Fermilab 1983

U.S. ATOM SMASHER ATTAINS A RECORD

PAGE ONE

Fermi Device Propels Protons at Highest Energies Ever

3554

By WILLIAM J. BROAD

One of the biggest gambles in the history ... understanding the infinite ... and the infinite ... Holy Grail of ... scientists ... first instant of ... existed in ... form.

Fermilab poised to leapfrog

discovery of the W and Z particles. Fermilab is now building the antiproton accumulator and other machinery necessary to ...

Chicago THE Fermi National Accelerator Laboratory is jubilant over its achievement

... particle accelerators ... four-mile ring, the Tevatron ... Fermilab scientists ... conducting ... universe would ... perpetually expand ... theory of an ... cond Big Bang. If ... "closed" universe ... cosmic balance in favor ... gravity needed to ...

Scientists Take a Peek At Universal Mysteries

BATAVIA, Ill. (AP) — Thirty feet below the northern Illinois prairie, the ... The collisions throw off particles — some existing only for an instant — that can ...

known as superconductivity. When a metal or other conductor of electricity is cooled ...

A key to that question is a ... particle called the neutrino ... Scientists have detected neutrinos but do not know whether the particles have ... any mass. If they have even a tiny bit, the large number of neutrinos could produce the gravity needed to tip the cosmic balance in favor of a "closed" universe and a second Big Bang. If not, the "open" theory of an ...

... ducting magnets ... The technique ... had hoped. The ... cated matters by ...

Building blocks of matter sought with accelerator

Big physics gamble pays off

"We were quite nervous, having made all the ...

at the forefront of physics," said George Key...

Atom smasher takes science to the future

Atom smasher to help in study of universe

3554 BATAVIA, Ill. (AP) — Thirty ...

... 3 test reached a peak of 512 billion ... in volts, the highest energy ever produced by an accelerator.

... are shunted out of the tunnel and slammed into a target. The collisions throw off particles — "All those attempts to join up with the astrophysicists who are concerned with the early universe ...

degrees below zero, about 5 degrees above absolute zero. "It's building an accelerator inside a Thermos bottle," Lederman said.

Engineers had to develop technology to build the bottle ...

Atom smasher gives clues on 'Big Bang'

Physicists hope to simulate world's creation.

Atom smasher

By WILLIAM BROAD 3554

BATAVIA, Ill. (AP) — Thirty feet below the northern Illinois prairie, the world's most powerful atom smasher is opening an infinitesimal realm in which scientists hope to find the building blocks of the universe and a hint of the future of the ... machine, a particle ... the centerpiece ... laboratory.

... CERN will be ... perhaps the last ... as well as a determination of the total number of neutrinos ... universe (by measurements of ...

SCIENCES

Le Monde 6-VII

AUX ÉTATS-UNIS

Énergie record pour l'accélérateur de particules du Fermi National Laboratory

A l'automne, quand les ingé... eventually will more ... power to look into the atom. ... it as a microscope ... is more sharply ...

... lui a communiqué ... de 512 milliards ... (512 GeV) ... son direc...

Fermilab Feat

U.S. Physics Suddenly Back in the Running

By LEE DEMBART, Times Science Writer

... American physics, which in recent months ... in Europe ...

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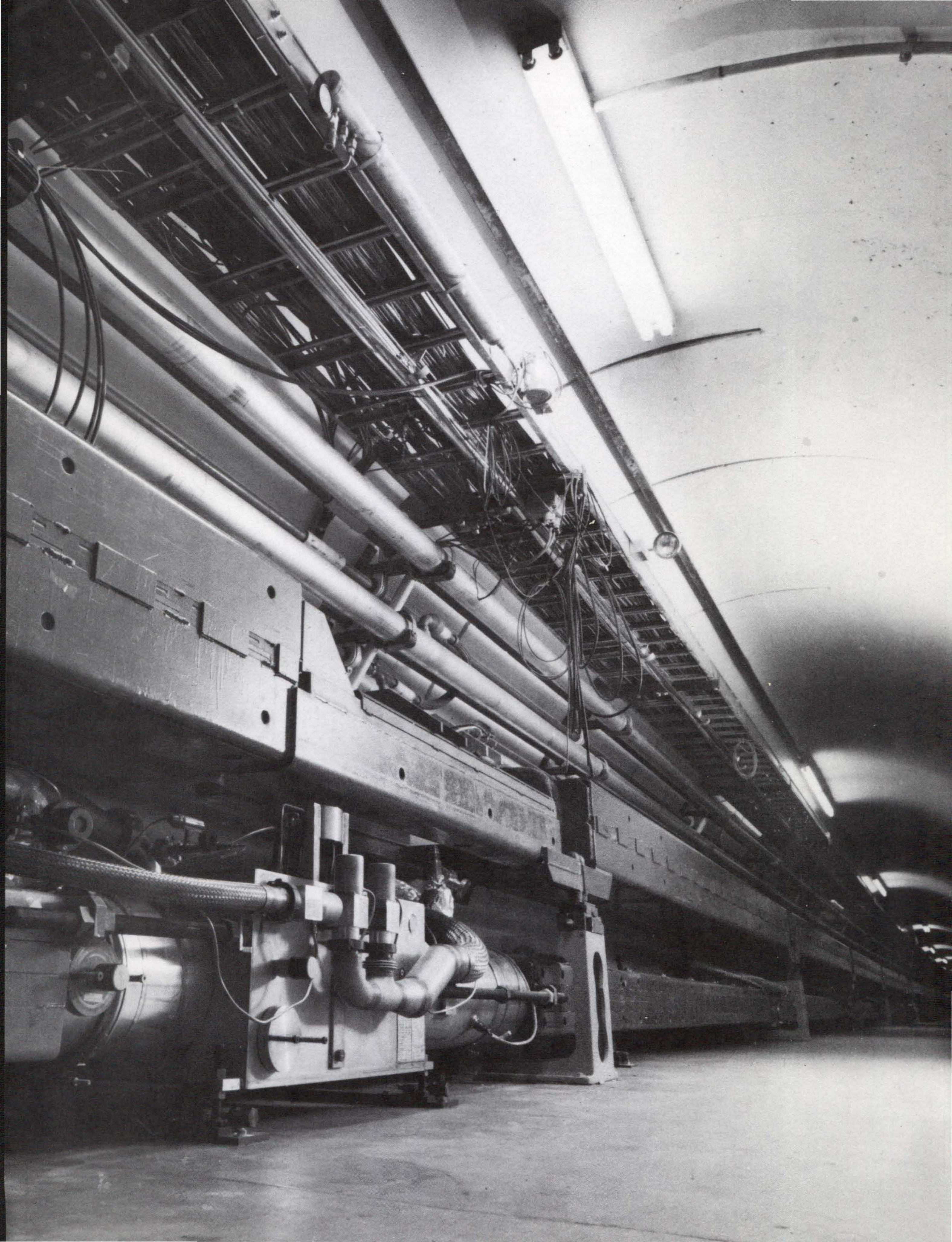
Fermilab 1983



Fermilab 1983

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

Table of Contents

XXC
LETLML
CDF
DOE
GEV
BO
E400
V
FTEV
Q
RRW

I. State of the Laboratory

Initials!

A free association of Fermilab activities generates a fog of letters, usually in the Latin alphabet. These swim, vibrate, float, and occasionally clump together like quarks in the early universe. They form TeV, CDF, SSC, DOE, URA, and just when each grouping begins to convey significance, nonsense arrangements appear: LEP, PEP, YEP, and AEC, BEC, DEC, and O SAY CAN YOU SEE.

TEV,CDF,SSC,DOE,URA,LEP,PEP,YEP,SEE

Steady!

This is a serious annual report. The fifth in the reign of the author. And it behooves us to have an incisive review of 1983 and an inspiring perception of the future. After all, each such annual report has such a review--has a basic theme, has a lesson. It is time to review the reports.

In 1979 we noted that HEP was in a revolutionary state, that Fermilab would have $p\bar{p}$ collisions by 1983, that the Energy Saver was underway and that our funding was too low.

In 1980 we reviewed the state of high-energy physics and how the Tevatron program would impact. We discussed the theoretical desert and the success of the Left Bend. We were concerned with the stability of Saver magnets but tried to describe a Gottingen-on-the-Prairie environment. We wept bitter tears about the funding problems.

In 1981 we were reduced to Shubert Lieder and in particular the one that sang:

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

We proudly defined the Energy Saver project as "mature." We were cautiously optimistic about a new TeV I design but were alarmed at European pace which, we said, threatened to convert collaborative competition into subservience. And we were strident about our underfunding.

In 1982 we looked forward, sideways, and backward to the end of the "old 400 GeV" machine. It was the tenth anniversary of the experimental program and we also gave fulsome albeit unnecessary praise to the theorists. The Saver had done the "3/4-A sector" test which greatly encouraged all of us. Oh yes, we described a Dedicated Collider and the Desertron was mentioned. We prayed earnestly for more money.

We come to 1983, a year in which our funding prayers were substantially answered. It was also a year made immortal by the operation of the Energy Saver. This is described here in adequate detail by Helen Edwards. Her article will be an important part of the history of our times since it is clear that the successful operation of the Saver has significance for the science that is now being done (TeV II), for the science to be done soon (TeV I) and for the long range future of this subject as it evolves worldwide.

The truly spectacular happening capping the 512-GeV exploit of July 3, its subsequent media blitz, and the spectacular lab-wide party that followed--the really splendid happening was the start of Tevatron physics on October 1, 1983. We started with a partly held-over 400-GeV program--the idea being to learn a lot about the machine before facing the very difficult problems of operation at high intensity close to the domain where the magnets may "quench." This has in fact been very fruitful. The gradually improving efficiency, the achievement of a 15 second spill, the improvement in our control of beam orbitry, the exercise of the new switchyard and cryogenic beam lines--all are historical milestones in the art of accelerators. Studies of the machine have been encouraging for TeV I (storage times in excess of 30 hours) and the SSC (successful deceleration of the injected beam to 60 GeV). The 400-GeV program will terminate early in February and, in a three week shutdown, an important test of the TeV I collider option will be installed: the "low β" quadrupoles in the B0 straight sections will teach us how to run the accelerator in the collider mode. When we resume in March, it should be in the 700-800 GeV range and an entirely new set of problems will be encountered and the results described in the '84 Annual Report.

What we are witnessing is the gradual restoration of Fermilab as an operating laboratory. We have still much to build and we will be building through part of 1986, but there is a revival of spirit that comes from doing physics again--a new-old sweetness of mood. Even the complaints are a joy: "the spill has 60 cycle ripple," "the cafeteria closes too soon," "we desperately need another week..." etc. The physics start is impressive.

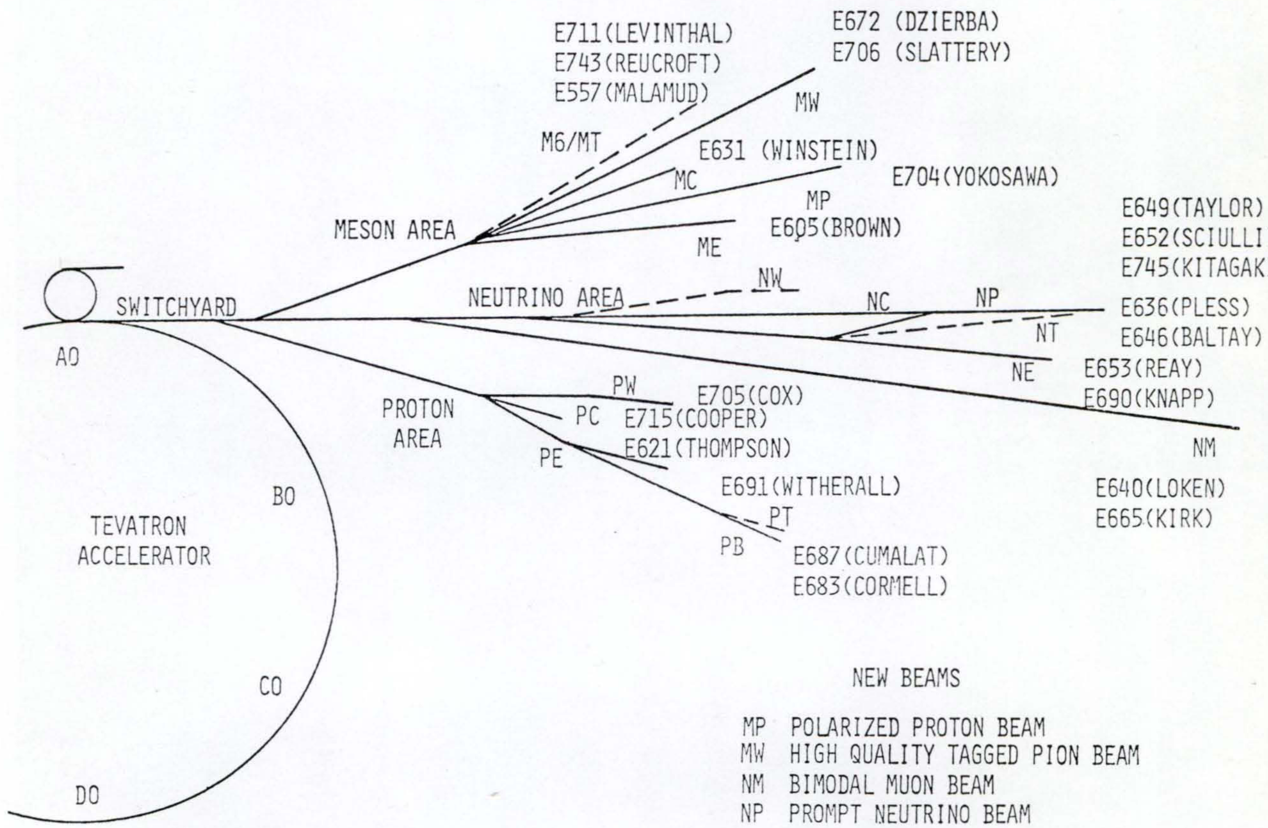
E-400, a collaboration of Colorado/Fermilab/Illinois/Milan/Pavia, is a third-generation attempt to capitalize on the enormous production of charmed particles by neutrons. The key here is an active target that will respond to the finite lifetime of the charmed objects. A large effort from Fermilab/Stony Brook/CERN/KEK/Columbia/University of Washington **(E-605)** has begun the study of leptons and hadrons at transverse momenta near the kinematic limit. In the current data taking, they hope to address curious effects observed when very hard collisions take place in nuclear targets.

E-609, an Argonne/Lehigh/Rice/Penn/Argonne/Wisconsin collaboration, is looking at quark-pair emission via identified "jet" pairs. Any doubts about the fact that quarks appear as jets were resolved by the CERN $\bar{p}p$ collider work. This makes the present experiments interesting in new ways. A Chicago/Princeton **(E-615)** group concentrates on the quark-antiquark annihilation process and, in particular, an arcane theoretical prediction that goes to the heart of our current favorite (QCD) strong interaction theory. The highest priority has gone to **E-715** which involves Chicago/Elmhurst/Fermilab/Iowa State/University of Iowa/Yale/Leningrad. This curious mixture has the obligation of settling a baffling dispute between four previous experiments and an unassailable theory of Professor N. Cabibbo which insists that electrons arising from the decay

E 715 IS HONORED AND PROUD TO BE
THE FIRST ENERGY SAVER USER
OCTOBER 1, 1983

THANK YOU FERMILAB!

TEVATRON II EXPERIMENTS



NEW BEAMS

MP	POLARIZED PROTON BEAM
MW	HIGH QUALITY TAGGED PION BEAM
NM	BIMODAL MUON BEAM
NP	PROMPT NEUTRINO BEAM
PB	WIDE BAND NEUTRAL BEAM

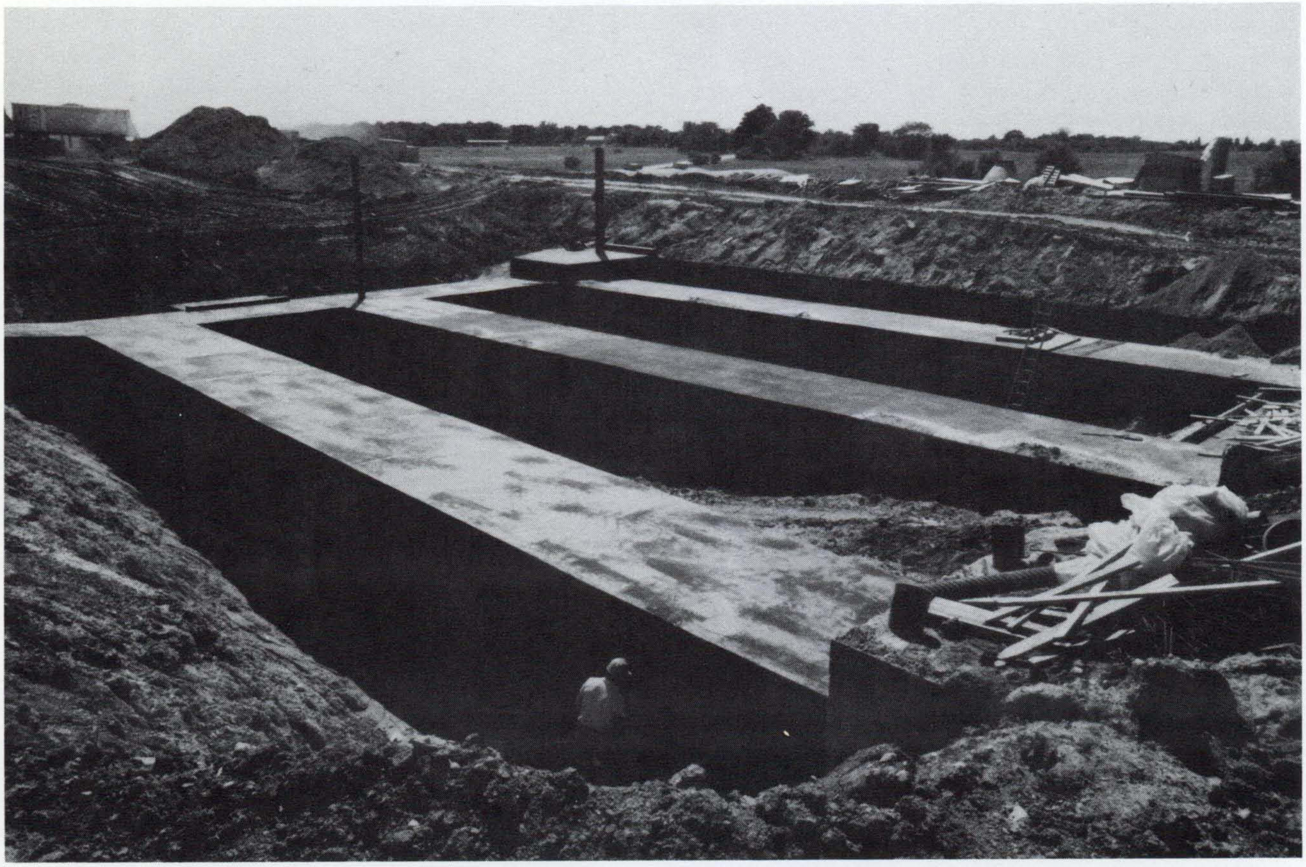
of the sigma minus come off in a particular direction. In addition to all of this data taking, two test beams are busy calibrating and testing apparatus for future runs.

In what follows, we touch on some of the highlights of Laboratory activities. In no way do we claim completeness.

Tevatron II

The Tevatron II Project is midway through its official lifetime, and (like other middle-aged organisms) there are some accomplishments behind, significant challenges ahead, and lots of present activity. The project end is also now visible and stimulates thoughts of mortality and the impulse to sum up the gains that will accrue at completion. Manager Tom Kirk and Deputy Ray Stefanski are the "summer uppers." Implementation takes place mainly in the Experimental Areas.

Nineteen eighty-three was a year of change for the Experimental Areas. It was the first full year after the reorganization that combined three previously separate departments into one. Hence, 1983 was a year for molding and testing the new organization, and the tests were not easy. Not only



New Meson beam enclosure upstream of the Meson Detector Building.

did this group have the responsibility for implementing the beam line changes inherent in the Tevatron II program but they became an operating group as of October 1, 1983, with the responsibility for tuning and stabilizing the various beams which were required for the program.

