Hough transform based track finding for BESIII
&
Tracking of COMET Drift Chamber

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Hough Transform in BESIII MDC Tracking

On behalf of BESIII Tracking Group

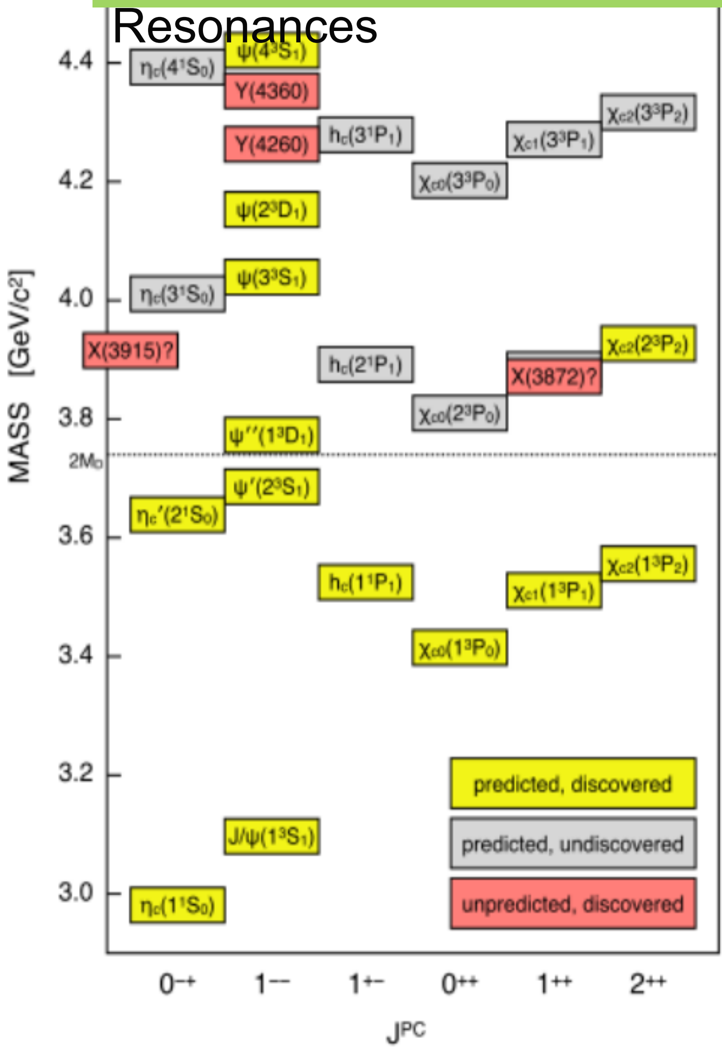
Outline

- Introduction to BESIII & MDC tracking
- Track finding based on Hough Transform
- Tracking performance
- Summary

Physics at BESIII

τ-charm factory, check and develop QCD at low energy

Charmonium(-like) Resonances



Search for and understand new charmonium-like resonances (XYZ particles)

- Are they new hadronic states?
- What're their quantum numbers?
- Their decay modes?

Study the decay at cc threshold (J/ψ)

- Search for new resonances in the decay (PWA)
- Measure the ordinary resonances' parameters, the decay mechanisms…

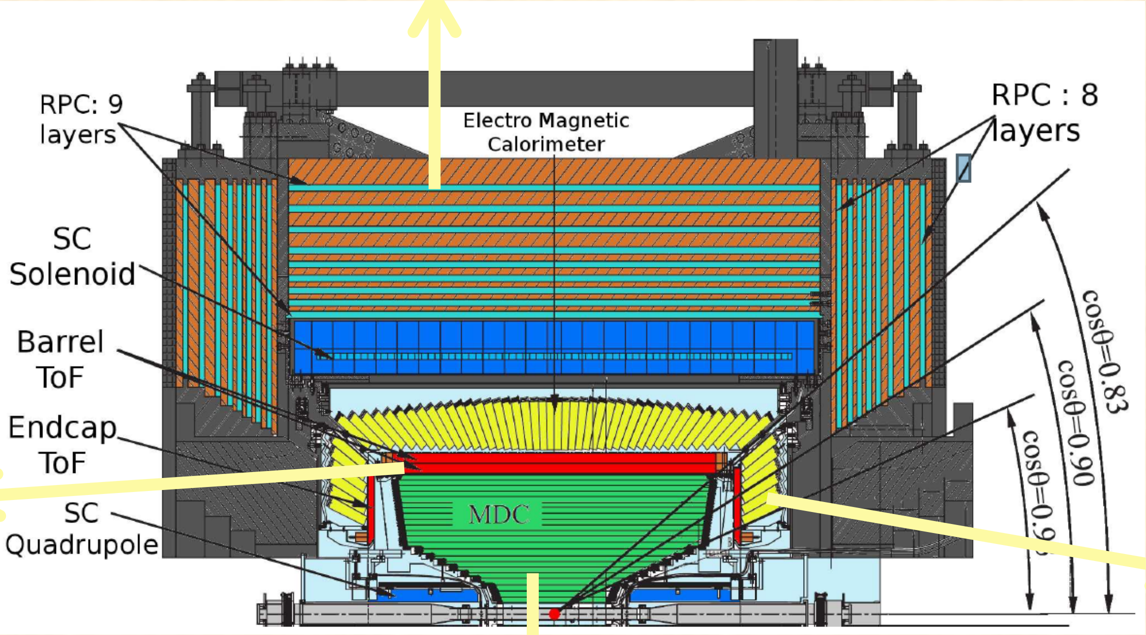
Precision measurements in D/D_s decays

Precise measurements of τ mass and R value in 2-5 GeV region

BESIII Detector

A general-purpose detector located at the upgraded Beijing Electron-Positron Collider (BEPCII), which runs at τ-charm physics energy region

MuC:μ measurement

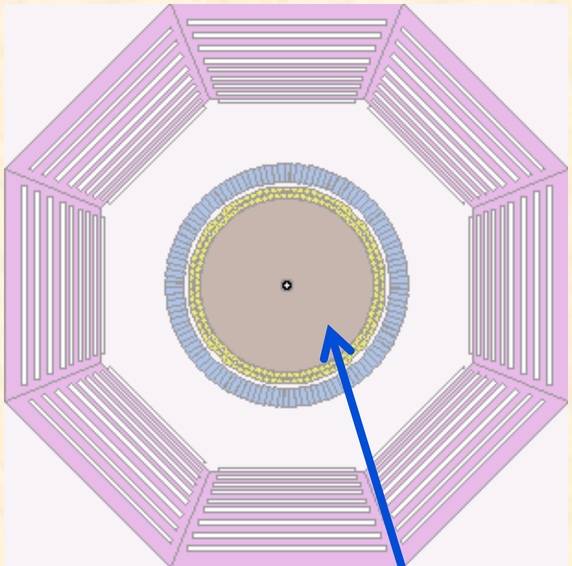


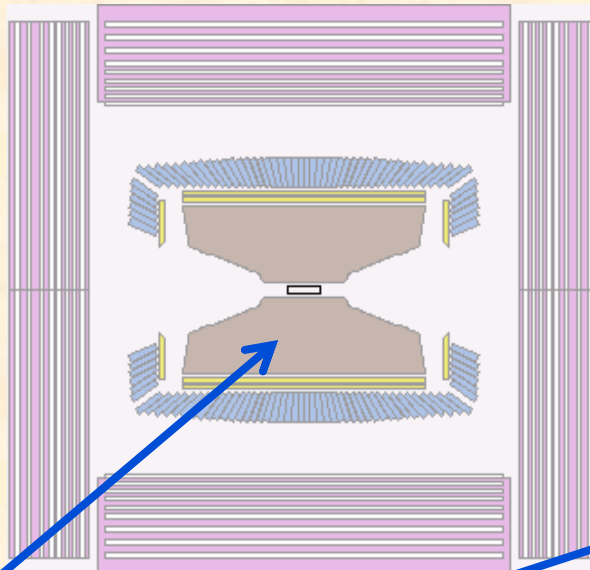
TOF (charged particle): Time of flight mea. for PID

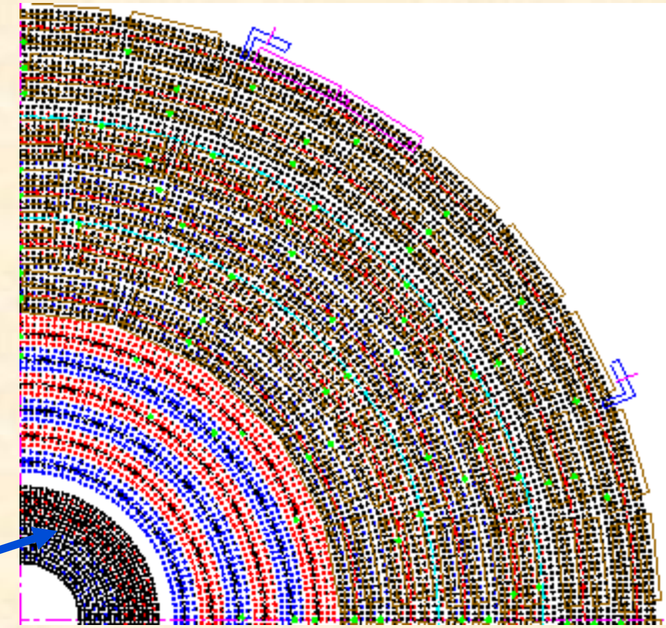
EMC:Energy and position meas.

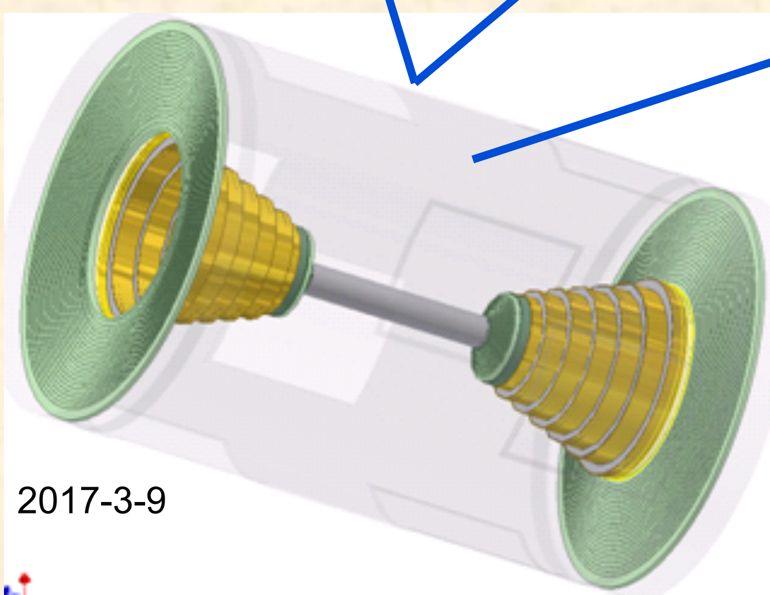
MDC (charged particle): Tracking, momentum mea., dE/dx mea.

