Status of CGEM μTPC Calibration and Reconstruction

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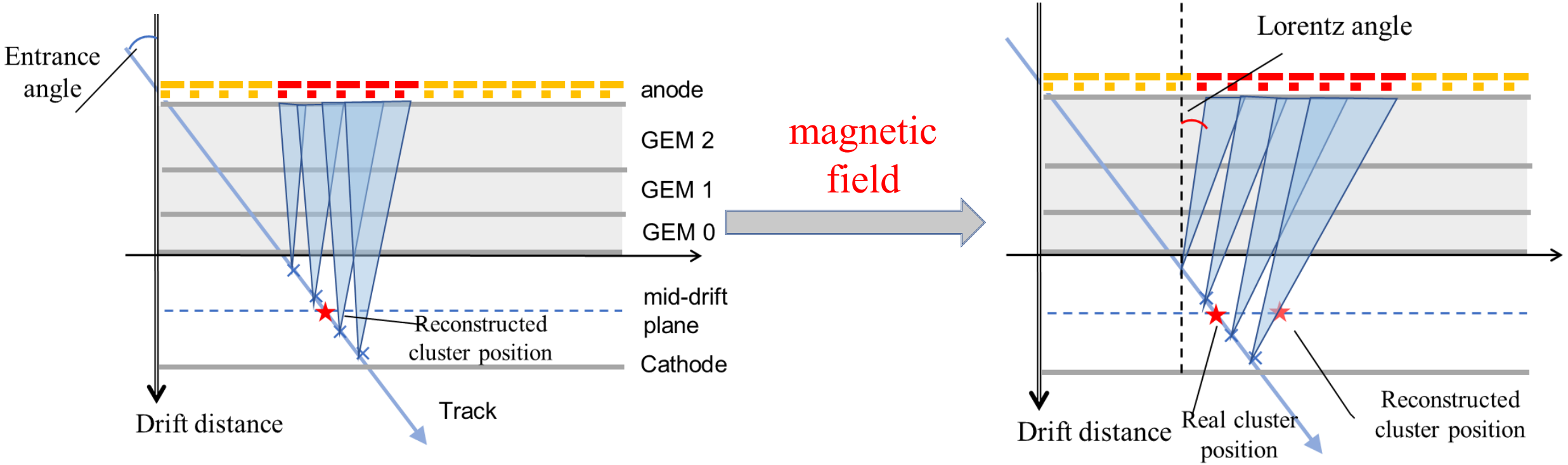
At Yantai University

Outline

- Introduction
- Cosmic ray MC
  - Status of Calibration
  - Spatial Residuals relative to MC Truth
- Collision Data
  - Status of Calibration
  - Spatial Residuals relative to ODC Track
- Summary and Plan

Introduction —— CGEM Cluster Reconstruction



Charge Centroid (CC)

Limitations

The charge distribution is not Gaussian under strong magnetic fields **-> Poor spatial resolution**

Micro-TPC (μTPC)

Approach

- Measure electron drift time
- Reconstruction ionization track

->Robust at B-field & large angle

Calibration

Prerequisite

- Drift Time
- Drift Velocity
- Lorentz angle

->Enable precise result

Introduction —— Calibration Plan

Cosmic ray calibration 2025~2026

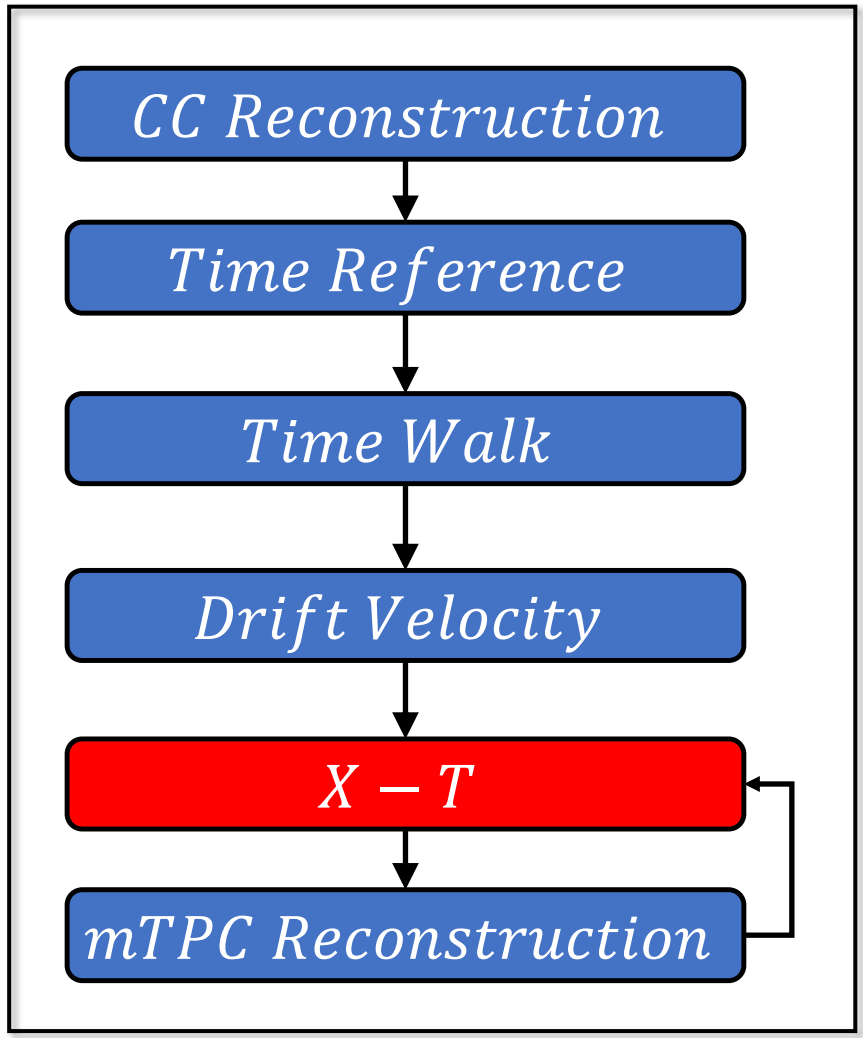
- No magnetic field, Before installing into BESIII
- Improve understanding of detector and electronics response
- Enhance comprehension of factors influencing time resolution

Collision calibration 2026~

- With magnetic field, After installing into BESIII
- Ensure the normal reconstruction of collision data

Cosmic Ray(w/o B) —— Status of calibration

Calibration Process



✗ Cosmic Ray Data

- Entanglement of Multiple effects, difficult to distinguish
- For calibrating the ~10^4 strips, the statistics are insufficient

✓ Cosmic Ray MC

- The effects are relatively clear and can be studied separately
- Can generate enough MC samples

$$Drfit\ Time: \quad T_{drift} = T - time\ refernce\ -\ time\ walk$$

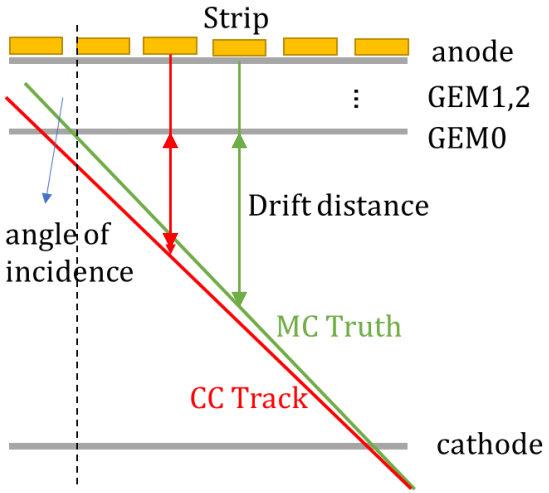
$$Drift\ velocity: \quad V_{drift} = \frac{Width_{drift}}{T_{fall} - T_{rise}}$$

- The entire process of the calibration has been basically completed, and the code is ready
- Obtained corrections for time reference, time walk, drift velocity and the **X–T relation**

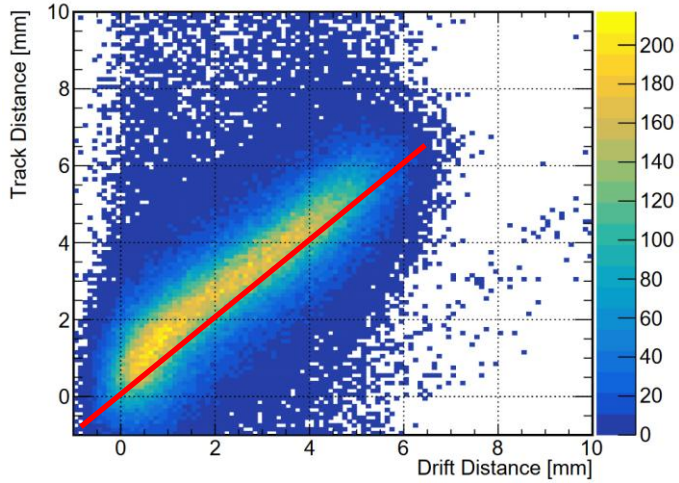
More details at 2026-3 BESIII

Cosmic Ray(w/o B)—— XT correction

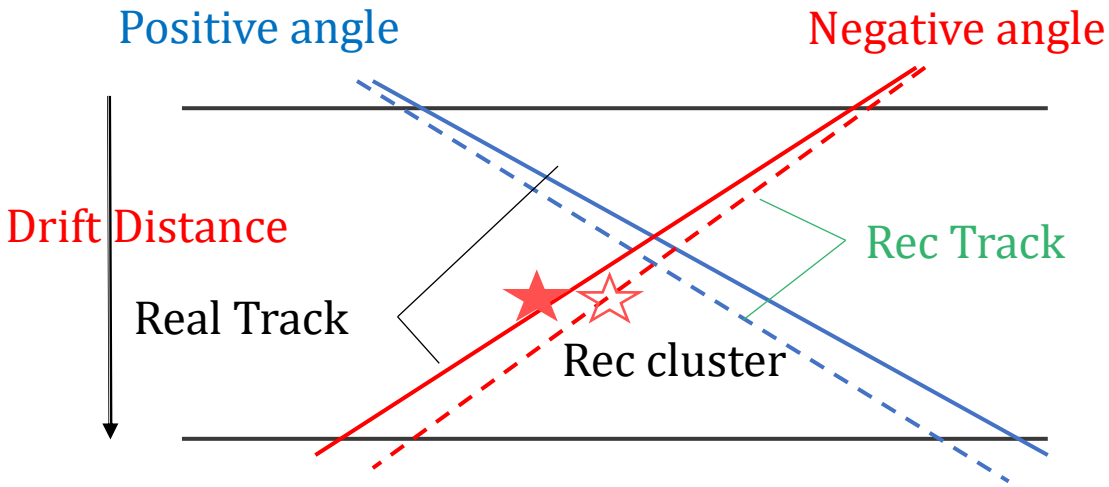
XT: Measured time(Replaced by drift distance) versus distance from the strip to the track is not perfectly linear, which can cause offset in the reconstructed cluster

