Alignment of BESIII Drift Chamber

Linghui Wu

For the BESIII MDC alignment working group

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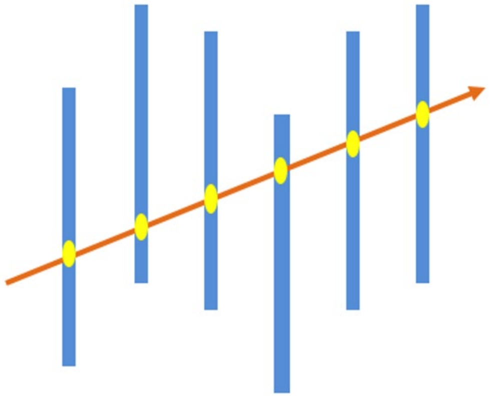
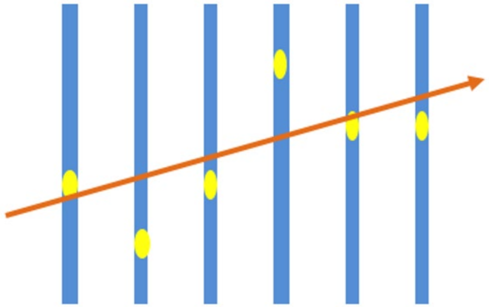
Misalignment of tracker

- In particle physics experiment, tracker is required to provide good spatial resolution for momentum reconstruction
  - ~100 μm with gaseous detectors, like DC or TPC
  - ~10 μm with silicon trackers
- Mechanical imperfection in the construction and assembly of the detector (a few hundred microns) may has significant impact on momentum measurement
- Track-based alignment is essential for track reconstruction

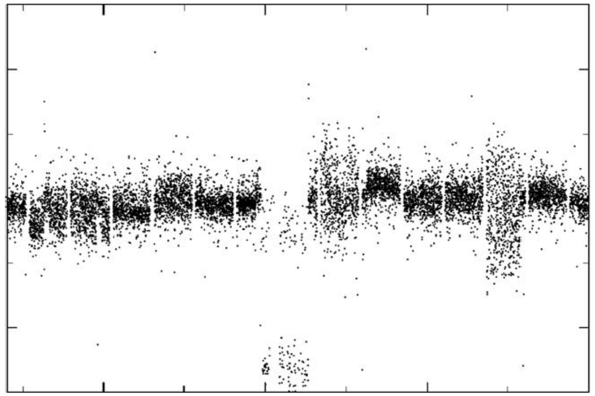
Misaligned detector



Reconstruction with uncorrected detector

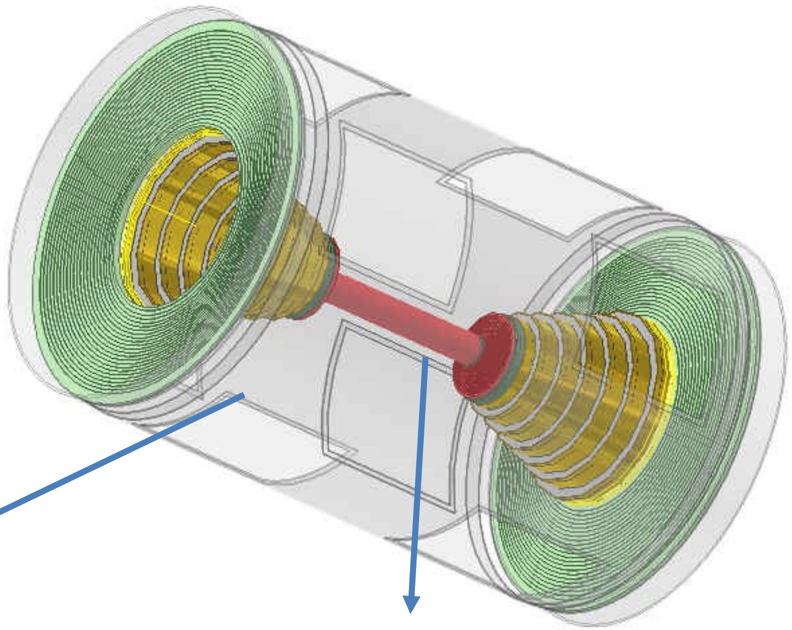


Shift of residuals

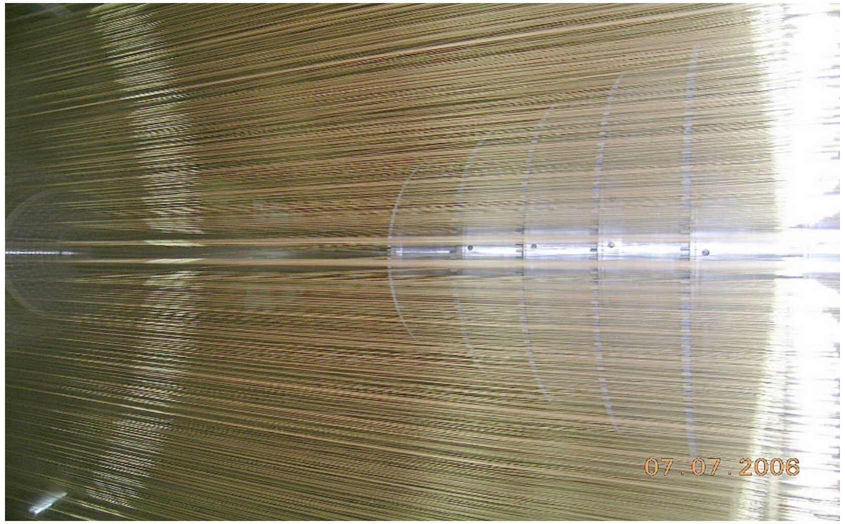


BESIII drift chamber

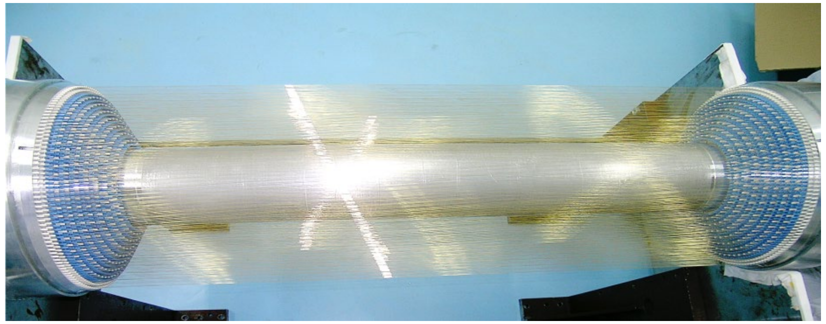
- 6792 cells in 43 cylindrical layers
  - Inner chamber: Layer 1 ~ 8
  - Outer chamber:
    - Layer 9 ~ 20 in six steps
    - Layer 21 ~ 43 fixed at big out endplates



Outer chamber



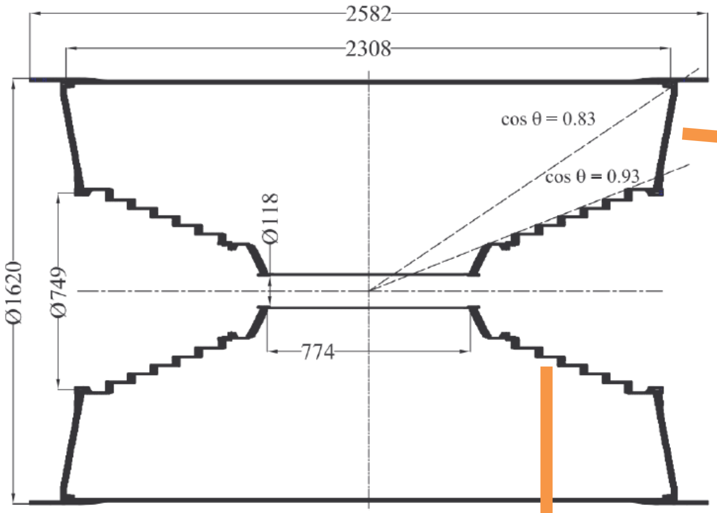
Inner chamber



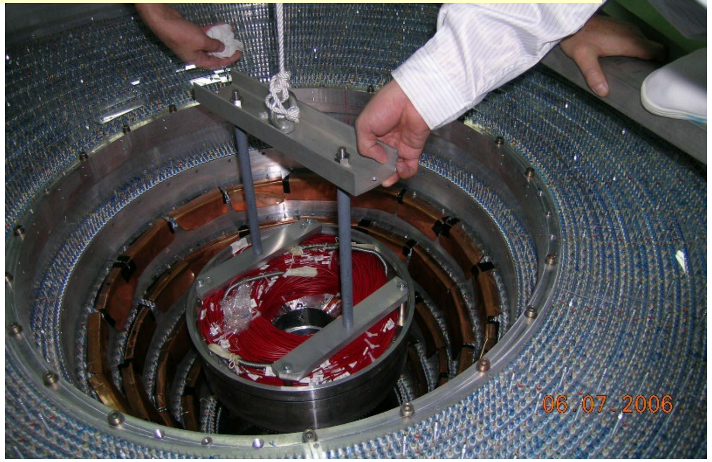
Sources of Misalignment

- Mechanical imperfection in assembly of endplates
  - 16 components
    - Inner section, 6 steps and outer section of both ends
- Single wire displacement

