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The CDF SVX II Detector Upgrade

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ABSTRACT

The proposed CDF SVX II detector upgrade for secondary vertex detection during the Fermilab Tevatron Run II collider run is described. The general design and important features of this silicon vertex detector are presented. The CDF physics goals which are addressed by this detector are also given.

1 Introduction

Experience with the present CDF[1] data make it clear that high resolution vertex detection is a key tracking component in the CDF program of high p_T physics, specifically the top search and mass measurement, and b physics. The planned increase in the number of p and $\bar{p}$ bunches in the accelerator in 1996, and the resulting shorter bunch spacing (132 ns or 395 ns) requires a replacement for the SVX and SVX′ detectors. Based on the experience gained with the current SVX detector[2], CDF is planning to build the SVX II detector[3] which is capable of operating with the shorter bunch spacing and which extends the high p_T and b physics capabilities of the present vertex detector.

The top physics program and other high p_T physics topics will be helped by increasing the length of the vertex detector in order to improve coverage of the luminous region in z at the interaction point. The SVX II detector will double the present vertex detector length and add $r - z$ information which will increase the b tag efficiency for top events by a factor of 1.6 to 2.0 depending on the top mass. In combination with an increase in luminosity, this increased efficiency will give a dramatic improvement to the overall physics capabilities of the CDF detector.

The capability of using impact parameter information obtained from a vertex detector in the level 2 trigger to select events with secondary vertices will be of fundamental importance for any experimental program of b physics in a hadron collider environment. Having an impact parameter trigger implemented for SVX II will significantly increase the size of the b sample on tape. The experience gained in installing and running this trigger will help CDF to design more ambitious triggering systems in the future.

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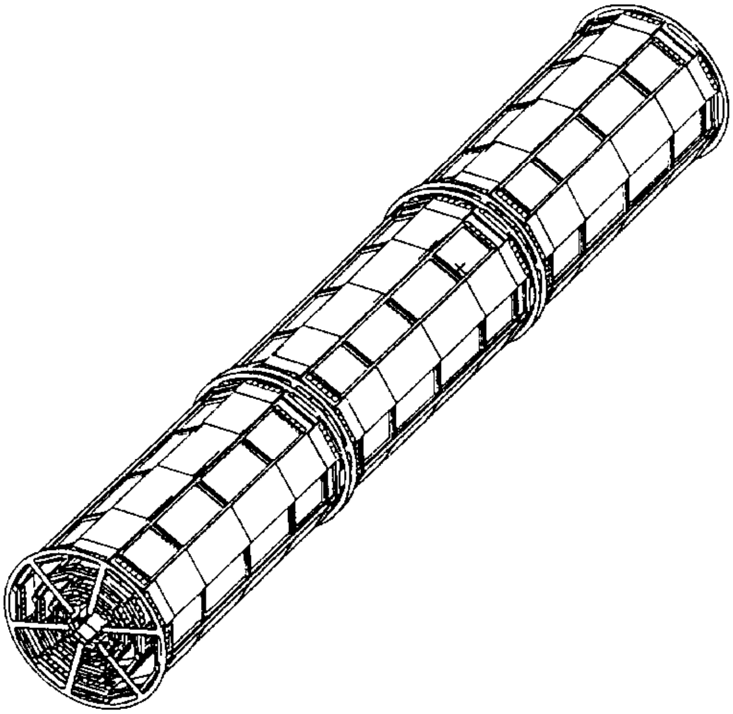

Figure 1: The CDF SVX II detector.

The SVX II detector described here is the detector required to pursue the high p_T physics goals of the CDF collaboration once the collider begins operation with the shorter bunch spacing. It is also the first stage in a two stage upgrade path. The second stage will add forward disks to extend the η coverage out to approximately three. This additional η coverage is necessary to obtain the good flavor tagging capabilities necessary for CDF to pursue b physics goals such as B_s mixing and CP violation studies.

2 General Description

2.1 *Mechanical*

The SVX II detector will be arranged in three identical barrel modules mounted symmetrically with respect to the interaction point (Figure 1). Each barrel will cover a region approximately 34 cm long in z and will consist of four radial layers of detector ladders. 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.

