Track Finding Based on Hough Transform for BESIII Drift Chamber

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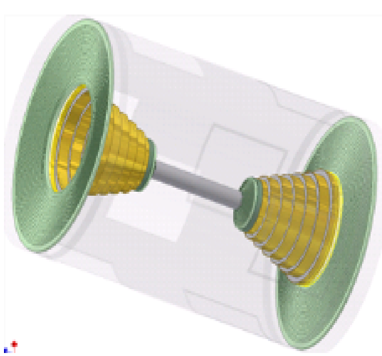
2018/6/22

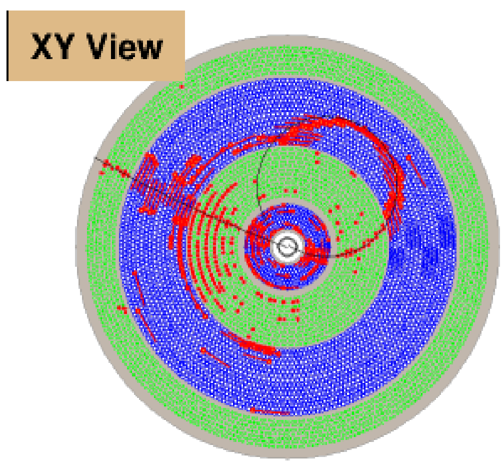
Outline

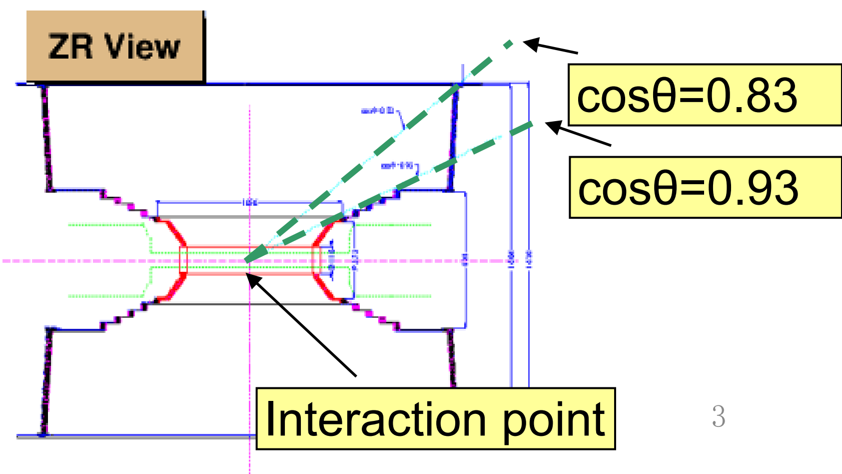
- Introduction to BESIII MDC tracking
- MDC Track finding based on Hough Transform
- CGEM-ODC Track finding based on Hough Transform
- Summary

BESIII Drift Chamber (MDC)

- Detect trajectory of charged particles
  - Requirement of precise momentum and direction
  - High efficiency for charged particles
  - Widely track angle coverage
- Design of MDC
  - 6796 wires arranged in 43 circular layers
  - **Axial** and **stereo** wires are grouped to superlayers
  - Axial wires: x-y information, stereo wires : z information
  - Max solid angle coverage is cosθ=0.93



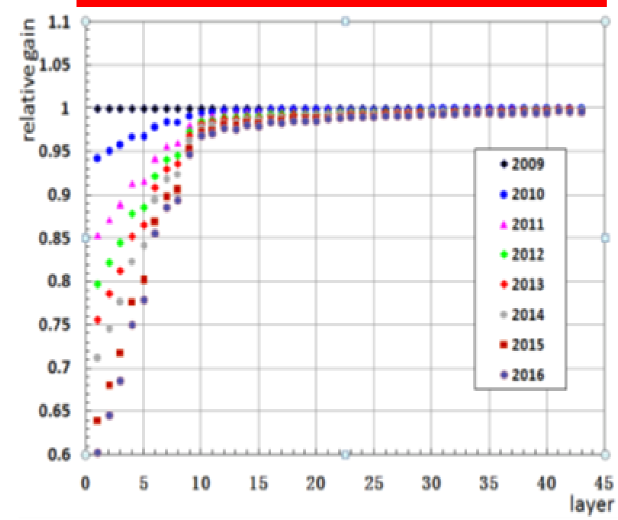




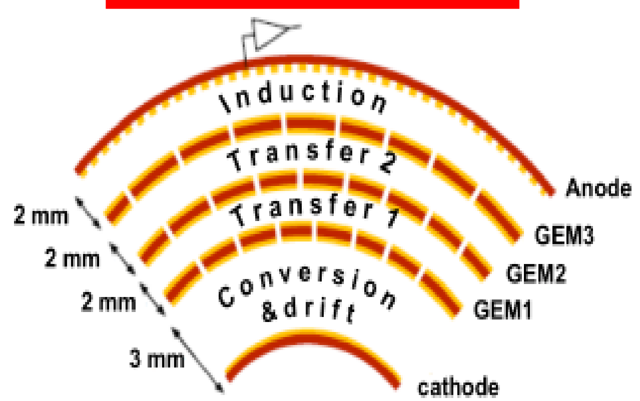
Upgrade of MDC Inner Drift Chamber

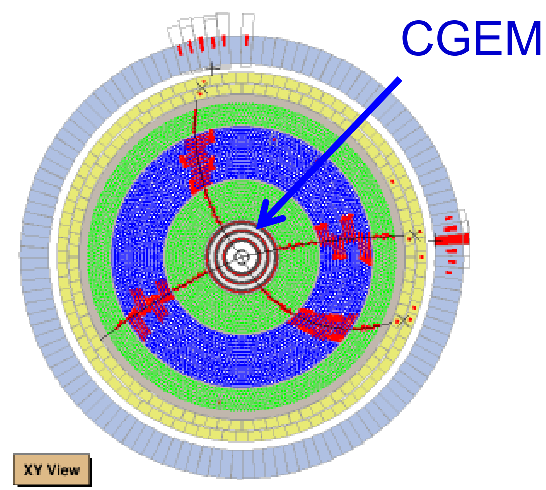
- The aging of inner 8 layers of drift chamber (Inner Drift Chamber)
- Inner Chamber -> CGEM detector
  - 3 layers of cylinder GEM detector
  - Anode and cathode and 3 layers of GEM foil
  - X&V reader
  - Charged particles leave clusters when passing CGEM

relative gain vs layer



One layer of CGEM

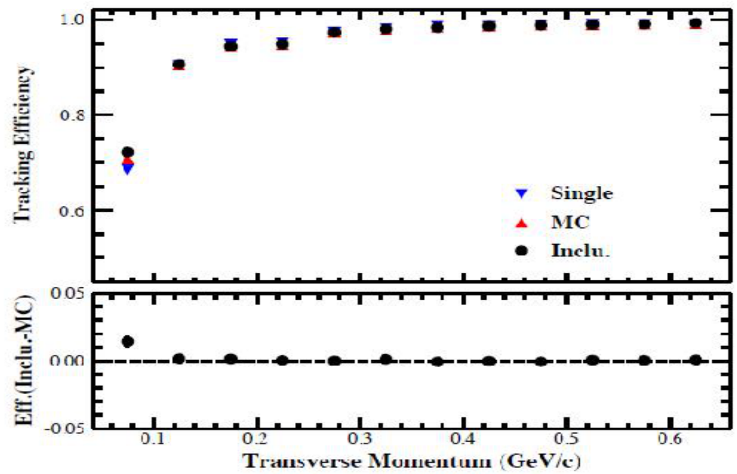




Motivation for new tracking algorithm

- Current tracking packages : find segment in superlayers
  - PAT&TSF: segment based finder
  - TCurlfinder: find continuous hits in superlayers (for low pT track)
- Requirement for a new tracking algorithm
  - BESIII tracking performs good at high pT region but can be improved for low pT tracks (pT<120MeV)

