# Tracking Software for STCF

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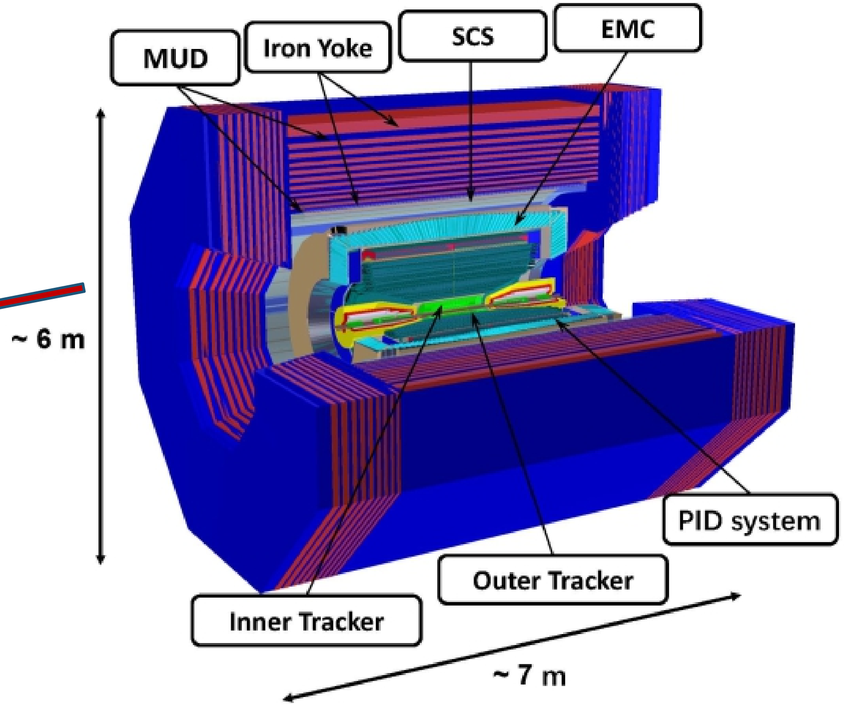
# Outline



- Introduction to STCF and its tracking system
- Global Track finding base on Hough Transform
- MDC backgroud filter with GNN
- Summary

# Super Tau-Charm Facility(STCF)



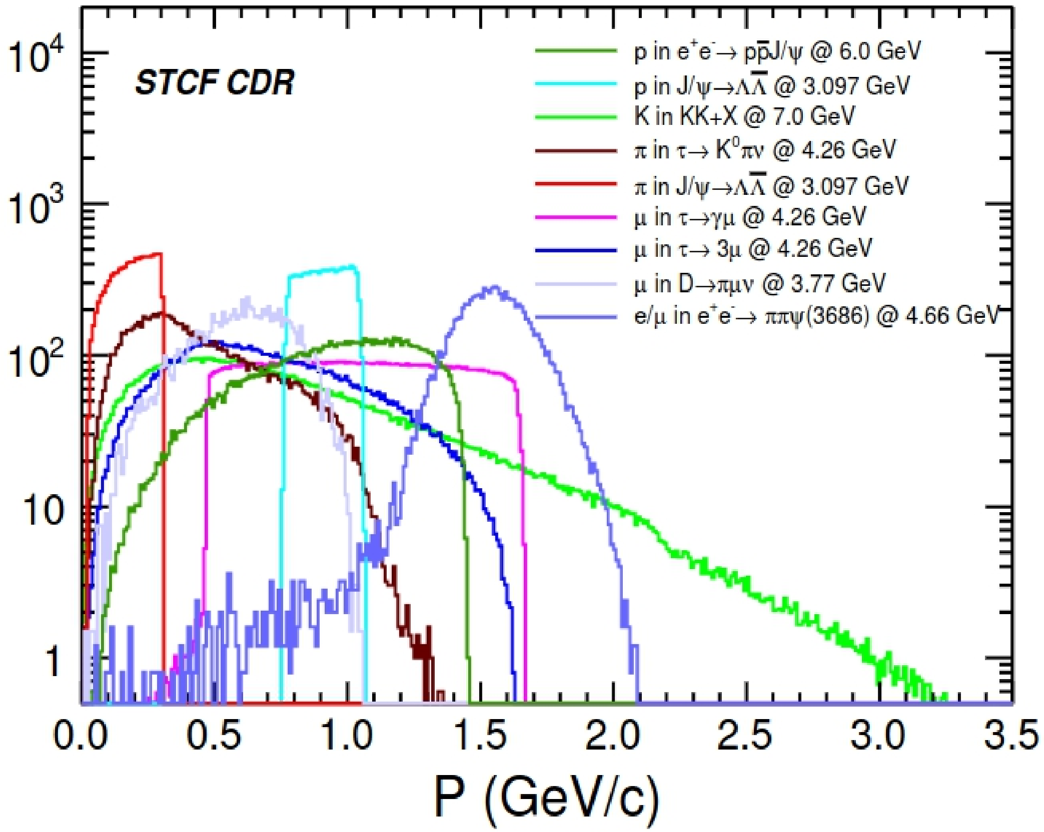



Overview of STCF detectors

- Electron-positron collider experiment
- Center-of-mass energy: 2-7GeV
- High Luminosity: > $0.5 \times 10^{35}$ $cm^{-2}$ $s^{-1}$@4GeV

# Requirements for the tracking detectors






Momentum distributions of charged particles

- Momentum resolution:

  $\sigma p/p$ = 0.5% at p = 1GeV

- Tracking efficiency:

  > 99% @ $p_T$ > 0.3 GeV, > 90% @ pT = 0.1GeV

- dE/dX(MDC) resolution: ~ 6% for PID

# Baseline design of the tracking system

- The STCF tracking system includes **Inner Tracker(ITK)** and Main **Drift Chamber(MDC)**

◆ ITK: 3 layers of detectors with high counting rate capability

– Two options:

monolithic active pixel sensor(MAPS)

micro-resistive well detector (μRWELL)

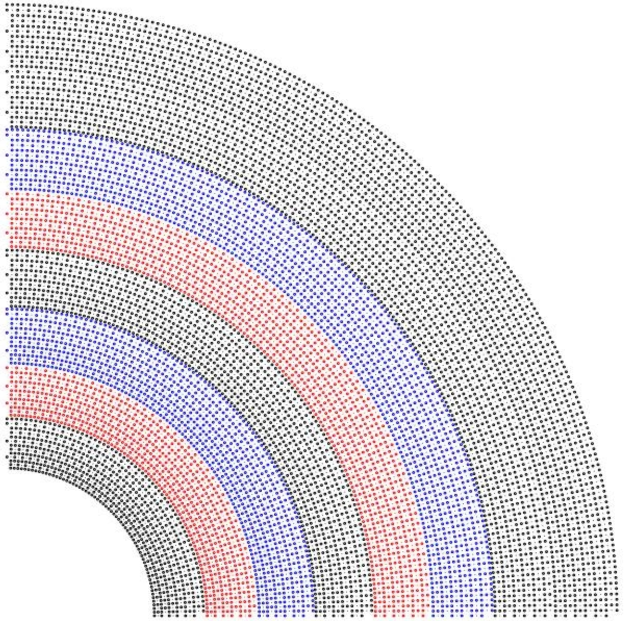
– Placed in the area close to the beam pipe(3-20cm)

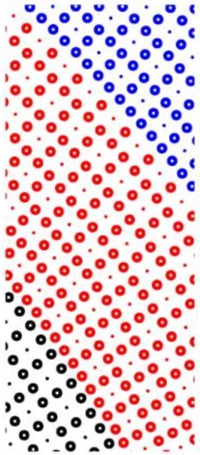
◆ MDC: main tracker provide provides most of the measurements

