Encapsulated Resistive-anode Micromegas TPC

Results of beam test
@ DESY 13/Nov ~ 28/Nov

LCTPC. 10/Jan. 2018

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and thanks to R. Diener, O. Schäfer, V. Prahl …

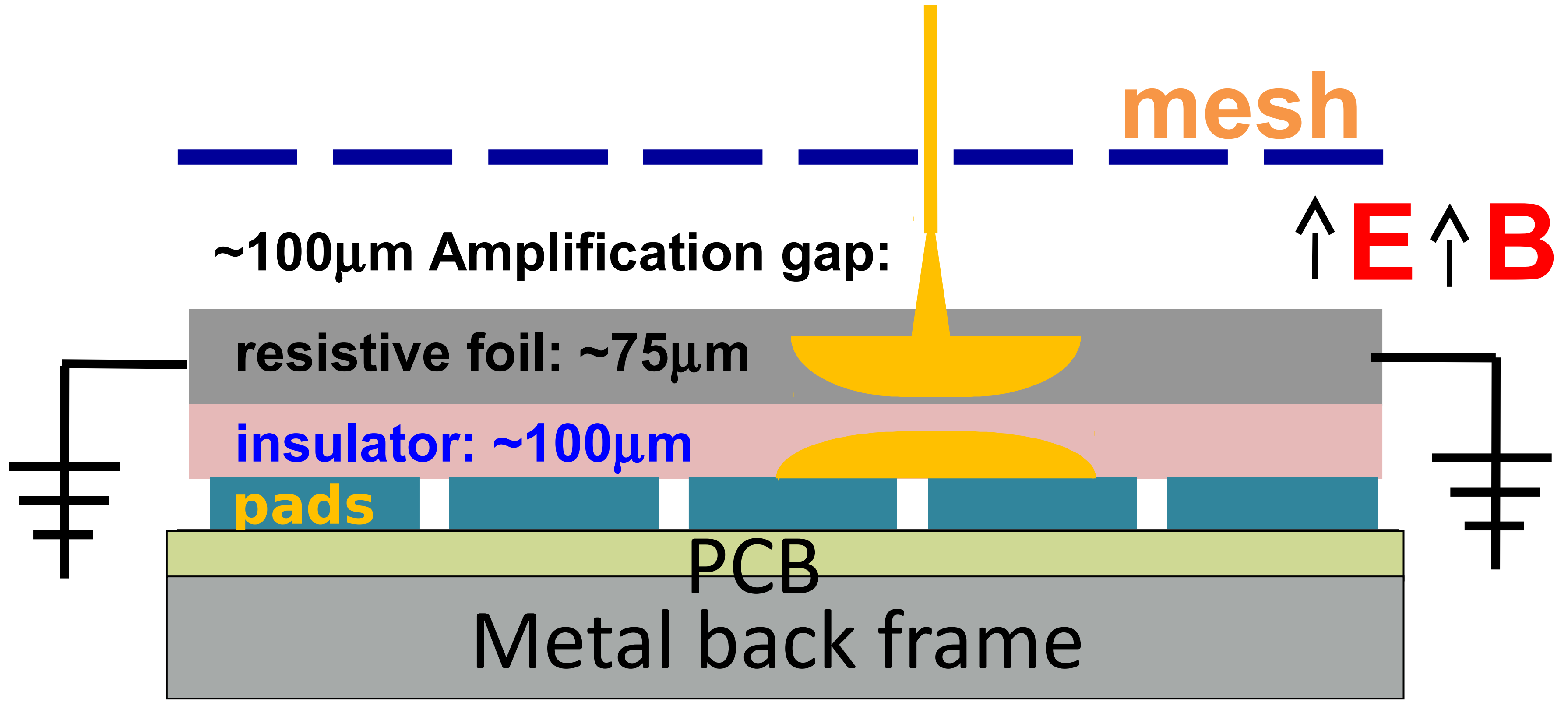
Outline

1. Motivation and detector
2. Experiment condition, gas, detector, H.V.
3. Uniformity on charge spread, hit charge
4. Distortions
5. σrφ, σz

1. dE/dx resolutions

Encapsulated Resistive-anode Micromegas

- **Resistive-anode Micromegas**



Performance requirement for ILC : ~ 100 µm spatial resolution

"T2K" gas gives small transverse diffusion because of CF4

which can make τ large (make e stay in Ramsauer dip)

under B~4T, Dt ~ 30 um/√cm (limit by pad size ~ width/√12)

Need sufficient #pads to evaluate barycenter

=> spread charge and share with several pads.

- **Encapsulated Resistive-anode Micromegas**

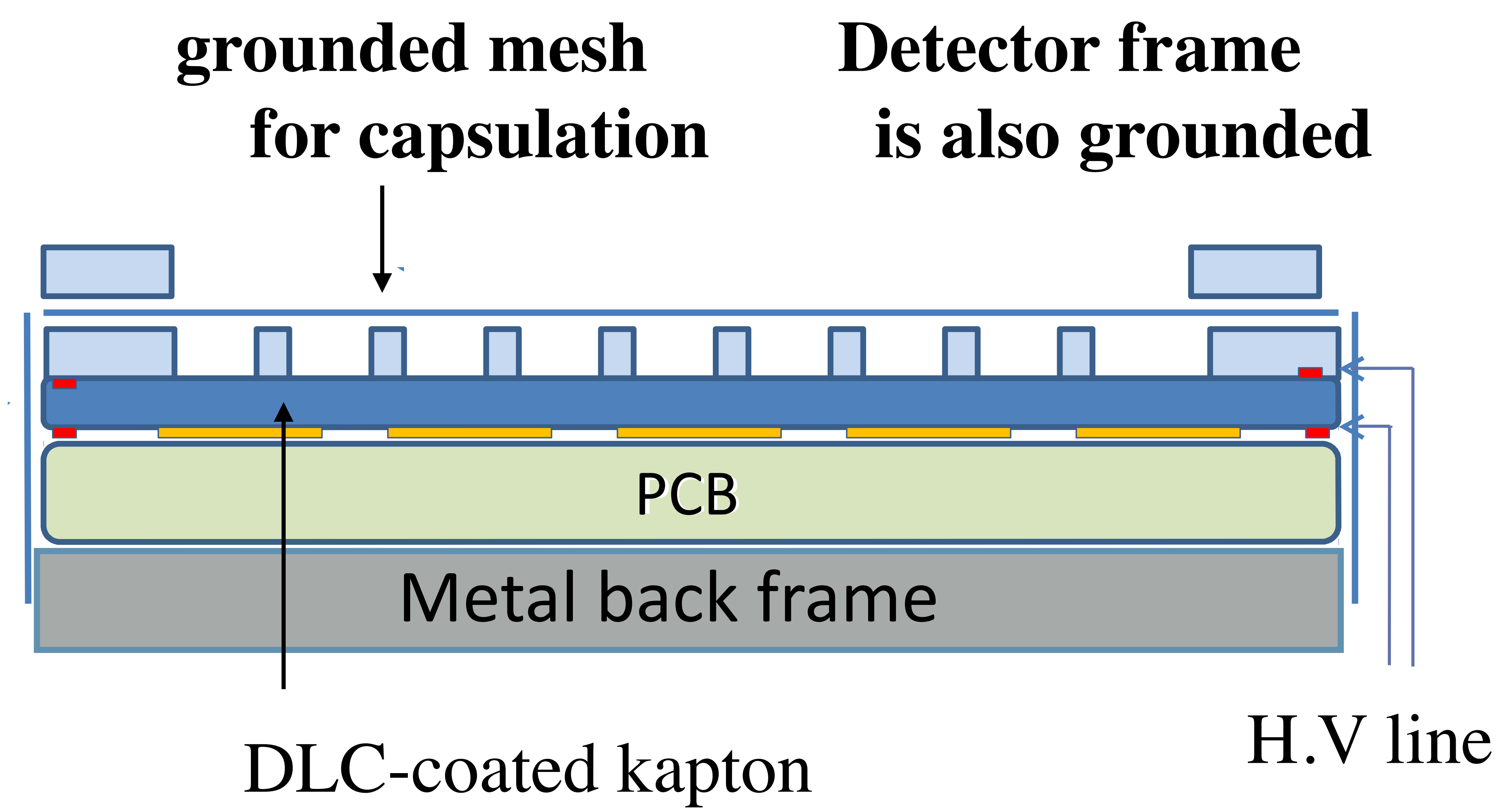
Mesh is connected to ground (Nobody did it).

Encapsulation shields against external noise

small signal can be acquired

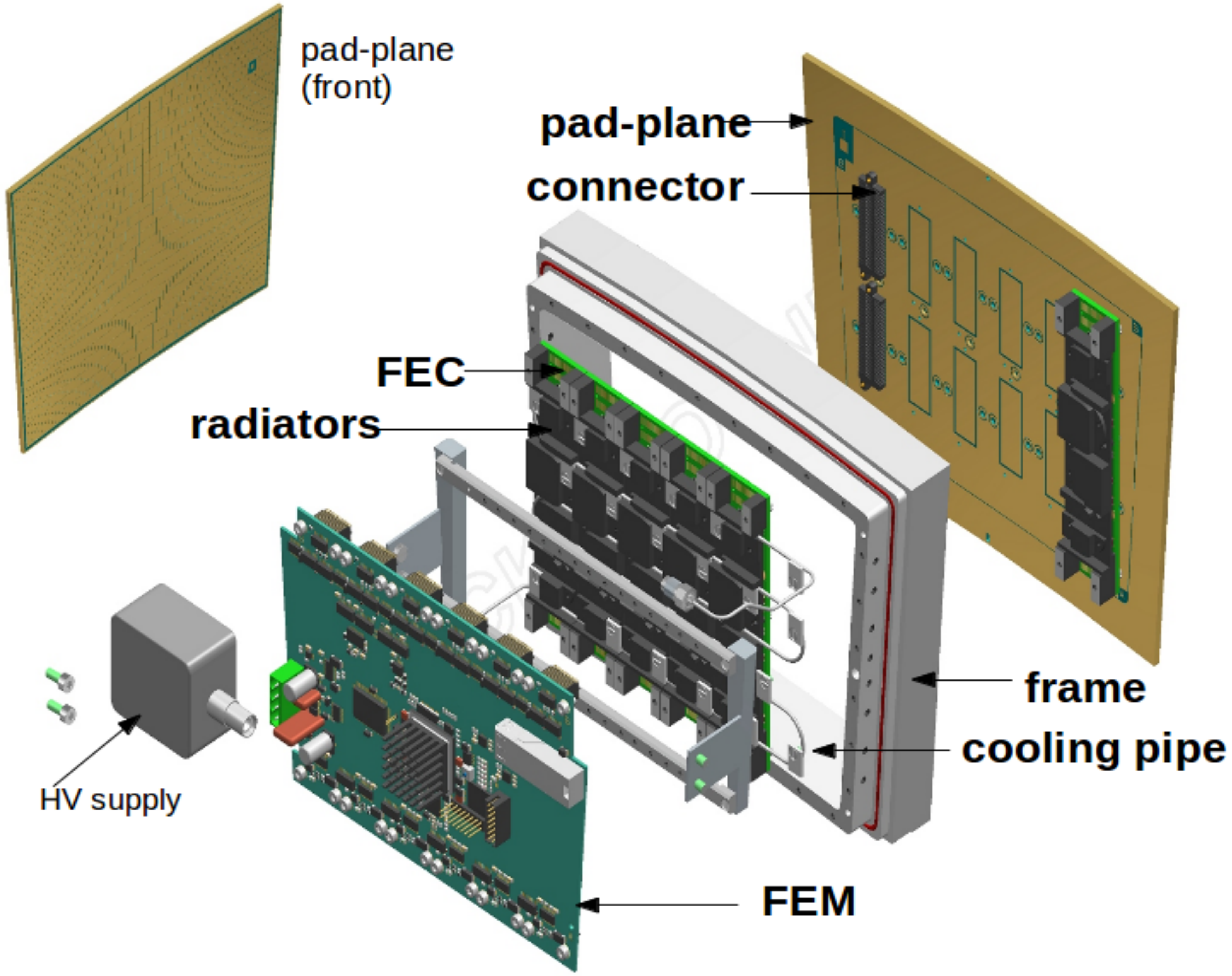
Module-Module boundary keep homogeneity of E field ,

reduce ExB => Mitigates track distortions



Detector configuration

- **Module**
  - Module size: 22 cm × 17 cm
  - 24 rows × 72 columns **(1726 Pads)**
  - **Pad size: 3 mm × 7 mm**



- **AFTER chip** produced by Saclay https://doi.org/10.1109/TNS.2008.924067

  for various kinds of detectors and **gas mixtures**

  - Different electronics gain
  - 25 MHz (50, 100 MHz) sampling frequency
  - Peaking time 100 ns to 600 ns

- **Resistive anode** for dispersing charge

  Diamond Like Carbon-coated kapton

  Surface R = 2.5 Mohm/sq is optimal
  when considering pad size,
  insulator thickness, and shaping time …

  => sufficient charge spreading
  & protection for sparks

Comparison of Resistive anode in 2015 beam test
=> 150119_D.S.Bhattacharya_AperoSPP

- Carbon Loaded Kapton
- Diamond Like Carbon

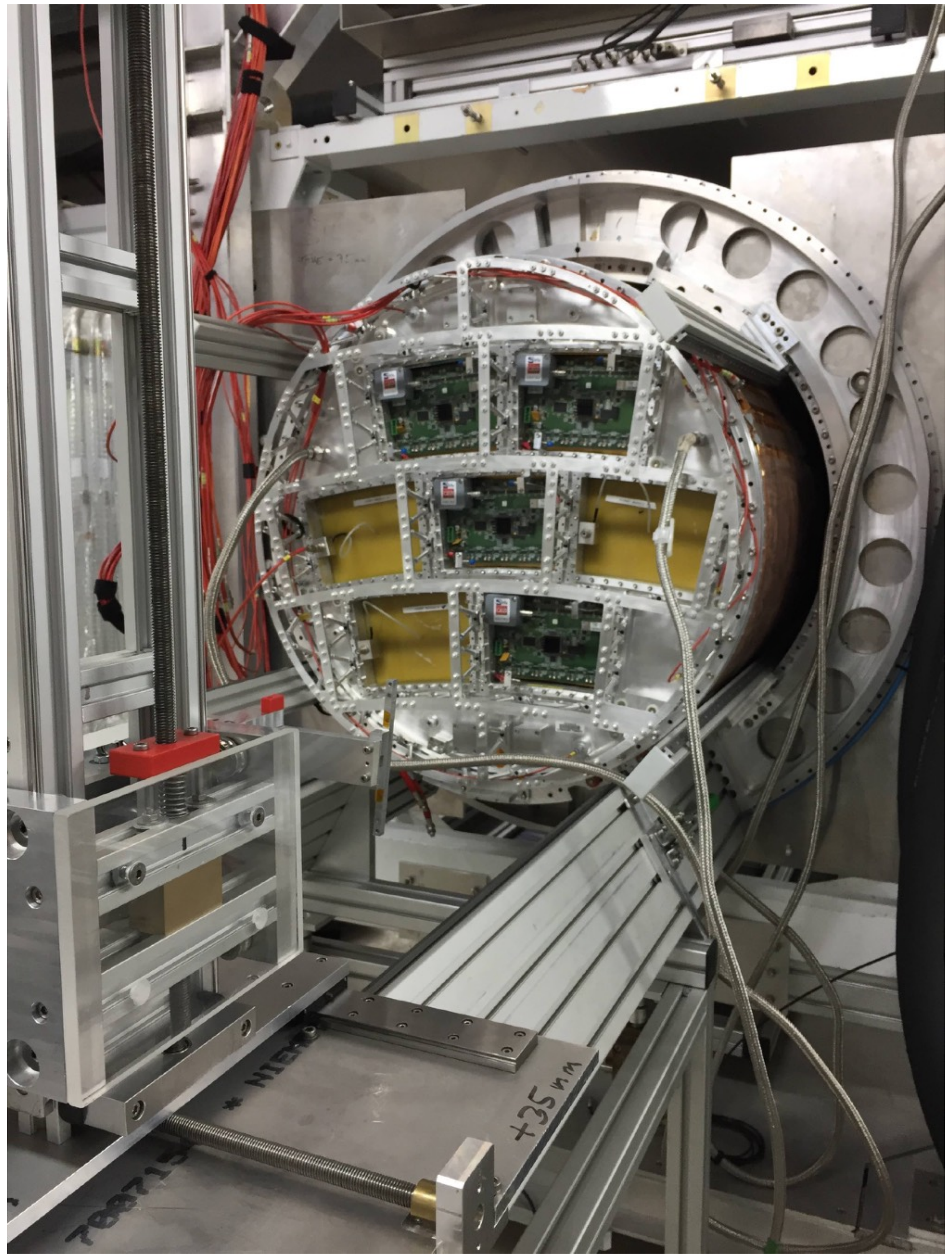
Conditions of the experiment
gas, modules, and so on

- **4 modules are installed**

- **2PCO2 cooling with TRACI**

  TRACI=Transportable Refrigeration Apparatus for Co2 Investigation

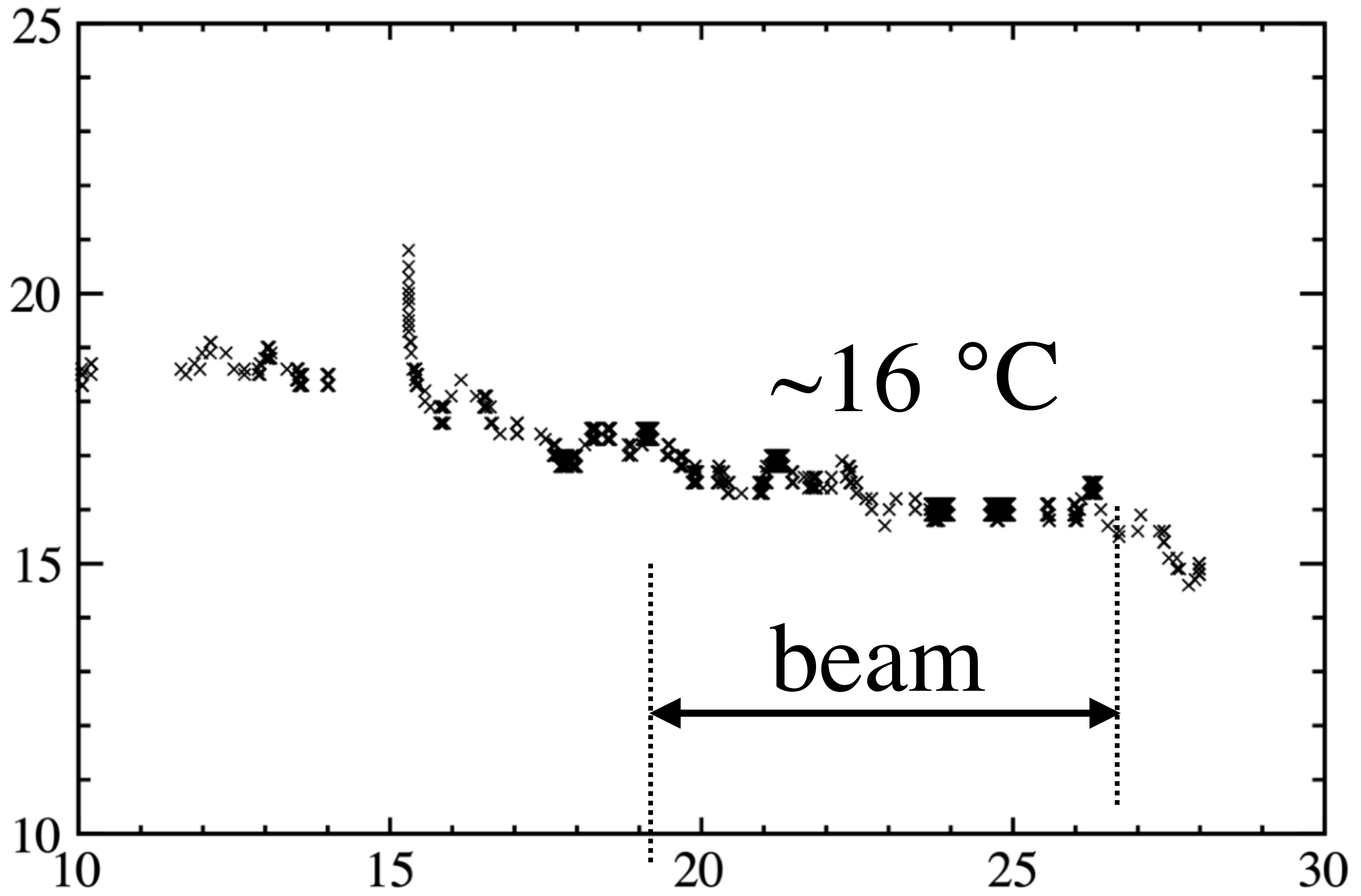
  Very stable operation during beam test.
  Keep the modules 28~30 °C



Conditions of the experiment

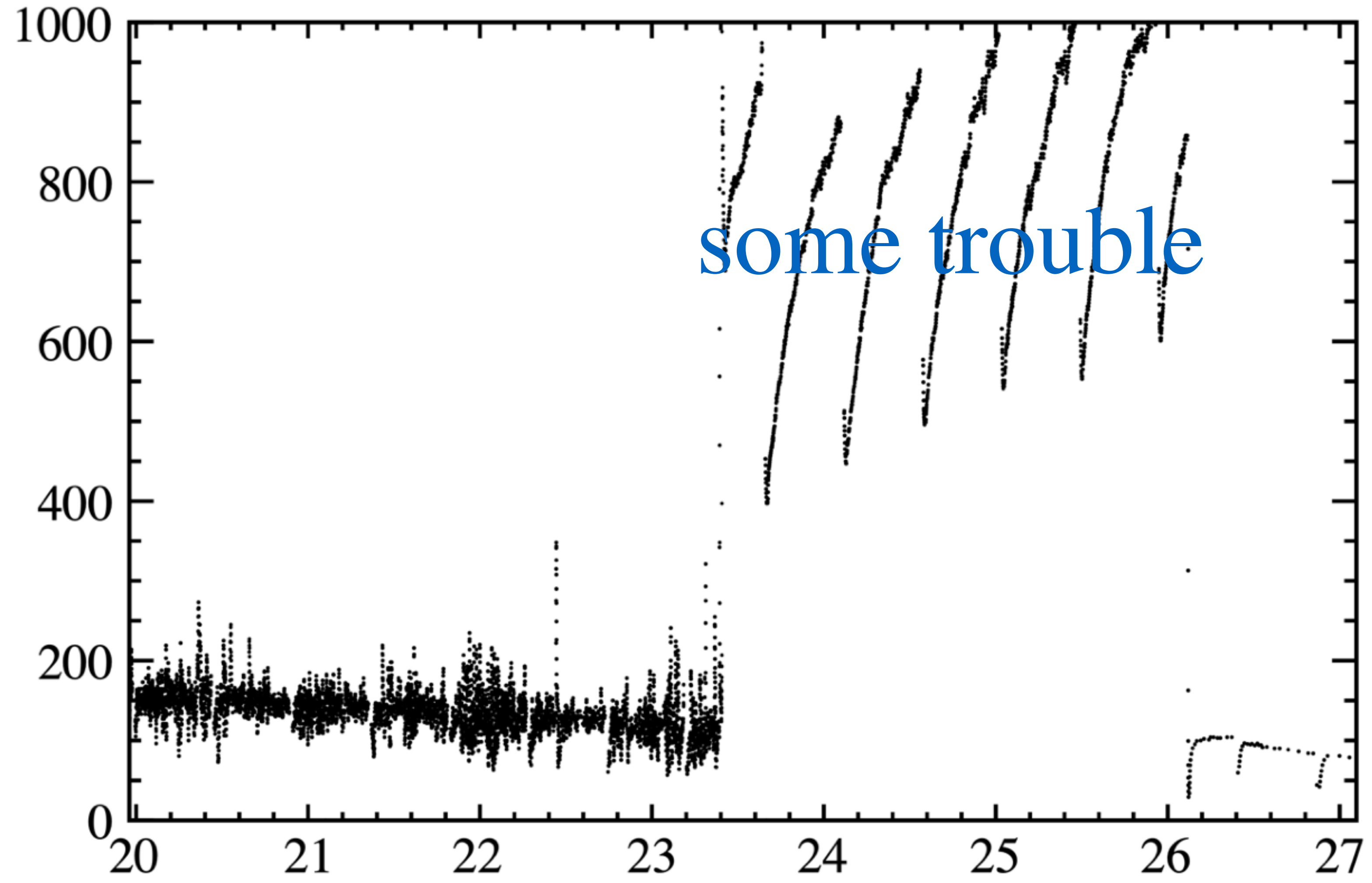
- **Gas condition was good**

system temperature [°C]



date in Nov.

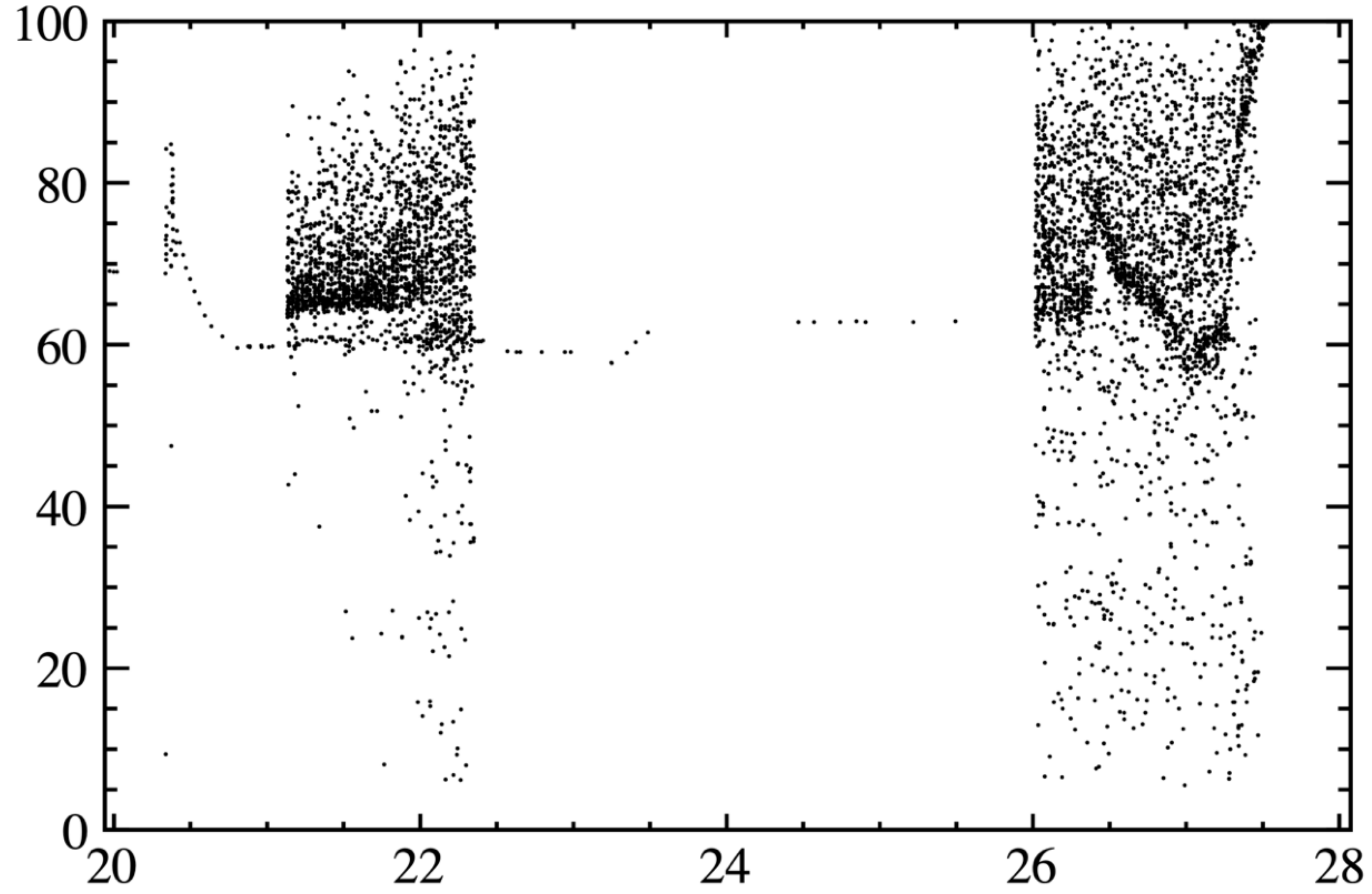
system H2O [ppm]



date in Nov.

H2O ~ 150~100 ppm

system O2 [ppm]



date in Nov.

