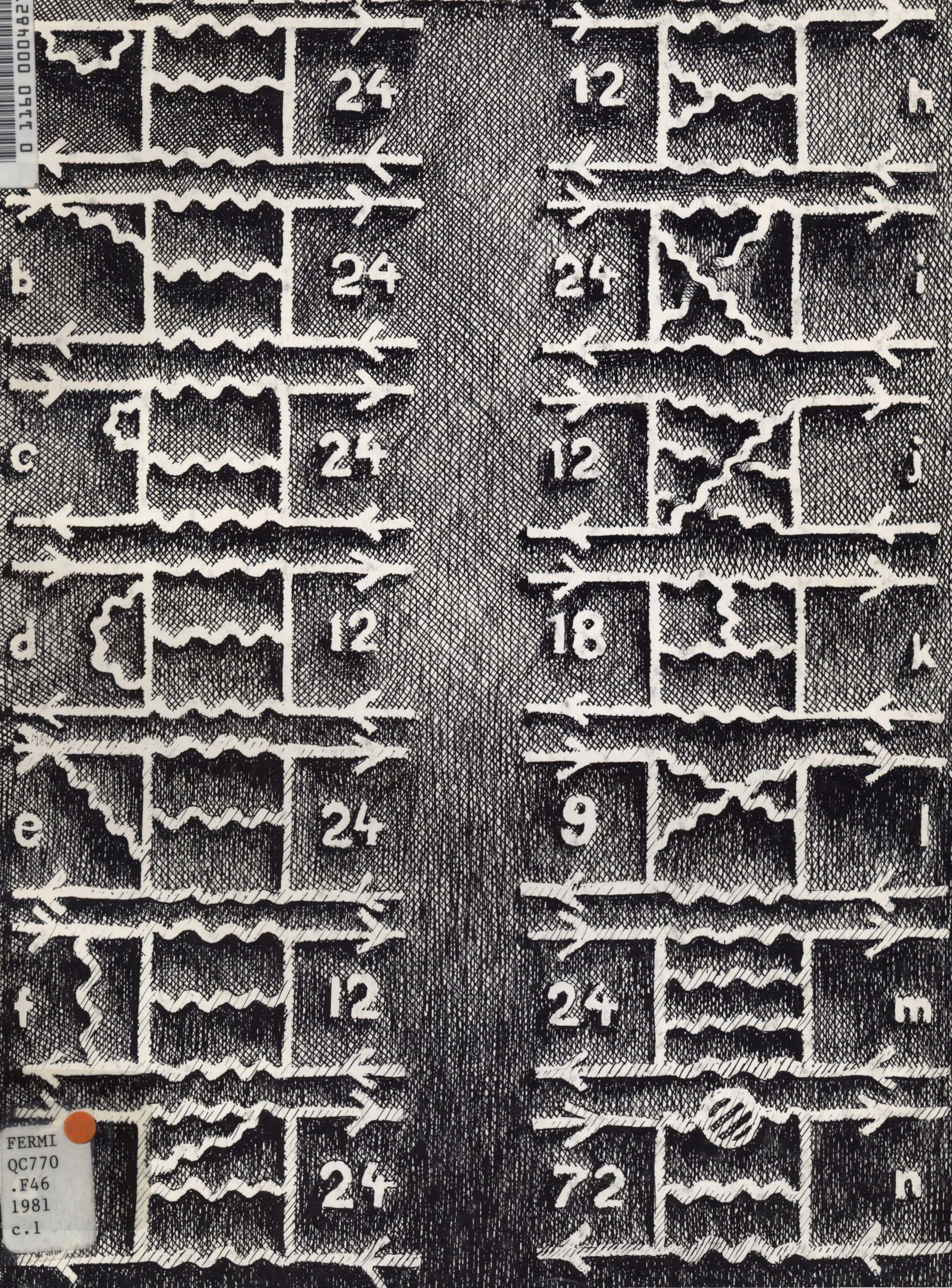
FERMILAB 1981



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Fermilab 1981

Annual Report of the Fermi National Accelerator Laboratory

Fermi National Accelerator Laboratory
Batavia, Illinois

Operated by Universities Research Association, Inc.
Under Contract with the United States Department of Energy

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F. von SCHOBER
(original key D major)

An die Musik

SCHUBERT
Op. 88, No. 4

8 I.

Beautiful 'science,' in how many grey hours
When life's complications overwhelm me
Have you kindled warm love with your powers
And charmed me into a better world.

I. The State of the Laboratory

In the long tradition of these overviews (going all the way back to 1980) we tend to reflect on the field of high-energy particle physics as the edifice to which our work at Fermilab adds; here a lintel, there a frieze, occasionally a lovely spire (or several closely spaced ones). Theoretical physics has achieved a dramatic synthesis of the data collected in our accelerator laboratories over the past three decades. There is a tremendous optimism that a deep understanding of the particles and the forces is close at hand. The justification of this optimism constitutes the central challenge to our research.

In 1981 our theory colleagues continued to steal the show. They are exuberantly elbowing us away from our computers and proclaiming that the lattice gauge calculations of QCD are producing rough but correct masses and splittings from (almost) no input. The Grand Unified Theories (GUTS) occupy a large part of the literature and in the supersymmetric version add a rich spectrum of speculated particles in the mass range of several hundred GeV to the already present technicolored ones.

As the year closed, we were delighted by the news that CERN, the sister laboratory we love to hate, had achieved proton-antiproton collisions. Streamer chamber pictures of awe-inspiring complexity soon appeared. We will watch with mixed emotions as this bold project begins to explore the energy domain of 540 GeV in the center of mass, equivalent to a conventional accelerator of 150 TeV! Somewhat earlier in the year, we learned of the official approval of LEP. This is the European project to build a ~ 30-km circumference ring that will house an electron-positron collider. LEP is scheduled to operate in 1987-8, with a total energy of 100 GeV plus growth possibilities to 140 GeV. The tunnel itself is both a resource to the science and a threat to the U. S. competitive position; if it is paved with superconducting magnets, protons will reach 10 TeV for a 10-Tesla magnet. We have also learned that the Hamburg project, HERA, an 800-GeV superconducting proton ring designed to collide with 30-GeV electrons, has advanced another step towards approval. Western Europe is clearly playing hardball in particle physics. In October we also visited the Soviet accelerator complex at Serpukhov and observed their progress on building magnets for UNK, the 3-TeV proton accelerator they are constructing in very close analogy to Fermilab's Tevatron. This machine will also produce $\bar{p}p$ collisions at 6 TeV when it is finished in the early 1990's.

In these shadows of coming events, we find the Tevatron program described below as unique and correctly aimed at some of the most crucial problems posed by our subject--in perhaps its most vibrant state since the 1920-1930 period. A glance at the publication list suggests the breadth and depth of contributions from this Laboratory. It represents a program remarkable for its rich variety. By these experiments, we probe and poke at the standard theoretical picture; we clarify and extend the data base. In the forthcoming Tevatron era the confrontations will be more incisive.

The most outstanding development at Fermilab in 1981 was the maturing of the Energy Saver project. This project was officially declared "go" in July of 1979. In the ensuing months we began to appreciate the technological challenge of the task. We had to assemble 774 superconducting dipoles, 216 superconducting quadrupoles, and 216 "spool pieces" that contain correction windings (also superconducting), and a complex assortment of other devices. When one includes spares and replacements for magnets that do not meet the rigid accelerator quality specification, about 1400 substantial superconducting elements must be assembled. Associated with this task is the requirement of a monumental cryogenic system that cools the ring to 4.6K and a very sophisticated array of controls and protection devices to assure that nothing can go wrong, go wrong, go wrong ....

It was one thing to have a heritage of a long and fruitful research and development program which included the mass-production assembly of many tens of magnets. It was another to establish an organization with the talent to achieve and sustain the production averaging over 14 units per week, every week, for almost two solid years. Each unit is subjected to meticulous testing. Statistically significant distributions of measured parameters led to the discovery of numerous technical problems through 1980. Solutions had to be found rapidly in order to maintain the production rates. Complicating the entire project were a tight time scale and funding constraints. We envy the funding levels which permit design overkill and redundancy in NASA-like approaches to advanced technological programs.

By the end of 1981, production of dipoles was steady at about 10 per week; spool pieces were being made at 4 per week. Quadrupole assembly was behind and had become the critical path item for completion of the ring. Today we project this completion for the end of 1982. Further details on the status of the Saver are contained in this report. The Saver team under Rich Orr and Helen Edwards and the key managers, Richard Lundy, William Fowler, Peter Limon, Frank Turkot, Claus Rode, Don Edwards, and the accelerator support and systems groups still have many challenges ahead. Opportunities for trouble and delay abound as the system is being assembled and new domains of complexity are confronted. The year ahead will not be dull.

Building toward the future, Tevatron I, the production of an intense antiproton ($\bar{p}$) source for $p\bar{p}$ collisions, had a major change in course. The long research and development program based upon the experimental electron-cooling ring culminated in a complete design in May of 1981. The Director called in an independent panel of experts under the chairmanship of Maury Tigner of Cornell University. This group stressed the long-range importance of luminosity and urged that all options be kept open which preserved the power of Fermilab to produce, collect, and cool antiprotons.

Taking several deep breaths and with small prayers for Department of Energy indulgence, we started a new design along the directions noted by the Tigner group, which was also along the lines taken by our CERN competitors. John Peoples took over management of the project with Don Young as his deputy. Roy Schwitters, our Harvard joint appointee, chairs a parameters committee. Alvin Tollestrup joined the project to study stochastic cooling.

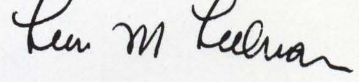
The group, beginning to work in June of 1981, met an October 2 deadline for presentation of a new technical design to a committee of the HEPAP subpanel on Long Range Planning. This went very well and we look forward to a much more serious definition of technical components, costs, and schedules to be ready early in 1982. The new design looks simpler, and indeed has the potential to exceed the luminosity goals of CERN by an order of magnitude.

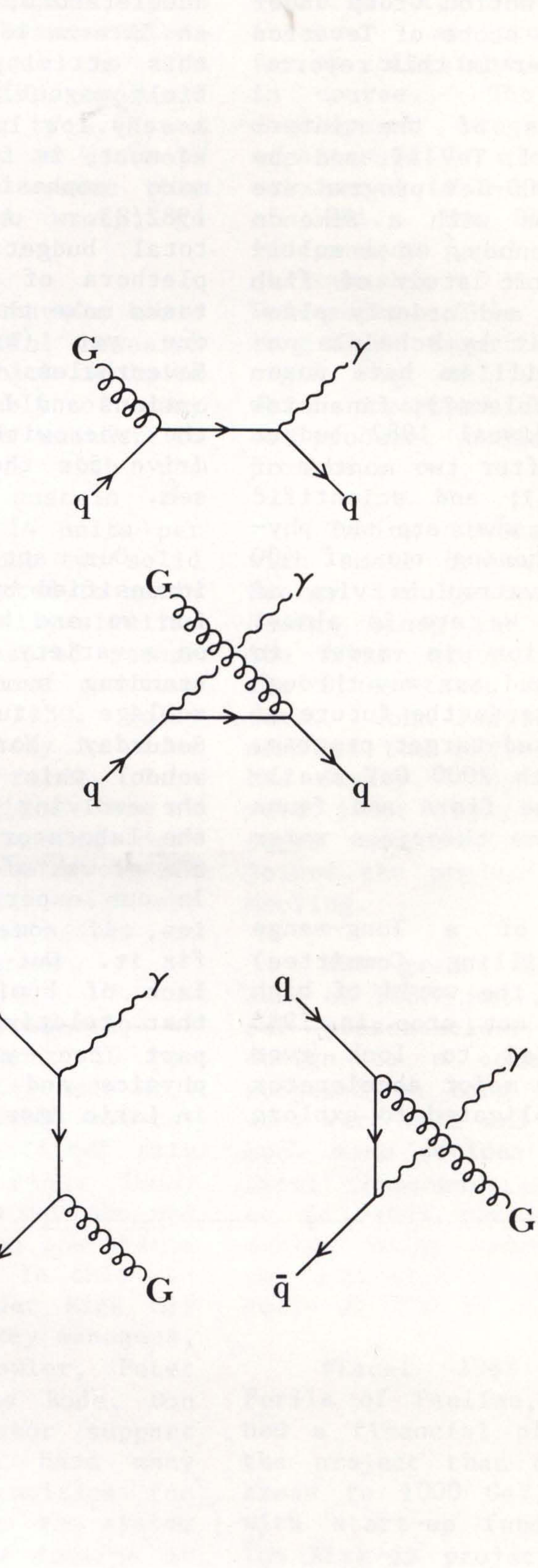
Fiscal 1982 went through the Perils of Pauline, but by December we had a financial plan and Tevatron II, the project that converts the 400-GeV areas to 1000 GeV, was in the budget with start-up funding of $6 million. Tom Kirk is project mannager and Roger Dixon is his deputy. In order to handle the extensive civil construction implied by Tevatron I and II, we formed a new Tevatron Construction Group under Wayne Nestander. The scope of Tevatron II is described further in this report.

The complexities of the interaction of Saver, TeV I, TeV II, and the demands of the our 400-GeV program are worthy of comparisons with a Simenon plot, Penderecki Threnody, or a multidimensional econometric study of fish hatcheries. Logical and orderly planning is made difficult by schedule uncertainties (e.g., will we have unanticipated systems problems?); financial uncertainties (our fiscal 1982 budget was revealed to us after two months of the year had passed); and scientific unpredictables (e.g., what are the physics criteria for phasing out of 400 GeV and into the Tevatron in view of CERN competition?). We are in almost continuous consultation in order to devise a plan to thread our way through the labyrinth and towards the future of a robust 1000-GeV fixed-target program, and a $\bar{p}p$ collider with 2000 GeV available for exposing the flora and fauna that inhabit what some theorists refer to as the "desert."

The existence of a long-range planning group (Trilling Committee) also reminds us that the world of high energy physics will not stop in 1985 and we are obligated to look ever further ahead. As a major accelerator laboratory, we are obligated to explore avenues towards the next generation of accelerators, perhaps in the context of an International Laboratory. In 1981, this activity (towards a super high field magnet) was being carried out at a very low level, for obvious reasons. We must, in facing our future, put **much** more emphasis on this activity in 1982/83. Although our fiscal 1982 total budget is up from 1981, the plethora of construction and related tasks make this year the most difficult one yet (since my 1979 baptism). Nevertheless we must preserve future options and I can't imagine not finding the wherewithal to participate in a drive for the step beyond the one we see.

Our attention to human values, intensified by a sense of guilt for the fun we are having, continues to focus on a variety of efforts: the very outstanding summer program for minority college students, the tumultuous Saturday Morning Physics for high school whiz kids, and most recently, the evolving idea of forging a role for the Laboratory in the effort to assist the growth of physics in Latin America. In our experiments, and in our theories, if something isn't working, you fix it. Out of this has come a certain lack of humility. We are convinced that relatively litle effort on our part can yield large benefits to physics and inevitably to development in Latin America.

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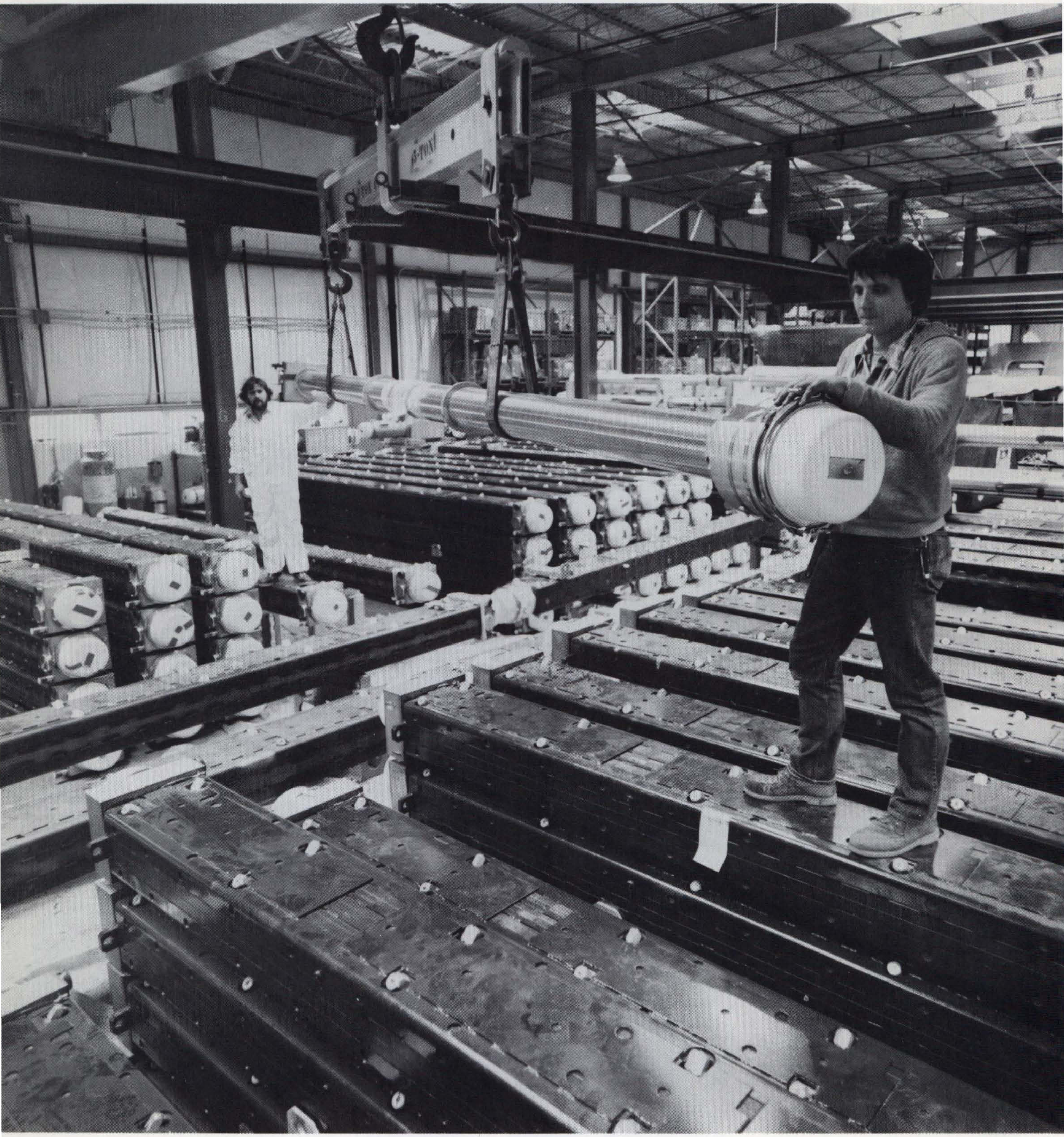


Glen Mundell (left) and Gary Andrews move an Energy Saver cryostat over the stacks of completed superconducting magnets in Industrial Building 4. By the end of 1981, the stack had grown to approximately 350.

II. Building for Future Physics

The Energy Saver

Fermilab is adding a fifth accelerator, a superconducting synchrotron ring to the acceleration sequence. With the completion of the new ring in 1983, protons will be accelerated successively by the 750-keV Cockcroft-Walton, the 200-MeV linac, the 8-GeV booster, the 500-GeV Main Ring, and the 1-TeV superconducting ring. Initially the superconducting ring will operate at 500 GeV, to be increased later to 1000 GeV (1 TeV). It will also operate as a storage ring for colliding-beam experiments at the highest energy in the world.

Since this will be the first time a synchrotron has been built using superconducting technology, that technology has necessarily been developed at Fermilab. The technology developed at Fermilab has already been incorporated into new accelerators being planned or in early stages of construction in Japan, Germany, the USSR, and to some extent in the U. S. in the ISABELLE colliding-beams project.

Besides making possible a future doubling of the energy of the proton beam, use of superconducting magnets has the potential of reducing the Laboratory's electrical power bill by more than $12 million per year.

Magnets

The heart of any accelerator is the magnets that guide the particles during the acceleration cycle. Beginning in 1972 with the completion of the 500-GeV accelerator, development of practical superconducting magnets of accelerator quality was a high priority activity at Fermilab. Because a large number of magnets are required for a synchrotron, it was recognized early that as well as the magnets, the tooling for producing the magnets must be developed. Major emphasis in the development program was on the dipole magnets that bend the beam around the ring and their production tooling. These magnets are each 21 feet long and 774 of them are required for the ring, filling 80% of the 4-mile circumference of the synchrotron.

In the course of developing these magnets, it was first necessary to develop the superconducting wire and then the cable used for the coils of the magnets.

Production of dipole magnets has reached a rate of greater than 10 per week, and the full complement of 774 dipoles is expected to be completed in the summer of 1982.

Quadrupole magnets serve as lenses to focus the beam of protons in the accelerator into a narrow pencil beam, making it possible to contain the more than 2×10^{13} protons circulating in the ring within an aperture of less than 1.5 inches in radius. One-hundred eighty 5-foot long quadrupoles and 36 special quadrupoles of various lengths are needed to complete the synchrotron. Development of the quadrupoles was based on the successful completion of the dipole development so production began much later. The production rate for these has exceeded 4 per week, and the full complement is scheduled for completion in the fall of 1982, consistent with the dipole schedule.

The normal lattice is completed by a euphemistically named "spoolpiece," which is associated with each quadrupole in the ring, 216 in all. The "spoolpieces" contain up to six small, 30-inch long, magnet coils--quadrupoles, sextupoles, octupoles, skew quadrupoles, etc., along with vacuum pumpouts, safety systems, temmperature sensors, etc. The "spoolpiece" concept only developed gradually as the development of the dipoles and quadrupoles proceeded, so production started well behind the dipoles and quadrupoles. The production rate has exceeded 3 per week without stretching the capacity of the production facility. Completion of the full complement of 216 is projected for fall of 1982.

By the end of November 1981, 443 dipoles had been produced, as well as 56 quadrupoles and 49 spoolpieces. These can only be installed in the accelerator tunnel when the accelerator is not operating. When the accelerator started up for high-energy physics research at the end of November, 210 dipoles, 24 quadrupoles, and 24 spoolpieces had been installed in the accelerator tunnel along with associated vacuum and cryogenic systems.

Cryogenic System

To operate the cryogenic accelerator, the magnets must be cooled to 4.6K, close to absolute zero. To accomplish this, helium must be liquefied and supplied to the magnets. Primary liquefaction is provided by a Central Helium Liquefier (CHL) capable of producing 4000 liters per hour of liquid. Twenty-four 1000-watt Fermilab designed refrigerators spaced around the four-mile circumference of the accelerator deliver the liquid to the magnets, collect the helium gas that is boiled off, and return the gas to the CHL for reliquefaction. Connecting this complex are 4 miles of special 6-inch diameter vacuum-jacketed piping for transporting the liquid helium along with liquid nitrogen for the heat shields, over 4 miles of 3-inch diameter high-pressure piping for the compressed helium gas, 4 miles of 8-inch diameter piping to collect the boiled-off helium gas, and 4 miles of 3-inch diameter piping to collect the nitrogen gas that is boiled off.

By the end of November, 5 of the 24 satellite refrigerators along with the CHL were in operation, 8 additional were complete except for installation of the expansion engines, which are ready for installation. The remainder are close to completion and will be put into service through the spring of 1982. All of the piping was in position, including the 4 miles of vacuum-jacketed piping put in place on top of the shielding berm by helicopter (see technical innovations section). Above ground, 2.4 miles, or 61%, of the vacuum-jacketed liquid transfer line has been welded up and put in service; the entire 4 miles of 3-inch high pressure helium gas line has been put into service; all of the complicated piping work within the 24 refrigerator buildings has been completed along with the connections to the accelerator tunnel. In the tunnel 83%, or 3.25 miles, of both the 8-inch diameter helium collection header and the 3-inch diameter nitrogen collection header have been completed. Further work in the tunnel must await the completion of the 400-GeV operating period of the accelerator. The above-ground work will continue until bad weather forces a halt. All of the piping interconnections will be completed in early summer of 1982.

Controls

Successful trials in A-sector and at B12 Test Facility of distributed control systems for "utilities" (vacuum, refrigeration, quench protection) have demonstrated that the concept of distributed systems works. This concept is representative of many future complex control technologies. Remote control of the systems from the Main Control Room has become routine during the year.

The advent of commercially available microprocessor technology about six years ago provided the basis for substantially increasing the capabilities of a control system. The Fermilab Accelerator Controls Group is actively engaged in the design of distributed micrprocessor-based sysems. Such systems will be used extensively in the implementation of the Saver controls and also in a new control system being prepared for the Linac.

Reliance on a centralized control computer introduces great vulnerability if there is a failure in the central computer, or in the communications system. It also assumes a very powerful central system and a high-speed, high-density communications network. For the Saver project, more than 400 microcomputer systems will be distributed among the thirty service buildings. This structure will improve the reliability of the Saver as a whole, especially during recovery from emergency conditions of various types. Individual microcomputer hardware systems have been designed with the capability of supporting future enhancement of the processor power without requiring the alteration of the interfaces to the actual equipment being controlled.

Commissioning

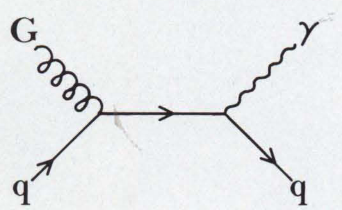
Commissioning of a system as complicated as the superconducting accelerator requires the commissioning of each subsystem as soon as it is available. Some idea of the complexity of the system may be gained by reflecting on the fact that each one of the satellite refrigerators provides as many data ports to the control system as the entire conventional accelerator.

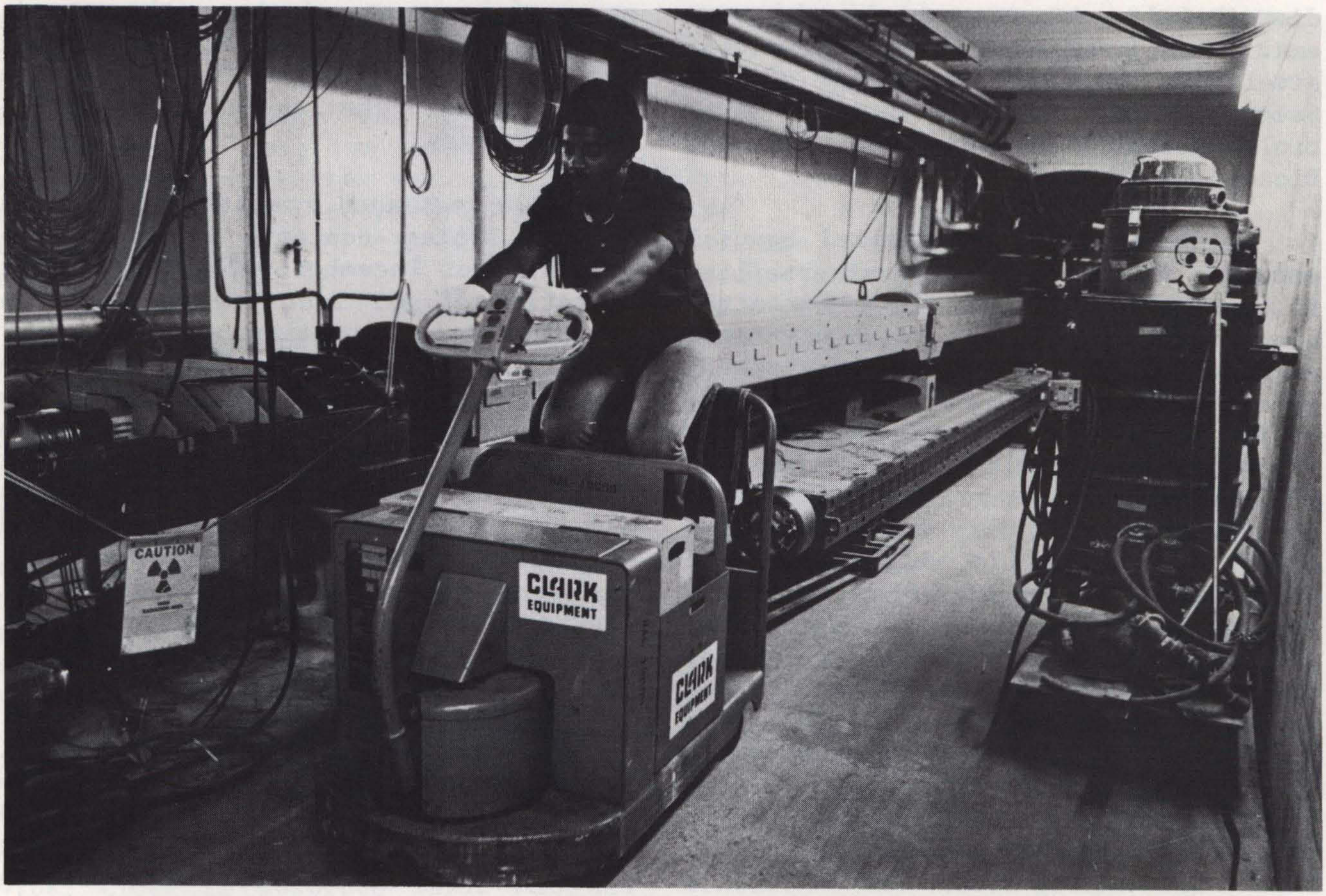
In line with this mode of commissioning the CHL has had several successful runs during the year, proving out its capacity and also testing its operation in conjunction with one of the A-sector satellite refrigerators.

More extended commissioning tests of the system concepts began at the beginning of December with simultaneous operation of all four refrigerators in A-sector in conjunction with the CHL. Three of the four refrigerators were connected to six full operational cryogenic magnet systems. These tests are a full test of the entire superconducting accelerator system, including controls and the full power system. By the end of December this test, the 3/4A test, was proceeding smoothly under full control from the Main Control Room.

Other Systems

In addition to the magnet system, it is necessary to inject protons into the synchrotron, accelerate them, and extract them. During the year the prototype rf cavity for accelerating the proton beam was installed in the conventional Main Ring and successfully tested. At the E0 straight section of the accelerator the full beam injection system was installed to transfer the proton beam at 150 GeV from the conventional Main Ring to the superconducting accelerator. Finally, fabrication work continued on technical components needed to extract the proton beam from the superconducting accelerator, either to the experimental areas, or to the beam dump near the C0 straight section.

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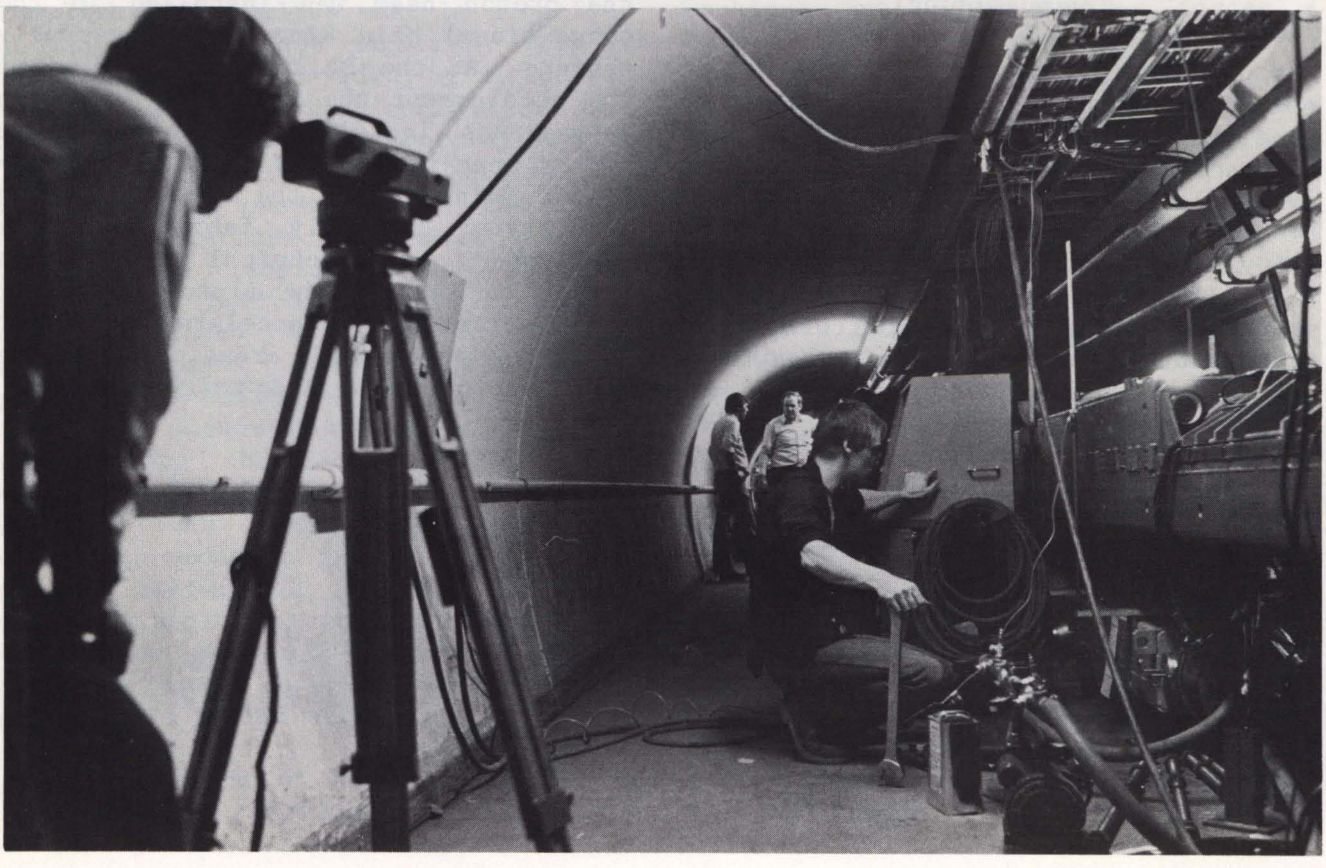
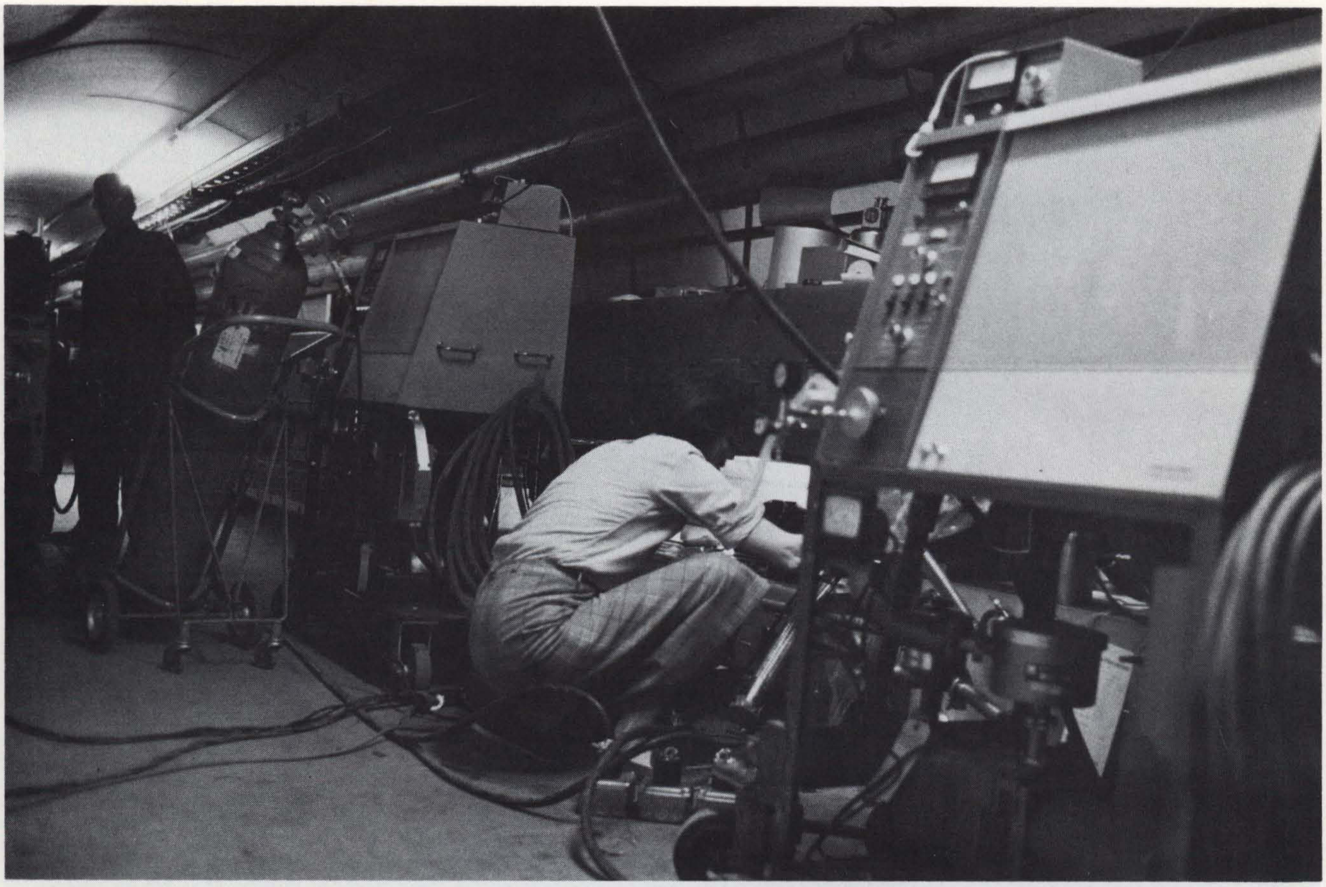




Helen Edwards makes final vacuum checks of an Energy Saver installation. Mike Gold is at the left.

