Experience with Radiation Protection for a Silicon Vertex Detector at a Hadronic Collider

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Abstract

The Collider Detector at Fermilab (CDF) incorporates a Silicon Vertex Detector (SVX) in the study of proton antiproton collisions at the Fermilab Tevatron Collider. We describe here our experience with SVX radiation protection issues during the commissioning and subsequent operation of the Collider. We outline the catalog of typical accelerator loss mechanisms, the radiation dose associated with each, and our eventual protection strategy in each case. We map the total radiation dose received by the SVX in space as well as in time. We also discuss measured radiation damage to the SVX, and its correlation with the independently measured radiation dose.

1 Introduction

The CDF SVX is a high precision Silicon Microvertex tracking detector [1] installed as part of the CDF experiment at the Fermilab Tevatron Collider. It is the first Silicon Microvertex detector installed at a hadron collider. It is used for the study of short lived particles produced in the proton antiproton collisions at the Tevatron [2].

The SVX detector is built of high quality single sided DC coupled silicon detectors in a four inch technology, connected to a custom VLSI chip developed at Lawrence Berkeley Laboratory [3]. The SVX chip contains 128 channels of low noise charge amplification, sample and hold, and comparator latch circuitry followed by a digital section which allows readout of only those channels in which the integrated charge exceeds an injected analog threshold level. The chip was fabricated using a 3 micron CMOS technology, a radiation "soft" technology. The high cross section at a hadron collider means that this device will be exposed to a large radiation dose coming from the physics processes.

The inner most layer of the SVX detector is located 3 cm from the beam axis. The high loss conditions of a hadron collider, in conjunction with the radiation softness of the SVX detector, led to the design and implementation of a dedicated loss monitor system to protect the SVX against accidental radiation dose. This system was designed to be part of the general Tevatron control system, including inputs to the abort network [4].

2 Expected Radiation Damage

During the 1988-89 Tevatron collider run, measurements of the radiation were made in the CDF collision hall. These records showed a rate of approximately 900 rads/pb^{-1} during the early stages, which declined to the level of 300 rads/pb^{-1} as the run continued. At the start of the 1992-93 Tevatron Collider run, the expected 25 pb^{-1} of delivered luminosity would lead to an integral dose of 12 krads, which is enough to have an impact on the device performance. Based on these numbers, we adopted an upper limit of 15 krad as a goal for the 1992-3 Tevatron Collider run.

In addition, various accelerator "accidents" can deposit large radiation doses in the SVX. These accidents range from abort kicker prefires (5 μsec time scale) to sparks in electrostatic separators (1 msec time scale, or 50 turns) to trips of correction elements (100 msec time scale). The Tevatron lattice contains two low-β insertions, at D0 and CDF. In the injection lattice, β^*=1.7 m., and β_{max}=100 m., and in the low-β lattice, 0.5 m. and 1200 m. Thus, oscillations induced anywhere in the ring can lead to losses at the low-β insertions, and the SVX in particular.

3 Protection System

Radiation backgrounds are monitored with two systems, located approximately 2.8 m from the interaction region in both the proton and antiproton directions, at a distance of 5 cm from the beam axis. Silicon diodes are used to measure the minimum ionizing particle rates and ionizing dose levels are measured with Tevatron Beam Loss Monitors (BLMs) [5]. Rate information is processed via 3 digital ratemeters with integration on 10 turn (5 kHz), 100 turn (500 Hz), and 10,000 turn (5 Hz)

