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CEAL-1056

SEMI-ANNUAL REPORT

For the Period

January 1 through June 30, 1971

K. Strauch, Director

W. A. Shurcliff

July 21, 1971

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
and HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

CAMBRIDGE, MASSACHUSETTS 02138

DISCLAIMER

The research work described in
this report was performed under
Contract AT(30-1)-2076 between
the U.S. Atomic Energy Commission
and the President and Fellows of
Harvard College.

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42 OXFORD STREET
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SUMMARY

Part I indicates the purpose of the contract: to operate and improve the 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 Boards and Review Boards are described.

Part II summarizes accelerator operation.

Part III summarizes progress made in PROJECT BYPASS. The new 200-kw-ave rf system was installed and performs well. On May 21 we for the first time succeeded in making a reliable measurement of luminosity with crossing beams of 2 GeV each ($L = 1 \times 10^{27}$ cm^{-2} sec^{-1}). This was the result of many improvements in control of beam instabilities and beam position. Coherent betatron oscillations were successfully damped by means of octupole magnets, chromaticity was largely eliminated

by correcting with distributed sextupole magnets, and an avenue for controlling coherent synchrotron oscillations (by means of a 1427 MHz Landau cavity) was demonstrated. Preparations for increasing the luminosity were made.

Part IV describes the bypass on-line detector (BOLD) which is ready for use on short notice.

Part V describes the magnetic on-line detector (MAGNOLIA) which will be needed in the analysis of hadron events, now expected to be more numerous and interesting than had been anticipated only a few years ago.

Part VI deals with repairs and improvements to the accelerator proper.

Part VII discusses other programs.

Part VIII lists the major publications.

PART I - INTRODUCTION

A. The Contract

This report summarizes work done under the Harvard-AEC Contract AT(30-1)-2076 during the six-month period from January 1 through June 30, 1971. 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.

B. Committees and Boards

The general policies of the Laboratory are determined by a joint M.I.T.-Harvard "Executive Committee of the CEA". Early in 1971 this Committee included the following:

from M.I.T.:	Prof. Albert G. Hill
	*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

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

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*denotes member of Scientific Subcommittee 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 early 1971 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
Dept. of Physics, Univ. of Calif., Berkeley

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

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

PART II - ACCELERATOR OPERATION

As explained in the previous semi-annual report (CEAL-1055), 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.

During the period January 1 - June 30, 1971, the distribution of accelerator time was as shown in Table 1.

Table 1

Accelerator Use in First Half of 1971

(Number of 8-hour shifts)

Month	Studies of Beam Accumulation, Storage and Collision	Installation of New Equipment, Maintenance, and Repair, Unscheduled Downtime	Total
January	44.6	19.4	64.0
February	46.4	14.6	61.0
March	42.4	29.5	72.0
April	44.3	22.7	67.0
May	46.2	19.8	66.0
June	40.8	28.2	69.0
	264.7	134.2	399.0

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 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.

PART III - COLLIDING BEAM FACILITY

A. Operation of Colliding Beam Facility

The procedure 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 Figs. 1 and 2) and remain in orbit with a 1/e lifetime of the order of one half hour. In most of the

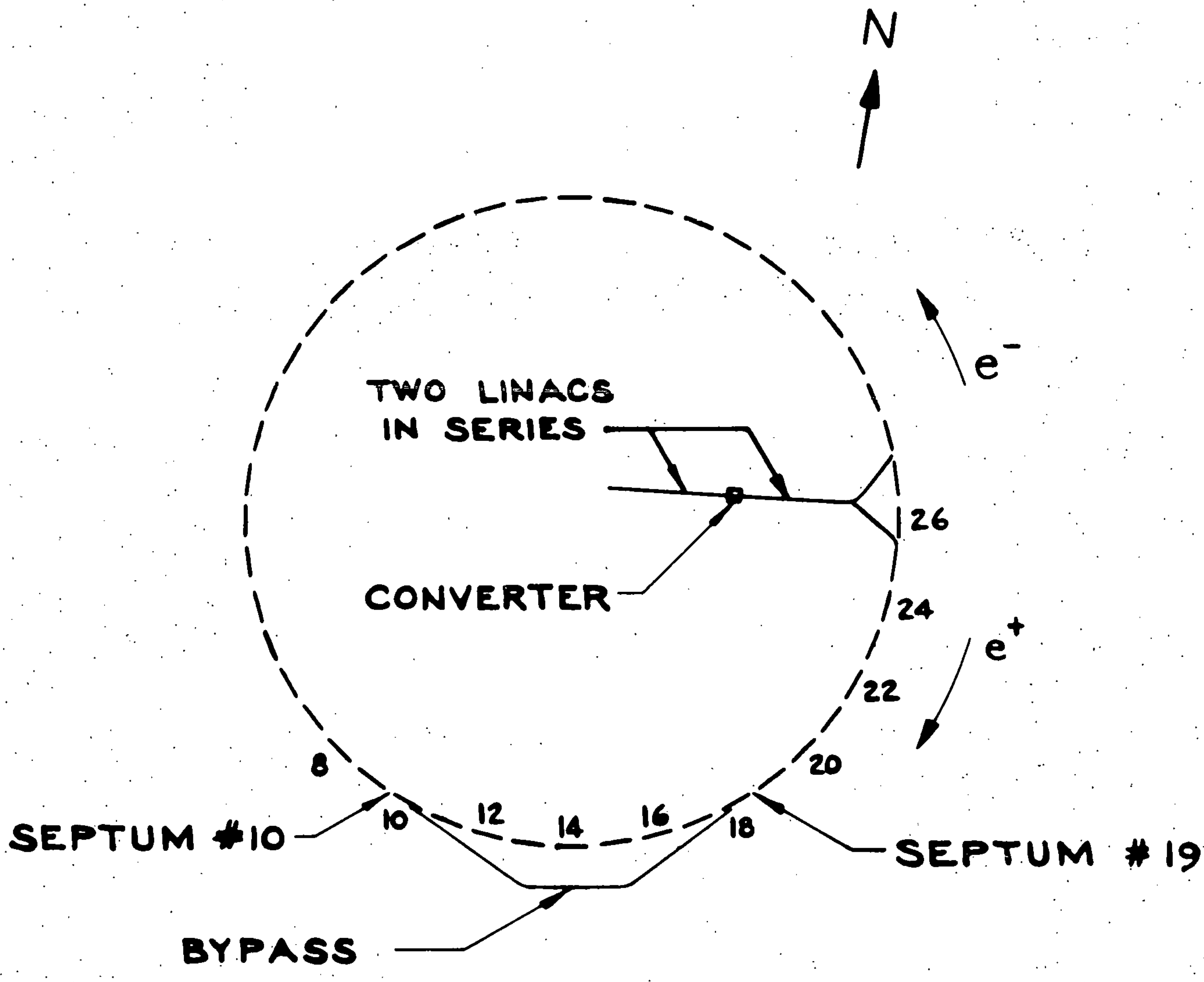
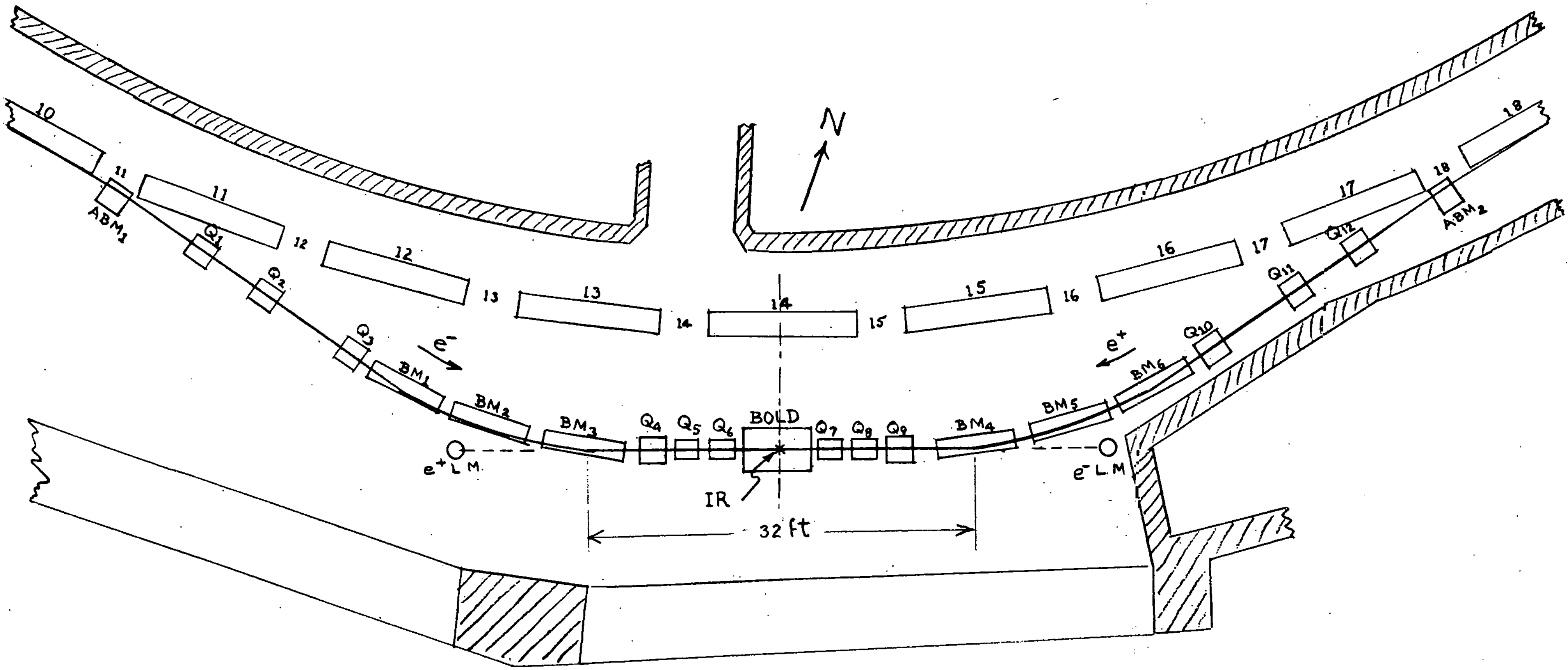


Fig. 1. Relationship of the bypass to the synchrotron ring of 48 magnets. The terminations of the bypass, and likewise the septum magnets used in switching, are at straight sections 10 and 19.

