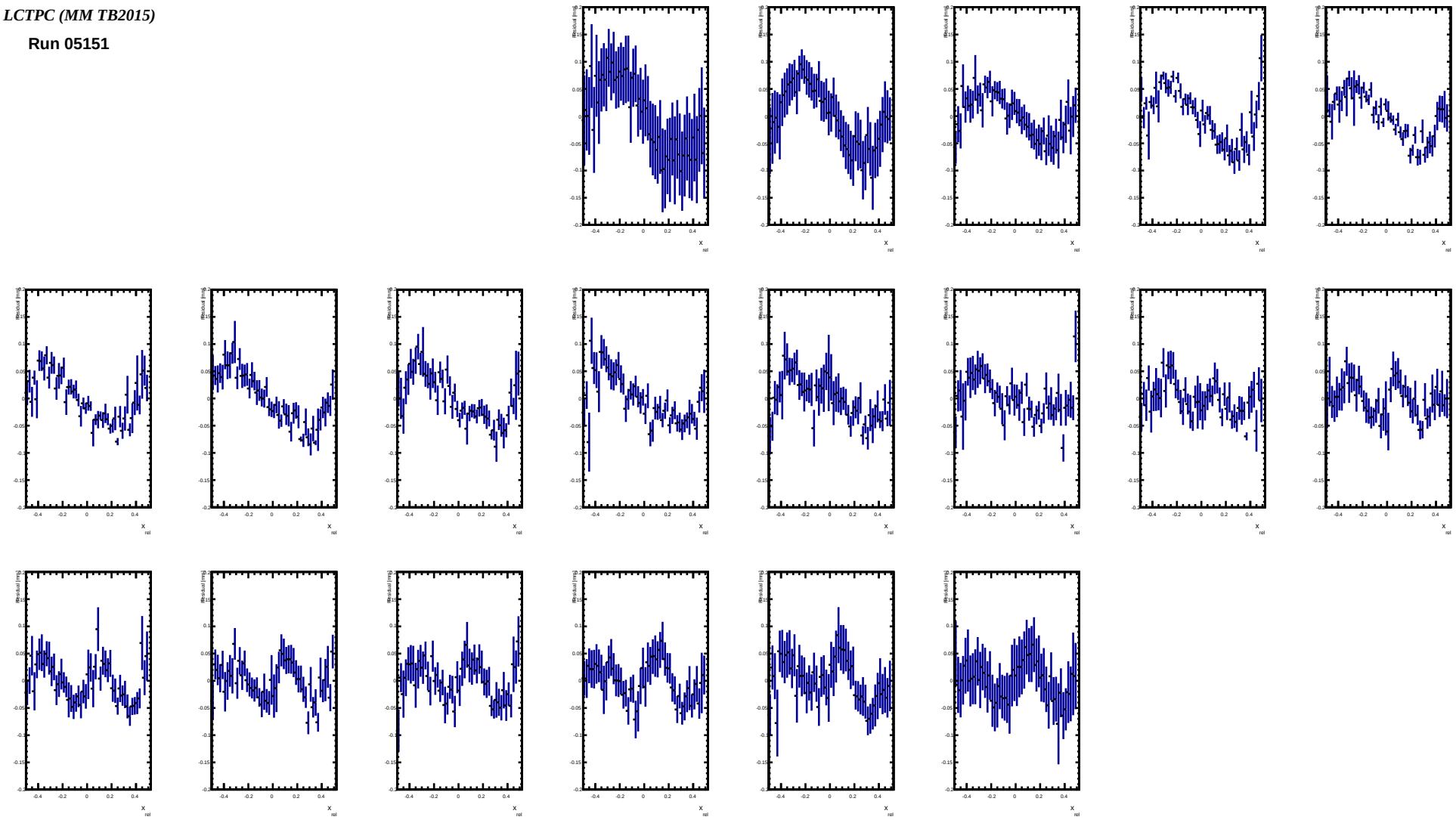




Bias Before

LCTPC (MM TB2015)

