CDC

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Calibration
Alignment
Performance study
dE/dx calibration
Two Problems

Performance study

- One cosmic track which passes through CDC is fitted as two separate tracks. We compared fit results of these two tracks to study the performance of CDC.

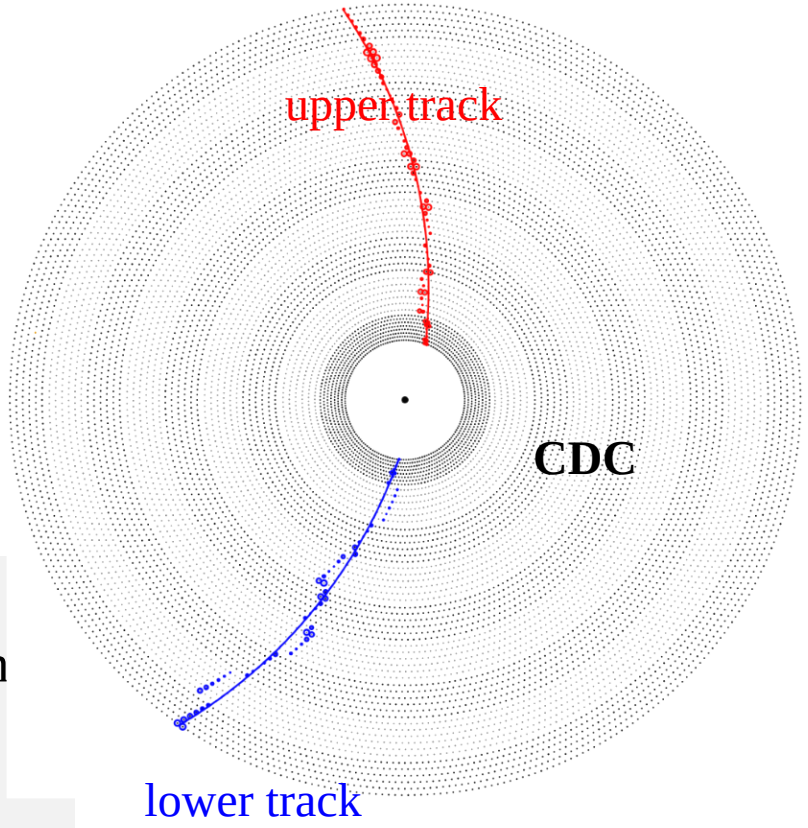
$\Delta P_t = P_t^{upper} - P_t^{lower}$

$\Delta d_0 = d_0^{upper} - d_0^{lower}$

$\Delta z_0 = z_0^{upper} - z_0^{lower}$

$\Delta \varphi_0 = \varphi_0^{upper} - \varphi_0^{lower}$

$\Delta \tan\lambda = \tan\lambda^{upper} - \tan\lambda^{lower}$

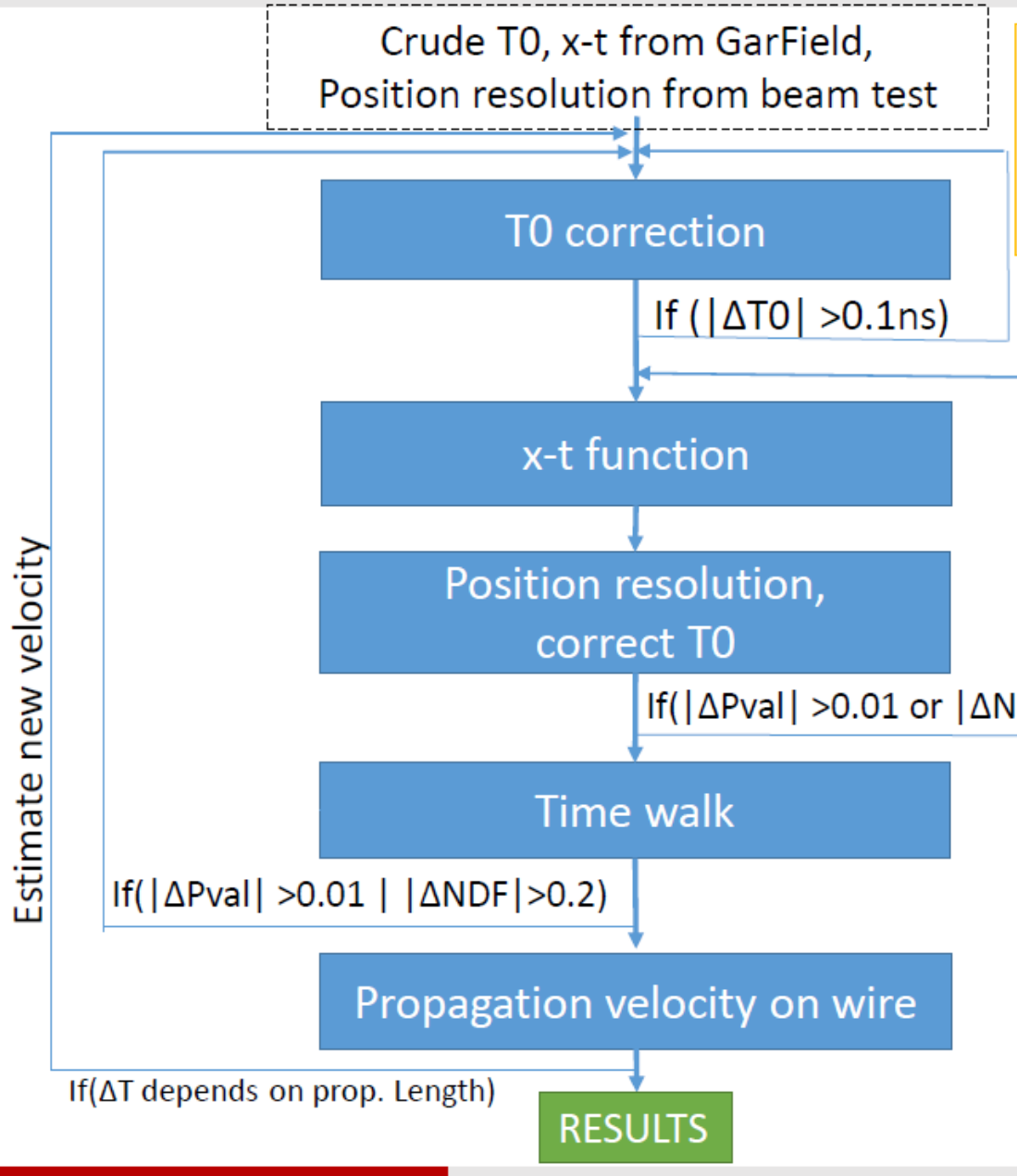


Event selections:

1. Two tracks are same direction (correct dirrection
2. $|d_0| < 3$cm (~IP tracks)
3. $-5\text{cm} < z_0 < 15$ (~IP track)
4. $|\tan\lambda| < 0.45$ (reduce the affect of mapper
5. NDF>25 (better track)

Calibration (with/without B field)

Calibration procedure



Time residual:

$\Delta T0 = T_{drift}(mea) - T_{drift}(fit)$

$T_{drift}(fit)$ is calculated from drift length in track fitting

x-t: Time to space relation

Probability(χ^2):

$\Delta Pval = \langle Pval_i \rangle - \langle Pval_{i-1} \rangle$

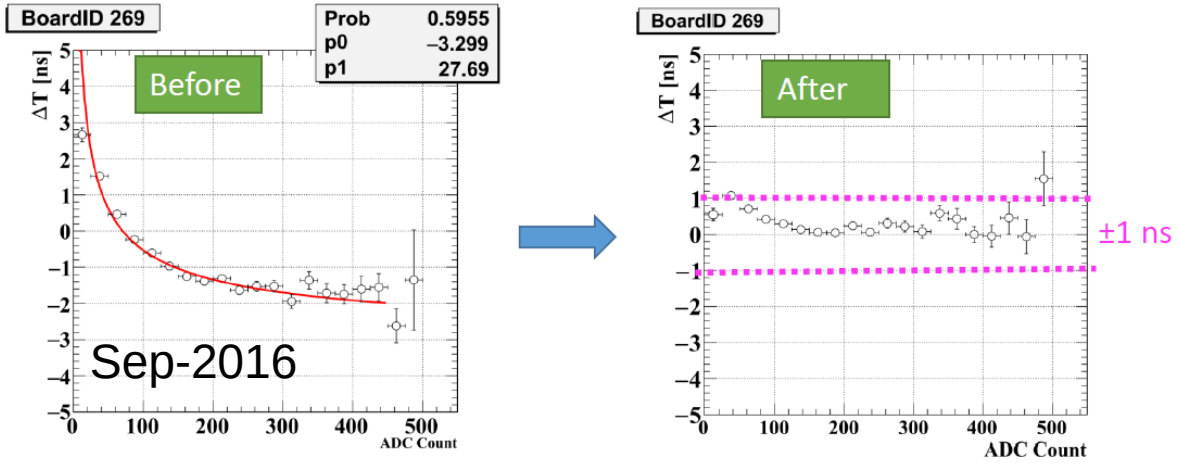
Number of Degree Freedoms:

$\Delta NDF = \langle NDF_i \rangle - \langle NDF_{i-1} \rangle$

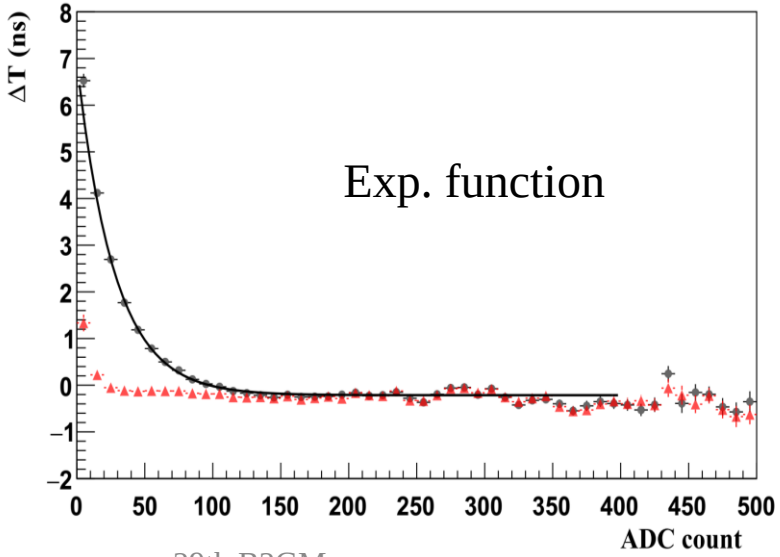
i, i-1, is iteration i^{th}

Time walk

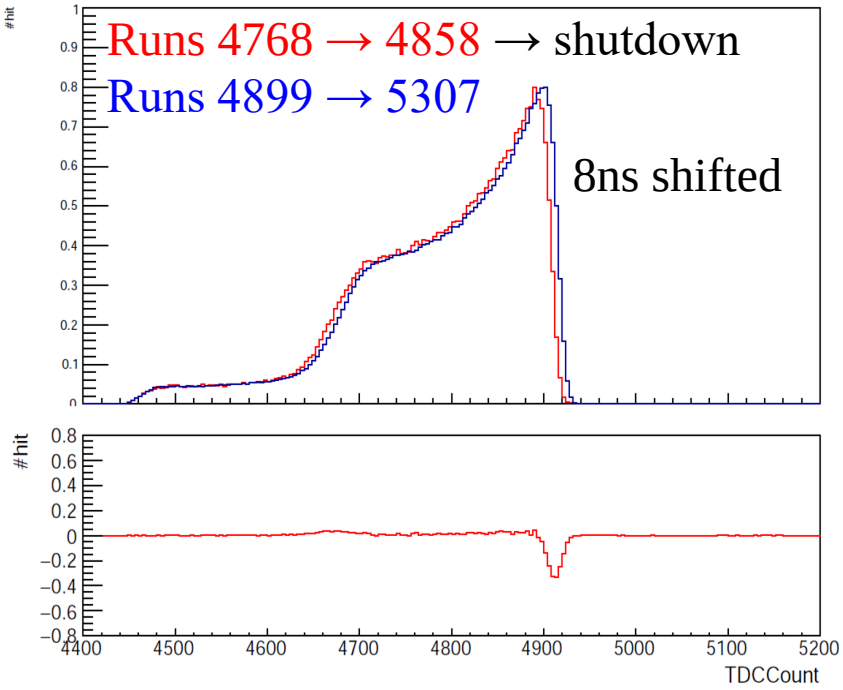
$$\Delta T = A + \frac{B}{\sqrt{ADC}}$$



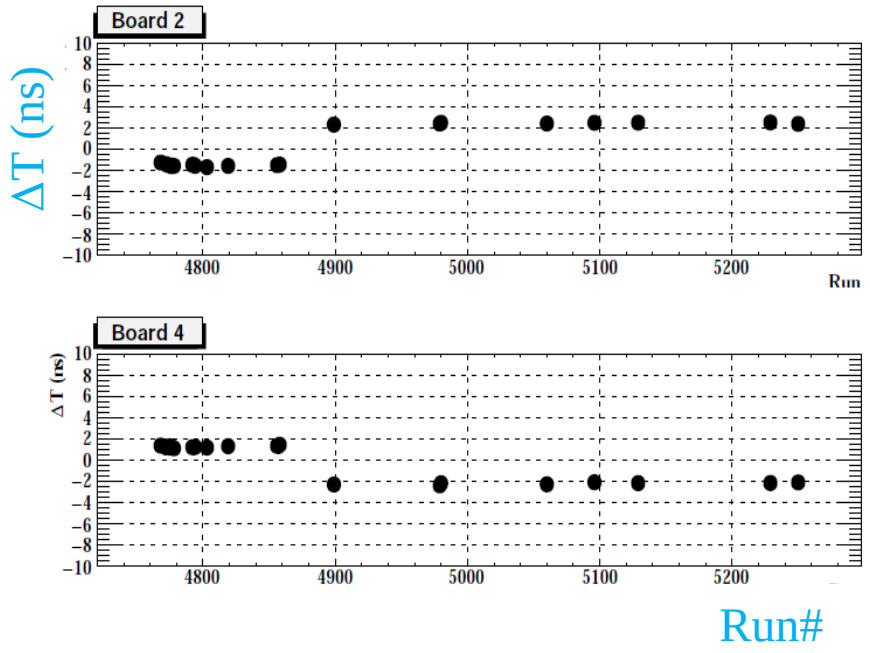
new



Timing



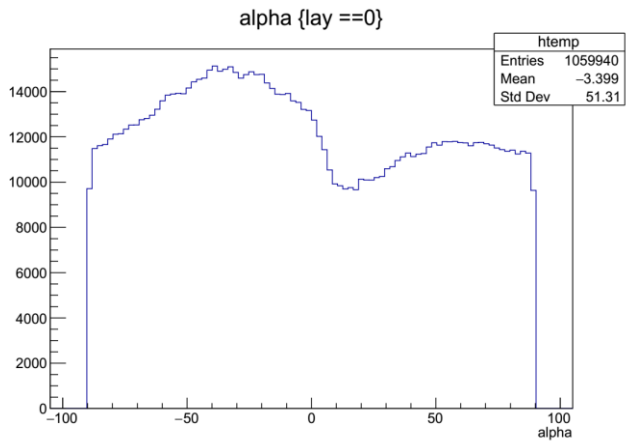
After shutdown, T_0s change board by boards



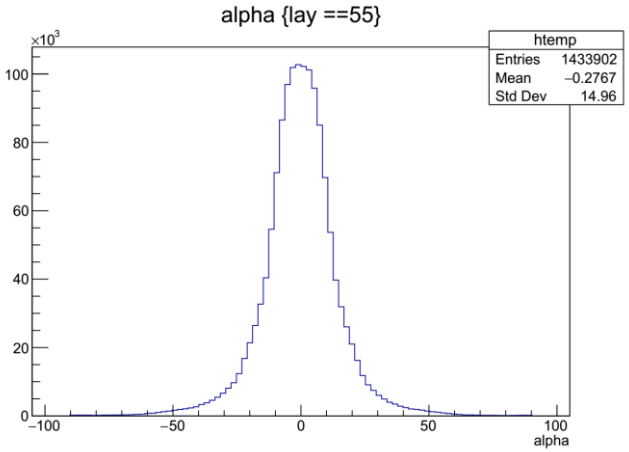
- Since GCR will start soon, I would very happy if timing conditions are kept stable during data taking.

