

Track Fitting with GENFIT2 for STCF experiment

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Abstract

Track fitting is a key step in charged particle reconstruction at the Super Tau-Charm Facility (STCF), where tracks cover a wide momentum range and detector background is non negligible. In this work, the GENFIT2 toolkit is integrated into the baseline reconstruction chain of the STCF offline software framework, and the deterministic annealing filter (DAF) is adopted as the default track fitting algorithm. The DAF is applied to reduce the influence of background hits and to obtain reliable estimates of track parameters. The fitting performance is studied based on full detector simulation. The results show stable track parameter resolutions over a broad momentum range under different background conditions, which is suitable for detector optimization and physics performance studies at STCF.

Full Text

Preamble

Track Fitting with GENFIT2 for the Super Tau-Charm Facility* Zhen-Na Lu,¹ Hang Zhou,^{2, 3} Xiao-qian Jia,⁴ Xiao-Cong Ai,⁵ Xiao-shuai Qin,⁴ Xing-Tao Huang,⁴ Jian-Bei Liu,^{2, 3} and Jin Zhang^{1, †}

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key step in charged particle reconstruction at the Super Tau-Charm Facility (STCF), where tracks cover a wide momentum range and detector background is non negligible. In this work, the GENFIT2 toolkit is integrated into the baseline reconstruction chain of the STCF offline software framework, and the deterministic annealing filter (DAF) is adopted as the default track fitting algorithm. The DAF is applied to reduce the influence of background hits and to obtain reliable estimates of track parameters. The fitting performance is studied using single particle samples and the $\psi(3686) \rightarrow \pi + \pi - J/\psi$, $J/\psi \rightarrow \mu + \mu -$ decay channel based on full detector simulation. The results show stable track parameter resolutions over a broad momentum range under different background conditions, which is suitable for detector optimization and physics performance studies at STCF.

Keywords

STCF, track fitting, GENFIT2, deterministic annealing filter

characterized by a broad momentum spectrum, ranging from 50 MeV/c to 3.5 GeV/c, with a substantial fraction of tracks 32 below 400 MeV/c as shown in Fig.1.

The Super Tau-Charm Facility (STCF) [1, 2] is the next 3 generation electron-positron collider in China, currently in 4 the technical design phase. It is intended for precision stud33 At the stage of STCF detector design and optimization, 5 ies of hadron structure and the properties of non-perturbative 34 reliable evaluation of detector performance and physics po6 strong interactions, as well as exploring the asymmetry be35 tential relies on a complete reconstruction chain under real7 tween matter and antimatter, and searching for particles and 36 istic experimental conditions. In previous studies, a Hough8 physics beyond the Standard Model [3]. It is designed to op37 transform-based track finding algorithm has been developed 9 erate in a center-of-mass energy range from 2 to 7 GeV/c, 38 in STCF [19], achieving high efficiency under background 10 with a peak luminosity of about $5 \times 10 \text{ cm}^{-2} \text{ s}^{-1}$ at 39 conditions and detector hit inefficiencies. The accurate de $\sqrt{s} = 4 \text{ GeV/c}$, providing a significantly higher luminosity 40 termination of track parameters depends on the track-fitting 12 and an extended energy coverage compared with BEPCII/BE41 stage, particularly under the high-background conditions as13 SIII [4, 5]. The high luminosity and wide energy coverage of 42 sociated with high-luminosity operation. This work focuses 14 STCF improve the statistical precision of physics observables 43 on the implementation and performance study of track fitting 15 in the τ -charm region, while also imposing greater demands 44 in the STCF reconstruction workflow. 16 on detector performance and event reconstruction.

