CEAL- 1051

MASTER

SEMI-ANNUAL REPORT

For the Period

July 1 through December 31, 1969

K. Strauch, Director

W. A. Shurcliff

April 10, 1970

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
and HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

CAMBRIDGE, MASSACHUSETTS 02138

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THE NEW JOURNAL

for the year 1954

Part I through December 31, 1954

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this report was performed under
Contract AT(30-1)-2076 between
the U.S. Atomic Energy Commission
and the President and Fellows of
Harvard College.
W. A. Shoenberger

April 10, 1955

TABLE OF CONTENTS

	<u>Page</u>
SUMMARY	1
Part I INTRODUCTION	3
Part II ACCELERATOR OPERATION	6
A. Statistics on Accelerator Use	6
B. Operation, Maintenance, and Minor Improvements	7
Part III EXPERIMENTS IN HIGH-ENERGY PHYSICS	17
A. Experiments in Which Analysis of Data was in Progress during the Period in Question.	17
B. Experiments Involving Use of Machine Time in the Period in Question	23
C. Experiments in Which the Data Taking is to Start in a Later Period	28
Part IV PROJECT BYPASS	29
A. Introduction	29
B. Injection	30
C. Beam Storage in Synchrotron Ring	33
D. Bypass Trials	33
E. On-Line Detector	35
F. Optical Detector	38
G. Magnetic Detector	39
Part V OTHER ACTIVITIES AND NEW PROJECTS	41
A. Theoretical Studies	41
B. Source of Polarized Electrons	41
C. Miniature Storage Ring for Production of Light of Unmatched Monochromaticity	42

	<u>Page</u>
Part VI OTHER PROGRAMS	43
A. Safety	43
B. Training of Disadvantaged Persons	43
Part VII PUBLICATIONS RESULTING FROM WORK DONE AT THE CEA . .	44
A. Publications on High-Energy Research Performed at CEA	44
B. Papers Presented at the August 1969 Am. Phys. Society Meeting in Boulder, Colorado	46
C. Papers Presented at the September 1969 International Symposium on Electron and Photon Interactions at High Energies, Daresbury, England	46
D. Other Papers and Preprints	48
E. Theses on High-Energy Research Performed at CEA	49
F. CEAL Reports	50
G. CEAL-TM Reports	50

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY • HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

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42 OXFORD STREET
CAMBRIDGE, MASS. 02138

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SEMI-ANNUAL REPORT FOR THE PERIOD

July 1 - December 31, 1969

SUMMARY

Part I indicates the purpose of the contract, which is concerned with operating and improving the 6-GeV Cambridge Electron Accelerator. The main guiding committees are listed.

Part II, on accelerator operation, shows that the total number of delivered prime-user hours and parasite-user hours was 2915. The number of delivered prime-time hours was 2257 compared to 2854 originally scheduled; the delivery factor was 0.79. The number of hours delivered to project bypass was 658, compared to 781 originally scheduled; the delivery factor was 0.84.

Part III describes the 19 experiments underway or in preparation.

Part IV summarizes progress on the colliding beam facility in which electron and positron beams, each with an energy as high as 3.5 GeV will collide with an available energy of 7.0 GeV in the center-of-mass system. The performance of the 130-MeV electron linac was improved and the Varian 130-MeV positron linac was installed and tried out successfully. The vacuum system of the accelerator ring was improved and we succeeded in achieving, with a 2.6-GeV constant-energy electron beam stored in the synchrotron, a $1/e$ lifetime of two hours. The bypass hardware also was improved and we succeeded in obtaining, with a 2-GeV electron beam stored in ring and bypass, a $1/e$ lifetime of 45 minutes. The 120-ft-long, low-beta bypass train in which the collisions are to occur was tuned and adjusted. Many studies were made of apertures, betatron frequencies, and other parameters.

Construction of the on-line detector for analyzing results of the e^-e^+ collisions is nearing completion and many tests on component and component sub-assemblies have been completed successfully. Progress was made also on an optical detector and a magnetic detector.

Part V summarizes the work done on various new projects, the most ambitious of which is the development of a source of polarized electrons.

Part VI deals with safety and Part VII lists the major publications.

PART I - INTRODUCTION

This report summarizes work done under the Harvard-AEC Contract AT(30-1)-2076 during the six-month period from July 1 through December 31, 1969. The contract calls for the operation and maintenance of the CEA 6-billion-electron-volt synchrotron and for designing, procuring, installing and operating various essential facilities.

The general policies of the laboratory were determined by a joint MIT-Harvard "Executive Committee of the CEA", comprising the following:

from MIT: Dr. Malcolm G. Kispert
 *Prof. Francis E. Low
 *Prof. Louis S. Osborne
 *Prof. Victor F. Weisskopf
 Prof. Jerome B. Wiesner, Chairman

from Harvard: Dean Franklin L. Ford
 *Prof. Francis M. Pipkin
 *Prof. J. Curry Street
 Mr. L. Gard Wiggins
 *Prof. Richard Wilson

The "Cambridge Electron Program Advisory Committee" (CEPAC) reviewed the status of experiments in progress and examined proposals for future experiments. During the

*denotes member of Scientific Subcommittee

half-year in question this committee included (in addition to the Director):

Dr. Samuel Berman, SLAC

Prof. Louis N. Hand, Cornell

Prof. Clemens A. Heusch, C.I.T.

Prof. Francis E. Low, M.I.T.

Prof. Louis S. Osborne, M.I.T.

Prof. Burton Richter, SLAC

Prof. Roy Weinstein, Northeastern

Prof. Richard Wilson, Harvard

Prof. Donald Yennie, Cornell

Dr. Gustav-Adolf Voss, CEA

Dr. James M. Paterson, CEA, secretary

The Committee met at the CEA on November 21 and 22, 1969.

The "CEA Scheduling Committee" determined the day-to-day priorities in assignment of eight-hour shifts of accelerator time to the experimenter groups. In the half-year in question the committee included:

Dr. Wolfhard Kern, S.M.U.

Dr. John J. Russell, Harvard

Dr. Herman Winick, CEA

Dr. William A. Shurcliff, CEA, secretary

On December 3 the CEA Visiting Board met at CEA to examine the conditions and program of the laboratory and its plans for the future. The Board is to submit a report

on its conclusions to the presidents of M.I.T. and Harvard.

The Board included:

Dr. James B. Fisk, Chairman
President, Bell Telephone Laboratories

Prof. James W. Cronin
Dept. of Physics, Princeton University

Prof. Maurice Goldhaber
Director, Brookhaven National Laboratory

Prof. J. David Jackson
Dept. of Physics, Univ. of Calif., Berkeley

Prof. Boyce D. McDaniel
Director, Lab. of Nuclear Science, Cornell

Prof. W. K. H. Panofsky
Director, Stanford Linear Accelerator Center

The CEA staff was strengthened by the addition of a theoretical physicist, Dr. Lars Fäldt (University of Lund, Sweden, 1969) in September 1969.

