Application of ACTS for drift chambers

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Abstract. Track reconstruction is a complex and time-consuming task in HEP event processing. It will become even more challenging in future HEP experiments with much increased combinatorics. ACTS aims to provide a set of performant track reconstruction modules for both current and future HEP experiments. While ACTS has already been deployed for data production with silicon tracking detectors at a few experiments, its application for gaseous tracking detector is still being explored. In this study, ACTS has been developed and applied for drift chambers with its performance evaluated with two prototype drift chambers at two proposed future electron-positron particle collider experiments, the Circular Electron Positron Collider (CEPC) and the Super Tau Charm Factory (STCF).

1 Introduction

To maximize the precision of Standard Model (SM) measurements and sensitivity to New Physics (NP) at future High Energy Physics (HEP) experiments, where more complicated tracking environment with both increased track multiplicity and extended fiducial phase space of the particles is foreseen, reconstruction of the trajectories of charged particle, i.e. tracking, with both good efficiency and precision, becomes particularly important. While HEP tracking detectors can have different geometry and detector technologies, the core tracking algorithms of experiments have much in common. See Ref. [1] for a review of the common tracking strategies in HEP and nuclear physics experiments.

A Common Tracking Software (ACTS) [2] is an open-source tracking software which provides a set of modular algorithms or tools, which are abstracted from the details of the detector technologies and geometry, for track reconstruction and vertex reconstruction for both HEP and nuclear physics experiments. Tracking performance of ACTS using measurements of silicon tracking detectors constructed with planar sensitive modules, has been well validated by both on-going experiments [3, 4, 5] and proposed future experiments [6, 7]. In this study, ACTS has been explored for reconstructing tracks using measurements which are partially provided by a drift chamber. The prototype drift chambers proposed for two future electron-positron particle collider experiments, Circular Electron Positron Collider (CEPC) [8] and Super Tau Charm Factory (STCF) [9], are used for the tracking performance evaluation [10, 11].

2 Tracking system at CEPC and STCF

The tracking system layout of the 4^{th} conceptual detector of CEPC is shown in Fig. 1, which is composed of the VerteX Detector (VXD), Silicon Internal Tracker (SIT), Drift Chamber (DC), Silicon External Tracker (SET) and Forward Tracking Detector (FTD). The VXD, SIT, SET and FTD are all silicon trackers using either pixel or microstrip sensor technology. The DC has the radial range from 800 mm to 1800 mm and half length of 2980 mm in the Z direction. The cell size is 18 mm $\times$ 18 mm with single wire resolution about 110 μm. The DC is composed of only stereo wires, which are grouped into 55 layers. The stereo angle ranges from 0.028 to 0.062 rad, with the stereo angles for any two neighboring layers having opposite sign.

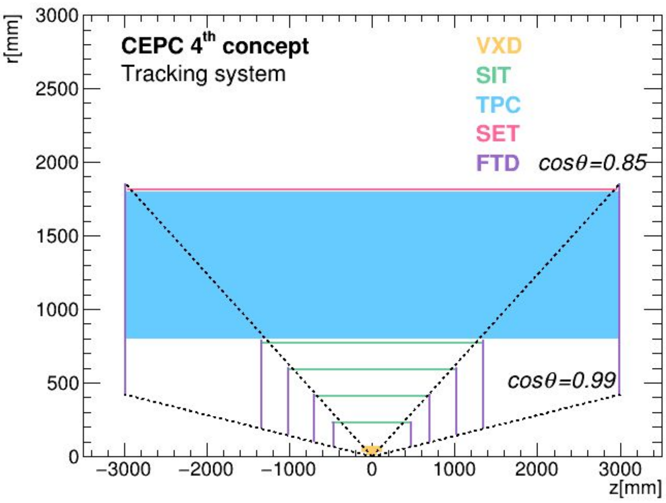

Figure 1: Schematic view of the tracking system of the CEPC 4^{th} conceptual design.

The STCF tracking system is composed of an Inner Tracker (ITK) and a Main Drfit Chamber (MDC), as shown in Fig. 2. The baseline option of the ITK is micro pattern gaseous detector based on μRWELL technology, while a silicon pixel detector based on the CMOS MAPS technology is considered as an alternative option. 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.

