CERN *Symposium on High-Energy Accelerators and Pion Physics*

a summary report

By M. Hildred Blewett

DURING the two weeks of June 11 to 23, this summer, a conference was held in Geneva, Switzerland, to discuss present and future problems in the building of high-energy accelerators, instruments for using them, and the results obtained or to be expected from them. The three to four hundred physicists present represented more than twenty countries, ranging alphabetically from Australia to Yugoslavia, with the largest delegations, of over 50 each, from the United States and the Soviet Union. Hosts for the conference were the members of CERN (European Organization for Nuclear Research): the organization, established by 12 Western European countries, that is building a laboratory for research in nuclear physics located just outside the city of Geneva.

The conference was both exciting and exhausting. The formal papers and discussions started at 9 A.M. and lasted until almost 7 P.M. These were held in the Institute of Physics of the University of Geneva and Professor Extermann, chairman of the Institute, even held some of his lectures at 7 A.M. to keep his large lecture hall free for our use. Next to the Institute, a large tent was erected where we had coffee and tea during short breaks in the morning and afternoon sessions and where lunch could be obtained. It was here that we learned that, although few of the Russian delegates could speak much English, they were just as adept as we at using the paper table cloths or table napkins for rough sketches of equipment or approximations to theories. In the evenings we were feted at many receptions held by CERN and by some of its staff members, by the Canton and the Republic of Geneva, and by the Soviet delegation (with caviar and vodka imported for the occasion). Although the receptions were scheduled from 6:30 to 8:30 P.M. they usually lasted much longer with further discussions continuing over supper and cafe tables until the early morning hours. Short sight-seeing trips to the Jungfrau, Matterhorn, or Mont Blanc used up any remaining spare time. In short, there were not many hours for sleeping and, besides, we could postpone that until we were back home.

The full proceedings of the symposium will be published by CERN this year. Preprints of most of the scheduled talks were made available shortly before the meetings, discussion speakers were urged to write down their remarks, a large number of the CERN personnel took extensive notes, a tape recorder was continually operating, the blackboards were photographed at frequent intervals, and all slides were held for three days by CERN for reproduction. Thus, the proceedings should be fairly complete and the following impressions, it is hoped, will serve only as a very small appetizer for the feast to come.

The official languages of the symposium were English and French; the Soviet delegation brought several interpreters to translate the Russian papers into English (and their preprints were in English). One side of the lecture hall was provided with earphones for use when the interpreters translated the other papers into Russian. Since these interpreters had not had specialized training in physics, the discussion periods might have been rather difficult had it not been for the bilingual abilities of G. M. Volkoff of the University of British Columbia, Canada. General conversation proved to be quite possible even without translation but, for specific discussions, the translators were much in demand. The very friendly and open exchange of information between all those attending, and the closer feeling of association, were major features of the conference. The same view was expressed many times by the participants from the Soviet Union.

THE first week's meetings, on accelerators, were concerned with two main topics: new ideas for accelerating machines, and the specific detailed problems that are confronting those who are now designing or beginning construction of high-energy accelerators. High energy, as applied to accelerators, now means several Bev or higher, and new ideas are aimed at not only

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A session in progress. The Symposium on High-Energy Accelerators and Pion Physics, reported here, was held June 11–23 in Geneva, Switzerland, by the European Organization for Nuclear Research.

trying to increase the resultant energy but, also, to increase the intensity of the accelerated beams. Then, again, the size of accelerators seems to be getting out of hand—the 25-Bev synchrotrons being constructed by CERN and by the Brookhaven National Laboratory, in this country, are a half-mile in circumference!

