STORAGE RING FOR ENHANCED ANTIPROTON PRODUCTION AT FERMILAB

G. Jackson and G.W. Foster
Fermi National Accelerator Laboratory[1], MS 345, P.O.Box 500, Batavia, IL 60510 USA

ABSTRACT

There is interest in the high energy physics community to upgrade the luminosity of the Tevatron Collider to a value greater than $1x10^{33}$ cm^{-2} sec^{-1} per detector. The only feasible means to increase the luminosity by this factor of 10 over the design goal of the Main Injector project is to increase the antiproton production rate by almost the same factor. Using excess space in the Main Injector tunnel it is possible to build an additional storage ring whose purpose is to provide the flexibility necessary to produce and store the increased number of antiprotons. In this paper the motivation for this ring is discussed. The details of the scheme to recycle the antiprotons left over at the end of each Tevatron Collider store is also reviewed.

I. MOTIVATION

Given that Tevatron Collider luminosity is proportional to the initial antiproton intensity, which in turn depends on the rate at which antiprotons are produced (stacked), it is essential to understand how to generate high stacking rates to support the Tevatron33 [2] luminosity goal of $1x10^{33}$ cm^{-2} s^{-1}. The antiproton stacking rate achievable with the Main Ring at this time [3] at small Accumulator stack sizes is $7x10^{10}$/hr. The design stacking rate for the Main Injector [4] in the absence of the Recycler is $15x10^{10}$/hr. The Tevatron33 upgrade has a stacking rate of $100x10^{10}$/hr for the design goal.

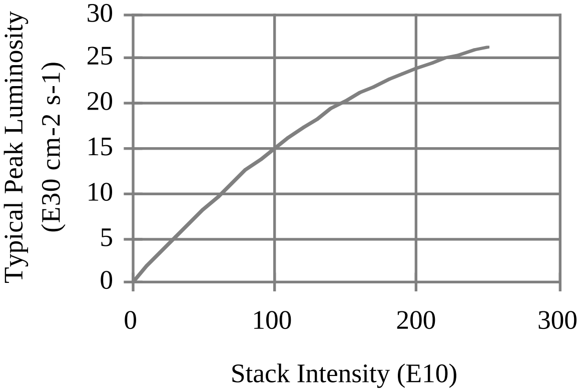

Figure 1 Observed luminosity vs. Accumulator stack size curve for the present Tevatron collider run. Instead of growing linearly, the luminosity saturates due to the increased transverse emittance of the antiproton stack.

The dependence of initial Tevatron luminosity on the antiproton intensity (stack size) in the Accumulator 8 GeV storage ring saturates as the beam current increases (see figure 1). This effect comes from the fact that the transverse emittance of the Accumulator antiproton stack increases linearly with increased current. At higher stack sizes the beam size exceeds the aperture of the Main Ring, thus reducing the antiproton intensity in the Tevatron Collider, and hence the initial luminosity.

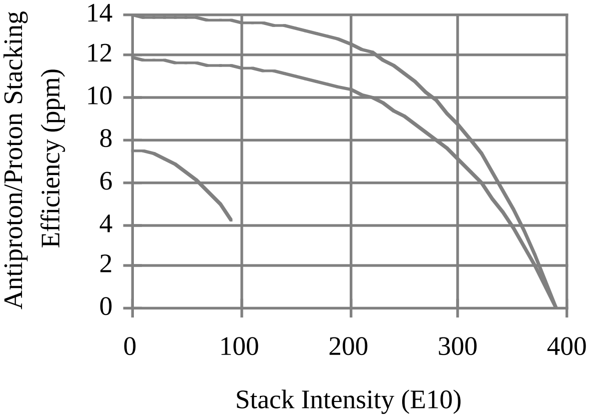

Figure 2 Stacking efficiency as a function of the antiproton stack size in the Accumulator. The lowest curve was measured during the 1988-9 collider run. The middle curve is the expected stacking profile given upgrades of some stochastic cooling systems. Finally, the top curve is the prediction of the stacking rate planned for the Main Injector.