O2 ~ 60 ppm

Conditions of the experiment

- **Drift velocities** (time estimator: gaussian inflection)

21 Nov. 2018 B=1T, Vanode=380V

- **Meas.**
  140V/cm : **V= 57.0 ± 0.1mm/μs**
  230V/cm : **V= 75.0 ±0.1 mm/μs**

- **Magboltz T2K**
  - **16°C, 1015 hPa**
  - **H2O: 150 ppm**
  - **O2: 60 ppm**

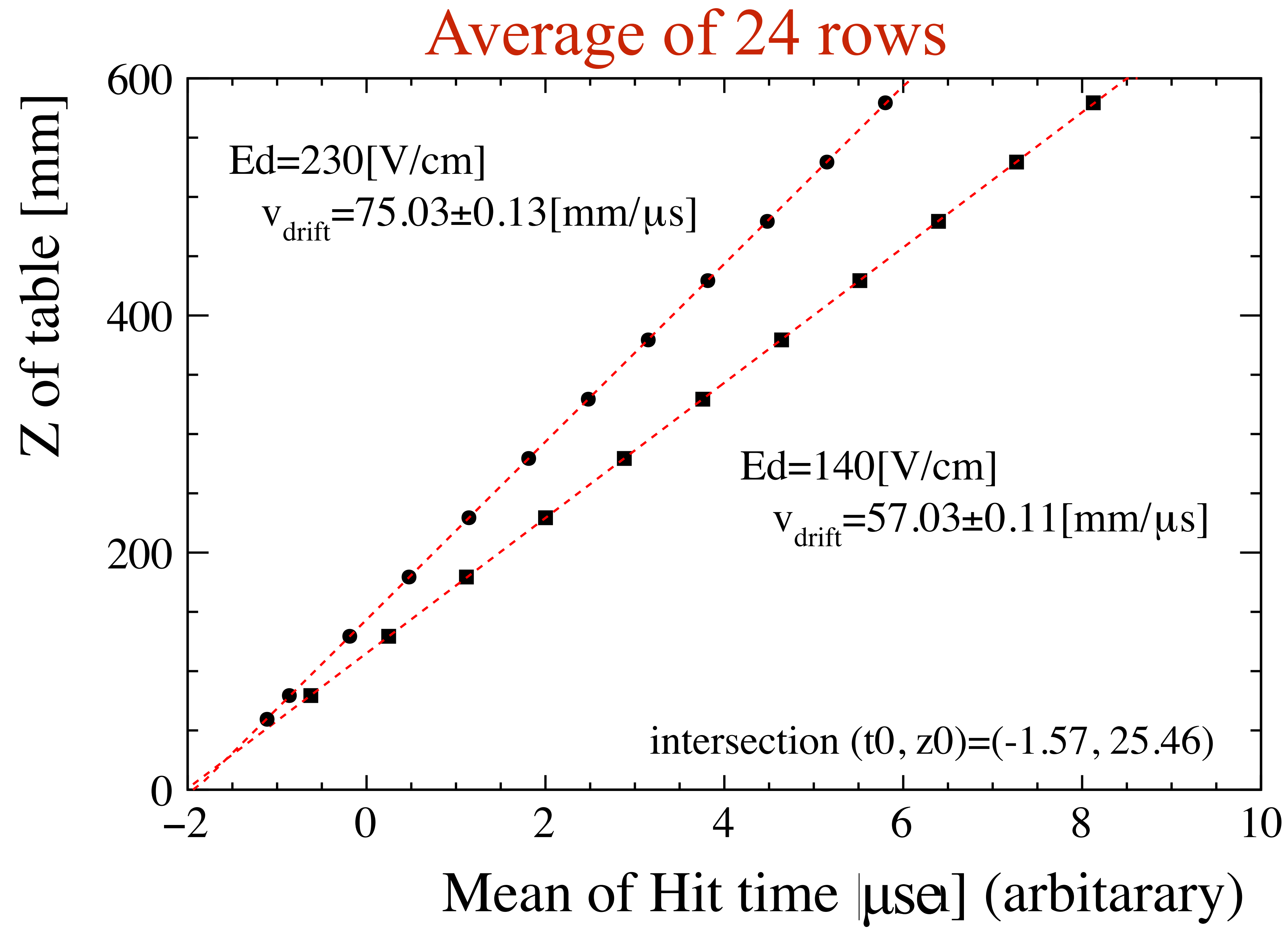
  140V/cm : **V= 57.2** ± $5*10^{-3}$ % ,
  Dl = 308.4 ± 1 % , Dt= 75.7 ± 1 %
  230V/cm : **V= 75.2** ± $3*10^{-3}$ %,
  Dl = 230.0 ±1% Dt= 94.0 ± 1%

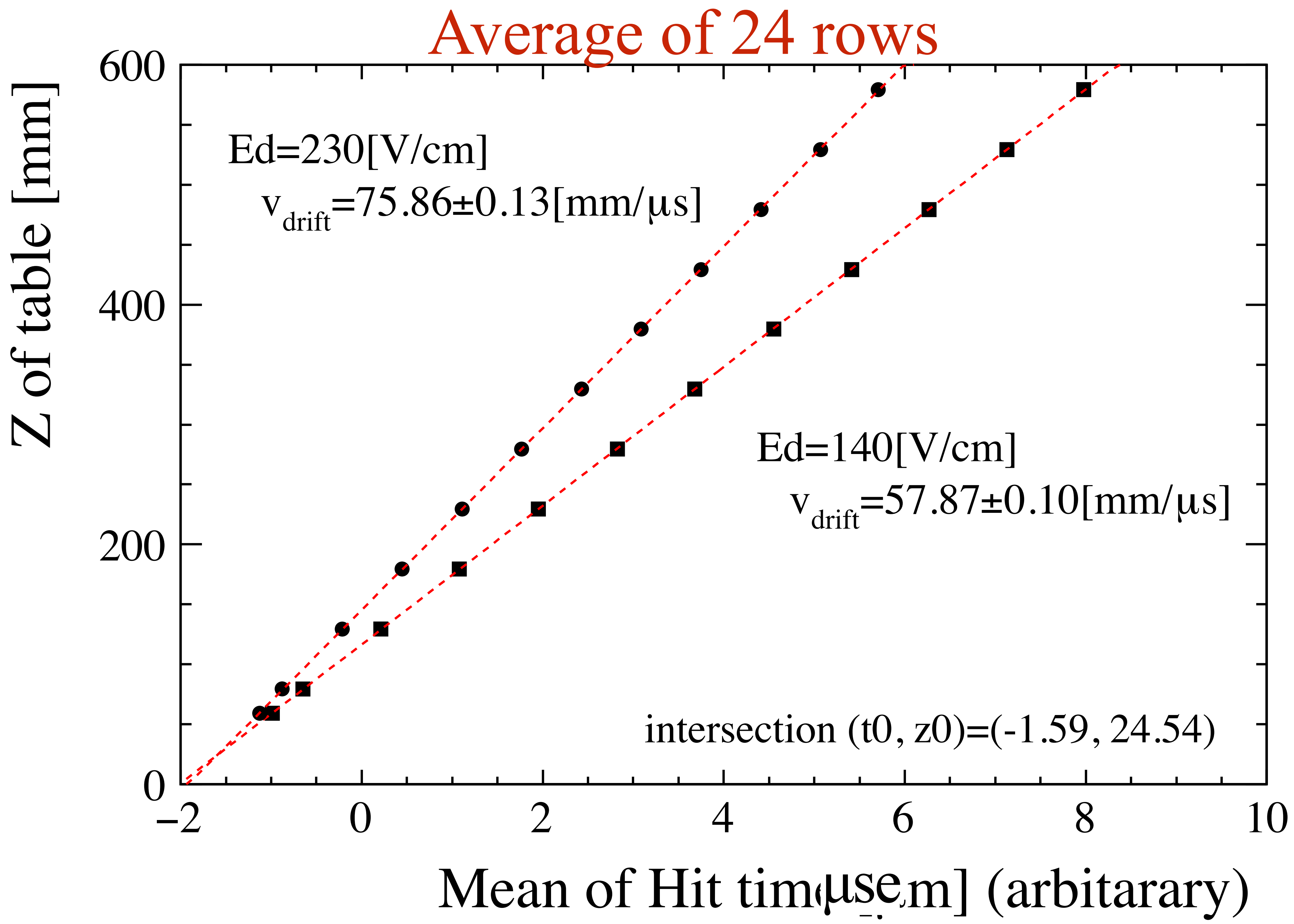
24 Nov. 2018 B=1T, Vanode=370V

- **Meas.**
  140V/cm : **V= 57.9 ± 0.1mm/μs**
  230V/cm : **V= 75.9 ± 0.1mm/μs**

- **Magboltz T2K**
  - **16°C, 1020 hPa**
  - **H2O: 100 ppm**
  - **O2: 60 ppm**

  140V/cm : **V= 57.7** ± $3*10^{-3}$ % ,
  Dl = 308.3 ± 1 % , Dt= 74.9 ± 1 %
  230V/cm : **V= 75.5** ± $4*10^{-3}$ %,
  Dl = 230.0 ±1% Dt= 93.6 ± 1%

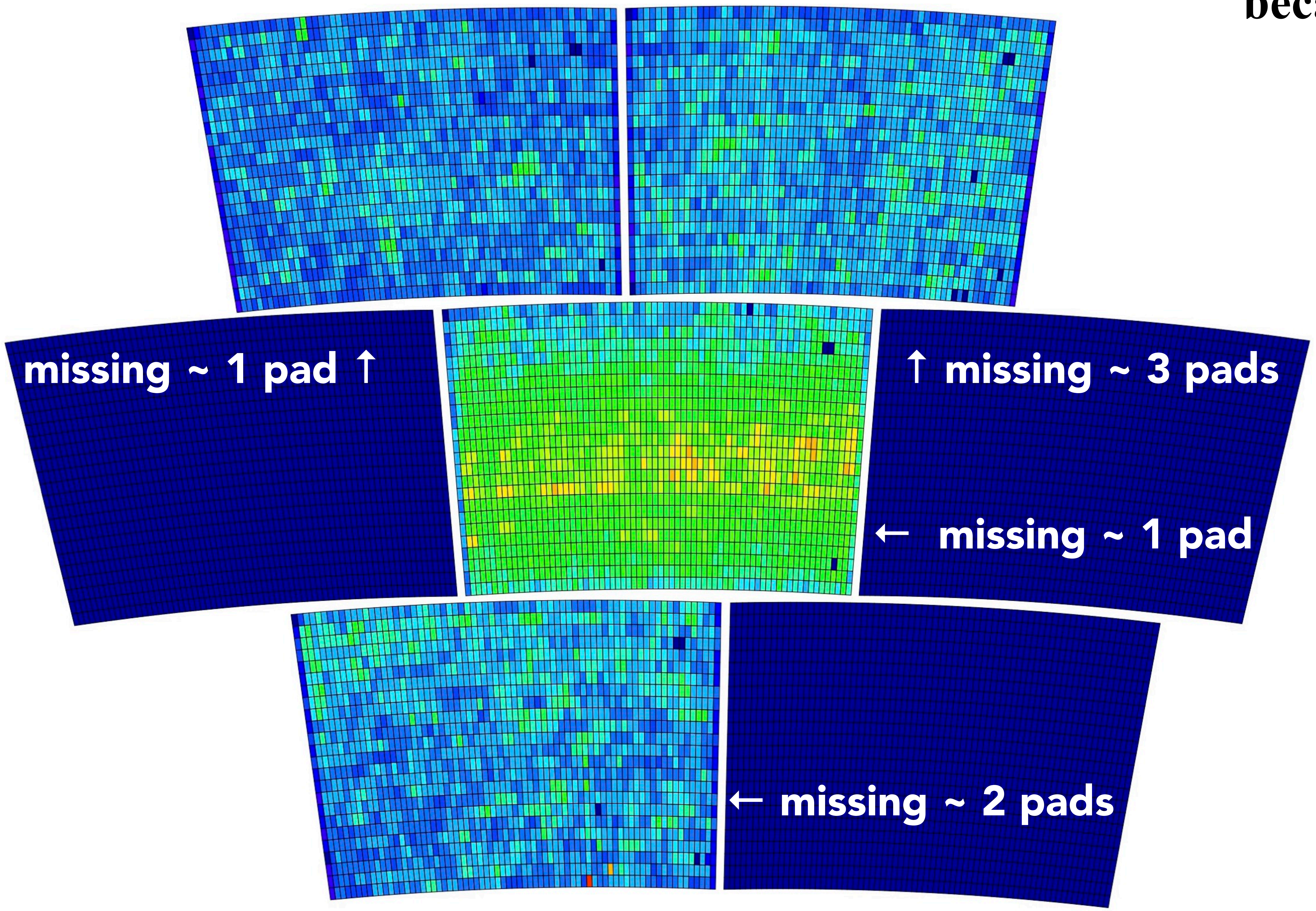




Condition of the modules

- ~ 99.9% channels are active

Accumulation of cosmics

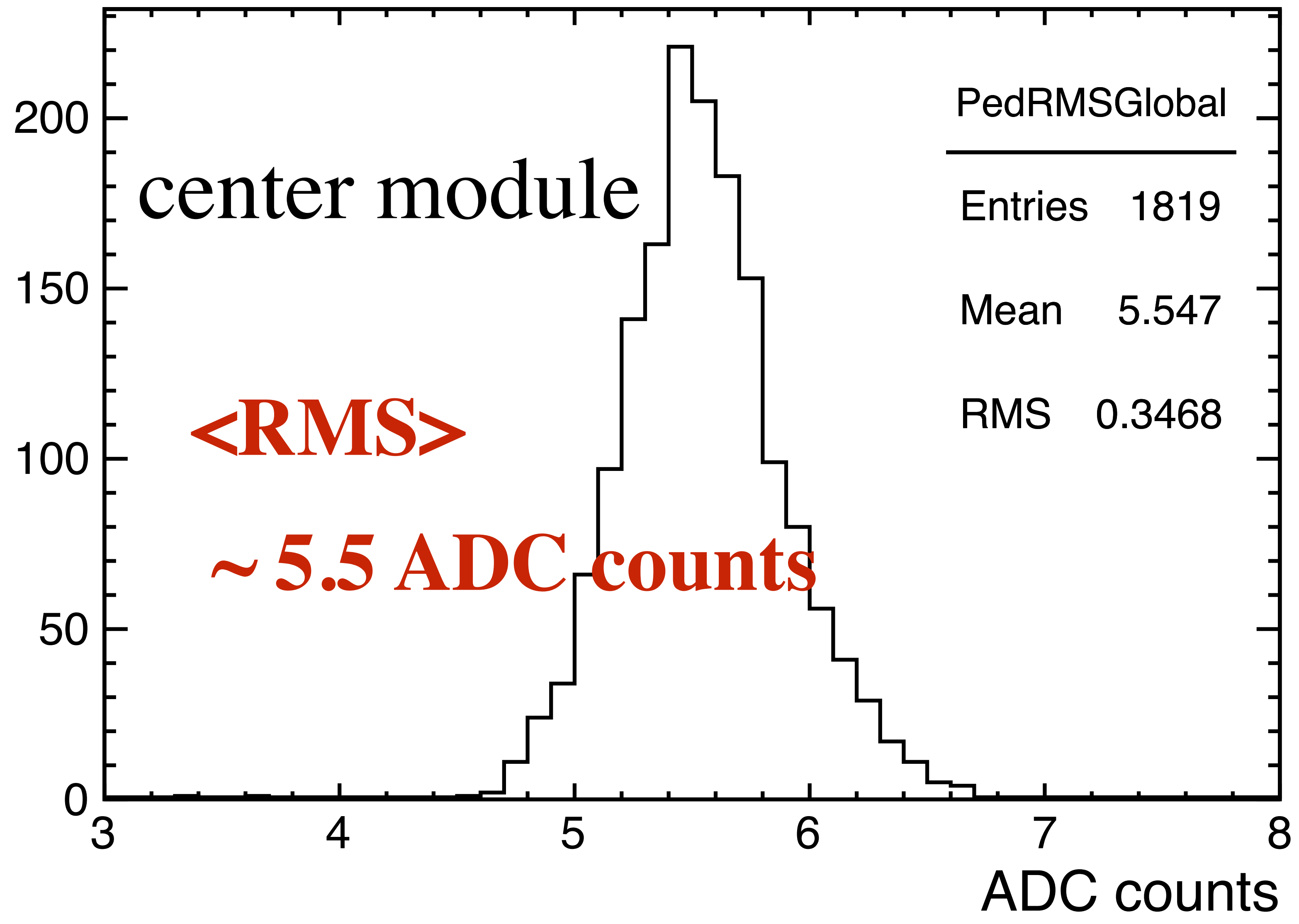


Due to electric circuit error
2pads in each module are missing.
=> it can be modified in next production.

1 ~4 missing pads in each module
because of disconnection btw connector &FEC

- Less noise contribution

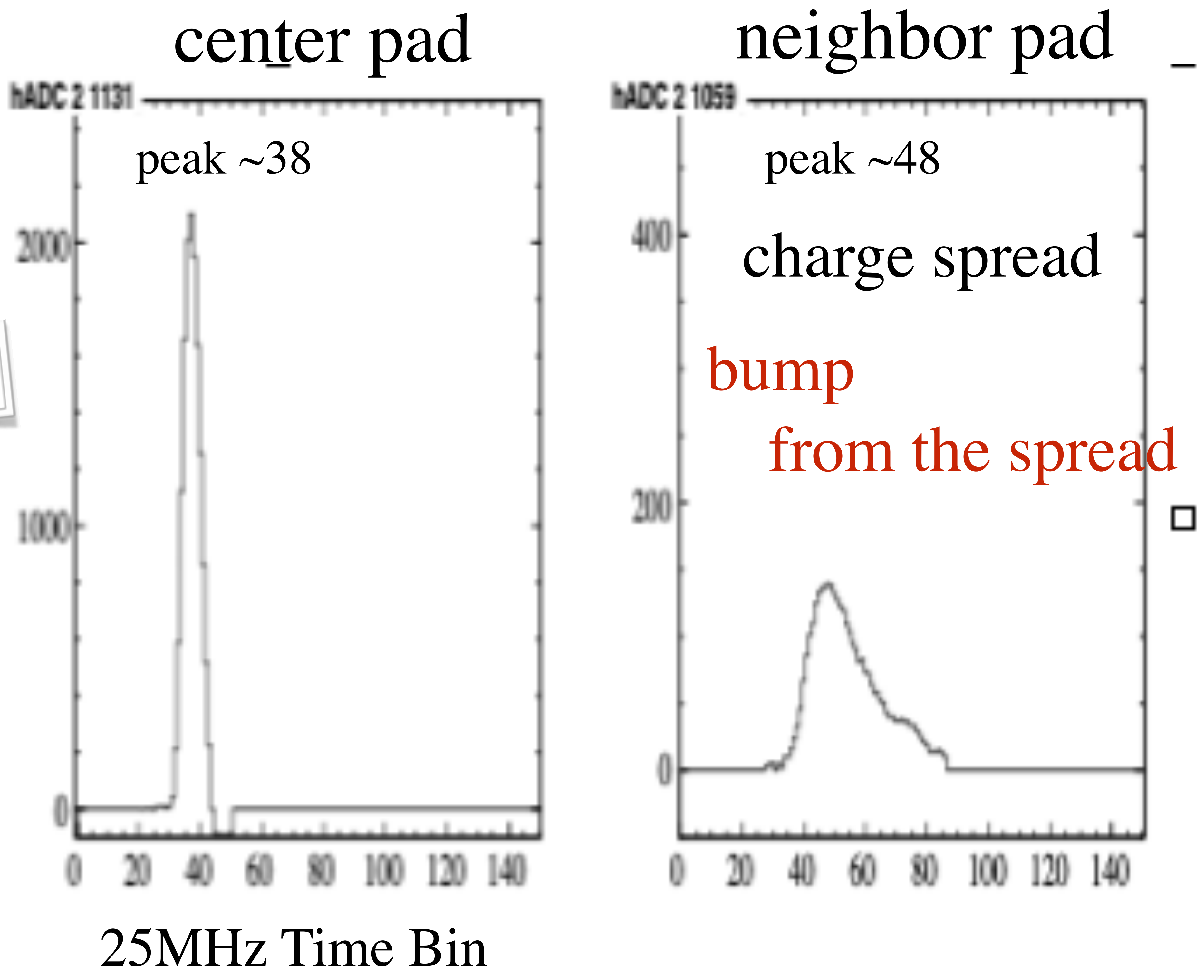
Pedestal-RMS dist. measured under B=1T



Dynamic range of ADC is 12 bit

Condition of pulse finding

- **Typical raw pulses**

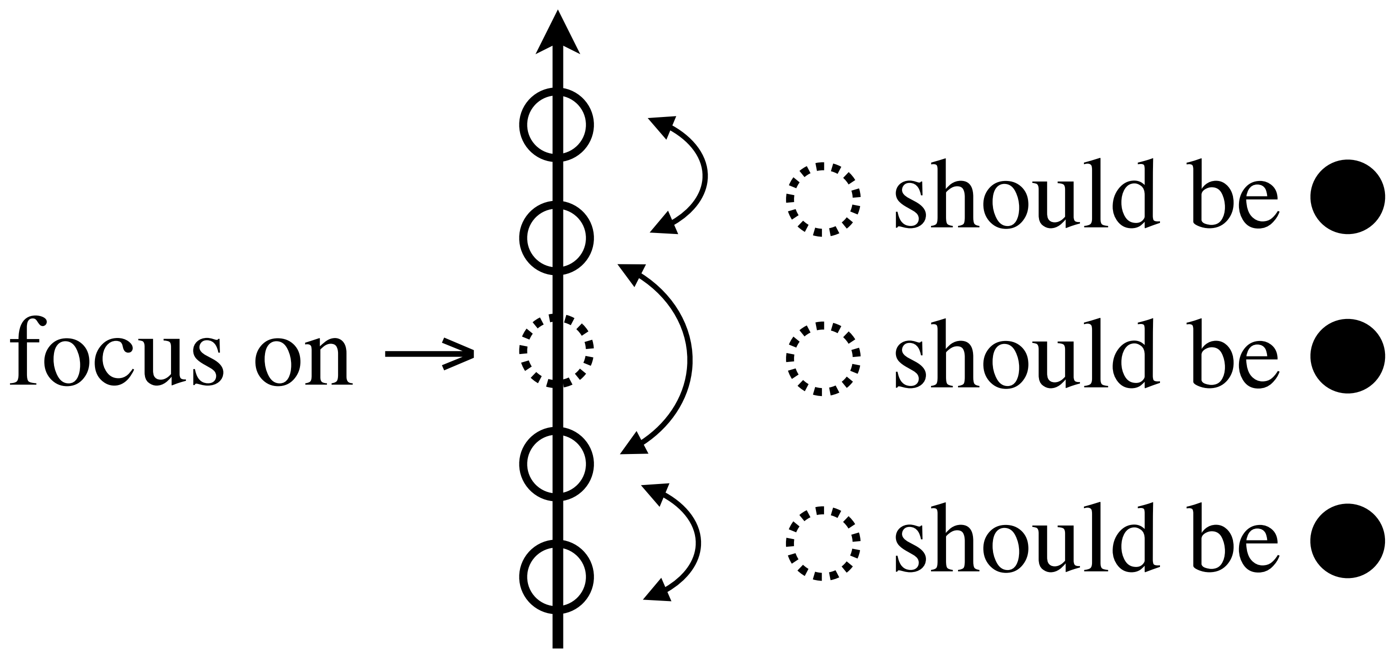


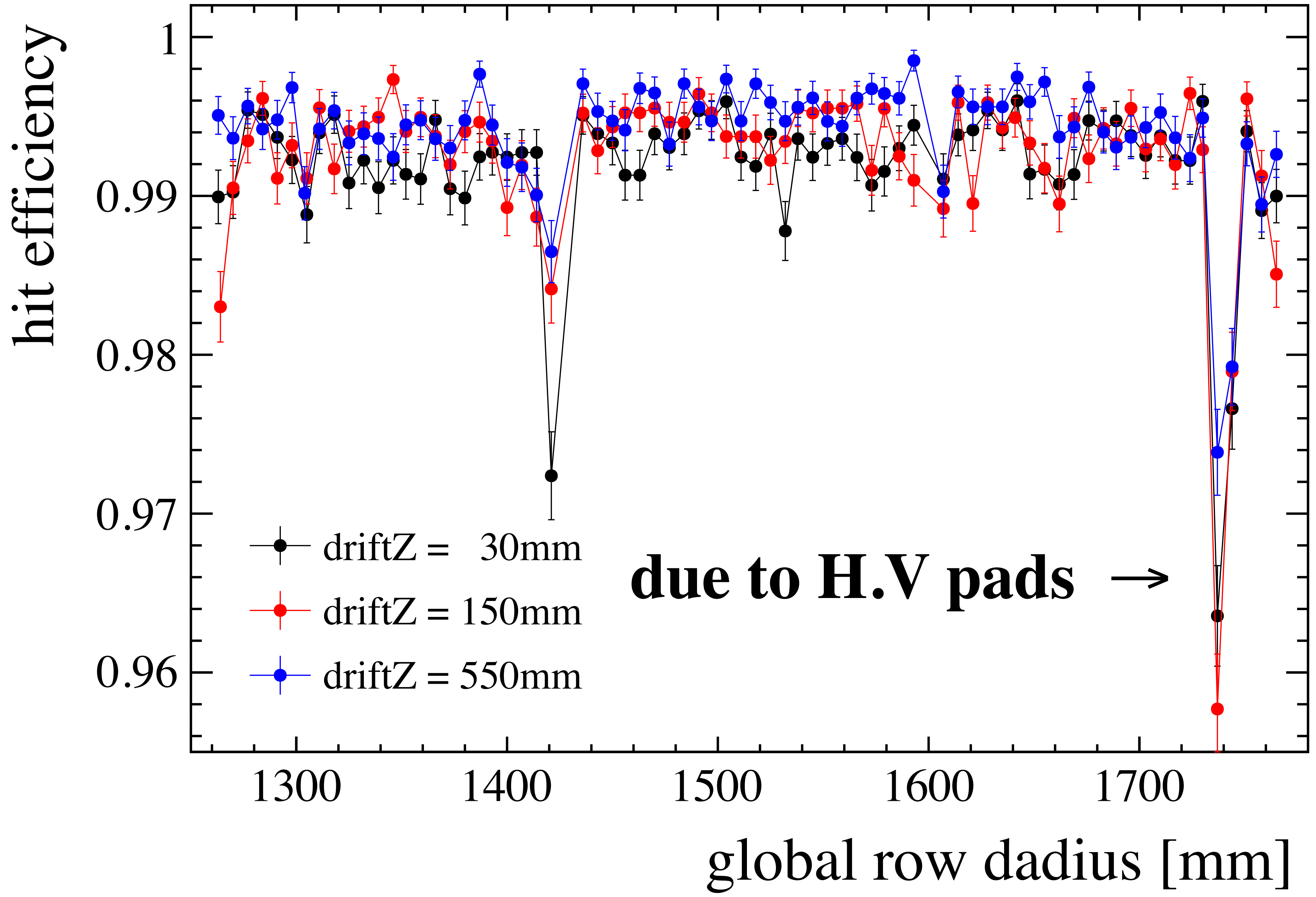
drift 3 cm

pulse clustering

- threshould **: 30**
- charge calculation **: Maximum** (avoid double counting)
- time calculation **: gaussian inflection point**

- **Hit efficiency** = $\frac{\textbf{\#of actual Hit}}{\textbf{\#of expected Hit}}$





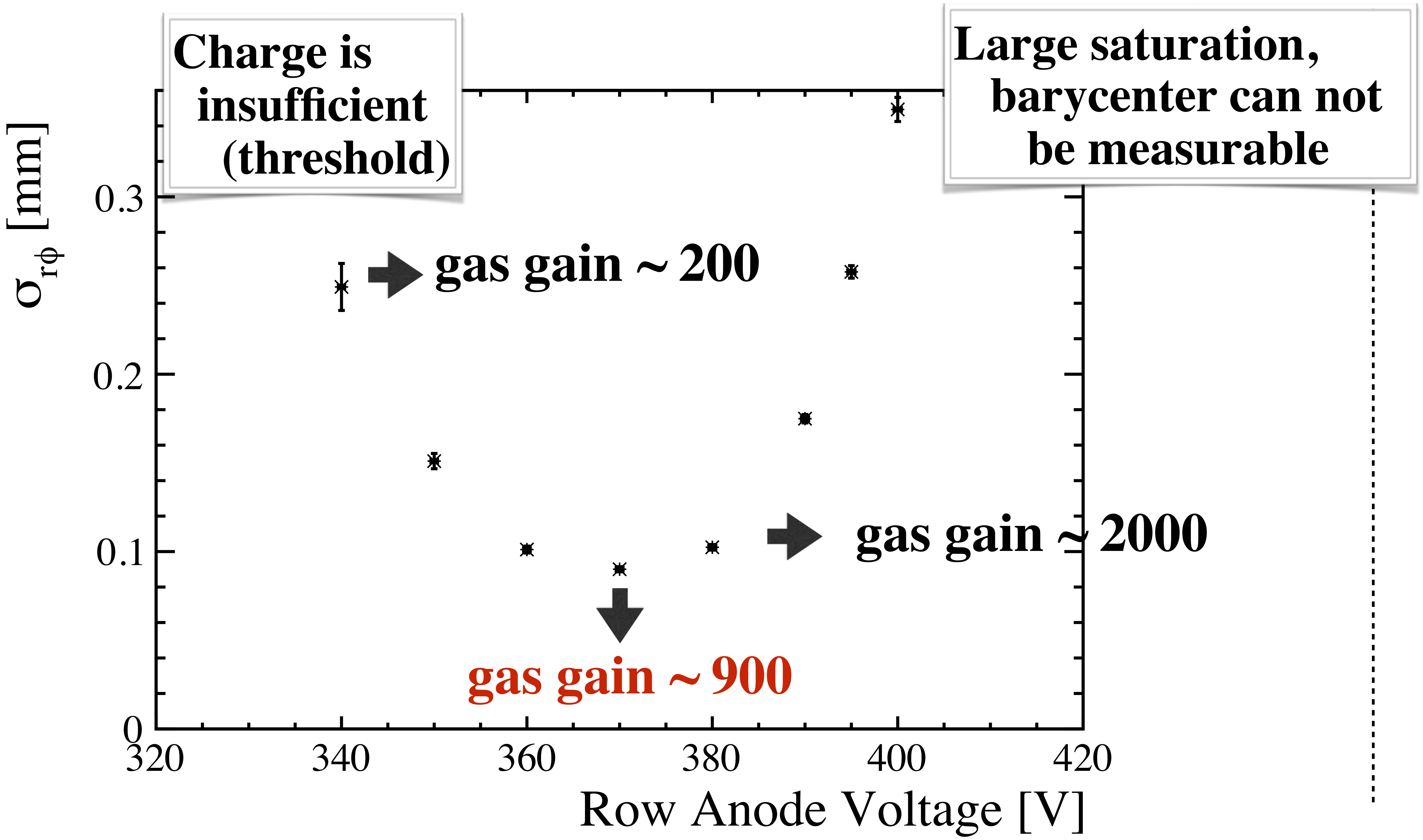
efficiency > 99%

Condition H.V and gain drop

- **Optimization of H.V.**

- **σrφ as a function of anode voltage (amplification)**

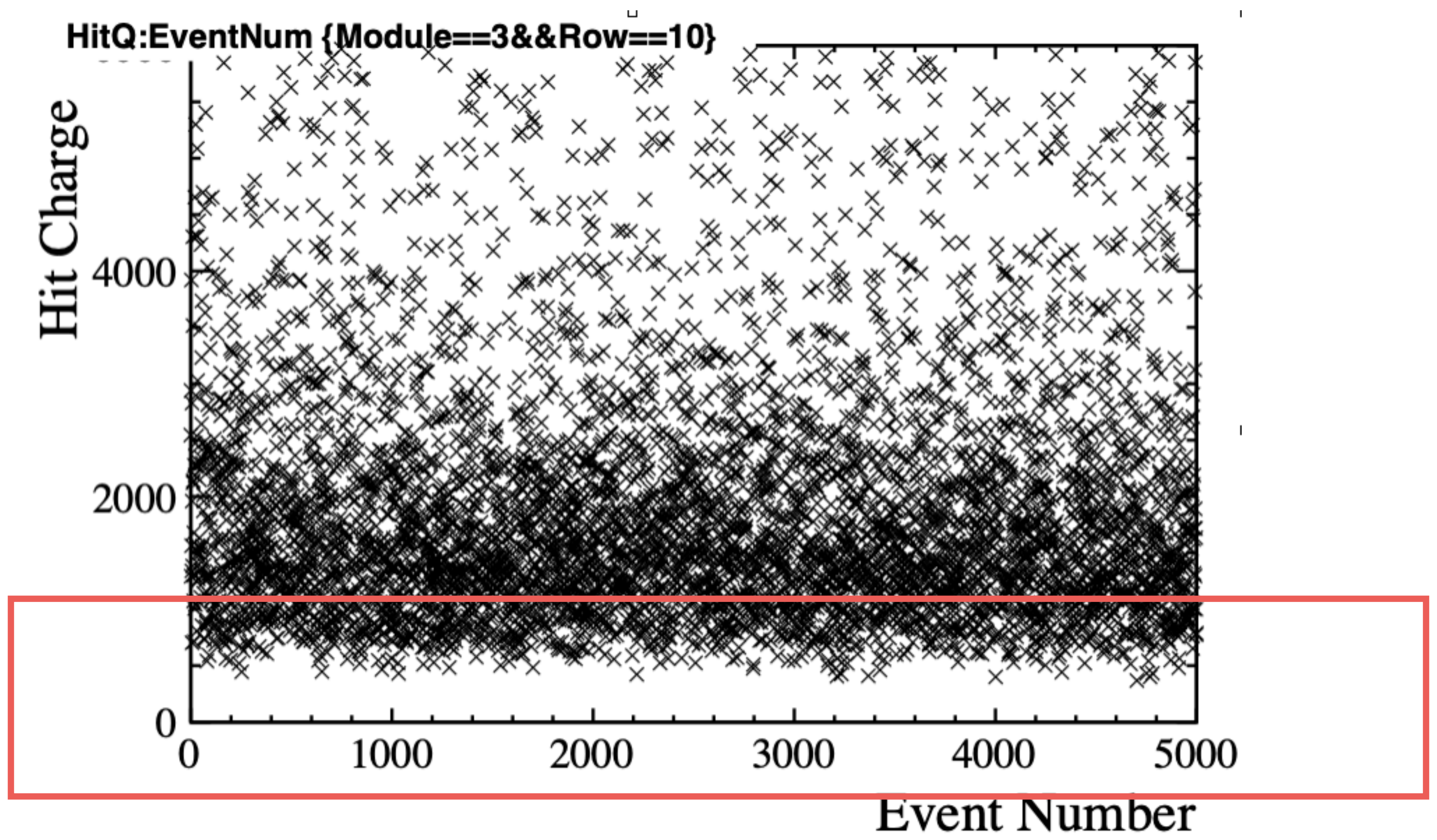
  (σrφ : width of a $\Delta = x_{track} - x_{hit}$ distribution)



