Institute of High Energy Physics,
Chinese Academy of Sciences

Track reconstruction and Performance of COMET

Tianyu XING, Yao ZHANG, Ye YUAN
from IHEP, CAS

Workshop of Tracking in Particle Physics Experiments

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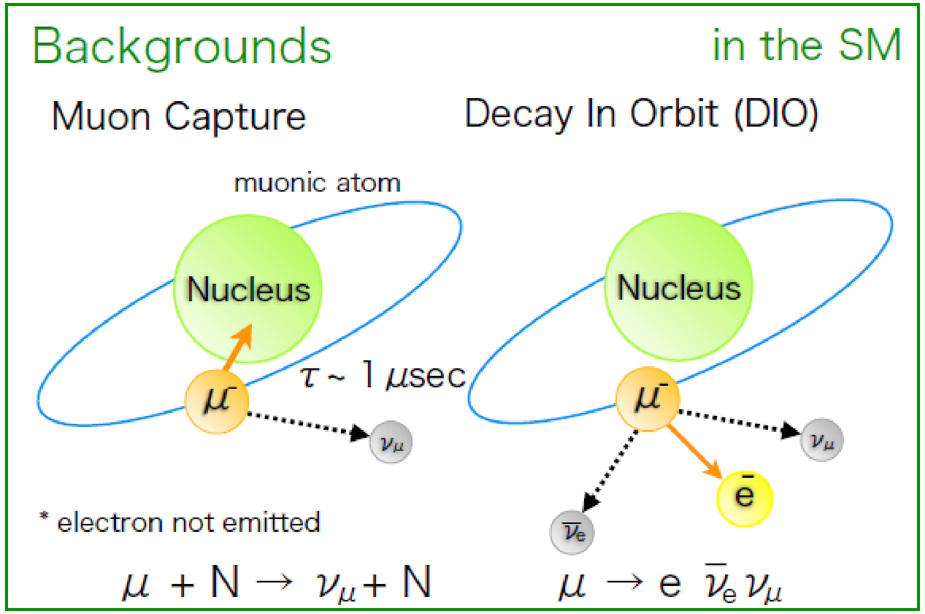
CONTENTS

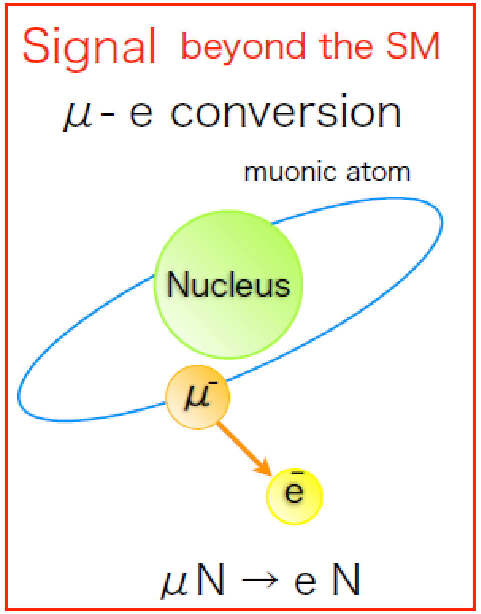
Introduction

COMET(COherent Muon Electron Transition)

- Search for μ-e conversion in Japan J-PARC hadron hall
  - Using $8\ GeV, 56\ kW$ proton beam to generate muon beam
- Experiment Target:
  - $B(\mu^- + Al \rightarrow e^- + Al) = 2.6 \times 10^{-17}$ (S.E.S)
  - This is 10000 times improvement!

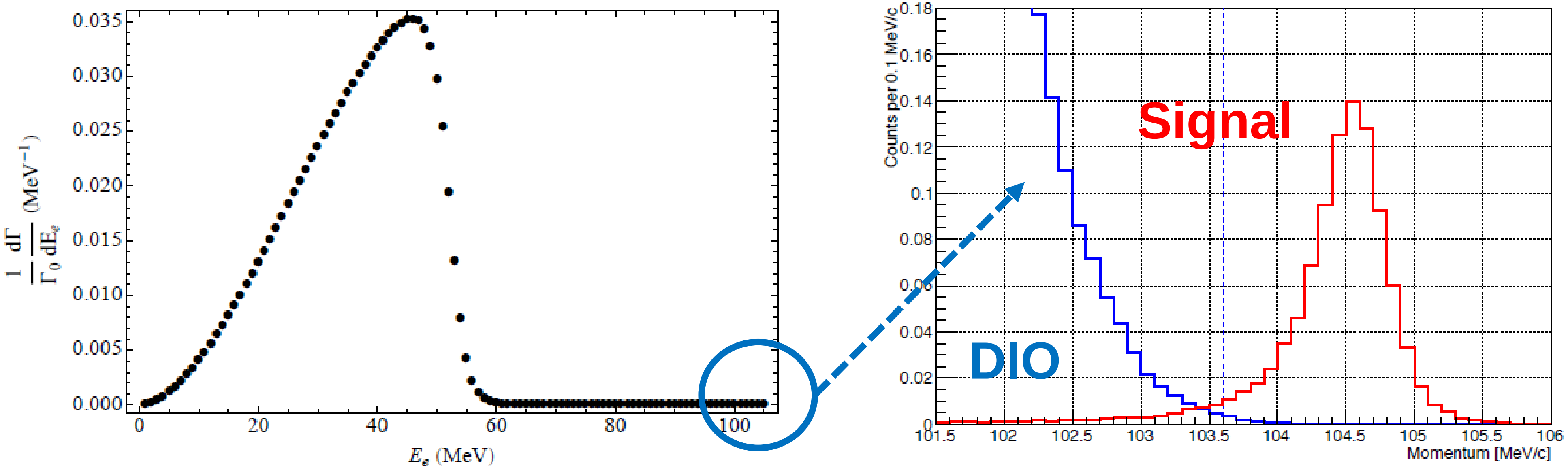
- Atomic capture of μ-
- μ-e conversion signal is mono-energetic ~105 MeV





