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The CDF Online Silicon Vertex Tracker

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Abstract

The CDF Online Silicon Vertex Tracker recontructs 2-D tracks by linking hit positions measured by the Silicon Vertex Detector to the Central Outer Chamber tracks found by the eXtremely Fast Tracker. The system has been completely built and assembled and it is now being commissioned using the first CDF run II data. The precision measurement of the track impact parameter will allow triggering on B hadron decay vertices and thus investigating important areas in the B sector, like CP violation and B_s mixing. In this paper we briefly review the architecture and the tracking algorithms implemented in the SVT and we report on the performance of the system achieved in the early phase of CDF run II.

Key words: Data Acquisition; Tracking and position-sensitive detectors

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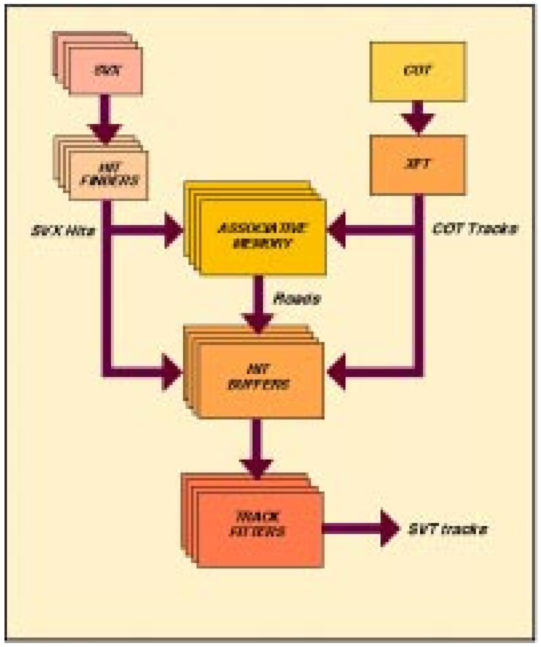

Fig. 1. The CDF Online Silicon Vertex Tracker architecture.

1 Introduction

The Online Silicon Vertex Tracker (SVT) is the new processor dedicated to the reconstruction of charged particle trajectories at Level 2 of the CDF trigger. The SVT refines the Level 1 tracking information from the eXtremely Fast Tracker (XFT), which reconstructs tracks in the Central Outer Chamber (COT), by linking Silicon Vertex Detector (SVXII) hits. Track reconstruction is performed by the SVT in the plane transverse to the beamline. The Level 2 latency time is about 20 μs, therefore the design of the SVT has concentrated on parallelizing the various tasks: hit reconstruction from the single strip pulse heights, the pattern recognition and final high precision track fitting. The core of the SVT is organised as 12 identical systems (slices) running in parallel. This implementation directly reflects the SVXII geometry, which is divided in 12 independent wedges along the azimuthal angle. Each SVT slice links the digitised pulse heights found within one SVXII wedge to the tracks reconstructed in the corresponding 30° angular region of the COT by the XFT. The SVT is built on 9U Eurocard boards which implement a VME-bus interface for diagnostics and control. The architecture is data driven and pipelined. Specifications require 30 MHz operation for each module with an asynchronous data transfer rate of 630 Mbit/sec on custom data paths. The SVT tracking strategy and architecture have been widely reviewed in (1). The main functional blocks of each SVT sector are the Hit Finders, the Associative Memory system, the Hit Buffer and the Track Fitter (Fig.1). Every time an event is accepted by the Level 1 trigger, the digitised pulse heights in the Silicon Vertex detector are sent to the Hit Finders which calculate hit positions.

Hits found by the Hit Finders and tracks found in the COT are then fed to the Associative Memory system and to the Hit Buffer. The Associative Memory system performs pattern recognition by selecting for further processing only combinations of COT tracks and SVXII hits which represent good track candidates. This is done by comparing the input data with a stored set of patterns in a massively parallel architecture, using a dedicated custom VLSI chip (2). The output of the Associative Memory system is a list of "roads". Each road is defined as a combination of five superstrips detected on five different detector layers. The five superstrips correspond to the hit positions on four silicon detector layers, while the fifth superstrip is a function of the curvature and azimuthal angle of the COT track reconstructed by the XFT. To reduce the amount of required memory this pattern recognition process is performed at a coarser resolution than the full available detector resolution. The roads found by the Associative Memory system are sent to the Hit Buffer (3), which retrieves the original full-resolution silicon hit coordinates and XFT track associated with each road and delivers them to the Track Fitter for full precision calculation of track parameters.

