Fermilab Recycler Ring Electron Cooling

Run II Conceptual Design Report

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Revision 0.0

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1. Introduction

This report describes the conceptual design of the Run II medium energy electron cooling system in the Fermilab Recycler ring. The purpose of this electron cooling system is to augment the luminosity increase anticipated from the implementation of the Recycler stochastic cooling systems, which are part of the Fermilab Main Injector construction project.

The Recycler is a fixed 8 GeV kinetic energy antiproton storage ring. It is located in the Main Injector tunnel directly above the Main Injector beamline, near the ceiling. The cooling systems in the ring are necessary to compress the transverse and longitudinal phase space of beam injected from the Accumulator and Tevatron Collider, and to counteract longitudinal emittance growth expected from intrabeam scattering. Since electron cooling is a more powerful means of implementing antiproton phase space cooling, improvements in Accumulator antiproton stacking rate and Tevatron Collider luminosity are anticipated.

1.1 Role in the Fermilab III Program

The Tevatron Collider provides the highest energy collisions in the world. To fully exploit this unique tool, Fermilab is committed to a program of accelerator upgrades for the purpose of increasing the Collider luminosity. Over the past 8 years the luminosity has been increased from a typical peak of $1.6x10^{30}$ $cm^{-2}sec^{-1}$ in 1989 to over $2x10^{31}$ $cm^{-2}sec^{-1}$ during 1995. Note that the original design peak luminosity of the Tevatron Collider was $1.0x10^{30}$ $cm^{-2}sec^{-1}$.

The Main Injector will supply a larger flux of protons for antiproton production, more intense proton bunches for use in the Collider, and a higher efficiency acceleration of antiprotons. The role of the Recycler ring is to provide more antiprotons for the Tevatron, which proportionally increases the luminosity. This is accomplished by acting as a high reliability post-Accumulator and receptacle for recycled antiprotons from the previous Collider store. Prior to the development of the Recycler ring, the peak luminosity goal of the Fermi III upgrade program was $8x10^{31}$ cm^{-2} sec^{-1}. With the construction of the Recycler ring, a typical peak luminosity of $2x10^{32}$ cm^{-2} sec^{-1} is expected. This factor of 2-3 increase in luminosity comes from the availability of more antiprotons at Tevatron injection. The Reycler is also the foundation of future accelerator upgrades which can generate another order of magnitude luminosity increase up to an ultimate goal of greater than $1x10^{33}$ $cm^{-2}sec^{-1}$.

Figure 1.1 displays the history of the typical peak luminosity as a function of time since 1989, which shows an exponential growth with a doubling time of 1.5 years. With the addition of the Recycler ring and its commissioning along with the Main Injector, the Tevatron Collider will be able to remain on this exponential slope. The first open point represents the initial typical peak luminosity goal of the Main Injector project with the addition of the Recycler ring. The second open point, at a luminosity of $4x10^{32}$ $cm^{-2}sec^{-1}$ shows the performance goal after implementation of electron cooling in the Recycler. Though with luminosity leveling the maxium luminosity will never exceed the $2x10^{32}$ $cm^{-2}sec^{-1}$ level without electron cooling, for consistency this scenario is

Should note that with lum leveling $\int L$ is higher, even though L isn't.

placed on the plot assuming the absence of luminosity leveling. It should be possible, with further accelerator upgrades, to achieve a luminosity of 1×10^{33} $cm^{-2}sec^{-1}$, which is the highest luminosity open point in figure 1.1.

