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STCF tracking with ACTS

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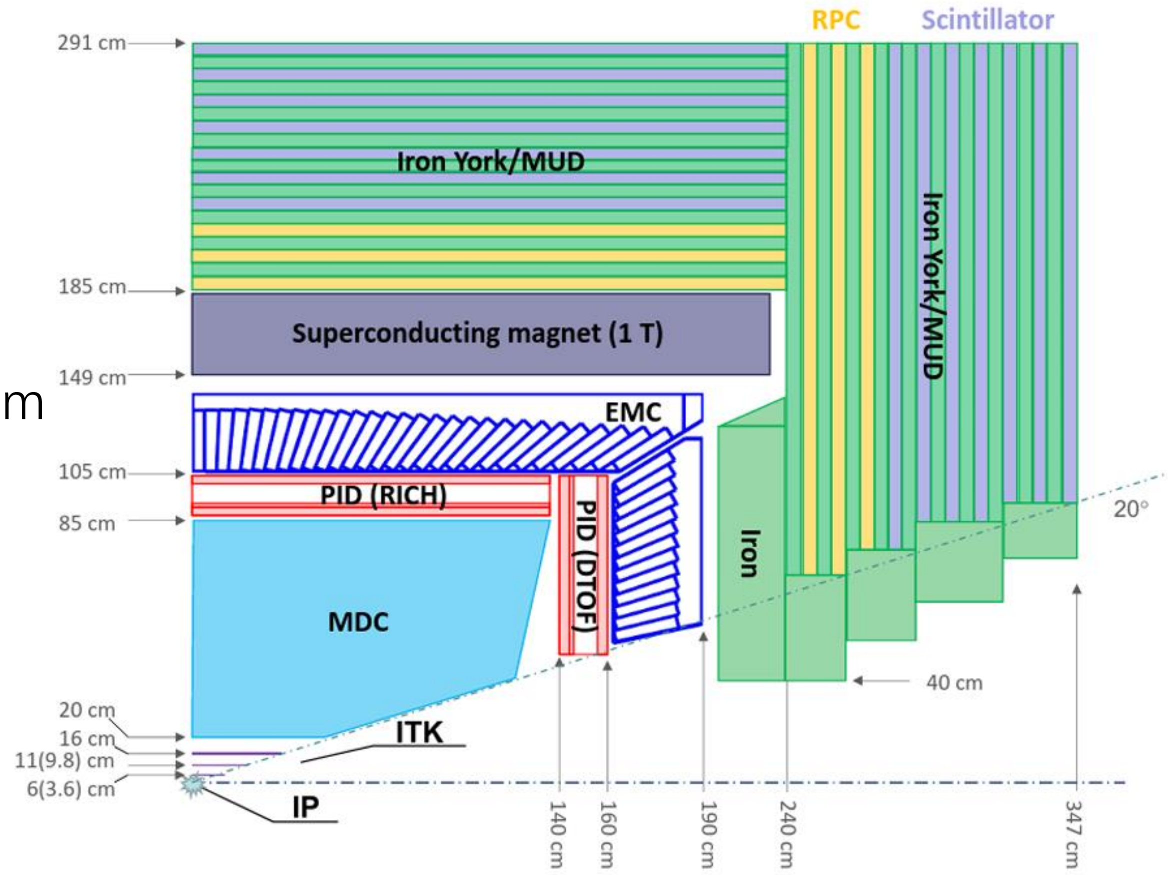
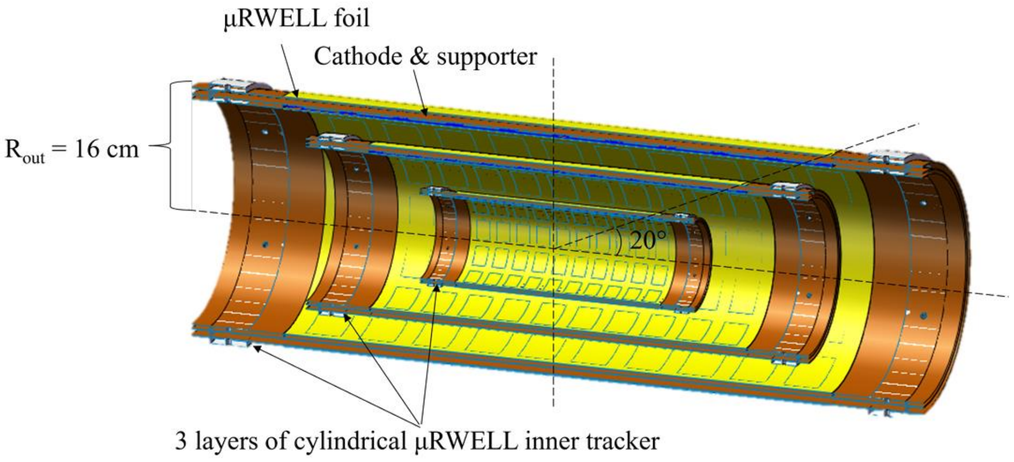
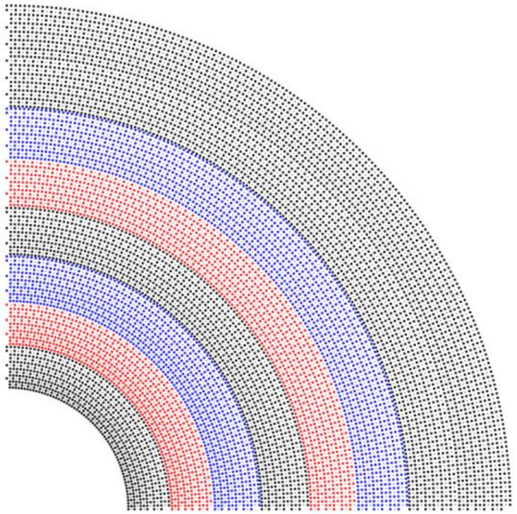
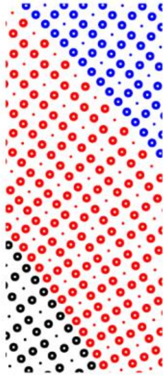
STCF tracking system

- The baseline tracking system includes uRWELL-based Inner Tracker (ITK) and Main Drift Chamber (MDC)
  - ITK: 3 layers with radii of 60 mm, 110 mm, and 160mm
    $\sigma_{r-\varphi} \times \sigma_z \approx$100um × 400um
  - MDC: 48 layers, $\sigma_{drift\ dist} \approx$ 120~130um









Figures from STCF CDR (arXiv:2303.15790)

A Commom Tracking Software(ACTS)

- A modern open-source detector-independent tracking toolkit for current&future HEP experiments (ATLAS, ALICE, sPHENIX, FASER, MUC, CEPC, STCF…) 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***

Readthedocs: ***https://acts.readthedocs.io/en/latest/***

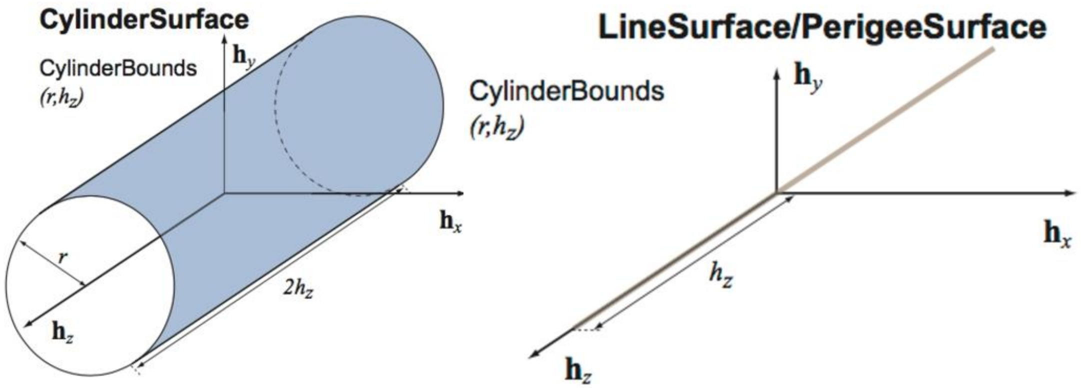
ACTS application on STCF

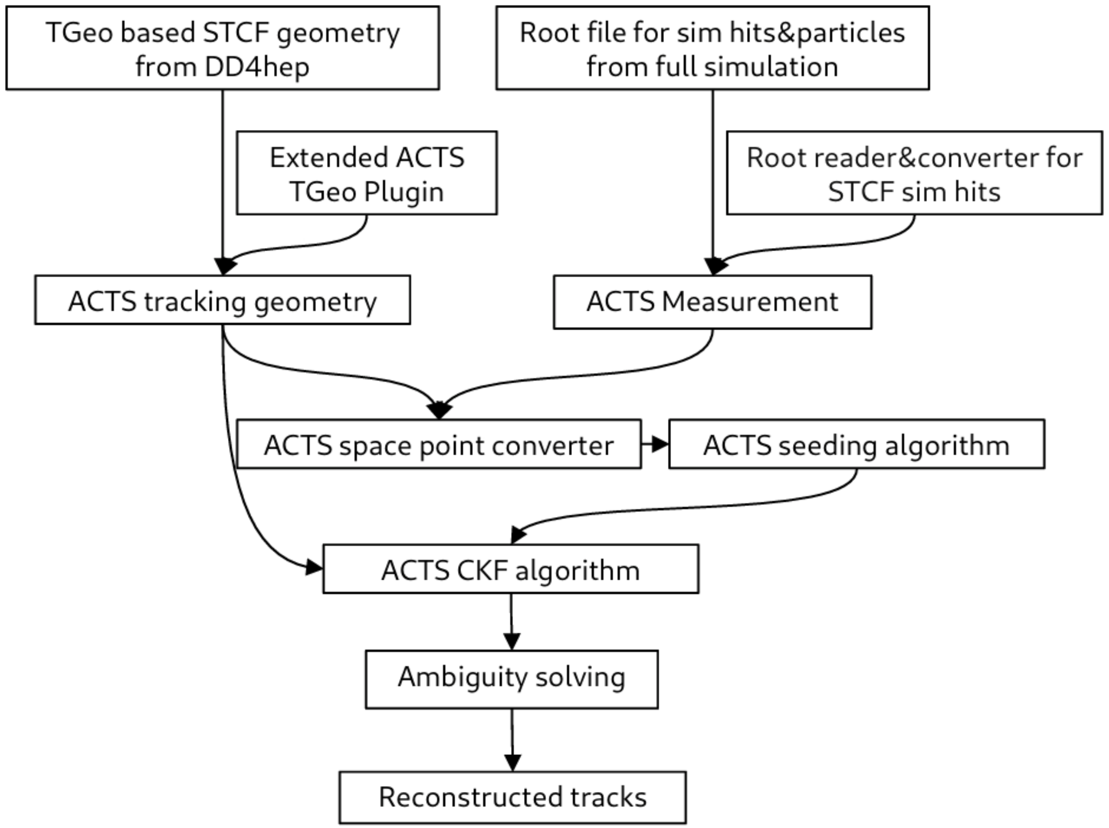
- STCF fullsim geometry is converted to ACTS tracking geometry using ACTS plugin
  - ITK layer —> ACTS layer with sensitive **CylinderSurface**
  - MDC layer —> ACTS layer with **LineSurface**

- Measurement creation: using Oscar Geant4 full sim hits as inputs, smeared with detector resolution
  - ITk : 100 um ($\mathrm{r} * \varphi$) x400 um (z)
  - MDC: 125 um (drift distance)

- ACTS seeding algorithm and CKF algorithm are used tracking

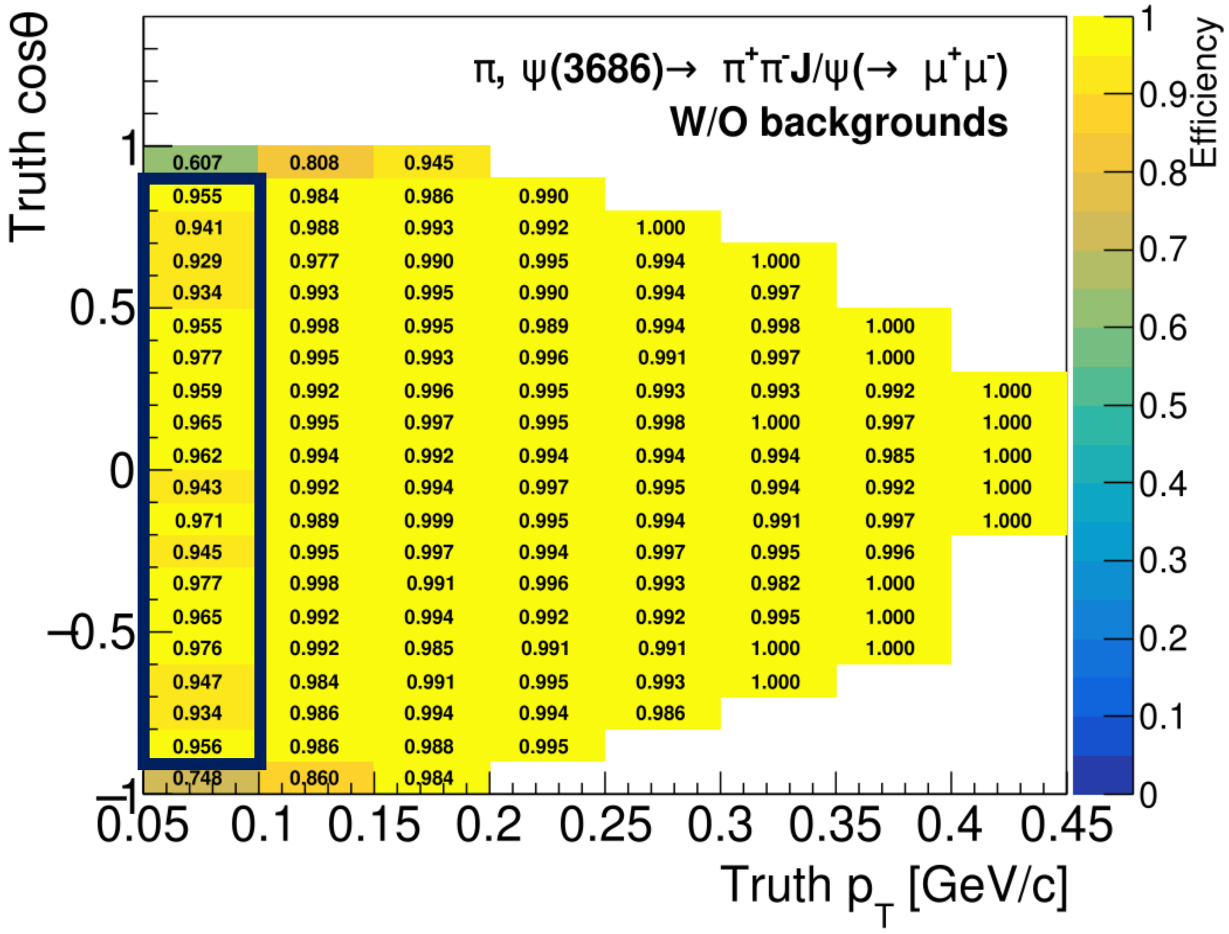
- **ACTS has been added as Oscar external package**

