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Inside-out tracking at CDF

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Abstract

The Central Outer Tracker (COT) at the Collider Detector at Fermilab (CDF) is used to reconstruct charged particles in the central rapidity region. The silicon tracker is used to improve the central track measurement and to reconstruct charged particles in the forward rapidity region. We describe the inside-out tracking algorithm, which improves the track measurement in the intermediate rapidity region by attaching COT hits to reconstructed silicon tracks.

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1. Introduction

The CDF tracking system consists of a large open-cell drift chamber (the Central Outer Tracker, or COT [1]) surrounding up to 8 layers of silicon [2] (Fig. 1). The CDF central “outside-in”

(OI) tracking algorithm finds charged-particle tracks in the COT and attaches hits in the inner silicon tracker. The forward tracking algorithm reconstructs “silicon standalone” (SiSA) tracks from the silicon hits alone [3]. By design, the central algorithm only finds tracks that traverse at least half the COT in the radial direction. In the region where particles traverse part of the COT (but less than half), the COT information of the track is ignored by the central and forward

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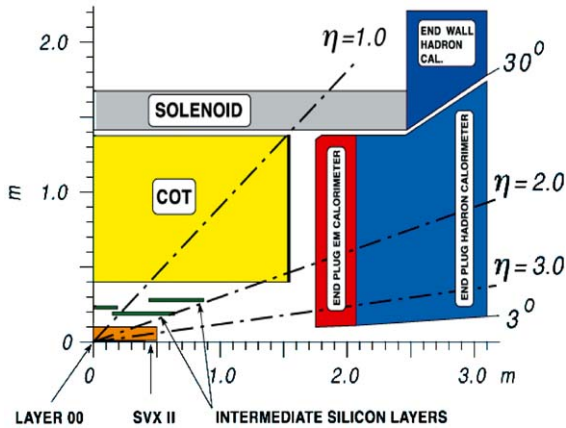


Fig. 1. The r - z view of the COT and inner silicon tracking detectors.

algorithms. We have developed an “inside-out” (IO) tracking algorithm to recover this information, and to improve the efficiency of reconstructing tracks passing through more than half the COT. The algorithm also validates the reconstructed SiSA tracks that pass through the entire COT.¹

2. Inside-out algorithm

The IO algorithm uses SiSA tracks to define a search road in the COT detector. The hits in the road are used to create and fit a COT track. The silicon hits are then refit using the new COT track parameters and covariance matrix as initial values. The parameters from this final fit define the IO track.

SiSA tracks are formed from seeds defined by two hits with 3-dimensional information (3D hits) and a beam position estimate. To reduce combinatorics, the seeds are required to be consistent with a z -vertex candidate. Silicon and COT information are used independently to form seeds of z -vertex candidates. Combinations of three 3D silicon hits or two 3D silicon hits and the transverse beam position form one set of z -vertex seeds. Tracks using only COT information (OI

tracks without silicon hits) form a second set of z -vertex seeds. The two sets seed a vertexing algorithm that uses OI tracks to form the set of z -vertex candidates used by the SiSA algorithm. The SiSA track seeds define candidate tracks for a silicon hit search, and candidate tracks consistent with four or more $r - \phi$ silicon hits become SiSA tracks.

In the first step of the IO algorithm, each SiSA track is propagated from the collision point through the silicon detector using a progressive Kalman fit [3] to obtain track parameters at the COT inner cylinder wall. This propagation estimates the energy loss and multiple scattering of the charged particle. The track parameters at the COT inner wall define a trajectory through the COT. At each layer l of the COT, the wires are searched for the hit with the smallest azimuthal distance to the trajectory. If this distance is within $(1.4 + 0.006 \times (l - 1))$ mm of the trajectory, the hit is saved as part of a potential IO track. The road size was tuned for the identification of high-momentum cosmic rays [4] and was not retuned for this algorithm.

If at least 6 axial hits and 2 stereo hits are found, the hits are fit for the track parameters by a χ^2 minimization method. All CDF tracks are parameterized at the point of closest approach to the origin in the x - y plane. The axial parameters are the impact parameter (d_0), azimuthal angle (ϕ_0), and curvature (c). The stereo parameters are the z position (z_0) and the cotangent of the angle with respect to the z -axis ($\cot \theta$). The fit is constrained to the z_0 and d_0 of the SiSA track. Given the new COT track parameters and covariance matrix, the track is propagated back toward the collision point, and the fit updated with each silicon hit.

