超级陶粲装置
Super Tau-Charm Facility

ACTS tracking for STCF

Hao Li(ZZU) , Hang Zhou(USTC), Hongkun Mo(USTC),Xiaocong Ai(ZZU), Xingtao Huang(SDU), Lailin Xu(USTC) ,Jin Zhang(SYSU)

FTCF2025, Huangshan, Nov 25, 2025

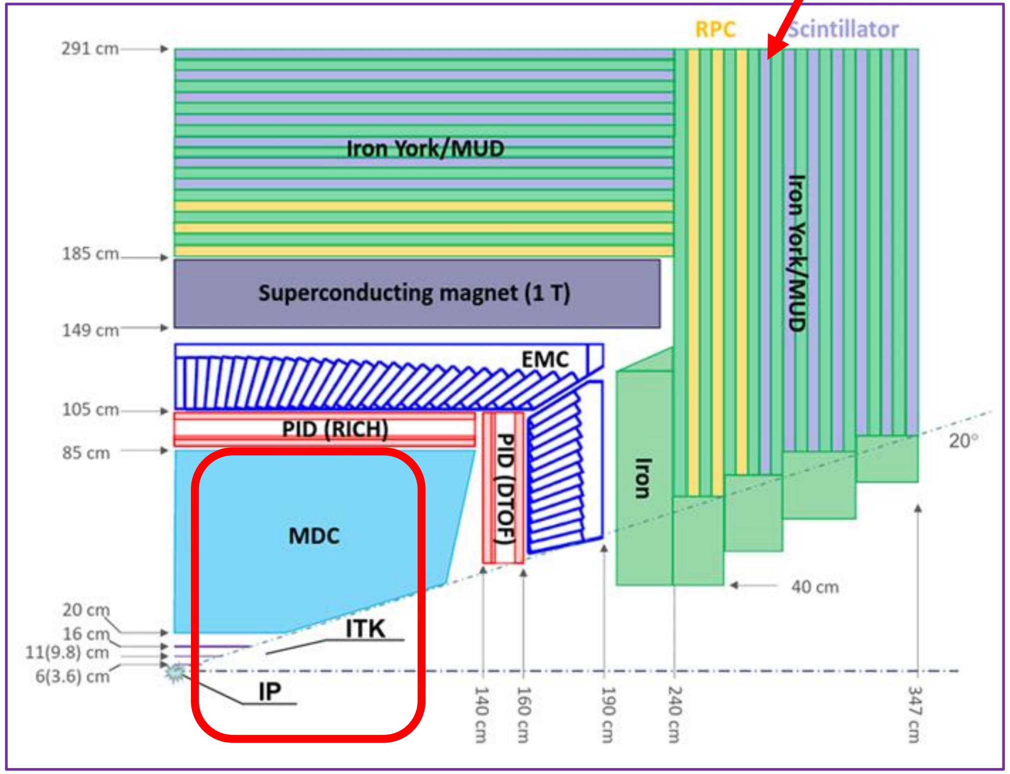
Outline

- Overview of STCF
  - STCF tracking system
  - STCF tracking challenges
- Tracking with ACTS
  - Introduction of ACTS
  - ACTS tracking geometry
  - ACTS tracking strategy on STCF
- Performance
  - Performance for non-displaced tracks
  - Performance for displaced tracks
- Summary

Super Tau-Charm Facility

- A future e+e- collider operating at tau-charm region:
  - Center-of-mass energy: 2–7GeV
  - Peak luminosity: 0.5–1×$10^{35}cm^{-2}s^{-1}$
- Physics topics:
  - QCD and Hadron spectroscopy
  - Flavor physics and CP violation
  - Exotic decays and new physics
- Tracker performance requirements:

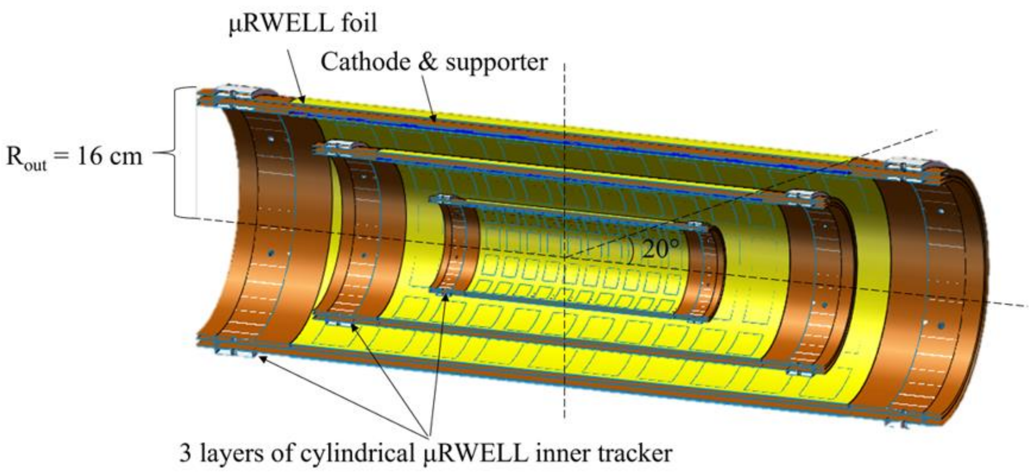
ITK	MDC
• <0.25% X_0 for one layer • σ_{xy}< 100 μm	• σ_{xy}< 130 um, σp/p< 0.5% at 1 GeV/c • dE/dx resolution < 6%



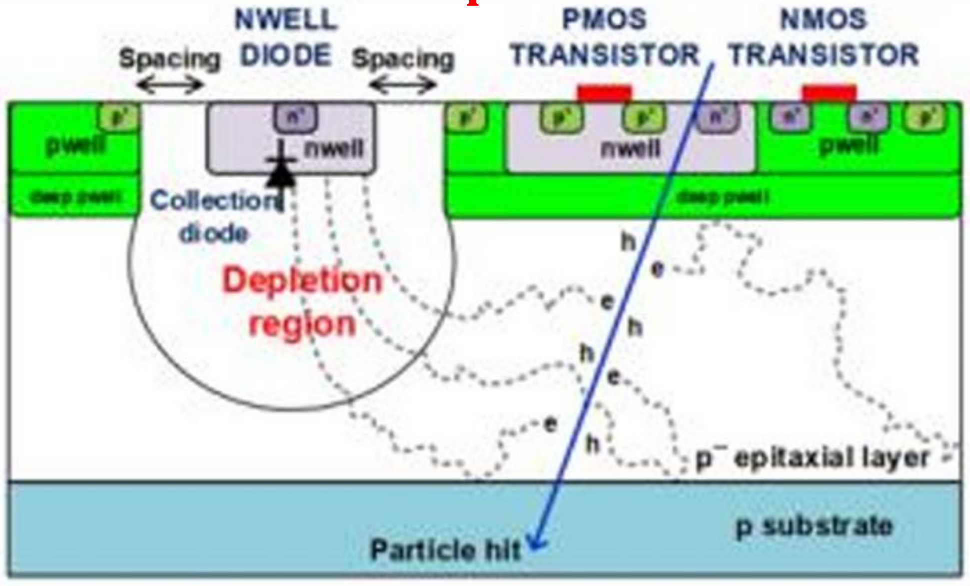
STCF tracking system

- Inner tracker(ITK):
  - “outdated" baseline option:CMOS MAPS(ITKM)
  - 3 layers with radius of 36 , 98, 160mm
- Main tracker(MDC):
  - Radius:200~8400mm
  - 48 layers:axial layers and stereo layers (to be updated as well)

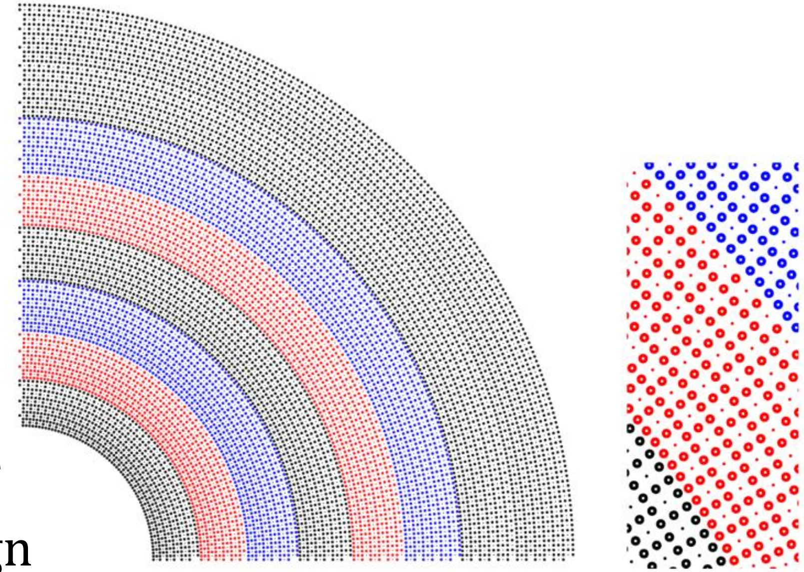
ITK gaseous option:MPGD



ITK Silicon option:CMOS MAPS



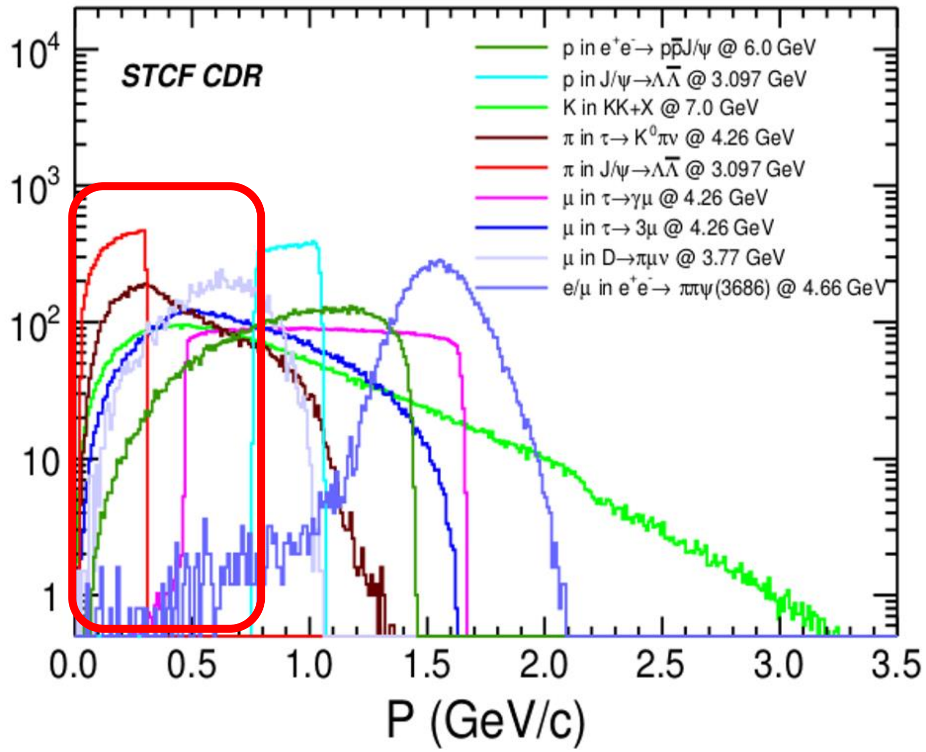
Figures from STCF CDR （arXiv:2303.15790）

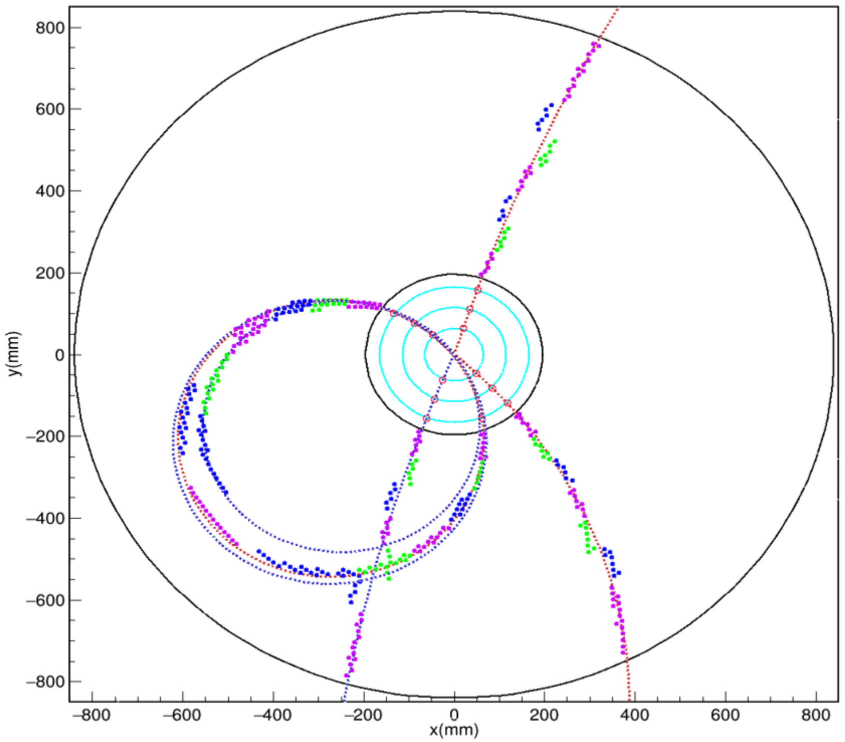


See Jianbei Liu's talk for more about the future tracker design

STCF tracking challenges

- Most physics processes have charged particles with p_T < 500 MeV/c
  - More material effects → worse resolution
  - Looping tracks with p_T < 130 MeV/c → fake/duplicate tracks
- Long-lived particles (Λ, Ξ, Ks, …) can decay outside Inner tracker





A Commom Tracking Software(ACTS)

- A modern open-source detector-independent tracking toolkit for current&future HEP experiments based on LHC tracking experience

- A R&D platform for innovative tracking techniques (ML) & computing architectures

