Track reconstruction in the STCF detector

Hang Zhou
on behalf of the STCF tracking group

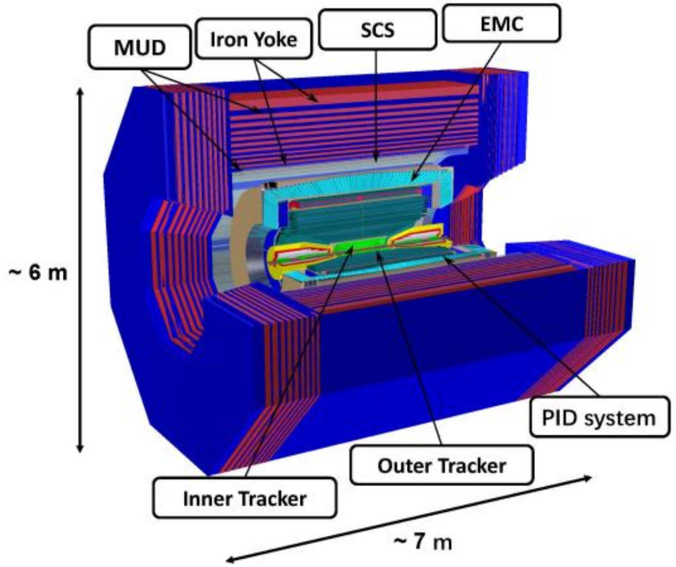
2024.10.24, CHEP2024, Kraków, Poland

Outline

- Introduction
- Global track finding based on the Hough transform
- Track reconstruction at STCF using ACTS
- ML techniques in STCF track reconstruction
- Outlook and summary

Super Tau-Charm Facility(STCF)

- Electron-positron collider (China)
- E_{cm}=2-7GeV, L> 0.5×10^{35} cm^{-2} s^{-1}(peak)
- Potential for an upgrade to increase L and realize polarized beam

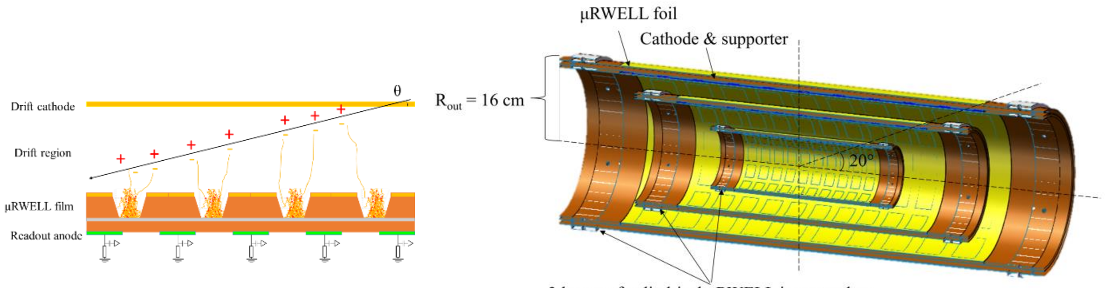


- Energy region bridges perturbative and non-perturbative QCD.
- Abundant resonance structures, huge production cross-sections for charmonium states.
- Threshold effect of pair production of hadron and τ.
- Copious production of exotic hadrons (multi-quark, and hybrid states).

Tracking System : ITK + MDC

- Two options inner tracker(ITK)

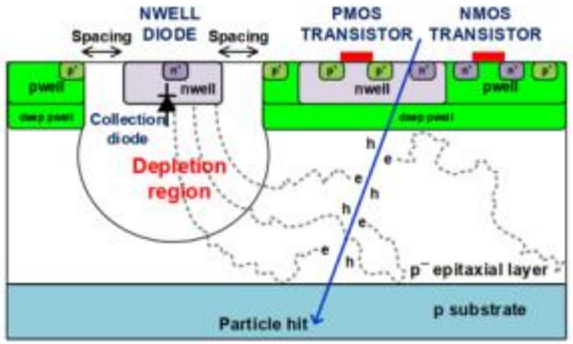
ITK Gaseous option : MPGD



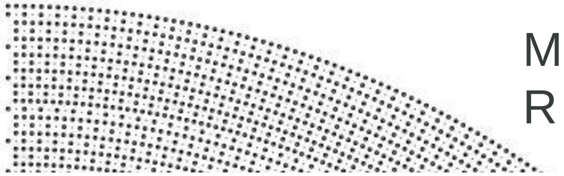
3 layers of cylindrical µRWELL inner tracker
(with sensitive length of 33, 61, 88 cm respectively)

3 layers(R = 6, 11, 16cm)

ITK Silicon option: CMOS MAPS

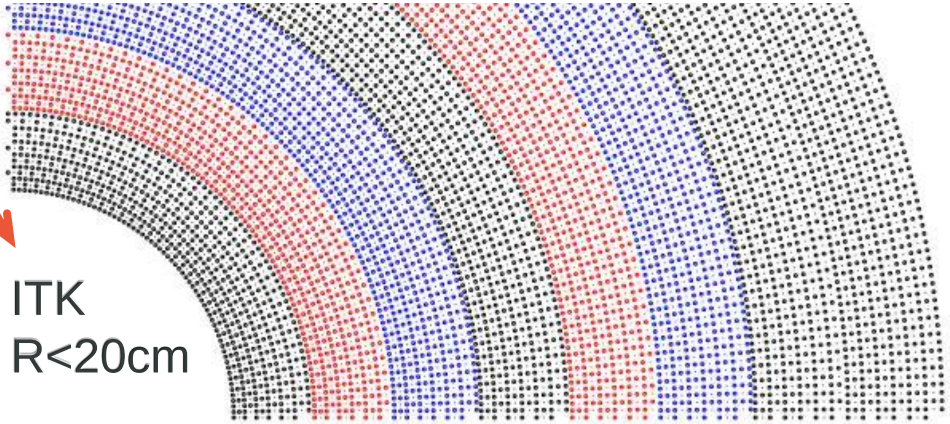


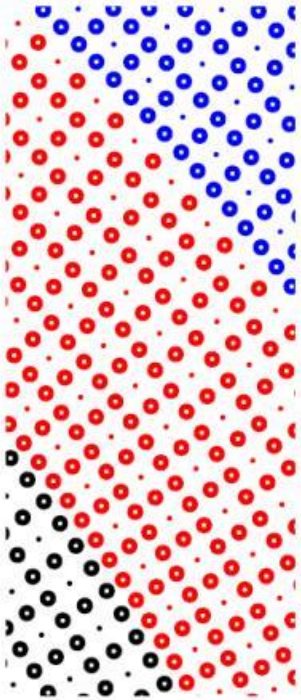
- Main tracker



MDC(Main Drift Chamber)
R 20cm-840cm, 48layers

Superlayer	Radius (mm)	Num. of Layers	Stereo angle (mrad)	Num. of Cells	Cell size (mm)
A	200.0	6	0	128	9.8 to 12.5
U	271.6	6	39.3 to 47.6	160	10.7 to 12.9
V	342.2	6	-41.2 to -48.4	192	11.2 to 13.2
A	419.2	6	0	224	11.7 to 13.5
U	499.8	6	50.0 to 56.4	256	12.3 to 13.8
V	578.1	6	-51.3 to -57.2	288	12.6 to 14.0
A	662.0	6	0	320	13.0 to 14.3
A	744.0	6	0	352	13.3 to 14.5
total	200 to 827.3	48		11520	

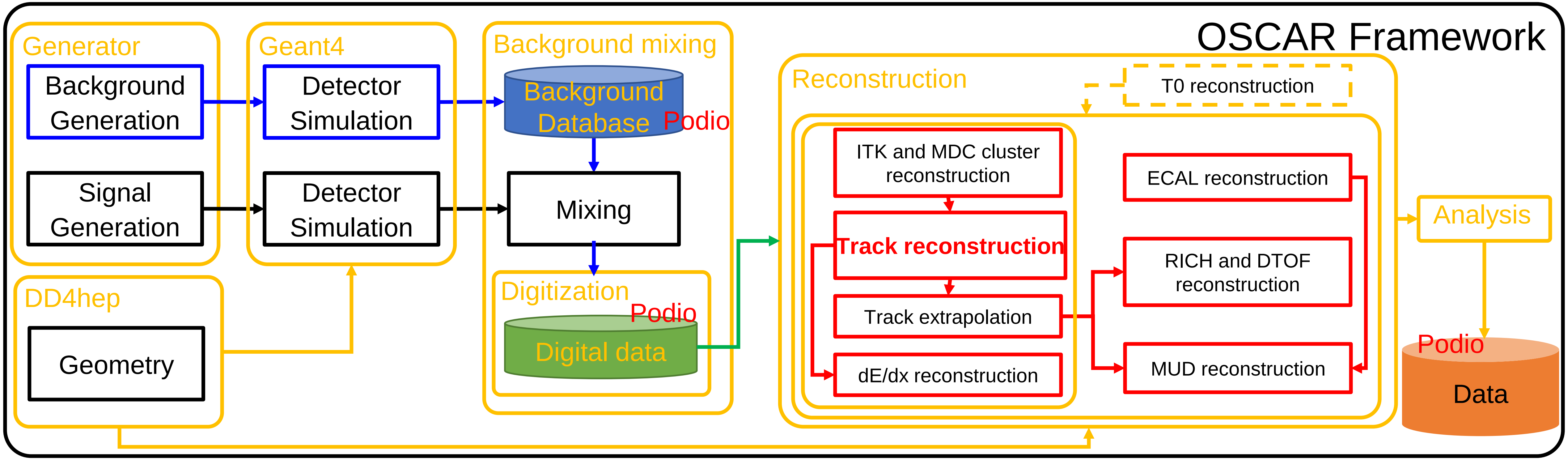




- Tracking system works in a 1T magnetic field.
- The presented results are based on the MPGD ITK +MDC.

