# Micromegas TPC Analysis Status

**R. Yonamine**

*Université Libre de Bruxelles (ULB), Brussels, Belgium*

**A. Bellerive, M. Dixit, P. Hayman,**
**R. Mehdiyev, S. Weber**

*Carleton University, Ottawa, Canada*

**D. Attié, D. Bhattacharya,**
**P. Colas, S. Ganjour**

*CEA-Saclay/IRFU, Gif-sur-Yvette, France*

*LCTPC Collaboration Meeting*
*DESY*
*June 30 – July 1, 2014*

## The EUDET/AIDA test beam facility at DESY provide a 6 GeV electron beam

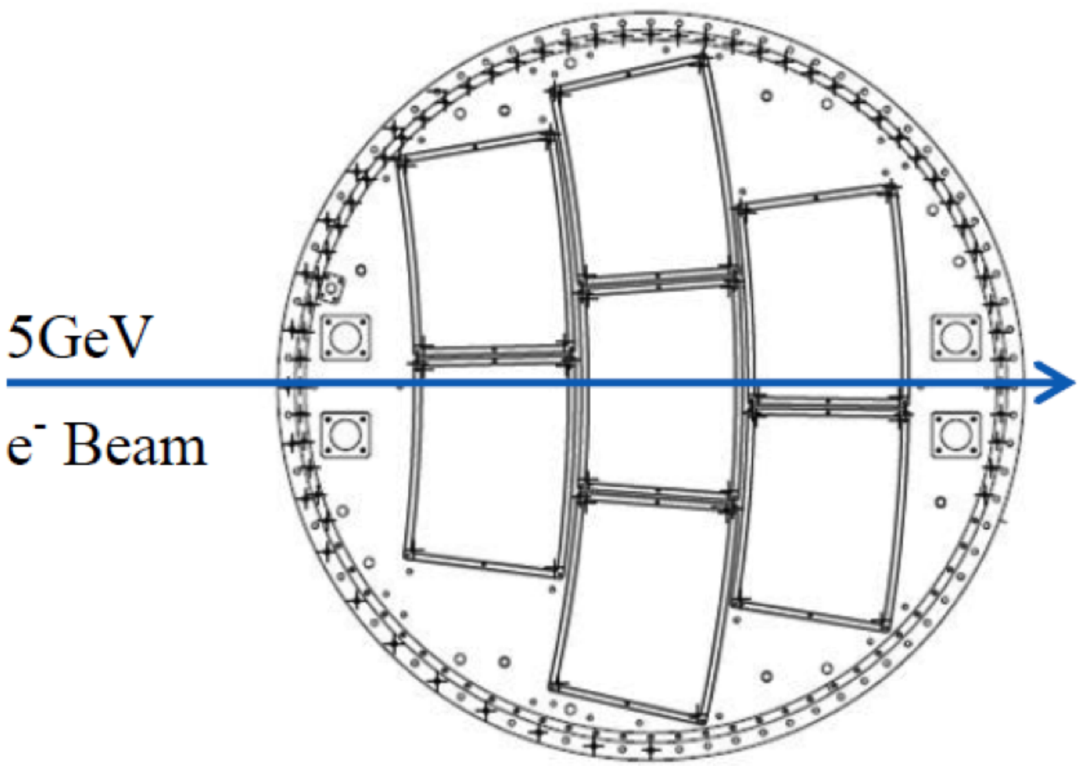
- Consists of a field cage equipped with an endplate with 7 windows to receive up to 7 fully equipped identical modules

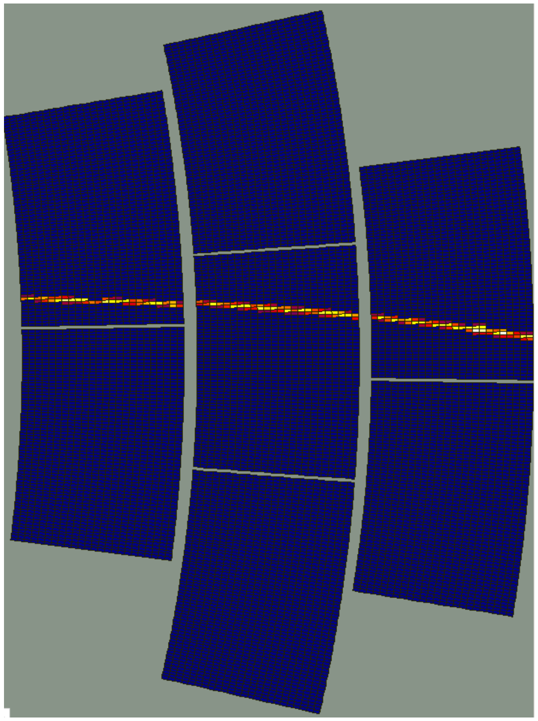
**Last beam test of 7 MicroMegas (MM) TPC modules at DESY (Feb. 17– Mar. 2, 2014)**

- **Principal goals** of 2014 test beam
  - test of the $CO_2$ cooling system
  - combined test of 5 MM with 2 Timepix modules

## Prehistory of beam tests with MM modules:

- **Mar 2010:** 1 module, simple cuts to enrich the "one track" event content; analysis with **FTPC 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**

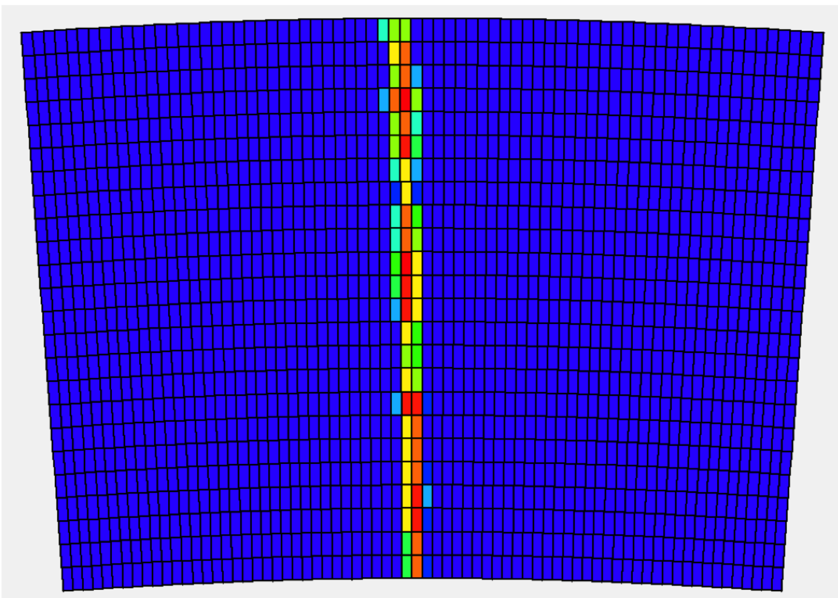


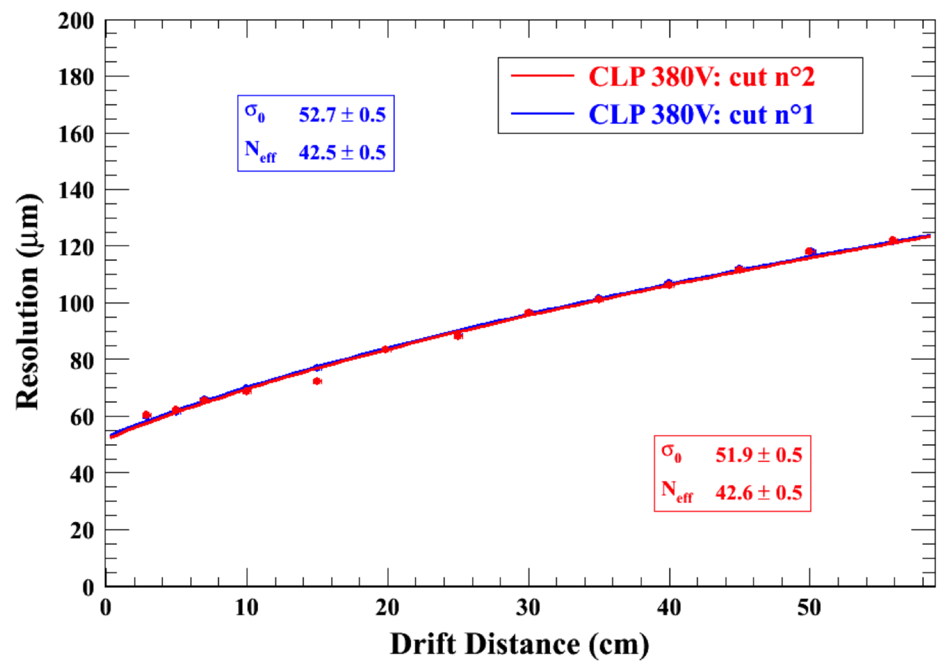



*Most studies was done with a multi-module setup of the LP Micromegas TPC detector using beam test data at DESY facility*

*Most data were taken with B=0, 1 T and E=140, 230 V/cm at* $\Delta z = 5\,\mathrm{cm}$

*One-Module setup analyzed with FTPC framework and deployed simple selections to enrich "single track" event content*






- **Relaxed selections** do not bias the resolution
  - reject multiple-track events
  - require less than 5 hits with more than 40 ADC counts outside 10 central pad lines

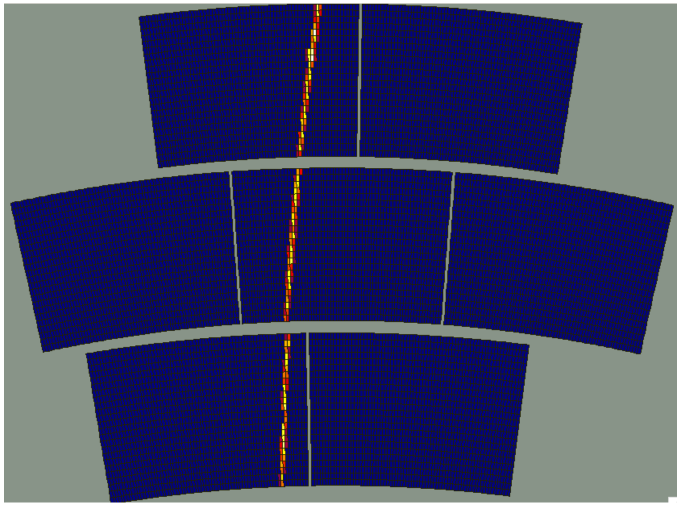
*Consistent results are obtained for z>30 and z<30 fitted ranges*