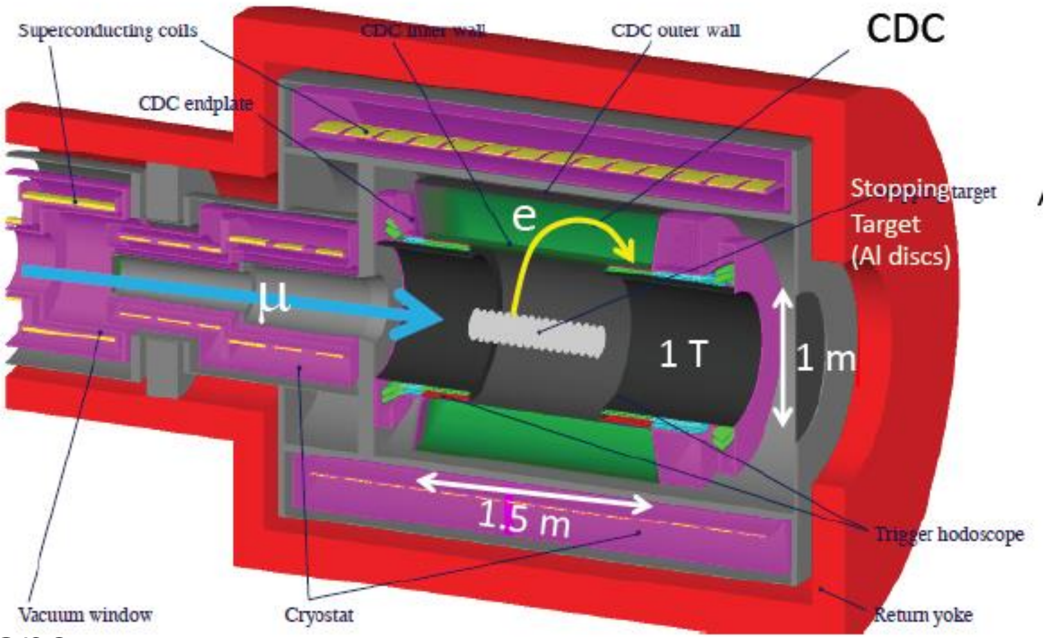
Introduction

- **Intrinsic physics background**
- Mostly from muon decay in orbit (DIO)
  - Calculated by Czarnecki with radiative correction. Branching ratio drops very quickly near end point
  - **Momentum resolution** required to be good enough



Introduction

The Cylindrical Detector system (CyDet) is specially designed for Phase-I. Consists of:



- Cylindrical trigger hodoscope (CTH):
  - Two layers: plastic scintillator for trigger time and Cerenkov counter for PID.
  - Finemesh PMT readout
  - 4-fold coincidence trigger
- Cylindrical drift chamber (CDC):
  - 20 stereo layers: z information with few layers' hits.
  - Helium based gas: minimize multiple scattering.
  - Large inner bore: to avoid beam flash and DIO electrons.
  - Momentum resolution: 200 keV/c (for p=105 MeV/c)
- Stopping target
  - Aluminum target with 17 disks
  - 100-mm radius, 0.2-mm thickness, 50-mm spacing.

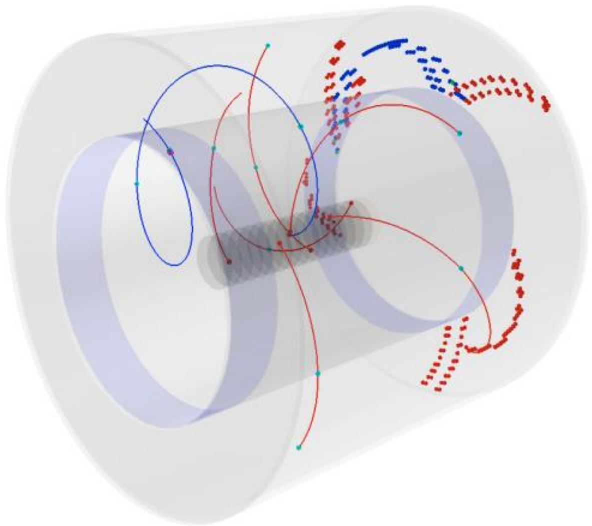
Introduction

Challenges of tracking algorithm of CDC:

- All stereo layers which can’t provide information in z axis directly
- No vertex constraint
- No seed from sub-detector could be used
- Tracks with low transverse momentum is circle inside detector
- Overlapping between tracks from different turns

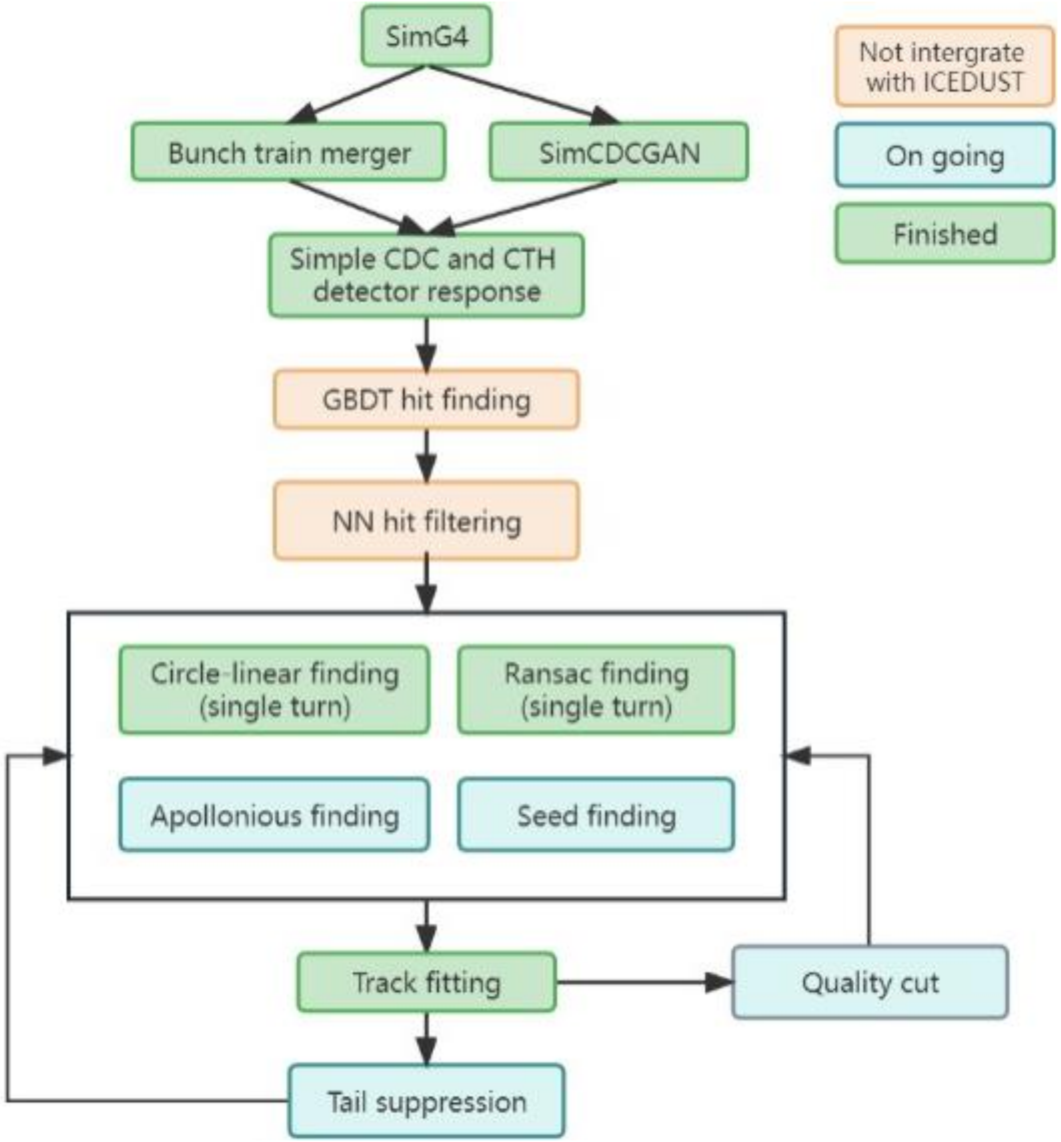
Major problem of tracking algorithm of CDC