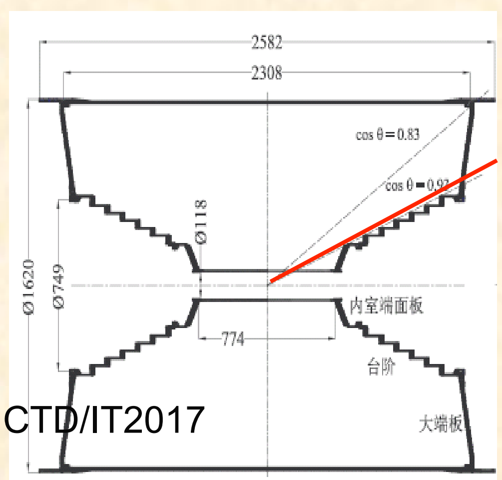
MDC Chamber







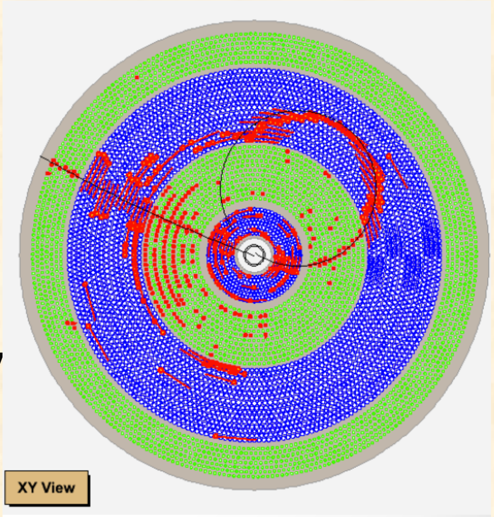




- Measurement of charge particle trajectories within $|\cos\theta|<0.93$
- 6796 cells arranged in 43 circular layers

Introduction to MDC

- BesIII drift chamber
  - Axial and stereo wires
  - Super layers with 4 or 3 layers
  - Continues axial/stereo layers
  - Big gap between axial & stereo lay



- Data quality
  - High background
  - Electron noises
  - non-uniformed magnetic field especially at big dip angle places

Status of current MDC tracking

1. Segment based finders : PAT & TSF
   - Find **segment in super-layers** by template matching or hit searching in window area and then **group** them to track
   - Use axial and stereo super-layers respectively

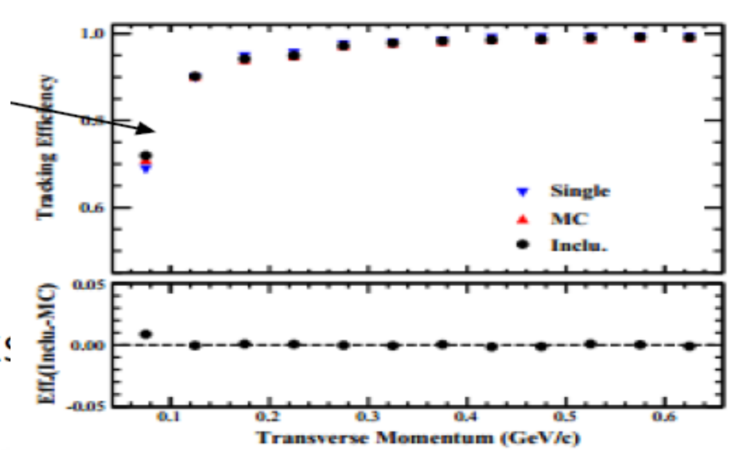
   Sensitive to hit inefficient , detector design and track momentum

2. Road method for curled track: CurlFinder
   - **Select continuous hits** in one layer
   - Pick up hits in road

   Effect by noise or background on the road

- High efficiency and good quality for high Pt tracks
- Low Pt tracking efficiency should be improved

efficiency vs pt



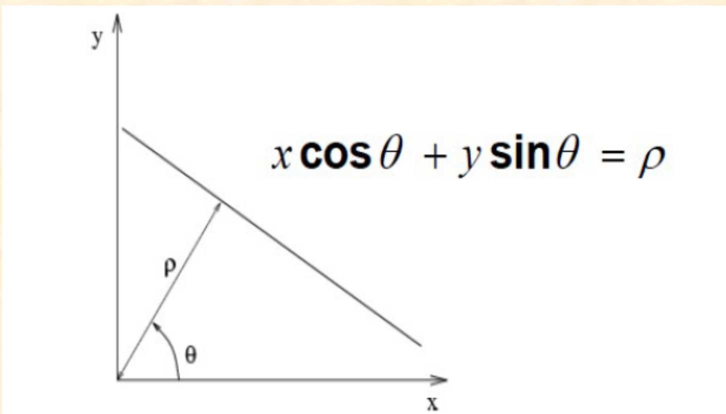
(d) Tracking efficiency of π^- with P_T

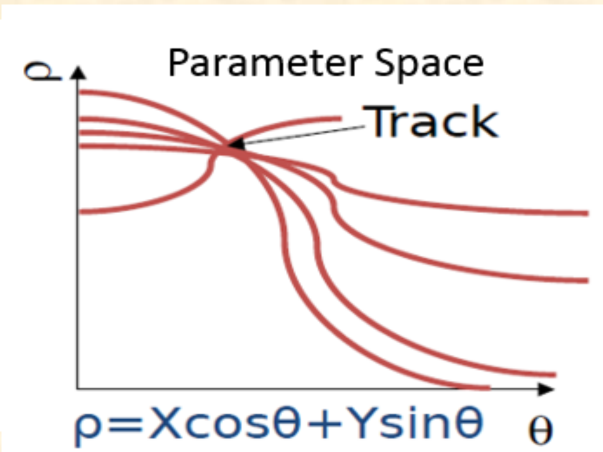
from Yuan Wenlong

Hough Transform

•Transform a point in real space to a parameter space

- ρ=xcos(θ)+ysin(θ)   hits become sine curves

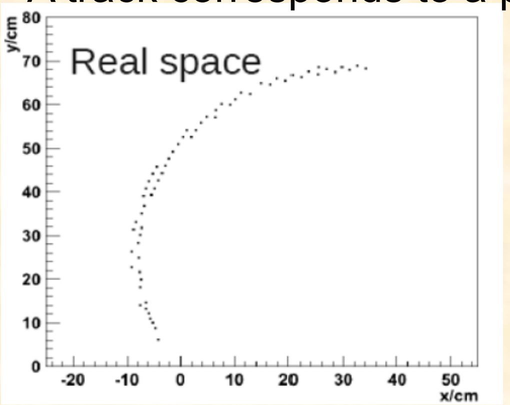


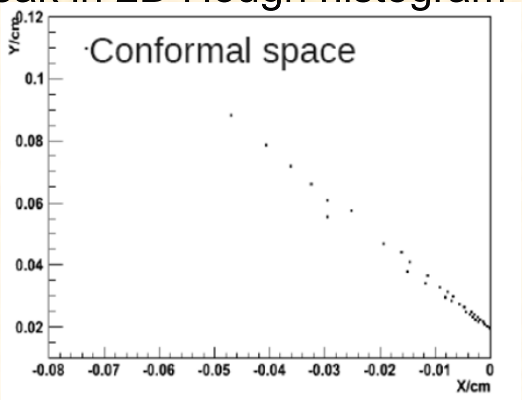


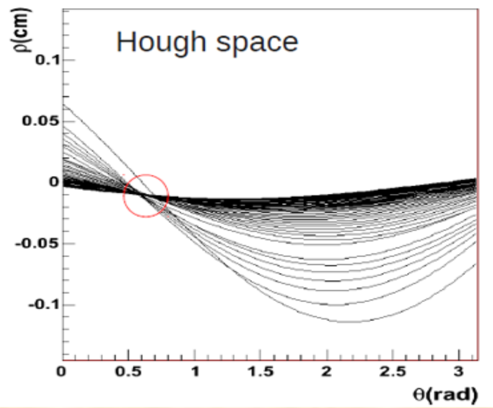
- Global method that can take advantage of all detector and noise resistant

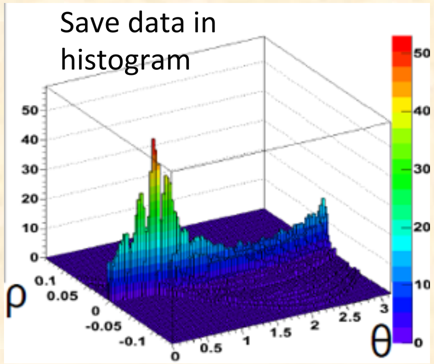
Hough Tracking implemented in MDC

1. Use conformal transform to convert points in a circle track to points on a line in conformal space
2. Use HOUGH transform to convert points on a line to curves in the HOUGH space
3. If curves in HOUGH space focus or aggregate in a small region, it means a track is found
4. A track corresponds to a peak in 2D Hough histogram





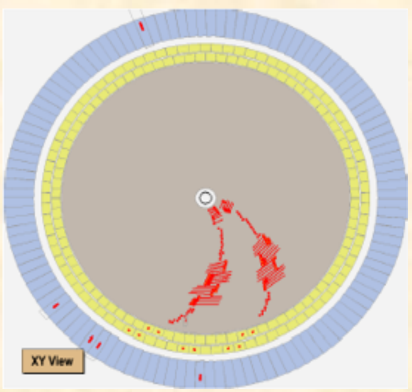


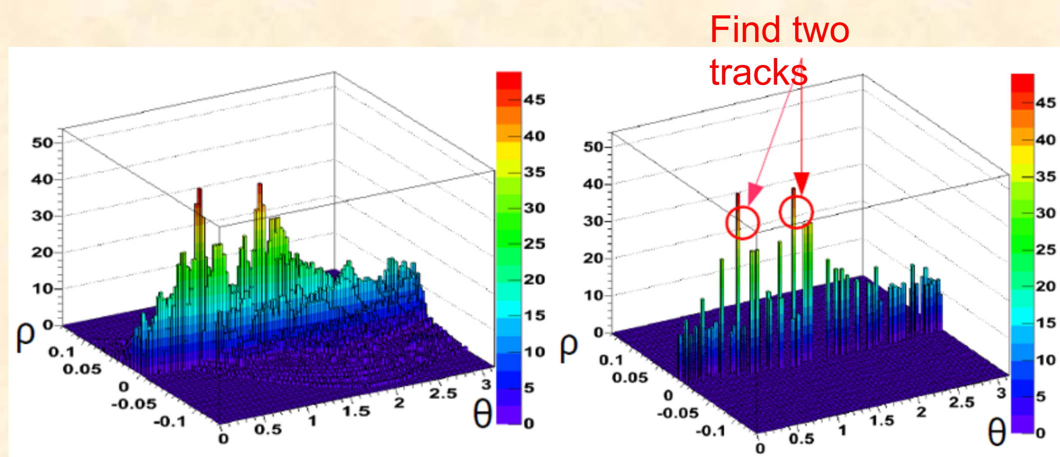


- A peak in 2D histogram corresponding to a track
- Peak finding method is used to determine a track