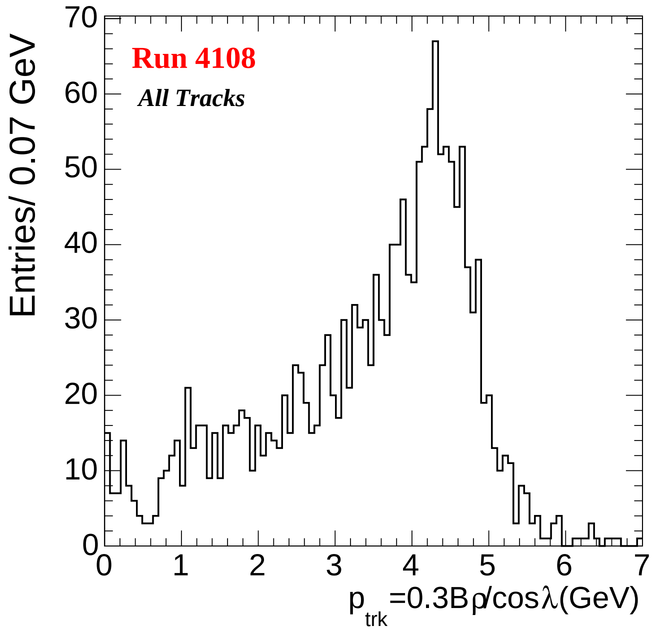
*Meet stable results with relaxed cuts which satisfy ILD TPC requirements*

**Coherent analysis of 2013/14 data is performed in MarlinTPC framework**

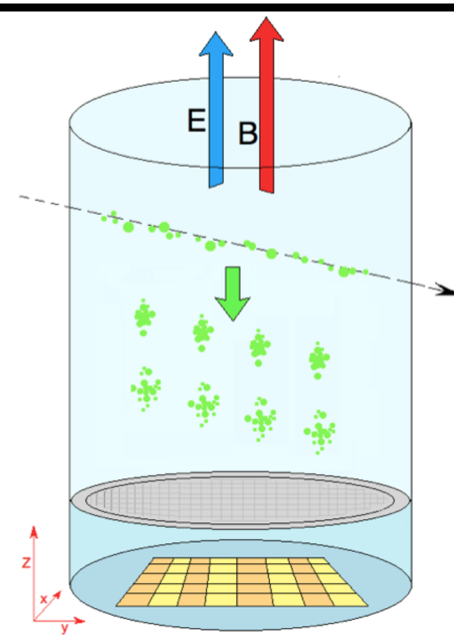
- Dataflow has two major steps: DAQ and Analysis
  - DAQ software store data in **raw format** (calib. view, event dispay, slow control)
  - High level analysis with **MarlinTPC**
    - ➔ subtract pedestals
    - ➔ build hits from pulses
    - ➔ reconstruct tracks (KalmanFit)
    - ➔ analysis (resolution, distortion, etc)

*Determine resolution from residuals of the whole 3D track fit, e.g. Kalman algorithm (Disclamer: triplet finder is being used often since it is a faster algorithm and gives comparable results)*





- The TPC acts as a 3D camera taking a snapshot of the passing particle
- **Z resolution** is its major characteristic
  - measure time between ionization and detection multiply by drift velocity
  - ILD TPC requirements: $\sigma_z \sim 400\mu m$
- Each pad readout provide charge (ADC) as a function of time with 40 ns intervals
- It is possible to determine **arrival time** $(\mathbf{T_{max}})$ and **amplitude (A)** for each pad
  - best estimation if **pulse shape** is known
  - build one hit per row by grouping pulses
  - fit a Pad Response Function (PRF) to the pulse amplitude **A** to find **XY position** of the hit




*Several time estimators were tested and compared*

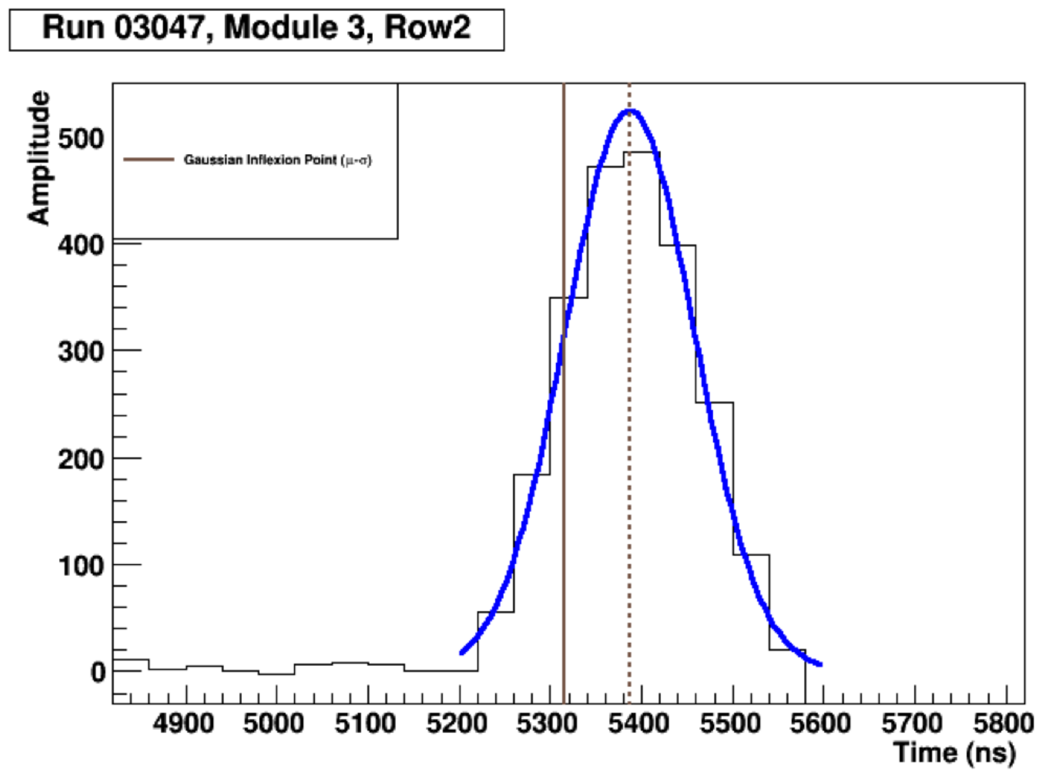
- We put forward 2 new methods based on **pulse shape**
  - gaussian inflexion point
  - pulse shape fit

*Met a significant improvement toward ILD TPC requirement*

- Readout electronics shapes the pulse in a Gaussian-like form
  - fit with 3 floated parameters: **amplitude (A)**, **mean ($T_{max}$)**, **sigma ($\sigma$)**
  - fit is done in the **range +5 and -5 samples** around the maximum bin
- Determine gaussian **inflexion point** as

$$T_{max} - \sigma$$

*Also test Gaussian mean as alternative approach for arrival time determination*




*An example of the gaussian fit: 2013 data, Module=3, Row=2, B=1T*

# *Pulse Shape*

- Pulse shape is determined from electronics shaping (also for GEM)

$$f(t) = A \cdot e^{\alpha} \cdot \left(\frac{t-T_0}{T_{rise}}\right)^{\alpha} e^{-\alpha\frac{t-T_0}{T_{rise}}} \theta(t-T_0)$$

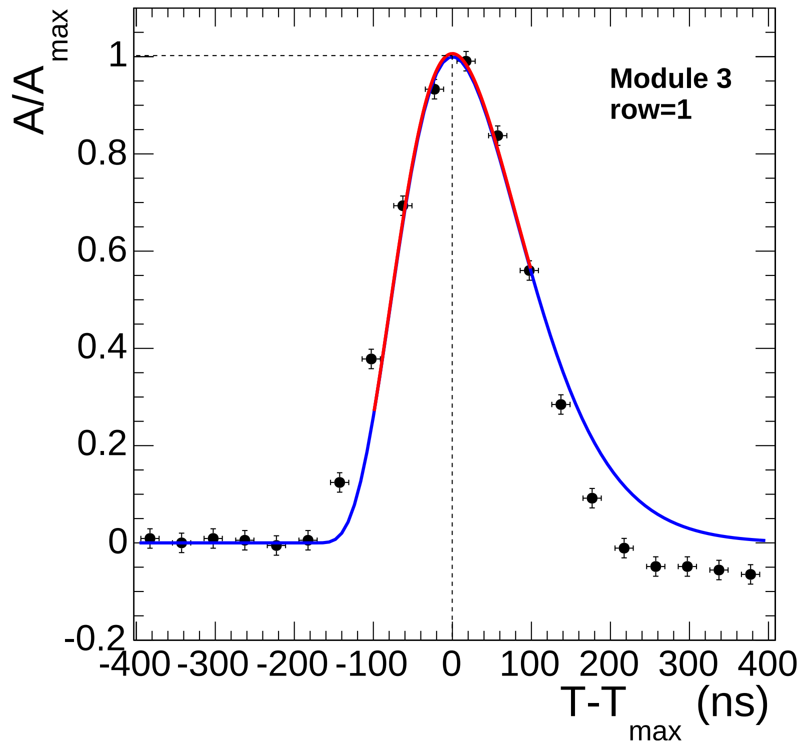
$A$ - amplitude $T_0$ - offset, $T_{rise}$ - risetime, $\alpha$ - pulse width,

- There is strong correlation between $T_0$ and $T_{rise}$ (limited fit range)
- Modify function in such a way that both $A$ and $T_{max}$ are direct fit parameters

