Luminosity Lifetime in the Tevatron Collider

D.A. Herrup, D. Finley, G. Jackson
*Fermi National Accelerator Laboratory**
P.O. Box 500
Batavia, Illinois 60510

Abstract

We have measured the luminosity lifetime of the Tevatron under a variety of conditions. We present results for the lifetimes and analyze them in terms of the contributions from various sources of emittance growth and intensity lifetimes. We have used these data to make improvements to the Tevatron which have resulted in longer luminosity lifetimes.

Introduction

During the initial (1987) Tevatron Collider run the luminosity lifetime (τ_l) averaged 8 hrs., about 25% of the design value. The principal cause of the short τ_l was traced to transverse emittance growth rates of up to 8π mm-mr/hr., which were an order of magnitude larger than the design values[1]. Before the 1988-1989 Collider run the principal causes of this emittance growth were found and fixed. In the 1988-1989 run τ_l has been much higher - 15 hrs. at the beginning of a store and increasing to 40 hrs. at the end of a long (30 hr.) store. We will present data that show that τ_l is controlled by three factors: the p and $\bar{p}$ intensity lifetimes (τ_p and $\tau_{\bar{p}}$) and the transverse emittance growth rates. We have identified several additional sources of transverse emittance growth and are taking steps to eliminate them.

The luminosity lifetimes for low-β stores from Aug. 1988 to Mar. 1989 are displayed in Fig. 1. Only stores which lasted longer than 12 hours are included, and the lifetime plotted is that for the 9^{th} hour to the end of the store. We do not include the first 9 hours of a store in any of the analysis. The beam intensity lifetimes during this period can be much smaller than their final values, and the measured transverse emittance can actually decrease. We attribute this to the effects of the ramp and the squeeze to low-β, in which the tunes and orbits of the Tevatron may not be perfectly controlled with the result that a significant number of particles may have large betatron amplitudes. These particles then leave the Tevatron in the first hours of a store, contributing to shorter beam lifetimes and decreasing emittances.

Data Sets

Depending upon the specific questions being asked we have used different data sets in the analysis. To measure τ_l we use $p\bar{p}$ stores. The luminosity is measured with a set of beam-beam counters on each side of the B0 collision point and recorded every two minutes. The p and $\bar{p}$ bunch intensities and bunch lengths are recorded every two minutes[2]. The transverse emittance in each plane is measured with a 'Flying Wire' system[3] every two hours and stored. To isolate specific contributions to τ_l we performed several 'proton-only' stores. These are treated as $p\bar{p}$ stores except that only p's are in the Tevatron. All data are recorded the same as for $p\bar{p}$ stores except for the Flying Wire data, which were recorded every 3 minutes.

All $p\bar{p}$ data are taken in the 'low-β' lattice. The low-β lattice has been designed to lower the β function at the B0 interaction point. This is accomplished by powering 4 quadrupoles circuits on each side of the B0 interaction region. Each proton-only store was divided into two sections, each lasting several hours. In the first section the lattice used is the injection lattice, and after several hours the lattice was changed to the low-β lattice.

*Operated by the Universities Research Association under contract with the U. S. Department of Energy

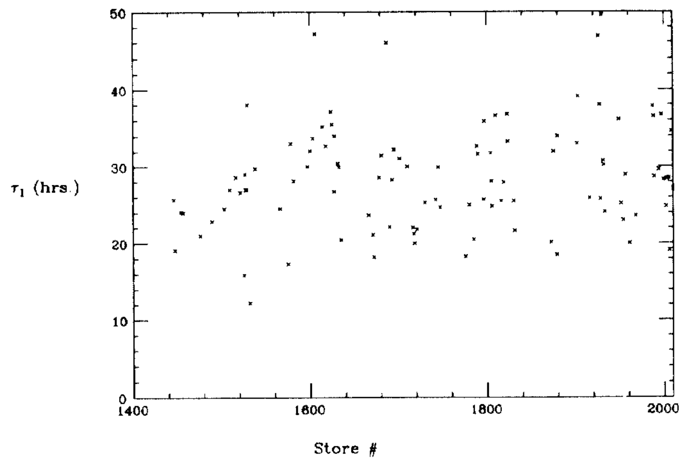

Figure 1: Luminosity lifetimes for Tevatron $p\bar{p}$ stores from Aug., 1988 to Mar. 1989.