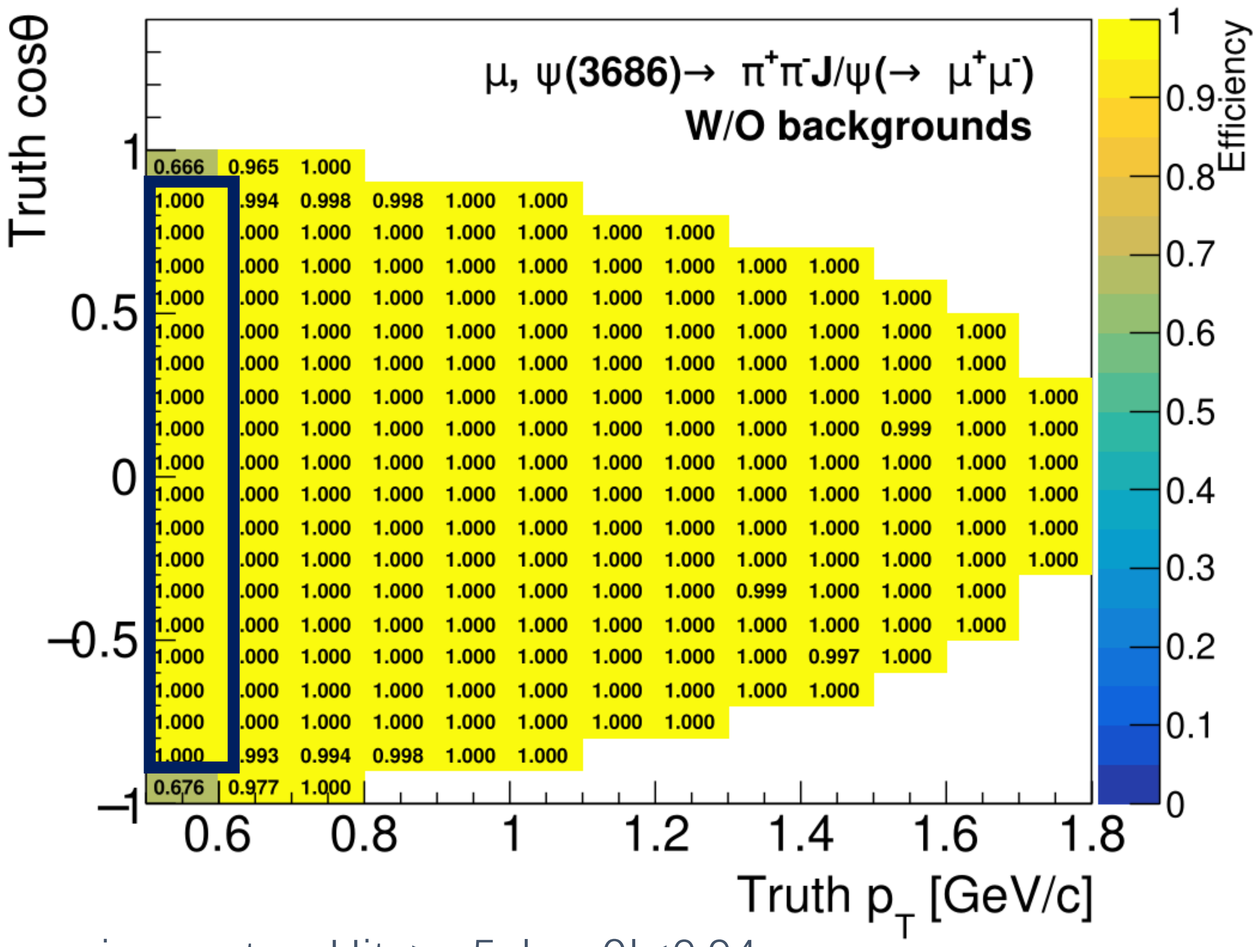




Tracking efficiency without backgrounds

- >93% tracking efficiency for π in the region |cosθ|<0.9, 50< P_T<100 MeV
- 100% tracking efficiency for μ in the region |cosθ|< 0.9, 500<P_T <600 MeV





Particle requirements: nHits>=5, |cosθ|<0.94
Track requirements: nHits>=5, matchingProb > 0.5

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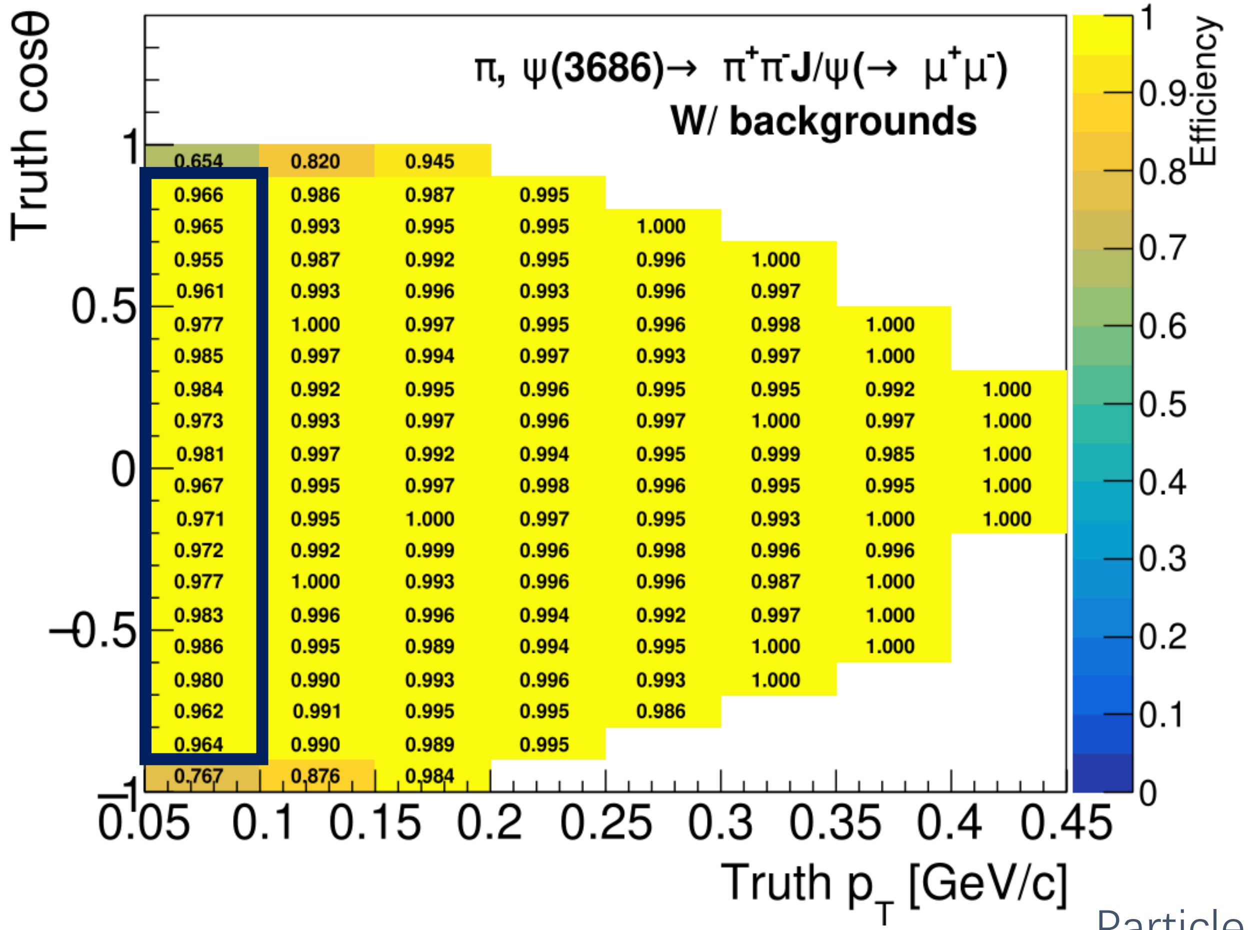

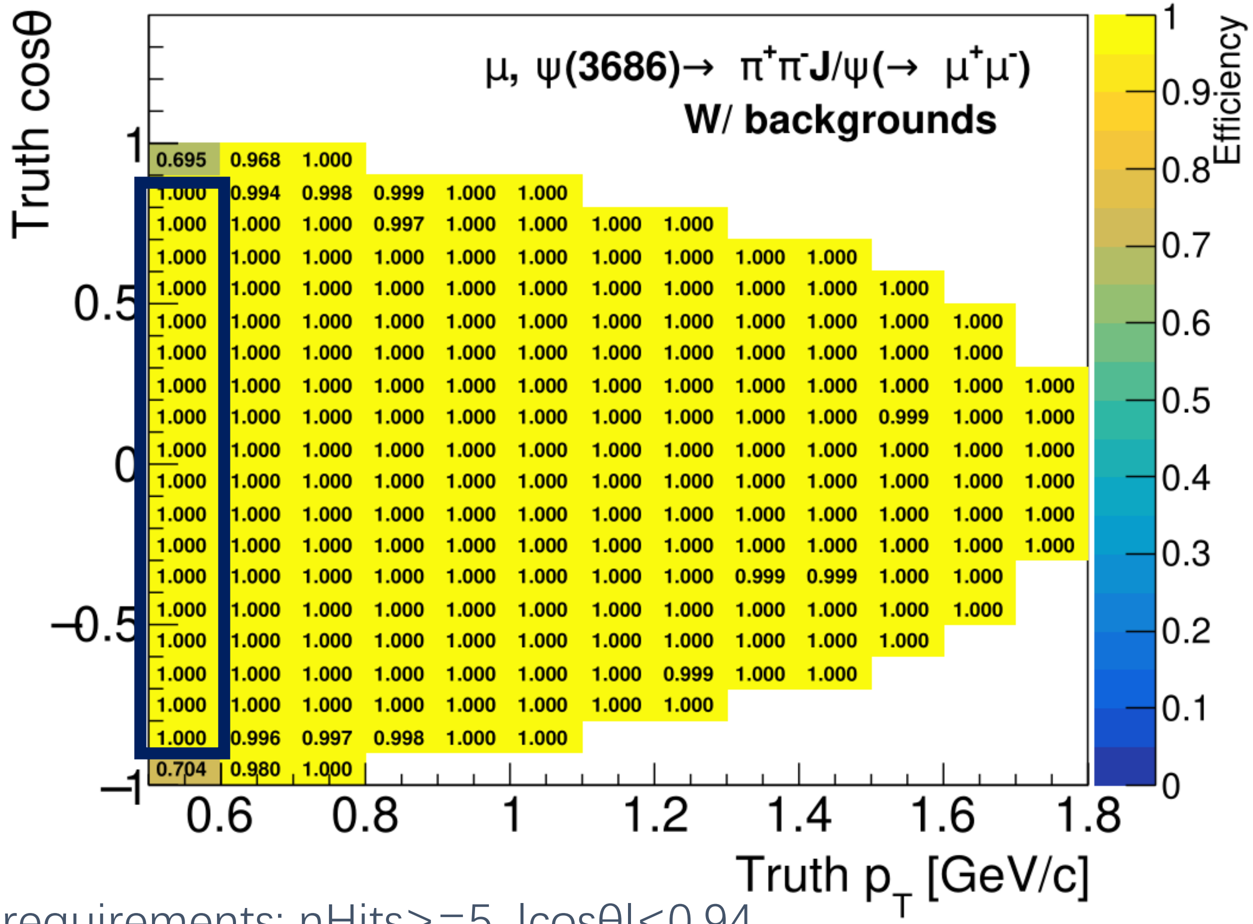

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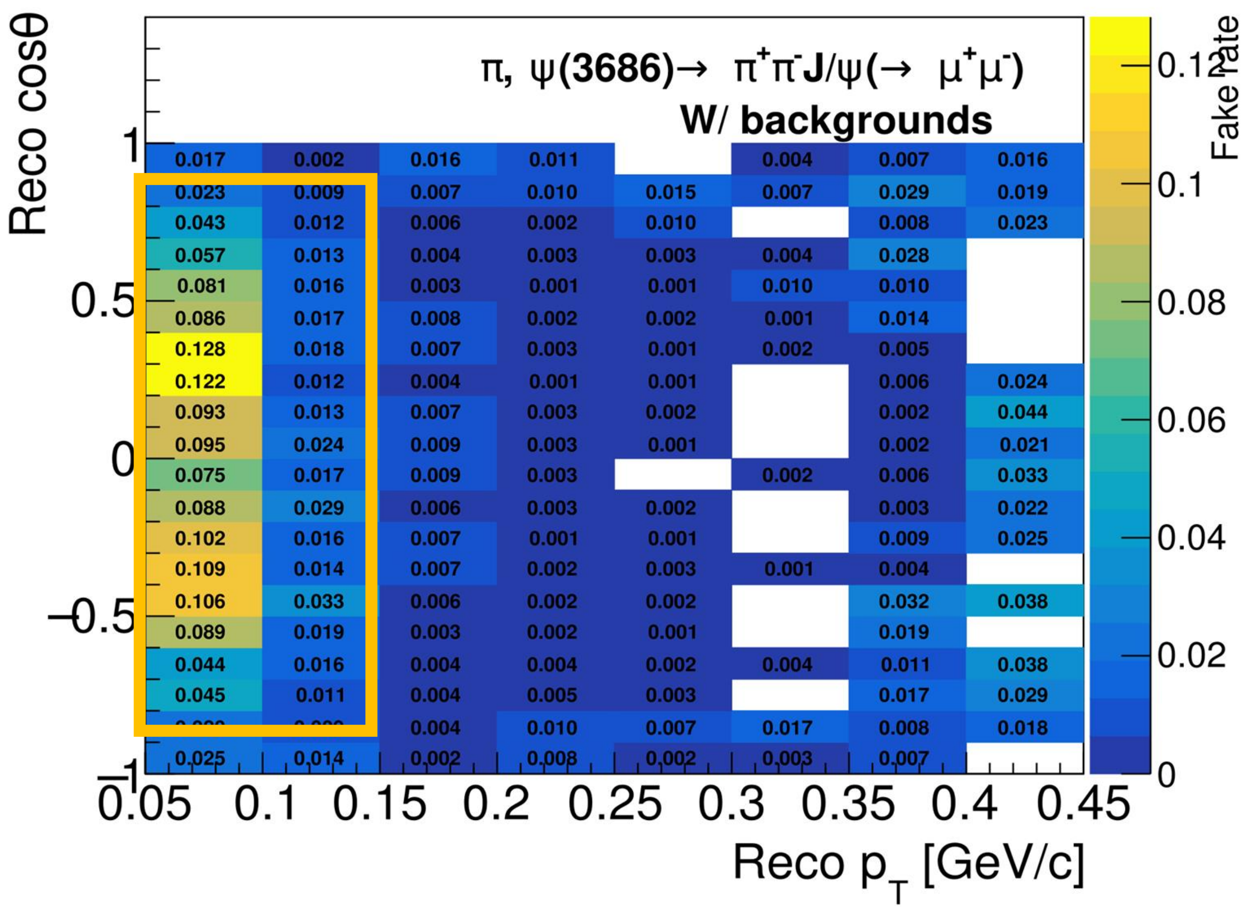
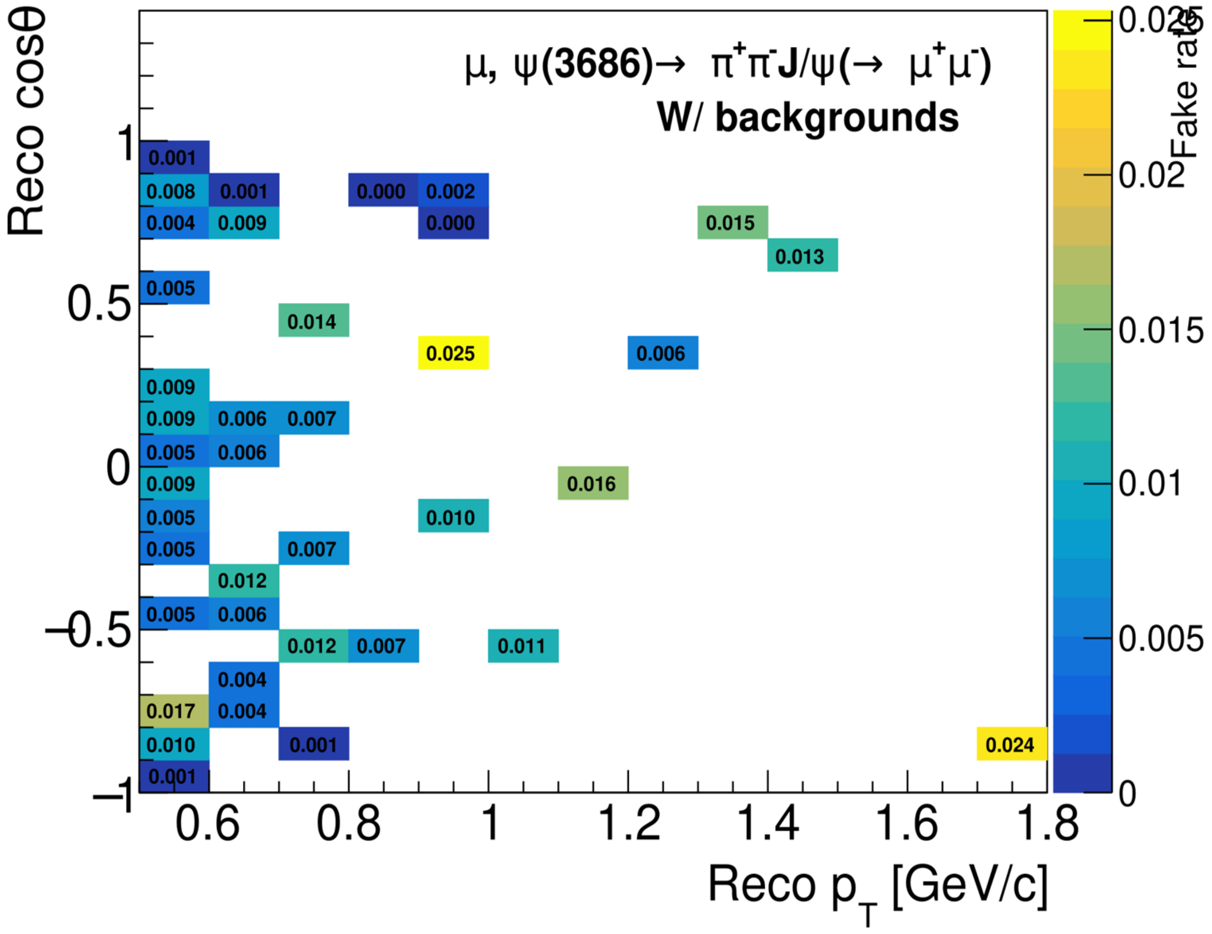
Track requirements: nHits>=5, matchingProb > 0.5

