Alignment of BESIII Tracker

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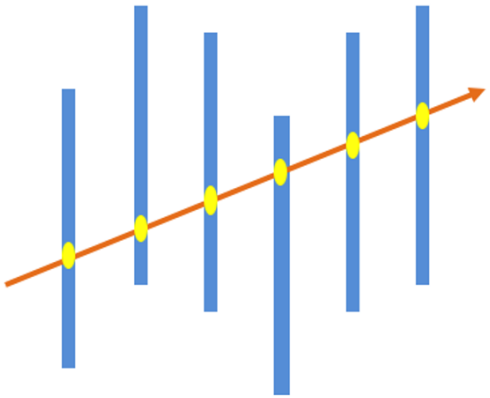
For the BESIII offline alignment group

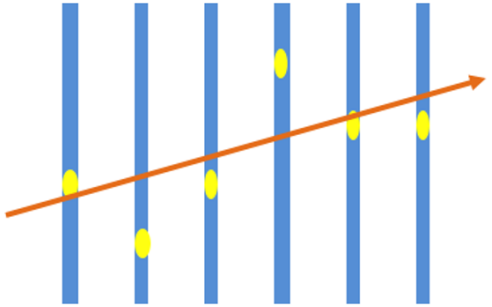
Misalignment of tracking detector

- 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

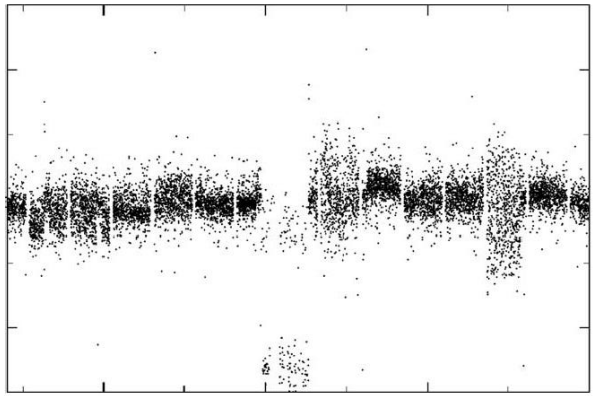
Misaligned detector



Reconstruction with uncorrected detector

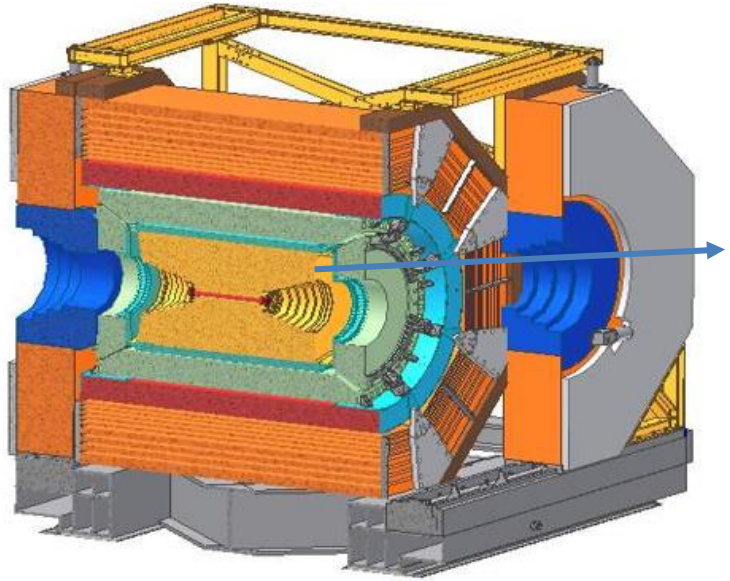


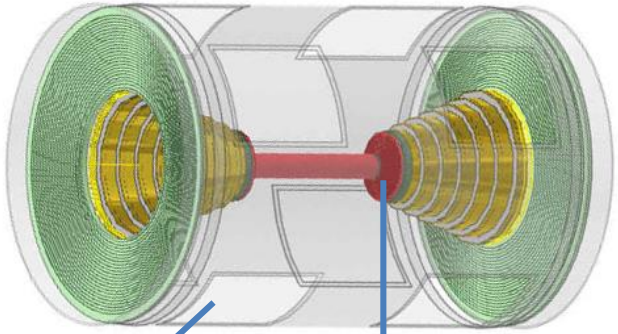
Shift of residuals



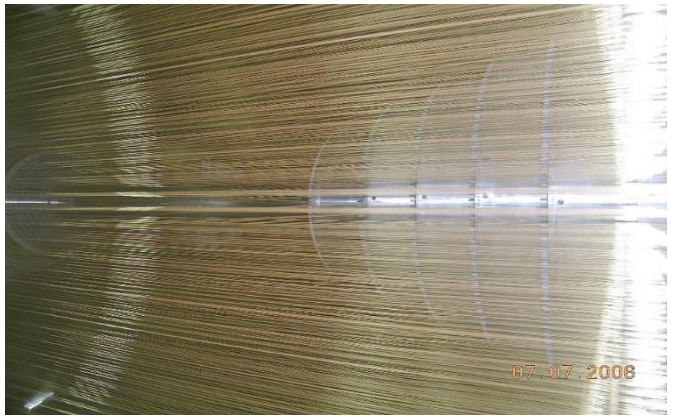
BESIII drift chamber

- Purpose:
  - Tracking for momentum measurement, vertex reconstruction and track extrapolation
  - PID for charged hadrons
- 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

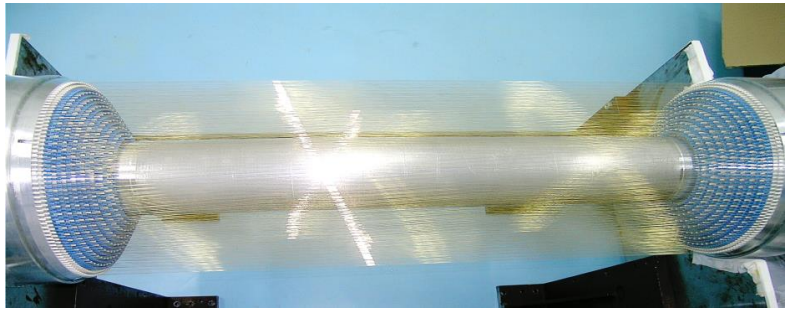




Outer chamber

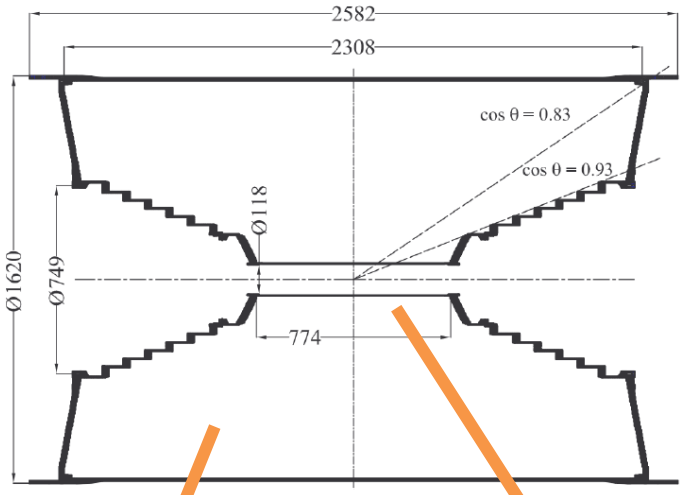


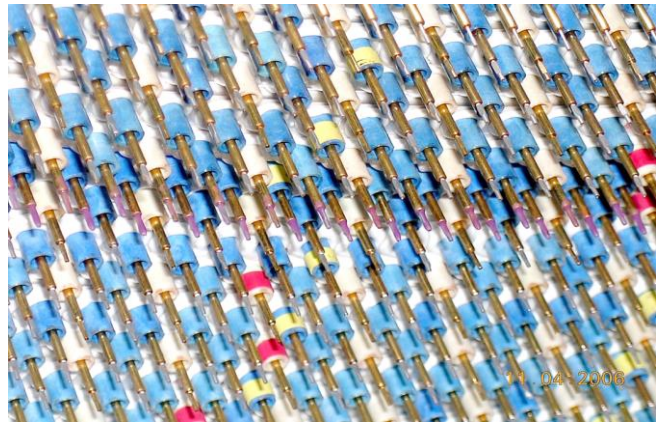
Inner chamber



Sources of Misalignment

- Mechanical imperfection in assembly of endplates (more than 200μm)
  - 16 components: Inner section, 6 steps and outer section of both ends
- Single wire displacement (~ 40μm)





