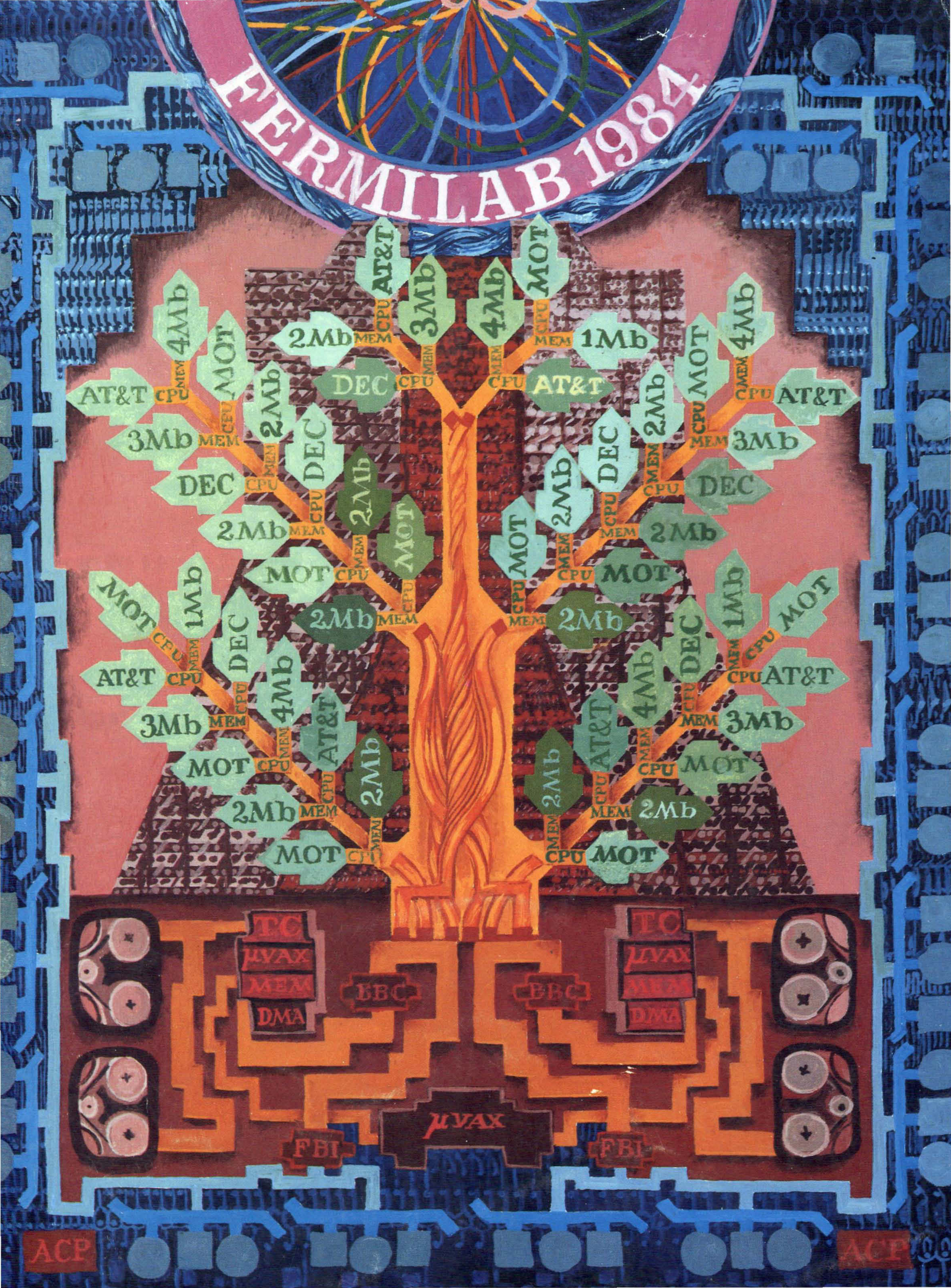

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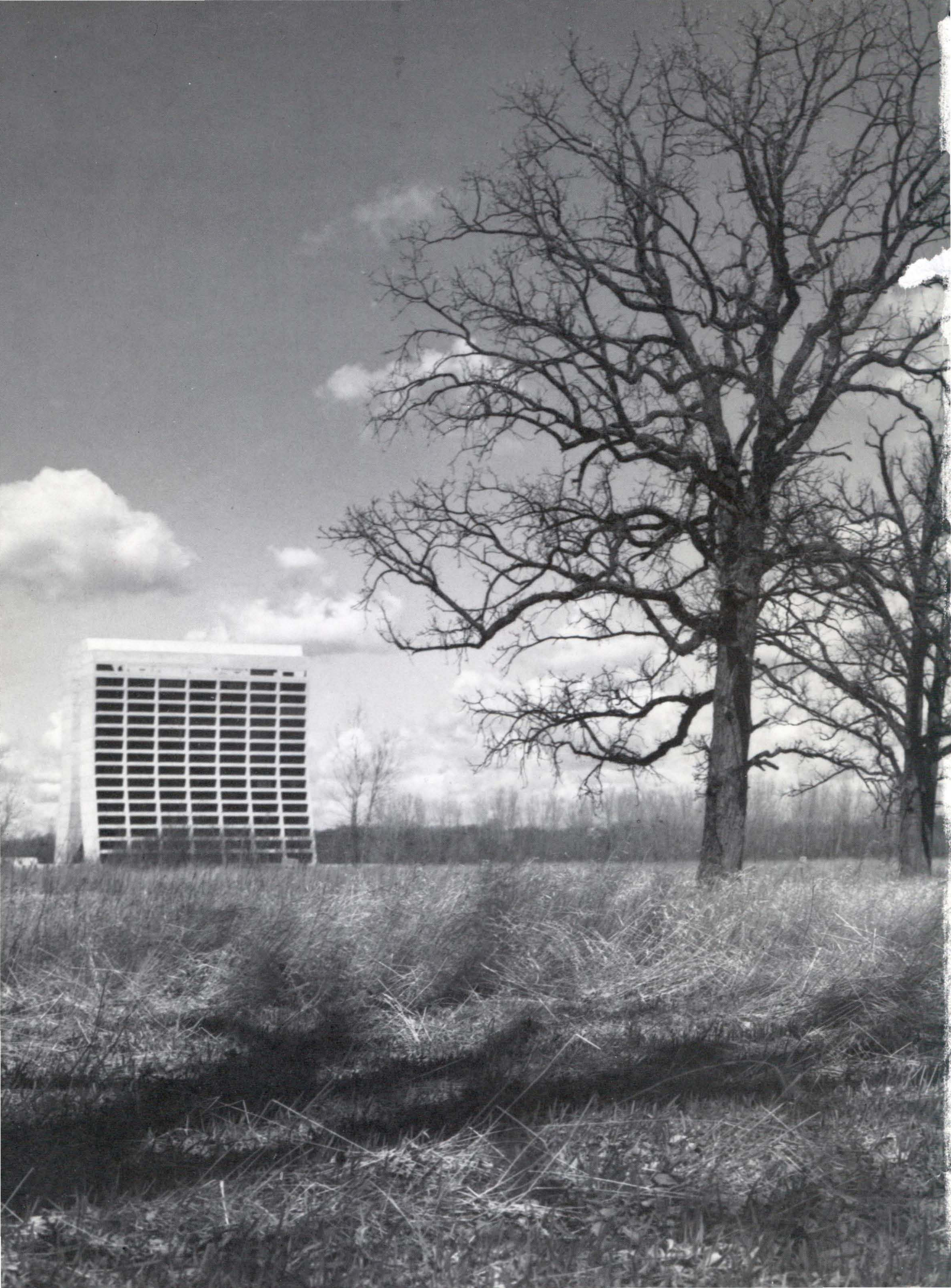


Fermilab 1984

The cover: Adequate computing resources have become a critically scarce tool that high-energy physicists need to carry out their science. Fermilab's Advanced Computer Program (ACP) is attacking the problem with the development of a multimicroprocessor system based on the latest in commercially available integrated circuits (see page 49). The cover is Angela Gonzales' abstraction of the tree structure of the ACP system and is based on the figure on page 54. The branches of the tree support memory (MEM) and numerous central processing units (CPUs). The memory leaves come in various sizes measured in megabytes (Mb). The 32-bit microCPUs are now becoming available from a number of firms, including AT&T, Motorola (MOT), and Digital Equipment Corporation (DEC). The branches and trunk represent high-speed busses and a switch that carry data from the roots which handle the input of raw information and the final output of results. Four tape drives appear at the corners of the roots. At the center are various controllers and interfaces that manage the system. In online trigger applications, a Fastbus Interface (FBI) connects to data acquisition hardware in Fastbus standard crates. The background suggests the intricacy of the micron dimension patterns seen in photomicrographs of the incredible 32-bit microprocessors used in the leaves. Above the title is a typical colliding-beam experiment event. Behind the tree, lurking in the magenta mist, is Fermilab's Wilson Hall, teeming with researchers anxious to reconstruct such events.

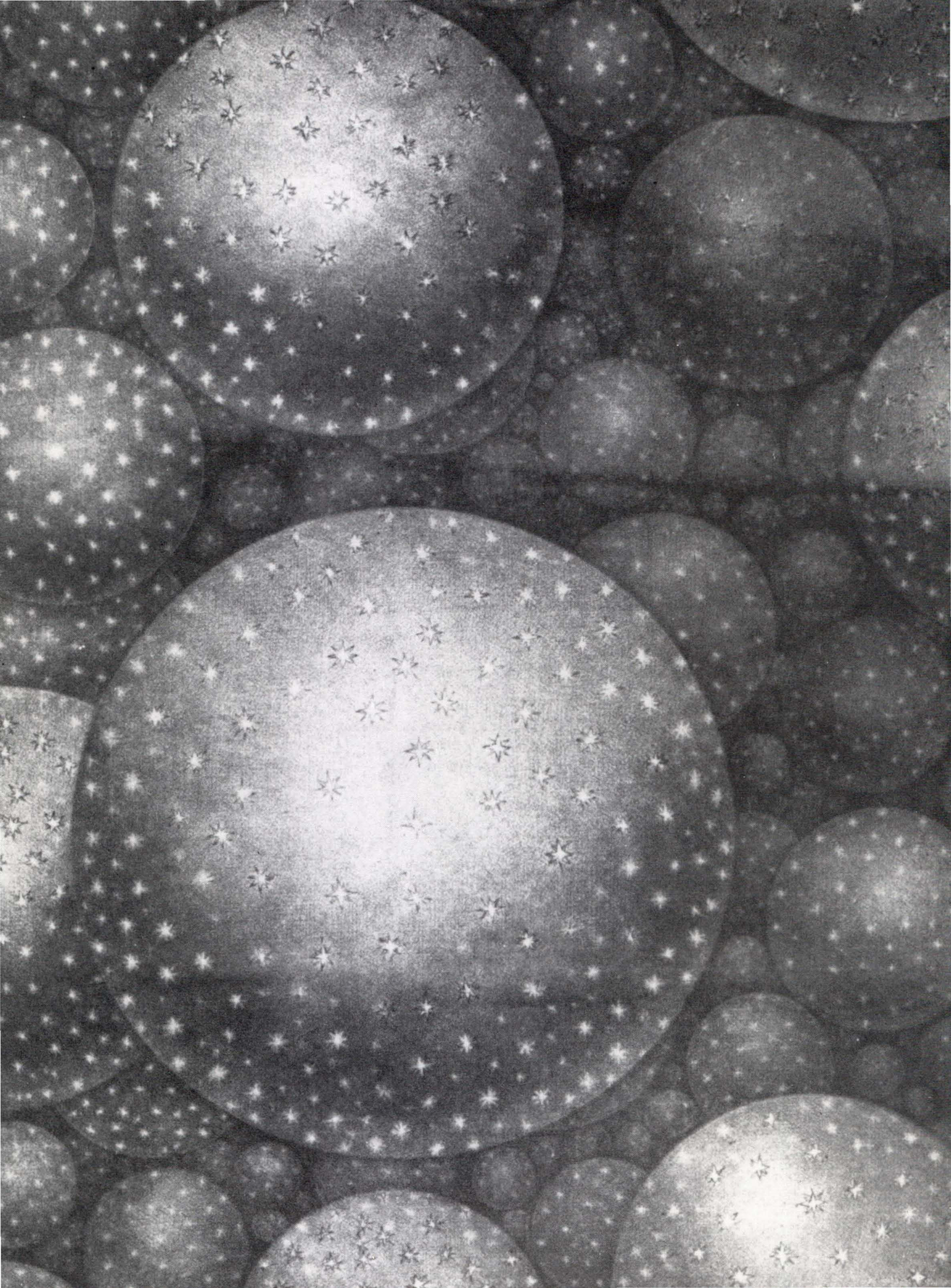
— Tom Nash

Fermilab 1984

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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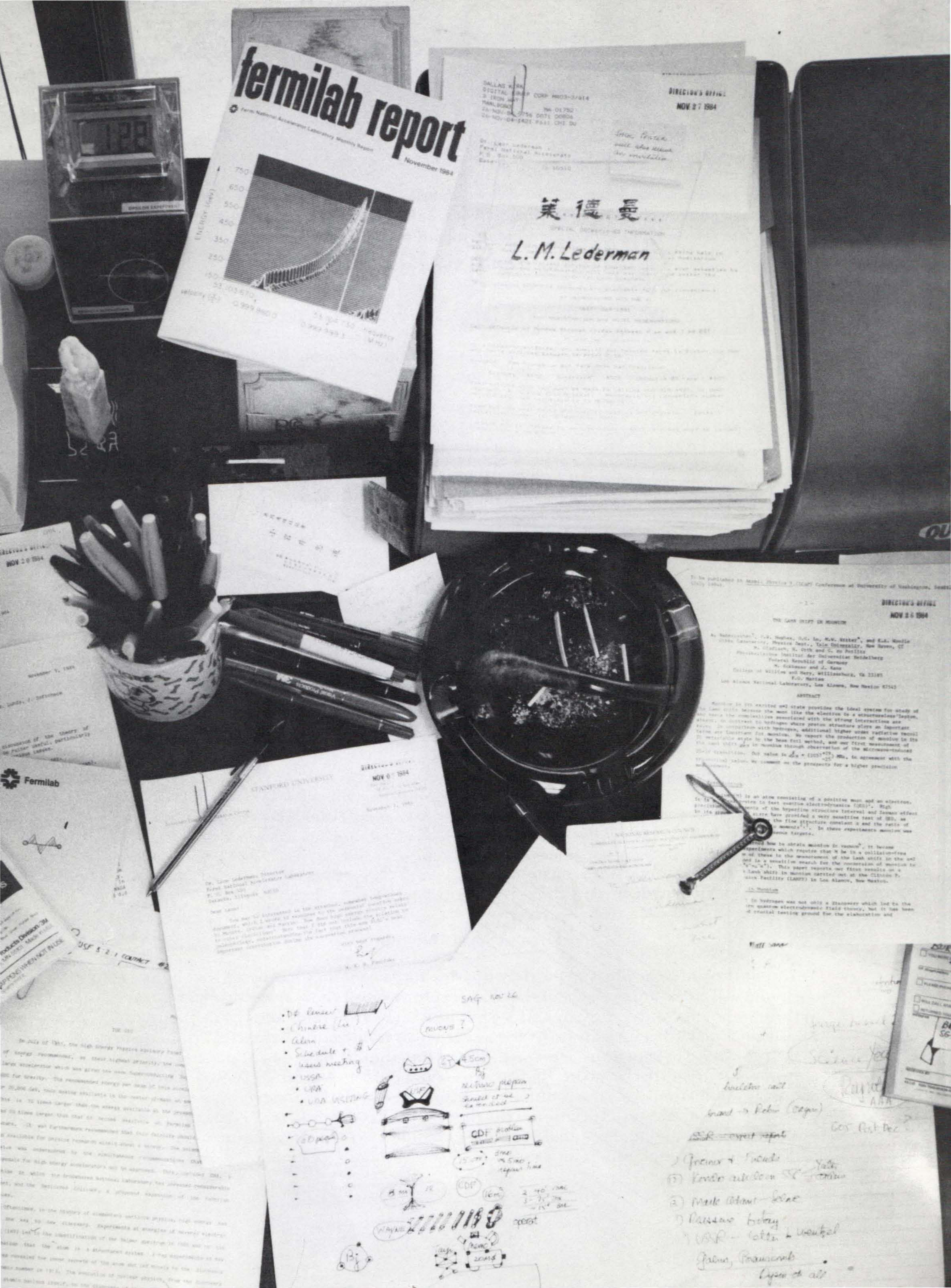
Cosmological Inflation

← Out of the union of ideas in particle physics and cosmology has come the theory of cosmological inflation; a concept that has revolutionized the way we think about the earliest moments of the big bang. As we explore higher energies and probe matter on smaller scales, we become aware of the existence of hidden and beautiful symmetries that are not apparent in the Universe today, but should have been manifest at the enormous temperatures in the first microseconds of the big bang. As the Universe cooled, it underwent a series of phase transitions in which the underlying symmetries were broken step by step. Inflation is the theory that in one of these transitions a single bubble of the low-symmetry phase rapidly expanded to a size large enough to encompass our entire observable Universe.

— E. Kolb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Fermi National Accelerator Laboratory Monthly Report
November 1984
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CDF problem

I. State of the Laboratory

The year 1984 may be summarized by its major activity, the Taming of the Tevatron. (The names Energy Saver and Energy Doubler should pass into history even though the new superconducting accelerator did double and does save energy, some 40 megawatts, in fact). Our runs in '84 were ragged as we tried to manage the complexity of the new machinery, the neglect of the old machines and the implementation of new beam lines and new experiments. However, enough of our goals were met to list the run as successful. A score card is presented elsewhere in this volume. The unfinished part of the Tevatron, the Antiproton Source (Tevatron I) was also a high priority activity and, when we add in the continuing construction of the Collider Detector Facility (CDF), we see a very substantial effort. In the euphoria of doing physics again we were struck with the fact that, since 1979, the Laboratory had been gradually transformed in order to best manage its construction tasks. This put us in poor posture to apply creative attention to the challenges of getting physics out of the Tevatron. So we reorganized. The aim is as stated, to finish our construction tasks as quickly as possible and to organize ourselves to conquer the planet in the years from now until the Tevatron fades into the shadow of the Supercollider. *Sic transit gloria mundi*.

The reorganization strategy was to deploy our strengths to match the altered priorities of an operating laboratory. A simplified circuit diagram is around here somewhere. The Laboratory priorities need to be reiterated; they are logical but the large overlaps still make for confusion and uncertainty. With customary caveats that a numerical ordering on a flat page does injustice to a multidimensional nature of the problem, we list:

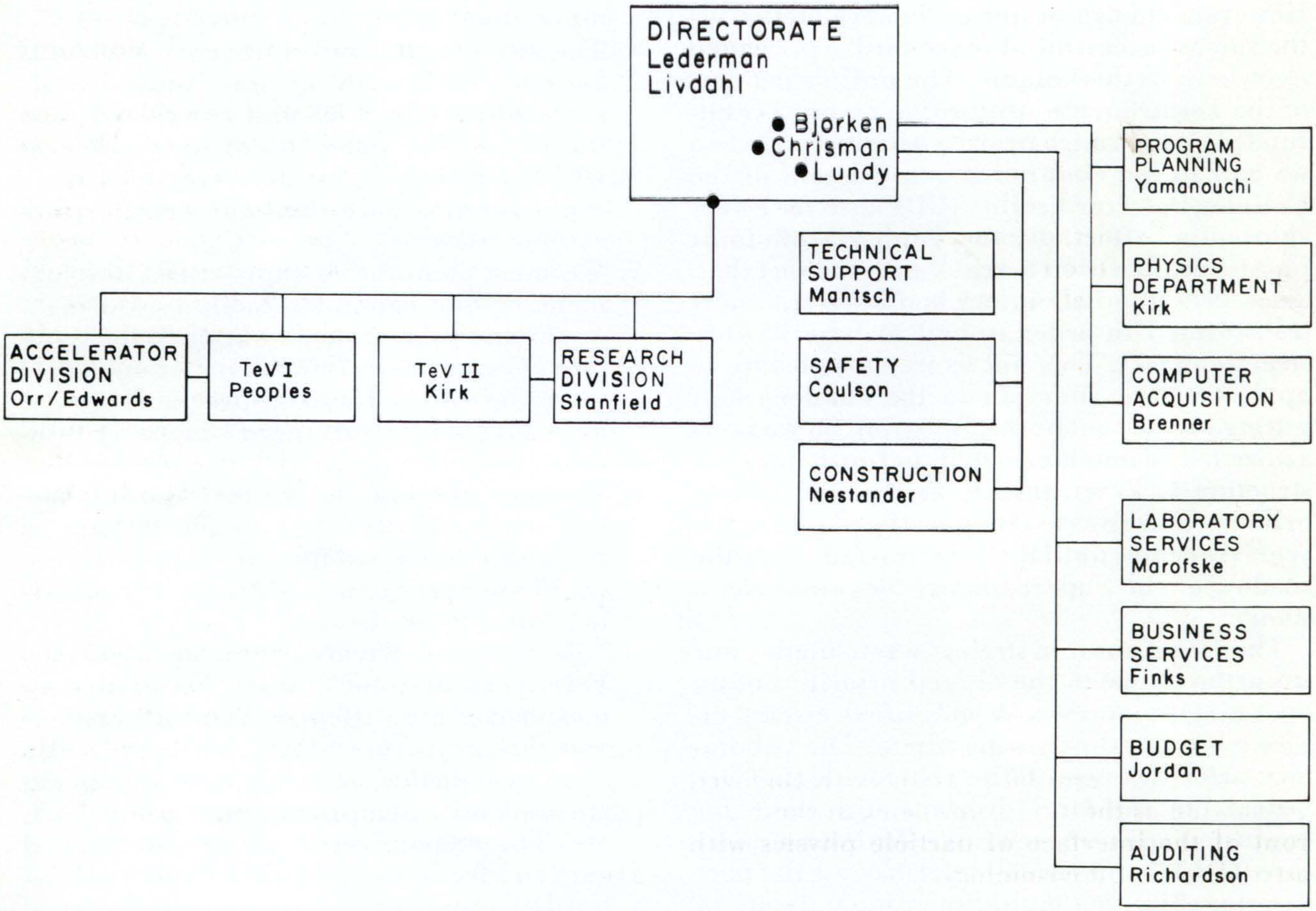
1. We must bring the accelerator up for reliability and increasing intensity to service the 1985 fixed-target program.
2. We must complete TeV I (the $\bar{p}$ source) so that a good physics run can be carried out in the fall of '86.
3. This implies the essential completion of an excellent detector, CDF, capable of addressing the new physics issues that go with 2 TeV.
4. TeV II, the fixed-target beam lines and areas, must be completed (within budget, of course) on time and the 1986 fixed-target experiments and beam lines must be ready to go by spring 1986.
5. The Tevatron accelerator must reach close to 1000 GeV by a combination of replacing weak magnets and lowering the ring temperature about 0.5°K.
6. The second major colliding beam detector at D0 must be brought on line, phased to do some physics by 1988 and completed soon thereafter. We need to convince whoever will listen that this is deserving of a more rapid funding pace than our present projections allow.
7. We must continue to support the development of our computer facilities via manpower and a major new addition to the Computer Center. Even this will not be enough to serve the entire Tevatron program, and we must support the Advanced Computer Project.
8. We must continue to improve the intellectual environment of the Laboratory: here we recognize the important role of the Theoretical Physics group, now aided by our maturing Astrophysics Group.

A comment: We are concerned about the Fermilab "post-docs" since Fermilab's atmospherics are different from universities' and different from SLAC, BNL, and LBL. Here we note that we do not have permanent groups under semi-permanent group leaders. The responsibility for the intellectual care and feeding of post-docs (poor beasts of burden, only exceeded by graduate students) is then diffuse and our Physics Department is now instructed to study and solve the problem. Here we should add that the reorganization must assume that Fermilab physics staff will have greater opportunities to participate in research and, again, the appropriate structure to see to this is the Physics Department.

9. We have serious responsibilities relative to SSC on at least two fronts. One is to do our share of the national effort on R&D and design. The other is to look into the Tevatron as a possible injector. It seems clear that any improvements in the Tevatron as SSC injector will help the current program. A third obligation is to provide assistance to the State of Illinois (and anyone else who asks) in efforts to compete for the SSC.

10.-15. Here we simply shrug and remind our readers that we do R&D on instrumentation, we stimulate the HEP community to think hard about new experiments via workshops, we reach out to the external community for science education, technology transfer, collaboration with developing countries, etc., etc.

The foregoing is a restatement of the goals of the Laboratory over the next several years. The remainder of this overview and the articles that follow constitute a progress report.



Particle Theory

Reviewing those highlights which are not described in greater detail in this issue, we note first that the Theory group has now grown to six permanent members (Bardeen, Bjorken, Eichten, McLerran, Quigg, and Thacker) and there are now six associate scientists (Ellis, Hill, Parke, Pisarski, Schonfeld, and Taylor). There are seven post-docs and the usual deluge of unusual visitors. In addition to their own work on the full spectrum of particle theory fascinations, Theory has served the community via very active participation in SSC activities. A major product is the "bible" of SSC physics (the **Reviews of Modern Physics** article known as EHLQ, pronounced ELK, probably because the authors are Eichten, Hinchliffe, Lane, and Quigg.)

The Physics of Theory

The phenomenology relevant to colliding beam physics has been a major focus of research. A detailed survey of SSC physics prospects was completed (Eichten, Quigg), along with related work on the signals for Higgs bosons and technicolor. The search for supersymmetry has been brought into sharper focus with a critical examination of the current limits and the detection prospects (Eichten, Quigg). The interpretation of high-energy jet production at the Sp$\bar{p}$S collider has been clarified by Monte Carlo studies (Sjostrand) and by perturbative QCD calculations (Ellis, Parke, Taylor).

Significant progress has also been achieved in the application of lattice gauge theory to physics problems. For the first time, hadronic decay parameters have been computed using lattice Monte Carlo methods (Thacker). A study of finite-size effects on spectrum calculations has also been completed (Thacker). Monte Carlo methods have been applied to the study of the renormalization properties of QCD and to phase structure of the theory at finite temperature (Das). Lattice methods have also been adapted to the study of possible composite structure of weak interactions (Sexton).

Research interests have also turned to higher dimensions, gravity, supergravity, and strings. The structure of anomalies for gauge and gravitational theories in any dimension was clarified (Bardeen). The effects of quantum fluctuations on the vacuum structure of Kaluza-Klein models have been analyzed (Rubin). A covariant functional Schrodinger method has been developed to study the quantum evolution of the states in the early universe and the implications of inflationary scenarios (Hill). The consistency of renormalizable, higher derivative theories of gravity has been examined, including the implications for the vanishing of the cosmological constant (Pisarski).

Mathematical methods have been developed for the study of colliding beam instabilities in electron-positron storage rings (Schonfeld).

In addition to publishing to avoid perishing, the group has maintained the pace of theory seminar, wine and cheese seminar, Journal Club, and a new TeV I Collider Physics Journal Club. Academic lectures were given on a wide set of subjects selected by the trapped population of graduate students and post-docs. In a more ideal world, these honored guests would be living on a university campus where, in that ideal world, one could walk to the accelerator.

NASA/Fermilab Astrophysics Center

The NASA/Fermilab Astrophysics Center was started at Fermilab in 1983 with a grant from the NASA Office of Space Science and Applications Innovative Research Program. In less than two years Fermilab has become recognized worldwide as the center for work at the forefront of the interface of particle physics with astrophysics and cosmology.

Cosmology is the study of the origin and evolution of the Universe. Cosmology includes everything from the origin of the Universe, to the primordial production of light nuclei, to the decoupling of the present microwave background radiation, to galaxy formation, to the present structure of galaxies, clusters of galaxies, and beyond. Cosmology provides a background upon which we understand and interpret the Universe in which we live. In the past few years, it has become increasingly apparent that an understanding of the present large-scale structure of the Universe is impossible without understanding its small-scale structure. The discovery of this deep connection between particle physics and cosmology has started the entire new field of particle physics and cosmology. Fermilab offers a rich and unique environment for research at the particle physics/astrophysics interface.

The Physics of Astrophysics

One of the oldest of the modern cosmological questions has to do with the "missing mass" necessary to "close" the Universe. If there is enough mass in the Universe, the expansion we observe will eventually stop, and the Universe will recollapse. The possibility that the "missing mass" in the Universe is in the form of the decay products of massive neutrinos has been studied by members of the Fermilab Astrophysics group. This possibility was first proposed in 1978 by Dicus (Texas), Kolb (Fermilab), and Teplitz (VPI). In the past year at Fermilab, the idea has been developed, and the effect of decaying particles in galaxy formation has been studied. Turner (Fermilab/Chicago), Steigman (Bartol), and Krauss (Harvard) extended the original idea in a **Physical Review** letter. Other ideas for decaying particles have been studied by Schramm (Fermilab/Chicago), Gelmini (CERN), and Valle (Rutherford) in an article in **Physics Letters.** Olive (Fermilab), Schramm (Fermilab/Chicago), and Srednicki (Santa Barbara) have considered the possibility that the decay products of gravitinos could close the Universe. Olive (Fermilab), Seckel (Fermilab), and Vishniac (Texas) have studied further astrophysical effects of decaying particles in an article in **Astrophysical Journal.** Finally, Kolb (Fermilab) reviewed the staus of the cosmological effects of decaying particles at NEUTRINO '84, the yearly international neutrino conference.

"Inner Space/Outer Space"

During the first week of May, an international conference on science at the interface of particle physics and cosmology/astrophysics was held at Fermilab. The conference was organized by members of the Fermilab Astrophysics Center. The "Inner Space/Outer Space" conference was attended by 230 scientists, including astronomers, astrophysicists, cosmologists, low-temperature physicists, and particle theorists and experimentalists. Plans are now being made to hold annual workshops on cosmology and particle physics at Fermilab. The proceedings of the May 1984 conference will soon be published by the University of Chicago Press. Inner Space/Outer Space conference T-shirts have become collectors items.

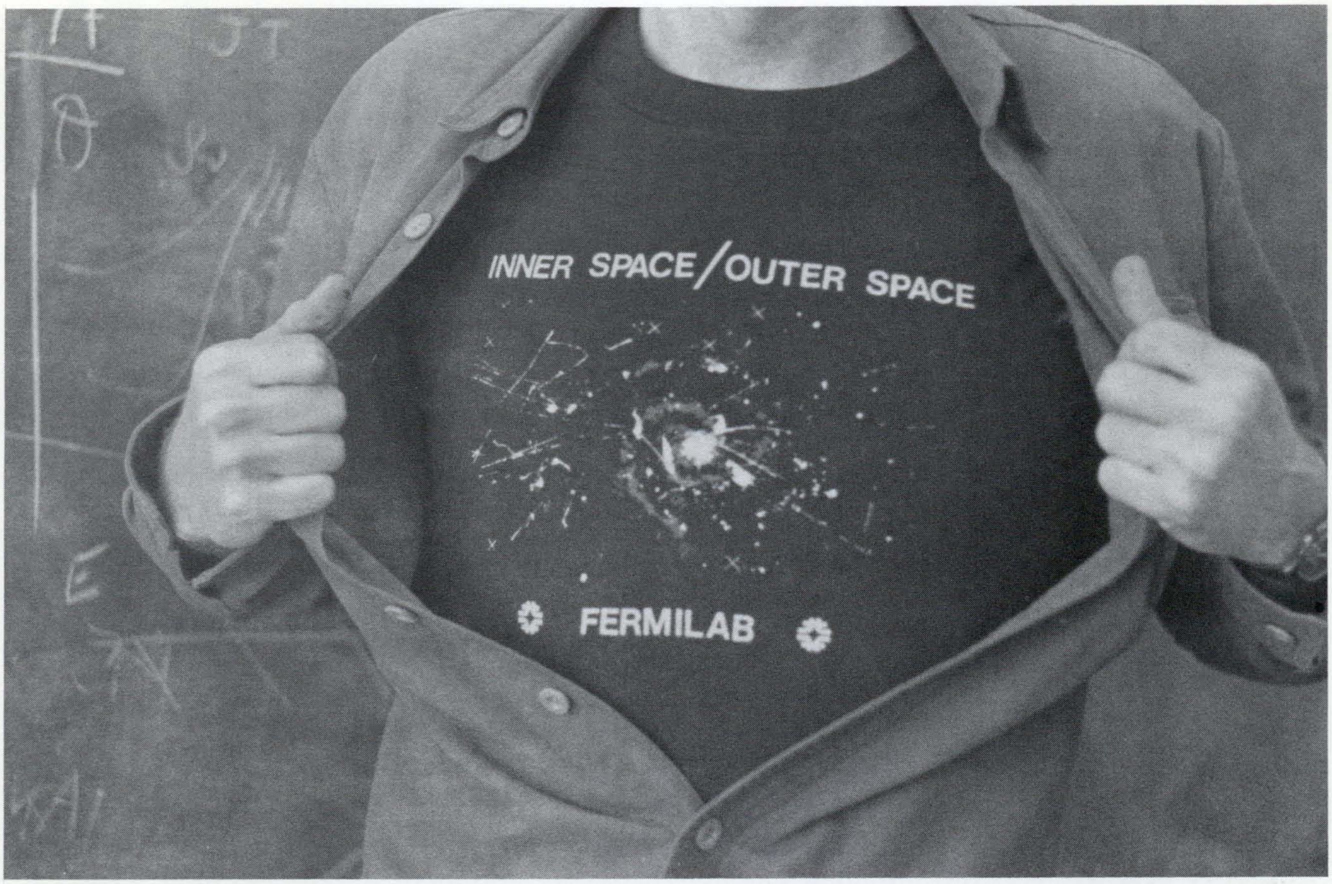
Astrophysics Seminar Series

In addition to the annual conference, the Astrophysics Center holds a weekly seminar series on Monday afternoons. In the spring of 1984 the seminar series focused on the cosmological implication of theories of extra dimensions. The fall seminar series topic was the microwave background radiation, and its implications for galaxy formation. The Monday astrophysics seminars often complement the Tuesday theoretical physics seminars. Several of the Laboratory colloquia have been in various areas of astrophysics. Cosmology and astrophysics have also become part of the public image of the Laboratory. Michael Turner of the Astrophysics Group gave a public lecture at Fermilab on the cosmology-particle physics connection. This Friday night public lecture was sponsored by the Fermilab Auditorium Committee and was attended by over 700 members of the local community. One of the goals of the Astrophysics Group is to make cosmology and astrophysics an integral part of the intellectual atmosphere of Fermilab. By doing so, particle physicists at Fermilab are provided a unique perspective through which they may interpret and appreciate advances in their field in a wider scope of its influence in other fields of physics.

Astrophysics Group

The present Astrophysics Group was originally headed by Edward Kolb, who joined Fermilab from the Theoretical Astrophysics group at Los Alamos National Laboratory, and by Michael Turner, who spent the '83-'84 academic year at Fermilab on leave from the University of Chicago. In the fall of 1984, Turner returned to the University of Chicago, but will continue to spend one quarter per year in residence at Fermilab as a visiting scientist.

In the fall, Alex Szalay joined the Group. Alex is a Hungarian astrophysicist who specializes in models of galaxy formation. Szalay will be a visiting staff member and will be at Fermilab for eighteen months. David Schramm, from the University of Chicago, will continue to split his time between Fermilab and Chicago. This fall, Bernard Carr of the University of Cambridge was in residence. The active visitor program benefits both Fermilab and the astrophysics community by making experimental and theoretical advances in particle physics accessible to the astrophysics community. In addition to Kolb, Turner, Szalay, Schramm, and visitors, the Group has four post-docs and several graduate students, making it one of the largest cosmology groups in the civilized world, perhaps in the universe, certainly in Warrenville, Illinois.



Tevatron I, The Antiproton Source and Collider

This is the project which will permit Fermilab to produce collisions between counter-rotating beams of protons and antiprotons. When we bring the beams close to 1 TeV, the resulting 2 TeV will be a planetary record energy — over three times the energy of the CERN collider.

TeV I proposes to extract protons from the old Main Ring and target them to produce antiprotons. These are collected, stored, cooled, and accumulated in two new concentric rings located just south of the Booster. No, the particle choreography is not complete: the above processes are sandwiched by rf manipulations before extraction and by reinjection of ice-cold antiprotons in the Main Ring for acceleration and delivery to the Tevatron.

The manager of TeV I goes on to write:

If physics were a horse race, the Tevatron I project would be spinning out of the final turn at the top of the stretch. 1984 has been a year of major accomplishments for TeV I in both conventional construction and technical components. The story can perhaps be best told in the photo essay in this Report.

The accomplishments of the project are made even more noteworthy by the obstacles that had to be overcome this year. The year began with a terrible winter for construction. In spite of the weather, construction of the tunnels and service buildings was completed, and we have been installing equipment for several months. More and more of the Tevatron I Section has moved out to the trailers next to the rings to be close to their work. The Target Station and Target Service Building are also complete. During the summer shutdown, the Main-Ring tunnel was uncovered and new, wider tunnel sections installed for Tev I extraction.

The technical components have also moved ahead, although that work has also had obstacles. The TeV I Debuncher, Accumulator, and transport magnets are larger and have tighter field-quality specifications than any conventional magnets Fermilab has built before. The year saw all the quadrupoles of both aperture sizes completed, measured, and accepted. The coils for nearly all of the dipoles are finished. The assembly of the laminations into magnet cores did not come easily. The magnet performance has been affected by the quality of the steel and the condition of the stamping die. By carefully testing the magnetic properties of several hundred samples of steel and accurately measuring the lamination dimensions, it has been possible to obtain the desired quality. In some instances magnets which did not meet the demanding tolerances of the project were brought to specifications by adding a small number of thin shims. At the end of the year, installation of magnets in the tunnel was underway.

There were also some difficulties to overcome in the target area. The first lithium lens for antiproton collection failed when the bolts holding the assembly together yielded. When the cause of this failure was remedied on prototypes two and three, cracks developed in the titanium water jacket. Detailed investigation showed that this failure was caused by metal fatigue and a redesign has fixed the problem. The most advanced prototype lithium lens has now been pulsed to its design current more than 100,000 times. Lens number 2 has operated for more than one million pulses, albeit at 50% of the design current, in the AA target station at CERN. Other special magnets and devices for the Target Station are being fabricated.

Equipment for stochastic cooling is also being assembled. After some initial problems, the traveling-wave tube amplifiers for cooling met design specifications. The pickups and kickers, preamplifiers, and other electronics are under construction and the superconducting correlator filter is well along. Similarly, all of the enormous amounts of equipment for the two major storage rings are well along in fabrication, including the controls system.

During 1984, the superconducting low-beta system that will squeeze the beam down and improve the luminosity at B0 in the Tevatron was installed and successfully tested at 800 GeV. At the end of the year, the Main-Ring Overpass to carry the beam around the detector at D0 was installed and successfully operated. The Main Ring bunch-coalescing cavities, used to increase the peak proton intensity on the antiproton production target, were installed in 1984 and are ready to go.

At the end of 1984, the people of the Tevatron I Section were all busy installing, surveying, and testing equipment. The new year, 1985, should see us thunder down the home stretch and cross the finish line.

Tevatron II, The Fixed-Target Program

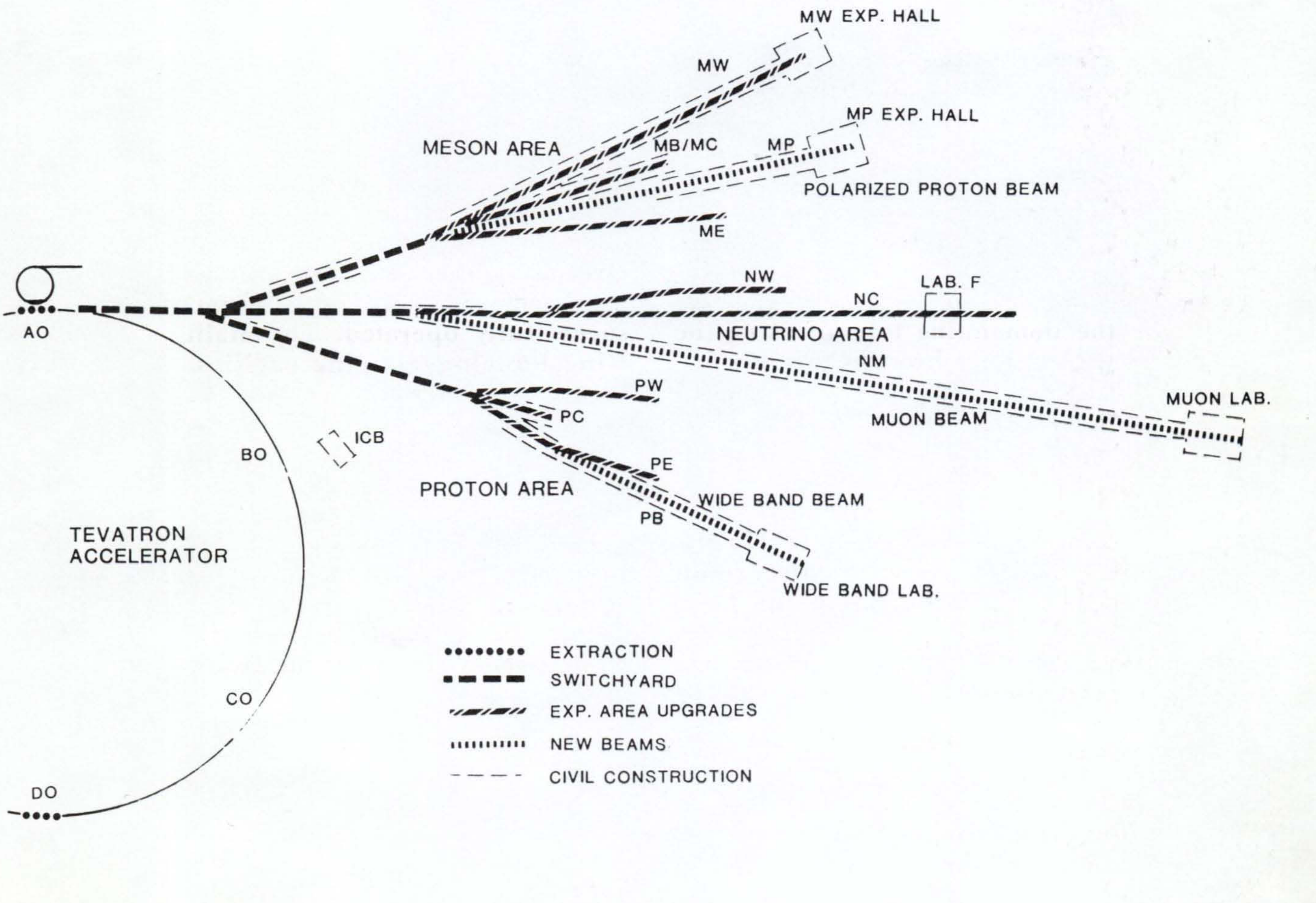
1984 was the third year of the TeV II construction project and will probably turn out to be the year in which the activity on this project reached an almost unbearable crescendo. The construction project as a whole is divided roughly into two parts, a technical upgrade of the primary beam transport facilities from 400 to 1000 GeV, and a civil construction portion in which various experimental halls, beam enclosures, and other facilities are constructed to accommodate both the primary beam upgrade and the experimental facilities that will be needed for the 1000-GeV fixed-target program.

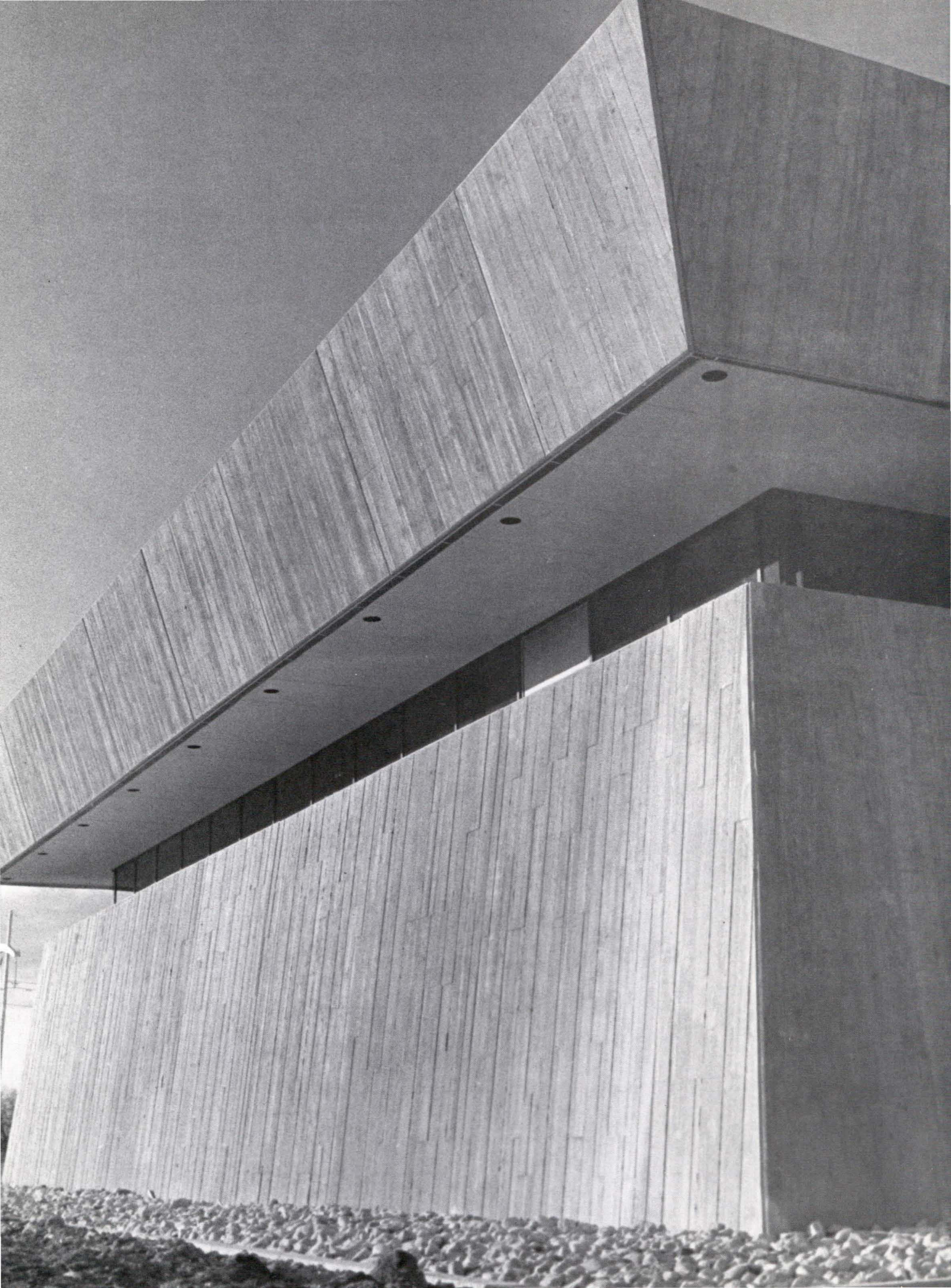
During the past year, the primary emphasis for the technical upgrade part of the TeV II Project has been in developing and installing primary beam transports for new beams that had not existed prior to Tevatron II. These were specifically the Wide Band Beam in the Proton Area and the new Muon Beam in the Neutrino Area. The extraction of fast beam for the conventional neutrino program was also an area of significant activity in 1984. Finally, a significant amount of work took place in construction of the M-West Target Pile. This new primary target station will become the source of a high-energy hadron beam to be built in 1985 and 1986.