Tracking fake rate

- Almost zero fake rates W/O backgrounds → become non negligible W/ backgrounds





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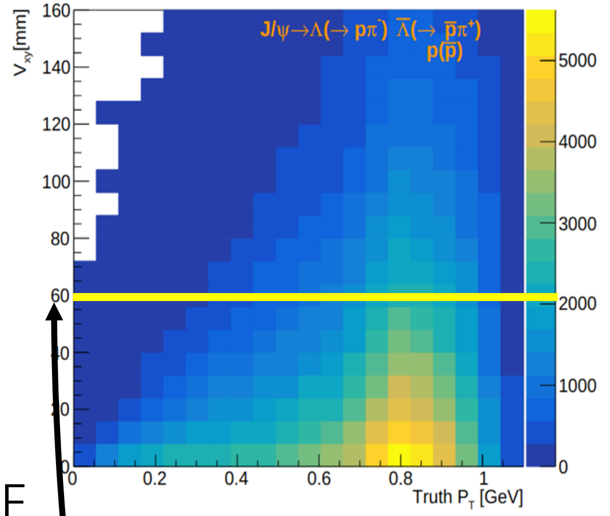
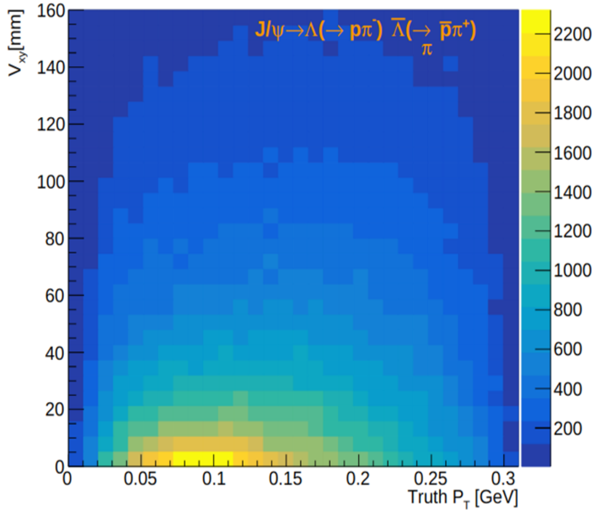
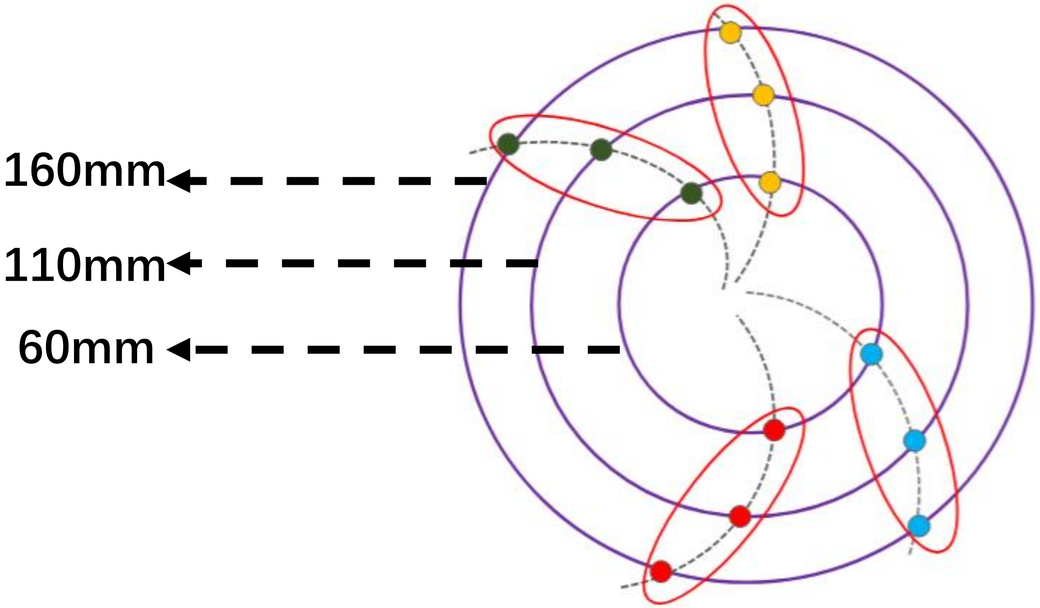
Long-lived particles on STCF





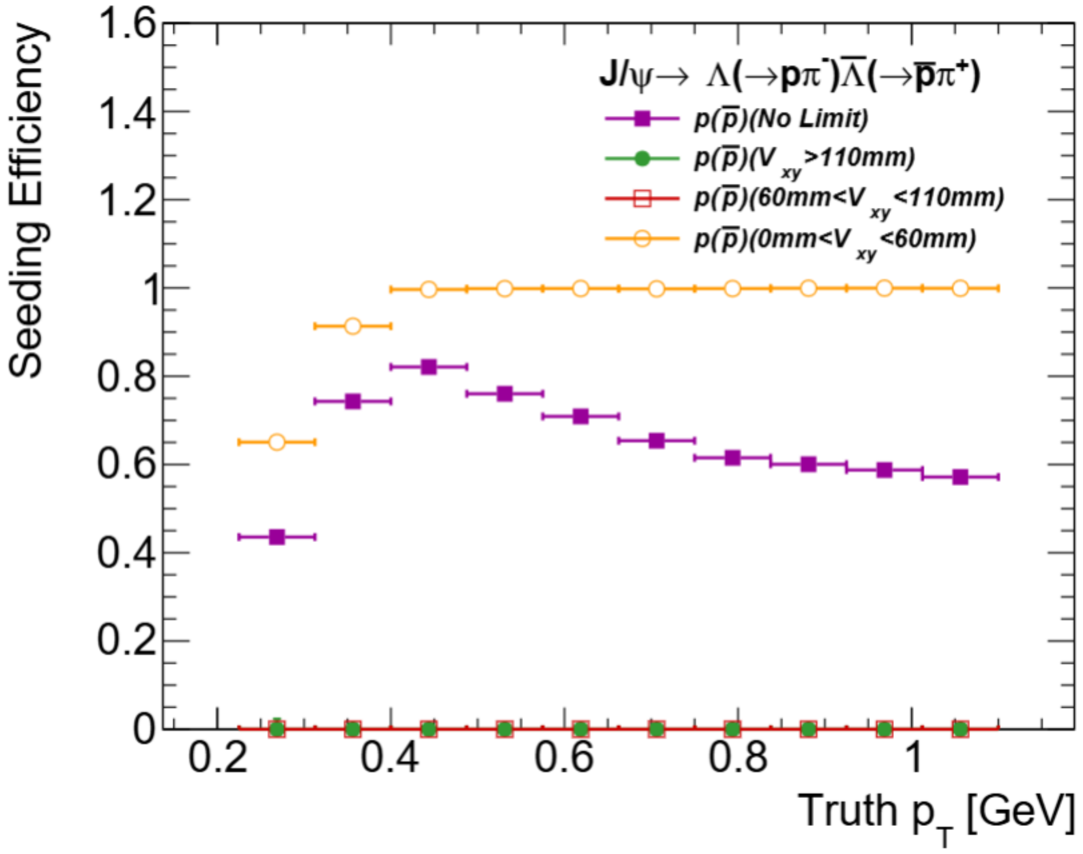
- Long-lived particles, e.g. the lambda baryon, may decay within or outside the inner tracker hence leaving very limited number of hits at the ITK of STCF

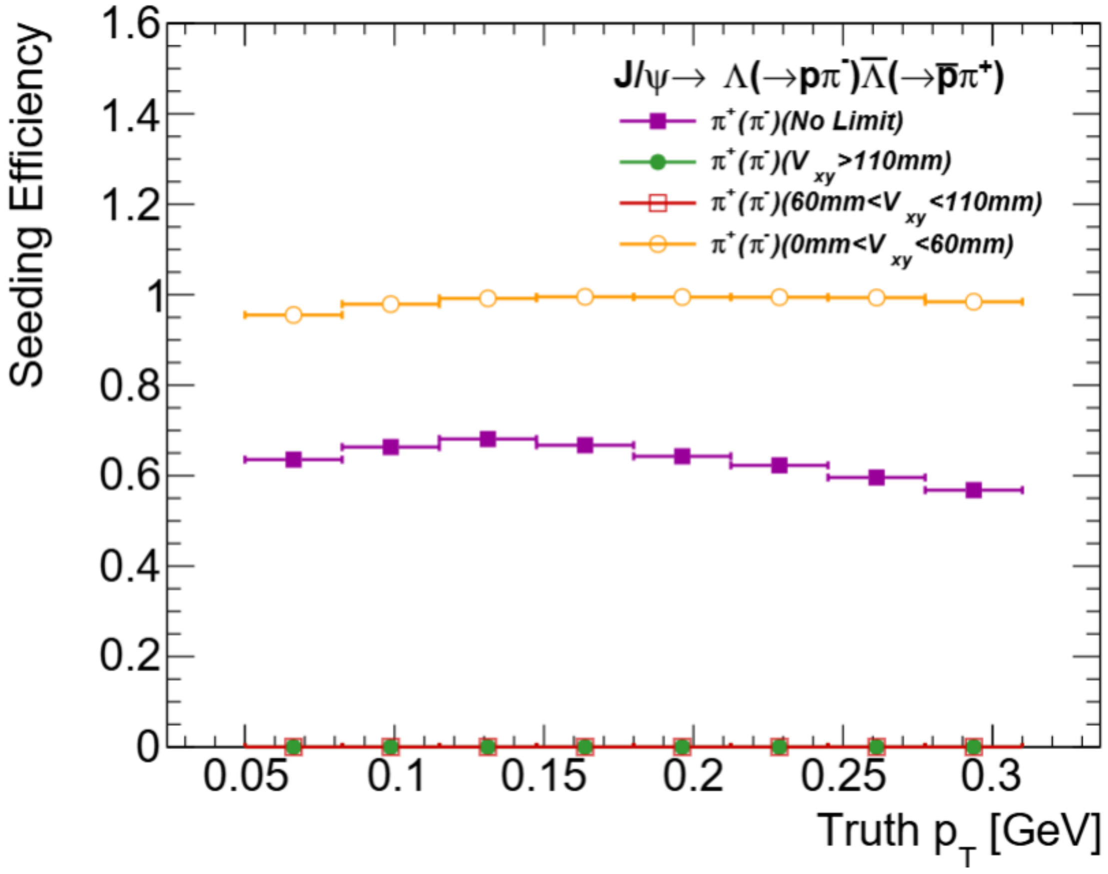
- Reconstruction of long-lived particles is difficult and challenging



ACTS seeding efficiency for long-lived particles

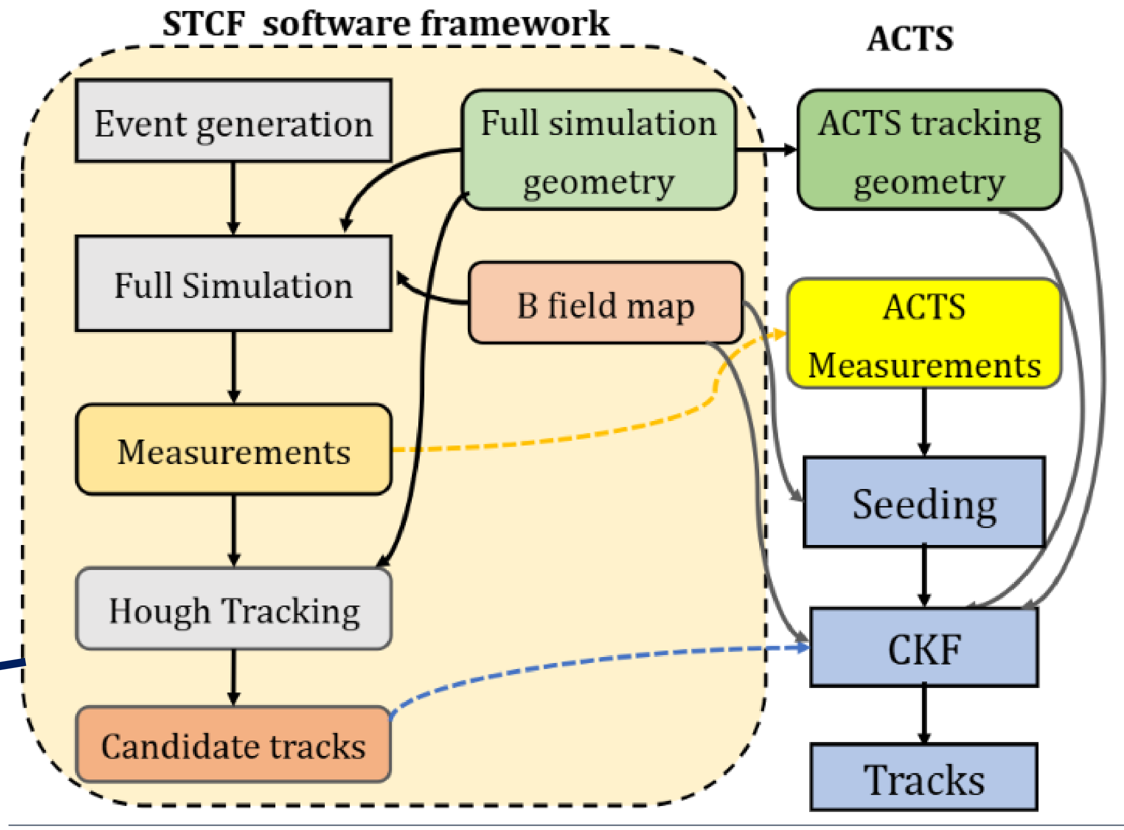
- ACTS seeding efficiency approaches 100% when the vertex displacement of particles is below 60 mm
- ACTS seeding efficiency drops to 0% if displacement exceeds 60 mm