Installation of inner chamber

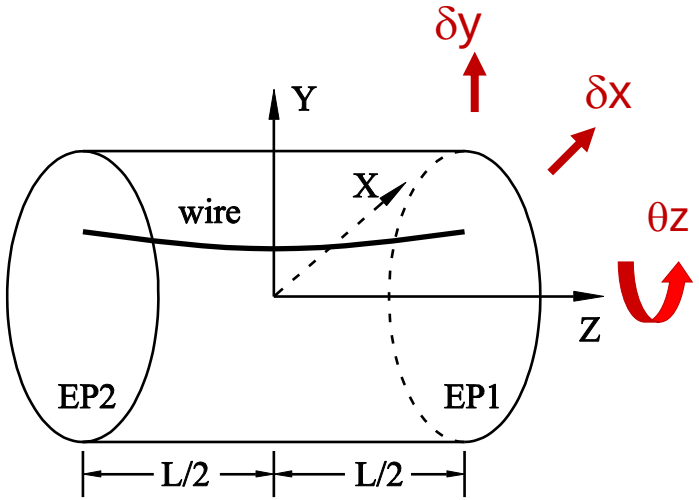
Errors of single wire position

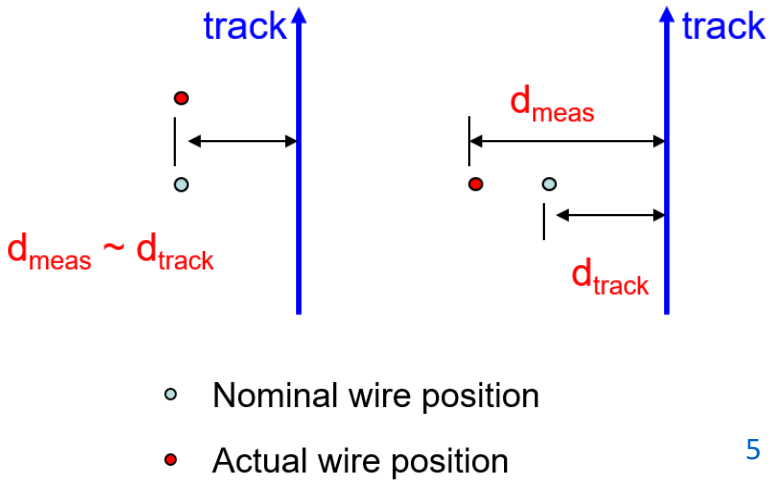
item	rms/μm	
	sense wire	field wire
hole location	25.0	25.0
feedthrough in hole	6.3	6.3
crimp pin hole	12.5	12.5
wire in pin hole	31.3	10.0
total rms	42.4	30.3

Much less than the position error 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

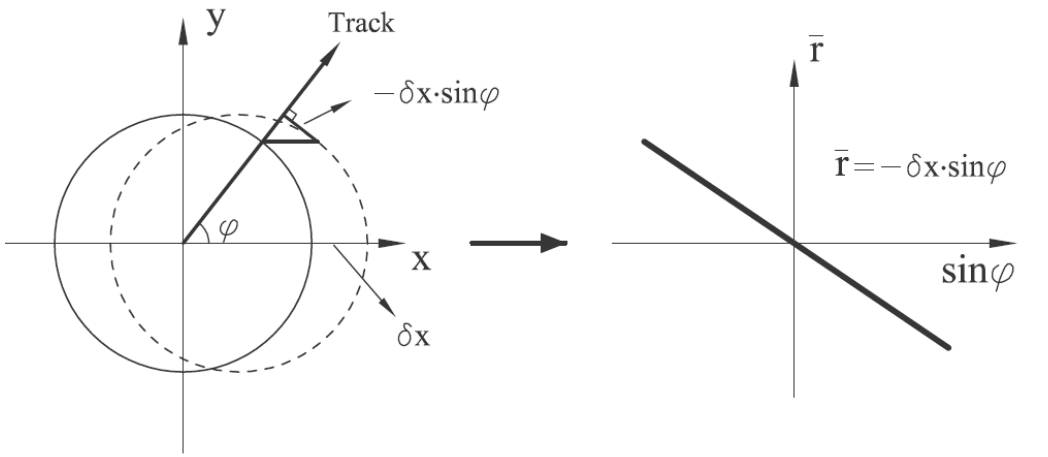


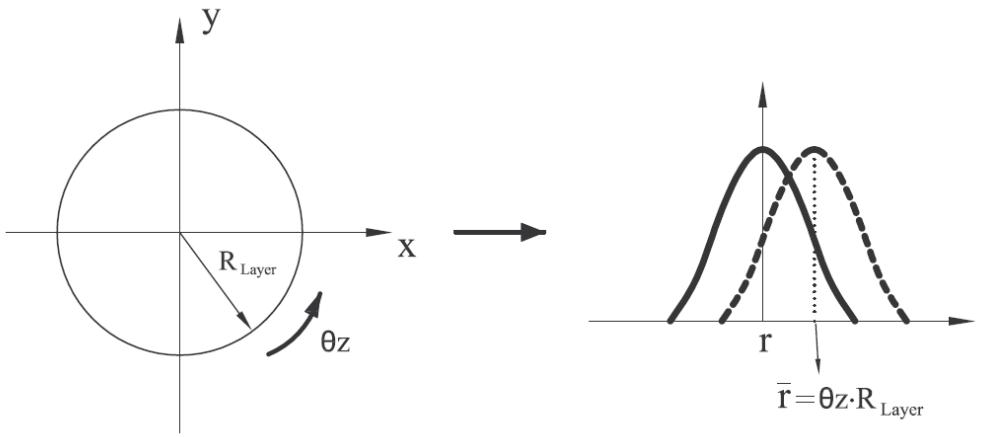


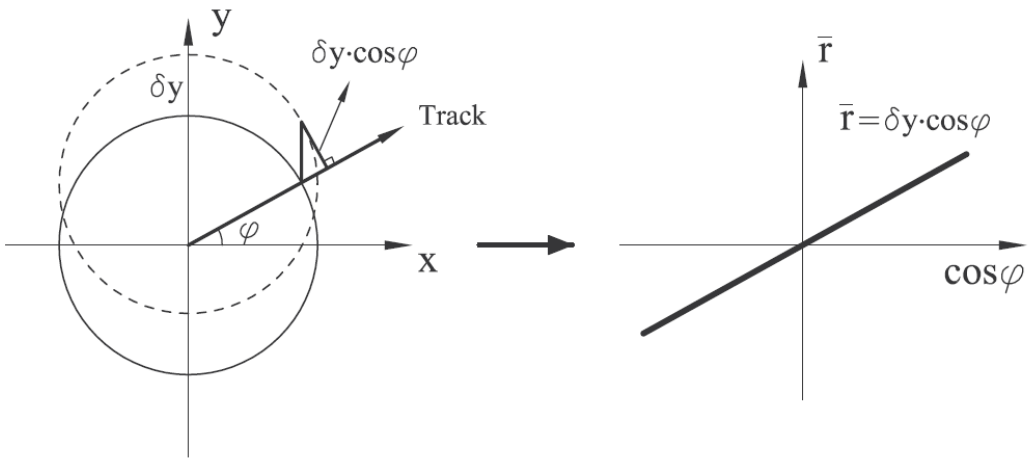
Software alignment methods

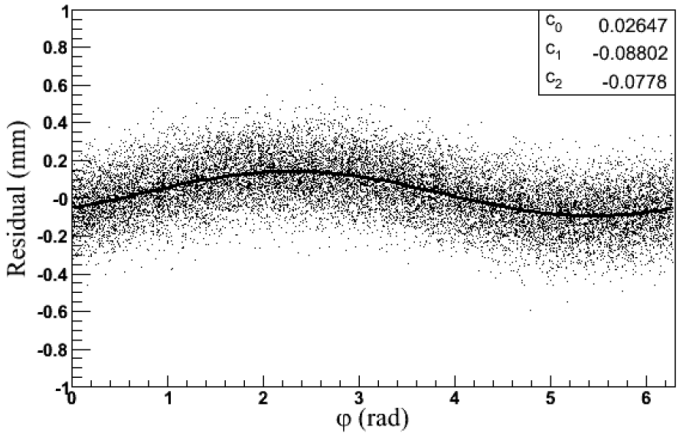
- Parameterization of residual dependence
- Millepede matrix method

Parameterization of residual dependence









- Estimate alignment parameters from fitting residual distribution
- Used for pre-alignment

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.

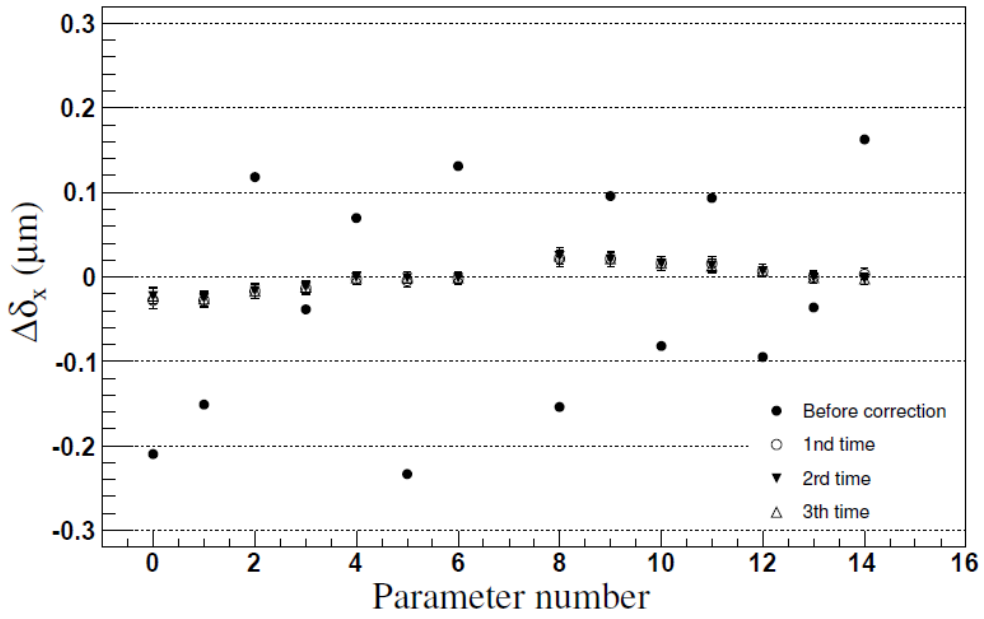
Millepede matrix method

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

- 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 ($n + m \times N_{track}$)