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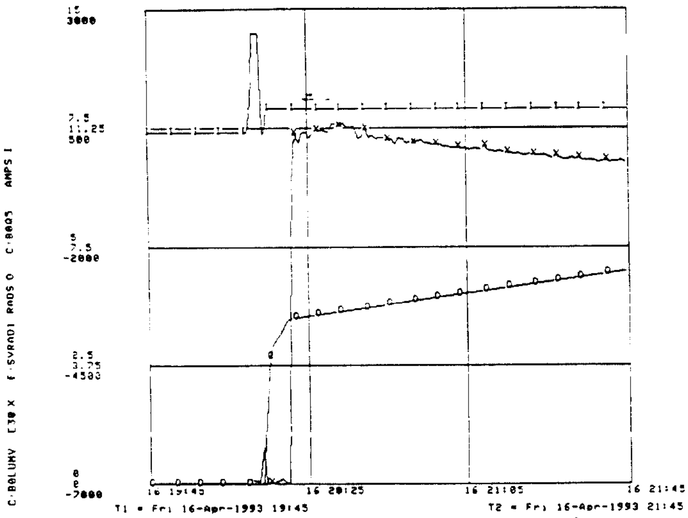

Figure 1: Integrated radiation (O), instantaneous luminosity (X), and low–β quad current (I) for time covering injection, ramp, squeeze, scrape, and stable colliding beam for a typical Tevatron store.

time scales, synchronous with the Tevatron beam clock [6]. Ionizing dose information is sampled every 10 turns (5 kHz) and compared to programmable alarm and abort thresholds. Abort thresholds are set at a dose rate of greater than 10 rads/sec during shot setup or 2 rads/sec during stable beam. The rate and dose information is loaded into circular buffers of 2048 samples which function as high resolution snapshots of loss patterns. In addition, the dose buffer is read into a companion processor which integrates the total exposure.

In addition to the rate and dose information which is available on a real–time basis, we also have an array of thermo-luminescent dosimeters (TLDs) installed at the same location as the diodes and BLMs. The TLDs are extracted at approximately monthly intervals and compared to the integral BLM record. We make use of the TLDs to give us the radial dependence of the radiation dose, since the innermost layer of the SVX detector is closer to the beam axis than the loss monitor systems.

4 Operational Experience

We work in units where the measured radial dependence has been used to extrapolate to the radius of the innermost SVX layer (3 cm), but we emphasize that this quoted exposure is at the monitor stations, 2.8 m upstream and downstream of the SVX. From the TLD measurements, we see that the radiation dose drops off with a radial dependence of $r^{-1.75}$.

Figure 1 shows the integrated radiation, instantaneous luminosity, and low–β quad current for a typical Tevatron store. During the beam injection and ramp from the injection energy of 150 GeV to 900 GeV, there is very little radiation integrated. The transition from the injection lattice to the low–β lattice is when the dose rate is the highest, averaging an integrated total of 4.5-7 rads during the transition (the store in question integrated a total of 6 rads). Following the transition, the beams are scraped to reduce beam halo, again giving a significant dose (in this case, approximately 3 rads). The last two thirds of the figure show the integration of radiation from the colliding beams.

The worst case situations seen thus far have been higher than the standard numbers above by an order of magnitude (50 rads during the low–β transition and 30 rads during scraping). Stores which fall into this category have been infrequent (on order of 1 every 3 months).

The time history, in Figure 2, shows some steep ascents during the initial stages of Tevatron commissioning, and then a steady climb related to the reliable delivery of luminosity. We can see that more than one third of the total dose to the SVX occurred in the first tenth of the integrated luminosity, followed by a break to a linear regime where the dose of approximately 300 rads/pb^{-1} is in remarkable agreement with measurements from the 1988-89 Collider run.

In terms of specific loss situations, we have found that most of the losses have occurred during situations where the Tevatron operating point was not well established (during the ramp from the injection energy of 150 GeV to 900 GeV, during the transition to low β). The most significant situation, which took place in a studies period before the installation of the SVX, delivered approximately 8 krads during an 8 hour time period. This situation was caused by the low–β system being at half field strength and shows the sensitivity of the Tevatron to perturbed lattices. Other significant loss situations also occurred when the Tevatron lattice was perturbed from the injection lattice.

The BLM system was a frequent cause of aborts during the early Tevatron commissioning. However, we discovered that almost all aborts from this system could be traced to situations where there were component failures in the Tevatron. In addition, other monitoring systems in the Tevatron showed the same losses, though perhaps not at the abort level. This system was a frequent cause of aborts because it was designed as the most sensitive measure of the losses in the Tevatron.

