THE BROOKHAVEN INTERNATIONAL CONFERENCE ON HIGH-ENERGY ACCELERATORS

A Summary Report by ***M. Hildred Blewett***

SPONSORED by the International Union for Pure and Applied Physics, the United States Atomic Energy Commission, and Associated Universities, Inc., an International Conference on High-Energy Accelerators was held from September 6 to 12, 1961, with the Brookhaven National Laboratory serving as the host organization. The first part of the conference took place at the Barbizon-Plaza Hotel in New York City; then, over the weekend, all the participants were moved out to Long Island to the Brookhaven Laboratory for the remaining sessions. Almost all the delegates remained for the day after the conference was officially over to share in the celebrations connected with the dedication of Brookhaven's 33-Bev Alternating-Gradient Synchrotron.

Although representatives attended from most of the countries of the world where large accelerators are in use, under construction, or being given serious consideration, a telegram was received during the first day stating that none of the expected delegates from the Soviet Union would be present. This was a source of considerable personal regret to many of us who had been looking forward to renewing acquaintance with those we had met at previous conferences or during private visits. The absence of the Soviet delegation also represented a serious deficiency in the program of the conference. It is very unfortunate that we have been left in a state of almost complete ignorance concerning the present status of the accelerators that are being built in the USSR and the ideas for future development that might have been forthcoming.

The major theme, which characterized many of the formal talks and much of the informal discussion, was, "Well, where do we go from here?" The successful completion of the 30-Bev machines at CERN and Brookhaven, both now engaged in full-scale high-energy research programs and both having reached, with relative ease, intensities of 2 to 3×10^{11} protons per pulse, has encouraged accelerator builders to be enthusiastic about reaching into higher ranges of both energy and intensity. Many of the delegates had attended one or more of three meetings which had taken place during the summer months, and which provided background for this general subject during the conference.

The first of these, held at CERN from June 5 to 9, was attended chiefly by theorists who discussed investigations of high-energy phenomena with the present 30-Bev machines, as well as those that might be fruitfully conducted with future possible accelerators. Primarily, this meeting was to provide guidance in making plans for further facilities for high-energy research at the CERN Laboratory. For about six weeks, during July and the first half of August, a series of seminars was held at the Lawrence Radiation Laboratory (under the leadership of Dr. Lloyd Smith), again chiefly on the theoretical and experimental aspects of high-energy phenomena for the benefit of those who have been working on the design of proton accelerators in the 100- to 300-Bev range. During the past year many persons, primarily at Caltech and LRL, have been giving serious consideration to such design problems. Finally, at Brookhaven, during August, an intensive study was made by a number of American and European experts on actual machine design for accelerators of 300- to 1000-Bev energies. This was the culmination of a six-month effort, stimulated by the McCone-Emelyanov agreement of 1959, that had been undertaken at Brookhaven (under the direction of J. P. Blewett) to prepare preliminary designs for possible future international cooperation in a very-high-energy accelerator project. In parallel with the machine-design work, another study group at Brookhaven (under the guidance of L. C. L. Yuan) had been considering the experimental use of a machine of these energies and the possible extension of techniques for the detection and study of the resultant secondary particles.

With the background of these meetings, and other smaller ones on the same subject, the delegates gathered in New York City on the day before the conference and were welcomed at a cocktail party sponsored by Associated Universities, Inc. Interspersed with greetings to old friends was much discussion on future accelerator design and the present status of existing or nearly completed machines. As an aid in such discussion, a cata-

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One of the conference sessions at the Barbizon-Plaza Hotel.

logue of high-energy accelerators, compiled for the conference by M. Q. Barton, was included in the briefcases given to registering delegates. It is indicative of the growth of the accelerator field that this catalogue lists as complete, or very nearly so, eleven proton synchrotons, seven electron synchrotons, and two linear accelerators, all one Bev or more in energy.

THE conference opened with a welcoming address by G. K. Green, chairman of the conference's Organizing Committee, on behalf of both the committee and the Brookhaven Laboratory. He noted that he had, in his own experience, seen an increase in energy of accelerators of a factor of 2×10^4 and was quite hopeful of seeing at least two more powers of ten.

