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CEAL- 1047

SEMI-ANNUAL REPORT

For the Period

JULY 1 through DECEMBER 31, 1968

K. Strauch

Director

February 12, 1969

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
and HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

CAMBRIDGE 38, MASSACHUSETTS

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DISCLAIMER

The research work described in 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.

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY · HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

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CEAL-1047
Karl Strauch
February 12, 1969

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SUMMARY

Part I indicates the purpose of the contract, which is concerned with the operation of the 6-GeV Cambridge Electron Accelerator, and lists the main guiding committees.

Part II, on accelerator operation, shows that the total number of prime-user hours and parasite-user hours of accelerator operation in the six-month period was 2590.

Part III describes the 25 experiments underway or in preparation.

Part IV summarizes progress on the colliding beam facility (Project Bypass). Multicycle injection was improved to the extent that, on repeatedly injecting 3 milliamperes of electrons, we accumulated within one half a second a circulating beam of 45 mA peak intensity.

Conversion from cycling-mode operation to d.c. storage mode was accomplished without detectable loss of beam, and beams were stored for as long as one half hour. (In January of 1969 major improvements to the vacuum system were completed, average pressures as low as 4×10^{-8} torr were achieved, and a 2 GeV beam of 3 mA initial intensity was stored for two and one-half hours, with a 1/e decay time of 35 minutes.) The bypass train itself is complete, and in trial efforts (during cycling mode operation) to switch the orbiting beam into the bypass at the peak of the cycle we were successful on a few occasions, achieving the hoped-for 0.5 millisecond (700 turn) traversal of the bypass.

The design of the on-line detector is nearly complete and many of the main components are being fabricated. Design work on the magnetic detector and the optical detector is progressing satisfactorily. The 130 MeV positron linac is scheduled for delivery in April 1969.

Although an enormous amount of work must be done before the remaining problems of beam accumulation, beam stability and storage, and beam switching into the bypass can be solved, we are pleased that no new and serious problems have arisen.

Part V summarizes major improvements and new projects. The principal improvements were: doubling the rf power capability so that electron and positron beams of 100 mA peak intensity can be produced and stored; building more versatile equipment for exciting betatron oscillations and determining the oscillation frequencies; developing more efficient liquid hydrogen target systems; extending the usefulness of the computer facility to new kinds of data processing and equipment control; installing a new water treatment system and a machine for cleaning the water conductors of magnet coils.

The new projects include: assisting and advising on the construction of the Synchrotron Radiation Room (carried out by Harvard University Physics Department with its own funds) in which the unique continous, soft-x-ray, polarized, synchrotron radiation from the accelerator can be put to research use; completing the 95 x 45 ft Engineering Support Building; carrying forward the pilot project for producing a low-energy beam of polarized electrons; further exploration of the possibility of building a miniature storage ring for producing monochromatic spectral lines with frequencies known to one part in 10^{12}.

Part VI deals with safety. 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, 1968. 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.

The general policies of the Laboratory were determined by a joint M.I.T.-Harvard "Executive Committee of the CEA", comprising the following:

from M.I.T.	Prof. Carl F. Floe
	*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 Scientific Subcommittee met on Sept. 30, 1968.

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*denotes member of Scientific Subcommittee

The "Cambridge Electron Program Advisory Committee" (CEPAC) reviewed the status of experiments in progress and examined proposals for future experiments. During the half-year in question this committee included (in addition to the Director):

Dr. Samuel Berman, SLAC
Prof. Louis N. Hand, Cornell
Prof. Louis S. Osborne, M.I.T.
Dr. Burton Richter, SLAC
Prof. Julian Schwinger, Harvard
Prof. Steven Weinberg, M.I.T.
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 on Oct. 12 and 13, 1968.

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, Southeastern Massachusetts
  Technological Institute
Dr. John J. Russell, Harvard
Dr. Herman Winick, CEA
Dr. William A. Shurcliff, CEA, secretary

On December 4 and 5 the CEA Visiting Board met at the CEA to critically examine the condition and program of the laboratory and its plans for the future. The

Board will 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
Professor James W. Cronin,
    Dept. of Physics, Princeton University
Professor Maurice Goldhaber,
    Director, Brookhaven National Laboratory
Professor J. David Jackson,
    Dept. of Physics, Univ. of Calif., Berkeley, Calif.
Professor Boyce D. McDaniel,
    Director, Laboratory of Nuclear Studies, Cornell University
Professor W. K. H. Panofsky,
    Director, Stanford Linear Accelerator Center

The CEA staff was strengthened by the addition of two theoretical high-energy physicists (Dr. G. West, Ph.D. 1966, Stanford University, and Dr. F. Berends, Ph.D. 1967, University of Leiden, the Netherlands) in the autumn of 1968.

PART II - ACCELERATOR OPERATION

A. Statistics on Accelerator Use

During the period July - December 1968 the efficiency and distribution of accelerator time were as follows:

TABLE 1

EFFICIENCY OF SCHEDULED OPERATION

	Hours	Percent
Delivered Prime Time	1545.5	73.1
Unscheduled Downtime	566.5	26.9
	2112.0	100.0

TABLE 2

USE OF DELIVERED PRIME TIME

	Hours	Percent
High Energy Physics	1164	75.3
Accelerator Physics	381.5	24.7
	1545.5	100.0

TABLE 3

USE OF PRIME AND SECONDARY TIME IN HIGH ENERGY PHYSICS

User	Exp't No.	No. of Prime Hours		Delivery Eff. (%)	Delivered Sec'd Hrs.
		Scheduled	Delivered		
Pipkin et al	102h	26	26	100	28.5
Brenner et al	103h	142	72	50.7	240
Wilson et al	105f	596	479	80.4	1
Russell et al	107a	0	0	-	3
Osborne et al	109b	23	19.5	84.7	16
Frisch et al	112a	0	0	-	268
Kendall et al	113b	200	167	83.5	0
Milburn et al	115a	8	4	50	263
Bar-Yam et al	117a	375	231.5	61.7	99
Weinstein et al	118d	64	35	54.7	33.5
Weinstein et al	118g	224	130	55.5	0
Dell et al	119a	0	0	-	93
		1658	1164	70.1 weighted average	1045

Note: Total delivered prime and secondary time for high energy physics: 2209 hours.

TABLE 4

USE IN ACCELERATOR PHYSICS

	Scheduled Hours	Delivered Hours	Eff. (%)
Single Cycle Injection	24	24	100
Multicycle Injection	136	122	89.7
Bypass Trials	286	227.5	79.6
Beam Storage	8	8	100
	454	381.5	84.0 weighted average

Note: Total delivered prime and secondary time for high energy physics and accelerator physics: 2590.5 hours.

TABLE 5

ANALYSIS OF UNSCHEDULED DOWNTIME

Cause	Hours	Percent
Linac	225.0	39.7
RF System	107.5	18.9
Vacuum System	78.5	13.8
Magnets	41.5	7.3
Emergent Beam	30.5	5.4
Starting and Tuning	22.5	3.9
Experimental Magnet Power Supplies	22.0	3.8
Low Energy Instabilities	22.0	3.9
Water Leaks	8.0	1.4
Interlock	2.5	0.4
60-ton Inductor	2.0	0.3
Miscellaneous	4.5	0.8
	566.5	100 %

Three-Week Operations Cycle. On December 2, 1968, the general operations cycle was changed from two weeks to three weeks, to provide longer and more efficient runs for experimenters, to permit performing maintenance work during week-days, and to permit making economies in manpower.

Shutdown of Accelerator Operation. The accelerator was shut down for scheduled repairs and improvements from August 9 through September 27 and again from December 18 through January 6 of 1969.

B. Problems, Maintenance, and Minor Improvements

Magnets and Magnet Powering. We suceeded in adjusting the regulation circuitry for magnet powering so that the accelerator could be operated reliably at energies as low as 460 MeV, well below the originally planned range of operation. At that energy, a peak energy stability of 0.1% was achieved. The experiment of Wilson et al (see Part III) required operation at such energies.

Vacuum Ring. We replaced the 18 remaining epoxy vacuum chambers with ceramic chambers. Using an ultrasonic degreaser, we cleaned all 16 rf cavities for use at pressures down to 10^{-9} torr; also we cleaned 85% of the remaining components of the vacuum ring, e.g., pumps, straight section tanks, target assemblies, beam monitors, inflectors, and ejection magnets. We provided bake-out capability for most of the remaining components of the ring. Nine Varian high-vacuum pumps (250 liters/sec at 3×10^{-10} torr) were installed. Fifty elliptical bellows were installed between ceramic vacuum chambers and straight section tanks in order to reduce vibration and flexural strain.

These improvements have already resulted in greatly increased reliability of the vacuum system and lower average pressure - 4 x 10^{-8} torr in a recent test during storage of a 1-milliampere beam at 2 GeV.

Linac. On several occasions failure of the diodes of the high-voltage power supply of the 130 MeV linac occurred and it was necessary to insert new sets of diodes. To prevent such failure we installed two additional overcurrent protection circuits: one for excessive peak current and one for excessive average current. We inserted a current-limiting resistor in series with the high-voltage power supply, and we installed surge suppressing networks across the secondaries of the high-voltage-power-supply transformers. In the two months since these improvements were made, no diodes have failed.