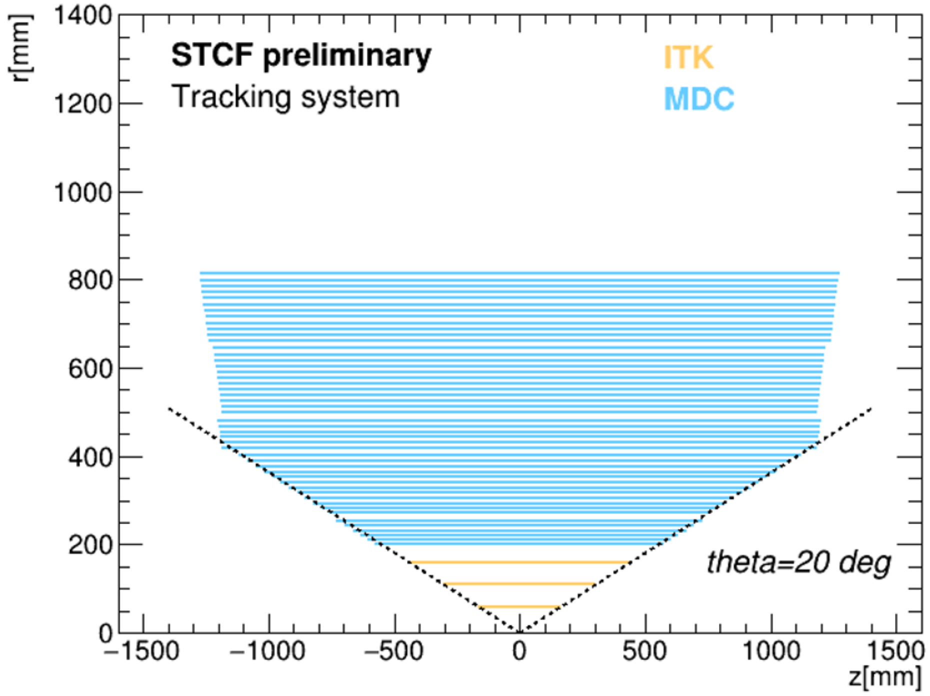
  - Developed based on **C++17**(—>20)
  - Detector and magnetic field agnostic
  - Strict thread safety
  - Less dependence (Eigen)
  - Highly configurable
  - Adapt to modern computing frameworks

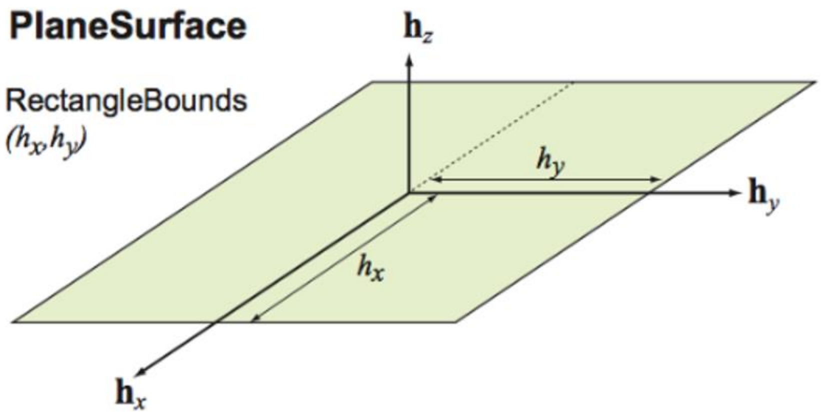
Github: [***https://github.com/acts-project/acts***](https://github.com/acts-project/acts)

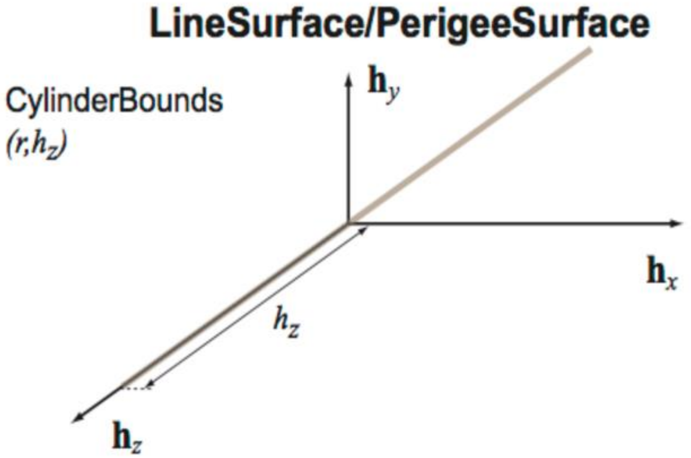
Readthedocs: [***https://acts.readthedocs.io/en/latest/***](https://acts.readthedocs.io/en/latest/)

ACTS tracking geometry

- Transform full Geant4 simulation geometry (described with DD4hep) into ACTS tracking geometry :
  - ACTS TGeo plugin
  - Acts::KDTreeTrackingGeometryBuilder
- Tracking geometey of STCF tracker:
  - 3 CMOS MAPS layers → 3 layers with composed of **ACTS::PlaneSurface**
  - 48 straw layers → 48 layers with composed of **ACTS::LineSurface**

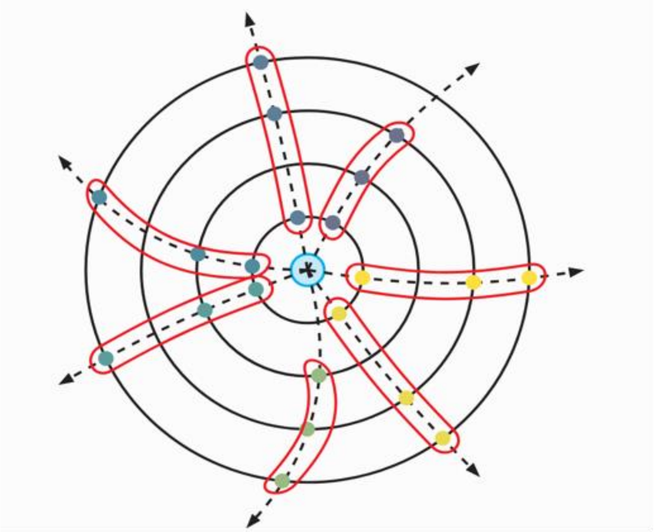


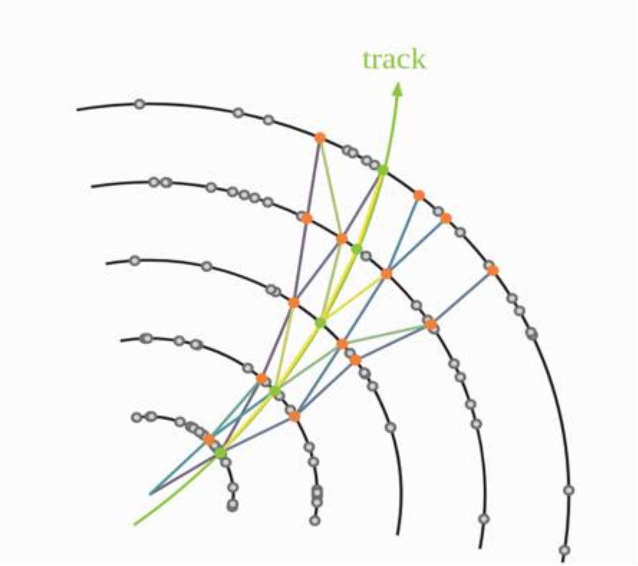




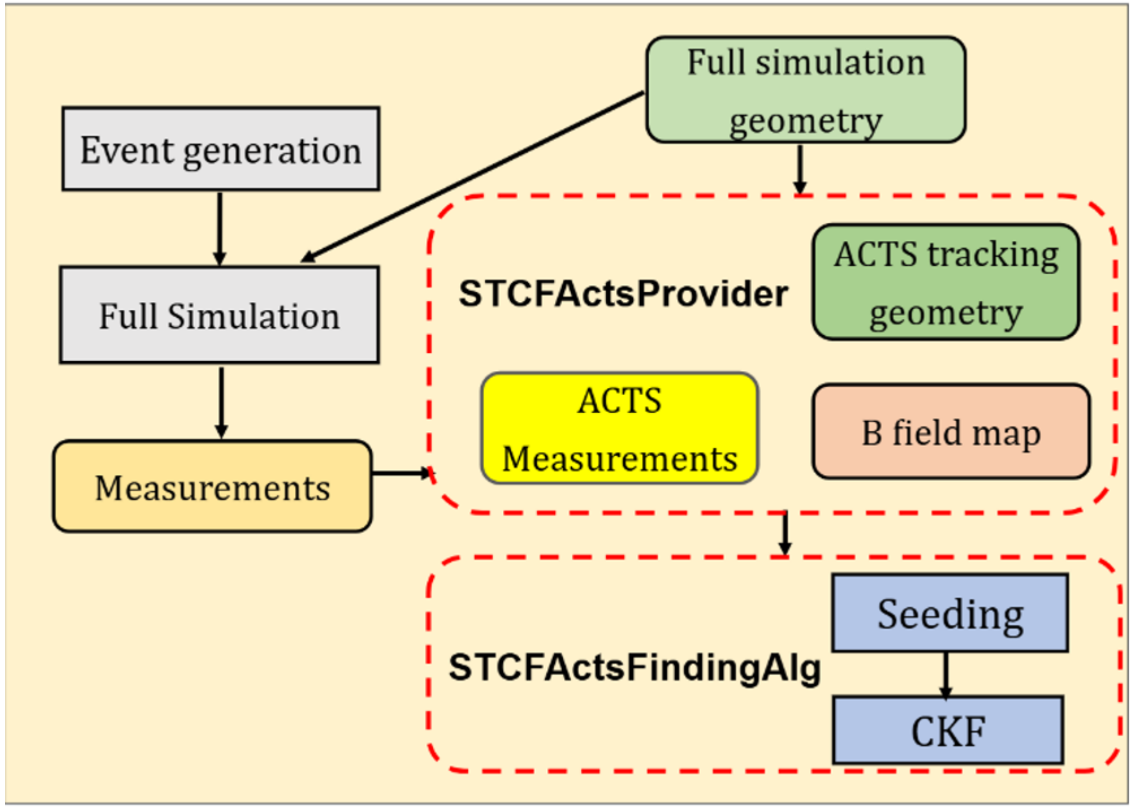
ACTS tracking strategy at STCF

- First tracking option: **Hough + GenFit**
  - Hough + GenFit has been well optimized
  - GNN was uesd to reduce noise
- Second tracking option: **seeding+CKF(ACTS)**
  - ACTS has been integrated into STCF offline software





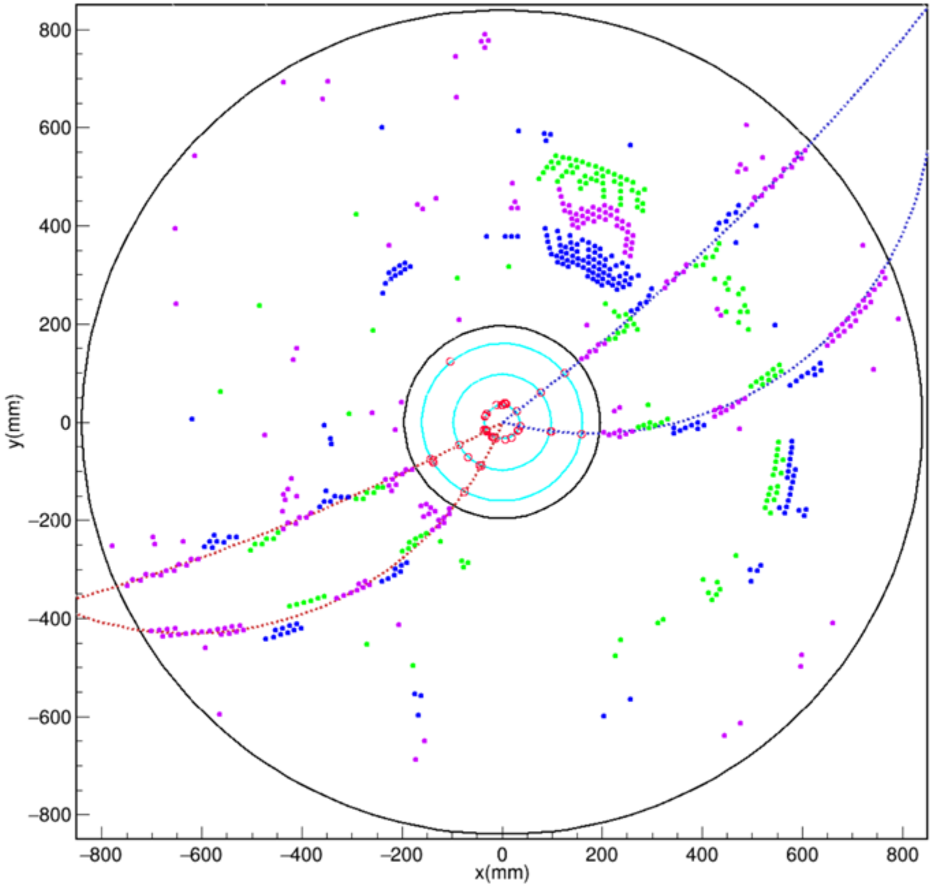
STCF software framework



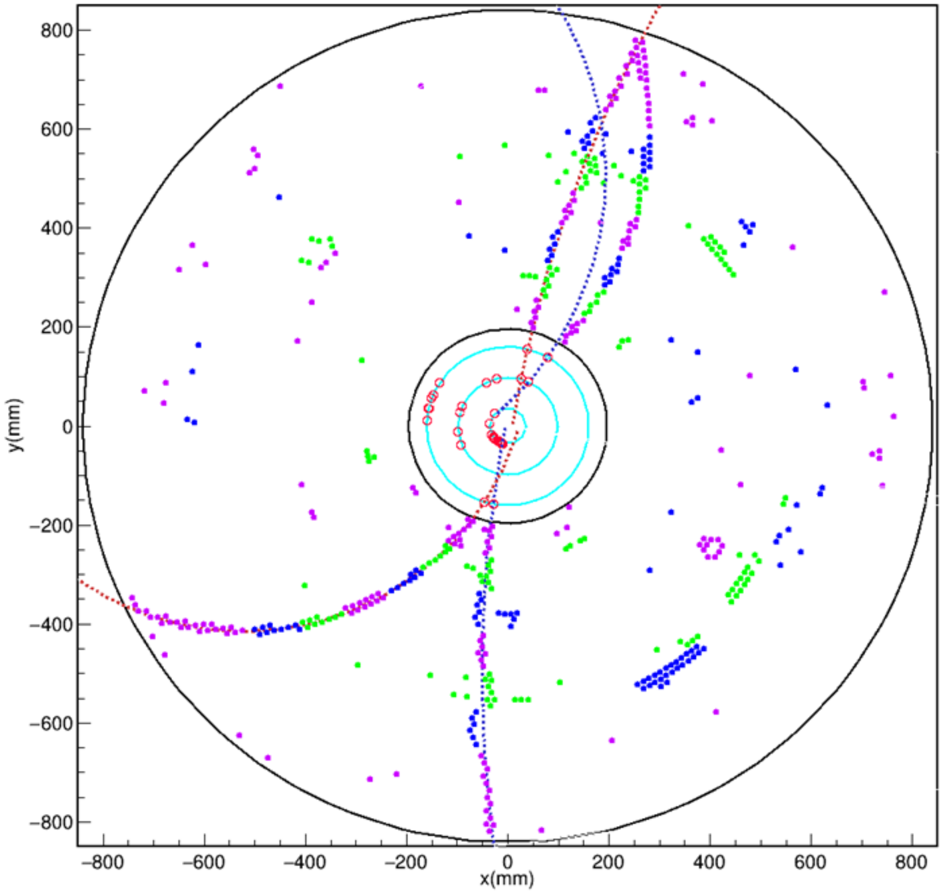
Details about Hough and GNN in Jin Zhang's talk and Xiaoshuai Qin's talk

