

PHOTON INTERACTIONS

in the BeV-Energy Range

During the period January 26-30, 1963, some 300 physicists gathered at the Massachusetts Institute of Technology for an international conference on the physics of photons at energies greater than 1 BeV. The conference was sponsored jointly by the International Union of Pure and Applied Physics, the United States Atomic Energy Commission, the National Science Foundation, and the Office of Naval Research. The author of this informal summary of the discussions is professor of physics at MIT.

By Bernard T. Feld

THE idea of holding a conference early in 1963 on high-energy photon interactions was a natural one for at least two reasons: first, the Cambridge Electron Accelerator, producing electron and photon beams of energies up to about 6 BeV, came into operation in 1962, so that the time was ripe for detailed consideration of what could be accomplished with such facilities; second, it had been apparent for some time that the traditional "Rochester Conferences" on high-energy physics could not fully satisfy the needs of all the workers in the field for exchange of information and ideas on all of its aspects. Thus, the IUPAP Commission on High-Energy Physics had decided that it would be appropriate to hold the Rochester-type conferences only every second year, and to sponsor regional conferences on specialized topics in the "off-years".

The plans for the conference at MIT were formulated early in 1962 when a proposal was prepared for consideration by IUPAP and by possible American supporting agencies. The proposal was considered by the Commission on High-Energy Physics of IUPAP during the July 1962 High-Energy Physics Conference at CERN (Geneva, Switzerland) and, upon their acceptance of sponsorship, was submitted to the appropriate US government agencies, who responded with enthusiastic support.

During the discussions in Geneva on our proposal, it was suggested that such specialized regional conferences should, if possible, be "open", in the sense that all who desired to participate could attend, subject only to space and other physical limitations. Although it was our original intention to try to limit the number of participants to somewhere around 100, and we were certain that this limitation could not be maintained in an open conference, we nevertheless decided, with some reluctance, to accept this suggestion. No attempt was made to limit participation, although we (purposely) did not advertise the conference widely beyond those laboratories and institutions known to have an active interest in the field.

The number of conference participants was, in the end, around 300, with some 75 from foreign, 90 from nonlocal, and 135 from local (i.e., New England) institutions. But the remarkable fact was that, despite these numbers, the conference sessions remained relatively informal, and the exchanges and discussions were not inhibited by the numbers. The conference had the "feeling" of a small one. In retrospect, as far as this occasion was concerned, the idea of an open conference was completely vindicated.

I believe that the main reasons were that the limitation on the subject matter attracted only



Three of the speakers at the conference: B. T. Feld of the Massachusetts Institute of Technology; A. Salam of Imperial College, London; and M. L. Goldberger of Princeton and MIT.

those participants with a serious, working interest in the field (we worked all day Saturday and Sunday, and Boston at the end of January is no picnic!) and that the openness of the conference permitted many active, younger, less-known physicists to participate. At the same time, the participation was broad and varied enough to reflect the true flavor of an international conference.

But, mainly, it turned out that there is a great deal of active research, of exciting new development, and of widespread interest in photon physics in the BeV-energy range; there is, after all, no substitute for solid content.

This content was presented in nine sessions, each occupying half a day. Each session was initiated by an introductory paper followed by short contributed papers, with ample time left for discussion from the floor.

The first session was on quantum electrodynamics and electromagnetic form factors. In his introductory remarks, D. R. Yennie reviewed the experimental evidence bearing on the validity of quantum electrodynamics. Two types of tests of QED were discussed: The first, and more obvious, relates to experiments involving large momentum transfers, thereby testing the validity of the theory at very small distances in accordance with the uncertainty relationship $\Delta x \simeq h/\Delta p$.

Such tests have, in the last few years, demonstrated the applicability of QED down to distances of a few times 10^{-14} cm. Some of these tests—e.g., the wide-angle production of pairs of electrons or muons by photons or the scattering of muons and

electrons—are currently being extended to the higher energies now available.

