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A Completely Redesigned Vertex Detector

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ABSTRACT

Over the last year and a half, the DØ collaboration has undertaken a complete redesign of the Silicon Tracker for its upgrade. The new design optimizes geometrical acceptance and tracking efficiency for $|\eta| \leq 2$, in order to maximize the high transverse momentum physics accessible to DØ such as the top quark search. Details of the new design and reasons for the changes are presented here.

1. Introduction

The Fermilab Tevatron will be upgraded with the Main Injector in 1997. The first physics run is scheduled to start at the end of 1998. The luminosity will increase by a factor of ten, to $>10^{32}$ cm^{-2}s^{-1} and the bunch crossing time will decrease from 3.5 μs to 132 ns. The existing wire chamber tracking system will be inoperable under such conditions and will be replaced with a large silicon vertex detector[1] (the Silicon Tracker), a scintillating fiber tracker with four superlayers, a 2 T solenoid magnet and a preshower detector. The new system is expected to be operated for several years in order to accumulate between 0.5 and 2 fb^{-1} of data, up to 150 × more than collected during the 1992–3 collider run.

Since the previous silicon tracker was designed[2], the physics goals of DØ have been adjusted to take into account the cancellation of the SSC and the delay of the LHC until ~2004. The Tevatron experiments will now operate at the world energy frontier for ~5 years after Main Injector installation. The focus for the DØ upgrade is high p_T physics, with the emphasis for tracking on the central pseudorapidity region $|\eta| \leq 2$. In addition to the Silicon Tracker and Fiber Tracker, there will also be a forward tracking system, which is currently being designed.

2. New Silicon Tracker Geometry

The DØ Silicon Tracker consists of seven barrel segments, each made from 12 cm long ladders. There are four barrel layers for good track-finding efficiency. The inner layer 1, and layer 3 are made of single-sided r–ϕ measuring detectors and layers 2 and 4 consist of double-sided r–ϕ and r–z measuring detectors. Between each barrel segment there is a double-sided disk, which provides high resolution r–ϕ–z information. There are three additional disks at each end of the tracker to provide a track stub near the interaction region pointing out towards the future forward tracking system. The barrel radii span the region from 2.77 cm to 9.99 cm.

The goals of the tracker include high resolution (~10 μm) tracking in r–ϕ for efficient track-finding within highly collimated jets from top and tracking in r–z with ~0.5–1 mm resolution in the central region to aid pattern recognition and separate multiple interactions within a single beam crossing. The Main Injector with 132 ns crossing time will have an average of <1 interaction per bunch crossing. The proposed DiTevatron may have as high an average as 17 interactions per crossing[3]. Using the Silicon Tracker, Scintillating Fiber Tracker and 2 T magnetic field, the transverse momentum resolution in the central region will be $p_T\ \sigma(p_T^{-1}) \sim$ 5–18% for tracks with p_T > 10 GeV/c. High resolution tracking and efficient track-finding will allow the tracker to tag leptons as coming from primary or secondary vertices. Top decays into b jets will be tagged when the b quark decays hadronically, with an impact parameter resolution ~15 μm. The final goal for the Silicon Tracker is for its tracking information to form part of the L1.5 trigger. In combination with the Fiber Tracker, the transverse momentum of all central tracks will be measured within 10 μs.

3. New Features of the Tracker Geometry

Figure 1 shows a comparison between the former staged Silicon Trackers for DØ and the new tracker geometry. In addition, it shows the existing CDF SVX[4] and the proposed CDF SVX II[5]. The sketches are approximately to scale, where the length of the new DØ tracker is 88.8 cm from end to end of the barrel section, including six 8 mm gaps. The following changes have been made to the DØ Silicon Tracker design:

Improved Acceptance

The active barrel length has been increased from 48 cm in the Step 1 tracker to 84 cm in the new tracker. This increases the geometrical acceptance of high p_T leptons from ISAJET $t\bar{t}$ decays in the interaction region with $\sigma(z)$ = 22 cm from 72% to 94%. A track is counted within the geometrical acceptance when it passes through at least three layers of active silicon. The gaps between the barrel segments have been reduced from ~20 mm to ~8 mm when there is a disk present, and to ~1 mm if there is no disk. This has been partly achieved by reducing the disk thickness between the barrel ladders to 4.85 mm and by moving the disk readout structure outside the outer barrel layer radius. It has also been achieved by designing the high density interconnect cables and choosing ladder radii to allow the ladder cables to be wound out between the ladders within the active tracker volume, so that there is no dead region in z for readout and cables. Reduction of the interbarrel gap from 20 to 8 mm increases the geometrical acceptance for leptons from top from 89% to 94%.

Improved Efficiency

The silicon microstrip detectors have been specified to have no more than 0.5% bad strips when they are delivered. An additional 0.5–1% of strips will probably be lost during testing, assembly and installation. The remaining strips will operate with approximately 97% efficiency[6], leading to a global figure of ~96% efficiency per barrel layer. When this value is combined with the geometrical acceptances for the new tracker geometry, then the total efficiency for getting at least three hits on the track of a lepton from top is 75% with three barrel layers and 93% for four barrel layers. Therefore, we have chosen to add a fourth barrel layer to the Silicon Tracker in order to achieve acceptable pattern recognition efficiency.