PART II - ACCELERATOR OPERATION

A. Statistics on Accelerator Use

During the period July 1 - December 31, 1969, the efficiency and distribution of accelerator time were as follows:

TABLE 1

EFFICIENCY OF SCHEDULED OPERATION

	<u>Hours</u>	<u>Percent</u>
Delivered Prime Time	2257	79
Unscheduled Downtime	596.5	21
	2853.5	100

TABLE 2

USE OF DELIVERED PRIME TIME

	<u>Hours</u>	<u>Percent</u>
High Energy Physics	1505.5	66.7
Accelerator Physics	751.5	33.3
	2257	100

TABLE 3

USE OF PRIME AND SECONDARY TIME IN HIGH ENERGY PHYSICS

<u>User</u>	<u>Exp't No.</u>	<u>No. of Prime Hours</u>		<u>Delivery Eff. (%)</u>	<u>Delivered Sec'd Hrs.</u>
		<u>Scheduled</u>	<u>Delivered</u>		
Pipkin et al	102h	346.0	274.5	79.3	98.5
Wilson et al	105f	151.0	127.0	84.1	12.0
Russell et al	107a	288.0	231.5	80.4	252.5
Luckey et al	109i	614.0	452.0	73.6	0
Deutsch et al	111d	145.0	124.0	85.5	24.5
Bar-Yam et al	117a	40.0	16.5	41.2	40.5
Dell et al	119a	1.5	1.5	100.0	0
Yuan et al	120a	0	0	-	123.0
Pipkin et al	121a	358.5	278.5	77.7	8.5
Deutsch special tests	-	0	0	-	31.0
Bypass on-line detector	-	0	0	-	35.5
Columbia Univ. & Harvard Group	-	0	0	-	32.0
		1944.0	1505.5	77.4 weighted average	658.0

TABLE 4

USE IN ACCELERATOR PHYSICS

<u>Scheduled Hours</u>	<u>Delivered Hours</u>	<u>Eff. (%)</u>
909.5	751.5*	82.4

*657.5 hours were allocated to the colliding beam project and 94 hours to calibration of beam monitors etc.

Note: Total delivered prime and secondary time for high energy physics and accelerator physics: 2915 hours.

TABLE 5

ANALYSIS OF UNSCHEDULED DOWNTIME

<u>Cause</u>	<u>Hours</u>	<u>Percent</u>
Linac and injection	199.0	33.4
Tune-up	120.5	20.2
Synchrotron Magnet	100.5	16.8
Rf System	58.5	9.8
Vacuum System	28.0	4.7
Miscellaneous	<u>90.0</u>	<u>15.1</u>
	596.5	100

B. Operation, Maintenance, and Minor Improvements

In the six-month period in question the synchrotron performed well. The principal difficulties encountered were with the linac and the rf system. A three-week scheduled shutdown of accelerator operation occurred from September 15 to October 7 to permit necessary maintenance work and installation of new components.

Linac

In July, August, and September we made use of the old (30-MeV) linac situated in the Spur Tunnel because the new (130-MeV) linac in the Radial Tunnel could not be operated while the positron linac was being installed there. During this period the old linac ran well for use in connection with conventional experiments but was not, of course, applicable to most types of studies required for Project Bypass.

In August the acceptance tests of the Varian Associates positron linac were completed successfully. In September most of the positron transport and inflection systems were installed; also the necessary vacuum pumps, pressure gages, shutters, and radiation monitors were installed.

In September the 130-MeV electron linac was put back into service again, after installation of new shutters, bending magnets, focusing elements, and radiation monitors and after shifting the principal controls from the linac console area to the Main Control Room. Preparations were made for operating the two linacs in series (electron linac upstream, positron downstream) so as to provide an electron injection energy of 250 MeV rather than 130 MeV. The increase in energy is beneficial to multicycle injection of electrons.

The electron linac presented a number of difficulties in October, November, and December, and was the major cause

of accelerator downtime in the half-year in question. Shortcomings of the support structure for the electron-beam transport system caused misalignment of the bending magnets and resulting loss in acceptance of the beam injected into the ring. The alignment was corrected at the end of October. There were occasional failures of capacitors of the pulse-forming network of the first modulator, until capacitors of more reliable type were installed in November. The energy spectrum of electrons issuing from the linac was insufficiently flat, and made tuning difficult, until adjustments were made in the pulse lines from modulators to accelerating waveguides. In mid-November the charging choke of the linac high-voltage power supply failed, halting accelerator operation for several days. At the end of that month we installed, as a temporary solution, three small chokes lent to us by SLAC. In mid-December we replaced these with a single, rebuilt CEA choke.

In November we increased the amount of shielding employed in critical portions of the Linac Tunnel in order to reduce the radiation levels in the overhead parking area to the same order of magnitude as the natural background. The improvement in shielding also reduced, by an order of magnitude, the levels of residual radioactivity in work areas of the Linac Tunnel.

Synchrotron Magnet Ring

On July 6 arcing occurred in the dc portion of the power supply for the ring of 48 magnets and damaged two ignitrons and associated wiring. A substitute power supply consisting of two series-connected supplies normally used for powering experimental magnets was put into operation. The regular supply was repaired and put back into use three weeks later. In June a spare coreblock assembly for the 60-ton inductor was completed. In August a vertical tie-rod of the inductor failed and was replaced, and in September the inductor as a whole was overhauled. Also a new pulser ignitron tube was installed. The temperature regulation of the pulser was improved in November.

The regulation of magnet excitation current was improved to provide uniformity within 0.1% at 1 GeV and 0.05% above 2 GeV.

In July and August we made careful measurements of the energy of the emergent electron beam as a function of magnet excitation with the purpose of improving the basic energy calibration of the synchrotron. We found that the earlier calibration was correct within 1/2 percent at energies between 2 to 4 GeV and 1% at energies of 1 GeV and 5 GeV.

Rf System

Further failures of RCA HPA 4612 triodes occurred, accentuating the need for an alternative rf supply. The Serial X-1 triode ordered in October 1968 had been tried out extensively

for acceptance at our laboratory in the first half of 1968; it failed, was repaired, failed again on June 30, 1969, and was sent back to RCA for repair.

In March 1969 we asked RCA to repair the Serial A4R1 triode that we had used earlier. Repair was completed by August and the tube was put into trial use at CEA in September. In October the system frequently broke into parasitic oscillations and there were frequent trip-outs at power levels of 50 to 60 kW, about half the rated power level. We improved the performance somewhat by replacing a defective air-cooled cathode resistor with a water-cooled resistor. Late in October a small water leak (to the outside) developed and the tube was replaced by our Serial U-1 tube that had already operated successfully for 8440 hours. Early in November this tube in turn failed, and the A4R1 (repaired again but still safely operable only up to 50 kW, corresponding to a peak accelerator energy of 5.6 GeV with a 10 mA beam) was installed.

In September we installed a 25-HP rotary air compressor for the pneumatic control system for rf cavity temperature regulation.

In October an rf driver tube failed after 9500 hours of use and was replaced. An SCR voltage control unit installed in October failed in initial tests and was returned to the manufacturer.

In November we completed construction of equipment for use in testing alumina windows for rf cavities by subjecting the windows to 100-kW levels of 475 MHz power under conditions simulating actual use.

Much effort was given to finding a long-term solution to the HPA problem. The present system is approaching obsolescence because RCA is having increasing difficulty manufacturing the 4612 triode just for one customer. A majority of the 4612 tubes supplied to us by RCA in recent years have developed faults far sooner than had been expected and in many instances RCA was unable to repair the defective tubes either reliably or promptly. In any event it is essential that we at least double the average power capability of the rf system in order that we be able to store a 100-mA electron beam and a 100-mA positron beam (with circumferential filling factor of 0.25) at an energy as great as 3 to 4 GeV.

