Alignment Analysis of Cosmic Ray Test for COMET-CDC

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ICEPP Symposium @ Hakuba

Osaka University

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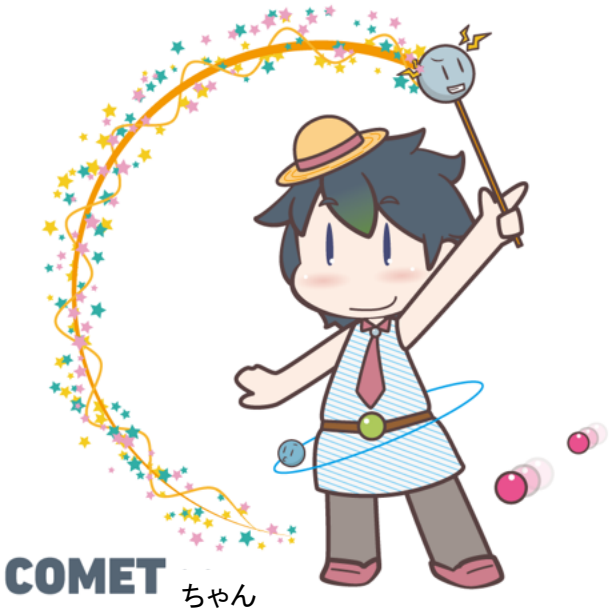
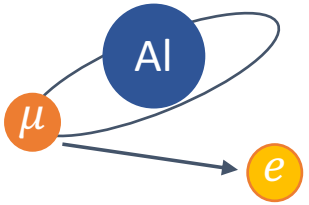


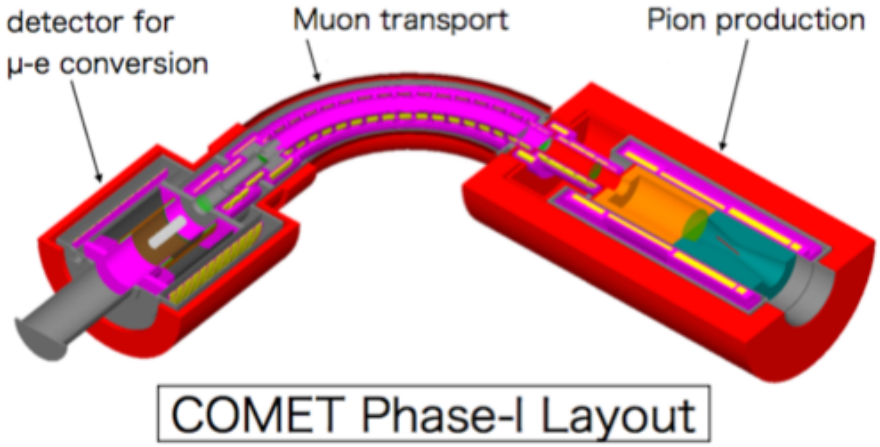
Introduction – COMET Experiment (Phase-I)

- The COMET Phase-I experiment is seeking to measure the neutrinoless, coherent transition of a muon to an electron ($\mu - e$ conversion) in the field of an aluminium nucleus, $\mu^- N \rightarrow e^- N$, with a single event sensitivity of 3×10^{-15}.



- The $\mu - e$ conversion is one of the charged Lepton Family Violation (cLFV) processes. The cLFV is definitely prohibited in the Standard Model (BR $(\mu \rightarrow e\gamma) \sim 10^{-54}$).

- The COMET experiment will be built and started in the Hadron Hall at J-PARK in 2019.



COMET Phase-I Layout

Other Experiments related to cLFV

- MEG Experiment at PSI

$\mu^+ \rightarrow e^+\gamma$ (BR $< 4.2\times10^{-13}$) 90 C.L.

- SINDRUM Ⅱ Experiment at PSI

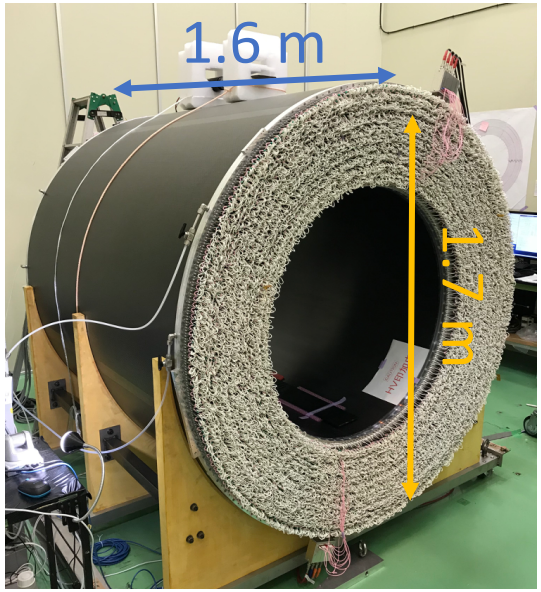
$\mu^-\mathrm{Au} \rightarrow e^-\mathrm{Au}$ (BR $< 7\times10^{-13}$) 90 C.L.

Introduction – COMET CDC

- The Cylindrical Drift Chamber (CDC) is the main detector for the $\mu - e$ conversion conversion search in COMET Phase-I.

Requirements of CDC

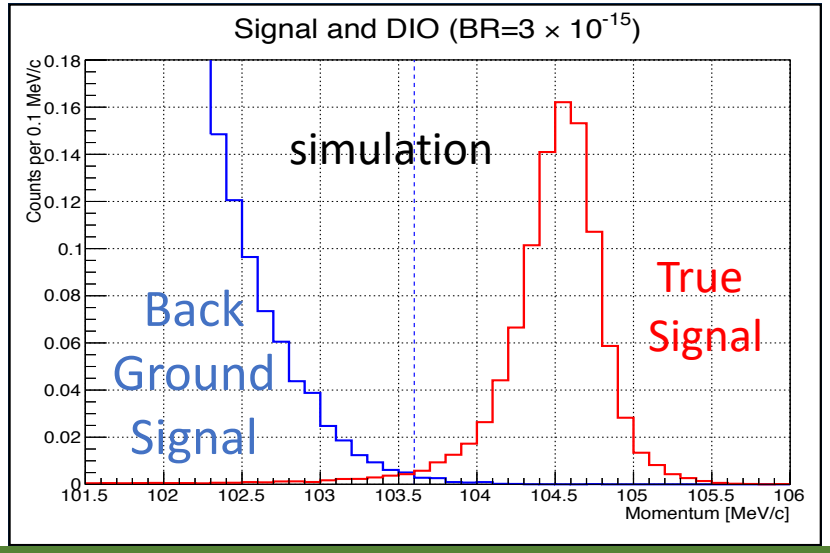
- Momentum resolution of CDC must be less than 200 keV/c. (for the 105 MeV electrons)
- Spatial resolution should be less than 200 μm. (for the two gas mixtures at 1 T magnetic field)

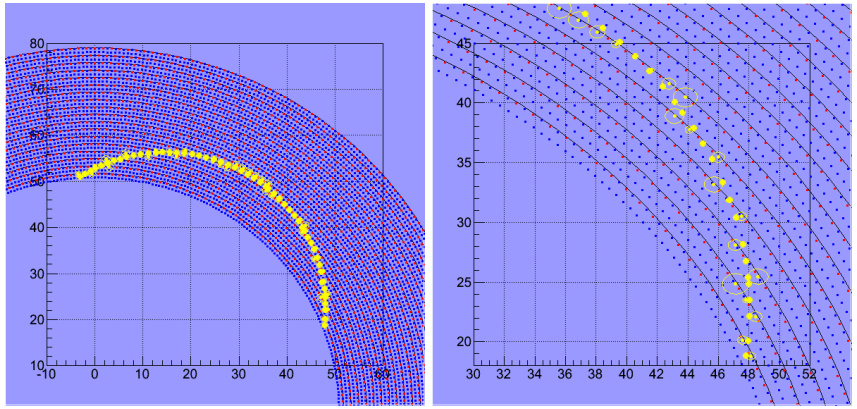


COMET-CDC

μ e conversion : $\mu^- + \mathrm{Al} \rightarrow \mathrm{e}^-(105\mathrm{MeV/c}) + \mathrm{Al}$

Back Ground (DIO) : $\mu^- + \mathrm{Al} \rightarrow \mathrm{e}^- + \bar{\nu}_\mathrm{e} + \nu_\mu + \mathrm{Al}$





A typical track display from simulation

Introduction – COMET CDC

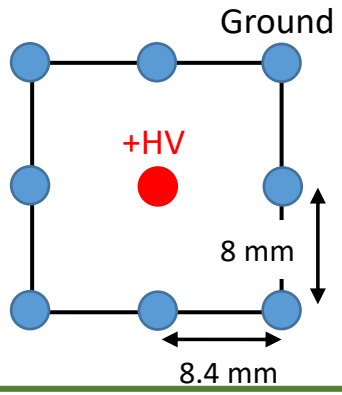
Status of CDC

- CDC is arranged in 20 sense layers (including 2 guard layers) with alternating positive and negative stereo angles.
- Wire (2 types)

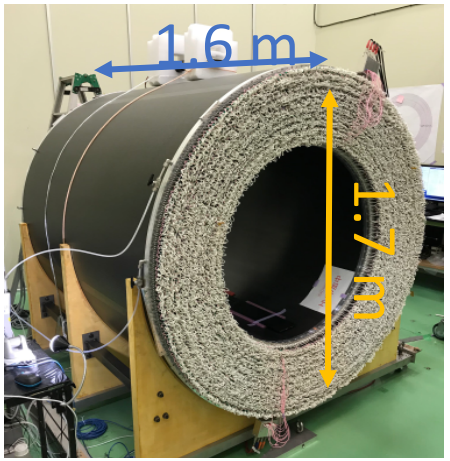
Wire	material	# of Wires	Diameter
Sense	Au plated W	4986	$25\ \mu m$
Field	Al	14562	$126\ \mu m$