Misalignment from assembly of endplates



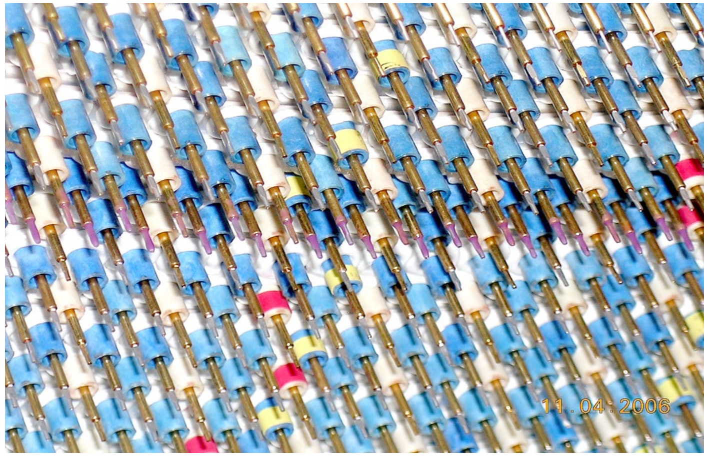
Installation of inner chamber



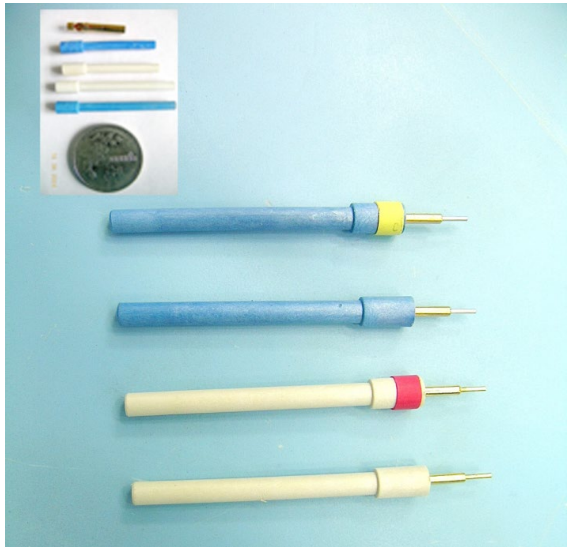
- Mechanical error ~ 200 μm

Single wire displacements

item	rms/μm	
	sense wire	field wire
hole location	25.0	25.0
feedthrough in hole	6.3	6.3
crimp pin hole	12.5	12.5
wire in pin hole	31.3	10.0
total rms	42.4	30.3

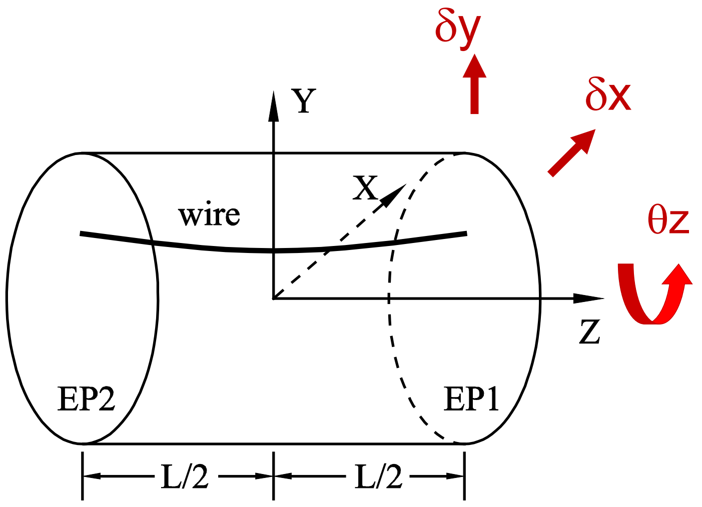


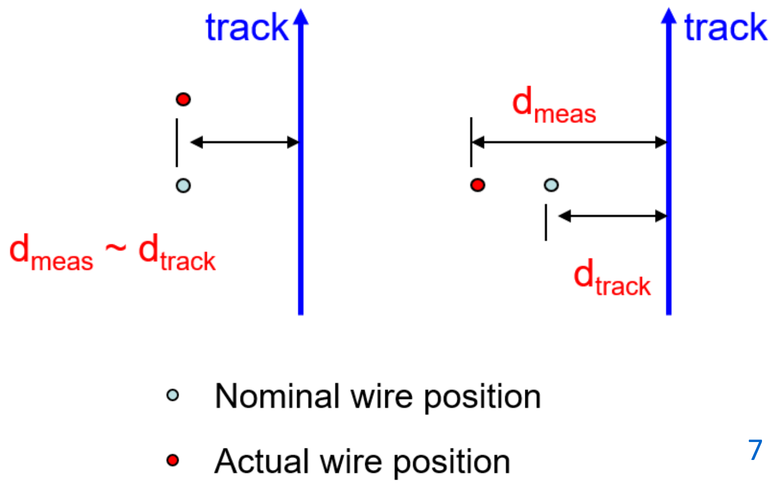
- Much less than the error in assembly of endplates



Alignment parameters

- 6 degree of freedoms for each component
  - Translation in x, y and z
  - Rotation in x, y and z
- Some degree of freedoms constrained to guarantee the stability and avoid weak modes
  - θx, θy, δz
- 48 alignment parameters in total and the average displacement of both big endplates fixed