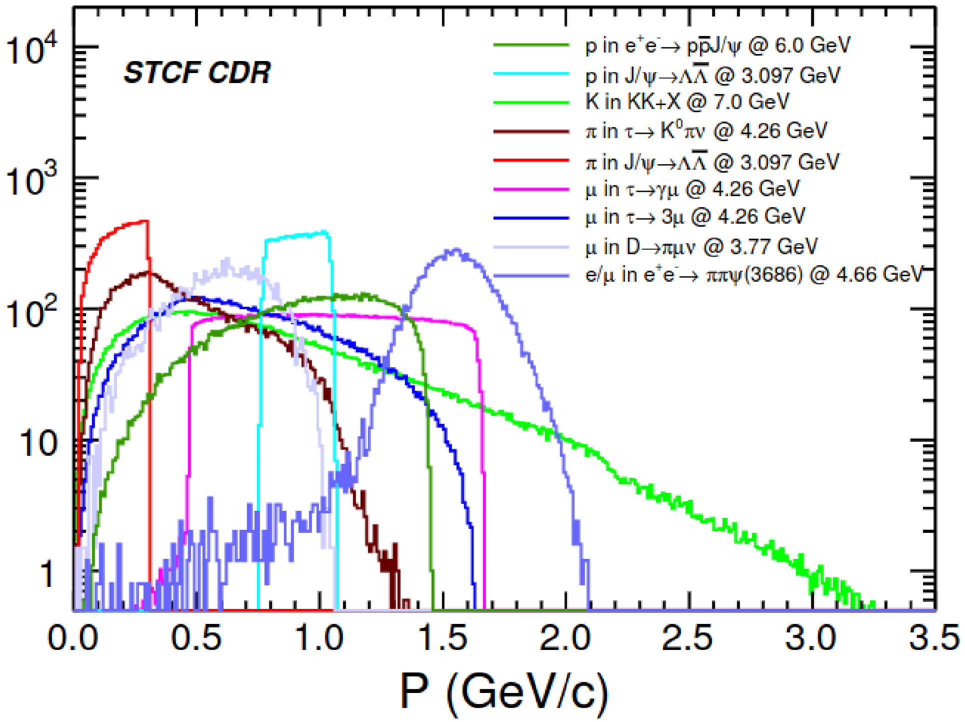
STCF offline software

- The Offline Software of Super Tau-Charm Facility**(OSCAR)** provides a comprehensive platform for offline event processing, including simulation, digitization, reconstruction and analysis.



- The reconstruction of (charged) particle tracks is the key part of reconstruction.
- Expected detector resolution: - MDC: 120μm(drift distance) - ITK: 100 μm (rφ) x 400 μm (z)

Momentum distributions of charged particles



- most particles p < 1 GeV
- a considerable number of particles with $p < 0.4$ GeV
- Goal: reconstruct particles with p 50 MeV - 3.5 GeV

only three layers of ITK →

The seeding(use ITK hits) efficiency is greatly influenced by the detector efficiency

- Global track finding based on Hough transform
  - handle the hits form ITK and MDC simultaneously
  - Kalman fitting using Genfit2
- Local method(using ACTS)
  - Seeding + Combinatorial Kalman Filter (CKF)
  - find seeds using hits(space point) on ITK layers
  - associate compatible MDC hits to tracks
- Machine learning techniques
  - GNN for background filter
  - clustering(track finding) using DBSCAN、RANSAC

Track finding based on the Hough transform

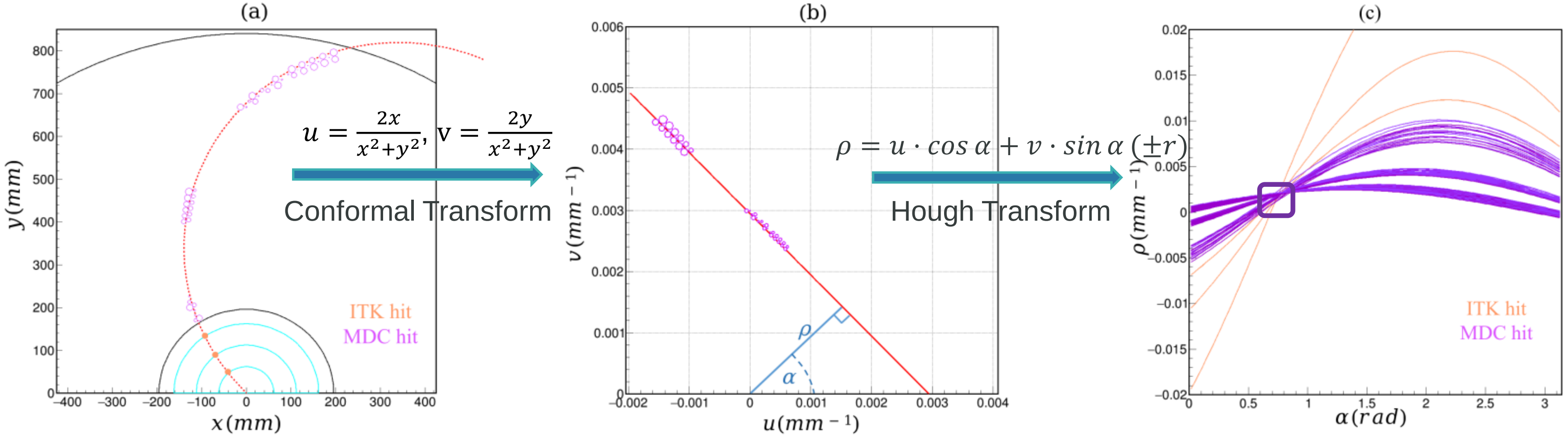
2-D track finding

- Conformal Transform
- Hough Transform1
- Histogram filling
Peak finding
- Global fitting(circle)
Hit selection

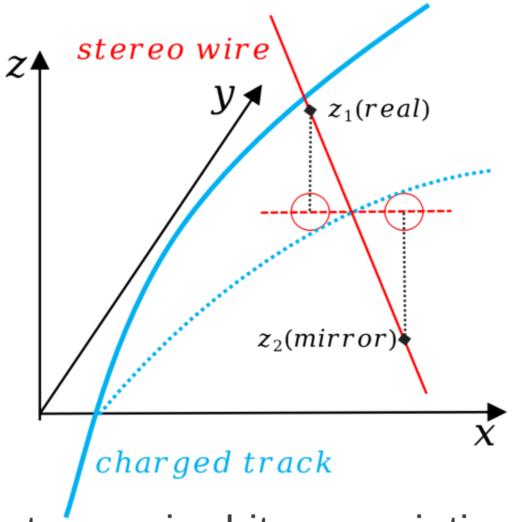
3-D track finding

- Stereo hits association
- Hough Transform2
- s-z track finding
- Global fitting(helix)