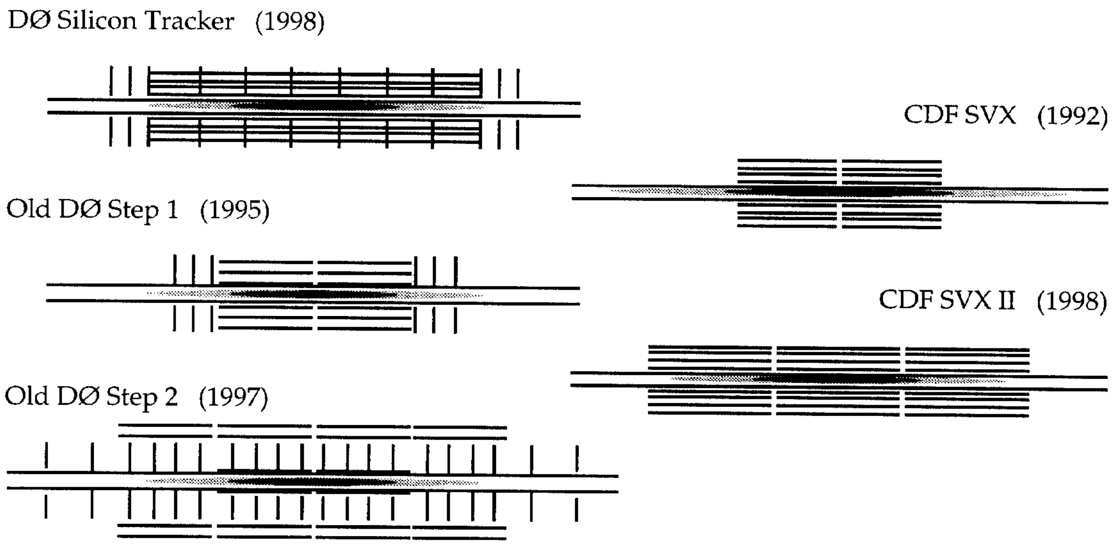

Fig.1 A comparison of silicon tracker designs at the Tevatron collider.

Two r–z measuring layers have been added to the tracker barrels to improve the pattern recognition. Ladders in layers 2 and 4 now have 2° stereo microstrips on the reverse side of the silicon wafers from the r–ϕ strips. Readout strips on both sides are at 50 μm pitch for good resolution. In the z direction, the resolution will be ~0.5–1 mm, which is equivalent to that obtained from the Fiber Tracker stereo layers.

System Simplification

Despite the new longer barrel length, extra barrel layer and the addition of z measurements to the barrels, there are ~63,000 fewer readout channels in the new tracker than in the Step 2 tracker shown in Fig. 1. This is because there are fewer disks, which have a high ratio of the number of readout strips to the active area.

The new tracker design costs ~$2.5M less than the former Step 2 tracker. The majority of this saving has been achieved by reducing the outer radius of the barrels, which significantly reduces the number of ladders needed for full coverage. The number of disks has also been nearly halved. The main physics loss from these design changes is that the momentum resolution deteriorates in the forward region beyond $|\eta| = 2$ where there are not as many tracking points and where there is more material between the disks which increases multiple scattering.

4. Radiation Damage

The radiation dose from accumulating 2 fb^{-1} of data has been calculated to be ~1.1 Mrad (31.6×10^{12} charged particles / cm^2) on the inner barrel layer at 2.77 cm radius, plus an additional 3.6×10^{12} neutrons / cm^2. This amount of radiation will raise the noise by ~800 electrons. When added in quadrature to the initial detector noise and SVX II chip noise, the signal to noise ratio is expected to decrease from 17 to 15 which will not have a significant effect on the efficiency of the tracker. The main effect of the 1.1 Mrad dose will be the rise of the depletion voltage to ~130 V if the detectors are operated at ~20°C [7]. The breakdown voltage of the coupling capacitors is ~100 V, and so the inner barrel layer detectors will become inoperable about half way through the run if they are inadequately cooled. If the silicon detectors are operated at ~0–10°C, and kept at that temperature between running periods, then the anti-annealing will be controlled and the full depletion voltage will be kept below ~80 V.

5. Summary

The DØ Silicon Tracker has been completely redesigned over the last year and a half. A technical design report was completed in July 1994. Almost all parts of the system have been prototyped and tested. Orders have been placed for the first 300 silicon microstrip detectors. The next step involves setting up complete working subsystems for testing. The Silicon Tracker is on schedule to be installed in mid 1998 ready for data-taking with the Main Injector.

References

1. The DØ Collaboration, "DØ Silicon Tracker Technical Design Report", (July 1994) DØ note 2169.
2. A.P. Heinson, "The DØ Upgrade Silicon Tracker", in the proceedings of the American Physical Society Division of Particles and Fields Fermilab Meeting (November 1992), World Scientific, (eds. Albright, Kasper, Raja, Yoh), 1731-3.
3. R.H. Siemann and G.P. Jackson, "A High Luminosity, 2 × 2 TeV Collider in the Tevatron Tunnel", presented at the Future Hadron Facilities Workshop, Indiana, (July 1994), DØ note 2207.
4. W.C. Carithers et al., "The CDF SVX: A Silicon Vertex Detector for a Hadron Collider", Nucl. Instrum. Methods **A289** (1990) 388-399.
5. J. Spalding et al., "The SVX II Silicon Vertex Detector Upgrade at CDF", to appear in the proceedings of the 6th Pisa Meeting on Advanced Detectors at Isola d'Elba, Italy, (May 1994), submitted to Nucl. Instrum. Methods.
6. S. Tkaczyk for the CDF Collaboration, "The CDF Silicon Vertex Detector", presented at the International Symposium on Development and Application of Semiconductor Tracking Devices, Hiroshima, Japan, (May 1993).
7. H.J. Ziock et al., "Temperature Dependence of the Radiation Damage Induced Change of Depletion Voltage in Silicon PIN Diodes", Nucl. Instrum. Methods **A342** (1994) 96–104.