Initial experience with the CDF SVT trigger

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Abstract

The CDF Silicon Vertex Tracker (SVT) is a device that works inside the CDF Level 2 trigger to find and fit tracks in real time using the central silicon vertex information. SVT starts from tracks found in the previous Level 1 trigger by the central chamber fast trigger and adds the silicon information to compute transverse track parameter with offline quality in about 15μsec. The CDF SVT is fully installed and functional and has been exercised with real data during the spring and summer 2001. It is a complex digital device of more then 100 VME boards that performs a dramatic data reduction (only about one event in a thousand is accepted by the trigger), diagnosing rare failures poses a special challenge and SVT internal data flow is monitored by dedicated hardware and software. This paper briefly cover SVT architecture and design and reports on the SVT building/commissioning experience (hardware and software) and on the first results from the initial running.

Preprint submitted to Elsevier Science *13 November 2001*

1 The CDF upgrade and the Silicon Vertex Tracker

The Collider Detector at Fermilab (CDF) is a general purpose detector for the study of high energy proton-antiproton interactions produced in the Fermilab Tevatron Collider particle accelerator. CDF completed its first period of data taking (Run1) in 1994. The Tevatron has now been upgraded (Run2) to higher energy (from 800 to 1000 GeV per beam) and luminosity (from 2×10^{31} to 1×10^{32}). CDF has been upgraded as well to cope with the new accelerator conditions (higher instantaneous luminosity and reduced bunch spacing from 3.5μsec to $132n$sec) and extend its physics reach.
Four upgrades are relevant to this paper: 1) A 3 level digital trigger: Level 1 is completely pipelined and deadtime-less, completes in 4μsec and has an accept frequency $\simeq$ 50kHz, the Level2 operates after detector readout and completes in $\sim 20\mu$sec with accept rate $200 \sim 300$Hz, Level3 will work after event building to bring the accepted rate down to $\sim$ 50Hz for data storage and offline analysis. 2) A new silicon vertex detector (SVXII [1]) with 5 layers of microstrip sensors arranged in a 12-fold azimuthal geometry (ϕ) and segmented in 6 longitudinal barrels (3 mechanical units, each read out at both ends) along the $z-$axis. 3) A new fast trigger processor (XFT [2]) for the central drift chamber that finds tracks in the transverse ($r - \phi$) projection in time to be used in the L1 trigger decision and with resolution, from actual Run2 data, $\delta\phi = 4m$rad, $\delta P_t/P_t = 1.6\%$. 4) The SVT (Silicon Vertex Tracker) device [3], which works inside the L2 trigger to combine XFT tracks with SVXII data to fit tracks with offline-like quality. Design goals for SVT, from simulation of the actual algorithm on Run1 data, are $\delta\phi \simeq 1m$rad, $\delta P_t/P_t \simeq 0.3\%$ and $\delta d \simeq 35\mu$m, where d is the track *impact parameter* i.e. the minimum distance between the particle trajectory and the primary vertex.
By providing precision information on the impact parameter, SVT allows CDF to select events containing long lived particles ($B-$baryons in particular) in the trigger process. This novel feature, available for the first time in a hadron collider experiment, greatly enriches the CDF physics program, in particular uniquely provides access to hadronic B decays like $B^0 \rightarrow \pi\pi$ or $B_{(s)} \rightarrow D_{s)}\pi \rightarrow \geq$hadrons. A typical trigger path will require two tracks with $P_t \geq 2$GeV at L1 from XFT with a $\sim 30kHz$ expected accept rate that will be reduced to $\sim$ 30Hz at L2 when including impact parameter in the cuts, typically: 1mm$> d_1, d_2 > 100\mu$m.
SVT is a parallel pipelined data driven device. Tracks are found independently in the twelve 30^0 sectors of SVXII (wedges). Raw SVX data flow from the front-end to Hit Finder boards that find clusters of strips with a significant energy deposit and compute the coordinate of the centroid (Hits). The P_t and ϕ of tracks from XFT are received, fanned out to the 12 SVT wedges and fed both to Associative Memory and to Hit Buffer boards together with all SVX Hits. The Associative Memory finds track candidates (Roads) using a coarse spatial resolution in the SVX (250μm) and sends them to the Hit Buffer. Each

