MASTER

CEAL-1048

OPERATION OF
THE CAMBRIDGE ELECTRON ACCELERATOR
FOR
FISCAL YEARS 1969, 1970, and 1971

AEC Contract AT(30-1)-2076

and

AEC Contract AT(30-1)-3025

Karl Strauch
Director

May 1, 1969

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
and HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

CAMBRIDGE, MASSACHUSETTS 02138

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42 OXFORD STREET
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14. Scope

Introduction

The two primary tasks of the Cambridge Electron Accelerator are (1) operations, improvement and development of the 6-GeV electron synchrotron facility, and (2) support of an experimental program in particle physics. The aim is to carry out these tasks so as to combine excellence in research with the training of a large number of professional physicists. Indeed the organization of the laboratory and its research activities reflects the belief that the best training is obtained in a laboratory working at the frontiers of knowledge in the most fundamental aspects of physics, and that in turn the research itself greatly benefits from the participation of the young questioning minds of students. The close proximity of the Cambridge Electron Accelerator to the major educational institutions in the Boston Area is a major factor in the success in carrying out the combined research and training functions.

The 6-GeV electron accelerator furnishes several external beams of 1 to 6-GeV electrons and bremsstrahlung. Internal targets are also used. Two tagged photon beams and two polarized beams exist or are being developed.

CEA support of the experimental program includes: technical assistance in the setup of experiments on the floor, operation of experimental magnets, cryogenic targets, and vacuum systems for experiments, operation of the on-line computer interface equipment which is tied in with the IBM 360/50 computer at the

14. Scope (continued)

Harvard Computation Center, and support for experiments by the CEA electronics shop.

In addition, the CEA provides the following services: design and procurement of most of the heavy experimental equipment and its power circuitry, design and construction or procurement of hydrogen targets, coolers and related cryogenic equipment, and safety control of all experimental equipment.

Accelerator Utilization

From January 1967 through December 1968, CEA operated the Synchrotron on a 10 experimental shift/week basis. The balance of the 21 shifts consisted of 4 for bypass operation, 3 for maintenance, and 4 during which the laboratory was closed. The completion of the installation of ceramic chambers in the ring, improved bakeout, and other accelerator systems improvements have increased the reliability of the machine to the extent that we have been able to reduce the number of operators in an accelerator crew. This has permitted us to form an additional crew without increase in laboratory personnel. Starting in January 1969 the 21 shifts available each week were distributed as follows: 13 shifts for High Energy Physics, 4 shifts for Accelerator Physics (primarily Project Bypass) and 4 shifts for maintenance. In addition we have scheduled this operation in a three week cycle in which 12 maintenance shifts occur together from Monday to Friday when the majority of maintenance personnel are at CEA. Another major advantage is that the new schedule provides longer consecutive runs for increased efficiency.

14. Scope (continued)

Laboratory Program

During FY 69 the average number of persons employed at CEA was 192, which is the complement at which we have stabilized for operation under our present budget limitations.

Active projects for improvement of the Synchrotron facility include continued improvement of the ring vacuum, increase in the power capability of the rf system, upgrading of the external electron beam delivery system, continued development of a source of polarized electrons, installation of a positron injector (to be complete by August 1969) and installation of a two-arm electron scattering spectrometer. The major project continues to be the colliding beam facility. The bypass train is complete and beams have been successfully switched into the bypass for as many as 700 turns.

The non-magnetic detector is continuing at a rate as rapid as is allowed by available funds and is expected to be completed early in 1970. The magnetic detector has been redesigned. By reducing the goals, i.e. by lowering the energy up to which pions and kaons can be identified, a considerable cost reduction has been achieved. The solenoid and materials for prototype spark chambers will be purchased in FY 69. However, no further purchases are possible in FY 70 unless we obtain funds in addition to those presently recommended in the presidential budget. The development of a high power (500 kW) rf system has been postponed for another year for the same reason. This latter improvement is necessary to allow colliding beam experiments to be extended to 5 GeV and 50 mA.

14. Scope (continued)

During FY 69, 11 groups from Harvard, M.I.T., Northeastern, Oak Ridge, S.M.T.I., and Tufts have carried out or prepared experiments at CEA. Forty-one Ph.D. physicists, 51 graduate students, and several CEA staff members were involved in these projects.

Active and approved experiments as of April 15, 1969, include:

1. Compton Scattering at High Energy and Small Momentum Transfer (Brenner-Walker)
2. Photoproduction of π^0 from Neutrons (Luckey)
3. Proton Compton Effect at 2 GeV and $t = 0.16 \text{ (GeV/c)}^2$ (Deutsch)
4. Heavy Boson Mass Search (Northeastern)
5. Electron Reaction Cross Section (Dell-Oak Ridge)
6. Boson Resonance Photoproduction (Russell-Tannenbaum)
7. Photoproduction of π^+ with Polarized Photons (S.M.T.I.-M.I.T.)
8. Particle Detector Development (Yuan)
9. Elastic π^+ Photoproduction (Pipkin)

The Cambridge Electron Program Advisory Committee (CEPAC) reviewed the status of experiments in progress and examined proposals for future experiments. They met on October 12-13, 1968, and February 14, 1969, and are scheduled to meet again in May 1969. This committee included (in addition to the Director):

Dr. Samuel Berman, SLAC
Prof. Louis N. Hand, Cornell
Prof. Louis S. Osborne, M.I.T.
Prof. 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

14. Scope (continued)

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

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

Prof. 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.