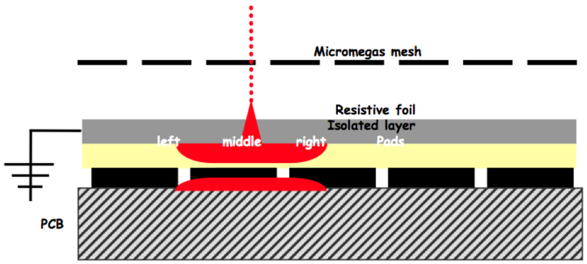
$$f(t) = A \cdot \left[\frac{t-(T_{max}-T_{rise})}{T_{rise}}\right]^{\alpha} e^{-\alpha\frac{t-T_{max}}{T_{rise}}} \theta(t-T_{max}-T_{rise})$$

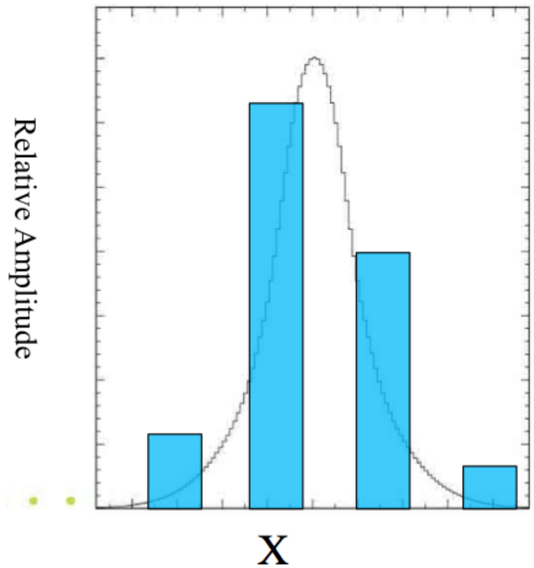
- Modify parametric form according to transfromation $T_{rise} = \alpha\beta$ so that $\beta \simeq 1$ at $\alpha = 5$ and define $\Delta t = t - T_{max}$

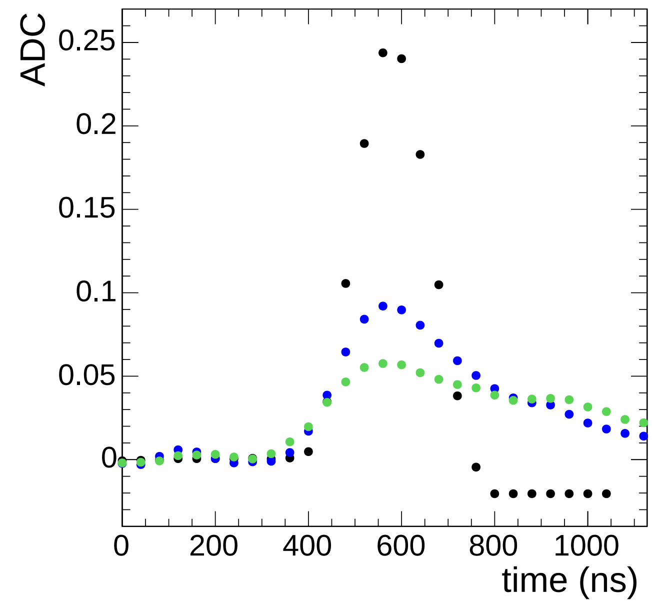
$$f(t) = A \cdot \left(1 + \frac{\Delta t}{\alpha\beta}\right)^{\alpha} e^{-\frac{\Delta t}{\beta}} \cdot \theta(\Delta t + \alpha\beta)$$




*Single pulse fit with 3 floated parameters ($\alpha = 5$): restricted the fit range to +3 and -2 time samples around the maximum bin*



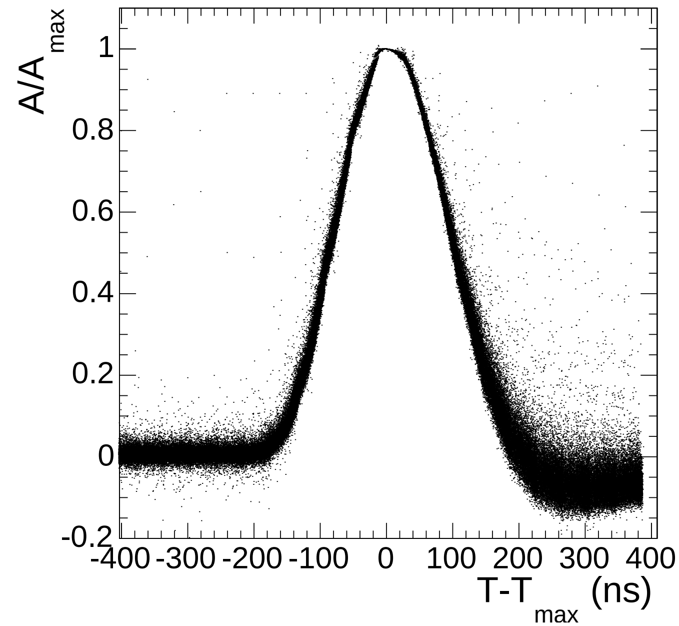

- **Pulse variations**
  - channel-by-channel (electronics, shaping)
  - leading and subleading pulses (charge, time)
- **Hit Finding Procedure**
  - group adjacent pulses
  - fit PRF to the pulse amplitudes

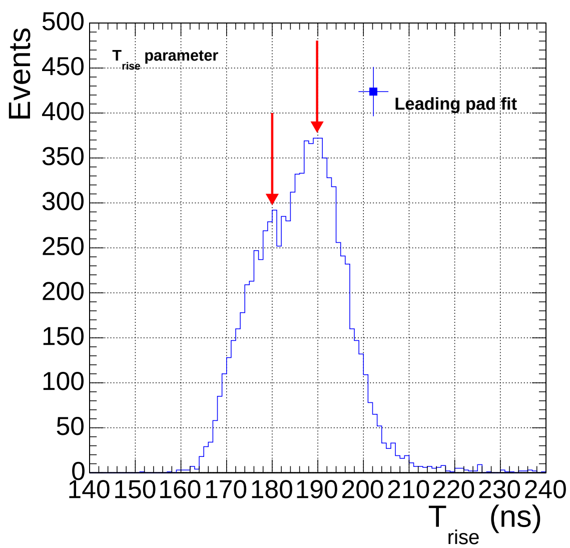
*Currently focuses on the leading pulse time reconstruciton only and use the maximum time bin for the amplitude estimate*

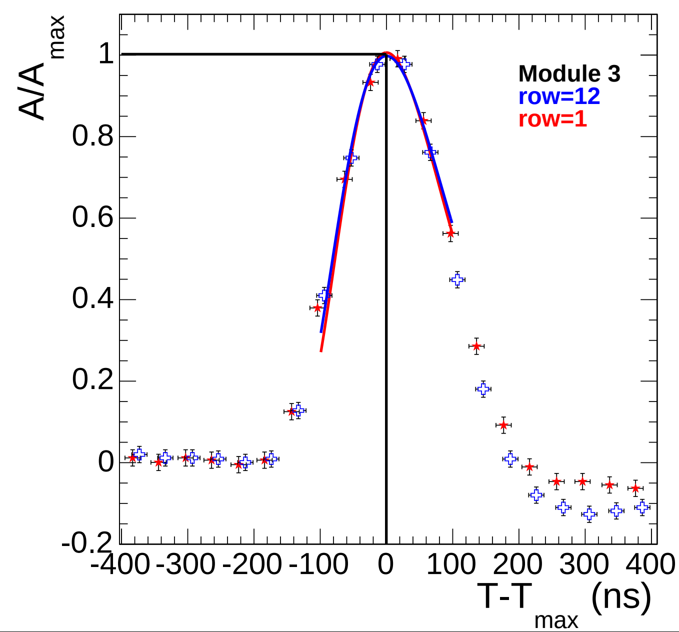
- Improved estimtion of amplitude **A** of the group of adjacend pulses can go beyond the current **precision for XY position**
  - deserves special study (foreseen to be implemented in the future)
    - ➔ subleading pulses have quite different shape

☞ Fit each individual (leading) pulse with f(t)

- normalize amplitude to $A_{max}$ pulse-by-pulse
- force pulse maximum at zero
- reasonable stability of the pulse shape
  - ➔ difference is minimal around the peak
  - ➔ sizable uncertainty around $T_0$
  - ➔ large variation in tails (can be negative)



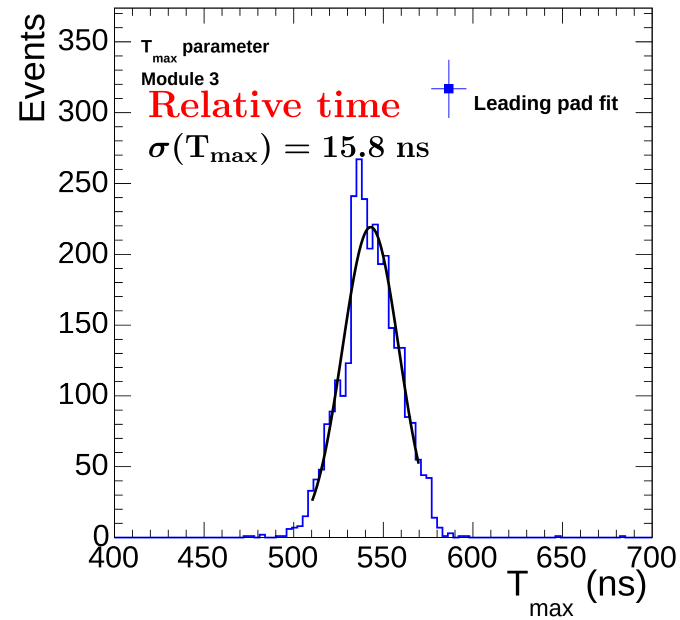



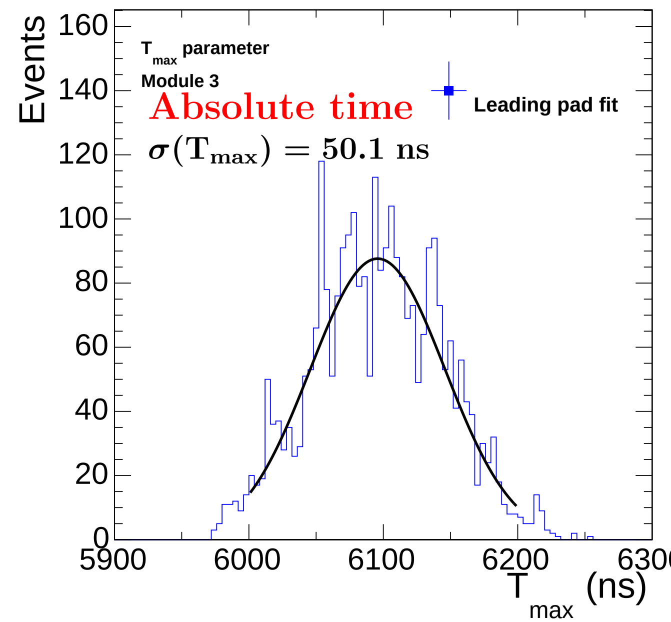

*Shoulders indicate possible $T_{rise}$ variation from channel-by-channel (event-by-event)*

