All hadronic B decay trigger with the CDF Silicon Vertex Tracker

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Abstract: Silicon Vertex tracks are of fundamental importance for reconstructing B meson decays at a hadron collider. The upgraded CDF detector will deploy an online Silicon Vertex Tracker in the level 2 trigger. We have studied how this new device exploits the Tevatron large B meson production to select hadronic B decays fundamental for measuring CP violation and B_s mixing.

1. Introduction

The Tevatron $pp$ Collider and the CDF detector are presently being upgraded for run II operation (to begin in the year 2000) [1]. The Silicon Vertex Tracker (SVT) has been designed to reconstruct silicon vertex tracks in the transverse plane to the beam axis at the level 2 of CDF trigger [2]. The SVT receives input tracks reconstructed in the central drift chamber (COT) by the eXtremely Fast Tracker (XFT) at level 1, and the digitized pulse heights from the silicon vertex detector (SVX) front end electronics. The SVT determines the transverse momentum ($p_t$), the azimuthal angle ($\phi$) and the impact parameter ($d$) of all the tracks with $p_t > 2$ GeV/c. Tracking quality is very close to offline: $\sigma_{p_t} = 0.003 \cdot p_t^2$ GeV/c ($p_t$ in GeV/c), $\sigma_\phi = 1$ mrad and $\sigma_d = 35 \mu$m (at $p_t = 2$ GeV/c). Precision measurement of the track impact parameter at the trigger level permits triggering directly on secondary vertices. This exploits the Tevatron large $b\bar{b}$ cross section much more efficiently than leptonic triggers. In this paper we report on the simulation of a trigger which uses the SVT to select fully hadronic B decays [3].

2. SVT tracking strategy

Pattern recognition is performed by the Associative Memory system, which identifies low resolution track candidates called roads [3]. The roads found by the Associative Memory and the full resolution hits corresponding to them are passed to the Track Fitters which calculate track parameters. This is done using a linearized fitting algorithm implemented in hardware.

2.1 Pattern recognition

A track which traverses a multi-layer detector, produces a certain pattern of hits on each detector layer. Since detector resolution is finite, one could imagine to subdivide each detector layer into a finite number of elements with a size comparable to their resolution and to identify a track with the list of fired elements. Hit patterns corresponding to candidate tracks are stored in a memory, the Associative Memory, and are continuously compared in parallel to the data coming from the detector: a track candidate is found when all the hits corresponding to it are in the data. To reduce the size of the needed memory, pattern recognition is performed by the Associative Memory with a limited spatial resolution, for this purpose the Silicon Vertex Detector layers are segmented into 250 $\mu$m wide superstrips, while the actual strip pitch is $\sim 60$ $\mu$m.

The Associative Memory functions are implemented in a full custom VLSI chip with 0.7 $\mu$m tech-
nology. Each chip can store 128 patterns of 6 words (layers) of 12 bits. Operation of the chip has been tested up to 40 MHz, with the SVT specification being 30 MHz.

2.2 Track fitting

Track fitting is the problem of estimating the parameters of the candidate tracks found in the phase of pattern recognition by the Associative Memory. The SVT reconstructs tracks projected on the plane transverse to the beam axis and measures transverse momentum, azimuthal angle and impact parameter \(p_t\), \(\phi\), \(d\). Track parameters are expressed as scalar products:

\[ p_i = \tilde{f}_i \cdot \tilde{x} + q_i \]  (2.1)

\[ p_{0i} + \delta p_i = (\tilde{f}_i \cdot \tilde{x}_0 + q_i) + \tilde{f}_i \cdot \tilde{d} \]  (2.2)

\[ p_{0i} + \delta p_i = (\tilde{f}_i \cdot \tilde{x}_0 + q_i) + \tilde{f}_i \cdot \tilde{d} \]  (2.3)

where \(p_i\) is one of the track parameters and \(\tilde{x}\) is the array containing hit positions and track curvature and azimuthal angle. The parameters \(\tilde{f}_i\) and \(q_i\) are given by the linear expansion of the equations used to determine the track parameters. Within each 30° SVX wedge \(\tilde{f}_i\) and \(q_i\) are constants. Since variations of track parameters are small within a road, it is possible to expand \(p_i\) around a position \(x_0\) in the hit space (typically the lower road edge). The following algorithm can thus be used:

\[ p_i = \tilde{f}_i \cdot (\tilde{x} + \tilde{d}) + q_i \]  (2.1)

\[ p_{0i} + \delta p_i = (\tilde{f}_i \cdot \tilde{x}_0 + q_i) + \tilde{f}_i \cdot \tilde{d} \]  (2.2)

The use of this trigger has been extended to similar decay channels like \(B^0 \rightarrow D_s^- \pi^+\) and \(B^0 \rightarrow D_s^- \pi^+\pi^-\pi^+\); the \(D^-\) are reconstructed through the hadronic decays \(D^- \rightarrow \phi\pi^-\) and \(D^- \rightarrow K^0K^-\). This allows us to attack the problem of \(B^0\) mixing: since \(\Delta m_s\) is expected to be large, its measurement will require fully reconstructed \(B^0\) decays in order to achieve the necessary momentum resolution.

