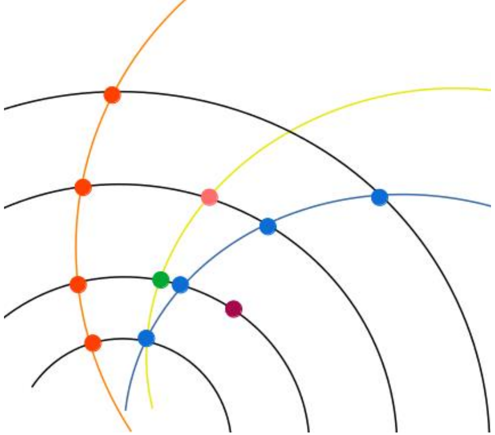

Performance of track reconstruction at STCF using ACTS

arXiv: 2301.04306

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[1] Zhengzhou University
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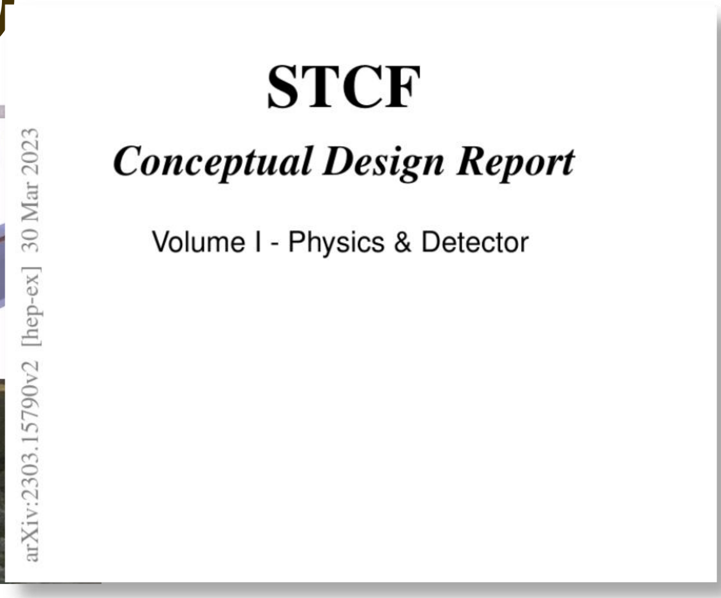
CHEP 2023, May 09, 2023

Super Tau-Charm Facility (STCF)


STCF

Conceptual Design Report

Volume I - Physics & Detector

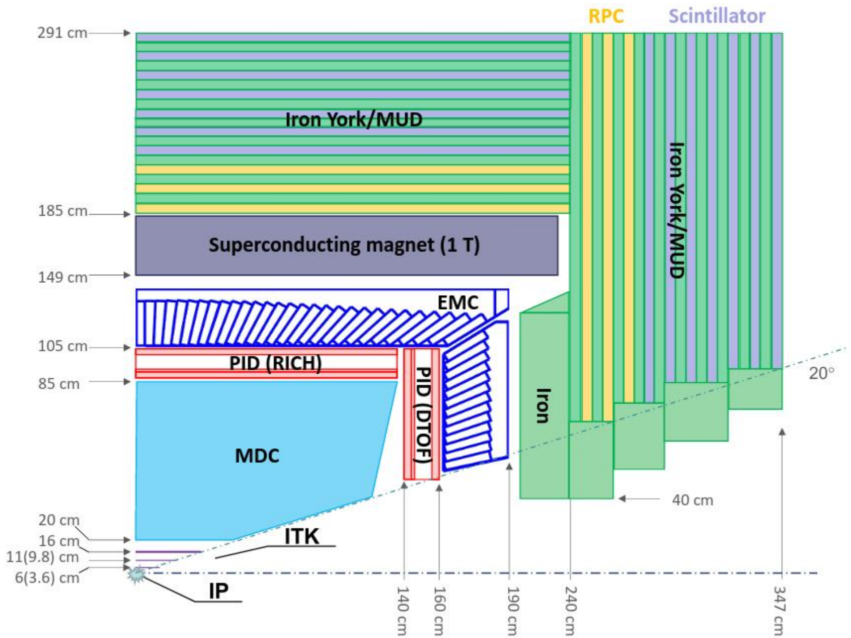
arXiv:2303.15790v2 [hep-ex] 30 Mar 2023

- A future e+e- collider in China operating at tau-charm region (s = 2~7 GeV) with peak lumi of 0.5×10^{35} cm^{-2} s^{-1} (>x50 of current BEPCII collider) to study:
  - c-quark and τ lepton physics
  - QCD and Hadron physics
  - Exotic decays and new physics beyond the SM