The first session continued with addresses by two theorists, R. Serber and L. Van Hove, who had been invited to review the present status of high-energy physics and to recommend future lines of investigation. Both speakers spoke of the difficulty of making predictions, as illustrated by the fact that the present 30-Bev machines already had under way, or in preparation, experiments (neutrino investigations, for instance) that had not been contemplated when these accelerators were first being designed. During his rather general considerations of the justifications for building machines of considerably higher energy, Dr. Serber felt that one could summarize the situation best by saying, "Every time in the past, when we have entered a new energy range, we have struck gold. Why not in the next energy range?" Dr. Van Hove went into a bit more detail in his talk and gave, in essence, a summary of the June meetings at CERN. Since even the highest energy contemplated will not be sufficient for a merging of the various types of interactions, he considered separately the problems associated with weak, electromagnetic, and strong interactions. Existing machines will be able to answer some questions, particularly some of the qualitative ones. In the weak interactions, for example, it may be possible to determine whether there are two kinds of neutrinos and whether an intermediate boson exists. For many cases, however, we know that much higher energies are necessary; further work with the present machines may show this even more clearly.

In addition to the desire for higher energy, Dr. Van Hove stressed the need for the higher intensity that it may be possible to reach, as well as a high degree of flexibility in order to use, as projectiles, as many types of stable and unstable particles as possible. When these two speakers were pressed to be somewhat more explicit about a particular energy range, their answer was that this would probably be determined by how much money was available.

The second session of the conference was devoted to the performance of the 30-Bev machines and opened with a review of particle-production data by R. L. Cool. The greater part of his information came from an extensive survey carried out at Brookhaven by several groups during previous months. It extended and corroborated similar work at CERN that had previously been reported by Cocconi at a Rochester conference. Since this conference summary is primarily concerned with accelerators rather than high-energy physics, and since the work reported by Dr. Cool is either in print or in press, these data will not be summarized here.

Reports on the synchrotons, presented by M. G. N. Hine for CERN and by G. K. Green for Brookhaven, reflected justifiable satisfaction with these alternating-gradient machines. In the first trials, both reached their full design energy almost immediately, with an intensity at least ten times what had been optimistically expected, and have already passed another factor of ten. They can be operated relatively easily and reliably; the beam behavior seems to be fairly close to the theoretical predictions, and, because the beam's position can be controlled so accurately, targeting is simple and straightforward. It is not surprising that the builders appear happy. Both speakers felt that another factor of ten in intensity (10^{12} particles per pulse) would be reached in the fairly near future. This will present quite serious problems from residual radioactivity, which have already become apparent at the present levels. More complicated remote-control devices for target removal (and, perhaps, for machine maintenance) will be necessary. Because the CERN machine has been in operation about a year longer than the Brookhaven AGS, there has been time to learn somewhat more of the beam dynamics and to provide more variety in targeting arrangements and duration of bursts. Also, at CERN, there have been more hours of operation for experiments. Starting in October (1961) this machine is to be operated 110 hours per week, with 93 hours for experimenters. On the other hand, the Brookhaven machine will not be able to provide more than 40 hours per week for high-energy physics experiments until early in 1962.

There were no reports on the status of accelerators now under construction since their design had been covered at previous accelerator conferences. They were also listed in the catalogue mentioned above. However, the proposed designs of two high-intensity machines, one in the United States and one in Japan, were discussed in the third session.

B. Waldman described the design for a 10-Bev spiral-sector FFAG proton accelerator that the Midwestern Universities Research Association will soon present to the AEC as a proposal for construction. With a fairly conservative design, this proposed accelerator should accelerate at least 2×10^{14} particles per second. In a spiral-sector model, the MURA group has successfully extracted a primary beam in one turn and plans for such extraction are included. A great deal of computational and model work, including magnet models, has been already carried out to prepare this proposal.

Colin Ramm and M. Stanley Livingston.

Robert Serber and Robert F. Bacher.

In Japan, there has been much discussion about building a high-energy accelerator, and T. Kitagaki outlined the present plans. The proposed machine would be an AG synchrotron designed to produce 12-Bev protons and to operate at 16 pulses per second. In his last slide, he showed a site layout providing for the future development of a proposed 300-Bev ring for which the 12-Bev machine might serve as an injector.