Track efficiency of π^- vs pT



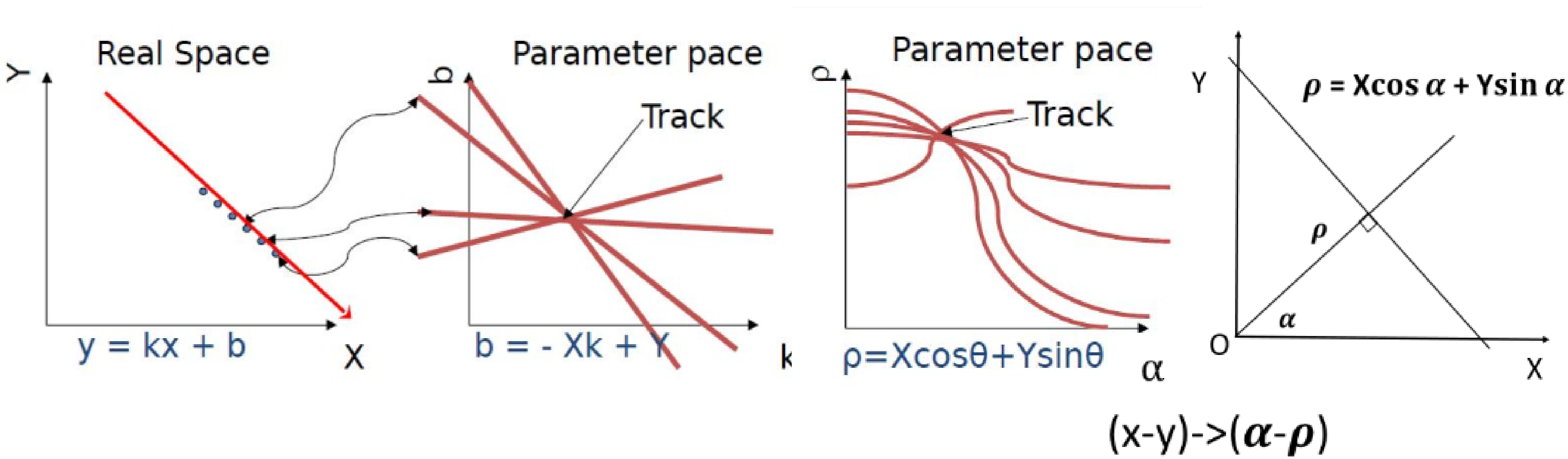
  - The upgrade of Inner Drift Chamber requires a new algorithm

We develop a tracking package based on Hough transform,

it is the first time to develop a tracking algorithm in BESIII independently

Hough Transform

- Transform a point in real space to a line or a curve in parameter space
- Points rest on a line in real space ←→ lines or curves focus in Hough space



Introduction to Hough transform

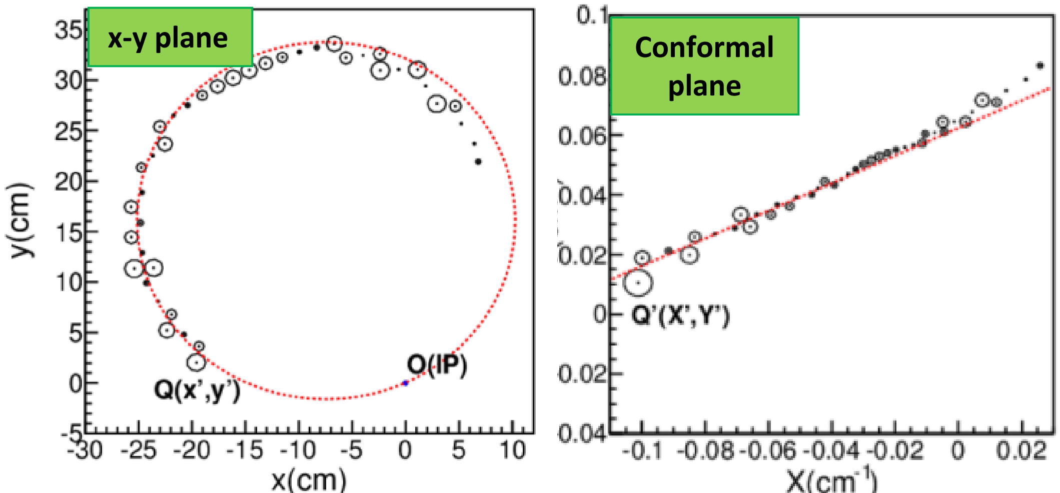
- Global method
  - All hits are treated simultaneously
- Mathematical
  - Hits on real space are transformed into a mathematical space in which the track candidates can be found more conveniently and insensitive to detector design

Advantages

- More hits can be included at the first step
- Good noise resistant
- Hit inefficient resistant
- Quick

How about helix track

1. Finding circle tracks(x-y plane) : conformal transform
    - Conformal transform
        - $X = \frac{2x}{x^2+y^2}, Y = \frac{2y}{x^2+y^2}$
        - Circles passing the origin point transform into straight lines
        - Circles not passing the origin point transform into new circles



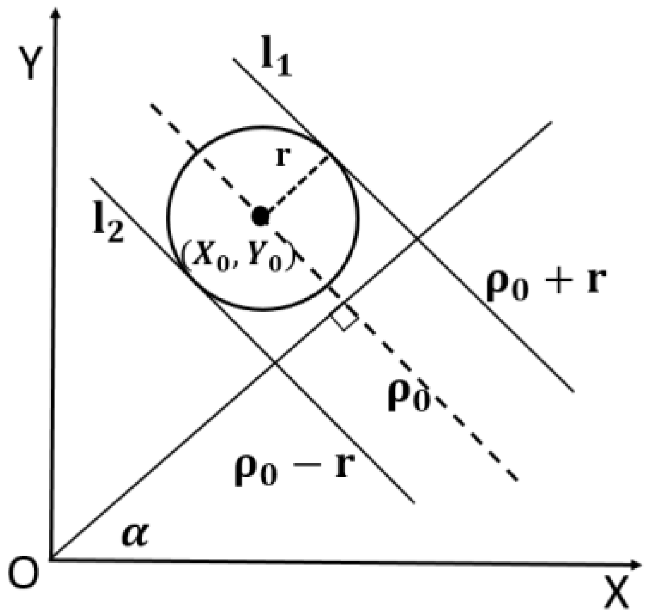
Circular track -> straight line
Drift circles -> new circles tangent to the straight line