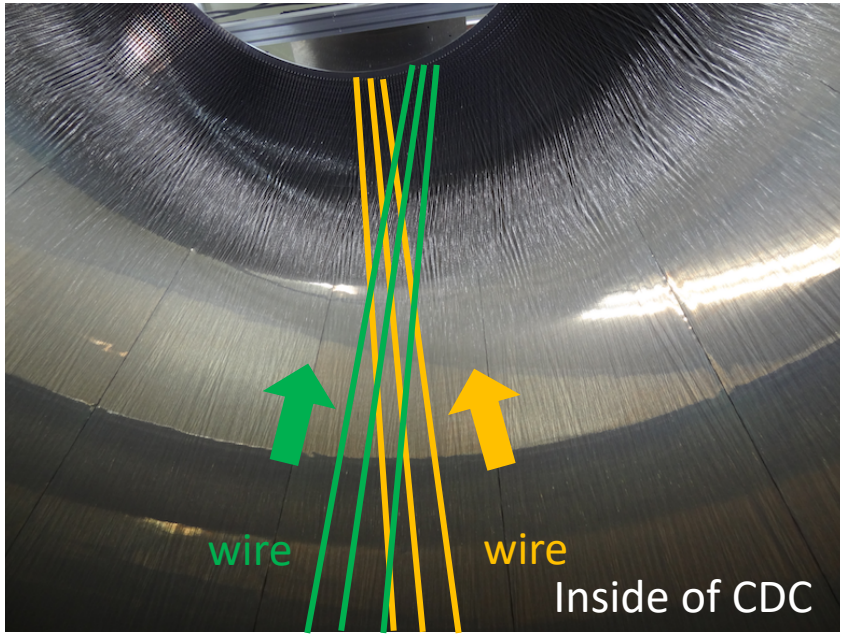
- Gas & Magnetic Field

Gas	Magnetic Field
$He: i-C_4H_{10} = 90:10$	1 T



The size of 1 cell
16mm × 16.8mm

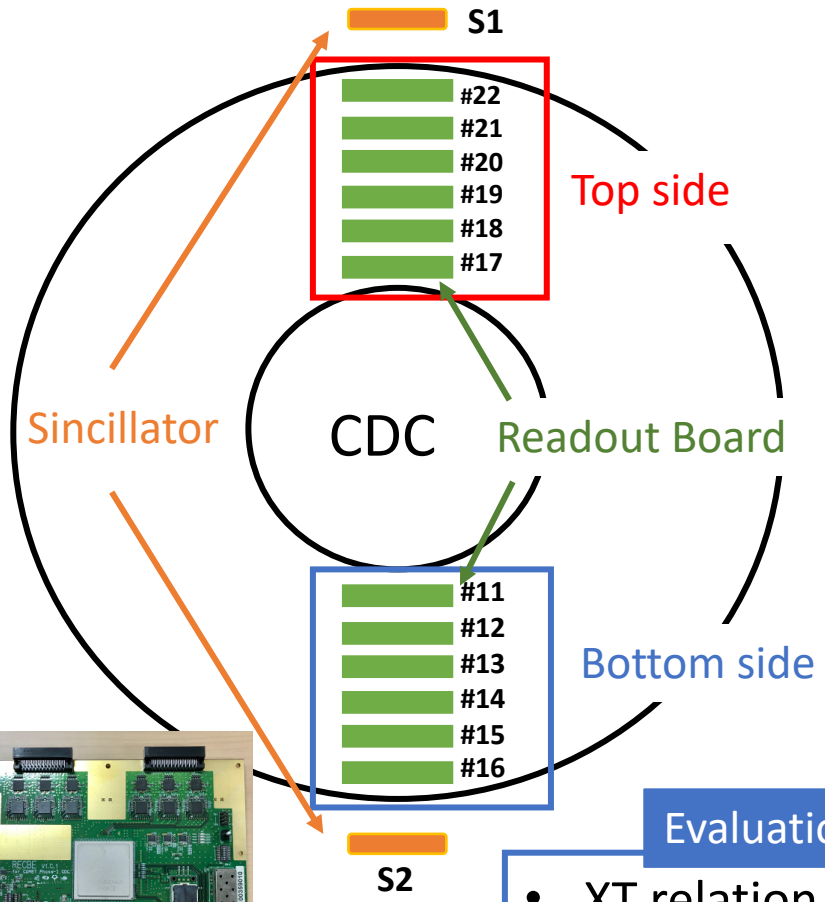


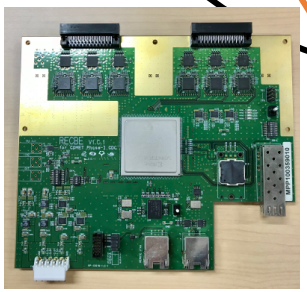


Analysis of Cosmic Ray Test for CDC

Analysis of CRT – Setup for Cosmic Ray Test

- The Cosmic Ray Test for the CDC is now ongoing at Fuji building B4 in KEK.





Readout board
(RECBE)

Condition

- **Applied HV**
  1825 V
- **Gas ratio**
  $\mathrm{He:i-C_4H_{10}} = 90:10$
- **Trigger**
  Coincidence signal of S1 and S2
- **Trigger Rate**
  S1 × S2 = 0.03 Hz
- **Magnetic Field**
  not applied
- **Measurement time & Events**
  427.5 hours & 52298 events

Evaluation

- XT relation (relation between drift length and drift time).
- Spatial resolution -> should be less than 200 μm.
- Hit Efficiency -> should be enough high.
- Alignment -> Track difference between top and bottom.

Analysis of CRT – Setup for Cosmic Ray Test

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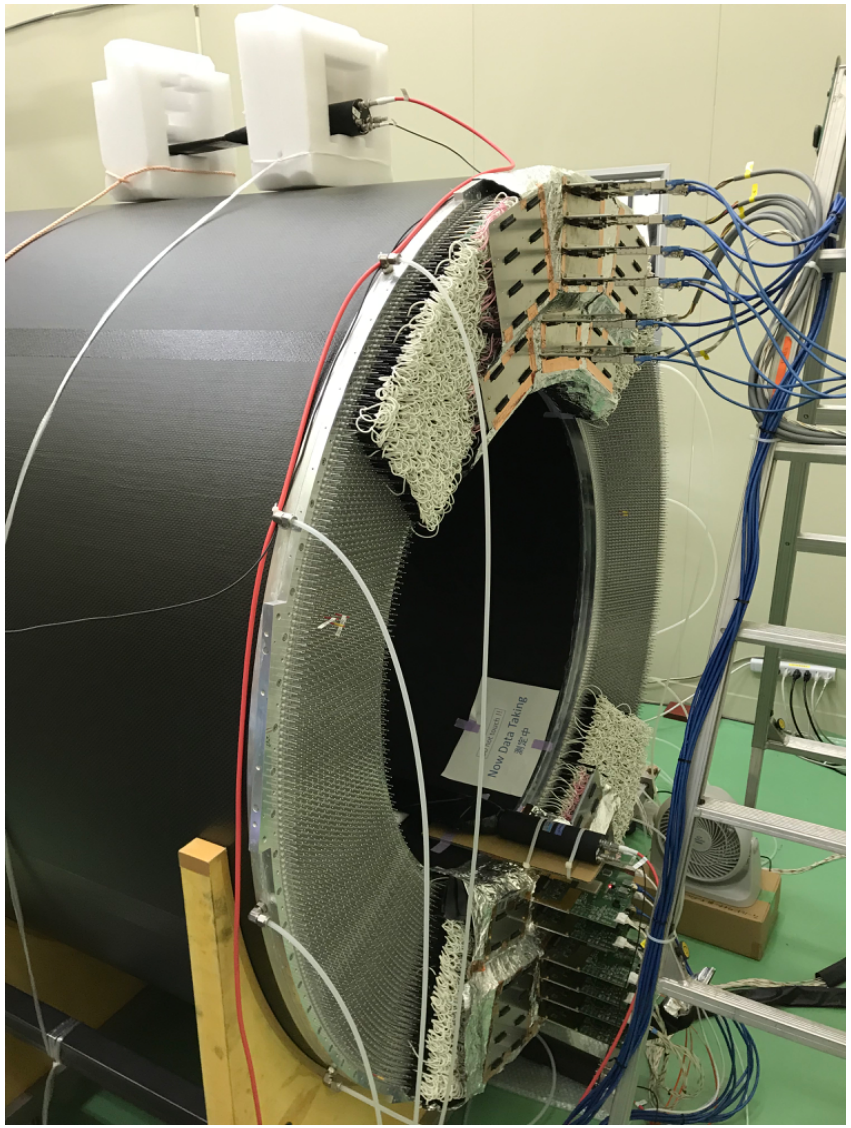

Condition

- **Applied HV**
  1825 V
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  Coincidence signal of S1 and S2
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Evaluation

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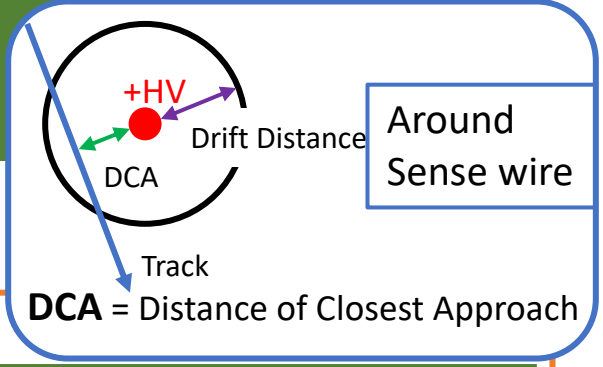
- Spatial resolution
- Hit Efficiency
- Alignment

Analysis of CRT – Tracking



- The way to get drift time and drift distance.

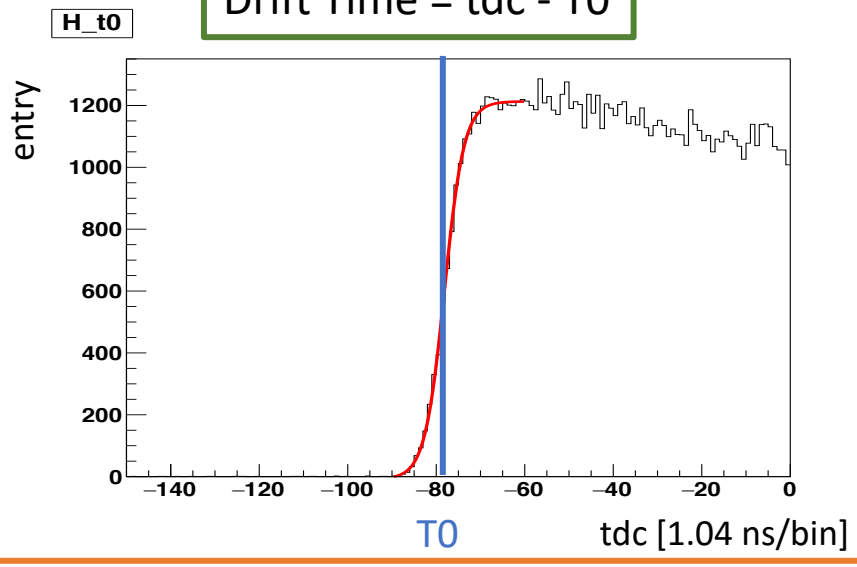
Drift Time

- Get T0 value (basement time)
  by fitting the tdc distribution with function:

$$f(t) = p_0 + p_1 \frac{e^{p_2(t-p_3)}}{1+e^{-\frac{(t-p_4)}{p_5}}}$$ (by Belle II)

-> able to fit more correct than gausian.

Drift Time = tdc - T0



Drift Distance

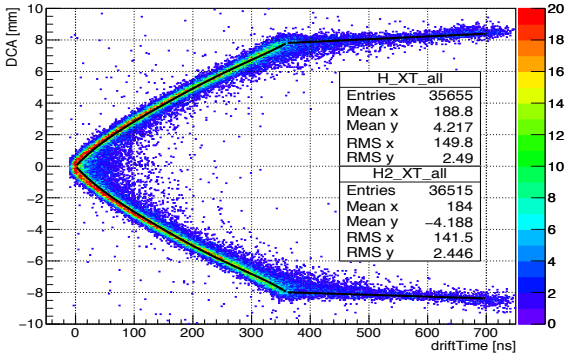
First Tracking

- Create XT Curve (DCA vs Drift Time) from the result of Garfield simulation.

  Get the Drift Distance from Drift Time.

Second and more Tracking

- Use the XT Curve which is created in the last tracking result.
  -> Get Drift Distance from Drift Time
  -> Iterate this process
  to improve the XT Curve and tracking.



Analysis of CRT – Tracking Reconstruction

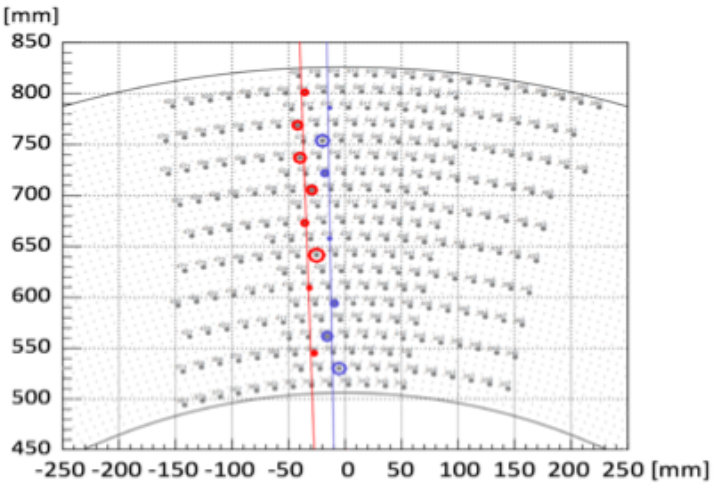
- To improve XT curve and Tracking, select appropriate hits.