The second type of check on QED concerns the radiative corrections, which must be applied to all charged-particle processes in which the charges suffer sufficiently large accelerations so as to lead to appreciable radiation. Until now, these corrections have mostly tested the adequacy of the approximation techniques used in their computation rather than the foundations of the theory itself.

A review of the elastic scattering of electrons by protons and neutrons revealed that the interpretation, in terms of electric and magnetic form factors, is still in a somewhat unsettled state. While it is evident that the experiments require the assumption of one or more “resonances”—reflecting the importance of some of the newly discovered unstable vector mesons, in particular the ρ and ω mesons, in determining the charge and magnetic structures of nucleons—the precise positions of the resonances, and their number, cannot uniquely be determined from the electron-scattering data. Especially, the measurements of the neutron form factors suffer from a serious uncertainty in the theory of the interpretation of electron-neutron scattering observations, where the target neutron is in the deuterium nucleus.

The introduction to the second session, on the theory of Regge poles, was given by M. Gell-Mann. In reviewing this new approach to the understanding of high-energy scattering of “elementary particles” based on the work of Regge, in which the solutions of the nonrelativistic Schrödinger equation



Participants in the conference on photon interactions in the BeV-energy range visited the recently inaugurated Cambridge Electron Accelerator, which is capable of producing electron and photon beams of approximately 6 BeV. Those shown are G. Diambrini of Frascati, C. Tsara of Saclay, and W. Blanpied of Yale.

for particles interacting via Yukawa potentials are described in terms of a continuously variable angular momentum whose integral values correspond to observable states, Gell-Mann described how the successive introduction of additional physical conditions on the solutions leads to the further delineation of the properties of the so-called Regge trajectories describing high-energy scattering. Thus, the introduction of exchange forces leads to the concept of "signature", which requires that observable states occur only at alternating integral values of the angular momentum; the introduction of other physical requirements, such as particle spins and the recognition of possible reaction channels involving more than two particles, leads to further restrictions on the nature and behavior of the possible Regge trajectories.

Most of the theoretical work in this field has been concerned with attempts at a proof, or disproof, of the conjecture that the concept of Regge trajectories corresponds to the actual interactions of particles in the relativistic domain. On the one hand, it has been postulated by some physicists, notably by G. F. Chew and coworkers, that this approach can provide the groundwork for an axiomatic description of all particle interactions which will follow from the specification of only the properties of the scattering (S) matrix; others have insisted that, if the approach is a valid and useful one, it must be derivable from a proper field-theoretic treatment of the interaction of elementary particles. With respect to the first approach, a number of difficulties have arisen in the relativistic theory which indicate that, at the very least, the prop-

erties of the "Regge trajectories" are considerably more complicated than is derived in the nonrelativistic approximation. In contrast, the field-theoretic approach, as outlined at the conference by M. L. Goldberger, has been successful in reproducing many of the Regge features for the case of the scattering of vector mesons by nucleons.

In introducing the third session, S. J. Lindenbaum reported on some experiments done at the new (AGS) accelerator at Brookhaven, designed to test the most spectacular prediction of the Regge theory—that the forward peaking in the diffraction scattering of elementary particles should shrink with increasing bombarding energy. The result of these experiments has, on the one hand, been to confirm the observations of the CERN group on the shrinking of the diffraction peak in proton-proton scattering; but the expected shrinking has not been observed in pion-nucleon scattering!

In the case of electron-nucleon scattering, experiments were reported by R. Wilson of Harvard and by K. Berkelman of Cornell, in which effects of a possible Regge behavior of the photon might have been observed as deviations from the Rosenbluth formula at small angles and high momenta. The absence of such effects in the Cambridge Electron Accelerator (CEA) and Cornell experiments set upper limits of $\frac{1}{10}$ and $\frac{1}{2}$, respectively, for the slope of the "Regge trajectory" applicable to photon scattering as compared to that observed for the nucleon in p - p scattering.