All SiSA tracks in an event are used to search for an IO track. If the track is central (i.e., it passes through the entire COT, see Fig. 1) and no IO track is found, the track is assumed to be poorly measured or “fake” and is removed from the track collection. “Fake” tracks are tracks reconstructed from combinations of hits from several particles or noise, and whose parameters do not correspond to an actual charged particle. If a central IO track is found, the track is compared with each OI track and removed if more than 15% of the two tracks’

¹Work on CDF track reconstruction is ongoing; this description is current as of June, 2004.

COT hits are shared. In this way, central fake and duplicate SiSA tracks are removed from the track collection. The validation of SiSA tracks is a crucial component of the IO algorithm. The rate of fake SiSA tracks is considerably higher than the rate of fake COT tracks, due to the smaller number of radial layers (8 versus 96), and to the higher hit and material densities in the silicon detector. Validating the central SiSA tracks with COT hits allows their use for general-purpose physics analyses.

3. Inside-out algorithm performance

We have studied the performance of the IO algorithm using $Z \rightarrow \mu\mu$ Monte Carlo simulation and $Z \rightarrow ee/\mu\mu$ data. We generate the Monte Carlo events with the PYTHIA [5] event generator and simulate the detector response with a hit-level GEANT [6] simulation of the silicon and COT. The simulation includes multiple scattering and energy loss in the tracking material. We use data from $\sqrt{s} = 1.96$ TeV collisions collected with the CDF detector between February, 2002, and September, 2003. We select opposite-sign dimuons and dielectrons with masses in the range 76 to 106 GeV.

We obtain tracking efficiencies and parameter resolutions of IO tracks from the Monte Carlo, and compare these quantities to those of the original SiSA tracks. From the data, we measure tracking efficiencies using $Z \rightarrow ee$ events, and study the distributions sensitive to tracking resolution: the $Z \rightarrow \mu\mu$ mass, and the ratio of calorimeter energy to track momentum (E/p) for electrons. The widths of both distributions are dominated by the curvature resolution of the tracks, which we expect to significantly improve with the application of the IO algorithm.

3.1. Monte Carlo

The IO tracking algorithm has a high efficiency of attaching COT hits to high-transverse-momentum (p_T) SiSA tracks. Fig. 2 shows this efficiency as functions of p_T and pseudorapidity (η). Since the COT hit-search road was tuned for cosmic

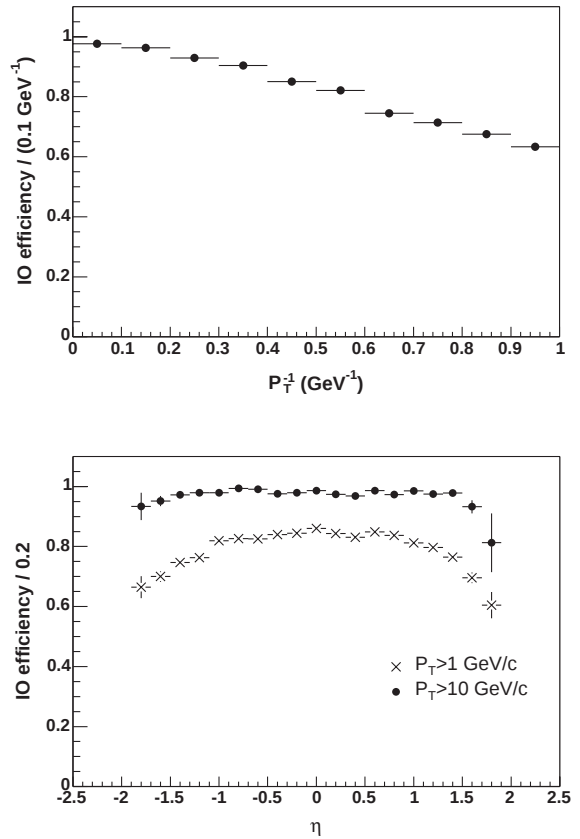


Fig. 2. The efficiency of the IO algorithm as functions of $1/p_T$ (top) and η (bottom), given a SiSA track that passes through at least 2 COT superlayers and has $p_T > 1$ GeV, $|z_0| < 60$ cm, and $|d_0| < 2$ cm. The events are simulated $Z \rightarrow \mu\mu$ events.

rays, it is most efficient ($>95\%$) for high- p_T tracks.

