D0 Silicon Trackers

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Abstract

The present Fermilab D0 silicon microstrip tracker, the silicon microstrip tracker which was designed to replace it, and plans for upgrading the present silicon tracker are described.

Keywords: Silicon ; microstrip ; tracker

1. Present Silicon Tracker

D0 designed, constructed, and installed a 792,576 channel, 1248 sensor, silicon microstrip tracker for Run II of the Fermilab Collider program [1] [2]. The central portion of the tracker comprises six barrels, each with four layers, six "F-disks", one attached to each barrel, and six additional F-disks divided evenly between two end disk modules. Two independently supported "H-disks" at each end of the central silicon region complete the tracker. The general arrangement of silicon within surrounding D0 detector elements is shown in Figure 1.

The silicon barrels and F-disks occupy a 1066 mm long region. They are positioned symmetrically about the center of the interaction diamond within two double-walled cylinders made of carbon fiber - epoxy (CFE) laminate. Each cylinder is supported from one end of the innermost barrel of the D0 central scintillating fiber tracker (CFT) and, near z = 0, from a pair of feet extending to the inner surface of that CFT barrel. Azimuthal orientation and transverse and longitudinal positions of the outer end of each cylinder are set by twelve sapphire ball and conical CFE mounts. The feet near z = 0 engage spring loaded structures glued to the inner surface of the fiber tracker barrel and provide transverse positioning.

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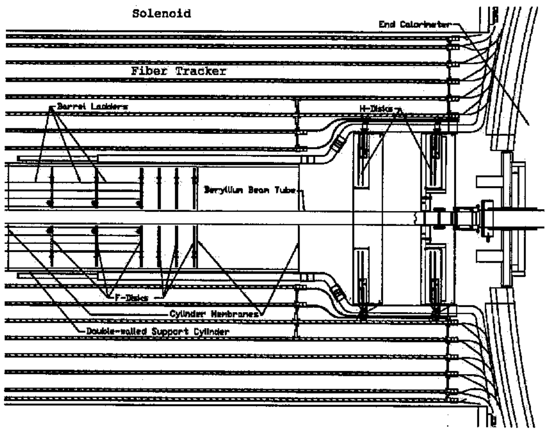

Figure 1. Plan view of silicon tracker elements within the Run II Fermilab D0 detector.

H-disks are supported from the inner surface of the third scintillating fiber tracker barrel with their silicon centered at z = ±1004 mm and z = ±1210 mm. Each H-disk is positioned by four sets of sapphire ball mounts; the mounts ensure that a disk can be removed and reinstalled with a precision of approximately 3 μm.

Seven varieties of sensors were used. All sensors are 0.300 mm thick. Barrels employ a combination of single-sided sensors, double-sided sensors with 2° stereo, and double-sided, double-metal sensors with 90° stereo. Trace pitches of ladder and F-disk sensors are 50 μm on p-side surfaces, 62.5 μm on n-side surfaces, and 153.5 μm on double-metal surfaces. Double-sided F-disk sensors have an effective stereo angle of 30°. In H-disks, single-sided sensors with 40 μm trace pitch and 80 μm readout pitch are glued back-to-back to provide 15° stereo.

Within a given barrel (Figure 2), readout structures attached to ladders are cooled and positioned by a 9.525 mm thick beryllium bulkhead. A 0.762 mm thick, uncooled, beryllium bulkhead positions the opposite ends of ladders relative to one another. All mechanical connections between a barrel and the silicon support cylinder are made via adjustable kinematic mounts to the cooled bulkhead.

Sensors of F-disk wedges (Figure 3) are attached to beryllium substrates, which carry the wedge readout structures. A beryllium ring cools and positions the wedges. Readout is at a larger radius than the cooling channel to aid in isolating heat sources from the silicon.

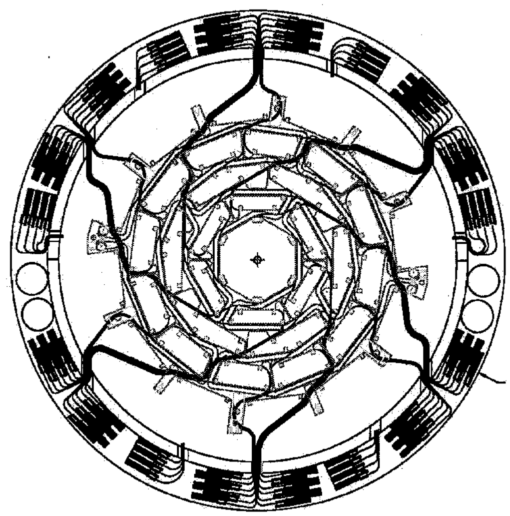

Figure 2. End view of ladder positions on the cooled bulkhead of the third barrel. The two coolant passages per bulkhead, three locations for connections to kinmatic mounts, protrusions for disk support posts, the CFE support cylinder, and low-mass cable bundles and coolant distribution manifolds on the exterior of the support cylinder are shown.

