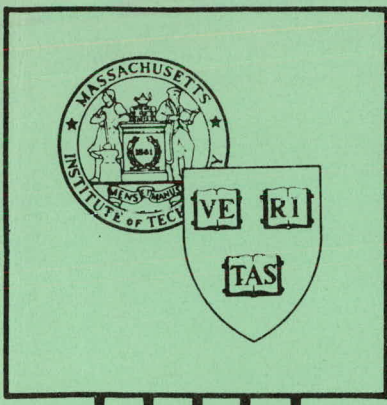


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CEAL-1055

SEMI-ANNUAL REPORT

For the Period

July 1 through December 31, 1970

K. Strauch, Director

W. A. Shurcliff

June 1, 1971

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
and HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

CAMBRIDGE, MASSACHUSETTS 02138

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TABLE OF CONTENTS

	<u>Page</u>
SUMMARY	1
PART I INTRODUCTION	3
A. Completion of Revision of Laboratory Program	3
B. Committees and Boards	4
PART II COLLIDING BEAM FACILITY	6
A. Introduction	6
B. Multicycle Injection and Beam Accumulation.	8
C. AC Turn-Off	11
D. Switching the Stored Beams into the Bypass.	13
E. Improvements in Hardware.	14
PART III BYPASS ON-LINE DETECTOR (BOLD).	21
A. General Design	21
B. Progress and Status	22
PART IV MAGNETIC ON-LINE DETECTOR (MAGNOLIA)	24
A. General Design	24
B. Progress and Status	25
PART V ACCELERATOR OPERATION AND IMPROVEMENT	27
A. Statistics on Accelerator Use	27
B. Operation, Maintenance, Minor Improvements.	27
C. New Rf System	37
PART VI OTHER ACTIVITIES AND PROGRAMS	38
A. Analysis of Results of Experiments Carried Out in Experimental Hall Prior to 5/31/70 .	38
B. Theoretical Studies in Particle Physics . .	40
C. Safety	41
D. Training of Disadvantaged Persons	41
PART VII PUBLICATIONS RESULTING FROM WORK DONE AT CEA . .	42
A. Publications on High-Energy Research Performed at CEA	42
B. Papers Presented at Conferences and Meetings	44
C. Theses on High-Energy Research Performed at CEA	45
D. CEAL Reports	45
E. CEAL-TM Reports	45

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July 1 - December 31, 1970

SUMMARY

Part I indicates the purpose of the contract: to operate and improve the 6-GeV Cambridge Electron Accelerator. It indicates that essentially all effort is now being concentrated on the colliding beam project (BYPASS) and the two detection systems (BOLD and MAGNOLIA) being built to analyze the results of the colliding beam events. Advisory Committees and Review Boards are described.

Part II summarizes progress made in Project BYPASS. As a result of improvements in the control system and procedures for multicycle injection, we achieved single-beam circulating e^- and e^+ currents of 70 and 25 mA peak in the cycling mode. Methods of converting to dc storage were improved and e^+ and e^- currents of 7 and 10 mA peak (at 2.7 GeV energy in each beam) were maintained simultaneously in the circular orbit. The efficiency of switching a dc stored beam into the 150-ft-long

low-beta bypass was improved, and in November we succeeded in switching a 25-mA peak electron beam into the bypass without loss. In December we obtained, in the bypass, countertraveling e^+ and e^- beams of a few mA peak current each. Since these beams were not spatially separated, if one beam had much higher current than the other, the latter was quickly destroyed by a beam-beam instability.

Part III describes the bypass on-line detector (BOLD), the assembly and testing of which is nearly completed. The quadrants of the detector core have been found to provide the planned resolution, single-spark and multi-spark efficiencies.

Part IV describes the magnetic on-line detector (MAGNOLIA) which will be needed in the analysis of hadron events which are expected to be more numerous than had been anticipated. The revised design will employ the 64" x 98" rectangular solenoidal coil (providing 5000 gauss) procured for the earlier design of magnetic detector, and will employ wire chambers and proportional chambers.

Part V deals with repairs and improvements to the accelerator proper. The new, higher-power (200-kW average) rf system was installed and made ready for routine use. Important improvements were made also in the vacuum system, injection controls, and regulation of magnet-ring excitation.

Part VI discusses other programs. Most of these have been eliminated or reduced to allow concentration of effort on the colliding beam program.

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, 1970, through December 31, 1970. The contract calls for the operation and maintenance of the CEA 6-billion-electron volt synchrotron and for designing, procuring, installing, and operating various essential facilities.

A. Completion of Revision of Laboratory Program

During the six-month period in question we largely completed the painful task of reducing staff and curtailing less essential programs to live within the FY 71 budget. The 30% reduction in funds announced by the A.E.C. on February 2, 1970, necessitated reduction in personnel from 180 to 112; by June 30 nearly all persons to be released had left the CEA, but several others (e.g., with appointments of one or more years' duration) left in the period from July 1 to December 31. Persons remaining who had not been working on the colliding beam program were given new assignments in furtherance of that program which became the main activity of CEA.

During the period, July 1 - December 31, 1970, we maintained intact the following major experimental installations in the Experimental Hall - so that experimentation with external electron or photon beams could be resumed promptly should opportunity present:

Area 4 equipment used early in 1970 by Deutsch, Rutherford, et al (M.I.T. and Tufts) in Experiment 114b: Recoil proton polarization in π^0 photoproduction near $t = -0.30(\text{GeV}/c)^2$.

Area 5 equipment used early in 1970 by Russell, Tannenbaum, et al (Harvard) in Experiment 107a: Boson resonance photo-production.

Area 7 equipment used early in 1970 by Pipkin et al (Harvard) in Experiment 121a: Elastic π^+ electroproduction near 0° and at pion-nucleon c.m. energies above the nucleon resonances.

Area 10 equipment used early in 1970 by Bar-Yam, Luckey, Osborne, et al (Southeastern Mass. Univ. and M.I.T.) in Experiment 109j: Asymmetry in single pion photoproduction, by polarized photon, in the resonance region, and Experiment 117b: Photoproduction of single charged pions by polarized photons of 3-GeV energy.

B. Committees and Boards

The general policies of the Laboratory are determined by a joint M.I.T.-Harvard "Executive Committee of the CEA". In 1970 this Committee included the following:

from M.I.T.: Dr. Malcolm G. Kispert

*Prof. Francis E. Low

*Prof. Louis S. Osborne

*Prof. Victor F. Weisskopf

Prof. Jerome B. Wiesner, Chairman

from Harvard: Dean John T. Dunlop

*Prof. Francis M. Pipkin

*Prof. J. Curry Street

Mr. L. Gard Wiggins

*Prof. Richard Wilson

*denotes member of Scientific Subcommittee

The Cambridge Electron Program Advisory Committee (CEPAC) reviews the status of experiments in progress and examines proposals for future experiments. CEPAC serves in an advisory capacity to the Director. During the half-year in question this committee included, in addition to the Director:

Prof. Stanley Brodsky, SLAC

Prof. Martin Deutsch, M.I.T.

Prof. Clemens A. Heusch, Univ. of Calif, Santa Cruz

Prof. Wolfhard Kern, Southeastern Mass. Univ.

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

Prof. Francis M. Pipkin, Harvard

Prof. Burton Richter, SLAC

Prof. Albert Silverman, Cornell

Dr. Gustav-Adolf Voss, CEA

Dr. James M. Paterson, CEA, secretary

The CEA Visiting Board reports to the presidents of M.I.T. and Harvard. Its membership in 1970 was:

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

Prof. James W. Cronin
Dept. of Physics, Univ. of Chicago

Prof. Maurice Goldhaber
Director, Brookhaven National Laboratory

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

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

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

PART II - COLLIDING BEAM FACILITY

A. Introduction

As explained in the previous semi-annual report (CEAL-1053), since June 1, 1970, all work at CEA has been concentrated on the colliding beam facility - a facility designed for

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

The plan is to fill the orbit of the existing synchrotron with countertraveling, high-intensity electron and positron beams by means of multicycle injection. Positrons and electrons are injected by means of two 130-MeV linacs arranged in tandem in the (nearly radial) Linac Tunnel. When positrons are to be injected, the upstream linac produces 130-MeV electrons which strike a tungsten converter from which gamma radiation and electron-positron pairs emerge; positrons of ~ 10 -MeV energy are collected and guided into the downstream linac whence they emerge with an energy of 130 MeV; they are then deflected to the right so as to enter the circular orbit in clockwise sense. When electrons are to be injected, the converter is removed (in a few seconds, by remote control), the phase of the second linac is shifted suitably, and the two linacs are operated in series to accelerate electrons to 260 MeV; these are deflected to the left and are inflected into the orbit in counterclockwise sense.

When the beam intensities have been built up sufficiently (the design intensity is 100-mA peak with a 30% circumferential filling factor) synchrotron operation is converted to dc mode and the particle energies are increased to the desired value. The stored beams are then switched into a 150-ft-long detour or bypass (see Fig. 1) and remain in orbit with a $1/e$ lifetime of the order of one half hour. In most of the ring and bypass, the two beams are kept vertically separated by means of electrostatic fields so as to minimize beam-beam interactions; but they are guided so as to collide at the interaction region, at the center of the bypass. Focusing magnets reduce the beam cross section here to ~ 0.01 -mm high by 0.3-mm wide and accordingly the interaction rate (number of collisions per second) will be relatively high; the design luminosity is expected to be $1.5 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$.

The interaction region will be surrounded by a detector array that will include spark chambers, absorbers and scintillation counters. Initially a non-magnetic "bypass on-line detector" (BOLD) will be used. The spark chambers are of wire type, digitized; all signals from spark chambers and scintillation counters are read out and analyzed by an IBM 360/65 computer. A magnetic on-line detector (MAGNOLIA) is also under development; it will provide a more detailed analysis of complex events.

By June 30, 1970, most of the equipment known to be necessary for beam storage was in place, many studies of multicycle injection, ac turn-off, and switching into the bypass had been

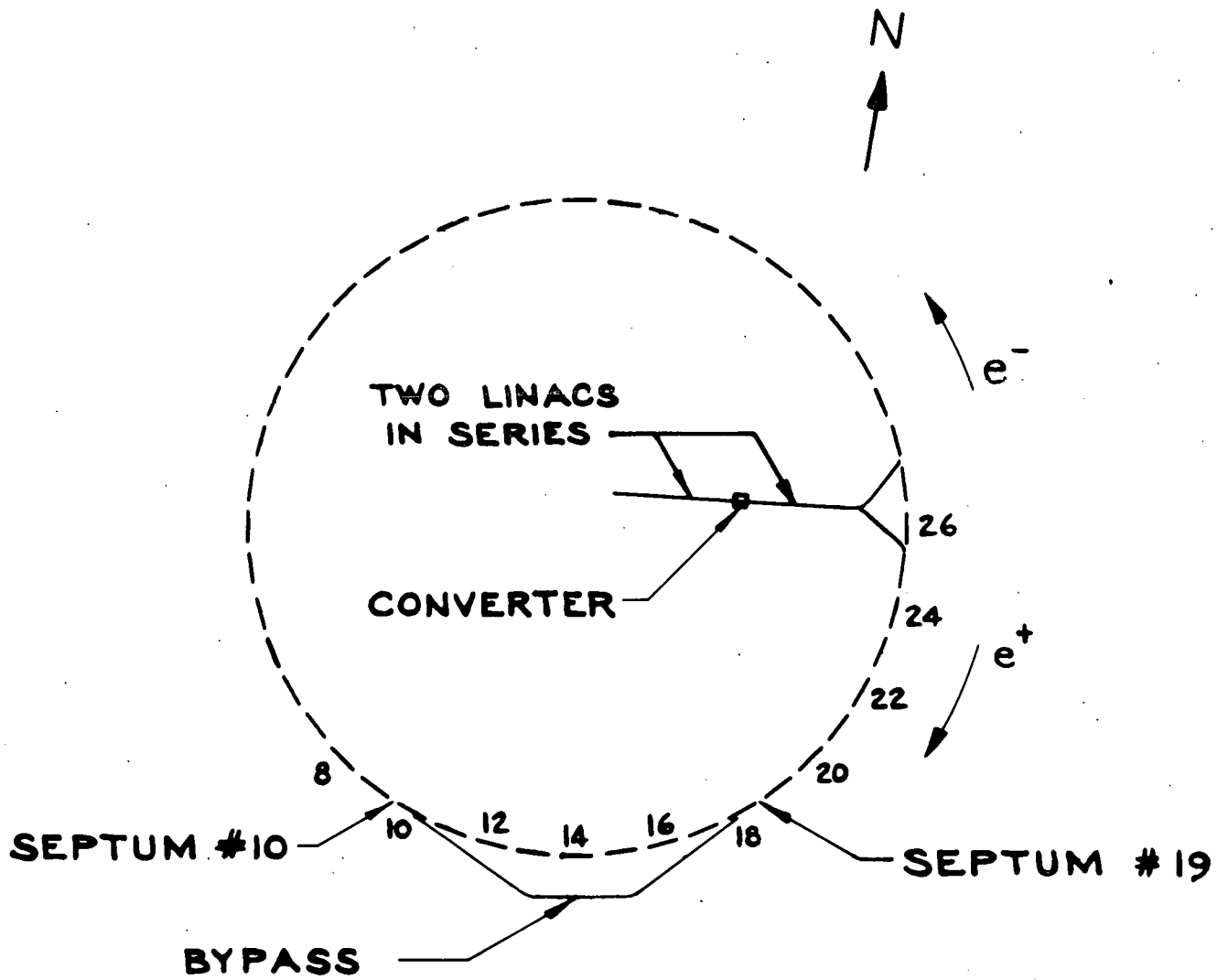


Fig. 1. Relationship of the bypass to the synchrotron ring of 48 magnets. The terminations of the bypass, and likewise the septum magnets used in switching, are at straight sections 10 and 19.

made, several resonances and instabilities had been identified, and plans for avoiding instabilities and increasing beam currents and lifetimes had been formulated.

The progress made in the latter half of 1970 is summarized below. Important improvements were made in (i) multicycle injection and beam accumulation, (ii) ac turn-off, i.e. conversion to storage at constant energy, and (iii) switching the stored beams into the bypass.

B. Multicycle Injection and Beam Accumulation

Using new control devices and improved injection procedures, we were able to achieve a cycling-mode accumulated e^+ current of 25 mA peak and, on a different occasion, an accumulated e^- current of 70 mA peak. After learning how to greatly reduce beam-beam interactions we were able to maintain a satisfactorily long (several minute) lifetime of 1-mA-peak cycling-mode e^+ beam in the presence of a much stronger (25-mA-peak) e^- beam.

