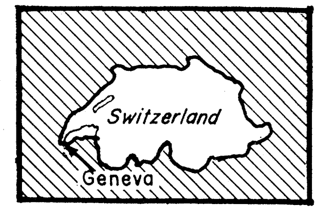
Particle Accelators at CERN



Geneva. Discussion of the next generation of high-energy nuclear particle accelerators is intensifying in Europe, as in America. Physicists are pressing for decisions soon, so that the new machines may be ready early in the 1970's.

In Europe, the debate focuses on the continent's major laboratory for high-energy physics, the European Center for Nuclear Research. On 40 hectares (100 acres) in the suburb of Meyrin, 250 CERN scientists and 1800 others work around one of the world's two largest proton synchrotrons.

The proton machines here and at Brookhaven National Laboratory have been yielding, since 1960, a very large number of facts about forces within the atomic nucleus. The forces reveal themselves in many "strong" and "weak" interactions between particles of varying, usually short, lifetimes.

Studies of strong interactions (interactions in which the recently discovered particles are involved are mainly of this type) led in February to the identification at Brookhaven of the omega-minus particle predicted by the mathematics of "unitary symmetry."

Recently, physicists have seen a new orderliness appear in their picture of the strongly interacting particles which have continued to emerge from several generations of accelerating machines built since World War II.

The newly discovered particles are arranging themselves in families in a kind of periodic table, on which the particles are plotted according to their "rest mass energy." No one of the strongly interacting particles seems to be any more "elementary" than the others. The table of the strongly interacting particles contains many "recurrences" at higher energies of particles at lower energies (*Sci. Am.*, Feb. 1964, pp. 74–93; *Phys. Today*, Apr. 1964, pp. 30–34). Further recurrences have been predicted, at energies which physicists feel would require proton accelerators of at least five times the energy of the present CERN and Brookhaven machines, which develop maximum energies of 28 and 33 billion electron volts (Bev), respectively.

Weak interactions involve such processes as the decay of a neutron, giving rise to a proton, an electron, and an apparently massless neutrino. More attention has recently been focused on the weak interactions, and in 1962 physicists at Brookhaven discovered that there is a *pair* of neutrinos, each with its own antiparticle. In response, CERN has greatly expanded its own neutrino studies to search for a particle that has been named the "intermediate boson." This particle could serve as a quantum for weak interactions, a carrier of the weak forces, in the same way that the photon, or light quantum, serves electromagnetic reactions. Although CERN physicists have found a few possible "candidates" among many thousands of spark-chamber photographs, it is also possible that the intermediate boson will have a rest mass energy that could only be achieved in an accelerator of higher energy.

Collaborating on such experiments at CERN are about 70 staff scientists and 180 visiting researchers, from such nonmember countries as the United States and the Soviet Union and from CERN's member nations: Austria, Belgium, Britain, Denmark, France, Greece, Holland, Italy, Norway, Spain, Sweden, Switzerland, and West Germany.

Physicists are saying to the governments of these countries that the scientific potentials of high-energy studies are already visible and will become larger in the 7 or 8 years it would take to build a machine 5 to 10 times the size of CERN's. A much larger machine would have to be built elsewhere—say, in England or southern France—but the planning for it proceeds here at CERN. Plans have also been made to extend the usefulness of the proton synchrotron by adding a pair of "storage rings" for experiments with colliding proton beams. This December, CERN's council will be asked for a decision to build the $67-million storage rings on land donated by France. Physicists hope for approval by the end of 1965 of the $340-million project to build a 300-Bev proton accelerator.

The studies behind both projects began in 1957 in what has become CERN's accelerator research division, formerly headed by Arnold Schoch and now headed by K. Johnsen. The group started thinking about future accelerators as soon as design work on the proton synchrotron tapered off.

The research group began with two ideas: a plasma accelerator and a clashing-beam accelerator.