One promising development for obtaining higher intensities in synchrotrons has been the FFAG (fixed-field, alternating-gradient) principle first proposed by K. R. Symon, and the extensive work done by members of the MURA (Midwestern Universities Research Association) group on these ideas was presented by D. W. Kerst, K. Symon, and L. W. Jones. In this type of accelerator, the magnetic field is kept constant in time but its magnitude varies across the space enclosed by the vacuum chamber in such a way that particles of all energies, from injection to final, have stable orbits within the chamber, thus providing the possibility of continuous operation. Strong, alternating-gradient focusing can be obtained in several ways. The radial-sector type consists of a magnet with a field that increases with radius; the gradients are alternated by having radial sectors wherein the field itself is reversed. Another type involves a magnet which has a radially increasing basic field with the alternating gradients produced by superposed spiralling ridges that give azimuthally alternating troughs and ridges in the basic field.

In order to obtain the equivalent of much higher energies, the MURA group has suggested placing two 15-Bev machines tangential to each other, with a common field-free section at the tangent point where collision processes occurring between the two beams, circulating in opposition to each other, would correspond to a fixed target being bombarded by particles from one accelerator of over 500 Bev. However, for good experiments, the colliding beams would need much higher intensities than are present in beams from existing high-energy machines. There is the possibility that, in a FFAG accelerator, since the magnetic field is constant in time, many pulses could be accelerated and "stacked" at some fixed energy and could continue to circulate in the equilibrium orbit of that energy.

Futher ideas in connection with colliding beams were presented by G. K. O'Neill, of Princeton, who proposed the use of two "storage-ring" magnets, i.e., two annular dc magnets into which could be deflected alternate pulses from an accelerator like the one now under design in the joint project of Princeton University and the University of Pennsylvania. This machine, a 3-Bev proton synchrotron, is planned to operate at 20 cycles per second in the interest of getting higher intensity, and was described by M. G. White. The storage magnets, since they can be somewhat smaller in radius and of smaller cross section than the accelerator, might be built for about 20 percent of the cost of the main accelerator. The stored pulses could, perhaps, keep circulating in the magnets for two or three seconds so that 20 or 30 pulses could be stored in each ring. W. M. Brobeck, from the Berkeley Radiation Laboratory of the University of California, where some general studies on higher-energy accelerator design are in progress, reported that the storage-ring idea looked quite interesting in view of some stacking experiments that had been done some time ago in the 184-inch cyclotron where 6 or 7 pulses had been successfully accumulated.

The application of the spiral-ridge FFAG principle to constant-frequency cyclotrons has been studied, at length, by the accelerator group at the British Atomic Energy Research Establishment at Harwell but, according to a report given by T. G. Pickavance, it appears that serious resonance effects place an upper limit at 900 Mev for such machines. A. Roberts, of the University of Rochester, has made some investigations of a cyclotron made up of separated radial sectors, like that proposed some time ago by Thomas, but modified by the addition of spiral field variations, and he is optimistic about being able to reach 2 Bev with almost constant frequency.

The most speculative new ideas for accelerators came from the scientists from the Soviet Union where, apparently, developments in thermonuclear work have led to interesting possibilities for focusing and accelerating particles, and they have examined many problems concerned with ions which are being accelerated in a highly dense, quasi-neutral plasma of relativistic electrons and ions. Considerable theoretical work, including a study of the stability of such a system, has been done by G. J. Budker, in Moscow, and was presented by A. Naumov, one of his co-workers. If an electron beam, traveling at relativistic velocity, has its space-charge forces neutralized by positive ions, the beam will shrink to a very small diameter with a very high-current density. The calculations show that beams of well over 10 000 amp can have a cross section of only a very small fraction of a millimeter. In such a plasma, the very high magnetic fields with very steep gradients might be useful for guiding and focusing accelerated particles. As a numerical example, if one could produce a circulating beam of about 10 000 amp, at about 15 Mev, the energy of the ions which could be held in an orbit of 3-meter radius could be as high as 100 Bev. To study such high-current electron beams, Naumov and Budker have been using a modified betatron in which they have had a 10-amp electron beam circulating at about 3 Mev and they are now trying for 100 amp at 10 Mev. This reported experiment had not included the addition of positive ions for neutralization. Acceleration processes arising from consideration of induced plasma oscillations were discussed by V. I. Veksler, of Moscow, but, to those of us who have not been working in this field, the ideas were not too clear. One method for obtaining high-current beams at not-too-high energies involves an acceleration process that is the inverse of the Cerenkov effect in the plasma medium. For getting very high energies (he quoted 10^{13} ev), he proposed a collision-type of energy transfer between the plasma and the particles to be accelerated. Ya. B. Fainberg, from Kharkov, continued the discussion of acceleration by plasma oscillations as this might be applied to a linear accelerator with the plasma acting as wave guide.