– Large detection volume(20-85cm)

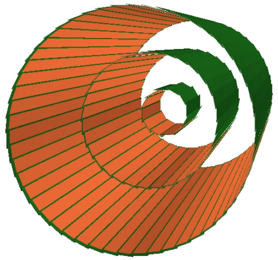
– 48 layers, 4 stereo super-layers, 4 axial super-layers

– Approximate rectangular cell

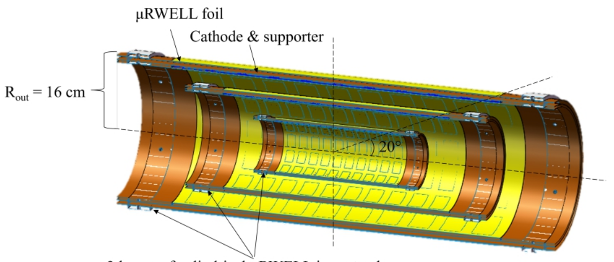




MAPS option



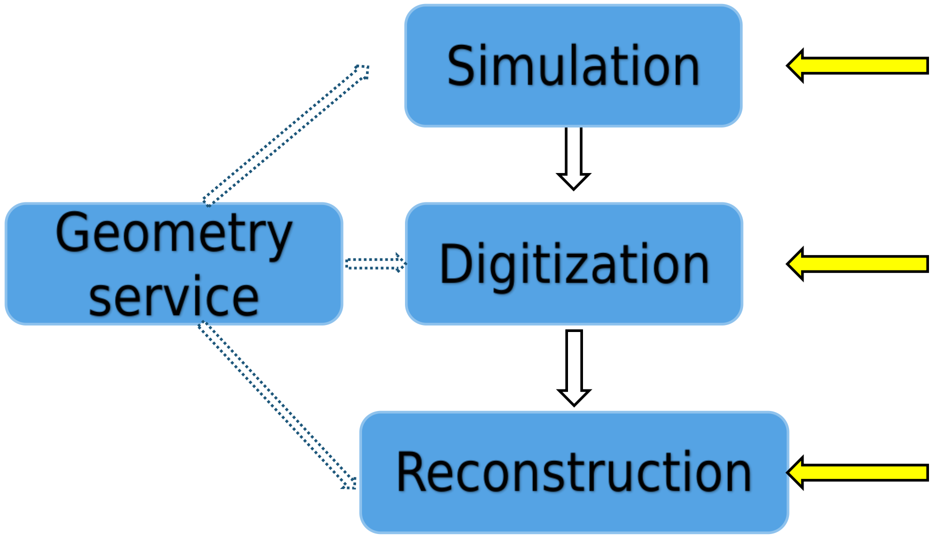
μRWELL option



# Tracker offline software



- Most parts have implementations in the STCF offline software framework(OSCAR), now in improving
  - All stages use consistent geometry




- Full simulation with geant4 and garfield++
- 1T homogeneous magnetic field is used
- Backgroud hits mixed before digitization
- Considering signal pile-up
- Cluster reconstruction
- Track reconstruction: track finding→track fitting

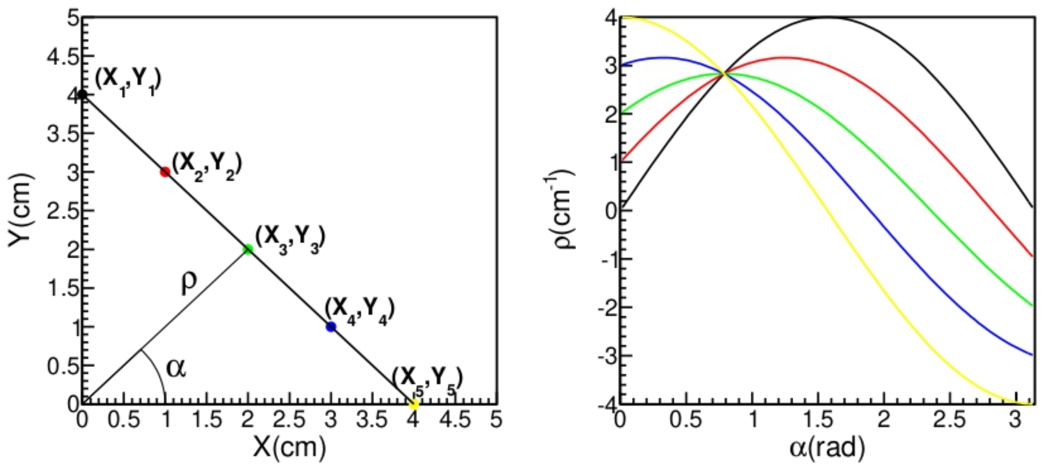
In current reconstruction study

- μRWELL-based ITK is used,
  - placement radii: 6,11,16cm      0.25% X/X0 each layer
- Full sim hits smeared with detector resolution as inputs
  - MDC: 120μm(drift distance)      - ITK: 100 μm (rφ) x400 μm (z)
- Assuming 100% detecting efficiency for both ITK and MDC

- Basic idea: conformal transform + Hough transform
  - Conformal transform: circular trajectories starting from the origin to straight lines
  - Dealing with ITK and MDC hits combined using Hough(Legendre) transform
  - Detecting efficiency does not significantly affect the performance