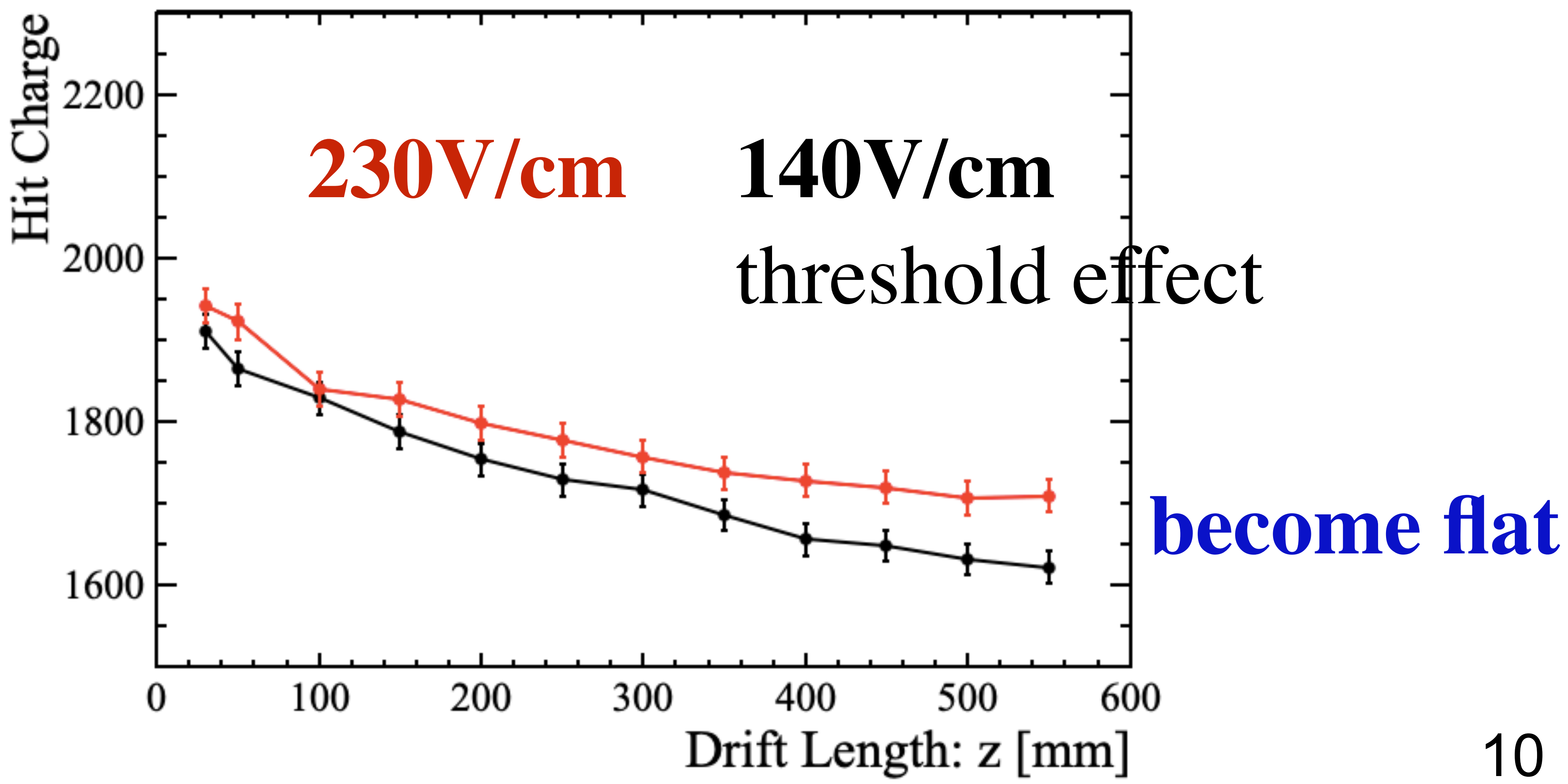
No gain drop during the operation

(at least 50 physics runs ~ 500 min.)

anode voltage = 370V, #ofTracks>0

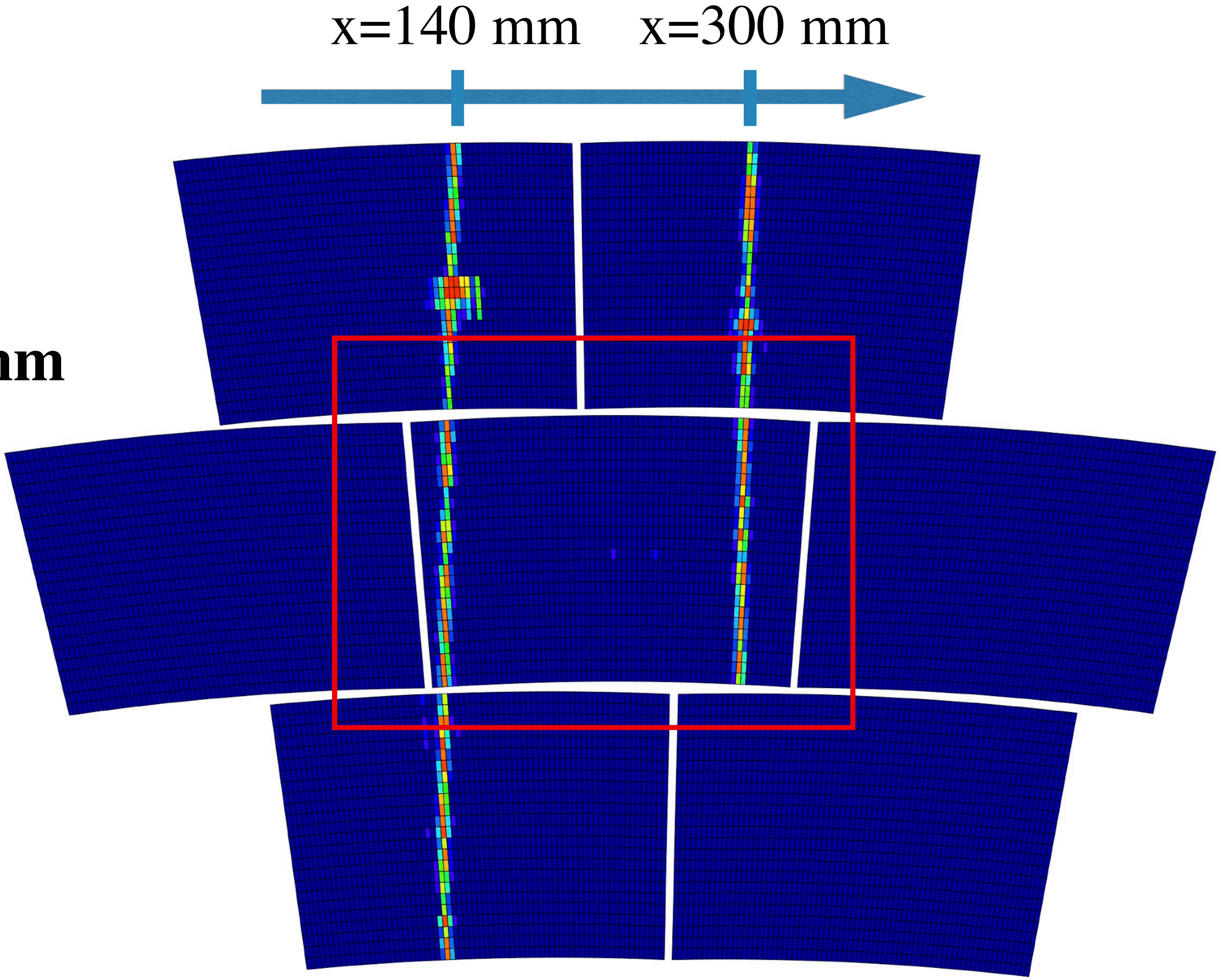


No absorption of seed electrons



gas gain : reference Figure 5-2 in PhD:WANG_WENXIN (Fig 7-3 with 5GeV) .

Uniformities in rφ for charge spread, resolution



Drift length ~ 70 mm

Kill the other modules in analysis level

Uniformity of charge spread (center)

https://indico.cern.ch/event/698927/contributions/2872364/

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

Gaussian spreading as a function of time with σ_r = sqrt(2t/RC)

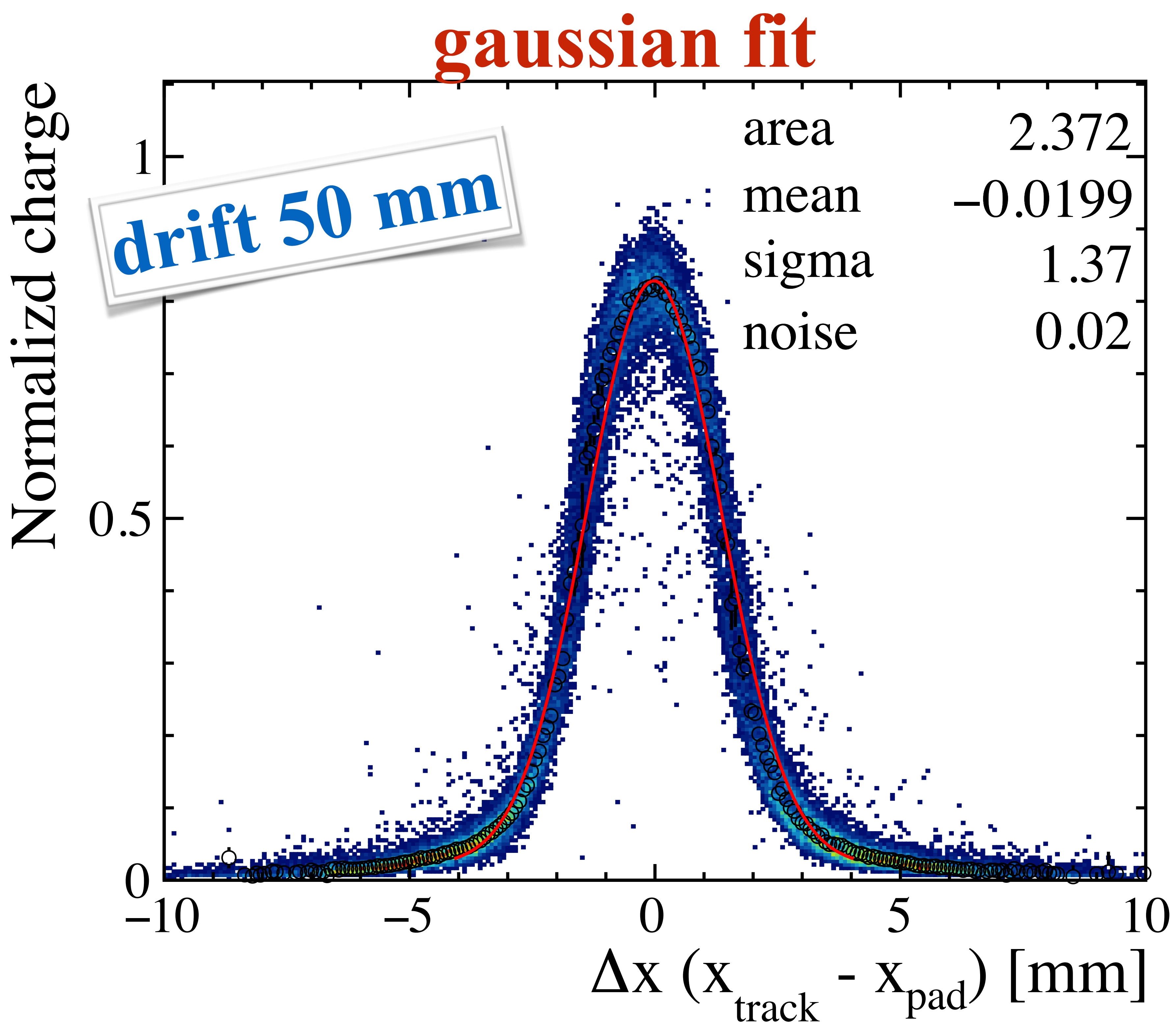
R- surface resistivity
C- capacitance/unit area

- **Pad responce function**

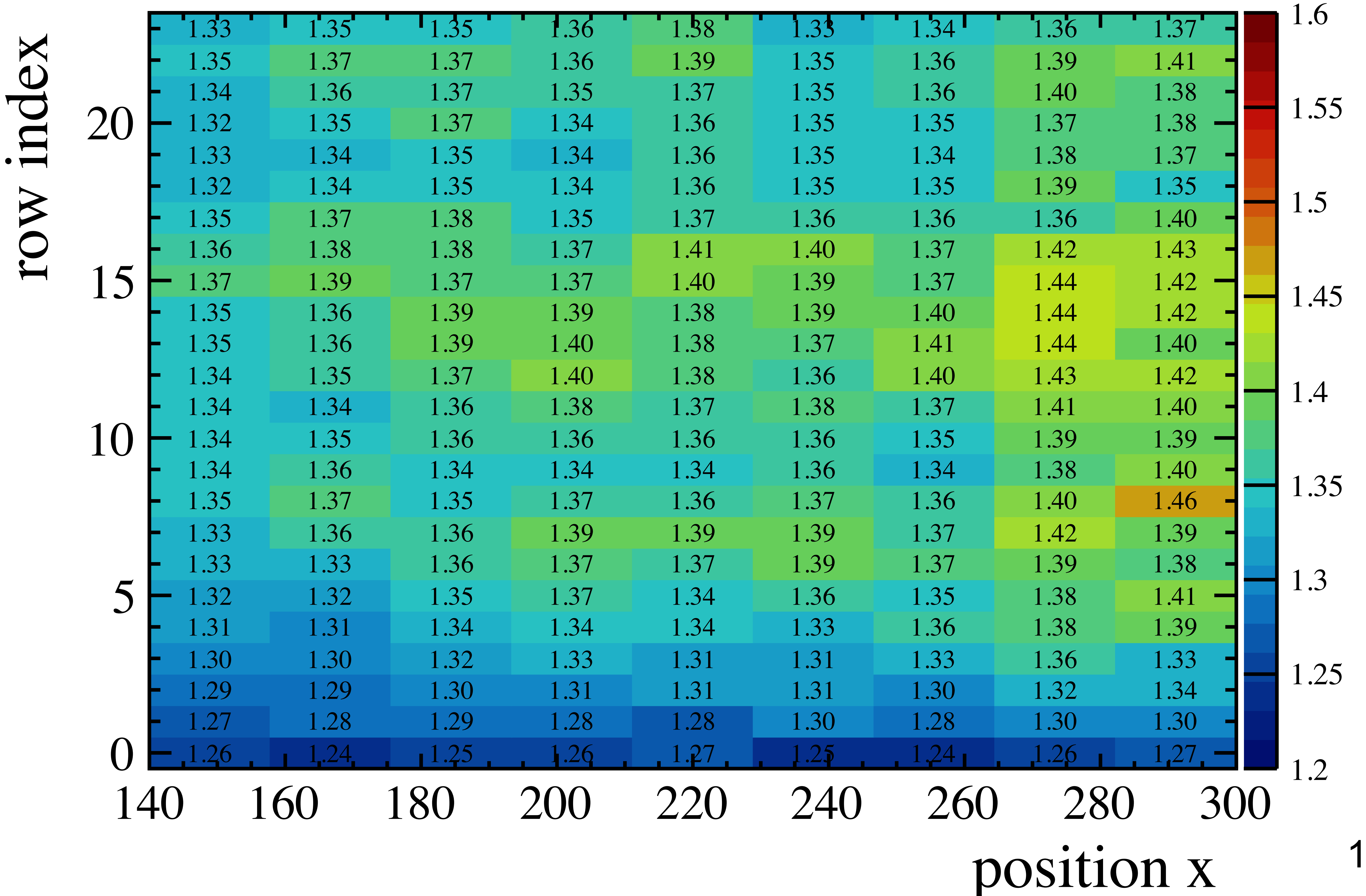
σ = 1.4 mm is suited for 3mm-width to share amplified charge with a few pads

Expectation : for **R= 2.5 Mohm/sq, shaping 200ns,**

200+50μm kapton, σ will be ~ 1.4 mm

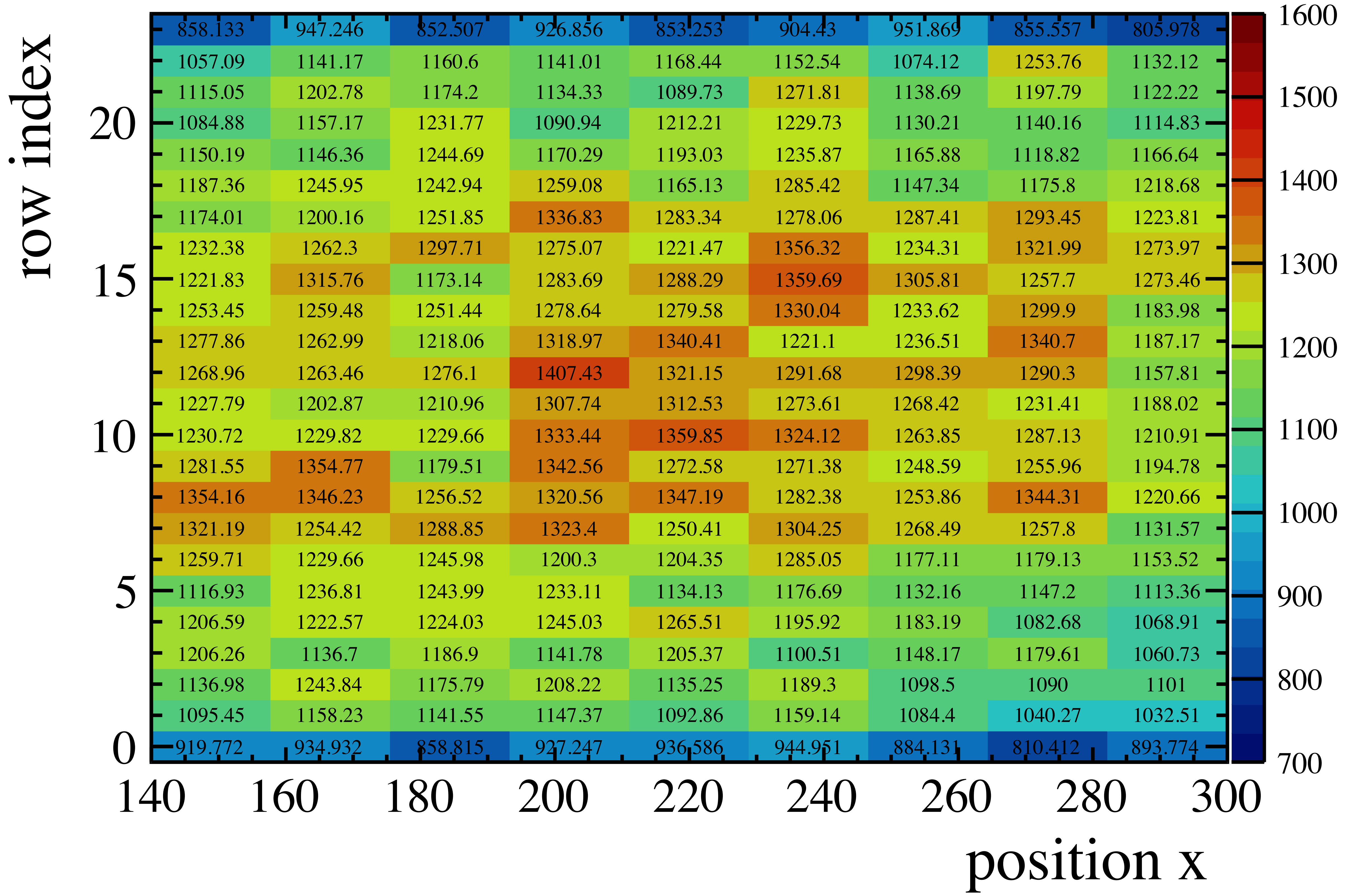


Map showing width of gaussian [mm]
over the center module

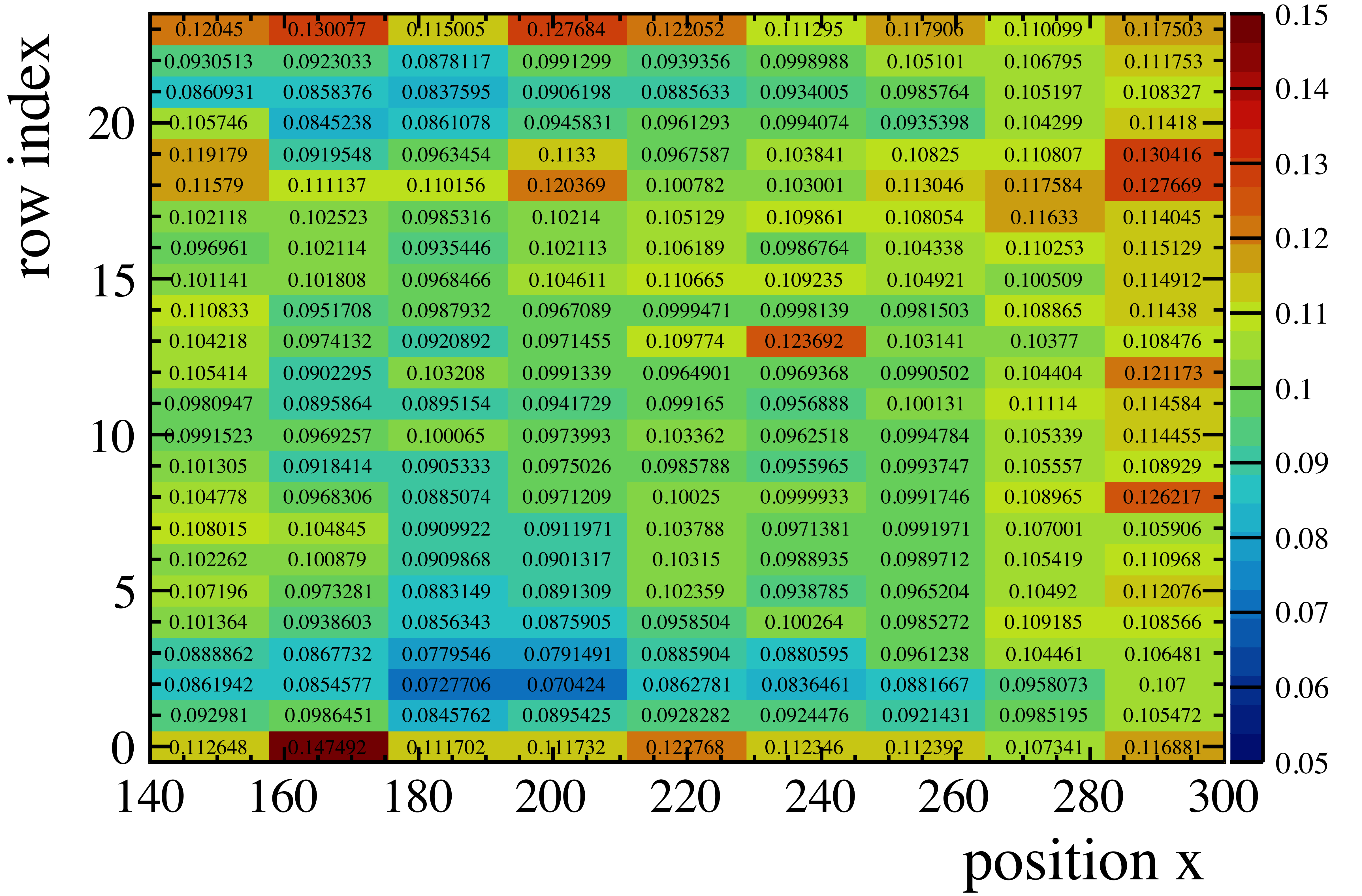


Uniformity of Hit charge & σrφ (center)

Map showing an associated HIT charge
over the center module



Map showing σrϕ
over the center module

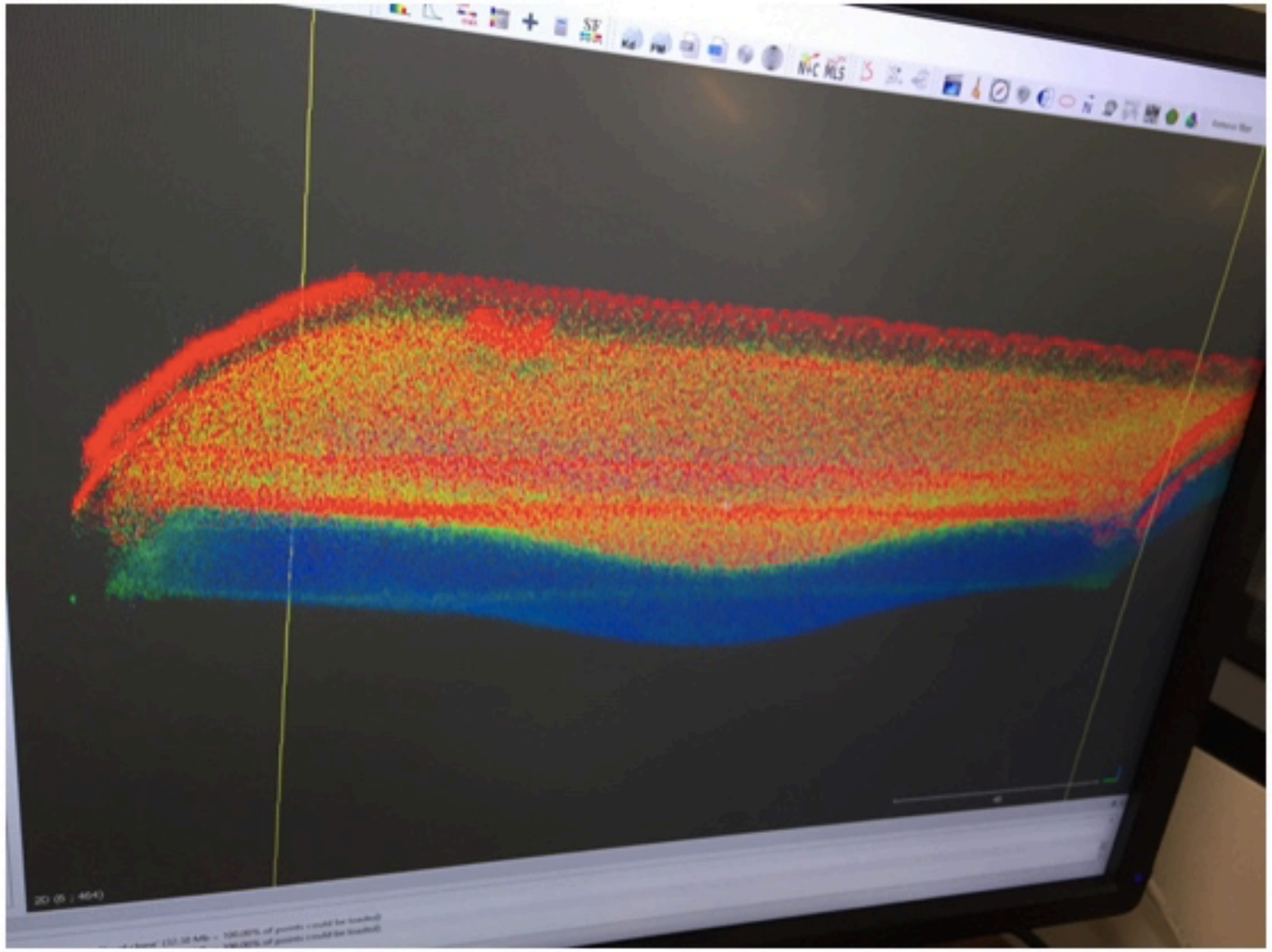


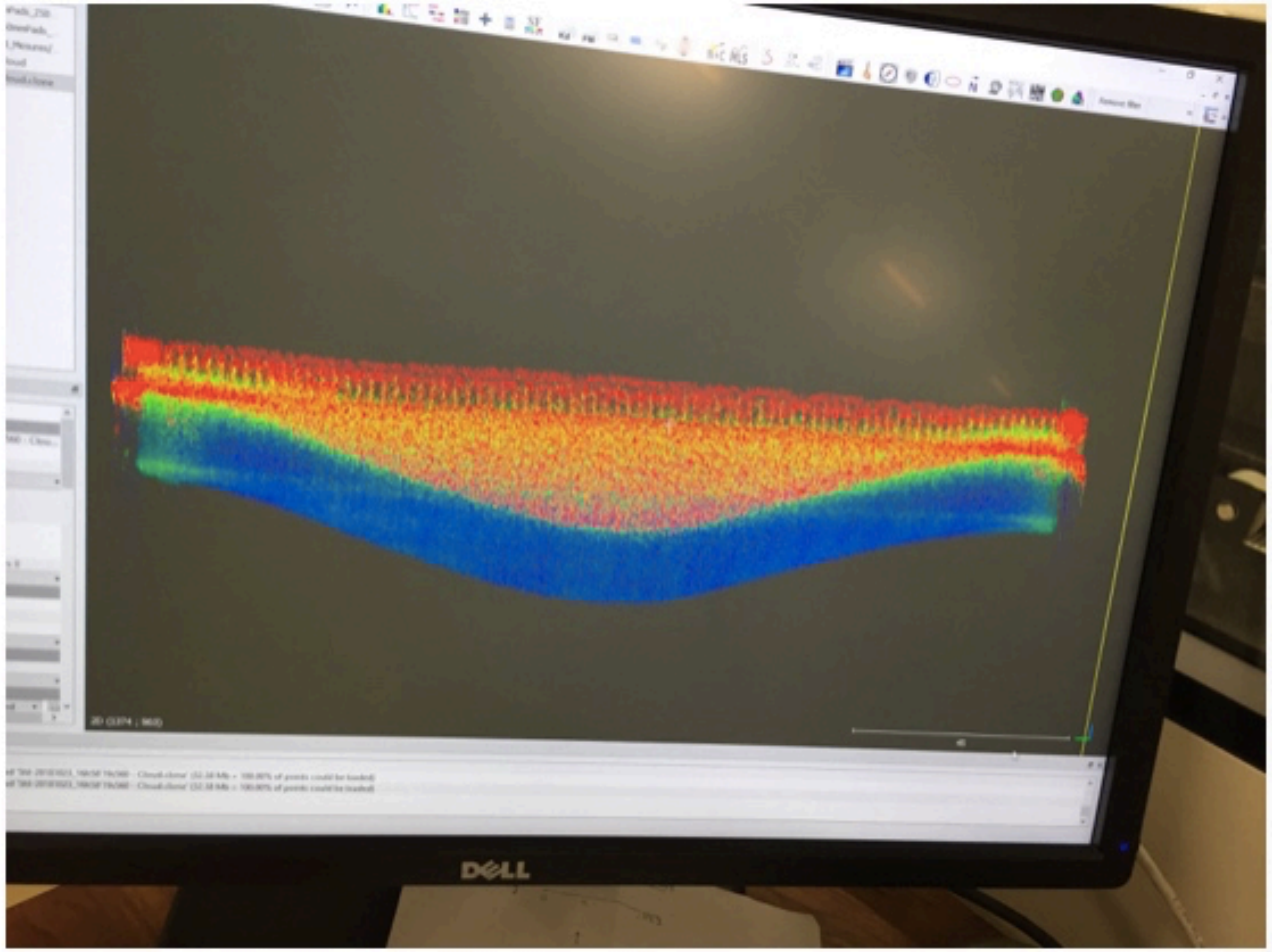
Looks that the center part has large charge
because of geometrical effect (deformation around the center)
gain variation ~ 30% (1300 vs 1000)

