IMPROVING THE TEVATRON COLLISION HELIX*

R. S. Moore, Y. Alexahin, J. Johnstone, T. Sen

Fermi National Accelerator Laboratory, Batavia, IL 60510, U.S.A.

Abstract

In the Tevatron, protons and antiprotons circulate in a single beam pipe, so electrostatic separators are used to create helical orbits that keep the two beams separated except at the two interaction points (IP). Increasing the separation outside of the IPs is desirable in order to decrease long range beam-beam effects during high energy physics (HEP) stores. We can increase separation by running the separators at higher gradients or by installing additional separators. We are pursuing both strategies in parallel. Here, we describe Tevatron operation with higher separator gradients and with new separators installed during a recent shutdown. We also describe possible future installations.

INTRODUCTION

The Tevatron provides collisions of 980 GeV protons and antiprotons (36 bunches each) at the two IPs, denoted B0 and D0. The bunches are grouped in three symmetric trains of 12 bunches each. The bunches are separated by 396 ns (21 buckets) within the trains. Gaps between the trains are used for injecting antiprotons and for ramping up the extraction kickers when aborting beam. Typical beam parameters for recent high-energy physics stores are given in Table 1. Additional information on the Fermilab accelerator complex can be found in [1].

Since the two beams circulate within a single beam pipe in the Tevatron, 24 electrostatic separators are used to separate them around the ring, except the IPs where head-on collisions are desired for HEP stores. The electrostatic separators comprise two 100 inch stainless steel, parallel plate electrodes separated by a 5 cm gap through which the beams pass. Each electrode is connected to its own power supply. The maximum design separator gradient for HEP operation was 40 kV/cm, but we have been testing the use of the higher gradients to provide additional beam separation.

For colliding beam operation, the separators are grouped to form closed three-bumps in each plane (horizontal and vertical) in the so-called short (B0→D0) and long (D0→B0) arcs between the two IPs. This arrangement allows control of beam-crossing offsets and angles in each plane at the two IPs independently. Figure 1 shows the separation between the two beams at all parasitic crossing points around the Tevatron. The separation s is defined as:

$$s = \sqrt{(d_x/\sigma_x)^2 + (d_y/\sigma_y)^2}, \quad (1)$$

where d_x, d_y are the horizontal, vertical distances between the protons and antiprotons, and σ_x, σ_y are the horizontal, vertical beam size assuming 95% transverse emittances of 20 π mm mrad. The first parasitic crossings, located 59 m away from the IPs, have the smallest separations, so they are the dominant contributors to long-range beam-beam effects during HEP stores. Improving the collision helix entails increasing the beam separation to help mitigate detrimental long-range beam-beam effects [2-4].

Table 1: Typical beam parameters at the beginning of recent Tevatron HEP stores.

Proton Intensity / Bunch	230-240 E9
Proton Transverse Emittance (95%)	16-18 π mm mrad
Proton Bunch Length	1.58-1.68 ns
Pbar Intensity / Bunch	25-75 E9
Pbar Transverse Emittance (95%)	9-15 π mm mrad
Pbar Bunch Length	1.52-1.62 ns

ADDITIONAL SEPARATORS

Employing additional separators is one way to provide additional separation between the protons and antiprotons. However, available warm space at appropriate betatron phase advances is rather limited, and some spare separators must be retained for use in the event of a failure. We have developed a proposal to install five additional separators at four locations: two vertical separators at D17 (long arc), one horizontal at A17 (long arc), as well as one horizontal and one vertical at B48 (short arc). These additional separators help increase separation in the specified plane only for the arc in which they are placed. The new separators combine with the old to form closed horizontal or vertical four-bumps within each arc. Consequently, the new separators do not need to be installed all at once in order to gain increased separation. As an example, the D17 separators were installed during the fall 2004 shutdown, and they have been used for HEP stores since then.

Figure 1 demonstrates how the beam separation benefits from the additional separators. The separations at

*Work supported by the U.S. Department of Energy under contract No. DE-AC02-76CH03000.

