Simulation of an All-Silicon Tracker

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We present recent improvements in the performance of the reconstruction of non-prompt track in the SiD Detector Concept Design, including initial results on the effect of longitudinal segmentation in the SiD tracker. We also describe a generic tracking validation package developed at SCIPP.

The SiD Detector Concept offers a number of potential advantages in the reconstruction of ILC collisions, but to be confident of the quality of this reconstruction, several of the SiD's innovative features need to be studied via realistic simulation. In particular, it must be demonstrated that the use of a limited number (five in the baseline design) of precise silicon layers for track reconstruction is sufficient to exploit the physics potential of the ILC machine. While there is little question that such a device can provide superior transverse momentum resolution, the capability of the design to recognize and reconstruct tracks – particularly those that originate outside the first layer or two of the vertex detector – is less clear.

To explore the performance of the tracker under realistic settings, we have developed a tracking performance package that evaluates the tracking efficiency and reconstruction accuracy of tracking algorithms. This package has been developed as a stand-alone C++ package, and thus is fully versatile, being easily applied to any ILC detector concept within any reconstruction framework (in fact, it is generally applicable to any cylindrical geometry track reconstruction package). In the interest of space, we do not present further details of this package here; sample output is to be found in reference [1]. We encourage interested groups to contact us for details.

One of the novel aspects of the baseline SiD design is that it proposes to do tracking reconstruction with only ten tracking layers, of which five are concentrated around the beampipe in a pixelated vertex detector. While previous studies [2, 1] have suggested that such an approach can be sufficiently efficient for prompt tracks, the reconstruction algorithm used in these prior studies was unable to reconstruct tracks originating outside of the first layer of the vertex detector. Over the past year, the SCIPP ILC simulation group has explored the capability of the SiD tracker to reconstruct such non-prompt tracks, and how that capability depends upon the longitudinal segmentation of the tracker. The results presented here are somewhat updated relative to the results presented at the workshop in May 2007.

The SCIPP group's work on non-prompt track reconstruction has been based on refining and extending AxialBarrelTracker, an algorithm originally written by Tim Nelson (SLAC) to reconstruct SiD tracks in the absence of the vertex detector. This algorithm works inward from the outside of the SiD tracker, beginning with three-hit seeds that lie on circles in the plane transverse to the beam line that miss the collision point by no more than 1 centimeter. To search for non-prompt tracks, the SCIPP group relaxed the miss-distance requirement to 10 centimeters, finding that, once the hits from prompt tracks were removed, the number of seeds remained tractable with the relaxed DOCA constraint.

The group explored the nature of the hits remaining after the hits from prompt tracks were removed. Roughly 5% of hits were due to tracks that went through three or more tracking layers and then exited the tracker. Approximately 45% of the hits appeared to be coming from tracks that looped through the tracker, striking each tracking layer a number of times. Roughly 35% of hits were due to material interactions of prompt tracks. The remaining 15% were hits from tracks with momentum too low to reconstruct.

In this light, a set of 'findable' non-prompt particles was identified by requiring that the underlying ('Monte-Carlo Truth') tracks lie within $|\cos\theta| < 0.8$, have a radius of origin between 2 and 40 cm and a path length in the tracker of of at least 50cm, not arise via back-scatter off of the calorimeter, and have a transverse momentum of no less than 0.75 GeV/c. In a sample of 137 Z-pole $b\overline{b}$ events with thrust greater than 0.94 and a thrust axis with $|\cos\theta_{thrust}| < 0.5$, these selection requirements identified 304 findable non-prompt particles. This set of findable particles represents approximately 5% of the number of findable particles that would be identified if there were no restriction on the radius of origin (in other words, approximately 5% of all tracks are non-prompt).

Tracks found by AxialBarrelTracker were accepted provided they were comprised of at least four hits, had a reconstructed transverse momentum of at least 0.75 GeV/c, and a reconstructed distance of closest approach in the plane perpendicular to the beam of no more than 10 cm. The results that follow were achieved under the assumption that the tracker was composed of two unsegmented halves: one extending to positive value of z and the other to negative values; only tracks for which all hits had the same sign z coordinate were accepted.

Findable particles were deemed 'found' provided they were associated with accepted tracks that had at least four hits caused by the findable particle under consideration. No more than one accepted track was permitted to be associated with each findable particle. Any accepted track not associated with a findable particle was deemed 'fake'.

With these criteria, 131 (43%) of findable non-prompt particles were found with 5 hits, with only one fake five-hit track. Another 100 non-prompt tracks were found with 4 hits; however, these were accompanied by an additional 270 four-hit fake tracks, rendering four-hit tracks too impure for use. The remaining findable particles (73, or 24% of the sample) had no associated accepted track.

Upon examination, it was discovered that AxialBarrelTracker was often being confused by three-hit seeds for which not all of the hits came from the same underlying particle. Thus, to improve the efficiency as well as reduce the number of fake tracks, we added to AxialBarrelTracker a requirement that all the hits on the seed lie within an azimuthal slice of width $\pi/2$. This requirement was also applied to the larger set of hits as additional hits were added to the seed.