The ladder support structure should maintain detector-to-detector alignment to within ±5 microns in the $r-\phi$ direction and provide sufficient stiffness and thermal

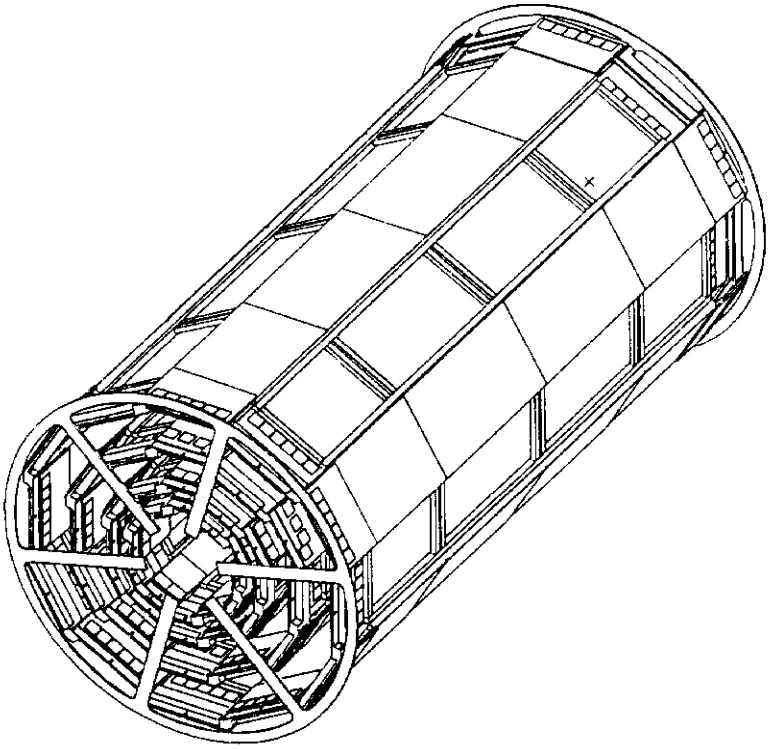

Figure 2: SVX II barrel geometry.

stability to eliminate gravitational and thermal mechanical bowing. The maximum amount of intrinsic bow in the ladder support structure after construction is designed to be less than 50 microns and should be measured to an accuracy of ±10 microns. Since the double-sided detectors used in SVX II have an orthogonal stereo angle to optimize the $r - z$ vertex resolution, a tight tolerance on the radial uncertainty of the detectors is 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 thus also be ±10 microns. All of the ladder designs that are being pursued should be able to achieve these tolerances.

The ladders will be arranged in wedges in a 12-sided geometry. Each wedge will span slightly more than 30 degrees and in the latest design, the wedges are staggered in radius with respect to each other in order to provide a small amount of overlap. This overlap is included to allow for wedge-to-wedge alignment using tracks. The staggered radius geometry should simplify the barrel construction and allow additional overlap between neighboring wedges compared to the SVX and SVX′ detectors. At present, the optimum mechanical length of the individual silicon detectors is still being explored. With four detectors of 8.5 cm length in each barrel, the total SVX II detector length will be 1.020 meters. The SVX II barrel geometry is shown in Figure 2.

Detector Parameter	SVX	SVX II
Readout coordinates	r-ϕ	r-ϕ;r-z
# barrels	2	3
# layers per barrel	4	4
# wedges per barrel	12	12
# ladders	96	144
Ladder length	25.5 cm	34.0 cm
Combined barrel length	51 cm	102 cm
Layer geometry	3° tilt	staggered radii
First layer radius	2.989 cm	2.416 cm
r-ϕ readout pitch (4 layers)	60;60;60;55 μm	60;55;60;55 μm
r-z readout pitch (4 layers)	-	166;111;166;166 μm
Active length of readout channel (r-ϕ)	25.5 cm	17.0 cm
# r-ϕ readout chips/ladder (4 layers)	2;3;4;6	4;6;8;12
# r-z readout chips/ladder (4 layers)	-	4;6;8;8
# readout chips/wedge (r-ϕ;r-z)	15;-	30;26
# r-ϕ readout channels	46,080	138,240
# r-z readout channels	-	119,808

Table 1: Comparison of the geometrical layout and design parameters of the SVX and SVX II detectors.

In SVX, laser-drilled holes in the hybrid circuit boards at each end of the ladder were used to define a reference line to which the silicon detectors were aligned with a 5 micron accuracy. The same approach will be taken with SVX II, except that the reference feature will be masked onto the hybrid, and the hybrid will be mounted on the silicon surface. This design will achieve less dead space between the neighboring barrels than in SVX. The SVX dead space between barrels was ~4 cm whereas the goal for SVX II (including space for readout cables) will be 1.5 cm or less.

Overall construction tolerances for SVX II will be similar to those achieved in the construction of SVX. The SVX II ladder design is 8.5 cm longer and the ladders may need to be somewhat stiffer, but the 50 micron bow limit should be achievable. An additional consideration in the construction and handling of the SVX II ladders is that there will be exposed wirebonds on both sides of the double-sided detector ladders.

The design requirements of SVX II are also similar to those of the SVX, however the power generated by the front-end electronics will be greater for each ladder because of the additional channels read out from the double-sided detectors. The radiation dose expected during the detector lifetime (up to 1 Mrad) is also much higher than that for SVX and SVX′. This higher radiation dose will have implications for the choice of detector electronics and structural materials. Table 1 shows a comparison between the SVX and SVX II detector parameters.

