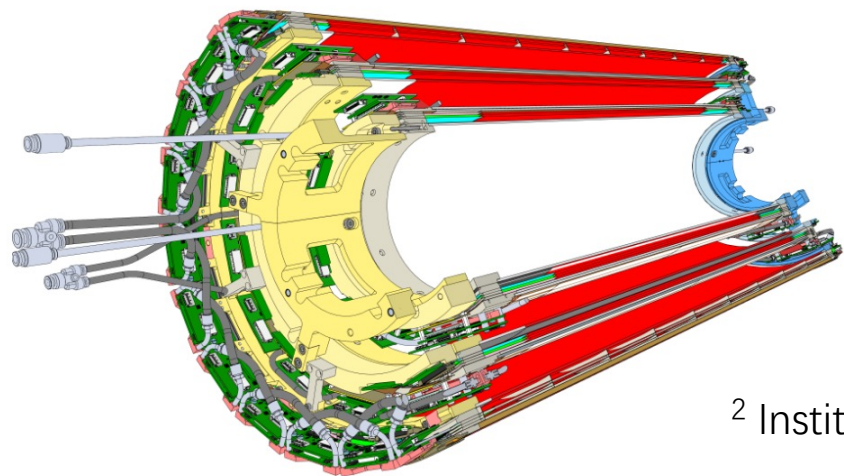


# Calibration, Alignment and Preliminary Performance of CGEM-IT at BESIII



Li Yaxuan<sup>1,2</sup>, Wu Linghui<sup>2</sup>,

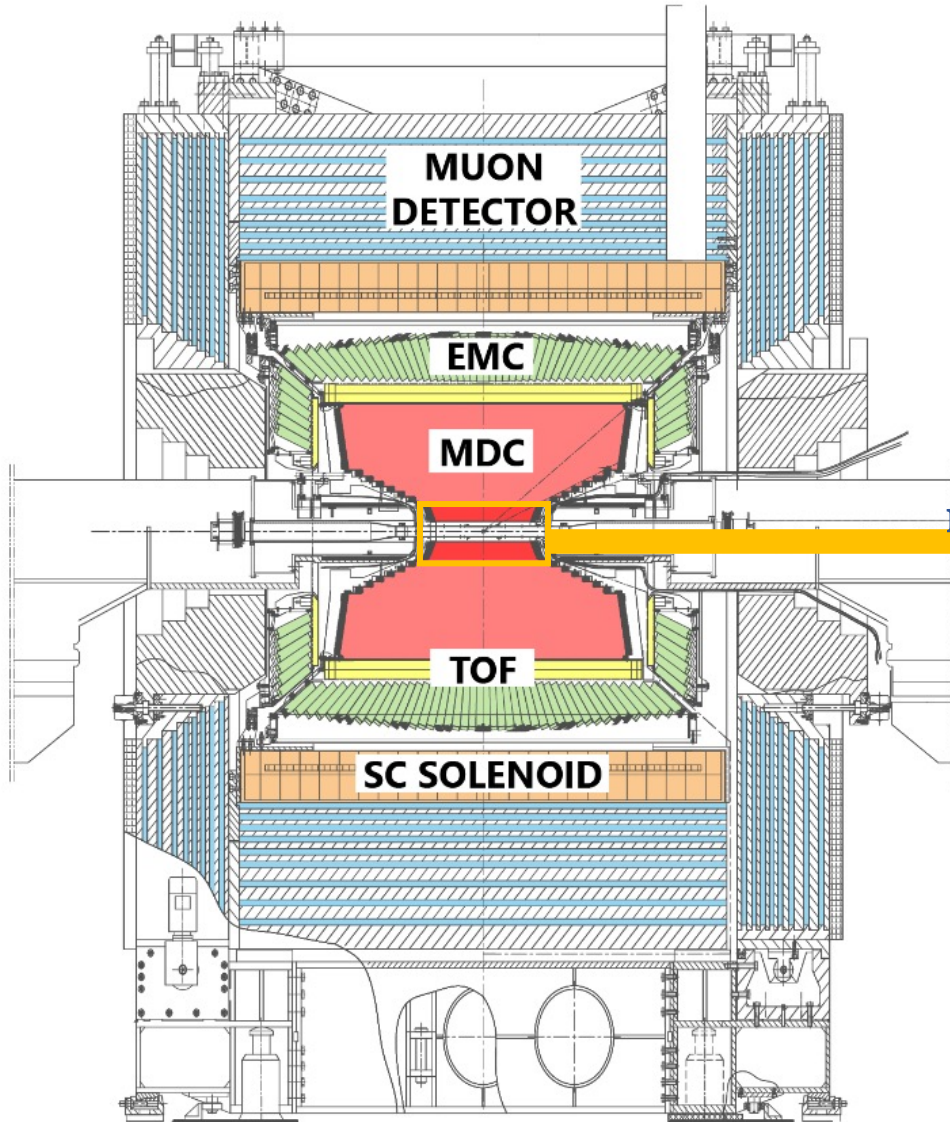
on behalf of the CGEM-IT software group

[liyaxuan@ihep.ac.cn](mailto:liyaxuan@ihep.ac.cn)

<sup>1</sup> Nankai University, Tianjin, China

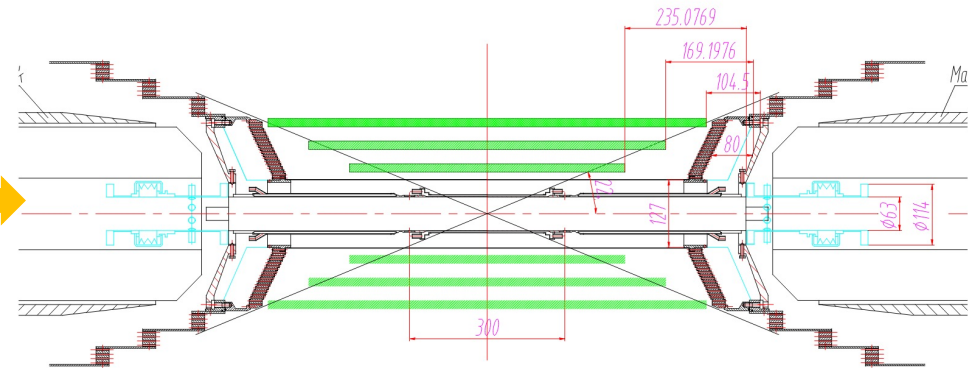
<sup>2</sup> Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China

# Inner Tracker Update at BESIII



Due to the aging of the inner layers of the MDC ,  
CGEM-IT was installed to replace the inner chamber of  
the MDC at BESIII