To cap all of this, experiments due to run in the spring of '84 had to be installed when areas became ready. Direction of this group changed from the founding leader, Ken Stanfield (who moved to the Business Office), to Roger Dixon.

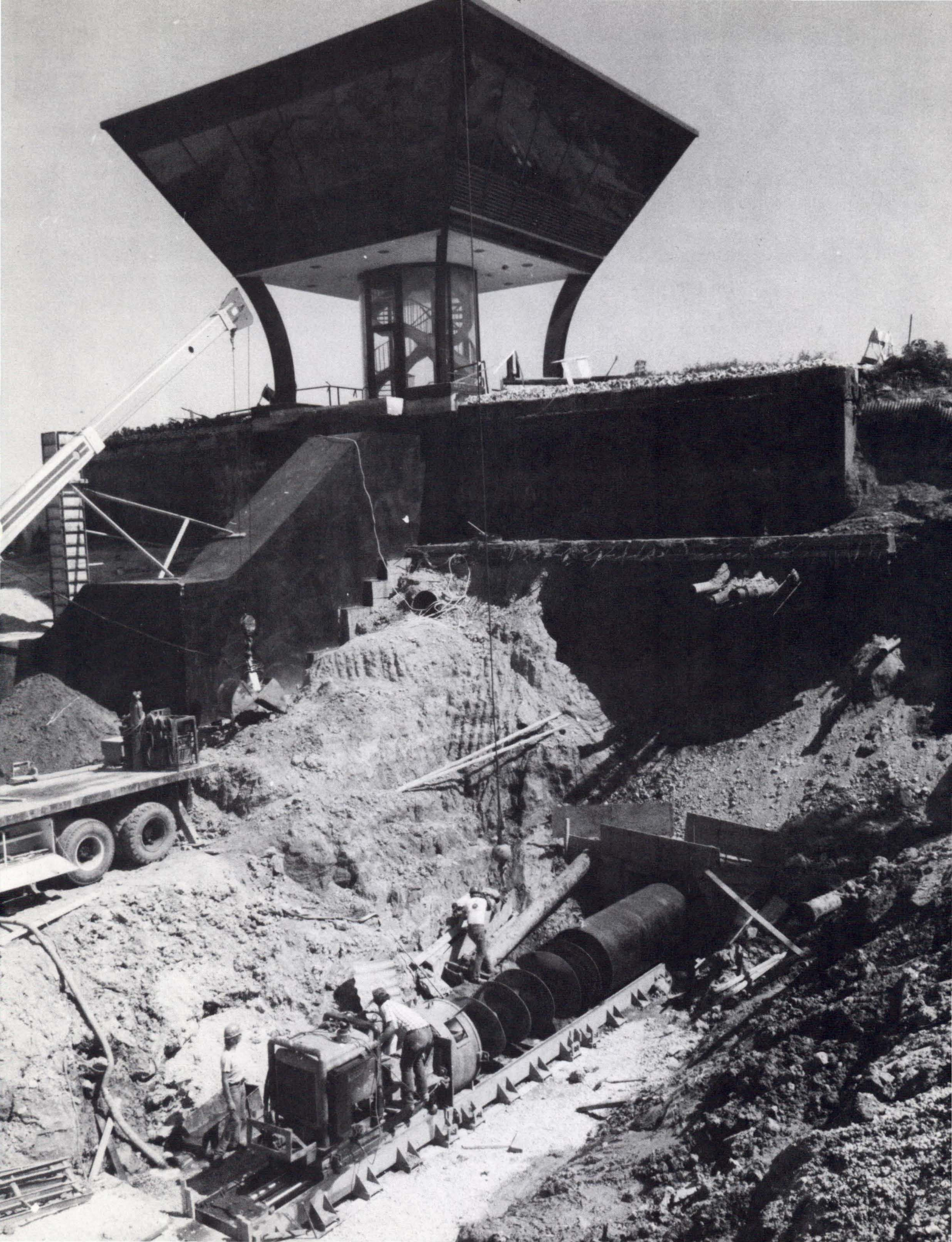
In the **Meson Area**, three beam lines have been rebuilt and are being commissioned. They are the new M-East beam line which presently serves E-605, the MT beam which delivers protons to E-609, and the MB beam which serves as a test beam for the old M4 area. Some of the major new components in these beam lines include five (5) cryogenic bends, 3 in ME and 2 in MT. A new cryogenic refrigeration center was constructed in the Meson Area to service these bend points. This center includes 3 satellite refrigerators. In addition, the beam enclosures just upstream of the Meson Detector Building have been modified to allow future installation of the new MW, MC, and MP beam lines. In the 1 TeV plan, primary protons for these beam lines will be delivered to target piles located in the detector building. A 3-way split to the Meson Area now exists in the

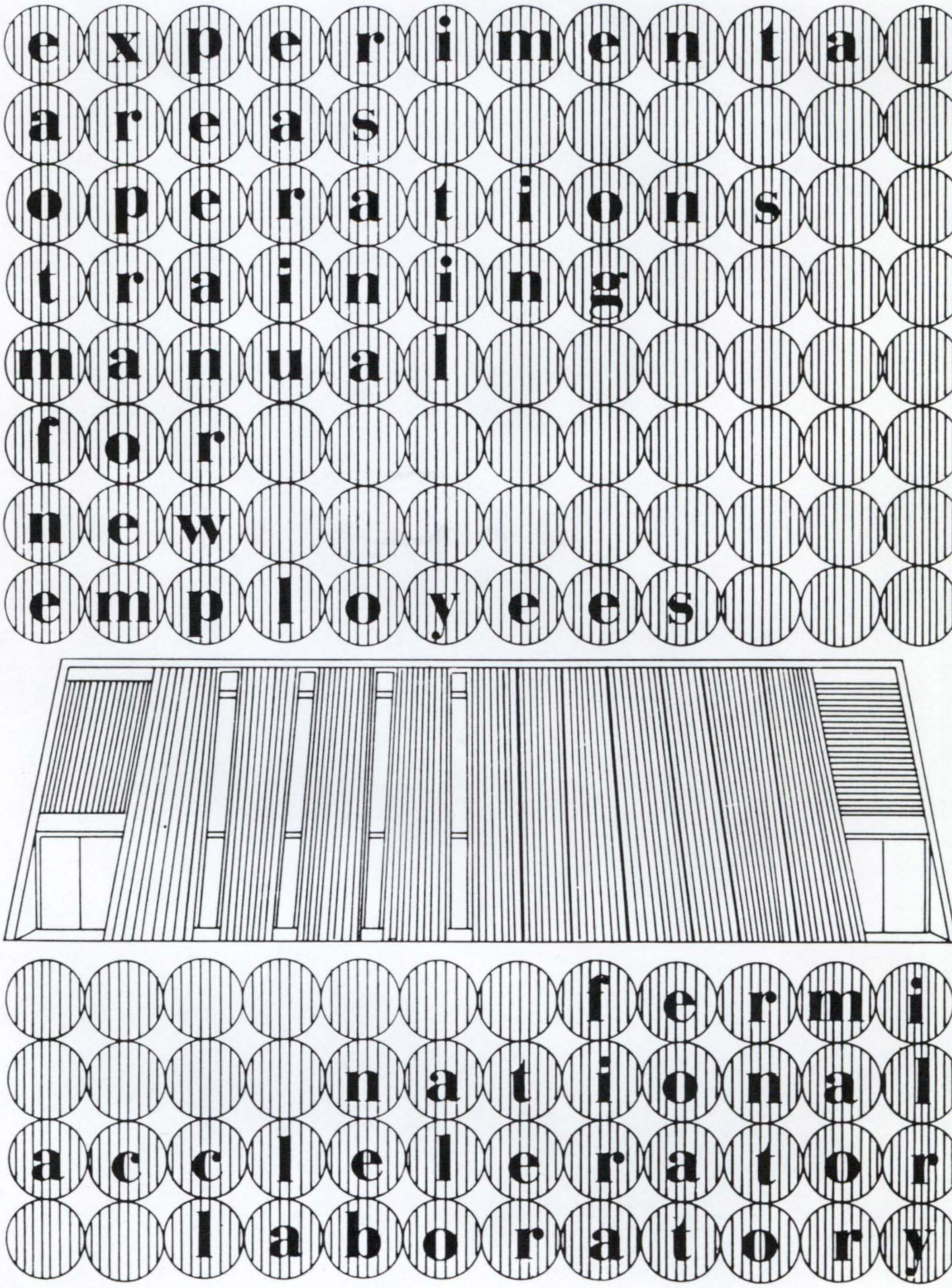
Installation of Tevatron II one-meter bubble chamber steel in Lab F.

switchyard. In the future it will be possible to run ME, MW, and one of MC, MP, or MB simultaneously and independently.

Neutrino Area activities include construction of Lab G, Lab F, and modification of Lab E. In addition, some of the upstream beam pipe for the new muon beam were installed as well as modifications to NW1 to accommodate the new beam. In preparation for the construction of the new Muon Laboratory, the Chicago Cyclotron Magnet was moved from the old muon laboratory and is being installed at the new laboratory. In the meantime, the old muon lab will house the NW test beam facility with many users lining up to make use of it. Other work in the Neutrino Area includes the construction of the new N-East hadron beam. This beam will be transported to Lab D for initial use by E-653. The bubble-chamber crews are busy outfitting the 15-foot bubble chamber with a new laser holography system that should provide 100-micron resolution in the chamber.

In the **Proton Area**, the three primary beam lines have been upgraded to 1-TeV capability. The upgrade included the installation of one new cryogenic bend string to service the PW primary beam line. Also, five superconducting quadrupoles have been installed in PE. One satellite refrigerator was installed for each beam line. In addition, a new enclosure (PE2) was constructed to house the





Lambertson magnets which will eventually split the new Wide Band Beam from the PE primary beam. A new quadrupole enclosure for P-Center (PC2) was also constructed as part of the same contract.

Since the reorganization, it was also necessary to consolidate the operation of the three areas. The Operations Center is temporarily located in the NS3 service building while a new building is being constructed just north of NS3. It is anticipated that the operations for the next physics run beginning in the fall of 1984 will be centered in the new Operations Center.

Delivery of new computer equipment to Wilson Hall.

Computing at Fermilab

During the last year, the load on the Central Computing Facility at Fermilab has grown to levels which have brought the system to complete saturation. This saturation had been projected to occur at this time when the present system of three Cyber 175's was ordered in 1979. Consequently we authorized the acquisition of additional equipment. For the acquisition, a fully competitive bid procedure was utilized. The winner was a dual Control Data Cyber 875 processor with 750K words of storage.

The new CDC hardware will be delivered stepwise over the next 20 months, first one CPU and then a second. It also provides for additional peripherals, including tape drives, disk drives, and printers. By the end there will be the equivalent of seven Cyber 175 CPU's installed in the Central Computing Facility. The additional disks to be delivered will more than double the presently available disk storage capability, bringing the total to 30 gigabytes.

Another major change in the Central Computing Facility is the addition of a Network Systems Hyperchannel local area network. This is a 50 megabit coaxial cable system capable of transferring files among all of the machines connected to it over distances spanning a few hundred feet. All the existing large computers currently installed on the 7th and 8th floors of Wilson Hall will be connected to this network. Thus, the existing Cyber 175 complex will be on the system as will the new 875 processor. In addition, the IBM business computer, recently changed from a model 4331 to a 4341, will be connected to the Hyperchannel. At the end of the year, two 4 megabyte VAX's with 2.7 gigabyte of disk storage capacity will also be installed and connected to the Hyperchannel. These VAX computers will serve as an alternate front end to any computer connected to the Hyperchannel for those users who prefer that route into the system. This facility will be particularly attractive for those programs which only run on VAX's.

The most important feature of the Hyperchannel is that once it is installed and working in a mature manner, it will be possible to add new computers into the network in a relatively straightforward manner. This will give us the future capability of adding powerful but not particularly user-friendly machines for additional compute functions.

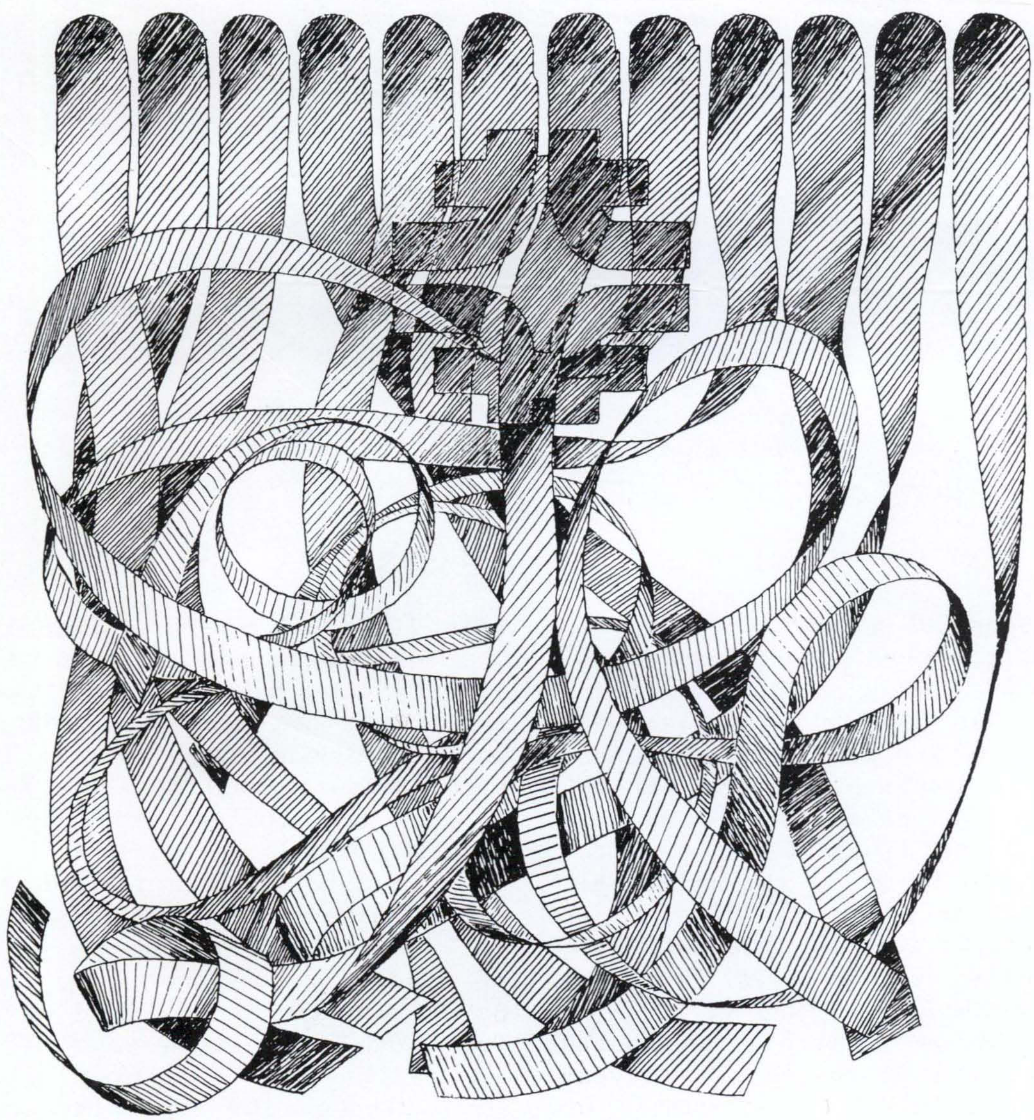
With the resumption of the experimental program this fall, the major effort in the Computing Department data acquisition and electronics support groups was to help experimenters with their experiments. The most significant part of this effort was in turning on systems with whole new architectures, consisting of coupled, multiple computer systems. The Computing Department has developed and is now distributing pairs of computers (either two PDP-11's or a PDP-11 front-ending a VAX 11/780) to the largest of the experiments. The Department's efforts have included the integration of new hardware and the development of a large amount of new software. This new software is built on the software which is still in wide use in the good old single computer systems.

Just as the data-acquisition computing has required significant new extensions of capability, so too has the electronics which resides between the particle detectors and the computers at the experiments. The international high-energy physics community has combined efforts to develop a new standard, called FASTBUS, which is directed at the specific distributed processing needs of the future detectors in this field. The Computing Department has participated in defining the specifications for this system, in evaluating prototype devices, and in preparing the software to use them. The software efforts in the Department include work on drivers for computer interfaces, general subroutines, a higher level interpretive language, and a data base and other system management tools. The Department also shoulders the responsibility for drafting and maintaining the internationally used standards for FASTBUS software. Commercially available FASTBUS devices are also beginning to enter the electronics pool and training of personnel on these new devices has begun in earnest.

Projection of Computer Needs
In Equivalent CYBER Hours

	1984	1985	1986	1987
Proton Area	3	4	5	5
Neutrino Area	1	1	1	1
Meson Area	1.5	1.5	1.5	1.5
Collider	1	3	10	16
Accelerator	1	1	1	1
Theory	*	*	*	*
Sums	7.5	10.5	18.5	24.5

Looking further ahead, we convened a new Computer Advisory group chaired by Joe Ballam of SLAC and composed not so much of users as of computer professionals. The Ballam Report looked towards 1986 and confirmed our worst fears--the colliding detectors observing 2-TeV collisions would swamp the system many times over. Their recommendations are very sweeping and a new acquisition study (looking towards '86) is underway to cope with the problem. In parallel we are trying to develop specific computer architectures for our own specific problems. To this end we have formed an **Advanced Computer Program** group under Tom Nash. This group is designing a processor with track reconstruction and other Fermilab specific problems in mind. Close liaison with CDF and other customers is essential. This brings up **CDF**, one of our major construction projects. It gets a special section further on in this annual report.



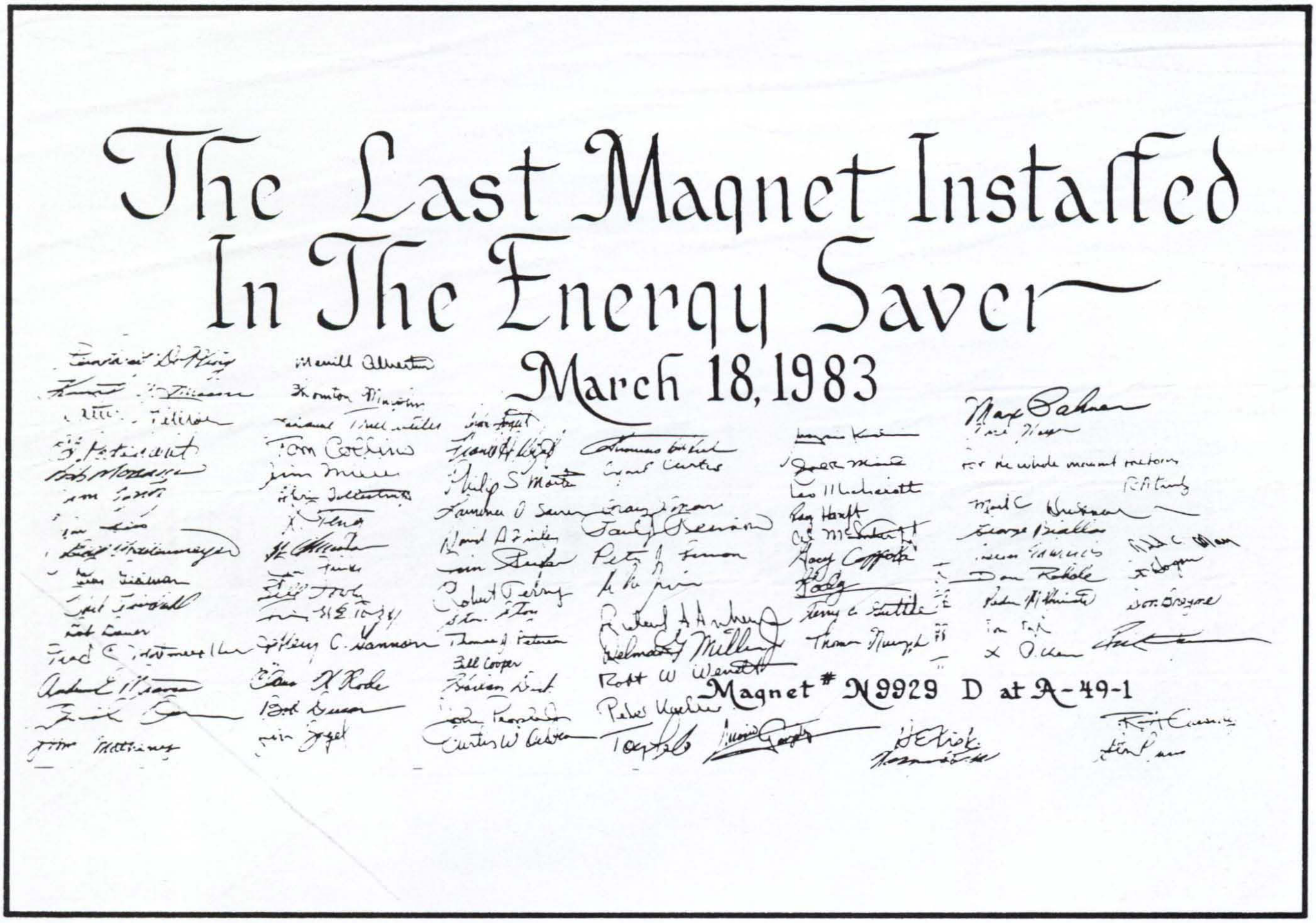
Report of the Ballam Committee **December 1983**

Helen Edwards signs placard seen on the facing page. Her article on "The Startup of the Energy Saver" is next in this report.