1. Improved Injection Procedures

To achieve these currents we first gave close attention to linac adjustment. We studied the effects of linac modulator phase shifts, transient temperature changes in linac waveguides, and linac tune-up procedures. We found it highly desirable, in preparing for multicycle injection of positrons, to reduce the energy-acceptance slit to 1/8 inch, corresponding to 0.6% FWHM energy band, and to adjust the linac parameters during single cycle injection so as to maximize the current passing through this slit. Then, still using single cycle injection so that we can cleanly follow the history of an individual pulse, we

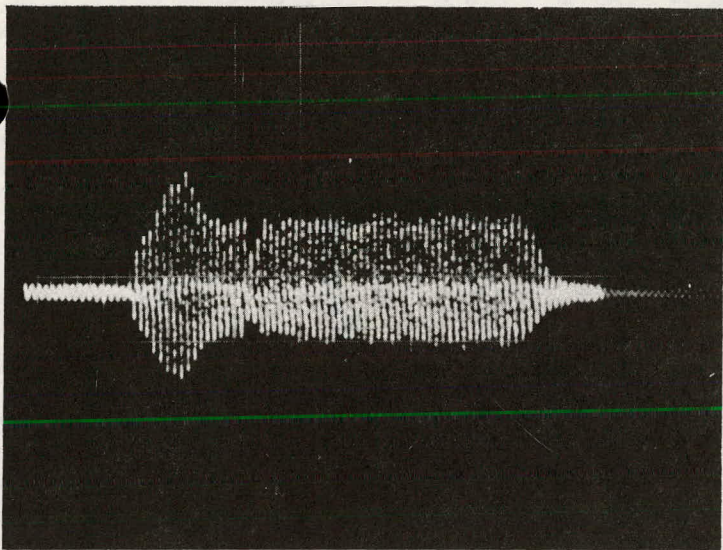
adjust the injection parameters so as to maximize the current surviving one magnet-excitation cycle, i.e. one " B_{\min} ". At B_{\min} , beam cross-sectional area and beam losses are large. Loss occurs also at the damping magnets when the beam is bumped toward them. Such loss is greatly reduced by carefully adjusting the v -separation quadrupole magnets which are pulsed just at the instant that the bump occurs. Adjustment of the coils that correct vertical orbit distortions is important also. When all these adjustments are made, about 35 μA of positrons injected in a given pulse are captured and accelerated throughout at least one magnet-excitation cycle, and about 7 μA survives an indefinite number of cycles.

We then change to multicycle injection. We find the e^+ filling rate to be as large as 0.4 mA/sec. The beam $1/e$ lifetime in cycling mode is ~ 120 sec.

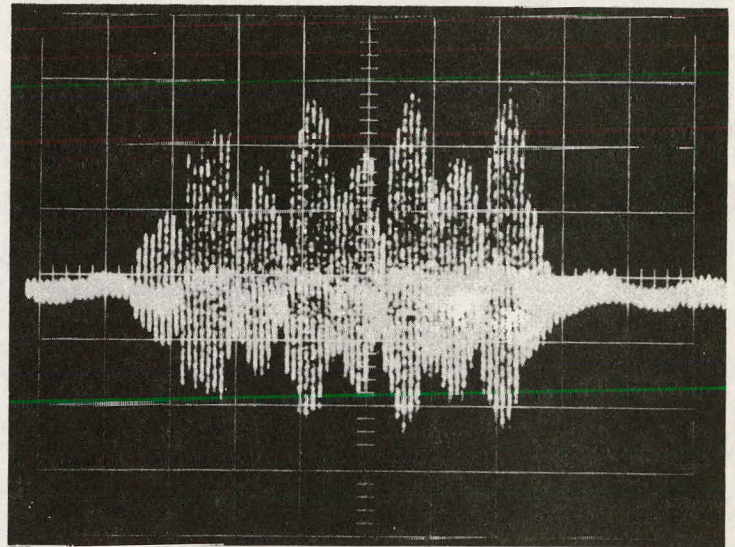
2. Use of Rf Quadrupole

We tried out the rf quadrupole magnet (see Section E3) designed to assign slightly different v -values to successive bunches and thus reduce bunch-to-bunch betatron-oscillation interactions, and found that this device made it possible to increase the accumulated electron current by more than 50% under certain conditions.

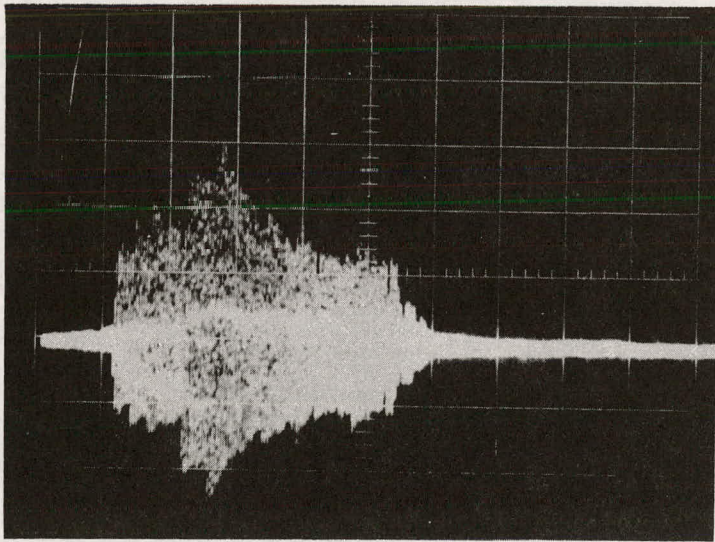
Figure 2 shows the effects of producing excessively large values of Δv . The betatron frequencies of certain bunches are shifted into stop-bands and accordingly these bunches are greatly weakened or eliminated. The effect is periodic along



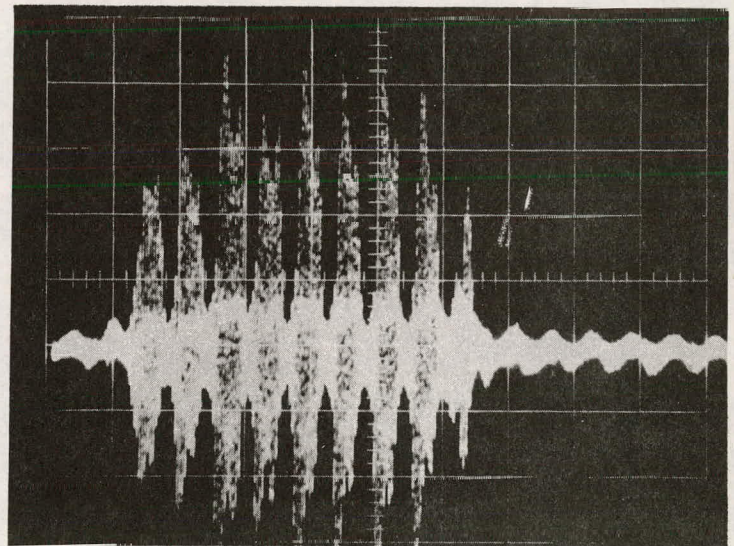
A: e^- beam; quad off.
20 ns/cm



B: e^- beam; quad on.
20 ns/cm



C: e^+ beam; quad off.
50 ns/cm



D: e^+ beam; quad on.
50 ns/cm

Fig. 2. CRO traces of signals from sampling-type monitor of beam intensity during multicycle injection - with and without use of the 32-MHz quadrupole. The abscissa (time) corresponds to position along the sausage, with the leading end of the sausage at the left. Each slender vertical line represents one bunch. Bunches are of the order of 1 in. long and 24 in. apart. Peak intensities range from 10 to 50 mA.

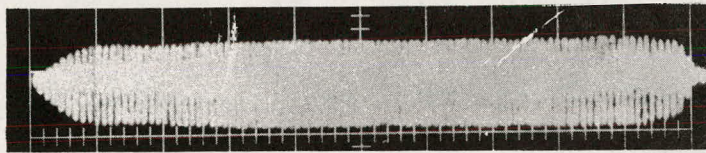
the sausage. Normally, the power level of the rf quadrupole is set lower, so that stop-bands are avoided.

When the rf quadrupole was not powered, the sausage of an electron or positron beam showed a gradually developing jagged structure as multicycle injection continued; see Fig. 3. A partially destructive instability appeared to propagate along the sausage (from the head toward the tail) through several bunches, but bunches slightly farther toward the tail sometimes retained full intensity.

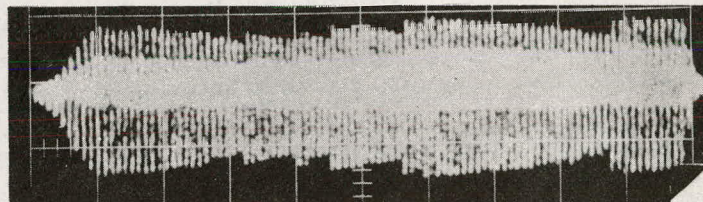
3. Multicycle Injection with Two Beams in Orbit

In October we studied multicycle accumulation of electrons while an e^+ beam was already in orbit. The most successful procedure was one in which (1) the two beams were kept vertically separated, in order to avoid (non-linear) beam-beam interactions and avoid the linear ν -shift through which a stop-band may be encountered with resulting weakening or destruction of the weaker beam, and (2) simultaneous use was made of magnetic quadrupole and electrostatic quadrupole to counteract the tendency of the ν -values of the weaker beam to shift into a stop-band (but without changing the ν -values of the stronger beam). The electrostatic quadrupole, built in September and installed in October, is capable of producing, in a constant-energy 1-GeV beam, a $\Delta\nu$ of 0.02.

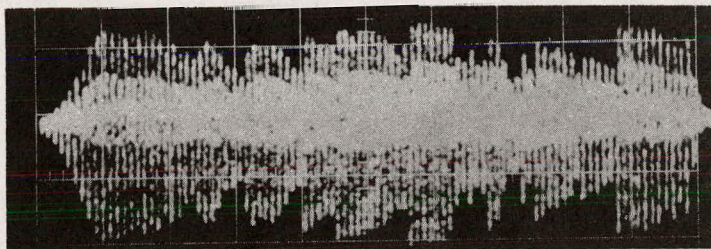
Using such controls, we were able to maintain a long lifetime of a 1-mA peak, cycling-mode, positron beam in the presence of a much stronger (25-mA peak) electron beam. (For a cycling



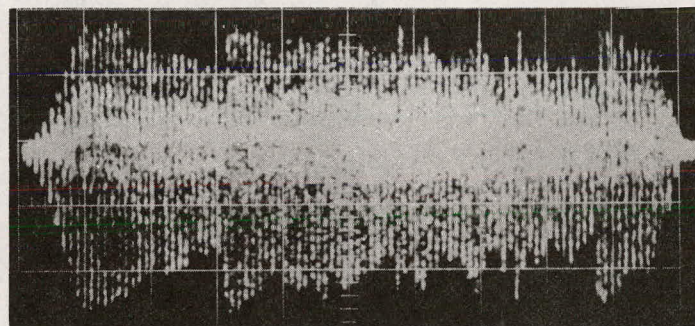
A



B



C



D

Fig. 3. Progressive changes in structure of sausage of positron beam during multicycle injection (without use of the rf quadrupole). Photographs were taken at 15-second intervals. Beam peak current increased from 2 to 3 to 4 to 5 mA in photographs A, B, C, D. Energy range of cycling synchrotron magnet: 120 MeV to 2 GeV. Head of sausage is at left end. Note gradually increasing (and abruptly terminated) intensity fall-off regions in photographs B, C, D.

beam, which at B_{\min} has a large cross section and suffers much gas scattering, a $1/e$ lifetime of several minutes is considered long. It is long relative to the electron and positron filling times which are of the order of 1 second and 1 minute respectively.)

C. AC Turn-Off

1. Status in Previous Six-Month Period

In two-beam ac turn-off trials made in the previous six-month period, we found that we could produce a significant increase in the level at which instabilities occurred by de-energizing the electrostatic separation plates (after injection was completed) and allowing the two beams to travel through one another so that each caused, in the other, strong effects (increased in ν values) that varied with amplitude of the betatron oscillations and thus produced additional Landau damping. By this method we were able to convert the combination of a 7-mA peak e^+ beam and 7-mA peak e^- beam to dc storage without loss of current. But when starting with cycling-mode beams of greater current, incoherent beam-beam instabilities occurred during the conversion process and caused loss of current, especially in whichever beam was the weaker of the two.

Clearly, some more powerful approach was needed.

2. Use of Octupole Magnet

We constructed a small octupole magnet and installed it in Straight Section 32. Having a field strength that varies with the cube of distance of the particle from the equilibrium orbit, such a magnet imparts different ν values to particles

having different amplitudes of transverse excursion and thus produces Landau damping of coherent betatron oscillations. Later (December) we constructed a corresponding octupole magnet for installation in the bypass.

Tests have confirmed the effectiveness of such magnets in increasing Landau damping and permitting accumulation of higher beam currents.

3. Improvement in AC Turn-Off Procedure

Old AC Turn-Off Procedure: Earlier, our method of accomplishing ac turn-off was to hold the dc component of magnet ring excitation constant while steadily decreasing the ac component, as indicated in Fig. 4a. At the start of the turn-off procedure, B_{\max} corresponded to a particle energy of 2.7 GeV, and after ac turn-off the (steady) value of B corresponded to 1.5 GeV.

New AC Turn-Off Procedure: The new procedure consists of raising the dc level of magnet excitation gradually while progressively turning off the ac component (in about 20 seconds) so that B_{\max} is always great enough to correspond to at least 2 GeV. See Fig. 4b.

At the same time, we modified the wave-form of beam-bump for bumping the beam into the damping magnets (Fig. 5). We now use an SCR-controlled power supply that provides a flat-topped bump of any desired width. As ac turn-off progresses, the width of the bump is increased until finally the bump becomes permanent.

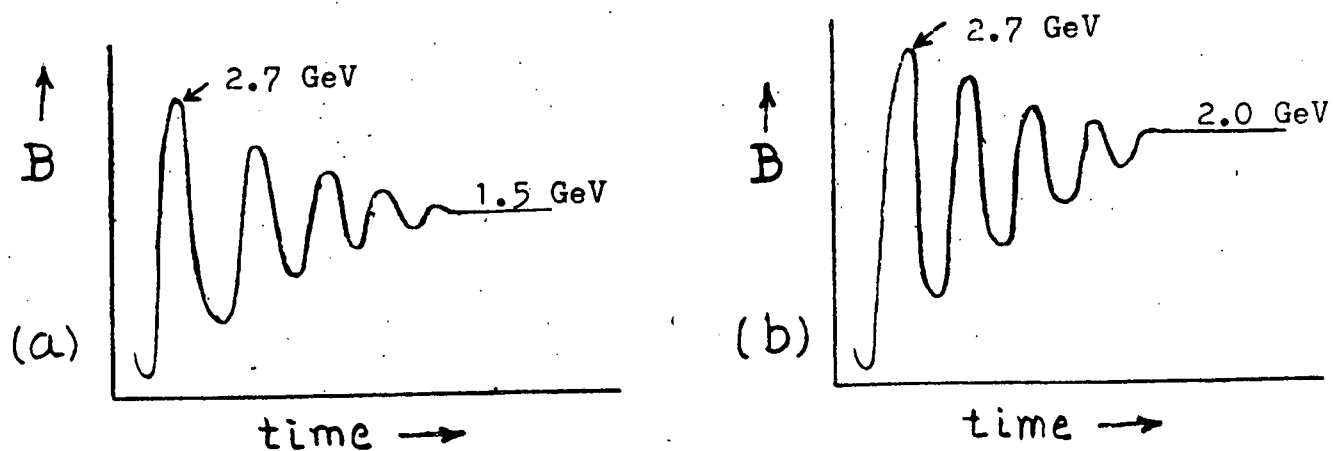


Figure 4

Old Schedule (a) and new schedule (b) of excitation of ring of 48 magnets during ac turn-off. In (a) the dc level is held constant while the 60 Hz ac level is reduced to zero in about 1 sec. In (b) both levels are changed gradually (about 20 sec) so that B_{\max} never drops below 2 GeV.