The operational experience here is that the accelerator startup was plagued by high losses and BLM aborts until the Tevatron operations crew learned to evade the abort system (and hence major losses into the SVX). The BLM system became a "limiting aperture" in the Tevatron lattice which needed to be understood and corrected.

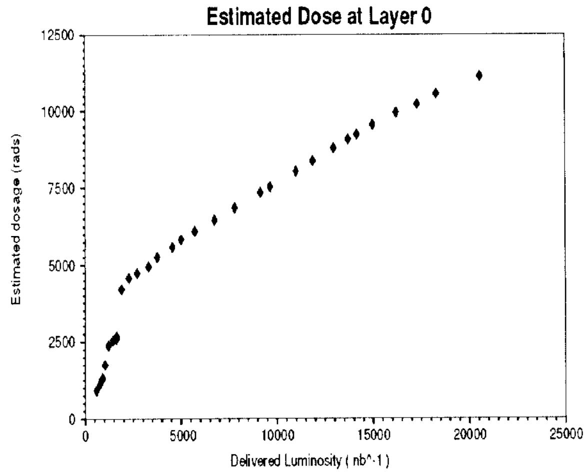

Figure 2: Extrapolated inner layer radiation dose as a function of delivered luminosity.

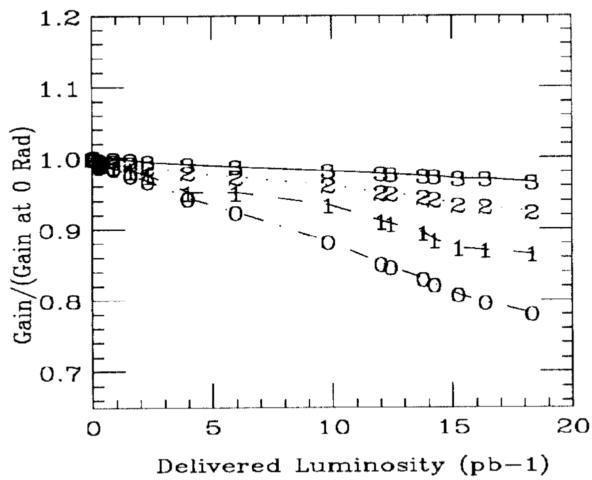

Figure 3: The *in situ* measured change in gain as a function of delivered luminosity, for the 4 layers of the SVX (0 is the inner most layer, 3 the outermost layer).

5 Total Damage Estimates

As displayed in Figure 2, the BLM and TLD data imply a total of approximately 12 krad delivered to the SVX inner layer with 18 pb^{-1} of delivered luminosity. In Figure 3, we show the average change in gain for the 4 layers of the SVX. The changes in gain show a similar radial dependence to what has been measured with the TLDs, though the overall change in gain is inconsistent at the factor of two level with the other measures. The total change in noise at the inner layer predicts a radiation dose of 13 krad at this point in time. Both the gain and noise have changed linearly with the delivered luminosity (except for the early commissioning period), which is indicative of damage caused by the flux of particles coming from the beam collisions and not from accidents.

6 Conclusions

We have designed and built a system to monitor the Tevatron losses in the vicinity of the CDF SVX and operated it through the 1992-3 Tevatron Collider run. We have received a total dose consistent with expectations from luminosity related causes, with a small addition due to Tevatron accidents. Significant accidents have only occurred in situations where the Tevatron lattice was perturbed and not at well understood operating points. We wish to emphasize that the total dose is small compared to what one might have expected at a hadron collider. We have demonstrated that it is possible to achieve relatively "lossless commissioning" and clean running conditions in the hadron collider environment.

Acknowledgements

We wish to thank the members of the Fermilab Accelerator Operations Group for assistance during the 1992-3 Tevatron Collider run and Kathy Graden and Dave Boehnlein of the Fermilab Radiation Physics Staff Group for help with the TLD measurements.

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