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Status of the CDF silicon detector

Gino Bolla, on behalf of the CDF collaboration

Purdue University, Dep. of Physics, 525 Northwestern Av., W. Lafayette, Indiana, 47907-2036 USA
e-mail: `bolla@fnal.gov`

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Abstract. CDF is a collider experiment that is running at the Tevatron. The core of the CDF detector is an 8 layer silicon micro strip tracker. There are 722,432 active strips with pitches that range from 25 to 140 μm. This device is an essential part of the heavy flavor tagging and forward tracking capabilities of the experiment and it is one of the largest silicon detectors in present use by an HEP experiment. A summary of the experience in commissioning and operating this double-sided detector during the first 2 years of Run II is presented. A description of the encountered failure modes follows a general view of the design. After more than 2 years of data taking, we report on the performance of the tracker and its effect on physics analyses. A short description of the SVT, the level 2 Silicon Vertex Trigger, will be given as well.

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1 Introduction

CDF II is a multipurpose collider experiment with a very broad physics program. It is installed at the Tevatron which is a $p\bar{p}$ collider with $\sqrt{s} = 1.96TeV$, the bunch time interval is $396ns$ ($36 + 36$ bunches) and an instantaneous luminosity up to $210^{32}cm^{-2}s^{-1}$ is expected. A more detailed description of the apparatus can be found elsewhere [1]. Run II of the Tevatron has been underway since March, 2001. Up to July, 2003, around $250pb^{-1}$ of $p\bar{p}$ collisions have been delivered to the experiment. Running is now stable, 90 % efficiency for data taking is regularly achieved and $\sim 7pb^{-1}$ per week are accumulated.

2 CDF silicon design

All layers except the innermost are double sided to allow full 3D standalone tracking to a forward coverage to pseudorapidity(η) of 2. Figure 1 shows the three subsystems in the detector.

L00 consists of single-sided AC coupled rad-hard p-in-n silicon, that is physically mounted and supported by the beam pipe at an average radius of $1.5cm$. These sensors have an implant pitch of $25\mu m$ and every other strip is read-out. Fine pitch kapton cables carry the signals from the sensitive strips to hybrids with the front end ASICs mounted at the ends of the array. L00 significantly improves the vertexing resolution and the radiation lifespan of the tracker.

The main central vertexing device, SVXII, is a five layer tracker with two small angle stereo (1.2 deg) and three 90 deg stereo layers spanning radii from 2.4 to $10.6cm$. All sensors are AC coupled. The design is highly symmetric, which is crucial for finding displaced tracks at

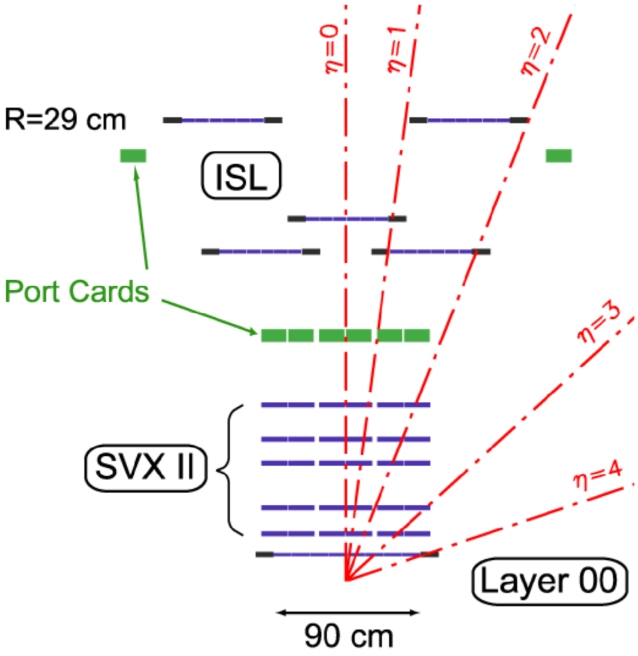

Fig. 1. A side view of half of the CDF Run II silicon showing the three subsystem : L00, SVXII and ISL. The Z coordinate is highly compressed on this scale

the L2 trigger level. The detector consists of three barrels in z, twelve wedges in ϕ and five layers in R.