During the rest of the third session, the subject was high-energy linear accelerators, starting with a general review by Lloyd Smith on proton linacs. In connection with the consideration of synchrotrons of much higher energy, further interest has now developed in linacs having energies of several Bev. The usual thought has been to extend the design of the present 50-Mev linac structure to about 200 Mev and then to change to a design similar to that used in electron linacs. Dr. Smith pointed out that there are several serious problems that arise from the differences between proton and electron linacs. Even at several Bev, protons are not very relativistic and would still need transverse focusing, an injector linac would need a long pulse length, the general beam dynamics is more complex for protons, and so on. Dr. Smith also mentioned work that was presented, more fully, later in the session. This included a description by J. W. Dickson of studies made at the Rutherford Laboratory (Harwell, England) for using superconducting resonators in a linear accelerator to obtain an almost 100-percent duty cycle. In Japan, where a high-energy linac had been considered as a competitor to a synchrotron, some of the problems mentioned above had been considered. T. Nishikawa presented a report on some of the beam dynamics of a disk-loaded proton linac that might form the higher-energy part of the system. R. L. Gluckstern described the results of extensive computations of shapes of drift tubes and irises for such a high-energy linac—an extension of some of the ideas incorporated in the Brookhaven 50-Mev machine.

The present status of the design studies for Stanford's project M (for Monster), the two-mile long electron linac, was briefly presented by W. K. H. Panofsky. He had time to mention only a few of the items and show some interesting slides. (A full report will appear in the conference *Proceedings*.) This accelerator is designed to produce a beam of 10- to 20-Bev electrons at an average current of 15 to 30 microamps in its first stage of operation. Later, it could be extended to 20 to 40 Bev in energy, and to an intensity of 30 to 60 microamps, by increasing the number of klystron power sources. To add to the interest of this paper, Congress was then in the process of debating the appropriation of funds for the construction of Project M.*

A general resumé of the thoughts, in the US, about the possibly much higher-energy accelerators was given by M. Sands in the fourth session. About two years ago, he had proposed a two-stage proton accelerator in which a 10-Bev AG machine, something like the Brookhaven AGS, would be used as an injector for a 300-Bev AG ring. Although the circumference of the latter ring would be about five miles, he showed that the magnet cross section could be reduced below that in the present 30-Bev machines, and his first proposal gave a total magnet weight of about 7000 tons for both rings, which would be somewhat less than twice that of the Brookhaven AGS magnet. About a year ago, as mentioned above, a group at the Lawrence Radiation Laboratory started to study the possibility of scaling up the 30-Bev designs to 100 to 300 Bev, with a several-Bev linac as injector. Some thought has also been given to using an FFAG accelerator as injector. Mention has already been made of the Brookhaven studies for machines in the 300- to 1000-Bev range. In all of these studies, it has been concluded that the alternating-gradient principle can be extended almost indefinitely, provided that sufficient money and manpower are available. The costs seem to grow at a rate that might be a little less than linear, with a figure (very tentative) of about $700 million being mentioned for the 1000-Bev accelerator. Another feature of these machines is that high intensities, of the order of 10^{13} protons per second, seem quite probable. For such an intensity at 1000 Bev, however, the energy in the beam itself would be 1.6 megajoules, which would pose a distinct problem in targeting, shielding, and radioactive contamination. Two developments should be given special mention. T. Collins, of the Cambridge Electron Accelerator group, has suggested a means of adding quadrupoles in the field-free sections to make some of these sections 50 to 80 meters long, which would be particularly advantageous for studying the secondary particles that, at these high energies, are concentrated in the very small forward angles. The other idea, developed during the Brookhaven Summer Study, involves a method for providing "beam sidings" whereby a primary beam required for experiments can be taken along an extra outer track. When the experiment is finished, the beam is switched to an inside track behind a permanent shielding wall. With several such sidings, experimental shielding and magnet arrangements could be made (a process needing at least a month or two) without shutting down the accelerator operation. Much of this speculation seems a bit frightening, but the designers talk quite glibly about construction teams of more than 1000 people, machine circumferences of 12 miles or so, and experimental areas of many acres!

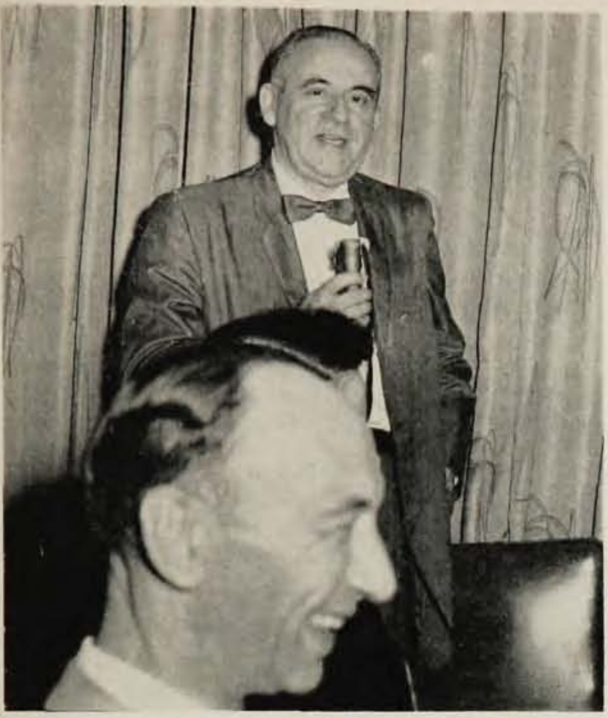
* It has since been learned that the Congress has approved this funding.