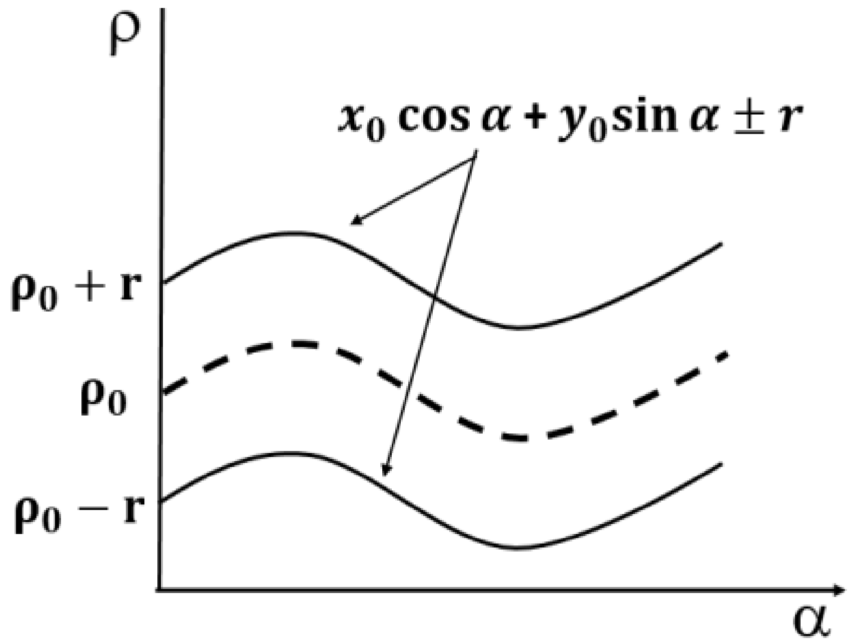
2.Find helix track with stereo hits using circle track information

Hough Transform with drift circle

$$\rho = X \cos\alpha + Y \sin\alpha + r, (upper\ half\ circle)$$

$$\rho = X \cos\alpha + Y \sin\alpha - r, (lower\ half\ circle)$$



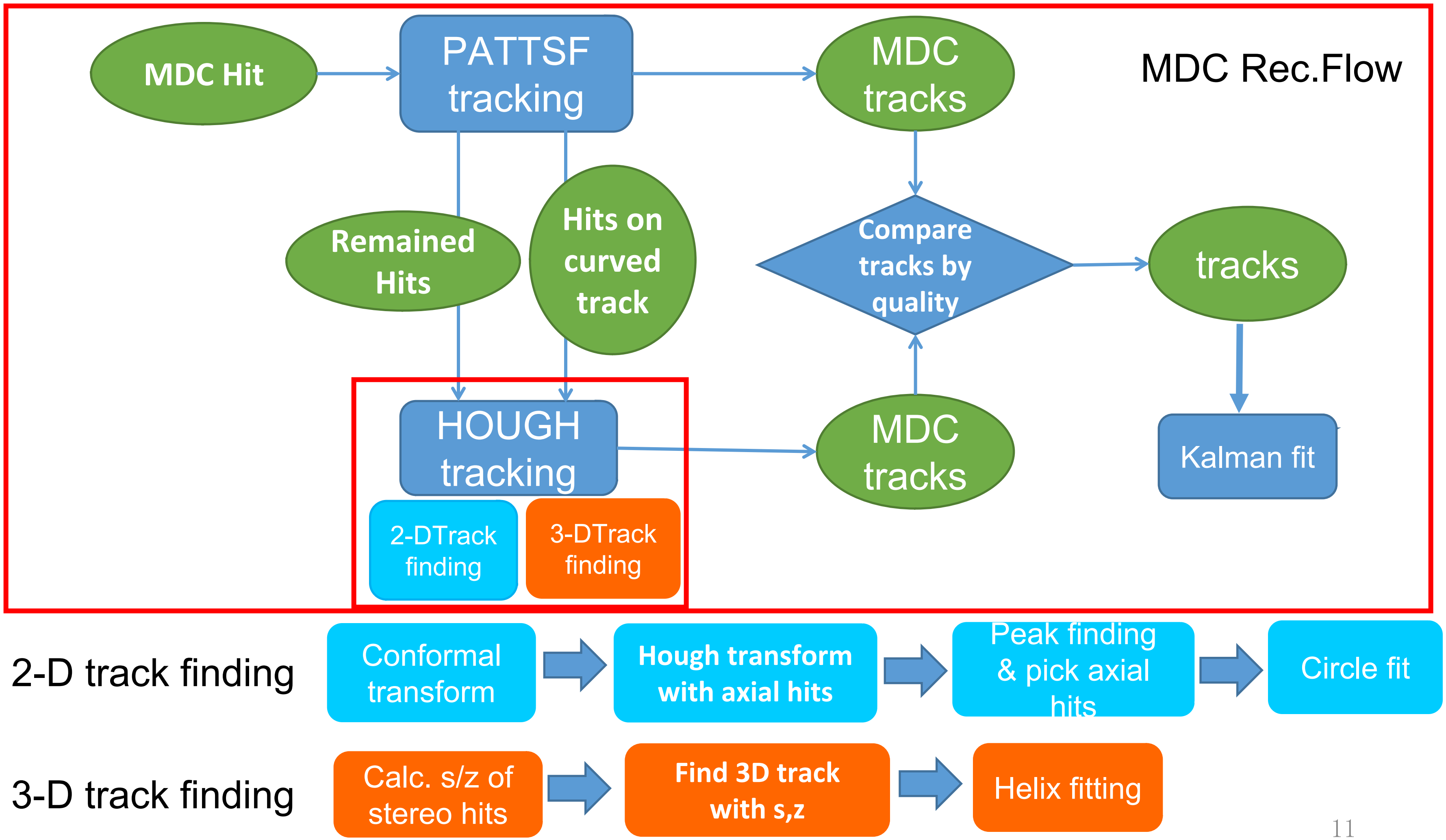


One drift circle->two curve lines on Hough space

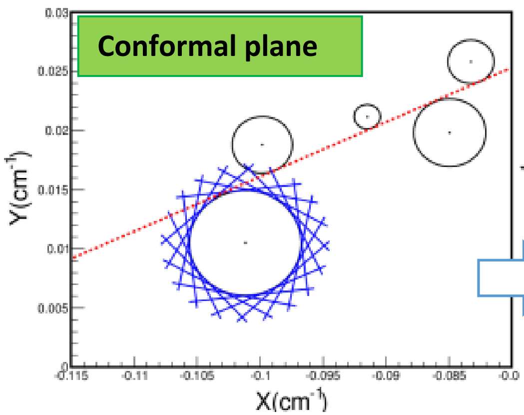
Implementation of Hough Transform in MDC tracking

HOUGH in MDC Reconstruction Flow

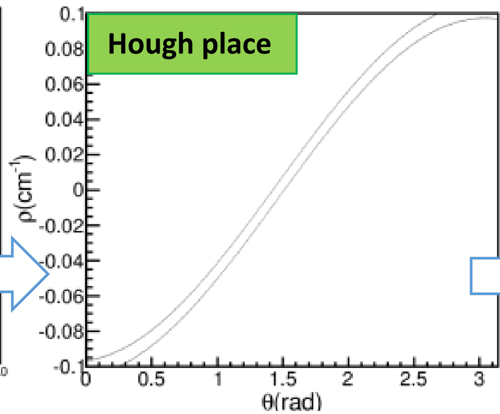
HOUGH tracking package is taken as a supplementary of original tracking