Tracking signatures

$\psi(3686) \rightarrow \pi^+\pi^- J/\psi \rightarrow \pi^+\pi^-\mu^+\mu^-$



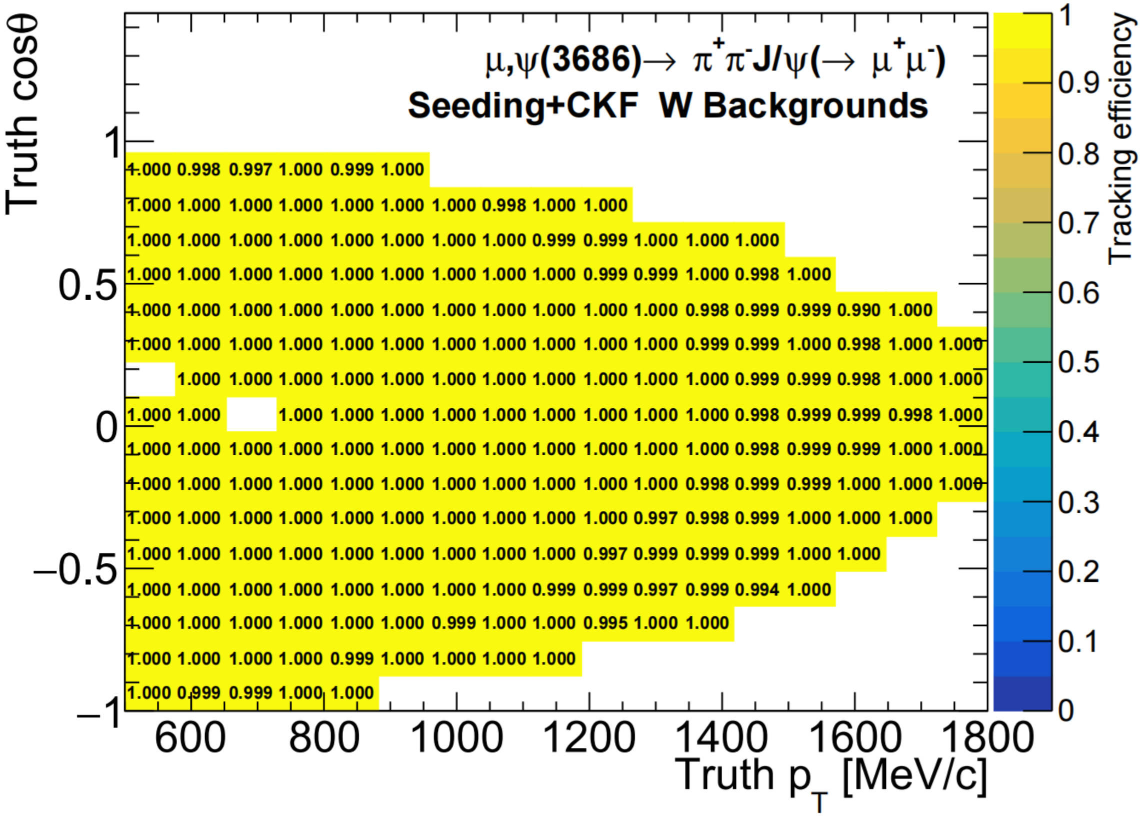
$J/\psi \rightarrow \Lambda\bar{\Lambda} \rightarrow p\pi^-\bar{p}\pi^+$

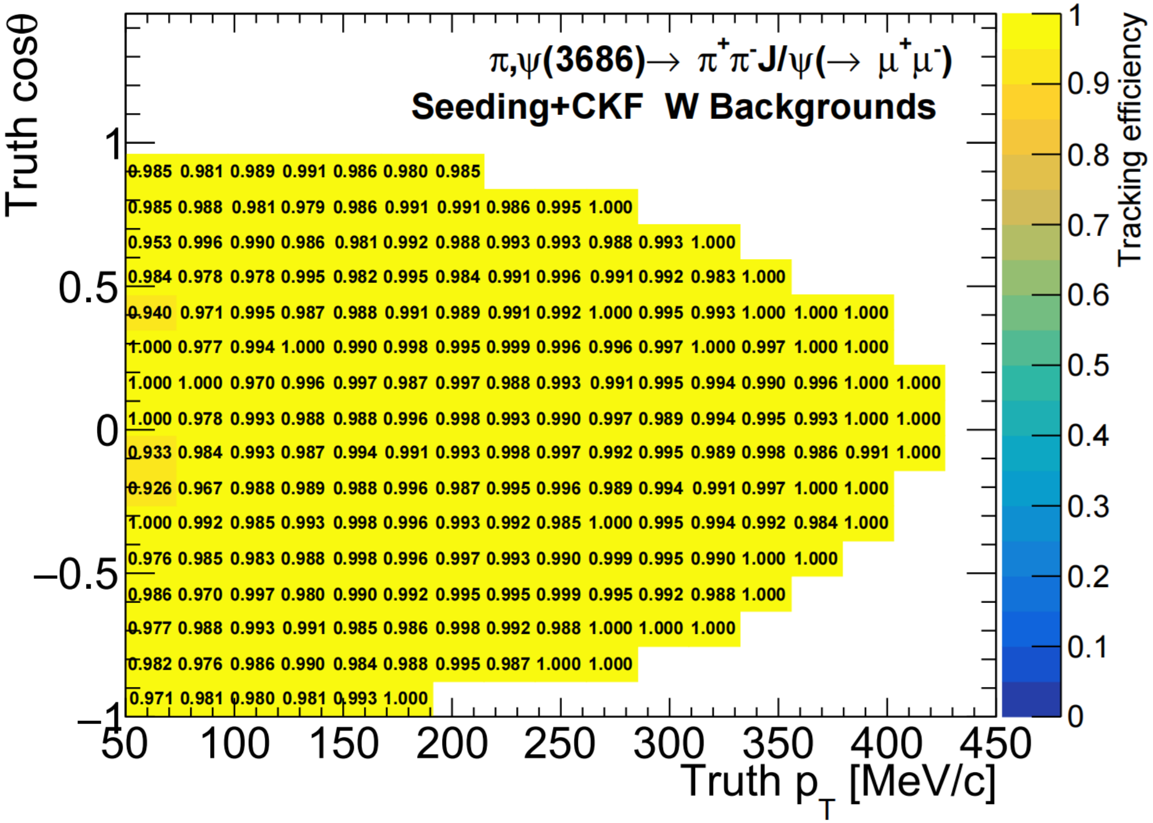


Performance for non-displaced tracks

Tracking efficiency (ACTS seeding + CKF)

- 100% tracking efficiency for μ in the region |cosθ|< 0.94, 500<P_T <600 MeV/c
- >93% tracking efficiency for π in the region |cosθ|<0.94, 50< P_T<100 MeV/c





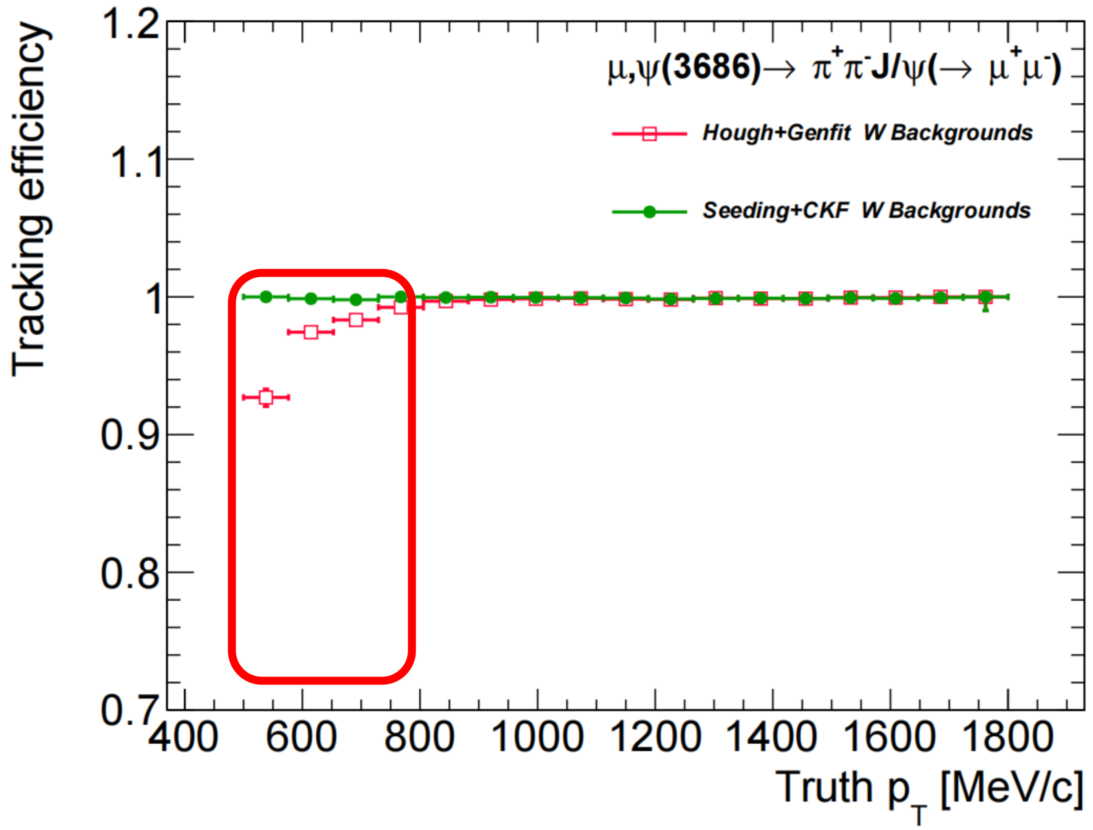
Particle requirements: nHits>=5, |cosθ|<0.94

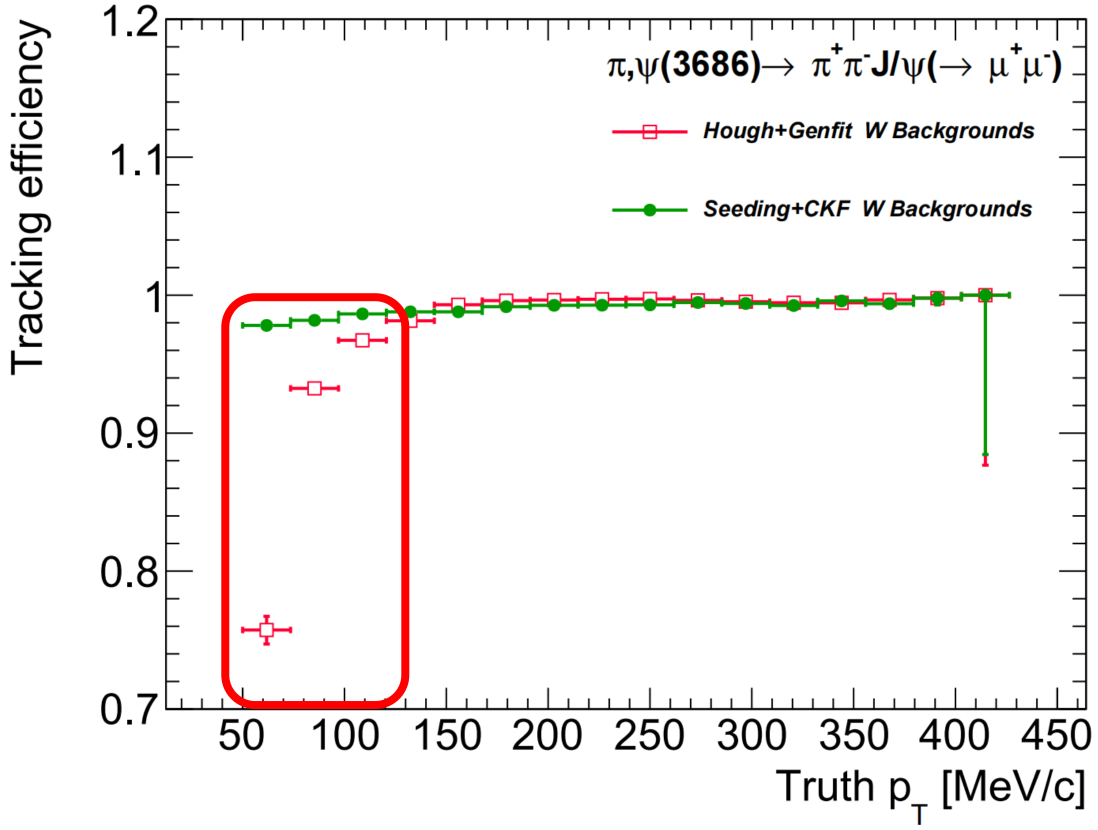
Track requirements: matchingProb（purity） > 0.8