As seen in figure 2, the other repercussion of large stack sizes is a reduced stacking efficiency (defined as the number of antiprotons produced for every proton delivered to the production target). To achieve the Tevatron33 luminosity goal a total stack size of $800x10^{10}$ antiprotons is required. Given that the stacking rate vanishes well before this level, an additional storage ring capable of holding more antiprotons is needed.

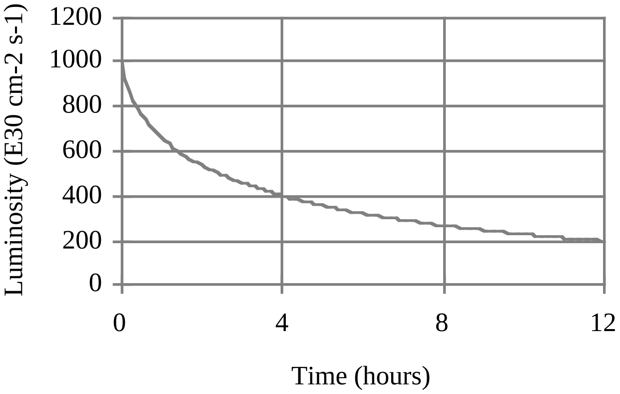

Figure 3: Expected evolution of the luminosity in the Tevatron Collider given the typical Tevatron33 initial luminosity. Note that the useful luminosity occurs in the first 4 hours.

One of the shortcomings of the present Tevatron Collider facility is the fact that the antiprotons are dumped at the end of each store. Given that the luminosity lifetime is quite short at high luminosity due to high particle collision rates and intrabeam scattering induced emittance growth, the required stacking rate could be dramatically reduced if the antiprotons could be recycled after each store. Figure 3 contains the results of a simulation of the anticipated luminosity evolution at Tevatron33 luminosities. By the time that 4 hours have passed, the luminosity has dropped to a point where another store is desired. As can be seen from figure 4, 80% of the antiprotons are still in the Tevatron at that point. Assuming even pessimistic deceleration and recapture efficiencies, the required stacking rate can be reduced by more than a factor of two.

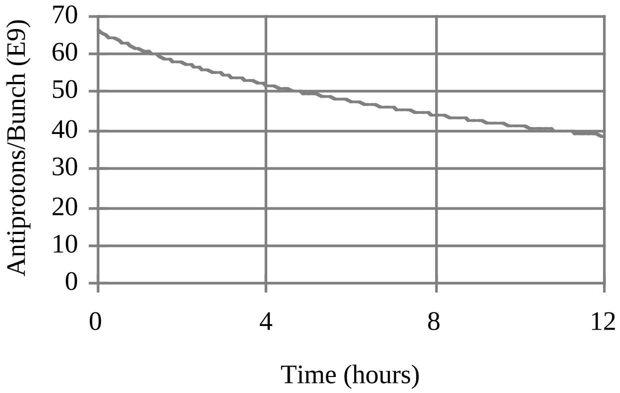

Figure 4: Evolution of the antiproton bunch intensity in the Tevatron during the store assumed in figure 3.

At present the Accumulator is used to store antiprotons. Unfortunately, the antiproton stack is lost on average once per week due to equipment failure, electrical outages, or human error. If the storage ring used to preserve the high intensity stacks had a higher reliability, the average luminosity would increase substantially.

II. ANTIPROTON STORAGE RING

In the last year a number of options have been studied for increasing the number of antiprotons available to the Tevatron Collider. A second storage ring at a kinetic energy of 8 GeV in the Main Injector tunnel was found to provide for the storage, recycling, and reliability criteria outlined above. Because of the added desires of low cost and fast magnet production, permanent magnets [5] were chosen for the entire 3.3 km ring circumference.