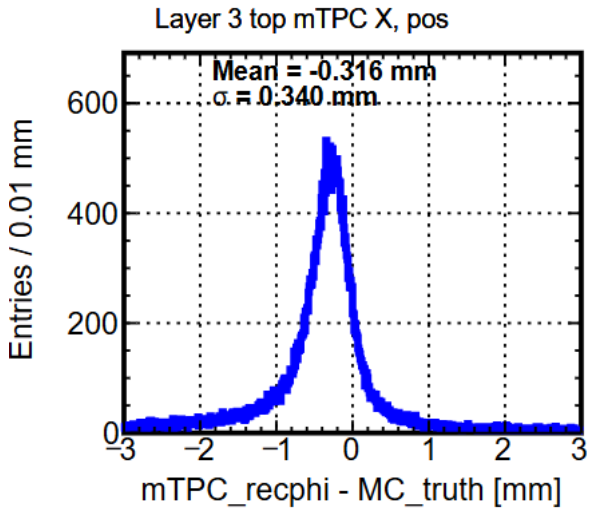


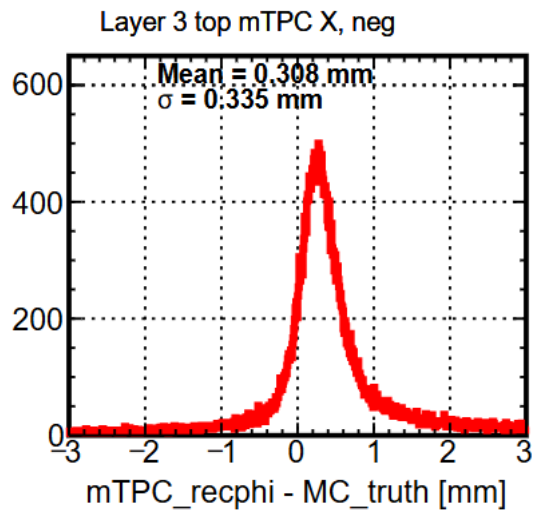
Incidence angle 24~30 [Deg]



Drift distance: drift time × drift velocity
Track distance: Distance from the Strip along the radial direction to the track in the drift region





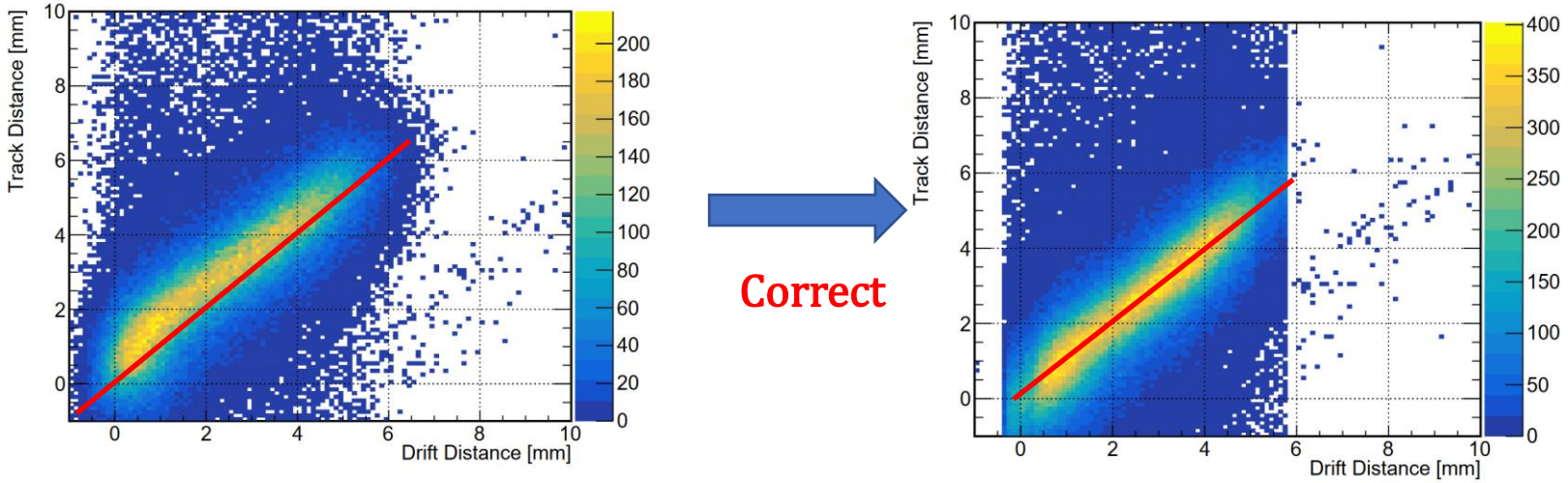


Cosmic Ray(w/o B)—— XT correction

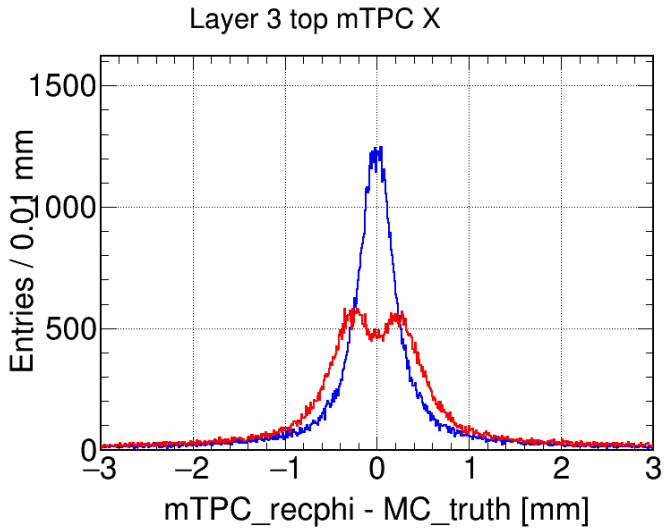
Calibration:

- Gaussian fitting of track distance distribution
- Polynomial fitting of Gaussian fitted center values to obtain a correction function for drift distance

Incidence angle 24~30 [Deg]



- ✓ The relationship between drift distance and track distance becomes linear
- ✓ Unbiased cluster reconstruction



