CDF - Secondary Vertex Trigger

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Abstract

At the beginning of 2002 a new data taking with an upgraded trigger system started for the CDF collaboration. One of the major improvements is the track trigger. A fast processor reconstructs tracks in the central drift chamber and the Silicon Vertex Tracker combines these tracks with the silicon vertex detector information to have track parameters with a precision as good as the offline reconstruction. This system allows CDF to trigger on tracks significantly displaced from the primary vertex with high efficiency for signal events like charm and beauty and to keep low background rates. The performances, in terms of resolution and efficiency, of both the processors are illustrated and the firsts physics results are discussed.

1 Introduction

CDF has produced many important and competitive b physics results since the first data taking in the 1988. All of them have been obtained by using samples of events collected with conventional trigger, i.e. lepton triggers. In this way only $b \to J/\psi \to leptons$ or semileptonic b decays are accessible resulting in a small statistics data sample due to low branching fraction.

Moreover, high precision measurements as B_s mixing demand fully reconstructed decays that are no achievable with leptonic trigger since the neutrino presence. Therefore, in order to have large sample of b completely reconstructed, it is desirable to collect also hadronic b decays.

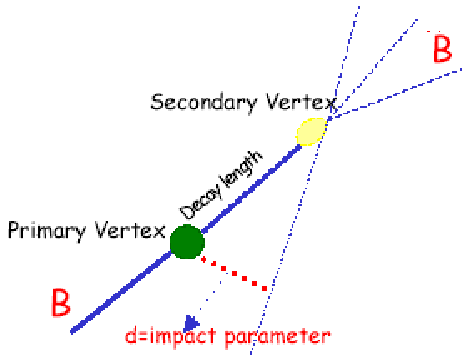

Figure 1: Generic b decay cartoon.

The main issue to address in this case is the background suppression at the trigger level. The only characteristic that can be exploited to separate signal from background is that tracks from b decay are displaced from the primary vertex and therefore have an impact parameter significantly different from zero, as is shown in the cartoon of figure 1. Following this idea, CDF, for the first time at hadron colliders, has built a trigger which selects b hadronic decays.

2 Trigger System Overview

CDF has a three level architecture trigger system which reduces the collision rate of 2.5 MHz to less than 70 Hz, the tape writing speed, while keeping dead time as short as possible. It exploits the characteristics of the upgraded CDF detector, described in detail in [1].

Level-1 decision is based on the existence of physics objects like electrons, muons or tracks and has to be taken within 5.5 μs. There are three synchronous processing streams. One finds calorimeter objects, electrons, photons and jets by applying thresholds to the single trigger calorimetry towers. The global trigger total transverse energy and the missing transverse energy are also part of this stream. An other stream finds muons looking at the the information from the muon chambers. The third stream finds tracks in the Central Outer Tracker (COT) and it will be described in section 3. Since muon and electrons trigger require track pointing to corresponding detector component, track information have to be sent to the calorimetry and muon streams.

Events matching level 1 requirements are downloaded into one of four asynchronous event buffers, and further analyzed by hardware processors. Trigger Level-2 is asynchronous: events remain in the buffer until they are accepted or rejected. This can cause dead time, when all four buffers are full. In order to keep dead time at 10%, with Level-1 rate of 50 kHz, Level-2 has been split in two pipelined steps of 10 μs each. In the first phase the event is partially reconstructed and analyzed depending on the detector.

Muons, electrons and jets are better defined allowing a higher fakes rejection. The Silicon Vertex Tracker (SVT) operates a this level and it will be described in 4. During the second pipelined steps, the results of the first phase are fed to a set of Alpha processors, where the event is examined for different characteristics. Level-2 accept rate is around 300 Hz, with a rejection of about 150.

After being accepted by Level-2 trigger the entire event is read and loaded into a Linux PC farm, where it is fully reconstructed. The Level-3 reconstruction code is the same used, with different parameters, in offline analysis.

3 Level-1 Track Trigger

The eXtremely Fast Tracker (XFT) is a synchronous, parallel, pipelined track processor which reconstructs tracks on the transverse plane of the COT with $P_t > 1.5$ GeV/c . An extrapolator module (XTRP) propagates these tracks into the other parts to build the Level-1 trigger: muons, electrons and silicon tracks.