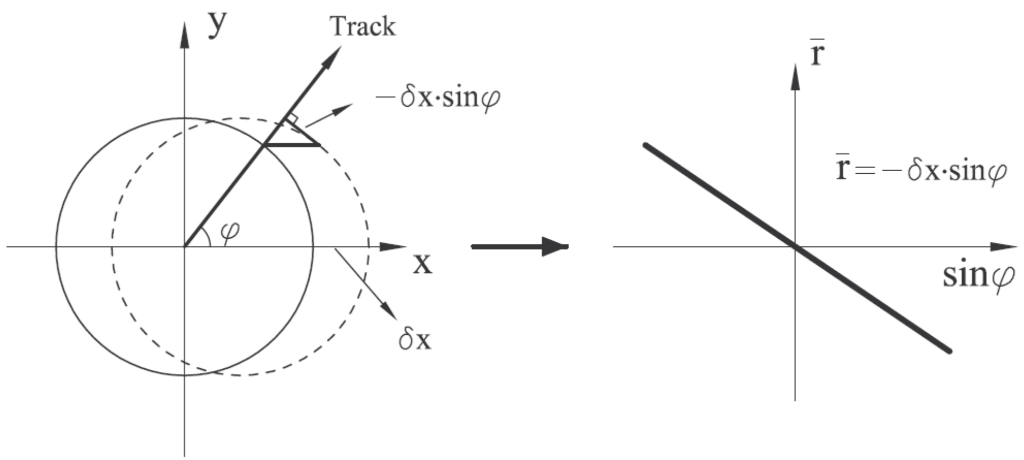


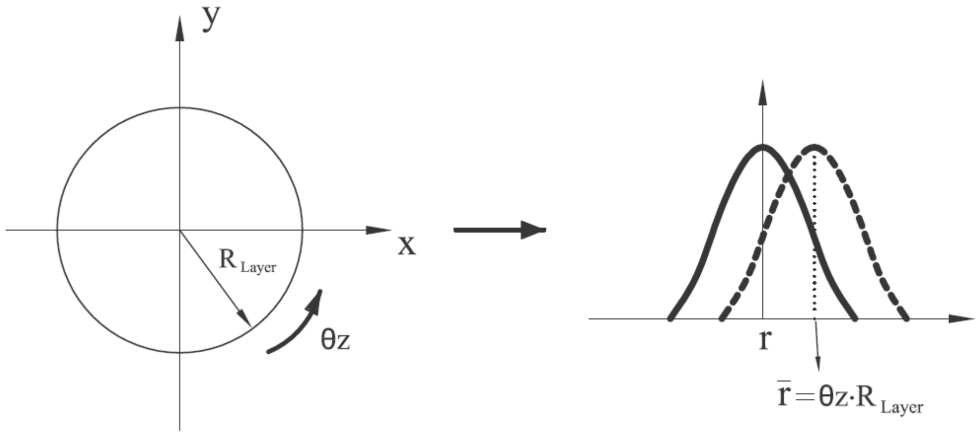


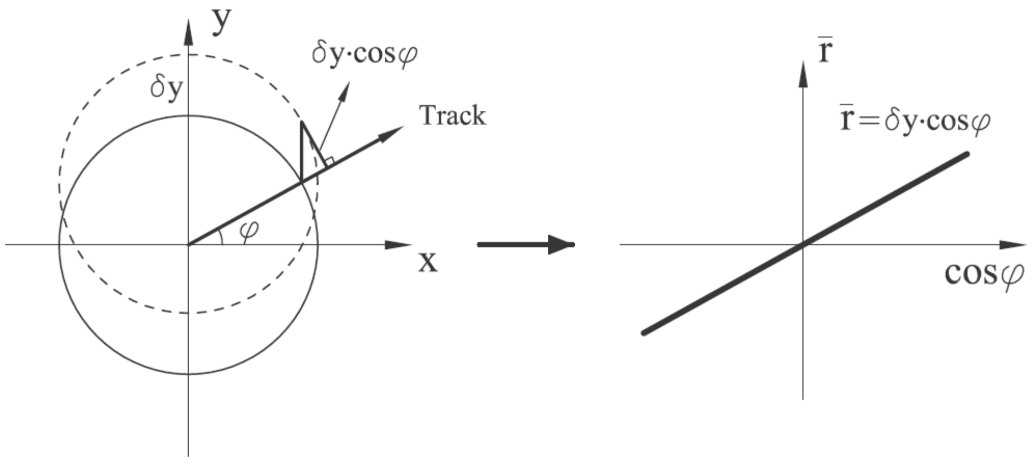
Software alignment methods

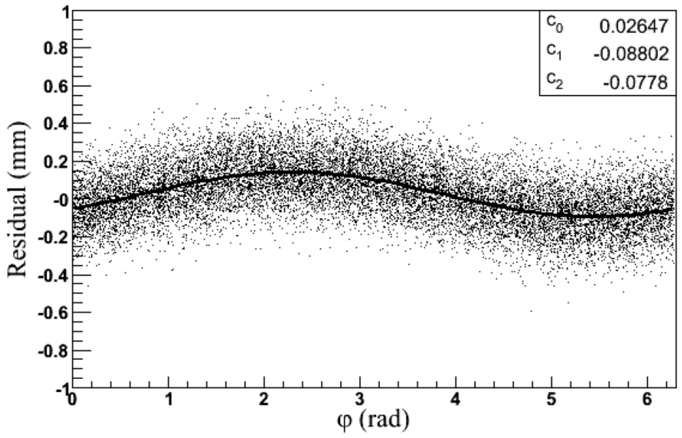
- Parameterization of residual dependence √
- Millepede matrix method √
- Kalman filter method
- Kalman filter track fit based alignment (to be studied)

Parameterization of residual dependence









- Estimate alignment parameters from fitting residual distribution

Millepede matrix method

- d_{track} as a function of alignment parameters (a) and track parameters (p) in theory

$$d_{track} = f(\boldsymbol{p}^{local}; \boldsymbol{a}^{global})$$

- For a set of measurements, the residual of the *i-th* measurement in the *k-th* track is defined as:

$$r_{ki} = d_{meas}^{(k,i)} - d_{track}^{(k,i)} = d_{meas}^{(k,i)} - ((\boldsymbol{\delta}_{ki}^{local})^T \boldsymbol{p}_k + (\boldsymbol{d}_{ki}^{global})^T \boldsymbol{a})$$

- For simultaneous fit of all global and local parameters, χ^2 is defined as

$$\chi^2 = \sum_{data\ sets} (\sum_{events} (\sum_{tracks} (\sum_{hits} w_{ki} r_{ki}^2)))$$

- Use least square method and a matrix equation with large dimensions is obtained (see next page)
- Solve the matrix equation.

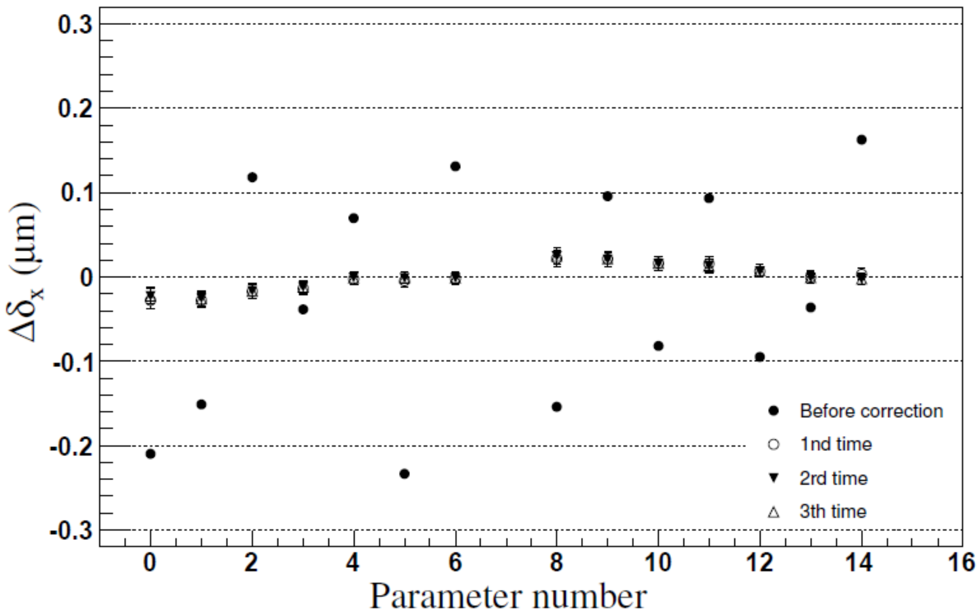
Millepede matrix method

$$\left(\begin{array}{c|c|c|c} \sum_k C_k^{global} & \cdots & H_k^{global-local} & \cdots \\ \hline \vdots & \ddots & 0 & 0 \\ \hline (H_k^{global-local})^T & 0 & \Gamma_k^{local} & 0 \\ \hline \vdots & 0 & 0 & \ddots \end{array}\right) \times \left(\begin{array}{c} a^{global} \\ \hline \vdots \\ \hline p_k^{local} \\ \hline \vdots \end{array}\right) = \left(\begin{array}{c} \sum_k b_k^{global} \\ \hline \vdots \\ \hline \beta_k^{local} \\ \hline \vdots \end{array}\right)$$

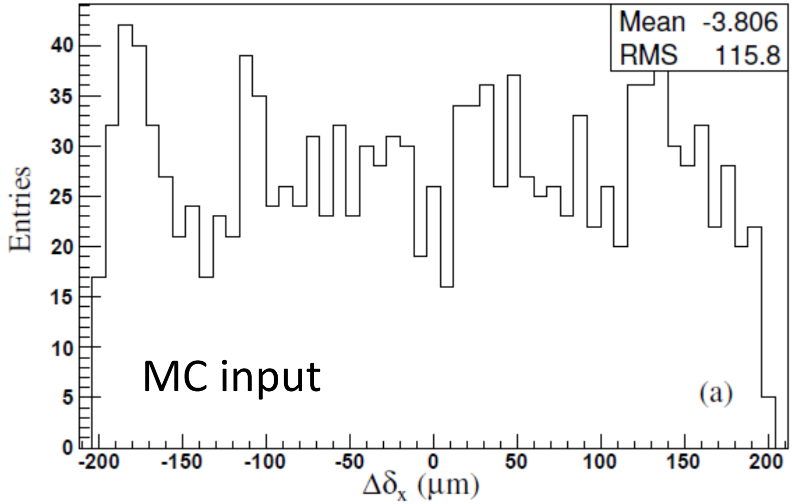
- C_k is a $n \times n$ symmetric matrix which is correlative with global parameters (n is the number of global parameters)
- Γ_k is a $m \times m$ symmetric matrix which is correlative with the local parameters of the *k-th* track (m is the number of local parameters in an event)
- H_k is a rectangular $n \times m$ matrix, which correlates the parameters of track k with the alignment parameters.
- The first item on the left of the above equation is a huge symmetric matrix with dimensions ($n + m \times N_{track}$)