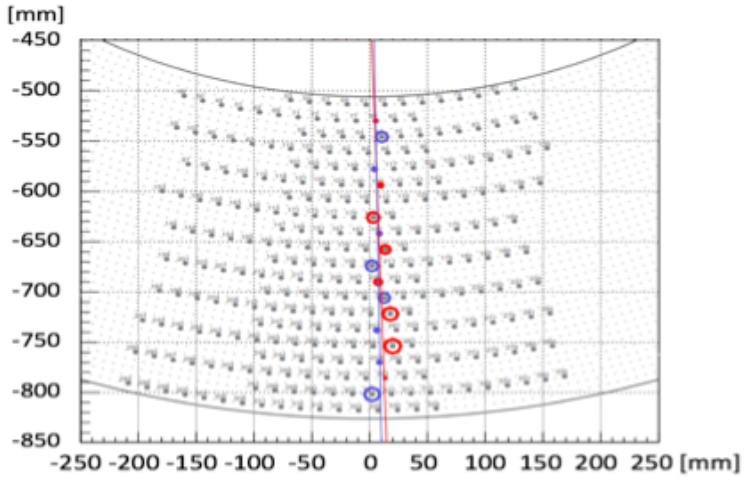
Iteration

Iteration

1. Chose 1 layer and suspect this layer makes the tracking bad.
2. Select appropriate hit and cut others.
3. Make XT curve from appropriate hits.
4. Draw new track and improve XT curve from this tracking result.

Multi hits
Should improve





Tracking result of top side and bottom side of CDC

Analysis of CRT – Tracking confirmation

- To confirm the tracking result is good or not, check the XT Curve and fitting of it.

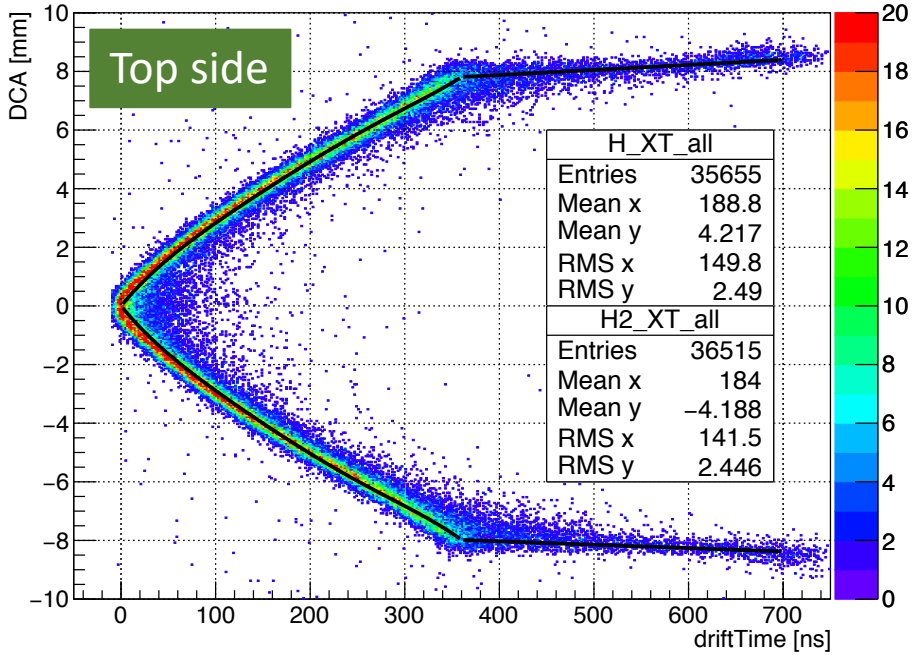
Hit condition for XT Curve

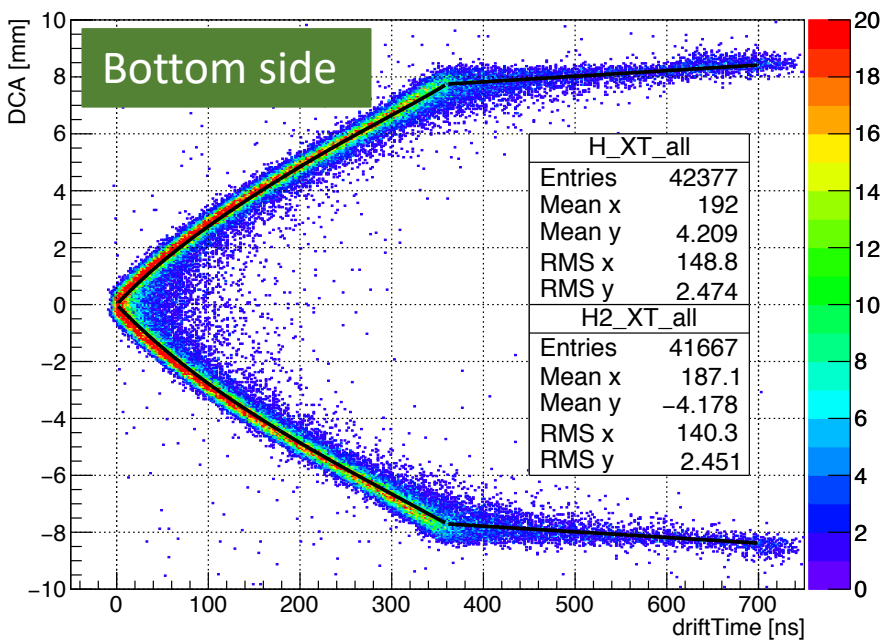
- Prob $\chi^2 \geq 0.05$
- # of single hit layers ≥ 16
- # of multi hit layers ≤ 1
- $|\mathrm{DCA}| < 10$

Fitting function for XT Curve

$$f(t) = \begin{cases} 0 & t < 0\ \mathrm{ns} \\ 5^{\mathrm{th}}\ \mathrm{pol} & 0\ \mathrm{ns} \leq t < 360\ \mathrm{ns} \\ \mathrm{linear} & 360\ \mathrm{ns} \leq t < 700\ \mathrm{ns} \\ \mathrm{N/A} & t \leq 700\ \mathrm{ns} \end{cases}$$

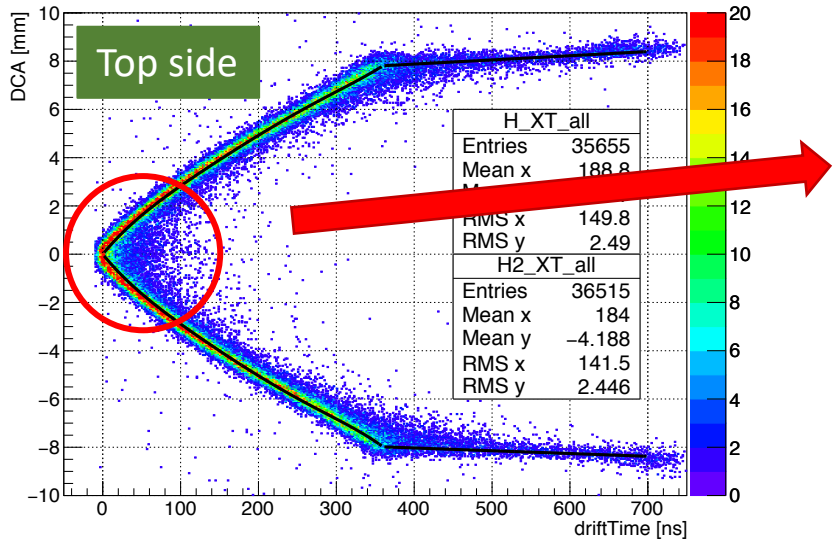
- XT Curve for all layer (After 4 iterations)

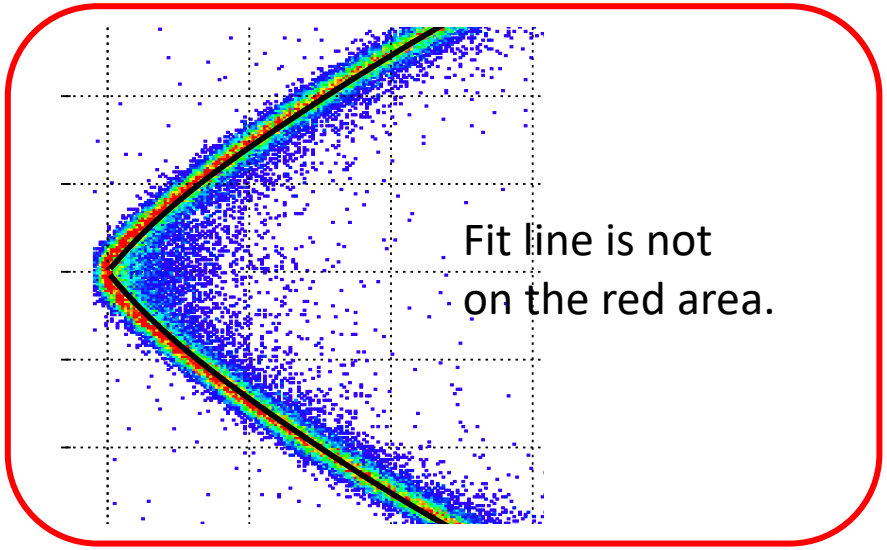




Analysis of CRT – Tracking confirmation

- Fitting of XT curve dose not match the peak of XT distribution.





- As a result, this fitting problem leads to **spatial resolution** and **tracking result**.
- There is room for improvement.

Plan : 1. pick up the peak of XT distribution and fit again. -> Back up
2. separate 0~100 ns area and use another fitting function.

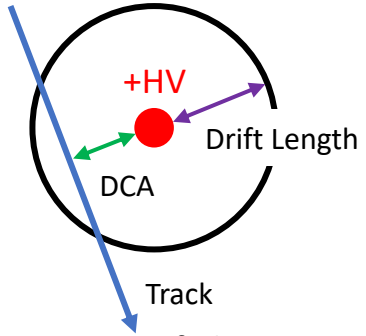
Analysis of CRT – Spatial Resolution

- Evaluate the special resolution of top & bottom side of CDC with residual.

  Residual = Drift Length - |DCA|

- By fitting the residual distribution with gausian, get σ and define it as a kind of spatial resolution.

  $\sigma_{\mathrm{residual}}$ = spatial resolution + tracking error



DCA = Distance of Closest Approach

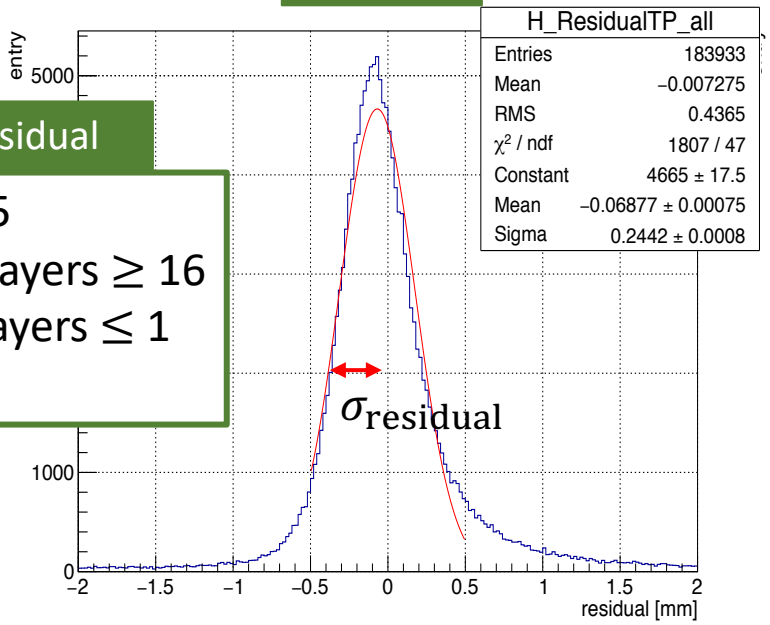
Residual distribution

After 4 iterations

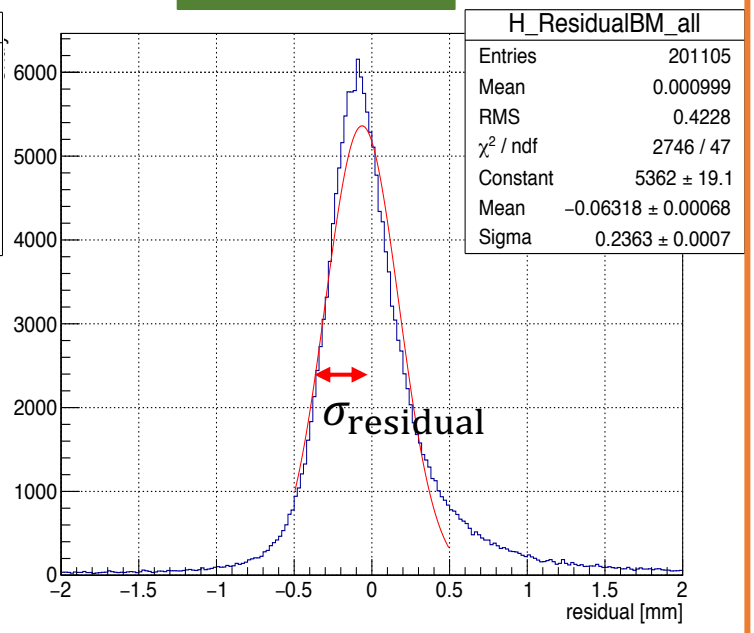
Cut condition for Residual

- Prob $\chi^2 \geq 0.05$
- # of single hit layers ≥ 16
- # of multi hit layers ≤ 1
- $|\mathrm{DCA}| < 10$