The fourth session was devoted to experiments on the photoproduction of mesons. R. L. Walker summarized the most recent experimental informa-

tion on the photoproduction of pions for energies up to ~ 1 BeV. In addition to their dependence on the effects of the known isobars, whose properties have, to a large extent, been derived from the photoproduction experiments, such observations are capable of elucidating further details of the properties of the meson-baryon interactions, such as the relative parities of the mesons and their coupling constants to baryons through their dependence on the details of the meson-exchange processes. Applications to the study of η - and K -meson photoproduction were described, respectively, by V. Silvestrini of Frascati and B. D. McDaniel of Cornell.

Another application of photoproduction, in which the coherent production of particles in the Coulomb fields of nuclei is used to derive the rate of radiative decay of these particles (e.g., $\pi^0 \rightarrow 2\gamma$, $\eta^0 \rightarrow 2\gamma$, $\Sigma^0 \rightarrow \Lambda^0 + \gamma$), was outlined by H. Primakoff. Application of the Primakoff effect, in π^0 - and η^0 -production experiments at Frascati, was described by G. Bellettini.

In his introduction to the fifth session, devoted to the theory of the photoproduction of mesons, S. M. Berman stressed the special role of photons in the production of vector mesons (ρ , ω) resulting from their direct coupling to photons, which also have spin -1 . As this direct coupling is presumably also responsible for the main features of the nucleon form factors, as derived from experiments on electron-nucleon scattering, it is possible, on the one hand, to make fairly detailed predictions on the photoproduction of vector mesons, especially at high energies, and, on the other hand, to use such experiments to obtain further information relating to the strong interactions responsible for the production and decay of these mesons. The investigation of such connections between the electromagnetic properties of particles and the photoproduction of vector mesons is one of the most interesting fields of investigation open to multi-Bev electron accelerators.

The sixth session considered some new experimental approaches involving the use of high-energy photons. Most of this session was devoted to the theory and application of coherent bremsstrahlung of high-energy electrons traversing crystalline materials. The beautiful experiments in this field, which have been carried out at Frascati, were discussed by G. Diambrini and G. Bologna; these experiments have demonstrated the possibilities for producing monoenergetic photon beams with a high degree of polarization by taking advantage of the predictable features of such coherent bremsstrahlung processes. Of particular interest for further experi-

mentation with BeV-energy electron accelerators were the extrapolations of the Frascati results to higher energies, presented by Diambrini, and the clear and simple theoretical approaches developed by Diambrini, Bologna, H. Uberall, and R. Mozley.

Alternative methods for producing monoenergetic and polarized photons were presented by R. H. Milburn, who described a scheme which utilizes the Compton back-scattering of polarized photons from a high-intensity beam of laser radiation against the electron beam from a multi-BeV accelerator, such as the CEA, and by V. W. Hughes, who discussed a number of possible methods of obtaining sources of polarized electrons for injection into high-energy electron accelerators.

In addition, this session concerned itself with the current status of work on the production of intense currents of high-energy electrons and positrons in storage rings and their utilization in clashing-beam experiments. Results from the Frascati storage ring (ADA) experiment, as reported by B. Touschek, and the Stanford colliding-beam experiment, reported by B. Richter, are still inconclusive as regards the technical feasibility of these techniques, since both projects have encountered serious prac-



The conference in session: S. J. Lindenbaum of Brookhaven National Laboratory comments from the audience.

tical problems whose origins are not yet completely understood and whose solutions have yet to be demonstrated.

The seventh session considered new detection methods, with emphasis on those which are particularly applicable to high-energy electron accelerators. In his introductory remarks, D. A. Hill reviewed the use of counters, bubble chambers, and

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spark chambers in this connection; he concluded his review with a description of an exciting new technical development, the discharge chamber as demonstrated by Charpak and Massonet at CERN, which gives promise of combining the time-discriminating features of counters and spark chambers with the space and ionization density discrimination of bubble chambers and nuclear emulsions.

