
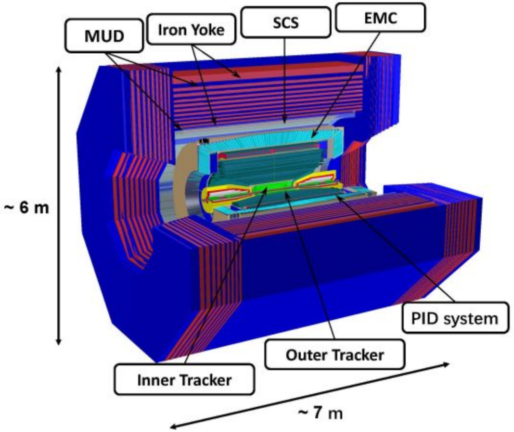


# STCF tracking with ACTS

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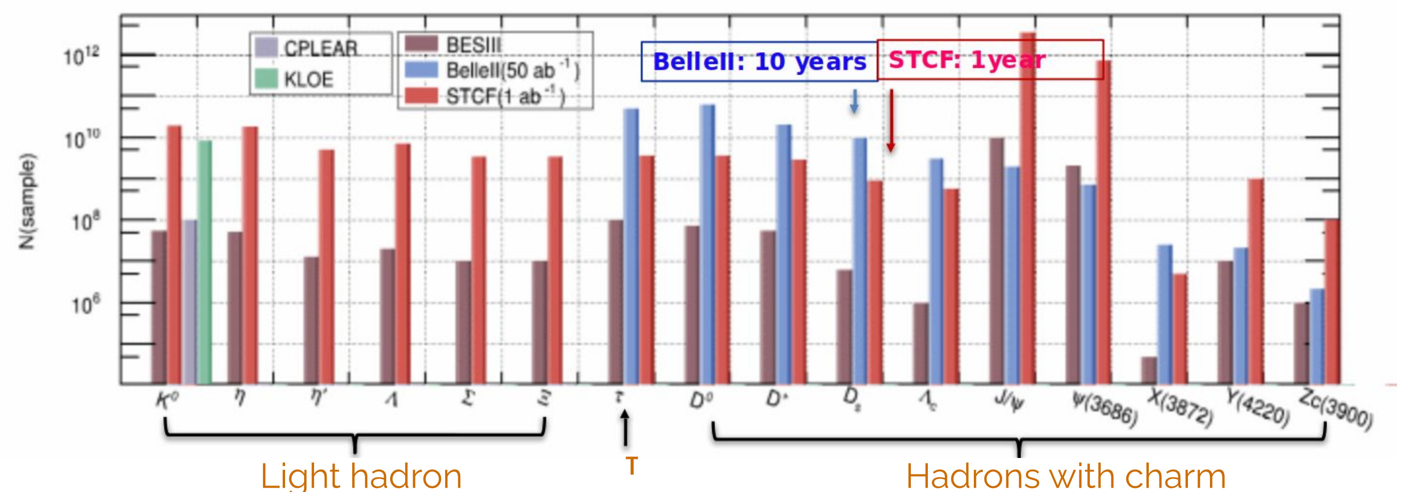
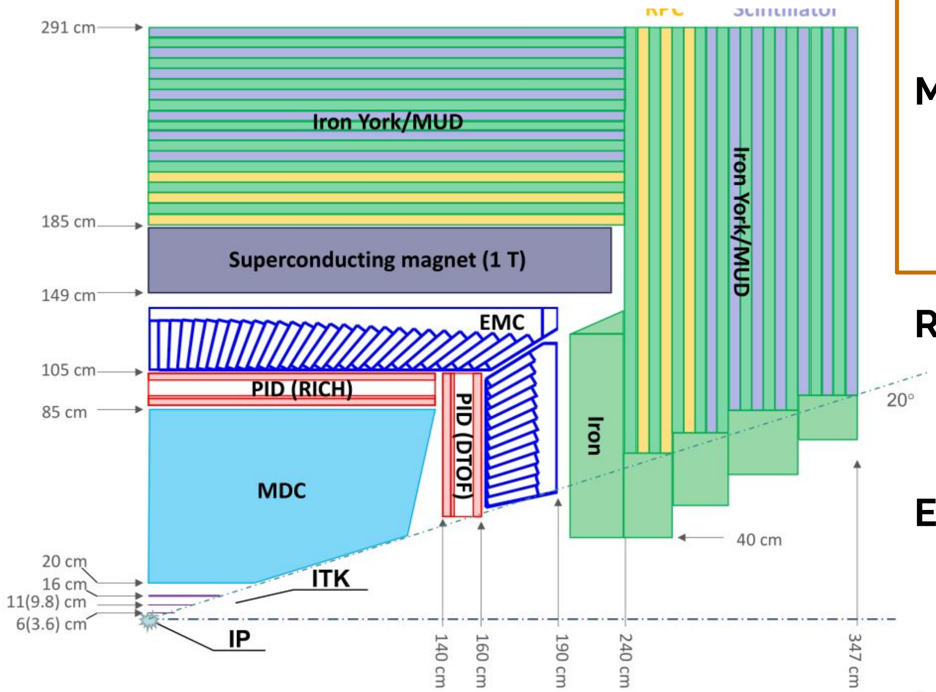
**ACTS Developers Workshop 2024, Nov 18, 2024**

# Super Tau-Charm Facility (STCF) physics goals

- A future e+e- collider in China operating at tau-charm region ($\sqrt{s}$ = 2~7 GeV) with peak lumi of $0.5 \times 10^{35}$ $cm^{-2}$ $s^{-1}$ (>x50 of current BEPCII collider)
  - A factory of charmonium (J/ψ, ψ(3686), …), open charm meson, τ …
- Physics topics:
  - QCD and Hadron spectroscopy (new hadrons, e.g. glueballs, hybrid hadrons…)
  - Flavor physics and CP violation
  - Exotic decays and new physics



# The detector and performance requirements




**ITK** (cylindrical MPGD/ CMOS MAPS)

- Material < 0.01 X0, $\sigma_{xy}$ < 100 um

**MDC** (drift chamber)

- Material < 0.05 X0
- $\sigma_{xy}$ < 130 um, $\sigma_p/p$ < 0.5% at 1 GeV/c
- dE/dx resolution < 6%

**RICH** (CsI-MPGD) & **DTOF** (DIRC-like TOF)

- PID π/K PID efficiency > 97% up to 2 GeV/c @mis-ID rate 2%

**EMC** (pure CsI + APD)

- $\sigma_E$ < 2.5%, $\sigma_{pos}$ < 5 mm, $\sigma_t$ < 300 ps @ 1 GeV

**MUD** (RPC + scintillator strips)

- μ PID efficiency > 95% with π→ μ mis-ID rate < 3.3% @ p = 1 GeV/c

See an overview in J.B. Liu's talk

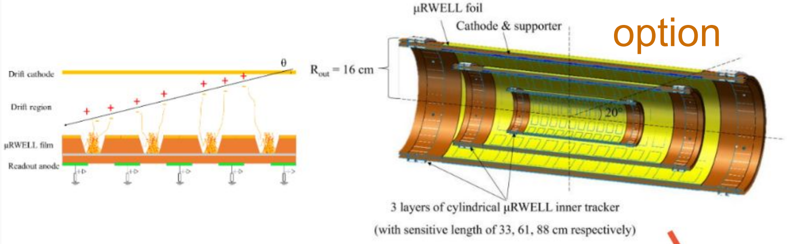
# STCF tracking system

From H. Zhou's CHEP2024 talk

- Two options inner tracker(ITK)

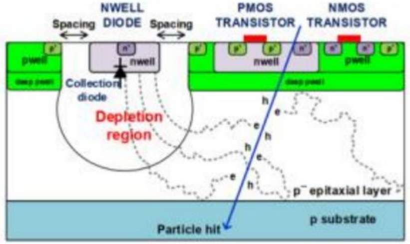
ITK Gaseous option : MPGD

Current baseline option




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

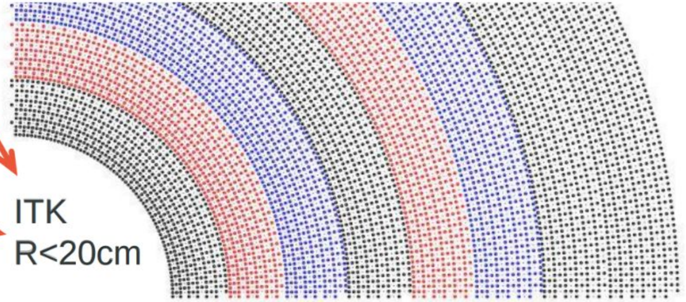
ITK Silicon option: CMOS MAPS

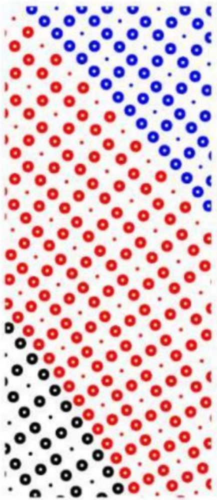



- Main tracker

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

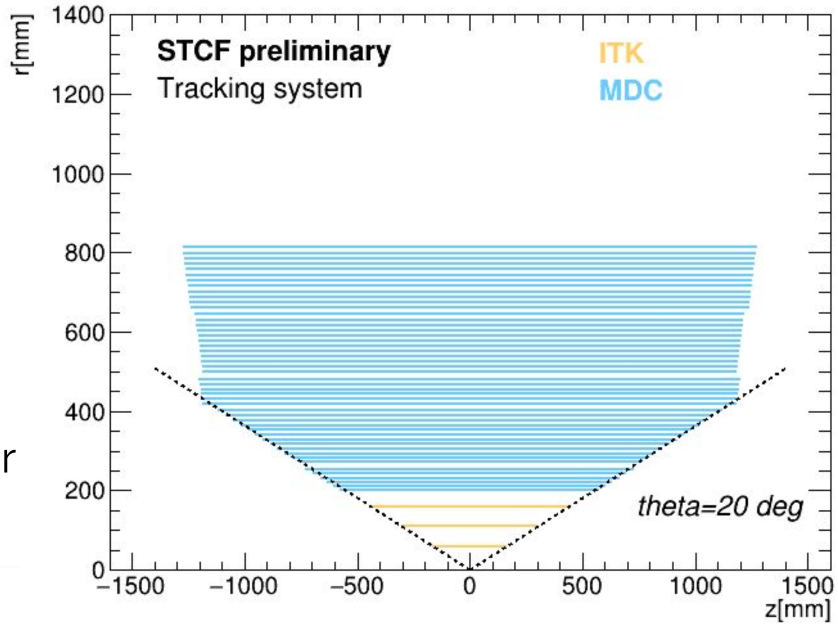
| Superlayer | Radius (mm) | Num. of Layers | Stereo angle (mrad) | Num. of Cells | Cell size (mm) |
|---|---|---|---|---|---|
| A | 200.0 | 6 | 0 | 128 | 9.8 to 12.5 |
| U | 271.6 | 6 | 39.3 to 47.6 | 160 | 10.7 to 12.9 |
| V | 342.2 | 6 | -41.2 to -48.4 | 192 | 11.2 to 13.2 |
| A | 419.2 | 6 | 0 | 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 | |

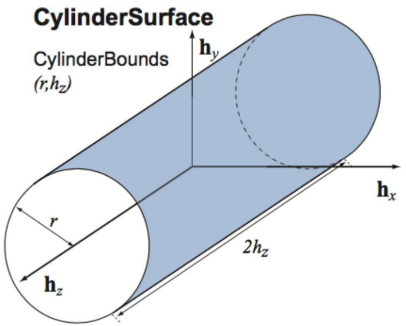


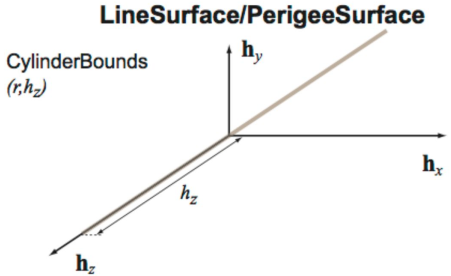



# ACTS tracking geometry

- Working approaches to transform full G4 simulation geometry (described with DD4hep) into ACTS geometry through:
  - ACTS TGeo plugin (DD4hep plugin should also work)
  - Acts::KDTreeTrackingGeometryBuilder