Method in Peak Detecting

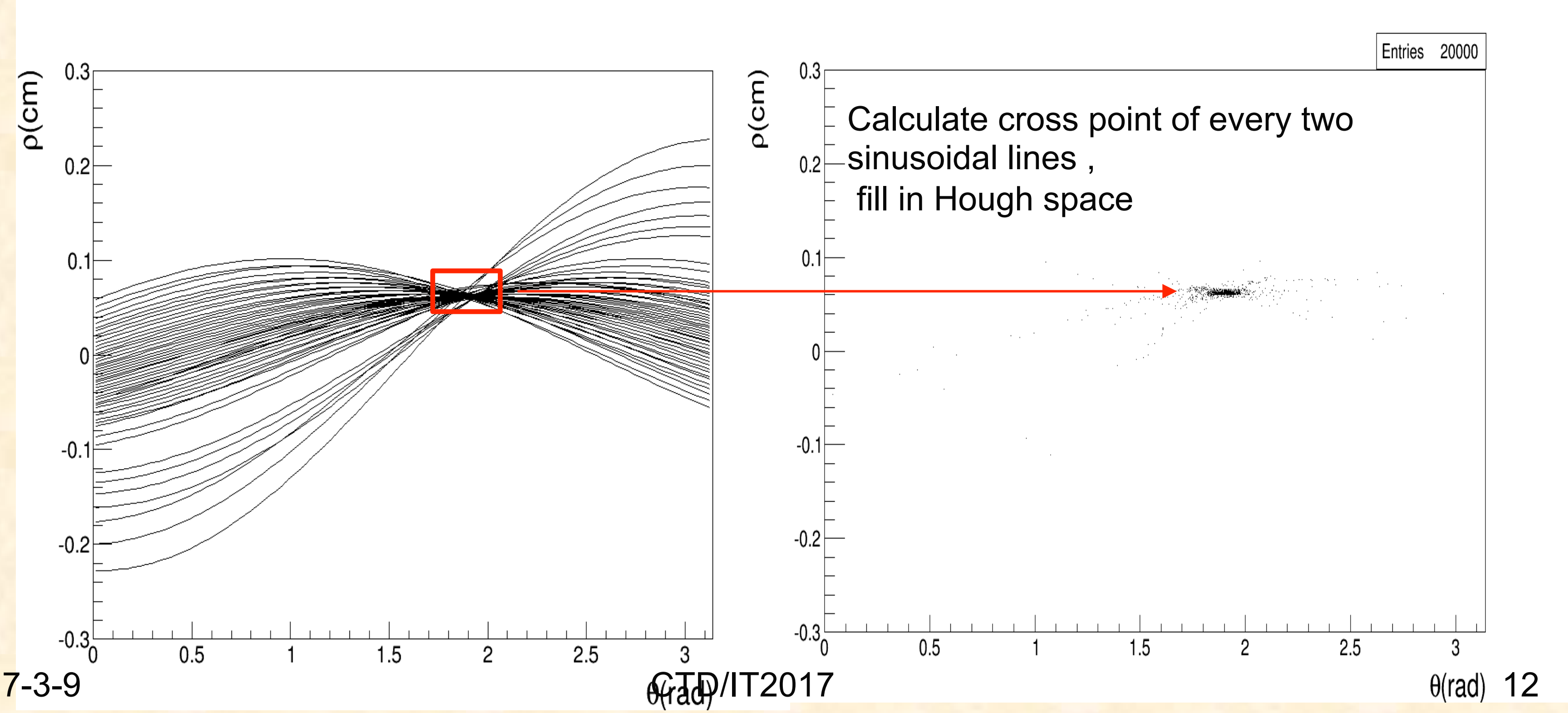
- Find peak in local area -> cell which is higher than the 8 cells around it
- Allow a minimum height
- Merge peaks with cells inside track width->candidate tracks
- Combine candidate tracks with many common hits





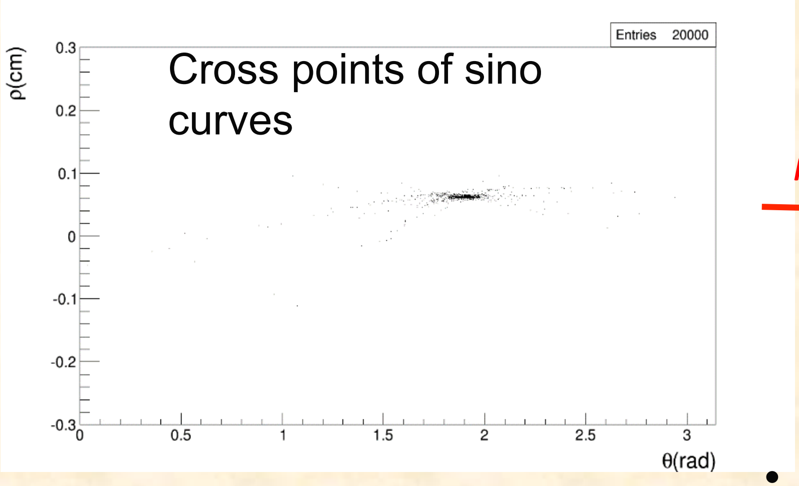
Track Distribution in Hough Space

- A sinusoidal line means a hit
- A track formulates a concentrated area in Hough space
- Imagine rectangle to describe the concentrated area
- We should determine the length&width of the rectangle to collect as more hits as possible simultaneous resist background hit

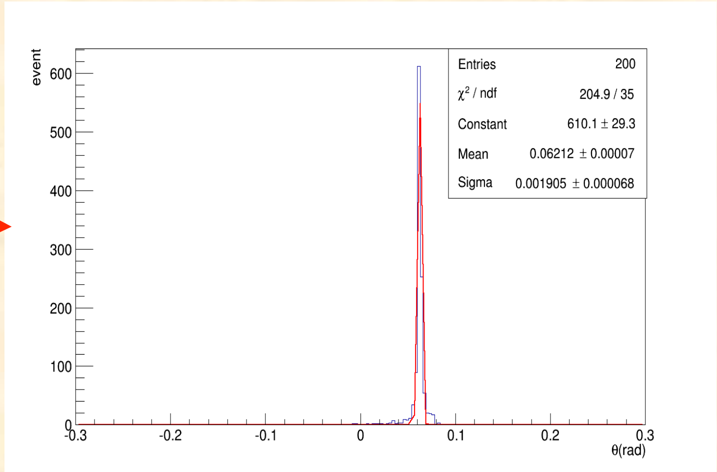


A typical MC track in Hough space

(Pt = 50 MeV, Muon)

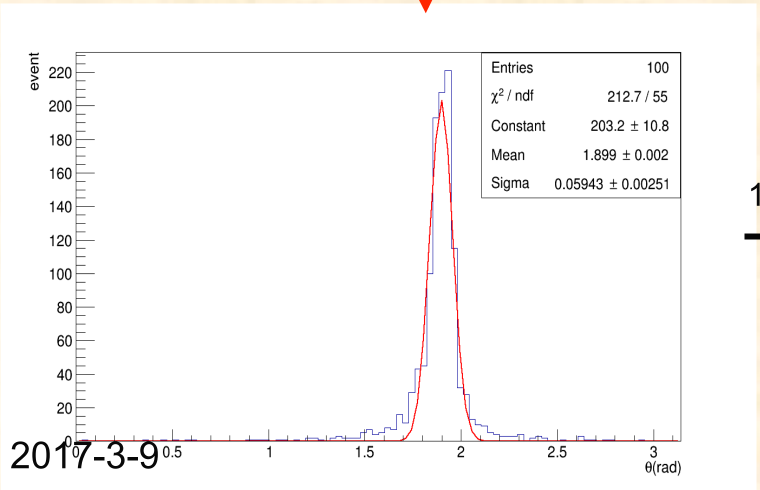


ρ

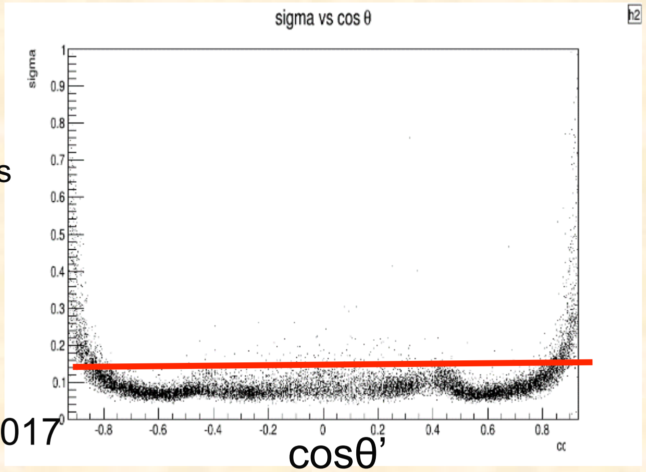


- Resolutions are different for different track angles
- Almost flat except |cosθ'|>0.85
- Use resolution cuts to discard fake tracks

ϑ

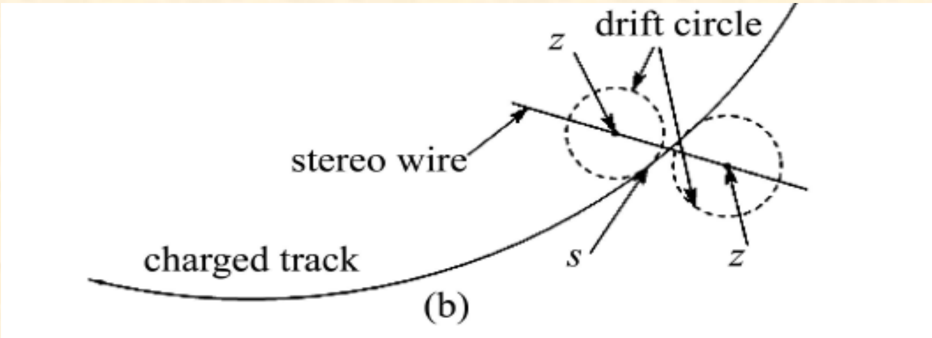


10000 events



3D Tracking

- When 2D Hough tracking is done, do 2D circle fitting to get track on x-y space



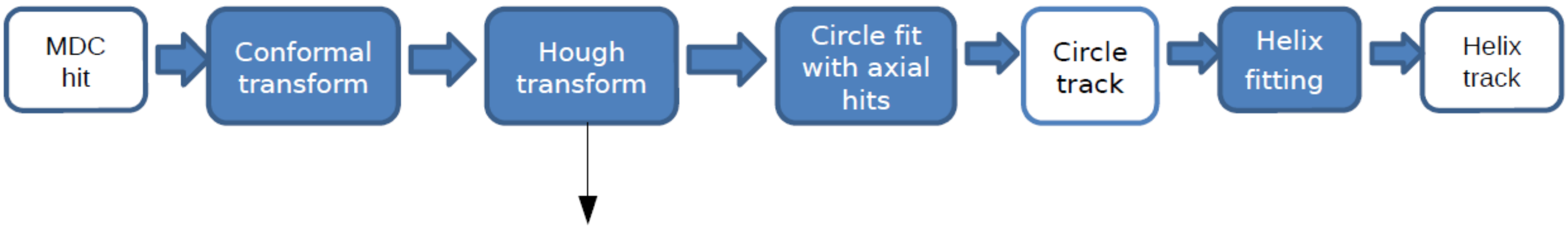
s: flight length in x-y place
z: hit position on wire

- 3D tracking to get correct Z information
- Left/right ambiguity is considered

- When 3D tracking, a global fitting is performed to get the track parameters

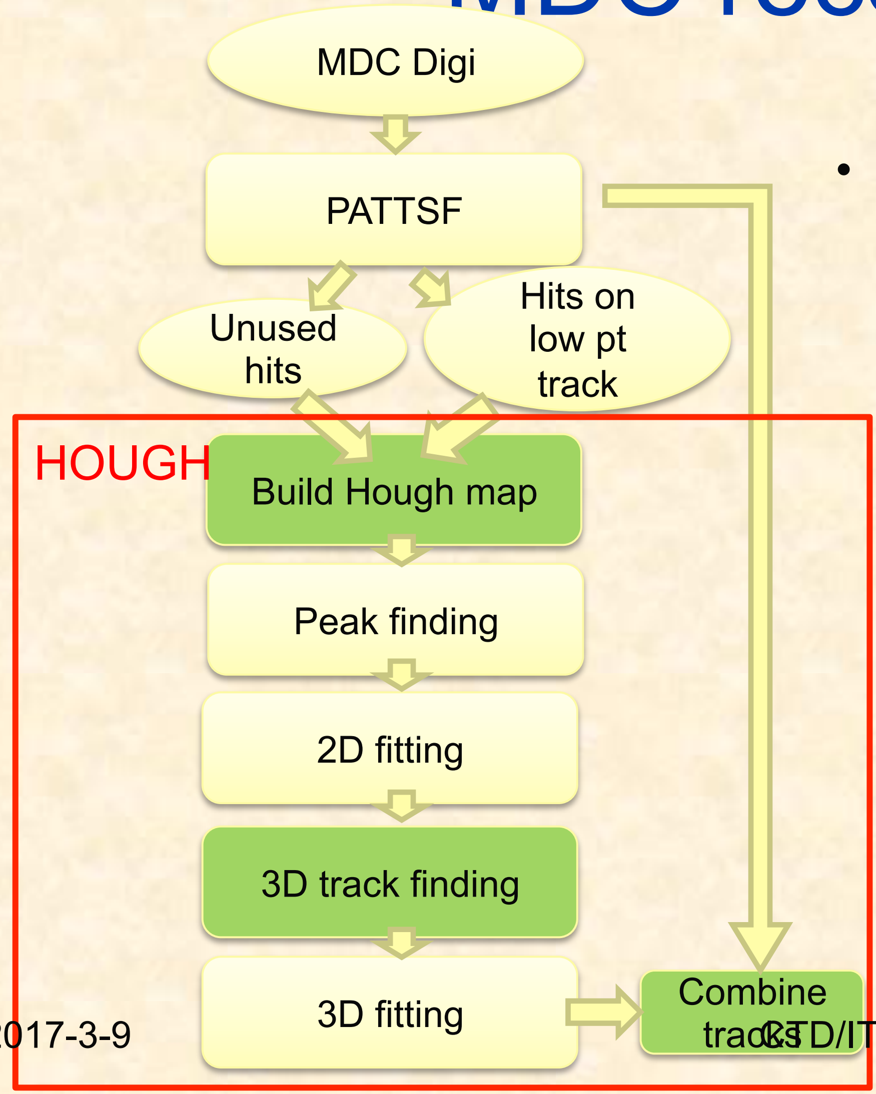
Hough Finder algorithm development for MDC tracking