A majority of the activity in the TeV II project in 1984 was concentrated in civil construction projects associated with the new Wide Band Photon Beam and the new Muon Beam. For the former, two existing enclosures in the Proton Area were converted into fully shielded areas capable of transporting and targeting primary proton beams. One of these, the PE4 enclosure, will be the source of the Wide Band Beam. It was necessary to partly demolish the old enclosure and rebuild it in order to insure the desired amount of radiation shielding and achieve the technical capabilities needed for the Wide Band Beam.

Downstream of this enclosure, a new tunnel

TeV II Construction Areas





extension was added which will be used for the early sections of the Wide Band Beam transport; a second new enclosure was built next to the Tagged Photon Laboratory for momentum selection, and downstream of the momentum selection enclosure the new Wide Band Experimental Hall and counting house were constructed. This last is far and away the largest TeV II project in the Proton Area and the hall has been under construction since early 1984. The new building will house two experiments, E-687 and E-683, both of which have been approved to do photon experiments in the 1986 run.

Through experience, it has become clear that the construction of a new experimental hall takes almost one year from the time that the bid package is released until the building is fully available to experimenters. Work on the Wide Band Hall began in the early spring of 1984; it is hoped that the building will be available for full use by the experimenters by February of 1985. In order to help the users get an early start in the erection of their apparatus, early occupancy of the high bay areas of the hall has been arranged. This is a strategy that seems to pay significant time dividends and is much appreciated by experimenters.

Meanwhile, back at the Neutrino Area, an even larger civil construction effort has been underway in 1984. This is the construction of the new Muon Laboratory, and of the twenty-four beam line enclosures that are necessary for the new muon beam. These two projects have been pursued as separate construction contracts and, as noted in the Wide Band case, the laboratory building will probably take about one year to complete. The new Muon Lab was started in February of 1984 and is expected to be fully complete only in February 1985. The Muon Laboratory is a large building that combines a high bay experimental area and the associated counting and computing rooms in a single structure. This building, when complete, will be one of the most striking and aesthetically pleasing structures on the Fermilab site. An itinerant architectural consultant, one R. R. Wilson, is to be credited here.

If all the muon beam civil construction can be completed on schedule, it is hoped that the Muon Beam will be commissioned in the spring of 1985. Perhaps it will even be possible to begin preliminary tests for E-665, the experiment that plans to take data in this beam in 1986.

In addition to the active civil construction projects, a great deal of planning in the Tevatron Construction Group has gone forward in 1984 for the final phase of the Tevatron II Project, the new beams for the Meson Area. The two beams presently planned for this area are the M West Pion Beam (which will be the only pion beam in the Laboratory capable of going to 800

GeV) and the Polarized Proton Beam, a facility unique in the world. This latter beam will exploit the observed experimental fact that polarization persists in secondary particles even at high energies. This polarization, an early Fermilab discovery, was theoretically unexpected.

In 1984, the conceptual plan for the Meson Area civil construction was completed and the engineering design begun. In order to speed up construction of the M-West Experimental Hall, a plan was decided upon to phase the construction. It is now hoped that the foundation for this building, its associated counting house, and a related service building will be completed before severe winter weather sets in. Then, even during the coldest months, it is anticipated that structural steel can be erected by taking advantage of favorable breaks in the weather. This will enable us to get a rapid start on the rest of the buildings in the spring of 1985 and, hopefully, complete the M-West Experimental Hall by the end of summer.

Unfortunately, the Polarized Proton Hall cannot be maintained on the same rapid schedule, and this Hall will probably not be complete until the end of 1985. The associated beam line enclosures for the M West Pion Beam and the Polarized Proton Beam are also under design as 1984 draws to a close, and precast concrete sections needed in their construction will be procured during the winter. Next spring, the civil construction on these beam line enclosures will be undertaken at approximately the same time as the structures for the experimental halls begin to take shape.

The Physics of TeV II

The reorganization created an Associate Director for Physics and Dr. J. D. Bjorken was named to this post. His article addressing TeV II physics is in this volume.

In 1984, we began to "review" the future of the fixed-target program. This began with a fine workshop on Fixed-Target Physics. Out of this came an organization of users devoted to this subject: Tevatron Association of Fixed-Target Spokespersons (TAFTS). This was followed by in-depth workshops on Vertex Detection (September), Direct Neutral Lepton Workshop (October), and Hyperon Physics at the Tevatron (December). The richness and potential of Tevatron research was made crystal clear in these studies. Much of this clarity is contained in Bjorken's section of this review. The Santa Fe meeting of the Division of Particles and Fields witnessed an explosion of contributions coming out of the Tevatron. We counted about 50 papers. The most dramatic result was the clarification of a long-standing puzzle: the beta decay of the sigma hyperon. Some four previous experiments, collecting a grand total of about 400 examples of this decay, produced a unanimous result that was in disagreement with standard theory. A Fermilab-Yale-Iowa State-Leningrad-Elmhurst collaboration, capitalizing on the power of the Tevatron, collected some 80,000 sigma beta decay events and a new result which settled the issue in favor of the theory.

This is the opening curtain in the long vision we have had of providing facilities for high-energy physics which would be seminal to the evolution of the field. The Tevatron provides the combination of the essential data of fixed-target research and the bold thrust into the highest energy domain. If the beautiful results of this experiment on sigma-beta decay are indicative of the coming scientific payoff of the Tevatron II Project, we can look forward to a long, satisfying, and significant impact on the high-energy physics community.

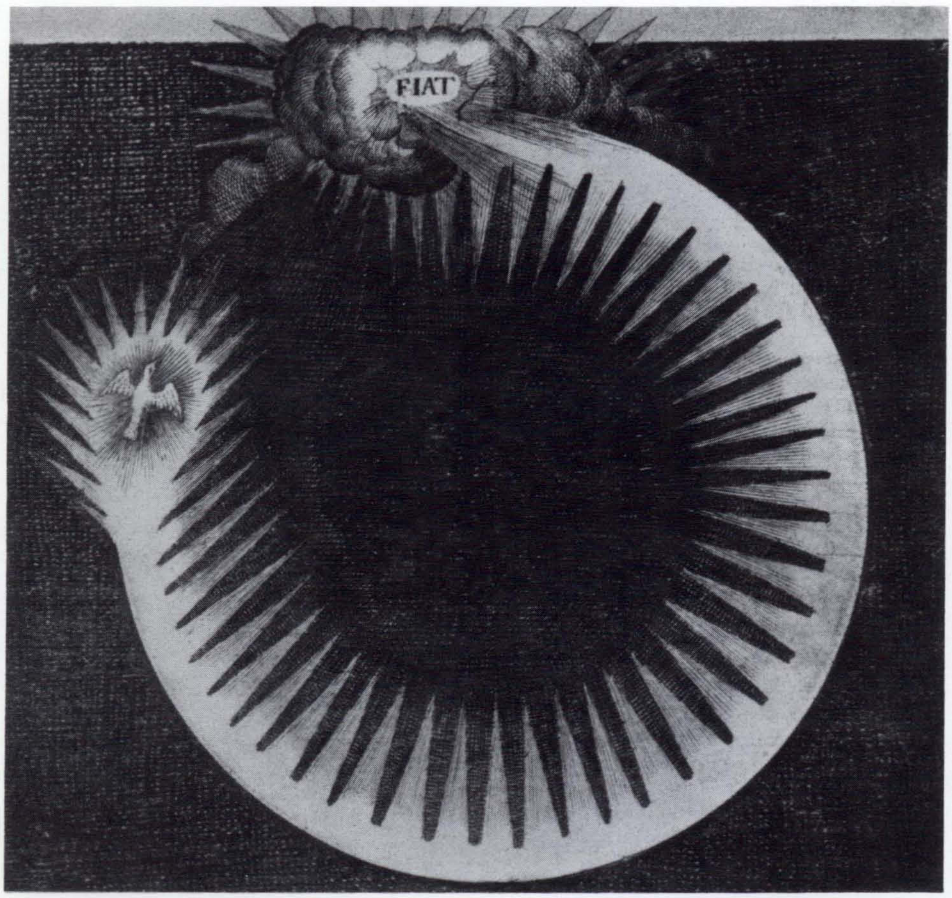
The Rest of the Laboratory

Other articles in this volume address the Saver, the fixed-target physics program, some magnet production nostalgia, the Advanced Computer Project, and photo essays on TeV I and the Collider Detector at Fermilab. We should mention that 1984 saw the final DOE approval of the D0 collider detector — now a mature design with emphasis on complementary attributes to CDF. In combination, the two detectors will make a powerful attack on the *terra incognita* of 2-TeV collisions. The trouble is the pace with which funding will become available for D0. In 1985 we will try hard to convince everyone who will listen that D0 must go faster and be complete as soon as possible. We must not lose the thrust of 2-TeV physics.

In this issue, what of the unsung heroes in the support sectors of the Laboratory — of those that pay the payroll and buy the things and write the contracts and serve the food and maintain the Lab and plow the roads and groom the buffaloes and fill the auditorium and machine the parts and produce the drawings and invent the gadgets and guard the ramparts...of all of thee we sing!

Philosophical Finale I

At a History of Science Society meeting in November we were stimulated to review the sociology of high-energy physics. Sources indicate that in the 1950s one could do two or so experiments a year, each one involving two or four collaborators. In a more-or-less gradual development, one now does an experiment every three years with 20 or 40 collaborators in the fixed-target program and one enjoys 100-200 dear colleagues in the collider teams. The colliders take three to six years to build but of course physics pours out. It may be difficult to explain this to your humanities colleague or your father-in-law, but the large group isn't necessarily a catastrophe. Participants combine to build a complex detector, each university subteam of five or fifteen fully challenged to deliver a complex component. When physics comes, the subteams that have developed particular pieces have use of all the components of a coherent detector. We have not yet learned to apportion special credit to these subteams in recognition of how the various pieces of physics are really done, but this will come. When we face SSC detectors with, perhaps 300-500 member teams, the mind boggles, the hands sweat, the pulse quickens. We must be very creative in treating the sociology here. CDF and D0 will be U.S. pilot programs. The central issue is whether the universities, the intellectual owners of this Laboratory, can continue to use and manage this research with profit and pleasure.



Philosophical Finale II

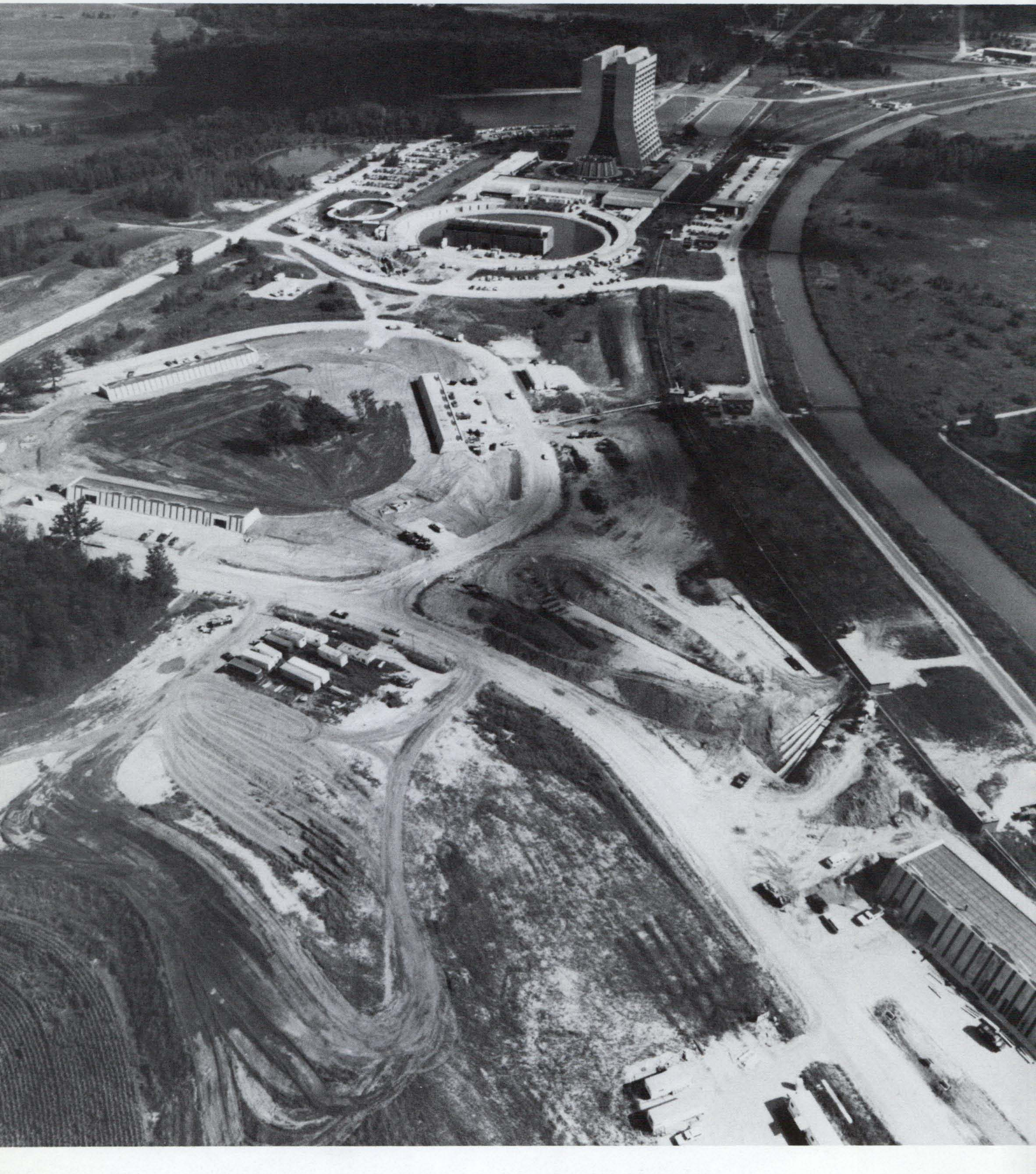
Avid readers of the science fiction of the '30s may be impatient with the failure of the '80s to match the predicted technology, lifestyle, and romanticism, but we can hardly fault the progress of physics. At Fermilab, overworked, obsessed with getting through the day and week not to mention the fiscal year, we tend to neglect the culture of physics, the progress made by our former colleagues, fellow graduate students in such dynamic fields as quantum optics, condensed matter, and polymer physics. We tend to overlook the interdependence of our discipline, yet some of our theorists first learned about symmetry-breaking from condensed matter theory, and our superconducting alloys were developed in materials science labs. We should be pleased that the first priorities among colleagues in nuclear science and in materials science is for powerful accelerators to provide electrons for nuclear probes and for blinding synchrotron light. We are witnessing changes in the boundaries of our subject as relativistic heavy ion collisions merge from one side, and on the other side we have a de facto joining of particle physics and cosmology.

Why this sudden glow of physics culture? Quite frankly, it comes from the vision of the high-energy community (some critics would call it an apparition) which is the superaccelerator, SSC. When this is discussed outside, with good scientists in other disciplines, there results a lively exchange which often leads to a new appreciation of the interdependence of our diverse fascinations.

The decision makers will be facing proposals for a variety of expensive, centrally shared facilities in the next five years, and some very deep thinking will have to go into setting priorities. This is because it is highly unlikely that there is enough statesmanship around to recognize that a doubling of the very basic research budget (say from \$3 billion to \$6 billion) would very likely produce fantastic social and economic dividends over the next three decades. We hasten to add that basic research, and our own subject, have fared relatively well in recent years. We do have a Tevatron and we will use it as well as we can! We will do this in spite of the admonition not of the DOE, not of our graduate students but of that seventeenth century poet and anguished spirit, John Donne:

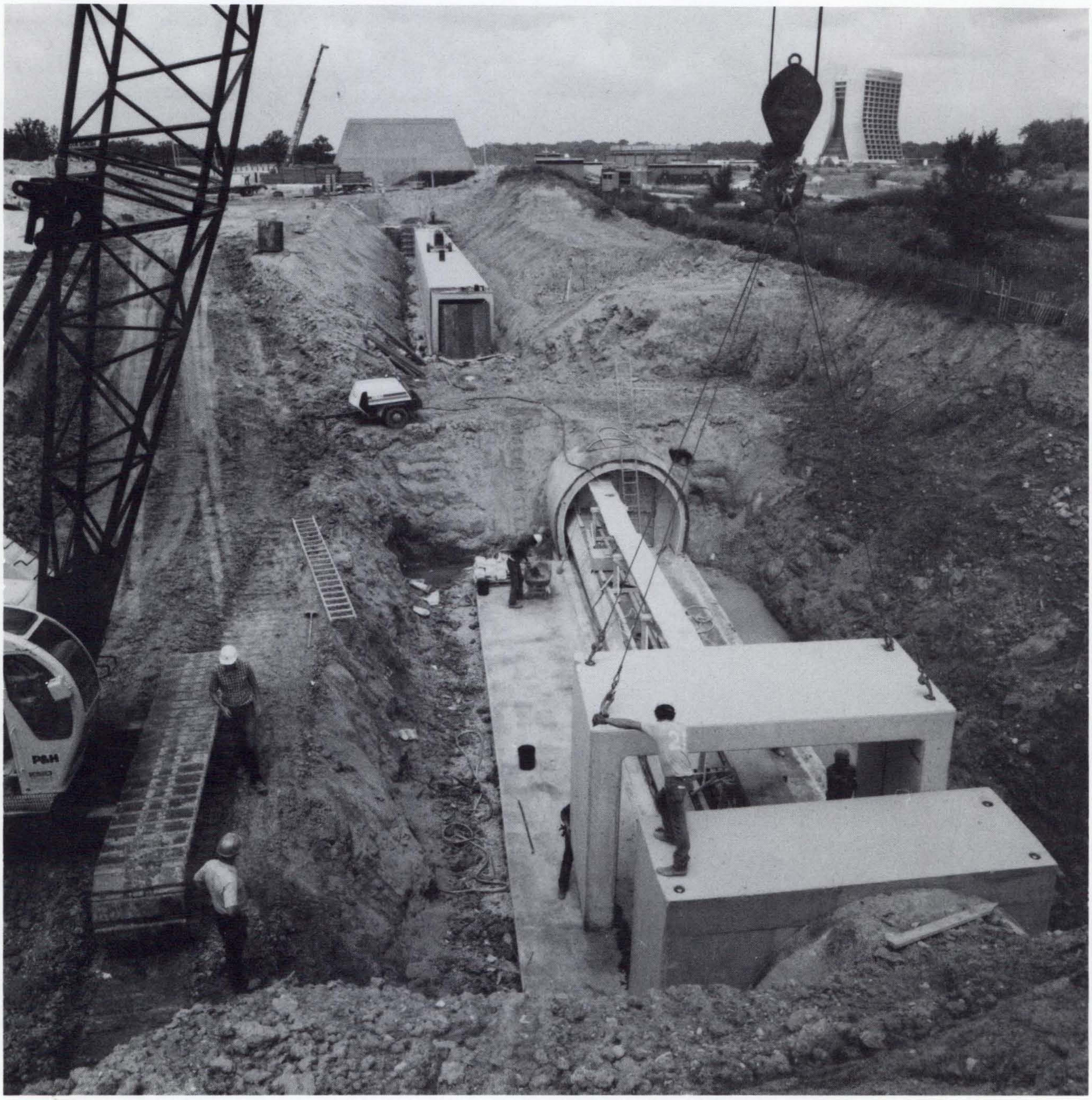
> We gape, we grasp, we gripe, add store to store;
> Enough requires too much; too much craves more. . .
> Thus we, poor little worlds! with blood and sweat,
> In vain attempts to comprehend the great.

Leon M. Lederman

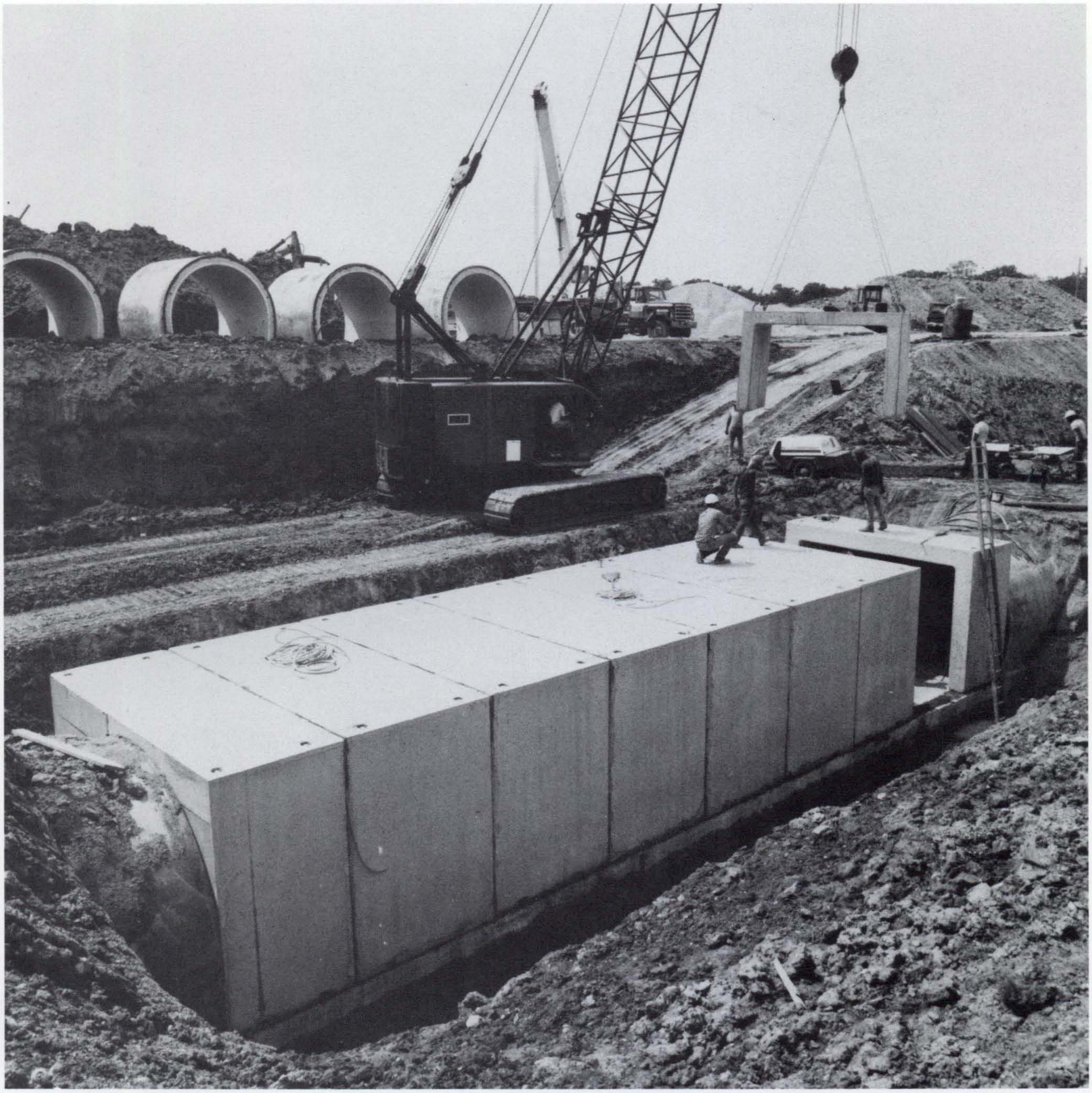


II. Construction of the TeV I Antiproton Source

The Antiproton Source from the air, looking north toward Wilson Hall. The Target Service Building is at the lower right next to the Main Ring. The three service buildings clearly show the triangular shape of the Antiproton Source rings.



Installation of new precast hoops in the Main Ring at F17. The new Pretarget Enclosure is visible in the background.

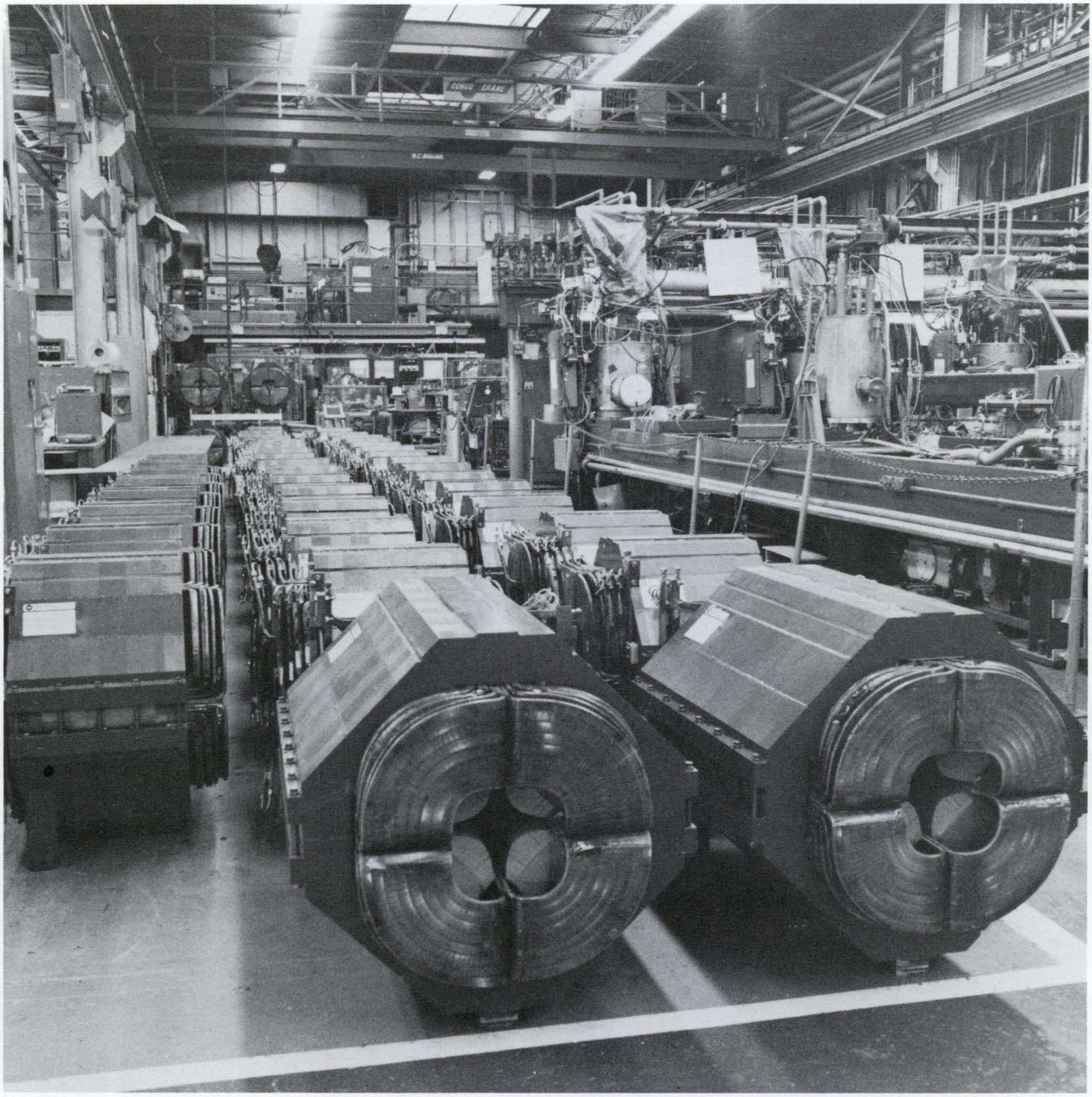


New, larger Main-Ring tunnel sections being lowered into place at location F17. These sections are designed to allow beam extraction for antiproton production.

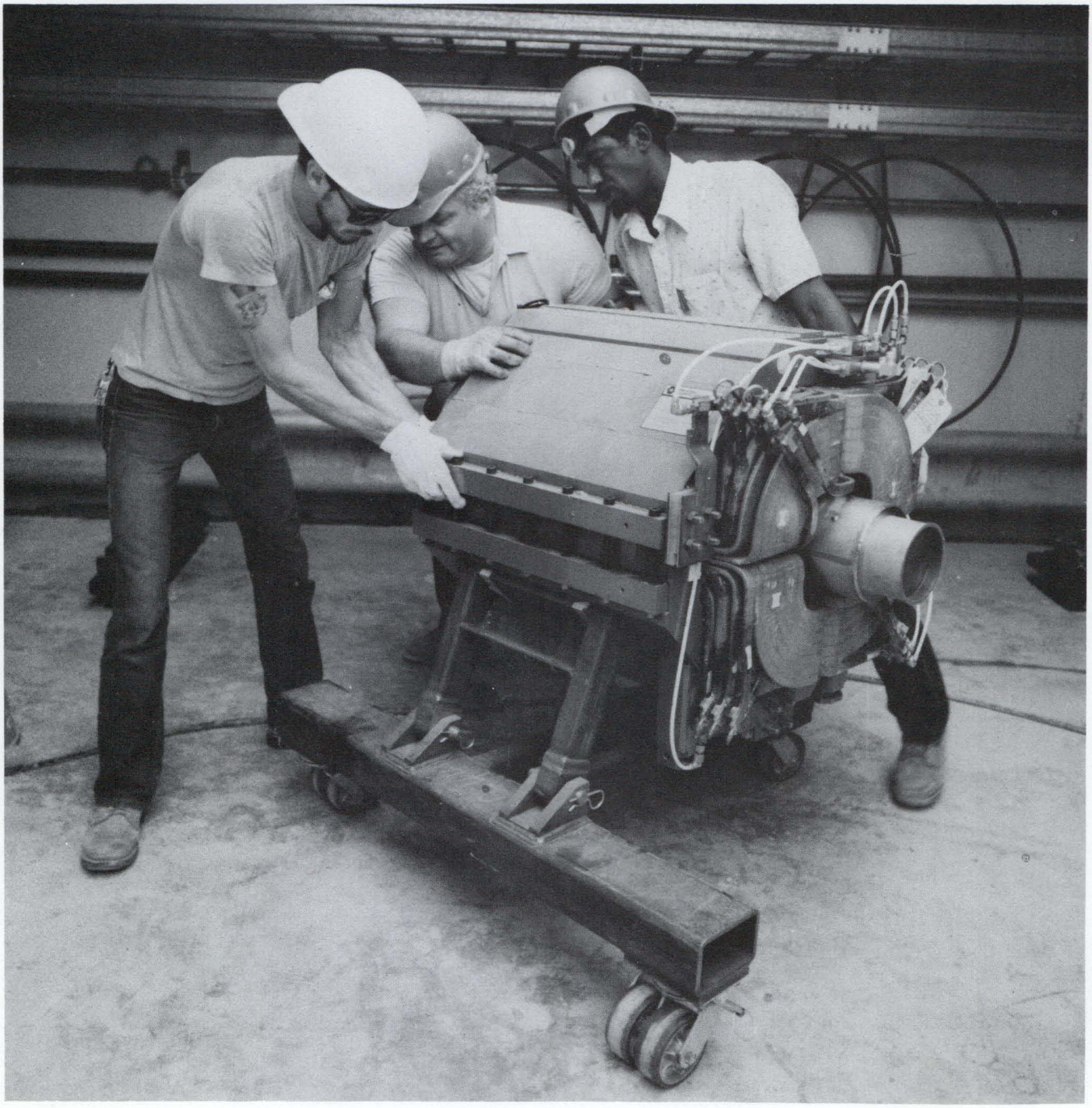
The Antiproton Source tunnel, prior to installation activities.

Debuncher quadrupoles installed in the tunnel.

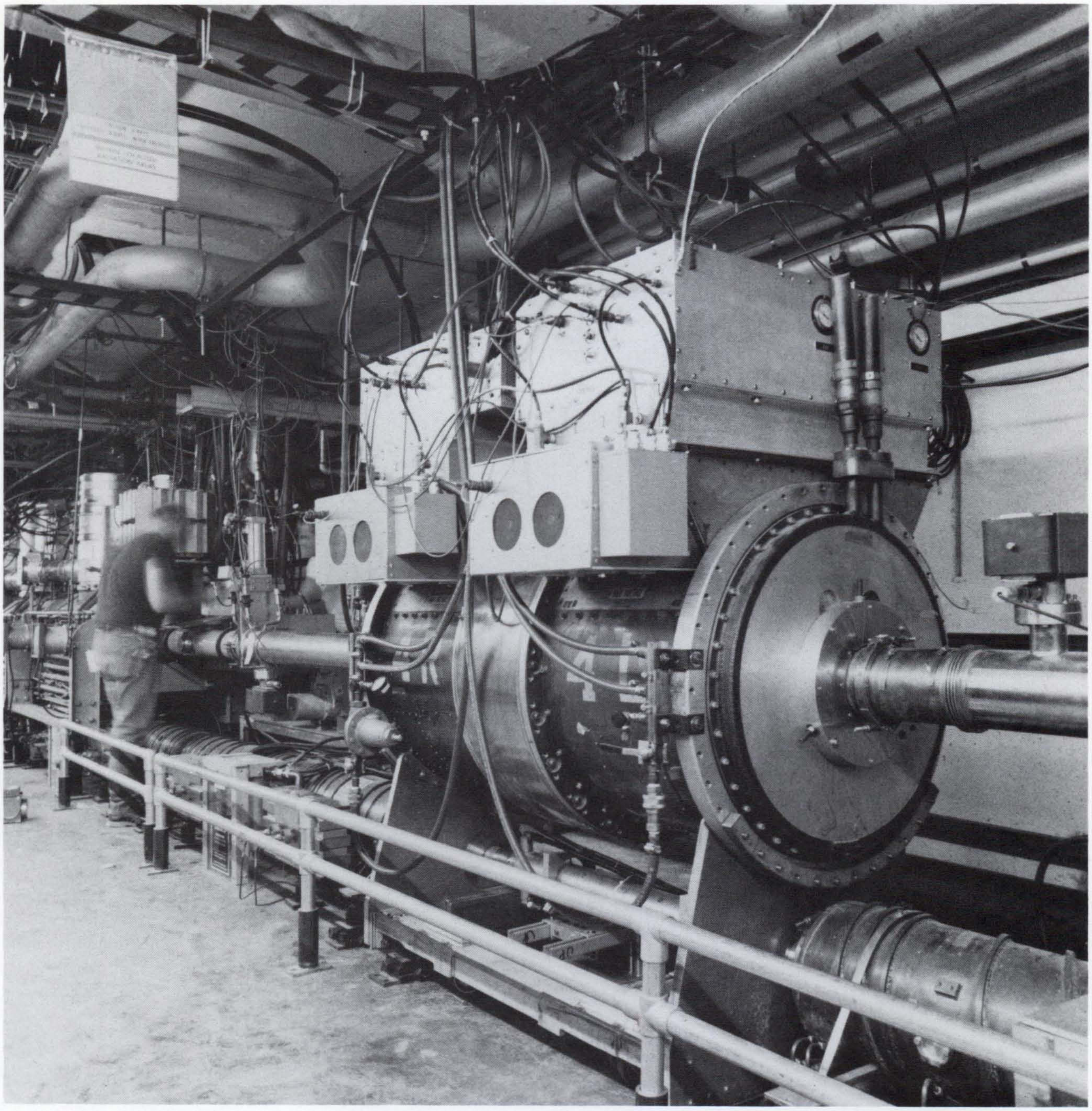
Assembling a large dipole.



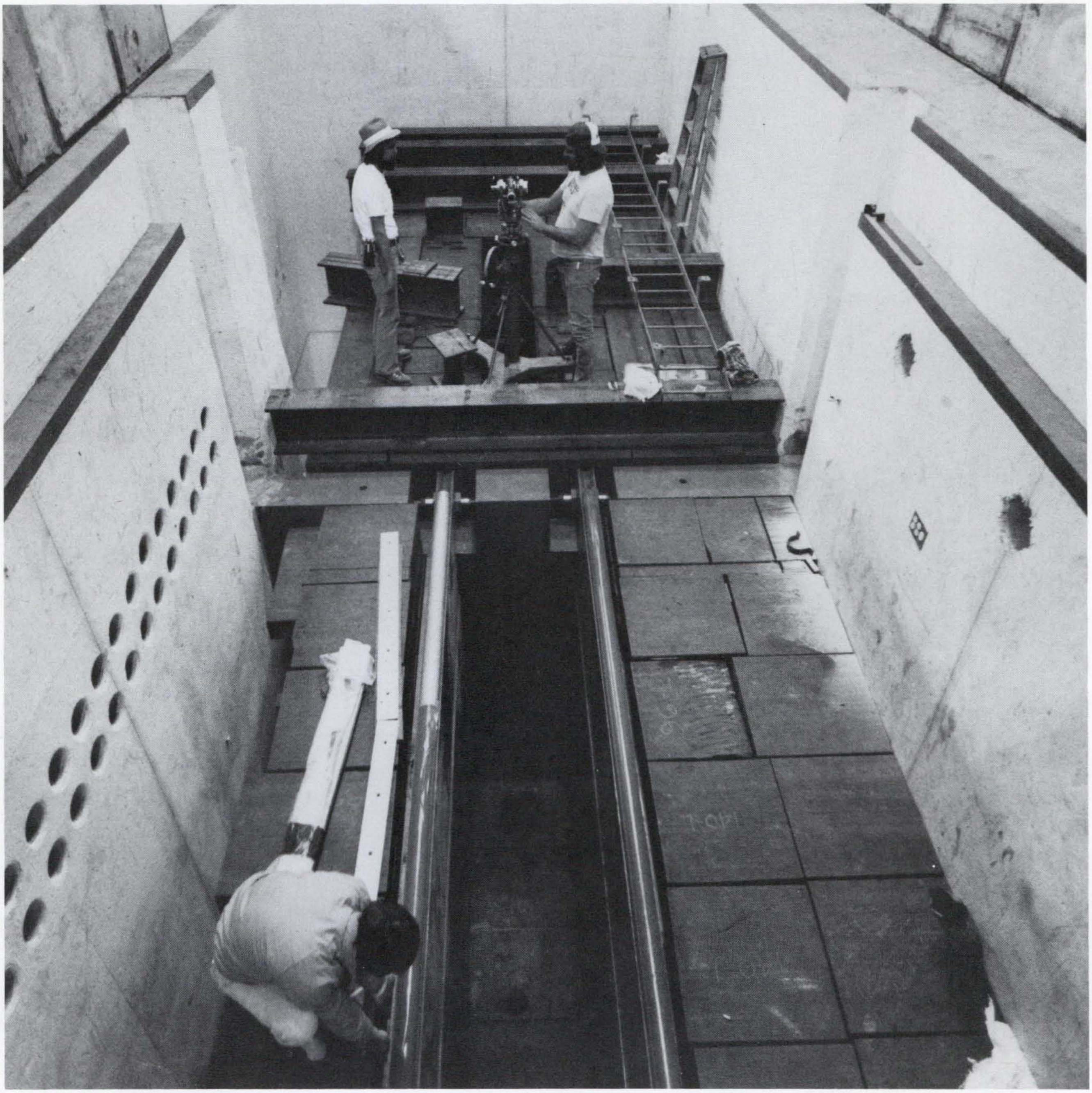
Completed quadrupoles in the Magnet Facility.



A quadrupole being installed in the tunnel.

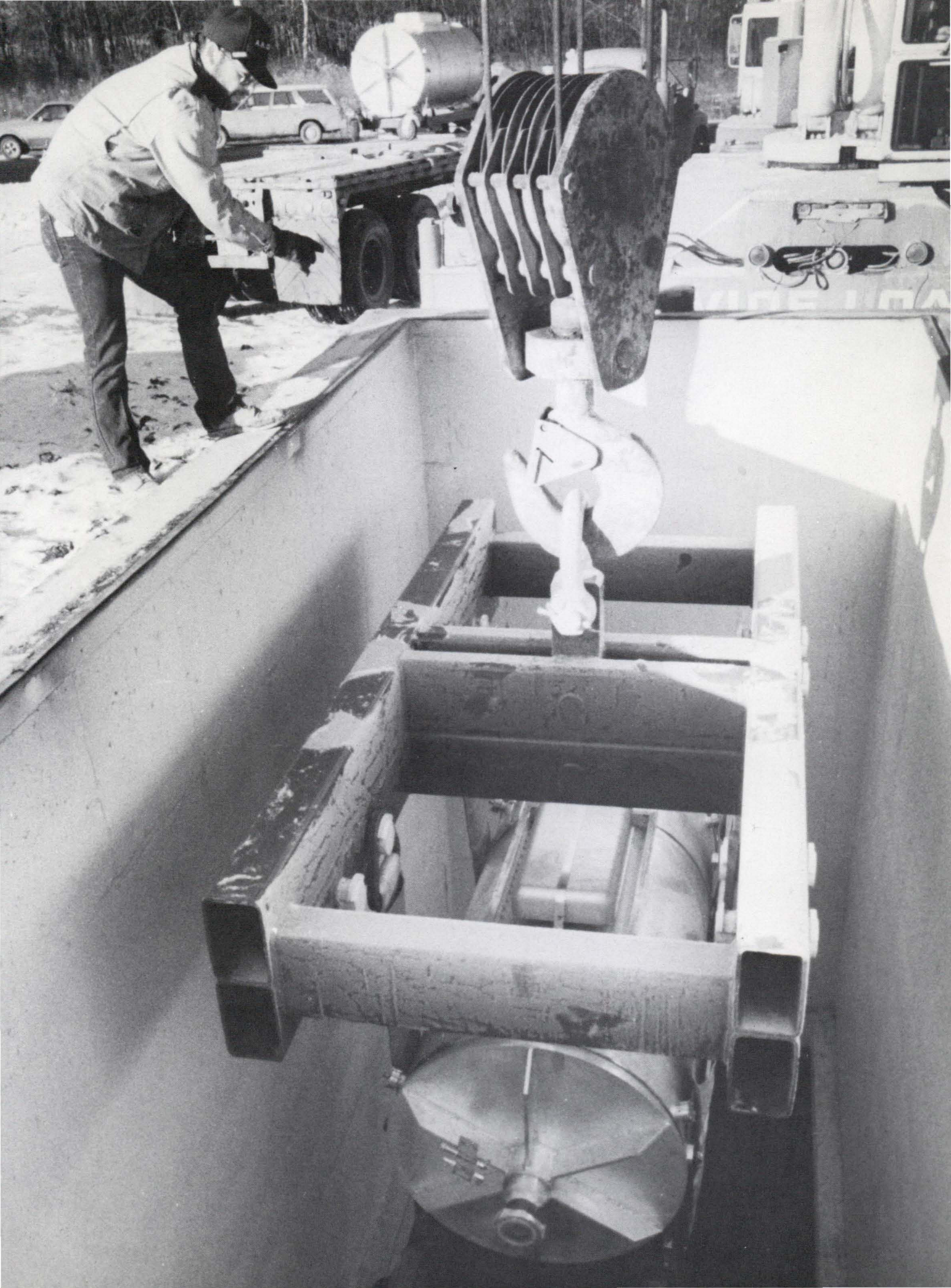


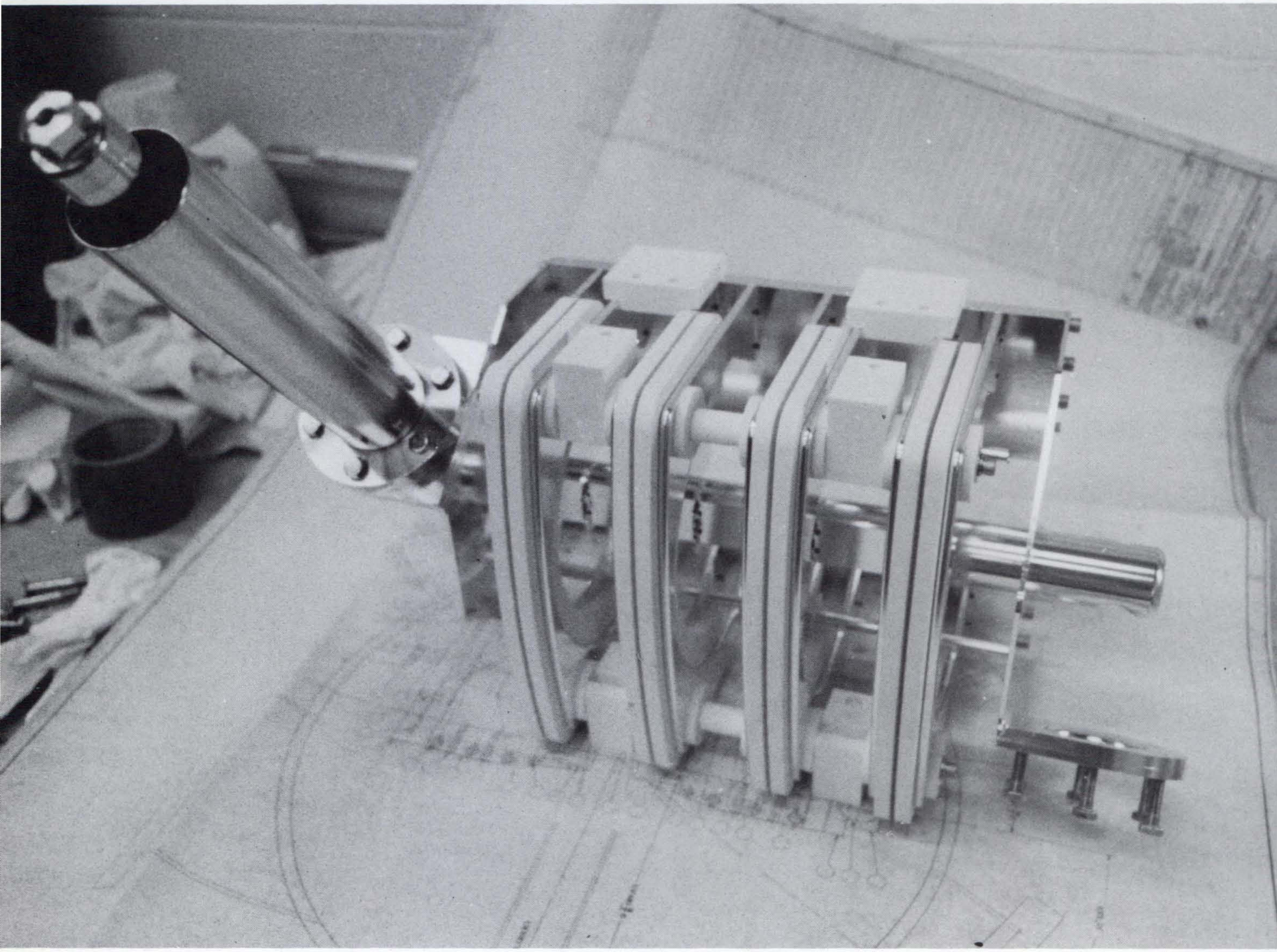
A Princeton-Pennsylvania Accelerator coalescing cavity installed in the Main Ring.