Global

Hough transform



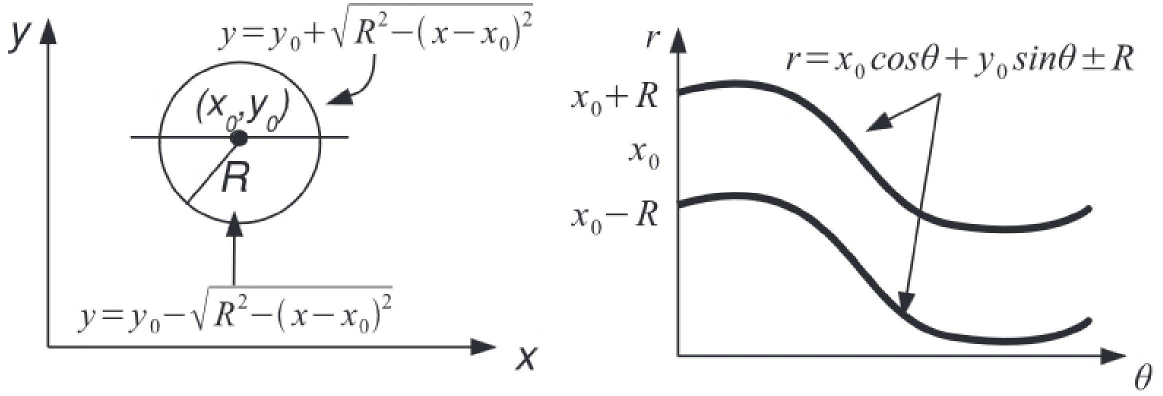

$\rho = X\cos\alpha + Y\sin\alpha$

(a) X-Y plane (b) parameter space

a point in the image space
→ a sinogram in Hough space

Handling of MDC hits: Legendre transform

https://doi.org/10.1016/j.nima.2008.04.038

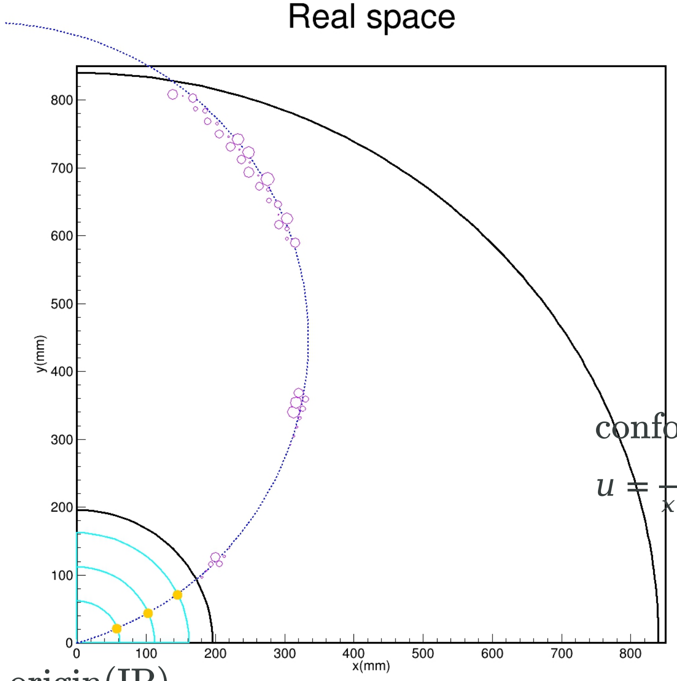



MDC hits→drift circle
The circle corresponds to two sinograms in the Legendre space

# Track finding based on Hough transform



Real space

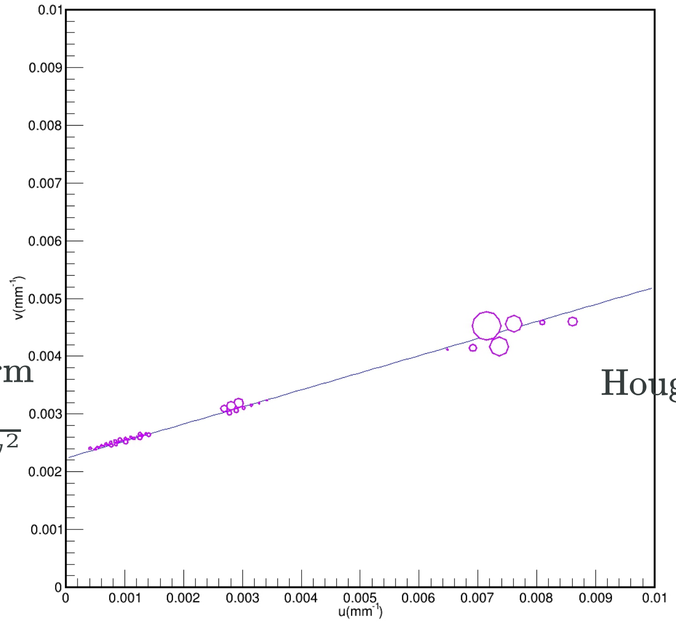



origin(IP)

conformal transform

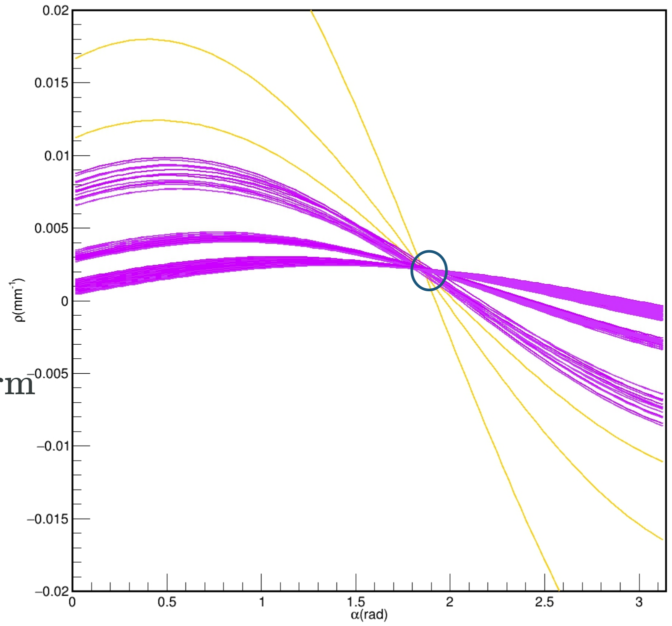
$u = \frac{2x}{x^2+y^2}, \mathrm{v} = \frac{2y}{x^2+y^2}$

Conformal space

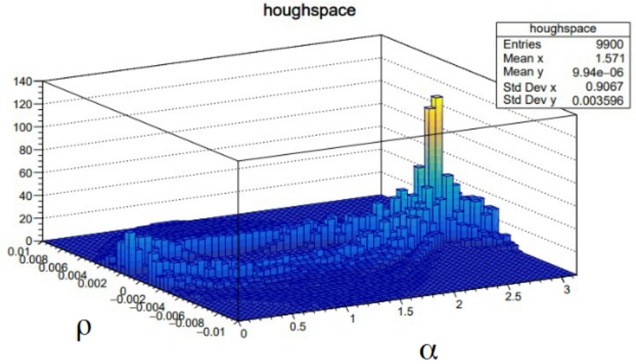



Hough transform

Hough space



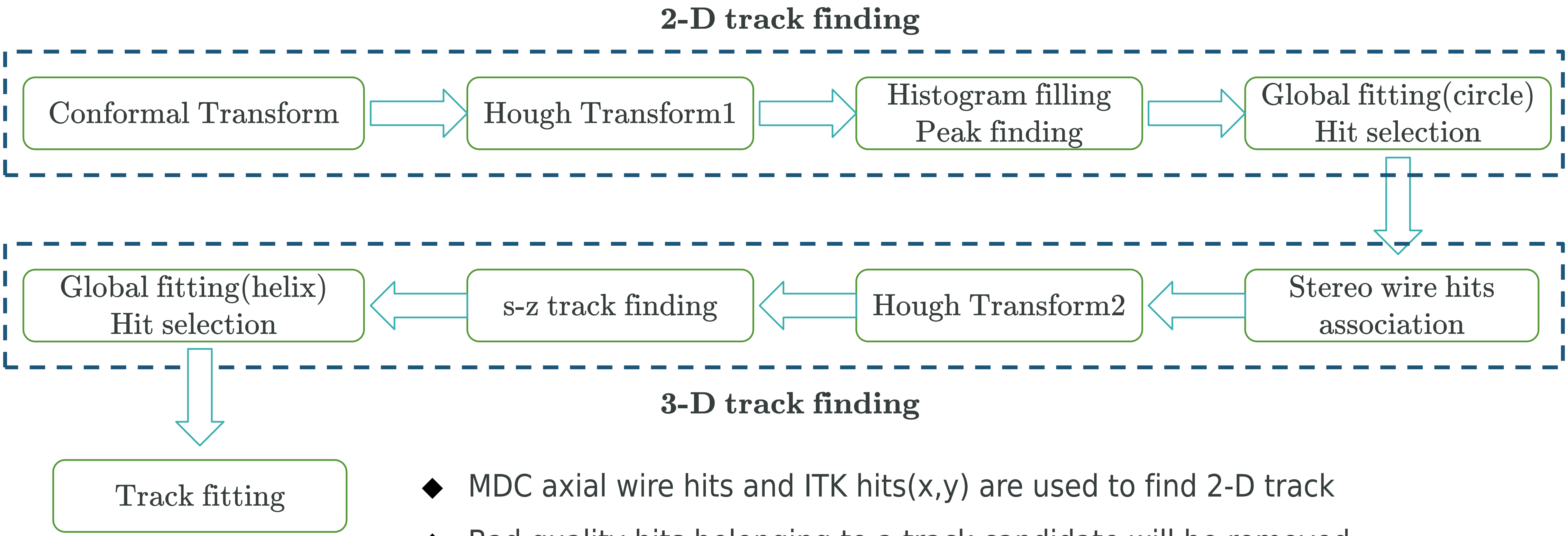

• ITK hit
• MDC hit




- Finding the regions with high density in ρ-α space
  - Use 2D histogram
  - Calculate the number of sinograms crossed in each bin
  - Peak position corresponding to track(circle) parameters: $(\rho, \alpha) \Leftrightarrow (\varphi_0, r)$