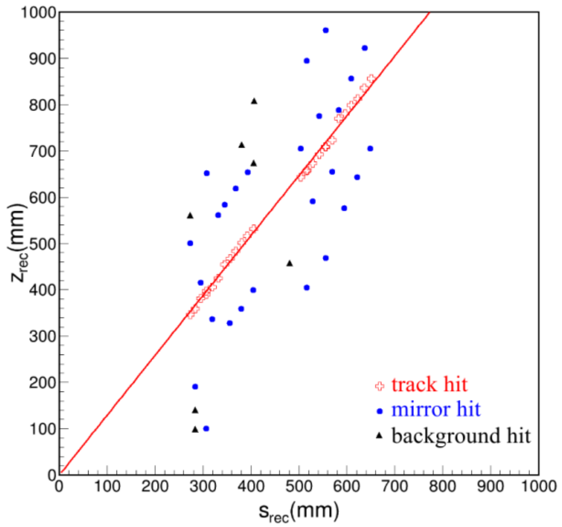
Kalman Track fitting



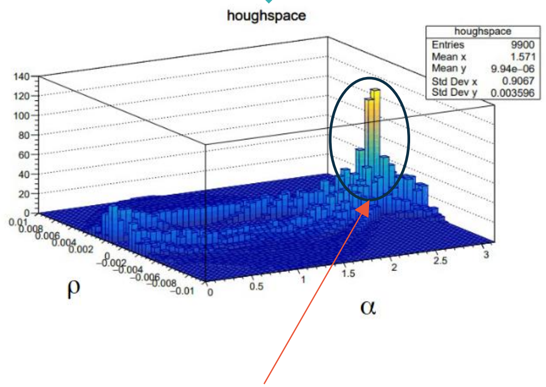
Find areas of local maximum density in parameter space



stereo wire hits association



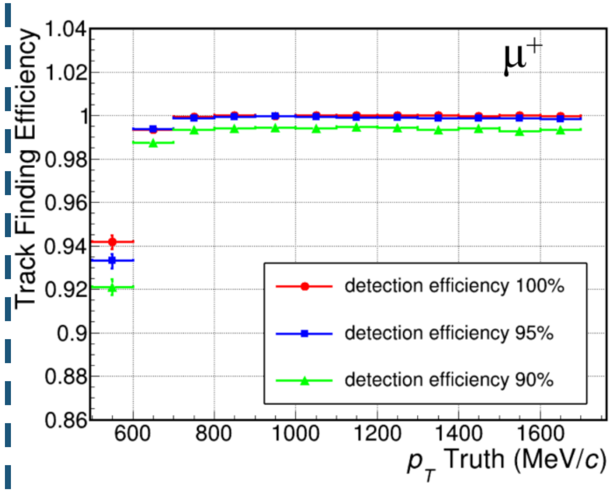
track hits on the s-z plane

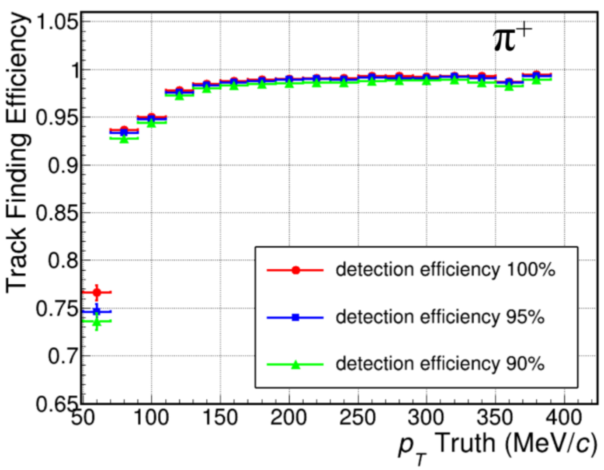


Track candidate

Tracking Performance in Full Simulation

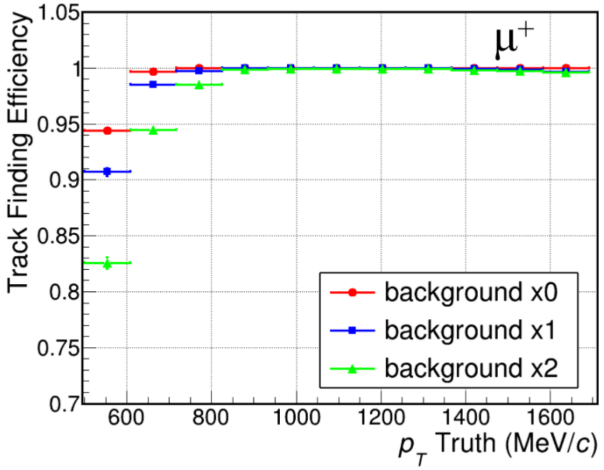
- particles in ψ(3686) → π+π- J/ψ, J/ψ → μ+μ- events are studied

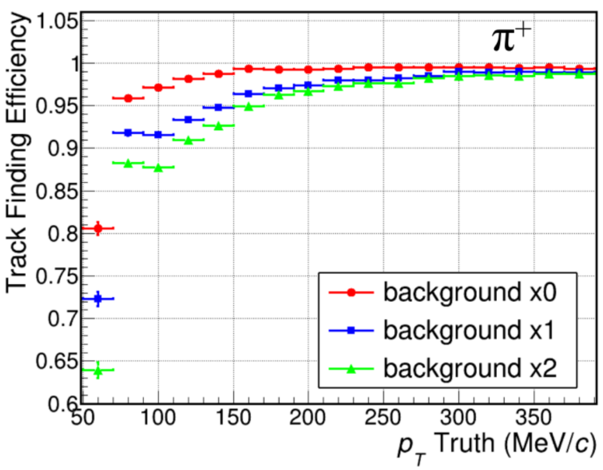




- Without background
- Varying detection efficiencies of both ITK and MDC.
- The global algorithm is robust against local inefficiency.

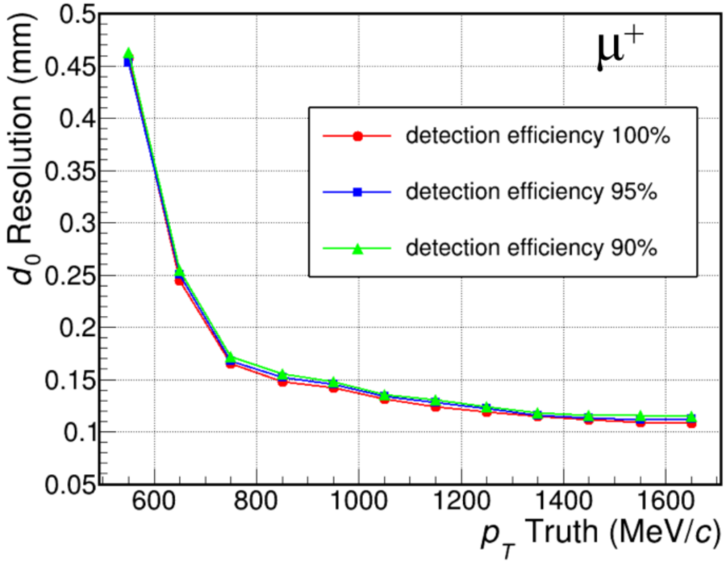
➢ High track finding efficiency is maintained even with reduced detector efficiency.

