Return to Fermilab's Chain of Accelerators (movie clip)

Fermilab's Chain of Accelerators

Accelerator Details: the Antiproton Source

Return to Accelerator Details Main Page

Why use antiprotons?

A collider has an enormous advantage in energy over a fixed target machine (see relativity)

To build a proton-proton collider requires two separate sets of magnets (or complicated 2 in 1 magnets) in the same tunnel. This is expensive.

Since protons and antiprotons have equal and opposite electric charge, they will travel in opposite directions through the magnets. So an antiproton-proton collider can be built with **one ring** of magnets instead of **two**.

At collision energies up to about 3 TeV, the production rate for some processes is higher for antiprotons colliding with protons than in head on collisions of two proton beams. At higher collision energies, such as the 14 TeV that will be available with CERN's LHC, this advantage disappears and an antiproton-proton collision is expected to exhibit the same behavior as a proton-proton collision.

The disadvantage of antiproton-proton collisions is that one has to design and build an antiproton source, a difficult and expensive undertaking.

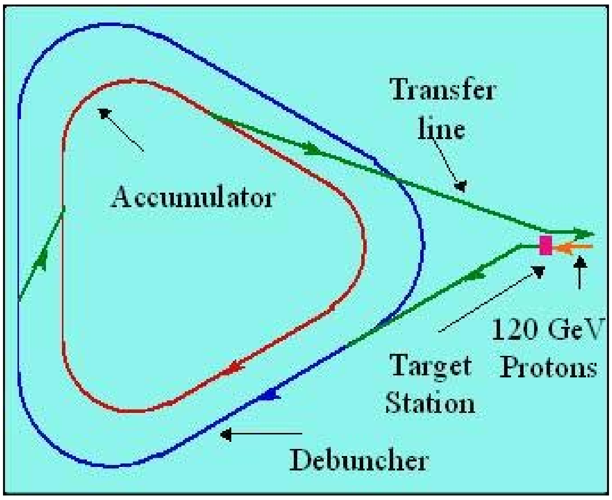
The Anti-Proton Source consists of three major components:

The **Target Station**

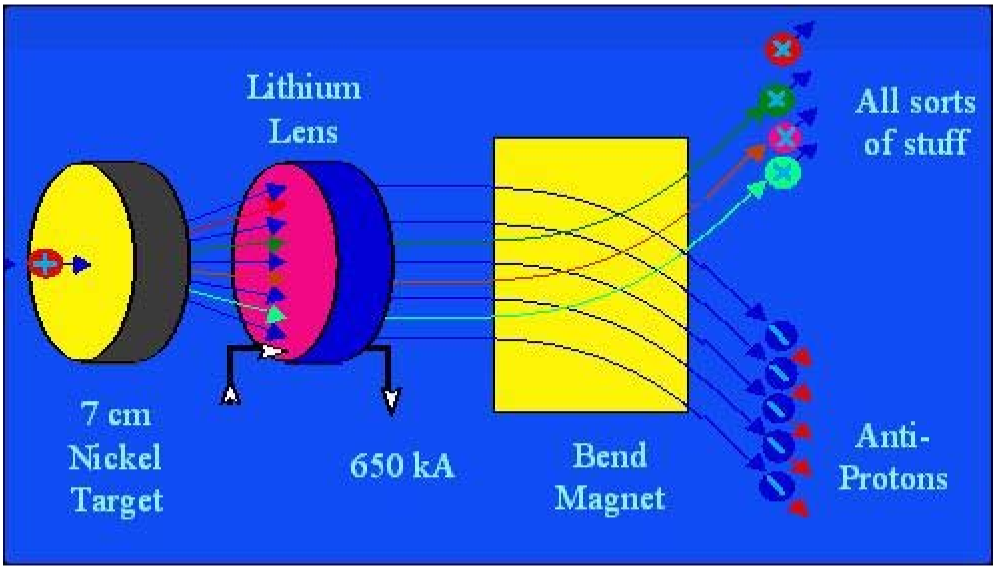
The **Debuncher**, an 8 GeV synchrotron

The **Accumulator**, an 8 GeV synchrotron

The key to accumulating a large number of antiprotons is **Stochastic Cooling**



The Target Station



A beam of 120 GeV protons from the Main Injector is smashed on to a Nickel Target every 1.5 sec. In the collisions many particles are created. (remember $E=mc^2$). For every 1 million protons that hit the target, only about twenty 8 GeV pbars survive to make it into the Accumulator.

The pbars come off the target at many different angles. They are focused into a beam line
with a Lithium lens. The beam after the Lithium lens contains many different particles besides antiprotons. Many of these particles are filtered away by sending the beam through a pulsed magnet which acts as a charge-mass spectrometer.