Technical Support Section

The Technical Support Section is a 1983 invention and is composed of groups whose nearly total commitment during the past four years has been the production of superconducting magnets and other components for the Energy Saver. The high point of 1983 was the delivery of the final magnet for the Saver ring, followed by the remarkably successful commissioning. Early in 1983 the completion of this work allowed a shift of emphasis from the Saver to the Tevatron I and Tevatron II projects. These new projects require the construction of nearly 700 conventional magnets and a large number of complex beam electrodes for the antiproton source and for higher energy beam lines for the experimental areas. The merging of the conventional magnet effort with the superconducting magnet facility, the mechanical design group and the machine shops to form the Technical Support Section was in fact a way to meet the challenge of the TeV I and TeV II project schedules. This was done in 1983 and the section entrusted to the direction of Richard Lundy with Paul Mantsch as his deputy. The bulk of production manpower that once built Saver magnets is now hard at work on TeV I and TeV II magnets.

Although the final production and measurement of the Saver magnets was completed in February of 1983, a

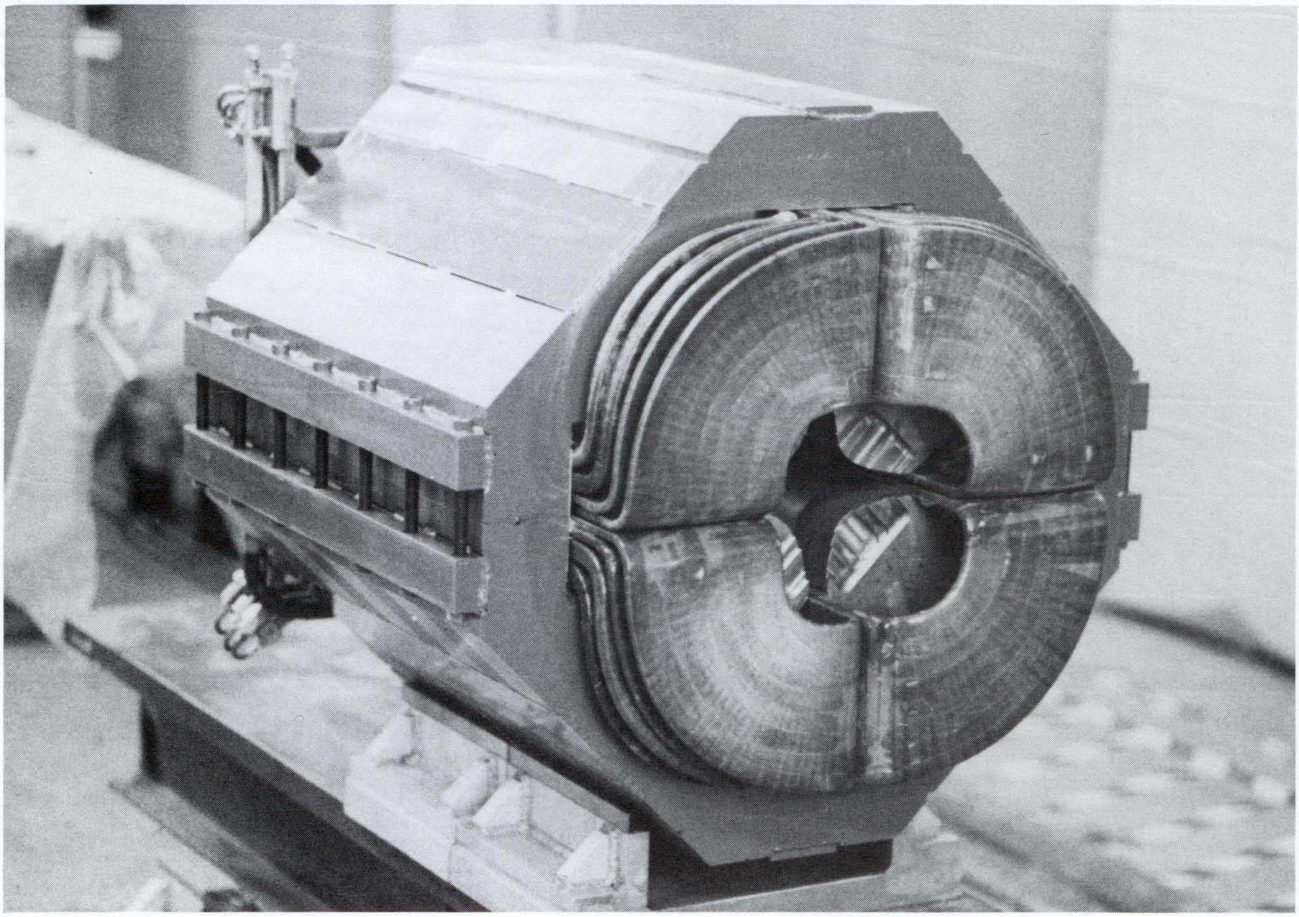


reduced work force remained to build spares as well as special purpose superconductor magnets. In particular high gradient quadrupoles needed for the colliding beams interaction region were built and tested.

The Tevatron I project consists of the production of over 400 conventional magnets that make up the debuncher and accumulator rings as well as beam lines within the antiproton source. There are two sizes of quadrupoles and two sizes of dipoles. Each of these come in various lengths. Once complete, the magnets will be measured magnetically at the Magnet Test Facility using a newly designed data-acquisition system incorporating substantial improvements arising from our experience with measuring over 1000 Saver magnets.

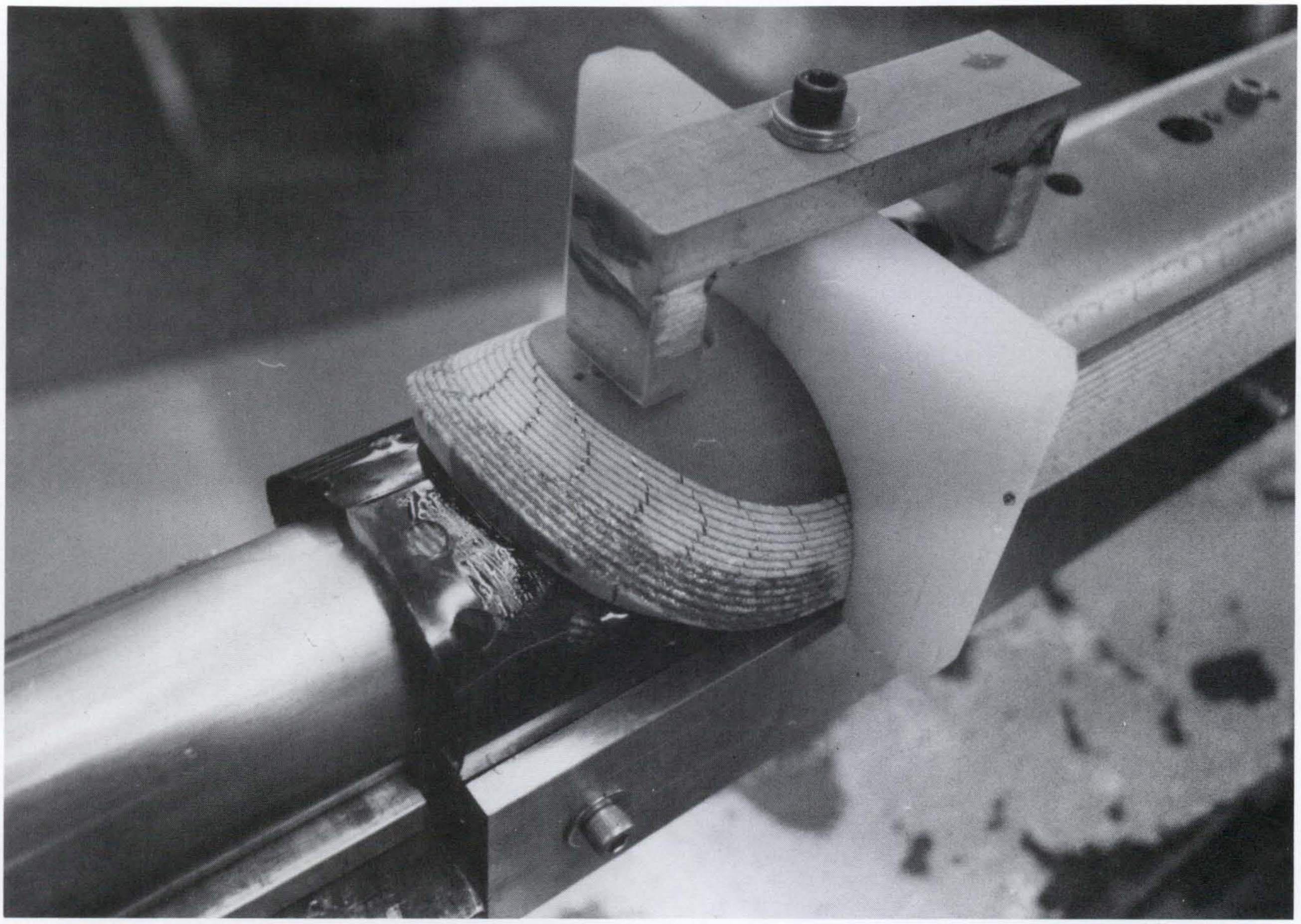
Technical Support also started the fabrication of the beam pickup electrodes which are the heart of the antiproton cooling system. A fully electronic "traveler" (a quality control document) was introduced to monitor electrode production by presenting assembly steps and recording quality control measurements.

The Tevatron II effort consists of providing a variety of magnets for upgrade of the beam lines for 1000-GeV beam. There are about 275 new conventional magnets built for this purpose. An additional 50 Saver-type magnets were placed in the beam lines.

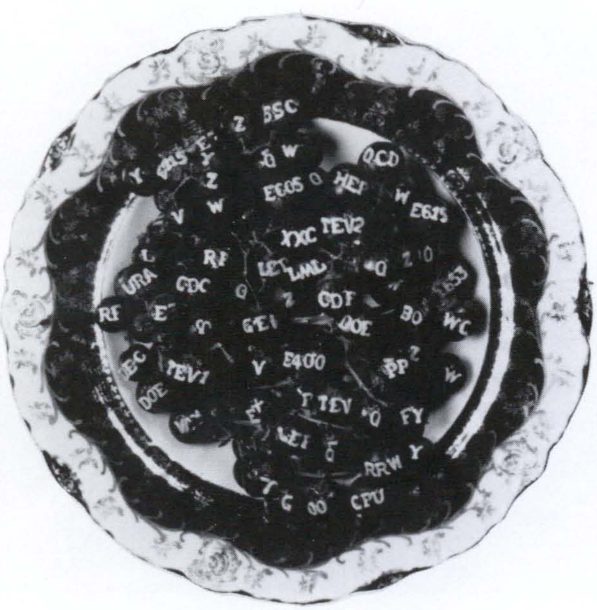


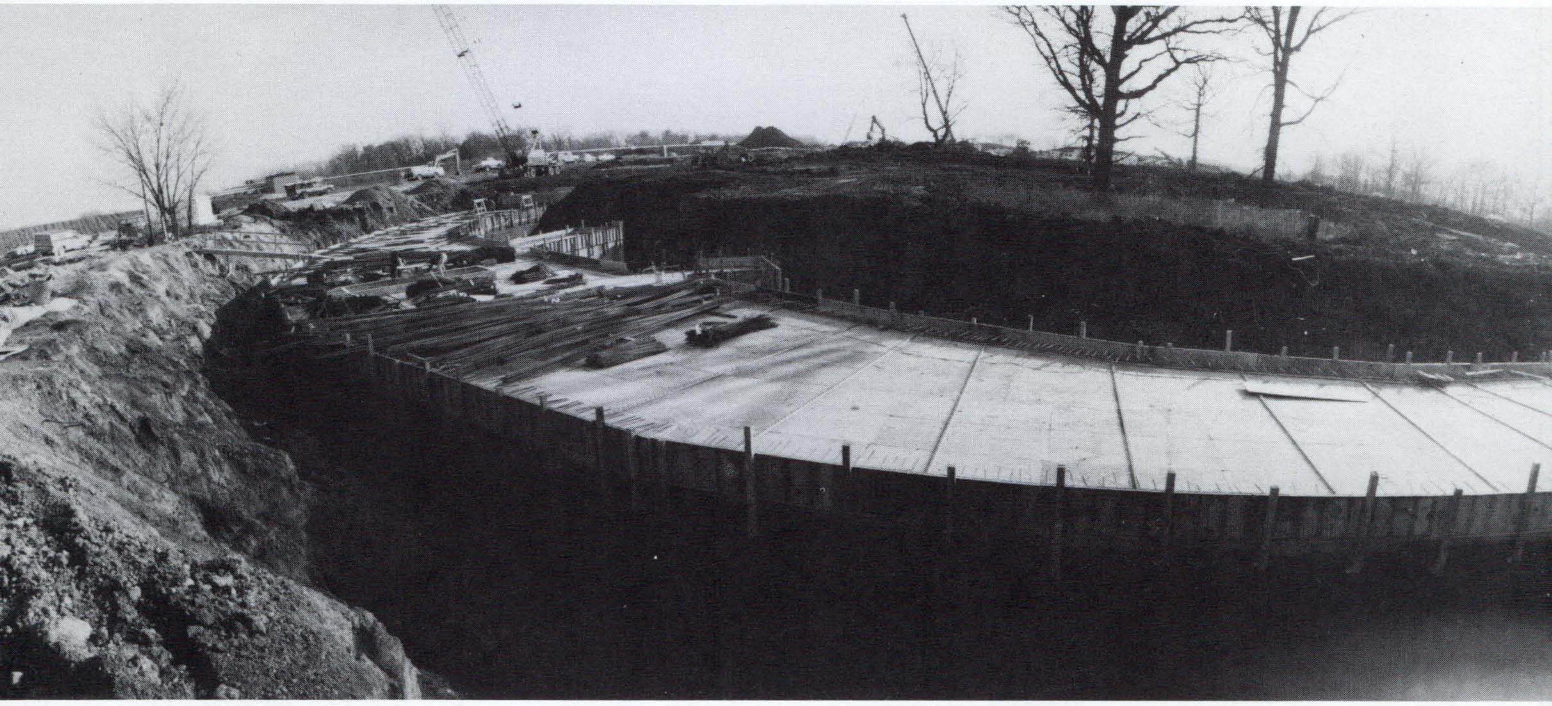
Prototype quadrupole for the Tevatron I project. Note shaping of the poles at the ends.

During 1983 an effort was started within the Technical Support Section to develop magnet designs for the Superconducting Super Collider (SSC). The unique contribution which Fermilab can bring to this project is of course our recent experience with the Energy Saver. Although effort has been invested in both high field (8-10 Tesla) and superferric (2-3 Tesla) magnets, the focus of the work is an extrapolation of design concepts proven in the Saver. The program of magnet development that was undertaken included magnet design, field calculations, structural analysis, and an extensive modeling program. The goal of these activities is to build and test a string of production prototype SSC magnets in a period of three years.