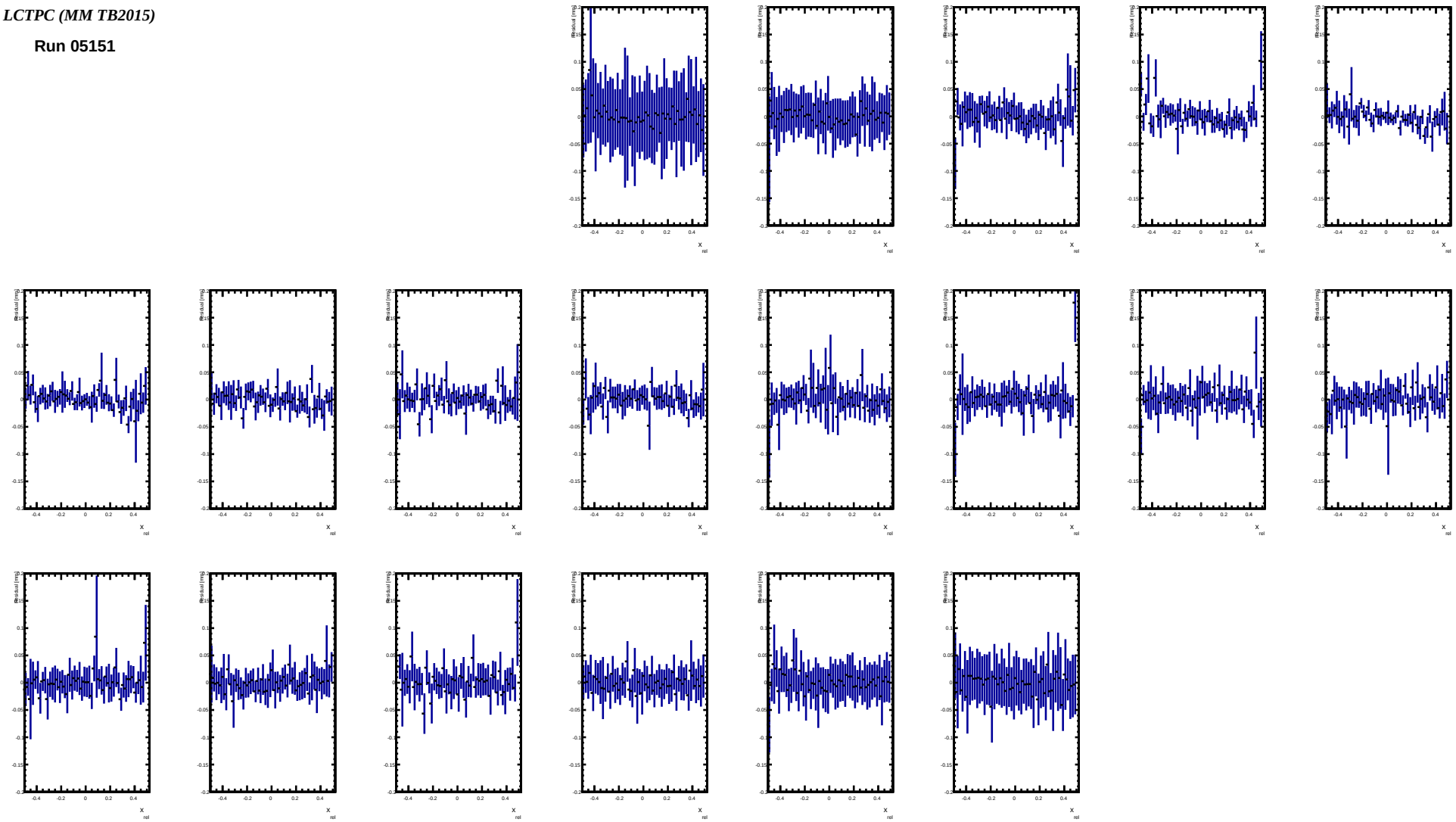
Run 05151



Bias After

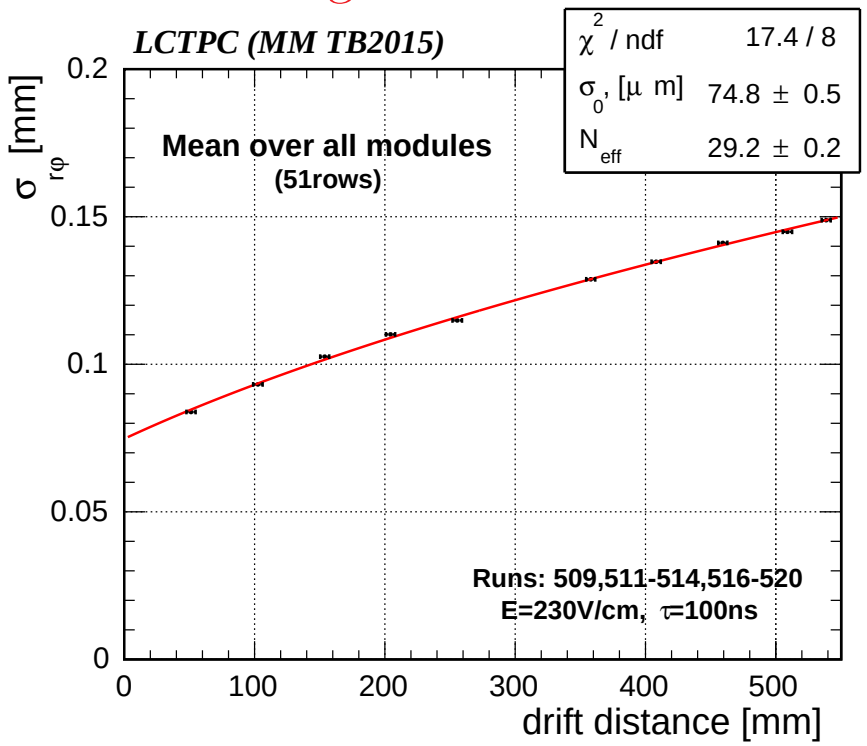
LCTPC (MM TB2015)