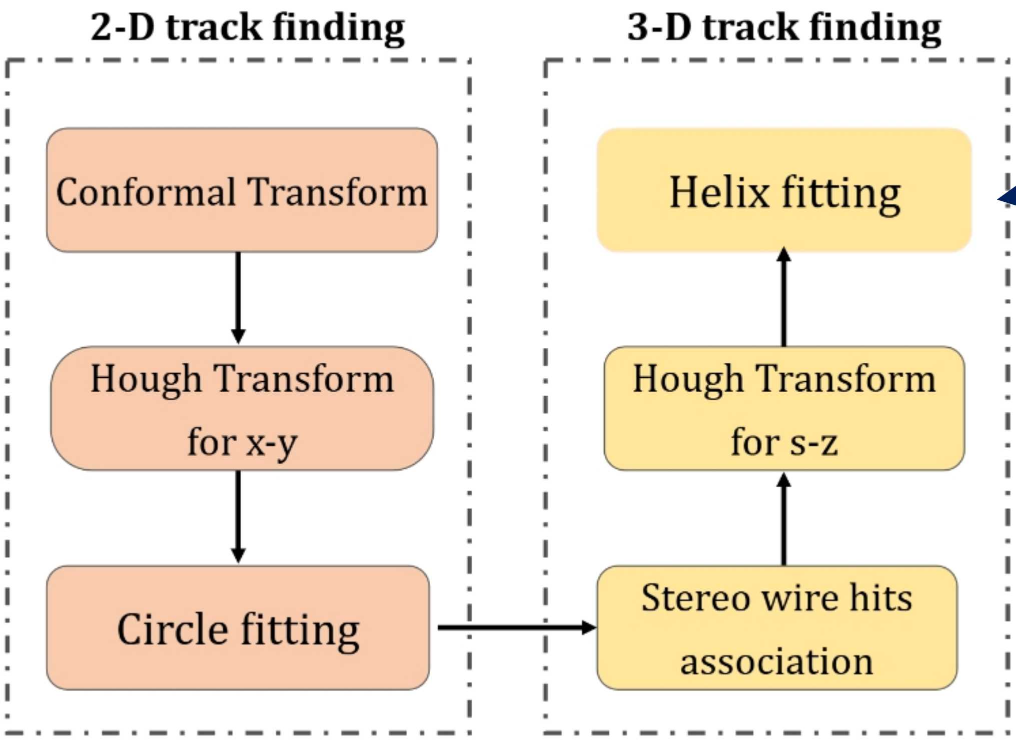




Tracking strategy for long-lived particles

- Hough Transform is used to find tracks at STCF as a global tracking algorithm
- Hough (as seeding) + ACTS CKF is being studied for long-lived particles tracking

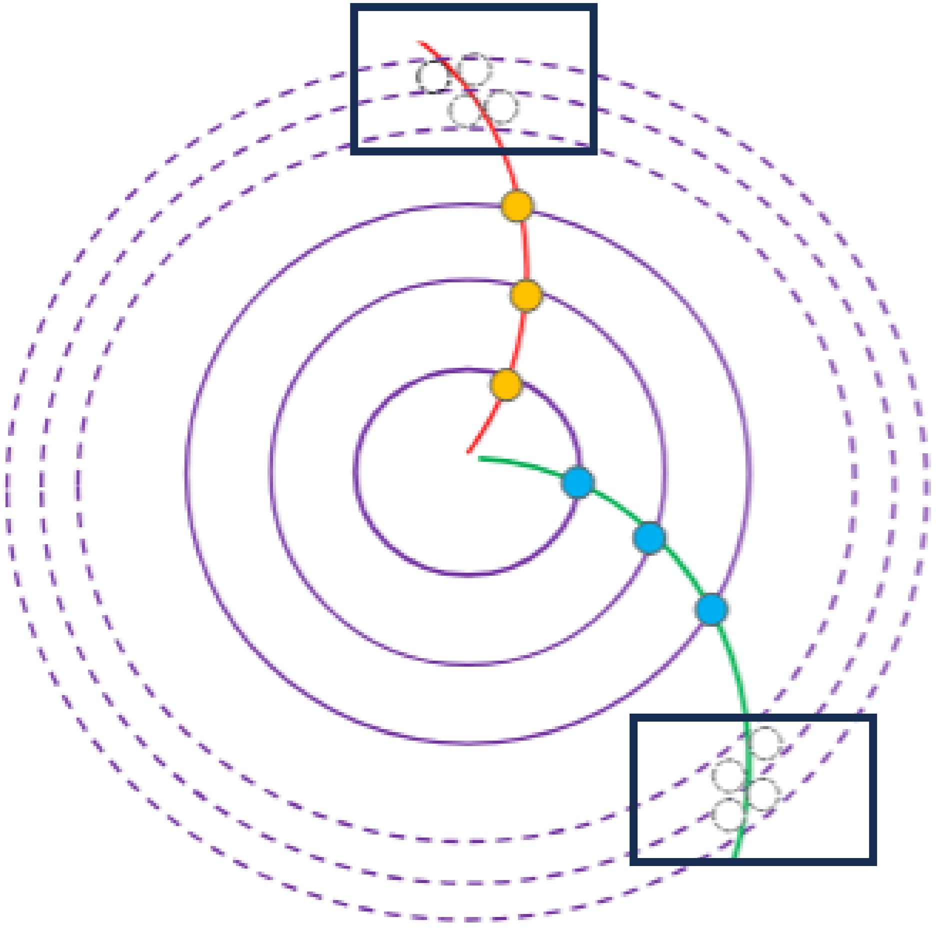




Details about Hough Transform in [Jin Zhang's talk]

CKF for STCF

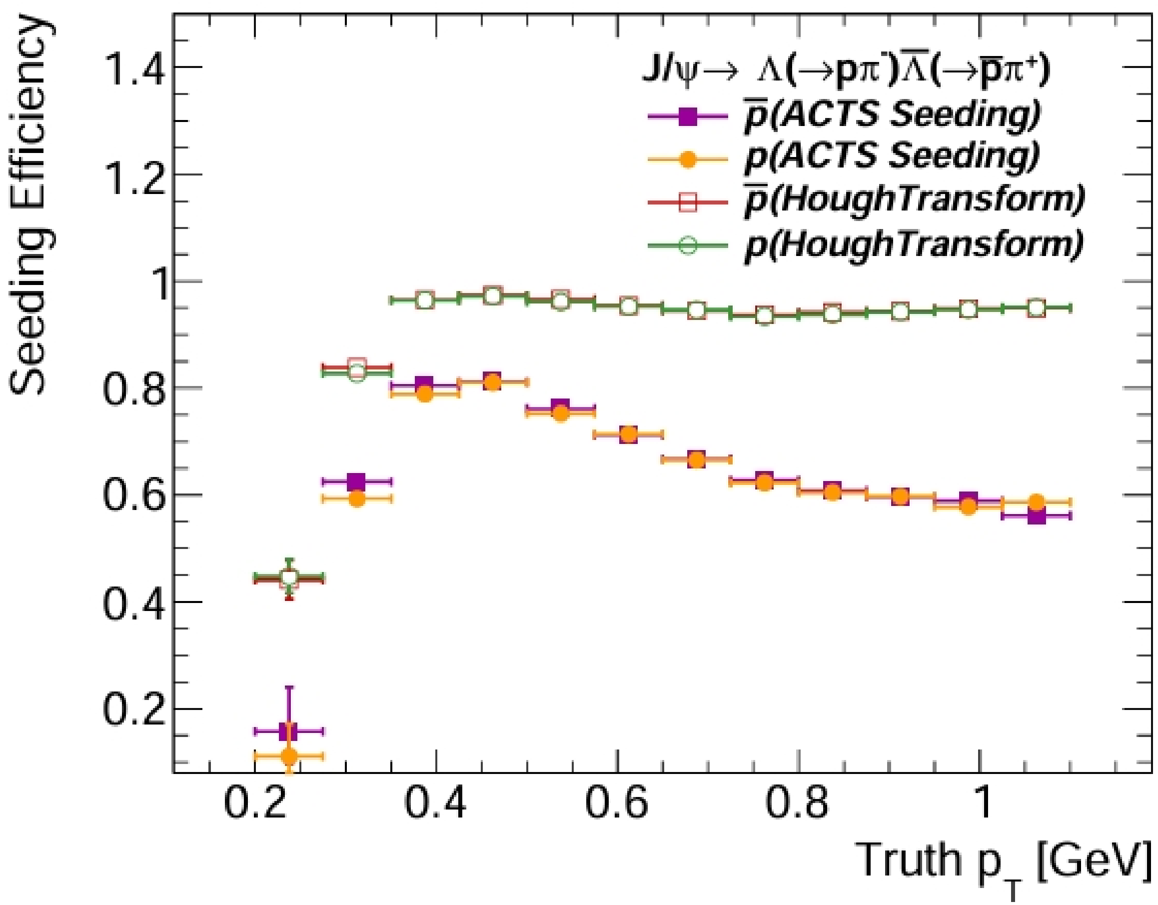
- CKF relies on an initial track seed and a set of measurements associated with the sensitive surfaces of the tracking geometry.
- CKF propagates the track states in the direction of momentum and upon reaching a surface, the CKF searches for compatible measurements.
- Progressingly associate compatible hits to tracks based on prediction χ^2:
  $\chi^2 = r^T(HCH^T + V)^{-1}r$
  – r: residual
  – H: projection from track parameters to measurement
  – V: measurement covariance
- Currently, left/right sign of drift circle is taken to be the same as the predicted track parameters
  – Explosive combinatorics if considering two measurements

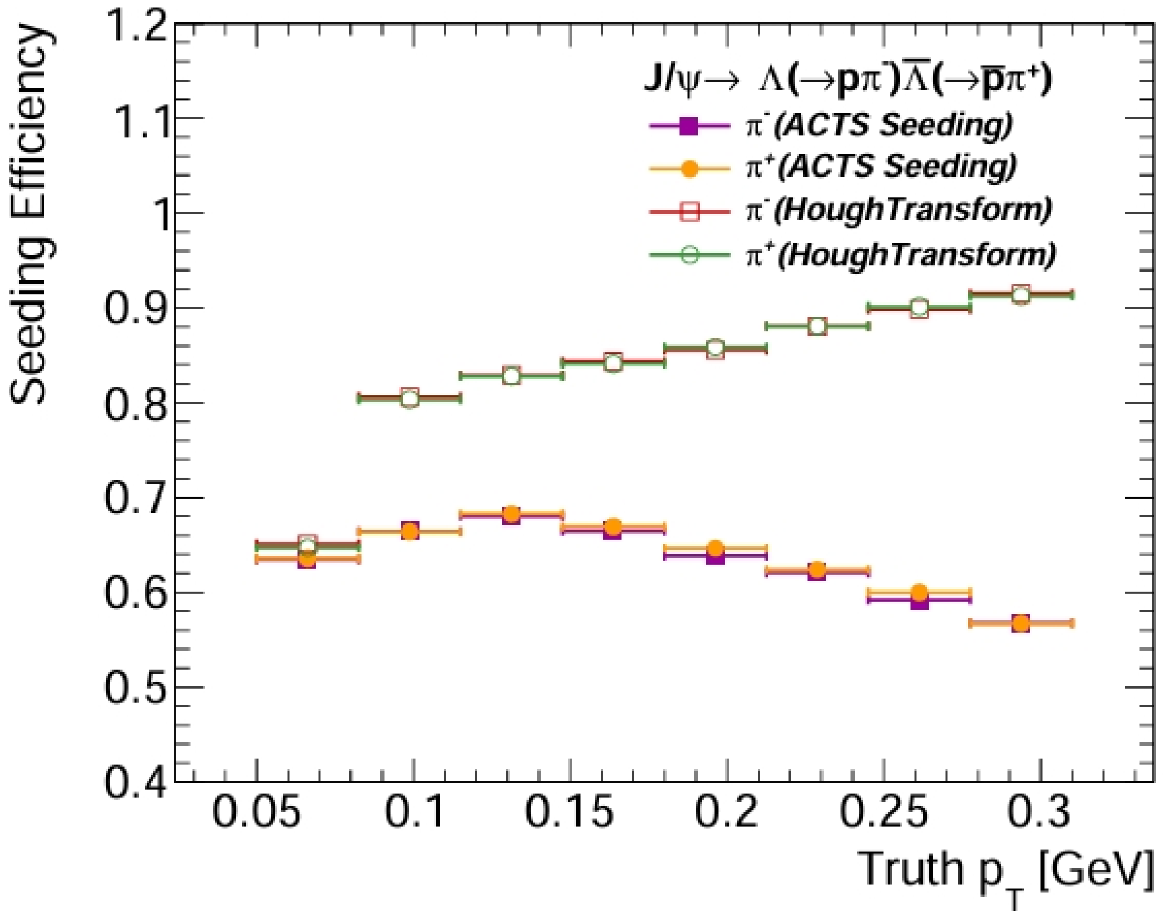


Hough Transform for seeding

For Hough Transform:

- > 90% seeding efficiency for particles **p** with $P_T > 400\text{MeV}$
- > 80% seeding efficiency for particles **π** with $P_T > 100\text{MeV}$