No clear variation

Geometry scan (old module)

Still under study



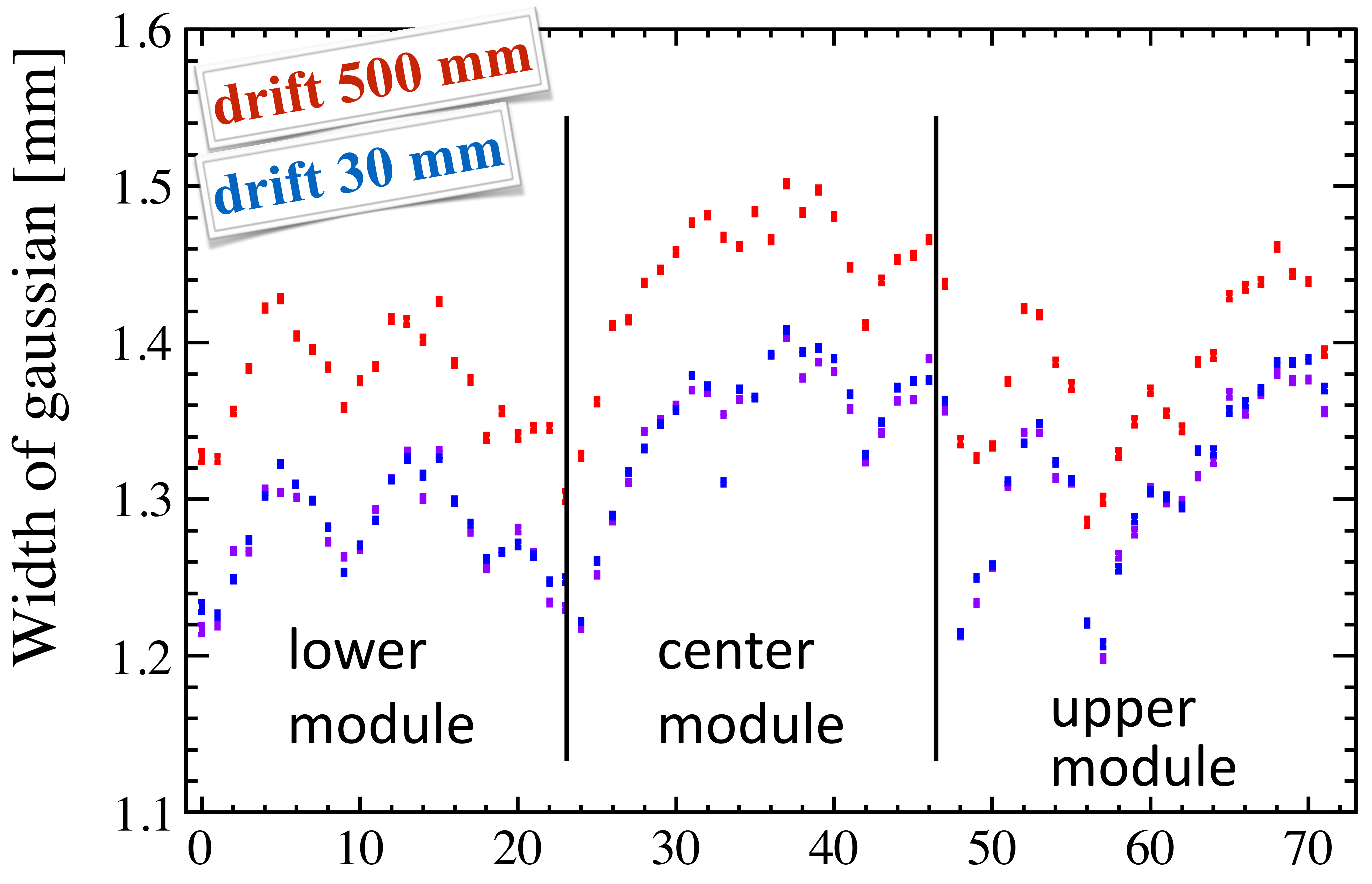


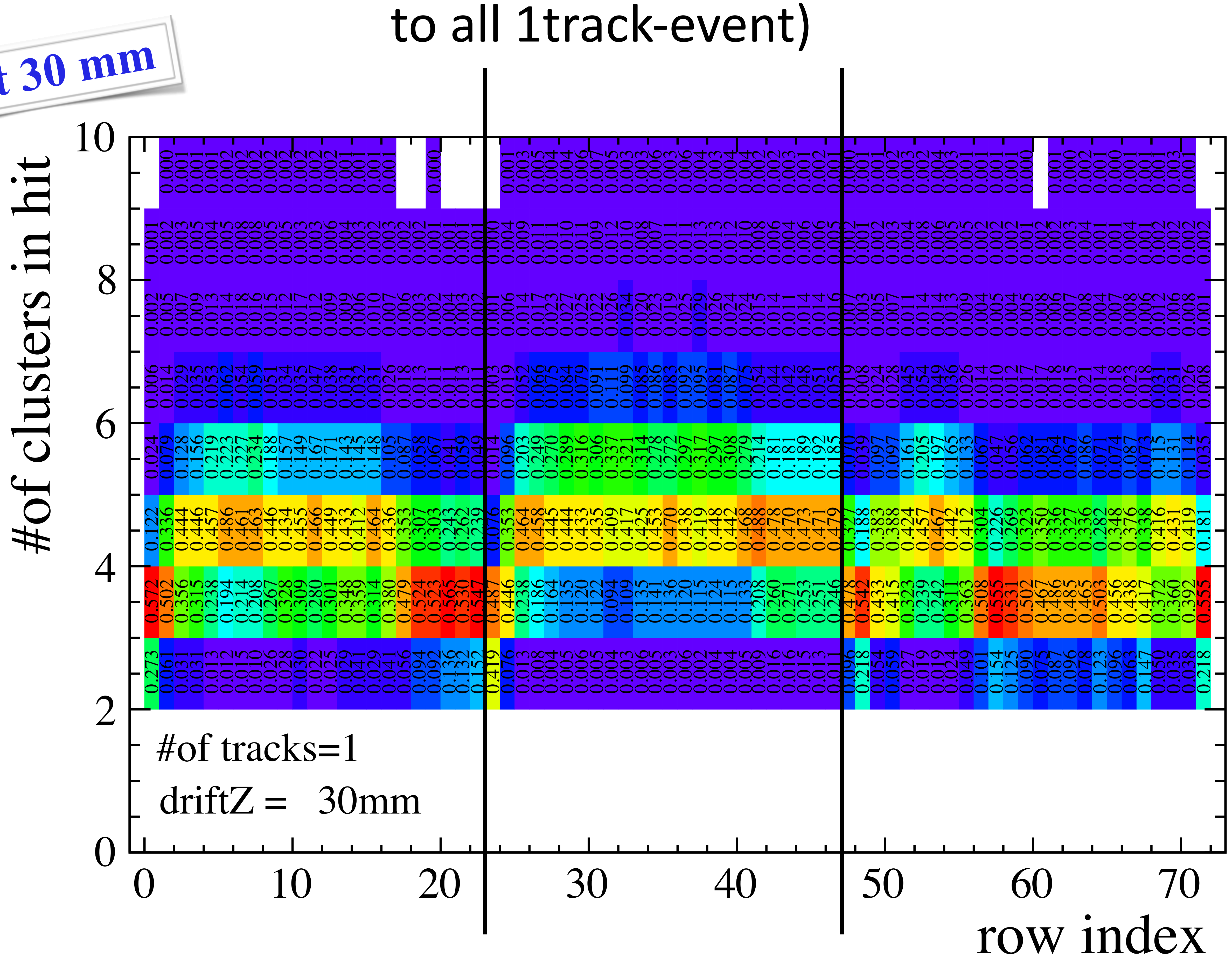
Uniformity of Hit charge & σrφ (3modules)

- **Charge spread for 3-module**

#of clusters/pulses in Hit object
(each row is normalized
to all 1track-event)

width of gaussian [mm]





center: #of 3 pulses ~ 10%

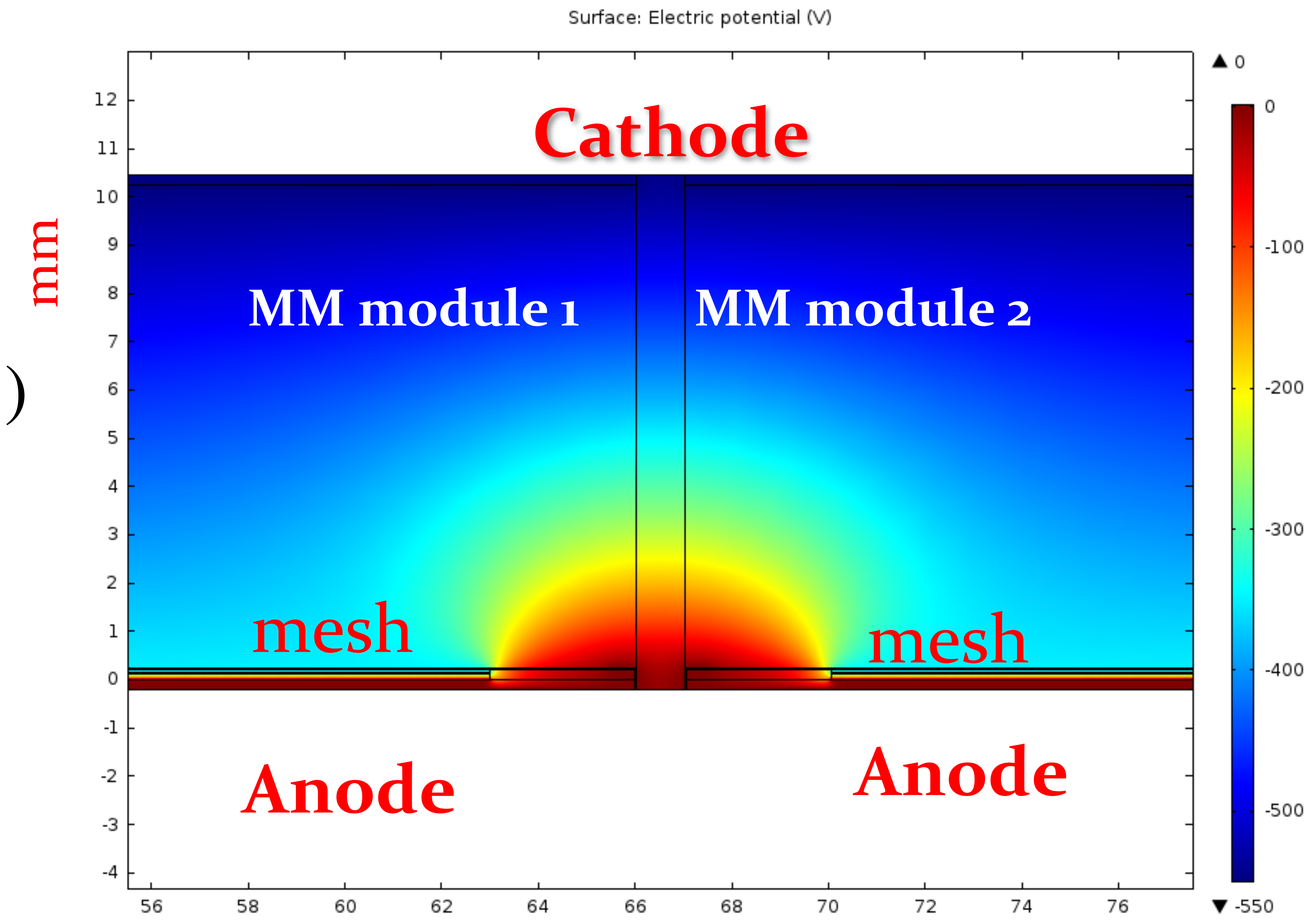
#of 2 pulses ~ 0%

the over all behavior is consistent with the spread

Track distortions
B=0, 1T

=> <u>*150119_D.S.Bhattacharya_AperoSPP*</u>

potential map [V]



large difference of potential in the module boundary

The inhomogeneity of

the magnetic field (non-uniformity of material budget of magnet)

the electric field in the detector (the anode/ module gaps)

=> induce ExB effects

=> drift paths of electrons are affected.

Track distortions B= 0 T

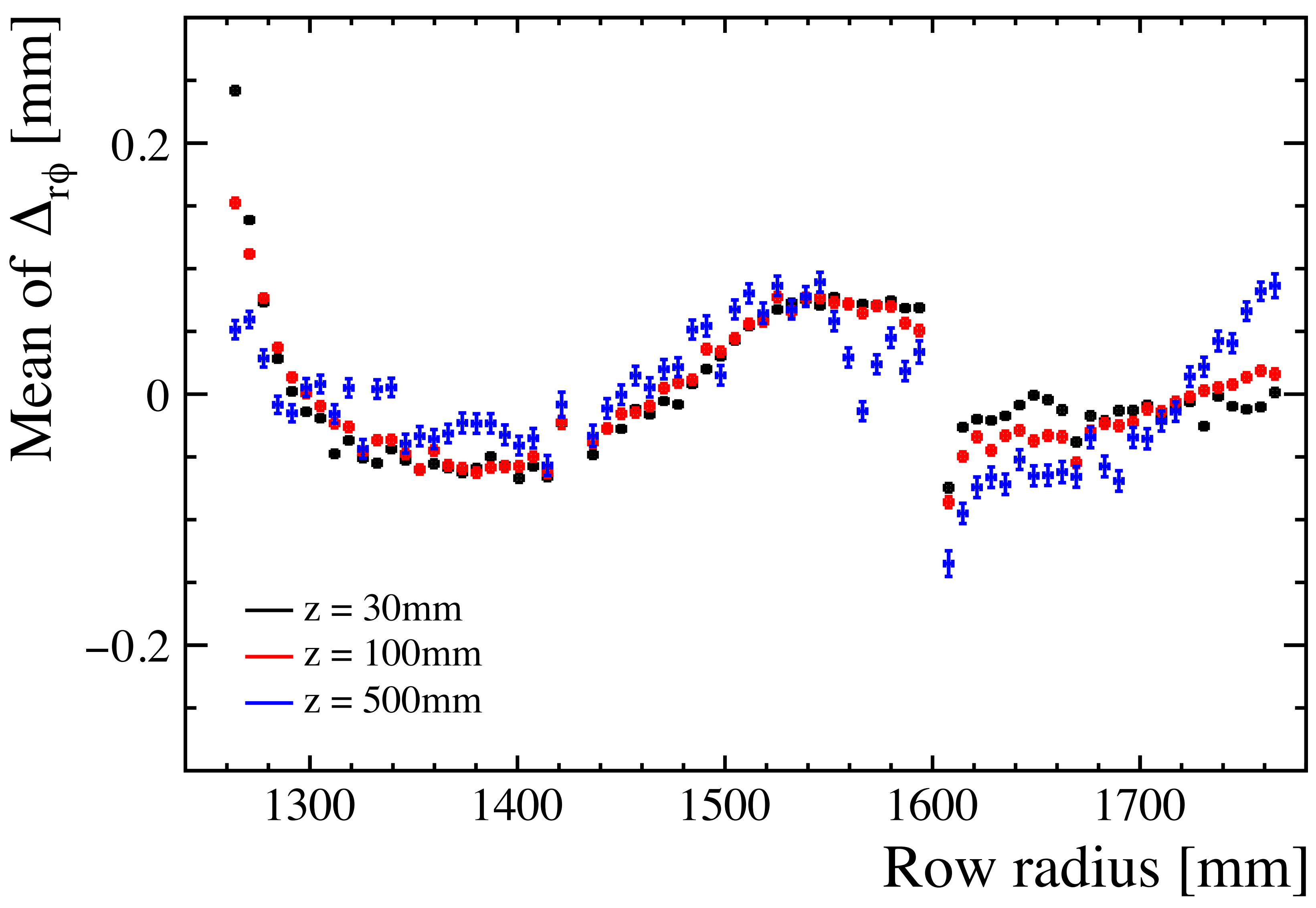
(After bias corrections (local RC properties))

- **Essential distortion**

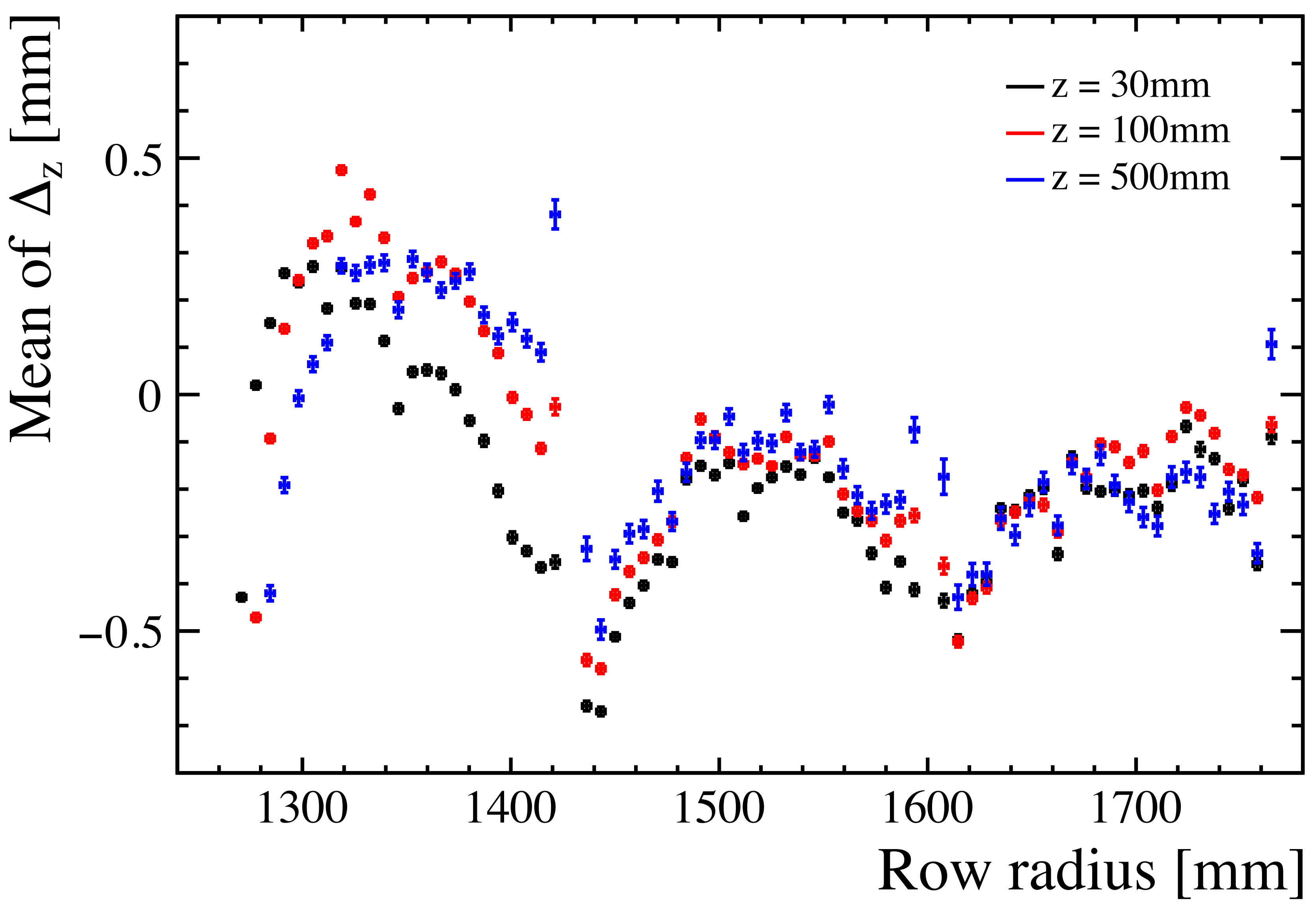
Ed= 230V/cm
Data selection :
#of tracks=1,
No saturated pulse

Δx = Hit - track

track distortion in rφ



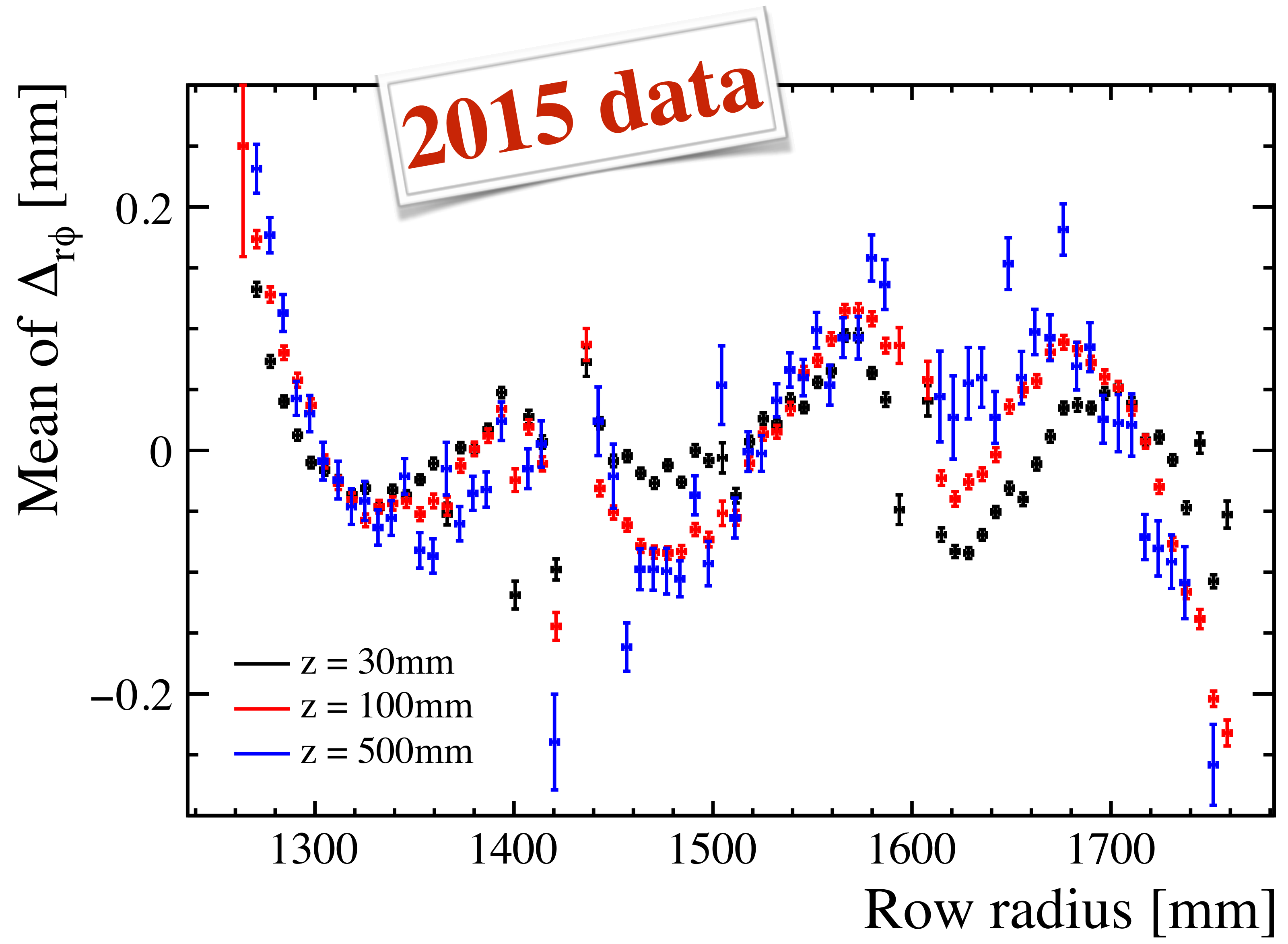
track distortion in Z



Good improvement
for over the (center) module

Distortion between
module & field cage
must be investigated

electrode is tilted ….



↑ **Hight of the detector is not uniform …**

Need to do alignment study…

↑ **Δz has the structure**
electric force line is distorted

Track distortions B= 1 T

(After bias corrections (local RC properties))

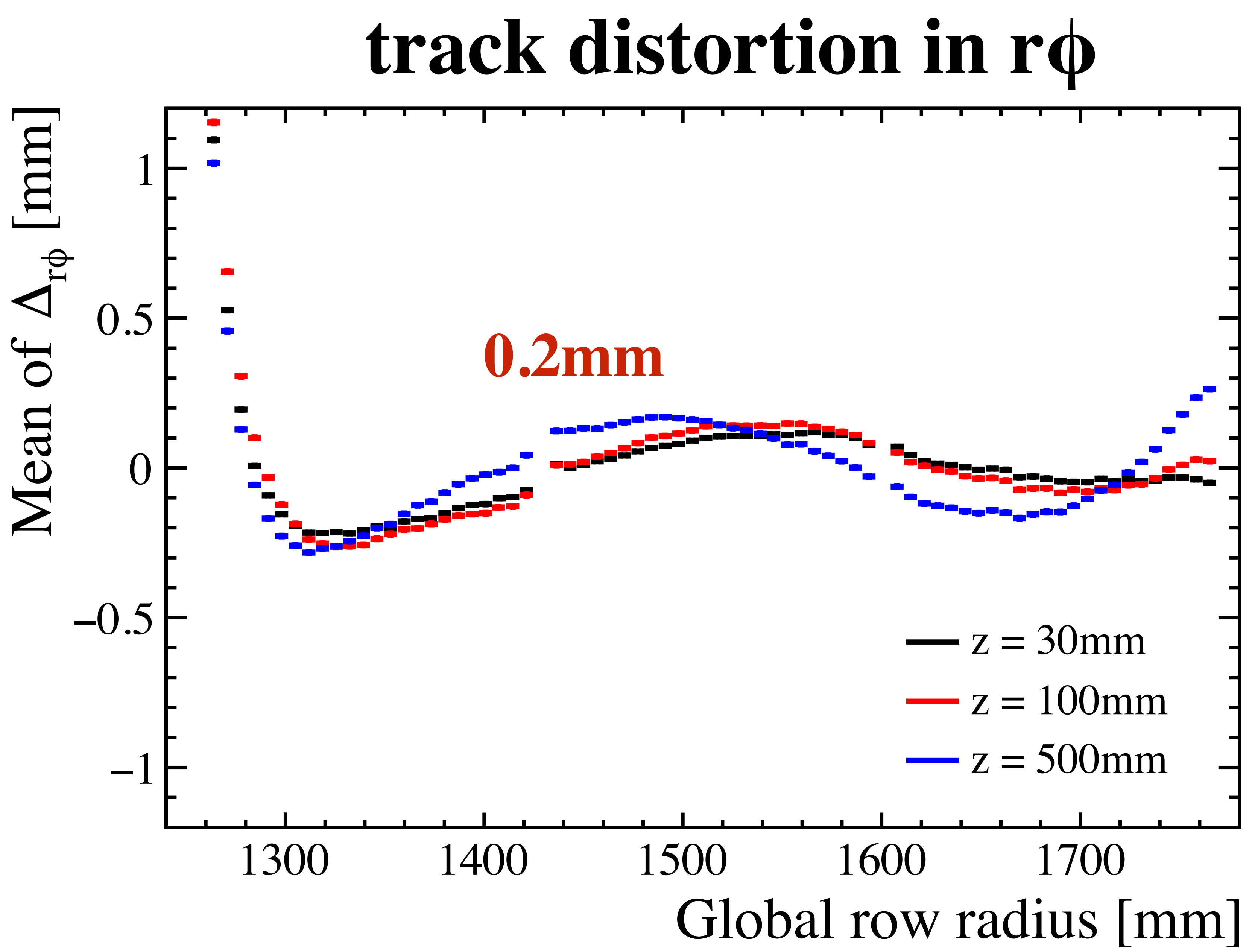
- **Including ExB**

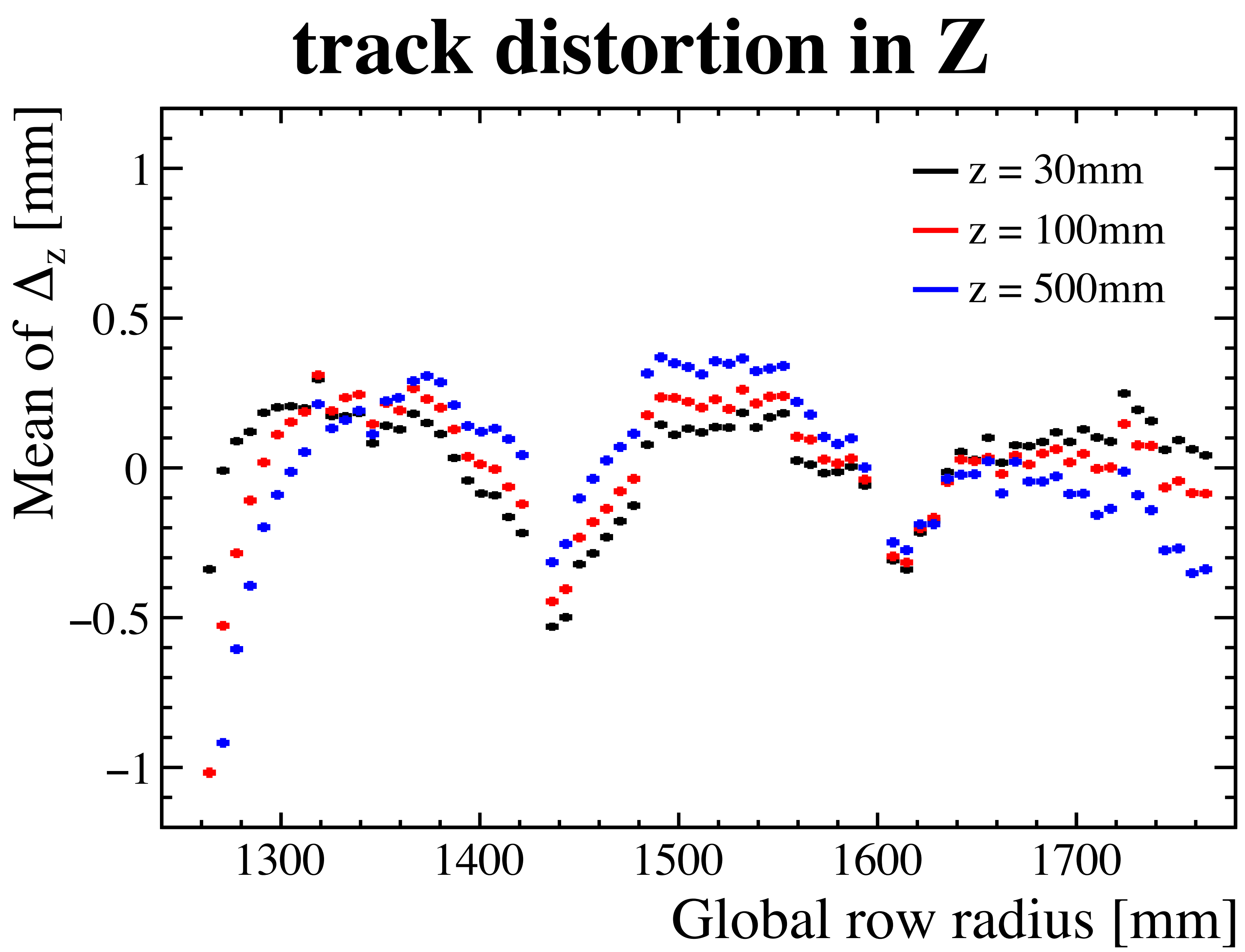
Ed= 230V/cm
Data selection :
#of tracks=1,
No saturated pulse