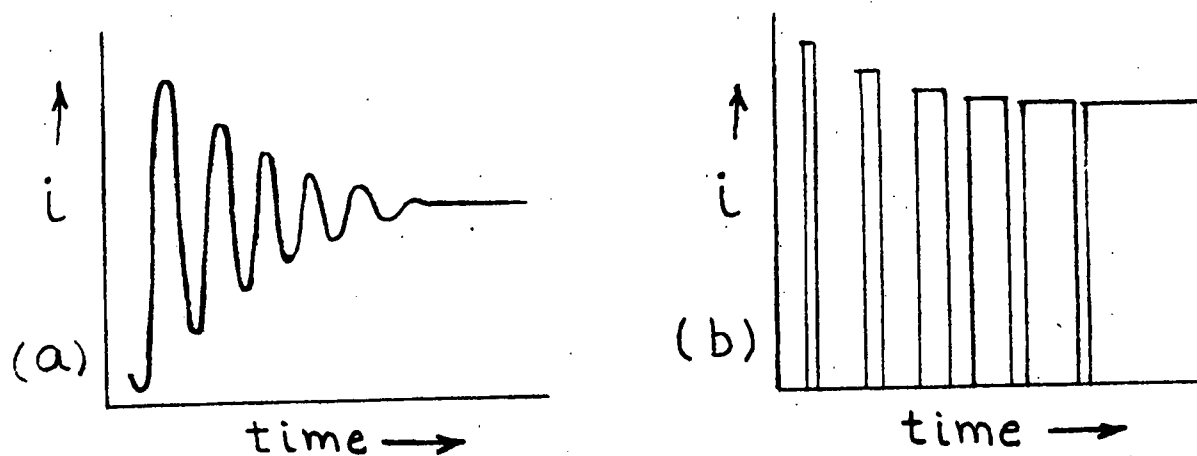


Figure 5

Old schedule (a) and new schedule (b) of excitation of coils for bumping the beam into the damping magnet during the intervals in which magnet-ring-excitation B is close to B_{\max} and the ac component of magnet-ring power is gradually reduced.

Discussion: Maintaining a higher B_{\max} (i.e., higher value of maximum particle energy) during ac turn-off helps in several ways. It increases the width of beam cross section and thus increases the amount of Landau damping produced by a given intensity of octupole field; the increase in damping varies approximately as the square of beam energy. Also it increases the beam stiffness (in direct proportion to energy). The overall effect produces large increases in threshold on single-beam instabilities.

The new ac turn-off procedure requires better control of radiation damping by the damping magnets, and such control is provided by the new beam-bump system. The transition from cycling energy to fixed energy is tracked by the beam-bump system, which provides successively increasing length of dwell of beam in the high-gradient portion of the damping-magnet field until, when dc mode is reached, the dwell becomes permanent (see Fig. 5b).

Using the new procedures we succeeded, in November, in accomplishing ac turn-off for a 12-mA-peak, 3.2-mA-average, positron beam without loss of current. Likewise we were able to make the transition with a 28-mA-peak, 5.5-mA-average electron beam without loss. We then accomplished the transition - without loss - for two beams in orbit at the same time: a 7-mA-peak positron beam and a 10-mA-peak electron beam.

D. Switching the Stored Beams into the Bypass

In November, after improving the bypass train and bypass vacuum system in several ways (explained in Section E), we found

that, under some circumstances, losses on switching a beam into the bypass could be avoided by (i) adjusting the timing of ultraflexor turn-on and (ii) eliminating ripple from the ultraflexor power supply. On some occasions we were able to switch a 2-GeV, 25-mA-peak e^- beam into the bypass without detectable loss.

However, results were variable. Often, instabilities were encountered, especially with a high-current beam. See Fig. 6. Use of a low-power octupole magnet in the bypass, to produce Landau damping of betatron oscillations, was found to be helpful, and construction of a more powerful octupole magnet for the bypass was started.

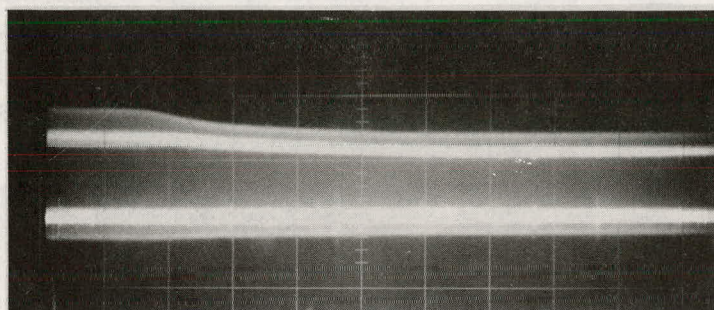
E. Improvements in Hardware

The main improvements made in components of the injection system, synchrotron ring, and bypass are discussed in the following paragraphs.

1. Post-Acceleration Chopper

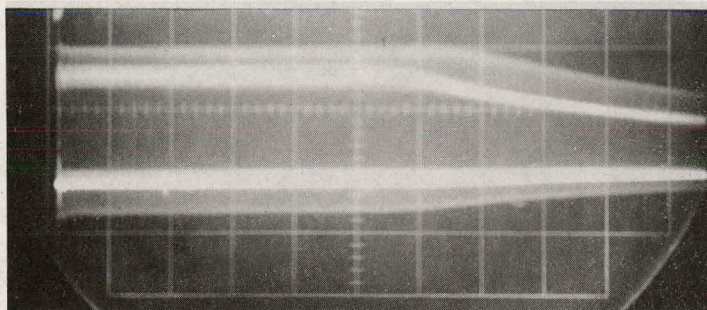
In October we developed a linac post-accelerator chopper (PAC) for (1) providing the desired length of the individual e^+ and e^- sausage, (2) providing the desired time relationship between the two sausages so that they will collide symmetrically at the bypass midpoint, and (3) increasing the uniformity of filling of each sausage. Situated just downstream from the tandem pair of linacs, the PAC consists of an air-core magnet which, when on, deflects particles toward a water-cooled collimator, and when off allows the particles to proceed into the ring.

a



2 ms/cm

b



200 μs/cm

Fig. 6. CRO traces showing the delay in onset of instability of a 2-GeV electron beam (after beam is switched into the bypass) as a function of beam current. (a) 7.5-mA-peak beam, for which the delay was 3.5 msec, and (b) 18-mA-peak beam, with 1.2 msec delay. (The scales are different in the two photographs.)

The PAC timing is locked to the rf frequency and orbital frequency and thus (on successive injection cycles) transmits bunches throughout intervals that conform (within a few nanoseconds) to the length and position of the sausage already in orbit. When the operator shifts from e^+ to e^- injection, a preset timing change is introduced such that the two sausages have the desired phase relationship (symmetric with respect to bypass midpoint) despite the fact that the pair of linacs is situated asymmetrically with respect to the bypass.

The PAC, besides insuring that the sausages have the desired geometry and phase relationship, makes it possible to achieve uniform current along the individual sausage. The operator's procedure is to "wobble" the delay between linac and PAC by about 1 microsec so as to direct the best portion of the linac output pulse to successively different portions of the sausage and thus fill up any low-current portions.

2. Electrostatic Plates for Controlling Beam Vertical Separation and Crossing

In the six-month period in question we considerably improved the electrostatic plate system for controlling the vertical separation of the e^- and e^+ beams and controlling the angle of crossing at the midpoint of the bypass (interaction region). Improvements were made in plate insulation, powering, and switching. The new switching system permits the operator to change (within one second) the geometry of orbiting electron and positron sausages between no-separation mode, complete

separation mode, and one-crossing mode, depicted in Fig. 7. The change is accomplished by making appropriate changes in potentials of the electrostatic separation plates in the south and north sectors of the ring.

In the no-separation mode (Fig. 7a) the separation plates are not powered. The e^+ and e^- sausages, each 160 - 250 ft ($90^\circ - 120^\circ$) long, intersect in the 120° north and 120° south sectors. Throughout the 60° east sector and the 60° west sector the paths coincide but the sausages, being $\sim 180^\circ$ out of phase here, pass sequentially and do not encounter one another.

In the complete-separation mode (Fig. 7b) the sausages are vertically separated throughout the south and north sectors. Throughout the east and west sectors the beampaths are coincident but the sausages pass sequentially.

In the one-crossing mode (Fig. 7c) the two sausages cross at the midpoint of the 120° south sector (midpoint of Magnet 14); they intersect one another here. Throughout the rest of the ring the sausages travel as in the complete-separation mode.

The complete-separation mode is used during the accumulation of the e^- sausage after a large e^+ sausage has been accumulated. This mode is used in order to minimize interactions between the two sausages. If the two sausages were to intersect or become collinear, harmful non-linear effects (incoherent space charge effects) would be exerted on both sausages; also each sausage would increase the v_h and v_v values of the other and might shift such a value far enough so that it would encounter a stop-band.

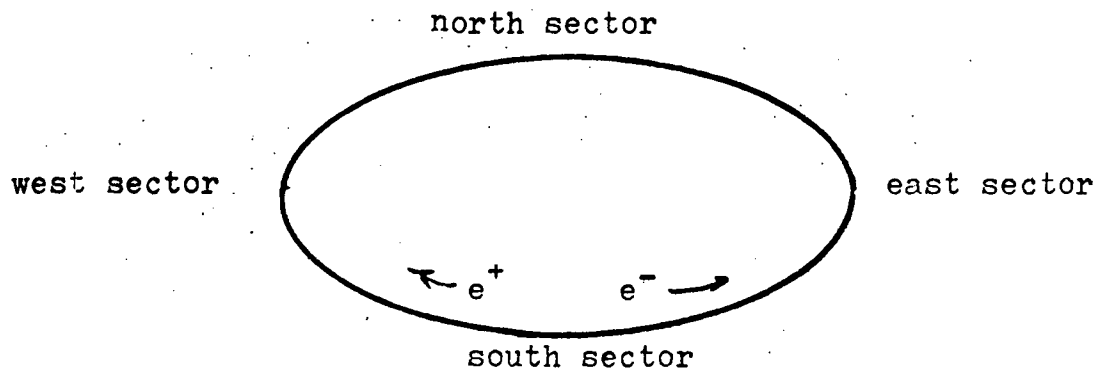


Fig. 7a No-separation mode.

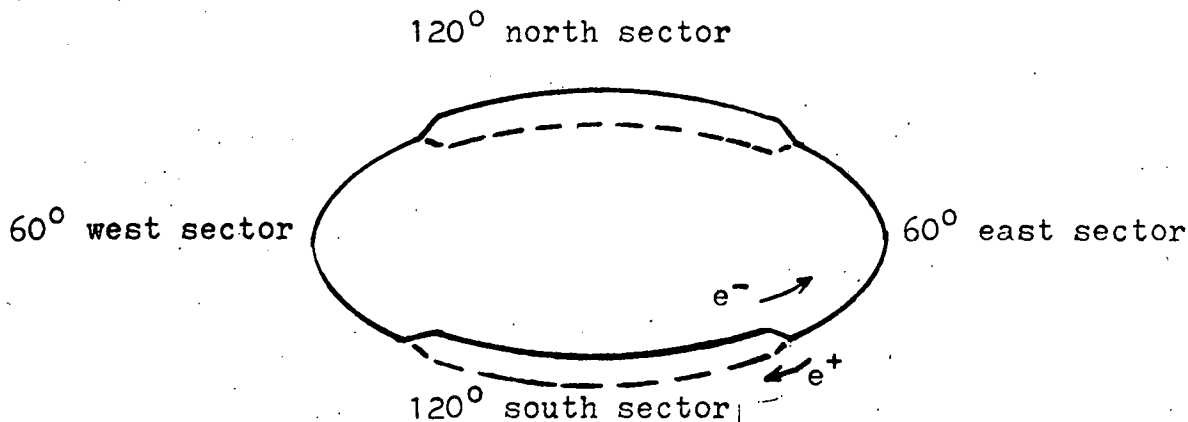


Fig. 7b Complete-separation mode. In north and south sectors the sausages are separated spatially (vertically) and in east and west sectors they are separated in time.

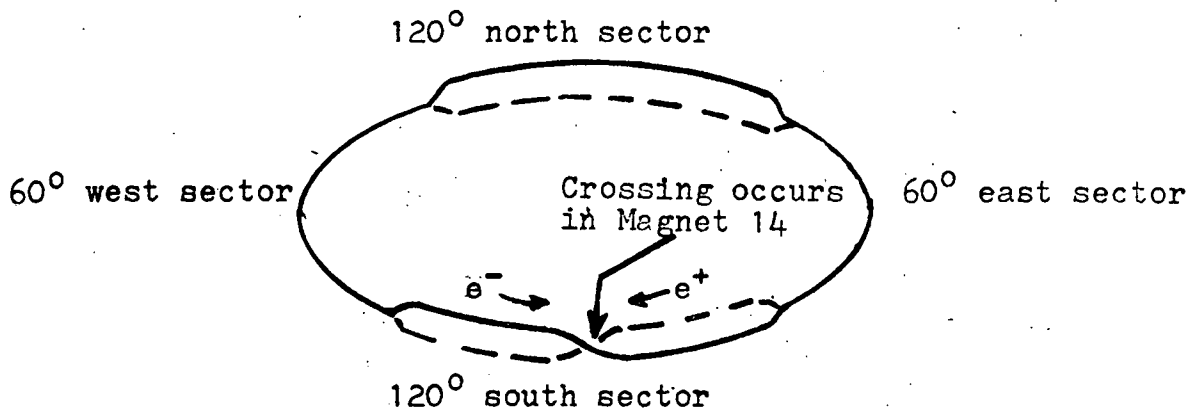


Fig. 7c One-crossing mode. In south sector the sausages intersect one another in Magnet 14. In north sector they are separated spatially (vertically) and in east and west sectors they are separated in time. Bypass interaction region (not shown) is 10 ft. south of Magnet 14.

The one-crossing mode is used prior to, and during, switching the beam into the bypass. The bypass has its own electrostatic separation plates, powered to produce - in conjunction with the plates in the two end-segments of the south sector of the ring - one crossing at the bypass midpoint. When the sausages are switched into the bypass this one-crossing mode is maintained. Note that the plate system of the 120° south sector is much longer than the plate system in the 60° bypass, and that the time-constant of energizing plates is much greater than that of switching the sausages into the bypass. Thus it is not possible to simultaneously deflect the beam into the bypass and shift from complete-separation mode to one-crossing mode.