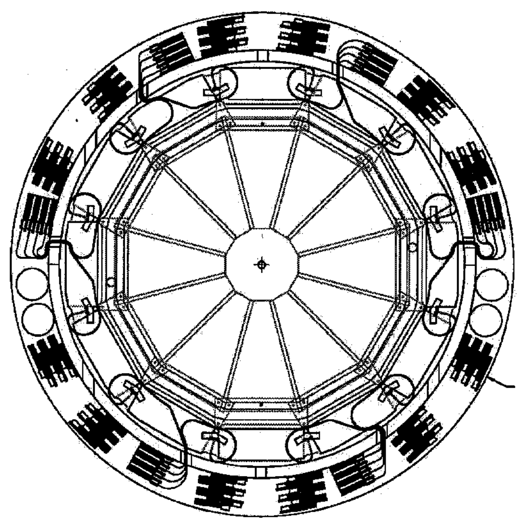

Figure 3. End view of the associated F-disk. The twelve wedges of the disk, the beryllium cooling / support channel, the locations of "outboard" readout HDI's, and pigtail paths are shown.

The three outer F-disks are joined using posts into an end F-disk module. Each of the two end F-disk modules is connected to the silicon support cylinder by adjustable, kinematic mounts.

H-wedges (Figure 4) are cooled and positioned by beryllium channels similar to those of the F-disks.

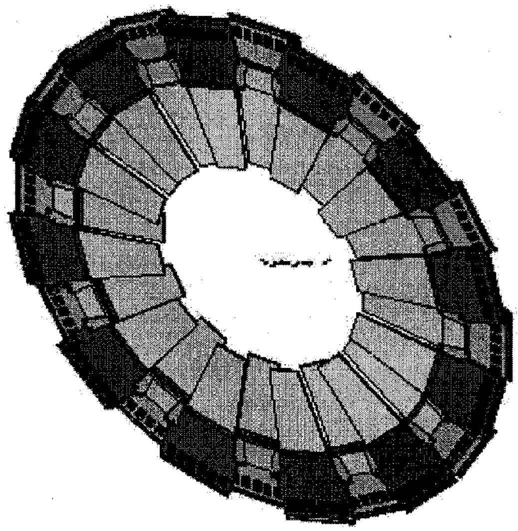

Figure 4. Isometric view of an H-disk assembly. Each wedge comprises four sensors. Pairs of sensors are mated back-to-back to provide 15° stereo. Readout structures are located on the exposed surfaces of the larger radius pair of sensors.

The silicon microstrip tracker was installed at D0 during the fall of 2000. Commissioning began in March 2001 and extended through May 2001. The silicon tracker has been in continuous operation since then and has performed well, with the exception that unexpectedly large fractions of ladders and wedges have needed to be disabled. Disabled devices are distributed over barrels and wedges with no clear pattern. While some devices which were disabled have been recovered, the fraction of disabled devices rose from roughly 6% to 13% for ladders, from 6% to 11% for F-wedges, and from 13% to 21% for H-wedges during the period November 2002 to September 2003. In the majority of failures, SVX-IIe chips do not download properly. Work to diagnose and remedy causes of failures was planned for the Tevatron maintenance period which began in September 2003.

Silicon alignment has proven to be quite good. Care was taken to ensure good alignment during ladder and wedge production, the installation of ladders and wedges on their cooling and support structures, and the alignment of those support structures in the global coordinate system of the D0 detector. Fabrication and assembly of most individual devices was conducted on Zeiss UM500, UPMC850, and UMC850 coordinate measuring machines which provide a typical measurement precision of 3 μm.

Checks of alignment with tracking data have shown that excellent alignment was obtained. Required adjustments to transverse positions of barrel layers were typically less than 20 μm. Radial and longitudinal adjustments were typically less than 60 μm and 100 μm, respectively. Figure 5 shows preliminary results for impact parameter resolution based upon the distance of closest approach of an individual track to a reconstructed primary vertex position.