3 Description of drift chamber in ACTS

In ACTS, the tracking detector geometry used for track reconstruction, i.e. tracking geometry, is simplified from the detailed detector description used in full simulation. The ACTS tracking geometry is built from the surface objects, which is the fundamental building block of ACTS tracking geometry. The surface can be either a real detector surface such as the planar surface of a silicon detector or a virtual surface such as the line surface[1] used to describe a track near an anode wire in the drift chamber and the perigee surface used to describe a track near a vertex.

ACTS provides plugins to translate a geometry from an existing representation, such as DD4Hep [12], ROOT TGeo [13], GeoModel [14] and Geant4 [15], into ACTS tracking geometry. The TGeo plugin can collect the sensitive nodes of the detector described by TGeo and transform each of them into an ACTS

[1]Suppose the wire has a direction of $\vec{w}$ and the track direction is $\vec{t}$ in the global coordinate frame, the x axis and y axis in the local coordinate frame of a line surface is $\vec{w} \times \vec{t}$ and $\vec{w}$, respectively

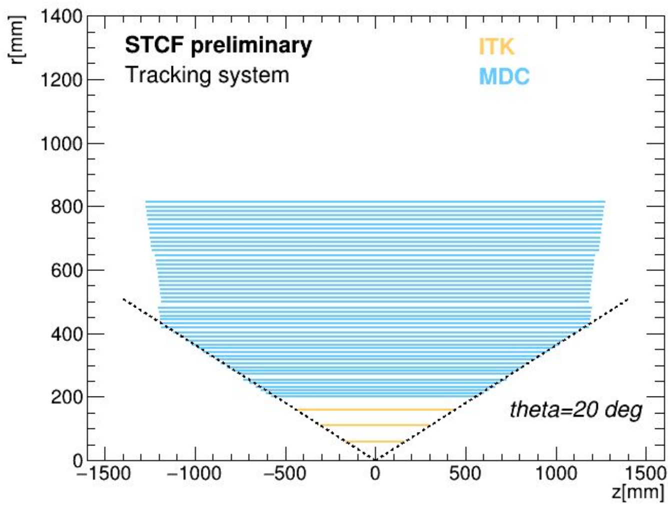

Figure 2: Schematic view of the tracking system of the STCF. The ITK with the μRWELL approach is shown here.

surface object according to the type of the detector. For instance, each signal wire of the drift chamber will be transformed into an ACTS line surface. The transformed surface objects will be grouped into individual ACTS layers where the surfaces in one ACTS layer have same radii or global Z coordinates.

The material mapping tools [2] in ACTS can associate material of the full simulation geometry to internal auxiliary surfaces of the ACTS tracking geometry. The material of the drift chamber is mapped to concentric cylinder layers. Fig. 3 shows a comparison of the mapped material with the material used in the full simulation geometry for CEPC and STCF. The material budget described in Geant4 and ACTS tracking geometry agrees well in the central region and can be improved in the endcap/forward fiducial regions by using finer binning of the material maps.

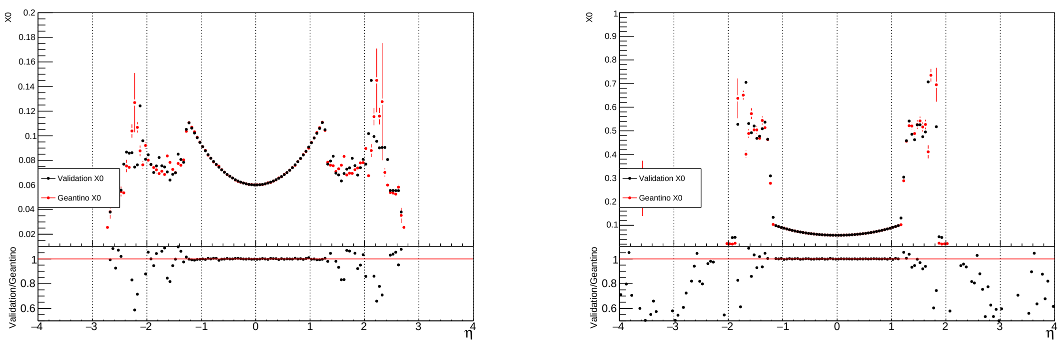

Figure 3: Comparison of the mapped material obtained from ACTS material mapping tool (black) and the Geant4 material (red) as a function of η for the CEPC (left) and STCF (right).

