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Mechanical Design of the CDF SVX II Silicon Vertex Detector

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ABSTRACT

A next generation silicon vertex detector is planned at CDF for the 1998 Tevatron collider run with the Main Injector. The SVX II silicon vertex detector will allow high luminosity data-taking, enable online triggering of secondary vertex production, and greatly increase the acceptance for heavy flavor physics at CDF. The design specifications, geometric layout, and early mechanical prototyping work for this detector are discussed.

1. Introduction

The heavy flavor physics program of the Collider Detector at Fermilab (CDF[1]) has greatly benefitted from the successful operation of the CDF SVX silicon vertex detector.[2] Precise SVX position measurements have been used in the tagging of b-jets to identify top quark candidate events[3] and for lifetime measurements of b-hadrons.[4] The need for high resolution vertex detection will become even more important with the high luminosity ($\sim 10^{32}$ cm^{-2} sec^{-1}) running and shorter bunch spacing (132 or 395 ns) during the Main Injector era starting in 1998. The change in bunch spacing forces the replacement of the present radiation-hard SVX′ detector.[5] A second generation silicon vertex detector, the SVX II,[6] is currently in the design and early prototyping stages and will double the geometric coverage of the long interaction region at the Tevatron and extend the tracking coverage in pseudo-rapidity. The use of double-sided detectors will provide 3D vertex reconstruction, improving the background rejection in both top and b physics analyses. A Level 2 trigger processor, the Silicon Vertex Tracker (SVT),[7] will apply impact parameter cuts using the vertex detector information for tracks found at Level 1 in the outer central tracking chamber. Such vertex based triggering is particularly important for high statistics studies of B decay modes such as $B^0 \rightarrow \pi^+\pi^-$.

2. General Description

In order to reduce the channel occupancy and the input capacitance for the readout electronics, the SVX II detector will be arranged in three identical barrel modules mounted symmetrically with respect to the interaction point (Fig. 1). Each barrel will

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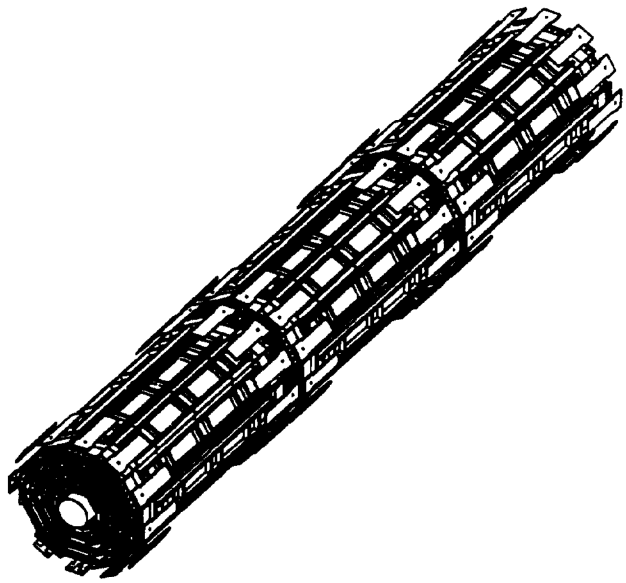

Fig. 1: The three barrels of the CDF SVX II silicon vertex detector.

be 32 cm in length, with four layers of silicon (numbered 0 to 3) grouped into ladders and arranged in 12 wedges in azimuth. Each ladder will consist of four silicon detectors mounted together into a single mechanical unit and wirebonded electrically in pairs which are read out at each end of the ladder. In order to reduce the dead space between barrels, the kapton readout hybrids will be attached to a beryllium substrates and mounted on the surface of the outer detectors of a ladder. The kapton/beryllium combination should have good cooling performance and lower mass than standard thick film hybrids. The ladders themselves are mounted between two precision machined beryllium bulkheads which have a staggered radii geometry and allow for overlap between neighboring ladders.

Figure 2 shows the geometry of the SVX II bulkhead. In contrast to SVX, the SVX II bulkhead has an integrated cooling channel within each mounting ring. This is accomplished by 4 separate cooling rings which are glued to the mounting rings to form the cooling channel for each layer. There is 1 input and output coolant connection for each layer. Such a design improves the cooling performance and minimizes the overall bulkhead plus cooling system mass.

The SVX II ladder design (Fig. 3) has evolved from that used for SVX and uses a structure formed out of boron-carbon fiber and Rohacell foam to couple 2 two-detector half-ladders together to form a complete 4 detector ladder. Significant engineering effort has gone into designing the ladder support to have the same thermal expansion coefficient as silicon in order to minimize stresses in the silicon during temperature changes. The ladder support structure should maintain detector-to-detector alignment to within ± 5 microns in the $r - \phi$ direction. Since the double-sided detectors[8] in the

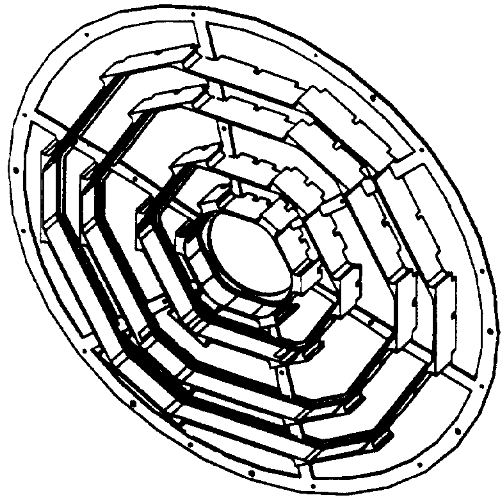

Fig. 2: A solid model of the SVX II bulkhead.

present SVX II design have an orthogonal stereo angle to optimize the $r-z$ vertex resolution, a tight tolerance on the radial uncertainty of the detectors is also required. This is because for tracks at large incident angles, there is a strong coupling between the radial and z position uncertainties. The z position uncertainty in the placement of the detectors during the ladder construction process should be $\sim \pm 10$ microns.