In the period May - November 1969, CEA physicists and engineers visited three accelerator laboratories (SLAC, DESY, NINA) and two tube manufacturers (Varian in the USA and CSF in France) and consulted with other suppliers of high-power rf equipment to discuss the more attractive alternatives for obtaining a satisfactory source of rf power. One alternative was to have a manufacturer develop for us a single tube that should be ideally suited for the purpose. Another alternative, expected to minimize delays and uncertainties, was to make use of a parallel-connected group of tubes (of

lower power rating) already in routine production. At the end of December these exploratory studies were continuing. (In January 1970 the decision was made to adopt the latter alternative; on March 4 we ordered a set of four Varian 953-C UHF klystrons rated at 50-kW average power output each.)

Vacuum System

The vacuum system performed excellently in the six-month period in question. None of the vacuum chambers failed and, after July, no high-vacuum pump failed. Throughout the three-month period October - December no difficulty with the vacuum ring was encountered and a pressure of 1×10^{-8} torr was maintained routinely.

The last of the remaining circular bellows between straight-section tanks and (elliptical-section) vacuum chambers were replaced by elliptical bellows.

By the end of December, 23 of the 48 high-vacuum pumps were new Varian pumps; the remainder, to be replaced in the next year, were Drivac pumps. The Varian pumps can be baked at higher temperature than is permissible for Drivac pumps, have higher pumping speeds at low pressures, and are much more reliable than the nine-year-old Drivac pumps.

Miscellaneous Components

A new system for connecting power supplies to experimental magnets was inaugurated; the new system provides greater speed and reliability of change-over. In a systematic

inspection of the connections of all experimental magnets, we found and corrected leakage-to-ground problems and other faults. We procured temperature-controlled Hall probes for use in accurate monitoring, from the Control Room, of the actual field strengths of critical focusing and analyzing magnets. A new 36-ton 12 x (24 to 36) x 36 inch spectrometer magnet for use in Area 7 was received and tested.

We largely completed the installation of greatly improved systems for filtering, deionizing, and deoxygenating our 150-gpm cooling-water system for magnets and our 5-gpm make-up water system.

Improvements were made in beam monitors of several types. A prototype thick-plate secondary emission monitor (SEM quantameter) was constructed; see Fig. 1. Three SEM monitors were tested and recalibrated.

A 4-liter liquid hydrogen target and target-cooler system for use by Russell-Tannenbaum et al was assembled, tested, and put into routine use. The mechanical refrigerator is noteworthy in that it has an output of 70 watts and employs, as heat transfer fluid, gaseous helium at 25 atmospheres pressure. Likewise we completed work on a 1/2 liter liquid hydrogen target and cooling system for use by Pipkin et al. In October the last of our liquid-helium-cooled hydrogen targets was converted to mechanical cooling.

Our computer facility, with its four SDS-92 computers for interfacing the experimental installations on-line to

Fig. 1. Prototype thick-plate, secondary-emission monitor (SEM quantameter). The device includes a stack of 77 gold-plated, $1/32$ -in.-thick aluminum plates separated by evacuated (10^{-7} torr) spaces $1/16$ in. thick. Diameter of useful aperture: $9\frac{1}{2}$ in.

the Harvard IBM 360/65 computer, worked with increasing reliability. In June the equipment was used successfully by two experimenter groups simultaneously, and such simultaneous use is now routine.

Development of computer control of the powering of experimental magnets continued and by the end of 1969 the control system was ready for application either to a conventional experiment in the Experimental Hall or to the colliding beam project.

We modified the personnel exclusion system of the east portion of the Circular Tunnel (the special injection portion) to make it possible to operate the linac and linac transport runs without need for excluding personnel from the main portion of the Circular Tunnel. Thus the efficiency of linac tune-up and the efficiency of maintenance work in the Circular Tunnel were increased.

We replaced several standard Nuclear Measurements Corp. gamma-radiation area monitors with monitors of more modern type, employing solid-state electronics. These are expected to exhibit greater radiation resistance than the earlier type, which contained vacuum tubes and a contacting-type meter relay.

We refined our methods of measuring radiation dose at the adjacent streets and determined dose rate as a function of altitude (up to 57 ft) at the location of greatest interest (near the junction of Gorham and Museum Streets).

At ground level locations the annual doses from CEA-produced radiation were less than the natural background, and at 50-ft altitude at the junction in question the level of CEA-produced radiation was twice the ground-level value. (Note: this altitude is higher than the tops of the nearest houses.)

To improve electrical safety in the Circular Tunnel we installed electrically interlocked safety curtains and shields at all straight sections that contain high-power ejection magnets.

PART III - EXPERIMENTS IN HIGH-ENERGY PHYSICS

During the six-month period in question there were 19 experiments in high-energy physics in progress or in various stages of preparation or completion. These are described below.

A. Experiments in Which Analysis of Data Was in Progress
During the Period in Question

Pipkin, Stanfield, et al (Harvard), Experiment 102f: Continuation of Small Angle Scattering of Electrons by Carbon. Seeking additional information on the form factor of the carbon nucleus, the investigators employed an external electron beam of 1.5 to 4.0 GeV electrons, a carbon target, and a single-arm spectrometer that detected and analyzed the scattered electrons. Data taking was completed in February 1968. Analysis of results continued throughout 1969. A detailed account of the work was presented in the August 1969 thesis by K. C. Stanfield, "Quasi-Elastic Electron Scattering and Pion Electroproduction off C^{12} from 1.0 to 5.0 BeV". Also, a summary article was submitted to Phys. Rev. and plans were completed for presenting a paper at the April 1970 meeting of the Am. Phys. Society in Washington, D.C.

Pipkin, Hicks, et al (Harvard), Experiment 102g: Search for the R Meson. A two-spectrometer system capable of detecting the decay products (the π^+ and π^-) of the R^0 was used in March 1968 to search the mass range 1500 to 1800 MeV. No evidence was found for the photoproduction of R^0 mesons with

a differential cross section $d\sigma/(dt dM)$ exceeding $1 \mu\text{b}$ per $[(\text{GeV})^3 \text{ nucleon}]$. A summary of the principal results was presented at the September 1969 International Symposium on Electron and Photon Interactions at High Energies, Daresbury, England, and also in Phys. Rev. Letters 29B, 602 (1969).

Brenner, Walker, et al (Harvard), Experiment 103h: Study of Small-Angle Compton Scattering of Photons, at 2° to 6° lab, from protons. The group used tagged photons (of known energy, from 2.0 to 4.6 GeV) and measured the energy of the scattered photons by converting them to electron-positron pairs and determining the energy of these with the aid of a wide-gap spark chamber and the Jolly Green Giant magnet. In the second half of 1968 the investigators obtained and analyzed a large amount of data; they also improved the operation of the spark chambers so that the tracks would be more nearly distortion-free and improved the accuracy of their analysis techniques. Much additional data was taken in the first half of 1969 and was analyzed in the latter half of that year. Publication of results is expected by mid-1970.