We improved the linac remote control system and beam monitoring system, to facilitate tune-up.

A Sperry klystron of SLAC type (but without electromagnet) failed after 2400 plate hours of use, and was replaced by an RCA klystron.

On September 27, 1968, the linac was accidentally let up to atmospheric pressure while the gun filament was on, with the result that the emission of the cathode was greatly reduced. We succeeded in reactivating the cathode to an emission of 50 mA chopped, i.e. about 1/4 of the original emission. Although 50 mA has been adequate for operating needs in recent months, we intend to replace the cathode at the first opportunity.

RF System. Two HPA tubes failed. Tube A3 failed after 10,349 hours use when a small air leak occurred in the output ceramic-to-metal seal. The leak was sealed temporarily with silicone varnish, but a much larger leak soon developed in the stainless steel tubing connected to the Vac-Ion pump. The tube was replaced by tube A4. This tube in turn failed after 5,585 hours use when an overheated cathode cup impaired the lower input ceramic-to-metal seal. This tube was replaced by Tube U1, which has operated well and is still in use.

On 12/31/68 we had no operable spare HPA tube on hand, but an additional tube that had been ordered earlier was nearly ready for shipment to CEA. Possibilities of repairing the two tubes that failed are under discussion.

To reduce the tendency of such tubes to fail from overheating of the grid cathode structure (and from resulting thermal expansion that may crack the enclosing input ceramic seal), we increased the amount of air cooling of this portion of the tube by drilling 128 1/8-in. diameter holes through the cylindrical shell grid flange to allow better circulation of air.

Two windows of rf cavities failed on September 19 when a water-cooled component of the Straight Section 10 septum magnet failed and allowed an inrush of air and some water into the vacuum system while the rf power was on. We installed spare windows of recent manufacture, but they failed almost immediately. Accordingly we replaced them with two of the few remaining windows of the original lot; these performed excellently. We are designing a special station in which testing of windows with the usual rf transmitter can be carried out when the accelerator as a whole is off. We will compare various techniques of window fabrication and select the best technique to specify when procuring additional windows.

Special Devices in the Ring. We installed a new bakeable current-strip magnet for use in slow extraction of the electron beam. We made a four-fold increase in the control capability of the horizontal orbit correction equipment. We installed a field correction coil for use when the beam is bumped into the damping magnets. We modified certain pole face windings for use on closed magnets to provide room for ceramic vacuum chambers and installed such windings on four closed magnets.

Monitors of External Beams. The Faraday cup, quantameters, and secondary emission monitors (SEMs) continued to perform well. The SEMs were calibrated on several occasions, and the efficiency was found to remain constant within 1%.

Interlock System. We modified the synchrotron interlock system so that 90% of the Circular Tunnel can be left open for maintenance work etc. even when the linac and linac transport system are being operated (e.g., for tune-up) -- provided the synchrotron proper is off. Only that portion of the ring directly downstream from the (radial) linac tunnel is closed and interlocked. The new mode of linac operation permits the operator to tune the linac and transport system before closing the ring as a whole. Thus the efficiency of maintenance work in the ring is greatly increased.

Radiation Monitoring. The radiation monitoring equipment adjacent to Hammond and Gorham Streets was improved by the installation of two additional $Li^6I(Eu)$ sphere-type monitors of neutron radiation and additional strip-chart recorders for the 20-liter ionization chambers situated there. Additional quantities of ordinary emulsions for measuring gamma radiation and boron-loaded emulsions for measuring neutron radiation were placed at strategic locations. The locations of most of the principal monitors are shown in Fig. 1.

A detailed and standardized periodic survey along the boundary of CEA property was inaugurated in October and continued until the Christmas shutdown of accelerator operation.

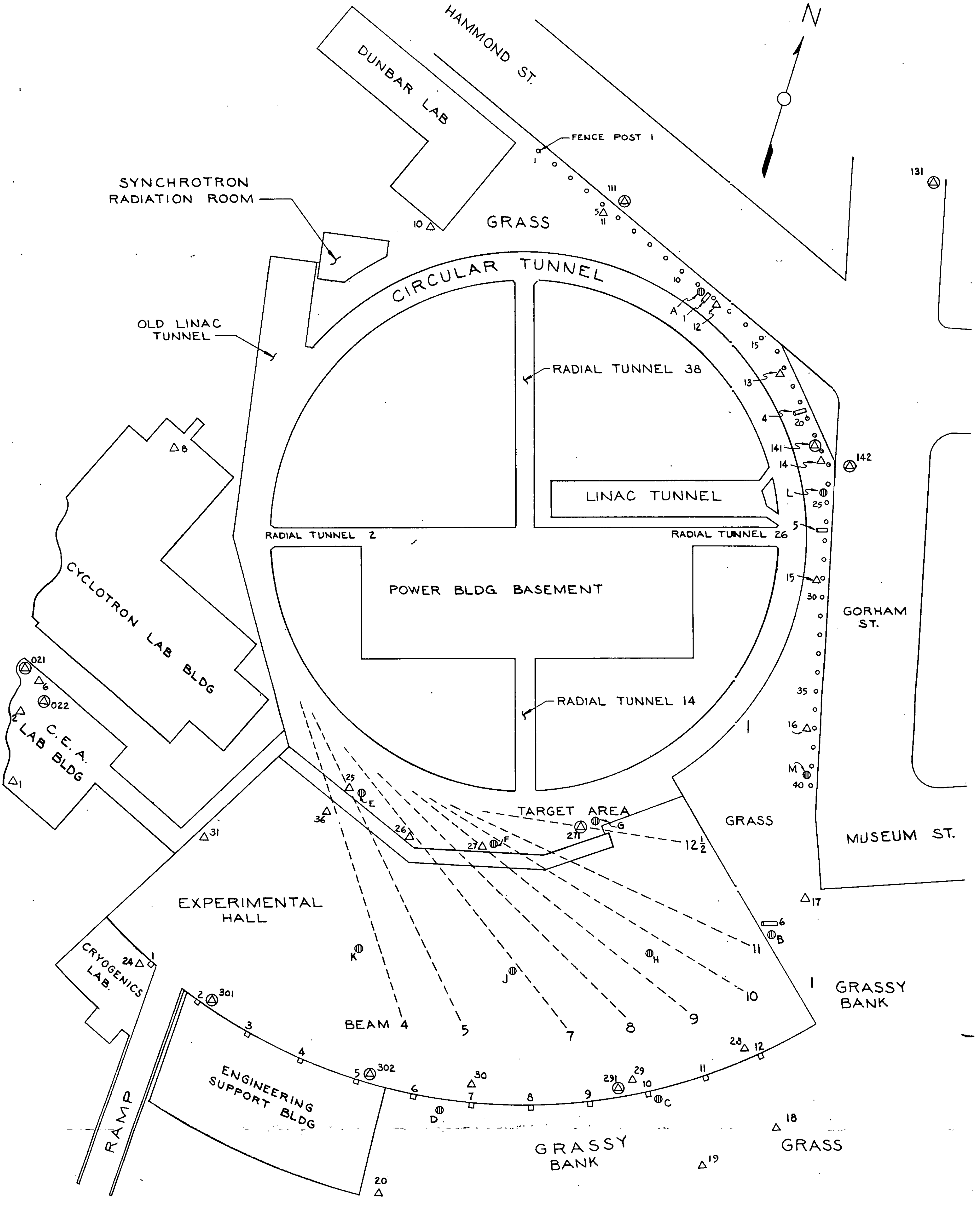

FIG. 1 LOCATION OF PRINCIPAL RECORDERS OF γ AND n RADIATION

KEY

⦶ 12" SPHERE NEUTRON MONITOR

▭ 20 ℓ IONIZATION CHAMBER γ MONITOR

△ γ OR n EMULSION

Ⓐ BORON - LOADED EMULSION AT CENTER OF MODERATING SPHERE

Analysis of the results showed that there were no significant hot-spots along the boundary, and the decision was made to carry out along-boundary surveys only when high-level accelerator operation, or operation under new circumstances, is planned.

Detailed reports on the radiation safety system were prepared. The 15-page radiation safety regulations were revised.

PART III - EXPERIMENTS IN HIGH-ENERGY PHYSICS

During the six-month period in question there were 25 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, Randolph, Tenenbaum, et al (Harvard). Experiment 102a: Study of Wide-Angle Electron Pair Production. In runs made in 1967 the investigators repeated their previous experiment in which apparent departures from QED at large momentum transfers had been observed. The apparatus used was almost identical to that used earlier; again two half-quadrupole spectrometers were used. A major difference was that the solid angle in the first experiment was determined by magnet apertures whereas in the second experiment it was determined by additional small counters. The present results on symmetric pairs are in agreement with QED to within 10% at an invariant mass of 600 MeV. No explanation for the previous observations was found. The observations on asymmetric pairs show no evidence for a Compton interference term up to 500 MeV. A detailed account of the work is being prepared.

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, and analysis of results is about 60% complete.