Top side



Bottom side



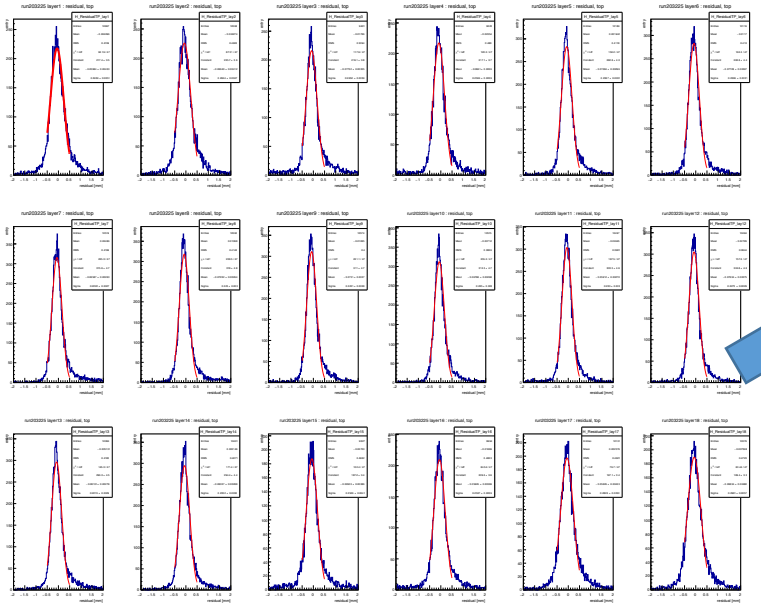
Analysis of CRT – Spatial Resolution

- Evaluate the spatial resolution for each layer.

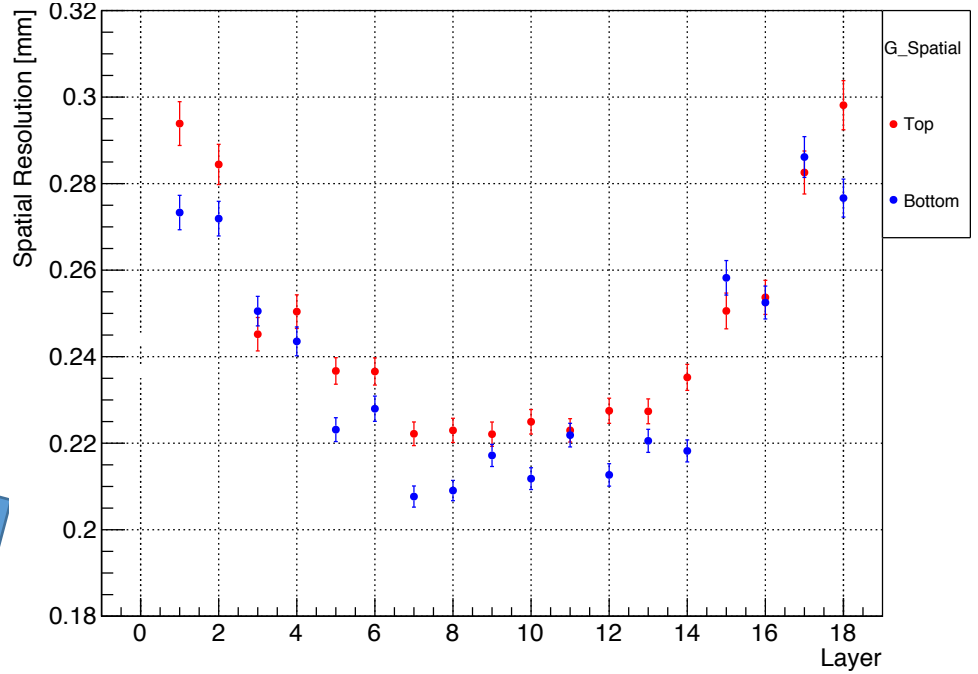
Sigma of Residual

Top side of CDC

Bottom side of CDC



Sigma of residual for each layer of top & bottom side



- $\sigma_{\mathrm{residual}}$ of all layers are higher than the requirement (200 μm).
  However in different Setup, $\sigma_{\mathrm{residual}}$ is lower than 200 μm (already tested).
  -> this is because of fitting problem.
  -> cannot move on to the next alignment analysis so far…

The way of Alignment Analysis

- One cosmic track should pass through 2 sectors (top and bottom).
- I'm planning to compare these 2 tracks and check the performance and alignment.

Top side coordinates

$x_{\mathrm{tt}}, y_{\mathrm{tt}}$: xy positon of top area by top readout track

$x_{\mathrm{tb}}, y_{\mathrm{tb}}$: xy position of bottom area by top readout track

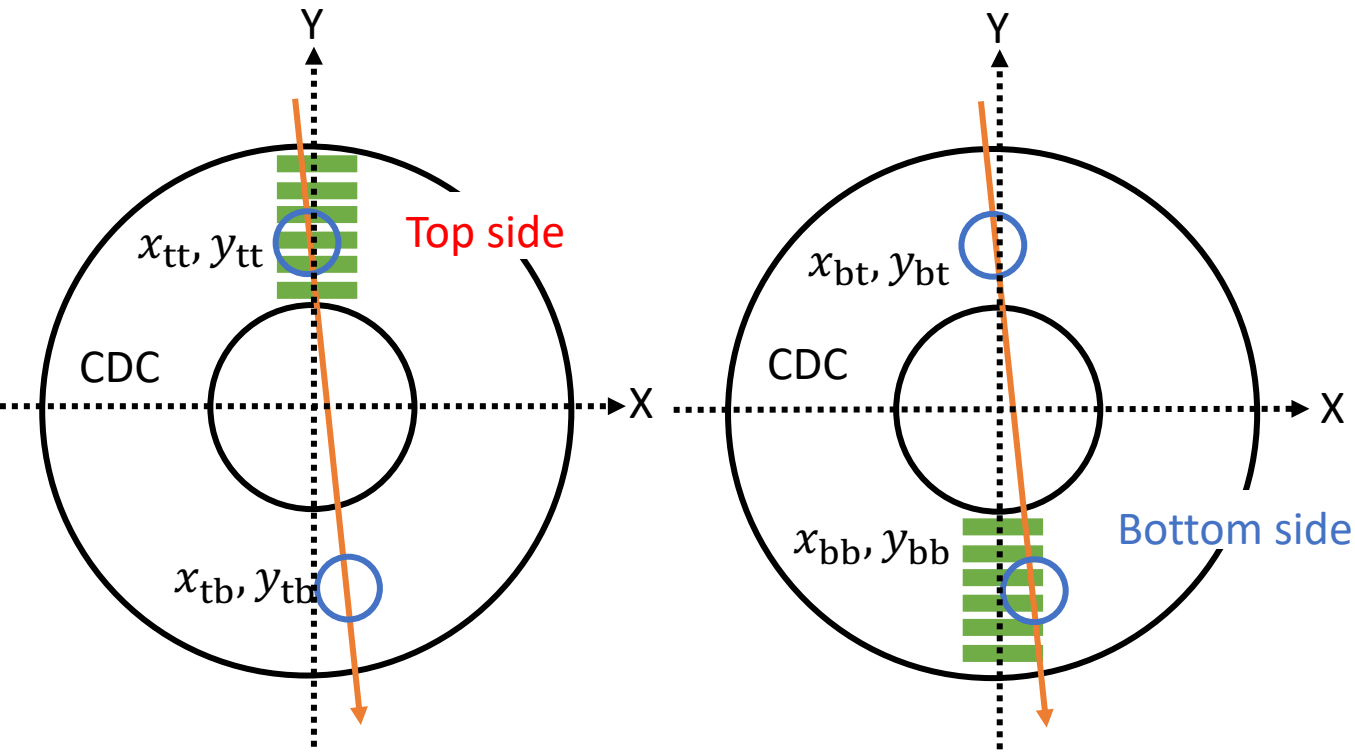
θ_{t} : incident angle of track by top readout track

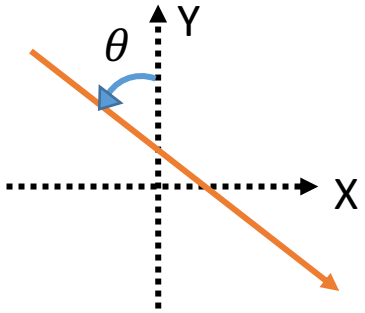
Bottom side coordinates

$x_{\mathrm{bb}}, y_{\mathrm{bb}}$: Same definition

$x_{\mathrm{bt}}, y_{\mathrm{bt}}$: Same definition

θ_{b} : Same definition





Evaluate these values

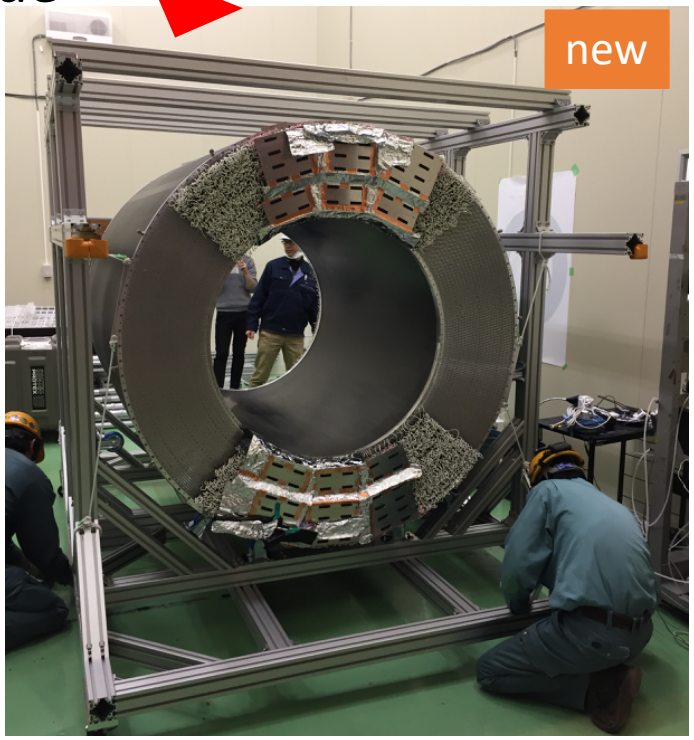
$$\Delta x_{\mathrm{t}} = x_{\mathrm{tt}} - x_{\mathrm{bt}}$$
$$\Delta y_{\mathrm{t}} = y_{\mathrm{tt}} - y_{\mathrm{bt}}$$
$$\Delta x_{\mathrm{b}} = x_{\mathrm{tb}} - x_{\mathrm{bb}}$$
$$\Delta y_{\mathrm{b}} = y_{\mathrm{tb}} - y_{\mathrm{bb}}$$
$$\Delta\theta = \theta_{\mathrm{t}} - \theta_{\mathrm{b}}$$

Next Plan

- Continue to analyze the data.
  -> must modify the fitting problem.

- Combine both top side & bottom side data and analyze the it again (Alignment).
  -> Is the track from top side and bottom side really the same track? (some error?)
  -> How about the wire position error?

- Use larger trigger scintillator and more readout boards.
  Take data from broader region.
  -> already moved CDC to new cradle.
  -> can put large scintillator on it.