2-D track finding

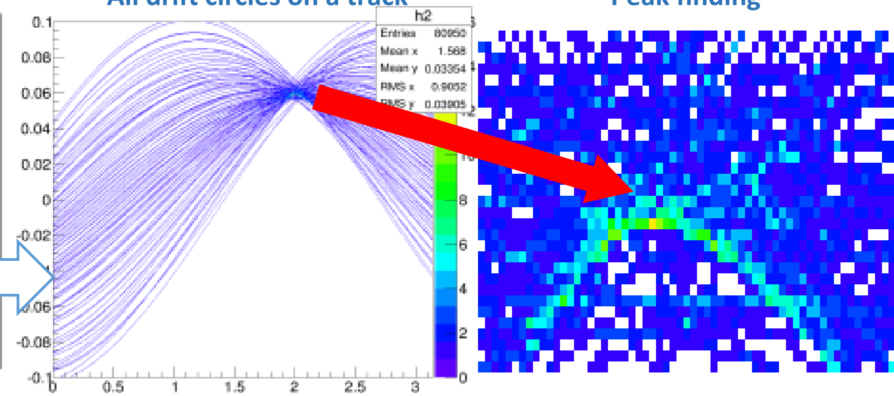


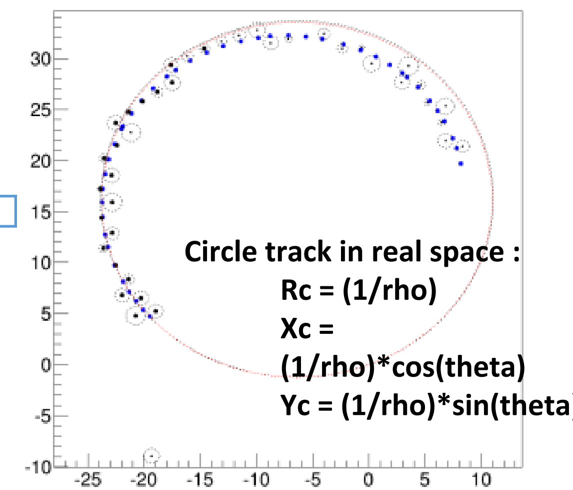
One drift circle



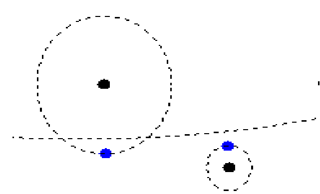
All drift circles on a track

Peak finding

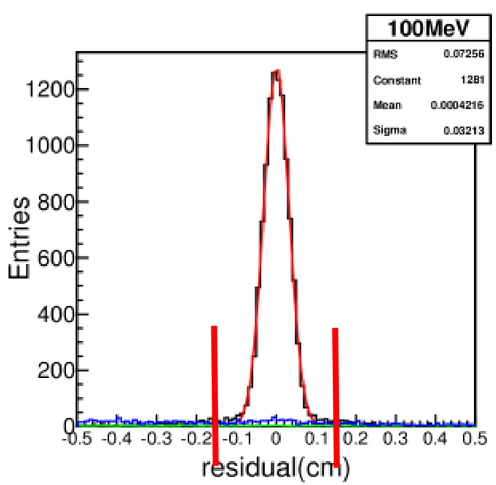




Pick axial hits:
Calc. distance between
candidate track and drift circles

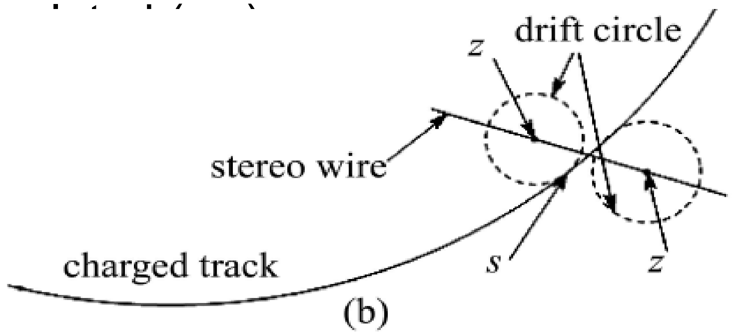


Hits Distance distribution



3-D Tracking

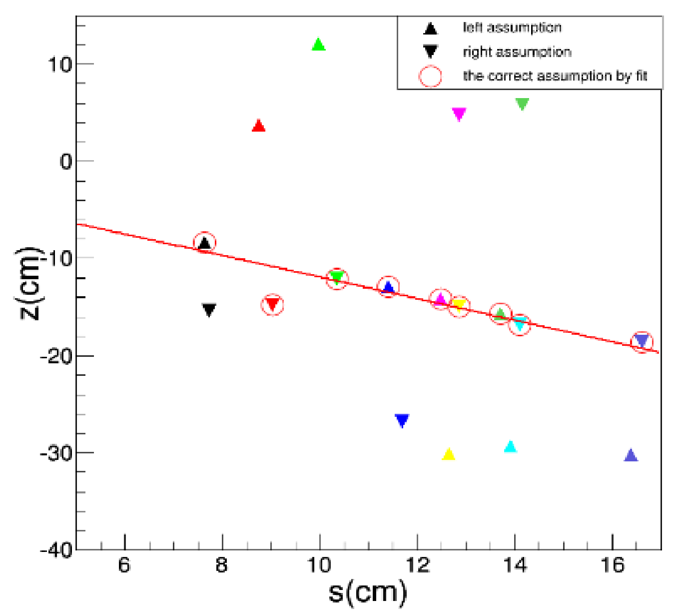
- When 2D Hough tracking is done, do 2D circle fitting to get track on x-y space
- With 2D information, stereo hits are picked neared the track and



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

- 3D tracking to get correct Z information
- Left/right ambiguity is considered - with a straight line fit on s-z plane

Straight line fit on s-z plane

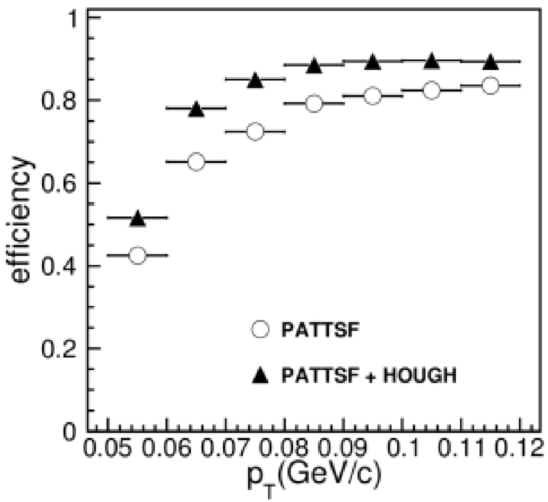


- A global fitting is performed to get the parameters of helix track

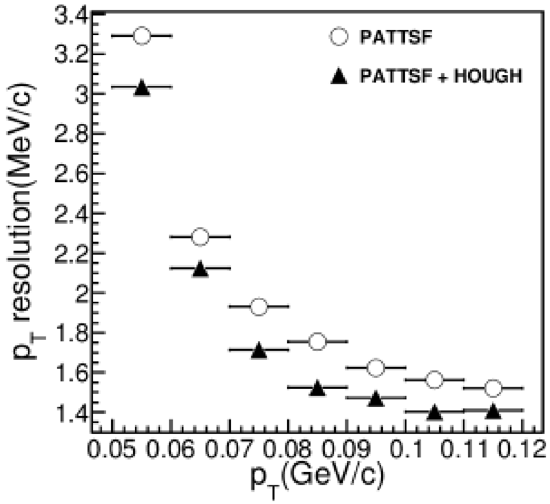
Tracking performance of MC single track

- Tracking efficiency
  - Sample： MC single π^+， pT and cos θ generated uniformly
  - Definition： efficiency $= N_1/N_{all}$,
    - N_1: number of events find at least one good track
    - N_{all}: number of all events
    - Good track： |Vr|<1cm && |Vz|<10cm， correct charge reconstructed

