Performance of Track Reconstruction at STCF Using ACTS

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Abstract. The STCF physics program will provide an unique platform for studies of hadron physics, strong interactions and searches for new physics beyond the Standard Model in the τ-charm region. To deliver those physics programs, the charged particles at STCF are required to be reconstructed with high efficiency and excellent momentum resolution. In particular, charged particles with transverse momentum down to 50 MeV are required to be reconstructed. The tracking performance at STCF is studied using A Common Tracking Software (ACTS) based on the information of the STCF tracking system, a μRWELL-based inner tracker and a drift chamber. We demonstrated the first application of ACTS for a drift chamber. The implementation and tracking performance are presented.

1 Introduction

The Beijing Spectrometer (BESIII) [1] at the Beijing Electron Positron Collider (BEPCII) has had great success producing rich physics results about hadron spectroscopy, τ physics, CP violation and so on [2] in the τ-charm sector. The future τ-charm factory, Super Tau-Charm Facility (STCF) [3], with a luminosity two orders of magnitude higher (peak luminosity is above $0.5 \times 10^{35} \mathrm{cm}^{-2} s^{-1}$) than that at BEPCII and a center-of-mass energy range spanning from 2 to 7 GeV, aims to continue and extend the physics programs at BESIII in the post-BEPCII era.

To improve the performance of vertex reconstruction, particle identification and background suppression at STCF, which will have much increased luminosity than BEPCII, the charged tracks at STCF must be reconstructed with both high efficiency and high accuracy. As shown in Figure 1 from Ref. [3], the momentum of charged tracks spans as high as 3.5 GeV and there is a large fraction of charged tracks with momentum below 150 MeV at STCF. To maximize the physics potential at STCF, those low momentum tracks with momentum down to 50 MeV must be reconstructed with good efficiency.

A Common Tracking Software (ACTS) [4, 5] provides a tracking toolkit with a set of performant detector-independent and framework-independent modular tools for track reconstruction and vertex reconstruction for both High Energy Physics (HEP) and nuclear physics experiments. It has already been used for track reconstruction by a few HEP and nuclear physics experiments and demonstrated promising track performance [6, 7], for different types

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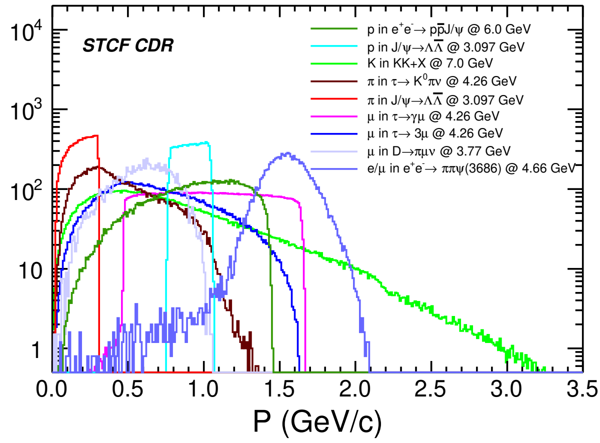

Figure 1. Momentum distributions of charged particles from various processes at the truth level, normalized to 104 entries (Figure taken from Ref. [3]).

of tracking detectors. However, so far, the performance of ACTS for a drift chamber is less validated.

In this study, ACTS is implemented for track reconstruction at STCF, which consists of a μRWELL [8]-based inner tracker (ITK) and a main drift chamber (MDC) as the tracking system. The tracking performance based on the ACTS Combinatorial Kalman Filter (CKF) [9, 10] is briefly presented. See Ref. [11] for more details about this study.

2 The STCF detector

As shown in Figure 2, the STCF detector consists of a tracking system composed of the ITK and the MDC, a particle identification (PID) system, an electromagnetic calorimeter (EMC), a superconducting solenoid (SCS) and a muon detector (MUD).

To achieve the physics goals of STCF, the STCF tracking system is required to provide a tracking efficiency above 99% (90%) for charged tracks with $p_T > 300$ (100) MeV, and a momentum resolution of $\sigma_{p_T}/p_T < 0.5\%$ in a 1 T magnetic field for charged tracks with $p_T = 1$ GeV.

