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# The CDF silicon detector: Performance and longevity

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**Abstract**

The CDF silicon vertex detector is one of the largest operating silicon detectors in particle physics. Its silicon sensors have 722,432 channels readout by 5456 chips and cover an area of $6\,m^2$. The detector is used for precision tracking and in the hardware trigger for events with a displaced vertex. This paper includes a brief review of the detector performance and mainly focuses on issues of longevity and effects of radiation damage. An analysis of the time evolution of depletion voltages and signal-to-noise ratios indicates that the CDF silicon detector should outlast the Tevatron Run II without major degradation of performance.
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## 1. The CDF silicon detector in Run II

The Collider Detector at Fermilab (CDF) [1] is one of two multi-purpose particle physics detectors at the Tevatron collider at Fermi National Accelerator Laboratory. At the Tevatron, protons and antiprotons are brought into collisions at a center-of-mass energy of 1.96 TeV, making it the highest energy collider in the world. To date, the Tevatron has delivered an integrated luminosity of $2.5\,fb^{-1}$ per experiment. The Run II program is expected to continue till 2009 with a goal to deliver from 5 to $8\,fb^{-1}$.

The silicon vertex detector is one of the core components of CDF. It allows for precision tracking and vertexing and is used in the CDF Silicon Vertex Trigger (SVT) [2], the first hardware displaced vertex trigger implemented at a hadron collider detector. The CDF silicon vertex detector is one of the largest operating silicon detectors in particle physics. It comprises eight concentric layers of silicon microstrip sensors with a total of 722,432 channels readout by 5456 SVX3D chips [3]. The total surface area covered by the silicon sensors amounts to $6\,m^2$. The detector is sub-divided into three sub-detectors (see Figs. 1 and 2): Layer 00 (L00), SVX-II, and the Intermediate Silicon Layers (ISL).

### *1.1. L00*

The L00 detector [4] is installed directly on the Tevatron beam pipe with sensors as close as 1.35 cm from the beam pipe. Its small thickness (only ~1% of radiation length, $X_0$) and proximity to the interaction point allow for precision position measurements before charged particles undergo any significant scattering in the detector material. L00 uses radiation hard, single-sided sensors (see Table 1), including Hamamatsu (HPK) sensors fabricated with design rules similar to those of sensors in use at the Compact Muon Solenoid (CMS) experiment. The strip pitch is 25 μm, but only every other strip is readout. The L00 sensors can be biased by up to 500 V.

### *1.2. SVX-II*

SVX-II [5] is the core of the silicon detector and it is the only component used in the hardware trigger for events with displaced vertices [2]. The SVX-II detector has five layers of double-sided sensors located at radii from 2.5 to 10.6 cm. Three layers (see Table 1) are made of Hamamatsu silicon with strips at 90° angle to each other. The remaining two layers are Micron sensors with strips at 1.2° angle to each other. The strip pitch varies between 60 and 140 μm,

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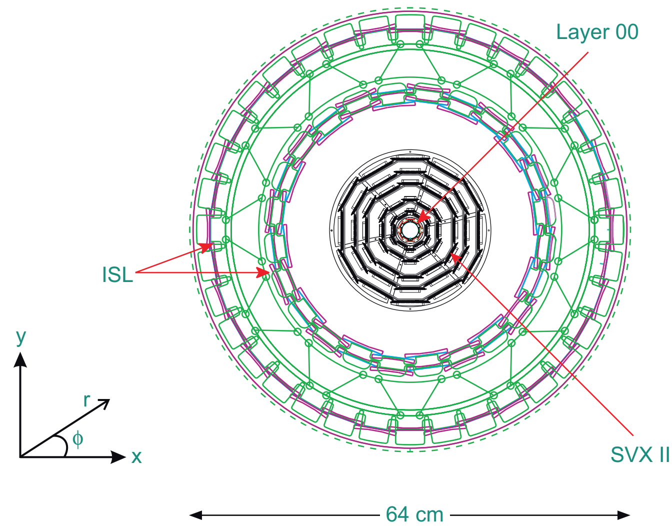


Fig. 1. $r\phi$ view of the CDF silicon detector.