replaced by

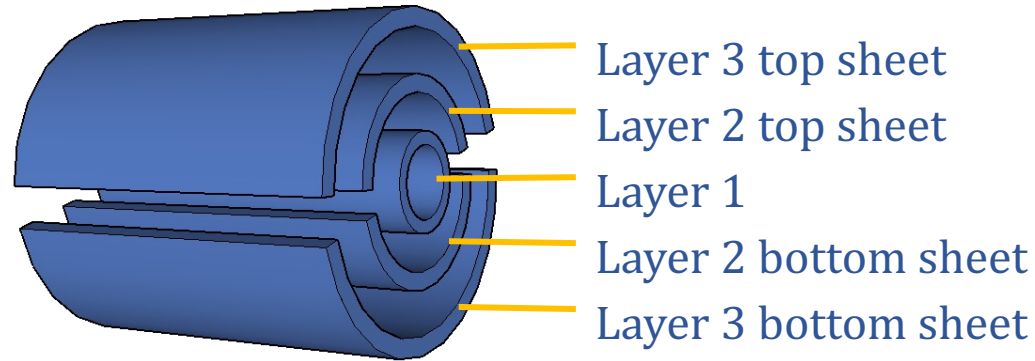


**CGEM: Cylindrical Gas Electron Multiplier**

For details, please refer to Chiara's presentation

# CGEM-IT: Geometry and Alignment

- 3 cylindrical layers
- 5 parts mechanically



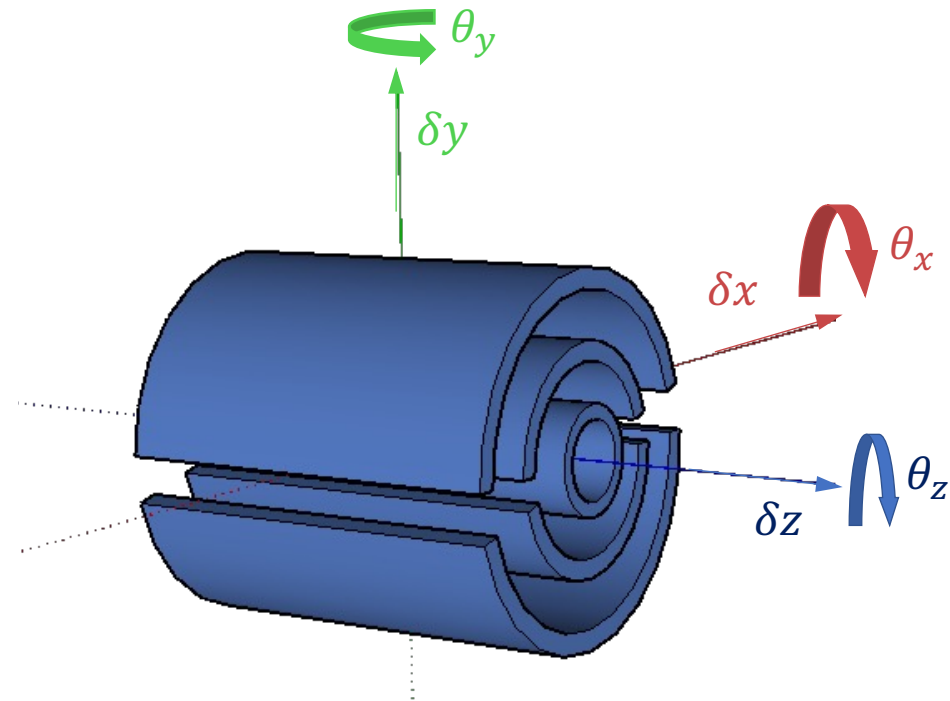
## Geometrical misalignment

**Due to:** mechanical imperfection during the detector construction and assembly

**Causing:** systematic biases in track reconstruction and degradation of momentum resolution

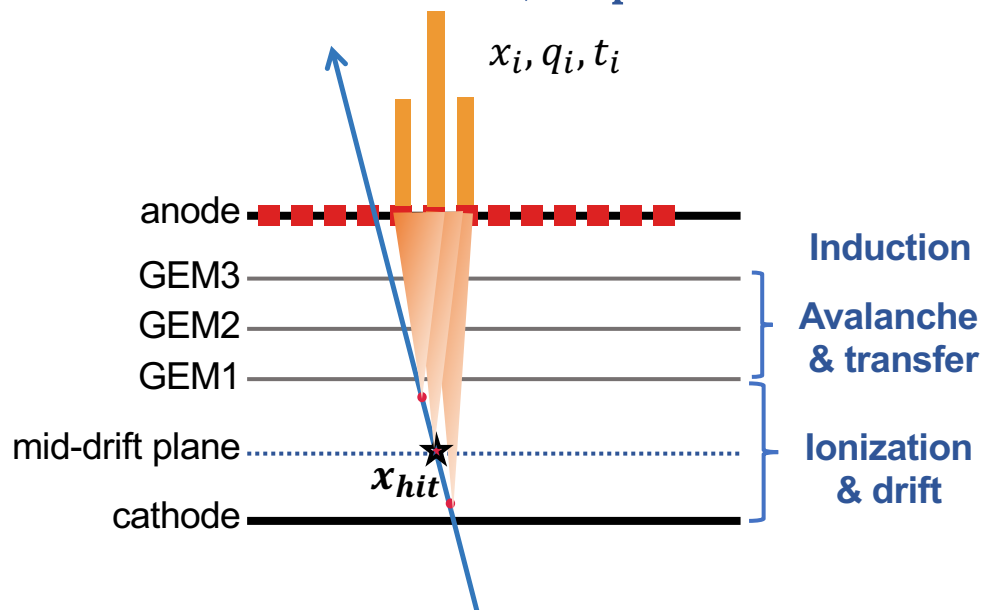
30 alignment parameters for CGEM-IT:

5 (components) \* 6 (degrees of freedom)

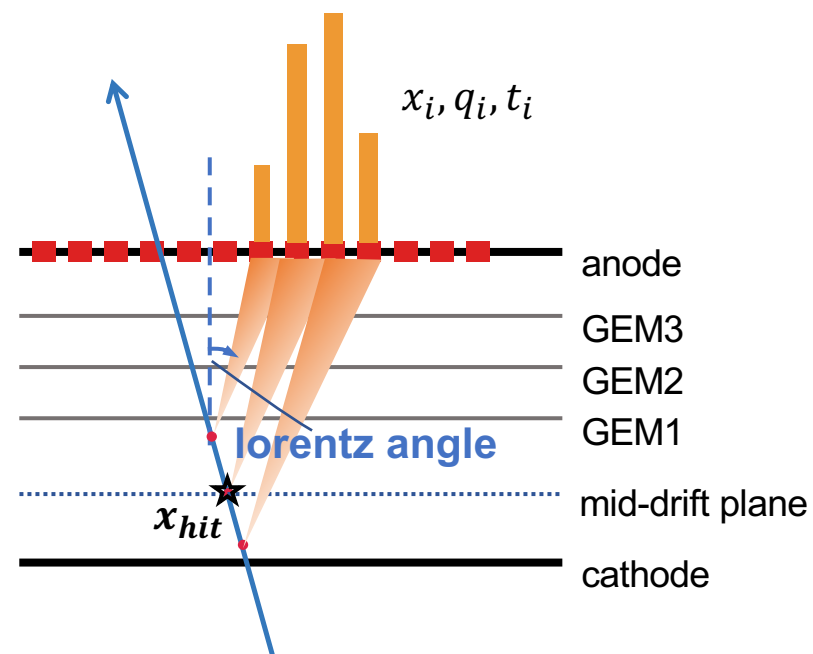


# CGEM-IT: Working Principle and Lorentz Angle

## ➤ Ionized electron drift, amplification and Induction



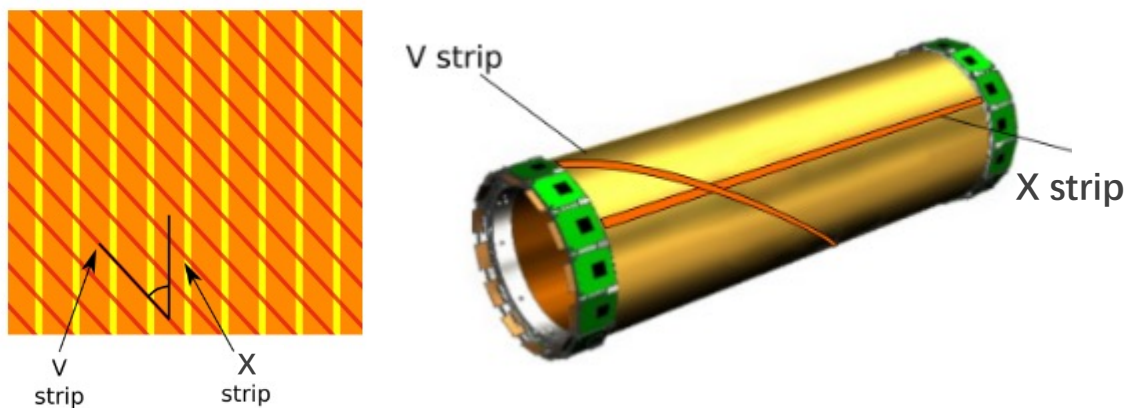
## ➤ Lorentz angle shift under a magnetic field



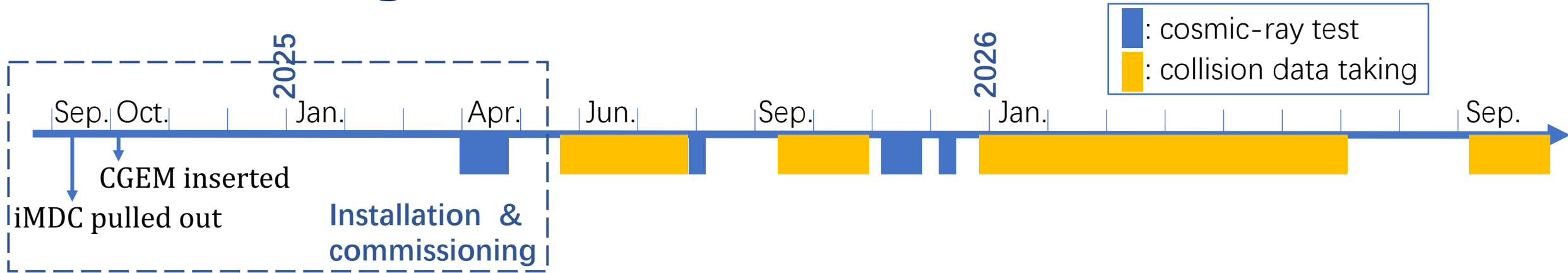
Causing a position shift between measured cluster and ionization

Shift caused by Lorentz angle  
need to be determined by calibration

## ➤ Independent readout strips in 2 directions: X, V

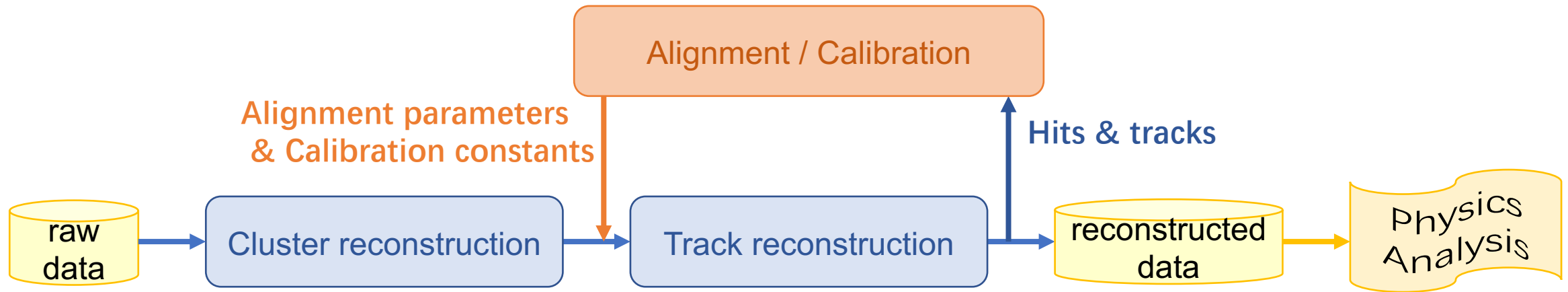


# Data Taking and Reconstruction



After the replacement of inner tracker, detector commissioning was carried out.