Wilson et al (Harvard), Experiment 105f: Backward Angle e-p and e-d Scattering, as part of the determination of the electric and magnetic form factors of the neutron and an effort to obtain a better understanding of the structure of the deuteron. Electrons of 0.45 to 2 GeV energy that were quasi-elastically scattered at 90° lab from a liquid hydrogen or liquid deuterium target were measured by means of a quadrupole

spectrometer, scintillation counters, a lead-lucite shower counter, and a freon Cerenkov counter -- connected on-line to the Harvard Physics Department PDP-1 computer. Late in 1968 the investigators took a large amount of data and determined the ratio σ_n/σ_p with an accuracy of a few percent at six q^2 values between 7 and 45 f^{-2} . In May 1969 the investigators confirmed the calibration of the main beam monitor used, and in July and August much additional data was taken. Analysis of results was then begun and is now nearly complete.

Luckey et al (M.I.T.), Experiment 109h: Photoproduction of π^0 from Neutrons. In an effort to understand the mechanism of photoproduction of π^0 from nucleons in the t -value range from -0.2 to -2.0 $(\text{GeV}/c)^2$, the investigators directed a beam of 4-GeV unpolarized photons at a liquid deuterium target and detected the π^0 particle by means of two lead-glass Cerenkov counters that responded to the two resulting photons, and detected the recoil neutron by means of a special neutron counter consisting of a 12 x 12 x 15 inch scintillator block viewed by 20 photomultiplier tubes. The equipment was set up late in 1968 and tested in February 1969. Data taking occurred in March through June, and subsequent months were devoted to analysis of results -- presented at the September 1969 Daresbury Symposium. Preparation of a detailed report is underway.

Frisch et al (M.I.T.), Experiment 112a: Study of Photo-production of a $2 \pi^0$ Resonance (f^0 particle) with tagged photons. The investigators used tagged photons from the internal beam-tagging facility in Magnet 12; photon energy was known to within 2%. A search for f^0 and other meson resonances was undertaken with a $0.1 X_0$ polyethylene target. The direction of the recoil proton was determined by means of a thin-foil spark chamber. To determine the directions of the four photons produced in the decay of the two neutral pions, the investigators found the locations of the resulting showers by means of a spark chamber containing thick iron plates that had an aggregate thickness of $7.3 X_0$. By the end of June 1969 the investigators had analyzed 50,000 photographs and obtained four events of the type $\gamma + p \rightarrow 2\pi^0 + p$. They found that, within a dipion mass range from 850 to 1400 MeV and at forward angles up to 60° c.m., the upper limit on production cross section was $0.9 \mu\text{b}$. Results were summarized in a thesis "Upper Limit on the Cross Section for Photoproduction of Neutral Pion Pairs Having an Invariant Mass Near 1 BeV" by S. R. Smith of M.I.T. In the latter half of 1969 the photographs were analyzed for three pion (π^-, π^0, π^+) events and a thesis presenting the results is in preparation.

Kendall, Friedman, et al (M.I.T.), Experiment 113b: Study of Inelastic e,d Scattering with the purpose of exploring the electro-disintegration of the deuteron near threshold and exploring the short-range structure of the n,p interaction at low energy in the n,p center-of-mass system. The

investigators used an external beam of 1 to 4 GeV electrons and a liquid deuterium target. The scattered electron was detected by a quadrupole spectrometer that included wire chambers and scintillation counter hodoscopes. In 1969 the investigators completed the analysis of results, used the results in an investigation of the validity of one of the leading theories as to electro-disintegration of the deuteron, and started preparation of an article to be submitted to the Physical Review.

Milburn et al (Tufts), Experiment 114a Part I: Measurement of the Polarization of the Proton Recoiling in $\gamma + p \rightarrow p + \pi^0$ Events in which the pion is ejected at 65° c.m. and the photon energy varies from 1.2 to 1.8 GeV. The investigators employed (a) a small spark chamber and lead glass Cerenkov counters for detecting photons from the decay of π^0 , (b) a magnet and four small spark chambers for determining the momentum of the recoiling proton, and (c) a large spark chamber, containing 61 graphite plates, for determining the asymmetry of scattering of the proton by the carbon nucleus. The experimental work was done in the fall of 1968 and the analysis of results was completed in 1969. No significant polarization of the proton was observed. Brief reports of the work were presented at the 1969 winter meeting of the Am. Phys. Society and the September 1969 Daresbury Symposium. A full account of the work is in preparation as a Ph.D. thesis.

Weinstein et al (Northeastern University), Experiment 118d: Study of Photoproduction of Muon Pairs at High Mass, with the purpose of observing the decay $\phi^0 \rightarrow \mu^+ + \mu^-$ and thus providing an accurate test of vector dominance and of e, μ universality. Electrons of 5 GeV energy struck a thin lead converter (situated in the target area) and produced bremsstrahlung photons with energies up to 5 GeV. These struck a carbon target and the resulting ϕ^0 particles immediately decayed into μ^+ and μ^- . The two-arm spectrograph included 5-ft-thick stacks of iron plates and a 200-counter hodoscope; the equipment permitted determination of the muon ranges and directions. Data-taking runs were made early in 1969 and analysis of results was completed by the fall of that year. Results were summarized in a talk given at the Daresbury Symposium and in an article in Phys. Rev. Letters. A detailed account was prepared as a Ph.D. thesis.

Weinstein et al (Northeastern Univ.), Experiment 118i: Search for Heavy Vector Mesons. Employing a high-intensity 6-GeV external electron beam incident on a $0.2 X_0$ lead converter, the experimenters concentrated the resulting bremsstrahlung beam on a carbon target. Muon pairs corresponding to invariant mass between 0.9 and 1.9 GeV were detected by means of a two-arm spectrometer each arm of which covered an angular range from 10° to 21° lab from the beam axis. Each arm carried iron plates with an aggregate thickness of six feet, with intervening arrays of scintillators. Data taking

occurred in March and April, and by the fall of 1969 the analysis of results was nearly complete. Results were summarized in talks given at the Daresbury Symposium and at the Boulder, Colorado meeting of the Am. Phys. Society. A Ph.D. thesis presented a detailed account of the work.

B. Experiments Involving Use of Machine Time in the Period in Question

Pipkin et al (Harvard), Experiment 102h: Beam 7 Spectrometer Testing. The spectrometer consists of two arms which can be swung horizontally with the aid of pneumatic lifting pads. Each arm supports an 8-inch half-quadrupole magnet, a 6-ft analyzing magnet mounted on edge so as to deflect particles in a vertical plane, a 12-inch half-quadrupole magnet, and an elevated tail structure on which scintillation counters, wire spark chambers, differential gas Cerenkov counter, and shower counters are mounted. The 30-inch cylindrical spectrometer magnet Orpheus is mounted at the pivot point. The majority of the equipment was installed in 1968; adjustment and calibration were completed in October 1969. Resolution, limited mainly by multiple scattering, was found to be 12 MeV rms for all particles for which $\beta \approx 1$. The spectrometer was put into use in November 1969 in connection with Experiment 121a on elastic π^+ electroproduction near 0° and at pion-nucleon c.m. energies above the nucleon resonances.