- A Hough transform-based tracking method have been implemented in BOSS



- Hough transform process

Process of Hough transform in MDC reconstruction

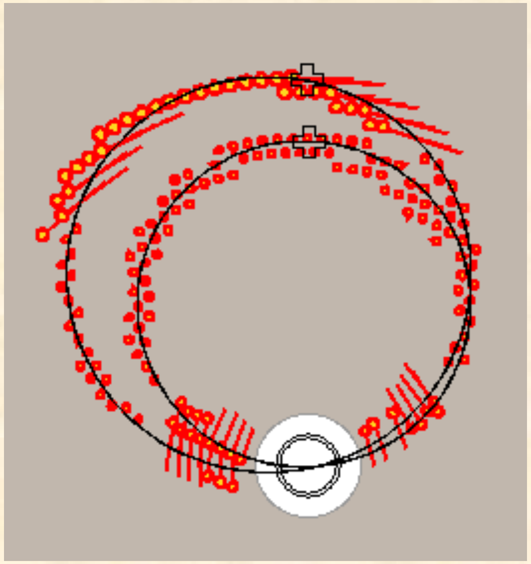


- Hough tracking is as supplementary of PAT/TSF for low Pt tracks
    - For 50MeV<pt<120MeV track
    - Aims to salvage lost tracks after PAT/TSF
    - Bad quality track of PAT/TSF will be abandoned and track in HOUGH again

Merge multi-turn tracks

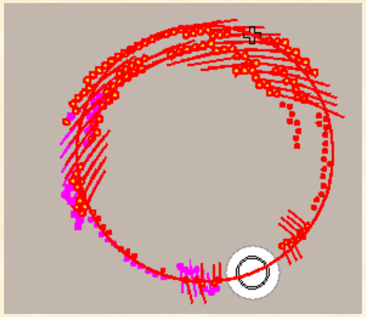
Low pt particle with small dip angle may leave multi-turn track in MDC

- Merge method
  1. Sort all tracks by pt
  2. Compare each 2 tracks to check if from same particle
     - Pt and center position
     - Same charge
  3. Abandon track with smaller pt

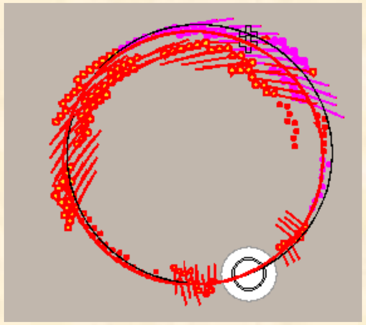


Combine track with PAT/TSF

- PAT/TSF use the hits on first half turn



- Hits on second half turn may reconstructed a track by HOUGH



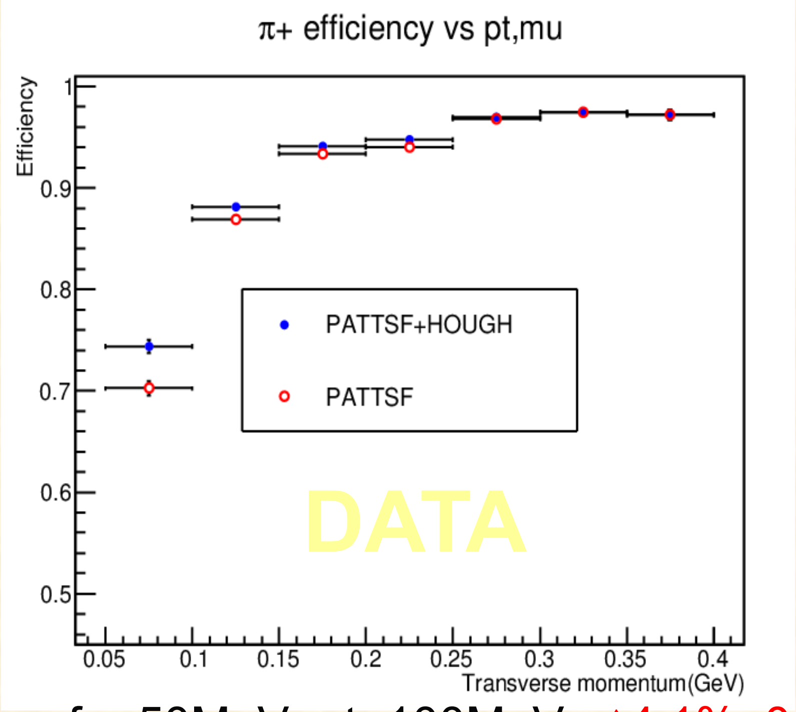
- Compare tracks

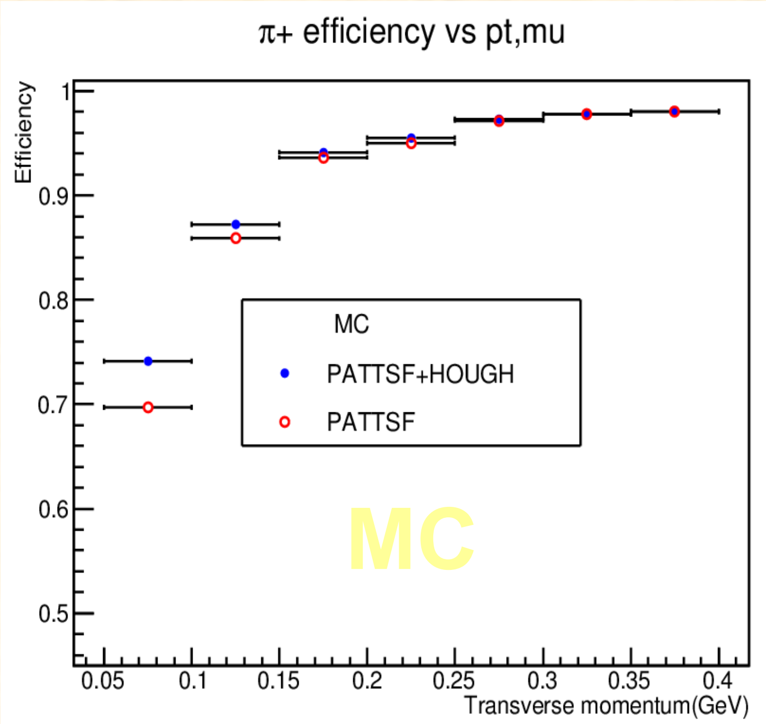
 If pt and center position satisfy certain condition , abandon track reconstructed by HOUGH

Tracking efficiency with

$\Psi(2s) \to J/\Psi \pi^{+} \pi^{-}$, $J/\Psi \to l^{+} l^{-}$

Data(run 8093 to 8195) , Boss version 6.6.5





for 50MeV<pt<100MeV ↑4.1%±0.7%
relative increased ~5.9%

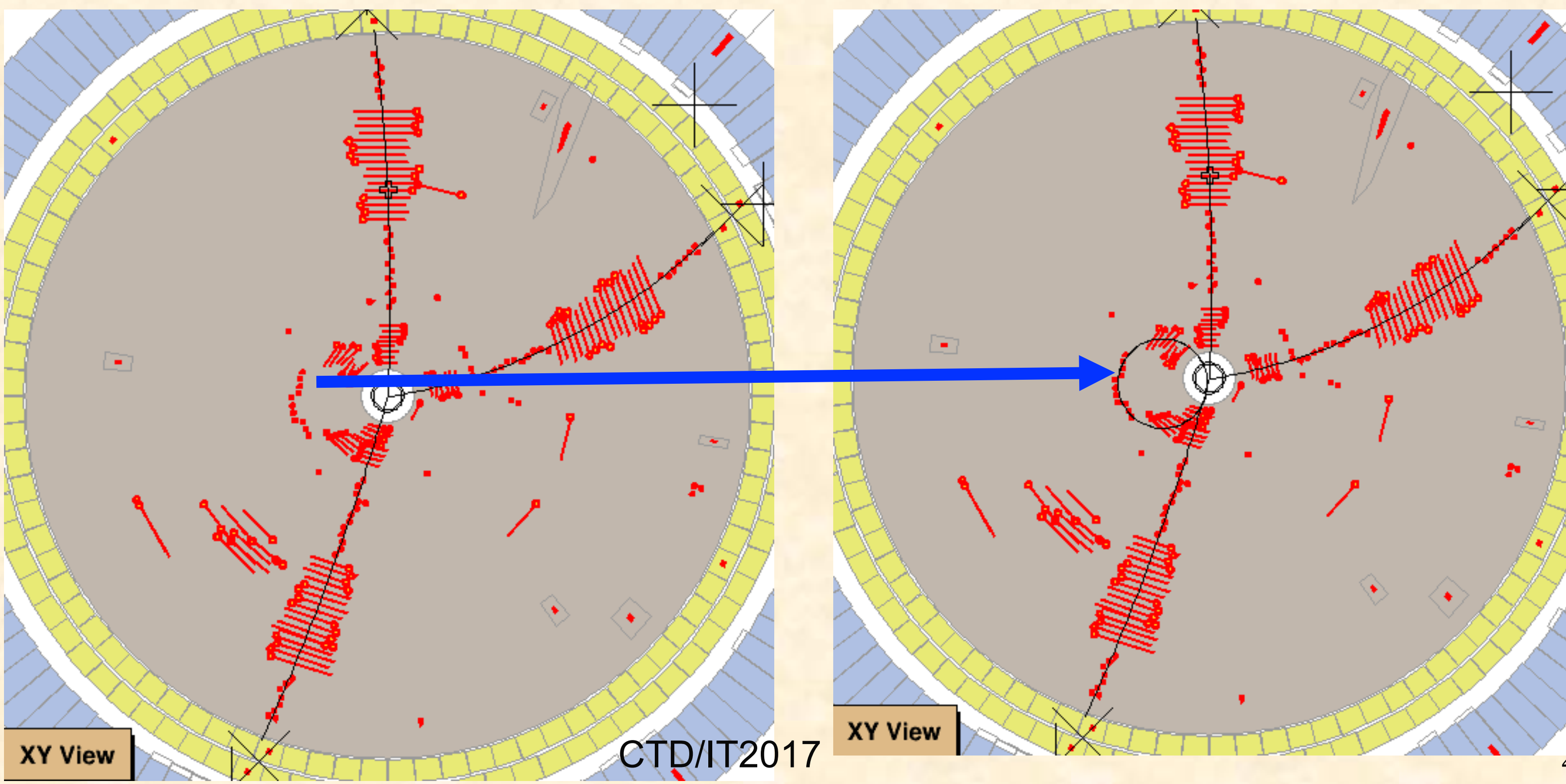
for 50MeV<pt<100MeV ↑4.5%±0.03%
relative increased ~6.5%