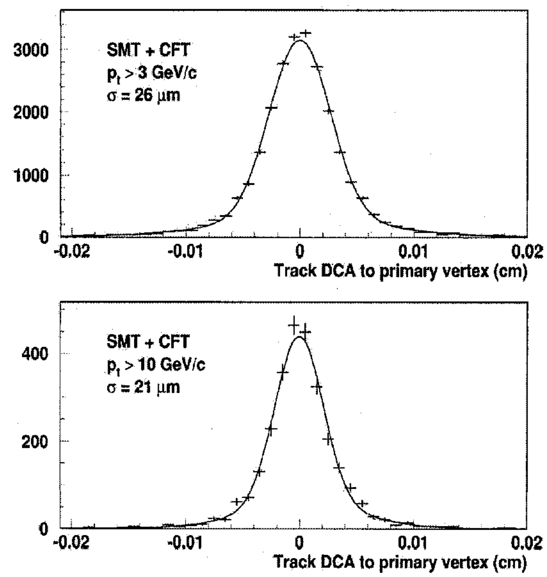

Figure 5. Measured impact parameter resolution from silicon microstrip and CFT data.

The silicon cooling and dry gas systems have performed as designed for more than 20,000 hours. [3]. Silicon cooling is based upon the forced flow of ethylene glycol – water mixture through beryllium cooling passages on which sensor structures are mounted. With –8° C coolant, the highest observed silicon temperature is +3° C. The average temperature of silicon in ladders is –3° C.

2. Replacement Silicon Microstrip Tracker

A new silicon microstrip tracker, with six barrel-layers spanning 1660 mm and no disks, was designed as a full replacement for the barrels and F-disks of the present silicon tracker [4]. A recent evaluation suggested that the present silicon tracker should exceed its design goal of operation to an integrated luminosity of 2 fb^{-1}, should operate well to an integrated luminosity between 3 and 4 fb^{-1}, and should be satisfactory for the duration of Fermilab Run II. Therefore, the full replacement silicon tracker is not needed and will not be built. However, a brief description of its design, which includes a number of features applicable to other silicon trackers, follows. An end view of the tracker is shown in Figure 6.

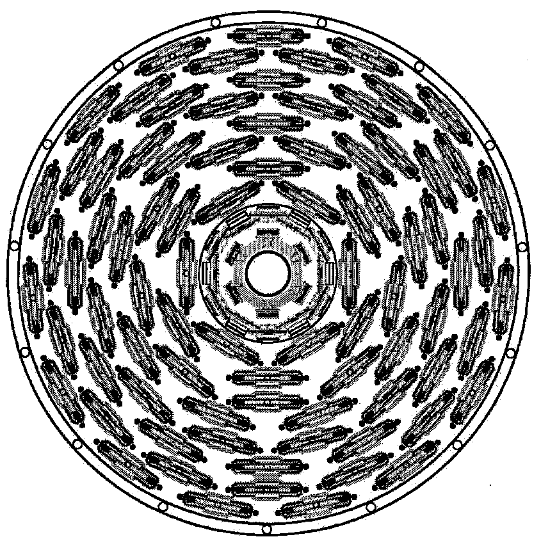

Figure 6. End view of the arrangement of layer 2-5 staves and layer 0 and 1 silicon, support structures, and readout.

To optimize the available radial space, stave-style construction is used in layers 2 through 5. That allows cables and cooling to run from the ends of the silicon region and the silicon support cylinders to be placed at a larger radius. Double-walled, CFE support cylinders run from z = 0 to z = ±860 mm. End membranes of the cylinders support and position the staves. Separate CFE structures support layer 0 and 1 silicon. Those structures would be aligned with the layer 2 through 5 structures using sapphire pin and bearing connections.

A prototype, electrically functional stave was produced, populated with double-ended SVX-4 readout hybrids, and successfully read out. An end view drawing of the stave is shown in Figure 7. CFE C-channels provide stiffness and position silicon sensors and their onboard readout. Cooling is provided via an ethylene glycol – water mixture, which flows through centrally located passages of PEEK tubing.