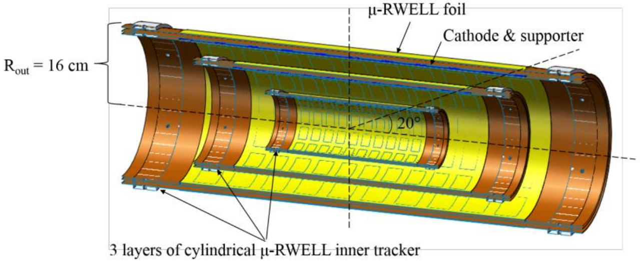
arXiv: 2303.15790

STCF tracking system

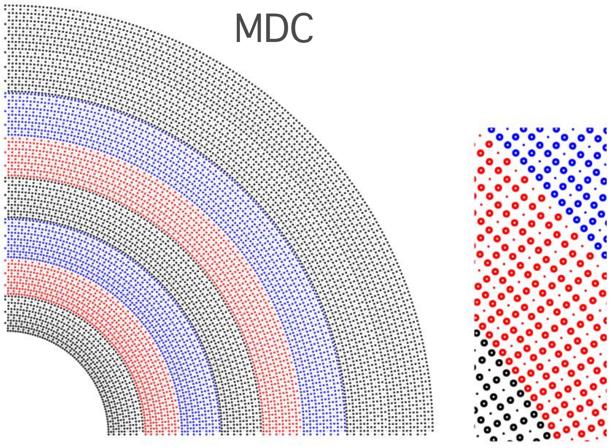
- The baseline tracking system includes uRWELL-based Inner Tracker (ITK) and Main Drift Chamber (MDC)
  - ITK: 3 layers, $\sigma_{r\text{-}\phi} \times \sigma_z \approx$ 100 um x 400 um
  - MDC: 48 layers, $\sigma_{\text{drift dist}} \approx$ 120~130 um



uRWELL-based ITK



MDC



(a) (b)

Figures from STCF CDR (arXiv: 2303.15790)

STCF tracking requirements

Momentum distributions of charged particles

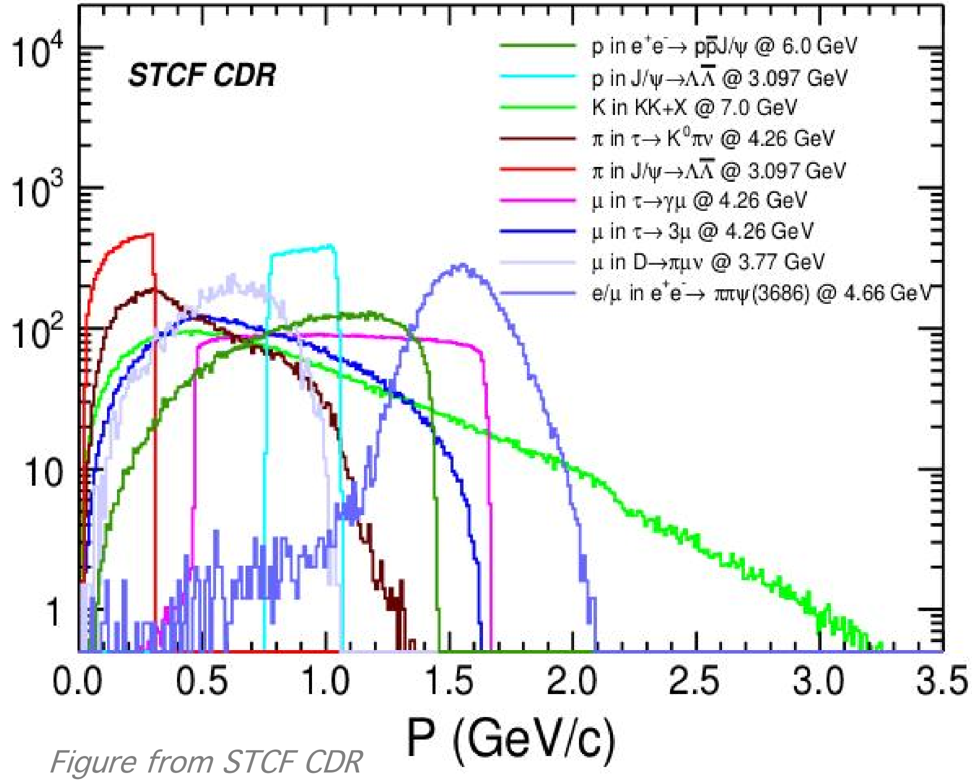
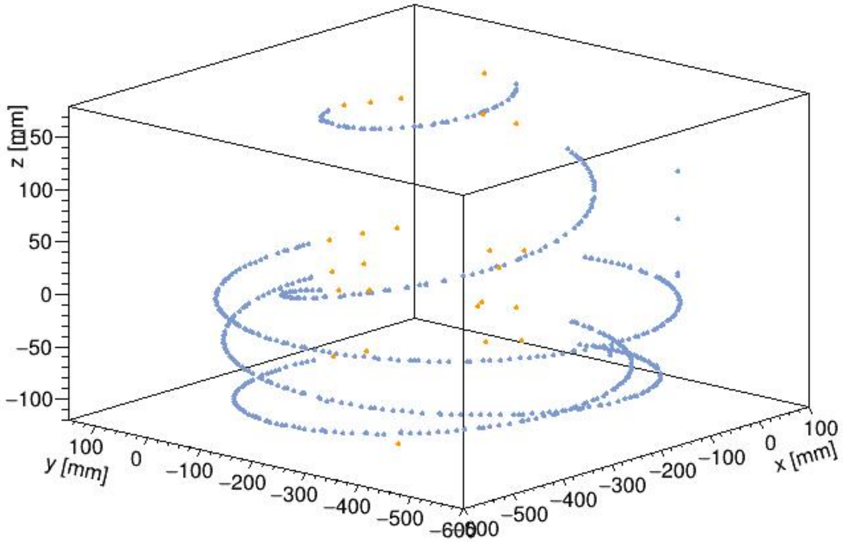