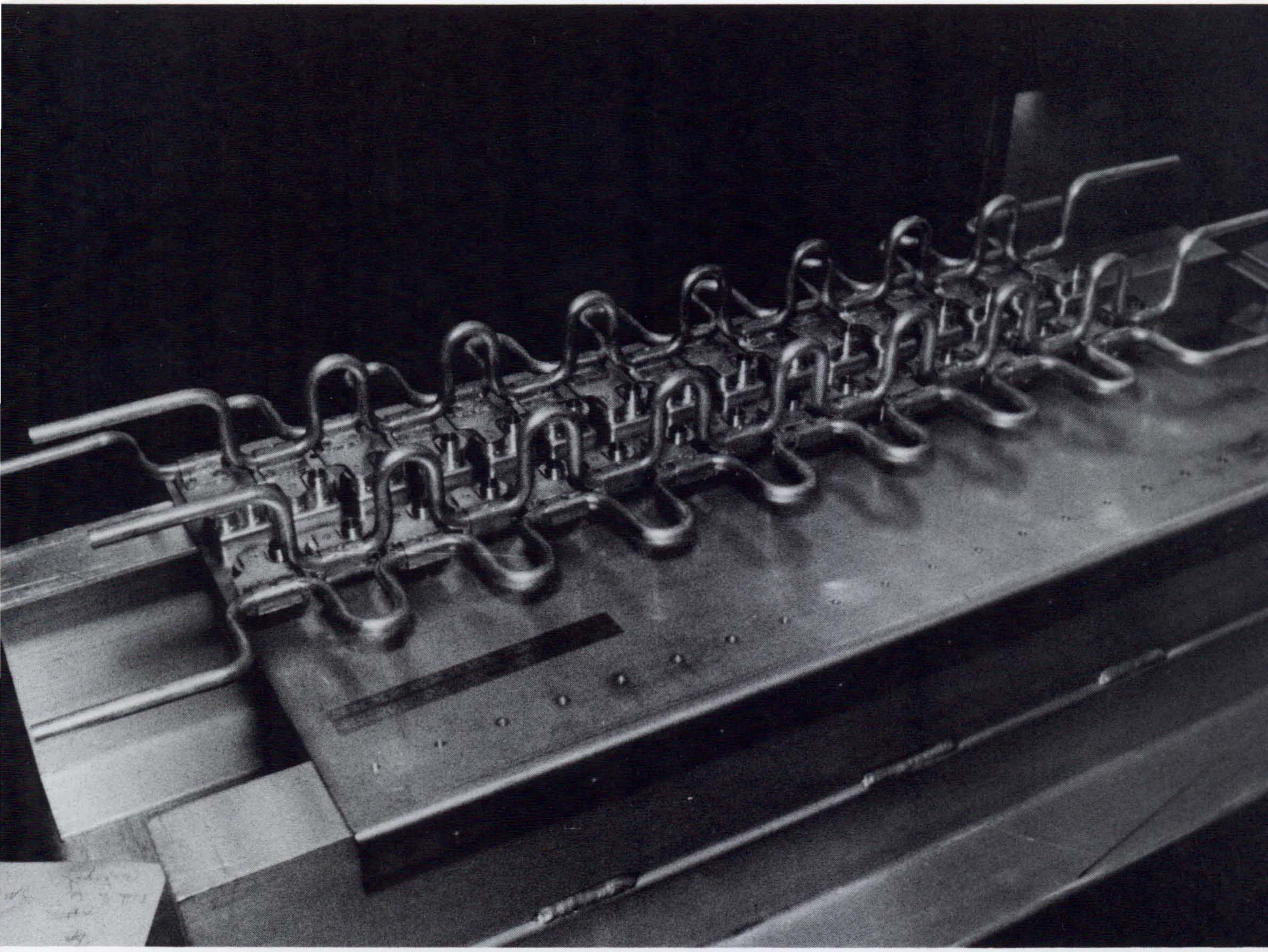
Building the shielding around the antiproton-production target.

A 53-MHz rf cavity being lowered into the tunnel. →

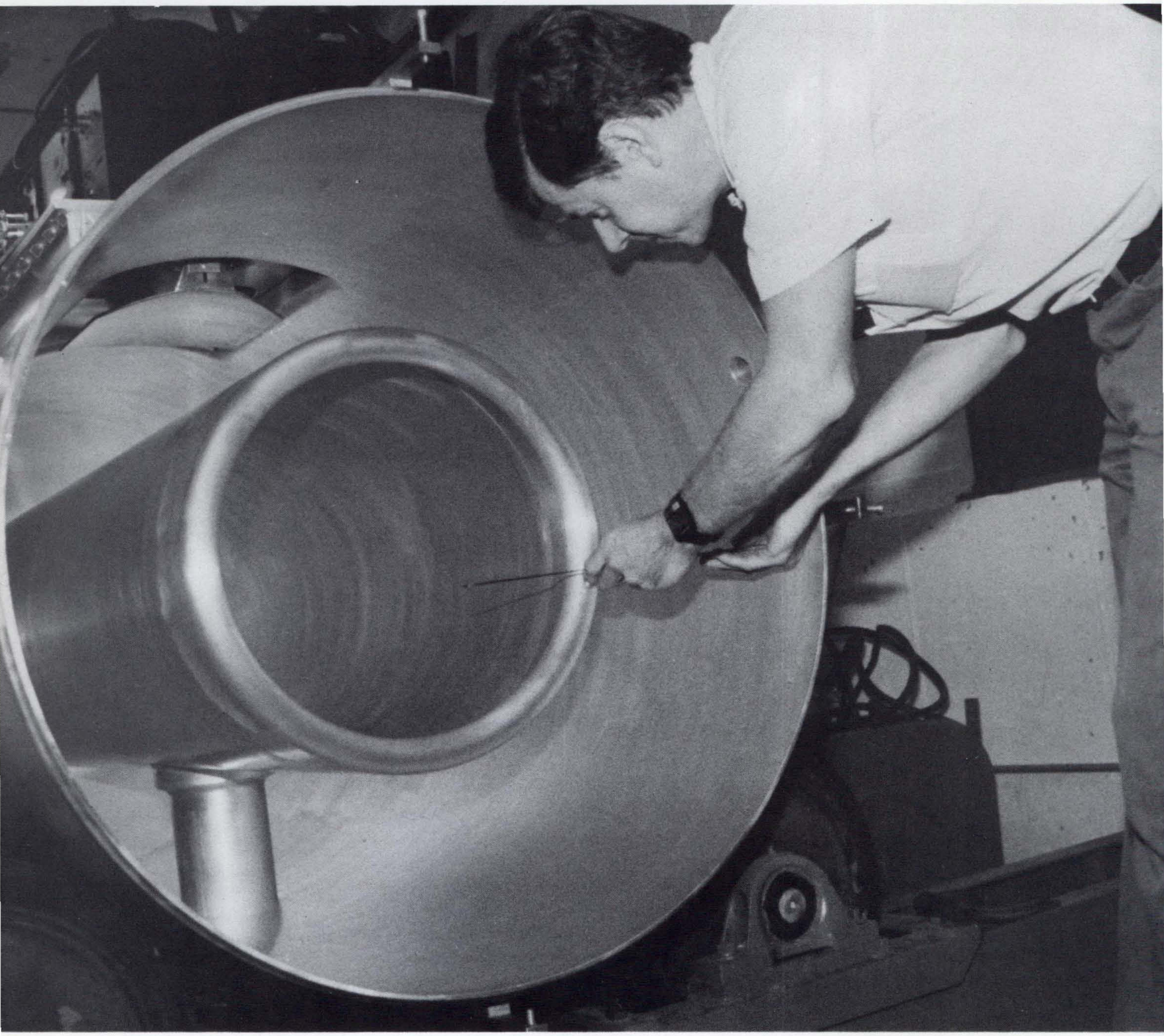




The beam shutter for the Accumulator.

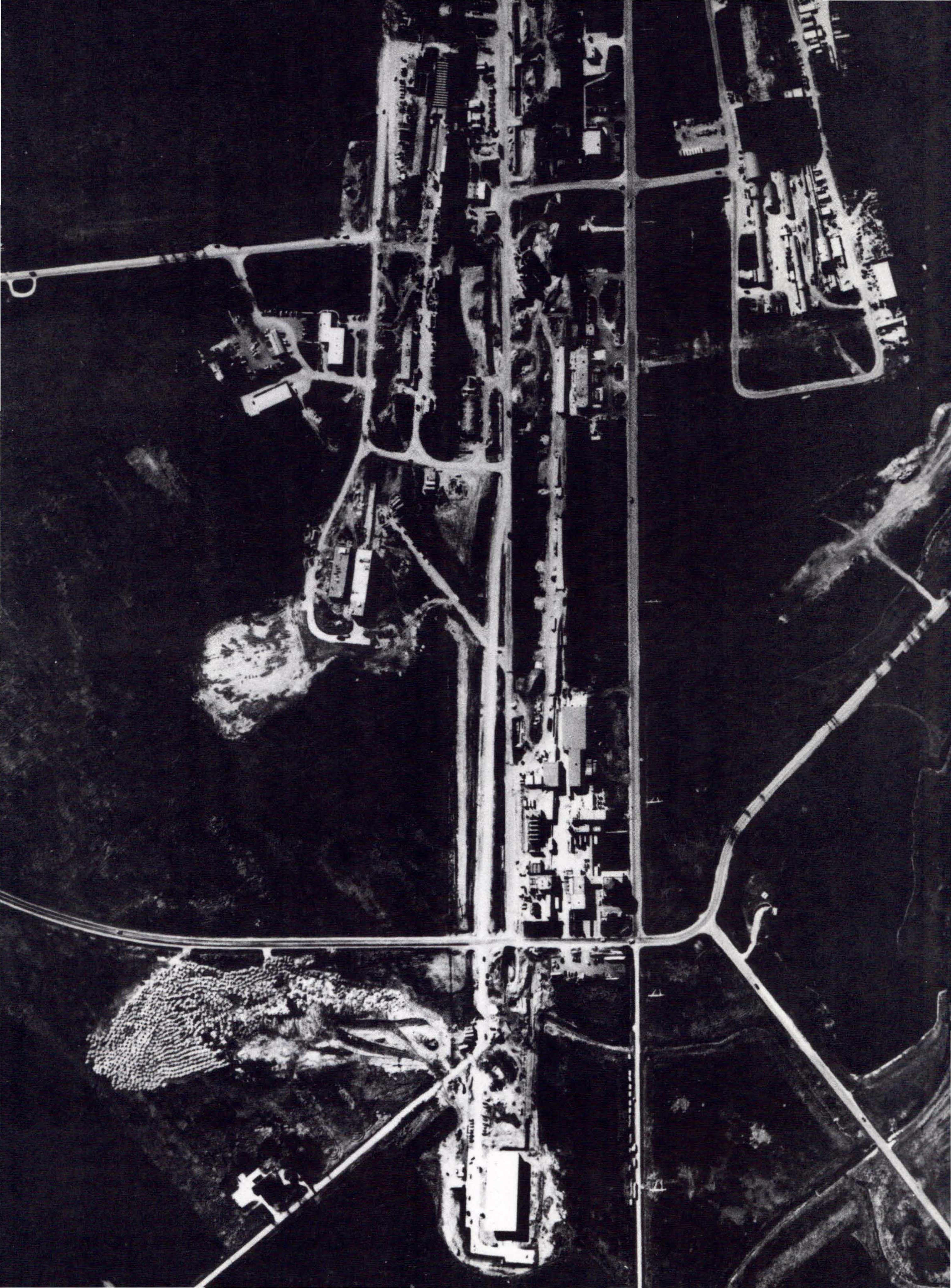


A stochastic-cooling pickup.



Joel Misek checking dimensions on an rf cavity in the manufacturer's shop.

Lee Brown installing the first conductors in a lithium lens.



III. Fixed-Target Physics at 800 GeV

With commissioning of the Tevatron, Fermilab possesses the highest energy particle beams in the world. The challenge now is their full utilization. In anticipation of this challenge, a large number of new facilities, under the rubric TeV II, have been constructed, with more on the way. Completion of the construction program is expected within a year. There exist several new beam lines and their ancillary enclosures, as well as new experimental halls, such as the splendid new Muon Lab.

Already some of the higher-energy beams have been used, and new physics results are beginning to emerge. In this report, we review recent accomplishments in this "fixed-target" program and describe experiments in progress and others yet to come.

Physics Goals

The research of the past two decades has led to the remarkably successful picture of fundamental forces (strong, electroweak) and constituents (up, down, charm, strange, bottom, top quarks) comprising the standard model. An apparently solid framework now exists for going further and attacking the great unanswered questions remaining before us, such as the origin of elementary particle masses. Most of the TeV II program concerns this standard-model framework — how strong and solid is it? We need not just the existing skeleton, but also all the vital elements that turn it into a complete structure. The basic parameters of electroweak theory need to be precisely found. The theory of strong interactions, quantum chromodynamics, is far from developed and its implications on how hadrons are built up from constituent quarks not well enough worked out. The heavier charm and bottom quarks are especially valuable here, and the Fermilab beams produce an enormous number of them. CP violation, which goes to the heart of the deep, unanswered questions, is being studied in TeV II beams, as well as pursuits of other phenomena which seem to lie beyond the standard model.

New Capabilities

It is important to realize that the energy improvement of the Tevatron means much more than just a factor of two in laboratory energy, or a 40% increase in center-of-mass energy. This occurs for several reasons:

1. First of all, in going from 400 GeV to 800 GeV laboratory energy, one is crossing the threshold for production of systems containing bottom quarks. At the higher energy, the cross sections are expected to be between a factor of 5-10 greater than at the previous energies.
2. There is a major improvement in flux in the secondary hadron beams. This comes about because the higher energy superconducting transport lines accept a much larger bite in transverse momentum than was the case at lower energy.
3. There is a large improvement in duty factor, which used to be 1 second out of every 10 or 15 seconds. In present running it is about 20 seconds per minute.
4. The extra two-thirds of a unit of rapidity which is available in produced phase space at the higher energies allows better separation of the various fragmentation regions for ordinary processes. In particular, there is emergence of the "central plateau" separating the target and projectile fragmentation regions. This is important for studies which attempt to sort out production mechanisms and especially relevant for A-dependence studies.
5. The larger Lorentz factor for particles with short lifetimes, e.g., charm, can be useful in helping to sort them out from the collision debris.
6. While one might expect a lower flux for neutrino experiments because of the longer cycle time at the Tevatron, this is essentially compensated by the rise in the total cross section and the improvement in acceptance due to the smaller angular divergence of the neutrino beam.

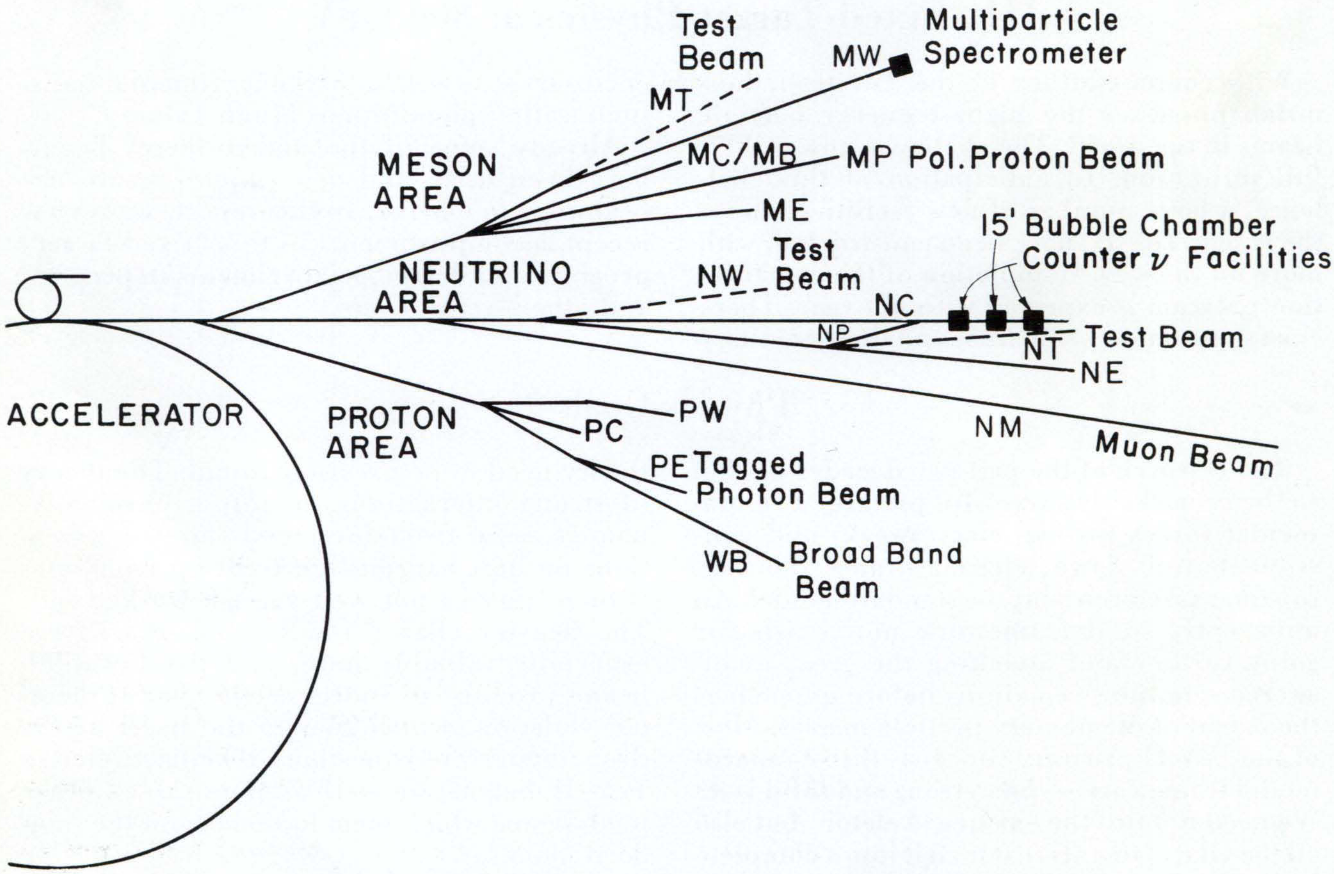


Figure 1. Fermilab secondary beams and the locale of experiments.

Thus, for all of these reasons one may expect a qualitatively different situation at the Tevatron than has existed in previous machines, either the SPS or the Fermilab Main Ring.

The existing fixed-target program is a very broad one, comprising about two dozen approved experiments. About a dozen of these will be on-line in the coming year. While these experiments cover a diverse set of topics, they can be roughly categorized into the following groups: heavy quarks, lepton-induced processes, hard collisions, and tests of QCD. There are, in addition, studies of weak decays and magnetic moments, and strong-interaction studies using polarized beams of p and $\bar{p}$. Table I exhibits the experimental program. The experiments in progress are classified into these categories. Figure 1 shows their location in the fixed-target area.

In the following sections, we will look at experiments by category, irrespective of their status in time; thus, we look both at recent results and future programs.

Table I

Glossary of Approved Experiments in the Fermilab Fixed-Target Program

Electroweak

E-632 WIDE BAND NEUTRINOS IN THE 15 FT BUBBLE CHAMBER (Berkeley, Birmingham, Brussels, CEN/Saclay, CERN, Fermilab, Hawaii, IIT, Imperial College, MPI/Munich, Oxford, Rutgers, Rutherford-Appleton, Stevens, Tufts)

E-635 SEARCH FOR AXION-LIKE OBJECTS (Fermilab, VPI)

E-636 STUDY OF BEAM DUMP PRODUCED NEUTRINOS (Beijing, Brown, Fermilab, Haifa, Indiana, MIT, ORNL, Seton Hall, Tel-Aviv, Tennessee, Tohoku, Tohoku Gakuin)

Table I Continued

E-646 STUDY OF PROMPT NEUTRINO PRODUCTION (Berkeley, Columbia, Fermilab, Hawaii, Rutgers)
E-649 NUCLEON STRUCTURE FUNCTIONS AT HIGH Q^2 (Fermilab, MIT, Michigan State)
E-652 NEUTRINO PHYSICS AT THE TEVATRON (Chicago, Columbia, Fermilab, Rochester)
E-665 MUON SCATTERING WITH HADRON DETECTION (Argonne, Cracow, CERN, Fermilab, Freiburg, Harvard, Maryland, MIT, MPI/Munich, San Diego, Washington, Wuppertal, Yale)
E-733 NEUTRINO INTERACTIONS WITH QUAD TRIPLET BEAM (Fermilab, Florida, MIT, Michigan State)
E-744 NEUTRINO PHYSICS WITH QUAD TRIPLET BEAM (Chicago, Columbia, Fermilab, Rochester)
E-745 NEUTRINO PHYSICS WITH QUAD TRIPLET BEAM (Beijing, Brown, Fermilab, Haifa, Indiana, MIT, Nagoya, ORNL, Tel-Aviv, Tennessee, Tohoku, Tohoku Gakuin)

Decays and CP

E-621 MEASUREMENT OF n_{+-0} (Michigan, Minnesota, Rutgers, Wisconsin)
E-721 CP VIOLATION (Arizona, Athens, Duke, McGill, Northwestern, Shandong)
E-731 MEASUREMENT OF ϵ'/ϵ (CEN/Saclay, Chicago, Elmhurst, Fermilab, Princeton)

Heavy Quarks

E/653 HADRONIC PRODUCTION OF CHARM AND B (Aichi, Carnegie-Mellon, Chonnam, UC/Davis, Gifu, Gyeongsang, Jeonbug, Kobe, Korea, Nagoya, Ohio State, Okayama, Oklahoma, Osaka City, Osaka Sci. Ed. Inst., Sookmyong Womans, Toho, Won Kwang)
E-687 PHOTOPRODUCTION OF CHARM AND B (Colorado, Fermilab, Illinois, INFN/Frascati, INFN/Milano, U. Milano, Northwestern, Notre Dame)
E-690 STUDY OF CHARM AND B PRODUCTION (Columbia, Fermilab, Massachusetts, Mexico)
E-691 PHOTON PHYSICS WITH TAGGED PHOTON SPECTROMETER (UC/Santa Barbara, Carleton, CBPF/Brazil, Colorado, Fermilab, NRC/Canada, Oklahoma, Sao Paulo, Toronto)
E-705 CHARMONIUM AND DIRECT PHOTON PRODUCTION (Arizona, Athens, Duke, Fermilab, McGill, Northwestern, Shandong)
E-743 CHARM PRODUCTION IN PP COLLISIONS (Aachen, Brussels, CERN, Duke, Fermilab, Florida State, Coll. of France, Kansas, LPNHE/France, Michigan, Michigan State, Mons, Notre Dame, Strasbourg, Vanderbilt)

Hard Collisions

E-605 LEPTONS AND HADRONS NEAR THE KINEMATIC LIMIT (CERN, Columbia, Fermilab, KEK, Kyoto, Saclay, SUNY/Stony Brook, Washington)
E-672 HIGH P_T JETS AND HIGH MASS DIMUONS (Arizona, Caltech, Chicago Circle, Fermilab, Florida State, George Mason, Indiana, Maryland, Rutgers, Serpukhov)
E-683 PHOTOPRODUCTION OF HIGH P_T JETS (Arizona, Fermilab, Lehigh, Rice, Vanderbilt, Wisconsin)
E-704 EXPERIMENTS WITH POLARIZED BEAM FACILITY (Argonne, Austin, UC/Berkeley, Fermilab, KEK, Kyoto, LAPP/France, LBL, Northwestern, Rice, Saclay, Serpukhov, Trieste)
E-706 DIRECT PHOTON PRODUCTION (Delhi, Fermilab, Michigan State, Minnesota, Northeastern, Pennsylvania, Pittsburgh, Rochester, Rajasthan)
E-711 CONSTITUENT SCATTERING (UC/Davis, Fermilab, Florida State, Michigan)

Others

E-466 NUCLEAR FRAGMENTS (Argonne, Chicago, Chicago Circle, Purdue)
E-508 EMULSION/MULTIPARTICLE PRODUCTION (Cracow, Louisiana State, Tashkent)
E-524 EMULSION/PROTONS GREATER THAN 500 GEV (Washington)

Table I Continued

E-576	EMULSION/500 GEV PROTONS (Belgrade, Fermilab, Lund, Lyon, Nancy, Ottawa, Paris VI, Santander, Strasbourg, Valencia)
E-750	EMULSION/MULTIPARTICLE PRODUCTION (Delhi)
E-751	EMULSION/1 TEV PROTONS (SUNY/Buffalo)
E-753	CHANNELING STUDIES (Bell Northern Research, Chalk River, Fermilab, New Mexico, SUNY/Albany)
E-754	CHANNELING TESTS (Case Western Reserve, Fermilab, GE R&D Center, Sandia, SUNY/Albany)

Weak Decays and Magnetic Moments

Perhaps the most important recent result from Fermilab is the measurement (E-617) of ϵ'/ϵ shown in Fig. 2. The result is consistent with zero and begins to put constraints on the standard Kobayashi/Maskawa-plus-penguin picture of CP violation. The theoretical uncertainties are large and one cannot claim disagreement with theory at this time. Perhaps the main result of this measurement is to decrease, if not eliminate, the theoretical hubris surrounding the attempts to calculate or minimize uncertainties in the long-distance contributions to the $K\bar{K}$-mixing phenomenon. Also shown in Fig. 2 is the recent Yale/Brookhaven measurement, which also shows consistency with zero. The E-617 group is now rebuilding their apparatus and will soon embark on new measurements (E-731) using the same technique. The anticipated improvements in the control of both systematic and statistical errors should considerably reduce the uncertainty in the result.

A highlight of the Fermilab program for many years has been the systematic measurement of the polarization of leading hyperons together with measurements of their magnetic moments. This program is nearly complete at this time, as shown in Table II. There is, let us say, agreement to within 10-15% with the quark-model predictions. The accuracy of the

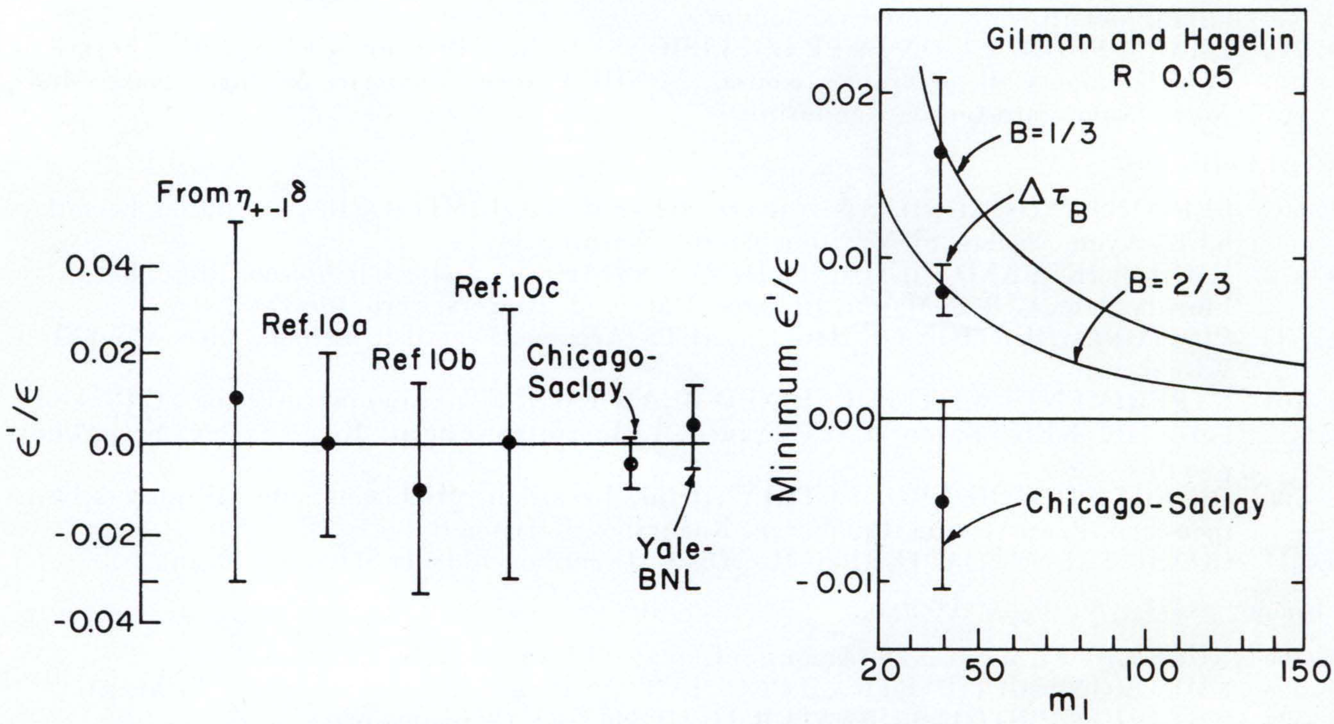


Figure 2. Comparison of measurements of the CP violation parameter ϵ'/ϵ and theory.

measurements has reached a point where the comparisions are dominated by theoretical systematic errors rather than experimental ones. It remains to be seen how much these can be beaten down by theorists in the future.

There has been a nagging discrepancy with the standard model in old measurements of the electron asymmetry in the β-decay of polarized Σ^- hyperons. A new Fermilab experiment (E-715) has very beautifully remeasured this quantity, and the results have been reported. They are shown in Fig. 3. Whereas the old measurements disagreed with Cabibbo theory in magnitude and sign, the new measurement is decisively in accordance with the predictions. Had this not occurred, there would have been mass suicide in the theoretical community. It would have been very hard to accommodate the old results within the standard picture.

Another CP measurement is underway at Fermilab. A group from Michigan, Minnesota, Rutgers, and Wisconsin (E-621) is attempting the ambitious, difficult task of measuring CP violation in the three-pion decays of the K_S and K_L; in other words, to measure η^{+0}. This experiment, which uses a double beam technique, has been set up and has taken some test data. Production running will commence in the next running period. The experimentalists hope to reach the 10^{-3} level, where there is expected to be an effect. However, the problems of systematic errors are difficult, and it remains to be seen how close they really will get.

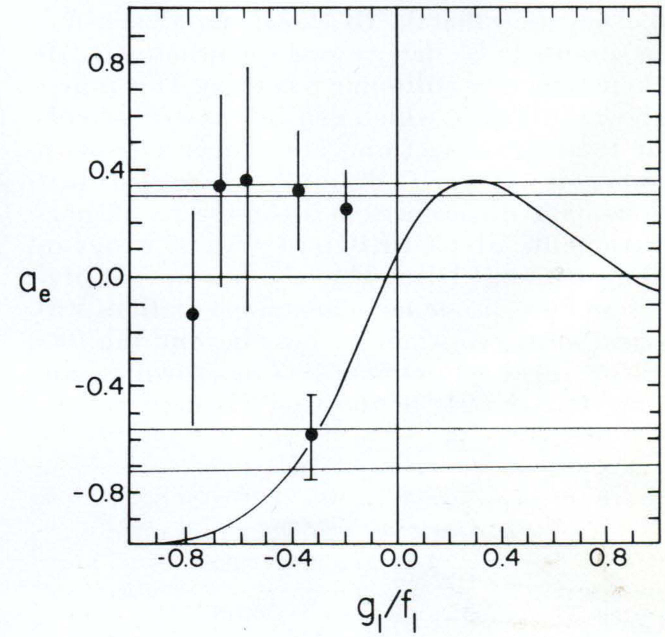


Figure 3. Comparison of measurements of the electron asymmetry in Σ^- β-decay with theory.

Table II

Baryon Magnetic Moments[a]

Baryon	Experimental μ, units $e^+n/2m_pc$	Quark Model Prediction	μ-μ_Q	g/2-1
p	2.7928456 (11)	input	—	1.79
n	−1.91304184 (88)	input	—	—
Λ	− 0.6138 ± 0.0047	input	—	—
Σ^+	2.357 ± 0.012	2.67	− 0.30 ± 0.01	2.00 ± 0.014
$\lvert\Sigma^0\to\Lambda\rvert$	$1.82^{+2.5}_{-.81}$	− 1.63	$-0.19^{+.28}_{-.18}$	—
Σ^-	− 1.151 ± 0.021	− 1.09	− 0.06 ± 0.021	0.47 ± 0.03
Ξ^0	− 1.253 ± 0.014	− 1.43	+ 0.18 ± 0.014	—
Ξ^-	− 0.69 ± 0.04	− 0.49	− 0.20 ± 0.04	− 0.03 ± 0.05

a) Data from Rev. Mod. Phys. 52, S1 (1980), except for $\mu_{\Sigma}{}^{+}$, $\mu_{\Sigma}{}^{-}$, $\mu_{\Xi}{}^{0}$, and $\mu_{\Xi}{}^{-}$.
± (10-15)% agreement with quark model

Electroweak Parameters

Neutrino physics by now has become a rather mature subject, with a demanding level of precision. Recent results (E-616) from the CCFRR group on structure functions are shown in Fig. 4. They show that the QCD scale parameter Λ is beginning to be determined quantitatively, although there is still some way to go. This is best shown in Fig. 5, which exhibits measurements of total cross section. The linear rise with energy is well verified, but there are also clear systematic differences between the set of measurements of CCFRR and their European competition, CDHS. Thus the business of precision measurements in neutrino reactions still has a way to go when pushing beyond the 10% error level of accuracy. The downstream neighbor (E-594) of the CCFRR experiment, one which emphasizes neutral current physics, has also reported new data (Fig. 6). The ratio of x-distributions from neutral currents to those for charged currents are seen to be independent of the scaling-variable x as expected from standard electroweak theory. Some typical events from this fine-grained calorimeter are shown in Fig. 7. Both experiments also measure the ratio of neutral current to charged-currect cross sections. The numbers are shown below, along with the new result from the neutrino-electron scattering experiment at Brookhaven:

$\sin^2\theta_W = 0.242 \pm 0.010 \pm 0.005$ CCFRR
$0.243 \pm 0.014 \pm (\sim 0.014)$ FNMM (preliminary)
$0.209 \pm 0.029 \pm 0.013$ BNL

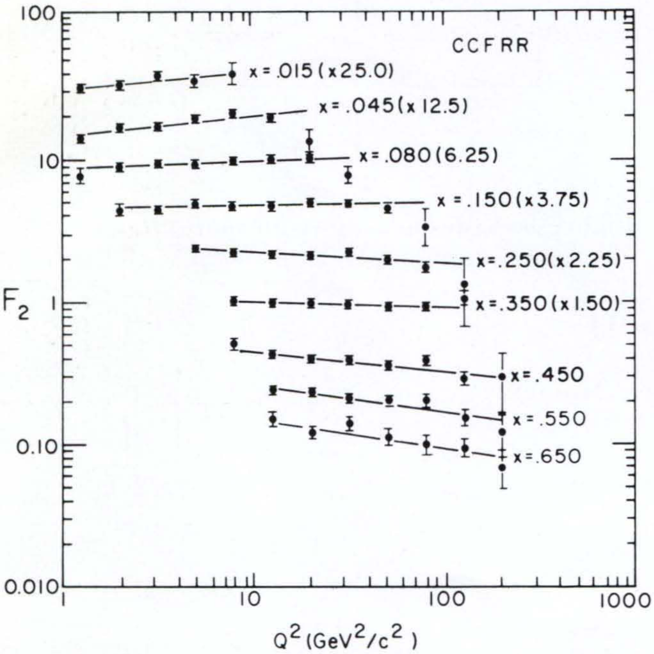


Figure 4. Structure function F_2 as measured by the CCFRR group at Fermilab.

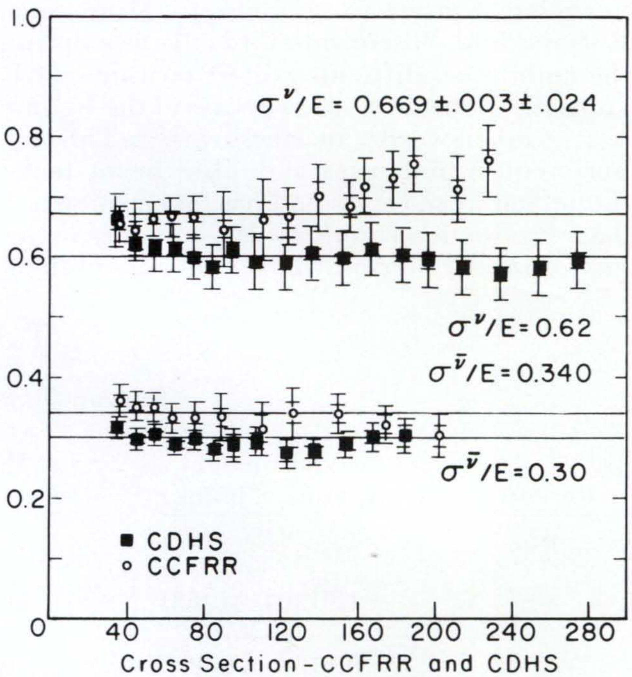


Figure 5. Neutrino total cross sections as measured by CCFRR and CDHS.

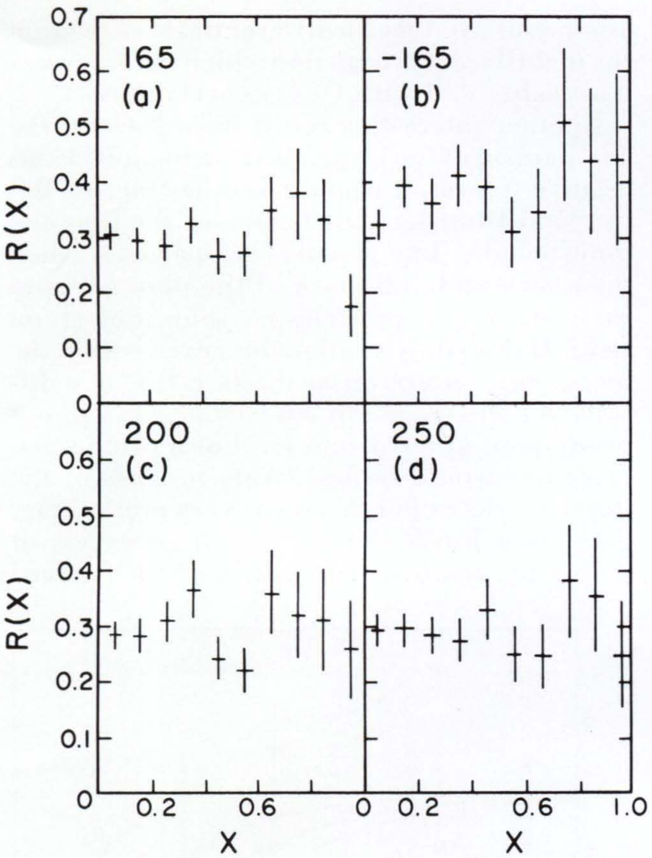
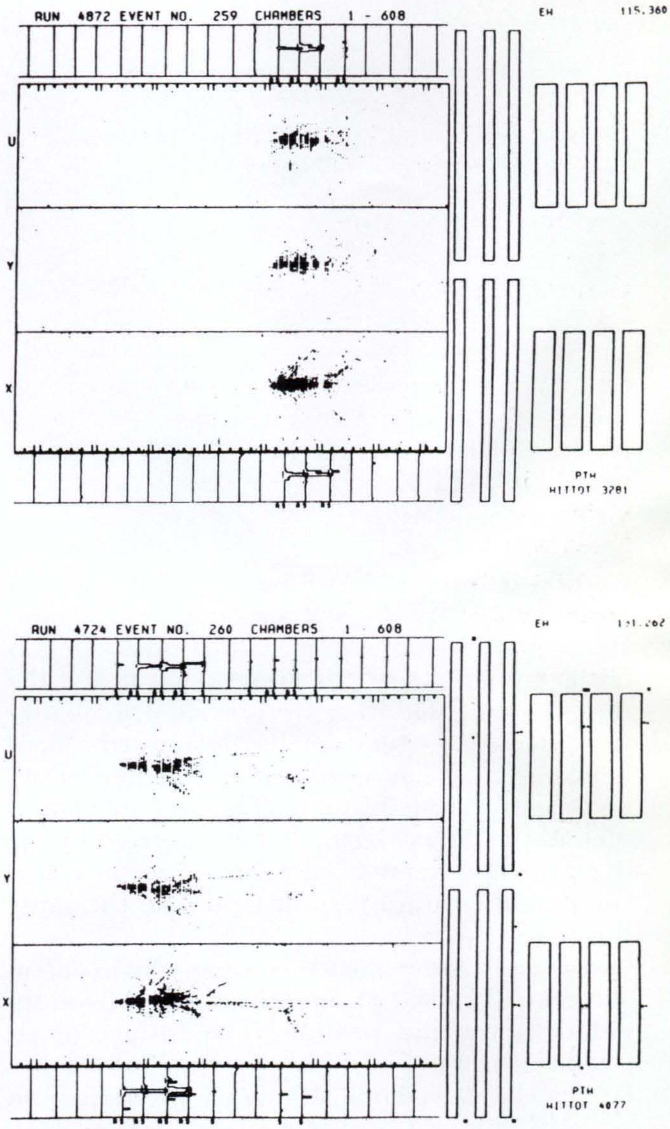


Figure 6. Dependence on scaling variable x of the ratio of neutral-current and charged-current structure functions as measured by the FNMM group (E-594) at Fermilab.

Figure 7. Typical events as seen in the FNMM calorimeter. →



QCD and Hadron Structure

Cross section measurements in neutrino beams impinge as much on QCD properties as on electroweak theory. We have already mentioned Λ determinations from charged-current data. CCFRR has measured rather well the structure function xF_3 as shown in Fig. 8. Especially interesting to me is the determination of the Regge asymptotics at small x, and the establishment of the Gross-Llewellyn-Smith sum rule (including QCD radiative corrections). Structure functions from both neutrino-scattering and muon-scattering experiments at Fermilab and CERN are in reasonably good agreement with QCD and with each other. A new round of muon-scattering experiments (E-665) in a vastly improved beam and at much higher energy is being prepared at Fermilab. A large spectrometer using the Chicago Cyclotron Magnet and vertex spectrometer from the CERN EMC experiment is now being installed. The experiment will be commissioned in the 1986 running period. The principal goals of that experiment are the study of the A-dependence of structure functions and of the hadronization process.

We now turn to QCD tests done with incident hadrons. There is quite a variety of them in the program, using many different techniques.

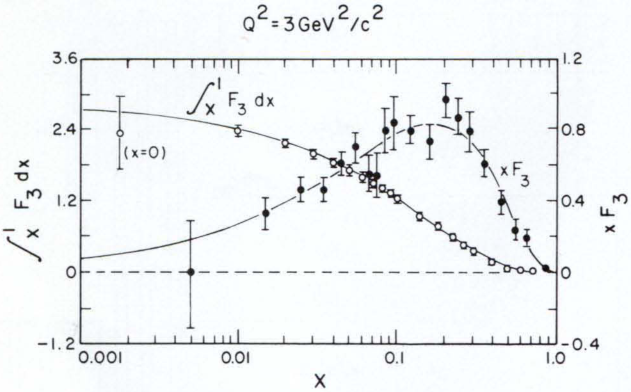


Figure 8. The structure function XF_3 as measured by CCFRR.

Results from E-615, which looks at forward Drell-Yan dileptons, were recently published. It was predicted by Berger and Brodsky that as the Feynman x variable approaches unity, the dilepton angular distribution should change from the usual $1+\cos^2\theta$ behavior toward a $\sin^2\theta$ behavior as a consequence of "higher twist" non-scaling contributions. This is very clearly seen in the data (Fig. 9). Not anticipated by the theorists is a decreasing value of mean transverse momentum of the dilepton in the same limit.

