SEMI-ANNUAL REPORT

for the period

July 1 to December 31, 1962

A.E.C. Contract AT(30-1)-2076

M. Stanley Livingston, Director
J. Curry Street, Acting Director
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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
and HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

CAMBRIDGE 38, MASSACHUSETTS

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NY Patent Group

By: C.B. D.

3/6 1963
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SUMMARY

During the six-month period from July 1, 1962 through December 31, 1962, preparations for carrying out the nine originally approved experiments in high-energy physics were continued. Three experiments were started, and one was nearly finished. Two additional proposals for experiments were received and approved. The purpose and status of each experiment is indicated briefly in Part II.

A summary of progress made by the CEA organization in providing special magnets, magnet power supplies, targets, photon-ejection-type vacuum chambers, drift-tube and collimator trains, detectors, cryogenics equipment, etc., is presented in Part III.

Alterations and improvements in the accelerator proper are described in Part IV. The design energy of 6 Bev was achieved on August 13th, and much improvement was made in beam intensity and general reliability. However, the need for greater reliability of operation is apparent, and efforts to achieve further increase in beam intensity are continuing.

Tune-up and operation are discussed in Part V. By December 31, the machine was running nearly every day. Perhaps half of the operating time was devoted to tune-up studies and half to actual experiments in high-energy physics.
PART I. INTRODUCTION

This report summarizes the work done under the Harvard-AEC Contract AT(30-1)-2076 during the period July 1 - December 31, 1962. The contract calls for the operation and maintenance of the CEA 6-billion-electron-volt synchrotron of strong focusing type, and for designing, procuring, installing, and operating, various equipments and facilities pertinent to the experiments to be performed.

The construction of the accelerator has been described in the final report on Harvard-AEC Contract AT(30-1)-1909.

The operation and maintenance of the accelerator through June 30, 1962 was described in a report dated July 20, 1962 and entitled "Summary Report for the Period from April 1, 1958 - June 30, 1962".

In the current six-month period, as in earlier periods, policies governing the use of the laboratory and its facilities by the various groups of experimentalists have been established by an Executive Committee of the CEA, which includes five representatives of Massachusetts Institute of Technology and five representatives of Harvard University. This group and the Director of CEA were assisted by a Planning Committee for CEA, which includes one representative from MIT (Prof. M. Deutsch) and one from Harvard (Prof. R. Wilson).
PART II. THE EXPERIMENTS

In the current six-month period, preparations for the nine experiments described in the previous report were continued. By December 31 one of these experiments was nearly completed and two others were well under way. Also, proposals for two additional experiments were approved.

CEA activities in support of the original nine experiments are summarized below.

1. Electron Scattering -(R. Wilson et al.)

The purpose of this experiment is to determine the form factors of the proton and the neutron by means of the elastic scattering of high-energy electrons from a target situated inside one of the accelerator's straight-section tanks, No. 14. By December the first stage of the experiment was under way. The equipment, situated near Straight Section 14 in the target area, included a traveling spectrometer carriage supporting a Dierdre-type, 10-ton quadrupole magnet and an array of scintillation counters. A remote-controlled array of targets situated within the straight-section tank was employed, and also a quantameter. CEA support included the providing of the magnet and quantameter and assistance in connection with alignment, shielding, and cabling. (Part III summarizes the status of many of the supporting programs of the CEA, including the design and procurement of magnets, magnet power supplies, targets, ejection-type vacuum chambers, drift tubes, collimators, detectors, cryogenics, etc.)

2. Bubble Chamber Investigations -(Cambridge Bubble Chamber Group)

In its first experiment, the bubble chamber group is planning to study the photoproduction of light and heavy mesons, and of strange particles. Also, information on electromagnetic processes will be obtained. The main tool for this investigation will be a 40-inch-diameter liquid-hydrogen filled chamber en-
closed in a 280-ton magnet. By December 31, the 280-ton magnet Colossus, designed and procured by CEA, had been assembled, and the large CEA cryogenics plant that will provide compressed helium gas for liquifying the hydrogen for the bubble chamber was nearly complete. A 12-inch-diameter liquid hydrogen bubble chamber had been readied to start the experimental program of the bubble chamber group.

3. Photoproduction of Mesons - (L. Osborne, et al.)

The purpose of this experiment is to determine the cross-section of production of pions (and later, kaons) by means of high-energy photons. By December 31, the equipment had been assembled and adjusted and made ready for trial operation. It includes a 40-foot spectrometer carriage mounted in Beam 10. Mounted on the carriage are: two Deirdre-type, 10-ton focusing magnets, two Scylla-type, 38-ton bending magnets, a differential Cerenkov counter, a chronotron, and six hodoscopes placed along the axis of the spectrometer. The magnets were designed, procured, assembled, mounted, and aligned by CEA. A CEA-built quantameter is used also. The apparatus is now operating satisfactorily.