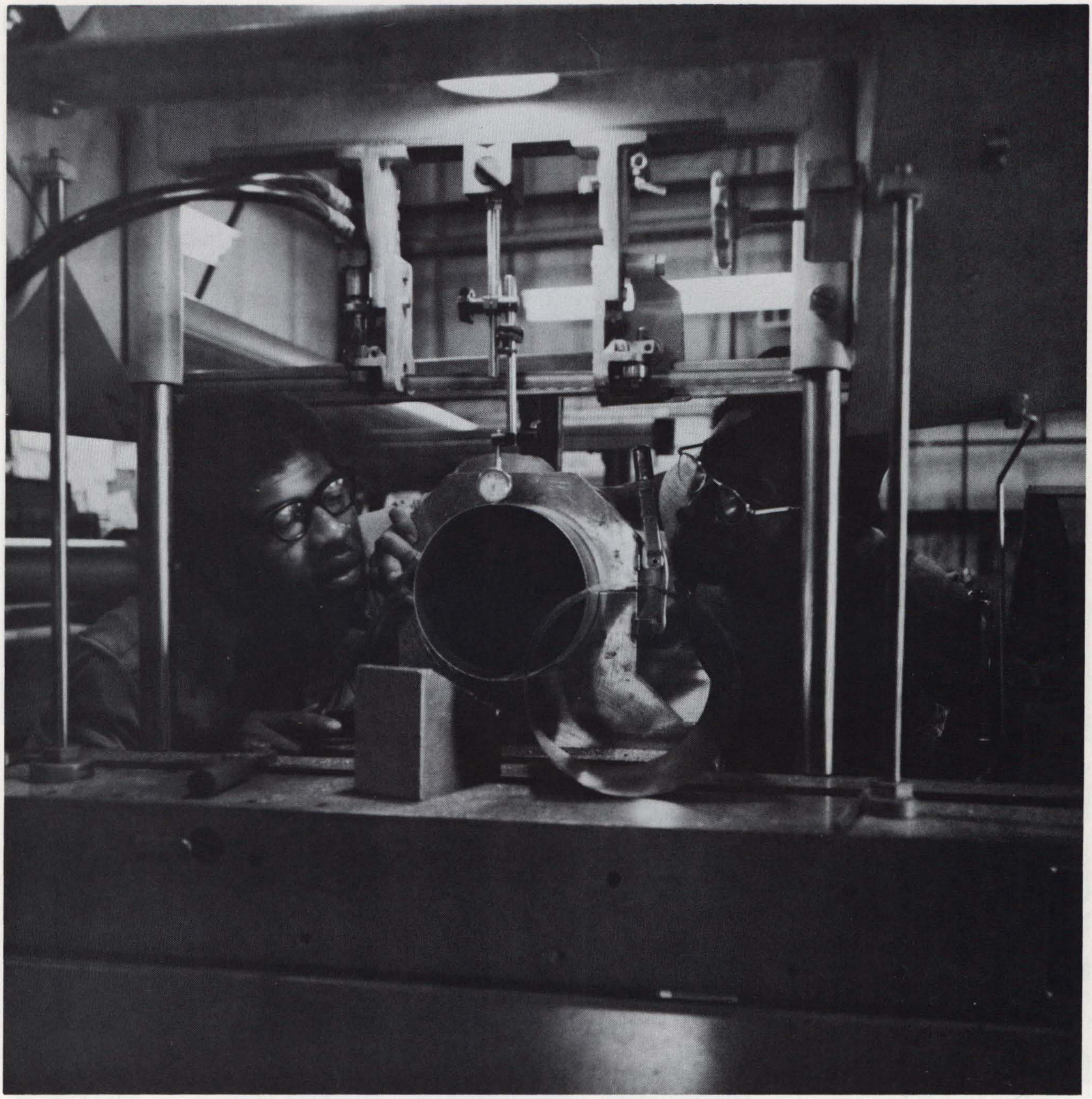
←

(top)

Tom Lassiter moves an Energy Saver magnet through the Main-Ring tunnel.

(bottom)

Rick Smith at the transit and Jim Dahlberg (kneeling) make magnet alignment adjustments. Larry Sauer and Hans Jostlein are in the distance.

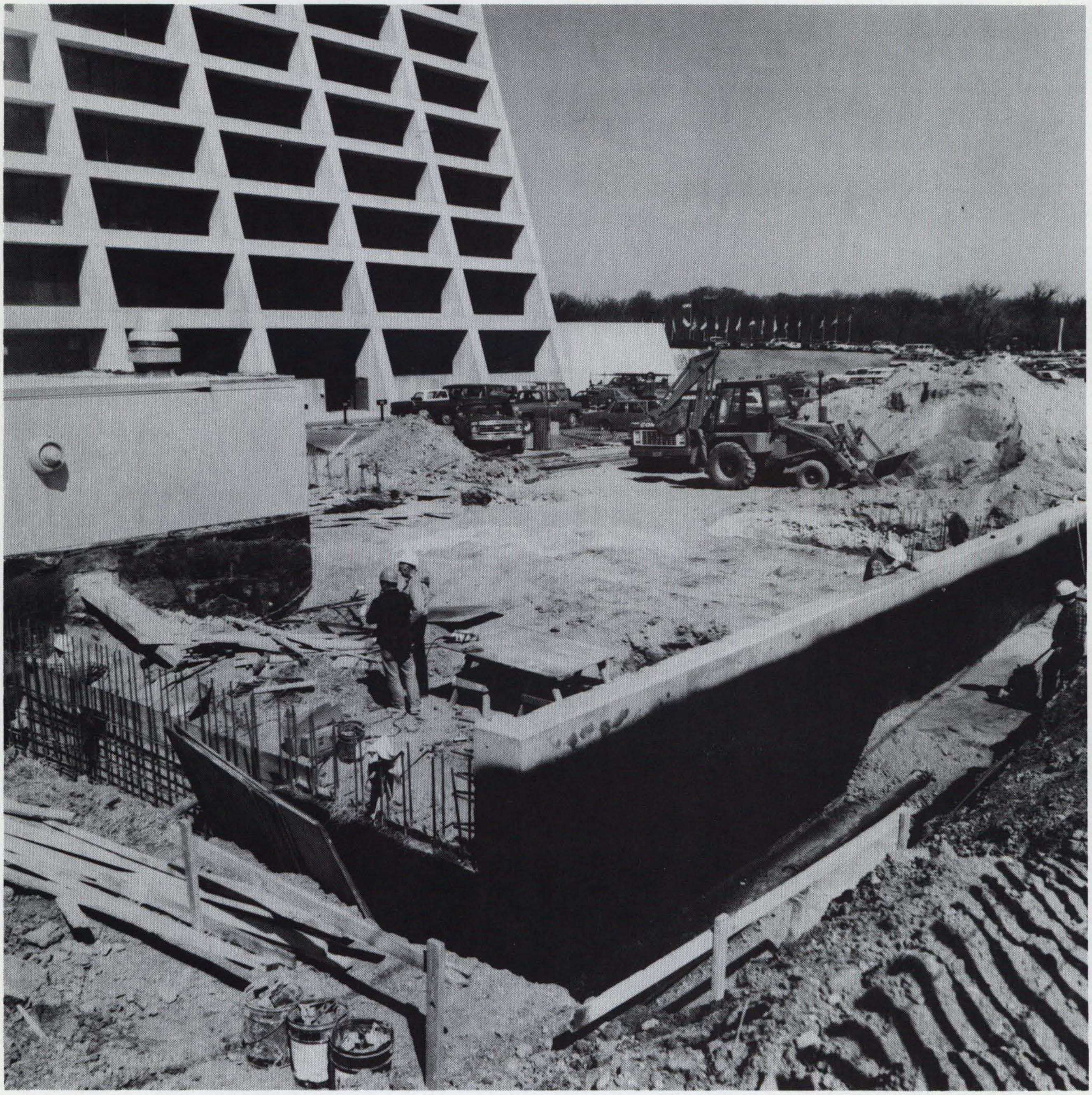


Mark Wegman (left) and Charles Matthews cut out a cryostat tube.

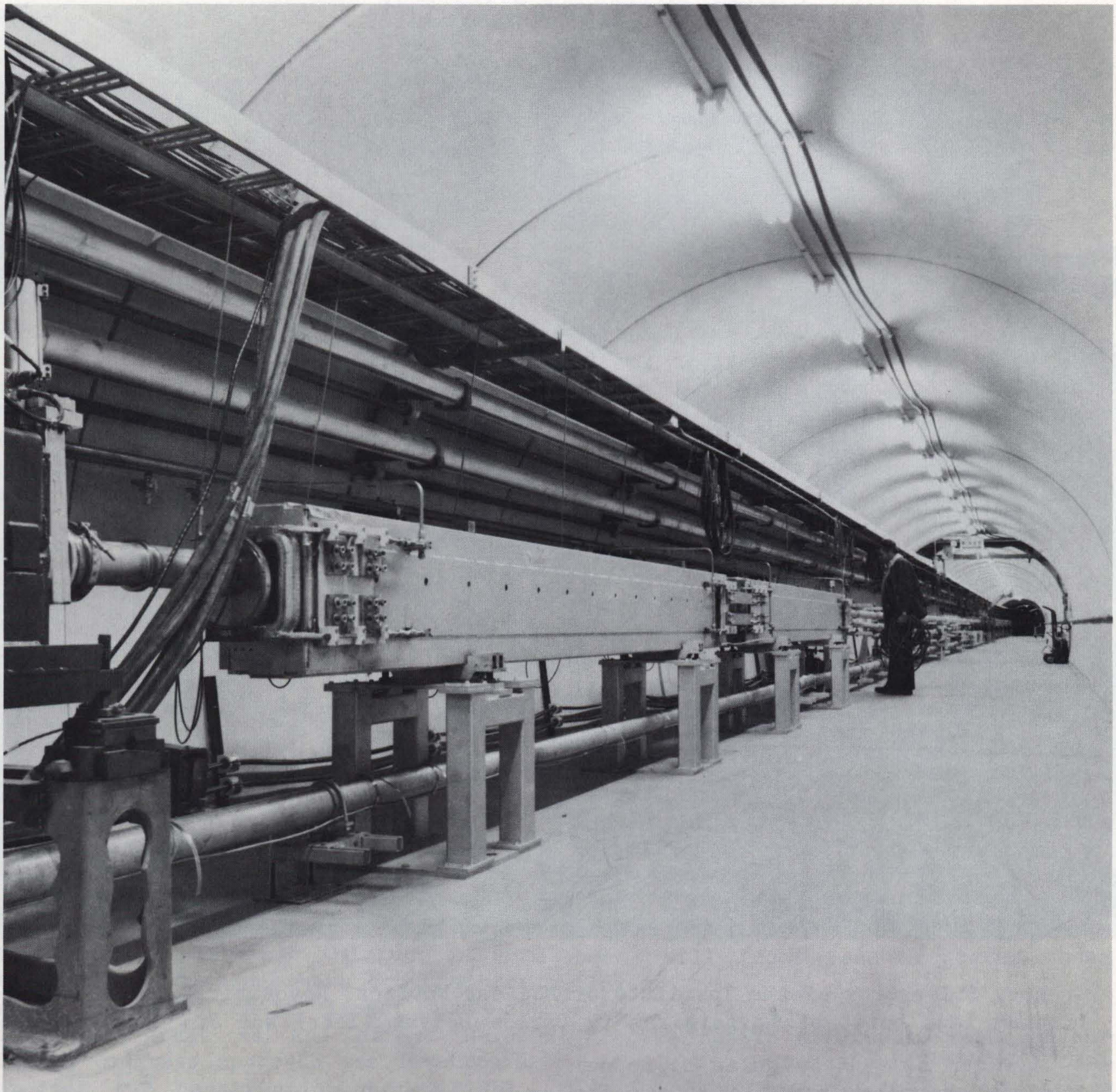
Ed Simmons and Carl Penson inspect a cryostat tube.

A view from Wilson Hall with the helium transfer line on top of the Main-Ring shielding berm. The Transfer Hall is at the lower right, the A0 assembly area and the F4 service building are at the left. The other F service buildings and the RF Building march off into the distance.

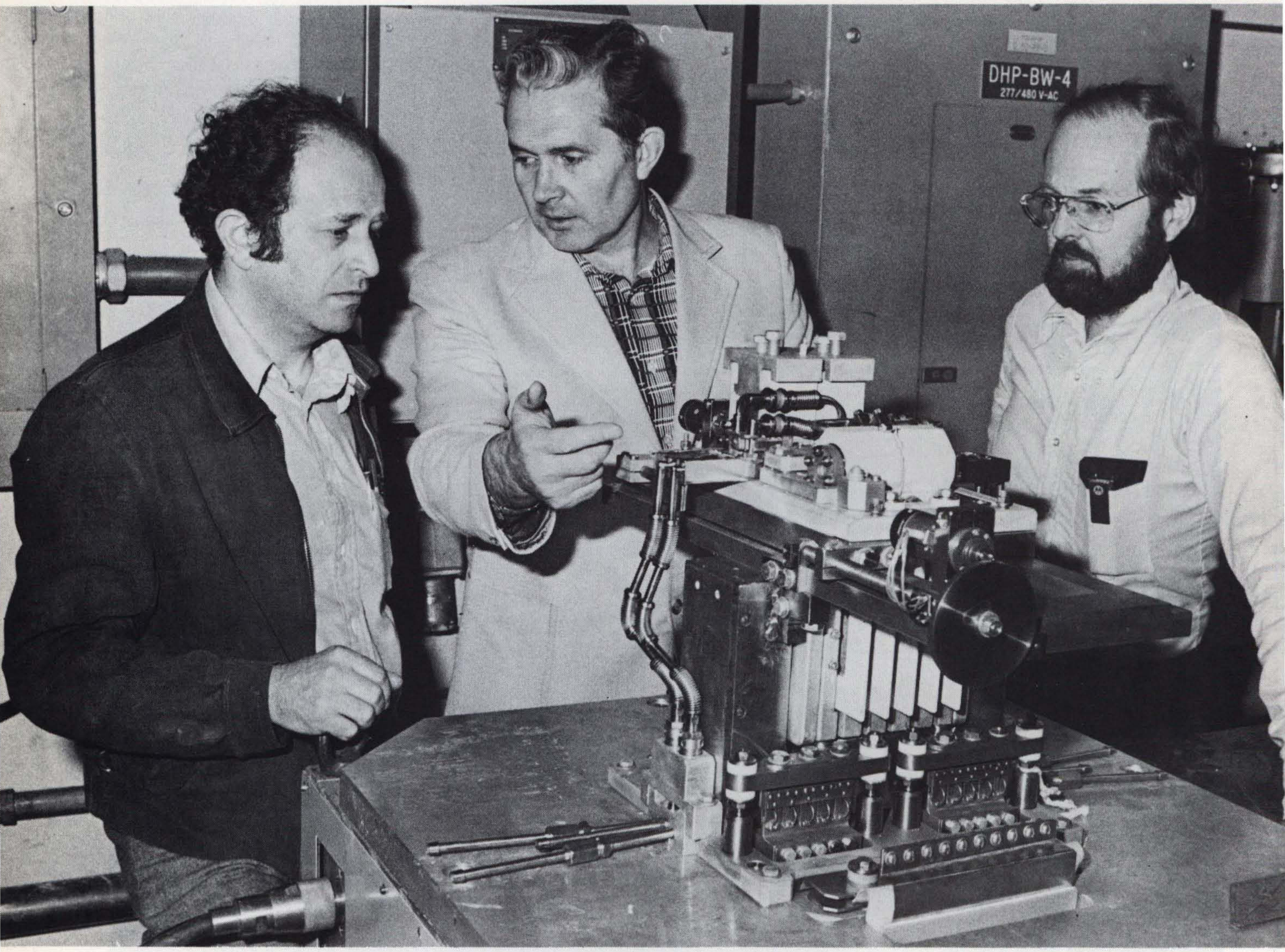
A closeup view of the helium transfer line on top of the berm.



Construction of the addition to the Transfer Hall built for the Energy Saver.



Leon Bartelson at the Saver injection line in the E0 straight section where 150-GeV beam will be bent downward from the Main Ring above to the Energy Saver below.



Gregory Silvestrov of the Institute of Nuclear Physics, Novosibirsk, shows the lithium lens built at Novosibirsk to Carlos Hojvat (left) and Jim MacLachlan (right).

The Antiproton Source–Tevatron I

The Fermilab Antiproton Source Project has been called "the brightest jewel in the crown of U. S. high-energy physics." Our goal is to provide colliding beams of 1-TeV protons and antiprotons with a luminosity of at least 10^{30} cm^{-2} sec^{-1}. We plan to produce antiprotons from Main-Ring protons and to accumulate them using beam cooling. When there are enough antiprotons to achieve our luminosity goal, we will accelerate them (simultaneously with protons) going counterclockwise in the Main Ring and Tevatron. The collider detector to be built in the B0 straight section is discussed in the next section of this report.

Design work and experiments toward our goal have been under way for several years. In this work, we have several other institutions as collaborators, Argonne National Laboratory, Lawrence Berkeley Laboratory, the Institute of Nuclear Physics in Novosibirsk, and the University of Wisconsin. A 200-MeV cooling ring for protons has been built and sucessfully operated. Both electron cooling and stochastic cooling have been demonstrated experimentally with this ring in late 1980.

Two events during 1981 have helped to bring the Fermilab Collider closer to reality. Although both occurred far from Fermilab, their impact was at least as great as the effort here. First, Congress approved the Tevatron I project for construction during 1981, thereby assuring that there would be funds for a colliding-beams program that could begin operation in 1985. Second, the CERN Antiproton Collider project achieved in rapid succession the storing and cooling of significant numbers of antiprotons, the acceleration and storage of antiprotons in the SPS, and finally the detection of $\bar{p}p$ collisions in the SPS. The latter clearly demonstrates the feasibility of a $\bar{p}p$ collider.

The major thrust of our effort in 1981 has been in design of accelerator and storage-ring systems to accumulate antiprotons. A conceptual design using both electron and stochastic cooling was completed in May.

Because of the CERN success and because of the enormous opportunity for discovery that the collisions of 1-TeV protons on 1-TeV antiprotons provide, it was decided to reconsider the source design in order to determine if it could be improved. The reexamination has led to the realization that the design can be improved if more ambitious and somewhat more expensive goals are pursued.

For example, it was decided to upgrade the 80-GeV line to 120 GeV, thereby increasing the yield of antiprotons ($\bar{p}$). It was elected to increase the collection energy and the antiproton beam emittance. These changes make it possible to produce in excess of 10^8 antiprotons every two seconds. These large fluxes lead to an accumulation time, the time needed to gather enough antiprotons to achieve our luminosity goal, of a few hours or less. The challenge has been to design an accumulator ring and cooling system that will cool and contain these fluxes.

The design effort has been concentrated on using stochastic cooling. We are now working to determine whether a flux of more than 3×10^7 antiprotons can be stochastically cooled without excessive losses until at least 3×10^{11} antiprotons have been accumulated. The work to date, which is based on the techniques developed at CERN, is very promising. One of the goals of this work is to design a system that will allow us to take advantage of technology changes in the future.

The R&D program, which was hampered both by a lack of funds and a lack of accelerator studies time during 1981, made some progress; 80-GeV protons were extracted from F17 and transported to $\bar{p}$ Hall. The efficiency of the coalescence of four proton bunches into a single bunch was improved from the work of the previous year. Moreover, an advanced prototype system for coalescing the bunches, based on two surplus PPA cavities, was designed and construction was started. In order to achieve a luminosity of 10^{30} it is necessary to have three bunches of protons and antiprotons, each containing about 10^{11} particles. Under normal conditions of Main-Ring operation, each bucket contains a bunch of 2.5×10^{10} protons, so that coalescence is a necessary step.

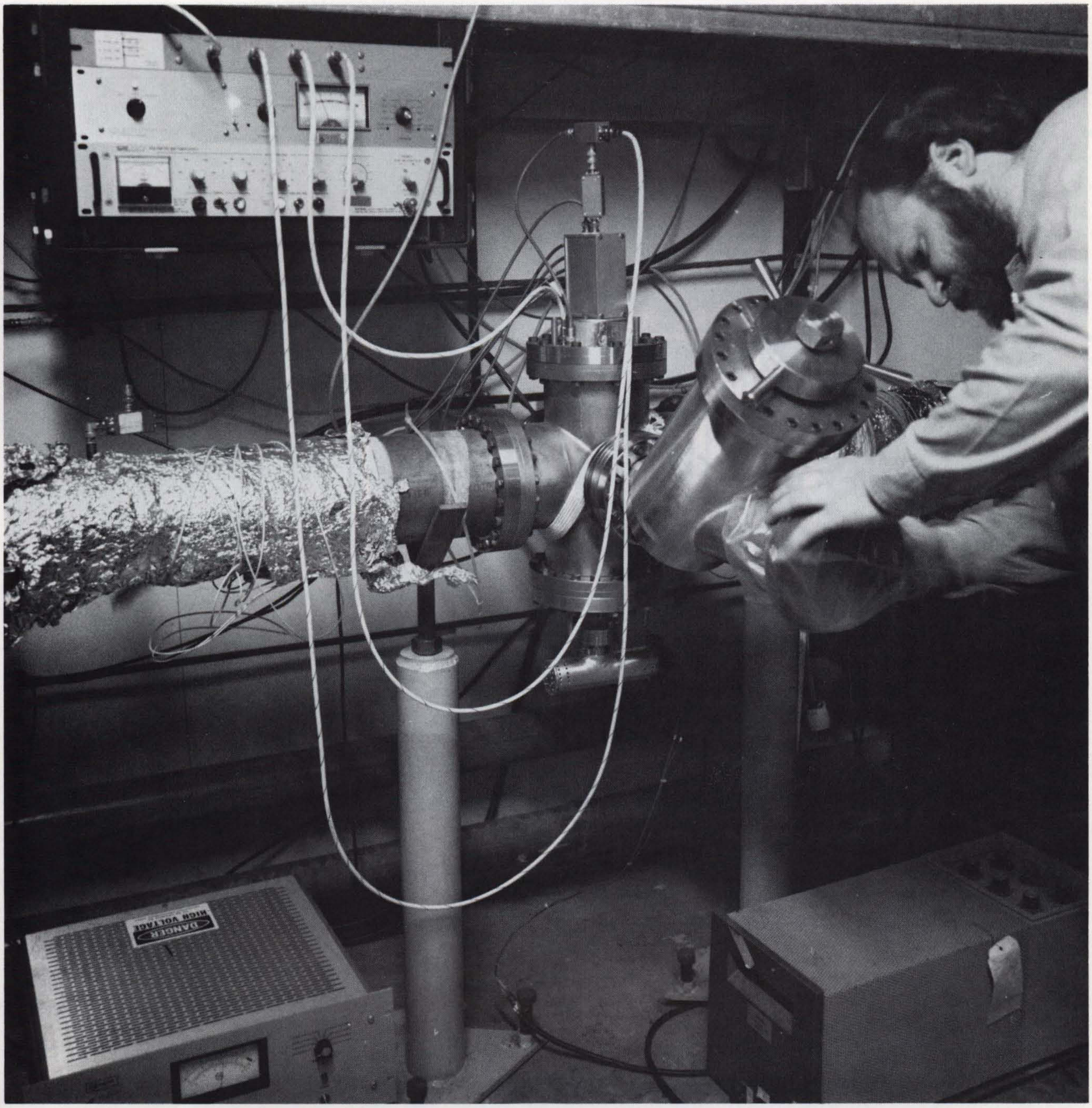
The experimental program in the 200-MeV cooling ring continued. Although the emphasis was on the evaluation of stochastic cooling, many modifications were made to improve it as a research tool. The principal improvements were a major upgrade of the magnet power-supply regulation and the construction of an injection kicker that would permit rf stacking. The former improvement has led to an improved beam lifetime, while the latter will allow the accumulation of up to 10^9 protons. Many improvements in reliability were made to the electron beam. These made it possible to reach the design voltage of 100 kV for the first time.

The first lithium lens from Novosibirsk arrived in April. It is expected that this lens and a larger aperture lens, which will arrive in 1982, will be tested in the beam once the $\bar{p}$ target station is upgraded. The exceptional collection properties of these devices is one of the reasons why it is possible to obtain such a large $\bar{p}$ flux at Fermilab. Visitors from Novosibirsk were also instrumental in making improvements in the electron cooling system reliability.

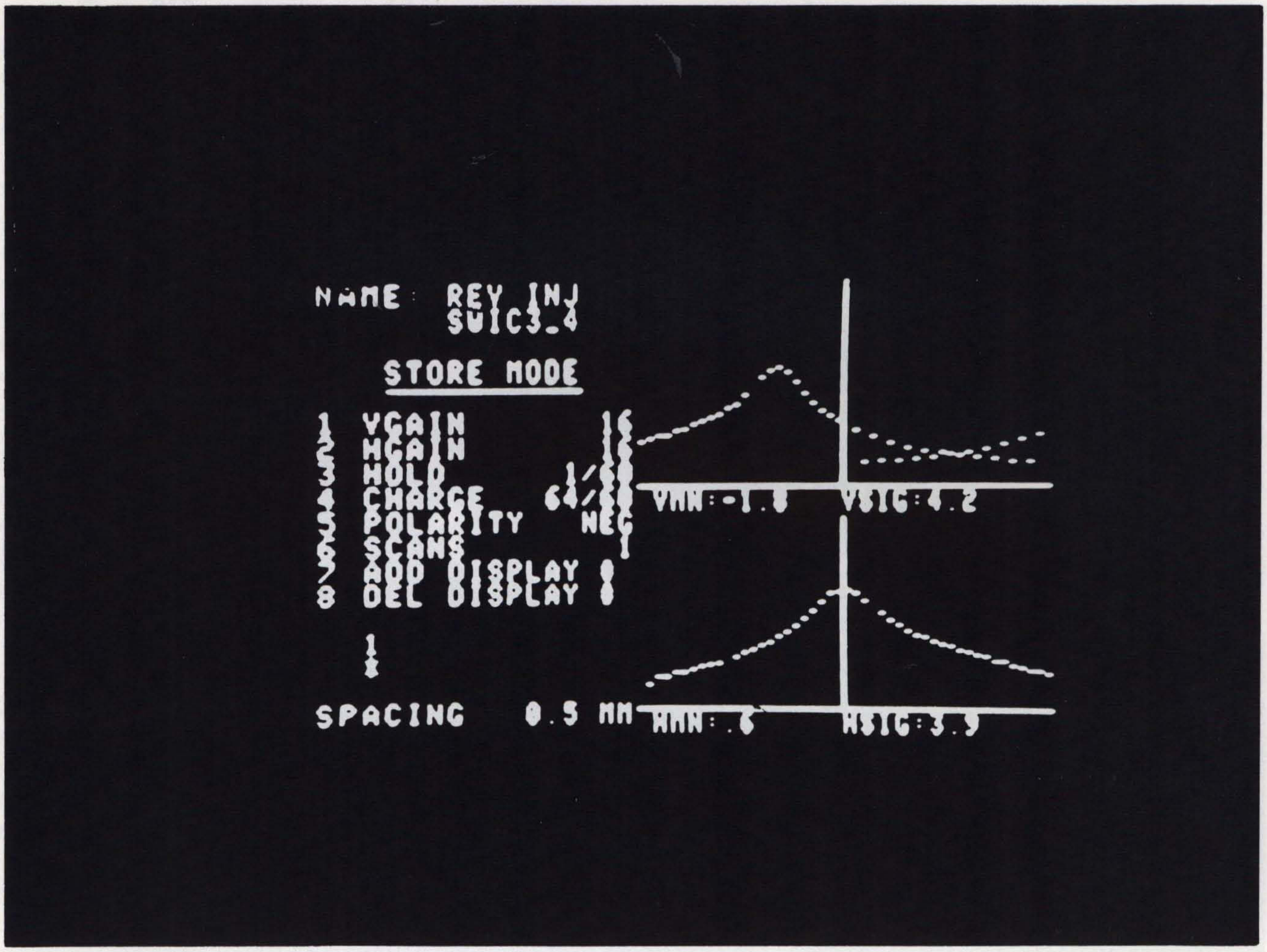
The Argonne and Berkeley groups constructed and tested stochastic cooling systems. These systems were used to cool 200-MeV protons in the Experimental Cooling Ring. Data from the measurements were reported at the 1981 Particle Accelerator Conference in April.

The Experimental Area at BO was designed and submitted for approval. Soon after the preliminary design had been approved, the bids were requested for a contract to prepare the BO site for construction next summer. Work on the site has now begun. A preliminary design of the DO area, compatible with the available funds, was shown to interested users. On the basis of that design a workshop was held to explore the opportunities for physics at DO. The response was very encouraging.

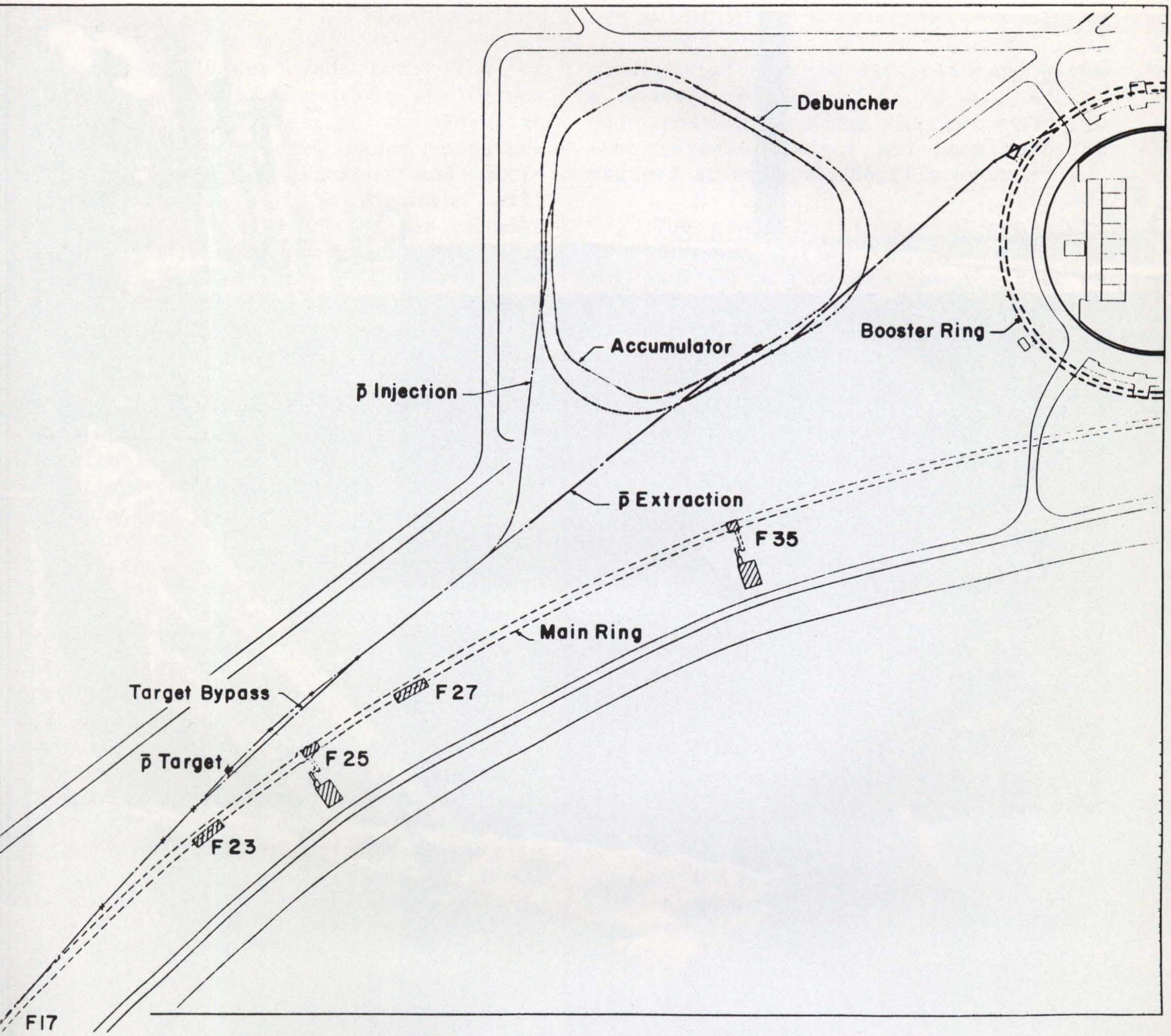
The procurement of the twelve satellite refrigerators that allow the Energy Saver to operate reliably at 1 TeV and of the rf systems for accelerating antiprotons and protons simultaneously was initiated. It is expected that all of this equipment will be in place when the Saver commissioning begins at the end of 1982. Thus it should be possible to determine the proton beam lifetime in the Saver well before the date on which colliding-beam physics is to begin. This in turn will make it possible to plan the improvements which may be needed in a timely manner.