Summary

1. Introduction
   - COMET (Phase-I) experiment is searching for $\mu\ e$ conversion .
   - COMET CDC is the main detector for COMET phase-I.

2. Cosmic Ray Test & Analysis
   - Cosmic Ray Test for CDC is ongoing at KEK.
   - Cosmic Ray Test evaluates the performance of CDC.
   - There is fitting problem in XT curve.
   - Spatial Resolution is still not good due to the fit.
     -> must modify

3. The way of Alignment Analysis
   - Compare two tracks between top and bottom.

Back Up

Analysis of CRT – improvement of XT curve

- The way of modification for XT curve.

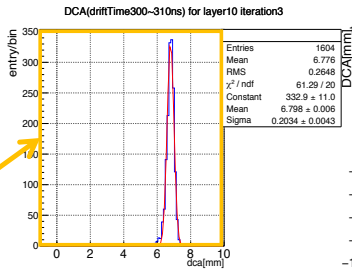
Refer to Okinaka-san (Osaka Univ.)

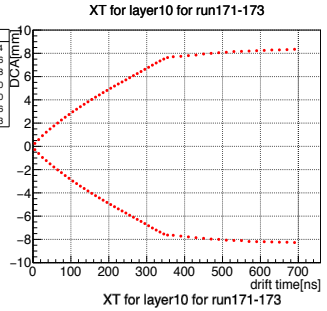
XTカーブの求め方

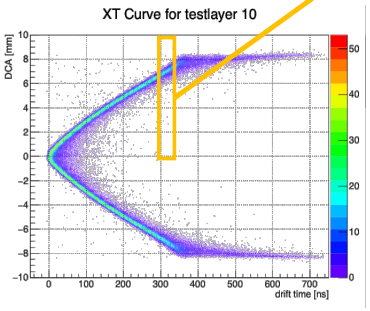
イベント条件
飛跡再構成のp値>0.05
ヒットが1つのみのレイヤー数≥ 15
ヒットが複数あるレイヤー数≤ 1

XT分布のヒット条件
テストレイヤー上でのヒット
レイヤー上で残差が最小のヒット

ドリフト時間ごとにDCA分布を作成。
ガウスフィッティングのピーク値を求める。

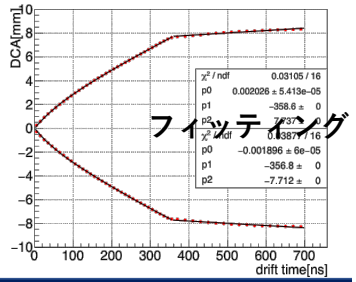






フィッティング関数

$$f(t) = \begin{cases} 0 \ldots & t < 0ns \\ 5\text{次関数} \ \ldots & 0ns \le t < T_{\mathrm{fit}} \\ 1\text{次関数} \ \ldots & T_{\mathrm{fit}} \le t < 700ns \\ N/A \ldots & 700ns < t \end{cases}$$



フィッティング

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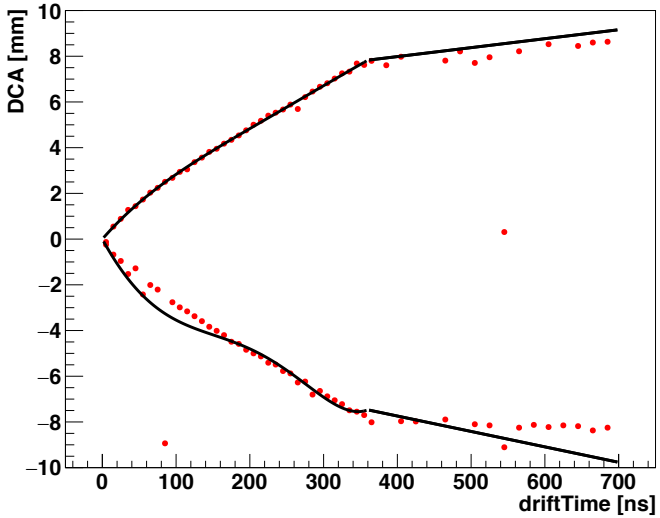
In my setup

XT curve of layer 10



Less events -> cannot fit well

Use all layers
Collect enough events
(try to do it now)

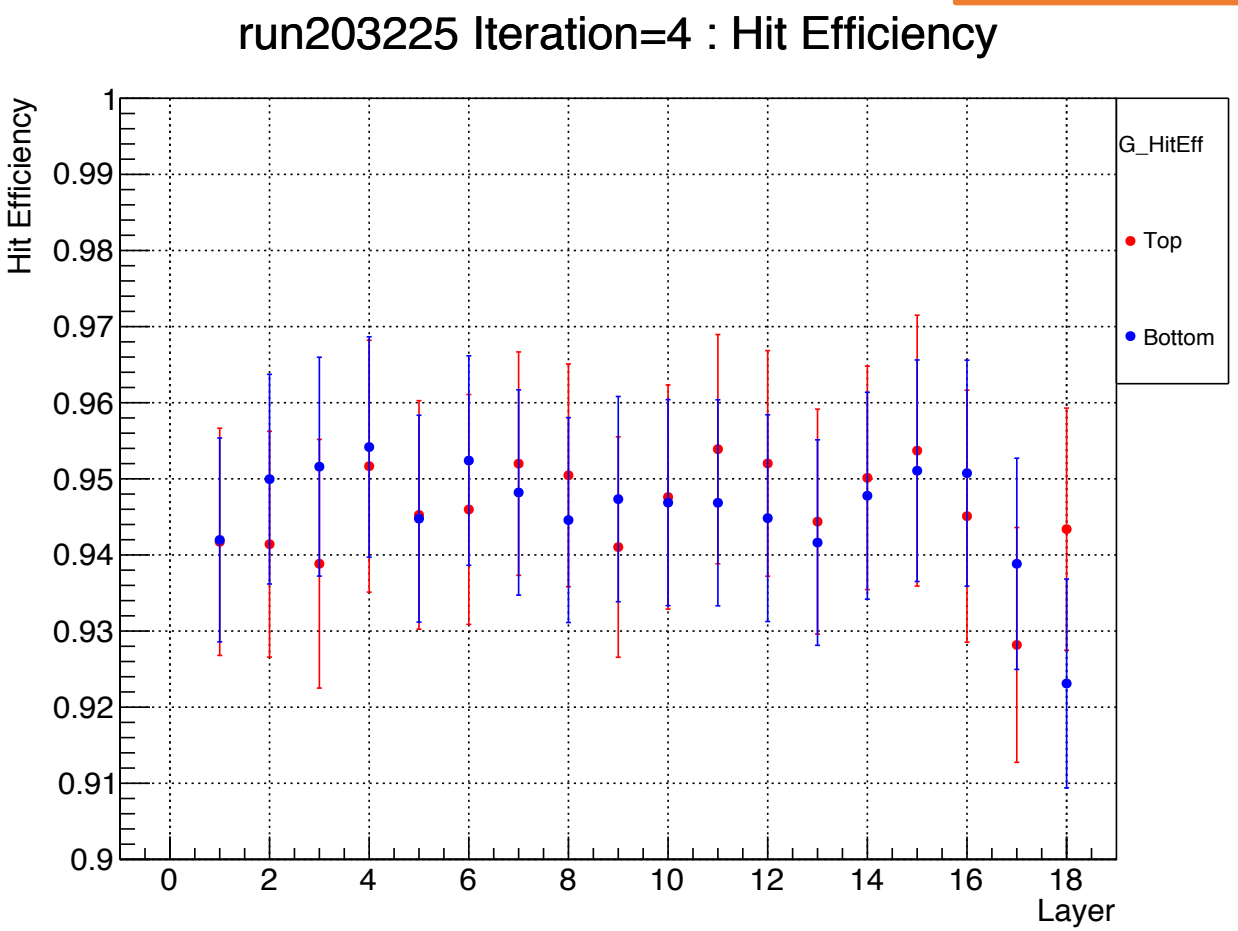
Analysis of CRT – Hit Efficiency

Hit efficiency

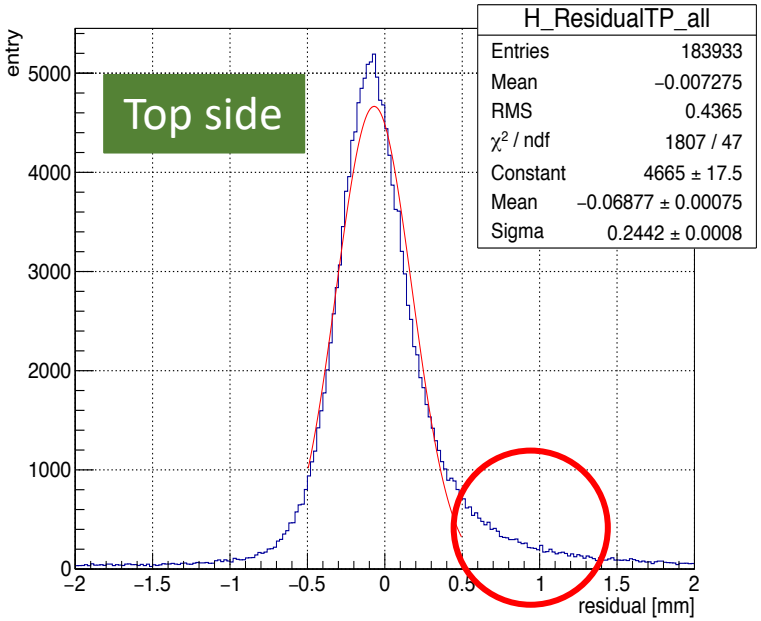
$$\text{Hit efficiency} = \frac{\#\text{ of events which has hit (residual}<3\sigma)}{\#\text{ of events which are selected}}$$

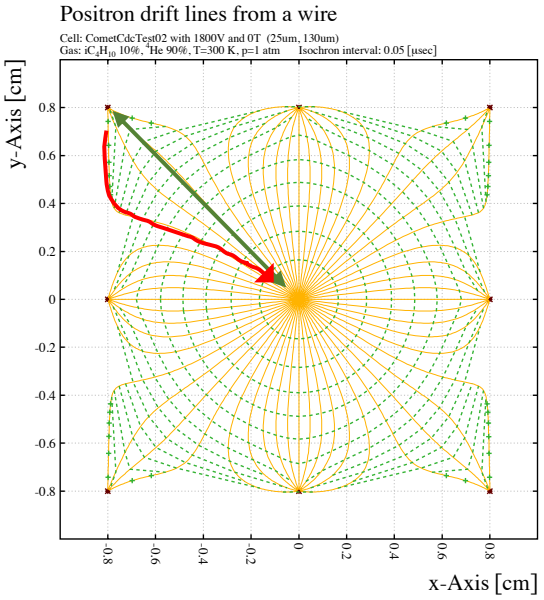
Event selection

- Prob $\chi^2 \geq 0.05$
- # of single hit layers ≥ 16
- # of multi hit layers ≤ 1



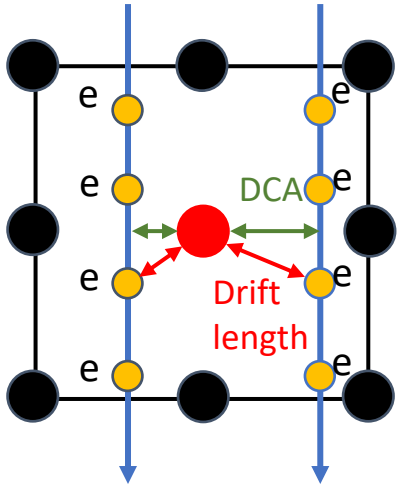
Analysis of CRT – tail of residual distribution





Gas	X_0 (m)	W (eV)	dE^{MIP}/dx (keV/cm)	n_T^{MIP} (cm^{-1})	n_p^{MIP} (cm^{-1})
He−iC_4H_{10}(85/15)	954	38	1.14	40	18
He−iC_4H_{10}(90/10)	1310	39	0.88	29	14
He−iC_4H_{10}(95/5)	2102	40	0.61	19	9
He−C_2H_6(50/50)	630	32	1.63	60	27
He−CH_4(73/27)	2166	39	1.47	17	11
He−CH_4(80/20)	3073	40	0.47	13	8