Hit Buffer store all hits and tracks in a wedge for each event in an internal memory, then for each Road output by the Associative Memory, retrieves the hits and the XFT track belonging to that road and sends them to Track Fitter boards, that perform quality cuts and and estimate track parameters using the full available spatial resolution in a linearised fit. A set of Merger boards, each providing 4-way fan-in and 2-way fan-out, ties together all boards in a chain that starts from 288 optical links from SVX and ends in a single data path to the CDF Level 2 processor.
Data flow through the SVT pipeline on uniform point-to-point connection on 23-bit LVDS data channel running at about 700 Mbit/sec each, SVT is made by over one hundred 9Ux400mm VME boards housed in 8 crates, connected by about 50 of those data paths and small busses on custom backplanes. Up to 4 events may be present at the same time in the SVT pipeline, data being stored on on-board FIFO's. The output list of high precision tracks is sent to CDF L2 processors for the final decision 15μsec after L1 decision on average, depending on event size.
SVT construction has been completed and all hardware is installed and fully operational since beginning of 2001.

2 Operational Challenges

SVT design has been fully simulated, both as digital simulation on electronic CAD of all boards, and as simulation of the tracking algorithm on real CDF data from Run1, so one could feel confident that it will perform as expected. Nevertheless there are issues that could not be studied with simulation and can only be addressed when operating the real system with beam data, primarily correct operation of hardware as a full system and z-alignment
The hardware operation has to do with making sure there are no hardware, firmware nor programming problems that may cause SVT to malfunction even in rare situations. All boards have been extensively tested before installation, but all bench tests are limited to either very low rate (limited by how fast a computer can feed data to SVT) or very small data variety (using SVT boards to send in a loop at full speed a preloaded set of data). Moreover one has to make sure of correctness and proper timing of input data from SVXII and XFT. Since only about 1/1000 of the events processed by SVT are available on tape, we can not rely on offline analysis only. Most SVT diagnostics is carried out in real time by dedicated hardware that monitors data integrity on all events. Special care has been taken to allow quickly reducing system problems to single boards or links: each board verifies that all input data come from the same event and checks parity of data on the input cables, all internal FIFO's are monitored for overflows (data loss) and data flowing on each link are continuously copied to large circular memories (Spy Buffers) providing a

snapshot of all data processed in SVT in the last few hundred events. These data are then compared with SVT simulation by processes running on the VME crate controllers. Operation of these memories is coordinated via one dedicated Spy Control board in each crate. Whenever an erroneous or illegal condition is detected, error flags are asserted locally in the boards and inside the data stream.
The $z-$alignment issue is the fact that SVT only fit tracks in the transverse plane (although separately in each of the six $z-$barrels). Therefore $z-$misalignment of the detector, either internal or relative to the beam line, spreads the beam profile, causing a worsening of the resolution, a higher trigger rate for a given impact parameter cut, and a higher background contamination in the selected sample. To make that spread small compared to natural beam width, SVT requires each SVXII strip and the beam line to be all parallel within 100μrad. Assembly of the SVXII barrels indeed met (even exceeded) this specification, more challenging is the SVX-beam relative alignment: the detector must be properly positioned in the collision hall, and the beam orbit must be steered in each store to be put on the same axis, and kept there. During Run1 the beam angle at the collision point showed variations beyond the required limits, the plan for Run2 is to use SVT feedback to continuously adjust the beam position. For this SVT must provide accurate beam position information in the $x-y$ plane in each of the 6 barrels with a time constant of about 1 second.

3 SVT performance on real data

SVT has been operated since one year, in the October 2000 CDF commissioning run (prototype SVX detector, no XFT tracks to SVT) and in the 2001 physics run period that started in April. Initial focus has been in system integration: debugging SVX and XFT communication to SVT, developing control and monitor software infrastructure, interfacing to DAQ startup and error handling, debugging the L2 processors. This activities are not completed yet, and while SVT data checking and diagnostics features are proving to be very useful in commissioning the surrounding systems, it has not been possible yet to use SVT to provide trigger decisions in the design framework and measure trigger rates. Anyhow SVT has processed real data routinely, with its output track list logged in the event data, so the tracking performance of SVT could be measured. Good tracking resolution is the fundamental ingredient to SVT operation, if the detector-algorithm combination does not provide the needed precision, there is no point in looking at efficiency, stability, rates, background and so on. In this respect the device performed remarkably well even without any parameter tuning. So far SVT has been operated with wide roads, nominal detector geometry, large cut on track χ^2, no correction for $z-$tilt between