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° was used in March 1968 to search the mass range 1500 to 1800 MeV. No evidence was found for the photoproduction of R° mesons with a cross-section exceeding one microbarn. A summary of results was presented at the August-September 1968 Vienna Conference on High Energy Physics: "Photoproduction Search for Dipion Resonances in the Mass Range from 1400 to 1800 MeV". A detailed account is now nearly ready for publication.

Walker, Knasel, et al (Harvard). Experiment 104a: Total Cross Section for Photoproduction of Electron-Positron Pairs with Low Momentum Transfer. The total pair production cross section for photons of energies 1.20 to 4.05 GeV was measured in 1967 and January 1968 for targets of carbon, aluminum, copper and lead by good geometry absorption technique to an accuracy of ±0.3%. The results are presented in "Accurate Determination of the Total Pair Production Cross Section in Carbon, Aluminum, Copper and Lead for Photons from 1.200 to 4.050 GeV", T. M. Knasel and J. K. Walker, Phys. Rev. Letters 27B, 103 (1968) and in "Incoherent-Scattering Function, Total Pair-Production Cross Section, and Pair-Production Length for Helium", T. M. Knasel, Phys. Rev. 171, 1643 (July 1968); also in an unpublished thesis by T. M. Knasel (same title as for Phys. Rev. Letters article).

Wilson et al (Harvard), Experiment 105b: Search for Violation of Time-Reversal Invariance in electromagnetic interactions involving strongly interacting particles. In data taking runs in December 1967 - March 1968, the investigators directed an external electron beam of about 6 GeV energy at an ethanol-water target (developed by Pound and others at Harvard) containing polarized hydrogen nuclei. They measured the inelastically scattered electrons by means of a single-arm spectrometer that included scintillation counters, a Freon Cerenkov counter, and a shower counter. A brief account of the results was presented in a paper "Test of Time-Reversal Invariance in Electroproduction Interactions Using a Polarized Proton Target", J. R. Chen, J. Sanderson, J. A. Appel, G. Gladding, M. Goitein, K. Hanson, D. C. Imrie, T. Kirk, R. Madaras, R. V. Pound, L. Price, Richard Wilson, C. Zajde, Phys. Rev. Letters 21, 1279 (October 1968). A more detailed account was presented in a thesis of identical title by J. Chen, Harvard University, August 1968. The investigators observed scattered electron energies corresponding to the excitation of the 1236-, 1512-, and 1688-MeV nucleon resonances at four-momentum-transfer-squared between 0.2 and 0.7 $(\mathrm{GeV}/c)^2$. They searched for changes in the intensity of the scattered electrons when the target polarization was reversed, but observed no change. The time-invariant phase angle was found to be: 0 ± 8°.

Alvarez et al (M.I.T.), Experiment 108a: Photoproduction of π^+ at Large Angles and Measurement of Angular Distributions. In May 1967 the investigators completed the experimental phase of this study of the photoproduction of single positive pions at laboratory angles of 110, 127.5, and 152 degrees by means of a 0.9 to 3.2 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 1967. The film was then scanned with the aid of the SPASS computer program. The investigators found that the cross section decreases rapidly with increasing energy, with superimposed shoulders at energies corresponding closely to the known resonances N(1688), Δ(1920), and Δ(2420). They found a shallow minimum at the energy corresponding to the N(2190) resonance. Results were summarized in "Photoproduction of Positive Pions at Backward Angles in the 1 - 3 GeV Energy Range", R. A. Alvarez, G. Cooperstein, K. Kalata, R. C. Lanza, and D. Luckey, Phys. Rev. Letters 21, 1019 (September 1968).

Luckey et al (M.I.T.), Experiment 109a: Study of Photoproduction of η^0 at Forward Angles. In data-taking runs made in 1967 and in February and March of 1968, the investigators studied η^0 photoproduction at forward angles (0 to 18° lab) by 4 GeV photons on liquid hydrogen. The photons resulting from decay of the η^0 were detected by glass Cerenkov counters mounted on a small spectrometer arm. On analyzing the data, the experimenters found the results to be consistent with a theoretical prediction relating this cross section to ω^0 production by π mesons using a vector dominance model. They obtained no evidence of a dip or change of slope at $-t = 0.6$ as seen in π^0 photoproduction. The results were reported in "Photoproduction of η^0 Mesons at 4 GeV", D. Bellenger, S. Deutsch, D. Luckey, L. S. Osborne, and R. Schwitters, Phys. Rev. Letters 21, 1205 (October 1968).

Deutsch et al (M.I.T.), Experiment 111b: Feasibility Study for the Determination of Polarization of Lambda Particles Produced in $\gamma + p \rightarrow \Lambda^0 + K^+$ by 2 GeV Photons. The equipment included a magnetic spectrometer, six spark chambers, and scintillation counters for trigger and time-of-flight determination. In 1967, working at energies of 1.2 to 1.6 GeV, the investigators took 8000 spark-chamber photographs and recorded information on the momentum and time-of-flight of K^+ particles. A total of 144 unambiguous K production events of the type $\gamma + p \rightarrow K^+ + \Lambda$ were obtained.

The results were summarized in a thesis "Lambda Polarization in Photoproduction", by K. J. Cleetus of M.I.T., August 1968. One main conclusion is that the method is basically successful. However, the background rates experienced were a serious handicap; these rates must be reduced if the method is to be put to practical use.

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. 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 1967 and the analysis of results is nearing completion.

Hughes et al (Yale), Experiment 116c: $K^{\pm}$ Photoproduction in Hydrogen. The purpose of the experiment was to obtain further evidence of the existence of doubly charged hyperon resonances of strangeness +1 photoproduced by 3 to 6 GeV photons on hydrogen: $\gamma + P \rightarrow K^- + Z^{++}$. The yield of K^- mesons at 150° lab was studied as a function of photon energy with the aid of a spectrometer comprising focusing magnets, momentum analyzing magnets, hodoscopes, and differential gas Cerenkov counters. Data taking was completed during the first half of 1968. The 15° yield curves show no structure, thus provide no additional support for the existence of Z^{++} isobars. The upper limit of differential cross section for resonant states was found to be about 4 nb/sr. A summary of the results was presented at the August 28 - September 5, 1968, Vienna Conference on High Energy Physics by S. Mori et al: "Further Search for $S = +1$ Baryon States in Photoproduction"; see also a paper with similar title in Phys. Letters 28B, 152 (November 1968) by S. Mori, J. S. Greenberg, V. W. Hughes, D. C. Lu, J. E. Rothberg, and P. A. Thompson.

Gettner, Weinstein, et al (Northeastern University), Experiment 118a: Electroproduction of Wide-Angle Muon Pairs. The experimental phase of the work, which included wide-angle production of 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, was completed in a previous period. A preliminary account of some of the work was presented at the September 1967 SLAC Electron Photon Conference. Some of the results were presented in a June 1967 thesis "Photoproduced and Electroproduced Muon Pairs", by P. Rothwell. Additional results are presented in a nearly-completed thesis "Electroproduction of Wide-Angle Muon Pairs", by D. Earles. In this preliminary experiment the investigators successfully probed the time-like form factors in e-μ scattering and their results are consistent with the validity of QED up to a time-like photon mass of several hundred MeV.

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

Pipkin et al (Harvard), Experiment 102h: Beam 7 Spectrometer Testing. The spectrometer, a general CEA facility, 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 common pivot point. During the six-month period in question the remaining components were installed, the equipment was aligned, and background tests were made. The spectrometer is to be used in 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 uses tagged photons (of known energy, from 2.0 to 4.6 GeV) and measures 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 analyzed a large amount of data taken in June and October, and improved the operation of the spark chambers so that the tracks would be more nearly distortion-free. Also they improved the accuracy of their analysis techniques. Data taking is to resume early in 1969.

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. Electrons of 0.45 to 2 GeV energy that are quasielastically 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. During November and December the investigators took a large amount of data -- some of it at machine energy lower than ever used before at CEA (0.45 GeV). The ratio σ_n/σ_p was determined with an accuracy of a few percent at six q^2 values between 7 and 45 f^{-2}. The present data will be analyzed in conjunction with similar data taken previously at 20° lab, to yield more accurate values of neutron form factor.

Osborne et al (M.I.T.), Experiment 109b: Study of Photoproduction of π^0 by Polarized Photons on Hydrogen. A diamond crystal mounted on a goniometer in the synchrotron ring produced the polarized photons, and the CEA pair spectrometer measured the spectrum of the coherent bremsstrahlung beam. The photons resulting from the decay of the π^0 were detected by a Cerenkov counter hodoscope, and the recoiling protons were measured by the Moby Dick spectrometer. The accelerator was operated at about 6 GeV, and the polarized photons used had energies of about 3 GeV. The range of four-momentum transfer squared (t-value) extended from 0 to -2.0 $(\mathrm{GeV}/c)^2$. In June the investigators took much data. The experimental phase of the project was completed in July 1968. The investigators found that the neutral pions are produced preferentially in the plane containing the B vector of the photon at all the t-values measured. This result is in disagreement with predictions of some models successful prior to this experiment. The polarization of the beam was checked using coherent ρ photoproduction and measuring the ρ decay plane. A brief summary of the work was presented by Bellenger et al at the August 28 - September 5, 1968, Vienna Conference on High-Energy Physics in a paper "Production of π^0 Mesons by Plane Polarized 3 GeV Photons"; see also Proceedings summary by R. Richter. A detailed account of the work is in preparation.