- Calculate track parameters of seed
- Distinguish tracks from different turns
- High momentum tail of reconstructed tracks



Introduction

- Track finding algorithm
  - Based on RANSAC algorithm
- Track fitting algorithm
  - Using Genfit2
- Track reconstruction software
- Test samples
  - Full simulation based on Geant4
  - Only signal events
  - After acceptance cuts and trigger



Track Finding

Random Sample Consensus (RANSAC):

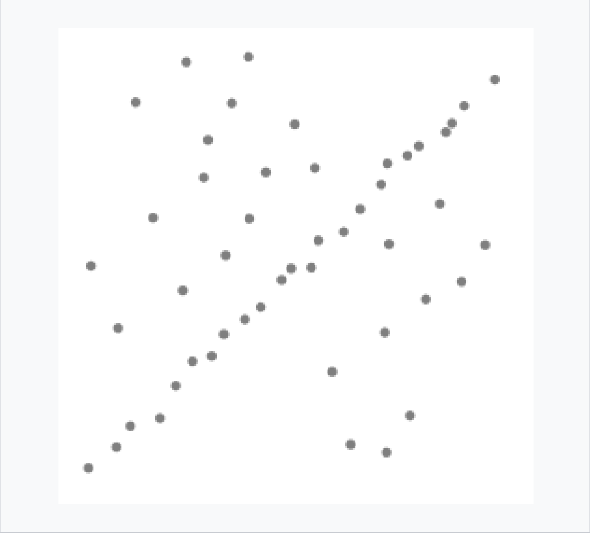
- An iterative method to estimate parameters of a mathematical model from a set of observed data that contains outliers
- The data consists of "inliers" whose distribution can be explained by some set of model parameters, and "outliers" which are data that do not fit the model.
- Assume that give a (usually small) set of inliers, there exists a procedure which can estimate the parameters of a model that optimally explains or fits this data.

Could be used to distinguish hits from different turns

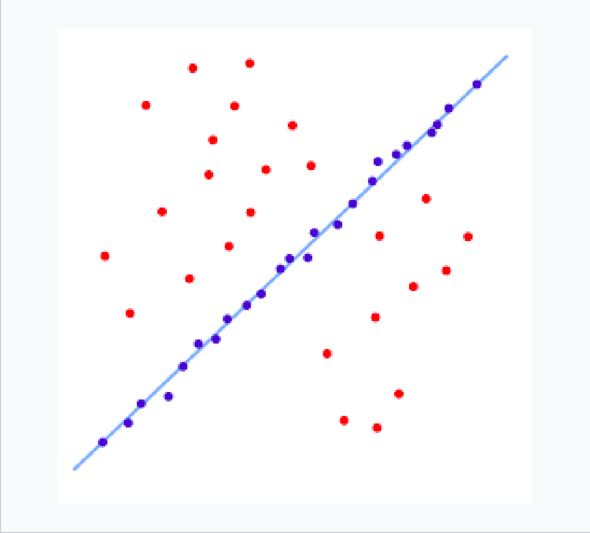
Track Finding

Random Sample Consensus (RANSAC):

1. Select a random subset of the original data (5/6 hits combination)
2. A model is fitted to the data set (helix fitting)
3. Points that fit the model well are considered as part of the set (pick-up signal hits)
4. The model is reasonably good if many points have been classified (track candidate)
5. The model may be improved by reestimating it using all sets (track fitting with genfit)



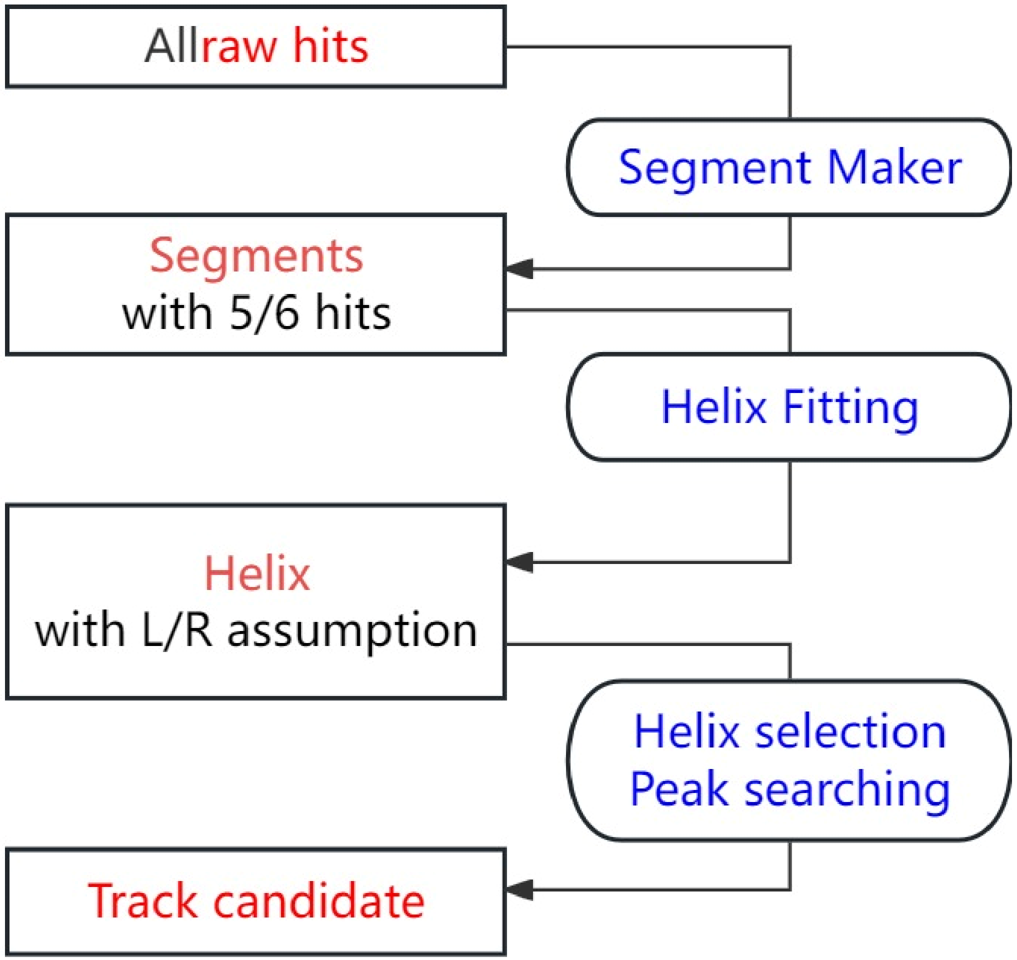
A data set with many outliers for which a line has to be fitted.