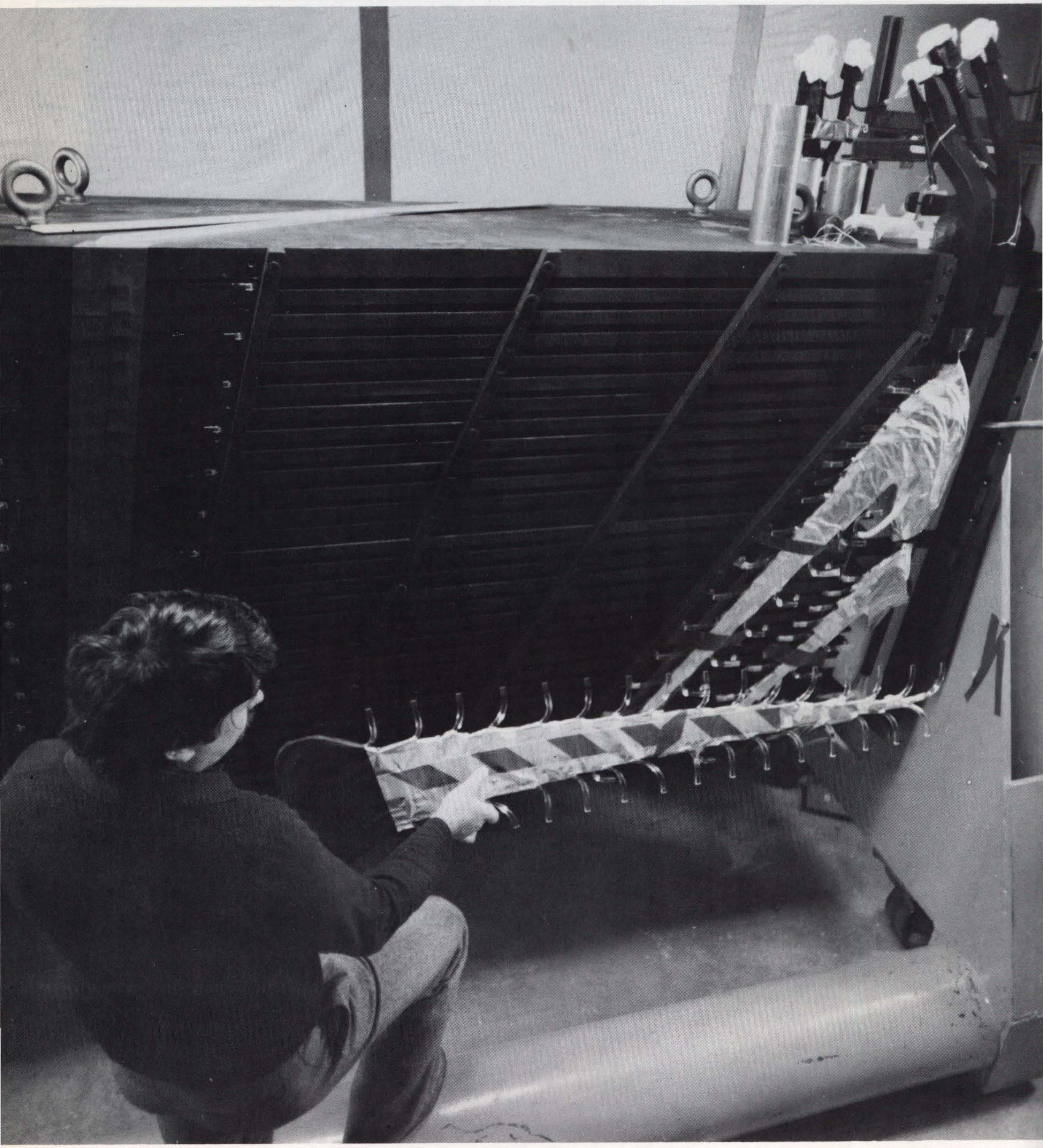
Don Poll works on the vacuum system of the Electron Cooling Ring.



Beam signals from 80-GeV protons extracted from the Main Ring at F17 for antiproton production. The upper trace shows the vertical distribution, the lower trace the horizontal.



Fermilab Antiproton Source.



Sergio Bertolucci of Frascati checks a model of a central calorimeter for the Collider Detector.

The Collider Detector Facility

The Collider Detector Facility (CDF) is planned to exploit the unique physics opportunities of the Fermilab Tevatron I project, where counter-rotating beams of protons and antiprotons stored in the Tevatron will collide at 2 TeV in the center of mass (c.m.). This will be the highest available energy in the world for particle-physics experiments through at least the 1980's. The exploitation of $\bar{p}p$ colliders for high-energy physics began at CERN during 1981 at a center-of-mass energy of 540 GeV. The significantly higher c.m. energy of the Fermilab Collider will also ensure an exciting physics program at Fermilab. In searches for new, heavy particles and investigations of very high p_T phenomena, for instance, the larger production cross sections that result from the higher collision energy at Tevatron I could make the difference between detectable and undetectable production rates. Important examples of heavy particles and processes that will be looked for include the intermediate vector bosons Z^0 and $W^{\pm}$, the lepton asymmetry in $W^{\pm}$ decays, the pair production of charged W's, possible heavier Z^0's, Higgs particles, heavy t-quarks, and many more exotic particles like technihadrons and leptoquarks.

The fact that so many fundamental questions can be explored at Tevatron I will make CDF a unique and exciting addition to the Fermilab research program.

During the last year, the CDF collaboration has finished the conceptual detector design. The detector consists of electromagnetic and hadronic calorimetry over almost 4π solid angle around the interaction region. Fine-grain spatial segmentation has been matched to the large energies and high multiplicities characteristic of the high energy events expected. A large superconducting solenoidal magnet containing drift chambers measures the momentum of charged particles and gives a visual reconstruction of the event. Muon chambers around the perimeter of the central detector and iron toroidal magnets at one end identify muons.

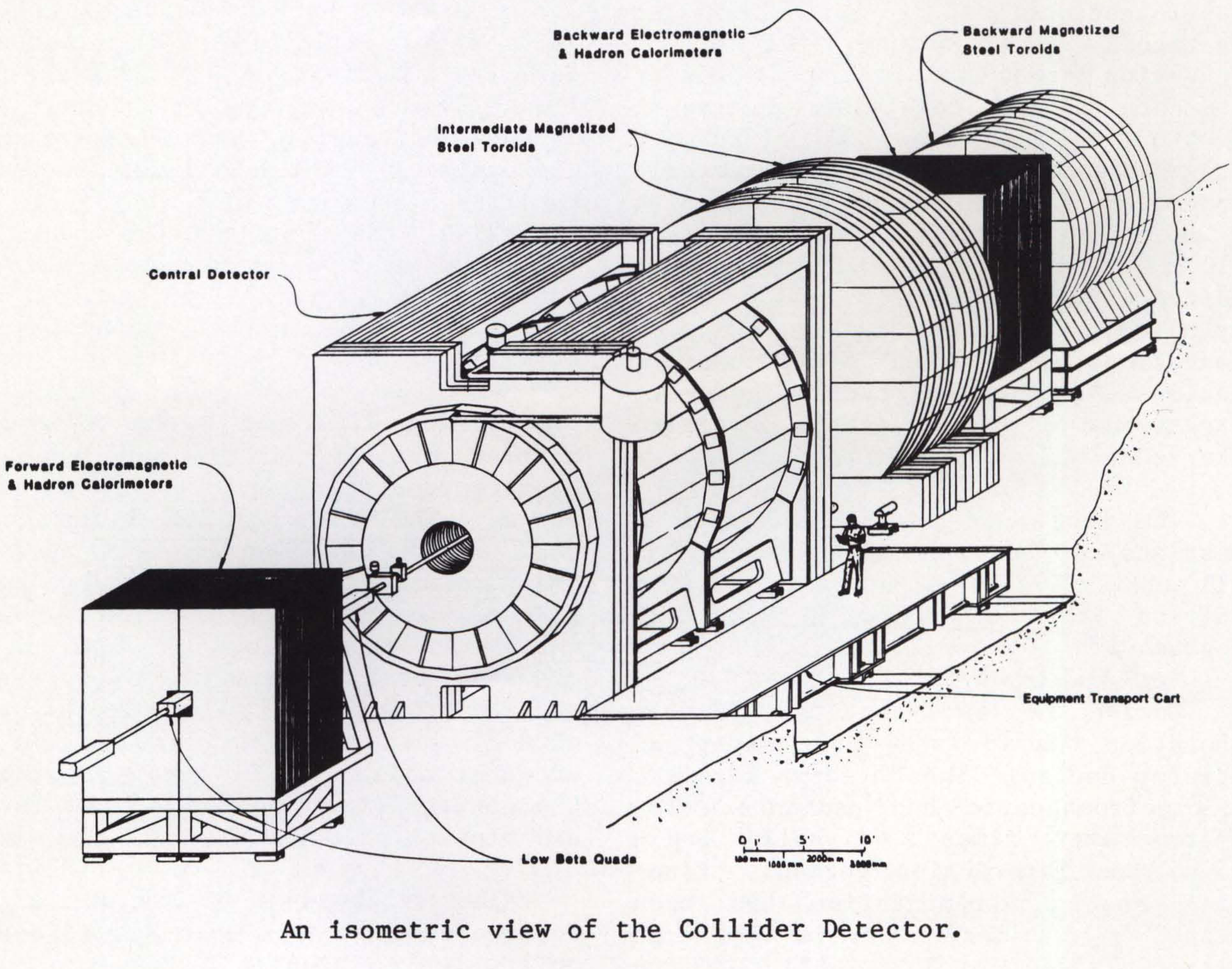
The group has increased considerably in size during the past year and has started to organize for the task of constructing the detector. We plan to have as many components as possible built by our collaborators. All of them have now been assigned responsibilities for some component of the detector. The present list of collaborating institutions is Argonne National Laboratory, University of Chicago, Laboratori Nazionali dell' INFN-Frascati, Harvard University, University of Illinois, KEK, Lawrence Berkeley Laboratory, University of Pisa, Purdue University, Texas A&M, Tsukuba University, and University of Wisconsin. The Collider Detector Facility Department will coordinate and supervise the construction and, in addition, will be responsible for the central tracking chamber, magnet, and any other component that cannot be constructed elsewhere.

During the year tests have been carried out on models for both the electromagnetic and hadron calorimeters. The design of these units for the central detector is well advanced and assembly lines are now being planned for their production. Tests were also carried out at SLAC in an electron beam to measure the behavior of electromagnetic calorimeters using wire chambers operating in the limited streamer mode. Models for a segment of the central tracking chamber and for an end plug calorimeter are well underway.

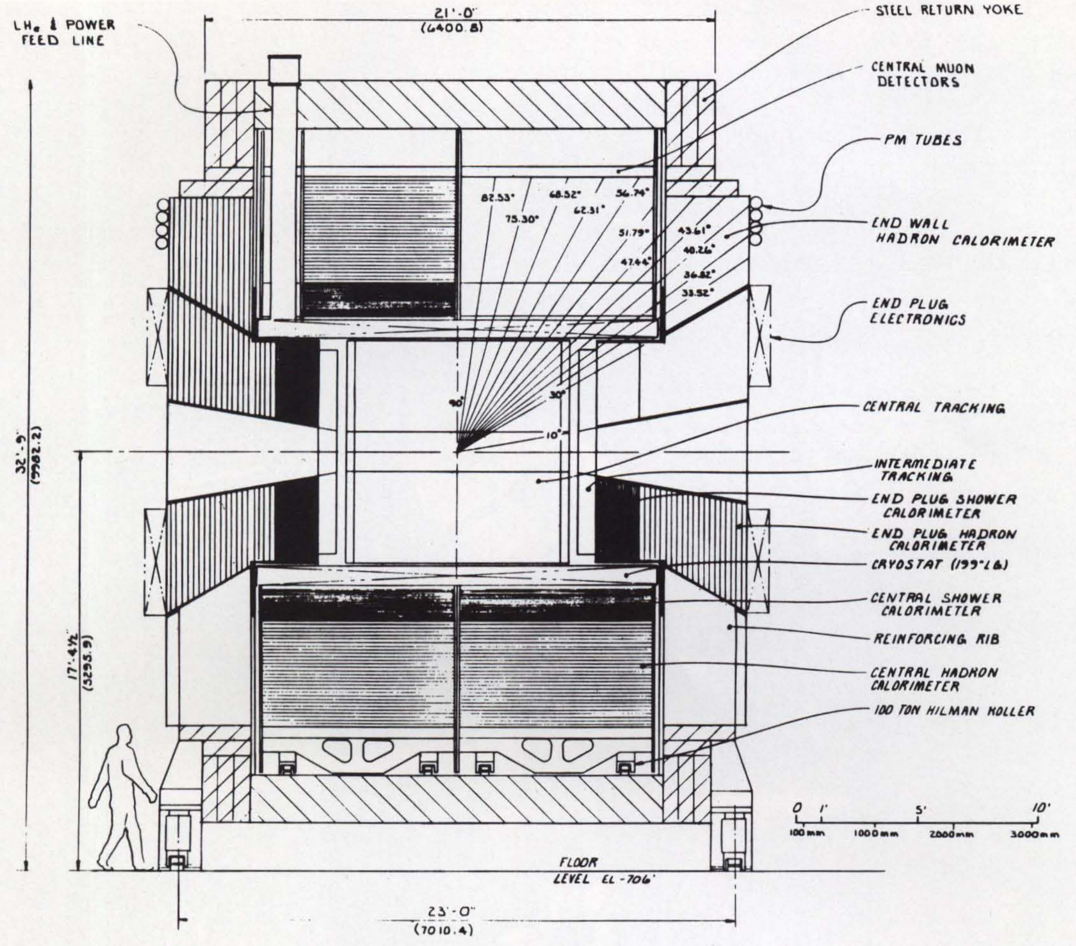
The solenoid will be the largest superconducting coil that has ever been built. Design studies on ways to integrate this coil into the detector have been carried out in the last year and will continue into 1982. The design of the magnet yoke has also received extensive attention at Fermilab. The yoke weight is well over 1,000 tons, and is 30 ft high, 25 ft wide, and 21 ft long. The design and construction of such a large magnet present a challenge to our mechanical engineering group, especially because the magnet with all of its associated instrumentation must easily move in and out of the collision hall.

The Collider Detector Facility Department also contributed to the design of the B0 collision hall. The B0 structure has two sections, one a collision hall centered around the Tevatron beam line, and the second an assembly area located off to the side and protected by massive concrete shielding. A major amount of work has gone into understanding how the detector will be assembled and operated in this new area. In addition, plans have been made for housing the electronics control room and ancillary instrumentation in the building.

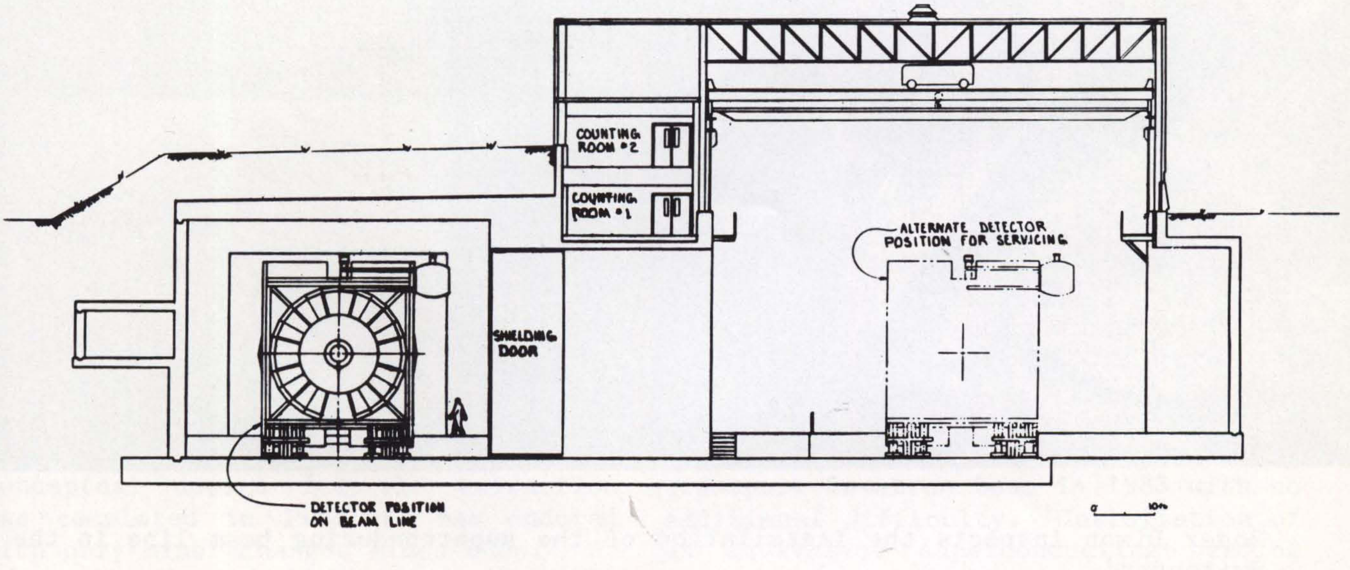
During the next year construction of B0 will start as well as fabrication of many of the detector components.



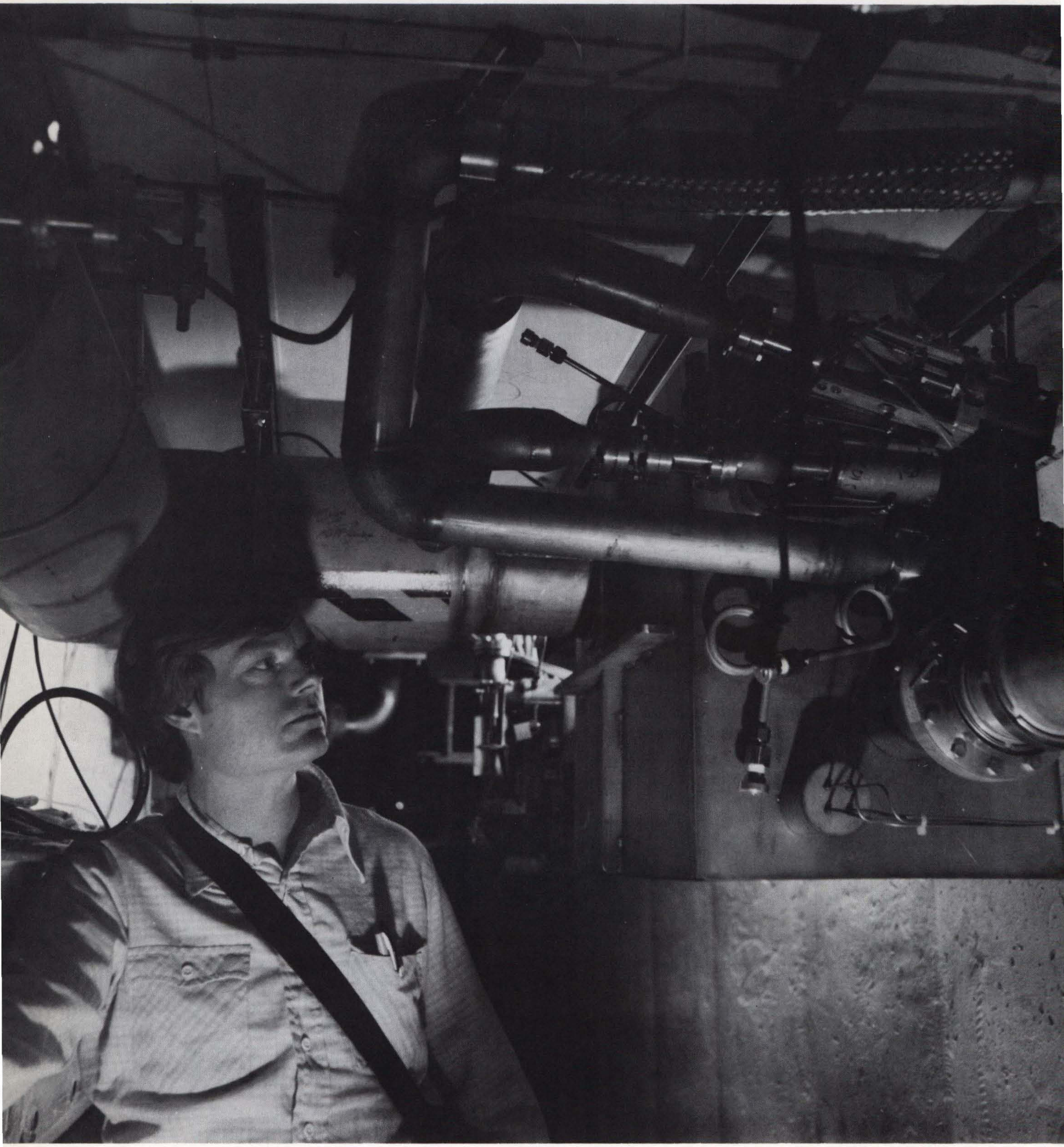
An isometric view of the Collider Detector.



A side view of the details of the Collider Detector.



An end view of the entire facility. The beam tunnel and collision area are at the left and the Assembly Area at the right.



Roger Dixon inspects the installation of the superconducing beam line in the Switchyard.

Tevatron II

The coming of the superconducting accelerator at Fermilab means that beam extraction from the accelerator and all external proton beam-transport lines need to be improved to handle the doubled energy. Most of the secondary beam lines will also undergo an increase in energy to take maximum advantage of the new accelerator. Four entirely new beam lines will be built. The project that accomplishes all this is called Tevatron II. We give here a discussion of current and planned work in each of the project areas.

The Tevatron II Construction Project was authorized for Fiscal Year 1982, which began in October of this year. But a number of related smaller, self-contained subprojects were accomplished in 1981. These included converting the Left Bend that carries beam to the Meson Area to a superconducting beam line, installation of five more superconducting magnets in the M6 beam line, completing the Pion Target Hall in the M1 beam line of the Meson Area, an extension of Enclosure G2 in the Neutrino Area that will house another superconducting beam line, and enlargements of Enclosure H and two service buildings to contain components for the planned upgrades of the beam lines in the Proton Area. All of these 1981 projects represent a step forward into the Tevatron era.

Extraction

The first task for the Tevatron II Project will be the construction of a system for slow resonant extraction of the circulating proton beam from the superconducting accelerator. The scheme involves use of dipole, quadrupole, and octupole magnets plus electrostatic and magnetic septa. A conceptual design for the extraction was completed in 1980 and has endured with only minor changes since then.

Detailed design of the necessary magnets and septa is proceeding at a steady pace and construction of the devices has begun. Installation will take place during the summer 1982 shutdown. The dramatic moment for testing the extraction system with real beam should occur during late fall or winter of 1982.

Switchyard

The beam switchyard is the complex of tunnels and beam pipes that house the magnets, septa, vacuum pumps, detectors, and monitors which split the extracted proton beam into parts, transport them to the experimental areas, and target them on the primary production targets.

With the energy doubling many of the transport devices will have to be strengthened to handle the beam. Every attempt has been made to continue using existing enclosures and beam pipes. The strengthening in most cases requires that bending magnets be replaced with superconducting dipoles, while quadrupoles are doubled in number; doubling of the lengths of electrostatic and magnetic septa is also necessary. Designs for all the beam lines in the Switchyard are now complete and fabrication of the new devices has begun.

Perhaps the most difficult part of the Switchyard upgrade has already been successfully accomplished, that is, the installation and operation of a string of 21 superconducting dipoles in the Meson Switchyard. This pioneering project paved the way for the remaining Switchyard upgrade, and although the magnets have been run only at moderate magnetic fields for the 400-GeV program, it is expected that they will transport Tevatron beam in 1983 with no additional difficulty. Installation of an equivalent superconducting bending string for the Proton Area beam will be done during the summer of 1982 shutdown.

An area of heavy concentration for Switchyard people has been the development of reliable and effective controls for the superconducting magnets. A basic philosophy guiding the controls development has been to use as much of the already developed Energy Saver technology as possible, even though the operating environment is significantly different in the Switchyard than in the accelerator.

Finally, in the Switchyard, some civil construction needs to be done. This work is in the form of extension of the underground concrete tunnels and enclosures that house the magnets and detectors. This work is in the design stage and will be undertaken during the summer 1982 accelerator shutdown.

Meson Area

The Meson area has been in the superconducting age for two years with a magnet string in the M6 line. At the end of 1981 a second magnet string was installed, cooled down, and tested. The helium is supplied to these superconducting magnets from a centralized satellite refrigerator via low-loss transfer lines which now extend from one end of the Meson Area to the other.

We are working to be ready for the future. The Pion Target Hall for high-intensity pi-meson beams in M1 was completed in 1981. The Polarized Proton Facility underwent a complete redesign. Its estimated cost has been cut almost in half without loss of physics potential.

Emphasis for the Meson Area Tevatron II work in the next year will be on providing beam in existing secondary lines from a completely rebuilt primary target area. The new target area will be capable of accepting proton beams up to 1 TeV in energy, and will eventually allow the Meson primary beam to be split into three parts, each independently targeted.

Providing the target capability noted above will involve digging up and removing the present Meson target box and replacing it by a Target Gallery that contains a concrete shielded iron beam dump. In this dump a number of magnets will be incorporated to form the first elements in the upgraded Meson secondary beams. Design work on both the Target Gallery and the dump magnets is going ahead, with construction to follow in the summer of 1982.

In addition to the large Target Hall project, Meson will continue design and planning for the other Meson Area Tevatron projects. These include construction of a new polarized proton beam and a number of civil construction activities needed to complete the strengthening of the secondary beam lines. Construction on these projects will begin in 1983.

Neutrino Area

The Neutrino Area will have a very large piece of the Tevatron II action. Two new beam lines, a prompt-neutrino source and a new muon beam, will be built and a new target train for conventional neutrinos will be constructed. In addition to the new beam lines two new experimental halls will be constructed and some existing apparatus will be improved and moved to new locations in the area.

The plans for all this work have been developed over a three-year period and much of the preliminary work is completed already. In particular, some 15,000 tons of iron shielding for the neutrino beam were already added in 1980.

An extension of enclosure G2 was completed in the summer of 1981. This enclosure will house a major superconducting magnet string that will transport 1-TeV protons to the new muon beam. It will also contain a switching station to transport protons to the conventional neutrino targets and to the new prompt-neutrino area. In 1982 a series of beam pipes will be added to complete the construction for the Tevatron upgrade of the Neutrino Switchyard.

The current activity centers on the conceptual and engineering designs for the new prompt-neutrino and muon beams. Plans for a large magnetic iron shield of novel design associated with the prompt beam are being completed. When finished, the shield will sweep unwanted muons out of the detectors that record the prompt-neutrino interactions. In the muon beam, a design is being completed that will permit muon beams of known helicity to be produced with useful intensities for asymmetry experiments. Design work on both of these projects will be completed in time to allow the first phases of construction to begin in the summer of 1982.

Proton Area

Early work for Tevatron II in the Proton Area will concentrate on conversion of existing primary beam lines to superconducting magnets capable of handling 1-TeV protons from the superconducting accelerator. In the later years of the project a new wide-band photon beam will be constructed to replace the existing line. A new experimental hall will be constructed at the end of the new beam line to accommodate experiments that use the upgraded wide-band photons. Design work for all of these Tevatron II activities is underway at present and will continue into future years.

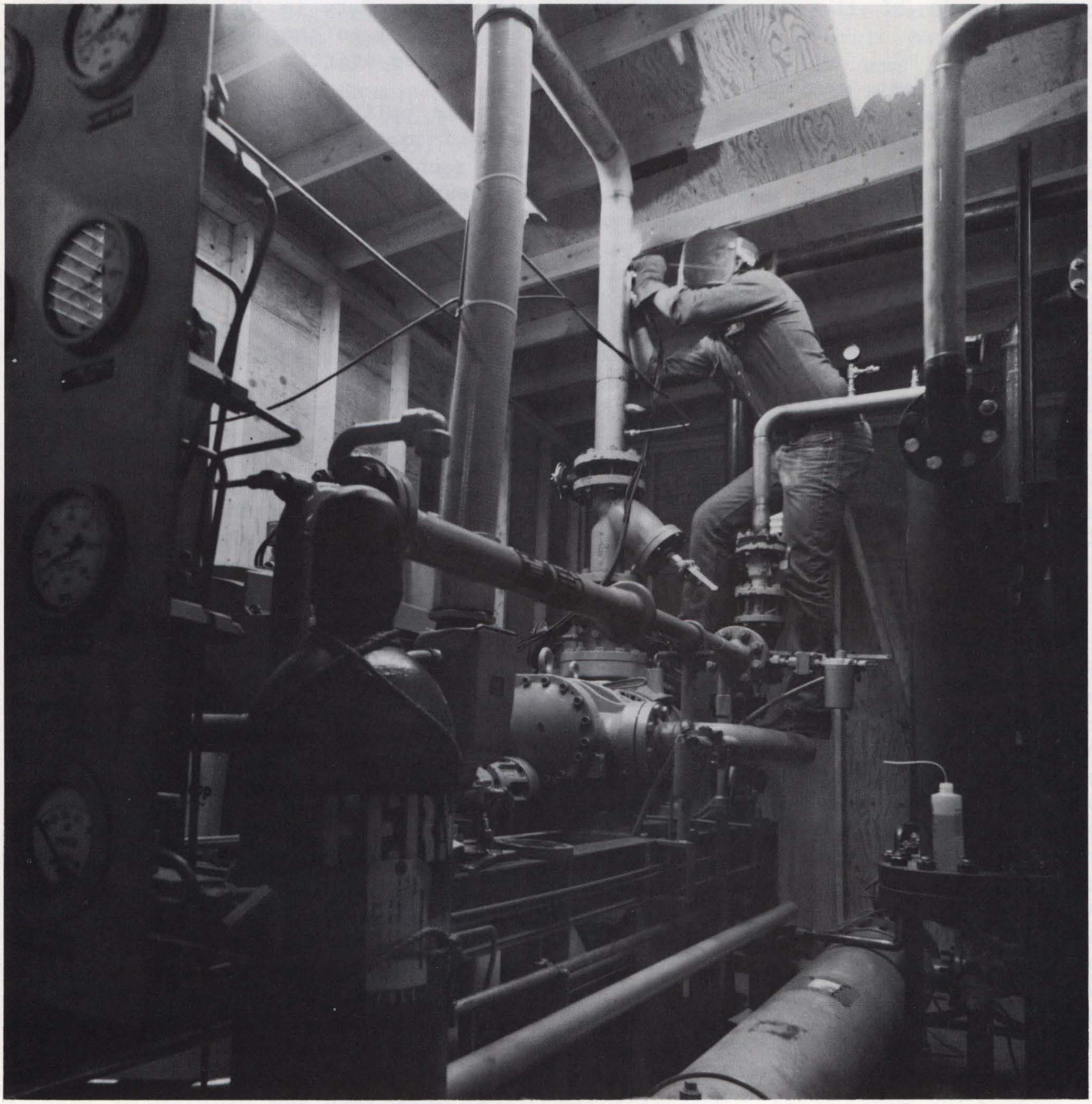
In past years major construction activities were completed in the Meson Area and the Neutrino Area. The summer of 1981 marked the beginning of similar improvement projects in the Proton Area. The projects were the enlargement of Enclosure H, which contains components for the Proton Area three-way split, the enlargement of two service buildings (P1 and P2), and the construction of a new Shop and Assembly Building at the Proton Area Site. These projects are aimed at improving radiation safety in the area as well as contributing to the 1-TeV upgrade to be implemented starting in 1982.

The splitting of the 1-TeV primary beams into three independent beams will be accomplished in the enlarged Enclosure H. There is adequate space in the east branch to install electrostatic septa that will allow further subdivision of the east beam into two independently targeted beams. Solutions for targeting protons on each of three existing target stations have been developed. In addition, design work for the new high-energy Wide-Band Neutral Beam has been completed. This beam will replace the existing Broad-Band Neutral Beam in Proton East. A first experiment, E-687, was approved by the Fermilab Physics Advisory Committee. It will perform high luminosity measurements on the production of massive states.

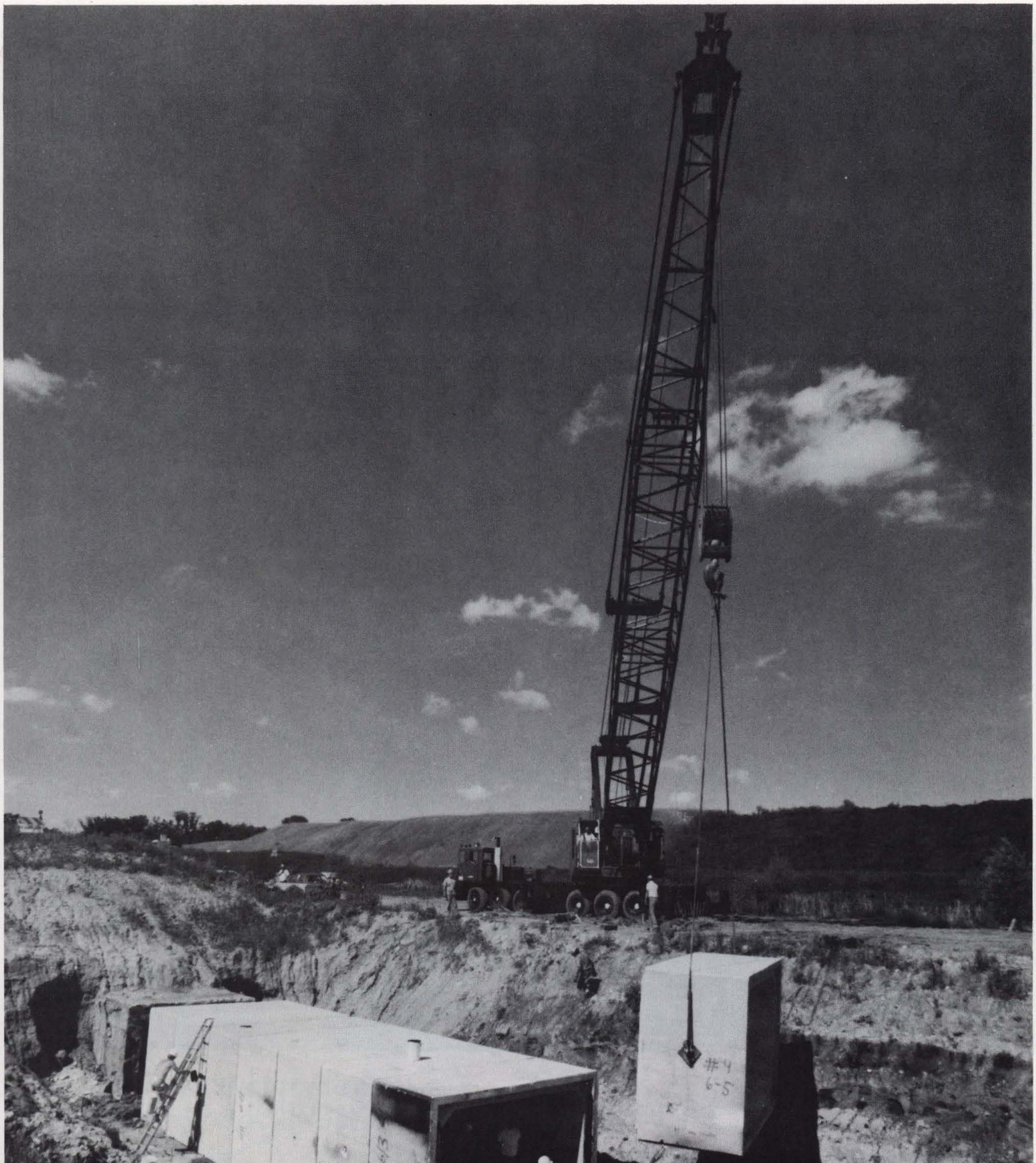
A principal focus for work in the Proton Area during the summer 1982 shutdown will be the rebuilding of two primary-beam enclosures in the area to allow them to handle the enhanced radiation levels that will come with 1-TeV protons. These enclosures, heretofore used for experiments as well as for beam handling, will be more heavily shielded with earth and modified inside for easier handling of beam-line magnets and other devices.

Another large effort will be the installation and commissioning of additional satellite refrigerators to cool superconducting magnets and handle the higher energy beams. A significant part of this work has already been completed with improvement projects geared to the 400-GeV program.

