Status and performance of the new innermost layer of silicon detector at DØ

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Abstract

The DØ experiment at the Fermilab Tevatron collider currently operates one of the largest silicon detectors in the world. The new DØ inner-layer detector (Layer 0) was installed during the spring 2006 Tevatron shutdown. It features a novel-type, low mass, radiation-hard layer of silicon at a very small radius. The Layer 0 sensors are connected to the readout chips outside the tracking volume via fine-pitched Kapton flex circuit cable (analog cable). The layer 0 is now fully operational and is integrated part of the DØ silicon microstrip tracker (SMT). Preliminary performance of Layer 0 is described.

Key words: Silicon microstrip detector; Layer 0; D0

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1. Introduction

The DØ silicon microstrip tracker is located inside a 2 Tesla solenoid magnet and provides both tracking and vertexing over nearly the full η coverage of the calorimeter and muons systems (1). The full detector has been fully operational since April 2002.

The length of the interaction region ($\sigma \approx 25$ cm) and large pseudorapidity acceptance led to a hybrid detector design of SMT, which consists of barrel modules interpersed with disks in the center and assemblies of disks in the forward regions. A drawing of the SMT is shown in Fig. 1. It consists of six barrels, which are 12 cm long and have 72 ladders arranged in four layers. The two outer barrels have single sided silicon sensors in odd numbered layers. The four inner barrels have double-sided double-metal 90° stereo ladders in odd numbered layers. The even numbered layers in all barrels have double sided 2° stereo ladders. The ladders are mounted between two precision machined Beryllium bulkheads. Each barrel is capped at high $|z|$ with a disk of 12 double sided wedge detectors, called an “F-disk”. The three disk/barrel assemblies are completed with a set of three F-disks in the forward region on either side. In the far forward regions two large diameter “H-disks” provide tracking at high η. The H-disks are made of 24 full wedges, each consisting of two back-to-back single

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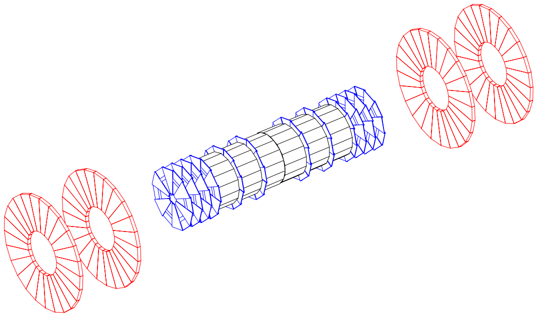

Fig. 1. Isometric view of the DØ Silicon Microstip Tracker. The design includes six barrels intercept with discs. There are 12 central F-disks and 4 forward H-discs.

sided silicon sensors.

In addition, the DØ collaboration has installed a new innermost layer of silicon inside the existing detector during the spring 2006 Tevatron shutdown(2; 3). This layer was to address three main issues with the current detector. First, the impact parameter resolution is significantly degraded for low momentum tracks due to the material associated with electronic and cooling inside the tracking volume. Second, the additional layer improves the pattern recognition, especially at higher instantaneous luminosities. Finally, it mitigates the possible tracking efficiency losses and degradation in impact parameter resolution due to the detector failures in the first layer of SMT (4). For the issues related to the radiation damage to the detector see (5) in these proceedings.

2. DØ Layer 0 Design

The requirement of in situ insertion into the existing detector imposed severe constraints on the design of the new Layer 0 detector. It had to fit between a new beryllium beam pipe ($r = 15$ mm) and the inner bore of SMT ($r = 23$ mm). The design includes a 1.0 mm separation from the beam pipe to limit capacitive coupled noise. Material must be minimized to best benefit the tracking for lower momentum particles.

The small diameter of the detector and insufficient cooling did not allow the direct mounting of the readout chips on the sensors, therefore a Kapton flex circuit cable (called the analog cable) is used to bring the detector signal to the readout electronics. This type of detectors was pioneered by CDF for Layer 00 (6). The performance of the Layer 00 is degraded significantly by the high level common mode noise (8). Therefore, we used their experience and paid special attention during the design stage to address the noise issues.