The new Engineering Support Building was completed during the Summer of 1968 and is now being fully utilized.

16. Technical Progress in FY 1969

I. Accelerator Developments

(1) Operation

Between July 1, 1968 and April 1, 1969, a total of 802 and 2896 machine hours were scheduled for accelerator development and physics experiments respectively. The delivered hours for physics experiments totaled 2119, implying a 73.2% efficiency. Because of the substantial use of parasite time by experimenters, a total of 3843 user hours were available to experimenters. It is expected that an additional 1688 machine hours will be made available between April 1 and June 30, 1969. As noted under "Scope" the number of shifts available per week for high energy physics was increased from 10 to 13 in the second half of FY 1969. Accelerator physics used 4 shifts/week throughout FY 1969.

(2) Vacuum System

The elimination of all organic material in the accelerator vacuum ring has been accomplished with the installation of the last of the 48 ceramic chambers. A special chamber suspension system was developed successfully to decouple the chambers from machine vibrations. Ultrasonic clearing of other components such as rf cavities has been carried out.

By the end of FY 69 we expect to have completed the change over to elliptical bellows which are necessary to reduce forces on the ceramic vacuum chambers in order to increase reliability. We also expect to complete the cleaning and installation of bake-out capability of the entire vacuum

16. Technical Progress in FY 1969 (continued)

system. This will enable us to routinely achieve average base pressures of $\approx 1 \times 10^{-8}$ torr and stored beam lifetimes of ≈ 1 hour. On April 1, average pressures of 3×10^{-8} torr and beam lifetimes of 1/2 hour were routinely available.

We are continuing our gradual replacement of ion pumps with a more advanced pump as the present ring pumps fail and as funds allow. By the end of FY 69 we expect to have about one half of the pumps replaced.

An improved high vacuum ejection magnet for external electron beams was installed during FY 69. This had considerably better vacuum performance and radiation resistance than previous ejection magnets. However, mechanical problems resulted in two failures of this magnet and a more rugged version is presently being designed. This design should be complete in FY 69.

(3) RF Power System

During July 1 through December 31, 1968, the accelerator was down for substantial amounts of its scheduled running time because of faults in the rf system. The system includes back-up equipment and switching networks which give options of bypassing faulty equipment, and for running with reduced power. Most of the experiments conducted during FY 69 have required high-energy, high-intensity beams and have needed full rf capability. Experimenters have preferred to wait for rf repairs rather than utilize the lower power options. The demands for high rf capability have increased; the percentage of downtime attributable to rf has also increased.

16. Technical Progress in FY 1969 (continued)

Foreseeing the need for sufficient rf power to operate the accelerator at high electron energies and currents, and realizing that the desired 500 kW system was years from being operational, we undertook modifications to our rf system equipment which would enable our utilizing the high power amplifier (RCA 4612) to its full capability. This tube is rated at 100 kW but we had hoped that it might be able to operate at even higher power levels.

The equipment needed (high voltage, high power dc power supply, amplifier cooling system, isolator, and accelerator cavity temperature control system) has been acquired and is operational. As of April 1969, there remains some additional work on the power supply (voltage control) and amplifier cooling system to achieve the desired performance from the equipment.

While operating the accelerator with this equipment, we have restricted the system to near a 100 kW limit in order to gain sufficient experience on the operation of this system under steady operation near the rated limit of the RCA 4612 tube. Some serious weaknesses have been uncovered under these operating conditions. We have found that there are contacts which are part of the 4612 which often cannot maintain sufficient force perhaps because of thermal effects locally in the spring. This results in contact with subsequent arcing. Much damage can be done to the tube rather quickly. There is evidence of poor contacts causing damage both within the vacuum of the tube, and on the external parts of the tube.

16. Technical Progress in FY 1969 (continued)

Another serious problem encountered at high power levels is the failure of some accelerator cavity windows which have developed leaks. The window failures are presently thought to be due to localized heating at the interface where the ceramic window is joined to a copper ring. (This ring is then in turn welded to the rf accelerating cavity to provide a vacuum window through which rf energy couples to the cavity.)

These two problems, the contact problem of the 4612, and the accelerating cavity window problem require studies, new designs, and evaluation of the effectiveness of the changes. RCA recommended our changing to a different tube type, the 2504, utilizing a structure which has, at slightly lower frequencies, proven capable of high power use. The cavity window problem is expected to be solved by changes in the method of attaching the ceramic to the cavity.

(4) Linac Injector

The 120-MeV linac installed and accepted in FY 68 has been used routinely as injector until April 21, 1969. At that time, installation of the converter and positron accelerator section required the shutdown of the 120-MeV linac for a period of about 4 months. The old 30-MeV linac will serve as injector during the time of positron source installation. During FY 69, the Linac Division has improved the monitoring of various parameters of the 120-MeV linac to aid in trouble shooting. Several improvements have been made in the area of the high voltage power supply. A set of electrostatic plates for controlling the linac beam pulse length (0.1 to 2.5 μ sec) has been powered and is in

16. Technical Progress in FY 1969 (continued)

routine use. Normal synchrotron operation requires a .8 μ sec pulse; multicycle injection for bypass operation requires a .25 μ sec pulse.

