



Fermilab

PBAR NOTE #445

STOCHASTIC COOLING OF ANTIPROTONS AT THE
TEVATRON

Sekazi Mtingwa

January 1986

Stochastic Cooling of Antiprotons at the Tevatron

The 1984 Nobel prize for physics was shared by Harvard University's Carlo Rubbia and CERN (The European Laboratory for Particle Physics located in Geneva, Switzerland) senior engineer, Simon van der Meer. Rubbia led one of the two experimental teams at CERN which discovered the greatly anticipated elementary particles called the W^+ , W^- , and Z^0 . The electrically charged W 's and neutral Z^0 are quite heavy in comparison to the other most elementary constituents of matter. Their masses are about 81 GeV (giga, or billion electron volts) for the W 's and 93 GeV for the Z^0 . By comparison, the proton mass is close to 1 GeV.

According to our present understanding, there are four basic forces which govern how objects in nature interact with one another. They are the gravitational, weak, electromagnetic and the strong forces. Physicists believe that the way two elementary particles interact is that one particle emits some mediator of one of the basic forces and the other particle subsequently absorbs this mediator, thereby altering their energy states. Thus, familiar electromagnetic phenomena occur via the emission and absorption of light particles called photons, which we detect everyday with our eyes.

The existence of the W 's and Z^0 is crucial to our understanding of beta decay, perhaps the most famous example of the weak interaction. In beta decay, a neu-

tron decays into a proton, an electron and an antineutrino. Hence, the discovery of the W 's and Z^0 as the mediators of the weak force greatly substantiated our theoretical framework.

The W 's and Z^0 were produced at CERN by colliding a beam containing 270 GeV protons into a beam of 270 GeV antiprotons in a circular accelerator ring about four miles around called the SPS (Super Proton Synchrotron). By accelerator ring we mean a system of magnets which guide and focus a beam of charged particles along a well-defined path. Antiprotons do not normally exist in large enough quantities to be useful for such experiments. However, they are produced regularly in high energy accelerator collisions, but the range of values of their momenta coming out of such collisions is much too large to be readily useful.

Also, the antiprotons oscillate (called betatron oscillations) with large amplitudes transverse to their longitudinal direction of motion so that the beam would appear large and diffuse to an observer looking directly at the approaching antiprotons.

Over the years there have been two main schools of thought on how to "cool" or reduce the betatron amplitudes and momentum spread of antiprotons produced in particle accelerators. One method was suggested by G. Budker in 1966 at the Nuclear Physics Institute in Novosibirsk, USSR. His method, called electron cooling, is still being vigorously pursued by a team of accelerator physicists in Novosibirsk. In this method, the cooling is accomplished by allowing an electron beam to interact with and absorb the unwanted part of the motion of the antiprotons over a short segment of the antiprotons' circular accelerator ring. Electron cooling was successfully demonstrated in 1974 by a Novosibirsk team

led by A. Skrinsky.

Simon van der Meer shared the 1984 Nobel prize for the other cooling method, called stochastic cooling, which he proposed in 1968. Stochastic means random. This method uses a series of devices called pickups and kickers. As the antiprotons pass by the momentum pickups, their average momentum deviation from some central value is measured. This information is then relayed electronically across the antiproton ring to the kickers, so that when the antiprotons arrive at the kickers they receive an electromagnetic kick, so that their average momentum deviation from the central value is reduced. Horizontal and vertical betatron cooling systems act similarly to reduce the large betatron oscillation amplitudes. During the cooling process, the pickups and kickers act millions of times, progressively cooling the beam. Stochastic cooling played a crucial role in obtaining good enough antiproton beams at the CERN proton-antiproton collider so that Rubbia and the other experimenters could discover the W^+ , W^- , and Z^0 .

One of the problems faced by CERN has been getting enough proton-antiproton collisions to produce large quantities of the W 's and Z^0 's to enable the experimenters to more carefully study their properties, such as their masses and decay products.

In a continuing effort to produce greater quantities of proton-antiproton collisions and higher energies, Fermilab's Tevatron I collider hopes to improve the rate of collisions by about a factor of 10 over that at CERN. Also, it is important that the time it will take Fermilab to cool and accumulate the necessary number of antiprotons to produce a useful beam will be reduced by many hours. It is called the Tevatron since the design calls for a one TeV (tera, or trillion electron

volts) proton beam to collide with a one TeV antiproton beam. Originally, the laboratory consisted of a series of smaller accelerators which injected protons into the main accelerator ring of four miles in circumference, wherein the protons were accelerated up to 400 GeV. In 1983, a superconducting ring was added just below the main ring. The superconducting technology allowed the beam energy to double to 800 GeV while cutting electrical power consumption by one-third. In order to convert the superconducting ring into a collider facility, a huge detector called CDF (Collider Detector at Fermilab) and two small accelerator rings called the Antiproton Source, for cooling and accumulating antiprotons, were built at a cost of about \$140 million. The CDF collaboration consists of about 200 physicists from the United States, Japan and Italy, while over 800 Fermilab staff contributed to the construction of the Antiproton Source.