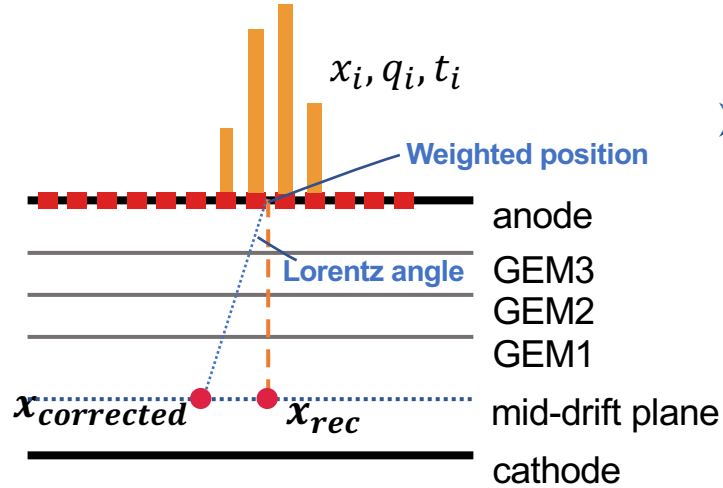
Then, CGEM-IT participated in cosmic-ray test and collision data taking .



The CGEM-IT reconstruction workflow was developed and supplemented with track-based alignment and calibration.



## Two methods adopted in CGEM cluster reconstruction:

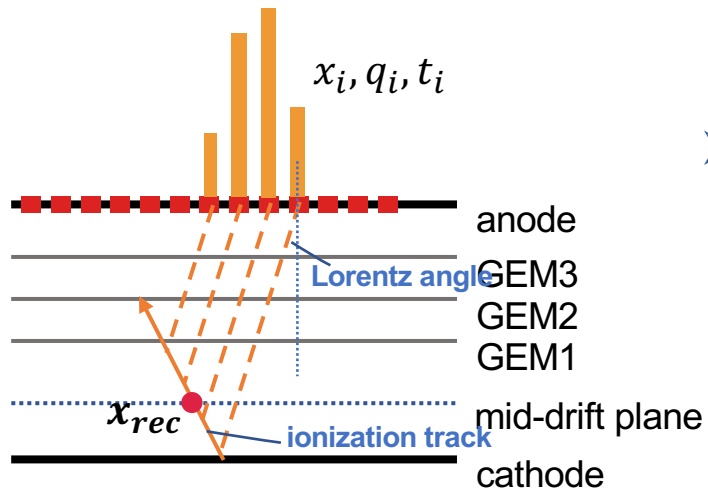


### ➤ Charge Centroid (C.C.):

The charge-weighted average of the fired strip positions

$$x_{rec} = \sum_i \frac{q_i x_i}{\sum_i q_i}$$

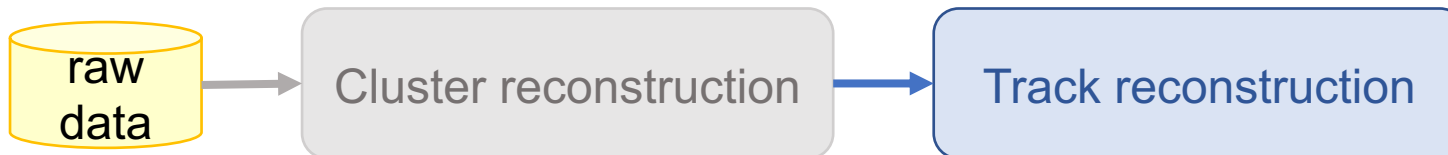
- ✓ Simple and fast
- ✓ Better performance at **small incident angles**
- ✗ Sensitive to charge-sharing distortion at large incident angles



### ➤ $\mu$ TPC:

Reconstruction based on the **relation between ionization position and drift time (to be calibrated)**

- ✓ Better performance at **large incident angles**
- ✗ More complex reconstruction and calibration



### Cosmic-ray:

Hough/Legendre Transform + global least-squares fit

### Collision data:

Hough Transform + Kalman Filter fit

residual  $\Delta_M$ :  $M_{\text{measured}} - M_{\text{estimated}}$  (M: X or V)

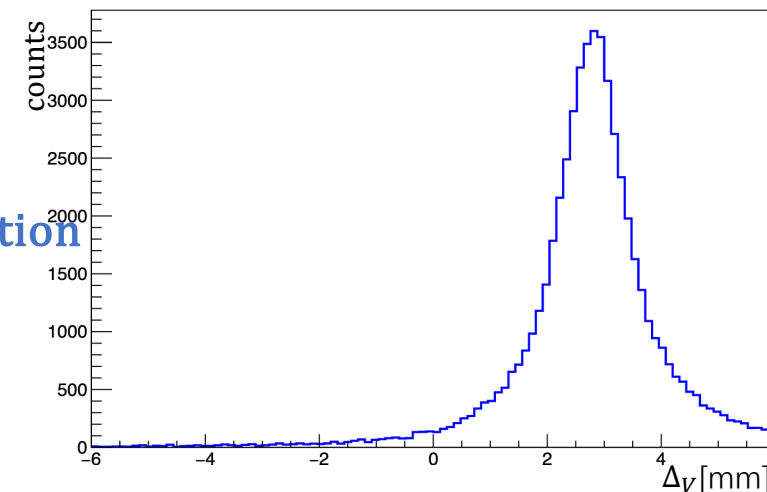
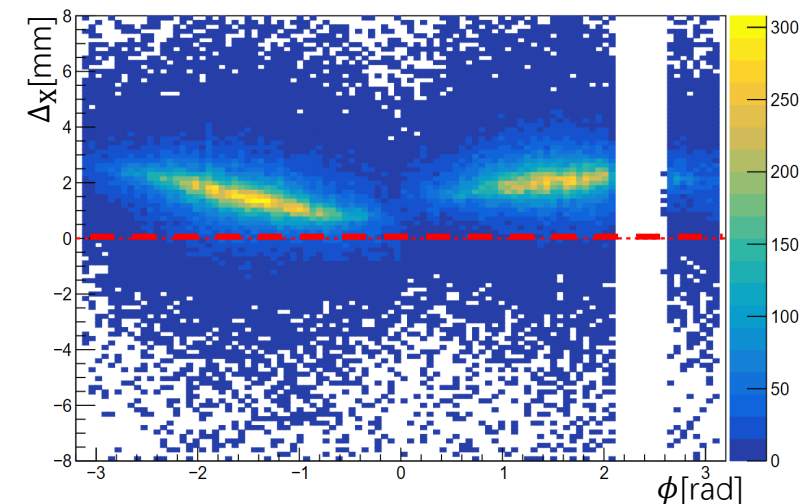
$M_{\text{measured}}$ : position from cluster reconstruction

$M_{\text{estimated}}$ : Intersection of the reconstructed track, excluding the hit in the layer under study, with the detector geometry

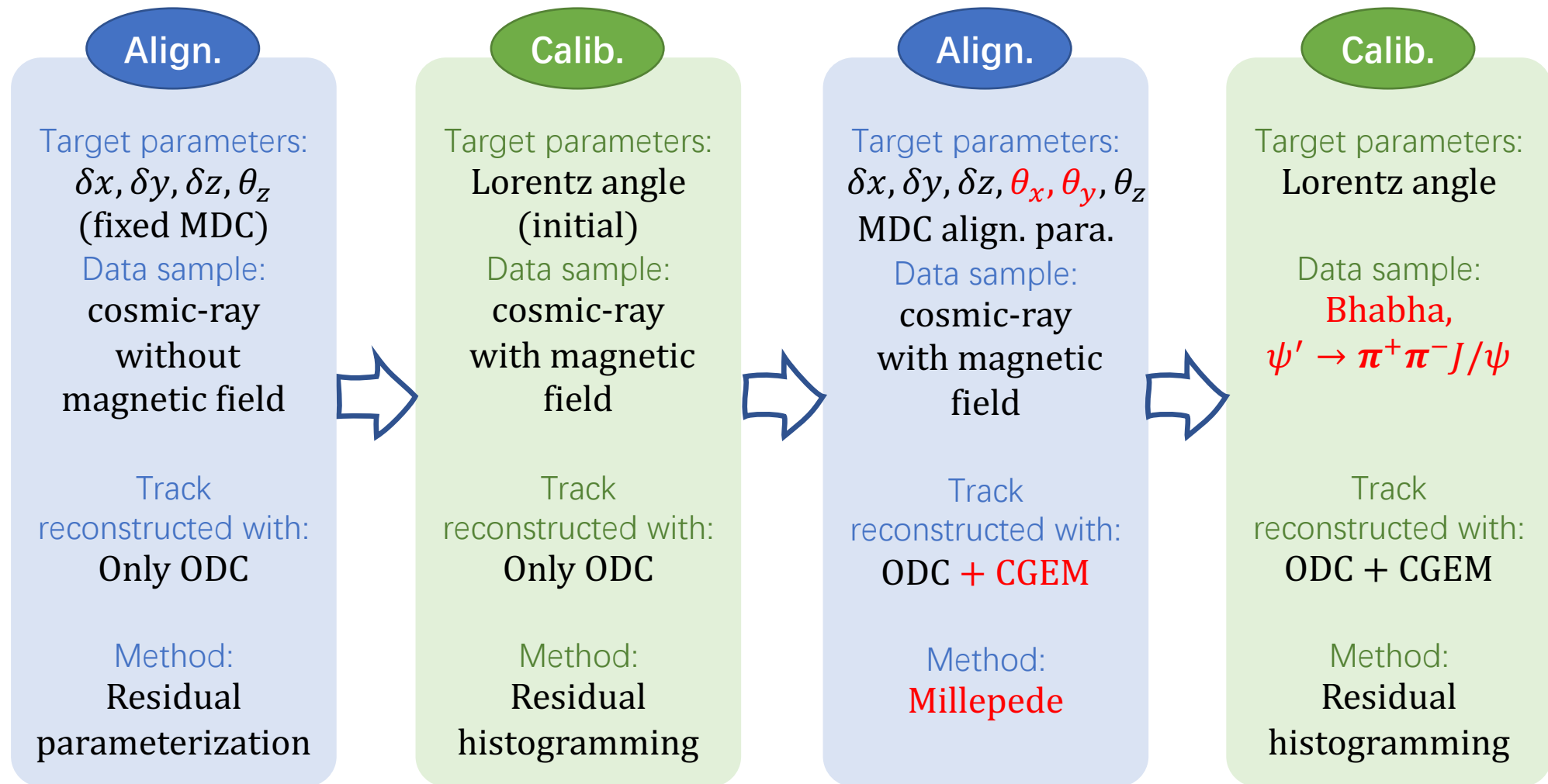
### Significant peak shift and shape distortion observed in residual distribution