*Direct study of arrival time stability is troublesome with current setup*

- Jitter of $T_{max}$ takes place due to
  - absolute variation of the start bin
  - finite size of the beam (absolute time)
- Direct stability test is feasible with facility upgrade
  - includes a few silicon layers for precision beam position determination

*However, it is not a problem for the resolution, which can be determined from residuals of the track fit*

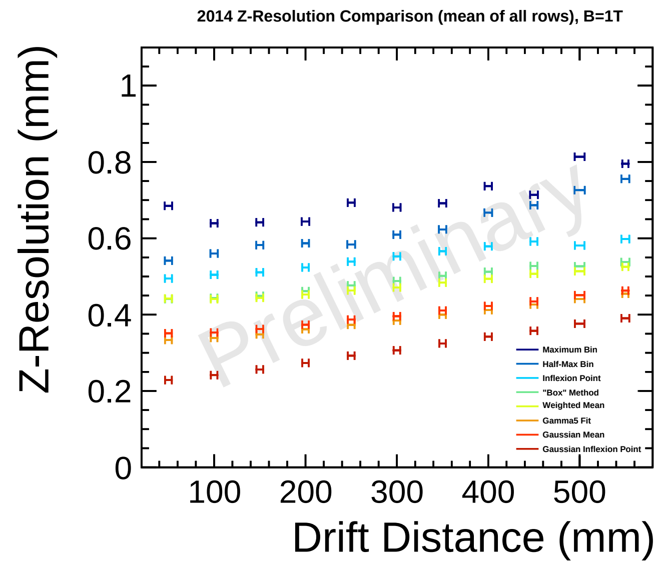


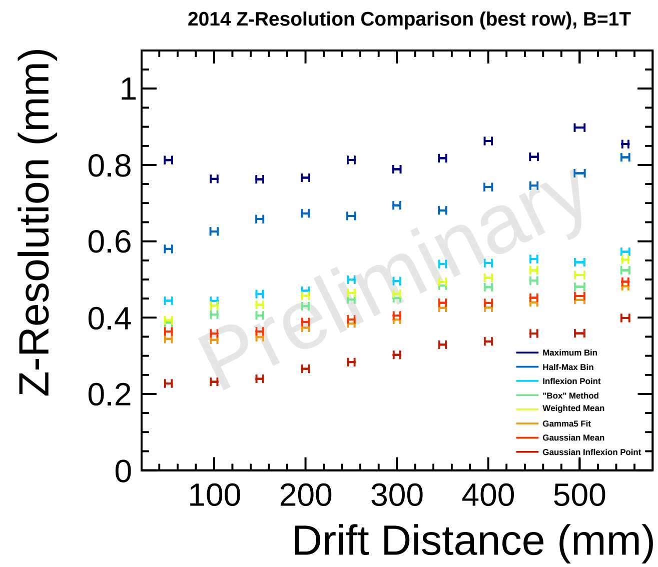



# Longitudinal Resolution

**Z resolution has been measured with the triplet finder algorithm**

- ☞ Significant improment is achieved with respect to **the box method**
  - ➠ **about 25%** at short drift distance with a pulse peak estimators
  - ➠ **about 50%** at short drift distance with an inflection point estimator
  - ➠ slightly reduces the improvement at long distance due to diffusion contribution
  - ➠ precision functional form inspired from the electronic shaping accounts possible imperfections of the gaussian approach
  - ➠ in general the inflection point approach offers smaller residuals than a peak position

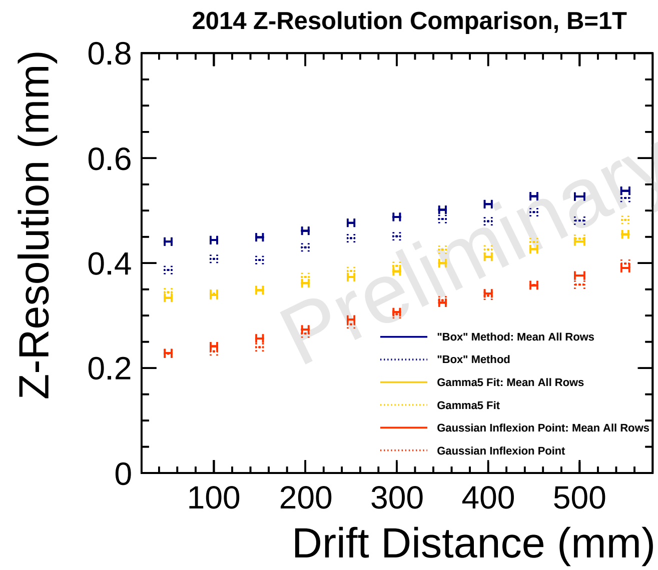


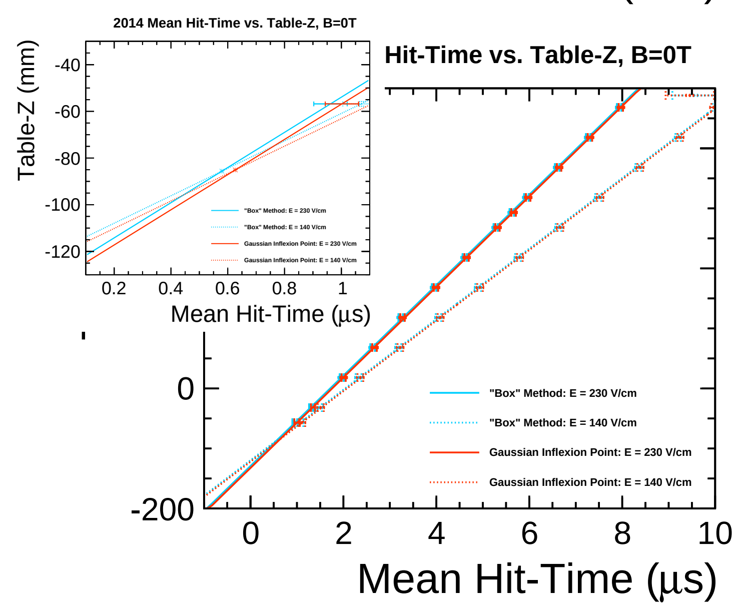



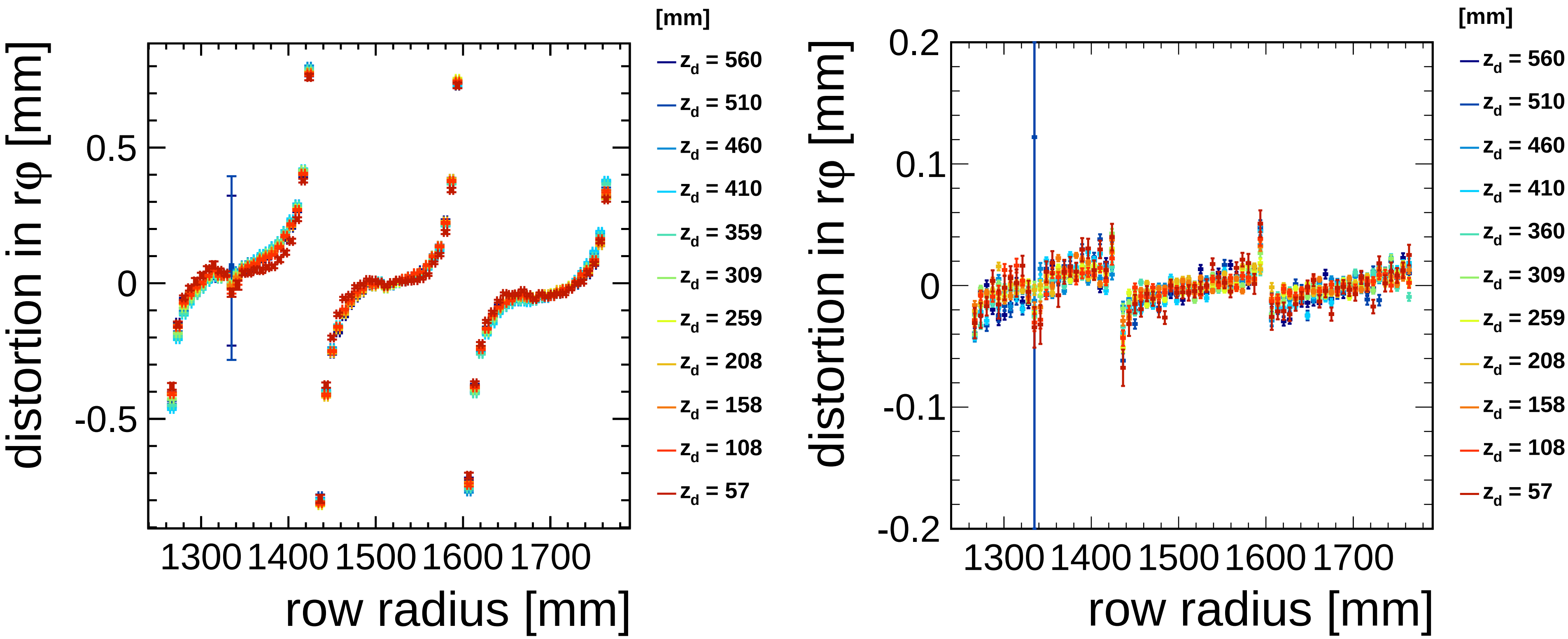

*Estimate with inflection point of the precision functional form is foreseen*

- ☞ New estimators account possible channel-by-channel shape variation and **offers homogeneous z resolution accross the module**
  - ➠ reach about $\boldsymbol{\sigma_z = 0.2(0.4)}$ **mm** for short (long) drift distance
  - ➠ absolute z position calibration has to be done separately
  - ➠ pulse shape channel-by-channel calibration has to be considered
    - ➔ only 2 parameters **amplitude** and **arrival time** would remain for data reconstruciton