W. K. H. Panofsky and E. M. McMillan.

In a somewhat more modest approach, H. Bruck described some methods he has developed for optimizing parameters for a high-repetition-rate AG accelerator for energies up to 25 Bev. This could be used in conjunction with storage rings, or in a cascade type of high-energy accelerator.

A sobering note was injected with two reports on intensity limitations that have been found in the constant-gradient machines. C. E. Nielsen spoke about some theoretical work that has been done and about observations that he and M. Q. Barton have been making at the Brookhaven 3-Bev Cosmotron. In this machine, the particles behave somewhat like the particles in the rings of the planet Saturn in that, although they are subject to some mutually repulsive forces, they can have stable performance. Certain instabilities can occur, however, and Dr. Nielsen had many interesting oscillograms showing strange cluster formations and losses of particles during the beginning of the accelerating cycle. At Saclay, losses have also been observed at injection in a similar accelerator, known as Saturne, and some relevant theoretical studies and observations were reported by G. Gendreau.

In the evening, the conference banquet provided relaxation in the company of many of the wives. After dinner, S. A. Goudsmit, managing editor of the Ameri-



Banquet speaker Goudsmit amuses G. K. Green.

can Physical Society, spoke briefly and humorously, comparing the simplicity of physics in his early years with its present complexity, particularly in the high-energy field. His comments about large projects were heartily enjoyed, especially in view of the afternoon's session.

The next day, the morning session was entirely given over to theoretical papers. D. A. Swenson, in the first paper, described some computer work wherein he studied various problems connected with beam stacking. The next two papers, by K. Johnsen and E. D. Courant, reported on theoretical and computational studies of a phenomenon that had been found, almost accidentally, at CERN's proton synchrotron. It was discovered that a larger fraction of the injected protons can be successfully accelerated if the rf system is tuned to a slightly different frequency than had previously been considered proper. This mistuning had been tried at Brookhaven with equal success, and it is one of the factors responsible for good intensity in these machines. A study of a first-approximation theory of bunching, in electron linacs, was presented by H. Zyngier. A proposal for using the accelerating rf for beam bunching, or debunching, was described by L. C. Teng. This might be useful in transferring beams from one stage to another in a multi-stage accelerator or for transporting accelerated beams into experimental apparatus. J. R. Holt discussed the effects of certain types of magnet arrangement and super-period structure in connection with design studies for an electron AG synchrotron at the University of Liverpool. H. G. Hereward presented two papers, one on means of damping radial betatron oscillations in strong-focusing storage rings for electrons. Such rings, of about 100-meter radius, have been considered at CERN for protons, and he has looked into the possibility of using them for electrons. His second paper described some theoretical second-order effects in beam-control systems of particle accelerators. A method of resonant injection and ejection for sector-field accelerators was proposed in a second paper by L. C. Teng.

The sixth session was entirely concerned with the controversial subject of storage rings and colliding-beam rings. In such arrangements, beams from a conventional accelerator can be stacked, under the proper conditions, to give very high intensities. For colliding beams, there are two such rings, either tangential or crossing at a small angle, and the advantage is that, for a relatively small cost, one can observe collision processes that have center-of-mass energies corresponding to extremely high energies in a conventional accelerator. For example, even for a 1000-Bev primary beam striking a stationary target, the available center-of-mass energy is only 45 Bev. However, it is usually conceded that the ability to study secondary particles gives the advantage to the high-energy accelerator.

A joint Princeton-Stanford project for a 500-Mev colliding-electron-beam experiment has been in preparation for about two years. G. K. O'Neill, who described its present status, showed pictures of various component parts and mentioned some of the construction difficulties which had been overcome. The complete system is now almost fully assembled at Stanford, and this very interesting experiment should begin soon. At Frascati (Italy) a single storage ring has been built to study colliding electrons and positrons, each with 250-Mev energy, for use with the one-Bev electron synchrotron. C. Bernardini reported some preliminary

Lee Teng, Bernard Waldman, Donald Swenson,

M. G. N. Hine, Lyle Smith, R. L. Cool, L. T. Kerth.

results that have been obtained with this storage ring, which is to serve as a model for a larger one for beams up to about 1.5 Bev, and F. Amman discussed some of the considerations involved in designing the projects at Frascati.