Performance for non-displaced tracks

Tracking efficiency (ACTS seeding + CKF vs Hough+GenFit)

- ACTS shows higher tracking efficiency in low transverse momentum region





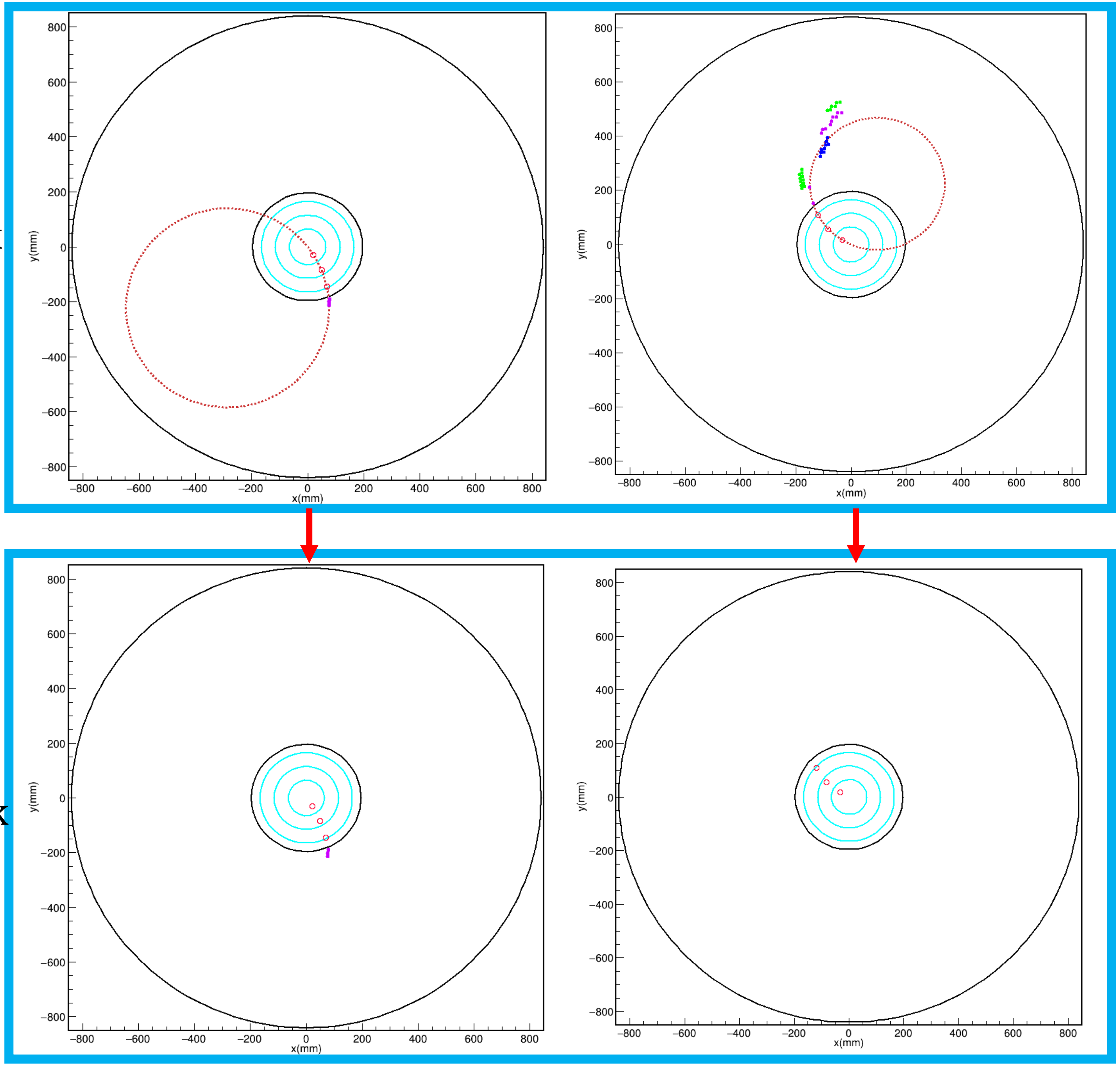
Particle requirements: nHits>=5, |cosθ|<0.94

Track requirements: matchingProb（purity） > 0.8

π,[50-150]Mev/c, can be reconstructed by ACTS but not Hough

Hits on MCtrack

Hits on Rectrack



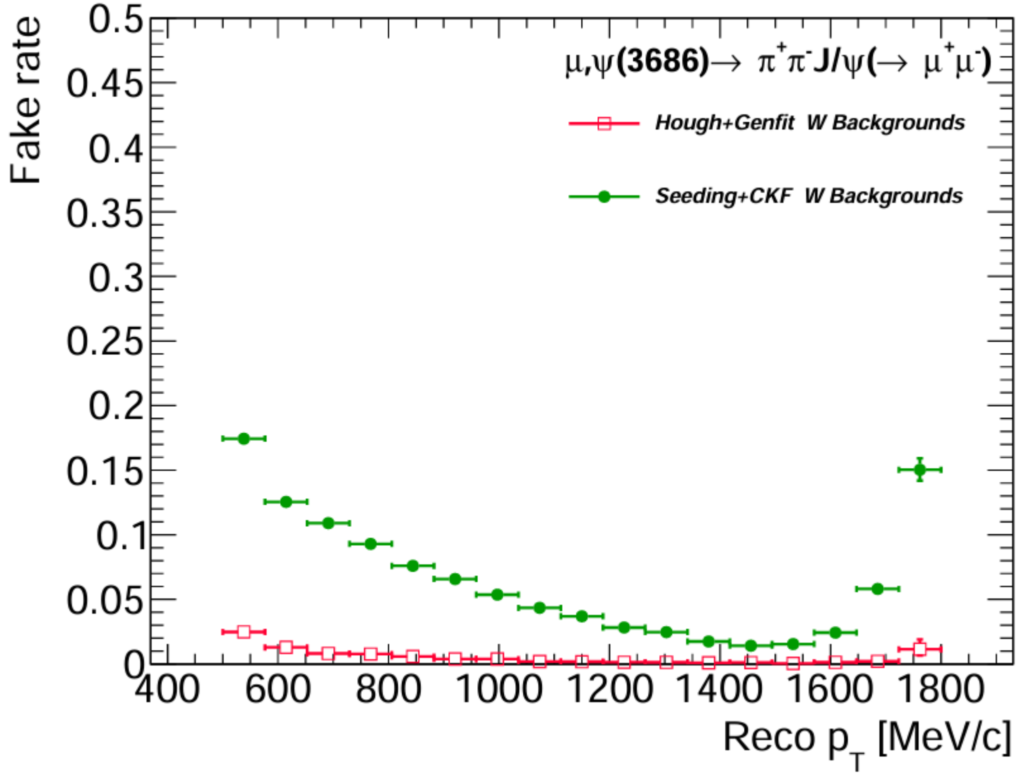
It's found that:

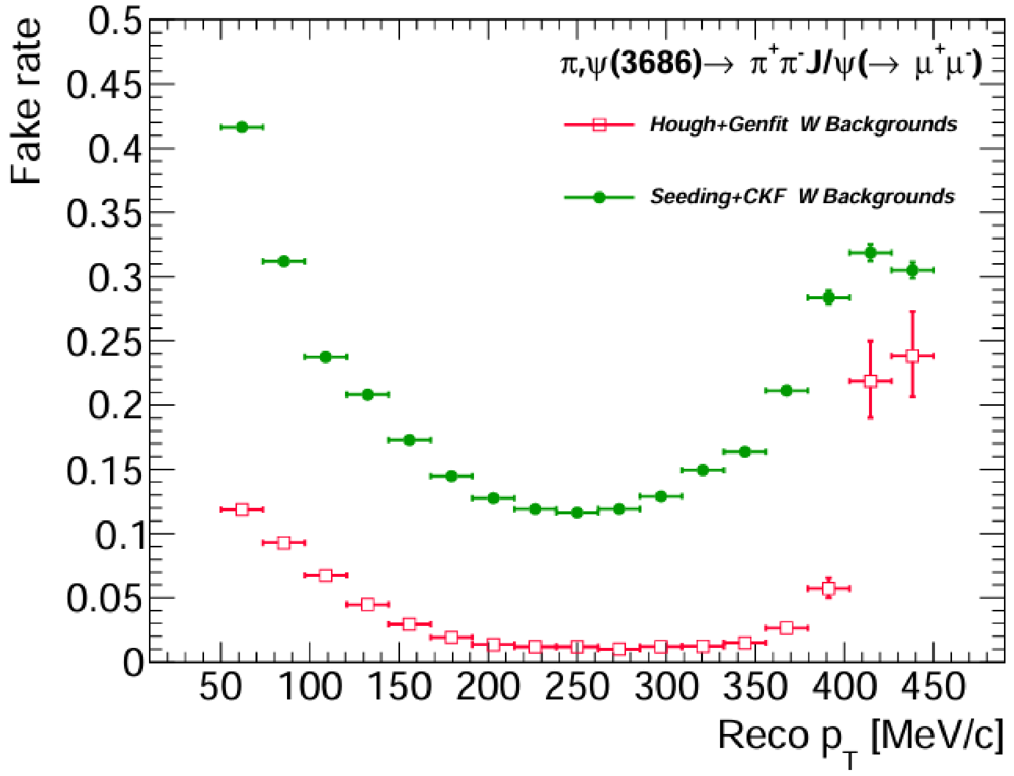
- ACTS is robust for low momentum tracks and short tracks (as long as the track has hit at each ITK layer)

Performance for non-displaced tracks

Fake rate (ACTS seeding + CKF vs Hough+GenFit)

- ACTS has higher and non negligible fake rate
  - ML technique can further remove/filter those fake tracks

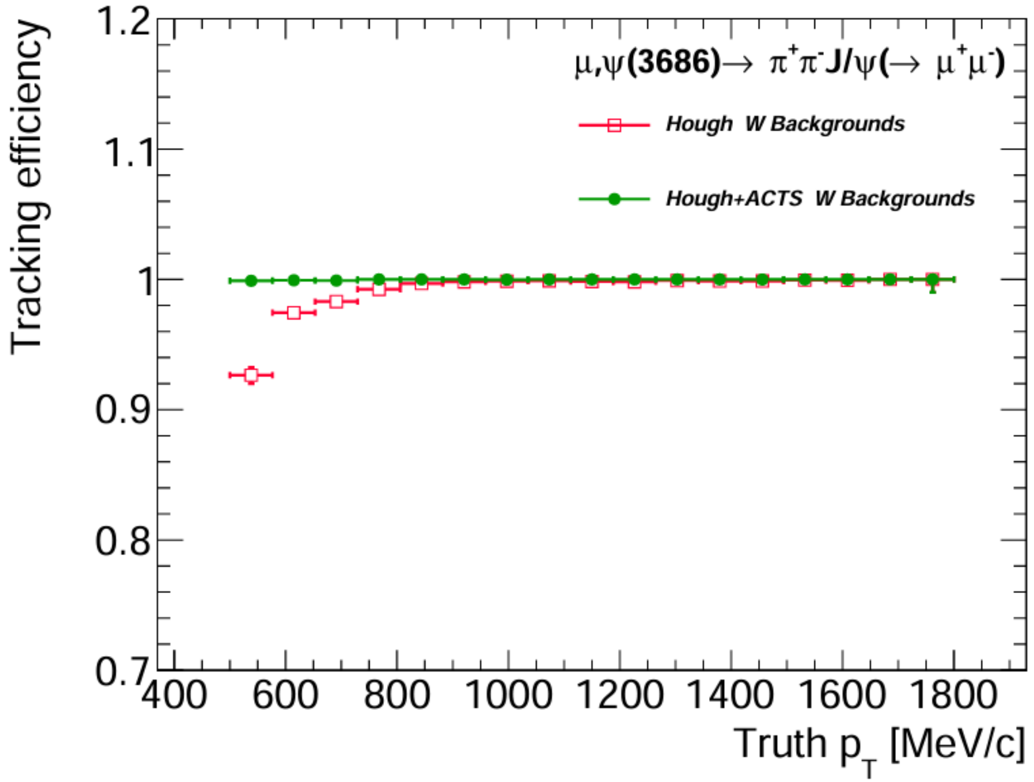


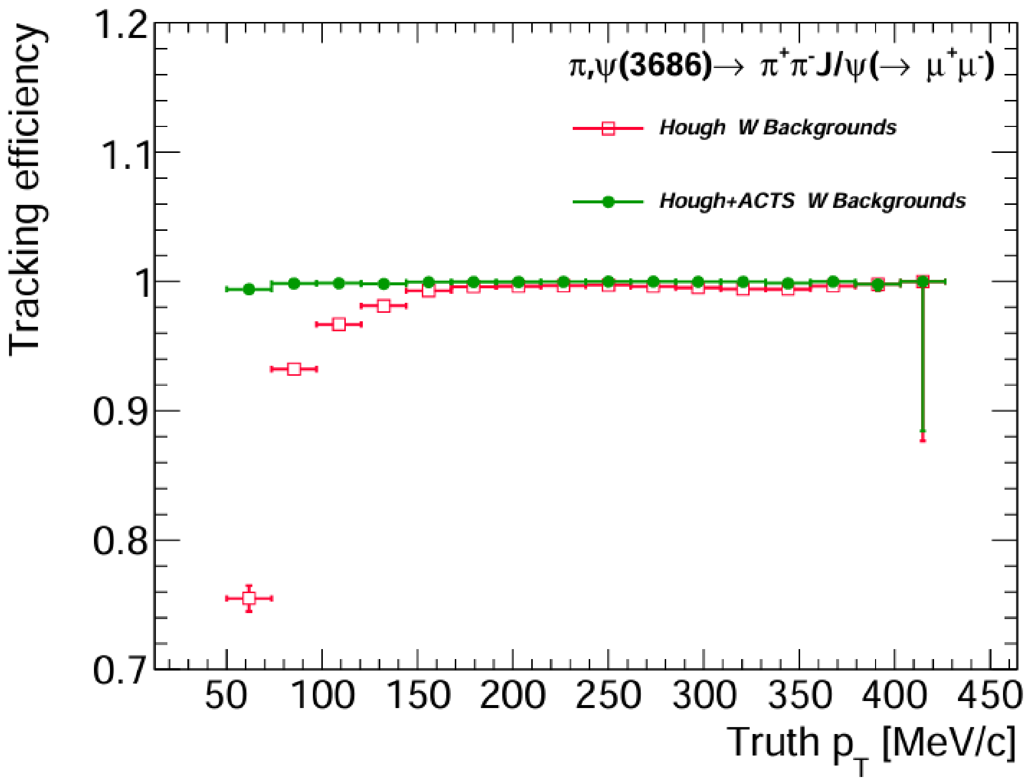


Performance for non-displaced tracks

Tracking efficiency (combining Hough with ACTS)