Beam Intensity Lifetimes

Beam intensity lifetimes have been measured in both $p\bar{p}$ stores and p-only stores. Due to beam-beam effects the p beam lifetimes in the two types of stores need not be equal, nor must the p lifetime equal the $\bar{p}$ lifetime. In a p-only store done in Dec. 1988 we injected 6 proton bunches with intensities ranging from 8E9 to 8E10 p's/bunch. We measured the intensities over a 6 hour period. Table 1 contains the result. The lifetime is 180 hrs. and is independent of bunch intensity. The exponential fits to the intensity vs. time were excellent.

TABLE 1: Bunch intensities and intensity lifetimes during a p-only store.

INTENSITY	LIFETIME
77.5E9	191 hrs.
7.2E9	162 hrs.
13.4E9	201 hrs.
24.8E9	188 hrs.
38.6E9	168 hrs.
51.2E9	180 hrs.

At the ends of long (greater than 12 hrs.) $p\bar{p}$ stores we measure τ_p of 150 hrs. and $\tau_{\bar{p}}$ of 140 hrs. These are averages over all stores from Aug. 1988 - Mar. 1989 and include large variations in both p and $\bar{p}$ intensities and emittances, and thus beam-beam tune shift. Furthermore there are variations in the Tevatron base tune during this period. All of these can effect the intensity lifetimes. We consider the difference between the lifetime measured in p-only stores and $p\bar{p}$ stores

CH2669-0/89/0000-1824$01.00©1989 IEEE

to be real, but believe that it reflects changes in Tevatron operation conditions. For all calculations we will use the values measured during $p\bar{p}$ stores.

Emittance Growth Rates

During $p\bar{p}$ stores the transverse emittances are measured with the 'Flying Wire' system. The data from these measurements are bunch-by-bunch vertical beam profiles at one point in the Tevatron and horizontal profiles at two points. The vertical emittances are calculated directly from the vertical Flying Wire profiles. The two horizontal Flying Wires are located in positions with different dispersions and can be used to measure both the emittances and $(\Delta p/p)$ of the bunches, and from this the longitudinal emittances. However, the horizontal dispersion is a complication in measuring emittances, and we will assume that the vertical and horizontal emittance growth rates are identical and use the vertical growth rate for both. This is justified because of the large coupling in the Tevatron.

Averaged over runs from Aug. to March the vertical p emittance growth rate after 9 hours was 0.48π mm-mr/hr., and the vertical $\bar{p}$ emittance growth rate was 0.41π mm-mr/hr. The growth rates ($\dot{\epsilon}$) were calculated from linear fits to the emittance vs. time data plots. The longitudinal growth rate is 0.06 ev-sec/hr. In Fig. 2 we plot the time development of the luminosity and emittances for the p's and $\bar{p}$'s during an entire store. We believe that the shorter lifetimes at the beginning of the store are due to the effects of the ramp and squeeze, and during the last several hours of this store we performed experiments which required the injection of noise into the beams.

Given a linear emittance growth rate we can calculate an 'equivalent lifetime' given by $\epsilon_0/\dot{\epsilon}$ where ϵ_0 is the initial emittance, ie. the emittance after 9 hours of storage and $\dot{\epsilon}$ the emittance growth rate. The p emittances ranged from 28-35π mm-mr in each plane, and the $\bar{p}$ emittances from 10-14π mm-mr. This yields p emittance lifetimes of 58-72 hrs. and $\bar{p}$ lifetimes of 24-34 hrs. Errors on the emittance measurements are much smaller than the error from averaging over many stores with different conditions.