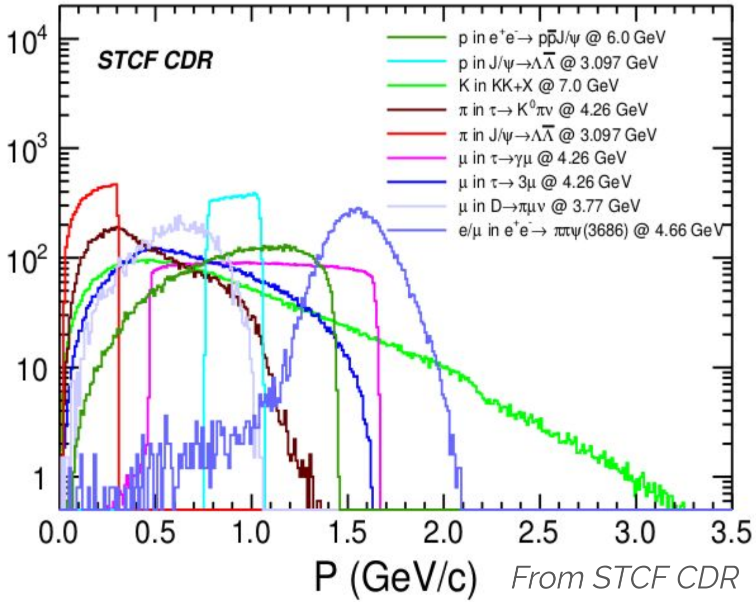



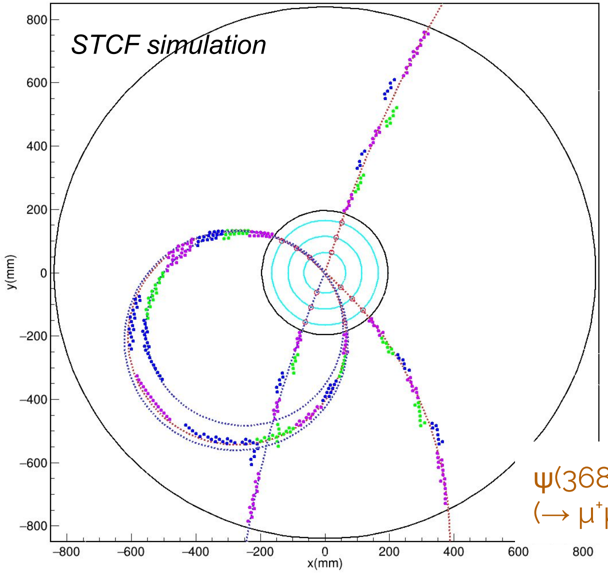

- 3 MPGD layers → 3 layers (one ACTS::CylinderSurface for each layer)
- 48 straw layers → 48 layers with composed of ACTS::LineSurface

# 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 ($\Lambda$, $K_s$, …) can decay outside ITK



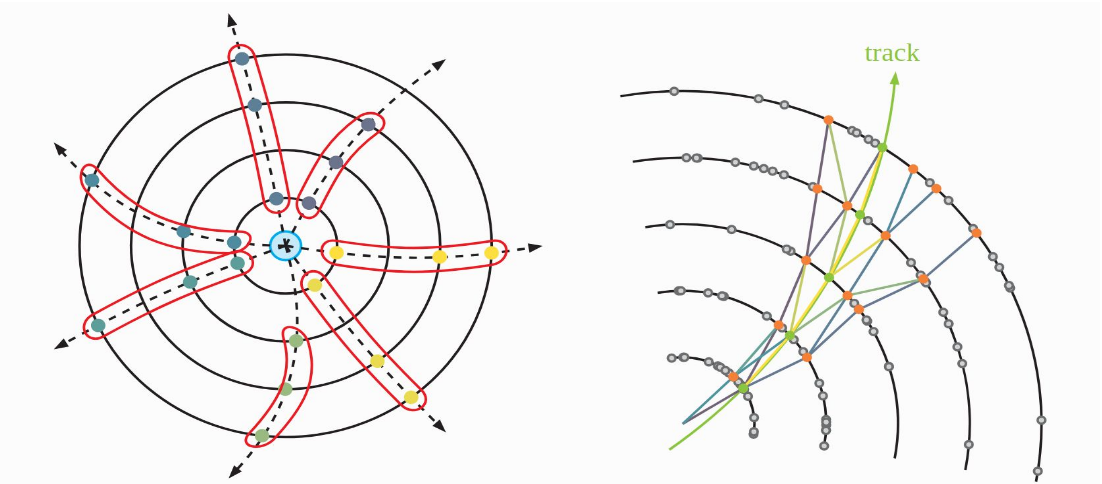

*From STCF CDR*

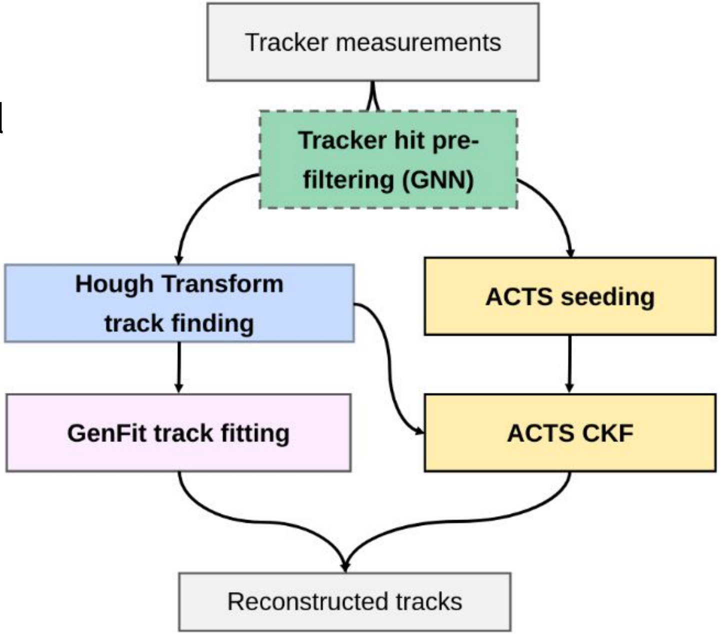



$\psi(3686) \rightarrow \pi^+\pi^- J/\psi$ ($\rightarrow \mu^+\mu^-$)

# ACTS tracking strategy

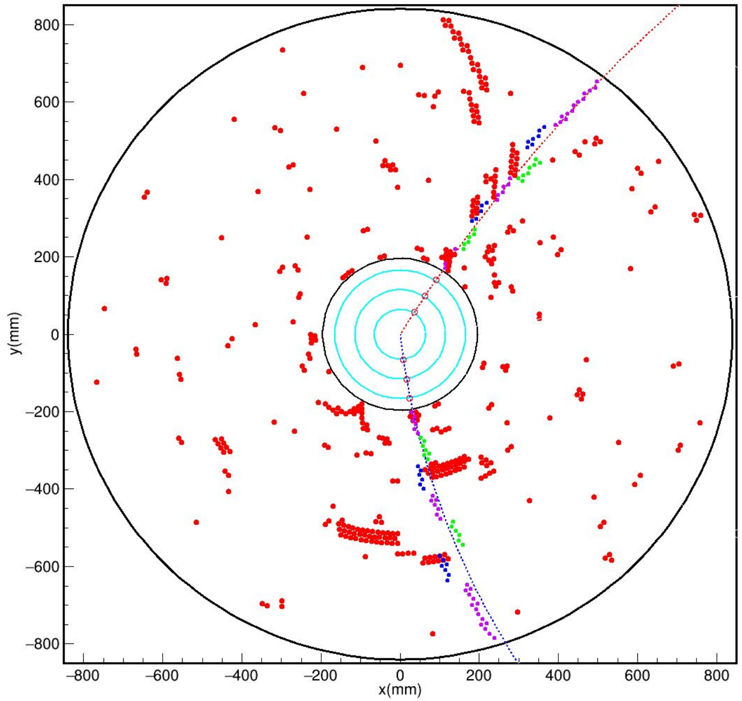
- ACTS has been integrated into STCF offline software
  - Hough + GenFit has been well optimized
  - ACTS seeding + ACTS CKF is used as second tracking option at STCF (No ambiguity Resolving yet)
  - Hough (as seeding) + ACTS CKF is also being studied for long-lived particle tracking



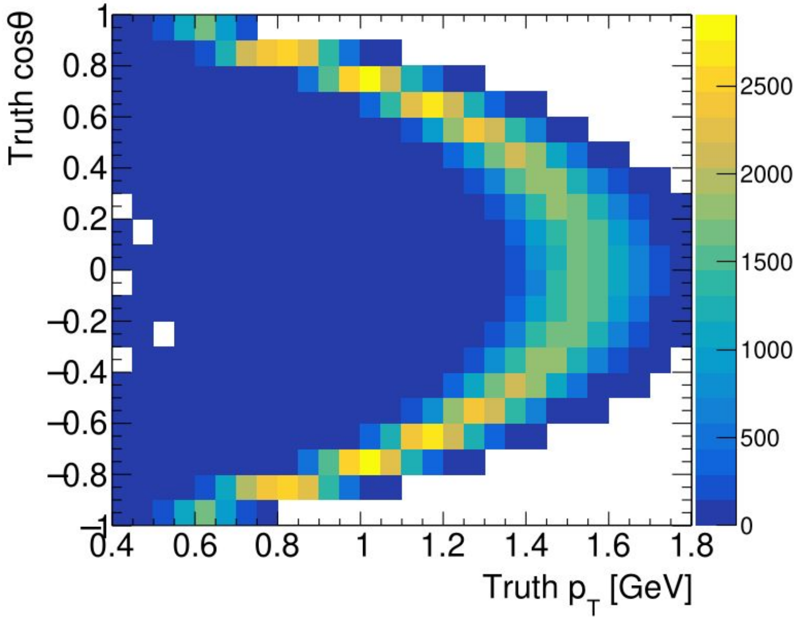

Details about Hough + GenFit in [H. Zhou's CHEP2024 talk]