*Worth a combination of efforts between MM and GEM groups for further study and elaboration of strategy*



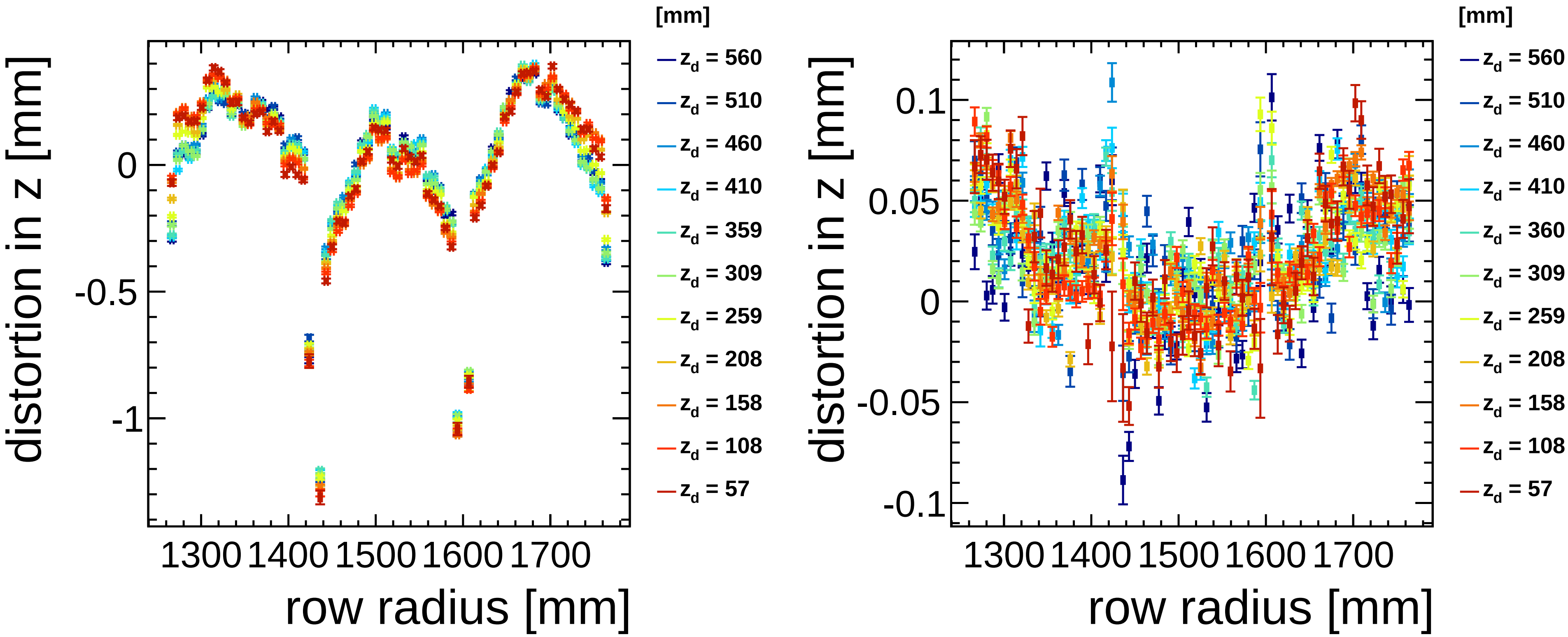






**Non-uniform E-field near module boundaries induces ExB effects**

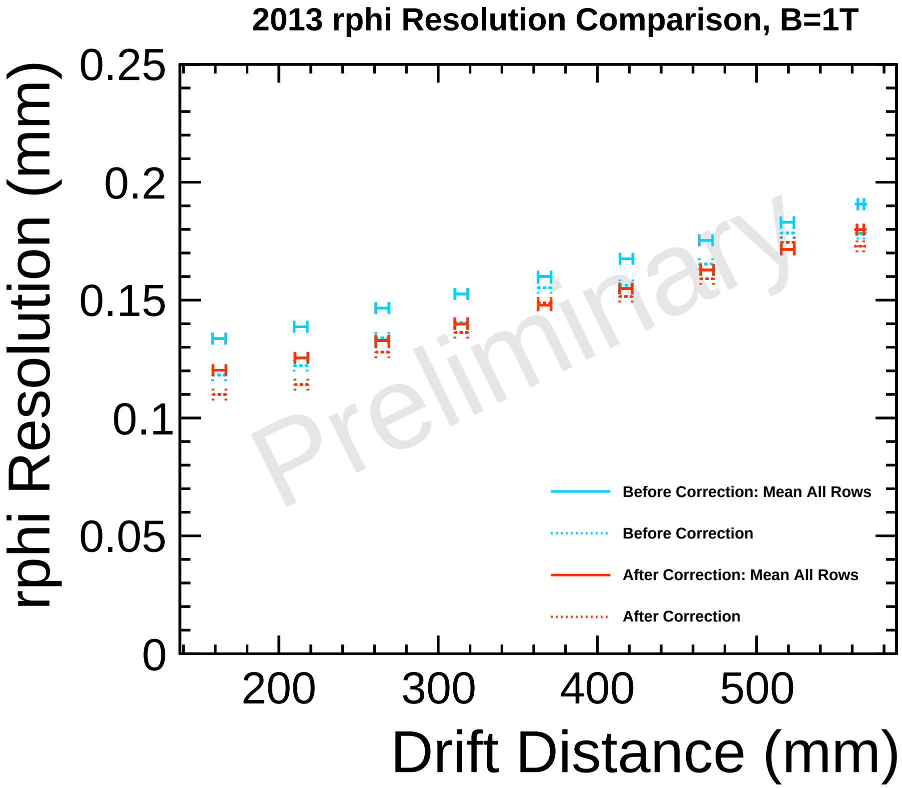
- At B=0 T: distortions about 200 $\mu$m are due to E only
  - can be easily pinned down to 20 $\mu$m (see P. Colas Novosibirsk talk)
- At B=1 T: distortions about 1 mm are observed

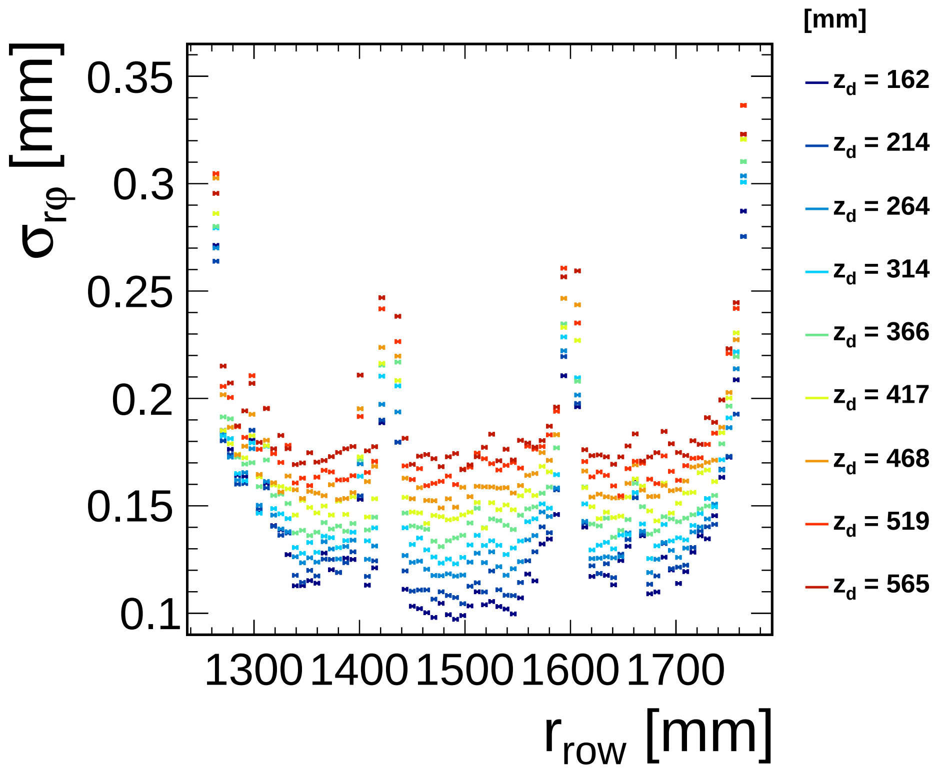
*Better than 50 $\mu$m distortions remain after corrections at B=1 T*