After application of this azimuthal restriction, the sample of 304 findable particles were reconstructed as follows. 145 (48%) were reconstructed with five hits, 112 (37%) were reconstructed with four hits, and 47 (15%) had no associated accepted track. The number of five-hit fake tracks remained unchanged at one, while the number of four hit fake tracks was reduced from 270 to 157. It should be point out that, of the 304 findable particles, only 166 left one and only one hit in each of the five layers; for this set of tracks, the reconstruction efficiency with the azimuthal restriction approached 85%.

Thus, it appears that non-prompt particles leaving hits in all five central tracking layers can be reconstructed with reasonable efficiency and good purity, but that more work needs to be done to reconstruct particles leaving only four hits (the majority of four-hit particles

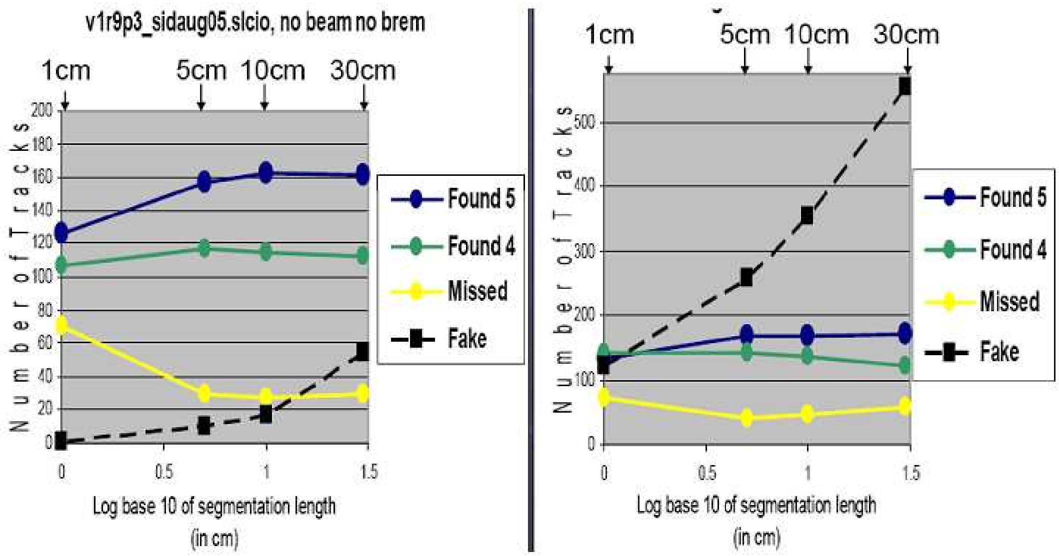

Figure 1: Performance of AxialBarrelTracker as a function of the z length of the tracker modules for Z pole $b\overline{b}$ events (left) and uds events at $E_{cm} = 500$ GeV. The trajectories correspond to the numbers of findable particles found with five hits and four hits, the number of findable particles with no associated track, and the number of fake tracks.

originate outside of the first central tracking layer, rather than originating at smaller radius but curling up or leaving the detector before reaching the fifth tracking layer). To this end, the group developed code that takes advantage of longitudinal segmentation, testing for the consistency of the pattern of struck modules with the hypothesis that the pattern was produced by a single particle. The performance of AxialBarrelTracker as a function of the z length of the tracker modules is shown in Figure 1, for two data samples: $b\overline{b}$ events at the Z pole and uds events at $E_{cm} = 500$ GeV. As stated above, the $b\overline{b}$ events contained 304 findable non-prompt tracks; the $E_{cm} = 500$ GeV events contained 352 findable non-prompt tracks. It is seen that 10 cm segmentation (the SiD baseline) can be very helpful for intermediate energy ($\sim$50 GeV) jets, but does not appear to make too a qualitative difference for high energy ($\sim$250 GeV) jets.

In summary, the SCIPP simulation group has optimized Tim Nelson's AxialBarrelTracker routine to find non-prompt tracks. The efficiency and purity for non-prompt tracks hitting all five tracking layers is good, but without z segmentation, it seems difficult to reconstruct tracks that hit four or fewer layers. The inclusion of z segmentation can provide a substantial benefit by reducing the number of fake four-hit tracks. However, the degree of segmentation needed to reduce the fake-track contribution enough to make four-hit tracks usable depends upon the physics being studied. For low-energy (45 GeV) jets, the proposed 10cm segmentation of the SiD baseline may be sufficient. For high-energy (250 GeV) jets, however, the current reconstruction seems to require segmentation on the order of 1cm or less to recover four-hit tracks. The SCIPP simulation group continues to explore the capability of the SiD baseline tracker to reconstruct non-prompt tracks, and is in the process of implementing the GARFIELD tracker [3], which uses minimum-ionizing calorimeter stubs to seed tracks, as an additional layer in the SiD reconstruction.

References

[1] B. Schumm, *VXDBasedReco Track Performance Studies*, http://scipp.ucsc.edu/ schumm/talks/national_meetings/snowmass/.

[2] N. Sinev, *The Efficiency of Track Reconstruction using the Vertex Detector as the Primary Tracking Device*, 2005 International Linear Collider Workshop, Stanford, CA, 2005.

[3] The Garfield Calorimeter-Assisted Tracking package was authored by Eckhard von Toerne and Dima Onoprienko of Kansas State University.