- Use ACTS to further reconstruct tracks using hits not associated to Hough tracks
- Efficiency has improved especially in the low transverse momentum region





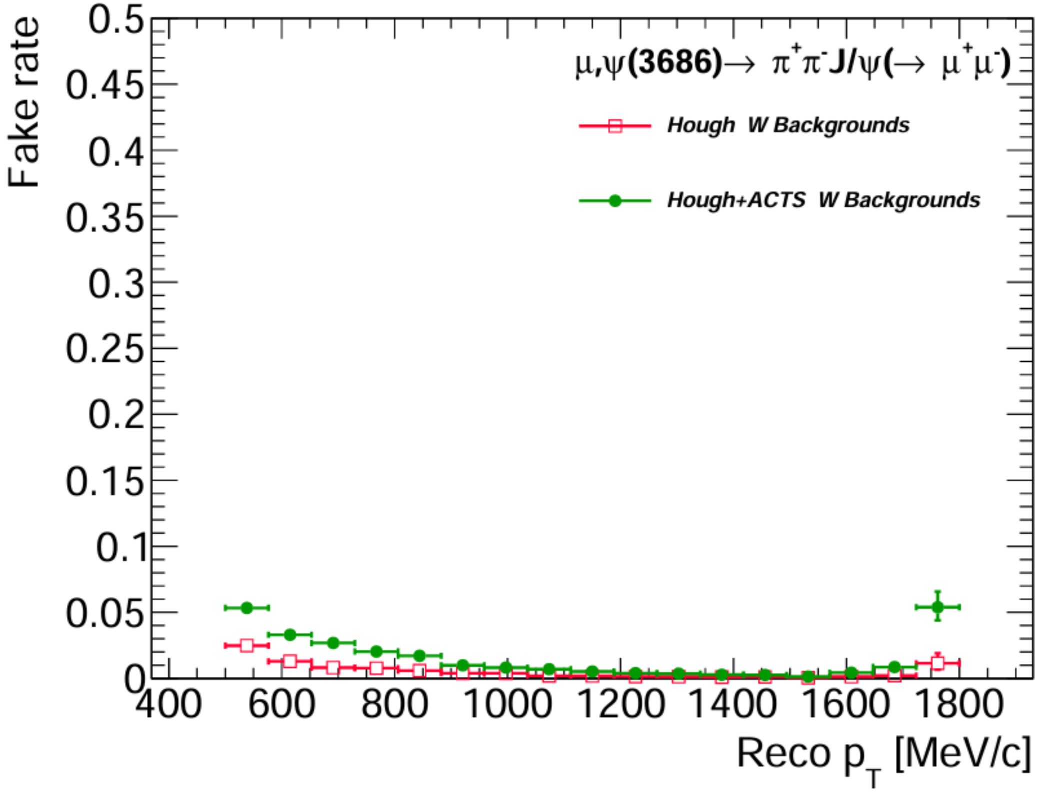
Particle requirements: nHits>=5, |cosθ|<0.94

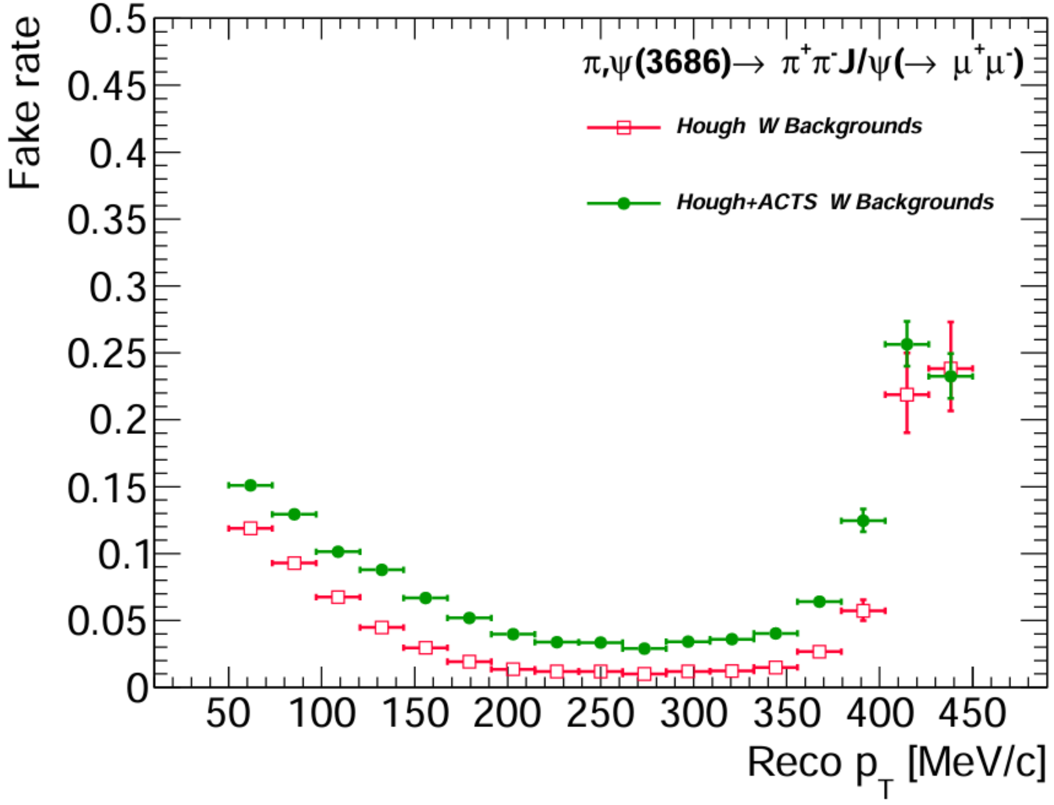
Track requirements: matchingProb（purity） > 0.8

Performance for non-displaced tracks

Fake rate (combining Hough with ACTS)

- Compared to ACTS-only tracking , fake rate has decreased, but increased compared to Hough-only tracking

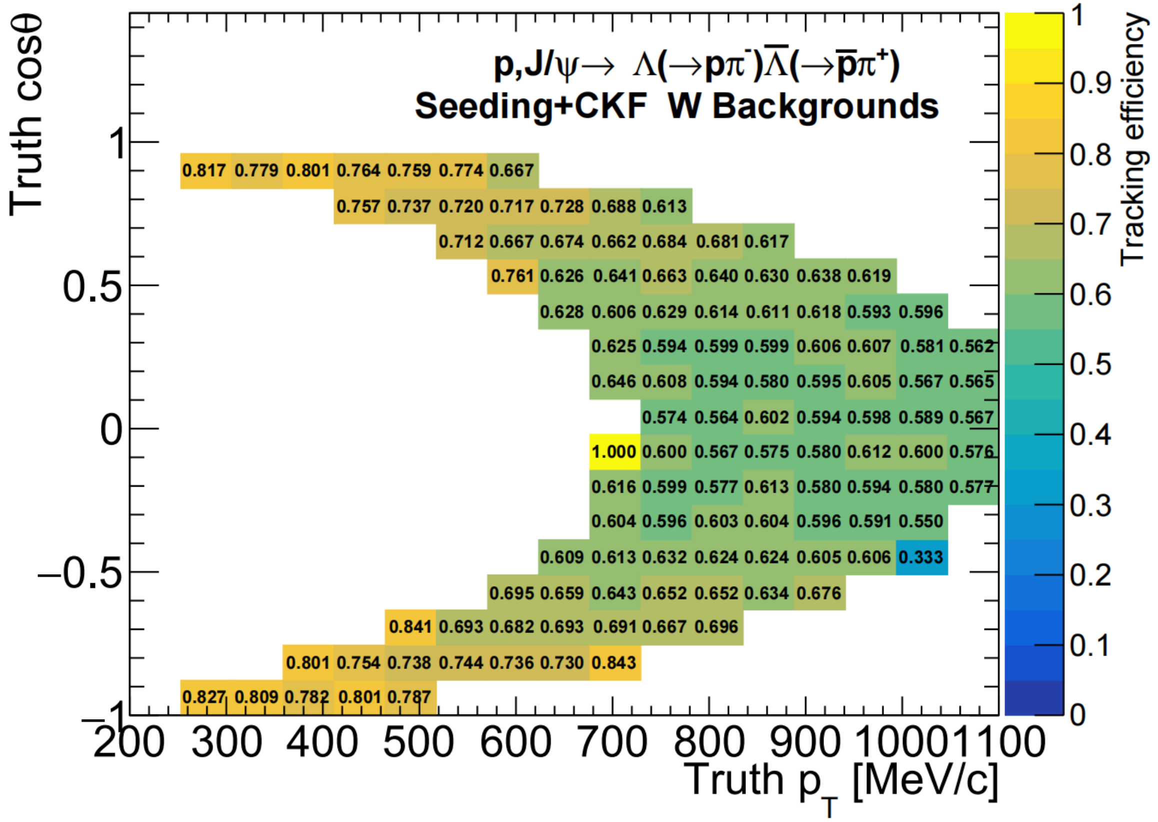


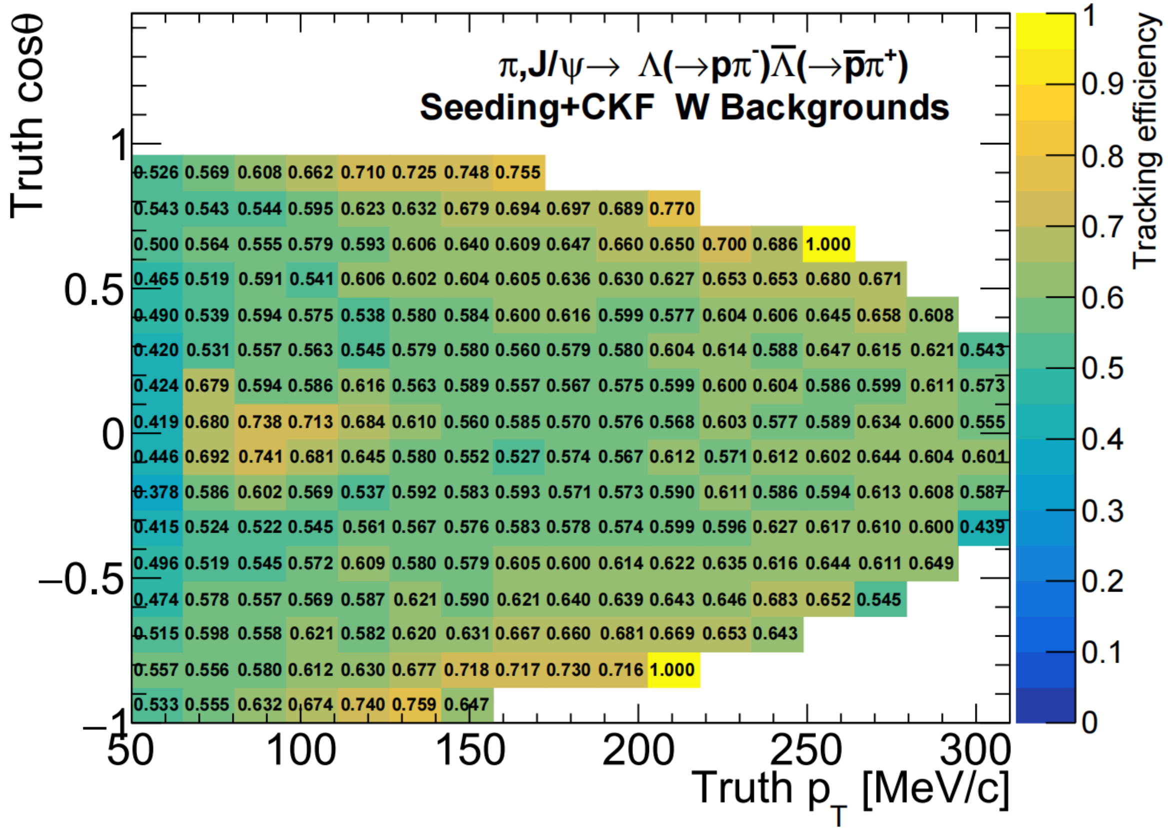


Performance for displaced tracks

Tracking efficiency (ACTS seeding + CKF)