After installation of the positron source, 240-MeV electrons and 120-MeV positrons will be available for injection into the accelerator.

For optimum injection of electrons and positrons into the synchrotron the bending magnets of the transport system require excitations to current and voltage levels not available from existing power supplies.

While there are two magnets per system, at the present we plan to purchase only one supply and to employ a switch to transfer energy from one to the other.

The initial invitation to bid did not receive the desired number of replies. Some manufacturers declined because the specifications called for a single highly complex item which would require engineering effort out of proportion to their policy ratio of engineering attention to production effort.

After a series of conferences, engineers of the CEA decided to assume some of the technical problems. The specifications were revised and a second set of bid invitations were issued. We have now received competitive bids for the power supply and will soon be placing the order.

16. Technical Progress in FY 1969 (continued)II. Colliding Beam Facility(1) Accelerator and Bypass

In FY 69 we made good progress on Project Bypass, which has as its goal the development of a facility in which 3.5-GeV, 100-milliampere stored beams of electrons and positrons will be made to collide head-on in an interaction region at the center of a 120-ft-long beam run bypassing one-sixth of the existing CEA synchrotron ring. We completed assembly of the bypass proper with its eight bending magnets (six large, two small), twelve quadrupole magnets, four sextupole magnets, twelve steering magnets, high-vacuum pumps, high-conductance vacuum manifolds, beam monitors, etc. Fabrication and installation of the two 0.1-microsecond fast switching ultra-flector magnets and two septum magnets was completed. These serve to deflect the beam stored in the accelerator into the bypass and return it into the accelerator. We improved the synchrotron vacuum system by two orders of magnitude by completing the replacement of epoxy vacuum chambers by ceramic vacuum chambers, ultra-cleaning the straight section tanks and rf cavities, installing bake-out equipment on nearly all vacuum chambers, tanks, and cavities, and reconditioning the high-vacuum pumps. Average pressure around the ring is now 3×10^{-8} torr under low load conditions of 2 GeV, 1 mA. We built and installed new types of beam monitors which provide information on beam lifetime and beam cross section, as well as the usual information on intensity and vertical and horizontal displacement.

16. Technical Progress in FY 1969 (continued)

In tests of multi-cycle injection we succeeded in accumulating, in a few seconds, 45 mA peak of electron current, compared to our goal of 100 mA. Injection development continues.

With an average pressure of 3×10^{-8} torr in the ring, we succeeded in storing a 2.5-GeV, 1-mA beam for 2.7 hours, with a $1/e$ decay constant of 35 minutes. This is approximately the lifetime needed for efficient colliding beam experimentation.

Fast-switching of the stored 3-GeV beam from the ring into the bypass has been accomplished with retention of the beam for 1 second. The $1/e$ decay constant was 0.3 second, corresponding to 400,000 turns. This decay constant must be improved by several orders of magnitude before colliding beam experimentation becomes practice.

We made preliminary studies of (a) ion clearing by means of electrostatic fields, (b) v -values of the bypassed beam, (c) synchrotron oscillations resulting from slight errors in length of the bypass, and (d) beam resonances and instabilities. These studies continue.

(2) On-Line Detector

The on-line detector is one of the two first-generation detectors designed to make use of the colliding beam facility at the CEA. The apparatus consists of wire spark chambers, scintillators, and absorbers. It covers 2π steradians and is optimized to collect data from the reactions:

$$e^+e^- \rightarrow e^+e^-, \gamma\gamma, \mu^+\mu^-$$

In addition it will survey the field of hadron physics.

16. Technical Progress in FY 1969 (continued)

During the first part of FY 69 much work was done to produce satisfactory spark chamber frames for the core of the detector, and these are scheduled to be delivered in May 1969. In the second half of the year effort is being expended on quantitative estimates of the spark chambers' performance using both cosmic rays and low-intensity beams from the synchrotron. The production of the final spark chambers will be started as the frames arrive at the laboratory.

Thyratrons will be used to pulse the spark chambers, since investigation showed that spark gaps did not have long enough lifetime. Prototype pulsers have been built and operate well. The final units will be built commercially.

Scintillator and radiator sizes have been determined and these items will be procured before the end of the fiscal year. Tests were made to determine the feasibility of using large area time-of-flight scintillators in rejecting cosmic-ray muons in the experiment. The projected rejection efficiency is greater than 98% and the design has been integrated in the detector geometry.

Sufficient fast logic has been procured to provide selective triggering of the spark chambers on interesting events. Investigations are continuing on the possible use of integrated circuits in this application -- the benefit is lower cost than the existing electronics. All fast electronics is scheduled to be ordered before the end of the fiscal year.

16. Technical Progress in FY 1969 (continued)

Luminosity monitoring systems have been designed and will be built during the summer of 1969. A bremsstrahlung shower monitor is intended for fast feedback of information, and small angle scattering of electrons and positrons for an absolute calibration of the luminosity.

The programming effort has concentrated on two main fronts: on-line data reduction, and off-line final data analysis. In the on-line case sufficient programming has been done to permit recording on magnetic tape all raw data, with some checks to ensure that the data is reasonable. Before the end of the fiscal year the capability of producing histograms and efficiencies for spark chambers should have been achieved. An elementary subroutine to extract q.e.d. cross sections should be available by this time also.

