MEASUREMENTS OF THE LONGITUDINAL AND TRANSVERSE BEAM LOSS AT THE TEVATRON

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Abstract

Measurements of the transverse and longitudinal beam losses during a Tevatron store will be presented. The measurements utilize scintillation counters to monitor the nuclear interactions of the 1 TeV halo particles with a scraper that is located near the beam. If the particles are in time with the primary bunches, they are assumed to come from transverse perturbations inducing large betatron oscillations. Particles lost longitudinally drift around the ring due to synchrotron radiation and become asynchronous with respect to the bunches. A pulsed electron lens is then used to induce large betatron oscillations that extract these particles onto the scraper. The resulting nuclear interactions in the scraper are recorded by a gated scintillating counter system. The counting rates from the two channels provide an online measurement of the two types of beam loss. Known beam loss due to interactions at the IP and to nuclear collisions in the residual gas can be subtracted which then exposes the underlying losses from longitudinal and transverse instabilities.

OVERVIEW

When the Tevatron is in the colliding mode, the luminosity decreases over time due to the loss of particles from the beams or due to emittance blow up of the bunches[1]. For instance, the collision of protons and pbars removes particles and is the main source of pbar loss. Interaction of the beam particles with the residual gas in the vacuum chamber can both remove particles by nuclear collisions and scatter particles thru coulomb scattering, Intra beam scattering will increase both the longitudinal and transverse emittances and can cause particle loss from the bucket. And finally beam-beam interaction at the points where the bunches come near each other on their separate helices can cause losses. The instrumentation used to detect and monitor these beam losses is described below. Methods for monitoring the emittance increase are described elsewhere [2]

Current Monitoring

The total DC beam in the machine is monitored by a high precision current transformer, DCT, which in a typical store measures a total beam of about 1 E13 particles with a digitizing error of 1.25 E9 particles and is used to check the calibration of other instruments. There are 36 proton and 36 par bunches in the machine and their separate intensities are measured by resistive wall current monitor, SBD, described elsewhere in these proceedings [3]. The absolute calibration of the SBD is checked against the DCT.

Once the intensities of the proton and pbar beams are known as a function of time, they can be differentiated to give the particle loss per second. A plot showing the loss rate of p current in Store 2424 is shown as the solid curve in Fig. 1.

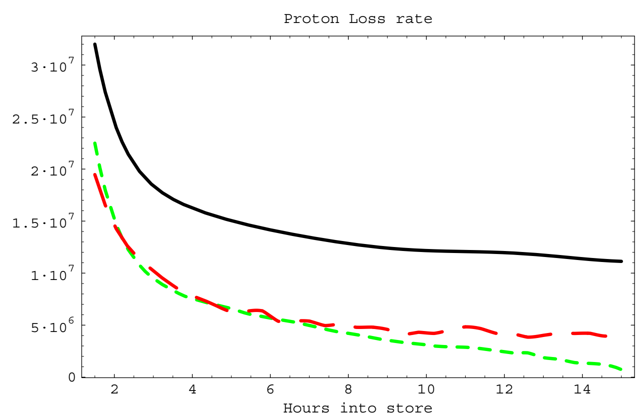

Fig. 1 Loss rate in protons/sec. vs. time in hours near the start of Store 2424. The solid curve is the total proton loss rate. The dotted curve is the loss rate after subtracting the losses due to luminosity, diffusion from the RF bucket, and collisions with the residual gas. The dashed curve is 25 times the E0LTOT counter rate.

Nuclear Interactions in the Vacuum Chamber Gas

The simplest loss to calculate is that due to nuclear interactions in the vacuum chamber. The measurement is made with a small emittance proton beam injected onto the central orbit and accelerated to 980 GeV/c. All loss mechanisms under these conditions are calculated to be small except for the nuclear interactions. The life time measured under these conditions is between 600 and 1000 hours and is a upper limit on the loss rate due to residual gas. The limited accuracy is a reflection of the limited time spent on runs of this type. In what follows we will use 600 hours.

Since the total cross section is known for the various elements, it is possible to relate gas concentration to lifetime. Table 1 gives this calculated relation between residual pressure (room temperature) and gas type for a fixed life time of 1000 hours using cross sections from Drozhdin [4] and making a small correction for coherent scattering at angles so small that they are not intercepted by the collimators. It is interesting to note that except for He there is little A dependence as the effect of Argon being monatomic is nearly cancelled by the cross section increase with A. The gas composition in the Tevatron can be measured in the warm regions, but is unknown inside the magnets which are at liquid He temperature. Assuming the gas is some mixture of the three heavy gasses, the 600 hour lifetime corresponds to pressure of $5\ 10^{-9}$ torr (room temperature equivalent).

