Fermi National Accelerator Laboratory

FERMILAB-Conf-96/443-E
CDF

# The CDF Central Outer Tracker

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January 1997

Published Proceedings of the *5th International Conference on Advanced Technology and Particle Physics*, Como, Italy, October 7-11, 1996

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CH03000 with the United States Department of Energy

# The CDF Central Outer Tracker

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We describe the CDF Central Outer Tracker (COT), an open-cell drift chamber currently being constructed for the CDF detector to run at the upgraded Fermilab Tevatron collider. This detector will provide central tracking with excellent momentum resolution in the high-density environment of a hadron collider. It will be able to resolve 132 ns beam crossings and provide tracking trigger information to the Level 1 trigger. The design is based upon the existing and successful CDF Central Tracking Chamber. The preliminary mechanical and electrical designs are presented.

## 1. INTRODUCTION

The CDF detector is undergoing a major upgrade [1] in conjunction with the construction of the Fermilab Main Injector. The detector upgrade is required in order to handle higher the luminosities and shorter bunch spacings of the Main Injector runs. During the first running period of the Main Injector, the luminosity is expected to reach $1 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ with a bunch spacing of 396 ns. Subsequent running periods are likely to produce higher luminosity with a bunch spacing of 132 ns.

The design of the CDF Central Outer Tracker (COT) is based upon the CDF Central Tracking Chamber (CTC) which operated within CDF from 1987-1996 [2]. The COT will provide central tracking in the high luminosity environment of the Tevatron in the Main Injector era by measuring charged tracks with transverse momentum ($p_T$) as low as 400 MeV/c in the 1.4 Tesla field of the CDF solenoid with a resolution of $\delta p_T/{p_T}^2 \leq 0.1\%/\mathrm{GeV/c}$. The pointing resolution of the COT is well matched to the interior silicon detectors [3], so that charged tracks can be extrapolated and linked to the silicon hits with high efficiency. Additionally, the detector will provide hit information to the Level 1 tracking trigger system, so that tracks above $p_T = 1.5\,\mathrm{GeV/c}$ can be utilized in the trigger.

In the following sections, we will describe the preliminary mechanical and electrical designs of the COT.

*Work supported by the U.S. Department of Energy.

## 2. OVERVIEW

The layout of the COT is segmented in to 8 super-layers, each super-layer consisting of 12 sense wire layers. The super-layers alternate stereo–axial–stereo–axial, with the stereo angle of $\pm 3°$. This gives 96 measurements of a track passing through all 8 super-layers. Within a super-layer, the 12 sense wires alternate with 13 potential wires, the potential wires providing field shaping within the cell. For ease of installation, the 25 wires of each cell are are premade into "wire planes", such that all the wires of a single cell can be strung simultaneously. For the entire chamber, there are 30,240 sense wires and 32,760 potential wires. The original Central Tracking Chamber utilized a series of wires between cells to complete the field region. In the COT, this task is handled by gold-on-mylar sheets, in order to reduce the overall mass and tension of the chamber. Operating with an Argon-Ethane-$CF_4$ (50:35:15) gas mixture the maximum drift time is approximately 100 ns. The cells are tilted at 35° to account for the Lorentz angle such that the drift direction is azimuthal.

The active volume of the COT begins at a radius of 43 cm from the beamline and extends out to a radius of 133 cm. The chamber is 310 cm long. Tracks originating from the interaction point which have $|\eta| < 1$ pass through all 8 superlayers of the COT. Tracks which have $|\eta| < 1.3$ pass through 4 or more superlayers. Table 1 gives a mechanical summary of the COT.

Figure 1 shows the COT cell structure. A single cell has 12 sense wires, 13 potential wires and 4 shaper wires in addition to a gold on mylar field plane on either side of the wire plane. The 25 sense plus potential wires are fabricated as a single unit, which allows for fast construction and pretesting (at tension) of the planes. Wire separation is 7.62 mm [0.3″] in the plane of the wires. The maximum drift distance is defined by the azimuthal separation between the sense wires and the field planes and is 0.88 cm [0.346″].