Off-line programming has a more general aim, namely to produce the capability of analysing thoroughly all events, without the severe computing time limitations of the on-line system. A routine has been produced which draws on paper a replica of any particular event. This will be used to examine particularly interesting events and also those which are too complicated for computer analysis. Various routines have been written to trace particles through the detector and calculate efficiencies. By the end of the fiscal year it will be possible to accept the data tape produced by the on-line program and perform some off-line analysis of the events.

16. Technical Progress in FY 1969 (continued)

A large fraction of these programs will be tested by using a known low-intensity beam from the synchrotron. This testing will be started before June 1969, and will continue until the operation of the hardware and software is understood.

(3) Optical Detector

This is the second first-generation detector for colliding beam experimentation.

In FY 69 we have completed design and are now constructing an optical spark chamber system. This includes a "final" written proposal, some Monte Carlo calculations on showers, test work on a water Cerenkov cosmic ray veto counter, construction of some integrated fast electronic circuitry, construction of the spark chambers, scintillators, and optics, and design of rapid film data selection equipment.

(4) Magnetic Detector

The magnetic detector is a second-generation detector which will extend some of the quantum electrodynamic measurements and concentrate on separating hadron channels.

The group designing the magnetic detector has revised its plans due to budget limitations. The reduced scope detector uses a conventional solenoid which reaches $4\frac{1}{2}$ kG. Later replacement by a superconducting solenoid which reaches 18 kG will increase the analyzing power to the originally desired value.

The dimensions and size of the detector (new design) as well as the detailed design of the iron spark chamber and main coil have been determined. A computer analysis of the magnetic

16. Technical Progress in FY 1969 (continued)

field and the design of the modifications needed in the bypass beam transport are completed. Design of the compensating coils, inner spark chambers, optics, mechanical structure and the assembly procedure will be finished in FY 69. A set of iron plates are on order and the spark chamber will be assembled and tested before the end of FY 69. The solenoid is expected to be ordered before the end of FY 69.

The triggering scheme, the design of the counters, the high voltage circuitry and the logic will be decided upon before the end of FY 69.

16. Technical Progress in FY 1969 (continued)III. Support of the Experimental Program

During FY 69, the CEA staff continued to exert a considerable part of its effort in the support of the experimental program. A total of 19 experiments received or will receive such support. Of these, the following 18 experiments have or will have received substantial running time in FY 69.

1. Beam 7 Spectrometer Testing (Pipkin)
2. Compton Scattering at High Energy and Small Momentum Transfer (Brenner-Walker)
3. Inelastic e-d Scattering at Backward Angles (Wilson)
4. Boson Resonance Photoproduction (Russell-Tannenbaum)
5. Photoproduction of π^0 by Polarized Gammas (Osborne)
6. Photoproduction of π^0 from Neutrons (Luckey)
7. Photoproduction of π^+ with Polarized Photons (S.M.T.I.-M.I.T.)
8. Hyperon Polarization Feasibility Study (Deutsch)
9. Proton Compton Effect at 2 GeV and $t = 0.16 \text{ (GeV/c)}^2$ (Deutsch)
10. Photoproduction of the f^0 and Other Mesons (Frisch)
11. Final State Interaction in Inelastic Electron Deuteron Scattering (Kendall-Friedman)
12. Laser Experiment (Phase I) (Milburn)
13. Photoproduction of π^- with Polarized Photons (S.M.T.I.)
14. Muon Photoproduction at High Mass Values (Northeastern)
15. Check of Iron Spectrograph (Northeastern)
16. Heavy Boson Mass Search (Northeastern)
17. Electron Reaction Cross Section (Dell-Oak Ridge)
18. Particle Detector Development (Yuan, Brookhaven)

16. Technical Progress in FY 1969 (continued)

In addition counter calibration experiments have been carried out on a parasitic base for the following groups:

1. Smithsonian Astrophysical Observatory
2. University of Chicago, Enrico Fermi Institute
3. Air Force Cambridge Research Laboratories

The following is a list of special projects carried out to improve the experimental facilities at CEA.

(1) Experimental Magnets

Two large magnets, 5" x 22" x 84" and 12" x 24"/36" x 36", were completed and tested in FY 69. These magnets will be used in two new spectrometer assemblies. Several small magnets which have been in service for several years were modified and/or re-conditioned.

(2) Beam 7 - Spectrometer Facility

A two-arm high energy and high resolution spectrometer system was assembled and tested in Beam 7. It is planned that further development of this facility, e.g., the addition of a large solid angle magnet system on a third arm, will continue in FY 70.

(3) Cryogenic Targets

Three new hydrogen/deuterium target cooler systems were put into operation at the CEA. All use 12-watt mechanical refrigerators and service 50 to 300 cc target cups. A fourth, a 100-watt refrigeration system, is being assembled to a target cooler with a 4-liter mylar target vessel.

16. Technical Progress in FY 1969 (continued)

One of the new systems includes some automatic equipment to permit unattended operation for extended periods of time.

A hydrogen target bubbling suppression device was developed and used. It is based on induced circulation of hydrogen from condenser to target and back to condenser.

(4) Computer Control of Magnet Power Supplies

As experiments and accelerators become more complex there has developed the requirement to automate adjustment, recording of settings, and programming of various sequences of transport systems.