☞ At B=1 T: distortions about 1 mm are observed

*Better than 100 $\mu$m distortions remain after corrections in z coordinate*

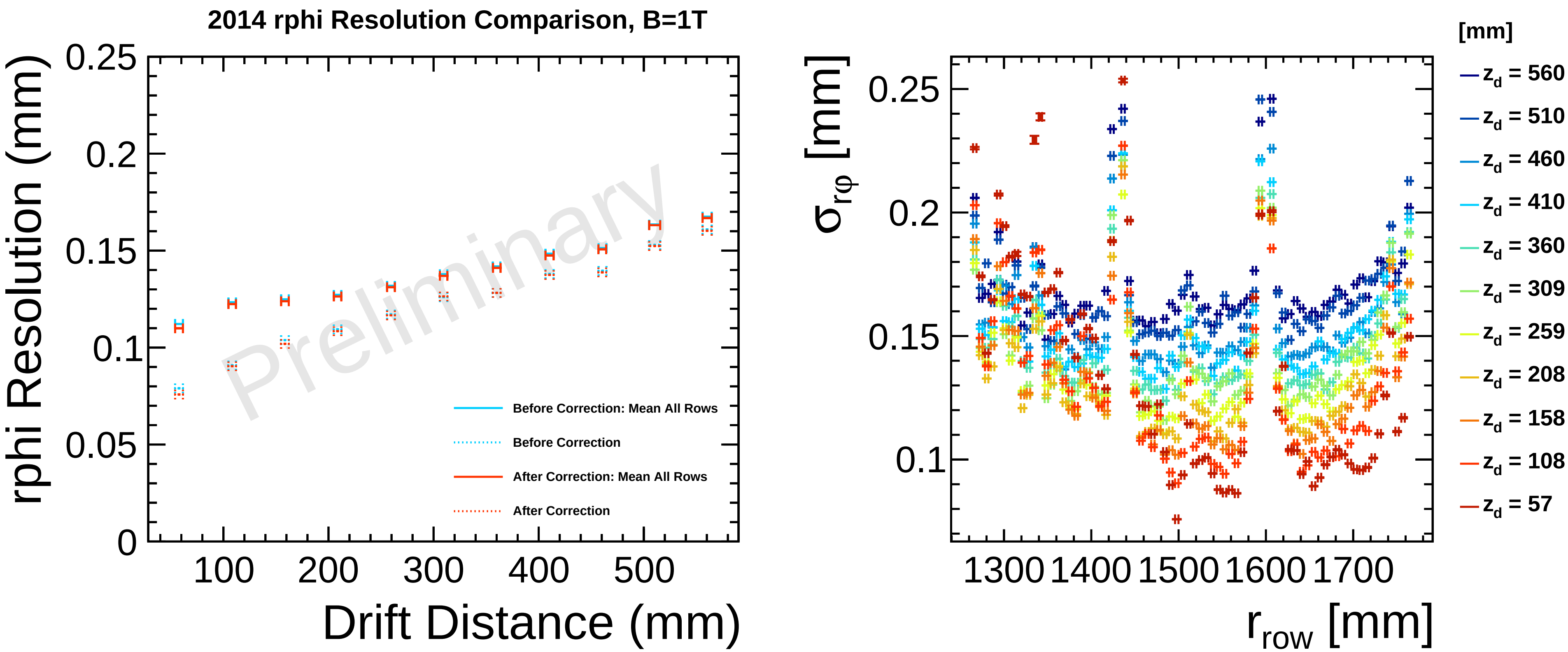



☞ Significantly larger distortions were observed in 2013 multi-module setup (see backup), specially for the inner and the outer most rings

- improvement after corrections is sizeable
- difference between best and overall resolution is small

*Transverse resolution for 2013 dataset is a bit worse with respect to the ILD TPC requirements possibly due to many disconnected pads and worse distortion*




*Transverse resolution for 2014 dataset meets the ILD TPC requirements and in good agreement with 2010 dataset analysis performed in FTPC framework*

*(there is a room for further improvement, work is still going on)*

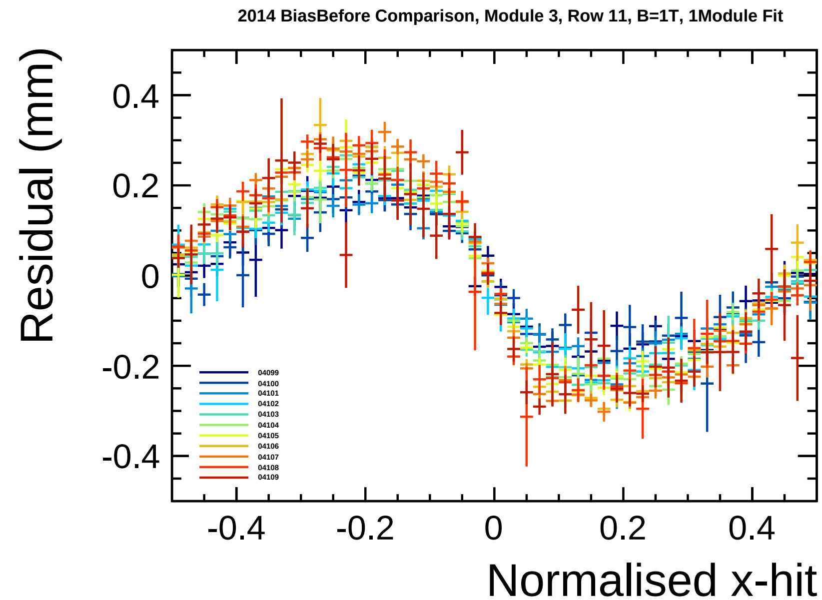
*Charge sharing between adjacent pads is not linear (well-known S-curve effect)*

- ☞ About 400$\mu$m residual oscillation occurs
  - ➠ if weighted mean is used for x-hit

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

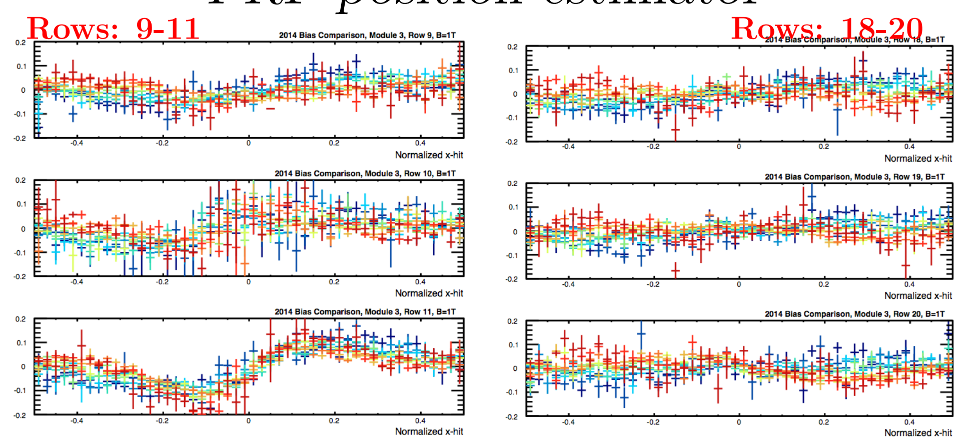
  - ➠ it is stable with drift distance
  - ➠ PRF takes into account real charge distribution and addresses this bias

*Weighted mean position estimator*




- ☞ PRF imperfections are also possible
  - ➠ inhomogeneity in the resistive coating
  - ➠ non accounted charge in outliers possibly introduces the dependence of shower position from the pad center

*PRF position estimator*




*Remnant oscillation about 100 $\mu$m occurs in some rows periodically (possibly due to inhomogeneity in the resistive coating)*

# Conclusions

- **Vast analysis program of the test beam data is carring out**
  - study of multi-module effects includes the field distortions
  - coherent analysis of 2013 and 2014 data exploit **the official MarlinTPC**
  - resolutions become overlaping with previous one-module setup study with FTPC
- **Longitudinal resolution has been significantly improved using the pulse shape fit methods: functional fit and Gaussian inflection point**
  - reach about $\boldsymbol{\sigma_z = 0.2(0.4)}$ **mm** for 6(56) cm of the drift distance
  - accounts channel-by-channel pulse shape variation and offers **homogeneous resolution accross the module**
- Other vital studies are foreseen in the futures
  - implement alignment of the multi-module setup
  - investigate possible inhomogeneity of resistive coating (bias study)
  - improve amplitude estimation including subleading pads
  - coherent implementation of new algorithms into MarlinTPC

**Backup**

*Study of time reconstruction with pulse shape method for GEM was reported by F. Müller*

☞ The following analytic function was proposed:

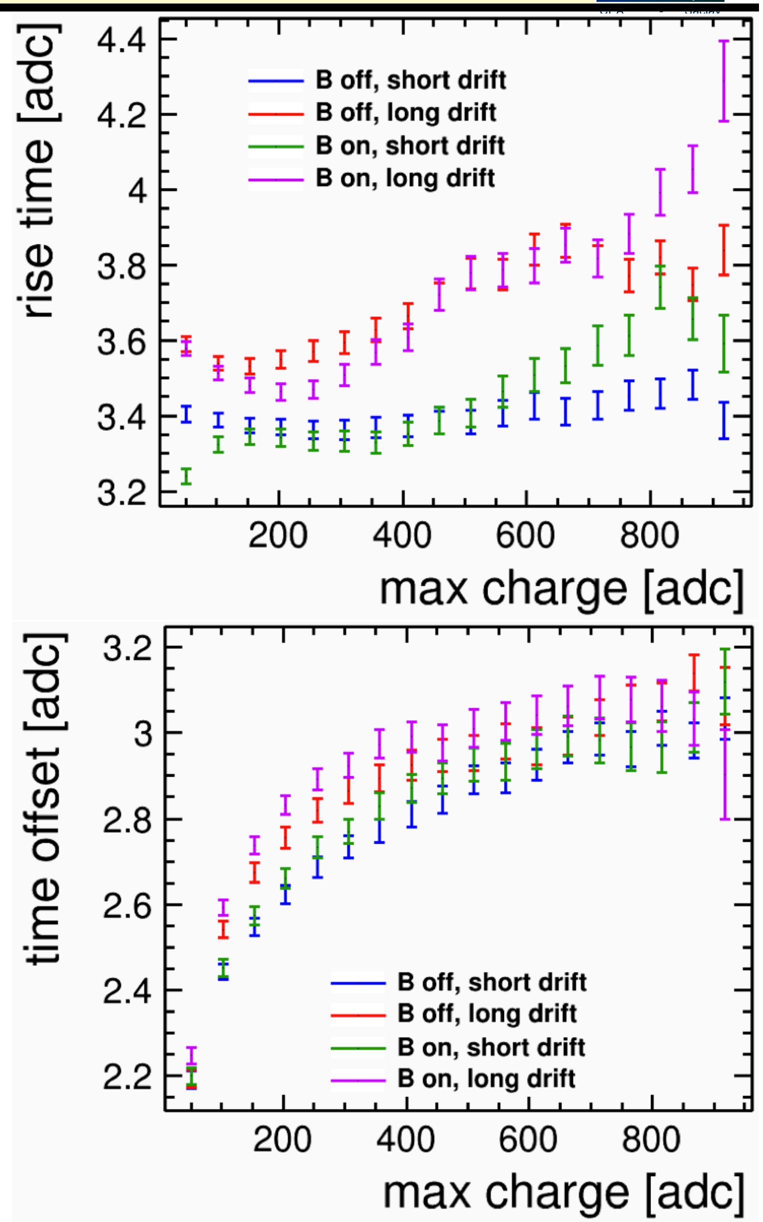
$$f(t) = A \cdot e^{\alpha} \cdot \left(\frac{t - T_0}{T_{rise}}\right)^{\alpha} e^{-\alpha \frac{t-T_0}{T_{rise}}} \theta(t - T_0)$$