# Performance for non-displaced tracks

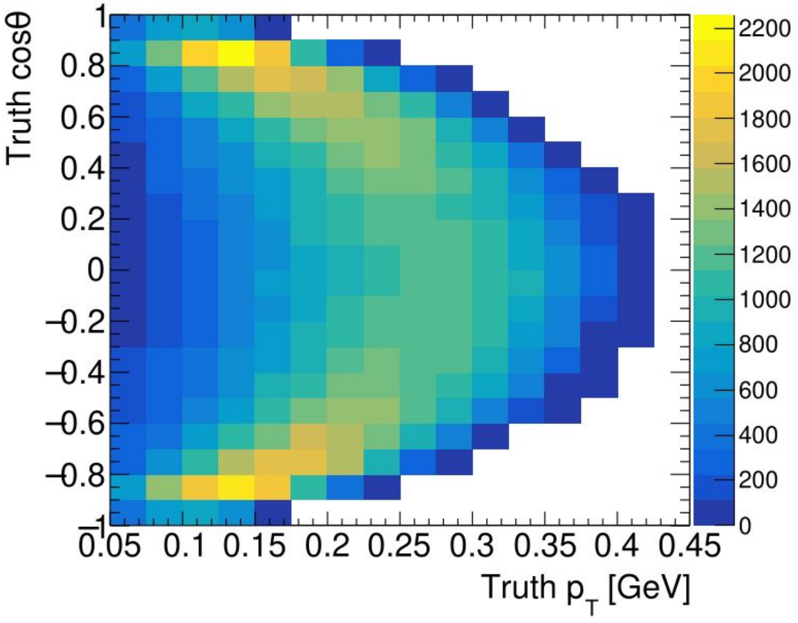


# Particle cosθ vs. $p_T$

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

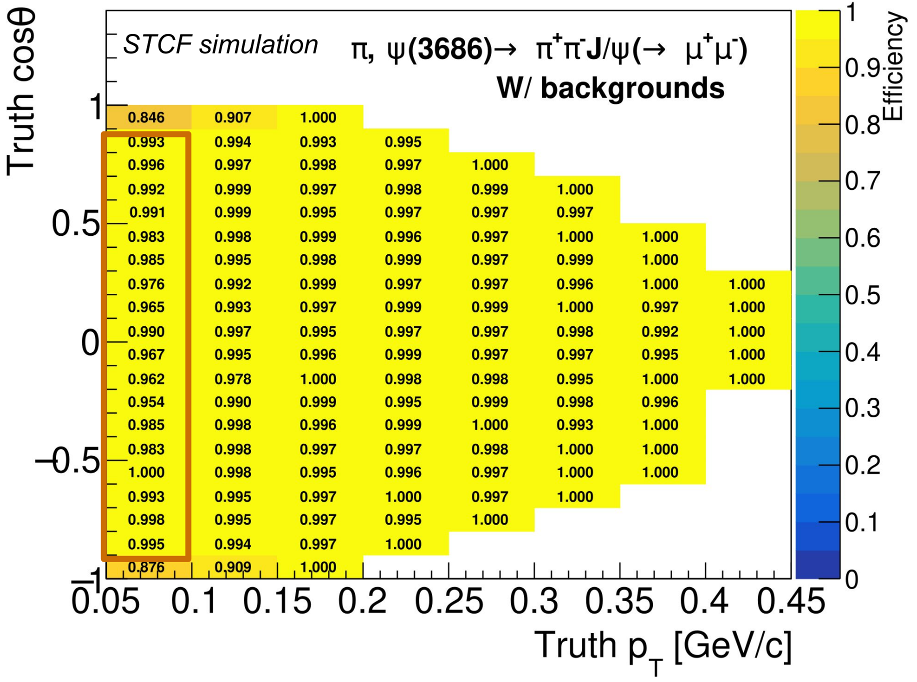


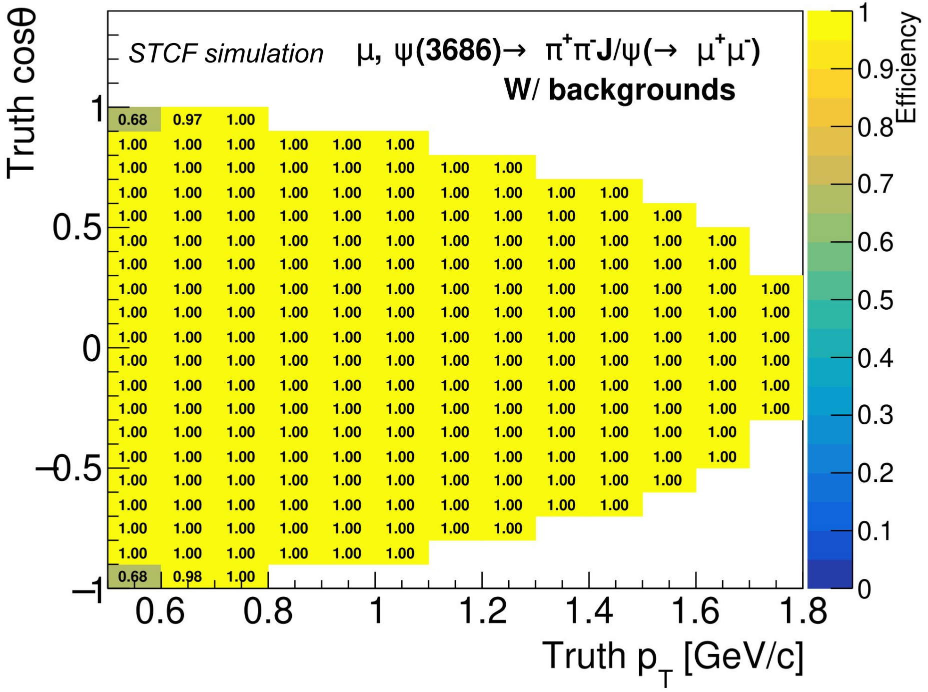

$\pi$, $\psi(3686) \rightarrow \pi^+\pi^- J/\psi(\rightarrow \mu^+\mu^-)$



# Seeding efficiency

>96% seeding efficiency for particles in the region |cosθ|<0.9, 50 MeV < $p_T$<100 MeV !

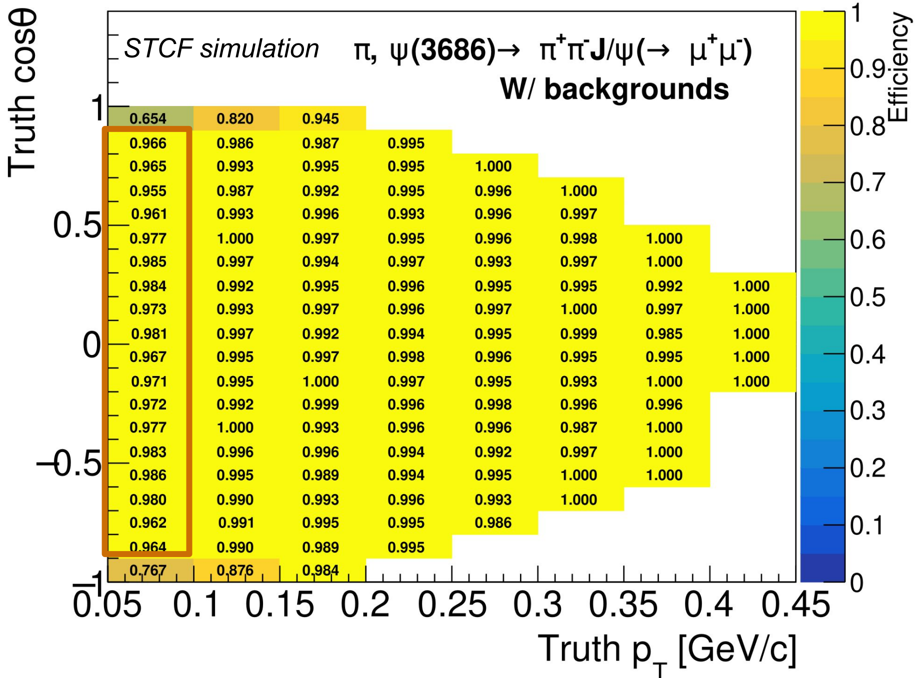


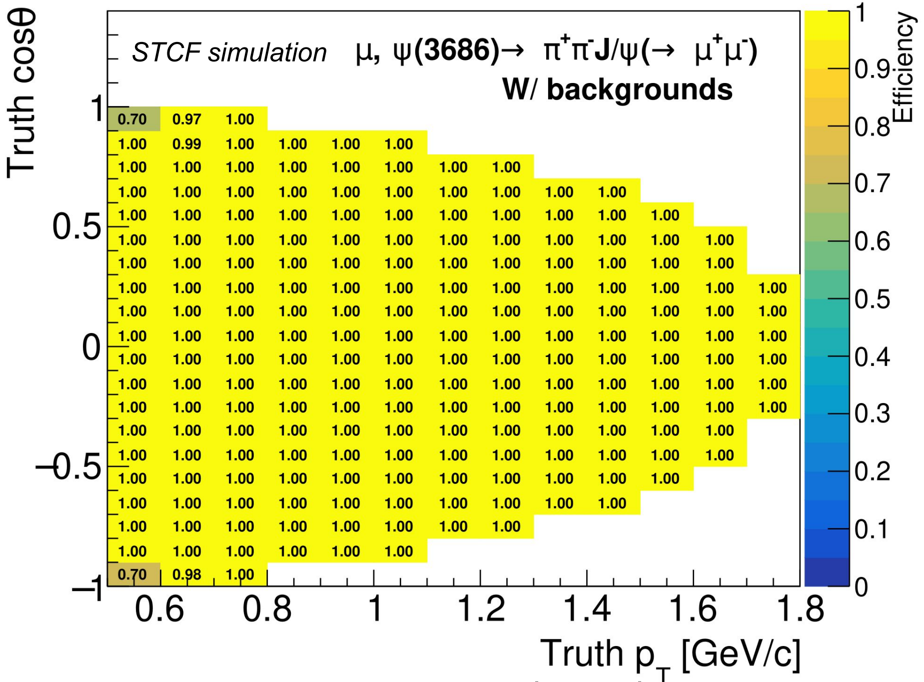




Particle requirements: nHits>=5, |cosθ|<0.94

# Tracking (seeding + CKF) efficiency

>96% tracking efficiency for particles in the region |cosθ|<0.9, 50 MeV < $p_T$<100 MeV !



