# Tom Swift and His Electric Synchrotron

Will Fermilab's management ever stop dreaming up additions and emendations to their giant accelerator? Probably never.

BY DIETRICK E. THOMSEN


Fermilab

*A view of Fermilab's four-mile ring from nearer the ground than the one on the cover.*

When the giant synchrotron at the Fermi National Accelerator Laboratory near Chicago accelerated its first protons to an energy of 500 billion electron-volts (500 GeV), it had surpassed its original design energy by a factor of two-and-one half. Even now that its West European counterpart, the Super Proton Synchrotron at the CERN laboratory near Geneva, has gone on line, Fermilab's synchrotron remains the world's most energetic accelerator, because the West European consortium that operates CERN decided to hold their machine at 400 GeV.

The rather substantial design changes that doubled the originally planned 200-GeV maximum energy were made while the project was underway. Getting the last 100 GeV out took a bit of squeezing, but the system stood the pressure. It should be added that all this was done without any budget overruns. Getting more than twice the kick for the same money is possibly a record among expensive projects financed by the United States government. Maybe that's because it was administered by impractical ivory-tower types instead of down-to-earth businessmen the Air Force deals with.

Even before the first protons flew through the main accelerator, Fermilab's management was already planning how to double its energy once more. An accelerator of this type is a more or less circular arrangement in which the accelerating sections where the protons are energized by radiofrequency waves are alternated with bending and focusing magnets that keep the beam on its circular track. The trick to making an energy doubler without building a new, bigger tunnel—because of radioactivity the synchrotron has to be buried under a berm of earth—is to use superconducting magnets. Magnets with ordinary conductors in their coils cannot produce strong enough fields to bend the path of 1,000-GeV protons sharply enough. Space was left in the tunnel that houses the existing four-mile circle for a second circle with superconducting magnets.


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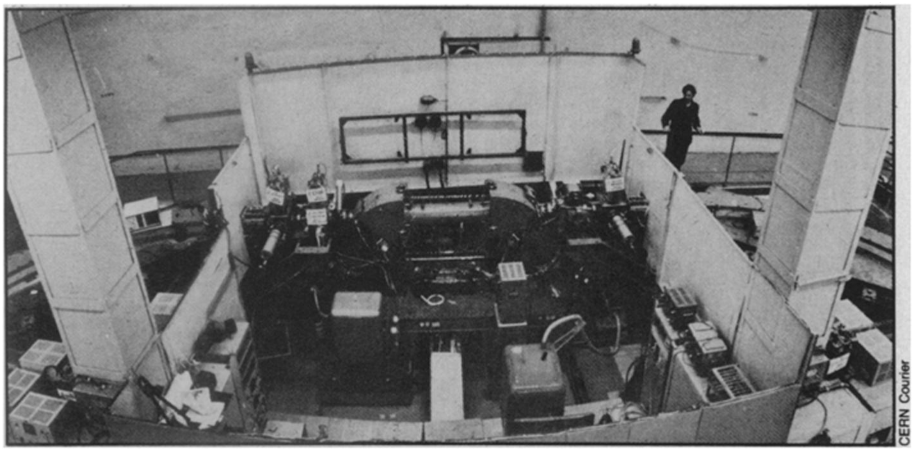
*Energy doubler will be under main ring.*

Since the requisite magnets did not exist at the time, some members of the Fermilab staff set out to invent them and to teach manufacturers to build them. Even the superconductor in the windings had to be designed. It is niobium-titanium coated with copper, and the method of casting it, extruding it and forming it into insulated bands of fibers is the subject of a display at Fermilab that was set up to show interested accelerator builders attending the recent Particle Accelerator Conference at Chicago how the thing is done. The magnets themselves, being experimental, have gone through several shapes in an attempt to find the best one for the purpose. The builders, according to William Fowler, have finally settled more or less on one design.

While all this was going on, Fermilab's management was thinking of colliding beams. Colliding beams are the latest thing in particle-physics experimentation. Their advantage is energy: Two accelerated beams strike each other head on. Since they stop each other's momentum, all the energy both beams possess is available for producing new phenomena to study. In fixed-target accelerators, like Fermilab's present synchrotron, the forward momentum must continue after the collision, so a lot of energy remains invested in motion of the particles.

Conversely, fixed-target accelerators have advantages of their own. A given pair of colliding beams can do only one experiment, the particular collision for which they are designed. A fixed-target accelerator can use almost anything as a target, and its targets can be used to produce beams of secondary particles, which are either too shortlived to be accelerated themselves (muons, various mesons) or electrically neutral (neutrinos, neutrons, gamma rays), and these can be used as probes of the structure of other particles or larger pieces of matter. Every up-and-coming accelerator laboratory would like to have both kinds.