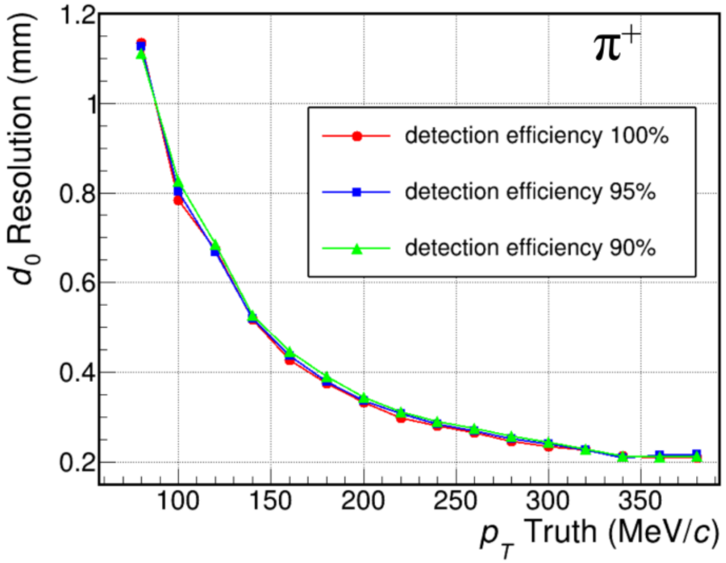


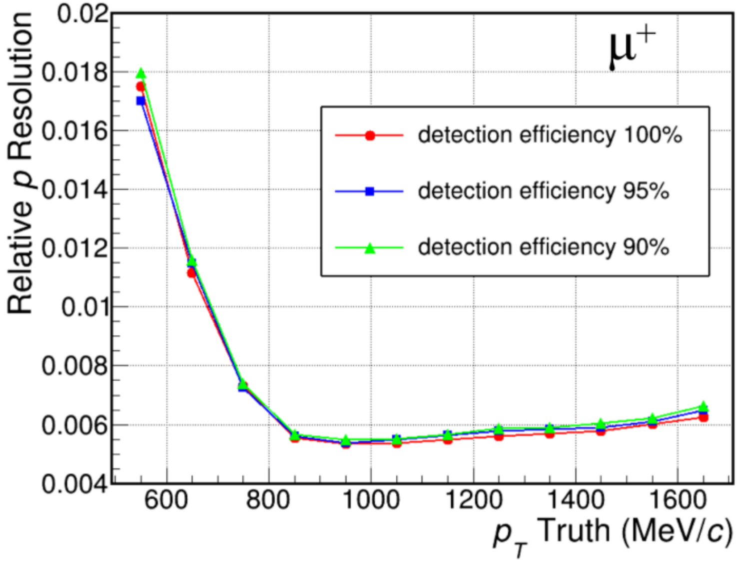


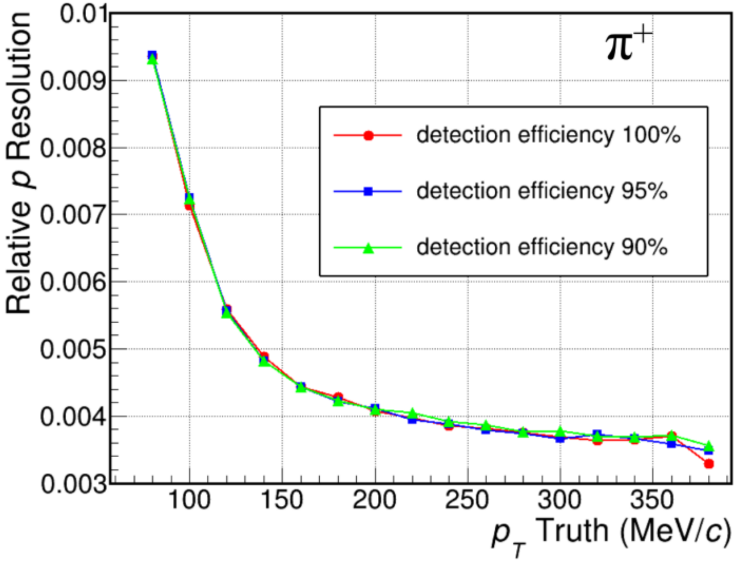
- Track finding efficiency under different background levels (with detection efficiency at 100%)
- The track finding efficiency of particles with low transverse momentum and large dip angles is more significantly influenced by the background.

Performance in MC



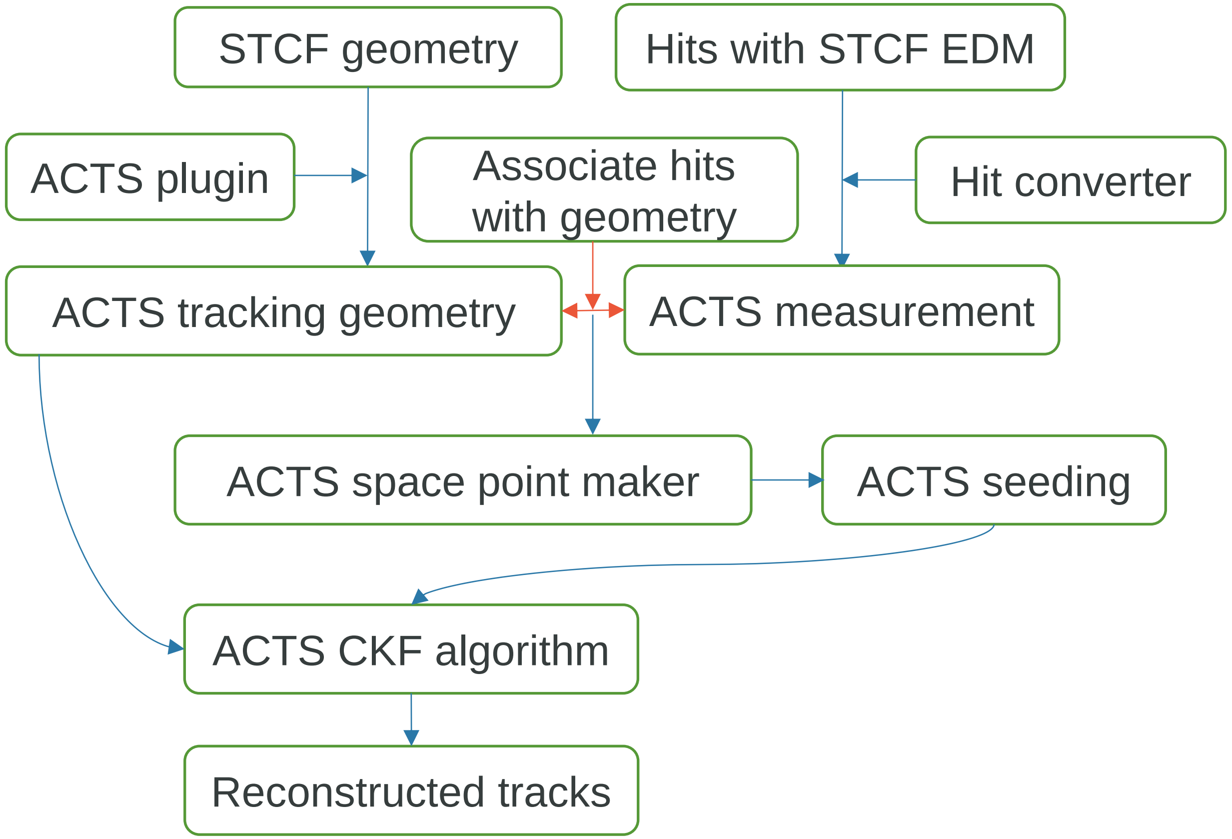






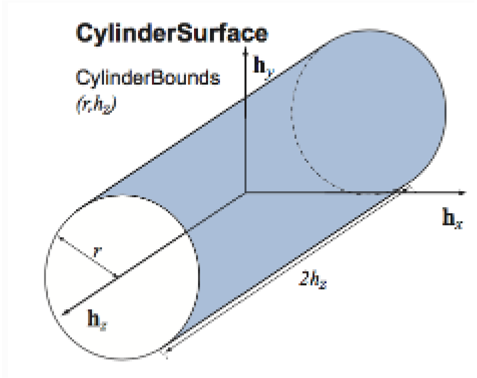
- In the majority of momentum ranges, the relative momentum resolution is better than 0.6%
- The parameter resolution deteriorates as the detection efficiency decreases (with fewer hits)
- An increase in background levels affects efficiency but has very little impact on resolution (hence resolutions for different background levels are not shown)

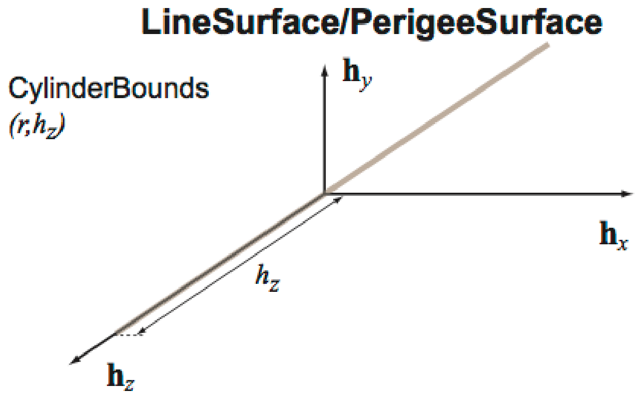
Implemention of ACTS into OSCAR



- ACTS(A Common Tracking Software) is an experiment-independent toolkit for (charged) particle track reconstruction
- The chain for track reconstruction using the ACTS modules has been established in OSCAR

ACTS tracking geometry

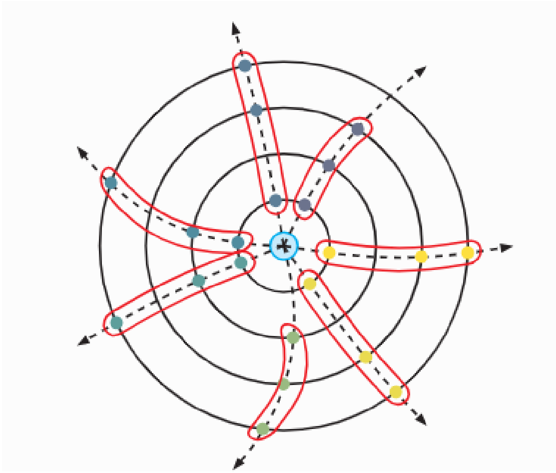




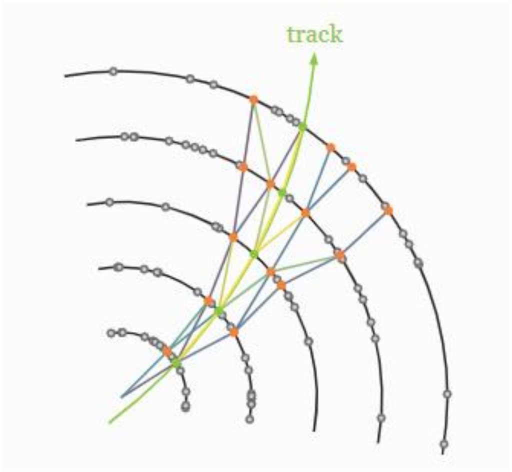
ITK layer→CylinderSurface

MDC cell→LineSurface

ACTS tracking chain



Seeding(only ITK hits)