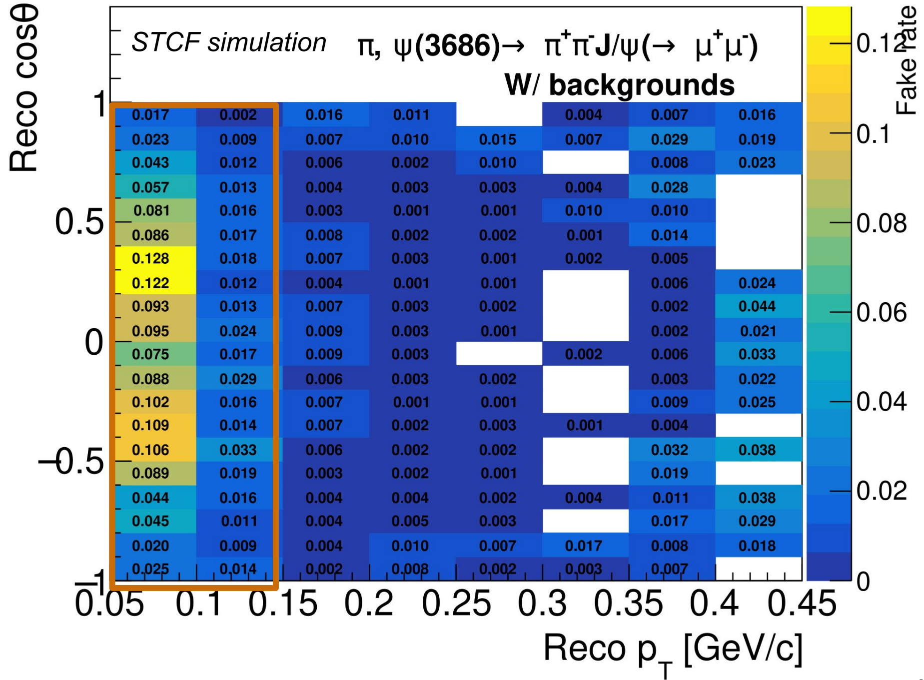



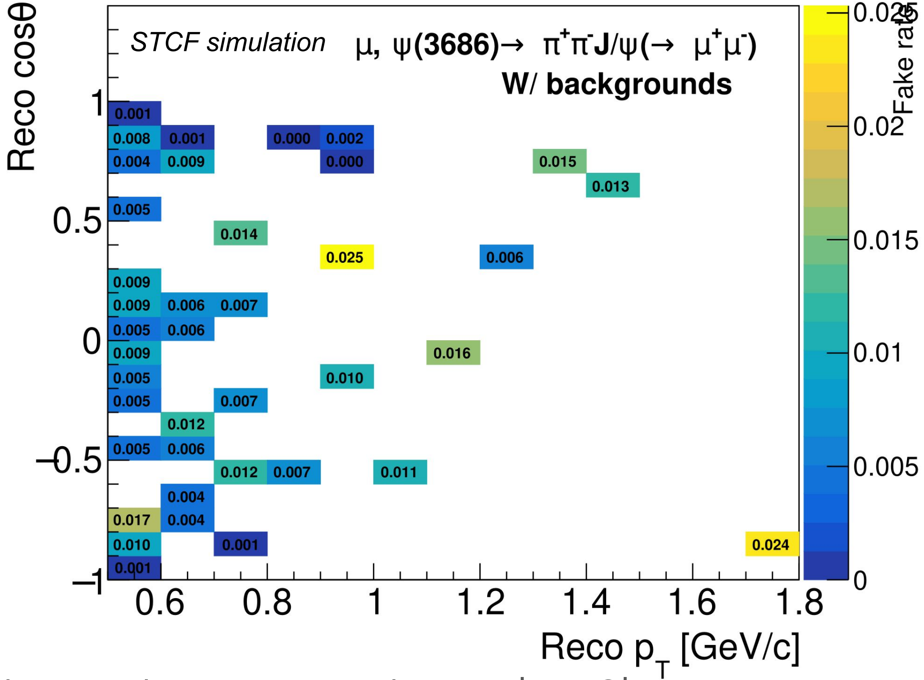

Particle requirements: nHits>=5, |cosθ|<0.94

Track requirements: nHits>=5, matchingProb > 0.5

# Tracking fake rate

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

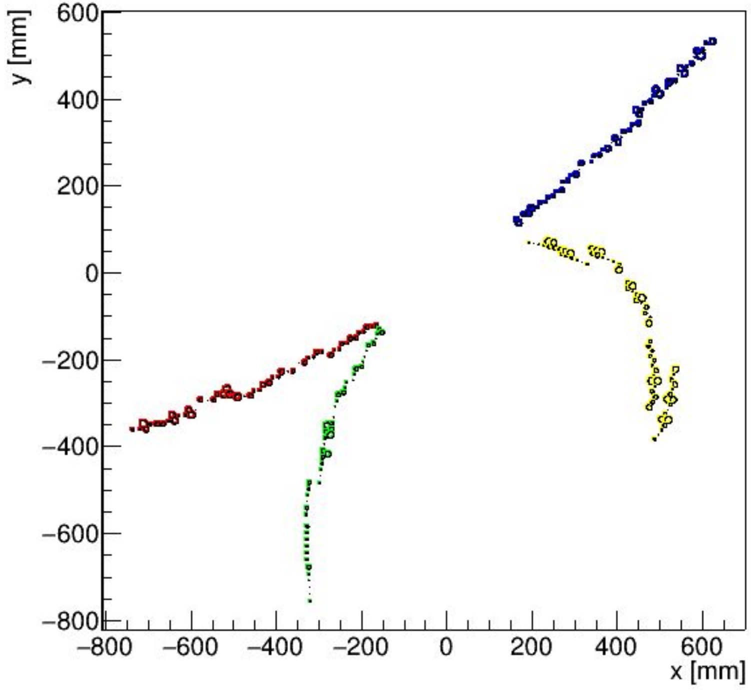


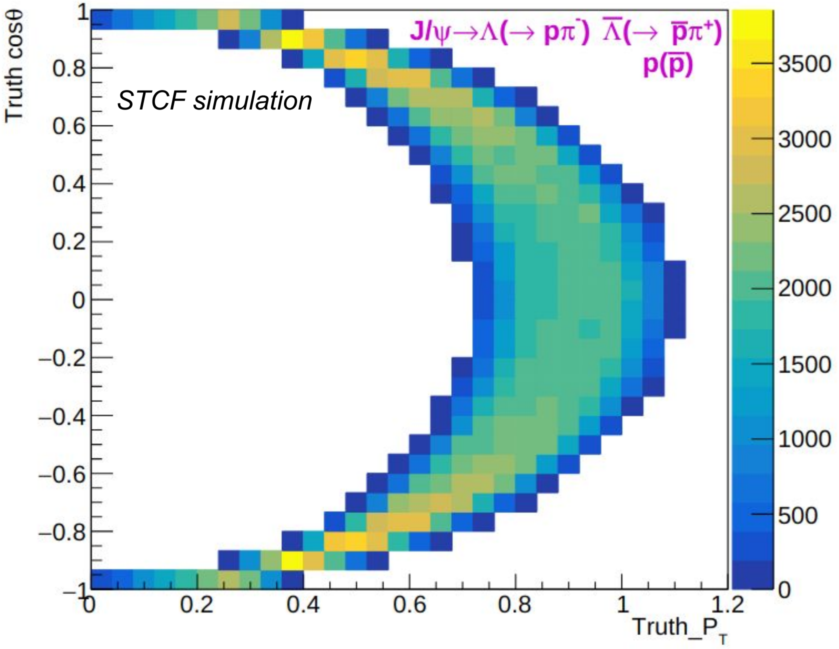

Particle requirements: nHits>=5, |cosθ|<0.94

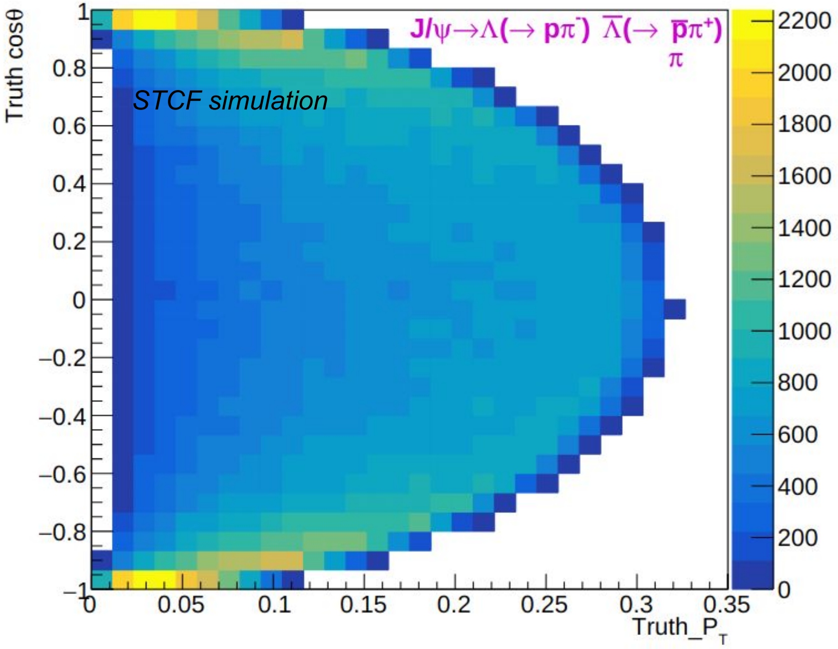
Track requirements: nHits>=5, matchingProb > 0.5

# Performance for displaced tracks



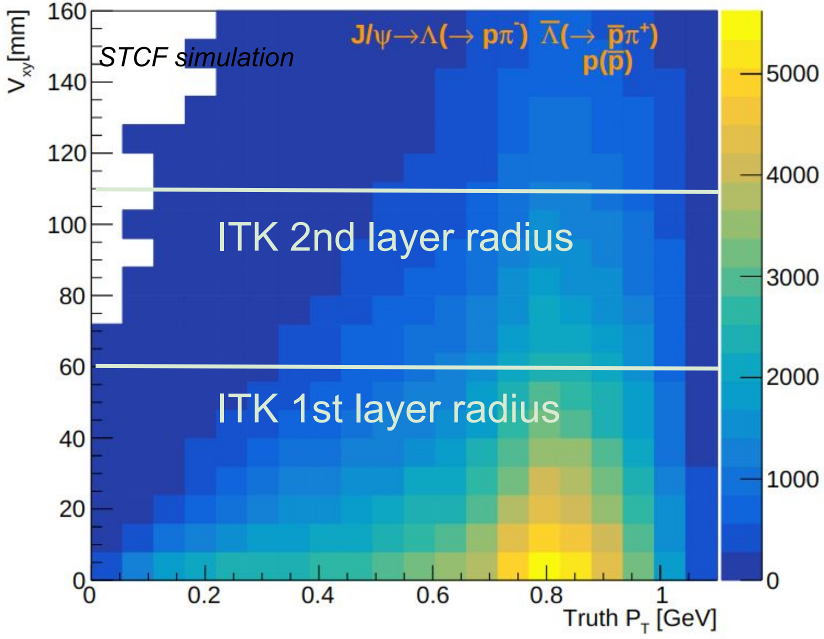
# Particle cosθ vs. $p_T$

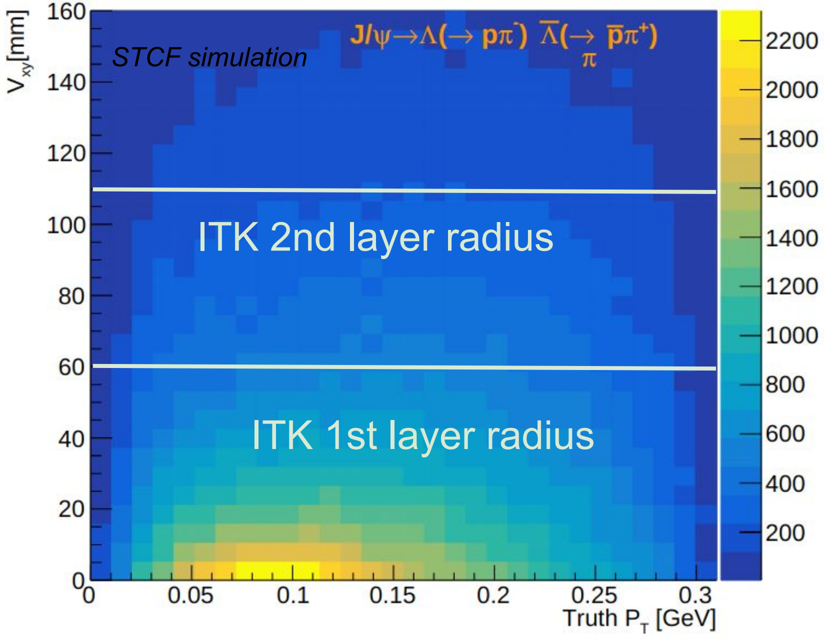


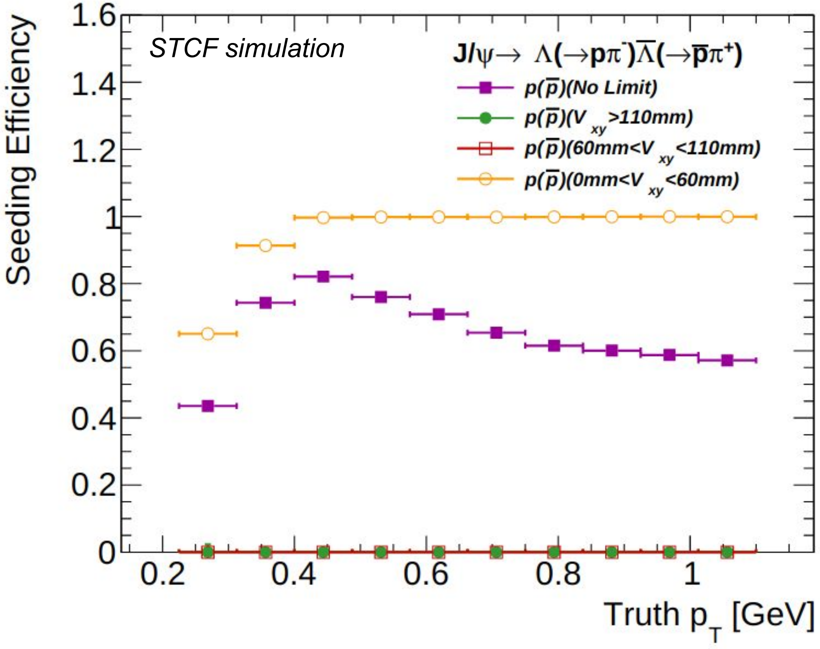
# Particle displacement $V_{xy}$ vs. $p_T$