There are a number of accelerators in the several-Bev range that are now either under construction or seriously under design. As mentioned earlier, 25-Bev proton synchrotrons of the conventional alternating-gradient type are under construction at both Brookhaven and CERN and are expected to be completed around 1960. One of the serious problems of these machines occurs at an intermediate energy, around 7 Bev, where the particles have no phase-stability, the so-called transition energy. This is the energy when the stable phase changes from the rising side of the rf wave to the falling side. In the Soviet Union, a method of avoiding this point has been proposed through the addition of compensating magnets where the sign of the magnetic field, but not its gradient, is reversed. Designs based on this idea, for machines to accelerate protons to 7 Bev and to around 50 Bev, were reported by V. V. Vladimirsky, one of the originators of the idea. At present, a working model of 4-meter radius, to accelerate protons to between 300 and 600 Mev, is being constructed to be finished in about a year. To study orbit dynamics and the effects at the transition energy an electron accelerator (an analogue) was built at Brookhaven; the results presented by G. K. Green showed that the particles had no difficulty going through this transition point and, in fact, behaved much better than indicated by theory. Both K. Johnsen, of CERN, and A. A. Kolomensky, from Moscow, discussed some of the theoretical aspects of the transition region.

In the 15-Bev region, the MURA group has been studying the design of a FFAG accelerator; a model of the spiral-ridge type is being built at the University of Illinois and an electron-betatron model of the radial-sector type is in operation at the University of Michigan. J. J. Livingood, from the accelerator group at the Argonne National Laboratory, described studies for a 12-Bev proton accelerator wherein the magnet would have a radially constant, pulsed field that could, perhaps, reach as high a value as 20 kilogauss; focusing would be provided by the edge fields at the ends of 8 wedge-shaped sectors. Near Moscow, the 10-Bev weak-focusing (low, constant-gradient) proton synchrotron is almost ready for operation and, across the world, at the Australian National University, at Canberra, a 10-Bev air-cored machine is partially constructed. Following down the energy scale, the Harwell group is now studying the design of a 6–7 Bev proton synchrotron with a low radial gradient (weak focusing) but with stronger vertical focusing provided by spiral ridges.

Receiving line at Soviet reception: (left to right) E. J. Lofgren, R. L. Thornton, E. McMillan, D. Blokhintzev, V. I. Veksler, M. G. Mescheryakov, and K. D. Sinelnikov.

Aerial view showing construction in progress at CERN's Meyrin site, near Geneva, Switzerland. (Photograph taken in March 1956.)

They have also considered a sort of double-aperture synchrotron where the magnet core could be fairly small in cross-section surrounding a small aperture that would be sufficient to contain particles at higher energies. From this magnet, jaws would extend, radially, to encompass the larger aperture required at injection. A very similar idea, discussed by G. Salvini, has been proposed, independently, by the group at the University of Rome that is building a 1-Bev electron synchrotron. At the French Atomic Energy Commission's Laboratory at Saclay, near Paris, a 2.5-Bev constant-gradient proton synchrotron should be completed in somewhat over a year. The Princeton-Pennsylvania 3-Bev, 20-cycle machine has already been mentioned.

