ANTIPROTONS GO ROUND AND ROUND

"Maîtriser l'antimatière" said CERN, and that mastery is intended to organize a new circle of storage rings

BY DIETRICK E. THOMSEN

Antimatter, it seems, has now become a physicists' laboratory tool like electrons, protons or liquid helium. At the CERN laboratory in Geneva they have succeeded in holding a beam of antiprotons in a specially made storage ring called the Initial Cooling Experiment for 85 hours, apparently in good control (SN: 8/26/78, p.132). This is a first step toward using antiprotons as projectiles in physics experiments in the same ways as less exotic particles.

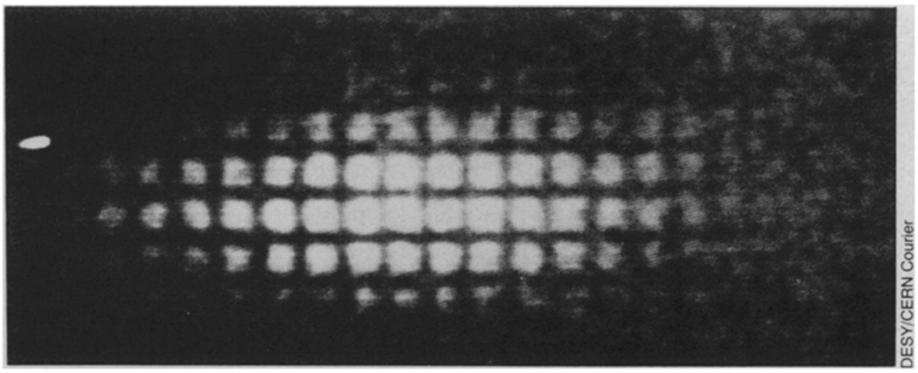
Fifty years ago antiprotons were imagined by a theorist who needed to balance energy states with each other; the energy states of antimatter balance those of ordinary matter. There was not a scintilla of evidence in the grubby physics of the laboratory that such a thing could exist, but in the early 1950s, when the first particle accelerator of a billion volts' energy was built, one of its aims was to see whether antiprotons could be materialized (or maybe antimaterialized). In 1955 it recorded the required scintilla. Today 240 antiprotons waltz happily around a ring in Geneva. If the story proves anything, it is perhaps the antiphilosophical principle that whatever a theoretical physicist can imagine, an experimental physicist can turn into technical reality.

The main purpose of this reduction of antimatter to the status of electric current is to strike high-energy antiprotons against high-energy protons in head-on collisions and see what happens when matter meets antimatter in a big way. It may be that this event, when it comes — at this point it seems almost too cautious to say "If and when" — will confirm the opinion expressed by many physicists that the colliding beam technique is the one that will uncover the deeper and subtler unknowns of the structure of matter in the most elegant way. The strength that this opinion now has is already a reversal of the situation that existed a decade ago when colliding beams were still untried, and it arises largely from the events that have been reported from Stanford and Hamburg over the last few years.

In those days fixed-target accelerators were *the* instruments with which to do particle physics. Colliding beams were an idea that seemed rather wild. The traditional technique was to take bunches of protons or electrons (nowadays it can be trillions per bunch), accelerate them with electric fields until they have high energy (and speeds near that of light) and shoot them at a target that contains protons, neutrons or electrons (usually all three) for them to hit. The target can be a metal foil, a ball of wax (no kidding) or a tank of liquid or gas. What happens in the collision reveals information about the nature and structure of target, projectile and any new particles that may be generated in the collision as well as about the forces that act among them. This is the basic information on which the science of the fundamental structure of matter is built.

But there is a basic disadvantage to this kind of experiment that becomes especially apparent at the high energies now in use: A projectile moving at a speed close to that of light has a large forward momentum that must be preserved after the collision. (Newton had a law about this.) A lot of energy is associated with this momentum, and after the collision this energy is carried away by the projectile, any particles knocked from the target and any new particles created. It gets dissipated in a beam dump or heavy metal backstop where it is not available for interesting physics.