We study the IO duplicate rate using a sample of ≈ 7500 tracks reconstructed in $Z \rightarrow \mu\mu$ events. Of all reconstructed IO tracks, 9.2% are duplicates of tracks already found by the OI algorithm. Two tracks are considered duplicates if each has more than 50% of its hits originating from the same Monte Carlo particle. The duplicate-removal phase of the IO algorithm reduces the fraction of duplicates to 0.9%. The OI tracking algorithm has a duplicate fraction (i.e., both members of the duplicate pair are found by the OI algorithm) of 0.07%. After including IO tracks, the total duplicate fraction is 0.13%. Within the central region, the duplicate rate is 0.19%; in the forward

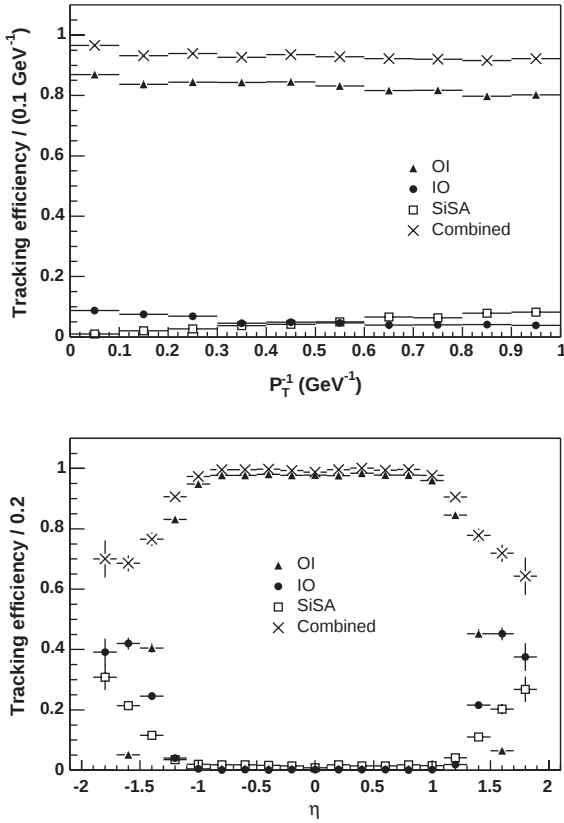


Fig. 3. The tracking efficiency as functions of $1/p_T$ (top) and η (bottom) for the different tracking algorithms. When multiple tracks are found for a given particle, the algorithms are given the following order of preference: OI, IO, and SiSA. Though included here, central SiSA tracks are removed after the IO tracking algorithm. The efficiency is defined as the fraction of reconstructed tracks for particles passing through at least 2 COT superlayers with $p_T > 1$ GeV, $|z_0| < 60$ cm, and $|d_0| < 2$ cm. The events are simulated $Z \rightarrow \mu\mu$ events.

region, where no duplicates are found, the rate is less than 0.04%. The central duplicate rate is independent of η and p_T .

We show the efficiency for OI, IO, and SiSA track reconstruction, after duplicate removal, as functions of p_T and η in Fig. 3. The efficiency is defined as the fraction of reconstructed tracks for particles with $p_T > 1$ GeV passing through at least 2 COT superlayers. The particles are required to have $|z_0| < 60$ cm and $|d_0| < 2$ cm. The figure shows that IO tracks compose the largest fraction of tracks for $|\eta|$ between 1.5 and 1.9.

Table 1

The RMS resolutions of the silicon stand-alone and inside-out tracking algorithms. The resolutions are measured relative to the true particle parameters in simulated $Z \rightarrow \mu\mu$ events.

Method	Curv. RMS	ϕ_0 RMS	d_0 RMS	z_0 RMS	Scot θ RMS
SiSA	$1.1 \times 10^{-4} \text{ cm}^{-1}$	2.5×10^{-3}	61 μm	920 μm	0.015
IO	$4.6 \times 10^{-5} \text{ cm}^{-1}$	2.1×10^{-3}	53 μm	650 μm	0.011

The IO algorithm improves the resolution of the measured track parameters. Table 1 shows the RMS of the reconstructed IO and original SiSA track parameters relative to the generated parameters in the simulation. The IO algorithm improves the curvature resolution by more than a factor of 2 and the other parameter resolutions by 13–29%.

3.2. Data

We have studied the performance of the IO algorithm using $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$ data events with one IO track. The dielectron events consist of one central electron and one forward electron, while the dimuon events consist of one central muon and one forward muon. The events are selected using single-lepton triggers, and the central electrons and muons are identified using standard CDF lepton identification [7]. The forward electrons are identified using calorimeter information, with no track requirement; the forward muons are identified with track and minimum-ionizing-particle requirements, but no muon chamber selection. The lepton pairs are required to have an invariant mass consistent with that of a Z boson ($76 \text{ GeV} < m_{\ell\ell} < 106 \text{ GeV}$).