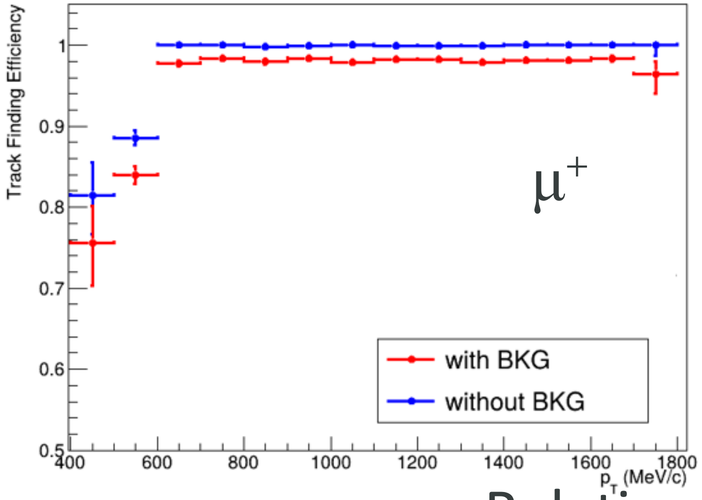


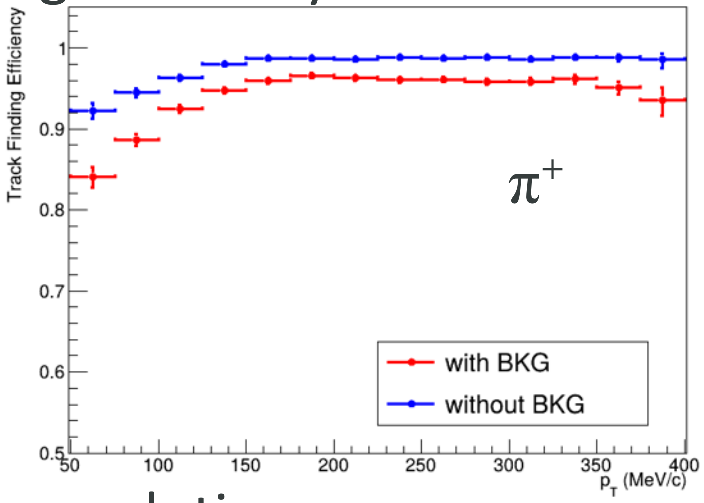
CKF(connect MDC hits + fitting)

Performance in MC

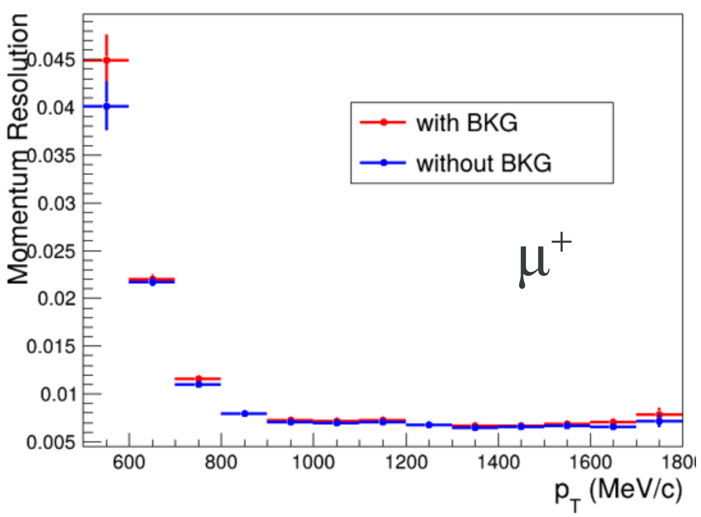
Preliminary results

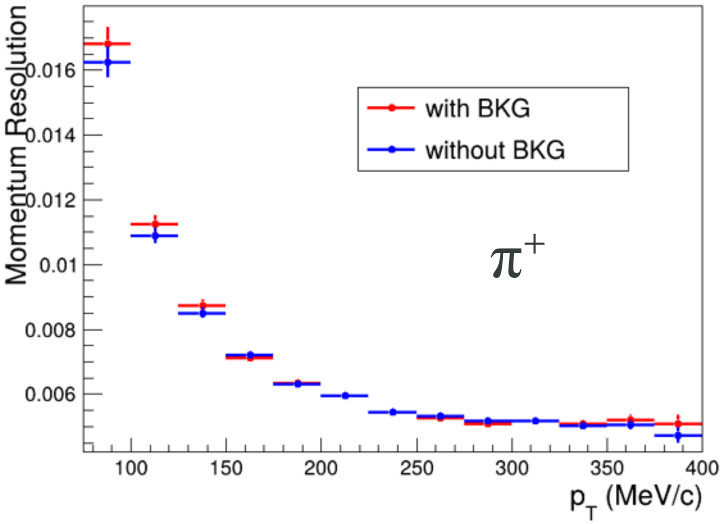
Track finding efficiency





Relative p resolution

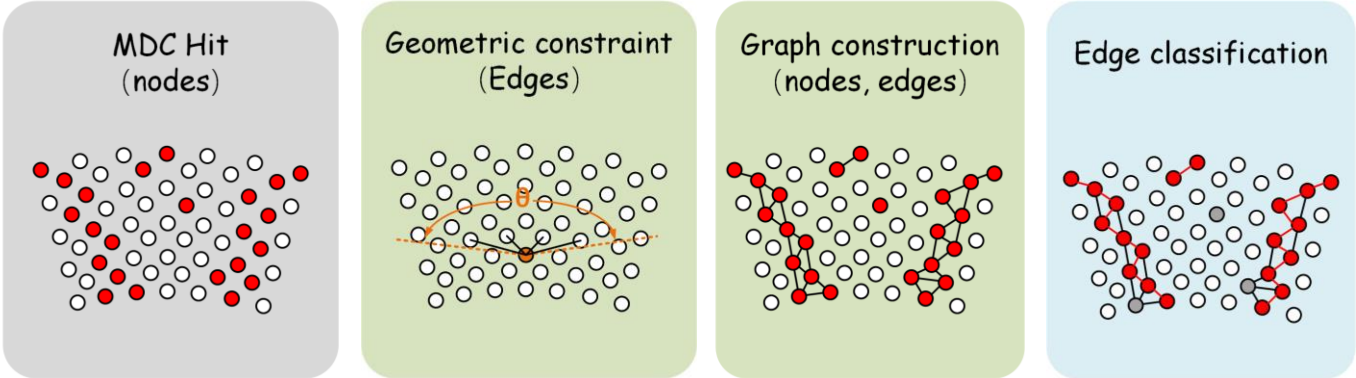


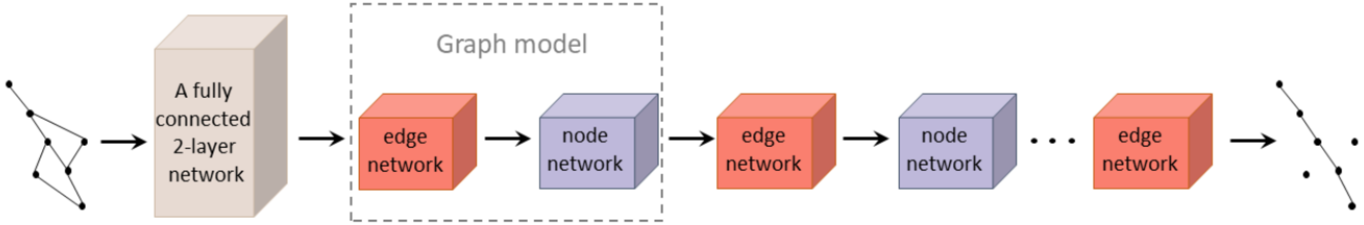


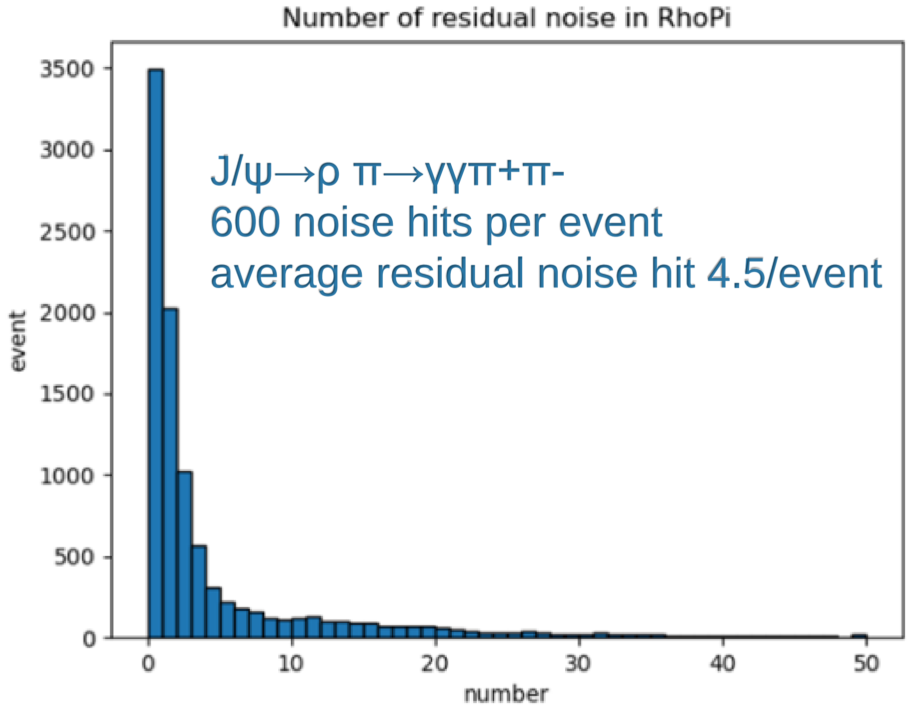
- The results demonstrate that ACTS performs well, especially in reconstructing very low momentum particles since the algorithm can consider material effects during track finding.
- Some algorithm parameters need to be further optimized
  - ➢ When performing CKF, some MDC stereo hits were not correctly assigned to the track.
  - ➢ When reconstructing with background, there are many fake seeds.