In this context, charged particle tracking [6] plays a cen45 Track fitting at STCF needs to perform robustly in the pres18 tral role in the reconstruction chain and directly impacts the 46 ence of background and to accommodate changes in detector 19 determination of particle momenta and interaction vertices. 47 ge-

ometry during detector optimization. The GENFIT2 [20] In general, tracking involves track finding for hit associa48 toolkit is introduced in the STCF reconstruction software, as 21 tion and track fitting for the precise determination of the 49 it provides an experiment-independent interface to detector 22 track parameters. Track finding employs local approaches, 50 geometry and material description, and has been successfully 23 such as pattern recognition [7-10], combinatorial kalman fil51 used in experiments such as BelleII [21], and PANDA [22]. 24 ter (CKF) [11, 12], as well as global approaches based on 52 Its modular design supports track propagation in magnetic 25 the Hough transform [13, 14]. Track fitting typically relies 53 fields and detector material [23, 24], as well as established 26 on Kalman filter [15] and nonlinear filtering methods, includ54 fitting approaches such as Kalman filter and the DAF. These 27 ing deterministic annealing filter (DAF) [16, 17] and gaussian 55 features allow the track-fitting procedure to be configured for 28 sum filter (GSF) [18]. At STCF, these track finding and fit56 the specific detector configuration and experimental environ29 ting approaches must operate under challenging conditions 57 ment. In this work, GENFIT2 is adopted and optimized for 58 the STCF baseline reconstruction and performance is studied. 59 The paper is organized as follows. Section II gives a brief in* This work was supported by the National Natural Science Foundation of 60 troduction of the STCF detector. Section III provides the imChina (Nos.12375197, 12341504, 12375194, 12175124, 12025502). 61 plementation and studies of GENFIT2 in STCF. Section IV † Corresponding author, zhangjin5@mail.sysu.edu.cn 62 presents the track fitting performance in STCF.

INTRODUCTION

The STCF tracking system consists of ITK and MDC. ITK is located close to the beam pipe covering a polar angle range 82 of 20° -160°. It copes with the high counting-rate environ83 ment in this region and to improve the precision of vertex re84 construction. Two technological options have been proposed 85 for the ITK during the conceptual design phase, based on μ 86 RWELL detectors [28, 29] as a baseline and monolithic active 87 pixel sensors (MAPS) [30] as an alternative option. In this 88 work, detector description and performance studies are based 89 on the μ -RWELL ITK configuration adopted in the current 90 STCF baseline design. The μ -RWELL-based ITK consists of 91 three cylindrical layers placed at radii of 60, 110, and 160 mm 92 from the beam axis. Each layer has a thickness of approxi93 mately 6.5 mm and provides a spatial resolution of approxi94 mately 100 μ m in the r - ϕ direction and about 400 μ m along 95 the z direction.

MDC is located outside the inner tracker and provides the benchmark physics processes at STCF. 97 main tracking volume at larger radii for momentum measure98 ment. It operates with a He/C3 H8 (60/40) gas mixture and 99 covers a radial range from 200 mm to 840 mm. The cham100 ber consists of eight super-layers, each consisting six layers 101 of drift cells. From the innermost to the outermost region, the 102 super-layer configuration follows the

sequence AUVAUVAA. The axial layers (“A”) are parallel to the beam axis, while the stereo layers (“U” and “V”) are inclined with respect to the beam axis, providing additional spatial information along the beam direction. The MDC provides spatial resolutions ranging from 120 μm to 130 μm .

IMPLEMENTATION AND STUDIES OF GENFIT2 IN

This section describes the baseline track fitting strategy of the STCF offline software, based on the GENFIT2 framework. The Offline Software System of the Super Tau-Charm experiment for detector design studies, performance evaluation, and physics studies. It comprises external libraries (such as DD4hep [33], PODIO, ROOT, and Geant4, core software for II. STCF DETECTORS AND THE TRACKING SYSTEM) data-processing, and applications specific to the STCF experiment.