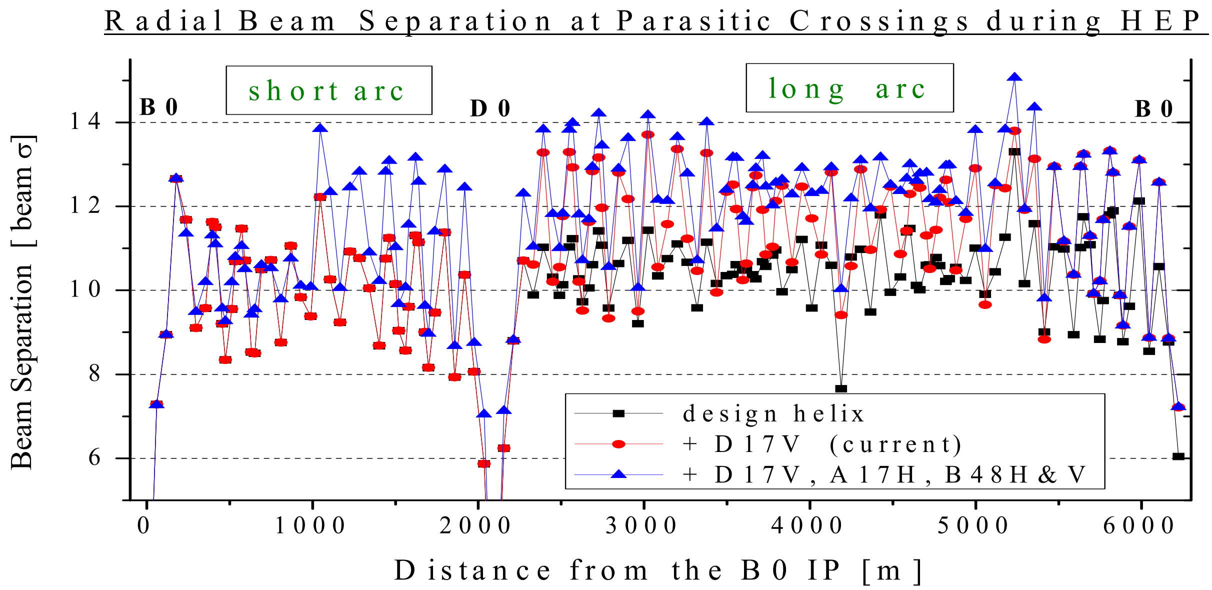

Figure 1: Separation between protons and antiprotons at all parasitic crossings for the design separator configuration (black squares), with the addition of vertical separators at the D17 location (red circles), and with all proposed additional separators (blue triangles).

the first parasitic crossings can be increased by approximately 1σ (≈15%), while the *average* separation in the arcs increases by a similar amount. In addition, the additional separators allow greater flexibility in controlling the beam angles as they enter the IPs.

HIGHER SEPARATOR GRADIENTS

Running the separators at higher gradients is the most direct way to increase beam-beam separation. Higher separator voltages can increase the amplitude of the orbit helix, and, hence, the separation between the protons and antiprotons. The separator voltages must be scaled to maintain the 3-bump (or 4-bump) closure conditions in the arcs. It turns out that the separation scales as the voltage of the IP separators, i.e., scaling the helix such that the IP separator voltages increase by 10% results in a 10% increase of the separation.

Although the power supplies are limited to provide a 60 kV/cm maximum gradient, the breakdown (spark) rate of the separators determines the practical maximum of the gradient. When a spark occurs between the two plates of a separator during an HEP store, the resulting orbit deviation can drive beam into collimators (typically placed < 1 mm from the beam tails), causing a quench of nearby superconducting magnets and loss of the store. The breakdown rate rises exponentially with gradient; we would likely tolerate at most 1 spark per month among all the separators during HEP stores. This practical maximum should be determined operationally by trying higher separator voltages and retreating if the spark rate becomes intolerable.

We have recently run a number of HEP stores with collision helix sizes (90%, 100%, and 110% of nominal) in order to investigate the impact on operations. As expected, the tune changes caused by feeddown effects for the different orbits were small (<0.0003), so we did not need to compensate the working point of the machine. Studying many stores allowed us to sample over a range of conditions, e.g., luminosities, beam intensities and emittances. For example, Figure 2 shows the initial luminosity lifetime, obtained from an exponential decay fit from the CDF experiment's luminosity counters, as a function of the initial luminosity and the so-called effective emittance of the beams. The effective emittance is defined as:

$$\varepsilon_{eff} = \frac{10^{-5} * f * B * N_P * N_A * (6\beta\gamma)}{4\pi\beta^* L} H\left(\sigma_z \big/ \beta^*\right), \quad (2)$$

where f is the revolution frequency, B = 36 is the number of bunches, N_P is the number of protons per bunch, N_A is the number of antiproton per bunch, β^* = 35 cm is the design beta function at the IPs, L is the luminosity, $(6\beta\gamma)$ is the kinematic factor for calculating 95% emittance, and H is the hourglass factor depending upon the bunch lengths σ_z and β^*. Effective emittance is a measure of the particle intensities per unit luminosity; the lower the effective emittance, the more luminosity per beam particle. The correlations are obvious: luminosity lifetime decreases for larger luminosities and smaller effective emittances. The range of effective emittances stems primarily from the number of antiproton bunches originating from the Accumulator and the Recycler; antiprotons from the Recycler typically have transverse emittances 5-8 π mm mrad smaller than those from the Accumulator. The brighter Recycler antiprotons lead to Tevatron stores with smaller effective emittance stores.