MDC backgroud filter using GNN

- Graph nodes → Hits, Graph edges → track segments
- GNN structure: input network, node network, edge network
- Input: node features(drift distance, coordinate of signal wires), adjacency matrices, edge labels
- Output: edge weight
  - High weight → *the edge belongs to a true particle track*
  - Low weight → *it is a spurious or noise edge*



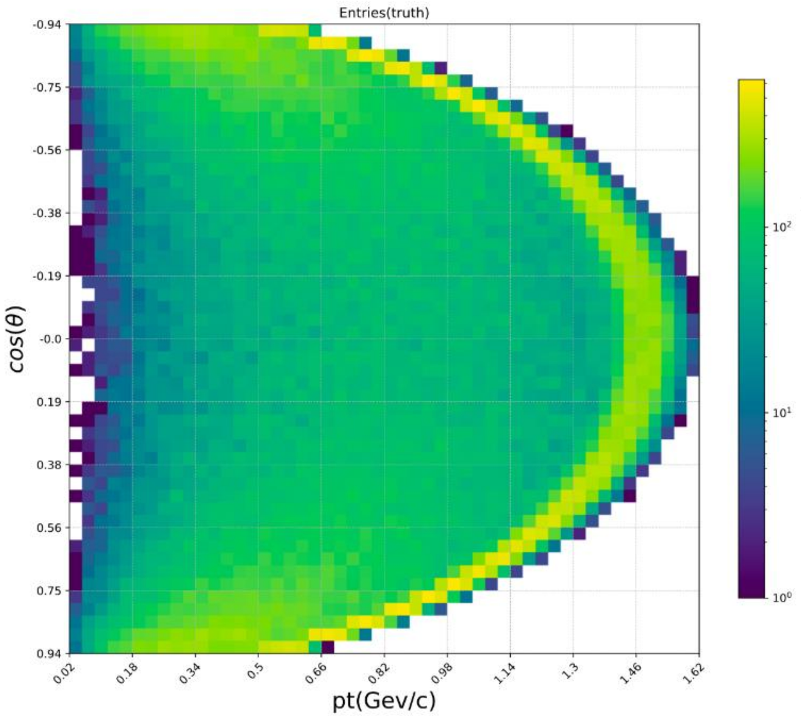




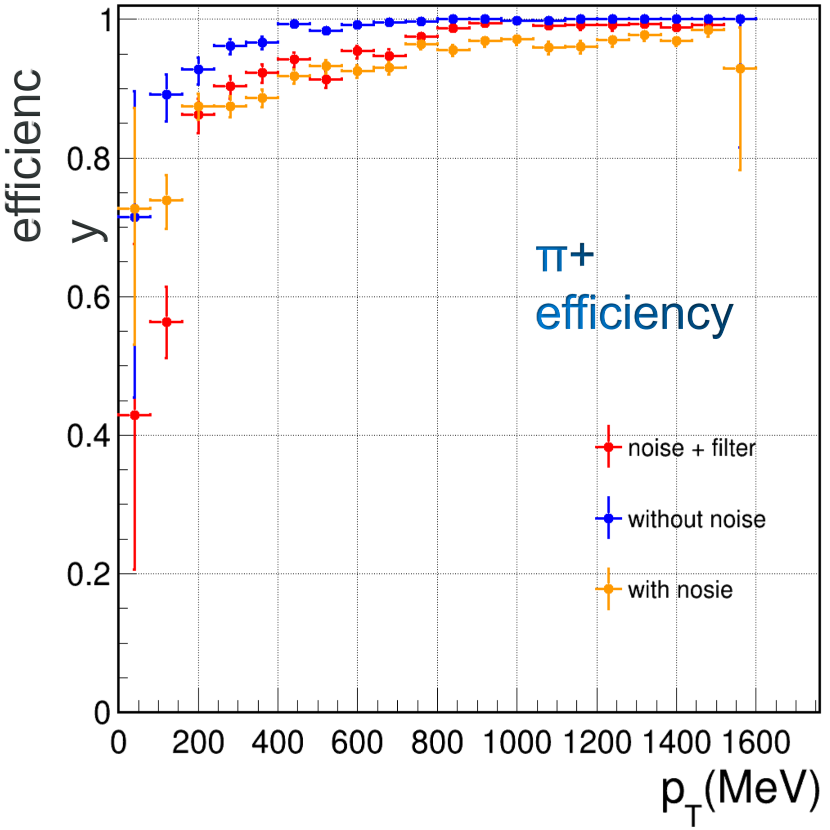
- Hit selection Efficiency $\frac{N^{predicted}_{signal}}{N^{real}_{signal}} = 91.1\%$
- Hit selection Purity $\frac{N^{predicted}_{signal}}{N^{predicted}_{all}} = 91.4\%$
- Noise removal efficiency $\frac{N^{predicted}_{noise}}{N^{real}_{noise}} = 98.6\%$

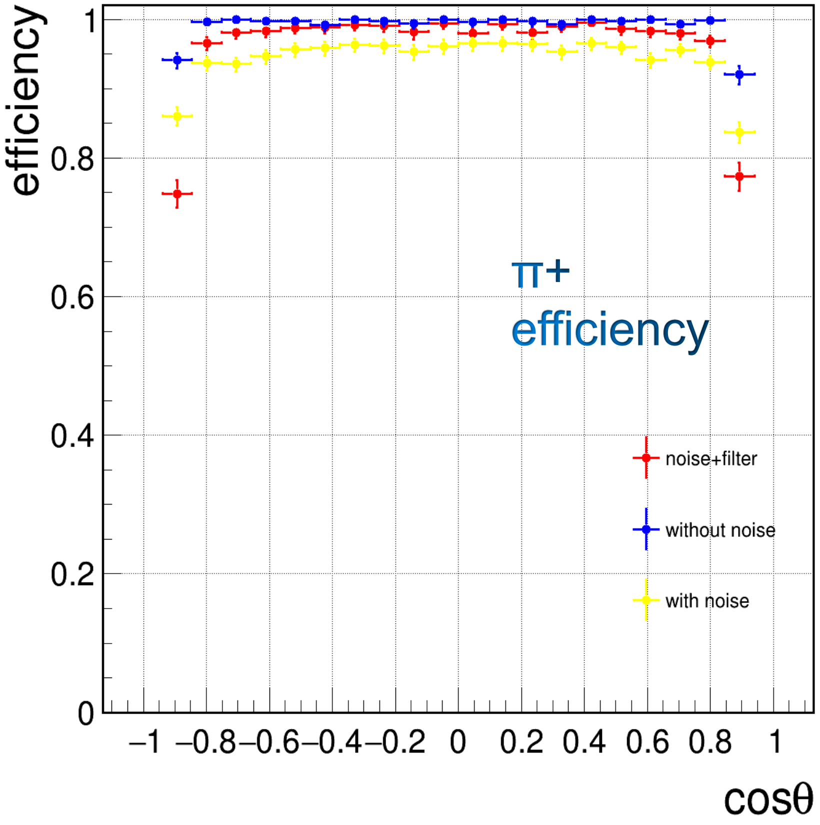
MDC backgroud filter using GNN

- Simulated J/ψ→ρ π→γγπ+π- events, Hough-transform-based reconstruction



truth p_T-cosθ distribution of π





- The reconstruction efficiency after GNN filtering noise is significantly improved
- At large |cosθ|, the tracking efficiency decreases due to fewer signal and more noise