4. Wide-Angle Muon Pair Production - (R. Weinstein et al.)

This experiment is concerned with the photoproduction of muon pairs by means of a 6-Bev photon beam incident on a liquid hydrogen target. The detection equipment is of wide-angle type, suitable for analyzing pairs having paths at large angles to the axis of the photon beam, and thus implying short inter-particle distance. By December 31, the assembly of components essential to the first stage of the experiment was complete, and data had been taken on the nuclear absorption length of mesonic iron. The heaviest components for the equipment, i.e., two trains of two-ton and six-ton iron blocks for use in
discriminating against other types of particles and for determining the energy of the muons, were procured by CEA. The necessary drift tube runs, collimators, and quantameter were made by CEA. The tape recorder and display system for dealing with the enormous amount of data from a large scintillation-type hodoscope were procured by CEA. Components for a digital device to put the data in I.B.M. magnetic tape format were also procured by CEA.

5. Photoproduction of Pairs with Large Momentum Transfers - (V.W. Hughes, et al.)

A series of experiments are in progress to measure the ratio of the cross-sections for photoproduction of electron and muon pairs with similar momentum transfers to the nucleus, by detecting one member of each pair at large angles (10° - 15°) to the photon beam direction. The detection system consists of a combination of momentum analysis and velocity analysis by differential Čerenkov counters to identify e's, μ's, and π's. The cross-sections will be studied as a function of angle and energy of production. The equipment has been partially assembled at the Beam W position and is presently undergoing extensive tests with a 5-Bev photon beam. The magnetic analysis system consisting of a 38-ton pair spectrometer magnet and a quadrupole doublet has been supplied by CEA.

6. Photoproduction of Sigma Particles - (R. Milburn, et al.)

This group is preparing to study the photoproduction of sigma particles by a high-energy photon beam that is sufficiently slender and clean, that photographic emulsions situated only one inch from the beam axis may be used as detector. By December 31, most of the equipment had been assembled. The CEA supplied the special drift tube system and collimators, the high-precision alignment equipment, the power supply for the Tufts
Victoria magnet, and the lithium hydride hardener.

7. **Pion Production in Peripheral Processes - (D. Caldwell, et al.)**

The purpose of this experiment is to study single charged pion (and possibly kaon) production by high-energy photons of known energy in order to determine the nature of the virtual particle involved in the production near the forward direction. Using magnetic analysis and a 20-channel hodoscope, the energy is measured to ± 2½%, and the pion angle and momentum are even more accurately found with spark chambers and a magnet. In this way, accurate momentum transfer and missing mass determinations can be made. By December 31, nearly all of the apparatus had been designed or ordered and some assembly started.

8. **Wide-Angle Electron Pair Production - (F. Pipkin et al.)**

This group has been preparing to study the wide-angle, 6-Bev, photoproduction of electron-positron pairs, with the object of finding whether the laws of quantum electrodynamics continue to hold at the high energies and the short inter-particle distances involved. (The group is planning also to cooperate with representatives of the Stanford University SLAC project in making a number of preliminary measurements at CEA relating to the Drell process of photoproduction of pions, to provide a firmer basis for decisions and plans soon to be made by the Stanford group.) By December 31, it appeared that the equipment would be in shape for certain trial runs in Beam 7 in a few weeks. The CEA had completed the procurement of the necessary magnets, which include an Orpheus-type, 21-ton pair spectrometer magnet and two Aideen-type, 7-ton half quadrupole focusing magnets.

9. **Study of Higgs - (L. Livingston et al.)**

This experiment has been performed.
9. Study of Shielding - (M.S. Livingston, et al.)

This experiment was performed in September, 1962 by CEA staff. The attenuation of radiation produced by inserting a lead brick in a 4-Bev photon beam was determined for a variety of geometries, using various thicknesses of iron-loaded concrete blocks (density 240 lb/ft\(^3\)) and various detectors. The results (to be reported soon) will assist persons planning the shielding wall and hutments to be used in various future experiments.

In the last few months of 1962, two proposals for additional experiments were submitted to the Scientific Subcommittee of the CEA Executive Committee, and were approved. These experiments are described below.

10. Spark Chamber Studies of Photoproduction - (D. Frisch)

In this experiment, a variety of photoproduction processes will be studied with the aid of a large spark chamber situated between the poles of a very large magnet. On December 31, the preparations for this experiment were still in an early stage. However, the CEA had completed the design of the special large magnet required; the magnet will weigh approximately 200 tons.

