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JANUARY 1 through JUNE 30, 1967

K. Strauch,
Director

December 15, 1967

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
and HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

CAMBRIDGE 38, MASSACHUSETTS

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CAMBRIDGE ELECTRON ACCELERATOR

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CEAL-1038
Prof. Karl Strauch
December 15, 1967

SUMMARY

Part I indicates the purpose of the contract, which is concerned with the operation of the 6-GeV Cambridge Electron Accelerator. Part II summarizes accelerator operation, and indicates that the total number of user-hours was 3782. Part III lists the principal improvements made in the accelerator and in the associated facilities. Part IV discusses the delivery and assembly of the new 100 MeV linac. Part V indicates the general nature of each of the 34 experiments that were in progress or in preparation. Part VI deals with safety, and indicates that there were no lost time accidents. Part VII summarizes the steady progress on Project Bypass. Part VIII deals with the planning of the Sixth International Conference on High Energy Accelerators, which was scheduled for Sept. 11 - 15, 1967, at Cambridge, Mass.

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PART I. INTRODUCTION

This report summarizes work done under the Harvard-AEC Contract AT (30-1)-2076 during the six-month period from Jan. 1 through June 30, 1967. The contract calls for the operation and maintenance of the CEA 6-billion-electron-volt synchrotron and for designing, procuring, installing, and operating various facilities essential to the experiments to be performed here.

General policies of the Laboratory were determined by a joint M.I.T. - Harvard "Executive Committee of the CEA". During the first half of 1967 this Committee included the following:

from M.I.T.: Dr. Carl F. Floe
Prof. Jerome I. Friedman
Prof. Francis E. Low
Prof. Victor F. Wiesskopf
Dr. Jerome B. Wiesner

from Harvard: Dean Franklin L. Ford
Prof. Sheldon L. Glashow
Prof. Francis M. Pipkin
Prof. Karl Strauch
Mr. L. Gard Wiggins

Scientific policies were established by a Scientific Committee which included representatives of MIT, Harvard, and other institutions. During the latter portion of the half-year in question, this Committee included:

from M.I.T.: Prof. Jerome I. Friedman
Prof. Francis E. Low
Prof. Victor F. Weisskopf

from Harvard: Prof. Sheldon L. Glashow
Prof. Francis M. Pipkin
Prof. Karl Strauch

from the CEA: Dr. Thomas L. Collins
Dr. M. Stanley Livingston
Dr. Gustav-Adolf Voss
Mr. Caspar W. Wooldredge, Jr.
(sec'y)

others: Dr. Robert K. Adair (Yale, BNL)
Prof. Richard H. Milburn (Tufts)

Scheduling of research experiments on a day-to-day basis was the responsibility of the Director of the CEA assisted by a "Scheduling Committee for the CEA". During the half-year in question this Committee included the following:

from M.I.T.: Dr. David P. Luckey

from Harvard: Dr. Alfred E. Brenner

from CEA: Dr. Gustav-Adolf Voss
Dr. William A. Shurcliff (sec'y)

PART II. ACCELERATOR OPERATION

During the half-year in question the accelerator furnished a total of 3782 user-hours. This is about 10% less than in the previous half-year: for reasons of economy, it was necessary to reduce accelerator operation from 14-shifts per week (nominal) to 10 shifts per week.

The number of user-hours furnished per month was as follows:

<u>Month in 1967</u>	<u>Number of User-Hours</u>
January	481
February	602½
March	783
April	581½
May	640
June	694
<hr/>	
Total for 6-month period	3782

PART III. EQUIPMENT AND FACILITIES

A. Accelerator Proper

Throughout the half-year in question we continued to improve the vacuum forelines and to process straight section tanks, etc., to permit achieving much higher vacuum (such as 10^{-8} torr) that will be needed during long-term storage of electrons and positrons. New cleaning and bake-out procedures were developed, and 48 heating mantles for facilitating bake-out of straight section tanks and rf cavities were purchased. We succeeded in conditioning Drivac high-vacuum pumps so that, operated with no external load, they could achieve 3×10^{-10} torr.

By February 1967 we had eight vacuum chambers of ceramic type in use. They performed excellently and we ordered 48 more. By June a number of such chambers had developed leaks at the stainless steel junctions between ceramic segments; at first we attributed the difficulty to imperfect welding by the manufacturer, but more recent studies suggest that vibration and strain contributed to the difficulty. Typically, a chamber shows no leak until after several months of use; thus it may take us some months to find the exact cause of the leak and find how to revise the design so that no leak will develop.