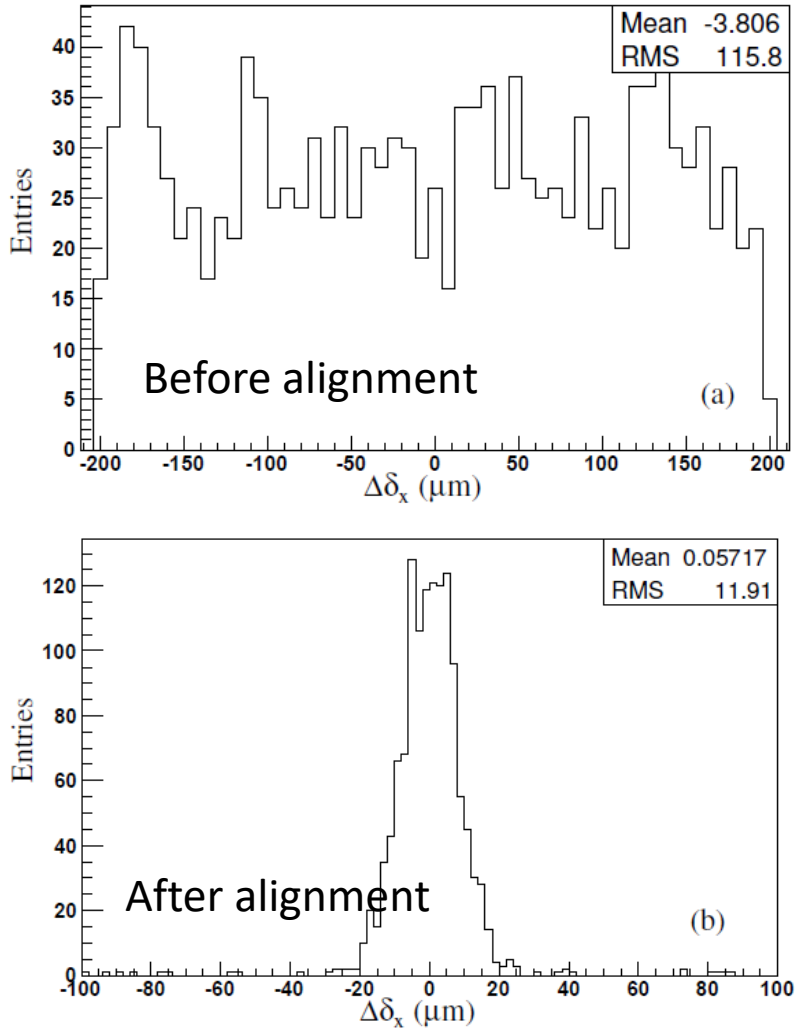
Validation with MC

Alignment of displacement in x



- Fast convergence
- Displacements well corrected

Result of 100 input-output test



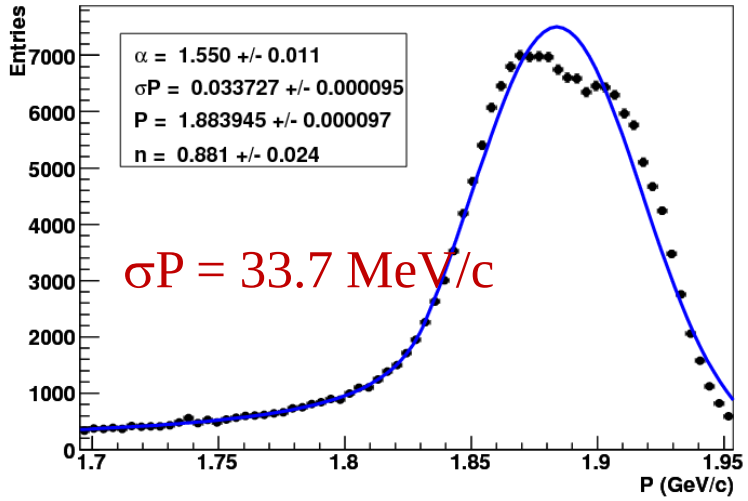
Alignment of BESIII drift chamber

Misalignment effect in data

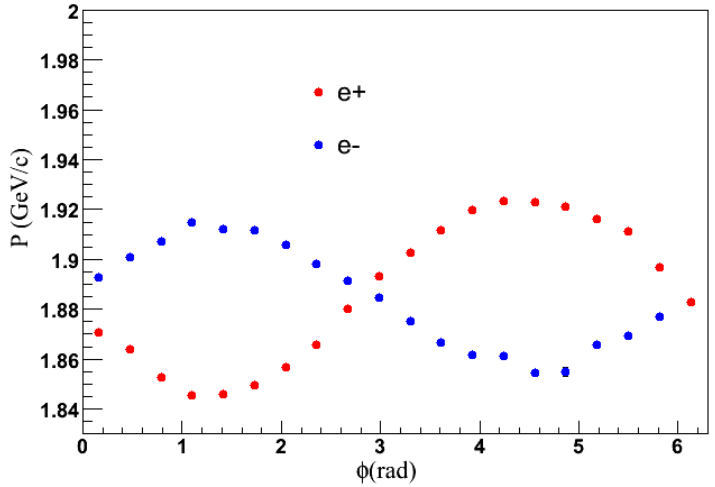
- Misalignment effect in psi(3770) data in 2009