Tracking efficiency vs pT



pT resolution vs pT

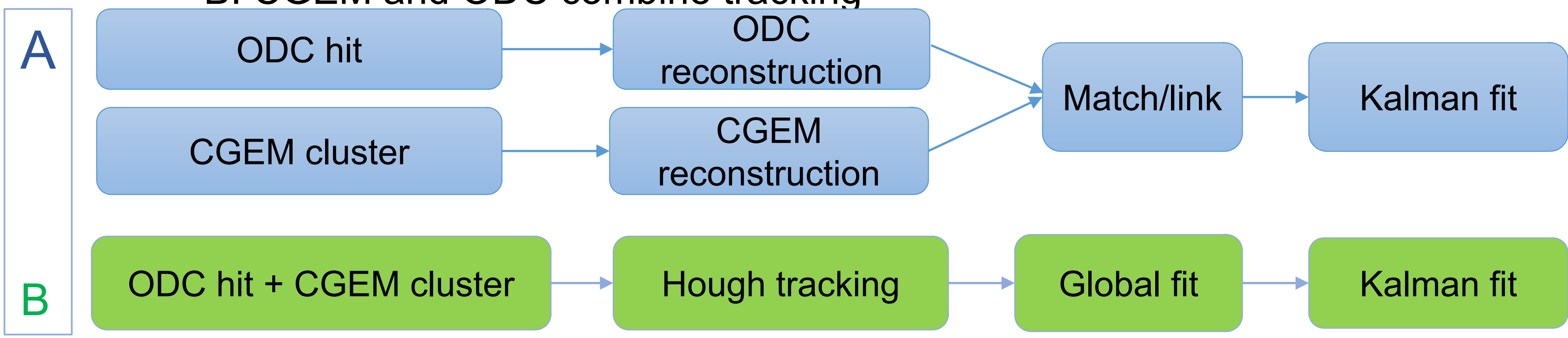


Tracking efficiency improves about 9% at low pT region(50~120MeV/c)
pT resolution slightly improves

Implementation of Hough Transform in MDC-ODC tracking

Reconstruction of CGEM with Outer-Drift-Chamber (ODC)

Two methods :
- ☐ A: CGEM and ODC tracking seperately
- ✓ B: CGEM and ODC combine tracking



Why method B?

Problems of tracking with CGEM and ODC seperately :

- CGEM : Number of clusters is not enough – efficiency & noise
- ODC: Low efficiency without inner chamber when at large angle & low pT

Solutions: Take all the measurements from ODC and CGEM at the finding stage

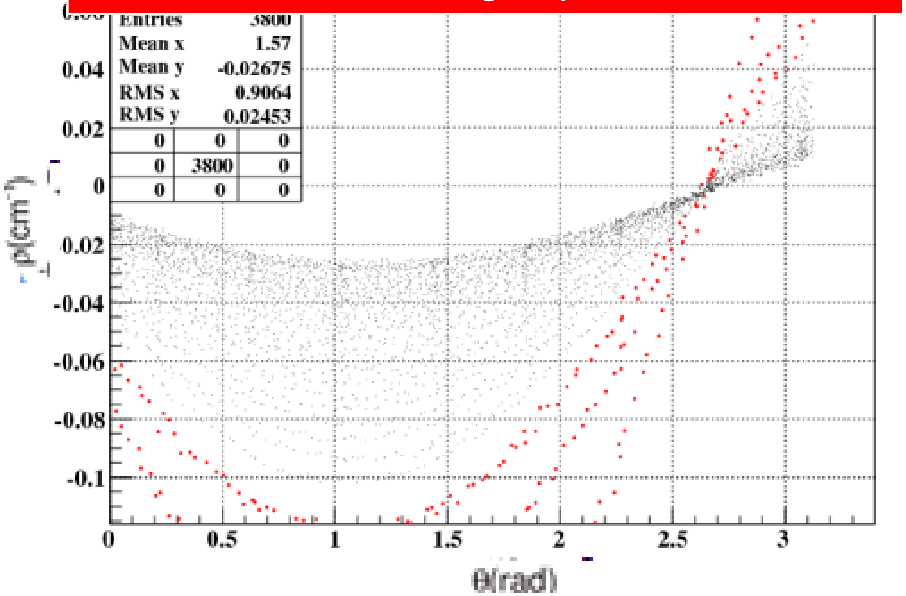
- It is insensitive to the measurement inefficiency
- It will improve the vertex estimate of the track

CGEM-ODC tracking algorithm based on Hough transform

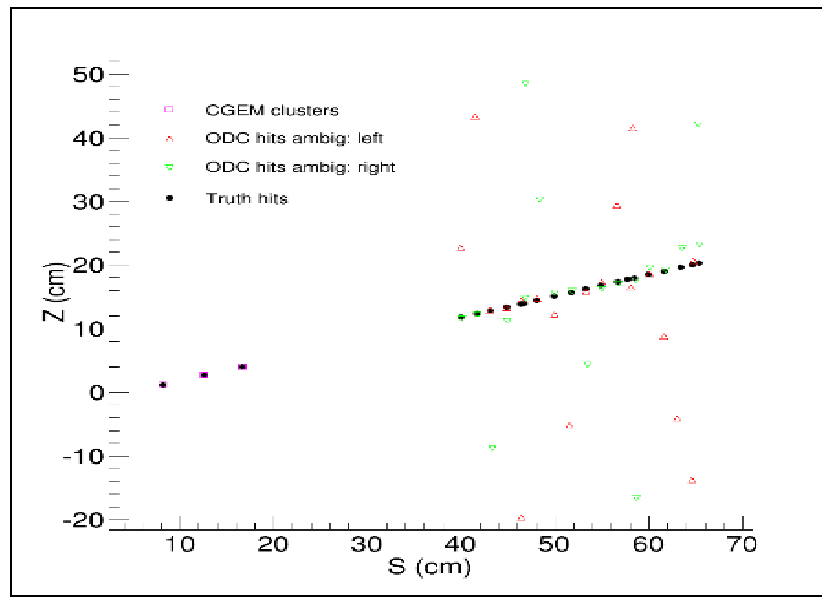
The CGEM-ODC tracking is based on the MDC Hough tracking package

- 2-D tracking: Input of inner chamber hits -> CGEM clusters
- 3-D tracking: 3-D Hough transform in s-z plane (CGEM has better vertex resolution and don't need to consider left/right