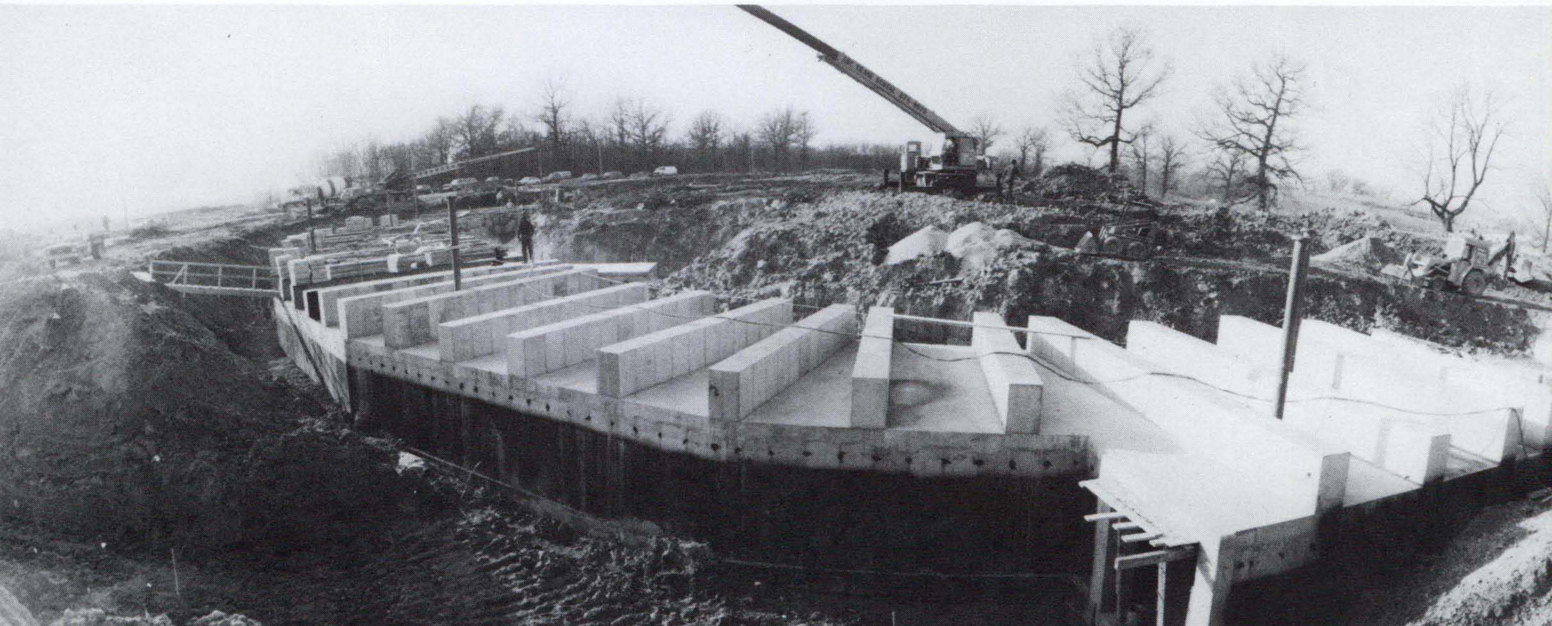


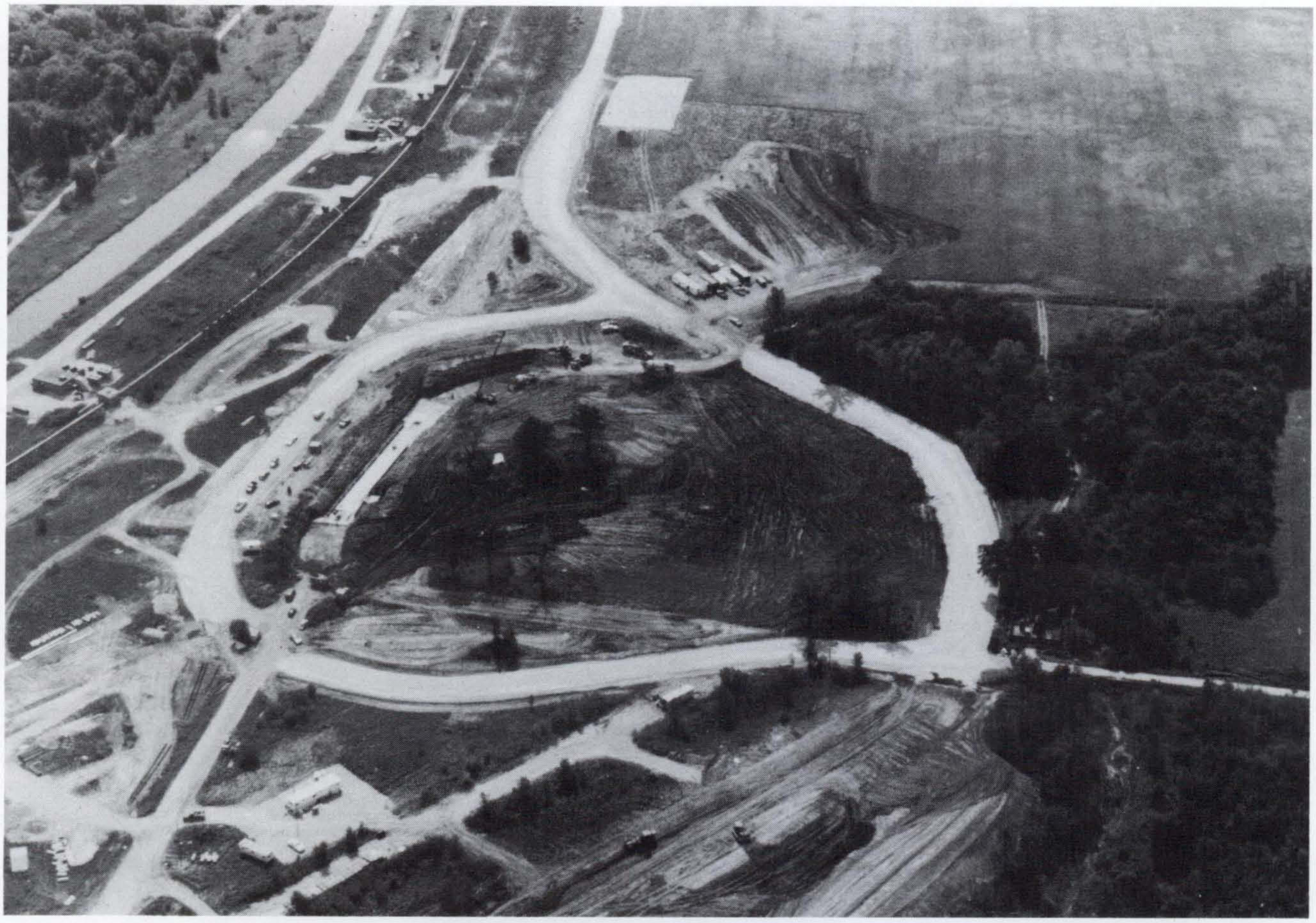
Coil of a 2-in. superconducting dipole prototype.





Two stages in the Tevatron I tunnel construction. Roof beams have been put in place in the lower photograph.





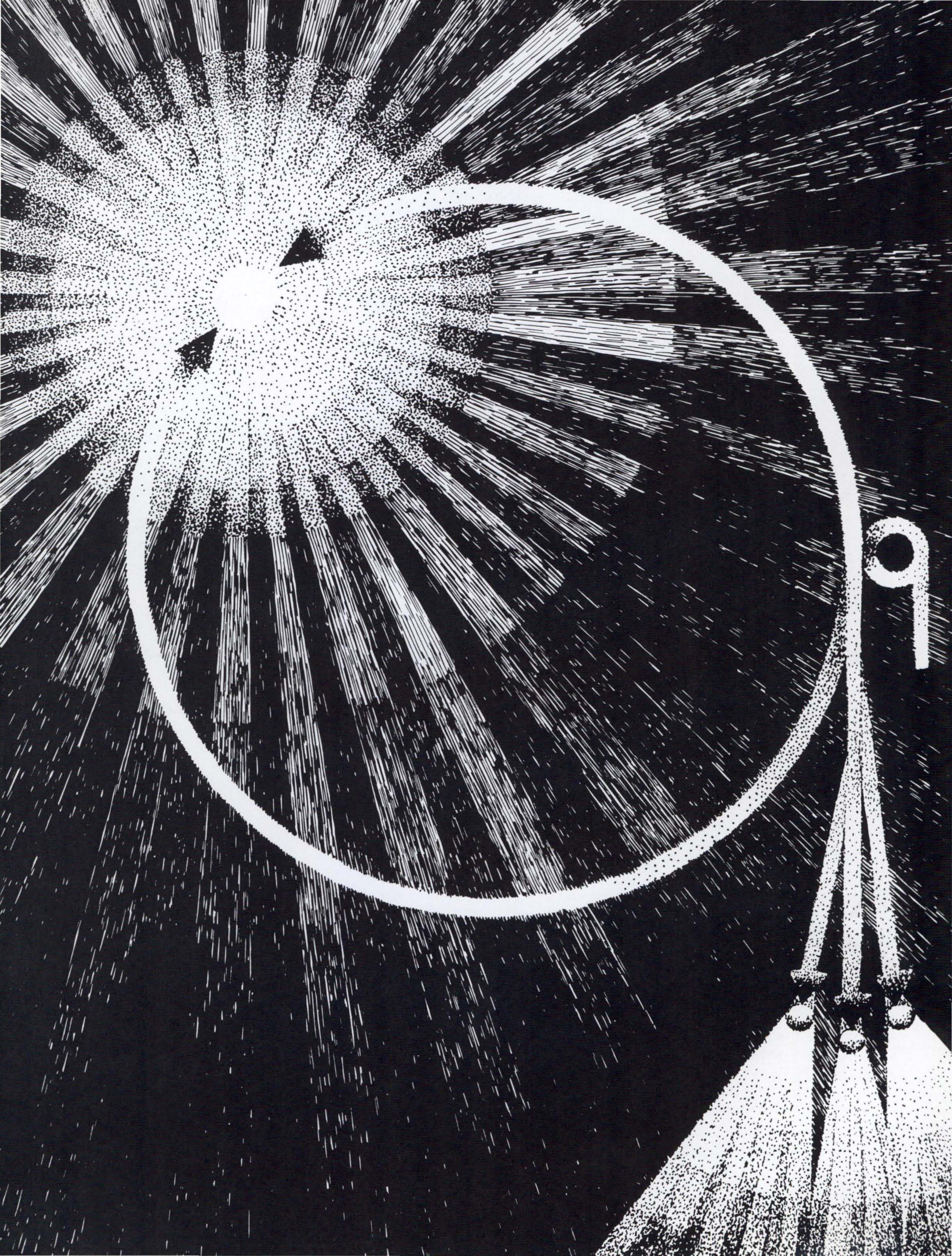
Aerial view of the Tevatron I tunnel construction.

Tevatron I

The year 1983 saw the Tevatron I project make a great leap forward toward our goal of colliding-beams experiments with 1-TeV protons and 1-TeV antiprotons. The project, under John Peoples and Don Young, has moved from a largely design phase to a mature phase of construction and fabrication. Some of the impetus for our advance came from external events, but the largest factor was certainly the inspired perspiration of everyone working on Tevatron I.

First, the external events. The great success of the CERN SPS Collider and the important physics results in 1983 from that work confirmed what we already knew, that there is gold to be mined in the hills of $p\bar{p}$ physics at our higher energy. The CERN work shows that we are building a feasible system for doing physics. Considerable theoretical work gives hints of interesting new phenomena in our energy range. In addition, the HEPAP-DOE decision to press forward with the Superconducting Super Collider as the step for the 1990's gives Tevatron I additional importance as the U.S. hadron-hadron collider of the 1980's.

These bright stimuli pale into insignificance compared with the drive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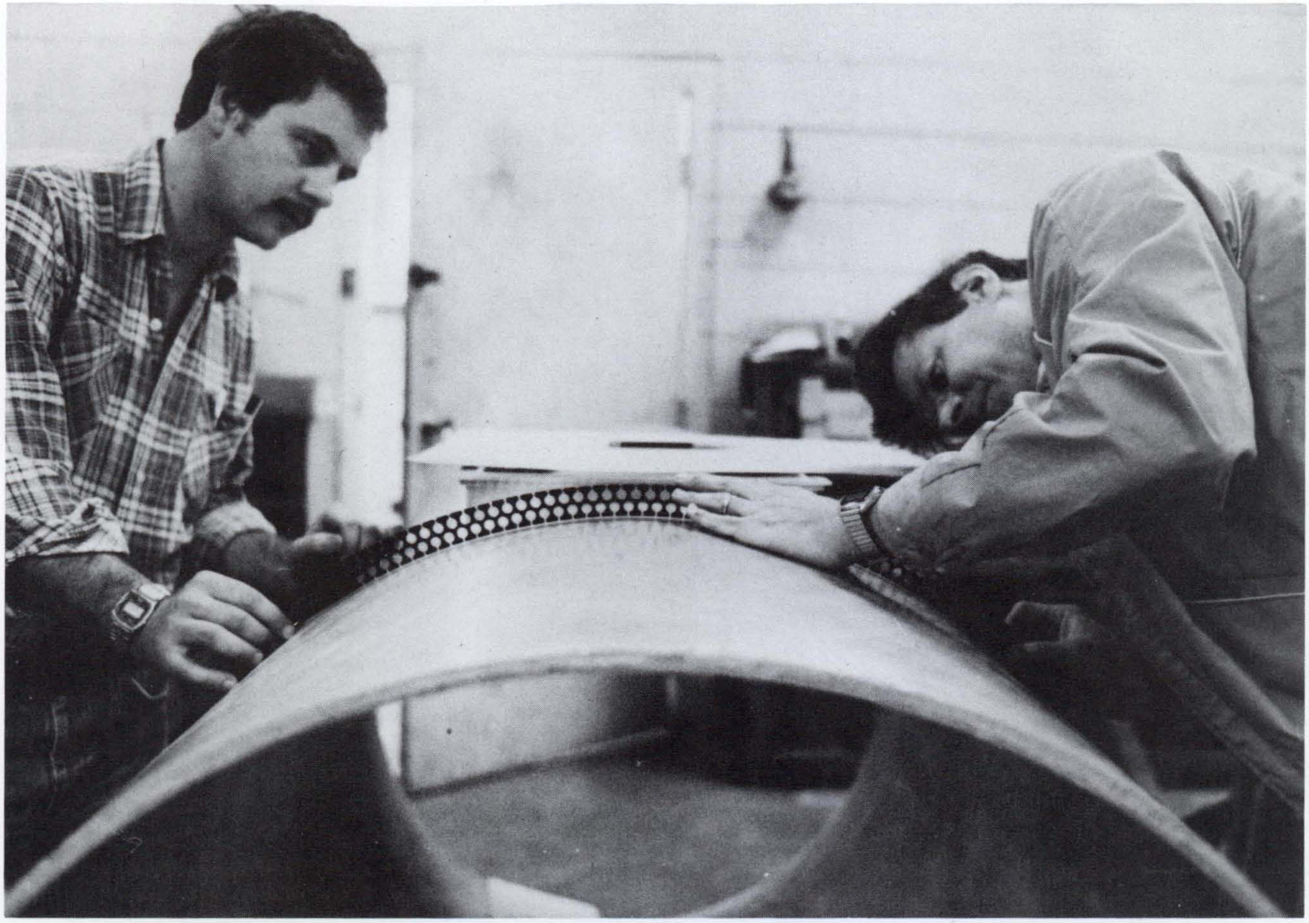
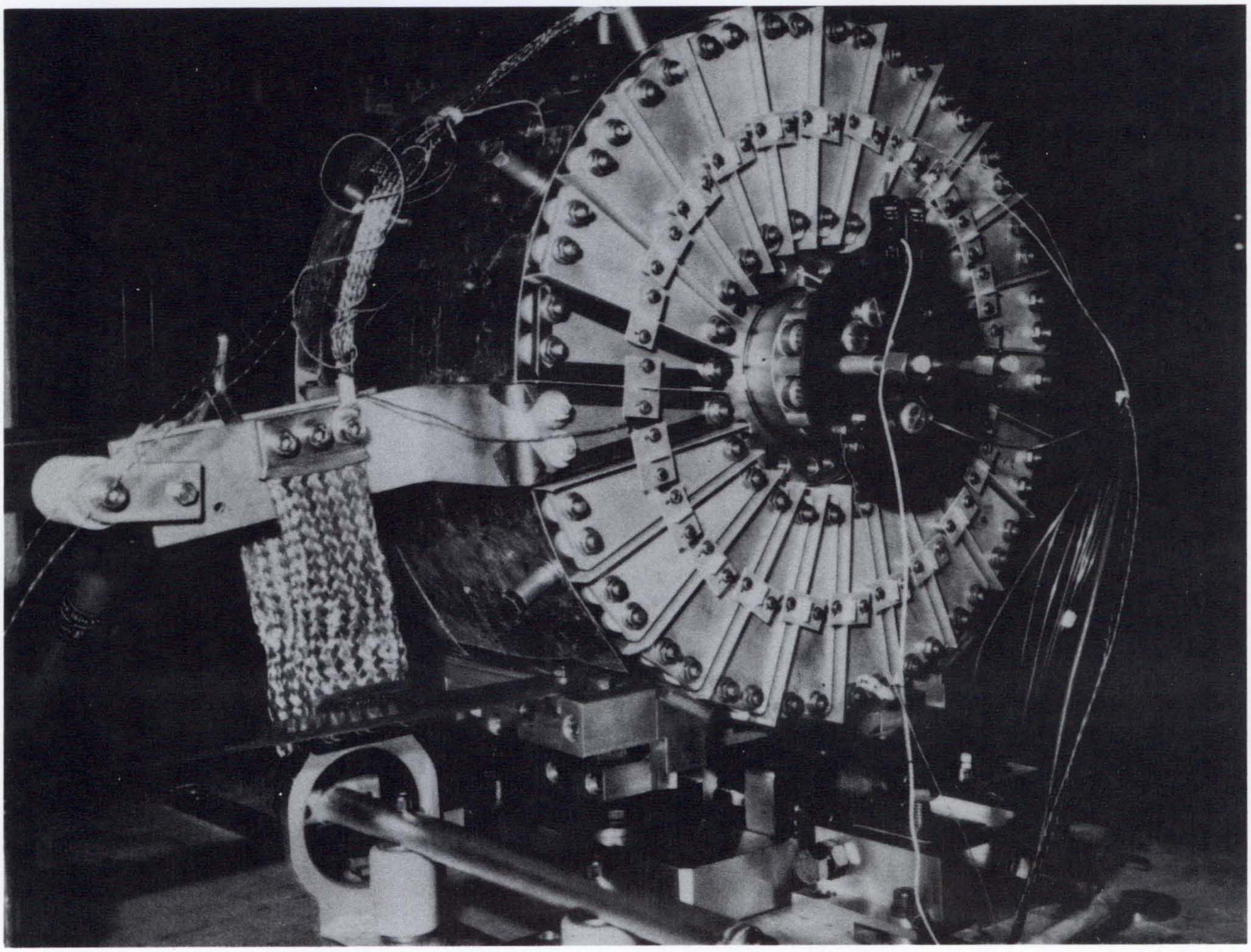


Tom Petrak (left) of Meyer Tool and Joel Misek assemble a prototype Tevatron I rf cavity.

← Cover from the Tevatron Phase 1 Project Design Report.

of the Tevatron I people to move their project along. In 1983, this drive has produced prototypes of all the major pieces of hardware in the antiproton source. In addition, the experimental hall at B0 has been completed and is now in use by the Laboratory.

The low-beta superconducting magnets that make the beam neck down to a small waist for high luminosity at B0 have been built and testing is virtually complete. These magnets have higher fields and are more difficult than the ordinary superconducting magnets of the Tevatron ring. Design work is going on for an equivalent low-beta system for the D0 interaction region. We are also working on designing and building equipment for the overpasses that will

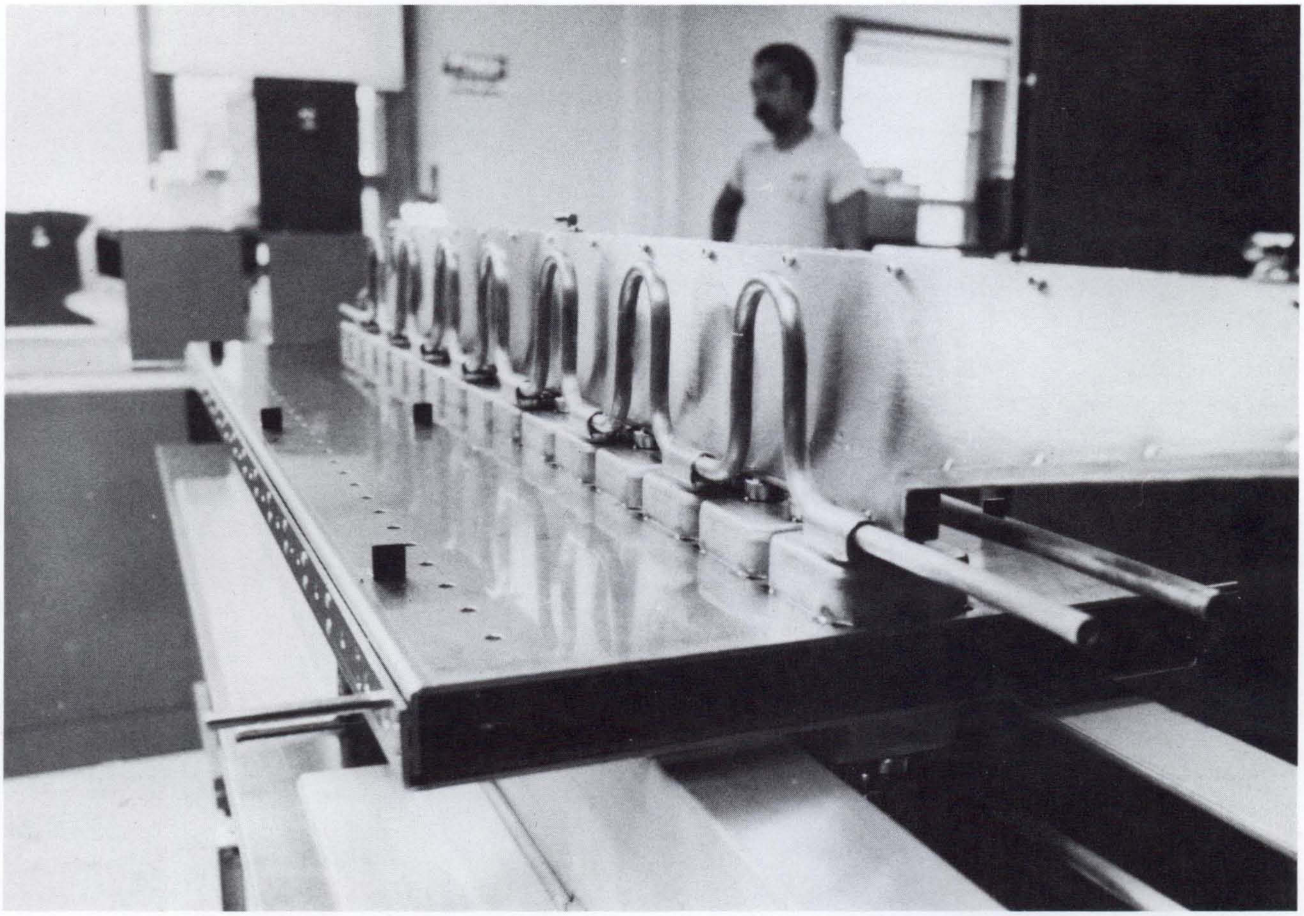


The Fermilab lithium bus and transformer mounted at CERN for testing. The lens can be seen jutting out from the transformer aperture. Water-cooling lines have not been connected in this photograph.

carry Main-Ring beam around the detectors at B0 and D0. It goes without saying that in all of this, TeV I is Technical Service's best customer and vice versa.