Figure from STCF CDR

Tracking low momentum particles is vital for various physics studies

- $\sigma(p)/p$ = 0.5% with p = 1 GeV
- Tracking eff. > 50/90/99 % with pt > 50/100/300 MeV
- dE/dx resolution: < 6%

An example of muon trajectory (p_T = 100 MeV, θ = 90°)



A Common 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

- **Modern C++ 17** (→20) concepts
- **Detector and magnetic field agnostic**
- Strict **thread-safety** to facilitate concurrency
- Minimal dependency (Eigen)
- Highly configurable, well documented and maintained

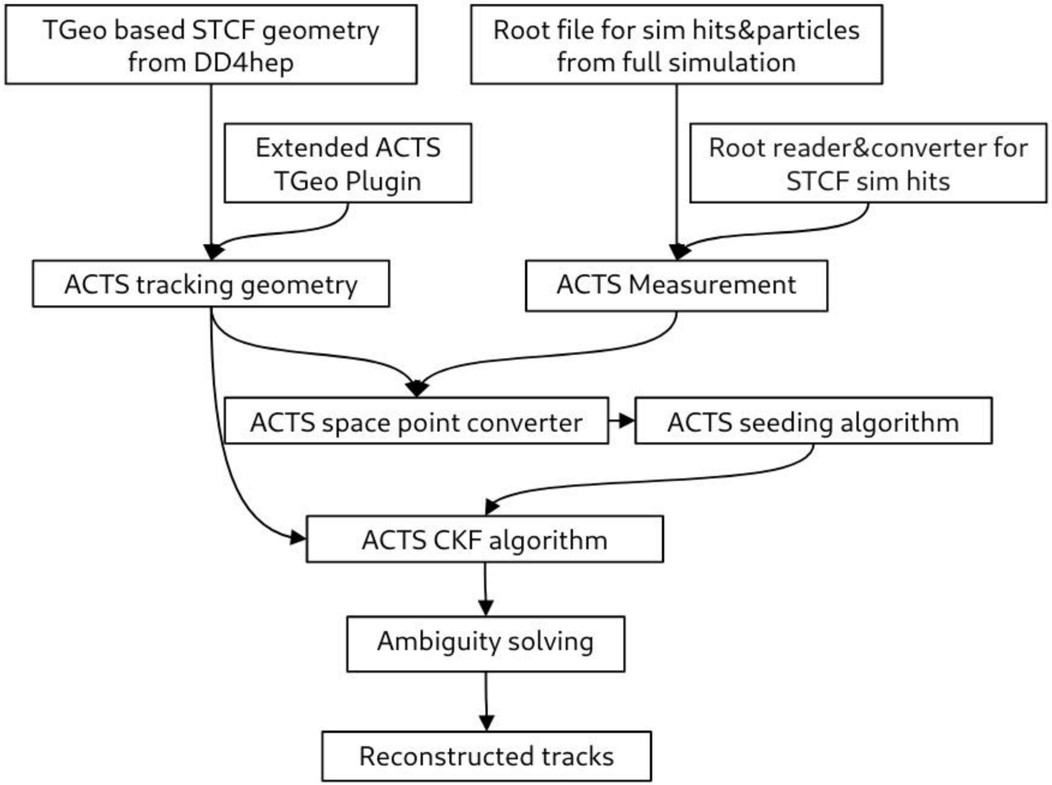
Github:
https://github.com/acts-project/acts
Readthedocs:
https://acts.readthedocs.io/en/latest/

See other talks related with ACTS:

- “Machine learning for ambiguity resolution in ACTS” by Corentin ALLAIRE
- “Kiwaku, a C++20 library for multidimensional arrays, applied to ACTS tracking” by Sylvain Joube
- “Flexible, robust and minimal-overhead Event Data Model for track reconstruction in ACTS” by Paul Gessinger
- “Potentiality of automatic parameter tuning suite available in ACTS track reconstruction software framework” by Rocky Garg

ACTS application strategies

- ACTS is designed with the capability to work for ITk + MDC at STCF (though limited application at e^+e^- colliders so far)
- STCF fullsim geometry is converted to ACTS tracking geometry using ACTS plugin
- Measurement creation: using Oscar Geant4 full sim hits as inputs, smeared with detector resolution
  - ITk : 100 um (r*phi) x400 um (Z)
  - MDC: 125 um (drift distance)