The idea behind the plasma accelerator was the production of very strong guiding and focusing fields by self-confined, very dense electron beams traveling at relativistic velocities. A modest amount of work convinced the study group that a plasma accelerator would not be ready in time to be useful, and that its performance probably would not be as interesting as that of a machine which extended to high energies the principle of focusing the proton beam with magnets of alternating gradients.

Several members of the research division went to the United States in 1960 and 1961 to take part in summer studies of alternating-gradient machines with energies 3 to 30 times those of the CERN and Brookhaven accelerators. It was concluded that the principle would work up to energies of at least 1000 Bev. It was also concluded that clashing-beam experiments were no substitute for experiments that could be made with the bigger accelerator.

Clashing-beam studies were continued, however, because the CERN machine was developing more intense beams than the physicists had dared to hope for. Instead of a limit of about 10^{10} protons at the end of a

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Aerial view of the CERN nuclear research laboratories. [CERN]

3-second period of acceleration of one pulse, the machine was producing several times that number, and it has recently been approaching 10^{12} protons per pulse.

From the idea of building a separate clashing-beam accelerator, the CERN group turned to consideration of some way to store successive pulses from the proton accelerator in "storage rings" where two beams could be built up to clash with each other. The accelerator research group began building an electron model in order to study problems of "stacking" beams of particles.

E. H. S. Burhop of University College, London, has described the advantages of storage rings in this way (*CERN Courier*, Feb. 1964, pp. 16–17):

"Owing to the peculiarities of the mechanics of relativity, only a small fraction of the energy of high energy particles impinging on a stationary target is available for producing new particles or processes. Most of it is required to ensure that the overall momentum is conserved. In fact, the effective energy of a conventional accelerator only increases as the square root of the actual energy of the high energy particles.

"In the case of experiments with intersecting beams, however, the momenta of the two interacting particles are almost equal and opposite so that the resulting momentum is small. Almost the full energy of the two particles is then available for producing new processes. For example, the effective energy in the case of the collision of two protons, each of energy 25 bev, moving in opposite directions would be equal to protons of about 1400 bev from a conventional accelerator impinging on a stationary target. . . .

"The storage rings should be regarded as an exploratory device. They will not produce super-high-energy beams of secondary particles and can only be used for the study of proton-proton interactions."

By the end of 1961 the accelerator research division was ready to ask the CERN council to approve establishment of an expanded study group to work on a new proton synchrotron and on storage rings for the present one. The council said yes, and the group now has 16 members—scientists and engineers.

Since late 1961, the study group has worked out detailed projections for the two devices. Among the projections are the following.

The proton synchrotron would need a site of 20 square kilometers. It would be built in the form of a circle with a diameter of 2.4 kilometers; a dozen 52-meter straight sections would be available to feed experimental areas. The dimensions of the experimental buildings might have to be 60 by 400 meters. Particles would be accelerated in three stages, first by a 200-Mev linear accelerator, second in an 8-Bev synchrotron (which might be used also for a considerable number of independent experiments), and finally in the 300-Bev accelerator itself. The beam intensity achieved might be several times 10^{13} protons per pulse. Of the total budget of $340 million for a 9-year period ending in 1973, $228 million would be spent on the machine and its buildings and the rest on the first experiments, beams, data-handling systems, and laboratory services. By the end of the construction period the staff for operating the machine would be about 1860 people. (An accelerator of half the size—150 Bev—would cost almost two-thirds as much and require a staff about five-sixths as large.) The 300-Bev machine would require 27,000 tons of steel plate and 2500 tons of copper.

For the storage rings, 300 meters in diameter, 11,500 tons of steel and 1100 tons of copper would be needed, chiefly for the magnet units. Successive beams from the proton synchrotron would be stacked in alternate rings. At least 500 beams could be placed side by side in the vacuum chambers of each ring; each of these chambers would be about 15 centimeters wide and 5 centimeters high. To prevent a crippling number of interactions with the stored protons, the vacuum would have to be about 10^4 times that in the proton synchrotron. If construction were started in 1965, the rings could be completed in 1970. A staff of about 470 would be needed to operate them.