The layout of the STCF detector system is shown in Fig. 2 [Figure 2: see original paper]. For physics simulation and algorithm validation, high precision event generators including KKMC [34] and EVTGEN [35] are used to model τ -charm processes. Starting from the interaction region and moving outward, the detector comprises a tracking system composed of an Inner Tracker (ITK) and a Main Drift Chamber (MDC). Particle identification is provided by a geometry is described with DD4hep using XML-based [36] ring-imaging Cherenkov detector (RICH) [25] and a DIRC-like time-of-flight detector (DToF) [26] in both the barrel and endcap regions. The detector includes a homogeneous electromagnetic calorimeter (EMC) [27], a superconducting solenoid with an axial magnetic field of 1 T, and a muon detector (MUD) located at the outermost region. The particle identification system provides separation of charged hadrons with momentum from 700 MeV/c to 2 GeV/c. The electromagnetic calorimeter measures the energy and direction of standard track fitting component of the baseline reconstruction chain, as illustrated in Fig. 3 [Figure 3: see original paper]. Track candidates produced by the upstream tracking algorithms, including GNN-based methods provides additional information for muon identification.

hit filtering [37] and Hough-transform-based track finding, are fed to GENFIT2, providing initial track parameters together with associated candidate hits.

Event Generation

Geometric Parameters

Full Simulation

Geant4 Geometry

DD4hep

Measurements Hit pre-filtering (GNN)

Hough Track Finding

Magnetic Field

Geometry

GENFIT Tracking Geometry

GENFIT Tracks

GENFIT Track Fitting

Candidate Tracks

u and v) for a wirebased drift detector [39].

proach (POCA) to the origin in the x - y plane. The detector geometry used for track fitting is described [136] with DD4hep and transferred to GENFIT2 via the ROOT [172]. z_0 is the distance in the z direction to the POCA. [137] TGeo geometry [38]. The same geometry description is used. θ_0 is the angle between the tangent to the helix at the [138] consistently in simulation and track fitting. Material information [173] POCA in the x - y plane and the x axis. [139] mation is passed together with the geometry and handled by [174] [140] the internal material-effects model of GENFIT2. The consistency [175]. $\tan \lambda$ is the tangent of the dip angle. λ takes values [141] tency between the geometry and material descriptions affects between 0 and π . $\tan \lambda$ is equal to dz/ds , where s is [142] the accuracy of the fitted track parameters, as material effects the arc length. [143] enter directly into track propagation. The magnetic-field information [144] formation is also provided through the interface and used during [178]. κ is the signed curvature of the helix in the x - y plane. [145] ing track propagation.

ITK hits are converted into PlanarMeasurement objects [179] This parameterization is used for storing reconstructed tracks [147] in GENFIT2 for track fitting.

Each hit is associated with [180] and for subsequent performance studies and physics analyzes [148] a local detector plane, where the measurement and covariance [181] within OSCAR. During track fitting, for track extrapolation [149] ance matrix are defined in the local coordinate system. For [182] through the detector geometry, magnetic field, and material [150] MDC measurements, the WireMeasurement representation of [183] rial, GENFIT2 uses an internal seven-dimensional track state [151] GENFIT2 is used. MDC measurements are associated with a [184] (x, T, pq) which is composed of the position x , the momentum [152] sense wire and a drift distance, and the virtual detector plane [185] tum direction unit vector T and charge over momentum of [153] is therefore constructed dynamically for each track extrapolation [186] the track. For consistency with the OSCAR framework, the [154] lation during the fitting process. The virtual detector plane [187] fitted

track state is converted at the point of closest approach 155 is defined by the sense wire and the point of the closest approach 188 with respect to the z-axis into the five-parameter helix representation 156 approach between the track and the sense wire. In this plane, a representation used in OSCAR. The corresponding covariance matrix 157 local coordinate system is constructed, where the basis vector 190 matrix is transformed at the same point and provided together 158 v is aligned with the wire direction and the orthogonal vector 191 with the track parameters as the final reconstruction output. 159 u is defined perpendicular to the wire, as depicted in Fig.4. 160 Once the plane is defined, each MDC hit is represented by 161 a WireMeasurement object that contains both left and right B. Track fitting with Deterministic Annealing Filter 162 measurements on the plane, as well as the associated covariance matrix in the local plane. The measurements are then in the high-luminosity environment of STCF, the detector 164 passed to the track fitting stage and the left-right ambiguities 194 operates with a non-negligible background occupancy. Duration 165 of these measurements are resolved with DAF.