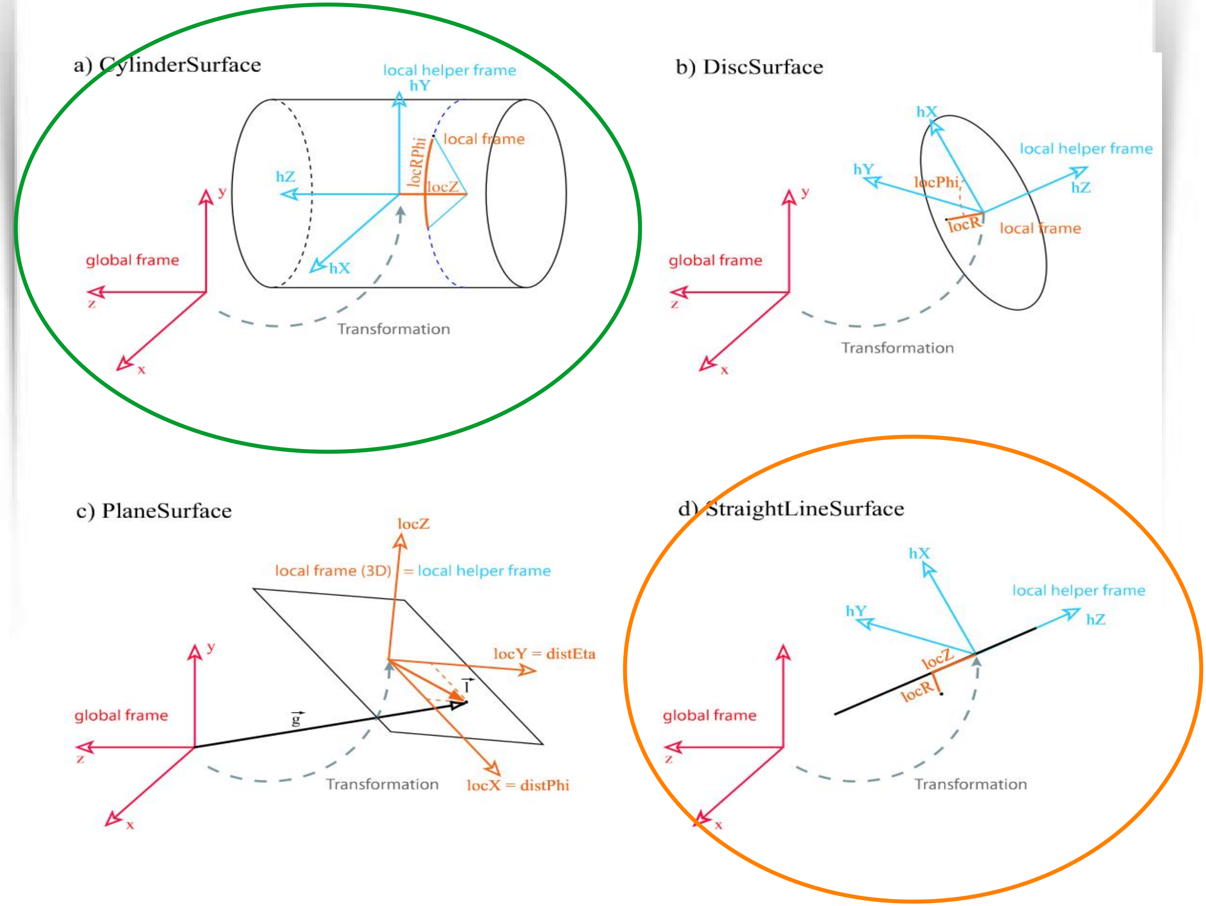


See my another talk about STCF offline software (Oscar)

ACTS tracking geometry for STCF

- Full sim geometry of STCF based on DD4hep is exported as ROOT TGeo
- TGeo then converted to ACTS tracking geometry by extended ACTS TGeo Plugin
  - Each layer of ITk is converted to an ACTS Layer with a sensitive CylinderSurface
  - Each layer of MDC containing N cells is converted to an ACTS Layer with LineSurfaces

Surface types in ATLAS SW & ACTS



Tracking chain

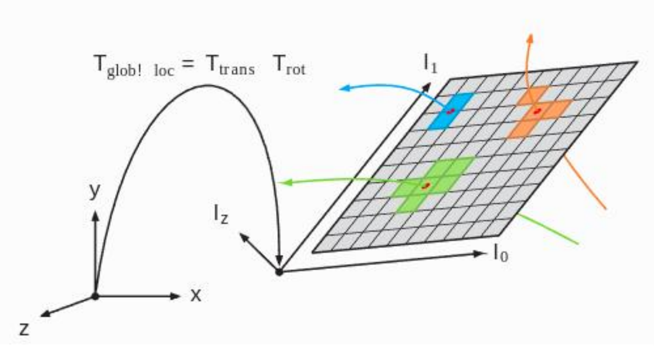
space point making
(ITk local coordinates→ 3D global coordinates)