2-D Hough space

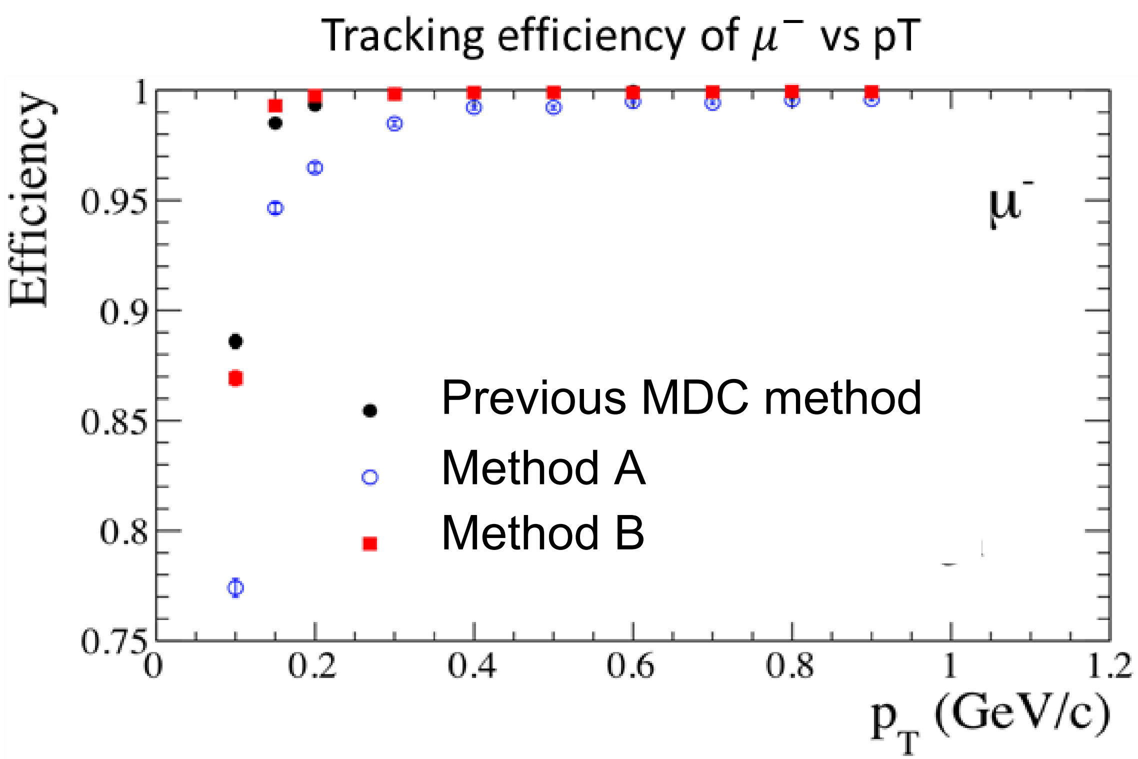


3-D (z-s) plane



Some optimizations have been done with the new algorithm

Status of Hough transform for CGEM-ODC tracking



The algorithm for CGEM-ODC tracking is being optimized, we hope it will be the future global tracking method

Summary

- A new MDC tracking method based on Hough transform is implemented in BESIII software and is used for data reconstruction
- Results show the new method improves the tracking efficiency at low pT region
- We are developing a global tracking algorithm for the future CGEM-ODC tracking with Hough transform, and the preliminary results shows promising
- It is the first time to develop a tracking algorithm independently in BESIII, the experience may be useful for the future CEPC tracking

Thank you !

Backup

Peak Finding method

Local peak on Hough space

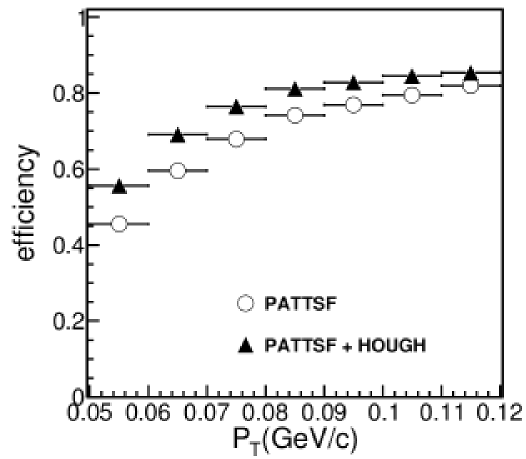
	2	6	5	4				
	3	7	9	6				
	6	9	7	6	5			
	5	5	5	9	3			
			6	7	6			
					5	7	5	
					4	8	7	
					6	3	3	

- Local peak
  - Not lower than the eight bins around it
- Threshold: get candidate tracks
- Parameters of candidate tracks $r_c = \frac{1}{\rho};\ x_c = \frac{1}{\rho} \times \cos\theta;\ y_c = \frac{1}{\rho} \times \sin\theta;$
- Select axial hits
  - Cut window of the distance from hits to a track
- Combine candidate tracks
  - One track may form more than one tracks
  - Combine tracks with many common hits

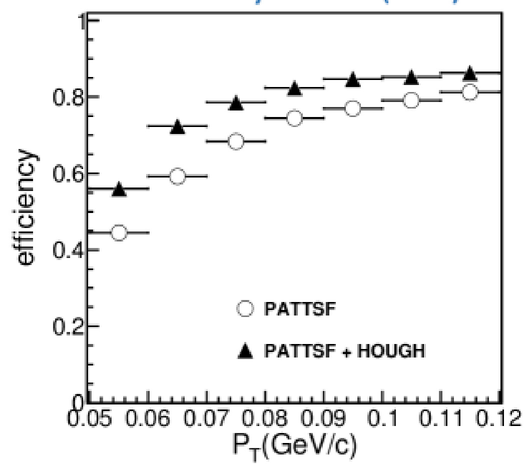
Physics check : J/Ψ ->$p\bar{p}\pi^+\pi^-$

- Select criterion
  - Track level
    - Vertex: |vz|<10cm && |vr|<1cm
    - ✓Angle: |cosθ|<0.93
    - ✓PID
  - Event level
    - ✓$Mass_{p\pi}$ > 1.15GeV/c^2
    - ✓3 or 4 charged tracks
- Track efficiency (π^+)
  - $\varepsilon = \frac{n_4}{n_3+n_4}$
  - n_4: $(p\ \bar{p}, \pi^+, \pi^-)$
  - n_3: $(p, \bar{p}, \pi^-)$

Efficiency of π^+ (DATA)



Efficiency of π^+ (MC)

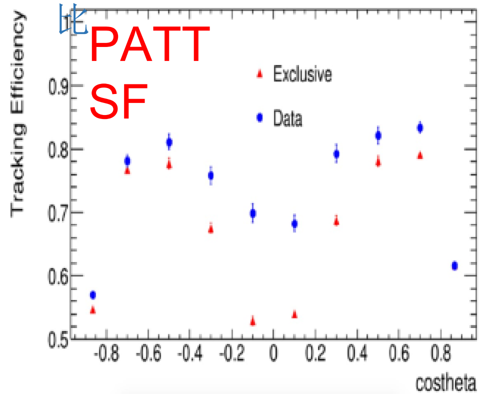


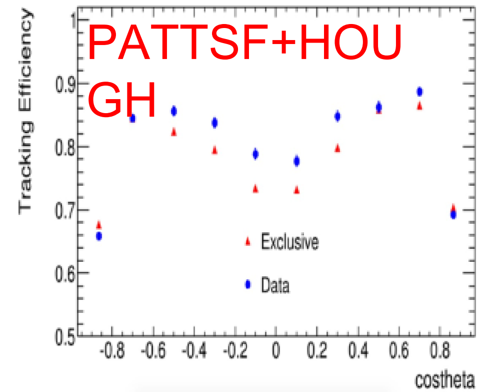
Tracking efficiency of π^+ in J/Ψ ->$p\bar{p}\pi^+\pi^-$ increases about 7%