Before alignment

Momentum distribution

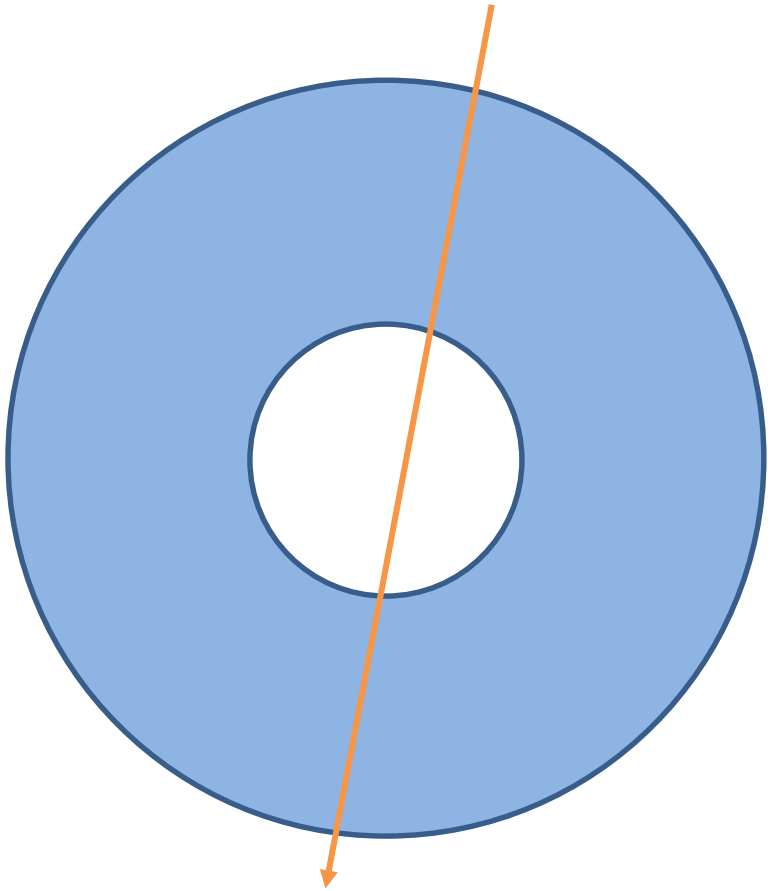


P vs ϕ

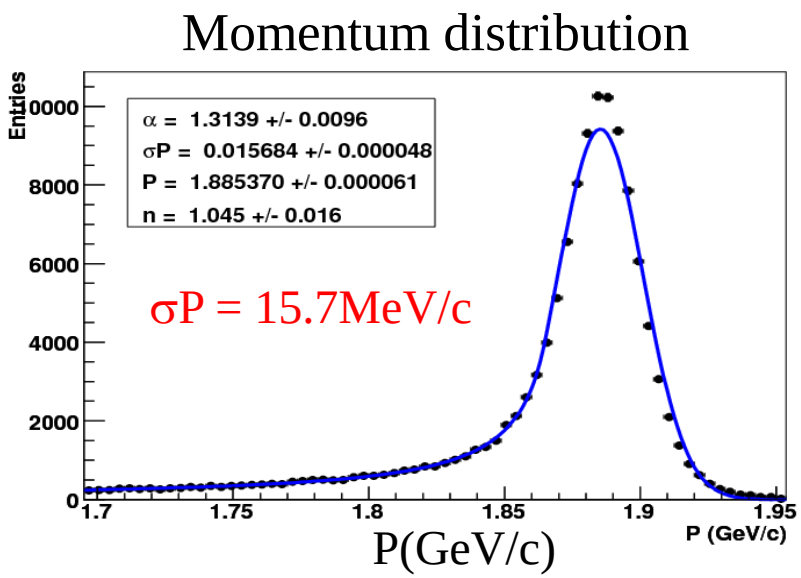


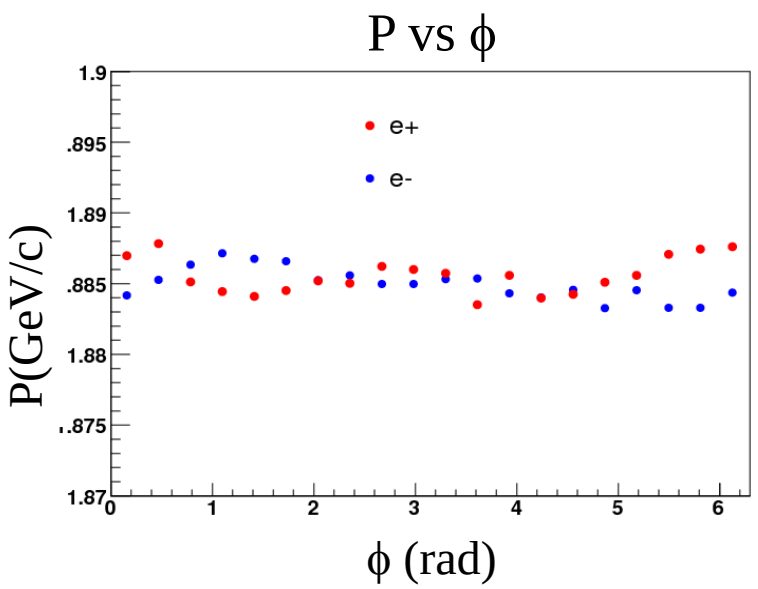
Alignment procedure of BESIII DC

- 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



Momentum resolution after alignment



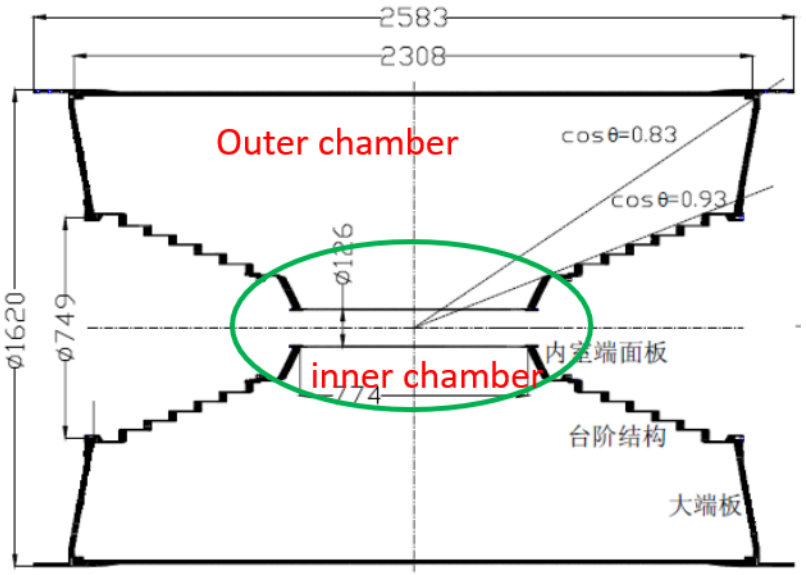


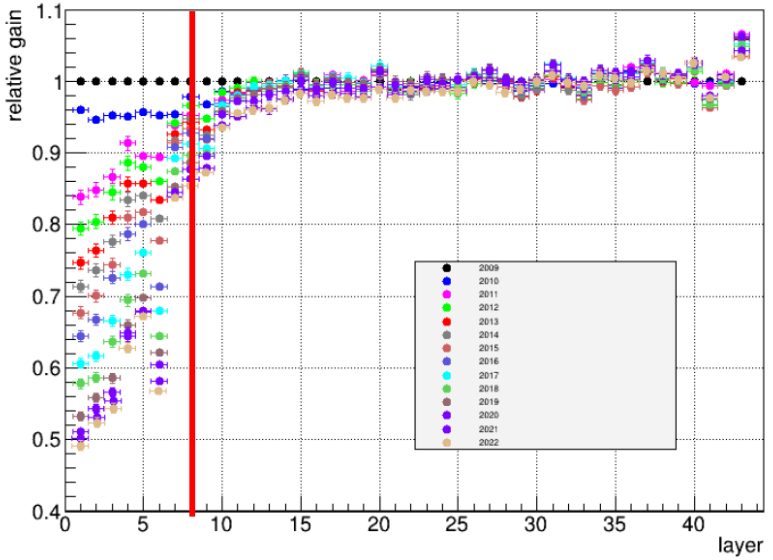
- Momentum resolution improved significantly

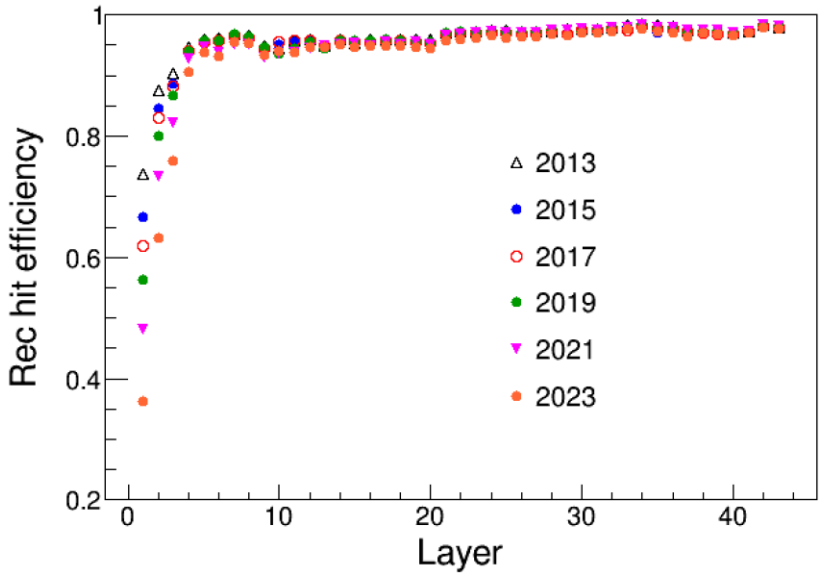
Alignment for upgraded tracker

Aging of BESIII inner drift chamber

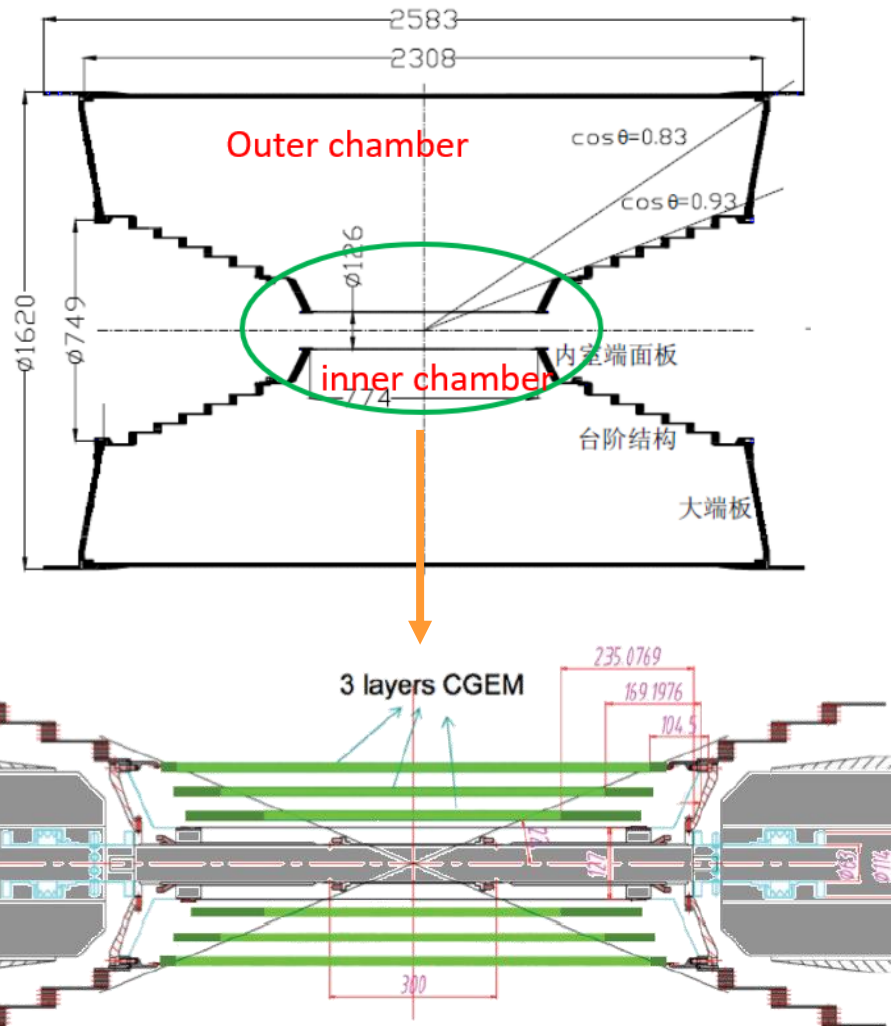
- Operating since 2008
- Close to beam pipe → aging due to high beam induced background
  - Gain deceases with time
  - Degradation of hit efficiency and spatial resolution year by year