11. Proton-Compton Effect at 1 to 3 Bev - (M. Deutsch et al.)

The group expects to study elastic scattering of photons by protons in energy ranges not available at other laboratories. Apparatus for initial measurements has been operating successfully for several months at the Cornell synchrotron and experiments at CEA await availability of a hydrogen target. CEA has designed an analyzing magnet for later phases of the experiment.
PART III. EQUIPMENT AND FACILITIES

During the current six-month period much progress was made in designing and procuring equipment and facilities for use in the various experiments under way or in preparation.

Magnets: Two additional focusing magnets were designed. Six additional Deirdre-type, 10-ton focusing magnets were received, and likewise two Scylla-type, 38-ton bending magnets, two Orpheus type, 21-ton pair spectrometer type magnets, and one Minerva-type, 38-ton pair spectrometer magnet. The Colossus-type, 280-ton bubble chamber magnet was received and assembled. Table 1 lists the magnets on hand or on order as of December 31, 1962.

Rugged, adjustable supports for most of the magnets were obtained in September. Additional power supplies and regulators were received.

Targets: Additional tungsten target systems, for use closely adjacent to the orbit and within a straight section tank, were built and put into service. They are controlled quickly and accurately from the main control room.

Ejection-Type Vacuum Chambers: Several photon-ejection-type vacuum chambers, designed to allow a high-energy photon beam to emerge tangentially with no appreciable attenuation or scattering, were built and installed and put into routine use. Other such chambers are under construction.

External Beams of Photons: Several photon-beam drift tubes and collimators were built and installed. Beam 8 was activated and used in the shielding experiment described on a previous page, and was then dismantled. By December 31, the Beam 7 and Beam 10 drift tube and collimator trains had been installed and were in routine use. Tests have shown that the center lines of the actual beams of photons crossing the experimental hall lie within a fraction of an inch of the paths that had been computed more than a
### TABLE 1

**STATUS OF MAGNET PROCUREMENT**

**December 31, 1962**

<table>
<thead>
<tr>
<th>Type Name</th>
<th>Key Dimensions</th>
<th>Weight (tons)</th>
<th>Number on Hand</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Focusing Magnets, i.e. Quadrupole Magnets.</strong> <em>(Key dimensions are dia. of bore, length.)</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metis</td>
<td>4&quot; x 12&quot;</td>
<td>½</td>
<td>12</td>
</tr>
<tr>
<td>Deirdre</td>
<td>12&quot; x 48&quot;</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Aideen</td>
<td>12&quot; x 48&quot;</td>
<td>77</td>
<td>2</td>
</tr>
<tr>
<td>-</td>
<td>(6&quot;x24&quot;) x 36&quot;</td>
<td></td>
<td>0 (in design stage)</td>
</tr>
<tr>
<td>-</td>
<td>8&quot; x 36&quot;</td>
<td></td>
<td>0 (in design stage)</td>
</tr>
<tr>
<td><strong>Deflecting, Clearing, Analyzing Magnets.</strong> <em>(Key dimensions are height, width, length of gap.)</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boadicea</td>
<td>6&quot; x 12&quot; x 72&quot;</td>
<td>18</td>
<td>1 (with 25° bend)</td>
</tr>
<tr>
<td>Castor</td>
<td>3&quot; x 10&quot; x 72&quot;</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>Scylla</td>
<td>10&quot; x 22&quot; x 48&quot;</td>
<td>38</td>
<td>2</td>
</tr>
<tr>
<td>-</td>
<td>11&quot; x 26&quot; x 48&quot;</td>
<td>35</td>
<td>0 (in order)</td>
</tr>
<tr>
<td>Tinkerbell</td>
<td>3&quot; x 5&quot; x 36&quot;</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td><strong>Pair Spectrometer Magnets.</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orpheus</td>
<td>5&quot; x (32&quot; dia.)</td>
<td>21</td>
<td>2</td>
</tr>
<tr>
<td>Minerva</td>
<td>4&quot; x (15&quot;x4&quot;) x 58&quot;</td>
<td>38</td>
<td>1 (trapezoidal)</td>
</tr>
<tr>
<td><strong>Other Types.</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colossus</td>
<td>15&quot; x (40&quot; dia.)</td>
<td>280</td>
<td>1 (Bubble chamber type)</td>
</tr>
</tbody>
</table>

Note: Design work is nearly complete on two other, especially large magnets.
year ago (computed with respect to the ten-foot modulus grid marked on the floor in accurate relationship to the ring of 48 magnets of the synchrotron).