For the ITK, a micro pattern gaseous detector based on μRWELL technology, which consists of three cylindrical layers located with the radii of 6, 11 and 16 cm, respectively, is proposed as the baseline option, while a silicon pixel detector based on the CMOS MAPS technology is considered as an alternative option. The ITK with the baseline option provides a spatial resolution around 100 μm in the r-ϕ direction and around 400 μm in the z direction. The MDC operated with the gas He/C_3H_8 (60/40) spanning from 200 to 820 mm in radius is adopted as the outer tracker. The MDC contains eight superlayers and each superlayer contains six layers of drift cells. The superlayers alternate between axial ("A") orientation, aligned with the direction of the beam line, and stereo ("U", "V") orientation. The eight superlayers are arranged in AUVAUVAA. The MDC is designed to provide a spatial resolution between 120 μm and 130 μm, and a dE/dx resolution around 6%.

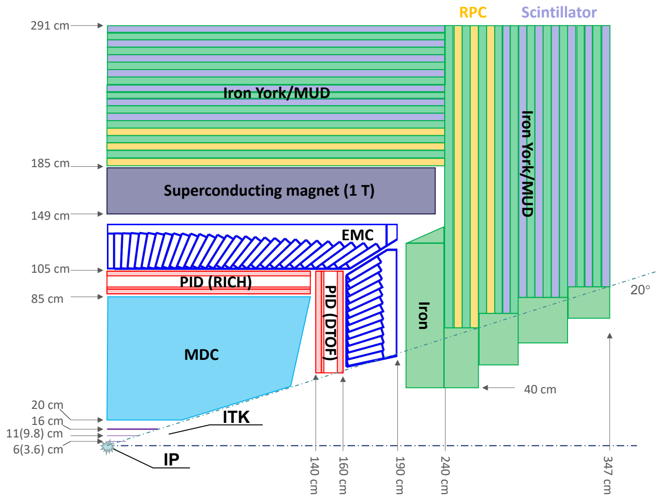

Figure 2. Schematic layout of the STCF detector. The number in brackets indicate the radii of the MAPS-based ITK (Figure taken from Ref. [3]).

3 STCF track reconstruction using ACTS

The strategies of using ACTS for track reconstruction at STCF are presented in this section.

3.1 Implementation of ACTS for STCF

The workflow of applying the ACTS tracking toolkit for tracking at STCF is shown in Figure 3. The STCF full simulation geometry is transcribed into ACTS tracking geometry using the ACTS TGeo [12] plugin, which has been extended for both ITK and MDC. The tube describing the ITK layer is transformed into the ACTS cylinder layer and the tube describing the signal wire of the MDC is transcribed into the ACTS line surface. The material of the full simulation geometry is associated to internal auxiliary surfaces of the ACTS tracking geometry using a dedicated material mapping tool [4].

The hits on ITK and MDC obtained from full simulation performed in the Offline Software System of Super Tau-Charm Facility (OSCAR) [13] are smeared based on the resolution of the detectors [1] and fed into ACTS using the extended ROOT-based reader in ACTS.

3.2 Tracking strategies for STCF

The ACTS CKF, which associates hits to tracks through track fitting, is used to find the tracks based on the seeds provided by the ACTS seed finding algorithm. The found tracks are filtered using an ambiguity solver based on the number of shared hits between two reconstructed tracks to remove incomplete or duplicate tracks.

Details of the ACTS seeding and CKF algorithms can be found in Ref. [4]. The criteria of seeding and CKF algorithms are optimized using the Optuna Hyperparameter optimization [14] approach implemented into ACTS. During the track finding, it's found that optimal number of branches allowed in CKF is one, which means that only the measurement which

[1] For the MDC, the resolution of the drift distance is set to be 125 μm in this study.

is most compatible with the track is associated to the track. The sign of the drift distance of the MDC is assumed to be the same as the sign of the predicted track parameters, which is sub-optimal and the Deterministic Annealing Filter [15] will be investigated for possible improvement.

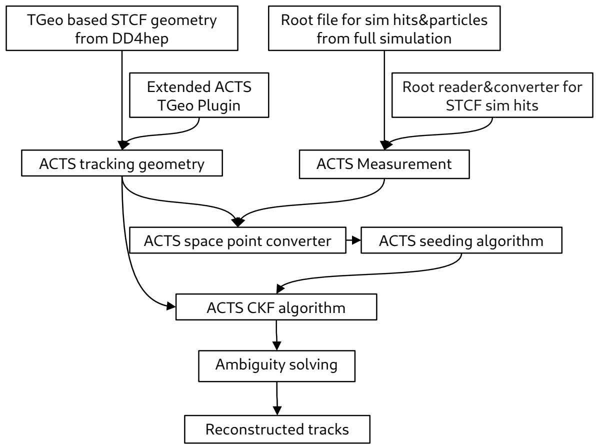

Figure 3. The workflow of applying ACTS for track reconstruction at STCF.