$A$ - amplitude $T_0$ - offset, $T_{rise}$ - risetime, $\alpha$ - pulse width,

☞ Two major obeservations with simulation study:

- dependency of $T_{rise}$ and $T_0$ on the pulse charge
- inconsistency with drift distances and B-field

*Due to such an instability of the fit parameters steek to barycenter and inflection point methods*

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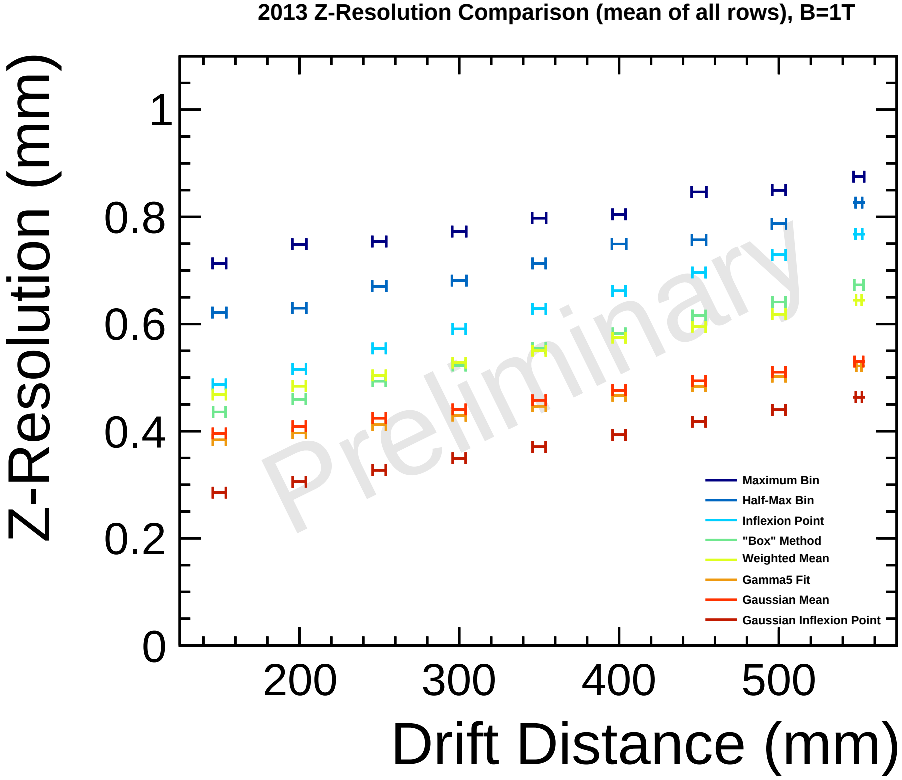
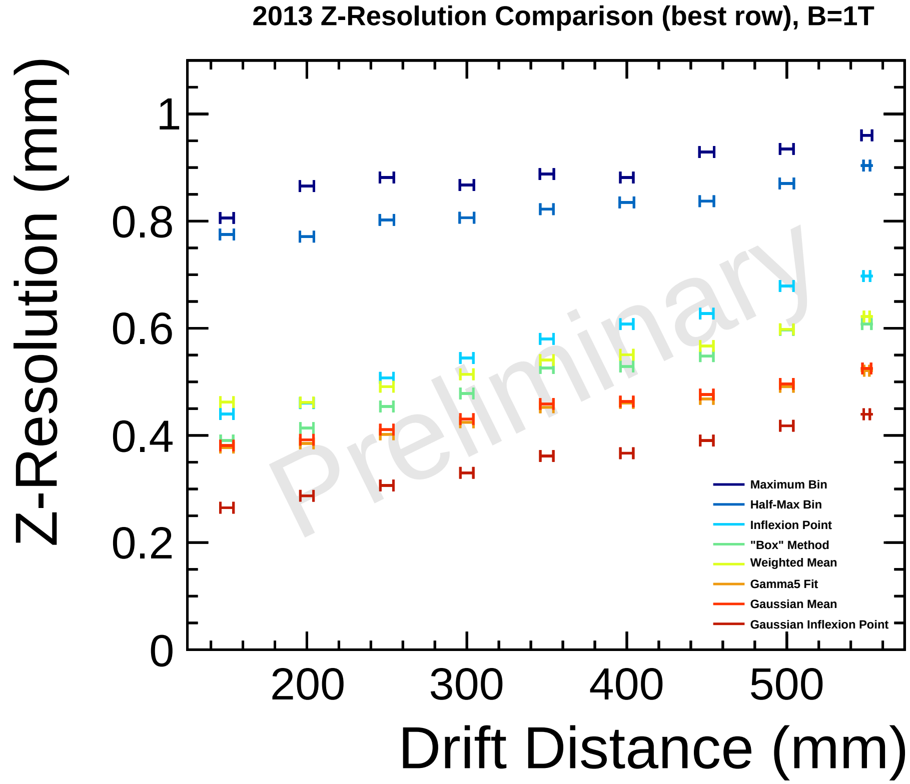
*All rows*