In order to see any effect of the helix size on the luminosity lifetime, we looked at lifetime in different

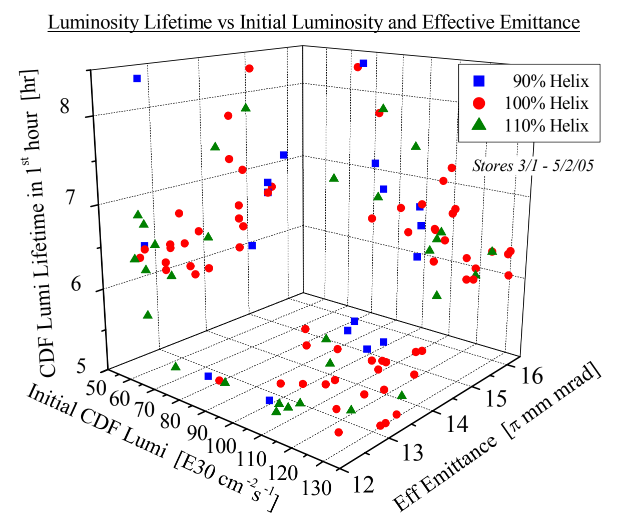

Figure 2: Luminosity lifetime in the first hour for the CDF experiment as a function of the initial luminosity and effective emittance for many HEP stores with different collision helix sizes; only the projections onto the three planes are shown. The luminosity lifetime was obtained from a fit to an exponential decay. The statistical uncertainties of the luminosity lifetime values are all less than 0.1 hr.

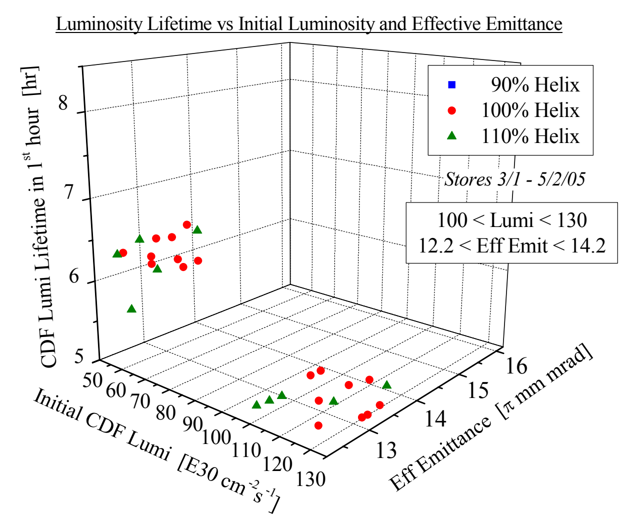

Figure 3: Luminosity lifetime in the first hour for the CDF experiment as a function for a specific set of initial luminosities and effective emittances; only projections onto two planes are shown. No 90% helix stores are in this population of stores.

ranges of initial luminosity and effective emittance. The benefit of 110% versus 100% helix is not obvious, but it seems clear that the 90% helix results in lower luminosity lifetimes. Figure 3 shows the initial luminosity lifetimes for the stores with the highest initial luminosities and the smallest effective emittances. The approximate 1 hour spread in lifetimes for a given a helix size makes it difficult to identify the smaller (few tenths of an hour) expected improvements from the 110% helix.

The benefits of a larger helix size are more obvious when looking at the so-called non-luminous loss rate of the antiprotons. The non-luminous loss rate represents how quickly particles are lost from sources other than being "burned-up" in proton-antiproton collisions at the IPs. Figure 4 demonstrates how the non-luminous antiproton losses decrease as the helix size increases. The antiproton non-luminous loss rate early in a store is dominated by burn-up in collisions (≈4 %/hr), and it also depends on the antiproton emittances [4]. The non-luminous lifetime of proton bunches do not depend on the helix size.

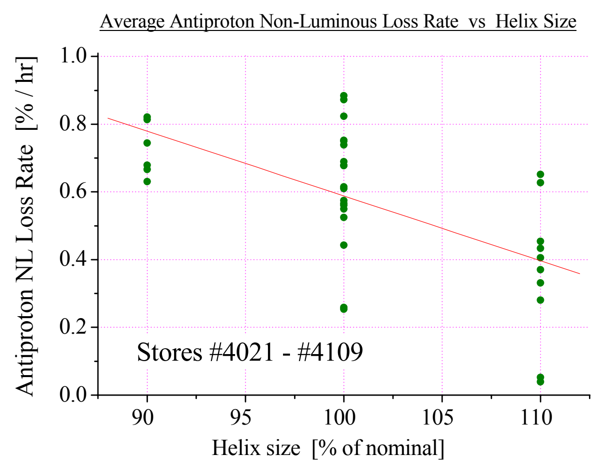

Figure 4: Average non-luminous loss rate of the 36 antiproton bunches in the first hour of many HEP stores for various collision helix sizes. The red line is the result of a linear fit

CONCLUSION

In order to decrease long-range beam-beam effects in the Tevatron during HEP stores, we are attempting to increase the separation between the protons and antiprotons at the parasitic crossing points. Additional electrostatic separators are being installed into the arcs during long maintenance shutdown periods to gain up to 15% more separation. In addition, running the separators at higher voltages also increases the separations around the ring. We do observe improved non-luminous lifetimes for antiprotons with 10% higher separator voltages. The ultimate separation increase via higher voltages depends upon separator spark rates which increases exponentially with voltage across the gap.

REFERENCES

[1] D. McGinnis, these Proceedings (MOAA005).
[2] Y. Alexahin, these Proceedings (MOPA006).
[3] A. Valishev *et al.*, these Proceedings (TPAT083).
[4] V. Shiltsev *et al.*, these Proceedings (TPAP032).