Another new result comes from measurements (E-609) of dijet production from incident pions and protons. The history of jet production in fixed-target experiments has been a checkered one. If one tries to trigger on jets with a total transverse energy trigger, such as done in the collider experiments at CERN, one is swamped by a background from azimuthally isotropic events of very high multiplicity. These events are interesting in their own right, but do not seem to have much to do with simple binary QCD hard collisions. There is, however, increasingly strong evidence that the jets are there, albeit buried in heavy background, and that other triggers which are sufficiently unbiased to be convincing may be used to pull out the jet signal. One successful example demands at least two isolated high-p_T particles above a prescribed p_T threshold irrespective of their azimuthal correlation. This trigger succeeds in producing events of high planarity. Indeed, as the total E_T of the events increase, the planarity increases despite a constant threshold p_T. Thus, by this and other means E-609 has with reasonably convincing arguments produced a differential cross section for inclusive jet production which in fact agrees reasonably well with QCD expectations.

Another interesting result from E-609 is the comparison of the jet production in pion beams relative to proton beams. Another idea of Berger and Brodsky is that some of the time the pion behaves like a point-like particle, when the quark and antiquark of the pion are atop each other and produce no source of gluon field. If this configuration does exist within the pion, then on arrival at the target it may diffractively dissociate into a pair of jets without production of any beam jet. For a proton primary this would be less likely because of the three quarks rather than two. Very preliminary data from E-609 show (Fig. 10) an excess of events in which there is little or no forward

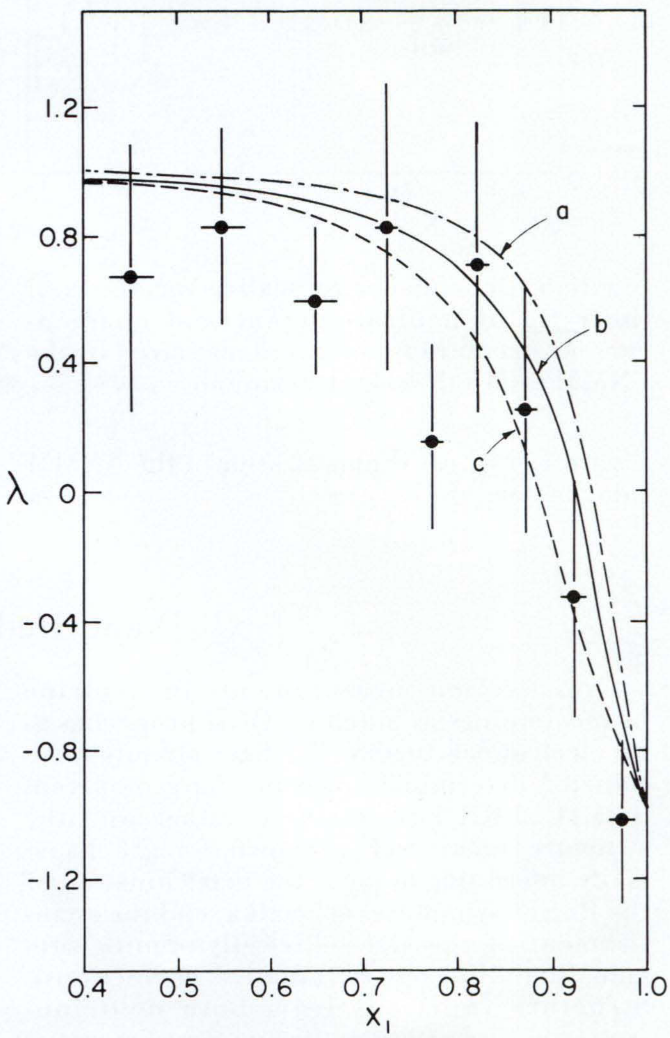


Figure 9. Angular distribution of forward Drell-Yan dileptons as measured by E-615.

"beam jet" energy. Whether this is simply a reflection of the stiffer quark distribution in the pion relative to the proton is not clear at this time and requires considerably more analysis. What is clearly shown is that jet phenomena produced by pion beams differ significantly from those in proton processes.

A variant of this same idea will be pursued by E-683, which uses a photon in the initial state to produce two jets. Half of the time the photon is not "vector-dominated" by ρ, but is, on arrival at the target, believed to be a bare $q\bar{q}$. If that is the case, it can also materialize into a jet pair without any beam jet being produced in the direction of the initial photon. It is this process for which the experimentalists will search. This is a considerably cleaner situation than for pion-induced dijets.

To go further in the study of fixed-target hard collisions will probably require more precisely defined experimental quantities than the rather amorphous objects of 5-10 GeV p_T, which are difficult to accurately define as jets, especially given the very steeply falling production spectrum. One attempt to do this is via measurement of leading dihadrons of high p_T. This is attempted in two experiments: E-605 is a very high resolution spectrometer which observes dihadrons produced symmetrically at 90° in the center-of-mass, with rather small angular acceptance. Complementary to this is E-711, which will look at charged dihadrons without further particle identification but with very large angular acceptance. Experiment 605 has taken data, which is now under analysis. Experiment 711 is under preparation and should run during this running period.

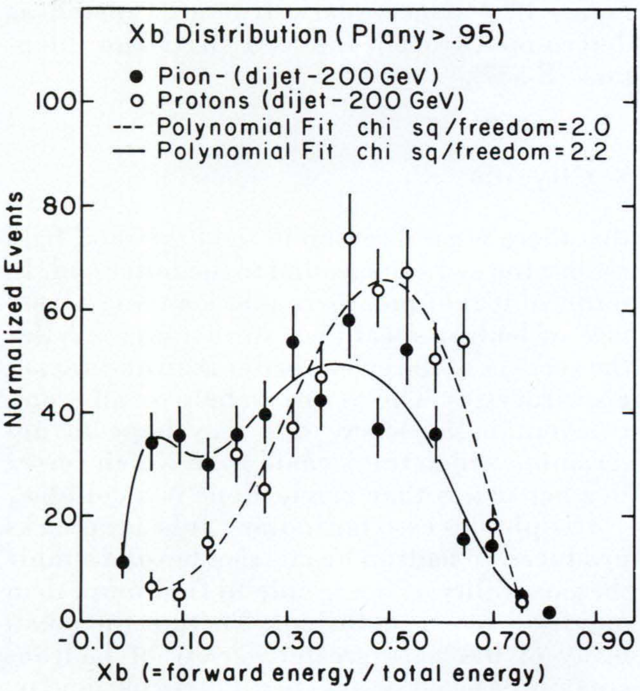


Figure 10. Distribution of the fraction of incident energy contained in the E-609 beam-jet calorimeter.

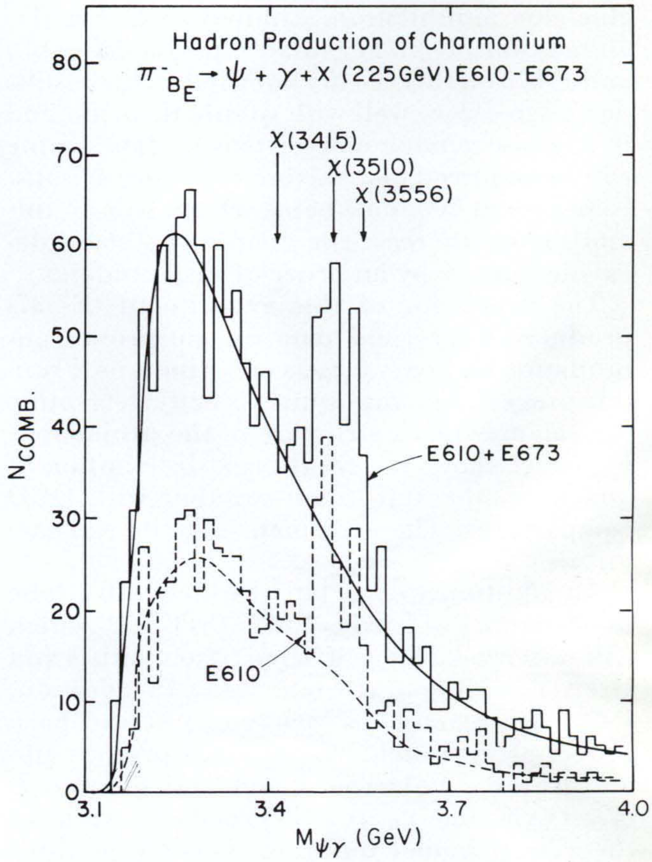


Figure 11. Observation of hadronically produced χ states in E-610 and E-673.

Another attack is to look at direct photons produced in hard collisions. The direct-photon process provides a precise measurement in terms of the yield of inclusive photons as a function of their kinematic angle and transverse momentum. The presence of this electromagnetic particle also makes theoretical calculations easier and less ambiguous. A new experiment (E-706) will not only measure photons with high precision and very large coverage but will also look at the properties of the associated jets.

Yet another approach is to study onia, in particular χ states presumably produced by glue-glue annihilation. Limited data (Fig. 11) already exist from Fermilab experiments E-610 and E-673 on this. To my knowledge, the results don't agree very well with simple theories, and in any case a much more extensive data sample will be required to make incisive comparisons. Experiment 705, now being set up, will do this and should increase the sample of χ states decaying into $\psi\gamma$ by an order of magnitude.

The precursor of this experiment (E-537) produced very good data on antiproton annihilation on heavy targets into dimuons. From this process, one may quite directly determine the valence-quark structure of the projectiles. Figure 12 shows the resulting x distribution of quarks in the antiproton together with QCD comparisons. The agreement is quite satisfactory.

An additional experiment which will probe the dynamics of hard collisions is E-672, which will observe hadrons in association with ψ and Drell-Yan dilepton production. In addition, E-704 will examine a variety of soft and hard processes with incident polarized protons and antiprotons. Polarized-beam and polarized-target experiments are a very good constraint on theoretical model building. There is nothing which ensures the continued humility of theorists as well as measurements of polarization phenomena. Theorists who successfully explain unpolarized data are often brought to their knees when the polarization information comes in.

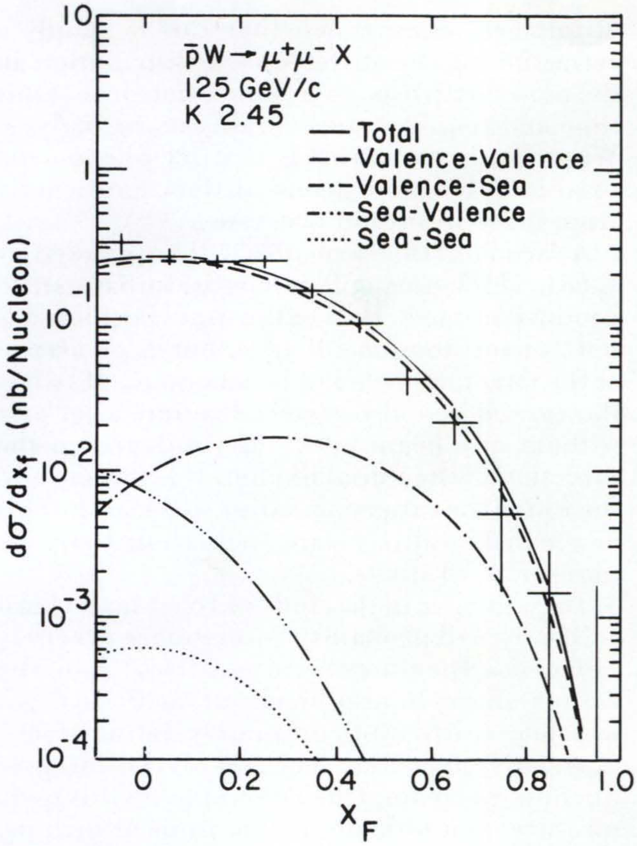


Figure 12. Valence-quark structure function as determined from $\bar{p}$ induced Drell-Yan dileptons (E-537).

Heavy-Quark Physics

In principle, prospects for charm and bottom physics at a fixed-target hadron machine are great. Given 10^{11} interacting hadrons per experiment, one may expect a yield of 3-million produced $b\bar{b}$ and 100-million produced $c\bar{c}$ pairs. This easily exceeds the world production of such quantities in e^+e^- collisions from now into the foreseeable future — including Z factories such as LEP and SLC. Of course the problem is signal-to-noise. In addition to all those bottom and charm quarks, there is a tremendous number of ordinary ones produced as well. Whether a fixed-target program in heavy-quark physics can compete with e^+e^- colliders is therefore a serious issue. I think it is too early to tell what the ultimate situation will be. But I do feel that there is real cause for optimism in the case of hadron machines, and that there is good reason to fight the good fight against the evil background to the bitter end. In terms of technique, there is at least one advantage of hadron machines, in that one may see the vertices of the events better than one does in e^+e^- processes. This is sure to help on an event-by-event basis, where one may hope to unscramble which track came from which vertex in a better way than can be done in a collider.

The physics case for looking at heavy quarks produced in hadron beams goes beyond simply the possibility of being able to find more than one finds in e^+e^- collisions. There is the possibility of having a greater variety of hadrons containing heavy quarks to study. In particular, baryons may well become much more interesting as the properties of mesons are flushed out and well determined by the e^+e^- colliders.

In terms of understanding strong interaction dynamics, baryon structure may be a more crucial test than the rather boring two-body potentials which one uses for the mesons. If there are strings connecting quarks, do they imply intrinsic three-body forces as well as pair forces within a baryon? Table III shows the variety of different kinds of mesons and baryons one may hope to see. Already there is some evidence for the usc and ssc baryons. Some of my other favorites are the ccd and possibly ccs. Further down the list, one has to be optimistic in hoping that one can find them in hadron beams, but things such as the bcd or bss would be most interesting to find. The b$\bar{c}$ meson should also be interesting to observe. It is not clear whether e^+e^- or hadron machines are a better way to make it — it's not easy for anyone.

What is important about the physics of charm and bottom? In the case of hadron collisions, production dynamics should teach us more about QCD. It is simply **not understood** at present. Normalization and energy dependence of the cross section, A-dependence of the cross section, x-dependence of the cross section, and beam dependence of the cross section are only a few of the major uncertainties. Beyond QCD production dynamics, the spectroscopy and decay properties are of great interest. In particular, the bottom quark is especially beautiful. Its long lifetime implies that it undergoes in some sense a forbidden decay. Therefore the b

Table III

Catalogue of Q$\bar{Q}$, Qgq, QQq, and QQQ States of Future Interest

Particle	Number Produced in Typical Experiment	Comments
c$\bar{u}$	$\sim 18^8$	Bread and butter
c$\bar{s}$	10^7	
b$\bar{u}$	$\sim 3\times10^5$	Learn from CESR/
b$\bar{s}$	3×10^4	DORIS what to do
b$\bar{c}$	3×10^3?	Possible?
cud	$\sim 10^7$	Large samples
cuu		should be found
cdd		
usc	$\sim 10^6$	Found already
ssc	10^5	
bud	$\sim 3\times10^4$	Find them!
buu		
bdd		
ccd	$\sim 10^4$	Possible?
ccs	$\sim 10^3$	
bus	$\sim 3\times10^3$?	Marginal
bss	300?	
cub	300?	
bcs		Prayers required
ccc		
bcc		
bbc		
•		
•		
•		

should be more sensitive to rare, hidden phenomena. That is, the branching ratio associated with a rare process will be larger for bottom than for other quarks simply because the total width is smaller. In the field of b-decays, the e^+e^- colliders at present are far ahead. But in the long run it may be important to study a variety of weak decays of bottom (and charm) particles for the same reason it was important for the strange system. The basic parameters, such as Cabbibo angles, were determined through a variety of experiments, not just a single one. Overdetermination of these parameters make their measured values more credible. In the case of heavier quarks, one believes that simple spectator and/or "factorization" models should be more reliable. Nevertheless, there have already been surprises in the charm system, and surprises in the bottom system are not yet ruled out. The more measurements that become available, the greater can be our confidence in determining the very important basic parameters of the standard model.

What have hadron beams provided us in charm and bottom physics thus far? In bottom physics, it of course gave us the γ itself. But beyond onia, there is not much at all. In charm physics, information on lifetimes has been found from a variety of experiments, most of which originated in hadron beams using high-precision vertex detectors such as nuclear emulsion or bubble chambers. In Fig. 13 a recent summary of these determinations is given. In terms of the number of reconstructed charm particles per exclusive decay channel, hadron-induced processes were until recently competitive with e^+e^--induced processes. As an example, in a photoproduction experiment at Fermilab (E-516) (see Fig. 4), very clear D* signals have been seen (Fig. 14). Another intriguing result has been reported by E-623. It is a byproduct of a search for η_c decay into $\phi\phi$. Within a data sample containing 4 charged kaons, evidence has been found for the Cabbibo **forbidden** decay of D^+ into $\phi\pi$, as shown in Fig. 15. There are about 240 entries in the peak, which regrettably suffers from a very biased trigger because of the nature of the $\phi\phi$ search. Surprising is the absence of a corresponding F nearby, since the branching ratio for F to $\phi\pi$ is a few percent, as measured by e^+e^- collider experiments. One might expect the production cross section ratio F^+/D^+ to be of the order of 10%. Thus a comparable F peak might have been seen. However, the experimentalists caution that because of the bias in the trigger, one should not draw strong conclusions about the relative production of F to D from this measurement. Low-statistics evidence for compar-

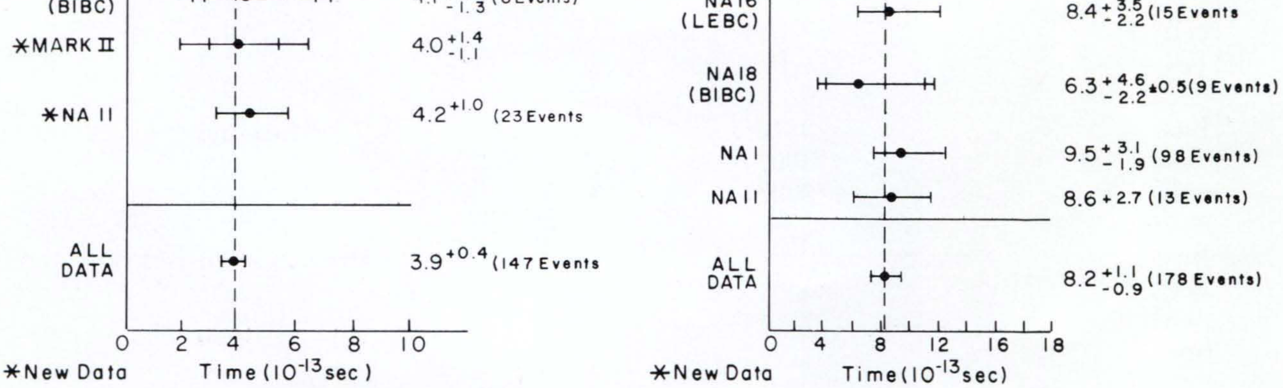


Figure 13. Status of D^+ and D^0 meson lifetime measurements.

able strengths of F and D production does exist from the ACCMOR experiments NA11/32 at CERN. In any case, this $\phi\pi$ decay mode looks very promising for future studies of charm, in particular for comparison of the relative production dynamics of F and D in hadron collisions.

The upcoming program in charm physics at Fermilab contains several experiments. In the forthcoming running period, E-691, a continuation of tagged-photon photoproduction, will utilize a transverse energy trigger which ought to enhance the charm signal. Silicon strip vertex detection has been added as well. Experiment 653 will use protons incident on an emulsion-plus-silicon-strip target followed by a multiparticle spectrometer of high resolution. With use of the downstream spectrometer, vertices in the emulsion may be located with sufficient accuracy to allow scanning of the events to be done in a reasonable length of time. Both these experiments promise to yield between 100 and 1000 reconstructed charms per "easy" exclusive channel.

In addition, the "little European bubble chamber" LEBC has moved to Fermilab and will take data this year (E-743) in conjunction with the Fermilab multiparticle spectrometer. This experiment should yield quite unbiased cross-section measurements of charm production in hydrogen. In addition, two high-resolution bubble chambers (E-632, E-745) will take data this run in the neutrino beam. A sizeable charm sample should be seen.

Further down the line is E-690, an ambitious enterprise which will utilize a sophisticated on-line fast-trigger processor. Events will be reconstructed on-line by the processor, and a search will be made for exclusive channels. These will then be selected; those with charm candidates (or other options) will be retained for later analysis. A smaller version of this experiment is now running at Brookhaven. After the processor is proven there, the experiment will be moved to Fermilab, probably within a year or so.

Finally, a second-generation broad-band photon beam experiment (E-687) will soon be set up. The spectrometer used in this experiment promises to be as powerful as any at Fermilab, and it will be a very strong facility for charm and bottom studies in the future. It can operate not only in photon beams but also a variety of hadron beams.

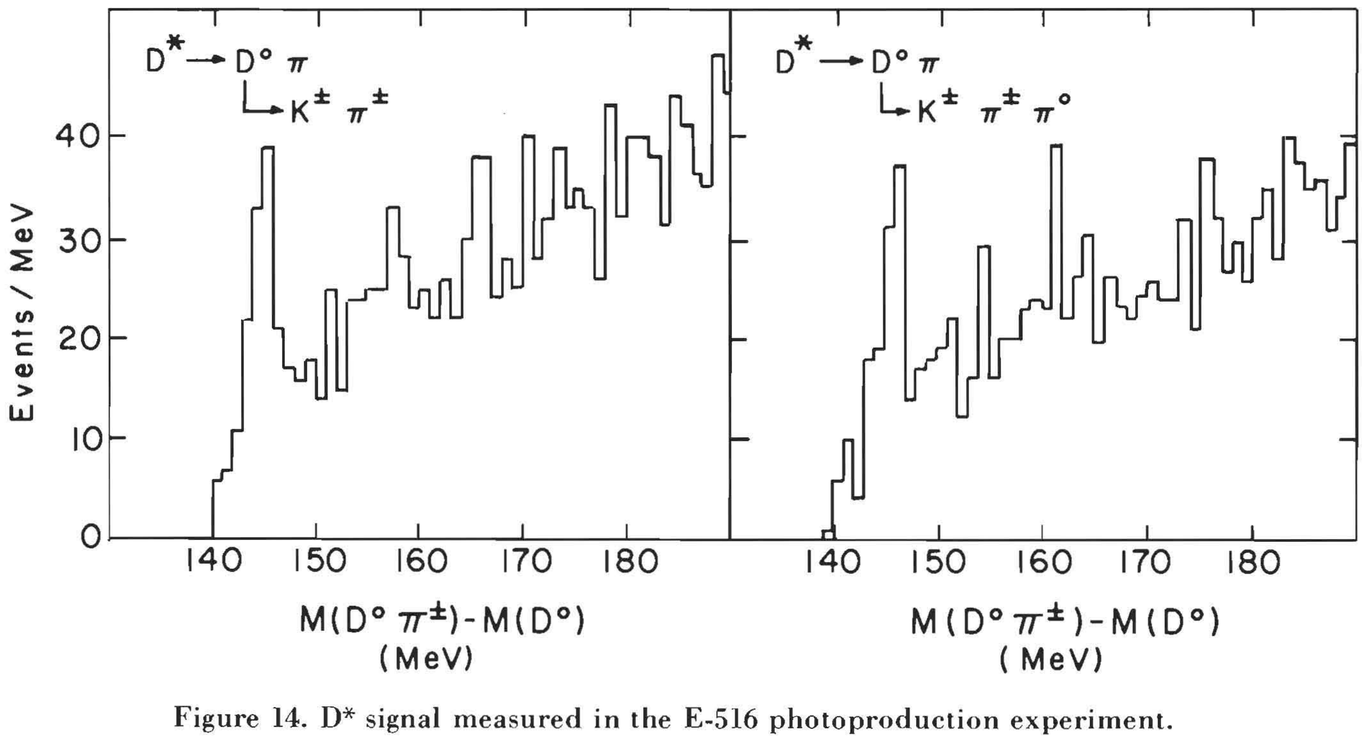


Figure 14. D* signal measured in the E-516 photoproduction experiment.

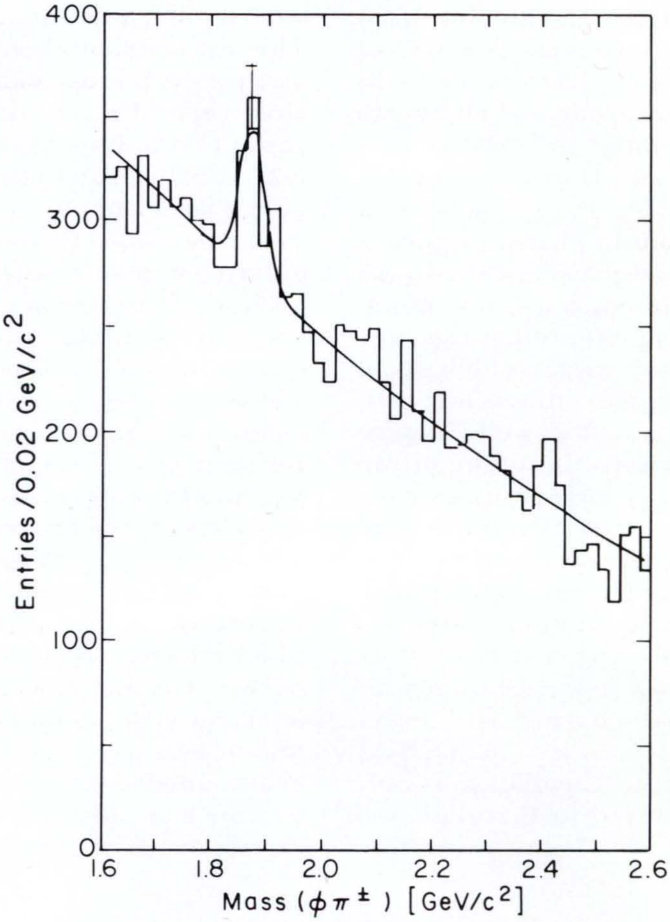


Figure 15. The Cabibbo-forbidden decay D $\rightarrow$ $\phi\pi$ observed in E-623, designed to search for η_c $\rightarrow$ $\phi\phi$.

Beyond the Standard Model

In general, the Tevatron fixed-target program must be said to be programmatic. That is, it deals mainly within the standard model with phenomena which need to be better understood and parameters which need to be better measured. But there do exist discovery opportunities which go beyond the standard model. One of these is the long-standing problem of same-sign dilepton production by neutrinos. In several experiments, it has been found that the process

$$\nu N \rightarrow \mu^- \mu^- X$$

occurs at a rate too high to be easily explained by conventional sources of background. A new measurement, using the Fermilab 15-ft bubble chamber (E-53) has been made of the very closely related process $\nu N \rightarrow \mu^- e^- X$. This process is not seen at the level of observation claimed for same-sign dimuon production. This may indicate either that the same-sign dimuon effect is spurious or that the effect is real, but violates the μe universality. This latter hypothesis need not be considered too radical if indeed something crazy is the source of the phenomenon. Because the purported $\mu^- \mu^-$ signal appears to increase with energy, the forthcoming neutrino running with 800-GeV primary protons should have much higher sensitivity to this process.

Another possibility of discovery physics has been stimulated by the observation of the ζ at DESY by the Crystal Ball collaboration. I am not fully convinced that the phenomenon has gone away, despite the negative second-round results, because to my knowledge the hypothesis of Tye and Rosenzweig has not been fully refuted. To me, their model is the most reasonable explanation of the original results. To refute it requires precise knowledge of operating conditions of the machine in both the original run and in subsequent running. (Ideally, one would want to run some fraction of the time at one sigma or so off the resonant peak of the γ on each side in order to be sure that the Tye mechanism is inoperable.) The relevance of this phenomenon to the Fermilab fixed-target program has to do with E-605, already mentioned in connection with high-p_T dihadron production. This is the follow-up experiment to the one which discovered the γ particle. In the next running period, the emphasis will be on high intensity, with observation of dimuons with high mass resolution (20 MeV?). This resolution will be sufficient to resolve cleanly the various upsilon excited states. If there is any ζ-like entity, there is a good chance of seeing it. If Tye and Rosenzweig are right, one might see a first excited state at somewhere around 9 GeV.

Yet another fixed-target experimental program which contains discovery potential is the set of beam-dump experiments (E-635, E-636, and E-646). The bread-and-butter part of that program is direct observation of the tau neutrino and study of its properties. But, beam dumps also provide good opportunities to search for axions, neutral leptons, and the long-lived neutral penetrating particles of supersymmetric theories. The monojet events from UA1 provide new stimulus for these kinds of searches, because a reasonable hypothesis for explaining the monojets is decay of the Z into a new neutral long-lived penetrating particle plus the jet.

However, the beam dump program at Fermilab is in trouble. Although there are three approved experiments and a satisfactory dump design (Fig. 16), the facility is expensive. Because of funding shortfalls at Fermilab, it has been decided to defer beam-dump construction in order not to disrupt too much of the remaining program. In order to minimize the delay, the Laboratory and DOE have submitted a line-item construction request for the FY87 high-energy physics budget to fund this facility.

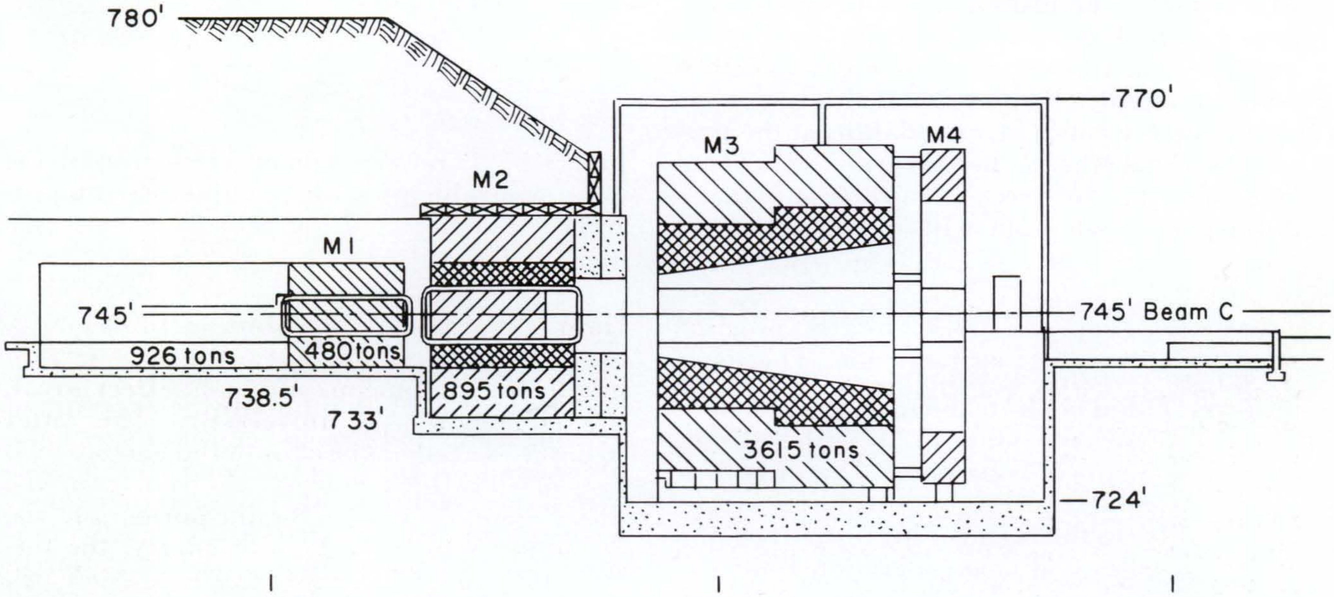


Figure 16. Design for the Fermilab Direct Neutral Lepton Facility.

The TeV II Problem

The status of the beam dump is one example of a general problem (Fig. 17) which the TeV II program faces. As I see it, this problem has a three-fold source. The first source is user perceptions of delays, insufficient Laboratory support, insufficient agency support, competition with TeV I, as well as possibly greater security for the future of a group within a large colliding beam facility. There may also be a physics issue: being behind the high-energy frontier, where the physics is likely to be more programmatic and have less headline-making potential. The source of the delays as seen by the Laboratory is that there is simply not enough money to do the job. And it does not help if the Laboratory, when viewing the user community, sees a flagging of interest or lack of stamina. The third source of the problem comes from the national scene, where funding agencies, HEPAP, and other nationally-based advisory groups may see too many competing demands for funds, given all the collider initiatives here and abroad, as well as underground experiments, and R&D for the SSC. TeV II looks like just one more program competing with all the others, despite its diversity and breadth. Since it is a broadly-based program with many components, it also is a prime candidate for cuts. Anyone looking at the program will have his or her favorite experiment and his or her turkey. (The problem is that a dozen people in a room will find no agreement whatsoever on which experiment is the turkey.) Thus, everyone will agree that something can be cut out of the program without anybody noticing, but no one can agree on how to do it without severe damage, with everyone noticing.

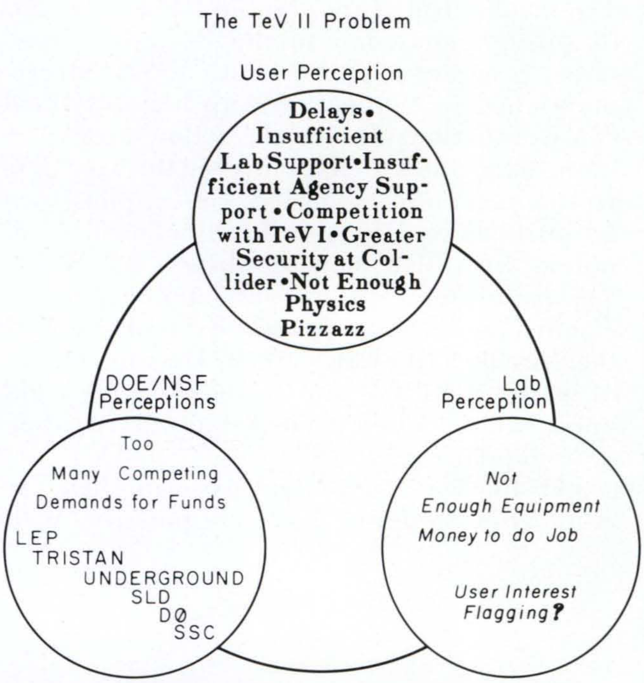


Figure 17. Three-way vicious circle underlying existing problems with the fixed-target program.

Longer Range Opportunities

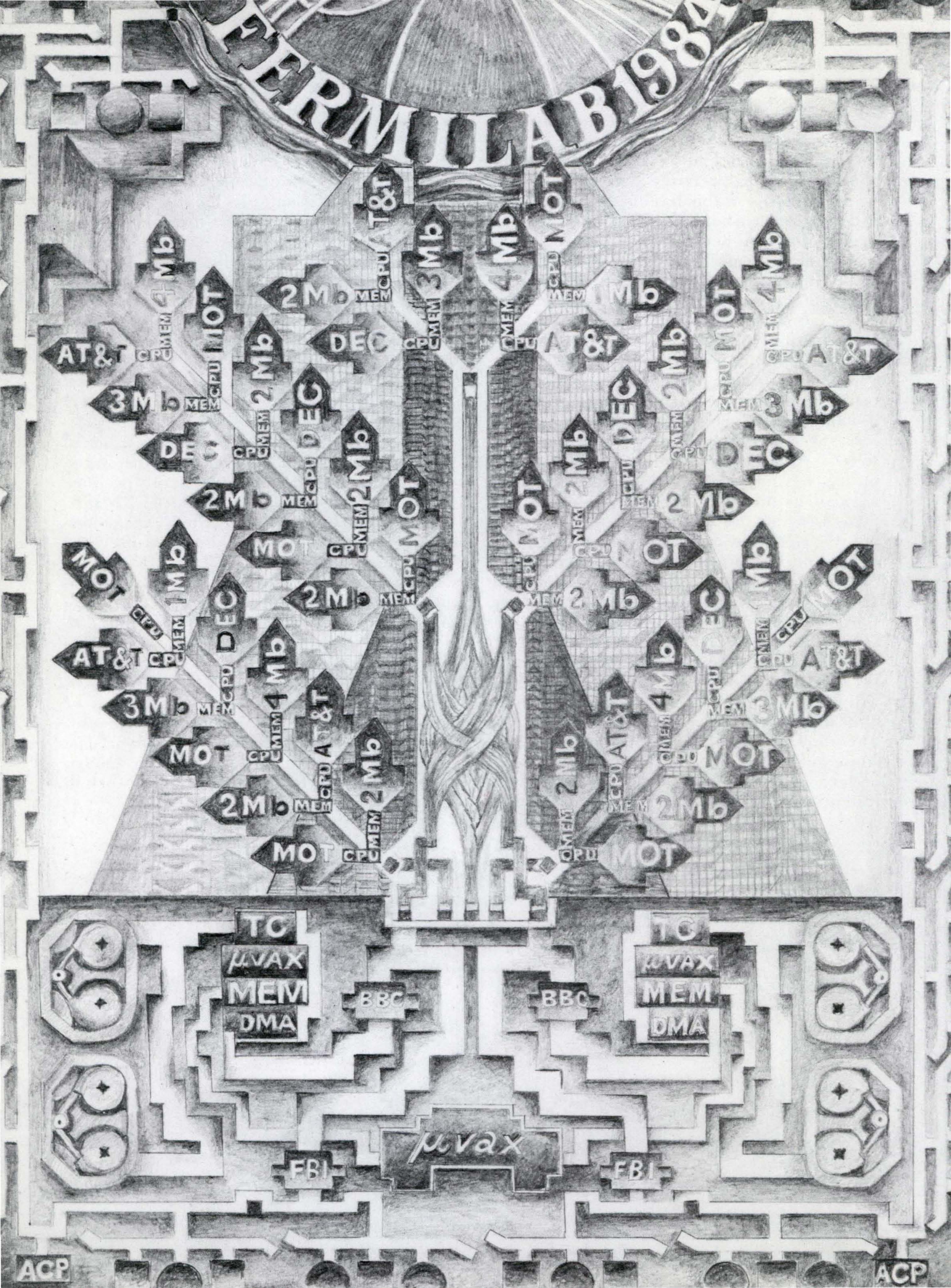
Such pessimistic words about the fixed-target program should not be taken to indicate that, in fact, the physics is drying out. As we have seen, there is very much to be done. The physics is extremely good and the opportunities are of high quality. In the realm of big initiatives, one of my favorites is a next-generation round of heavy-quark physics. This may require a new spectrometer facility, one which can go an order of magnitude beyond what is hoped for in the upcoming runs. I would like to see 10^4 to 10^5 detected charms per easy channel as the goal. There is a question of how to proceed with such a large initiative — or whether one should proceed. One option is to rely on existing initiatives in the program or new initiatives of comparable scale. The arguments in favor of this are, first, that it would exploit optimally the expertise of existing teams and provide continuity with the programs now going on. Second, the physics with several groups would come out in parallel, with competition providing additional stimulus. And one might not need escalation in group size or apparatus to do the job. One could also cite examples of very big comprehensive spectrometers which haven't done as well as more modest apparatus with greater specificity.

On the other hand, the physics may simply require, just as it has in colliding beams, concentrating most of the effort into a very big centralized facility which might approach collider detectors in size and scope. It may be arguable that existing groups doing charm and bottom physics are too small, and that the spectrometers which are being built, or exist now, are simply not powerful enough to do this kind of physics. Certainly a necessary condition for physics at this level is that a variety of incident beams should be available, not only protons but also neutrons, mesons, hyperons, and photons as well. One will need to make comparisions, as well as produce a variety of different kinds of hadrons containing heavy quarks. Another argument for a very big facility is its visibility; it is easier for the national community to notice and thus support. Finally, another reason for a large charm-bottom spectrometer may have to do with the SSC. If $200 to $500 million will be spent on detectors for the SSC, there should be a considerable amount of R&D devoted to that enterprise. This R&D must go beyond paper designs and construction of small modules which are put into test beams. Systems which are large enough to capture an entire hadron jet of several hundred GeV (a bread-and-butter phenomenon for the SSC) should be tested. Secondary beams at Fermilab are certainly a very good source of such jets. Certainly Fermilab should provide facilities for this kind of R&D. But, just like all R&D efforts, if there is physics that can be attached to the instrumental development, the whole effort will be better focused, gain more momentum, and in general have greater productivity. Therefore, it seems reasonable that Fermilab, while welcoming detector R&D done in its secondary beams, will welcome even more those initiatives which have a strong physics motivation as well. Therefore, it may make sense to integrate SSC detector R&D into a large heavy-quark spectrometer program.

At the opposite extreme, there are opportunities for small initiatives within the fixed-target program. Examples now discussed or presently pursued include a program on crystal channeling which may even have applications to accelerator physics (including SSC) in providing small septum magnets, measurement of the magnetic moment of Ω^-, quark searches, searches for rare decays such as $\Xi^0 \rightarrow p\pi^-$, searches for anomalons, and soft muon physics. These have obvious sociological importance in this age of giant collaborations. But they must stand on their own in terms of physics quality. I think most do.

There exist more exotic possibilities in fixed-target physics, such as colliding stored antiprotons on gas targets to resonantly produce ψ and χ states, such as done at the CERN ISR. Storing muons and pions in order to make low-energy neutrino beams has also been discussed from time to time. The desirability of doing this depends somewhat on the future of neutrino-mass measurements. Certainly, if neutrino masses and mixings are convincingly found to be non-vanishing there may well be a renaissance of interest in this kind of physics at Fermilab.

In any case, the bottom line on the future of fixed-target physics is one of commitment. Much very good physics is there to be done. The necessary condition is that there be enough people who are willing to do the hard work to get it out.


FERMILAB 1984
AT&T
CPU
MEM
4 Mb
MOT
2 Mb
3 Mb
DEC
1 Mb
TC
μVAX
MEM
DMA
BBC
TC
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ACP

IV. Fermilab's Advanced Computer Program

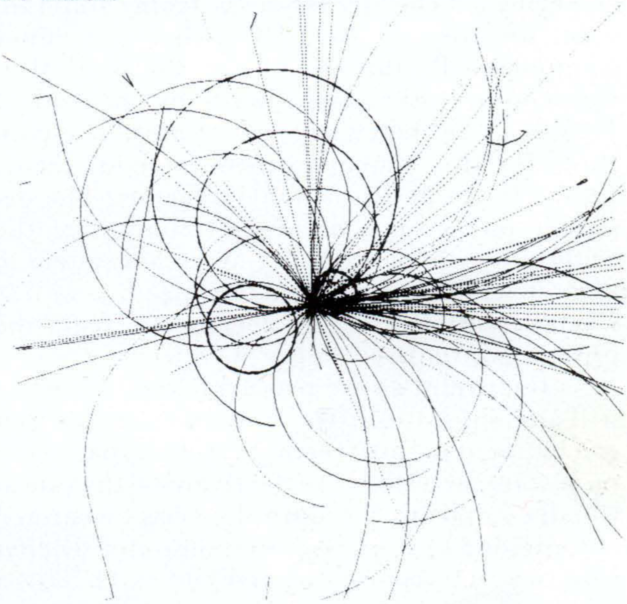
Introduction

By its very nature, experimental basic research has always pressed hard against the existing limits of technology, expanding those limits when necessary and possible. Nature does not release its secrets easily. The challenge of exciting new experimental possiblities frequently lures physicists into technological development areas. A familiar example, Fermilab's leadership in superconducting technology has been motivated by a need for improved accelerators to allow experiments at higher energy. Since the 1930s, electronics and computing have, along with accelerators, been the focus of recurring interest in the high-energy physics community. Among the first to build and use electronic logic gates (ORs and coincidence circuits) were high-energy experimentalists for their detectors. These gates later became the fundamental building blocks of all digital electronics and computers.

In the early sixties, high-energy physics made important early contributions to computer hardware, especially on-line processing. It was also the first field to exploit the very high speed ECL (Emitter Coupled Logic) circuit technology. From that period until recently, commercial computing hardware and system software proved adequate for most of high-energy physics needs and were not a major impediment to progress. No longer is this true. Computing limitations now have severe impact in a number of important areas, affecting the progress of experimental and theoretical efforts as well as new accelerator design.

The biggest demand on Fermilab computing is for what is called experiment event reconstruction. Physicists study the interactions of fundamental particles by producing millions of individual collisions between them, and studying how other particles, the debris, fly off into their detectors. Sophisticated as they are, the experimental detectors provide only the sparest information about where and when these secondary particles passed. To analyze the physics, the physicist needs to know the type of each particle and the momentum and angle with which it emerged from the interaction.

Reconstructing these parameters for each of dozens of particles, for each of millions of collision events, from the bits of detector information recorded during the experiment, requires a monumental scale of computation. Large experiments already measure the amount of time they use on Fermilab's large main frame computers in years. As the energy of accelerators increase, so do the number of secondary particles and of interaction events to be studied. But interesting physics events tend to be rarer.



Bigger haystack, smaller needle: we need advanced computer ideas. In 1982 Fermilab formed the Advanced Computer Program to confront computing problems at the R&D level. This group is known by its initials (ACP). It now has a dozen technical people with backgrounds in experimental and theoretical physics as well as electronic and computer engineering. In its work the ACP interacts strongly with industry and university computer science efforts, mingling ideas and technology from outside of high-energy physics with its own.

For experiments, the ACP goal is simple: remove the mechanics of computing from contributing significantly to the "turn-around time" between the idea for an experiment and the physics conclusions derived from the experiment. Similar motivations apply in the theoretical and accelerator areas. Presently, a major part of this turn-around time is spent by computers carrying out the trillions of elementary calculations required for various aspects of the research. The ACP has focused its efforts on developing ways to carryout this "number crunching" that are far more cost effective than those available commercially. Studies by ACP people have concluded that we can now attack this problem effectively by creating new computer architectures built out of large numbers of the very powerful VLSI (Very Large Scale Integration) microprocessor circuits being produced by industry. In the following, we will explain how this is possible and how the ACP group will build a supercomputer for high-energy physics at Fermilab.

A High-Energy Physics Supercomputer

"A super computer is a system that is only one generation behind the computing requirements of leading edge efforts in science and engineering." (The quotation is from Neil Lincoln, designer of the CDC Cyber 205 Super Computer.) By this definition, the ACP Multiprocessor system to be built by the end of 1985, is more than a supercomputer. The concepts for this system were developed during 1984. Circuit design is now underway. The design is based on a careful evaluation of the criteria by which the value of such a system to high-energy physics should be judged, as well as what is required to gain acceptance from the physicists who need to use it.