The track reconstruction is performed in two steps. In the first one, the Finder searches for tracks segments in each of the four axial superlayers based on the list of all patterns of hits that correspond to a line segment. In the second step the Linker searches for combinations of segments that could belong to the same track. When such combinations are found, the transverse momentum and the angular position of the tracks are reconstructed. The φ position is measured at the center of the third axial superlayer, the resolution is 5.1 mrad better than 8 mrad specified in the Technical Design Report (TDR) [1]. The track finding efficiency is $96.1 \pm 0.1\%$[2] and it is shown in figure 2 as function of the track P_t for three different momentum threshold: 1.5 GeV/c (top), 4.0 GeV/c (center) and 8 GeV/c (bottom). The momentum resolution, defined with respect to the offline, is $\Delta P_t / P_t^2 = 1.65\%$ per GeV/c while the TDR value is 2%.

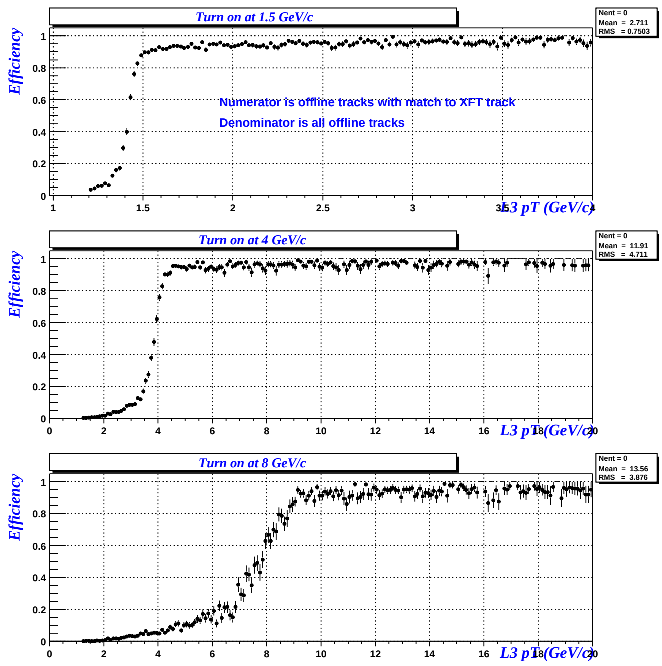

Figure 2: XFT efficiency versus track momentum for three different P_t thresholds (see text).

4 Level-2 Track Trigger

The online Silicon Vertex Tracker inputs are the list of COT tracks found by XFT and the data from four axial silicon layers. It associates a set of silicon hits to each XFT track and fits the results to a circle in the transverse plane, thus determining the track parameters with a precision comparable to the offline. One of them is the impact parameter, cutting on which events with displaced vertices can be selected.

SVT is divided in several subsystems, each performing a specific task. In figure 3 the architecture and the data flow is shown. The SVT core is organized as 12 identical systems (sectors) which correspond to the 12 silicon wedges in φ. The Hit Finder, three per sector, calculates the cluster centroid position of the silicon hits and sends them to the Hit Buffer where they are stored for future reference and to the Associative Memory (AM) units. This system performs the pattern recognition. Upon receiving the list of silicon hits and XFT tracks, each AM chip searches for all the coincidences of 4 silicon hits and XFT tracks which represent a legitimate particle trajectory (roads). This is done by comparing the input data with a stored set of precalculated patterns. In order to limit the number of roads that would be needed to match all the possible tracks the AM system groups clusters into "superstrips" each covering about 250 μm. In this way the number of channels is reduced but the coarse resolution increases the number of fake tracks and may cause multiple candidates to fall within the same road. This width is a good compromise between cost, performances and processing time. For each Hit Finder there are 2 AM boards with 128 chips each and 128 roads per chip which is about 32,000 roads. This gives a coverage of about 95%. As soon as the last hit of an event is read the pattern recognition is ended and the list of the "active" roads is sent to the Hit Buffer. It retrieves the full XFT and SVX clusters information and send them to the Track Fitter. This last subsystem checks all clusters combinations in each road and outputs the track parameters. A detailed description of the fitting algorithm can be found in [3] , only the general idea is described in the following.

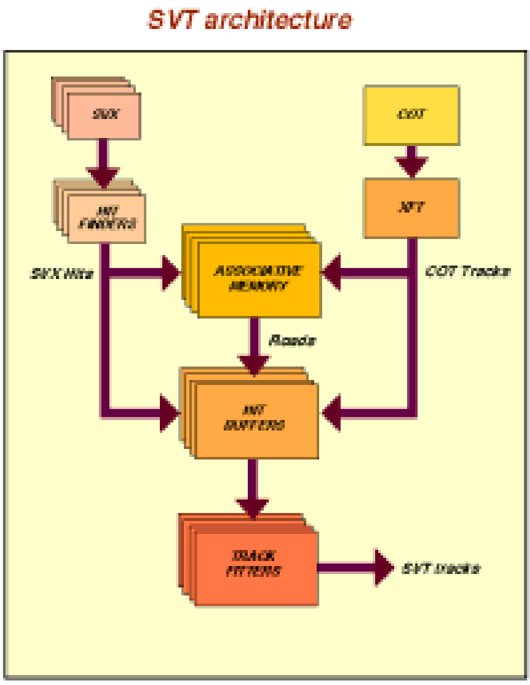

Figure 3: SVT components list and data flow.