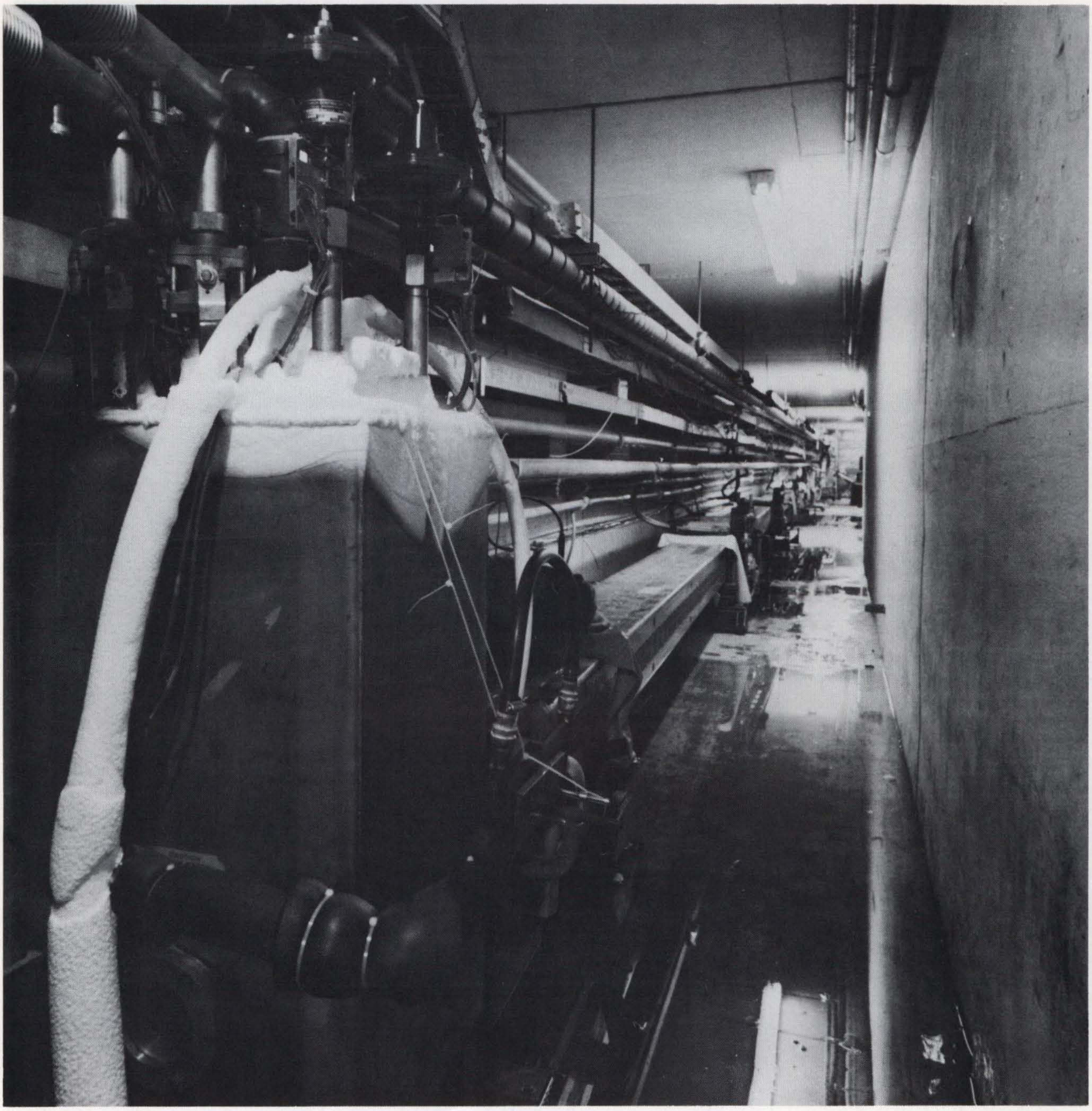
As all these pieces of the Tevatron II program come to fruition, we shall enter the 1-TeV age with fixed-target facilities for an intensive research program by users from the entire particle-physics community.



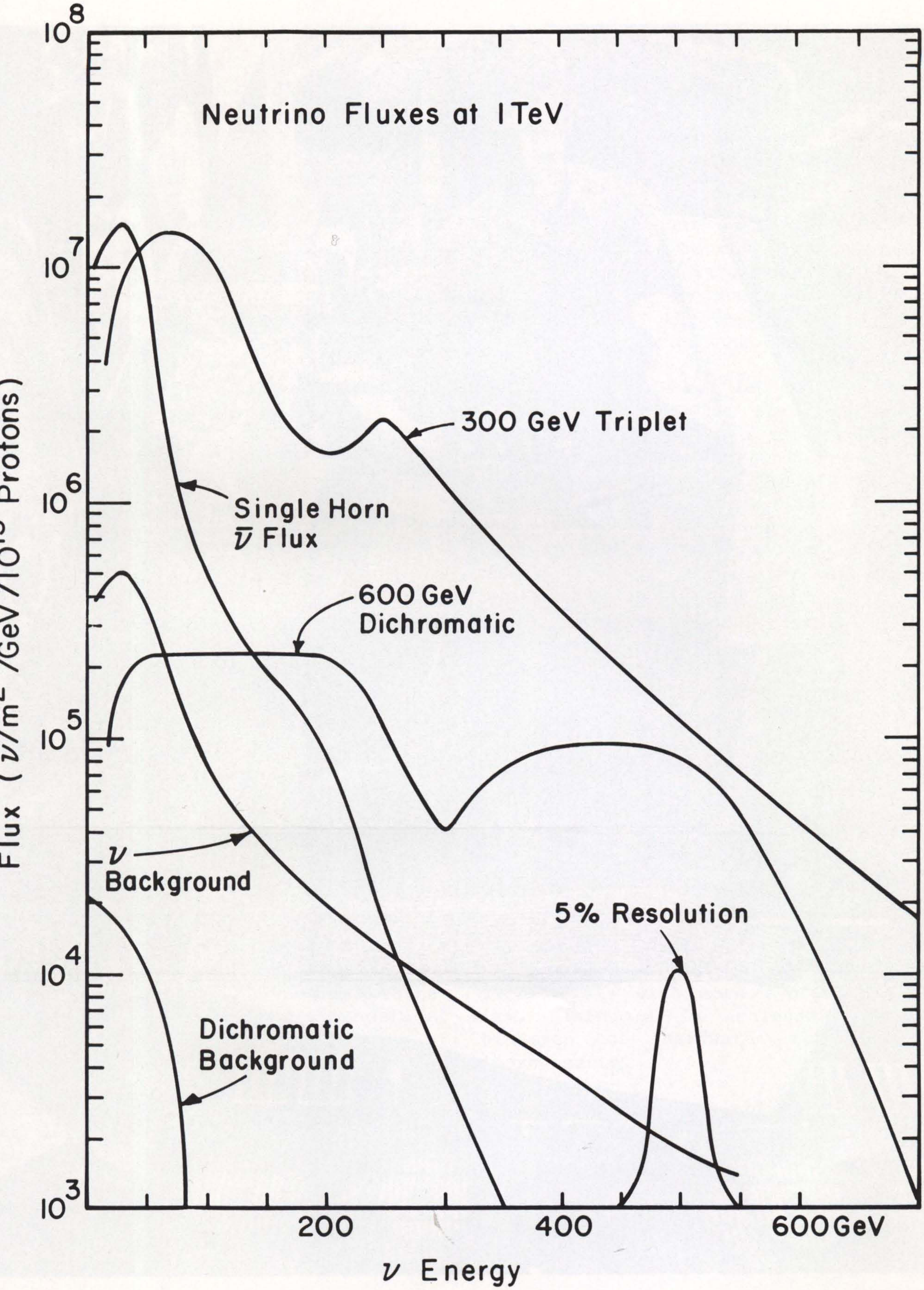
A welder works on superconducting refrigeration-system installation.



A concrete tunnel section for the Enclosure H extension being installed.



Superconducting beam line in Meson.


Neutrino Fluxes at 1 TeV
300 GeV Triplet
Single Horn
$\bar{\nu}$ Flux
600 GeV
Dichromatic
ν
Background
5% Resolution
Dichromatic
Background
10^8
10^7
10^6
10^5
10^4
10^3
Flux (ν/m^2 /GeV/10^{13} Protons)
200
400
600 GeV
ν Energy

Marc Haibeck maintains a tape unit.

Computing

During 1981 the Computing Department has taken a number of initiatives to meet our responsibilities to the Fermilab physics program. Our support role for a new generation of larger and more complex experiments will require considerable effort in meeting computing and electronics needs. As one instance, data-acquisition requirements have expanded rapidly because of the larger and more complex detectors being used. Two new devices have been adopted to enhance the performance of minicomputers used in the data-acquisition function.

The first new hardware extension is a more flexible additional memory device called a "bank-switchable bulk memory." The bulk memory is organized in banks, any one of which can be switched into the computer for the temporary storage of data during beam-spill time. By switching from bank to bank, it is possible to record more data than could be handled by the original minicomputer. Since the buffers are now much larger, the bulk memory allows data to be effectively acquired at a higher rate. The first experiment to use this new hardware achieved twice the data rate that was possible with their previous computer system. A second experiment is now preparing to use the bulk memory with its data-acquisition minicomputer.

The second new hardware is a high-density magnetic tape drive. Previous tape drives in operation at the Laboratory were capable of recording data at a density of 800 or 1600 bpi (bytes of data per inch of magnetic tape). The new tape drives record data at the much higher density of 6250 bpi. By recording information at higher density the new tape drives make it possible to copy the data to tape at greater speed, allowing more data to be taken during the course of the experiment.

In order to incorporate these two new pieces of hardware into the Fermilab data-acquisition systems it has been necessary to update the software that makes use of them. In addition, the hardware itself required a significant amount of development and testing. This was done in cooperation with the vendors involved. The Fermilab portion of the hardware effort was carried out by the Computing Department hardware-maintenance group.

This hardware is most directly related to improving the quantity of data taken in the high-energy physics experiments at the Laboratory, but by freeing up memory in the minicomputer these hardware devices also increase the ability of the computer to monitor the data. Thus the new hardware helps the experimenter to monitor the data to guarantee that it is of the highest quality.

A number of important developments have also occurred recently with FASTBUS, the new high-energy physics data acquisition standard. The PDP-11 host interface prototype, developed by Research Services, became operational and the software developed for it was demonstrated at the recent IEEE Nuclear Science Symposium. Commitments to use FASTBUS for future experiments are now being formulated.

Central computing efforts have concentrated on achieving higher service levels with more systems stability. This goal is achieved by a combination of hardware and software improvements.

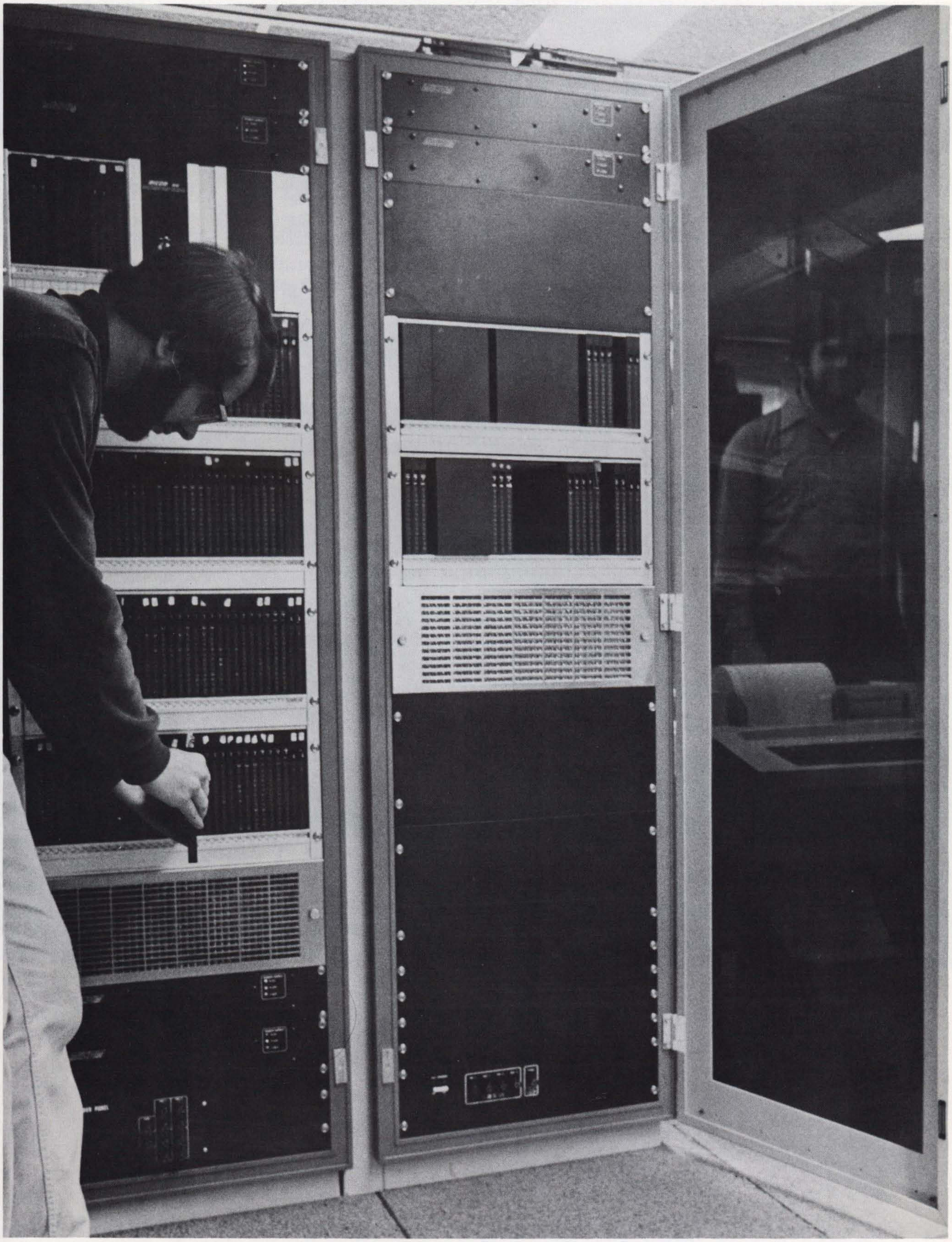
In particular, additional higher-performance disks and tape drives have been installed and made operational. New plotting equipment has been added to the complement of input/output equipment and now includes a 36-in.

drum plotter. Software improvements include a new level of operating system that will provide a base for more effective system resource control and management as well as a performance analyzer tool which is available to users to assess the efficiency of their codes.

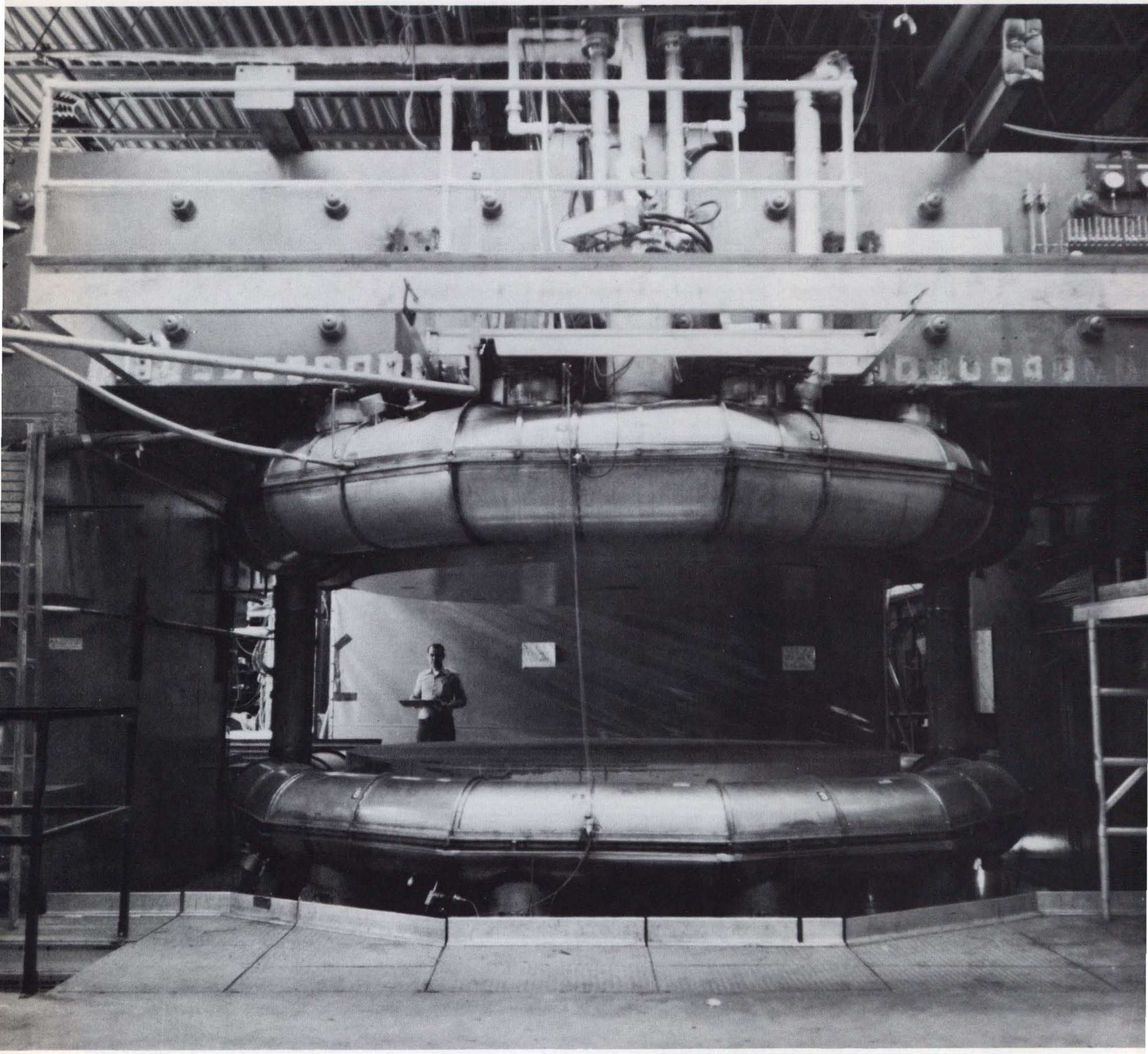
The achievement of hardware and software stability allows us to direct much-needed effort to the future. These "futures" include installation and support of computer aided design and drafting, network connections for computer systems, and an active training and support program, including courses for CYBER computer users, tutorials on installed high-energy physics applications software, and performance tools for users in their physics analysis program development.

Larry Bays works on the design of a printed circuit.

Donald Eyman checks a BISON unit.



Greg Chartran installs a circuit board (with Don Hendricks in a mirror image).



Howard Hart stands in the magnet gap between the new superconducting coils built and installed in the Chicago Cyclotron spectrometer.

Research Services

Research Services has been involved with several major projects during the past year in the area of cryogenic magnet development. A major engineering effort has gone into the conceptual design of a superconducting solenoid magnet for the Collider Detector Facility. In the process of designing the coil considerable use has been made of finite-element analysis techniques to investigate possible structural weak points. Preliminary parameters of the refrigeration and power-supply systems for this magnet have been specified.

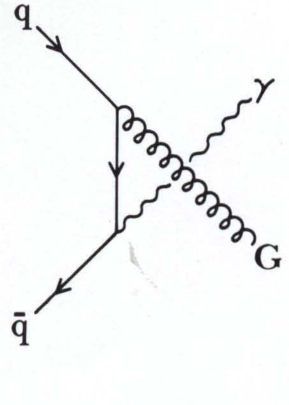
A second major effort from the cryogenic component of the Department has been a project to build the correction coils and ten different subsystems associated with the cryogenic lead boxes for the Energy Saver. Of the total of 375 correction coils needed for the new accelerator, some 175 have been completed to date. This effort will be completed in 1982. Research Services is also designing beam-position monitors and extraction power-supply controllers for the Energy Saver.

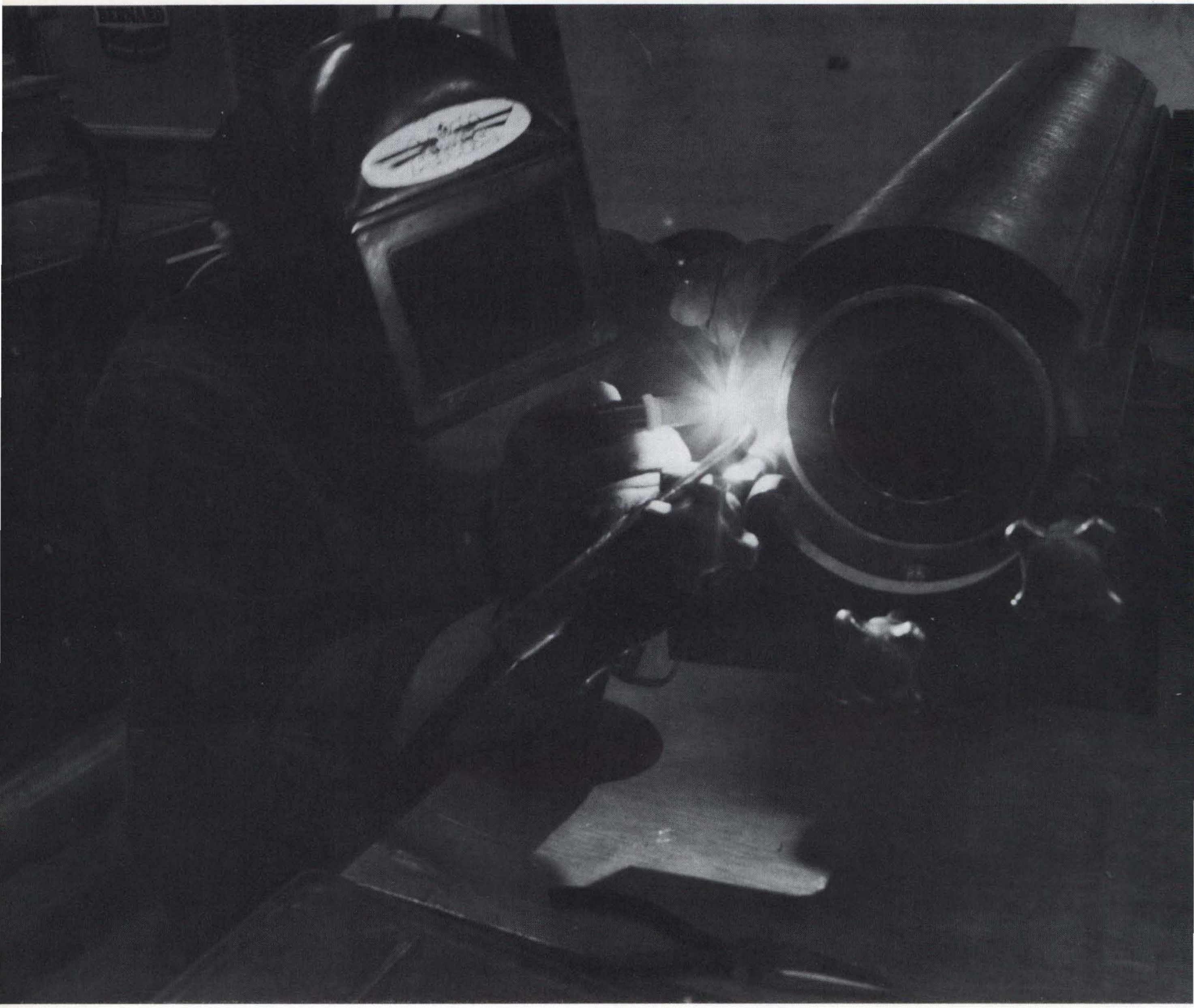
A third effort has been the construction of superconducting coils for the 30-inch bubble-chamber. This project is part of a Laboratory effort to reduce power consumption. One coil has been wound and the other one started.

A major effort undertaken by Research Services this year has been the upgrade of the magnetic measurement device (Ziptrack). This automated measuring device has been redone both electrically and mechanically in order to be able to map large, new magnets for experiments E-615 and E-605.

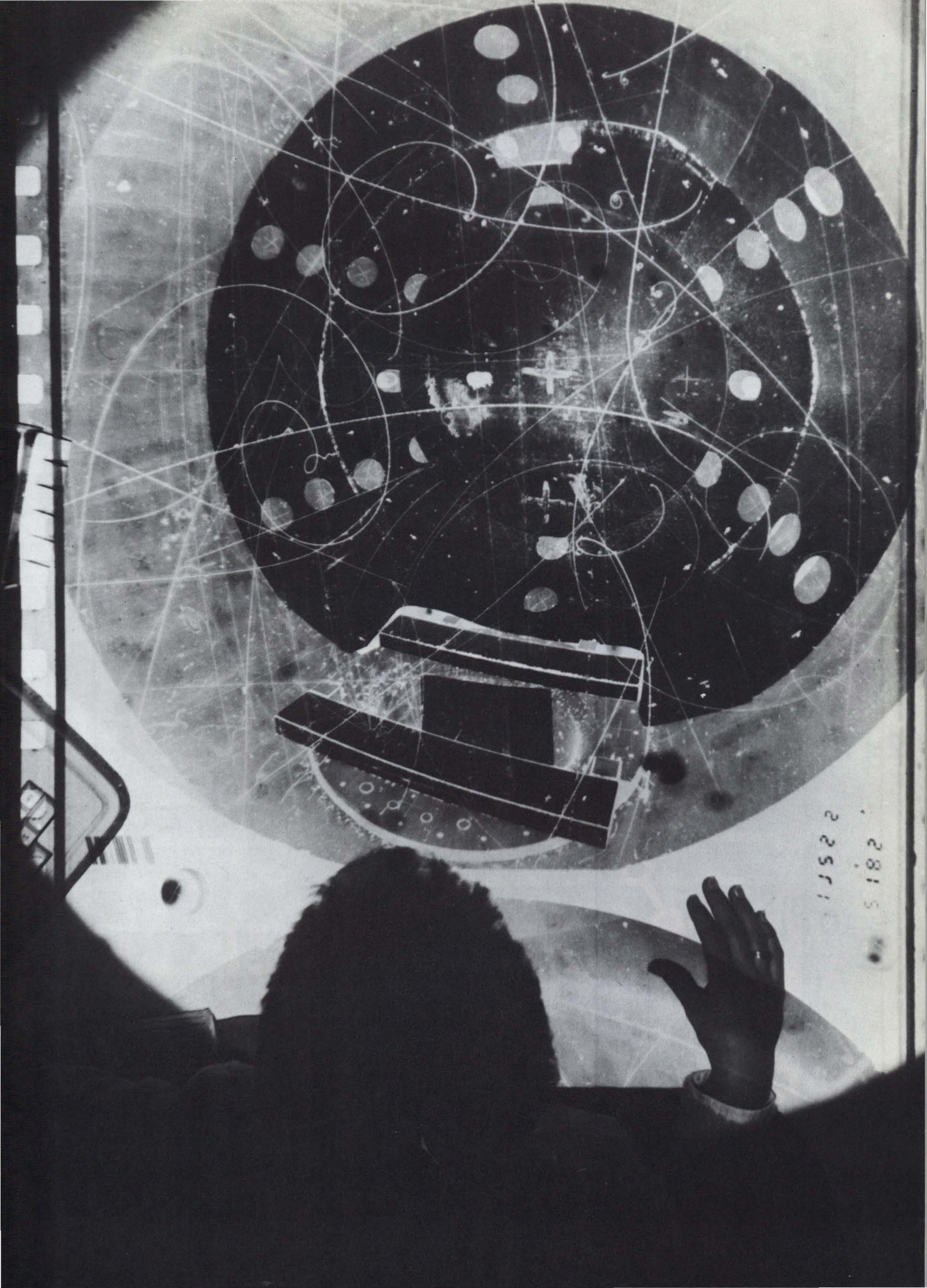
Research Services has recently turned its attention to the development of low-current, large-aperture, superconducting beam-line magnets for the experimental areas. The department was involved in the successful effort to develop a low-current quadrupole. The present effort is to develop a full-scale 10-foot low-current dipole.

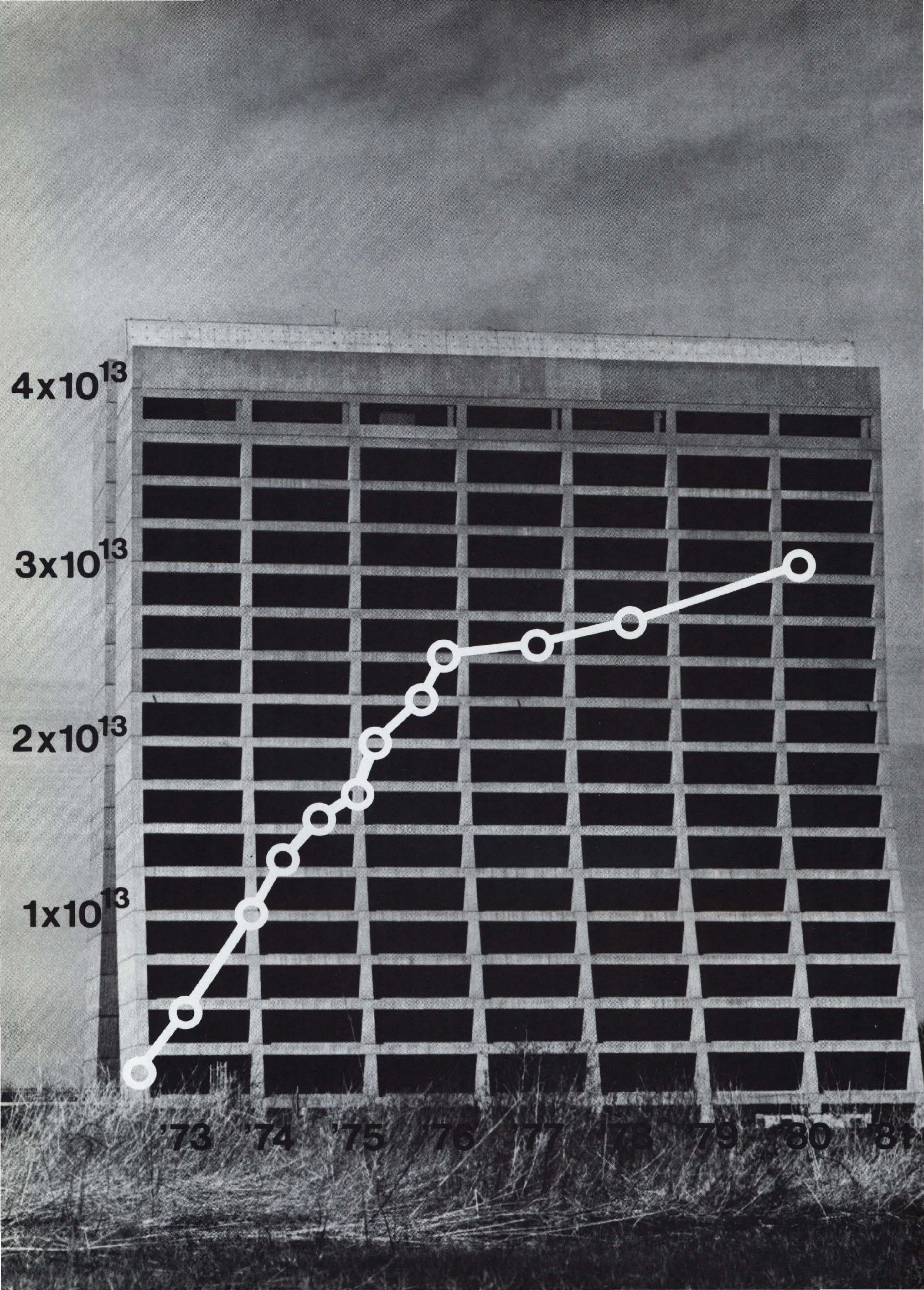
The major hardware and software effort necessary to upgrade the controls system for the Fermilab experimental areas has been continued. All the necessary computers have been brought into operation in the last year and software efforts are proceeding to get the operating system prepared for use in the coming year.





A welder at work on a correction coil being built by Research Services for the Energy Saver.

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III. Present Physics (Physics at 400 GeV)

Introduction

In addition to the work of building for the future, a vigorous program of physics research at present energies was carried out at Fermilab, involving a large community of users.

The accelerator operated reliably at 400 GeV for a 5-month running period in 1981. New intensity records were set during this run.

The experimental activity at the 400-GeV accelerator was extensive in 1981, despite the abbreviated running schedule. A large variety of detectors were used, including emulsions to study Σ interactions and charm decays, the large bubble chamber to study neutrino interactions, and the small bubble chamber to study strong interactions. A number of multiparticle spectrometers were used to investigate a variety of different phenomena such as hadronic production of charm, photoproduction of charm, dimuon production, and hadronic jet production. Other detectors such as a high-precision streamer chamber, a time-projection chamber, and calorimeters were employed in still other experiments. It is too soon to have final results from these experiments, but preliminary analyses indicate that most of them succeeded in reaching their objectives and that exciting results will come from the operation of the Fermilab accelerator in 1981. After the conclusion of the running period, each of the areas carried out improvement projects to prepare for future operation.