Binning for x-t and sigma

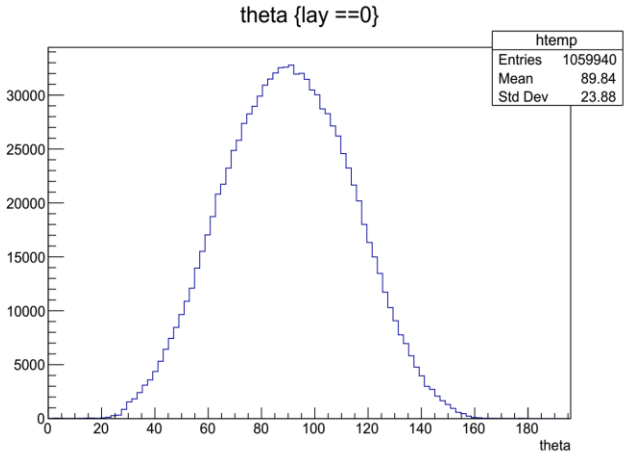
Incident angle, layer=0



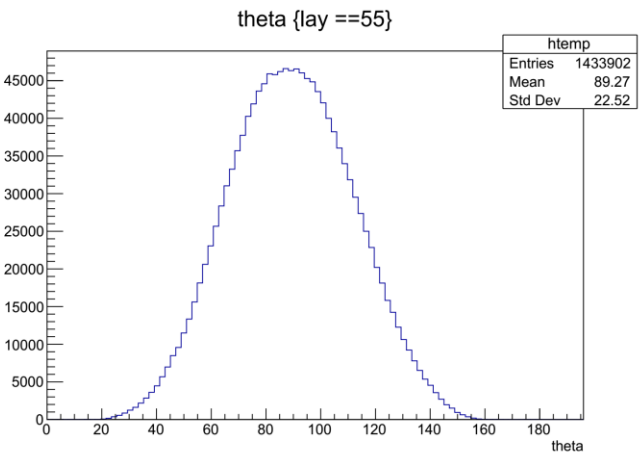
Incident angle, layer=55



Polar angle, layer=0

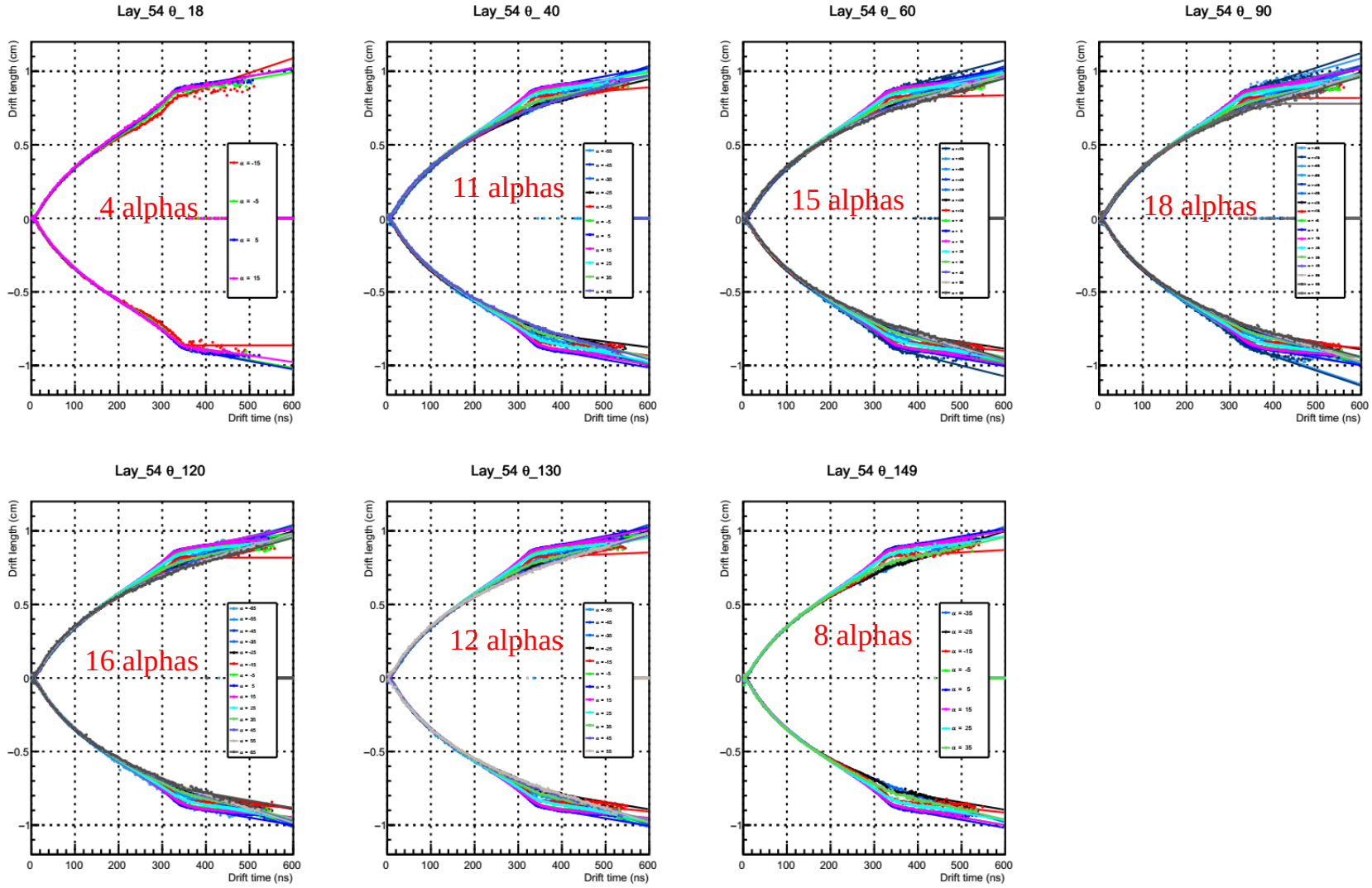


Polar angle, layer=55



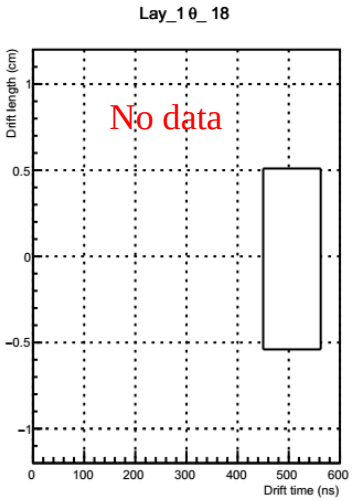
- We use default binning for both xt and position resolution
- 18α bins, every 10 degrees.
- 7 θ bins
- Total: **14112 functions**

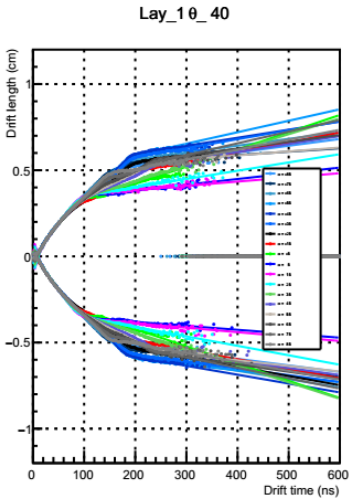
[August] x-t of outer layers

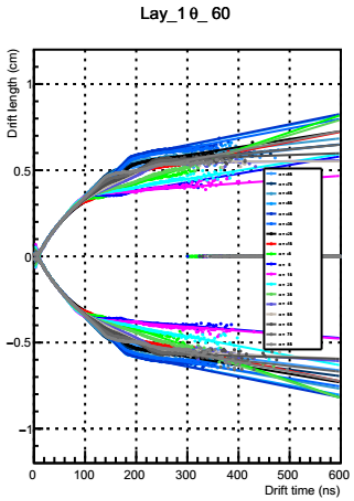


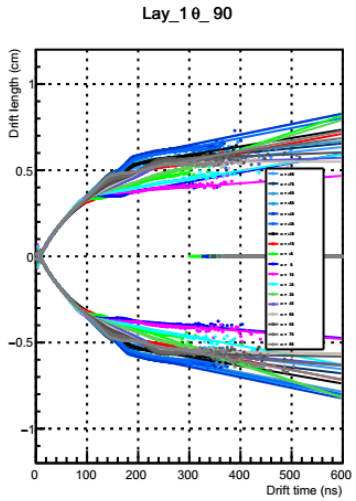
We can calibrate ~9500 in total 14112 xt-functions

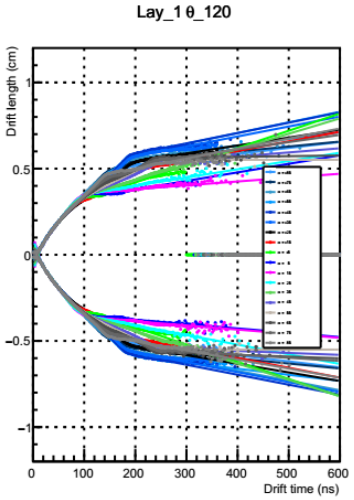
[August] x-t of inner layers

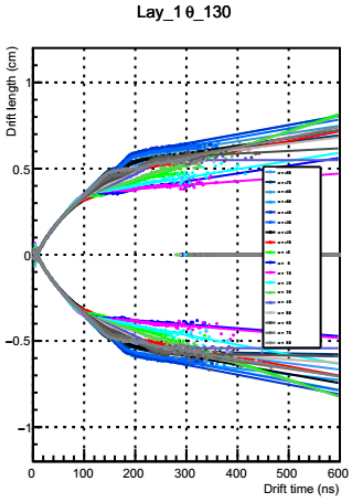


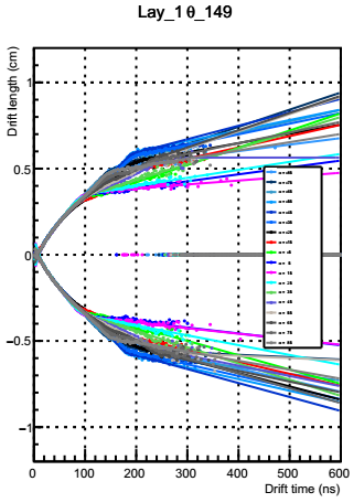






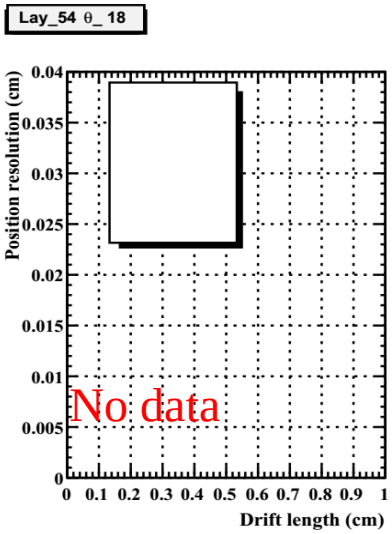


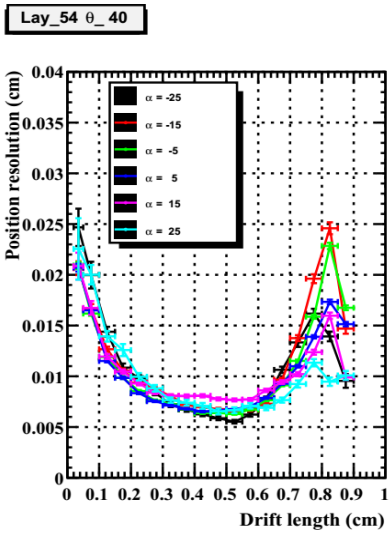


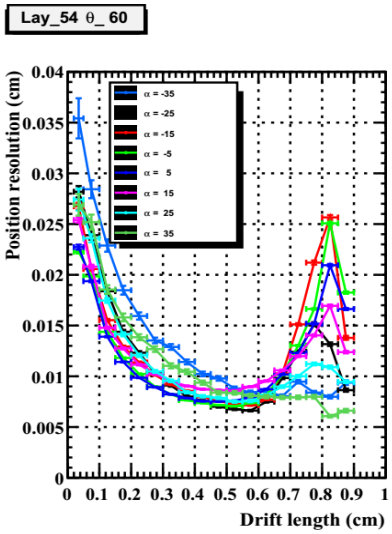


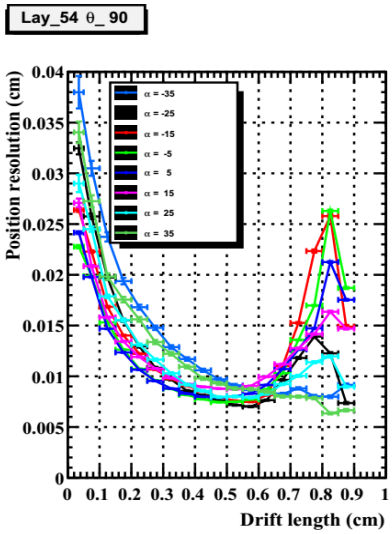
- We don't have data for $\theta=18^{o}$.
- We can calibrated xt for all of $18\alpha \times 6\theta$ bins .

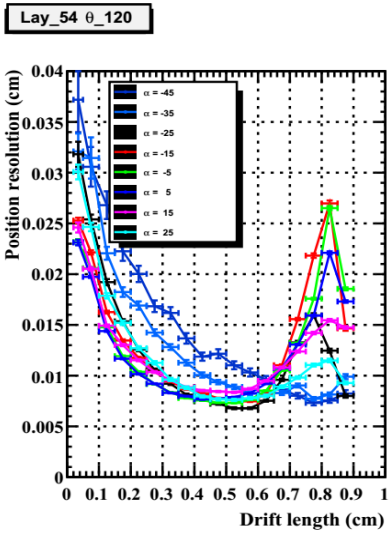
[Aug] Position resolution for inner

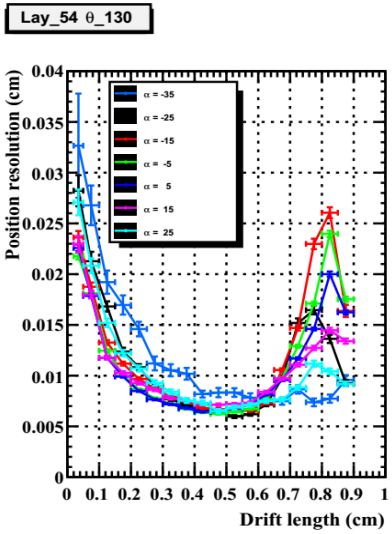


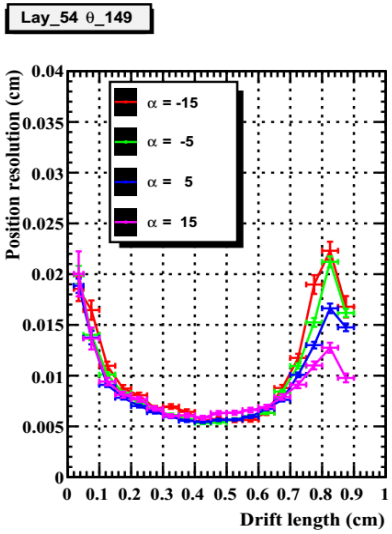










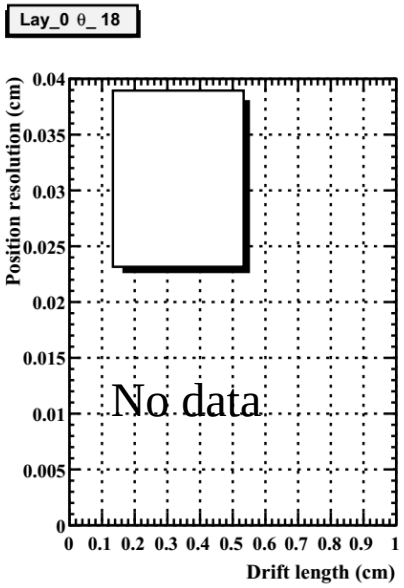


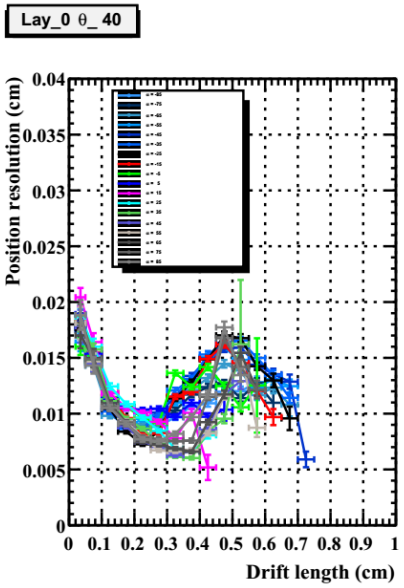
At θ=149, σ ~60um at x=0.45cm.