In April we obtained two bakeable gate valves for the ring, and in May we made extensive tests of outgassing rate of epoxy-type and ceramic-type vacuum chambers as a function of beam energy and intensity. We found that the ceramic chambers have approximately 20-fold lower gas pressure than the epoxy chambers. Also, we found that, at pressures of 10^{-9} and 10^{-10} torr, our standard Drivac pumps have a pumping speed of 5 to 30 liters/sec., and that, by employing special titanium cartridges, we can perhaps increase the pumping speed (at 10^{-9} torr) by a factor of ten. When we increased the machine energy, in steps, from 1 GeV to 5 GeV, the amount of gas emitted from vacuum chambers walls, etc., as a result of incident synchrotron radiation increased approximately with the first power of machine energy. Our general conclusion was that when the synchrotron ring is used for storing 50 ma currents of electrons and positrons at 3 or 4 GeV adequately low pressure can be maintained.

In January we received and tried out a standby TFU-1B radio transmitter for supplying rf power to the ring, and in March we placed orders for power supplies to be used to extend our beam-bump capability.

We developed a new and improved type of monitor of beam position and beam intensity and made plans for constructing eight such devices. Employing four small pick-up loops flanked by an assembly of four hybrids, the new device provides increased sensitivity and greater discrimination against background. It is extremely compact, and it is highly resistant to radiation.

B. External Beams

In January 1967 we found that, thanks to the re-survey and re-alignment of the ring of 48 magnets in December 1966, the efficiency of ejection of the electron beam increased to the normal value of about 70%.

In February 1967 we set up an additional external-electron-beam run (called Beam 9) to the Experimental Hall. The beam was to be used initially by investigators from Northeastern University. In March, equipment to be used in transporting an electron beam and a photon beam from the synchrotron to Area 7 of the Experimental Hall was installed; the equipment included an automatically invoked, pneumatically actuated gate valve.

Much effort was devoted to modifying the target-actuation portion of the special vacuum chamber to be used by Frisch et al in experiments with (Beam 12 $\frac{1}{2}$) tagged photons originating at a very fine wire situated at the center of Magnet 12. By the end of March the equipment had been tested and found to perform well.

C. Study of Orbiting Beam

In February and March we made detailed analyses of the height and width of the cross-section of the orbiting electron beam at injection. Also, using an optical scanning device operating on synchrotron radiation from the orbit, we explored the dependence of beam height on various orbit parameters and investigated the coupling between horizontal and vertical oscillations and the resulting effects on beam spread.

D. Facilities for Use by Experimenters

Equipment in the Experimental Hall was rearranged as required for replacement of completed experiments by new ones. In February we assembled spectrometer platforms and other equipment needed in Area 7, and the acceptance tests on the Hovair pneumatic system for moving the platforms were completed. A new, small, spectrometer arm for use by the Kendall-Friedman group and other groups was

ordered. Installation of two 1.2 MW Acme power supplies for powering large experimental magnets was completed.

In April we completed arrangements for field tests on the explosion properties of certain small liquid hydrogen targets. The tests were designed to give experimenters a better understanding of the dangers involved and to encourage them to design and operate hydrogen targets without creating a significant hazard.

We completed construction of a control system for linking our four SDS-92 interface computer units with the Harvard IBM 360/50 computer. The control system is to be used by experimenter groups that wish to connect their experimental equipment on-line to the IBM 360/50. We prepared a manual explaining the capabilities of the control system and the optimum operating procedures.

E. Buildings

In March we completed the transfer of material in storage from the Watertown Arsenal (which is to be decommissioned) to our Dane St. warehouse.

In June we completed general plans for the proposed New Engineering Building, to be situated adjacent to the Experimental Hall and the truck ramp.

F. Source of Polarized Electrons

Plans for producing a source of polarized electrons advanced satisfactorily. By March, tests on electron storage had been completed satisfactorily and the design of a working prototype had been begun. In April an 80-kv stabilized power supply was received. It is the goal of this development to supply a polarized electron beam to the linac and then to the synchrotron proper, so that a beam of polarized electrons could be furnished to experimenters.

PART IV NEW LINAC

In February two CEA engineers visited the plant of Varian Associates to inspect the 100-MeV linac nearing completion there. On finding the work essentially complete and a majority of the tests finished, they authorized shipment of the equipment to the CEA.

Most of the components reached the CEA on March 20, and a team of Varian engineers went to work to assemble and test the equipment. By the end of June the work was nearly complete, and acceptance tests were scheduled for July. (The tests were completed on July 29, 1967.)