Clustering using ML techniques

Density-Based Spatial Clustering of Application with Noise (DBSCAN)

a) Real space

b) Conformal plane

c) Parameter space

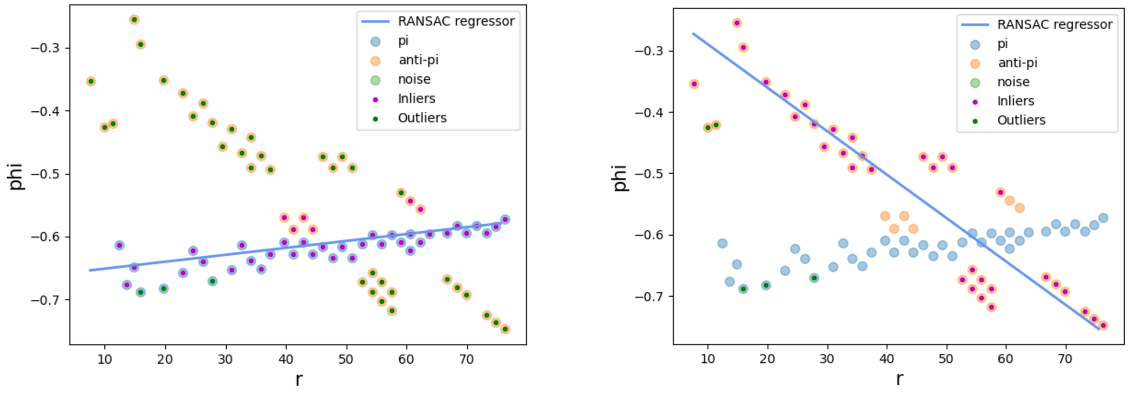
- Hits connected in the X-Y plane in a straight line
- α as the angle between the straight line and X axis
- The parameter space as cosα and sinα

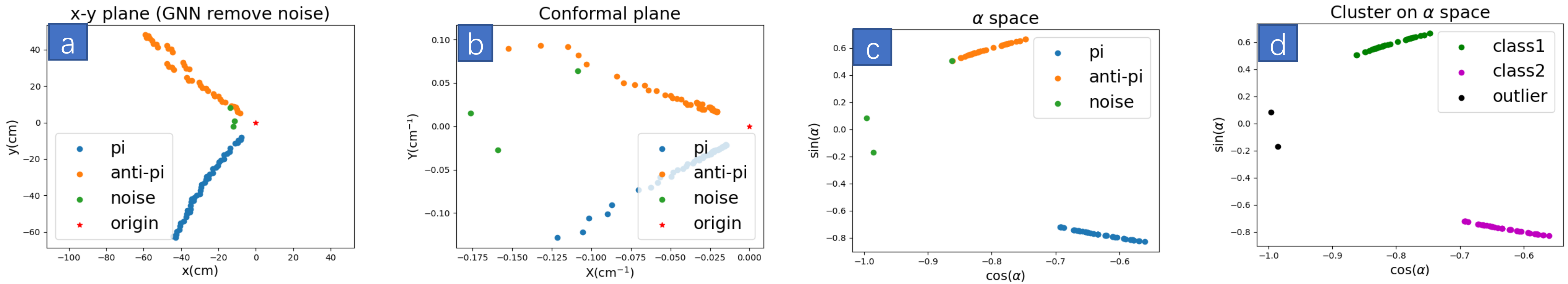
d) DBSCAN clustering in ‘α’parameter plane

- Hits in a cluster are considered to be in the same track

Random Sample Consensus (RANSAC) - salvage algorithm

- Polar coordinate space
- Fit a track through one set of points, then fit through the remaining points
- linear model
- Its good robustness to noise and outliers





Summary and Outlook

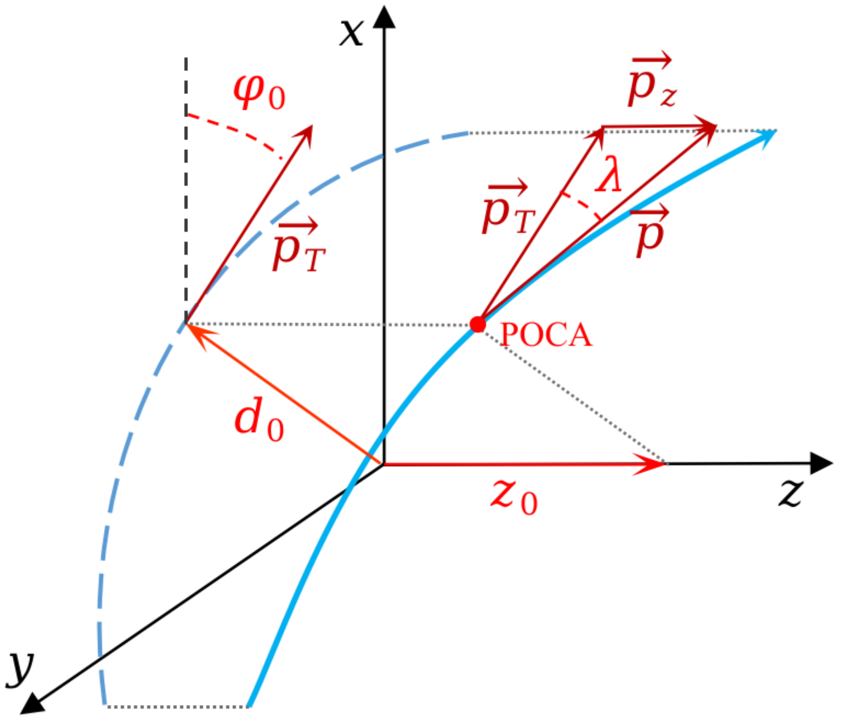
Thanks for your attention

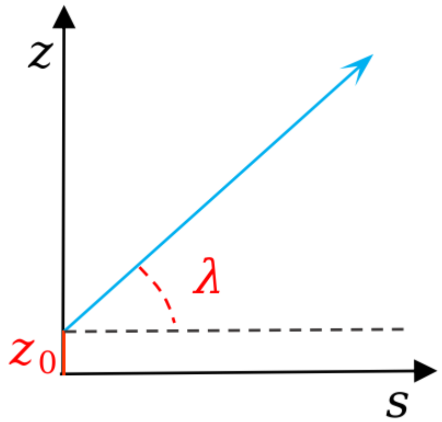
- Summary
  - The complete chain for track reconstruction has been established.
  - Currently, two track reconstruction algorithm are available for use, still under continuous optimization
    - ✓ Track finding based on the Hough transform
    - ✓ Seeding + CKF using ACTS
  - A GNN-based MDC noise filter has been developed, and research is underway to utilize machine learning methods for track finding.
  - MC results show promising performance, still under continuous optimization

Poster(TUE 36): Hough transform + ACTS for long-lived particles tracking

- Outlook
  - Combining and tunning different algorithms to achieve better overall performance.
  - Develop a seeding algorithm more suitable for STCF (using MDC hits rather than only ITK)
  - Further optimization for long-lived particles
  - Detector spectrometer optimization
    - Detector performance and spectrometer design determine the reconstruction quality and choice of algorithms.

Back up



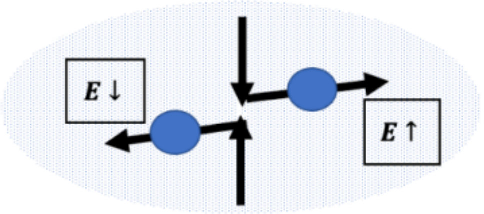


Helix parametrization

Background

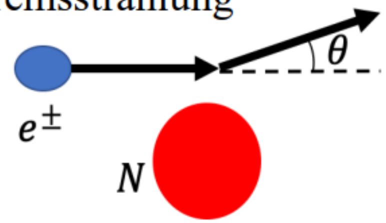
Touschek effect

- Scattering between inner beam particles
- Generation rate ∝ N_{bunch}, beam size^{-1}, energy^{-3}
- Main Background



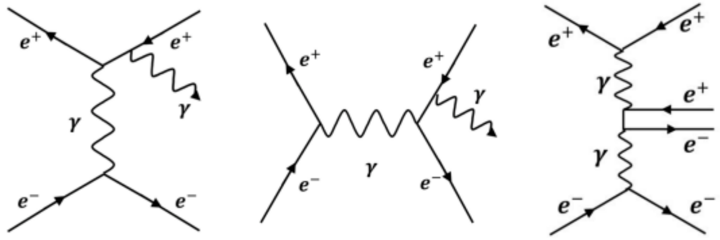
Beam-gas effect

- Effect with residual gas in the beam pipe
- Coulomb scattering， bremsstrahlung
- Generation ∝ pressure



Luminosity-related background

- Radiative Bhabha: $e^+e^- \rightarrow e^+e^-\gamma$
- Two-photon process:
  $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^-e^+e^-$