# Track finding chain





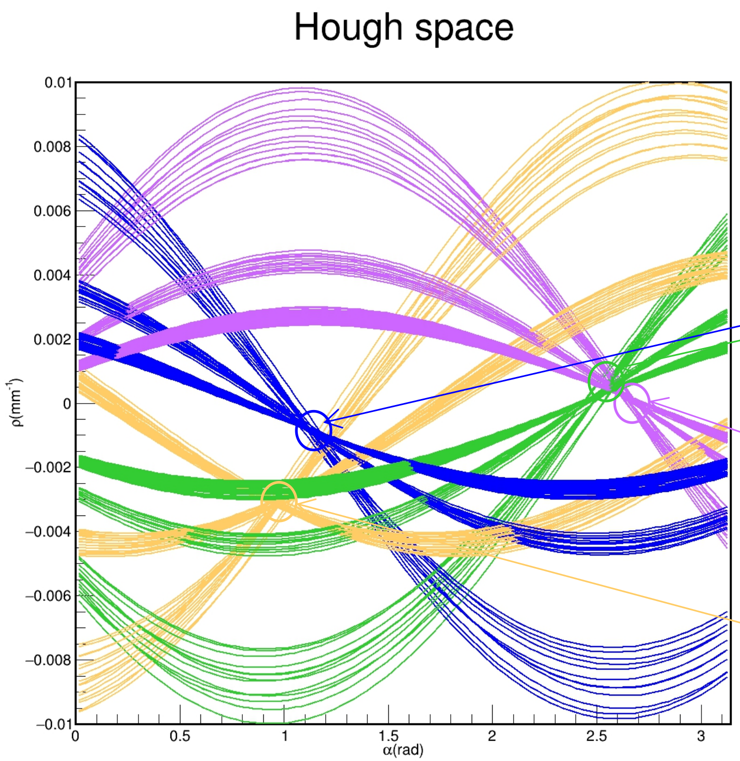

- MDC axial wire hits and ITK hits(x,y) are used to find 2-D track
- Bad quality hits belonging to a track candidate will be removed
- The trajectory is straight in the s-z space → similar to the 2-D tarck finding

# Track finding based on Hough transform

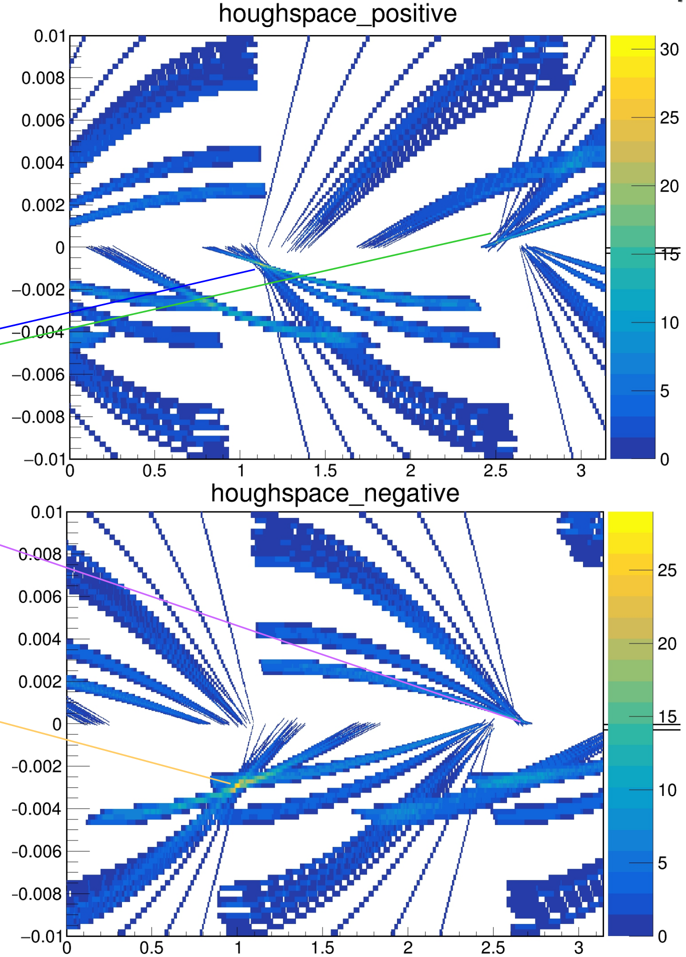


- Two histograms are used, filling which histogram is judged by calculating ρdρ/dα

→ hits from different charged particles don't interfere with each other when peak finding



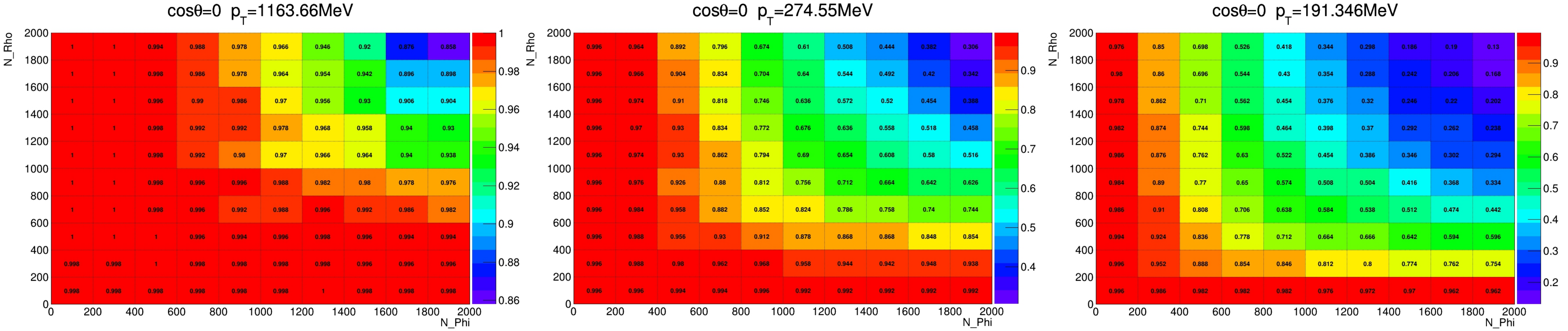

An example of 4 tracks(π+π-μ+μ-)



# Track finding based on Hough transform



- The bin size is not the same in the ρ direction
  - Related to the resolution of the track parameter(ρ⇔$p_T$)
  - The bin size in ρ-direction is optimized using simulated events