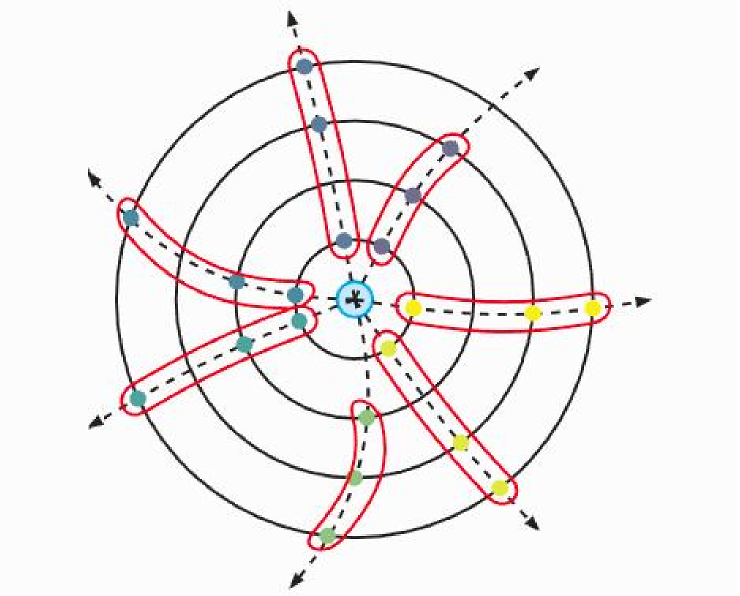
→

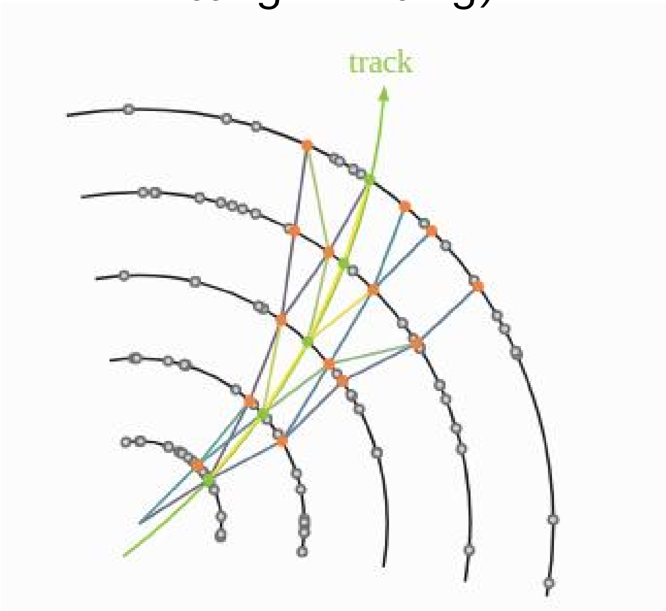
Seeding
(find seeds using hits on ITk layers)

→

Combinatorial Kalman Filter (CKF)
(simultaneous track fitting + finding)





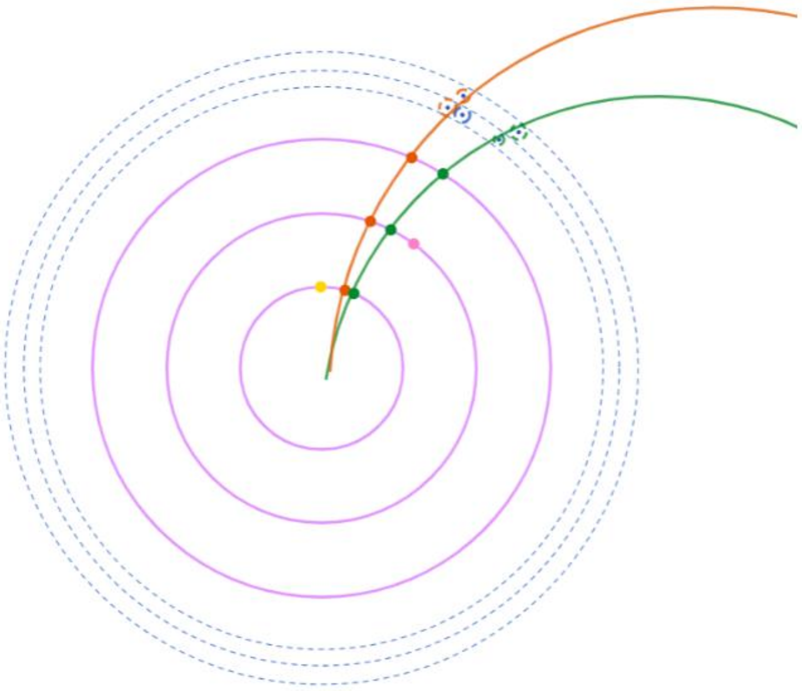


Figures from ACTS readthedocs

Automatic tuning of seeding parameters
(See talk by Rocky Garg)