Frisch et al (M.I.T.), Experiment 112a: Study of Photoproduction of a $2\pi^0$ Resonance (f° 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° and other meson resonances was undertaken with a 0.1 X_o 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_o. By the end of October the investigators had analyzed 40,000 photographs and obtained three clearly valid events of the type $\gamma + P \rightarrow 2\pi^o + P$ in the pertinent mass range (1000 to 2500 MeV/c^2). In December the investigators obtained 25,000 additional photographs, which are now being scanned for f_o events and will be scanned also for ρ^o, ρ^+ and (π^-, π^+, π^o) events. Data taking is complete, and the tagging equipment has been removed.

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 May, June, and July the investigators took much data at electron energies of 1.8, 2.2, 2.5, and 3.2 GeV. The results are being analyzed.

Milburn et al (Tufts and CEA), Experiment 115a: Study of Production of Polarized Photons with the aid of a laser. The investigators continued development of the method of producing polarized high energy photon beams demonstrated on a pilot scale in 1964 and 1965. Using a ruby laser pulsed once a second and producing about 15 joules per pulse, they directed a very intense beam of polarized 2 eV photons head-on at the 6 GeV electrons in orbit in the synchrotron; the photons recoiled with energies as great as 850 MeV and were presumed to retain their original polarization. In recent months the investigators determined the spectral energy distribution of the recoiling photons and used the system to explore the cross section of the orbiting electron beam. Also, they measured the background radiation incident on the counter system, located (inside the tunnel) in the polarized photon beam, and found the ratio of signal to background to be disappointingly low. A few additional runs are scheduled for January 1969, after which the equipment will be dismantled. Principal results are summarized in report CEAL-1046 of November 15, 1968: "Laser-Induced Polarized Photon Beam at the CEA".

Bar-Yam et al (S.M.T.I.), Experiment 117a: Study of Photoproduction of Single π^- on Deuterium by Polarized Photons. A beam of photons with a linearly polarized 3 GeV spike is produced by a diamond situated in the synchrotron orbit. The beam strikes a liquid deuterium target and the π^- particles photoproduced singly are detected by a magnetic spectrometer in coincidence with the recoil proton. A photon subtraction method is used to determine the energy of the incoming photon and to show that the pion in question was produced singly. One portion of the data was taken in July and August; from analysis of these results the investigators found that, at t-values of -0.6 and -1.2 $(\mathrm{GeV}/c)^2$, the asymmetry of photoproduction was 0.08 ± 0.2 and 0.2 ± 0.3 respectively. (Asymmetry is here defined as the ratio $(\sigma_\perp - \sigma_\parallel)/(\sigma_\perp + \sigma_\parallel)$, where $\sigma_\perp$, for example, is the cross section applicable when the electric vector of the incident photon is perpendicular to the plane of production.) The value 0.08 is in good accord with theory, but the value 0.2 is much higher than is predicted by available theory. In December the investigators took much additional data at a wider range of t-values, from -0.3 to -2.4 $(\mathrm{GeV}/c)^2$. Additional runs were scheduled for January 1969.

Weinstein et al (Northeastern University), Experiment 118g: Tests on Iron Spectrograph. The investigators made a few runs using a spectrograph that included thick iron absorbers (to separate muons from pions) and scintillation hodoscopes, with the purpose of evaluating small sources of error that influenced the conclusions drawn in previous experiments on wide-angle muon pair production. Successful runs were made in September and October. The investigators obtained preliminary indication that the equipment is well suited to detection of ϕ resonances(of concern in Experiment 118d, discussed in Section C).

Fulmer, Dell, et al (ORNL and CEA), Experiment 119: Study of Electro-Induced and Photo-Induced Spallation. The investigators exposed foils of uranium, iron, aluminum, and other metals to a 3 GeV electron beam, as part of a continuing study of electro-induced and photo-produced spallation. Some recent results were presented in a paper "Evidence for Photofission of Iron" by C. B. Fulmer, K. S. Toth, T. H. Handley, I. R. Williams, G. F. Dell, E. L. Callis, T. M. Jenkins, J. W. Wyckoff, at the Fall Meeting of the Am. Phys. Society, Nuclear Physics Division, Miami Beach, Florida, November 25 - 27, 1968. Data taking is continuing.

C. Approved Experiments in Which the Data Taking is to Start in a Later Period

Russell, Tannenbaum, et al (Harvard), Experiment 107a: Boson Resonance Photoproduction. The investigators began preparations for surveying the spectrum of neutral boson (in the boson mass range from 500 to 1800 MeV) in the reaction $\gamma + p \rightarrow p + \text{boson}$. They hope to determine the energy- and angular-dependence of production of known bosons (e.g., the ω^0 particle) and perhaps new ones also. They will employ a tagged photon beam and a liquid hydrogen target. Protons recoiling at 20° to 60° lab will be detected by two sets of wire spark chambers and an intervening magnet 'Enry 'Iggins. Decay products of the bosons produced will be detected by wire spark chambers downstream from the target. The data will be interfaced by a CEA SDS-92 computer to the Harvard IBM 360/50 computer. By the end of 1968 most of the wire chambers had been built and most of the computer programs were completed. The equipment is to be set up and tested in Area 5 early in 1969, and data-taking is to start a few months thereafter.

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 $(\mathrm{GeV}/c)^2$, the investigators will direct a beam of 4-GeV unpolarized photons at a liquid deuterium target and detect the π^0 particle by means of two lead-glass Cerenkov counters that respond to the two resulting photons, and detect 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. Later, if feasible, a beam of 3 GeV linearly polarized photons will be used, to complement the measurements made with polarized photons on protons. By the end of 1968 essentially all of the equipment was complete and the investigators were awaiting machine time in order to test the equipment in parasite runs.

Deutsch et al (M.I.T.), Experiment 111a: Proton Compton Effect. One portion of the experimental work on γ-p scattering at 65° c.m. was done in 1967. The results were analyzed with the SPASS computer program, and a central finding was that as the energy increases from 0.8 to 2.5 GeV the cross section decreases by almost two orders of magnitude. Up to 2.7 GeV the cross section shows no outstanding features. A preliminary account of the results was presented at the September 1967 SLAC Electron Photon Conference. The investigators are now preparing to work at angles as small as 30° c.m. and t-values as small as $-0.20\ (\mathrm{GeV}/c)^2$. The energy of the recoil proton will be determined by range measurement with spark chambers rather than by use of a magnetic spectrometer. By the end of December almost all of the equipment was on hand and in rough alignment, and final positioning was underway. The investigators hope to make preliminary runs within a few months.

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 strike a thin lead converter (situated in the Target Area) and produce bremsstrahlung photons with energies up to 5 GeV. These strike a carbon target and produce ϕ^0 particles that immediately decay into μ^+ and μ^-.

The two-arm spectrograph includes 5-ft thick stacks of iron plates and a 200-counter hodoscope; the equipment permits determination of the muon ranges and directions. In November the investigators completed the conversion of their hodoscope from cylindrical geometry to Cartesian geometry, and in December they were awaiting completion of the adjacent Experiment 105f by Wilson et al, so that the desired Photon Beam 9, produced from the external electron beam by conversion, could be established. Data taking was scheduled to begin in January.

Special Users. In December, physicists from the Smithsonian Astrophysical Observatory visited the CEA and calibrated a glass Cerenkov counter for use in cosmic gamma ray studies at high altitude.

PART IV - PROJECT BYPASS

A. Introduction

By far the largest 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) analyzing the results of the collisions by means of a versatile, large-solid-angle detection system.

The plan is to fill the orbit of the existing synchrotron with countertraveling, 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) synchrotron operation is converted to dc mode (storage mode) and the particles remain in orbit with constant energy with a predicted lifetime of the order of one hour. The stored beams are promptly switched into a special 120-ft detour or bypass and thence back into the synchrotron. Throughout the synchrotron proper and a major portion of the bypass, the countertraveling beams are kept vertically separated by means of electrostatic fields; but the beams are guided so as to collide head-on at the interaction region, at the center of the bypass. Focusing magnets make the beam cross section very small here (about 0.3 x 0.01 mm) and accordingly the interaction rate (number of collisions per second) will be relatively high. The computed nominal luminosity to be expected is 1.5 x 10^{31} cm^{-2} sec^{-1}.

Figure 2 shows the appearance of the bypass on January 29, 1969.

The interaction region will be nearly surrounded by arrays of spark chambers, absorbers (converters), and scintillation counters, comprising a roughly cubic detection system approximately 8 ft on an edge. Initially, an on-line, magnetic-field-free detector will be used; the spark chambers will be of wire-type, digitized; all signals from spark chambers and scintillation counters will be read out and analyzed by an IBM 360/50 computer. Later, a magnetic detector will be used and will provide a more detailed analysis of complex events. An optical detector is under development also.