The project, computer control of power supplies, has been initiated to meet these requirements. The development is divided into three phases:

- (a) Computer surveillance and print-out of deviations from set value. Manual adjustment of current and operation of other controls on a single magnet at a time.
- (b) Computer surveillance, print-out and correction of deviation from set value. Response by the computer to teletype instructions on a single magnet at a time.
- (c) Computer surveillance, print-out and correction of deviation from set value, plus programmed control of complete transport system characteristics in response to sub-routines or externally derived data signals from on-line beam characteristic sensors.

16. Technical Progress in FY 1969 (continued)

A prototype system control of a single power supply has been assembled. Its principal function is the testing of a number of programs and sub-routines. An additional eight systems will be assembled in FY 70.

16. Technical Progress in FY 1969 (continued)

IV. Miscellaneous Development Projects

(1) Theoretical Physics Developments

Various theoretical investigations were undertaken during the year. Among these were hard pion calculations, speculations on tensor and scalar meson dominance, uniqueness of the Veneziano representation, dispersion treatment and the problem of gauge invariance in pion electroproduction, and the production of single W-mesons in e^+e^- colliding beams. In addition, a high energy theoretical physics course designed specifically for experimentalists using the CEA is being presented.

(2) External Beam Monitors

A comparison of the efficiencies of the CEA and SLAC Faraday cups was made in March 1968. The efficiencies of these devices, used as the absolute monitor of beam charge for normalizing experimental data, agreed to within 0.4% at 3 GeV. The dependence on beam energy, beam intensity and beam focusing of the response of secondary emission monitors was measured, and this work will continue throughout FY 69. Initial tests on an evacuated quantameter to determine its response with energy were conducted. It is thought that the response of such monitors should be independent of beam intensity.

(3) Neutron Background Measurements

A detector to measure the flux of neutrons with energy greater than 20 MeV is being assembled in order to obtain an upper limit to the high energy neutron background in the environs of CEA. Supplementary methods of measuring the neutron background

16. Technical Progress in FY 1969 (continued)

are being investigated. In addition a calculation based upon the penetration of neutron and photon fluxes through thick shields is planned. This project will continue in FY 70.

(4) Positron Inflector (Linac Injector)

The off-axis positron inflector has been fabricated; the special straight section in which it will be located was delivered in March 1969. Installation of the assembly should be completed by the end of FY 69.

(5) Polarized Electron Source

Installation and assembly of major electronic and mechanical components was completed. Tests were initiated on the performance of the vacuum system and the polarized hydrogen source was put in operation.

(6) Data Analysis Systems

During FY 69 the IBM 360/50 at the Harvard Computing Center was replaced by an IBM 360/65. The transition required almost no reprogramming and no modifications to hardware. The entire transition was completed within a 24-hour period. This upgrading of the facilities at the Computing Center gives on-line users about 10 times more computing capacity at their disposal.

(7) Scientific Programming

The group's major effort is being directed toward developing programs for the on-line detector being assembled for the colliding beam experiment.

16. Technical Progress in FY 1969 (continued)

(8) Improved High-Voltage Shut-Off System

In the Experimental Hall and in the Target Area there are associated with each experiment many devices (photomultiplier tubes, spark chambers, etc.) that require from 1000 volts up to 20,000 volts, and in one case 100,000 volts.

It was sufficient, several years ago, to have an emergency shut-off and lock-out switch for each group of high-voltage devices. As the experiments become more complex, extend over greater areas, and include remote control of the sources of energy, it has been necessary to devise a standardized system which permits system lock-out and shut-off by operation of a single control.

During FY 69, shut-down stations were installed which consist of a master and one or more auxiliaries, any of which will permit simultaneous shut-down of high-voltage sources, magnet power and other equipment, or lock-out of a particular circuit. The warning signs for these circuits (in which it takes time for voltages to fall to zero) remain illuminated until it is safe.

(9) Water Treatment

When CEA was originally designed, it was thought that addition of a phosphate to the experimental cooling water was sufficient to inhibit corrosion. This premise has been proven incorrect.

The original decision to install an iron pipe distribution system was based on a requirement for high pressure capability

16. Technical Progress in FY 1969 (continued)

at low initial cost. The cumulative effect of the oxidation of dissolved iron, coating of the inner walls of isolation hoses with conducting material, and high conductivity water has resulted in the failure of several magnets. Complete rebuilding of the manifold and hose connection portion of all magnets in use is necessary.

Investigation of the problem has resulted in the decision to install new components into the experimental cooling water system. The aim is to:

- (a) Dionize the water that is introduced in the system.
- (b) Increase the amount of water in the closed loop system in which the on-line dionizer is located.
- (c) Install larger and finer particle filters.
- (d) Install oxygen removing equipment in the closed loop system.
- (e) Install activated carbon filters in the make-up water supply line to remove organic matter.

During FY 69 the new water treatment equipment was ordered and received. A small water treatment assembly was installed in the experimental water system to provide operation experience and training. An outdoor shelter has been erected to house the water treatment equipment.

16. Technical Progress in FY 1969 (continued)

V. Construction

(1) Engineering Support Building

The engineering support building was essentially completed by July of 1968. However, additional work was needed on the crane, and several change orders were issued to cover contingencies that arose, so that the work was not completely finished until the fall of 1968.

(2) Synchrotron Radiation Room

In August and September a 25 x 35 ft synchrotron radiation room was built adjacent to the circular tunnel. 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.