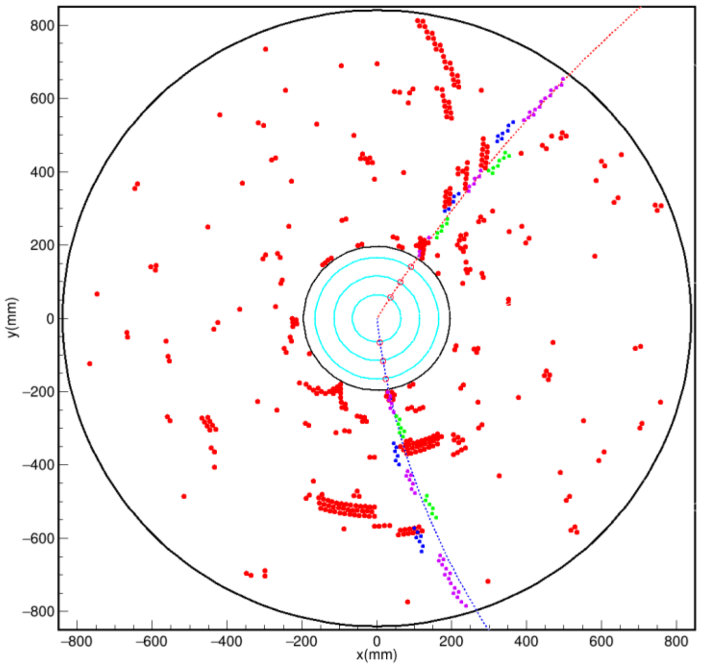


Other background

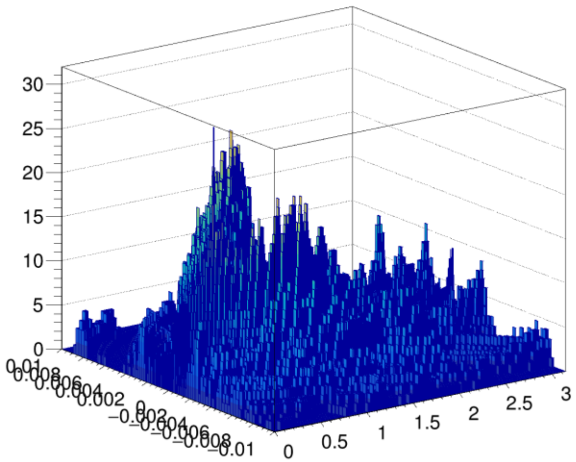
- Injection
- Synchrotron radiation

Yupeng Pei

5



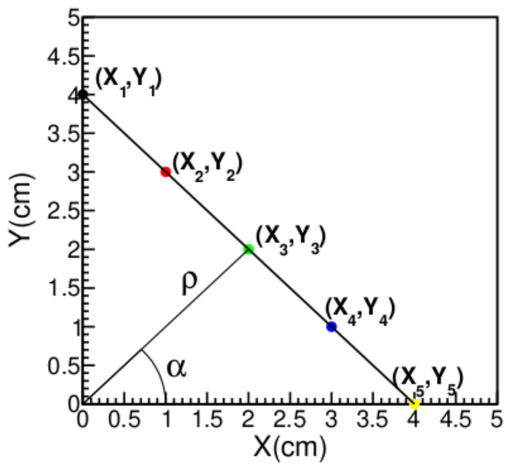
Hough map with background



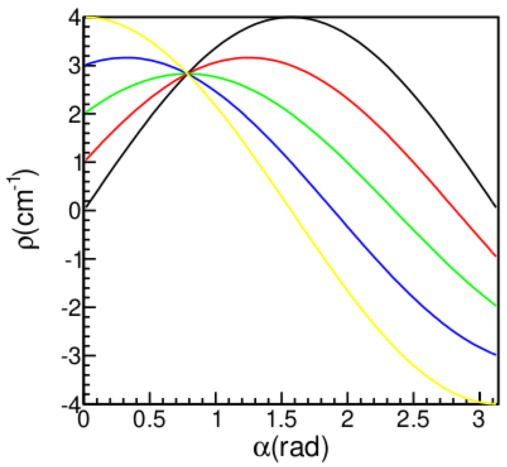
Background hits count per event

ITK1	ITK2	ITK3	MDC1	MDC2	MDC3	MDC4	MDC5	MDC6	MDC7	MDC8
37.3	13.6	8.2	60.3	42.4	24.8	25.1	60.0	67.8	30.8	30.0

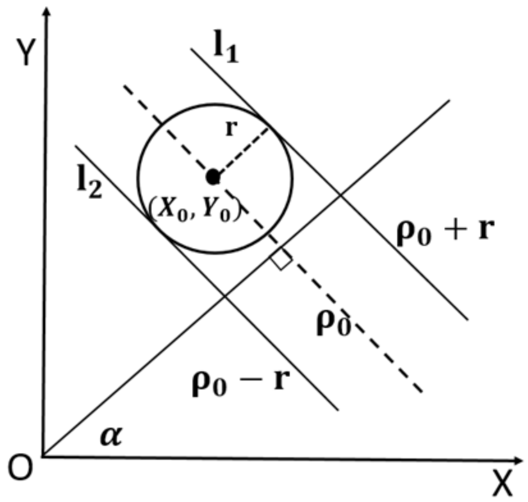
Hough(Legendre) transform

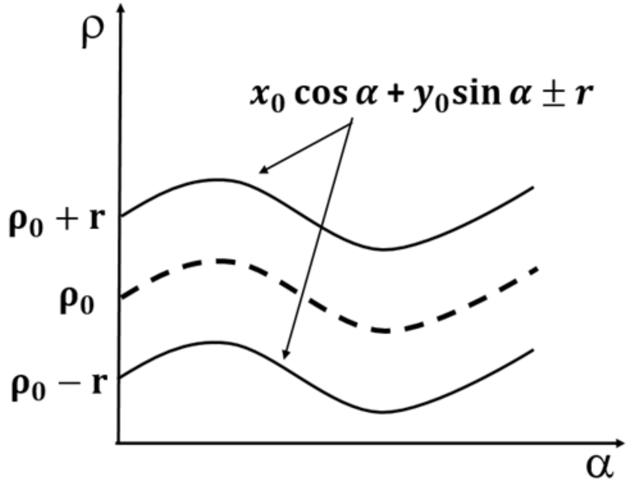


(a) X-Y plane



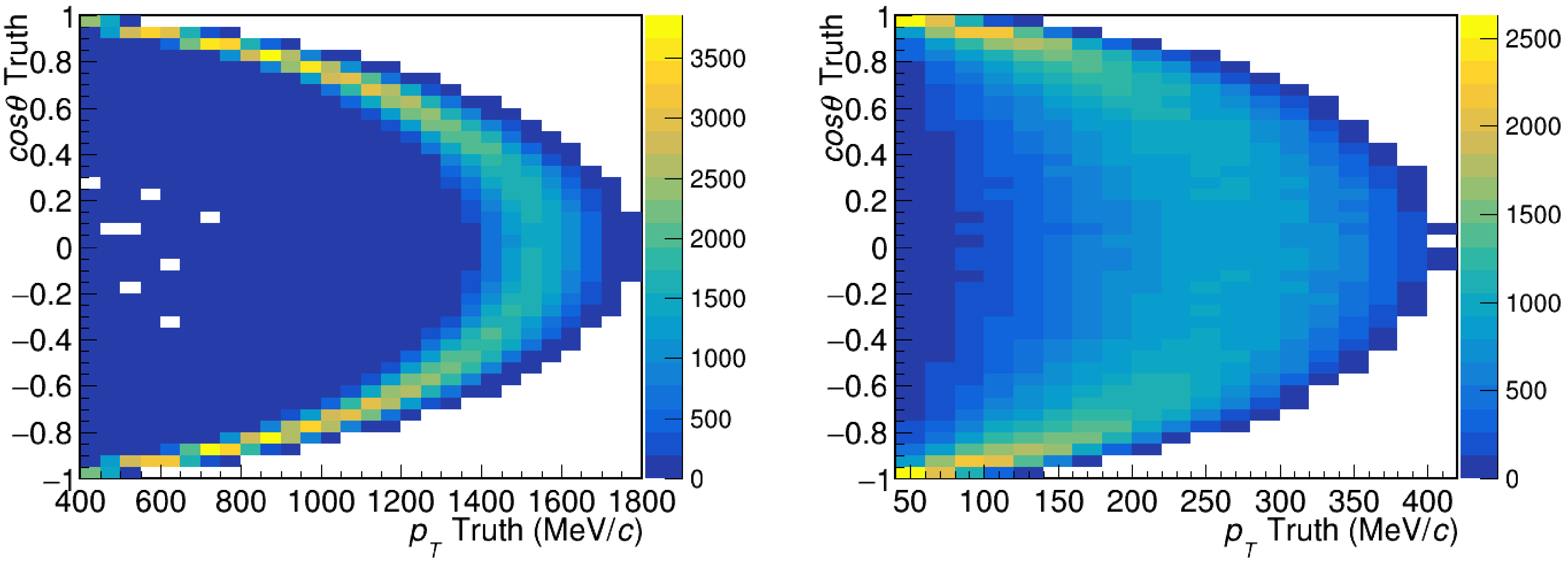
(b) parameter space





- a point in the image space -> a line(or a curve) in Hough space
- some points on a line -> lines intersecting at a point in Hough space
- The intersection point in the Hough space corresponds to the line in the image space
- Hough transform with drift distance (Legendre transform)

  one MDC hit -> two curve in Hough space



The distributions of p_T versus cosθ for μ (left) and π (right)
in ψ(3686) → π+π- J/ψ, J/ψ → μ+μ- events