The no-separation mode is used during change-over from ac to dc storage. (The monthly report for September 1970 describes studies of the effect of one beam on the other when the two beams are allowed to travel through one another along the circular orbit.)

In December residual difficulties with the electrostatic separation plates were corrected and the relative potentials of the different pairs of plates were adjusted empirically so that when the plates in ring and bypass were turned on simultaneously there was no change in beam transverse position in those segments of the ring where there are no plates, namely the east and west segments from Straight Sections 22 - 30 and 46 - 47.

3. Rf Quadrupole Magnet

In July we made tests confirming that greater single-beam intensity could be achieved by employing a special quadrupole magnet powered at orbital frequency or harmonic thereof so as to impart, near the time of injection at least, slightly different ν -values to successive bunches and thereby reduce bunch-to-bunch interaction.

We then constructed an improved rf-powered quadrupole (Fig. 8) and a more powerful, modulated power supply - so that a ν -value difference of ~ 0.001 could be maintained throughout the acceleration and deceleration intervals during multicycle injection. An rf frequency 24 times the orbital frequency (rather than the orbital frequency itself) was chosen in order to minimize the power requirement and allow maximum flexibility of choice of straight section in which to install the device.

By the end of August excellent results were obtained with the new rf quadrupole, as indicated in Section B2.

4. 362nd Harmonic Rf Cavity

In September we disconnected one of the sixteen rf cavities (#6) from the rf waveguide ring and powered it by a special supply operating on the 362nd harmonic of the orbital period. (The rf ring as a whole is powered at the 360th harmonic.) This special cavity imparts a different phase of field to successive bunches and thus was expected to reduce bunch-to-bunch interaction associated with coherent synchrotron oscillations and permit an increase in beam current.

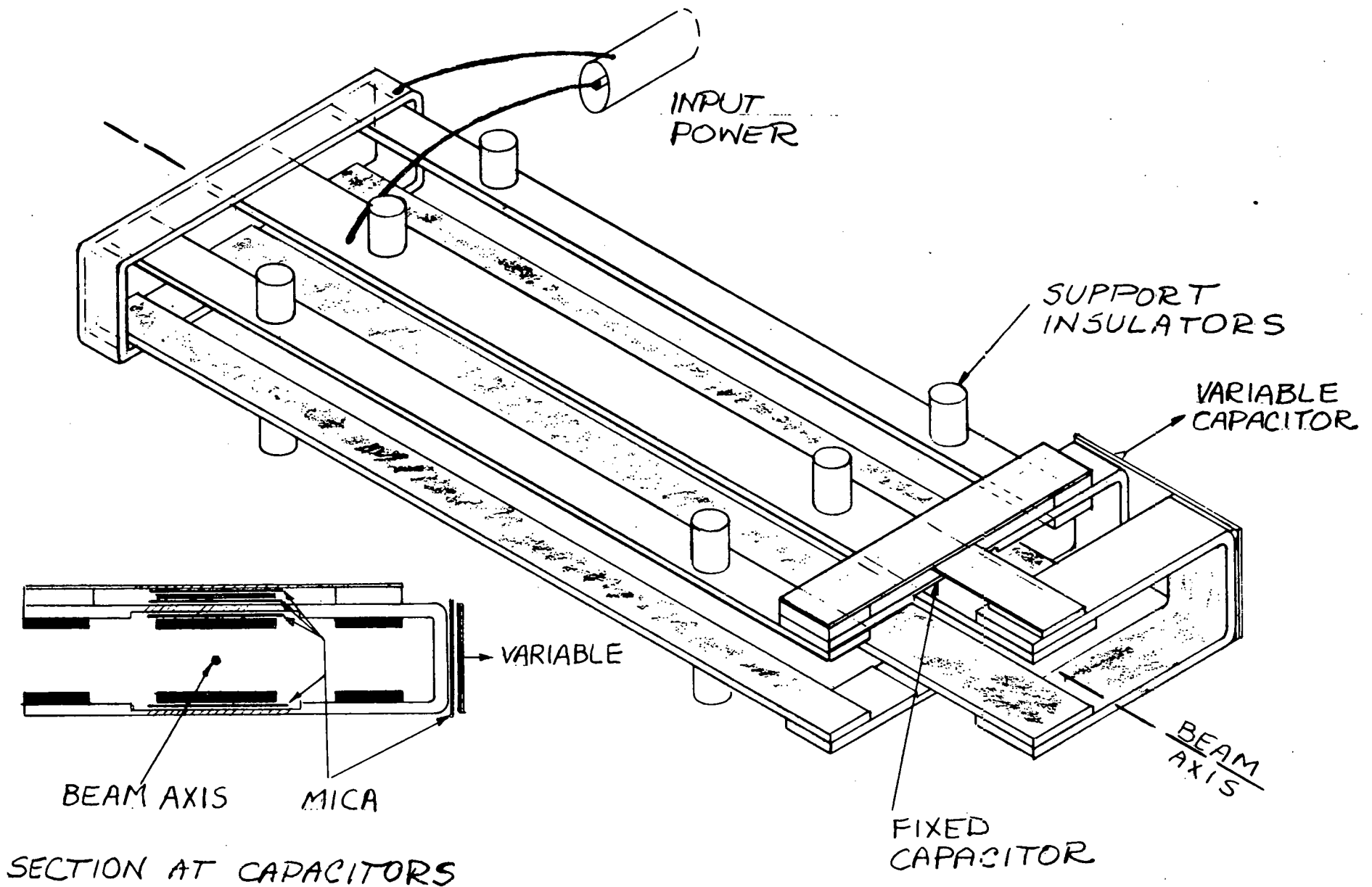


Fig. 8. Quadrupole magnet for assigning slightly different ν -values to successive bunches of orbiting particles. The device consists of six copper conductors, a fixed mica capacitor, and a variable mica capacitor, which together make the system resonant at 32 MHz with a Q of 40.

Early in 1971 the great effectiveness of such rf cavity was demonstrated and construction of a special cavity operating on a much higher harmonic was started.

5. Other Hardware Improvements

In July we installed, at the center of the bypass, an 8-inch-diameter, thin-walled (60-mil stainless steel) beampipe, shown in Figs. 9 and 10. A vacuum ion-gage and a titanium sublimation pump are mounted at the ends of the pipe. Thin windows are mounted off-axis at each end of the beampipe to permit egress of electrons scattered at small angles toward the 5-degree luminosity monitors discussed below.

Many small improvements were made in the bypass vacuum system (see Part V) with the purpose of increasing beam lifetime and reducing the background of gas scattering events near the interaction region.

Important improvements in bypass beam controls were made, as indicated in Part V.

In October, zero-degree luminosity monitors for detecting photons from single and double bremsstrahlung were installed at each end of the bypass central beampipe. Each monitor included a collimator, a vetoing scintillation counter, and a shower counter.

By December 31, construction of the five-degree luminosity monitors (for detecting e^+ and e^- scattered in coincidence at 5° and 185° from the axis) was 75% complete.

The zero-degree monitors were tried out successfully in November and December. However, the new octupole magnet for

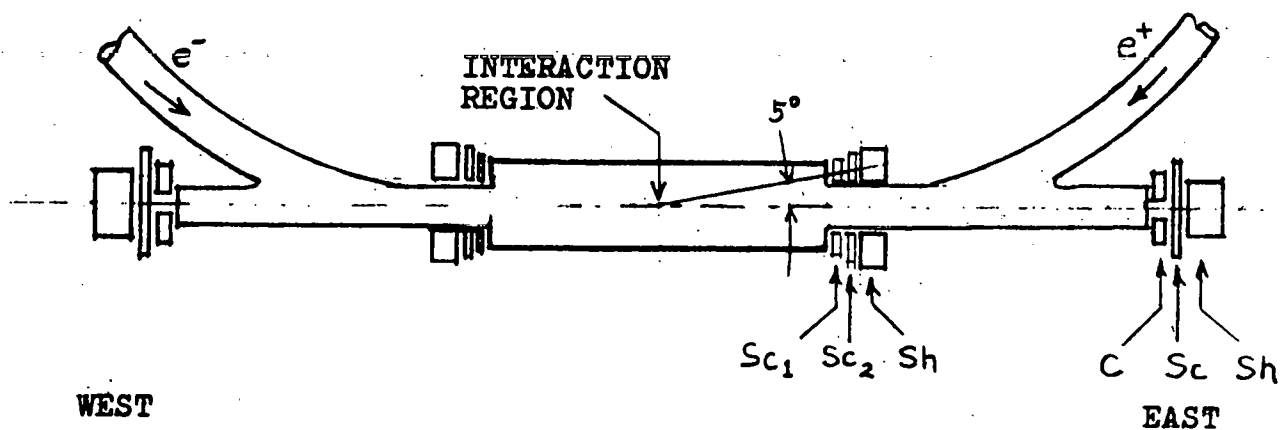


Figure 9

Schematic diagram of central portion of bypass and the two luminosity-monitor systems. The zero-degree monitors at east and west include a collimator C, a vetoing scintillation counter Sc, and a shower counter Sh. Each of the four assemblies of the five-degree monitor includes an aperture-defining scintillation counter Sc₁, a larger scintillation counter Sc₂, and a shower counter Sh.

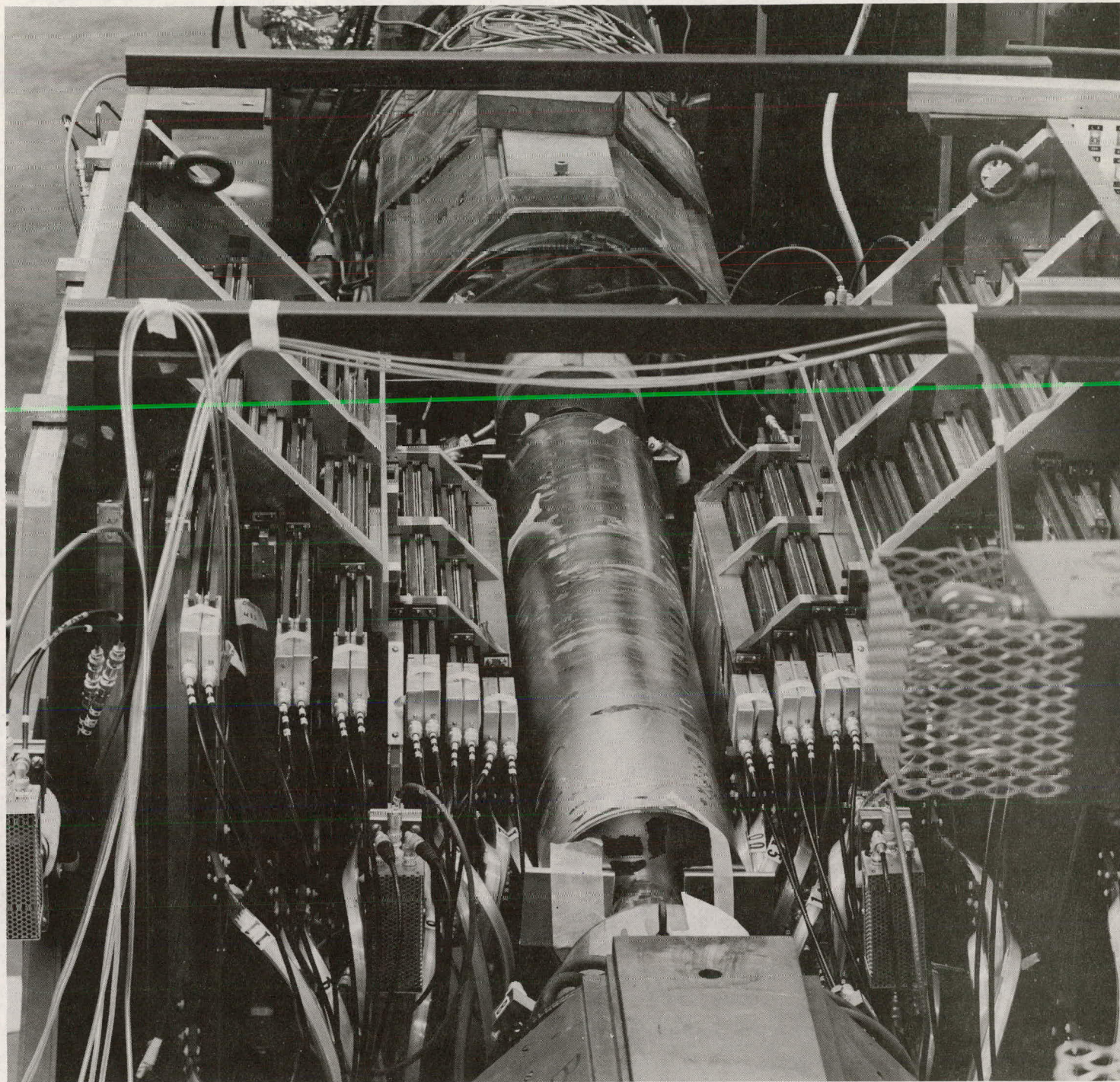


Fig. 10. General view of the interaction region of the bypass and two flanking quadrants of the bypass on-line detector, on July 31, 1970. At the center of the photograph is the thin-walled, 8-inch-diameter vacuum pipe in which the countertraveling e^- and e^+ beams will collide. A collision-product particle traveling to left or right encounters three spark chambers, a scintillator, and then a mixed sequence of lead radiators, spark chambers, and scintillators. At top and bottom of the photograph, portions of the quadrupole triplet focusing magnets may be seen.

controlling coherent betatron oscillations was not yet in use, and only low-current e^+ and e^- beams (of the order of 2-mA peak) were employed.

PART III - BYPASS ON-LINE DETECTOR (BOLD)

A. General Design

Figures 10, 11, 12 show the general design of the bypass on-line detector (BOLD), which is to be the first detection system used with the CEA colliding beam facility. Designed jointly by the CEA staff and a Harvard group, the system is designed to detect photons, electrons, muons and hadrons.

As explained in earlier reports, the detector consists essentially of four core-quadrants and two flanking assemblies, the hadron converters. Each quadrant contains six spark chambers, five scintillators, and five radiators (with thicknesses of 1.25, 1.25, 1.25, 1.25, and 1.5 radiation lengths). The outermost scintillators are used in distinguishing (by time-of-flight data) cosmic-ray particles from particles originating at the interaction region at the center of the assembly.

Each spark chamber includes two gaps, defined by four planar arrays of wires X, U, (-X), V at angles of 0, 75, 180, and 105 degrees respectively. Each array is served by one magnetostrictive pick-up wand, and the arrival times of sonic pulses reaching the transducer at the output end of the wand correlate with the positions of the wires supporting sparks. The analog time-delay data are converted to digital form, stored temporarily in scalars, and forwarded to the interface (an SDS-92 computer) and thence to the main computer (IBM-360/65), as indicated in Fig. 13.