A. Lattice

A number of lattices based on the Main Injector design were considered. After weighing the relative merits of separated and combined function, a combined function lattice based on 4 m long gradient sector magnets is presently favored. With a dipole field of 1.5 kG and a 3.5 kG/m quadrupoles field, the standard cell length of 34 m is dominated by empty beam pipe. Straight sections contain 1 m long quadrupoles which have a gradient of 30 kG/m. A sketch of the magnet placement in this lattice is displayed in figure 5, showing the bellows which provide the bend between otherwise straight sections of beam pipe. All magnets are straight, since the sagitta is relatively small. Table 1 contains the parameters for a first pass of such a combined function lattice.

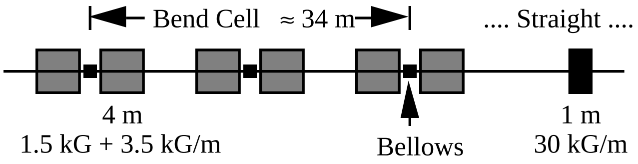

Figure 5: Sketch of the relative magnet placement and lengths in the lattice favored at present.

Table 1: Summary of preliminary lattice parameters for the combined function lattice.

Parameter	Value
Ring Circumference (m)	3319.414
Arc Cell Maximum Beta Function (m)	56.1
Arc Cell Minimum Beta Function (m)	9.75
Maximum Dispersion (m)	2.23
e Cooling Insert Max. Horz. Beta (m)	210
e Cooling Insert Max. Vert. Beta (m)	542
Beta Function in e Cooling Insert (m)	200
Horizontal Tune	25.45
Vertical Tune	25.45
Horizontal Chromaticity	-34.7
Vertical Chromaticity	-36.3

B. Location

Because of the existing transfer lines and RF power amplifiers, the only space available in the tunnel at the same radius as the Main Injector was up on the ceiling. Because the weight of the magnets is approximately 200 lbs/ft, they can be hung from the ceiling using stands bolted into the concrete tunnel roof.

C. Temperature Compensation

Strontium Ferrite, the material to be used in the permanent magnets, has a field which varies with temperature. The magnitude of this dependence is -0.2%/°C. To determine if this level of field variation is a problem, the history of tunnel temperature variations in the Main Ring tunnel was studied. Figure 6 contains a summary of that data, in which the peak air temperature difference around the tunnel is plotted as a function of time. Given a calculated maximum allowable field variation of $1\mathrm{x}10^{-3}$, it is necessary to reduce either the temperature fluctuations in the Main Injector by an order of magnitude or stabilize the field in the magnets themselves.

To achieve this magnetic field stabilization, an iron/nickel alloy used as a flux shunt was suggested [6] and tested. Figure 7 contains the results of this test. The average temperature variation was reduced to approximately

9 ppm/°C. This level of temperature compensation removes all concerns about stability of the magnetic field in permanent magnets.

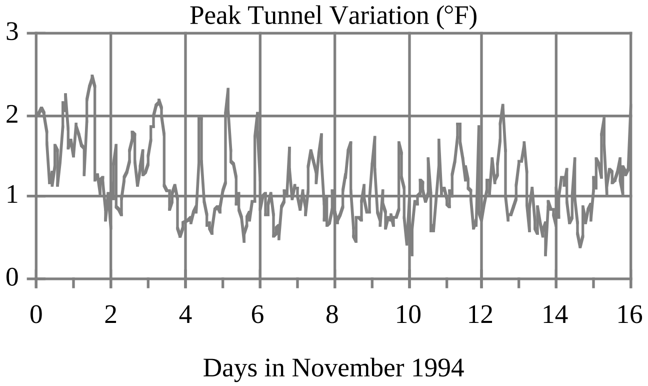

Figure 6: Peak air temperature variation around the Main Ring tunnel as a function of time.

