Overview of SiD Tracking

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This report gives an overview of R&D done for the SiD tracker, including the baseline design plus options that are being considered.

1 Introduction

All of the elements in the tracking system of the SiD detector are made from silicon pixels or strips. Figure 1 shows an overview of this system, which comprises a silicon pixel vertex detector, a silicon strip tracker, and silicon forward disks. Figure 2 shows a detail of the elements near the beam line. Higher quality versions of these figures can be found in the slides that were shown at the workshop [1]. The vertex detector and the tracker are both built from cylindrical barrel layers plus planar disk endcap layers. The drivers for this design are the robustness of silicon against unexpected beam conditions, its excellent two-particle separation, its ability to resolve hits from a single beam crossing, and its exquisite spatial resolution which, when material is controlled, yields state of the art momentum resolution.

This report will focus on the tracker subsystem. Many additional details are available in the SiD report to the ILC Tracker Review [2], in its accompanying presentations [3], and in several contributions included in these proceedings [4]-[8].

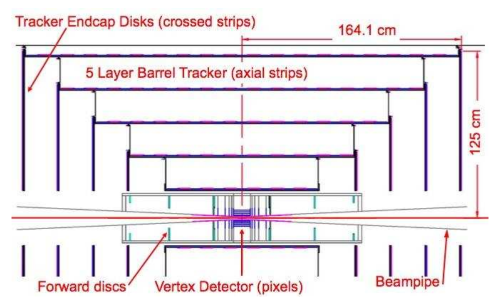

Figure 1: Vertical section of the SiD tracking system.

2 Tracker Layout and Options

In the tracker barrel, the baseline design is for 5 layers of axial strips, in which a single module design tiles the entire barrel, using a pinwheel scheme to implement overlaps in φ and radial offsets to implement overlaps in z. The design is for 25 μm trace pitch, 50 μm readout pitch and $S/N > 25$. A module has a length of about 10 cm. Options include more layers, different placement of layers, shorter strips, and stereo angles, either large or small, on some layers. There is also a question about the large radial gap between the vertex detector and the tracker; is an additional layer required in this gap?

For the tracker endcap, the baseline design is for crossed pairs of one-sided sensors, but a detailed module design remains to be developed. An option is to use a single layer of two-sided sensors with crossed readout; if a vendor is identified who can supply sufficiently high quality devices, this would be the preferred option because of the potential for lower mass. A second option is to transition from strips to pixels at small radii; the options for pixels include square, rectangular, and hexagonal. Similar options are on the table for the design of the forward tracker.

A mechanical design for the major support structures exists and was presented at the ILC Tracker Review [2] [3]. There is high confidence in this design because it derives from the experience of the D0 Central Fiber Tracker during Run IIa.

3 Readout Options

SiD is currently evaluating 3 readout options for the tracker, all of which have single bunch-crossing timing. The baseline readout option is to use the KPiX chip, which would be bump bonded (AC coupled) at a central location in each module. The chip has 4 sample and hold analog buffers, which will be digitized and read out between bunch trains. The design requires a double metal layer on the sensors to route signals and power; bench tests will be performed to verify that the power traces, which cross the signal traces, do not induce too much noise. The KPiX chip is also proposed for the SiD electromagnetic calorimeter (ECAL).

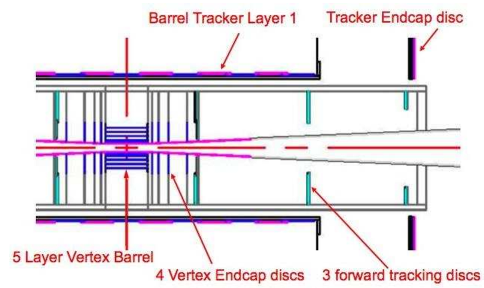

Figure 2: Detail of vertex detector and forward tracking system.

A second option is to read out each strip at both ends and to interpolate the z position using charge division. This design does not require double metal but it does require a longer shaping time. It is estimated that a spatial resolution of 5.5 mm can be achieved, which gives a resolution on $\tan \lambda$ of about 0.007, comparable to that of small angle stereo strips. Test sensors optimized for charge division will be ordered in the next SiD sensor submission.

The third option is a time over threshold scheme. Relative to the KPiX design, this has the advantage that it does not require analog buffering but it does require a shaping time of order 10 beam crossings. This option is discussed in detail elsewhere in these proceedings [4].

SiD is open to other read out options and is happy to evaluate sample chips from other R&D groups.

4 Alignment

The University of Michigan group in SiD is evaluating Frequency Scanned Interferometry (FSI) as a method for monitoring the alignment of the tracking system. In this technique, an absolute distance is measured by reflecting laser light from a reflector and counting fringe shifts as the laser frequency is scanned. The Michigan group has developed a method that uses two lasers to reduce systematics and has achieved a resolution of 0.20 μm in a bench test with a high degree of realism [5].