In the OSCAR framework, track states are provided in a 195 track finding, hits spatially close to the particle trajectories 196 may be included in track candidates. Such hits can remain 167 unified five-parameter helix representation, defined by d_0 , z_0 , 197 associated with the candidates after track finding and are subsequently 168 $\tan \lambda$, λ , and κ , as illustrated in Fig. 5 [Figure 5: see original paper]. 198 subsequently passed to the track fitting stage. To mitigate the The definition of each parameter is as follows: 199 impact of such hits on the reconstructed track parameters, a d_0 is the signed distance of the point of closest approach 200 robust fitting approach is required at the fitting stage.

The weights can be calculated according to the distance between the measurement and the smoothed state: $\phi_{ik} =$

$$\dim(m_i)$$

$$T \det(V_{ik})$$

$\cdot \exp - (m_{ik} - H_k x_{sm})^T (V_{ik})^{-1} (m_{ik} - H_k x_{sm})$ where x_{sm} denotes the smoothed state, and $\dim(m_{ik})$ is 242 the measurement dimension. T is the temperature parameter.

The weights $\phi_{ik} |_{i=1, \dots, n_k}$ are normalized according to

$$p_{ik} = P$$

$$j (\Lambda_k + \phi_k)$$

To account for the circumstance that no measurement can be assigned to the track in layer k , a cut term $P \Lambda_j$ is introduced in the 246 GENFIT2 framework.

Unlike the standard Kalman filter, 247 which assigns equal weights to all measurements at each update 204 step, the DAF extends the Kalman filter by introducing ϕ_{cut} (6) $\dim(m)$ 205 measurement weights together

with an annealing mechanism. It is used to improve the robustness of track fitting in the presence of background hits and outliers. In each DAF iteration, where χ_{cut} defines the cut-off value that corresponds to a pre-defined p-value threshold via $P(\chi < \chi_{\text{cut}}) = 1 - p_{\text{cut}}$ and the forward and backward filtering results are combined according to an annealing schedule defined sequence of temperatures in a smoothing step to obtain the track-state estimate for the current iteration. Based on the smoothed track state, a weight decreasing over iterations is assigned to each measurement according to its residual. In GENFIT2, the initial temperature is set to $T_0 = 100$ and different measurements contribute to the parameter update exponentially to $T_{\text{final}} = 0.1$ within $n_{\text{step}} = 5$ update with different weights.

The DAF proceeds iteratively in two steps: first, running a modified Kalman filter; second, calculate the measurement weights. In the Kalman filter stage, the propagation step is identical to the standard Kalman filter, while the filter step incorporates the weights. For measurements at layer k , denoted m_i , $i = 1, \dots, n_k$, the covariance matrix V_k is modified dimensional measurements, the corresponding cut-off value according to the weight assignment. If p_k is the assignment obtained from the cumulative χ distribution with one degree of freedom, yielding $\chi_{\text{cut}} = 10.828$. In subsequent iterations, inverse covariance matrix weighting procedure is coupled to an annealing process of each measurement is scaled by the corresponding weight, controlled by the annealing parameter T . Assuming a single measurement in a detector layer without competitors, the evolution of the weighting function for different annealing influence on the track-parameter estimation. Factor T are illustrated in Fig.6. At early iterations, T is large The corresponding Kalman gain K_k is written as

$$K_k = (C^{-1} H^T T_k V^{-1}) (1) \quad (268)$$
As the temperature decreases, the weights become increasingly sensitive to the residuals, hits with large residuals are where H_k denotes the measurement matrix, p_k is the sum of progressively assigned smaller weights, while hits with small residuals acquire larger weights. At sufficiently low temperatures, the weights approach either 0 or 1, effectively leading to a binary decision on whether a measurement is accepted or rejected. This process continues until the weight distribution stabilizes and the fit converges. Further details of the DAF and the covariance update reads algorithm and its implementation can be found in Ref [17].