Russell, Tannenbaum, et al (Harvard), Experiment 107a: Boson Resonance Photoproduction. The goal is to survey the spectrum of neutral bosons (in the boson mass range from 500 to 1800 MeV) in the reaction $\gamma + p \rightarrow p + \text{boson}$. The investigators are attempting to determine the energy dependence and angular dependence of production of known bosons (e.g. the ρ^0, ω^0 particles) and perhaps new ones also. They employ a tagged photon beam and a liquid hydrogen target. Protons recoiling at 20° to 60° lab are detected by two sets of wire spark chambers (8 in all) and an intervening magnet 'Enry 'Iggins. Decay products of the bosons produced are detected by six wire spark chambers situated downstream from the target. The data are interfaced by a CEA SDS-92 computer to the Harvard IBM 360/65 computer. The equipment was assembled early in 1969 and in later months adjustments and calibrations were completed and some data was taken using just one arm of the spectrometer. Long data-taking runs were scheduled for early 1970.

Luckey, Bar-Yam, et al (M.I.T. and S.M.U.), Experiment 109i: Photoproduction of π^+ from Polarized Photons. This experiment complemented Experiment 117a (by Bar-Yam et al) on photoproduction of π^- from polarized photons. Again 6-GeV electrons in the synchrotron orbit struck a diamond and produced bremsstrahlung having a linearly polarized spike at 3 GeV. The target was of liquid hydrogen, rather than deuterium. The π^+ was detected by the Moby Dick magnetic

spectrometer, augmented by a gas-filled threshold Cerenkov counter to discriminate against protons. The neutron was detected by a large (12 x 12 x 15 inch) scintillator counter assembly viewed by 20 photomultiplier tubes. The investigation covered the t -value range from -0.2 to -1.2 (GeV/c)². In the latter half of 1969 data taking was completed, a large portion of the analysis was finished, and a summary of results was presented at the September 1969 Daresbury Symposium.

Deutsch et al (M.I.T.), Experiment 111d: Proton Compton Effect at 2 GeV and $t = -0.16$ (GeV/c)². In 1967 the investigators studied γ, p scattering at 65° c.m. with photon energies from 0.8 to 2.5 GeV and with t -values of -0.35 to 1.15 (GeV/c)². In the present experiment measurements were made at angles as small as 30° c.m., t -values as small as -0.16 (GeV/c)², and photon energies as high as 4.5 GeV. Energy of the recoil proton was determined by means of range measurements with spark chambers rather than by use of a magnetic spectrometer. Data taking was completed in November 1969. Analysis of the data indicated that for an average photon energy of 3.5 GeV the differential cross section extrapolates at $t = 0$ to the value expected from total cross section and optical theorem, and the slope is approximately 5 (GeV/c)⁻². Plans were made for presenting a summary of the results at the April 1970 meeting of the Am. Phys. Society, and an article for publication in Phys. Rev. Letters is in preparation.

Bar-Yam et al (S.M.U.), Experiment 117a: Study of Photo-production of Single π^- on Deuterium by Polarized Photons.

A beam of photons with a linearly-polarized 3-GeV spike was produced by a diamond situated in the synchrotron orbit. The beam struck a liquid deuterium target and the π^- particles photoproduced singly were detected by a magnetic spectrometer in coincidence with the recoil proton. A photon subtraction method was used to determine the energy of the incoming photon and to substantially eliminate the incoherent production as well as the multi-pion production. The investigators then determined the photoproduction asymmetry, defined as the ratio $(\sigma_{\perp} - \sigma_{\parallel})/(\sigma_{\perp} + \sigma_{\parallel})$, where $\sigma_{\perp}$, for example, is the differential cross section when the electric vector of the incident photon is perpendicular to the plane of production. The asymmetry was measured between 0.15 and 2.0 (GeV/c)² and was found to be positive at -t values below 0.3 (GeV/c)², dipping to negative values between 0.4 and 0.6 (GeV/c)² and rising again to positive values above 0.7 (GeV/c)². Results have been summarized in several talks and a full report is being prepared for publication.

Fulmer, Dell, et al (ORNL and CEA), Experiment 119a: Study of Electro-Induced and Photo-Induced Spallation. Iron sheets were exposed to 1.5-GeV electrons and shipped by air to Oak Ridge for prompt analysis.

Yuan et al (BNL), Experiment 120a: Energy Dependence of Transition Radiation. In 17 parasite shifts the investigators

made further measurements of the energy dependence of transition radiation from a stack of several hundred aluminum foils mounted perpendicular to a positron beam in Area 5. Their results demonstrate that such radiation will provide a uniquely effective means of determining (at NAL, for example) the speed of highly-relativistic protons or other charged hadrons for which $\gamma \geq 10^2$.

Pipkin et al (Harvard), Experiment 121a: Elastic π^+ Electroproduction near 0° and at pion-nucleon c.m. energy above the nucleon resonances. With the purpose of testing Regge-pole models and other models of hadron photoproduction, the investigators take the photon off the mass shell and study the narrow peak of elastic π^+ production at small momentum transfer and with energy high enough to be above the nucleon resonances and in the region where the structure of forward production is no longer changing with energy. The investigators use a liquid hydrogen target and the Beam 7 spectrometer. The two arms are similar; each bends the particles in a vertical plane. Wire spark chambers provide information as to trajectories, and Cerenkov counters, time-of-flight sensors, and shower counters provide particle identification. Data taking started in October 1969, at a c.m. energy from 1.8 to 2.5 GeV. Much additional data taking was scheduled for early 1970.

The B.O.L.D. (Bypass On-Line Detector) Group devoted five shifts of parasite time to tests of spark chambers, shower counters, and other components of the on-line detector.

University of Pennsylvania physicists exposed iron foils to a 3-GeV photon beam to explore the feasibility of studying photon-induced reactions (above 0.8 GeV) in iron.

A group from Columbia University and Harvard made use of an external positron beam to calibrate shower counters and NaI scintillation counters to be used in high-energy experiments at BNL.

C. Experiments in Which the Data Taking Was Scheduled to Start in 1970

Deutsch, Milburn et al (M.I.T.-Tufts), Experiment 114b: Recoil Proton Polarization in π^0 Photoproduction ($\gamma + p \rightarrow p + \pi^0$) near $t = -0.30 \text{ (GeV/c)}^2$. Employing a beam of unpolarized photons incident on a liquid hydrogen target, the investigators measure the direction and energy of the resulting π^0 by means of an arm containing a lead converter, a scintillation counter hodoscope, and a lead glass hodoscope. The direction, energy, and polarization of the scattered proton are measured by means of a sequence of spark chambers with intervening carbon plates. The resulting data will permit the investigators to compare (a) the relationship of proton spin asymmetry to four-momentum transfer squared in the neighborhood of $t = -0.3 \text{ (GeV/c)}^2$ and (b) the relationships predicted by various competing theories. In November 1969 assembly of equipment was essentially complete and in December various preliminary tests were made in parasite runs.

PART IV - PROJECT BYPASS

A. Introduction

The principal development project at the CEA is Project Bypass, the goal of which is to develop a facility for

- (1) producing head-on collisions of electrons and positrons with energies up to 3.5 GeV in each beam, and
- (2) investigating the results of such collisions by means of large-solid-angle detection systems.