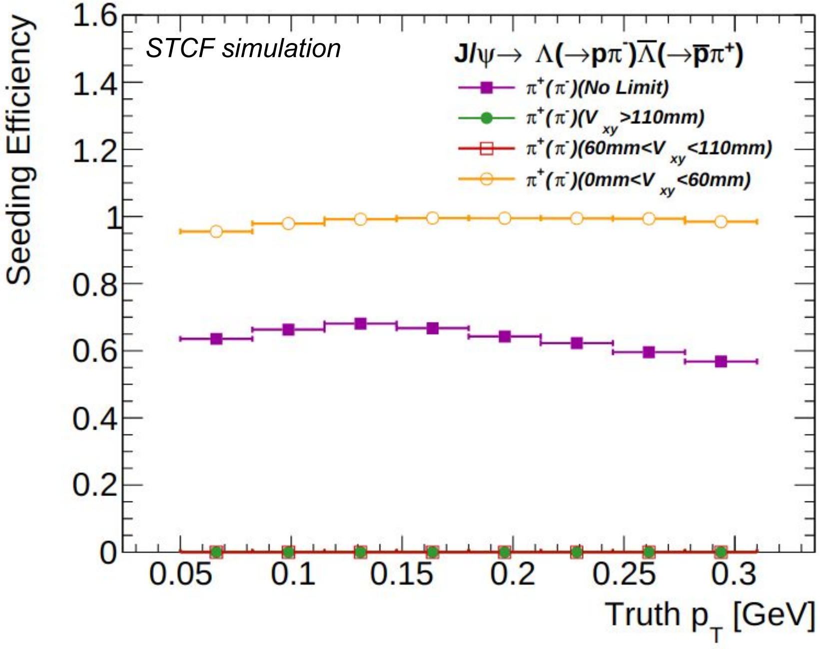
A considerable amount of particles decay outside of first layer of ITK



# Zero seeding efficiency if nHits$_{ITK}$ < 3

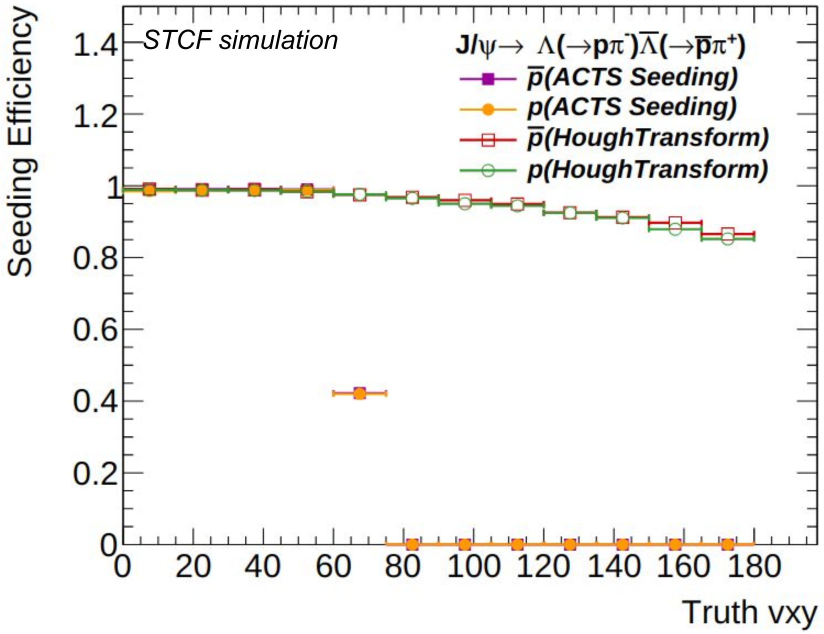


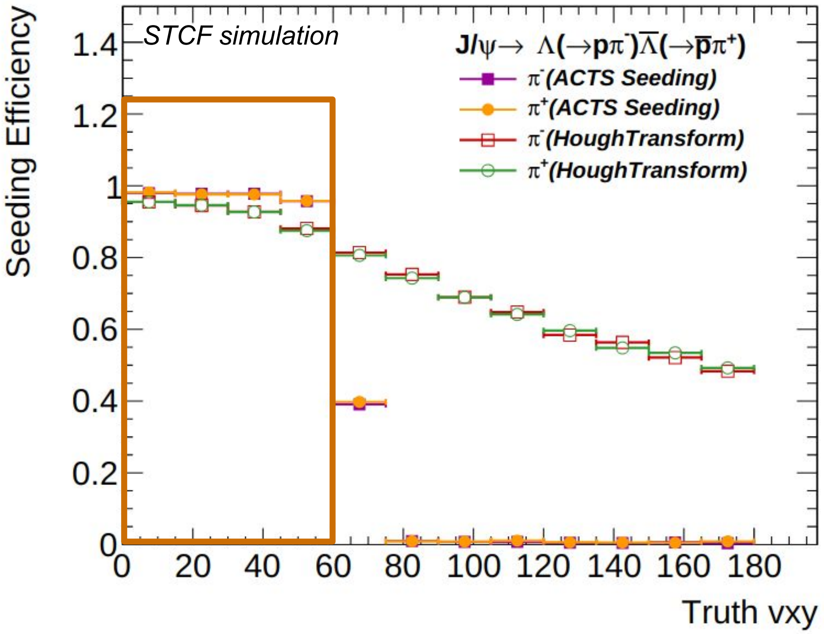




Backgrounds not included

# 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

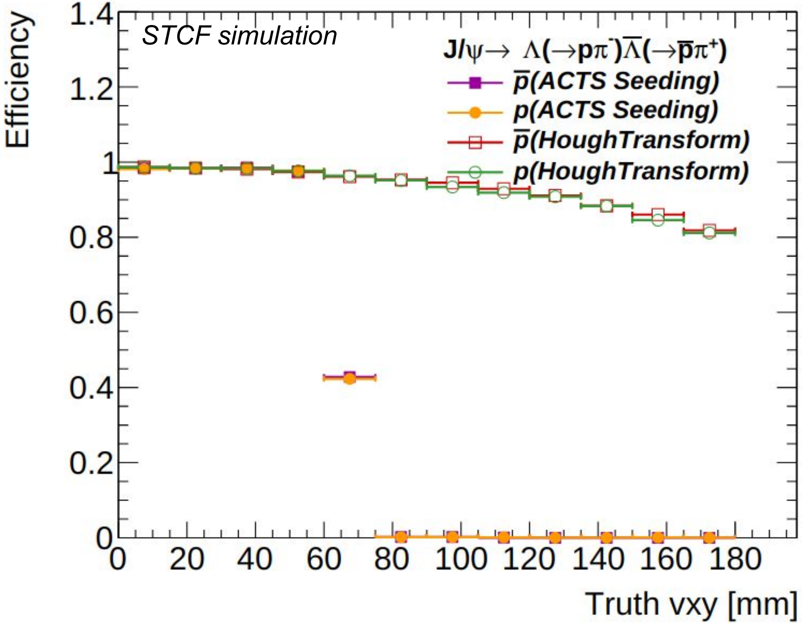


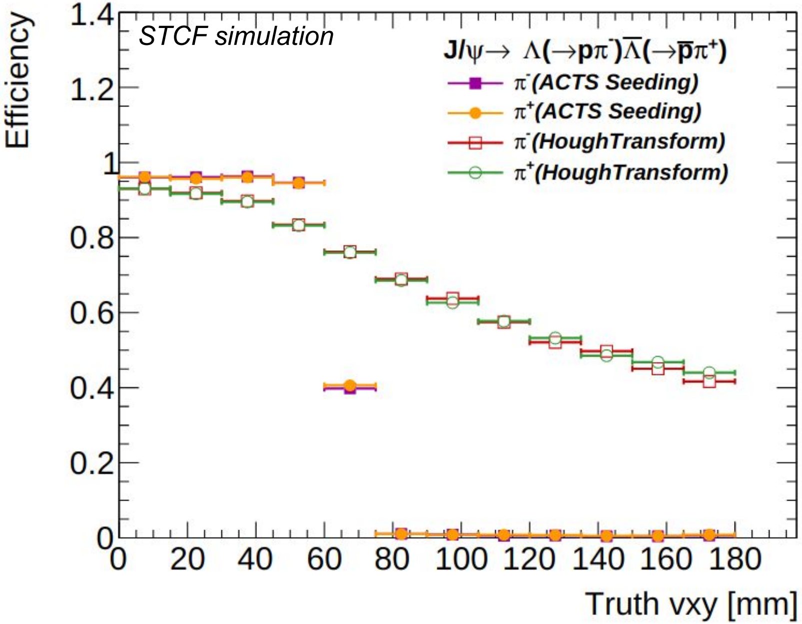




Backgrounds not included

# Hough Transform + CKF performance

Efficiency loss can be recovered by using Hough as seeding




Backgrounds not included

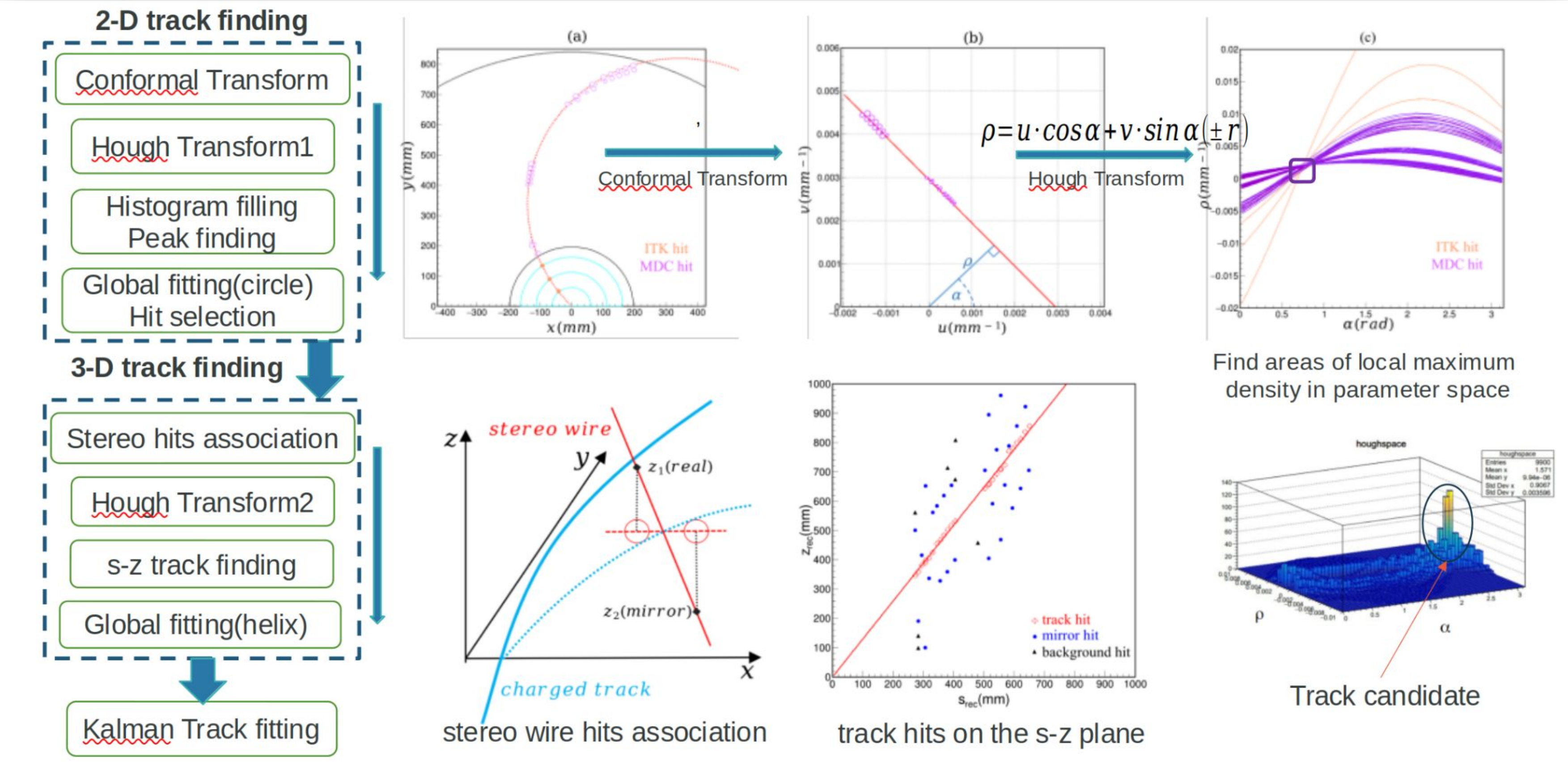
Particle requirements: nHits>=5, |cosθ|<0.94
Track requirements: nHits>=5, matchingProb > 0.5

