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Report of the Run 2B Tracking Godparent Committee

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1 Introduction

The Run 2B Tracking Godparent Committee was formed to review the possible upgrades to CDF's tracking systems in Run 2B. The main focus of the committee has been to ensure that CDF has a robust and integrated tracking system for running at high luminosities. The PAC has stated that the Run 2B upgrades should be justified in terms of sensitivities for the Higgs Boson search. The new Silicon Vertex Detector for Run 2B (SVXIIB) represents the major component of manpower, cost, and schedule of the Run 2B upgrade. It is currently the only upgrade which directly impacts the tracking system[1] . The committee first met in August 2001 and meetings took place over the course of about 6 months. Several interim reports were issueed to the leaders of the Run 2B project, the Spokespersons and to the Executive Board. This document attempts to summarize in one place the recommendations of the committee. This note is separated into several sections. First, we comment on several general points about the upgrade. Second, we discuss the major mechanical components of the SVXIIB detector. Third, we cover the layout (geometry) of the SVXIIB detector. We then conclude with several additional recommendations about the future. For a detailed presentation of the design of the SVXIIB detector and the Monte Carlo and data studies please see the CDF Run 2B Technical Design Report.

2 General Recommendations and Comments

We have several general comments regarding the upgrades for Run 2B. They are summarized as follows:

1. It is essential that we maximize the useful integrated luminosity of Run 2A. If the SVXII is functioning, we should be very hesitant as a collaboration to end Run 2A unless we are certain we can get back online with the shortest possible disruption to *physics-quality* running.

2. Radiation Damage: The premise for replacing the silicon detectors is based upon the belief that the current device will not survive 5 fb^{-1} of integrated luminosity. The committee strongly recommends that projected lifetime of the current detector be monitored and regular updates made to the collaboration.

3. The collaboration must maintain a focused effort on the Run 2B upgrades. The task of commissioning and integrating the new hardware into the offline reconstruction and simulation software packages should not be underestimated. The upgrade will be taking place in an environment where a large fraction of the collaboration will be busy extracting physics from Run 2A and some portion of the collaboration begins switching over to LHC based experiments. We recommend

[1]Some upgrades to the inner layers of the COT have been discussed informally in meetings of the committee. These include splitting the sense wires, and more recently deadening the large rapidity regions of the sense wires. Since no formal presentations or documents have been presented, this report does not include a discussion of these options.

that the spokespersons and the upgrade leaders establish MOUs, at the earliest possible time, for both the hardware project and the offline aspects.

4. It is important to keep the SVXIIB design simple so that, within the constraints of the schedule, we can build a reliable device that will meet our physics goals.

5. Our experience with the commissioning, operation, and data analysis of the Run 2A silicon detector may be one of the most important tools for optimizing/finalizing the design for the Run 2B detector. The Run 2B silicon group should continue to work in close contact with the commissioning and operations group for the Run 2A detector.

3 Mechanical Design

The mechanical design of the SVXIIB detector is an enormous challenge. The Run 2B Silicon group has done an excellent job of designing a device that can be constructed quickly and reliably. Some important early choices were necessary and the committee believes there are certain aspects of the design that are firmly established.

- The SVX4 chip is the only viable choice.
- We must use the stave concept to simplify construction.
- We must use single-sided silicon for ease of fabrication and radiation hardness.

We make several further comments below regarding the some of the major components of the detector.

Stave Design:
The stave concept has the potential to save time in the fabrication of the device. However, this is a new approach. It will require engineering and prototyping. Some prototyping has already begun. It is essential that the design and assembly techniques be fully explored early to avoid costly delays in later re-engineering. We recommended that the project managers investigate having a prototype stave built and thoroughly tested. (Note: the current schedule shows a prototype stave ready in September 2002). Furthermore, within the stave design, we encourage the project managers to reduce, as much as possible, the material budget, which is a concern of this committee. The cooling system should be carefully engineered, and the implications of the large gradients within the detectors should be understood not just at the stave level but also taken globally for the whole system. We expect this aspect will be addressed with engineering calculations checked against measurement performed on prototypes.

SVX4 Chips:
The design of the SVX4 chip seems to be well underway. The design was submitted in April for a prototype run. The design under went many detailed simulations, which revealed problems prior to the submission. This should reduce the chances of having to resubmit the chip several times. Nonetheless the SVX4 chip remains a potential bottle neck for the prototyping of the stave and eventual assembly of hybrids and staves. We are concerned about the manpower need for the development and production run chip testing. This is one area where establishing MOUs early will be critical. The committee would also like to see thorough testing of the radiation hardness and noise characteristics of these devices. Some testing has already occurred but more may be required.