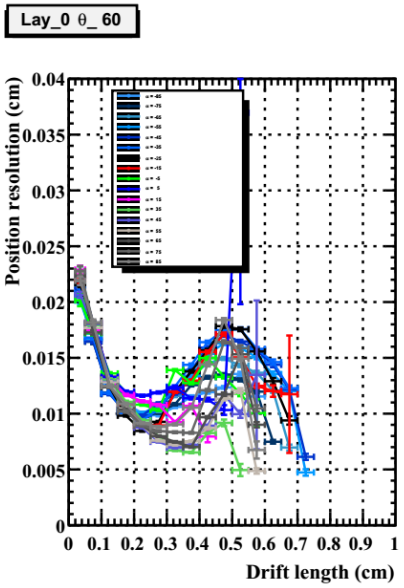
Common value, σ ~70-100um at middle of cell

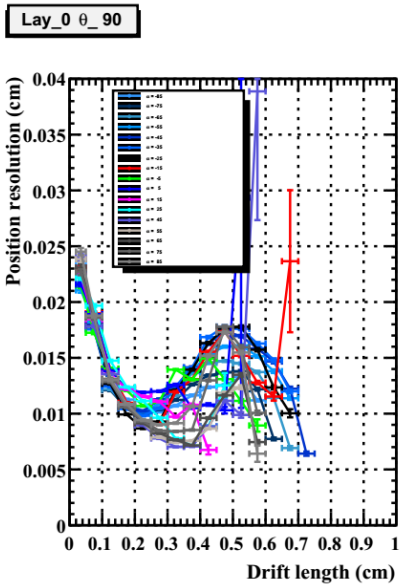
We can calibrate ~7200 in total 14112 sigma-functions

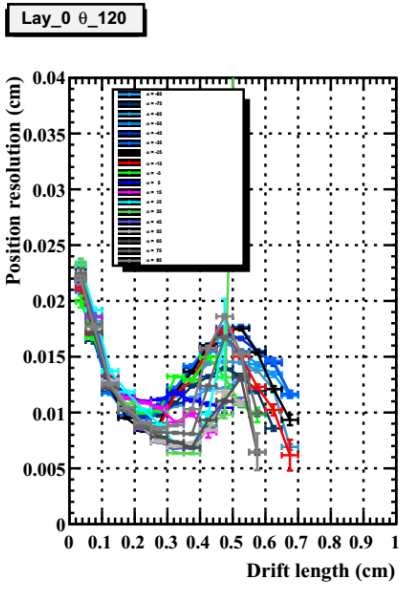
[Aug] Position resolution for inner

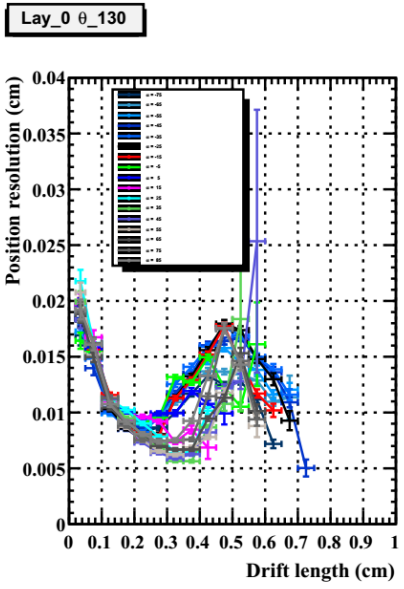


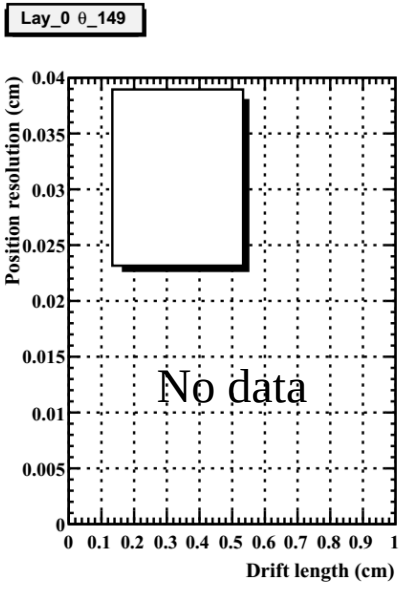






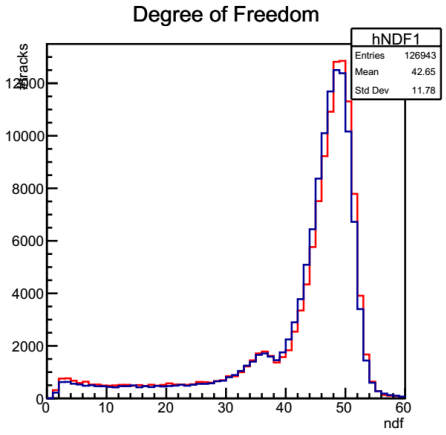


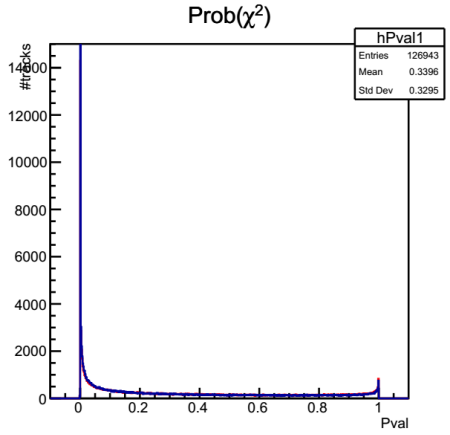




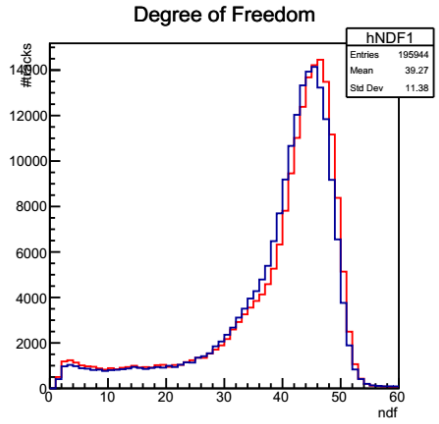
We don't have data to calibrate sigma for $\theta = 18^{o}, 149^{o}$

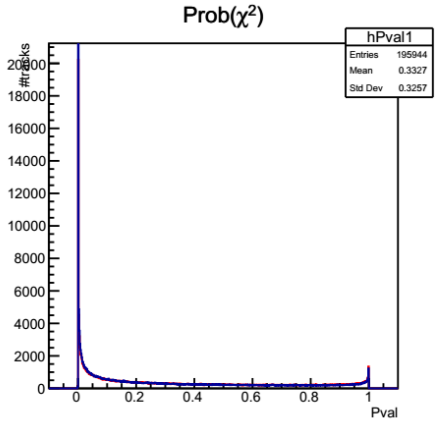
Run 1583-1589 170k events,
good data set but low statistic



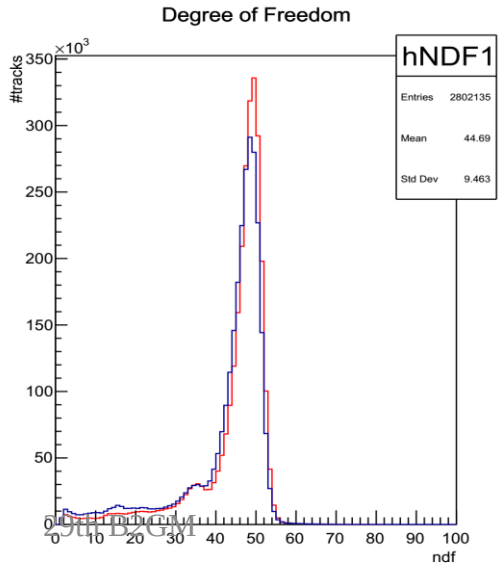


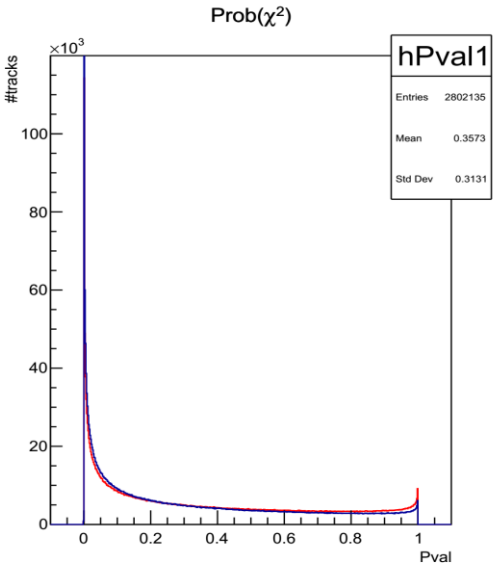
Run 1630-1661,… 270k events
(used for March alignment)
Gas conditions is not good





This data

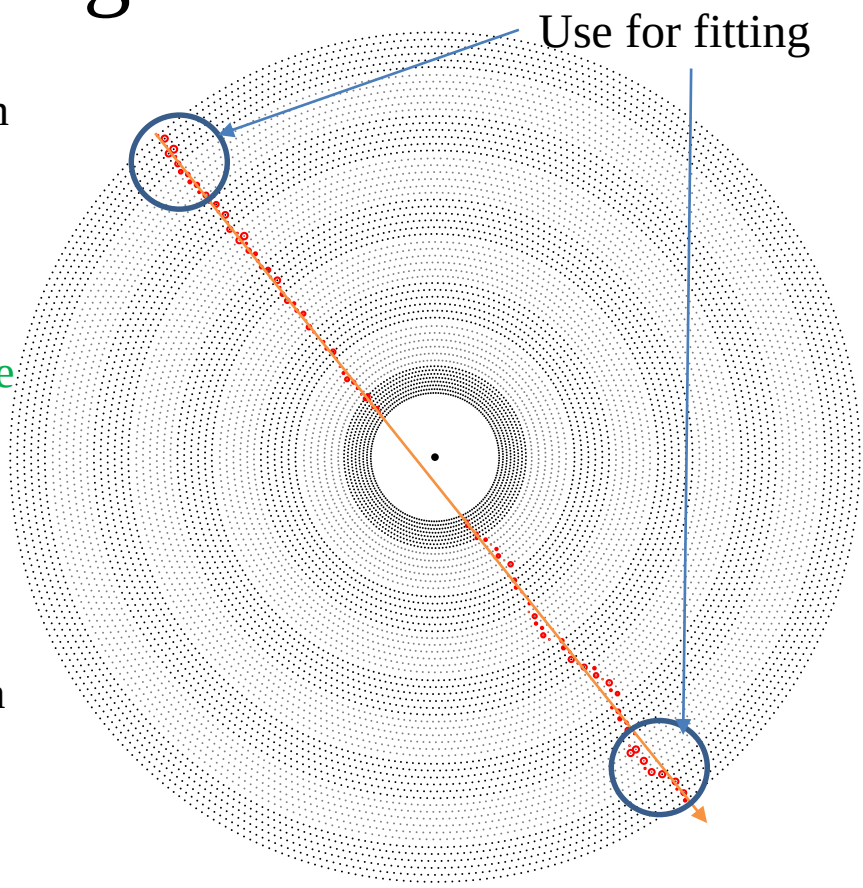




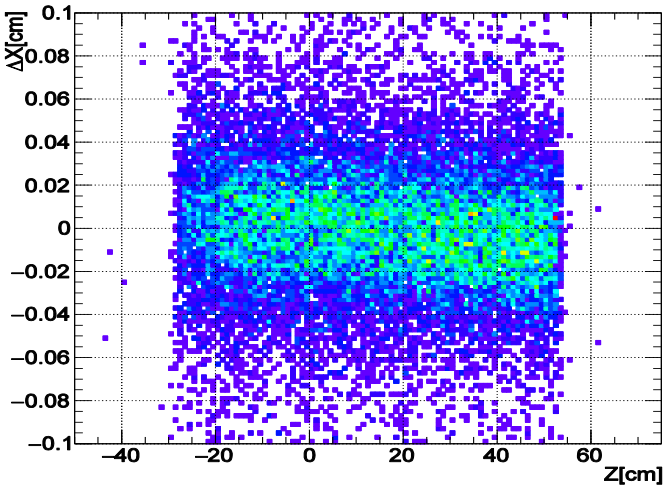
Alignment (without B field)

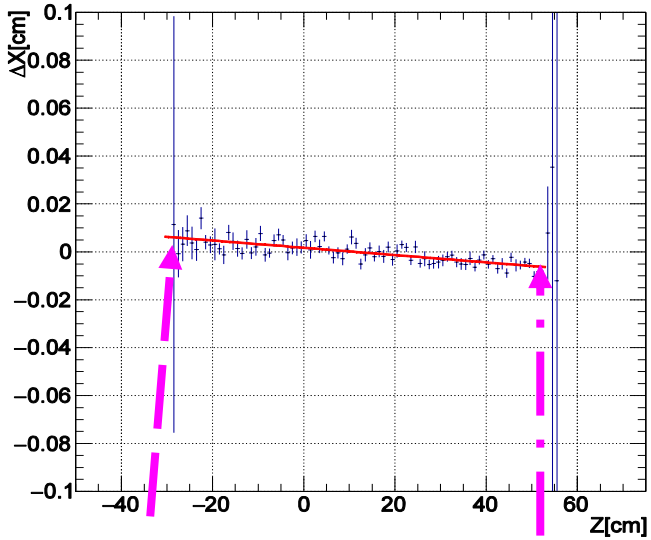
layer by layer alignment

- Select cosmic events have two tracks up/down and merge them together
- Fit track with Super layer 7,8 and extrapolate to inner layers to align inner layers.
- Use track with incident polar angle ~90 degree ($\tan\lambda < 0.2$) → new
- Residual of each channel is fitted with linear function of z, Then extrapolated to end-plates position to estimated residual at end-plates.
- Residual at endplates will be fitted as function of φ to extract rotation, shift value of each layer.
- Align outer layers by fitting with inner layer.



Residual at endplates position

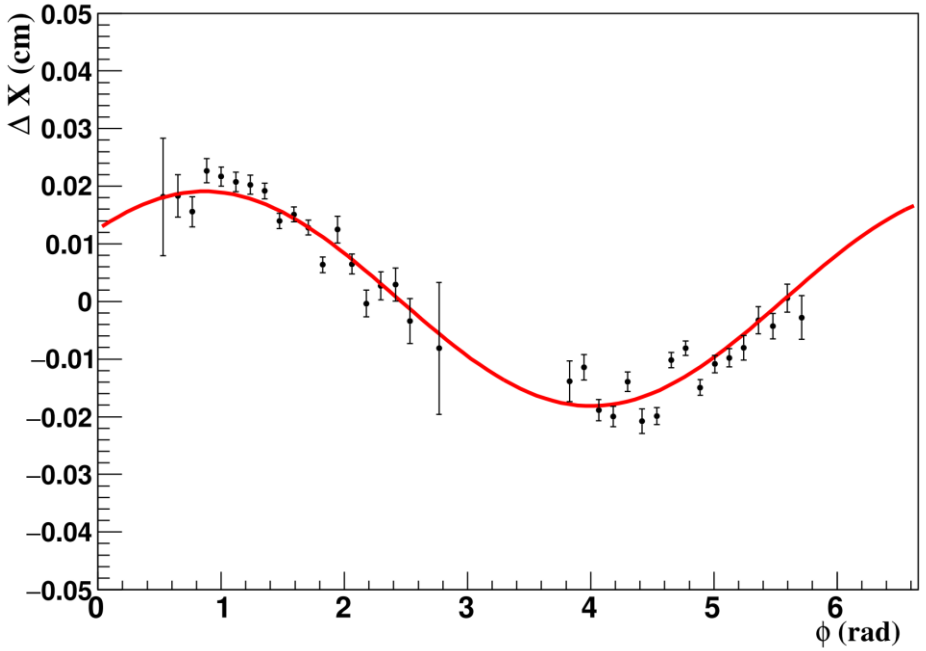




Residual at backward endplate

Residual at end-plates as function of φ are fitted with function

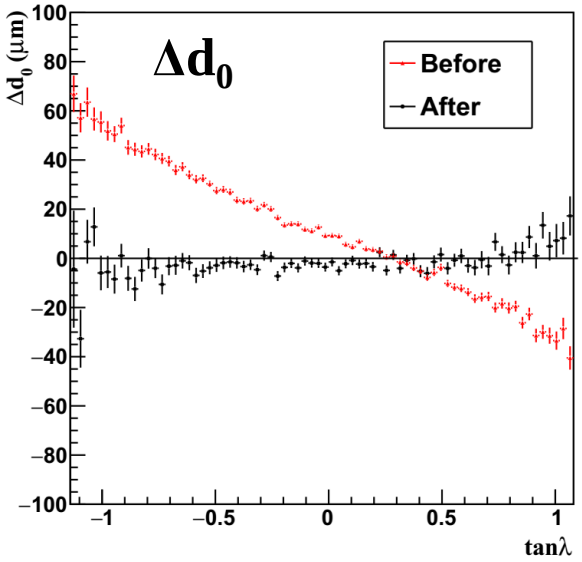
$$\Delta X_{observed} = -\mathrm{R}\sin(\delta\phi) + \delta x * \sin(\phi) - \delta y \cos(\phi)$$