As important as the problems are, there are still obvious limits to the amount of money that can be spent to solve them. It is clear that a very important factor is cost effectiveness: the rate at which computing for a problem can be carried out, divided by the cost of the computer. Digital Equipment Corporation's (DEC) Vax 11/780 is a super-mini computer that is very popular in the scientific community and is a good standard for comparison of cost effectiveness. One can buy about 4 Vaxes per $M (million dollars).

Cost effectiveness is not the sole criterion. It is possible to obtain extraordinary cost effectiveness, approaching a million Vaxes/M$, using special purpose hardware aimed at extremely well-defined problems. Examples may be found in high-energy physics experiment trigger hardware (that decides which interactions detected by an experiment should be recorded on tape) and military signal processors. Such systems are very inflexible and difficult to program. Getting them working makes strong demands on technical people's time.

These problems point to the two other requirements, beyond cost effectiveness, that the ACP makes of its systems. The first is ease of use and programmability. In one phrase, this is what has come to be known as "user friendliness." The second is easy system set-up by non-experts. This requirement encourages a modular system with units, such as circuit board subsystems, built and tested to industry standards. These modules may be based on Fermilab or commercial designs, and should be routinely available from commercial vendors or fabrication houses.

It is easy to sympathize with scientists who resist new programming languages and complicated computer mumbo-jumbo. Learning a whole new language or a complicated set of procedures would be, clearly, an "unfriendly" requirement. Among high-energy physicists, Fortran is the nearly universal programming language. Although there are several more modern languages with strong proponents in the computer science world, asking high-energy physicists to leave Fortran would be much like asking Frenchmen to speak Esperanto. In fact, the analogy is appropriate since Fortran is a "living" computer language continuously being updated with syntax and concepts deriving from computer science work in languages. At the research stage, before the language has had time to adapt, new functional tools can be made available in the form of subroutines. Subroutines are previously prepared sequences of instructions that are convenient for users of a new computer to invoke from their programs.

An important component of user friendliness is what is called the operating system. The operating system manages the user's files of programs and data, runs computing operations on request, provides tools to help find errors in programs, supports text editors, and, if user friendly, generally assists the user in response to only a minimum of simple commands. The Vax VMS operating system has become very popular among high-energy physicists. Other, more portable systems (AT&T's Unix™, in particular) may in time take hold. Until then, VMS will be the system environment, and Fortran the language in which physicists using the ACP's computers will work.

Computer Architectures for High-Energy Physics

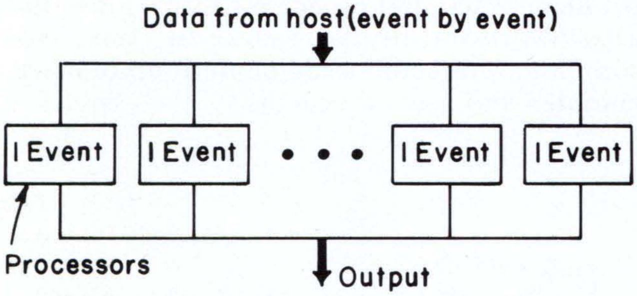
The most cost effective commercially available computing engines are the VLSI microprocessors. A single board computer based on one of the newly emerging 32 bit super micros (such as Motorola's 68020, AT&T's 32100, and DEC's microVax chip) will run large Fortran programs at speeds approaching those of a Vax. Critically important to using these tiny computers are the programs, called compilers, that translate the scientists' programming language, Fortran, to the machine instructions that control the microprocessors. Much inefficiency is possible in this translation. A particularly good compiler for the 68020 is now available from Absoft, a small company in Royal Oak, Michigan. The ACP has already measured physics programs to run at upwards of 1/2 Vax speed with it.

Such a single board computer can be built for about $2500, implying a cost effectiveness of at least 200 Vaxes/M$. Further improvements are expected by 1986 in compiler and hardware technology. Clearly, to bring revolutionary amounts of computing at this cost effectiveness to a computing problem, one must get all the little engines to work together, in parallel, on the problem.

The general problem of parallel computing is a very difficult one. Much computer science effort is directed at optimizing parallel computation for a generalized mix of computer programs. This involves development of mechanisms for communicating between and synchronizing the activities going on in the different little engines. Further complications result from allowing access by each processor into the memory of the others and in the management of the processors and their allocation to different parts of the problem.

Driven by pleasantly easy structures in high-energy physics computing problems, the ACP is able to use the simplest multiprocessor architectures. These involve little or no communication between the processors. Yet, such systems will greatly increase the computing capacity available for this research. In fact, very much can be learned about the general problem of parallel processing from conceptually simple multiprocessors. In time, the simplest architectures can be built up to more complex and general systems.

Why can the ACP avoid the complexities confronting so much other parallel computer research? The secret of how to apply a simple parallel computer to the experimentalist's needle and haystack problem is the haystack itself. It is made of millions of individual events. The reconstruction of what happened in each can be carried out with no regard for what went on in any of the others. Only when the reconstruction of all events is complete do the analyzing physicists want to look at them all together for statistical studies. The problem has designed the computer architecture for us: each of our many little computing engines works, by itself, on one event at a time, never needing to communicate with the others which are working simultaneously on different events. Raw detector data is passed to each processor as it becomes ready. When the procesor has completed working on the event, the reconstructed physics parameters are stored for the later analysis.



Now, you might think, this is a specially simple architecture. How can it work for any other problem? Physicists are very excited about the studies going on for the Superconducting Super Collider (SSC) which will require accelerator rings about 100 miles around. Projected costs of several billion dollars clearly motivate an intensive computer simulation of accelerator design possibilities. The simulation calculates step by step how individual particles would pass through magnet after magnet, revolution after revolution for thousands of turns around the imagined ring. Many individual particles, starting out with small differences, are followed. The calculation of each track is essentially independent of the others. We can treat each particle like an experiment interaction and put it into its own processor. The processors, once again, need communicate little or nothing with each other.

Both of these important Fermilab problems are, we now see, of an "event-oriented" nature. They are perfectly matched to our simple parallel architecture. We are learning that outside our world, there are many important problems of an event-oriented nature. Some of these are surprising at first glance: process simulation, robotics, animation, and finite element analysis. Of course, we cannot get away with applying our event-oriented architecture to every computing problem. Some, like weather forecasting and molecular dynamics, require heavy communication between all processors. Many others in mathematical physics require only nearest neighbors talk to each other. An example is the key theoretical problem of particle physics.

Theorists have developed a numerical calculational technique, called Lattice Gauge Theory, to make approximate predictions that test the theory of strong interactions. They simulate the world, at the elementary particle level, on a lattice of points in space and time and calculate the interaction of quarks as if they lived on that lattice. These calculations are of the highest importance. To do them with reasonable accuracy, they require orders of magnitude more computing than presently available. A grid of processors each speaking to only a limited group of neighbors matches this problem in an obvious way. The individual processors are just like those the ACP is designing for event-oriented problems. In the future, the ACP may configure systems as grids. However, with work on grids in progress at Cal Tech and Columbia, the group is presently not emphasizing them.

Software

Scientists, like other computer users, are accustomed to preparing programmed instructions for traditional machines that compute by carrying out arithmetic or logic operation serially, one after another. The present generation of commercial supercomputers, like the Cray 1 and Cyber 205, are called vector processors. They are capable of carrying out the same operation, on one command, for each of the set of numbers that make up what is called a vector. In order to take full advantage of this capability for a scientific problem one needs to identify, throughout the problem, groups of calculations that can be ganged together in the vector processor. Automatic tools that "vectorize" a problem have not proven very effective. Doing this job by hand is difficult and time consuming. Rarely have scientific problems used more than 10% on average of a vector computer's capacity. This experience shows how critically important it is to have software support that makes it possible to take full advantage of new hardware.

Truly parallel machines, where different operations may be carried out simultaneously on groups of numbers, are expected to be less constraining. Event-oriented problems like experiment reconstruction should be particularly easy to adapt to the simple parallelism of the

ACP multiprocessor architecture, which is designed for them. During 1984, the ACP built a small six unit testbed multiprocessor and developed an extensive repertoire of software to support use of large multiprocessors by experimentalists. Several Fermilab experimental groups tested this software over the summer months. They found it pleasantly easy and quick to convert their traditionally serial programs to multiprocessor operation.

A program that is to run on the ACP multiprocessor is separated into two major pieces. The first runs on a single processor, called the host. It contains all instructions that control bringing in raw data from, and sending processed results to, outside storage devices, such as magnetic tape. The real number crunching is carried on in the second piece of the program. This is duplicated many times over to control the activities of each of the many little microprocessors that together do the heavy work. The host computer is instructed to send the raw data corresponding to one physics interaction event "down" to a processor by a simple request to start a sequence of instructions, a subroutine, previously prepared by the ACP.

The name of this subroutine is obvious, SENDEVENT. There is a similarly obvious name, GETEVENT, for the subroutine that retrieves processed results from a finished microprocessor. What is not obvious is the "resource management" problem of keeping track of which of over a hundred processors is ready for data, ready for retrieval, or requires some other action. These matters are handled automatically by ACP subroutines. The scientist using the system does not have to bother with them. He or she is required only to determine how to split the program into the host part and the microprocessor part and to identify appropriate places to insert the SENDEVENT and GETEVENT commands that communicate data between the host computer and the little number cruncher. This is an easy task since all large reconstruction programs have separate input-output and number-crunching sections.

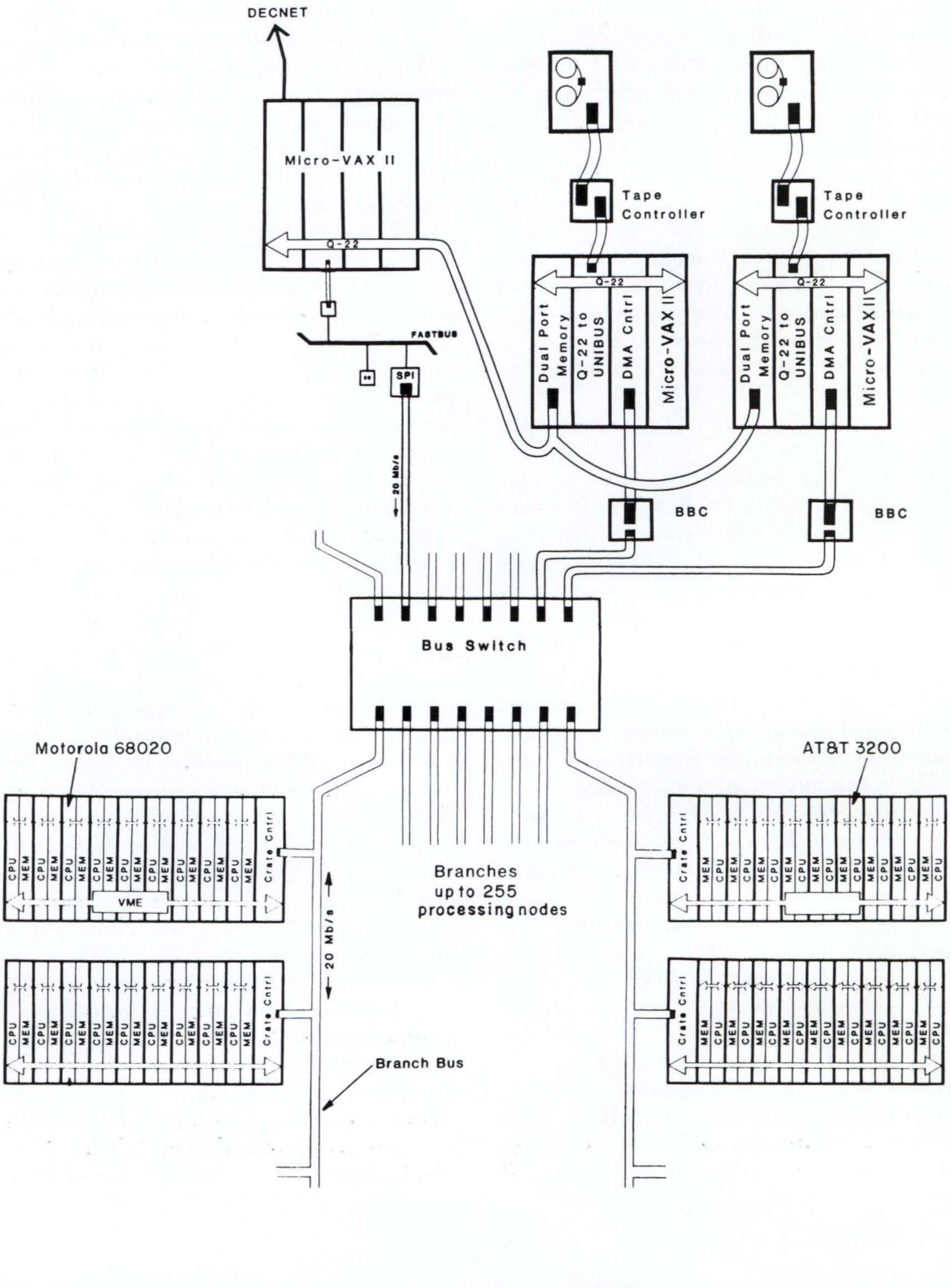
The host computer also takes care of tasks needed to start up and complete a reconstruction program's operation. At the beginning, many numbers that describe where the detectors are located, and otherwise give meaning to the raw readings, must be prepared. These numbers are then broadcast to all the processors, where they will be used to reconstruct the event, with the command BROADCAST. At the end, statistical summaries and graphs are normally prepared so that physicists can determine that the operation proceeded normally. These summaries are based on subtotals stored in the many individual processors. The subtotals are gathered and summed together on command to the ACP software. There is also help when problems occur. Hardware and software errors are identified and tools provided to track down program mistakes.

Hardware

The tests of the ACP software demonstrated that it will be easy to apply a simple multi-microprocessor to high-energy experiment computing. The enthusiasm of computer-starved experimentalists has put a high priority on a project to build a full-scale, high-performance system before the end of 1985. It will consist of 128 processors. Of these, 64 will be based on Motorola's 68020, and the remainder, depending on availability, on AT&T's or DEC's 32-bit microprocessors. Using more than one processor type is part of the ACP's philosophy of keeping its system receptive to the best industry has to offer in performance and in price.

Experience with this first system, running real experiment problems, will allow ACP people to improve software and hardware. If, as expected, all goes well, other large systems, of up to 255 processors each, will be built quickly to meet the needs of Fermilab's Computer Department and the Collider Detector at Fermilab (CDF). Many outside groups, at American and Western European universities and laboratories, have followed ACP activities with interest. To make duplicating the system easy, Fermilab will make available system designs, software, and lists of commercial sources where modules may be purchased.

Even though the architecture is simple, putting together this large a multiprocessor requires careful design. Up to 20 processors can be assembled in a box, called a "crate," using commercial packaging and interconnection circuits. For larger numbers of processors, new schemes are required. The ACP multiprocessor will be built as a tree (which is usually pictured upside down in diagrams). The leaves are the individual processors sitting in a commercial crate. The crates are connected in groups to a Fermilab designed "branch bus" which in turn can be connected as needed to any of the one or more roots of the system. Each root is connected to a source of data from the outside world. In some systems, there will be two roots each with a magnetic tape drive, one with raw data coming in, one with processed data going out. Other systems will process data as quickly as it is taken in the real time of an experiment. There, roots will be connected directly to the experiment's data acquisition system absorbing data at huge rates. Twenty million characters per second are possible in each of several roots. A simple, but high speed switch is the trunk of the system. It connects 8 roots to 8 branches.



Each root is controlled by a small commercial microcomputer (DEC's microVAX II). These speak with a DEC microVax II supermicrocomputer which is the boss of the system as a whole and is called the production host. This computer carries out the host part of the experimentalist's program and has the popular VMS operating system we referred to earlier. One experiment's activity at a time goes on in the production host and multiprocessor, which is connected to Fermilab's network of computers. Also on this network is a "development host" computer, a full size Vax that can handle many people each working on developing new programs. They can test the programs on small ACP systems intended for this purpose and connected to the network. The development host has available all the ACP supplied tools, as well as the usual Vax VMS aids to development, that help prepare for a multiprocessor calculation.

The first system will be built in 1985 for under $1/2 million in equipment costs and will deliver the computing power of at least 60 Vaxes. Later copies will be cheaper and more powerful. The ACP schedule is "aggressive," to use a popular computer industry word, because it depends on the ability of industry to manufacture, in quantity, 32 bit microprocessors. These devices are certainly among the most technologically aggressive creations ever contemplated. However, delays, if they occur, will not be long, and are part of the ACP's mandate to work on the cutting edge of technology.

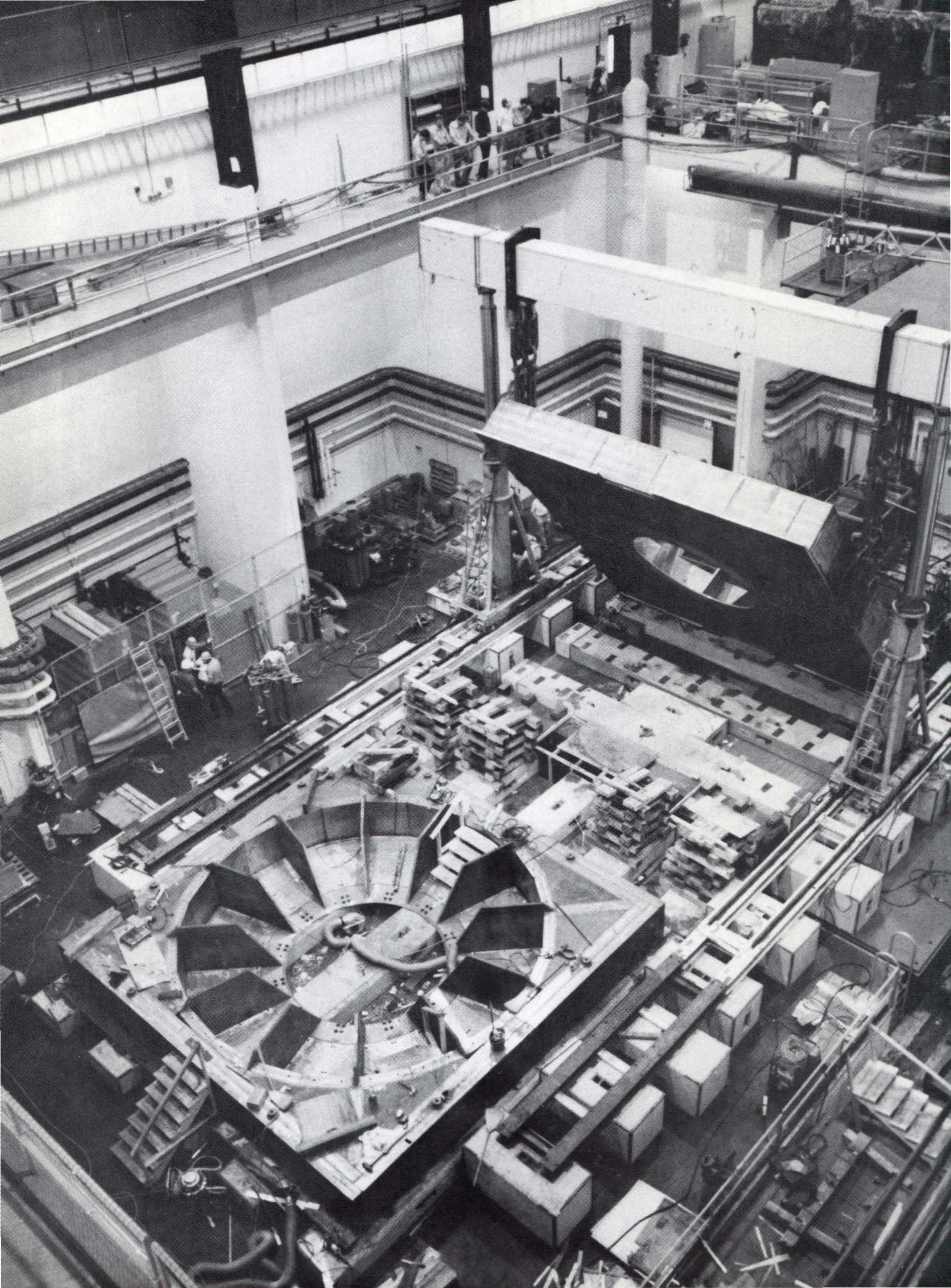
Future Activities and Projects

We have hinted at areas where further ACP development work potentially could make still more dramatic improvements in productivity. One such area of research is on special-purpose devices. We said these are hard to program. But suppose that ACP experts do the difficult work as they have done for multiprocessor management software. Then these super powerful techniques could be made available to physicists with only a subroutine command. This concept, which we call "hardware subroutines," appears to be very promising. It is particularly easy to implement when one can identify time consuming little calculations that are repeated over and over again. This appears to be possible for all the problems that interest us. Since the approach can be so fruitful, the ACP group will focus on it in 1986.

Number crunching is the major source of long delays in physics turn-around times. Another leading contribution is simply the time necessary to plow through huge amounts of processed data. Reconstruction of an experiment produces tens of billions of words. These are used by physicists to make graphs and statistical calculations that describe what went on in the experiment. Little actual computation is required for this analysis. Yet, each time a physicist passes through this enormous amount of data, hundreds (or even thousands) of tapes must be read, and often several days are lost. Typically, an experiment requires many such passes as physicists try out new ideas and develop an understanding of the data.

New data base technology (similar to that used for TV laser disks) is appearing on the technological horizon that will make it possible to improve this situation. Using the new technology, future ACP efforts will be directed at allowing physicists to turn around their analysis ideas almost as fast as they can think of them. For now this is a dream, and Fermilab's Advanced Computer Program is fully occupied developing its exciting new supercomputer for high-energy physics.

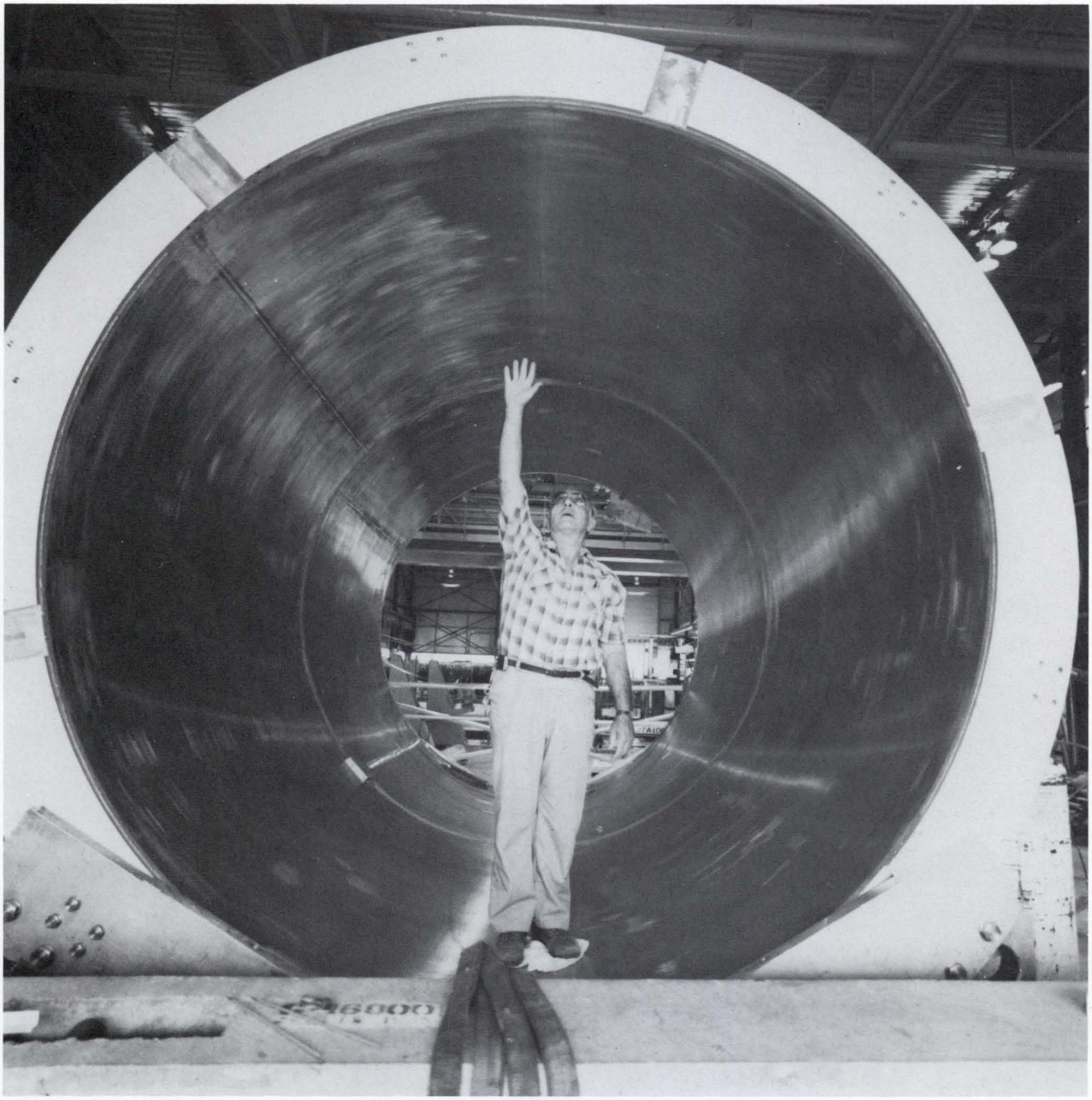
Thomas Nash



V. Progress on the Fermilab Collider Detector

The south end wall of the Collider Detector under construction as the north end wall is raised into final position.


G-BEPS
Heavy
Heavy



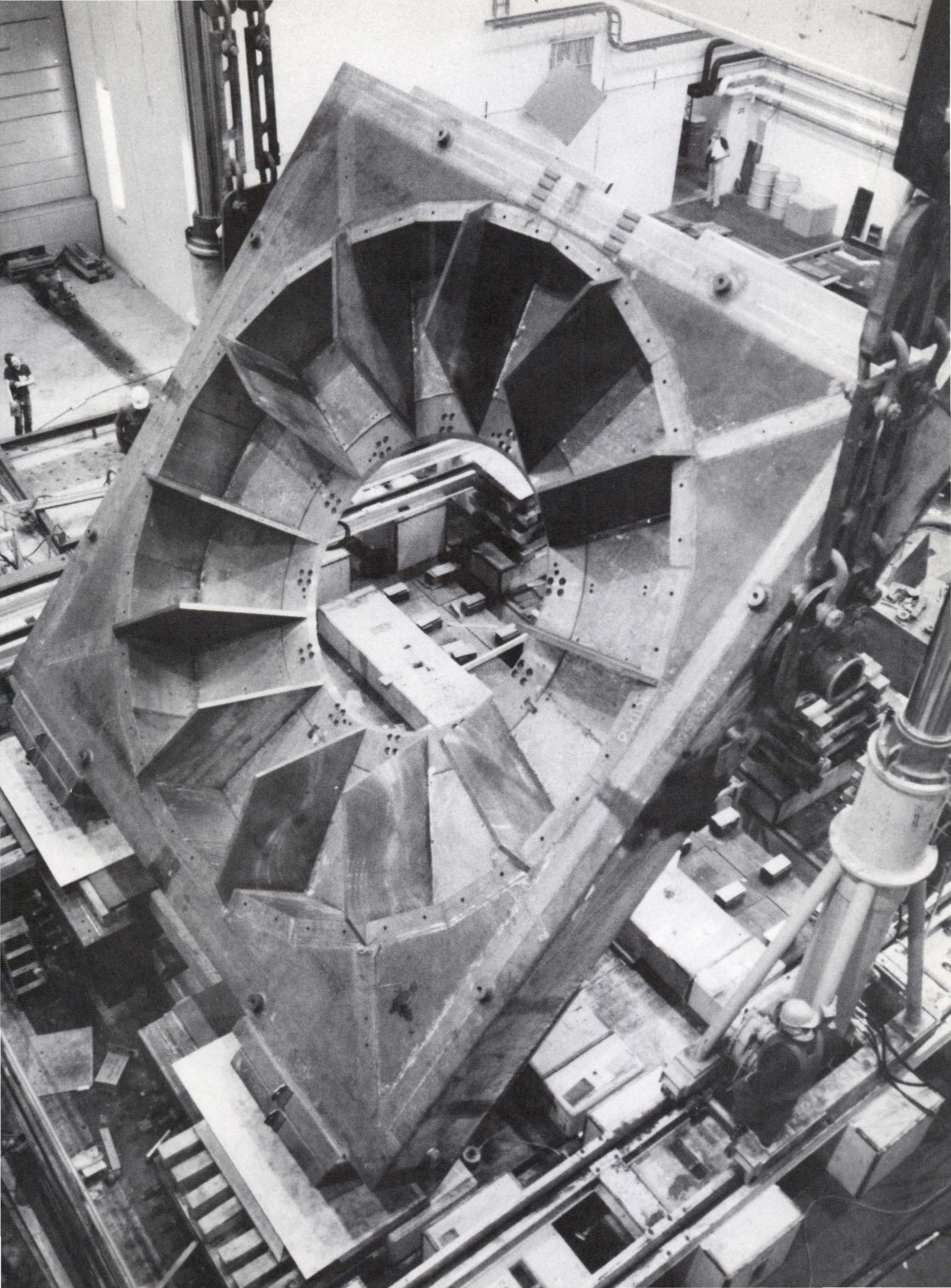
Pete Lentini measures up against the superconducting solenoid coil.

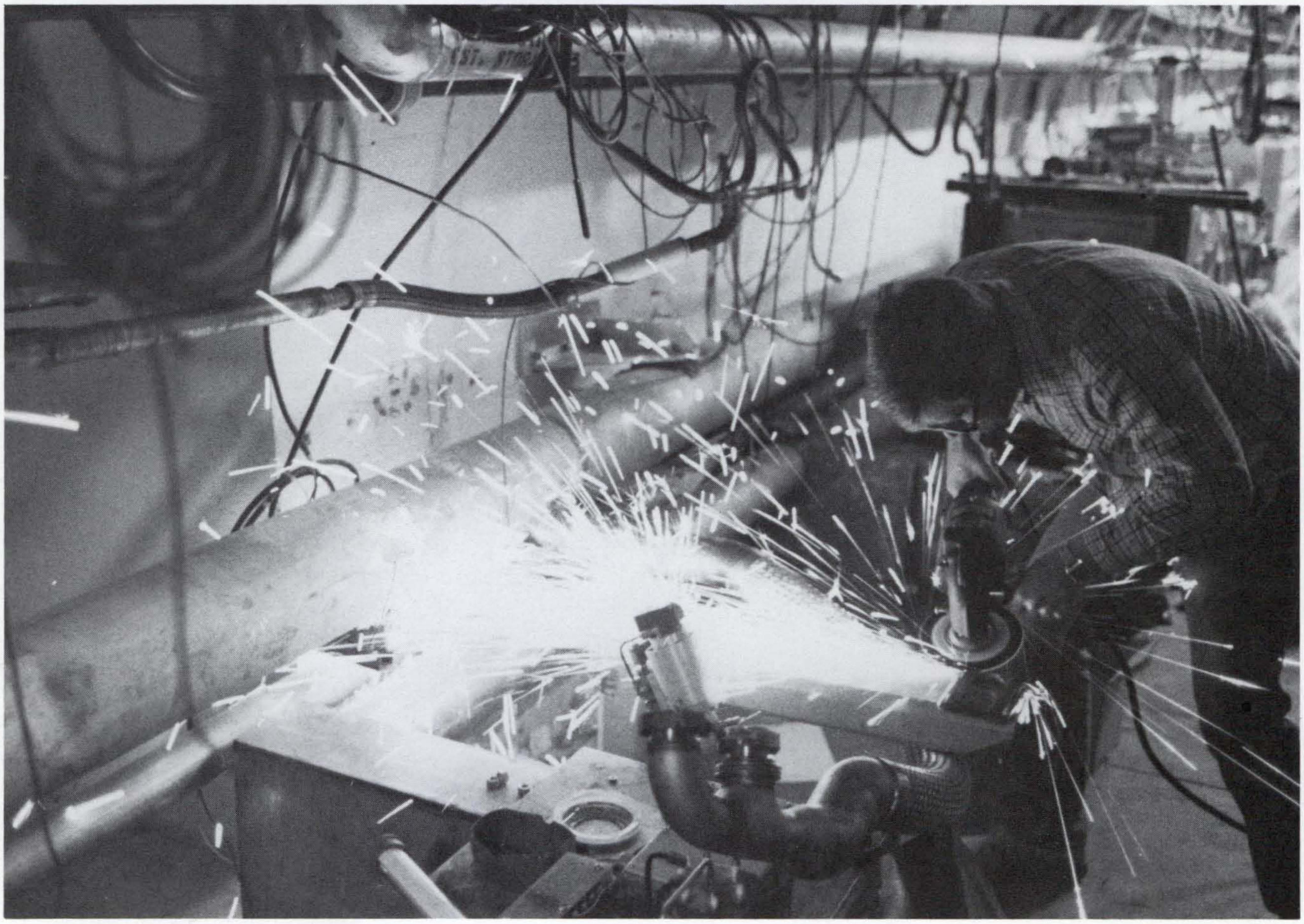
←

The solenoid coil arrives at O'Hare International Airport from Japan.

Welding the support ribs on the magnet end wall.

Raising the north end wall of the solenoid magnet yoke. →

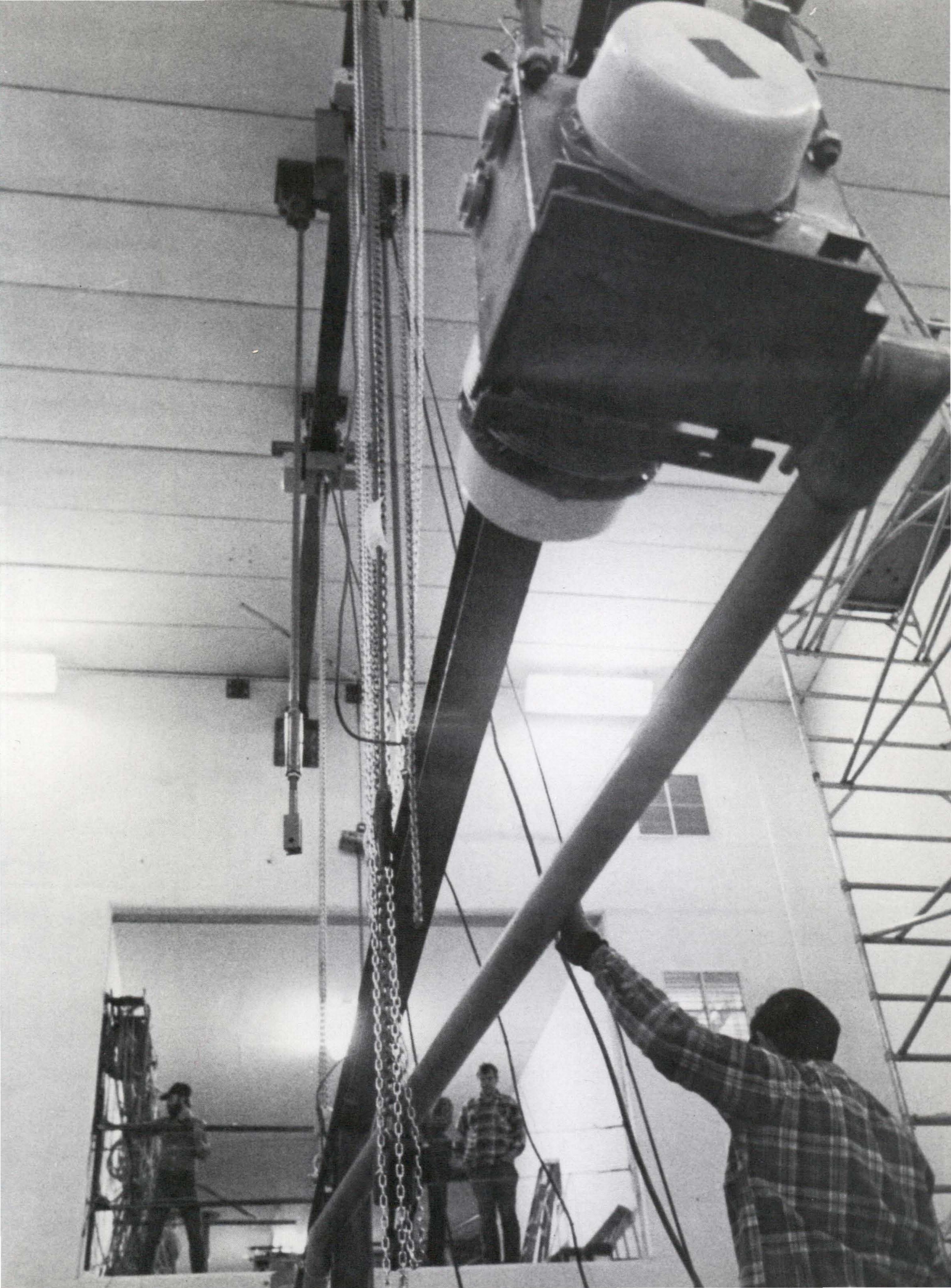


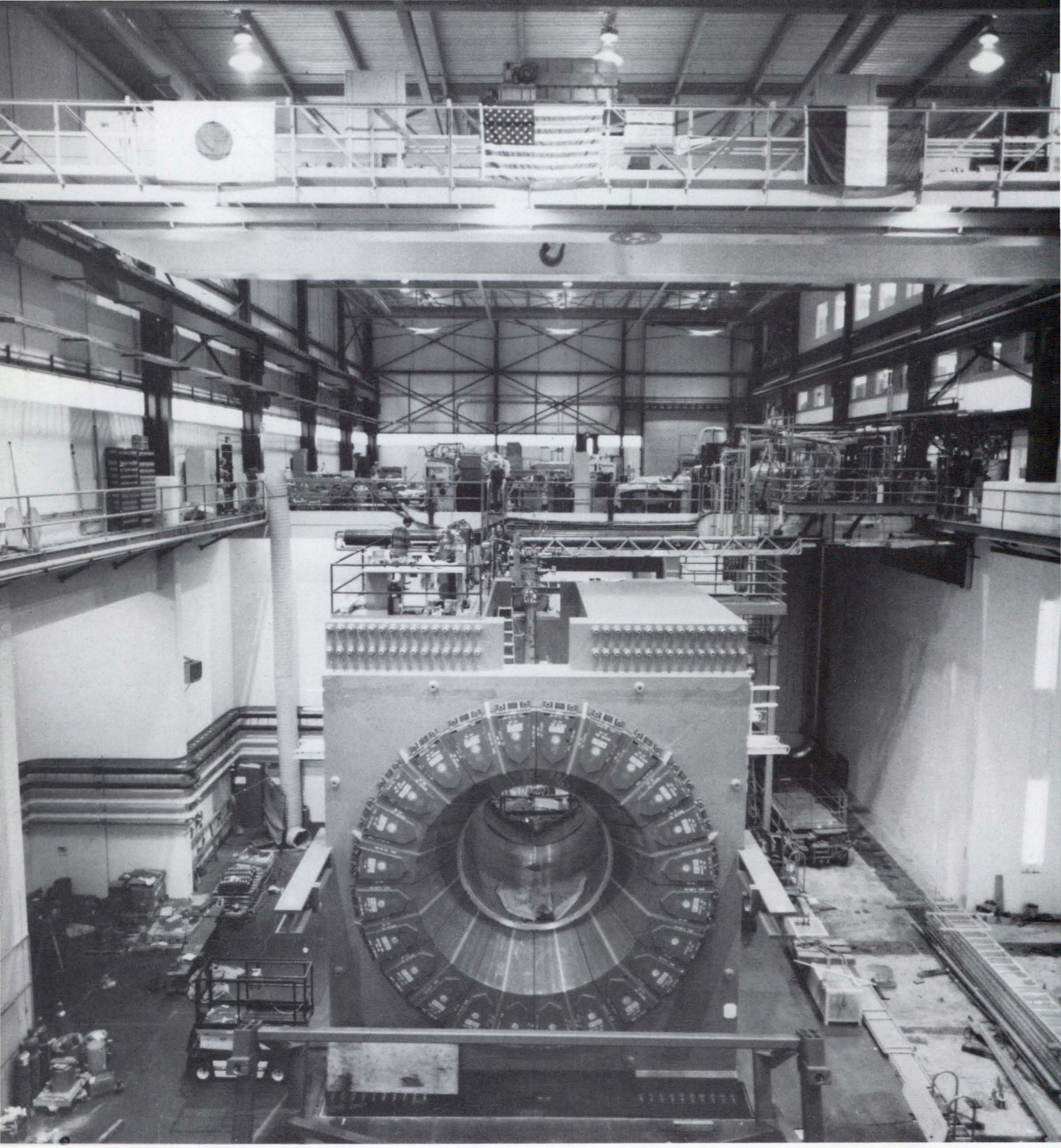


Preparations for the installation of the final-focus magnets (low-β quadrupoles).

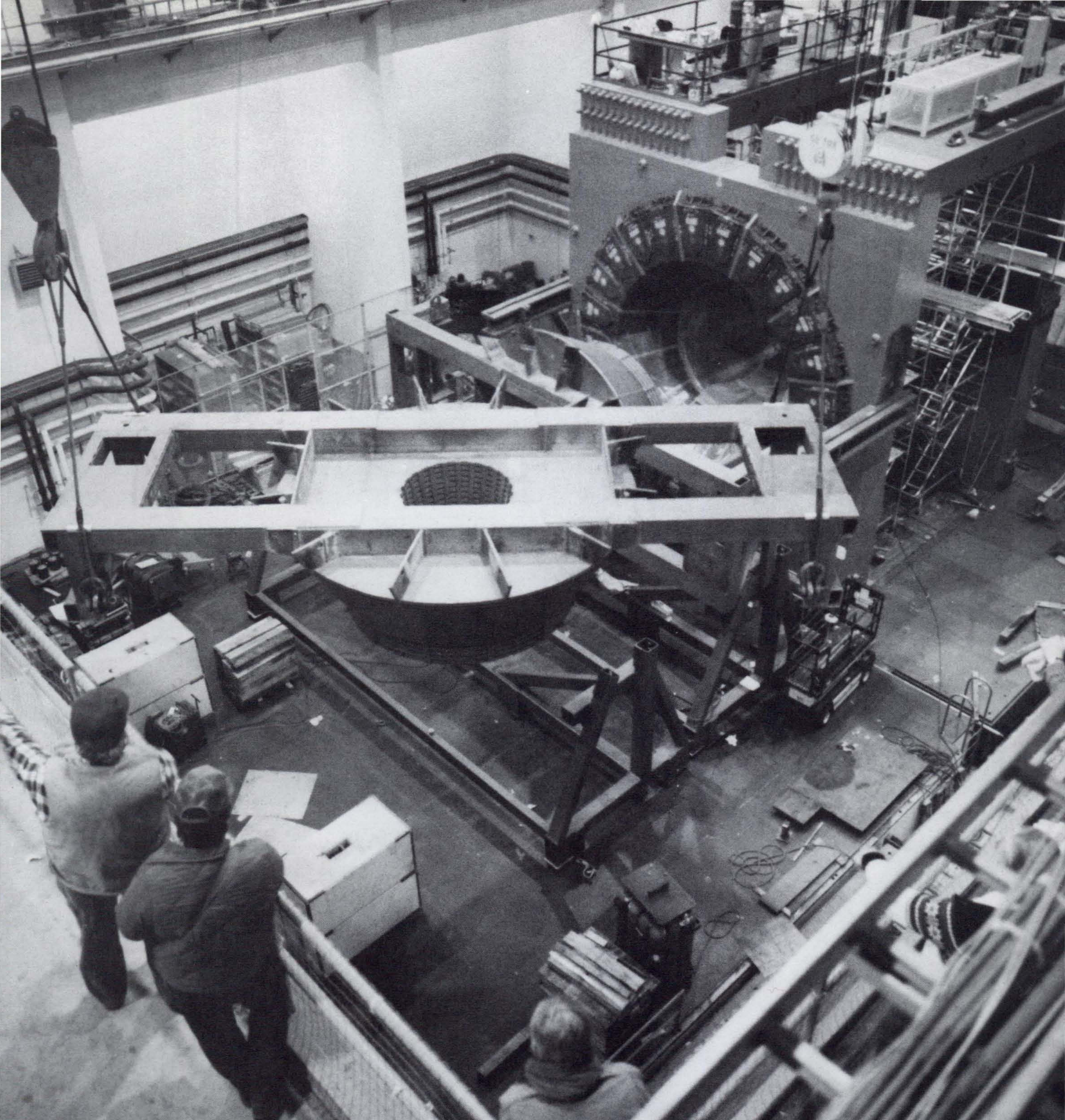
→

Installation of the low-β quadrupoles into the Tevatron at BO.