$$C_k |k = (C_k |k-1 + p_k H_k V_k H_k^T) \quad (3) \quad (277)$$
The noise rejection of the DAF

is studied within the OS278 CAR framework using simulated 1 GeV/c muon tracks with The smoothed states, together with their covariance matrix- 279 a background level corresponding to the nominal occupancy. 236 ces, are then used to calculate the assignment probabilities for 280 Background simulation is included in OSCAR framework, 237 the next iterations. 281 and hits produced by background particles are mixed with

cut 10.828 cut 3.291

iteration 3 iteration 6

iteration 1

Number of hits

weight

function of the standardized distance χ^2 for different annealing factors T .

signal hits before reconstruction. The noise hits considered in this study originate from background particles and remain 284 in the track candidates after the Hough-transform-based track 291 to the different spatial resolutions of the two detectors. For 285 finding. These noise hits, located close to the track candidate- 292 noise hits, shown in Fig. 8 [Figure 8: see original paper], the weight distribution separates 286 dates, are passed to the subsequent DAF track-fitting stage. 293 into two components: one component consists of hits whose 294 weights decrease toward zero and are removed from the fit, 295 while the other component converges to weights close to unity 296 and remains associated with the reconstructed track. To further 297 understand the noise hits that remain associated with the iteration 1 298 track after the DAF iterations, a study is performed for noise 299 hits with weights close to unity. Fig. 9 [Figure 9: see original paper] shows the residual iteration 3 300 distributions of noise hits, separated by their final weights. iteration 6 301 Noise hits with large weights ($w \geq 0.99$) are concentrated 302 at small residual values, while noise hits with small weights 303 ($w \leq 0.01$) exhibit a much larger residual. This separation reflects 304 the different spatial compatibility of the noise hits with 305 respect to the fitted track.

Number of hits

ITK hit retrieval for low momentum tracks

At low transverse momentum, track segments in the ITK strongly deflected by multiple scattering and energy loss 309 in the detector material. These effects lead to hit in the inner 310 layers that deviate significantly from an ideal helical trajectory 311 tory. In the current reconstruction chain based on a Hough 312 track-finding method, track candidates are searched for us 313 in a Hough transform with circular templates in the transverse plane. Fig. 7 [Figure 7: see original paper]. Weight evolution of the signal hits weights during the iterative 314 procedure. Although the track-finding procedure successive procedure. 315

fully identifies track candidates, ITK inner layer hits associated with low-momentum tracks are often not selected at the As shown in Fig. 7, the weights of signal hits evolve toward 317 track finding stage.

As a consequence of missing ITK inner layer hits at the 288 unity over the iterations. The isolated small distributions observed during the iterations are mainly attributed to ITK hits, 319 track finding stage, the constraints on the track origin and direction which are separated from the distribution of MDC hits due to resection are weakened for low-momentum tracks, leading to

hit. The matching window is chosen to account for extrapolation and detector resolution uncertainties, and optimized 334 using simulation. Fig. 11 [Figure 11: see original paper] and Fig. 12 [Figure 12: see original paper] compares the reconstruction performance for single muons with momenta in the 336 range 50-100 MeV/c that miss ITK hits at the track-finding 337 stage, showing more concentrated parameter resolutions after 338 ITK hit retrieval. And Table 1 lists the resolutions of track 339 parameter under different background conditions, with ITK 340 retrieval. As the background level increases, the algorithm 341 still achieves good performance. These results indicate that 342 this procedure provides a practical improvement to the baseline reconstruction for low-momentum tracks with missing 344 ITK information.

weight ≥ 0.99

Number of hits

weight ≤ 0.01

with ITK hit retrieval

residual(mm)

without ITK hit retrieval

final weight. extrapolate backward from the 1st MDC measurement

Events

d0 residual(mm) : origin point : ITK : MDC inner wall : sense wire
 measured ITK hit position : measured MDC hit position : extrapolated
 position d_i ($i=1,2,3$) : the distance between extrapolated and measured
 hit position

conditions, with ITK retrieval.