B. Injection

Positrons and electrons are to be 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 electrons which strike a converter from which gamma radiation and electron-positron pairs emerge; positrons having of the order of 10 MeV energy are collected and guided into the downstream linac, from which 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

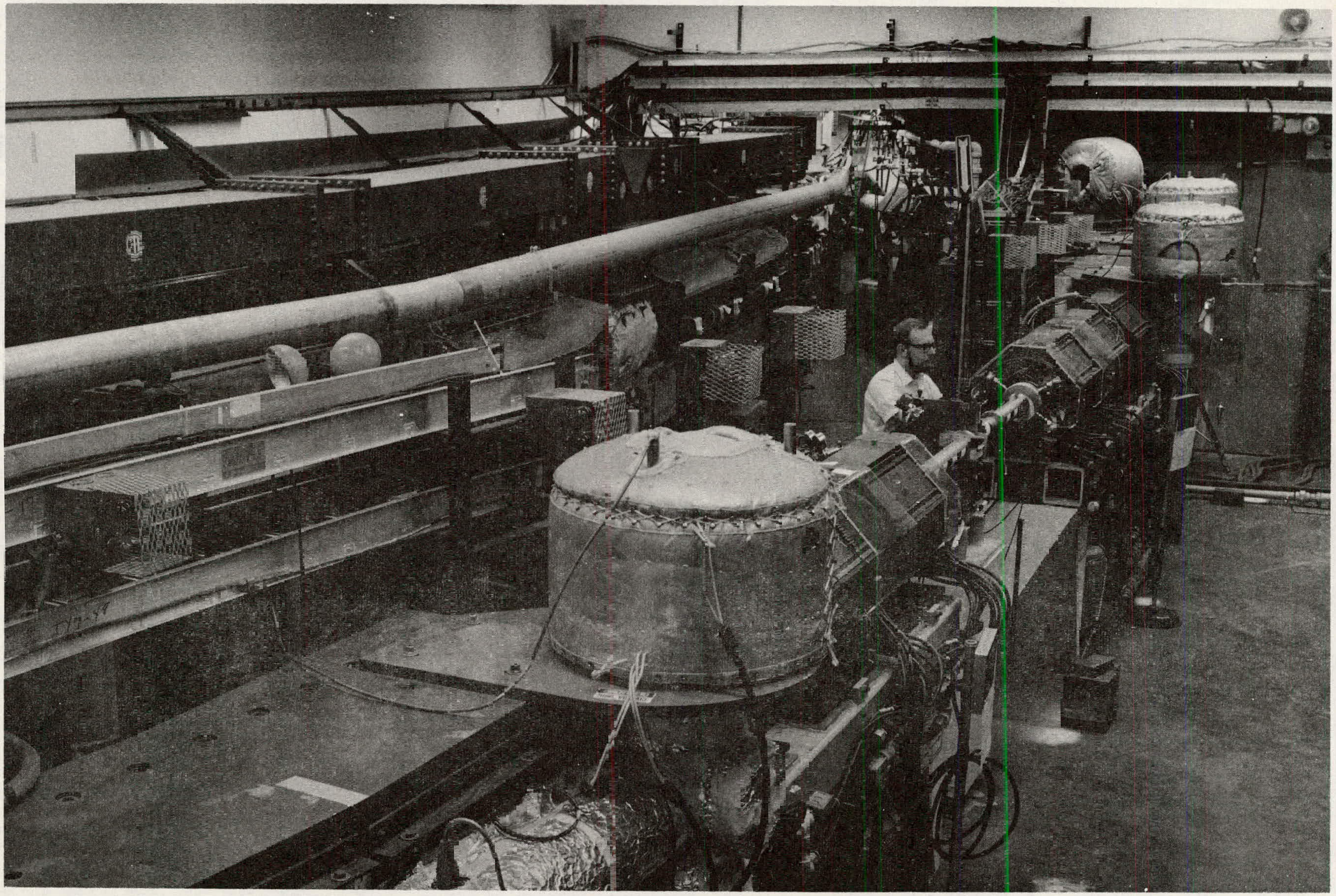

FIG. 2. General View of the CEA bypass on January 29, 1969. The engineer is facing the bypass mid-point (interaction region). To his left are three 4-inch quadrupole magnets; there are three more to his right. In the extreme foreground is one of the six main bending magnets, supporting one of the G.E. titanium high-vacuum pumps enclosed in a bake-out mantle. At the left is the 120-ft-long bypassed segment of the 240-ft-diameter 6-GeV synchrotron ring. The detection system has not been installed.

(in a few seconds), the phase of the second linac is shifted suitably, and the two linacs operate in series to accelerate electrons to 260 MeV; these are deflected to the left and enter the orbit in counterclockwise sense.

The upstream linac is the one already in use for normal operation of the accelerator. Its operation has been improved steadily, as indicated in Part II. The downstream linac and the converter are being built by Varian Associates, and are scheduled for delivery in April 1969, two months later than had been expected a year ago. The necessary switching magnet, to divert the two kinds of particles into the two respective transport paths, has been built, and most of the components of the two transport and deflection systems are on hand. Most of the components needed for multicycle off-axis injection (inflectors, kicker magnets, orbit correction magnets) have been installed and operated successfully.

In actual trials of multicycle injection of 130 MeV electrons, we succeeded in accumulating, in a half second, a peak intensity of 45 mA and an average intensity of 18 mA. (The factor of three difference is indicative of the circumferential filling factor, which is intended to be about 1/3.) The reason for this upper limit on intensity (equivalent to loss of injection efficiency when the stored beam intensity is high) is not clear; the limit is not what one would expect knowing the individual injected intensity (a few milliamperes) and the measured decay time of orbiting particles in the cycling synchrotron (up to 150 seconds). There is evidence that horizontal beam instabilities are responsible. We found that insertion of an octupole lens in the synchrotron orbit produced a 30% increase in the intensity level at which saturation occurs. We expect further improvement when the octupole is powered in programmed manner so that its field will be effective throughout the cycle.

C. Beam Storage

Efficient colliding beam experimentation requires long life of the stored beams, preferably lifetimes of an hour or more. This in turn requires adequate damping of horizontal betatron oscillations, adequate rf-average-power capability, and very low gas pressure, of the order of 10^{-8} torr. The necessary damping magnets were installed 2½ years ago and continue to perform well. Efforts to double the rf power capability were nearly completed in the second half of 1968, as explained in Section V-A. Major improvements in the vacuum system were nearly completed also; see Section II-B. (In an electron storage test made in January 1969, an average pressure of 4×10^{-8} torr was achieved and a 3 mA beam of 2 GeV electrons was stored for 2½ hours with a 1/e decay constant of 35 minutes.)

We have developed procedures for quickly converting the synchrotron magnet ring from biased ac operation (cycling mode) to dc operation (storage mode) without detectable loss of beam. We developed and successfully tried out an "energy-ramp-up" control for raising the energy of the stored beam from the initial value (about 1.5 GeV, typically) to any desired value (up to 3.5 GeV) within a few seconds.

We tried out our electrostatic system for clearing ions from the orbit, and we studied the effect of ion clearing on beam life, beam intensity limitations, and instabilities.

We made many improvements in instrumentation. Beam lifetime (of seconds, minutes, or hours) can now be displayed in digital form after a 1 to 10 second measuring period. It has become possible for the operator to tune the machine directly for maximum lifetime.

D. Bypass Trials

In the first half of 1968 the assembly of the 120-ft-long bypass, with its six large and two small bending magnets, twelve quadrupole magnets, four sextupole magnets, and twelve steering magnets, was complete and first efforts were made to switch the electron beam into the bypass and back into the synchrotron ring; only three turns were achieved. In the second half of 1968, after modifying the ejection septum magnets and relocating the auxiliary bending magnets, we obtained 700 turns. (Because the accelerator was in ac mode and the bypass was powered by dc, magnetic match for 2 GeV particles persisted for only 0.5 ms at the top of the cycle; consequently no more than 700 turns could be expected.)

The beam returning to the synchrotron ring exhibited a large coherent synchrotron oscillation, indicating an error in pathlength of the bypass. Such oscillation preempted much of the free aperture of the bypass, and accordingly the decision was made to move the bypass physically by about 0.6 inches radially to eliminate all, or most, of the pathlength mismatch. (The adjustment was made late in January 1969.)

The electro-optical properties of the bypass turned out to be slightly different from the expected properties. Accordingly we made a succession of adjustments of bypass quadrupole magnet excitations while determining the consequent changes in betatron frequencies; and from this information we computed the values of beta-function and beam cross section in these quadrupole magnets. From time to time during this sequence of adjustments we used a fast off-line computer to see whether reconciliation could be made between the deliberately introduced adjustments and the resulting measured properties. We found that reconciliation could be achieved if we adopted a somewhat different set of elements for the transfer matrices of the synchrotron magnet fringing fields through which the electrons traveled when leaving or reentering the synchrotron ring. We are confident that the resulting better understanding of the bypass optics will be helpful in future trials of the bypass.

E. On-Line Detector

By December 31, 1968, the general design of the magnetic-field-free on-line detector for recording the results of electron-positron collisions at the interaction region of the bypass was complete, much of the detailed design work had been done, and construction of many of the main components was underway. The detector will consist of four nearly-identical assemblies (quadrants) of wire spark chambers interspersed with scintillation counters and absorbers arranged symmetrically around the beam as indicated in Fig. 3. The active area of each spark chamber and scintillation counter is approximately square; the size varies from about 1 ft x 1 ft for the chambers closest to the interaction station to 7 ft x 7 ft for the outermost chambers. The combination of wire spark chambers, absorbers, and shower scintillation counters will allow identification of photons, electrons, and muons. Two one-foot-thick iron absorbers on either side of the detector in conjunction with four interspersed wire spark chambers will allow discrimination between pions and muons. The information from wire spark chambers and scintillation counters will be digitized and then recorded and analyzed on-line by the Harvard IBM 360/50 computer.