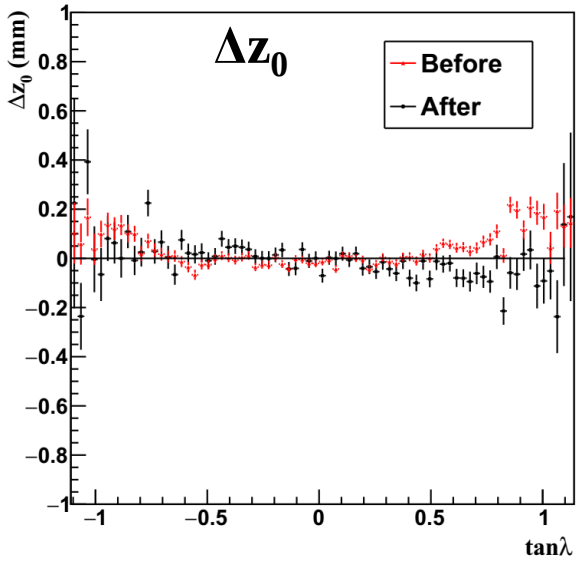


Residual at forward endplate

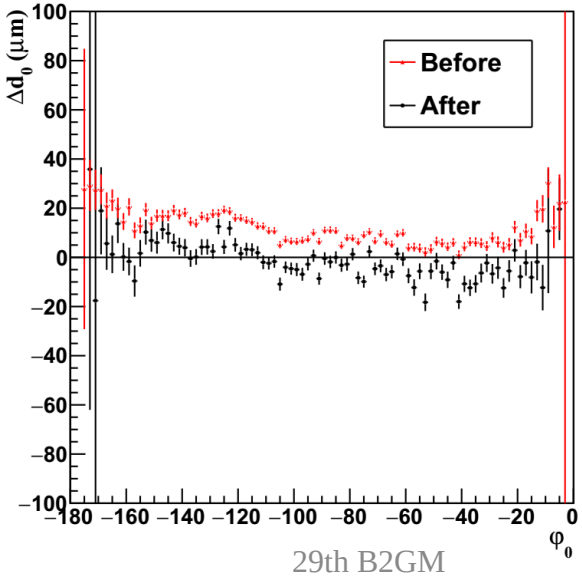
Results after layer by layer alignment

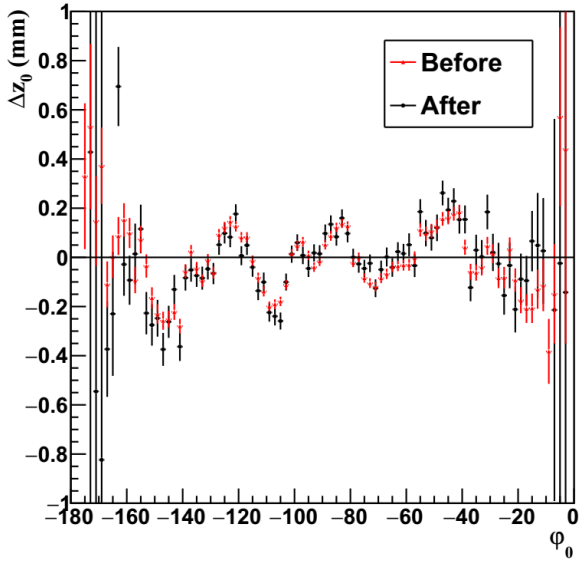
tanλ dependence





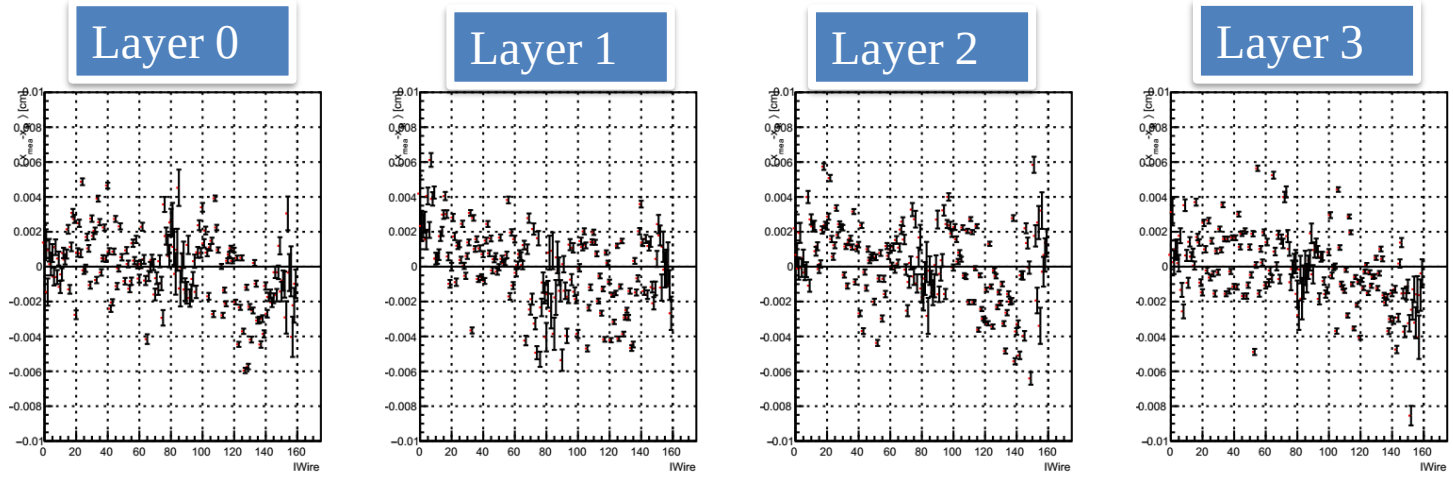
φ_0 dependence



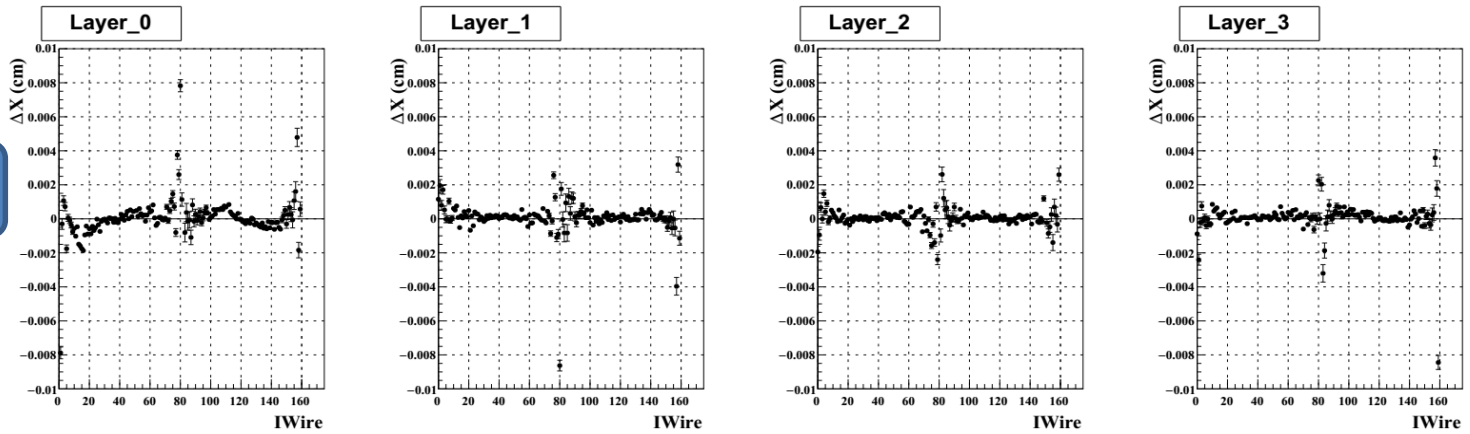


Mean of residual of each channel

Before

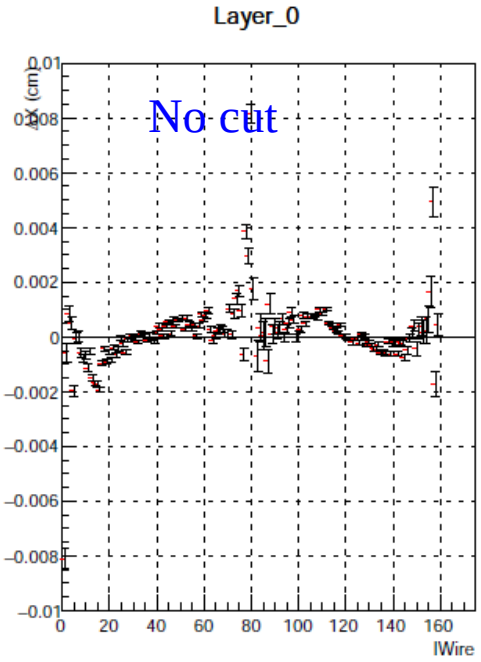


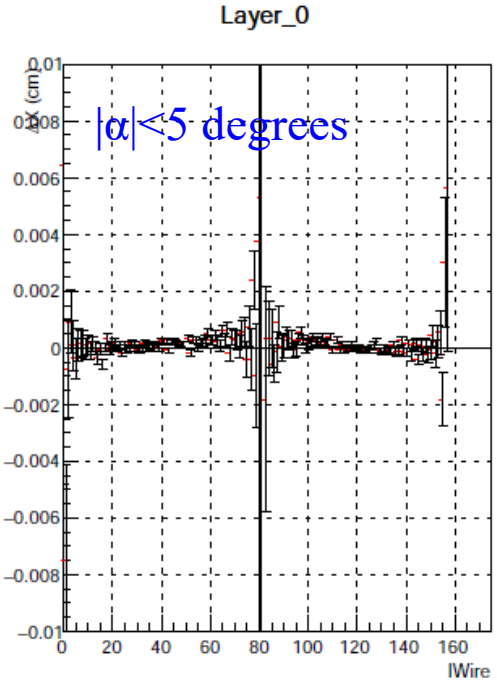
After



Layer 0 (special)

- It is inner most layer, α distribution a bit wider than outer layers. But only |α|<5 is used for alignment w-b-w



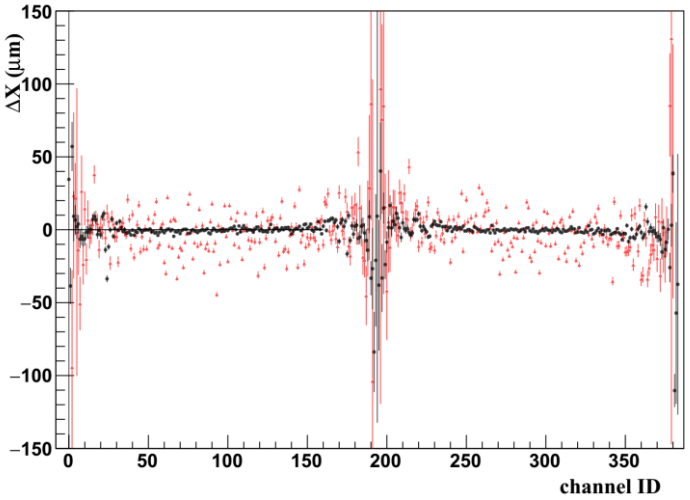


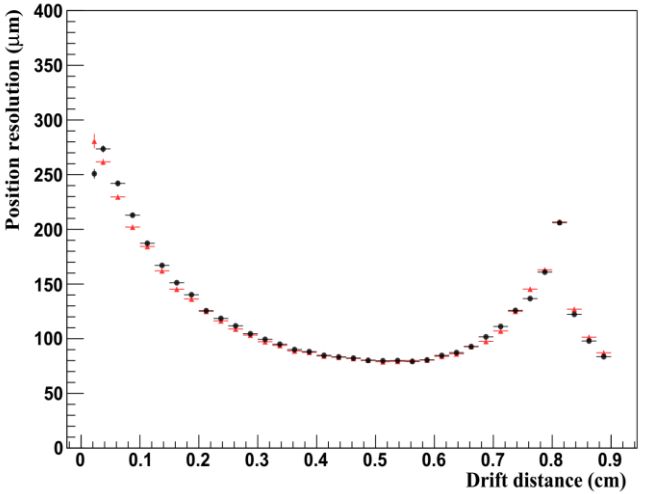
The mis-alignment in r direction of layer 0 is larger compare with other layers

Effect wire by wire alignment on position resolution

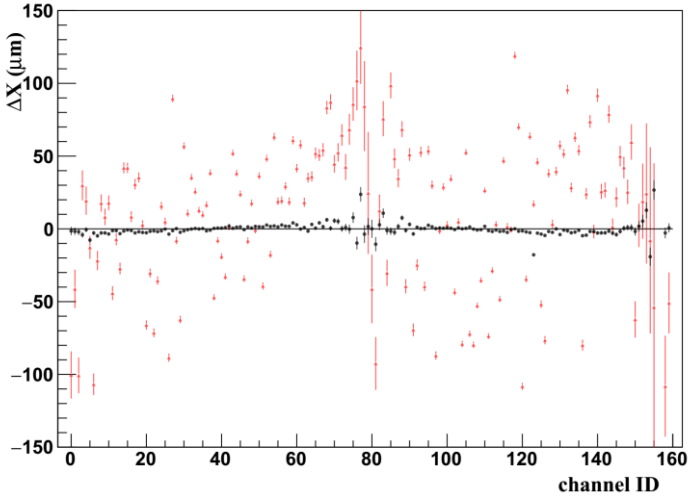
Layer 55

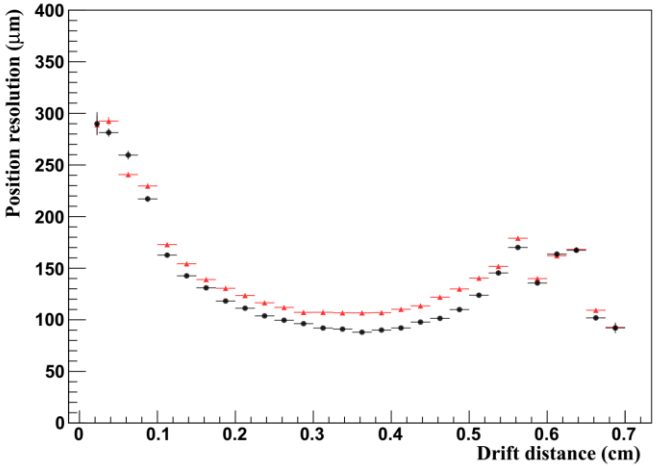
- Before
- After





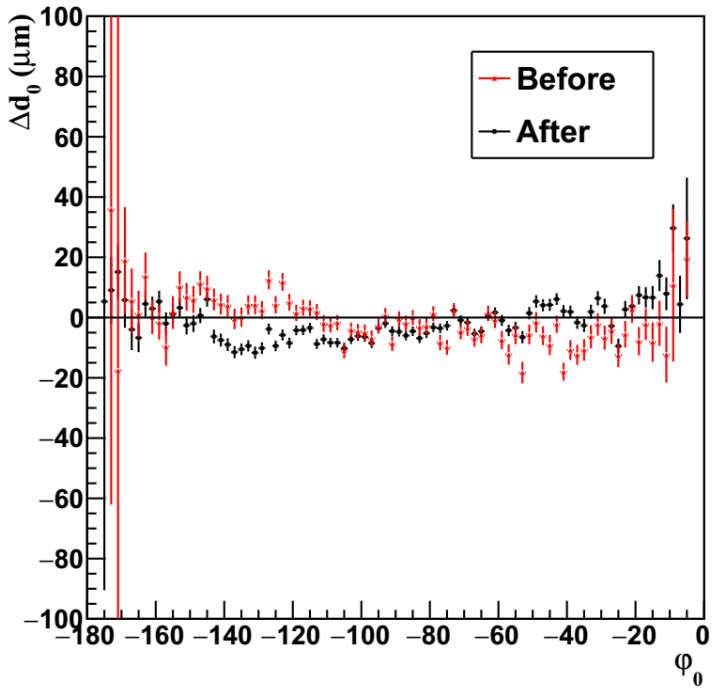
Layer 12

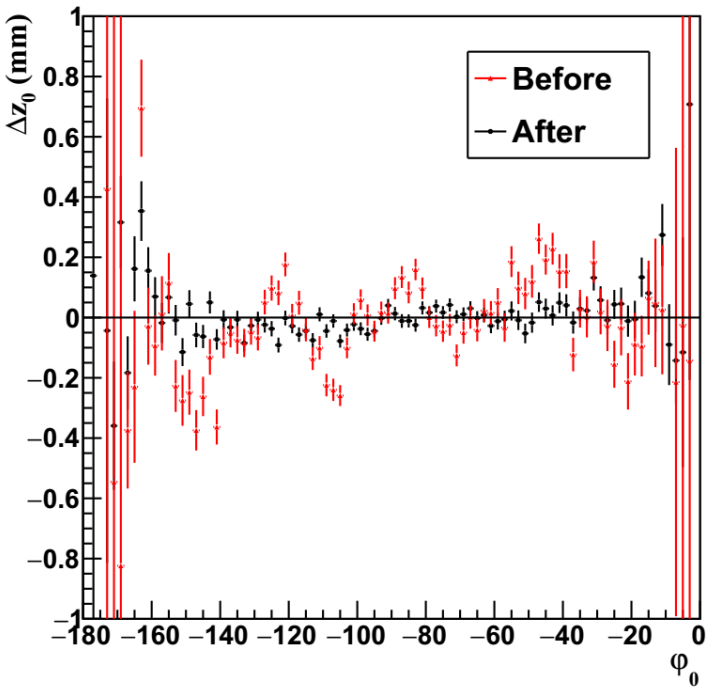




=>Position resolution is improved after wire by wire alignment.

After wire by wire

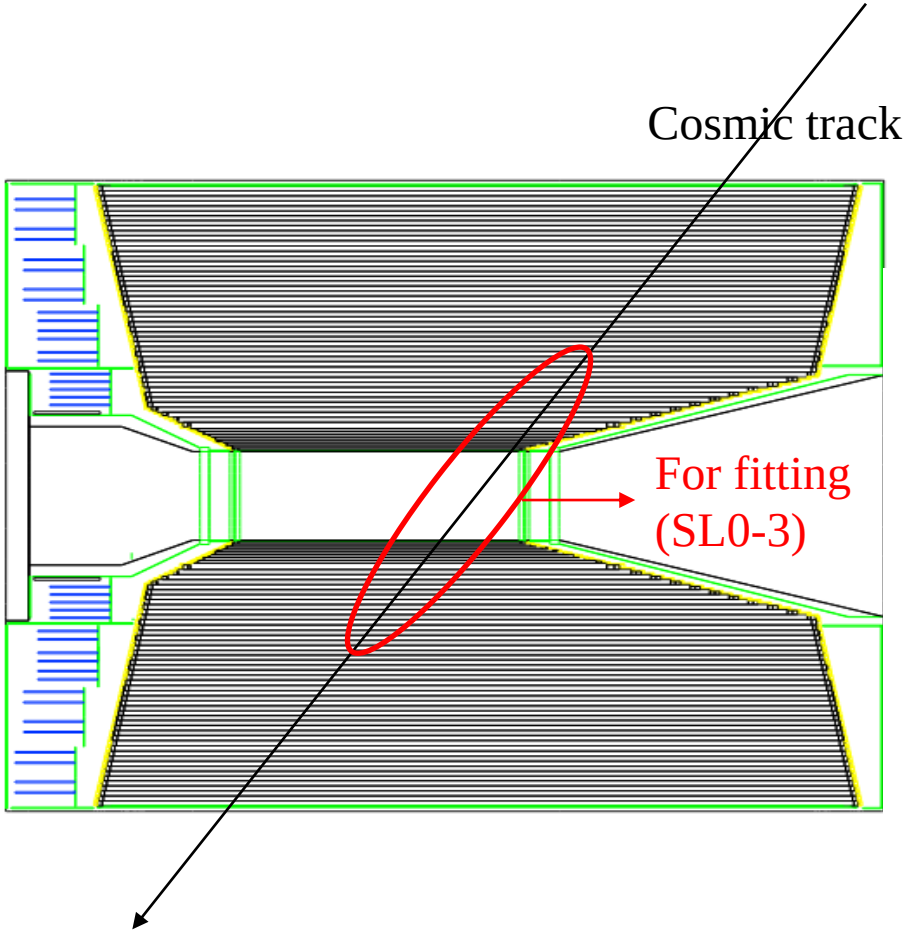




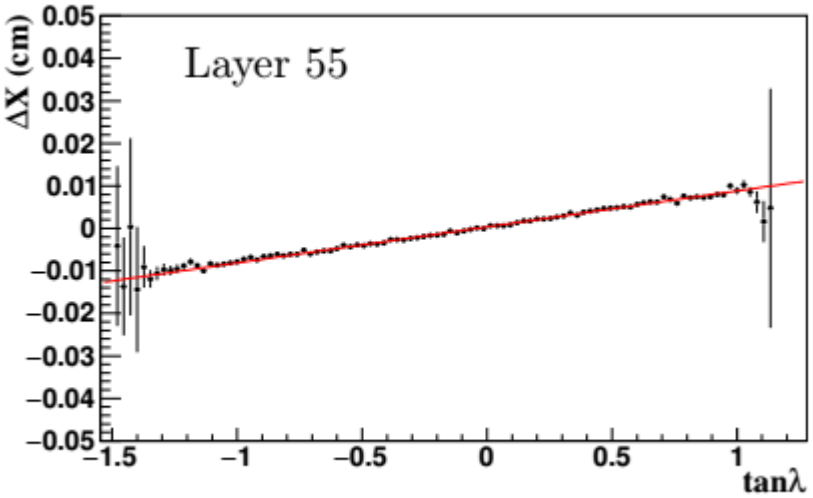
- Structure of Δz_0 disappear after wire by wire alignment as expected.
- Small systematic shift of d_0 (~10μm) at $\varphi_0 \sim 140^0$ might due to the remaining misalignment in r direction of layer 0.