Background

d0 resolution p resolution without background 3.048 ± 0.046 1.079 ± 0.017
 background $\times \$1$ 3.552 ± 0.064 1.144 ± 0.020 background $\times \$2$ 3.872 ± 0.076
 1.248 ± 0.025

degraded track-parameter and vertex resolutions. To address this effect, an ITK hit retrieval procedure is applied after the track finding stage. As illustrated in Fig.10, the reconstructed track is extrapolated backward from the first valid measurement in the MDC toward the ITK layers. The inward extrapolation is performed using a Runge-Kutta-based propagator. When charged particles traverse detector material, energy loss depends on the assumed particle kind and is explicitly taken into account in the track fit. An incorrect hypothesis compared with the measured hit positions, and compatible hits are therefore introduced in the fitted track parameters. Three hypotheses are selected based on the spatial distance d_i ($i = 1, 2, 3$) between the extrapolated position and the corresponding ITK hit. At low momentum material effects depend sensitively on the

obtained with the K and p mass hypotheses show substantial deviations. For a lower momentum of $p = 100$ MeV/c, the relative residual distribution obtained with the π hypothesis is noticeably closer to zero than that obtained with the μ hypothesis, as shown in Fig. 14 [Figure 14: see original paper]. Moreover, the use of the correct particle hypothesis yields well-behaved residual distributions for low-momentum tracks.

with ITK hit retrieval without ITK hit retrieval

Events

muon hypothesis pion hypothesis kaon hypothesis

proton hypothesis

p residual(MeV/c)

Events

-10 -8

for low-momentum tracks with missing ITK hits.

-0.02

particle kind and need to be properly accounted for when selecting the particle hypothesis.

In high energy physics experiments, track fits are typically performed under multiple particle hypotheses; For BESIII five hypotheses— e , μ , π , K, and p—are employed and all fit results are retained [40]. At the STCF, given the large data volume expected at high luminosity, performing track fits under all five particle hypotheses for the full data set leads to increased demands on computing resources and storage.

In Fig.15, the mean relative momentum residuals for the To study the impact of different particle hypotheses on 390 generated μ , π , K, and p tracks are plotted versus the trans362 track fitting, tracks are fitted under different mass hy391 verse momentum under different particle hypotheses. Kaons 363 potheses and the relative momentum residuals are com392 and protons at very low momen- tum are not included, since 364 pared with the OSCAR simulation. Due to the presence of 393 their large energy loss in the detector material makes it diffi365 bremsstrahlung [41, 42], electrons require additional correc394 cult for them to reach the MDC. In Figs.15(a) and15(b), dif366 tions, which are not considered in this study. Single-particle 395 ferences between the hypotheses π and μ are observed for 367 samples of different particle types (μ , π , K, and p) are gener396 the π and μ tracks at momenta below 200 MeV/c. At higher 368 ated at fixed momenta of [100, 150, 200, 250, 300, 350, 400, 397 momentum, the fitting results obtained with the hypotheses π 369 450, 500] MeV/c, with a uniform distribution in the azimuthal 398 and μ become similar, and either hypothesis can be used for 370 angle ϕ and a polar angle fixed to $\theta = 60^\circ$. The relative trans399 the fitting of the tracks. In Figs.15(c) and 15(d), for K and p 371 verse momentum residual, Δp_T , is defined as 400 tracks, fits obtained with incorrect hypotheses exhibit obvious 401 deviations, demonstrating that alternative particle hypotheses $p_T - p_T^{\text{prel}}$ (7) 402 cannot be used for accurate track fitting in this momentum 403 range. According to this study, three particle hypotheses (π , 404 K, and p) are retained in the current imple- mentation. For 373 here p denotes the reconstructed transverse momentum 405 low-momentum tracks below 200 MeV/c, the μ hypothesis is 374 and p the cor- responding Monte Carlo truth value. The reT 406 additionally included. 375 sulting residual distribution is approximately Gaussian and its 376 mean value $\bar{\mu}$ is used to quantify the bias of the reconstructed 377 transverse momentum. Fig. 13 [Figure 13: see original paper] shows the relative momentum IV. PER- FORMANCE 378 residual distributions of the above sample of generated pion 379 with $p = 350$ MeV/c, obtained using four particle hypotheses Performance studies are carried out using single-particle 380 in the track fitting. The residual distributions obtained with 408 de381 the μ and π hypotheses are centered close to zero, while those 409 samples and the $\psi(3686) \rightarrow \pi \pi J/\psi, J/\psi \rightarrow \mu \mu$