- Low seeding efficiency (due to <3 hits on ITK) —>low tracking efficiency





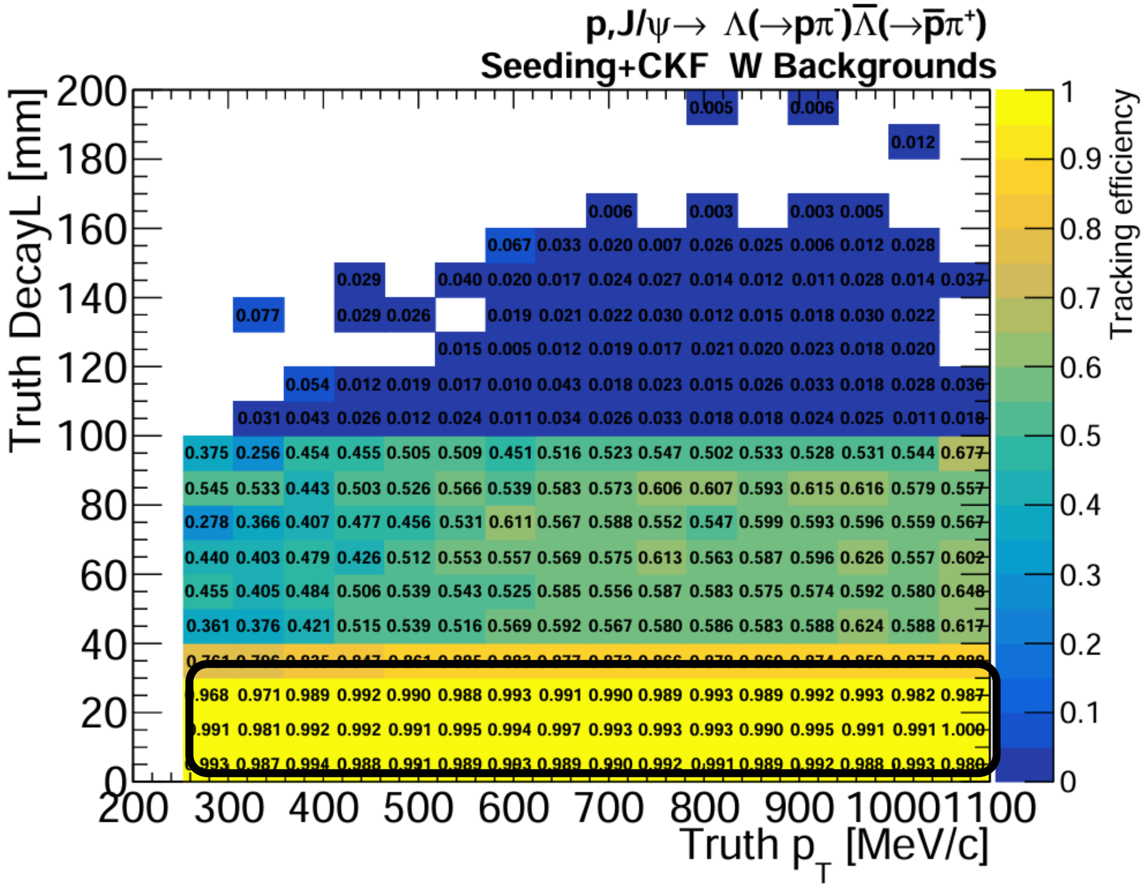
Particle requirements: nHits>=5, |cosθ|<0.94

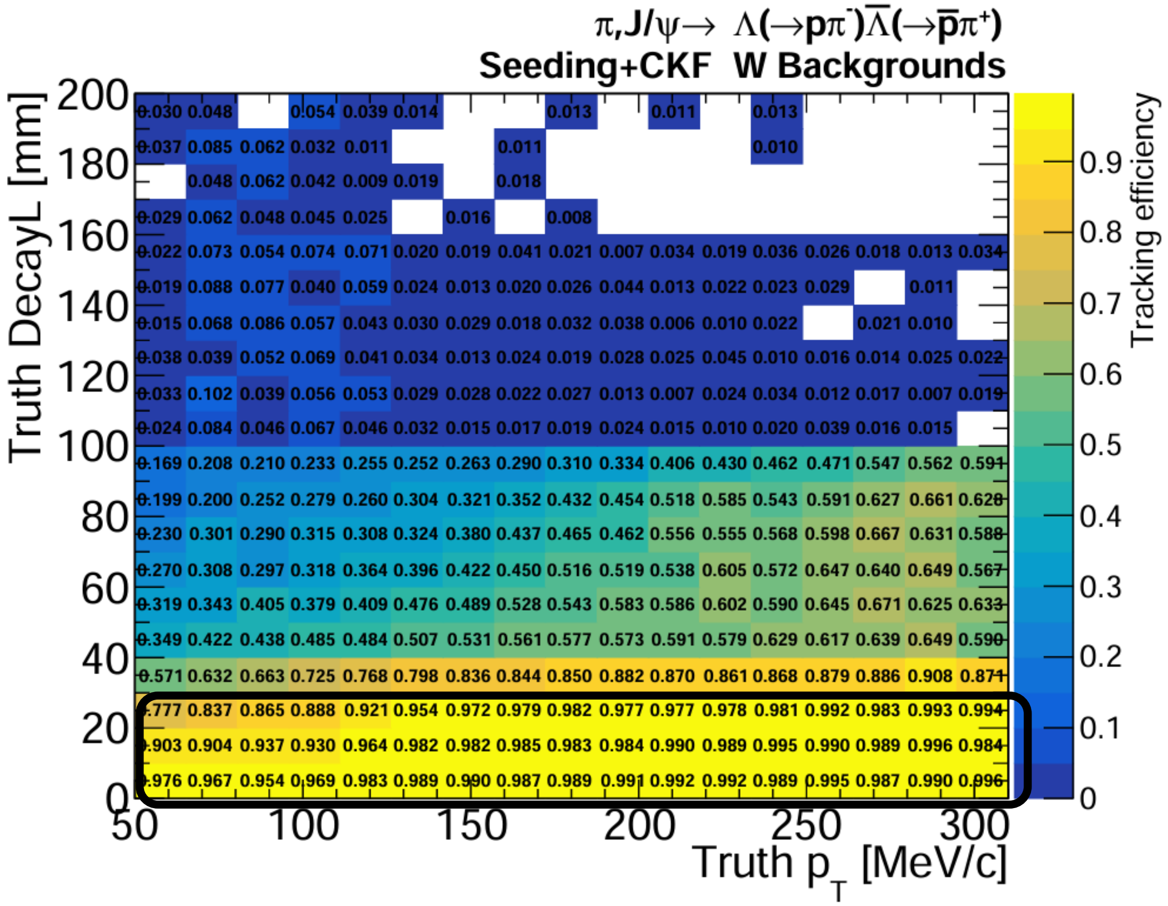
Track requirements: matchingProb（purity） > 0.8

Performance for displaced tracks

Tracking efficiency (ACTS seeding + CKF)

- Good efficiency for particles that decay within first layer of ITK





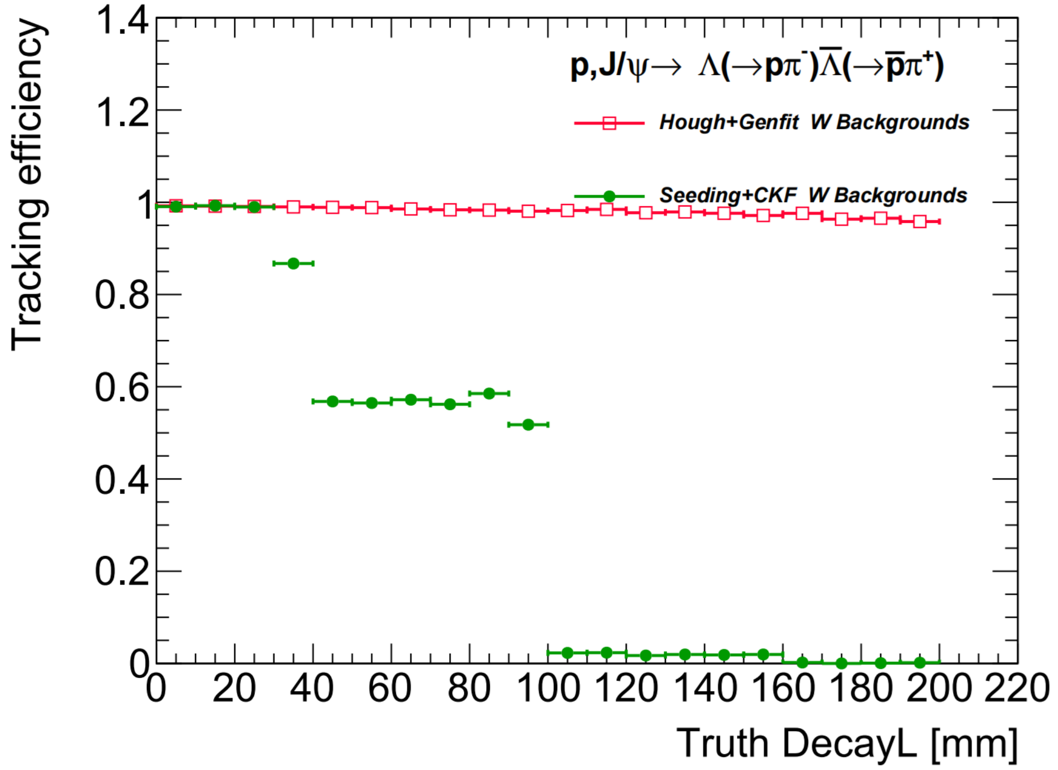
Particle requirements: nHits>=5, |cosθ|<0.94

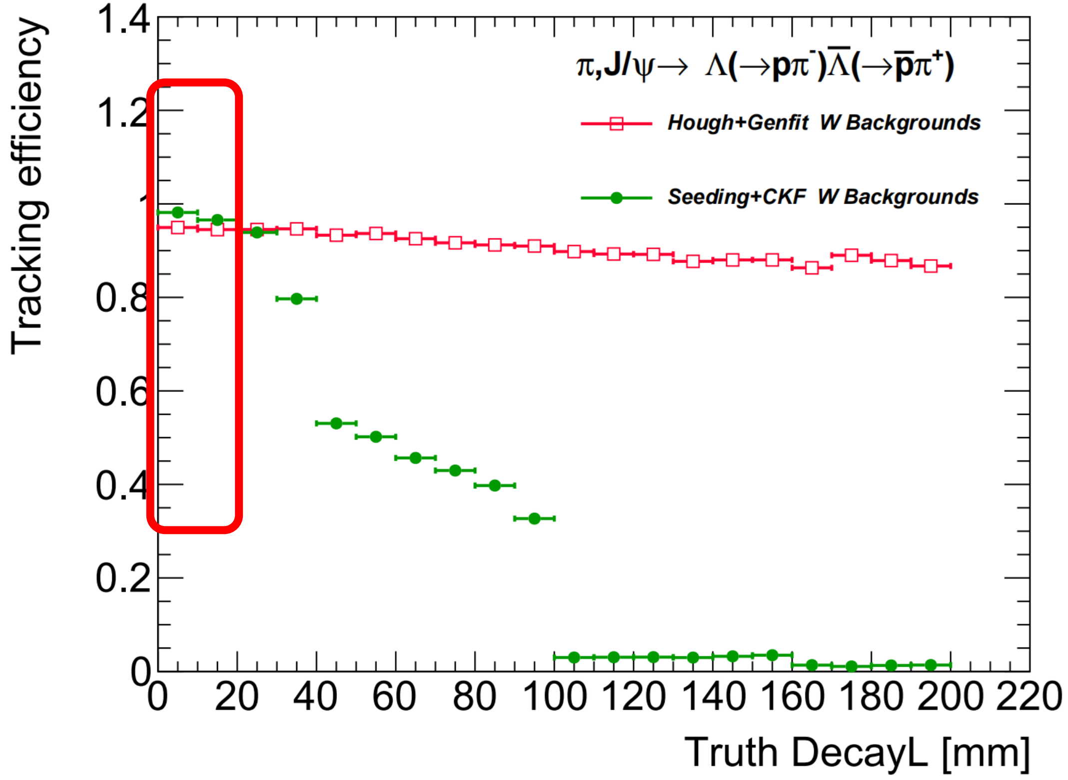
Track requirements: matchingProb（purity） > 0.8

Performance for displaced tracks

Tracking efficiency (ACTS seeding + CKF vs Hough+GenFit)

- Hough transform is more robust against local hit loss/inefficiency
- ACTS has slightly better seeding efficiency if there are enough ITK hits





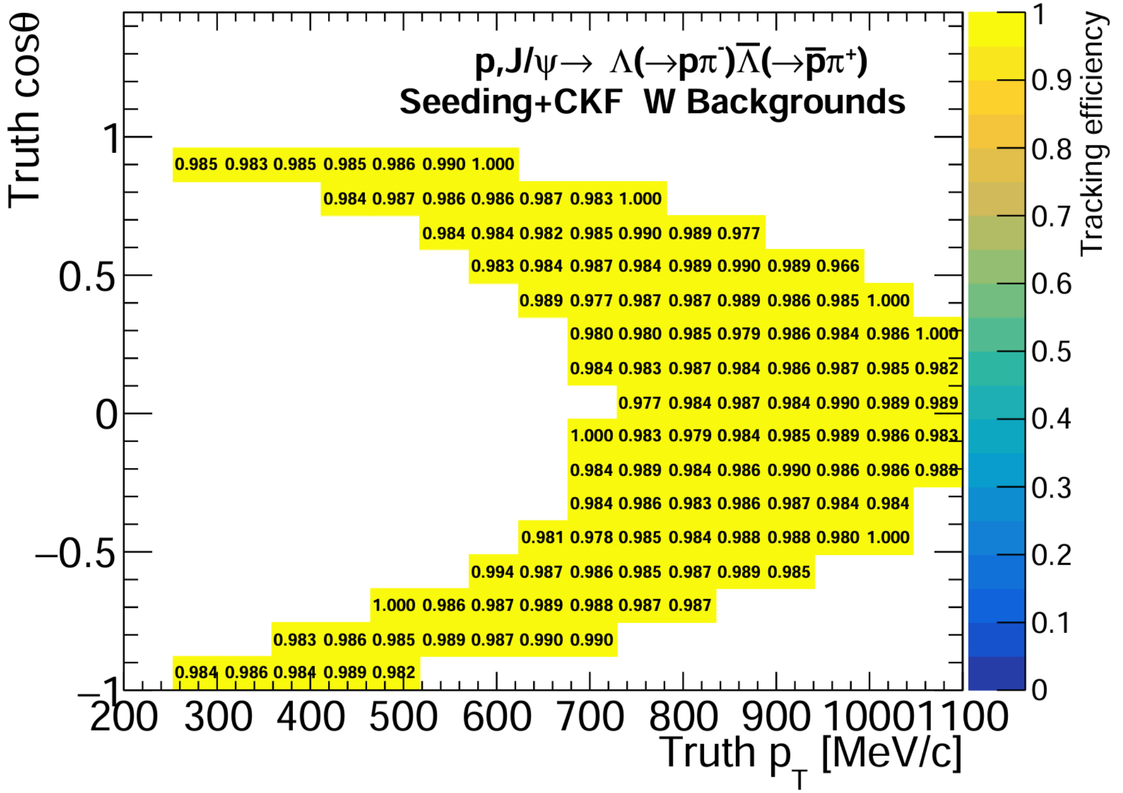
Particle requirements: nHits>=5, |cosθ|<0.94