The plan is to fill the orbit of the existing synchrotron with counter-traveling, high-intensity electron and positron beams by means of multicycle injection. When the beam intensities have been built-up sufficiently (design intensity is 100 mA peak with a 30% circumferential filling factor) synchrotron operation is converted to dc mode (storage mode) and the particles remain in orbit with constant energy. The stored beams are then switched into a 120-ft-long detour or bypass. See Fig. 2. In the ring and most of the bypass the two beams are kept vertically separated by means of electrostatic fields so as to minimize beam-beam interactions; but they are guided so as to collide at the interaction region, at the center of the bypass. Focusing magnets reduce the beam cross section here to ~ 0.01 mm high by 0.3 mm wide and accordingly the interaction rate (number of collisions per second) will be relatively high; the design luminosity is expected to be $1.5 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$.

Fig. 2. Relationship of the bypass to the synchrotron ring of 48 magnets. The terminations of the bypass, and likewise the septum magnets used in switching, are at straight sections 10 and 19.

The interaction region will be surrounded by a detector array that will include spark chambers, absorbers (converters, or radiators) and scintillation counters. Three kinds of detector arrays are under development. Initially non-magnetic detectors will be used. The main detector B.O.L.D. is on-line; the spark chambers are of wire type, digitized; all signals from spark chambers and scintillation counters are read out and analyzed by an IBM 360/65 computer. An optical detector is under development also. A magnetic detector is also under development; it will provide a more detailed analysis of complex events.

B. Injection

Positrons and electrons are injected by means of two 130-MeV linacs arranged in tandem in the (nearly radial) Linac Tunnel. When positrons are to be injected, the upstream linac produces accelerated (~ 130 MeV) electrons which strike a tungsten converter (see Fig. 3) from which gamma radiation and electron-positron pairs emerge; positrons of ~ 10 MeV energy are collected and guided into the downstream linac whence they emerge with an energy of 130 MeV; they are then deflected to the right so as to enter the circular orbit in clockwise sense. When electrons are to be injected, the converter is removed (in a few seconds, by remote control), the phase of the second linac is shifted suitably, and the two linacs are operated in series to

Fig. 3. View downstream along Linac Tunnel. 130-MeV electrons focused by the large cylindrical quadrupole-doublet at right strike the water-cooled tungsten converter (in large housing at left) and the resulting 4-to-10 MeV photoproduced positrons enter the positron-linac waveguide at extreme left and are accelerated to 130 MeV.

accelerate electrons to 260 MeV; these are deflected to the left and are inflected into the orbit in counterclockwise sense.

The upstream (electron) linac has been used for a year in normal operation of the accelerator. Its performance has been improved steadily, as was indicated in Part II.

The downstream (positron) linac was ordered from Varian Associates on July 26, 1967. Components were received at CEA in January - March 1969 and were assembled by Varian engineers in April - June 1969. On June 30, during preliminary tests, an air leak developed in one of the accelerating waveguides. Repair was completed in July, and when testing was resumed several capacitors of the power supply for the solenoidal coils failed. In August capacitors of more appropriate type were installed and operation was found to be satisfactory.

An eight-hour acceptance test was completed on August 14. In this run the two linacs were operated in series to produce a beam of 258-MeV electrons. The output current was 25 mA of which 15 mA was accepted by the analyzing system.

The first run in which the converter was used and the positron beam was detected occurred on August 19. A more successful run was made on August 29 when 250 mA of 95-MeV electrons from the upstream linac struck the converter and produced a 1-mA beam of positrons having a wide energy spread near 100 MeV. In December we produced a beam with well

controlled energy spread: a 0.5-mA positron beam of which 0.1 mA had a momentum spread within 2% at 124 MeV.

Throughout the six-month period in question we continued to improve the electron and positron transport systems between Linac Tunnel and Synchrotron proper. We installed additional bending magnets and focusing magnets, two three-cavity devices for monitoring beam intensity and beam transverse position, two improved Hevimet shutters, improved support systems for the bending magnets, and two 500-liter/sec high-vacuum pumps.

In September the off-axis inflector for the positron beam was installed and power connections for the adjacent bending magnets were completed; see Fig. 4.

In preparation for injection and storage trials, a number of changes were made in the synchrotron ring. The two damping magnets for controlling amplitudes of horizontal betatron oscillations of stored beams were transferred from Straight Sections 34 and 35 to their permanent locations in Straight Sections 46 and 47. The Straight Section 1 inflector, not needed with the 130-MeV linacs, was removed. The rf cavity-type intensity monitor and likewise the beam widener and the coils for exciting horizontal betatron oscillations were moved to more appropriate locations in the ring. Additional loop-type monitors of intensity and transverse position were installed.

Fig. 4. The 3000-amp-d.c., feed-and-return coaxial conductor for the positron-beam-transport-system bending magnet in the Circular Tunnel. The two conductors are coaxial and the two passages for cooling water likewise. The terminals also are water cooled. Flexible braided straps join the conductors to the bending magnet terminals. The coaxial assembly is very compact and produces almost no external magnetic field.

Water-cooled beam-bump windings for producing beam-bump 46-star used in deflecting the beams into the damping-magnet gaps were installed. Twenty-three pairs of electrostatic plates for keeping the electron and positron beams vertically separated in the ring were installed in straight section tanks and vacuum-chamber end-boxes.

C. Beam Storage in Synchrotron Ring

In November, with a gradually improving vacuum (10^{-7} to 10^{-8} torr) we succeeded in achieving, for a 2.6 GeV constant-energy electron beam, a 1/e lifetime of two hours.

D. Bypass Trials

In preparing for further trials of switching a stored beam into the 120-ft-long bypass train (Figs. 2, 5, 6, 7, and 8) we made several improvements. We made 0.075-inch radial displacements of eight of the 48 magnets (Nos. 3, 7, 11, 13, 15, 17, 21, 25) in order to displace the equilibrium orbit in Straight Sections 10 and 19 so as to increase the radial clearance of the septum magnets situated there and thus increase the horizontal acceptance of the ring. The scheme was designed so as not to change the ν -values and the widths of half-integral stop-bands.

We discovered and corrected a small inconsistency between longitudinal positions of the bending magnets of the bypass and the transverse positions of the bypass quadrupole magnets. The vertical alignment was improved also. Residual ripple in the power supplies serving the (dc) magnets of the bypass was eliminated.

Fig. 5. West portion of the 120-ft-long bypass train (portion near Magnets 10-12). In the foreground one sees quadrupole magnets resting on concrete blocks. The beam-pipe, 5 ft. above the floor, is wrapped in aluminum foil to assist bake-out. The conspicuous pipe at 8-ft height is the vacuum fore-line.

Fig. 6. East portion of the bypass train, adjacent to Magnet 17 at left. The quadrupole magnets are clearly visible and, at the extreme right, one of the six bending magnets. A special cut was made in the adjacent concrete wall to allow room for the magnets visible at the right.

Fig. 7. One of the two quadrupole triplet lenses of the bypass. Such focusing elements reduce the beta-function sufficiently that the cross-sectional area of the beam at the bypass midpoint is only 0.008 of the area at a straight section of the synchrotron. Thus a 125-fold increase in luminosity is achieved.

Fig. 8. Interaction region of bypass. Mounted here temporarily are: (a) at center, a pneumatically actuated device for sweeping a 1- μ -diameter quartz fiber downward across the beam for evaluation of height of beam cross section, (b) at left, a test array of scintillation counters, and (c) at lower right, a test array of spark chambers. In a few months we will replace the beampipe by one of greater (8 inch) diameter and assemble, around it, the on-line detector.

