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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 $p\overline{p}$ 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 (ϕ) and the impact parameter (d) of all the tracks with $p_t > 2$ GeV/c. Tracking quality is very close to offline: $\sigma_{pt} = 0.003 \cdot p_t^2$ 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 $b\overline{b}$ 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 [6].

2. SVT tracking strategy

The SVT separates the phases of pattern recognition and track fitting into two pipelined stages. 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 subdividing 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 μm wide superstrips, while the actual strip pitch is ~ 60 μm.
The Associative Memory functions are implemented in a full custom VLSI chip with 0.7 μm tech-

nology [4], [5]. 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, ϕ, d). Track parameters are expressed as scalar products:

$$p_i = \vec{f_i} \cdot \vec{x} + q_i \tag{2.1}$$

where p_i is one of the track parameters and $\vec{x}$ is the array containing hit positions and track curvature and azimuthal angle. The parameters $\vec{f_i}$ and q_i are given by the linear expansion of the equations used to determine the track parameters. Within each 30^o SVX wedge $\vec{f_i}$ 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:

$$p_i = \vec{f_i} \cdot (\vec{x}_0 + \vec{d}) + q_i \tag{2.2}$$

$$p_{0i} + \delta p_i = (\vec{f_i} \cdot \vec{x}_0 + q_i) + \vec{f_i} \cdot \vec{d} \tag{2.3}$$

where $p_{0i} = \vec{f_i} \cdot \vec{x}_0 + q_i$ and $\delta p_i = \vec{f_i} \cdot \vec{d}$. The advantage of this algorithm is that the p_{0i} can be pre-calculated and stored in a look-up-table reducing the computational load required by eq. 2.1. Since $\vec{d}$ varies within the road edges ($\sim$250 μm wide), a lower number of bits is necessary to have the full hit resolution.

SVT performance has been tested reconstructing real CDF run I data using a bit-level simulation program of the device and it has been proven that track parameters are measured with offline quality resolution: $\sigma_{p_t} = 0.003 \cdot p_t^2$, $\sigma_\phi = 1$ mrad and $\sigma_d = 35$ μm (at $p_t = 2$ GeV/c).

3. All hadronic B decay trigger

We have designed a trigger to select the $B_d^0 \to \pi^+\pi^-$ decay [6] which is of fundamental importance in the study of CP violation in the SM. The use of this trigger has been extended to similar decay channels like $B_s^0 \to D_s^-\pi^+$ and $B_s^0 \to D_s^-\pi^+\pi^-\pi^+$; the D_s^- are reconstructed through the hadronic decays $D_s^- \to \phi\pi^-$ and $D_s^- \to K^{*0}K^-$ [7]. This allows us to attack the problem of B_s^0 mixing: since Δm_s is expected to be large [8] [9], its measurement will require fully reconstructed B_s^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 $p_t > 1.5$ GeV/c with a momentum resolution $\Delta p_t/p_t^2 = 0.015$ (GeV/c)$^{-1}$ and an azimuthal resolution of $\Delta\phi < 1.5$ 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 $\Delta\phi < 135^o$ to remove back-to-back pairs from dijet events. The estimate for level 1 rate is 18 kHz at the instantaneous luminosity $0.7 \cdot 10^{32}$ cm^{-2} 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 ($> 100\mu m$) 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 $B_d^0 \to \pi^+\pi^-$ and B_s^0 decays. We require $2^o < \Delta\phi < 90^o$ for B_s^0 decays and $20^o < \Delta\phi < 135^o$ for $B_d^0 \to \pi^+\pi^-$. Since in the case of $B_d^0 \to \pi^+\pi^-$ the track pairs fully reconstruct the B_d^0 candidate, which exits from the primary vertex, for $B_d^0 \to \pi^+\pi^-$ 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 pararameter cut on both the selected tracks for the $B_d^0 \to \pi^+\pi^-$ selection. In Figure 2 we show the efficiency of the level 2 trigger on the $B_d^0 \to \pi^+\pi^-$ 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_d^0 production cross section measured by CDF [10], our efficiency estimate and assuming [11]:

$$BR(B_d^0 \to \pi^+\pi^-) = (0.47^{+0.18}_{-0.15} \pm 0.13) \cdot 10^{-5} \tag{3.1}$$

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

$$BR(B_s^0 \to D_s^-\pi^+) = (0.30 \pm 0.04)\ \% \tag{3.2}$$

$$BR(B_s^0 \to D_s^-\pi^+\pi^-\pi^+) = (0.80 \pm 0.25)\ \% \tag{3.3}$$

we expect a total of 25,000 B_s^0 events.

Work is in progress to evaluate the sensitivity to CP violation and mixing measurements. For the $\mathrm{B}_d^0 \to \pi^+\pi^-$ decay the question is whether it will be possible to extract the signal from the potentially enormous level of combinatorial background, while physics backgrounds such as $\mathrm{B}_d^0 \to K^+\pi^-$ and $\mathrm{B}_s^0 \to K^+K^-$ 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_s^0 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 ~40, which easily covers the currently favoured value of the SM for x_s ($18 < x_s < 27$) [9].

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 violation 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.

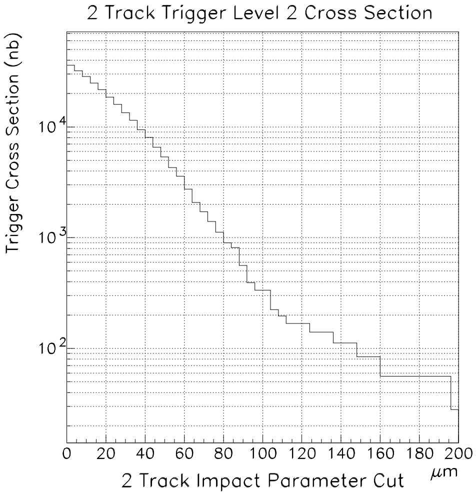

Figure 1: Level 2 cross section of the $\mathrm{B}_d^0 \to \pi^+\pi^-$ selection as a function of the impact parameter cut.

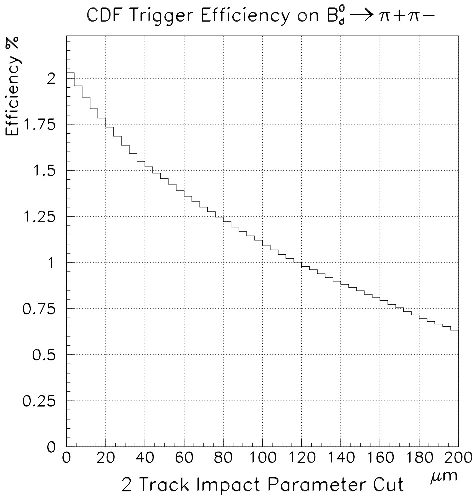

Figure 2: Level 2 trigger efficiency on the $\mathrm{B}_d^0 \to \pi^+\pi^-$ signal as a function of the impact parameter cut.

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