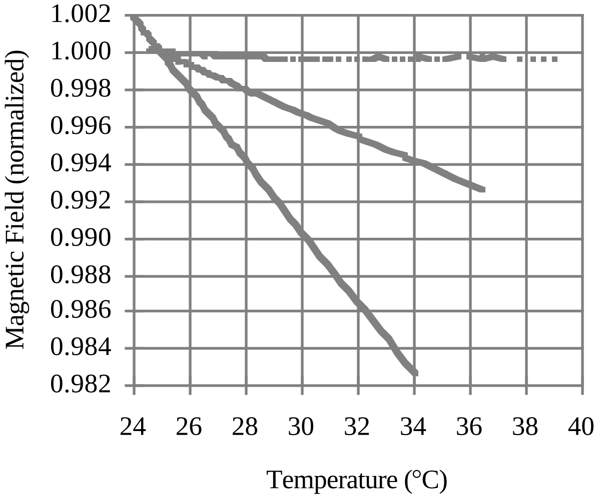

Figure 7: Variation of the magnetic field in a permanent magnet before (lower line) and after (horizontal line) temperature compensation with an iron/nickel alloy.

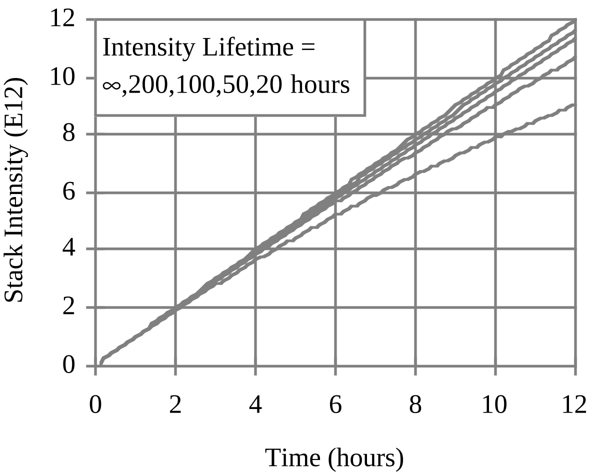

Figure 8: Calculation of the stack size vs. time as a function of the vacuum driven intensity lifetime of the antiprotons.

D. Vacuum

The need to store antiprotons with sufficient lifetime to efficiently produce and store the beam leads to a value for the maximum allowable average vacuum pressure in the storage ring. Because the Tevatron Collider luminosity drops to an insufficient level in about 4 hours, for normal operations an vacuum lifetime of 20-40 hours would be sufficient. Because failures sometimes occur in the proton injector chain or in the Tevatron, the ability to hold beam for extended periods of time is also desirable in this ring. As can be seen from figure 8, in that 4 hours the new antiproton stack is sufficiently large that the combination of recycled antiprotons and the new stack is sufficient to reach the Tevatron33 luminosity design goal.

E. Electron Cooling

The present plan for transverse and longitudinal phase space cooling required to stack and recycle antiprotons is to use electron cooling. Because the kinetic energy of the antiprotons is 8 GeV, the electron beam energy must be 4.5 MeV in order to match velocities. The design current for the electron beam at present is approximately 2 Amperes. The beam is generated and recovered by an electron gun and collector inside of a Pellatron [7] electrostatic accelerator.

One of the unique features of the proposed electron cooling system is that the direction of electron flow is reversible. With an injection scenario which calls for antiprotons transferred into the Tevatron first, the protons destined for the Collider can also be electron cooled. The most significant benefit of this procedure is the elimination of the process of coalescing [8]. By instead forming the collider bunches at 8 GeV in the presence of electron cooling, the longitudinal emittance of the proton and antiproton bunches will be significantly smaller than at present. The allows the Tevatron Collider to run with smaller β^* (and hence higher luminosity) and with crossing angles at the interaction points.

III. REFERENCES

[1] Operated by Universities Research Association Inc., under contract with the U.S. Department of Energy.

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[8] J. Dey, et al., "Improvements in Bunch Coalescing in the Fermilab Main Ring", this proceedings.