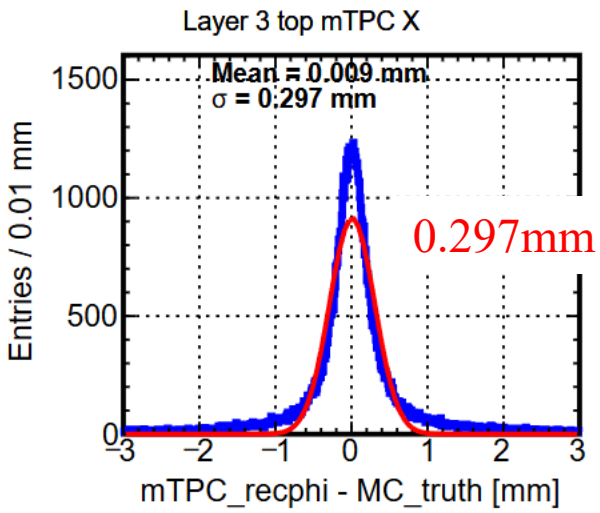
Rec cluster

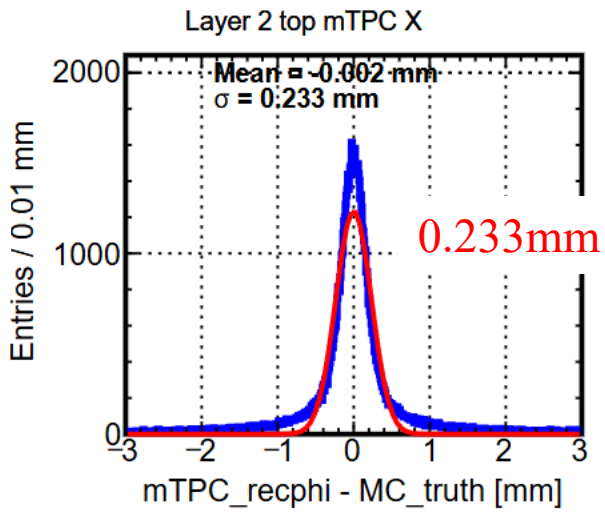
— before calibration

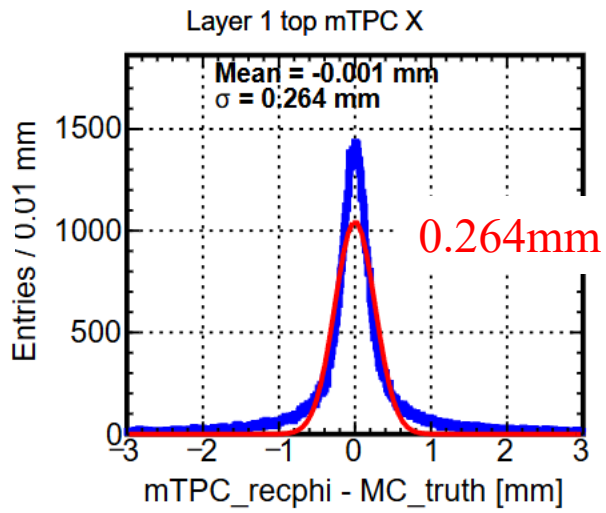
— after calibration

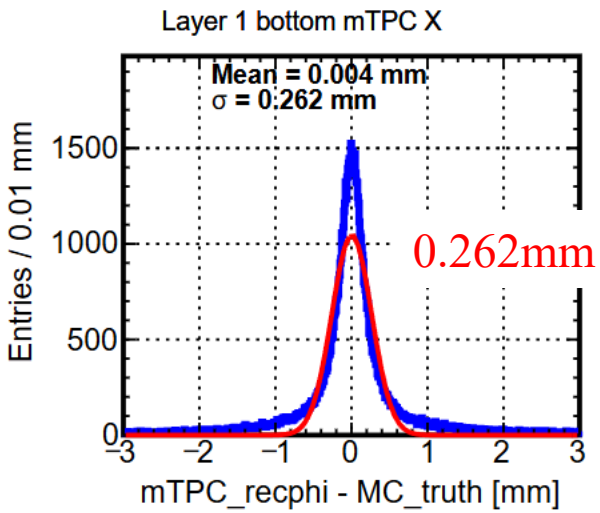
Cosmic Ray(w/o B)—— Residual

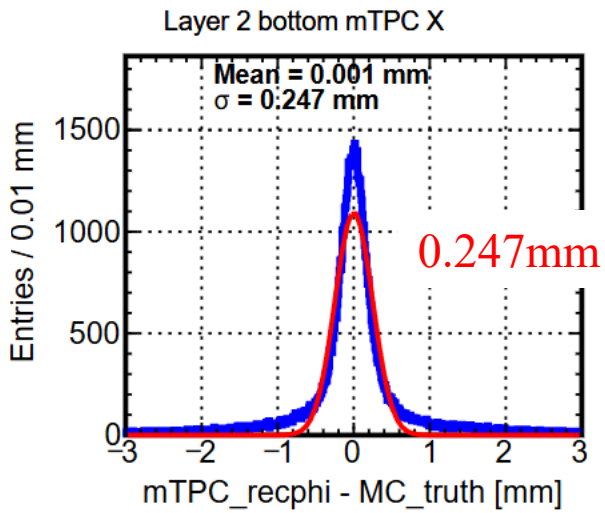
At the cluster-reconstruction level, the residuals relative to MC Truth < 0.3mm

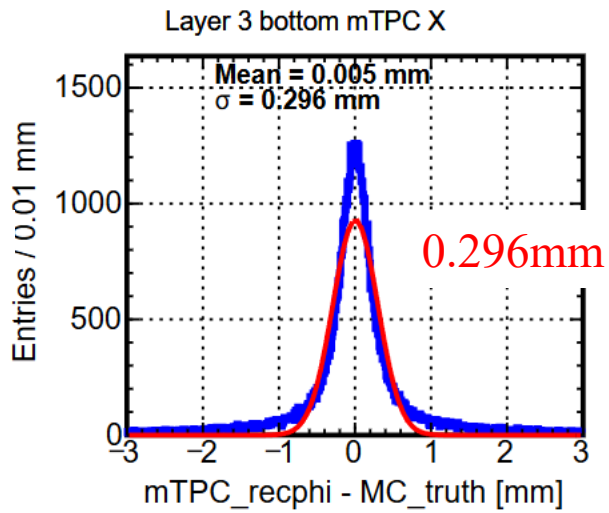






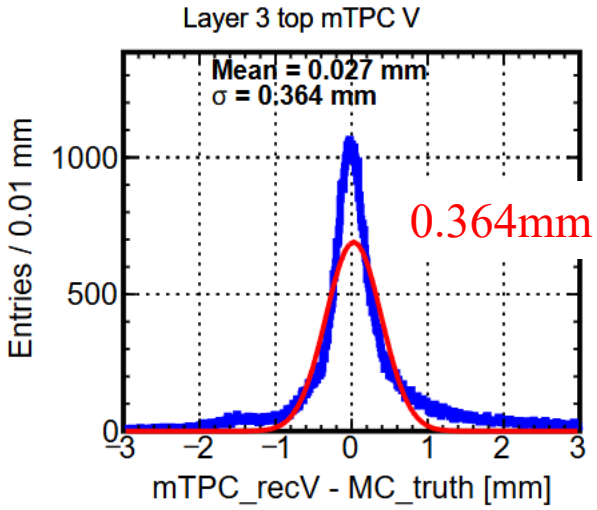


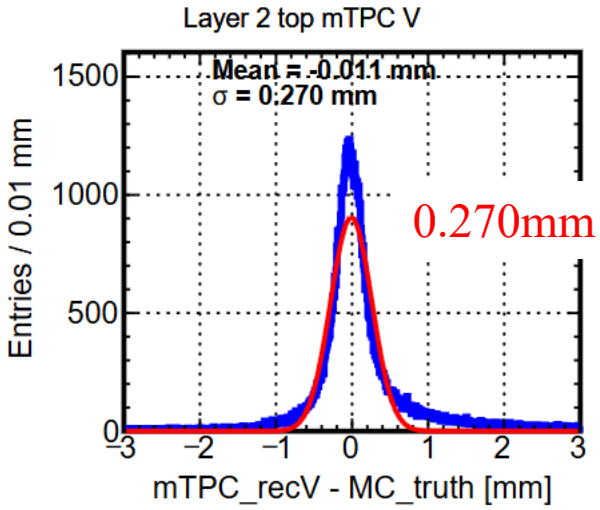


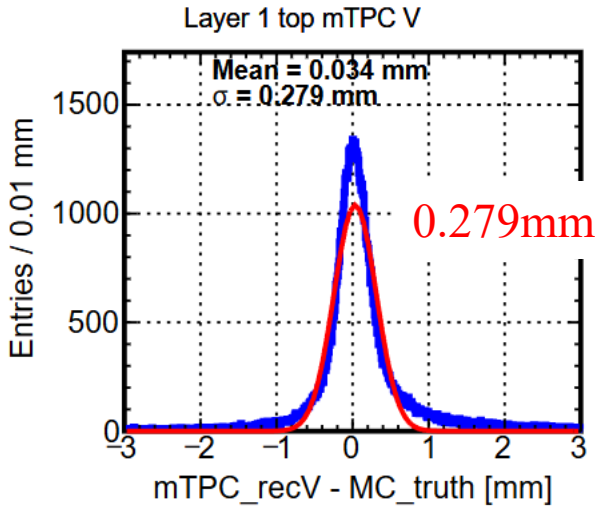


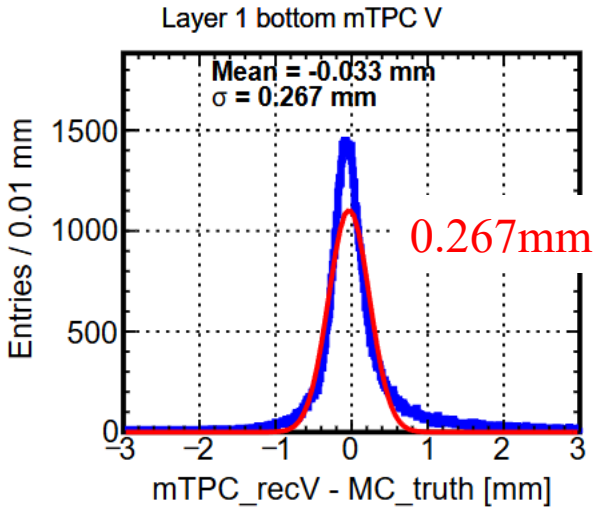
Cosmic Ray(w/o B)—— Residual

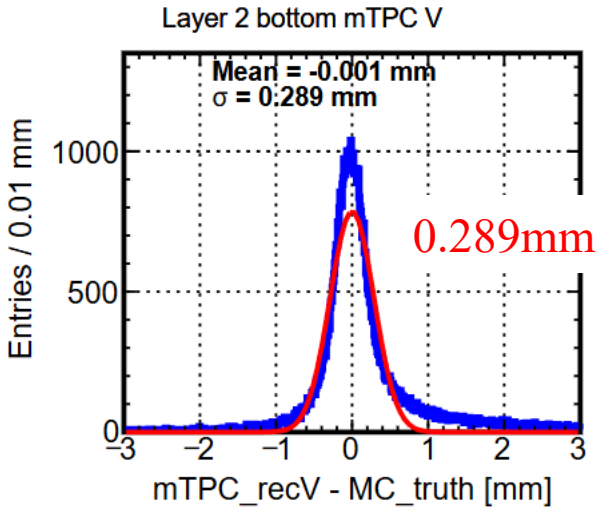
At the cluster-reconstruction level, the residuals relative to MC Truth ~ 0.3mm

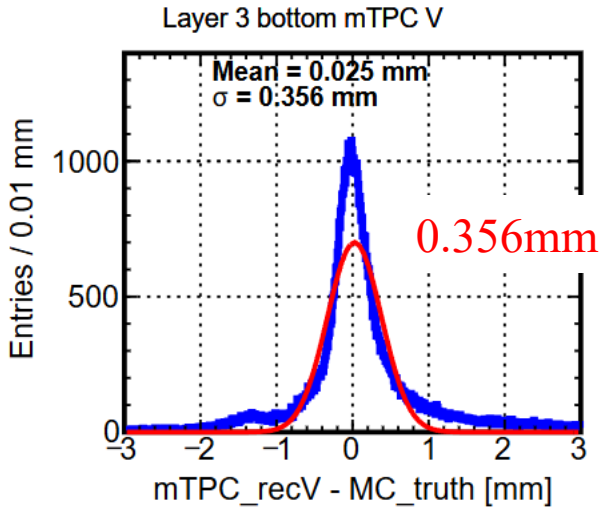










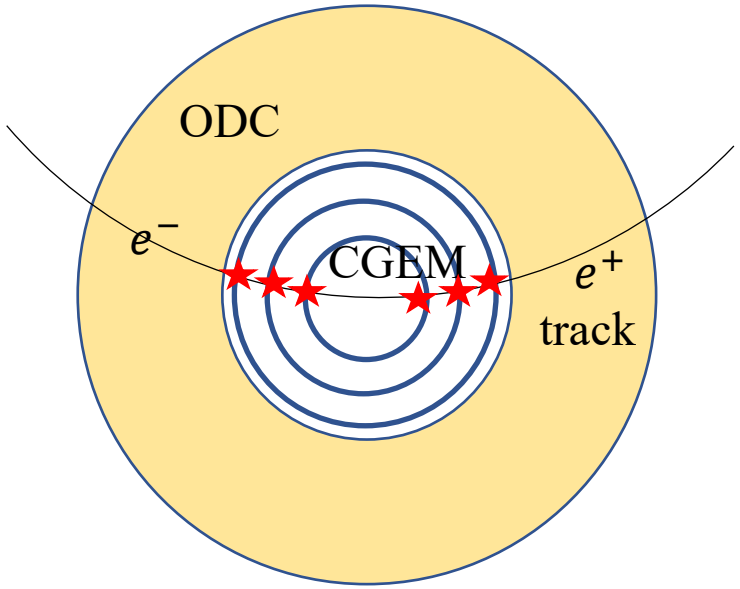


Collision Data —— Data Sample

Collision Data: Bhabha event **25.07.03~07.26**

- HV and threshold settings remain relatively stable
- Sufficient amount of data
- Extrapolate ODC tracks inward to the CGEM and select the cluster closest to each track
- High saturation rate