During the period July - December 1968 we made many tests on prototype wire spark chambers and finally arrived

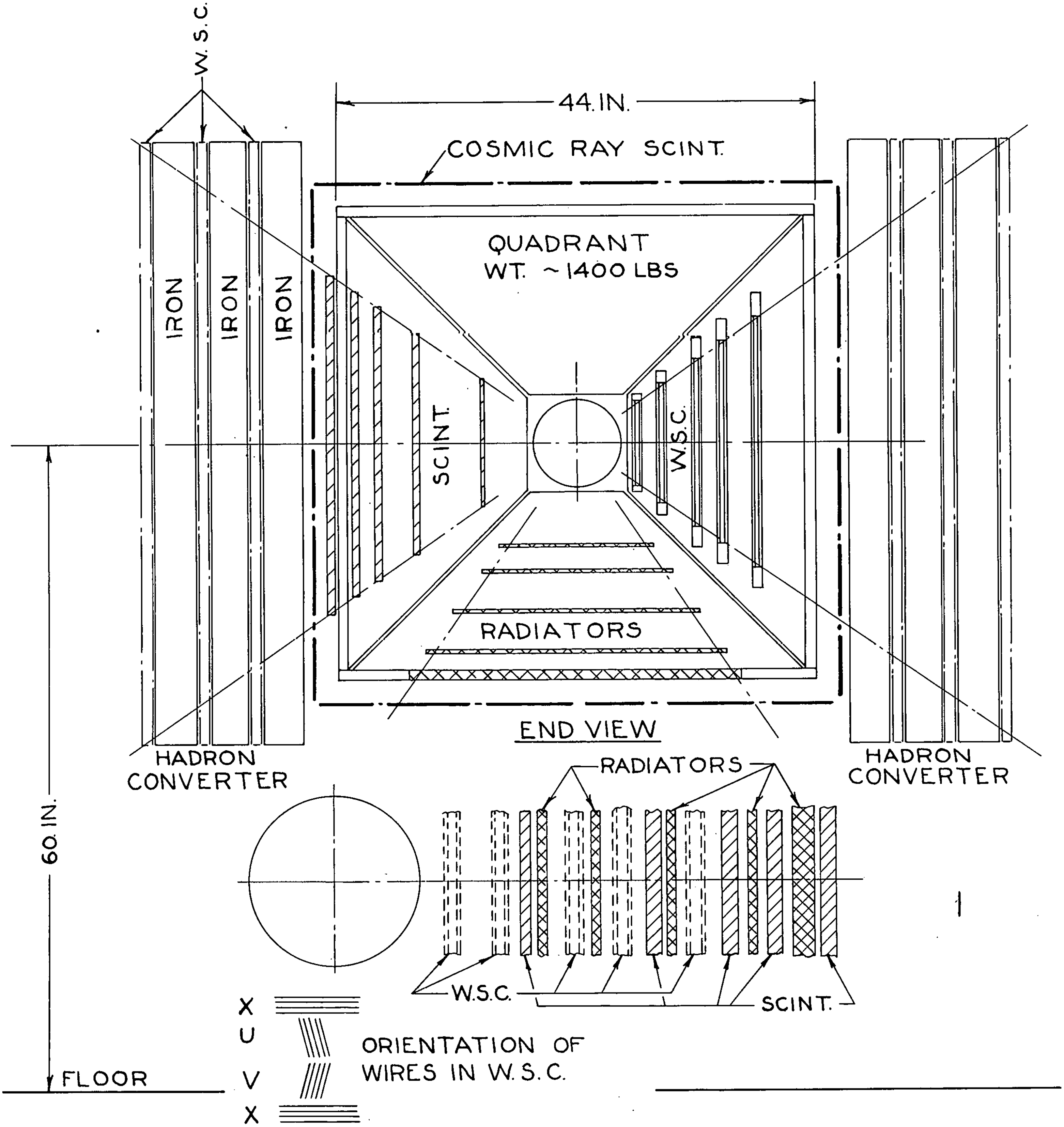

FIG. 3. Cross section of the on-line detector. The electron and positron beams travel perpendicular to the plane of the paper, and pass through the center of the circle representing the cross-section of the beam pipe. The four quadrants are similar; each contains an alternating series of wire spark chambers (WSC), scintillators, and radiators, as indicated more fully in the diagram at the bottom. Just outside the core proper is the envelope of scintillators for vetoing cosmic ray muons, and the thick iron plates for hadron conversion.

at a satisfactory set of parameters. The high-voltage pulse will be a 6 to 7 kV square pulse approximately 120 ns long. Problems were experienced with extra sparks accompanying the desired spark when a particle passes through, and with systematic variation of output-pulse-height over the chamber area. The problems were largely overcome by changing the wire diameter from 2 mils to 5 mils and by increasing the inductance of the high-voltage straps and ground straps connected to the wires.

The general dimensions of the core (the four quadrants) were fixed, and specifications for manufacture of the spark chamber frames and auxiliary items were sent to various manufacturers for bids. Satisfactory devices for holding and reflection-damping the magnetostrictive wires were designed and tested.

We decided to use thyratrons, rather than spark gaps, for pulsing the wire spark chambers because of the unsatisfactory lifetime of the spark gaps tested. Prototype thyratron pulsers were built and tested, and were found to have satisfactorily short delay time and long lifetime. Production of pulsers is to start early in 1969.

In July we received the electronic system that is to digitize the coordinate information from the wire spark chambers. A prototype electronic interface to feed this information to an SDS-92 computer was built and tried out, but was found to suffer from interference when the spark chambers were pulsed. It is being redesigned.

We ordered a large portion of the fast electronics for triggering the spark chambers.

We performed experiments to evaluate the performance of a cosmic-ray-muon anti-coincidence system which employs scintillation counters to measure time-of-flight. The results indicated that a system employing counters 4 ft apart will have a cosmic-ray-rejection efficiency exceeding 99%.

Much effort was given to preparing specifications for on-line and off-line programming of detector data. We prepared a minimal on-line program (for SDS-92 and IBM 360/50) which is capable of recording all of the raw data on magnetic tape. We prepared off-line programs that calculate efficiency of each spark chamber, calculate the range of any specified particle, and display the paths of any specified event on a high-resolution plotting device.

F. Optical Detector

The proposed optical detector will employ scintillation counters, optical spark chambers with stereo-photographic recording, lead and aluminum absorbers, and a large overhead hemispherical dome for vetoing cosmic ray muons. This detector serves as a back-up for the on-line detector, particularly for the confirmation and/or identification of unexpected or complex events.

During the present six-month period the designers gave principal attention to the design of the hemispherical dome, which is to have inner and outer radii of 42 and 54 inches and is to be water-filled. Seventy photomultiplier tubes will detect the Cerenkov light produced in the water and will determine, by anti-coincidence circuits, whether a charged particle responsible for light production was proceeding inward from the sky (e.g., a cosmic ray muon) or outward from the interaction station of the Bypass (e.g., a muon or other charged particle produced in a head-on e^+e^- collision). The functioning of a prototype segment of dome was tested with cosmic ray muons and the efficiency of rejection was found to be 92%.

Work proceeded on other portions of the detector. A prototype aluminum-and-lead sandwich plate for the shower spark chambers was ordered and several optical spark chambers for use in background measurements adjacent to a stored beam were prepared.

G. Magnetic Detector

Good progress was made in further design studies of the magnetic detector, which will employ scintillation counters and optical spark chambers mounted inside and outside a large rectangular solenoid the axis of which is parallel to the beams. See Fig. 4. The present plan is to install and use a magnetic detector after the non-magnetic detector