# Summary

- ACTS has been used as one of the tracking methods at STCF
  - Encouraging performance even at $p_T$ below 100 MeV
- Obvious seeding efficiency loss for long-lived particles at STCF
  - Hough transform as a global track finding algorithm can recover the seeding efficiency loss
- Non-negligible amount of fake (and also duplicate) tracks exist
- Next:
  - Investigate ML ambiguity resolver to remove fake/duplicate tracks

# backup

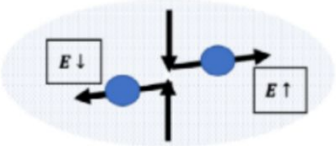
# Hough Transform at STCF



# Backgrounds

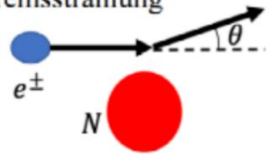
**Touschek effect**

- 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

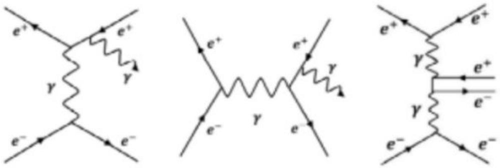



Yupeng Pei

**Luminosity-related background**

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

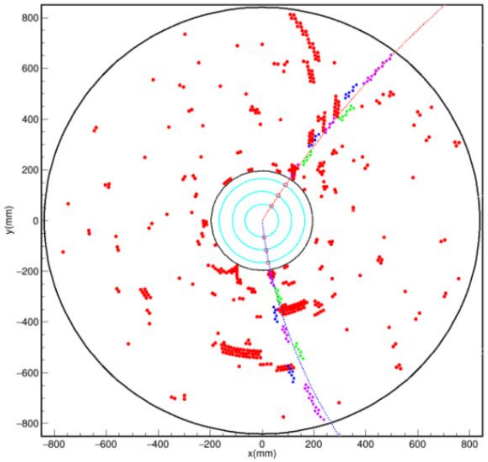
$e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-e^+e^-$



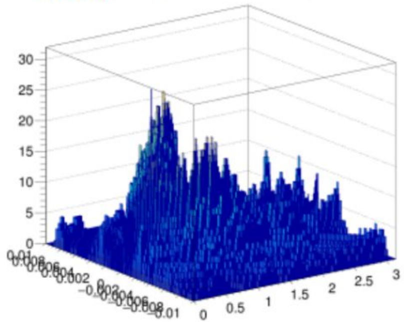
**Other background**

- Injection
- Synchrotron radiation

5

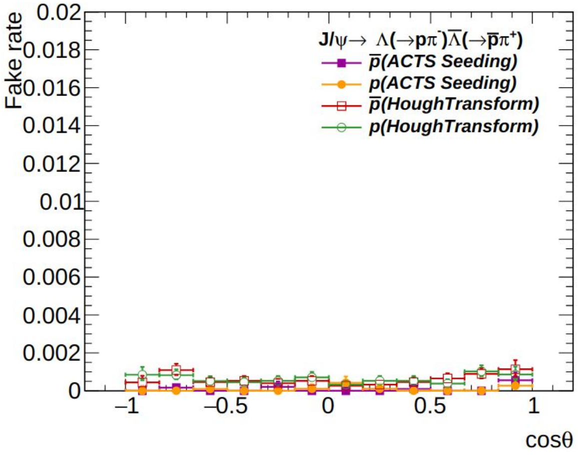


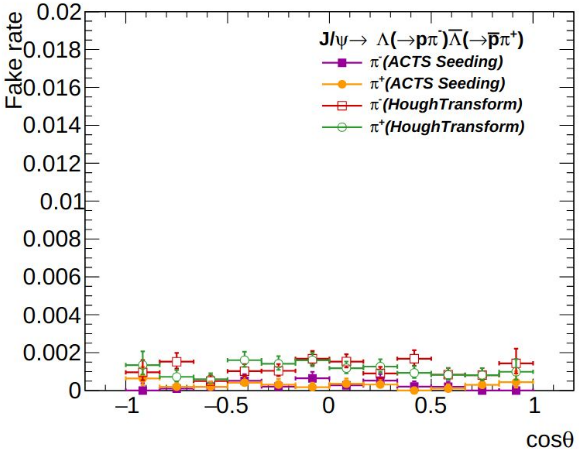

Hough map with background

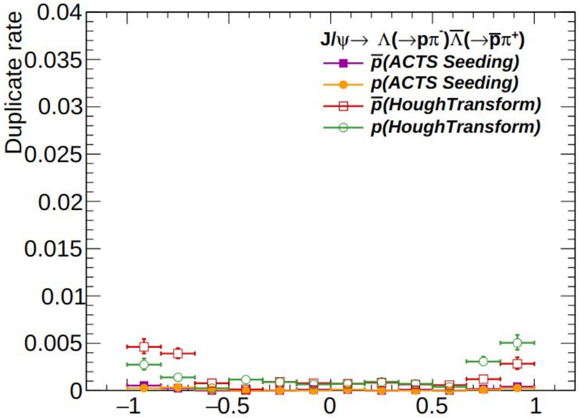


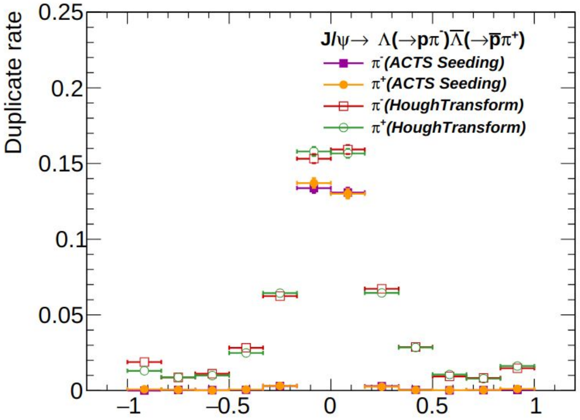
Background hits count per event

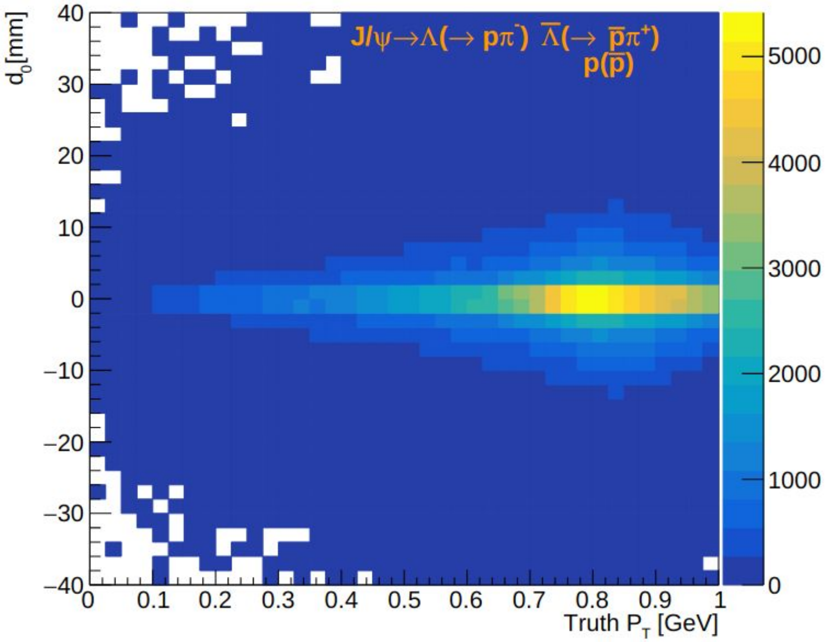
| ITK1 | ITK2 | ITK3 | MDC1 | MDC2 | MDC3 | MDC4 | MDC5 | MDC6 | MDC7 | MDC8 |
|---|---|---|---|---|---|---|---|---|---|---|
| 37.3 | 13.6 | 8.2 | 60.3 | 42.4 | 24.8 | 25.1 | 60.0 | 67.8 | 30.8 | 30.0 |

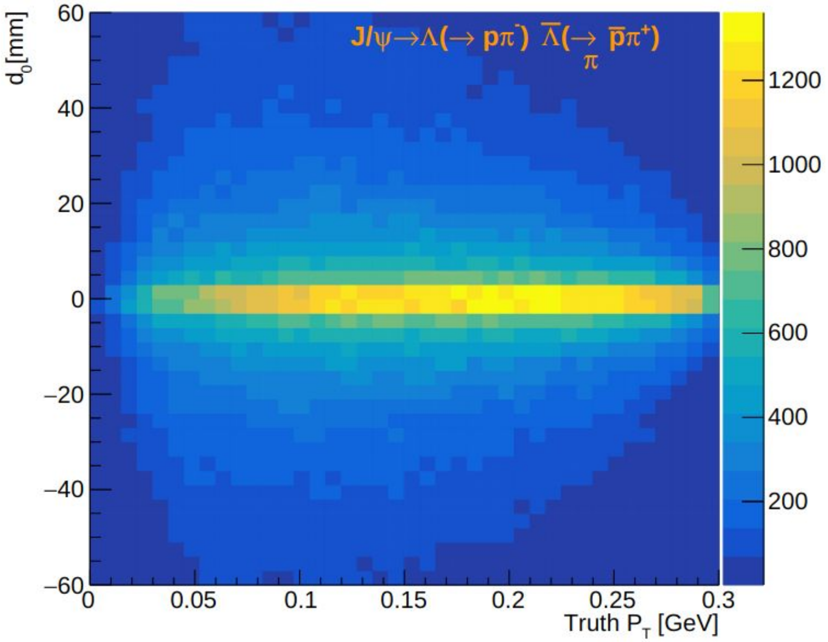

Fake rate
cosθ
$J/\psi \to \Lambda(\to p\pi^-)\bar{\Lambda}(\to \bar{p}\pi^+)$
$\bar{p}$(ACTS Seeding)
p(ACTS Seeding)
$\bar{p}$(HoughTransform)
p(HoughTransform)

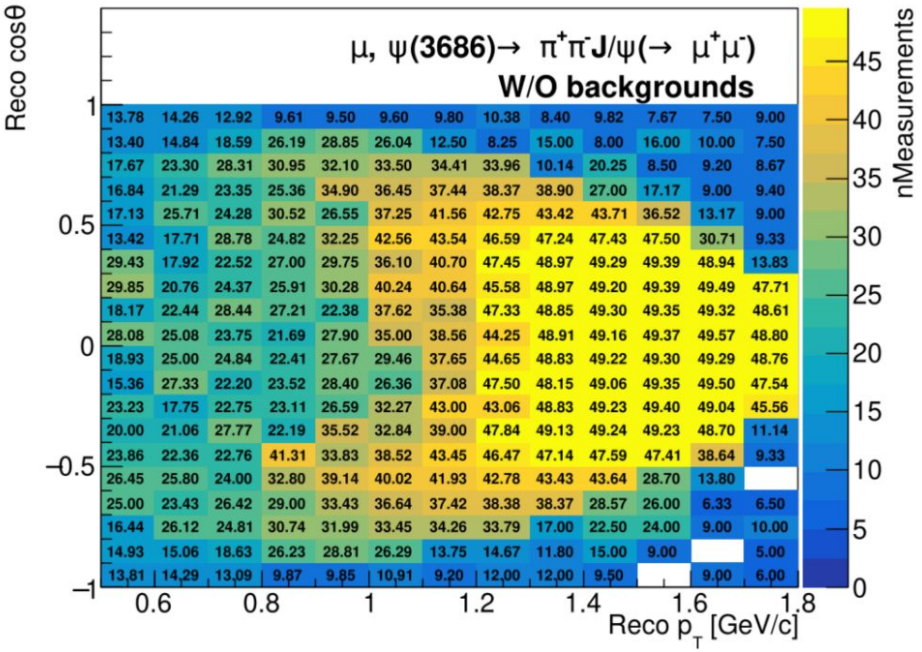

Fake rate
cosθ
$J/\psi \to \Lambda(\to p\pi^-)\bar{\Lambda}(\to \bar{p}\pi^+)$
$\pi^-$(ACTS Seeding)
$\pi^+$(ACTS Seeding)
$\pi^-$(HoughTransform)
$\pi^+$(HoughTransform)