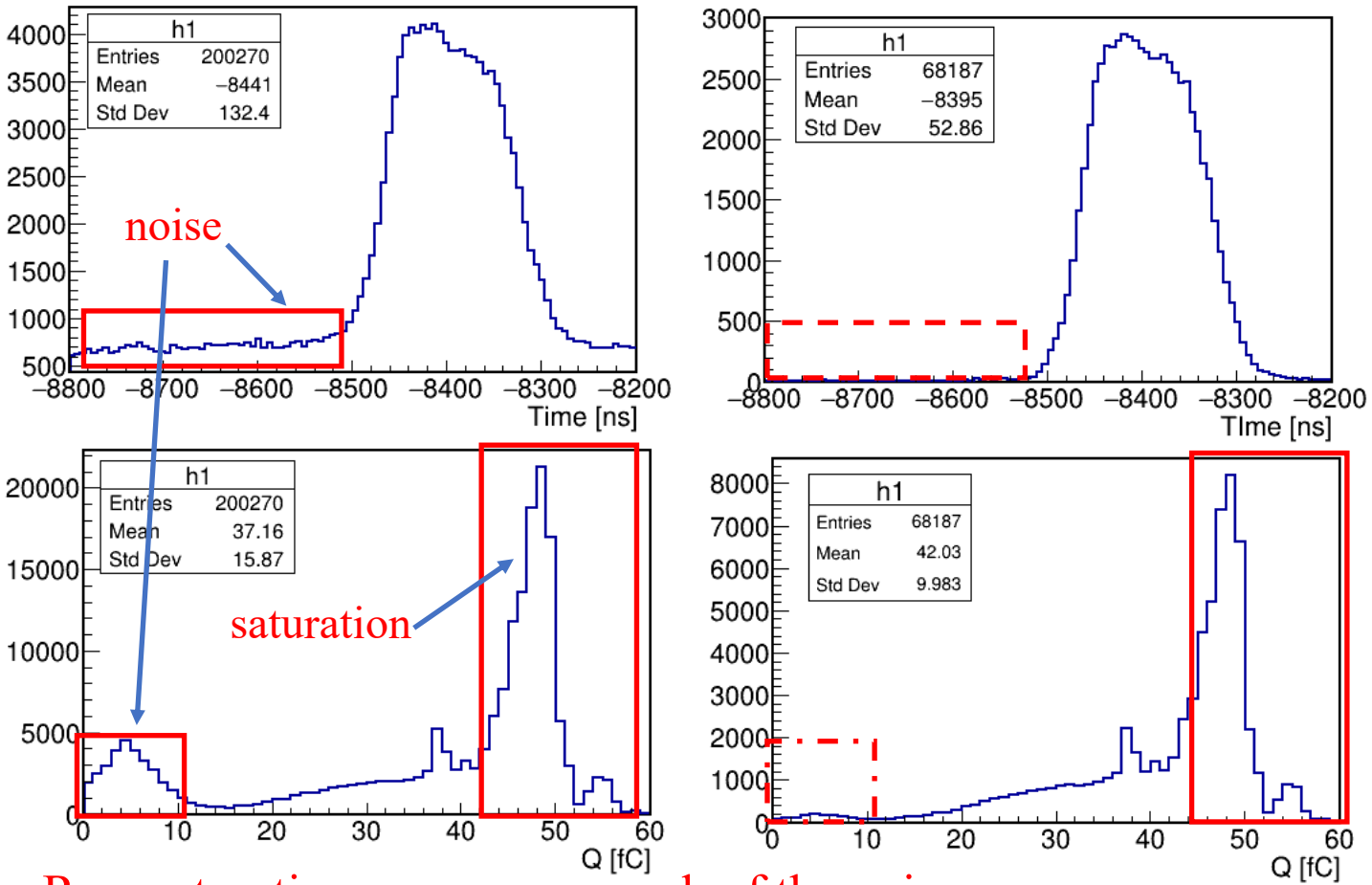
Bhabha event



Layer 1 Sheet 0 X Run 86902 25.07.24

w/o Rec/Select

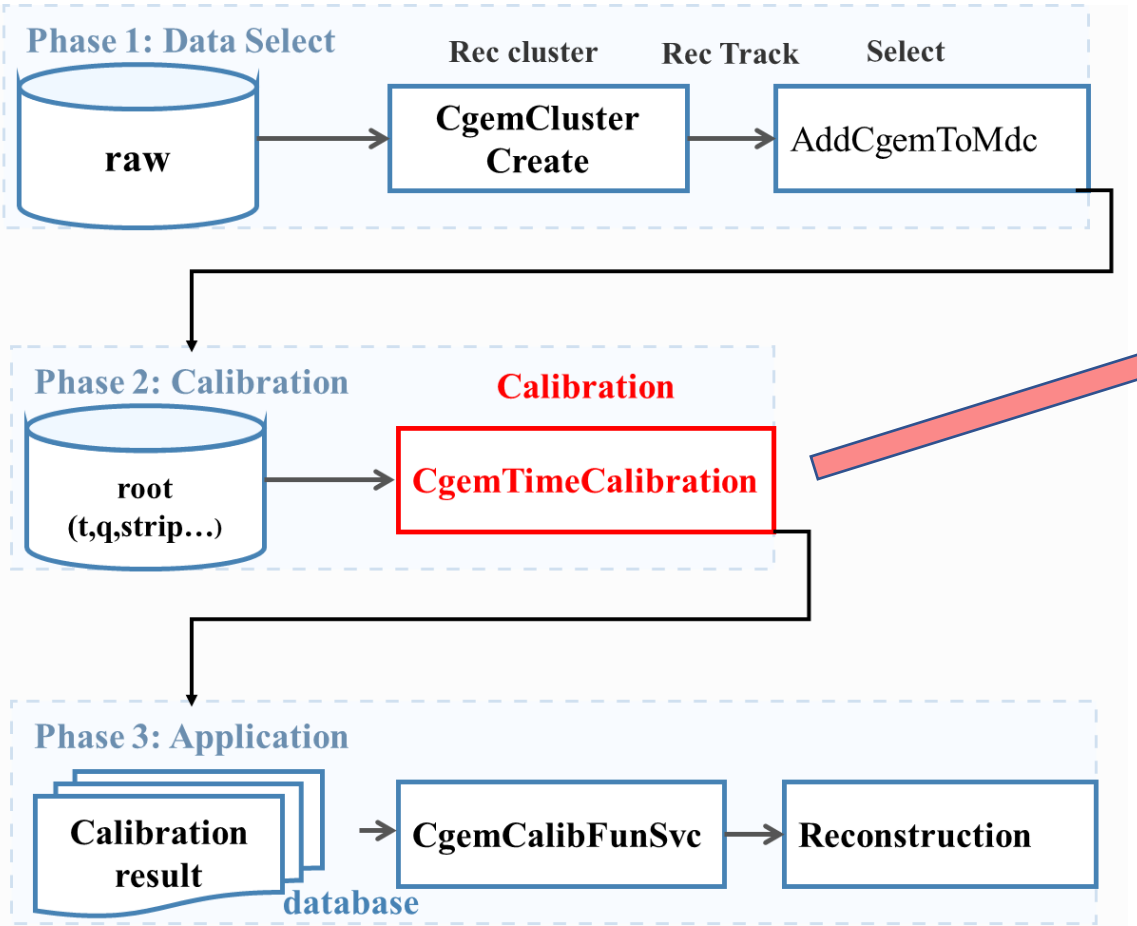
w Rec/Select

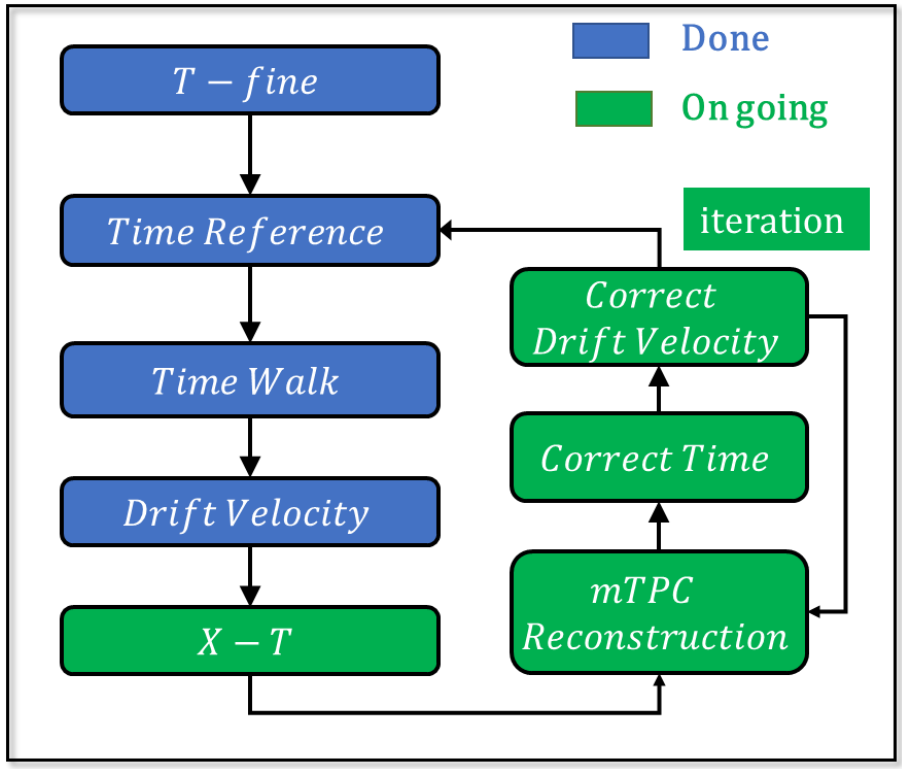


Reconstruction suppresses much of the noise, but the charge saturation ratio is still very high