Table 1

Gas	He	N_2	O_2	Ar
Pressure, Torr	$1.4\ 10^{-9}$	$3.19\ 10^{-10}$	$2.92\ 10^{-10}$	$3.17\ 10^{-10}$

The second effect of residual gas, which is proportional to Z^2, is to increase the emittance of the beam by Coulomb scattering. This effect is minimized by making lifetime measurements at 980 GeV/c.

Transverse Losses

Losses in the transverse direction (called transverse losses in this paper) arise from particle betatron amplitude increasing to the point that it exceeds the machine aperture. In order to remove beam halo, there is a complex system of scrapers [5] in the machine that scrape in both the vertical and horizontal direction. A scintillation counter, E0LTOT that observes nuclear interactions of protons with the innermost scraper has been installed. This scraper is positioned at the start of each store to be at the edge of the circulating beam, and thus any subsequent growth of the transverse size will be reflected in the interaction rate increasing as recorded by the scintillation counter. The counter is ungated and records the total rate of protons hitting the scraper. Most of the lost protons are in coincidence with the 36 bunches (see below) and thus this counter primarily monitors the transverse loss rate and it correlates well with the background observed in the CDF and D0 detectors. A similar arrangement for the pbars exists, but uses background counters at CDF that are gated to be sensitive to particles arriving from the pbar direction. Neither of these systems is an absolute monitor of the loss rate, and they are only roughly calibrated.

Longitudinal Losses

Losses in the longitudinal direction (losses from the RF bucket) can arise from intrabeam scattering and from noise on the RF voltage [6] which excites synchrotron oscillations. At the end of acceleration, the injected beam is well confined inside of a phase space ellipse of 4 eV-sec whereas the RF bucket area is about 11 eV-sec. As the time duration of the store increases, stochastic processes cause the bunch length to grow and finally some particles cross the separatrix. At 980 GeV/c, a free proton looses about 9.5 eV / turn and slowly spirals inward until it hits the collimator in about 1000 seconds. As it drifts inward, it also drifts around the ring and thus losses from the bucket generate a ring of charge in the machine whose total intensity is a function of the distance between the edge of the bucket and the nearest collimator. Conversely, the proton and pbar bunch structures consist of 36 bunches arranged in three groups of 12 equally spaced by 21 RF buckets and the three groups spaced by 140 buckets. These larger gaps are used for injection and extraction of the beam.

Early in the commissioning, it was found that a few E9 drifting protons could be stored in the machine in this manner. Since they are non synchronous, they were not handled properly by the abort system and a significant fraction would reach the SC dipoles and cause a quench. An electron lens system [7], TEL, is used to limit the accumulation of protons lost from the bucket. It is gated on in the abort gaps and causes large betatron oscillations to develop for any protons passing by. These protons in a few turns develop a large enough amplitude to be intercepted by the collimator and are detected by the E0LTOT Scintillation counter. A second output from this counter is gated in coincidence with the abort gaps passage and thus measures the intensity of the protons that are in the abort gaps.

A histogram of the time distribution of counts relative to a turn marker for the E0LTOT counter is shown in Fig. 2. The transverse losses in coincidence with the bunches are clearly seen, and in the middle of the abort gap one sees the effect of the TEL cleaning out protons. The 18.8 ns RF structure is seen because of the radial change due to the spiraling particles drifting in and out of phase with the RF voltage.

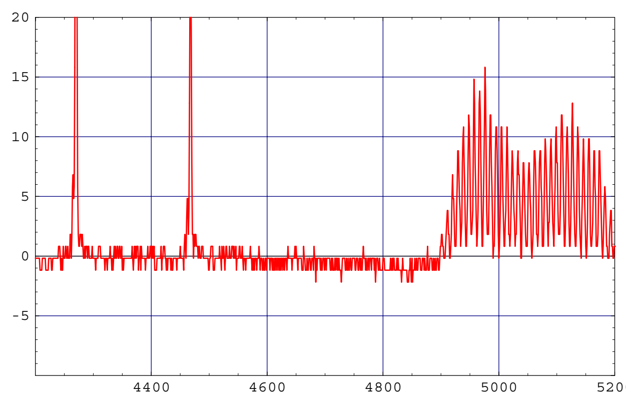

Figure 2. A histogram of the counts in the E0LTOT counter. The time bins are 2 ns and only a fraction of a turn is shown. To the left are two proton bunches and on the right are the counts caused by the TEL extracting protons that have drifted into the abort gap.