CDF has a three level trigger system with a maximum output of 50 kHz at level 1 and 300 Hz at level 2. We have used a detailed simulation of the XFT and SVT processors and real CDF data from run I (1992-1996) to extrapolate the rates expected for the all hadronic B decay trigger in run II.

The trigger strategy is to select two oppositely charged tracks found by the XFT at level 1. The XFT finds tracks with \(p_t > 1.5\text{ GeV}/c\) with a momentum resolution \(\Delta p_t/p_t^2 = 0.015\text{ (GeV/c)}^{-1}\) and an azimuthal resolution of \(\Delta \phi < 1.5\text{ mrad}\). To reduce the level 1 rate we have chosen to set a \(p_t\) threshold of 2 GeV/c on both the selected tracks. We require \(\Delta \phi < 135^\circ\) to remove back-to-back pairs from dijet events. The estimate for level 1 rate is 18 kHz at the instantaneous luminosity \(0.7 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}\) expected at the beginning of run II.

At level 2 we use the SVT. The first step is to find pairs of tracks with significant \((> 100\mu \text{m})\) impact parameters which also satisfy level 1 requirements. Next we require that the pair has a positive decay length. To optimize trigger efficiency on signal, we have developed separate selections for \(B^0 \rightarrow \pi^+\pi^-\) and \(B^0\) decays. We require \(2^\circ < \Delta \phi < 90^\circ\) for \(B^0\) decays and \(20^\circ < \Delta \phi < 135^\circ\) for \(B^0\). Since in the case of \(B^0 \rightarrow \pi^+\pi^-\) the track pairs fully reconstruct the \(B^0\) candidate, which exits from the primary vertex, for \(B^0 \rightarrow \pi^+\pi^-\) we also require that the impact parameter of the two-track combination \(d_B\) is consistent with zero. Our estimates also show that level 2 rates are well within the trigger bandwidth. As an example, in Figure 1 we show the level 2 trigger cross section dependence on the impact parameter cut on both the selected tracks for the \(B^0 \rightarrow \pi^+\pi^-\) selection. In Figure 2 we show the efficiency of the level 2 trigger on the \(B^0 \rightarrow \pi^+\pi^-\) signal. Both the quoted level 2
trigger cross section and signal efficiency include
the level 1 cuts.
At level 3 the full event reconstruction will be
available and we expect to keep the trigger rate
at an easily managable level with full signal
efficiency. Signal yields are estimated from Monte
Carlo simulation. Using the value of the $B^0_d$ pro-
duction cross section measured by CDF $\frac{2}{3}$, our
efficiency estimate and assuming $\frac{1}{2}$:

$$BR(B^0_d \rightarrow \pi^+\pi^-) = (0.47^{+0.18}_{-0.15} \pm 0.13) \cdot 10^{-5}$$

(3.1)
the expectation is to collect 7,000 events in 2 fb$^{-1}$.
From similar estimates, assuming:

$$BR(B^0_s \rightarrow D^- \pi^+) = (0.30 \pm 0.04) \%$$

(3.2)

$$BR(B^0_s \rightarrow D^- \pi^+\pi^-) = (0.80\pm0.25) \%$$

(3.3)
we expect a total of 25,000 $B^0_s$ events.

Work is in progress to evaluate the sensitivity
to CP violation and mixing measurements. For
the $B^0_d \rightarrow \pi^+\pi^-$ decay the question is whether
it will be possible to extract the signal from the
potentially enormous level of combinatorial back-
ground, while physics backgrounds such as $B^0_d \rightarrow K^+\pi^-$ and $B^0_s \rightarrow K^+K^-$ can be extracted by
making use of the invariant $\pi\pi$ mass distribution
as well as the dE/dx information provided by the
COT and particle identification provided by the
ToF. For the $B^0_s$ channels the estimate is to have
a Signal/Background between 1/2 and 2/1, with
an estimated sensitivity on the mixing parameter
$x_s$ up to $\sim 40$, which easily covers the currently
favoured value of the SM for $x_s (18<x_s<27)$ $\frac{3}{4}$.

4. Conclusions

In this paper we have reported on the new trigger
strategies the CDF experiment is planning to adopt in run II to select fully hadronic B decays
which are fundamental for measuring CP vi-
olation and $B_s$ mixing. The trigger exploits the
online precision tracking provided by the Silicon
Vertex Tracker and selects track pairs with large
impact parameters as candidates for hadronic B
decays. Our studies show that the rates for this
trigger are managable by the CDF data acquisition
and that the efficiency on signals is sufficient
to allow the collection of high statistics samples.

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