PART V. THE EXPERIMENTS

During the six-month period in question (Jan. 1- June 30, 1967) there were 34 experiments in progress or in various stages of preparation or completion. These are described briefly below, arranged alphabetically by name of a principal investigator.

1. Photoproduction of π^+ at Large Angles and Measurement of Angular Distributions and Spins (Alvarez et al).

Physicists from M.I.T. completed the experimental phase of a study of the photoproduction of positive pions, at laboratory angles of 90 to 160 degrees, by means of a 1 to 3 GeV photon beam incident on a liquid hydrogen target. They used a large deflecting magnet, several precision, wide-gap spark chambers, and other detectors. Data-taking was completed in May, and scanning of the film with the aid of the SPASS computer program was to start within a few months.

2. Single Pion Photoproduction on Deuterium (Bar Yam et al).

Physicists from Southeastern Massachusetts Technological Institute and from M.I.T. and CEA completed an experiment on single pion photoproduction (at c.o.m. angles of 30 to 90 degrees) on deuterium. Photons of 3 to 4 GeV energy were employed. During the period in question this group analyzed

the results and reported them. A summary of the results was presented at the January 1967 meeting of the Am. Phys. Soc., and further details were presented in Phys. Rev. Ltrs. 19, 40 (July 3, 1967). One noteworthy result was that the ratio of cross sections for production of π^- and π^+ is appreciably less than unity, being approximately 1/2 for certain of the energies and angles chosen.

3. Photoproduction of Charged Pions on Hydrogen and Deuterium, Using Polarized Photon Beam (Bar Yam et al). Physicists from Southeastern Massachusetts Technological Institute and from M.I.T. were preparing an experiment on single pion photoproduction on hydrogen and deuterium using a polarized photon beam. A diamond crystal is to be used as internal target (to produce the polarized beam) and the CEA pair spectrometer will be used to verify the polarization. The photoproduced pions will be detected by the Moby Dick spectrometer equipped with scintillation counter hodoscopes, wire chambers, and a gas Cerenkov counter. Data taking is to start in 1968.

4. Proton Compton Effect (Deutsch et al). Physicists from M.I.T. completed the experimental phase of a study of gamma, proton scattering at 65 degrees c.o.m. In this work, which was an extension of a study performed

several years ago at the CEA, the investigators used a magnetic spectrometer, spark chambers, and a shower counter. Data taking was completed in March 1967, and by 6/30/67 most of the data had been analyzed -- with the SPASS computer program. The results for the energy range from 0.6 to 1.7 GeV were presented at the September 1967 SLAC Electron Photon Conference. Results for the range from 1.7 to 2.5 GeV are now being analyzed. One central finding is that, as the energy increases from 0.8 GeV to 2.5 GeV, the cross section decreases by almost two orders of magnitude.

5. Determination of the Polarization of Lambda Particles Jointly Photoproduced with Kaons (Deutsch et al).

Physicists from M.I.T. were preparing to direct a beam of 2 GeV photons at a liquid hydrogen target and study the polarization of the lambda particle found in the photoproduction of the (lambda, kaon) final state. The equipment includes a magnetic spectrometer, six spark chambers, scintillation counters for trigger and time-of-flight determination, and a water Cerenkov counter for pion rejection. Data taking is to start in 1968.

6. Survey of Photoproduction of K_2^0 (Engels, Hand, et al). Physicists from Harvard and Elsewhere measured the cross sections of photoproduction of neutral kaons at 0 to 10 degrees in the laboratory. The photons employed originated as bremsstrahlung from a beam of 4.25 and 5.5 GeV electrons incident on a thin target (of aluminum, e.g.) situated within the field of a deflecting magnet (which deflected the electrons through 3°). The detection equipment included spark chambers, scintillation counters, and Cerenkov counters. K_1^0 particles were regenerated from K_2^0 particles in a block of tungsten or copper, and pions resulting from the decay of the K_1^0 were detected. The runs were made in January - May 1967. The results showed that the K_2^0 particles were produced in great abundance (from ϕ resonances, presumably) and with interesting momentum spectrum and angular distribution. They concluded that electron accelerators are likely to be useful tools for studies of neutral kaons. A short account of the results obtained at 3° appears in Phys. Rev. Ltrs. 19, 1349 (Dec. 4, 1967).

7. Internal Beam Tagging Facility (Frisch et al). M.I.T. physicists completed preparations for producing, in the Beam 12 $\frac{1}{2}$ Area, a stream of tagged multi-GeV photons.