The counting rate in the abort gap can be calibrated so that it gives an online measurement of the bucket losses. The procedure is to measure the slope of the DCT output which is proportional to the total charge loss in the machine. The TEL is then switched off. This removes the mechanism by which protons lost from the bucket are removed from the machine. They are still lost from the bucket, but they continue to circulate and so are measured by the DCT. The change in slope of the DCT output then measures the RF bucket loss and can be used to calibrate the counter.

Results

Fig. 3 shows a graphical summary of these measurements on a single store, 2424. The luminosity loss is shown and calculated from the L measured at CDF and D0. The loss due to gas in the vacuum chamber is obtained using a 600 hour lifetime and should be considered an upper limit. The losses from the RF bucket are given by the E0LTOT counter gated on the abort gap and are very small at the beginning as the protons are very well contained in the bucket. As the run progresses the longitudinal emittance grows and protons start to diffuse out of the bucket. The three losses just mentioned do not add up to the total losses shown in Figure 1 as a dotted curve. The difference between this sum and the total losses represent transverse losses from all causes and as such they should be measured by the E0LTOT counter. The rate from this counter scaled by 25 is shown as the dashed curve in Fig 1. The agreement in shape of the two curves suggests that this interpretation is correct.

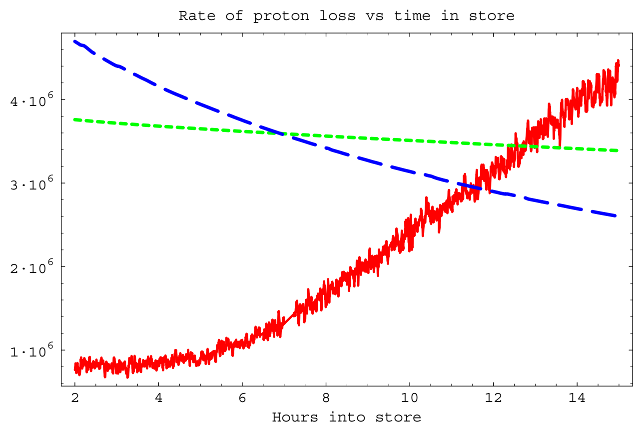

Figure 3. The proton loss rate in store 2424. The dotted curve is due to residual gas losses. The dashed curve is calculated from the measured luminosity at CDF and D0. The curve increasing to the right is obtained from the measured abort gap losses.

Although the accuracy of these measurements is not high, they do furnish on line information and guidance for each store and are also recorded in a data base for later detailed analysis. They provide a good monitor of the various loss mechanisms in the machine and have helped elucidate the physical process occurring in the machine.

The pbar behavior is interesting in contrast. The residual gas interactions and other loss mechanisms seem to be small. A loss plot for the pbars is shown in Fig. 4. The main loss is from the pbar-p interactions. There is a slight error in the absolute values used for some of the constants that result in the sum being greater than the total pbar loss rate. In any case, it is apparent that losses in the pbar bunches are primarily due to the luminosity. One method of increasing the luminosity is to increase the pbar bunch intensity, and so behavior similar to that observed in the proton case can be anticipated.

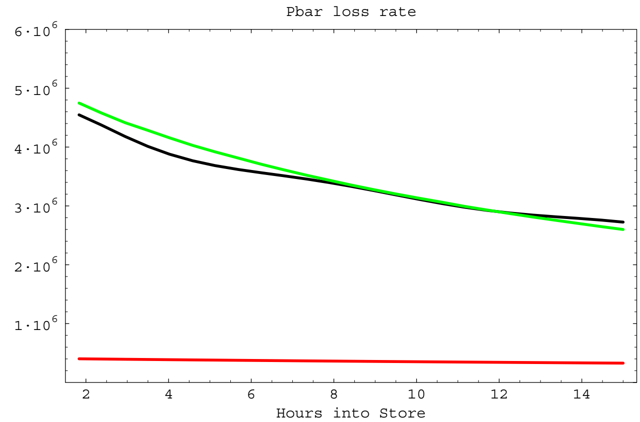

Figure 4. The top black curve is the total pbar loss rate. The top green/grey curve represents the loss due to pbar-p interactions, and the bottom curve is loss in the residual gas.

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