Fig. 2. Main components of the CEA Bypass. The symbols Q, BM, ABM, LM, IR stand for quadrupole magnet, bending magnet, auxiliary bending magnet, luminosity monitor and interaction region



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 (the goal is a cross section ∿ 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 $10^{31}cm^{-2}sec^{-1}$.

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 computer. A magnetic on-line detector (MAGNOLIA) is also under construction; it will provide a more detailed analysis of complex events.

By December 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 made, many preliminary problems had been identified and solved.

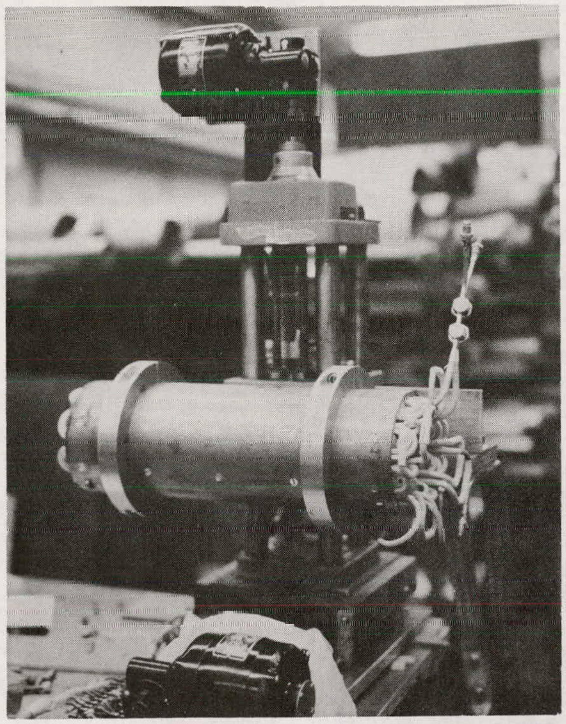
The progress made in the first half of 1971 is summarized below. Some of the principal improvements were: completing the new RF system, greatly increasing the damping of coherent betatron oscillations and synchrotron oscillations, reducing chromaticity, installing improved means for measuring beam geometry at the interaction region, increasing the intensity of stored beams, and (on May 21) making a reliable measurement of luminosity with crossing beams ($L \sim 10^{27}$ cm^{-2} sec^{-1}). Plans for increasing the luminosity to a useful value were formulated.

B. New RF System

In February we completed the installation and testing of the new, 200-kw-ave. rf transmitter system (employing four Varian 953-C five-cavity klystrons) and put it into routine use. It has performed excellently. Detailed accounts of the design are presented in the Monthly Report for January and in CEAL-TM-195. The reliability of the new system has been so high that the system has caused virtually no downtime of the accelerator.

C. Damping Coherent Betatron Oscillations

Although, in the previous half-year, we had succeeded in controlling bunch-to-bunch betatron-oscillation interactions by means of an rf quadrupole, limits on current accumulation continued to be imposed by coherent within-bunch betatron oscillations. In December 1970 an octupole magnet had been installed in the bypass to produce Landau damping of such oscillation, but was of insufficient power. A ten-times more powerful octupole was installed in January (see Fig. 3); provision was made for accurate empirical, remotely-controlled centration on the beam. Using this octupole, we were able to accumulate currents up to 25 mA peak without encountering instabilities.



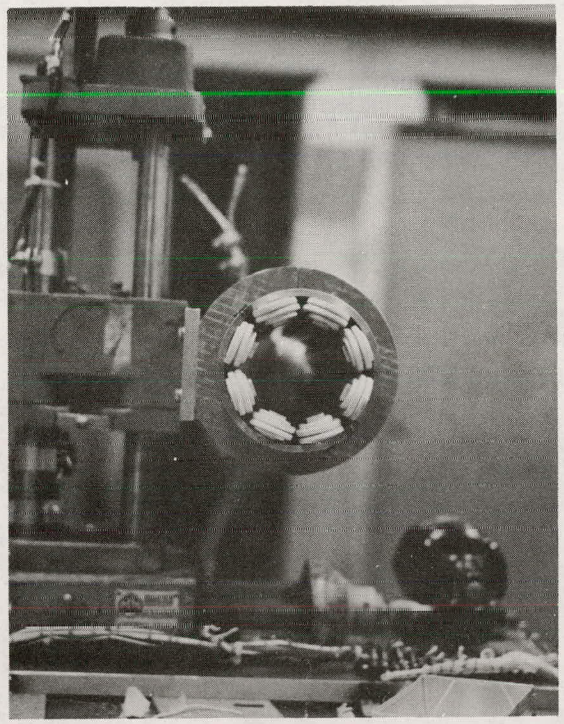


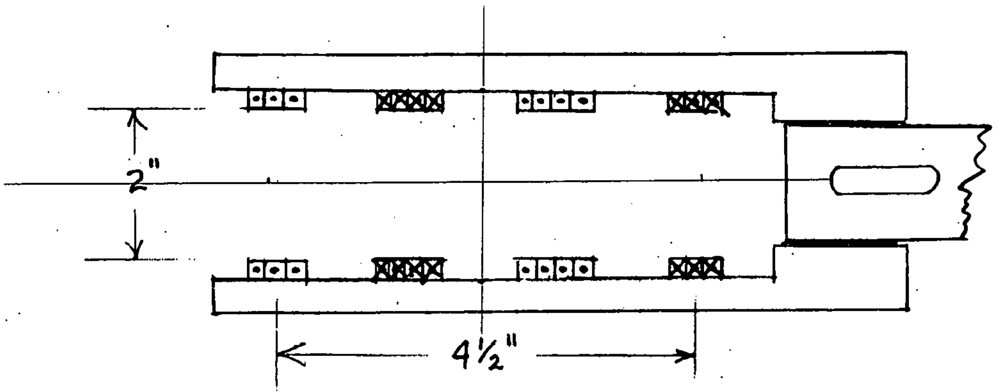
Fig. 3. New Bypass Octupole with support system. The octupole can be remotely centered on the beam.

D. Reducing Chromaticity

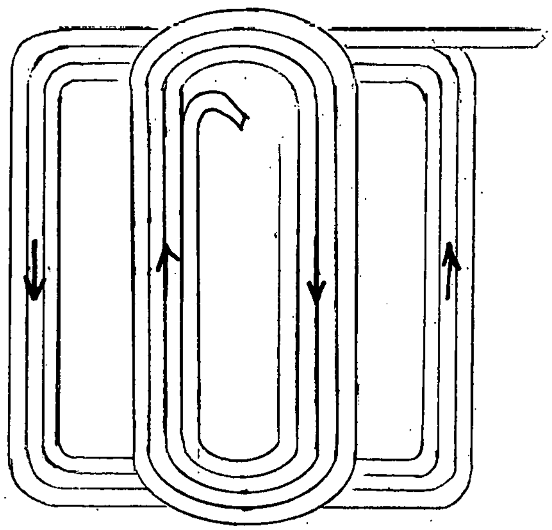
After having achieved better control of the betatron frequencies ν_h and ν_v by means of magnetic and electrostatic quadrupoles and avoidance of bunch-to-bunch betatron-oscillation interaction and coherent within-bunch betatron oscillation, we found that beam accumulation and lifetime were limited by the extreme narrowness of operating plateaus between stop-bands, this narrowness being, in large part, a result of chromaticity ($\xi = \frac{d\nu}{dp/p}$) associated with fringe-fields at the ends of half-magnets and with special magnets along the orbit. In February we found the horizontal and vertical chromaticities ξ_h and ξ_v to be -15 and -10.

We then built and installed a distributed set of 12 air-core sextupole magnets (see Fig. 4). Six were installed in closed magnets to control ξ_h and six in open magnets to control ξ_v. The distributed arrangement greatly relaxes the requirements on centration. In March, using a 400 amp. d.c. power supply, we evaluated the effectiveness of the set of sextupoles. We found the magnitudes of the chromaticities to be reduced by an order of magnitude; chromaticity of the ring as a whole could be eliminated and chromaticity of ring-plus-bypass almost eliminated. Greater beam currents could be accumulated, stored, and switched into the bypass. Several troublesome and hard-to-identify resonances disappeared, and most of those that remained were easily identified (for example, the sum resonance: $3\nu_h + 2\nu_v$ = integer).

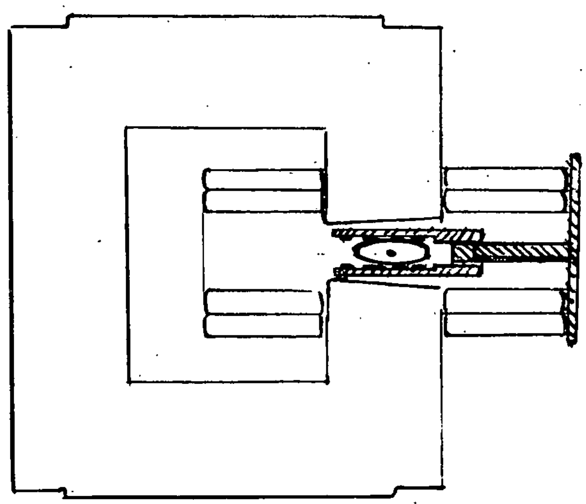
The most significant effect of eliminating chromaticity



a. Cross-section of sextupole magnet. Support members are of cotton fabric and phenolic resin.



b. Plan-view of one set of coils of 1/8-inch pierced rectangular copper conductor.



c. Location of device at central junction of an open magnet.