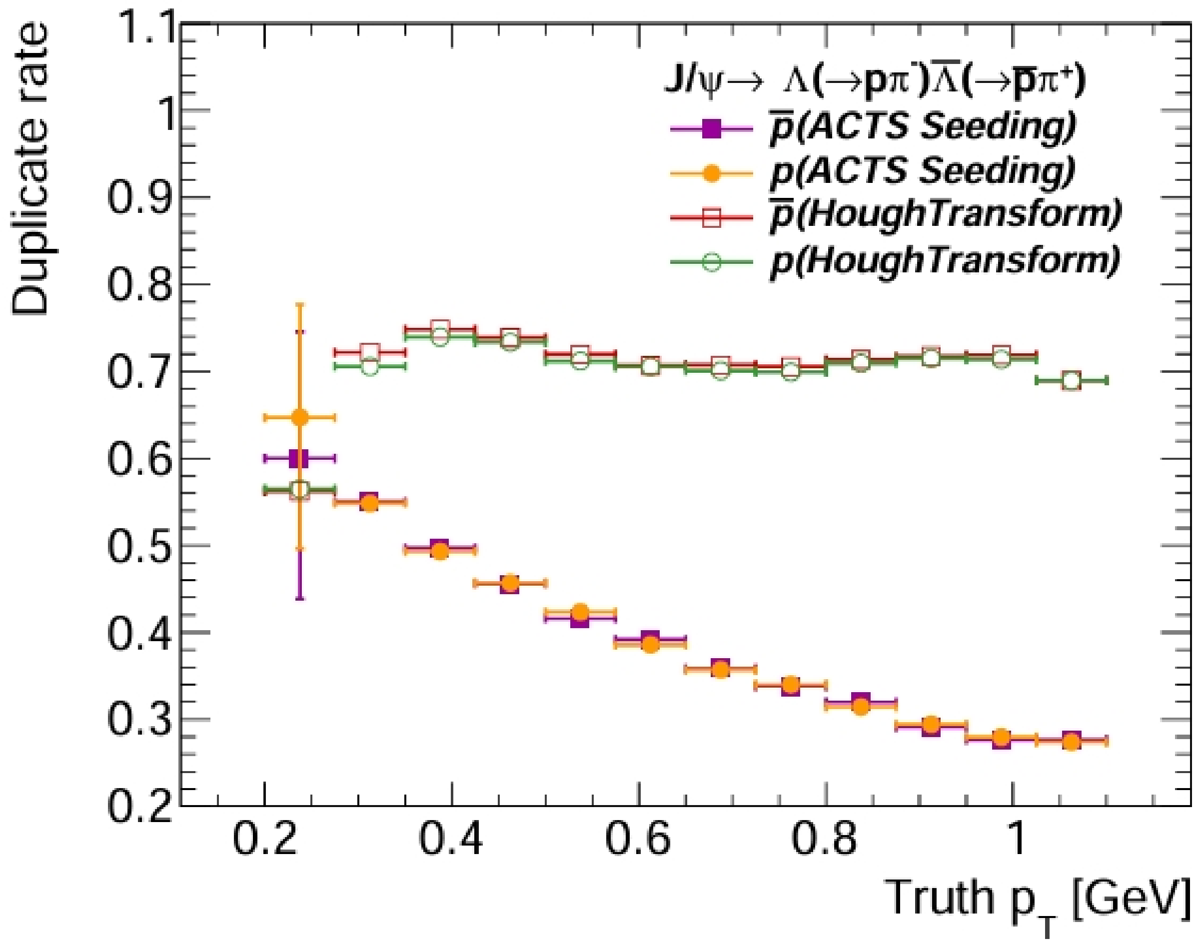


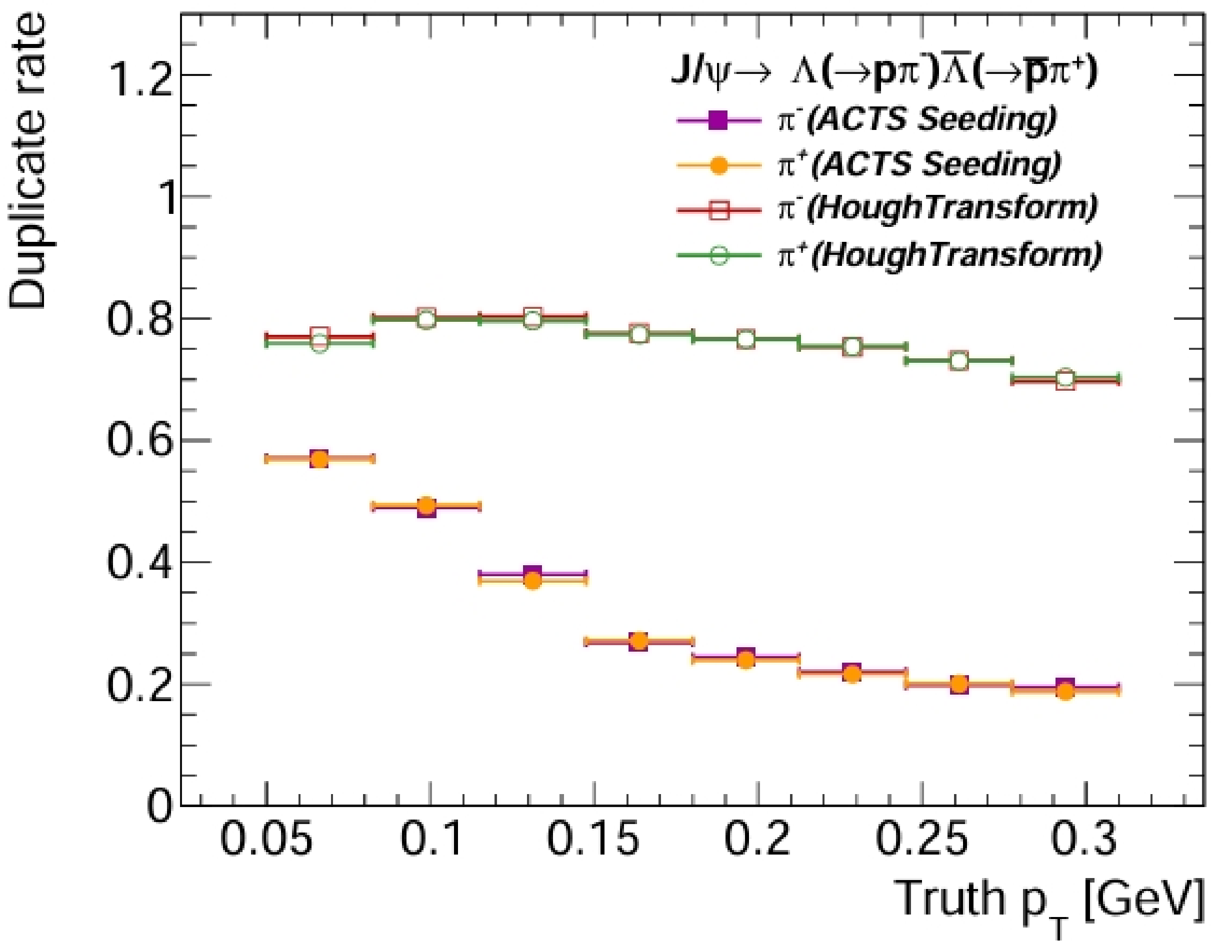
Backgrounds not included

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

Hough Transform for seeding

- Duplicate tracks are retained to ensure an ample supply of seeds for CKF



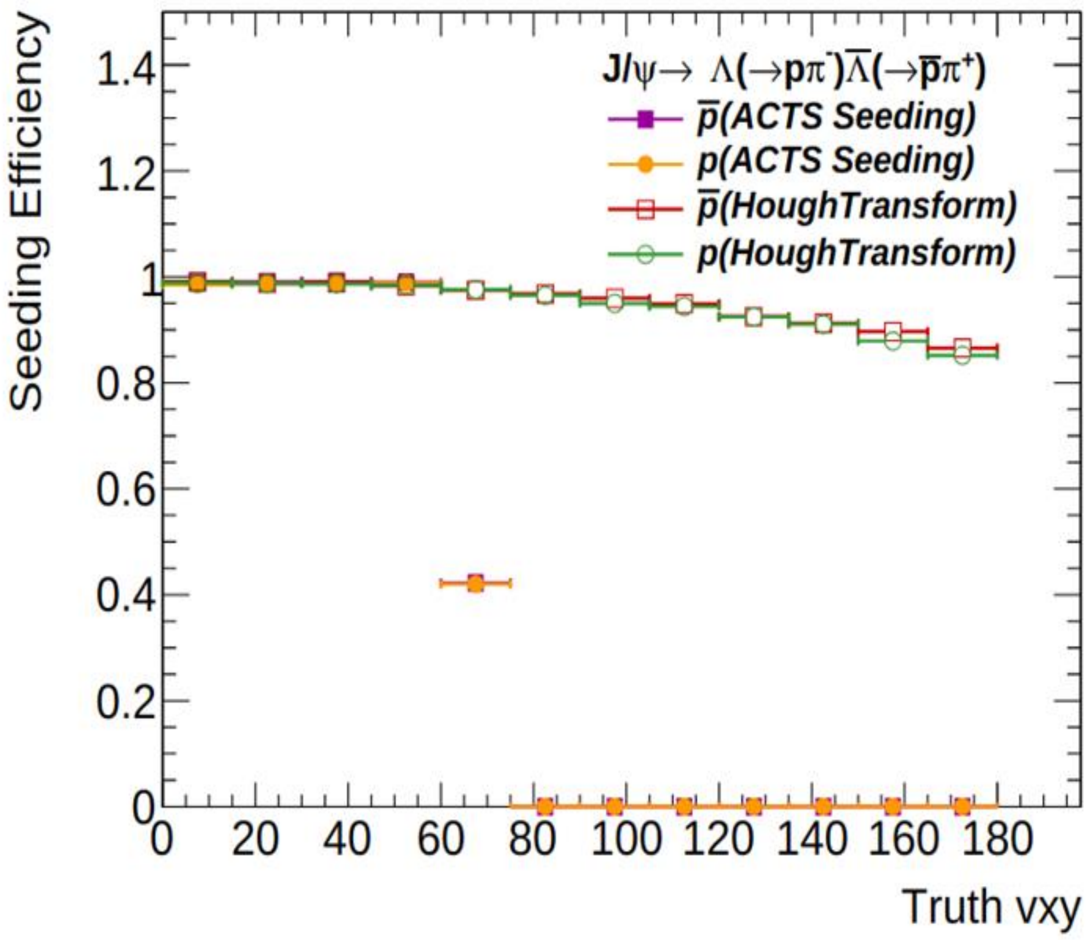


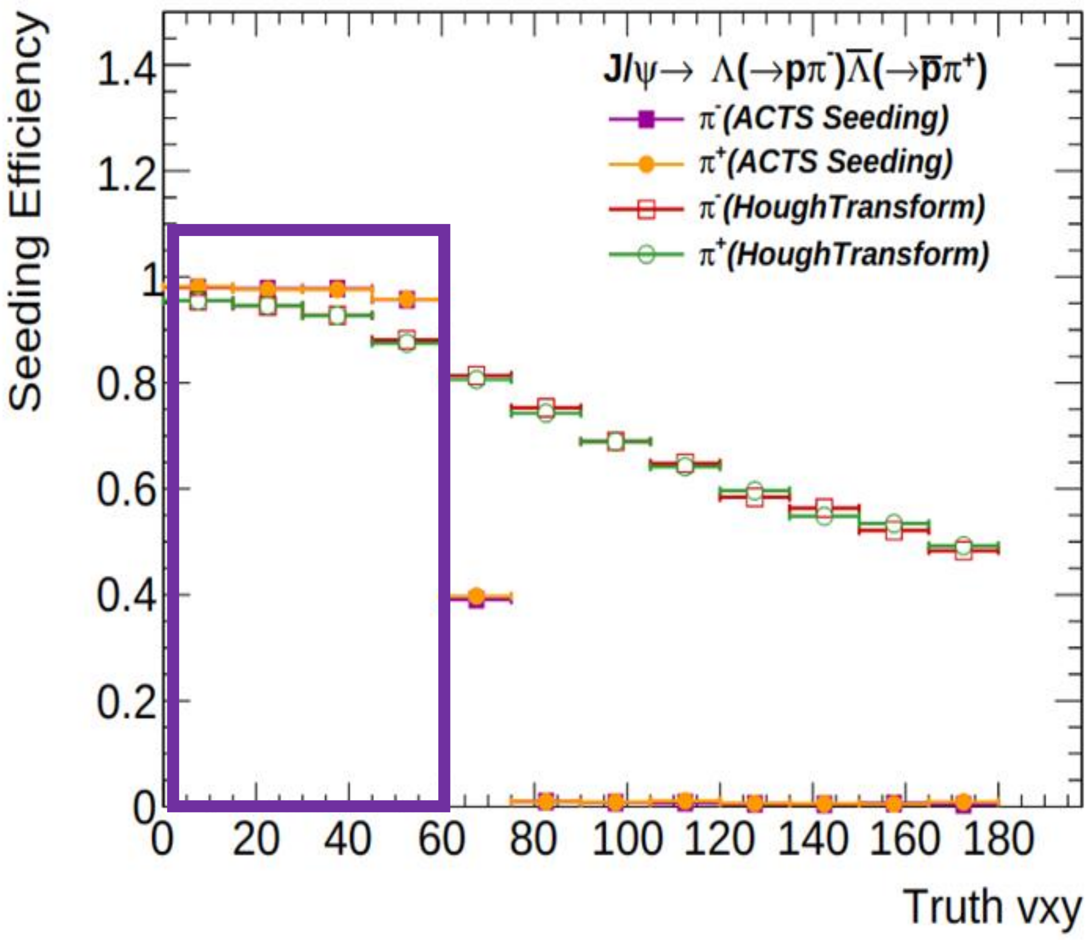
Backgrounds not included

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

Hough Transform for seeding

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





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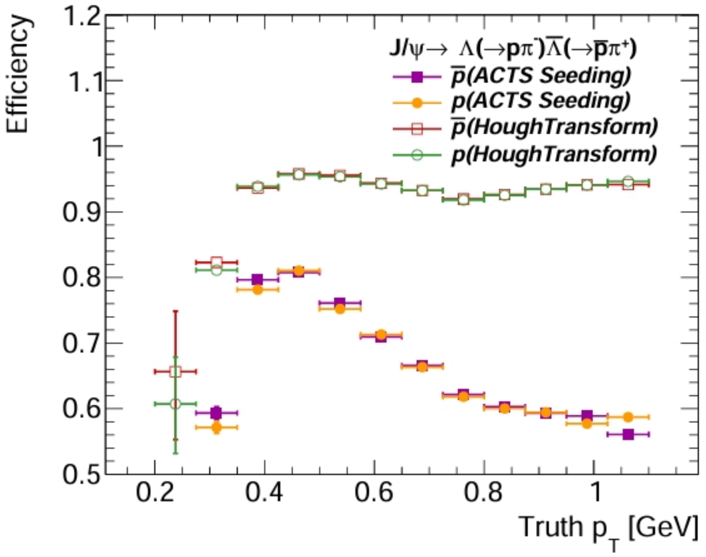
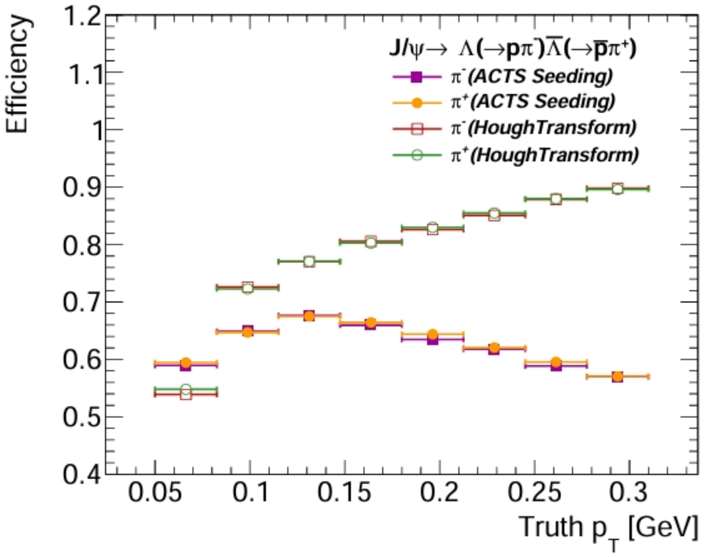
Particle requirements: nHits>=5, |cosθ|<0.94

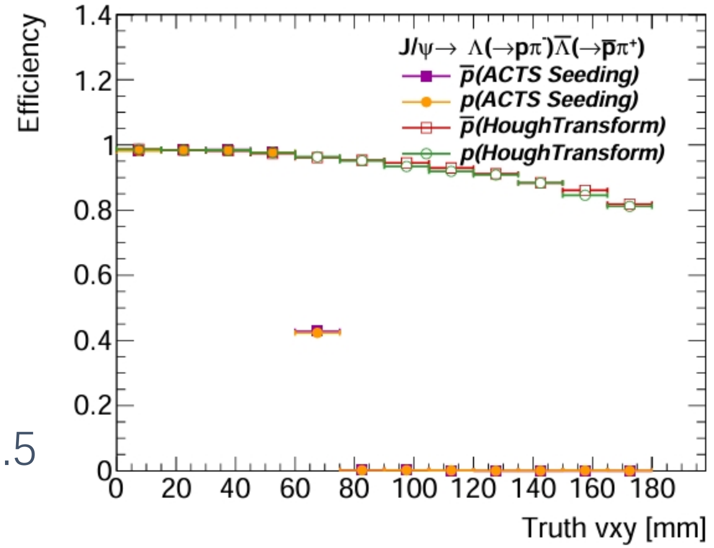
Hough Transform + CKF performance

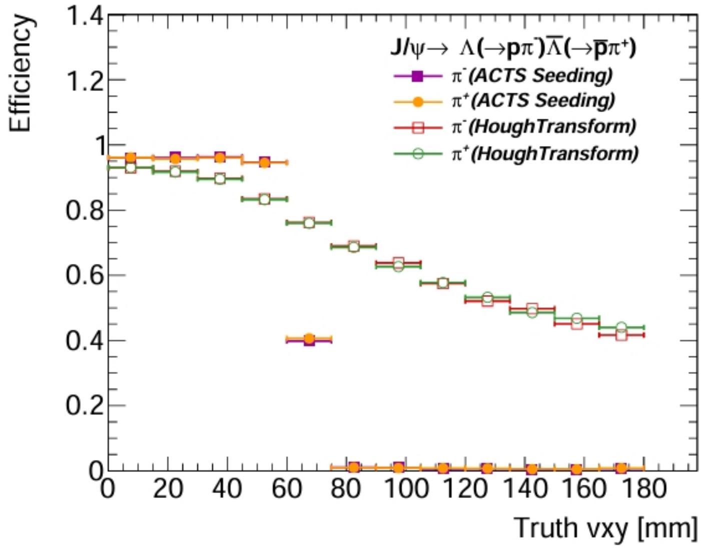
- For Hough Transform+CKF:
  - > 90% tracking efficiency for particles **p** with $P_T > 400\text{MeV}$
  - > 80% tracking efficiency for particles **π** with $P_T > 150\text{MeV}$

- Efficiency loss can be recovered by using Hough as seeding









Particle requirements: nHits>=5, |cosθ|<0.94
Track requirements: nHits>=5, matchingProb > 0.5

Backgrounds not included

Summary

- ACTS has been implemented for track reconstruction at STCF

  – First application and validation of ACTS for a drift chamber
  – 94% tracking efficiency with P_T in [50, 100] MeV

- Hough+CKF in ACTS has been implemented for longlived particles at STCF

  – Above 90% seeding efficiency for particles p with $P_T > 0.4$GeV
  – Above 80% seeding efficiency for particles π with $P_T >0.1$GeV