Track candidates are characterized by a set of six numbers, x_i: the position of the silicon cluster on each of four layers used by SVT, the curvature and φ position of the seed XFT track. These points are fitted to a circumference described by three parameters curvature, φ and impact parameter and must obey three independent constraints which can be written as $f(x_i) \simeq 0$. Fitted track parameters can be expressed as function of the x_i. Both track parameters and constraints can be linearized and written as scalar products, easy and quick to compute. For each candidate, a χ^2 is computed and only tracks whose χ^2 is below a predetermined threshold are accepted. Main issues in this reconstruction are primary vertex determination and detector alignment. Since tracks reconstruction is done only in the transverse plane it is necessary to know where the beam line is. Each detector element has to be correctly aligned to each other and to the beam. The internal detector alignment was performed with high precision when it was assembled. The beam position is evaluated every few minutes of each run and used to correct online inside SVT the impact parameter for small drift of the beam line. It should also be sent back to the Tevatron for correction when the beam movement between one store and next one is so large that a loading of a new set of pattern would be necessary. The current impact parameter resolution is $\sigma_d = 48\ \mu\text{m} = 33\ \mu\text{m} \bigoplus 35\ \mu\text{m}$, where the first term is the beam spot and the second one is SVT resolution, well in agreement with the design value, 35 μm[1].

The SVT performances have been evaluated by using a sample of $J/\psi \rightarrow \mu\mu$ collected with the muon trigger. In figure 4 the efficiency (ϵ) is shown as function of the track impact parameter. The average value is around 80% with a decrease over 1 mm. This behavior is due to a partially coverage of AM patterns over 1 mm. In figure 5 the efficiency is studied as function pseudorapidity, η (upper plot) and track momentum (lower plot). The flat η dependence between -1 and +1 is expected while the low efficiency at low transverse momentum is due to the fact that the AM patterns are generated flat in curvature causing a lower coverage at low P_t. Both efficiencies are around 80%. It is to understand that part of the inefficiency can be recovered with a new set of AM pattern.

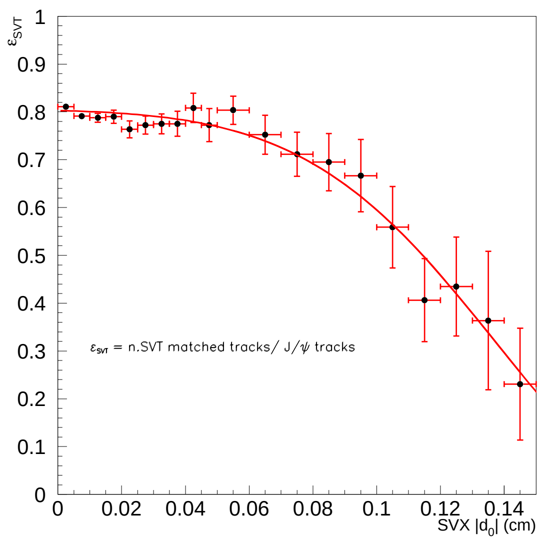

Figure 4: SVT efficiency vs. impact parameter

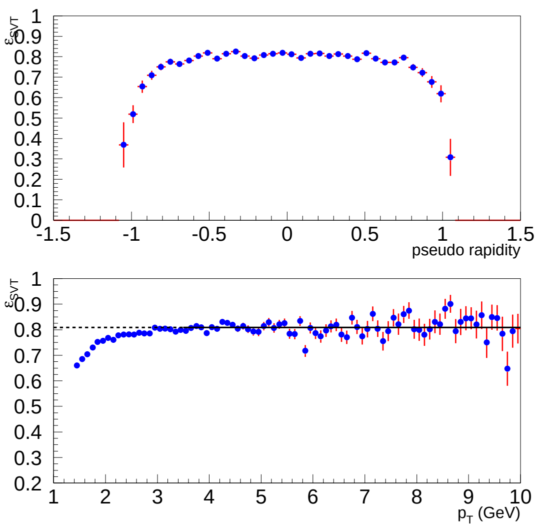

Figure 5: SVT efficiency vs η (top) and P_t(bottom).