Fitted line with RANSAC; outliers have no influence on the result.

Track Finding

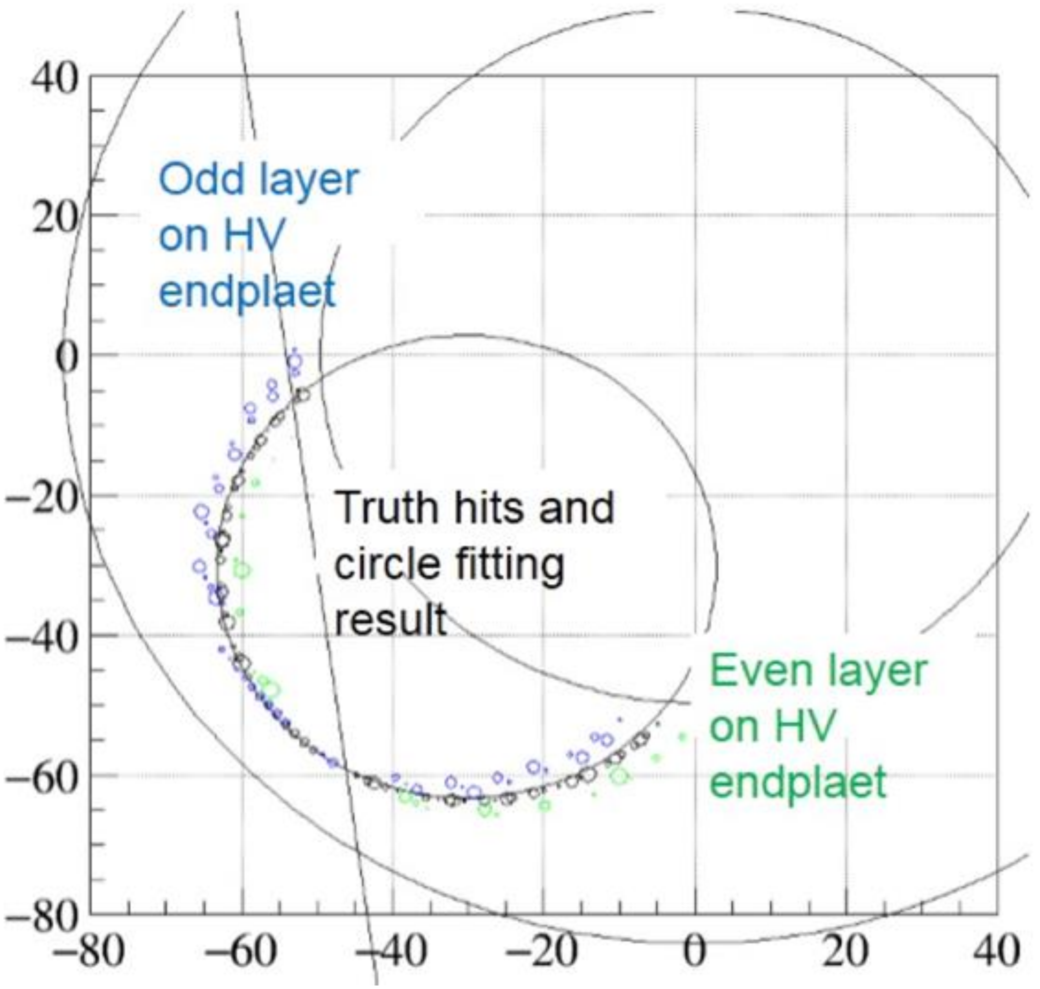
- Helix fitting algorithm
  - Solve the problem of track parameter calculation
  - Provide quality cuts
- Peak searching of helix
  - Eliminate “bad” helix (wrong L/R, with hits from different turn, fitting failed,….)
  - Select helix with hits from same turn



Circle Fitting

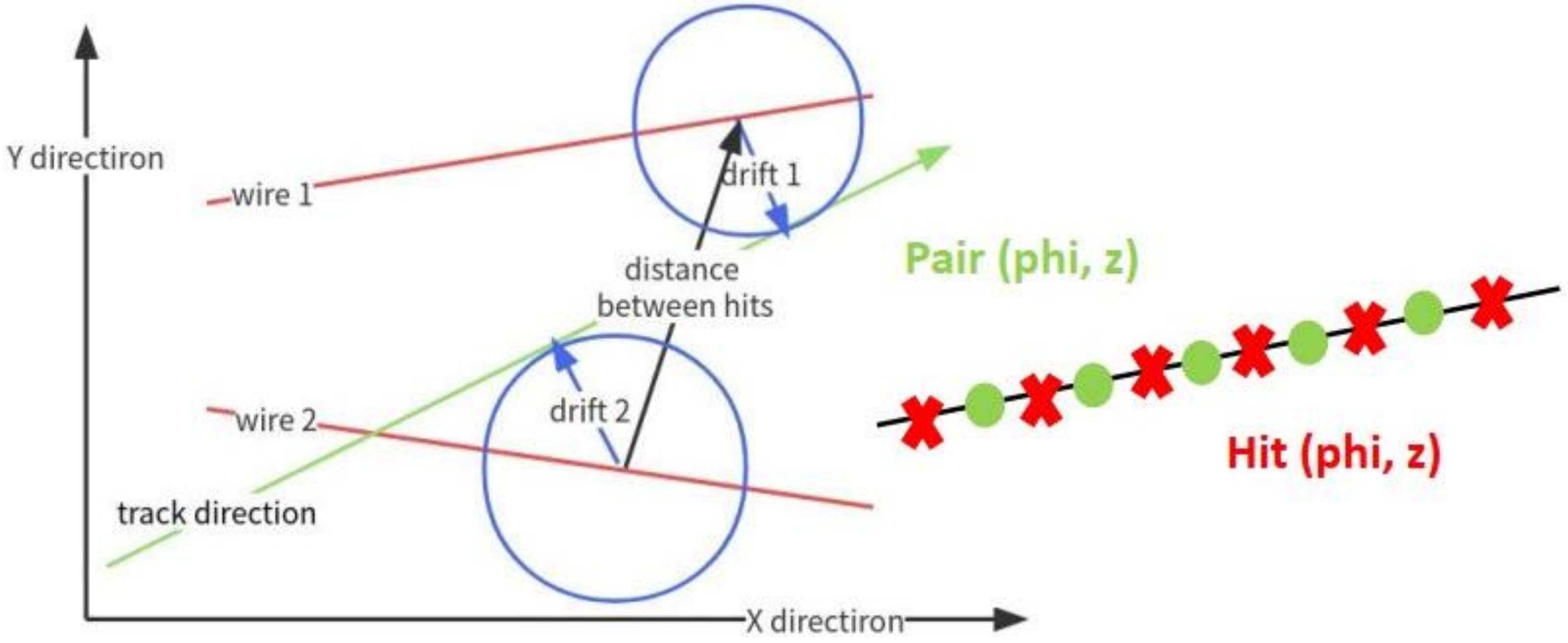
- **Using wire position on endplate**
  - No super layer to provide XY position of hits
- **Circle fitting on odd/even layers** respectively
  - Different stereo angles