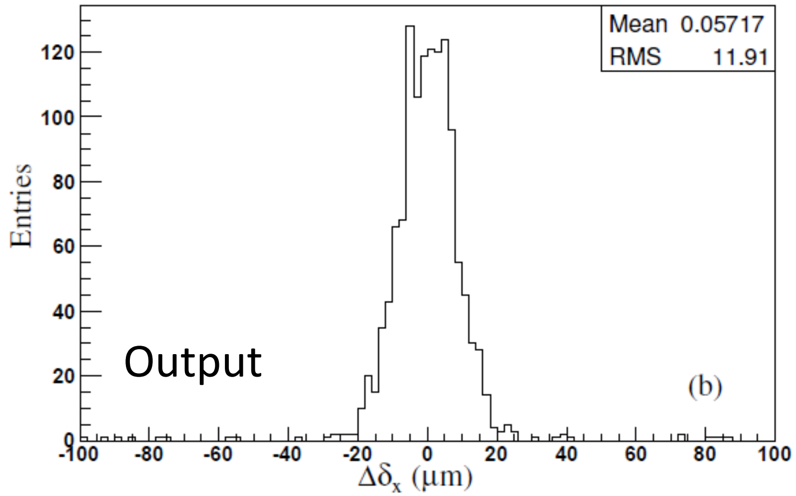
Validation with toy MC

Alignment of displacement in x



Result of 100 input-output test





- Fast convergence
- Displacements well corrected

Kalman filter method

$$d_{meas} = f(p_0, a_o) + H(p - p_0) + D(a - a_0) + \epsilon$$

ε: vector of measurement errors

$$H = \frac{\partial f}{\partial p}(p_0, a_0)$$

For local (track) parameters

$$D = \frac{\partial f}{\partial a}(p_0, a_0)$$

For global (alignment) parameters

$$a_1 = a_0 + E_0 D^T W [m - f(p_0, a_0)]$$

$$E_1 = E_0 - E_0 D^T W D E_0$$

$$W = [\alpha^{(k)} V + H C_0 H^T + D E_0 D^T]^{-1}$$

$\alpha(k)$: annealing factor of the k-th track

V: covariance matrix of ε

Validation with toy MC

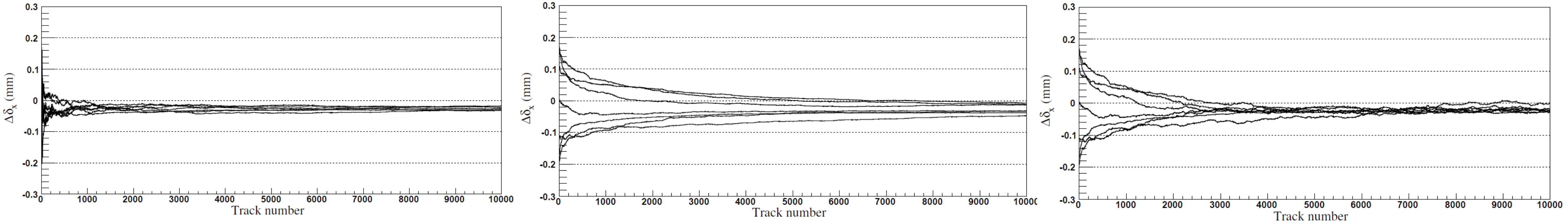
Different annealing strategies

	$\alpha^{(1)}$	$\alpha^{(n)}$	$\alpha^{(k)}$
A	1	1	1
B	10000	10000	10000
C	10000	1	$10000^{\frac{n-k}{n-1}}$

n: number of tracks

→ Standard Kalman filter

A B C



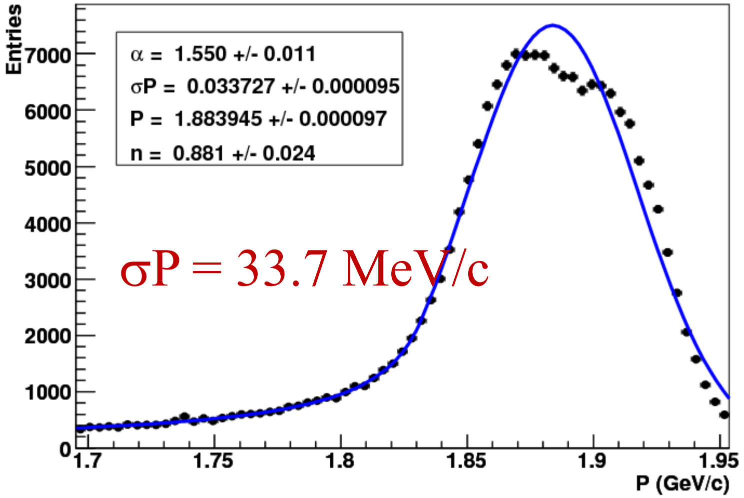
- Alignment parameters updated after each track reconstruction
- Hard to be implemented in our data processing framework

Alignment using BESIII data

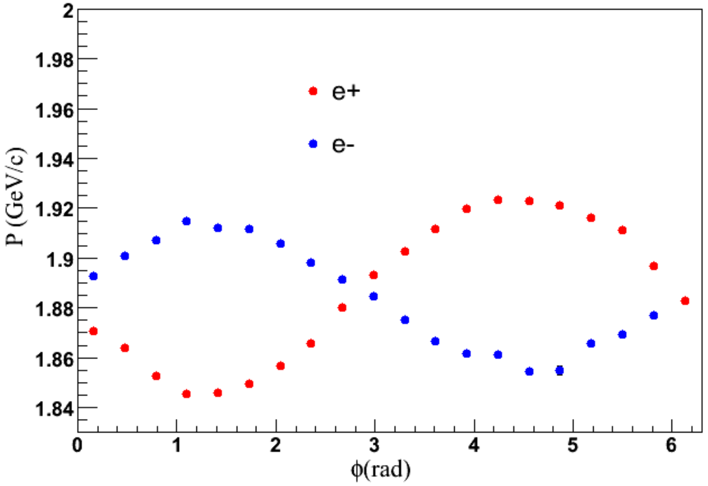
Misalignment effect in data

- Serious misalignment effect in psi(3770) data in 2009
- Momentum resolution is bad