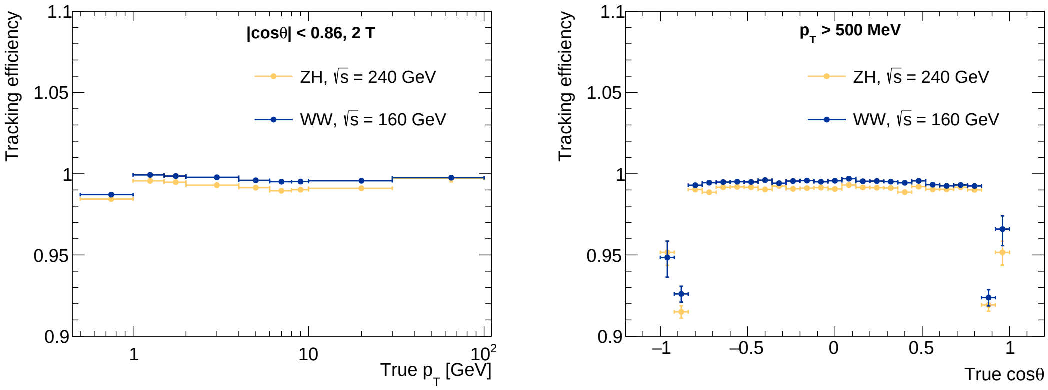

Figure 4: The tracking efficiency of ZH (yellow) and WW (blue) events as a function of particle p_T (left) and cosθ (right) at CEPC.

4 Performance studies

The samples for tracking performance studies are generated using the STCF offline software [16] for STCF and using ACTS Fast simulation tool [2] for CEPC. A uniform magnetic field of 2 T and 1 T is used for CEPC and STCF, respectively, in the simulation.

The generated simulated hits are smeared with the detector resolution to emulate the measurements. The two-dimensional measurements from the inner track are transformed into three-dimensional space points. The space points in the first few layers of the inner tracker are used to find seeds, which are three measurements that are likely to be detector responses to the same particle. The seeds are further used to find the tracks using track following algorithm based on the Combinatorial Kalman Filter, which performs track finding through track fitting based on Kalman Filter therefore requires no subsequent refitting.

The tracking efficiency for two benchmark processes at CEPC, ZH and WW, are shown in Fig. 4. It's found that the tracking efficiency is above 98% for particles with $p_T > 1$ GeV in the CEPC barrel region ($|\cos\theta| < 0.86$).

The tracking efficiency for the μ and π in the $\psi(3686) \to \pi^+\pi^- J/\psi$ events at STCF, are shown in Fig. 5. A track efficiency of above 99% for tracks with p_T above 150 MeV is achieved.

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 at STCF are shown in Fig. 6. 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 cos$\theta = 0$.

5 Conclusion

Using the prototype drift chambers at future particle physics colliders, CEPC and STCF, the tracking performance of ACTS for drift chambers has been validated with the drift chamber represented as a couple of concentric layers filled with drift wires represented by ACTS line surfaces. Meanwhile, an open drift chamber is being implemented into the Open Data Detector [17], which will provide a useful platform for developing common tracking algorithms dedicated to the drift chambers.