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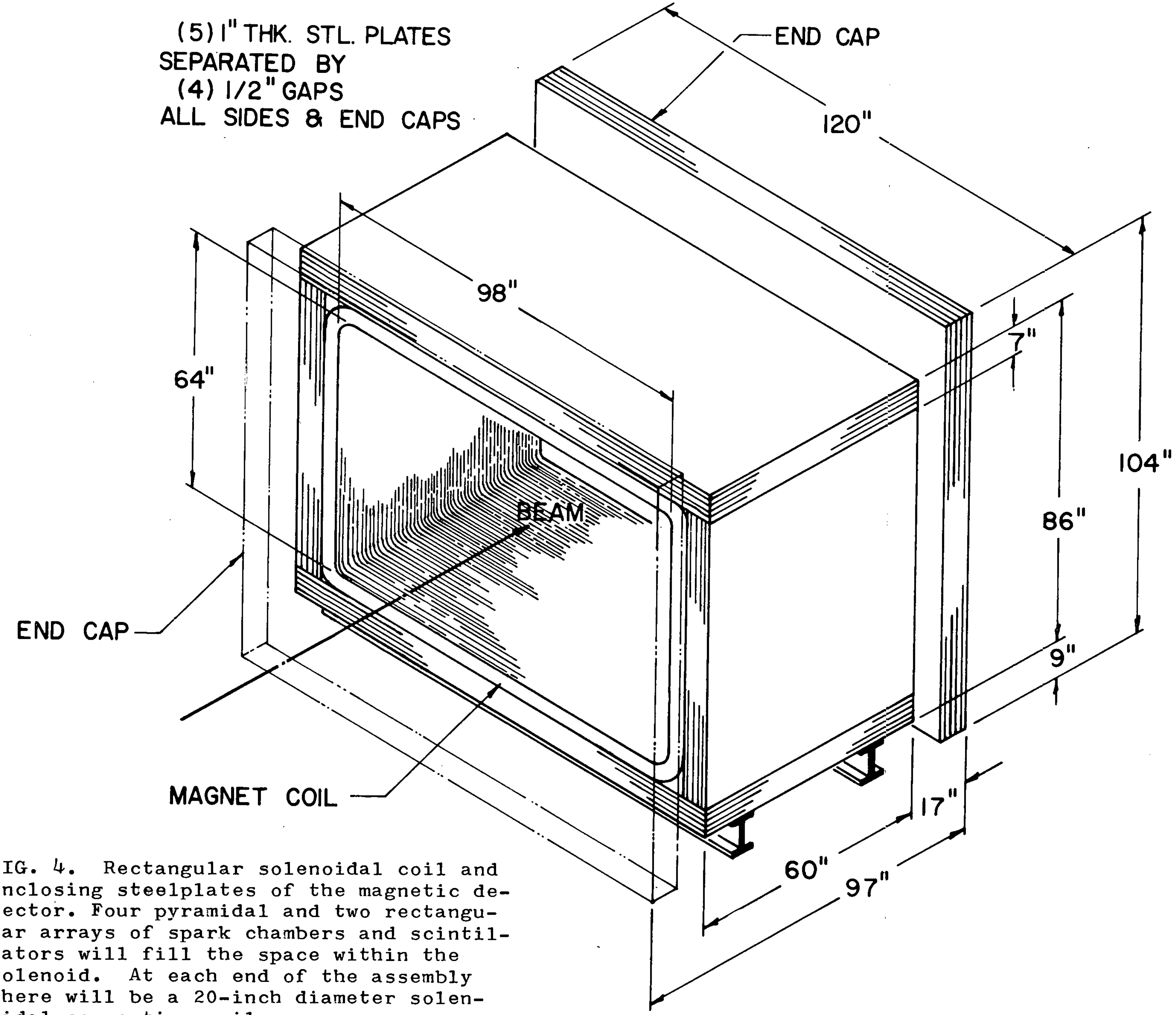

FIG. 4. Rectangular solenoidal coil and enclosing steelplates of the magnetic detector. Four pyramidal and two rectangular arrays of spark chambers and scintillators will fill the space within the solenoid. At each end of the assembly there will be a 20-inch diameter solenoidal correction coil.

(discussed in the preceding section) has taken an appreciable amount of data.

The magnetic detector is designed to:

1. Confirm results found with the on-line detector and extend the measurements. The magnetic detector can distinguish e^+ from e^- and thus will be able to test the time-like photon term with greater accuracy than is afforded by the field-free detector.
2. Separate the various baryon channels.
3. Identify new particles, if any.

In the six-month period in question, the design group devised an abridged design of detector that can be built more economically and more quickly than the design proposed earlier. The main simplification was in the solenoid, which will provide an analyzing field of 3.5 kG, as compared to 18 kG in the earlier design. Solenoid and correction coils will employ conventional copper conductors, rather than superconducting coils. Less iron is required for flux return and attenuation of stray fields; consequently the six sets of steel plates enclosing the solenoid can be made thinner. The overall length of the detector, measured along the beam, is 96 inches and the entire device can be inserted in the 99-inch-long straight section of the bypass.

The transverse horizontal dimension of the solenoid is 98 inches, compared to 60 inches in the earlier design.

Because the analyzing power varies with the square of this dimension, the detector will be able, despite the reduced field intensity, to distinguish pions from kaons with a reliability of three standard deviations, provided the energy of each of the colliding beams does not exceed 1.2 GeV.

In general, Project Bypass is progressing well, and on a schedule close to that originally proposed. No notable unforeseen difficulties have yet been encountered, but many individually small problems remain to be solved. If the positron source arrives in April as promised, we should be ready for storing both electron and positron beams before the end of 1969.

PART V - MAJOR IMPROVEMENTS AND NEW PROJECTS

A. Increase in RF Power Capability

We essentially completed our program for doubling the accelerator rf power capability -- from 100 kW average to 200 kW average. The higher power is essential to storage of very-high-intensity (100 mA) beams of electrons and positrons at energies up to 3.5 GeV, and is useful also in normal operation with the increased (10 to 30 mA) intensities provided by the new linac.

We learned from RCA that the existing rf high power amplifier tube has adequate power capability, but it was apparent that major improvements were needed in other components. We needed a greater supply of power to the HPA, improved cooling of the HPA, increased isolation capability between HPA and the rf cavity ring, and more accurate control of rf cavity temperature.

The necessary increase in power to the HPA (increase from 0.3 MW to 1.0 MW) is provided by two Airco Temescal transformers rated at 1/2 MW each. These devices were obtained a year ago and were installed in a specially built rf shed in July 1968. Each transformer is served by 3-phase full-wave rectifiers employing six stacks of diodes (52 diodes per stack). The input is 60-cycle, 480-volt current, and the output is 15 kV direct current. Protection is provided by six ITT-Jennings vacuum interrupters. Six capacitors suppress transients. The equipment is now in routine use.

We procured and tested an air refrigeration system for cooling the rf transmitter. Some shortcomings were found, and we are now modifying the system.

We installed, between rf transmitter and the rf cavity ring, a Raytheon isolator rated at 500 kW peak forward power and 250 kW average forward power. The rated insertion loss is 0.4 db and the isolation is 10 db. With this isolator, we can drive the 16 cavities with the maximum power available from the transmitter irrespective of whether the transmitter frequency and cavity resonant frequency are matched.

We installed a more accurate, more versatile, and faster acting temperature control system for the 16 rf cavities. The system can change the cavity temperature at a rate corresponding to a rate-of-tuning of 25 kc/minute. Small changes in tuning can be accomplished in a few seconds, as compared to 15 minutes using the old control system.

B. Other Improvements to the Accelerator

We designed and installed an automatic capacitor switching system for maintaining proper capacitance to keep the magnet excitation in phase with the line.

We built and installed an improved type of magnet for exciting horizontal and vertical betatron oscillations at any time during the acceleration interval. The new device, installed in Straight Section 32, makes it possible to determine betatron frequencies accurately and conveniently at any phase in the magnet cycle. The new device is about 25% the size of the previous equipment and thus leaves more space for installation of other special devices.

We made progress toward developing a secondary emission quantameter (SEQ) for monitoring external multi-GeV photon beams. An experimental model was found to perform far more reliably than a quantameter, although with two orders of magnitude less sensitivity.

Two A.D.Little Co. refrigerators for the direct mechanical refrigeration of liquid hydrogen targets were received. We now have three A.D.Little Co. devices and a similar device made by Cryomech Inc. All four units have performed well. They reduce the amount of liquid helium required by an order of magnitude, and they eliminate the need for interrupting experiment operation to permit replenishing liquid helium.

We nearly completed construction of a liquid hydrogen target system designed to be sufficiently simple and reliable so that the experimenter himself can operate it. There is no need for constant attendance by a cryogenics technician. Using only two simple controls, the experimenter can fill the thin-walled target vessel proper from a rugged condenser (already containing liquid hydrogen), or can transfer the liquid hydrogen back from target vessel to condenser in order that target-out background measurements can be made.

We designed and ordered two special magnets, one for analyzing high-momentum particles and the other for low-momentum analysis throughout a large volume. The former has a gap-height, width, and length of 5", 22", and 84". The latter has a 12" gap-height and a length of 48"; the width tapers from 24" to 36". Delivery is scheduled for March 1969. The 45-ton 'Enry 'Iggins magnet was modified by the addition of fringe-field shielding plates to permit operating photomultiplier tubes very close to the magnet.

Our computer facility, employing four CEA SDS-92 computers and also the Harvard IBM 360/50 computer, has been improved to the extent that it is now possible for three different experimental groups to operate simultaneously on-line to the IBM 360/50.

We made good progress toward completing a program for connecting the on-line detector of the colliding beam experiment to the IBM 360/50, via one of our SDS-92 computers.

We modified an available program (Berkeley program POISSON) for predicting the detailed performance of dipole, quadrupole, and octupole magnets having any specified configurations of iron core and copper coils. The program was modified for use on the Harvard IBM 360/50 computer.

We have been preparing to control the powering of trains of experimental magnets by means of one of our SDS-92 computers. By increasing the accuracy, speed, and convenience of control, the computer will save machine time and increase the accuracy of experimental results. Also, the proposed system will provide permanent records of magnet powering for later reference by the experimenters.

We completed the first stage of computerizing our principal accounting records.