- due to both geometrical misalignment and Lorentz angel
- **Alignment and calibration need to be carried out iteratively**

C.C.-based Residual of CGEM  
(layer 3) (cosmic ray)



# C.C.-based Alignment and Calibration Strategy



**Note:** performed using CGEM clusters reconstructed with C.C. method, avoiding the effects of time calibration in  $\mu$ TPC method.

## Align.

Target parameters:

$\delta x, \delta y, \delta z, \theta_z$   
(fixed MDC)

Data sample:

cosmic-ray

without  
magnetic field

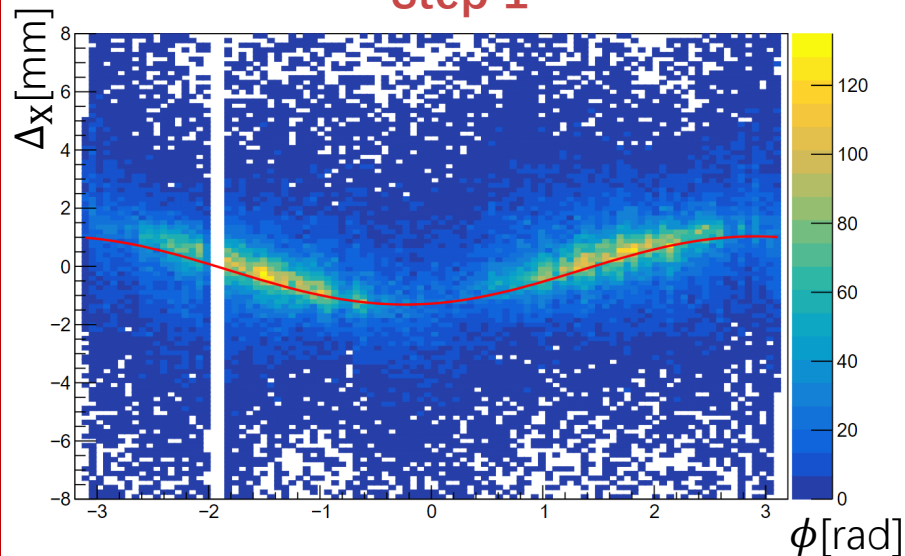
Track  
reconstructed with:  
Only ODC

Method:  
Residual  
parameterization

## Method

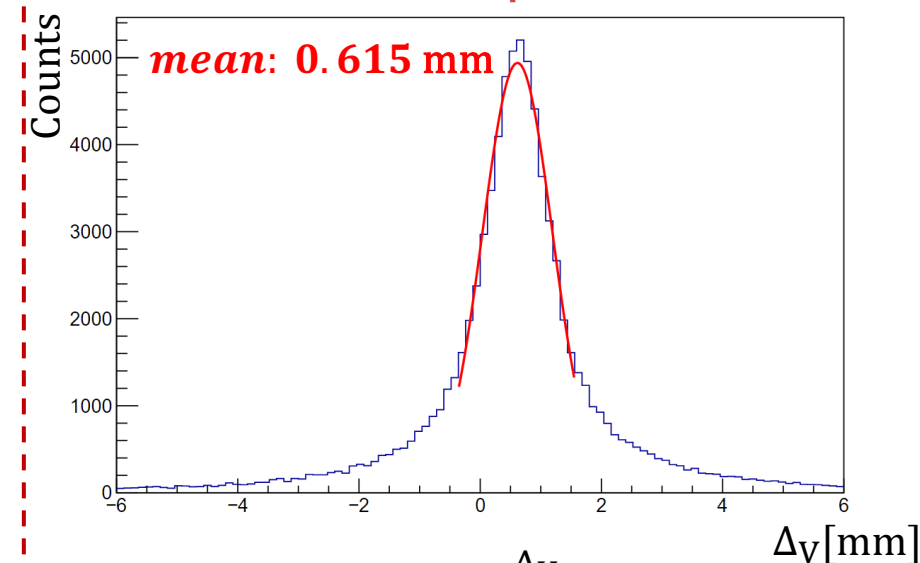
Taking two sheets in the same layer as one part to align preliminarily

### Step 1



$$\Delta_X = \delta x * \sin \phi - \delta y * \cos \phi - \theta_z * R_{\text{layer}}$$

### Step 2



$$\delta z = \frac{\Delta_V}{\sin \alpha}$$

( $\alpha$ : the angle between X and V strips)

## Result

| Layer | $\delta x$ [mm] | $\delta y$ [mm] | $\delta z$ [mm] | $\theta_x$ [mrad] | $\theta_y$ [mrad] | $\theta_z$ [mrad] |
|-------|-----------------|-----------------|-----------------|-------------------|-------------------|-------------------|
| 1     | 0.214           | 1.169           | 0.868           | -                 | -                 | 0.292             |
| 2     | 0.148           | 0.421           | 2.598           | -                 | -                 | -3.130            |
| 3     | 0.312           | 0.643           | 2.263           | -                 | -                 | -10.012           |

## Align.

Target parameters:

$\delta x, \delta y, \delta z, \theta_z$   
(fixed MDC)

Data sample:

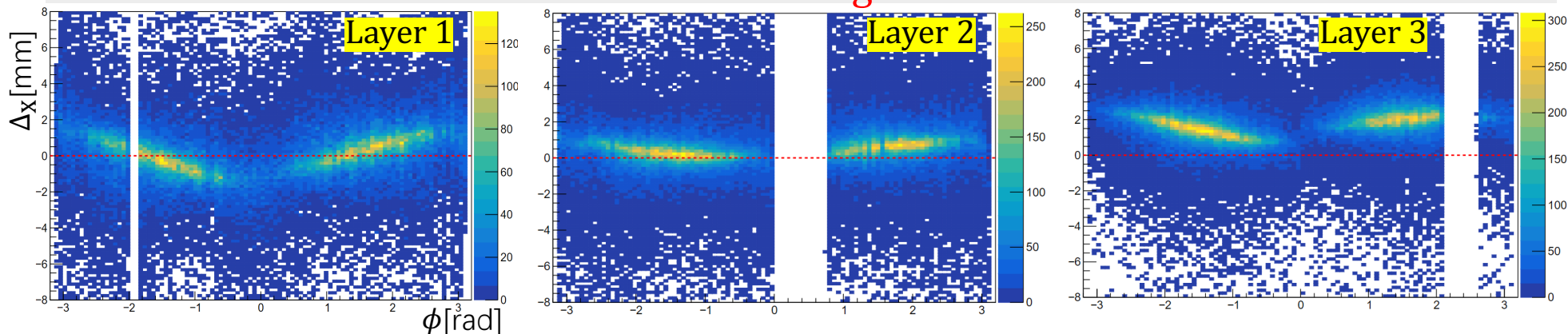
cosmic-ray  
without  
magnetic field

Track  
reconstructed with:  
Only ODC

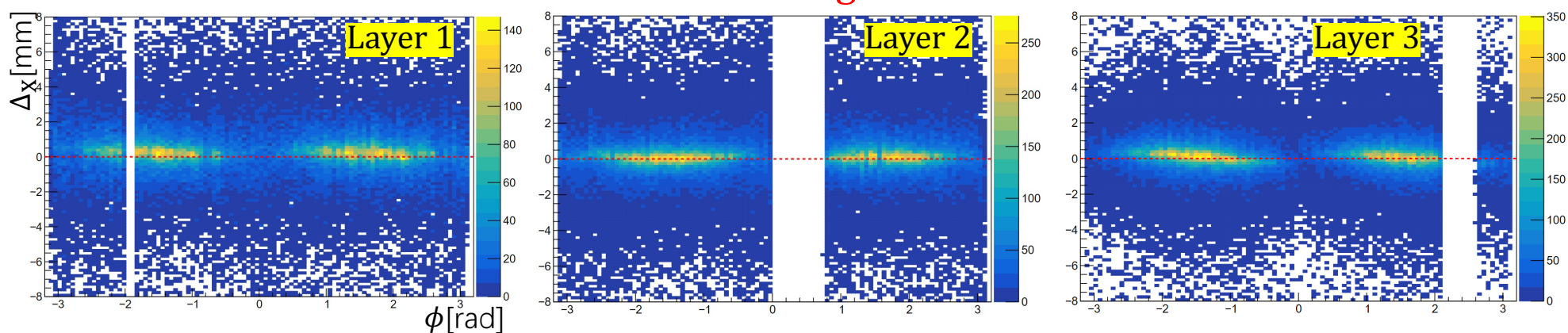
Method:  
Residual  
parameterization

## Residual in X view vs. $\phi$

Before the alignment



After the alignment



The distribution is flattened and the peak shift is corrected.

