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Journal
Nuclear Instruments & Methods in Physics Research Section A-Accelerators Spectrometers Detectors and Associated Equipment, 546(1-2)

ISSN
0168-9002

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Publication Date
2005-07-01

Peer reviewed

Status and Performance of the CDF Run II Silicon Detector

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Abstract

We report our experience commissioning and operating the CDF Run II silicon detector during the first three years of Run II. The performance of the system and its impact on physics analysis are reviewed. As the luminosity delivered by the Tevatron increases, measurable effects of radiation damage have been observed. Studies of charge collection and noise versus applied bias voltage at several different integrated luminosities are presented. These results and their impact on the expected lifetime of the detector are discussed.

Key words: Silicon vertex detector, CDF Run II upgrade, radiation damage.
PACS: 29.40.Gx, 29.40.Wk

1 The CDF Silicon Detector in Run II

The CDF Run II silicon detector with its 8 layers of double-sided silicon microstrip sensors sensors and a total 722,432 readout channels is one of the largest silicon detector devices presently in use by a HEP experiment. It replaced the Run I silicon detector thereby providing nearly double the coverage of both the luminous region and pseudo-rapidity (η), the ability to do three dimensional tracking, and enhanced impact parameter resolution for better B tagging [1,2]. The system comprises three subdetectors: SVXII, ISL (Intermediate Silicon Layers), and L00 ("Layer Zero Zero"). SVXII consists of 360 double-sided ladders in a layout of six 15 cm axial sections $\times$ twelve 30° ϕ slices $\times$ five radial layers between 2.5 and 10.6 cm. The symmetric segmentation in ϕ allows the processing of the silicon data with a fast Level-2 displaced vertex trigger processor [3]. ISL covers the area between SVXII and the CDF wire

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tracker (COT), with 296 double-sided ladders at radii of 20 or 28 cm, in total 1.9 m long, providing silicon hits out to $|\eta| \leq 2$. L00 is a single-sided layer of 48 ladders mounted directly on the beampipe, 1.5 cm from the beamline, which enhances the impact parameter resolution by providing a precision space point before particles scatter in non-sensitive material of the beam pipe and services between the SVXII bulkheads. The $r\phi$ and rz views of the detector are shown in figure 1.

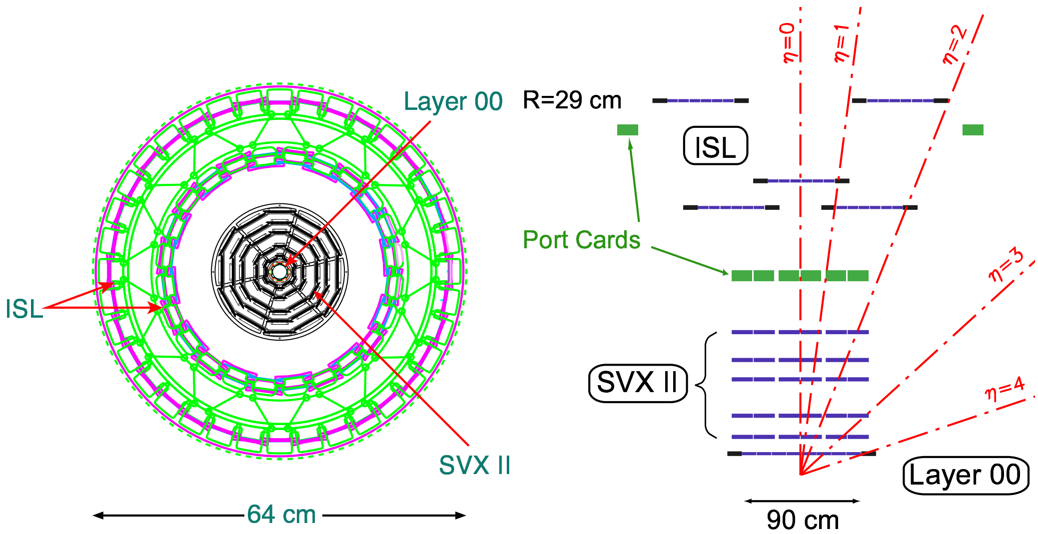

Fig. 1. $r - \phi$ and $r - z$ perspectives of the Silicon detector, showing all sub-components. Note the compression of the z scale.

The three subdetectors share the same readout system, starting with the SVX3D chip, a custom designed ASIC with a 128 channel × 42 capacitor analog storage ring, which makes it possible to acquire data in a "deadtime-less" fashion, integrating charge on one capacitor while reading out another. The SVX3D chip also features common mode noise suppression, sparsification, and other settings used to optimize the charge collection. By the middle of 2002, the detector was commissioned and taking physics quality data. During commissioning, several unexpected failure modes emerged: including wire bond failures due to Lorentz forces which induced mechanical fatigue on wire bonds in non-standard trigger conditions; epoxy blocked cooling lines in part of ISL; and analog pickup on cables in L00. These failure modes and their mitigation are described elsewhere [4–6]. As of September 2004, the detector has been operating with 92% of ladders powered and 85% providing data with an error rate of less than 1%. The signal-to-noise (S/N) ratios are determined as 10 for L00, 14(12) for the SVXII ϕ(z)-side and 12 for ISL ladders. The efficiency for associating rϕ hits to tracks in 3 layers of the silicon system is found to be 94% and 90% if hits in 4 layers are required.