The highly sophisticated stochastic cooling systems in the Antiproton Source continue to cool and accumulate antiprotons until diffusion forces, mainly from intrabeam scattering, blow the beam up faster than the cooling systems can reduce its size. The phenomenon of intrabeam scattering is well understood and the theory was worked out by A. Piwinski of DESY and independently by James D. Bjorken and Sekazi K. Mtingwa of Fermilab. Beam blowup from intrabeam scattering is due to the fact that one can pack particles of the same electric charge, namely antiprotons in our case, tightly together only until the forces of repulsion among the particles become too great to be compensated by the coherent forces of the cooling systems.

On October 13, 1985 at 3:30 AM, Fermilab's Tevatron observed its first proton-antiproton collisions at an energy of 800 GeV per beam, or 1.6 TeV total reaction energy. The laboratory will be working vigorously to increase

this reaction energy to two TeV. The utility of colliders for producing higher reaction energies can be seen by comparison to the 40 GeV reaction energy that results from the 800 GeV proton beam striking a stationary target, which is the traditional operational mode of the laboratory.

The proton-antiproton collisions occur in the CDF detector, which is 25 feet wide, 31 feet high, 75 feet long, and weighs 4500 tons. The detector surrounds the beampipe of the superconducting accelerator. Out of 50,000 collisions per second occurring in the detector, only about one per second is interesting. Protons and antiprotons are thought to be composed of more elementary constituents called quarks and gluons, so that when they collide, it is their inner constituents which interact, allowing the exploration of mass scales of the order of 200 GeV.

The antiprotons are provided by the Antiproton Source, which is located in a tunnel 20 feet below the ground and 1800 feet in circumference. It consists of a target station, beam transport lines, and two small accelerator rings called the Debuncher and the Accumulator. Every two seconds, a batch of protons is accelerated to 120 GeV in the main accelerator, then extracted and focused to strike a metallic target. The antiprotons are then collected, refocused, injected into the Debuncher where betatron stochastic cooling systems reduce the beam size in the plane perpendicular to the primary direction of motion, and then stored in the Accumulator. In the Accumulator, betatron stochastic cooling systems further reduce the beam size and momentum stochastic cooling systems reduce the spread in the particles' momenta. Antiprotons are cooled and accumulated in the Accumulator for several hours before they are re-injected into the main accelerator and accelerated up to one TeV.

The Tevatron should keep high energy physicists busy collecting and analyzing data for the next 10 to 15 years. Much should be learned in our quest to understand strong, weak, electromagnetic, and gravitational forces. Many physicists believe the next exciting mass scale needing exploration is on the order of a few TeV. Since it is the constituents of the protons which interact during these high energy collisions and since each constituent carries about one-tenth of the total proton energy, one would need to build an accelerator with about 20 TeV per beam. Thus, the proposed Superconducting Super Collider, or SSC, would be most timely if construction could begin by 1988 and experiments start around 1995.

As planned, the SSC would be a proton-proton collider. Due to the extreme difficulty of cooling and accumulating large quantities of antiprotons, it is felt that the physics at these ultra-high energies could best be explored by maximizing the number of collisions by utilizing 20 TeV protons in each beam. The countercirculating proton beams would be accelerated and guided around two separate rings of superconducting magnets, similar to those in use at the Tevatron. The circumference of the rings would be 60 miles, and the proton beams would collide at six strategically located points around the rings. While the Tevatron is composed of 1000 superconducting magnets, the SSC would employ some 8000 such magnets. The estimated cost of the SSC is about three billion 1984 dollars. As with the Tevatron, private industry would be intimately involved in and greatly benefit from the solutions to myriad technological problems which would have to be solved. A complete conceptual design for the SSC based upon the recently selected magnet style is due during the spring of 1986.

Many theorists believe the SSC would simulate the conditions in our very

early universe 10^{-15} , or a millionth of a billionth of a second, after the "big bang". Many believe that, for the first time, experimenters would have an opportunity to observe the Higgs particle, which is equally as important as the W 's and Z^0 in understanding the weak force. Perhaps other mediators of the weak force more massive than the W 's and Z^0 would be observed; perhaps new quarks will be found, or perhaps the known quarks will display an inner structure. The realm of possibilities is endless.

Fermilab is operated by Universities Research Association, Inc. for the United States Department of Energy. Members of the corporation are 56 research-oriented universities in the United States, and one in Canada.