For more than a year, a CERN group has been contemplating the construction of two storage rings for use with the large proton synchrotron. A. Schoch outlined possible parameters. These rings would be about the same size as that of the CERN-PS and the group has considered having a magnet system the same as that of the synchrotron, as well as the possibility of having separate bending magnets and focusing quadrupoles. Further theoretical and computational results were reported by E. J. Woods (of Princeton) concerning magnet-cell structures for concentric storage rings and a study, made by F. Gross, on beam stability against interaction-region forces in a proton storage ring.

The most heated discussion of the whole conference took place at the end of this session, with much argument on the pros and cons of storage rings. Some contestants argued that, in view of their limited use, storage rings should be considered as a single experiment and not a complete facility. Other, more vigorous, proponents maintained that there was good value for the money expended and that, with further study, many types of experiments might be carried out. Some conclusions about the preference of the theorists for very high energy rather than a colliding-beam device were quoted from the June meeting at CERN. In answer, L. Van Hove tried to soften these conclusions a bit by saying that he thought colliding-beam experiments would certainly be of great interest and that it would be a pity if no such device were to be built; however, if one is forced to make a choice between a colliding-beam facility and a higher-energy accelerator, the latter is still to be favored.

The next morning, C. E. Taylor reviewed the work, at Berkeley and Livermore, on cryogenic and superconducting magnets to produce very high fields. Some of the experiments on supercooled, nonsuperconducting magnets had been discussed at earlier meetings, but Dr. Taylor gave further details, particularly about coils made from sodium. At Livermore, several hundred pounds of high-purity sodium have been distilled to make a solenoid (the sodium is cast in stainless-steel tubing) about 8 inches in inside diameter, 16 inches in outside diameter, and 16 inches long. This should be ready for test very soon. At Berkeley, a group has been investigating superconducting coils, particularly those made with niobium-tin alloys. Dr. Taylor reviewed the results together with extensive similar studies being done at many other laboratories throughout the country. Much of this is still quite puzzling. Short lengths of wire seem to behave quite promisingly but longer lengths are disappointing. Results from loosely wound and tightly wound coils are very different. There have been enough successes to whet the appetite but there is much still to be done. As far as accelerator interests are concerned, such supercooled, high-field magnets are probably not too suitable for the accelerators themselves, but would be extremely useful in beam-transport systems. It has been found that in setting up experimental beams with the 30-Bev machines, very large bending and focusing magnets take up much floor space and cannot be placed close enough to targets.

In a short paper, S. Suwa described some results from the Tokyo synchrocyclotron group on efficient beam extraction. The beam has been taken past the region in the magnet where $n = 0.2$ and vertical blowup can occur, to the region where $n = 1$, and an efficiency of extraction of about 60 percent has been achieved. He also gave the results of some rf debunching experiments.

The final part of this session was concerned with FFAG synchrotrons, and a general review of recent developments was given by F. T. Cole. The greater part of this work has been carried out at MURA, much of it in connection with the design and component models for the proposed 10-Bev machine. Several groups in Europe have also been studying FFAG designs for energies from 100 Mev to several Bev. Dr. Cole felt that for a few hundred Mev the radial-sector design is probably advantageous. Around one Bev, however, a spiral-sector FFAG machine may be very useful, particularly to provide large quantities of π-mesons, and preliminary thoughts of the MURA group have led to the conclusion that such a machine could be quite competitive with a linear accelerator, with regard to both intensity and cost. A theoretical paper presented by N. Vogt-Nilsen dealt extensively with orbit dynamics in two-way scaling FFAG synchrotrons. The final paper in this session was a progress report given by W. A. Wallenmeyer on the MURA two-way electron accelerator. In this machine, electrons were to be accelerated in both directions of circulation.

This had been successfully accomplished up to about 27 Mev nearly two years ago. Then, in order to reach higher energies, it was found necessary to correct some of the magnetic fields and it was decided to make these corrections suitable for accelerating electrons only in one direction. The primary goal for this accelerator model was the production and study of highly intense, stacked beams—not necessarily the two-way operation. Just a couple of weeks before the conference, these modifications had been completed and successful trial operation of the accelerator was obtained. Electrons had been accelerated, somewhat beyond the design energy, to a little over 50 Mev. Moreover, several successful attempts to stack many accelerated beams had been made, and a final current of several amperes was reported.