Detector layer Average background hits per event

ITK1 ITK2 ITK3 MDC1 MDC2 MDC3 MDC4

with v_{fit} denoting the fitted value of the track parameter, v_{truth} the corre- sponding Monte Carlo truth value, and σ_{fit} the 431 estimated uncertainty of the fitted parameter. Fig. 16 [Figure 16: see original paper] shows 432 the pull distributions of the track parameters evaluated at the 433 point of closest approach. The fitted Gaussian distributions 434 are approximately consistent with standard normal distribu435 tions. 437 Gaussian fits, with nominal background.

The distribution 438 closely follows a Gaussian distribution, yielding a relative 439 momentum resolution remains below 0.5%, which satisfies 440 the perfor- mance requirements of the STCF tracking system.

muon hypothesis pion hypothesis

Events

Performance of physics events

The tracking performance is also studied using the $\psi(3686) \rightarrow \pi^+ \pi^- J/\psi$, $J/\psi \rightarrow \mu^+ \mu^-$ decay channel. For 444 both muons and pions in this channel, the transverse momentum residual 445 momentum of particles is correlated with their polar angles. In 446 general, tracks with lower transverse momentum correspond 447 to larger polar angles. Figures 18 and 19 show the d_0 and pion tracks with $p = 100$ MeV/c under different particle mass hy449 for muon and pion tracks under different background conpotheses. 450 ditions.

For tracks at lower momentum region, the tracks 451 traverse fewer detector layers, resulting in relatively poorer 452 resolutions. Comparisons performed at different background 410 cay channel, based on full detector simulation and the base- 453 levels show no observable change in track quality. It clearly 411 line reconstruction chain, with track fitting performed using 454 shows that the reconstructed track parameters exhibit stable 412 the GENFIT2 framework within OSCAR. To evaluate the ro- 455 resolutions across different background levels. 413 bustness of the baseline algorithm, the studies are performed 414 under different background levels. Background hits are simuV. CONCLUSION 415 lated within the OSCAR framework [43] and mixed with sig- 456 416 nal hits before track reconstruction. Table 2 lists the average 417 number of background hits per event in the ITK and MDC, 457 In this work, the GENFIT2 track fitting toolkit is integrated 418 with labels corresponding to the ITK layer indices and MDC 458 into the STCF experiment and studied in the OSCAR full 419 super-layer indices. 459 simulation. The DAF is applied to address the requirements 460 of track fitting in high background conditions, and its noise 461 rejection behavior is studied under background levels rele462 vant to current STCF simulation studies. The reconstruction 463 performance is evaluated using single particle samples and A. The quality of track fitting 464 physics decay channels. The results show that the track fit465 ting performance is stable under different background levels The track parameter resolutions are evaluated by compar- 466 and provides reliable track parameter resolutions over a wide 422 ing the fitted track parameters to their corresponding truth val- 467 range of transverse momenta. Further studies will focus on 423 ues. Single-muon samples are generated with a fixed polar 468 very low-momentum tracks ($p_T < 100$ MeV/c), including the 424 angle of $\theta = 60$ and a uniformly distributed azimuthal angle 469 treatment of multi-turn trajectories. In addition, fitting strate425 ϕ , with a momentum of $p = 1$ GeV/c. Gaussian fits are ap- 470 gies for electron tracks affected by bremsstrahlung will be in426 plied to the pull distributions, where the pull for a given track 471 vestigated. GENFIT2 is currently adopted as the default track 427 parameter v is defined as 472 fitting approach in the STCF baseline reconstruction chain, 473 used for physics studies as well as detector optimization, and 474 it exhibits potential to be a reliable track fitting software for $v_{\text{fit}} - v_{\text{truth}} \text{pull}(v) = (8) 475$ the STCF experiment. $-0.06 -0.04 -0.02$

