B-identification for Level 2: The Silicon Track Trigger at DØ

Sascha Caron a * for the DØ collaboration

aNikhef, Amsterdam
The Netherlands
scaron@nikhef.nl

This article describes the Silicon Track Trigger (STT) which has been fully commissioned in 2004 at the DØ experiment. The STT allows to enrich already at the second trigger level the data sample with events containing B-mesons. The STT achieves this by providing within about 50µs tracks with an impact parameter resolution of around 50µm. The article shows preliminary results of the trigger performance and presents a fast b-identification algorithm for the second trigger level.

1. Introduction

The discovery of the Higgs boson is one of the main objectives of high energy physics today. Especially at the Tevatron this is a very difficult task, because it requires to study all possible decay channels with the best achievable efficiency. The overwhelming amount of light quarks produced by QCD processes swamps interesting signals with b-quarks like pp → H → b̅b or the important calibration process pp → ZZ → b̅b. Even Higgs processes with the associated production of additional b-jets or neutrinos (HZ → b̅bνν) have huge background from light quark jets, such that the limited trigger bandwidth of an experiment results in a loss of some of those events. Physics topics as the study of low PT B-physics face similar performance issues.

If the early trigger levels of an experiment cannot discriminate between light quarks and b-quarks, both will be reduced by an equal factor. The Silicon Track Trigger (STT) [1], however, can early recognize events where a b-quark was produced and dominantly pass those events, reducing the background effectively. B mesons lead to trajectories of the order of millimeter before they decay. The trajectories of the decay products do not point back to the vertex of the primary interaction. Hence the measurement of the impact parameter allows the separation of interesting b-events from events containing only lighter quarks. The impact parameter (or distance of closest approach) is the minimum distance between the primary interaction point and the particles trajectory. Note that such a method, unlike the usual selection of B-meson via muon decays, works for all decay modes and provides a less biased sample of decay modes in the selected b-event sample.

In RunII the DØ experiment also selects b-events using the high resolution Silicon Microstrip Detector (SMT) to reconstruct the tracks of the charged particles in the event and by feeding the track information into b-identification algorithms. Without the Silicon Track Trigger this can only be performed in offline analyzes and the third trigger level. Since early 2004 the STT provides the capability of a fast selection of events with large impact parameter. This allows B-meson identification already at the second trigger level.

2. The STT in the DØ trigger framework

The DØ experiment triggers events in three stages [2]. Several sub-detectors provide information to make a decision. At DØ the first level (L1) trigger system is a hardware system filtering the 2.5 MHz beam crossing rate with a minimal dead time to an accept rate of about 2 kHz. A
calorimeter trigger looks for energy depositions of high transverse energy; the central track trigger (CTT) and the muon trigger provide tracks.

The second level trigger (L2) receives information from all major detectors to build a trigger decision using hardware and software algorithms. Each major DØ detector component has a corresponding L2 preprocessor, the STT is the preprocessor of the Silicon Microstrip Detector. The information of all the L2 preprocessors are sent to the L2 global processor, which can run filter algorithms to select the events and sends the information to the third trigger level. To maintain an acceptable dead time the mean decision time for L2 must be about 100 $\mu$s. The L2 output rate is about 1 kHz. Finally, the third level software trigger partially reconstructs the events using a farm of processors and reduces the rate to 50 Hz, which is recorded for offline analysis.

3. How does the STT work?

The DØ tracking system consists of the Silicon Microstrip Tracker and the Central Fiber Tracker (CFT) both located in an about 2 Tesla solenoidal magnetic field. The STT uses both devices to reconstruct the trajectories of charged particles.

In the first trigger level the Central Track Trigger can reconstruct tracks with a minimum $p_T$ of 1.5 GeV using information from the three scintillator-based detectors, the Central Fiber Tracker and the central and forward preshower detectors. The CFT consists of about 80000 scintillating fibers and because of its fast readout time its information can already be used in the first trigger level. The position resolution without the Silicon Tracker is, however, not sufficient to provide precise information of the particle decay lengths.

The SMT has six central barrels with four silicon layers each and in total about 800000 readout channels. The barrel sensors parallel to the beam pipe are used for the STT. They have a 50$\mu$m pitch width. Offline tracks made using the SMT have an impact parameter resolution of up to 15–20$\mu$m for high $p_T$ tracks, which is sufficient to detect B-mesons.

The STT uses the Level 1 tracks provided by the CTT as seeds to define ‘roads’ into the SMT (see Fig. 1). These roads are cylinders of ±2 mm radius around each CTT track. The STT forms clusters from the pedestal subtracted SMT hits and only clusters within these roads are considered for track fitting. Clusters are made by summing up a group of contiguous strips above some threshold.