OutLook

- Optimization of CKF performance for a drift chamber

- Comparison with track finding based on Hough Transform+genfit2

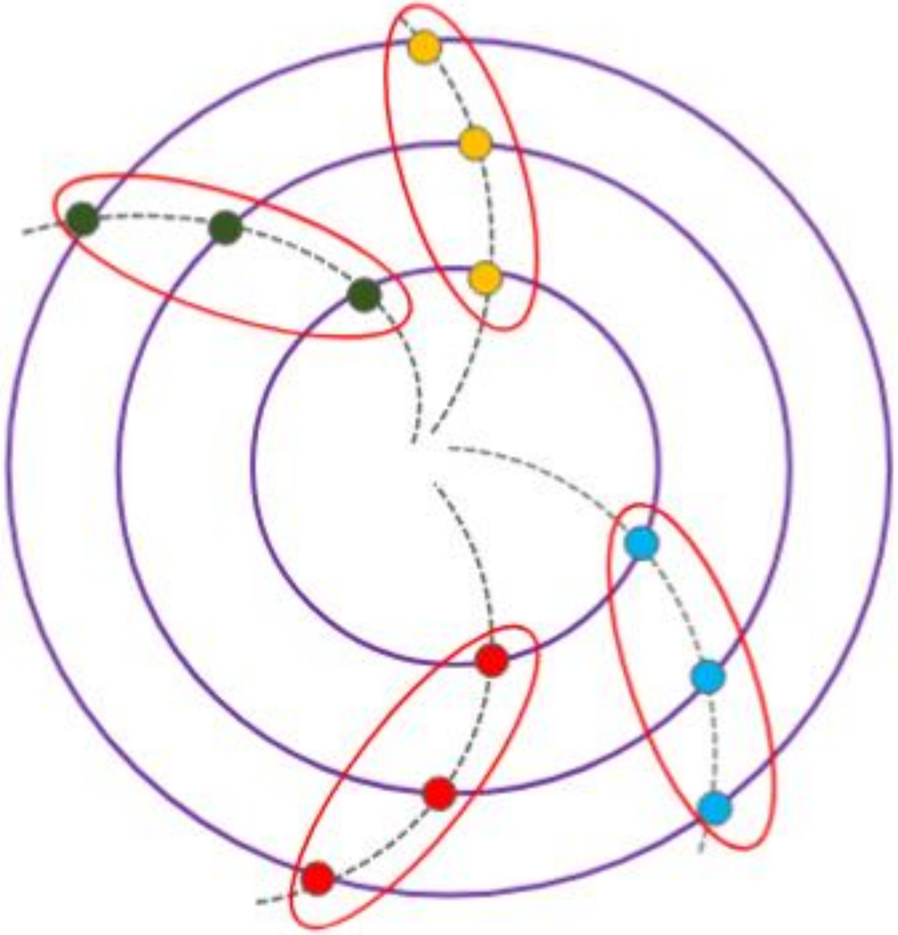
- Investigate ML ambiguity resolver to remove fake/duplicate tracks

Back Up

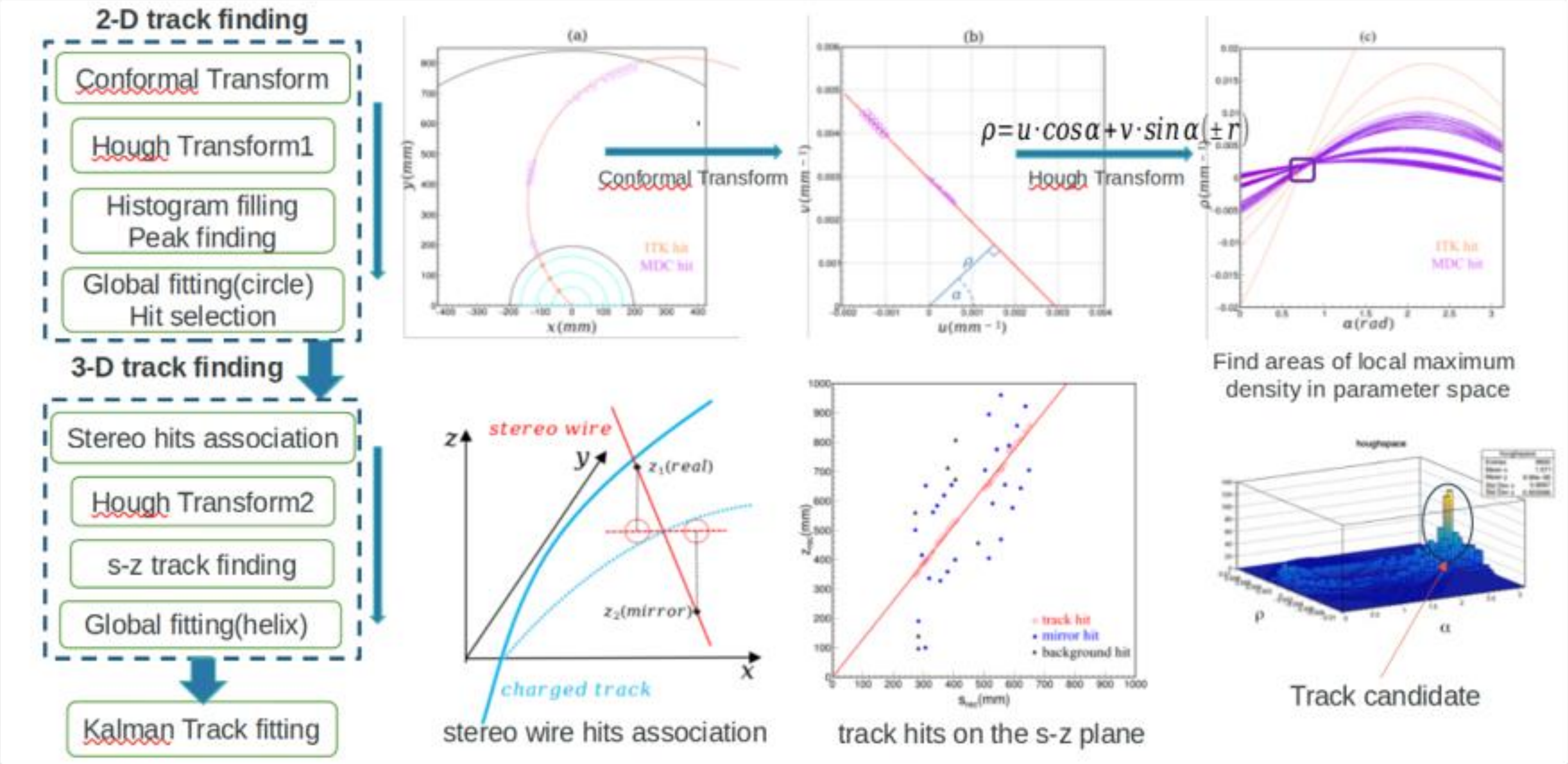
ACTS seeding

- ACTS uses the typical way to create seeds is to combine measurements which finds 3 measurements to describe the helical path of a charged particle .

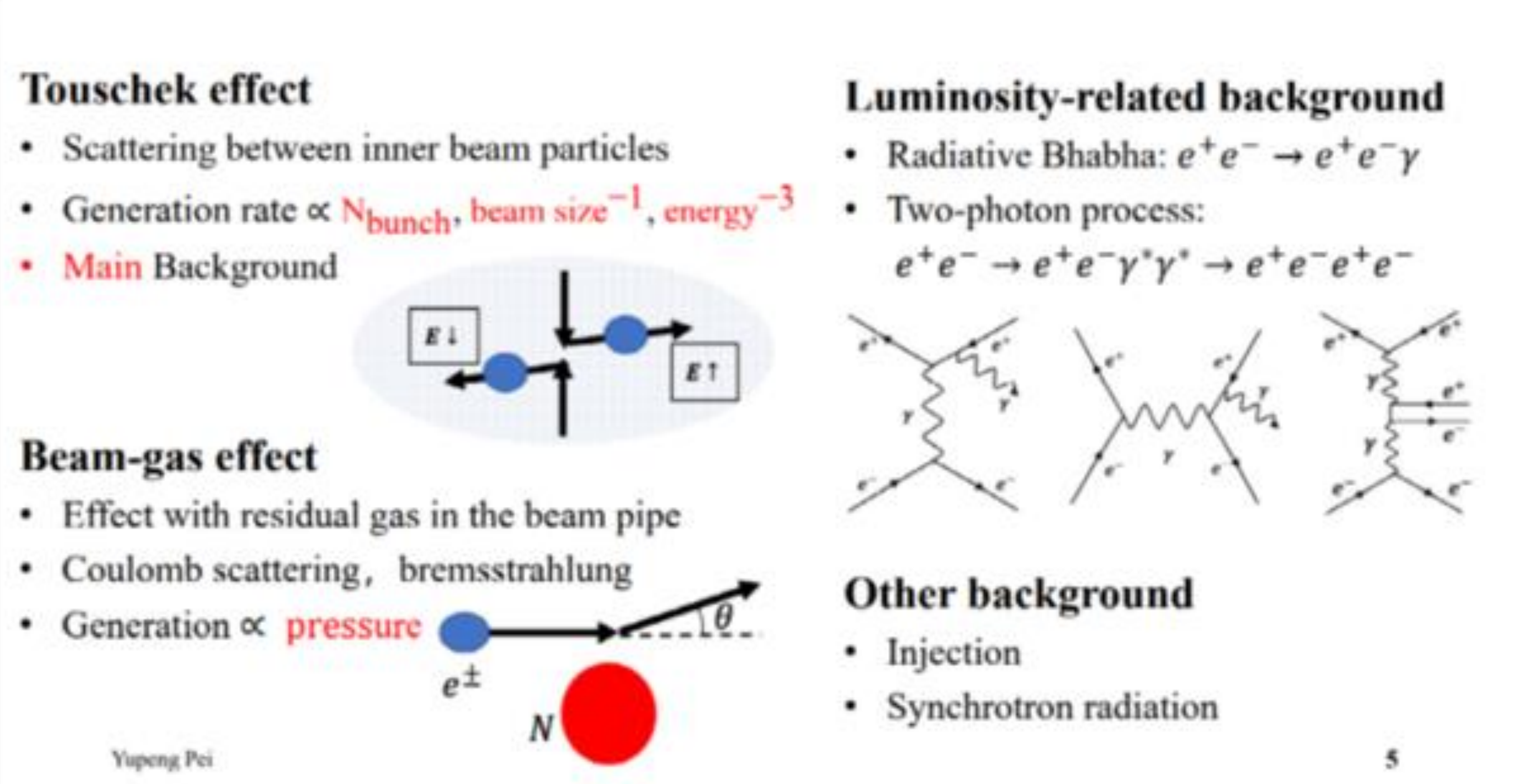
- One such triplet of measurements would then constitute a seed and defines, in close bounds, where the tracking needs to look for additional measurements to create a track spanning the whole detector.