The outermost silicon tracker, ISL, has small angle stereo strips at 20 and 28 cm. It allows for precise extrapolation from the drift chamber inwards and increases the coverage of the silicon in forward direction beyond the drift chamber into the plug calorimeter.

3 Commissioning and operations

Commissioning of the CDFII silicon detector took place from February 2001 until spring 2002. This long commissioning period was due to several technical problems [2] and due to the inherent large scale and complexity of the system. Stable operations of the detector was achieved through a program of monitoring, maintenance and repair of relatively ordinary problems expected for such a complex device. Furthermore two other extraordinary issues had to be addressed to maintain the performance level necessary for physics quality data.

3.1 Beam incidents

Nine silicon modules (out of more than 400) failed in two separate incidents in which the detector received anomalously high dose-rates from the Tevatron. Both incidents were generated by the abort kicker magnets deflecting the proton beam into CDF. In the first case a malfunctioning RF system turned the bunched Tevatron beam into a 100% DC beam. The subsequent high losses implied an automatic beam abort without having the time to switch off the silicon system. The second case involved an accidental Tevatron abort due to a spontaneous breakdown of the thyratron used to switch on the kicker magnets; the so called "kicker pre-fire" causes up to two beam bunches to be deflected into CDF. In both cases an exposure with a particle flux $\geq 10^7 mip's/cm^2$ in a period of time $\leq 150ns$ is estimated.

The high particle flux was replicated in a controlled environment with spare silicon modules but the damage to the SVX3d [4] chips was not reproduced. Without a detailed understanding of the damage mechanism nothing could be done to the silicon system in order to prevent further damage. On the beam side, a fast interlock that aborts the beam before it has time to de-bunch has been implemented to prevent the first type of incident. For the second, collimators have been installed in order to intercept deflected particles and so minimize the dose rate in an event of a kicker pre-fire.

After these implementations no additional damage has been recorded despite the occurence of several RF failures and kicker pre-fires.

3.2 Wire-bond failures due to Lorentz forces

Fourteen silicon modules (out of more than 400) failed during data taking with anomalous trigger conditions. During tests designed to explore the speed capabilities of the trigger and readout system, high dead-time caused triggers to be issued at a fixed rate. The symptoms were unambiguously reproduced on test parts and are consistent with the loss of the digital power to the ASICs. The wire-bonds used on these power lines all have a component that is orthogonal to the magnetic field. Synchronous readout of the Silicon detector can excite resonant vibrations due to Lorentz forces on the wire-bonds. These failures are explained by wire-bonds breaking due to fatigue stress induced by resonant vibration. These resonant vibrations are a direct consequence of the oscillating Lorentz forces induced by the 1.4 T magnetic field on wire-bonds carrying non-DC current.

The failures were reproduced with spare modules by replicating the anomalous trigger condition whith the parts immersed in a $1.4T$ magnetic field. Wire-bonds failing in these tests have been analyzed with a SEM camera. Bonds failed in minutes when driven at resonance (at 10kHz this is about 10^5 - 10^6 cycles).

The width of the resonances has been measured to be $1 - 200Hz$. The whole analysis is consistent with a very high Q resonant system. If pulsed with a frequency matching one of the natural modes of the wire the first 3-4 pulses are enough to start the motion. The amplitude saturates at several wire diameters depending on the driving force (amplitude and width of the current pulse) on a time scale of 50-100 pulses. A natural resonance f is excited by pulsing the wire with trains of pulses at the same frequency f as well as $f/2$, $f/4$ etc.

In order to reduce the occurrence of this failure mode, the digital current consumption of the SVX3d chips has been lowered by reducing the power output of their digital drivers. Furthermore, the readout thresholds have been raised to minimize the noise occupancy narrowing the width of the current pulse and so minimizing the energy released to the bond at each pulse. With hundreds of modules in the experiment it was not possible to select a range of trigger frequencies to be avoided. Procedures have been implemented to avoid the use of the silicon detector in any test with fixed period trigger rate. Finally a trigger inhibit on potential resonant behavior has been commissioned. A simple firmware algorithm, executed in a programmable logic device, computes the interval between successive readout commands issued to the silicon system.

Since these counter measures have been implemented (Fall 2002), no further failures have been detected.