Collision Data —— Status of Calibration

Algorithm Flow

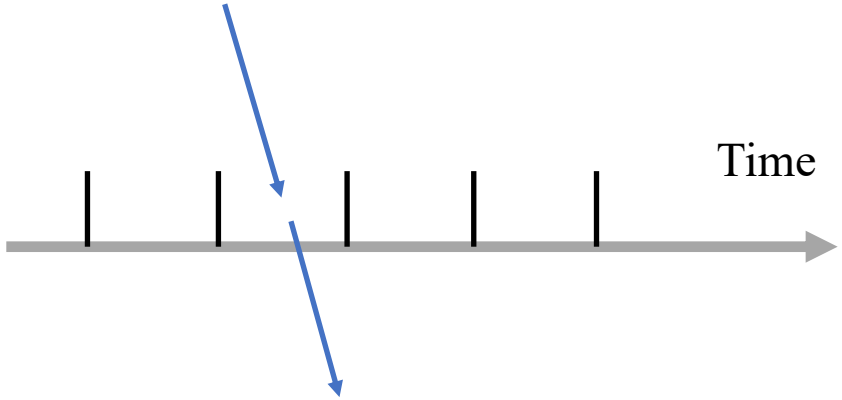




- ✓ Algorithm Basic Implementation
- ✓ Preliminary Calibration Results Obtained
- ☐ Further Improvements to Be Made(XT, iteration)

Collision Data —— T-fine

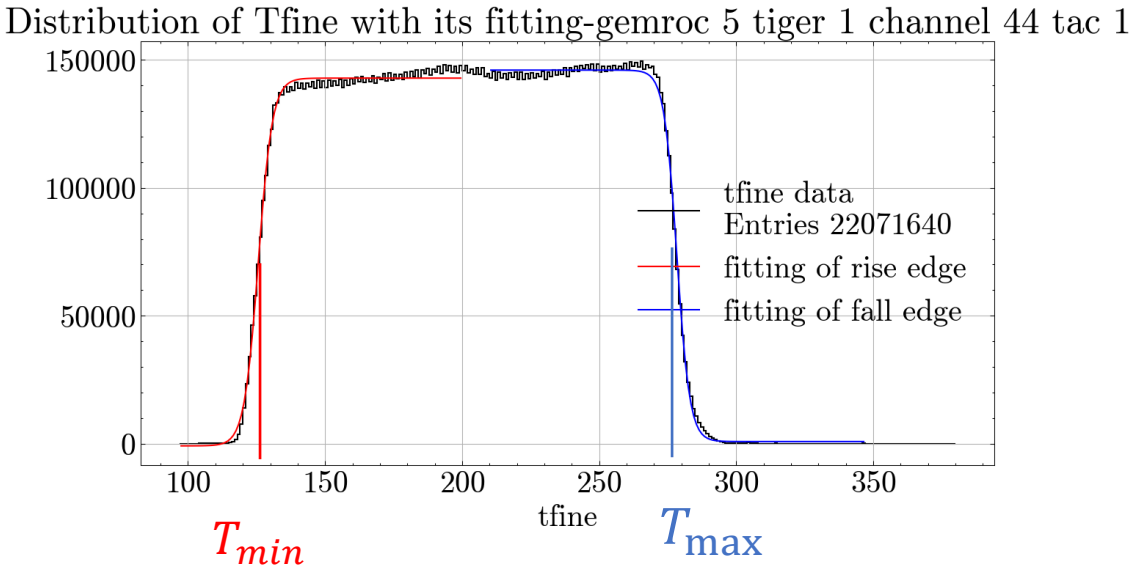
T-fine: Reduce the time accuracy error of electronic readout, **Coarse time (~6 ns)** **T-fine (40~50 ps)**



- Due to electronic design reasons, it is not possible to directly determine the matching relationship between coarse time and fine time, need to use the following formula to calculate

$$Time = Tcoarse * Coarse\ time - Time\ correction$$

$$Time\ correction = (Tfine - T_{min}) * \frac{Coarse\ time}{T_{max} - T_{min}}$$

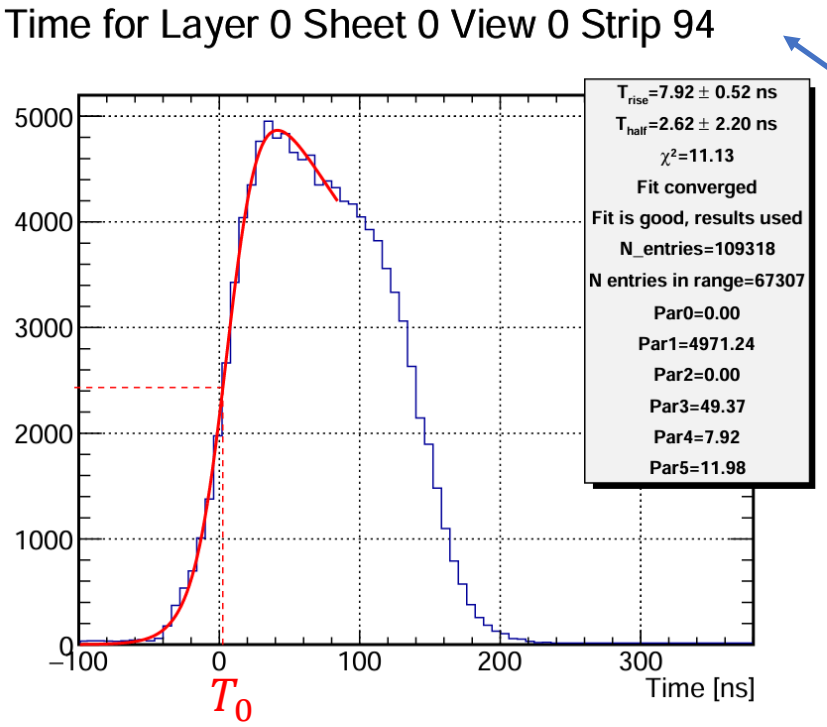


- T-Fine calibration does not depend on threshold or noise level
- Used collision data before reconstruction
- The final time resolution is influenced by multiple factors, and this is just one of them