CKF for STCF

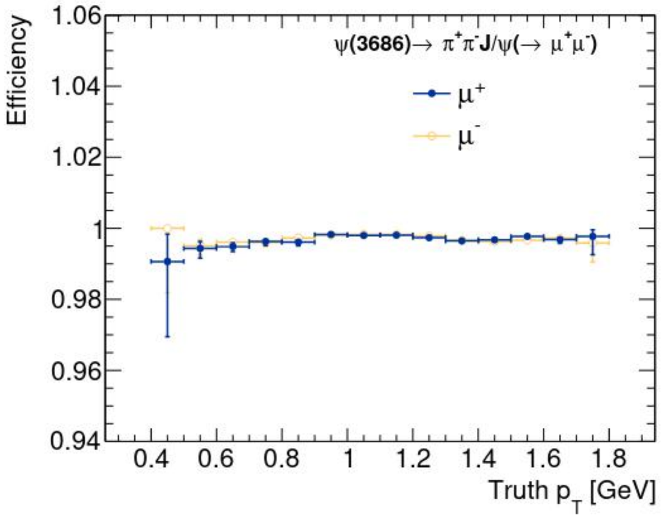
- Progressingly associate compatible hits to tracks based on prediction χ^2:
  $\chi^2 = r^T (HCH^T + V)^{-1} r$
  - r : residual
  - H: projection from track parameters to measurement
  - V: measurement covariance
- Currently, left/right sign of drift circle is taken to be the same as the predicted track parameters
  - Explosive combinatorics if considering two measurements with opposite signs for each drift distance

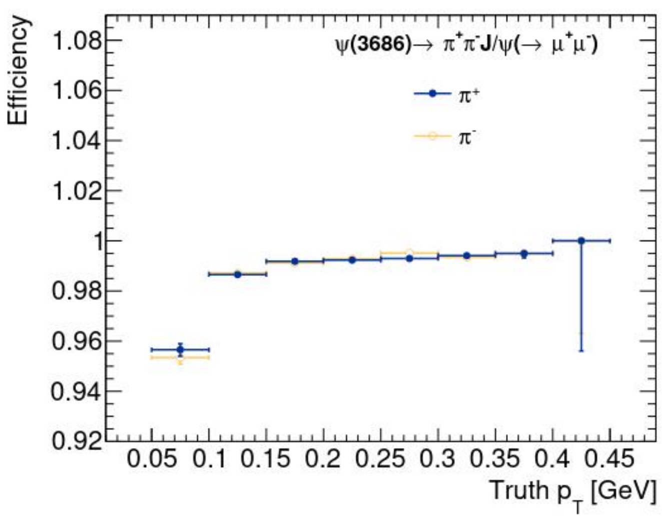


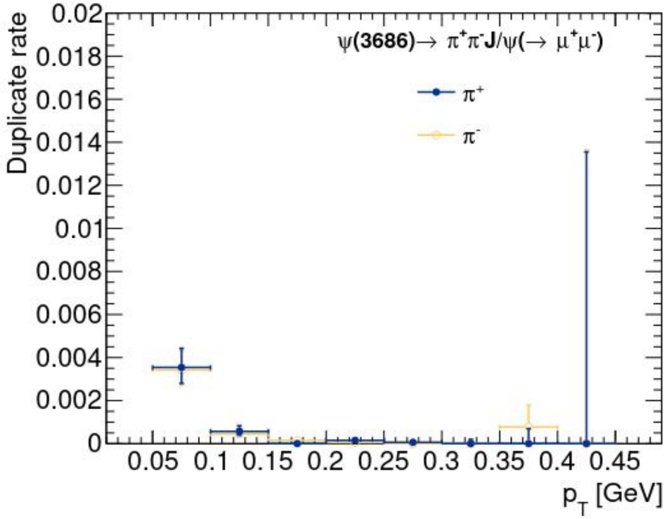
arXiv: 2301.04306

Track finding performance with ACTS

- Above 99% efficiency for p_T > 400 MeV
- 95% efficiency for pion with p_T in [50, 100] MeV
- <0.5% duplicate tracks for p_T < 130 MeV due to duplicate seeds for looping tracks
- Negligible fake tracks (<0.01%)







arXiv: 2301.04306

Track parameters resolution with ACTS

- CKF provides track parameters at specified target surface, e.g. beam line. No refitting is needed
- When θ = 90° ,
  - σ(d0) ≈ 150 um, σ(z0) ≈ 400 um
  - $\sigma(p_T)/p_T$ = 0.45%