5 The Two Track Trigger

Level-1 and Level-2 track processors are currently used in the so called Two Track Trigger (TTT) at CDF with the following settings:

Level-1 at least 2 XFT tracks with $P_t > 2$ GeV/c oppositely charged with $\Delta\phi^{1,2} < 135^o$ and $P_t^1 + P_t^2 > 5.5$ GeV/c.

Level-2 at least 2 SVT tracks with $P_t > 2$ GeV/c, 100 μm$< |d| < 1$ mm and $\chi^2_{SVT} < 25$.

Level-3 match of the 2 SVT trigger tracks with those reconstructed in the COT and confirmation of $P_t > 2$ GeV/c, 100 μm$< |d| < 1$ mm plus the requirements $2^o < \Delta\phi^{1,2} < 90^o$ and the decay length in transverse plane projected toward the flight direction of the 2 trigger tracks (L_{xy}) grater than 200 μm.

CDF is collecting data at low luminosity ($\mathcal{L} \sim 10^{31}$) right now and with the cuts described Level-1 rate is $\sim$ 3 KHz and Level-2 $\sim$ 50 Hz for the Two Track Trigger. At Level-3 the hadronic B decays are written at $\sim$ 1 Hz. When the luminosity will rise up to keep the rates around these value other cuts not yet implemented will be used. At Level-3 by using information from SVT and COT tracking it has been possible to calculate the invariant mass of trigger tracks assuming kaon and pion mass. In figure 6 the D^0 peak is shown only for 1.3 pb^{-1} of data. Since the number of reconstructed D^0 is so large it has become a very important monitor for the TTT. In fact the number of D^0 per pb^{-1} is constant if the trigger is working properly. At hadron collider this is possible now for the first time thanks to the impact parameter trigger.

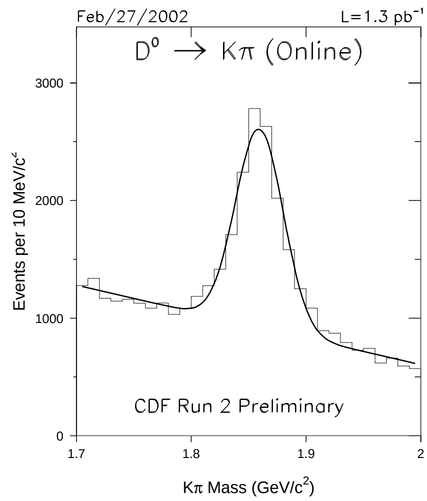

Figure 6: Online invariant mass.

6 First look at the data

Data collected from January 2002 to April 2002 with the TTT trigger correspond to about 11 pb^{-1}. A preliminary analysis has reconstructed several decay channels with a good signal to noise ratio. In figure 7 is shown the D^0 peak, reconstructed with more sophisticated cuts respect to the online:

- at least 20 axial and stereo COT hits and at least 3 SVX axial hits;

- tracks within 5 cm in z and impact parameter product less than 0;

- $L_{xy}(D) > 500$ μm and $P_t^D > 5.5$ GeV/c.

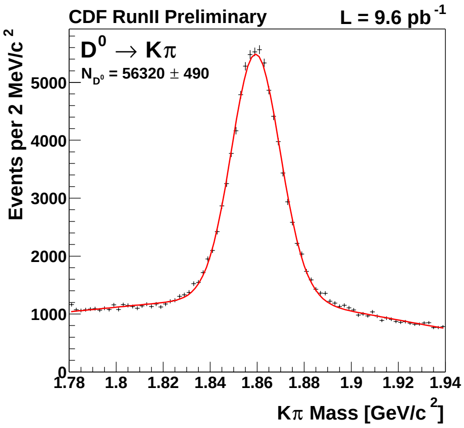

Figure 7: D^0 invariant mass distribution

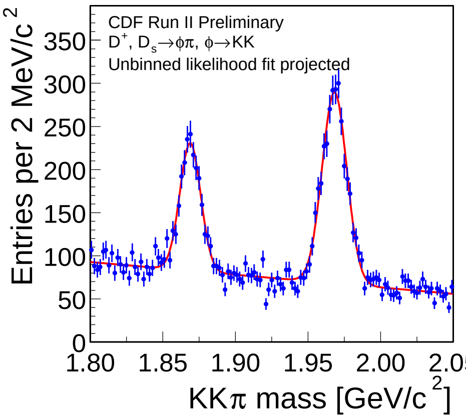

Figure 8: $\varphi\pi$ invariant mass.