Run 05151

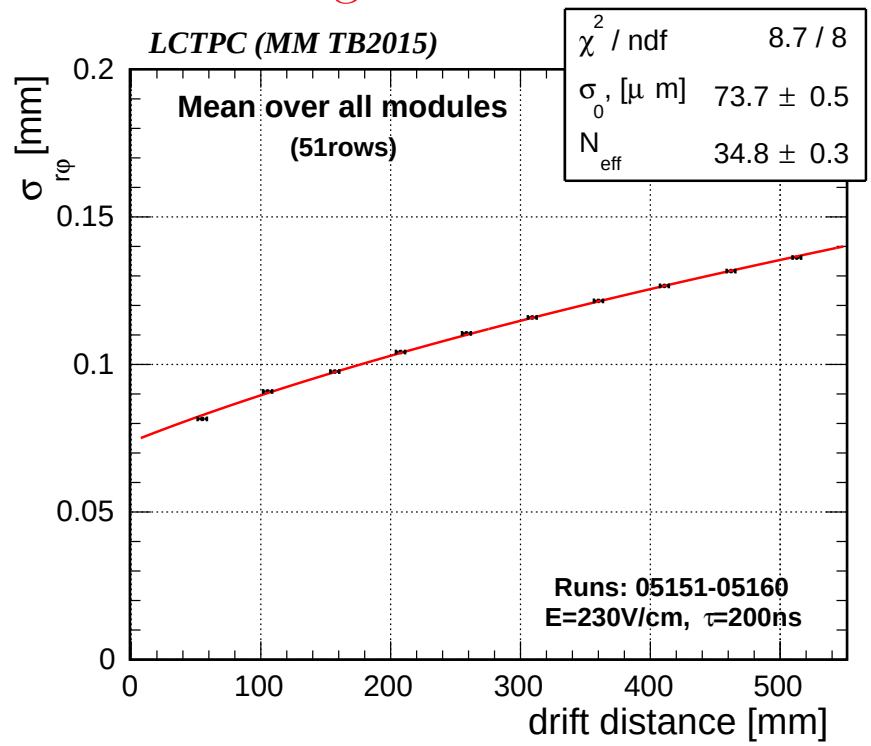


$r\phi$ Resolution: 230 V/cm

Peaking time 100 ns



Peaking time 200 ns

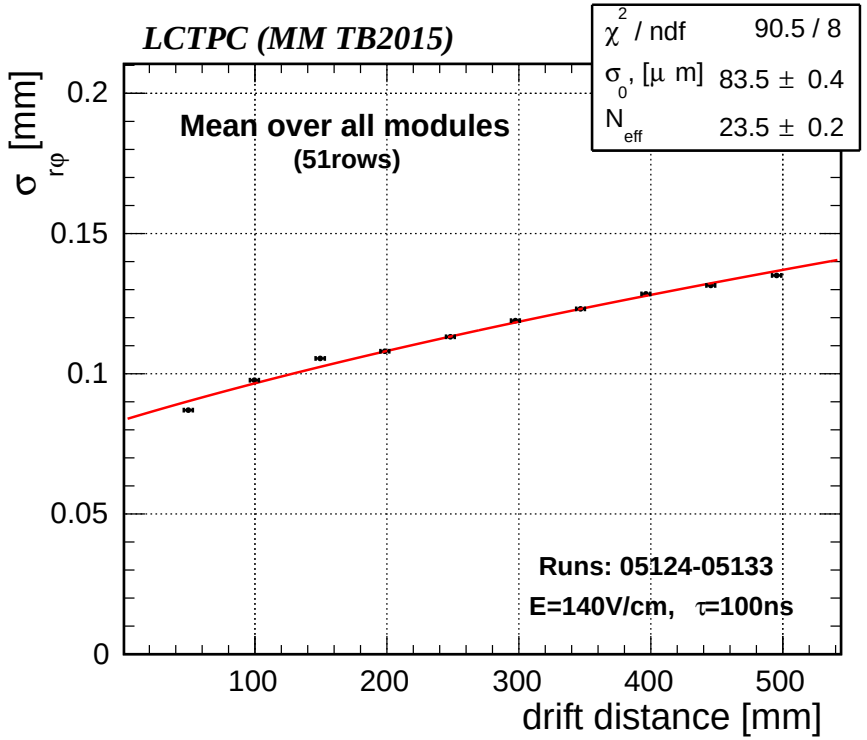


☞ **Fit data with:** $\boldsymbol{\sigma(z) = \sqrt{\sigma_0^2 + \frac{D_\perp^2}{N_{eff}} z},\ \sigma_0^2 = b^2/N_{eff}}$

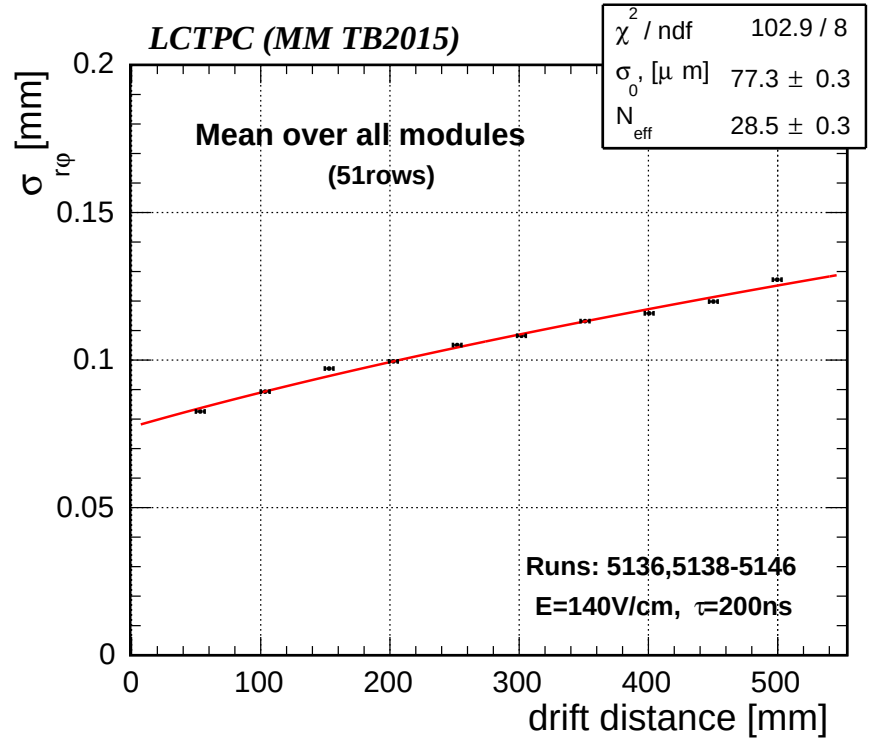
- σ_0 - the resolution at z=0, N_{eff} - the effective number of electrons
- `Magboltz` calculations of $\mathrm{D}_\perp$ at about 3% precision