TABLE 2.2: *Comparison of different Helium-based low-Z gas mixtures, where X_0 is the radiation length, W is mean energy to generate one electron-ion pair, dE^{MIP}/dx, n_T^{MIP}, and n_p^{MIP} mean is energy loss per cm, the number of electron-ion pairs per cm, and the number of primary ions per cm for minimum ionizing particles, respectively.*

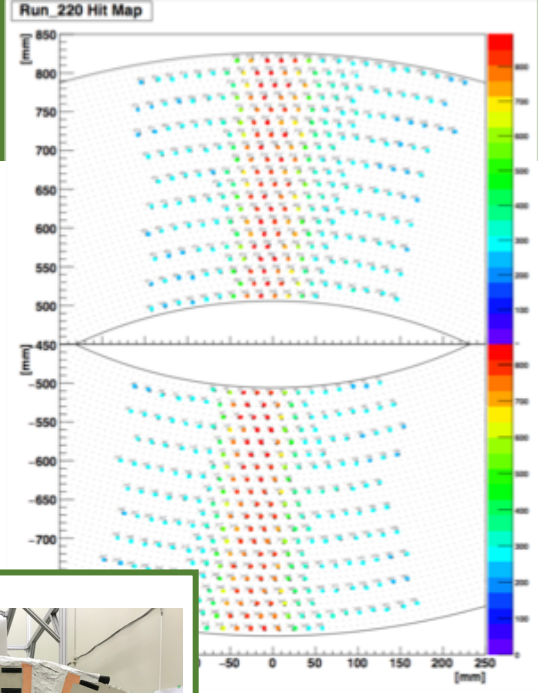


Near the sense wire

DCA < Drift Length

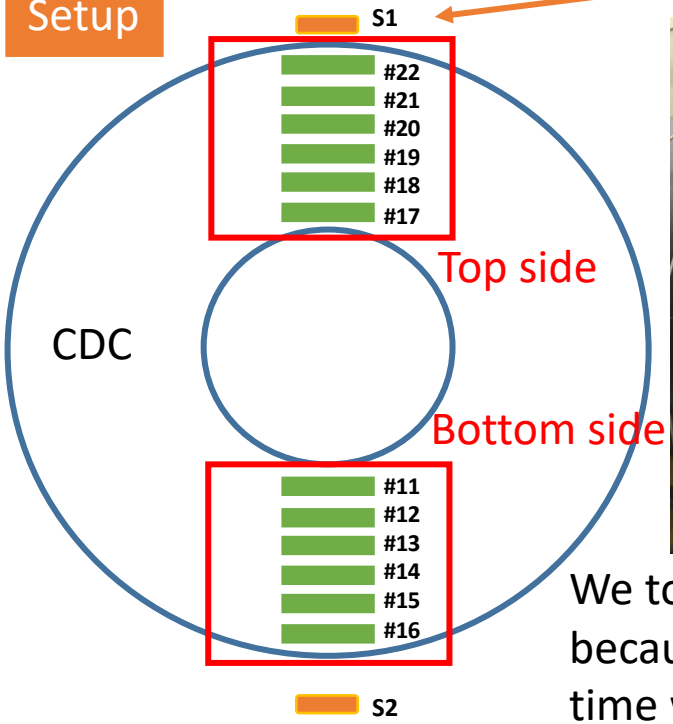
Analysis of Cosmic Ray Test for CDC

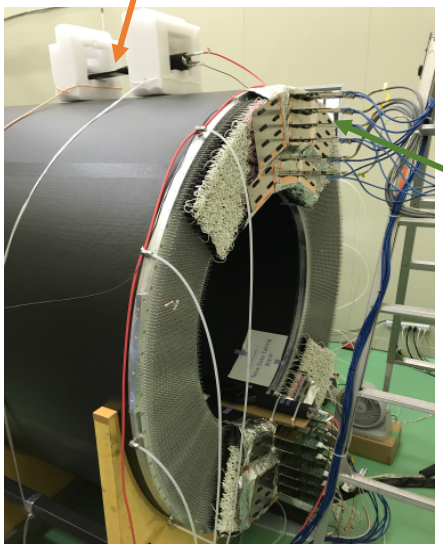
- In the stage 2 of Cosmic Ray Test,
  stared taking data and finished in the new SETUP
- Totally use 12+1 RECBE boards.
  6 RECBEs -> Top, 6 RECBEs -> Bottom, 1 is used for trigger
- One of the small trigger scintillator S1 is located on the top of CDC.

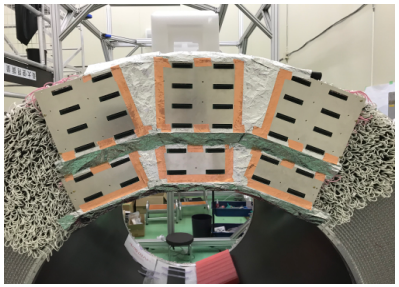


Hit Map

Setup







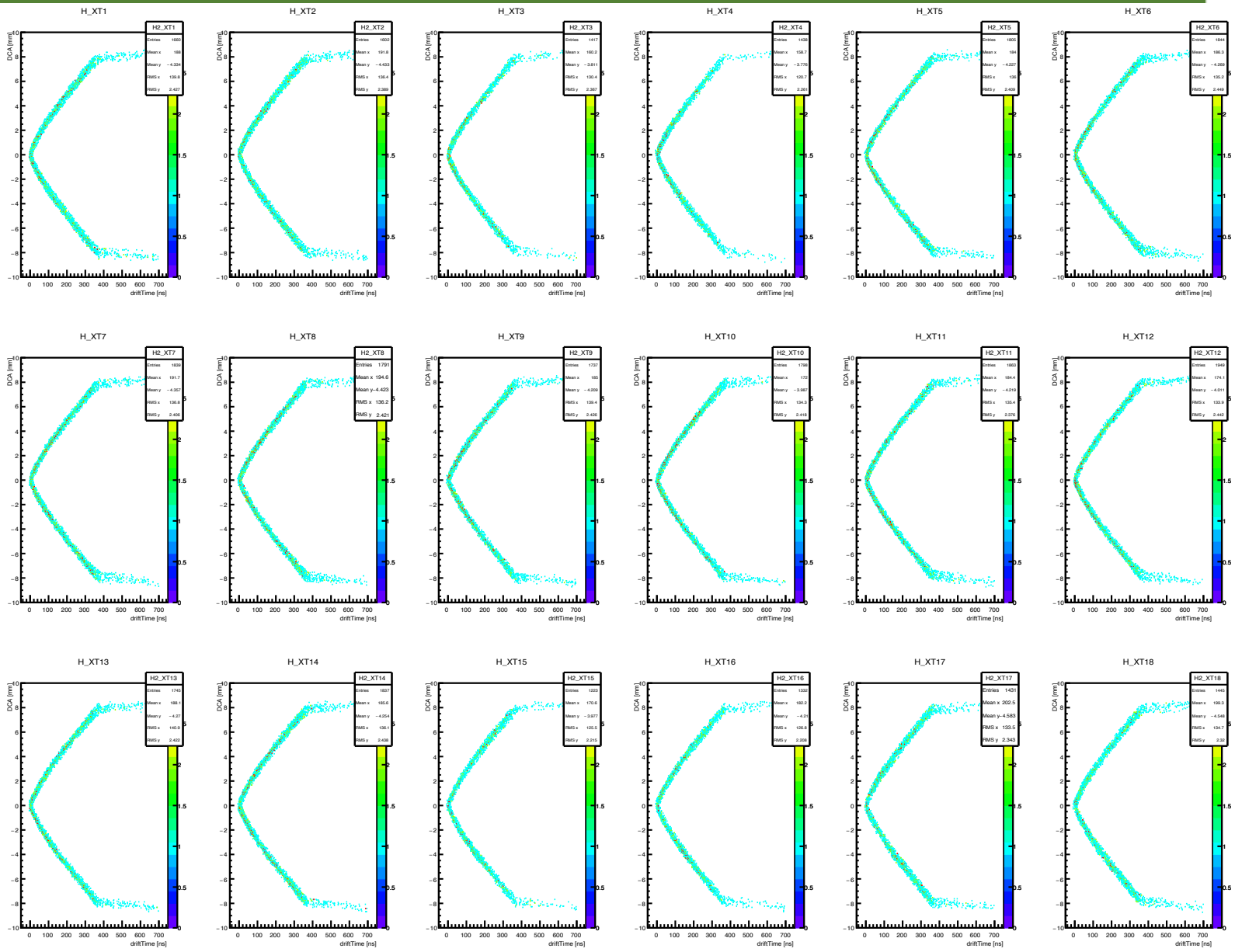
Also covered with
Al foil to shield.

We took take data with only @1825V because trigger rate was so small and time was limited.

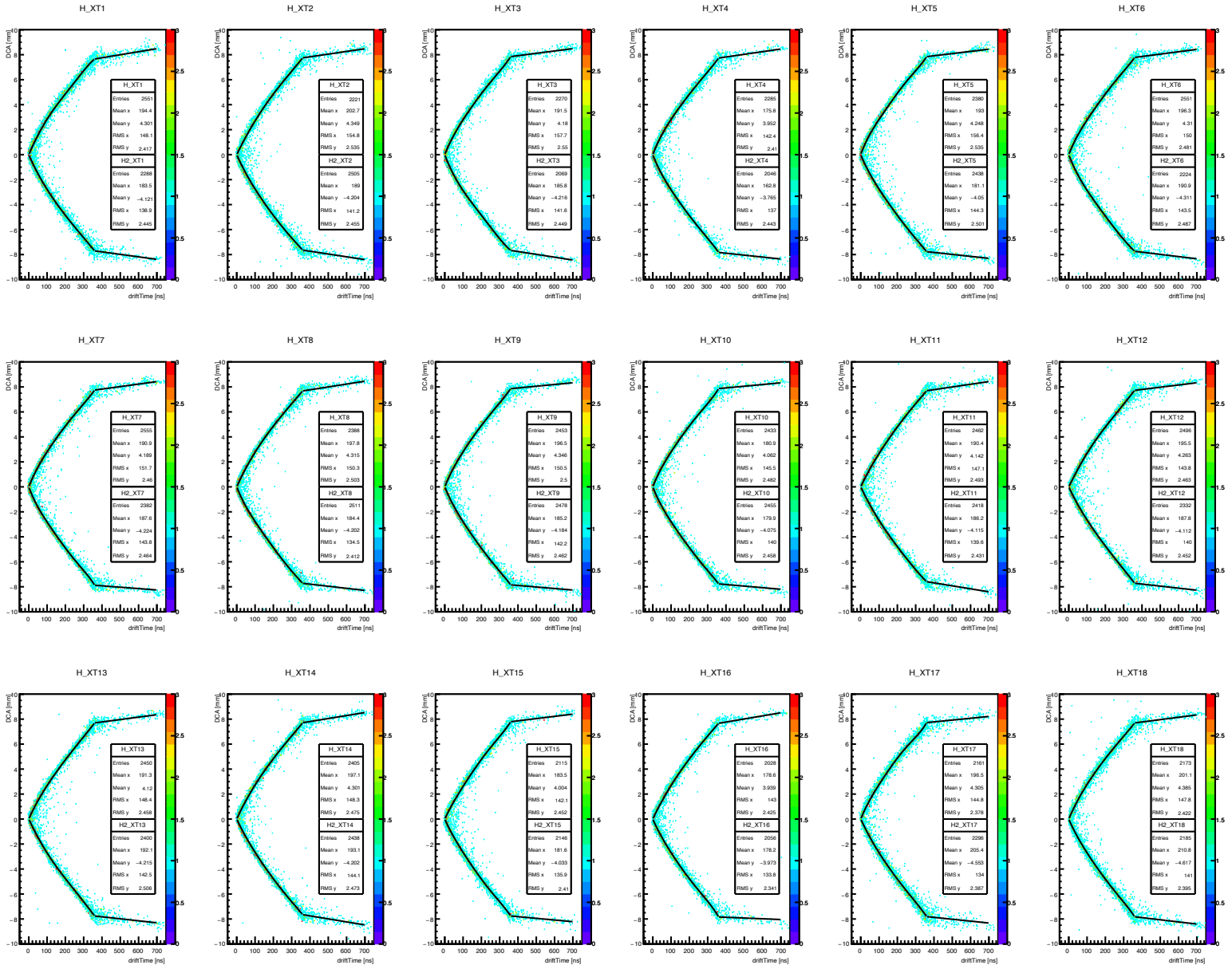
Condition
HV = 1825 V
Trigger = S1&S2
Trigger rate = 0.03 Hz

- As the first step, start to analyze the top & bottom side of CDC separately.