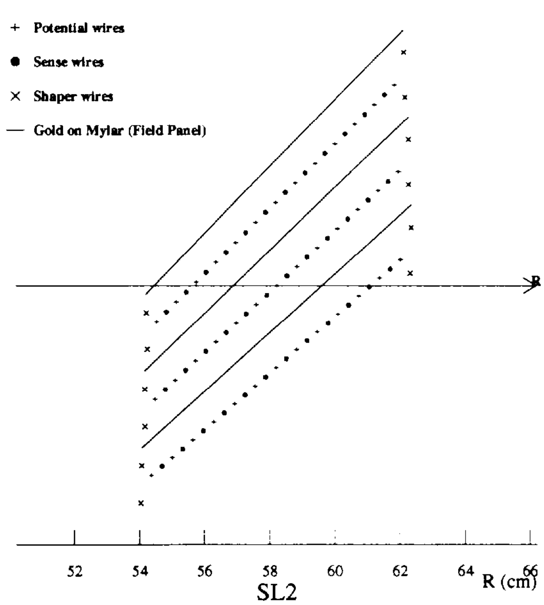


Figure 1. Three COT cells. Each cell has 12 sense wires, 13 potential wires, 4 shaper wires and a Au-mylar cathode field panel on both sides of the sense wire plane.

Figure 2 shows the drift trajectories for a single COT cell while operating in the 1.4 Tesla magnetic field. The Au-mylar foils (field panels) are maintained at ground potential. The potential wires are run at positive high voltage (∼2 kV) and the sense wires are run at positive high voltage greater than that of the potential wires (∼3 kV). In order to maintain a uniform drift field, each of the potential wires and each of the sense wires are run at slightly different voltages. The variation across a cell for the sense or potential wire voltages is less than 400 V.

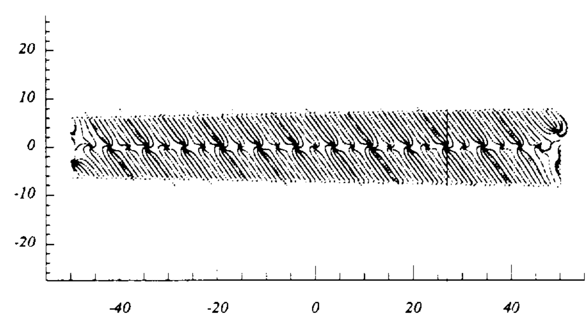


Figure 2. Drift trajectories for a COT cell.

## 3. MECHANICAL DESIGN

Mechanically, the COT has two aluminum endplates which carry the tension and provide much of the precision in the wire and field plane locations. The endplates are separated by a low mass carbon-fiber composite inner cylinder and an aluminum outer cylinder. Wire planes and field sheets are strung between the two endplates. The chamber is made gas-tight by a combination of aluminum extrusion pieces and G10 boards.

The endplates are 4.13 cm [1.625″] thick 6061-T651 aluminum. A view of a portion of one endplate is shown in Figure 3. The endplates are machined with slots: one wire plane and one field sheet slot per cell per side. Precision edges of the slots determine the absolute location of the wire planes and field sheets. The tension on the endplates is approximately 40 metric tons, which

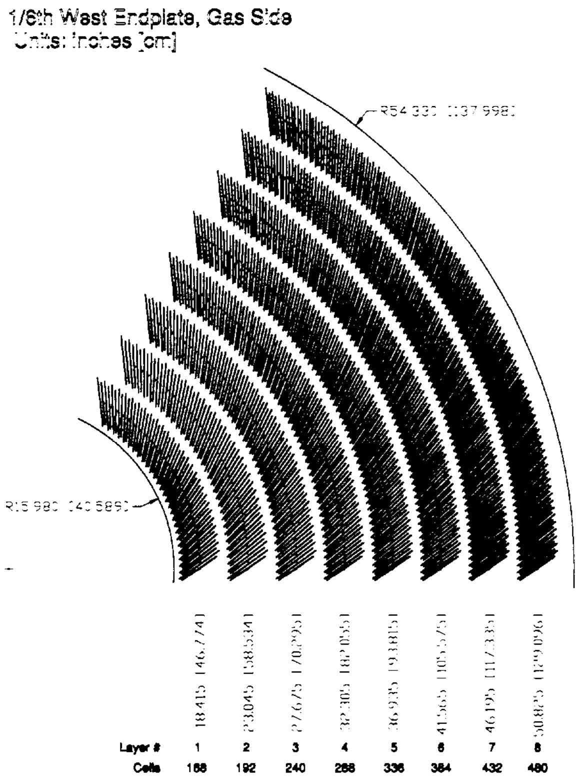


Figure 3. A view of a portion of one COT endplate. The slots define the radii of the 8 superlayers. Within a superlayer, wire-plane slots and field sheet slots alternate.

leads to a maximum deflection of less than 7.6 mm [0.30″].

