The DØ silicon micro-strip tracker

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The DØ silicon micro-strip tracker (SMT) is part of the DØ upgrade for the Tevatron RunII at Fermilab. The detector has been running successfully since the start of the RunII physics data taking. The tracking and vertexing performance match the expectation from Monte-Carlo studies. An additional inner layer (Layer0) of silicon sensors at $R = 1.6\text{cm}$ will be installed in 2005.

1. Introduction

The DØ silicon micro-strip tracker (SMT) is located inside a 2 Tesla solenoid magnet and provides track and vertex reconstruction capabilities over the pseudo-rapidity coverage η of the DØ detector. The impact parameter of the reconstructed tracks is used to identify a vertex displaced from the beam interaction point (IP). This is used, for example, in Higgs search, top physics and B physics. The construction was finished in December 2000, installation was completed in March 2001.

In the following we discuss the design [1], performance and operation of the DØ SMT, and the design of Layer 0.

2. Design

Due to the length of the luminous region at the Tevatron ($\text{RMS} \simeq 25\text{cm}$) a design with barrels intercept with discs was chosen. A drawing of the DØsilicon tracker is shown in figure 1.

The six barrels provide tracking for high p_T particles with $|\eta| < 1.5$ and disk detectors for forward particles with pseudo-rapidity up to $|\eta| = 3$. The barrels are 12 cm long and consists of 72 ladders arranged in 8 layers, with pairs of layers forming four super-layers (L1 to L4). The barrels cover the radial region from 2.7 cm to 9.4 cm. L1 and L3 consist of single layer (SS) sensors for the two outer barrels (in beam direction), and double sided double metal (DSDM) technologies with 90° stereo for the four central barrels. Double sided (DS) ladders with $\sim 2^\circ$ stereo are used

Figure 1. Isomeric view of the DØsilicon tracker. The design includes six barrels intercept with discs. There are 12 central F-discs and four forward H-discs.

for L2 and L4 in all barrels. The 12 F-discs are located inbetween and just in front of the barrels. They are composed of 12 DS wedge 30° stereo detectors. The 4 H-discs cover the most forward tracking and are composed of 24 pairs of SS detectors glued back to back. The vendors are Micron for the barrel ladders, 67% Micron and 33% Eurysis for the F-discs, and Elma for the H-discs. The number of modules is 912 in total, comprising 792,576 readout channels. Read-

out assemblies, referred to as HDIs (High Density Interconnects), are made of Kapton flex circuits laminated to Beryllium substrates and carry the SVXIIe readout chips [2] and related components and provide bias voltage to the sensors. Each readout assembly is glued onto a silicon sensor, forming a module. The cooling system is operated at sub-atmospheric pressure and uses a mixture of 30% glycol and 70% water circulated at -10°C so that the detectors run between -5°C and 4°C when powered.

3. Performance

After installing and commissioning the detector, the signal to noise ratio has been measured to be $S/N=10$ to $S/N=15$ depending on the module type. The signal was taken as the cluster charge

Figure 2. Energy loss as a function of momentum. One can see the separation between proton, kaon and pions. The sample used to generate the plot is enriched with kaons.

for a MIP and was corrected for the track incident angle. For the noise the RMS of the pedestal distributions was taken. The noise consists of intrinsic

(random) noise coming from the front-end of the readout chip, and environmental (coherent) noise. The signal to noise ratio calculated only from random noise is between $S/N = 12$ and $S/N = 18$. The signal can be used to separate protons, kaons and pions by plotting the energy loss dE/dx as a function of the track momentum, as shown in figure 2. Figure 3 shows the track impact parameter resolution at the interaction point as a function of the transverse momentum (p_T) of charged particles. Superimposed is the MC expectation. The p_T dependence is caused by multi-

Figure 3. Impact parameter resolution (μm) as a function of p_T (GeV/c). The stars show the results measured in data, and the triangles show the expectation from simulation.

ple scattering and hence the amount of material, while the constant term depends on the alignment. Both the p_T dependence and constant term are in reasonable agreement between the data and MC.

4. Operational issues

Currently 85% of the modules are operational. The fraction of operating modules shows a slow downwards trend, as shown in figure 4. Several

Figure 4. The fraction of disabled HDIs as a function of time. The diamonds are for ladders, the squares for F-disks, and the triangles for H-disks.

modules are usually recovered by repair work performed during shutdown periods of the accelerator. However, approximately half of the disabled modules have problems in a non-accessible area, i.e. either SVXIIe chips, HDIs, or low mass cable connecting to HDIs. Around 10% of the modules show an unstable behavior in terms of being able to include them in the readout. Some Micron F-disk sensors show breakdown-related noise starting after several months of operation. A typical example is shown in figure 5. This noise appears mostly at the p-side, and looks like micro-discharges at the p-n junction, although there is no temperature dependence one would expect from micro-discharges.