A 2-micron-diameter quartz filament is mounted near the center of Magnet 12 and, by remote control, may be moved into the beam of orbiting electrons (without appreciably affecting it). An electron that strikes the filament and produces there a bremsstrahlung photon will have reduced energy and momentum and will be deflected strongly by the magnetic field; its position will be determined by means of a bank of 20 detectors situated near the downstream end of the magnet. Knowing the decrease in energy of the electron, an experimenter can compute the energy of the photon with an accuracy of about $\pm 2\%$. The tagged photon passes into the Experimental Hall and may be employed in photoproduction experiments. In the six-month period in question the special vacuum chamber and mechanism for controlling the position of the filament were completed and tried out successfully.

8. Study of $2\pi^0$ Resonances With the Aid of an Internal Beam Tagging Facility. (Frisch et al). M.I.T. physicists made preparations for investigating the little-known photoproduction of f_0 resonances by studying the pair of neutral pions resulting therefrom. They plan to use tagged photons of known ($\pm 2\%$) energy, and a polyethylene target $0.1X_0$ thick. A thin-foil spark chamber

will determine the direction of the recoil proton, and another spark chamber ; containing thick iron plates (having an aggregate thickness of $7.3X_0$) will determine the directions of the showers from the four photons produced in the decay of the two neutral pions. Data taking is expected to start early in 1968.

9. Photo-Induced Evaporation of Nucleons from the Nuclei or Atoms of Uranium and Other Metals. (Fulmer, Handley, Dell). Physicists from Oak Ridge National Laboratory and the CEA continued their studies of the evaporation of nucleons from nuclei of uranium and other elements (in the form of foils) by means of multi-GeV electrons and photons. Photo-induced fission of the iron nucleus was studied. The exposures were made in the CEA Beam 9, and the results were being studied at ORNL. Preliminary reports of results were presented at the Spring, 1967, meeting of the Am. Phys. Soc. and in Phys. Rev. Ltrs. 19, 522 (1967).

10. Electroproduction of Wide-Angle Muon Pairs (Gettner, Weinstein, et al). Physicists from Northeastern University completed the assembly of apparatus for the study of wide angle muon pairs (produced at forward angles of 4 to 10° lab) by means of 4.9 GeV electrons and the exploration of

the time-like form factor of the (e, μ) scattering process, as part of an investigation of the validity of quantum electrodynamics. Troublesome background effects were controlled successfully, and a large amount of useful data was obtained. The experimental phase of the program was completed, and analysis of results is continuing. A preliminary account of some of the results was presented at the Sept. 1967 SLAC Electron Photon Conference and in the June 1967 thesis "Photoproduced and electroproduced muon pairs" by P. Rothwell.

11. Photoproduction of Hyperon Resonances with Strangeness +1 and -1 (Hughes et al). In January 1967 physicists from Yale University completed the first phase of a search for new hyperon resonances. They obtained evidence for hyperon resonances of strangeness +1 and strangeness -1, photoproduced by 3 to 6 GeV photons on hydrogen according to the interactions:

$$\gamma + P \rightarrow K^+ + Y^* \quad \text{and} \quad \gamma + P \rightarrow K^- + Z^*$$

The K^- and K^+ mesons were studied with the aid of a spectrometer comprising focusing magnets, momentum analyzing magnets, hodoscopes, and differential gas Cerenkov counters. The data showed evidence of the existence of several new resonances in the mass range

1800 to 2500 MeV, with strangeness +1 and -1. Some of the results were reported in Phys. Rev. Ltrs. 19, 255 (31 July 1967); another article is to be published soon. Some of the results were presented by K. Strauch at the September, 1967, SIAC Electron Photon Conference and by V. Hughes at the September Heidelberg, 1967, High Energy Physics Conference.

12. Elastic Scattering of Electrons by Deuterons (Kendall, Friedman, et al). M.I.T. physicists nearly completed the analysis of results on the elastic scattering of electrons by deuterons. The experimental work was done in 1965, and by 6/20/67 the preparation of a thesis by G.C. Hartman was nearly complete.

13. Search for e^+ particle (Kendall, Friedman, et al). M.I.T. physicists nearly completed the analysis and write-up of results of a brief search (in 1965) for the hypothetical e^+ particle. The result was negative.

14. Inelastic Scattering of Electrons by Deuterons (Kendall, Friedman, et al). M.I.T. physicists continued preparations for studying the inelastic scattering of electrons by deuterons, to supplement the elastic scattering work mentioned in a previous paragraph. This new

experiment constitutes an exploration of the electro-disintegration of the deuteron near threshold and an exploration of the short-range structure of the (n,p) interaction at low energy in the (n,p) center-of-mass system. The recoiling proton will be detected by scintillation counters and the scattered electron will be detected by a quadrupole spectrometer that includes wire chambers and scintillation-counter detectors. Data-taking is expected to start early in 1968.