To reduce radiation and multiple scattering of charge tracks as they enter the COT tracking volume, the inner cylinder is a 2.46 mm [0.097″] carbon-fiber composite tube. The outer cylinder is 6.35 mm [0.250″] aluminum with hatches for access to the chamber once the cylinder is attached.

The sense and potential wires are 40 $\mu$m [1.6 mil] diameter gold-plated tungsten. The wire planes are fabricated on a winding machine. The wire spacing is determined by a precision fixture on the winding machine. The wire ends are soldered and epoxied to a G10 printed circuit board which has traces which connect to pins on the end of the board. The location of a wire plane is determined by the location of an alignment pin and shim as they are held in contact with the precision machined edge of the endplate. The wire plane assembly is shown in Figure 4.

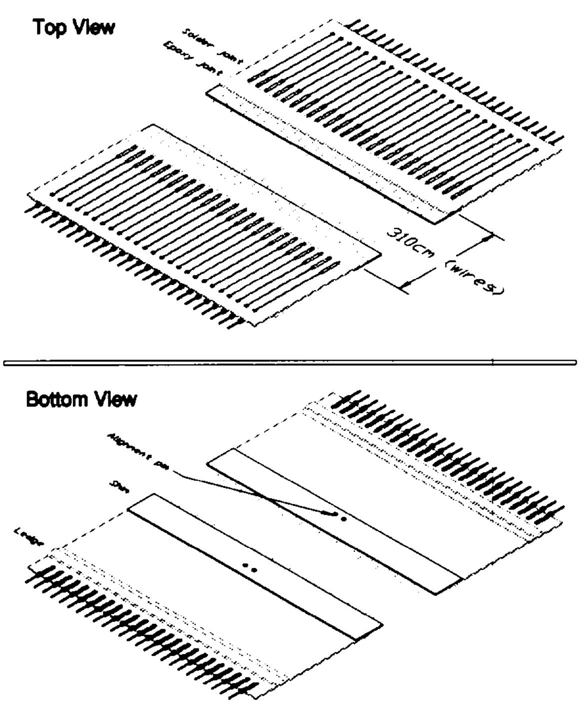


Figure 4. The COT wire plane assembly. The top view shows the solder pads and the location of the epoxy joint. The bottom view shows the alignment pin and shim. The pins which make electrical connection to the readout electronics and high voltage can be seen in both views.

Field sheets, which are 350Å gold on 6.35 $\mu$m [0.25 mil] mylar, form the cathode planes for the cells. The sheets are epoxied to aluminum end boards which latch onto the endplate. To insure that the foils remain flat, two 305 $\mu$m [12 mil] stainless steel wires are epoxied directly to the foils in a parabolic shape. When the nominal 10 kg tension is applied to the sheet, a fraction of the longitudinal tension is transferred to lateral tension via the stainless steel wires. Figure 5 shows the field sheet assembly.

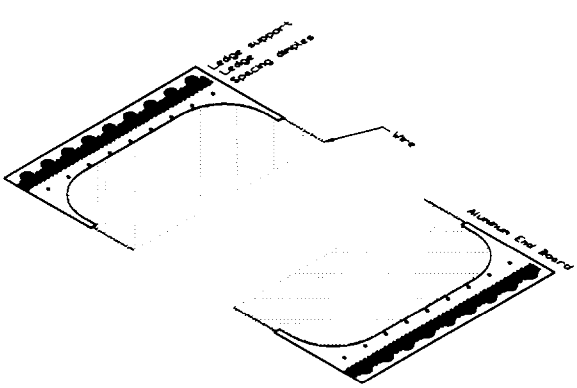

Figure 5. The COT field sheet assembly.

Two shaper wires, 40 $\mu$m [1.6 mil] gold-plated tungsten, at each end of the cell serve to close the cell electrostatically. The shaper assembly is constructed manner similar to the wire plane such that the wires are affixed to small G10 boards. They are installed through the wire plane slot. An alternative design under consideration has the shaper wires in the plane of the sense and potential wires and attached to the same board.