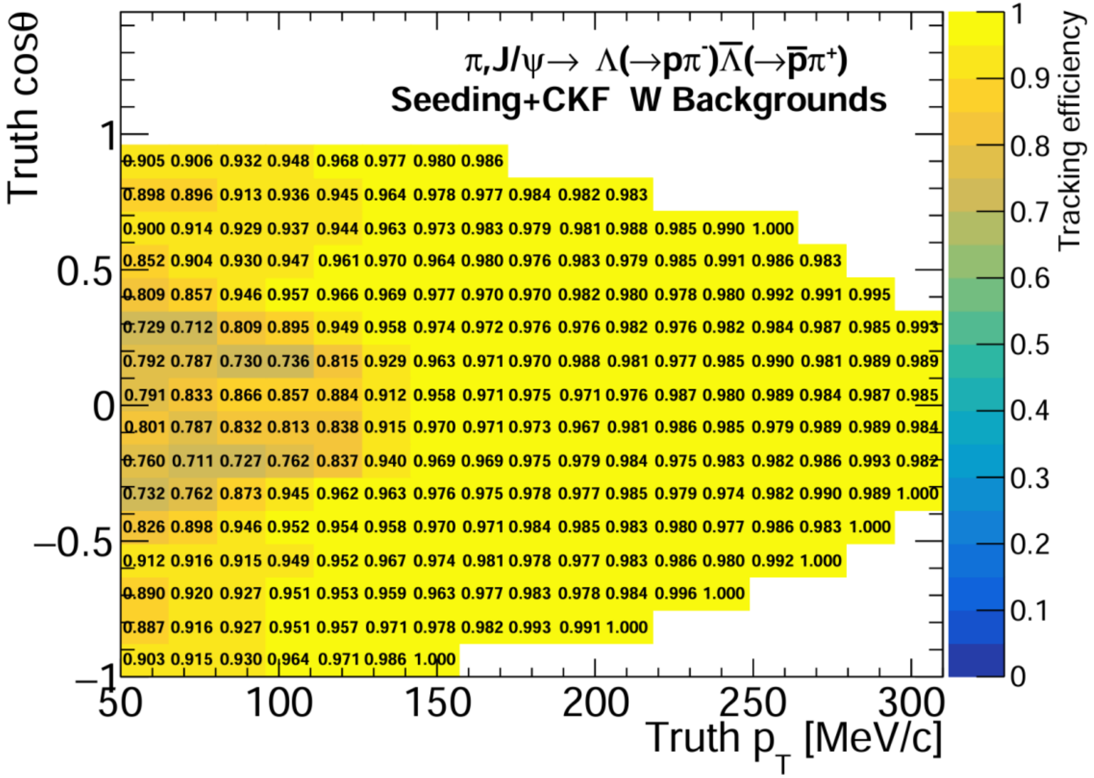
Track requirements: matchingProb（purity） > 0.8

Performance for displaced tracks

Tracking efficiency (ACTS seeding + CKF) if requiring 3 hits at ITK

- Check tracking efficiency of particles which has 3 hits at ITK
- The success of finding a seed is crucial for ACTS tracking





Particle requirements: nHits>=5, |cosθ|<0.94

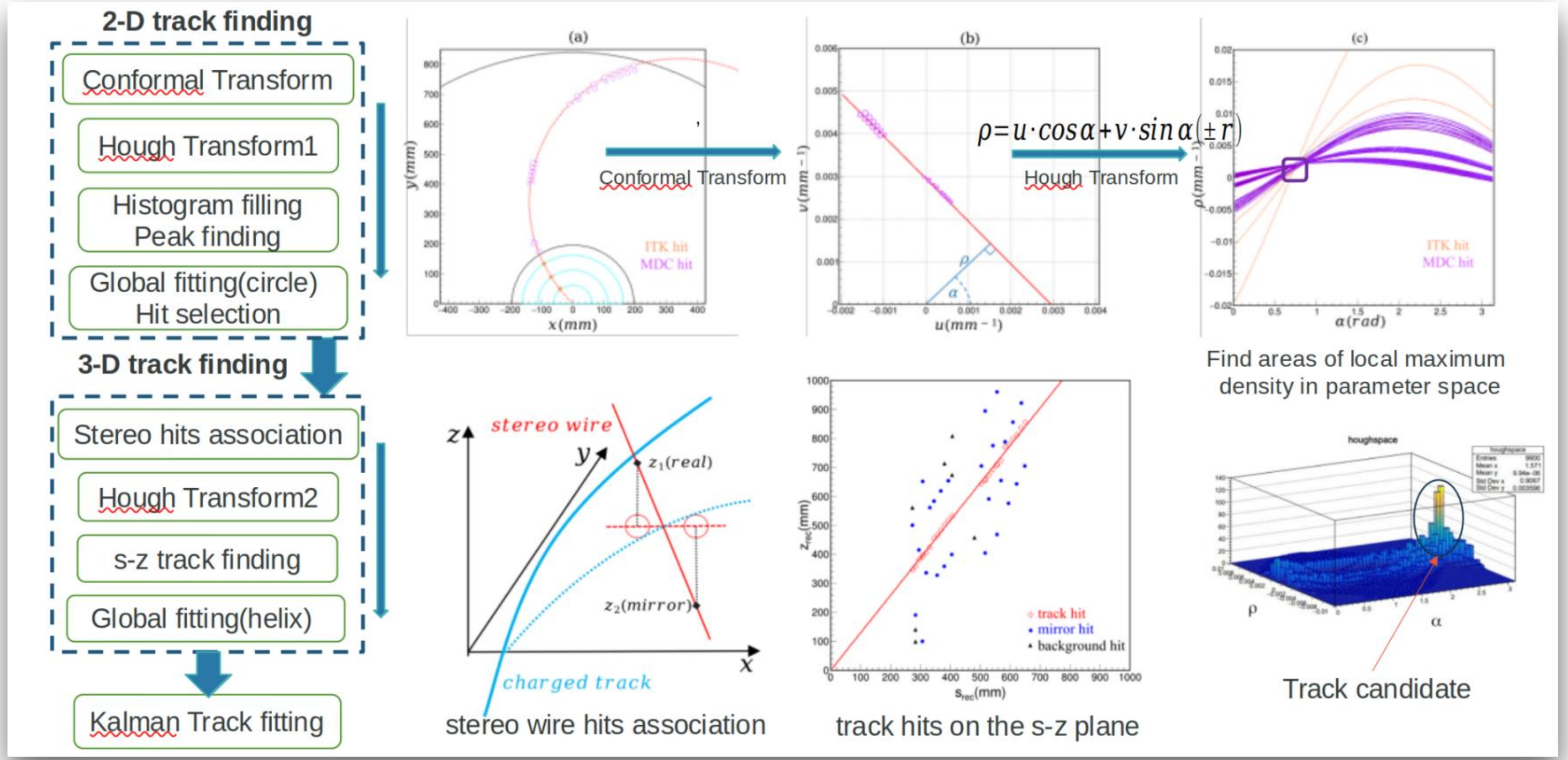
Track requirements: matchingProb（purity） > 0.8

Summary

- ACTS has been used as one of the tracking methods at STCF
  - ACTS has been integrated into STCF offline software
  - Encouraging performance even at p_T below 100 MeV/c
- Obvious tracking efficiency loss for long-lived particles at STCF for ACTS
- Non-negligible amount of fake (and also duplicate) tracks exist
- Next:
  - Further investigate the performance of combining Hough + ACTS for displaced particles
  - Investigate ML ambiguity resolver to remove fake/duplicate tracks

Back up

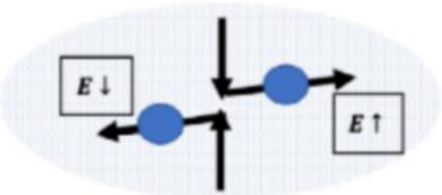
Hough Transform at STCF



Backgrounds

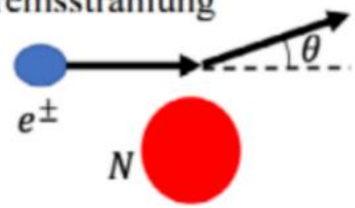
Touschek effect

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



Beam-gas effect

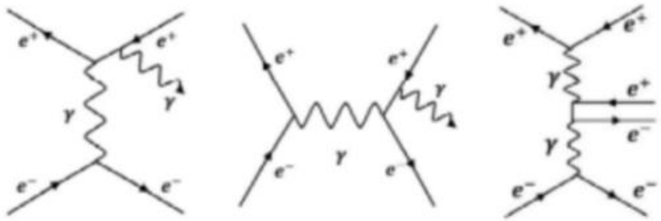
- Effect with residual gas in the beam pipe
- Coulomb scattering， bremsstrahlung
- Generation ∝ pressure



Yupeng Pei

Luminosity-related background

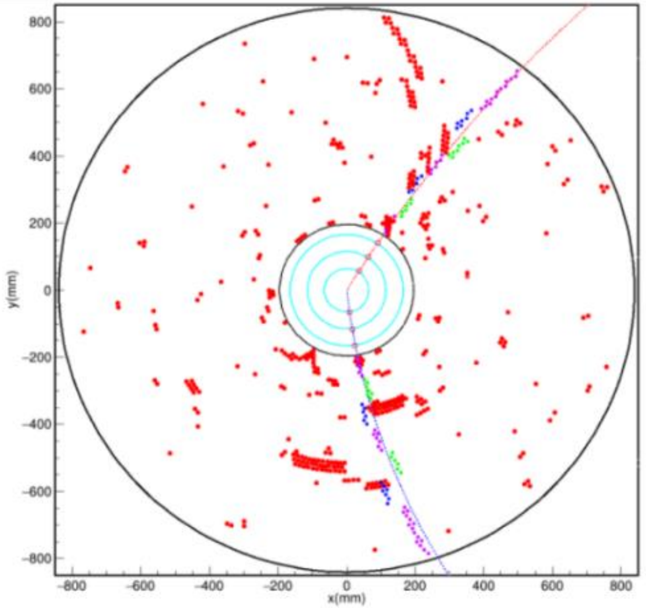
- Radiative Bhabha: $e^+e^- \to e^+e^-\gamma$
- Two-photon process:
  $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-e^+e^-$