Increase of tracking efficiency is consistent for data and MC

Sample events

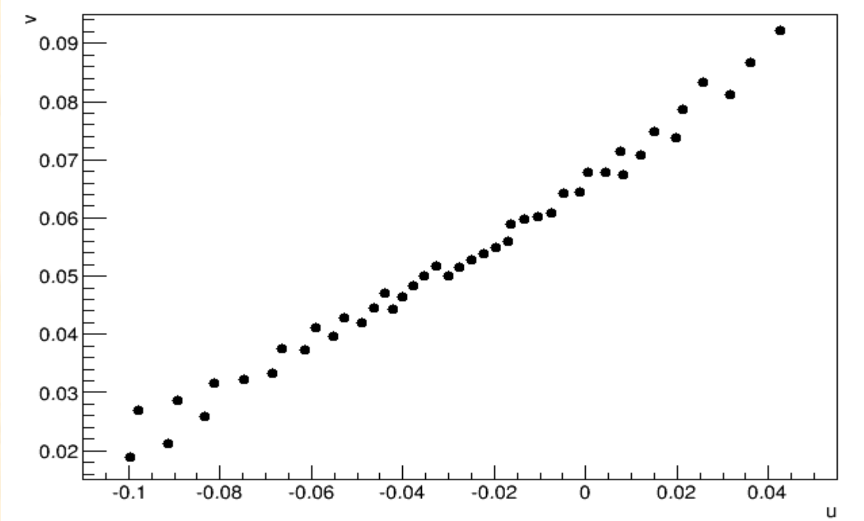
- Lost track is salvaged by Hough

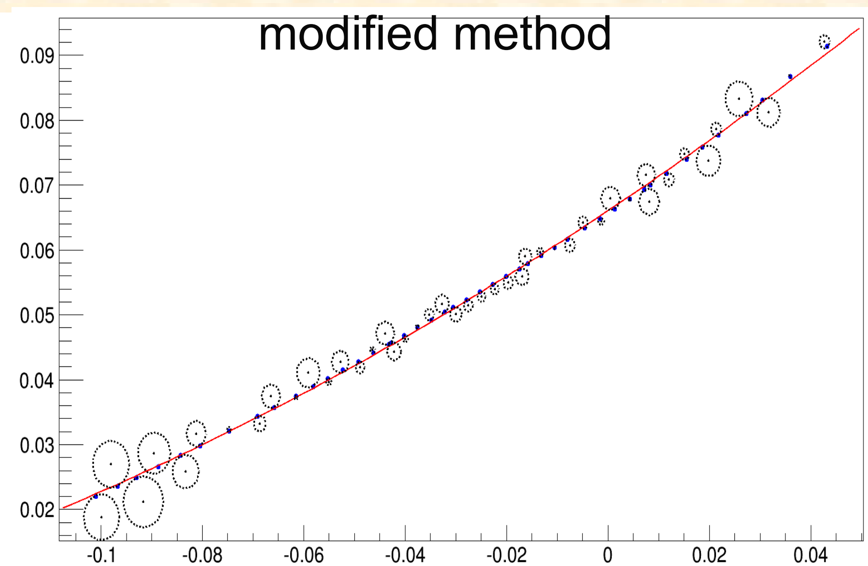
PAT/TSF PAT/TSF+HOUGH



Next to do

- Include drift distance in Hough Transform
  - Old method: Use only mid point of axial hits
  - Modified method: Each drift circle is transformed by to new "drift circle"





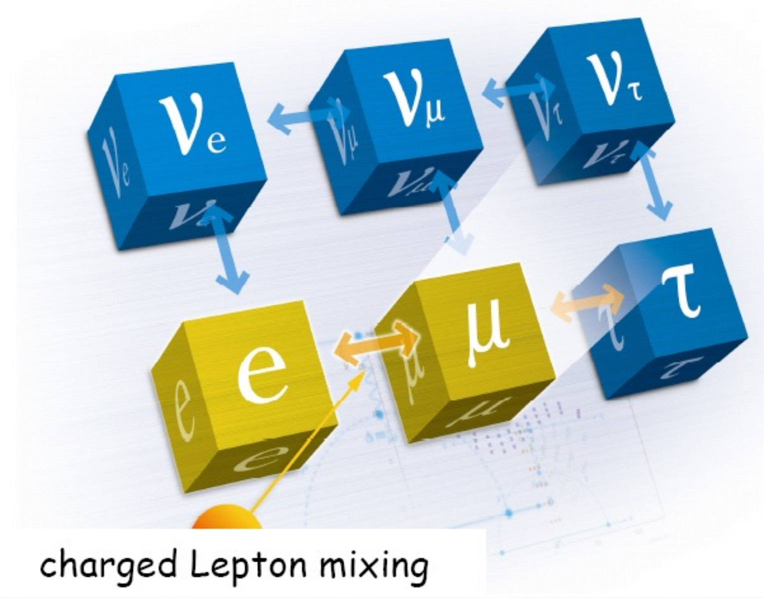
Error from drift distance will be taken into account

Summary

- Hough Transform is implemented in BESIII
- Hough has been applied as a supplement in MDC reconstruction
- improvement can be seen with soft pion form the simulation

Tracking of COMET Drift Chamber

On behalf of COMET Collaboration

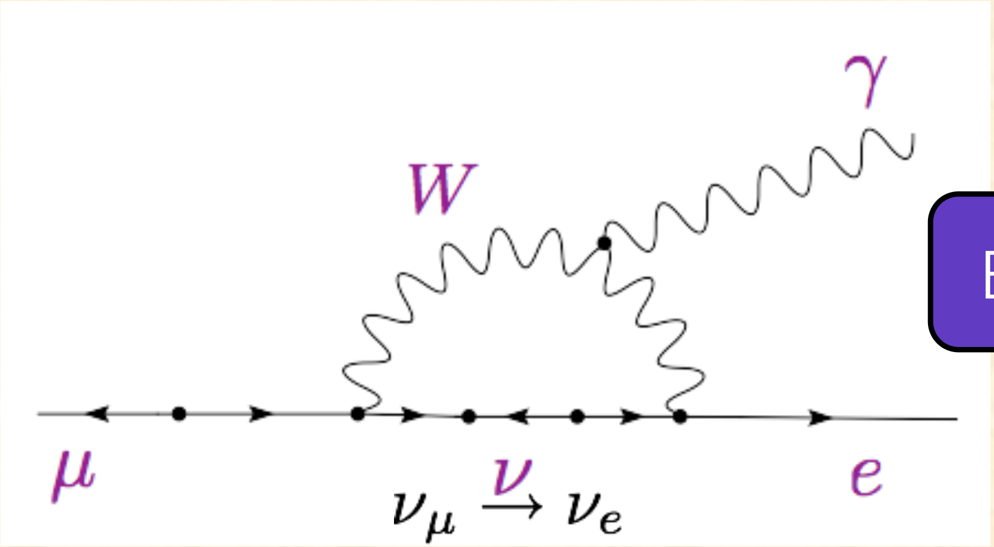


Outline

- **LFV & COMET**
- **Cylindrical drift chamber (CDC)**
- **Tracking**

Muon-to-electron flavour violation

$$B(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_l (V_{MNS})^*_{\mu l}(V_{MNS})_{el}\frac{m^2_{\nu_l}}{M^2_W}\right|^2$$



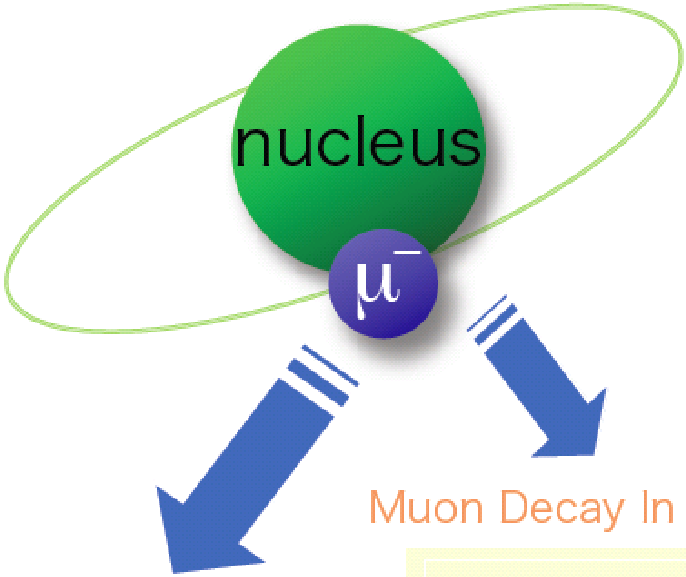
BR~O(10^{-54})

Once observed， clear signal of new physics

COMET:basic design

$\mu^- \rightarrow e^-$ conversion

1s state in a muonic atom



Muon Decay In Orbit

$$\mu^- \rightarrow e^- \nu \bar{\nu}$$

nuclear muon capture

$$\mu^- + (A,Z) \rightarrow \nu_\mu + (A, Z-1)$$

Neutrino-less muon nuclear capture (=μ-e conversion)

$$\mu^- + (A,Z) \rightarrow e^- + (A,Z)$$

- ✓ Signal:
  monoenergetic electron
  104.96 MeV for Al, 95.56 MeV for Au
- ✓ Main background：
  Muon Decay in Orbit （10^{-16}）
  Radiative muon Capture