Aluminum extrusions extend from the endplates between superlayers to provide a portion of the gas seal, bus grounds and low voltage across the chamber face, and house piping for the water cooling system. G10 motherboards with pin receptacles plug into the pins on the wire plane boards on both ends. These motherboards are epoxied to the extrusions to form the chamber gas seal. Connectors or feed-through pins on the motherboards allow for daughterboards to plug in which hold either high voltage distribution or readout components. The power dissipation from the preamps plus positive ion current is approximately 600 W per side, or 1.2 kW total.

## 4. CONSTRUCTION

The modular design of the COT lends itself to fast, distributed construction. During the period of the construction of the endplates, the wire planes will be fabricated at Fermilab and the field sheets will fabricated at Harvard University and Lawrence Berkeley National Laboratory. Several other institutions will perform testing of all of these components.

Once the machining of the endplates is completed, the plates will be aligned and pretensioned. Although finite element analyses have been performed on the loaded endplate, the measured endplate deflection from the pretensioning procedure will be used to set the precise length of the wire planes and field sheets. This is done by affixing the ledge which hooks onto the endplate after the precise degree of enplate deflection (and hence, the proper length of the chamber as a function of radius) is measured.

The actual stringing of the chamber will proceed much more rapidly than in traditional cylindrical drift chambers. Although there are 73,080 wires in the chamber, all of the stringing activities (*e.g.* pulling through sense/potential wires, field sheets, shaper wires) occur at the cell level, not the wire level. The COT has 2520 cells. Additionally, the mechanical and electrical properties of the wire planes and field sheets will have been pretested.

## 5. GAS SYSTEM

For 396 ns operation, we plan to use Argon-Ethane-$CF_4$ (50:45:5) bubbled through isopropyl alcohol. The expected COT operating point in this mixture is 2.3 kV/cm drift field and 64 $\mu$m/ns drift velocity. Argon-Ethane (50:50) has a sufficiently high drift velocity to resolve beam crossings. The addition of as little as 5% $CF_4$ has been shown to reduce or eliminate wire aging [4].

When the Tevatron switches to For 132 ns operation, we will use a faster gas, Argon-Ethane-$CF_4$ (50:35:15) bubbled through isopropyl alcohol, in order to resolve beam crossings. The COT operating point in this mixture is 2.5 kV/cm drift field and 88 $\mu$m/ns drift velocity.

Table 1
COT Mechanical Summary.

| | |
|---|---|
| Number of Layers | 96 |
| Number of Super-layers | 8 |
| Material ($X_0$) | 1.6% |
| Sense wire Spacing | 7.62 mm [0.3″] in plane of wires |
| Wire Diameter | 40 $\mu$m gold plated tungsten |
| Wire tension | 135 g |
| Drift Field | 1.9 – 2.5 kV/cm (depending on gas) |
| Maximum Drift Distance | 0.88 cm |
| Maximum Drift Time | 100 ns* |
| Tilt Angle | 35° |
| Length of Active Region | 310 cm |
| Total number of Wires | 73,080 |
| Endplate Load | ~40 metric tons |

| | superlayer | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Stereo Angle (degrees) | +3 | 0 | -3 | 0 | +3 | 0 | -3 | 0 |
| Cells/Layer | 168 | 192 | 240 | 288 | 336 | 384 | 432 | 480 |
| Sense wires/Cell | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Radius at Center of SL (cm) | 47 | 59 | 70 | 82 | 94 | 106 | 117 | 129 |

*Assuming Ar-Et-$CF_4$ (50:35:15); 140ns with Ar-Et-$CF_4$ (50:45:5)

We have measured the aging properties of this gas mixture using a realistic prototype COT cell, including vapor deposited gold on mylar field panels. In the 2 $fb^{-1}$ anticipated in Tevatron Run II, the wires closest to the beamline will accumulate approximately 0.1 Coul/cm. No significant aging was seen in the prototype chamber with charge accumulations as high as 0.5 Coul/cm.