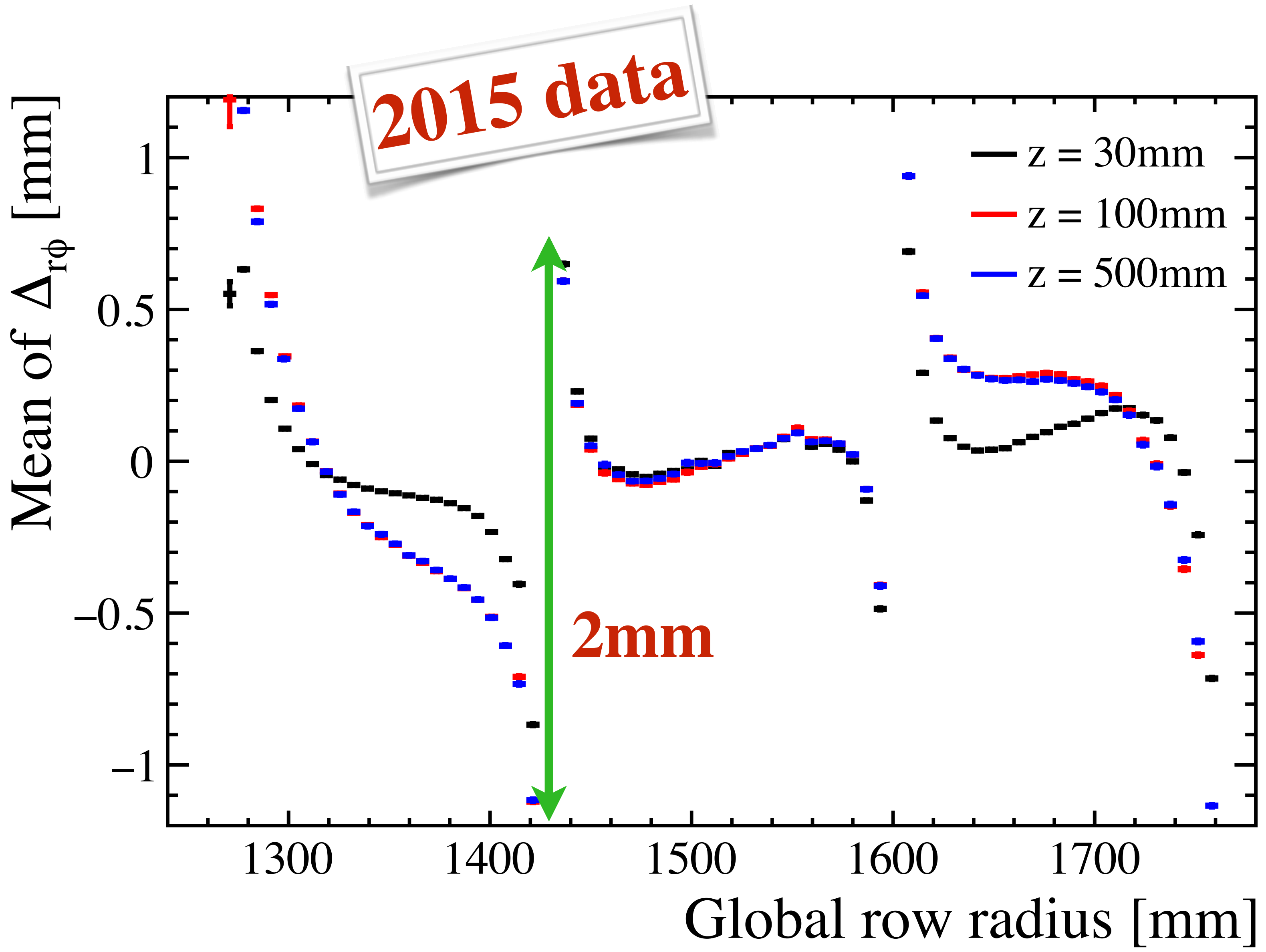
Δ = Hit - track

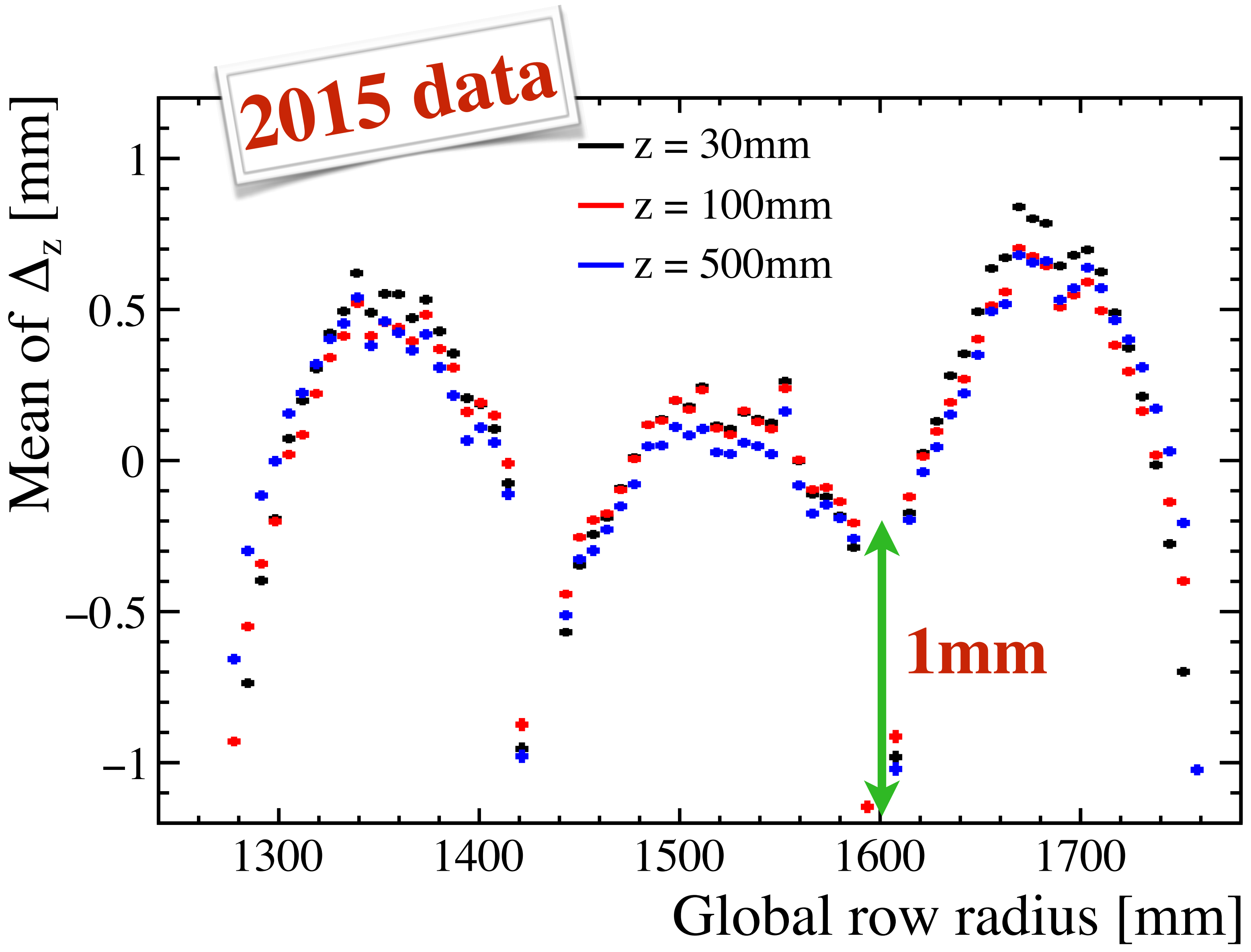
In 2015, z=100 mm has already big distortions.

Huge improvement (10 times) between the module boundary









Track distortions B= 1 T

- **Different (flexibility) H.V. configuration**

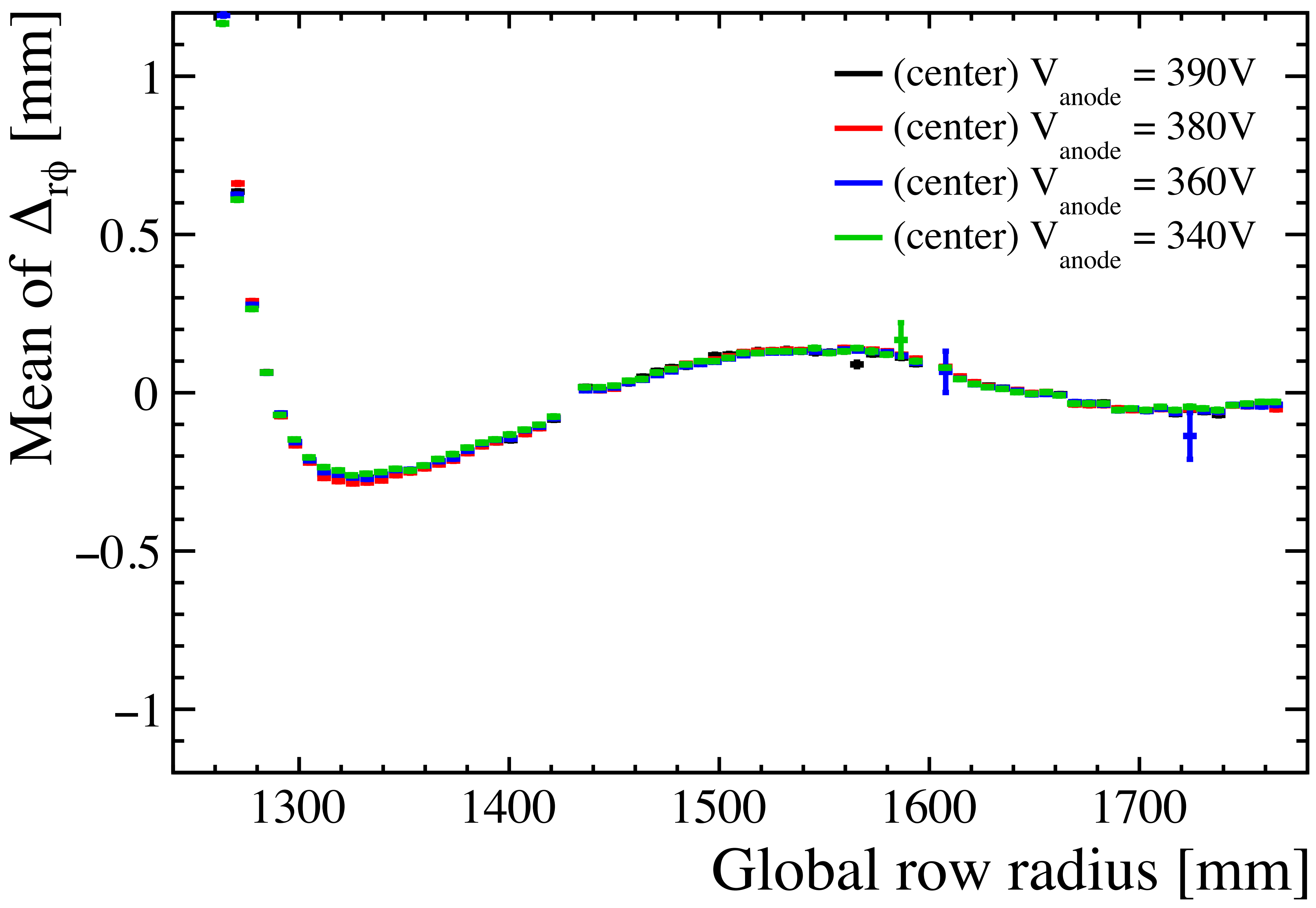
Ed= 230V/cm
Data selection :
#of tracks=1,
No saturated pulse

Anode (lower&upper) = 380V

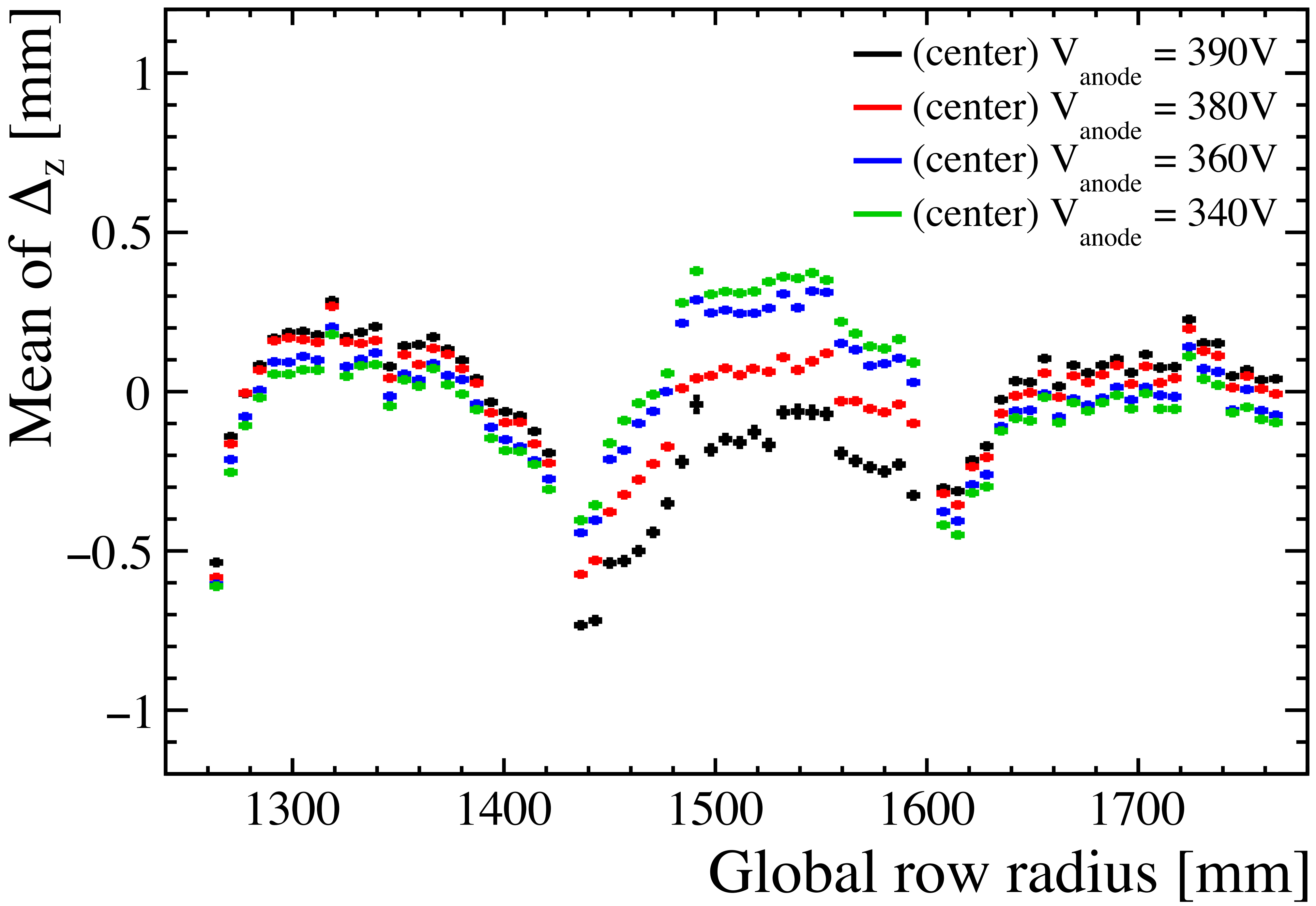
Anode (center) = 390, 380, 360, 340 …. 0 V

No distortion in rϕ, but Z has something

track distortion in rϕ



track distortion in Z



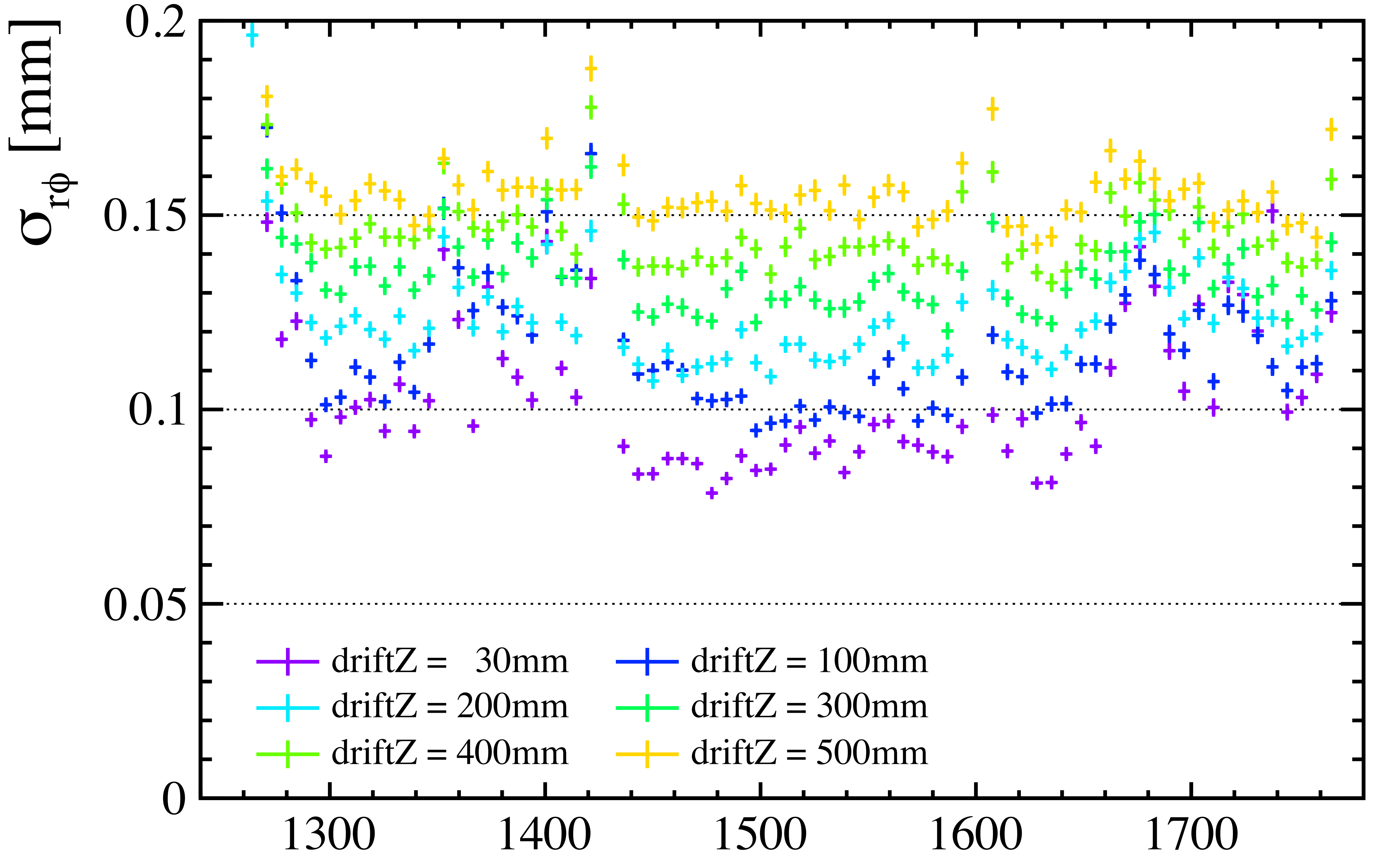
rφ & z resolutions over the 3modules

- **Magnetic field 1T with Ed=230V/cm**

Diffusion is dominant for longer drifts and σrϕ is uniform

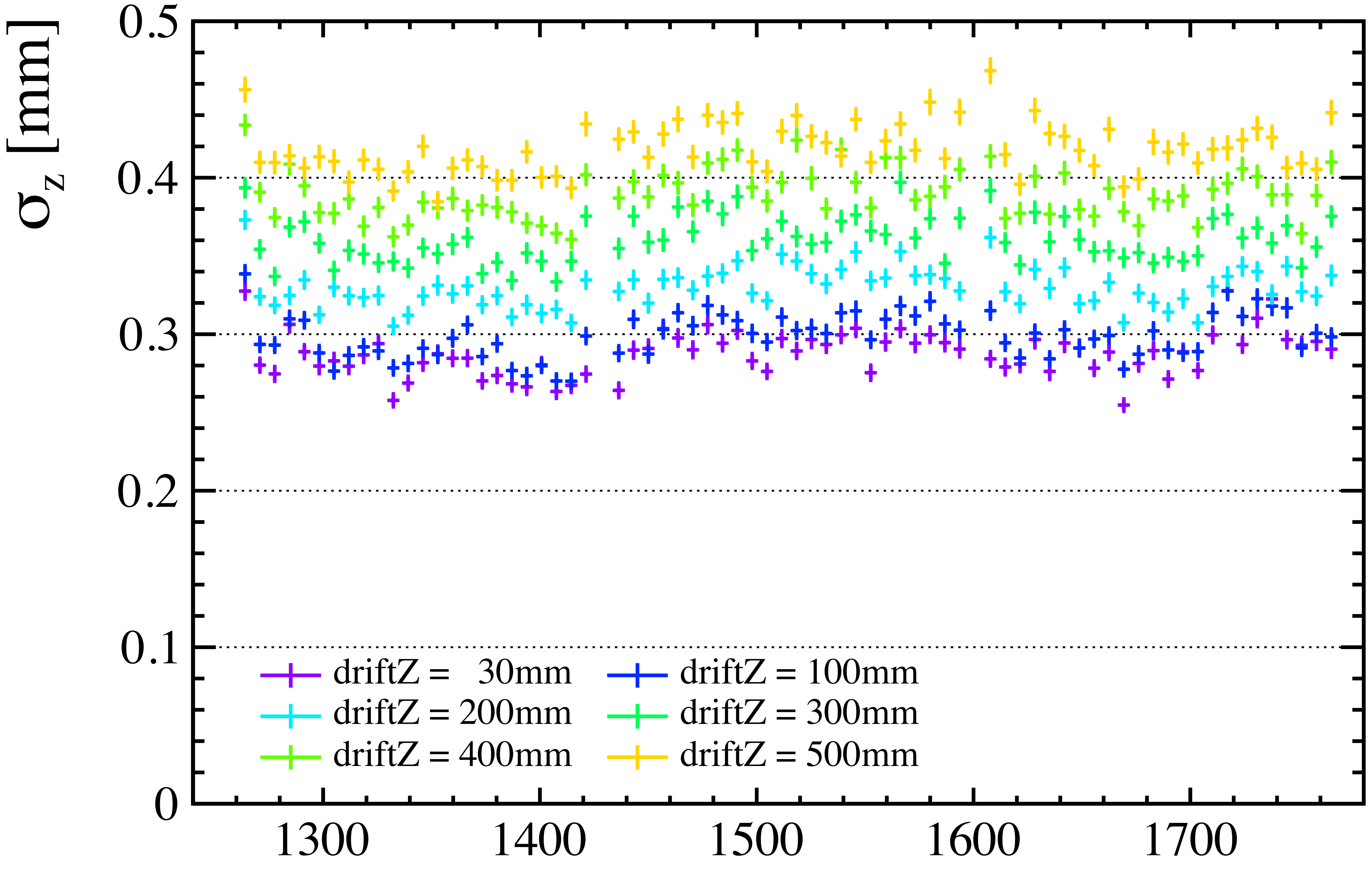
σrϕ is not uniform for shorter drifts due to #of clustered -> charge spread

Row dependence on σrϕ



Global row radius

Row dependence on σz



Global row radius

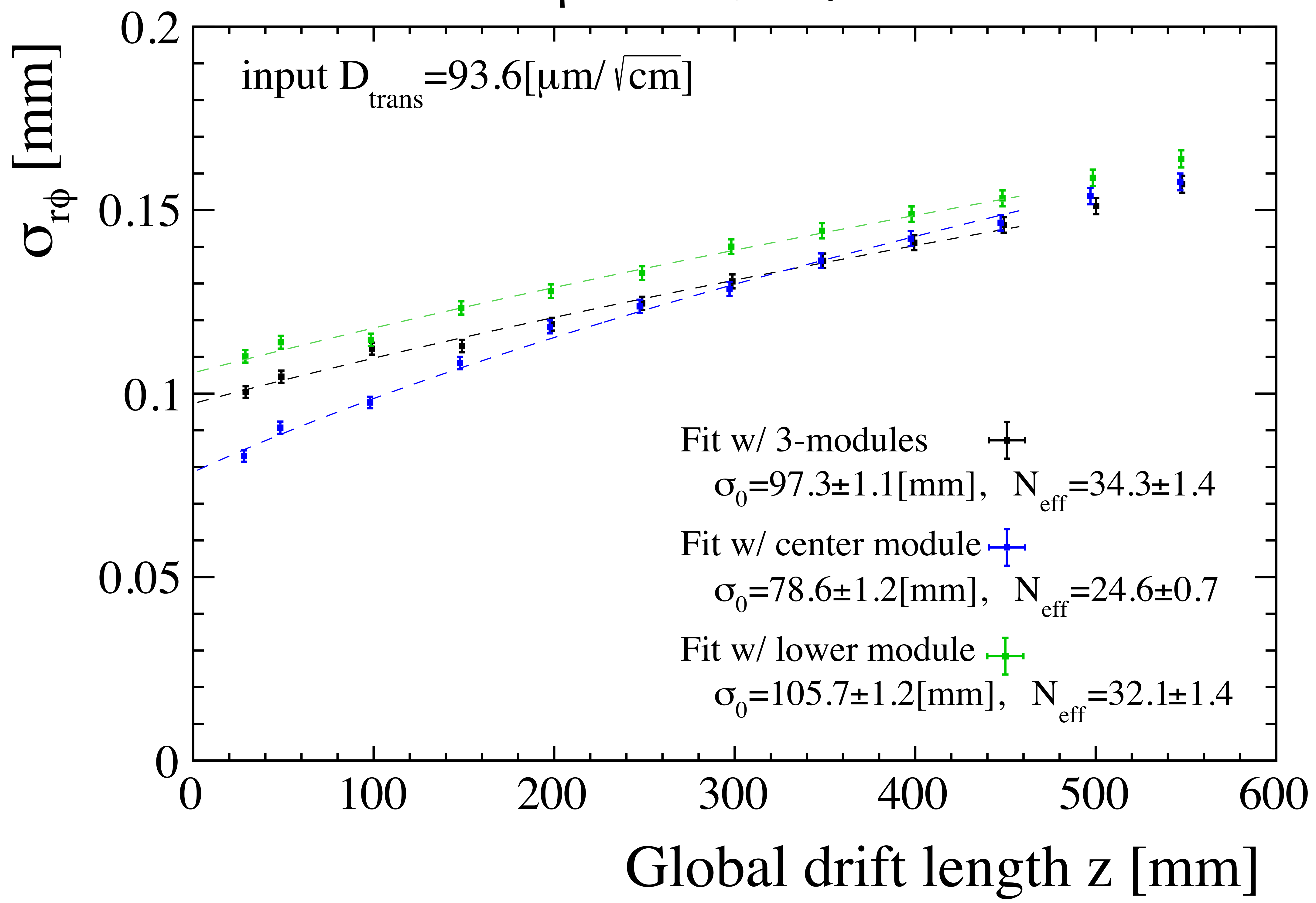
rφ & z resolutions

- **Magnetic field 1T with Ed=230V/cm**

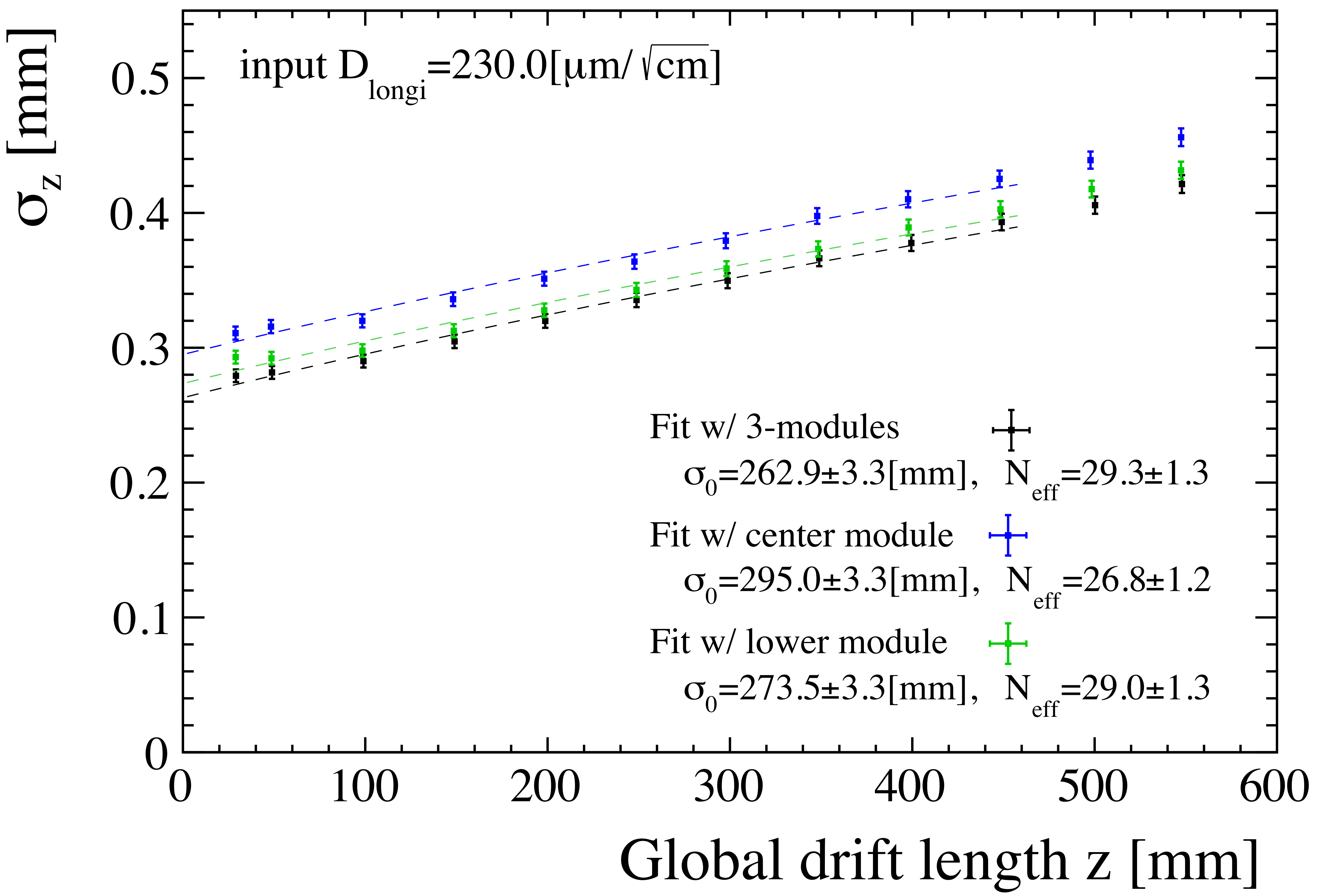
Data selection :
{ **#of tracks=1,**
#of saturated pulses=0