This preliminary alignment successfully corrects the main geometrical offsets

## Align.

Target parameters:

$\delta x, \delta y, \delta z, \theta_z$   
(fixed MDC)

Data sample:

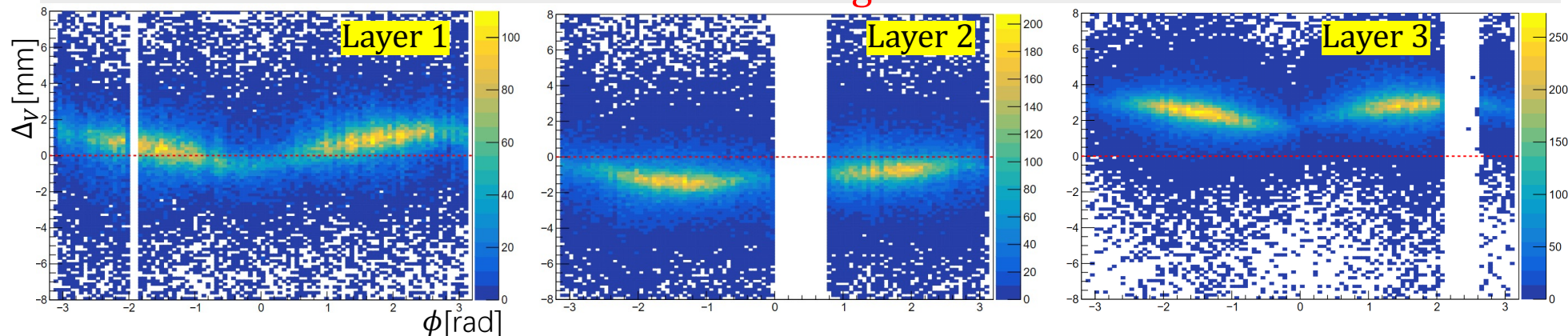
cosmic-ray  
without  
magnetic field

Track  
reconstructed with:  
Only ODC

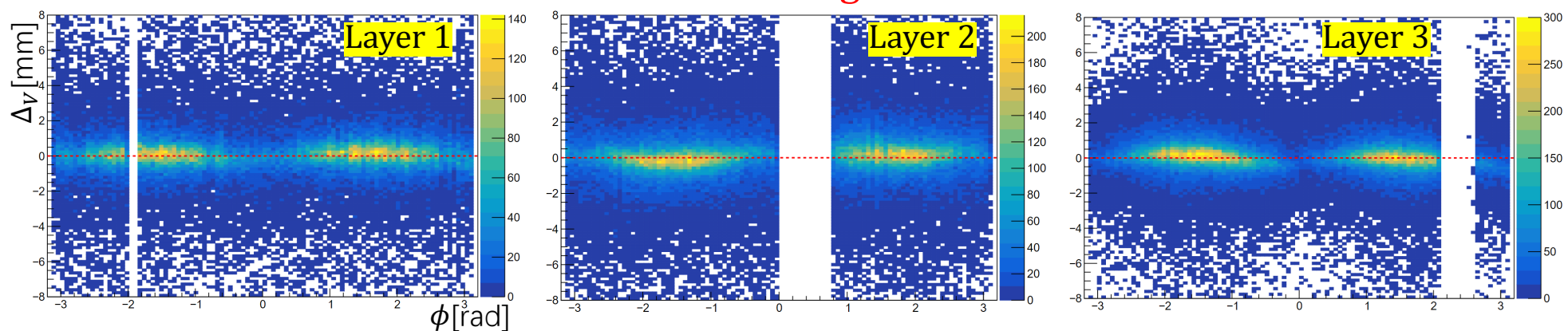
Method:  
Residual  
parameterization

## Residual in V view vs. $\phi$

Before the alignment



After the alignment



The distribution is flattened and the peak shift is corrected.

This preliminary alignment successfully corrects the main geometrical offsets

## Calib.

Target parameters:

Lorentz angle  
(initial)

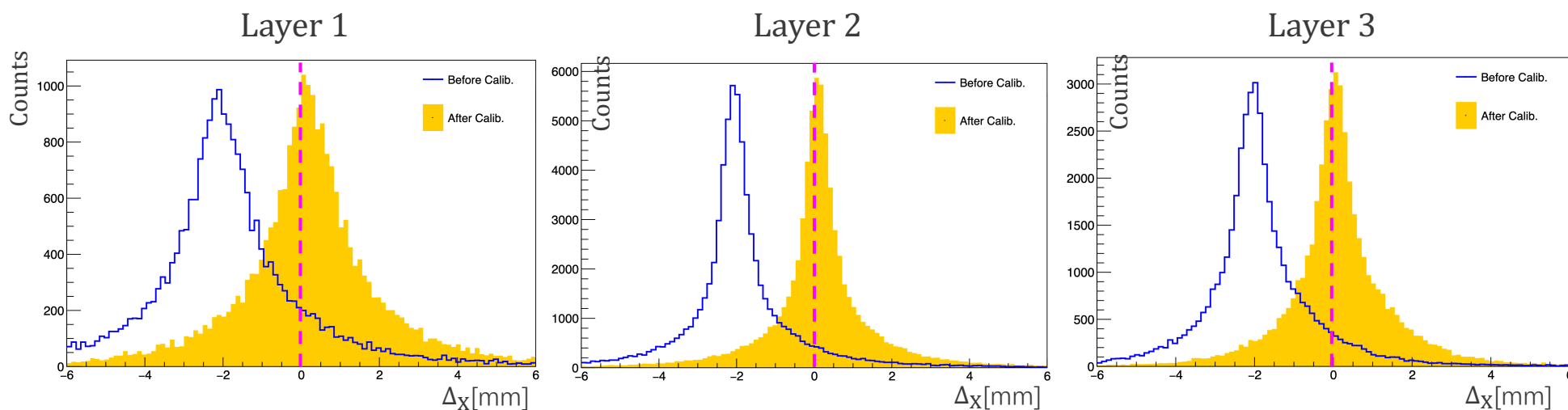
Data sample:  
cosmic-ray  
with magnetic  
field

Track  
reconstructed with:  
Only ODC

Method:  
Residual  
histogramming

After applying the initial alignment parameters, the remaining peak shift in the X-view residual distribution is mainly associated with the Lorentz angle effect.

Residual distribution in X view



The peak shifts are corrected significantly using the calibrated Lorentz angle correction.

**Millepede method:** Using a sparse matrix formulation and the least-squares principle, determine the global parameters (alignment parameters) by eliminating local parameters (track parameters).

## Align.

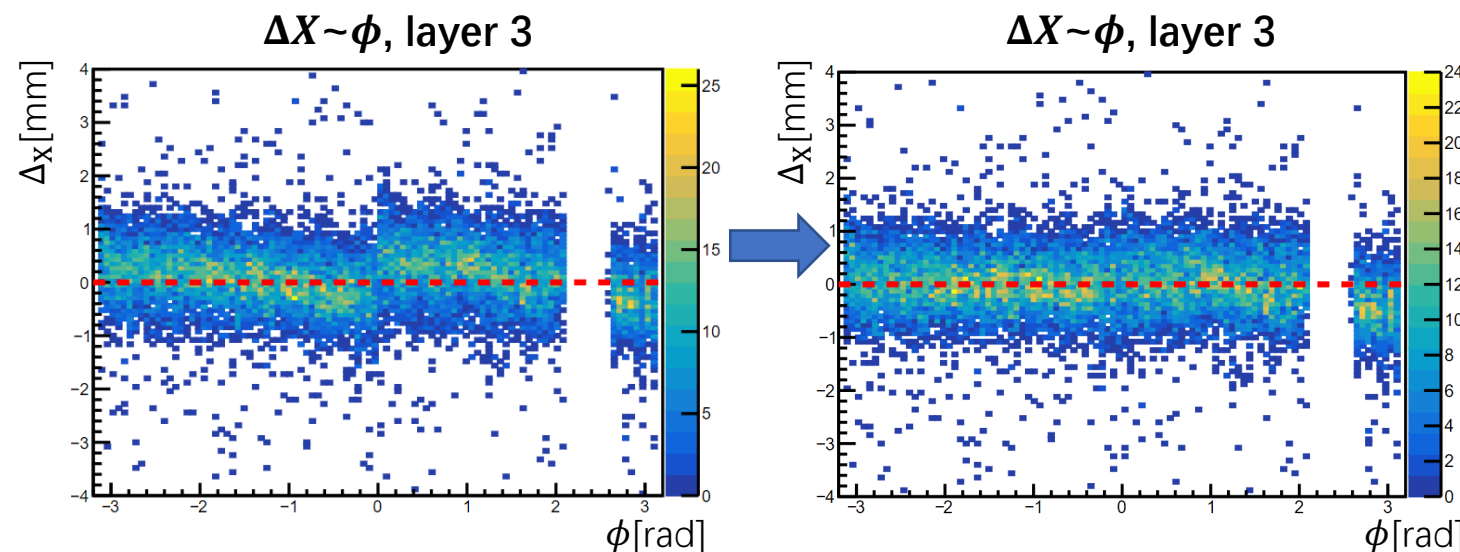
Target parameters:  
 $\delta x, \delta y, \delta z, \theta_x, \theta_y, \theta_z$

MDC align. para.