17. Expected Results in FY 1970

I. Accelerator Development

(1) Operation

Based on 17 shifts/week operation and 4 shifts/week maintenance for 10 months, we expect to schedule 5700 machine hours for both physics research and accelerator development. We are giving first priority to maintaining this level of operation within the budget figures recommended in the FY 70 presidential budget (FY 70 Budget 1). This priority decision will result in:

- (a) Reducing our stock of spare components below a safe minimum for efficient repairs
- (b) A drastic cutback in the development and the installation of new experimental facilities
- (c) Delay in the installation of already approved programs such as the improvements for the Beam 7 spectrometer.

The FY 70 Budget 2 would permit us to proceed more efficiently in the implementation of our present program by making unnecessary the above cutbacks and delays. In addition and as importantly, the FY 70 Budget 2 would permit us to start on the development of new experimental facilities such as more intense tagged photon facility capable of also producing polarized photons.

(2) Vacuum System

We will continue to replace our original ion pumps as rapidly as budgetary considerations permit with new, improved pumps. These new pumps offer greater reliability than the present pumps.

17. Expected Results in FY 1970 (continued)

(3) RF Power System

During FY 70 we expect to finish the rebuilding of our rf transmitter for improved reliability at higher power levels. This will require:

- (a) Replacement of our present high power amplifier by another tube such as the RCA triode 2504, or by C.S.F. Klystron KAP 1183; as of April 30, 1969, no final decision had been made.
- (b) Improvement of the rf accelerator cavity windows and testing of new designs.

We will continue to improve the designs for additional upgrading of our rf power system to 500 kW average power. This power is required to increase the internal accelerator beam from 10 mA to 50 mA, to store beams with energies up to 5 GeV, and gives us the capability of substantially increasing the colliding beam facility luminosity at 3 GeV. The placing of orders for this system is again being postponed in FY 70 for fiscal reasons.

(4) Linac Injector

The Linac Division expects to complete the positron linac installation in the first quarter of FY 70. At that time we expect to have available 50 mA of 240-MeV electrons and approximately one-half mA of 120-MeV positrons. Continued efforts will be concentrated in the area of increasing the reliability of the linac and increasing our monitoring of operating parameters of the electron and positron linac sections.

17. Expected Results in FY 1970 (continued)

(5) Miscellaneous Accelerator Improvements

(a) Beam Leveller System

We are presently designing a more flexible and reliable beam leveller system which should be operational during FY 70.

(b) Beam Intensity Monitor

A beam intensity monitoring system is being designed and constructed to improve measurement accuracy and provide facilities to experimenters during time-sharing of the accelerator.

(c) Water-Cooled Beam Bumps

A change-over to water-cooled beam bump windings is now being planned. We will change all beam bumps over to this water-cooled type in FY 70.

(d) Flat Topping

We will try out the following scheme to increase the duty cycle by flat topping the magnetic field at energies of 1 - 6 GeV for 1 msec. A 4/0 single-turn 5000-V insulated cable will be installed around each of the 48 synchrotron magnets. These cables will be connected in series. A prototype pulser circuit (one similar to prototype magnet power supply) will be built and an existing power supply will be used to power the one-turn winding.

(e) RF Feedback System

A feedback system to hold the rf cavity voltage at the demanded level is being investigated. If found to be feasible, a system will be designed and constructed.

17. Expected Results in FY 1970 (continued)

II. Colliding Beam Facility

(1) Accelerator and Bypass

The main tasks for FY 70 are:

- (a) Completing the adjustment of the bypass proper so that the beam lifetime here will be as great as that in the synchrotron itself.
- (b) Installing the positron linac and converter and developing procedures for efficient multicycle injection of positrons. Installation is scheduled for May - August 1969.
- (c) Installing and testing the electrostatic system for keeping the electron and positron beams vertically separated except at the interaction region.
- (d) Searching for, and controlling, beam-beam interactions.
- (e) Evaluating the beam cross section at the interaction station, and maximizing the luminosity.

We expect to complete the installation and instrumentation required for these tasks in the first half of FY 70. It is difficult to predict with certainty the date when experiments with the colliding beam will start.

(2) On-Line Detector

The first-half of FY 70 will be devoted to producing and testing the large number of spark chambers and their pulsing system, the scintillator assemblies, and the mechanical supports.

17. Expected Results in FY 1970 (continued)

The on-line program will be complete, at least in its initial form, suitable for analyzing q.e.d. events. The off-line analysis program should be capable of analyzing a large fraction of the events produced. During this period good measurements are planned on single-beam background problems, so that realistic methods of removing background events can be implemented.

The target date for completion of the detector is spring 1970. When sufficient luminosity is available the first experiments will start.

There are tentative ideas on some second generation experiments with the colliding beams. During this fiscal year these ideas will be investigated in detail. Designs will be produced for any additional equipment which may be required.

(3) Optical Detector

We expect to finish construction, put slow electronic logic together, and get this equipment assembled and working in FY 70.

(4) Magnetic Detector

The activities of the group responsible for the design and construction of the magnetic detector are very much determined by the availability of funds.

The minimum program based on FY 70 Budget 1 is to:

- (a) Procure, assemble and test the various components ordered in FY 69. This will be for both the hardware as well as the electronics. Towards the later

17. Expected Results in FY 1970 (continued)

portion of FY 70, the coil will be energized and the magnetic field of the whole assembly will be mapped, using the available computer programs.