Twist alignment

(The rotation of forward w.r.t to back ward)



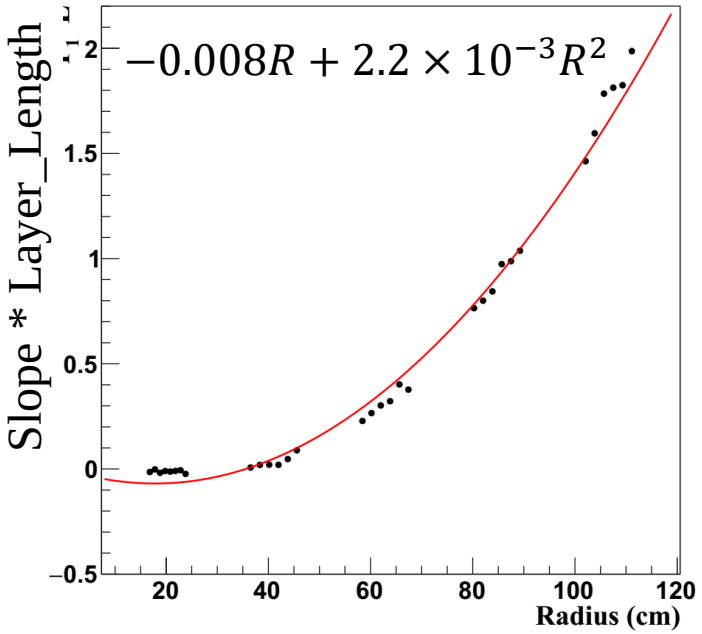
The dependence of Δ X on tanλ is fitted with linear function to obtain slope.



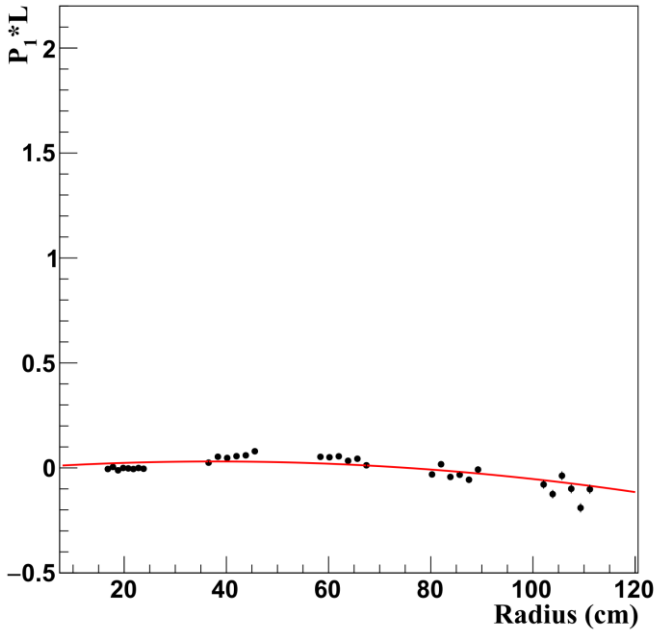
- Slope depends on Layer radius and the twist angle

Summary of twist

At first iteration of twist



At last iteration of twist

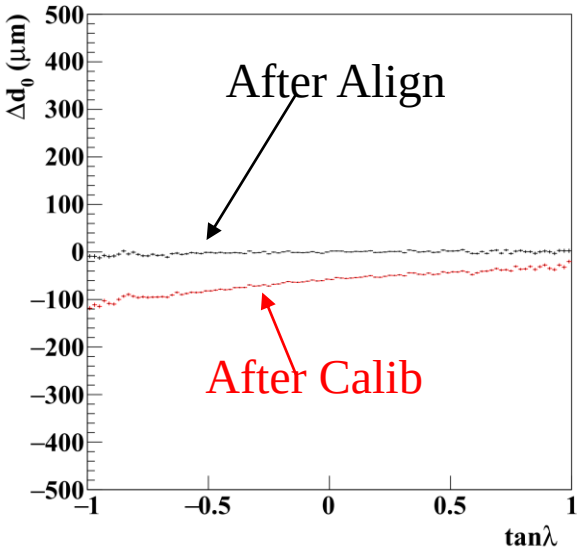


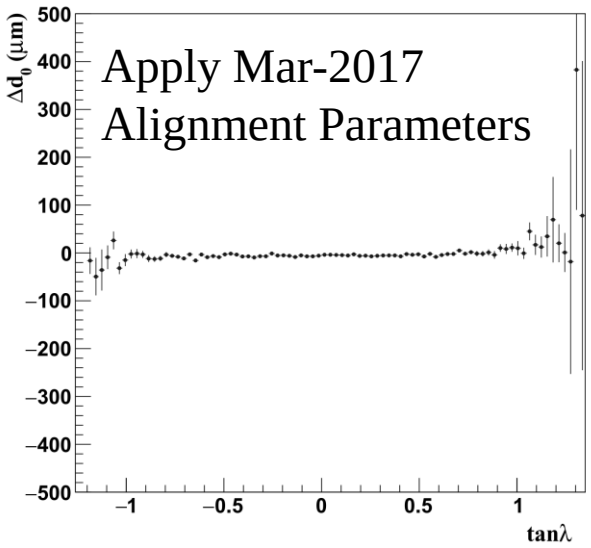
Sum of all iterations: forward end-plate is rotated **0.3 mrad** w.r.t to backward side.

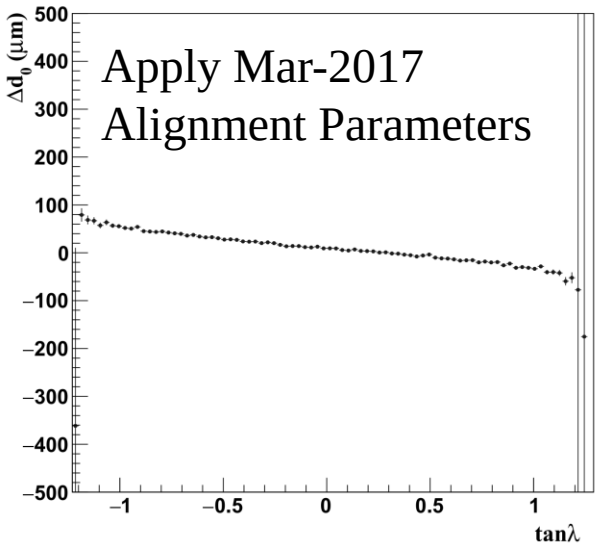
tanλ dependence history

Remove B-field mapper

Mar-2017 GCR-2017 Oct-2017



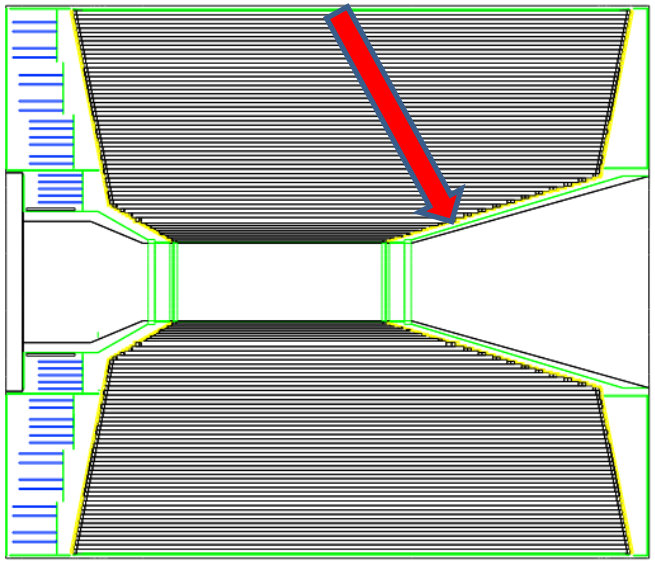


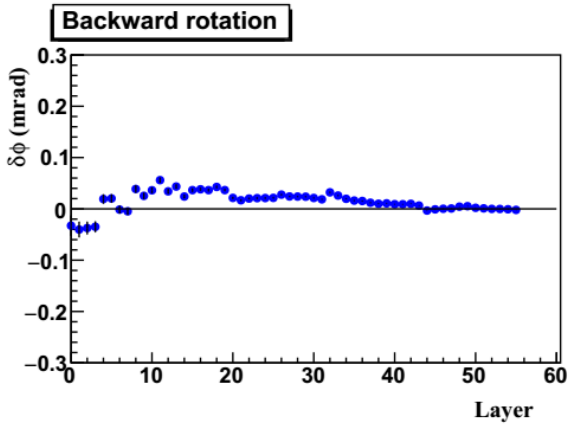


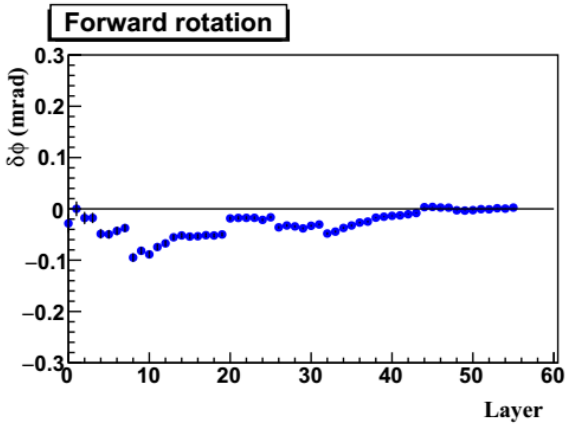
=> Something happen with CDC or I do something wrong

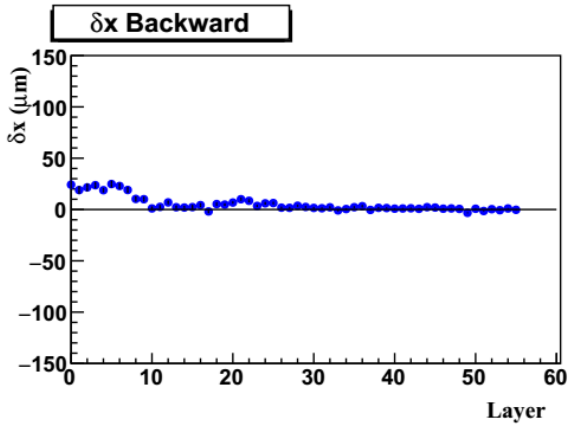
Align inner layers

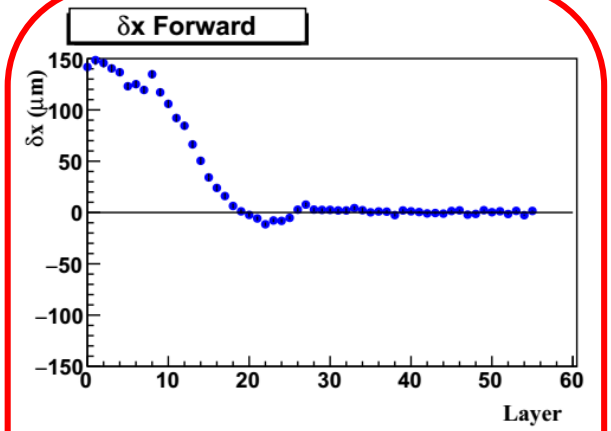
- A very large shift appear at forward side of conical and small cell part