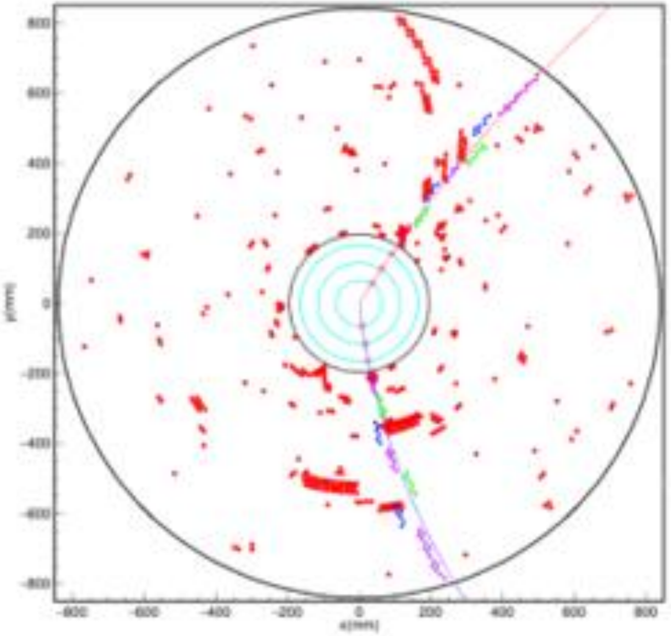


Hough Transform at STCF

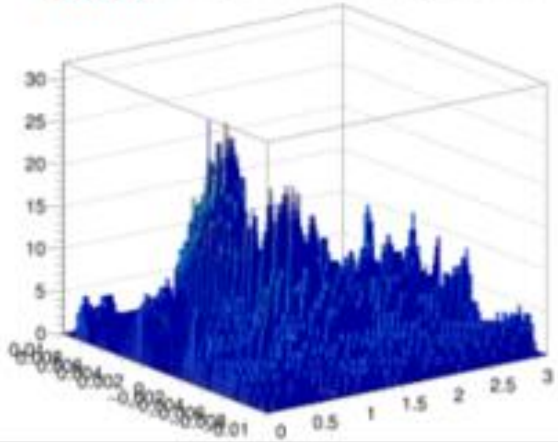


Backgrounds





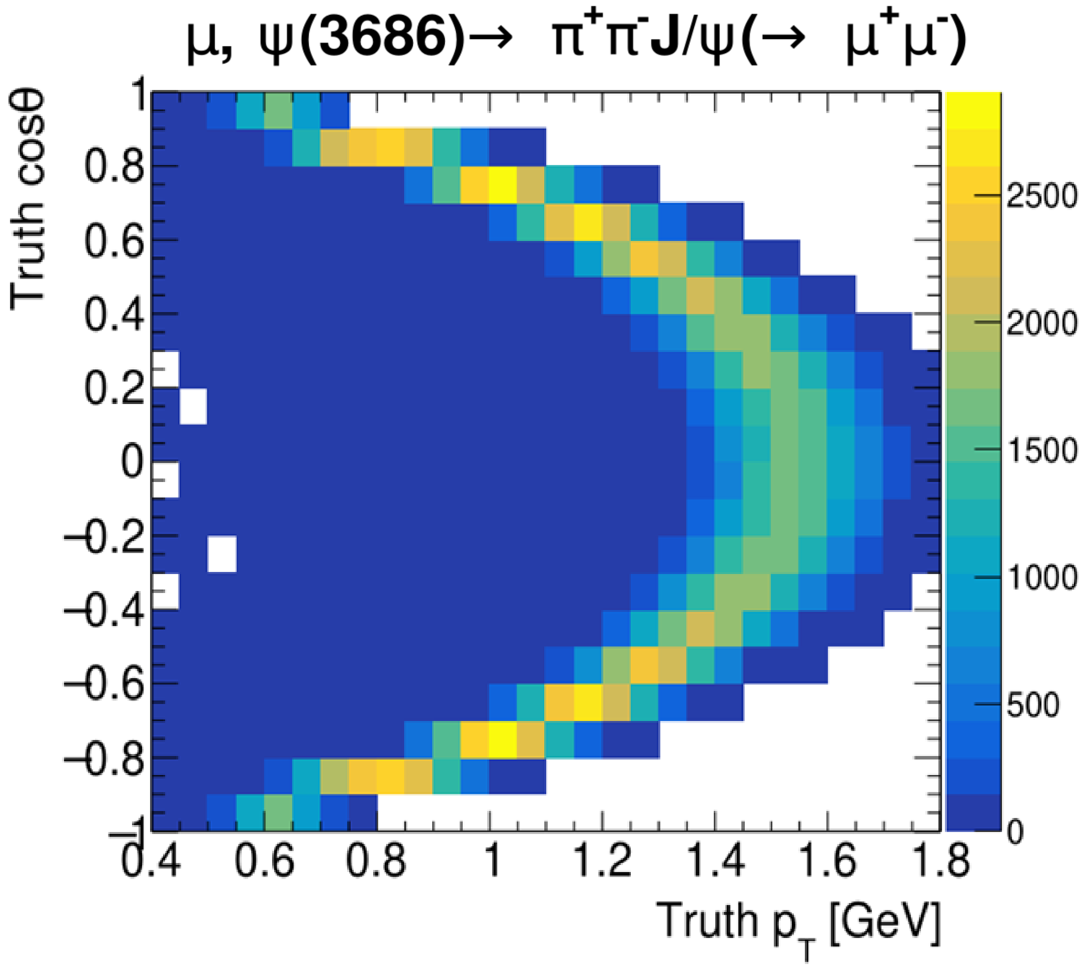
Hough map with background

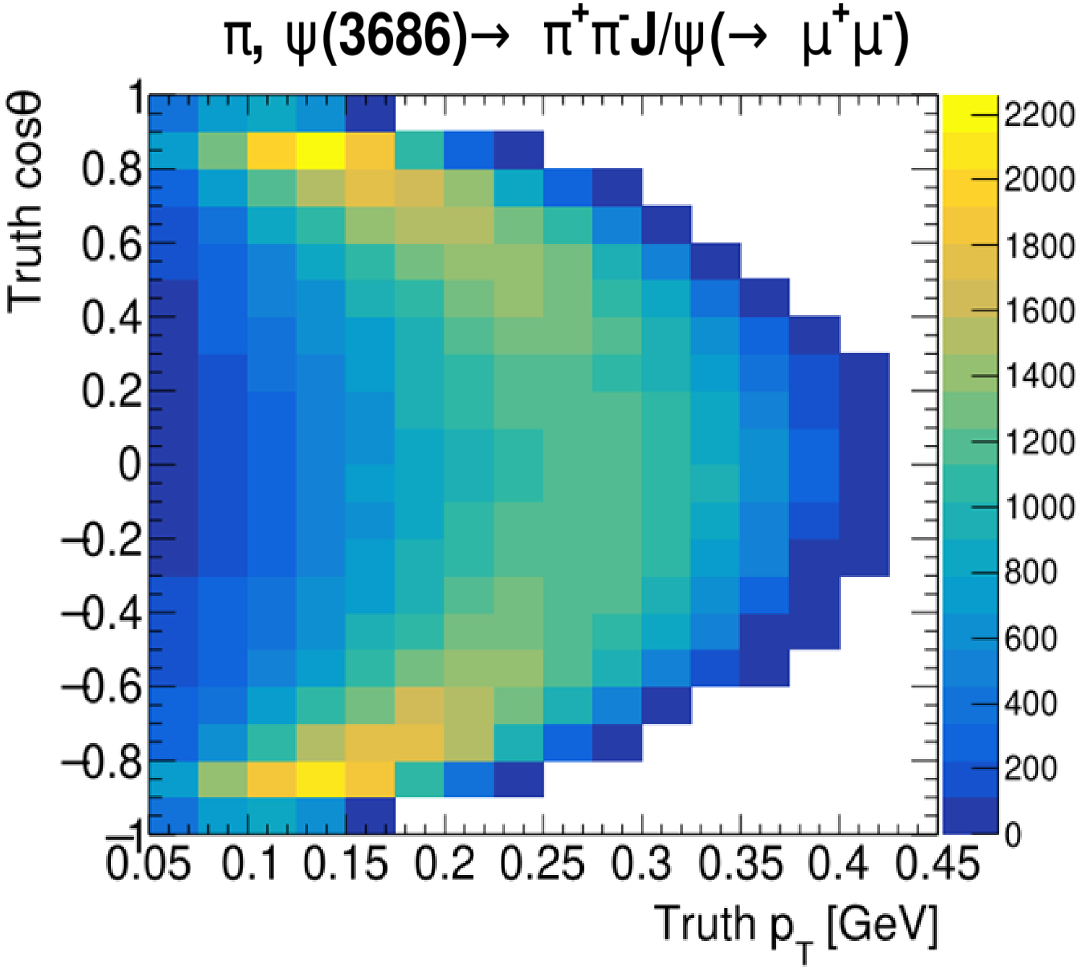


Background hits count per event

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

Particle $COS\theta$ vs P_T





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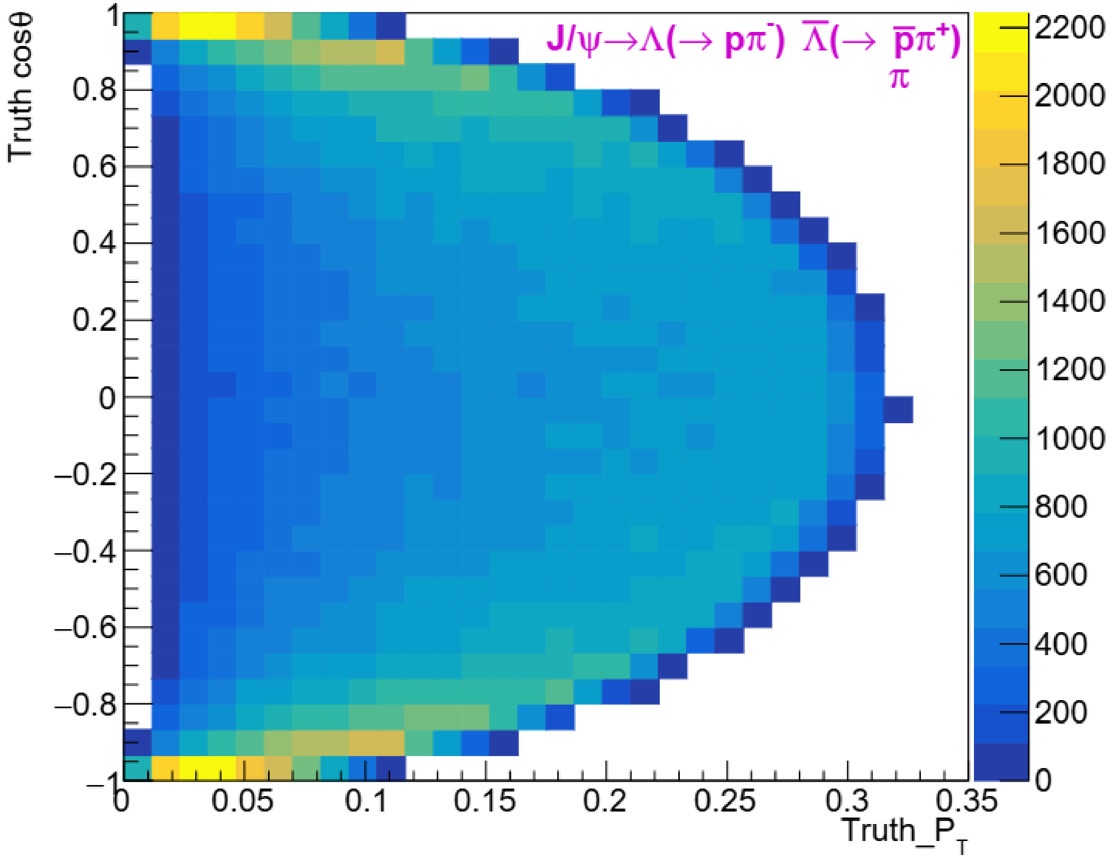
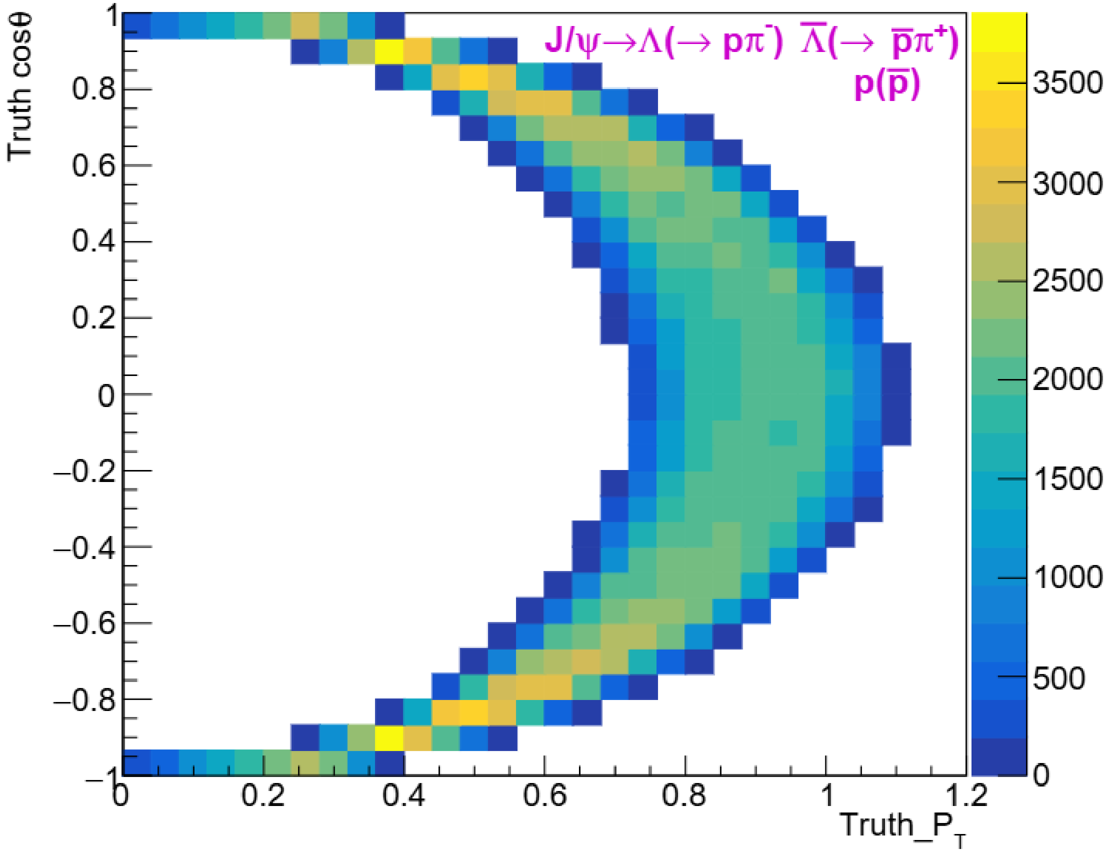




Merits for track finding performance

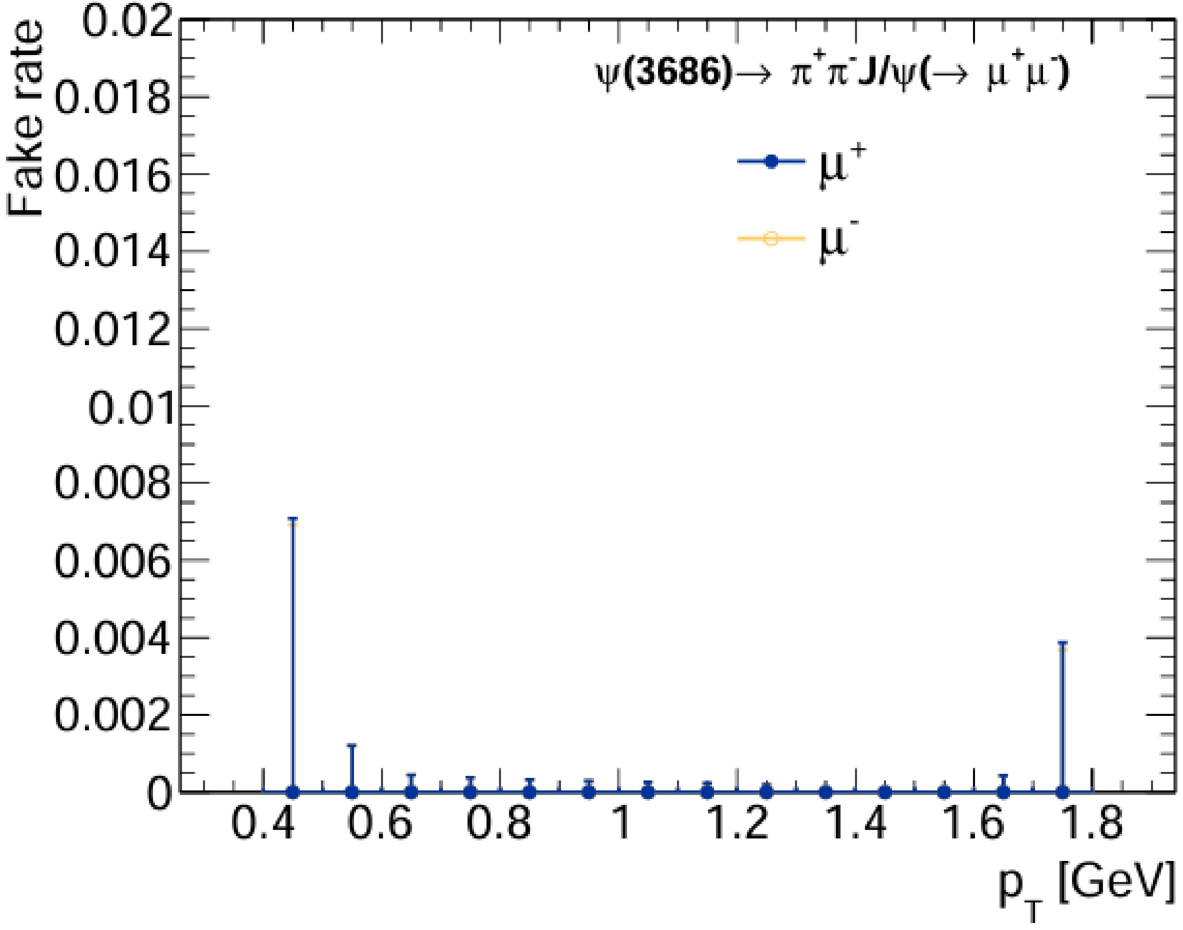
- seeding efficiency: $\frac{N_{seed}(selected,matched)}{N_{truth}(selected)}$
- Track finding efficiency: $\frac{N_{reco}(selected,matched)}{N_{truth}(selected)}$
- Fake rate: $\frac{N_{reco}(selected,unmatched)}{N_{truth}(selected)}$
- Duplication rate: $\frac{N_{reco}(selected,matched,duplicated)}{N_{truth}(selected,matched)}$

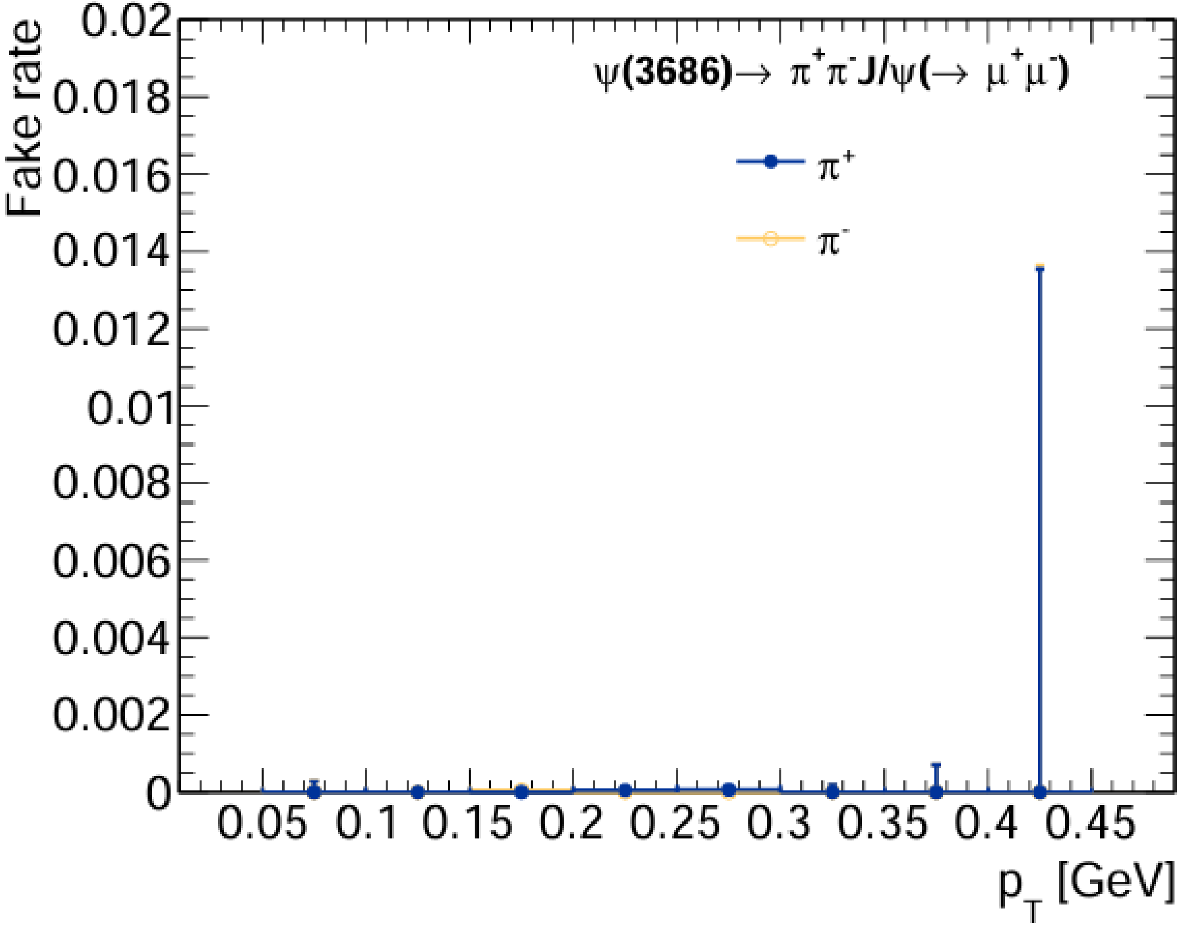
➔Reco-truth matching: $\frac{N_{hits}(Majority)}{N_{hits}(Total)}$ >0.5