Fig. 4. Sketches indicating design of sextupole magnet.

(or even reversing its sign to positive) was the large increase in threshold currents for beam instabilities.

At the highest currents used in the tests (30 mA peak), with electrostatic separation plates on, no instability was encountered and the beam was switched into the bypass without loss.

In general, control of ξ_h appeared far more important than control of ξ_v. With the present set of sextupole magnets, the magnitudes of both of these quantities can be reduced to zero.

Some of the sextupoles are powered in series with the synchrotron magnet ring and are used to provide close control of chromaticity during multicycle injection.

After proper adjustment of sextupole fields, stable operating conditions were found for both beams, and the most critical of the bypass magnets had current plateaus 0.2% wide -- large compared to the variability of the power supplies.

Some refinement of the sextupole field in the synchrotron ring is now underway, with the purpose of increasing the useful magnetic aperture with respect to six-pole component and thus increasing beam lifetime when the beams are especially wide, i.e., at B_{min} during positron multicycle injection.

E. Damping Coherent Synchrotron Oscillations

In September 1970 we first tried damping the coherent synchrotron oscillations by means of a cavity (#6) powered at the 362nd harmonic (rather than the usual 360th harmonic) of the orbital period -- with the purpose of assigning a slightly different synchrotron-oscillation frequency to successive bunches. Although the power supplied to the special cavity was only 0.3 kw, a significant increase in Landau damping was observed.

In February, 1971 we installed a ten-times more powerful source of 362nd harmonic power, and in March we found the amount of Landau damping to be greatly increased. Inspection of CRO patterns indicated that the remaining coherent oscillations were small. Beam lifetime was long, and the maximum attainable peak current was approximately doubled. For example, we achieved a 25 mA peak, 7.5 mA ave. positron current.

In April, having achieved greatly improved control of chromaticity and coherent betatron oscillations, we found it necessary to provide greater control of beam-cavity interactions and coherent synchrotron oscillations. Suspecting that the high shunt impedance of the rf cavity system was causing high-current beams to induce cavity voltages great enough to produce partial loss of beam, we decided to see what improvement could be made by greatly reducing the induced voltages. Such reduction would permit reducing the main applied rf voltage -- without sacrificing large ratio of applied voltage to induced voltage -- and thus would lead to greater length of bunch and increased amount of Landau damping of coherent synchrotron oscillations.

Two approaches were available: (1) tuning the cavities to a frequency well-removed from the rf transmitter frequency and (2) disconnecting most of the cavities and powering only a few. At the end of April we tried out the first of these schemes. While holding the rf transmitter frequency constant at 475.790 MHz, we adjusted the cavity tuners so as to produce cavity natural frequencies of 475.725 -- 65 KHz (3/2 bandwidths) below the rf frequency. Immediately we succeeded in accumulating an e^- sausage of 100-mA peak current and 8-mA average current. Some portions of the sausage had peak currents as high as 125-mA peak.

In May we tried the second approach: we disconnected all except one of the 16 rf cavities. Only #39 remained connected. Immediately we succeeded in producing a 70-mA-peak, 10-mA-ave electron beam.

We then tried powering <u>two</u> cavities: #39 and #42. Even better performance resulted: we produced a 100-mA-peak, 18-mA-ave e^- beam with a sausage length of 40% of the orbit circumference, and we produced a 100-mA-peak, 13-mA-ave e^- beam with the desired (25 to 30%) sausage length. In general, beam stability was excellent, although on some occasions ten or twenty successive bunches were absent. Ramp-up was accomplished easily. <u>Positron</u> injection likewise was more successful than in previous months.

We found that use of the 362nd harmonic cavity was still helpful. Without it, there was clear evidence of coherence of synchrotron oscillation whenever beam current in cycling mode exceeded $\sim$ 6 mA peak. Using this special cavity, no coherence of oscillation was detected; also, efficiency of injection was increased -- and we were able to accumulate a

35-mA-peak electron beam without disturbing an accumulated positron beam already in orbit.

It was clear, however, that the present special cavity did not produce a sufficiently strong effect, and accordingly we started a study of possible avenues for increasing the Landau damping. We recognized that a large increase in harmonic number would be desirable inasmuch as the amount of damping varies as the cube of harmonic number, for a given amplitude of this rf power. Merely increasing the voltage at the 362nd harmonic (at 478 MHz) would be unsatisfactory: we would be obliged to use voltages so high as to produce electrical breakdown and to shorten the sausages unacceptably.

We decided on a frequency of 1427 MHz, i.e., the 1080th harmonic of orbital frequency and the third harmonic of the frequency of the main rf power. We designed a cylindrical "Landau cavity" (see Fig. 5) resembling a portion of a 1427 MHz, π-mode linac with an inside diameter (7 in.) and length (2 ft.) such that it could be fitted inside a slightly modified standard straight-section tank. Construction and testing were completed in June, and the device was installed in Straight Section 6 on June 12. The Q of the cavity was found to be 24,000 and the shunt impedance was $\sim$ 3.5 MΩ. The device is tunable and bakeable.

In first trials, the device was self-powered, i.e., by the passage of the 1-to-3-inch-long bunches. When beam energy and current were high (and bunch length was short), the induced 1427 MHz voltage produced an adequate amount of

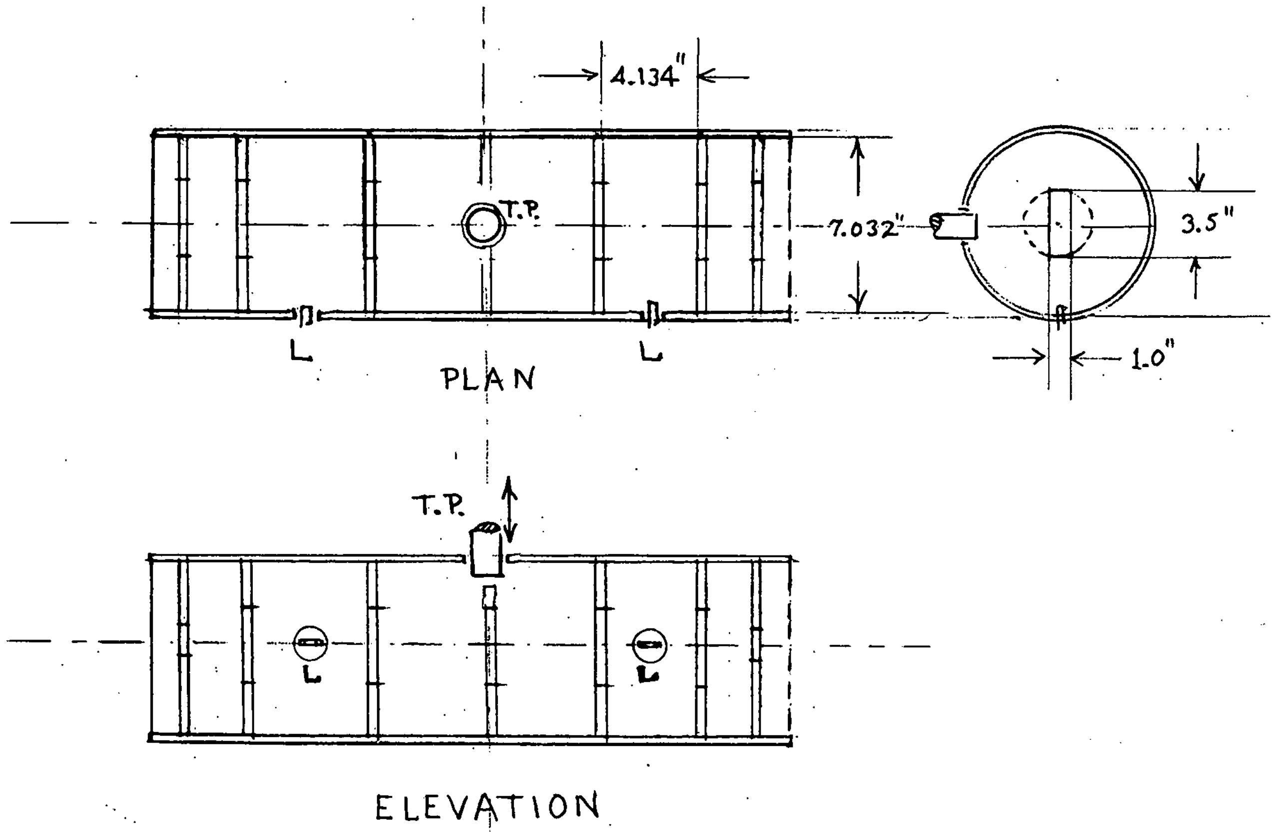


Fig. 5. 1427 MHz Landau cavity, with four full chambers and two half-chambers. At top center there is a tuning post (T.P.) and on one side there are two rf loops (L). The water cooling system, the holes for egress of gas from the chambers, and the enclosing vacuum tank are not shown.

Landau damping. But during the low-energy portion of the multi-cycle injection cycle the bunch length was so great that the induced voltage was too small to be effective.

At the end of June construction of a several-kw source of 1427 MHz power was underway.

F. Measuring Beam Size in the Interaction Region

In April we started studies of beam size in the interaction region by means of a fiber flicked rapidly across the beam and a spill detector connected to a CRO. A variety of silica and carbon fibers were available, mounted in a spare 3-inch-diameter interaction-region beampipe. Fiber diameters were 1- and 5 microns.