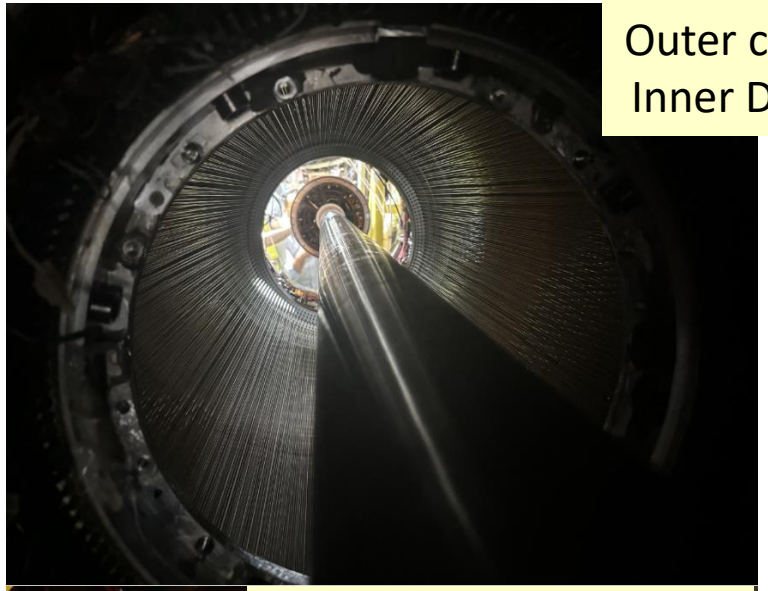




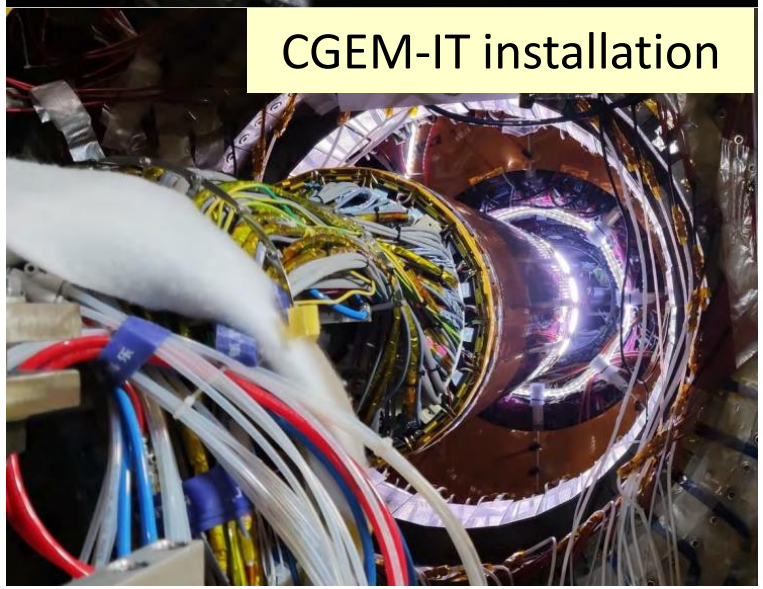
Upgrade of Inner Tracker: CGEM-IT



Data taking will start in 2025

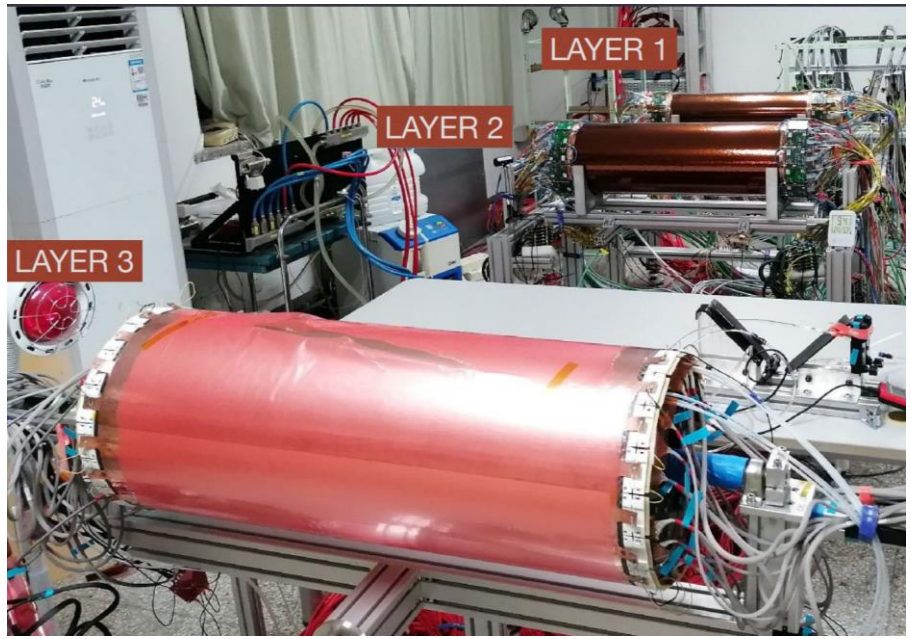


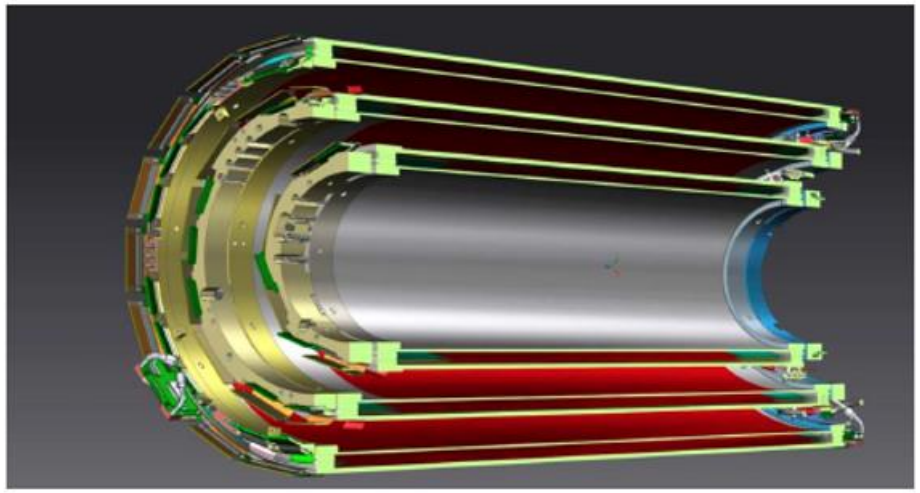
Outer chamber with Inner DC pulled out

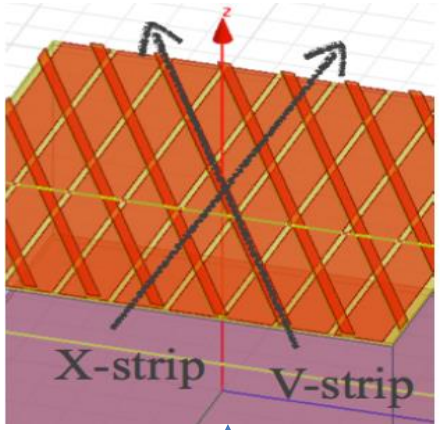


CGEM-IT installation

CGEM inner tracker

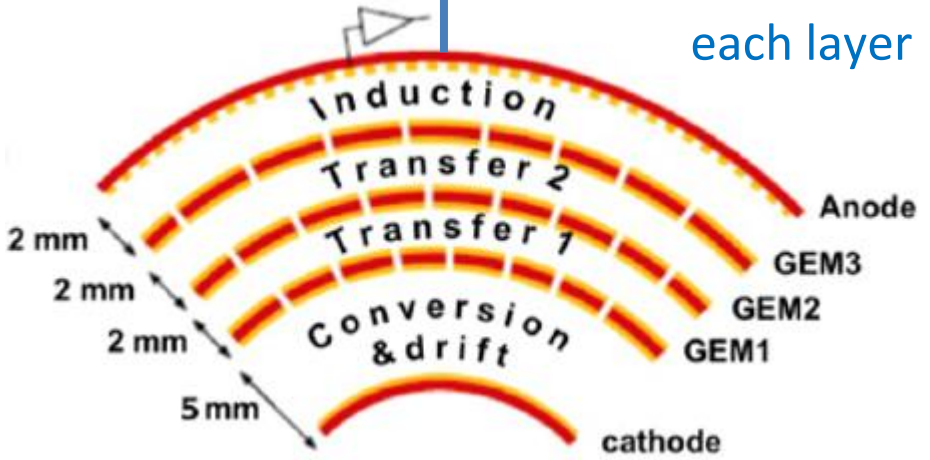






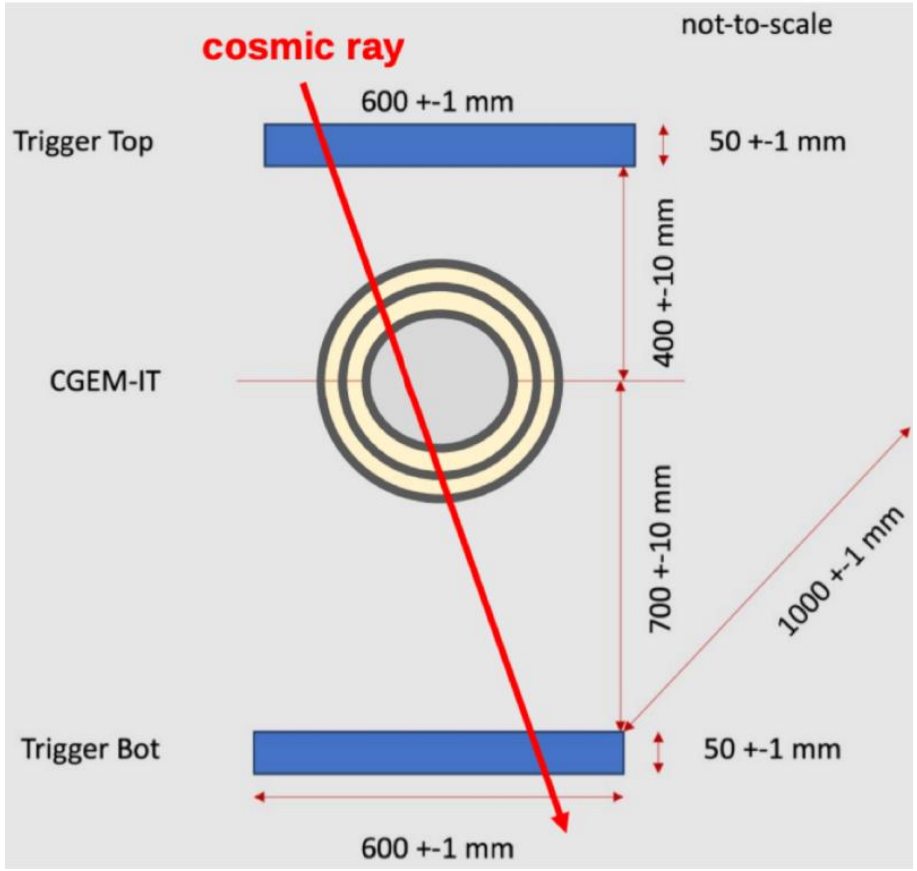
Anode readout strips

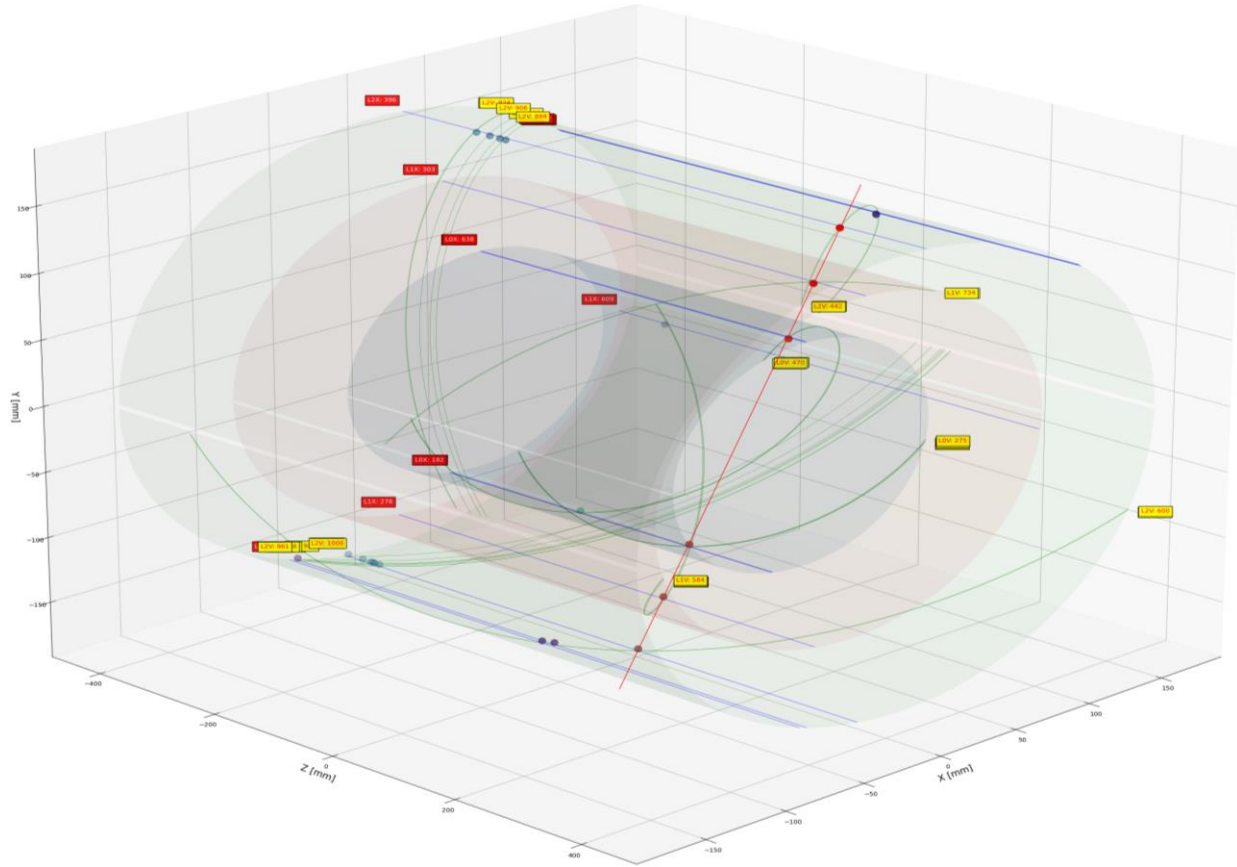
Structure of each layer



Cosmic ray test and event display