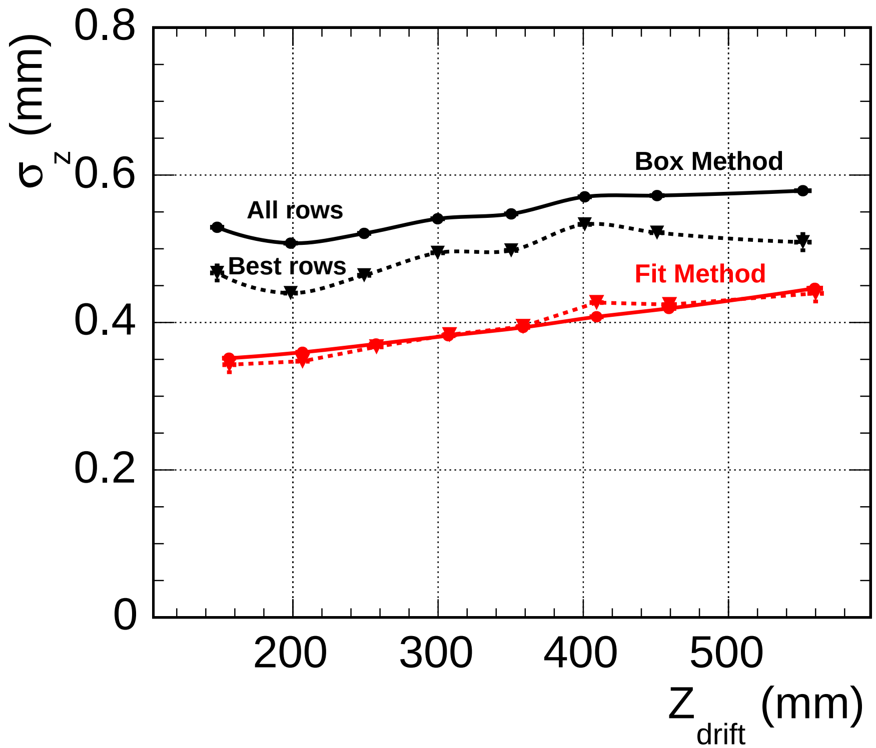


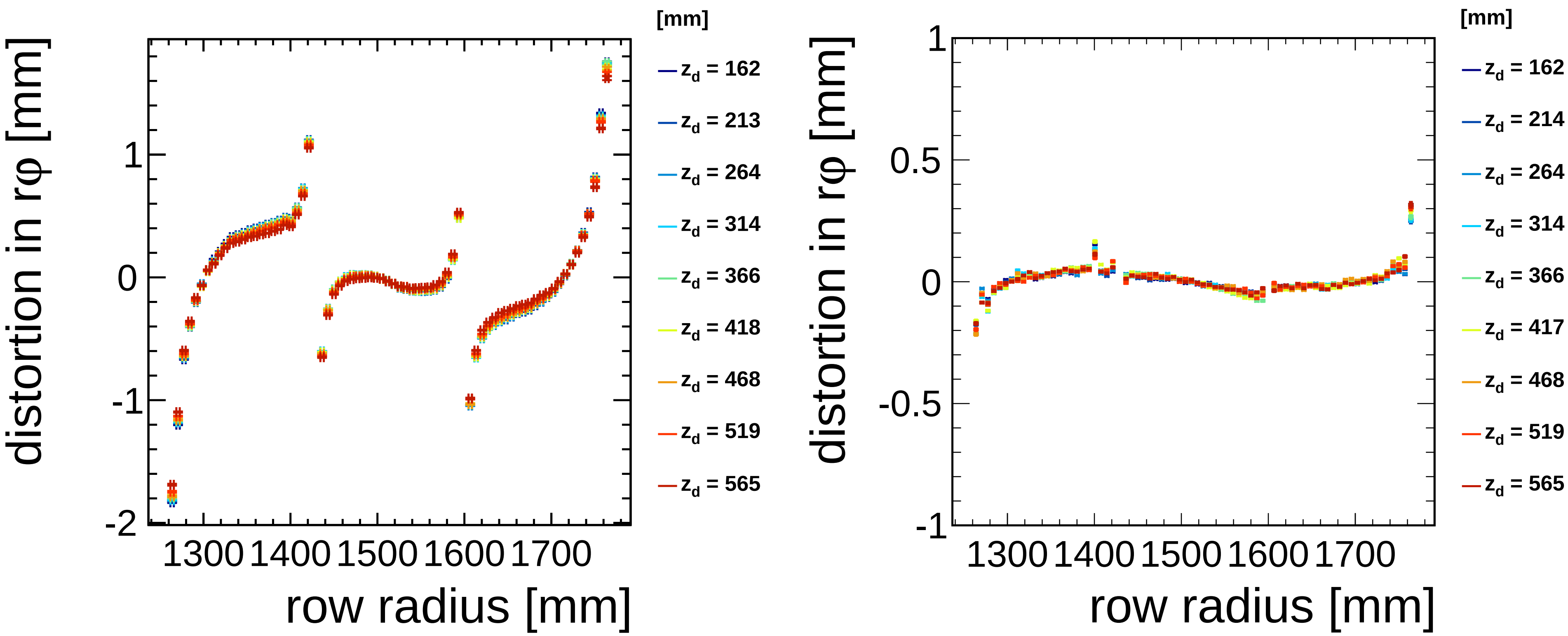

*Best row*



- ☞ Z resolution study with the Kalman fitter has been performed with the functional shape method
  - ➠ `TrackFitterKalmanProcessor` is deploed for the track finding
  - ➠ `ResolutionPerformanceRrocesso`: is used for the resolution calculations

*Results obtained with Kalman and triplet finder fits are in good agreement*

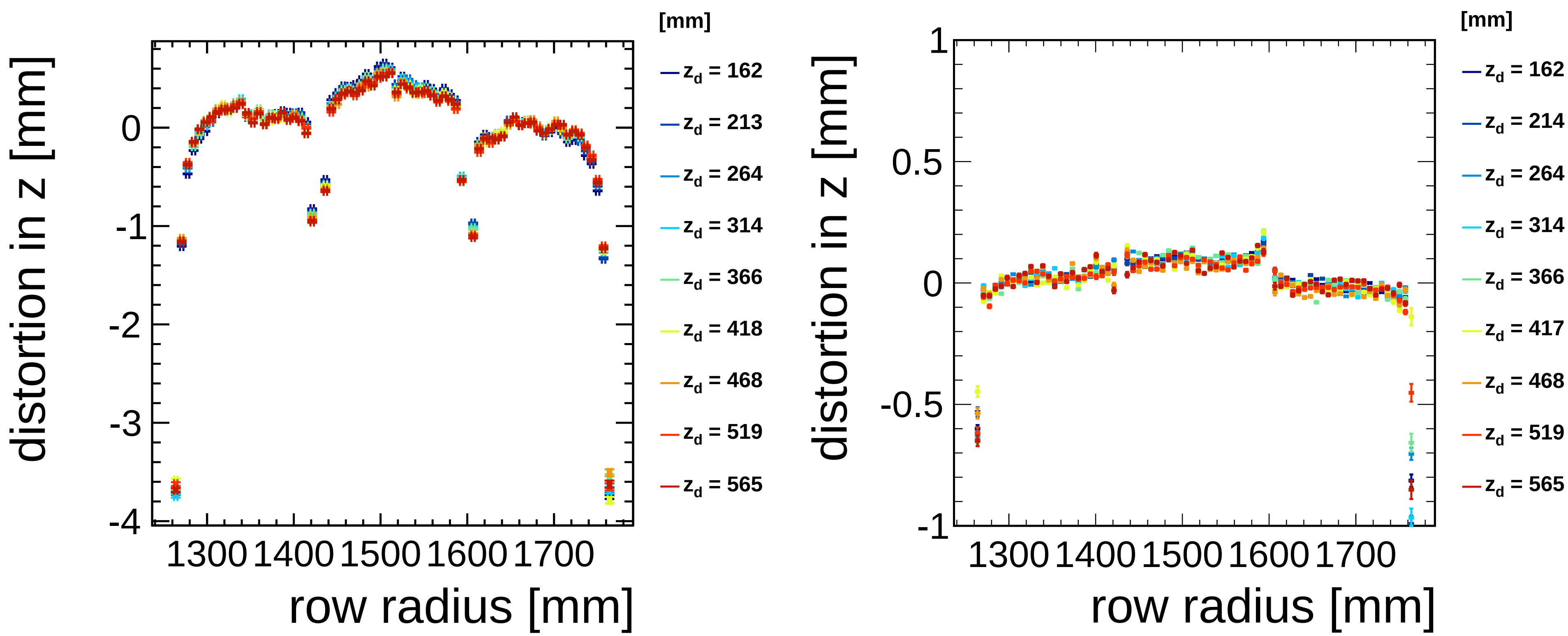





**Non-uniform E-field near module boundaries induces ExB effects**

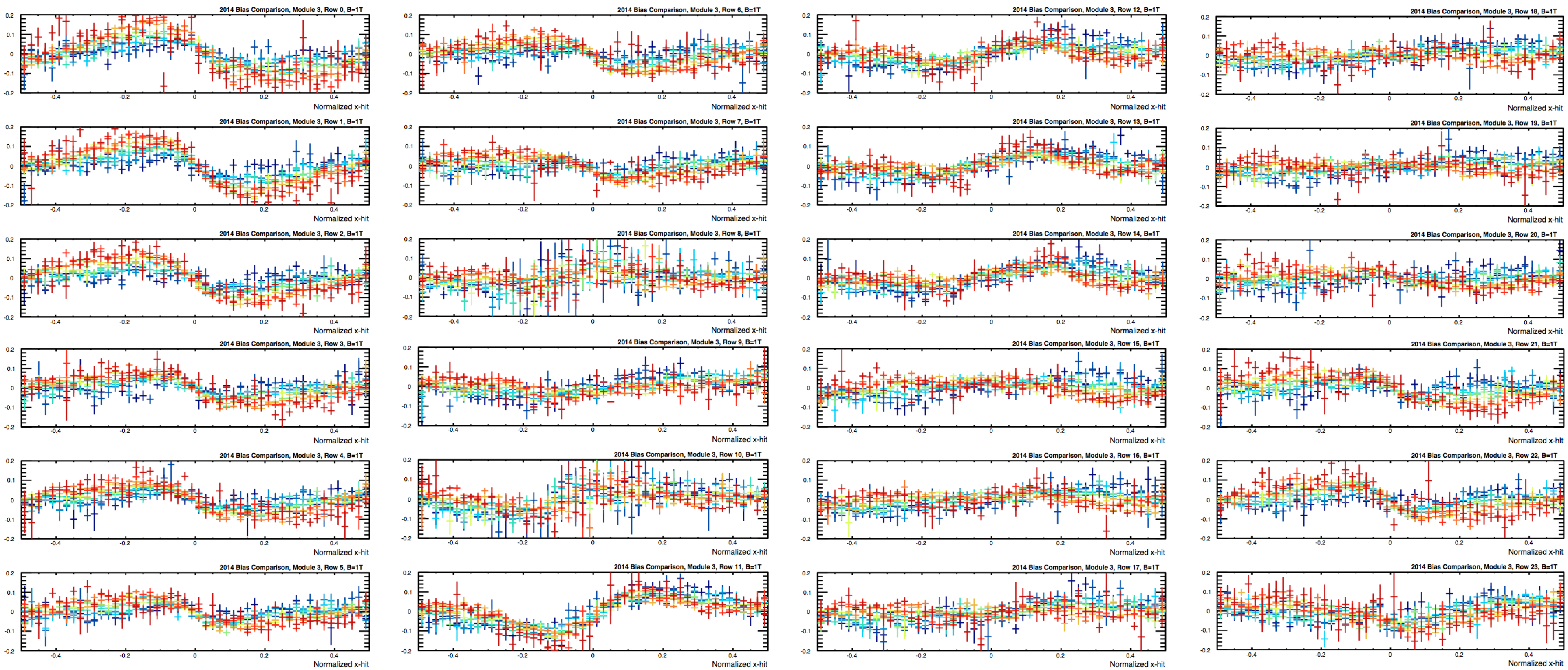
- ☞ Significantly larger multi-module effects take place in 2013 data
- ☞ At B=1 T: distortions about 2 mm are observed

*Better than 200 $\mu m$ distortions remain after corrections at B=1 T*




☞ At B=1 T: distortions about a few mm are observed

*Better than 100 $\mu$m distortions remain after corrections in z coordinate*


2014 Bias Comparison, Module 3, Row 0, B=1T
2014 Bias Comparison, Module 3, Row 1, B=1T
2014 Bias Comparison, Module 3, Row 2, B=1T
2014 Bias Comparison, Module 3, Row 3, B=1T
2014 Bias Comparison, Module 3, Row 4, B=1T
2014 Bias Comparison, Module 3, Row 5, B=1T
2014 Bias Comparison, Module 3, Row 6, B=1T
2014 Bias Comparison, Module 3, Row 7, B=1T
2014 Bias Comparison, Module 3, Row 8, B=1T
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2014 Bias Comparison, Module 3, Row 18, B=1T
2014 Bias Comparison, Module 3, Row 19, B=1T
2014 Bias Comparison, Module 3, Row 20, B=1T
2014 Bias Comparison, Module 3, Row 21, B=1T
2014 Bias Comparison, Module 3, Row 22, B=1T
2014 Bias Comparison, Module 3, Row 23, B=1T
Normalized x-hit