4 Tracking performance

The resolutions of the impact track parameters, d_0, z_0 and transverse momentum p_T at different p_T and polar angles for single μ and single π events are shown in Figure 4. It's found that the resolution of d_0, z_0 and relative resolution of p_T are about 150 μm, 400 μm and 0.45%, respectively, for μ^- and π^- tracks with p_T = 1 GeV and cosθ = 0.0.

The track finding efficiency, which is defined as the fraction of particles which have a matched reconstructed track, and the rate of duplicated tracks, which is defined as the fraction of reconstructed tracks which are tagged as duplicate (when a particle has multiple matched reconstructed tracks), for the μ and π in the $\psi(3686) \to \pi^+\pi^-J/\psi$ events, are shown in Figure 5. A track efficiency of above 99% for tracks with p_T above 150 MeV is achieved. For π with p_T in the range of [50, 100] MeV in this process, the tracking efficiency is about 95%. A small amount of duplicate tracks, about 0.4%, can occur for particles below 150 MeV due to looping particle trajectories. Figure 6 shows the track finding efficiency and the rate of duplicate tracks for the μ in the $e^+e^- \to \mu^+\mu^-$ events. For the μ with p_T above 100 MeV in those events, the tracking efficiency is above 99% with the rate of duplicate tracks below 0.5%.

5 Conclusion

Track reconstruction plays a crucial role for STCF to achieve its physics goals. ACTS, as a modern common tracking software, was implemented to perform track reconstruction for STCF. A tracking efficiency above 95% for tracks with p_T above 50 MeV in the process of $\psi(3686) \to \pi^+\pi^-J/\psi$ and $e^+e^- \to \mu^+\mu^-$ was achieved. For tracks with p_T > 150 MeV, the

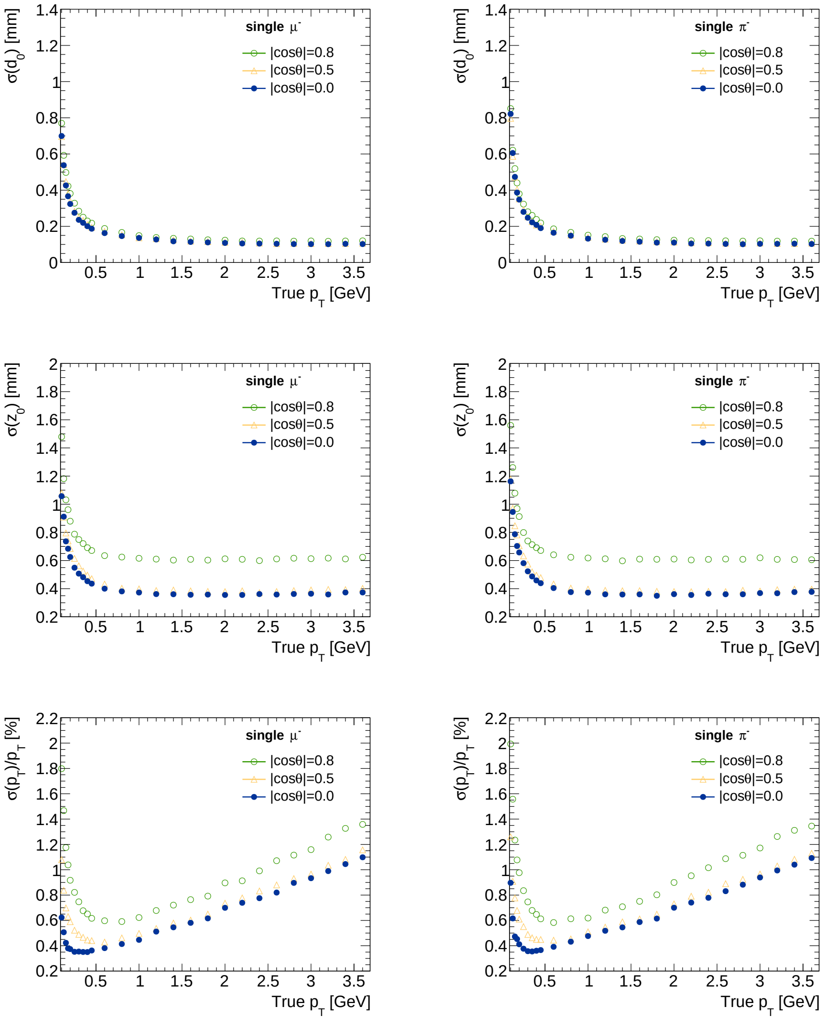

Figure 4. The resolution of d_0 (top panels), z_0 (middle panels) and relative resolution of p_T (bottom panels) for single μ^- (left panels) and single π^- (right panels) as a function of particle p_T. The blue dot, yellow triangle and green circle represent the results with $|\cos\theta| = 0.0$, 0.5 and 0.8, respectively. For each p_T and $|\cos\theta|$, a sample of 5k events is generated for the study.