Data sample:  
 cosmic-ray  
 with magnetic  
 field

Track  
 reconstructed with:  
 ODC + CGEM

Method:  
**Millepede**



The relative  
 misalignment  
 between the top and  
 bottom sections of  
 the same layer  
 corrected.

## Result

(Courtesy of Wang Jiajv)

|                | $\delta x$ [mm] | $\delta y$ [mm] | $\delta z$ [mm] | $\theta_x$ [mrad] | $\theta_y$ [mrad] | $\theta_z$ [mrad] |
|----------------|-----------------|-----------------|-----------------|-------------------|-------------------|-------------------|
| Layer 1        | 0.258           | 1.067           | 0.989           | 0.700             | -1.223            | -0.823            |
| Layer 2 bottom | 0.489           | 0.541           | 3.244           | 0.390             | 0.196             | -6.539            |
| Layer 2 top    | 0.310           | 0.504           | 2.828           | -0.799            | 1.504             | -2.663            |
| Layer 3 bottom | 0.203           | 0.824           | 2.561           | 0.937             | 0.093             | -8.831            |
| Layer 3 top    | 0.254           | 0.547           | 2.200           | -0.398            | -0.198            | -10.451           |

## Calib.

Target parameters:  
Lorentz angle

Data sample:  
Bhabha,  
 $\psi' \rightarrow \pi^+ \pi^- J/\psi$

Track  
reconstructed with:  
ODC + CGEM

Method:  
Residual  
histogramming

# Calibration result of Lorentz angle

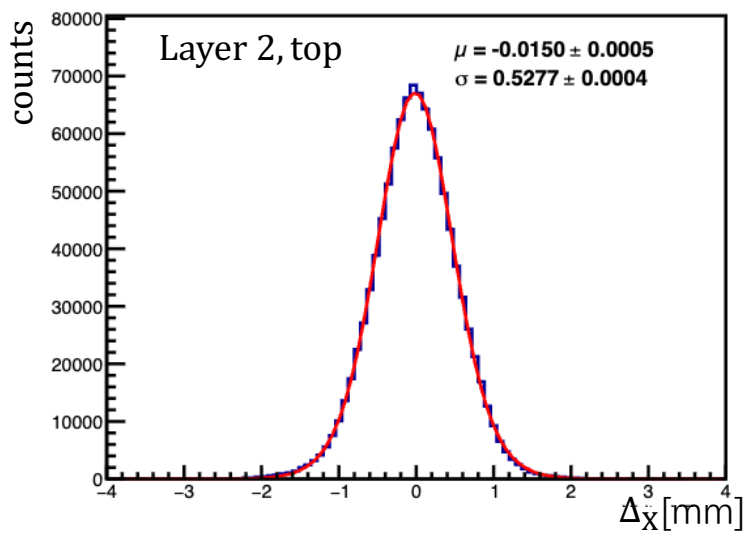
|                        | Layer1 | Layer2                        | Layer3                        |
|------------------------|--------|-------------------------------|-------------------------------|
| Lorentz Angle [degree] | 13.52  | 16.42 (top)<br>17.31 (bottom) | 12.93 (top)<br>12.94 (bottom) |

| High Voltage Configuration |     |     |     |
|----------------------------|-----|-----|-----|
|                            | L1  | L2  | L3  |
| DRIFT                      | 750 | 750 | 750 |
| IND                        | 850 | 700 | 800 |
| T1                         | 600 | 400 | 600 |
| T2                         | 600 | 400 | 600 |

Consistent with the high voltage configuration:

Layer 2 has the lowest applied high voltage and the largest Lorentz angle.

# Preliminary Result of Spatial Resolution with C.C. Method

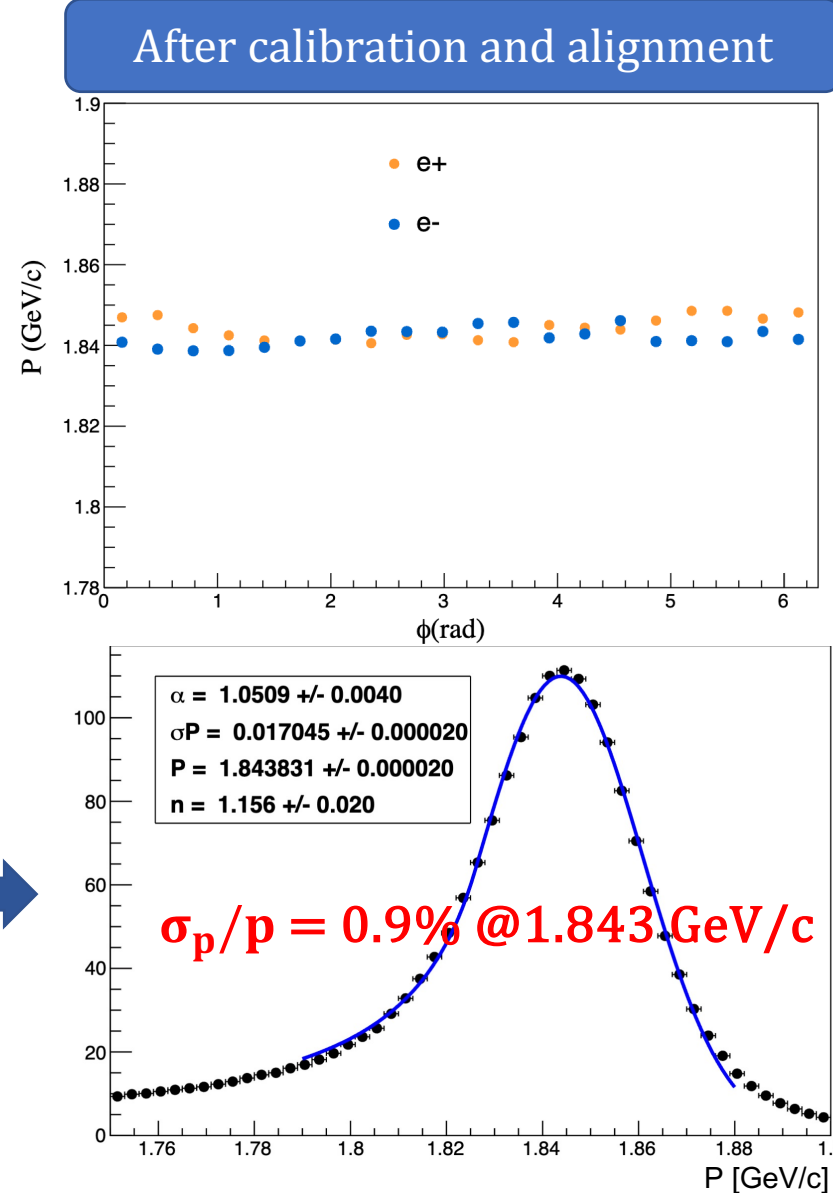
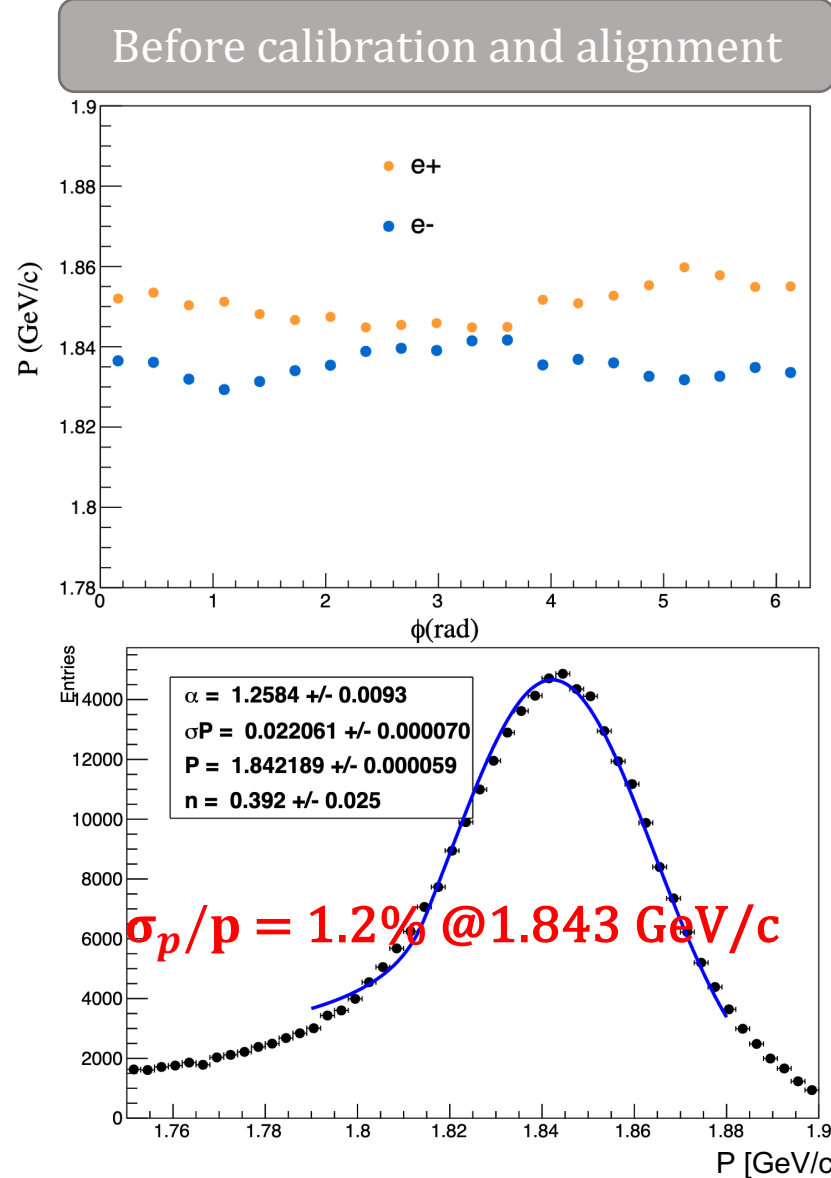