J/Ψ ->$p\bar{p}\pi^+\pi^-$数据-蒙卡一致性

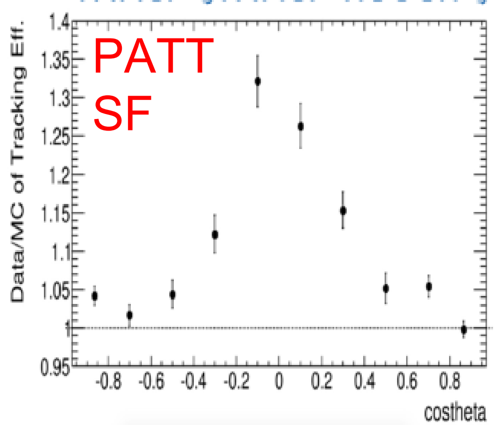
横动量区间：50MeV~120MeV

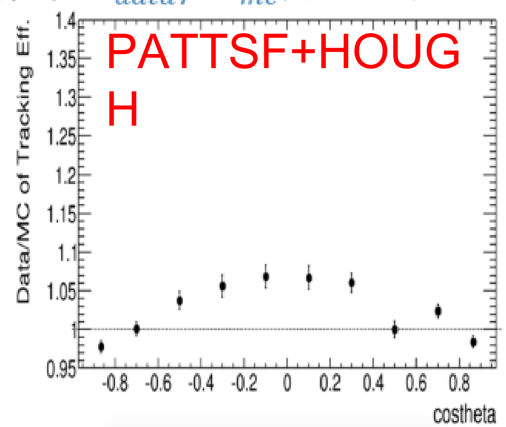
PATTSF与PATTSF+HOUGH数据蒙卡寻迹效率随cosθ对比





PATTSF与PATTSF+HOUGH寻迹效率eff_{data}/eff_{mc}随cosθ对比



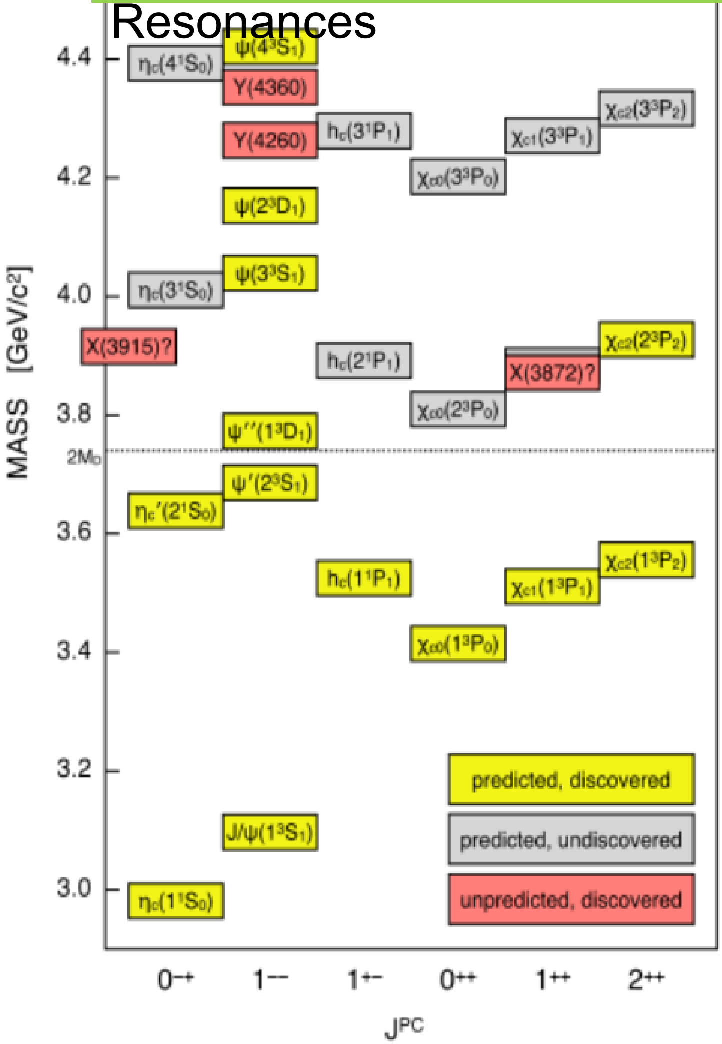


低动量区间数据-蒙卡一致性得到改善，改进后差别在10%以内

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 $c\bar{c}$ threshold (J/ψ)

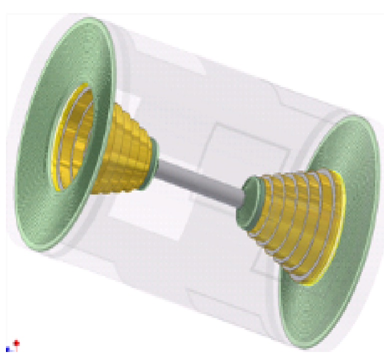
- Search for new resonances in the decay (PWA)
- Measure the ordinary resonances' parameters, the decay mechanisms…

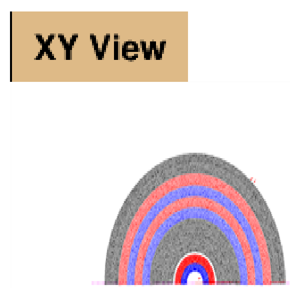
Precision measurements in D/D_s decays

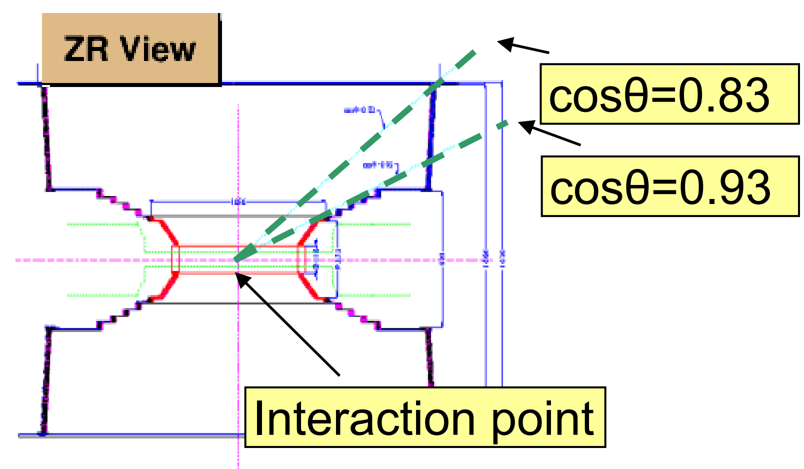
Precise measurements of τ mass and R value in 2-5 GeV region

BESIII Drift Chamber

- Detect trajectory of charged particles
  - Precise momentum and direction
  - High efficiency for charged particles
  - Widely track angle coverage
- MDC geometry
  - Measurement of charge particle trajectories within |cosθ|<0.93
  - 6796 cells arranged in 43 circular layers
  - 11 superlayers
  - Axial wire: x-y measurement , Stereo wire : z measurement







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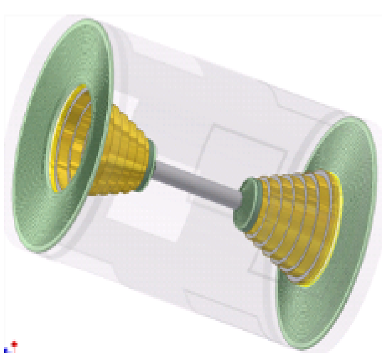
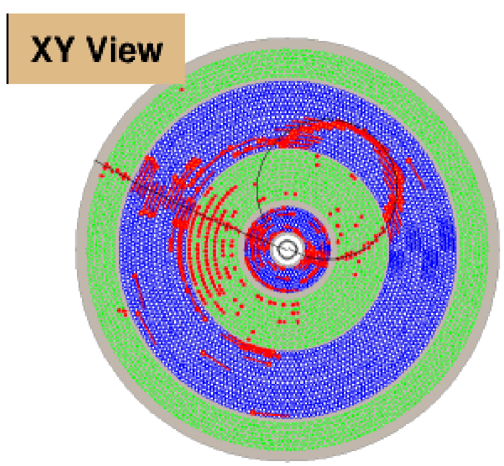
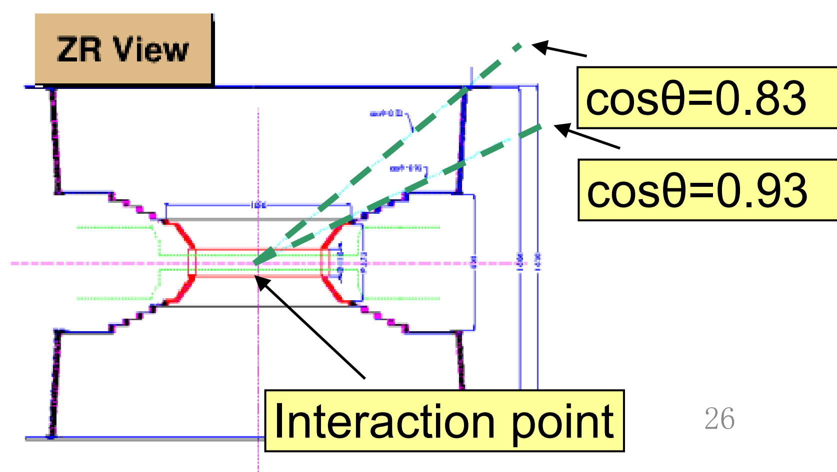
- Design of MDC
  - 6796 cells arranged in 43 cylindrical layers cosθ=0.93
  - **Axial** and **stereo** wires are grouped to superlayers
  - Big "gap" between axial & stereo layers
  - Max solid angle coverage is 0.93%