3-module fit :
including the most inn/outer rows,
in total 72 rows

$\sigma_{r\phi}$ Angle ϕ=1.2°



σ_Z Angle θ=0°



$\sigma_{r\phi}$ {
σ0 ~ 97 um
Neff ~ 34 (5GeV) ~ 24 (MIP)
Dt ~ 27 um / √cm (B~3.5T)

$\sigma_{r\phi}$ ~ 120 [μm] (full drift 2.2 m @3.5T)

σ_Z {
σ0 ~ 260 um
Neff ~ 29 (5GeV) ~ 20 (MIP)
Dt ~ 230 um / √cm (B~3.5T)

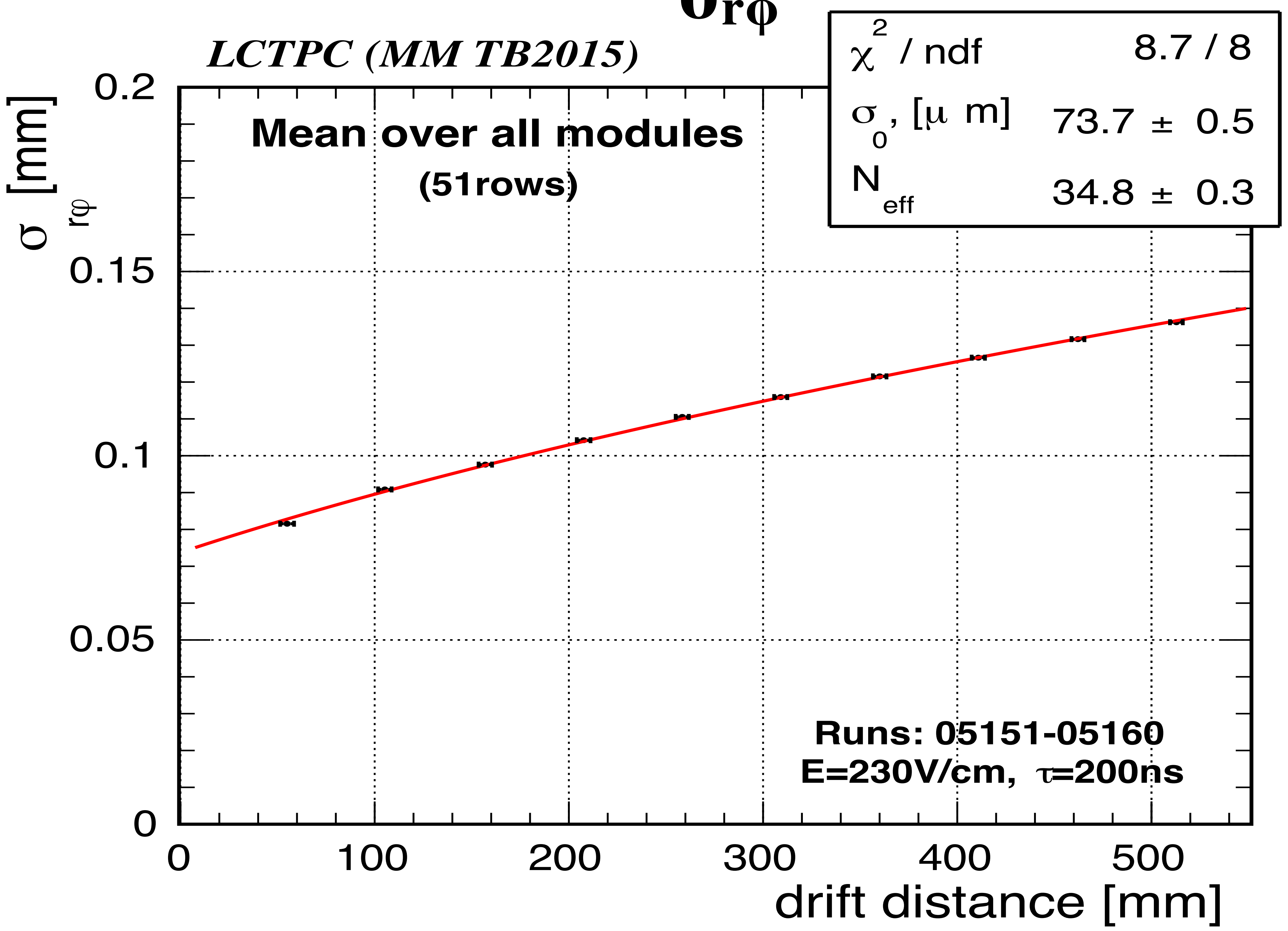
σ_Z ~ 0.8 [mm] (full drift 2.2 m @3.5T)

rφ & z resolutions (2018MM and 2015MM)

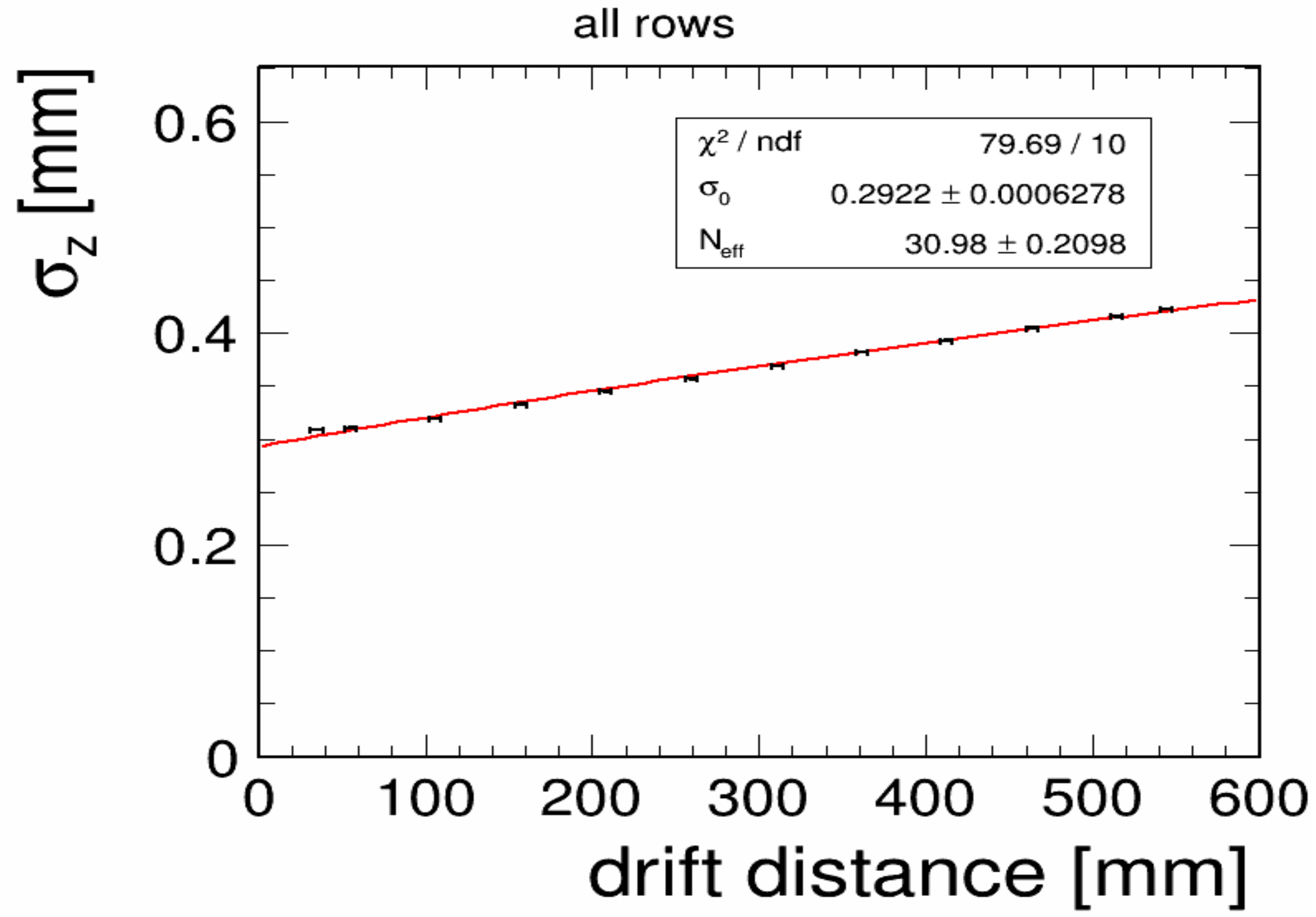
IEEE 16

CEA/Irfu, Apero, D S Bhattacharya, 19th June 2015

$\sigma_{r\phi}$



σ_Z



3 module fit (51 rows)

σ0 ~ 74, Neff ~ 35

much better

(how about the most inn/outer rows)

B=1T, peaking time = 200 ns,
E=230 V/cm, phi =0

3 module fit

σ0 ~ 290, Neff ~ 31

rφ (φ dependence)

Rotating LP1,

$$\sigma_{r\varphi}(z,\alpha) \approx \sqrt{\sigma_{r\varphi}^{2}(z) + \frac{L^{2}}{12\widehat{N}_{\text{eff}}}\tan^{2}\alpha}\,. \quad \text{(DESY paper)}$$

Rotation was done by hands,

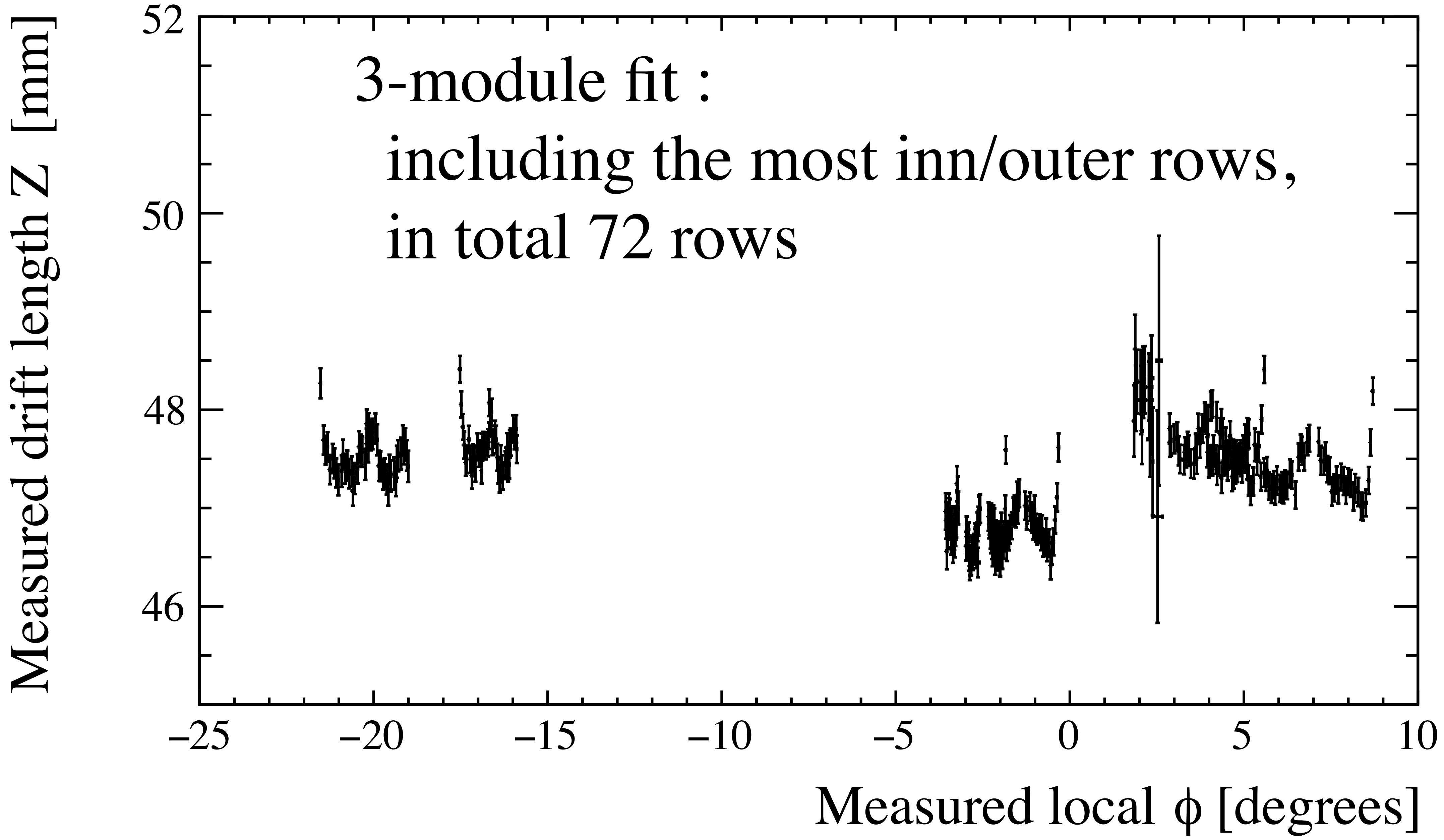
Z was not took care

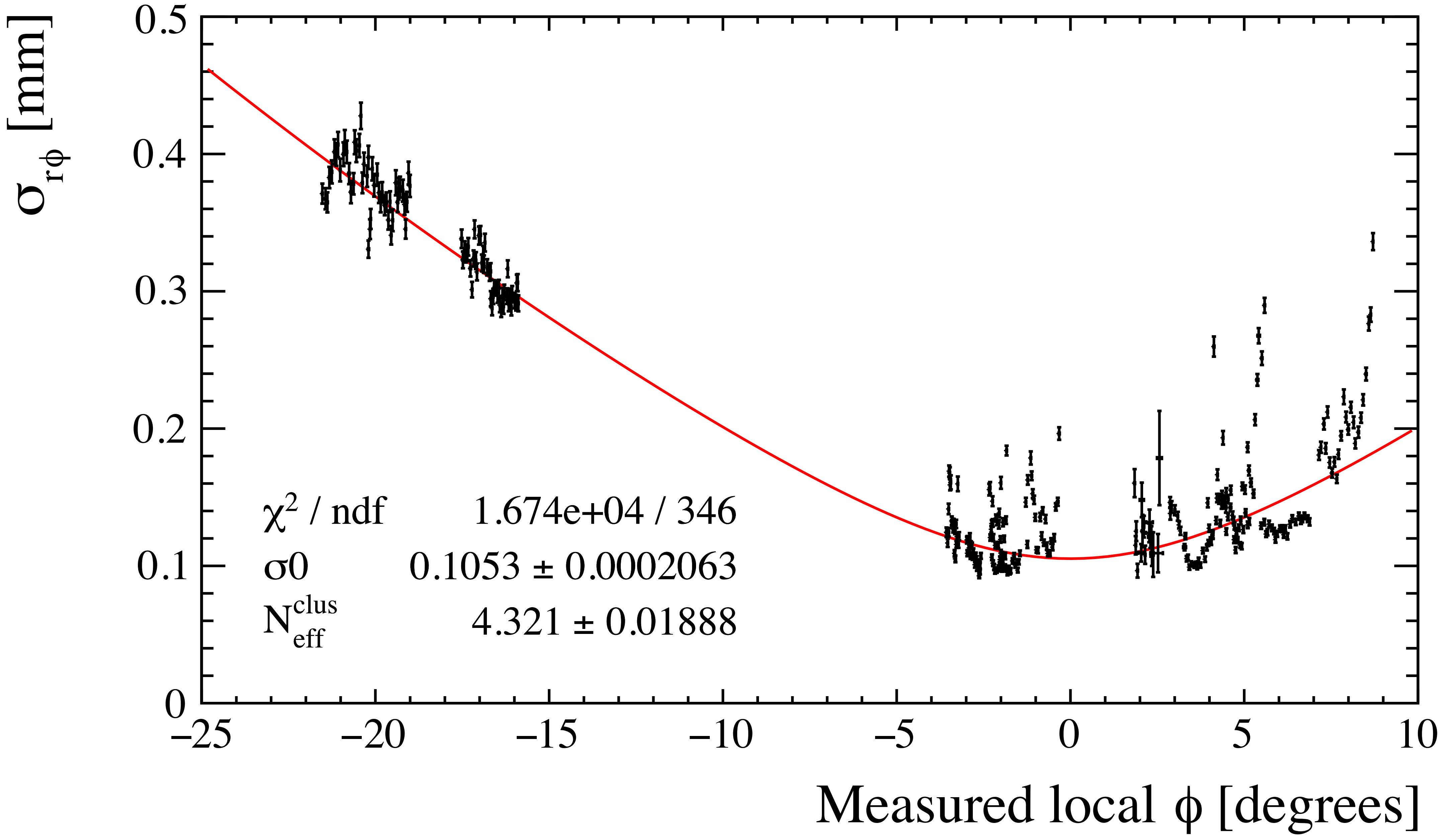
Remove several run data

the effective number of clusters

~ 4.3

I could not find the value in DESY paper.

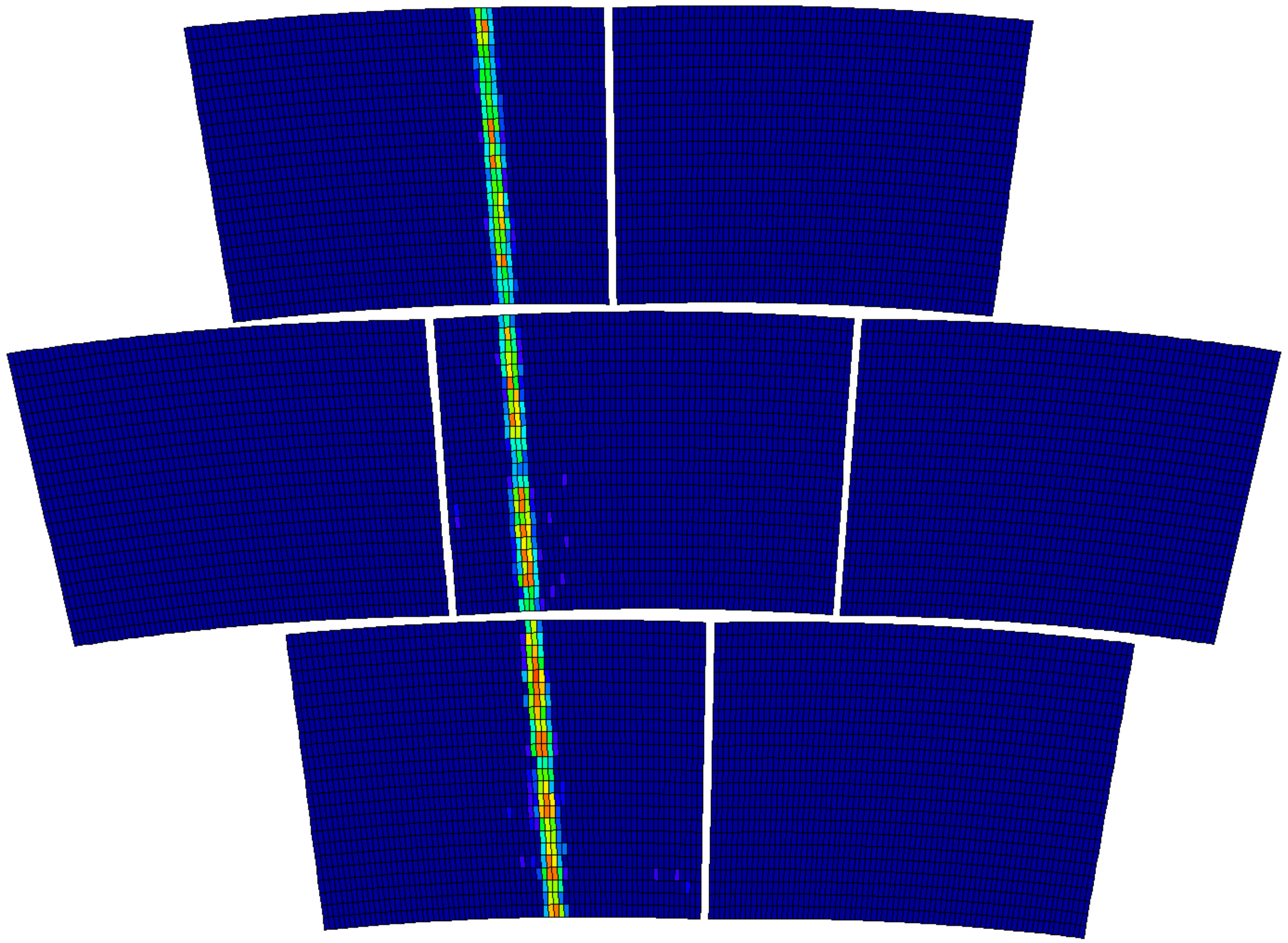




Summary

- The detectors were almost perfectly working in 2018BT
- Small non-uniformity was observed for the charge distribution. (study geometry)
- No 2pulses-Hit in short drift (center module)
- Huge improvement is observed for the track distortions.
- Detector alignment studies are must
- Control electrodes of the field cage to match with surface of the MM
- $r\phi$ & z resolutions reach to requirements of ILD-TPC

dE/dx resolution



dE/dx resolution

- **Charge correlation between rows**
  - **Pad size: width 3 mm × height 7 mm**

Row by row charge correlation
make resolution worse
(due to large deposit from δ-ray and diffusion)

charge correlation Qrow : Qrow+1

B=0T, correlation factors are
δ-ray and diffusion cover the rows

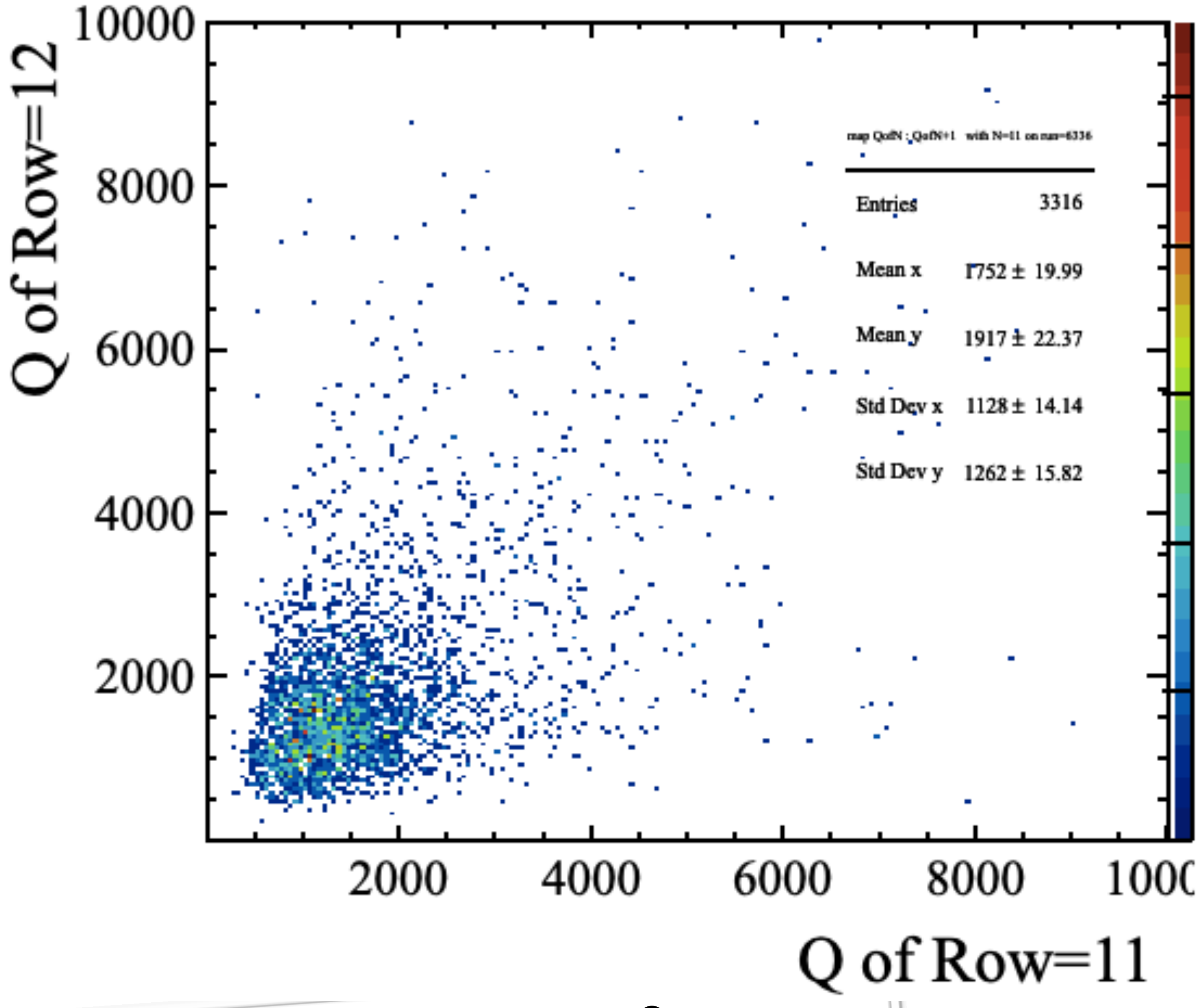
```
Z= 50 aveCorr = 0.341
Z=300 aveCorr = 0.459
Z=550 aveCorr = 0.545
```

B=1T,
small correlation …

```
Z=100 aveCorr = 0.136
Z=300 aveCorr = 0.151
Z=550 aveCorr = 0.155
```

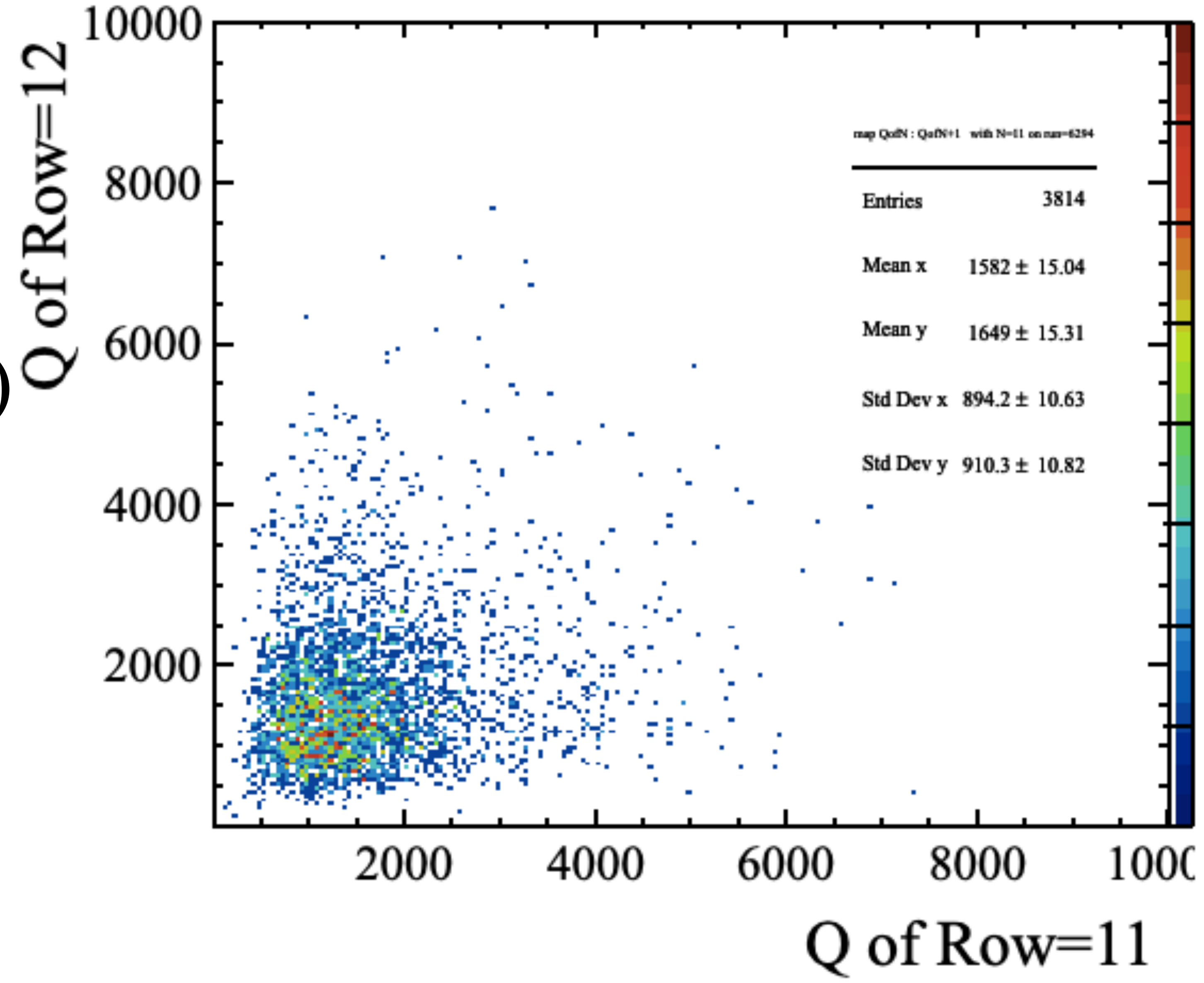
B=0T, Drift length ~ 500 mm

(example)



B=1T, Drift length ~ 500 mm

(example)



dE/dx resolution

- **Truncated Mean method**

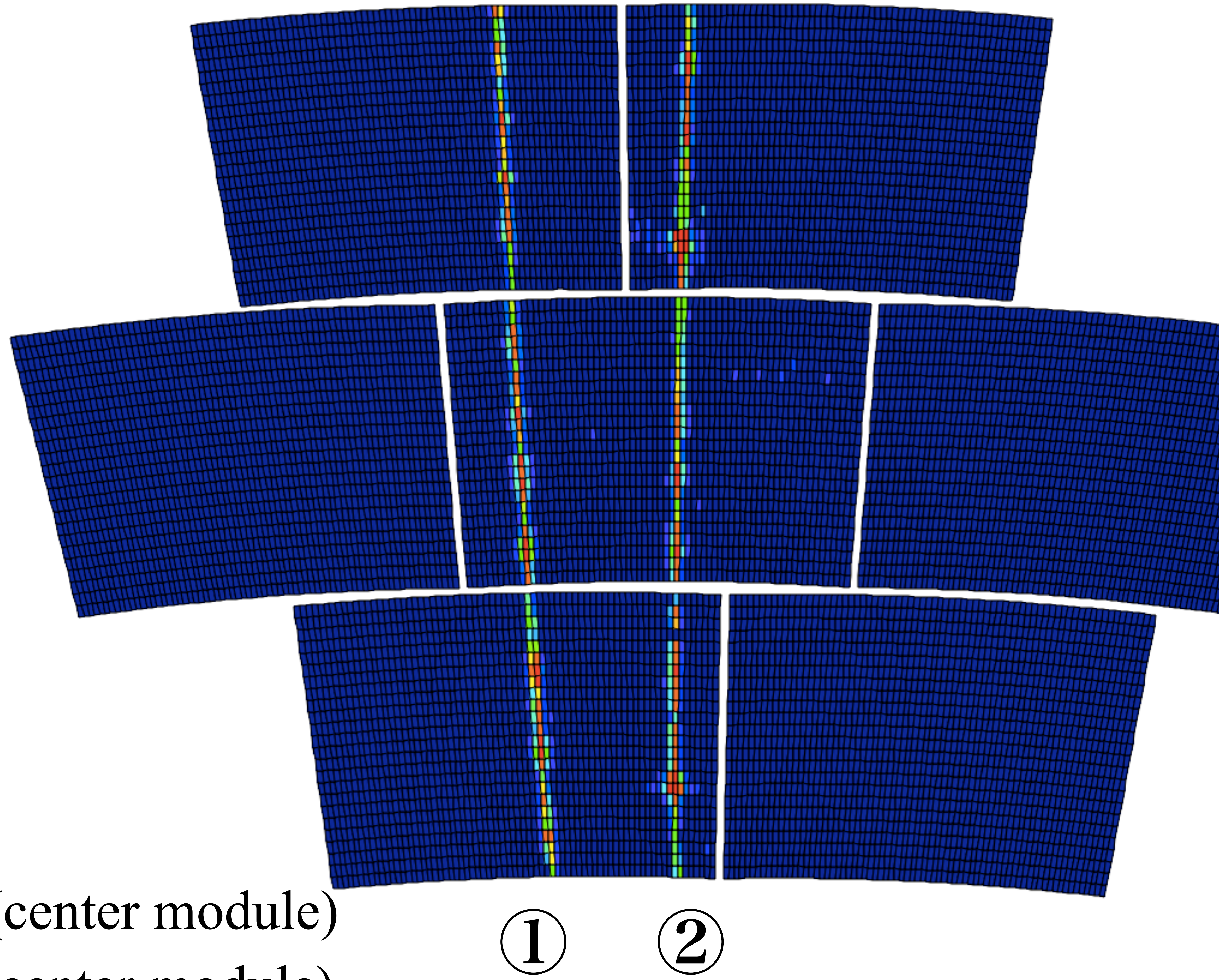
  The most robust estimator

  Ed= 230V/cm
  Data selection :
  { **#of tracks=1,** **~2000 events available**

- **2 data set (drift 30 ~ 300 mm are merged)**

Look the center module.