← **Debuncher** **Accumulator** →

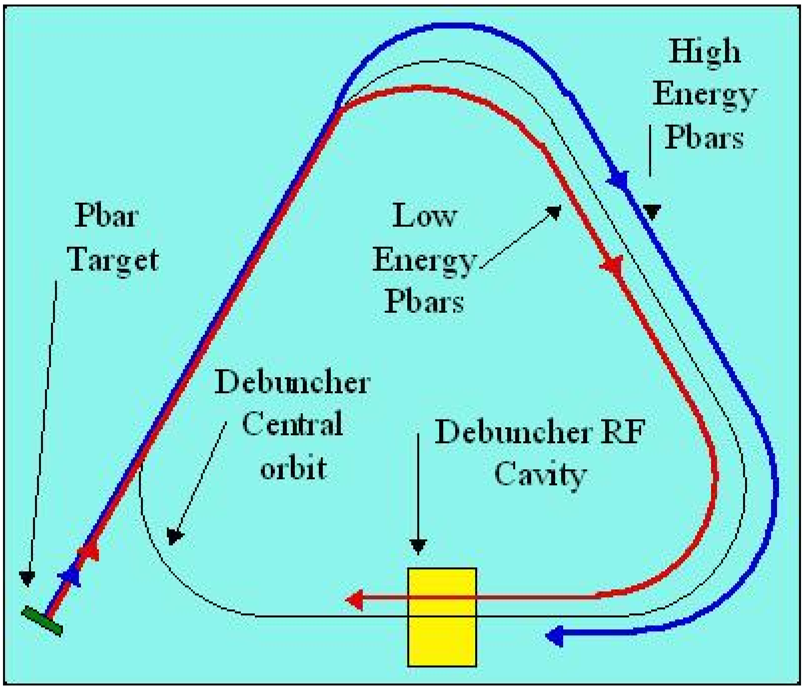
← **Debuncher** **Accumulator** →

The beam line coming down from the top brings antiprotons from the target station to the Accumulator and sends them back from the Accumulator to the Main Injector

The Debuncher

The 120 GeV protons that arrive at the target station are **bunched** because RF is used to
accelerate the beam in the Main Injector. Because the protons arriving on the target are bunched, the antiprotons [***sometimes called "pbars"***] coming off the target will also be bunched. Because of the details of the collision process the antiprotons coming off the target will have a very large spread in energy. This large spread in energy of the pbars will be difficult for downstream accelerators to accept.

The Debuncher accelerator is used to exchange the large energy spread and narrow time
spread into a narrow energy spread and large time spread.

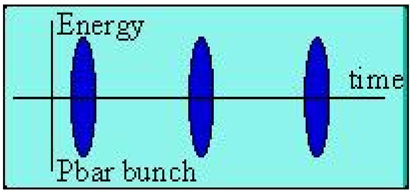


[see relativity for the equations]

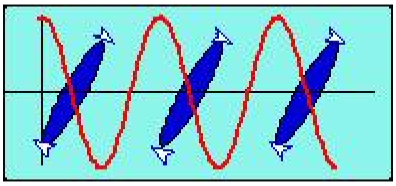
The antiprotons have velocity very close to the velocity of light independent of their energy. The antiprotons with more energy have more mass so they travel on the outside of the Debuncher ring. The lower energy (lighter) ones will travel on the inside of the ring. Thus the lower energy antiprotonss arrive at the RF cavity before the higher energy ones because of the difference in path lengths around the accelerator.

The low energy antiprotons will see a different phase of the RF than the high energy ones. This different RF phase will cause the low energy particles to be accelerated and the high
energy particles to be decelerated. As this process happens over and over, eventually the energy spread will be reduced. The energy spread has been traded for a large time spread. The debunching process takes about 100 milliseconds.

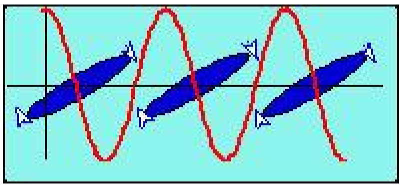
Antiprotons right after the target



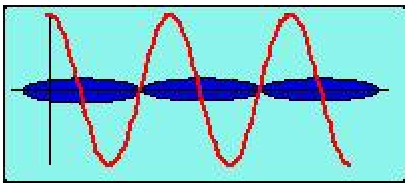
Antiprotons arriving at the RF cavity



Antiprotons after many turns through the RF cavity



Antiprotons at the end of debunching



The Main Injector ramp rate is limited to once every 1.5 seconds. Therefore, the debunched
beam can "hang around" in the Debuncher for almost 1.5 seconds before it needs to be transfered to the Accumulator and make room for a new batch of bunched antiprotons.

This extra time is used to “cool” the pbars.