On putting this equipment to work, we found that, on adjusting beam controls so as to produce known resonances, large increase in beam height resulted; the corresponding increases at locations in the synchrotron ring could be detected also -- via TV views of beam-cross-section images produced by synchrotron radiation. When the bypass electrostatic separation plates were not used and the beams passed through one another collinearly, the height of beam cross section was found, typically, to be several-fold greater than when the plates were powered so as to keep the beams separate except at the bypass midpoint. See Fig. 6. Normally the plates were powered so as to produce a 1-milliradian crossing angle.

We were surprised to find that some unsuspected resonances caused increases in beam height. Many of these increases, although easily revealed by the fiber, did not show up in the

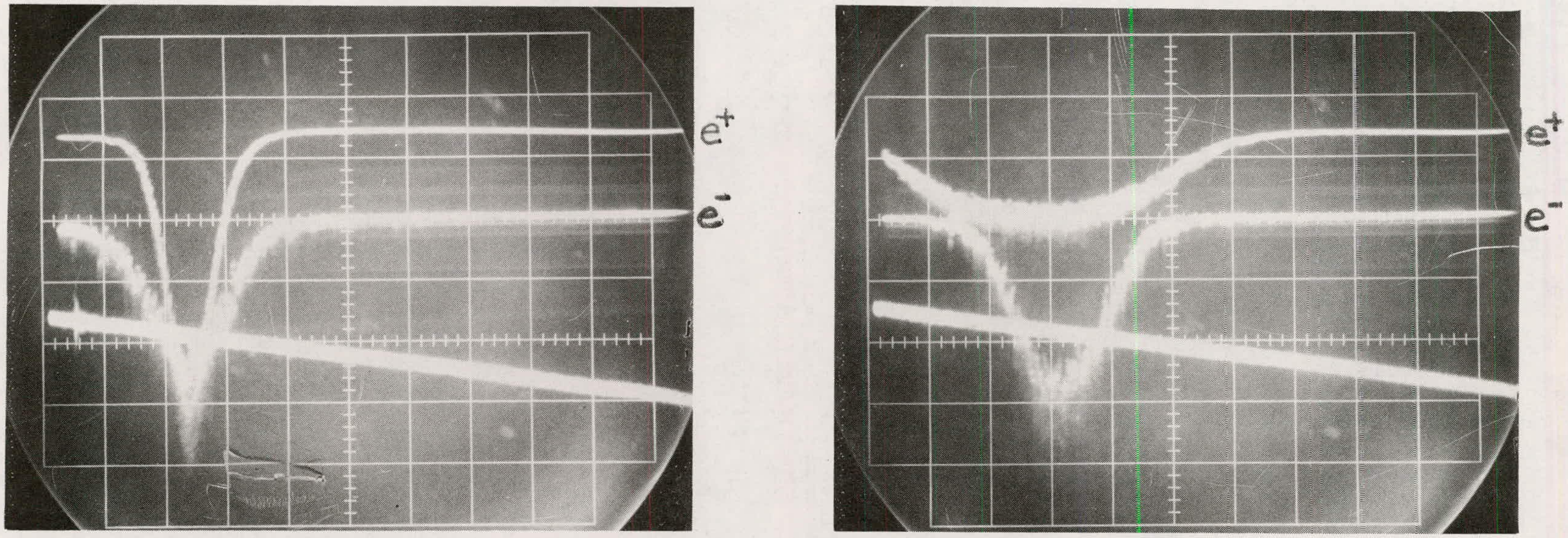


Fig. 6. Height of beam cross-sections with and without use of the bypass electrostatic separation plates. Each pulse represents the bremsstrahlung pulse produced when a horizontal 5-micron-diameter fiber was moved vertically through the beams at a speed of approximately 10in./sec. Height of beam cross section is indicated by the pulse width. (The straight sloping traces are to be ignored.) Horizontal scale: 1 cm = 0.0012 inch. Left view: Electrostatic separation plates powered; beams vertically separate except at bypass midpoint. Right view: Electrostatic separation plates not powered; beam axes coincident; note approximately three-fold greater height of cross section.

TV views, because the resolution provided by the fiber is an order of magnitude greater than that provided by the synchrotron-radiation image. We mapped the new resonances, then readjusted the beam controls to keep clear of them.

We then found that, with but a single beam in orbit and a current less than 5 mA average, the FWHH height of beam cross section was ≤ 0.0025 inch, close to expectation. The lower limit on height could not be ascertained, partly because the diameter of the fiber was appreciable and partly because beam size gradually increased, through scattering by the fiber, during the 0.0001-sec interval (corresponding to 140 orbital periods) in which the fiber was moving across the beampath.

With e^- and e^+ beams of a few-mA-average current in the bypass simultaneously and with the separation plates powered so as to make the beams cross at an angle of 1 milliradian, it was a simple matter (using the fiber) to find the vertical positions of the two beams, find how the vertical positions varied with separation-plate potential, and to arrange to have the beampaths cross exactly at the bypass centerpoint. Figure 7 shows traces indicating approximately correct and incorrect location of beampath intersection point.

We found that tilting the adjacent quadrupole magnets in either sense caused an increase in beam cross-section height. In other words, the usual orientations of these quadrupoles appear to be optimum.

A further question remained: Did the e^- and e^+ bunches

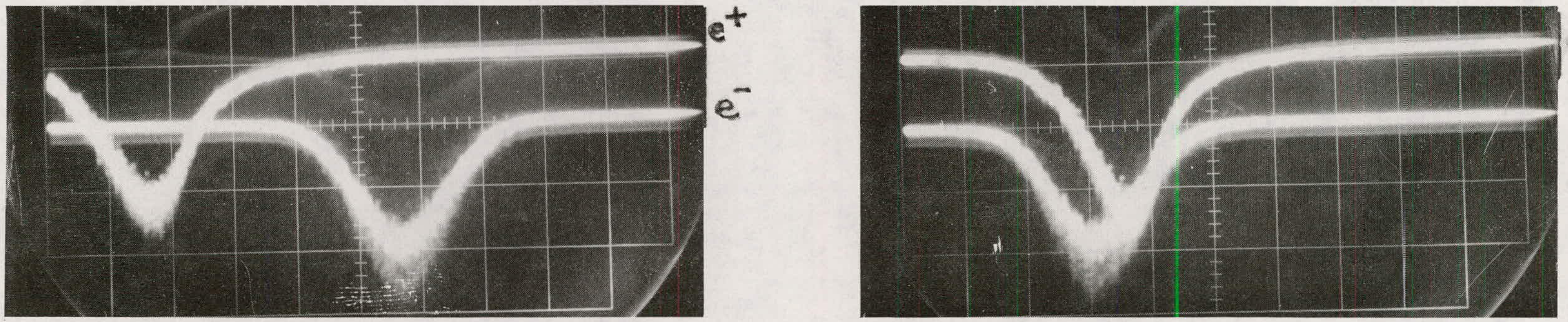


Fig. 7. Measurement of vertical positions of e^+ and e^- beams at center of bypass. Vertical position of beam is indicated by position of pulse along the horizontal axis. Upper and lower traces represent e^+ and e^- beams respectively. Left view: before adjusting vertical positions. Right view: after adjusting the electrostatic separation plates so as to make the positions identical within 0.001 inch.

arrive at the beampath intersection point at the same time? Did they actually pass through one another? Tests made with a fast loop-type monitor (situated 3 ft. from the intersection point) and a sampling scope showed that the two kinds of bunches had the proper relative longitudinal positions within ∿ 3/4 inch. We hope to improve the accuracy of the method by at least a factor of 2, since the bunch length is only 1 or 2 inches and, with 0.001-inch height of beam cross section and a 1-milliradian crossing angle, there would be significant loss of luminosity if the longitudinal positions failed to agree within a small fraction of an inch.

When there was a few-mA-average electron beam in orbit simultaneously with a weaker positron beam, with the separation plates turned off so that the beams traveled collinearly through one another, the height of the positron-beam cross section was found to be increased by an amount that depended strongly on the average current in the electron beam. However, if the crossing angle was at least 1 milliradian, the height of the positron-beam cross section remained small and equal to that of the electron beam.

G. Preparations for Luminosity Trials in May

In preparing for luminosity trials of May, we constructed a new, bakeable fiber system and installed it in an interaction-region beampipe of larger diameter: 8 inches instead of 3 inches. Because of the greater pneumatic conductance provided, and the capability of bakeout, we expected the new equipment to permit us to achieve a much higher vacuum near the interaction region than had been possible before.

In addition we provided in the bypass, additional sublimation pumps, and synchrotron-radiation-absorbing vanes. We improved the bake-out system and installed additional pressure gages.

The zero-degree luminosity monitors (discussed in the Monthly Report for November 1970, and indicated schematically in Fig. 8) were improved and tested.

In mid-May we tried out the new beampipe and found it to perform well. When a beam of 5 mA ave was introduced into the bypass, the pressure in this beampipe rose to two orders of magnitude above the base pressure of 3×10^{-10} torr, but within one day the sublimation pump reduced the pressure rise here to approximately one third. The major axis of the beam cross-section ellipse at the interaction point was found to be horizontal and the cross-section height and width were approximately 2.5 and 19 mils respectively.