1. Least Square circle fitting without drift
2. Circle fitting with Tminuit for odd and even layers respectively.



Z Position Calculation

- For two hits from adjacent layers:
- $F(\overrightarrow{w_1}, \overrightarrow{w_1}, d_1, d_2, \varphi_{track}, Z_{pair}, \Delta Z, LR), Z_{pair} = \frac{Z_1+Z_2}{2}, \Delta Z = Z_1 - Z_2$
- Pair Z could be calculated with different LR assumption
- Linear fitting of φ and Z could be used to calculate hit z position
- Hit z position used to update circle and helix fitting



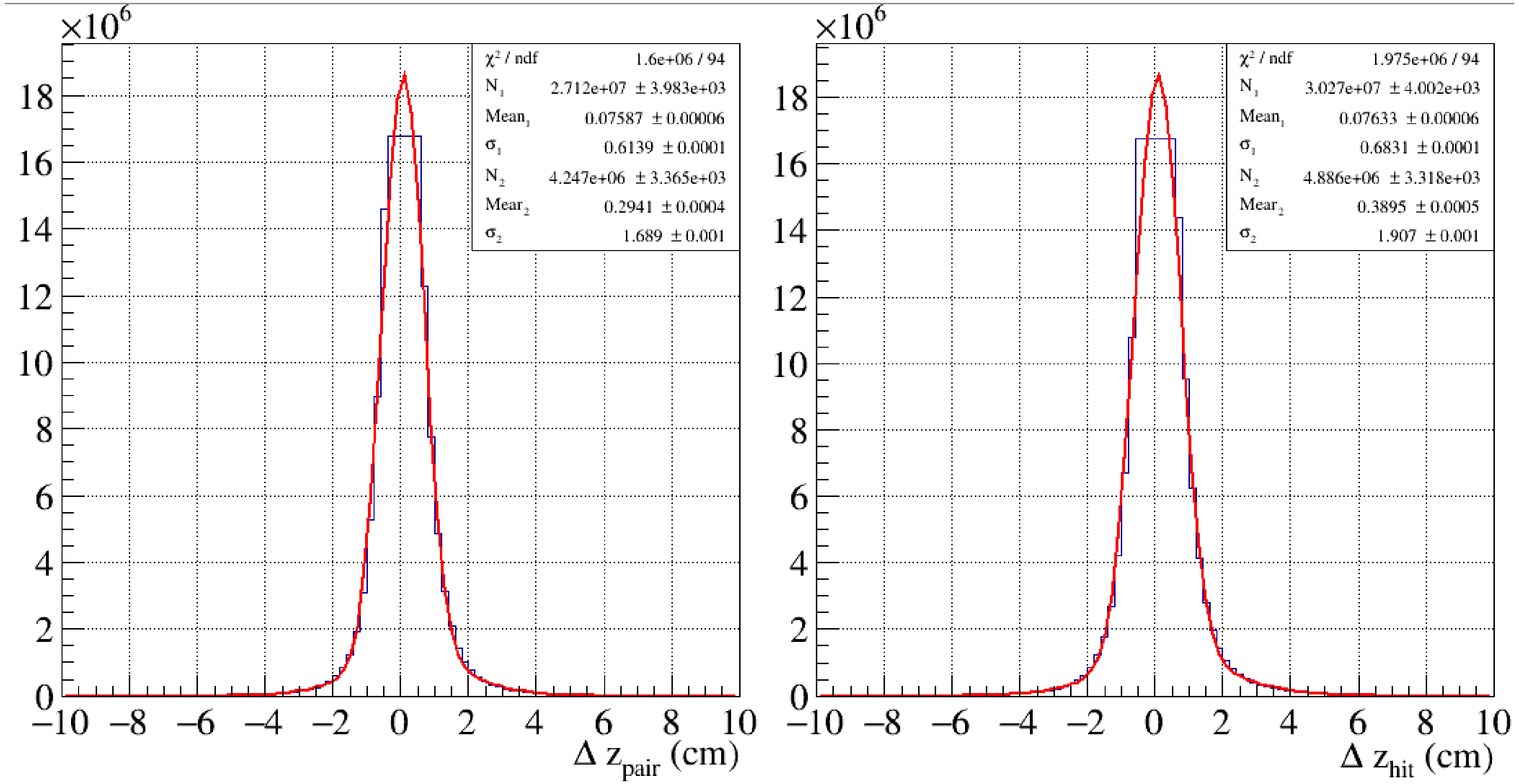
1. Circle fitting
2. Pair z calculation
3. Phi-z linear fitting
4. Hit z calculation
5. Helix fitting
6. Iteration of 1-5

Helix fitting and cuts

- Helix parameters of seed:
  - Circle center and radius from circle fitting
  - d_0 and tanλ from φ-Z linear fitting
- Helix fitting with TMinuit
- Quality cuts used to eliminate “bad” helix
  - Fitting successful and converged
  - Pz direction (given by CTH)
  - Fitted L/R
  - χ^2
  - ….

Performance

- Resolution:
- Circle center: 3.7mm
- Circle radius: 2.5mm
- Z_{pair}: 8.4mm
- Z_{hit}: 9.5mm