5 Power Cycling

In order to reduce generated heat, the SiD readout electronics will be powered down between pulse trains. The pulse trains come at a rate of 5 Hz, with duration of about 1 ms, and it is anticipated that the time averaged heat load can be reduced to about 1/80 of the powered-on load. Calculations show that the time averaged heat generation of the tracker, barrel plus endcaps, will be about 500 watts, a level that can be cooled by flowing about 100 cfm of dry air through the tracker volume. While detailed air flow and heat flow calculations remain to be done, this is not a particularly fast air flow rate and there remains plenty of headroom.

Another concern is vibrations induced by Lorentz forces caused by the large currents required to power-up the electronics in a short time. SiD plans to design a support structure that has sufficient stiffness at 5 Hz so that these vibrations are not an issue. The design will be validated using optical measurements on prototypes driven at 5 Hz.

6 Software

The SiD R&D effort uses the ALCPG software suite that is described elsewhere in these proceedings [6].

Detailed simulations are required to evaluate many of the outstanding design issues. One task is to evaluate the occupancy of the candidate tiling solutions for the tracker endcap and forward tracker layers. Another task is to develop a set of pattern recognition algorithms that find all tracks of physics interest with high efficiency. A Kalman filter will be used to study the resolution on the track parameters as a function of the detailed design of material layout. Once these codes are available the final optimization of the tracker can take place, within the context of optimizing the integrated tracking system. Whenever possible, the optimization will use as its metrics the results of simulated analyses of benchmark physics processes.

Most tracks of physics interest originate inside of layer 2 of the vertex detector. These tracks can be found with high efficiency by using the pixel vertex detector as a stand-alone pattern recognition device to find track seeds. While the pair background from beamstrahlung is large, simulations have shown this to be sufficiently mitigated by SiD's high magnetic field (5 T) and the fine segmentation of the vertex detector. These so-called "vertex seeds" are extrapolated to the tracker to pick up additional hits. This algorithm has been demonstrated to work well in the barrel region.

In the endcap and forward regions, the main issue is resolving ambiguities caused by ghost hits in the crossed strips. Work on these algorithms will begin as soon as candidate tiling solutions are coded.

About 5% of tracks of physics interest originate outside of layer 2 of the vertex detector and do not have sufficient vertex detector hits to produce track seeds in the vertex detector. These tracks include the decay products of long lived B and D mesons and the decay products of kaons and hyperons. Two strategies have been developed to deal with these tracks, calorimeter assisted tracking and stand-alone pattern recognition, both of which will be run after excluding hits found by vertex detector seeded pattern recognition. These algorithms are most important for barrel tracks, which, in the baseline design, have only axial strip measurements. Both algorithms, however, could prove useful to improve track finding efficiency for tracks that go through the tracker endcap or the forward disks.

Most non-electron charged tracks leave a clearly identifiable track stub in the SiD ECAL, which is made from alternating layers of tungsten sheets with pixel detectors. These calorimeter stubs have 3D information about the track trajectory, albeit with poor resolution. Calorimeter assisted tracking begins by finding stubs in the calorimeter and then extrapolating them into the tracker to pick up additional hits. A detailed description of this algorithm and a presentation of results can be found elsewhere in these proceedings [7].

The final pattern recognition algorithm is to use the tracker as a stand alone pattern recognition device. In the baseline design, all of the barrel layers are axial so the projection of tracks in the $r\varphi$ plane will be easy to find. As will be discussed in the next paragraph crude z measurements are available in all scenarios but there are scenarios in which high precision z measurements can be added to the track. A detailed description of this algorithm and a presentation of results can be found elsewhere in these proceedings [8].

For calorimeter assisted and stand-alone pattern recognition there are several options for obtaining z measurements. Each barrel module has a length of about 10 cm, which provides a z measurement with a resolution of $10/\sqrt{12} \simeq 2.9$ cm. For tracks that traverse adjacent modules that overlap in z, a higher precision z measurement is available. If vertex detector pixel hits can be added to the track, they provide high precision z measurements. If the track comes from a calorimeter seed, that seed provides measurements of both a z position and $\tan\lambda$. Finally, if the charge division option is chosen, it provides z measurements; moreover charge division measurements will greatly simplify both calorimeter assisted tracking and stand-alone tracking.

7 Summary

The physics drivers of the ILC have lead the SiD R&D group to propose an all silicon tracking system with three subsystems that perform in an integrated fashion. This report has discussed the baseline design and the main options for one of these systems, the tracker. The present tracker design is complete in the big picture and additional detail will be added throughout the coming year. The most pressing issue is to demonstrate that the proposed design has both the required pattern recognition power and the required resolution on track parameters; this is particularly important for tracks that traverse the endcap or forward disk regions and for tracks that originate far from the interaction point.

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8 Bibliography

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