$r\phi$ Resolution: 140 V/cm

Peaking time 100 ns



Peaking time 200 ns



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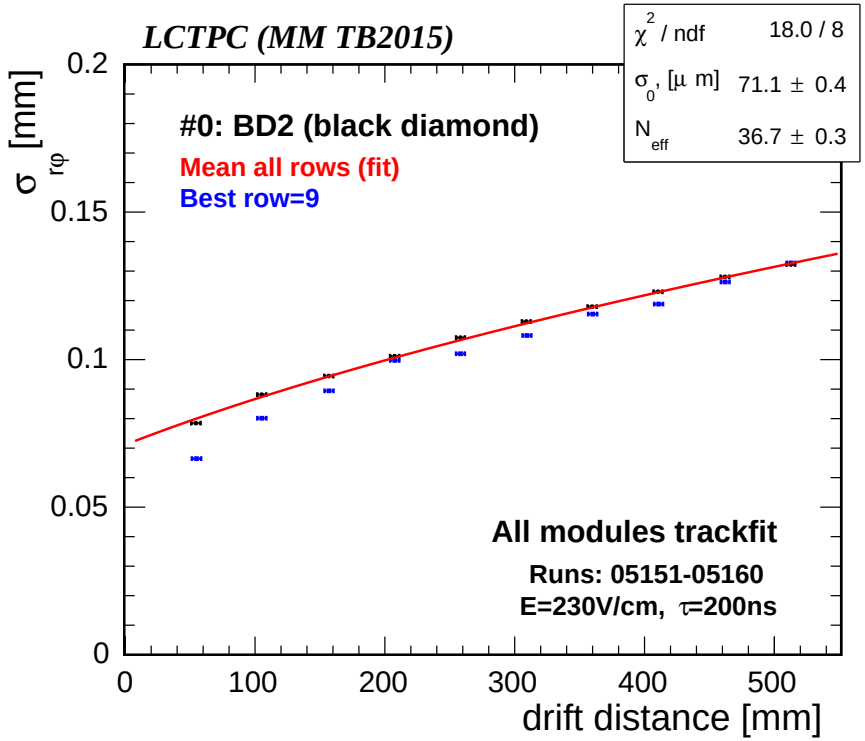
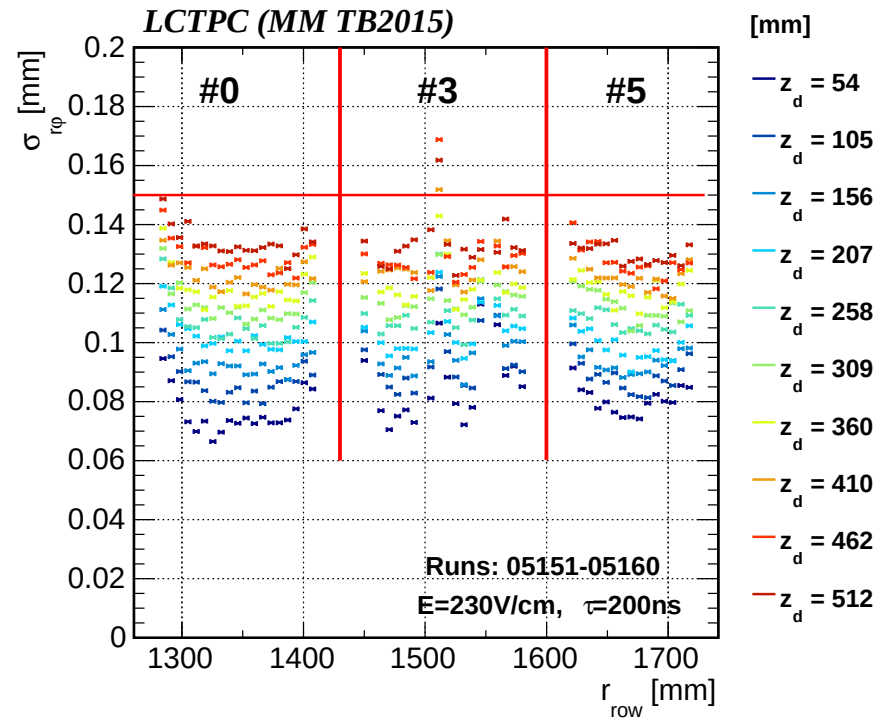
Module Dependence





☞ 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