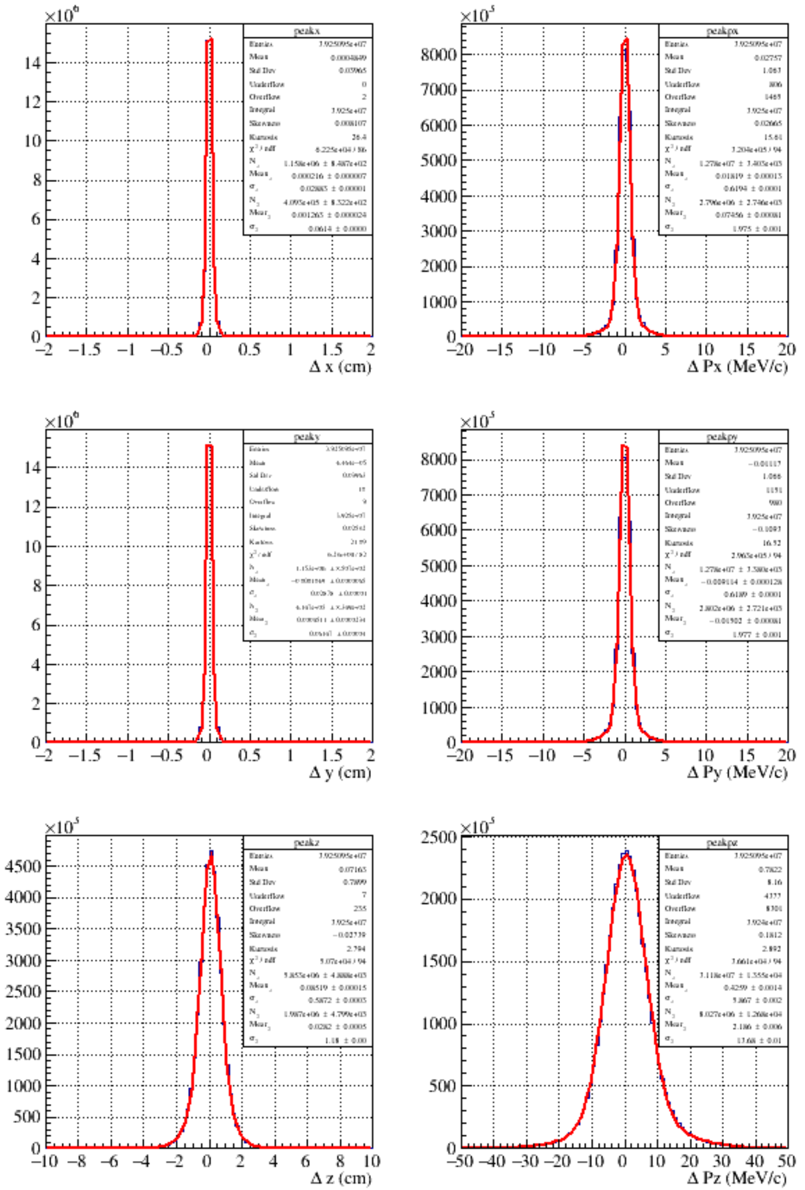


Performance

- After quality cut:

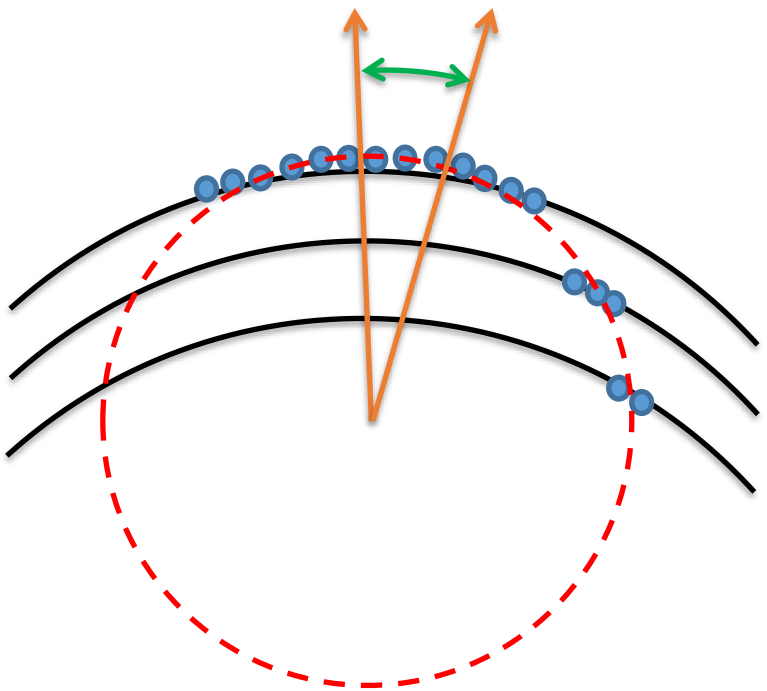
	Signal helix	Bkg Helix
Single Turn	97.5%	1.85%
Double Turn	75%	0.15%

- Resolution:
- $\sigma_x = 0.4\ mm, \sigma_y = 0.4mm,\ \sigma_x = 7.8mm$
- $\sigma_{px} = 1\ \text{MeV}, \sigma_{py} = 1\ \text{MeV},\ \sigma_{pz} = 8.1\ \text{MeV}$



Segment Maker

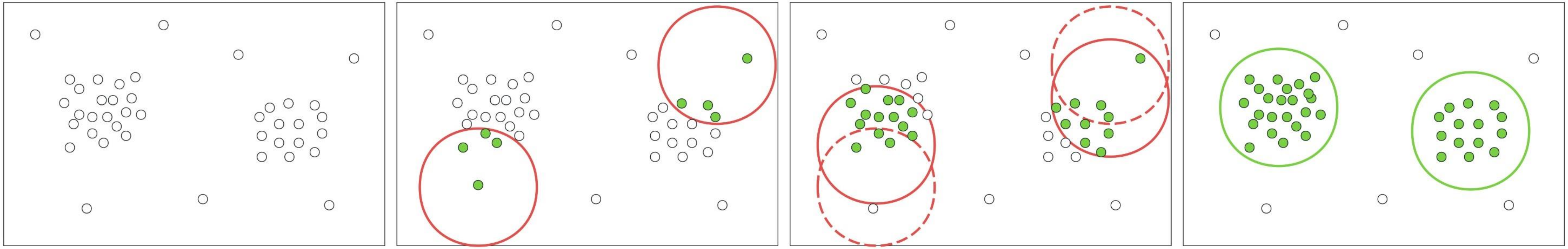
- Big problem1: too many fitted helix!
- $N_{seg} = N_{hits1} * N_{hits2} \ldots * N_{hits6}$
- $N_{helix} = 64*N_{seg}$ or $32*N_{seg}$
- Too many segments (>1000) due to N_{hits6}
- A cut of theta is added to reduce N_{hits6}
- Big problem2: bad SNR
- Strict quality cut of helix fitting



	Ratio	Effiency	N_{segs}	SNR	SNR after cuts
Single Turn	14.0%	96.1%	401	1/60	1.1
Double Turn	4.3%	99.6%	21k	1/1891	0.268

Peak searching

- Find peaks in parameter space of fitted helix
  - Find helix near to initial peak
  - Update peak with selected helix
  - Iteration until peaks don’t move
- Use peaks to construct track candidates
  - Pick up hits
  - Track parameters