$$\mu^-(A,Z) \rightarrow \gamma(A,Z-1)^* \nu_\mu$$

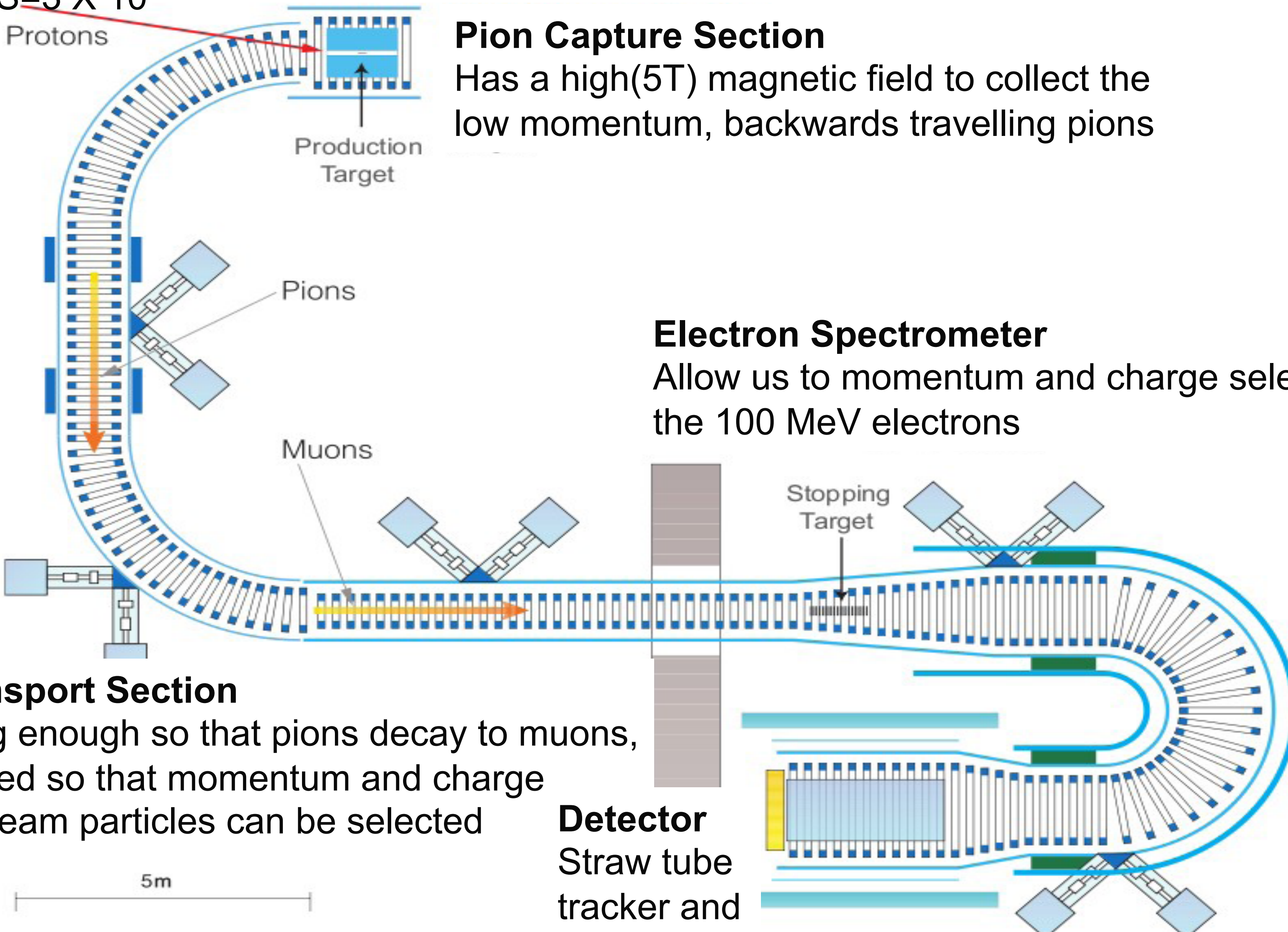
  Radiative pion capture

$$\pi^- + (A,Z) \rightarrow (A,Z-1)^* \rightarrow \gamma + (A,Z-1)$$
$$\gamma \rightarrow e^+ e^-$$

- ✓ No limit from accidental background, higher beam intensity!

COMET(Phase-II）

Starting in 2020
Measurement in 2022
S.E.S=3 X 10^{-17}



Pion Capture Section
Has a high(5T) magnetic field to collect the low momentum, backwards travelling pions

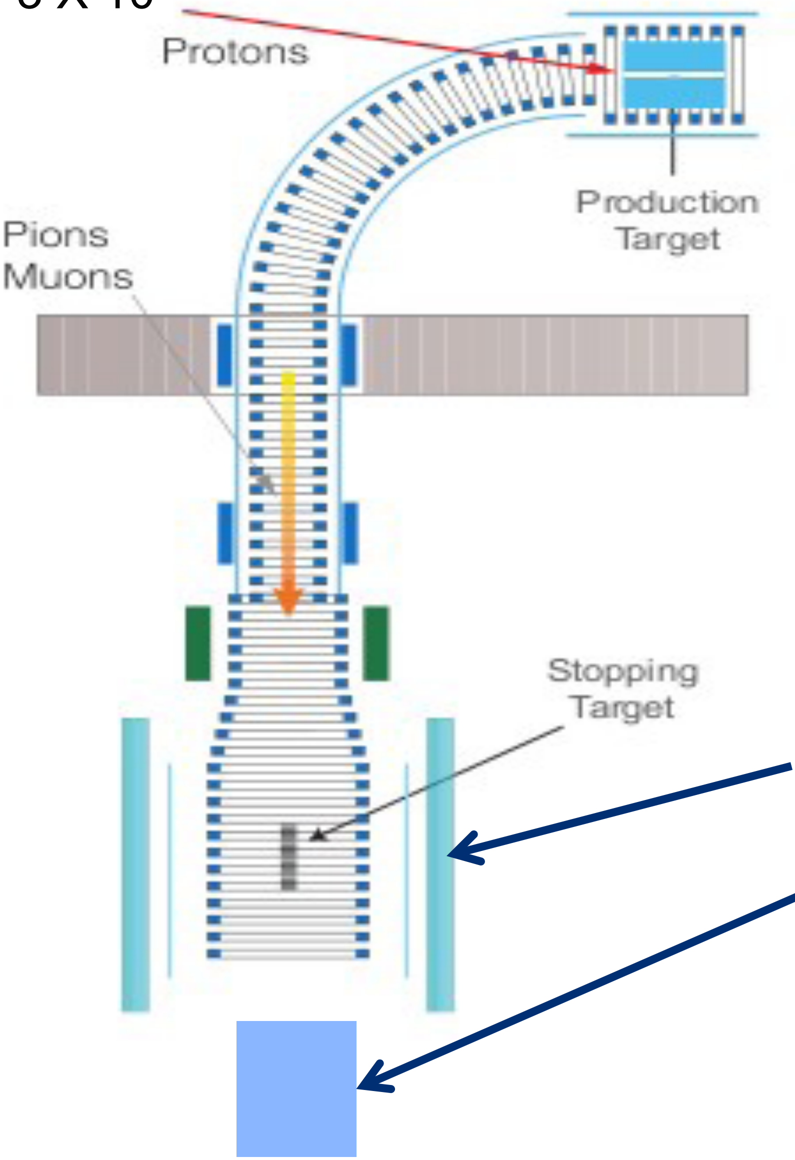
Electron Spectrometer
Allow us to momentum and charge select the 100 MeV electrons

Transport Section
Long enough so that pions decay to muons, curved so that momentum and charge of beam particles can be selected

Detector
Straw tube tracker and ECAL

Starting in 2016
Measurement in 2018
S.E.S=3 X 10^{-15}

COMET(Phase-I）



Pion Capture Section

Has a high(5T) magnetic field to collect the low momentum, backwards travelling pions

Phase-I Aims

Search for μ→e conversion process with a S.E.S. of 3 X 10^{-15}

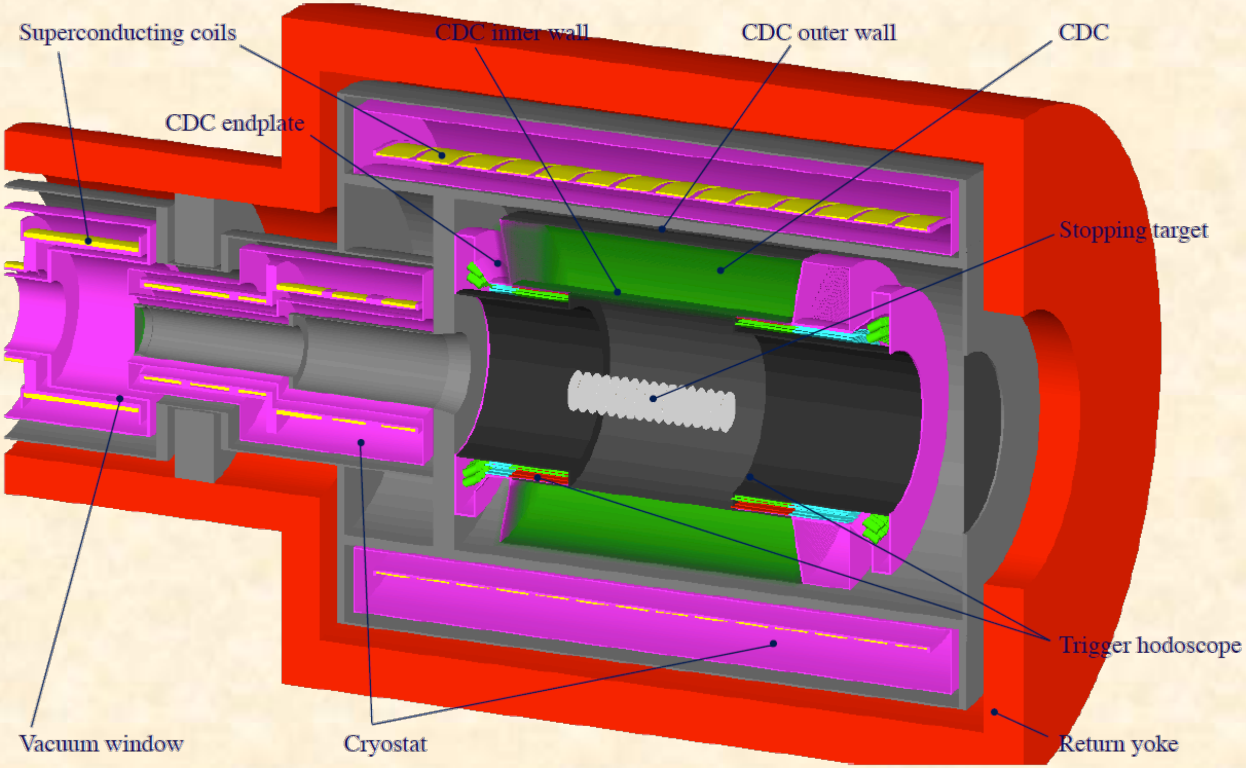
Study the backgrounds for Phase-II

Phase-I Detector

A cylindrical drift chamber (CDC) for the μ→e conversion search

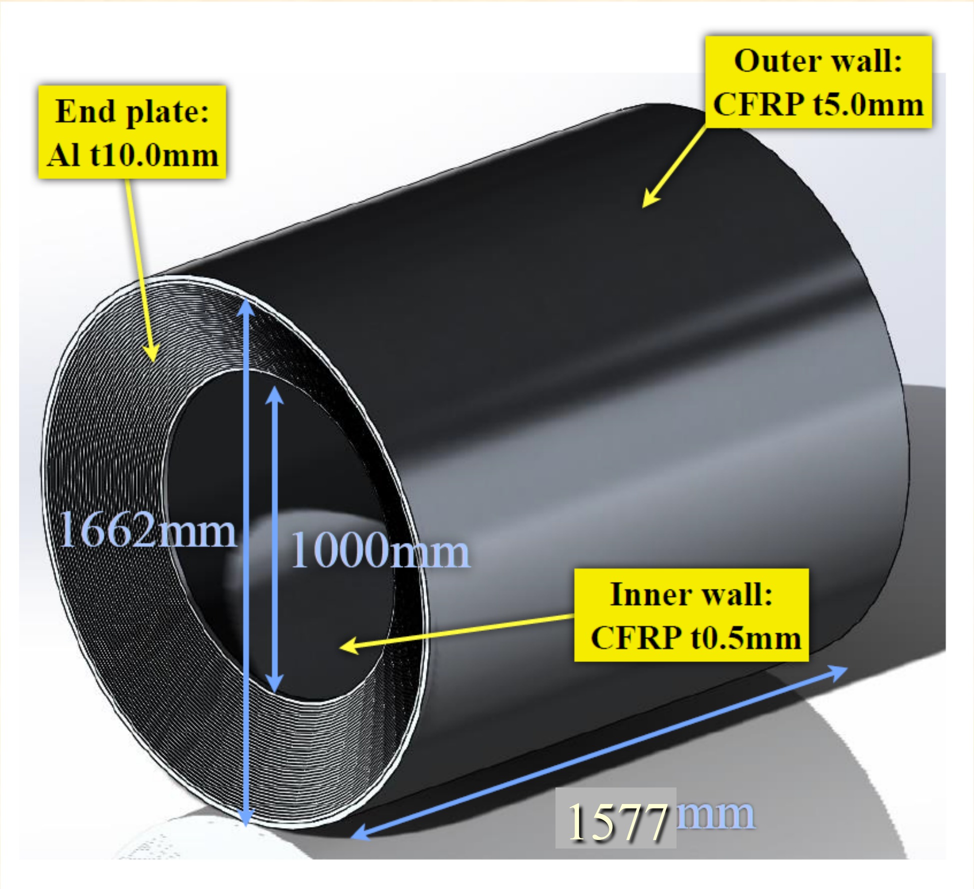
A prototype ECAL and straw tube tracker for the background studies