Momentum distribution

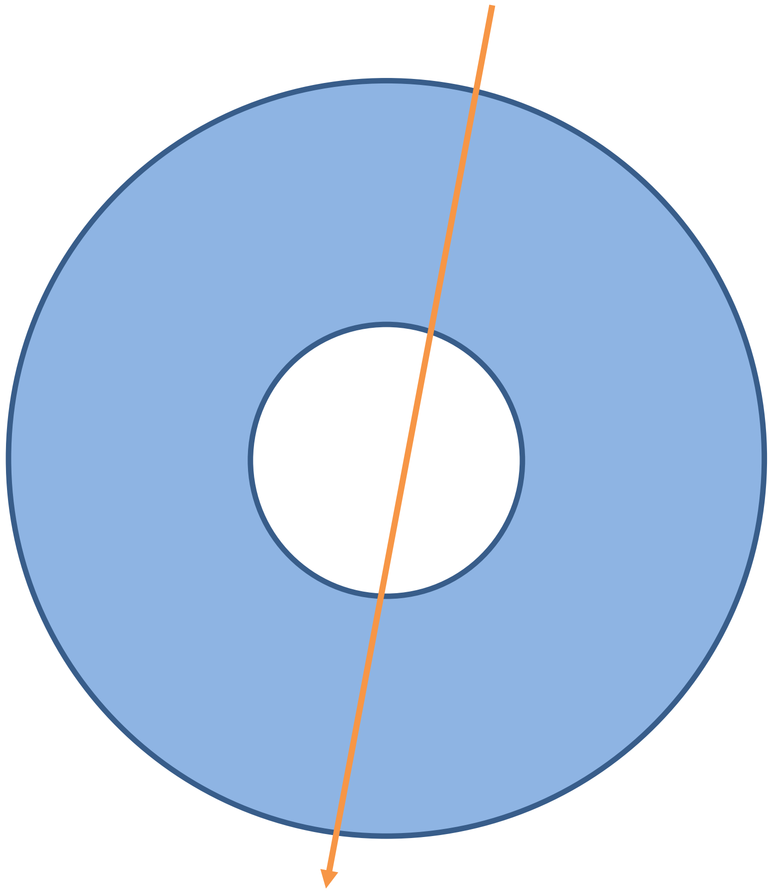


P vs ϕ



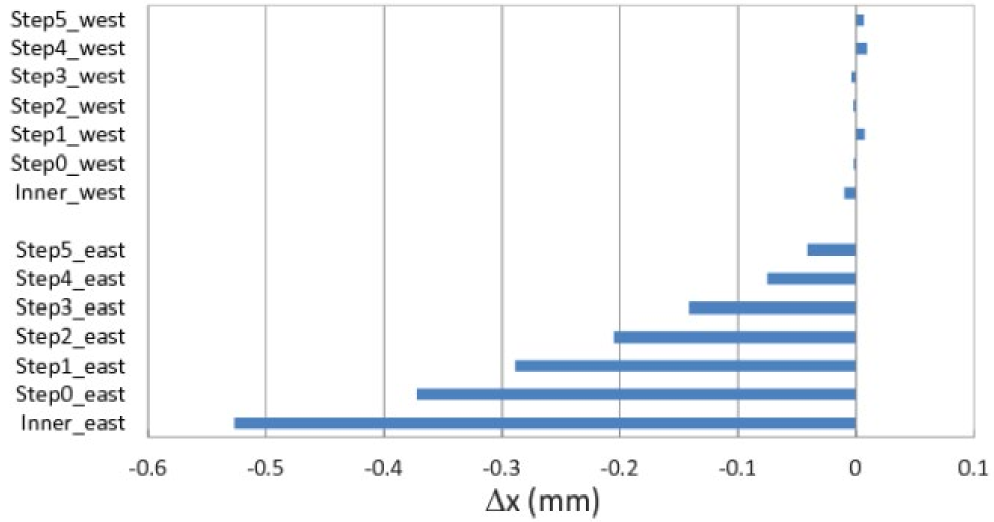
Alignment procedure of BESIII DC

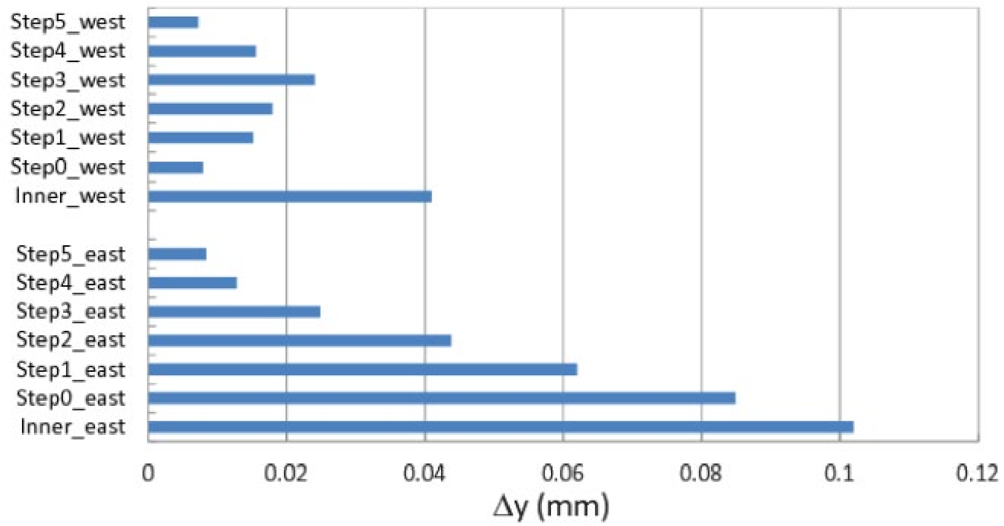
- Preliminary result using parameterization of residual dependence to correct big displacements
  - Track fit using hits of the big outer endplate to align the inner components
- Precise alignment with Millepede matrix method
  - MillepedeII implemented to combine cosmic and dimuon data samples

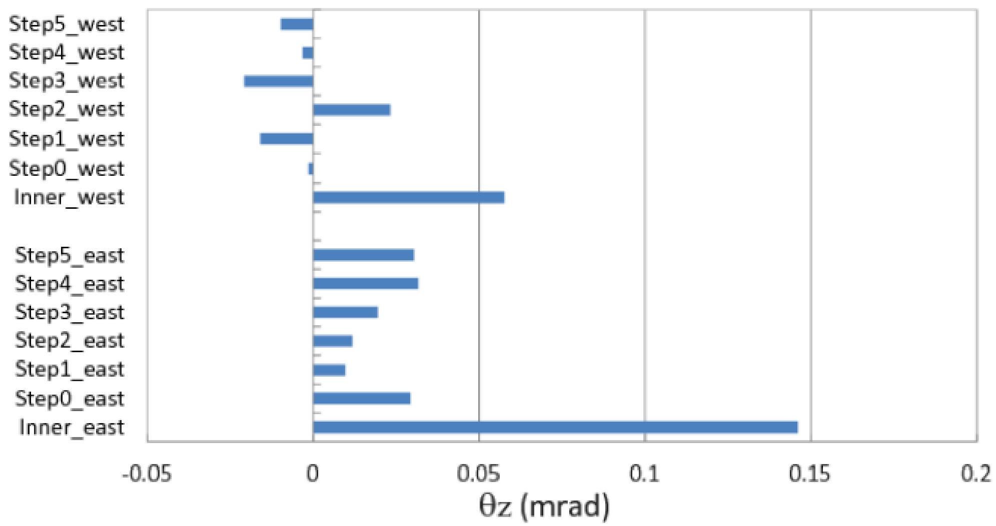


Alignment result

- Big displacements in x direction
  - Up to more than 500 μm

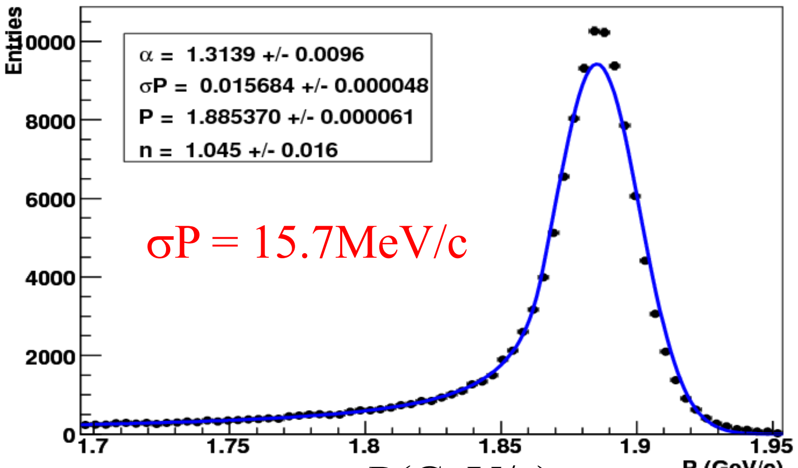






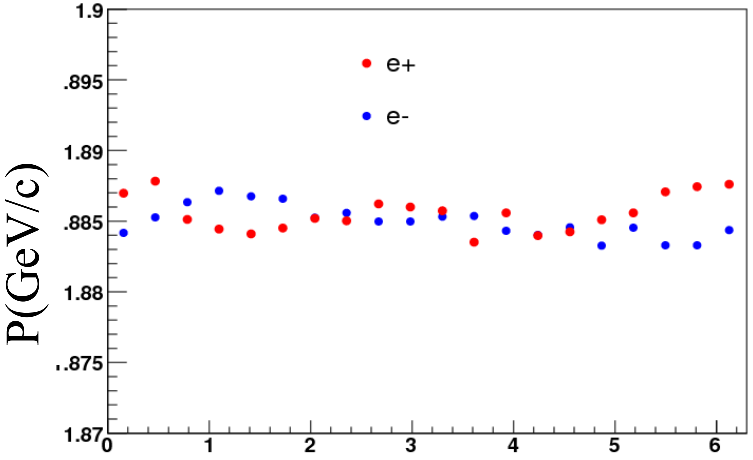
Momentum resolution after alignment

Momentum distribution



P(GeV/c)

P vs ϕ

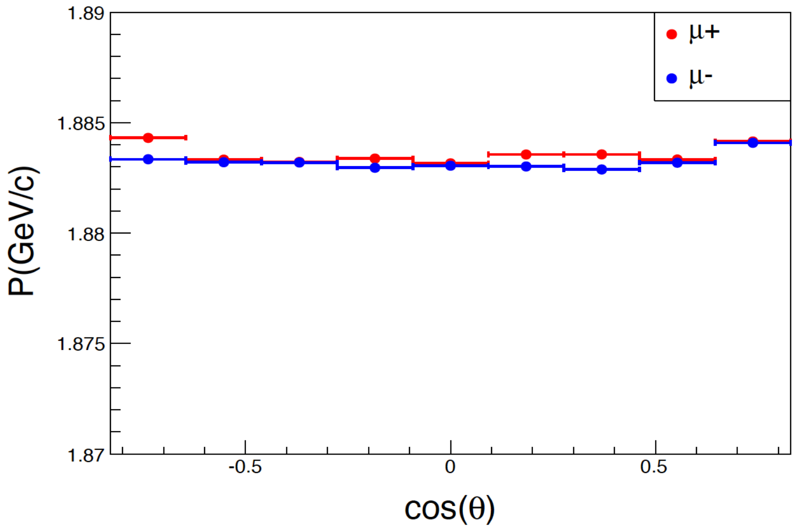


ϕ (rad)

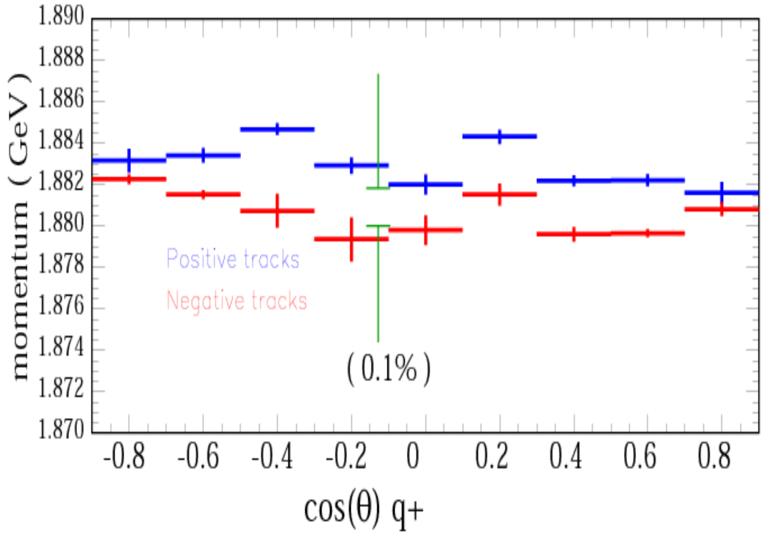
- Momentum resolution improved significantly