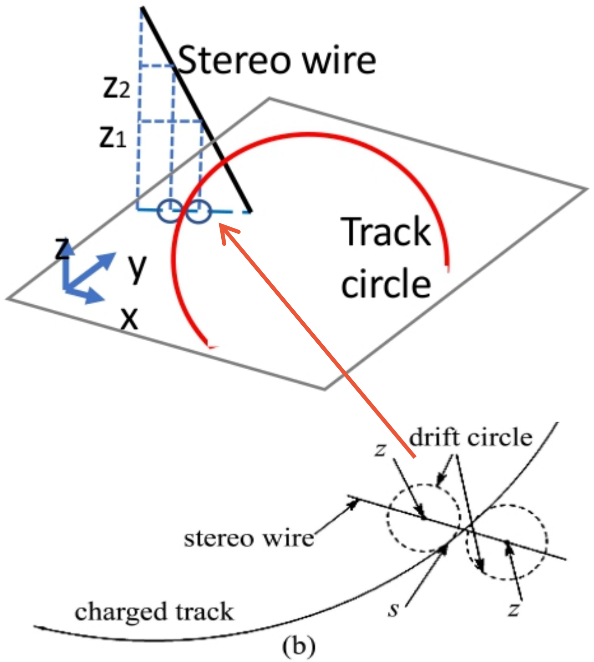


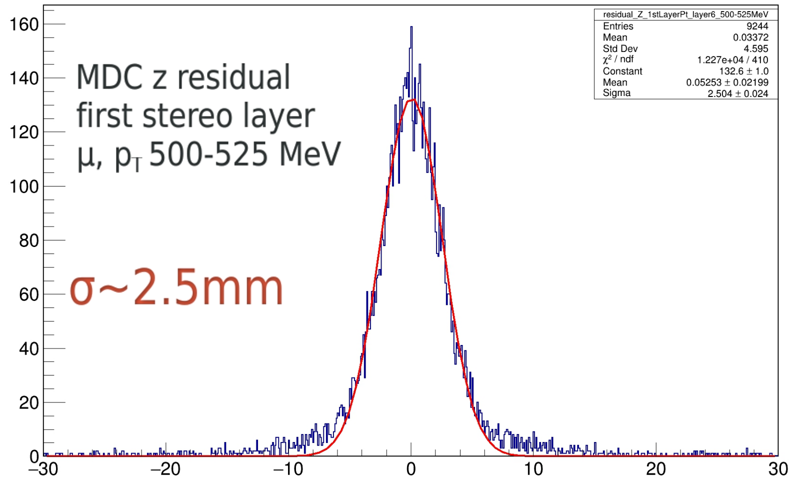

"Good Event" ratio(for single muon track)

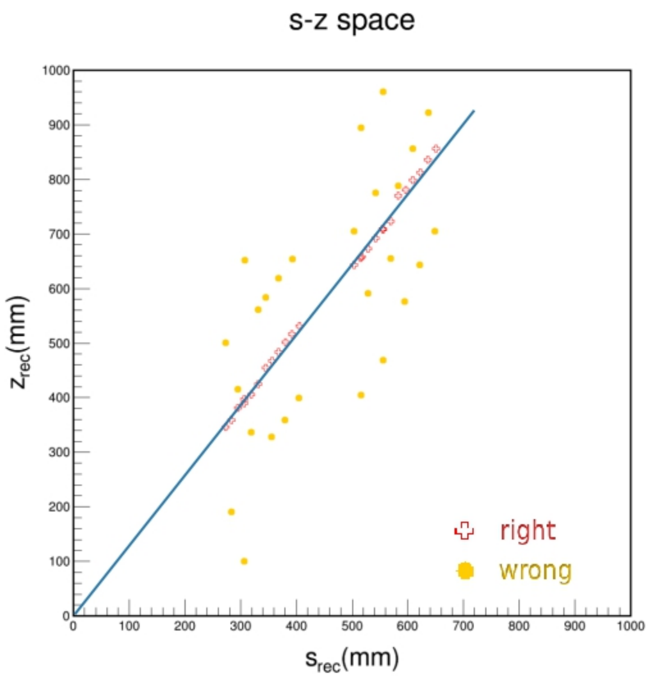
Good Event: At least one of the peaks contains most(>95%) of the hits belonging to the same track

# Track finding based on Hough transform

- Linear fitting(in conformal place) and circle fitting performed to get track parameters
- Match MDC stereo wire hits, calculate z position values
- The trajectory is straight in the s-z space, $z_0 = z_{rec} - \tan\lambda \cdot s_{rec}$



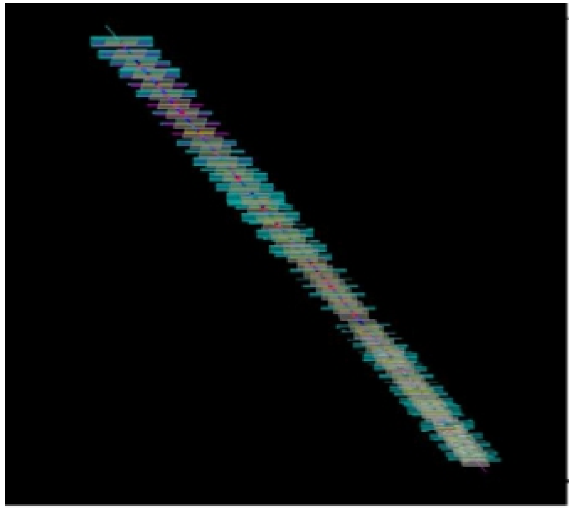



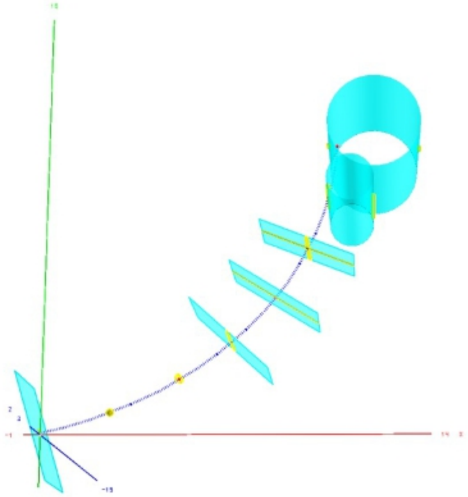




- Track finding in s-z space is similar to that in the conformal plane

# Track fitting by Genfit2

- Track fitting use generic track-titting toolkit Genfit2
  - Experiment-independent track fitting software used in Belle2, PANDA…
  - Supports track fitting that combine different measurement types
  - Deterministic annealing fitter(DAF) is used
  - Five hypotheses for e, μ , π , k , p
  - Read detector geometry directly from the geometry service in OSCAR
  - Currently using a uniform 1T magnetic field