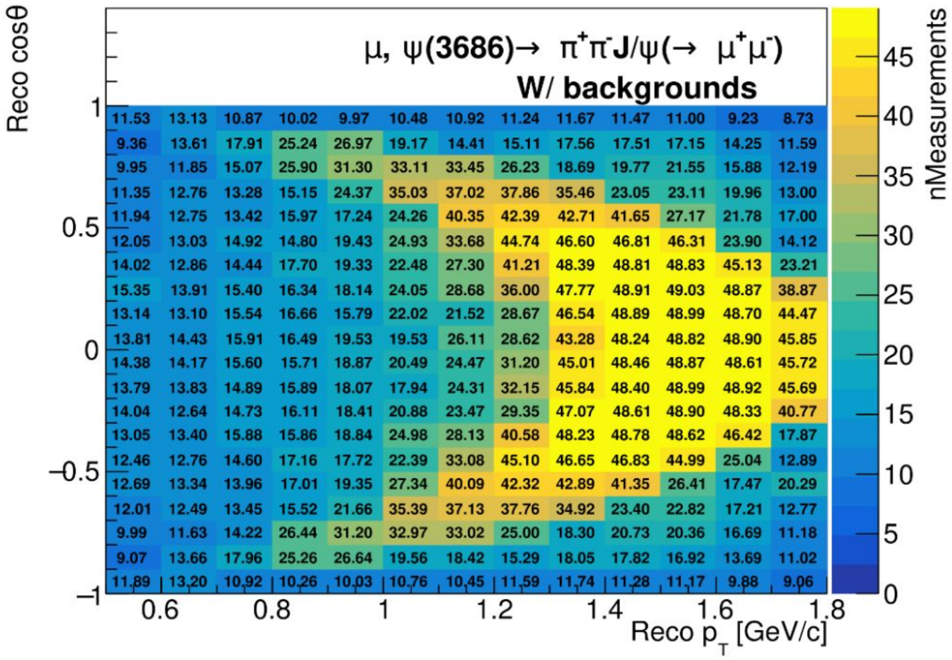

Duplicate rate
$J/\psi \to \Lambda(\to p\pi^-)\bar{\Lambda}(\to \bar{p}\pi^+)$
$\bar{p}$(ACTS Seeding)
p(ACTS Seeding)
$\bar{p}$(HoughTransform)
p(HoughTransform)

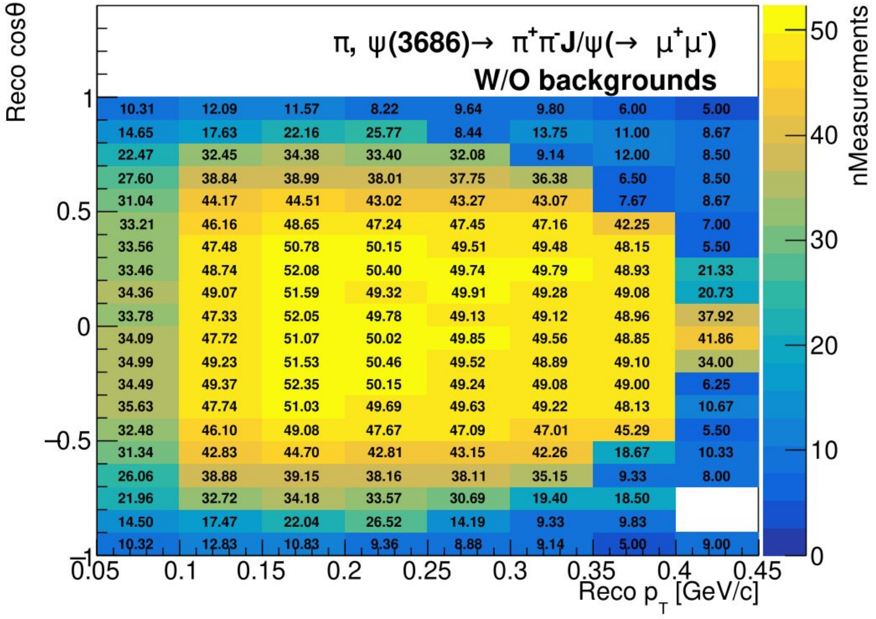

Duplicate rate
$J/\psi \to \Lambda(\to p\pi^-)\bar{\Lambda}(\to \bar{p}\pi^+)$
$\pi^-$(ACTS Seeding)
$\pi^+$(ACTS Seeding)
$\pi^-$(HoughTransform)
$\pi^+$(HoughTransform)

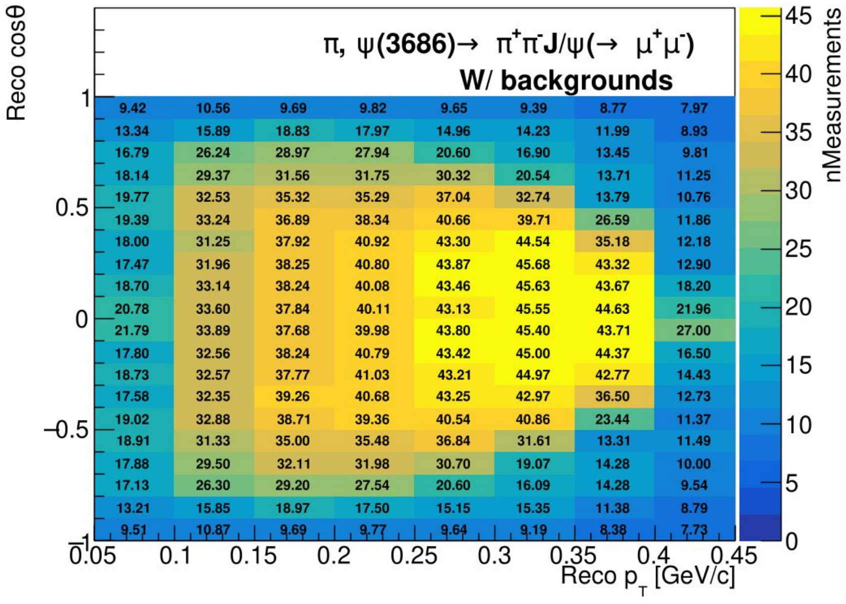

$J/\psi \to \Lambda(\to p\pi^-)\ \bar{\Lambda}(\to \bar{p}\pi^+)$
$p(\bar{p})$
$d_0$[mm]
Truth $P_T$ [GeV]

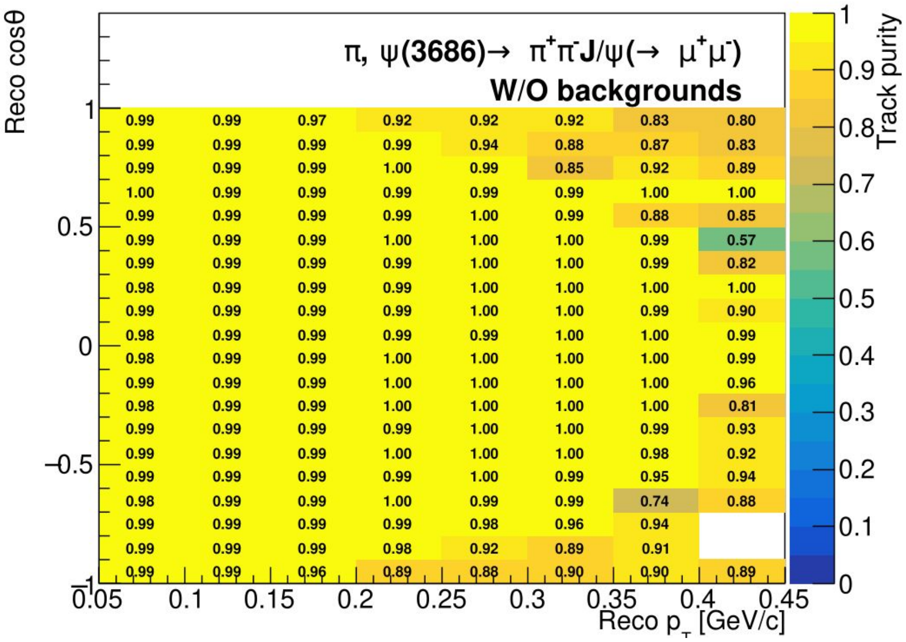

$J/\psi \to \Lambda(\to p\pi^-)\ \bar{\Lambda}(\to \bar{p}\pi^+)$
$\pi$
$d_0$[mm]
Truth $P_T$ [GeV]

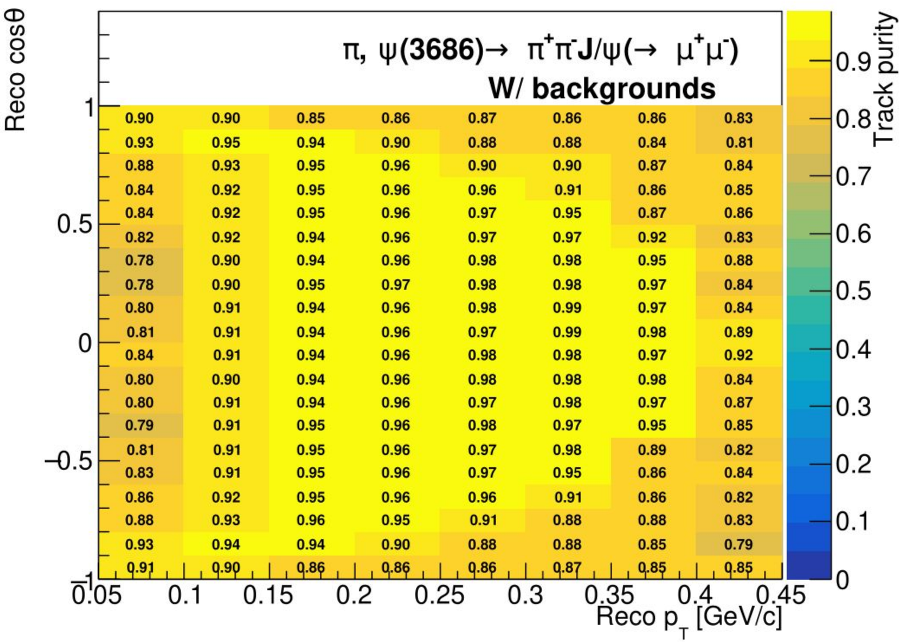

μ, ψ(3686)→ π⁺π⁻J/ψ(→ μ⁺μ⁻)
W/O backgrounds
Reco cosθ
Reco p_T [GeV/c]
nMeasurements