Comparison with CLEO-c

BESIII



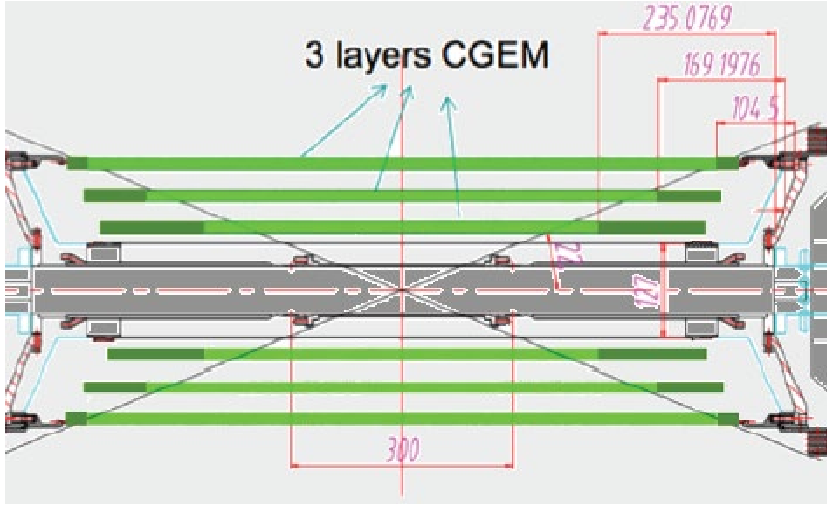
CLEO-c

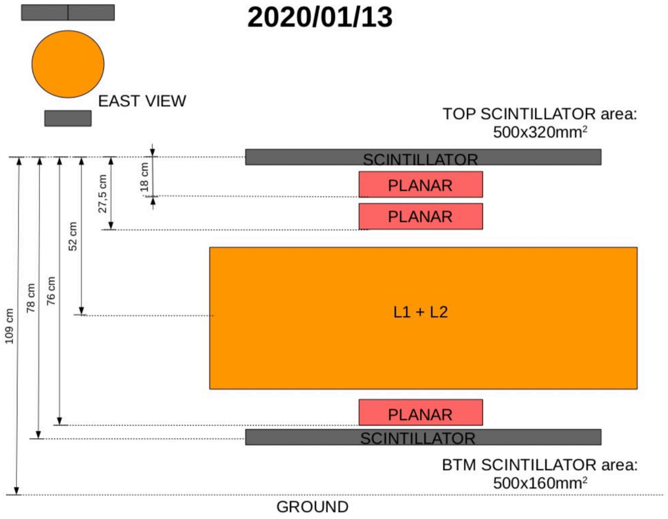


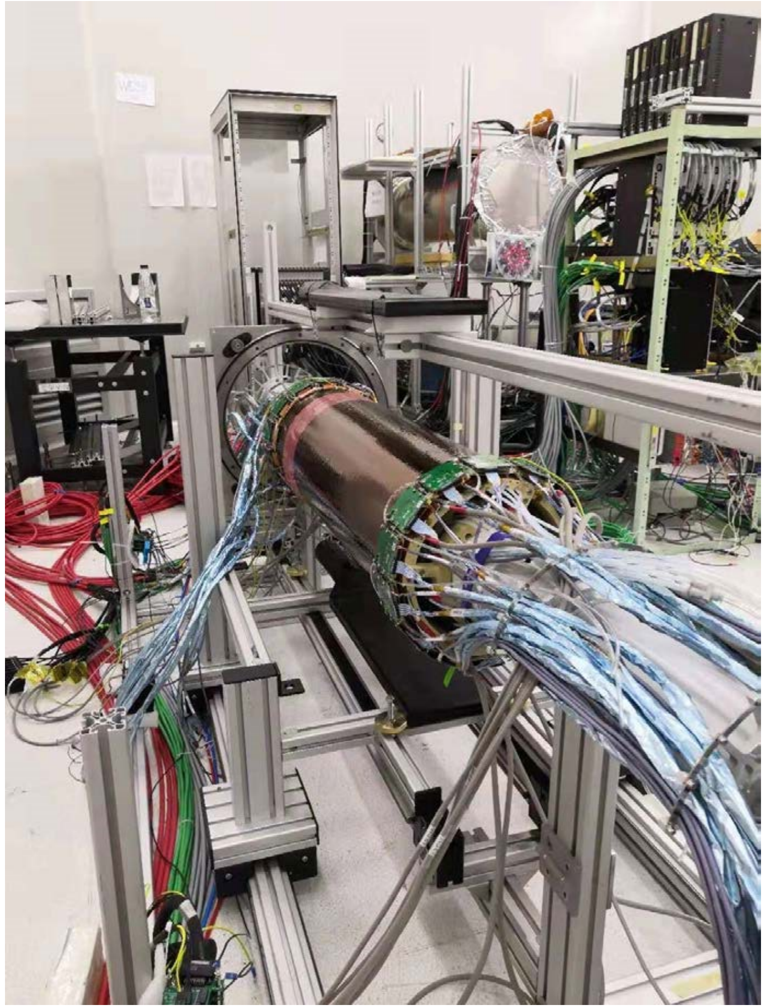
Alignment of CGEM tracker

CGEM inner tracker

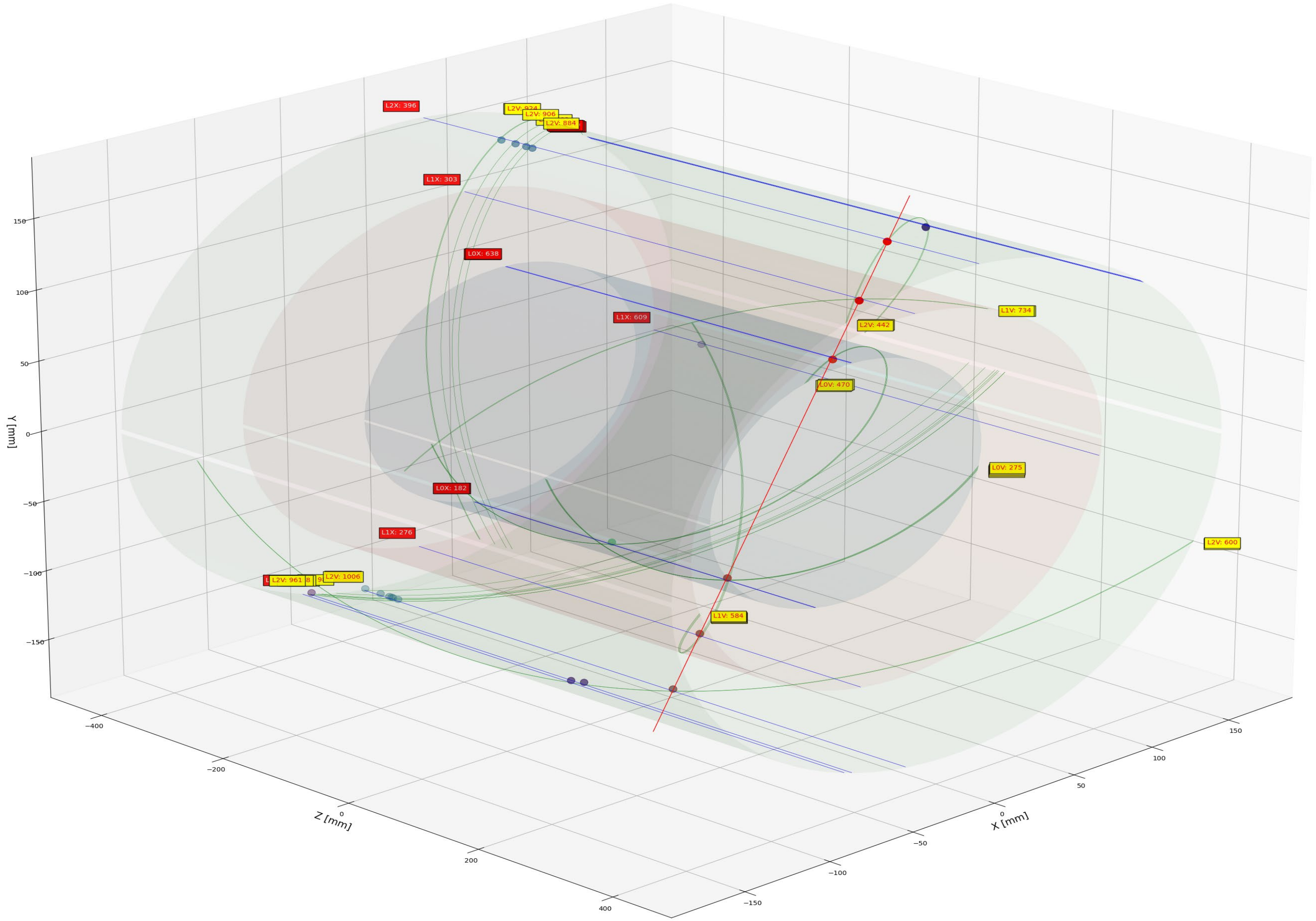
- Upgrade of BESIII inner tracker using CGEM detector
- Alignment of 3 CGEM layers using cosmic ray test finished