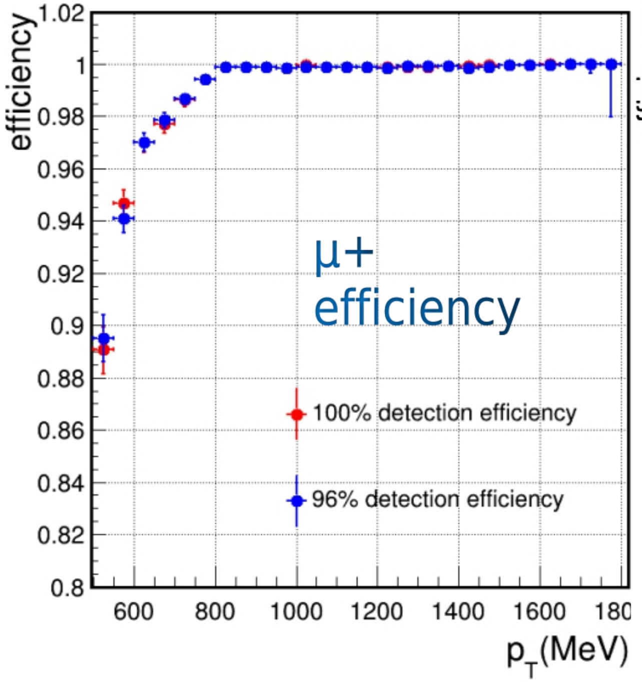


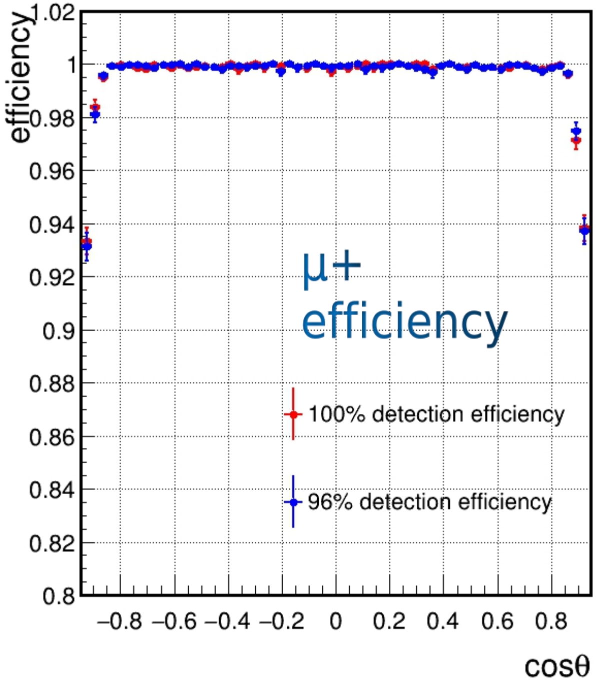


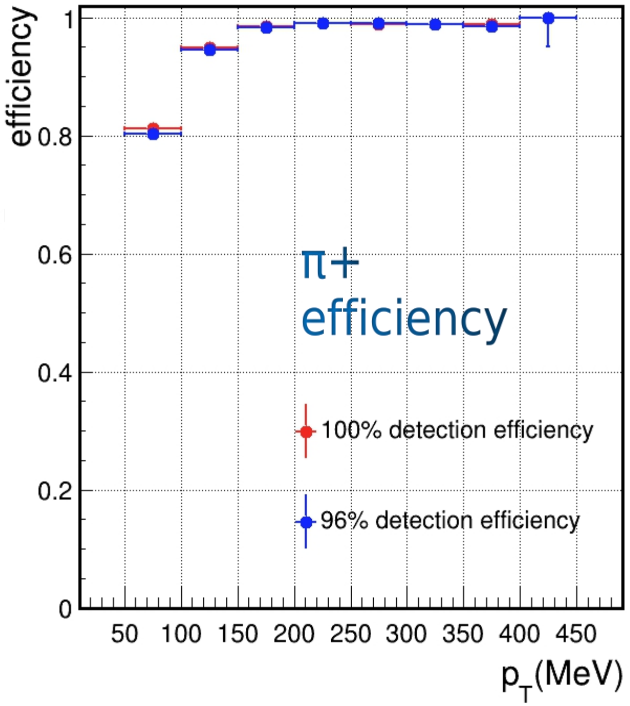
# Track finding Performance

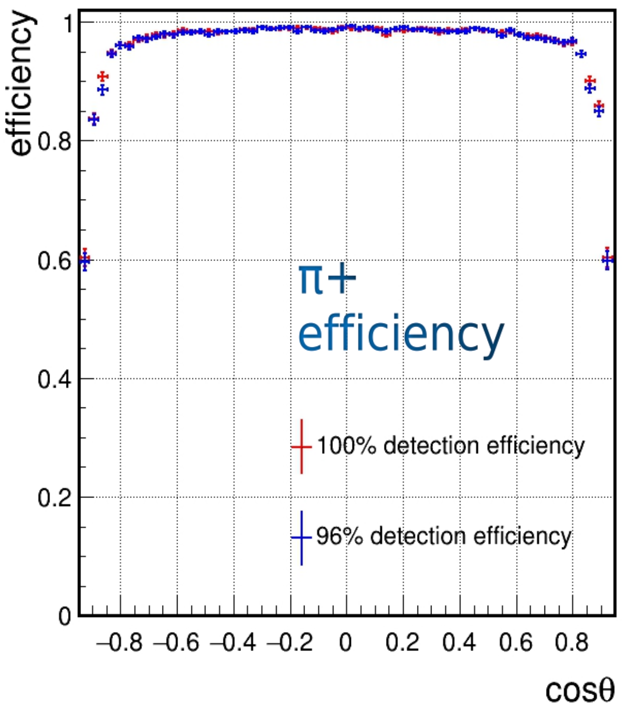


- Simulated ψ(3686)→ π+π- J/ψ(μ+μ-) events, without noise



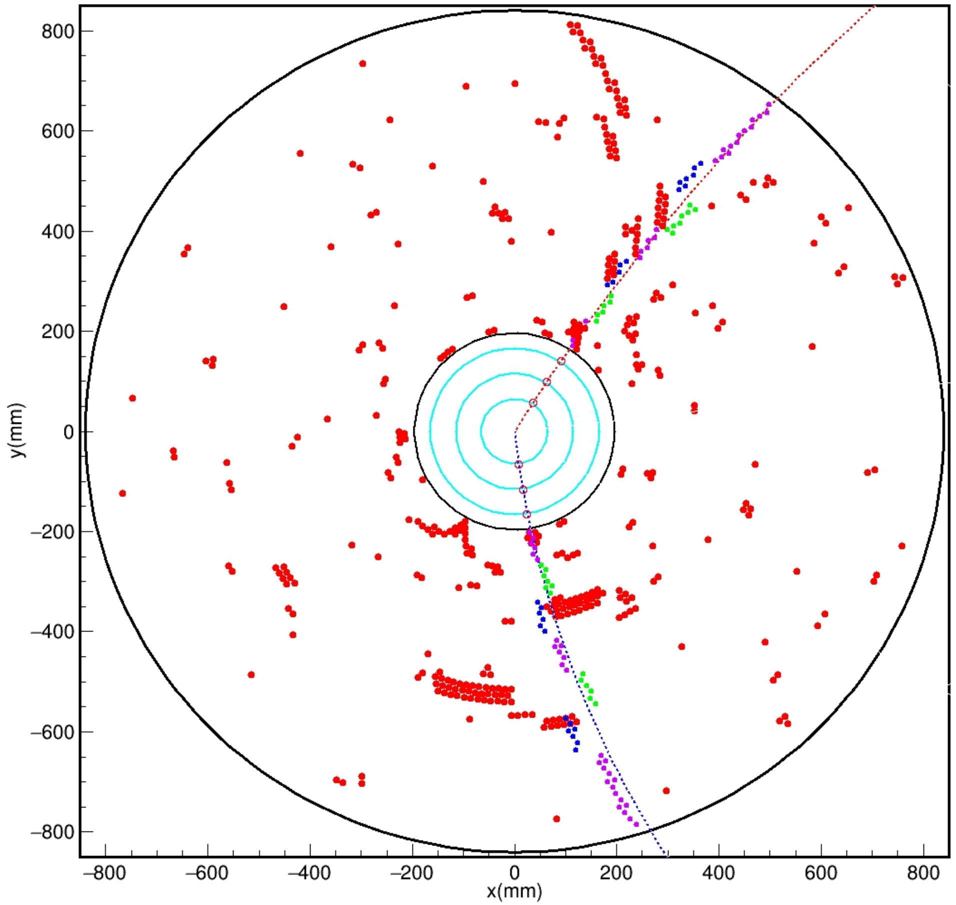




- Above 99% efficiency for muon with pT > 800MeV or |cosθ|<0.88, >80% for pion with pT[50,100] MeV
- The efficiency drops sharply when the dip angle is large(to be checked)
- Assuming 96% efficiency for both MDC and ITK(Dropping some hits by uniform sampling), the efficiency is almost unchanged