Hybrids:
Design and testing of the hybrids should be pursued at full speed. Its interplay with the chip and the sensor on one side and the DAQ on the other must be understood before starting the full construction.

4 Layout

The layout of the Silicon Vertex Detector is composed of many dependent features. The features include:

- Number of silicon layers
- Radial and ϕ orientation of the layers
- Strip pitch and ladder length
- Number of axial and stereo layers
- Small Angle versus 90^o stereo sensors
- Angle for the Small Angle Stereo

The answers to many of these choices must be determined together since they are interrelated and tied to the performance of other tracking systems. For example, the choice of 90^o stereo angle is related to sensor size, which impacts the mechanical choice on Layer #1. The 90^o sensors also impacts the choice of the angle for the small angle stereo. The interplay between small-angle stereo and 90^o depends on the radial location of these layer. The expected performance of the COT and ISL also have an impact on choices that need to be made. All have some impact on physics, which should be the driving force. The committee spent the vast majority of its time discussing these issues related to the layout. We had to depend upon toy Monte Carlos (although at times very sophisticated), generator studies, and occasionally Run 2A data. Unfortunately, the geometry of the SVX has not been implemented in the Run 2 simulation. Therefore, detailed comparison between some of these choices is not available. We were required to make decisions based on the studies that were available.

Below we address some of the key points with regard to the layout of the Run 2B Silicon Vertex Detector:

- **Layer Positioning:** Studies were performed to optimize the positioning of the layers. Since the SVXIIB design is based on the stave components, it does not possess the "wedge" structure of the Run 2A design. Instead the Run 2B design relies on identical staves (Layers 1-5) so the layers are composed of staggered layers of silicon sensors. The committee believes that the Run 2B silicon group made reasonable compromises between location and orientation of the staves to optimize performance and maintaining the use of the same stave through out the outer layers to simplify the design.

- **Layer 1:**[2] Layer 1 represented a particularly challenging layer. In this region it becomes mechanically difficult to arrange staves close to one another. This layer is also a very critical layer for pattern recognition. Studies have shown that during the pattern recognition process, picking up the correct hit on Layer 1 does not guarantee finding the correct hit on Layer 0. However, picking the *wrong* hit on Layer 1 almost always leads to picking the wrong hit on Layer 0, which then leads to a poorly measured track and potentially false impact parameters. The design of this layer under went many changes during the review process. The designs that were discussed included, (1) A separate stave with unique sensor and hybrid mounted on the beam pipe along with Layer 0. This was the original design. (2) A Layer 0 like structure (*i.e.* no stave) mount together with Layer 0. (3) Using a stave identical to the outer layers and mounted structurally to the outer layers (not Layer 0). Ultimately, the design converged on the third option. The committee felt, while this meant certain compromises with regard to how close the sensor were to the beam line and coverage, it ultimately resulted in a simpler design that put less stress on the cost and schedule.

[2]There is a Layer 0, which is the inner most layer. It is not made of staves but rather has a design that is similar to Layer 00 in Run 2A.

- **Ninety Degree Stereo:** The committee considered the option of having 90 degree stereo layers as part of the design. One of the primary physics goals of Run 2B as defined by the PAC is the search for the Higgs boson. The decay of the higgs is primarily into energetic ($\beta\gamma \sim 10$) b-quark jets. Other interesting high P_t processes, such as the decay of top quark, also involve high momentum b-quark jets. These analyses will rely on locating displaced vertices in the $r-\phi$ direction. In Run 2B, the number of interactions could be as large as 15 per crossing (5×10^{32} cm$^{-1}s^{-1}$ 396 ns). Tracking in this environment will be challenging. The inner layers of the COT will have high occupancy which will degrade their performance. **Robust $r-\phi$ tracking must be the top priority**. The addition of precision ($\sim$10's of μm) in the z direction did not have a large impact on the ability to tag b-jets. The precision in z_0 provided by small-angle stereo sensors ($1-2$ mm) is sufficient for separating out most multiple interaction. The committee recommended dropping the 90 degree stereo layers in order to improve the $r-\phi$ tracking and an additional small-angle stereo layer. The elimination of the 90 degree stereo layers also reduces the overall cost of the project and reduces some of the stress on an already tight schedule.