Fermilab Experiments 1981

Exp #	Short Title Of Experiment	Spokesperson & Institution	Participating Institution
53A	15-Ft Neutrino /H_2 & Ne	Baltay, Charles Columbia U.	Brookhaven Columbia U.
326	Di-Muon	Shochet, Melvyn J. U. of Chicago	U. of Chicago Princeton U.
497	Charged Hyperon	Lach, Joseph Fermilab	Fermilab Iowa State U. Yale U.
515	Particle Search	Rosen, Jerome L. Northwestern U.	Carnegie-Mellon U. Fermilab Northwestern U. U. of Notre Dame
516	Photoproduction	Nash, E. Thomas Fermilab	U. of California, Santa Barbara Carleton U. (Canada) U. of Colorado Fermilab National Research Council of Canada U. of Oklahoma U. of Toronto (Canada)

531	Neutrino	Reay, Neville W. Ohio State U.	Aichi U. of Education, Kariya (Japan) Fermilab Kobe U. (Japan) Korea U. (Seoul) McGill U. (Canada) Nagoya U. (Japan) Ohio State U. Okayama U. (Japan) Osaka U. (Japan) U. of Ottawa (Canada) Science Education Inst. of Osaka Prefecture (Japan) U. of Tokyo, Cosmic Ray Laboratory (Japan) U. of Toronto (Canada) Virginia Polytechnic Inst. & State U. Yokohama National U. (Japan)
537	Di-Muon	Cox, Bradley Fermilab	Fermilab McGill U. (Canada) U. of Michigan Shandong U. (China) U. of Athens (Greece)
557	Hadron Jets	Malamud, Ernest I. Fermilab	Fermilab U. of Illinois Chicago Circle Indiana U. U. of Maryland Rutgers U.
564	15-Ft & Emulsion /Neutrino	Voyvodic, Louis Fermilab	Fermilab Illinois Inst. of Technology Inst. of Theoretical and Exp. Physics, Moscow (USSR) Inst. of High Energy Physics Serpukhov (USSR) Inst. of Nuclear Physics Cracow (Poland) Joint Inst. for Nuclear Research Dubna (USSR) U. of Kansas U. of Sydney (Australia) U. of Nuclear Physics Sofia (Bulgaria) U. of Washington

565	30-In. Hybrid	Pless, Irwin A. Massachusetts Inst. of Technology	Brown U. CERN Indiana U. Israel Inst. of Technology Technion City, Haifa (Israel) Massachusetts Inst. of Technology Nijmegen U. (Netherlands) Oak Ridge National Laboratory U. of Padova (Italy) U. of Pavia (Italy) U. of Rome (Italy) Rutgers U. Stevens Inst. of Technology U. of Tel-Aviv (Israel) U. of Tennessee Tohoku Gakuin U. (Japan) Tohoku U. (Japan) U. degli Studi di Trieste (Italy) U. de l'Etat, Mons (Belgium) Weizmann Inst. of Science, Rehovot (Israel) Yale U.
570	30-In. Hybrid	Pless, Irwin A. Massachusetts Inst. of Technology	Brown U. CERN Indiana U. Israel Inst. of Technology Technion City, Haifa (Israel) Massachusetts Inst. of Technology Nijmegen U. (Netherlands) Oak Ridge National Laboratory U. of Padova (Italy) U. of Pavia (Italy) U. of Rome (Italy) Rutgers U. Stevens Inst. of Technology U. of Tel-Aviv (Israel) U. of Tennessee Tohoku Gakuin U. (Japan) Tohoku U. (Japan) U. degli Studi di Trieste (Italy) U. de L'Etat, Mons (Belgium) Weizmann Inst. of Science, Rehovot (Israel) Yale U.
577	Elastic Scattering	Rubinstein, Roy Fermilab	U. of Arizona U. of California, San Diego Cornell U. Fermilab

585	Kaon Charge Exchange	Francis, William R. Michigan State U.	U. of California at Davis U. of California at San Diego Carleton U. (Canada) Michigan State U.
591	Particle Search	Gutay, Laszlo J. Purdue U.	Fermilab Purdue U.
594	Neutrino	Walker, James K. Fermilab	Fermilab Massachusetts Inst. of Technology Michigan State U. Northern Illinois U.
612	Photon Dissociation	Goulianos, Konstantin Rockefeller U.	Rockefeller U.
613	Beam Dump	Roe, Byron P. U. of Michigan	U. di Firenze (Italy) U. of Michigan Ohio State U. U. of Washington U. of Wisconsin
617	CP Violation	Winstein, Bruce D. U. of Chicago	Centre de Recherches, Recherches Nucleaires de Saclay (France) U. of Chicago Stanford U.
629	Direct Photon Production	Nelson, Charles A. Fermilab	Fermilab Michigan State U. U. of Minnesota Northeastern U. U. of Rochester Texas A&M U.
630	B & Charm Particle	Sandweiss, Jack Yale U.	Fermilab Yale U.
666	Emulsion Exposure	Wilkes, Richard J. U. of Washington	Inst. of Nuclear Physics Cracow (Poland) U. of Washington

Accelerator

The major goals of the accelerator during the last year were reliability and high intensity. During 29 weeks of running (November 1980 - June 1981) 79% of the hours scheduled for high-energy physics were run. The intensity of the 400-GeV proton beam reached an all-time high during this period. On March 16, 1981, 3×10^{13} protons per pulse was achieved. During this running period the highest number of protons were accelerated to 400 GeV for one week (10.1×10^{17}), as well as the highest number for one month (37.33×10^{17}).

In addition, during this period the Booster reached its highest intensity, 4.011×10^{13} protons per Main-Ring cycle (13 Booster batches), with a transmission efficiency about 50% higher than had been achieved two years ago. These achievements are the result of a great amount of quiet, almost behind-the-scene work that goes on continually in order to improve the Booster and all other parts of the Fermilab accelerator.

During the summer of 1980 the 56 external proton beam dipoles in Enclosure C were removed and replaced by 21 Energy Saver dipoles. This meant that during the 1981 run period 400-GeV beam to the Meson Laboratory was transported through the superconducting Left Bend string. Tuning the beam through this string was not a problem; in fact, the Main-Ring intensity record could not have been achieved without running the beam through the Left Bend. Reliability was a problem during the initial operation of the Left Bend string. This was caused by several factors, most notably the two reciprocating helium compressors used with the switchyard refrigerator. These compressors were replaced with a higher-capacity two-stage screw compressor which performed much better. Several other sources of unreliability were found and corrected.

Accelerator Operations 1977-1981

	1977	**1978**	**1979**	**1980**	**1981**
HEP Actual	4786.9	3772.3	3835.8	2401.3	2149.05
HEP Scheduled	6421.5	5541.5	5166.6	3055.6	2716.2
Actual/Scheduled	74.5%	68.1%	74.2%	79%	79%
Studies Actual	525	401.2	756.3	530.3	126.04
Studies Scheduled	600.5	622.2	837.5	563.5	169.5
Actual/Scheduled	87.5%	64.5%	90%	94%	74%
Start up Actual	101.6	229.8	274.5	426.2	46.0
Start up Scheduled	108.0	268.5	206.5	360.2	42.5
Tuning Actual	316.6	527.3	226.1	23.7	76.12
Tuning Scheduled	0	0	12	0	0
Accelerator Failure	1351.1	1466.0	1084.4	591.6	524.79
Operations Hours Actual	7081.7	6396.5	6177.1	3973.1	2922.0
Operations Hours Scheduled	7130	6628	6222.6	3979.3	2928.2

	1977	1978	1979	1980	1981
Shutdown Actual	1629.7	2106.2	2550.2	4801.5	4354.9
Shutdown Scheduled	1630.0	2132.0	2537.4	4804.7	4368.8
Ad hoc Shutdown Actual	48.6	257.3	32.7	9.4	20.1
Ad hoc Shutdown Scheduled	0	0	0	0	0
Total Hours	8760	8760	8760	8784	7297
Total # of Protons Accelerated	252.07	202.45	254.15	114.64	141.42
Total # of MR Ramps	1,940,000	1,966,420	2,094,134	947,111	793,959
Total to Meson Area	52.9	23.42	18.98	23.45	16.25
Total to Neutrino Area	142.2	139.20	188.44	53.36	72.61
Total to Proton Area	25.7	26.70	39.55	27.62	45.02

Meson

This year was a year of productive work in Meson. Seven experiments were completed in various beams. In addition, other experiments took test data, and the M5 test beam was heavily used. Several modernization and improvement projects were completed and design work was carried through on many features to be built for the Tevatron era.

In the M1 beam line E-515 (Rosen) carried out a charm search with 2,000,000 triggers. This experiment utilizes a sodium-iodide scintillation camera that gives 10-micron resolution. In the same line, E-629 (Nelson) showed with their liquid-argon calorimeter that a direct photon search will be feasible at Tevatron energies.

In the M2 beam line E-613 (Roe) detected prompt neutrinos. In M3 E-617 (Winstein) had a successful test run and will begin taking data in January, 1982.

The long occupancy of the M4 beam line by the group from the University of California at San Diego and its collaborators came to a close with the completion of E-585. The test beam in M5 was heavily booked throughout 1981, with special emphasis on calorimeter module tests for E-609 (Selove) and the Collider Detector Facility and on the drift chambers for the CRISIS detector used in the 30-inch bubble chamber in Neutrino.

The M6 beam line saw the completion of E-577 (Rubinstein), investigating elastic scattering of π and K mesons and antiprotons. In addition, E-623 (Green) had a 60-hour run to test a trigger processor. They observed one reconstructed $\phi\phi$ event per 700 triggers, a factor 1000 times larger than any previous Fermilab $\phi\phi$ experiment. Experiment E-557 (Malamud) completed construction and took data with the first Fermilab full-azimuth calorimeter. They have taken data on high-p_T event production and searched for jets.

Carrying out all these experiments required the everyday originality, creativity, and innovation expected at Fermilab. We built several movable support systems for calorimeters and for a magnet system to vary the production angle. In work not specific to any one experiment a new target manipuany one experiment a new target manipulator for the Meson target train was built and installed.

A major new project in 1981 was the construction of a magnet for E-605. This is one of the largest magnets in the world and by far the largest ever built at Fermilab. The coil is 60 feet long and the magnet yoke, a reincarnation of the Nevis cyclotron magnet steel, is 47 feet long. The magnet coil was assembled in Industrial Building 4 and moved to the Meson Detector Building for installation in the yoke. At year's end the magnet was almost completely assembled and ready for testing in the M1 beam line where it will be the centerpiece of a focusing spectrometer (see Technology section).

Neutrino

There were three major areas of activity in the Neutrino Area in 1981. First, we carried out a program of 400-GeV experiments to study neutrino and hadron interactions. Second, we made a good beginning on preparations for higher-energy protons, in that we completed the extension of enclosure G2 and thoroughly reviewed our designs for Tevatron II. Finally, we began preparations for the 1982 running period by rebuilding the narrow-band neutrino beam and the N1 muon beam. We also installed a new experiment to search for neutrino oscillations.

In 1981 we completed several neutrino experiments. An important emulsion exposure was carried out to detect and measure directly the lifetime of charmed particles. This experiment, E-531 (Reay), greatly extends our understanding of charmed mesons and baryons. In addition, the 15-foot bubble chamber ran an exposure for E-53A and E-564. Charles Baltay of Columbia University carried out the E-53A experiment to study neutrino-electron elastic scattering. Louis Voyvodic used emulsions housed within the 15-foot chamber for E-564 to help extend the search for charmed-hadron production.

In 1981 we also resumed operation of the 30-inch bubble chamber for several experiments. Experiment 565/570 (Pless) and E-597 (Whitmore) together had an exposure of about 150,000 pictures. It was the first run of the bubble chamber with a sophisticated set of electronic detectors, cumulatively called the Downstream Particle Identifier (DPI). This involves a drift-chamber device called CRISIS that identifies particle type (K, π, and proton) by measuring the rate of energy loss as the particle passes through the device; in addition, a Forward Gamma Detector (FGD) was used to identify photons interacting in the chamber and to measure their energies. OSIRIS was also used by E-597; it is a Cherenkov counter used to identify particle types. The DPI also employs a calorimeter to measure hadron energies in interactions in the 30-inch chamber. These experiments will be completed in 1982 when a run of several million pictures will take place.

Work is also going forward in the bubble-chamber group on a new holographic optics system for the 15-foot bubble chamber to record bubbles of much smaller size than could ever be achieved with conventional optics. Smaller bubbles mean better resolution and better resolution will aid in the search for short-lived heavy quark and lepton states that leave finite but very short tracks in the chamber.

This year also saw the first run for E-594 (Walker). This large detector (400-ton fiducial volume) is designed to study neutrino interactions with high resolution. The experiment first ran with the wide-band neutrino beam. The resolution of the detector is essential to identify electrons and is well-suited for a definitive measurement of electron-neutrino interactions. This run helped to shake down the apparatus for important experiments that will extend well into the Tevatron era. In 1982 this device will run in the narrow-band neutrino beam to measure structure functions in neutral current interactions.

Looking to the future, a run at 400 GeV is planned for January 1981 through June 1982. In preparation for this a new neutrino detector was built in the Wonder Building for E-701. This experiment will search for neutrino oscillations using this new detector in conjunction with the 1000-ton neutrino detector in Laboratory E which has already been used to study the properties of neutrino interactions. A comparison of the number of neutrino interactions in the two detectors will reveal if any muon neutrinos have changed to other types.

In 1981 preparations were also made to continue E-610 and E-673 by groups from Fermilab, Illinois, Pennsylvania, Purdue, and Tufts. These experiments study hadronically produced charmonium states (J/ψ, χ, ψ') using the Chicago Cyclotron Particle Spectrometer (CYCLOPS). The eye of CYCLOPS is a 147-element lead-glass array used to detect photons in the decay $\chi \to J/\psi + \gamma$. Preliminary results from E-610 show substantial χ production. Experiment 673 will run in 1982 and will use the superconducting cyclotron magnet for the first time.

Proton

This was a year of significant progress in the Proton Area. Initial experiments were completed on several large new detectors that had been constructed and debugged in prior years. In addition, several major construction projects were undertaken and completed in order to provide better utilization of Proton Area resources and to prepare for 1-TeV operation of the area.

Nine experiments were run this year. These included three (E-326, E-537, E-615) in Proton-West, three in Proton-Center (E-497, E-619, E-630), and three in Proton-East (E-400, E-516, E-612).

In the P-West High Intensity Pion Beam a collaboration from the University of Chicago and Princeton University completed experiment E-326, which uses a large solid-iron toroidal magnet system for the detection and analysis of muon pairs produced in pion-nucleon collisions. This experiment completed a major run this year and will report on muon pairs with masses up to 15 GeV.

Also in the High Intensity Beam, good progress was made toward completion of E-537 which uses a large dipole spectrometer to study the production of dimuons from nuclear targets using an antiproton beam. This experiment, which will be completed in 1982, is expected to yield several thousand events above a dimuon mass of 4 GeV.

A large new detector has been approved for construction in the High Intensity Beam. A collaboration from Chicago, Iowa State, and Princeton will construct a spectrometer whose major elements are two large dipole magnets. The large mass selector magnet, with gap dimensions 15.5 in. × 54 in. × 24 ft long, was completed and the experiment will be installed in time for testing in spring, 1982.

The multiparticle spectrometer in the Tagged Photon Laboratory completed its first experiment during the past year. Experiment 516 studied the *dynamics of charmed-particle photoproduction using approximately 20* million events accumulated this year. The event trigger for this study involved a sophisticated recoil detector data preprocessor to select event candidates with a large forward missing mass.

Also in P-East, in the Broad Band Neutral Beam, modifications to the spectrometer were begun for E-400. This experiment will utilize the improved apparatus to study charm hadroproduction in the neutron beam.

A group from Rockefeller University and the People's Republic of China developed a recoil detector using high-pressure hydrogen gas, both as a target and as a detector to measure and identify slow recoil protons. This device was set up at the Tagged Photon Laboratory. Experiment 612, the first experiment to use this target, began taking data this year. The experiment *expects to study diffractively produced* states in the Tagged-Photon Beam.

The first experiment to use the new Charged Hyperon Beam in Proton *Center, E-497, measured hyperon production cross sections and associated* hyperon polarizations. The versatility of this beam was demonstrated later in the winter, when E-630 used the same target magnet to produce a high-intensity neutron beam. This neutron beam is very free of halo particles and will be used to study charmed-particle production in a high-resolution streamer chamber. Experiment 630 is expected to complete its data-taking phase early in 1982. In addition, the Neutral Hyperon Group (Rutgers, Michigan, and Wisconsin) from the M2 beam in Meson will move into P-Center this coming year to carry out E-619, which is a measurement of the $\Sigma^0 - \Lambda^0$ transition magnetic moment. Installation activities for this experiment were begun this year.

Physics Department

The most notable milestones of the 1981 year were the completion of construction and first data-taking runs of several major experiments: E-594, Large Neutrino Fine Grain Detector; E-537, A Dimuon Spectrometer of Large Acceptance; and E-497, Fine Resolution Hyperon Beam Spectrometer. All of these experiments were built and instrumented using the Physics Department's engineering and technical capabilities. The first data-taking runs were successful, a testimony to the fine work of the builders.

The fabrication of very fine wire high-resolution proportional-wire chambers has been carried out by the combination of two technical groups. The design group under Carl Lindenmeyer designed and built a precision machine for winding fine, 3-5 micron diameter wire (which is much thinner than hair) onto proportional chambers with very accurate spacing. Karen Kephart and Jack Upton are now busy with this machine, winding chambers to be used by E-400, the Hadronic-Production of Charm Experiment.

In the area of data analysis, an extensive effort is underway to digest the 25,000,000 events obtained during the run of E-516, Tagged-Photon Beam Experiment. The data run ended in June 1981 and at the end of 1981, massive data crunching began. Several programmers are assisting physicists in this elaborate task.

During the universities' summer recess time, approximately a dozen students were employed in the Physics Department. These young people were engaged in tasks ranging from the construction of scintillators to data analysis and processing. Four high-school seniors from the Saturday Morning Physics classes were included in this group. Thus, an opportunity was given to these prospective scientists to experience and participate in various facets of the particle-physics research.

The forthcoming 400-GeV run, starting in January 1982, has the Physics Department working at high pitch preparing assisting many experiments scheduled to take data in this period. To mention a few:

E-605 Dimuon Experiment. The Physics Department is making drift chambers and a calorimeter.

E-660 Channeling Experiment. A few drift chambers and a variety of small items are provided by the Physics Department.

E-623 Resonance Search Via $\phi\phi$ Production. A new set of drift chambers was made in the Physics Department basement shop.

E-537 Antiproton Production of Dimuons. Most of the equipment was made ready for last season's test run: chambers, trigger processors, and counters.

E-400 Charm Production by Hadrons. A totally new set of very high resolution chambers is being made by the Physics Department to allow charmed-particle vertex resolution. In addition, a new set of Cherenkov counters was fabricated.

E-701 Neutrino Oscillation. With aid from the Neutrino Department, a second massive neutrino detector weighing 700 tons was built in a record time of six months.

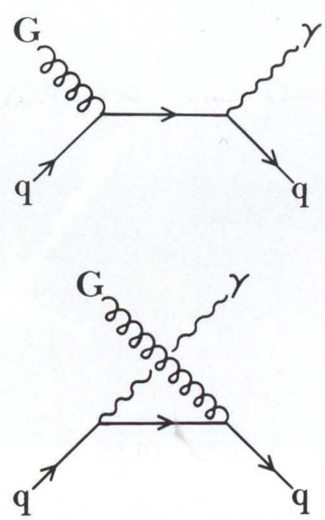
E-594 Neutrino Detector Neutral Current Measurements. The Physics Department has provided very substantial support in getting ready for this run, in addition to the scanning of data from previous runs.

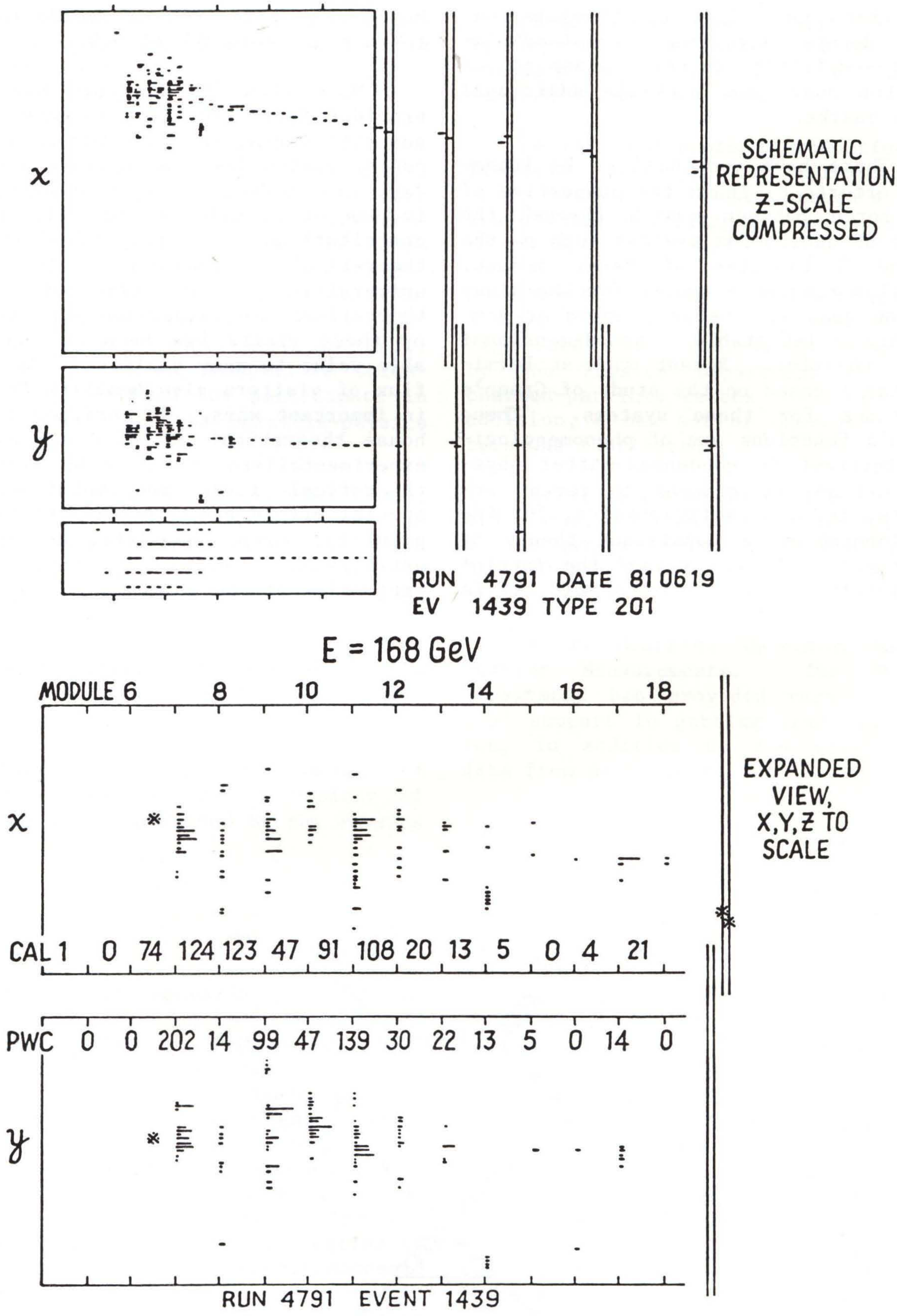
Theoretical Physics Department

Our recent research activity has covered many of the most timely and important topics in high-energy physics. Members of the group have continued to elaborate the predictions of perturbative Quantum Chromodynamics (QCD), the theory of the strong interactions among quarks and gluons, and to investigate the consequences of QCD in the nonperturbative regime. The experimental success of gauge theories of the strong, weak, and electromagnetic interactions has led to attempts to further unify the fundamental interactions. Several aspects of grand unification, including dynamical symmetry breaking, early unification, and implications of further generations, have been actively studied. The proliferation of apparently fundamental constituents, the quarks and leptons, has led some to question whether the quarks and leptons might not themselves be composite. Speculations of this sort, and the challenges they encounter, have been studied as well. Interest in the systematics of weak decays has been reinvigorated at Fermilab as elsewhere by the discovery of charmed particles and the examination of new possibilities for the origin of CP-violation. Rare decays have been examined for their sensitivity to certain aspects of the top quark and possible additional heavy quarks.

There have continued to be intensive efforts to learn the properties of the force between quarks through the study of quarkonium systems such as the ψ and Υ families of heavy mesons. Fermilab remains a center for the study of the quantum-inverse problem of completely integrable two-dimensional field theories. Recent work at Fermilab has focused on the study of Green's functions for these systems. These Green's functions are of phenomenological interest in condensed-matter physics and may be crucial to recent attempts, in high-energy physics, for the development of a consistent theory of quantized strings. Beyond the intrinsic interest these theories hold, it is hoped that this work may guide the way to an exact solution of QCD.

More than 200 visitors have been provided facilities (and in many cases, support) during the past year. In most cases, visits last for periods of a few days to a month. This vigorous program is one of Fermilab's most significant contributions to the well-being of theoretical research in the universities. The stimulation, both theoretical and experimental, provided by these visits has been of considerable value to many visitors. The large flux of visitors also benefits Fermilab in important ways. It enriches the in-house theoretical activity and exposes experimentalists to a wide range of theoretical ideas and opinions. A special effort has been made to involve promising young theorists, as well as established senior theorists, in activities of the Laboratory.





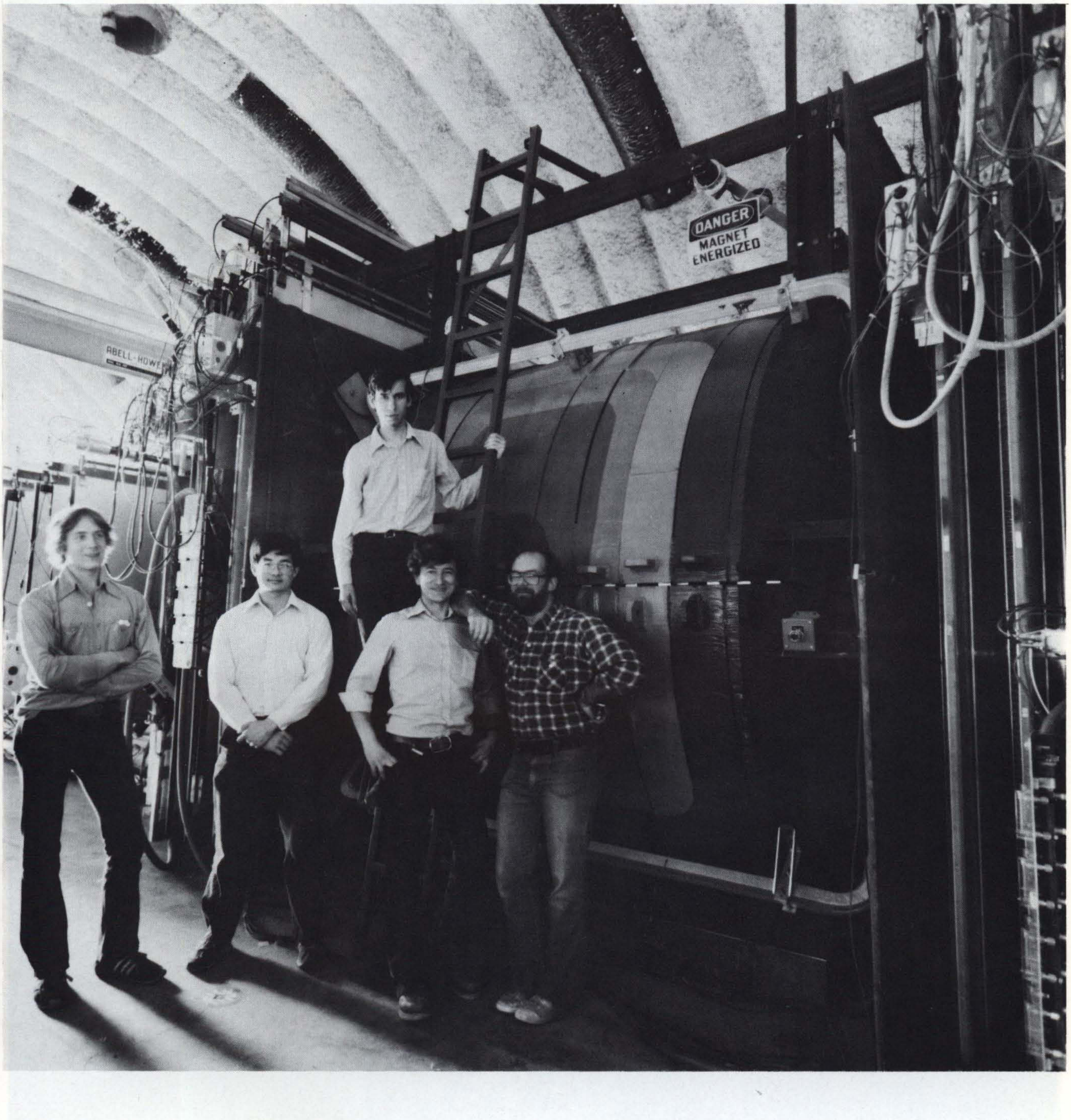
A typical ν_μ charged-current interaction in E-613. The visible hadronic energy is 168 GeV. In the expanded view, the calorimeter and proportional wire chamber energy depositions are expressed in terms of numbers of equivalent muons.

Interaction of a 200-GeV pion in the sodium-iodide scintillation camera of E-515. The 10-micron resolution of this system will permit direct observation of charmed-particle decays.

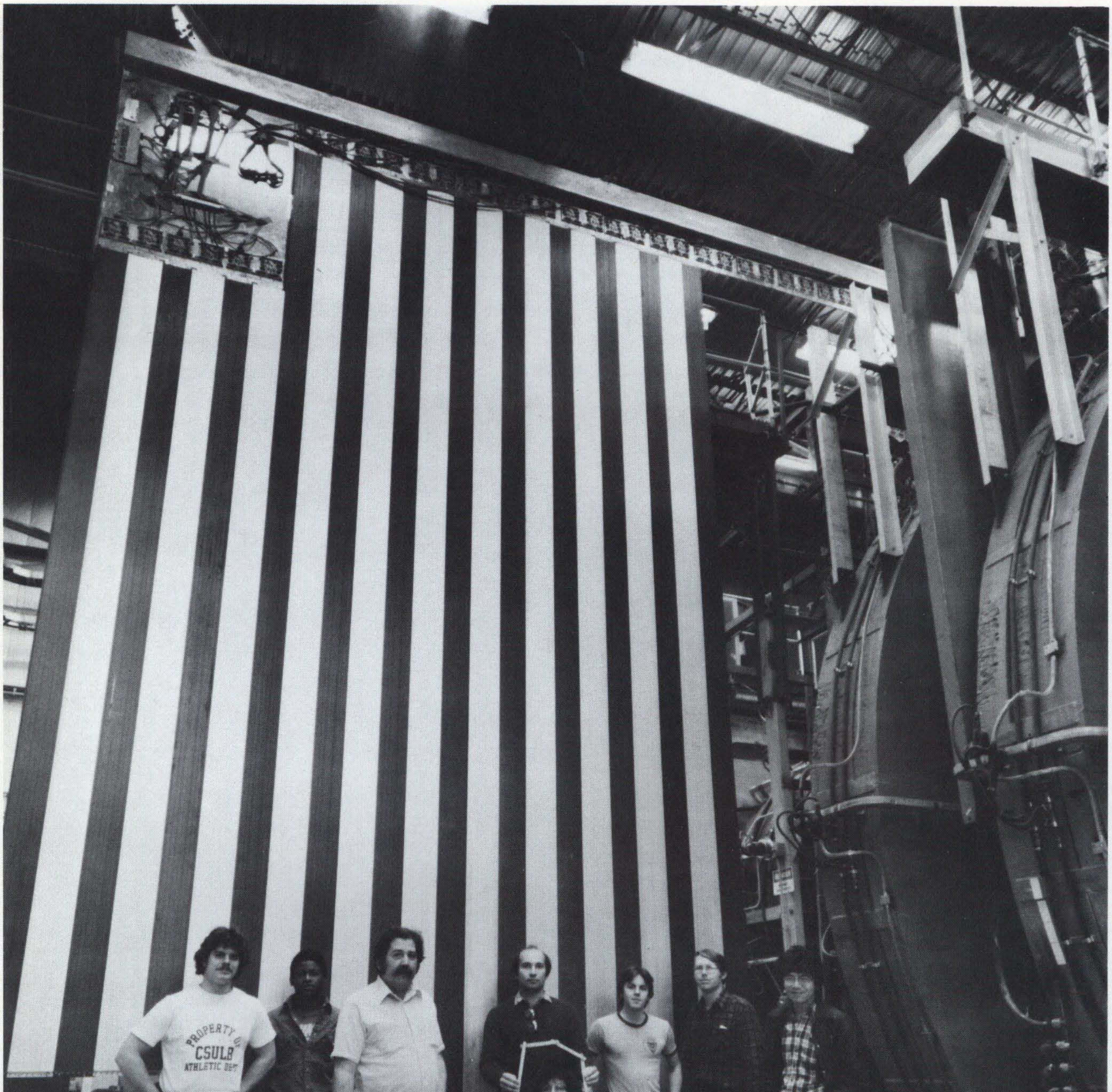
E-605 being built in the Meson Area.

The M6 beam line in Meson, with Roy Rubinstein beside it.

E-609 being built in the M6 pit.

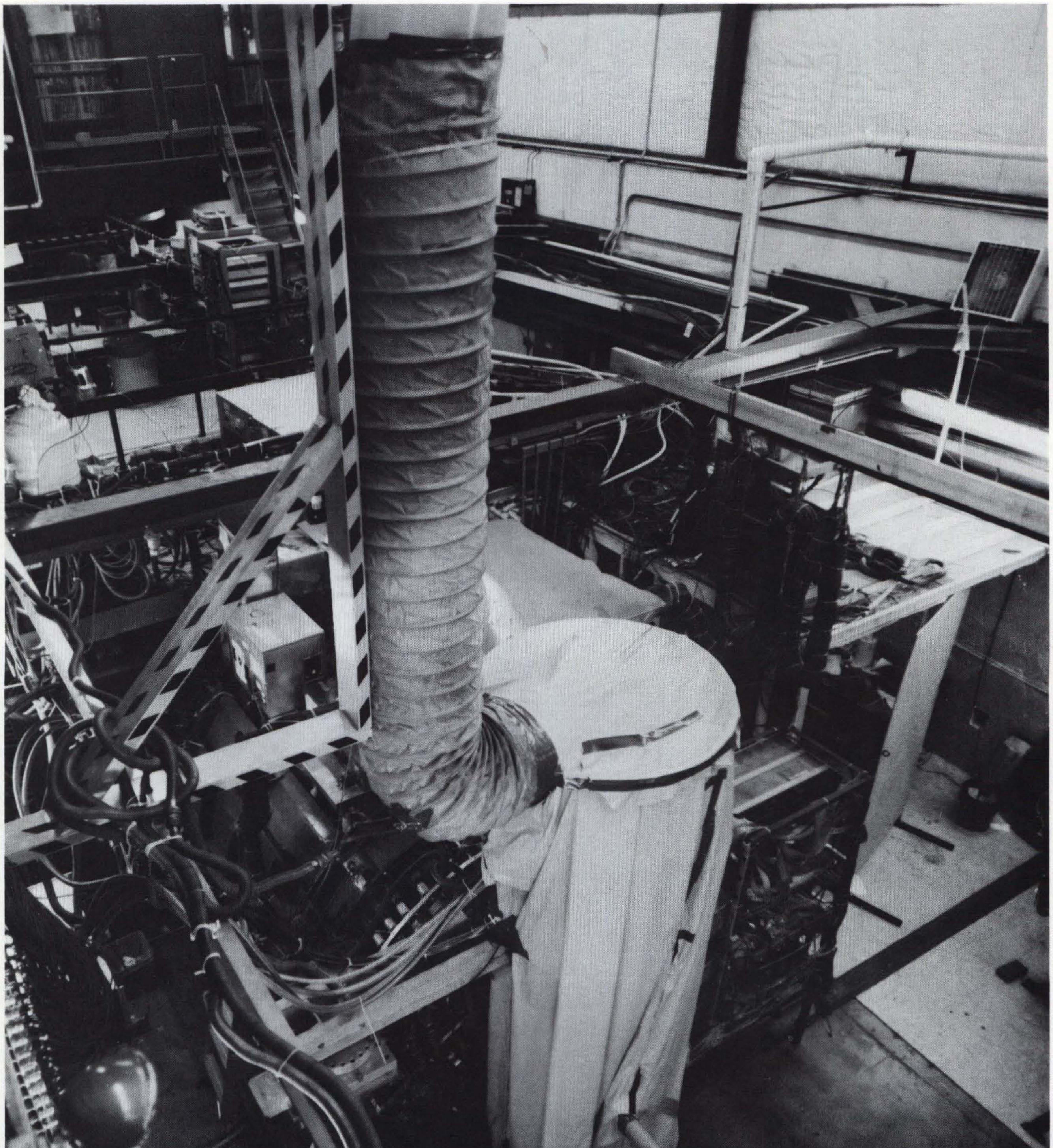


At E-701 in the Wonder Building. From left, Chuck Marofske (Fermilab), Patrick Reuters (Chicago), Nikos Giokaris (Rochester), Ian Stockdale (Rochester), on ladder, and Arthur Grant (Fermilab).