XT Curve for each layer (top)

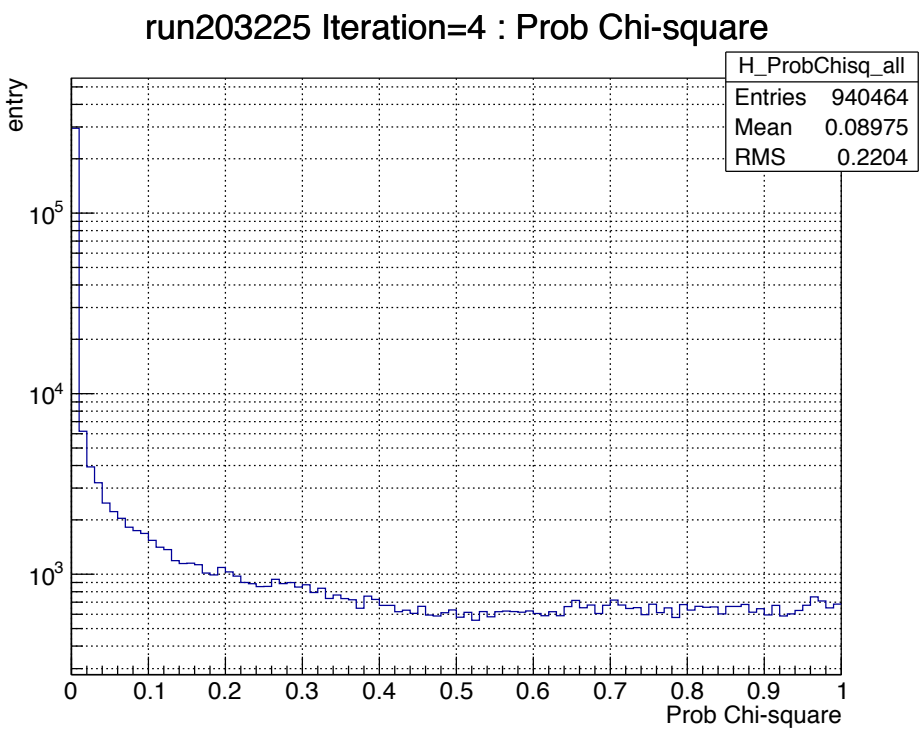


XT Curve for each layer (bottom)

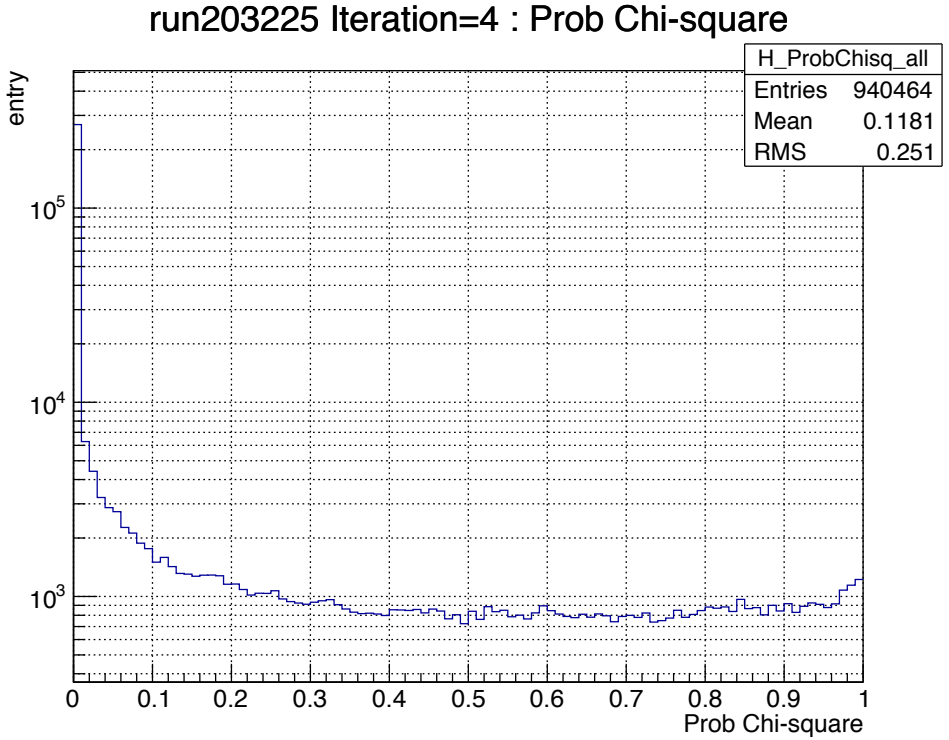


Prob Chi square for all layers (top & bottom)