The desired program based on FY 70 Budget 2 is to, in addition:

- (a) Order, procure and assemble the full complement of spark chambers, optics and counters.
- (b) Freeze the method of reading film, and adapt and test the necessary computer programs to the magnetic detector system.

17. Expected Results in FY 1970 (continued)

III. Support of the Experimental Program

The CEA will continue to pursue a vigorous program of research with the electron and photon beams provided by the accelerator. It is too early to specify which experiments will be carried out in FY 70. We expect that the major experimental programs will center on the polarized and unpolarized photon beams, the externally tagged photon beam and the Beam 7 spectrometer facility using either electron or photon beams.

Some of the experiments which will definitely take data are:

$\pi^+ \pi^- \pi^0$ Photoproduction with Polarized Photons (M.I.T.-S.M.T.I.)

Electroproduction of Pions (Pipkin, Harvard)

Compton Effect (Deutsch, M.I.T.)

Boson Resonance Photoproduction with Tagged Photons (Russell-Tannenbaum, Harvard)

It is hoped that in FY 70 experiments using the colliding beam facility will be initiated. The first experiments using the on-line and/or optical detectors will concentrate on the study of q.e.d. and a survey of hadron cross sections in the time-like region.

The following is a list of special projects which are scheduled to be carried out to improve the experimental facilities at CEA.

17. Expected Results in FY 1970 (continued)(1) Beam 7 - Spectrometer Facility

A third arm with a large solid angle magnet system has been planned since the inception of this facility. A suitable magnet was designed and ordered in FY 68. The FY 70 Budget 2 makes provision for the construction and installation of such an arm, the upgrading of the spectrometer by the installation of vacuum boxes and the improvement in the beam steering with additional magnets. None of these items are included in the FY 70 Budget 1.

(2) Cryogenic Targets

By the end of FY 1970 all CEA hydrogen and deuterium systems are scheduled to be mechanically refrigerated. Liquid helium will only be used for test purposes and for helium targets. In addition, it is planned to automate the target systems sufficiently to permit unattended operation for extended periods of time. A greater effort is also expected in the direction of reducing target boiling by means of internal shields, highly reflective metal films and thermal suppression.

(3) Computer Control of Magnet Power Supplies

Systems for the computer control of eight more power supplies are scheduled to be developed in FY 70. The total of 16 will enable much of the bypass magnet system to be placed under computer control.

(4) High Intensity Tagged Photon Beam

A tagged photon beam with an intensity larger by more than an order of magnitude compared to the present one is

17. Expected Results in FY 1970 (continued)

feasible with one or more of the following improvements:
faster electronics, stretching of electron beam by storage
and spatial correlation. Manpower for these developments
are included in the FY 70 Budget 2 - no funds for this pur-
pose are provided by FY Budget 1.

17. Expected Results in FY 1970 (continued)

IV. Miscellaneous Development Projects

(1) Theoretical Physics

The theoretical group will continue to examine problems in electron and photon physics of interest to the laboratory.

(2) External Beam Monitors

Plans include the absolute calibration of the CEA Faraday cups by a null device to determine any dependence of efficiency on the beam energy. Studies of the stability with time and of the sensitivity of the secondary emission monitors now in use are planned. Minor changes will be made to standardize all secondary emission monitors.

(3) Polarized Electron Source

FY 70 will be devoted to a completion of tests on various subsystems of the total prototype system. Polarization measurements will be made and efforts will be initiated to study the maximization of intensity and polarization parameters.

(4) Scientific Programming

FY 70 will see the continued writing of the on-line detector code for the bypass on-line detector experiment (BOLD).

(5) Water Treatment

During FY 70 we will complete the installation of the new water treatment equipment. The distribution pipes and pumps will be cleaned, and the rebuilding of the coolant portions of all magnets is scheduled for this year.

17. Expected Results in FY 1970 (continued)

V. Construction

(1) Engineering and Scientific Staff Offices

Additional engineering and scientific staff offices, to be located in a second-floor addition to the existing 120-MeV linac building, were proposed and funds had been requested in May 1968 for inclusion in the FY 70 budget. Since these funds are not included in the FY 70 Presidential Budget, and since this type of space is badly needed, we are submitting this request again for inclusion in the FY 71 budget.

18. Expected Results in FY 1971

I. Accelerator Developments

(1) Operation

Based on 1.7 shifts/week operation and 4 shifts/week maintenance for 10 months, we expect to schedule 5700 machine hours for both physics research and accelerator development. Funds are requested to build up to a safer level our stock of spare components depleted due to fiscal limitations in FY 70.

(2) Vacuum System

We will continue to replace pumps and components to increase the reliability of the accelerator vacuum system. Reliability of this system will be particularly important at a period when the colliding beam experiment is expected to use a large fraction of the available machine time.

(3) RF Power System

During FY 71 we propose to start the first half of our rf improvement project, the goal of which is to attain 500 kW average power. The AIP items are split into two parts of \$823,000 for FY 71 and \$809,000 for FY 72. Improvement of the rf system for an amount of \$823,000 would give an average power capability of 250 kW. The power capability of 250 kW (500 kW) average will allow acceleration of 50 mA (100 mA) of electrons to the full machine energy of 6 GeV (compared to the maximum of 10 mA at the present time). It will also allow beam storage up to energies of 5 GeV with currents of

18. Expected Results in FY 1971 (continued)

50 mA (100 mA) for colliding beam experiments and will increase luminosity at lower energies by a factor of 5 due to the larger currents which can be accumulated with larger rf power in a multicycle injection mode.