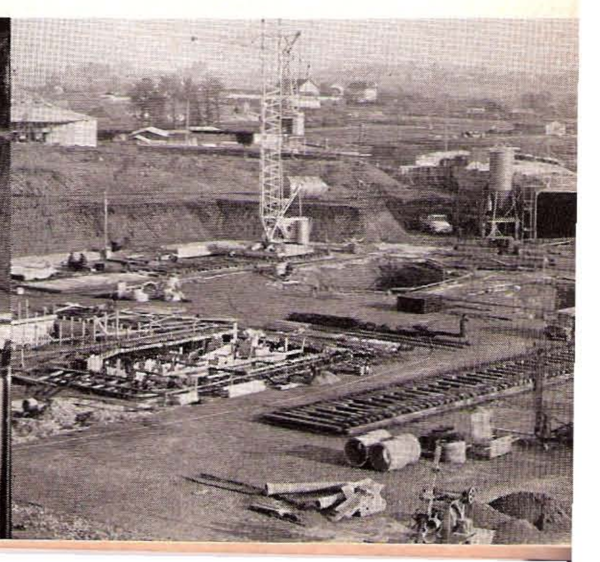
An alternating-gradient electron synchrotron for about 6 Bev is being planned by a joint Harvard-M.I.T. project in Cambridge and details of its design were given by M. S. Livingston. The top limit to the energy of this machine is set, not so much by the additional energy per turn that is required to make up the radiation losses, but by the extent of the radial oscillations which occur as a result of this radiation. In the Cambridge design, these oscillations fill the vacuum chamber at 5 Bev although there is some hope that the effects can be offset by suitable compensating magnetic fields. Theoretical aspects of this problem were presented by A. A. Kolomenski, from Moscow. For higher energies in electron accelerators, R. B. Neal recommended the use of a linear accelerator on the basis of the experience with the machine at Stanford University. He gave some speculations on problems associated with such an accelerator in the tens-of-Bev range which might be 2 or 3 miles long.

In the sessions of the meeting on more detailed aspects of machine design and construction, talks on injection problems and on the design of proton linear accelerators were given by J. P. Blewett of Brookhaven, P. Lapostolle of CERN, M. Salvat from Saclay, B. K. Shembel of Moscow, Ya. B. Fainberg of Kharkov, and P. D. Dunn from Harwell. Ejection techniques were presented by G. B. Collins of Brookhaven, V. V. Vladimirski of Moscow, A. Citron of CERN, A. V. Crewe from the University of Chicago, V. P. Dmitrievski of Moscow, and N. F. Verster of the Philips Company in the Netherlands. Various magnet problems were covered by C. A. Ramm of CERN, H. Bruck of Saclay, J. W. Blamey from the Australian National University, and D. W. Kerst of MURA. E. G. Komar described, in some detail, the measurements and necessary corrections for the 35 000-ton magnet in the Soviet 10-Bev machine. Rf acceleration techniques were discussed by C. Schmelzer of CERN, S. M. Rubchinski from Moscow, R. L. Thornton from Berkeley, and I. H. Neviajski from Moscow. Papers on nonlinear orbit theory were contributed by A. Schoch of CERN, E. D. Courant of Brookhaven, A. A. Kolomenski from Moscow, K. R. Symon of MURA, and J. Moser of New York University. M. Barbier, of CERN, described an ingenious mechanical model that has been used to study some of these problems. Gas-scattering losses in weak-focusing electron synchrotrons were discussed by C. Bernardini of the Rome group. The present operation and experimental arrangements of the Brookhaven Cosmotron (3 Bev), the Berkeley Bevatron (6 Bev), and the Soviet 6-m synchrocyclotron (680 Mev) were described in talks by L. W. Smith, E. J. Lofgren, and V. Djelepov, respectively, and, during the ensuing discussion, a few remarks were made by P. B. Moon about the operation of the 1-Bev proton synchrotron at the University of Birmingham, in Great Britain.

