Pattern Recognition Studies for a Silicon Outer Tracker

S. R. Wagner*
Stanford Linear Accelerator Center
Menlo Park, CA 94025 USA

We have studied pattern recognition in a variant of the proposed SiD detector where the outer five tracking layers ($r=20-125$ cm) are axial-only strips. The purpose of these studies is to determine if this detector, combined with a fully 3D (CCD) inner tracker, is sufficient for the reconstruction of tracks in the dense core of jets. Using standard algorithms, track finding efficiencies are presented for various track $p_T$ as a function of the distance from the jet center, and failure modes are discussed. The change in response due to event backgrounds (pair BG, other beam-related BG, and BG from overlapping $\gamma\gamma$ interactions) is also investigated, as is the gain from crude tiling in the longitudinal direction.

1 Introduction

One version of the SiD barrel outer tracker (Fig. 1) has 5 layers of silicon-strip detectors ($r_i = [20, 46.25, 72.5, 98.75, 125]$ cm) with single-sided (axial) read-out in a 5 T solenoid field. This will be referred to as the SOD, to differentiate it from other versions of the SiD outer tracker that have some $z$ information, ranging from almost as good as the $r\phi$ measurement (Si drift or $z$ strips) to good-but-not-great (small-angle stereo). Most previous studies of tracking in the outer SiD [1,2] have been made assuming detectors with 3D readout.

The first version of the SOD we consider has long ladders; each layer is split at $z = 0$ and read out at both ends. The driving force for this detector is excellent momentum resolution for charged tracks (Fig. 1 and Ref. [3]), but it may be too minimal an outer tracker for pattern recognition. Backgrounds and other tracks pile up, making assigning hits to tracks problematic. A new variant of the SOD, where each 10 cm-long wafer on a ladder is read-out separately, attempts to address this problem.

The tracking procedure we investigate in this talk is simply that of extending tracks found in the vertex detector (VXD) into a fully occupied SOD. The code we use is written in Java in the JAS2 framework, and is run on various SDJan03 MC data samples. This Gismo-based MC simulation includes resolution (7 $\mu$m in $r\phi$ in the SOD), scattering, energy-loss (including deltas), interactions (including calorimeter splash-back), and decays. Except when used to assign a hit to a detector section, any available $z$ information for a SOD hit is ignored.

*Work supported in part by Department of Energy contract DE-AC03-76SF00515.
2 Basic Algorithm

The hits from tracks in $p_T = 1$ and 50 GeV/c single muon events are helix fit in the VXD and projected out to the SOD. As a prototype algorithm, the closest hit is added and the track is refit at each SOD layer. Before refit at that layer, a 50 GeV/c tracks (example shown in Fig. 2) has a residual width of $\sigma_{\text{resid}} = 490 \, \mu m$ at layer 1 (L1). With the addition of hits, this improves to $\sigma_{\text{resid}} = 74 \, \mu m$ at L5. These numbers (and all results in this talk) are for helix fits, but they will only slightly improve with full Kalman fits.

The real problem, of course, is not clean events, so we mix in hits from $\sqrt{s} = 500$ GeV $q\bar{q}$ events to simulate the correlated BG of a real physics event. We take a sample of these events and write out the hits and Thrust axis ($\bar{T}$) if $\bar{T}$ is in the SOD barrel. We have 1810 BG events, with an average of about 45 hits per SOD layer. The hits from the $q\bar{q}$ events are read in and rotated in $\phi$ so the $\bar{T}$ is a desired $\Delta \phi$ from the “probe” track (the single muon). This allows us to scan the efficiency measurement from more problematic regions (probe track in center of jet) to easiest (90° from $\bar{T}$). We then mix the SOD hits for the rotated $q\bar{q}$ event and the probe track. The probe track hits are flagged, but this is inspected only after all track-finding is finished.

Since the tracking environment is now more realistic, we “improve” our tracking algorithm. We make 3 trial tracks using the 3 closest hits in L1 of the SOD added on to the VTX track and refit. If there is no additional close hit, a trial tracks is allowed to skip L1. Past L1 the trials pick up the closest hit.
in each layer and continuously refit, as before. Trials often share hits past L1
(that is, there is no poisoning except in L1). We pick the final track from the
3 trials on the basis of $\chi^2/dof$ and a preference for more hits. This removes a
small class of tracks that are duplicates in L2-L5 but achieve a lower $\chi^2/dof$
when no additional L1 hit is available.

The efficiencies for this algorithm as a function of the probe track distance
to $T$ are shown as the solid curves in Fig. 3. For the green curve, we require
the found track have all its correct hits (be “perfect”). The blue curve is where
at most 1 hit in SOD is wrong. We call tracks where 1 hit is wrong “close,”
so the blue curve is “perfect+close.” The purple curve corresponds to tracks
where at least 1 hit in SOD is correct, so the area above the purple curve is the
fraction at that angle (to $T$) where all SOD hits are wrong. The VDX track,
which is a short stub and does not have great momentum resolution for high
$pt$ tracks, has latched onto the wrong track in the SOD.

While tracks with all bad hits are clearly a problem, the close tracks are
not really that bad. They have 4/5 SOD hits right and all 5 VXD hits right.
The momentum resolution for these tracks is about a factor of 3 worse than
perfect tracks at high $pt$ and gets better as $pt$ decreases. These are the sort
of occurrences that give one unwanted but always observed “tails” on one’s $pt$
resolution, but still usable (and used) tracks. A $\chi^2$ comparator to MC truth
would consider most of the close tracks properly found, so we will also, but we

Figure 2: $pt = 50$ GeV track in a $\rho$ quadrant of VXD, and associated SOD hits (left);
same track with hits from 500 GeV $q\bar{q}$ event (red) and full complement of pair (green), $\gamma\gamma$
(blue) and photon (purple) BG hits overlaid, and the VXD track projected out to find and
fit to (correct) SOD hits.
will not consider tracks with $\geq 2/5$ wrong SOD hits properly found.