A number of other developments, operating and projected, were described. These included some special gamma-ray energy-discriminating devices developed at Hamburg; the sonic spark chamber (especially useful for on-line time and space discrimination) now being used by Maglič and collaborators at CERN; schemes for gamma-ray "tagging" by measuring the momentum of the recoil electron in coincidence with its bremsstrahlung photon; an operating automatic spark-chamber scanning and analysis system (SPASS) developed by M. Deutsch in connection with his measurements on Compton scattering of photons by protons; and the various methods, now well along the development stage, for pattern recognition and precision encoding of events recorded in bubble chamber photographs, described by I. A. Pless.

Session eight reviewed the work in progress and preparation at the Cambridge Electron Accelerator. These experiments fall into a number of categories.

1. Studies on the validity of quantum electrodynamics for large momentum transfers (at small distances): The most interesting are the measurements of electromagnetic production of pairs of electrons and/or muons at wide angles to the incident photon beam. Preliminary results were available on the muon pair-production experiment. (So far, apparently, no great surprises.)

2. Extension of electron-nucleon scattering to higher energies and larger momentum transfers: These experiments will yield further information on nucleon form factors, especially relating to the problem of the nucleon "core". Already, as noted in the preceding, a rather small upper limit can be placed on the possible "Regge" behavior of the photon in $e-N$ scattering.

3. Strong-interaction physics by counter techniques (photoproduction of mesons and baryonic states): A large magnet-hodoscope system, mounted on a 40-ft platform, has been constructed to serve as a particle spectrometer. Simultaneous measurement of particle momentum by curvature in the magnetic field, and velocity by time of flight or angle of emission of Čerenkov light, serves to identify the particles observed. The platform is mounted on rails, enabling its rotation about an

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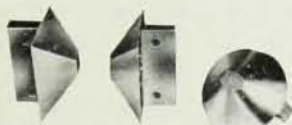


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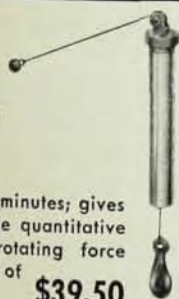
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axis passing through the hydrogen target. Additional counters can be placed in appropriate positions on the opposite side of the photon beam to provide a coincident choice of other reaction products. Thus far, the apparatus has been used to study the reaction $\gamma + p \rightarrow p + \pi^0$ up to a few BeV.

4. Strong-interaction physics by visual techniques: A number of experiments are being planned in which spark chambers, nuclear emulsions, and bubble chambers will be used to study photon interactions. For example, a spark-chamber and magnet system is being set up for the study of the "peripheral" photoproduction of pions in the forward direction; and a large, heavy-plate, 4π -geometry (cylindrical) spark chamber, planned to operate in a magnetic field, is being constructed for the study of the neutral products of photoproduction reactions. Both these spark chamber experiments are planning to use "tagged" photons—photons whose energy is determined by measurement of the momentum of the electron responsible (by bremsstrahlung) for the photon in question.

Another visual device now under construction is a 500-liter hydrogen bubble chamber in a 17-kilo-gauss magnetic field.

The review of CEA experiments was made more vivid by the opportunity provided the conference participants to see the apparatus under construction and on the experimental floor, and to discuss with the responsible experimenters the details of their operation.

The ninth and final session was devoted to reports on the status and progress of multi-BeV electron accelerators throughout the world. Reviews were presented from Italy (Frascati), France (Orsay), Germany (DESY-Hamburg), Sweden (Lund), the United Kingdom (NINA-Daresbury), Japan (Tokyo University), Stanford (SLAC), and Cornell. Unfortunately, the delegation which had been expected from the USSR was not able to come to the conference, and we could not, therefore, learn of the status and plans for the 6-BeV electron synchrotron at Yerevan, Armenia.

Judging from published reports, every conference is an unqualified success. It is, therefore, superfluous to record the satisfaction of most participants to this conference, both with its contents and its spirit.

Interested readers can obtain more detailed information through the conference *Proceedings*, which can be obtained (as long as they last) by writing to Miss Gail Sullivan, Laboratory for Nuclear Science, Room 26-505, Massachusetts Institute of Technology, Cambridge 39, Mass.