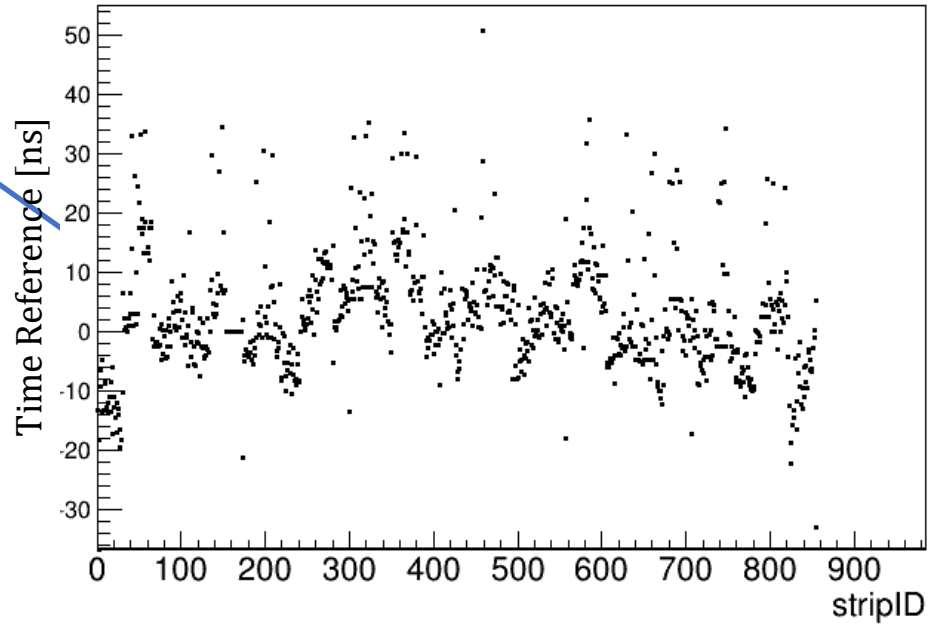
Collision Data —— Time Reference

Time Reference： Determine the time starting point of the electronic channel

Time Reference calibration



Time Reference calibration result

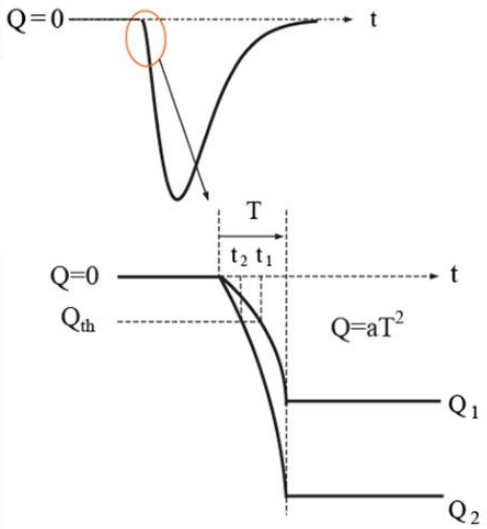


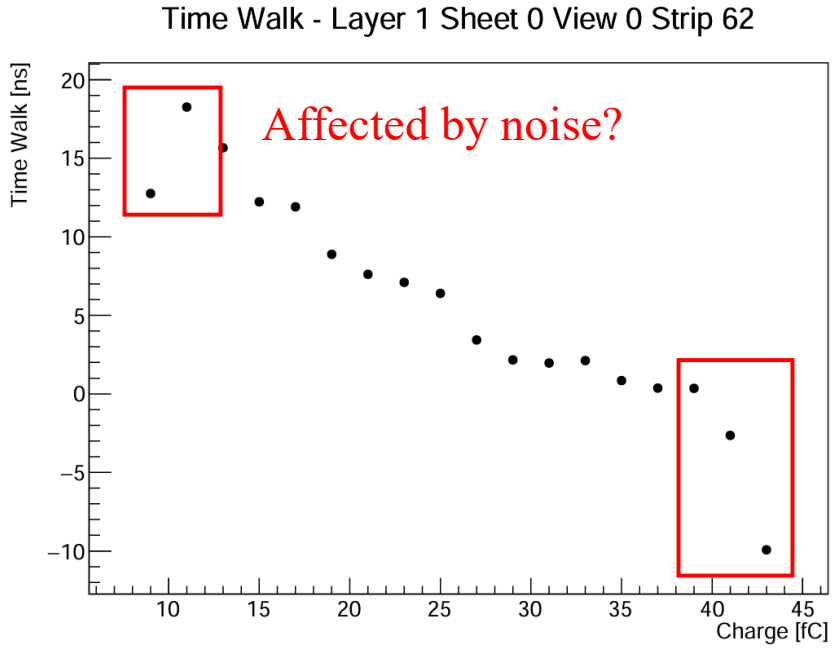
For strips with limited data, the average of multiple strips is used

Collision Data —— Time Walk

Time Walk:

- **Threshold-crossing time fluctuation caused by different signal amplitudes**





For each strip, divide into charge intervals and fit the rising edge of the time distribution

Affected by Saturation

The time walk effect in CGEM is significantly

Collision Data —— Drift Velocity

Drift Velocity： Changes in the drift velocity of ionized electrons caused by uneven electric fields or geometric deformations

Calculation method for initial drift velocity

GEM foil T_{min}

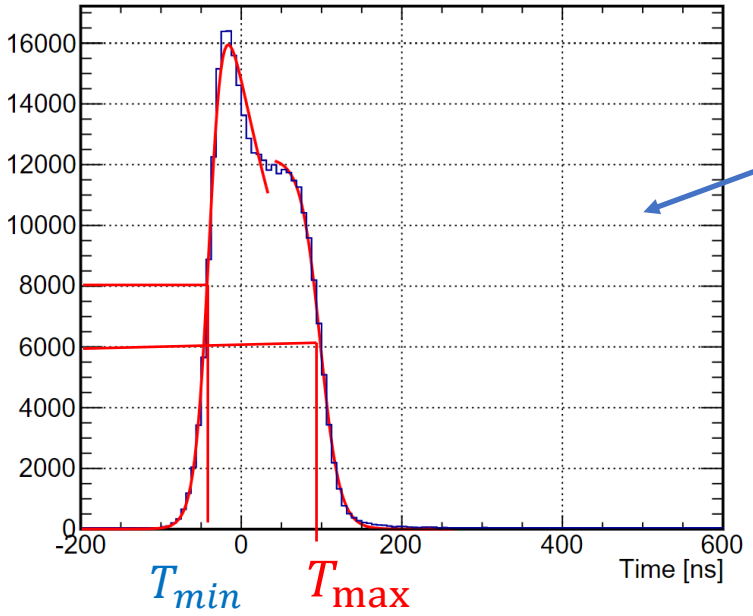
$$V_{drift} = \frac{\sim 5mm}{T_{max} - T_{min}}$$

Drift region width ~5mm

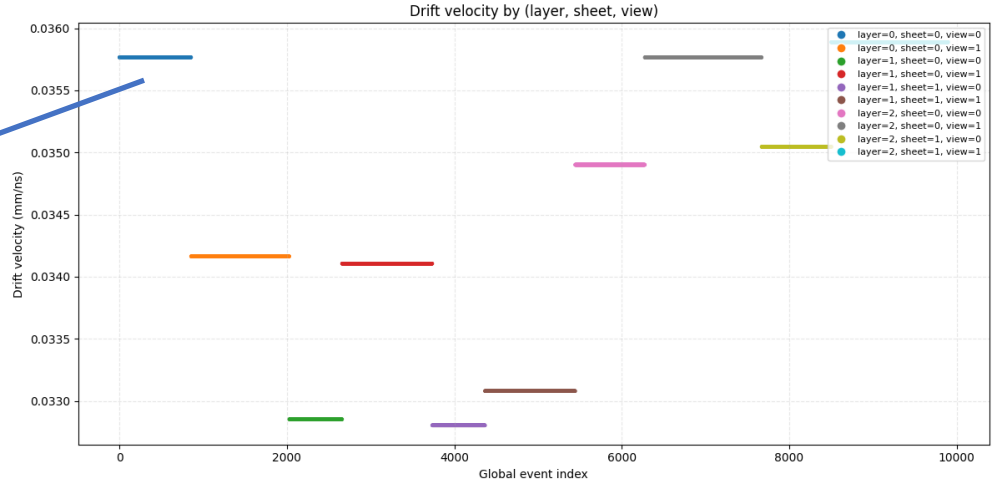
T_{max}

cathode

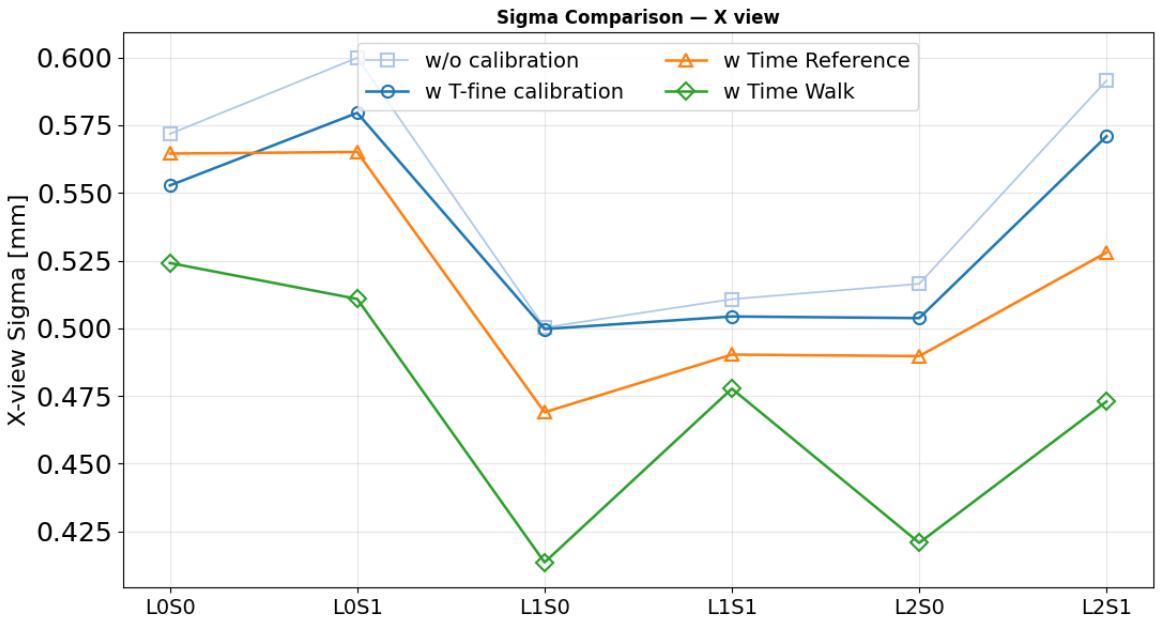
Layer 1 sheet0 view X

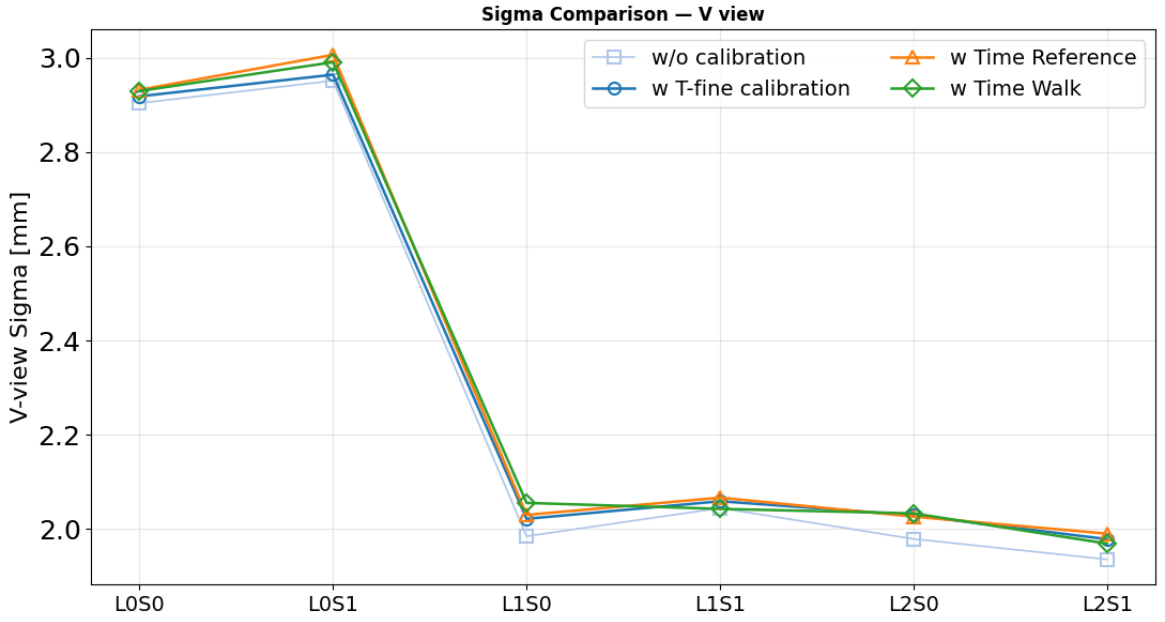


Drift velocity of each sheet



Collision Data —— Residual





This may be influenced by the poor Z-direction resolution of the ODC and the CV-direction cluster reconstruction algorithm

Comparison of the difference between the mTPC reconstructed clusters and the ODC reconstructed tracks(without CGEM) extrapolated to the CGEM

Summary and Plan

Cosmic Ray Monte Carlo Study :

- Obtained a comprehensive understanding of detector response and calibration procedures
- The calibration workflow was successfully run, producing the calibration results
- At the cluster-reconstruction level, the residuals relative to MC Truth are about 0.3mm

Collision data:

- Obtained preliminary calibration results for T-fine, Time Reference, Time Walk and drift velocity

Plan:

- Continue improving the reconstruction/calibration results through X-T and iteration
- Improve the calibration algorithm and calibration result calling algorithm

Thank you for your attention!