muon hypothesis

muon hypothesis

pion hypothesis

pion hypothesis

kaon hypothesis

kaon hypothesis

proton hypothesis

proton hypothesis

-0.02

-0.02

-0.04

-0.04

p (MeV/c)

p (MeV/c)

(a) real pions were fitted with the pion, kaon, proton and muon hypotheses.

(b) real muons were fitted with the pion, kaon, proton and muon hypotheses.

muon hypothesis

muon hypothesis

pion hypothesis kaon hypothesis proton hypothesis

kaon hypothesis proton hypothesis

pion hypothesis

relative p residual μ

relative p residual μ

relative p residual μ

relative p residual μ

-0.05

-0.05

p (MeV/c)

p (MeV/c)

(c) real kaons were fitted with the pion, kaon, proton and muon hypotheses.

(d) real protons were fitted with the pion, kaon, proton and muon hypotheses.

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Entries = 98364

Entries = 98364

Mean = -0.0011 ± 0.0031

Mean = 0.0002 ± 0.0037

Sigma = 0.9565 ± 0.0024

Sigma = 0.9795 ± 0.0028

Events

Events

Events

d0 pull

ϕ pull

dz pull

Entries = 98364

Entries = 98364

Mean = 0.0211 ± 0.0032

Sigma = 1.0014 ± 0.0028

Mean = 0.0033 ± 0.0029 Sigma = 0.8990 ± 0.0023

Events

Events

κ pull

λ pull

For each pull distribution, a Gaussian fit is performed, and the fitted values of the mean (μ) and the standard deviation (σ) are shown in the legend.

Entries = 9992

Entries = 9992

Mean = -0.000953 ± 0.001384

Entries = 9992

Mean = 0.000233 ± 0.008184

Sigma = 0.137732 ± 0.001044

Mean = 0.000035 ± 0.000046

Sigma = 0.687768 ± 0.005792

Sigma = 0.004497 ± 0.000041

Events

Events

Events

Sigma = 0.8638 ± 0.0023

Entries = 98363 Mean = 0.0010 ± 0.0028

-1 -0.8 -0.6 -0.4 -0.2 0

d0 residual(mm)

dz residual(mm)

-0.02

-0.01

relative p residual

background. The resolutions of the track parameters are extracted from Gaussian fits.

dz resolution(mm)

d0 resolution(mm)

Background x 0

Background x 1 Background x 3

Background x 0

Background x 1

Background x 3

Background x 0 Background x 1 Background x 3

relative p resolution

p (MeV/c)

p (MeV/c)

p (MeV/c)

Background x 0

Background x 1

dz resolution(mm)

Background x 3

Background x 0

relative p resolution

d0 resolution(mm)

Background x 1 Background x 3

Background x 0

Background x 1 Background x 3

p (MeV/c)

p (MeV/c)

p (MeV/c)

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