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Drift chamber alignment using cosmic rays

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ABSTRACT

The Collider Detector at Fermilab (CDF) is a general-purpose experimental apparatus with an inner tracking detector for measuring charged particles, surrounded by a calorimeter for measurements of electromagnetic and hadronic showers and a muon detector system. We present a technique for, and results of, a precise relative alignment of the drift chamber wires of the CDF tracker. This alignment has been an important component of the track momentum calibration, which is the basis for the charged-lepton calibration for the measurement of the W boson mass at CDF.

1. Introduction

The measurement of the W boson mass with the CDF detector [1] at the Fermilab Tevatron $p\overline{p}$ collider achieves a precision of one part per 10,000 on the measured energy of muons from W boson decays [2]. A key component of the momentum calibration is a precise relative alignment of the wires in the CDF drift chamber. In this paper we describe the alignment technique developed at CDF using cosmic rays collected *in situ* with collider operation. This technique was initiated in 2002 and used to perform the alignment for the first two measurements of the W boson mass from the CDF Run II data, based on 200 pb^{-1} [1] and 2.2 fb^{-1} [2] of integrated luminosity, respectively. We also present the results from the alignment analysis performed most recently using cosmic rays collected during the entire Run II collider operation, to be used in the next W-boson mass measurement at CDF.

The momentum calibration [2] is performed in two steps. First, the selected cosmic-ray sample is reconstructed using special pattern-recognition and track-fitting algorithms that reconstruct the complete cosmic-ray trajectory through both halves of the drift chamber. These algorithms and their performance are described in Ref. [3]. This fitted trajectory proves an excellent reference, with respect to which the average hit residuals can be minimized to achieve an internal alignment of the wires. Certain degrees of freedom associated with deformations of the tracker endplates cannot be constrained by minimizing residuals with respect to collider tracks. Examples of such deformations are relative rotations of the inner and outer cylinders of the drift chamber, and relative twists of the east and west endplates. They result in parameter biases in collider track fits but do not result in displaced residuals. On the other hand, such deformations result in differences between the trajectories on the two sides of the drift chamber of the same cosmic ray and can be constrained by using the complete two-sided helix fit. This property is exploited to remove a number of important sources of bias in the measurement of collider tracks.

In the second step of the calibration, $J/\psi \to \mu\mu$ and $\Upsilon \to \mu\mu$ mass peaks are reconstructed with the above alignment. Using the precisely known masses of these particles, a momentum scale factor and the ionization energy loss model are tuned simultaneously in the simulation and then applied to the W boson mass measurement [1]. Residual misalignments that cannot be constrained with cosmic-ray tracks are corrected using the ratio of calorimeter energy to track momentum of electrons and positrons from W-boson decays [1,2].

In the following we describe the procedure and the results obtained from the cosmic ray alignment. In Section 2 we provide a summary of the CDF drift chamber construction and the degrees of freedom we allow in the alignment procedure. In Section 3 we describe the spatial and kinematic distributions of the cosmic ray sample recorded with the CDF detector, and the sample selection. In Section 4 we show comparisons of the position residuals before and after the alignment procedure is performed. Corrections to the wire shape due to gravitational sag and electrostatic deflection are discussed in Section 5. The tuning of the drift model is discussed in Section 6. Finally, in Section 7 we show the reduction in the track

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parameter biases, as determined from the comparison of the two segments of the cosmic ray track.

2. Alignment degrees of freedom

The CDF detector [1,4–6] is shown in Fig. 1. The central tracking drift chamber [7] (COT) uses an open-cell geometry with 30,240 sense wires. Its tracking volume extends from an inner radius of 41 cm to an outer radius of 138 cm, with a longitudinal extent of 310 cm. A superconducting solenoid immediately outside the COT provides a nearly uniform 1.4 T magnetic field in the tracking volume. Within the COT sits a silicon detector to provide precise vertexing information. In the measurement of the W-boson mass, the momentum of the charged lepton produced promptly in the collision is measured using COT information and constrained to the beam collision region in the transverse plane; silicon detector hits do not improve the precision on the beam-constrained track parameters and are not used.

A section of one of the aluminum endplates of the COT is shown in Fig. 2. The drift chamber consists of 2520 drift cells, each containing 12 sense wires. The maximum drift distance is ≈ 8.8 mm. The cells are arranged in 8 radial superlayers (SL0 to SL7), with the number of cells per superlayer increasing with radius. Alternating superlayers consist of wires running along the longitudinal axis (axial superlayers) and wires with a $\pm 2^{\circ}$ stereo angle (stereo superlayers). The stereo angle changes sign from one stereo superlayer to the next.