- **Injection point difference (① & ② region)**
- **charge spread is a bit different**
- **track angles are slightly different** { ① **-3 degrees** (center module) ; ② **0 degrees** (center module)



According to Asian-GEM study,
$\phi = 0°$ and $20°$ give the same performance $4.7 \pm 0.02\%$ (220 sampling)

dE/dx resolution

Look the center module.

- **Truncated Mean method**

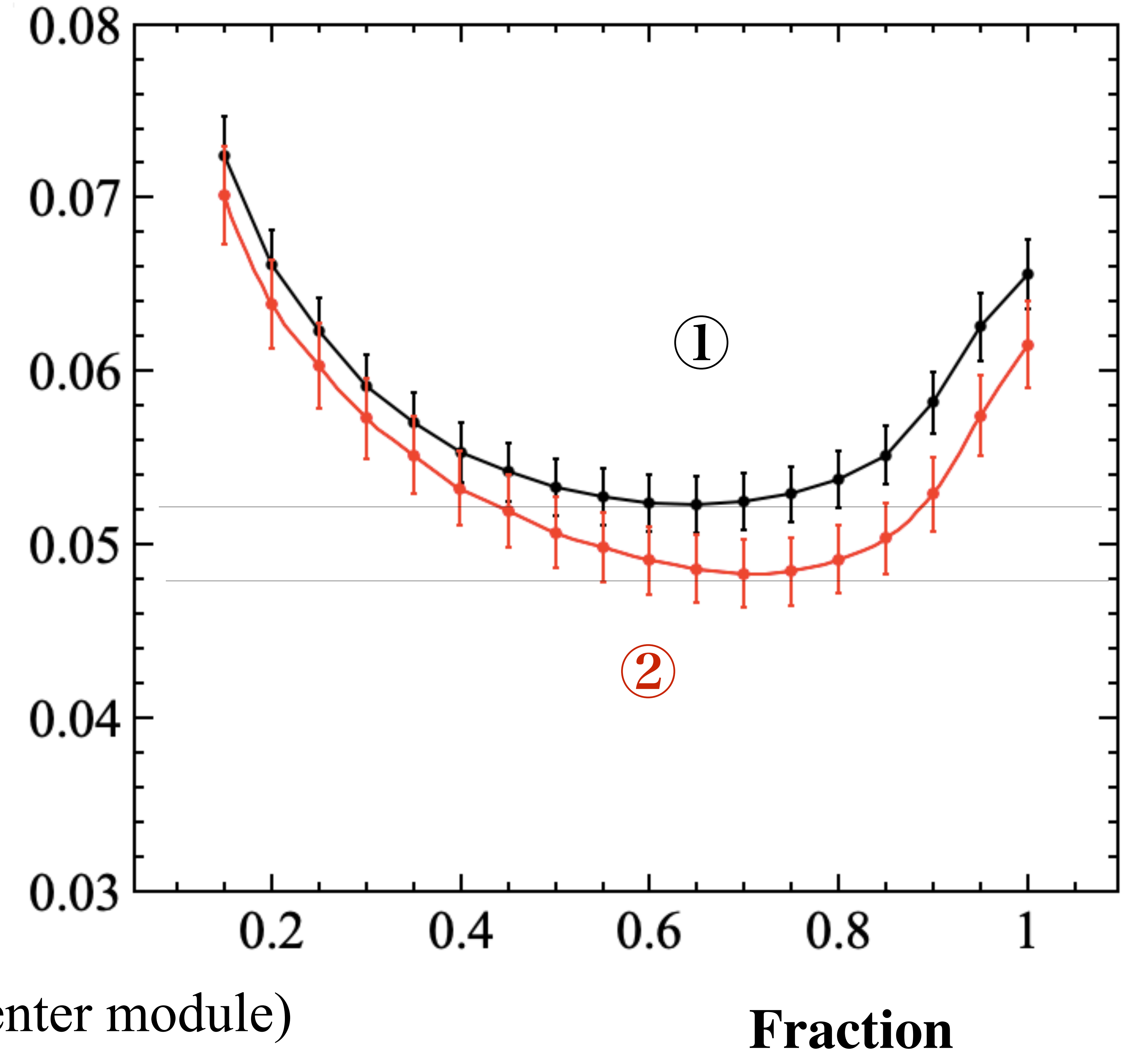
  The most robust estimator

  Ed= 230V/cm
  Data selection :
  { #of tracks=1, **~2000 events available**

- **2 data set (drift 30 ~ 300 mm are merged)**

Look the center module.

- **Injection point difference (① & ② region)**
- **charge spread is a bit different**
- **track angles are slightly different** { ① **-3 degrees** (center module) / ② **0 degrees** (center module)



{ • ① **5.2% ± 0.2%** / • ② **4.8% ± 0.2%**

stat error is large…
charge spread ?

dE/dx resolution

- **Truncated Mean method**

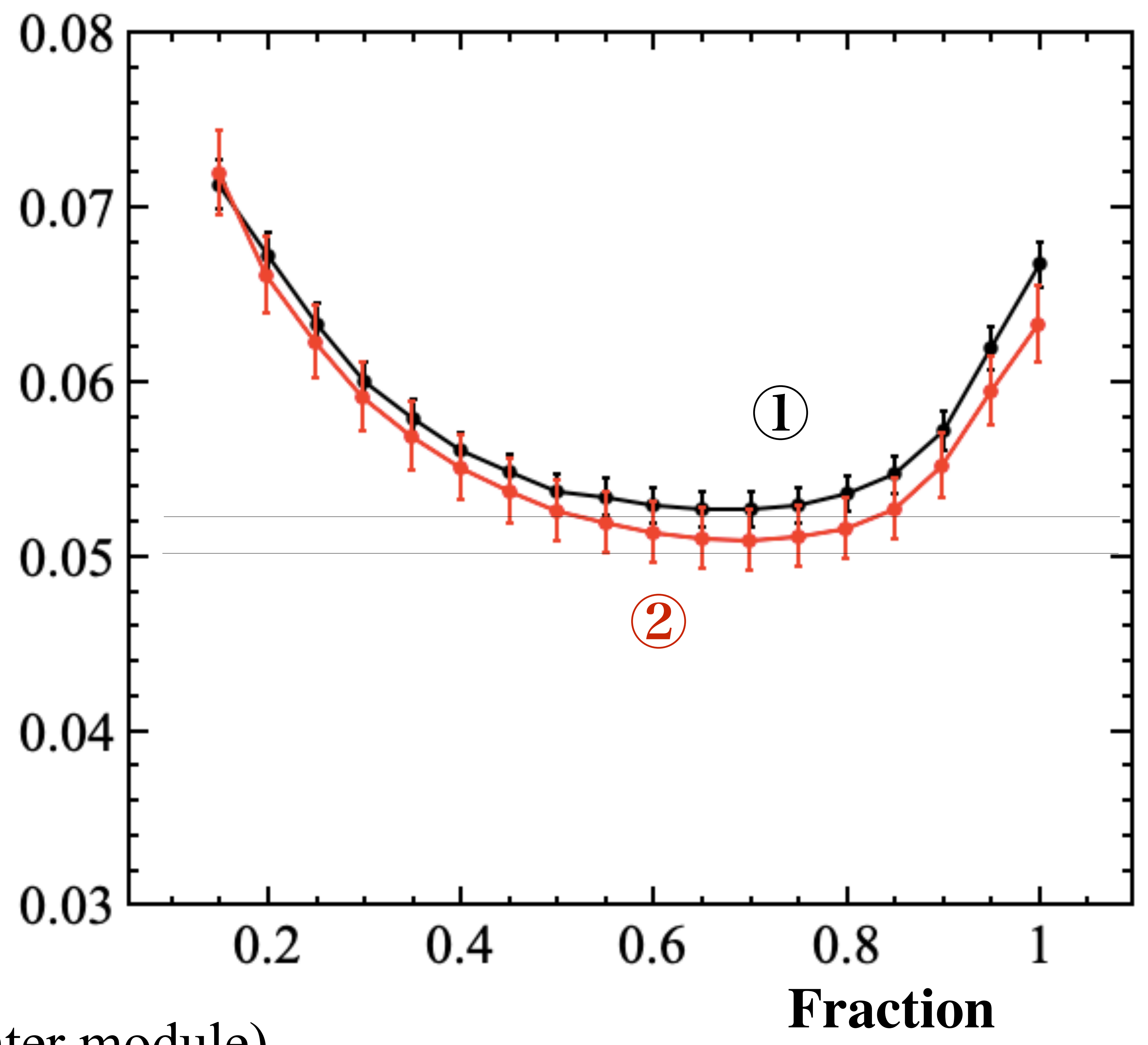
  The most robust estimator

  Ed= 230V/cm
  Data selection :
  { #of tracks=1,

- **2 data set (drift 30 ~ 300 mm are merged)**

Perform 3-module fitting:

- **Injection point difference (① & ② region)**
- **charge spread is a bit different**
- **track angles are slightly different** { ① **-3 degrees** (center module) / ② **0 degrees** (center module)



- ① **5.2% ± 0.1%**
- ② **5.0% ± 0.1%**

stat error is large…
charge spread ?

dE/dx resolution: understanding using Simulation

- **Heed + Garfield++**

Track heed 5 GeV electron : 110 electrons / cm

Drift distance 100 mm

AvalancheMicroscopic (under T2K gas)

Gas amplification : Polya function

<gain> = 1000, f = 0.7

- **pad-height is set to 7 mm**

B=0T, correlation factors is

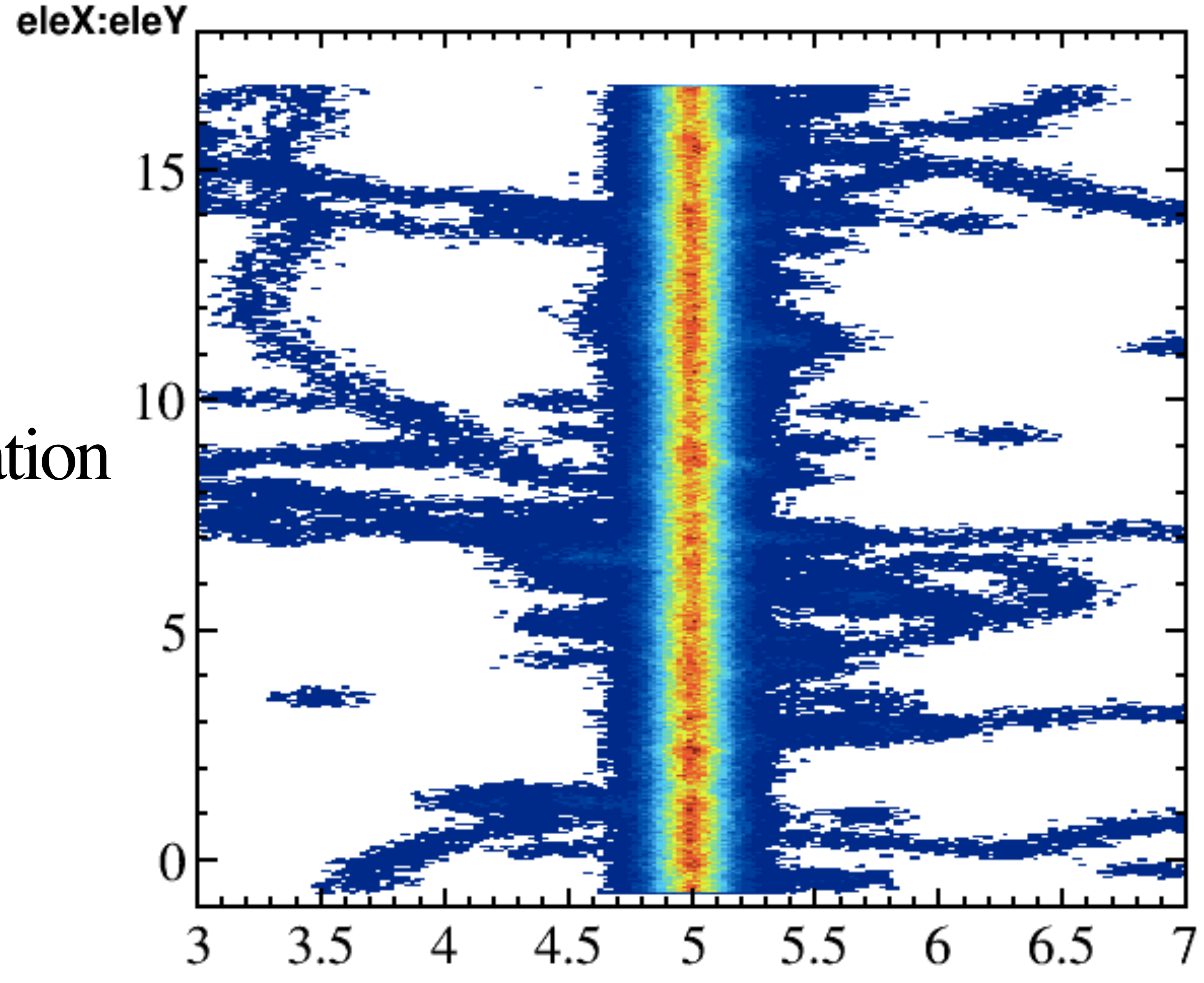
`Z= 100 aveCorre = 0.33 , similar with data`

B=1T, correlation factors is

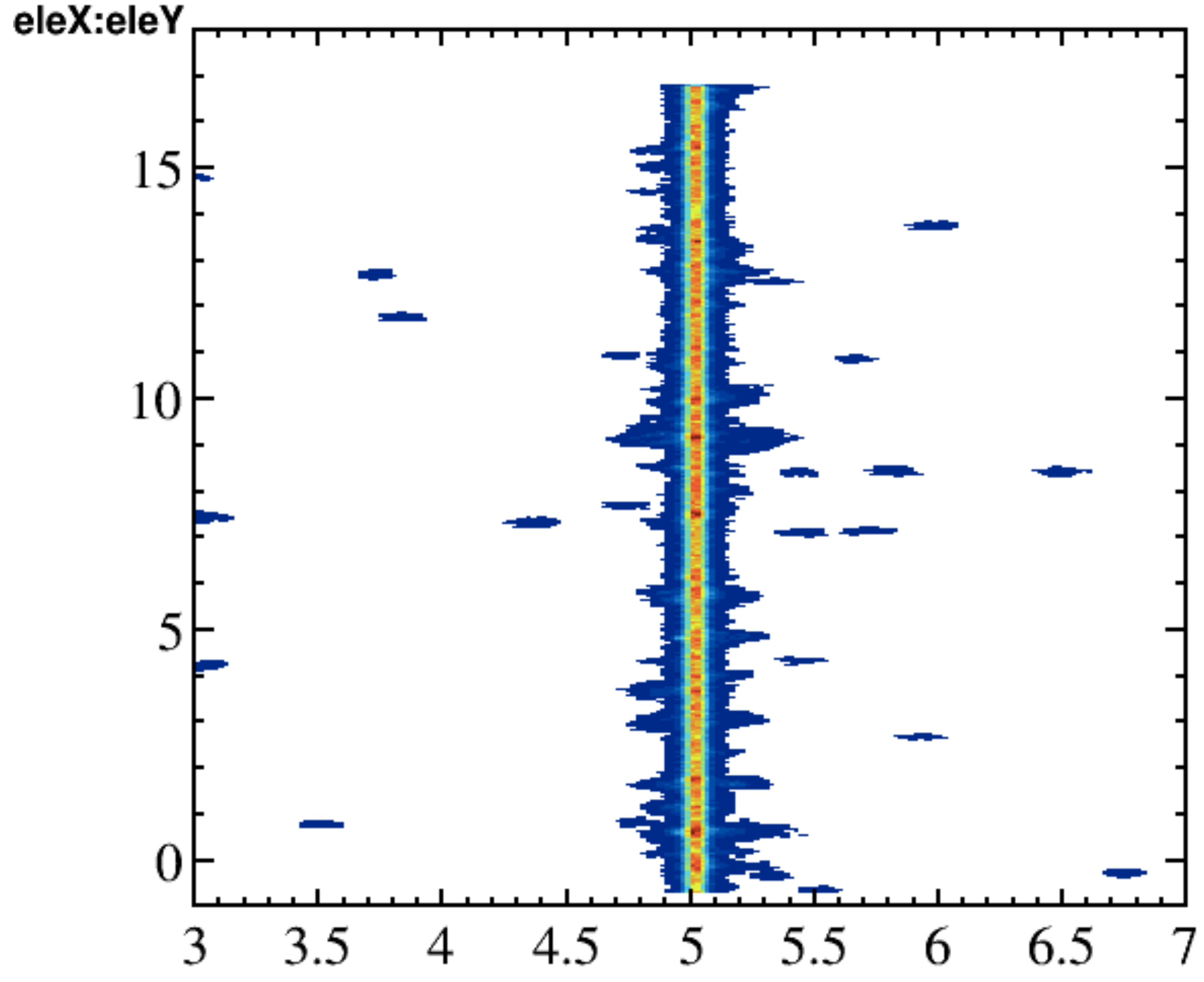
`Z= 100 aveCorre = 0.12 , similar with data`

Accumulation of tracks

B=0



B=1



dE/dx resolution: understanding using Simulation

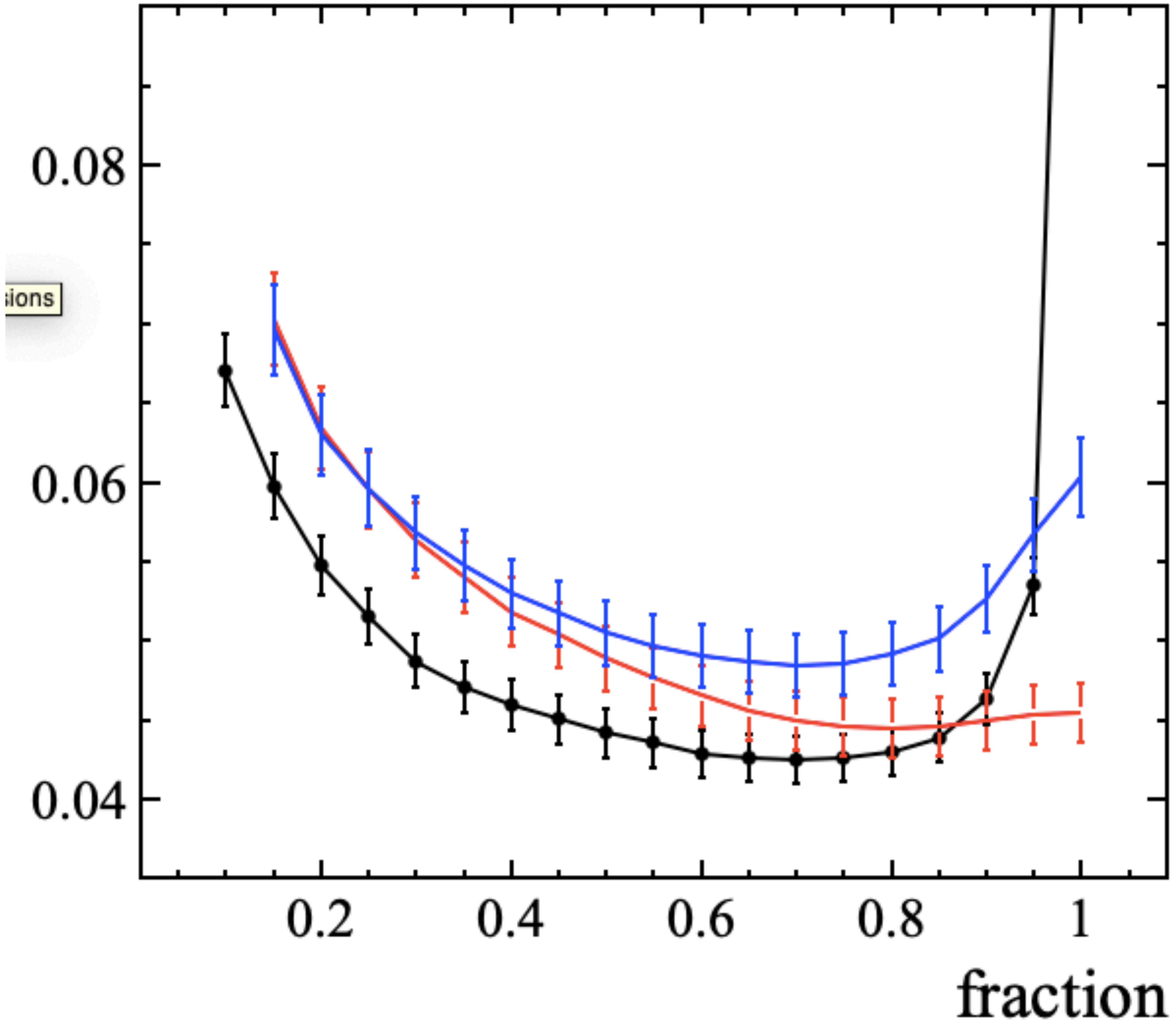
- **Magnetic field 1T with Ed=230V/cm**
  24 pad rows with 7mm pad-height are set
  #of sampling is 170

Black: simulation ～4.3%

Blue : Data (right reagion) ～4.8%
#of tracks = 1

Red : Data (right reagion) ～4.5%
#of tracks = 1
Exclude hits including saturated pulses

dE/dx resolution



- If charge is properly collected without saturation, data will reach minimum of simulation
- Behavior for small fraction is still unclear what main sources are…

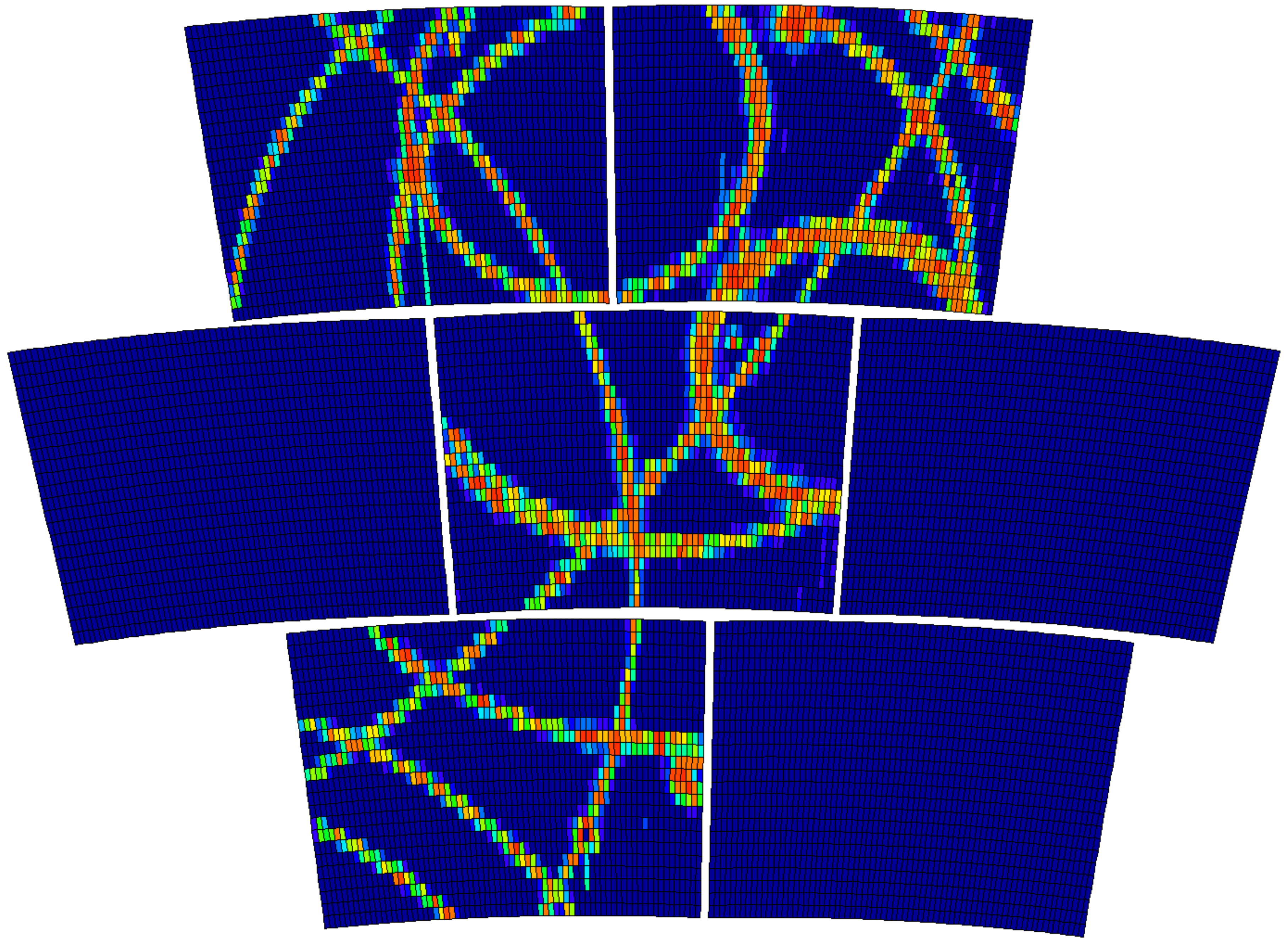
Summary

- dE/dx resolution with 3-module fit reaches to ~5%

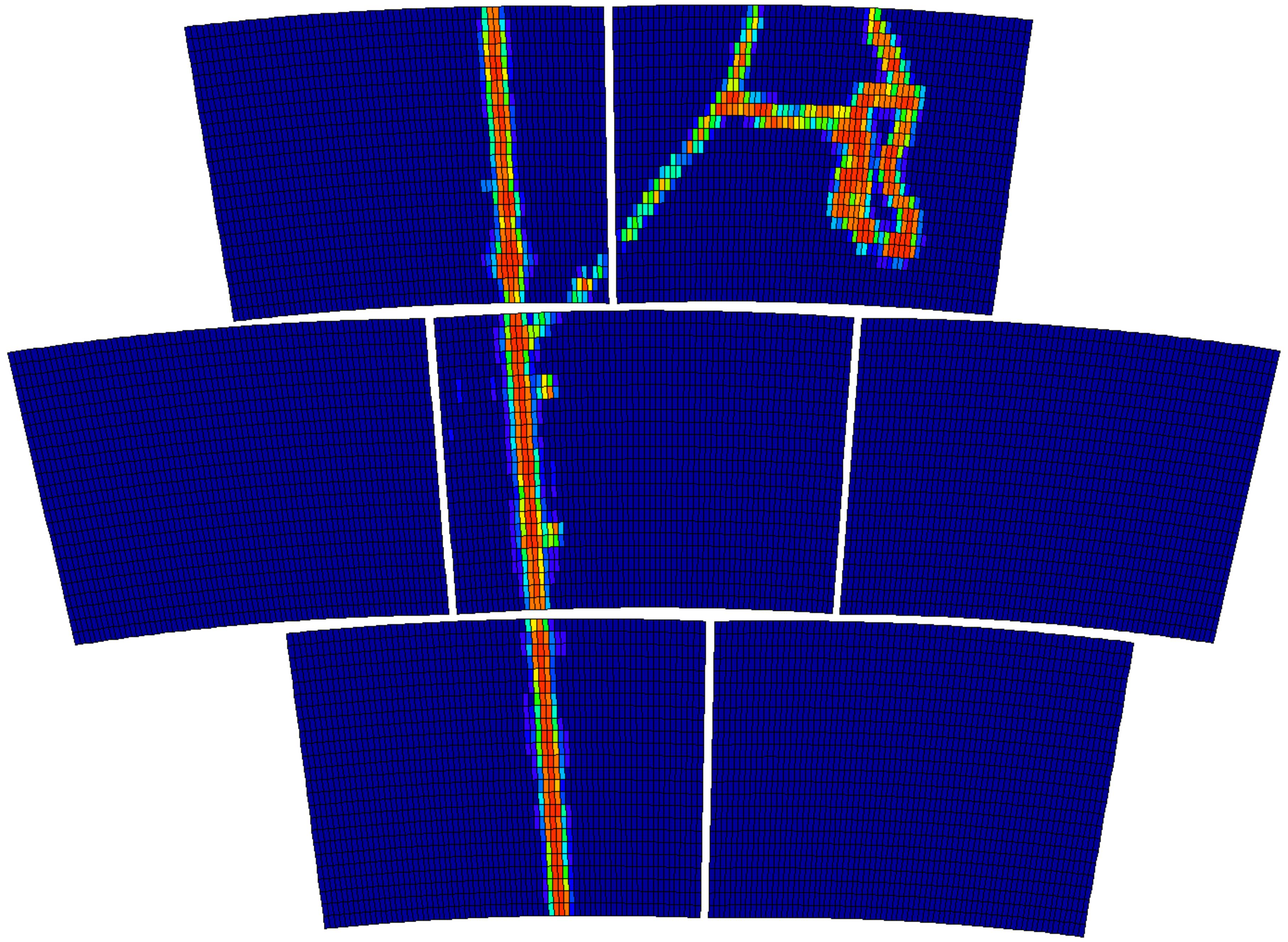
- The variation depending on the position is observed