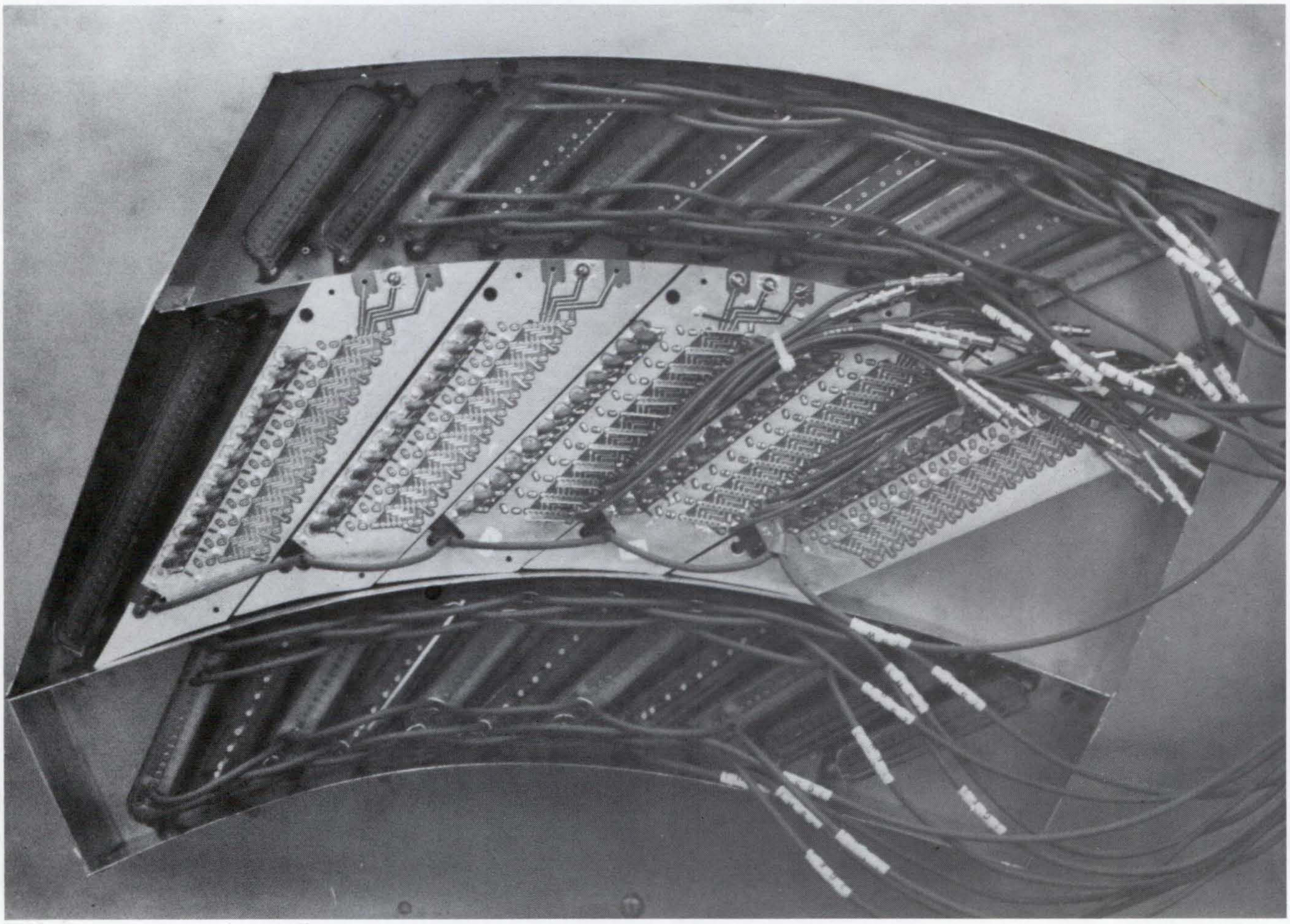




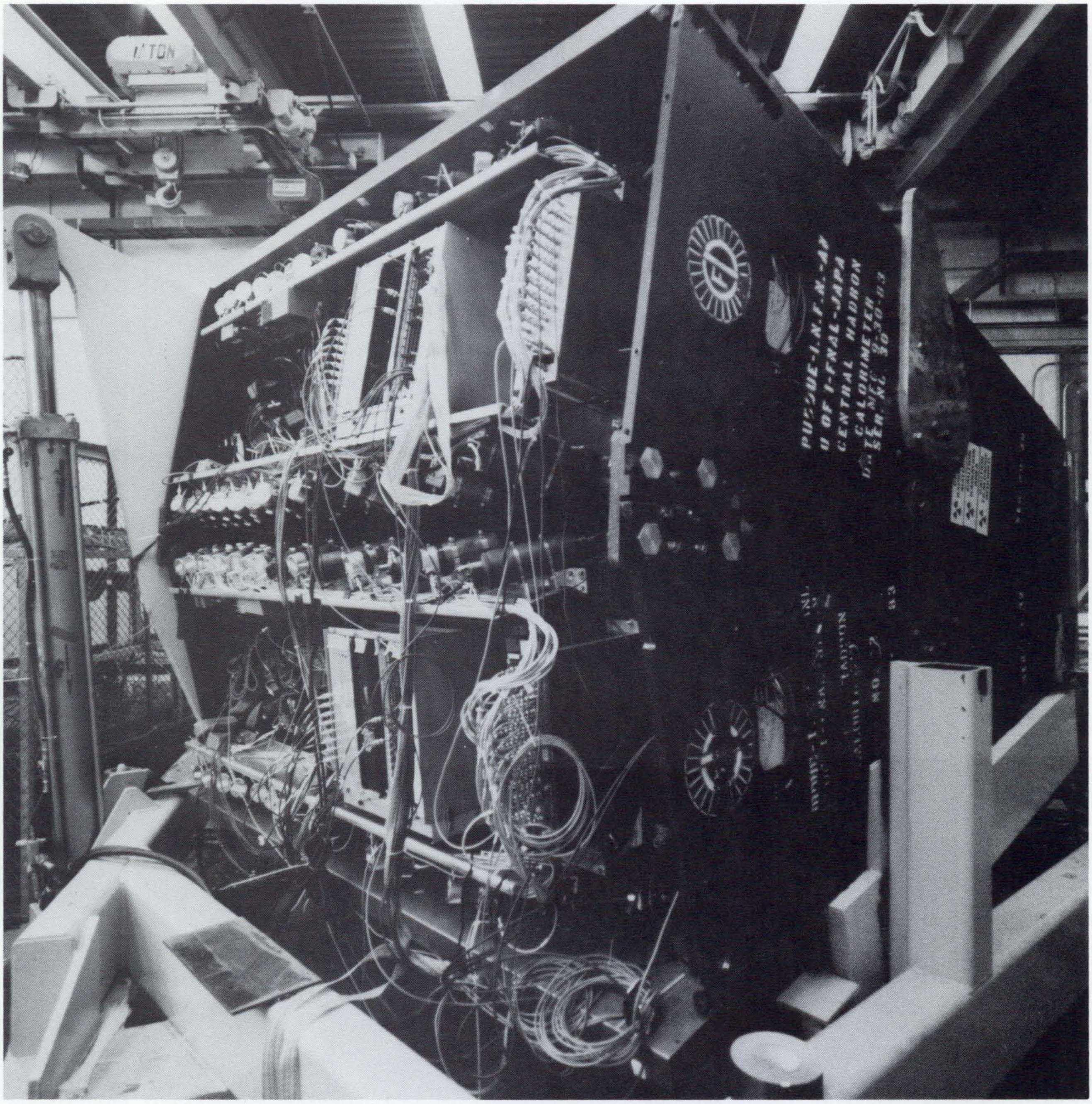
The completed magnet yoke with the solenoid coil, cryogenics, and end-wall calorimeter modules installed.



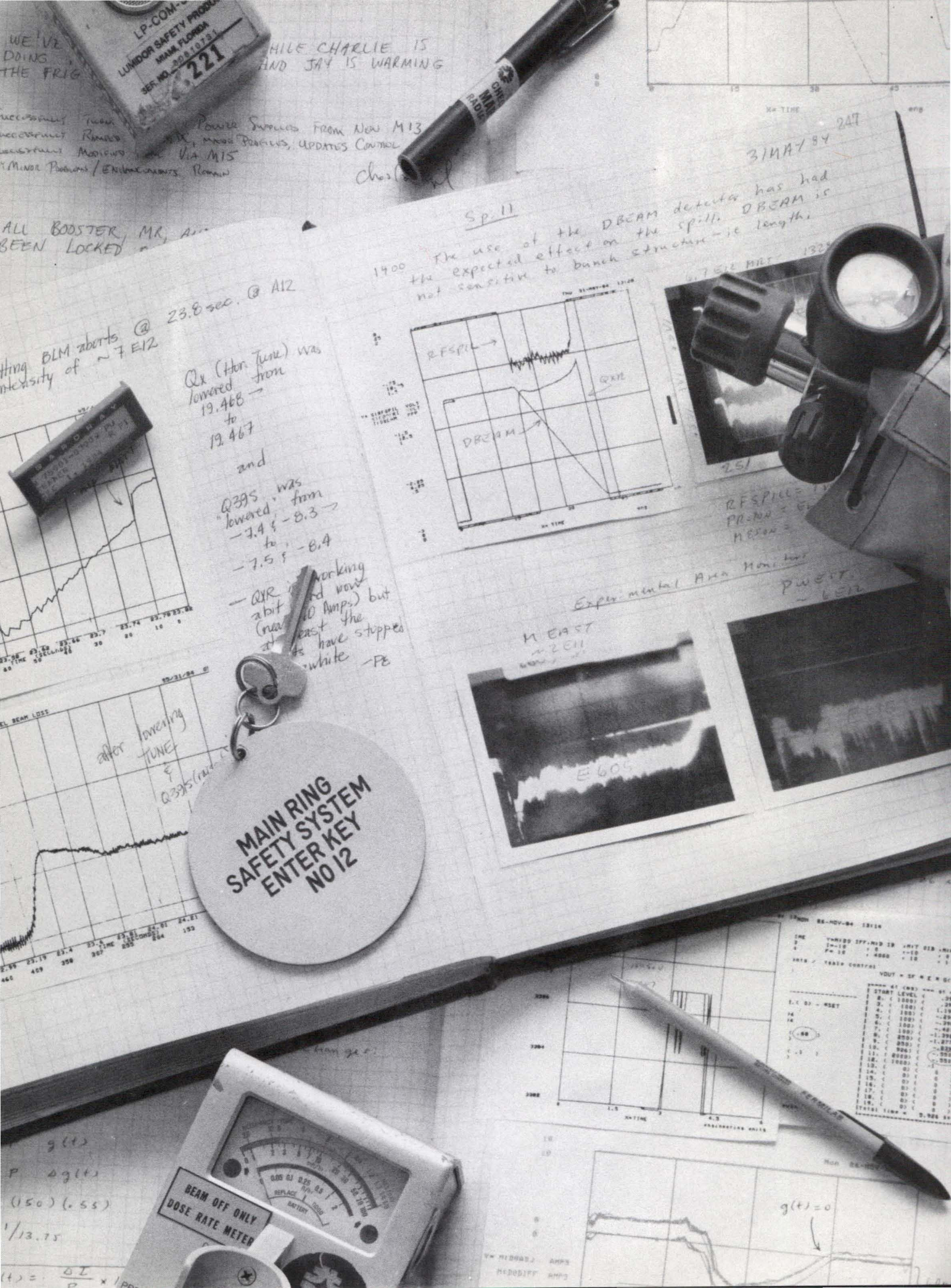
Lowering the second magnet end plug into the Assembly Building pit.



Prototype of the central tracking chamber preamplifiers and special wire alignment blocks.



Completed central calorimeter modules undergoing final testing and calibration in the NW beam line.


LUMIDOR SAFETY PRODUCTS
MIAMI, FLORIDA
221
WHILE CHARLIE IS
AND JAY IS WARMING
POWER SUPPLIES FROM NEW M13
31 MAY 84
The use of the DBEAM detector has had the expected effect on the spill. DBEAM is not sensitive to bunch structure - ie length.
RFSPILL
DBEAM
QXR
Qx (Hor. Tune) was lowered from 19.468 to 19.467
and
Q395 was "lowered" from -7.4 & -8.3 to -7.5 & -8.4
Experimental Area Monitor
M EAST
E605
after lowering TUNE
MAIN RING
SAFETY SYSTEM
ENTER KEY
NO 12
BEAM OFF ONLY
DOSE RATE METER
FERMILAB
g(t) = 0

VI. Development of the Energy Saver Operation.

Introduction

The completion of the Energy Saver commissioning, described in detail in last year's Annual Report, is only the beginning of the Laboratory's mission. Only when protons of appropriate intensity are being delivered to the targets in the Meson, Neutrino, and Proton Laboratories, with the uniform spill the various experiments require and for a reasonable number of hours per week, will we be able to consider our task successfully completed.

The primary objective in 1984 was, in fact, to establish again at Fermilab a valid high-energy physics experimental program, first at 400 GeV and then at 800 GeV. Preparations for the startup of colliding beams in 1985 also continued. This section presents the accelerator story, including the successes, failures, and activities during the '84 summer and fall shutdown, which should lead to substantial improvements in 1985 for the fixed-target program and allow proton-antiproton collisions in the Tevatron when the Antiproton Source commissioning is complete.

The Tevatron

This new accelerator was called the Energy Doubler (because it gives twice the proton energy of the original Fermilab Main Ring), the Energy Saver (because superconducting magnets and the necessary refrigeration use less energy than conventional copper-iron magnets), and it is now the Tevatron since one-trillion electron-volt energies are achieved. The performance specifications given for the Tevatron before its construction were that it should provide proton beams of energy 800 GeV to 1 TeV with an intensity of at least 2×10^{13} protons per pulse. The cycle time was to be 30 to 60 seconds, with a flattop of at least 10 seconds.

In the first full year of operation, most of these specifications have been met. The Tevatron has operated regularly at 800 GeV. The intensity is greater than 10^{13} protons per pulse and is not limited by the Tevatron, but by its injector. A cycle time of 60 seconds is standard; shorter times can be achieved when more rf is available. A flattop of 10 seconds was used during the first running period; 20 seconds is now standard.

Chronology of the Year

We have had a successful year in the sense that we met or almost met all performance specifications. We have worked hard to meet our operating schedules and here our success has not been as comprehensive. Let us step back a bit from the official start of the year 1984 for a running start, or a starting run.

High-energy physics experiments at 400 GeV with the Tevatron began October 3, 1983. By November 1, beam was delivered to the Meson Lab and experiments began taking data. A little later, on November 21, beam was delivered to the Neutrino Lab and soon seven target stations were in use, a solid experimental program.

The 400-GeV warmup run continued until February 14, when the accelerator was shut down on purpose. The main purpose of the shutdown was for installation of new equipment, but before that, operation at 800 GeV was tried. The tests were successful, accelerating beam to 800 GeV and storing it at that energy.

The Tevatron was shut down until March 17 for installation of the low-beta quadrupole system at B0. The purpose of this system is to reduce beam size and therefore to increase beam density at the interaction point. This will increase the luminosity of proton-antiproton colliding beams.

The obligatory odious ordeal of startup began on March 17, and the beam was ready for the first 800-GeV high-energy physics run on March 25. It was, however, a short interlude, because the first failure of a Tevatron magnet occurred the next day.

Replacing a superconducting magnet is much more lengthy than replacing a Main-Ring magnet because a portion of the ring (1/24, corresponding to one satellite refrigerator's worth of magnets) must be warmed up to room temperature, then cooled again after the magnet is replaced. The 800-GeV run was restarted on April 1 and went on from there.

There was an interruption of high-energy physics on April 18 for testing of the low-beta quadrupole system at location B0. The tests were very successful; it was possible to start with the low-beta system turned off, as will always be the case during acceleration. Turning the system on changes the operating characteristics of the beam already in the accelerator.

The only other scheduled interruptions of high-energy physics were for routine maintenance and briefly for the dedication of the accelerator on April 28. The run continued until July 16, but there were four more magnet failures in June and July. We discuss these failures in the following section.

The accelerator shutdown that started July 17 was a long one. The tunnel was excavated at F17, and a number of the precast tunnel hoops were replaced by ones of larger cross section to allow more room for equipment for extraction of beam to the antiproton-production target, and for reinjection of antiprotons. In addition, the tunnel was modified at D0, the second colliding-beams interaction region, for installation of the components for the overpass that locally raises the Main-Ring beam by approximately 6 feet to leave room for a detector. During this long shutdown, the ring was warmed up and modifications made to correct the problems causing magnet failures.

Startup began on November 3. There was a certain amount of discreet nail biting. Components for the D0 overpass were delivered from the Magnet Factory at the last moment, and there was some worry about whether the whole installation would work. Purposely taking the beam away from the plane of the accelerator was a brand new adventure. In fact, it worked very well after only a few days of commissioning. Beam was accelerated in the Main Ring and injected into the Tevatron on December 2. Tests continued through December, with the second 800-GeV high-energy physics run to begin on January 3, 1985.

Performance

The best way to talk about performance is in terms of the scheduled and actual hours and the number of protons on target. We give these data in the accompanying table.

Table I. 1984 Accelerator Performance.

	400 GeV	800 GeV	Total
Number of Weeks	18	10	28
Scheduled HEP Hrs.	2042	1276	3318
Actual HEP Hrs.	1131	648	1780
% Up Time for HEP	55	51	54
Weekly Averages			
Scheduled HEP Hrs./Week	113	128	
Actual HEP Hrs./Week	63	65	
Accelerated Protons			
Protons/10^3 Scheduled Hrs.	2.7×10^{17}	1.3×10^{17}	
Protons/10^3 Scheduled Hrs., Best Week	5.5×10^{17}	2.5×10^{17}	

In interpreting the data from the above table it is important to note that even in its initial running period from October 3, 1983, to February 14, 1984, problems with the Tevatron prevented running only about half of the scheduled time. For the best week 5.5×10^{17} protons/10^3 scheduled hours were accelerated, with the average for the 18 weeks of 400-GeV operation being 2.7×10^{17} protons/10^3 scheduled hours. The fraction of running time is at least as good and the intensity much higher than in the first year of Main-Ring operation.

The level of operation at 800-GeV is not typical of what we expect in the future because of the five Tevatron dipole magnet failures. These failures were due to an unsupported section of superconducting cable. Immediately after leaving the coil package, the cable is bent upward through 90° and held by an insulating block-clamp. The cable then is bent through a semicircle, at the end of which is another insulating block-clamp that directs the cable to the next magnet through the helium connection. Five magnet failures during the 800-GeV run were attributed to the 6 inches of unsupported cable between the two insulating blocks. When the magnets are ramped from injection field (150 GeV) to 800 GeV, the cable experiences a force of approximately 100 pounds which causes the cable to move and rub against cryostat parts, resulting in abraded cable insulation, a short-to-ground, and, ultimately, magnet failure. The cables at the other end of these magnets have proper support. Whenever this happened the magnet had to be replaced. In order to remove and replace each damaged magnet it was necessary to warm up 1/24 of the ring. After replacing each failed dipole, cooldown and refilling with liquid helium required approximately two days. Three to four days were lost for each magnet failure.

This major problem has been eliminated. Because of the already scheduled shutdown of the Tevatron from July to November 1984, it was possible to open the 380 magnets that needed to be modified. After grinding away approximately 10 inches of weld on the cryostats, a cable support was incorporated that was known to be adequate to prevent conductor motion. This work has been done and the Tevatron has been successfully ramped to 800 GeV (November 29, 1984) with the repaired magnets.

The Tevatron was also used for SSC studies. Even though these efforts have been kept at lower priority than the Fermilab experimental program, some interesting observations were possible which may influence the design of the SSC. Beam measurements made on the Tevatron were compared with computer simulations, showing a high level of predictability. Coasting-beam studies show long lifetimes and lack of strong resonance driving terms. Low-energy studies were made to demonstrate that injection energies of as low as 1/15 of final energy are possible.

Other Activities

In addition to providing support that made possible the work described above, the various accelerator departments participated in other activities during 1984. Several examples are given below by Curtis Owen, Injector Department Head; Gerald Tool, Electrical Engineering Support Group Leader; and Dixon Bogert, Accelerator Division Controls Group Leader:

Curtis Owen: Injector

Vacuum tube circuits in the anode modulator for the Linac final power amplifiers and in the screen modulator for the driver amplifier were replaced with much simpler and more reliable solid-state devices. After several months of prototype development, the conversion was accomplished very smoothly during the long 1984 shutdown. A second project was the design and installation of an additional 8-GeV extraction system for the Booster. The primary reason for this is to provide an 8-GeV test beam for the Debuncher Ring (TeV I); however, the extra extraction system and beam dump will be invaluable in the course of normal operation with the Main Ring and Tevatron. It will permit Booster beam studies and tuning at a reasonable rate parasitically without dumping 8-GeV beam in the Main Ring or in the Booster. The design allows an arbitrary fraction of the 84 bunches of beam in the Booster to be delivered to the Main Ring (for bunch coalescing studies or any other purpose) with the remainder delivered to the new beam dump.

Gerald Tool: Electrical Engineering Support

A program was carried out to rebuild the A2 and A3 Tevatron power supplies to provide steady-state operation of the Tevatron at energies up to 1 TeV for colliding beams. At any given time, one of these is the holding power supply, and the other is an installed spare operating as one of the 12 ramping supplies. This group, as well as other Accelerator Division support groups, made significant contributions to designing and implementing antiproton source systems. It is estimated that during 1984 about 80% of this group effort involved TeV I work.

Dixon Bogert: Accelerator Division Controls

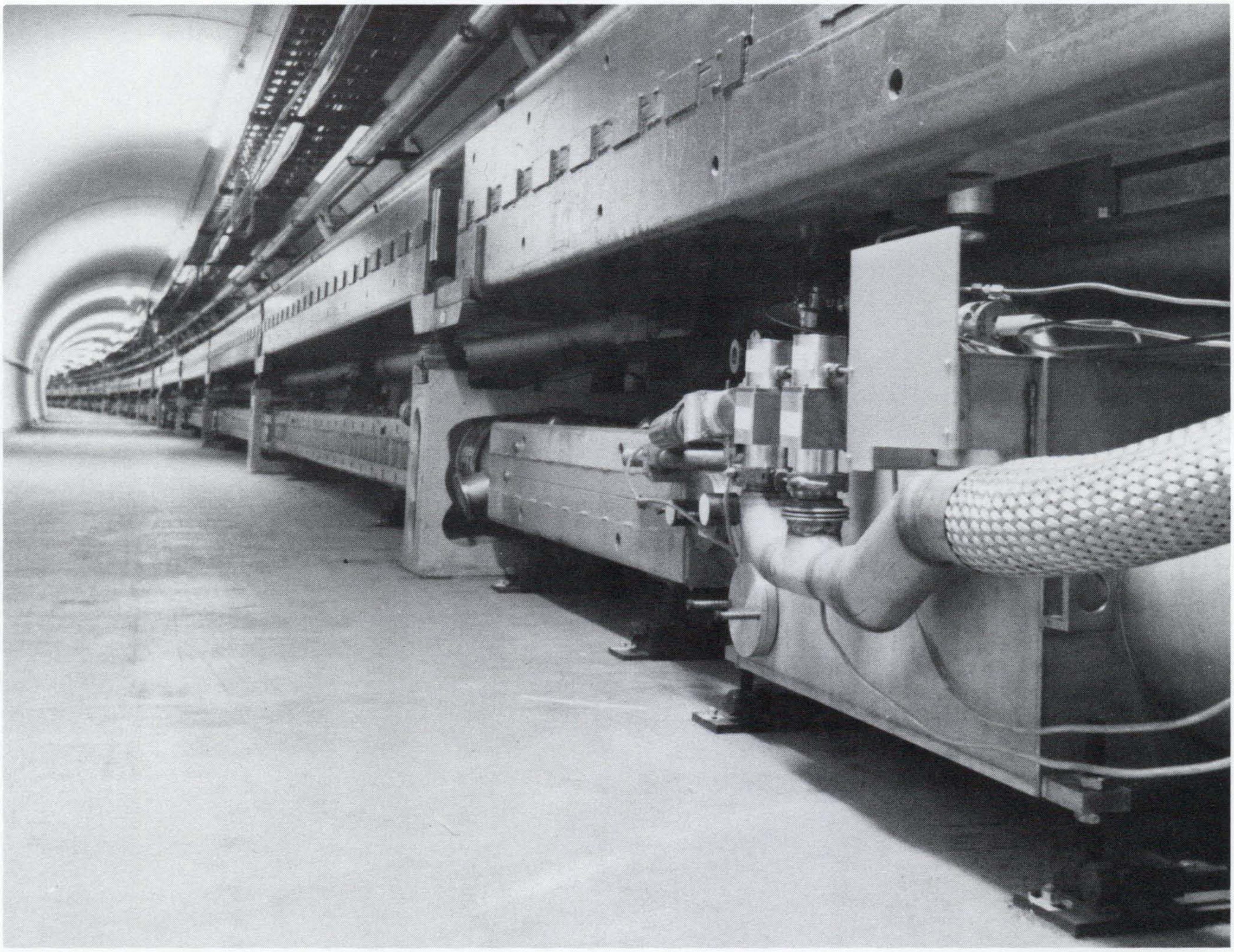
Major tasks undertaken were: 1) Conversion of the Main-Ring Control system to the ACNET system, culminating in the successful operation of the Main-Ring including the D0-overpass in November 1984; 2) Ongoing development of the controls required for the $\bar{p}$ source; 3) Continuing support for the improved operation of the Tevatron including new items such as the B0 low-beta region, the QXR system (quadrupole extraction system), and superdamper control with the possibility of tune measurements of the Saver made at 50 Hz; 4) The continued improvement of general ACNET services including alarms and Save-Compare-Restore capabilities; 5) The acquisition, in conjunction with the AD/Calculations Group, of a third VAX 11/785 computer and a Floating Point Systems FPS-164 attached processor. This equipment will greatly improve the Accelerator Division's ability to study and simulate accelerator performance and future accelerator designs. There were 62 man-years of effort recorded by AD/Controls during 1984. Nineteen of these years, or about 30% of the total, were devoted to support for the $\bar{p}$ source. The greatest part of this support was electronic development of control modules and systems, including microcomputer support. Nine man-years of effort, or about 15% of the total, were devoted to ongoing support for the Tevatron systems as outlined in number 3) above. The remaining 55% of the effort was devoted to a combination of conventional controls support and the Main-Ring Conversion project. The ACNET control system now has 14 consoles operational. With the exception of the Booster, all components of the accelerator are now controlled through ACNET.

Support for the $\bar{p}$ source controls has included several new micro-computer projects. The decisions made several years ago to support the $\bar{p}$ source as an extension of the ACNET/Tevatron controls system has greatly simplified the job of creating software interfaces for TeV I.

Conclusion

In summary, the first two high-energy physics runs, October 1983 to February 1984 at 400 GeV, and March 1984 to July 1984 at 800 GeV, were highly successful. Accelerators using superconducting magnets have come of age and future accelerators such as the proposed SSC can now, with confidence, move forward using the Tevatron as a solid technology base.

William B. Fowler



Half Core
#5201
Starrett

VII. Magnet Production at Fermilab

Introduction

Almost all of the work of Fermi National Accelerator Laboratory involves the use of electromagnets in one way or another. From its very beginning, the Laboratory has been involved in purchasing magnets, building magnets, modifying magnets, repairing magnets, or advising others on the subject of magnets. With the completion of magnet production for TeV I and TeV II, well over 3000 major electromagnets have been assembled at Fermilab for use in both accelerator construction and experimental programs. If smaller magnets ("trim" magnets for orbit correction or beam steering) are included the total number rises to 4-5000.

At different times, and in different places, magnet design and construction have gone forward under organizational names as diverse as: The Magnet Factory, Technical Services, Technical Support Section, Industrial Area, and Energy Doubler Magnet Group.

Whatever the designation or place, the central role of magnets in Fermilab's evolution has remained unchanged. The following review of this crucial activity provides a glimpse into some of the Laboratory's history.

Conventional Magnets

In the late 1960s-early 1970s, activity at what was then known as the National Accelerator Laboratory centered around planning the design and fabrication of magnets for the Main Ring, the 200-400 GeV conventional accelerator. Finding the answers to questions regarding design, external procurement of components, on-site versus off-site fabrication, assembly and measurement, and eventual rework of magnets as design modifications became necessary, led members of the design group through a chain of decisions that would prove useful in later years.

This was a large and revolutionary undertaking: the construction of upwards of 1000 magnets in the relatively short time frame set by Robert Wilson's desire to have an operating accelerator on time and under budget.

The process of 400-GeV magnet fabrication began with planning and design at an Oakbrook office complex, moved into early testing at Argonne National Laboratory, then to preliminary fabrication in rented warehouse space in West Chicago, and in the Village on the NAL site. The need for very precise alignment of the inner coils close to the median plane, and the reluctance of industry to try to meet this tight specification led the Laboratory to build the coils in-house. By 1970, decisions on fabrication and assembly had created the need for an industrial complex at Fermilab. Industrial Buildings 1 and 2 were constructed and occupied as a test facility, and coil-winding and assembly facility respectively.

As completed magnets were placed in the Main Ring, where they were subjected to actual operational loads, production-related electrical problems arose that occupied the Magnet Facility for nearly a year before the actual business of operating the accelerator could proceed.

With the completion of the 400-GeV accelerator, efforts in the Magnet Facility turned to supplying the magnets needed in the Experimental Areas. A proliferation of magnet types and variances were required, from analyzing magnets to bending magnets, from septum magnets to EPB dipoles. Since flexibility now assumed pre-eminence over quantity, the Magnet Facility underwent a transition from the mass-production techniques used on Main Ring magnets to the smaller-scale production better suited to specialized production.

The Saver Era

By 1975, planning for the Energy Doubler (later the Energy Saver, and then the Tevatron) had been approved, and serious development effort had begun on a new generation of magnet, the superconducting quadrupoles and dipoles that would be used in the existing Main Ring tunnel to raise the circulating proton energy toward 1000 GeV.

When, in mid-1979, the Department of Energy authorized construction of the Energy Doubler/Saver, a second major production phase commenced, one that repeated the production techniques and demands from 400-GeV days, but that promised an eventual yield of more than twice the energy.

The basic manufacturing philosophy adopted was that, while superconducting magnets could be readily built by highly trained personnel lavishing great care on each magnet on a one-at-a-time basis, production of 1000+ magnets on a tight schedule would not allow for such luxury. Therefore, an early decision was made to develop, once again, new tooling and fabrication techniques that would allow production of superconducting magnets by less-skilled persons at an increased rate of speed, as had been done with the magnets for the conventional Main Ring.

From mid-1979 until early 1983, production of superconducting magnet components spread throughout almost the entire Laboratory. Model cryostats were fabricated by personnel from various Magnet Facility shops in the Village, and final cryostat assembly was carried out in Lab 5 in the Village. Industrial Building 3, constructed and occupied in 1974 as warehousing and storage space, became the production center for superconducting magnets. Room was made available at Industrial 1 for a test facility that included a 1500-watt refrigerator, new water system, upgraded power supplies, state-of-the-art data-acquisition systems and six large test stands for full-scale magnet measurement. By 1978, the demands of completing the Energy Doubler/Saver made clear the need for a fourth building, and Industrial 4 soon was ready for occupancy. Here, completed components for superconducting magnets were tested and stored before final assembly.

Superconducting magnet production hit full stride by 1980, and by 1981 production had risen from 5 magnets per week to 10. By 1982, as many as 20 dipoles were completed in weeks of peak activity. Quadrupole magnets were regularly produced at a rate consistent with their need.

All through the Saver years, Magnet Facility people continued to work on specialized magnets for specific beam lines and experiments. Late in the Saver production sequence, the Magnet Facility was called upon to assemble coils for a very large (60 feet long, with an aperture measuring 4 feet × 4 feet) analyzing magnet for E-605. These coils were formed as two-layer "pancakes"by an industrial vendor, and these "pancakes"were then insulated, assembled, and welded together as single units in Industrial 4. This entire process was carried out in time to vacate Industrial 4 in advance of the onslaught of completed Saver magnets, which eventually claimed all available floor space.

By 1983, nearly 2000 individual components had been completed, assembled, and installed to comprise the Energy Doubler/Saver. In August, 1983, in the spotlight of publicity created by the simultaneous occurence of the International Accelerator Conference at Fermilab, the Energy Doubler/Saver was successfully turned on and commissioned, achieving a new record energy of 800 GeV.

Tev I/Tev II

One might have expected a respite following the commissioning of the Saver. But, as we have noted, activities in other areas of magnet production had carried on right through the Saver era, and were to escalate in the following years.

As a companion piece to completion of the Energy Saver, an antiproton source was required to produce copious quantities of antiprotons that could be re-injected into the Saver and brought into collision with protons to achieve 2 TeV in the center-of-mass physics.

In February of 1981, funding for this antiproton source, or TeV I as the project was to be called, became available from the Department of Energy. A second program, TeV II, was funded in January of 1982. The purpose of Tev II was the upgrading of experimental areas to prepare them for 1000-GeV beam from the new superconducting synchrotron. Taken together, TeV I and TeV II resulted in large demands for additional magnets to be provided by the Magnet Facility, and took Fermilab magnet construction into two years of the most intense effort yet expended.

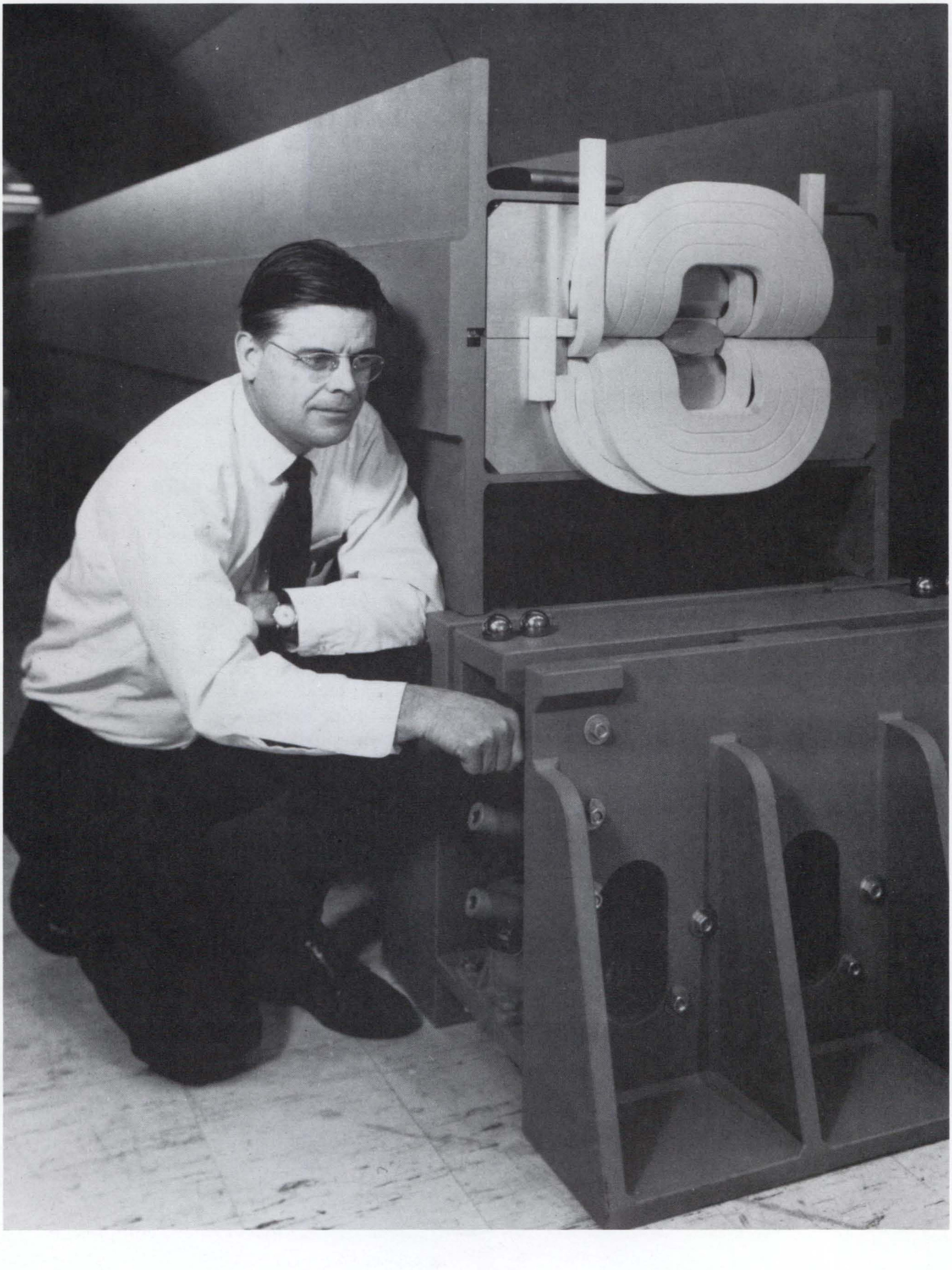
The Tev I program proved to be the larger of the two, since the number of different magnet characteristics within the program was greater than that of any previous Fermilab magnet production sequence. A total of more than 700 magnets consisting of 52 different types, many of which were to push conventional magnet technology to the very edge of feasibility, were called for in the TeV I program, including the largest bending magnets ever built at Fermilab (Accumulator dipoles, each of which weigh 53 tons), and the largest quadrupoles yet constructed at Fermilab. Each of these magnets required a prototyping stage in which production procedures were developed to achieve the required magnetic-field tolerances, low power consumption, and the ability to be taken apart, moved, and reassembled in a reproducible way. From final design through prototyping, production, and testing, the Magnet Facility utilized equipment and manpower to the fullest with around-the-clock and weekend shifts from 1983 through early 1985.

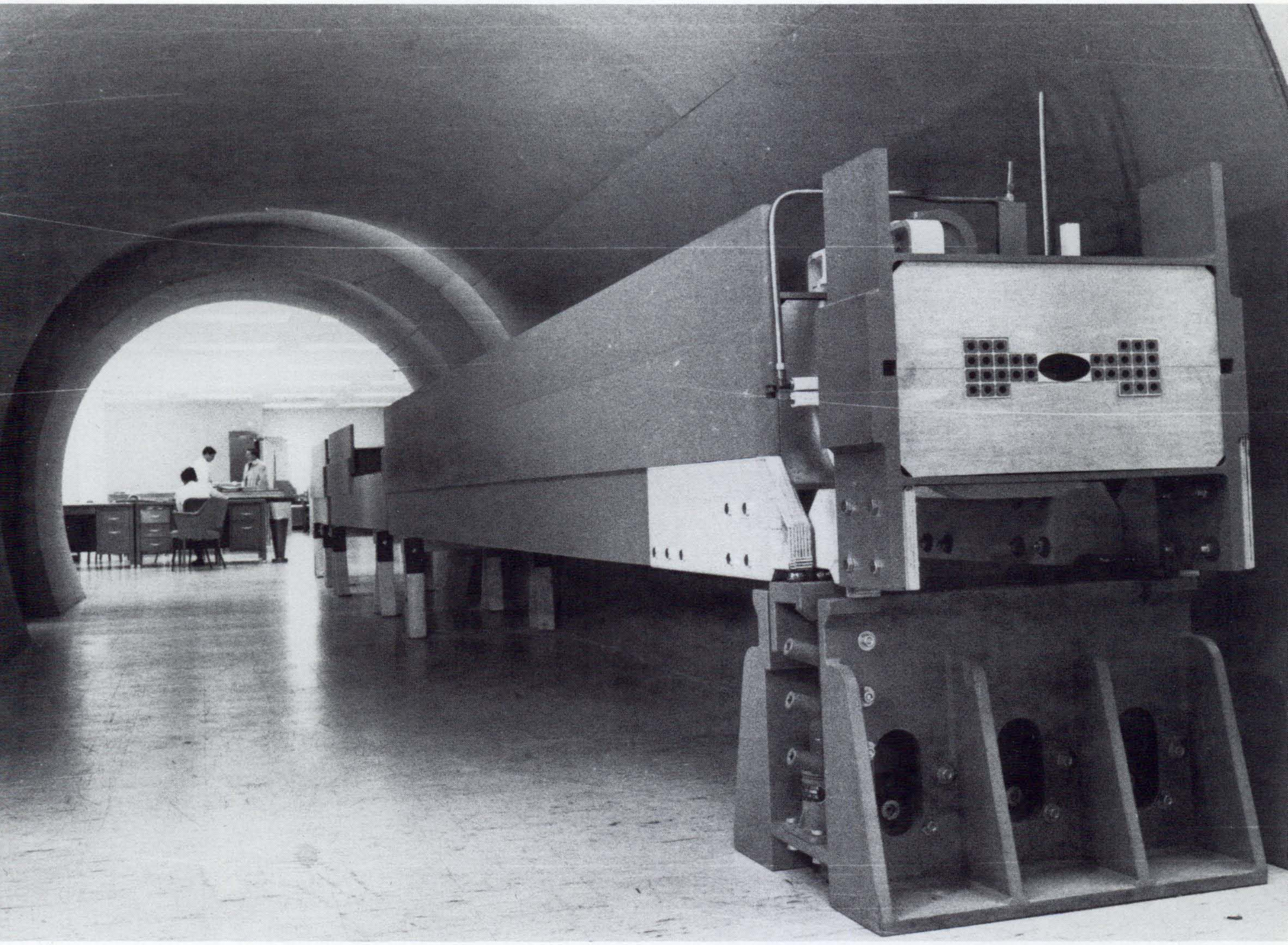
Fortunately, the magnets for TeV II were tried-and-true standbys: 4Q120 quadrupoles, 6-3-120 dipoles, 3Q120 quadrupoles, and special-function magnets for beam-extraction and beam-line use. All in all, it was necessary to build something over 200 additional magnets to meet TeV II needs. Wherever possible, coils and other sub-assemblies were ordered from outside vendors and assembled at the Laboratory in their final configuration.

To assist in this task, the Conventional Magnet Facility, the Energy Doubler Magnet Construction Group, the Central Machine Shop, and elements of Drafting and Design were combined in mid-1981 into one unit, the Technical Support Services Section. TeV I/TeV II production demands were such that a fifth building, Industrial Center, with a different architectural style and substantially greater floor space than the other four buildings, was designed and begun in late 1981. A very rapid construction period resulted in Industrial Center being ready for occupancy and use in little less than a year. Machinery utilized in the construction of TeV I magnets was brought to Industrial Center in late 1982. Existing production equipment was supplemented with help from DIPEC, a stockpile of machine tools maintained by the Government. Principally, 4 large coil-winders were built. The hearts of these machines were constructed from boring-mill turntables left over from Korean War-era tank turret production. Along with these winding tables, large hot-air curing ovens and additional sand-blasting equipment were installed, as well as innumerable small fixtures and peripheral production aids.

As magnet production for TeV I and TeV II draws to a close, the magnet builders at Fermilab see ahead of them yet another period of development work on superconducting magnets, but this time on a much grander scale: the 20 TeV collider, or SSC, which would operate at 40 TeV in the center-of-mass. These magnets would be made of superior superconductor, and would be 40 to 60 feet long. Some 100 or so of these giant magnets would have to be built and thoroughly tested to insure the success of SSC.

R. A. Cundy
Philip V. Livdahl





The mockup of an early Main-Ring dipole magnet at the Oakbrook office complex.

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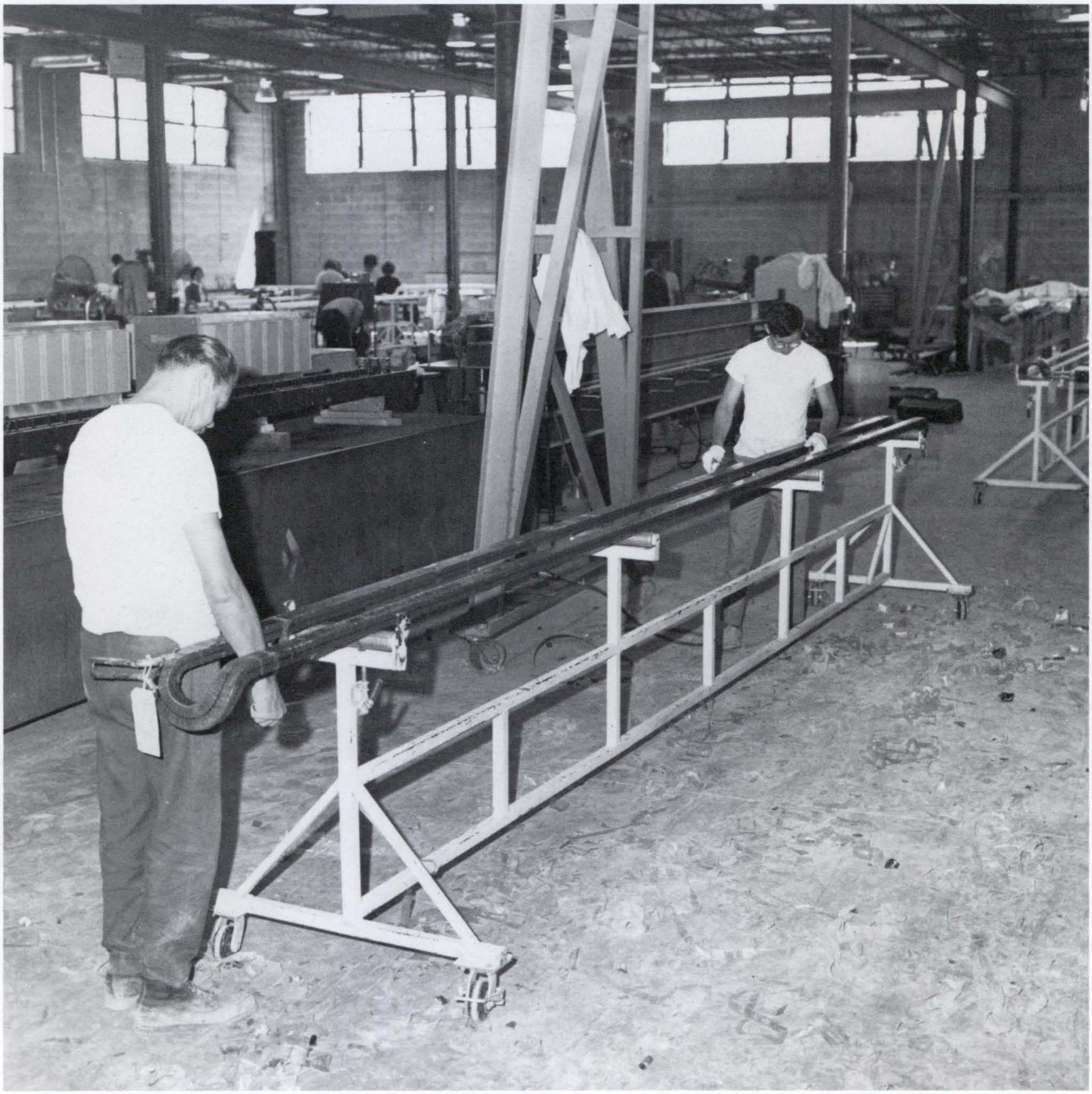
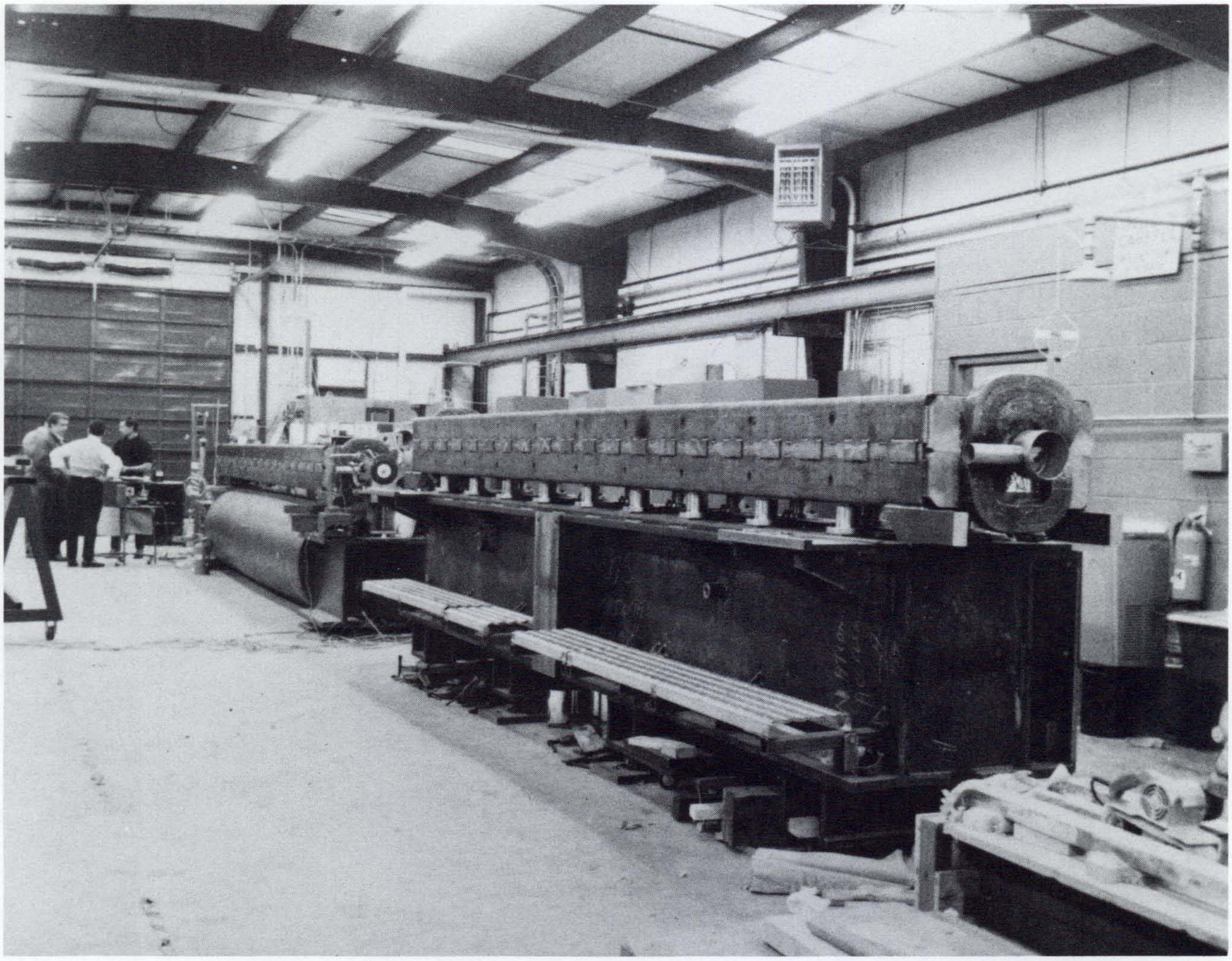
Robert Wilson with a model of an early Main-Ring dipole at the Oakbrook office complex in 1967.