2.2 *Electrical*

The SVX II DAQ system is designed to be compatible with the upgraded CDF trigger and DAQ planned for Run II (up to 132 nsec beam-crossing times) and to be capable of working with eventual higher-speed upgrades which could be proposed. For Run II, the trigger system is intended to handle up to 5 kHz of level 1 accepts into the level 2 trigger. Since the SVX II is designed to digitize and readout in response to a level 1 accept in $\leq 5\mu s$, it is compatible with this requirement. The high speed of the SVX II readout and the ability to provide digitized analog information is also required for compatibility with a level 2 displaced-track trigger processor (SVT[4]).

The use of analog information for the present SVX, to find the pulse-height weighted cluster centroid, provided a significant improvement in the resolution. In addition, for SVX II, the use of analog information in centroid finding will provide good z resolution for tracks out to high incidence angles (high rapidity). The large number of channels and the need for fast readout speeds, have lead to a design with digitization on-board the front-end SVX II chip. Many of the features of this chip, for example the "nearest neighbor" readout scheme, and the desire for a readout threshold which can be set per chip, are based directly on the experience with the present SVX detector. The data aquisition and the control of the front-end chips will be highly parallel to reduce the impact of a single component failure. To provide the necessary bandwidth with minimal material and low power consumption, SVX II will use optical fiber transmission from the detector to a VME based DAQ system and the SVT trigger processor. There has been significant R&D on optical readout for SSC experiments, and while this is a relatively new technology, the development appears timely for SVX II.

The use of fiber optics will reduce electromagnetic interference and speed up the readout of the data for use by the level 2 trigger processor. The intention is to develop a DAQ including the front-end chip which is common as far as possible to both the CDF and D0 vertex detector upgrades. At present the design of the readout chip for SVX II has reached the prototype stage at both Lawrence Berkeley Laboratory and Fermilab. It is expected that the final chip will be a collaborative effort between these two groups. The principal features of the SVX II chip are as follows:

- 128 channels per chip, <3 mW power dissipation per channel.
- S/N > 12/1 for 20 pf capacitance after 1 MRad ($\sim$2 fb^{-1}).
- On-chip analog to digital conversion (7 bit).
- front-end dynamic range 3-400 fC ($\sim$100 MIPS).
- Fast analog signal path - settling within 130 ns for the upgraded Tevatron.
- Continuous time analog signal path (no reset cycle necessary).
- Double sample capability for use with AC coupled detectors.

- An analog pipeline of programmable depth (16 deep for up to 2 μs of delay at 130 ns).
- Single clock operation during data acquisition (CMOS or balanced positive ECL).
- Digitally programmable threshold for sparse readout.
- Complete digitization and readout option (no sparse).
- Fast all-digital sparse readout (>20 MHz).

2.3 *Detectors*

The barrel of the SVX II will be constructed from double-sided detectors made with high resistivity n-type bulk silicon of 300 μm thickness. The exact dimensions of these rectangular devices depend upon the barrel layer in which they are located, but a typical device has an active area which is between 10 and 20 cm^2.

The $r-\phi$ measurement will be made with the p-side. On that side, charge will be collected by longitudinal strips with ~25 μm pitch. The 5 μm-wide implant strips will be capacitively coupled to each other and alternate ones will be read out, resulting in a 55-60 μm readout pitch. The strips will be coupled to the readout by a thin (typically 0.2 μm) layer of silicon dioxide and an aluminum electrode. Polysilicon resistors will be used for biasing because of their radiation resistance.

The $r-z$ measurement will be made by transverse strips on the n-side. As with the p-side, the strips will be AC-coupled to the readout, the biasing will be polysilicon, and the implant and aluminum strip widths will be minimized to reduce the capacitance. The present two z readout pitches–111 μm and 166 μm–result naturally from the use on this side of 85 mm-long detectors and an integer number of readout chips (with 128 channels per chip). In the preferred design, Layers 1, 3, and 4 will have 166 μm n-side pitch, and Layer 2 will have 111 μm n-side pitch, with all channels being read out. The use of 90° stereo strips with these pitches on a rectangular detector naturally results in the assignment of multiple sense strips to the same metal strip. The multiplexing ambiguities can lead to reconstruction of unphysical tracks known as ghost tracks. The detector pitch and dimensions are being selected so that the ghost tracks are identifiable with the aid of the pointing resolution of the outer tracking chamber.