Acknowledgments

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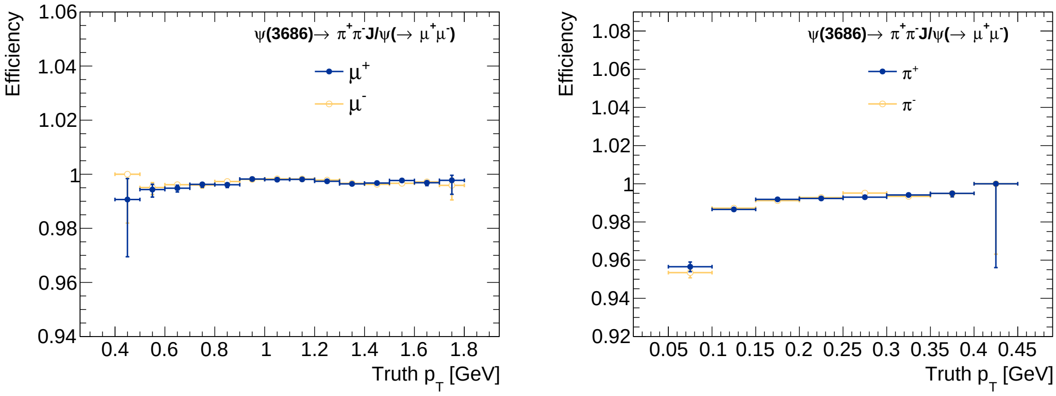

Figure 5: The tracking efficiency of μ (left) and π (right) in $\psi(3686) \to \pi^+\pi^- J/\psi$, $J/\psi \to \mu^+\mu^-$ events as a function of p_T at STCF. The blue dot and yellow circle represent the results for positive charge particles and negative charge particles, respectively.

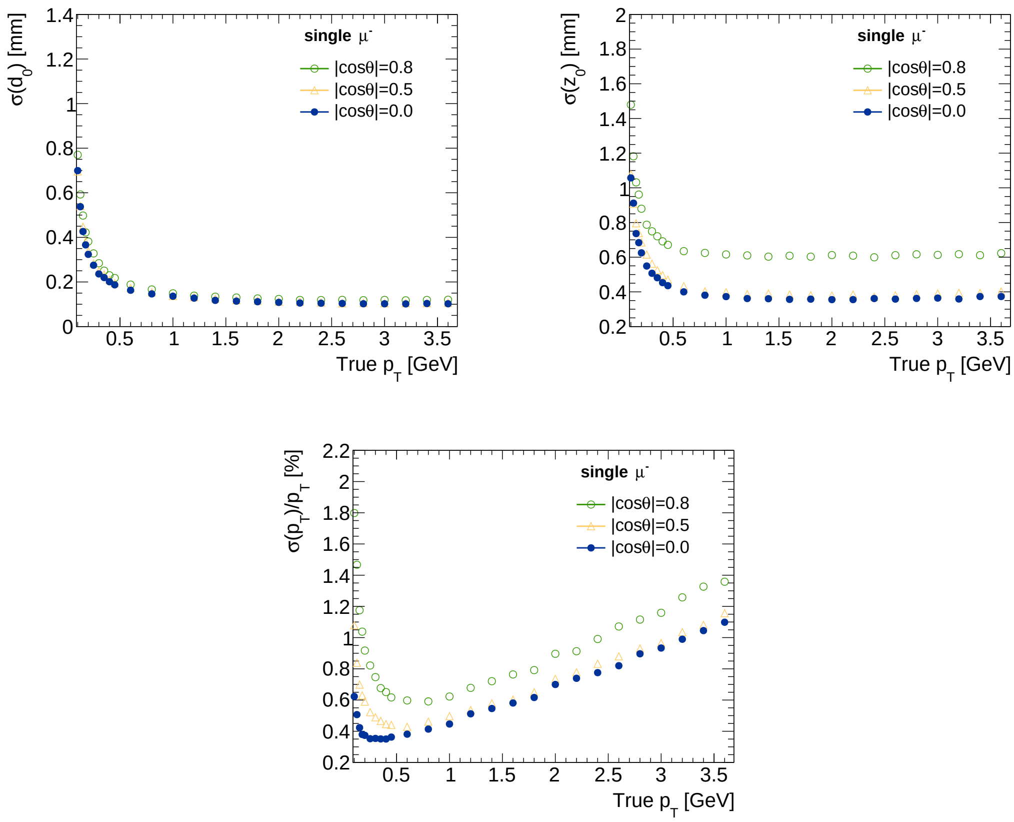

Figure 6: The resolution of d_0 (top left), z_0 (top right) and relative resolution of p_T (bottom) for single μ^- as a function of particle p_T at STCF. The blue dot, yellow triangle and green circle represent the results with $|\cos\theta| = 0$, 0.5 and 0.8, respectively.

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