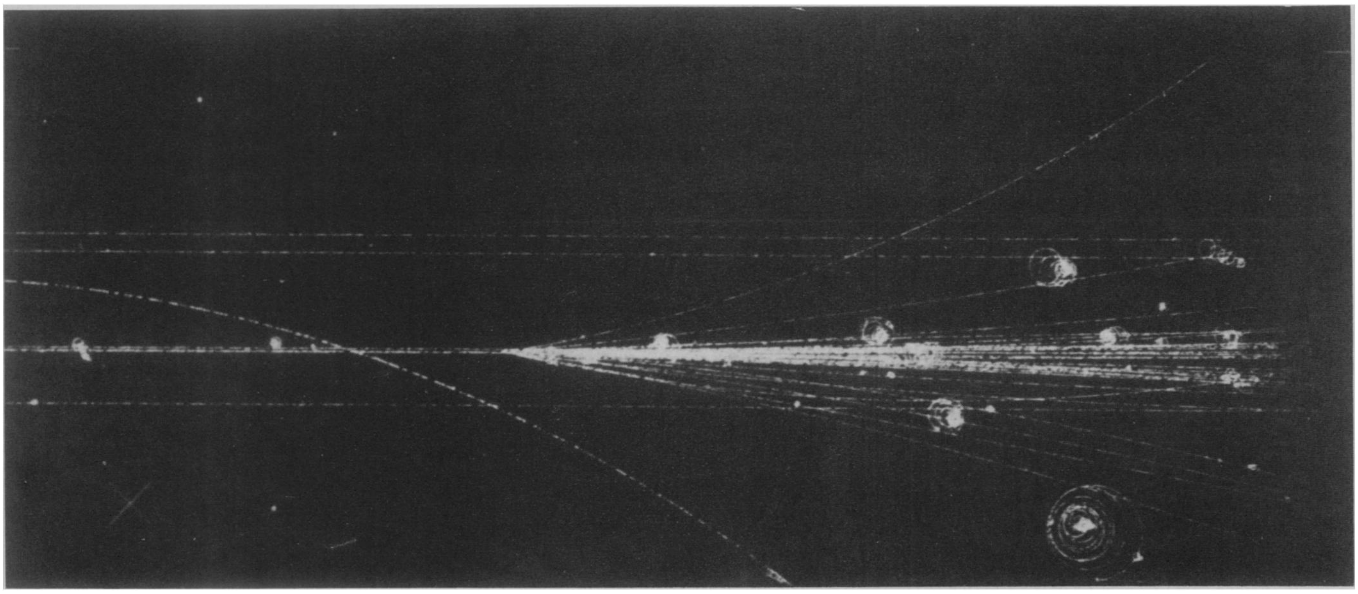


NAL

A 300-GeV proton meets a stationary one, producing a fan-shaped spray of more than a dozen secondary particles.

Probing the proton at high energy

The early results of ultrahigh-energy proton experiments are leading physicists into a strange new world

by Dietrick E. Thomsen

It is half a century since Rutherford and Chadwick deduced the existence of the atomic nucleus by bombarding thin foils with alpha particles (themselves helium nuclei) and observing the pattern of the scattered alpha particles. In the intervening time physicists have been able to probe deeply into pieces of matter much smaller than atoms, but the technique remains the same. Today, however, it is the proton that is the target of investigation and the proton that is one of the bombarding particles as well.

This point in history is an important one for physicists interested in proton-proton scattering. Two new pieces of equipment, the now 300 billion-electron-volt (300 GeV) accelerator at the National Accelerator Laboratory in Batavia, Ill., and the Intersecting Storage Rings at the CERN Laboratory in Geneva, are leading them into an uncharted region that seems qualitatively different from any place they have worked before. The new region is so strange that in the words of Victor F. Weisskopf of Massachusetts Institute of Technology, they are reduced to trying to define a new language in which to talk about it.