The radial spacing between sense wires in a cell is 5.8 mm [7]. The wires are attached at their ends to rigid cards which are precision-mounted on the COT endplates. In the alignment model, each cell's profile at the endplates is described by a straight line (see Fig. 3). Thus, the degrees of freedom to be constrained in order to precisely locate each sense wire at each endplate are the following:

(1) the transverse (x,y) coordinates of the center of each cell, at the longitudinal (z) coordinate ± 155 cm of the two endplates;
(2) the tilt angle (τ) of each cell relative to the radial vector from the transverse origin to the center of the cell at $z = \pm 155$ cm.

We parameterize the former degrees of freedom in terms of symmetrized (i.e. averaged over the two endplates) and anti-symmetrized (i.e. difference between the two endplates) cell-center coordinates. The advantage of these definitions is that the symmetrized and anti-symmetrized cell-coordinate residuals are,

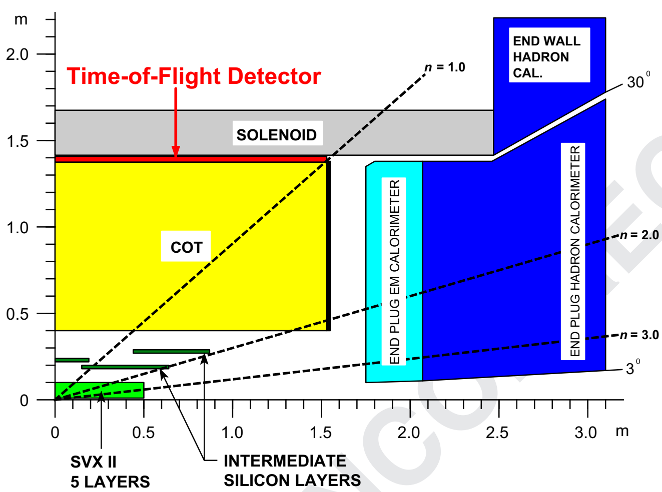

Fig. 1. A cut-away view of the CDF detector, reproduced from Ref. [7]. Not shown are the barrel calorimeters outside the solenoid, and the muon detectors outside the calorimeters.

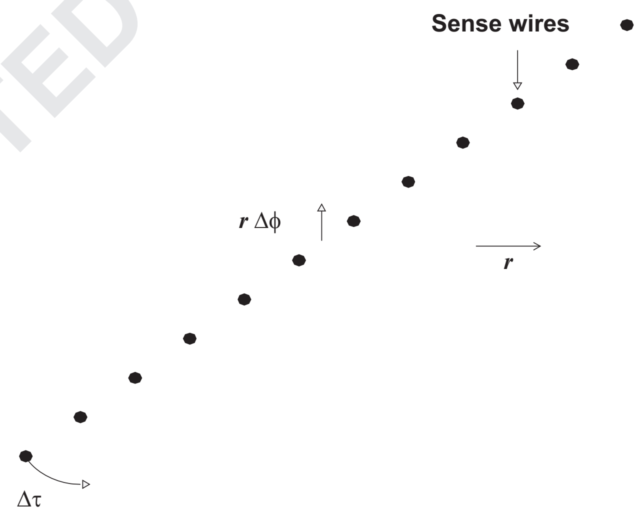

Fig. 3. A drift cell showing 12 sense wires, along with the radial (r) coordinate, and azimuthal $(r\Delta\phi)$ and tilt (τ) correction parameters.

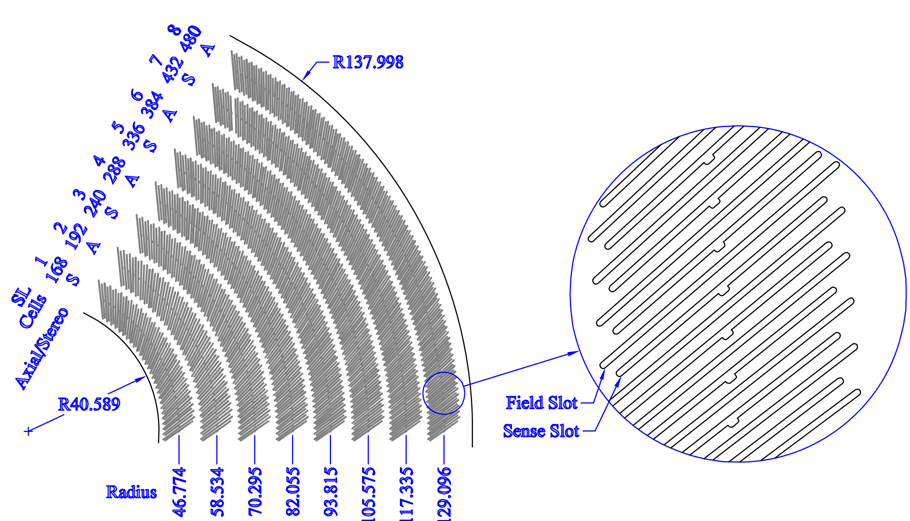

Fig. 2. A section of an aluminum endplate of the COT, reproduced from Ref. [7]. The slots cut in the endplates anchor individual drift cells containing 12 sense wires each.

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