Back up

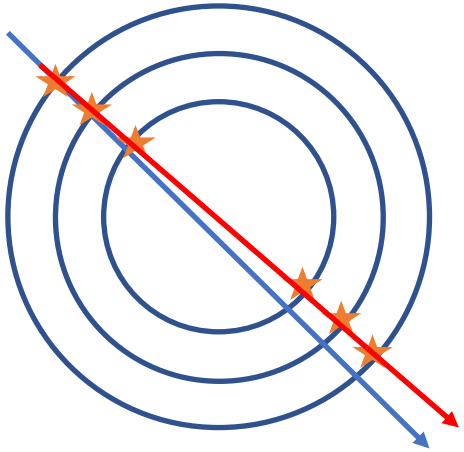
MC Truth

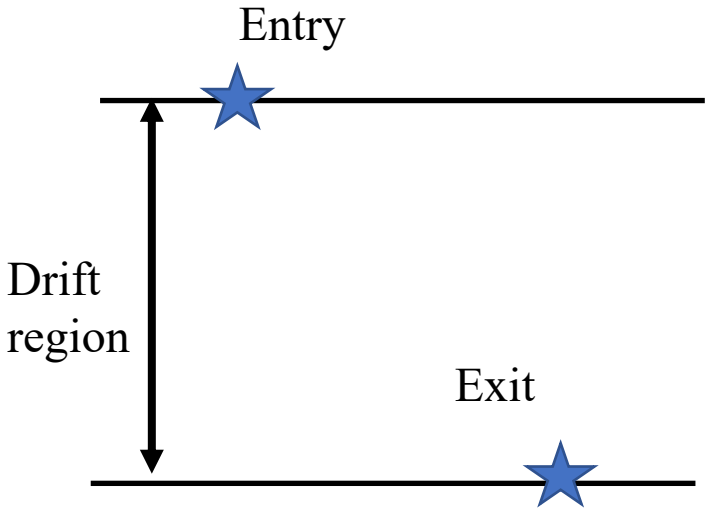
Calculate the intersection point between each layer and the plane in the drift region:

1. Using the cosmic ray track parameters of MC truth to calculate

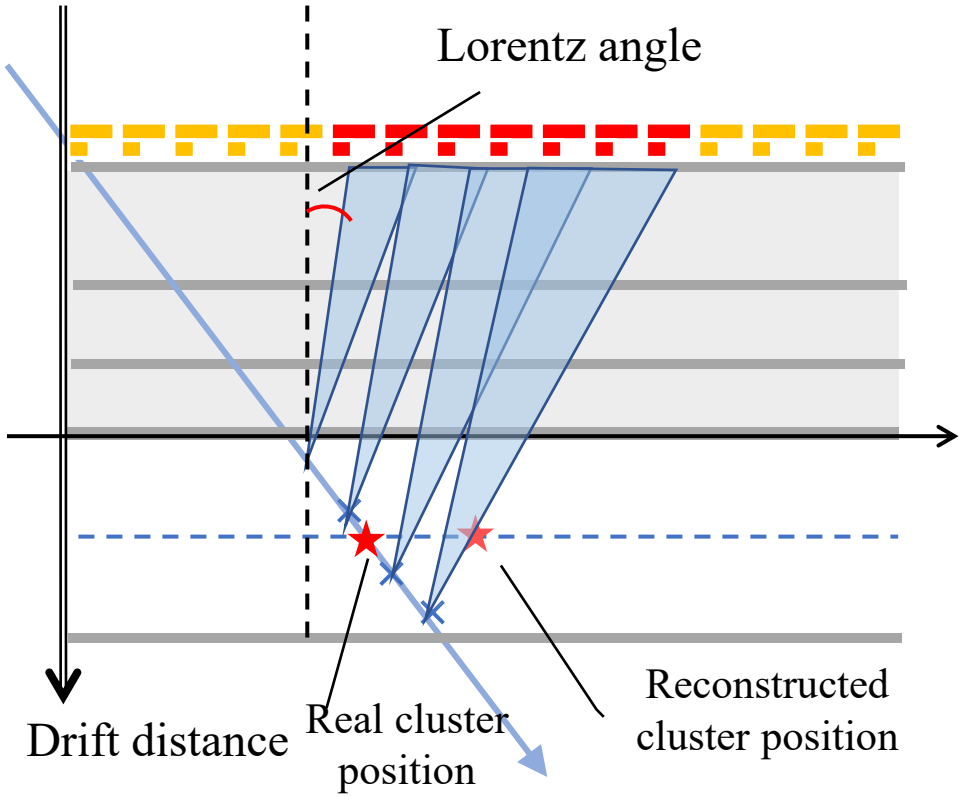
   The trajectory parameters are calculated based on the momentum at the time of creation. The lower the layer, the greater the trajectory displacement

2. Use the recorded cosmic rays at each layer's entry and exit points to calculate the intersection points





Introduction——μTPC



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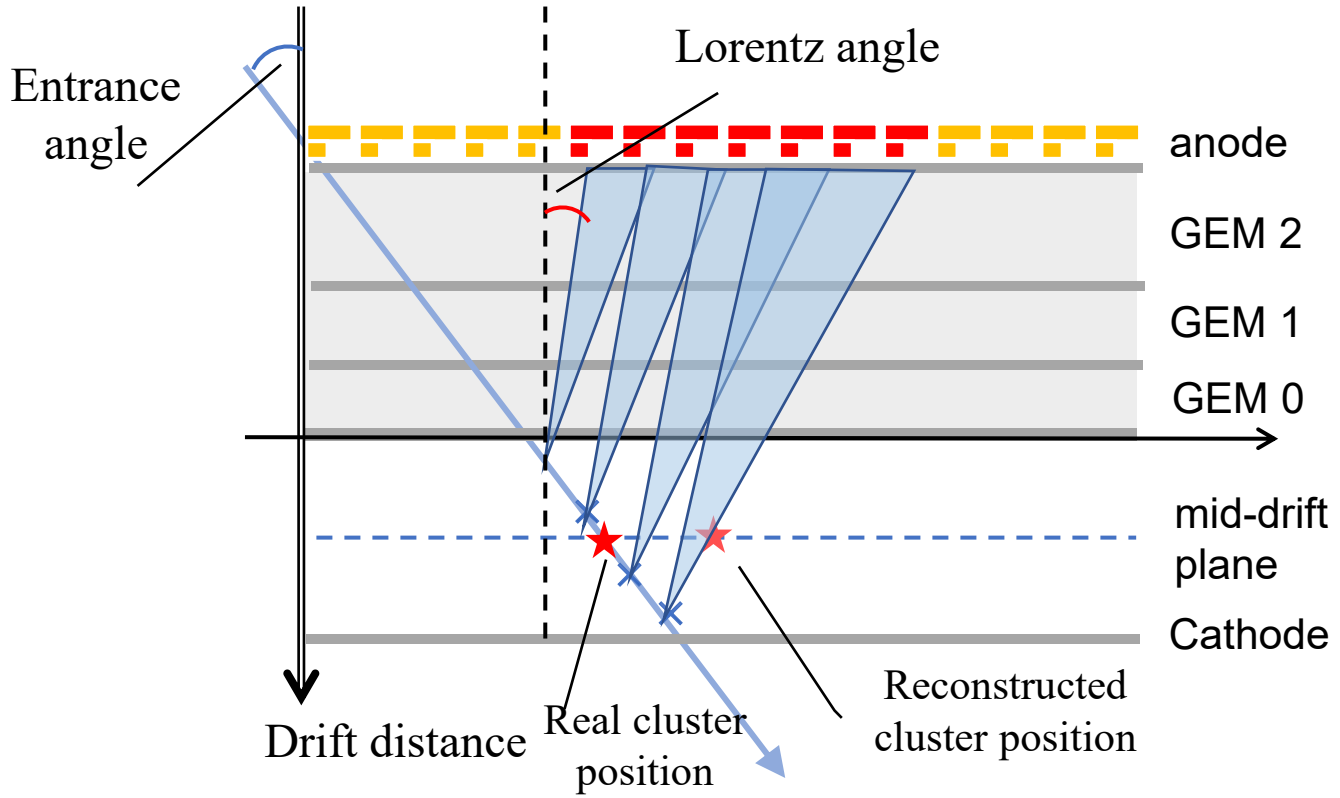