15. Elastic Scattering of Electrons by Alpha Particles (Kendall, Friedman, et al). M.I.T. physicists continued preparations for the study of scattering of electrons by alpha particles, with the purpose of determining the short-range structure (form factor) of the alpha-particle--a spin zero particle. They will use an external electron beam and a liquid helium target. The recoiling protons will be detected by scintillation counters, and the scattered electron will be detected by a quadrupole spectrometer that includes wire chambers and scintillation counter detectors. Data-taking is expected to start in the Spring of 1968.

16. Photoproduction of π^0 and η^0 at Forward Angles (Luckey et al). M.I.T. physicists continued preparations for studying the photoproduction, at forward angles, of π^0 and η^0 on a liquid hydrogen target. The study will supplement the investigations made by them in 1964 and 1965. The photons resulting from decay of the π^0 will be detected by glass Cerenkov shower counters mounted on a small spectrometer arm. Under circumstances that entail production of bad backgrounds and few π^0 particles, the recoil proton will be measured by the Moby Dick spectrometer arm, which includes a focusing magnet, analyzing magnets, spark chambers, and a scintillation counter hodoscope. Special wire chambers have been built and installed also. By 6/30/67 the equipment as a whole was nearly ready for data taking.

17. Photoproduction of Polarized Photons with the Aid of a Laser (Milburn et al). Physicists from Tufts University continued preparations for exploiting the method of producing polarized high-energy photon beams demonstrated on a pilot scale in 1964 and 1965. The method entails directing a very intense beam of polarized, 2 ev photons head-on at the electrons in orbit in the 6 GeV synchrotron; the photons recoil with energies as

great as 800 MeV and retain their original polarization. The laser, capable of producing 25 to 30 joules per pulse, was operated successfully during the first half of 1967, and the lead glass Cerenkov counter was installed. The group was awaiting CEA support in completing and assembling the vacuum system, to be situated at Straight Section 38.

18. Study of Bremsstrahlung Beam from Residual Gas in a Straight Section of the Synchrotron (Milburn et al). Physicists from Tufts University and CEA improved their equipment (for use near Straight Section 38 of the CEA-synchrotron) for studying the intensity and width of the bremsstrahlung beam resulting from collisions of the orbiting electrons and residual gas molecules. The dependence on machine energy, gas pressure, beam-bump conditions, etc., is being determined. Results are of interest to groups concerned with detection systems for the colliding beam studies discussed in the previous paragraph.

19. Spark Chamber Analysis of the Polarized Proton Recoiling from Photoproduction of π^0 (Milburn et al). Physicists from Tufts University and M.I.T. completed preparations for analyzing the polarized proton that recoils when a π^0 particle is photoproduced on liquid

hydrogen. The equipment includes (a) a small spark chamber and lead glass Cerenkov counters for detecting the photons from the decay of the π^0 , and (b) a magnet and small spark chambers for determining the momentum of the recoiling proton and (c) a large spark chamber (containing 60 graphite plates) for determining the asymmetry of scattering of the proton by the carbon nucleus. By 6/30/67 the equipment was ready for data-taking.

20. Study of Large-Angle Electron-Positron Pairs Produced in a Carbon Target (Osborne et al). Physicists from M.I.T. completed the analysis of results of a search (made in 1966 with the Moby Dick spectrometer and a set of gamma-ray hodoscopes) for possible breakdown of quantum electrodynamics when electron-positron pairs are produced by high-energy photons that strike a carbon target. The synchrotron energy was set at 3.0 and 4.14 GeV, and the results on symmetric pairs covered a range of virtual electron four-momentum of 200 to 400 MeV/c. Results were found to be in agreement with results of a recent DESY experiment and hence in agreement with QED, but in disagreement with results published earlier by Blumenthal et al. A detailed account of the work is

to be found in the 1967 M.I.T. thesis by Kenneth Cohen "Wide Angle Electron-Positron Pair Production".