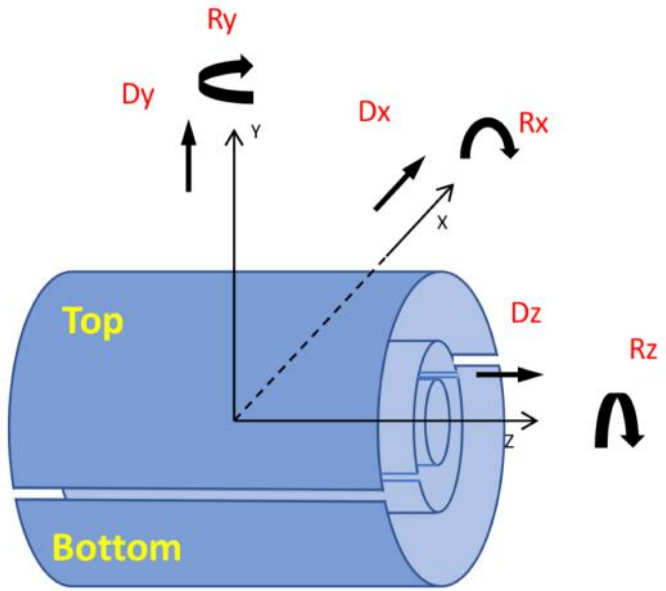
A cosmic ray test performed in this year

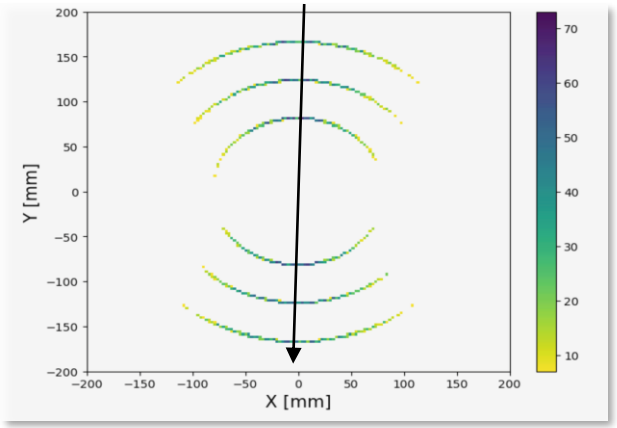




Alignment with Millepede

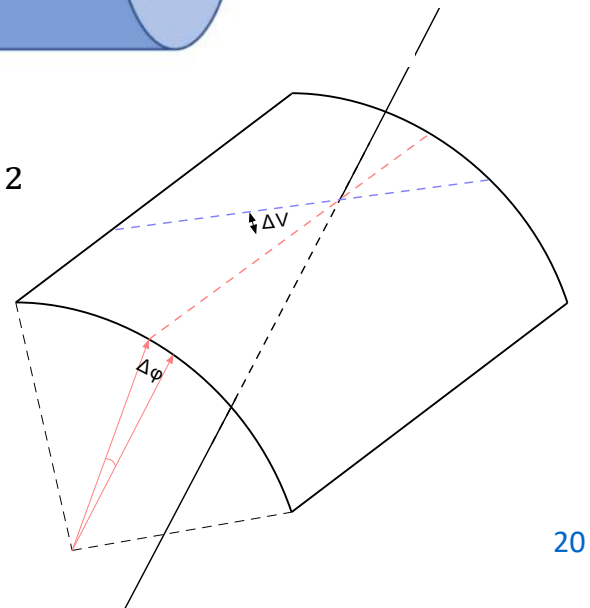
- Misalignment between 3 layers are studied
- Position of **innermost layer** is used as reference
- Each sheet of Layer2&3 is treated individually
- 6 parameters for each component
  - Translations: Dx, Dy, Dz
  - Rotations: Rx, Ry, Rz
- **Dy** fixed to 0 due to lack of horizontal tracks
- Both the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