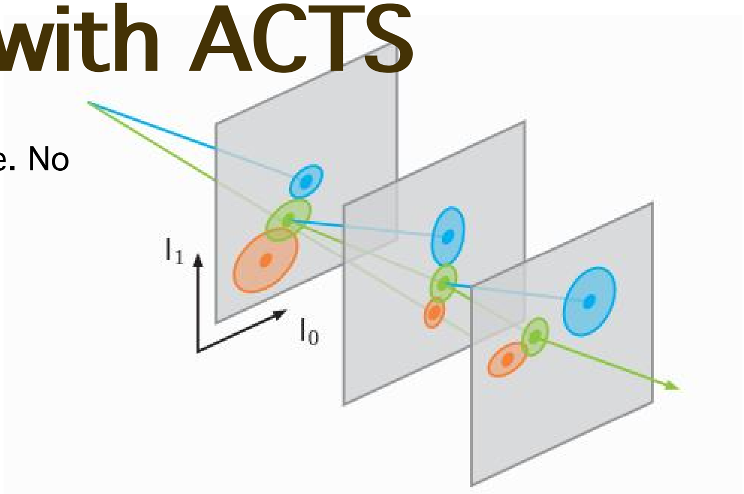
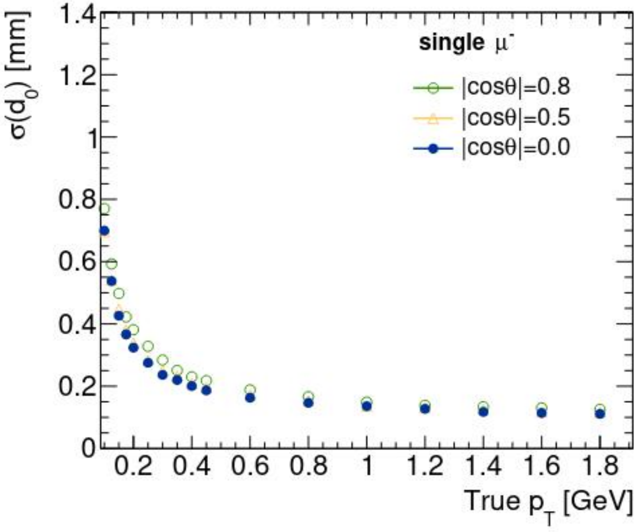
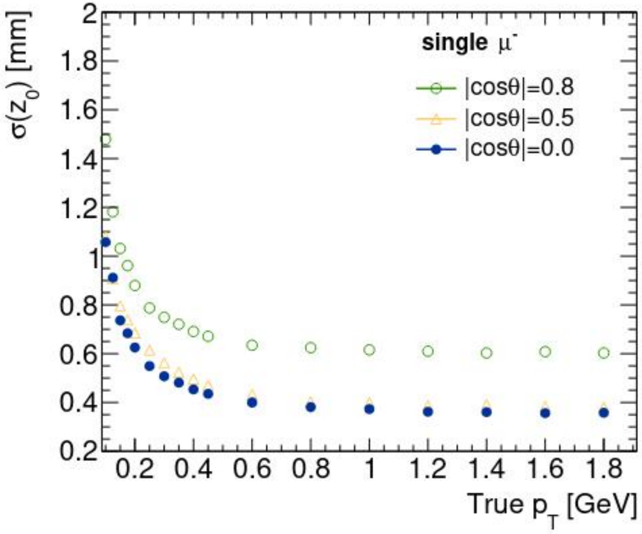
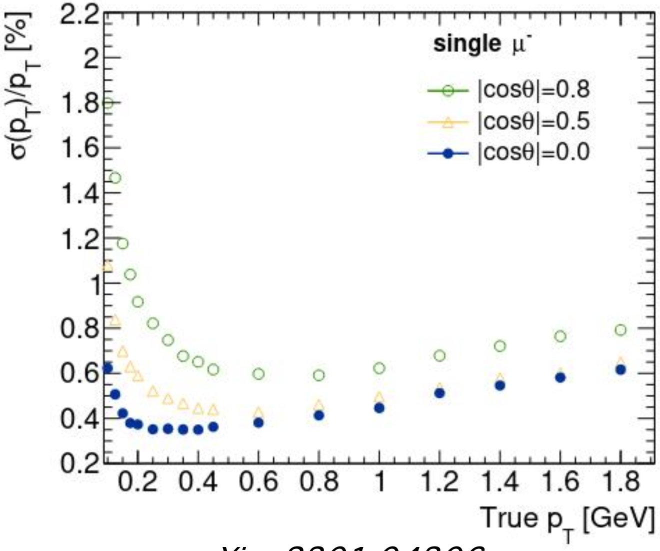


Figure from ACTS [readthedocs]()







arXiv: 2301.04306

Summary

- Efficient and accurate tracking software is needed by STCF to achieve its physics goals
  - Reconstruction of tracks with p_T down to 50 MeV is required
- ACTS has been implemented for track reconstruction at STCF
  - First application and validation of ACTS for a drift chamber
  - Promising tracking performance was achieved
    - 94% tracking efficiency with p_T in [50, 100] MeV
    - $\sigma(p_T)/p_T < 0.5\%$ with $p_T = 1$ GeV, $\theta = 90°$ is achieved
- Outlook:
  - Optimization of CKF performance for a drift chamber
  - Comparison with track finding based on Hough Transform

Back Up

Merits for track finding performance

A reconstructed track is assigned to the truth particle if the largest fraction of hits on the track is produced by this particle and if this fraction (P_{match}) exceeds a given assignment threshold, say 0.5.