To make use of this locked-in energy, the thing to do is to bang together two accelerated particles of the same mass, coming with equal energy from opposite directions. Momenta that are equal in size but oppositely directed add up to zero. The two particles stop each other cold, and all the energy brought by both is available. This colliding beam idea is especially appealing if one beam is matter and the other antimatter, that is, electrons and positrons (which are anti-electrons) or as now seems to be in prospect, protons and antiprotons. This kind of collision produces an annihilation reaction that turns both particles into a blob of energy, a virtual photon that is potentially anything it happens to have enough energy to become. Such experiments have in fact discovered a number of particles of a kind never seen before, one of which won a Nobel Prize.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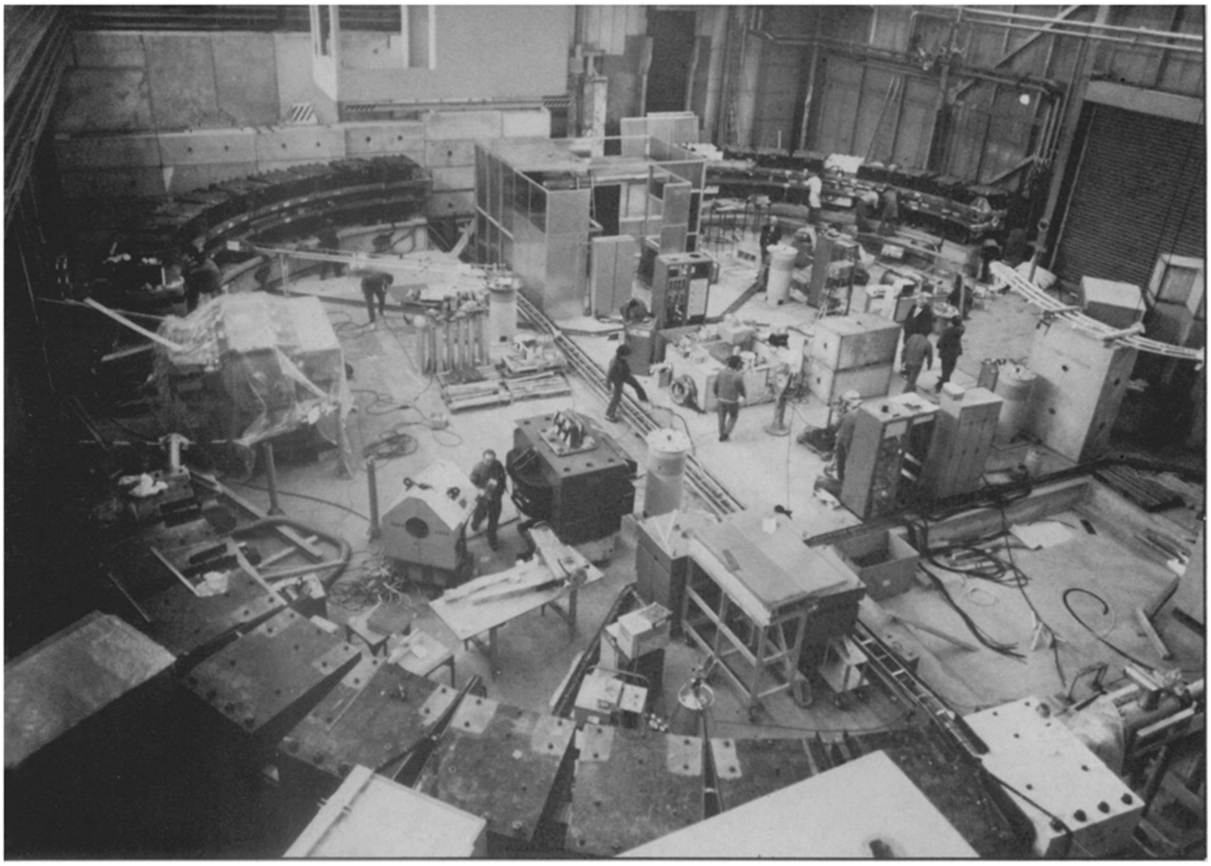
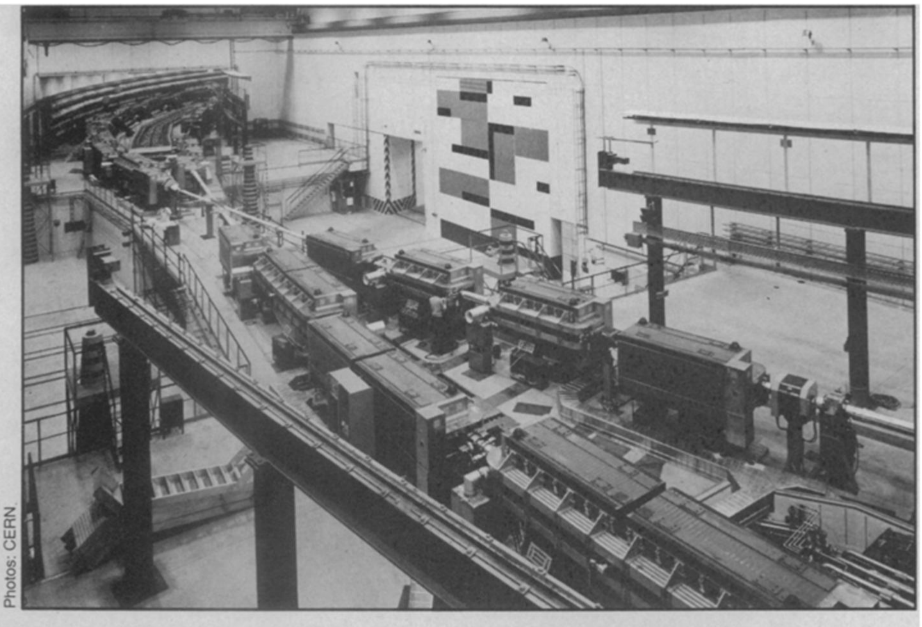
First light is a term usually used for the opening of a telescope, but it may be appropriate for a storage ring too. This is synchrotron light from PETRA's first 5 GeV electron beam.