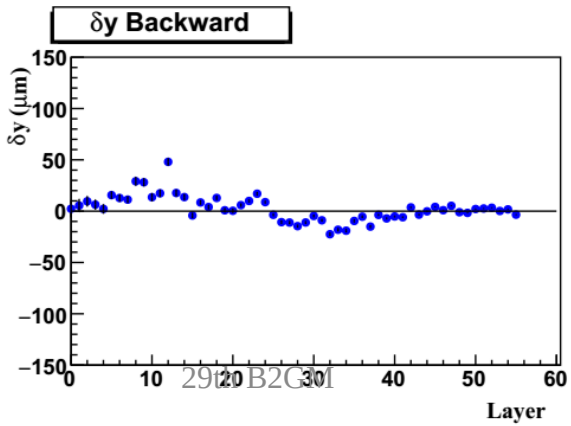


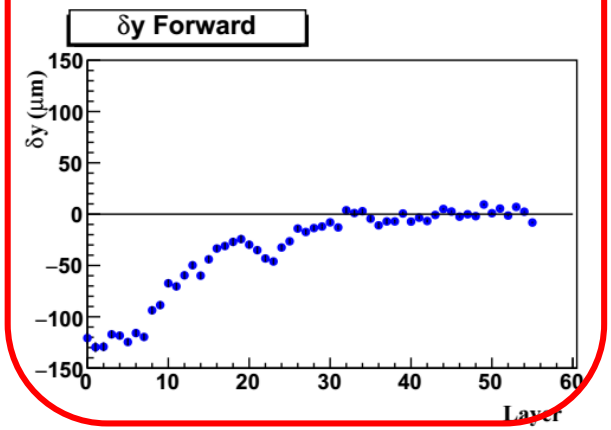








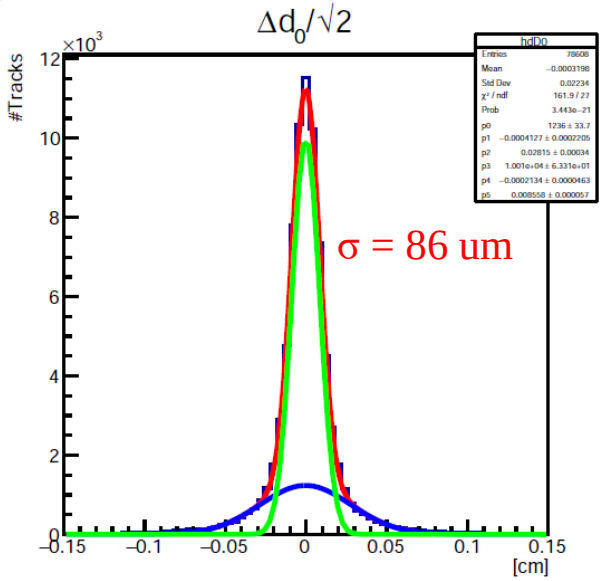


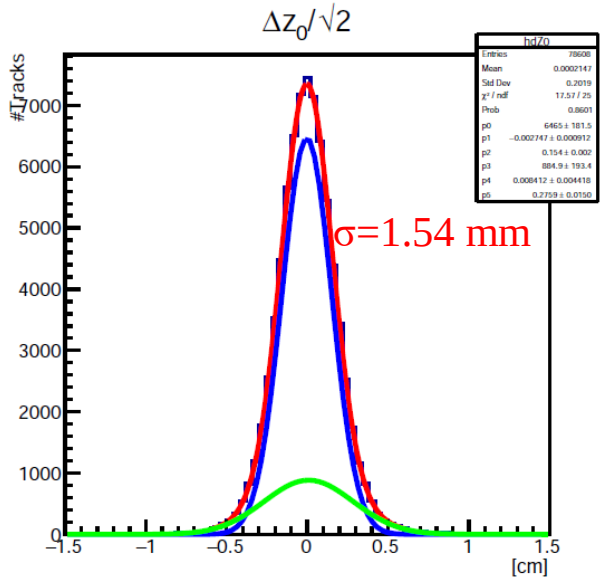


Final results at present

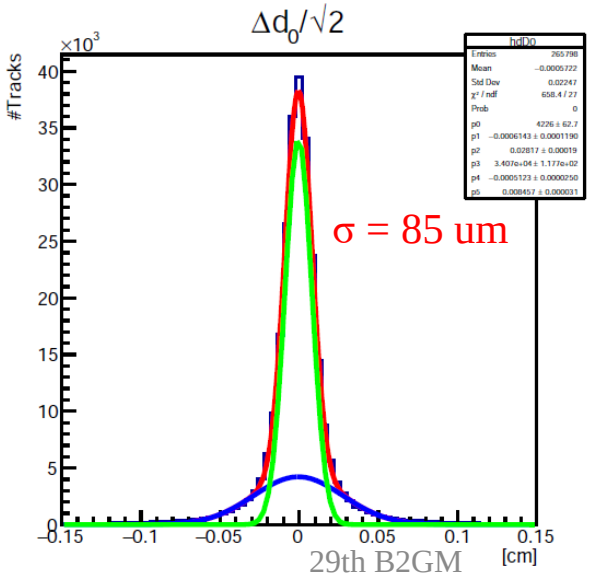
d_0 and z_0 resolutions

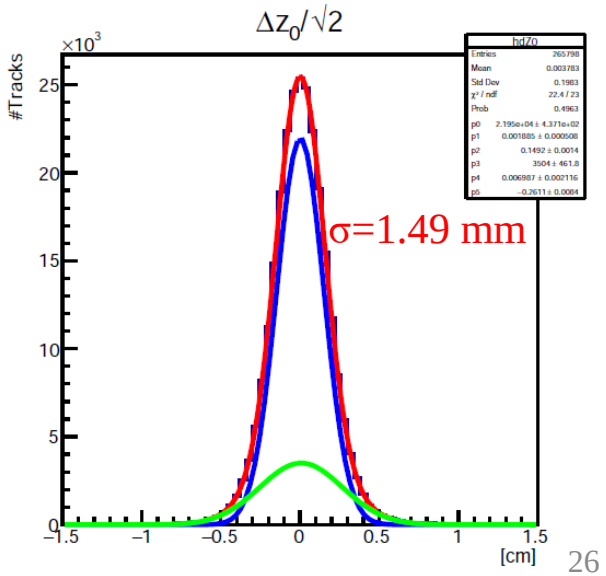
Before wire by wire alignment





After

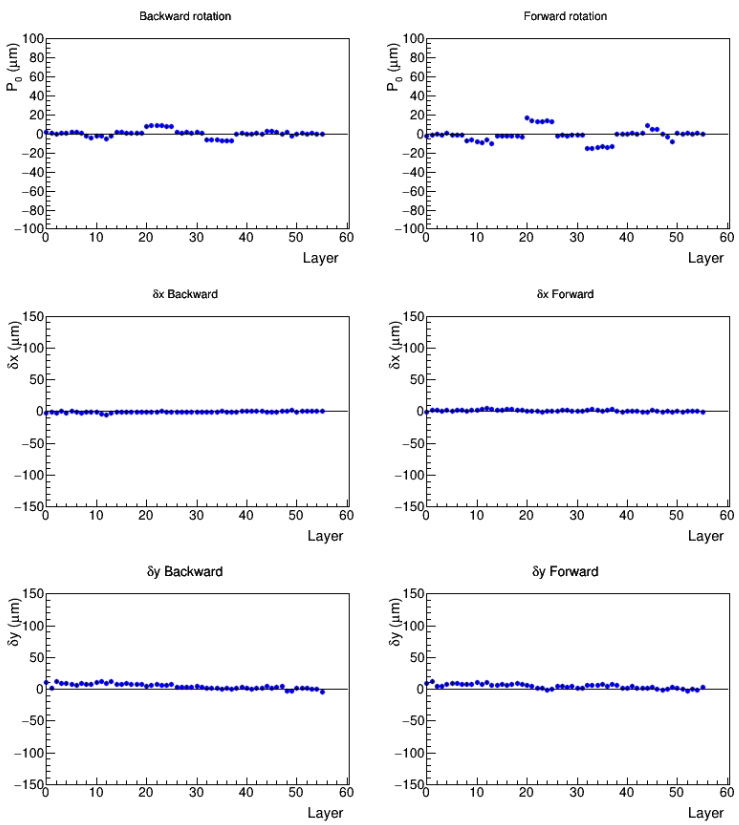




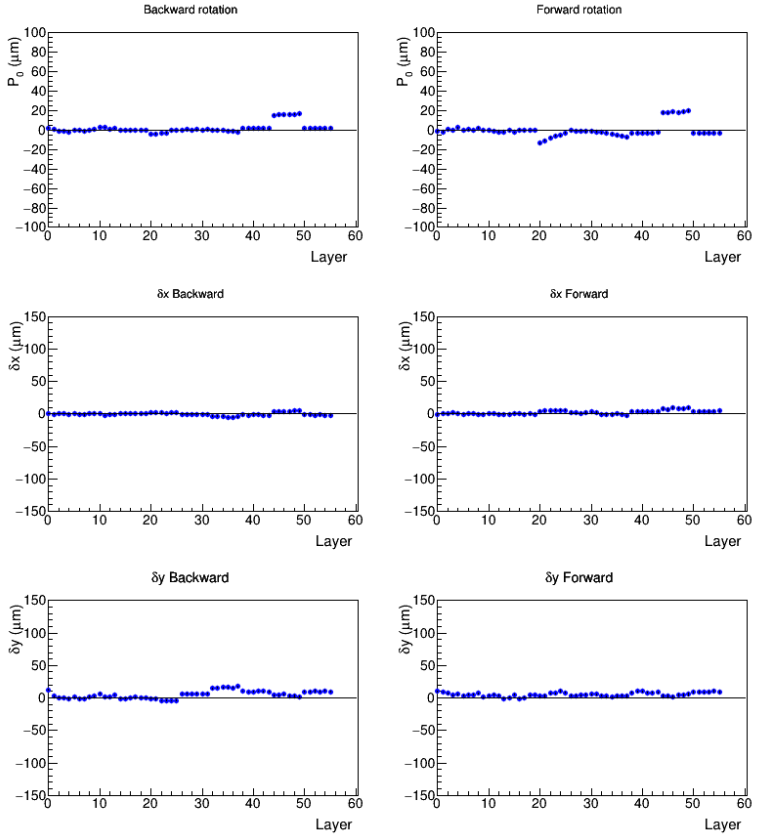
Remaining (don't know why)

Add one more axial for fitting.

Fit SL 6,7,8



Fit SL 0,1,2



This shift is strange because both backward and forward shift the same direction and values =>it mean no shift.

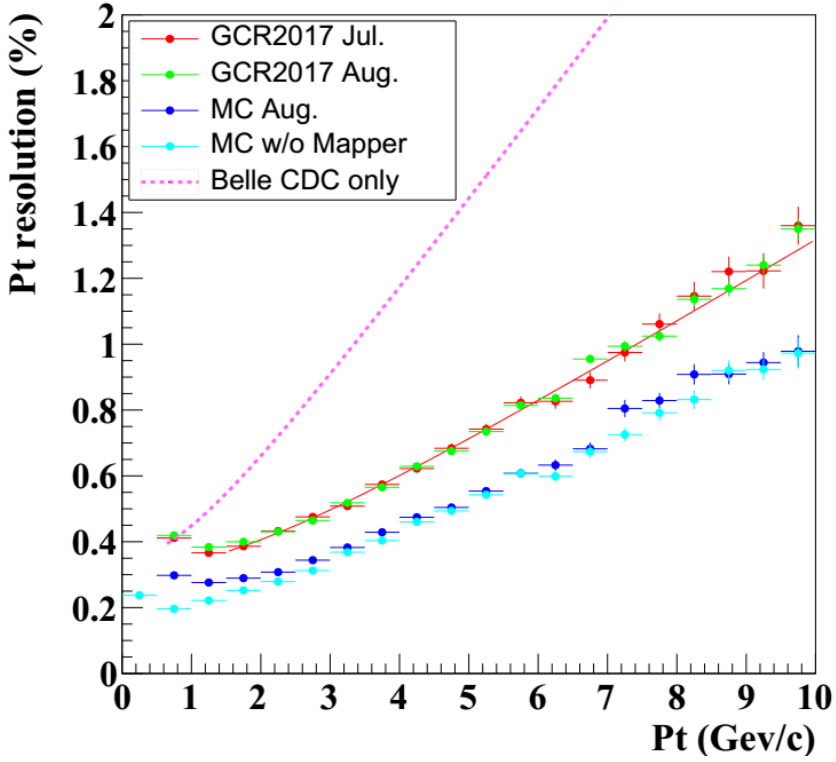
Transverse momentum (Pt) resolution

Belle CDC only: $\sim 0.28 P_t \oplus 0.35$ (%)

GCR2017 July: $\sim 0.13 P_t \oplus 0.31$ (%)

- P_t resolution = $\frac{\sigma_{P_t}}{P_t} = \sqrt{p_0^2 {P_t}^2 + p_1^2}$;

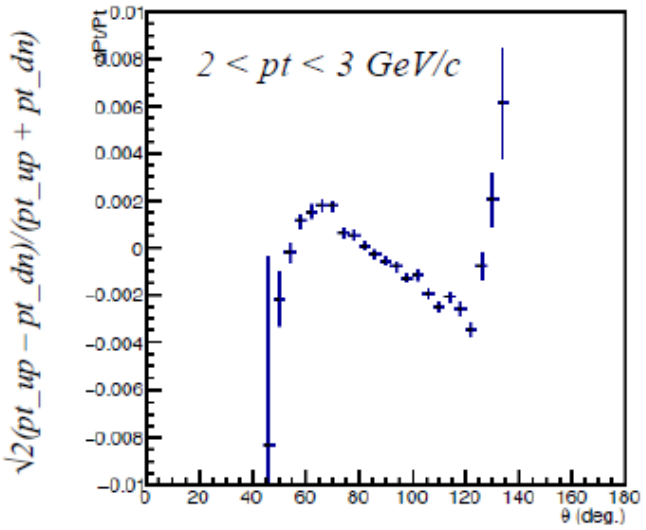
$$\sigma_{P_t} = \frac{\sigma[\Delta P_t]}{\sqrt{2}} \; ; \quad P_t = \frac{P_t^{up} + P_t^{down}}{2}$$



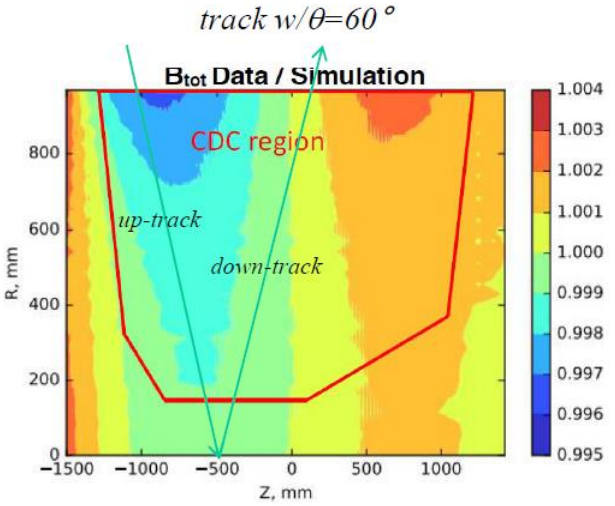
- P_t resolution is ~0.38% at P_t=1.5GeV.
- It's much improved as compared with Belle CDC, especially high Pt region.
- This great improvement is as a result of the increase CDC radius and also better calibration and alignment.
- The difference between MC and data might be due to the remaining misalignment in CDC and not-perfect magnetic field knowledge.

θ dependence of pt

Observed Pt difference
between upper and lower



Field difference
between measurement and calculation



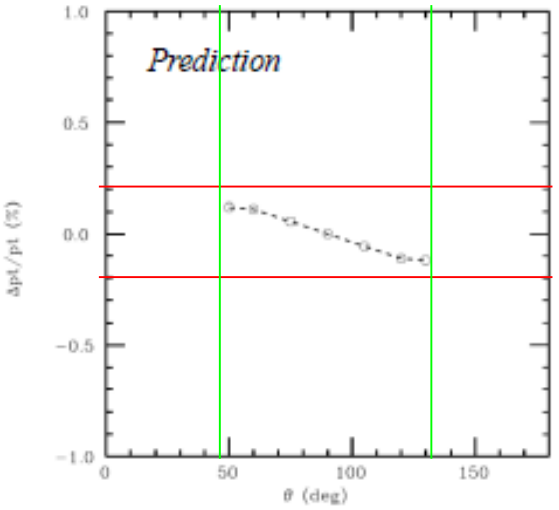
pt of up-track is higher;
pt of down-track is lower

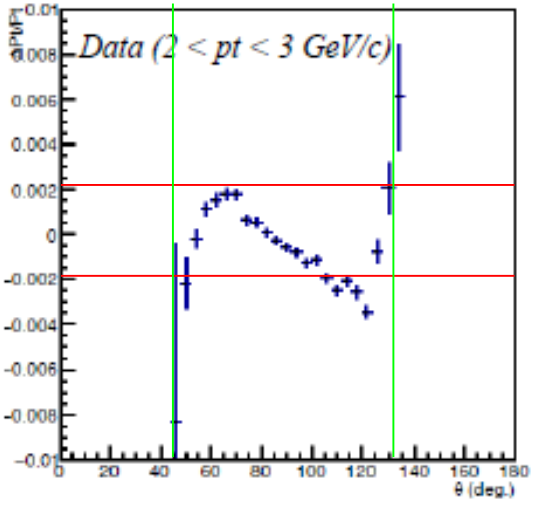
- θ dependence of pt was observed for the GCR data in the last summer.
- We expected the dependence is related to the difference of the magnetic field between calculation and real.
- More study is necessary to understand the situation and to know how to cure this dependence.

(A Bit) Quantitative Prediction for Pt-shift

- I got R(=B_meas/(nf*B_calc) from a DESY person. I performed detector simulation using the modified B-map. Then I reconstructed tracks using the nominal B-map.
- Result → see right Fig.

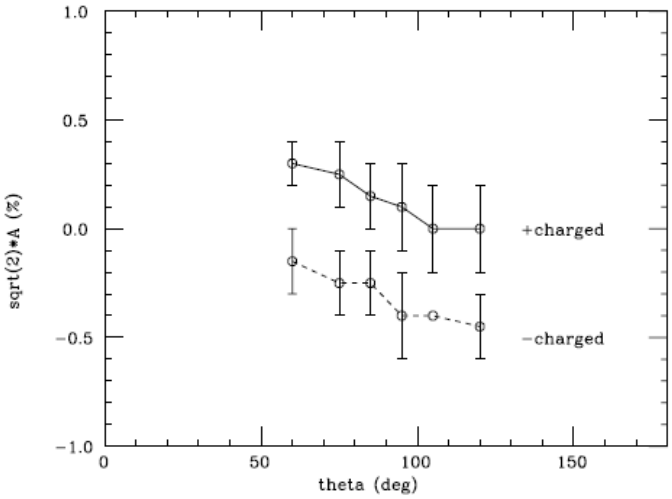
- Remarks
  - B-field meas. exist only up to r~97cm, while max r of CDC is ~112cm.
    I assume the same B-field for this region as the one at r~97cm.
  - B = B_solenoid + B_anti-solenoids + B_q-magnets
    Ideally, B → R*B_solenoid + B_anti-solenoids + B_q-magnets
    cf. B→ R*B in my prediction.
  - Calibrated xt will also be biased if B-field in reconst. is wrong. No consideration of this in my prediction (but I guess this effect is small…)