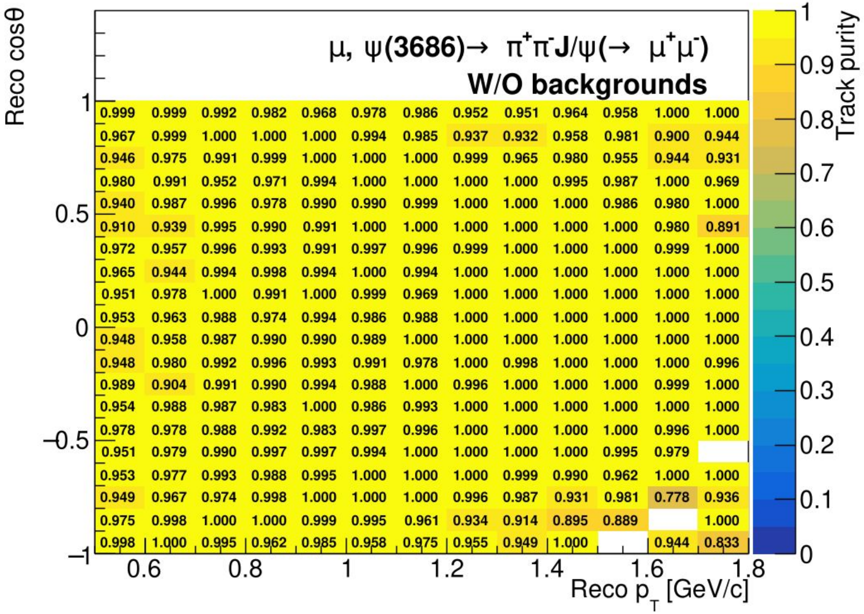

μ, ψ(3686)→ π⁺π⁻J/ψ(→ μ⁺μ⁻)
W/ backgrounds
Reco cosθ
Reco p_T [GeV/c]
nMeasurements

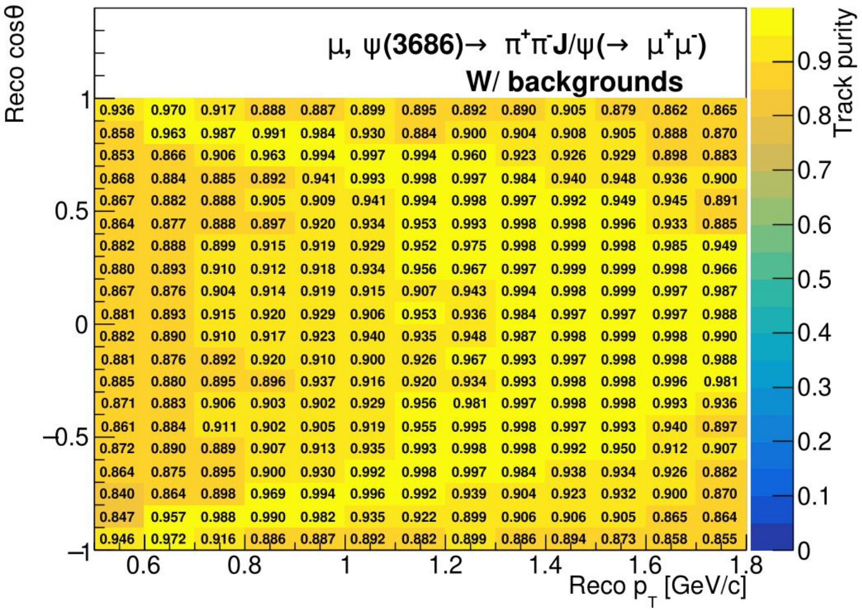

π, ψ(3686)→ π⁺π⁻J/ψ(→ μ⁺μ⁻)
W/O backgrounds
Reco cosθ
Reco p_T [GeV/c]
nMeasurements
10.31 12.09 11.57 8.22 9.64 9.80 6.00 5.00
14.65 17.63 22.16 25.77 8.44 13.75 11.00 8.67
22.47 32.45 34.38 33.40 32.08 9.14 12.00 8.50
27.60 38.84 38.99 38.01 37.75 36.38 6.50 8.50
31.04 44.17 44.51 43.02 43.27 43.07 7.67 8.67
33.21 46.16 48.65 47.24 47.45 47.16 42.25 7.00
33.56 47.48 50.78 50.15 49.51 49.48 48.15 5.50
33.46 48.74 52.08 50.40 49.74 49.79 48.93 21.33
34.36 49.07 51.59 49.32 49.91 49.28 49.08 20.73
33.78 47.33 52.05 49.78 49.13 49.12 48.96 37.92
34.09 47.72 51.07 50.02 49.85 49.56 48.85 41.86
34.99 49.23 51.53 50.46 49.52 48.89 49.10 34.00
34.49 49.37 52.35 50.15 49.24 49.08 49.00 6.25
35.63 47.74 51.03 49.69 49.63 49.22 48.13 10.67
32.48 46.10 49.08 47.67 47.09 47.01 45.29 5.50
31.34 42.83 44.70 42.81 43.15 42.26 18.67 10.33
26.06 38.88 39.15 38.16 38.11 35.15 9.33 8.00
21.96 32.72 34.18 33.57 30.69 19.40 18.50
14.50 17.47 22.04 26.52 14.19 9.33 9.83
10.32 12.83 10.83 9.36 8.88 9.14 5.00 9.00


π, ψ(3686)→ π⁺π⁻J/ψ(→ μ⁺μ⁻)
W/ backgrounds
Reco cosθ
Reco p_T [GeV/c]
nMeasurements
9.42 10.56 9.69 9.82 9.65 9.39 8.77 7.97
13.34 15.89 18.83 17.97 14.96 14.23 11.99 8.93
16.79 26.24 28.97 27.94 20.60 16.90 13.45 9.81
18.14 29.37 31.56 31.75 30.32 20.54 13.71 11.25
19.77 32.53 35.32 35.29 37.04 32.74 13.79 10.76
19.39 33.24 36.89 38.34 40.66 39.71 26.59 11.86
18.00 31.25 37.92 40.92 43.30 44.54 35.18 12.18
17.47 31.96 38.25 40.80 43.87 45.68 43.32 12.90
18.70 33.14 38.24 40.08 43.46 45.63 43.67 18.20
20.78 33.60 37.84 40.11 43.13 45.55 44.63 21.96
21.79 33.89 37.68 39.98 43.80 45.40 43.71 27.00
17.80 32.56 38.24 40.79 43.42 45.00 44.37 16.50
18.73 32.57 37.77 41.03 43.21 44.97 42.77 14.43
17.58 32.35 39.26 40.68 43.25 42.97 36.50 12.73
19.02 32.88 38.71 39.36 40.54 40.86 23.44 11.37
18.91 31.33 35.00 35.48 36.84 31.61 13.31 11.49
17.88 29.50 32.11 31.98 30.70 19.07 14.28 10.00
17.13 26.30 29.20 27.54 20.60 16.09 14.28 9.54
13.21 15.85 18.97 17.50 15.15 15.35 11.38 8.79
9.51 10.87 9.69 9.77 9.64 9.19 8.38 7.73


π, ψ(3686)→ π+π-J/ψ(→ μ+μ-)
W/O backgrounds
Reco cosθ
Reco pT [GeV/c]
Track purity


π, ψ(3686)→ π+π-J/ψ(→ μ+μ-)
W/ backgrounds
Reco cosθ
Reco pT [GeV/c]
Track purity


μ, ψ(3686)→ π⁺π⁻J/ψ(→ μ⁺μ⁻)
W/O backgrounds
Reco cosθ
Reco p_T [GeV/c]
Track purity
0.999 0.999 0.992 0.982 0.968 0.978 0.986 0.952 0.951 0.964 0.958 1.000 1.000
0.967 0.999 1.000 1.000 1.000 0.994 0.985 0.937 0.932 0.958 0.981 0.900 0.944
0.946 0.975 0.991 0.999 1.000 1.000 1.000 0.999 0.965 0.980 0.955 0.944 0.931
0.980 0.991 0.952 0.971 0.994 1.000 1.000 1.000 1.000 0.995 0.987 1.000 0.969
0.940 0.987 0.996 0.978 0.990 0.990 0.999 1.000 1.000 1.000 0.986 0.980 1.000
0.910 0.939 0.995 0.990 0.991 1.000 1.000 1.000 1.000 1.000 1.000 0.980 0.891
0.972 0.957 0.996 0.993 0.991 0.997 0.996 0.999 1.000 1.000 1.000 0.999 1.000
0.965 0.944 0.994 0.998 0.994 1.000 0.994 1.000 1.000 1.000 1.000 1.000 1.000
0.951 0.978 1.000 0.991 1.000 0.999 0.969 1.000 1.000 1.000 1.000 1.000 1.000
0.953 0.963 0.988 0.974 0.994 0.986 0.988 1.000 1.000 1.000 1.000 1.000 1.000
0.948 0.958 0.987 0.990 0.990 0.989 1.000 1.000 1.000 1.000 1.000 1.000 1.000
0.948 0.980 0.992 0.996 0.993 0.991 0.978 1.000 0.998 1.000 1.000 1.000 0.996
0.989 0.904 0.991 0.990 0.994 0.988 1.000 0.996 1.000 1.000 1.000 0.999 1.000
0.954 0.988 0.987 0.983 1.000 0.986 0.993 1.000 1.000 1.000 1.000 1.000 1.000
0.978 0.978 0.988 0.992 0.983 0.997 0.996 1.000 1.000 1.000 1.000 0.996 1.000
0.951 0.979 0.990 0.997 0.997 0.994 1.000 1.000 1.000 1.000 0.995 0.979
0.953 0.977 0.993 0.988 0.995 1.000 1.000 1.000 0.999 0.990 0.962 1.000 1.000
0.949 0.967 0.974 0.998 1.000 1.000 1.000 0.996 0.987 0.931 0.981 0.778 0.936
0.975 0.998 1.000 1.000 0.999 0.995 0.961 0.934 0.914 0.895 0.889 1.000
0.998 1.000 0.995 0.962 0.985 0.958 0.975 0.955 0.949 1.000 0.944 0.833


μ, ψ(3686)→ π⁺π⁻J/ψ(→ μ⁺μ⁻)
W/ backgrounds
Reco cosθ
Reco p_T [GeV/c]
Track purity
0.936 0.970 0.917 0.888 0.887 0.899 0.895 0.892 0.890 0.905 0.879 0.862 0.865
0.858 0.963 0.987 0.991 0.984 0.930 0.884 0.900 0.904 0.908 0.905 0.888 0.870
0.853 0.866 0.906 0.963 0.994 0.997 0.994 0.960 0.923 0.926 0.929 0.898 0.883
0.868 0.884 0.885 0.892 0.941 0.993 0.998 0.997 0.984 0.940 0.948 0.936 0.900
0.867 0.882 0.888 0.905 0.909 0.941 0.994 0.998 0.997 0.992 0.949 0.945 0.891
0.864 0.877 0.888 0.897 0.920 0.934 0.953 0.993 0.998 0.998 0.996 0.933 0.885
0.882 0.888 0.899 0.915 0.919 0.929 0.952 0.975 0.998 0.999 0.998 0.985 0.949
0.880 0.893 0.910 0.912 0.918 0.934 0.956 0.967 0.997 0.999 0.999 0.998 0.966
0.867 0.876 0.904 0.914 0.919 0.915 0.907 0.943 0.994 0.998 0.999 0.997 0.987
0.881 0.893 0.915 0.920 0.929 0.906 0.953 0.936 0.984 0.997 0.997 0.997 0.988
0.882 0.890 0.910 0.917 0.923 0.940 0.935 0.948 0.987 0.998 0.999 0.998 0.990
0.881 0.876 0.892 0.920 0.910 0.900 0.926 0.967 0.993 0.997 0.998 0.998 0.988
0.885 0.880 0.895 0.896 0.937 0.916 0.920 0.934 0.993 0.998 0.998 0.996 0.981
0.871 0.883 0.906 0.903 0.902 0.929 0.956 0.981 0.997 0.998 0.998 0.993 0.936
0.861 0.884 0.911 0.902 0.905 0.919 0.955 0.995 0.998 0.997 0.993 0.940 0.897
0.872 0.890 0.889 0.907 0.913 0.935 0.993 0.998 0.998 0.992 0.950 0.912 0.907
0.864 0.875 0.895 0.900 0.930 0.992 0.998 0.997 0.984 0.938 0.934 0.926 0.882
0.840 0.864 0.898 0.969 0.994 0.996 0.992 0.939 0.904 0.923 0.932 0.900 0.870
0.847 0.957 0.988 0.990 0.982 0.935 0.922 0.899 0.906 0.906 0.905 0.865 0.864
0.946 0.972 0.916 0.886 0.887 0.892 0.882 0.899 0.886 0.894 0.873 0.858 0.855