The SVX II design will be simplified by reading out both sides of the detector at the same edge. The plan is to use the "double metal" technique, in which each n-side transverse aluminum strip (the "first metal") is coupled by an aluminum via through a relatively thick insulator to a longitudinal metal strip (the "second metal") which lies on the detector surface. In an alternative to the double metal technology, signals from the transverse strips can be routed to the readout chips with an adhesive glass sheet or Kapton foil bearing copper laminated strips.

3 Physics Goals

3.1 *Top Physics*

The discovery and subsequent study of the top quark are major goals for the collider program. Top production at the Tevatron is expected to be dominated by the production of $t\bar{t}$ pairs. The cleanest signal for top will be the observation of two high p_T leptons from the semileptonic decays of both the t and $\bar{t}$ quarks. The $t\bar{t} \rightarrow 2l$ channel has a background from the direct production of W^+W^- pairs that subsequently decay leptonically. This background exceeds the top signal for values of $m_t \geq$160 GeV/c^2. The W pair background can be controlled by adding the requirement of high p_T jets in the event and/or by the requirement of a b tag in the event using the SVX II. The presence of a tagged b jet suppresses the W pair background and provides strong evidence for the top interpretation.

At CDF, b tagging is also needed for the effective use of the $t\bar{t} \rightarrow l - \nu - jets$ events. b tagging in CDF relies on either a lepton tag (from the semileptonic decay of the b) or on the identification of a displaced decay vertex with the vertex detector. In top events, the lepton tagging efficiency per b is ~10%. This efficiency is insufficient to extend the m_t measurement to the higher top masses or to effectively tag >1 b per event as needed in searches for possible deviations from Standard Model decays of the top. With the SVX II upgrade, the tagging efficiency per b will be significantly increased[3]. Knowing which jets are b jets will also improve the top mass measurement resolution.

3.2 *B Physics*

CDF has already demonstrated the ability to make B physics measurements[5]. By mid-decade, CDF will have reconstructed several hundred exclusive decays in ψK^+, ψK^{0*}, ψK_s^0, and other similar modes. A large fraction of these will have reconstructed secondary vertices using the SVX or SVX′. Nearly one hundred $B_s \rightarrow \psi\phi$ decays, several tens of $\Lambda_b \rightarrow \psi\Lambda$, and a few $B_c \rightarrow \psi\pi$ are expected in Run I. This is in addition to more than 2 million inclusive semileptonic B decays. These samples will allow cross section and $B\overline{B}$ correlation measurements, B spectroscopy and rare decay measurements, lifetime measurements to <5% statistical error for B^+ and B^0, and studies of b flavor tagging. Substantial improvements to the above analyses are possible by increasing the acceptance for b flavor tagging, by using three dimensional vertexing, and by implementing a level 2 secondary vertex trigger, all of which will be provided by the SVX II detector in Run II.

There are many important considerations for enhancing b physics at CDF. The low p_T of the B daughter particles means that good position resolution at the vertex requires minimum multiple scattering and thus minimum material usage in the SVX II. This requirement is also important in order to reduce the photon conversion background to the inclusive electron trigger. The need to have good mass resolution for fully reconstructed B decays and to have a large acceptance for flavor tagging is important for measurements of B_s mixing and CP violation. With upgrades, CDF will eventually have tracking and electron and muon coverage for $|\eta| < 3$. Initial estimates of the capability of SVX II to measure B_s mixing and CP violation show that CDF will be able to provide significant results for these challenging measurements using the 1 fb^{-1} data sample accumulated in Run II and beyond[6].

4 Conclusion

We have described the proposed CDF SVX II vertex detector for Run II. Many improvements to the CDF physics goals can be gained by doubling the barrel length over the present SVX, using double-sided silicon detectors, and by eventually adding forward disks or the equivalent forward tracking. It is expected that additional benefits in background rejection and in the use of 2-track vertices will be realized with the 3-D vertex information.

The double-sided SVX II detector for Run II will thus be a powerful tool for the exploration of high p_T physics, and for extending the b physics capabilities of CDF. The evolution toward a more comprehensive future b physics program, including B_s mixing and CP violation measurements, will be further enhanced by the natural addition of a forward tracking upgrade.

5 References

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[2] B. Barnett et al., *Nucl. Instrum. Methods Phys. Res., Sect. A* **315** (1992) 125; F. Bedeschi et al., *Fermilab Report No.* FERMILAB-CONF-92/263-E.

[3] SVX II Upgrade Proposal, *CDF Note No.* **1922**.

[4] G. Punzi et al, in the *Proceedings of the Workshop on B Physics at Hadron Accelerators*, Snowmass, 1993.

[5] See the talk by N. M. Shaw at this workshop. Also, F. Abe et al. (CDF Collaboration), *Phys. Rev. Lett.* **71** (1993) 500, and references therein.

[6] See for example the working group summary papers in the *Proceedings of the Workshop on B Physics at Hadron Accelerators*, Snowmass, 1993.