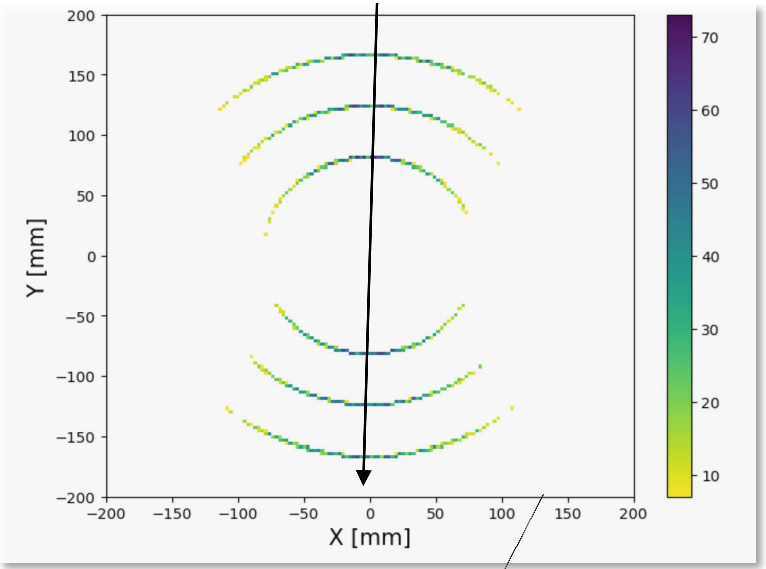


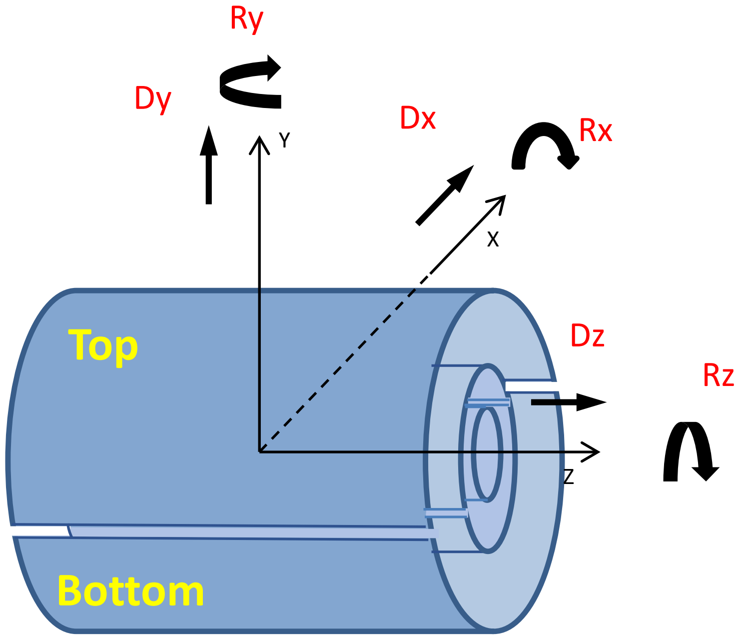
3D event display



Alignment with Millepede

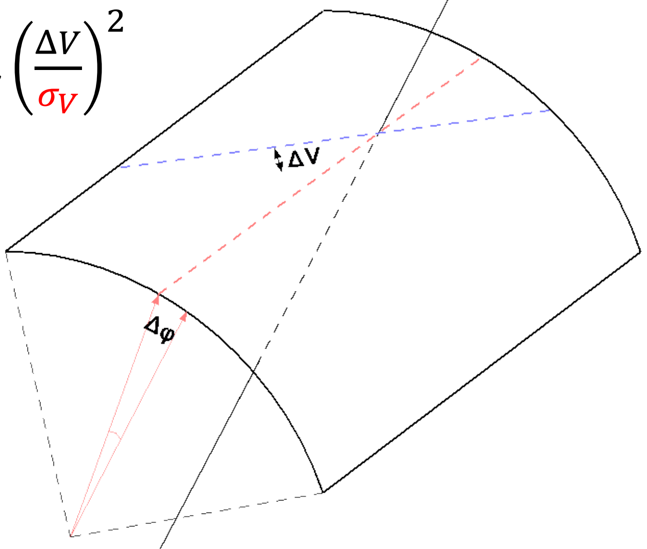
- Misalignment between 3 layers are studied
- Position of **innermost layer** is used as reference
- Each sheet of Layer2&3 is treated individually
- 6 parameters for each component
- **Dy** fixed to 0 due to lack of horizontal tracks
- Both the residuals of **X** and **V** are considered



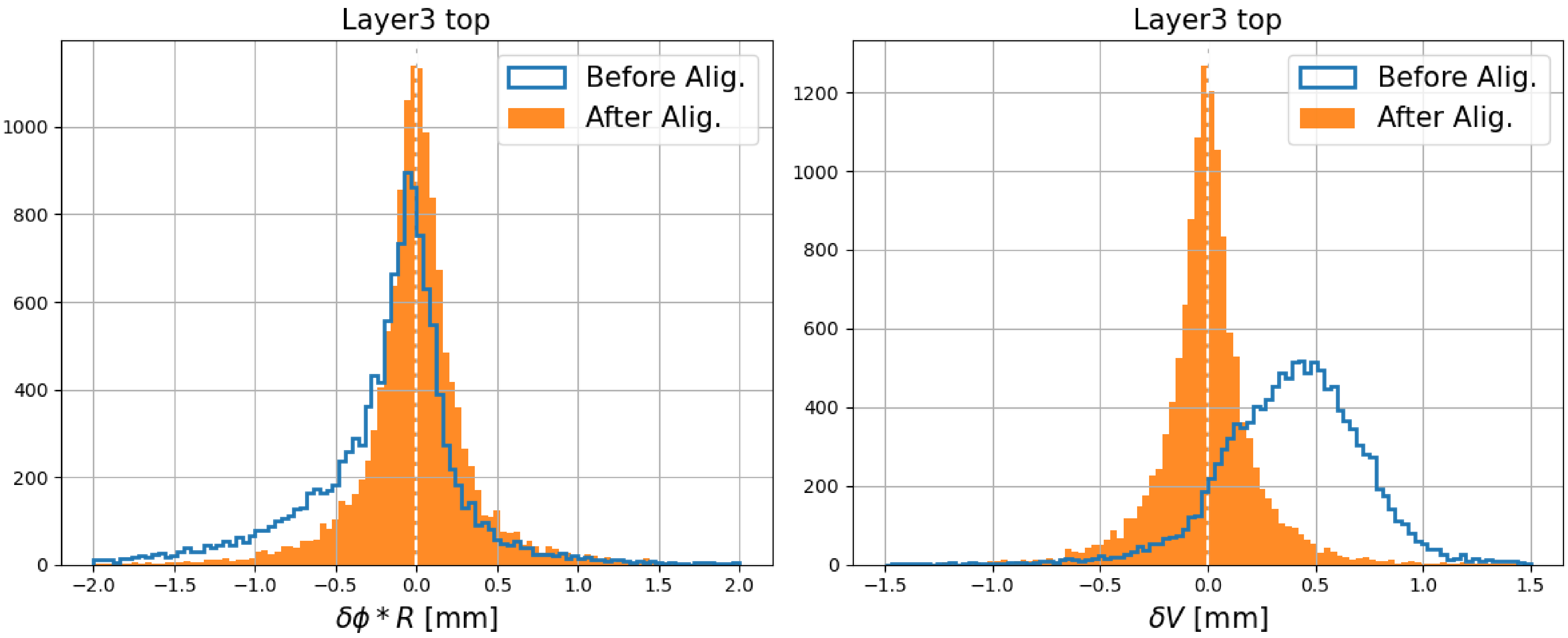


$$\chi^2_{tot} = \Sigma_{Lay}\left(\frac{\Delta\phi}{\sigma_\phi}\right)^2 + \Sigma_{Lay}\left(\frac{\Delta V}{\sigma_V}\right)^2$$