The STT design divides the SMT into 12 sectors, each 30 degrees in the azimuthal angle $\phi$ and the track fitting is performed in parallel for each of the sectors. Almost no efficiency loss is caused by tracks crossing sectors. The electronics for two sectors house in one of the 6 STT crates. Data of the same sector of all 6 SMT barrel detectors has to be routed to one crate. Each crate has one Fiber Road Card which receives and distributes the Level 1 tracks and communicates with the trigger framework. In each crate 9 Silicon Trigger Cards perform a pedestal correction, followed by the clustering of the SMT hits and associate the clusters to the roads.

The information of the Fiber Road Card and Silicon Trigger cards is then sent to the two Track Fit Cards. The Track Fit Cards receive the roads and axial clusters and convert them via a large lookup table to physical coordinates. Then the two dimensional track fit is performed in the $r-\phi$ plane with the form $\phi(r) = b/r + \kappa r + \phi_0$. Here $b$ is the impact parameter with respect to the de-
A B-identification algorithm for Level 2

Combining tracks offline with B-identification algorithms greatly enhances the performance of an experiment to detect B-mesons, obviously this may also work at Level 2. A problem is that the current offline algorithms are not fast enough to be run in less than $10 - 20 \mu s$. The algorithm described in the following uses the STT tracks as input to an efficient multivariate b-identification and is fast enough to be run on the L2 global processor in less than $1 - 5 \mu s$.

The method uses the ratio of the probability density functions of the signal prediction to the background prediction. The signal is given by data events with a soft offline B-identification, while background events are events without any offline B-identification. The two-dimensional signal, $\text{pdf}_{i,S}$, and background, $\text{pdf}_{i,B}$, probability densities are derived with a smoothing method as a function of the track impact parameter significance and the track $\chi^2$ of the track fit. The impact parameter significance is given by $\text{IP} \sigma(\text{IP})$ only includes the $P_T$ dependent effects of multiple Coulomb scattering and $\text{IP}$ is the impact parameter. Using $\chi^2$ in the pdf downgrades badly fitted tracks without cutting them and loosing efficiency. Tracks with a larger $\chi^2$ still have limited lifetime information as can be seen from Figure 2.

For the trigger the signal-to-background ratios $r(\text{IP} \sigma, \chi^2) = \text{pdf}_{S}(\text{IP} \sigma, \chi^2) / \text{pdf}_{B}(\text{IP} \sigma, \chi^2)$ are stored in a lookup table.

The final discriminant is then derived by a loop over the 5 tracks with highest impact parameter, accessing $r(\text{IP} \sigma, \chi^2)$ for each track and multiplying these values:

$$D = \prod_{i=1}^{5} r_i(\text{IP} \sigma, \chi^2)$$

The event selection in done by cuts on this discriminant.

Performance studies

The STT is fully operational since May 2004. Figure 3 shows the impact parameter resolution of the STT as a function of the $P_T$ of the track as determined with a recent data run. At the time of writing this article (Aug. 2005) a cut on two tracks with an impact parameter significance $> 2$ or $> 3$ and $\chi^2 < 5.5$ are implemented as L2 trigger requirement.

We show the STT B-identification performance by comparing a dijet sample without any offline b-tag (as background events) and a dijet sample...
where two secondary vertex tags and a muon tag are required (as signal events). The impact parameter significance distribution for both samples using STT tracks with $\chi^2 < 5.5$ is shown in Fig. 4.

Figure 5 compares the signal and background efficiency for cuts on the IP significance and on the discriminant of the B-id algorithm and for using STT tracks with $\chi^2 < 15.5$. Two secondary vertex tags are required for the signal sample. The additional use of such an algorithm increases the background reduction by up to a factor of 2 for the same signal efficiency. These findings are corroborated by using other offline B-selections as signal events.

6. Summary and Outlook

The Silicon Track Trigger is a new component of the DØ second level trigger. It is since 2004 in smooth and stable operation and allows to identify B-meson production by selecting events with a large impact parameter. It has a high potential of enhancing the potential of several physics analyzes that rely on B-identification. The implementation of a new SMT layer (Layer0) in the next shutdown period will further increase the precision and stability of the STT.

REFERENCES

1. DØ collaboration, A Silicon Track Trigger for the DØ experiment in RunII, DØ note 3516, Fermilab 1998.
2. V. M. Abazov et al. [DØ Collaboration], arXiv:physics/0507191