21. Exploratory Survey of π^0 Photoproduction (Osborne et al). M.I.T. physicists published the results of a 1966 investigation of the broad features of π^0 photoproduction under a variety of conditions, including photon energies from 2.0 to 5.0 GeV. A paper "Measurement of π^0 Photoproduction Cross Sections for Incident Gamma-Ray Energies of 2.0 to 5.0 GeV" by G. C. Bolon, D. Garelick, S. Homma, R. Lewis, W. Lobar, D. Luckey, L. S. Osborne, R. Schwitters, and J. Uglum was published in Phys. Rev. Ltrs. 18, 926 (1967). The article presents neutral pion photoproduction cross sections for baryon four-momentum-transfers squared of 0.5 to 4.0 (GeV/c)² and compares the results with predictions based on Reggeized vector-meson exchange.

22. Photoproduction of π^0 by Means of Polarized Gamma Radiation (Osborne et al). M.I.T. physicists started preparations for measuring the photoproduction of π^0 by means of polarized multi-GeV photons. The polarized photons, of energy up to 3 GeV, are to be produced by means of a diamond controlled by a goniometer and mounted directly in the synchrotron ring. Polarization is to be measured with the aid of a second goniometer situated

in Beam Run 10 in the Experimental Hall. Data-taking is expected to start in 1968.

23. Small Angle Scattering of Electrons by Carbon (Pipkin, Faissler, et al). Harvard physicists completed the analysis of results of an investigation of small-angle (3 to 12° in lab) scattering of 1 to 5 GeV electrons by a carbon target, an investigation designed to provide additional information on the form factor of the carbon nucleus. The experimental work, involving use of a single-arm spectrometer that detected and analyzed the scattered electrons, was completed in 1966. Results were presented in W. L. Faissler's May 1967 thesis "High-Energy Electron Scattering from Carbon in the Forward Direction" and in a manuscript published in Phys. Rev. Ltrs. 19, 1202 (Nov. 13, 1967) by W. L. Faissler, F. M. Pipkin, and K. C. Stanfield: "Experimental Test of Electron-Scattering Sum Rules for Carbon".

24. Photoproduction of Charged Pions and Kaons (Pipkin, Joseph, et al). Physicists from Harvard completed the write-up of their determination of the number of charged pions and kaons that are emitted at lab. angles of 5 to 15° from a target of carbon or liquid hydrogen as a function of the energy of the incident photon and the

direction of the emitted particle. The bremsstrahlung photons were produced by electrons of 3.4 GeV and 5.0 GeV energy. Results are presented in a May 1967 thesis by P.M. Joseph: "Photoproduction of Charged π and K Mesons at High Energy". See also an article in Phys. Rev. Ltrs. 19, 1206 (Nov. 13, 1967) by P.M. Joseph, N. Hicks, L. Litt, F. M. Pipkin, J. J. Russell: "Photoproduction of π^0 Mesons at 3.4 and 5.0 BeV".

25. Wide-Angle Electron Pair Production (Pipkin, Randolph, et al). Harvard physicists finished assembling the two large spectrometer arms to be used in a study of wide-angle electron-positron pair production with greater accuracy than was achievable earlier. They will employ a multi-GeV photon beam and a carbon target. The detection equipment includes focusing magnets, scintillation counters, and differential gas Cerenkov counters. By 6/30/67 most of the equipment had been adjusted and made ready for routine data-taking.

26. Wide-Angle Electron Pair Study with Tagged Photons and a Wide-Gap Spark Chamber (Strauch, Walker, et al). Harvard physicists completed preparations for a new experimental approach to the study of wide-angle electron-positron pair production up to an invariant

mass of 400 MeV. The method involves use of a tagged photon produced with the aid of momentum-analyzed positrons; the individual positron (of known energy) strikes a thin target and radiates by bremsstrahlung process; an open-sided tagging magnet (momentum analyzing magnet) and arrays of scintillation counters permit determination of the energy of the spent positron and, by subtraction, the energy of the bremsstrahlung photon. This tagged photon is put to use as follows: it is caused to strike a target of carbon (or liquid hydrogen) and produces here an electron-positron pair; an adjacent spark chamber shows the initial directions of these two particles, and a second spark chamber, situated within the large gap of a 200-ton H-type magnet, permits determination of the momentum of each particle; an array of 8-ft.-wide spark chambers with high-Z plates permits distinguishing electrons from pions. By the end of June 1967 the group had evolved satisfactory means of photographing tracks having different obliquities and very different brightness, and was ready for routine data-taking.