- **Angle for Small Angle Stereo:** The small angle stereo layers in the Run 2A silicon detector (including the ISL) have angles of 1.2 degrees. When the Run 2B design included the use of 90 degree stereo layers, studies showed that small angles stereo layers at 2.5 degrees provided better connection between the axial layers and the 90 degree stereo layers. The difficulty with having a larger angle is the increased number of "ghost hits". These arise because the small angle stereo strip shadows (or intersects) more axial strips. When the design eliminated the 90 degree stereo layers, the committee recommended returning to a 1.2 degree small angle stereo. This reduces the number of ghosts and therefore reduces that potential for pattern recognition errors. The trade off is a degradation of the z_0 resolution. However, the expected resolution of $1-2$ mm is adequate for good separation of multiple interactions.

- **Number of Layers:** The SVXIIB device has 6 layers of staves. Because the staves are arranged in a staggered fashion, tracks at different ϕ and P_T may pass through more or fewer layers. The lab management requested that we consider descoping plans that included dropping layers of Silicon. Dropping Layer 5 (or 4) would reduce the number of staves required by 30% (24 %), resulting in a savings in both cost and schedule. A study (see TDR) showed that dropping these outer layers had a significant impact on our b-tagging efficiency, which then directly impacts our reach for the Higgs. In addition, the reduction or loss of the inner layers of the COT impacts the b-tagging efficiency further. The outer layers of silicon may be critical for bolstering the performance of the full tracking system. The committee therefore believes that the baseline design should maintain six layers.

- **Double Axial versus Axial-Small Angle Stereo:** Removing the 90 degree stereo layer from the design, presents the possibility of replacing those layers either with small-angle stereo layers or with additional axial layers. The original design contained two small-angle layers. The committee recommended that this be increased to 3 layers (Layers 2,3,4). These along with the small angle stereo layers in the ISL should provide good z_0 resolution and good efficiency for finding these tracks. With 3 layers of small-angle stereo sensors we do not appear to be close to an edge with regard to the resolution or the efficiency (see Run 2B TDR).

  Since 3 layers of small-angle stereo layers give sufficient performance, the committee recommended that Layer 1 and Layer 5 be a "double-axial" layers. For Layer 1 there are a number of benefits from a double axial layer:

  - (i) it slightly simplifies the mechanical design in this region.
  - (ii) Two axial measurements provide simple redundancy. This improves the chances that a good axial hit should be present in this layer. (It can also be used as a veto if no hit is observed in either layer.)

- (iii) The two axial hits close together can provide additional information to the tracking algorithms. The two hits represent a small track stub or line segment. When a track is projected into this layer, the line segment must have a slope that is consistent with the slope of the projected track at that location. A simple generator level study in $t\bar{t}$ events indicated that 40% of hit combinations can be removed with this requirement.

On Layer 5 the benefits are very similar[3]. However, the generate level study indicated that 72% of track stubs can be eliminated with the slope matching requirement. On this outer layer this reduces the number of road searches into the inner layers and therefore also reduces the chances for making a pattern recognition mistake. This double axial layer could also be critical handle as the inner layers of the COT degrade in performance.

4.1 Remaining Studies

There are several areas where we would like to see further work and progress to ensure that we are designing the best silicon detector for Run 2B within the constraints of the budget and the schedule.

- The Run 2B geometry must be implemented into the CDF Run 2 simulation. This will allow for more detailed simulations of the proposed detector and will start the process of integrating the new design into the offline software packages.
- The performance of L00 in the Run 2A detector raises some concern about the design of the L0 in Run 2B, since the design of this inner layer is based on the L00 design. The group should focus R&D on ensuring that the problem with common mode noise is under control so that we do not need to run in "readall mode".
- Further studies of the performance of the the r-z tracking should be continued to ensure that the three small-angle stereo layers are sufficient.
- Full simulation of the effective use of the double-axial layers.
- Performance of the device in a large number of interactions per crossing. The lab is considering not moving to 132 ns bunch spacing. At 5×10^{32} cm$^{-1}s^{-1}$ and 396 ns bunch spacing, the average number of interactions per crossing is $\sim$15. How does the device perform?

5 Conclusions

The Run 2B Silicon Group has produced an excellent design for the new silicon vertex detector. This was accomplished in a remarkable short amount of time and with a tremendous amount of work by a relatively small group of people. On behalf of the CDF collaboration, the committee wishes to thank the Run 2B Silicon Group for its work. There is a substantial amount of work left to be done before this device sees beam. However, the committee believes that the design presented in the most recent Technical Design Report represents a detector that will be effectively integrated into the full CDF tracking system and help achieve the physics goals of Run 2B.

[3]There is very little difference in cost and schedule between having Layer 5 as a double axial layer or another axial-small angle stereo layer. A decision can be made up until the ordering of the sensors, currently scheduled for the fall or winter.