SVXII and the beam, no correction for SVX dead/hot channels, pedestals, gains, no tuning of the clustering algorithm.
Figure 1 shows the $d - \phi$ plot from data taken on August 2001. Even when SVT was used in an unforeseen situation, without XFT tracks, acting as standalone tracker in the innermost 4 SVXII layers, it clearly separated tracks coming from the beam (the sinusoidal wave reflects the $d - \phi$ relationship when the beam is offset in the $x - y$ plane with respect to the origin of the coordinate system). Vertical stripes in the left plot in this figure indicates silicon hot channels. The tracks are of course much cleaner when XFT information could be added (right plots). From distributions like the one in figure 1 it is

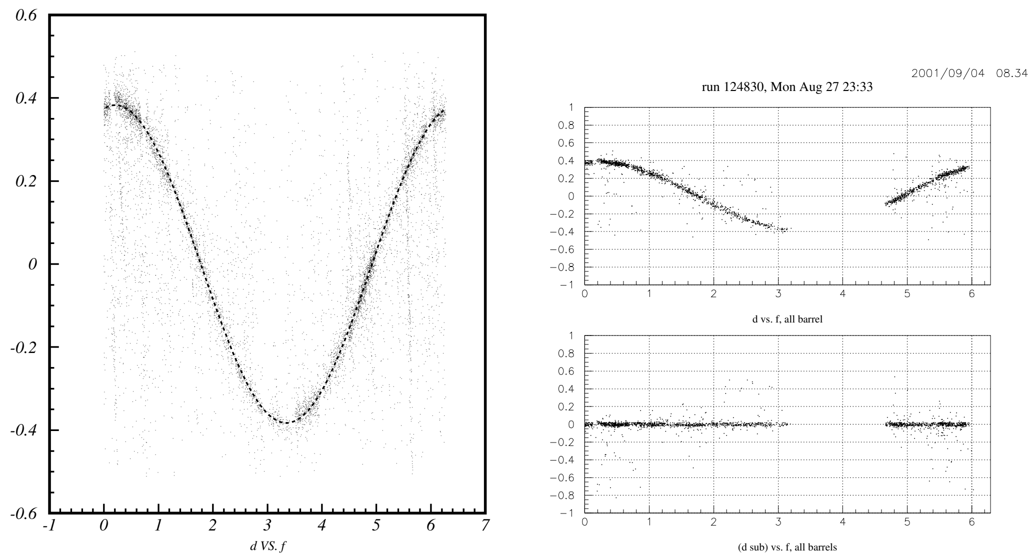

Fig. 1. impact parameter (vertical, cm) vs. polar angle (horizontal, rad). Left: using only SVX data. Right: using both SVX and XFT: uncorrected (top), after correcting for beam offset fit on top plot (bottom). The region without data points around $\phi = 4$rad on the right plots is due to HV problems in a sector of the drift chamber.

possible to extract the impact parameter resolution. A typical d distribution is shown in figure 2 on data collected in one run in July 2001. The width of the distribution ($\sim 50\mu$m) is the convolution of the SVT resolution with the intrinsic beam spread. This distribution is not corrected for difference between ideal and real detector geometry and for the beam $z-$tilt. The beam tilt is measured in real time by a task running on the SVT VME crate controller, that reads the track list from the SVT Spy Buffers and fits the $d - \phi$ distribution to obtain the $\{x_0, y_0\}$ beam position in each of the six barrels, a linear fit to this 6 pairs returns then the beam line direction. This proved to work smoothly and reliably providing the information needed for online beam orbit steering. In this way the z beam slope was found to be $\delta x/z \simeq 600\mu$rad, $\delta y/z \simeq 150\mu$rad, in agreement with offline studies using the central drift chamber and well beyond SVT specification. The deviation is also larger then the beam orbit adjustment range and thus moving the SVXII detector once is required. Using offline reconstruction to compute the z of each hit it is possible

