DØ Response to PAC Question 5:

Detailed Evaluation of Silicon Track Trigger update options

Prepared for the Fermilab PAC Meeting, Aspen, June 2002

As requested by the PAC, we have simulated the expected performance of various upgrade options for the level 2 Silicon Track Trigger (STT) under Run 2b conditions. We present a summary of our findings here.

There are two ways in which the STT may be upgraded: (a) The number of silicon microstrip tracker (SMT) modules with axial strips will increase in Run 2b. With additional hardware, these may be included in the trigger. (b) The number of processor cards (TFCs) may be increased to handle the increased hit multiplicity and layer count.

As inputs for this work, we use simulated event samples that were generated with the PYTHIA event generator and a GEANT simulation of the Run 2b silicon microstrip tracker (SMT) geometry and the central fiber tracker (CFT). The signal we are interested in triggering on is the decay of a heavy particle to a $b\bar{b}$ quark pair. This process is represented by a sample of events from the process $p\bar{p} \to WH$, followed by $W \to \mu\nu$ and $H \to b\bar{b}$. The backgrounds we want to discriminate against are light quark and gluon jets. This is represented by a sample of events from the process $p\bar{p} \to Z \to q\bar{q}$, where $q\bar{q}$ is a pair of light quarks (u or d).

At the Run 2b luminosity of 5×10^{32} cm^{-2}s^{-1} and a crossing interval of 132 ns, we expect to see on average about five soft proton-antiproton interactions in every triggered hard scattering event. We simulate the additional interactions with minimum bias events generated using PYTHIA. Comparison with data from Run 1 show that PYTHIA underestimates the particle multiplicity in these additional interactions so that we need on average 7.5 additional PYTHIA minimum bias events to simulate the conditions expected for Run 2b. We therefore superimpose additional interactions on the above events with a Poisson distribution with a mean of 7.5 (N_{mb}=7.5). To illustrate the effect of these additional interactions, we also show the performance of the level 2 silicon track trigger for simulated event samples without additional interactions (N_{mb}=0).

In order to simulate the level 1 track trigger inputs, we have used the tracks found in the CFT data by a track finding program. To simulate the limited track information used in the STT, we use only the hits closest to these tracks in the innermost (A) and outermost (H) layers of the CFT. The SMT inputs are clusters of hits in detectors with axial silicon microstrips. Since the STT algorithm uses only x and y information the data from detectors with stereo strips was ignored.

The CFT tracks define roads that go through the interaction point at the center of the detector. In each of the six SMT layers the cluster is used that is closest to the center of the road. A linearized trajectory given by $\phi(r) = b/r + kr + \phi_0$ is fit to the hits in the six silicon layers and the CFT A and H layers. The parameter r is the distance in the xy plane from the interaction point, b is the impact parameter, k the radius of curvature, and ϕ_0 the azimuth of the track. If $\chi^2/dof > 5$ the hit with the largest contribution to χ^2 is dropped and the trajectory refit. We require that at most one silicon layer is missing a hit and that $\chi^2/dof < 5$ for all good STT tracks. The impact parameter resolution is about 11 µm for good high-p_T tracks. The resolution gets worse for tracks with lower p_T (39 µm at 1 GeV) and with missing or dropped hits in the fit. We parameterize the impact parameter resolution σ as a function of these parameters and define the impact parameter significance $s_b = b/\sigma$. Figure 1(a) shows the distribution of s_b for tracks from the WH and Z samples with N_{mb}=0. The figure shows that tracks from displaced vertices are responsible for the tails of the impact parameter significance distribution and that the tracks from the Z sample, which should all be prompt, are almost Gaussian in their distribution, as expected.

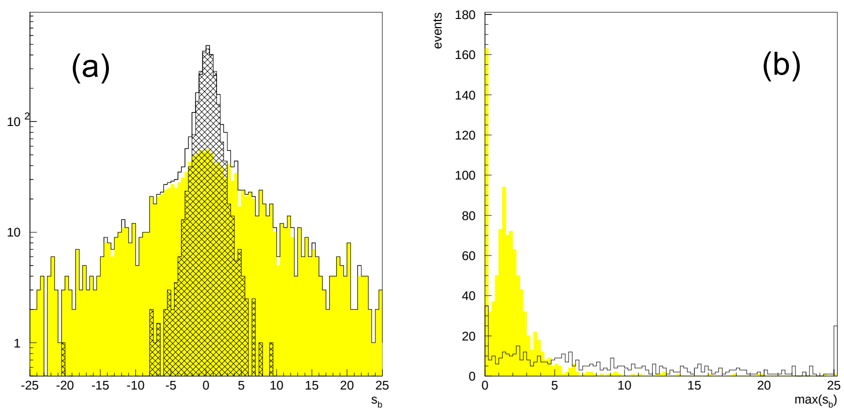

Figure 1: (a) Distribution of impact parameter significance of good tracks from the WH and Z samples with N_{mb}=0. The open histogram shows all good tracks from the WH sample, the colored histogram shows the subset that is matched to Monte Carlo particles from displaced vertices and the hatched histogram shows all good tracks from the Z sample. (b) Distribution of the largest value of impact parameter significance per event for good tracks with p_T>1.5 GeV. The colored histogram shows the Z sample and the open histogram the WH sample, both with N_{mb}=0.