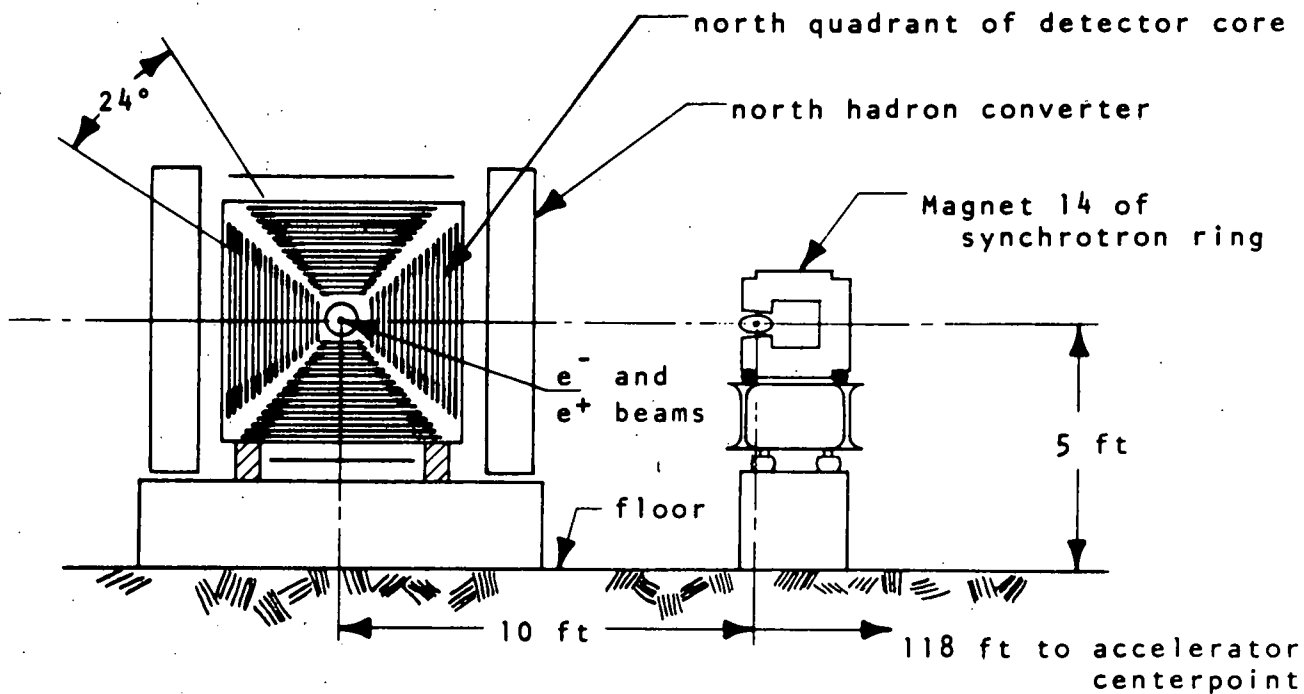


Fig. 11. Vertical section through bypass (and adjacent portion of synchrotron ring) at the bypass midpoint.

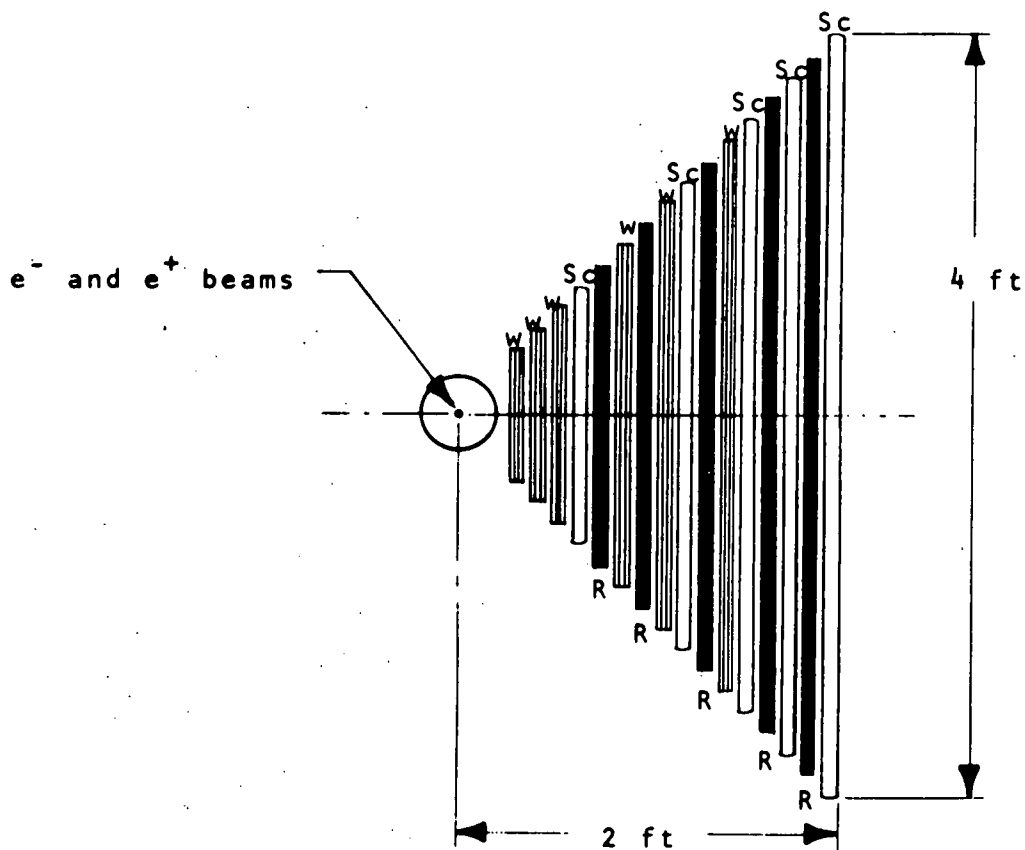


Fig. 12. Cross section of north quadrant of detector core, showing the six wire spark chambers (w), five scintillation counters (Sc), and five radiators (R). The e^- and e^+ beams are at the center of the beampipe.

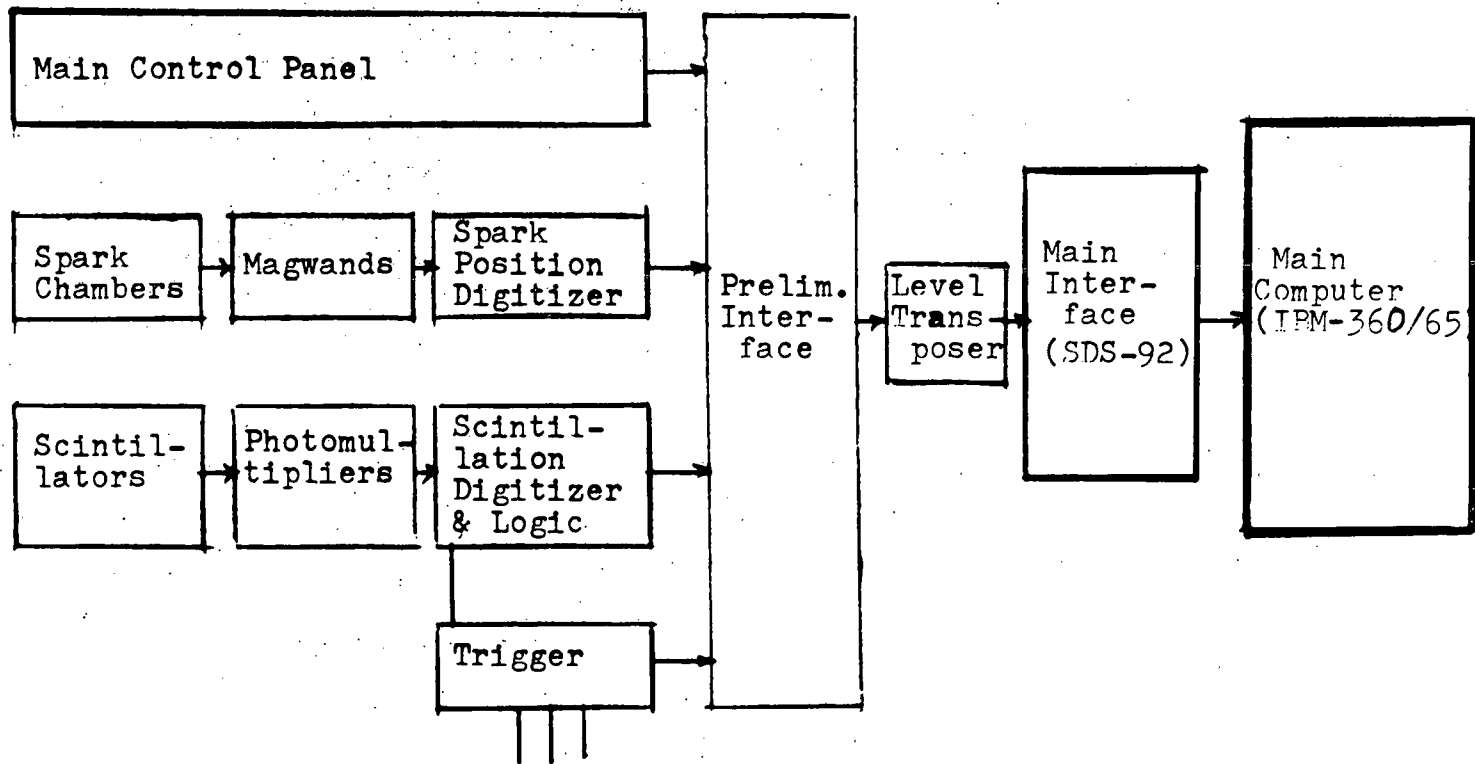


Fig. 13. Flow of BOLD data from primary sensors to on-line computer

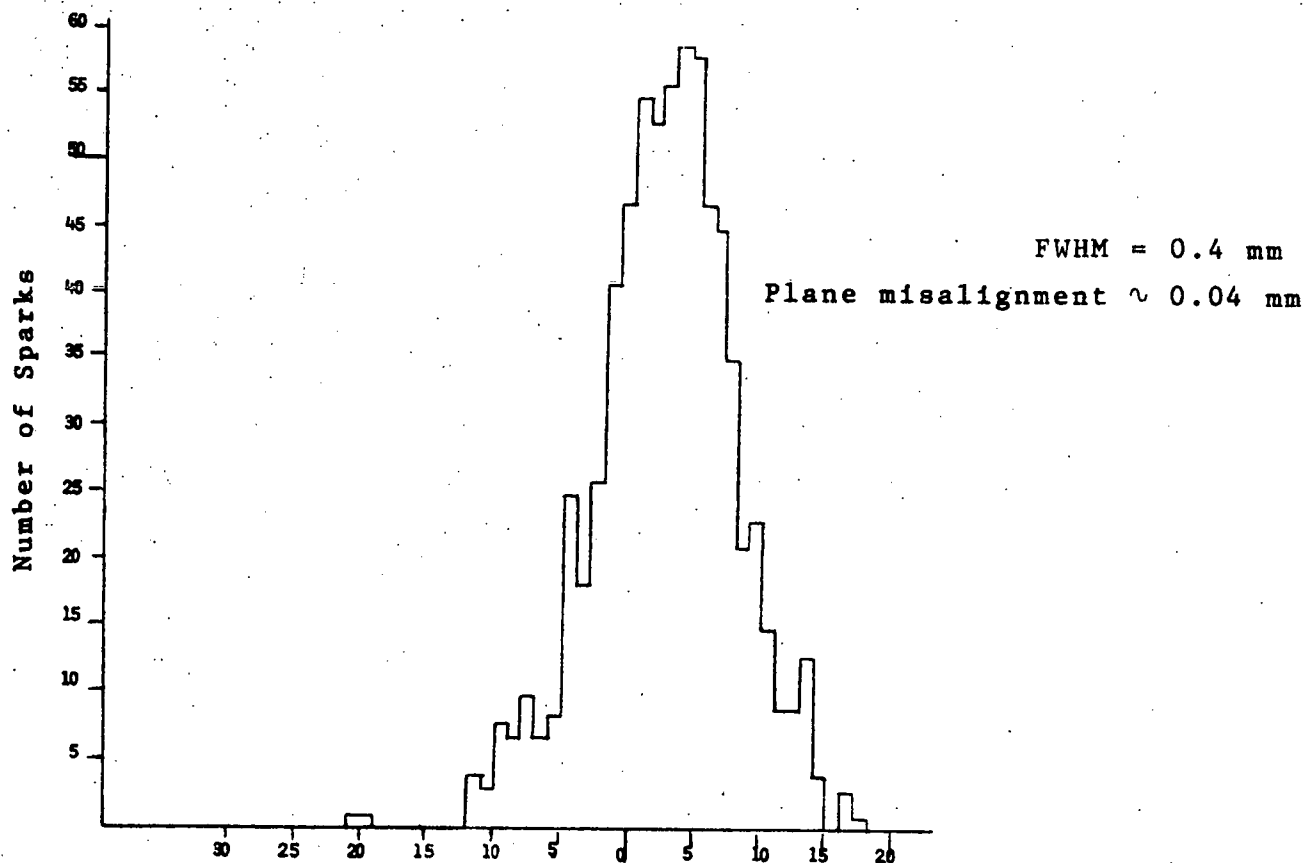
Pulses from photomultipliers that view the scintillators pass to discriminators and thence to pulse-area digitizers and a logic system. If these pulses satisfy the criteria for trigger, the spark chambers are powered (with an overall delay of ~ 500 nsec) and other key components are gated on. Also, the areas of pulses from those scintillators serving as shower counters (i.e., scintillators preceded by radiators) are measured, expressed in digital form, and forwarded to the main interface and main computer.

An on-line assembly-language computer program causes the IBM computer to record the useful data in compact form on mag-tape. A Fortran IV program causes this same computer to make an on-line, preliminary identification of event type and, on command, presents the operator with a quick visual reconstruction of the tracks of any given event.

An off-line Fortran IV program employing the CERN SUMX program processes the magtape in a more sophisticated manner. The interpretation of data from a given event is determined and recorded. Totals by class are maintained. The efficiencies of the individual spark chambers and scintillators are compiled. The program is normally executed on the IBM-360/65, but the Harvard Physics Department's Sigma-7 may be used instead.

B. Progress and Status

In the six-month period in question, extensive performance tests were made on the core quadrants. Figures 14, 15, 16 show typical results.



Distance of spark from best-fit straight line
(in units of bins. 1 bin = 0.04 mm)

Figure 14

Histogram of number of sparks in Plane 9 of upper quadrant spark chambers as a function of distance of spark from best-fit straight line determined from spark-position data in many spark chambers in series.

Incident particles: 500-MeV positrons at normal incidence. Data from Run 39, DMIN-9 of October 1970.