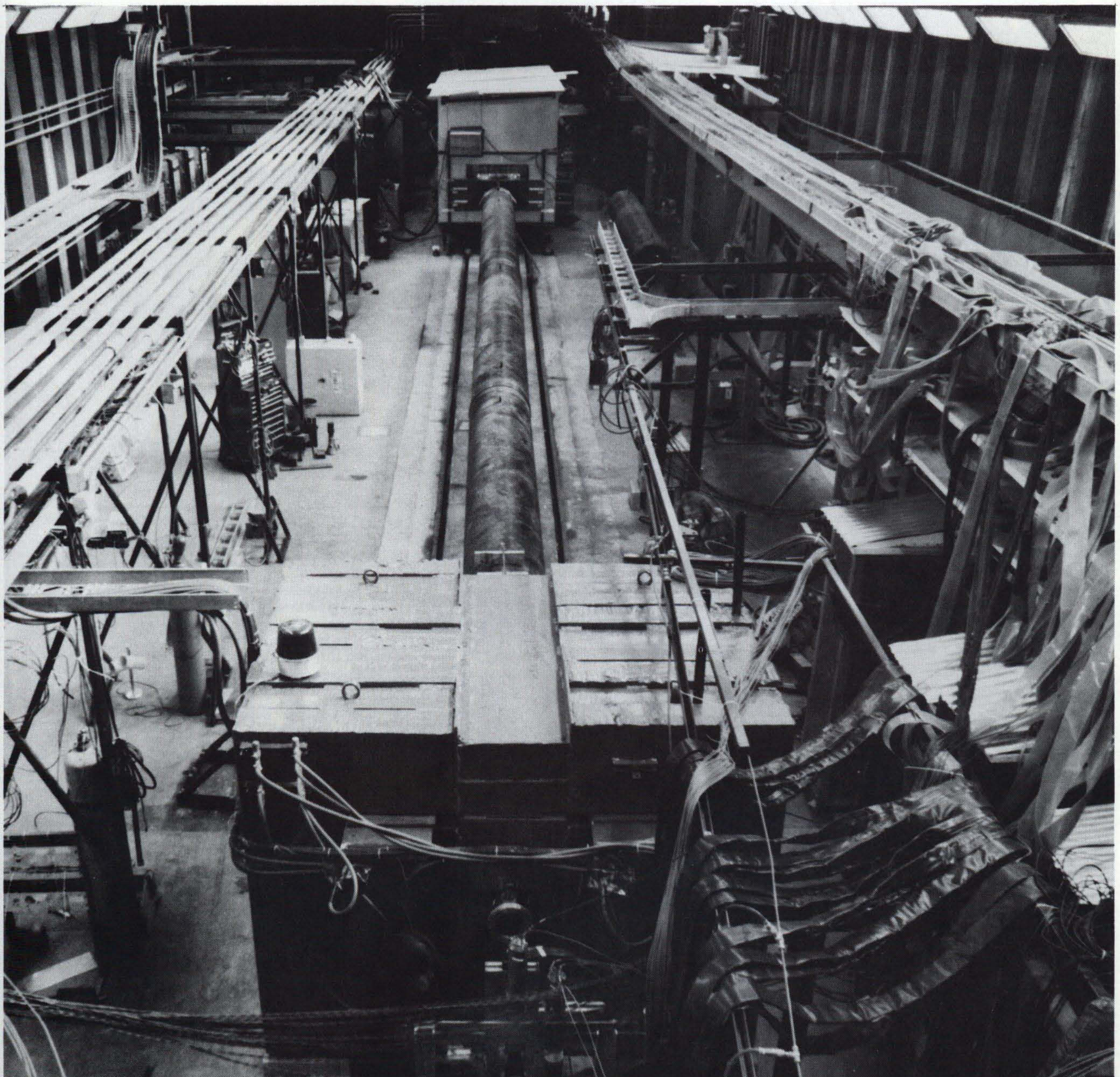


(Left to right) Pat Baker, Ivan Byrd, Tommy Lyons (MIT), Randy Carlson, Juan Bofil (MIT), Mike Tartaglia (MIT), Randy Pitt (MIT), and Gong-Ping Yeh (MIT) beside the apparatus of E-594 in the Neutrino Area. Behind them is the huge detector.

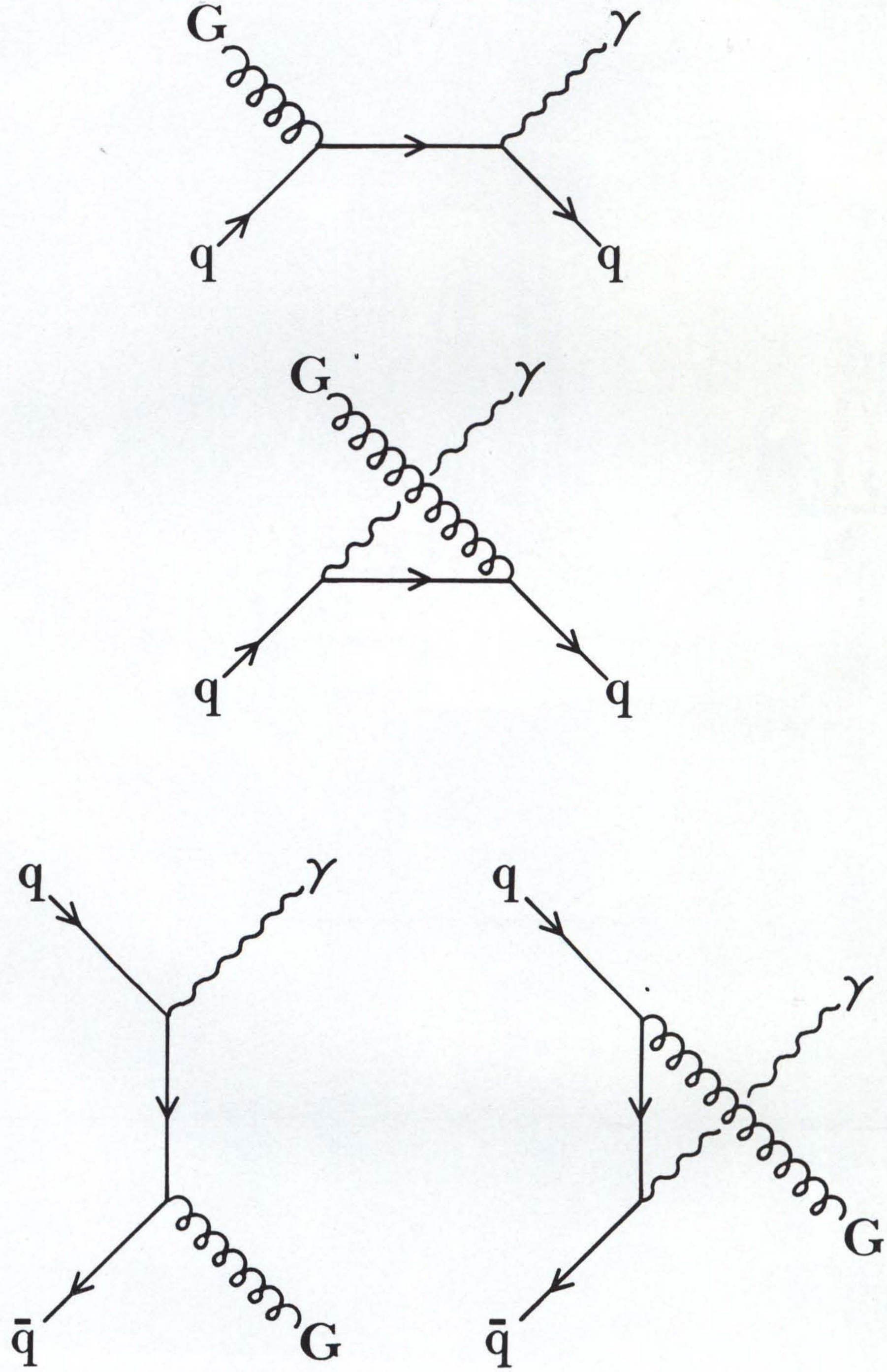
Pat Lukens (Illinois) installs detectors in E-673 in the Muon Laboratory.



E-516 in the Tagged Photon Laboratory.



Peter Martin and Pat McBride, both of Yale, at E-497 in the Proton Area.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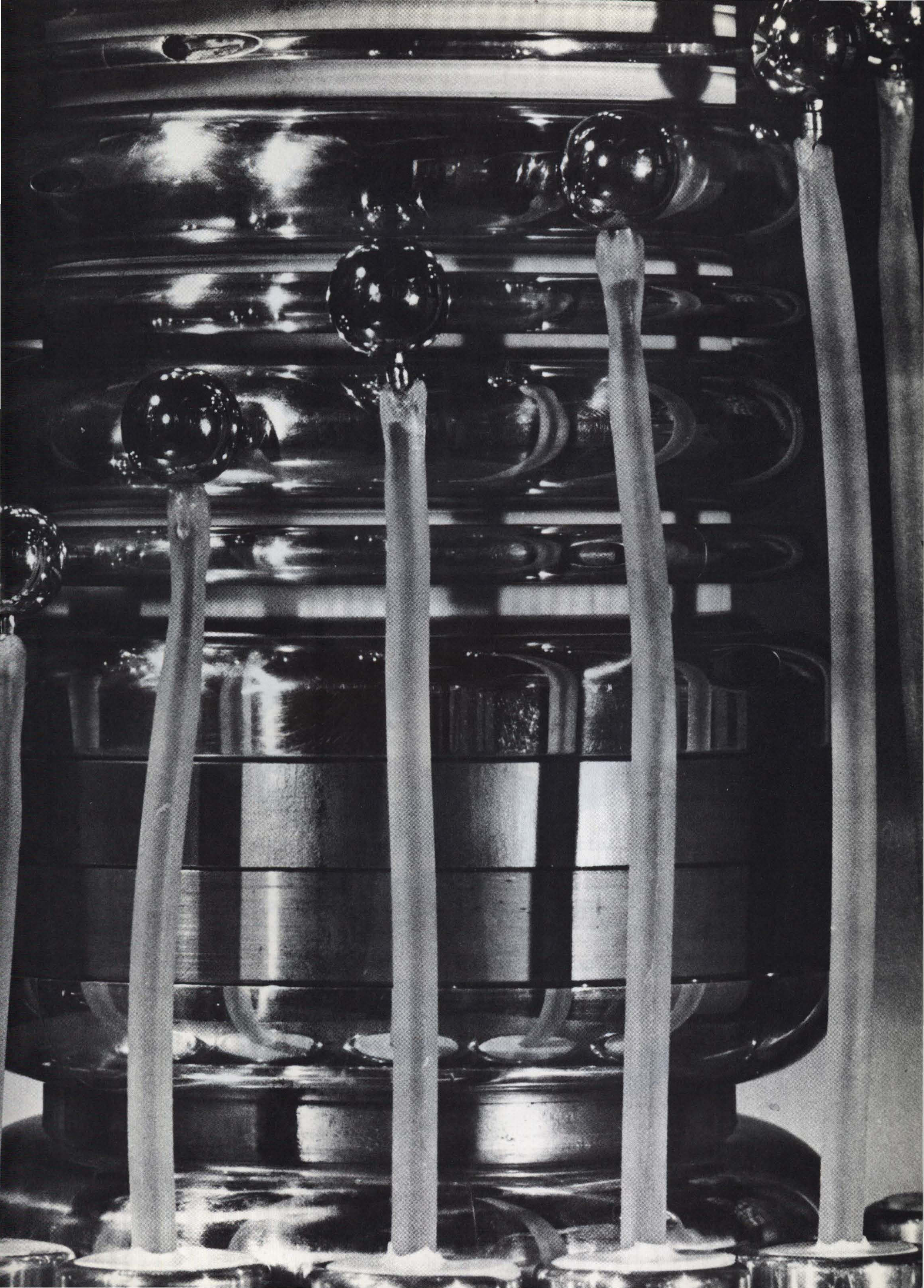
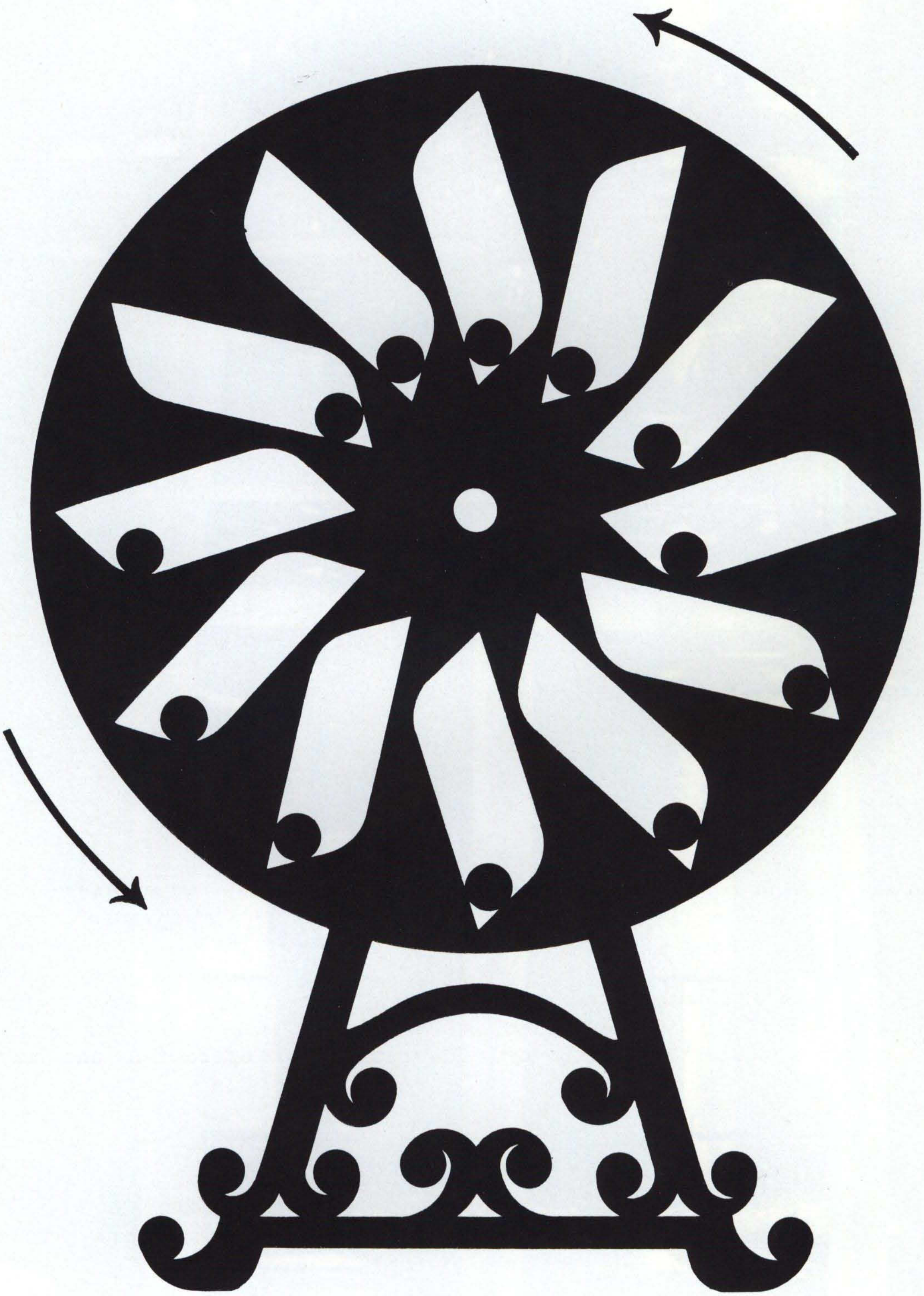




IV. Technology

Innovations

The primary purpose of Fermilab is to carry out research in particle physics. The size and complexity of the equipment required to accelerate particles and detect new events means that new technical innovations are needed all the time. Many of these innovations are of interest for technical work outside particle physics and Fermilab people try to share their new work with others. In this section, we chronicle some of the technical innovations in Fermilab work in 1981.

Portable Video Control Console for the Tevatron

Plans have existed for several years to install in a semi-permanent manner a small microcomputer-driven control console in each of the Main-Ring service buildings to provide a means for local read-out and control of the various Tevatron subsystems. In the past year it became evident that it would also be extremely useful to have portable consoles that could be carried by hand for use in the Main-Ring tunnel and in the small refrigerator houses on top of the Ring for vacuum and refrigeration work. Fortunately, the Linac secondary consoles, already designed and being produced by the Accelerator Controls Group personnel for use in the new linac control system, provided the basis for an answer to this need. An adaptation of the linac console design was developed by other members of the Accelerator Controls Group. Four Mark I versions of the console were built by the same personnel and those units brought into operation late in the year.

The portable console has somewhat the size and appearance of an aluminum portable typewriter case. A hinged top containing a keyboard becomes accessible when the top is in the open position. In addition to the keyboard, the unit provides a 5-in. video display, 13 switches that can be iterrogated and illuminated under computer control, as well as a knob encoder. In normal use, it sits on the floor and is viewed from above but other orientations are possible. Although the four Mark I units have been in use only a few weeks and the microcomputer software is not yet fully implemented, the portable consoles have already proven to be a major convenience for vacuum and refrigeration systems personnel. In view of this early experience, it seems likely that the devices will be used extensively in bringing the Tevatron into operation and may well prove useful for other applications elsewhere in and outside Fermilab.

ECL/CAMAC

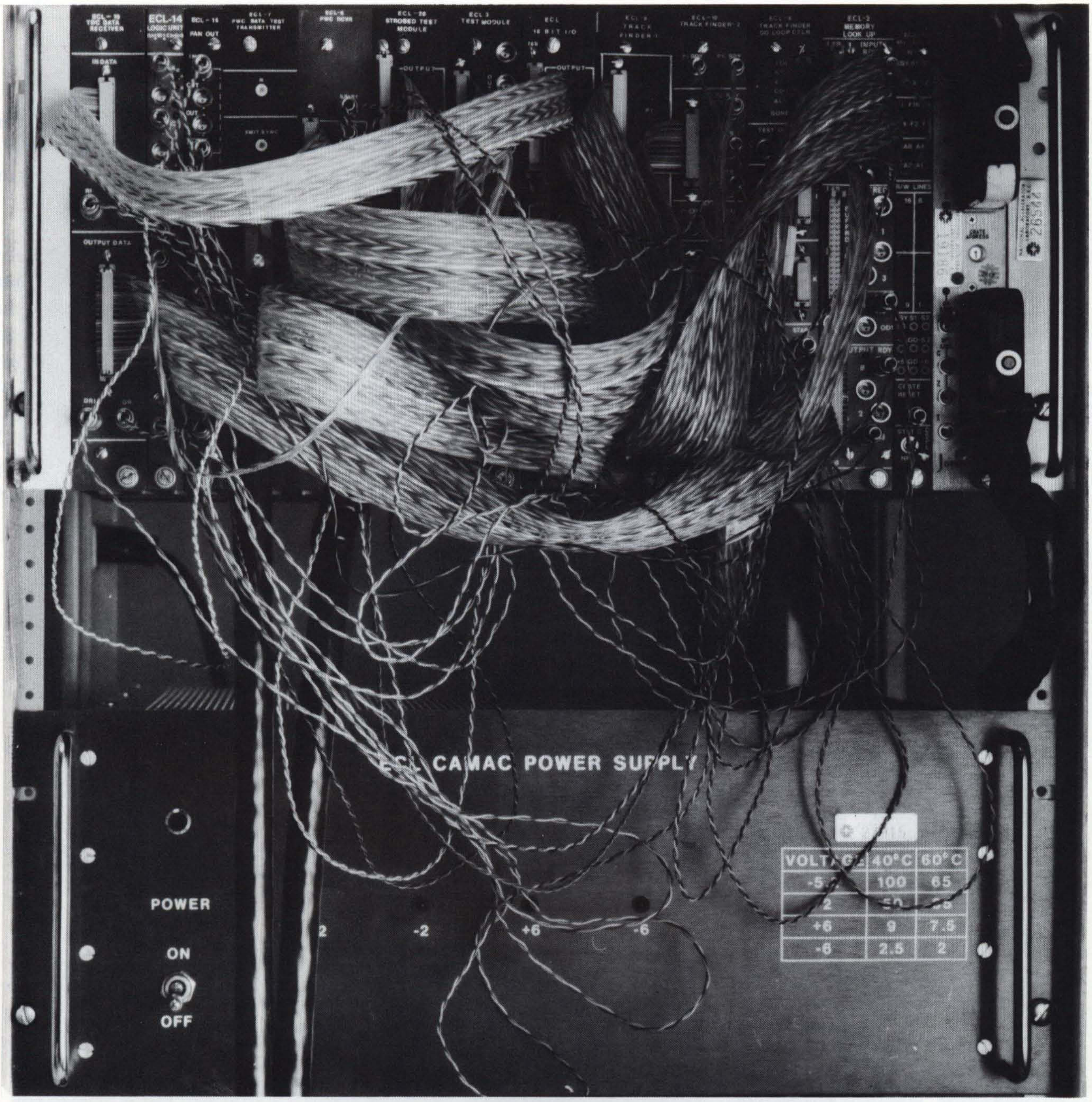
High-energy physics experiments require ultra-fast real-time filtering and preprocessing of data to ferret out interesting rare events from many other collisions prior to storing the information for later analysis on a large computer. Filtering such as particle-track finding can take many milliseconds if ordinary computing systems are used. For most experiments that is impractical. A system developed at Fermilab called the ECL/CAMAC Trigger Processor System performs these operations in less than ten microseconds. Because of the increasing size of experiments, trigger processing systems such as the ECL/CAMAC System are becoming increasingly vital to successful experimental physics.

The technology and packaging scheme used in the ECL/CAMAC system consists of high-speed ECL circuits packaged as modules and interconnected via industry-standard mass-terminated connectors and cabling. Each module contains as many as 80 ECL-integrated circuits totaling hundreds of gates and thousands of transistors. A system for a typical experiment may contain 10 to 100 modules.

The ECL/CAMAC system is based on Memory Look-Up modules consisting of high-speed memories that can be read or written. These memories are preloaded before data-taking with answers for all combinations of input data. Thus during data taking, these modules are able to perform their functions in roughly 50 billionths of a second, regardless of the complexity of the equations required to achieve these answers.

The system has gained wide acceptance thus far. In the last year two large experiments at Fermilab, E-516 and E-537, have achieved reductions of unwanted data by substantial factors. A third, E-615, will use the system in the spring of 1982. A commercial company now makes the Memory Look-Up Module as well as several other modules with similar functions to those developed at Fermilab.

Such high-speed systems are having a wide array of applications, just as the NIM and CAMAC systems that also grew out of particle physics now are used in fields far outside physics.



An ECL-CAMAC system.

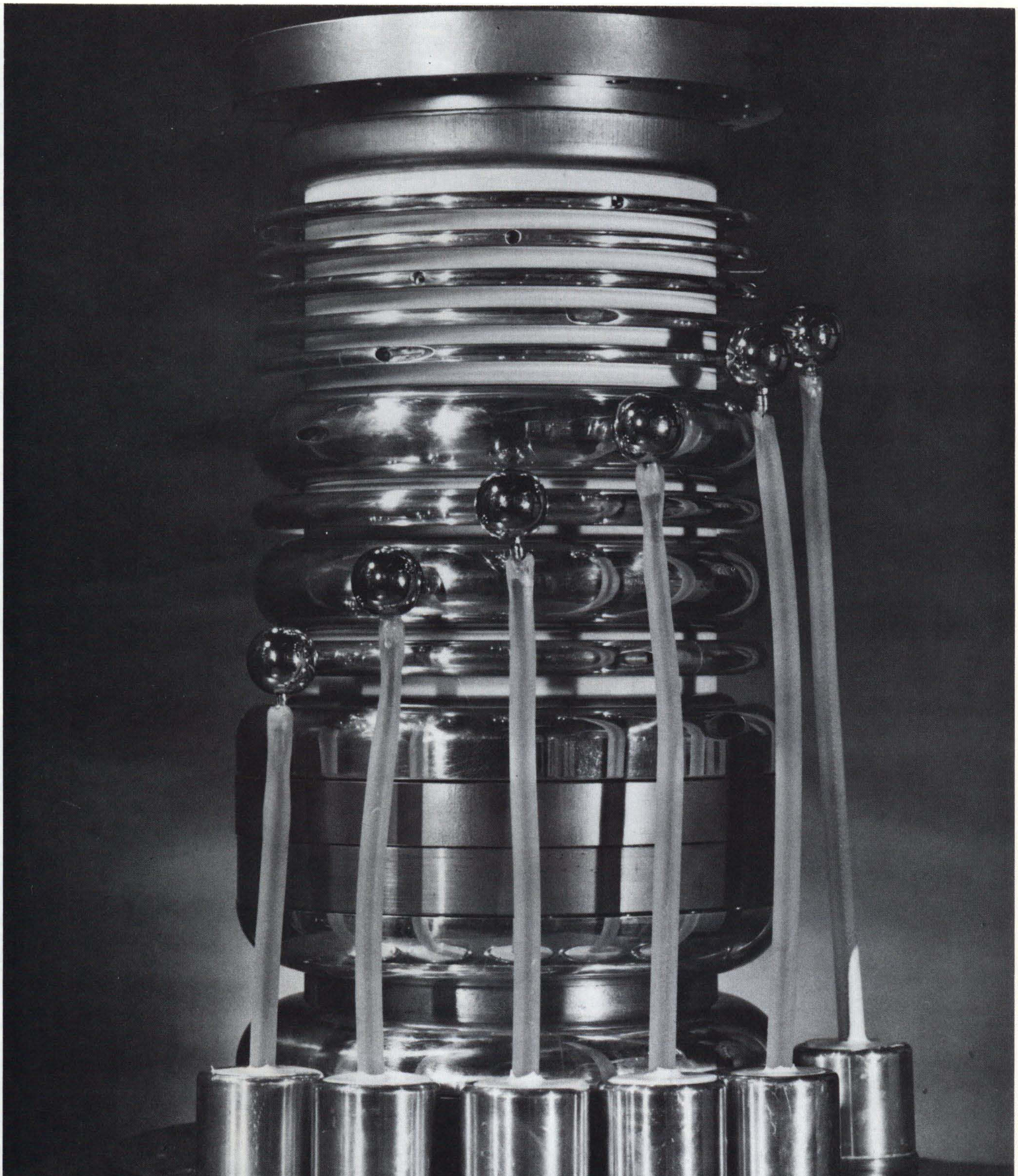
Electron Cooling System Receives Award

An electron cooling system developed at Fermilab has earned at IR-100 Award from **Industrial Research and Development Magazine.** The award is presented each year to the 100 most outstanding new technical developments and honors the institutions and scientists who worked on them.

In the electron cooling process, the large distribution of momentum (particles having different speeds and different directions) in a "hot" charged-particle beam, such as an antiproton beam, is decreased by having a beam of "cold" electrons (that is, all electrons traveling at the same speed and precisely parallel to each other) interact with the hot beam.

A test of electron cooling was carried out at Fermilab last year. This experiment was done at a proton energy of 115 million electron volts.

The development of the new electron cooling technology at Fermilab has rested on the original invention of the electron cooling process by Budker at Novosibirsk in the Soviet Union. Other important work has been carried out at CERN in Europe. The developments at Fermilab were done collaboratively with many other laboratories, including Argonne, SLAC, and the University of Wisconsin.



The accelerating column of the electron gun system for the Electron Cooling Ring.

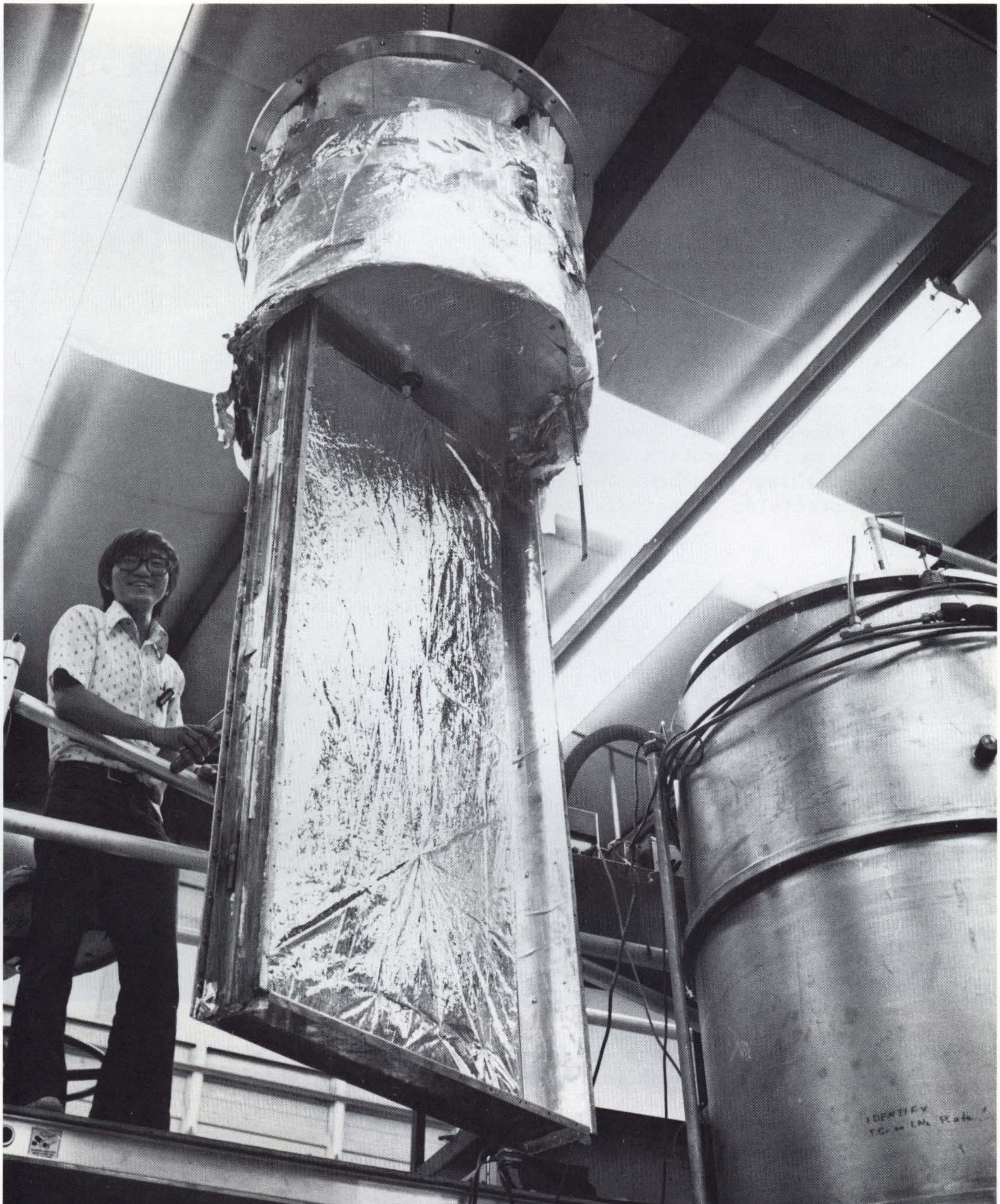
Reducing Heat Loss in Cryogenic Systems

One of the primary design criteria in cryogenic superconducting systems is to minimize liquid helium boil-off from the supercold environment (4.2 degrees above absolute zero) required for the superconductor. Over the years an approach has been used which consists of a large amount of special multi-layered insulation in a vacuum space between the helium cryostat and a shield at liquid-nitrogen temperature. While this method works, the material is difficult to apply and the actual performance does not approach theoretical expectations.

Several Fermilab staff members (Eddie Leung, Ron Fast, Joseph Heim, and Harold Hart) experimentally evaluated the performance of various thermal insulation schemes for applications below liquid nitrogen temperature. They developed a new method, using only 12 layers of multilayer insulation and a special reflective tape, the performance of which is at least 50% better than the conventional approach.

This method was used in the conversion of the famous Chicago Cyclotron Spectrometer to superconducting operation. That spectrometer is now in operation for physics and has a very low liquid helium use rate.

At the 1981 Cryogenic Engineering Conference, they were awarded the Russell B. Scott Cryogenic Engineering Award for their efforts, the first time Fermilab scientists and engineers have been so honored.



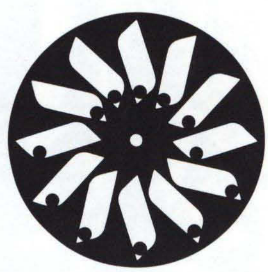
Eddie Leung with a partially disassembled helium dewar to reduce heat loss.

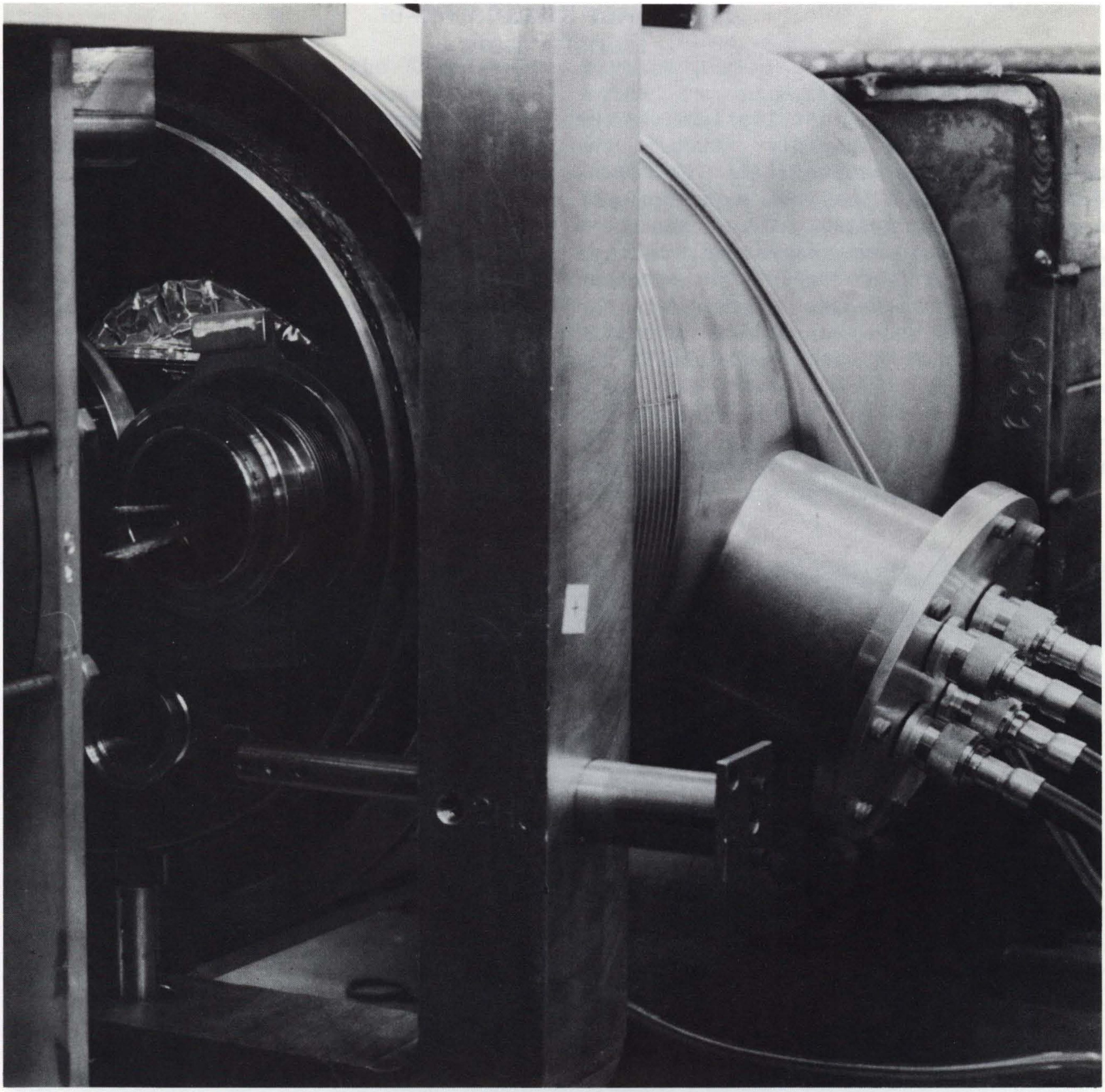
Beam Position Detectors

An innovative application of radiofrequency technology has been devised by Quentin Kerns and Frank Turkot in a system for making a precise calibration of the beam-position detectors that are integrally welded into the Energy Saver quadrupoles. The system has been brought into operation by Alan Wehmann and other members of the Magnetic Measurements Group who have been working feverishly on Saver measurements. A 53-megahertz current signal is fed into a 0.1-mm tungsten wire that is accurately positioned along the axis of the quadrupole in order to simulate the presence of either a beam of protons or anti-protons. Nothing touches the wire except its precision supports. An rf cavity at one end feeds the signal in while another cavity at the other end absorbs the power.

