Photos: CERN

*The CERN Laboratory near Geneva: The Intersecting Storage Rings are under the ring of earth at the top.*

# The strange behavior of high-energy protons

by Dietrick E. Thomsen

The big recent surprise in proton physics is that at the highest energies now available, in the Intersecting Storage Rings at the CERN Laboratory in Geneva, the value of the total cross section for proton-proton collisions begins to rise sharply (SN: 3/17/73, p. 165). It had been expected to remain steady at a constant value.

(The cross section is the area over which the proton has an influence in a collision. If the cross sections of a target particle and a projectile particle overlap, something will happen: The projectile may be deflected from its path or some new particles may be produced. Cross sections are measured in millibarns; one millibarn equals $10^{-27}$ centimeters.)

It was known that at very low energies the cross section rises to a maximum of about 47 millibarns at 2 billion electron-volts (2 GeV). Then, as energy rises, the cross section drops off. In the tens of GeV it seemed to reach a constant level of about 38 millibarns. This was brought out by experiments at the synchrotron at Serpukhov in Russia, which goes to 70 GeV and until about a year ago was the world's most energetic proton accelerator. Theorists were mildly surprised that the constant value was reached at energies below 70 GeV, but were inclined to let it go at that.

The behavior of the cross section, as observed up to that time, could be explained in a somewhat oversimplified way by recourse to the phenomenon of matter waves. According to modern physics there is a wave associated with every particle. The wavelength depends on the energy of the particle; the higher the energy the shorter the wave. At low energies the proton's wave is longer than the actual size of the particle. Because of the wave, the proton influences a larger area than its own size. As the energy goes up, the wavelength decreases until it is smaller than the physical size of the proton, and the cross section remains constant at approximately the physical size of the proton, which looked to be about 38 millibarns.

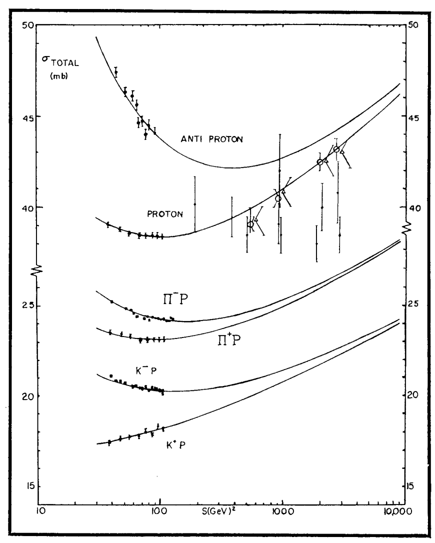
Then last month came the bombshell. It had been preceded by omens. Early experiments in the ISR and at the National Accelerator Laboratory at Batavia, Ill., had given indications of higher cross sections at values above 70 GeV, but these were very preliminary results, and the experimental errors were great enough that they might have been reconciled to a constant cross section.

The new work by two groups at CERN gives solid evidence that the total cross section rises rather dramatically at high energies. By the time an equivalent energy of 1,500 GeV is reached the cross section is back up to about 43 millibarns.

One way of explaining these results lies in the nature of the strong interaction. The most usual mathematical picture of the interaction is that of a force whose strength drops off exponentially with distance from the particle generating it. Thus most of the strength of the force is found within or close to the generating particle. This can be contrasted to gravity or electrical forces whose strength drops off with the square of distance, and whose influence can extend over light-years. But the strong force does have a so-called exponential tail, a very small strength extending some distance from the particle. It may be that at low energies the strength of this tail is too small to matter very much, but at high energies, it becomes important, and the proton can thus again influence areas somewhat larger than its own physical self. Another suggestion is that perhaps the physical size of the proton actually somehow increases at high energy.

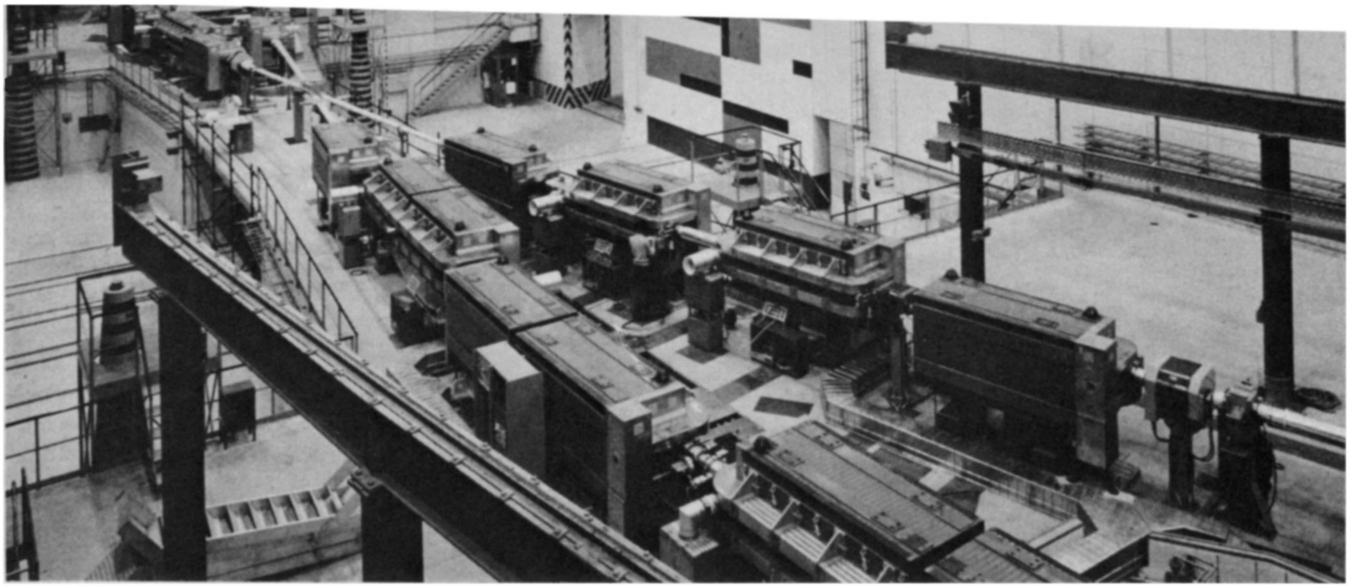
The CERN results did not exactly send theorists scurrying back to their drawing boards. Being theorists they had all their bets covered and were ready before the fact with theories that could be brought out to explain present behavior and predict the future. It is always more impressive and usually more convincing when theory precedes experiment than when it must be made ad hoc in response to experiment. What is happening is that the people who are working on approaches that fit the CERN experiments are suddenly finding their colleagues much more interested in their work than they used to be.