27. Photoproduction of Baryon-Antibaryon Pairs (Von Goeler, Weinstein, Gettner, et al). Physicists from Northeastern University completed the analysis of data on photoproduction of baryon-antibaryon pairs by the

reaction $\gamma + p \rightarrow \bar{n} + d$, using photons of 4 to 6 GeV energy. The experimental work, involving use of the Moby Dick spectrometer, was completed in 1966. The results imply antiproton and antineutron photoproduction cross sections generally similar to cross-sections found in earlier experiments. The present cross-sections are about two orders of magnitude smaller than predicted by Drell on the basis of a simple peripheral model, but are much more nearly comparable to predictions based on a recent modification of that model. An abstract of the results was presented at the Sept. 1967 SLAC Electron-Photon Conference, and a summary of the results was published in Phys. Rev. Ltrs. 19, 922 (Oct. 16, 1967) by D. Earles, M. Gettner, G. Glass, Y. Laohavanich, E. von Goeler, R. Weinstein, and D. Garelick: "Photoproduction of Antineutrons and Antiprotons for Photon Energy Between 4.0 and 5.7 BeV".

28. Total Cross-Section for Photoproduction of Electron-Positron Pairs with Low Momentum Transfer (Walker and Knasel). Harvard physicists completed preparations for measuring, with 20-fold improved precision, the total cross-section of photoproduction of electron-positron pairs in various materials. They employed tagged photons

produced with the aid of equipment described in the paragraph on the Strauch-Walker experiment on wide-angle electron pair production with tagged photons and a wide-gap spark chamber. During the first half of 1967 the group reduced the various sources of error so as to provide a precision of about 0.1% in cross section (as contrasted with about 0.5% achieved at the end of 1966). Data-taking was to start in August 1967.

29. Decay of Photoproduced ϕ Mesons into μ^+ and μ^- (Weinstein et al). In 1966 physicists from Northeastern University completed the analysis of data obtained in a previous year on the decay of photoproduced ϕ mesons into μ^+ and μ^- . They used a 6-GeV bremsstrahlung beam, a carbon target, and, to separate muons from other charged particles, a thick iron filter. From analysis of the data they were able to establish an upper limit of about 7.4×10^{-4} (under certain specified assumptions) for the branching ratio of decay into a muon pair. This upper limit stands today as the most definitive value available. The results were published in Phys. Rev. Ltrs. 18, 710 (April 24, 1967) by R.C. Chase, P. Rothwell, and R. Weinstein: "Search for the Decay of Photoproduced ϕ Mesons into μ^+ and μ^- ".

30. Precise Elastic (e, p) Scattering (Wilson, Goitein, et al). Harvard physicists were engaged in analyzing and reporting measurements made in 1966 on the absolute cross-section of the proton at four-momentum transfers up to 150 f^{-2} . In the experimental phase of the work, an external beam of 5.5 to 6.0 GeV electrons was used, and principal attention was given to electrons scattered at forward angles (20 to 33° lab.). The recoil protons were detected in coincidence with the scattered electrons to improve the reliability and precision of the results. Cross sections were determined with an accuracy of 3 to 10%. A summary of the results was published in Phys. Rev. Ltrs. 18, 1016 (June 5, 1967) by M. Goitein, R. J. Budnitz, L. Carroll, J. Chen, J. R. Dunning, Jr., K. Hanson, D. Imrie, C. Mistretta, J. K. Walker, and Richard Wilson: "Measurements of Elastic Electron-Proton Scattering at High Momentum Transfer by a Coincidence Method". A critique of the results was presented in Phys. Rev. Ltrs. 18, 1018 (June 5, 1967) by M. Goitein, J. R. Dunning, Jr., and Richard Wilson: "Comparison of Elastic Electron-Proton Scattering Cross-Sections with Some Theoretical Predictions".

31. Precise Quasi-Elastic (e, d) Scattering Study Involving a Coincidence Method (Wilson, Budnitz, et al). Physicists from Harvard completed the analysis and write-up of their determination of the electron-neutron elastic cross section by means of an external electron beam, a liquid deuterium target, and a coincidence method of detection and analysis. Neutron/proton cross-section ratios from deuterium were measured at q^2 of 7, 10, 15, 20, 30, 45, and 70 f^{-2} (at a lab. angle of 20°), at q^2 of 15 f^{-2} (at a lab angle of 90°), and at q^2 of 115 f^{-2} (at a lab. angle of 30°). The results were presented in a 1967 thesis by R. Budnitz: "Quasi-Elastic Electron, Deuteron Scattering".