H. Measurement of Luminosity

On May 21 we succeeded for the first time in making a reliable measurement of luminosity with crossing beams. The value obtained was 1×10^{27} cm^{-2} sec^{-1}. Each of the beams had an energy of 2 GeV and the crossing angle was 1 milliradian. The length of sausages was $\sim$ 200 ft. and the length of individual bunches was 1 to 2 inches. The height and width of the beam cross-section at the interaction region

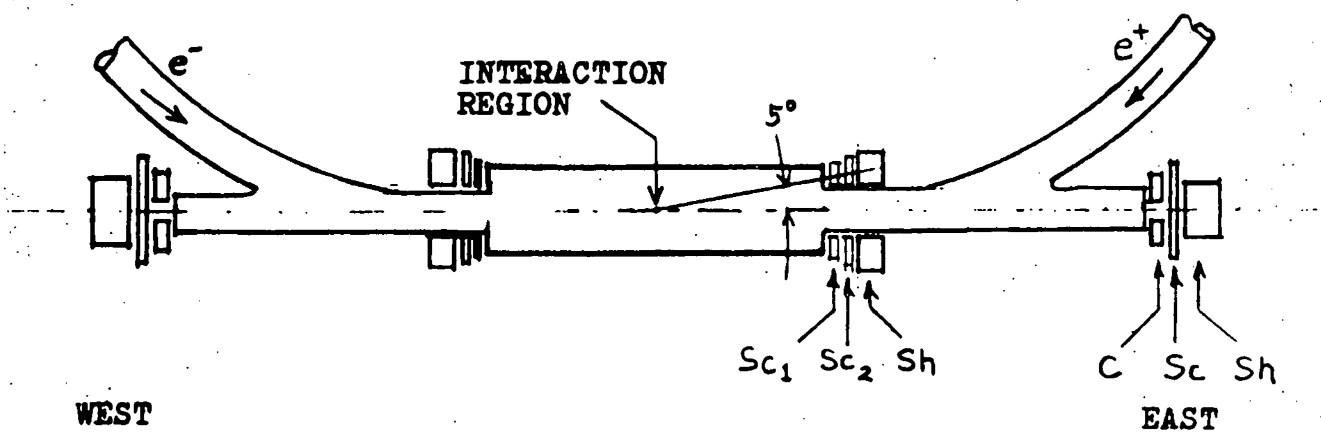


Figure 8.

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 Sc_1, a larger scintillation counter Sc_2, and a shower counter Sh.

were $\sim$ 2.5 and 19 mils, as determined earlier.

The procedure was to vary, in steps, the potentials applied to the electrostatic guide plates, so that the vertical positions of the two beams would change equally and oppositely and the crossing point would shift along the beam-pipe axis. Because bunch length was small (1 to 2 inches) and bunch height was extremely small (a few mils), the countertraveling bunches would no longer make contact with one another when the beam vertical displacements exceeded $\sim$ 2.5 mils. See Fig. 9. Under such circumstances any high-energy photons produced must be ascribed to bremsstrahlung from collision of e^+ or e^- with gas molecules.

Event rates were determined by the zero-degree luminosity monitors at either end of the 25-ft-long straight central portion of the bypass. Each monitor, designed to detect single photons having energies exceeding 0.7 GeV, included a scintillation counter for vetoing charged particles and a shower counter (with discriminator) for detecting the photon. Although the two monitors gave comparable results, we concentrated our attention on the monitor detecting bremsstrahlung produced by e^+.

Fig. 10 shows the counting rate in a typical set of runs with e^+ and e^- currents of 2.5 and 14 mA peak and a gas pressure in the 10^{-9} torr range. When the beam vertical separation at the bypass center exceeded 4.5 mils in either direction, the number of counts recorded in ten seconds held steady at $\sim$ 3500; the data presented in Fig. 10 have been corrected

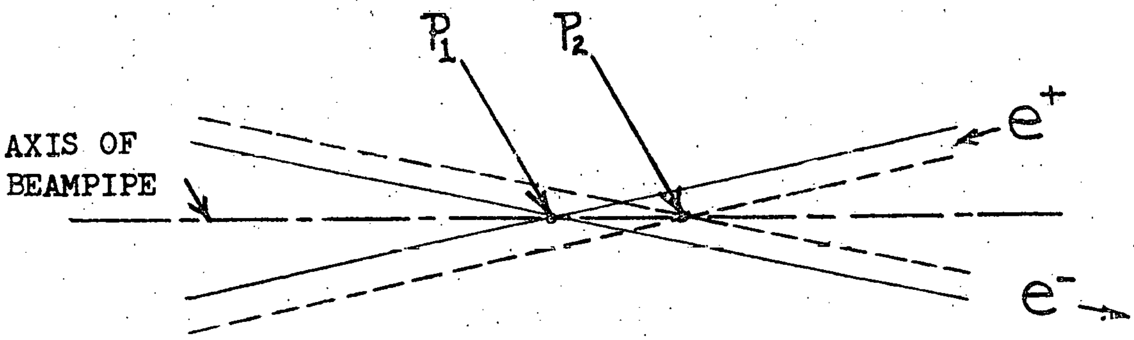


Fig. 9. Longitudinal shift of crossing point as the potentials applied to the electrostatic guide plates are changed. Full curve: correct potentials, producing crossing at P_1. Dotted curve: modified potentials, with crossing point shifted to right.

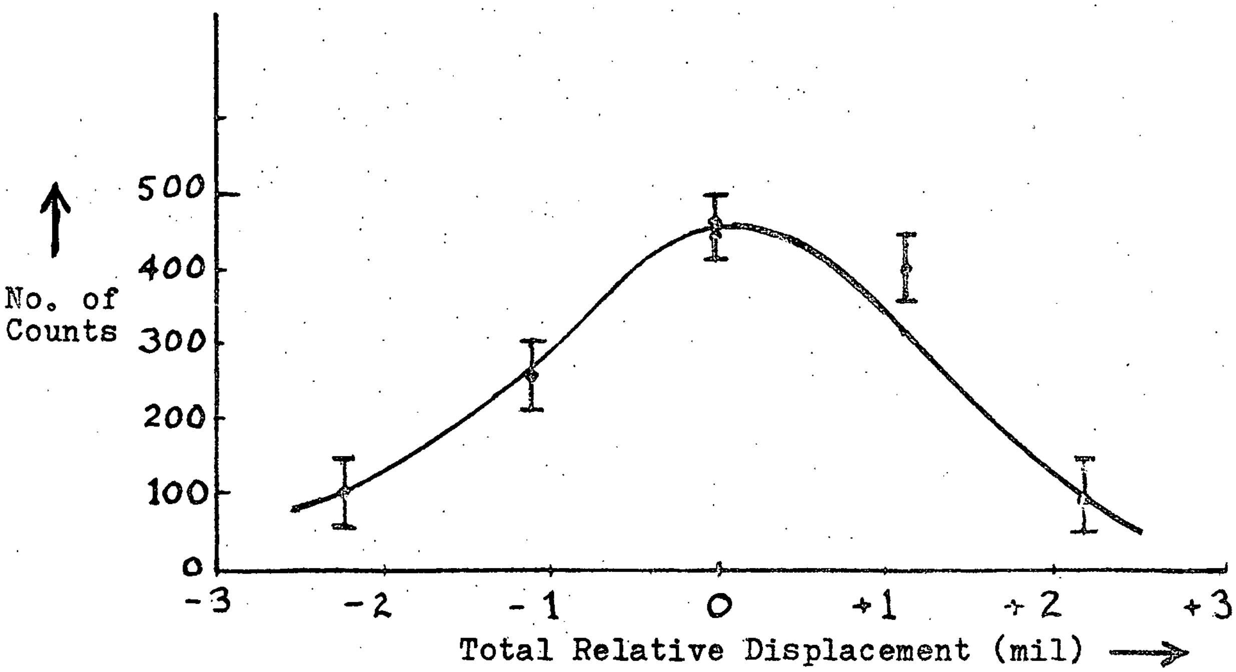


Fig. 10. Background-corrected count as a function of vertical displacement of e^+ beam relative to e^- beam. Counting period: 10 sec. Zero value of displacement is the absolute value determined independently with the aid of a transverse fiber flicked through the beams.

for this background rate. The height of the resulting peak (460 counts) implies a luminosity of 1 x 10^{27} cm^{-2} sec^{-1}.

It is to be noted that the absolute vertical relationship of the two beams implied by the results shown in Fig. 10 is in agreement within .5 mil with the absolute relationship established with the aid of a horizontal fiber flicked vertically through the beams. Also, the height of beam cross section implied by the results in Fig. 10 is in agreement with the height established with the fiber.

It is a valuable feature of a low-beta, short-bunch, crossing-beam machine that slight (few mil) displacement of the beams will shift the luminosity from full to zero, so that, at any time, background can be evaluated under conditions essentially identical to those existing during colliding beam runs.

We have already achieved more intense beams than were applicable in the present luminosity measurement. Further increases in luminosity are expected when we complete several new control devices now under construction and when we decrease beta function (discussed in the following paragraph).

I. Plans for Increasing the Luminosity

The luminosity reported in the previous paragraphs was accomplished with the smallest interaction-region beta function yet achieved anywhere. Nevertheless, the present scheme for powering quadrupole magnets and other magnets influencing the betatron frequencies and governing the values of horizontal and vertical beta functions at the interaction region leave these beta-function values several times greater than the original goals of 2 inches.

In June we computed several "tunes" (sets of values for the currents in the twelve quadrupole magnets of the bypass) which represent different ways of reducing the beta function at the interaction region.

It was apparent from the outset that reducing beta function at the interaction region would necessarily entail <u>increasing</u> beta function at the locations of Quadrupoles Q_4 and Q_9 and at locations of other nearby quadrupoles. This in turn would increase the actual width of beam here -- because beam width varies as $\sqrt{\beta}$.

Even with the beamwidth (at Q_4 and Q_9) typical of recent months' operation, the off-axis fields provided by those quadrupoles were not of pure quadrupole type, but contained significant amounts of 12-pole field and consequently there was some loss of useful aperture and some reduction in beam lifetime. Widening the beams here would certainly accentuate the 12-pole component of field and further reduce beam lifetime.