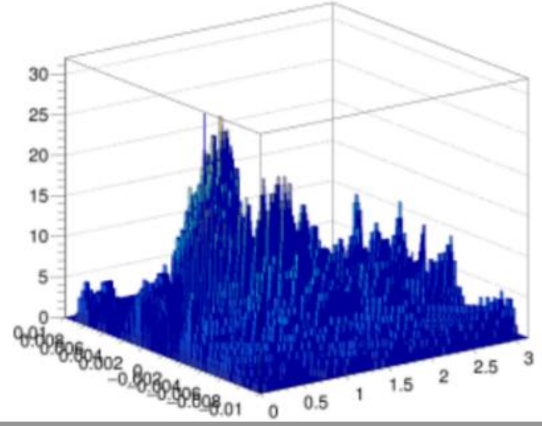
Other background

- Injection
- Synchrotron radiation

5

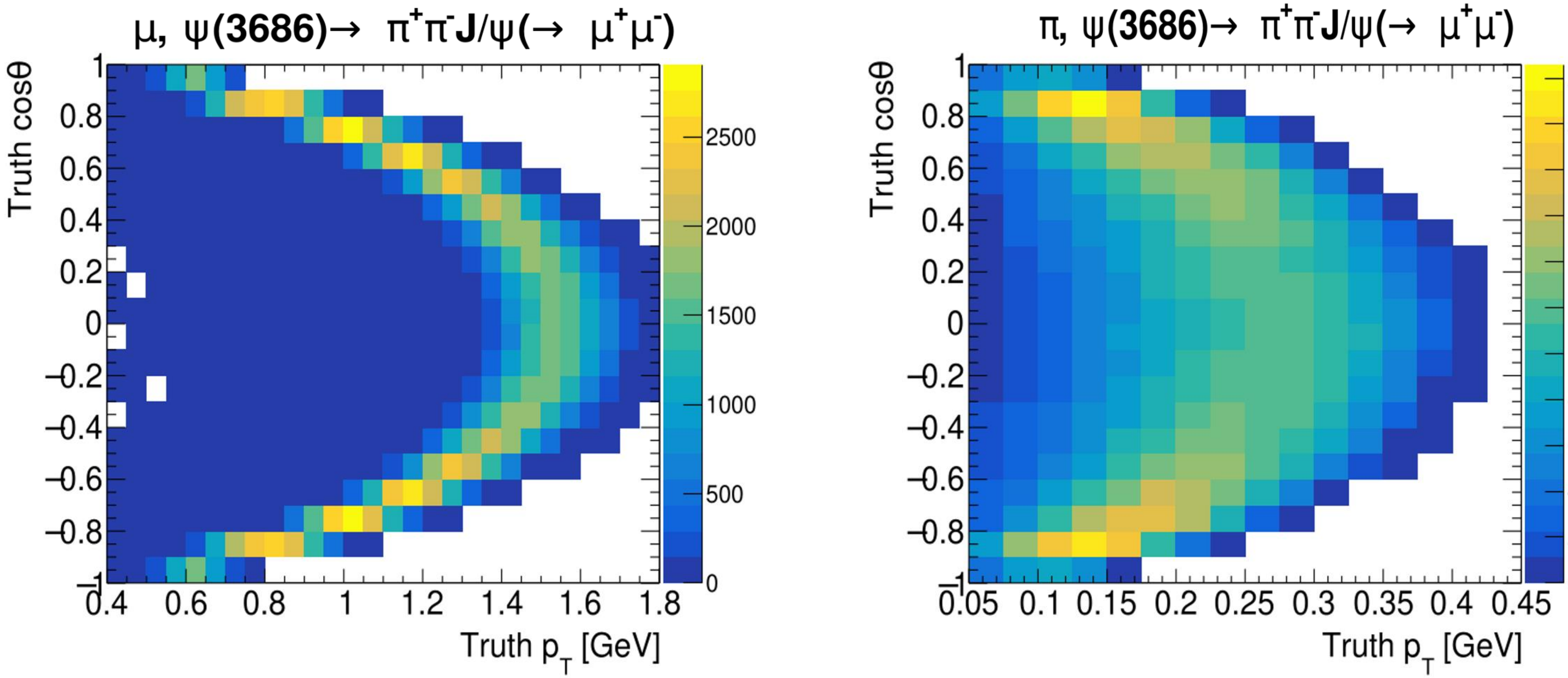


Hough map with background

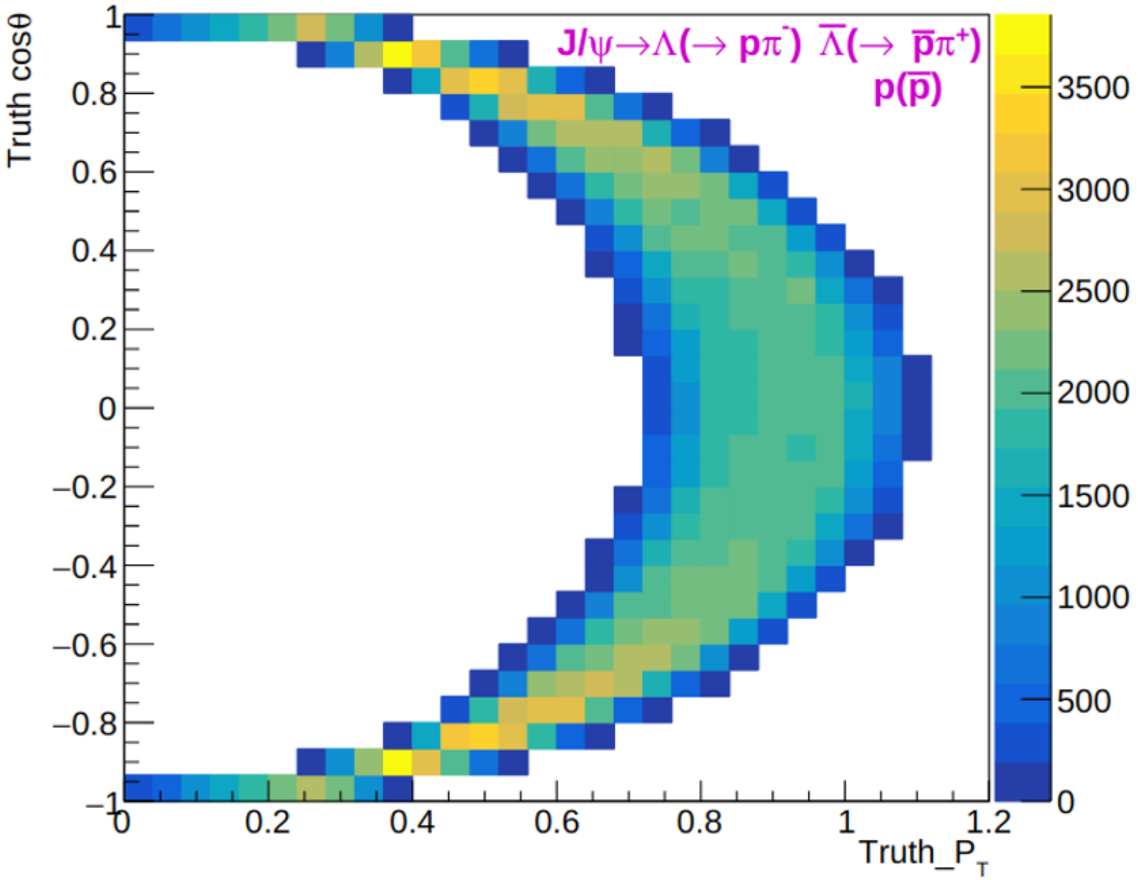


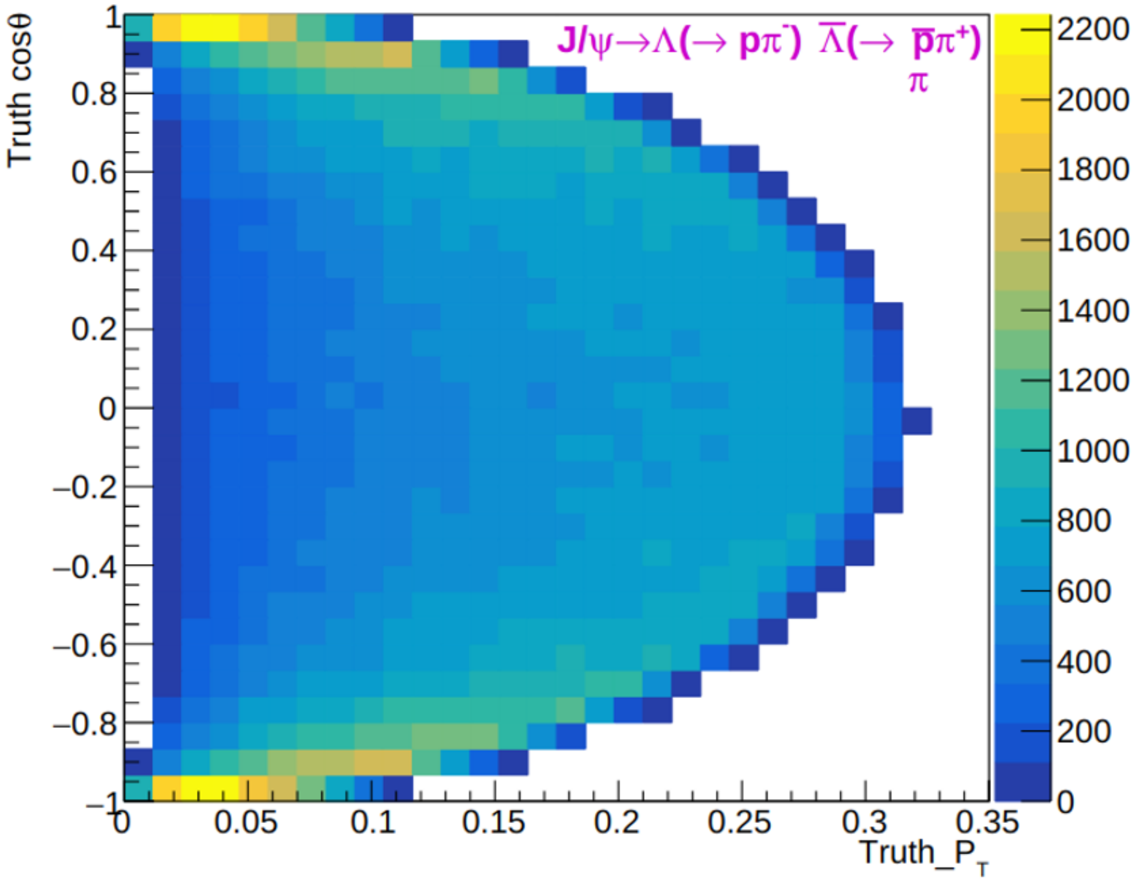
Background hits count per event

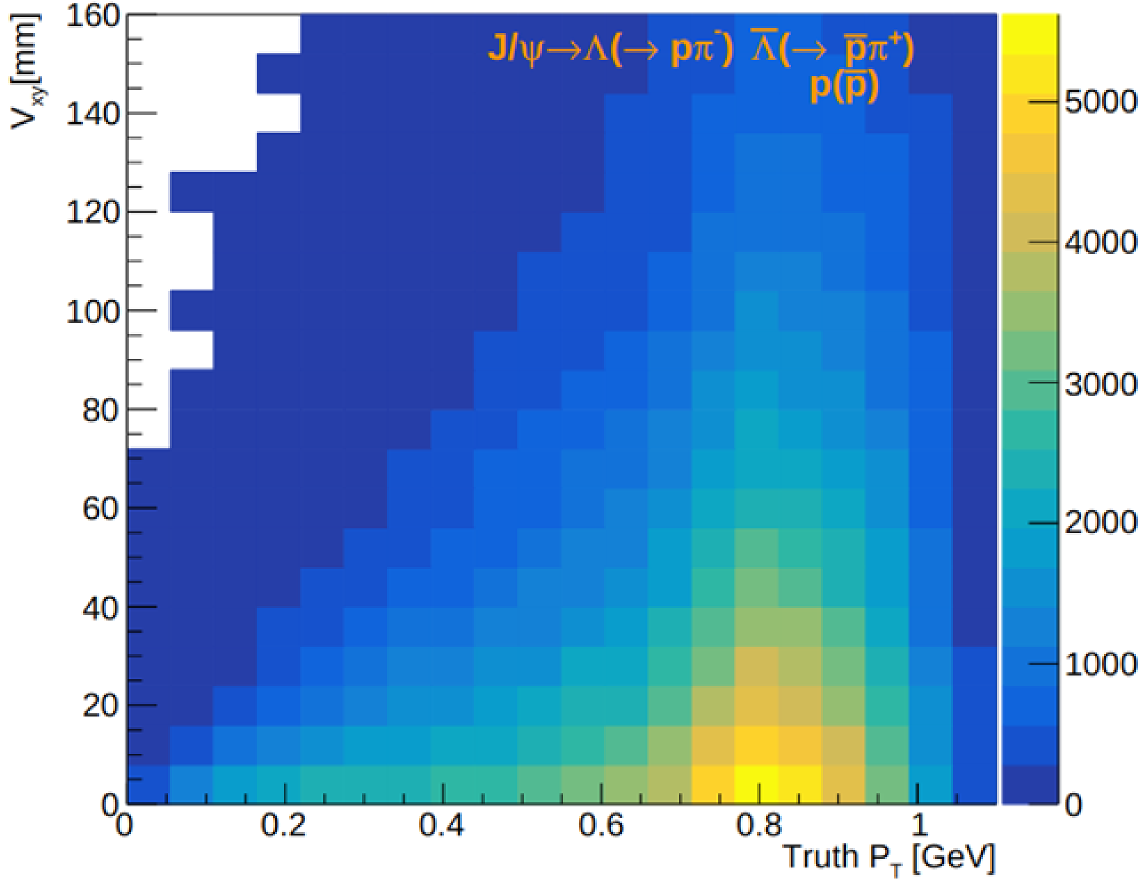
ITK1	ITK2	ITK3	MDC1	MDC2	MDC3	MDC4	MDC5	MDC6	MDC7	MDC8
37.3	13.6	8.2	60.3	42.4	24.8	25.1	60.0	67.8	30.8	30.0

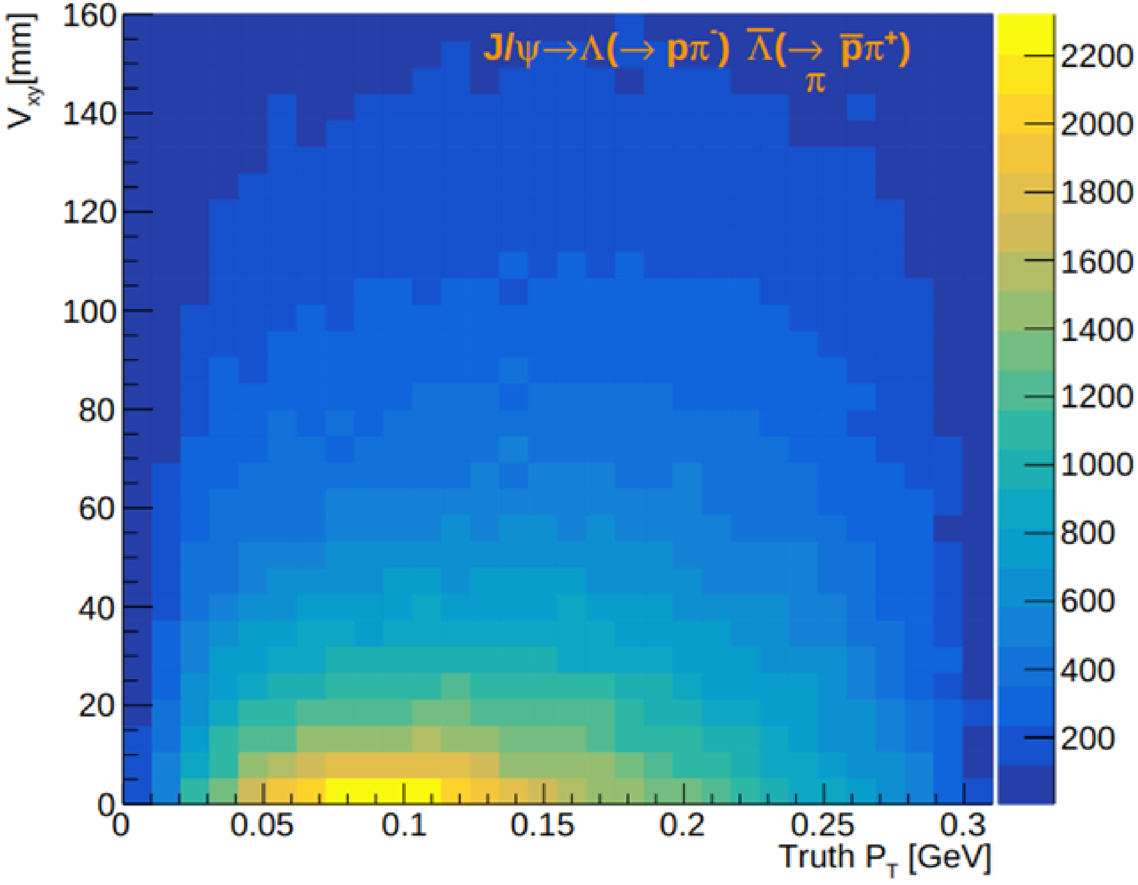


μ, ψ(3686)→ π+π-J/ψ(→ μ+μ-)
Truth cosθ
Truth p_T [GeV]
π, ψ(3686)→ π+π-J/ψ(→ μ+μ-)
Truth cosθ
Truth p_T [GeV]


Truth cosθ
Truth_P_T
J/ψ→Λ(→ pπ⁻) Λ̄(→ p̄π⁺)
p(p̄)


Truth cosθ
Truth_P_T
J/ψ→Λ(→ pπ⁻) Λ̄(→ p̄π⁺)
π


J/ψ→Λ(→ pπ⁻) Λ̄(→ p̄π⁺)
p(p̄)
V_xy[mm]
160
140
120
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
Truth P_T [GeV]
5000
4000
3000
2000
1000
0


J/ψ→Λ(→ pπ⁻) Λ̄(→ p̄π⁺)
π
V_xy[mm]
160
140
120
100
80
60
40
20
0
0
0.05
0.1
0.15
0.2
0.25
0.3
Truth P_T [GeV]
2200
2000
1800
1600
1400
1200
1000
800
600
400
200

- d_0 of some particles is above 60mm for π
- ImpactMax was set 60mm in ACTS seeding