Committee on Future Accelerators

In January 1963 a first meeting was called of the "European Committee on Future Accelerators." The committee formed a working party, with Edoardo Amaldi of Italy as chairman and with Burhop as secretary. Using the findings of the accelerator research division, the working group wrote a program for the development of high-energy physics in Europe; this went to the parent committee for endorsement last June, to CERN's scientific policy committee, and then to the CERN council last December. The council limited itself to approving the expenditure of more money for studies.

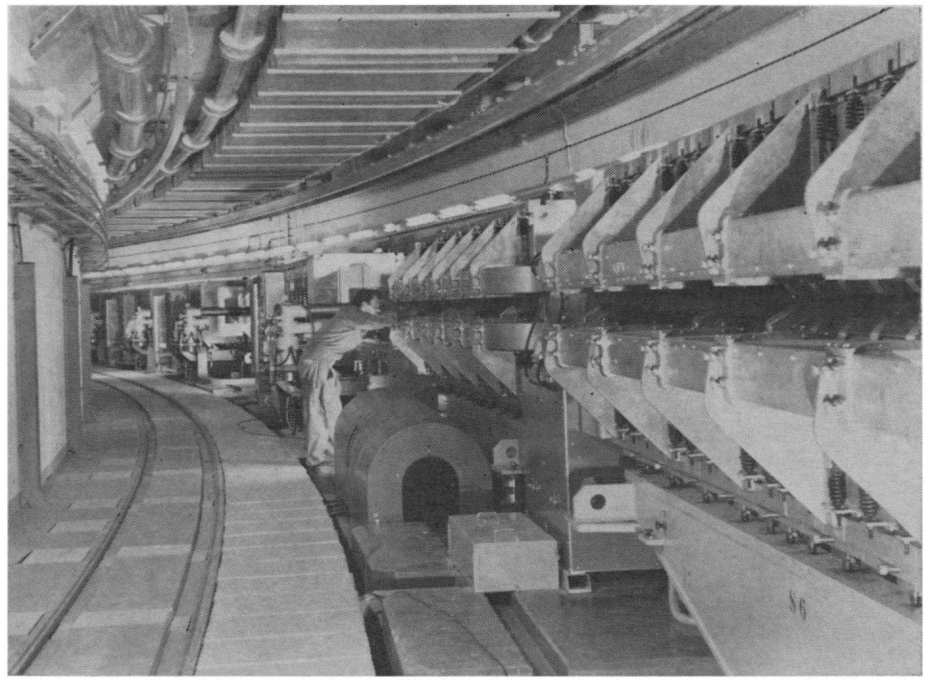
Amaldi's group recommended approval of construction of both the 300-Bev accelerator and the storage rings as a "summit program" within the CERN organization, but it also urged construction in member countries of a "kaon factory," to produce intense beams of K mesons, antiprotons, and higher-energy pi mesons; a "pion factory," to produce intense beams of pi mesons and mu particles; and a high-energy electron accelerator of 10 Bev or more.

Assuming that these machines, those for CERN and six others proposed for Western Europe, would be built, Amaldi's group estimated that high-energy physics would cost about $375 million a year by 1977 and would require 2500 physicists of Ph.D. standing and 1500 professional engineers. The spending Amaldi's group foresaw would represent about 15 percent of the probable total spending on basic research in Europe in 1977. It would be only a very small fraction of the probable total gross national product for countries of Western Europe, but it would still be three times more than the fraction being spent today—0.072 percent against 0.027 percent.

"It is very difficult to obtain reliable forecasts of professional manpower," the Amaldi panel said, "but from those available it appears that it should be possible to obtain the required number of physicists and engineers needed for the program without undue difficulty and without diverting a disproportionate number of available technical and scientific personnel into this field."