COMET Phase-I Detector -- CyDet



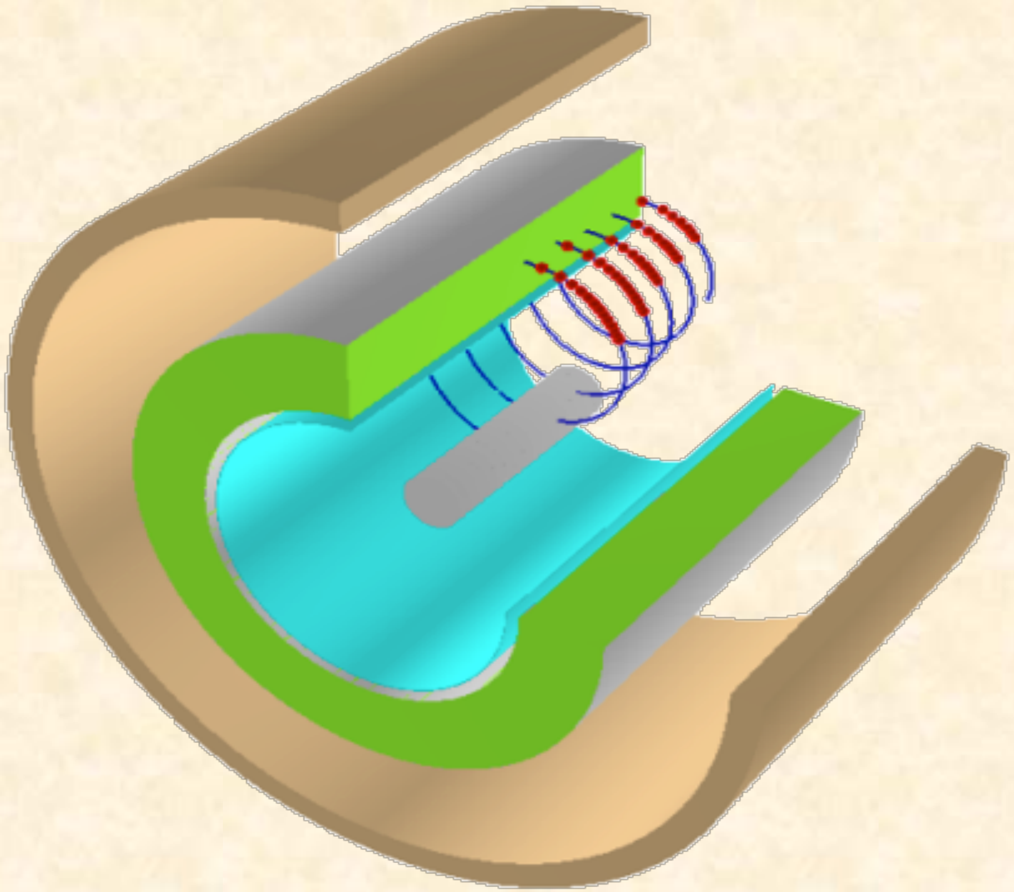
- A large Cylindrical drift chamber in a 1T solenoid magnet
- Trigger hodoscope (Plastic scintillator + Cherenkov)
- **Excellent momentum resolution** ~200keV needed

COMET **C**ylindrical **D**rift **C**hamber(CDC)



Geometric acceptance for electrons with p>60 MeV/c

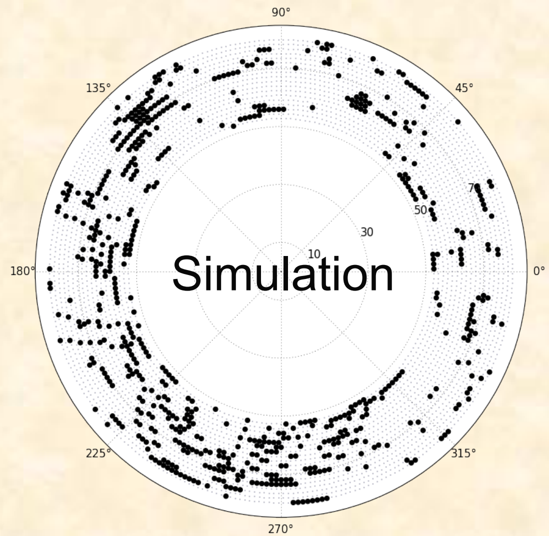
- 20 sense wire layers
  - including 2 guard layers
- All stereo layer
  - Alternating stereo angle +- 4 degrees
- Cell size
  - ~16 x 16 mm2
- Anode wire
  - Au plated W
  - ϕ 25um
- Field wire
  - Al
  - ϕ 126um
- Gas
  - Helium based gas mixture (Isobutane, Ethane or Methane)
  - Volume: 2084L
- Readout
  - 104 RECBE Boards

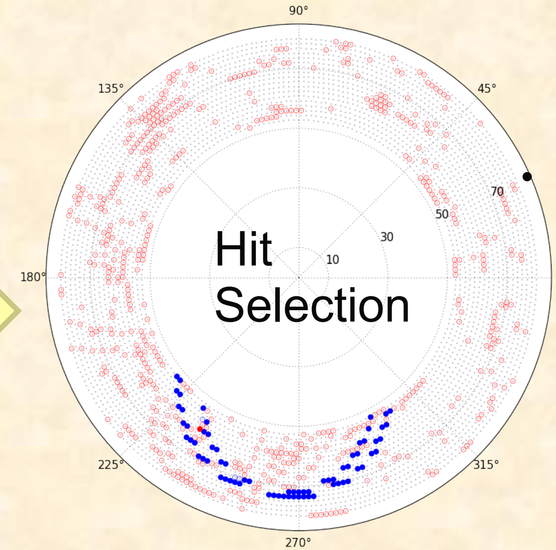


Particles curved before reach trigger,
38% tracks after trigger will be multi-turn,
at most 3 turns of track are hoped to be reconstructed,
so multi-turn hits distinguish is important

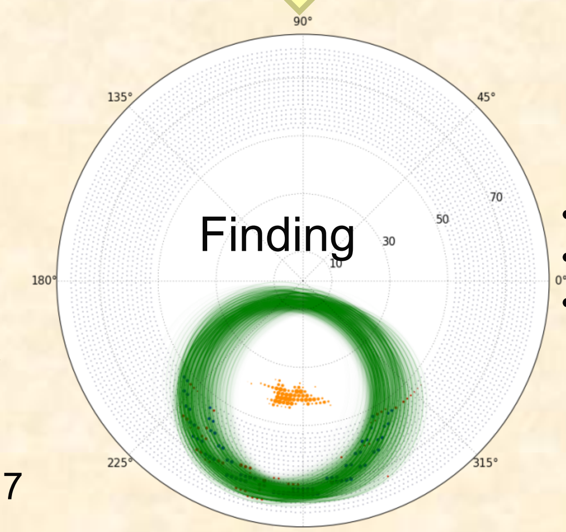
Tracking Procedure

- Signal track
- BG hit merge
- Detector response



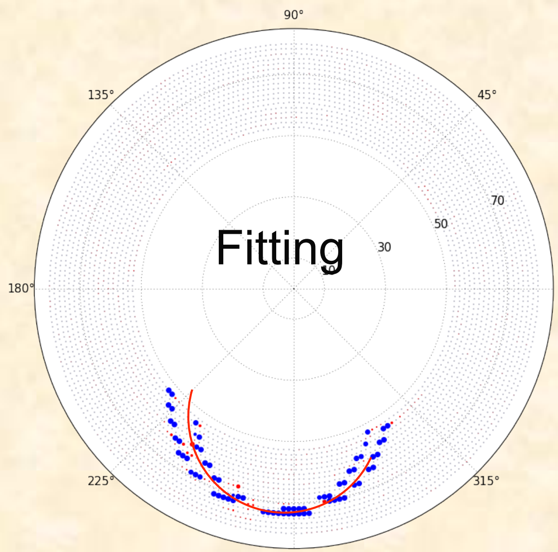


- Evaluate each hit with a weight to indicate signal/noise



- Find tracks
- Find turns
- Decide initial value

iteration

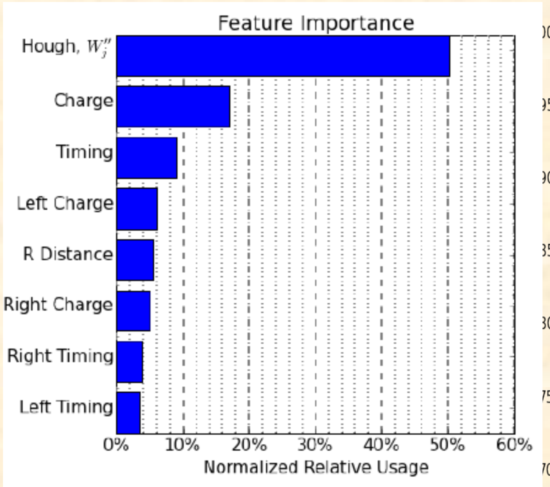


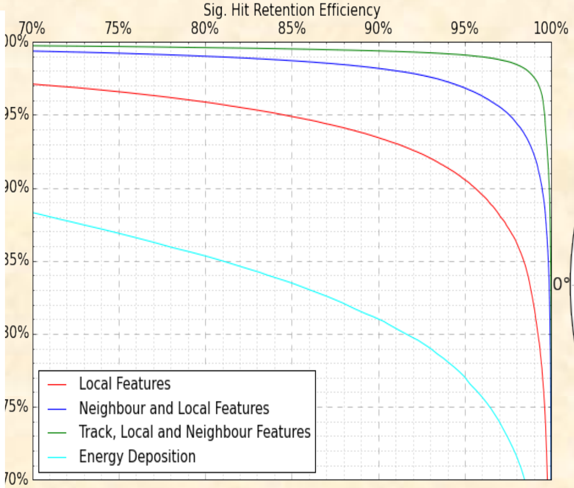
- Fitting with Kalman filter

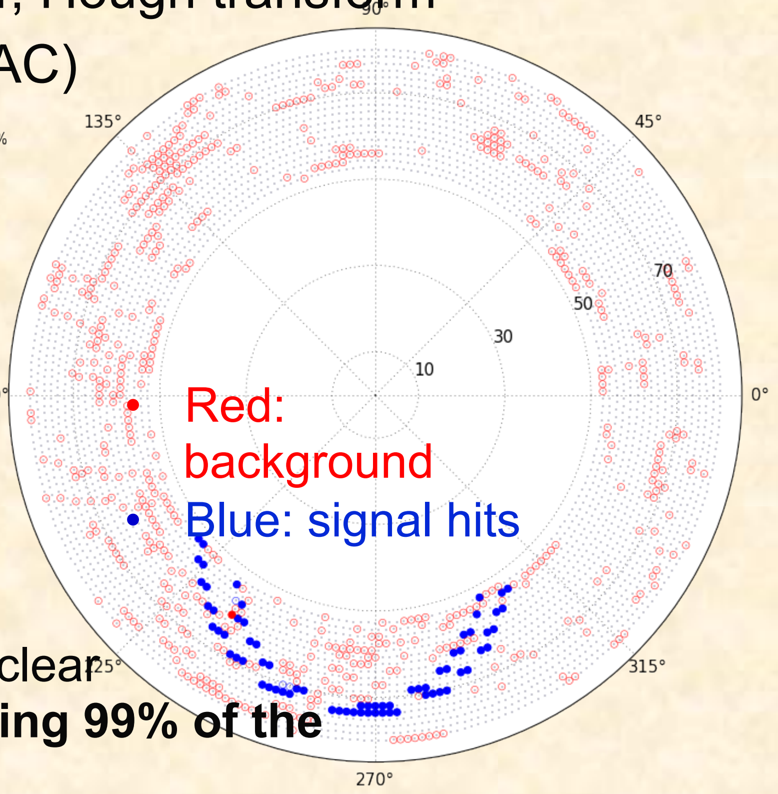
Hit Selection

Ewen Gillies
(Imperial College)