We trigger on an event if there is a good STT track with s_b greater than some threshold. Figure 1(b) shows the distribution of the largest impact parameter significance for good STT tracks per event. The trigger efficiency is given by the number of WH events that have a good STT track with s_b greater than a threshold. The rejection is the inverse of the efficiency for the Z event sample.

Figure 2 shows the rejection versus efficiency curves from event samples with N_{mb}=0 and N_{mb}=7.5 using all six silicon layers. We see that the rejection at fixed efficiency drops by about a factor 2 due to the additional events. We then consider removing various silicon layers from the STT processing. We studied the effect of removing layer 4, layer 0, and layers 1 and 3 together. Rejection at fixed efficiency drops every time a layer is removed. Removing layer 4 reduces the rejection by about 20%. Removing layer 0 reduces the rejection by about a factor 2, as does removing layers 1 and 3 together. We tabulate some benchmark values in Table 1.

Table 1: Benchmark values for rejection achieved by STT for different conditions.

SMT layers used	N_{mb}	rejection for 65% efficiency
012345	0	22
012345	7.5	11
01235	7.5	9
12345	7.5	6
0245	7.5	6

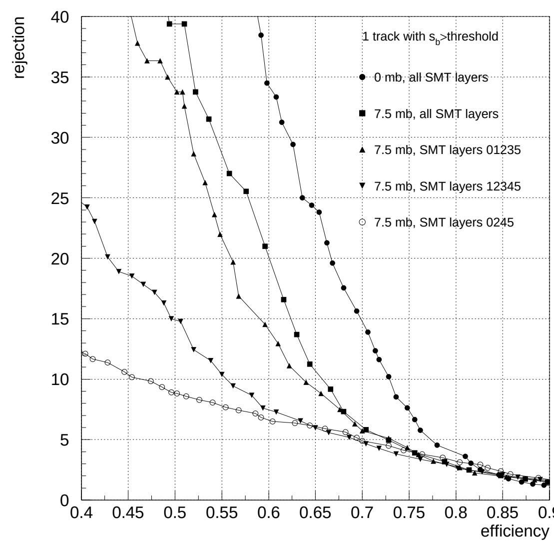

Figure 2: Curves of rejection versus efficiency for triggering on one good STT track with impact parameter significance above a threshold and p_T>1.5 GeV. The curve marked with ● is for N_{mb}=0 and using all six silicon layers. All other curves are for N_{mb}=7.5 and for various combination of silicon layers included in the trigger.

Figure 3 shows curves of rejection versus efficiency when the p_T threshold for the CFT tracks that define the roads is varied. In Run 2a, the level 1 track trigger can detect tracks with p_T>1.5 GeV. As the figure shows, it is important to maintain this capability in Run 2b, since the rejection at fixed efficiency drops when this threshold is raised above 1.5 GeV.

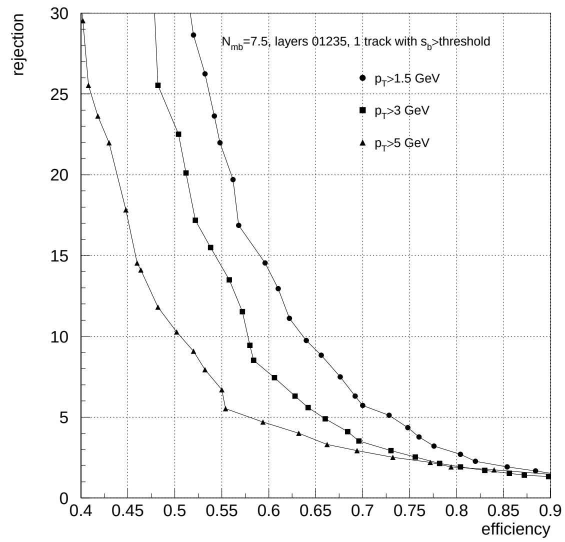

Figure 3: Curves of rejection versus efficiency for triggering on one good STT track with impact parameter significance above a threshold. For the three curves the minimum p_T of the CFT tracks that define the roads is varied as shown.