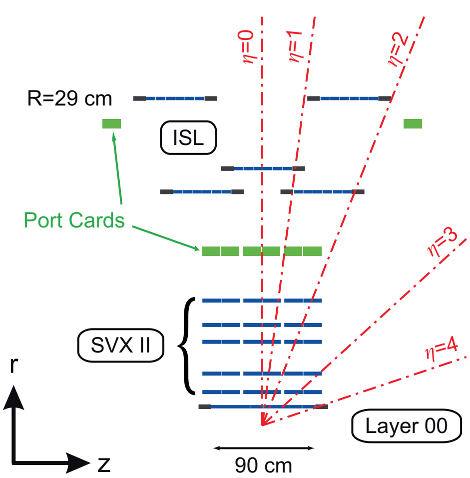


Fig. 2. $rz$ view of the CDF silicon detector (the $z$ scale is compressed).

Table 1
Summary of sensor properties of the L00 and SVX-II detectors

| Silicon layer | Radius (cm) | Manufacturer | Max. bias voltage (V) |
|---|---|---|---|
| Layer 00 | 1.35 | SGS-Thompson | 500 |
| Layer 00 | 1.35 | Micron (oxygenated) | 500 |
| Layer 00 | 1.62 | Hamamatsu | 500 |
| SVX-II Layer-0 | 2.54 | Hamamatsu | 170 |
| SVX-II Layer-1 | 4.12 | Hamamatsu | 170 |
| SVX-II Layer-2 | 6.52 | Micron | 70 |
| SVX-II Layer-3 | 8.22 | Hamamatsu | 170 |
| SVX-II Layer-4 | 10.60 | Micron | 70 |

depending on the layer radius. The maximum bias voltages that can be applied to Hamamatsu and Micron sensors are 170 and 70 V, respectively. It is limited by microdischarge effects and the breakdown voltage of the integrated coupling capacitors.

### 1.3. ISL

ISL [6] is the outermost component of the CDF silicon detector. It provides an extended forward coverage and links tracks between the CDF wire chamber and SVX-II. The ISL detector has one central layer at radius of 22 cm and two forward layers at radii of 20 and 28 cm. It is made of double-sided sensors with strips at a stereo angle of 1.2°. The strip pitch is 112 μm.

### 1.4. CDF silicon detector performance

The CDF silicon detector had a challenging commissioning period of 1.5 years due to a number of problems encountered: blockage of the ISL cooling lines [7]; burnouts of the L00 power supplies; pick-up noise in the L00 readout [4]; and wire bond resonances [8]. After the commissioning phase, the CDF silicon detector has been running reliably with ~92% of silicon sensor units[1] integrated in data taking and ~86% returning data with digital error rate $<1\%$. The performance is monitored by using muons from $J/\psi$ decays [9]. This is done by taking good muon tracks reconstructed by the wire tracking and muon chambers. These tracks are required to point into the silicon tracking volume. The efficiency of the silicon detector is then defined as a number of muon tracks with at least three silicon hits attached to them divided by the total number of muon tracks. The average efficiency is ~94%, and it is very stable after the commissioning period. The silicon detector has played a key role in the recent measurement of the $B_s-\bar{B}_s$ oscillation [10].

## 2. Lifetime projection for the CDF silicon detector

The Tevatron collider program is expected to continue till 2009 with projected delivered luminosity of $5-8\,\mathrm{fb}^{-1}$. This considerably exceeds the initial design goal for the silicon detector to be radiation hard for operation with a delivered luminosity of up to $3\,\mathrm{fb}^{-1}$. It is essential the CDF silicon detector remains operational throughout the entire duration of the Run II program. Given the fact that the detector is virtually inaccessible, the effects of beam incidents and long term radiation damage present the major concerns for its longevity.

Beam incidents have the potential for significant damage [11]. Analysis of about 150 uncontrolled beam aborts during the period between 2001 and February of 2006 suggests that 61 detector units (mostly in SVX-II) out of a total number of 728 units have been significantly affected by beam incidents (mostly during 2002–2003), resulting in reduced performance of these units. During one of the

[1]One detector unit includes a silicon sensor and a few readout chips: from 4 to 16 chips depending on a layer.