With the above definition of a good track (perfect or close), Fig. 3 shows that this simple algorithm is $> 99\%$ efficient for all tracks except those with high $p_T$ near the jet core. One obvious improvement of the algorithm would be hit arbitration. At least so far, there’s another real track that wants (produced) the bad hit on the “close” track, and the correct hit for this track is also near by. Hits can be arbitrated away later to lower global $\chi^2$. This is also the case where the VXD track latched onto the completely wrong track; there’s another VXD track that wants those hits. For approximately 60% of the completely bad tracks, the next best trial is the correct perfect track, with $\chi^2$ a little worse, and $\sim 20\%$ of the time the next best trial is a correct close track.

3 Efficiencies with Pair, $\gamma\gamma$ and Photon Backgrounds

The occupancy from hits due to pair and $\gamma\gamma$ interactions, and photons (created by pair BGs) converting in the strips, will also cause pattern recognition problems. The strip occupancies for these BGs have been calculated for the NLC bunch pattern and optics [4], and we mix in hits from generated pair and $\gamma\gamma$ events to get the right occupancies from those BGs in L1. Random hits are mixed in to represent the photon BG, and the random hit occupancy is adjusted to correctly replicate the total occupancy in each layer when combined with the other BG hits. The total occupancy per layer for the SOD split at
$z = 0$ is $(0.83, 0.27, 0.15, 0.10, 0.08)\%$. This occupancy is dominated by photon BG; $\gamma\gamma$ and pairs are only significant in L1.

We use the same tracking algorithm, and the same probe tracks and underlying physics events as before. Figure 1 also shows a sample probe track along with the full complement of hits from the $q\bar{q}$ event and all predicted BGs. In this case the probe track was buried at $\Delta\phi = 0$ from $\bar{T}$, and when the VXD track was projected out managed to find all the correct hits in the SOD (the next best trial track has a $\chi^2$ a factor of $5 \times 10^6$ worse, 2 bad hits, and 3 good ones, shared with best trial track). But not all tracks are this easy to find. The tracking efficiencies as a function of distance from $\bar{T}$ with the full BGs mixed in are shown as the dashed curves in Fig. 3.

For 50 GeV tracks, there is a noticeable effect on “perfect” efficiency, but the “perfect+close” efficiency is still $> 99\%$ over most of solid angle, and the “wrong track” effect still dominates near the jet core. The effect of BGs is quite dramatic on “perfect” $p_T = 1$ GeV tracks. The pattern of bad hits is different here than without BGs. Without BG usually it’s the L1 hit that’s bad; here it’s mostly L5 hits that are bad. Tracks with $p_T = 1$ GeV almost don’t exit the SOD; they enter L5 at a very steep angle, and have lots of BG to pick from. This is probably one place a full Kalman extrapolator, which we haven’t written yet, would really help. But the bad L5 hits don’t effect $p_T = 1$ GeV tracks as much as high $p_T$ tracks. The $p_T$ resolution is only degraded 20 – 30\%, so the “close” low $p_T$ tracks are pretty good, and the combined perfect+close efficiency is still $> 96\%$ over all $\Delta\phi$.

![Graph](image.png)

Figure 4: Same as Fig. 3, but with occupancies corresponding to a (10 cm) tiled SOD.
4 Effect of SOD Tiling on Pattern Recognition

The concept of “tiling” the SOD is to read out each 10 cm x 10 cm wafer separately, rather than chaining them together in half-barrels. The number of BG hits remains the same, but the number of strips really increases; the average occupancy now is (0.276, 0.043, 0.015, 0.008, 0.005)%. The efficiencies (dashed lines in Fig. 4) return to near what they were with only 97 hits mixed in. Tiling the SOD really helps lower $p_T$ tracks. The ladders in L5 are the longest and their occupancy is reduced by a factor of 16.7 by tiling, and L5 is where occupancy-caused problems for low $p_T$ tracks are most significant.

5 Conclusion

If we are willing to define efficiency as ≥ 9/10 hits correct (> 90% of tracks have ideal resolution, < 10% slightly degraded), then the efficiency is > 98.5% for the “tiled” detector, independent of momentum, except for high $p_T$ tracks in the core of jet (< 50 mrad), where efficiency drops to > 96.5%. If we can in addition use timing information (limiting BGs to approximately 4 crossings rather than 192), this probably gets us back to efficiencies with no BGs, or to tiled efficiencies if timing is used but tiling isn’t.

The efficiency dip at $\Delta \phi = 0^\circ$ to $\overline{T}$ is from swapping real track SOD hits (or whole SOD tracks) between VXD tracks. If one carries around multiple viable candidate tracks with hits, one should be able to arbitrate most/all of effect away, though this has not be proven yet. This effect is overestimated anyway, as the probe track is not subject to the energy-momentum conservation that the entire 97 event is, so there will not be as many real physics events with dual high $p_T$ tracks near jet core.

There are clearly many more approaches to try, but even in these basic studies, SOD hit adding to VXD tracks is viable at full BGs, at least with a tiled SOD. More difficult tasks, such as stand-alone pattern recognition for $K^0_s$ decays in a tiled SOD, need to be attempted. Our tests also need to be repeated with more realistic hit simulation.

References

3. B. Schumm, these proceedings.
4. J. Jaros, these proceedings.