The track resolution and acceptance significantly improve with the IO tracking algorithm. The RMS of the dimuon invariant mass distribution with one forward track is reduced from 12.1 GeV with the SiSA track to 8.5 GeV with the IO track (Fig. 4), and the use of the IO track results in a 64% reduction in the number of events with mass greater than 115 GeV. In addition, the IO algorithm provides a 27% increase in the

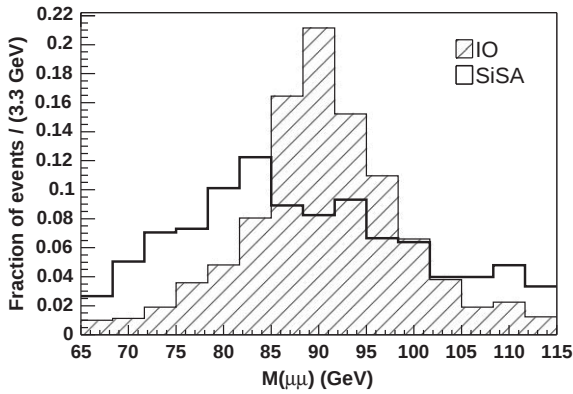


Fig. 4. The invariant mass distribution of dimuon data events with one IO (hatched) or SiSA (empty) track. The SiSA tracks are only those that seed IO tracks.

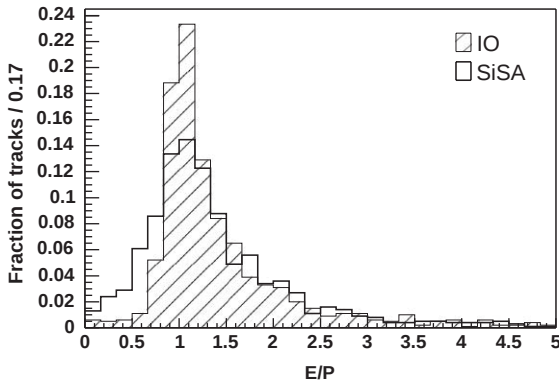


Fig. 5. The E/p for inside-out tracks in $Z \rightarrow ee$ data events with one inside-out track (hatched) or one SiSA (empty) track. The SiSA tracks are only those that seed IO tracks.

number of dimuon events relative to OI tracking alone.

Fig. 5 shows the distribution of calorimeter energy divided by track momentum (E/p) for forward electrons in dielectron Z events. The IO algorithm significantly decreases the number of electrons with very low E/p values, corresponding to tracks mismeasured to have very high momenta.

Large track parameter mismeasurements are reduced. We measure the rate of sign mismeasurement by counting the number of SiSA or IO tracks with the same sign as the central track and passing through at least 2 COT superlayers. We find 8 such IO tracks, compared to 12 SiSA tracks. The

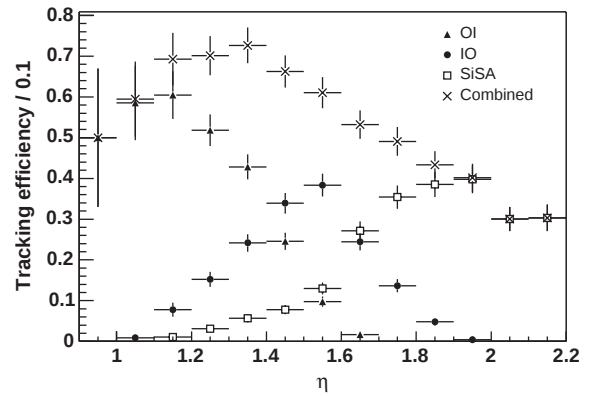


Fig. 6. The efficiency for reconstructing tracks from forward electrons in $Z \rightarrow ee$ data events. We show the efficiency for each track type.

reduction of same-sign events is evidence of the reduction of track sign mismeasurement.

We show the total tracking efficiency in the forward region in Fig. 6. We define the efficiency as the fraction of forward electrons in $Z \rightarrow ee$ events with a track. A significant fraction of the reconstructed tracks in the region $1.2 < |\eta| < 1.8$ are IO tracks.

4. Conclusions

We have developed an algorithm to attach COT hits to tracks found with silicon information alone. We have tested the algorithm on high-momentum electrons and muons using both data and simulation. We have demonstrated high efficiency ($>95\%$) for high-momentum tracks, as well as dramatic improvement in the track parameter resolutions. The algorithm reduces fake and duplicate tracks by confirming the true SiSA tracks and allowing the remaining central SiSA tracks to be discarded. The incorporation of IO tracking into the CDF tracking algorithm significantly improves the quality of reconstructed tracks at CDF.

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