The architectural design of the ring and beam-transport enclosures, the roads, and the utilities were completed and construction of these facilities is in full swing. We will begin the installation of equipment in them in the spring of 1984. This design work was held up for a time in 1983 because our detailed orbit studies showed us that some design changes were needed in the Debuncher lattice and these changes affected the tunnel dimensions.

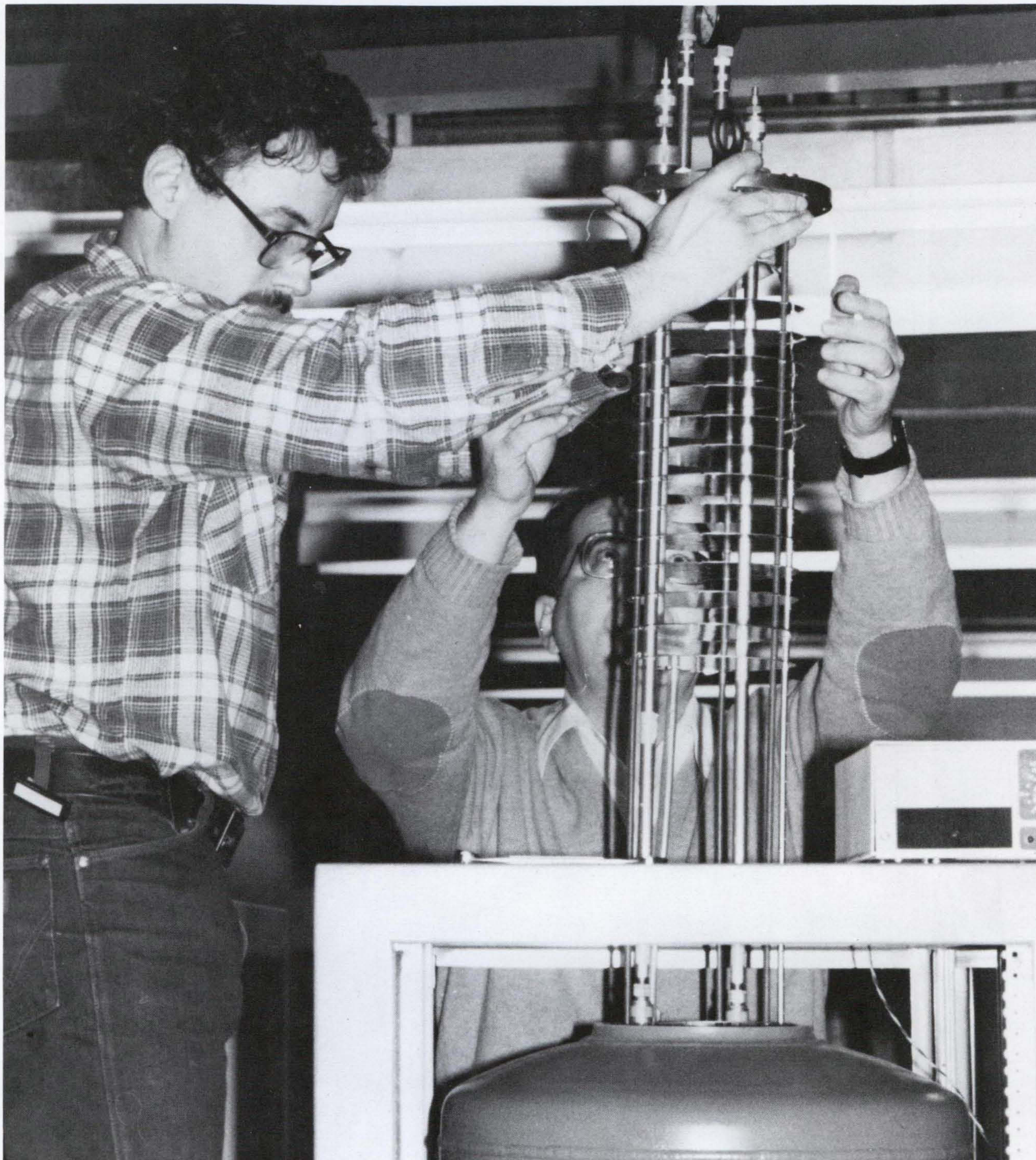
One of the many gratifying areas of advancement was the lithium lens used to focus antiprotons immediately downstream of the production target. The lithium lens, invented at Novosibirsk, is a challenging component because of its very large pulsed current and very large internal stresses. Our group built its own lithium lenses in 1983 and, after pulsing tests here, took one to CERN for testing in their



Prototype of a stochastic-cooling pickup for Tevatron I.

antiproton production system. These tests were successful--the lens performed according to design, giving us confidence in our entire production scheme.

Another difficult system that has made significant advances in 1983 is the stochastic-cooling hardware. Complete prototypes have been built and tested for the 1 to 2 GHz range, including, pickups, amplifiers, filters, and kickers. Their performance has reached the design goals. Work is also going on in the 2 to 4 GHz range. Here the prototype systems are close to the design goals. Included in this work is a new design feature, the use of superconducting notch filters constructed from a 330-m long transmission line. The filter is used to shield the core of accumulated antiprotons from the thermal noise generated by the very high gain stack tail cooling system. This work is a collaboration among our own group, Lawrence Berkeley Laboratory, and Argonne National Laboratory, and all have made solid contributions to the joint effort.

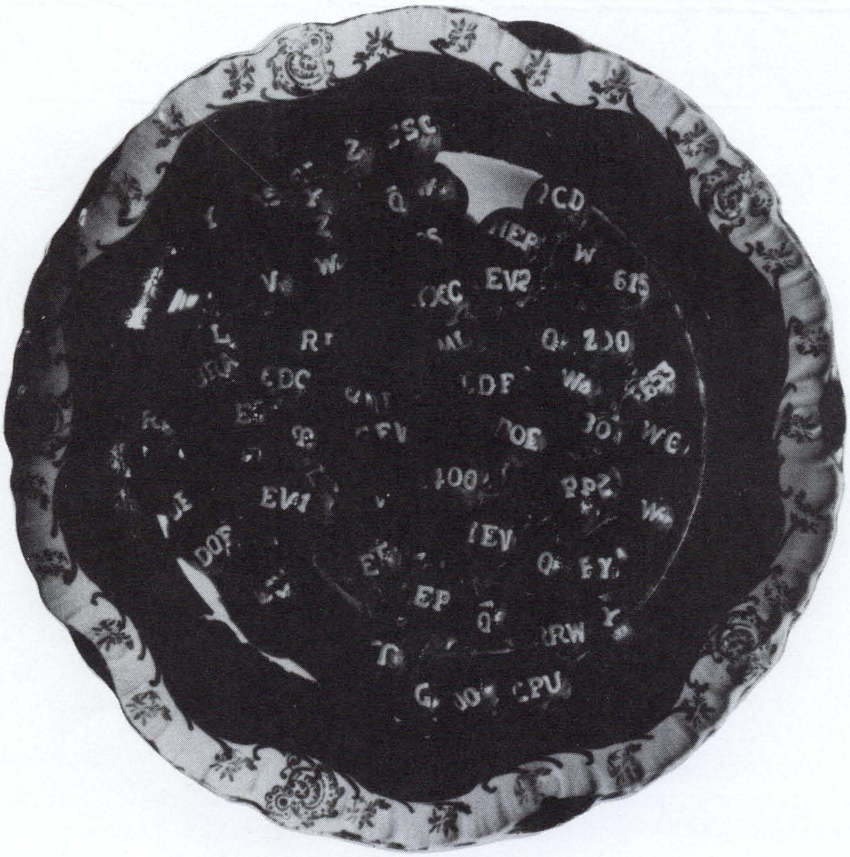


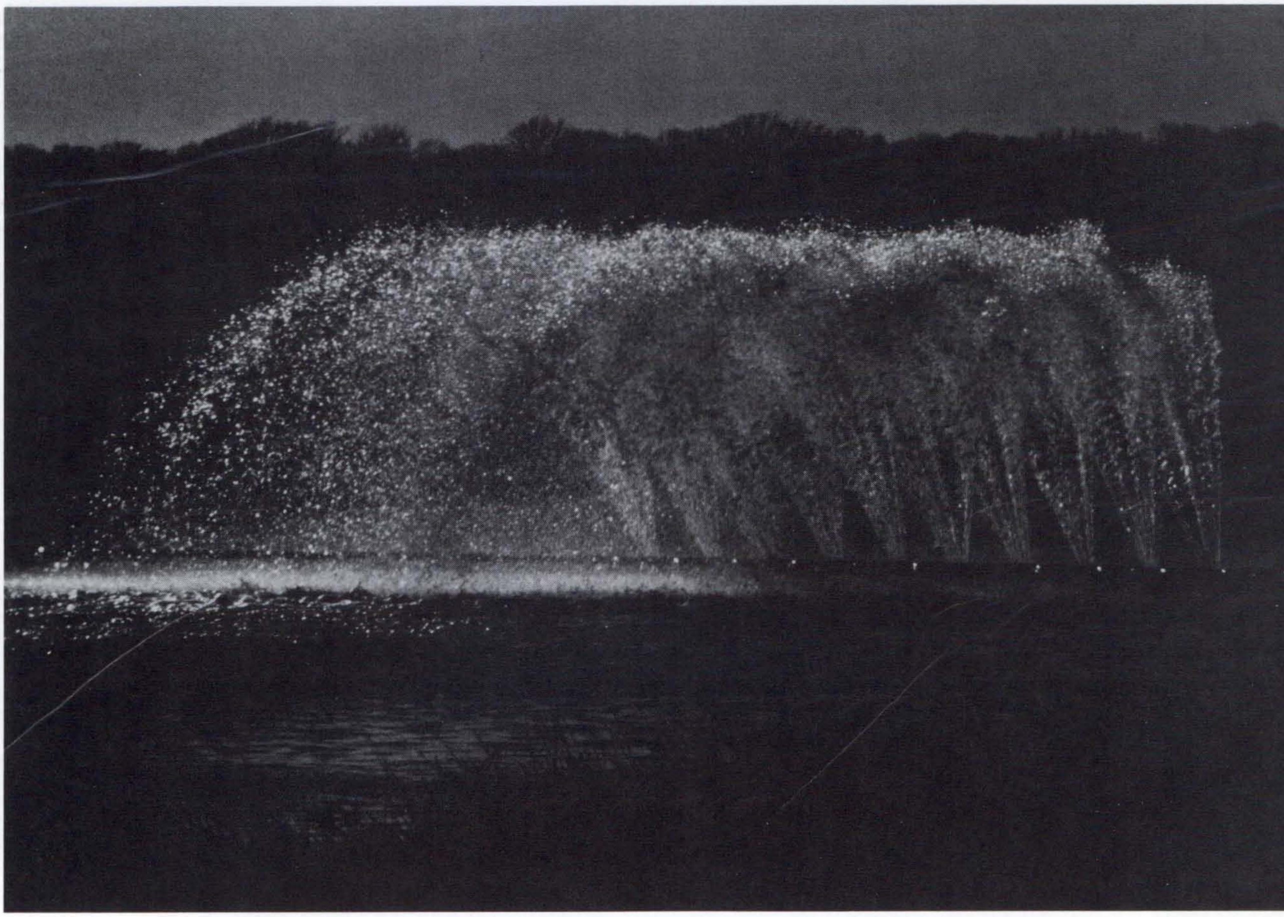
Ralph Pasquinelli (left) and Moyses Kuchnir lower a superconducting stochastic-cooling filter assembly into a dewar for tests.

We have already mentioned the conspiracy between TeV I and Technical Support to build 400 serious and multitudes of smaller magnets for the Debuncher, Accumulator, the many beam-transport lines, and the overpasses.

Many other components, such as kickers and rf cavities, have been tested experimentally in prototypes and are now being ordered for production. We have also ordered vacuum components, power supplies, control-system components, and many other parts for the antiproton source rings.

A year from now we will have completed the ring and will be deep in the throes of commissioning the Antiproton Source. The goal is to see the first $\bar{p}p$ collision in the Tevatron at 2 TeV in the center-of-mass before the 1985 shutdown begins.





A fountain in the Main-Ring cooling pond.

Business Services Section

This was the year that Yale University hired away our Business Manager, threatening a total breakdown of Laboratory operations. The crisis reminded us of a truism that the section which works best makes no trouble and does not appear in our annual review. We plotted a war on Yale. Cool heads prevailed and Ken Stanfield was bribed to take over provided he was helped by Jim Finks. Here is what he found out.

Because of the major construction projects (TeV I, TeV II, and the Saver), procurement activities for FY1983 increased 12% over FY1982, for a total of 29,176 requisitions. The dollar value increased 59% for a total of $97.8M. Several major contracts were awarded including the Antiproton Ring Enclosures, the Industrial Center Building, and the Large Computer Facility Augmentation.

All of this purchasing and contracting activity was reflected in an increased workload for Shipping and Receiving, which receives materials, and Accounting, which pays the bills.

Plant Maintenance activities included renovation of the Central Utility Building--painting inside and out, repair of pipe insulation and lines, etc. The Village natural gas system was also refurbished and cathodic protection added to all main lines.

Highlights of activities performed by Site Services include road and landscaping improvements, move of the brick Security Office to Site 50 because of muon tunnel work, repair of the ring pond dike system, several energy management projects, and upgrading of the pumping station at Casey's Pond. Additionally, the following facilities have been completed: Booster Gallery East Addition, shop facilities for Plant Maintenance, Magnet Storage and Assembly Buildings, and a new gymnasium. These items, plus structural maintenance throughout the Laboratory, nearly doubled the volume of work performed by the Time and Materials group to $6.2M.

The Information Systems department is responsible for much of Fermilab's administrative data processing, particularly those applications of a business nature. Due to their efforts, we can look forward to automated purchasing, accounting, and requisitions systems in the future.

Yes, Virginia, there is a Business Services Section.

Safety Section

Another vital cog, left out of several annual reports, is SAFETY. This Laboratory takes safety very seriously. In 1983 leadership passed from unsung hero Lincoln Read to not even (yet) unsung hero Larry Coulson.

1. Radiation Safety

The total personnel radiation dose for the Laboratory continued to decrease, as it has steadily since 1974. The 1982 total was 110 person-rems, and since protons were not accelerated during most of 1983, this year's doses have been considerably lower. The dose levels we experience are well below the permissible levels set by the U. S. EPA and DOE.

Radioactive waste storage and handling systems have been improved. Over 14,000 cu. ft of radioactive waste was shipped for burial for FY1983. A higher capacity solar evaporator was constructed this spring, and 1900 gallons of tritiated water was evaporated, resulting in a considerable cost savings.

The 4th Edition of the Radiation Guide was issued in May. A number of changes in requirements and procedures have been made to reflect the changing nature of radiation safety problems at Fermilab.

2. Environment and Safety

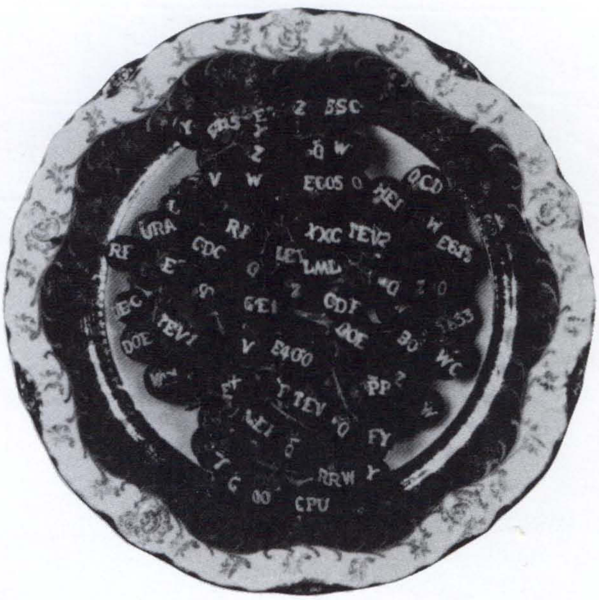
Occupational injury rates fell dramatically compared to previous years. This change is attributed to programmatic follow-up of work injuries. Below is a table showing the Total Reportable Case (TRC), Lost Work Case (LWC), and Lost Work Day (LWD) rates for 1982 and 1983. Rates are normalized to incidence per 200,000 person-hours.

Index	1982	1983*
TRC	2.4	0.87
LWC	2.3	0.66
LWD	16.6	4.7

*Statistics collected through third quarter

The Lab's industrial hygiene program got a big boost with the addition of an industrial hygienist and two industrial hygiene coop students. Day-to-day problems such as sampling the industrial environment and consulting on exposures are now handled in a timely fashion. In addition, a systematic review of industrial hygiene hazards has been initiated to more precisely characterize the working environment at the Lab. Reviews of personal protective equipment, chemical carcinogens, cyanide plating operations, and teratogens have produced numerous improvements.

The extensive use of liquefied gases in superconducting systems has caused the Lab to adopt rigid controls to prevent suffocation from accidental leaks. The Lab has developed and built area oxygen monitors which are superior to those available commercially. The approximately 150 monitors are employed largely in the accelerator ring and associated areas.



King Yuen Ng and daughter are being served at an evening event during the 12th International Conference on High-Energy Accelerators held at Fermilab in August.

Laboratory Services

Man and Woman do not live by quarks alone, they crave bread and wine and other things supplied by Lab Services, and Lab Services is directed by Chuck Marofske.

Laboratory Services is responsible for human resource support activities of the organization. Specific functions are quite varied in resonsibility and include housing, food services, employee recreation, library services, photography, duplicating, publications, medical, employment, personnel administration, equal opportunity, and public information.

Certainly one of the highlights of this year's activity was serving as host to the International Accelerator Conference in August. The Publications Office served as a conference organization and coordination center. We also organized a Laboratory open house event in September and welcomed close to 10,000 visitors on a Sunday afternoon. This was the third open house event in Laboratory history and it featured tours of facilities, pictorial displays and presentations by staff members.

During the past year we expanded our capabilities in video presentations to augment training efforts, introduce a series of supplemental retirement annuity options for employees, and added another HMO option to the employee benefit program.

Light parabola sculpture, the creation of Charles Derer, a College of DuPage instructor, for the 12th International Conference on High-Energy Accelerators, held at Fermilab in August, 1983.

Programs to provide student learning experiences at the high school and college level continued as an active adjunct. General employment levels continued to grow and the emphasis on advance technology in recruiting intensified. Attention to the special requirements for workers entering the Main Ring enclosure to perform activities necessitated the implementation of new medical testing practices in the occupation health services offices. Many employees and candidates were tested against standards set for tunnel work activities.

Our day care facility received attention from schools of education as a model resource for practical student learning experiences.

These are just some of the events which provide diversion from our ongoing regular responsiblites to keep the human resources of the Laboratory effectively capable of meeting the challenge of producing new science.

Fermilab Astrophysics Group

This novelty was briefly mentioned in our previous Annual Report. It is led by Edward (Rocky) Kolb and Michael Turner.

The Theoretical Astrophysics Group at Fermi National Accelerator Laboratory is jointly funded by NASA and Fermilab. The offices for the group are located in Wilson Hall on the west side of the building, interspersed among the offices of members of the Theory Group. Although the group is administratively not part of the Theory Group, there is substantial overlap in the interests and work of the two groups.

At present, the group consists of two staff members, three postdocs, a secretary, and one permanent part-time visitor. The visitor position will be filled by an 18-month visit by Alex Szalay, starting in June 1984, and a 2-month visit by Bernard Carr, starting in April 1984. In addition, David Schramm spends approximately one day per week at Fermilab. The arrangement with Schramm is expected to continue indefinitely.

Fermi National Accelerator Laboratory   May 2-5, 1984

This page is printed on stationery for Inner Space/Outer Space, a Conference on Physics at the Interface of Astrophysics/Cosmology and Particle Physics.

The group sponsors a weekly Astrophysics Seminar, which is usually given by people invited from outside the Laboratory, and a weekly Astrophysics Lunch where more informal reports and talks are given (usually by Fermilab personnel).