32. Determination of the Pion Form Factor through Study of Inelastic (e, p) Scattering Near the First Pion-Nucleon Resonance (Wilson, Mistretta, et al). Harvard physicists completed data-taking in their high-precision analysis of the form factor of the charged pion. They employed an external electron beam of 3 to 6 GeV energy, a liquid hydrogen target, and a two-arm spectrometer. One arm (Kontiki), which included a focusing magnet, arrays of scintillation counters, a gas-filled Cerenkov counter and a shower counter, detected the electron at 7 to 10° in the lab. The

other arm, employing a sweeping magnet, a 144-element scintillation counter hodoscope, and a Lucite Cerenkov counter, detected the pion in coincidence with the electron. Data taking was completed early in 1967, and analysis of results is underway.

33. Search for Violation of Time-Reversal-Invariance in Electromagnetic Interactions with the aid of a Polarized Target (Wilson, J. Chen, et al). Harvard physicists completed assembly of equipment for use in a search for violation of time-reversal-invariance in electromagnetic interactions among strongly interacting particles. They plan to analyze events in which incident electrons of about 5 GeV energy are scattered by protons inelastically. The polarized target, developed by Pound and others at Harvard, consists of ethanol (and a trace of water) in which approximately one quarter of the hydrogen nuclei are polarized with the aid of a magnet of 26 kilogauss intensity and an rf field. Just the (inelastically scattered) electrons will be detected, with the aid of a single-arm spectrometer. Data-taking runs started late in 1967.

34. Determination of Neutron Form Factor at Low Momentum Transfer by an Anti-Coincidence Method. (Wilson, Hanson, et al). The equipment and technique used were much the

same as those used by Wilson, Budnitz, et al in studying quasi-elastic (e, d) scattering. See a previous paragraph. The data-taking runs were made in May and June of 1967, and the results are being analyzed.

PART VI SAFETY

During the first six months of 1967 there were no lost-time accidents at CEA. A number of meetings of the Safety Committee were held, and various new and revised safety regulations were issued.

Radiation levels in outdoor areas and indoor work areas were held well below the permissible levels, and personal film badges showed that all doses to persons were well within permissible limits.

PART VII PROJECT BYPASS

In the period in question we made further progress in our "Project Bypass" effort to develop a colliding beam facility that utilizes the present accelerator ring to store electron and positron beams. We plan to inject electrons into the existing ring in counter-clockwise sense and inject positrons in clockwise sense, and we plan to accelerate and store both kinds of particles simultaneously in the same ring. During the storage interval of about one hour the beams will pass through a short detour, or bypass, in which the two counter-current streams of particles will collide head-on. The efficiency of collision -- and the usefulness of the results -- will be benefited by the extra strong focusing at the collision station, the extra-high vacuum that can be maintained here, and the great length of the straight interaction region which allows room for versatile detection equipment.

Many additional studies of the cross-section of the orbiting electron beam were carried out. Also, outgassing of vacuum chambers etc. (as a consequence of intense synchrotron radiation) was studied as a function of machine energy and intensity. In June we

learned how to provide adequate compensation, while bumping the orbiting beam into the damping magnet, so that the vertical and horizontal betatron frequencies remained adequately separated and no adverse coupling of such oscillations could occur.

Much effort was devoted to preparing equipment needed for inflecting the beam from the new linac into the synchrotron ring, and for accomplishing multicycle injection. The necessary kicker magnets and power supplies were prepared. We devised greatly improved equipment for measuring beam life-time quickly and repeatedly--many times a minute, even when the life-time itself is of the order of ten minutes or more. Equipment used in visual and photoelectric scanning of beam cross-sectional shape and size was improved.

Major components of the bypass proper were procured. In May we placed orders for the special stainless steel vacuum chambers required. Plans for cutting away concrete to allow room for the bypass beam-run near Magnet 16 were completed.

Physicists and engineers working on the Bypass project prepared talks to be given at the International Accelerator Conference discussed in the following section.

PART VIII. PREPARATIONS FOR SIXTH INTERNATIONAL CONFERENCE ON
HIGH-ENERGY ACCELERATORS

In January we sent out invitations to approximately 290 persons from 14 countries to attend the Sixth International Conference on High Energy Accelerators, to be held Sept. 11-15, 1967, at Harvard University in Cambridge, Massachusetts, with the Cambridge Electron Accelerator as host laboratory. Acceptances were received, and registration payments were deposited in a special bank account.

By June we had received more than 140 papers, and soon thereafter we mailed out a tentative program.

Much effort was devoted to obtaining Russian-English interpreters familiar with the terminology of high-energy physics, appointing session chairmen, and arranging adequate public address systems, renting pocket radio receivers, planning the registration area and luncheon facilities at Harkness Commons, and making preparations for an excursion to Ipswich, Massachusetts.

A draft of an abstracts volume was prepared.

By June 30, 1967 most of the planning was complete.

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