$\sigma_X, \sigma_V$  are obtained  
by fitting the residual distributions  
after alignment and Lorentz angle corrections.

Data sample: Bhabha

|                        | Layer1 | Layer2        | Layer3        |
|------------------------|--------|---------------|---------------|
| $\sigma_X [\text{mm}]$ | 0.54   | 0.53 (top)    | 0.54 (top)    |
|                        |        | 0.50 (bottom) | 0.49 (bottom) |
| $\sigma_V [\text{mm}]$ | 1.18   | 0.91 (top)    | 0.76 (top)    |
|                        |        | 0.92 (bottom) | 0.76 (bottom) |

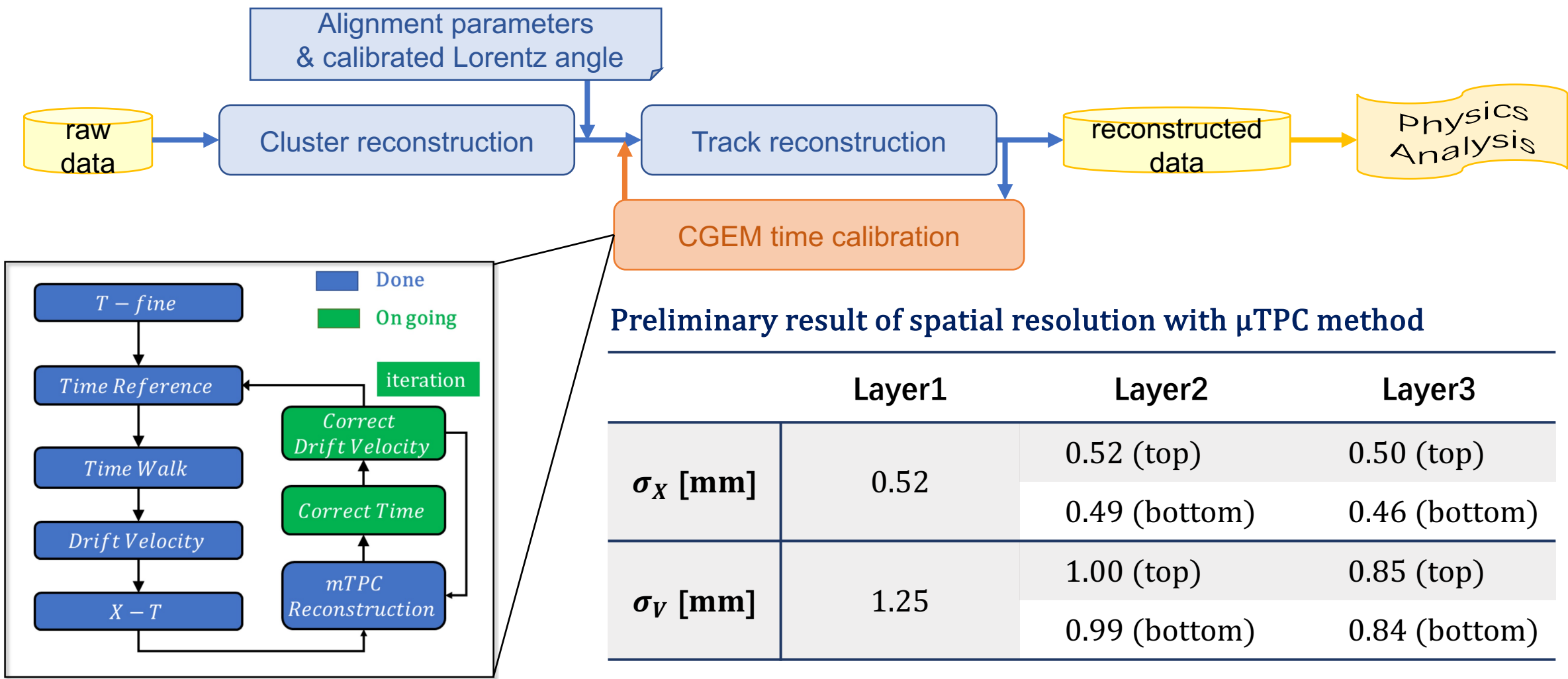
# Preliminary Result of Momentum Resolution with C.C. Method



Data sample:  
Bhabha @  $\psi(3686)$

# Calibration of $\mu$ TPC Method

(Courtesy of Yuan Hao)



Preliminary result of spatial resolution with  $\mu$ TPC method

|                 | Layer1 | Layer2        | Layer3        |
|-----------------|--------|---------------|---------------|
| $\sigma_X$ [mm] | 0.52   | 0.52 (top)    | 0.50 (top)    |
|                 |        | 0.49 (bottom) | 0.46 (bottom) |
| $\sigma_V$ [mm] | 1.25   | 1.00 (top)    | 0.85 (top)    |
|                 |        | 0.99 (bottom) | 0.84 (bottom) |

# Summary

- The CGEM-IT was installed in October 2024 to replace the inner chamber of the MDC and, following its commissioning, has participated in both cosmic-ray and physics data-taking campaigns.
- Alignment and calibration studies have been performed to optimize the detector performance.
- Preliminary results demonstrate proper detector operation and reliable tracking performance.
- Further calibration and alignment studies are ongoing to further improve its performance.
  - Alignment combining cosmic-ray and dimu data
  - Improvement of  $\mu$ TPC calibration

*Thank you for your attention!*

# BACKUP

# BESIII: the Beijing Spectrometer III experiment at BEPCII

## Physics aims:

precision measurements in the  $\tau$ -charm energy region

$E_{cm}$  : 2~5 GeV

$L_{peak}$ :  $1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$  @ 3.773 GeV

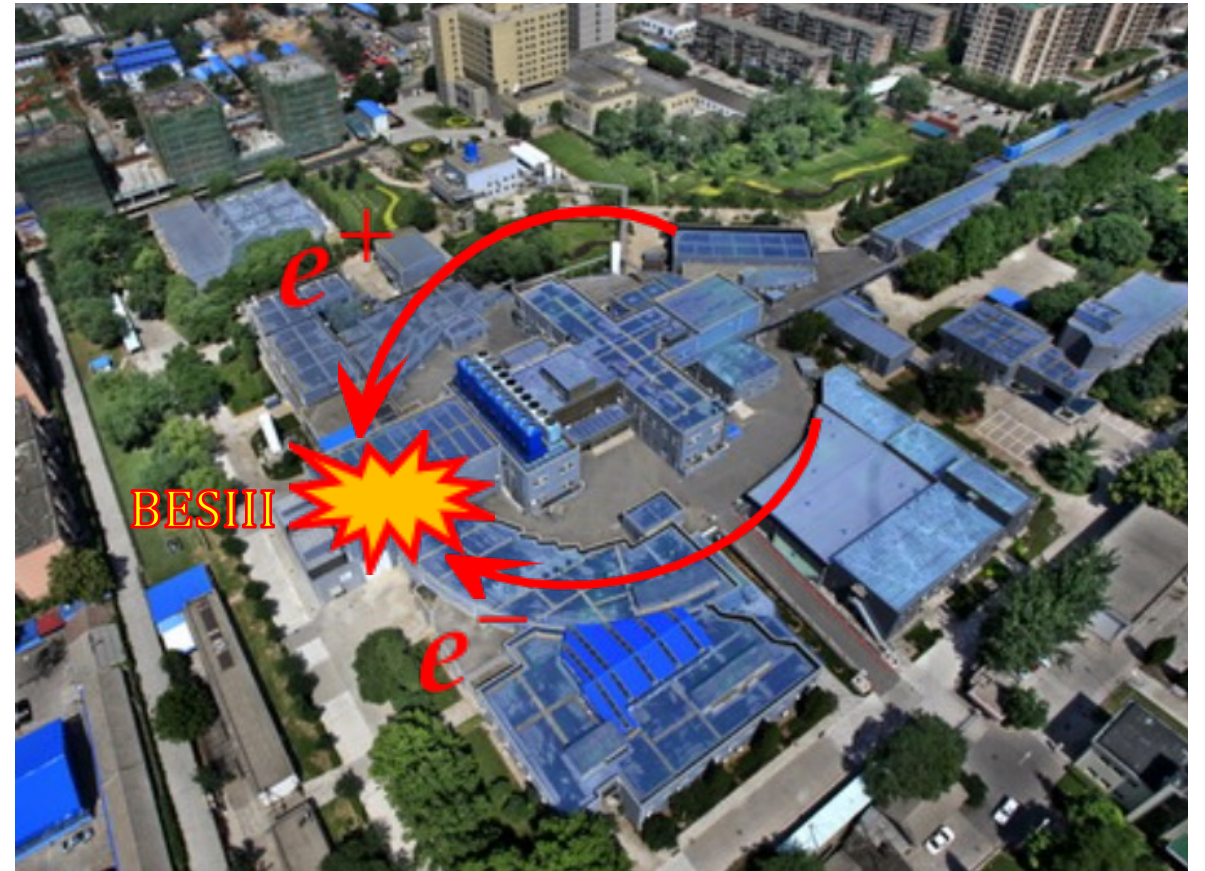
## Operation duration :