An individual Layer 0 module consists of a silicon sensor, a pair of the analog cables with 91μm pitch stacked on top of each other with 45μm offset and a hybrid with two SVX4 readout chips (7). The analog cable was fabricated by Dyconex. We use a ceramic pitch adapter mounted on the sensor to match the pitch of the cable and the sensor. The choice of sensors is Hamamtsu single-sided radiation-hard silicon with intermediate strips. The number of readout strips is 256 for all types of sensors. Layer 0 has a six-fold geometry with inner layer at $r = 16$ mm and the outer layer at $r = 17.6$ mm and 98.5% acceptance. There are four 7 cm long sensors in the central region and four 12 cm sensors in the forward regions. The segmentation along the beam axis is limited by the radial build up of the cable bundles. A cross section view of the detector is shown on Fig. 2.

Table 1 gives the specifications of the Layer 0 modules. The Layer 0 modules are mounted on the high modulus carbon fiber support structure. The hybrids are located on either side of the detector in forward region.

In light of the CDF experience with Layer 00, the dominant constraint on the electrical design was the need to eliminate common mode noise. The capacitance of analog cable (.35 pF/cm) doubles the detector capacitance, which then doubles the intrinsic noise of the detector. We match longer analog cables with shorter sensors to equalize the capacitive load (typical values of 22 pF) for all types of modules. Because of the added capacitance of the analog cable and the use of 300 μm thick detectors, even a small amount of common mode noise could seriously affect the performance of the detector. In addition the analog cable can act as a good antenna for picking up common mode noise.

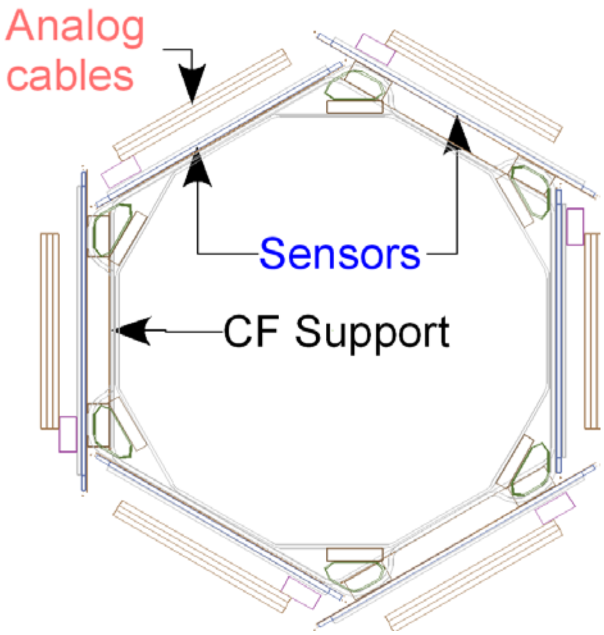

Fig. 2. Cross section of Layer-0 with carbon-fiber support structure, sensors and analog cables.

The overall philosophy is two fold. First, we isolate the detector grounds from the rest of the world to prevent any ground loops through the body of the detector. Second, we provide low impedance connections between the sensor and the SVX 4 chip so that there is little relative voltage between them at all frequencies in the pass band of the SVX 4. In addition, the hybrids and sensors use low inductance connection to a Kapton flex ground mesh circuit, which is cocured with the carbon fiber support structure.

The Layer 0 is isolated from the rest of the D0 by creating an isolated ground on the detector side of the electronics. This eliminates the ground loop through the detector. All single ended signals are converted to differential ones and sent the signals across the ground barrier to a differential receiver. The power supplies use local regulators that were chosen on the basis of their AC isolation specifications. This is implemented on a special adapter card that was installed during electrical connection of the detector. However, the isolation was not adequate so we added additional differential and common mode filters based on toroid coils outside the detector.

The two outermost H-disks were removed to accommodate the Layer 0 in the readout chain.