1.1 Overview of the track fitting method

The SVT reconstructs tracks projected on the plane transverse to the beam axis and measures track curvature, azimuthal angle and impact parameter (c, ϕ, d). Each detector layer measures one hit position along the track. There is an analytical relationship between the parameters of the track and the hit coordinate, which can be expressed in terms of n equations (n is the number of detector layers): $x_i = x_i(c, \phi, d)$. By eliminating the three track parameters (c, ϕ, d) from the previous equations, one can obtain a set of $n-3$ independent constraints ($f_k(\mathbf{x})$) which all real tracks must satisfy within detector resolution effects. Under the assumption that the constraints can be approximated by linear functions of the hit coordinates:

$$f_k(\mathbf{x}) = \mathbf{v}_k \cdot \mathbf{x} + c_k \simeq 0 \tag{1}$$

where the vectors $\mathbf{v_k}$ and c_k are constants which depend only on the detector geometry. It can be shown that the vectors $\mathbf{v_k}$ are the eigenvectors of the $(n \times n)$ covariance matrix of the hit coordinates ($\mathrm{M}_{il} = < x_i x_l >$ - $< x_i >< x_l >$, with $<>$ defined as the average over a sample of tracks) that correspond to null eigenvalues. Given the finite resolution of the detector, a combination of hits forms a track if the value of all constraints is approximately zero. Also the track parameters are computed as scalar products:

$$p_j(\mathbf{x}) = \mathbf{w}_j \cdot \mathbf{x} + q_j \tag{2}$$

where p_j is one of the track parameters and $\mathbf{x}$ is the array containing hit positions measured by SVXII and track curvature and azimuthal angle measured by the XFT. The parameters $\mathbf{w_i}$ and q_i are constant within each 30° SVXII wedge. The expected resolution is $\sigma_{p_t} = 0.003 \cdot p_t^2$ (p_t in GeV/c), $\sigma_\phi = 1$ mrad and $\sigma_d = 35\ \mu$m (at 2 GeV/c).

2 Preliminary results on SVT performance

CDF run II data taking began in spring 2001, after a short period of commissioning of the Tevatron Collider in October 2000. At the moment of writing this paper, all the SVT components were installed and operational and the system was in a full commissioning phase. The simplest test of the SVT functioning was checking the distribution of the constraints $f_k(\mathbf{x})$ for a sample of reconstructed tracks. To simplify the test, this was done first for tracks reconstructed with the SVT running in "silicon-only" mode. In this simplified running mode, the SVT disregarded XFT information and performed pattern recognition and track fitting using only the information of the four silicon layers. In this case there is only one constraint, while in the more general case, when also curvature and azimuthal angle measured by the XFT are used, the number of constraints is three. Top left plot in Fig. 2 shows the distribution of $f_1(\mathbf{x})$ calculated for SVT data (solid line) taken in "silicon-only" mode and for a sample of hit coordinates randomly distributed within the roads (dashed line). The presence of a narrow peak in the SVT data shows that a large fraction of the tracks found by the SVT are real. This check was then repeated with the SVT running in the standard mode, i.e. using both silicon and XFT information. The distribution of the three resulting constraints is reported in Fig. 2 (top right plot and bottom plots). Further information concerning the performance of the SVT was obtained from the study of the track parameters and of the correlation between track parameters. This was done both with the SVT running in "silicon-only" mode as well as in the standard mode. In this paper we report only on the performance achieved in the standard functioning mode. In Fig. 3 the correlation between the track impact parameter and the azimuthal angle is shown. The expected functional form is:

$$d = x_0 \cdot \sin(\phi) - y_0 \cdot \cos(\phi) \tag{3}$$

where (x_0, y_0) is the average beam spot position in the transverse plane. From a fit to the distribution we determined $x_0 = 0.0896 \pm 0.0005$ cm and $y_0 = -0.3550 \pm 0.0005$ cm. This fit was used to subtract the beam offset and measure impact parameters with respect to the beam center. The resulting distribution (Fig. 3) originates from the convolution of the actual beam profile, which has a width of about 30 micron, with the impact parameter resolution.