Due to the double-sided readout and having readout at both ends of the ladder, the power generated by the readout chips is substantial ($\sim 300-500$ milliwatts/chip). In addition, there is the power generated by the port card readout electronics[9] (up to a maximum of 6 watts per port card). Because of an estimated 1.4 kilowatts total power produced by the three barrel combination, lower temperature alcohol-based coolants delivered near 0°C are being considered as the best way of cooling the silicon to possibly 10°C in order to maintain good signal-to-noise after radiation damage. Low temperture dry gas will also have to be delivered to the closed detector volume in order to cool the silicon away from the bulkhead.

In order to achieve the 100 μradian alignment of the detector $r-\phi$ strips to the beam required by the SVT trigger to avoid high rates from fake impact parameter triggers, the three barrels will be mounted in an external space frame. Early designs of the space frame consist of a structurally strong, low mass web of carbon fiber strips molded into a half cylinder. The space frame is estimated to weigh less than 0.5 kg and have a deflection of $< 20\mu$m when fully loaded. The space frame will also provide mounting support for the portcards, cables, and cooling pipes.

Radiation damage is certainly expected to affect the performance of the SVX II detector over the lifetime of its operation. The silicon layer closest to the beam is most

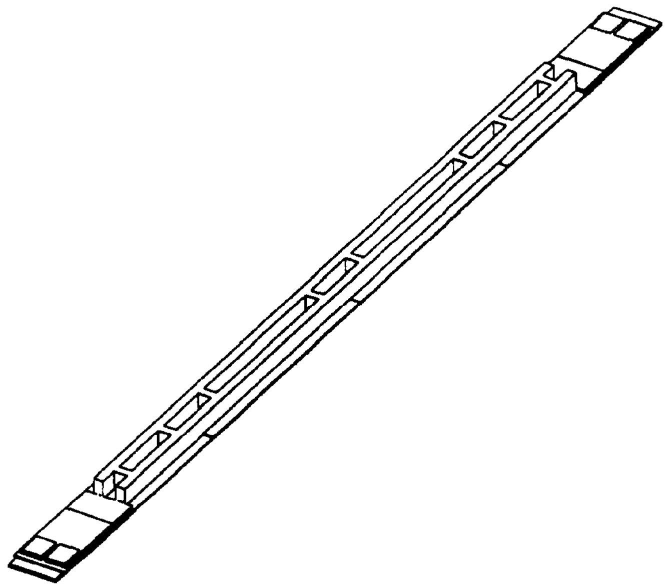

Fig. 3: Solid model of the SVX II layer 0 ladder.

affected since the radiation dose has been observed experimentally to be proportional to $r^{-1.7}$. The silicon strip detectors are expected to go through type inversion during colliding beam operation and layer 0 will probably need to be replaced after $\sim$ 1.5 Mrad exposure.

3. Comparison with SVX

Table 4 shows a comparison between the SVX and SVX II detector parameters. We see that the most dramatic difference is the doubling of the length has tripled the number of $r-\phi$ readout channels (due to the shorter electrical length) and that the addition of the $r-z$ readout nearly doubles again the number of channels.

4. Conclusions

We have described the mechanical design of the CDF SVX II vertex detector for Run II. This detector has double the barrel length over the present SVX′, uses double-sided silicon detectors, and allows for the possibility of triggering on high impact parameter tracks. The increased acceptance, efficiency, and background rejection should significantly improve the CDF top and bottom physics capabilities during the Fermilab Main Injector high luminosity running!

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Table 1: Comparison of the SVX and SVX II detector geometries.

Detector Parameter	SVX	SVX II
Readout coordinates	r-Φ	r-Φ;r-z
Number of barrels	2	3
Number of layers per barrel	4	4
Number of wedges per barrel	12	12
Ladder length	25.5 cm	32.0 cm
Combined barrel length	51.0 cm	96.0 cm
Layer geometry	3° tilt	staggered radii
Radius innermost layer	3.0 cm	2.4 cm
Radius outermost layer	7.8 cm	8.7 cm
r-ϕ readout pitch (4 layers)	60;60;60;55 μm	60;62;58;60 μm
r-z readout pitch (4 layers)	-	149;132;99;149 μm
Length of readout channel (r-ϕ)	25.5 cm	16.0 cm
r-ϕ readout chips/ladder (4 layers)	2;3;5;6	4;6;10;12
r-z readout chips/ladder (4 layers)	-	4;6;8;8
r-ϕ readout channels	46,080	147,456
r-z readout channels	-	119,808
Total number of channels	46,080	267,264
Total number of readout chips	360	2088
Total number of detectors	288	576
Total number of ladders	96	144
Silicon area (m^2)	0.68	1.5
Diode length (miles)	7.3	17.5

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