Plans are being made for a large conference on "Physics at the Interface of Astrophysics/Cosmology and Particle Physics" to be held at Fermilab on May 2-5, 1984. (This will be the first large conference on this subject.) The meeting was originally planned as a small workshop, but the response to the initial announcement was so great that we have changed it to a conference format.

The goals of the group are manifold. The foremost goal of the group is to do exciting and visible science at the interface of particle physics and cosmology/astrophysics. In particular, the latest experimental and theoretical developments in particle physics will be exploited to further our understanding of the origin and large-scale structure of the universe. In addition, cosmological and astrophysical data will be used to place constraints on particle physics theories [by using the results of the big-bang experiment (E000)]. Although the main thrust of the group will always be astrophysics related to particle physics, some effort will be made to keep the Fermilab scientific community aware of breakthroughs in other areas of astrophysics.

Research in the group at present is being done in the areas of inflation, galaxy formation with exotic particles, monopoles and astrophysics, cosmology of theories in more than four dimensions, cosmological effects of supergravity, and high-energy cosmic rays.

Local Organizing Committee

E. W. Kolb/M. S. Turner (Chair) D. Lindley, K. Olive, C. Quigg, D. N. Schramm, D. Seckel

Prospice

What is in store in eighty-four? During the summer shutdown (to build the proton beam line which will produce $\bar{p}$'s for TeV I and several other projects) we will fix Saver devices that need fixing and strive for as high as energy as we can reach. This may involve replacing some weak magnets. Another longer range prospect under design is to lower the temperature of the helium coolant by about one-half degree in order to gain about 100 GeV of magnet field. This will involve a major upgrade of the refrigeration system but will see only conceptual design in '84.

The experimental program for the fall of '84 will be even richer than the spring program. We hope to have ten experiments take data in that running period. The crucial issue is the funding level required to carry out the program. Funny that we didn't mention it but '84 will be a difficult year. Although it's difficult to reconcile the words "crucial" and "boring," the funding issue is both and, except for this brief record, more for history than anything else, we skip to a more fun theme: the SSC.

In spite of what appeared to us as agonizing slowness, the prospects for building a 20-TeV hadron collider have substantially improved since January of 1983. Notably, the HEPAP decision in July was to put forward the idea of the SSC as its highest priority. In the fall, the DOE in principle accepted the idea by offically asking Congress to reprogram funds for SSC R&D. The conceptual schedule as we now can guess it is to have a management consortium identified and an R&D director appointed by spring of '84. This parallels a paper reference design to be completed by May 1, '84. Meanwhile, all the laboratories have some assignment recognized by DOE but, hopefully, to be coordinated by the SSC R&D Director as soon as he or she is appointed. Fermilab is scraping every pot to free up talent for its contributions. Technical Services under Dick Lundy and Paul Mantsch had been working on a 5T magnet based upon the Saver design. Joe Lach heads up a small group looking at the possibility that Fermilab could provide the injection for the SSC ring. We are aided by the Geological Survey and by other State agencies, since the Governor of Illinois seems convinced that the Higgs problem should be solved under the cornfields of Kane County. We are obligated to study this question.

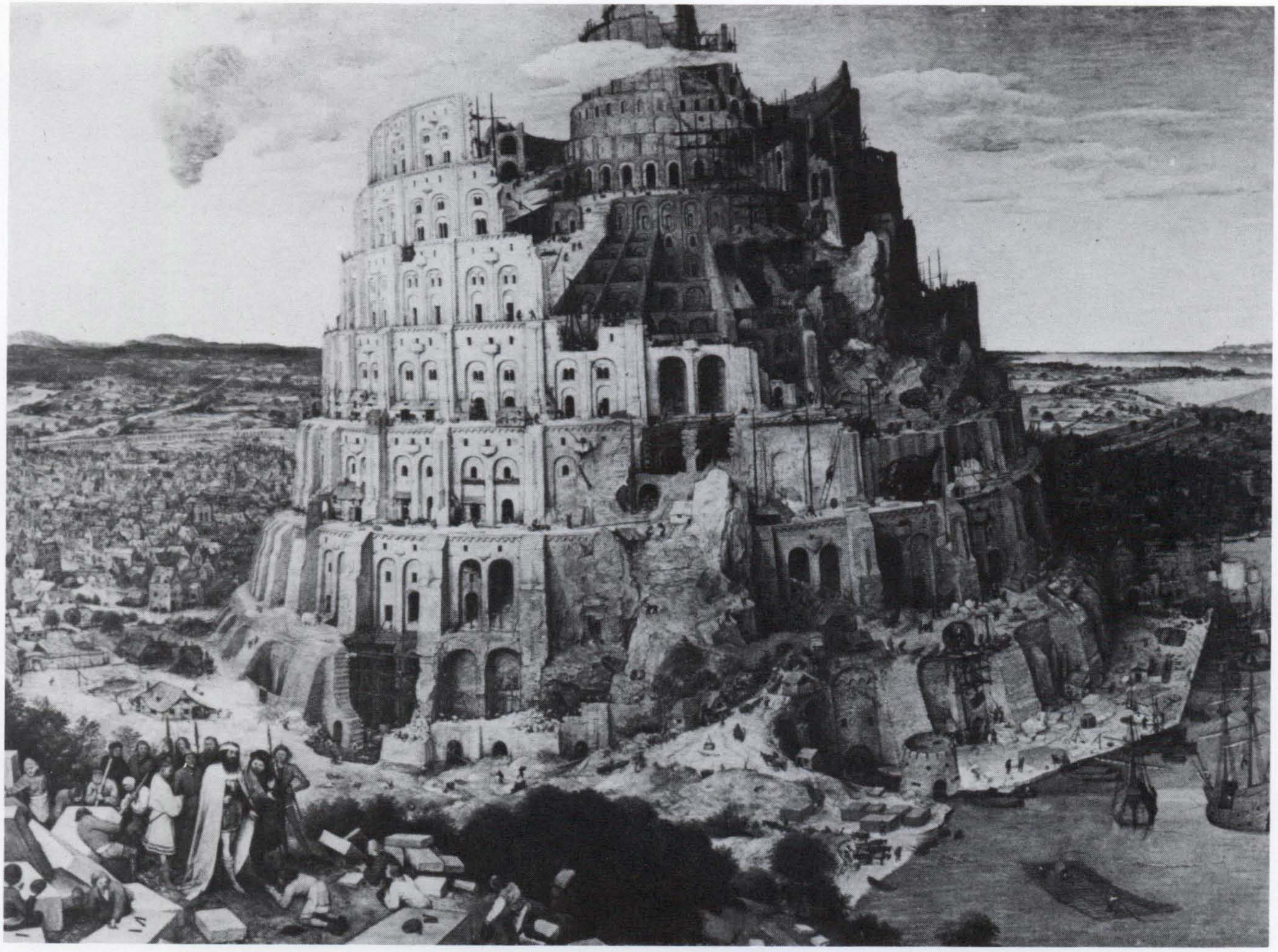
We should be very pleased with 1983. The Tevatron (nee Saver) has all the earmarks of working. The long range future of the field is to our tastes. Whereas I began this review by mocking our own seemingly perennial concerns with funding, I do remain convinced that this is a very serious determinant in our ability to get physics out of the Tevatron. Nichevo! The science is tremendously exciting. I'd like to steal a few paragraphs from our new, firm, unwavering five-year plan, forced out of our secret places by DOE requirements. There, where it says to fill out the form: Director's Overview, I scribbled:

> our fascination with quarks, leptons, the forces of nature and their underlying symmetries are among the most "natural" (and hence most profound) activites in which humans engage themselves.
> A child asks questions: "Where does the sun go at night?" "What keeps the stars from falling down?" "How many words do I have inside of me?"
>
> It takes only a small amount of poetry to recognize these as questions wholly appropriate to high-energy physics (or molecular biology...). Nothing to fear--the child goes to school and

learns how to think "properly." He bends to organized constraints and grows up. He grows up to become a lawyer or policeman or doctor or sanitation worker. But some children don't grow up and they become high-energy physicists (or molecular biologists...).

The state of high-energy physics in 1983 is crystallized by the discovery, at CERN, of the W and Z bosons, putting the finishing touches to the Standard Picture. The Standard Picture is a snapshot of our understanding of the physical universe. This has three generations of quarks and leptons, and three gauge theories of forces, two of which are collected into the electroweak quantum field theory, carried by a family of gauge bosons: γ, Z^0, W^+, W^-. The Standard Picture encompasses and is in accord with all of the data that have been obtained in all of the world's particle physics laboratories. As such it is an intellectual edifice of monumental proportions. But the past five years have led to a growing consensus that the Standard Picture is a far from complete description of the physical universe.

The limitations of the Standard Picture are in part illustrated by the difficulty of



incorporating the strong forces with the electroweak into a Grand Unified Theory and by the puzzling lack of conformity of the masses, for example, of the photon and the Z^0.

The situation may be compared to a group of mountain climbers, ascending the final slopes toward the summit. A long steep field is rapidly traversed and base camp (the Standard Picture) is made but the way seems to be blocked by a steep wall. For the past five years or so, all attempts to find a way up have failed. In our romantic metaphor, we know the summit is there, data provided by astrophysics from the early universe assure us of this and provide clues and constraints to the way up.

The task for physics is to continue to examine the domain of the Standard Picture--of ~ 100 GeV and less in the effective energy of point-like collisions. Surely the new physics beyond must leave tracks at lower energy. This involves precision and variety. We must look at hadron-hadron, lepton-lepton, and lepton-hadron collisions. We must examine the nature of the forces that bind quarks and the smallest corrections to the electroweak processes. A major contribution

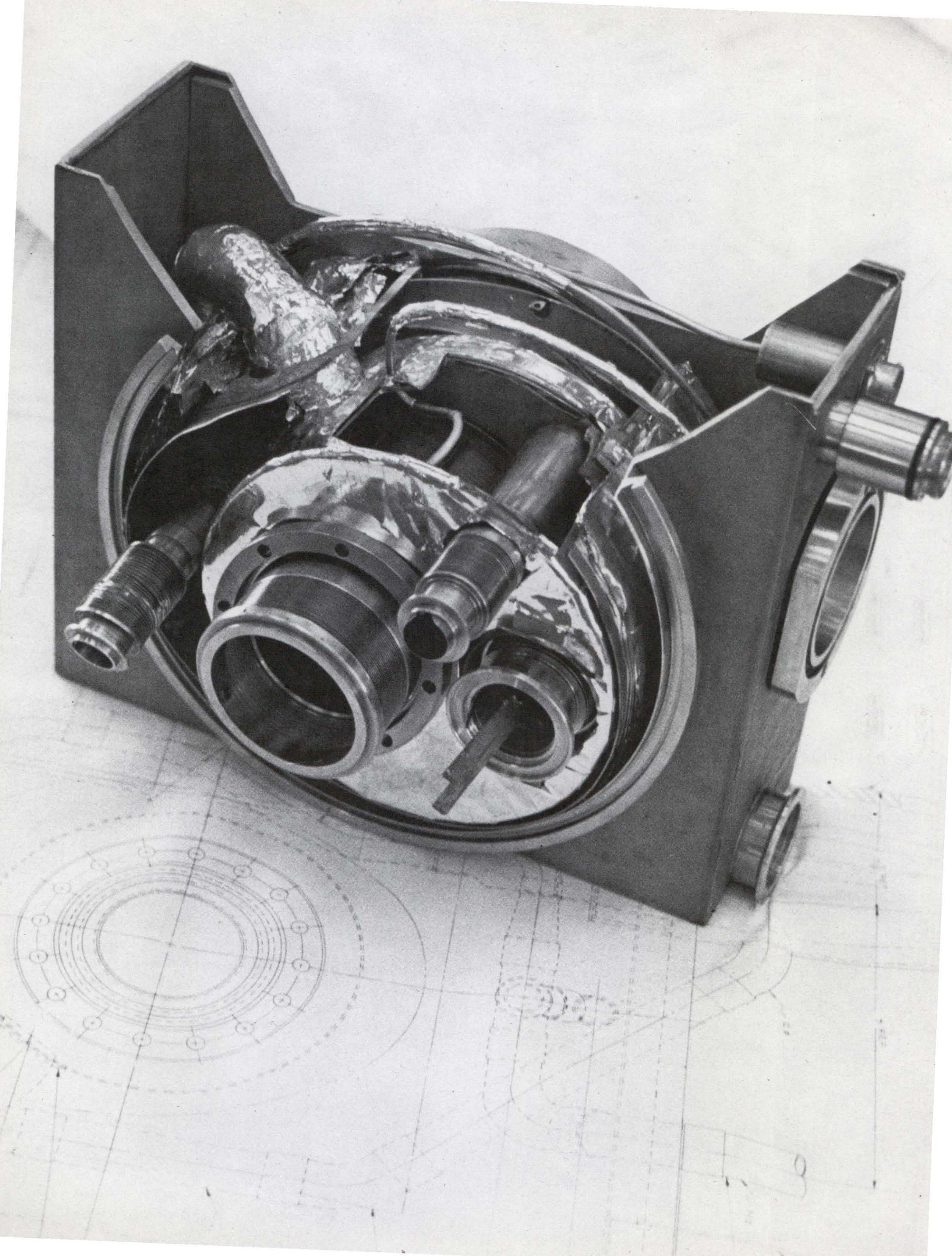
The Control Room on Sunday, July 3, at 3:37 p.m. as the Energy Saver reached its primary design goal and accelerated protons to 512 GeV, a new world record for accelerators. This photograph also appears on the cover of this report.

to this search will be the Tevatron's fixed-target program (TeV II) with secondary and tertiary beams of protons, neutrons, pions, kaons, hyperons, photons, muons, and neutrinos. This effort will be greatly aided by the SLC e^+e^- collider at SLAC and the similar effort at CERN, LEP. Data from Cornell's CESR, from LEP and Brookhaven's AGS will also contribute.

And of course we must continue to raise the energy beyond the W, Z domain--to look for handholds and crevices which will lead to the summit. Tevatron I, the collisions of protons and antiprotons at 2 TeV, effectively 400 GeV of point-like collision energy, will be the first look there. Ultimately, from what we can now perceive of the size and height of the wall, we will need much more energy. Only when we can go **beyond** 1 TeV in point-like energy--at least 20 TeV in the c.m. for hadron colliders, can we be sure that the wall we do see can be overcome.

I ended with the remark that there must be something fine and admirable about an institution whose firm, unwavering five year plan is revised so frequently.

Leon M Lederman



II. Starting Up the Energy Saver

Introduction

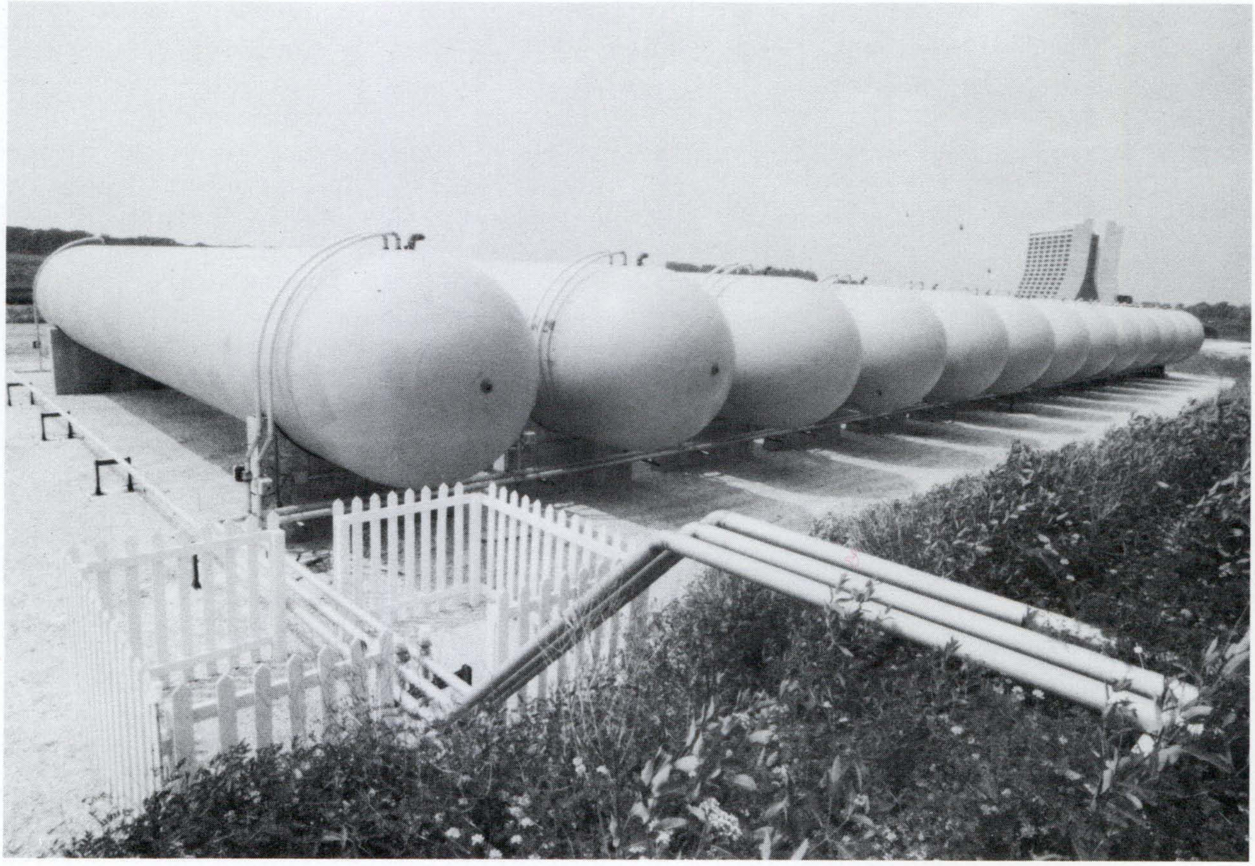
The Energy Saver has occupied a large part of the attention of many Fermilab people for some years. All this work reached a climax in 1983. Installation was complete and cooldown of the final sector began in May. Beam was first injected into the completed Energy Saver Superconducting Accelerator on June 2, accelerated beam was first achieved on July 3, and resonant extracted beam first sent to the Beam Switchyard Area on August 2. A new energy record of 700 GeV was reached on August 12, during the 12th International Conference on High-Energy Accelerators. These events were the culmination of ten-and-a-half years of R&D, tests, construction, and installation of the new accelerator system in the Main-Ring tunnel. The final goal of a 800 to 1000 GeV proton beam at approximately 2×10^{13} ppp for fixed-target physics and $\bar{p}$-p storage and collision at $10^{30}\,cm^{-2}sec^{-1}$ awaits further tuneup and the construction of the $\bar{p}$ source (TeV I), but there is a story to tell of how we got to where we are.

What is Different in This Accelerator?

The use of superconducting magnets in a large accelerator brings with it the necessity for major new engineering systems and their control. Together the magnitudes of the overall amount of equipment, system complexity, and fragility of these new utility-like systems not only dwarf the corresponding components of the conventional accelerator, but also influence their design. The conventional components must also work effectively so that during early stages of commissioning, when overall reliability is not high, progress can be made toward obtaining an accelerated beam.

The superconducting magnets require a large cryogenic system to supply both liquid helium at 4.7 K and liquid nitrogen. The cryogenic system for the Energy Doubler provides 24 kW of cooling at 4.7 K. This system is larger by several orders of magnitude than any previous one and its smooth operation is a major advance and triumph for its builders.