The Accumulator

The purpose of the Accumulator, as its name implies, is to accumulate antiprotons. This is accomplished by momentum stacking successive pulses of antiprotons from the Debuncher over several hours or days. Both RF and stochastic cooling systems are used in the momentum stacking process. The RF decelerates the recently injected pulses of antiprotons from the injection energy to the edge of the "stack tail." The stack tail momentum cooling system sweeps the beam deposited by the RF away from the edge of the tail and decelerates it towards the dense portion of the stack, known as the core.

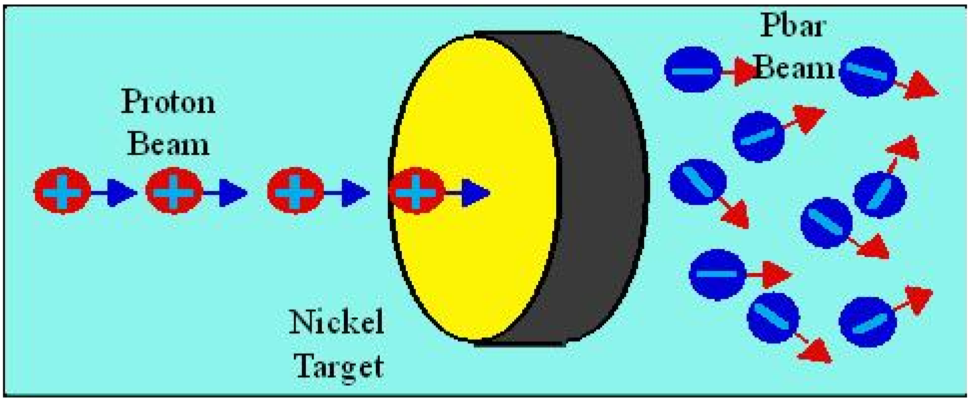
Additional cooling systems keep the antiprotons in the core at the desired momentum and minimize the transverse beam size.

The Accumulator "ring" resembles a triangle with flattened corners. The lattice (arrangment of bending and focusing magnets) has designed to accomodate the requirements of the different stochastic cooling systems. The Accumulator must be capable of storing an antiproton beam over many hours.

Stochastic Cooling

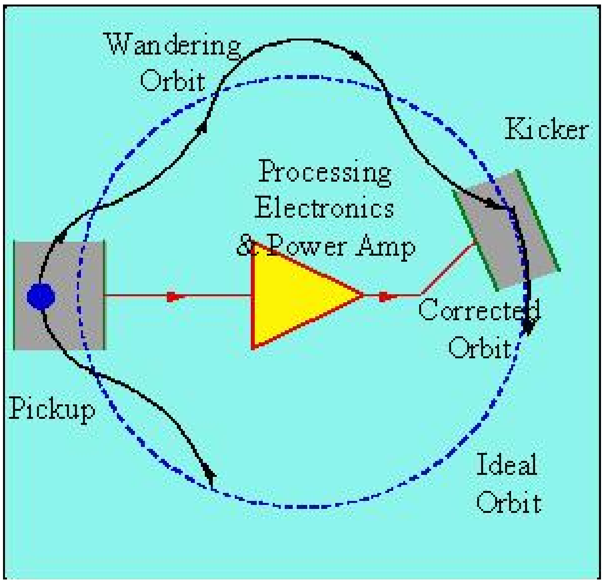
The antiprotons leave the target at a wide range of energies, positions and angles. This randomness is equivalent to temperature so we say that the beam coming off the target is "hot." This "hot" beam will have a difficult time fitting into a beam pipe of reasonable dimensions. Also, this hot beam is very diffuse and not very "bright". Bright beams are needed in the collider in order to increase the probability that a rare particle might be created.

Stochastic cooling is a technique that is used to remove the randomness of the "hot" beam on a particle by particle basis. Simone van der Meer won the Nobel prize for its invention.



Stochastic Cooling systems are used in both the Debuncher and the Accumulator.

Stochastic cooling uses feedback. A pickup electrode measures an "error" signal for a given particle. This "error" signal could be that particle's position or energy. The pickup signal can be extremely small, on the order of 2 trillionths of a Watt.



Many of the pickups are cooled to liquid Nitrogen tempertures (-320°F) to reduce the effect of thermal noise. In the future, the temperature of some of the pickups will be reduced to liquid Helium temperatures (-452°F).

This signal is processed and amplified. The gain of some systems is about 150 dB (a factor of 10^{15})

The opposite of the “error” signal is applied to the antiproton at the kicker. The kicker signal can be as large as 1500 Watts.

Circular machines, the Lorentz force and how synchrotrons work

Link to Beams Division Antiproton Source Department

Questions? Contact Ernie Malamud rev. August 16, 2000