As long as 20 years ago Werner Heisenberg predicted a rise in the total cross section at very high energies. More recently a Russian physicist, V. N. Gribov, suggested that the cross section should approach a constant value at very high energies but from




Cheng, Wu, Walker

*Model of Cheng et al to 10,000 GeV.*



*Part of the Intersecting Storage Rings: One of the intersecting points where beams of protons collide is shown.*

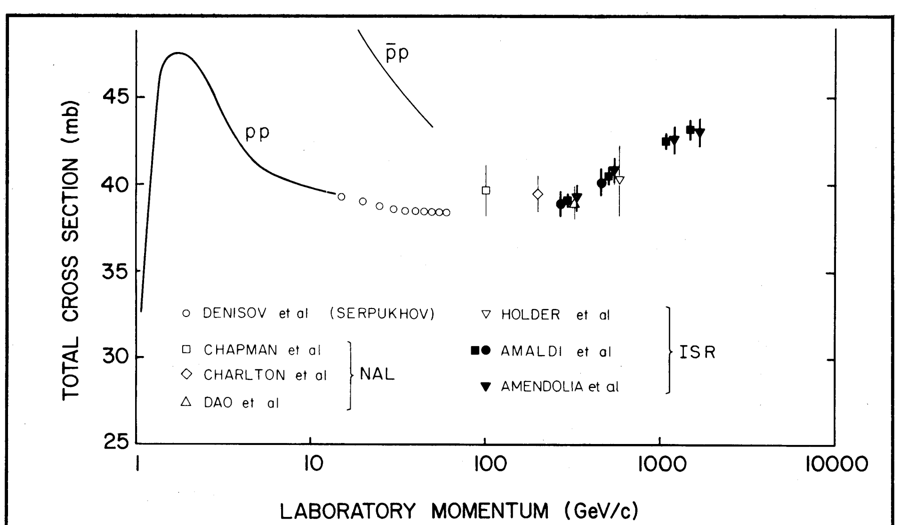
lower values, not from higher ones.

Of current theories at least one is based on Gribov's suggestion. It is being worked out by two students of Marshall Baker at the University of Washington at Seattle, John Ng and Uday Sukhatme. Another, which makes somewhat different predictions, is being worked out by Hung Cheng of Massachusetts Institute of Technology, Tai Tsun Wu of Harvard University and James K. Walker of NAL.

In 1970 Cheng and Wu published a paper in which, on mathematical bases of field theory, they predicted the rise of the proton-proton cross section. They predicted furthermore that it would continue to rise indefinitely, tending toward infinity as the energy did. They have extended the theory to predict the same fate for collisions of all particles subject to the strong interaction, events like pi mesons against protons or K mesons against protons.

The theory of the Washington group is quite different. Here the proton-proton cross section rises at the energies produced in the CERN experiment but tends toward a constant value. This is true across the board. It predicts that "all cross sections approach some constant value," says Baker.

Another point of difference between the theories is how they approach the insides of the proton. For the past three years a model has been prevalent that regards the proton (and other strongly interacting particles) as built up out of subparticles called partons. The idea was worked out by Richard P. Feynman of California Institute of Technology from the results of some experiments in electron-proton scattering. Cheng is rather proud of the fact that he and Wu independently worked out the parton model in the course of their field-theory calculations. Thus the Cheng-Wu-Walker theory contains the parton model. The Washington theory does not. The Washington theory is compatible with the parton model, says Baker, but is also patient of other possible explanations of the inside of the proton.

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*Experimentally determined p-p total cross section from 1 to 2,000 GeV.*

One place where there is general agreement between the two theories is that both respect the Pomeranchuk theorem. This was put forward by the Soviet physicist I. Y. Pomeranchuk, and it states that although the total cross section for a particle-*anti*particle collision can be greater than that for a particle-particle collision at low energies, the two should tend to the same value at high energies. For example, at low energies, the proton-antiproton cross section is greater than the proton-proton cross section. At energies in the tens of GeV it drops off sharply as energy increases.

The situation leads to some anxiety about the Pomeranchuk theorem since it looks as if, at higher energies, the proton-antiproton cross section might cross the proton-proton one. It must make a rather sharp U-turn to satisfy the Pomeranchuk theorem. Physicists would not like to throw out the Pomeranchuk theorem since it is built on very basic ideas regarding physical symmetries and the nature and relationship of matter and antimatter. Both of the theories under consideration save the Pomeranchuk theorem by giving the proton-antiproton cross section (and other particle-antiparticle cross sections) the necessary bend.

Whether all this conforms to experiment remains to be seen. As theorists continue to work, experimentalists have now to go after measurements of the other cross sections, especially pi-proton, K-proton and proton-antiproton. When enough data are in it may be possible to see which, if any, of current theories best fits the observed facts or whether a different, perhaps anti-Pomeranchukian, theory needs to be worked out. □