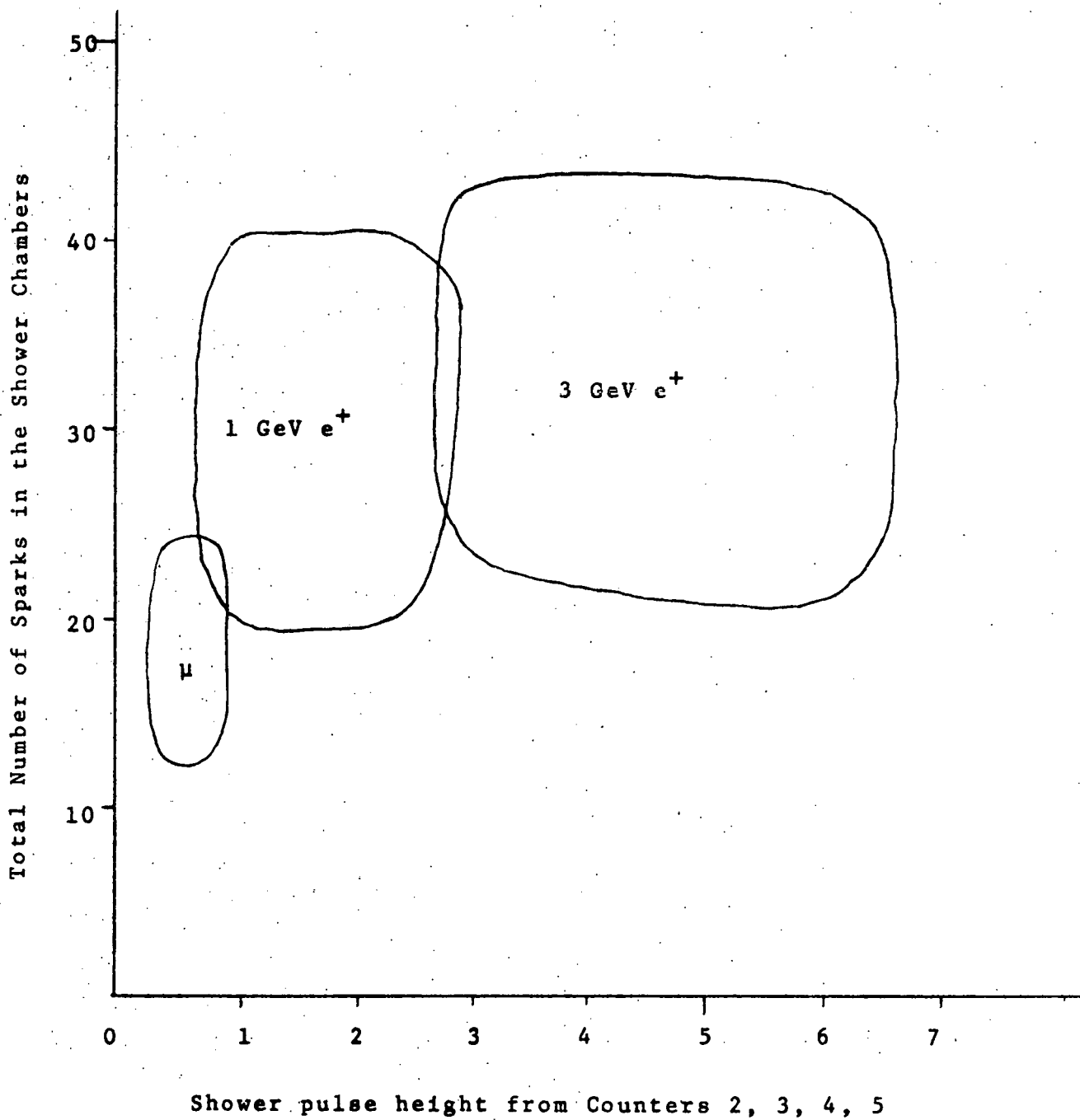


Figure 15

95% contours of data resulting from three kinds of particles incident on shower chambers (spark chambers) and shower scintillators of upper quadrant: 1-GeV and 3-GeV positrons incident along the normal, and cosmic ray muons. Data from Beam 5 run of October 10, 1970.

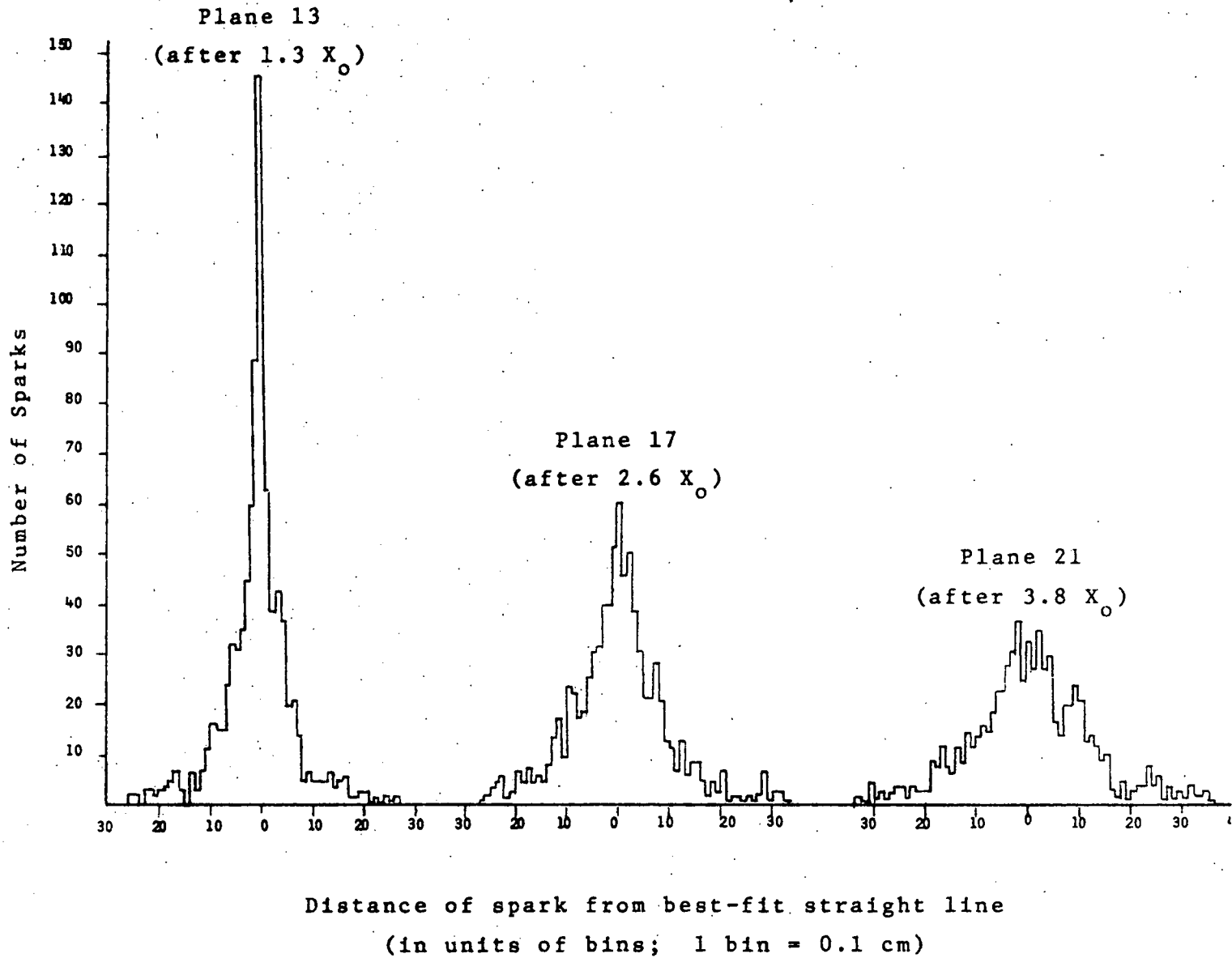


Figure 16

Histogram of number of sparks (in given plane) having the indicated distance from best-fit straight line inferred from position data from tracking chambers. Particle used: 2-GeV positron incident normally on chambers. Run 37 of October 1970.

In July the first two quadrants were moved into the Target Area and set up adjacent to the interaction region. By the end of December the other two quadrants had been constructed and tested. Also, construction of the equipment for pulsing the spark chambers was nearly complete and most of this equipment had been installed in a protected room close to the Target Area.

The 1-inch-thick iron plates for the hadron converters were on hand, and studies of prototype spark chambers to be inserted between the plates were underway.

We completed and tested the zero-degree luminosity monitors, and construction of the five-degree luminosity monitors was nearly complete.

The basic on-line and off-line computer programs are nearly complete. Many important extensions are in progress.

In general, the detector core, trigger system, spark chamber pulser system, and on-line and off-line computer programs are sufficiently near completion that they could be put into use on short notice.

PART IV - MAGNETIC ON-LINE DETECTOR (MAGNOLIA)

A. General Design .

In the six-month period in question greatly increased effort was devoted to the development of a magnetic on-line detector MAGNOLIA (formerly called MAGOLD). The design and test programs are being carried forward by a group of physicists and engineers from CEA, MIT, Northeastern University, and Southeastern Massachusetts University.

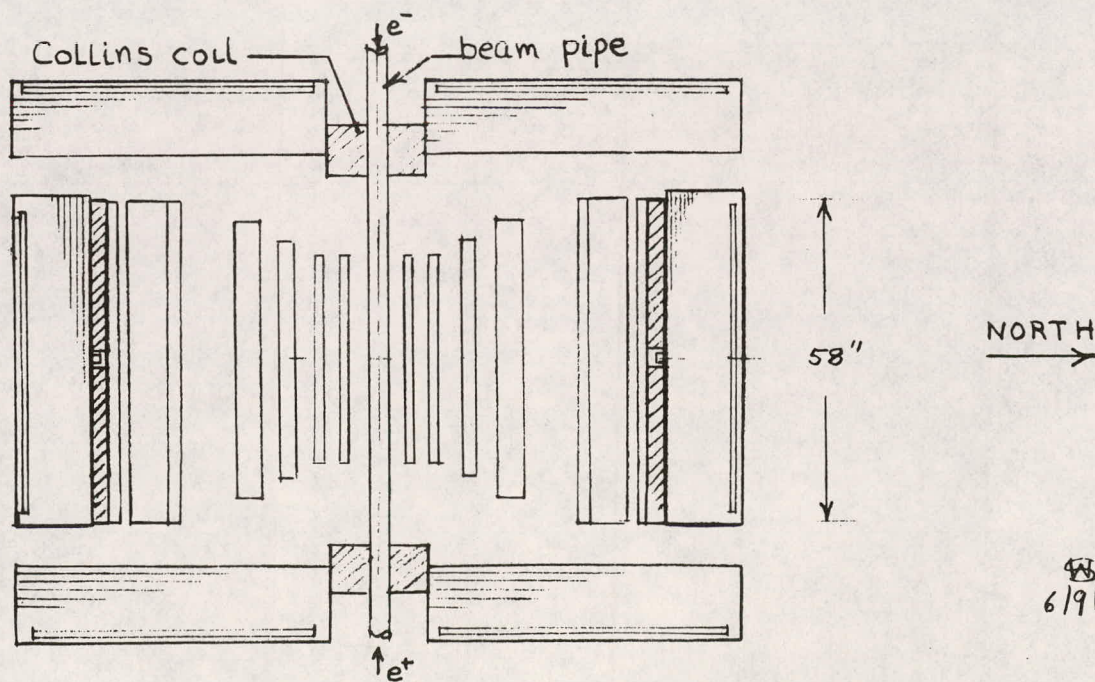
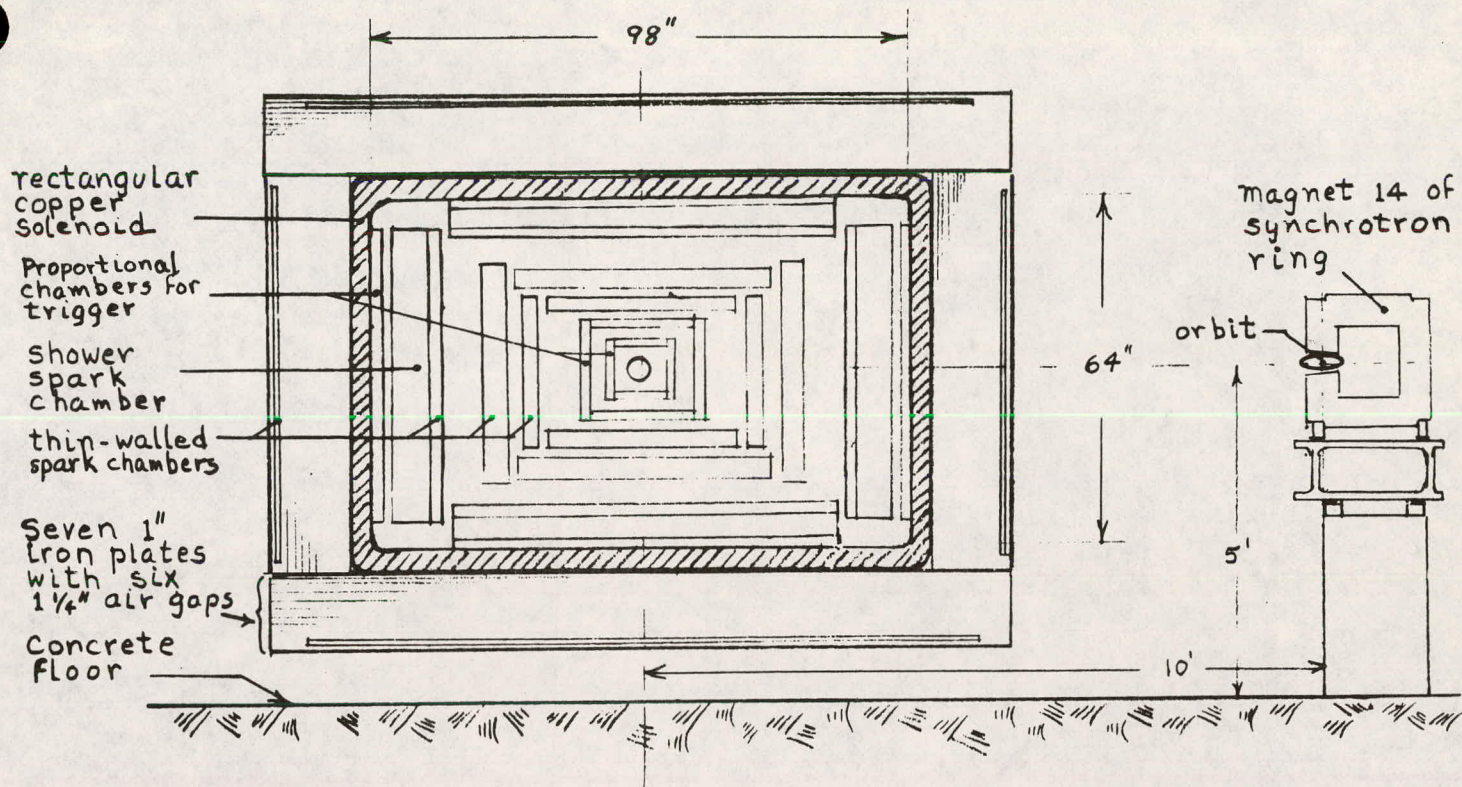
Employing a rectangular solenoidal coil having inside height, width, and length of 64, 98, and 58 inches respectively, this detector will make momentum determinations of the particles coming out of the interaction region. This will permit:

Testing of time-like photon term in e^+e^- scattering
by identifying e^+ and e^- particles,

Better identification of hadrons and possibly new
particles,

Increased knowledge of baryon and boson channels
resulting from e^+e^- annihilation.