Not only two prongs decay have been reconstructed but also three-prongs $D^{\pm} \to K^{\mp}\pi^{\pm}\pi^{\pm}$ and even more complicated decays like $D^{*\pm} \to D^0\pi^{\pm}$.

Since one of the main CDF interests is the B_s hadronic decay collection, D_s have been reconstructed through the decay $D_s \to \phi\pi$ with $\varphi \to K^+K^-$. Track selection is the same already described and the D_s candidate has to satisfy also 1010 <m(ϕ)< 1035 MeV/c², $L_{xy} > 500$ μm, $\chi^2 < 7$ of the fitted vertex and $|\cos(\theta^{\phi}_{helicity})| > 0.4$, where $\theta^{\phi}_{helicity}$ is the angle between a kaon from the ϕ decay and the direction of the $D_s^{\pm}$, all in the ϕ rest frame. Figure 8 shows two peaks representing D_s and $D^{\pm}$ decays. The latter is Cabibbo suppressed and a large number of events are reconstructed comparing to the D_s because of the trigger preference for decays with longer lifetimes. The huge number of D_s and $D^{\pm}$ events allowed the measurement of the mass difference $\Delta m(D_s, D^{\pm}) = 99.28 \pm 0.43$ (stat.)$\pm$0.27(syst.) competitive with the world average 99.2 ± 0.5 [4].

Moreover, the CP eigenstates $D^0 \to \pi^+\pi^-$ and $D^0 \to K^+K^-$ are reconstructed by CDF with cuts similar to $D^0 \to \pi^+K^-$ with yields such that ratios $\Gamma(D^0 \to \pi^+\pi^-)/\Gamma(D^0 \to \pi^+K^-) = 11.18 \pm 0.48$(stat.)$\pm$0.98(syst.)% and $\Gamma(D^0 \to K^+K^-)/\Gamma(D^0 \to \pi^+K^-) = 3.37 \pm 0.20$(stat.)$\pm$0.16(syst.)% are measured with an error close to the PDG value (10.83$\pm$ 0.27% and 3.76 $\pm$ 0.17% respectively [4]).

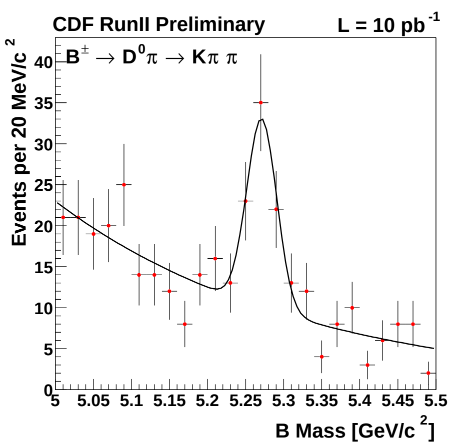

Figure 9: $D^0\pi^{\pm}$ invariant mass.

With the Two Track Trigger CDF has become a very important laboratory where D properties can be studied, but this trigger was designed for online B selection. Since the b cross section is lower than the c cross section the reconstructed B are expected to be less than the charm signal even if the B lifetime is longer than D one, giving an higher trigger efficiency. The ratio B/D is unknown and its precision determination is something that CDF now can do. At the moment CDF has 56 ± 12 events of $B^{\pm} \to D^0 \pi^{\pm}$ (see figure 9) reconstructed almost with the same cuts described for D selection. There is also a handful of events $B \to h^+ h^-$ where $h^{\pm}$ stands for any hadron π or K. Both analysis are very preliminary and soon with more statistics many interesting physics measurements will be performed.

7 Conclusion

CDF is collecting data with the new trigger on the impact parameter designed for online hadronic b decays selection. The trigger performances are almost the design ones with and impact parameter resolution of about 35 μm, as expected. In the firsts pb^{-1} of data several charm signals have been reconstructed opening a new physics field for CDF. The firsts B decays are also reconstructed as demonstration that the physics with B hadronic decays will be available at CDF very soon.

References

[1] R. Blair et al. “The CDF II Detector Technical Design Report ”, CDF Collaboration, FERMILAB-Pub-96/390-E

[2] E.J. Thomson et al. “Online Track Processor for the CDF Upgrade” Published Proceedings 2001 IEEE Nuclear Science Symposium (NSS) and Medical Imaging Conference (MIC), SanDiego, CA, November 4-10, 2001.

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[4] K. Hagiwara et al. “The review of Particle Physics” Phys. Rev. D 66, 010001 (2002).