The week of accelerator meetings closed with a visit, on the Saturday afternoon, to the CERN site at Meyrin, a few miles out of Geneva on the border between Switzerland and France. It was a stirring sight to see the flags of the 12 nations flying against a backdrop of the Jura mountains on one side and on the other, looking toward Geneva, the snow-covered Alps with Mont Blanc sometimes appearing out of the mists. On the site, the CERN Laboratory, which was started about two years ago, is making rapid progress. A splendid building, with large experimental rooms on each side, houses the 5-m (about 600 Mev) synchrocyclotron; the magnet is in place, the generator is being installed, the dees are delivered, and completion of the machine is scheduled for next year. Stretching off to one side of the synchrocyclotron building there is now under construction a spreading building that will contain a series of physics laboratories and a large auditorium. Over on the other

I. H. Neviajski, S. M. Rubchinski, V. I. Veksler, and other members of Soviet delegation at CERN Conference on High-Energy Physics.

CERN. Area of experimental halls and laboratories with proton synchrotron ring in the background. (Photograph taken in January, 1956.)



View of one of the eight bays symmetrically spaced on the ring of CERN's proton synchrotron. (Photograph taken in March 1956.)

side of the site, the buildings for the 25-Bev proton synchrotron are taking shape. The walls for the large experimental hall are going up and the tunnel which will house the magnet is about half built. As we walked through a section of this tunnel and looked at the operations from above ground, it is probable that most of the spectators (except for the Brookhaven group) had not previously realized the actual magnitude of such a machine. Also, speaking personally, it may be that only the Brookhaven group fully appreciated the fearsome headaches involved in trying to achieve a stable magnet foundation on such difficult terrain. To solve these problems, a full-scale model section of the tunnel was built last year at a separate location from the main ring. Near the ring is a small structure, looking like a carrousel, where the concrete is very carefully mixed according to strict composition specifications. It all makes a very impressive picture.

THE talks given during the second week of the conference, devoted to pion physics, fell into three general categories: experimental equipment and techniques, results of experiments, and present theoretical ideas. An average of eight scheduled papers of varying length were presented at each morning and afternoon session, with five papers given in one evening meeting. One full day was spent on details of bubble chambers, over-compression chambers, and other track chambers; Cerenkov counters and other fast-counter techniques occupied one half day. More than one full day was devoted to theoretical aspects of pion physics. The results of scattering experiments were reported in two half-day sessions, one for nucleon-nucleon scattering and one on pion-nucleon scattering. Pion production by nucleons and photoproduction of pions were discussed at several sessions. However, in spite of all this, many of the attendees of the first week (including the author) were frequently to be found in other more informal meetings, continuing the accelerator conversations on magnets, rf problems, orbit theory, linacs, and so on. But there was full, standing-room-only attendance on the afternoon when E. Segrè described some of the anti-proton experiments which are going on at Berkeley. The present counting rate is about one antiproton per minute and a study has been made of the interaction cross section, using Cu and Be as attenuators. The antiproton cross section appears to be about twice that for the proton, which is about geometric, and the annihiliation partial cross section is about half of the total for Be whereas it is about 65 per cent in the case of Cu. At the same session, E. Amaldi, of the University of Rome, discussed some observations in emulsions and mentioned a picture that might, perhaps, be a charge-exchange event, antiproton to antineutron.

Before the conference was over, an informal group met to consider future conferences. It was more or less agreed that, in 1958, another accelerator meeting might be held in Geneva in combination with a high-energy physics conference like those that have been held annually at Rochester and like the one held this year in Moscow. The offer of CERN hospitality, for another meeting, was most generous in view of the tremendous amount of work involved in this year's symposium by the members of CERN, especially C. J. Bakker, the director-general of the CERN Laboratory, W. Gentner, director of the synchro-cyclotron division, and J. B. Adams, director of the proton-synchrotron division. To these and the other members of CERN and, particularly, the always-smiling, ever-helpful ladies of the symposium secretariat, go the very sincere and grateful thanks of the participants. We are all, I am sure, looking forward to meeting again in 1958.