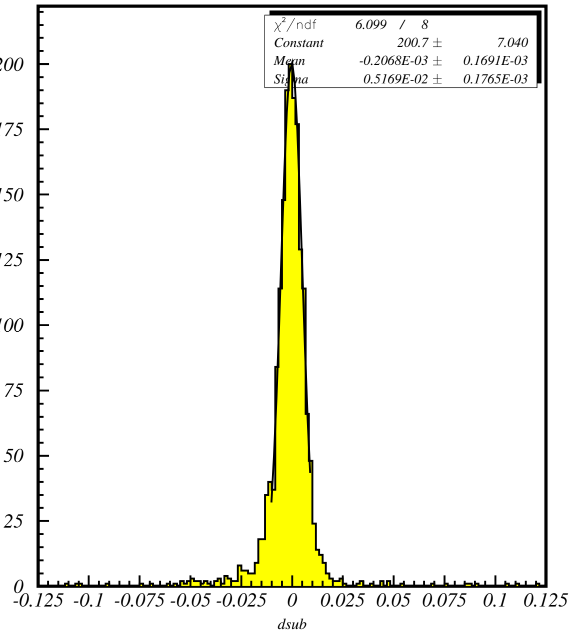

Fig. 2. impact parameter distribution (in cm) using XFT and SVX data

to correct for the beam tilt, this study allowed to single out the contribution to the impact parameter resolution from all sources and showed that present data, once correct for $z-$tilt and detector alignment, demonstrate a 45μm impact parameter resolution (convolution of SVT resolution and beam width), in agreement with expectations from Run1 data.

4 Learning from the SVT experience

During SVT construction, installation and commissioning, we did not encounter completely unexpected problems or difficulties, but, as it happens usually, some items remained under-manned, first priority being to have the hardware working and installed in time. Now we can identify among the large list of things that we would have liked to do, but didn't, the ones that would have been most useful.

About hardware, it is very important never to stop the design process until the very last moment. Early prototyping of realistic board operation is important [1] but so it is to keep the project as state of the art as possible to add flexibility and simplify the system by using less, more uniform and powerful components. Major drawbacks in our case have been: a large number of obsolete/overcrowded/non-reprogrammable FGA's/CPLD's, not all internal pipeline stages accessible for diagnostics, difficult/impossible to add useful

[1] many glitches fixed on SVT prototypes could not be found by CAD simulation and would have been disastrous had they only been discovered at installation time

new features, not enough common hardware solutions and common behaviour among different boards, hence the need for many hardware experts and some operational difficulty (we tried to uniform board designs, but should have pushed this more). Nevertheless the hardware construction has been largely a success, failure rate has been very small, and moving from bench test to real system operation exposed only a few minor problems which could be fixed with small firmware changes.
Looking at the SVT architecture and overall planning, the single most important lesson is: plan from the beginning for debug and commissioning, so to make to make this part fast, effective and easy. A key points is allowing to use the system in a completely realistic way even without the rest of the detector/DAQ, using the same control and monitor software used during data taking. SVT is capable to process test data in standalone mode, but during commissioning we realised the shortcoming of this, and had to improvise a way to synchronise the flow of test data with CDF DAQ/Trigger without using SVX and/or XFT as data sources. Only a fraction of SVT hardware can be exercised in this mode at present, but we are working to extend such a capability to the full system. We also learned that it would have been very useful to complement SVT's asynchronous SpyBuffer monitoring mechanism with the option to read intermediate data into the event record, both to use uniform offline tools to access internal and external data and to tie internal data to specific events on tape.
On the good side there are also features built into SVT which proved to be very useful: common data communication protocol and capability to inject/read data from any SVT board allows to easily recombine SVT boards in various configuration (often simply via software) to accommodate many different tests both of SVT and neighbour systems, data integrity and synchronisation controls in SVT helped to find and fix low rate problems in other systems, capability to operate SVT boards independently of DAQ/trigger framework make it possible to develop, test and repair boards away from the CDF control room with no (or minimal) additional hardware.
Finally, although not explicitly planned for, it turned out to be very easy, and immensely useful, to operate SVT when a subset of the detector was missing, allowing detector and trigger commissioning to proceed in parallel.

In conclusion, the Silicon Vertex Tracker has been successfully built, installed and operated on real CDF data taking, and performs as expected. Tracks are found and fit with the required precision and beam position feedback to accelerator in real time is possible. Trigger rates still have to be measured and device parameters optimised, but already impact parameter resolution is as good as needed for a successful operation of the trigger. Commissioning and debugging of such a complex device as SVT has shown the importance of flexible re-programmable hardware, uniform simple components, data integrity control and integrated planning for operation and debug/test/commission since the design stage.

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