- Hit selection using **G**radient **B**oosted **D**ecision **T**rees (GBDT) and Reweighted Inverse Hough Transform
- Classify hits using features: local, neighbor, Hough transform
- Fit track with random hit collection (RANSAC)



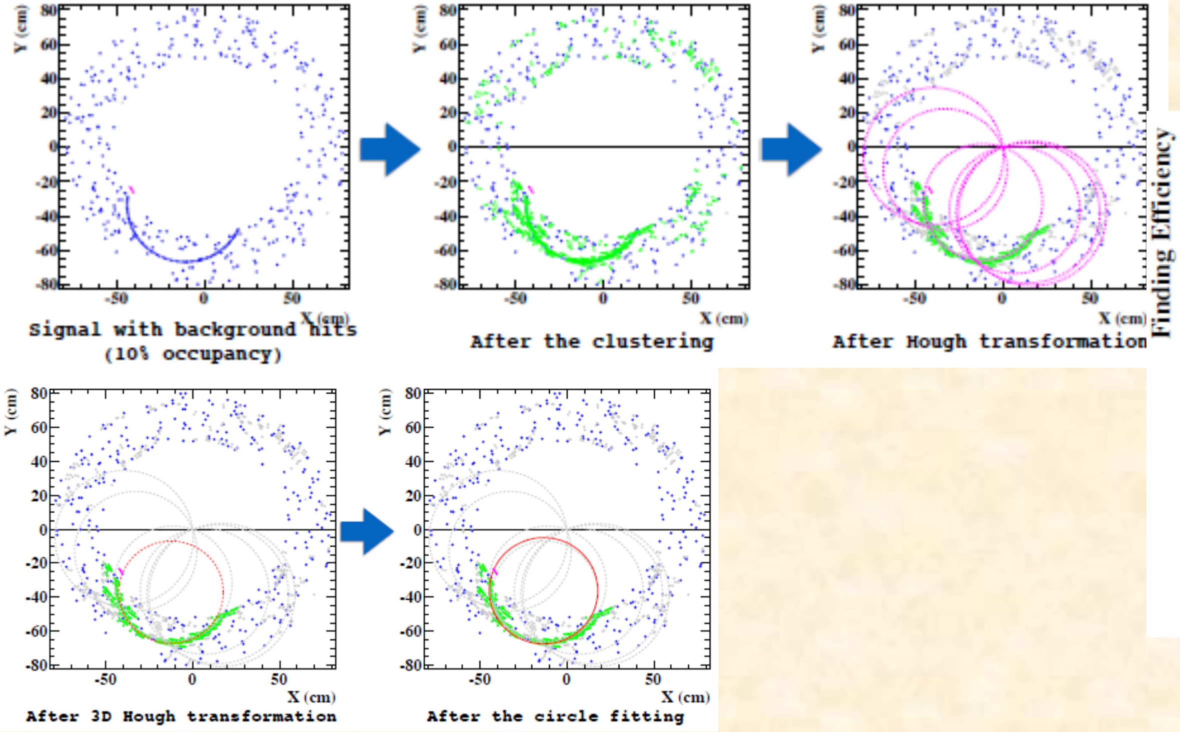


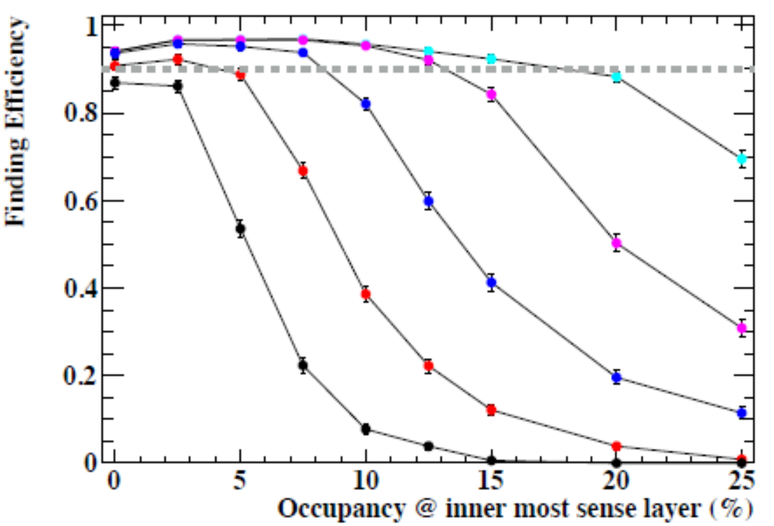


Separation between background and signal hits is clear
98 % of background can be rejected while keeping 99% of the signals，for the case of hit occupancy of 15%

Track Finding

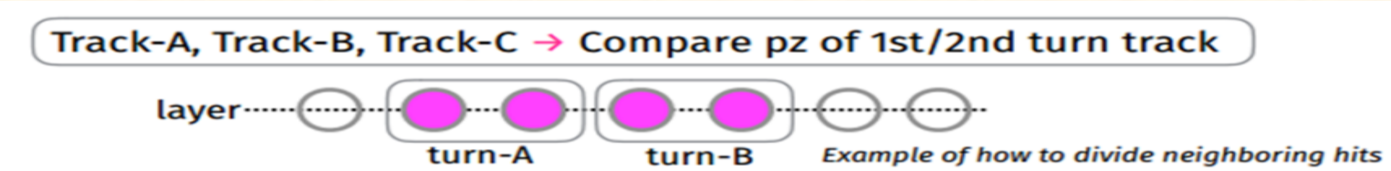
- Hough transformation
  - Clustering neighbor layer hits
  - Conformal mapping and Hough transform
  - 3D Hough transform
  - Circle fitting

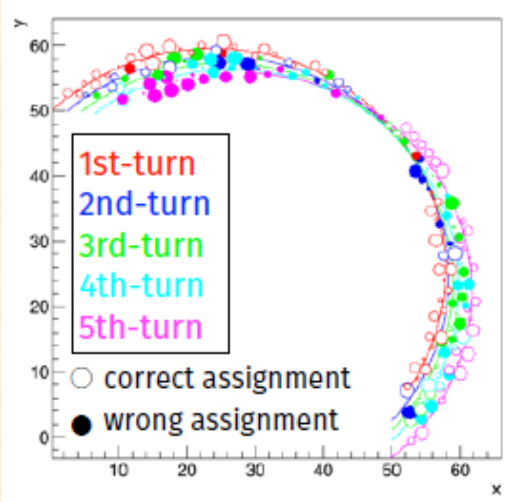




Track Fitting method 1

- genfit2 based fitting using Kalman filtering(DAF)
- Multi-turn fitting based on neighboring hits pile-up pattern
  - "Divide" sequential hits in same layer, odd/even, first/last 90 deg turn
  - Make ~50 different sets of hit candidates
  - Fit for each set and keep if fit result is "good" (NDF>20)
  - Using remaining hits, repeat fit procedure
  - Compare p_z of 1st and 2nd max. momentum tracks
  - If difference of p_z is smaller than 20 MeV/c, finish





Track Fitting method 2

- Due to the importance of the reliability another fitting algorithm is developed for cross-check
- Multi-turn fitting based on hit competition
  1. Fit track with different turn hypothesis in parallel
  2. Hits associated to at least one track and calc. assignment weight to each track
  3. fit tracks iteratively with annealing scheme to avoid local minimum

The possibility of hit *i* assigned to track *j* is defined as matrix Φ

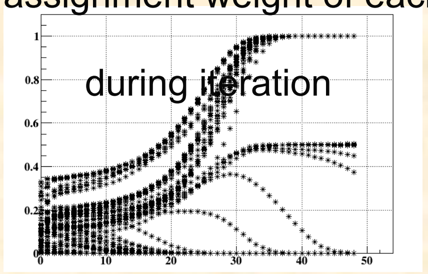
one hit associated with two tracks

$$(\Phi)_{ij} = \varphi_{ij} = \varphi(y_i; Hx_j, V_i),$$

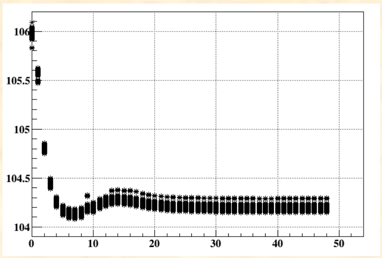
Assignment weight of hit i to track j

$$p_{i_k j} = \frac{\varphi_{i_k j}}{\sum_l \sum_\alpha \varphi_{i_\alpha l} + c}.$$

Hit assignment weight of each hit



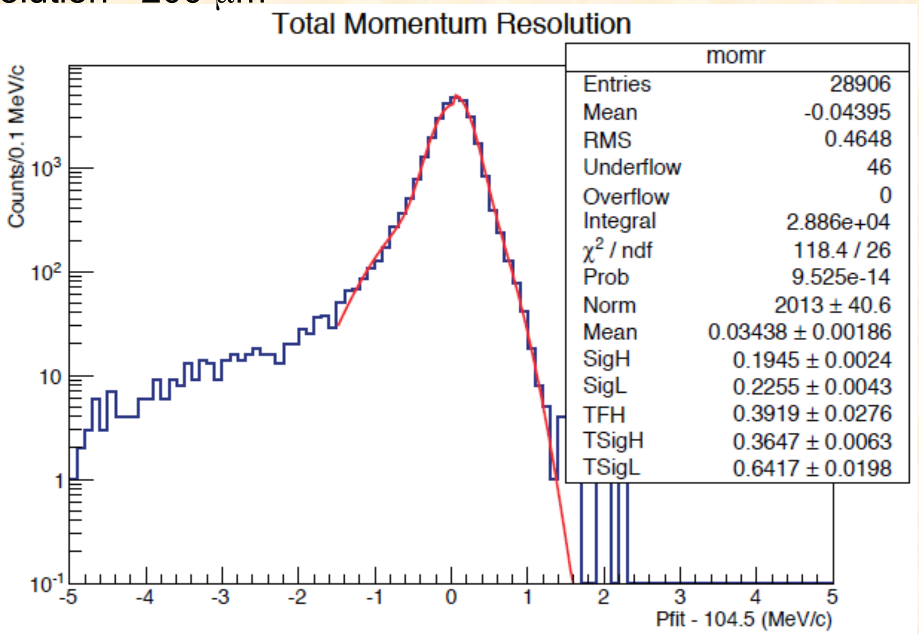
fitted momentum at each iteration



Momentum Resolution at Birth

gas mixture He:i-C4H10 (90:10)
position resolution ~200 μm

- Tail part still need study with more realistic track finding and fitting
  1. including noise
  2. fitting input from track finding



Core	σ of high-momentum half-Gaussian (SigH)	195 keV/c
	σ of low-momentum half-Gaussian (SigL)	226 keV/c
Fraction in tail distribution (TFH)		39%
Tail	σ of high-momentum half-Gaussian (TSigH)	365 keV/c
	σ of low-momentum half-Gaussian (TSigL)	642 keV/c

- The core part of resolution of the total momentum is below 200keV/c

Summary

- Track finding and fitting for CDC are in progress
- Momentum resolution from MC study can meet the requirements of the COMET experiment

Thanks!