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

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



- If the detector consists of ideal cylinders, these alignment parameters are sufficient to describe any displacement

Improvement of residual distribution with alignment

L1 bottom

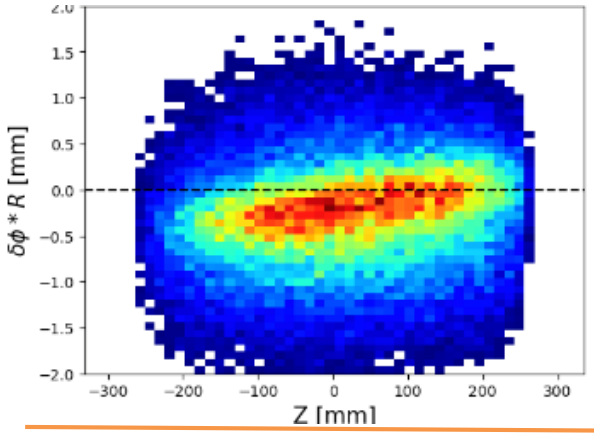
Rϕ residual vs z

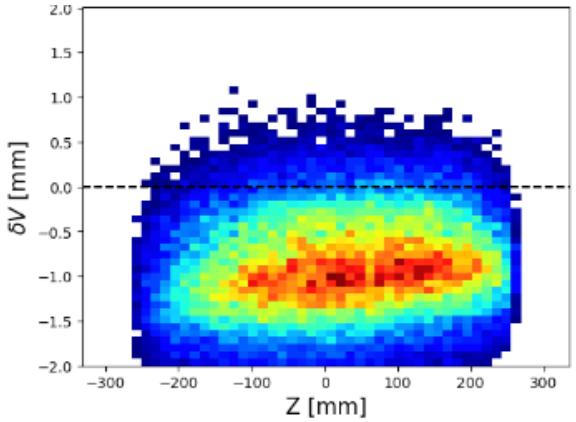
V residual vs z

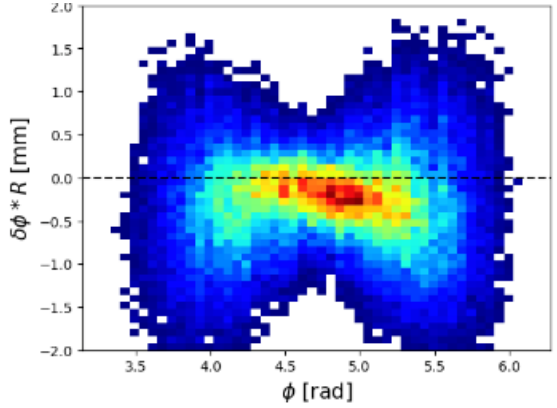
Rϕ residual vs ϕ

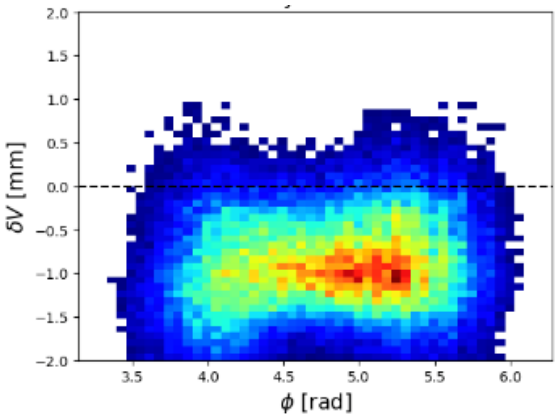
V residual vs ϕ

Before alignment

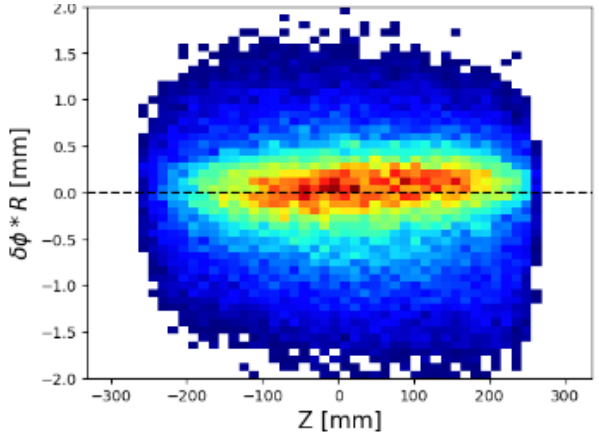


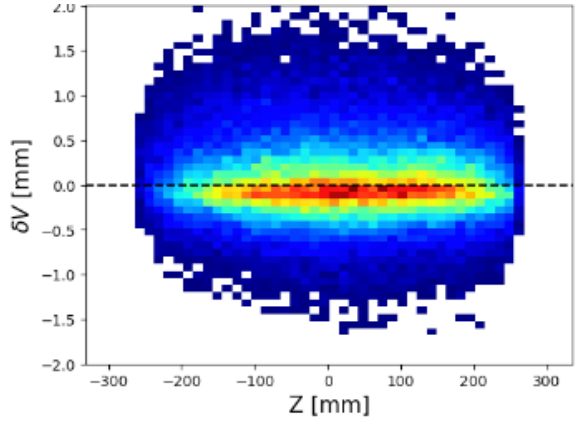


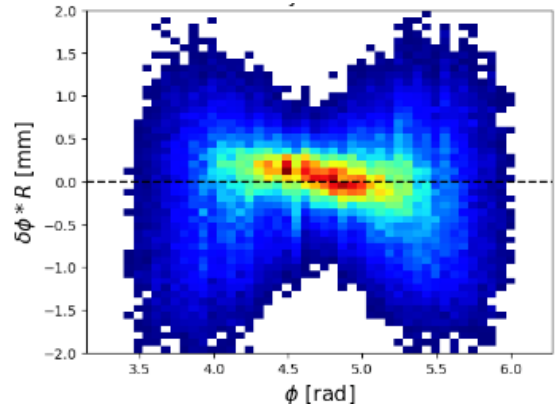


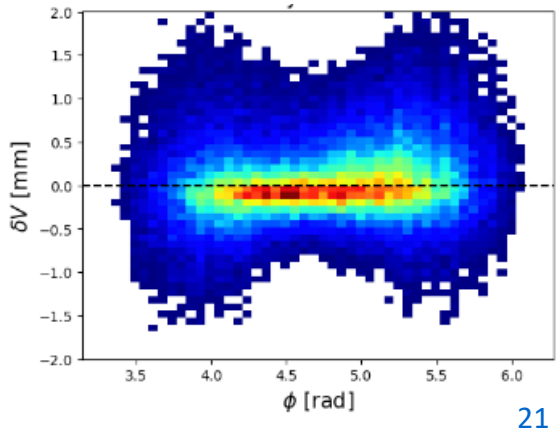


After alignment

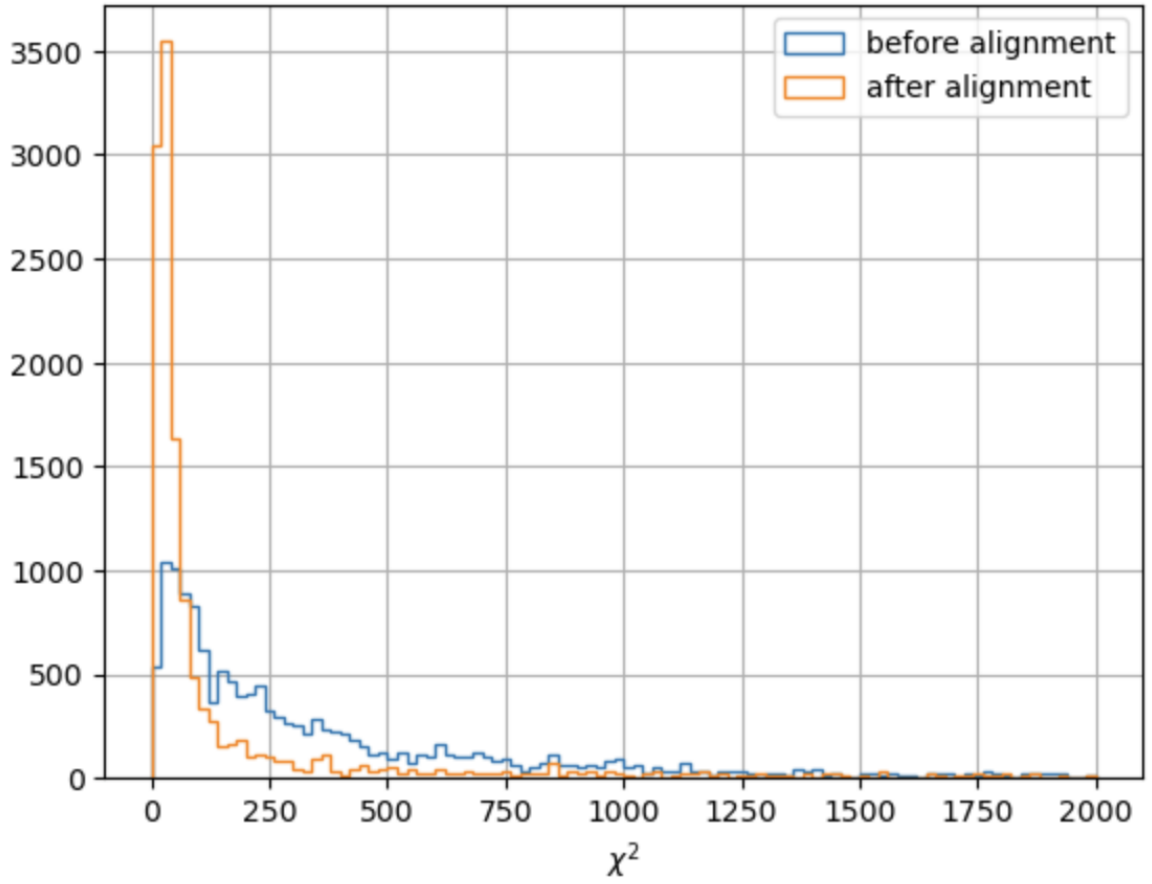








Improvement of chisquare distribution



χ^2 distribution improved significantly after alignment