- Results between the data and the simulation has still unknown

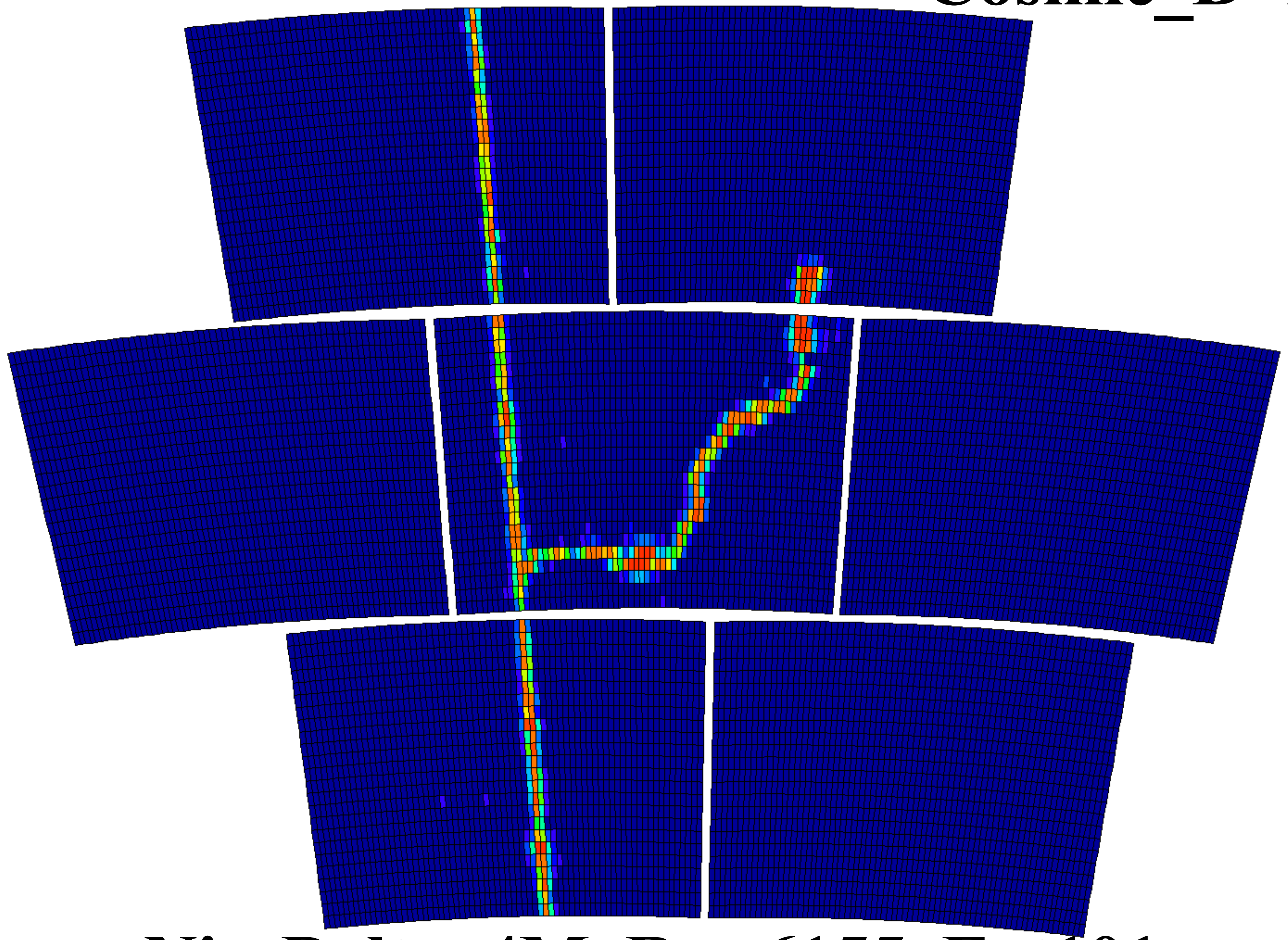
Nice events



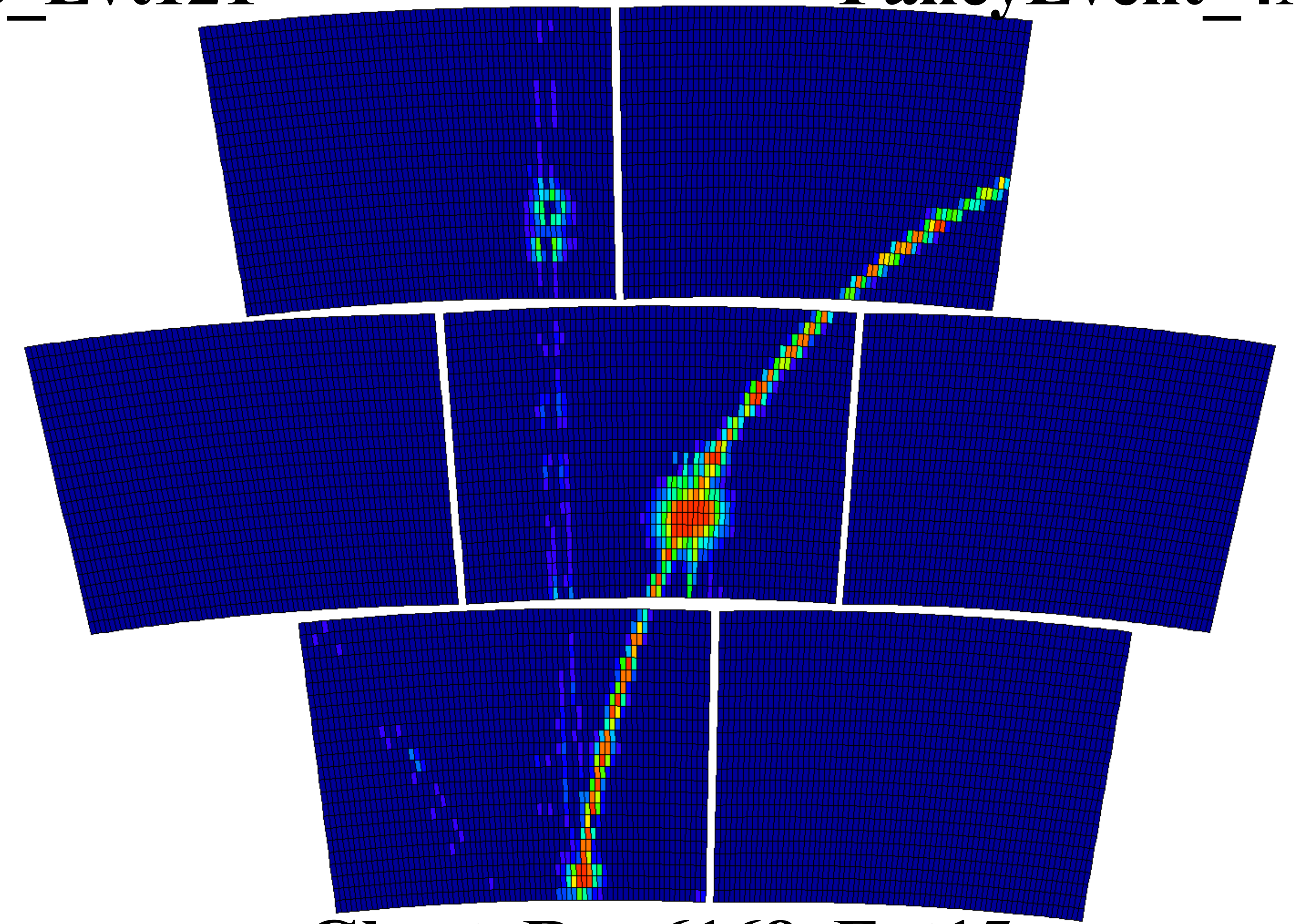
Cosmic_B=1T_Run6138_Evt121



FancyEvent_4M_Run6160_Evt46

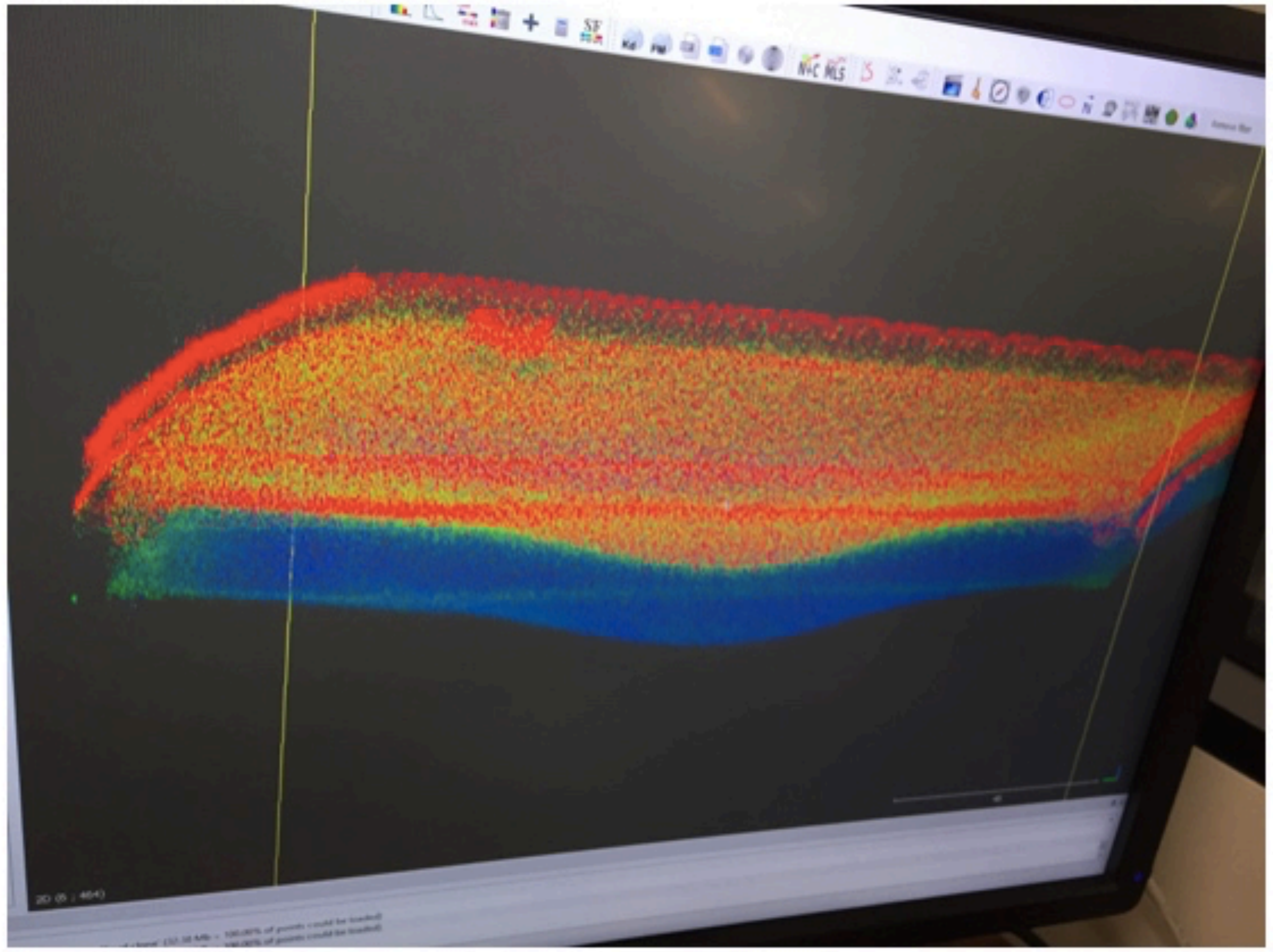


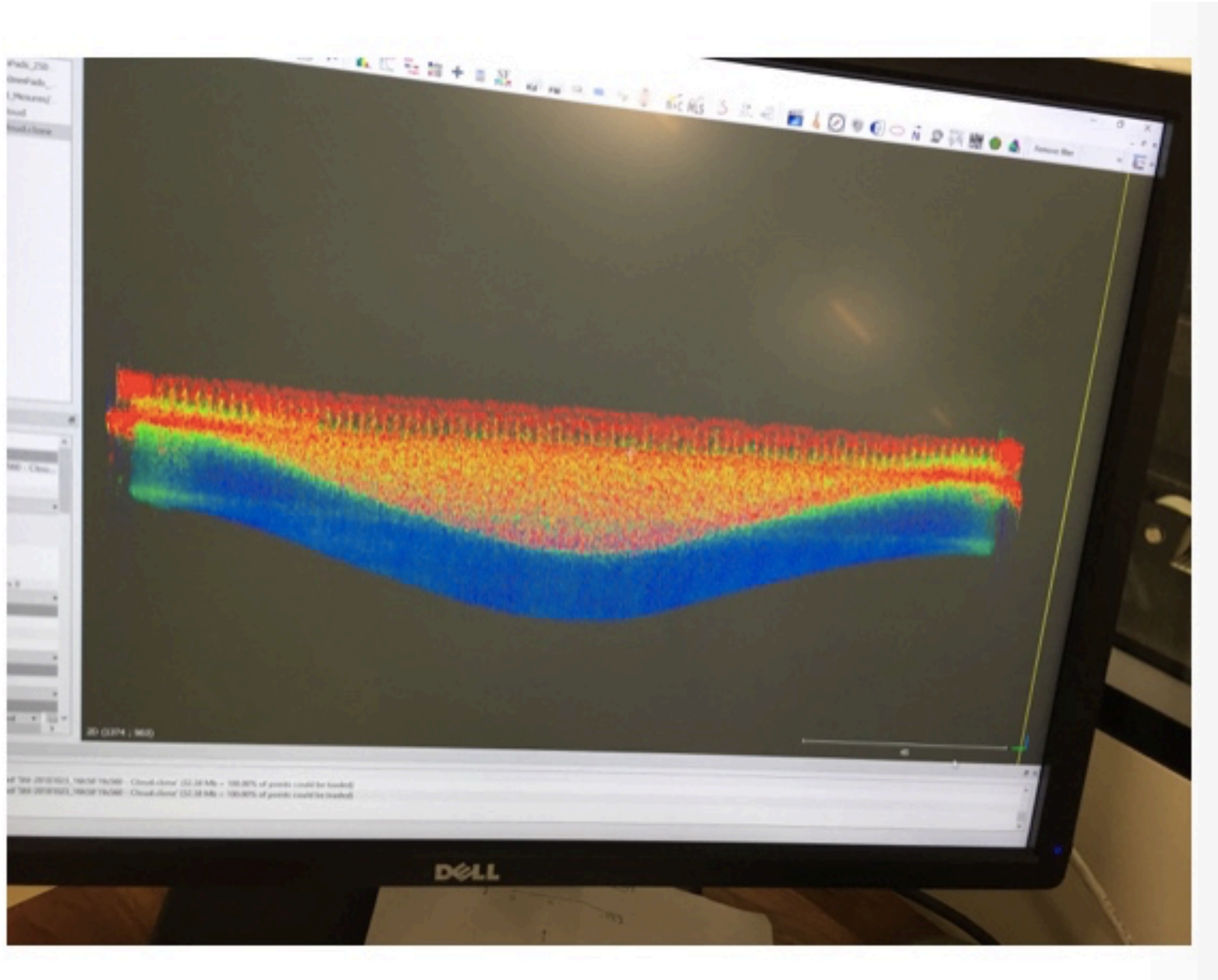
NiceDelta_4M_Run6155_Evt101



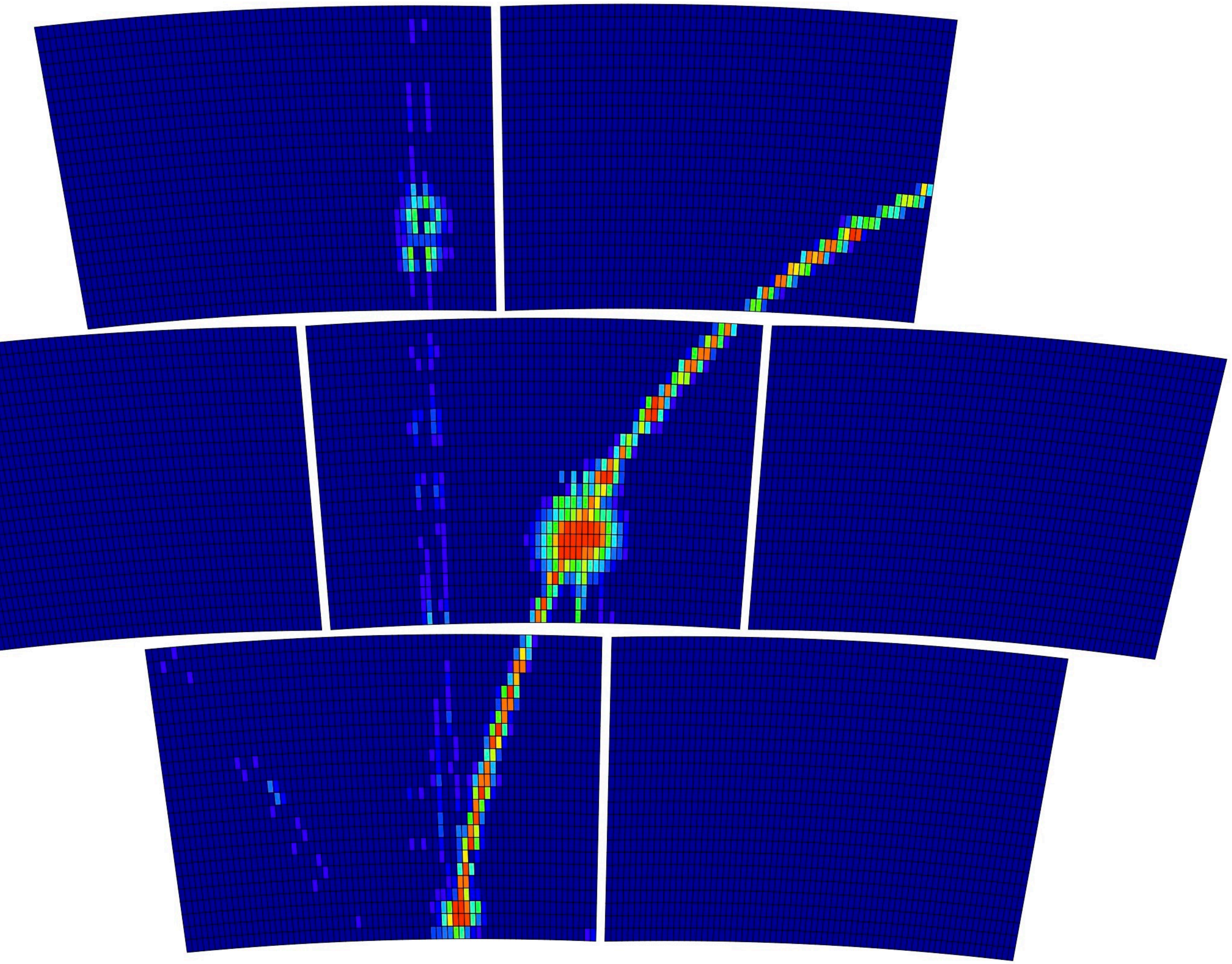
Ghost_Run6168_Evt15

Geometry scan (old module)

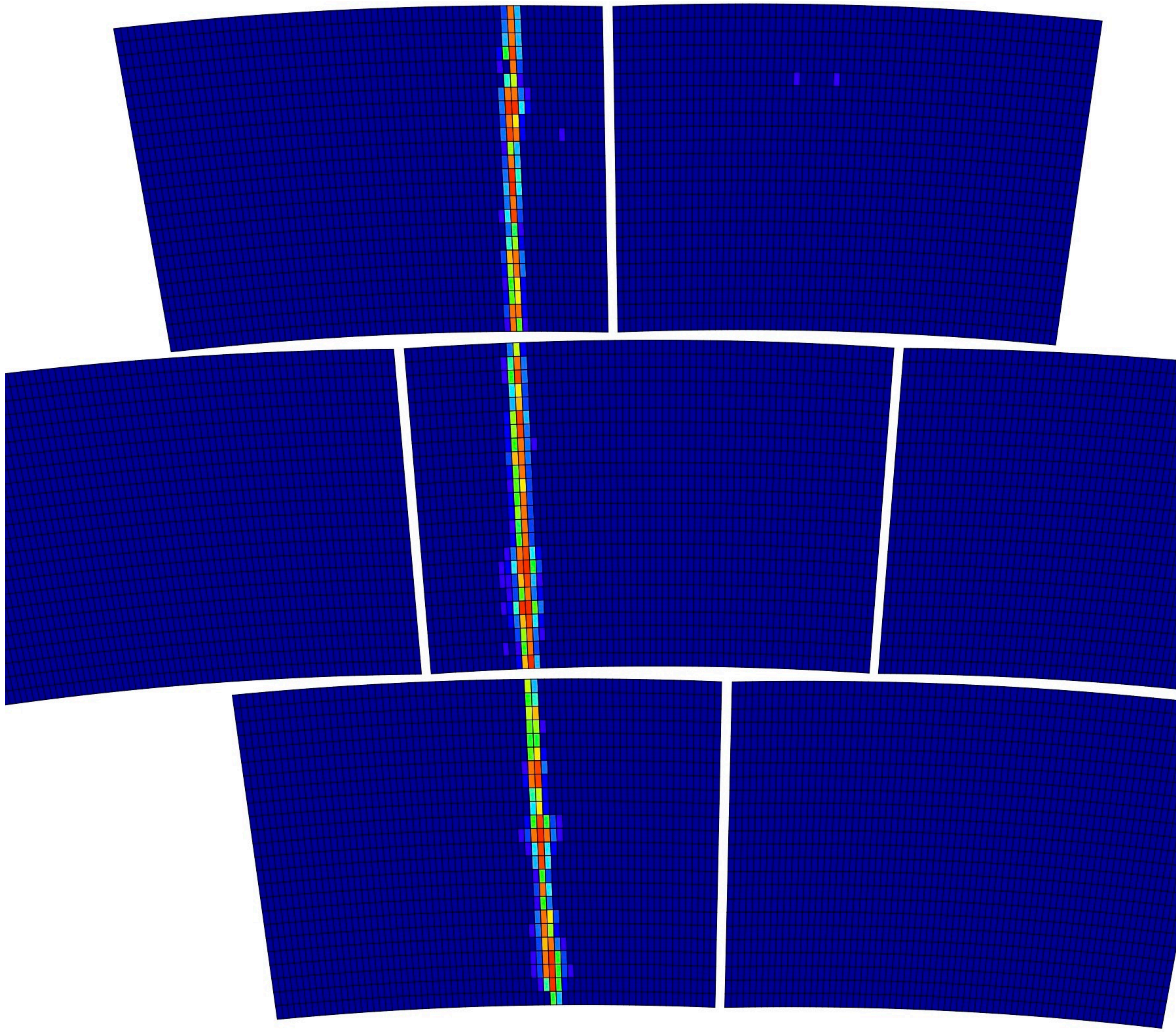


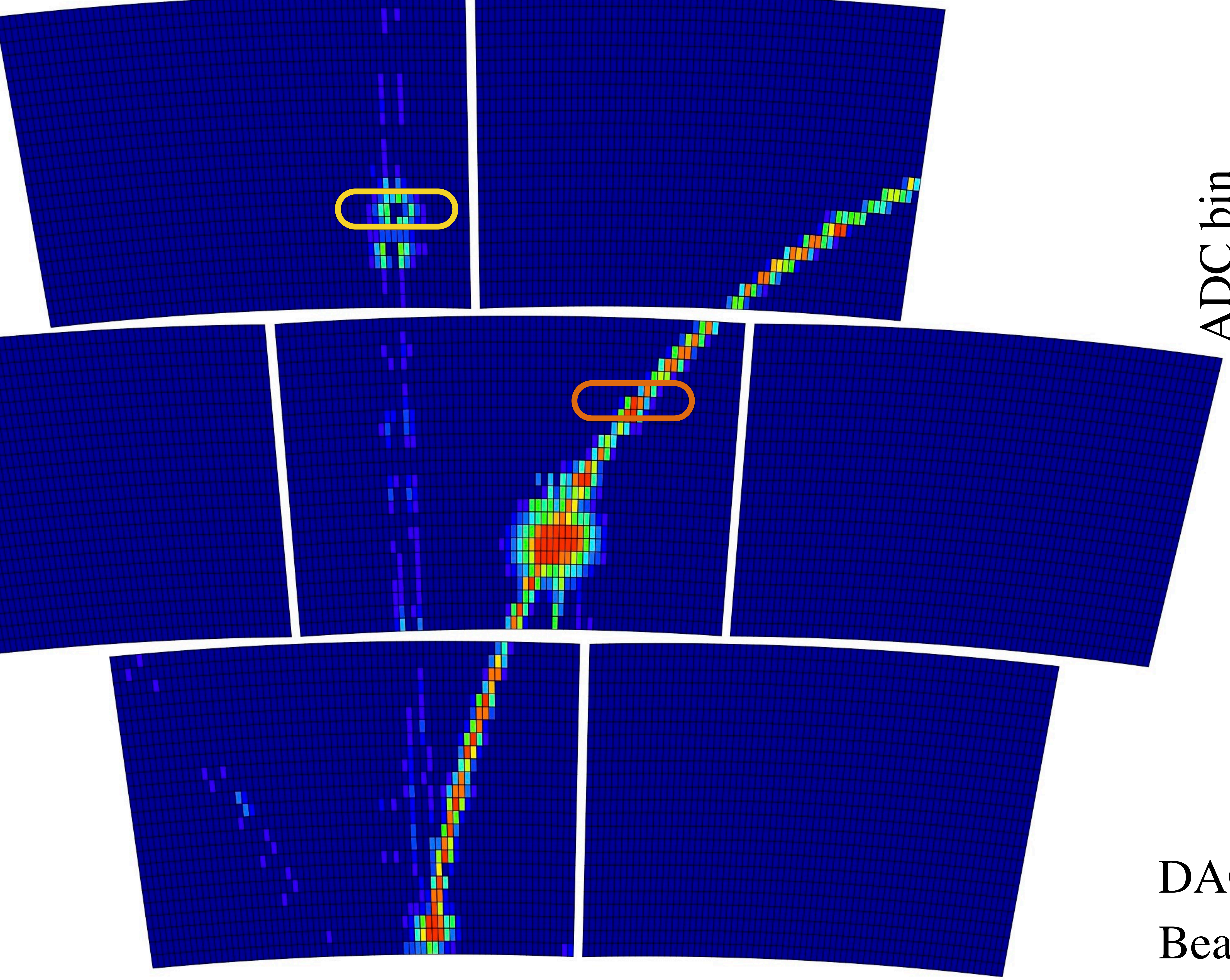


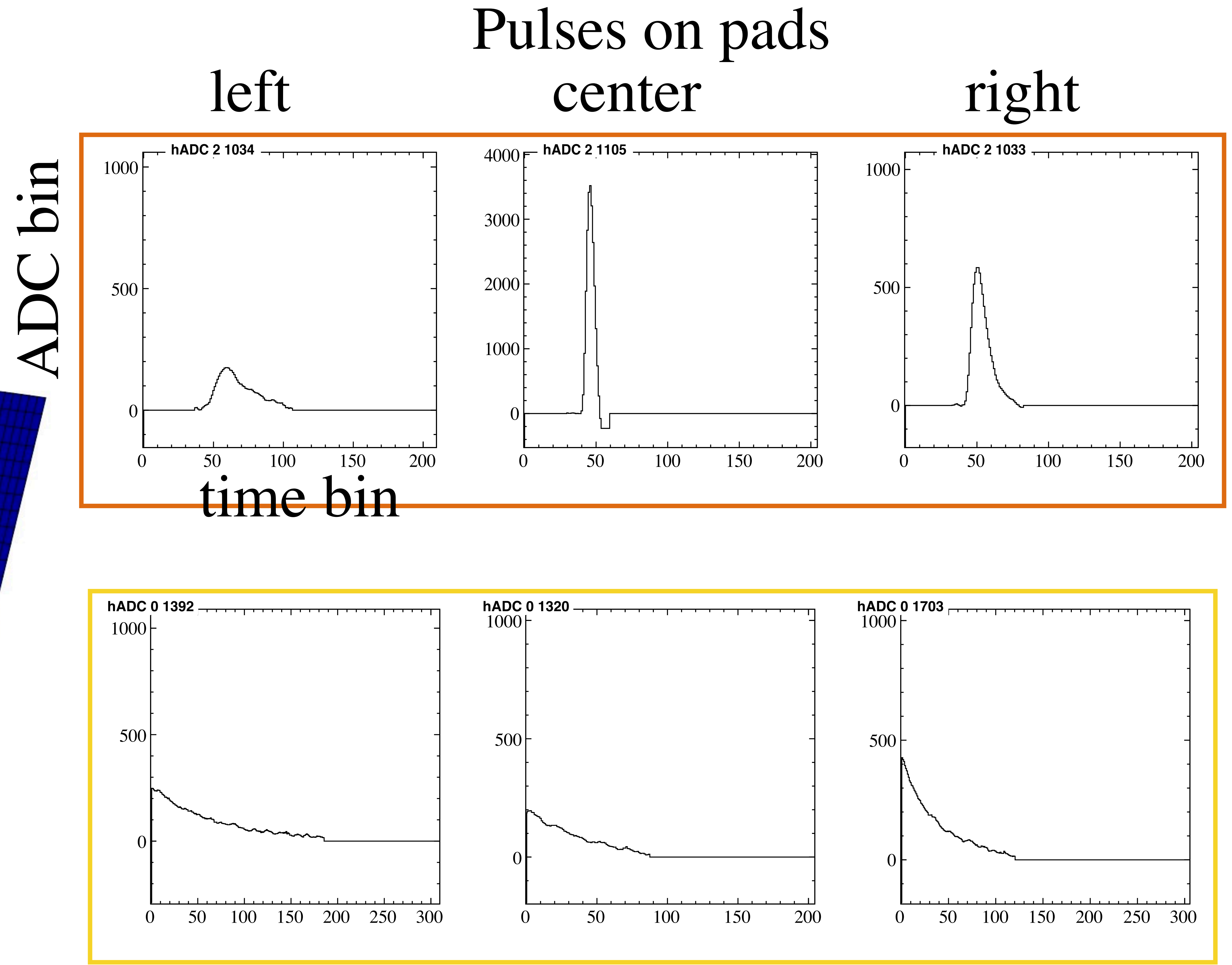
Event 15



Event 14







DAQ event acquisition ~ 6Hz

Beam trigger ~ 200 Hz

double trigger:

1st trigger(event) was not acquired because of “busy flag”

2nd trigger(event) was acquired when tail (spread) still existed.

Anyway it’s not pile up problem

A problem on the electronic, maybe

but, it is still under discussion…