2 Radiation Hardness and Lifetime of the CDF Run II Detector

Tevatron Run II was originally expected to deliver a total integrated luminosity of 15 fb^{-1} by 2008, to be accumulated in two stages. The present CDF Run II detector was designed for the initial Run IIa running period which was expected to yield an integrated luminosity of 2-3 fb^{-1} in the first three years. As the innermost silicon layers would have suffered significant radiation damage, a replacement detector, SVXIIb, was foreseen for the second stage called Run IIb. However, the initial performance of the Tevatron fell below these expectations. The revised Tevatron luminosity profile now projects an integrated luminosity between 4.4 fb^{-1}(base) and 8.6 fb^{-1}(design) by 2009 which led to the cancellation of the CDF silicon SVXIIb upgrade project in September 2003. The key concern now is to monitor the radiation damage of the detector and perform reliable estimates for its lifetime.

Radiation damage will render the innermost layers of the silicon detector system inoperational due to either degraded S/N or the inability to fully deplete the sensors. The shot noise of the sensors is estimated to increase as 900 $e^- \times \sqrt{I}$ [7] where I is the sensor leakage current which is expected to rise linearly with integrated luminosity. Assuming that the sensors can be fully depleted and provide the same signal size, the S/N of L00 and the inner layer L0 of SVXII will be around 6-8 after 8 fb^{-1} integrated luminosity, where the increase of noise due to the readout chips has also been taken into account. A preliminary study shows that S/N of better than six is required for B-tagging [8].

The single-sided L00 sensors withstand a bias voltage of up to 500V whereas the double sided innermost layer L0 of SVXII can only be biased up to 175V. This leads to a prediction of integrated luminosities of 7.5 fb^{-1} (L00) and 6.0 fb^{-1} (SVXII-L0) until the capability of fully depleting the sensors will be lost, with large uncertainties of the order of 1 fb^{-1}. The change in depletion voltage is monitored by scanning the bias voltages with and without Tevatron beam. During Tevatron operation, small samples of data are taking with different bias voltages applied.

The full depletion voltage is found by measuring the most probable value (MPV) of the charge distribution collected by hits associated with tracks as a function of the applied bias voltage where $\Delta V_{bias} = V_{bias} - V_{bias,nominal}$ indicates the difference between applied and nominal bias voltage. The result of such a scan is shown in figure 2 a). A preliminary measurement of the decrease of the depletion voltage of L00 ladders (before type inversion) yields (-39 $\pm$ 6) V/fb^{-1}. A complementary method is based on the observation that the noise measured on double-sided silicon sensors reduces appreciably as the p-stops on the n-side separate upon full depletion of the sensor. The result of such a scan is shown in figure 2 b). Both methods show consistent, preliminary, results of decreasing depletion voltage (before type inversion) of (-30 $\pm$ 2) V/fb^{-1} for SVXII layer L0. The effect of systematic uncertainties in both methods are currently being studied but the preliminary results are compatible with the prediction that both the innermost layers of the silicon detector (SVXII and L00) system will survive the projected base luminosity of 4.4 fb^{-1} but the innermost layer L0 of SVXII will fail before the design luminosity goals of 8.6 fb^{-1} are reached.

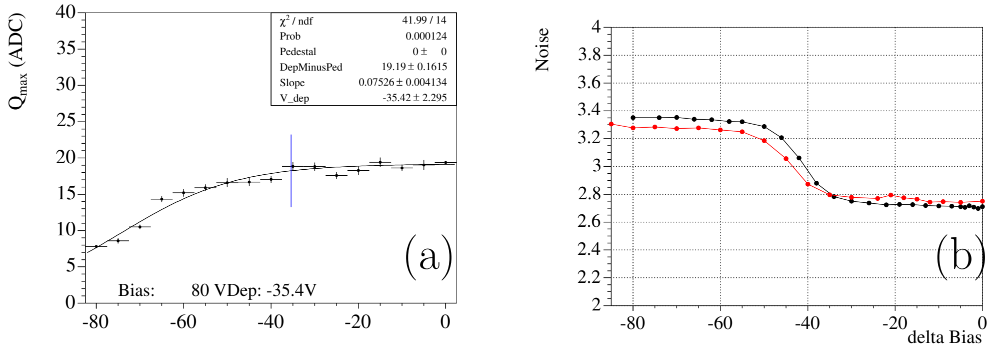

Fig. 2. (a) reconstructed MPV of the hits-on-tracks charge distribution as a function of ΔV_{bias} in arbitrary units of ADC counts. (b) Noise as a function of ΔV_{bias} in arbitrary units of ADC counts. The two curves indicate bias scans after 301 pb^{-1} (black curve) and 501 pb^{-1} (red curve) delivered luminosity.

3 Summary

The CDF Run II silicon detector has been performing well and providing physics quality data since June 2002. During commissioning, unexpected component failures were observed and countermeasures were successfully implemented. The current detector system will have to survive beyond its design goals and radiation damage will limit its lifetime. Monitoring procedures have been put in place to assess the accumulated radiation damage. Preliminary results are consistent with the prediction that the innermost layers of the silicon detector will survive the base scenario of 4.4 fb^{-1} but not the design scenario of 8.6 fb^{-1} integrated luminosity until 2009.

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