Figure 17 shows the general design of the detector and its relationship to the synchrotron and the bypass. The axis of the rectangular solenoid coincides with the e^+ and e^- beams, and when powered at 2 MW the coil will provide a 5-kilogauss field. At each end of the assembly there is a compact 20-inch-diameter correction coil (Collins coil) for canceling, along the interaction region, the defocusing effect of the main magnetic field on the e^+ and e^- particles.



6/9/71

Figure 17

Simplified diagram of the main features of the MAGNOLIA detector.

Above: Vertical cross section, looking toward west.

Below: Horizontal cross section. Supporting structure not shown.
Exact locations of chambers have not been decided.

Inside the region embraced by the coil there are arrays of spark chambers and proportional chambers. Outside the coil there are spaced assemblies of seven 1-inch-thick iron plates, with spark chambers mounted in some of the 1.25-inch gaps between plates.

Information from the detectors is to be processed on-line by an IBM-360/65 computer interfaced by one of the CEA SDS-92 computers.

B. Progress and Status

During the six-month period in question, many phases of the design were studied. Large numbers of model studies were made and promising design approaches identified.

The uniformity of magnetic field within the region enclosed by the rectangular coil was investigated by means of computer programs. The coil itself was on hand at the CEA and was subjected to voltage, current, and mechanical strength tests.

The design of the Collins coils was well advanced, and the same applies to the design of the external assemblies of iron plates.

In designing the spark chambers to be mounted inside the magnetic field region, the MIT design group faced problems of (a) minimizing the edge structures of the spark chambers, to avoid loss of useful solid angle, and (b) having the individual wires extend (via long "tails") outside the solenoidal coil so that magnetostrictive pick-up wands could be used without interference by the magnetic field of the solenoid.

A major effort by the designers was to devise proportional chambers that could be used in place of scintillation counters as trigger devices, as the photomultipliers associated with scintillators are inoperable in a strong magnetic field.

Planning for the necessary on-line and off-line computing power was begun.

Equipment for manufacturing spark chambers efficiently and economically was designed, and plans were made for setting up this equipment in a clean room at the CEA.

It was expected that most of the design specifications would be complete by mid-1971 and that most components having long procurement times would be on order by then.

PART V - ACCELERATOR OPERATION AND IMPROVEMENT

A. Statistics on Accelerator Use

During the period July 1 - December 31, 1970, the distribution of accelerator time was as shown in Table 1.

TABLE 1

Accelerator Use in the Second Half of 1970

(Number of 8-hour shifts)

Month	Studies of Beam Accumulation, Storage, Collision	Performance Tests on Detection Systems	Miscellaneous*	Total
July	23.0	2.0	51.0**	76
August	36.5	4.5	27.0	68
September	46.5	0	21.4	68
October	41.4	3.9	21.7	67
November	33.7	3.2	26.1	63
December	35.6	6.1	15.3	57
	216.7	19.7	162.5	399 (or 3192 hours)

* Installation of new equipment, maintenance and repair, and scheduled and unscheduled downtime.

** Includes the scheduled semi-annual two-week shutdown (July 9-26) for maintenance and installation of new equipment.

B. Operation, Maintenance, and Minor Improvements

Introduction. In the half-year in question we continued to follow the machine operations schedule inaugurated on June 1, 1970:

0800 - 2400 Monday through Friday: a full operations crew was maintained.

0000 - 0800 Tuesday through Saturday: a skeleton crew kept key components of the accelerator warmed up so as to permit prompt resumption of operation at 0800. This crew also performed various maintenance and repair tasks.

0800 - 2400 Saturday: full maintenance, installation, and repair crew available for work. The accelerator was normally not working during this period.

0000 Sunday through 0800 Monday: accelerator off and laboratory closed.

In the following pages we discuss the performance of each of the major components of the accelerator.

1. Linac

a. Operation

The linac performed well throughout most of the period.

Temporary interruptions were caused by failures of:

Several capacitors of pulse-forming networks,

The klystron of Modulator 3 (after 7000 hours of use),

The solenoidal focusing coils downstream from the converter
(as a result of radiation damage to the insulation),

A coil of the electromagnet of Klystron 3,

The submersible water-pump for the cooling system of the
linac buncher,

The three-phase Variac of the linac high-voltage power
supply.

b. Improvements

Control of phase shifters was improved by installation of stepping motors.

Drift of phase of linac Modulators 2, 3, 4, 5 relative to Modulator 1 was reduced by replacing the solid-dielectric drive cables (which had large thermal coefficients of phase shift) with air-dielectric cables.

We made several improvements that avoided below-normal electron-injection (a) in the minute or two following injection of positrons and (b) in the minute or two following trip-out of linac power supply or failure of the linac trigger. By installing electric heaters for regulating the temperature of the buncher section, we counteracted the tendency for the temperature of the buncher section to fall during positron injection or power-supply trip-out. Also, we installed a back-up trigger for maintaining continuity of linac operation even when the normal trigger is absent.

In November we installed a separate power supply for the linac gun, to avoid restrictions associated with using the same supply for gun and modulators, and to allow gradual turn-on of gun potential (to avoid component failures associated with transients).

Two of the fluorescent screens used to reveal linac-beam location and cross section via closed-circuit TV were replaced by new screens.

2. The e^- and e^+ Injection System

a. Operation

The system performed well. The only significant failures were:

Failure of the insulation of a coil of the 3000-ampere e^- bending magnet,

Failure of injection-run steering coils.

Repairs were completed promptly.

b. Improvements

We installed an additional steering coil just downstream from the momentum-matching magnet of the e^- beamrun to improve the efficiency of electron injection.

A new 3300-ampere dc power supply for the bending magnets of the e^- and e^+ beamruns was received in October from Alpha Scientific Corp. and was put into use in November. Protective thermal switches were installed on the bending magnets.

In October we installed a back-up shutter in the e^- beamrun between the Linac Tunnel and Ring to make it feasible to operate linac-plus-transport system even while 80% of the ring is open for maintenance work.

In November two spare coils for the e^- and e^+ bending magnets were received.

In December we installed, downstream from the first e^- bending magnet, a flip-up, remotely-controlled, thin metallic foil intended to produce enough small-angle scattering to fill the acceptance ellipse of the synchrotron ring.

3. Synchrotron Magnet Ring

a. Operation

Performance was uneventful during most of the period in question. Two failures occurred:

Failure (after 3360 hours of use) of pulser ignitron of the power supply for the ring of magnets,

Failure of power supply for producing beam bumps at the damping magnet stations.

b. Improvements

In July we installed quadrupole and sextupole pole-face windings on four of the radially focusing magnets of the ring. Also we installed peaking strips of new (air-cooled) type in three open magnets; they are used for machine trigger, regulation of magnet excitation, and zero-field detection; use of air-cooling permits operating the peaking strips with the higher biasing currents needed for matching the new, higher, (260 MeV) injection energy.

We made a radial survey of the magnet ring by a new method that is superior to the old method in (i) avoiding line-of-sight obstructions presented by the bypass, and (ii) reducing the survey time by a factor of three. Orbit distortions due to imperfections in radial alignment were calculated by a new computer program, and the distortions were found to be negligible.

In October we installed a new system for regulating the ac component of power to the ring of magnets. The new system permits close control of the ac power even when (as during ac turn-off) B_{\min} is large enough to correspond to a 250-MeV particle energy.

4. Old Rf System

The old rf system, the heart of which was an RCA HPA #4612 triode, continued to work, except for failure of:

The motor drive unit for the 3-phase breaker for Power Supply #2,

A stack of diodes for Power Supply #2,

Two type-2041 driver tubes,

A 480-volt circuit breaker,

A 5-ohm, 50-kW, water-cooled resistor of the rf power supply,

A hose used in pneumatic control of rf cavity temperature.

On several occasions the HPA triode performed poorly and was reconditioned. On one occasion it performed so badly that we replaced it with the sole existing spare (which itself was not in perfect condition).

The new rf system is described in Section C.

5. Vacuum System

a. Ring Vacuum System

The synchrotron-ring vacuum system performed excellently. The only noteworthy failure was that of one high-vacuum pump, which was replaced.

Many improvements were made. In July we installed three additional pneumatically operated high-vacuum segmenting valves in the ring, making a total of five. Also we replaced the circular-section exit spouts of Vacuum Chambers 10 and 18 with elliptical spouts, to allow more room for electrostatic plates

for maintaining vertical separation of the e^- and e^+ beams. We improved the vacuum integrity of Straight Section Tank 47 (which contains a damping magnet and hence is of special design) by attaching reinforcing bars to the tank back-plate.

In October we developed an alarm system for notifying the operator when a high-vacuum pump draws a current indicative of a pressure exceeding 10^{-6} torr. The system also turns off the rf system in the event of a large pressure rise.

Five additional Varian high-vacuum pumps were installed in the ring, bringing the total of such pumps to 39.

In November and December, we extended the bake-out system to include even the most complicated vacuum chambers - and also the straight-section tanks and high-vacuum pumps themselves. Bake-out temperature was increased to $\sim 80^\circ\text{C}$.

With such bake-out, we achieved, with a stored, dc, few-mA-peak, 2-GeV beam, a $1/e$ lifetime of 2 hours.

b. Bypass Vacuum System

We continued to improve the bypass vacuum with the object of increasing beam lifetime and reducing the background of gas-scattering events near the interaction region. In August we improved the bypass bake-out system by installing ammeters, fuses, and temperature recorders. In December we installed water-cooled, adjustable-position, synchrotron-radiation-absorbing vanes, and also four titanium sublimation pumps (making five such pumps in all). We protected the bypass ionization vacuum gages from synchrotron radiation by special baffles in order

that pressures as low as 10^{-10} torr could be measured reliably even when there were high-current beams and intense synchrotron radiation in the bypass.

The installation of the central, 8-inch-diameter beampipe has been discussed in Part II.

6. Beam Controls and Monitors

a. Ring Controls and Monitors

In August we installed an improved beam-intensity monitoring system that has proven to be useful in many ways. The new device employs mirrors that intercept visual-range synchrotron light emitted by the e^- and e^+ beams and direct the two light beams to two photomultipliers the outputs of which are presented as CRO traces in the Control Room. The time resolution (a few nanoseconds) is great enough so that the sausage ends can be located with a precision of a few feet. Because the mirrors face in opposite directions (to receive light from the oppositely-traveling beams), the amount of contamination of the two signals is negligible (< 0.0005). Using remotely controlled optical density filters, the operator can measure beam intensities throughout a range of 10^5 .

Also in August we installed, in Straight Section 5, the rf quadrupole magnet discussed in Part II-D.

In September we improved the performance of the ν -separation quadrupole magnets in the ring by powering some of these quadrupoles in series with the ring of 48 magnets, so that the ν -separation could be held approximately constant throughout the 60-Hz cycle.

By the end of 1970 there were more than 140 special monitoring and controlling devices in the 48 straight sections. Table 2 shows the locations of these devices.

b. Bypass Controls and Monitors

In November we reversed Septum Magnet 19 end-for-end in order that the arrangement of leads (and their fields) would be more nearly symmetric with respect to Septum Magnet 10. Also, we reduced the ripple in the ultraflexor power supply and improved the timing of the ultraflexor turn-on. A short-circuit in the leads of Ultraflexor 22 was corrected.

7. Miscellaneous Components

We overhauled the accumulation of cables between the west portion of the Power Building Basement and the Control Room, removed obsolete cables, and improved the routing of essential cables.

In September we made extensive repair to the wheels and wheel supports of the 40-ton crane in the Experimental Hall. Also, we improved the shielding around the converter between the two linacs and in October we installed much shielding around the bending magnets of the e^- and e^+ beamruns in the Linac Tunnel.

In November we installed metallic shields over bypass ports through which small amounts of synchrotron radiation might otherwise emerge.

Many of the experimental magnets in the Target Area and Experimental Hall were flushed with ethylene glycol and rust

TABLE 2

Locations of Devices in the 48 Straight Sections

Str. Sect. No.	Elec. Sep'n. Plate	Valve Fx or segm.	Ion Gage	Monitor		Sep. Quad.	Sext. Windings	Injectr or Inflectr	Other Device
				Loop or Coil	Sync Li. Mirz				
1			H				**		RF-cav. intens. monitor
2		T	H	FDDI		UI	**		
3rf			H				**		
4		T	UO				**		Current strip; Target DO
5			H		DO		**		RF quad., inside
6rf							**		
7	UIEB7D	T,U	UO		DI		**		Ultralector, inside
8			H						
9rf									
10	EB,9D		H						Septm OUTSD; multi-tgt DI
11	DI			T					caliper UI
12rf			H						Horiz. scraper, UI
13	DI	T	MO						
14	UI	T	MO			DI			
15rf			H						
16	UI	T,U	MO			DI			
17	DI		MO	UI					
18rf	EB17D		H						
19	EB19U		H						Septm OUTSD; caliper DI
20	UI	T	MO	D					Horiz. scraper DI
21rf			H						
22	EB21D	T	H				**		Ultralector, inside
23			H	FU		UI	**z		Kicker DI. Vert. caliper T
24rf			H				**		
25		T,D	UO	FU			**	MI&DO	
26			H				**	Inside	Kicker DO
27rf							**	DI	
28		T	DO				**		Fluoresc. screen UI
29			UO	FD			**		
30rf			H				**		
31	UI	T	H	U,MO			**z		Kicker DI
32	EB31U	T	MO				**		Octupole, inside
33rf			H				**		
34	UI	U	H		DI		**z		
35	UI		MO	D	DI		**		
36rf			H				**		
37	UI		H		DI		**		
38	UI	T	MO				**		Betatr. osc. exciter DI
39rf			H				**		
40	UI	T	DI				**z		Electrost. quad., outside
41	DI	U	MO			UI	**z		
42rf			H				**z		
43	DI	T	H						
44	UI	T	MO		DI		**z		
45rf			H						
46	EB45D		H						Damping magnet
47		B	H						Damping magnet
48rf			H				**		

Key: B: bottom. D: downstream. EB: end box. F: in flange and bellows. Fx: foreline. H: in pump header. I: inside, i.e., toward accelerator centerpoint. Li: light. M: middle. Mlti-t'gt: multi-target. O: outside. rf: rf cavity. Segm.: segmenting. Sext.: sextupole. T: top. U: upstream. Z: not connected.
 *: powered at 3 times the usual rf frequency, i.e., at 1427 MHz.
 : at junction of magnet bearing this number there is a sextupole winding powered by d.c. *: same, but powered by a.c. and d.c.
 Note: downstream and upstream mean counterclockwise and clockwise resp.

inhibitor so that they would remain in good condition for any subsequent use.