- More than 17 years (2009 ~ 2024)
- BEPC and inner tracker of BESIII were updated during 2024~2025

## Achievements:

- Largest number of some events in the world:  $J/\psi$ (10B),  $\psi'$ (4B),...
- >840 papers (>150 at PRL)

BEPCII: Beijing Electron-Positron Collider II



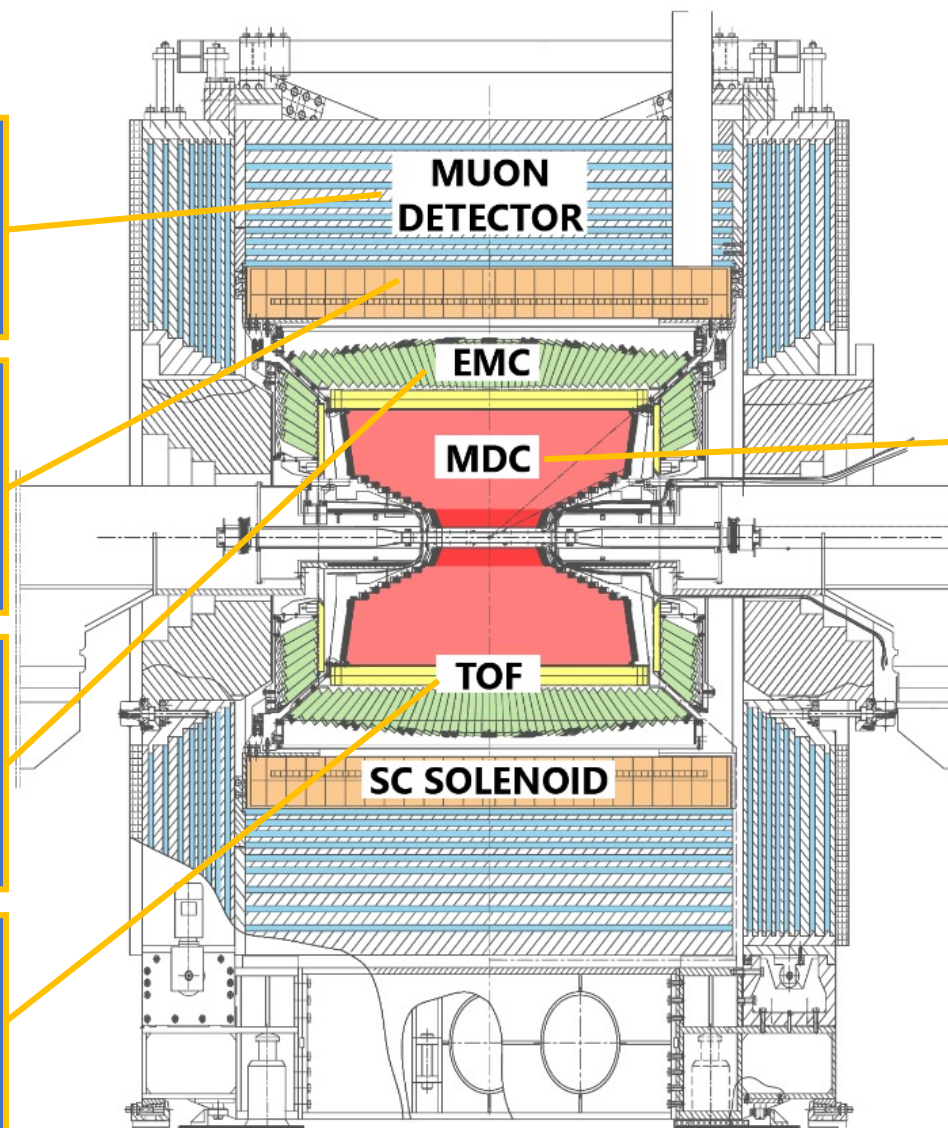
# BESIII layout before update

**Muon detector (MUC):**  
RPC-based

**Superconducting solenoid magnet(SSM) :**  
1 T magnetic field

**Electromagnetic calorimeter (EMC):**  
CsI(Tl) crystal

**Time of Flight (TOF):**  
time resolution <100 ps

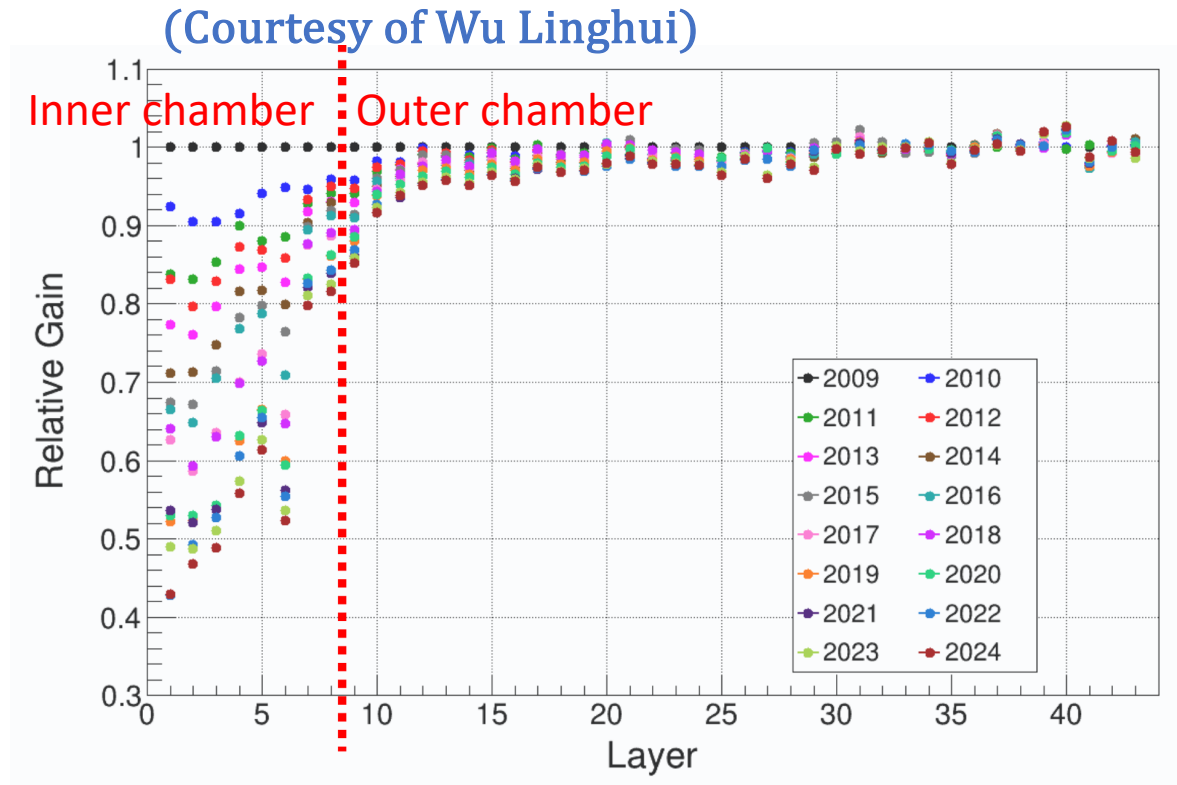


**Multilayer Drift Chamber(MDC) :**  
the Central Tracker on BESIII

- Consist of
  - Inner chamber  
( 8 layers of stereo wires)
  - Outer chamber  
( 12 axial, 16 stereo, 7 axial )
- Spatial resolution  $\sim 130 \mu\text{m}$
- Momentum resolution  
 $\sim 0.5\% @ 1 \text{ GeV}/c$
- dE/dx information for particle identification

# Inner Tracker Update at BESIII

Motivation: Aging effect of inner chamber of MDC



The effective gas gain dropped over the years.

(by  $>50\%$  for the first layer cells until 2024)