A compact quarter-wave spiral transmission line matches the 50-ohm characteristic impedance of the rf amplifier and cables to the 393-ohm characteristic impedance of the rf cavities. This device, devised by George Biallas, was practical only because its main body could be machined on a tape-controlled milling machine.

The system is capable of calibrating the position of the beam sensors to better than a tenth of a millimeter.





The location of a beam-position detector next to a quadrupole. The cables at the right are the leads to the detector, which was developed by Bob Shafer.

Helicopter Installation of Transfer Line

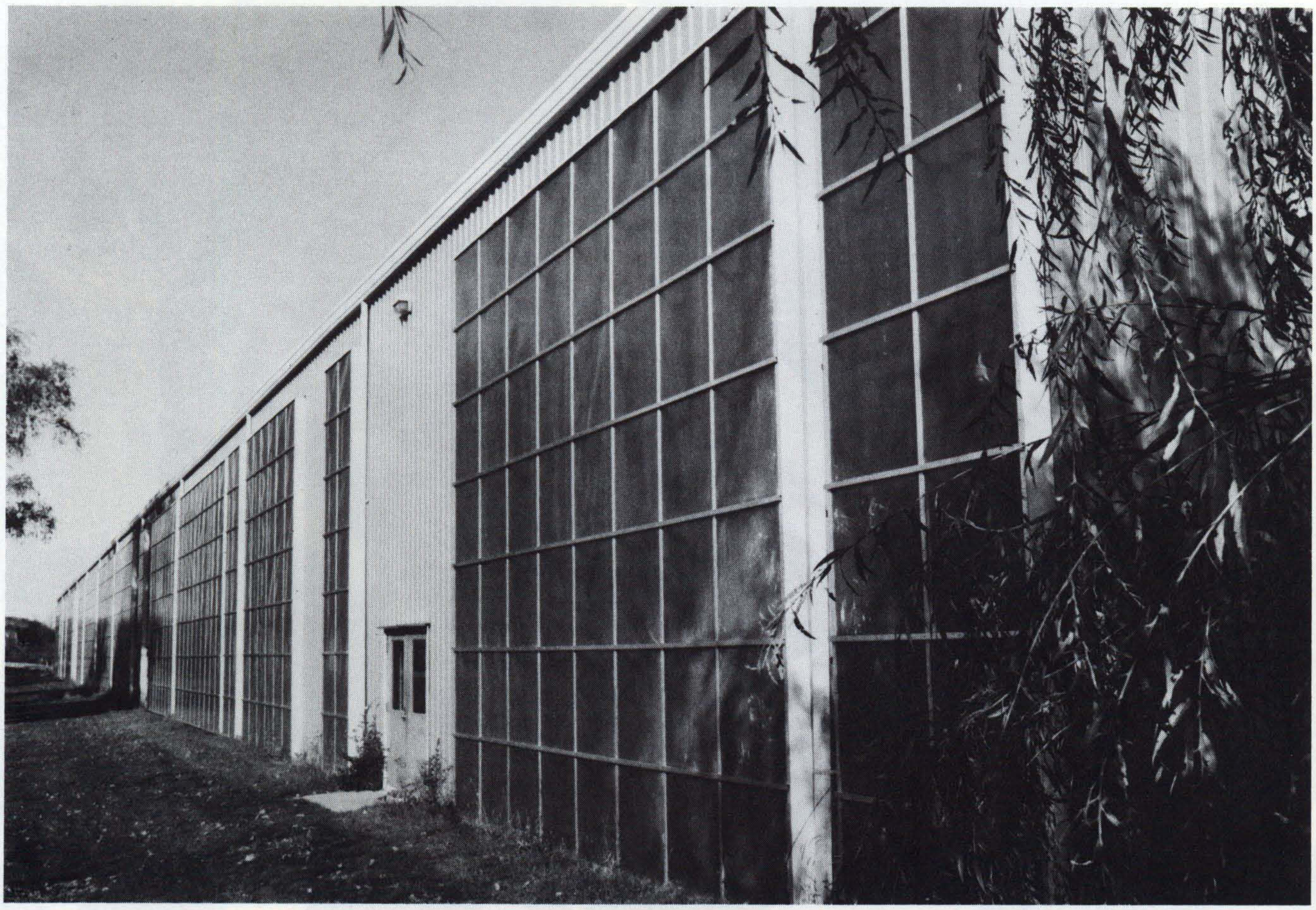
During 1981, installation of the Saver proceeded rapidly through the months of the summer-fall shutdown. With the world's largest superconducting cryogenic system, there has been plenty of room for innovation, both on the small and large scale. One particularly dramatic example of this was the installation of the helium transfer line using a helicopter. The light but stiff transfer line comes in 80-foot lengths that are difficult to handle with ordinary rigging techniques. On the other hand, the helicopter was able to lay 180 of the segments in a two-day period. This transfer line has some similarity to high-power dc transmission line test installations, so this helicopter technique may have relevance to other applications.

The helicopter lifts a section of helium-transfer line.

Low Cost Solar Heating

For several years the Laboratory has been pioneering approaches to the use of solar energy both in conventional applications and more exotic areas such as the use of solar for process heat to cure magnet epoxies. This year a passive solar wall was designed and constructed for the main warehouse. The warehouse is a large building with a south facing wall 400 feet long and 22 feet high. The goal of this project was not to be technically innovative, but rather to demonstrate that solar energy can be collected at low cost and with a reasonable payback period. The project, now completed, will have a payback period of three to four years, which is unusually short for solar projects.

The construction was extremely simple. The wall was painted black and vertical wooden spacer strips were fastened to the outside of the wall. Openings were cut in the top and bottom of the wall; plastic glazing was fastened over the wooden spacers. The air circulates through the solar panel that has been created and into the warehouse. There are no pumps, valves, or controls. The system is now providing about one-third of the heat required in the warehouse.



Passive solar wall on the warehouse.

SM-12 Magnet Coil Construction

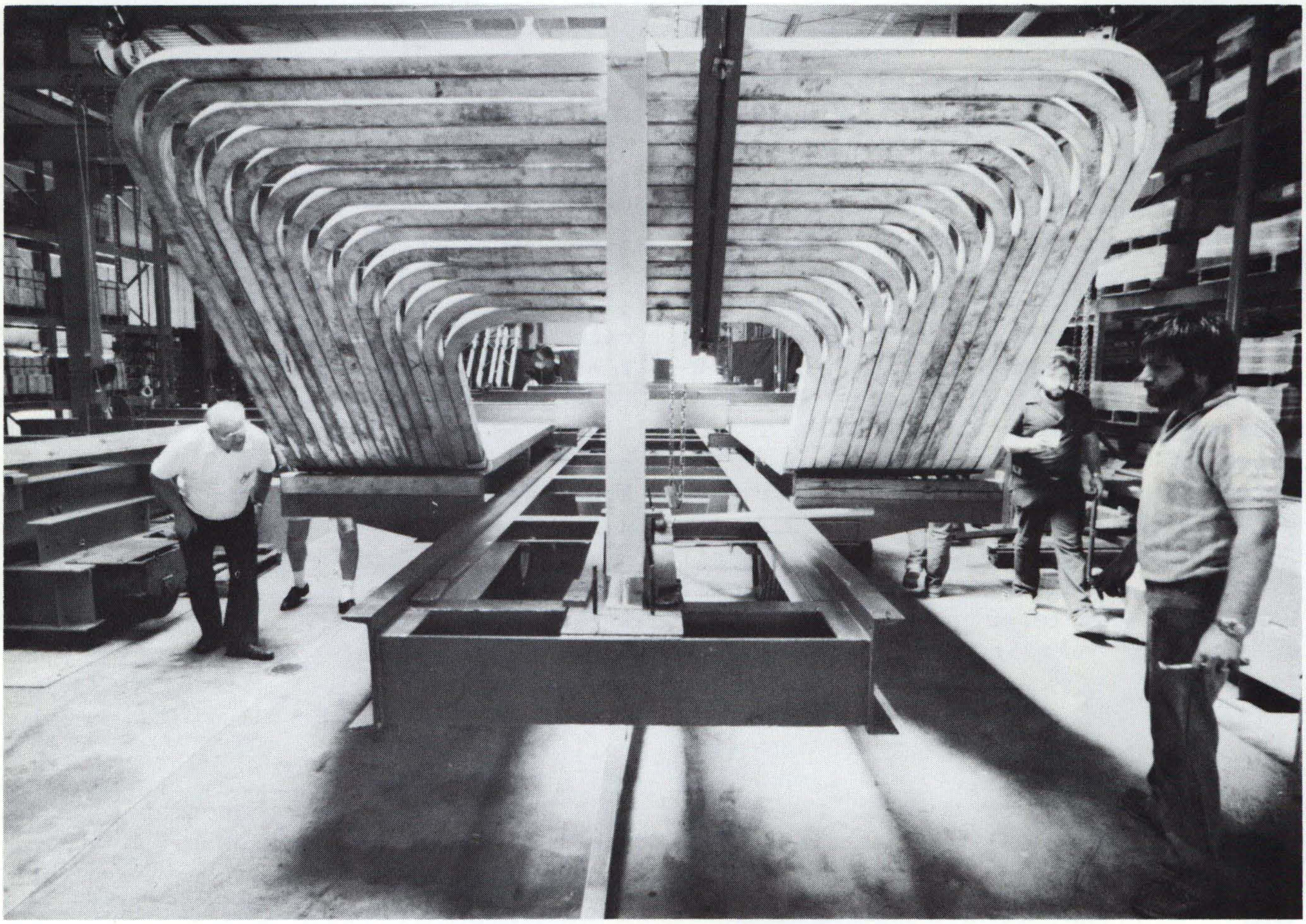
The aluminum coils for E-605, a Meson Area experiment that is a follow-on to the experiment that discovered the upsilon, have been under construction by the Magnet Facility at the Laboratory since mid-June. The Magnet Facility, working around the clock, took the pre-formed coil layers, built industrially, sprung the individual turns apart, and applied epoxy-glass B-stage tape insulation to the 2-1/2 inch square conductor. Approximately 5 miles of conductor was wrapped. The formed 3- or 4-layer coils were wrapped with tape and heated electrically to 300°F to cure the epoxy. All four coil assemblies, weighing 95 tons in total, have been completed and are installed on the iron yoke in the Meson Detector Building.

The steel in the yoke comes from the dismantled synchrocyclotron that was used for many years at the Nevis Laboratory at Columbia University. The yoke pieces were cut at Nevis before being shipped to Fermilab.

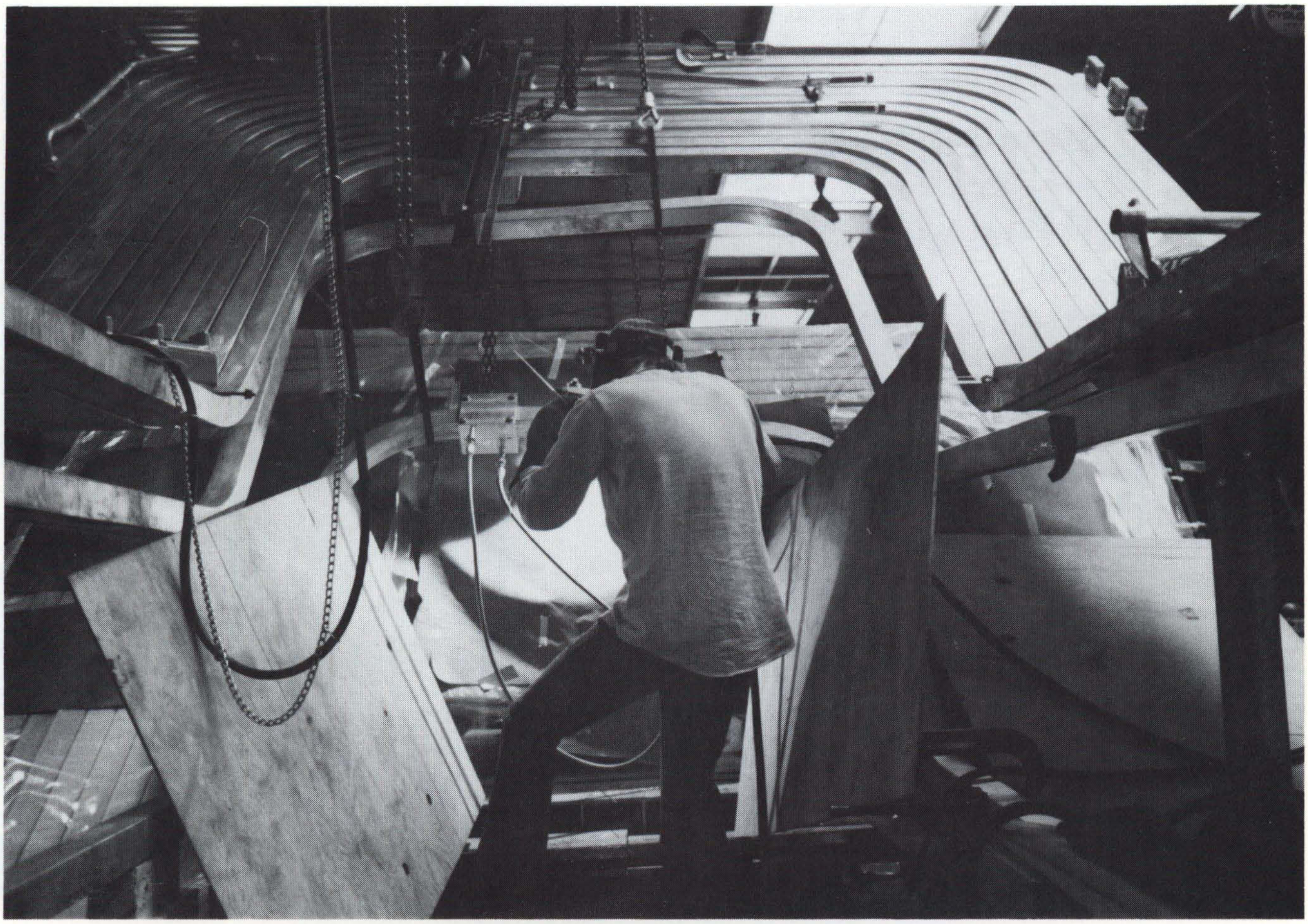
Colossal in its dimensions, the total magnet weighs around 1,500 tons. The steel return yoke that surrounds the coils is 17 feet tall, 9 ft wide, and 47 ft long. The beam aperture is 36.5 in. wide and 48 in. high and nests tapered poles, beam dump, and absorbers.

The coils, themselves a significant technological achievement, are 60 feet long from curved tip to curved top. They are made out of aluminum conductor, square in cross section and about 2-1/2 inches along an edge. Running through the center of the conductor is a half-inch hole for water to circulate through and cool the aluminum. A supply of more than 1000 liters/minute of water will be required to cool the magnet which operates at a power level of 1.5 megawatts. The total weight of the aluminum in the coils is 84 tons.

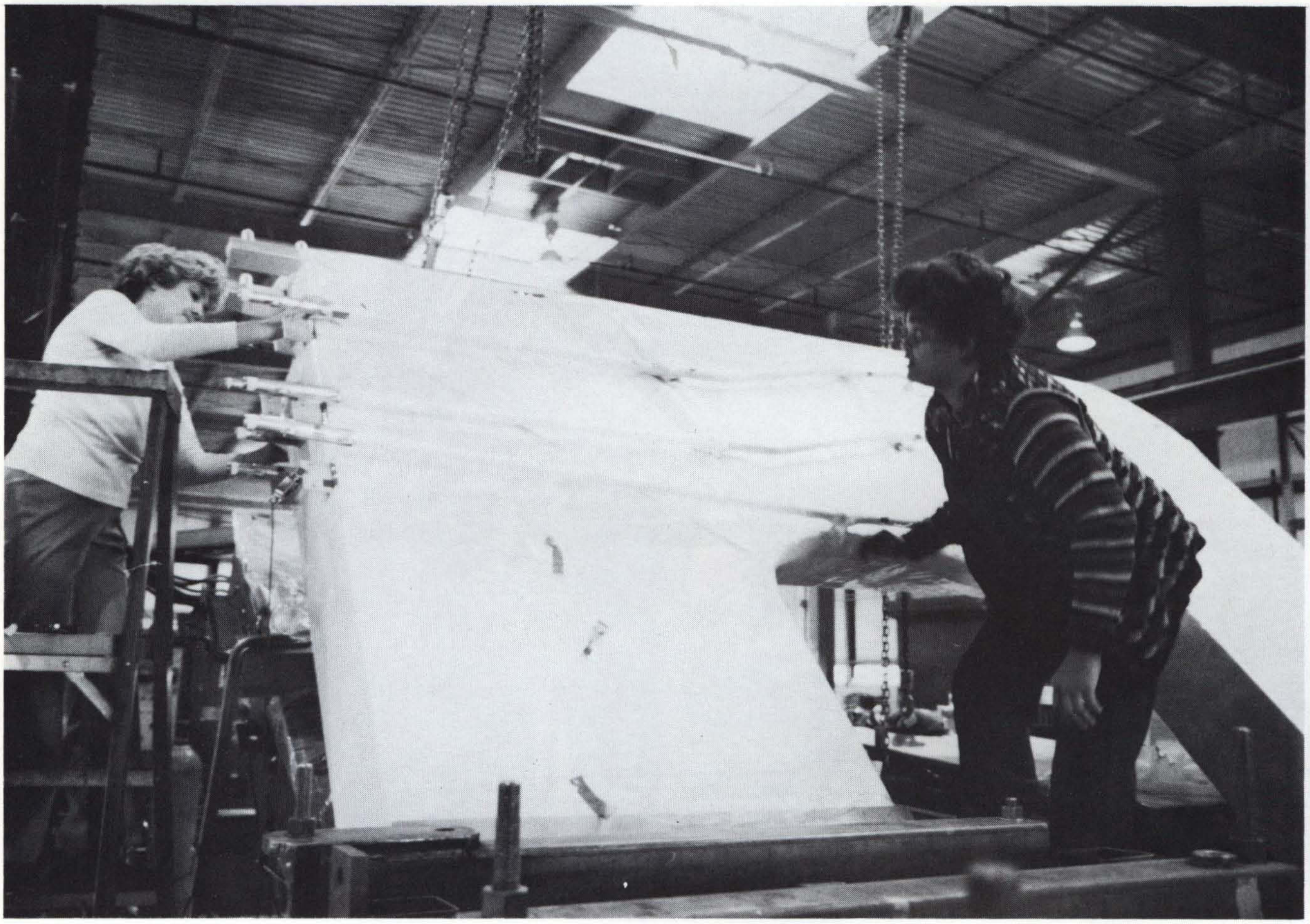
These sequence photographs, all taken by the Fermilab Photography Unit, show the work in progress as the magnet was assembled by Magnet Facility and Meson Department personnel.



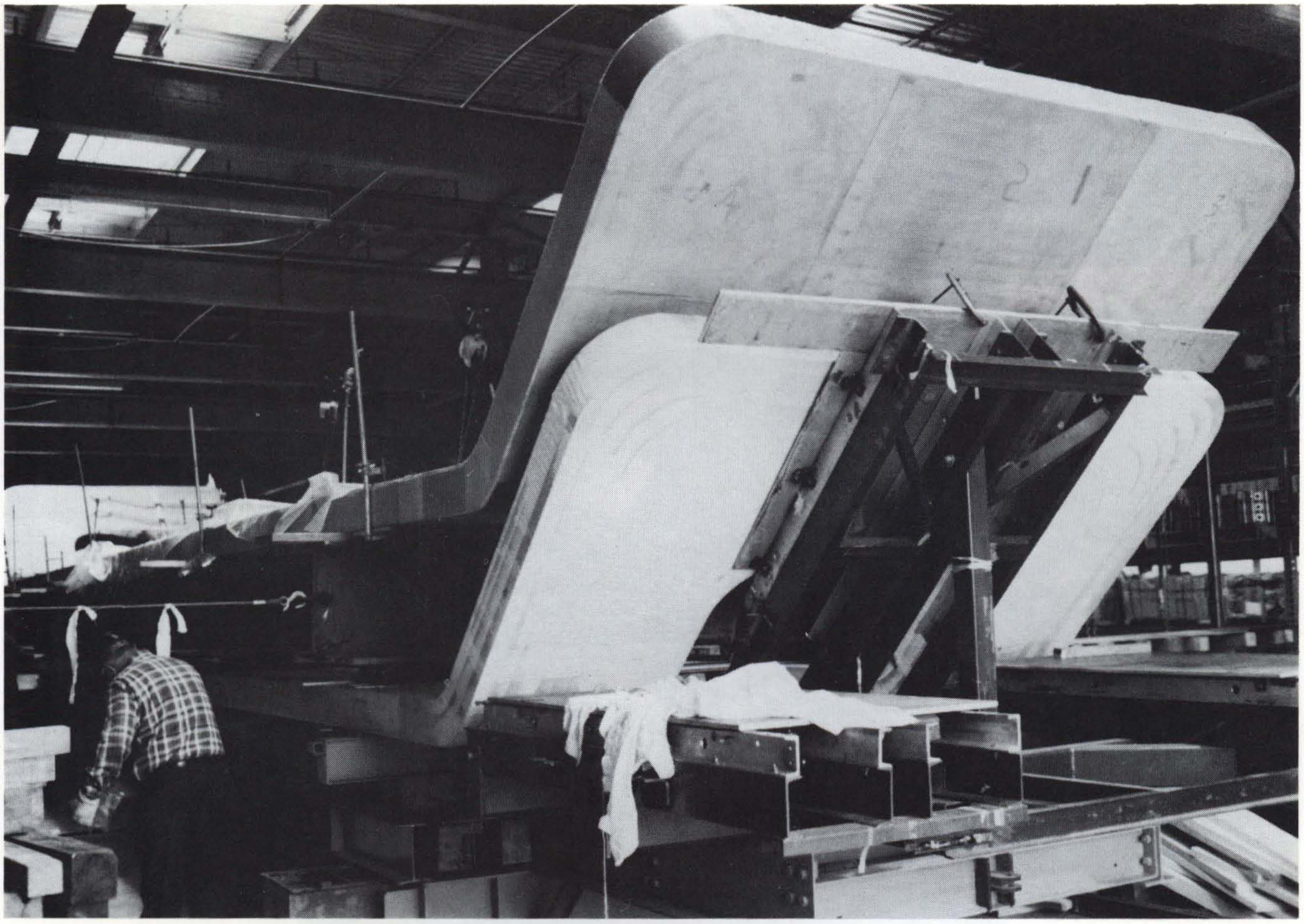
Les Bradstreet (left) and John Chyllo check positioning of the pancake coil moved into Industrial Building 4 to be off-loaded onto the assembly fixture.



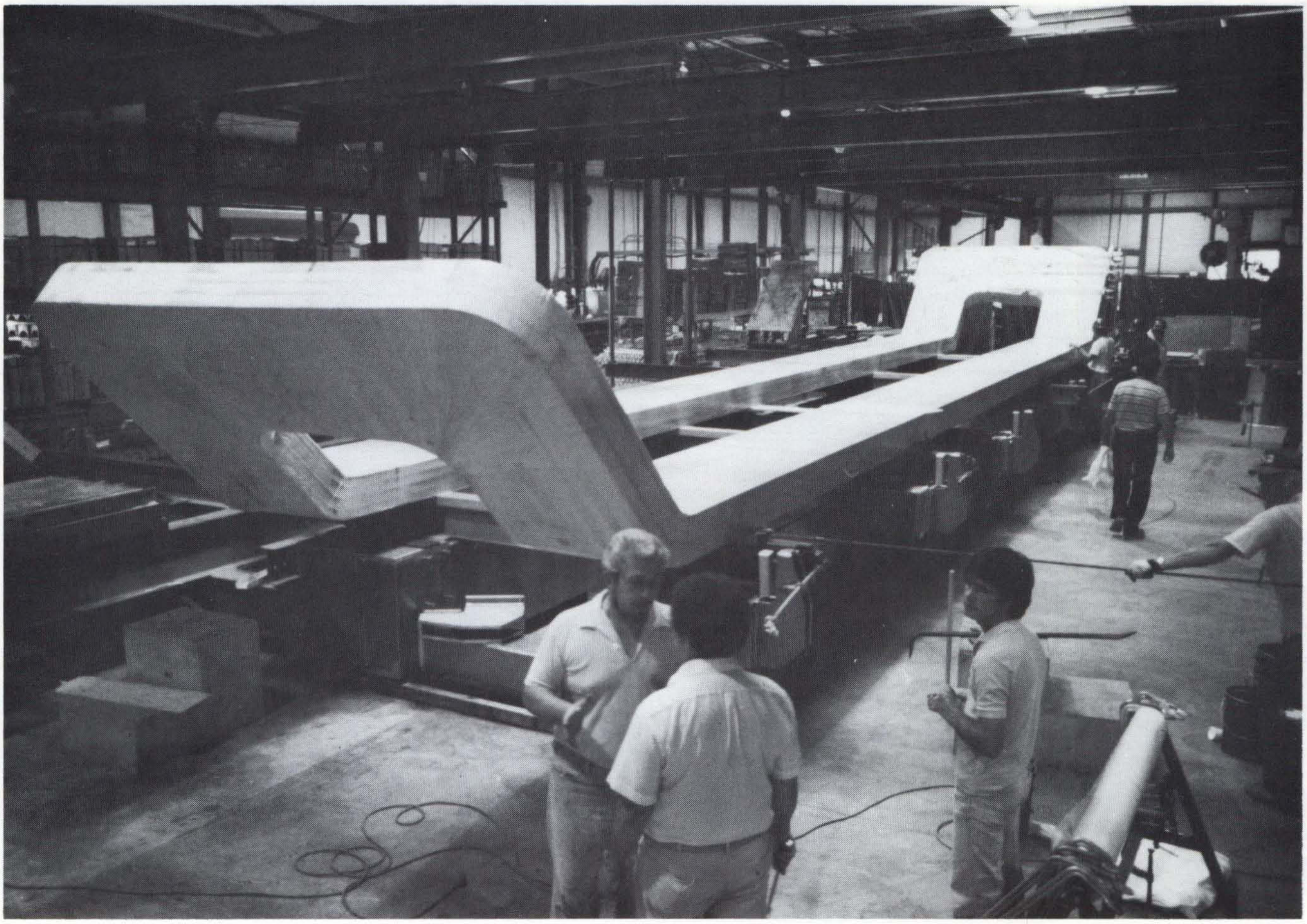
Mike Reynolds welds the crossover connection between layers ("pancakes") in a coil.



Mary Brooks (left) and Estella Lesure ground wrap a completed three-layer coil.

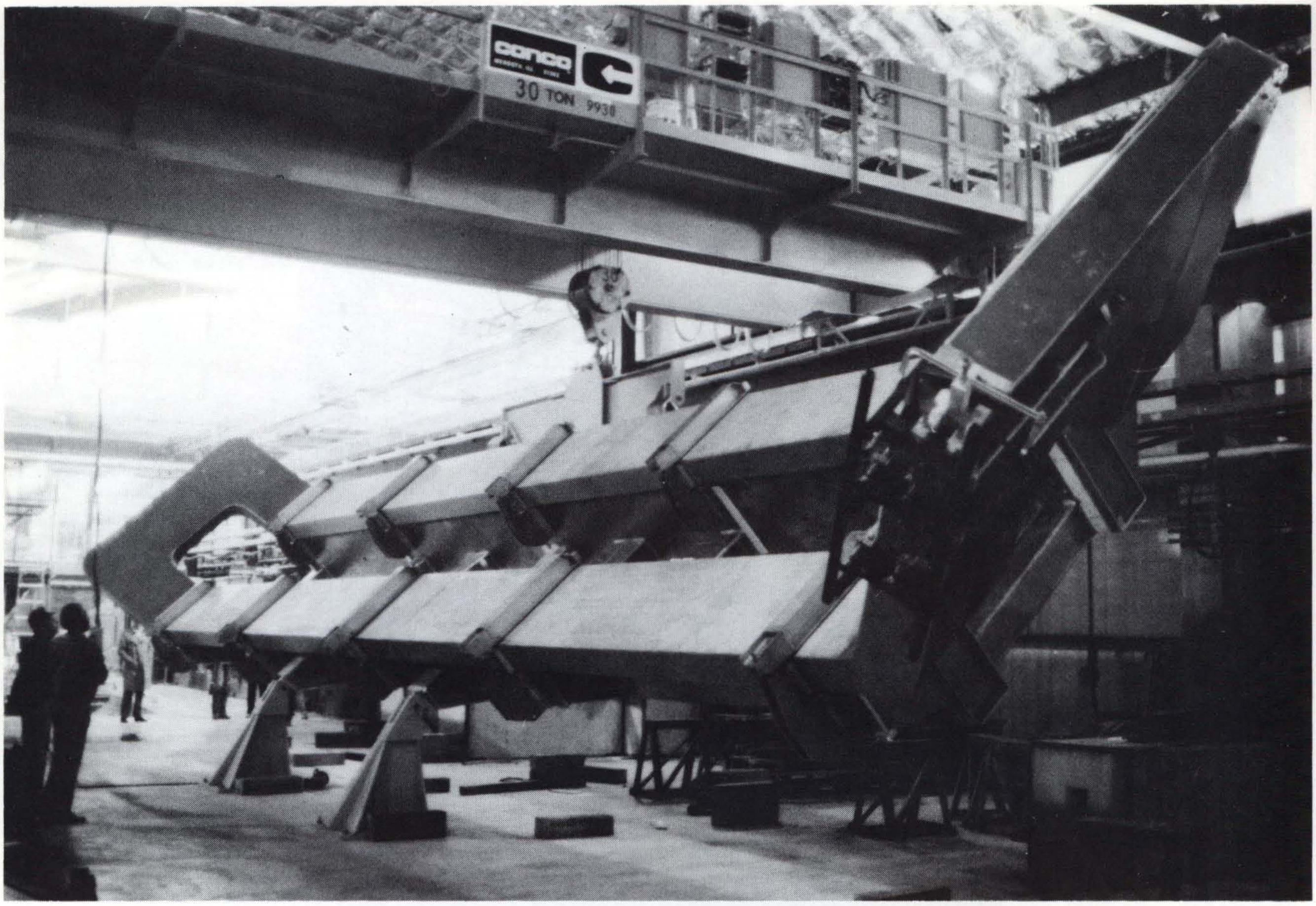


Temporary storage of one three-layer coil over another.

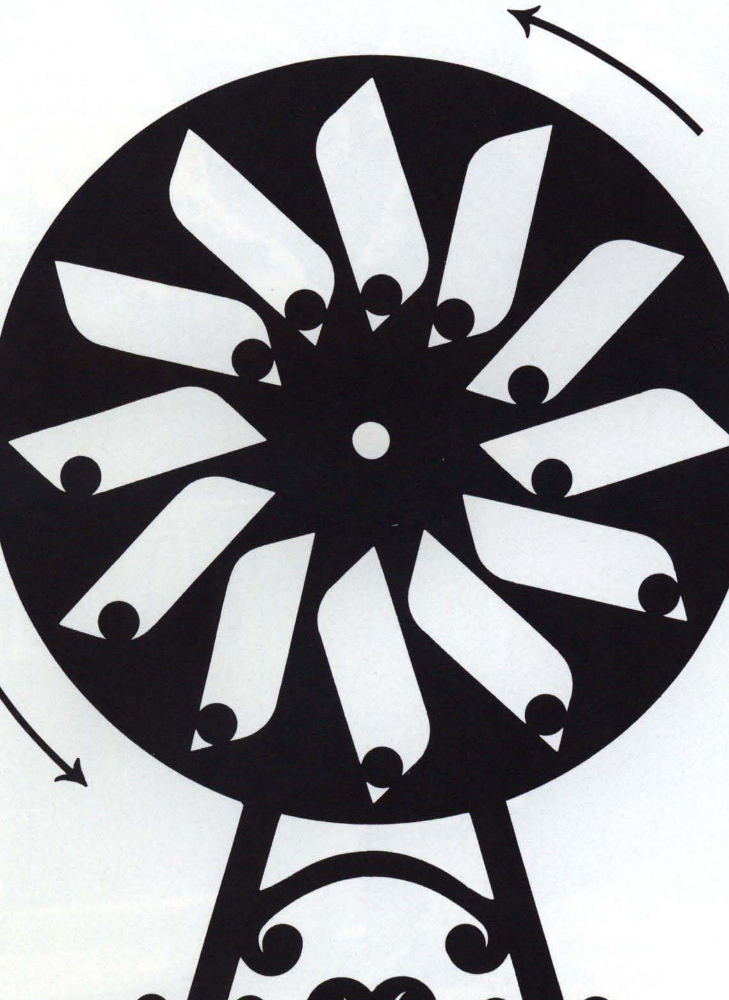


Foreground (left to right) Dominic Carullo, Isidro Gonzales, and Oscar Guerra check installation of a four-layer coil onto the Meson assembly fixture.

Riggers move the four-layer coil out of Industrial Building 4 on its way to the Meson Detector Building.



Four-layer coil tipped on its side for installation in the magnet yoke in the Meson Detector Building.



Randy Ten Haken and Michelle Gleason demonstrate the patient-positioning system in the Neutron Therapy Facility.

Neutron Therapy

This year marked the fifth anniversary of patient treatment at the Neutron Therapy Facility (NTF). During these five years, over one thousand patients were referred to the NTF for therapy. Of these, 432 were entered into randomized trials between treatment with and without neutrons, 270 were entered into non-randomized studies, and 260 into pilot studies. The facility has meshed well with the rest of the Accelerator Division operations in a most harmonious sharing of the injector between research in high-energy physics and cancer therapy.

The Fermilab beam is the most energetic and most penetrating neutron therapy beam anywhere. This higher energy has great advantages in that there is less skin injury and more energy deposited in the tumor being treated. It has been possible to carry out extensive new clinical studies at Fermilab because of the unique qualities of our beam.

In addition, neutrons are absorbed preferentially, more in fatty tissue and less in bone. Therefore, certain kinds of tumors, such as those of the brain, are particularly well suited to neutron therapy. We have preliminary clinical evidence that this preference is borne out in practice and that certain cancers, such as those of the salivary glands, that respond poorly to conventional treatment respond well to neutron therapy. Neutron therapy appears to have the same kinds of side effects as conventional radiation treatments, reactions, scarring, and various late effects.

A wide variety of tumor types reputed to be "radioresistant" have recently been shown to be amenable to complete local ablation without significant side effects by the use of appropriately planned neutron-beam therapy. These tumors have hitherto been treated exclusively by surgery or by mixed procedures (pre-operative irradiation and wide resection). The availability of neutron-beam generators provides another option for treatment of patients with radioresistant tumors.