tracking efficiency reaches 99%. The rate of duplicate tracks, which occur for particles with p_T below 150 MeV, was less than 0.5%. The $\sigma(p_T)/p_T$ was below 0.5% for particles with $p_T = 1$ GeV and $|\cos\theta| \leq 0.5$. The tracking performance achieved here meets the requirements of STCF [3]. However, no background hits were considered yet in this study. In a future study, the performance with background hits included will be investigated. Furthermore, the performance will be compared with other track finding strategy based on Hough Transform [16] and GenFit track fitting package [17] at STCF.

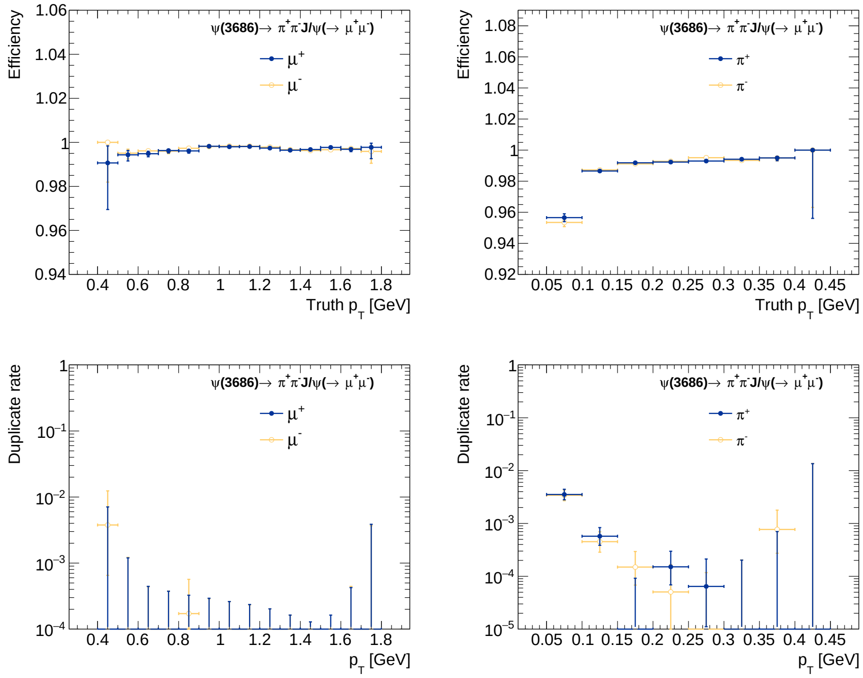

Figure 5. The tracking efficiency (top panels) and duplicate rate (bottom panels) with 100k $\psi(3686) \to \pi^+\pi^- J/\psi$, $J/\psi \to \mu^+\mu^-$ events as a function of p_T. The blue dot and yellow circle represent the results for positive charge particles and negative charge particles, respectively.

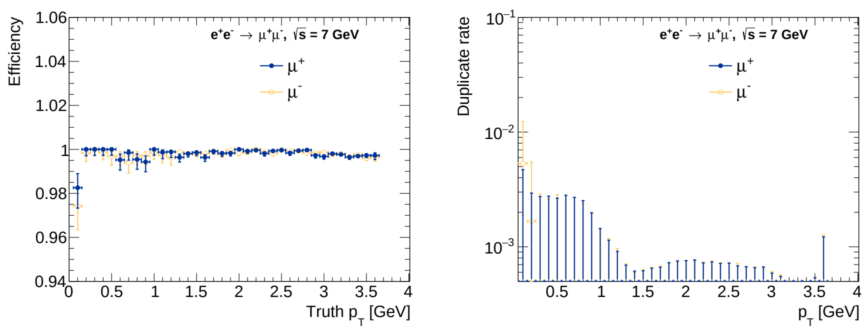

Figure 6. The tracking efficiency (left) and duplicate rate (right) of 100k $e^+e^- \to \mu^+\mu^-$ events as a function of p_T. The blue dot and yellow circle represent the results for μ^+ and μ^-, respectively.

Acknowledgement

The authors are grateful to the STCF group for the profitable discussions and express gratitude to the Hefei Comprehensive National Science Center for their strong support. This work is supported by the international partnership program of the Chinese Academy of Sciences (Grant No. 211134KYSB20200057) and the National Natural Science Foundation of China (Grant No. 12025502).

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