Improvement was made in the momentum space match and phase space match of bypass and synchrotron ring. See Fig. 9.

We installed guide rails for insuring accurate vertical positioning of the two septum magnets when they are moved radially inward preparatory to use.

Much effort was devoted to measurement of vertical and horizontal apertures of the system comprising bypass and ring. The vertical aperture of bypass-and-ring was found to be 0.45 inch, in agreement with the expected value. The horizontal aperture appeared considerably smaller than calculated; in December a portion of the difficulty was traced to misalignment of the exit spout joining the west end of the bypass to the ring. (When the alignment was corrected in January 1970, we found the horizontal aperture to be doubled and we succeeded in obtaining, with a 2-GeV bypass beam, a $1/e$ lifetime of 45 minutes -- to be compared to the 100-minute lifetime found before the beam was switched into the bypass.)

We found that use of a specially built twelve-pole winding system applied to the quadrupole magnets close to the interaction region of the bypass tended to increase the beam lifetime.

Methods of determining the frequencies of coherent betatron oscillations - simultaneously and within a millisecond - were developed and used. See Fig. 10.

We investigated the effects of increasing the vertical betatron frequency ν_v of the bypass-plus-ring from 6.8 to 7.3

Fig. 9. Cross-section of d.c.-stored beam of 2 GeV electrons observed (via synchrotron radiation, relay mirrors, and closed-circuit TV) at two locations along synchrotron ring before and after switching the beam into the bypass. Optical resolution is adequate for showing the width ($\sim 3\text{mm}$) but is inadequate for showing how extremely small ($< 1\text{mm}$) the height is. Left view: at Straight Section 37. Right view: at Straight Section 43. Upper views: before switching. Lower views: after switching. Note 1-mm vertical shift at Straight Section 43 (right) and negligible shift at Straight Section 37 (left). The small magnitudes of shift confirm that the transport properties of bypass and ring were reasonably well matched.

Fig. 10. CRO traces from which one can determine the frequencies of coherent betatron oscillation and synchrotron oscillation of a 2-GeV electron beam stored in ring and bypass. Each trace consists of a sequence of ~ 60 pips, each of which represents one trip of the 200-ft-long string-of-electron-bunches around the 750-ft-circumference orbit, i.e., represents $0.7 \mu\text{s}$. Pip height corresponds to the product of beam intensity and beam transverse displacement. Upper trace, showing signal from a monitor of vertical displacement, contains ten pips per wave; thus it indicates that the vertical betatron frequency ν_v differs from the nearest integer by 0.1. (The expected value was $\nu_v = 6.9$.) Lower trace, showing horizontal displacement, contains four pips per wave, from which it is inferred that the horizontal betatron ν_h differs from the nearest integer by 0.25. (Expected value: $\nu_h = 7.25$.) The long-period modulation of the latter pattern is evidence of a slow coherent synchrotron oscillation, attributable to imperfect adjustment of length of the bypass. Suitable readjustments were made subsequently.

while holding the horizontal frequency ν_h constant at 7.1, i.e., the effect of having both frequencies on the same side of the nearest integer. The change appeared to provide a broader area of stable operation in the ν_v, ν_h plane.

We made successful trial use of the quick-traverse, 1-micron-diameter, quartz-fiber device designed for use in dynamic measurement of the beam cross section at the interaction point of the bypass. We found the height of one particular 1.4-GeV beam to be 0.1 mm, which was within 50% of the value predicted for the given conditions of particle energy, beta-value, and gas pressure. See Fig. 11.

We found the average displacement component of momentum vector of the 1.4-GeV beam to be 31 inches, in good agreement with the predicted value.

E. On-Line Detector

At the end of the six-month period in question, construction of the on-line detector for analyzing results of e^-e^+ collisions was nearing completion. Designed to detect (a) minimum ionizing electrons, muons, pions, etc., (b) photons, and (c) charged hadrons, the detector consists of a 4-ft-cube core and an exterior array as shown in Fig. 12.

The detector core consists of four similar quadrants grouped close to the interaction-region beampipe. Each quadrant contains six digitized wire spark chambers interspersed with five scintillators and five radiators (absorbers), as indicated in Fig. 13. Each spark chamber contains four

Fig. 11. Measurement of height of beam cross-section at interaction point of bypass. As the horizontal 1- μ -diameter quartz fiber sweeps downward across the 2-GeV electron beam, a nearby scintillation counter produces a pip the width of which is proportional to the vertical dimension of the beam, which in this instance was found to be 0.1 mm. The lower trace provides a calibration of sweep speed.

Fig. 12. Vertical section through bypass (and adjacent portion of synchrotron ring) at the bypass midpoint.

Fig. 13. Cross section of north quadrant of detector core, showing the six wire spark chambers (w), five scintillation counters (Sc), and five radiators (R). The e^- and e^+ beams are at the center of the beampipe.

planes of wires that provide two gaps and permit unambiguous specification of the position of as many as four simultaneous tracks. The active area of a spark chamber ranges from 7" x 13" for a chamber close to the interaction point to 24" x 38" for a chamber at a distance of 16" from the interaction point. The scintillators, of Pilot B and Pilot Y poly-vinyl-toluene-base plastic, and likewise the radiators of lead and iron, have a wide range of areas.

The exterior array includes spark chambers, scintillators, and radiators. Scintillators are mounted above and below the core, to permit distinguishing (by time-of-flight data) downward-traveling cosmic-ray particles from particles traveling outward from the interaction region. On either side of the core there is a hadron converter consisting of ten 1" x 72" x 72" iron plates interspersed with additional wire chambers each of which has an active area of 58" x 65"; the hadron converters make it possible to distinguish hadrons from muons.

All of the information from the spark chambers and scintillators is recorded by the Harvard IBM-360/65 computer interfaced by an SDS-92 computer.

By the end of December the construction of the core spark chambers was nearly complete and a test program employing cosmic-ray muons as source and an SDS-92 computer program was underway. A typical chamber was found to have a single-muon-detection efficiency exceeding 99% and an associated spurious spark occurrence of less than 10%.

The necessary spark-chamber pulsing systems, employing English Electric Co. CX1157 tetrode thyratrons which have rise time and delay time of < 20 nsec and < 50 nsec respectively, are nearly ready for use. We found that the lifetime of such a thyatron exceeds 10^7 pulses. The triggering equipment, from Chronetic Co., is on hand. The spark digitizing electronics, capable of handling more than 600 sparks in an individual event, are on hand and have been tried out in token manner. A total of 144 high-gain amplifiers for amplifying the magnetostrictive signals from the spark chambers were procured.

Construction of the radiators was nearly complete and the scintillators, lucite lightpipes, and RCA 2-inch #8575 photomultipliers were on hand.

Preparation of on-line computer programs has advanced satisfactorily. A preliminary program for causing the IBM 360/65 computer to receive and process information from the spark chambers and scintillation counters and to record the data in coded form on magtape was completed. It was tried out, with promising results, on signals resulting from exposing an improvised portion of a core quadrant to (a) cosmic radiation and (b) synchrotron-produced multi-GeV electron and photon beams.

We largely completed the writing of simple programs for SDS-92 and IBM-360/65 off-line display of events. Working from coded magtape data the computer system can analyze

a given event and make a two-dimensional diagram, on graph paper or 35-mm film, of the spark chamber information. The SUMX histogram program has been incorporated in this analysis system.