Neutron-beam therapy can in many cases provide equally effective local control while avoiding surgery. Patients suitable for this approach are those with late-stage cancers of the head and neck, advanced salivary-gland tumors, sarcomas of bone and of soft tissue, non-resectable melanoma, and locally advanced tumors of the pelvis (carcinomas of uterus, bladder, prostate, and rectosigmoid). A promising combination of chemical sensitizer and neutron-beam therapy may have been found for malignant brain tumors. In the control of head and neck tumors, neutrons show an early advantage over photons. Neutrons are effective about 75% of the time in controlling large salivary gland tumors, and they seem to be about as effective in the local control of sarcomas of bone and soft tissues.

The impact of the new kind of treatment is fourfold: (i) Neutrons expand the scope of radiation therapy to include intrinsically radioresistant tumors that had been considered unsuitable for irradiation; (ii) Where tumor ablation can be accomplished by irradiation alone, new procedures for conservative or corrective surgery become feasible; (iii) With improved control of local disease, neutrons expand the role of elective chemotherapy for the prevention or retardation of metastatic growth; and (iv) Neutrons expand the range of options available to the cancer patient who may wish to consider conservative treatment as an alternative to surgery.

Our preliminary results are optimistic enough about the efficacy of neutron therapy to have stimulated the construction of new facilities for further testing. New accelerators are being built for neutron therapy at M. D. Anderson Hospital in Texas, at the UCLA Medical Center in Los Angeles, and at the University of Washington Hospital in Seattle. We are supporting the proposal to build a new facility at the West Side Medical Center in Chicago, close to a large number of patients who need treatment. All these facilities will benefit with respect to accelerator technology and clinical experience from the Fermilab work. Earlier facilities had accelerated deuterons to produce neutrons, but the new facilities, following the Fermilab experience, will use the proton-beryllium reaction for this purpose. Our experience and studies in targeting protons and observations on the biological characteristics of the neutron beams generated (with their unique energy spectra), will be directly applicable to the new facilities.


HELIUM

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TUESDAY, OCTOBER 6, 1981

THE WALL STREET JOURNAL.

Business Now Can Buy Ideas From Federally Funded Labs

By Laurel Sorenson
Staff Reporter of The Wall Street Journal

BATAVIA, Ill.—By congressional decree, the Fermi National Accelerator Laboratory became a scientific supermarket as of last Thursday.

On that day, the results of the laboratory's experiments, the contents of its computer data banks and even the note-pad doodlings of its 200 scientists became, in effect, public property.

U.S. entrepreneurs and corporate executives are able to shop in the 13-year-old basic research laboratory for the latest advances in high-energy physics, superconductivity and cryogenics. Whether companies must pay for the research is up to the individual laboratory.

The Stevenson-Wydler Technology Innovation Act of 1980, passed by Congress last October, requires, among other things, that Fermi Laboratory and some 500 other federally funded research agencies make their scientific advances available to industry.

Congress called it a "transfer of technology" and hoped it would contribute to industrial productivity and technological innovation. "We were convinced there was a lot of technical know-how and inventions in the federal labs that weren't utilized," says a congressional staff member who worked on the act.

Easier Said Than Done

But transferring technology is easier said than done, especially at a basic research facility like Fermi Laboratory, whose mission is to explore the building blocks of matter. "I naively thought all we'd have to do is bring people here and tell them what we're doing," says Leon Lederman, director of the lab, who began sharing research results even before the legislation was passed. "I thought they'd light up with dollar signs, rush out and make millions," he says.

A spring conference to show off Fermi Laboratory's research didn't succeed, Mr. Lederman says. The 40 companies that attended ranged from makers of construction equipment to high-technology concerns. All were interested in seeing what the lab had to offer and were hoping to pick up good ideas.

But talks were too short, the research was irrelevant for some companies, and others simply sent the wrong people, says Mr. Lederman. "We're groping," he says. "I've got to find a formula for doing this."

Industry Wary

Many industries are wary of ideas produced by government researchers. "What do a bunch of scientists at a federal lab know about the real world?" is a common reaction, says Eugene Stark, a spokesman for the Los Alamos National Laboratory in New Mexico. Businesses suspect that lab-produced ideas won't work commercially, he says. Or sometimes, they find that development costs are too high.

For example, it took seven years for Los Alamos scientists to see commercial use of their heat pipe, a cooling device used on the Alaskan pipeline to prevent the oil-warmed line from softening the frozen tundra. The lab is still seeking takers for its Subterrene, a device that penetrates rock and sand by melting them.

Finding uses for Fermi Laboratory's research is especially tough. Scientists on the 6,800-acre site spend their days sending protons zipping about a four-mile long tunnel, observing the particles as they smack into various materials and break apart. The idea is to discover the smallest, ultimate particles that make up matter and to learn how the particles interact.

In the course of pursuing that goal, however, the scientists do things common to all industries: manufacture equipment and invent tools and use sophisticated computers. They also develop know-how in associated fields, such as high-speed data processing and cryogenics.

"Our purpose is exotic, but what we do isn't" says Mr. Lederman. "We want to take our inventions and give them to someone who can introduce them to commerce and make a profit."

Some companies have already gained technological help from Fermi Laboratory.

"Fermilab is a good place for us to hope to find some technology," says an oil company manager, "because if you hit, you hit big."

Richard Bentley, a physicist at New England Nuclear Corp., a Boston-based maker of radioactive drugs, sent his engineers to study the lab's techniques for curbing excess radioactivity around its research equipment. That and other information was useful to the company in building new drug-manufacturing equipment, says Mr. Bentley. Without that help, "We probably would have had to do the construction twice: once to find out we did it wrong and once to do it right."

Best Information

McGraw-Edison Co., a maker of electrical equipment, hopes to improve computerized monitoring equipment for its compressors by learning how Fermi Laboratory does it. "Information from Fermilab is among the very best we could get," says Lennard Wharton, vice president of engineering and technology at the company's Worthington group.

Mr. Lederman has high hopes for what a transfer-of-technology program might ultimately accomplish.

The lab's work in superconductivity—the energy-saving property that some metals or alloys display when they are cooled to temperatures near absolute zero—could lead to creation of super-chilled power lines capable of sending electricity at a fraction of current costs. Or the technology used to develop huge superconducting magnets could lead to public transportation via trains that move at speeds up to 330 miles an hour along a magnetic field a foot off the ground.

Such possibilities are titillating but commercially remote. "Things like this develop slowly," says Philip Seiden, manager of astrophysics at International Business Machines Corp. "The technology they develop isn't always exactly what others want, and it takes time to develop the cross-connections."

But the possibility of securing something great is always there. "Research work is very circumstantial," says John J. Gilman, manager of corporate research at Standard Oil Co. (Indiana), which is interested in Fermi Laboratory's use of computers. "Fermilab is a good place for us to hope to find some technology—because if you hit, you hit big."

Fermilab Industrial Affiliates

The activities and involvements of the Fermilab Industrial Affiliates program during its first year of operation have been numerous and diverse.

In late May, the Industrial Affiliates held their first annual meeting and a Symposium on Technology Transfer for more than 70 representatives of industry. This was followed by the Affiliates-sponsored 1981 Exhibit of Technology for member companies during the month of September. Program membership reached 28, ranging from small computer companies to corporations prominent among the Fortune 500. The advent of new legislation for technology transfer, the Stevenson-Wydler Technology Innovation Act, found the Industrial Affiliates already in the forefront of Federal laboratories' efforts to transfer technology to the private and public sectors. Finally, the means and techniques of identifying and transferring high technology to industry were reevaluated, resulting in a rethinking of the initial goals and objectives of the Industrial Affiliates program.

The annual meeting was held on May 27 and 28 featuring technical presentations by Laboratory scientists and engineers. Companies attending represented differing fields from heavy construction to high technology to life insurance (with interests in neutron therapy). The array of topics covered included superconductivity, cryogenics, data processing, computer hardware processors, computer controls, fast pulsed electronics, ion beams and sources, computer-aided design, high-power radio-frequency systems, cryogenics vacuum technology, and particle detectors. Tours were also given of the Central Helium Liquefier, Magnet Assembly and Magnet Test Facilities, Laboratory A, and the 15-foot bubble chamber. Dr. James Leiss, Associate Director for High Energy and Nuclear Physics, Department of Energy, was guest speaker at the banquet the first evening. Senator Charles Percy visited and spoke to the meeting participants on the second day.

The Industrial Affiliates 1981 Exhibit of Technology was formally opened on September 11 in Wilson Hall with several hundred guests in attendance. Sixteen member companies put on displays of their products, technologies, and involvement in research. The exhibit was widely attended by visitors to Fermilab and by the general public.

During the year, to further explain the highly advanced and specialized scientific and engineering work carried on by the Laboratory, a new brochure was developed, "Technology Developments at Fermilab." It described the high technology in which Fermilab is engaged and gave examples of real and potential commercial applications. The brochure has been used to advise the general public on Fermilab research and to solicit new Industrial Affiliates members.

Because the establishment of the Industrial Affiliates Program had preceded the enactment of the Stevenson-Wydler Innovation Act, and had coincidental goals, the Program received special attention. Other laboratories in the midst of establishing technology transfer programs requested advice from Fermilab on how to do so. Beyond this, the Industrial Affiliates Program gained modest public recognition and was reported on extensively by the Chicago **Tribune**, **Business Week Magazine**, the **Wall Street Journal**, and elsewhere. The **Wall Street Journal** noted instances of technology transfer between Fermilab and several of its Industrial Affiliates, including providing techniques for curbing excessive radioactivity around research equipment, and making available improvements in computerized monitoring equipment for the remote control of cryogenic refrigeration systems. One Affiliate's remarks to the **Journal** reflected on the potential of the Program. . ."Fermilab is a good place to find technology... because when you hit, you hit big."

The first year's experience of the Industrial Affiliates Program has raised as many questions as it has resolved regarding technology transfer. The technology that the Laboratory develops isn't always what industry wants and it takes time to develop the cross connection for practical industrial application. How is this effected among industries with a multitude of needs at varying levels of complexity; what is the best technique for doing so; and what kind of lead times are necessary and meaningful to industry innovation and profit making?

As a consequence, the mechanics of the Fermilab Industrial Affiliates program are being reexamined to find ways of improving the focus on two-way communication between industrial research and Fermilab; to develop seminars for industrial laboratories on both scientific and technical subjects; and to create programs to receive industrial scientists at Fermilab to listen to their problems and successes, as commercial constraints permit. In essence, it is hoped that these measures will further evolve and institutionalize the technology-transfer process.

INDUSTRIAL AFFILIATE MEMBERS 1981

Bell Laboratories
Chevron Research
Chicago Bridge & Iron Company
Combustion Engineering, Inc.
Commonwealth Edison
Deere & Company
Digital Pathways, Inc.
Eaton Corporation
General Electric Corporation
The Harshaw Chemical Company
Hewlett-Packard
International Business Machines Corp.
International Harvester
State of Illinois
Johnson and Johnson
KineticSystems Corporation
Lester B. Knight & Associates, Inc.
Litton Industries
McGraw-Edison Company
Metropolitan Life Insurance Company
3M Company
Nalco Chemical Company
New England Nuclear Corporation
Nuclear Data, Inc.
Omnibyte Corporation
Raychem Corporation
Sargent-Welch Scientific Company
Shell Development Company
Standard Oil (Indiana)
Texaco, Inc.
Westinghouse Electric Corporation













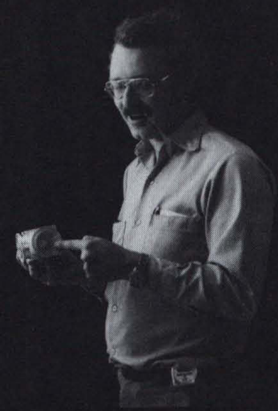











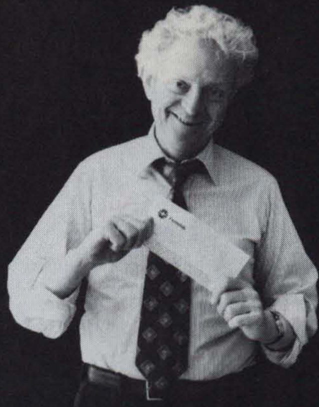



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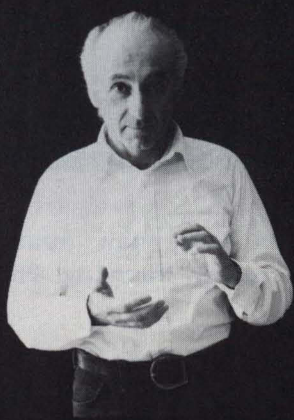
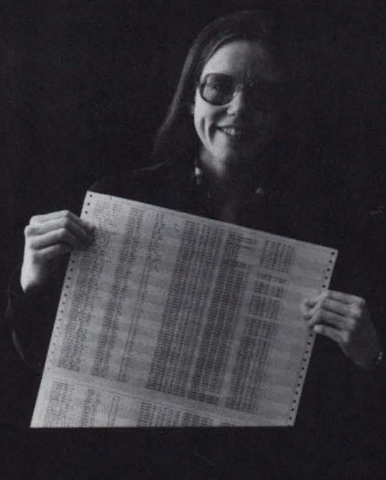





Leon Lederman awards diplomas to students at the conclusion of one of the Saturday Morning Physics courses.

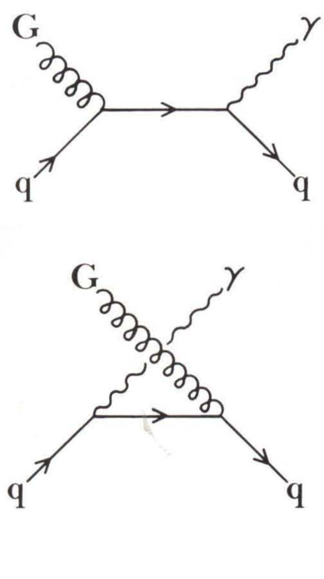
V. People

Saturday Morning Physics

Following a successful and enthusiastically received inaugural year in 1980-81, the Fermilab Saturday Morning Physics program for the 1981-1982 school year was launched in early October. To accommodate the increased demand for participation, classes were enlarged by 50% and held in the newly renovated 1-West conference room of Wilson Hall. The purpose of the program continued as before, to further the understanding and appreciation of modern physics among high school seniors with strong interests in mathematics, physics, chemistry, and science in general.

Enrollment in the ten-week curriculum, offered three times during the year, will reach about 360, representing nearly 130 schools, including 55 students from the Chicago Public High School system. Students are nominated by their principals and selected from a school population in excess of 200,000. Science teachers act as advisors. Volunteer Fermilab scientists and engineers serve as lecturers and tour leaders.

Lecture topics are comprehensive and broad in scope, ranging from the special theory of relativity, elementary particles and detectors, to conservation laws and symmetry, quantum theory, accelerators, the quark models, the forces of nature, cosmology and technology spin-off. Instruction includes ninety minutes of lecture, followed by a half-hour tutorial, and concluding with an hour tour of Laboratory facilities and projects. At the final session of each class, the Director awards Certificates of Accomplishment to students who successfully complete the course. Parents are invited to attend this ceremony, given tours of the Laboratory and urged to think of Fermilab as a regional resource. Saturday Morning Physics attempts to accomplish two objectives, to inspire young potential scientists and to communicate the results of our work to the public.



Users Executive Committee

Lawrence W. Jones, Chairman, University of Michigan; Maris Abolins, Michigan State; Jeffrey A. Appel, Fermi National Accelerator Laboratory; Richard Gustafson, University of Michigan; Sharon Hagopian, Florida State University; Vincent Peterson, University of Hawaii; Thomas Romanowski, Ohio State University; Jerome Rosen, Northwestern University; Melvin Schwartz, Stanford University; Michael Shaevitz, Columbia University; Frank Turkot, Fermi National Accelerator Laboratory; James K. Walker, Fermi National Accelerator Laboratory; Gaurang Yodh, University of Maryland

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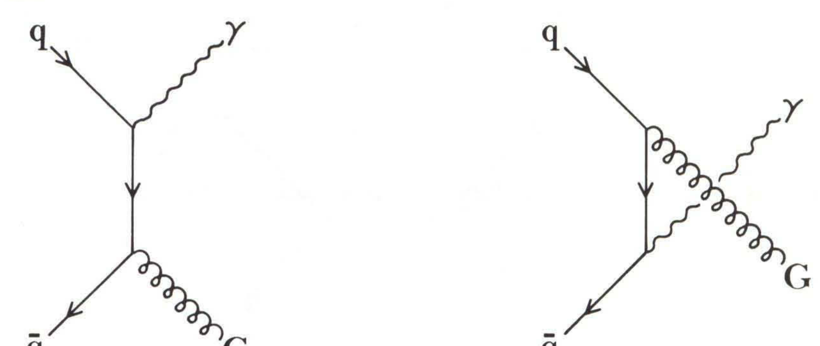
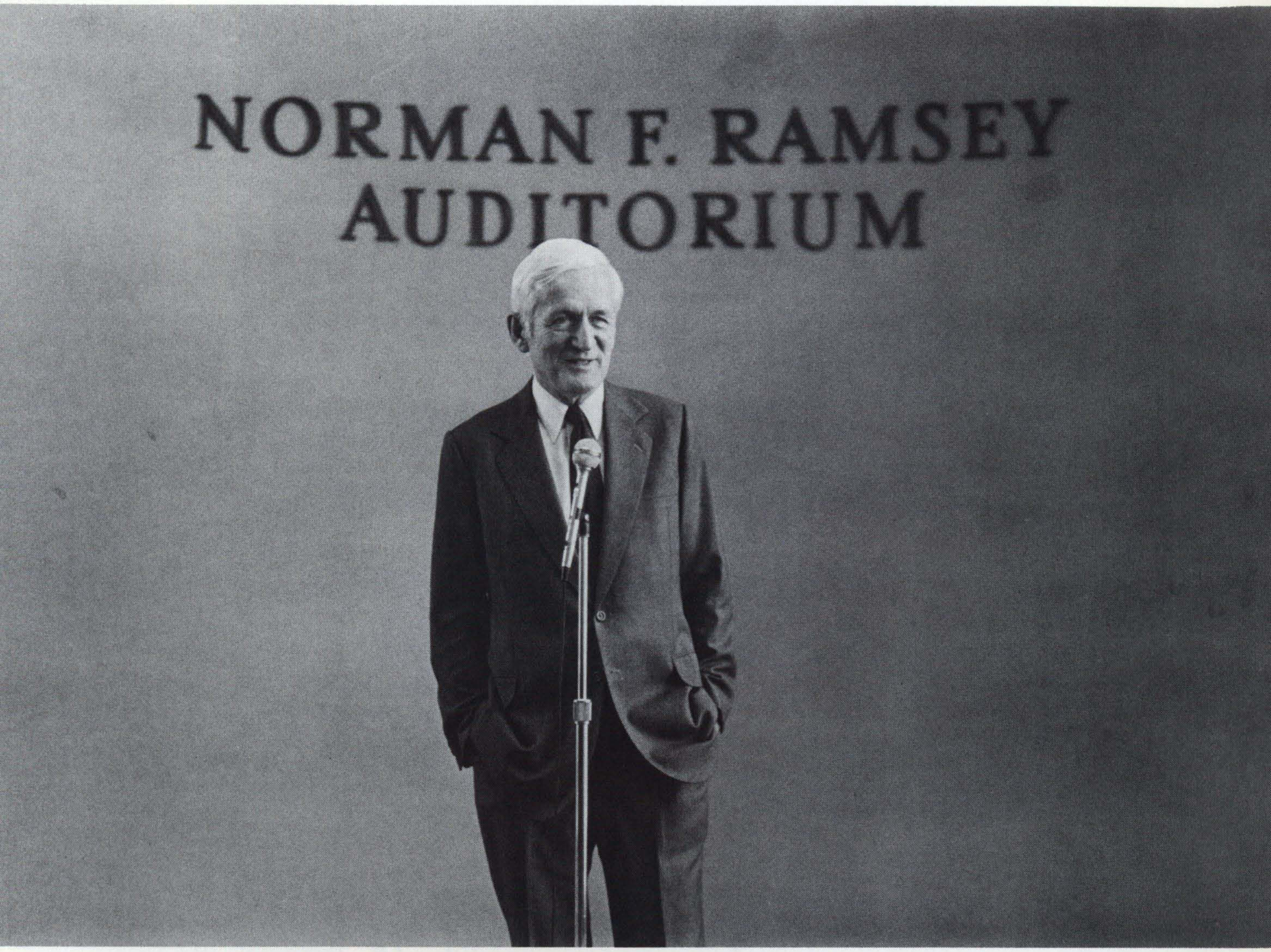
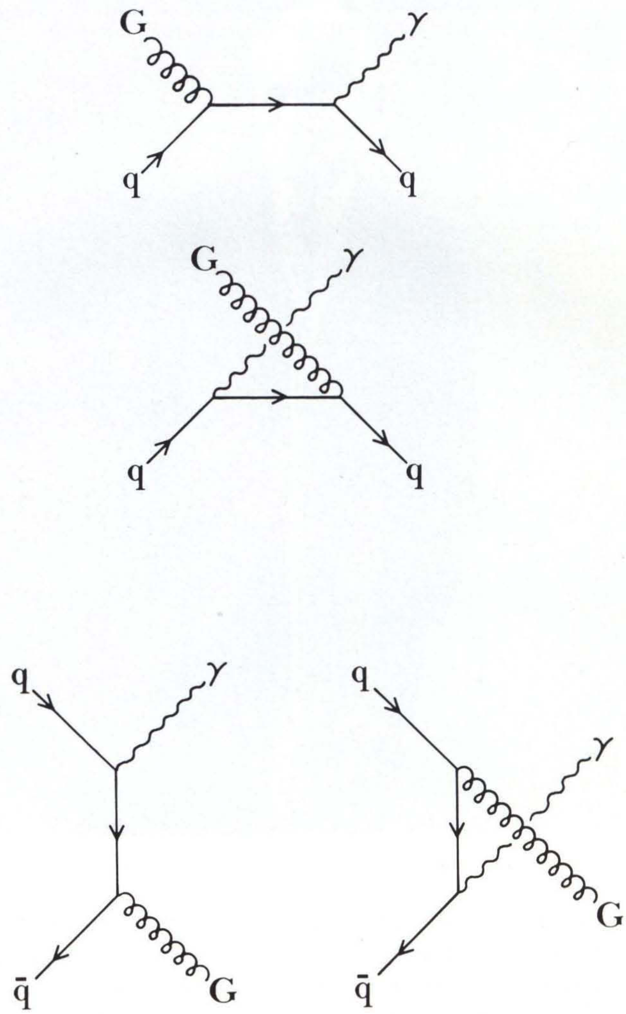




103.
Norman Ramsey was the founding president of Universities Research Association and worked as president for many years to serve Fermilab. As a symbol of the Laboratory's appreciation, the auditorium was dedicated in his name. In this photograph, he is responding at the dedication ceremony.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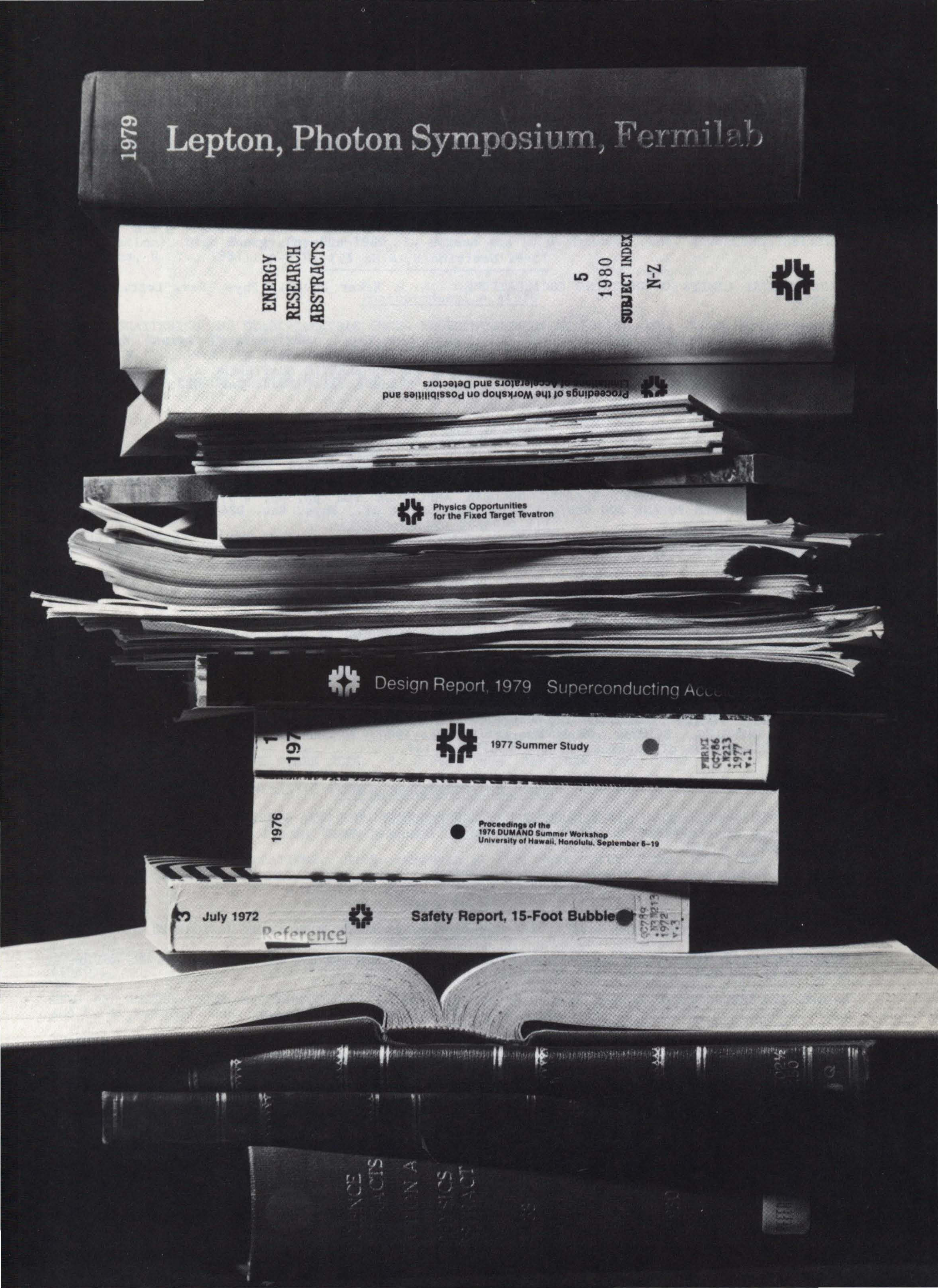
1979
Lepton, Photon Symposium, Fermilab
ENERGY RESEARCH ABSTRACTS
5 1980 SUBJECT INDEX N-Z
Proceedings of the Workshop on Possibilities and Limitations of Accelerators and Detectors
Physics Opportunities for the Fixed Target Tevatron
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1977 Summer Study
1976
Proceedings of the 1976 DUMAND Summer Workshop University of Hawaii, Honolulu, September 6–19
July 1972
Safety Report, 15-Foot
Reference

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15-Ft Antineutrino/H_2 #31

HADRON-PRODUCTION MECHANISMS IN ANTINEUTRINO-PROTON CHARGED-CURRENT INTERACTIONS. M. Derrick et al., Phys. Rev. **D24**, 1071 (1981).

15-Ft Neutrino/H_2 & Ne #53

EXPERIMENTAL LIMITS ON NEUTRINO OSCILLATIONS. N. J. Baker et al., Phys. Rev. Lett. **47**, 1576 (1981).

Polarized Scattering #61

POLARIZATION PARAMETERS AND ANGULAR DISTRIBUTIONS IN $\pi^{\pm}p$ ELASTIC SCATTERING AT 100 GeV/c AND IN pp ELASTIC SCATTERING AT 100 AND 300 GeV/c. R. V. Kline et al., Phys. Rev. **D22**, 553 (1980).

Elastic Scattering #69A

THE REAL PART OF THE FORWARD NUCLEAR AMPLITUDE FOR HADRON PROTON SCATTERING BETWEEN 70 GeV/c AND 200 GeV/c. L. A. Fajardo, Ph.D. Thesis, Yale University, 1980.

REAL PART OF THE FORWARD ELASTIC NUCLEAR AMPLITUDE FOR pp, $\bar{p}p$, π^+p, π^-p, K^+p, and K^-p SCATTERING BETWEEN 70 AND 200 GeV/c. L. A. Fajardo et al., Phys. Rev. **D24**, 46 (1981).

HIGH-STATISTICS STUDY OF π^+p, π^-p, AND pp ELASTIC SCATTERING AT 200 GeV/c. A. Schiz et al., Phys. Rev. **D24**, 26 (1981).

Photoproduction #87

PHOTOPRODUCTION OF CHARMED BARYONS. J. J. Russell et al., Phys. Rev. Lett. **46**, 799 (1981).

PHOTOPRODUCTION OF THE $D^{*\pm}$. P. R. Avery, Ph.D. Thesis, University of Illinois, Urbana.

Photon Search #95A

DIRECT SINGLE PHOTON PRODUCTION AND A SEARCH FOR DIPHOTON RESONANCE OR CONTINUUM PRODUCTION AT FERMILAB ENERGIES. B. Cox, **High Energy Physics-1980**, L. Durand and L. G. Pondrom, Eds. (American Institute of Physics, N. Y., 1981), p. 137.

Associated Production #99

MEASUREMENT OF EXCLUSIVE HYPERCHARGE-EXCHANGE REACTIONS AT 35 TO 140 GeV/c. E. N. May et al., **High Energy Physics-1980**, L. Durand and L. G. Pondrom, Eds. (American Institute of Physics, N. Y., 1981), p. 60.

COHERENT PRODUCTION OF ρ MESONS IN MUON-CARBON SCATTERING AT 150 AND 100 GeV. W. D. Shambroom et al., Phys. Rev. **D24**, 775 (1981).

Beam Dump #108

MEASUREMENTS OF RADIAL AND LONGITUDINAL HADRON SHOWER DEVELOPMENT AT 300 GeV. P. J. Gollon et al., Nucl. Instrum. Methods **189**, 387 (1981).

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*This list was compiled using 1980 (not in **Fermilab 1980**) and 1981 journal articles, theses, and conference papers. Some conference papers were submitted to a conference earlier and were not published until 1981. If there are changes, omissions, or comments, please notify the Publications Office.

Multiparticle #110

OBSERVATIONS OF THE D AND E MESONS AND POSSIBLE THREE-KAON ENHANCEMENTS IN $\pi^- p \rightarrow K^0 K^\pm \pi^\mp X$, $K^0 K^+ K^- X$ AT 50 AND 100 GeV/c. C. Bromberg et al., Phys. Rev. **D22**, 1513 (1980).

30-In. p-p at 400 #138

"MASSIVE MESON PRODUCTION, CORRELATIONS, PRIMORDIAL p_T etc." K. Takahashi (KEK-OCU-KINKI Collaboration), **High Energy Physics-1980**, L. Durand and L. G. Pondrom, Eds. (American Institute of Physics, N. Y., 1981), p. 70.

Photoproduction #152B

COMPTON SCATTERING AND QUASI-ELECTRIC OMEGA PHOTOPRODUCTION AT 50-130 GeV. A. M. Breakstone et al., **High Energy Physics-1980**, L. Durand and L. G. Pondrom, Eds. (American Institute of Physics, N. Y., 1981), p. 233.

ELASTIC PHOTON-PROTON SCATTERING IN THE 50-130-GeV RANGE. A. M. Breakstone et al., Phys. Rev. Lett. **47**, 1778 (1981).

30-In. p-p & Ne at 300 #161

MULTIPLICITY OF SECONDARY PARTICLES IN INELASTIC PROTON-NEON INTERACTIONS AT 300 GeV/c. S. A. Azimov et al., Phys. Rev. **D23**, 2512 (1981).

Proton-Proton Elastic #177

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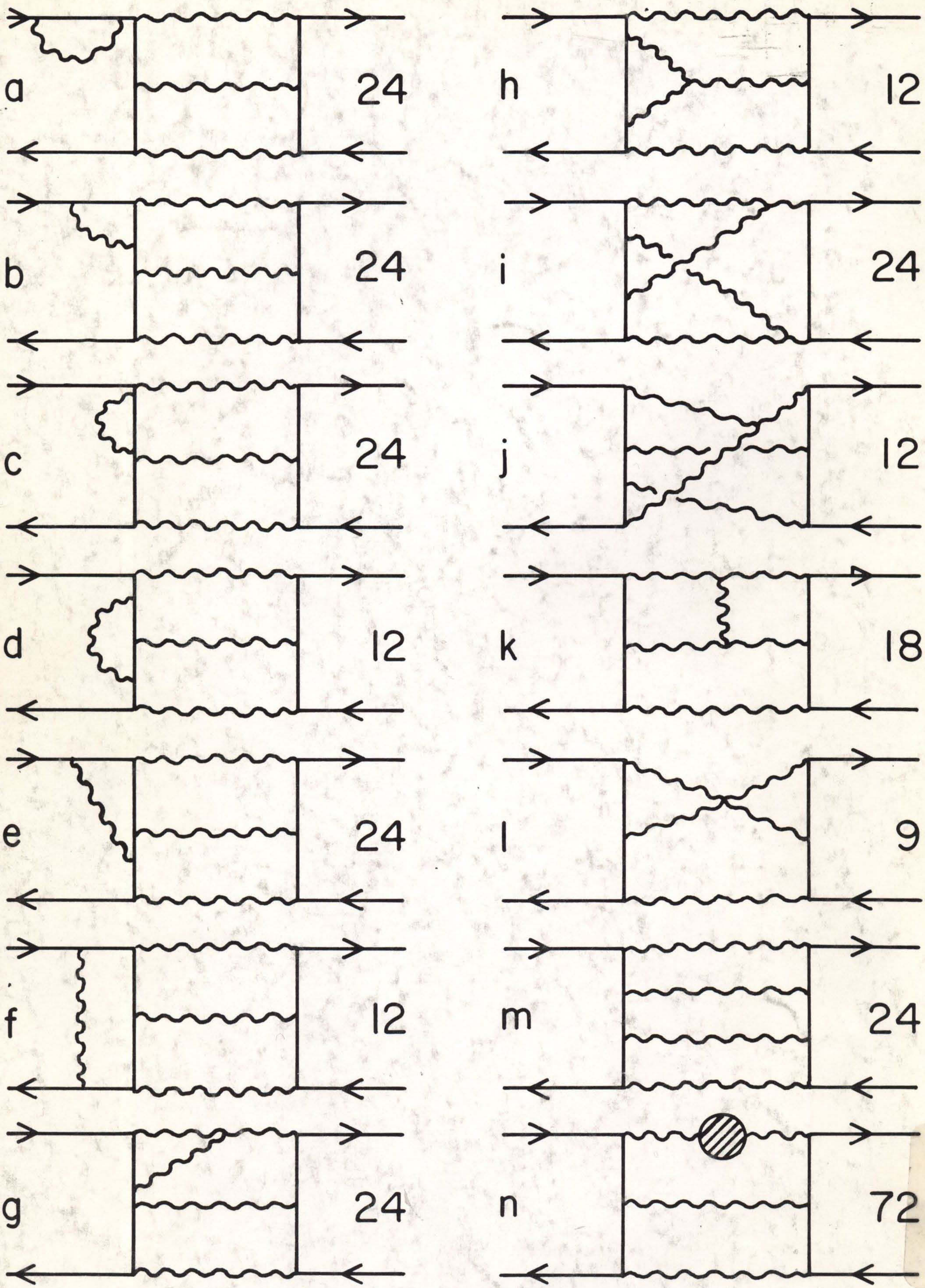
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