Table 1
Geometric parameters of the DØ Layer 0 detector

Layer	Radius (mm)	Z segment	Readout pitch (μm)	Length (mm)	Cable length (mm)
inner	16.0	central	71	70	320, 346
inner	16.0	central	71	120	167, 244
outer	17.6	forward	81	70	320, 346
outer	17.6	forward	81	120	167, 244

3. Performance

The Layer 0 commissioning began immediately after installation and completion of the electrical connections. Stable, error-free readout was achieved for all 96 chips in Layer 0. The total number of bad channels is less than 20, all due to the bad wire bonds defects during the module production. An outstanding noise performance was observed with both Layer 0 and SMT being readout. Figure 3 shows the typical pedestal, the total noise and the differential noise for one of the Layer 0 modules in normal running mode. The average differential noise is about 1.8 and the average total noise is about 1.7 ADC counts. From (9) we would expect the total noise to be 1.4 ADC counts so we conclude that there are about 0.3 ADC counts of common mode noise. An average signal-to-noise ratio of 18:1 is obtained for hits in Layer 0. The pedestals are very uniform across all the chips and they are read out in the zero suppressed mode, with a readout threshold set to pedestal plus 6 ADC counts.

Initial measurements show Layer 0 hit efficiencies greater than 90%, which is demonstrated on Fig. 4 and Fig. 5 as a function of the local x position in sensor and the inverse transverse momentum of the track respectively. Cosmic muon data with magnet on and off were collected to perform the alignment of the Layer 0 with respect to the SMT and to evaluate the improvement in the impact parameter and momentum resolution due to

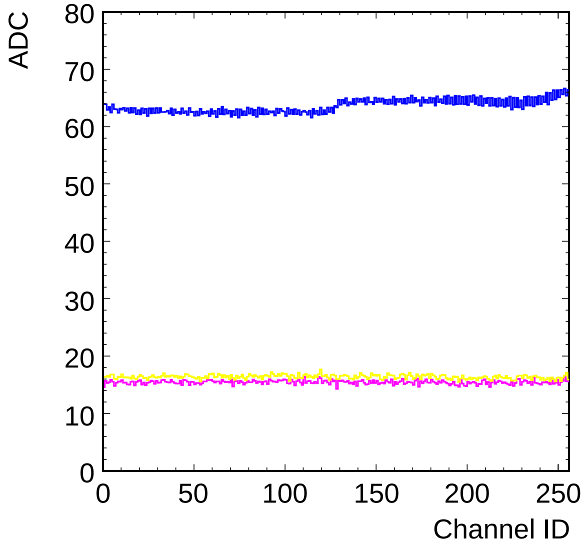

Fig. 3. Typical pedestal (black histogram), total noise ×10 (dark grey histogram) and differential noise ×10 (light grey histogram) as a function of channel for one module of Layer 0 after the installation inside the SMT.

Layer 0. The impact parameter resolution for the tracks with hits in Layer 0 and transverse momentum less than 5 GeV/c is 26.5 μm and the corresponding distribution is shown in Fig. 6. This can be compared with impact parameter resolution of 41.2 μm for the same tracks (Fig. 7) after refitting of the tracks with Layer 0 hits removed. Therefore, we observe ≈ 55% improvement in the impact parameter resolution due to Layer 0 for the tracks with low momentum. The corresponding improvement in the heavy-flavor tagging efficiency is expected to be ≈15%, which is important for example for identifying b-quark jets from top or Higgs decays.

4. Conclusion

The Layer 0 detector at DØ is a novel type silicon detector that has been successfully built, installed and commissioned by the DØ collaboration and is fully integrated in the operations of the rest of the detector. It is 100% functional with very low total noise and high signal to noise ratio. First results obtained with Layer 0 look very encouraging and should have big impact on both low- and high-p_T physics pursued by the collaboration.