Remaining misalignment effect

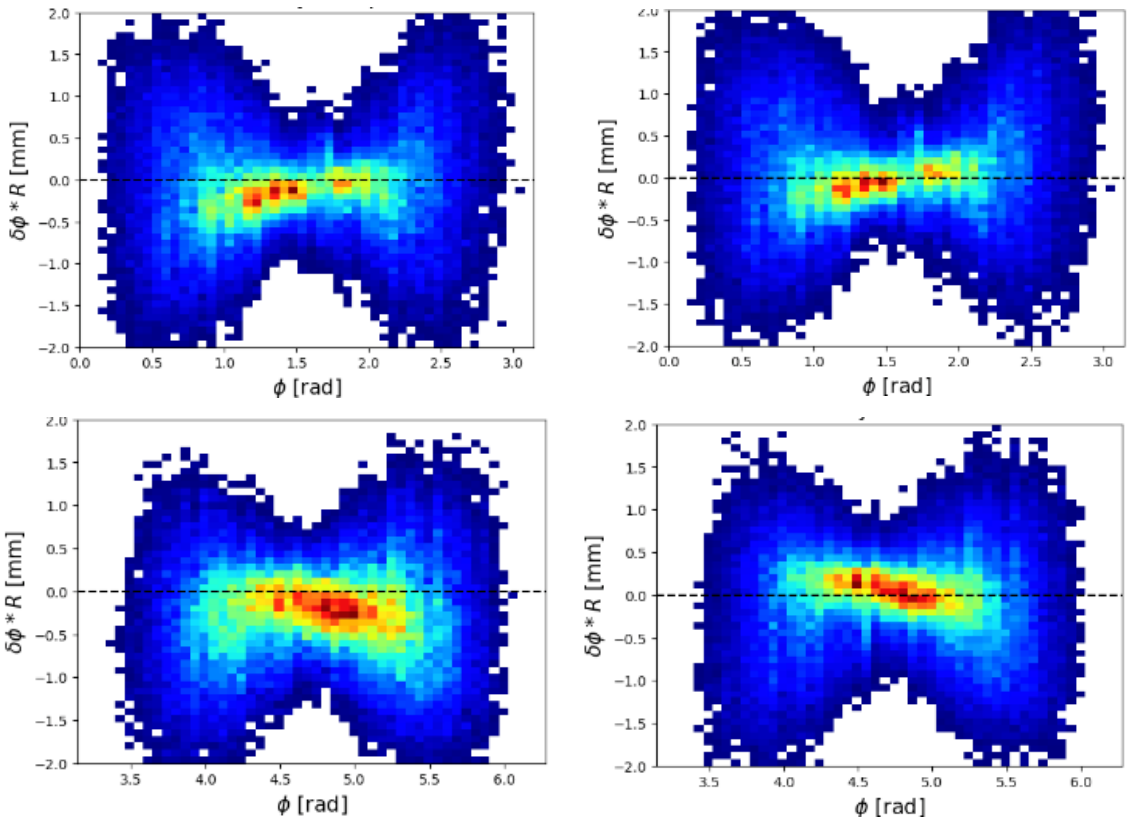
Before alignment

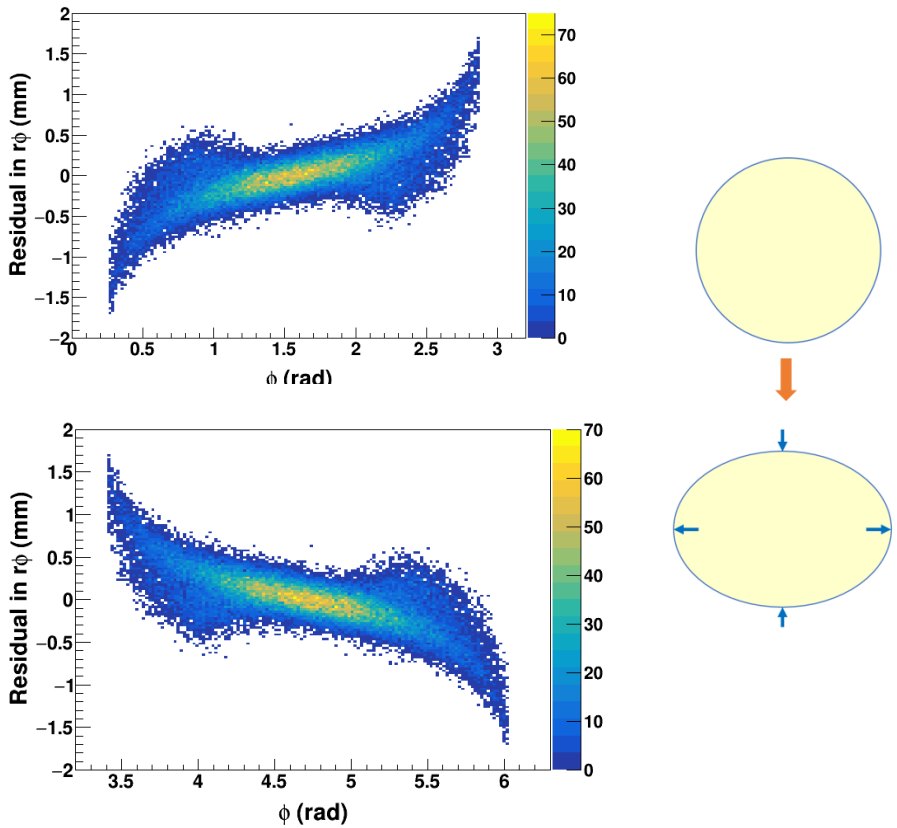
After alignment

Ellipse assumption with toy MC
(400 μm deformation)

L1 top

L1 bottom



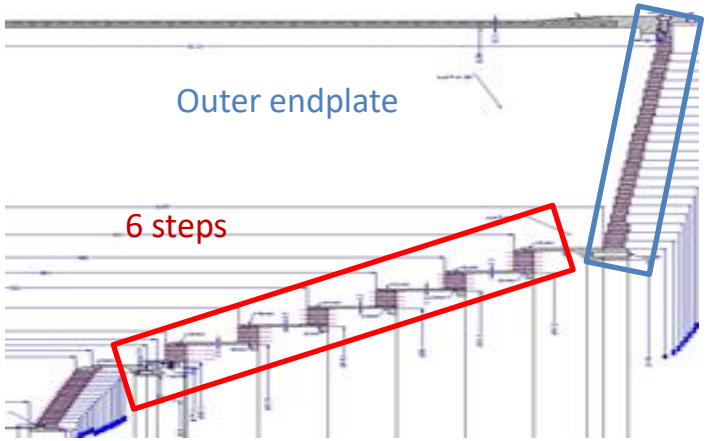


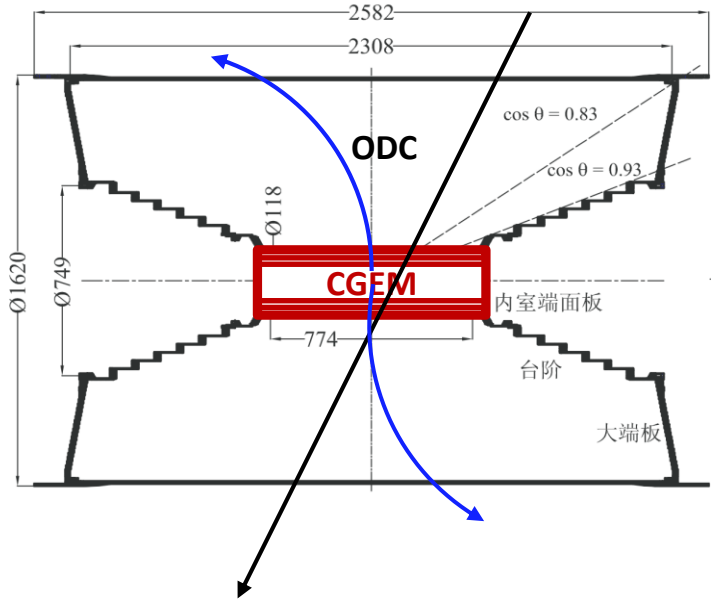
- Mean value of residuals can be well aligned, but dependency with ϕ not improved
- Possible due to other degree of freedom, further study ongoing

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

Software alignment in preparation





Summary

- Track-based alignment is essential for tracking reconstruction
- BESIII drift chamber is well aligned using residual parameterization and Millepede methods
- Preliminary alignment of CGEM detector performed with cosmic ray data but more work to be done
- Next to do: alignment of CGEM + outerDC

Thanks!