The colliding beam idea could have been suggested by a student in elementary physics, and a couple of them may have done so, but, when it began, the technical difficulties were so formidable that many physicists thought it would prove impossible in practice. Controlling one beam of bunches of protons or electrons, keeping it focused and bending its path properly so that it hits a target much larger than the bunches is difficult enough. Controlling two so that the bunches could be collided against each other seemed wildly impractical to many physicists.

A little more than a decade ago came the demonstration that it could be done. The installations that do it are called storage rings, because the beams circulate in



ICE (top) is the first antiproton storage ring. It could lead to matter-antimatter collisions in installations like this beam crossing in CERN's ISR (middle). Antiprotons for ICE were made in CERN's old Proton Synchrotron, shown here when it was the biggest thing on site (bottom).



Photos: CERN.

ring-shaped vacuum chambers. A storage ring can be its own accelerator, or it can accept already accelerated particles from another accelerator. The actual accelerating is done by electric fields oscillating at radio frequencies in resonance chambers spaced around the ring. The focusing and path bending are done by specially designed magnets. The particles make enough passes around the ring to reach the desired energy and then they are held for repeated collisions of bunch against bunch.

Until now development of colliding beams has been largely in the electron-positron department. The first generation of these includes machines at Frascati (Adone), Hamburg (DORIS), Stanford (SPEAR) and Yerevan. All of these produce maximum energies of a few billion electron-volts per beam; A descendant of DORIS, called PETRA, which will go to 20 GeV per beam, recently started test runs. An installation of similar energy, called PEP, is under construction at Stanford. Cornell University expects its Cornell Electron Storage Ring to begin to operate next year. At a maximum 8 GeV per beam it is intended to bridge the gap between the first and second generations. (There is one proton-proton storage ring of significant energy in operation, the CERN Intersecting Storage Rings.)

What CERN has achieved with antiprotons is to make and store a beam of antiprotons in a storage-ring device of this sort. This device, the aforementioned ICE, accepts antiprotons of 2.1 billion electron-volts (2.1 GeV) that have been made by striking protons from the CERN Proton Synchrotron against a target. The antipro-

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. . . Antiprotons

ton bunch here amounted to about 240 antiprotons. For antiprotons that's a great many, but it's still a long way from the numbers needed for colliding beams.

While this development went on, fixed-target accelerators took a 20-fold jump in energy with the construction of the synchrotron at the Fermi National Accelerator Laboratory and CERN's Super Proton Synchrotron. These machines have top energies of 400 to 500 GeV and were supposed to be a complementary development to the storage rings. It doesn't seem to have worked out that way. There are difficulties in operating the machines and keeping them up to maximum energy. In the collisions themselves, physicists are heard to complain about "hadronic background," which is a large spray of heavy particles that the proton-target collision tends to produce. It eats up energy and makes the wanted effects hard to find.

Colliding beam experiments are much cleaner. One physicist critic points out that although Fermilab was first to produce the most massive particle yet known, the upsilon, it had to strain hard to do it. A few months later the people at DORIS moved a few magnets intended for PETRA temporarily into the DORIS ring, tuned up DORIS to 10 GeV per beam and made upsilons. It is at Hamburg, not at Fermilab, that the physics of the upsilon will be studied, this critic feels. [See SN: 9/16/78, p. 196.] Indeed, colliding beam experiments seem not only to have opened one or two new chapters in physics, they are systematically developing them.