The Energy Saver magnets require an "active" quench protection system in order that the magnet conductor is not damaged by overheating when a magnet goes normal and "quenches." The active protection system continuously monitors voltage across the magnet cells at about 250 points and detects any resistive component greater than a given threshold. Upon quench detection, three things happen: a) Stainless-steel strips in the magnets adjacent to the coil are heated by discharging capacitors into them, thus causing uniform energy absorption in the quenched cell and reducing overheating at isolated spots; b) The main bus current is diverted around the quenched cell through a bypass circuit external to the cryogenic system; c) The main power supplies are bypassed and dump resistors are switched in to extract the total ring stored energy (350 MJ at 1000 TeV) with a 12-sec decay time constant. The quench-protection system is a ring-wide system with 24 microprocessors (one in each service building) which are in constant communication with one another. Each is constantly checking the voltage reading from its part of the magnet string. Any missed communication or

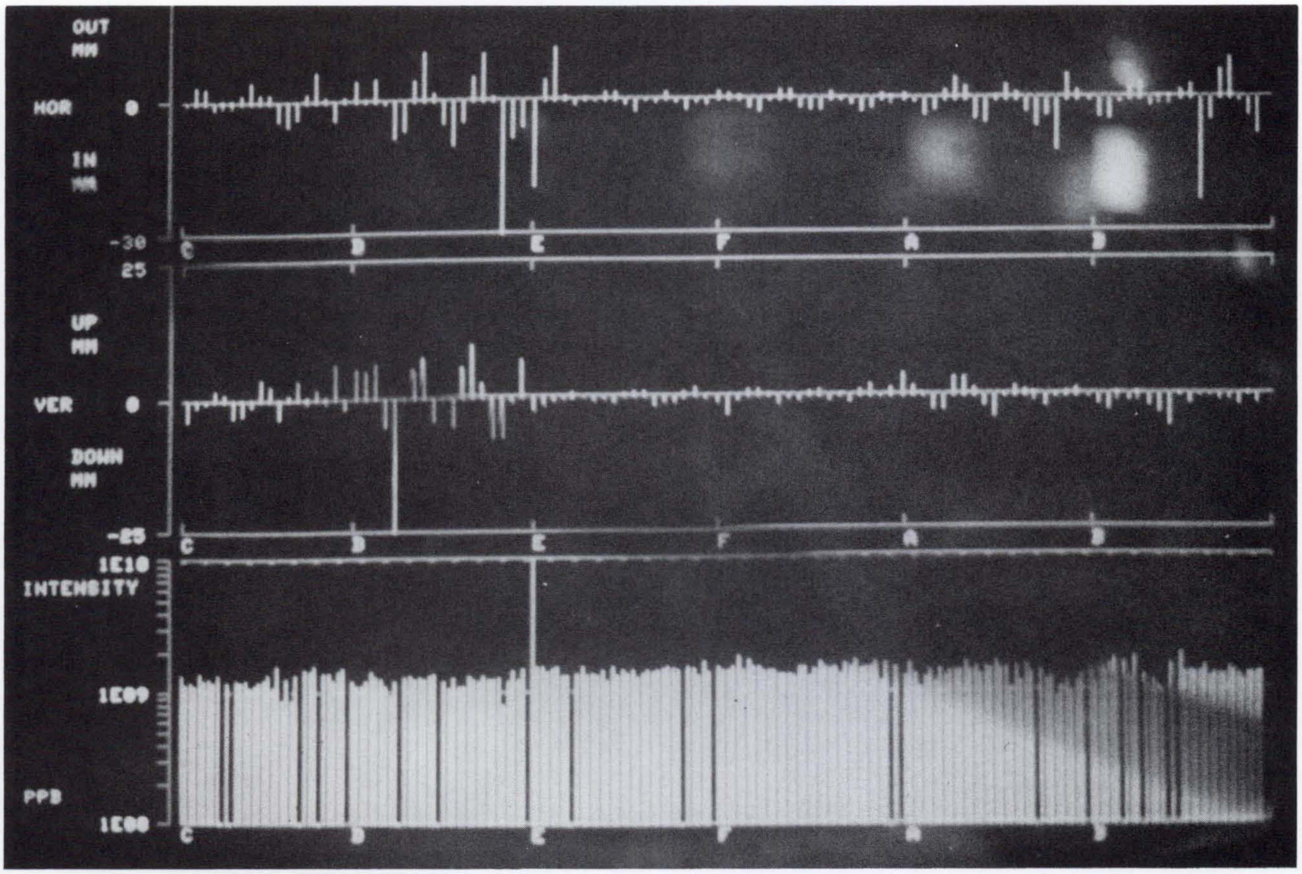


Helium storage tanks of the Energy Saver.

noise can potentially turn off the magnet power system or quench the magnet accidentally.

The vacuum system for the superconducting magnets is much more complicated than for a standard accelerator. The system consists of an outer insulating vacuum jacket with four isolated inner volumes, each of which must be leak-tight to the insulating vacuum. These volumes are a) the bore-tube high-vacuum region in which the beam runs; b) the single-phase helium space; c) the two-phase helium space; d) the nitrogen-shield space. Not only must one provide pumps and instrumentation for the two separate vacuum systems, but during installation, leak checking must be performed on the four separate internal volumes where the flange joints are not externally available for classical leak-check procedures. One potential advantage is that the beam vacuum bore tube is at low temperature and automatically provides very low pressure.

Because of worry about the feasibility of the operation of the cryogenic system, the quench-protection system, and the vacuum system, special efforts were made early on in order to develop workable engineering plans, both for implementing the systems and for successful installation procedures. Very substantial efforts were required from the electrical enginering and controls groups in order to meet the demands of the "utility systems" on a



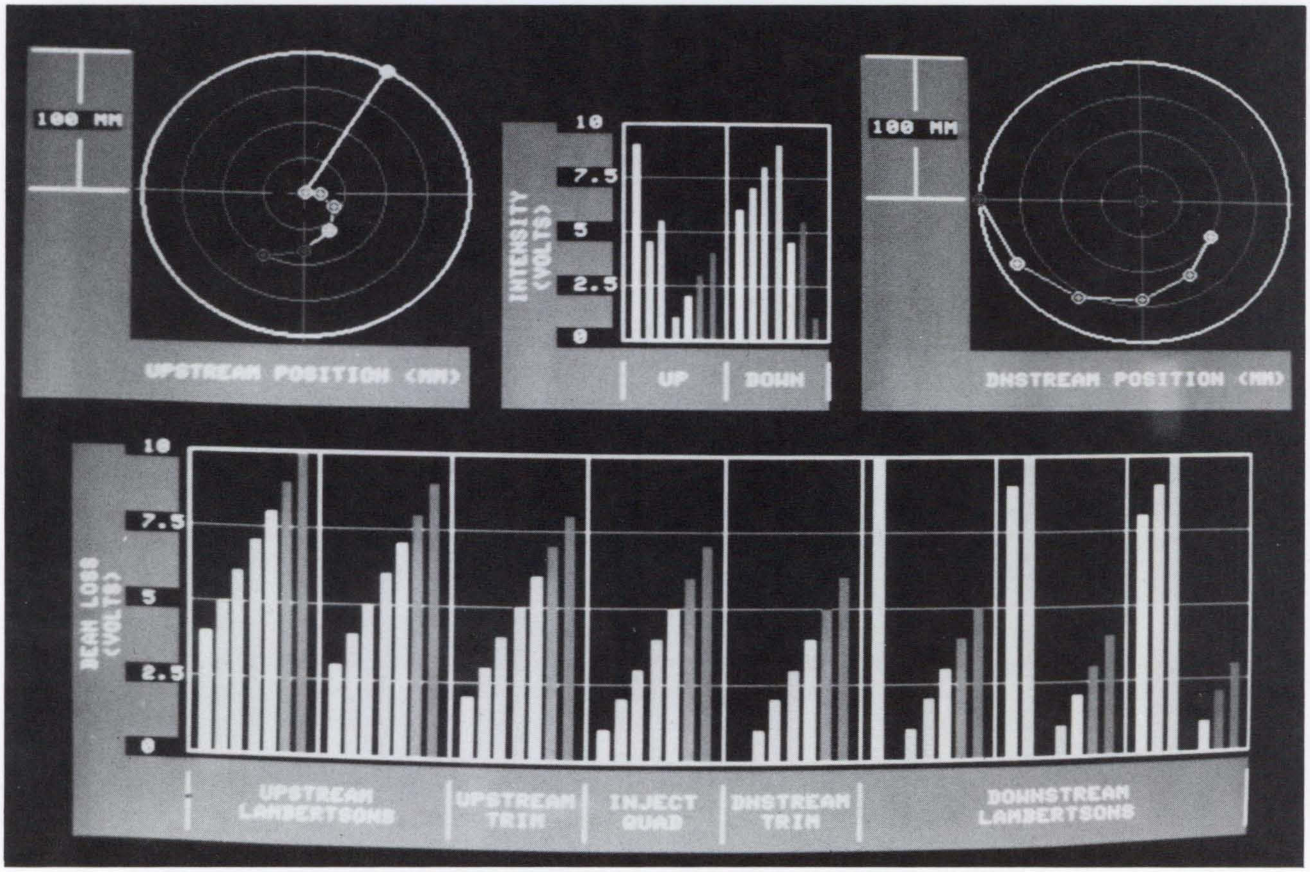
First complete turn around the Energy Saver: 5:42 p.m., June 2, 1983. The top two signals are horizontal and vertical beam positions around the ring. The bottom signal is intensity.

timescale that allowed for test debugging and refinement of techinques before the scheduled start of beam operation.

Superconducting magnets are sensitive to beam loss and have magnetic-field characteristics different from conventional iron magnets. Within the conventional accelerator systems, particular attention has been given to the correction and adjustment coil system and to the beam-position and loss-monitor systems.

The beam-position and loss-monitor systems were planned with the view that one wanted to obtain the most information possible from a single shot of injected beam. If the magnets quenched because of the beam being mis-steered, corrective action could be taken during the quench-recovery time (typically, 10 minutes to 2 hours) and the beam could get further on the next pulse. Special attention was also given to being able to run at very low intensity (10^{10}p) so as to reduce the magnet-quench probability. Thus the system was required to be very sensitive and at the same time very flexible, because it must be able to gather and store one-turn information and closed-orbit information at many positions and times through the cycle.

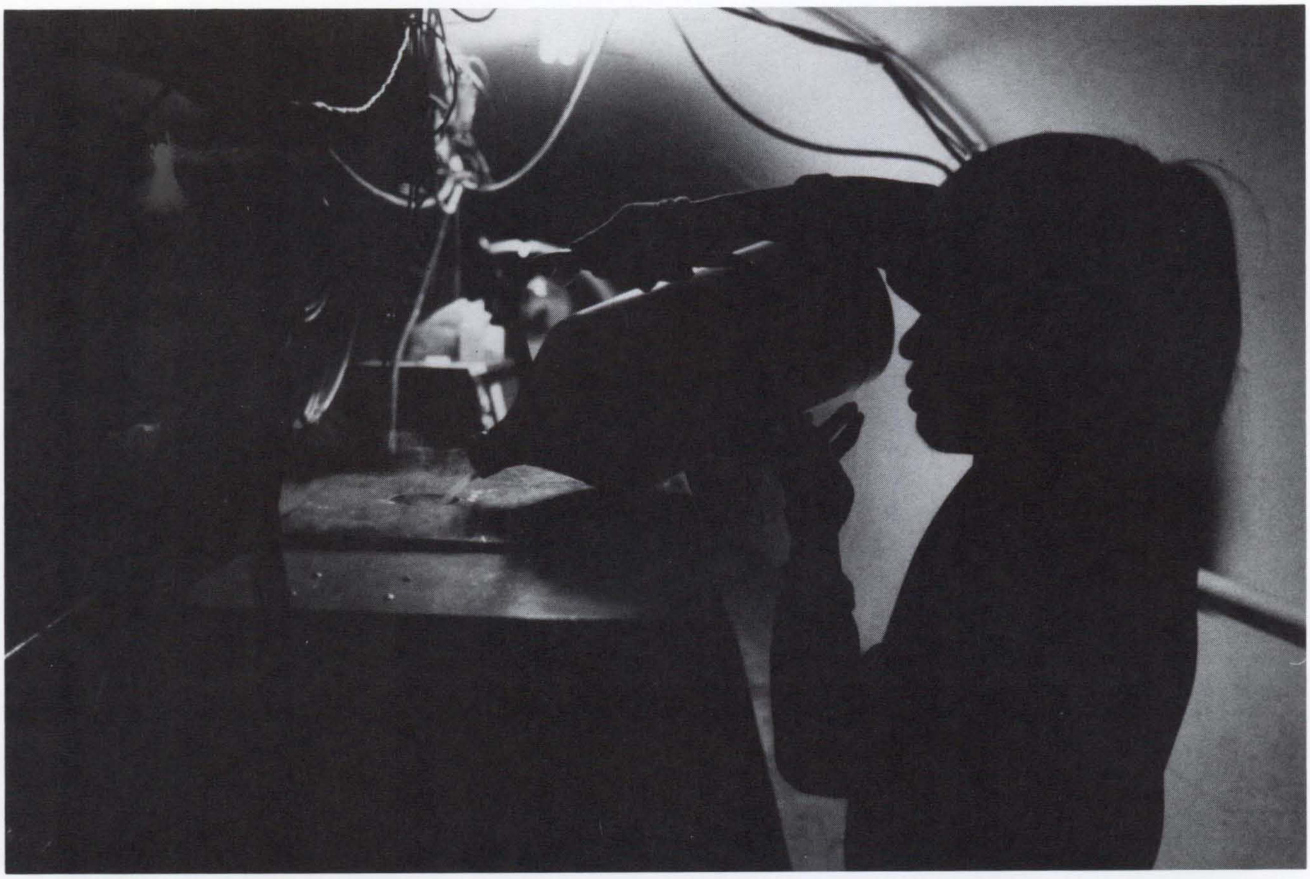
The one-turn position information, coupled with the one-turn abort system, and beam-loss information proved to be very effective in locating obstacles in



Control Room display of orbit position and beam loss during injection.

the aperture and in obtaining correct injection conditions, including guide field setting. The one-turn and closed-orbit information can be relayed to a program that determines dipole correction-coil adjustments. As it turned out, the closed orbit did not change appreciably with excitation, making the problem of accelerating to higher and higher energies less arduous than expected. The ability to abort the beam on loss has been of substantial use in trying to go to higher intensities, especially during extraction studies. The turn-by-turn position information has been of great value, not only at injection time for minimizing coherent oscillations, but also for minimizing injection guide-field mismatch and for doing tune measurements at any excitation with a "pinger" to induce coherent betatron oscillations.

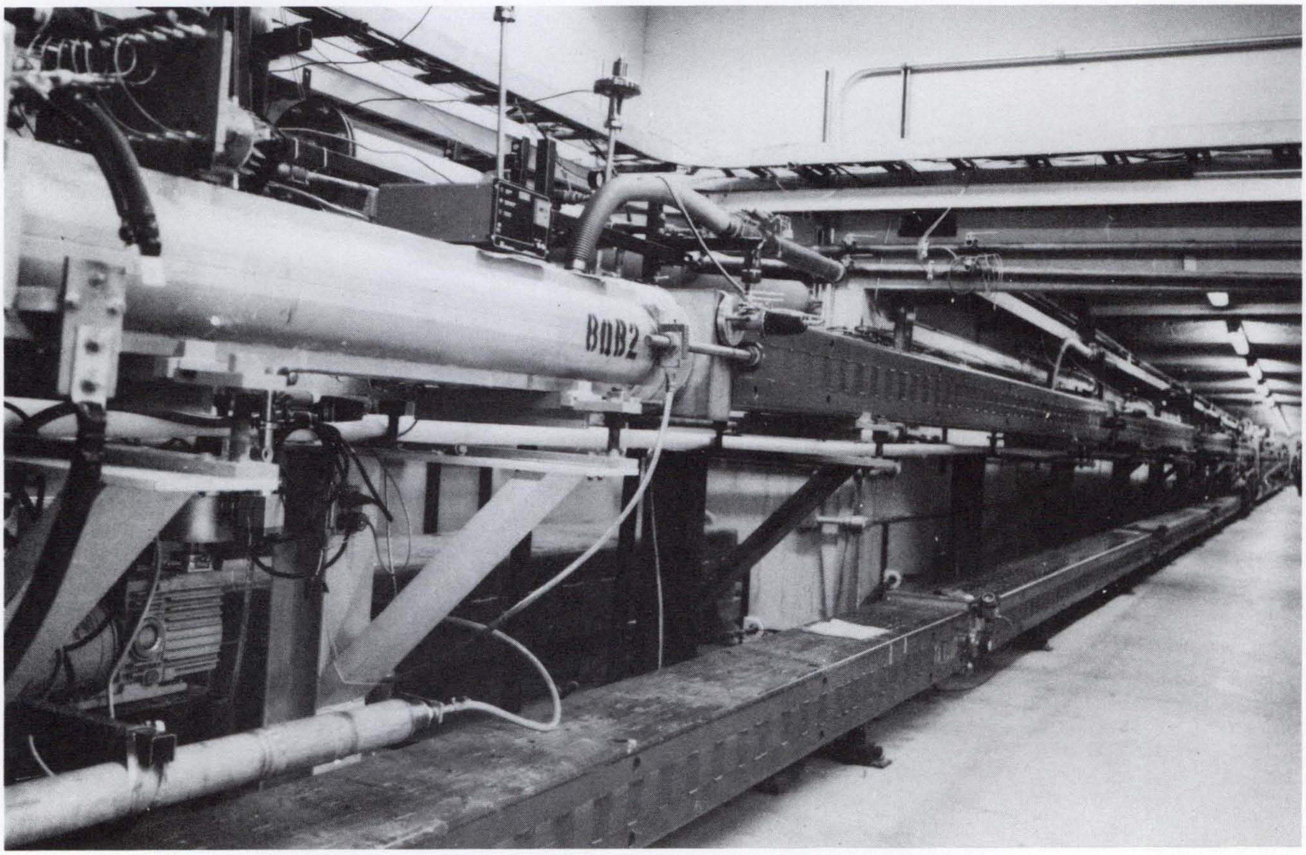
The correction-coil system is composed of corrections and adjustments for steering, tune and chromaticity control, and resonant-extraction control. The system allows for programming control of all circuits from injection to full excitation. It is desirable to be able to center the beam accurately with dipole corrections at any excitation, thus making full use of the available aperture. This is particularly true at extraction time, when the resonant beam is making large excursions. The system allows for any unexpected shift or rotation of the main magnets with excitation, quench,



Vacuum work on the Energy Saver.

or upon a warm-up/cool-down cycle, without recourse to magnet realignment, which would be somewhat risky to the vacuum integrity. Although the initial magnet-survey alignment and stability of the superconducting magnets so far seem good, the advantages of the full-excitation corrections in operational convenience seem well worth the expense in this machine and in any future large accelerator where strength of superconducting correction is not a problem.

Here again the control system plays an essential role in the success of these sophisticated correction and detection systems. Extensive use of microprocessors to provide local control-curve generation and data storage has been a fundamental feature of these systems.

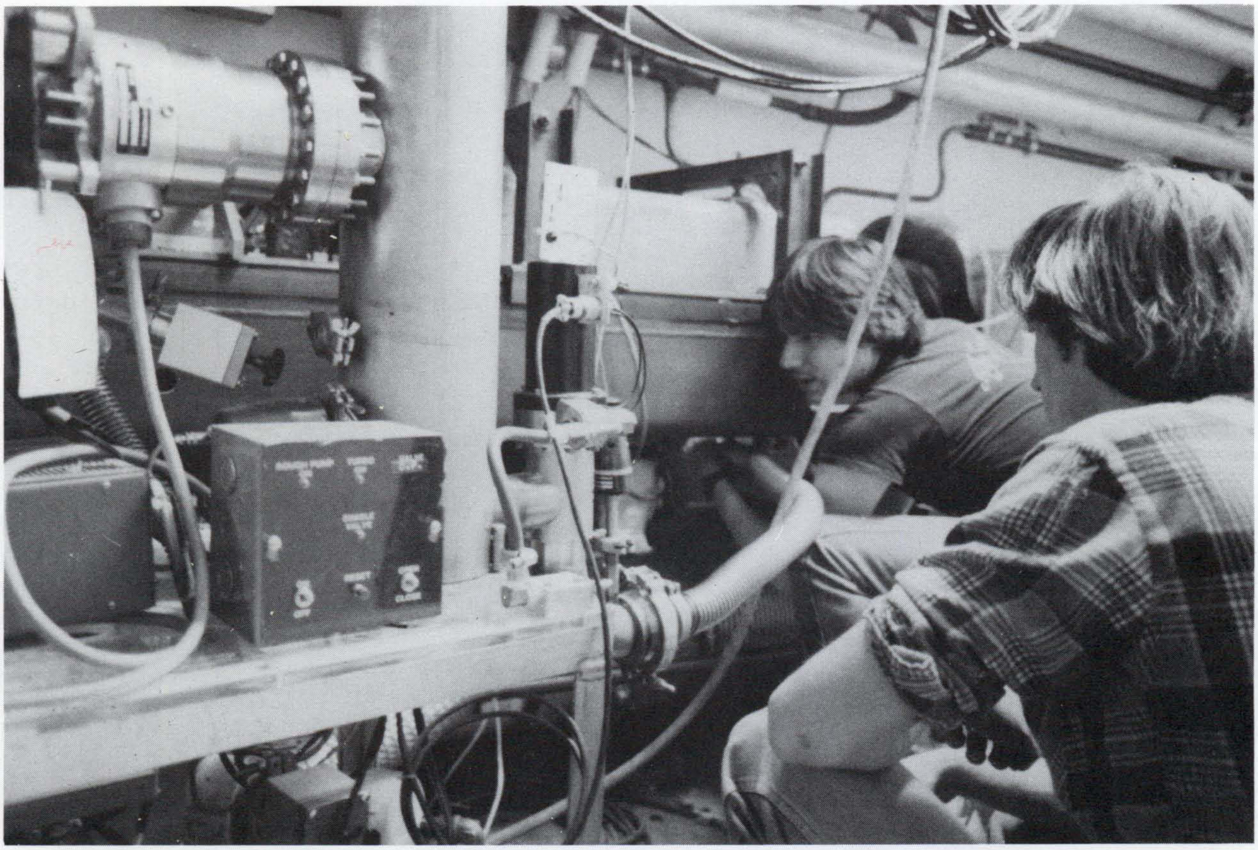


B12 test area.