To increase the useful apertures of the crucial bypass quadrupole magnets we replaced several of the 3-inch-bore quadrupoles with 4-inch bore quadrupoles, and we have installed 12-pole, pole-face windings to cancel the 12-pole component of field even at locations 1-inch off-axis. This improvement was expected to be completed in July.

Other improvements to increase the positron current are being planned.

PART IV - BYPASS ON-LINE DETECTOR (BOLD)

A. General Design

The general design of the bypass on-line detector (BOLD) is indicated in Figs. 11 and 12. Designed jointly by the CEA staff and a Harvard group, the system is designed primarily to detect photons, electrons, muons, and hadrons. It consists essentially of four core-quadrants and two flanking assemblies called 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-method) 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 at angles of 0, 75, 105, and 180 degrees. 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.

Pulses from photomultipliers that view the scintillators pass to discriminators and thence to pulse-area digitizers and a logic system. If the simultaneously received pulses satisfy the criteria for trigger, the spark chambers are powered and other key components are gated on. Also, the areas of pulses from the scintillators that serve as shower counters (i.e., scintillators preceded by radiators) are measured

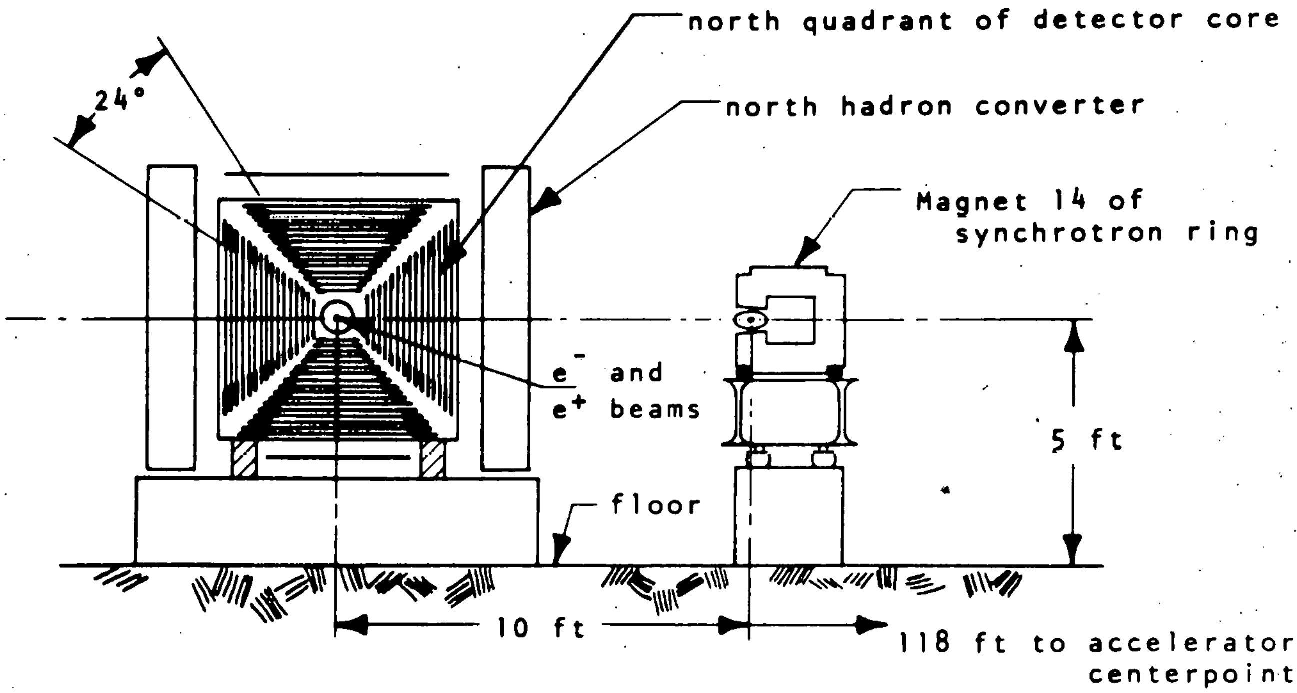


Fig. 11. Vertical section through bypass (and adjacent portion of synchrotron ring) at the bypass midpoint.

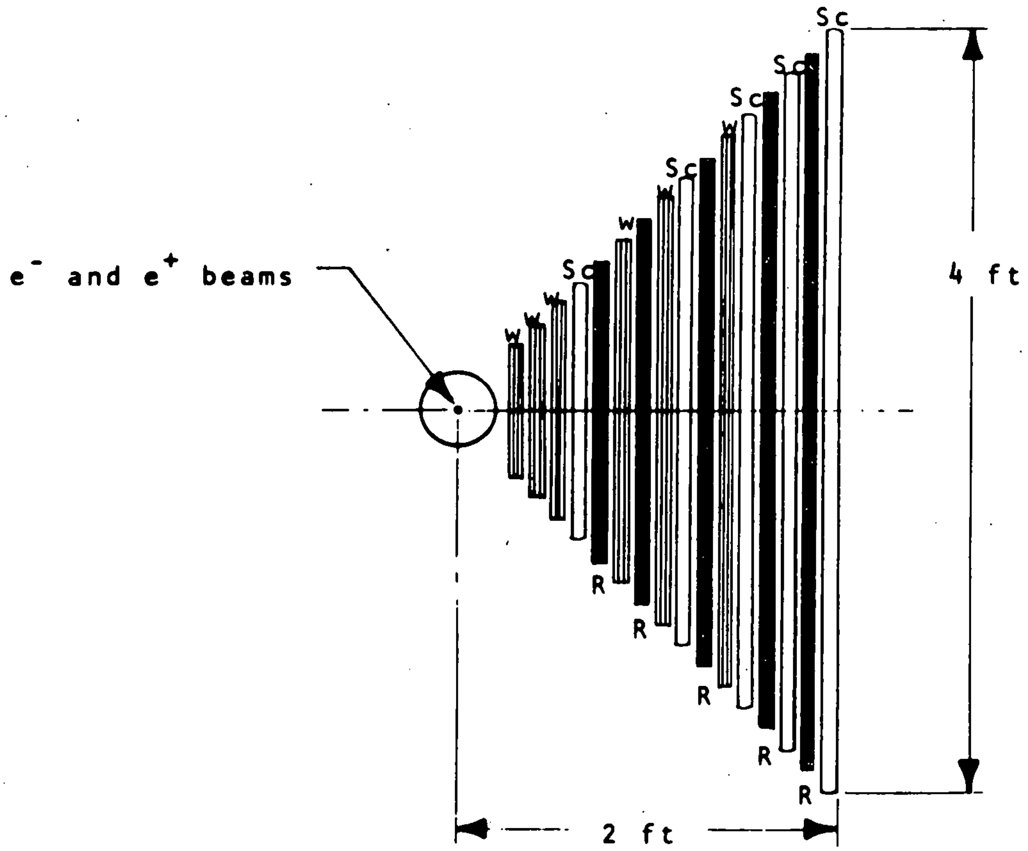


Fig. 12. Cross section of north quadrant of detector core, showing the six wire spark chambers (w), five scintillation counters (Sc), and five radiators (R). The e^- and e^+ beams are at the center of the beampipe.

and expressed in digital form.

As indicated in Fig. 13, digitized spark-chamber and scintillator data are sent via a main interface, to the main computer. Here the useful data are recorded in compact form on magtape; also, a Fortran IV program causes this same computer to make an on-line, preliminary determination of event-type and, on command, present 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 data 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 individual spark chambers and scintillators are compiled.

B. Progress and Status

By the end of June preliminary testing of all four of the quadrants of BOLD was complete, two quadrants (upper and lower) were installed at the interaction region, and the other two were situated nearby ready for installation.

Three prototype hadron spark chambers were built and much preliminary testing had been done.

The great majority of the electronics for the scintillator outputs and spark chamber outputs had been built and tested, and the same applies to the electronics for veto of cosmic-ray muons.

The on-line program has been essentially completed and is available for use on short notice, but we are still making