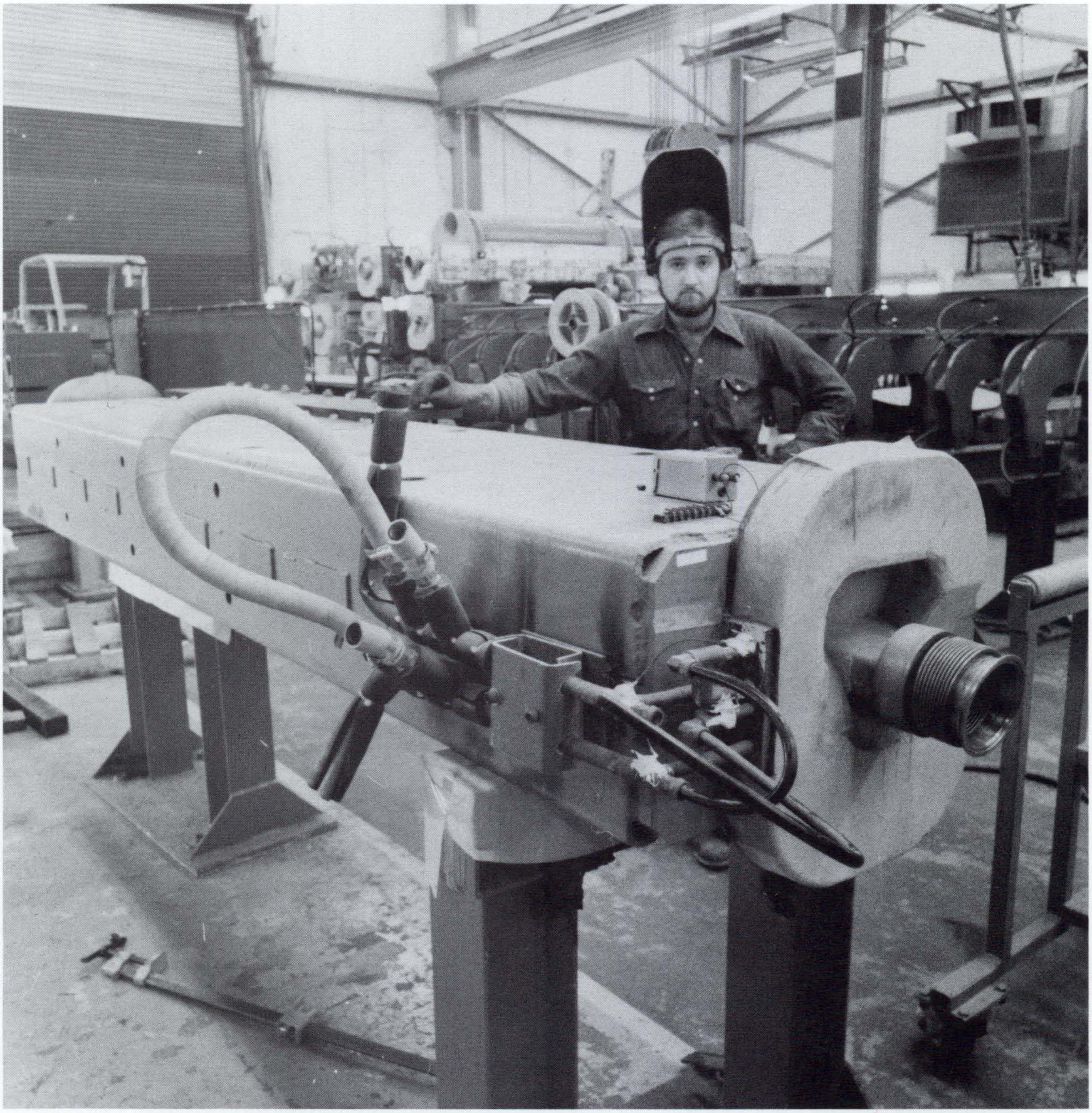


Insulating a coil for a conventional Main-Ring magnet at the West Chicago warehouse, 1970.

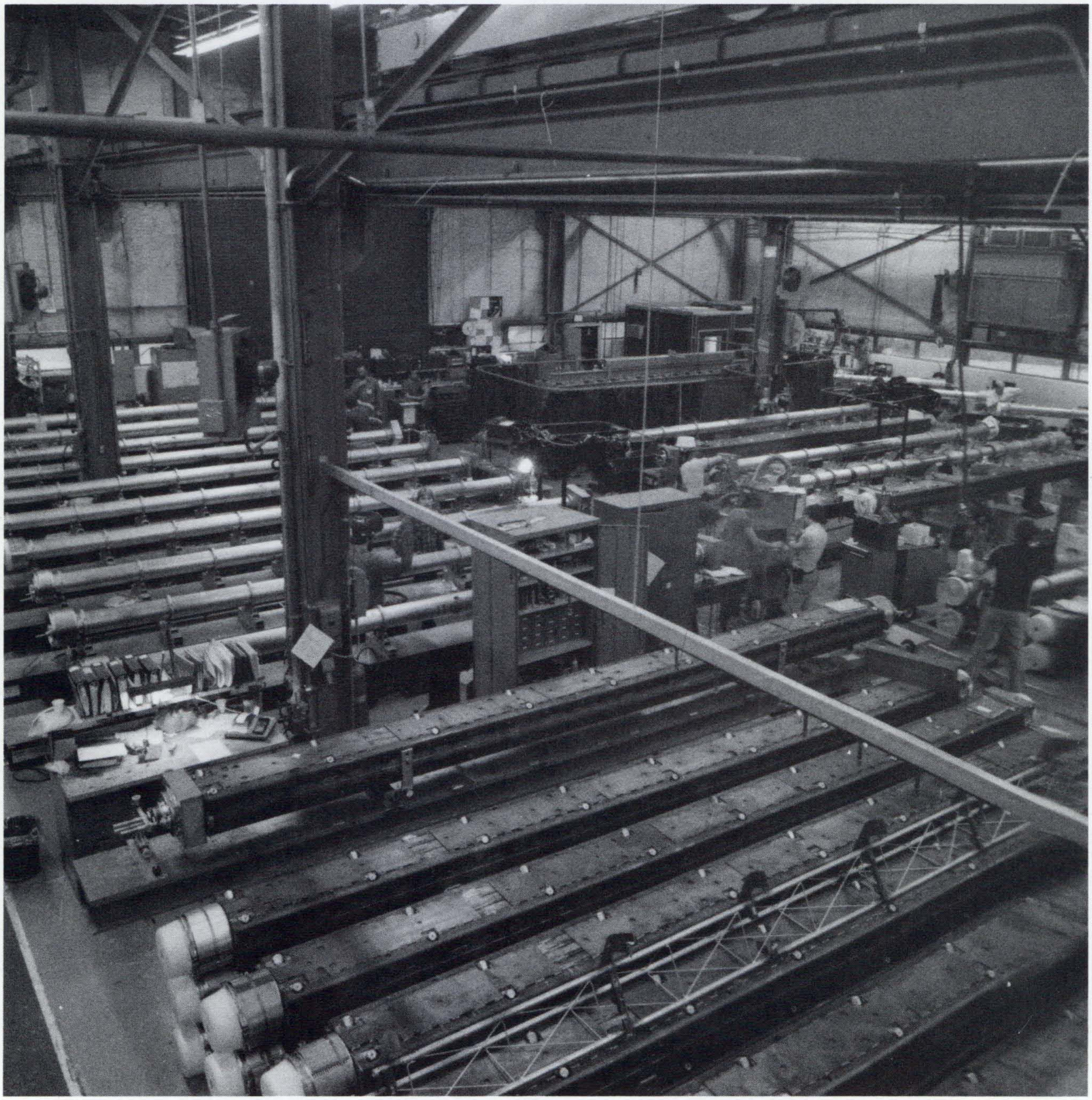


A Main-Ring dipole on the granite surface plate in Lab 5.

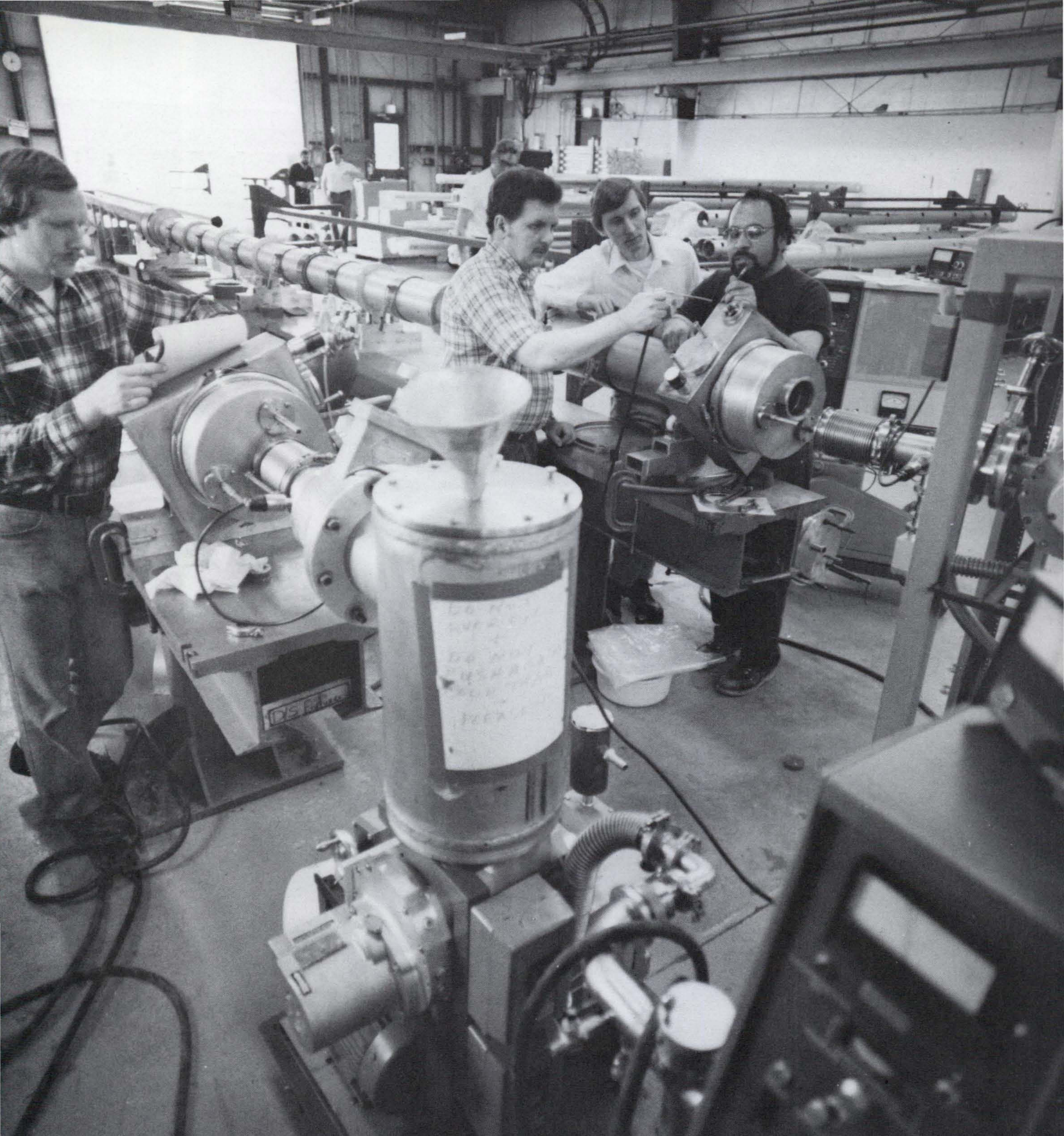
Carlos Hojvat with a dipole magnet for E-537 in P-West.



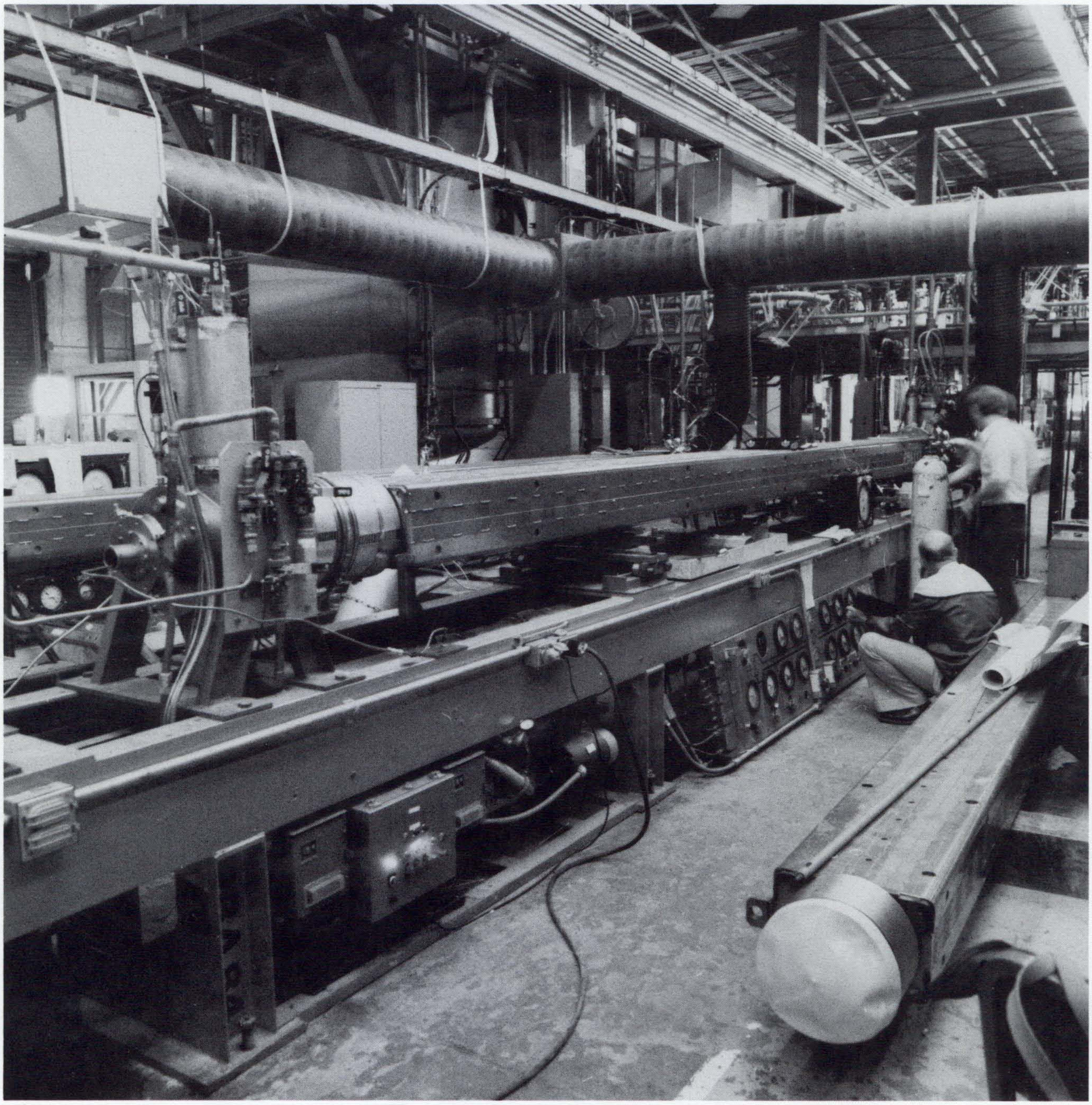
Welder Bruce Smith in Industrial 2 with a 63120 dipole magnet used in experimental area beam lines.



An overview of the Energy Saver dipole final assembly area at Industrial 1.

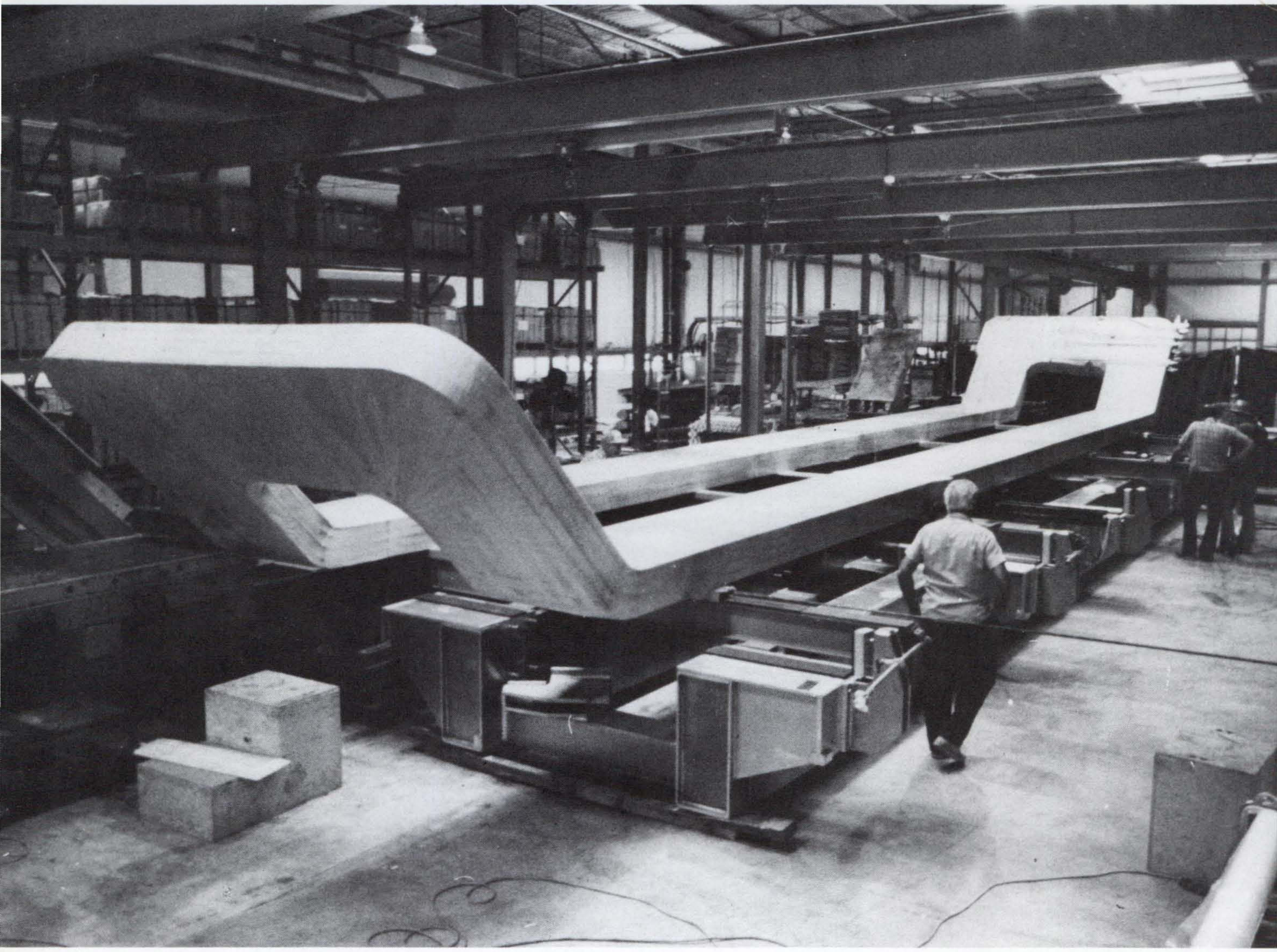


Bruce Kling, Dennis Ostrowski, Camillo Flores, and Steve Kliviwski assembling Saver cryostats at Lab 5 in the Village.

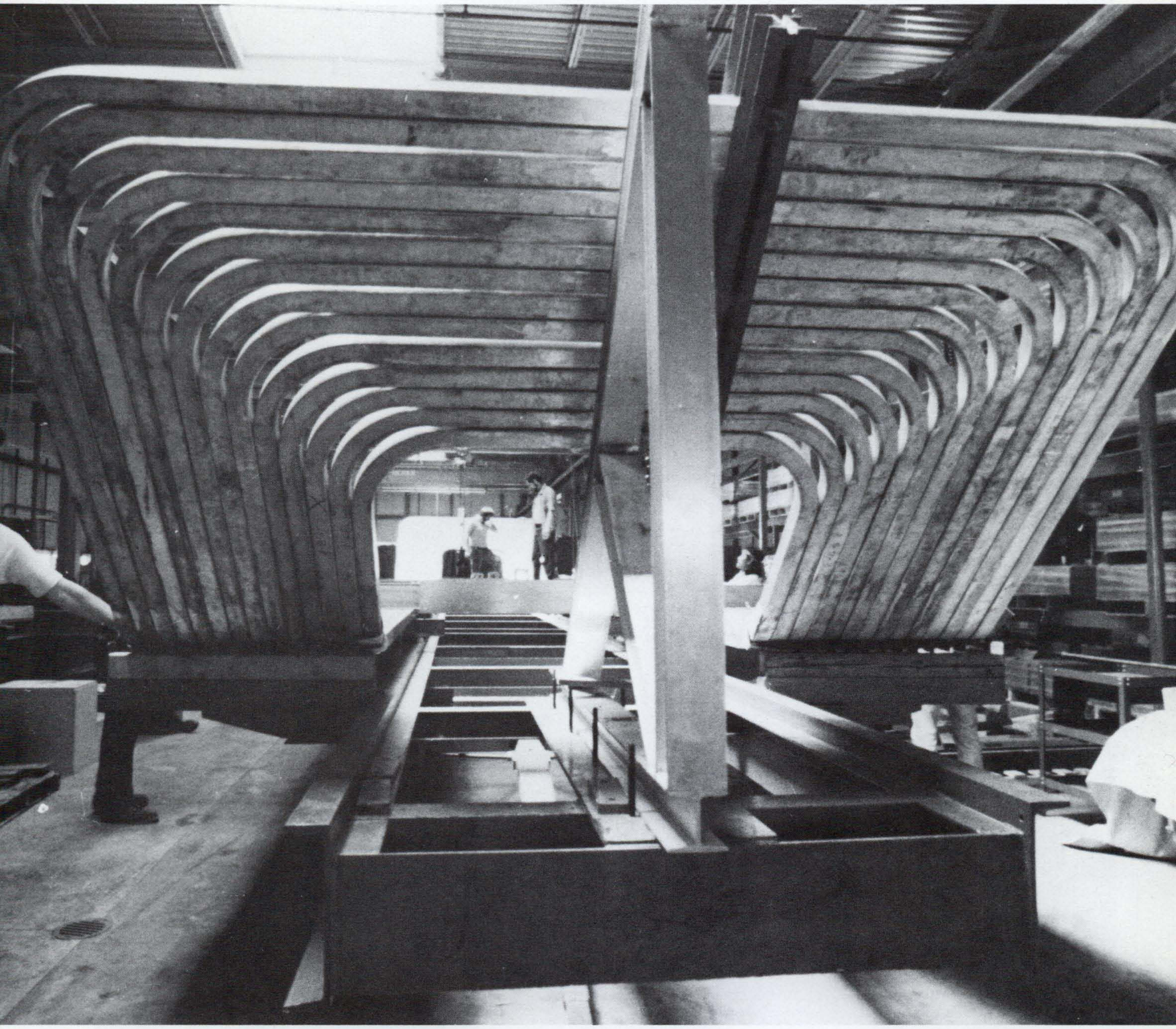


A test stand for Saver magnets at the Magnet Test Facility in Industrial 1.

Gary Andrews and Norm Leja stacking Saver magnets and spool-pieces at Industrial 4 prior to installation in the Main-Ring tunnel.

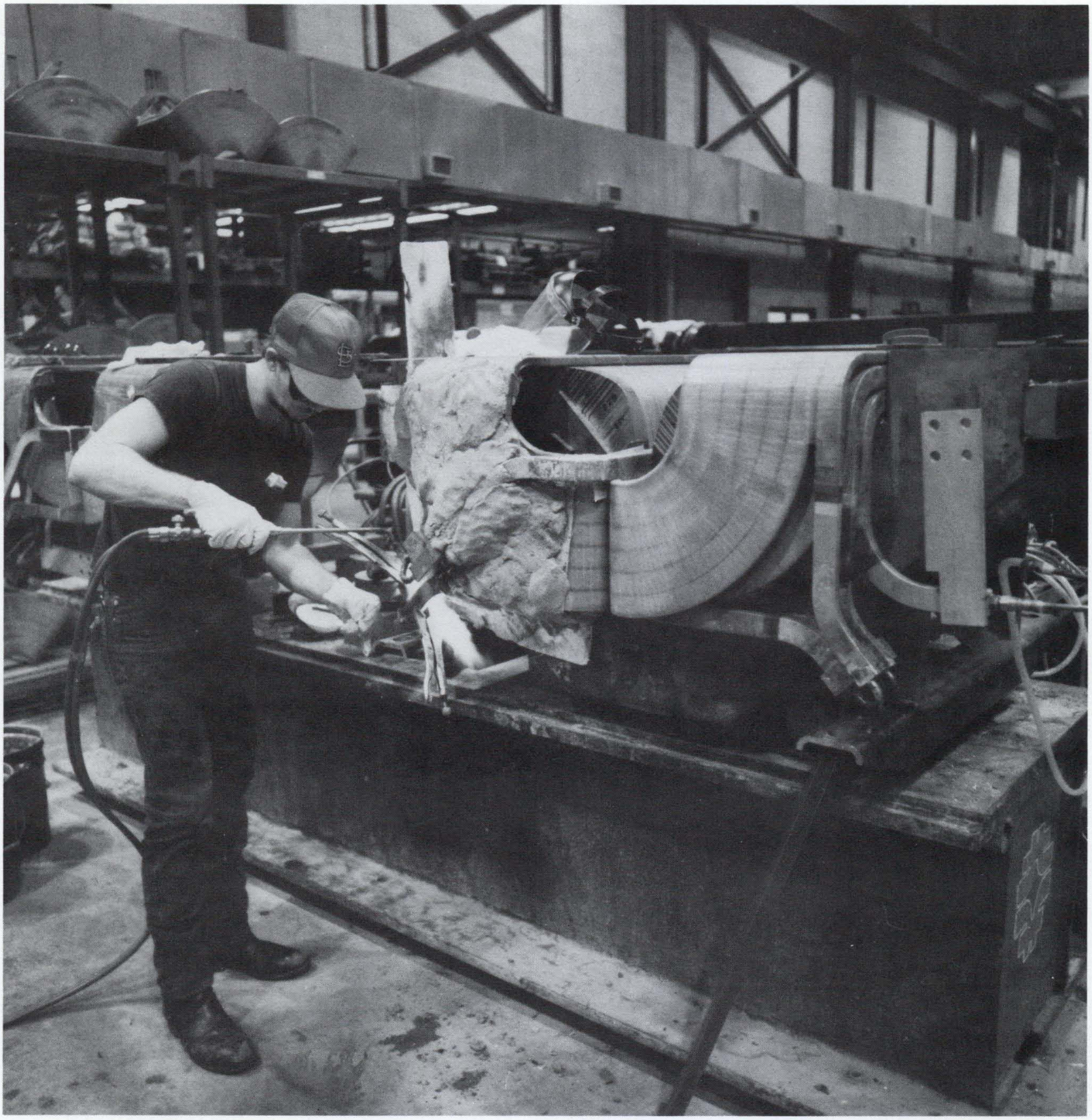


One of four coils for the E-605 dipole magnet being assembled in Industrial 4.

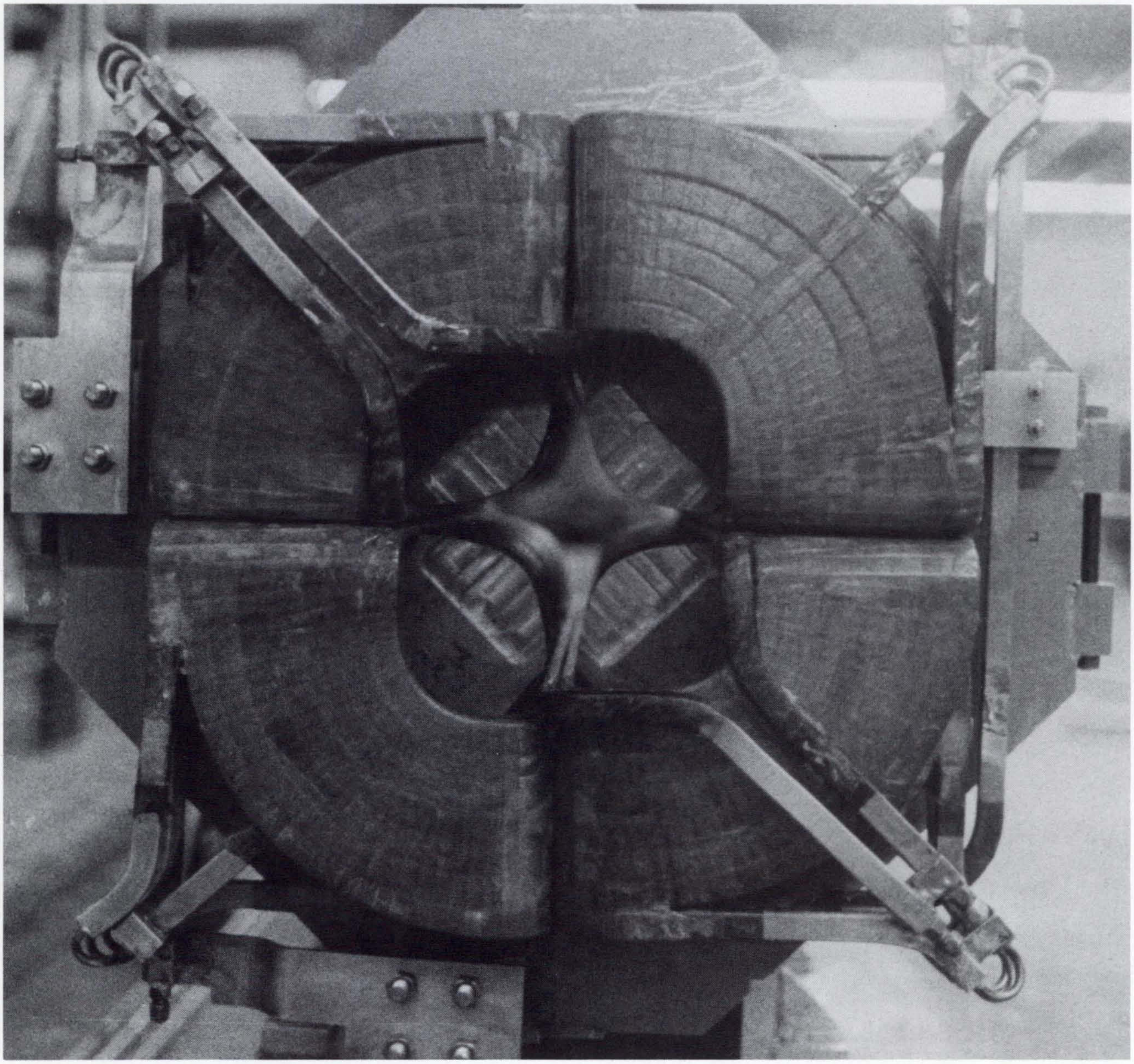


One of four coils for the E-605 dipole magnet being assembled in Industrial 4.

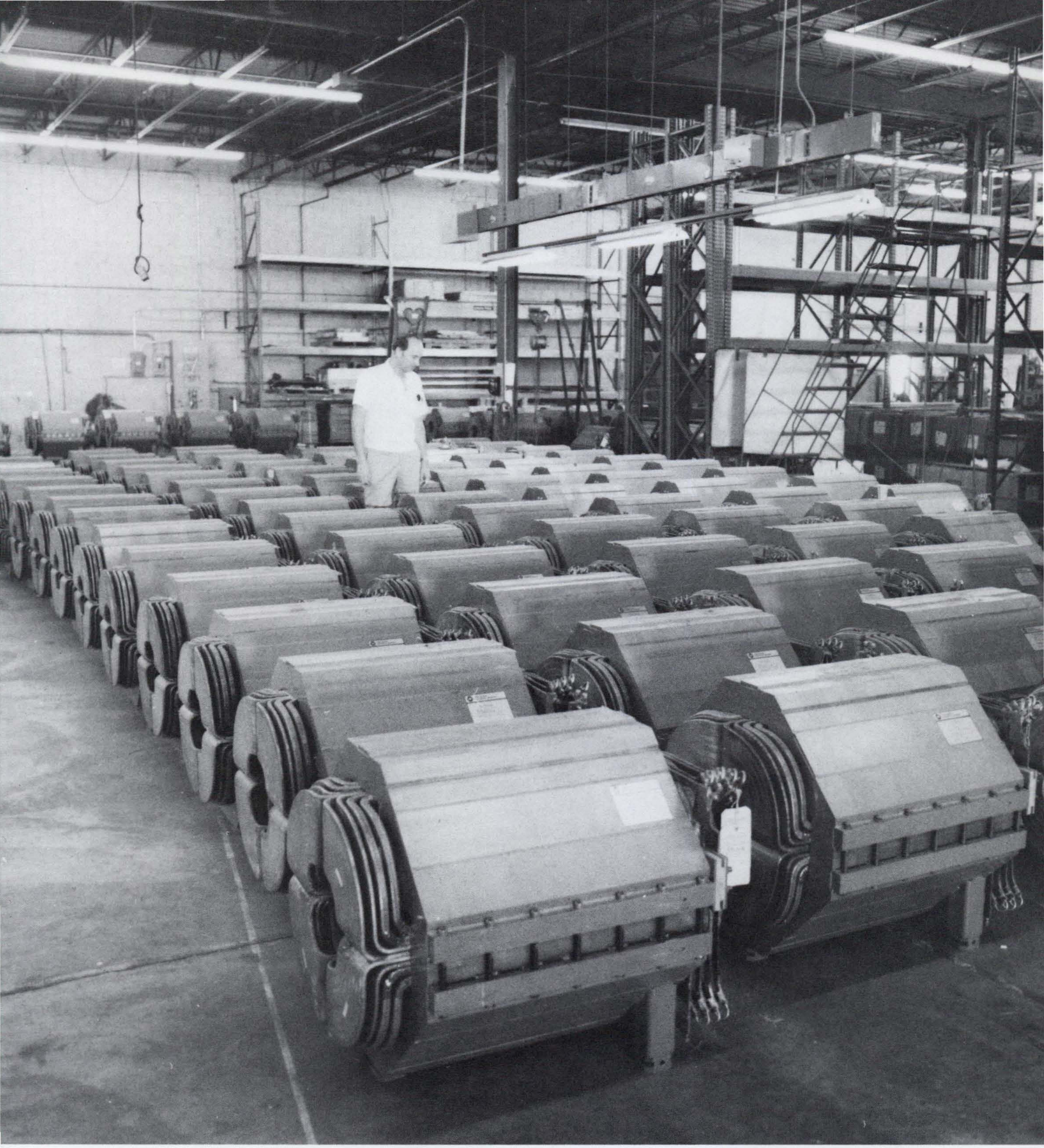
Jack Jagger with a coil for a TeV II 20-in. bump magnet.



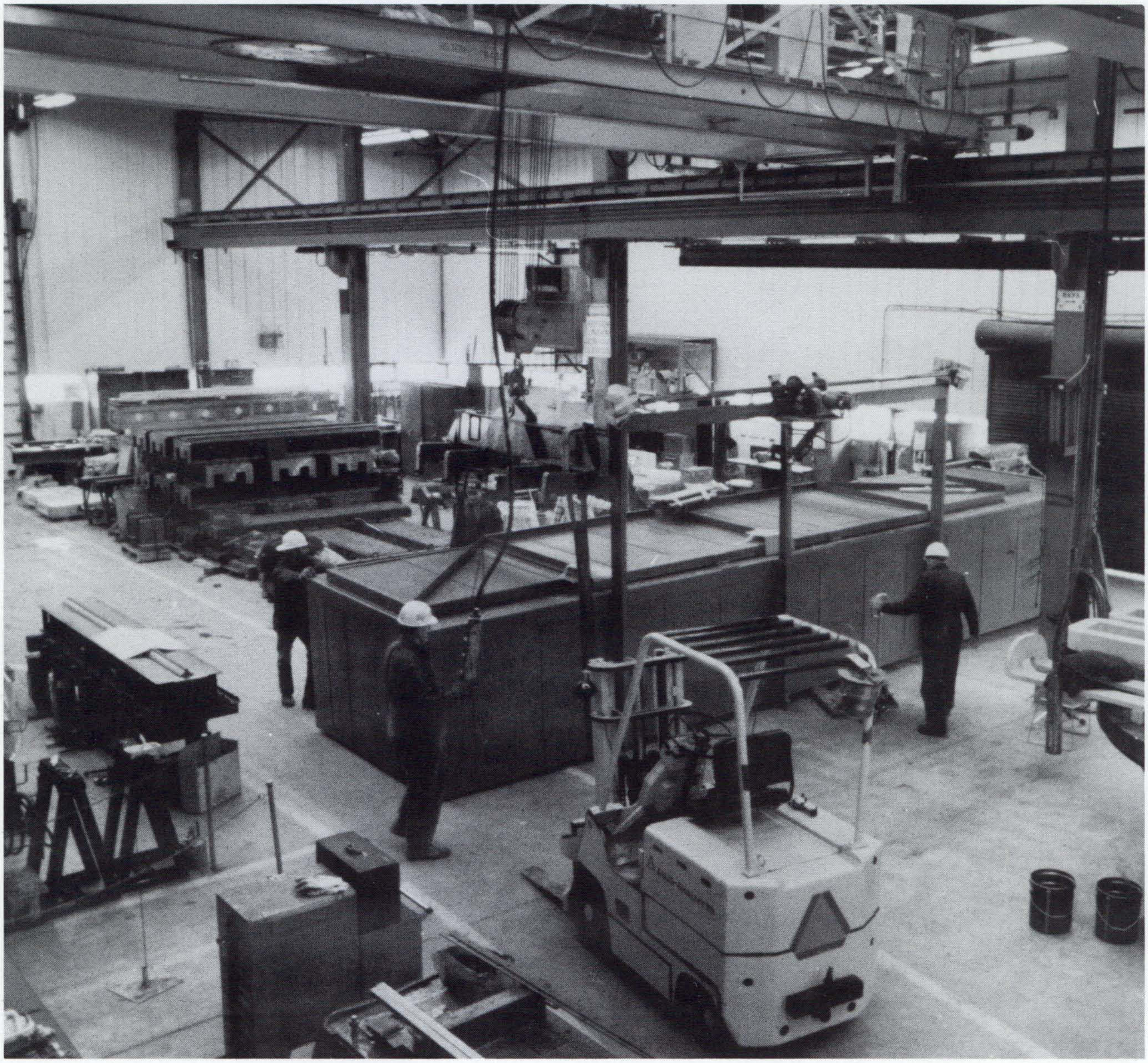
Bill Strickland, Jr., brazing a water manifold on half of a large quadrupole magnet for TeV I.



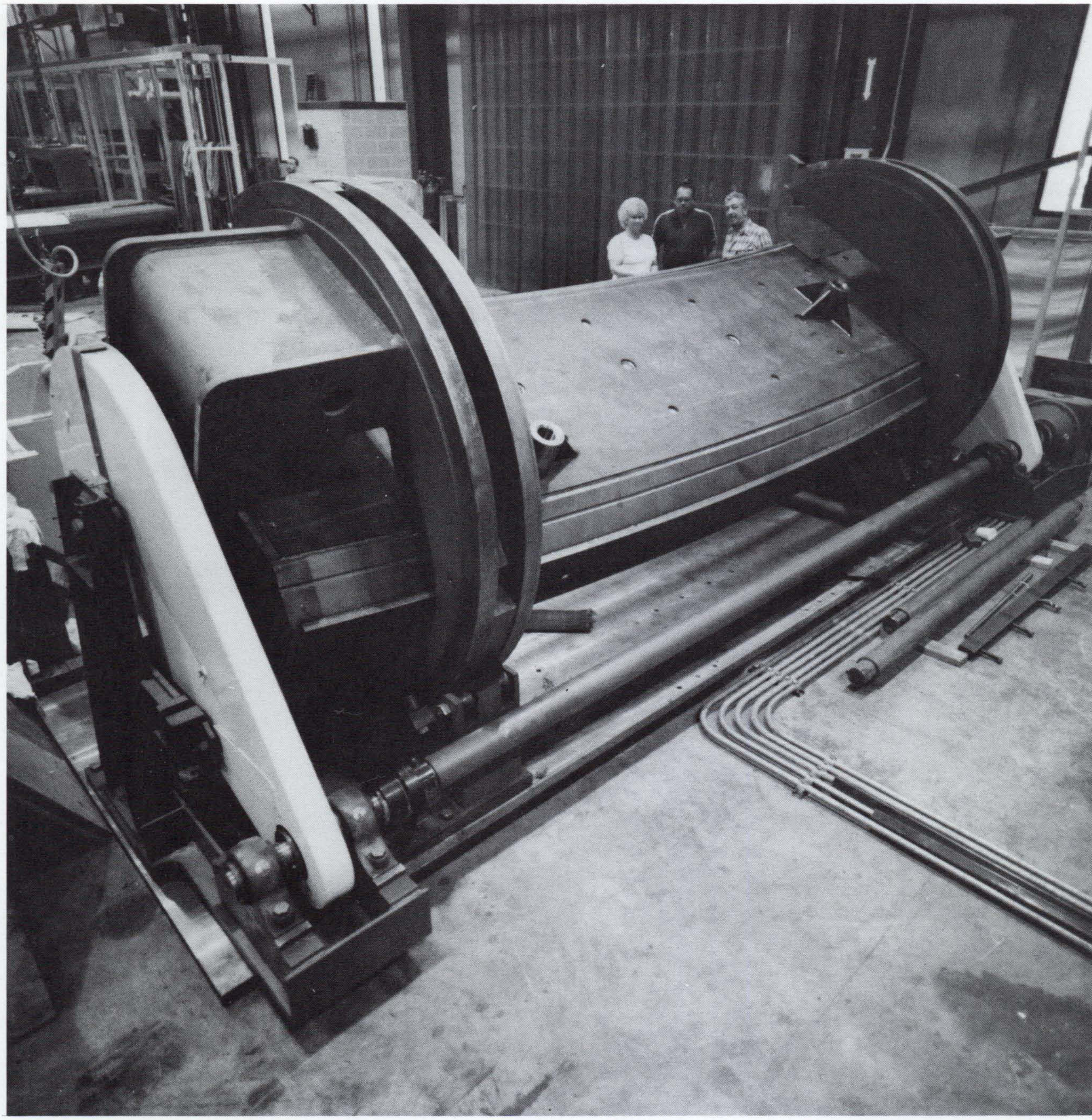
Looking down the center of the first TeV I small quadrupole magnet assembled at Paramount Park.