The Amaldi committee listed a number of subjects which it would be interesting to explore with higher-energy particles. The neutrinos figured prominently in the list. How does the frequency of reactions involving neutrinos vary with energy? What new neutrino reactions appear at high energies? Will the structures of such particles as protons or neutrons or pi mesons appear the same when neutrinos are the probes as they do when electrons are the probes?

According to the Amaldi committee, the high-energy machines might increase understanding of cosmic-ray observations which indicate that mesons are produced through a highly excited intermediary "fireball" object, a possible "pionic state of matter." With the higher-energy machines, physicists will be able to see whether new "excited states" or "resonances" of the particles continue to occur as abundantly as they have in the CERN and Brookhaven machines.



Tunnel sheltering the CERN 28-Bev particle accelerator. [CERN]

Views of the Director-General

Victor P. Weisskopf is another important scientist who has stressed the scientific potential of high-energy physics. In 1961 he became CERN's third director-general. Vienna-born Weisskopf has held the post on leaves of absence from the Massachusetts Institute of Technology that have been granted until at least July 1965. Weisskopf succeeded J. B. Adams of Britain, who served on an interim basis for a year after the death, in an airplane crash, of C. J. Bakker, CERN's first director-general.

Weisskopf often speaks to scientific audiences on major trends in physics, but he also attaches considerable importance to scientific understanding among laymen. He had an important forum for expressing his views about CERN's future when he addressed the Parliamentary and Scientific Committee in London on 21 February 1963. The audience included many men who may have to vote on appropriations for the proposed storage rings and 300-Bev machine. Weisskopf admitted that "it is extremely improbable that the experimental results obtained at CERN will themselves ever be of practical importance." But large-scale support of investigations of nuclear forces are justified, he said, because "the problems of sub-nuclear physics are today the basic questions of science. They are the perennial questions of 'why' in the structure of matter. Why are the proton, neutron and electron the fundamental constituents of matter? Why are there nuclear and electric forces between them which determine the course of the universe? Ultimately this most fundamental frontier of science will reveal to us the connexions between the phenomena of the infinitely large and the infinitely small, the questions of the origin of the universe and the nature of elementary particles. These questions are of basic significance for all our endeavours, from which stem not only our technology but also our existence as thinking human beings. . . .

". . . The pursuit of fundamental questions was and is the spearhead of science. It attracts the most sophisticated brains and it supplies vitality and vigor to the scientific community which benefits the totality of scientific development. . . .

"If the efforts toward the most fundamental explanations were reduced, the spirit of inquiry would eventually disappear from science. Technology would also suffer . . ., since it is the same spirit that creates new ways of exploiting nature here under terrestrial conditions."

All-European Collaboration

Weisskopf's speech is a recent example of a discussion that has been going on for years. In 1959 and 1960, chairman John A. McCone of the U.S. Atomic Energy Commission and chairman Vasily Yemelyanov of the Soviet Main Administration for Peaceful Uses of Atomic Energy exchanged visits. They discussed machines 10 to 30 times the size of the Brookhaven and CERN machines then just being completed. The next generation of machines, it was said, would be so expensive that world collaboration on meeting the costs might be essential.

Since then, the idea of "world machines" has faded, while construction of smaller machines has grown apace: electron synchrotrons at Cambridge, Massachusetts, and Hamburg, Germany; proton synchrotrons at Princeton, at Argonne National Laboratory, and at Harwell, England. At Stanford University construction has begun on the 2-mile linear electron accelerator, and the Soviet Union is well along on its 70-Bev proton synchrotron.

The great cost of building such machines (at least $1 million per billion electron volts) and of running them has aroused controversy about the amount of money that should be spent on high-energy physics relative to other sciences. Discussion in the United States has emphasized the limits to the expansion of scientific budgets, while debate here has focused more on Europe's relative position as a scientific center. CERN is thought of as a pioneer effort to meet a political objective of more all-European collaboration by setting up a real competitor to American scientific efforts. The scale of scientific spending is somewhat more modest in Europe than in the United States, and CERN, as the only major establishment of its kind in Europe, is of much more importance relative to other facilities than similar high-energy laboratories are in America.