Assuming no contribution from longitudinal emittance, $L \alpha N_p N_{\bar{p}}/\epsilon$ which implies the relationship $1/\tau_l = 1/\tau_p + 1/\tau_{\bar{p}} + 1/\tau_\epsilon$. If we assume that the horizontal and vertical emittance growth rates and emittances are equal (this is true because the Tevatron is a coupled synchrotron) and use the measured lifetimes (140 and 150 hrs. for p and $\bar{p}$ beam lifetimes and the emittance lifetimes above), within the large uncertainties due to averaging many stores the relationship holds. This also implies that longitudinal emittance growth does not contribute significantly to the observed luminosity lifetime

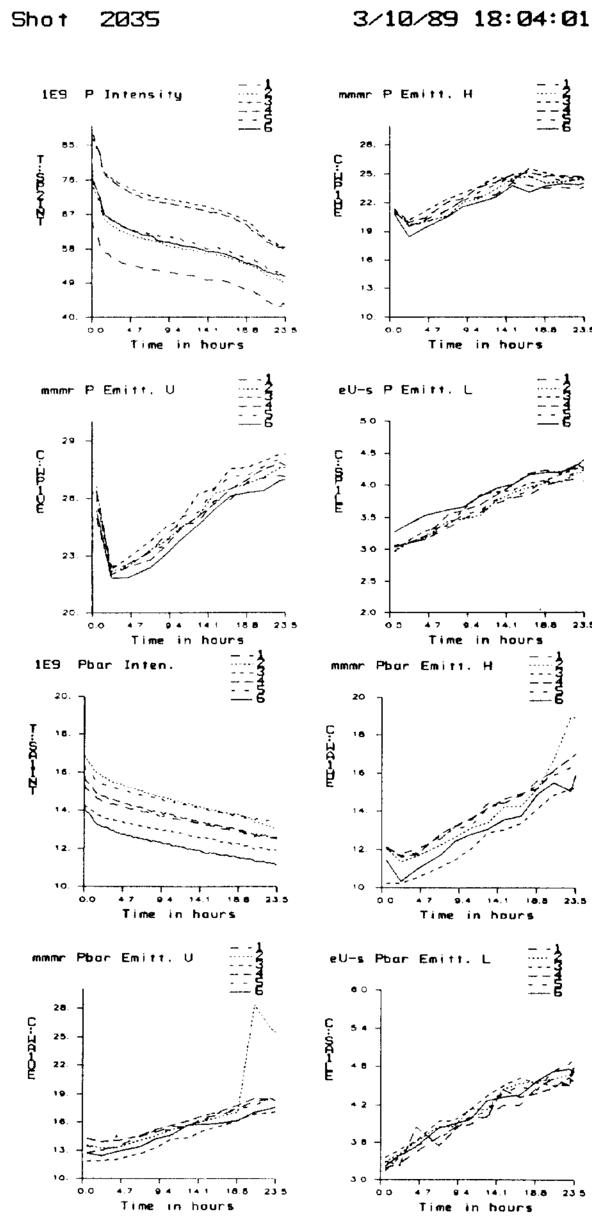

Figure 2: P (upper) and $\bar{p}$ (lower) bunch intensities and emittances during a store.

Sources of Emittance Growth

Several experiments have been done to attempt to identify additional sources of transverse emittance growth. In the proton only store mentioned above, data were first taken in the injection lattice for 6 hours and then for six hours in the low-β lattice. During the entire period Flying Wire data were taken every 3 minutes. The data are summarized in Table 2. The longitudinal emittance is derived from the two Flying Wire measurements. What we see quite clearly is that the emittance growth rates in the low-β lattice are almost twice as large as in the injection lattice. We also note that the emittance growth rates are independent of bunch intensity (as were the beam lifetimes). The emittance growth rates are also much larger than those measured in $p\bar{p}$ stores. This is not understood.

The low-β lattice is such that the β function changes rapidly in the region of the 4 quadrupoles and reaches its maximum value in the lattice here. Any noise near the betatron frequency (approximately 19 kHz.) in the power supplies for these quadrupoles will have a large effect. We have actually observed noise in those supplies, and recently installed a set of filters. We have not yet performed the measurements to see what their effect on the emittance growth rates is. We note, however, that the the quadrupoles are only one possible source. The low-β lattice has distortions all around the ring, and a noise source which is located at a small-β region for the injection lattice may be at a high-β region for the low-β lattice.

TABLE 2: Bunch intensities and emittance growth rates during a p-only store. Emittances are in π mm-mr and emittance growth rates in π mm-mr/hr.