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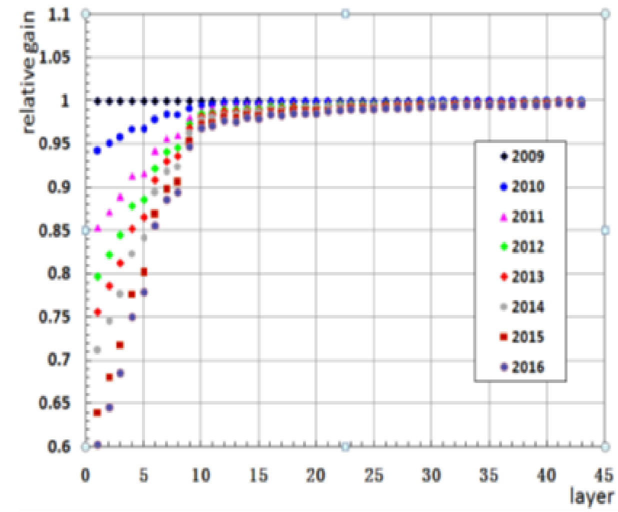
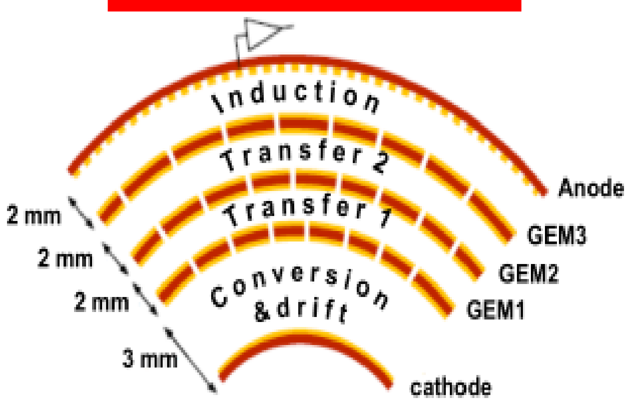
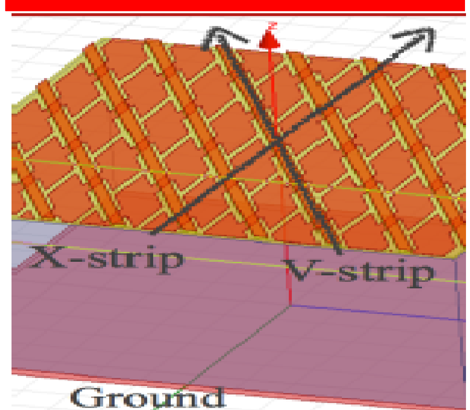
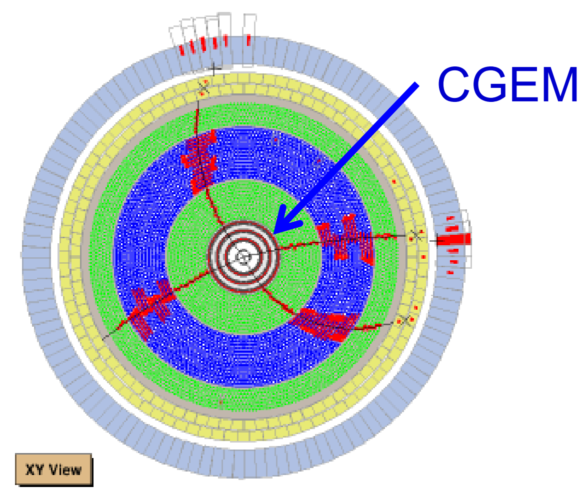


One layer of CGEM



Jagged anode





Tracking performance of MC single track

- Tracking efficiency
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  - Definition： efficiency $= N_1/N_{\mathrm{all}}$,
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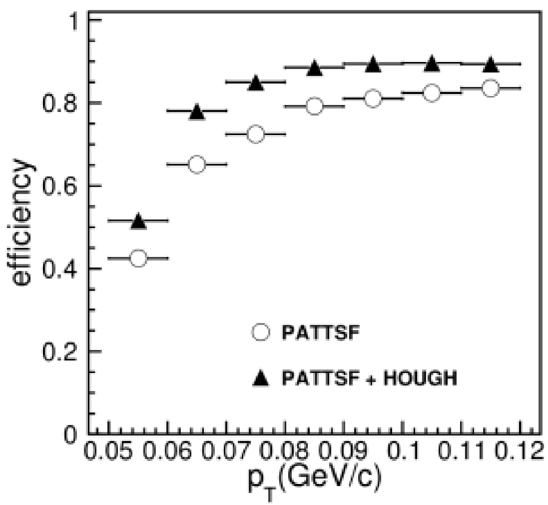
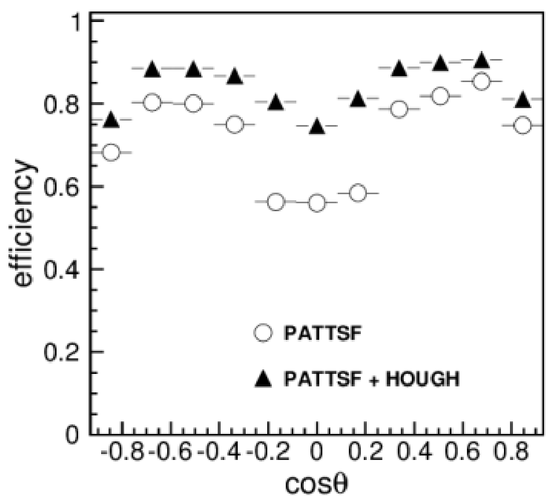
    - Good track： |Vr|<1cm && |Vz|<10cm， correct charge reconstructed

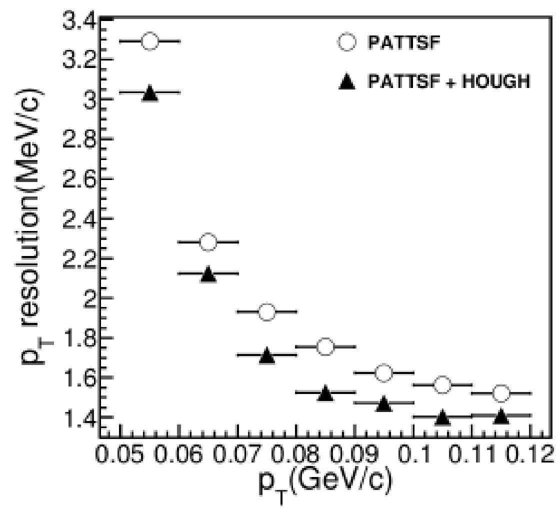
Tracking efficiency vs pT



Tracking efficiency vs cosθ (70~80MeV)



pT resolution vs pT



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pT resolution slightly improves

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