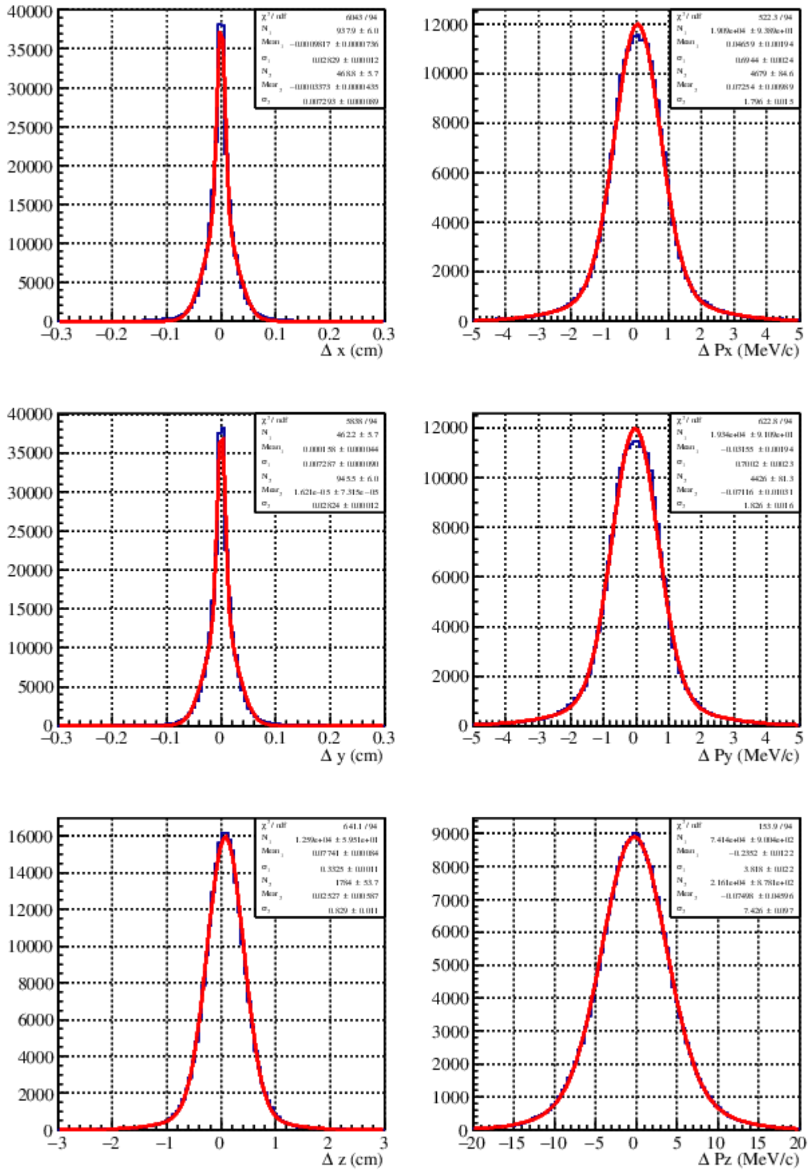


Performance

- Generate segments efficiency: 96.1%
- Peak finding efficiency: 99.99%
- Track finding efficiency: 96.1%
- Resolution:

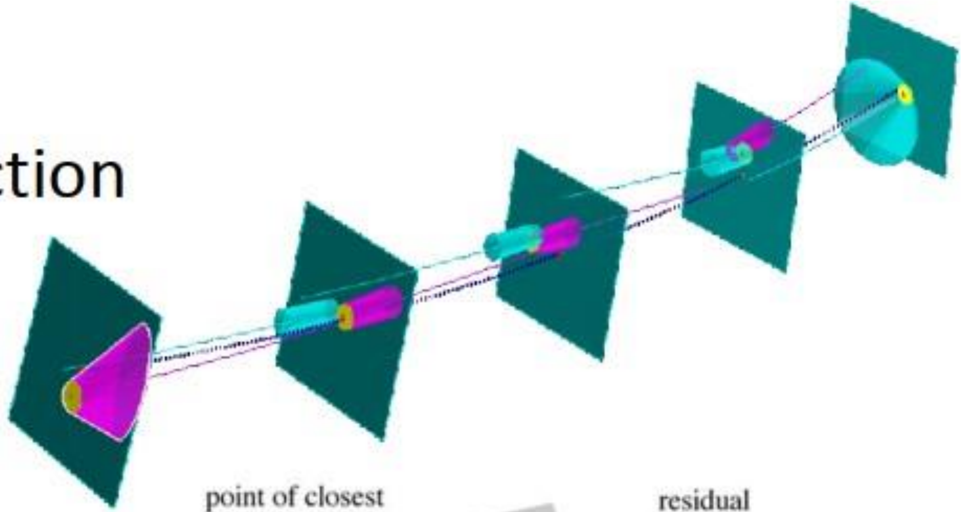
$\sigma_x = 0.24$ mm, $\sigma_y = 0.24$ mm, $\sigma_y = 4.3$ mm,

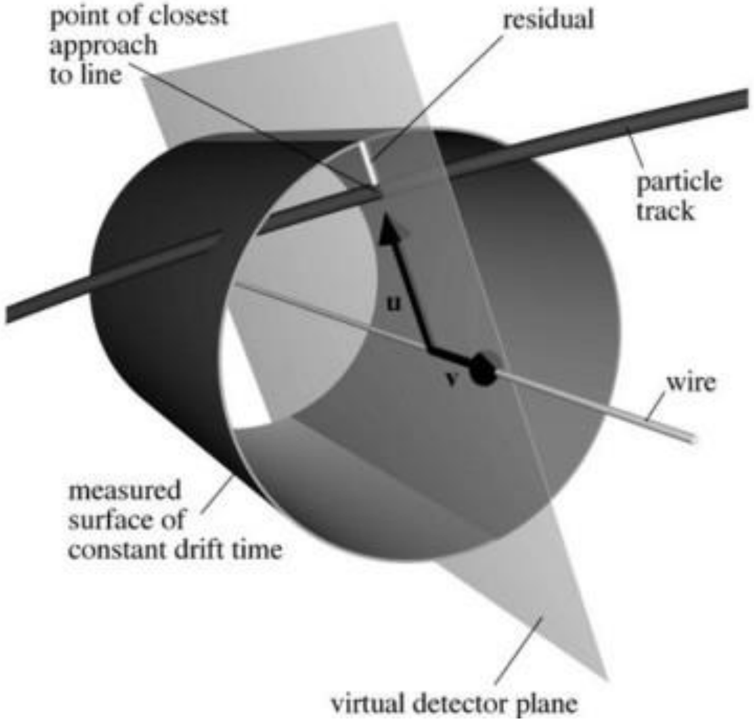
$\sigma_{px} = 1.0$ MeV/c, $\sigma_{py} = 1.0$ MeV/c, $\sigma_{pz} = 4.9$ MeV/c