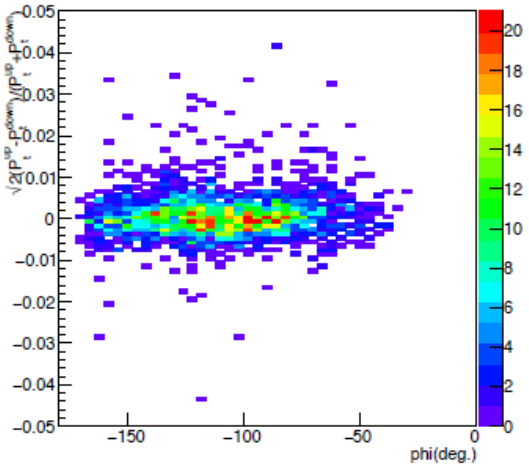


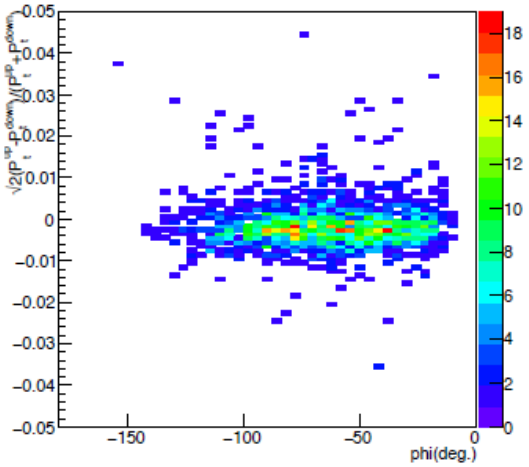
Other dependence

Charge dependence

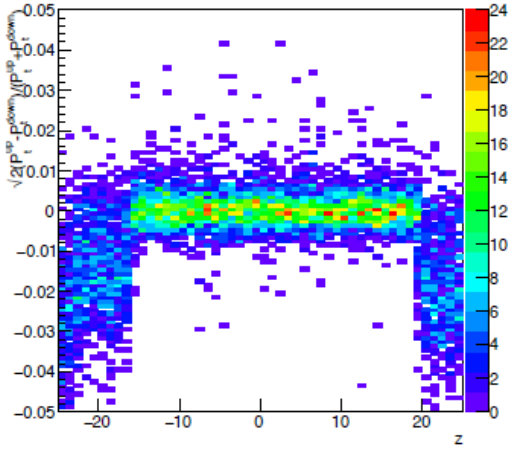


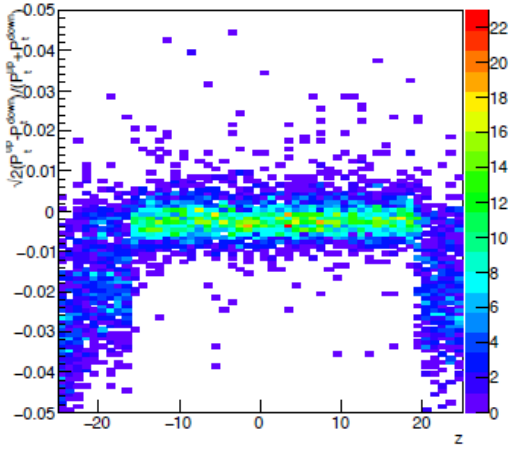
Phi dependence





Z dependence

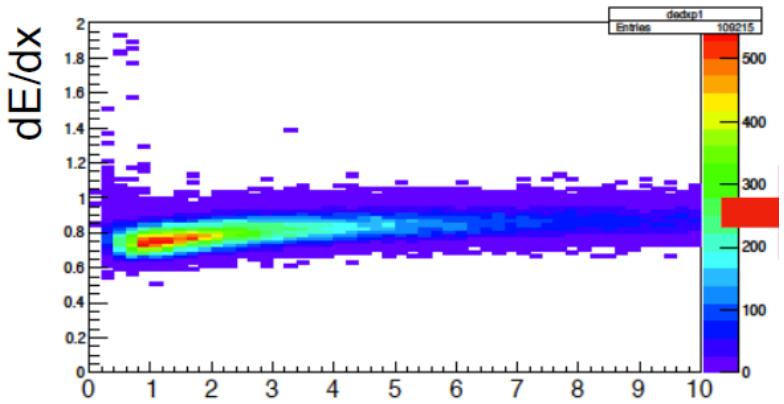


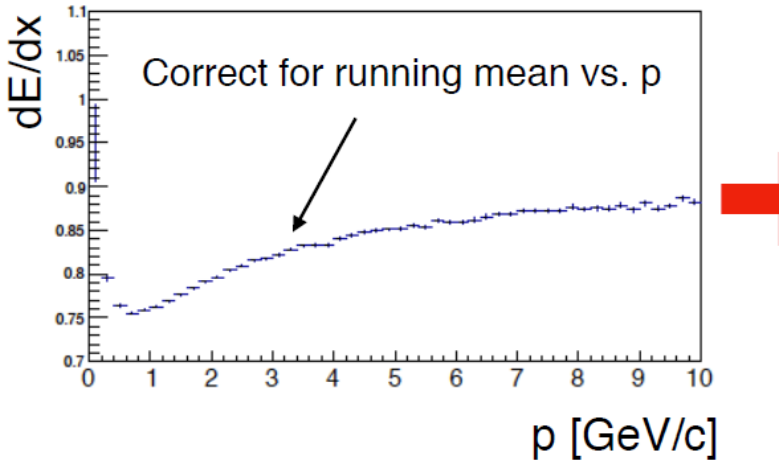


dE/dx calibration

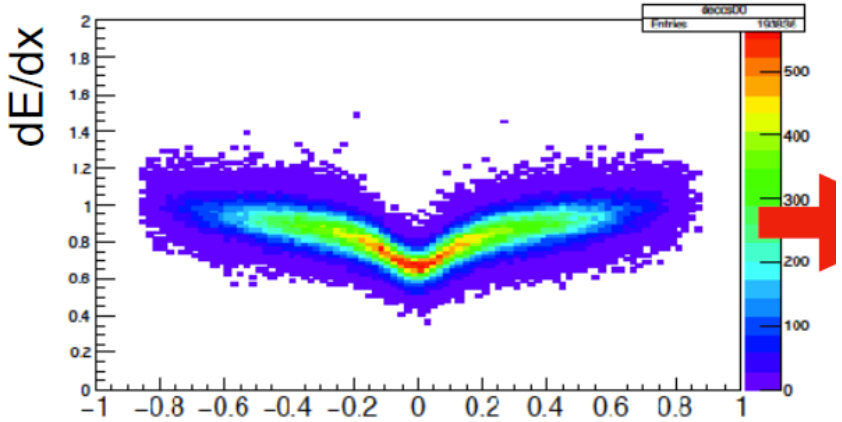
Normal dependence

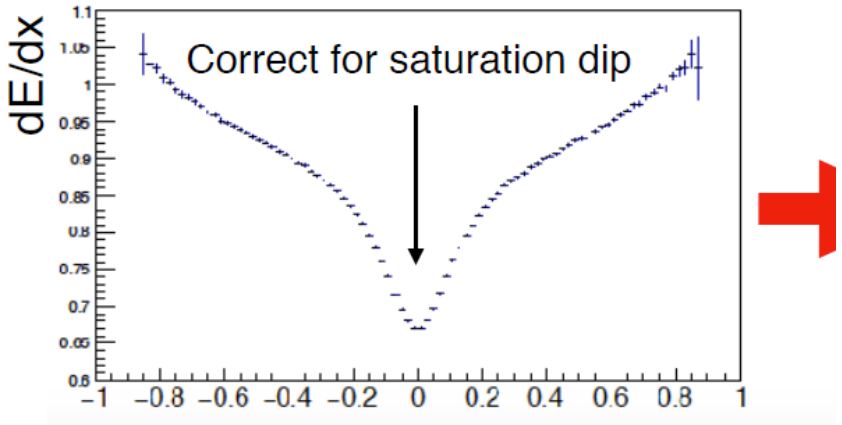
Bethe-Block Curve



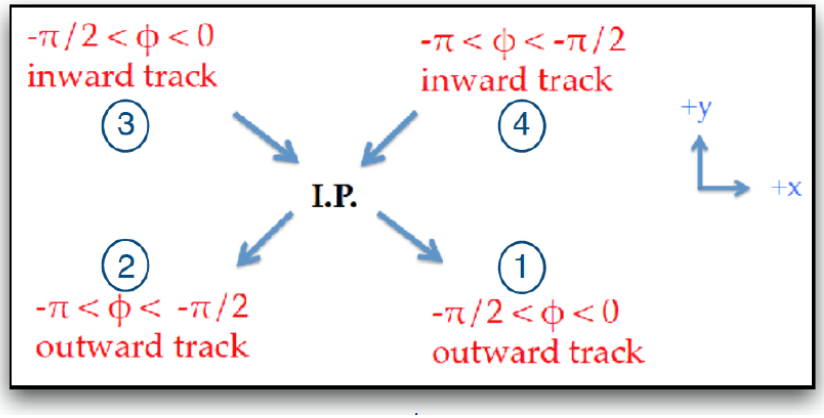


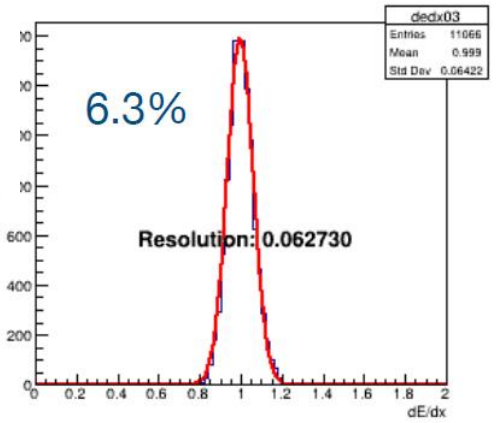
Gas gain saturation

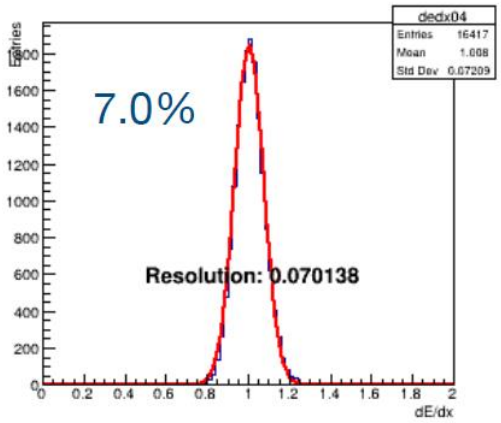


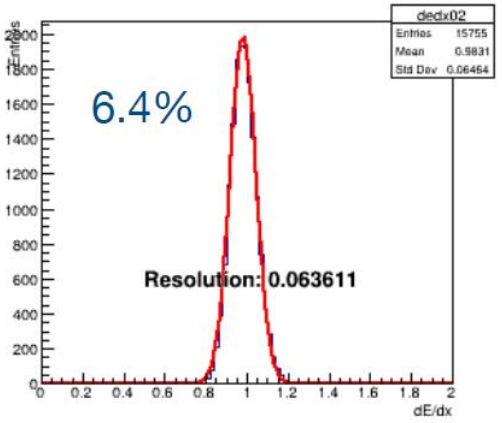


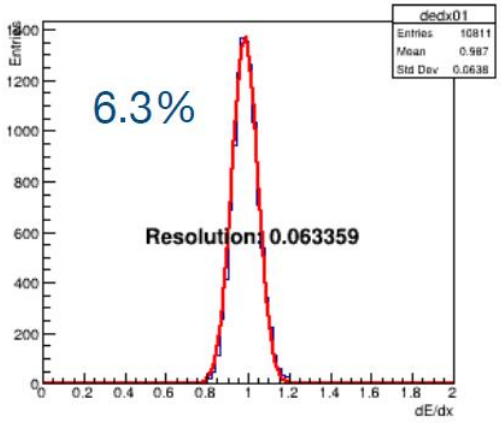
dE/dx resolution and phi dependence





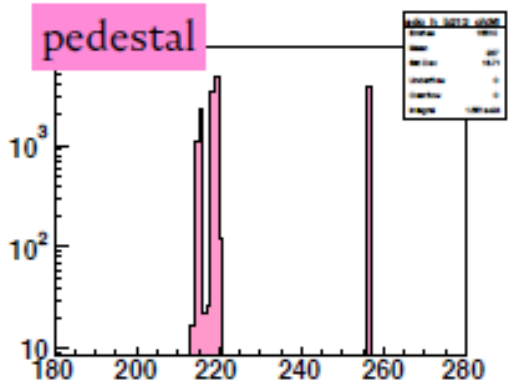






Two bad things

- HV problem
  - After FW endcap pushing,
    - Three HV channels (out of 224) became unstable.
    - Situation is not same for three channels.
    - HV cables had some damages???
  - During next summer shut down, we will investigate the reason.
- ADC problem
  - Some ADC channels are unstable.
  - TDC is OK.
  - Those boards are healthy in the test bench, when the boards are removed from CDC.
  - One LV is suspicious.
    - LV value is not sufficient enough inside CDC?
    - Higher temperature may affect also.
  - We will test soon to confirm it.



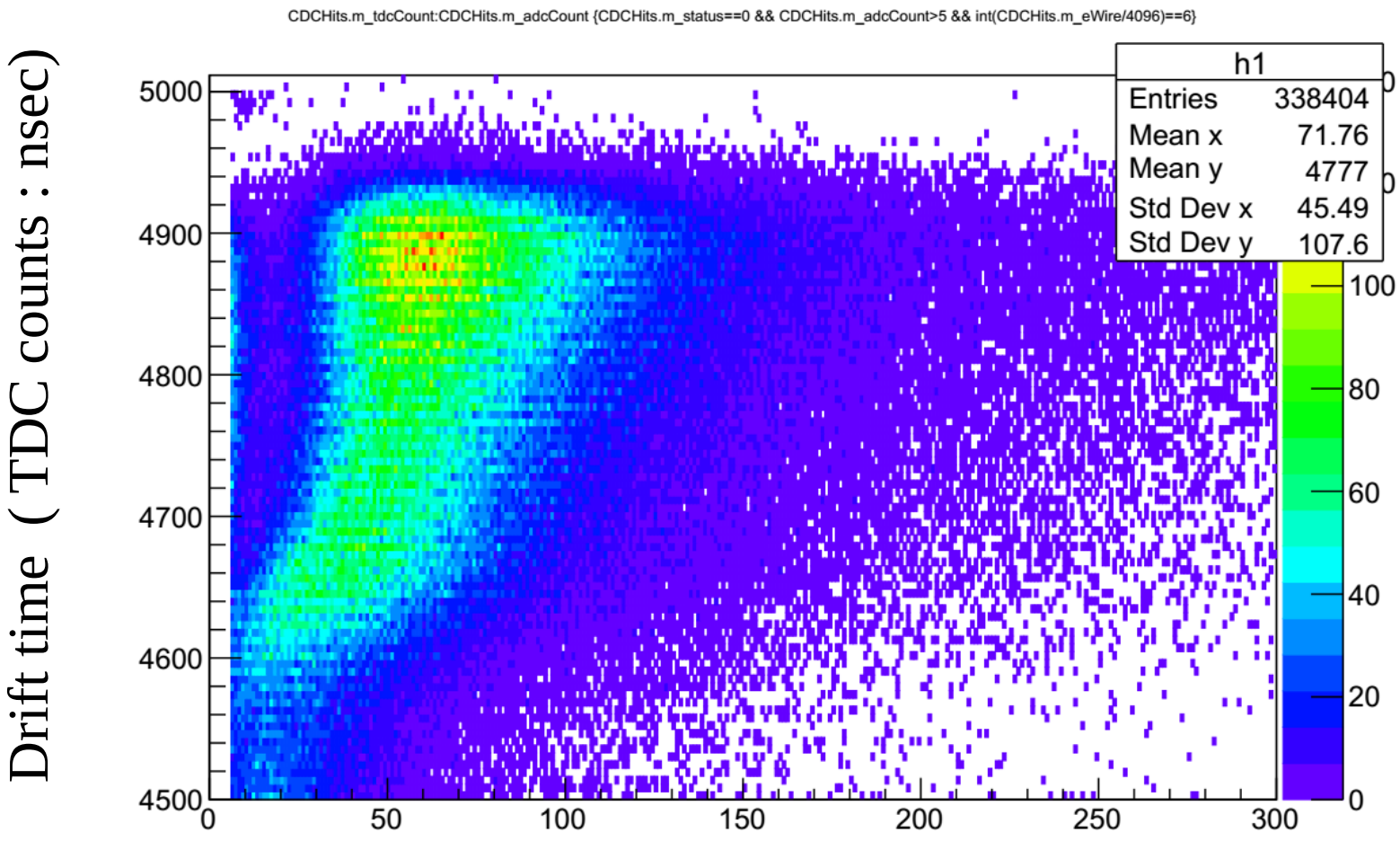
Summary

- Now, CDC is basically working even under 1.5 T magnetic field.
- Calibration and alignment works are going on.
  - Good performance is obtained already at the first step before the beam data.
  - I suppose it is good enough for other subdetectors.
- But, CDC has two problems.
  - HV
    - We will investigate during next summer shut down.
  - ADC
    - We will test soon to confirm our guess.

Backup

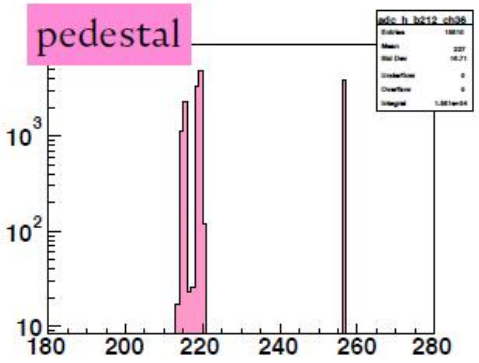
Dong Van Thanh
B = 1.5 Testla

TDC vs ADC



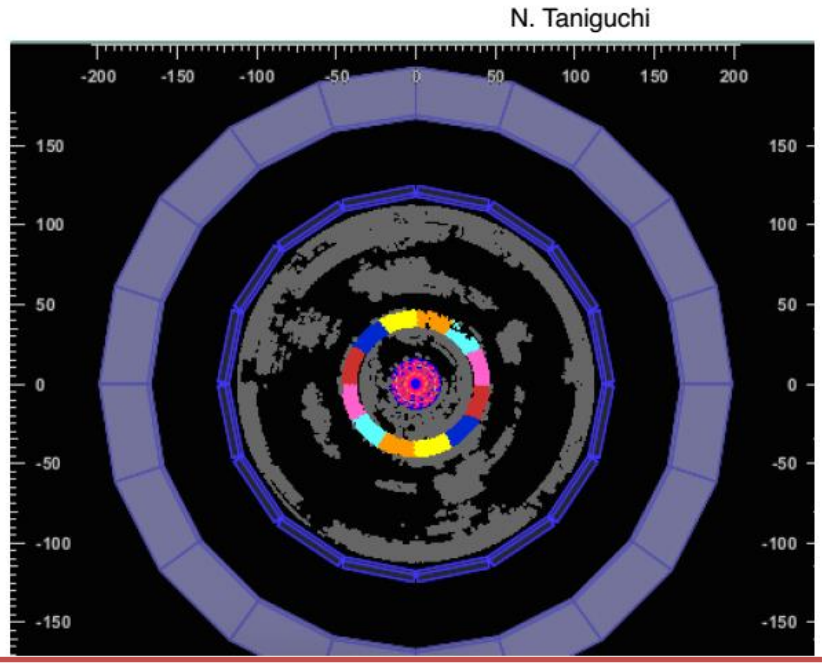
FADC problems

- remove ~20 FE boards
- put insulator tape on inner board and re-installed
  - check at test bench : O.K
- still bit error is seen in several board
  - unstable
  - bad channel ~ 1%
- investigation at test bench
  - it seems to be related to power supply of +1.8V (from +2.0V)
    - +1.8V(+2.0V) **can not** be monitored using FPGA function
  - DC PS is already set to upper limit



Setup of cosmic ray test and analysis

- Taking data with CDC+TOP+ECL+KLM
- Magnetic field: 1.5T + QCS
- Trigger conditions: CDC + ECL
  - CDC trigger: Track-Segment Finder (TSF) at super-layer 2
  - Trigger timing is determine by ECL
  - **July:** TSF back-to-back, required two TSFs at the same color region. ~3M events (good data)
  - **August:** single TSF, just required one TSF on Super-Layer 2. ~46M events



Simulation:

- Generator: CRY
- Trigger Simulation: both back-to back and single TSF

Reconstruction (for both MC and data):

- Track Finder: Belle II CDC cosmic finder
- Fitter: DAF (Deterministic Annealing Filter).