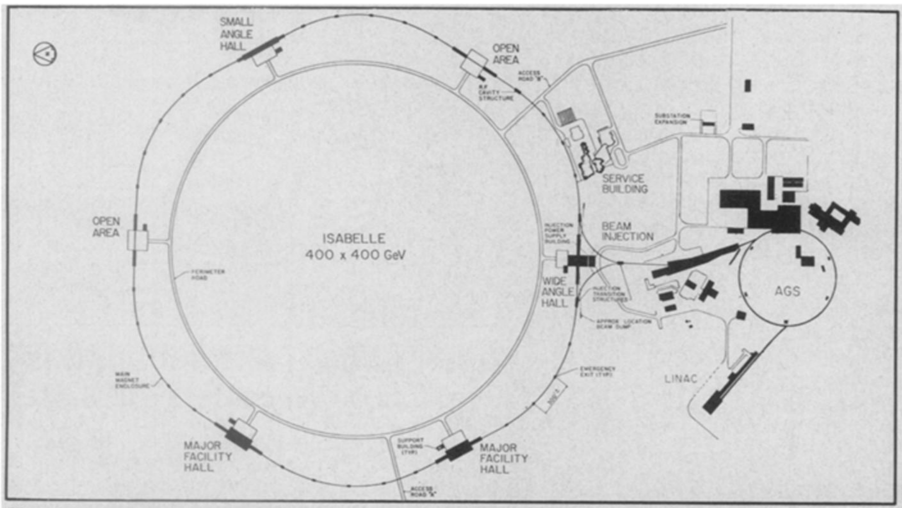
So most of the prophets are now saying that colliding beams are the wave of the future in particle physics. If not *the* wave of the future (prophets have been wrong before in this science) then at least the next good wave for your surfboard. The managements of the laboratories with the biggest fixed-target accelerators are all pushing colliding-beam projects. The Stanford Linear Accelerator Center — it has the world's most energetic fixed-target electron accelerator — got in early with SPEAR and PEP. Brookhaven National Laboratory, which has a proton accelerator that was once the world's most energetic, is working on a colliding-beam project called ISABELLE. CERN and Fermilab have a number of irons in the fire, and they are particularly well placed if proton-antiproton collisions become the next big excitement, as seems likely.

A major hurdle that will have to be overcome in that case is what is called beam cooling. The CERN experiment on antiprotons addressed this problem especially, and the result is being called a success. The necessity of cooling beams arises from the high density of particles necessary for colliding beams. There have to be a lot of particles close together so that when bunch hits bunch there is a good probability that individual particles will meet. In fact, the particles are so close together that physicists compare them with a number that is called luminosity, as if they were beams of light.

In a bunch of accelerated particles there is a small spread of momenta; it is impossible to get every particle to exactly the same speed. In a bunch as closely packed as these, the particles tend to overhaul one another and bounce. They also bounce off occasional gas atoms that the vacuum system left behind in the chamber. This produces a motion like that of a heated gas, and the beam must be "cooled" or the bunches will blow up.

CERN's method of cooling, called "stochastic cooling" depends on continually monitoring the state of the bunches. Quick feedback enables the controlling magnets to alter their fields so as to counter the disruption of the bunch. In the fall Fermilab will start experiments on another method, which will try to use beams of electrons to cool heavy particles. In principle if a bunch of electrons interacts with a bunch of antiprotons, the electrons, which have only 1/1,800 the mass of the antiprotons, will wind up with most of the momentum and the antiproton bunches will quiet down. The procedure should also work with proton bunches, which will need cooling, too. Electron cooling was first suggested by the late Gersh Istkovich Budker of the Soviet Academy of Sciences in Novosibirsk, and Fermilab is embarking on cooperative studies of electron cooling with Novosibirsk. They are also starting collaborative studies of stochastic cooling with accelerator scientists from Berkeley.

If it all works — and CERN expects proton-antiproton collisions at modest energy by 1981 — we shall see matter-antimatter interactions of a completely new order. Electron and positron are simple things. Neither theory nor experiment sees any structure in them. One is this and the other is that. Proton and antiproton are more complex. Theory sees them as being built of subunits called quarks, which are the basis of modern physical theory. Proton and antiproton are neither entirely this nor entirely that; each has a little of the other. In a proton, says theory, are two quarks and an antiquark; in an antiproton, two antiquarks and a quark. A little yin in the yang, so to speak. When they collide, electron and positron can make quarks, though they be none, but a proton-antiproton collision is quark against quark or, rather, one quark-antiquark system against its mirror image. It should be interesting. ☐



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The biggest proton storage ring project actually under way is Brookhaven's ISABELLE. America's only operating electron-positron storage ring is Stanford's SPEAR (bottom).

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