**Detectors:** A number of additional detectors, including several thin-wall ionization chambers and two quantameters for appraising the total energy flux of an emergent beam of photons, were built and tested.

**Cables:** Much effort was devoted to installing power cables and control lines for the thousands of detectors that are to be used in the various experiments. Also, large quantities of wires and coaxial cables for transmitting the output signals from the detectors to the data processing room (Room 104) were installed.

**Cryogenics:** Construction of the main equipment for cooling and liquefying helium at the rate of 100 litres an hour continued satisfactorily. The first semi-portable cooling unit for cooling liquid hydrogen targets was built and tested, and appears nearly ready for use.

**Supplementary Shielding Walls:** A four-foot thick concrete shielding wall for protecting the ramp region and the truck-unloading areas from radiation originating in the east half of the experimental hall was erected in August -- near the west end of the experimental hall. In October, when new assignments of experimental hall areas to various imminent experiments were made, the wall was dismantled and then erected between Beam paths 5 and 7, so that it divided the hall into a "hot half" and a "cold half" and thereby improved the utilization of each.

**Radiation Safety:** Additional types of radiation detectors and recorders were obtained and put into use. Interlock systems for excluding personnel from high-level radiation areas were improved and extended, and convenient yet safe "special access" procedures were worked out.
PART IV. ALTERATIONS TO THE ACCELERATOR PROPER

During the current six-month period, the accelerator proper was altered and improved in several ways.

The cooling system for the 60-ton choke of the magnet power supply was improved in July and August, and the method of clamping the core blocks was improved at the same time. Since then, the magnet power supply has operated for long periods at high power levels without trouble.

The spare superpower triode for the rf system was modified by R.C.A. engineers. Consequently, we now have one fully operable spare tube in addition to the tube that is in routine use. A frequency modulator for the rf system was built and installed, to permit shifting the rf frequency by 60 to 80 kc just in the early part of the acceleration cycle, thus reducing the beam-loading problem and permitting achievement of a greater beam intensity. Indicators and controllers for the rf modulation waveform were installed in the main control room (Room 103) to permit more direct adjustment of the waveform.

Many of the Drivac high-vacuum pumps were modified and improved, and a different type of pump (a Varian pump) was purchased and tried out with promising results.

Numerous minor changes were made in components of the linac power supply, linac triggering system, and the magnetic inflector, to increase the stability and reliability of operation. Also, many of the main controls for the linac were transferred to the main control room.

The heights of the 48 magnets were resurveyed, and were found to be almost unchanged since the previous survey, 6 months before.
The rms change in height was about 5 mils.

Improved equipment for inducing betatron oscillations was built and put into use in determining how the betatron frequencies vary with choices of currents in the pole face windings. Computer programs were worked out for finding how to readjust the currents in the median plane correction coils and other correction coils, for a given observed set of orbit distortions.

A new underground room was built between the labyrinth and the machine shop, and will be used as a repair shop for vacuum chambers, etc. The data handling room (Room 104) was enlarged and improved. Plans were made for transferring the main control consoles, etc. to the west portion of the ground floor of the power building.
PART V. ACCELERATOR TUNE-UP AND OPERATION

On May 21, after two months of operation at energies below 3.2 Bev and at low beam intensity, the accelerator was shut down to permit overhauling the cooling system and clamping system of the 60-ton choke of the magnet power supply.

On August 13 operation was resumed, and an energy of approximately 6.2 Bev was achieved. In the subsequent three months the machine was operated for a few hours on several days a week, usually at 2 Bev or 4 Bev, and usually with intensities of about 10 to 15% of the design intensity. (Design intensity is nominally $6 \times 10^{12}$ electrons/second.)

By the end of the year operation had been improved further. Operation at 4 Bev with an intensity of 15 to 20% of design was common, and 6 Bev operation with 15% of design intensity was achieved occasionally. Even better outputs were achieved for short intervals during special tune-up trials.

The reliability of operation was improved also, but short halts to correct minor difficulties in the linac and in the vacuum system were still a frequent occurrence. (On January 18, 1963, an uninterrupted run of 7 hours at 5 Bev and with 30% of design intensity was achieved. This was the best run to date.)

During the last two months it has been the practice to run the accelerator in the daytime to permit studies of machine performance and new improvements, and to run the accelerator in the evening (5:00 p.m. until midnight) for the benefit of various groups of experimentalists. We are hopeful that further improvements in beam intensity and in reliability of operation will be made in the following months, and that the groups of experimentalists will find the accelerator increasingly successful in serving the various high-energy experiments now getting under way.
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