INTENSITY	$\dot{\epsilon}_h^{inj}$	$\dot{\epsilon}_h^{Low-\beta}$	$\dot{\epsilon}_v^{inj}$	$\dot{\epsilon}_v^{Low-\beta}$
77.5E9	0.29	0.79	0.58	1.24
7.2E9	0.0	0.15	0.61	1.00
13.4E9	0.0	0.72	0.44	0.83
24.8E9	0.0	0.81	0.46	1.07
38.6E9	0.0	0.63	0.63	0.89
51.2E9	0.10	0.65	0.55	1.07

Another possible source of emittance growth is from the CDF toroids. One toroid is placed on either side of the B0 interaction region. Each toroid is 7.9 m. in diameter and has a 0.9 m. diameter hole through which the Tevatron beam pipe passes. Two of the low-β quads project into this hole. The two toroids are powered in series but with opposite polarities. In measurements made in Mar., 1989 the power supply was shown to have noise components at the betatron frequency. Powering the toroids also caused an increase in the signals on the Schottky detectors[4]. Fig. 3 shows the Schottky spectra at 150 GeV. with the toroids on and off. There is almost a factor of 2 difference in the power measured in the single betatron sideband which corresponds to the 27^{th} harmonic of 720 Hz. We have not directly correlated this with emittance growth, but in the past large Schottky signals have accompanied transverse emittance growth[1]. It is clear that the power supplies must be filtered better or the beam must be shielded better from the toroid magnetic field.

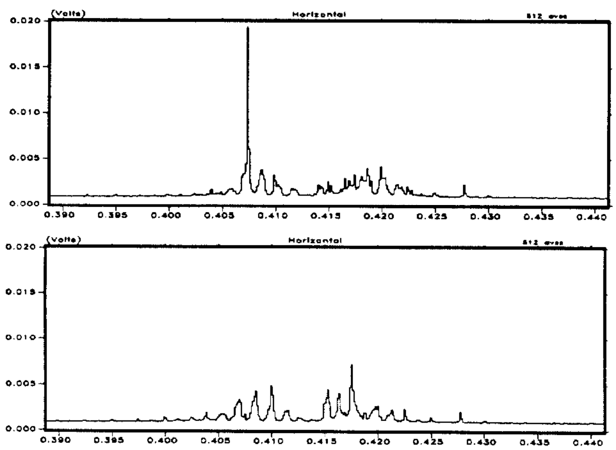

Figure 3: Signals on Schottky detectors with the CDF Toroid on (upper) and off (lower).

At 150 GeV we observe 60 Hz. noise on the Schottky detectors. It does not appear at 900 GeV or at low-β. However, we do not know the source of this noise, and until we determine it and eliminate it the 60 Hz. noise must be considered a possible cause of emittance growth. The power supplies for the individual correcting dipoles have also been observed to have voltage pulses with components near the betatron frequency. We plan on studying this further and taking steps to eliminate this noise.

Conclusions

The luminosity lifetime of the Tevatron collider can be understood in terms of beam lifetimes and transverse emittance growth. The beam intensity lifetimes are well understood. The transverse emittance growth rates have been calculated. The limiting value is 0.2π mm-mr/hr., determined from intra-beam scattering[6]. The rates we measure are 0.48π mm-m4/hr for p's and 0.41π mm-mr/hr for $\bar{p}$'s. Both the p-only store in which the individual bunch intensities varied by a factor of 10 and the $p\bar{p}$ stores, in which the $\bar{p}$ intensities are a factor of 2-10 less than the p intensities, show that we do not yet observe intra-beam scattering effects. It is also clear that the low-β lattice itself contributes to transverse emittance growth, and that the CDF toroids may also. These larger effects must be eliminated before we can observe clear signs of intra-beam scattering. We are continuing to study these problems.

References

1. G.P. Jackson et. al., "Luminosity Lifetime in the Tevatron", Proceedings of the 1^{st} European Accelerator Conference, Rome, 1988.

2. C. Moore et. al., "Single-Bunch Intensity Monitoring System Using an Improved Wall Current Monitor", paper T-19 presented at the conference.

3. J. Gannon et. al., "Flying Wires at Fermilab", paper C4 presented at this conference.

4. D. Martin et. al., "A Schottky Receiver for Non-Perturbative Tune Monitoring", paper T-9 presented at this conference.

5. G.P. Jackson, "Tune Spectra in the Tevatron Collider", paper L-28 presented at this conference.

6. D.A. Finley, "Calculation of Integrated Luminosity for Beams Stored in the Tevatron Collider", paper X-16 presented at this conference.