➔ Simple track selection: N_{hits} >=5

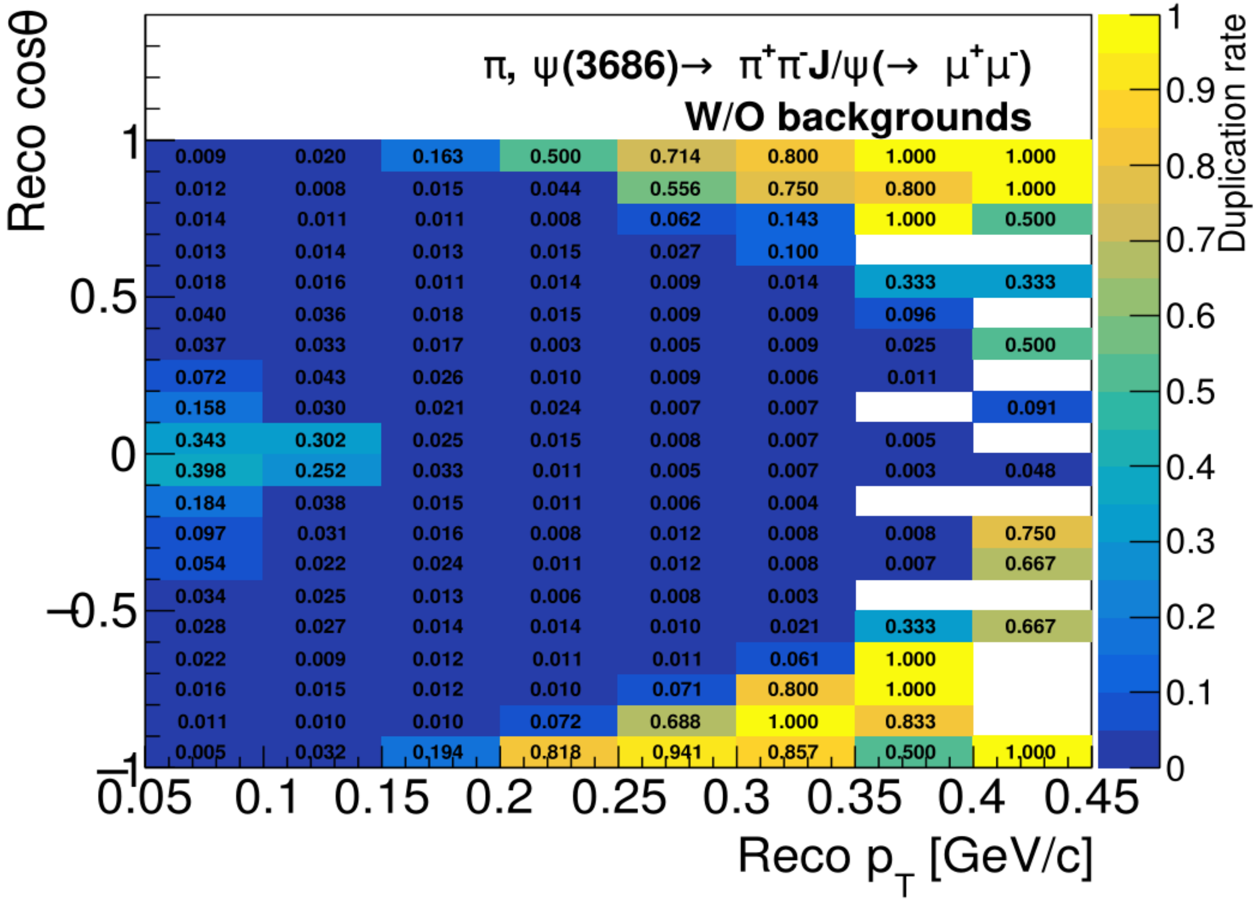
➔ Theta cut:20°<theta<160°

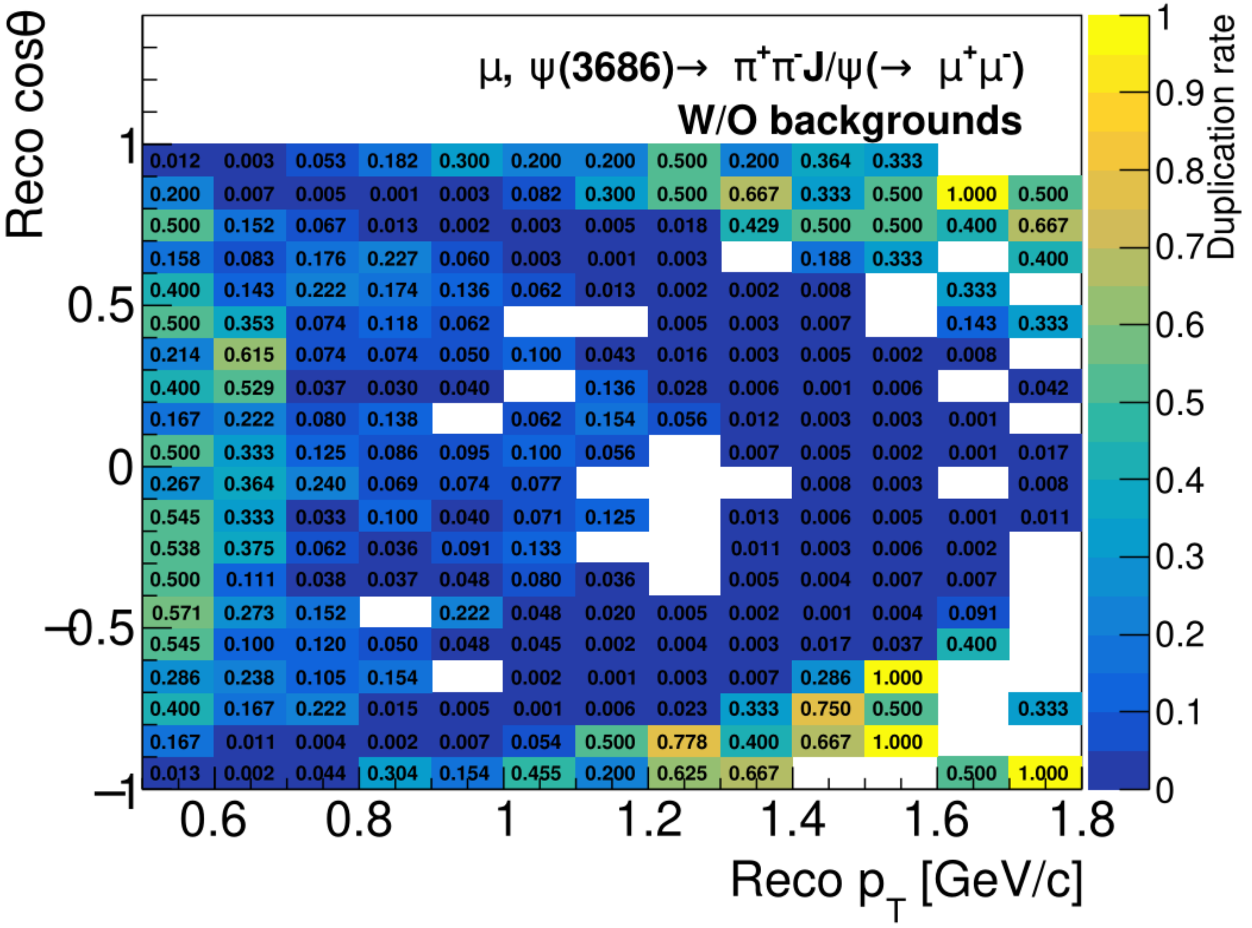
Tracking fake rate without Backgrounds





Duplicate rate without backgrounds





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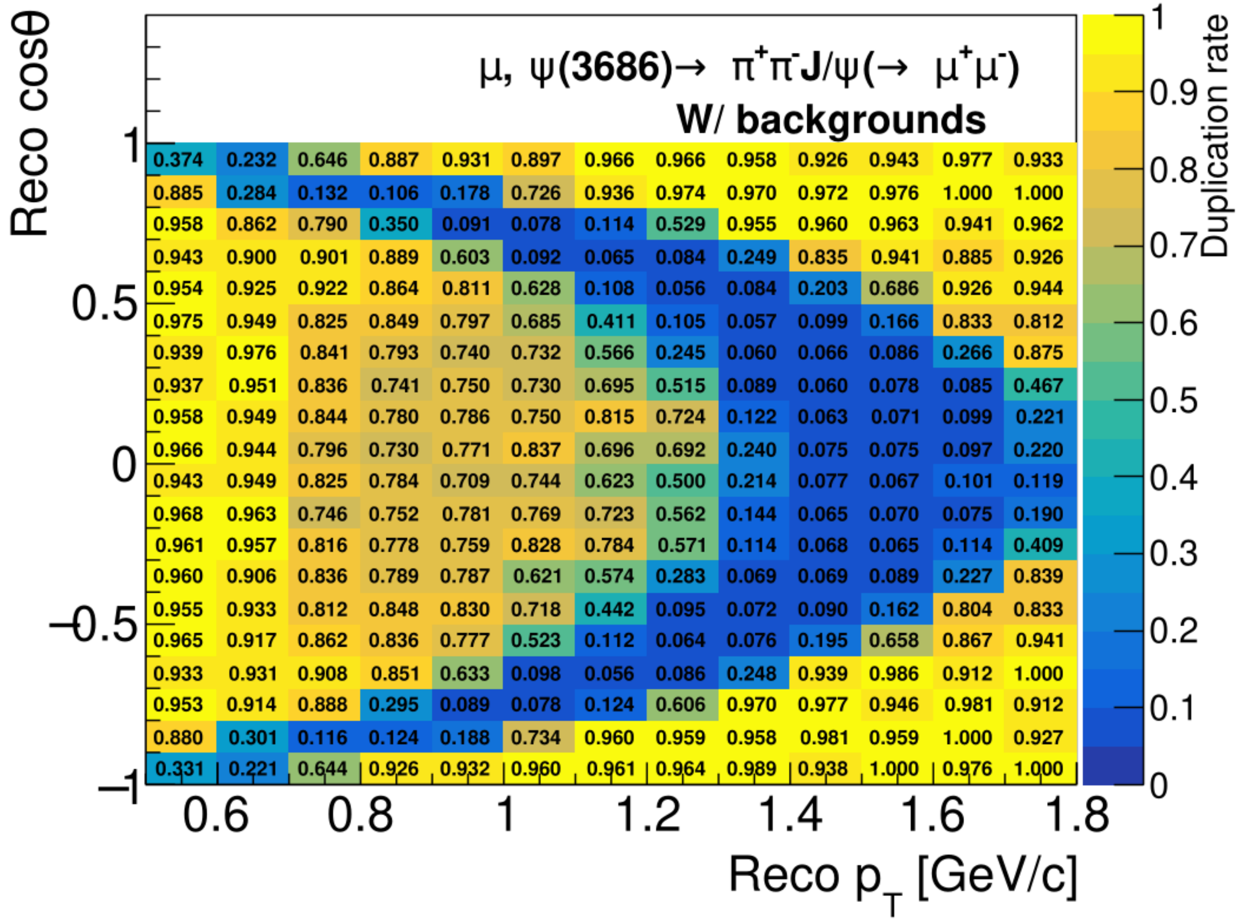

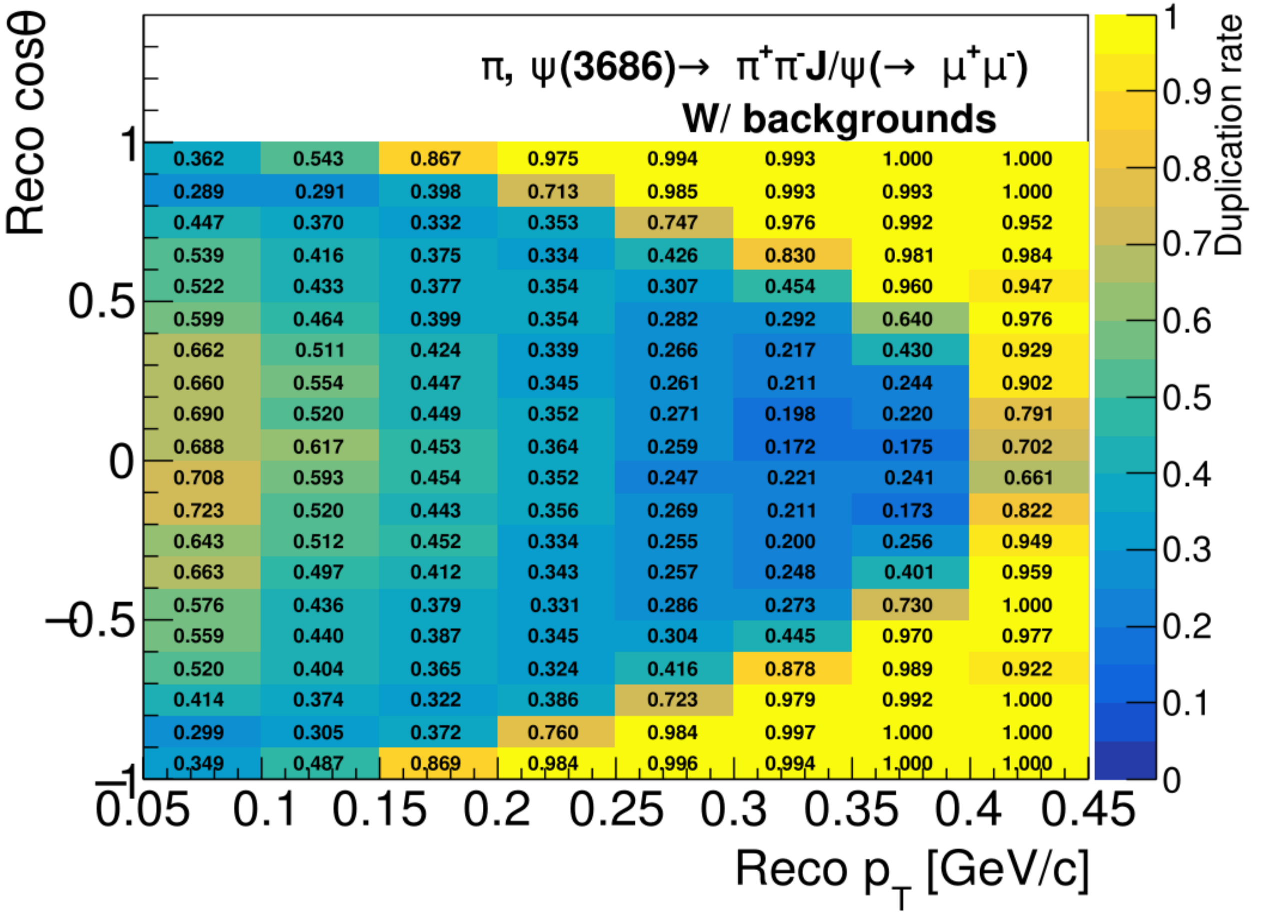

Duplicate rate and fake rate for long-lived particles $\boldsymbol{P_T}$