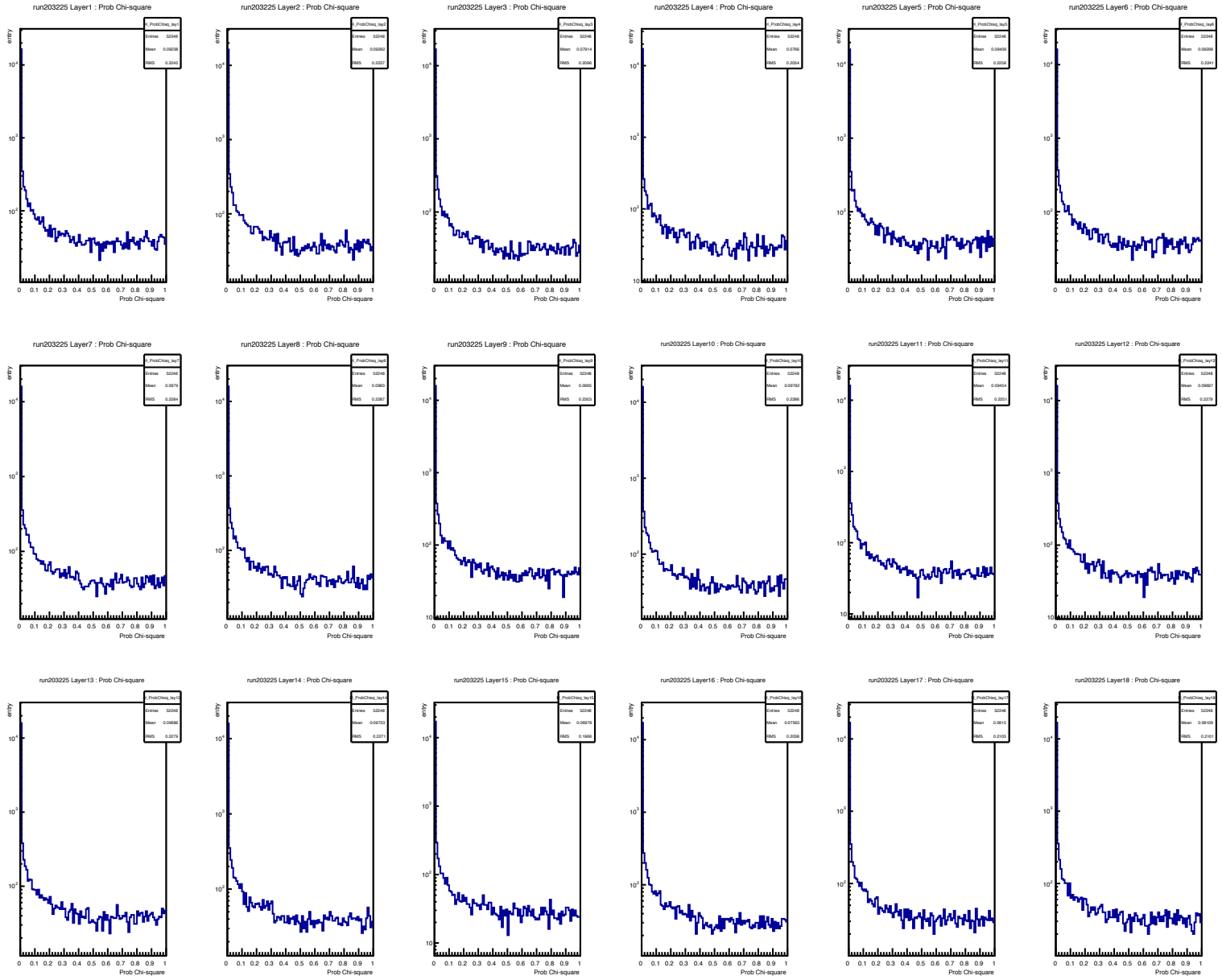
Top side



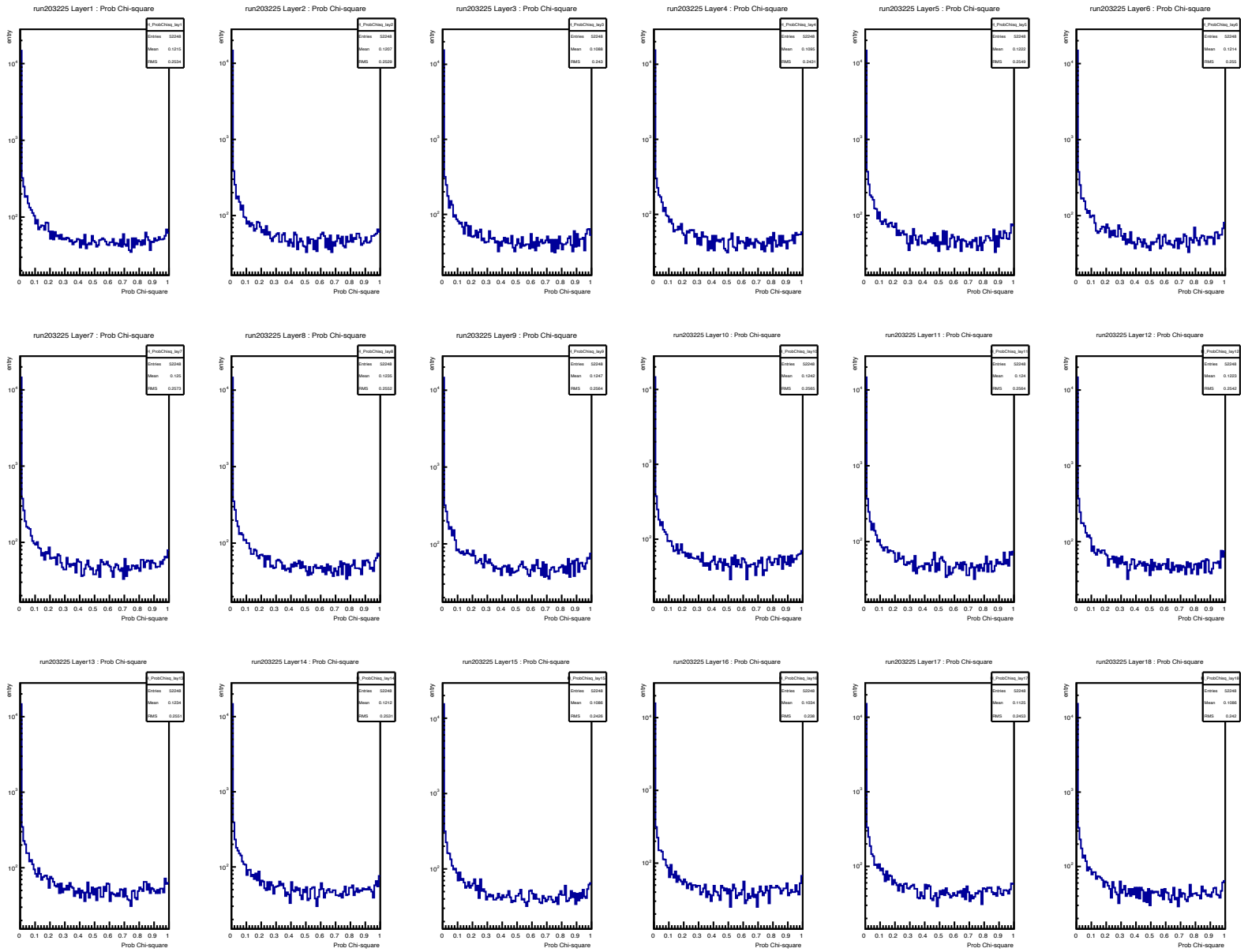
Bottom side



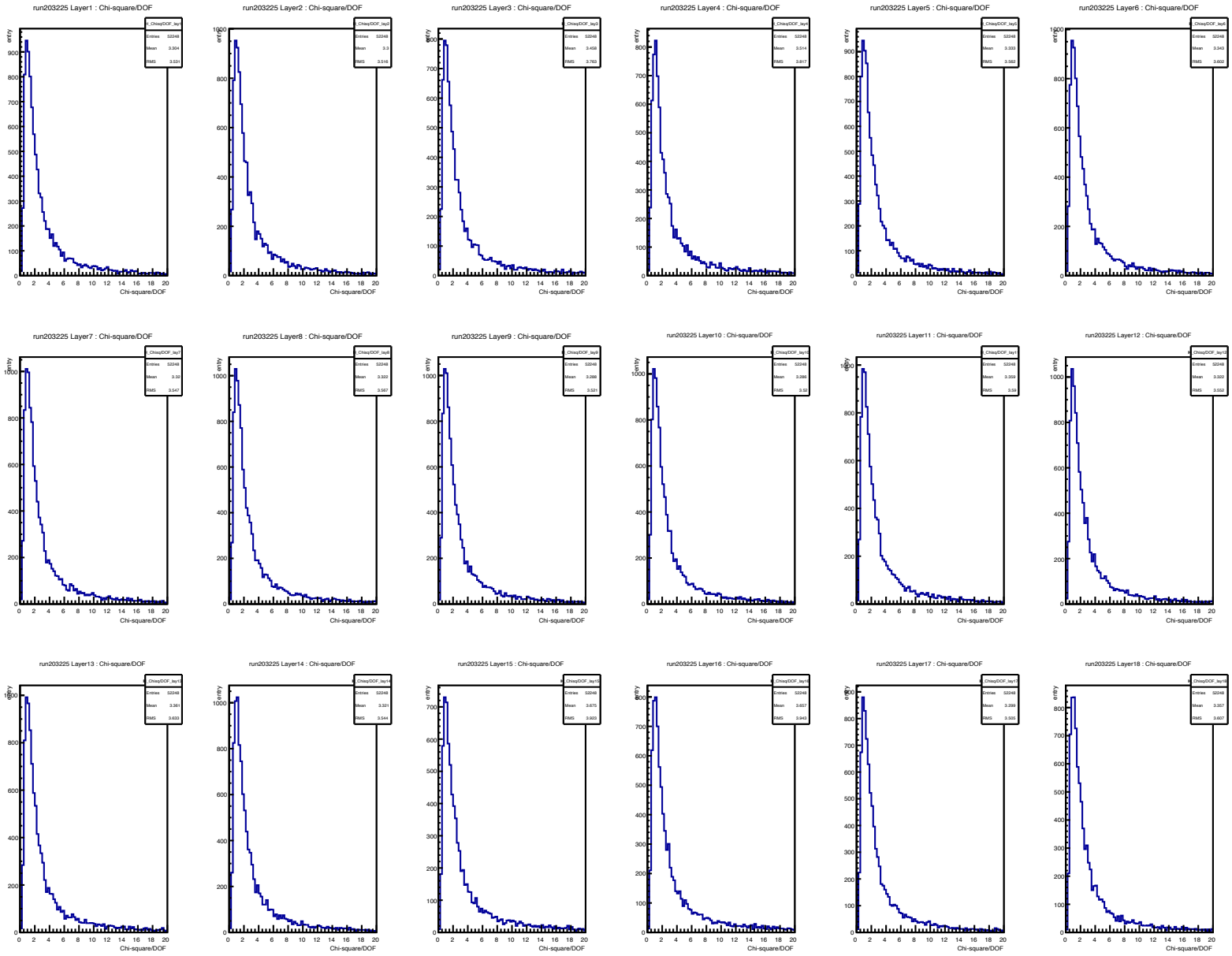
Prob Chi square for each layer (top)



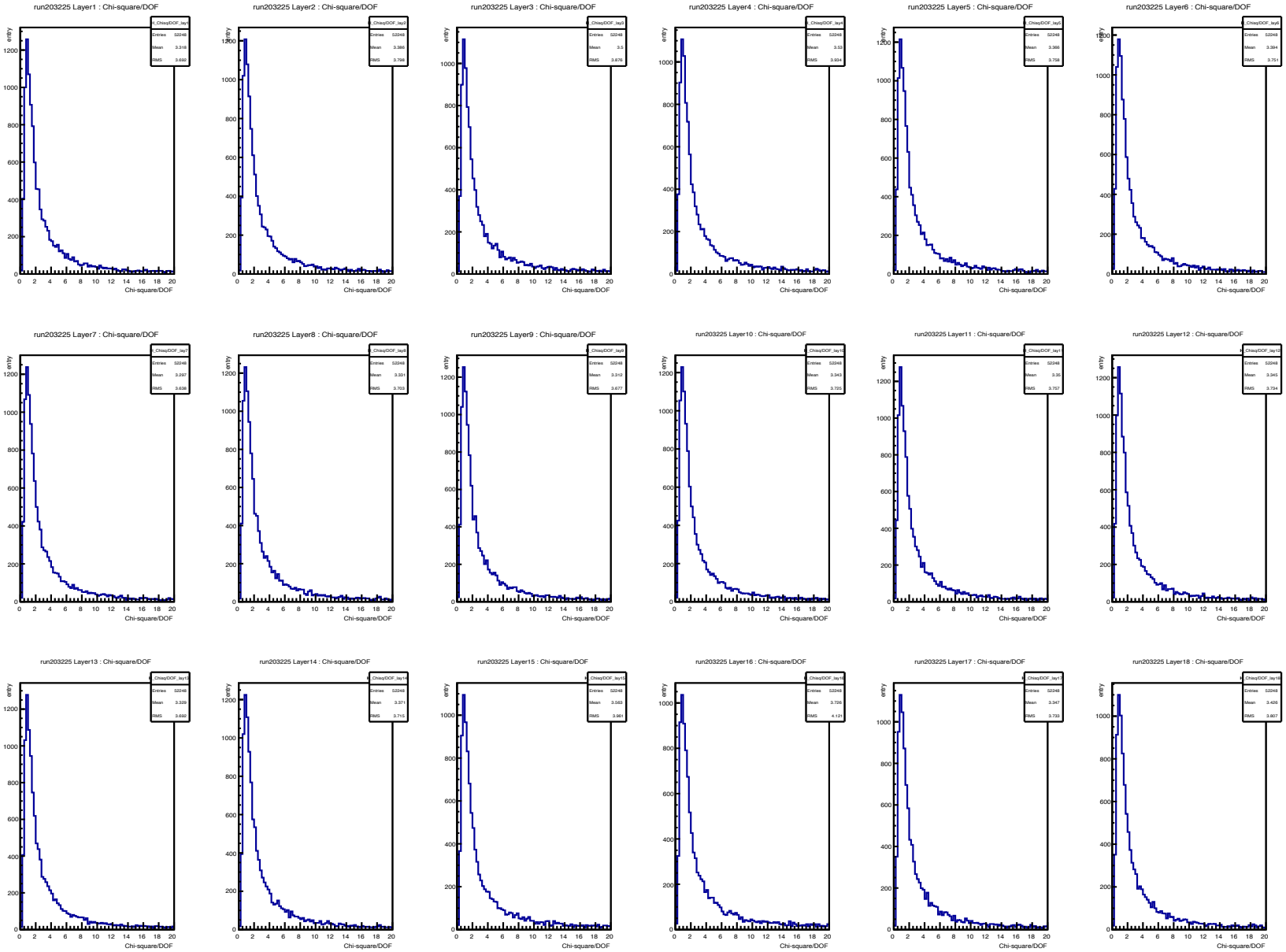
Prob Chi square for each layer (bottom)



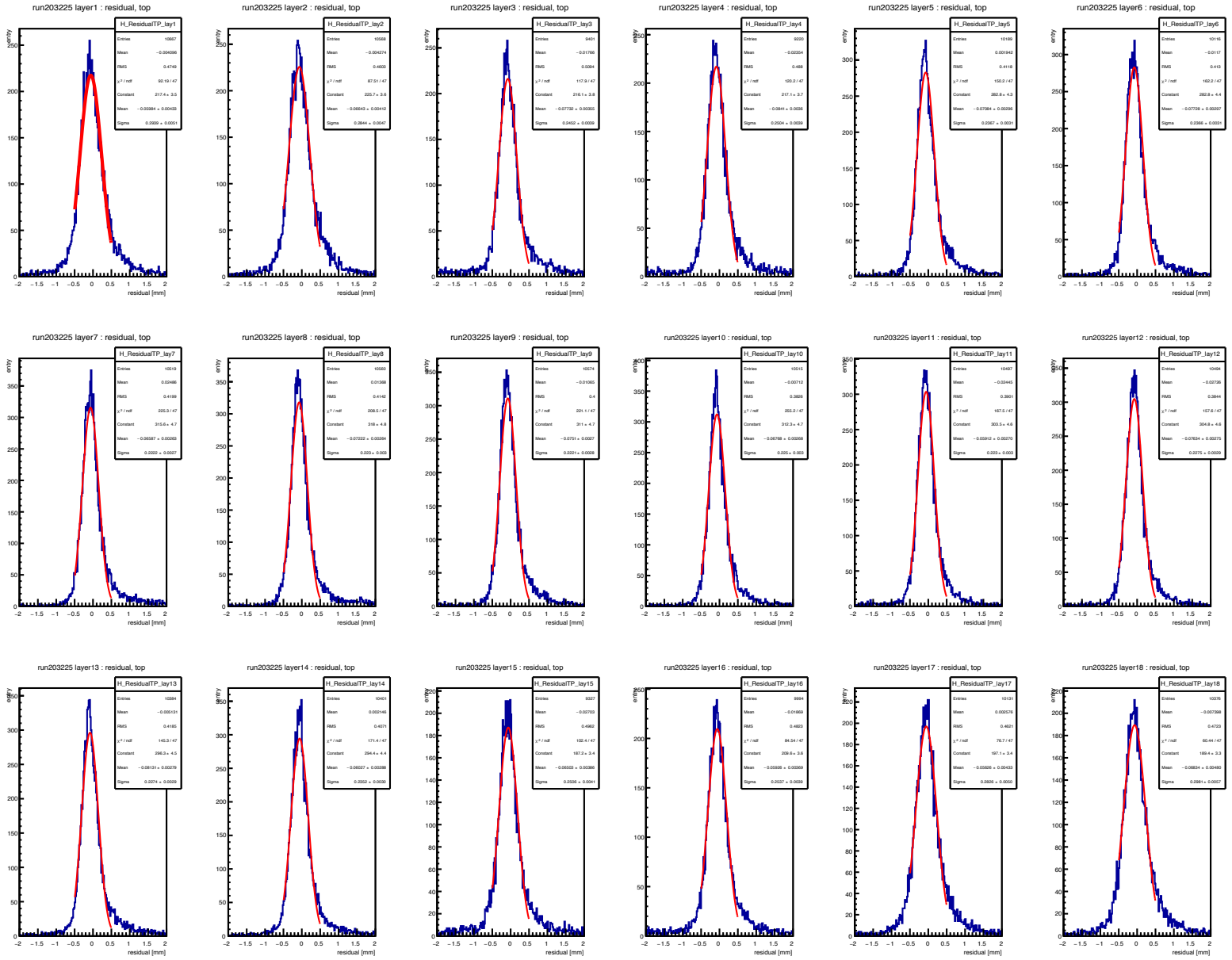
Chi square for each layer (top)



Chi square for each layer (bottom)



Residual for each layer (top)



Residual for each layer (bottom)