$L(d_\rho, \phi_0, d_z, \tan\lambda)$

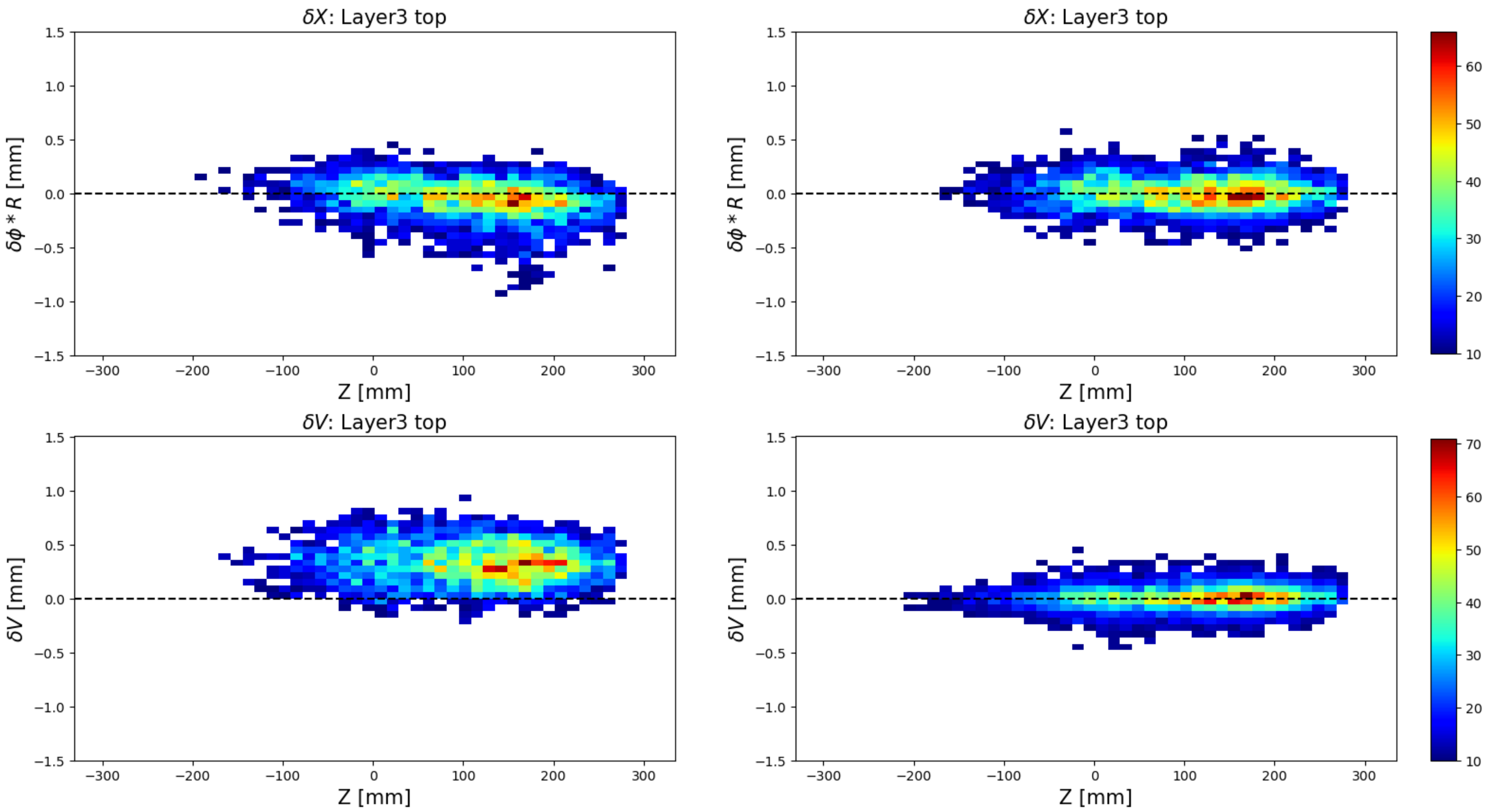


Improvement of residual distribution with alignment

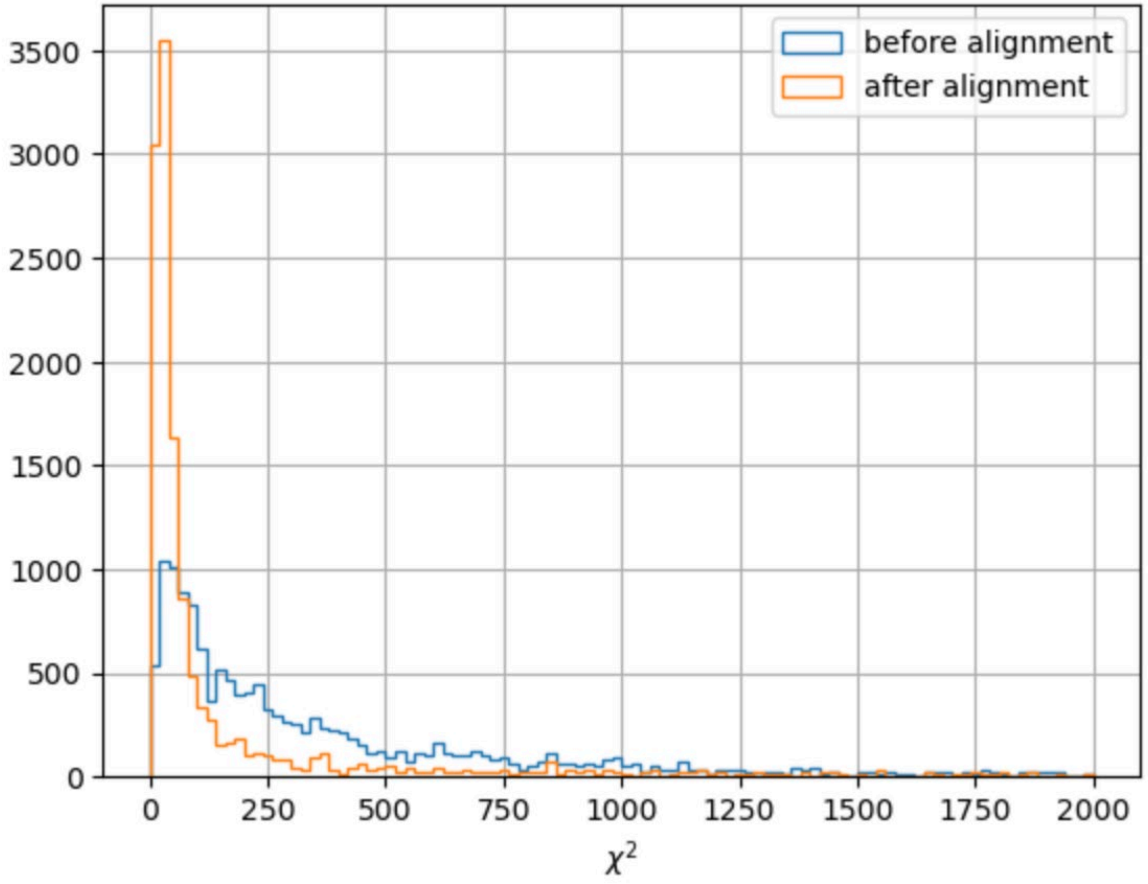


Residual vs z

Before alignment | **After alignment**



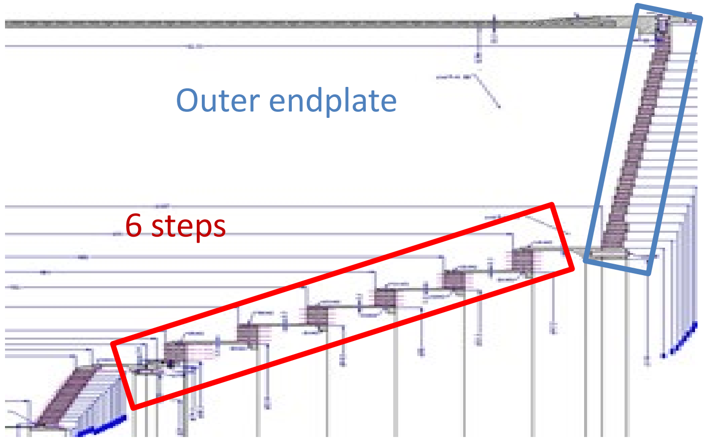
Improvement of chisquare distribution



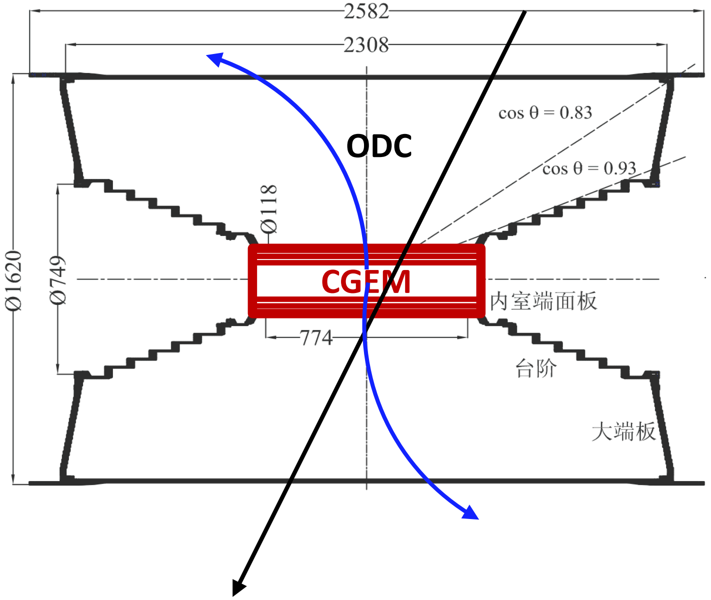
χ^2 distribution improved significantly after alignment

Alignment of CGEM+ODC

- Alignment of CGEM-IT + ODC will be much more complicated due to
  - Magnetic field
  - more degree of freedoms
  - limitation of precision in z
  - correlation with the Lorentz angle



- Alignment based on track fit with Kalman filter will be considered



Summary

- Track-based alignment is essential to improve tracking precision
- BESIII drift chamber is well aligned using residual parameterization and Millepede methods
- CGEM tracker is well aligned with cosmic ray data
- Next to do: alignment of CGEM+ODC