(4) Linac Injector

Plans for FY 71 include a reliable monitoring system for the electron and positron linac which will lend itself to use of a small computer. Separate power supplies for each modulator are also planned so as to gain flexibility of operation in the event the single power supply we now use for 5 modulators fails.

(5) Flat Topping

From the data obtained in FY 70 on the prototype flat topping scheme, parameters for a permanent system will be derived, and equipment purchased and installed.

(6) Computer Control of the Synchrotron

The experience at the CEA with computer control of individual power supplies for experiment magnets and the achievements at other accelerators in the control of complete transport systems gives us confidence that computer control of certain components of the synchrotron and the bypass is a reasonable and desirable feature, and it is planned for FY 71.

Computer control of the synchrotron would result in:

- (a) Greater fidelity in adherence to sequential steps in an accelerator/bypass cycle.

18. Expected Results in FY 1971 (continued)

- (b) Release from tedious, hence frequently inaccurately performed adjustments.
- (c) Accurate record keeping of a multiplicity of machine and experiment parameters.

18. Expected Results in FY 1971 (continued)II. Colliding Beam Facility(1) Accelerator and Bypass

The main task for FY 71 will be to increase the luminosity and improve the stability of the colliding beam facility. At this time it is difficult to predict what steps will be required; the history of operating storage rings indicates that careful studies of the beam properties and of the causes of instability will be necessary.

(2) On-Line and Optical Detectors

The major effort in FY 71 will be devoted to (a) performing the first generation experiments for which the detectors were designed, and (b) to analyzing the data produced.

It is expected that second-generation experiments to investigate in detail particular reactions will be designed, instrumented, and perhaps performed. The necessary extra equipment will be procured and tested. Plans are not yet firm, but Cerenkov counters to separate protons from pions and kaons are likely to be needed. A special magnet might be used to define the momentum of one particle in order to do missing mass spectroscopy.

(3) Magnetic Detector

Completion and testing of the magnetic detector is scheduled to proceed in FY 71. Every effort will be made to have this detector ready for insertion into the bypass after completion of the first-generation experiments with the non-magnetic detectors.

18. Expected Results in FY 1971 (continued)III. Support of Experimental Program

We will continue to support a comprehensive experimental program using beams from the accelerator and the colliding beam facility. There will be continuing development of instrumentation and equipment in support of experiments which cannot be specified at the present time. For example, the various spectrometer facilities will be modified and beam transport instrumentation improved.

It is expected that in FY 71, we will begin to use the stored beam capability which has been developed for colliding beams, to produce external electron and tagged photon beams with greatly increased duty cycle. This will require modification of beam extraction and monitoring equipment.

A considerable fraction of the laboratory effort will be directed toward support of the experiments using the colliding beam facility.

Listed below are some additional, presently known, special efforts required for the experimental program in FY 71.

(1) Beam 7 Spectrometer Facility

If fiscal limits have prevented the building of the third arm in FY 70, this facility will be added to the Beam 7 spectrometer in FY 71. This new arm is a very important part of the CEA spectrometer facility since its large solid

18. Expected Results in FY 1971 (continued)

angle will permit efficient studies of reactions involving low momentum recoil particles.

(2) Cryogenic Development

The main efforts of the Cryogenic Division will be in supplying experimenters with standard cooler systems. In addition, the division will be prepared to take responsibility for the design, testing, operation, and maintenance of superconducting magnet systems and associated refrigeration if such systems are selected for the bypass or other projects.

(3) High-Intensity Tagged Photon Beam

It is planned to replace the present CEA tagged photon beam with an improved version which utilizes the time stretched internally stored beam and faster electronics. We expect to order a new improved tagging magnet for this purpose, and the necessary added beam transport system.

18. Expected Results in FY 1971 (continued)

IV. Miscellaneous Development Projects

(1) Theoretical Physics

The theoretical physics group will continue to examine problems of special interest to our laboratory.

(2) Experimental High-Energy Physics

With the development and use of the colliding beam facility the CEA staff is participating directly and very importantly in the high-energy physics program of the laboratory. It is highly desirable to increase this participation further by the establishment of one research team at CEA to utilize our external electron and photon beams. This team is to be composed of one senior physicist, two or three junior physicists, graduate students; staff physicists from the universities are expected to join.

(3) Polarized Electron Source

Studies will continue on the performance of the pilot device and consideration will be given to the adaptation of the polarized electron source to the old linac. Design studies will be started of a final device which will yield the intensities that this method promises.

(4) Scientific Programming

It is expected that the group's major effort will continue to be in providing computational support for the bypass on-line detector experiment (BOLD).

18. Expected Results in FY 1971 (continued)

V. Construction

(1) Engineering and Scientific Staff Offices

We are resubmitting our request for this space. See FY 70 Budget, and attached Schedule 44.

(2) Inside Beam Bypass

The colliding beam facility currently being constructed will not be able to pass beams of more than 3.5 GeV. It is also quite restricted in space around the interaction region. We are therefore proposing a new inside bypass which will permit operation with beams from 1 - 5 GeV and have room for two interaction regions. Each interaction region will have more space than the present bypass, will be able to more efficiently use the higher energy region, and perform more refined experiments at lower energy.

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