The basic question is what's inside a proton, or, putting it in a more sophisticated way, what sort of structure can be deduced from the results of proton-proton scattering at these new high energies. The results, often very preliminary, that were presented at the recent Sixteenth International Conference on High Energy Physics held at the University of Chicago and the National Accelerator Laboratory give so far somewhat ambiguous answers.

One thing that complicates the work is that at these energies not only the proton and the proton come out of the collision, but many other particles as well. This phenomenon, the production of secondary particles, had been seen at lower energies, but the number of secondaries rises with energy. Experiments at NAL with 200-GeV protons yield an average of eight particles coming out, and single collisions with as high as 20 have been photographed.

MIT

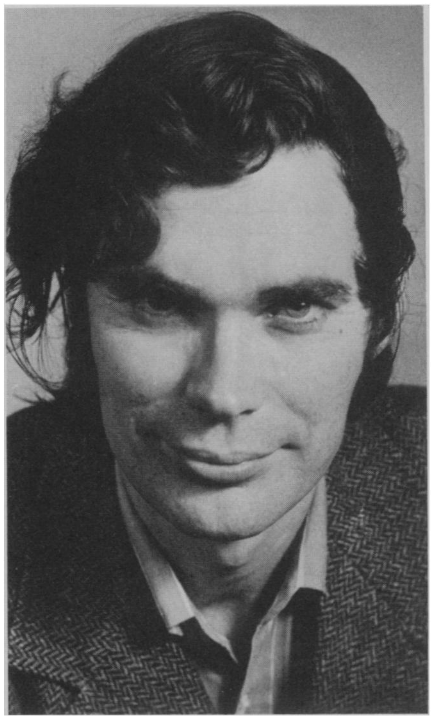
Weisskopf: Defining a new language.

It would be tempting to say, drawing an analogy with atomic or nuclear physics, that all these particles were somehow dormant within the proton and were knocked out by the projectile proton. Weisskopf warns against doing this too naively. In the atomic and nuclear cases the energies were much lower, too low to alter the structure they were investigating. Physicists could say with confidence that there was a hard core in the atom, and if an electron was knocked out, it was clear that the electron had existed as an electron within the atom. In the present experiments so much energy is delivered to the collision by the acceleration that it quite overwhelms the rest masses of the participants, and it is difficult to say that anything was inside anything else.

Nevertheless the physicists who are working on the high-energy collisions

Yale Univ.

Adair: A lot of things weakly bound.



Columbia Univ.

Mueller: Like a one-dimensional gas.

are taking a first step toward making a theory. They have built models based on the information they already have, and are looking to see whether further experiment coincides with the models. As time goes on, the models may lead to a predictive theory.

There are basically two models under consideration, the diffractive model and the multiperipheral model. The diffractive model is invoked often by people who measure the total cross section in these proton-proton collisions, that is, the probability that anything at all will happen. It takes its name from an analogy with optics. An object in a beam of light will cast a shadow. Likewise a proton in a beam of protons (or a nucleus in a beam of alpha particles in the Rutherford-Chadwick experiments) will cast a shadow. The important new datum is that as the energy increases, the total cross section approaches a constant value. There seems to be an inviolate minimum proton shadow. James E. Pilcher of Harvard University warns against taking this too literally as representing the "size" of the proton. The general view is that the proton is very fuzzy around the edges.

This asymptotically constant cross section combined with the rising number ("multiplicity") of secondary particles leads to another interesting consideration: At these energy levels the proton behaves athermodynamically. Normally if an object is heated, its temperature (its internal excitation) goes up. In this high-energy realm it seems that adding energy does not raise the proton's temperature. Instead it increases the multiplicity of particles coming off.

Concentrating on the particles that come out of the collision lends support to multiperipheral models. The term multiperipheral refers to the fuzzy periphery that a proton is supposed to have. The secondary particles, mostly various kinds of mesons, are supposed to live in this periphery in some way and get knocked out of it by the projectile proton. In this high-energy region, however, the proton appears to be mostly periphery. Robert Adair of Yale describes it as if it were a lot of things held together by very weak springs. Along comes the projectile proton and breaks a lot of the springs. Alfred H. Mueller of Brookhaven describes it as a kind of one-dimensional gas in phase space.