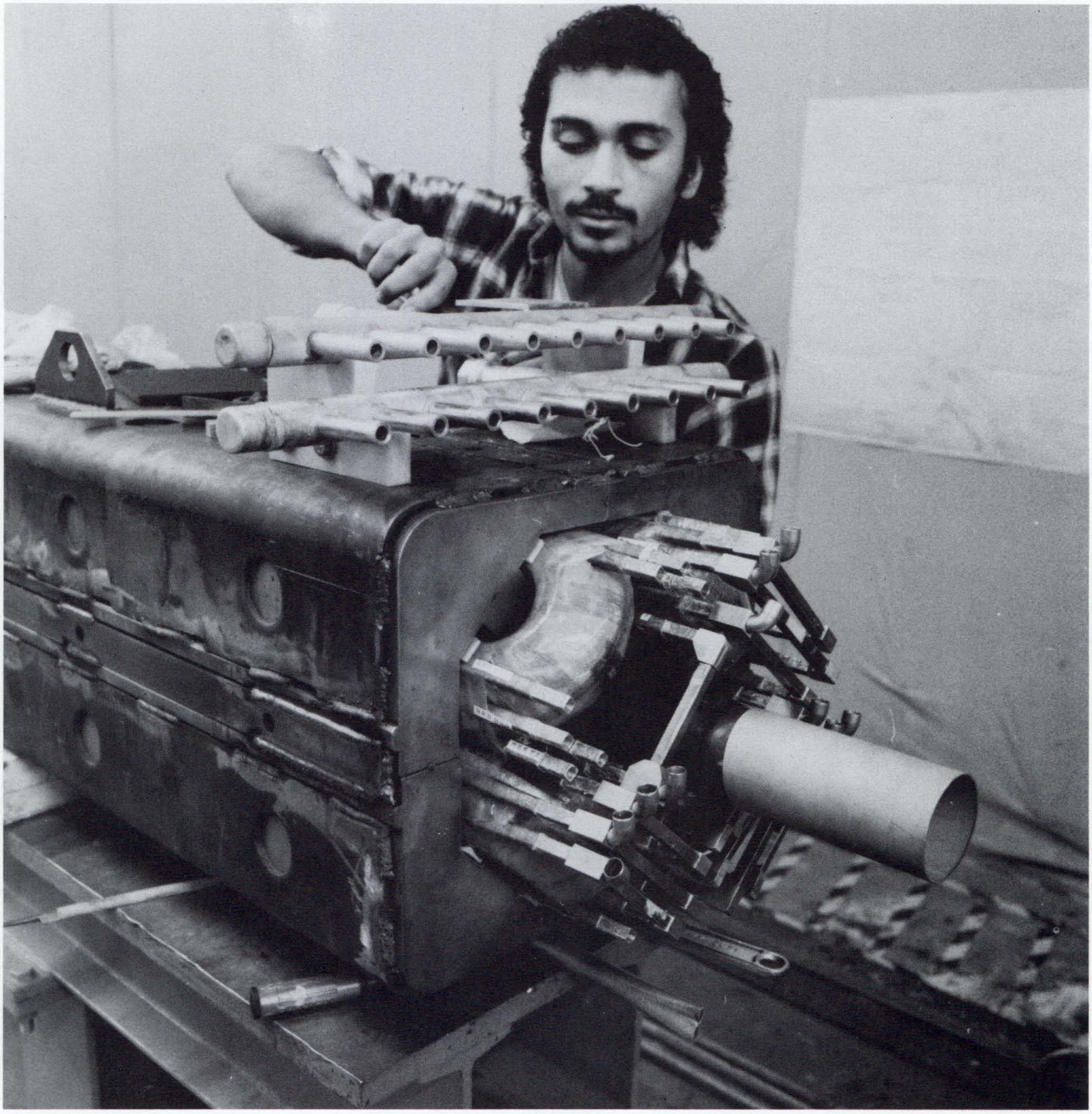
Jim Humbert with some of the small TeV I quadrupoles at the Paramount Park assembly plant.



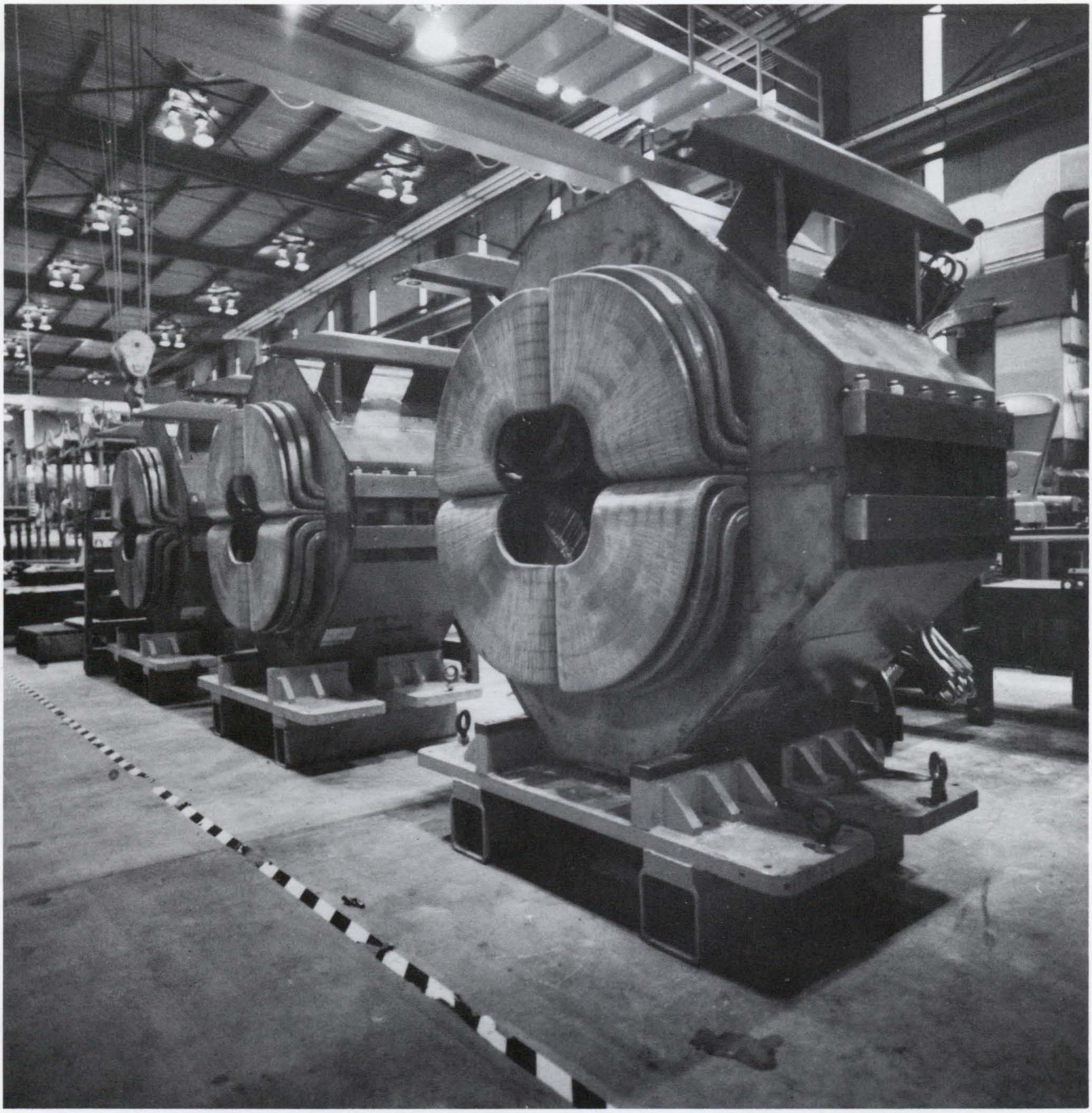
Moving the curing oven into Industrial 2.



Rolling-over a large TeV I dipole magnet half-core at Industrial Center.



Victor Ramierez working on a 3Q120A magnet for TeV I at the Paramount Park assembly plant.



Three completed TeV I quadrupole magnets at Industrial Center.

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Welding on a Superconducting Supercollider prototype magnet at Industrial 3.


Copies of Transparencies of the
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12 October 1984
Fermi National Accelerator Laboratory
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Fermi National Accelerator Laboratory
April 28, 1984
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ABSTRACT

VIII. Publications

Multiparticle #110

HIGHLIGHTS OF THE REACTION $\pi^-p \rightarrow \pi^-\pi^+n$ AT 100 AND 175 GeV/c. C. Bromberg et al., Phys. Rev. **D29**, 588 (1984).

PRODUCTION OF THE $K^0K^\pm\pi^\mp$ SYSTEM IN π^-p AND K^-p INTERACTIONS AT 50, 100, AND 175 GeV/c. C. Bromberg et al., Phys. Rev. **D30**, 2411 (1984).

STUDY OF K^{*-}(890) AND K^{*-}(1430) PRODUCTION IN THE REACTION $K^-p \rightarrow K^0\pi^-p$ AT 100 AND 175 GeV/c. C. Bromberg et al., Phys. Rev. **D29**, 2469 (1984).

15-Ft ν/H_2 & Ne #180

TOTAL ANTINEUTRINO-NUCLEON CHARGED CURRENT CROSS SECTION IN THE ENERGY RANGE 10-50 GeV. A. E. Asratyan et al., Phys. Lett. **137B**, 122 (1984).

Hadron Dissociation #272

A MEASUREMENT OF THE MASS, FULL WIDTH, AND RADIATIVE WIDTH OF THE B^+(1237) MESON. B. D. Collick, Ph.D. Thesis, University of Minnesota, April 1984.

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EVIDENCE FOR THE ELECTROMAGNETIC PRODUCTION OF THE A_1. M. Zielinski et al., Phys. Rev. Lett. **52**, 1195 (1984).

ELASTIC PION COMPTON SCATTERING. R. V. Kowalewski et al., Phys. Rev. **D29**, 1000 (1984).

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Particle Search #379

HADRONIC PRODUCTION OF PROMPT MUONS. A. Bodek et al., **The Search for Charm, Beauty, and Truth at High Energies**, Eds. G. Bellini and S. C. C. Ting (Plenum Press, N.Y. and London, 1984), p. 535.

Particle Search #400

A HIGHLY COMPACT MULTIWIRE PROPORTIONAL CHAMBER SYSTEM WITH 80 μm RESOLUTION. P. Coteus et al., Nucl. Instrum. Methods **222**, 474 (1984).

Nuclear Fragments #442/#591

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*This list was compiled using 1983 (not in **Fermilab 1983**) and 1984 journal articles, theses, and conference papers. Some conference papers were submitted to a conference prior to 1984 but were not published until 1984. If there are changes, omissions, or comments, please notify the Publications Office.

Particle Search #515

A STUDY OF CHARM PRODUCTION IN THE STRONG INTERACTIONS USING A PROMPT MUON TRIGGER. J. Bishop et al., **The Search for Charm, Beauty, and Truth at High Energies**, Proceedings of a Europhysics Study Conference on High-Energy Physics held November 15-22, 1981, in Erice, Sicily, Italy, Ed. G. Bellini and S. C. C. Ting (Plenum Press, New York and London, 1984), p. 545.

PRODUCTION OF LEPTONS IN COINCIDENCE WITH PROMPT MUONS. R. M. Edelstein et al., Phys. Rev. Lett. **53**, 1411 (1984).

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PHOTOPRODUCTION OF CHARM: RECENT RESULTS FROM THE TAGGED PHOTON SPECTROMETER. M. D. Sokoloff, Proceedings of the Ninth Hawaii Topical Conference in Particle Physics, Ed. E. Ma, August 11-24, 1983, p. 7.

A STUDY OF THE DECAY $D^0 \to K^-\pi^+\pi^-$ IN HIGH ENERGY PHOTOPRODUCTION. D. J. Summers, Ph.D. Thesis, University of California, Santa Barbara, March 1984.

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Dimuon #537

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STUDY OF JETLIKE STRUCTURE IN HIGH-TRANSVERSE-ENERGY EVENTS PRODUCED IN pp COLLISIONS AT 400 GeV/c. B. C. Brown et al., Phys. Rev. **D29**, 1895 (1984).

STUDY OF K^{*-}(890) AND K^{*-}(1430) PRODUCTION IN THE REACTION $K^-p \to \overline{K^0}\pi^-p$ AT 100 AND 175 GeV/c. Phys. Rev. **D29**, 2469 (1984).

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15-Ft & Emulsion/Neutrino #564

SEARCH FOR NARROW $\mu^\mp\pi^\pm$ MASS ENHANCEMENTS IN A NEUTRINO BUBBLE-CHAMBER EXPERIMENT. H. C. Ballagh et al., Phys. Rev. **D29**, 1300 (1984).

Elastic Scattering #577

LARGE-MOMENTUM-TRANSFER ELASTIC SCATTERING OF $\pi^\pm$, $K^\pm$, AND $p^\pm$ ON PROTONS AT 100 AND 200 GeV/c. Phys. Rev. **D30**, 1413 (1984).

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DIFFRACTIVE PRODUCTION OF $K_S^0 K_S^0 \pi^+ \pi^- \pi^-$ IN π^-N INTERACTIONS AT 200 GeV/c. C. C. Chang et al., Phys. Rev. **D29**, 1888 (1984).

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BARYON PRODUCTION AND DECAY INTO STRANGE-PARTICLE FINAL STATES IN 200-GeV/c π^-N INTERACTIONS. Phys. Rev. **D30**, 872 (1984).

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A STUDY OF HADRON-PROTON ELASTIC SCATTERING AT HIGH ENERGY AND LARGE MOMENTUM TRANSFER. S. F. McHugh, Ph.D. Thesis, University of California, San Diego, 1983.

Neutrino #594

A MEASUREMENT OF THE ELASTIC SCATTERING CROSS SECTION $\nu_\mu + e^- \rightarrow \nu_\mu + e^-$. M. A. Tartaglia, Ph.D. Thesis, Massachusetts Institute of Technology, July 1984.

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Particle Search #595

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STUDY OF THE ATOMIC WEIGHT DEPENDENCE OF HIGH Pt SINGLE HADRON PRODUCTION IN PROTON-NUCLEUS COLLISIONS AT 400 GeV/c. Y. Sakai, Ph.D. Thesis, Kyoto University, June 1984.

π/K/p IDENTIFICATION WITH A LARGE-APERTURE RING-IMAGING CHERENKOV COUNTER. M. Adams et al., Nucl. Instrum. Methods **217**, 237 (1983).

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HIGH TRANSVERSE ENERGY PROTON-NUCLEUS INTERACTIONS AT 400 GeV/c. H. E. Miettinen et al., Proceedings of the International Europhysics Conference on High Energy Physics, Brighton, July 20-27, 1983, p. 128.

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Particle Search #610

STRANGE QUARK SUPPRESSION IN 225 GeV/c π-BERYLLIUM INTERACTIONS. P. V. Schoessow, Ph.D. Thesis, University of Illinois, 1983.

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Beam Dump #613

PROMPT NEUTRINO RESULTS FROM FERMILAB. R. C. Ball et al., **Beyond the Standard Model**, Proceedings of the Leptonic Session of the Eighteenth Rencontre de Moriond, Vol. 2, Ed. J. Tran Thanh Van, La Plagne, Savoie, France, March 13-19, 1983, p. 231.

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Neutrino #616

STATUS OF THE CCFR NEUTRINO OSCILLATION EXPERIMENT AT FNAL. D. Garfinkle et al., **Beyond the Standard Model**, Proceedings of the Leptonic Session of the Eighteenth Rencontre de Moriond, Vol. 2, Ed. J. Tran Thanh Van, La Plagne, Savoie, France, March 13-19, 1983, p. 77.

RESULTS FROM THE CCFR NEUTRINO OSCILLATION EXPERIMENT. D. Garfinkle et al., Dynamics and Spectroscopy at High Energy, Proceedings of the SLAC Summer Institute on Particle Physics, Ed. P. M. McDonough, July 18-29, 1983, p. 527.

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MEASUREMENT OF THE Ξ^- MAGNETIC MOMENT. R. Rameika et al., Phys. Rev. Lett. **52**, 581 (1984).

Particle Search #623

$\phi\phi$ INCLUSIVE PRODUCTION IN 400 GeV p NUCLEON INTERACTIONS. D. R. Green for the Arizona/Fermilab/F.S.U./Notre Dame/Tufts/Vanderbilt/V.P.I. Collaboration, **Gluons and Heavy Flavours**, Proceedings of the Hadronic Session of the Eighteenth Rencontre de Moriond, Ed. J. Tran Thanh Van, La Plagne, Savoie, France, January 23-29, 1983, p. 485.

Direct Photon Production #629

A MEASUREMENT OF NEUTRAL MESON AND DIRECT PHOTON PRODUCTION AT LARGE TRANSVERSE MOMENTUM. J. D. Povlis, Ph.D. Thesis, University of Minnesota, May 1984.

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IX. 1984 Workshop and Seminar Series

Theoretical Physics Seminars

S. Nussinov, University of Pennsylvania, and Tel-Aviv, Israel: "Mass Inequalities in QCD," January 10, 1984

J. Sexton, Columbia University: "Local Lattice Fermion Actions," January 10, 1984

P. Kundu, University of Utah: "Spontaneous Symmetry Breaking in Cosmological Spacetimes," January 17, 1984

M. Rubin, University of Texas: "Dynamical Quantum Effects in Kaluza-Klein Theories," January 19, 1984

A. Pruisken, Schlumberger-Doll Research: "The Theta Vacuum Lives!--A Novel Explanation for the Integral Quantum Hall Effect," January 26, 1984

S. Chadha, Rutherford Appleton Laboratory, Chilton Didcot England: "Use of Chiral Lagrangians for Proton Decay," February 2, 1984

F. Green, Northeastern University: "The Confining Detransition," January 31, 1984

L. Smolin, University of Chicago: "Composite Higgs Bosons From an Extended Gauge Symmetry," February 7, 1984

X. Tata, University of Oregon: "Seeing SUSY," February 21, 1984

S. Das, Fermilab: "The Uses of Large N," February 28, 1984

M. Gunaydin, California Institute of Technology: "The Exceptional Supergravity Theories and the Magic Square," March 8, 1984

R. Pisarski, ITP, Santa Barbara, California: "Large N and Chiral Symmetries in Finite Temperature QCD," March 6, 1984

S. Libby, Brown University: "Quantized Hall Effect, Localization, and the Theta Vacuum," March 13, 1984

B. Svetitsky, Cornell University: "Lattice Gauge Theory at High Temperature," March 20, 1984

P. Lepage, Cornell University: "Effective Lagrangians for QED and QCD--A Renormalization Group Strategy for Bound States," March 27, 1984

G. Bhanot, Institute for Advanced Study: "Topology on the Lattice," April 3, 1984

S. Gupta, Institute for Advanced Study: "Problems with the New Inflationary Universe and A Possible Solution," April 10, 1984

K. Ellis, Fermilab: "Vector Boson Production at Collider and TeV I Energies," April 17, 1984

R. Jackiw, Massachusetts Institute of Technology: "Quantization of Physical Parameters," April 24, 1984

I. Antoniatis, Stanford Linear Accelerator Center: "Conformal Gravity and the Cosmological Constant," April 30, 1984

E. Farhi, Massachusetts Institute of Technology: "Strange Matter," May 8, 1984

J. P. Ralston, Argonne National Laboratory: "Chiral Calamity in the Skyrme Model," May 15, 1984

M. Veltman, University of Michigan: "Bound States of Vector Bosons," May 23, 1984

A. Kronfeld, Cornell University: "Lattice Analysis of Exclusive Processes and Deep Inelastic Scattering," May 24, 1984

Theory Group, Fermilab: "Discussion of the CERN "Zoo" Events," May 22, 1984

Jonathan Schonfeld, Fermilab: "Statistical Mechanics of Colliding Beams," May 29, 1984

Theory Group, Fermilab: "CERN Zoo Events: Theoretical Perspectives," May 31, 1984

S. Wadia, Tata Institute, Bombay: "The Low Energy Effective Lagrangian in QCD," June 5, 1984

C. P. Korthals Altes, CPT - CNRS, Marseille, France: "Gauge Fields in a Box, Zero Modes and Finite Size Effects," June 21, 1984

K. Olynyk, Ohio State: "A Gauge Invariant View of Symmetry Breaking," June 26, 1984

H. Steger, Max-Planck-Institute: "B-Meson Decay and CP Violation and Mixing in F and B Systems," July 3, 1984

A. Hasenfratz, University of Michigan: "Monte Carlo Renormalization Group Methods," July 10, 1984

O. Alvarez, University of California, Berkeley: "Geometry and Anomalies," July 17, 1984

C. Zachos, Argonne National Laboratory: "Topologically Induced Parallelization and I.R. Fixed Point," August 7, 1984

C. Schmid, Institute of Theoretical Physics, Eidgenössische Tech. Hochsch. Zurich, Switzerland: "Excitation and Decay of a Dyon and The Rubakov Callan Effect," August 14, 1984

K. Bitar, American Univeristy of Beirut, Lebanon: "Renormalization Flow of Lattice Gauge Actions," August 21, 1984

D. Caldi, Brookhaven National Laboratory: "Skyrmions and Vector Mesons: A Symmetric Approach," August 30, 1984

B. Kayser, National Science Foundation: "CP ad CPT Properties of Majorana Particles and Their Consequences," September 4, 1984

O. W. Greenberg, University of Maryland: "Nambu-Goldstone Fermions and Composite Models of Quarks and Leptons," September 11, 1984

A. Patrascioiu, University of Arizona: "Functional Integration on Compact Spaces," September 17, 1984

M. Gronau, Technion, Haifa, Israel: "Is CP Violation Maximal?" October 23, 1984

H. Hata, Kyoto University, Japan: "Color Confinement, BRS Symmetry and Negative Dimensions," October 25, 1984

U. Sarkar, University of Texas: "N = 2 SUSY and Compositeness," October 30, 1984

A. Jourjine, University of Wisconsin: "Dimensional Reduction as a Phase Transition," November 6, 1984

D. R. Yennie, Cornell University: "The Two Body Problem in Quantum Electrodynamics," November 13, 1984

S. Rao, Fermilab: "Fermions Interacting with Spherically Symmetric Monopoles," November 20, 1984

S. Elitzur, Hebrew University, Jerusalem: "Discrete Anomalies in Higher Dimensions," September 18, 1984

K. H. Streng, University of Munich: "Colored Weak Bosons: Possible Signals for Compositeness," September 25, 1984

M. Grady, Argonne National Laboratory: "An Improved Psuedo-Fermion Technique for Performing Monte-Carlo Simulation with Fermions," October 2, 1984

A. Masiero, CERN: "Split Light Composite Supermultiplets," October 9, 1984

L. Beaulieu, University of Paris: "Quantization of Generalized Gauge Theories in a Flat Space and Curved Space With or Without Local Supersymmetry," October 18, 1984

S. Shenker, University of Chicago: "String Compactification?" November 27, 1984

E. Mattala, ITP, Santa Barbara: "Thermodynamic Instability of deSitter Space," November 29, 1984

P. Hoyer, University of Wisconsin: "Gauge Covariant QCD Bound State," December 4, 1984

L. Mezincescu, University of Texas, Austin: "The σ - Model Interpretation of the Green-Schwarz Covariant Superstring Action," December 10, 1984

M. Green, Queen Mary College and Caltech: "Developments in Superstring Theory," December 11, 1984

Joint Experimental-Theoretical Physics Seminars

P. Meyers, Lawrence Berkeley Laboratory: "Nucleon Structure Function From Berkeley, Fermilab, Princeton Experiment," January 6, 1984

E. J. Siskind, NYCB Real-Time Computing Inc., and Cornell University Medical College: "Minimally Invasive Imaging of the Coronary Arteries in Man--An Operational VAX-Fastbus Experiment Outside of High Energy Physics," January 13, 1984

N. Giokaris, Fermilab: "Electron Scattering from Nuclear Targets," January 20, 1984

E. Paschos, University of Dortmund: "Charged Current Couplings and the Physics of the B-Mesons," January 27, 1984

M. M. Nieto, Los Alamos National Laboratory: "Physics at the Proposed National Underground Physics Facility," February 3, 1984

P. Drell, University of California-Berkeley, Lawrence Berkeley Laboratory: "Parity Non-Conservation in Atomic Transitions," February 10, 1984

S. Dawson, Lawrence Berkeley Laboratory: "Finding Supersymmetry in Colliders," February 17, 1984

J. Schonfeld, Fermilab: "What You Should Know (Things Your Mother Never Told You) About Colliding-Beam Storage Rings," February 24, 1984

T. Stanev, Bartol Research Foundation: "Things That People Really See In Proton Decay Detectors," March 9, 1984

D. Cline, University of Wisconsin: "Observation of Same Sign and Opposite Sign Dileptons At The CERN $p\bar{p}$ Collider," March 9, 1984

C. Quigg, Fermilab: "Super-Collider Physics," March 23, 1984

W. Hofmann, Lawrence Berkeley Laboratory: "Recent Results From the TPC at PEP," March 30, 1984

C. Matteuzzi, Stanford Linear Accelerator Center: "New Results from the Mark II Experiment," April 6, 1984

H. U. Martyn, I. Phys. Institute R. W. T. H., Aachen, Germany: "Recent Results From the TASSO Collaboration," April 13, 1984

M. Koshiba, University of Tokyo: "Results From The Kamioka Nucleon Decay Experiment," April 20, 1984

R. Bernstein, University of Chicago: "An Experimental Determination of ε'/ε In the Neutral Kaon System (E-617)," May 11, 1984

M. R. Whalley, University of Durham: "Data Compilations in HEP--The Durham--RAL Databases," May 18, 1984

N. Paver, ICTP, Trieste: "Multiple Parton Interactions and Multijet Events at Collider Energies," May 25, 1984

S. Fuess, Fermilab: "An Experimental Comparison of the Neutral Current Interactions to the Charged Current Interaction (E594)," June 1, 1984

J. Cooper, University of Pennsylvania: "Chi Production by Hadrons (E-610/673)," June 8, 1984

F. Dydak, CERN: "Recent CDHS Neutrino Results," June 14, 1984

T. Sjöstrand, University of Lund, Sweden: "New Developments in the Lund Jet Fragmentation Model," June 22, 1984

M. Anselmino, Indiana University: "Spin Dependence of the Fragmentation Process of Quarks and Gluons," June 29, 1984

D. Cline, University of Wisconsin: "Observation of Lepton + Multi-Jet Events in UA-1 Experiment and Search for the Top Quark," July 6, 1984

A. Zee, University of Washington, Seattle, Washington: "Dark Matter and Galaxies: An Overview," July 20, 1984

D. Lindley, Fermilab: "The Distribution of Matter in the Universe," July 27, and August 17, 1984

M. Bourquin, University of Geneva, Switzerland: "Baryons with Strangeness and Charm," August 10, 1984

B. Foster, Bristol University: "Lifetime Measurements and Experience with the TASSO Vertex Detector," August 31, 1984

G. Preparata, University of Bari: "Quarks in Collisions; e^+e^-, Lepton-Nucleon, $p(\bar{p})+p$," August 29, 1984

Assorted Members of the Theory Group, Fermilab: "The Zeta: Who Ordered That?" September 14, 1984

D. Klem, Stanford Linear Accelerator Center: "b-Lifetime Results from Delco," October 5, 1984

D. Carlsmith, University of Wisconsin: "K^{0*} (890) Radiative Decay Width," October 19, 1984

P. Grafstrom, Fermilab: "Electron Asymmetry from Polarized Σ- Beta Decay: A Critical Test of the Cabibbo Model," October 26, 1984

H. Tye, Cornell University: "Physics Interpretation of the Zeta," November 2, 1984

P. Reiner, University of Rochester: "Search for Anomalous Gravitational Effects at the Fermilab Accelerator," November 9, 1984

G. Giacomelli, University of Bologna: "Comparison of $\bar{p}p$ and pp at the ISR," November 5, 1984

J. Cronin, University of Chicago: "Direct Measurement of the π^0 Lifetime," November 16, 1984

R. Enomoto, University of Tokyo: "Evidence for the F^* Meson," November 20, 1984

N. Schmitz, Max Planck Inst., Munich: "W and Q^2 Depedence of Fragmentation Functions Measured in Deep Inelastic Leptoproduction," November 27, 1984

A. Yokosawa, Argonne National Laboratory: "Report on the International Symposium of High Energy Spin Physics at Marseille, France (Sept. 1984)," November 30, 1984

T. Nash, Fermilab: "Status Report on the ACP," December 14, 1984

L. Teig, Yale University: "Σ- Production Polarization and Magnetic Moment from E-497," December 21, 1984

Fermilab Colloquia

S. Brams, New York University: "'Approval Voting' A Better Way to Elect a President?" January 4, 1984

G. Yonas, Sandia National Laboratory: "A Modern View of Ballistic Missile Defenses," January 11, 1984

H. Kautzky, Fermilab: "Artificial Heart Valves," January 18, 1984

J. Hubbard, Cornell University: "Order and Chaos," January 25, 1984

P. Carruthers, Los Alamos National Laboratory: "Hadronization and Galaxy Counts: Examples of a Simple Stochastic Process," February 1, 1984

A. Crewe, University of Chicago: "Sub-Angstrom Electron Microscopy," February 7, 1984

L. Smarr, University of Illinois: "Exploring the Laws of Physics on a Supercomputer," February 8, 1984

M. Rees, University of Cambridge: "Evolution of Galactic Nuclei," February 15, 1984

F. Davidson, Massachusetts Institute of Technology: "Tunnels: Past, Present, and Future," February 22, 1984

S. Salzberg, Yale University: "Linguistics and Artificial Intelligence," February 29, 1984

J. C. Brandt, Goddard Space Flight Center: "U. S. Mission to Comet Giacobini-Zinner," March 7, 1984

T. Ackerman, NASA Ames Research Center: "Nuclear Winter: Global Consequences of Multiple Nuclear Explosions," March 14, 1984

G. McDonough, Marshall Space Flight Center: "The Space Shuttle Main Engine Design," March 21, 1984

E. P. Krider, University of Arizona: "Lightning--A Diferent Kind of High-Energy Physics," March 28, 1984

C. Van Degrift, National Bureau of Standards: "Macroscopic Effects of Nuclear Spin in Solid ^{3}He," April 4, 1984

L. Nirenberg, New York University: "Remarks on Nonlinear Problems," April 11, 1984

F. Parke, New York Institute of Technology: "Overview and Trends in Computer Animation," April 19, 1984

A. Guth, Massachusetts Institute of Technology: "The Inflationary Universe," May 4, 1984

S. Jachim, AT&T Bell Labs: "Terrestrial Microwave Digital Radio: A Growing Information Age Telecommunication Medium," May 9, 1984

P. Diaconis, Stanford University: "The Statistics of Shuffling Cards," May 16, 1984

F. Filas, Loyola University: "Basics & Latest Research Updates on the Shroud of Turin," May 23, 1984

S. Manabe, Princeton University: "CO_2 and Climate," May 30, 1984

J. Thomson, Rand Corporation: "Deterrence & Strategic Defense," June 6, 1984

P. Handler, University of Illinois: "Volcanoes, Sea Surface Temperatures and Global Climate," June 13, 1984

R. Hansen, AT&T Bell Labs: "Computers and Networking in AT&T Bell Labs," June 20, 1984

D. Frey, Bell and Howell: "Managing the Innovative Organization," June 27, 1984

J. H. McAlear, Gentronix, Inc.: "Biomolecular Electronics," September 13, 1984

C. Persson, Jet Propulsion Laboratory: "Infrared Astronomy Statellite," September 26, 1984

H. Davidson, Lawrence Livermore Laboratory: "How to Put a Cray I in a Tuna Fish Can and Make It Run Faster," October 3, 1984

C. F. Ehret, Argonne National Laboratory: "Circadian Clocks at the Base of Life: Recent Advances in Chronobiology and Chronobiotechnology," October 10, 1984

L. G. Mollenauer, Bell Lab: "Solitons in Optical Fibers and the Soliton Laser," October 17, 1984

E. Commins, University of California, Berkeley: "Parity Nonconservation in Atomic Thallium," October 24, 1984

A. T. Winfree, Purdue University: "3D Wave Topology in Excitable Media (the human heart, for example)," October 31, 1984

F. E. Dalton, Metropolitan Sanitary District of Greater Chicago: "Status of Chicagoland Tunnel and Reservoir Plan (TARP)," November 7, 1984

A. K. Dewdney, University of Western Ontario: "The Planiverse," November 14, 1984

P.G.O. Freund, University of California: "Modern Kaluza-Klein Theory," November 28, 1984

M. Mathews, AT&T Bell Labs: "Studies of Violin Tone by Electrical Simulation of the Resonances of the Violin Body," December 5, 1984

J. P. Kempton, Illinois State Geological Survey: "The Role of Geology in Siting Studies in Illinois; The Proposed SSC, A Premier Example," December 12, 1984

E. Carlson, Department of Blochemistry, New York: "H. J. Muller: Gadfly of Science," December 19, 1984

R. Bond, Stanford University: "Dark Matter and Cosmic Background Radiation Anisotropies," November 12, 1984

R. Juszkiewicz, University of California, Berkeley: "The Large-Scale Structure of the Microwave Background Radiation," December 3, 1984

J. Preskill, Caltech: "Voids as Fluctuations," December 17, 1984

Theoretical-Astrophysics Seminars

S. Barr, University of Washington: "Euclidean Chiral Fermions," January 16, 1984

A. Chodos, Yale University: "Quantum Aspects of Kaluza-Klein," January 30, 1984

M. Perry, Princeton University: "Kaluza-Klein Monopoles," February 6, 1984

M. Hereld, Caltech: "Gravity Waves and the Caltech Laser Interferometer," February 8, 1984

P. Sikivie, University of Florida: "Axionia," February 13, 1984

A. Vilenkin, Tufts University: "Creation of Universes from Nothing," February 27, 1984

I. Wasserman, Cornell University: "Plasma and Gravitational Dynamics of a Monopole Halo," March 12, 1984

G. Chapline, Lawrence Livermore National Laboratory: "Unification of Elementary Particle Physics and Cosmology in 10 Dimensions," March 19, 1984

N. Weiss, University of British Columbia: "Evolution Equations for the Higgs Field in a Hot, Expanding Universe," April 9, 1984

F. Graziani, University of Colorado: "Fragmentation in Molecular Clouds," April 9, 1984

F. Cooper, Los Alamos National Laboratory: "An Improved Method for Studying False-Vacuum Decay," April 19, 1984

S. Y. Pi, Boston University: "Inflation Without Tears," April 23, 1984

C. Hogan, Caltech: "Astrophysics of Strings," May 7, 1984

R. Rood, University of Virginia: "^{3}He Abundances," May 14, 1984

F. Cordova, Los Alamos National Laboratory: "EXOSAT X-Ray Observation of Close Binary Systems," May 21, 1984

B. Carr, University of Cambridge: "Pre-Galactic Stars and the Dark Matter Problem," October 1, 1984

J. Hills, Los Alamos National Laboratory: "Comet Showers and Nemesis the Death Star," October 15, 1984

N. Turok, ITP, Santa Barbara: "Self-Similarity of Cosmic Strings," October 22, 1984

T. Allen, University of Michigan: "Late Evolution of Cosmological Structure," October 29, 1984

Research Technique Seminars

A. Vorobiev, Leningrad Nuclear Physics Laboratory: "E715 Transition Radiation Detectors," February 16, 1984

D. Anderson, Fermilab: "Some New Ideas in Detectors," February 23, 1984

R. A. Holroyd, Brookhaven National Laboratory: "Physics and Chemistry of Room Temperature," March 8, 1984

G. Coutrakon, Fermilab: "Ring Imaging Cerenkov Results Using Multi-Needle Detectors," March 22, 1984

M. Atac, Fermilab: "Breakdowns, Sparks, Rates and Long Lifetimes," March 29, 1984

D. Kaplan, Fermilab: "A 40 MHz, Parallel, Pipelined Event Processor for E-605," April 19, 1984

P. Mangeot, Saclay: "Can Detectors Combined with Indium Targets Help Solar Neutrino Puzzle?" April 26, 1984

A. Breskin, Weizmann Institute: "New Prospects with Low Pressure Gaseous Detectors," May 3, 1984

M. Atac, Fermilab: "Radial Drift Chamber for the CDF," May 10, 1984

L. Holloway, University of Illinois: "High Precision Charge Division for the CDF," May 10, 1984

S. Majewski, Fermilab: "Thin Multiwire Chambers in the Highly Saturated Mode," May 31, 1984

P. Rehak, Brookhaven National Laboratory: "High Resolution Germanium Drift Detector," June 21, 1984

K. Peach, CERN: " Experience with FASTBUS at CERN," October 17, 1984

M. Panter, CERN: "High Density Projection Chamber Calorimeter for the DELPHI Experiment," October 24, 1984

P. Sharp, Rutherford and Appleton Laboratories: "Ring Imaging Cherenkov Detector for the CERN OMEGA Spectrometer," October 25, 1984

A. Policarpo, Universidade de Coimbra, Portugal: "The Gain Divergence at the Transition to the Self-Quenching Streamers," October 26, 1984

G. Harigel, CERN-EF: "Argon Bubble Chamber for Fixed Target Experiments at Multi-TeV Accelerators," November 29, 1984

G. Coutrakon, Fermilab: "Ring Imaging Cherenkov Results Using a Wire Chamber with Cathode Pad Readout," December 6, 1984

Arms Control and International Security Seminar Series

G. Yonas, Sandia National Laboratory: "A Modern View of Ballistic Missile Defenses," January 11, 1984

R. D. Woodruff, Lawrence Berkeley Laboratory: "Arms Control and Strategic Options for the 1990's," February 9, 1984

T. Ackerman, NASA Ames Research Center: "Nuclear Winter: Global Consequences Center of Multiple Nuclear Explosions," March 14, 1984

Workshops

Inner Space/Outer Space Workshop on High Energy Physics, Astrophysics, and Cosmology
May 2-4, 1984

Fermilab Workshop on Fixed Target Physics
June 9, 1984

Vertex Detectors: Charm and Beauty I Workshop
September 21-22, 1984

Direct Neutral Lepton Facility Workshop
October 12-13, 1984

Hyperon Physics at the Tevatron Workshop
December 7-8, 1984

Other

Fermilab Users Annual Meeting
April 27-28, 1984

Dedication of the Energy Saver
April 28, 1984

Fermilab Industrial Affliates Annual Meeting
May 24-25, 1984

U. S. Summer School on High Energy Particle Accelerators
August 13-24, 1984

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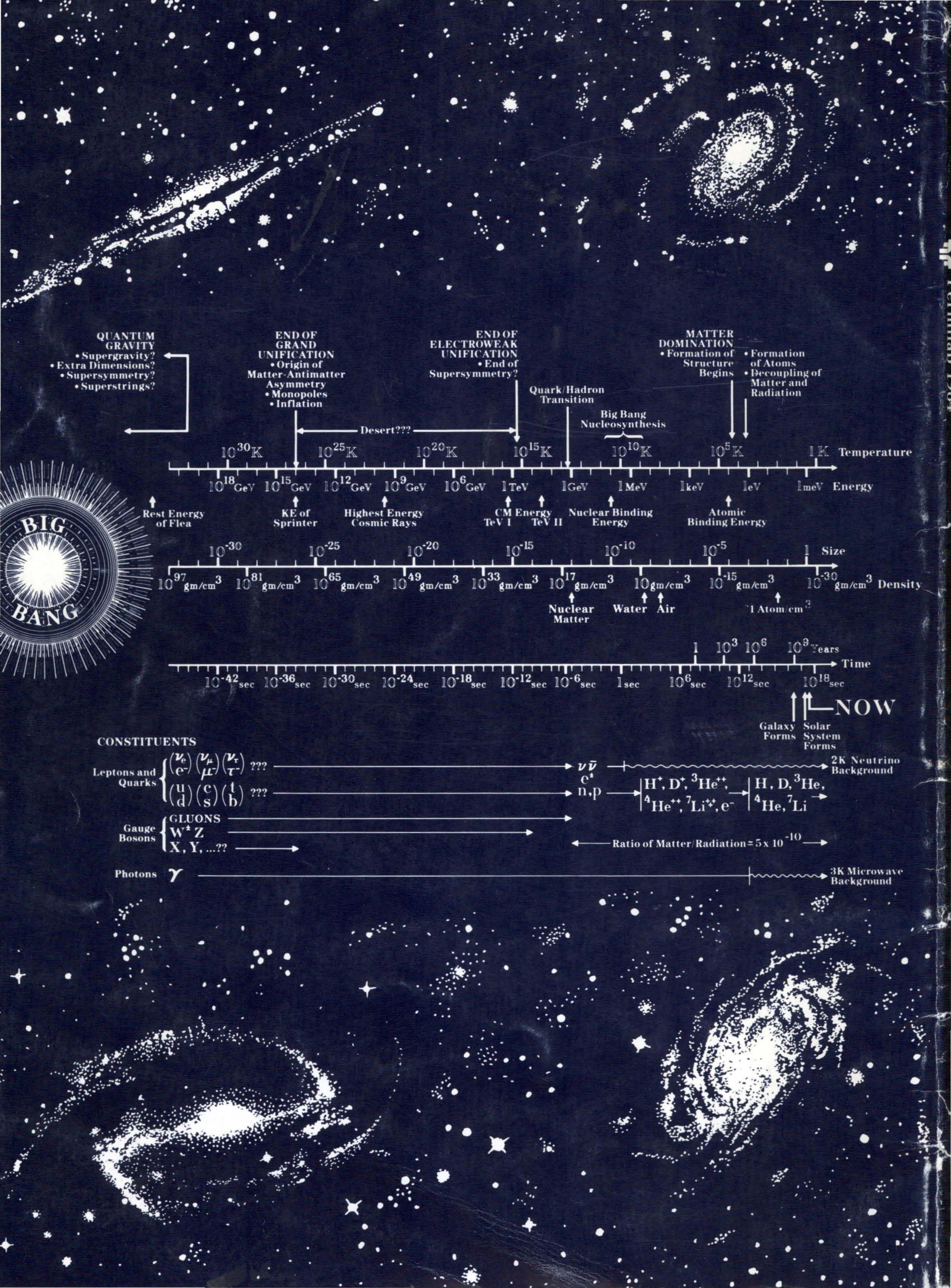
Page 11 illustration: "Creation of the World", 17th century copper engraving. Akademie, Wien.

Back cover: "History of the Universe." Fermilab.

The History of the Universe

With Newton's discovery of the universality of gravity came the realization that in our laboratories we can study, measure, and quantify the force responsible for the movements of the celestial bodies, and gain knowledge and understanding in an area that was thought to be forever outside the realm of human comprehension. Today, in collisions of particles at high-energy accelerators, we are able to create conditions of energy, temperature, and pressure that are similar to the conditions obtained in the earliest moments of the big bang. As we explore physics at higher energies we are able to explore the Universe at times closer to the moment of the big bang. The understanding of the behavior of matter under extreme conditions, and the knowledge of the fundamental constituents of matter allow us to understand the Universe as early as 10^{-12} seconds after the bang. Theoretical speculation allows us to make an outrageous extrapolation of our understanding of the Universe back to the time of the big bang itself. We present the "History of the Universe" as it reflects our present understanding. Physicists of the 22nd century will no doubt look upon our "History of the Universe" with the same amusement with which we look upon astronomical texts of the 18th century. We only hope that they see boldness and imagination in our attempts to study the origin of the Universe and to bring into the realm of human understanding yet another area once thought to be beyond our grasp.

-E. Kolb



QUANTUM GRAVITY
• Supergravity?
• Extra Dimensions?
• Supersymmetry?
• Superstrings?
END OF GRAND UNIFICATION
• Origin of Matter-Antimatter Asymmetry
• Monopoles
• Inflation
END OF ELECTROWEAK UNIFICATION
• End of Supersymmetry?
MATTER DOMINATION
• Formation of Structure Begins
• Formation of Atoms
• Decoupling of Matter and Radiation
Quark/Hadron Transition
Big Bang Nucleosynthesis
Desert???
10^{30}K 10^{25}K 10^{20}K 10^{15}K 10^{10}K 10^{5}K 1K Temperature
10^{18}GeV 10^{15}GeV 10^{12}GeV 10^{9}GeV 10^{6}GeV 1TeV 1GeV 1MeV 1keV 1eV 1meV Energy
Rest Energy of Flea
KE of Sprinter
Highest Energy Cosmic Rays
CM Energy TeV I TeV II
Nuclear Binding Energy
Atomic Binding Energy
BIG BANG
10^{-30} 10^{-25} 10^{-20} 10^{-15} 10^{-10} 10^{-5} 1 Size
10^{97}gm/cm^3 10^{81}gm/cm^3 10^{65}gm/cm^3 10^{49}gm/cm^3 10^{33}gm/cm^3 10^{17}gm/cm^3 10gm/cm^3 10^{-15}gm/cm^3 10^{-30}gm/cm^3 Density
Nuclear Matter
Water
Air
1 Atom/cm^3
1 10^3 10^6 10^9 Years
10^{-42}sec 10^{-36}sec 10^{-30}sec 10^{-24}sec 10^{-18}sec 10^{-12}sec 10^{-6}sec 1sec 10^{6}sec 10^{12}sec 10^{18}sec Time
NOW
Galaxy Forms
Solar System Forms
CONSTITUENTS
Leptons and Quarks $\begin{pmatrix}\nu_e\\e^-\end{pmatrix}\begin{pmatrix}\nu_\mu\\\mu^-\end{pmatrix}\begin{pmatrix}\nu_\tau\\\tau^-\end{pmatrix}$??? $\nu\bar{\nu}$
2K Neutrino Background
$e^\pm$
$\begin{pmatrix}u\\d\end{pmatrix}\begin{pmatrix}c\\s\end{pmatrix}\begin{pmatrix}t\\b\end{pmatrix}$??? n,p
$H^+, D^+, {}^3He^{++}, {}^4He^{++}, {}^7Li^{+++}, e^-$
$H, D, {}^3He, {}^4He, {}^7Li$
Gauge Bosons
GLUONS
$W^\pm Z$
X, Y, ...??
Ratio of Matter/Radiation = 5×10^{-10}
Photons γ
3K Microwave Background