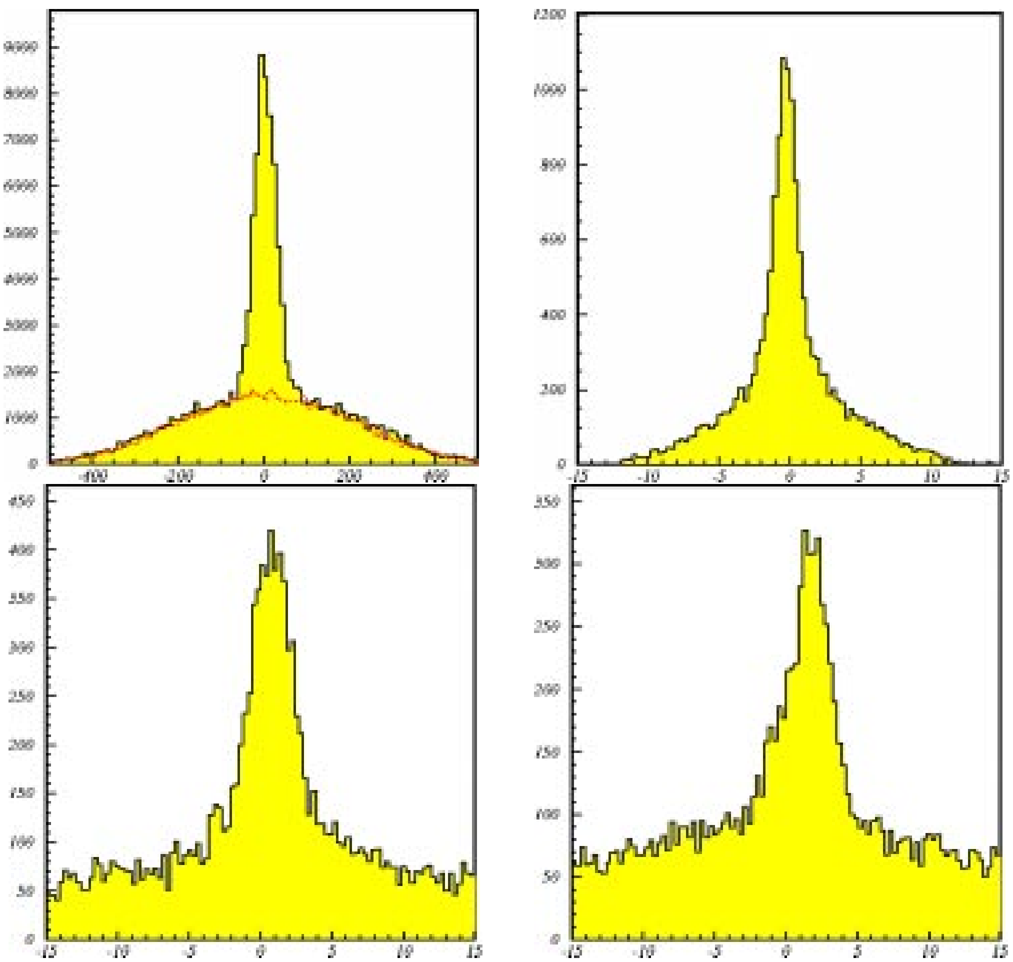

Fig. 2. Top left plot: constraint distribution for "silicon-only" SVT tracks. Solid line is for SVT data, while dashed line is generated by random hit combinations within the roads. The scale on the x axis is micron. Top right and bottom plots: constraint distributions for SVT running in standard mode. The scale on the x axis is arbitrary.

We found a gaussian distribution with a sigma of 53 micron for wedges 2 and 3. This is in agreement with results of early simulations of the SVT performed using CDF run I data.

3 Conclusions

In this paper the present status of the CDF Online Silicon Vertex Tracker has been reviewed. The SVT is now being commissioned using preliminary CDF run II data. Although the system still needs some fine tuning, preliminary results show that performance is close to design.

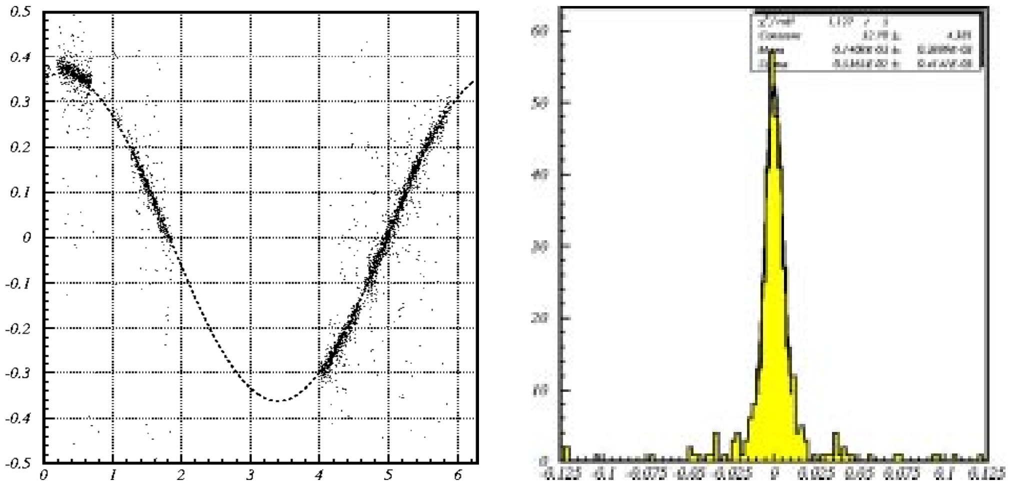

Fig. 3. Left plot: correlation between the track impact parameter (cm.) and azimuthal angle (rad.) for a sample of data taken in July 2001. There are no tracks in some angular regions because also the SVXII was in a commissioning phase and not all the wedges were powered at the same time. Right plot: impact parameter (cm.) measured with respect to the beam axis for tracks in wedges 2 and 3.

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