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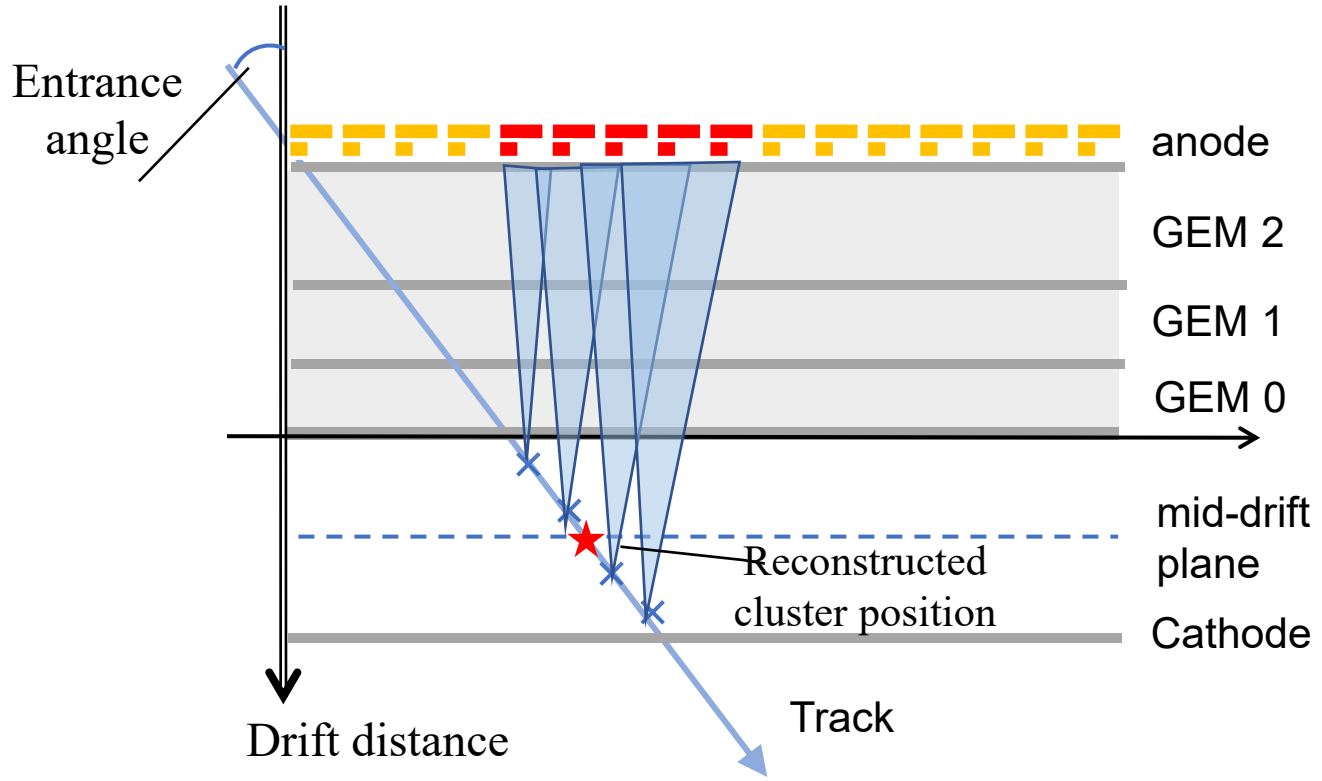
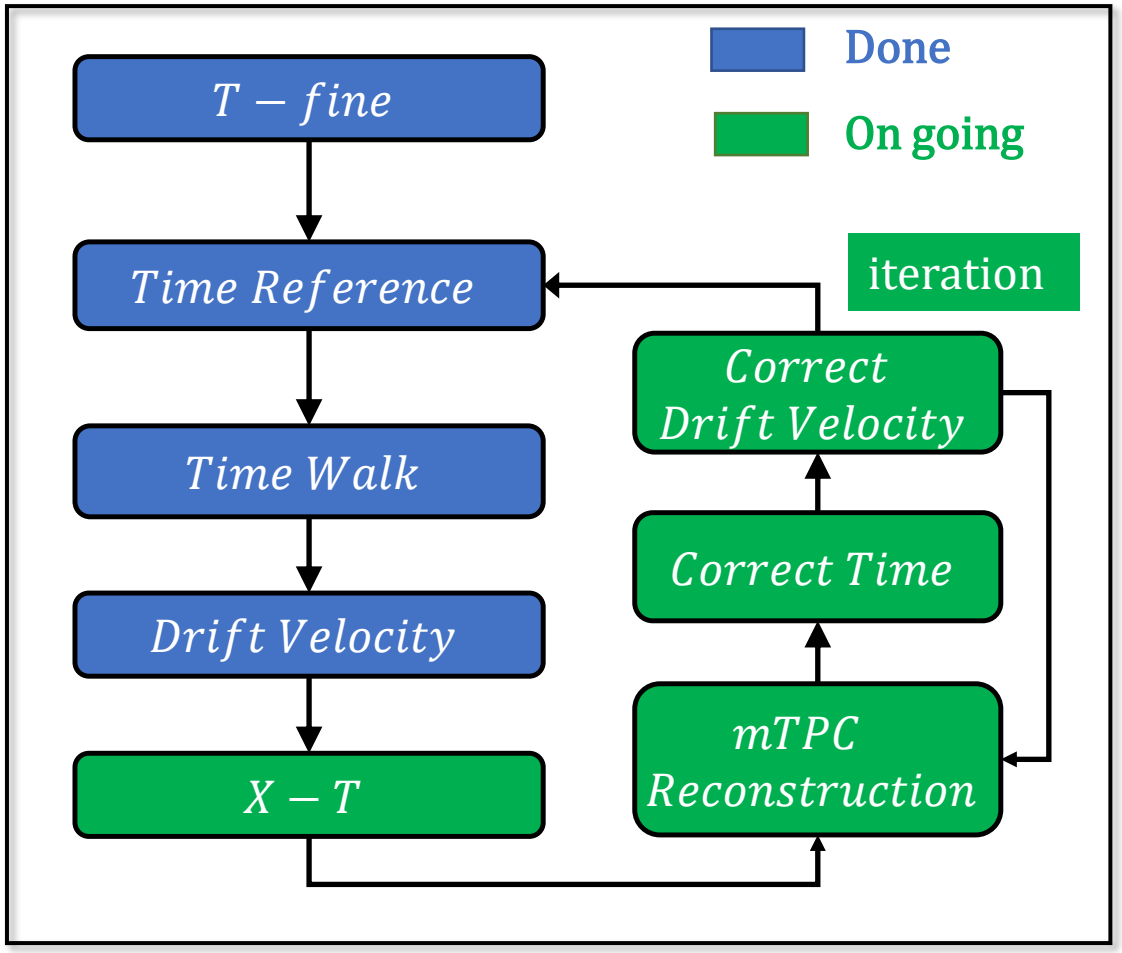


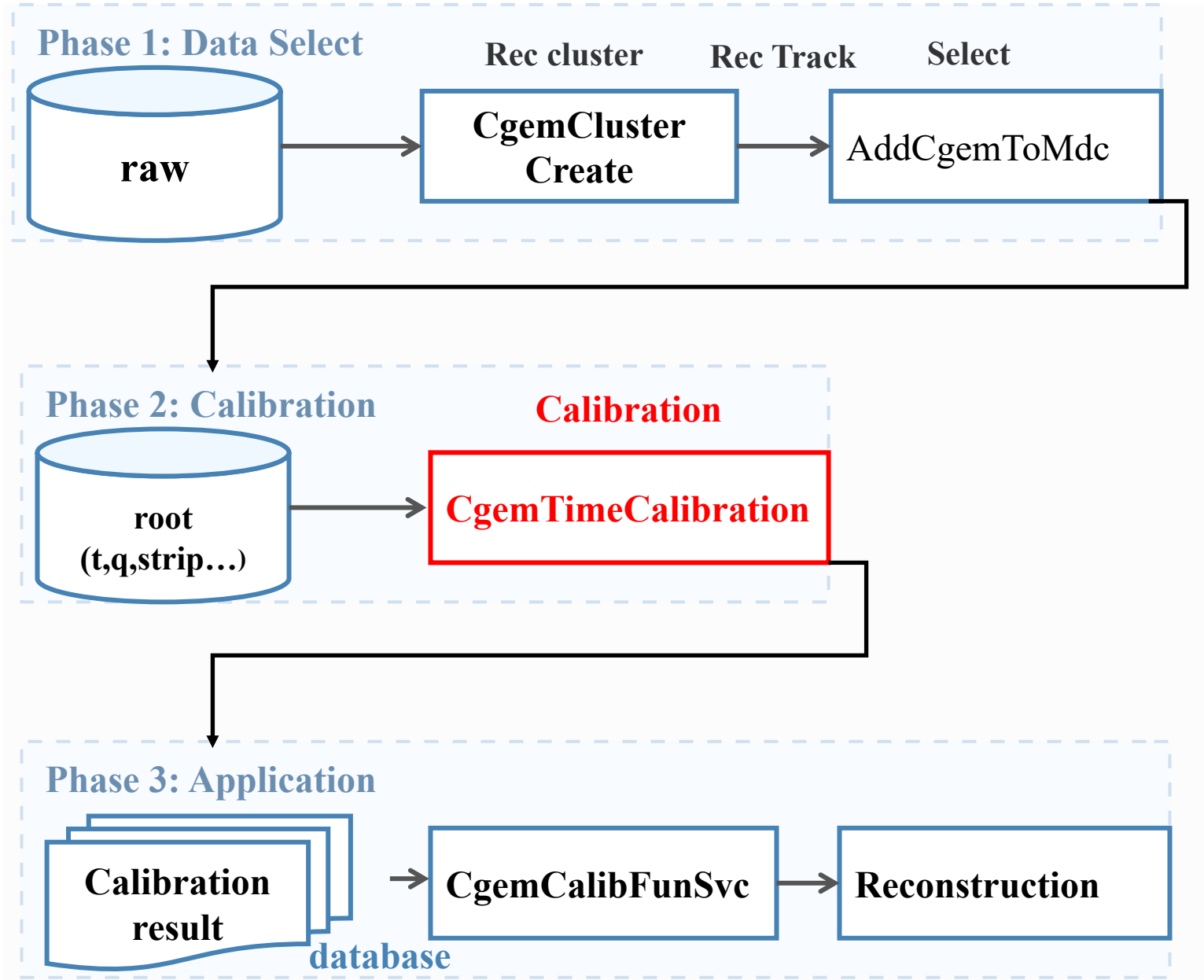
Collision Data —— Status of Calibration

Calibration Process



Algorithm Flow

- Electric-field distortions, high noise level and other effects pose even greater challenges for calibration
- Complete the code for the entire workflow by 2026.6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Rec cluster
Rec Track
Select
raw
CgemCluster Create
AddCgemToMdc
Phase 2: Calibration
Calibration
root (t,q,strip…)
CgemTimeCalibration
Phase 3: Application
Calibration result
database
CgemCalibFunSvc
Reconstruction