# MDC backgroud



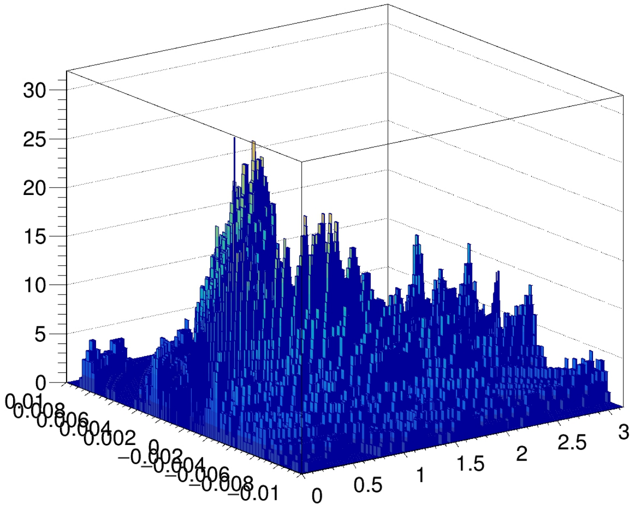

More about background, Yupeng's talk

https://indico.pnp.ustc.edu.cn/event/91/contributions/6450/

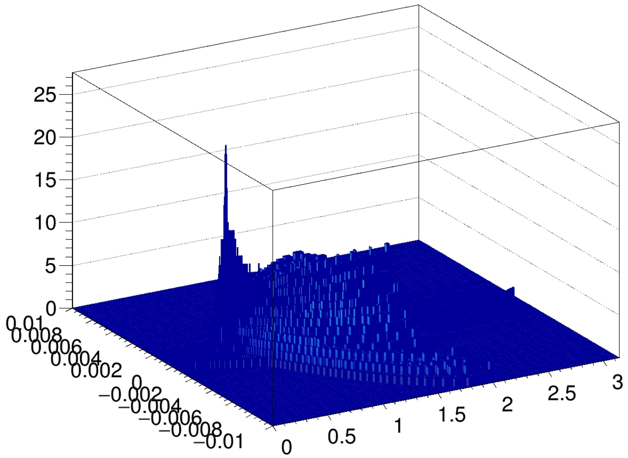
- May face high background
  - Background simulation v2: approximately 500hits/1 μs window
  - The newest simulation result is much larger
- Track finding is disturbed by the background hits
  - Decrease in efficiency
  - Fake tracks

a backgroud filter is needed

Hough map with backgroud



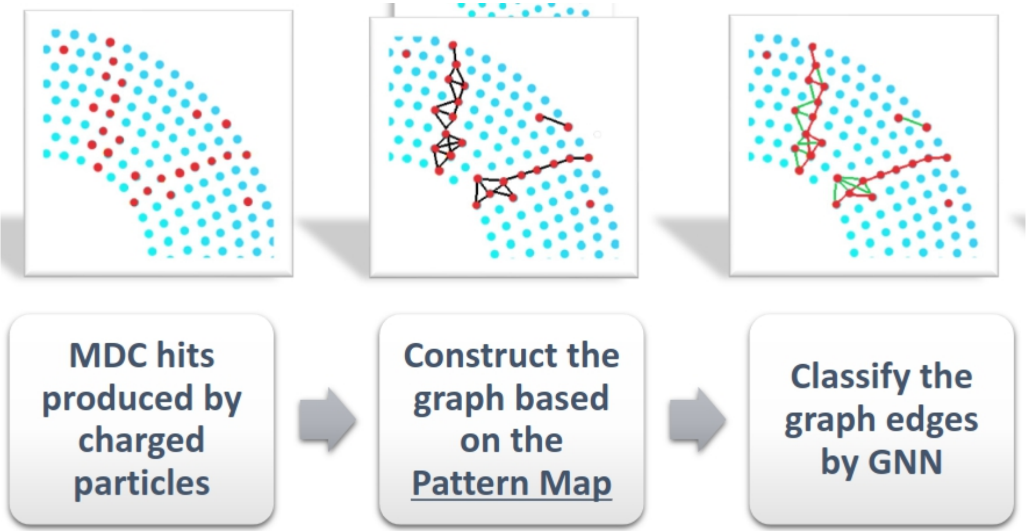

Hough map without backgroud

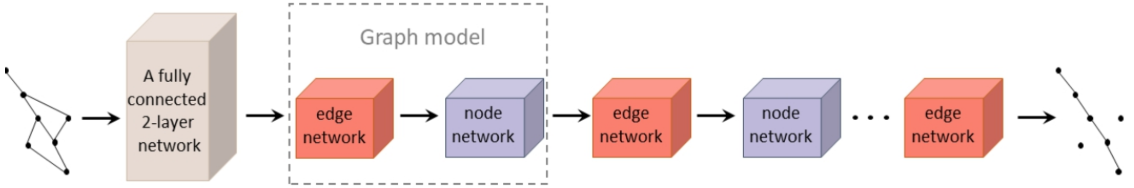


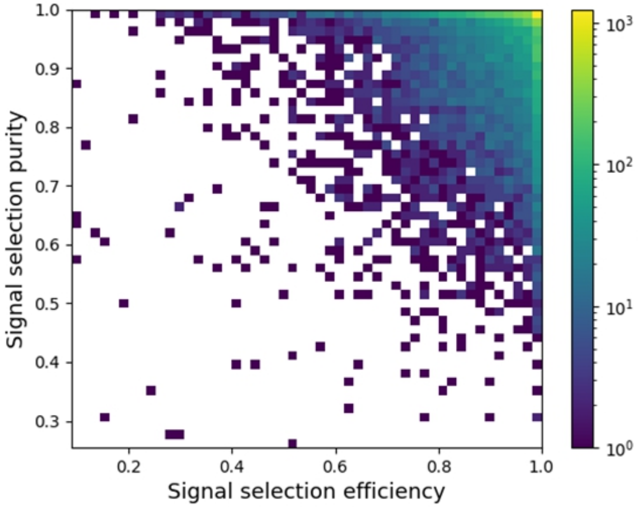
# MDC backgroud filter using GNN

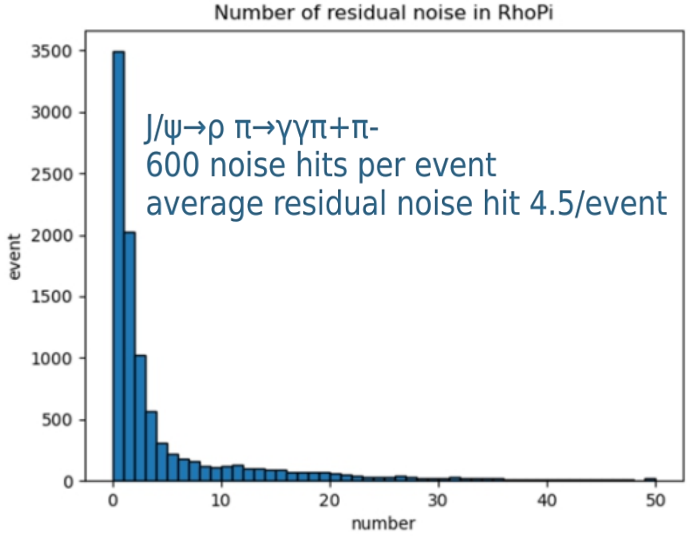


- Graph Neural Network edge classifier
  - Nodes → Hits, edges → track segments
  - Model structure: input network, node network, edge network
  - Input: node features(drift distance, coordinate of signal wires)
  - Output: hits classification and edge score,
  - Selecting hits depending on score