All equipment remaining in the Dane Street, Somerville, warehouse was removed before the lease expired on September 15.

C. New Rf System

In October and November we received the components of the 200-kW-average rf system, ordered from Visual Electronics Corp. in March 1970 as explained in the previous semi-annual report. By the end of December, installation of the new equipment, which provides 200-kW average power (more than twice the average power of the old system) was nearly complete and all four transmitter units had been tested briefly at full rated power. See Fig. 18.

In previous months extensive preparations had been made for installing the new system. Space had been cleared and electrical and cooling-water supplies had been made ready.

The new rf system was put into trial use in January 1971 and was used routinely starting in February 1971.

A detailed account of the new system is presented in the Monthly Report for January 1971. See also CEAL-TM-195 of 3/30/71, which discusses the rf system as a whole.

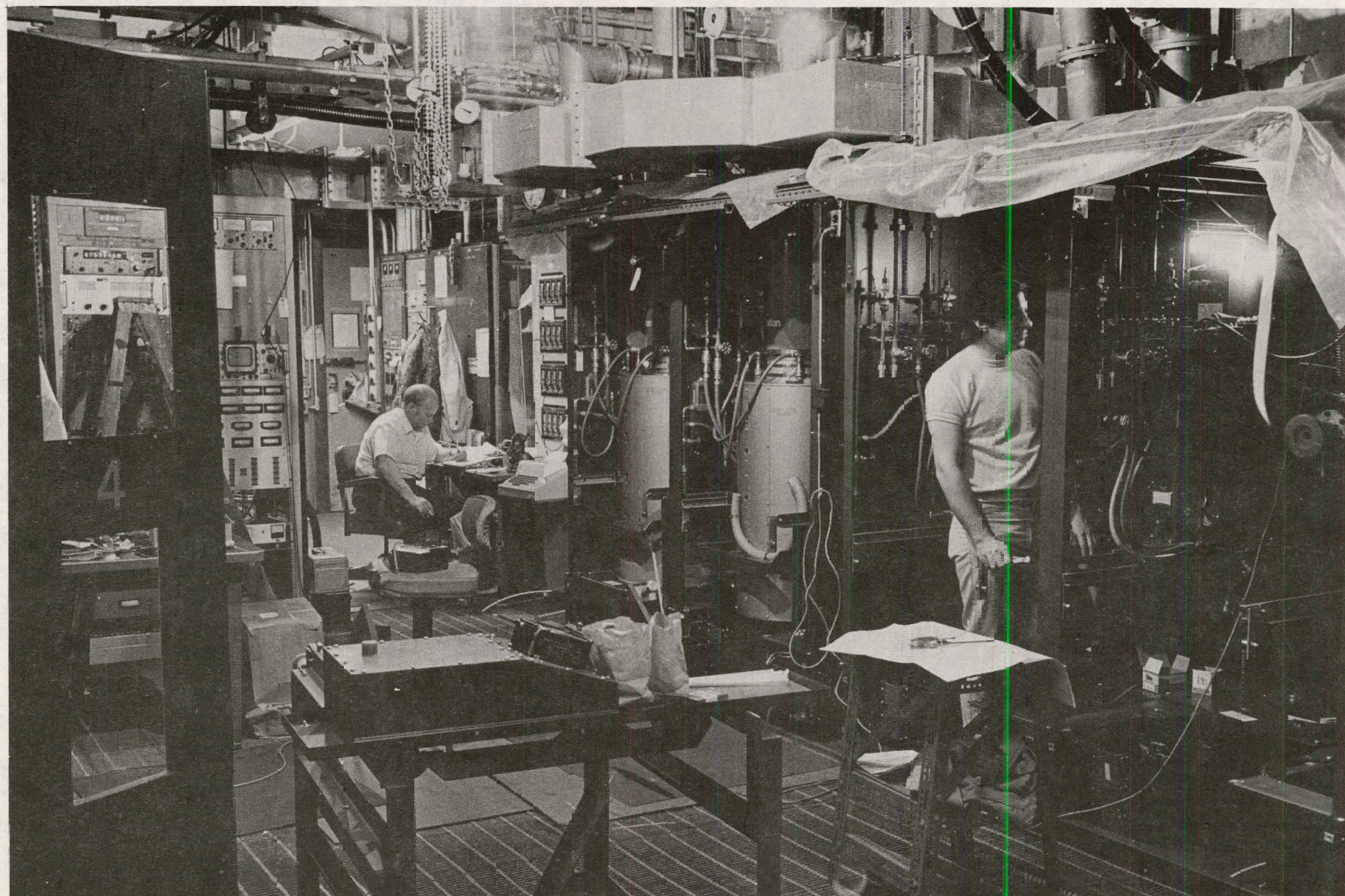


Fig. 18. New 200-kW-ave. 475-MHz rf system supplied by Visual Electronics Corporation. At center and right are the four 50-kW transmitter units. In Units 1 and 2 (at center) the Varian Type 953-C klystrons are already installed. Overhead portions of the hybrid combiners and the waveguides may be seen. The control console may be seen at extreme left. Photograph was taken in November 1970. Construction was completed in December.

PART VI - OTHER ACTIVITIES AND PROGRAMS

A. Analysis of Results of Experiments Carried Out in the
Experimental Hall Prior to May 31, 1970

During the six-month period in question the following investigator teams continued the analysis and reporting of experiments performed by them in the CEA Experimental Hall prior to 5/31/70.

Experiments Performed in 1969 or Earlier

Pipkin, Stanfield, et al (Harvard), Experiment 102f:

Continuation of Small-Angle Scattering of Electrons by Carbon.

Brenner, Walker, et al (Harvard), Experiment 103h:

Study of Small-Angle Compton Scattering of Photons at 2° to 6° Lab, from Protons.

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.

Luckey et al (M.I.T.), Experiment 109h:

Photoproduction of π^0 from Neutrons.

Luckey, Bar-Yam, et al (M.I.T. and S.M.U.), Experiment 109i:

Photoproduction of π^+ from Polarized Photons.

Deutsch et al (M.I.T.), Experiment 111d:

Proton Compton Effect at 2 to 4.5 GeV and $t = -0.16$ (GeV/c)².

Frisch et al (M.I.T.), Experiment 112a:

Study of Photoproduction of a $2\pi^0$ Resonance (f^0 Particle) with Tagged Photons.

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.

Milburn et al (Tufts), Experiment 114a, Part I:

Measurement of the Polarization of the Proton Recoiling in $\gamma + p \rightarrow p + \pi^0$ Events in which the Pion is Ejected at 65° c.m. and the Photon Energy Varies from 1.2 to 1.8 GeV.

Weinstein et al (Northeastern), 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.

Weinstein et al (Northeastern), Experiment 118i:

Search for Heavy Vector Mesons.

Experiments Performed in the First Five Months of 1970

Russell, Tannenbaum et al (Harvard), Experiment 107a:

Boson Resonance Photoproduction.

Deutsch, Rutherford, et al (M.I.T. and Tufts), Experiment

114b: Recoil Proton Polarization in π^0 Photoproduction ($\gamma + p \rightarrow p + \pi^0$) near $t = -0.30$ (GeV/c) 2 .

Bar-Yam et al (S.M.U.) and Luckey, Osborne, et al (M.I.T.).

Experiment 109j: Asymmetry in Single Pion Photo-production, by Polarized Photon, in the Resonance Region.

Bar-Yam et al (S.M.U.), Experiment 117b:

Extension of Measurements of Photoproduction of Single π^- on Deuterium by Polarized Photons.

Pipkin et al (Harvard), Experiment 121a:

Elastic π^+ Electroproduction near 0° and at Pion-Nucleon c.m. Energies above the Nucleon Resonances.

The detailed purposes of these experiments, and the general experimental approaches, are described in the previous semi-annual report (CEAL-1053).

The results of many of these experiments were published in the six-month period in question, as articles, letters, talks, or theses. These publications are listed in Part VII.

B. Theoretical Studies in Particle Physics

The theoretical physics staff (reduced from three to two by the departure of Dr. Geoffrey B. West at the end of June 1970, and later reduced from two to one by the departure of Dr. Göran L. Fäldt) continued the analysis of the photo-excitation of nucleon resonances, investigated the difference between muon and neutrino induced production of the intermediate vector boson, and continued calculations on hard photon corrections to colliding beam experiments.

Four papers resulting from these studies are listed in Part VII.

C. Safety

In the six-month period in question there were no tabulable disabling injuries and no one received a radiation dose as large as half the permissible dose.

Many portions of the Safety Manual, including the portion on radiation safety, were revised. An Emergency Procedures Manual was drafted and issued.

The CEA Safety Committee was active and a number of training sessions emphasizing safety were held.

Detailed plans for automatically detecting and extinguishing fires in the Control Room, Power Building Basement, Counting Room, and Computer Room were formulated.

D. Training of Disadvantaged Persons

We continued our participation in training programs, sponsored by the Cambridge School Department, TEST, and the Harvard Minority Recruitment Program, to introduce disadvantaged young persons to a variety of technical jobs. Thirteen persons participated in the training program at CEA.

PART VII - PUBLICATIONS RESULTING FROM WORK DONE AT CEA

A. Publications on High-Energy Research Performed at CEA

"Photoproduction of Electron-Positron Pairs at 2.3 and 5.6 GeV",
J. Tenenbaum, A. M. Eisner, G. J. Feldman, W. Lockeretz, F. M.
Pipkin and J. K. Randolph, Phys. Rev. D 2, 57 (1970).

"Dissociation and Stripping of High Energy Deuterons", G. Fäldt,
Phys. Rev. D 2, 846 (1970).

"Photoproduction of Y^* Resonances above 1800 MeV", D. C. Lu,
J. S. Greenberg, V. W. Hughes, R. C. Minehart, S. Mori, J. E.
Rothberg and J. Tyson, Phys. Rev. D 2, 1846 (1970).

"Bound on Virtual Compton Scattering at 185 and 460 MeV/c²",
J. K. Randolph, A. M. Eisner, G. J. Feldman, W. Lockeretz,
F. M. Pipkin and J. Tenenbaum, Phys. Rev. D 2, 1852 (1970).

"Measuring Light-Cone Singularities", R. Jackiw, R. Van Royen,
G. B. West, Phys. Rev. D 2, 2473 (1970).

"Measurement of Electroproduction of Muon Pairs", D. R. Earles,
R. C. Chase, W. L. Faissler, M. W. Gettner, G. Glass, G. Lutz,
R. G. Parsons, P. L. Rothwell, K. M. Moy, H. von Briesen, Jr.,
E. von Goeler and R. Weinstein, Phys. Rev. Letters 25, 129 (1970).

" π^+ Photoproduction from Hydrogen with Polarized Photons",
Z. Bar-Yam, J. de Pagter, J. Dowd, W. Kern, D. Luckey, L. S.
Osborne, Phys. Rev. Letters 25, 1053 (1970).

"Photoproduction of Muon Pairs with Invariant Masses between 930 and 1770 MeV", D. R. Earles, W. L. Faissler, M. Gettner, G. Lutz, K. M. Moy, Y. W. Tang, H. von Briesen, Jr., E. von Goeler and R. Weinstein, Phys. Rev. Letters 25, 1312 (1970).

"Formation-Zone Effect in Transition Radiation Due to Ultra-relativistic Particles", L. C. L. Yuan, C. L. Wang, H. Uto, S. Prunster, Phys. Rev. Letters 25, 1513 (1970).

"Production of Tagged Gammas using a Thin Internal Synchrotron Target", S. R. Smith, D. H. Frisch, S. W. Gray, D. E. Newman, and E. I. Shibata, Nuclear Instruments and Methods 86, 291 (1970).

"Why Do Neutrinos Produce More W's than Muons?", F. A. Berends and G. B. West, Phys. Rev. D 3, 262 (1971)

" ρ, ω Photoproduction Phase: A Possible Breakdown in Vector Dominance", G. Greenhut and R. Weinstein, Phys. Letters 33B, 363 (1970).

"Cambridge Electron Accelerator Bypass", G. A. Voss, Kerntechnik, 12, 534 (1970).

"An Energy Independent Multipole Analysis of Pion Photoproduction on Protons below 450 MeV", F. A. Berends and D. L. Weaver, to be published in Nuclear Physics D.

B. Papers Presented at Conferences and Meetings

XV International Conference on High Energy Physics
Kiev, USSR, August 28 - September 4, 1970

"Proton Compton Effect with Small Momentum Transfer for 3 GeV Photons", D. F. Jacobs, Martin Deutsch.

"Lepton-Hadron Interactions and Quantum Electrodynamics",
R. Wilson.

"Preliminary Report on CEA Electroproduction Experiment",
C. Brown, C. Canizares, W. Cooper, A. M. Eisner, G. J. Feldman,
C. Lichtenstein, L. Litt, W. Lockeretz, V. Montana, F. M. Pipkin.

Informal Meeting on e^+e^- Colliding Beams
Frascati, Italy, September 15 - 18, 1970

"Status of the CEA Colliding Beam Project", J. M. Paterson.

"Experimental Program with the Bypass", R. Little.

American Physical Society Meeting
Stanford, California, December 28 - 30, 1970

"Coincidence Measurements of Single π^+ Electroproduction: Angular Distribution for S near 4.5 GeV²", A. M. Eisner, C. N. Brown, C. R. Canizares, W. E. Cooper, G. J. Feldman, C. A. Lichtenstein, L. Litt, W. Lockeretz, V. B. Montana, and F. M. Pipkin, Bull. Am. Phys. Soc. II-15-12, 1634 (1970).

"Coincidence Measurements of Single π^+ Electroproduction: Dependence of the Forward Cross Section on S and k²", G. J. Feldman, C. N. Brown, C. R. Canizares, W. E. Cooper, A. M. Eisner, C. A. Lichtenstein, L. Litt, W. Lockeretz, V. B. Montana, and F. M. Pipkin, Bull. Am. Phys. Soc. II-15-12, 1634 (1970).

C. Theses on High-Energy Research Performed at CEA

"A Compton Back-Scattered High-Energy Photon Beam", thesis of August 1970 by J. R. Sauer of Tufts.

"Quasi-Elastic Electron-Deuteron Scattering", thesis of October 1970 by K. M. Hanson of Harvard.

D. CEAL Reports

CEAL-1052 "Simplified Radial Survey of the CEA Magnet Ring", K. W. Robinson and W. A. Shurcliff, August 10, 1970.

CEAL-1053 "Semi-Annual Report for the Period January 1 through June 30, 1970, K. Strauch, November 30, 1970.

CEAL-1054 "A Simple Threshold and Delay Circuit for Multiwire Proportional Chambers", C. Rubbia, October 5, 1970.

E. CEAL-TM Reports

CEAL-TM-193 "Status of CEA External Beam Monitors", G. F. Dell, September 1, 1970.

CEAL-TM-194 "Computer-Aided Control and Monitoring of Power Systems at the CEA", G. Conzalez, December 22, 1970.

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