Aside from triggering on tracks from displaced vertices, the STT also helps to reject fake level 1 track trigger candidates that are due to the overlap of other, softer, tracks. We find that at N_{mb}=7.5 and a track p_T threshold of 5 GeV, the STT only accepts 1 in 3.2 fake CFT tracks if all six silicon layers are used. This drops to 1 in 2.8 for 5 layers used and about 1 in 1.8 for 4 layers used in STT. This rejection of fake L1 track triggers is crucial since the rate of level 1 track triggers is expected to increase significantly (by a factor 30) at high luminosities as shown in our TDR.

In Run 2b the processing times and latencies for the STT preprocessor will become larger. The additional hits from the higher luminosity and the additional silicon detectors will increase transfer times. The timing of the STT is dominated by the fitting process in the TFCs. There are two main components that determine this timing. About 0.6 μs per hit are required to select the hit to include in the fit for each layer. This time scales linearly with the number of hits per road. The actual fit takes about 7-14 μs per track, depending on whether the fit is repeated after dropping a hit. Both components will increase in Run 2b.

Figure 4 shows the number of clusters in a 2 mm wide road for WH events with N_{mb}=7.5. If layers 0, 1, 2, 3, and 5 are used in the trigger, we expect on average 26 hits in the road of a given track. This is larger than in Run 2a, because of the closer distance to the interaction point of the innermost silicon layer and because of the larger number of layers.

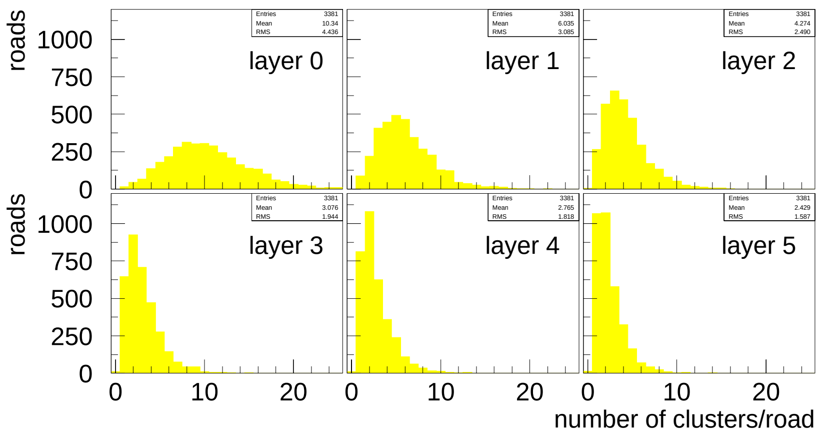

Figure 4: Distributions of hit multiplicity per road per layer for the WH sample with N_{mb}=7.5.

The time required for the fit will increase because of the additional layer included in the fit relative to Run 2a. In addition, for the large multiplicity in the first two layers, our hit selection algorithm may be inadequate. The algorithm currently selects the hit that is closest to the center of the road thus biasing the fit towards small impact parameters. We have in the past investigated different algorithms in which the road is not forced to the interaction point. These require more processing time and were not required for the lower luminosities of Run 2a.

Queuing simulations show that the STT operates within its time budget of about 100 μs on average. However latencies up to 250 μs are observed and these times will increase in Run 2b for the reasons mentioned in the previous paragraphs. In order to avoid exceeding our time budget, we will require additional processor cards (TFC).

From this work, we conclude that the STT must be upgraded to include at least five of the six layers of the Run 2b SMT. Without any upgrade, the STT performance will be severely degraded. Ideally, we would like to instrument all six silicon layers to create a trigger with the most rejection power. In light of the seemingly marginal gains upon addition of a sixth layer, however, and considering the tight fiscal constraints, we propose to drop layer 4 from our baseline plan and upgrade the STT to instrument five silicon layers only (0, 1, 2, 3, and 5). We note that, as with all of our upgrade trigger plans, this proposal is based upon the assumption that the accelerator will operate at 132 nsec crossing intervals for Run 2b. Should the laboratory decide to forego this upgrade to the Tevatron and run instead at 396 ns intervals (or some other intermediate bunch spacing), we would have to reexamine this issue in this context.

The completion of these studies has also led us to the conclusion that, given the high rate environment of Run 2b, it would be prudent to invest in additional Track Fit Cards (TFCs) for the STT. As mentioned above, the processing time required for the five layer STT relative to the four layer Run 2a version, coupled with the demands on the hit selection algorithms that will be required in light of the increased multiplicities, suggest that an additional safety margin be planned for. The cost estimate for the five layer upgrade has been amended to include an upgrade from 2 to 4 TFCs per readout crate, resulting in a total cost of this option of $258k. The total cost for the six layer option is $564k. Both of these estimates include 40% contingency. The savings in the baseline cost estimate in FY02 dollars associated with pursuing the five layer Silicon Track Trigger for Run 2b is therefore $306k.