Since before the synchrotron was finished, Fermilab's management has been thinking of colliding beams. An early suggestion was to build new rings bigger than the present synchrotron. At the accelerator conference, Phillip Livdahl, one of the people closely involved with the development of Fermilab's equipment, made public a new and ingenious proposal to use the energy doubler and the main ring to provide colliding beams. The beams could be either proton against proton or—something not yet attempted anywhere else—proton against antiproton. If it works out, the project will provide matter-antimatter collisions at energies around a teravolt (a trillion volts). This will enable studies of the very intimate details of proton structure. It will provide, says Fermilab's director Robert R. Wilson, an opportunity to see what happens when quark strikes antiquark.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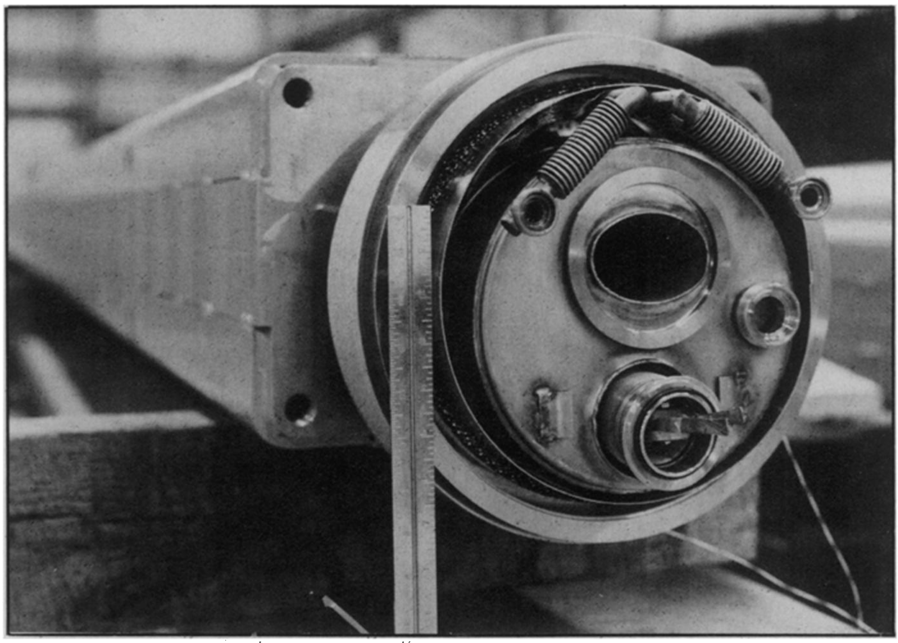
*Part of the apparatus for studying electron cooling of antiprotons at Novosibirsk.*

Meanwhile, back on the plains of Batavia, the highest priority is going to a less spectacular project that is nevertheless the foundation for everything else. According to Russell Huson, head of Fermilab's Accelerator Division, which is directly in charge of administering this sort of thing, the most important task is bringing the accelerator's beam intensity up to its design value of $10^{14}$ protons per pulse. At the moment it is about half that.

Beam intensity is generally a touchier technological problem than energy. Getting a bunch of protons to stay together for any length of time is difficult, because they all have positive electric charge and tend to repel each other.

Physicists call this phenomenon "space charge," because it constitutes a given amount of charge in a particular volume. The law of space charge is that, unconstrained, space charge tends to the minimum possible value; that is, the bunch blows up. The accelerator ring is fitted with focusing magnets to prevent the proton bunches from scattering apart, but in the preacceleration process, building up a sufficiently dense pulse is extremely difficult because bunches of protons resist addition: It is very hard to get them to lie side by side. Huson suggests that the solution is likely to be the use of negative hydrogen ions "to trick the space charge," Negative hydrogen ions are hydrogen atoms with an extra electron. These can be put through the preacceleration process, and their negative charge will allow them to be stacked with proton bunches. Then the lot can be put through a foil that strips the electrons from the negative ions, and—*voilà*—a thick bunch of protons is off around the track.

The high intensity is important for fixed-target experiments, because the phenomena of greatest interest nowadays are very rare, and high intensity gives a better statistical chance of seeing them. The high intensity is absolutely essential for colliding-beam applications, since the beams must be dense and well aimed to yield a useful number of collisions.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*A Fermilab doubler magnet. The particle beam will run through the oval tube.*

A second project at Fermilab that will be useful for high-intensity proton beams and essential for colliding antiproton beams is a small experimental ring to study a new technique of beam "cooling" invented in Siberia. The original idea is attributed to Gersh Budker of the Siberian Branch of the U.S.S.R. Academy of Sciences in Novosibirsk, and it was described at the accelerator conference by V. L. Auslander, also of Novosibirsk. The mutual repulsion involved in the space-charge effect gives the protons of a bunch a random spread of momenta in all directions that is analogous to the kinetic temperature of a gas. If you mix two gases of different temperatures, mutual bumping of their atoms will eventually bring both to the same temperature. If you run a beam of electrons in the same vacuum chamber with protons or antiprotons, the electric forces between them should produce a similar effect. The electrons are far less massive than the protons so at any given temperature they will have much higher momenta than the protons. Thus the electrons take away the unwanted random momenta and leave the protons in a dense, well-defined bunch. The technique should thus improve the character of high-density proton bunches, and it is necessary for making antiproton bunches at all. Antiprotons are made by striking protons against a target, and the antiprotons come off in a wide scattershot spray. Some technique of this sort is needed to make pulses of them.

And so it goes. By the time these projects are underway, Fermilab's management will surely have thought up still new projects and alterations. In a way it's expressive of national character: The giant West European accelerator at Geneva is built like a Swiss watch. Buried deep underground it is supposed to work as smoothly as possible with as little attention as possible for as long as possible like a good 17-jewel movement. When the Russians build something like this, it has a kind of brute-force look about it: Russian technology always seems to outrun its counterparts in other countries in bulk and tonnage. And the Americans can't stop tinkering. Fermilab will probably never be finished. Well, after all, we are the country that contributed Tom Swift to the world's juvenile literature. ☐