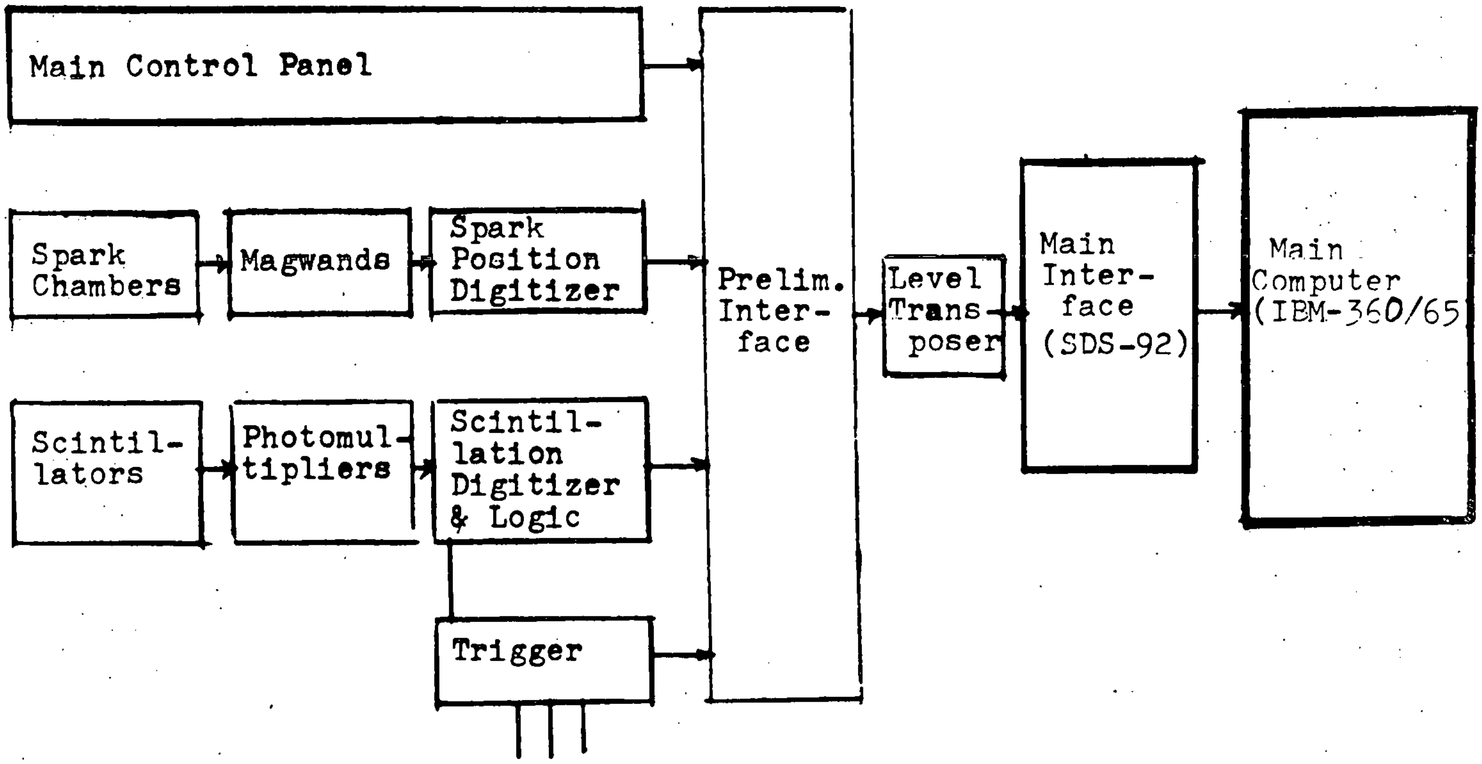


Fig. 13. Flow of BOLD data from primary sensors to on-line computer

additions. Recently we extended the program so as to provide the ability to compile differential cross-section (angular distribution) data for results resulting in an electron pair or muon pair. This extension increased the processing time of such an event by 55 msec -- to a total of 125 msec.

An off-line program also is ready for use on short notice, and is continually being extended. In April we added a routine that evaluates time-of-flight and thus provides a basis for distinguishing cosmic-ray muons from events produced by e^+e^- collision. The new routine was subjected to a number of token tests and was found to give satisfactory results. In June the program was extended to provide the capabilities of (1) making multi-quadrant analyses of events involving one or more charged-particle trajectories and one or more shower trajectories, (2) determining efficiency of pulse-production by a given plane of wires and evaluating the accuracy of resulting pulse-origin data, (3) measuring efficiency of scintillation counter, (4) determining dE/dx within the scintillator closest to the interaction region. This latter determination requires correcting for variation in path obliquity within the scintillator and variation in light-collection efficiency over the area of the scintillator.

We devoted considerable effort to exploring the implications of reactions of the types:

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

$$\rightarrow e^+ + e^- + \pi^+ + \pi^-$$

$$\rightarrow e^+ + e^- + K^+ + K^-$$

which proceed through the annihilation of two virtual photons. Characteristic of such reactions is a final $e^+ + e^-$ state having high energy and small scattering angles. We have started work on a preliminary design of a tagging system for identifying such reactions.

PART V - MAGNETIC ON-LINE DETECTOR (MAGNOLIA)

A. General Design

In the six-month period in question much progress was made on the magnetic on-line detector (MAGNOLIA) developed by a group of physicists and engineers from CEA, MIT, Northeastern University, and Southeastern Massachusetts University. Major components of the main magnet are on hand or on order, and production of shower spark chambers and proportional chambers is underway.

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 14 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.

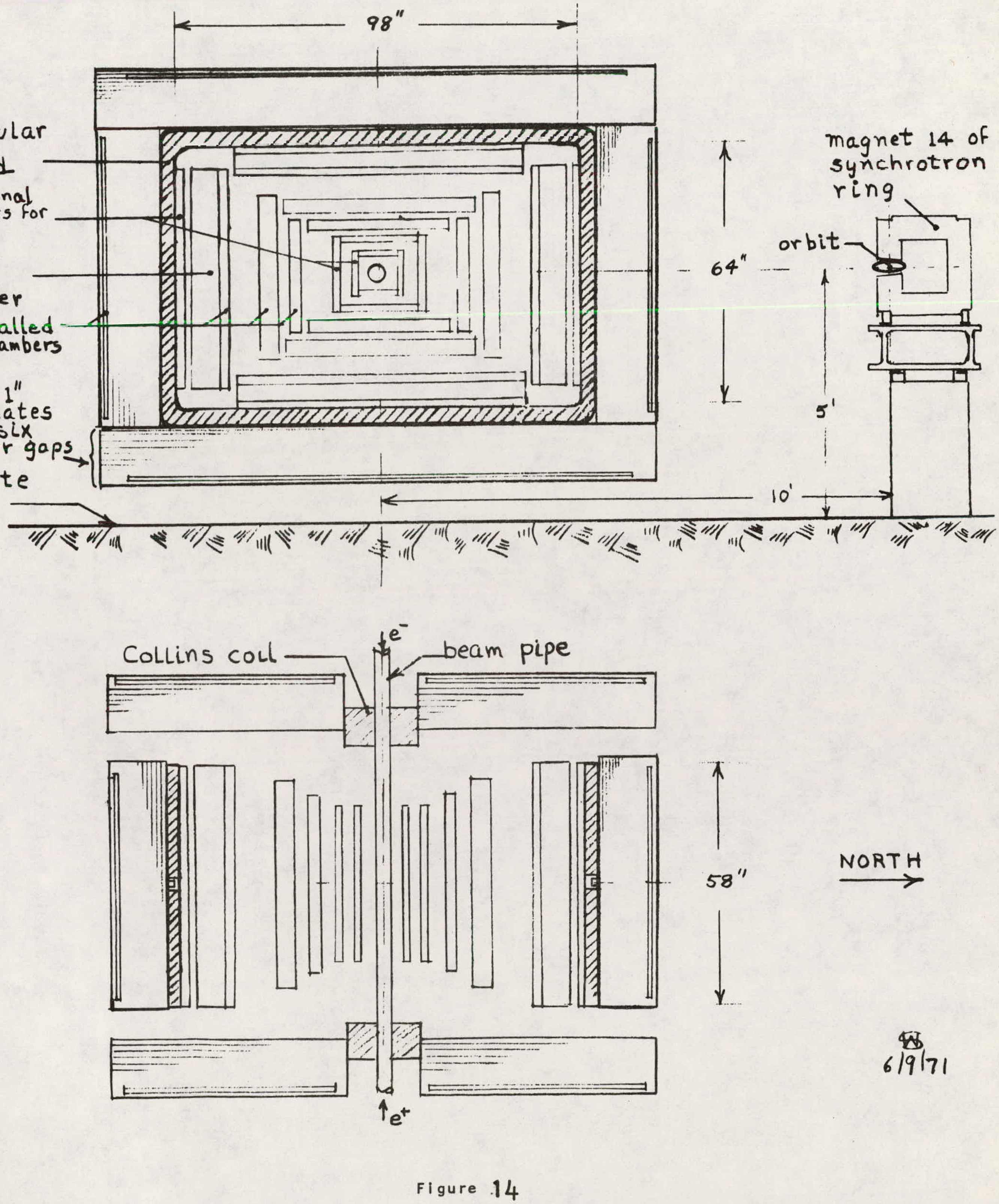


Figure 14

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 computer interfaced by one of the CEA SDS-92 computers.

B. Progress and Status

1. Magnet

Design of the magnet iron was completed. In April several manufacturers were invited to bid on fabricating the main sets of iron plates, and in June an order was placed with the low bidder: Framingham Welding and Engineering Co.

In May the designs of the Collins coils and the tracks for the door assemblies were completed and bids were invited. The proposed location of the magnet in the Target Area has been studied, and no interference was found; however, some shortening of the concrete supports for adjacent quadrupole magnets will be required. The magnet coils have been on hand for over a year.

2. Shower Spark Chambers

Design work on the four shower spark chambers continued, prototype chambers were built and tested, and by the end of June agreement was reached on a final design. Each of the two vertical chambers will employ 57 3/4" x 58" Lucite frames, 60 3/4" x 60" aluminum sheets, and 60 3/4" x 58" lead-aluminum sandwich plates having lead and aluminum thicknesses of 0.125" and 0.100". There will be twenty 0.012-inch copper wires per inch, with 1/2-inch gap width. Overall thickness of the shower chamber will be 7.2". Each of the two horizontal chambers will employ 59" x 58" Lucite frames, 63" x 60" aluminum plates, and 63" x 58" lead-aluminum sandwiches. Much attention has been given to the arrangement of the chamber tails, which bring the terminals of the copper wires outside the region of magnetic field (for magnetostrictive read-out), and to the means of installing and positioning the chambers. By the end of June one prototype chamber was built, and preparations for producing the required four chambers were nearly ready.

The largest component of the production equipment is an 8-ft-diameter, 6-ft-long drum used in applying the copper wire to the 3.5-mil-thick mylar-and-aluminum support sheet at linear speeds up to 30 ft/sec. and under ∿ 100 gram tension. The first of two drums was put into operation in May, and the second was expected to be ready for use by August 1.

Much effort was devoted to flattening the thin (1/16") aluminum plates to be used, arranging for the handling and layout of the spark chamber tails, and testing prototype models of spark chambers with cosmic ray muons. Nine of the twelve 16-kv power supplies for the chambers were received. Construction of the pulsers was started. Development of the necessary computer programs (for use with the M.I.T. IBM 360/65 computer, in testing chamber performance) was underway.