Position resolution calibration

- Position resolution (measurement error) was calculated from biased and unbiased track fit.

$$\sigma = \sqrt{\sigma_{biased} \cdot \sigma_{unbiased}}$$

  - *Biased track fit:* That hit was **included** in track fitting
  - *Unbiased track fit:* That hit was **excluded** in track fitting

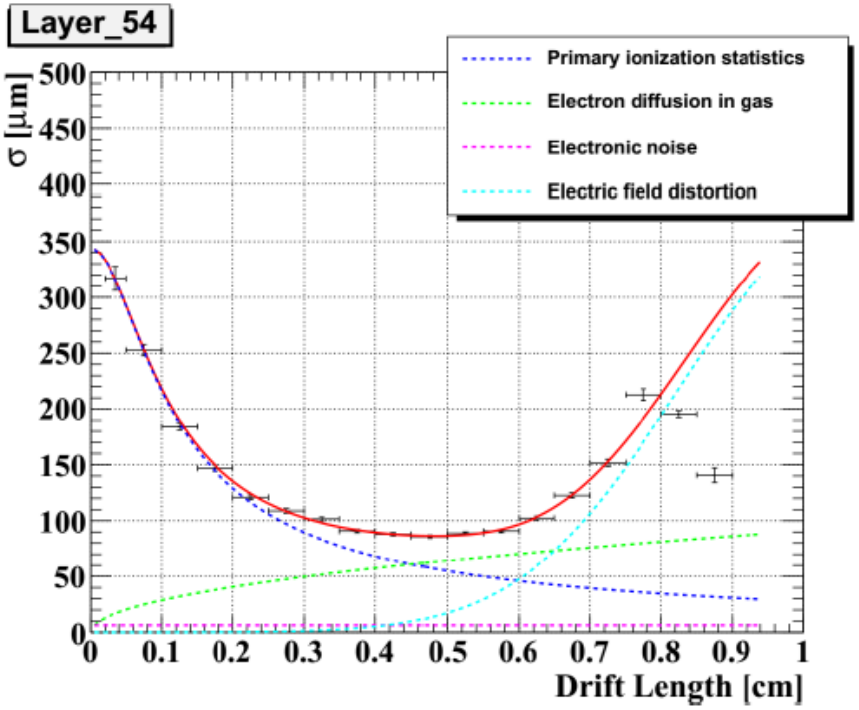
- Position resolution as a function of drift length:

$$\sigma = \sqrt{\sigma_{ion}^2 + \sigma_{diff}^2 + \sigma_{noise}^2 + \sigma_{distortion}^2}$$

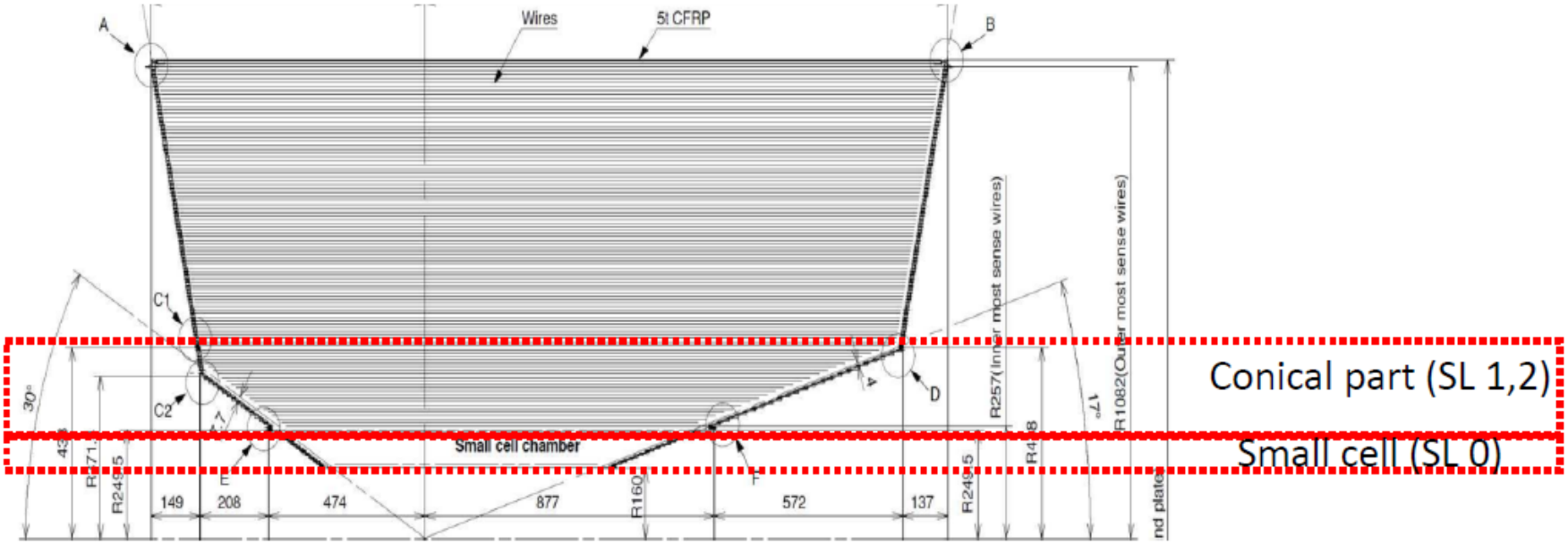
σ = f(layer, α, θ, lr, driftL)

- In this cosmic test

(56 layers) x (3 θ bins) x (1 α bin) x (left right).



CDC structure



- End-plates of main part and conical part was manufactured separately.

  Then they are joined togather before wire stringing.
- Small cell was manufactured and wire stringed before installed into main and conical part.

⇒ Misalignment may happen between endplates of main parts.

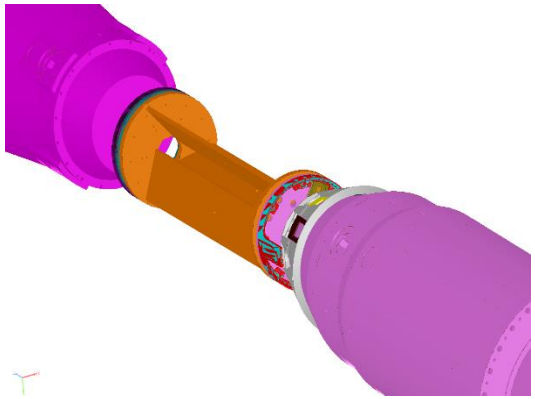
⇒ Inner part (conical and small cell) may not accurately aligned to main part

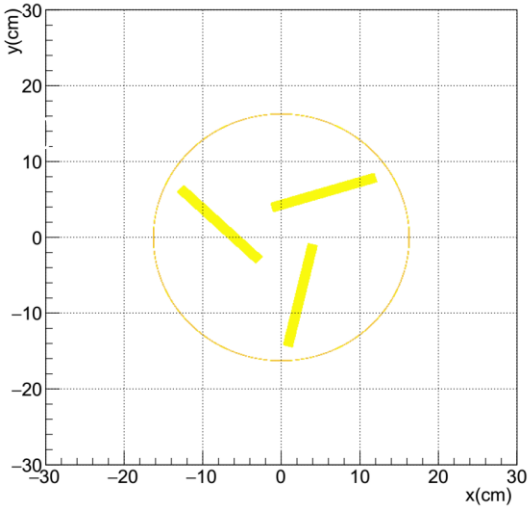
B field mapper

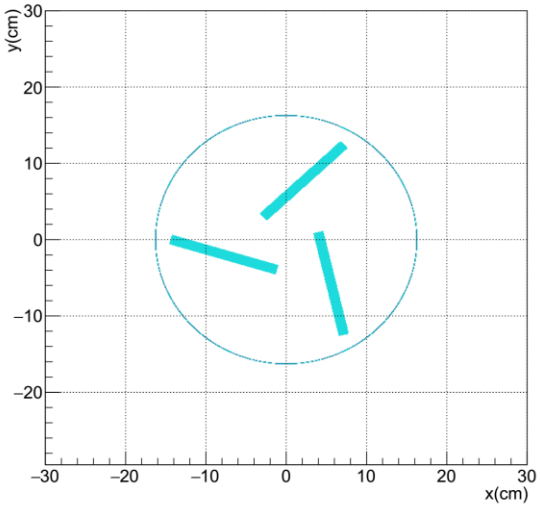
- B-Field mapper is located inside CDC during data taking period.

φ = 16.7° (July)
3085(start) -> 3882

φ = 43.3° (August)
3883 -> 4038(end)



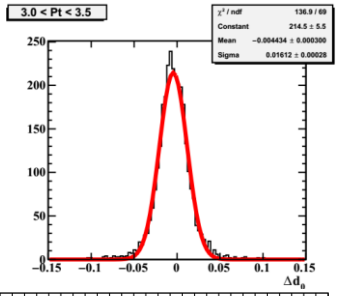


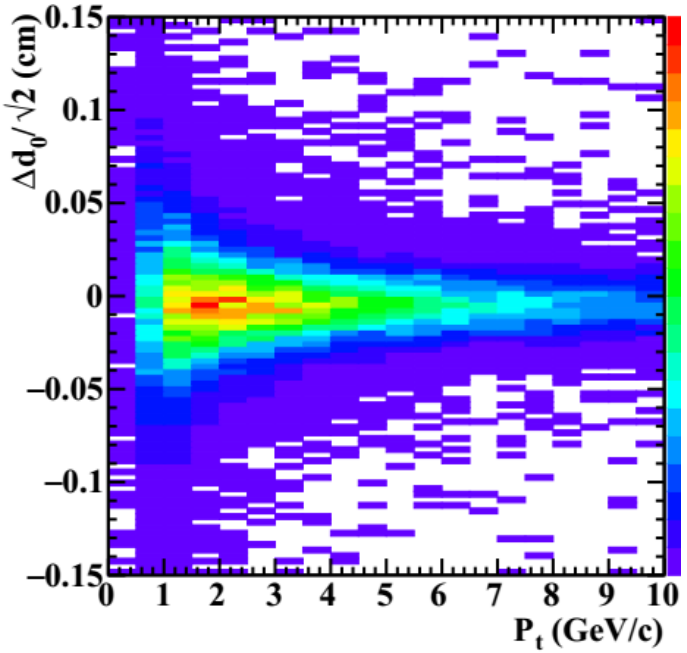


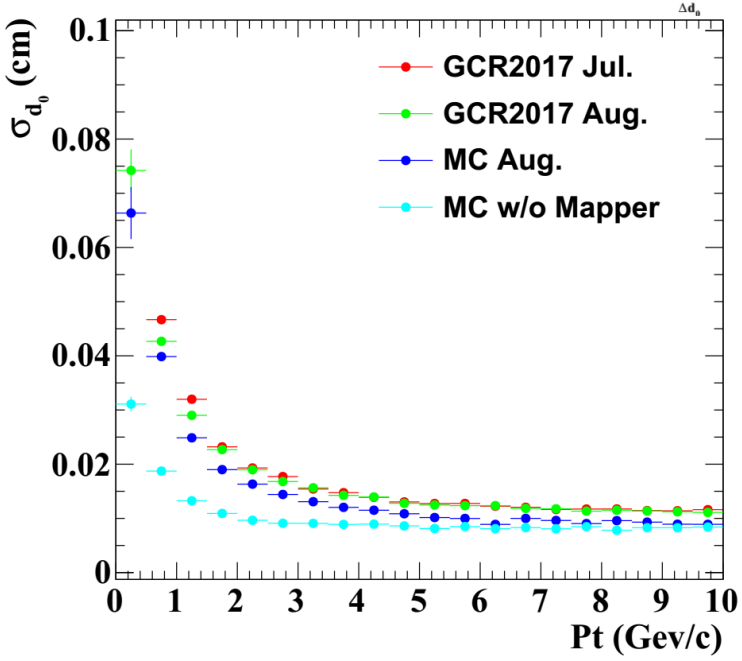
- Main material of mapper is Aluminum, thickness of each plate is **1.2cm.**
- Mapper causes larger effect on performance of CDC, especially low Pt region.

d_0 resolution

- Closet approach in x-y plane
- d_0 resolution is defined as: $\sigma_{d_0} = \frac{\sigma[d_0^{up} - d_0^{down}]}{\sqrt{2}}$
- Bin width = 0.5 GeV, fitted with a gaussian function



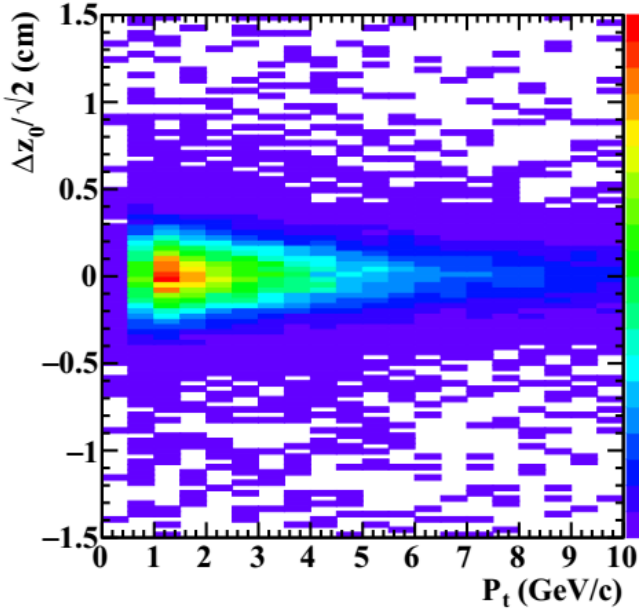


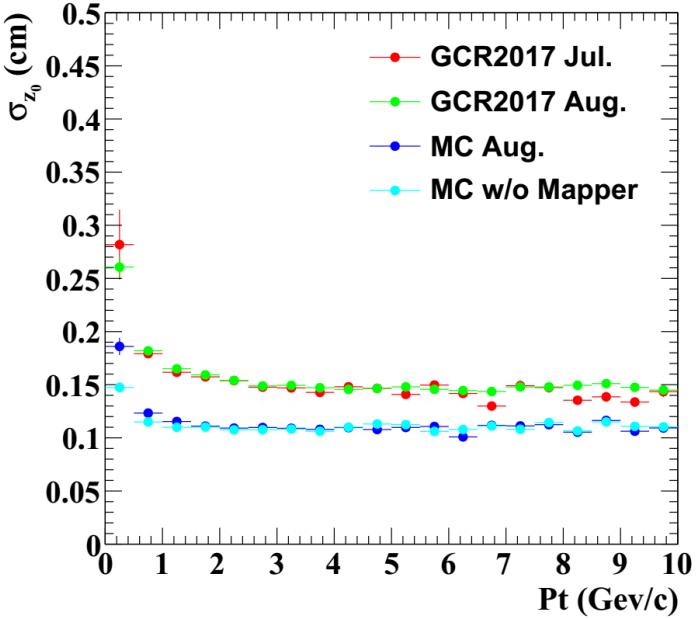


- d_0 resolution is about 120 μm at high Pt region. It is worse at low Pt region due to mapper effect.

z_0 resolution

- Closest approach to IP in r-z plane
- Z_0 resolution is defined as: $\sigma_{z_0} = \frac{\sigma[z_0^{up} - z_0^{down}]}{\sqrt{2}}$

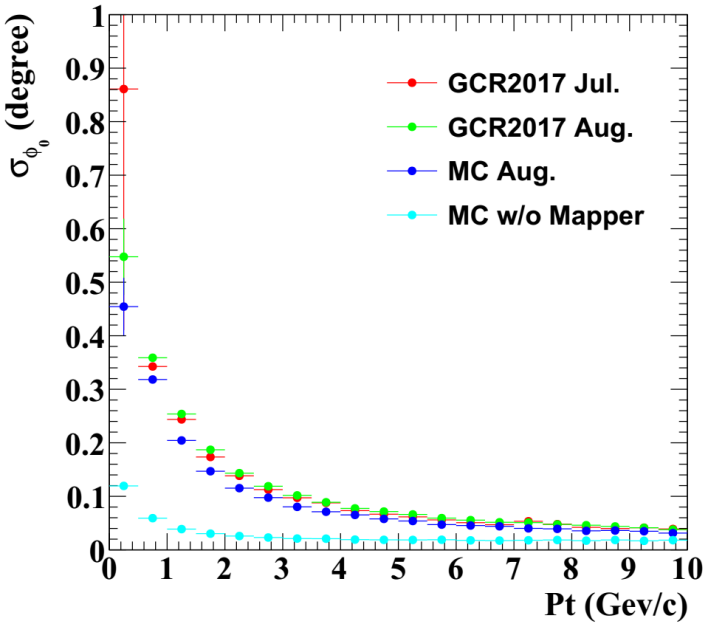


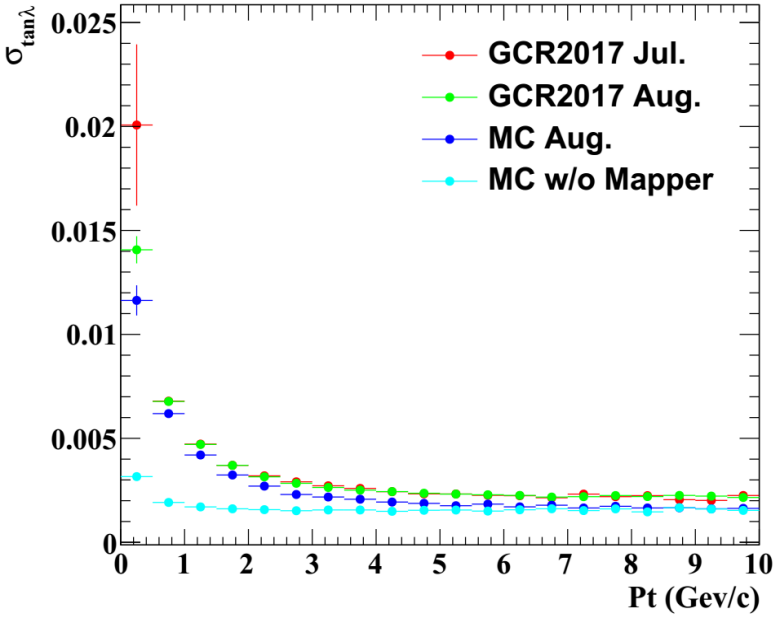


- Z_0 resolution is about ~1.5mm and 1.2mm for data and MC, respectively.
- The difference between MC and data might be due to remaining mis-alignment wire-by-wire at super-layer 1, first super-layer of CDC.
- Since stereo angle is small (~70 mrad) and wire length is short, so small mis-alignment in wire position leads to larger effect in z measurement, $\Delta z \sim \delta x/0.07$

ϕ_0 and tanλ resolution

- φ_0 angle between Pt and x-axis
- Tanλ = P_z/P_t





- φ_0 and tanλ resolution of real data are ~0.05 degree and 0.003 at high Pt region, respectively. The effect of mapper on φ_0 resolution is larger due to multiple scattering.
- Small difference between MC and data is the same as one observed at d_0 resolution.