I. Introduction

High energy physics is a branch of science that is concerned with the constituents of matter and their interactions. The particle accelerator is a tool that is used to help the high energy physicist probe the structure of matter. An accelerator provides a high energy beam of particles that can be used to unlock short-lived subatomic particles. For a number of years, the method of choice used by accelerator laboratories was to direct the beam of particles onto a stationary, or "fixed" target. In the 1970's a new method of creating the collisions was developed, colliding a beam with its antimatter counterpart in the same accelerator. By colliding beams of particles head-on, the center of mass energy of the collisions was doubled.

The first generation of colliders accelerated electrons and positrons. It wasn't until the early 1980's that CERN (The European particle accelerator laboratory Conseil Européan pour la Recherche Nucléaire, or "European Organization for Nuclear Research") first collided protons with antiprotons. Since the proton is much more massive than the electron, higher energy collisions could be achieved (although electron-positron collisions have the advantage of being much "cleaner"). The SPS accelerator at CERN was used as their first collider. The center of mass energy of the collisions was initially 540 GeV (270 GeV on 270 GeV), then was later increased to 630 GeV (315 GeV on 315 GeV). With the switch to colliding beams, the SPS became the highest energy accelerator, surpassing Fermilab's Main Ring which was then a 400 GeV fixed target machine. CERN wouldn't possess the highest energy accelerator for very long, installation work for the Tevatron was being completed back at Fermilab.

The Tevatron began operation as an 800 GeV fixed target machine in 1984, but the eventual goal was to use it as a proton-antiproton collider. Building on the CERN innovations and experiences, Fermilab began construction of its own antiproton source. The first colliding beams in the Tevatron were established late in 1985 during a study period following a Fixed Target Run. The Antiproton Source completed commissioning and the first Collider Run began in late 1986. With a center of mass energy that grew from 1.80 TeV (900 GeV on 900 GeV) to 1.96 TeV (980 GeV on 980 GeV), the worlds highest energy accelerator was again found at Fermilab. CERN has since built and operated the LEP (Large Electron Positron) accelerator and has finished its successor, the LHC (Large Hadron Collider). The LHC, a proton-proton collider with an eventual center of mass energy of 14.0 TeV (7.0 TeV on 7.0 TeV), has ended the Tevatron's 20 year reign as the worlds most powerful accelerator.

Luminosity is a measure of the rate of collisions at an experiment. Through a series of improvements to Fermilab's accelerators, there has been a steady increase in the Tevatron's luminosity since 1986. During the 1988-89 Collider Run, the design luminosity of $1.0 \times 10^{30} cm^{-2} sec^{-1}$ was achieved. Since that time the luminosity has increased by a factor of nearly 300, surpassing $3.0 \times 10^{32} cm^{-2} sec^{-1}$.

The largest bottleneck in a proton-antiproton collider is the time required to accumulate an adequate number of antiprotons. The process is inherently inefficient, typically for every 10^5 protons striking a target, only about 2 antiprotons are captured and stored. Considerable time and money has been spent improving the accumulation rate. Between the first Collider Run and Collider Run 1b, the peak stacking rate improved by an order of magnitude. Between Run 1b and Run II, there has been another factor of 3 increase in the peak stacking rate (and a factor of 5 increase in the <u>average</u> stacking rate with the use of the Recycler). Despite the improvements, it still takes hours to build up a suitable stack to use for a colliding beams store. The performance of the Antiproton Source and Recycler greatly affects the quality and duration of stores in the Tevatron.

The FNAL Antiproton Source is comprised of a target station, two rings called the Debuncher and Accumulator and the transport lines between those rings and the Main Injector. The following sequence of events is repeated to accumulate enough antiprotons for a proton-antiproton colliding beams store.

- Every 2.2 seconds or so, a "slip-stacked" single batch of protons with an intensity of 8×10^{12} or more is accelerated to 120 GeV in the Main Injector. The Main Injector cycle is usually shared with NuMI.
- At Main Injector flattop, the 82 or so bunches contained within the batch are rotated 90° in longitudinal phase space. The rotated bunches are extracted from the Main Injector and travel down the P1, P2 and AP-1 lines.

- Quadrupoles at the end of AP-1 focus the beam to a very small spot as it enters the Target Vault. The beam strikes the Inconel production target in the Target Vault and produces a shower of secondary particles
- The resulting cone of secondary particles is focused and rendered parallel by means of a lithium lens. The bunch structure of the beam coming off of the target is the same as that of the primary proton beam.
- A pulsed dipole magnet bends all negatively-charged particles that have a kinetic energy of approximately 8 GeV into the AP2 line. Most of the other particles are absorbed within a beam dump.
- Particles that survive the journey down the AP2 line are injected into the Debuncher, where the momentum spread of the 8 GeV antiprotons is reduced through bunch rotation and adiabatic debunching. Both betatron (transverse) stochastic cooling and momentum (longitudinal) cooling is applied to reduce the beam size and momentum spread.
- Just before the next pulse arrives from the target, the antiprotons are extracted from the Debuncher and injected into the Accumulator via the D to A line. Successive pulses of antiprotons are stacked into the Accumulator 'core' by means of RF deceleration and stochastic momentum cooling. The antiprotons in the core are maintained there by betatron and momentum stochastic cooling systems.
- Periodically, enough antiprotons have been accumulated to initiate a transfer via the Main Injector to the Recycler. Groups of 4 bunches of antiprotons are unstacked from the densest portion of the stack known as the core. The pbar bunches are extracted from the Accumulator, and transported to the Main Injector via the AP3, AP1, P2 and P1 lines. After a small energy adjustment in the Main Injector, the antiprotons are transferred to the Recycler.