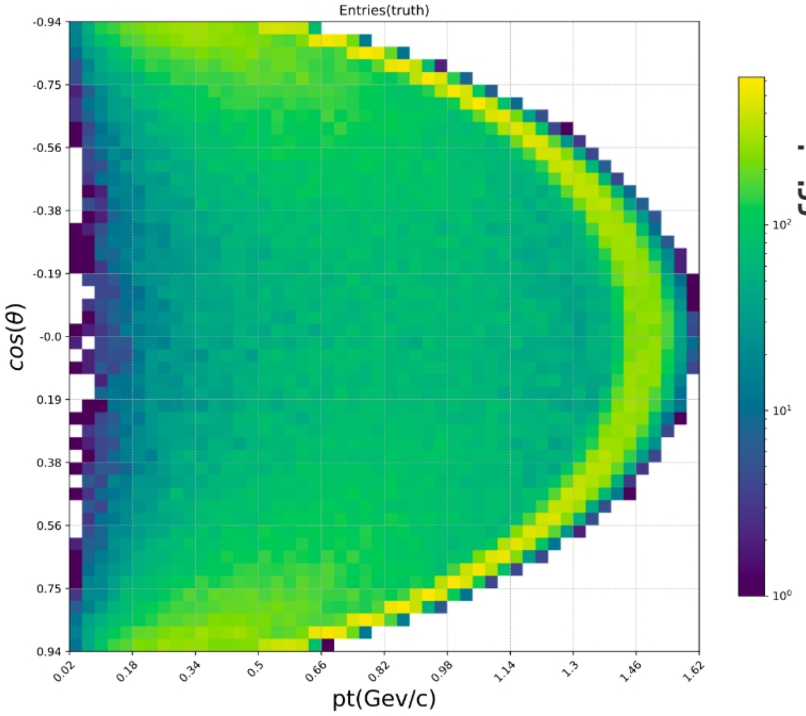



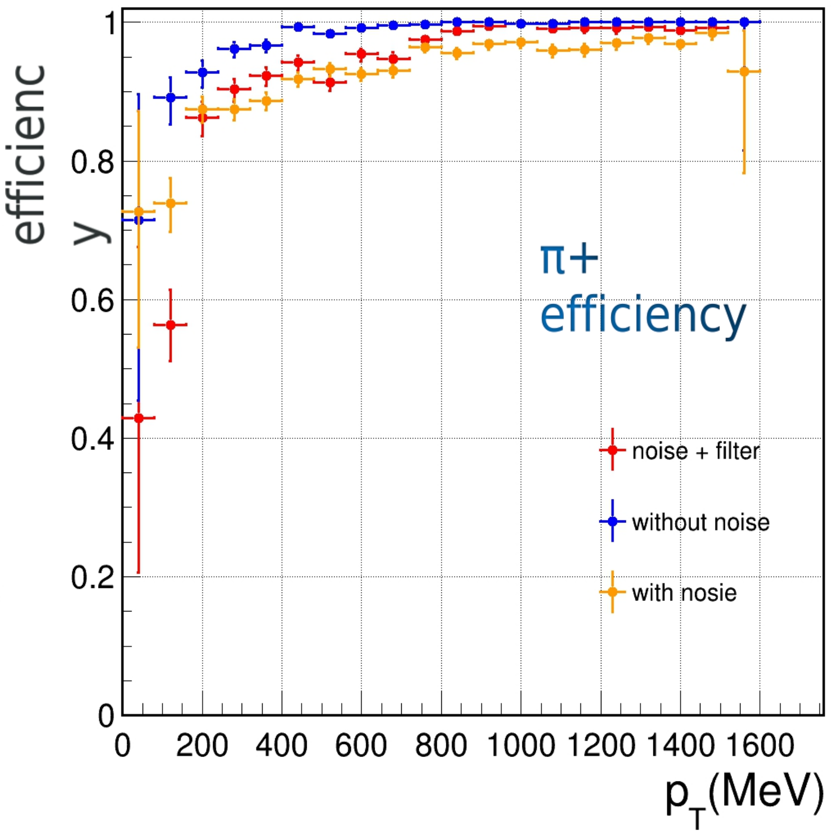

- Hit selection Efficiency $\frac{N_{signal}^{predicted}}{N_{signal}^{real}} = 91.1\%$
- Hit selection Purity $\frac{N_{signal}^{predicted}}{N_{all}^{predicted}} = 91.4\%$
- Noise removal efficiency $\frac{N_{noise}^{predicted}}{N_{noise}^{real}} = 98.6\%$

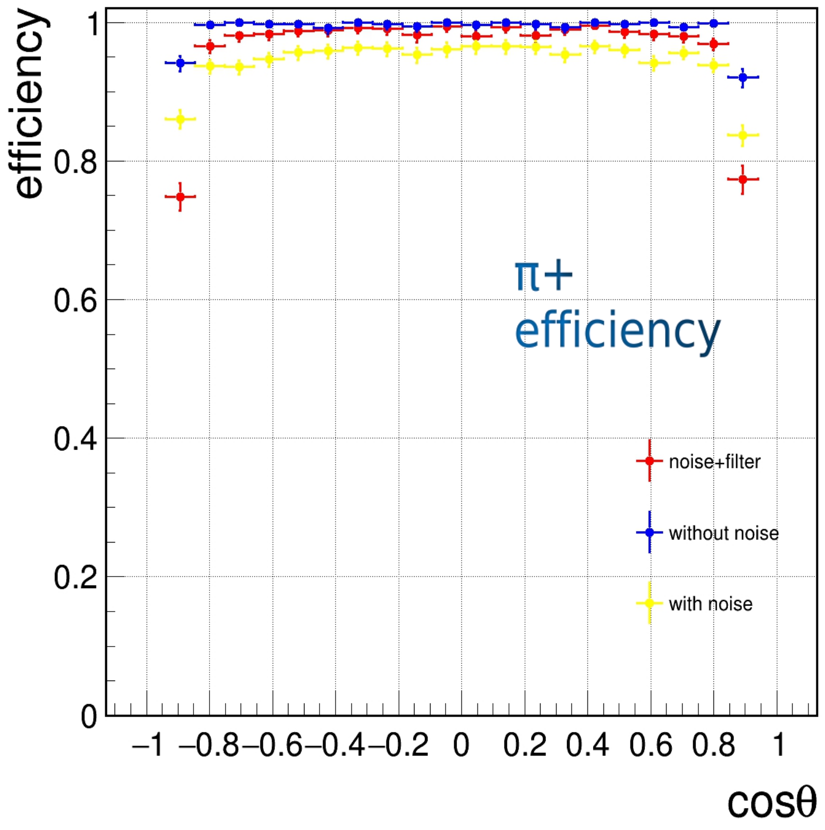
# MDC backgroud filter using GNN

Simulated J/ψ→ρ π→γγπ+π- events, noise hits of ITK are not added




truth $p_T$-cosθ distribution of π




- At large |cosθ|, the tracking efficiency decreases due to less hit

# Summary



- The key components of ITK/MDC software have been established
- A global track finding algorithm based on Hough transform implemented in OSCAR
  - It shows the potential to achieve a high performance
  - But there is still a lot to be optimised
- An algorithm based on GNN is used to reduce MDC background

## outlook

**Thank you**

- The tracking algorithm needs a lot of optimisation

  for instance: large dip angle/short/looping track, secondary vertex track, backbround
- Other method for STCF track reconstruction are also being researched (ACTS, ML)
- More realistic simulation and reconstruction need to be built to validate detector performance

# BACK UP

# Track finding Performance

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- Tracking efficiency: $N_{rectrack}/N_{particles}$

  $N_{rectrack}$: number of reconstructed tracks which matched to the selected particles, ech track satisfies

  – |Vr|<1cm && |Vz|<10cm

  $N_{particles}$: number of selected particles

  – number of hits> 5

  – 20°<theta<160°