## 6. HIGH VOLTAGE

Gain uniformity across a cell is controlled by stepping the high voltage settings layer by layer (both sense and potential wires.) Given that there are 12 sense wires and 13 potential wires per superlayer and 8 superlayers total, this implies that 200 high voltage supplies are required for the entire chamber. The voltage precision required and the high current draw (12.5 $\mu$A per sense wire maximum) rules out the use of a resistor-divider chain.

High voltage will be supplied by 200 BiRa VME-based supplies. The 200 supplies will be fanned-out 1-to-4 in order to deliver the high voltage to the chamber by quadrant. Sense wires are operated at $\sim$ 3 kV and the potential wires at $\sim$ 2 kV. However the voltage difference from wire-to-wire for all sense or all potential wires is less than 300 V and the difference between neighboring wires is less than 25 V. A 300 V rated ribbon cable is used for all sense wires, and a second ribbon cable is used for all potential wires within a superlayer. The cables are isolated from one another and from ground by kapton wrap and are mass terminated. The ribbon cables plug into daughterboards on the chamber face on the end opposite the readout electronics for each superlayer.

## 7. READOUT ELECTRONICS

Pulse amplification, shaping and discrimination will be performed on the chamber face using a custom ASIC developed at the University of Pennsylvania. The ASD (Amplifier-Shaper-Discriminator) was originally developed for the SDC straw tracking chamber [5]. The CDF version will have the shaping optimized for the COT, as well as baseline restoration and charge measurement ($dE/dx$).

The multihit nature of the COT requires that the ASD not only shape the signal for optimal two-track resolution but also that high rates and/or large hits do not cause large baseline variations. Changes in baseline can distort the pulse shape and degrade the time resolution performance on the second hit. A version of the ASD with baseline restoration has been developed for the ATLAS Transition Radiation Tracker. Optimization of the shaping and baseline restoration for the COT will be done using data from the CTC and COT prototype chamber, as well as from SPICE model simulations of chamber and circuit performance.

The ASD will also be designed to encode the magnitude of the charge deposited in the chamber cell in the trailing edge of the discriminator output pulse. In this scheme, the leading edge of the discriminator output indicates the time of arrival of the primary ionization and the trailing edge (*e.g.* the pulse width) is logarithmically related to the total charge deposited on that sense wire. A tradeoff between two-hit resolution and $dE/dx$ resolution is achieved by implementing a logarithmic relationship between the measured charge and the time over threshold ($\Delta t \sim log(Q)$). This keeps the time for the trailing edge encoding short (approximately $10 - 15$ ns beyond the width of the shaped pulse) while maintaining good resolution at the lower end of the $dE/dx$ spectrum. The proportionality between collected charge and pulse width will be externally controllable so that, as the luminosity increases, the additional time-over-threshold introduced by the $dE/dx$ circuit may be reduced or turned-off altogether in order to maintain an optimal two-track resolution.

The discriminated signals are driven out differentially (LVDS) on 560 $\mu$m [0.022″] microcoaxial cable. The motivation for this small cable is the desire to maintain calorimetric hermeticity and therefore having as little space as possible between the plug calorimeter and central calorimeter for cables. Once outside the detector volume, the signal is carried on flat cable with 1.27 mm [0.050″] pitch to the TDC cards which reside in VME crates mounted on the detector endwalls.

The TDC is a custom CMOS chip developed at the University of Michigan for the CDF COT and muon systems. The multi-hit TDC possesses one nanosecond binning and records the leading and trailing edge of each hit. Additionally, the TDC contains buffering for the pipelined Level 1 and Level 2 triggers.

For track-triggering, data from the TDC is latched (time-over-threshold) into time bins for the eXtremely Fast Tracker (XFT) Level 1 track trigger. The TDC hits are multiplexed to the XFT which performs pipelined segment finding and linking in order to find charged tracks with $p_T \geq 1.5$ GeV/c. The XFT provides a complete list of tracks in $\sim 1.7\,\mu$sec to other trigger hardware which performs matching to muon stubs and calorimeter clusters.

Upon an accept from the Level 2 trigger, the COT TDC data is read out to the Event Builder/Level 3 processor farm via high speed fiber optic serial link. Events satisfying the Level 3 trigger are then written to disk.

## 8. CONCLUSION

We have described the design and construction of the CDF Central Outer Tracker which is currently under construction. The COT will operate within the CDF detector at Fermilab during Tevatron Collider Run II.

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