4 The Silicon Vertex Trigger SVT

CDF uses a three-level trigger. On each beam crossing (every $396ns$), the entire front end digitizes (silicon sample and holds). A fast ($5.5\mu s$) pipeline of programmable logic forms axial drift chamber tracks (XFT tracks) and can match these with calorimeter and muon-chamber data. On Level 1 accept the silicon digitizes and transmits the data to the SVT and the event builder (where the data from all sub-detectors get put together). Level 2 processing, with about $30\mu s$ latency, adds fast silicon tracking, calorimeter clustering, and EM calorimeter shower-max data. On Level 2 accept, front-end VME crates transmit to the event builder. At Level 3, a farm of 250 commodity PCs runs full event reconstruction.

For each event passing Level 1, the Silicon Vertex Trigger (SVT) [3] swims each XFT track into the silicon detector, associates silicon hit data from four detector planes, and produces a transverse impact parameter measurement of $35\mu m$ resolution ($50\mu m$ when convoluted with the beam spot) with a mean latency of $24\mu s$. The impact parameter resolution for tracks with p_T around $2GeV$ is comparable to that using offline reconstruction. For fiducial offline muon tracks from J/ψ decays, having $p_T > 1.5GeV$ and hits in the four silicon planes used by SVT, the measured SVT efficiency is 85 %.

SVT is a system of 150 custom 9U VME boards containing FPGAs, FIFOs, and one ASIC design. SVT's input comprises 144 optical fibers, $1Gbit/s$ each, and one $0.2Mbit/s$ LVDS cable. Its output is one $0.7Mbit/s$ LVDS cable.

Three key features allow SVT to find a silicon track in $15\mu s$: a highly parallel/pipelined architecture, custom VLSI pattern recognition, and a linear fit in fast FPGAs. The silicon detector's modular, symmetric geometry lends itself to parallel processing. The overall structure of SVT reflects the detector 12-fold azimuthal symmetry. Each 30° azimuthal slice is processed in its own asynchronous, data driven pipeline that first computes hit centroids, then finds coincidences to form track candidates, then fits the silicon hits and drift chamber track for each candidate to extract circle parameters and the goodness of the fit.

The SVT has been commissioned and operated successfully for CDF's Run II. Among the key reasons for this system's success are its modular architecture and its ability to sink and source test data at a wide range of pipelined stages, both in test and during beam runs.

5 Summary and conclusions

In conclusion, the complex design of the CDF silicon tracker implied a long and challenging commissioning period. New failure modes have been encountered and dealt with. A complete maintenance plan is in place to maintain the performance of the system through Run II. The impact of the system on the physics capabilities of the experment is described elsewhere [6] and is yet to be fully exploited. The new trigger together with the improved silicon detector resulted in the CDF experiment producing new physics results out of the first few months of data collected in Run II [5]. The new capabilities allow the experiment to improve the measurements of Run I, like b-flavored hadrons lifetimes using the J/ψ di-muon trigger. The capability to reconstruct large samples of fully hadronic b decays is completely new. This is possible because of the new displaced track trigger.

References

1. CDFII Collaboration: Technical Design Report (TDR). FERMILAB-PUB-96/390-E
2. S. Nahn, the CDF Collaboration: FERMILAB-CONF-03/055-E. Published Proceedings 11th International Workshop on Vertex Detectors (Vertex 2002), Kona, Kailua, Hawayi, November 3-8, 2002
3. B. Ashmanskas et al. The CDF Collaboration: FERMILAB-CONF-03/168-E. Published Proceedings 9th Pisa Meeting on Advance Detectors: Frontier Detectors for Frontier Physics, La Biodola, Isola d'Elba, Italy, May 25-31, 2003
4. T. Zimmerman et al.: Nucl. Instrum. Meth. A **409:369-374**, (1998)
5. CDF II Collaboration: "Measurements of the Mass Difference $M(D_S^+) - M(D^+)$ at CDF II", FERMILAB-PUB-03-048-E
6. S. Nahn, the CDF Collaboration: FERMILAB-CONF-02/305-E. Published Proceedings 31st International Conference on High Energy Physics (ICHEP 2002), Amsterdam, The Netherlands, July 24-31, 2002