- A particle (passing some fiducial cuts) is counted as reconstructed if there is at least one reconstructed track (passing some fiducial cuts) matched to it (e.g. $P_{match}>0.5$), i.e.

$$Tracking efficiency = \frac{N_{selected-recomatched particles}}{N_{selected particles}}$$

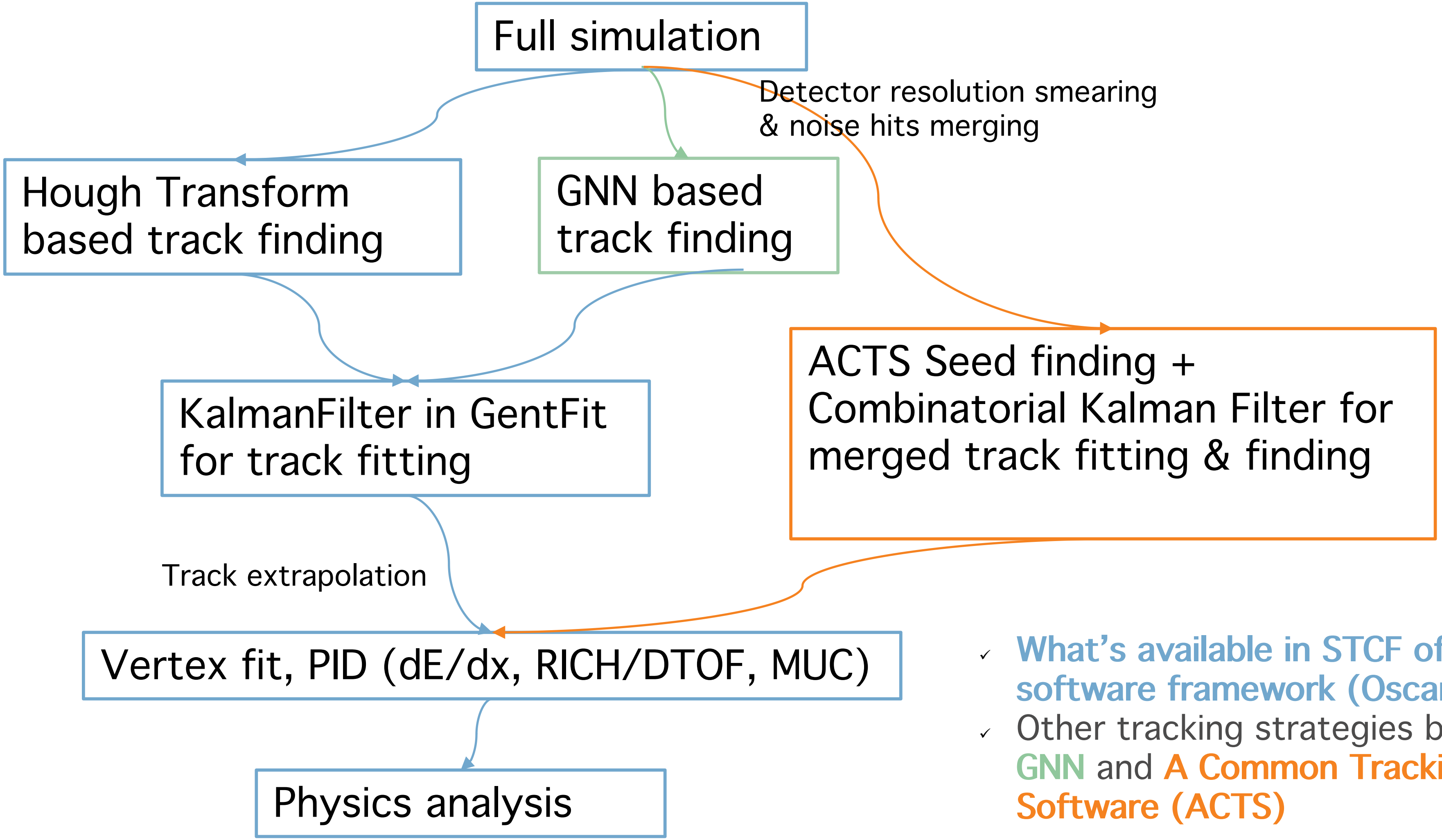
- A reconstructed track (passing some fiducial cuts) is referred to as a fake track if it can't be matched to a truth particle, i.e.

$$Fake rate = \frac{N_{selected reco tracks, non-matched}}{N_{selected reco tracks}}$$

- If a particle (passing some fiducial cuts) is matched more than one reconstructed tracks (passing some fiducial cuts), the best-quality track among them is tagged as the real reconstructed track and others are tagged as duplicate reconstructed tracks:

$$Duplicate rate = \frac{N_{selected reco tracks, matched, duplicate}}{N_{selected reco tracks, matched}}$$

STCF tracking landscape



- ✓ What's available in STCF offline software framework (Oscar)
- ✓ Other tracking strategies based on GNN and A Common Tracking Software (ACTS)