Track Fitting

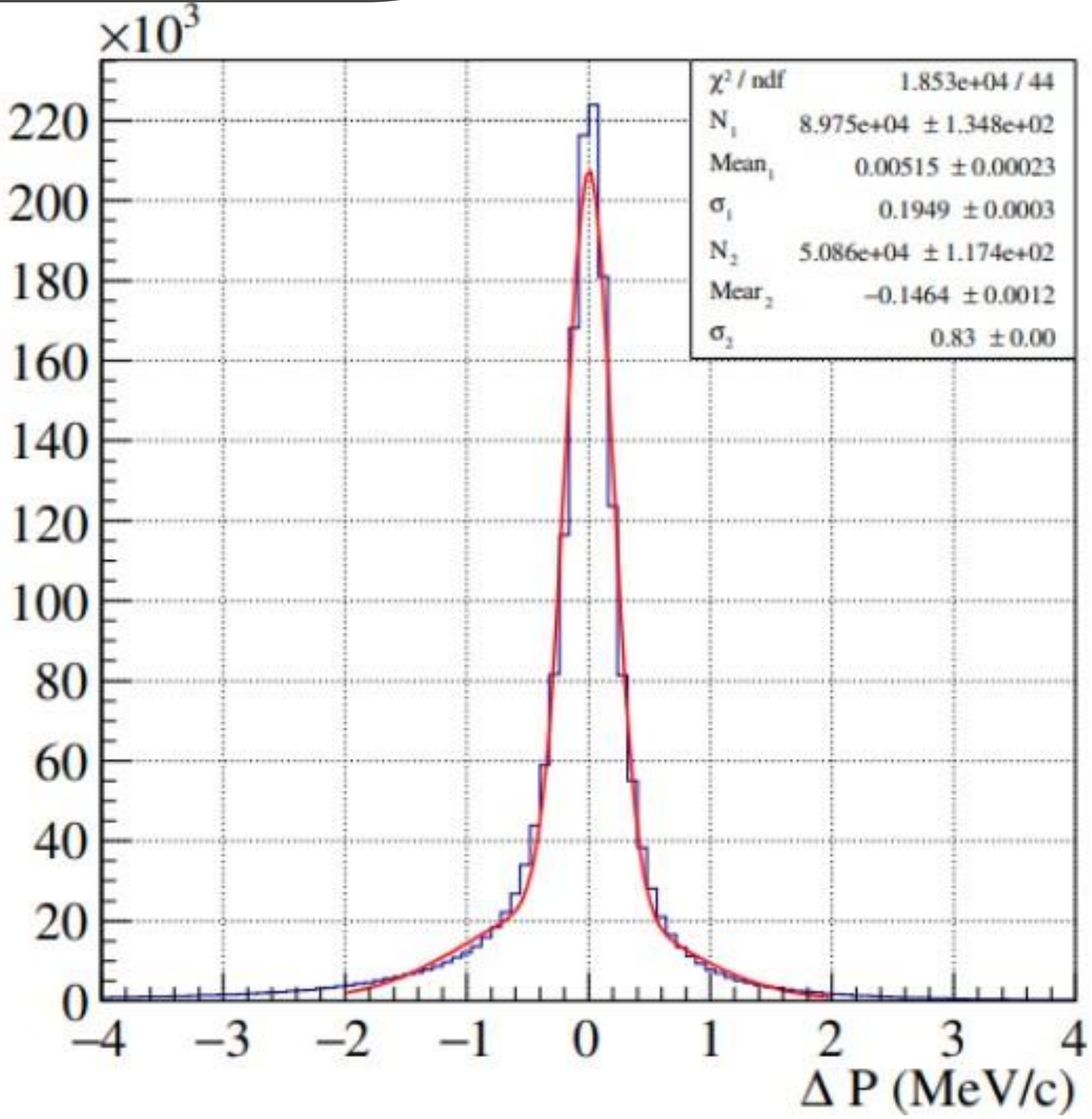
- Kalman fitter is widely used in reconstruction algorithm
- Based on GenFit (https://github.com/GenFit/GenFit)
- An experiment-independent generic track fitting framework
- Official track fitting for BelleII, also used by PANDA, CEPC,BESIII, GEM-TPC etc





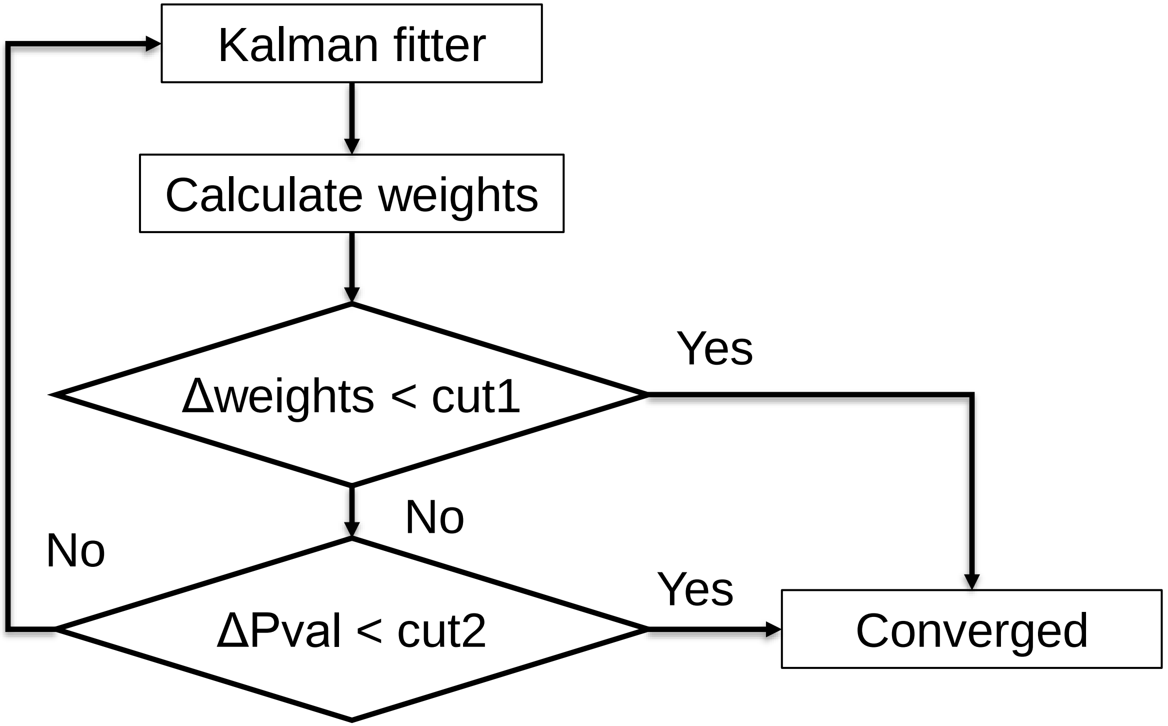
Performance

- Test the ultimate performance
  - No noise hit
  - 100% of finding efficiency
  - No resolution of finding
- Efficiency: 93.38%
- Momentum resolution: 523keV/c
- Body resolution: 195keV/c
- Tail events: 1.2%



Efficiency

- Efficiency of fitted: 99.998%
- Efficiency of converged: 93.38%
- Whether converged is controlled by two cuts inside Genfit2
- Efficiency increase to 99.4% after optimization



Tracking algorithm

- Single-turn events, without noise hits
- RANSAC track finder, track fitting with Genfit2
- No quality cut of fitting chisqure

	Geometrical Acceptance	Tracking		Totally	Tail	Mom resolution (body/tail)
		finding	fitting			
Single Turn	14.0%	96.2%	99.4%	12.7%	1.6%	214keV/533keV
		95.6%				

Conclusion

- The **RANSAC track finding algorithm** has basically finished
- The **full Tracking algorithm** for CyDet is available now
- The helix fitting of track segment in CDC shows good performance
- The **efficiency and resolution** of tracking is good after preliminary optimization
- Many optimizations are on-going

THANK YOU !