Operational experience with the silicon detector at CDF

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Available online 7 February 2007

Abstract

The CDF Run II silicon vertex detector is the largest operating silicon detector in high-energy physics. Besides being very important for tracking, the silicon detector plays a vital role in the level 2 decision making of the CDF trigger system. The silicon detector consists of eight layers of silicon with more than 720,000 readout channels. Since the commissioning period ended in 2002 the detector has been operating reliably and it has recorded more than 1.5 fb\(^{-1}\) of data. A summary of the operational experience with the silicon detector at CDF is given and aspects of the longevity of the detector are discussed.

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PACS: 81.05.Cy; 61.80.–x; 29.40.Gx; 10

Keywords: CDF; Silicon detectors; Radiation damage

1. CDF Run II silicon detector

The CDF detector [1] is a 5000 ton multi-purpose particle physics experiment dedicated to study proton–antiproton collisions at a center-of-mass energy of 1.96 TeV at the Fermilab Tevatron collider. One of the most important components is the silicon detector (see Fig. 1(a)). The CDF silicon detector is located closest of all sub-detectors to the beam and surrounds the beam pipe axially. This detector is essential for CDF’s high-precision tracking and for the displaced vertex trigger. The \(B\) physics program profits most from the silicon detector. The recent measurement of the \(B^0 - \bar{B}^0\) oscillation frequency [2] would not have been feasible without this detector component. The silicon detector is composed of three sub-detectors: SVX-II [3], Intermediate Silicon Layers (ISL) [4] and Layer Zero–Zero (L00) [5].

The SVX-II is the core of the CDF Run II silicon detector. It is designed as a high-resolution (<30 \(\mu\)m) vertex detector and to serve as input to the hardware displaced vertex trigger [6]. It is approximately 1 m long with five layers of double-sided silicon sensors at radii from 2.5 to 10.6 cm. Altogether there are 360 sensor modules and

Fig. 1. (a) x–y view of the silicon detector. (b) The efficiency for muons from J/ψ decays as defined in Section 2 [8]. The line indicates the average efficiency of 95%.
3168 chips which are read out in parallel. Three of five silicon layers have axial and 90° stereo strips while the remaining two have axial and small angle stereo strips at 1.2°.

The ISL have two roles: they extend the silicon tracking to high pseudorapidities of about $|\eta| < 2.0$ and they link tracks between the outer wire chamber (COT) and SVX-II as part of an integrated tracking system. One layer is located in the central region at radius 23 cm, and two layers each are located at radii 20 and 29 cm in the forward and backward region. The length of the ISL device is about 1.9 m. Altogether there are 296 sensor modules and 2368 readout chips. The ISL layers use double-sided small angle (1.2°) stereo strips.

The L00 provides a high-resolution tracking point before scattering by inactive detector material. It is a single layer of single-sided silicon strips mounted on the beam-pipe at approximately 1.5 cm. It is about 1 m long and consists of 532 radiation hard sensors with 108 readout chips.

2. Operational experience

The CDF silicon detector was installed in 2001. The commissioning phase lasted 1.5 years due to the complexity of the system and several problems that were encountered, such as blocked cooling lines in the ISL, burnouts of the L00 power supplies, pick-up noise in the L00 readout [5] and wire bond resonances [7].

After the commissioning phase, the CDF silicon detector is now used in routine data taking. The detector is in a very stable condition with 92% of the sensor modules powered and 84% of the sensor modules giving good data with an error rate of less than 1%. To monitor the performance of the silicon detector the efficiency of muons from $J/\psi$ decays is measured [8]. This is done by using good muon tracks from the muon chambers and the COT. These tracks are required to point into the silicon detector tracking volume. The tracking efficiency with the silicon detector is then defined as number of muon tracks with at least three silicon hits divided by the total number of muon tracks. The average efficiency is about 94.5% as shown in Fig. 1(b).

Maintaining the detector at this high efficiency level requires a significant effort compared to other CDF sub-detector systems, especially in human resources. There are five full time equivalents in the silicon operations group; at least two are on 24-h call. The power supplies as well as data acquisition (DAQ) boards are installed in the CDF collision hall. Both show beam-related, non-permanent failure modes, which are usually cured by resetting the affected component. The reset rate of power supply crates due to such failure modes seems to have increased over the last two years and there is a tendency that this rate increases with the integrated luminosity per month (see Fig. 2(a)). Due to the proximity of the silicon detector to the Tevatron beam line, it is particularly sensitive to any abnormal or unstable beam conditions. When the beam hits the beam pipe, secondary particles strike the silicon detector and lead to significant damage. The readout chips are affected the most in unplanned beam aborts. During the first weeks after an incident the affected readout chips return data with bit errors. After some months at least some of the affected readout chips recover.

![Fig. 2. (a) Averaged number of resets of power supply crates (see Section 2) as a function of the luminosity delivered per month. This is presented for all resets as well as for resets of power supplies located on the West and East side of the collision hall, separately. The proton beam comes from the West side, while the antiproton beam comes from the East side. The proton beam has usually a factor 5–10 higher intensity than the antiproton beam. (b) The depletion voltage predictions together with the measured depletion voltage (data) [10,11].](image-url)
3. Detector longevity

The silicon detector was intended to be replaced after the first $2\text{ fb}^{-1}$. However, the upgraded detector (Run IIb silicon) was canceled. Thus concerns over the longevity of the silicon detector were raised. The major concern was the effect of radiation damage upon the silicon sensors: can the sensors remain fully depleted to 2009 with no significant degradation to the signal-to-noise ratio [9].

The change in depletion voltage is measured by two methods [10]. If beam is available, then the bias voltage is varied and the change in collected charge is recorded. The bias at which the collected charge has maximized is defined as the bias voltage. The other method is to vary the bias voltage and to measure the change in noise. Here, the depletion voltage is defined as the bias which minimizes the noise. Both methods have been tested to be consistent with each other. In Fig. 2(b) the measured depletion voltage as a function of the integrated luminosity is compared to predictions [11] made beforehand. The measured curve follows the optimistic prediction which suggests that the detector will survive $8\text{ fb}^{-1}$ [10].

4. Conclusions

After a long commissioning period the CDF silicon detector is in a steady-state and has been used in regular data taking since 2002. Ninety-two percent of the detector is powered with 84% returning data with a digital error rate <1%. The current focus of activities is in maintaining the detector. Beam incidents are of concern for the detector. The effect of radiation damage is being monitored and preliminary results suggest the detector will survive $8\text{ fb}^{-1}$.

Acknowledgments

I would like to thank all members of the CDF silicon operations group for their support and their ongoing efforts to keep the silicon detector working at the highest possible level.

References