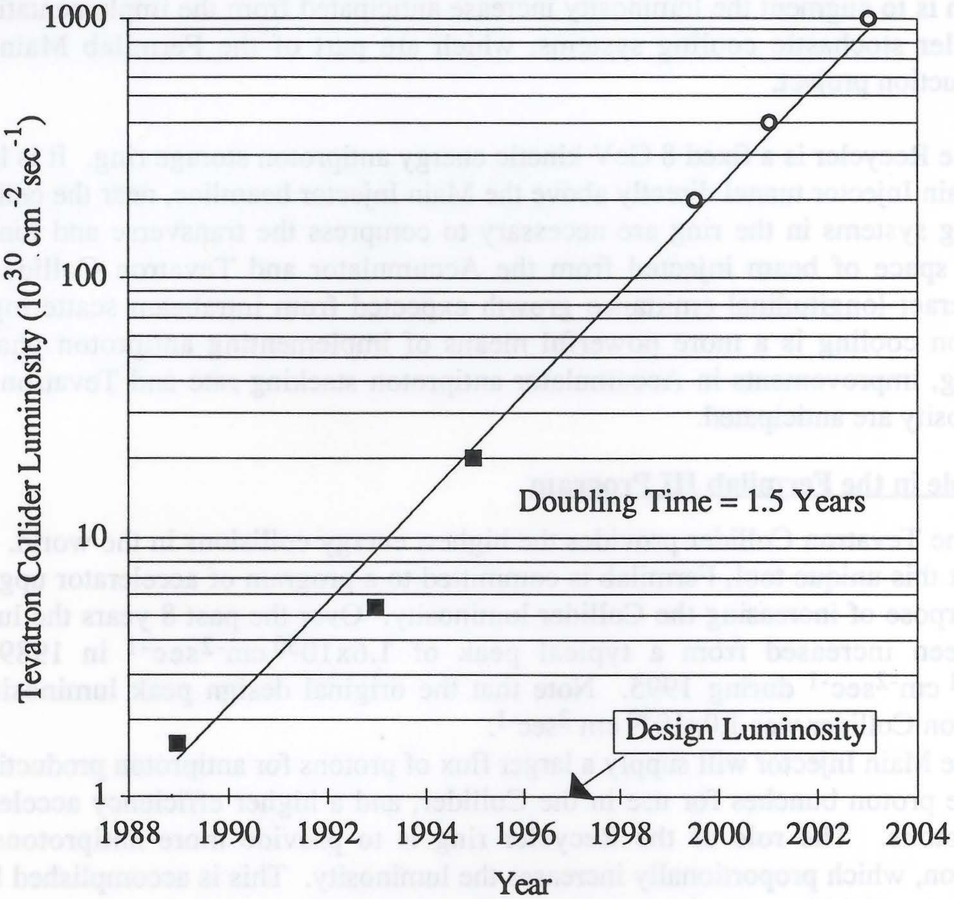

Figure 1.1: Tevatron Collider luminosity as a function of time. The filled circles are measured "best typical" peak luminosities, the line is an exponential fit to the data, and the open points represent goals for the future.

1.2. Performance Goals

The goal of the electron cooling upgrade to the Recycler ring is to double the rate at which integrated luminosity is provided to the high energy physics detectors. In other words, the goal is to double the average luminosity of the Tevatron Collider. But the detector upgrades for Run II only allow the detectors to operate with a peak luminosity of $2 \times 10^{32} cm^{-2}sec^{-1}$, which is already the reference scenario made possible by the Main Injector project (including the Recycler). With the development of luminosity leveling scenarios, it is now possible to roughly double the ratio between average luminosity and peak luminosity, making a doubling of the average luminosity consistent with the Run II incarnations of the detectors.

In order to double the average luminosity, the total antiproton intensity in the Tevatron Collider must also double. In the limit of negligible losses, where the dominant mechanism for consumption of antiprotons is the luminosity generating collisions at the interaction points, this luminosity increase requires a doubling of the antiproton stacking rate and improvements in the speed and efficiency of antiproton transfers.

Electron cooling in the Recycler allows one to perform the transfers between the Accumulator and Recycler much more often. This reduces the maximum stack size in the Accumulator, allowing tor Accumulator stack-tail stochastic cooling parameter optimizations that transport beam at a greater rate into the core.

1.3. Prerequisite Accelerator Complex Configuration

There are three upgrades beyond the standard Run II configuration of the accelerator complex (including both the Main Injector and Recycler) which must be accomplished before or during installation of electron cooling in order to achieve the increased average luminosity goals discussed above. The scale of these upgrades seems sufficiently modest compared to the electron cooling effort itself that there is reason to believe them to be within the manpower and funding scope of Fermilab.

The first of these three upgrades is the construction of a dedicated antiproton transfer line between the Accumulator and Recycler, presently named the AP5 line. Though at present a number of possible beamline geometries are being studied, they all make it possible to decrease the time between transfers from the Accumulator to the Recycler from once every two hours to once every 10 seconds. Not only does this allow the Accumulator stack-tail stochastic cooling systems to be reoptimized to accomodate the higher stacking rates, but it also relieves the Main Injector from its time consuming duties of acting as an 8 GeV transfer line.

The second upgrade is an increase in the stacking rate through the Accumulator from 20 mA/hr to 40 mA/hr. This improvement may be accomplished by increases in proton intensity on the target, cooling system enhancements, and greater acceptance in the AP2 line, Debuncher, and Accumulator.

The third upgrade is the implementation of luminosity leveling, without which it is doubtful that the two high energy physics detectors CDF and D0 will be able to use the average increased event rates. It is anticipated that the dominant effort necessary to implement luminosity leveling is software development. A control system program must be written which controls the curents in the low beta quadrupoles around both detectors, as well as the tunes and chromaticities and closed orbit of the Tevatron.

1.4. Organization of this Report

This report is organized into four chapters. Chapter 1 is the introduction. Chapter 2 is the summary of the accelerator physics issues concerning the Recycler ring electron cooling system. A major emphasis of this chapter is to describe the accelerator complex performance improvement expected from this cooling upgrade. Chapter 3 contains detailed descriptions of the various implementation options of electron cooling. The technical design of each option, as well as the relative pro's and con's of the various approaches, are detailed. Chapter 4 summarizes the civil construction required to implement electron cooling.