Additional equipment for chemically treating cooling water for the synchrotron magnets and experimental magnets was received and installed. Using this equipment, we hope to reduce the amount of corrosion in the cooling systems and reduce the tendency of cooling tubes of magnet coils to become clogged.

We designed and procured a special machine for use in cleaning the passages in magnet coils. The machine can deliver 50 gallons/minute of cleaning solution at pressures up to 180 psi and temperatures up to 250° F.

C. Synchrotron Radiation Room

In August and September, a 25 x 35 ft Synchrotron Radiation Room was built adjacent to the Circular Tunnel (near Magnet 38, and near the Spur Tunnel that houses the old linac). The room was planned and paid for by the Harvard Physics Department, with counsel from the CEA staff. The room is to be used by physicists from Harvard and elsewhere who wish to carry out research projects that require use of the intense, "white spectrum", linearly polarized, soft-x-ray synchrotron radiation emitted by the orbiting electrons. (Such emission is unavoidable, and ordinarily, no use is made of this radiation -- despite its unique character.) The floor of the room is 15 ft below ground level, and a six-foot-thick concrete shielding wall intervenes between the new room and the Circular Tunnel of the synchrotron. Synchrotron radiation may be admitted to the room via any of three straight horizontal passages each 2-ft in diameter and oriented tangential to the orbit at Stations 37, 37½, and 38.

The program of experimental use of this facility is to be determined by a committee chaired by Professor W. Paul of the Harvard Division of Engineering and Applied Physics.

D. Engineering Support Building

This 95 x 45 ft building, adjacent to the Experimental Hall and designed for use by CEA support divisions in assembling and testing large equipments, was largely completed in the previous six-month period. During the present period, lighting and power supply facilities were installed, a water-seal between the new building and the adjacent Experimental Hall was completed, and blowers and ducts for ventilating the building adequately in summer were installed.

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The building was accepted in October. The 40-ton crane was accepted in December, after the tracks had been realigned.

The Electrical Department and Rigger Group are now using the new building for assembly and testing of heavy equipment. The two prototype magnets, similar to those in the synchrotron ring, were set up here and the special ac and dc power supplies required were installed. These magnets are used in dimensional, thermal, and vibration tests on pole face windings, vacuum chambers, and other components to be used in conjunction with the synchrotron magnets.

E. Source of Polarized Electrons

The program for developing a source of polarized electrons (such as could make it possible to inject polarized electrons into the synchrotron ring and accelerate them without serious loss of polarization) progressed satisfactorily. Essentially all components of a trial device for polarizing electrons by spin exchange with polarized hydrogen atoms are on hand, assembly is underway, and the main assemblies are being tested.

F. Miniature Storage Ring for Production of Monochromatic Light

Further planning was done on the basis of a 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. Main effort was given to making the design of the 72-magnet ring sufficiently flexible so that, by readjusting the positions and gap-heights of the magnets, the operator could vary the betatron frequencies over a large (seven-fold) range, and the device as a whole could be operated either far from transition or (much more difficult!) at or very close to transition, to permit optimization of performance.

PART VI - SAFETY

During the six-month period in question there was one lost-time injury: a rigger suffered back injury and lost 11 days work.

No CEA employee or experimenter received, at CEA, a radiation dose as large as one-third of the permissible dose for the period. The three largest 6-month doses were 740, 425, and 415 mrem.

Data provided by integrating monitors of gamma radiation and neutron radiation showed that the maximum 6-month doses of CEA-produced radiation delivered to the boundary of CEA property near Hammond Street and Gorham Street were 43 mrem and 38 mrem respectively -- less than 10% of the permissible annual dose for the public.

Radiation safety training sessions were held on 8/28/68, 9/3/68, 9/5/68, and 9/6/68, with 10 to 30 persons attending a typical session. A total of 75 CEA employees received training.

The CEA smoke detection system was extended to include the linac tunnel and linac power building.

The CEA plant was inspected by safety engineers and health physics officials of the US AEC, the Commonwealth of Massachusetts, Harvard University, and M.I.T.

PART VII - PUBLICATIONS RESULTING FROM WORK DONE AT THE CEA

A. Publications on High Energy Research Performed at CEA

"Incoherent-Scattering Function, Total Pair-Production Cross Section, and Pair-Production Length for Helium", T. M. Knasel, Phys. Rev. 171, 1643 (1968).

"Photoproduction of Positive Pions at Backward Angles in the 1 - 3 GeV Energy Range", R. A. Alvarez, G. Cooperstein, K. Kalata, R. C. Lanza, and D. Luckey, Phys. Rev. Letters 21, 1019 (1968).

"Wide-Angle Electron-Positron Pair Production", K. J. Cohen, S. Homma, D. Luckey, and L. S. Osborne, Phys. Rev. 173, 1339 (1968).

"Neutron Form Factors from Quasi-Elastic Electron-Deuteron Scattering", R. J. Budnitz, J. Appel, L. Carroll, J. Chen, J. R. Dunning,Jr., M. Goitein, K. Hanson, D. Imrie, C. Mistretta, J. K. Walker, and Richard Wilson, Phys. Rev. 173, 1357 (1968).

"Photoproduction of η^{o} Mesons at 4 GeV", D. Bellenger, S. Deutsch, D. Luckey, L. S. Osborne, and R. Schwitters, Phys. Rev. Letters 21, 1205 (1968).

"Test of Time-Reversal Invariance in Electroproduction Interactions Using a Polarized Proton Target", J. R. Chen, J. Sanderson, J. A. Appel, G. Gladding, M. Goitein, K. Hanson, D. C. Imrie, T. Kirk, R. Madaras, R. V. Pound, L. Price, Richard Wilson, and C. Zajde, Phys. Rev. Letters 21, 1279 (1968).

"Further Search for S = +1 Baryon States in Photoproduction", S. Mori, J. S. Greenberg, V. W. Hughes, D. C. Lu, J. E. Rothberg, and P. A. Thompson, Phys. Letters 28B, 152 (1968).

B. Papers Presented at the Vienna Conference on High Energy Physics, August 28 - September 5, 1968

"Photoproduction Search for Dipion Resonances in the Mass Range from 1400 to 1800 MeV", N. Hicks et al.

"Angular Distributions for π^+ Electroproduction and the Pion Form Factor", C. Mistretta et al.

"A Search for the Electroproduction of the N'(1470) Resonance from Deuterium", J. L. Alberi et al.

"An Experimental Test of Time-Reversal Invariance in Inelastic Electron-Proton Scattering", J. A. Appel et al.

"Photoproduction of Positive Pions at Backward Angles in the 1 - 3 GeV Energy Range", R. A. Alvarez et al.

"Production of π^0 Mesons by Plane Polarized 3 GeV Photons", D. Bellenger et al.

"Photoproduction of η^0 Mesons at 4 GeV", D. Bellenger et al.

"Photoproduction of Negative Pions from Deuterium with Polarized Photons of 3.0 GeV at $-t = 0.6$ and $1.2\ (\mathrm{GeV}/c)^2$", Z. Bar-Yam et al.

"Further Search for S = +1 Baryon States in Photoproduction", S. Mori et al.

C. Other Papers on Work Done at CEA

"Study of K_L^o Photoproduction at the CEA", J. F. Schivell et al. Presented at Spring 1968 meeting of the New England Section of Am. Phys. Soc.

"Evidence for Photofission of Iron", C. B. Fulmer et al. Presented at Fall 1968 meeting of Nuclear Physics Division of Am. Phys. Soc.

"Secondary Emission from Aluminum and Gold by High-Energy Electrons and Positrons", M. Fotino et al. Presented at November 26, 1968, meeting of Nuclear Physics Division of Am. Phys. Soc.

"New Developments in Liquid Hydrogen Target Systems at the CEA", M. O. Hoenig et al. Presented at August 1968 Annual Cryogenics Engineering Conference.

"Behavior of Typical CEA Liquid Hydrogen Target Systems Under Simulated Failure Modes", H. E. Soini et al. Presented at August 1968 Annual Cryogenics Engineering Conference.

D. Theses on High-Energy Research Performed at CEA

"Test of Time Reversal Invariance in Electroproduction Interactions Using a Polarized Proton Target", August 1968 thesis by J. Chen of Harvard.

"Lambda Polarization in Photoproduction", August 1968 thesis by K. J. Cleetus of M.I.T.

E. CEAL Reports

CEAL-1044 "Semi-Annual Report for the Period January 1 through June 30, 1968", K. Strauch, October 25, 1968.

CEAL-1045 "The CEA Secondary Emission Monitors", G. F. Dell and M. Fotino, November 4, 1968.

CEAL-1046 "Laser-Induced Polarized Photon Beam at the CEA", R. H. Milburn, J. R. Sauer, C. K. Sinclair, M. Fotino, November 15, 1968.

F. CEAL-TM Reports

CEAL-TM-176 "Electron g-2 Measurement", R. J. Krisciokaitis, July 2, 1968.

CEAL-TM-177 "Hydrogen State Selection System", R. J. Krisciokaitis and J. C. Backler, October 21, 1968.

CEAL-TM-178 "Radiation Safety Results for the Period January 1, 1967, through September 30, 1968", W. A. Shurcliff, December 19, 1968.

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