Because of the absence of the delegation from the Soviet Union, the Saturday afternoon session was cancelled, leaving the participants free to enjoy the sights of New York. However, during the entire period of the conference, the metropolitan region was sizzling under a severe heat wave, and many persons found it more comfortable to remain inside the airconditioned hotel. (There was an informal session on cryogenic techniques, but this may have had nothing to do with outside temperatures.) On Sunday evening, many buses brought the delegates out to the Brookhaven Laboratory site, a process carried out with remarkable efficiency, with neither delegates nor baggage being lost on the way. Many of the participants expressed their appreciation to the staff that was never seen but worked long hours to keep the conference running smoothly.

At Brookhaven, during the next two days, sessions were held only in the morning when it was relatively cool. In the first of these, a report on the initial operation in August of the Oak Ridge electron cyclotron analogue was presented by R. S. Livingston. An eight-sector machine that has accelerated at least 1200 turns to full energy (about 500 kev), it has been built to serve as a model for a large proton cyclotron of similar design. The preliminary results appear promising and tribute must be paid to some of the beautiful work that went into the component parts shown in the slides.

Several papers on ion sources and injection problems followed. The polarized proton source for the Rutherford Laboratory's linear accelerator was described by J. M. Dickson, and work on polarized ion sources at Yale was reported by V. W. Hughes. A. Yokosawa (Argonne) gave details of the high-current, duoplasmatron source (Von Ardenne type) which he has been studying; particular emphasis was given to the associated focusing system required to use this type of source. A study of multi-turn injection into FFAG accelerators, carried out by F. E. Mills and D. C. Morin, was reported by the former. At the Cornell 1.3-Bev electron synchrotron, a new injection system, using a 10-Mev linac in place of the 2-Mev Van de Graaff injector, has been installed and its successful operation was described by R. Littauer. This injector eliminates the need for frequency modulation in the rf system and has improved the performance of the accelerator to give a twenty-fold increase in intensity to about 2×10^{10} electrons per pulse.

Finally, a review of shielding requirements for high-energy accelerators was given by E. A. Crosbie, who mentioned some of the previously reported early calculations made for the 30-Bev synchrotrons. The 1957 New York Shielding Conference stimulated an extensive computational program that is still going on, and when these calculations are complete there should be much information to compare with future experiments that can be planned for corroboration.

G. K. Green announced that the Brookhaven AGS would be turned on in the afternoon for the benefit of the visitors who would like to see it in operation. This announcement was a bit frightening to members of the staff who felt like the parents of a still very young and slightly obstreperous child, uncertain about its behavior in front of distinguished guests. But the AGS behaved beautifully, accelerating particles willingly to 33 Bev at an intensity of between 2.5 and 3×10^{11} protons per pulse. The staff members heaved a collective sigh of relief and were in a good mood to participate in the cocktail party and dinner that evening, where both they and the conferees were the guests of Associated Universities, Inc.

The final conference session covered the subject of beam-transport systems for experiments, and associated topics. The first paper, presented by F. E. Mills, described the beam extraction from an FFAG accelerator that has already been mentioned. N. M. King described some of the proposed facilities that may be used with Nimrod, the 7-Bev proton synchrotron now under construction at the Rutherford Laboratory, and gave details of some of the computational programs that have been used to plan the beam-handling systems. K. G. Steffen spoke about some work on quadrupoles and a computer for studying beam trajectories that has been developed at Hamburg. The production of a nanosecond modulated bremsstrahlung beam, at Cornell, by the inherent rf bunching in the electron synchrotron was described by B. D. McDaniel. A short description of the design and preliminary performance of the 3.3-Bev/c separated antiproton beam, at the Brookhaven AGS, was given by J. Sandweiss. This had been completed just prior to the beginning of the conference, and pictures in a 20-inch liquid-hydrogen bubble chamber had been taken during the previous week. An interesting feature of this beam was that, in tuning it for best performance, the computed values for the currents in the beam-transport magnets turned out to be the optimum ones. The final paper, presented by W. Richter, gave further details of targeting and machine performance at CERN.

The concluding event of the meeting was an afternoon tour of the high-energy facilities at Brookhaven. The AGS was, of course, not in operation and the visitors were free to see the entire machine and the associated experimental equipment.