We completed much of the planning for computer programs for on-line monitoring of the performance of most of the detector's 16,000 components and prompt notification of any malfunction.

Construction of a set of scintillators for vetoing cosmic ray particles (by time-of-flight data) is essentially complete. Preliminary tests indicated a $\sim 99\%$ rejection efficiency with respect to straight-through cosmic-ray muons, and most of the remaining cosmic-ray events are easily distinguished from true collision events.

We have nearly completed the design of a luminosity meter (employing single or double bremsstrahlung) the output of which depends simply on the number of e^-e^+ collisions per second (and not on the number of collisions with gas molecules or with the wall). The device is to employ scintillation counters and also shower counters of lead and scintillator.

The B.O.L.D. detector is being built in collaboration with the Harvard group of R. Wilson.

F. Optical Detector

We continued work on an optical detector to serve as back-up for the on-line detector, particularly for the

confirmation of unexpected or complex events. The device employs a main array of scintillation counters, optical spark chambers (with stereo-photographic recording), and lead and aluminum absorbers. Also there is to be a large overhead hemispherical dome (radius of curvature: 5 ft) comprised of solid scintillators for vetoing cosmic-ray muons by time-of-flight relative to a small scintillator situated a few inches above the bypass interaction region.

By the end of December 1969 we had largely completed construction of trial models of spark chambers, procured most of the necessary scintillators, completed a rough design of a support system for spark chambers and scintillation counters, completed the design of the fast logic (using integrated circuits) for spark chamber triggering, and made preliminary tests on many components and prototype assemblies.

This is a collaborative effort with the Frisch M.I.T. group.

G. Magnetic Detector

We made satisfactory progress on the design and construction of a magnetic detector designed to:

Confirm and extend certain results obtained with the non-magnetic detectors. The magnetic detector will be able to distinguish e^+ from e^- and thus will be able to test the time-like photon term with greater accuracy.

Separate the various baryon channels.

Identify new particles if any.

The heart of the magnetic detector is a core consisting of counters and conventional optical spark chambers mounted within a rectangular solenoidal coil having inside height, width, and length of 64, 98, and 60 inches respectively. The main (60-inch) axis is coincident with the e^- and e^+ beams. When powered at 2 MW the coil will provide a 5-kilogauss field. Outside the coil there are to be four arrays of iron plates and optical spark chambers; at each end of the coil there is to be an iron end-cap and a 20-inch-diameter solenoidal correction coil.

In the half-year in question the 2-MW solenoidal coil was being constructed by Westinghouse Electric Corp. and prototype arrays of wire proportional counters and optical spark chambers were assembled and made ready for testing.

The magnetic detector is a collaborative project with the M.I.T. group of L. S. Osborne.

PART V - OTHER ACTIVITIES AND NEW PROJECTS

A. Theoretical Studies

The staff theoretical physicists made studies of photo-excitation of nucleon resonances, production of the intermediate vector boson in colliding beam and lepton scattering experiments, and the formulation of gauge invariance for Born approximations. Also they made speculative studies of the electromagnetic structure of the proton.

Seven papers resulted from these and earlier studies. Part VII lists these papers.

B. Source of Polarized Electrons

We continued the development of a source of polarized electrons and believe that there is good prospect that, with such a source, we could inject spin-up electrons into the synchrotron ring and accelerate them, without serious loss of polarization, to an energy of several GeV. With such a polarized multi-GeV electron beam, used in conjunction with a polarized target, investigators could perform experiments of more refined type than are possible today.

In the six-month period in question much progress was made. The source of polarized hydrogen was made ready for joining to the spin exchange chamber and for trial operation. Actual trials of electron confinement within the spin exchange chamber were made and a confinement lifetime of 500 msec was obtained. Assembly of the Mott-type polarization detection system was completed. Preparations for

bringing the spin exchange chamber and associated equipment to potentials of 50 to 80 kV (to permit 50-to 80-KeV acceleration and measurement of degree of polarization of the emitted electrons) were underway.

C. Miniature Storage Ring for Production of Light of Unmatched Monochromaticity

We completed the general systems design of a miniature, 8-inch-diameter, electron storage ring (proposed in CEAL-1032 of 9/19/66 by K. W. Robinson) for producing uniformly spaced, highly monochromatic lines of synchrotron radiation of accurately known frequency (the frequency can be measured to an accuracy of greater than one part in 10^{12}). Such light could be used in determining the speed of light with greater accuracy than is possible today. A satisfactory set of basic parameters, including orbit diameter, betatron frequencies, characteristic value of the magnetic field, magnet length, and radio-frequency was determined. No reason why such a device could not be built and operated successfully has been found.

PART VI - OTHER PROGRAMS

A. Safety

In the half-year in question there was one lost-time accident: one employee lost 3 days work.

No CEA film-badge user's films showed a dose as great as 50% of the maximum permissible dose.

Eighteen hours of first-aid training was given to 20 Operations Division men by a representative of the American Red Cross. Radiation-safety training sessions were held on September 17 and October 24.

B. Training of Disadvantaged Persons

We participated in training programs, sponsored by the Cambridge School Department, TEST, and the Harvard Minority Recruitment Program, to introduce disadvantaged young persons to a variety of technical jobs. At the end of December 1969, seven such persons were being trained here for, typically, twenty hours per week.

PART VII - PUBLICATIONS RESULTING FROM WORK DONE AT CEA

A. Publications on High Energy Research Performed at CEA

"Hard Pion Results from the Algebra of Fields", S. G. Brown, G. B. West, Phys. Rev. 180, 1615 (1969).

"X-Ray Transition Radiation Applied to the Detection of Super-High Energy Particles", L. C. L. Yuan, C. L. Wang, Phys. Rev. Letters 23, 496 (1969).

"Photoproduction Search for Dipion Resonances in the Mass Range from 1360 to 1780 MeV", N. Hicks, A. Eisner, G. Feldman, L. Litt, W. Lockeretz, F. M. Pipkin, J. K. Randolph, K. C. Stanfield, Phys. Letters 29B, 602 (1969).

"Photoproduction of π^0 with Plane Polarized 3-GeV Photons", D. Bellenger, R. Bordelon, K. Cohen, S. B. Deutsch, W. Lobar, D. Luckey, L. S. Osborne, E. Pothier, R. Schwitters, Phys. Rev. Letters 23, 540 (1969).

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"Experimental Determination of the Transition Effect in Electromagnetic Cascade Showers", C. J. Crannell, H. Crannell, C. R. Gillespie, K. Pinkau, R. R. Whitney, Phys. Rev. 182, 1435 (1969).

"Tensor and Scalar-Meson Dominance", G. B. West, Phys. Rev. 183, 1496 (1969).

"Coincidence Measurements of Single-Pion Electroproduction near the $\Delta(1236)$ Resonance", C. Mistretta, J. A. Appel, R. J. Budnitz, L. Carroll, J. Chen, J. R. Dunning, Jr., M. Goitein, K. Hanson, D. C. Imrie, and Richard Wilson, Phys. Rev. 184, 1487 (1969).

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"Comment on the Photo-Excitation of the Roper Resonance", F. A. Berends and A. Donnachie, Phys. Letters 30B, 555 (1969).

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