Figure 5. Noise distribution of an F-disk sensor in units of ADC counts (energy deposited by a MIP is about 25 ADC counts).

5. Radiation dose studies

A reliable estimate of total absorbed dose is given by the increase in leakage current as a function of luminosity. Figure 6 shows the fluence Φ deduced from the measured leakage current increase ΔI using $\Delta I = \alpha \cdot V \cdot \Phi$, where $\alpha = 2.9 \times 10^{-17}$ A/cm is the damage coefficient after full annealing at 20°C and V is the volume of the sensor. The currents have been corrected for temperature according to $I \sim T^2 \cdot e^{(-1.23\text{eV}/kT)}$. Our measured fluence of $(3.5 \pm 1.0) \times 10^{12}/(\text{cm}^2 \text{fb}^{-1})$ 1 MeV neutron equivalent at $r = 2.7$ cm is consistent with a CDF measurement from Run I of $4.1 \times 10^{12}/(\text{cm}^2 \text{fb}^{-1})$. This result is also consistent with the dose measured by a radiation monitor consisting of 16 photo-diode sensors. Radiation effects on the sensors have been studied using a 8 GeV proton beam at the Fermilab Booster¹. After each step of irradiation, the depletion voltage was measured using a 1063 nm laser. The depletion voltage for each detector type is shown in

¹Data were taken at 0, 300, 600, 900, 1500, and 2100 kRad

Figure 6. The measured fluence equivalent to 1 MeV neutron as a function of distance from the IP (squares). Also shown in circles is the expectation based on CDF Run I measurement with a correction for different magnetic field.

Figure 7. Depletion voltage measured as a function of fluence equivalent to 1 MeV neutrons. The fluence is also expressed in terms of integrated luminosity in fb^{-1} and radiation dose in MRad at L1. The line is the expectation from Hamburg model[4]. The DSDM sensors used in L1 and L3 show abnormally fast reverse annealing.

figure 7 as a function of exposed dose. Superimposed is the expectation from the Hamburg model [4]. Also shown in figure 7 are axes for dose and luminosity². Abnormally fast reverse annealing is observed in the DSDM detector, while the other types behaves as expected. This is considered to be due to the $1.5 \mu\text{m}$ thick PECVD (plasma enhanced chemical vapor deposition) used as an insulator between the two metal layers in DSDM sensors. A test structure without such insulator does not show this abnormally fast reverse annealing. Coupling capacitor breakdown and micro-discharge are limiting the bias voltage to less than $\sim 150 \text{ V}$, which will limit the lifetime of the DSDM detector in the innermost layer to an integrated luminosity of $3.5\text{-}5.0 \text{ fb}^{-1}$. Until now the Tevatron has delivered 0.6 fb^{-1} , but the expectation is to get 8 fb^{-1} in RunII by 2009.

²The respective scaling factors are $3.5 \times 10^{12} \text{ 1 MeV n}/(\text{cm}^2 \text{ fb}^{-1})$ and $1.8 \times 10^{13} \text{ 1 MeV n}/\text{MRad}$

6. Layer0

DØ is building and plans to install a new layer of silicon strips (Layer0) inside the existing SMT in the fall of 2005. Layer0 consists of one layer of single sided Hamamatsu sensors directly supported by a carbon fiber structure at 1.6 cm from the interaction point. A six-fold geometry provides 98.5% acceptance in φ and there are 8 sensors in z . Besides mitigating the tracking loss due HDI failures and to the radiation damage for the innermost layer L1, Layer0 improves the impact parameter resolution due to its proximity to the interaction point. This will improve the physics reach by increasing the b -jet tagging efficiency by 20%. Radiation hard single sided sensor and SVX4 readout chips [3] will be used, which were originally developed for a full replacement of the current detectors³. A novel approach for the

³This upgrade has been cancelled in 2003

grounding will be pursued. All the carbon fiber surface will be covered with a copper mesh. This will provide electrical contact to the carbon fibers and allow us to use the carbon fiber structure as ground. Layer0 will be read out by existing data acquisition channels taken from the outermost H-discs, which will be removed.

7. Conclusions

The DØ SMT has been operational for 2.5 years and provides excellent tracking and vertexing capabilities. Operational problems include failures of readout modules, unstable modules and breakdown-related noise at F-disk sensors. Radiation studies indicate that the lifetime of the innermost layer L1 will be limited to 3.5fb^{-1} to 5fb^{-1} by micro-discharge and abnormally rapid reverse annealing of the DSDM sensor. In 2005 DØ plans to install a new layer of silicon detectors between a new beam pipe and the innermost layer of the existing detector. This new detector will ensure good tracking and vertexing capabilities to DØ throughout Run II.

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