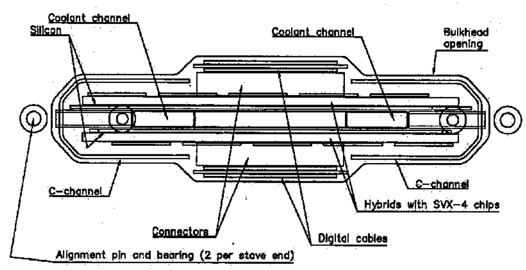

Figure 7. End view showing stave construction.

Layer 0 and layer 1 are constructed as separate units and then joined. Figure 8 shows the general construction of the two layers. Layer 1 readout employs double-ended onboard readout similar to that of layers 2 through 5. To reduce the amount of material in the sensitive volume, layer 0 readout is placed at the end of the silicon region. In layer 0, analogue cables connect sensors to hybrids.

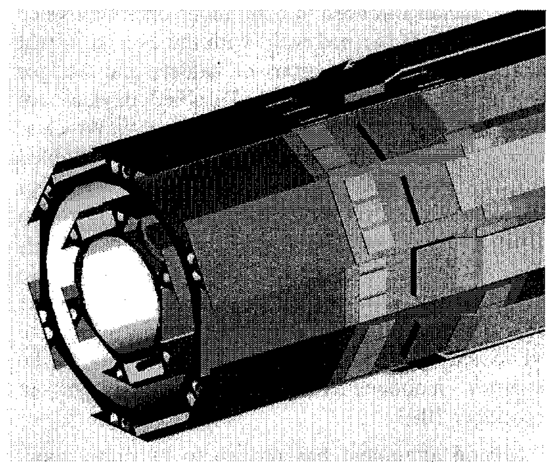

Figure 8. Isometric view of the z = 0 end of layers 0 and 1.

3. Plans for Upgrading the Present Tracker

To augment the capabilities of the present tracker without its full replacement and to partially compensate for any deterioration of its innermost layer, we have designed an additional silicon inner layer (layer 0) for the present tracker. Layer 0 must fit within the barrel and F-disk region of the present tracker. A conceptual design report has been submitted for Fermilab and U. S. Department of Energy approval. Figure 9 shows an end view of the sensor region of the present design.

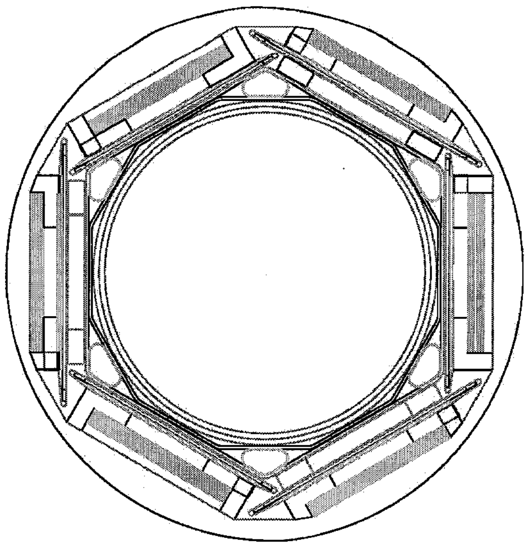

Figure 9. End view of the new layer 0 design. The double-walled CFE support cylinder, sensors, analogue cables, and the beryllium beam tube are shown.

The design takes advantage of R&D performed in conjunction with the full silicon replacement. Double-walled inner CFE cylinders provide support to the silicon sensors and their readout. PEEK tubing may be used for cooling passages, although other materials will be considered. Designs of hybrids, analogue cables, copper mesh on kapton grounding circuits, and readout electronics developed for layer 0 of the full silicon replacement should be adaptable with modest changes. The 29.464 mm diameter x 0.508 mm wall beryllium beam pipe of the full replacement would be used.

Silicon sensors are arranged at two radii in order to provide overlap. While sensor availability may require modest changes, the azimuthal coverage for present design is approximately 98%. Analogue cables carry signals to readout hybrids located just beyond the sensor region. The boundary of the tightest installation aperture, which occurs at z = 0 CFE membrane openings, is indicated.

Acknowledgments

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References

[1] The D0 Upgrade: The Detector and Its Physics, Fermilab Pub-96-357-E.
[2] E. Kajfasz, D0 Silicon Microstrip Tracker for Run IIA, Nucl. Instrum. Meth. A511:16-19, 2003.
[3] R. P. Stanek et al., Cooling of Electronics in Collider Experiments, Fermilab-Conf-03-352-E, 2003
[4] D0 Run IIB Upgrade Techinical Design Report, Fermilab Pub-02-327.