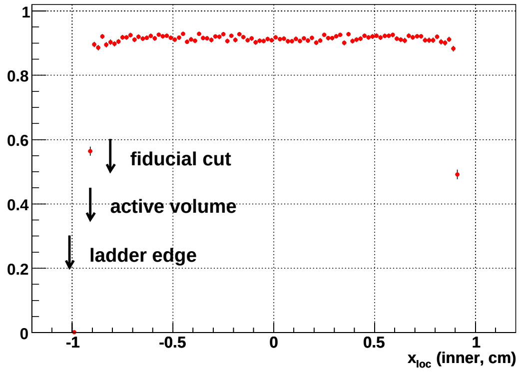

Fig. 4. Efficiency to attach a Layer 0 hit to a track as a function of the local x position in sensor.

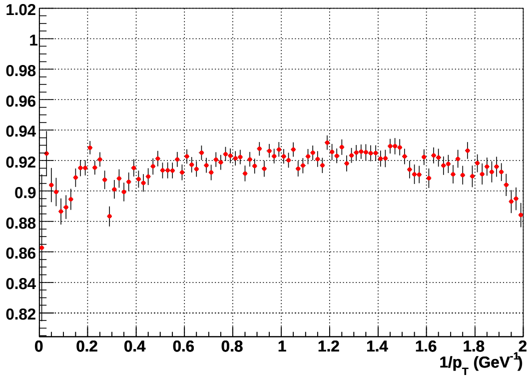

Fig. 5. Efficiency to attach a Layer 0 hit to a track as a function of the inverse transverse momentum of the track.

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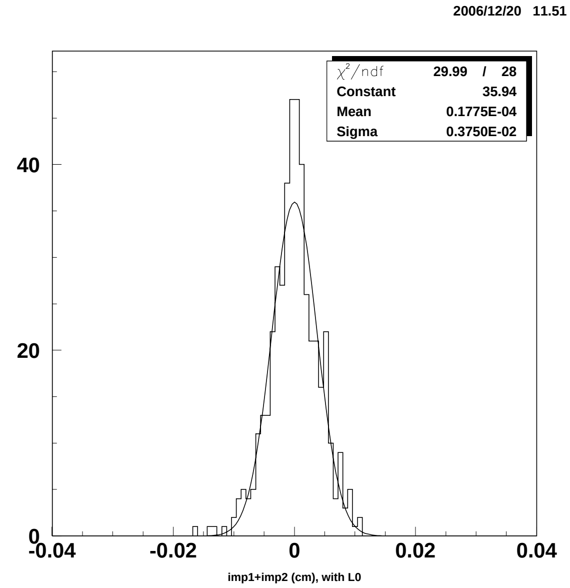

Fig. 6. Impact parameter resolution for tracks with a hit in Layer 0 and $p_{\mathrm{T}} < 5$ GeV/c from cosmic muon data. Sigma of the Gausian in the plot should be multiplied by $1/\sqrt{2}$.

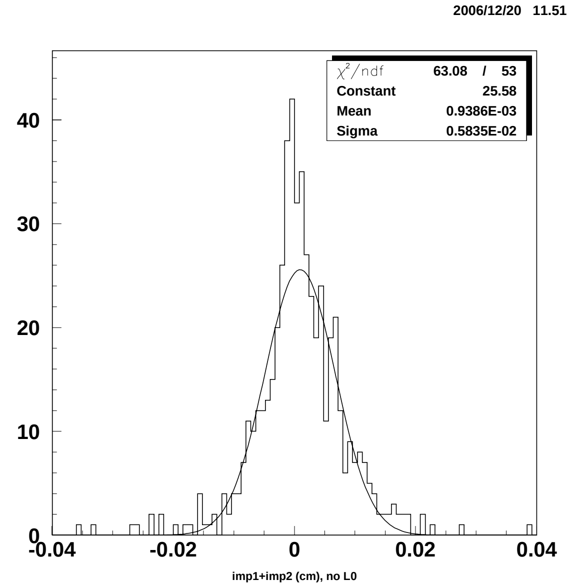

Fig. 7. Impact parameter resolution for tracks without a hit in Layer 0 and $p_{\mathrm{T}} < 5$ GeV/c from cosmic muon data. Sigma of the Gausian in the plot should be multiplied by $1/\sqrt{2}$.

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