Phase space is a mathematical construction, a multidimensional space in which there are three dimensions to represent a particle's location and three to represent the components of its velocity. Physicists find it convenient to deal with particle phenomena in terms of these phase-space variables. If one reduces the laws of gas behavior, as expressed in terms of these variables, to one dimension, they can describe what happens in these collisions.

Both kinds of models found support in the data reported at the conference, and neither seems to be ruled out or seriously contradicted. This ambiguous state ought not to remain for too long. Sooner or later someone will come forth with a serious disagreement to one or the other. This, says Weisskopf, will be when things become really interesting. A model, he says, is like an Austrian timetable. Austrian trains are always late. A Prussian visitor asks the Austrian conductor why they bother to print timetables. The conductor replies: "If we didn't, how would we know how late the trains are?" The points where experiment contradicts a model are the points where changes will be made, and this dialectic gradually leads to a well refined theory.

Some of the men whose names are associated with the current models did not receive Weisskopf's analysis with great rejoicing. They would be happier to see their models pass into theory substantially unaltered. The next few years should tell whether they will. □

films OF THE WEEK

DRAMA OF METAL FORMING. 16mm, color, sound, 28 min. Of the 350 million tons of metal used in the world every year, almost all is subjected to a "forming" process at some stage of its manufacture. That is, it is shaped plastically—pressed, squeezed or rolled, either hot or cold—as opposed to being cut or machined. Shown are many of the forming processes, from the forging of a massive turbo-generator rotor weighting 100 tons to the high-speed drawing of copper wire down to a few thousandths of an inch in diameter. In particular, the film shows hot and cold rolling, tube forming (both seamless and welded), wire drawing, forging, extrusing, deep drawing and pressing. The combination of power and delicacy, characteristic of metal forming, demands scrupulous lubrication. In hot forming, it is needed mainly for bearings, but in cold forming, lubrication of the metal surfaces is of key importance. Audience: general. Free loan to groups, clubs, organizations or schools from Shell Film Library, Dept. SN, 450 N. Meridian St., Indianapolis, Ind. 46204.

INTRODUCTION TO THE CATHODE-RAY OSCILLOSCOPE. 16mm, color, sound, 11 min. Introduces the oscilloscope by demonstrating the development of the cathode-ray tube, the heart of the oscilloscope. Further demonstrations indicate how the oscilloscope can function as a voltmeter, a clock and a graph plotter. The film also explores the principles of transducers, the instruments that convert heat, light and sound into voltages for analysis on the oscilloscope. Both animation and actual demonstrations illustrate how an oscilloscope works and some of its many uses. Audience: high school, college. Purchase $135 from Encyclopaedia Britannica Education, Dept. SN. 425 N. Michigan Ave., Chicago, Ill. 60611.

PROCESSES OF SCIENCE: CLASSIFYING ANIMALS. Super 8mm, color, silent, 12 film loops. Arranging objects into meaningful groups is an important activity of science. A different small animal is studied in each film loop by a slowly moving camera which circles the animal, showing it completely from all sides. The similarities and differences in the shapes, colors and sizes of the animals will suggest methods of comparing and classifying them. Titles include: Fly, Ladybird Beetle, Grasshopper, Garden Spider, Crab, Starfish, Sand Dollar, Lizard, Salamander, Centipede, Earth Worm and Planaria. Audience: elementary, junior high. Purchase series of 12 for $240 or each $20 from BFA Educational Media, Dept. SN, 2211 Michigan Ave., Santa Monica, Calif. 90404.

Listing is for readers' information of new 16mm and 8mm films on science, engineering, medicine and agriculture for professional, student and general audiences. For further information on purchase, rental or free loan, write to distributor.