The European debate about the future of high-energy physics also differs from the American discussion in that it comes not when scientific budgets have been high for many years but just after a sharp increase in political awareness of science's role.

Of most importance in the European debate is the attitude of the British government, which now pays 25 percent of CERN's cost. It is not clear in what spirit the British will treat the proposal for storage rings and a 300-Bev accelerator. Last year, after the Amaldi panel had made its report, Britain's minister for science, Quintin Hogg, asked for advice about the proposals. From a panel on nuclear research came three main arguments favoring support: the imminence of new discoveries in physics; the need to retain scientists in Europe; and the usefulness of high-energy physics as a training ground for engineers in problems of vacuums, data handling, and electronics.

Hogg's Advisory Council on Scientific Policy responded: "There is no reason to doubt the validity of the scientific case presented by the working group for this new step forward to higher energies in the field of nuclear physics, nor to question its interest and importance from the standpoint of pure science. In relation to our general level of expenditure on scientific research, however, its cost is very high and raises serious issues of priorities. . . .

"Nuclear physics is only a part of science, although it accounts for a disproportionate amount of our total expenditure on scientific research. It is much more expensive than most other types of scientific work, but, as the Council has repeatedly stressed, our expenditure on the rest of scientific research is too low. There is a widespread feeling of discontent among academic scientists at this state of affairs and an impression that nuclear physics is already getting a very large slice of a rather small cake, despite the fact that the results to be obtained from it are likely to be of much less immediate practical importance than those from many other types of research. . . ."

Other needs should be met first, the council argued. It also urged that efforts toward world cooperation in nuclear physics be intensified at once. "Every effort should be made by governments . . . to seek full international cooperation now, before beginning the construction of a 300 Bev machine. The need to cooperate now is the more urgent since machines of even higher energy will assuredly be demanded in a few years' time."

—VICTOR K. MCELHENY

British Physics Journals

In Great Britain the three major publications concerned with physics are published by The Institute of Physics and The Physical Society. This body resulted recently from the amalgamation of two separate bodies, the Physical Society, which published the *Proceedings of the Physical Society,* and the Institute of Physics, which published the *British Journal of Applied Physics* and the *Journal of Scientific Instruments*. During the 3 years which have elapsed since the amalgamation the journals have been coordinated so that, together, they now cover the whole range of physics in a logical manner.

Proceedings of the Physical Society publishes original contributions on such topics as nuclear physics, statistical thermodynamics, and quantum mechanics, together with theoretical studies and experiments of a fundamental nature related to the atomic and electronic structure of matter in all its forms, including solids, liquids, gases, and plasmas.

British Journal of Applied Physics publishes original contributions on such topics as the properties of materials (magnetic, crystallographic, elastic, plastic, optical); applied semiconductor and dielectric physics; wave propagation, including acoustics, optics, and electron optics; applied metal physics; and applications of magnetohydrodynamics and thermonuclear devices.

Journal of Scientific Instruments describes physical instruments, and its coverage is being extended to include description of instrumental and experimental techniques developed in the course of research work in pure and applied physics.

These three British journals are not as well known as they should be among American physicists, who may, therefore, remain unaware of important work carried out in Great Britain.

The speed of publication of papers in these journals compares very favorably with that in most other physics journals; an average time of 4 months between receipt of manuscript and final publication is now being achieved.

The other major activity of the Institute and Society which concerns physicists outside the United Kingdom is the Annual Exhibition of Scientific Instruments and Apparatus, which has been held, except during wartime, since 1905. This is an exhibition of new British instruments which are unique either in the physical principles on which they are based or in the way they have been developed; they are shown by instrument firms, by government establishments, and by university departments. The exhibition is considered one of the most important events of the year in the research-instrument field; this year it was attended by well over 20,000 physicists.

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