To facilitate spark chamber assembly and testing, a large area in the CEA Engineering Support Building was cleared, and likewise a large area in the central portion of the Experimental

Hall, where a special house (40" x 40") was constructed for operation of the drums and applying the wire to aluminum-mylar sheets.

3. Proportional Chambers

Much developmental work was done on proportional chambers, to arrive at the optimum geometrical configuration, optimum filling gas, and optimum electrical performance. A prototype chamber was built in March, and by the end of June preparations for routine production were nearly complete.

The proportional chambers closest to the interaction region will provide a spatial resolution of the order of a few millimeters and each wire will have a separate integrated-circuit amplifier. The outer proportional chambers will use ganged wires, one amplifier serving each gang.

PART VI - ACCELERATOR MAINTENANCE AND MINOR IMPROVEMENTS

A. Linac

In general the linac performed well. Minor difficulties are listed in the individual monthly reports. Improvements included better temperature control of the buncher section, and also of Waveguides 4 and 5, improvements in the post acceleration chopper, installation of a foil (scatterer) for increasing the uniformity of filling of the synchrotron emittance ellipse, improved monitors, a back-up positron-beam shutter.

B. Synchrotron Ring

Ring equipment performed well. Improvements (for example, installation of distributed sextupole windings and installation of a Landau cavity) have been discussed in Part II.

C. RF System

In February our new, 200-kw-ave rf transmitter system, employing four Varian 953-C five-cavity klystrons rated at 52 1/2-kw-ave each, was put into use. It has performed excellently, although brief trouble was encountered with the Kruse-Stork oscillator, a dummy load, and a combiner.

A full account of the new system is presented in the Monthly Report for January, and in CEAL-TM-195.

Use of 1 to 4 rf cavities instead of the usual 16, and use of a special Landau cavity for damping coherent synchrotron oscillations have been discussed in Part II.

D. Ring Vacuum System

The ring vacuum system performed excellently. Improved pumps and gages were installed, and bake-out procedures were greatly improved. (The Bypass vacuum system has been discussed in Part II.)

E. Miscellaneous

Improvements were made in Control-Room equipment, in shielding (at downstream end of Linac Tunnel), and the radiation-protection interlock system.

PART VII - OTHER ACTIVITIES AND PROGRAMS

A. Safety

In the six-month period in question there was one disabling injury (injured finger).

No one received a radiation dose as large as half the permissable dose.

B. Training of Disadvantaged Persons

We continued to participate in training programs (arranged by the Cambridge School Dept., Cambridge Chamber of Commerce, Cambridge Neighborhood Youth Corps, TEST, and the Harvard Minority Recruitment Program) to introduce disadvantaged young persons to a variety of technical jobs. Twelve persons participated in the training program at the CEA. One person was engaged in clerical work and the rest in technical work.

PART VIII - PUBLICATIONS RESULTING FROM WORK DONE AT CEA

A. Publications on High-Energy Research Performed at CEA

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

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

"Yields of Radionuclides in Thin Iron Targets Bombarded with 40-MeV to 16-GeV Electrons", C. B. Fulmer, K. S. Toth, I. R. Williams, G. F. Dell, T. M. Jenkins, submitted to Phys. Rev. Feb. 1971.

"Coincidence Measurements of Single π^+ Electroproduction", C. N. Brown, C. R. Canizares, W. E. Cooper, A. M. Eisner, G. J. Feldman, C. A. Lichtenstein, L. Litt, W. Lockeretz, V. B. Montana, F. M. Pipkin, Phys. Rev. Letters 26, 987 (1971).

"Interpretations of Single π^+ Electroproduction Data and a Determination of the Pion Form Factor", C. N. Brown, C. R. Canizares, W. E. Cooper, A. M. Eisner, G. J. Feldman, C. A. Lichtenstein, L. Litt, W. Lockeretz, V. B. Montana, F. M. Pipkin, Phys. Rev. Letters 26, 991 (1971).

B. Papers Presented at Conferences and Meetings

1. Papers presented at Feb. 1 - 4, 1971, Meeting of American Physical Society in New York City. See APS Bull. 16-1, 39-41, 1/1/71.

"Vector Meson and Missing Mass Photoproduction Using a Tagged Photon Beam", G. E. Gladding, M. J. Tannenbaum, G. B. Thomson, J. M. Weiss, J. J. Russell, Paper BG1.

"π^- Photoproduction with Polarized Photons at Large Momentum Transfers", G. Tarnopolsky, J. Alspector, D. Fox, D. Luckey, C. Nelson, L. S. Osborne, Z. Bar-Yam, J. de Pagter, J. Dowd, W. Kern, S. Matin, Paper BG2.

"A Measurement of the Asymmetry from Linearly Polarized Photons for the Reaction $\gamma + p \rightarrow \pi^+ + n$ in the Resonance Region", D. Fox, J. Alspector, D. Luckey, C. Nelson, L. Osborne, G. Tarnopolsky, Z. Bar-Yam, J. de Pagter, J. Dowd, W. Kern, S. M. Matin, Paper BG3.

"π^- Photoproduction with Polarized Photons in the Energy Range 0.7 to 2.2 GeV", C. Nelson, J. Alspector, D. Fox, D. Luckey, L. S. Osborne, G. Tarnopolsky, S. Matin, Z. Bar-Yam, J. de Pagter, J. Dowd, W. Kern, Paper BG4.

"Production of Single π^0's Using Polarized Photons in the Resonance Region", J. Alspector, D. Fox, D. Luckey, C. Nelson, L. Osborne, G. Tarnopolsky, Z. Bar-Yam, J. de Pagter, J. Dowd, W. Kern, S.M. Matin, Paper BG5.

"Coincidence Measurements of Forward π^+ Electroproduction", C. N. Brown, C. R. Canizares, W. E. Cooper, A. M. Eisner, G. J. Feldman, C. A. Lichtenstein. L. Litt, W. Lockeretz, V. B. Montana, F. M. Pipkin, Paper BG12.

"Coincidence Measurements of Forward $\pi^{\pm}$ Electroproduction off D_2", C. R. Canizares, C. N. Brown, W. E. Cooper, A. M. Eisner, G. J. Feldman, C. A. Lichtenstein, L. Litt, W. Lockeretz, V. B. Montana, F. M. Pipkin, Paper BG13.

"Coincidence Measurements of Electroproduction of Neutral Mesons in the Backward Direction", W. Lockeretz, C. N. Brown, C. R. Canizares, W. E. Cooper, A. M. Eisner, G. J. Feldman, C. A. Lichtenstein, L. Litt, V. B. Montana, F. M. Pipkin, Paper BG14.

2. Papers Announced in APS Bull 11-16-2, Feb. 1971, and Presented at March 1-3, 1971, National Accelerator Conference at Chicago

"Performance of the CEA Colliding Beam Facility", J. M. Paterson, Paper D-2.

"Positron-Electron Multicycle Injection at the CEA Colliding Beam Project", R. J. Averill, A. Hofmann, R. Little, H. Mieras, J. M. Paterson, K. W. Robinson, G. A. Voss, H. Winick, Paper D-10.

"Electrostatic Separation of Stored Beams at CEA", T. Dickinson, Paper D-11.

"Beam Bump with Programmable Width and Amplitude", W. F. Colby, A. Hofmann, Paper D-12.

"200-KW Amplifier Utilizing Four UHF TV Klystrons", G. Nicholls, Paper D-22.

"Six-Liter and Larger Liquid Hydrogen Target Systems for Accelerators", M. O. Hoenig, Paper J-41.

"Chemistry of Water Treatment", W. J. Jones, Paper K-23.

"Magnet AC Regulation at CEA", J. A. Carroll, Paper K-24.

"Estimation of Magnetic Field Distributions in Three Dimensions Using a Two-Dimensional Computer Program", S. M. Matin and R. D. Hay, Paper K-25.

"Measurement of Cross-Section of a High-Energy Electron Beam by Means of the X-ray Portion of the Synchrotron Radiation", A. Hofmann and K. W. Robinson, Paper K-40.

3. Papers Presented at Meeting of the American Physical Society April 26-29, 1971, Washington, D.C.

"Vector Meson and Missing Mass Photoproduction Using a Tagged Photon Beam", J. M. Weiss, G. E. Gladding, M. J. Tannenbaum, J. J. Russell. Paper DN-4.

"Coincidence π^+ Electroproduction and the Pion Form Factor", F. M. Pipkin. Paper KM-2.

"Clashing Beams at the Cambridge Electron Accelerator Laboratory", G. A. Voss. Paper JM-4.

C. Theses on High-Energy Research Performed at CEA

"$\pi^+\pi^-\pi^0$ Photoproduction from Carbon and CH_2 by Tagged Gammas between 3 and 4 GeV", S. W. Gray (M.I.T.), January 1971.

"A Determination of the Pion Form Factor by Measurements of Single π^+ Electroproduction", G. J. Feldman (Harvard).

"π^+ Electroproduction along the Virtual Photon at Fixed k^2", L. Litt (Harvard).

"Small Angle Proton Compton Scattering at 2.5 to 4.3 GeV", D. Petersen. February 1971.

"Photoproduction Search for High-Mass Dipion Resonances", N. Hicks. May 1971.

"Angular Distributions in the Coincidence Electroproduction of Single π Mesons", A. M. Eisner. May 1971.

D. Other Reports

CEAL-TM-195 "New RF System for Colliding Beam Facility", G. L. Nicholls. 3/30/71.

CEAL-1055 "Semi-Annual Report for the Period July 1 through December 31, 1970", K. Strauch and W. A. Shurcliff, June 1, 1971.