Magnet String History

The importance of the test efforts carried out during the Energy Saver R & D and Construction Phase cannot be emphasized enough. These test efforts included: 1) vertical dewar tests of short magnets and cable in order to measure quench propagation, to conquer coil motion, training and quench current restrictions of the basic coil package; 2) both room-temperature and cold magnetic measurements to obtain and maintain the necessary field quality and reproducibility during prototyping and construction; 3) the establishment of the B12 test area (an above-ground magnet string test area located near station B12 of the Main Ring tunnel), and finally 4) tunnel system testing in A Sector.

The B12 test area was where installation and vacuum problems were first addressed, then cryogenic operation, then quench propagation in the magnet-string environment. Quench-protection, power supply, vacuum, refrigeration, and control systems prototyping were also done here. Tunnel tests were done on individual magnets, on strings of prototype magnets, and on the A Sector R&D final system. This progression from single-component tests to the final large integrated systems tests over the



Dave Augustine (front) and Wayne Hibbard connect vacuum pumping equipment.

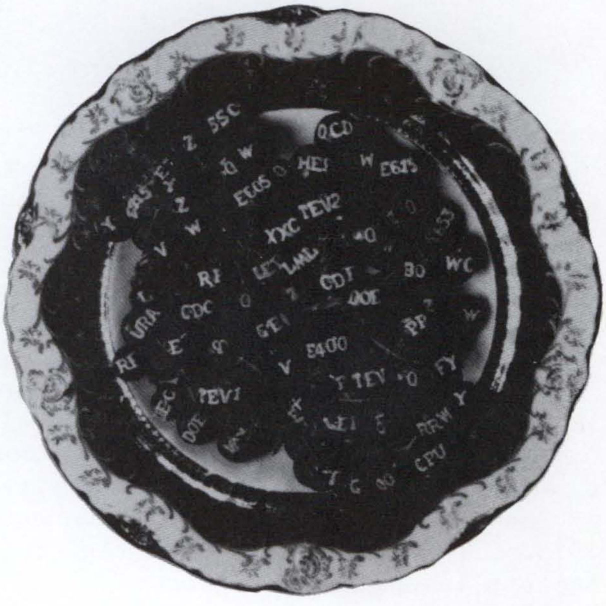
period of about nine years undoubtedly has been of paramount significance in the rapid turn-on and commissioning of the accelerator.

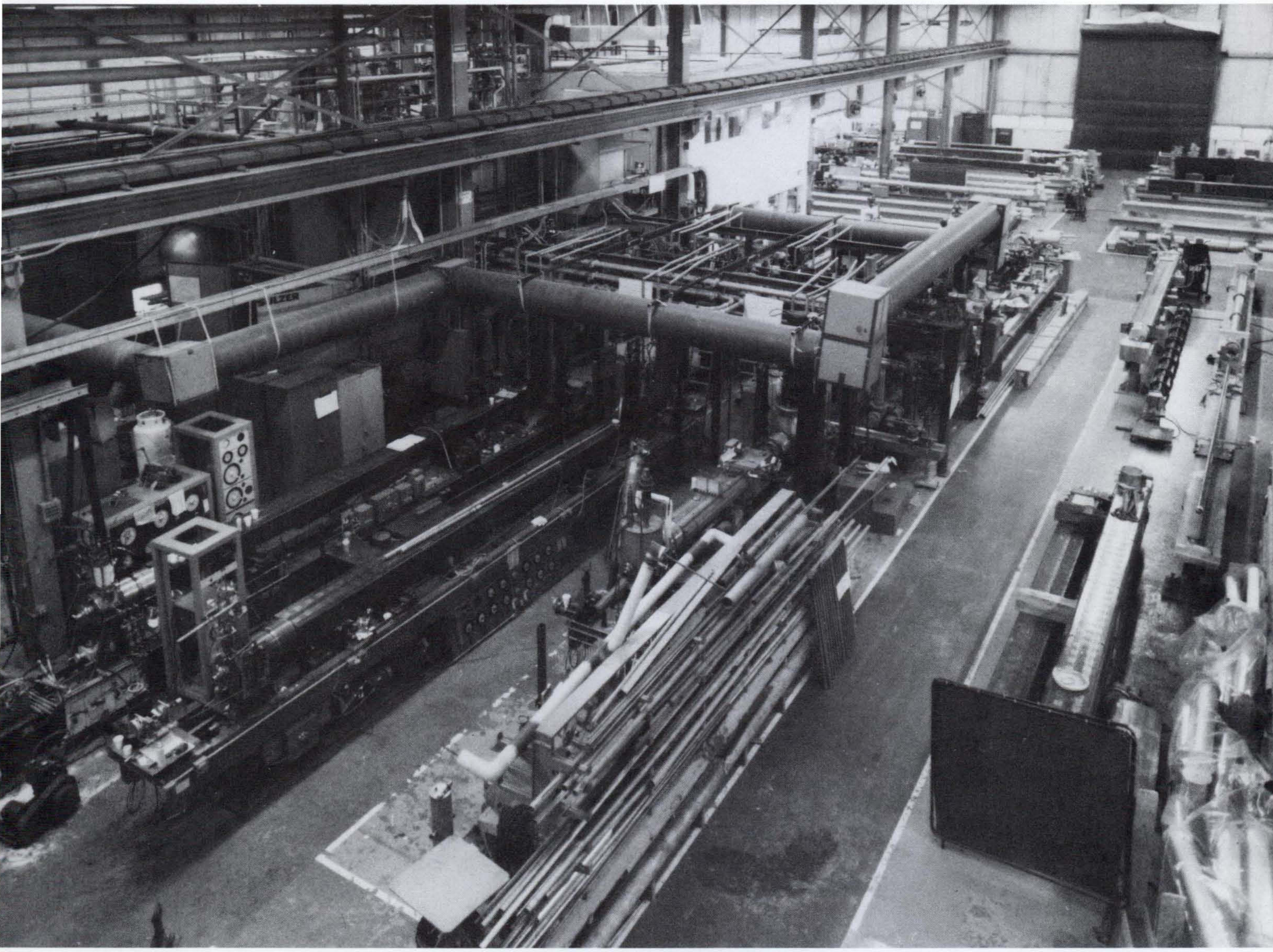
Talk about the idea of a superconducting magnet system started as early as September of 1970, but no serious discussions began until the fall of 1972, after the Main Ring had begun operation at 200 GeV for fixed-target experiments. Organized and committed R&D effort on the Energy Doubler began in the first part of 1973. By 1975, two tests had been carried out in which prototype magnets had been installed in the tunnel and beam transported through them. Not only were these installations basic milestones in the construction of cryogenic systems, but also they gave valuable data on the sensitivity of superconducting magnets to beam loss.

Early in 1976, the B12 test area was started with one 10-foot magnet. Tests continued until late spring of 1981, when the start of final installation in the tunnel took priority. The B12 area was reconfigured a number of times. It progressed to two 10-foot magnets, then two 22-foot magnets, then a four-dipole string which could not ramp above 2000 A because of an inadequate relief-valve system. The next configurations had two half cells of magnets, then four (one quad and four bends per half cell). The bends were still of the longer 22-foot variety. The final configuration had four half cells of the final ring-quality magnets and final correction-coil spools. A number of the configurations were changed when the tests terminated by the magnets blowing up.

Tunnel tests on magnet strings were carried out in two steps prior to the final ring installation shutdown. At the end of 1978, five half-cells of magnets were successully installed, made leak-tight, and cooled down. A 100-GeV beam was extracted from the Main Ring and transported through these magnets for 500 feet. Even though these magnets could not be ramped to appreciable excitation because of lack of quench-protection heaters, this was another important step in system development as well as a further test in transporting beam through magnets. One learned about how to survey the magnets (there were no correction coils), learned about quenches from injection errors, and to some extent, field stability after quench, and also tested the position-detector system.

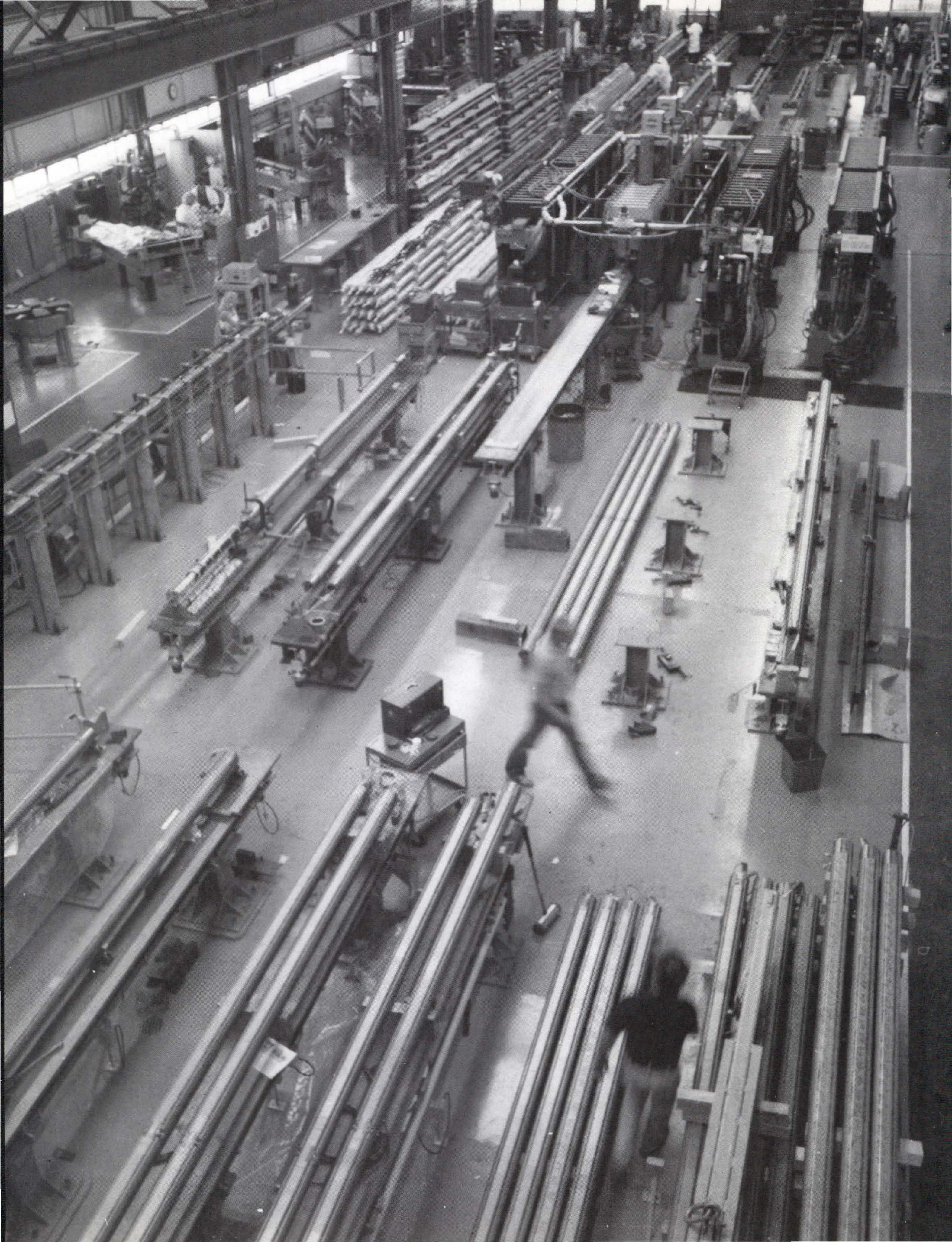
The most significant and final test program, "The 3/4 A-Sector Test" was carried out in the first half of 1982. It represented a full system test of 1/8 of the final ring components and controls. It tested to full potential all the cryogenic systems and pressure piping, the power-supply system and the quench-protection system. Extensive tests were performed to determine the possibility of voltage-to-ground breakdown of the electrical system during quench. The successful carrying out of the test was the final step in development of an overall system that would be reliable enough for operation when beam commissioning started about one year later.





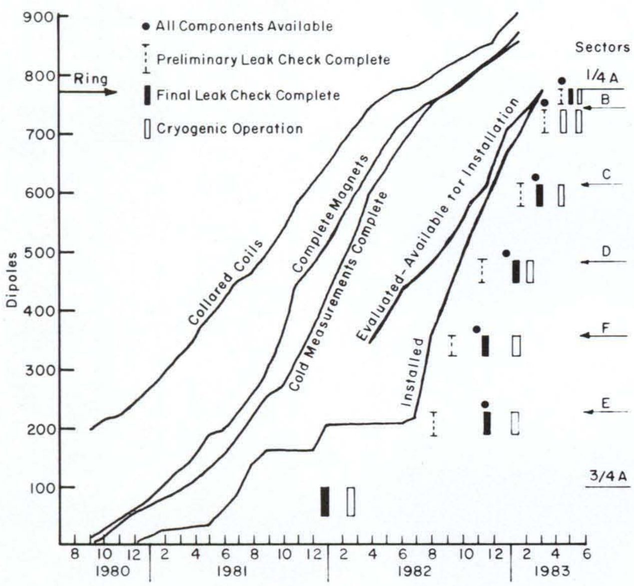
Magnet Test Facility.

Magnet Production Facility. Dipole coils are wound at the far end and completed collared coils are stored at the near end. →



Magnet Installation

The dipole production and installation time schedule is illustrated in the accompanying graph. It stretched over a four-year time period, beginning in the summer of 1979, when the decision to shorten the bend magnets from 22 feet to 21 feet was made in order to allow dedicated space for correction coils, instead of building them in the quadrupole magnet. The construction authorization for the project was given at this time and new shorter coils were soon available.



Dipole Production
and Ring Installation.

Availability of complete magnets lagged because of a movement problem found in the anchor system that ties the coil assembly to the outside of the cryostat. The learning curve is apparent both in the magnet production and in magnetic measurements. Coil production dropped off in 1982 because of problems in obtaining conductor. The gap between the curve of "measurement complete" and "available for installation" reflects not only the delay for paperwork between the time of measurement and the time at which the data became available, but also the need for a buffer from which to sort and select magnets to compensate for variations in field quality. It also reflects the fact that a number of magnets required rework in order to bring them up to the quality of the acceptance specification.

Initial installation proceeded during a shutdown in the summer of 1981, for a month at the end of 1981, and then the final installation started in June of 1982, with the last magnet going in the ring on March 18, 1983. Leak checking was first carried out on strings of four dipole magnets. Then quadrupoles and spoolpieces were installed for final leak check. Generally, special components were not quite ready when first needed, but did not hold up leak-check appreciably because of the option of moving and working in other sections of the tunnel.

Near the end of installation, the time delay between when magnets were first moved into A-Sector and when the string was finally cryogenically cold was six months.

Manpower for tunnel magnet installation, survey, flange hookup, and vacuum leak check took at peak about 54 people total. The total time period, counting work done in 1981, was about 15 months.

Handling damage during installation continued to be a problem throughout installation and many repairs were required in place in the tunnel.

Partway through installation a very high failure rate of the vacuum seals was experienced. This practically brought leak-checking progress to a stop. New types of seals reduced failures to an insignificant level.

There were worries that hipot of the magnets might be a problem, but no real difficulties were encountered during installation.

Specific failures that required warmup after initial cooldown, and remaining known faults are fortunately small enough to enumerate. Two cryo-sections (each 1/24 of ring) required warmup because of leaks and broken ceramics on correction leads. One dipole with a turn-to-turn short was found. (Later, when the collared coil was removed from the cryostat, the short disappeared.) Two splices of the power bus at interfaces were not soldered during installation. Six beam detectors near straight sections were in the wrong orientation (a universal accelerator problem) and five others had internally broken electrical connections out of over 200 units. Three correction magnets out of about 700 had low impedance to ground. Leaks in the insulating vacuum at eight locations required additional external pump carts to maintain sufficiently good vacuum.

Power Tests and Commissioning

Power-test commissioning history is given in the accompanying table. A total of 46 days over a four-month period were required (not counting the 3/4 A-Sector Test) to test the quench-protection system and ramp the magnets to 500-GeV excitation. During this time, the one magnet with a turn-to-turn short and two bad spliced joints were discovered. This fast turn-on did not allow much time for system reliablity to be hardened, as was reflected in later operation during beam tests.

Power Test 1983.

(660 A = 150 GeV)

E & F Sectors

2-22 ↓	500 A - 1 power supply. Quench bypass studies and power lead quenches.
3-3	2 kA
3-4 ↓ 4-15	Warm E-sector to repair vacuum leaks
4-15	4 power supply operation
4-22	Beam studies

C, D, E, & F Sectors

5-6	1 power supply
5-7	660 A
5-8	4 power supplies-can't ramp-bad dipole
5-11	Located bad dipole, C29-3

D, E, F, Sectors

5-12	660 A
5-14	2 kA

D, E, F, & A Sectors

5-25	900 A-Discover bad splice
5-26	Locate-A22

B, C, D, E, F, & A Sectors

5-31	220 A-Discover bad splice
6-1	Locate-B46-1
6-2	100 GeV beam studies
6-4 to 6-14	Repair A & B
6-15	Ramp to 400 GeV (1770 A)
6-16	Ramp to 500 GeV (2220 A)

Start beam tests

Beam Tests and Commissioning

A chronology of the beam tests and commissioning period is given in the accompanying table. The beam tests started April 22, 1983, with two weekends devoted to single-pass beam through E and F Sectors (one-third of the ring) before the full ring was completely installed and powered. Beam was transported through the two sectors within about 15 hours after first starting to inject. The major confusion during this exercise occurred because the first four out of five horizontal detectors were reversed in polarity (very few reversals were found in the rest of the ring). The rest of the time during these weekends was spent in testing the injection kicker (not required for a single pass), injecting into ramping magnets, and exercising a correction-dipole tuning program and exploring the aperture.

Beam was not injected again until June 2, when the ring was complete, but limited to 100-GeV excitation because of the bad bus splices. The correction-coil settings scaled from the April run were used in E and F Sectors and one turn of beam obtained within two hours of available beam time. The initial first-turn beam position data are shown in Figure 2. Beam is injected at the beginning of E Sector. Only a few steering corrections (approximately 6) were set in Sectors A, B, C, D.

An indication of up to 13 turns was obtained before turn-off two days later for warmup and repair of the bad bus splices. There was no real time-intensity signal available and the indication of turns came from the position detector turn-by-turn measurement-via the computer and perhaps was not the most credible of measurements.

Startup at 150-GeV injection began on June 17 with 150-GeV dc excitation. Up to 20-30 turns were obtained rather quickly but attenuation from turn to turn was severe. Over the next eight days, three aperture restrictions were found. The ability to look at single-turn beam positions and the ability to stop the beam after a fraction of a turn or after one-and-a-half turns, either by using the single turn extraction abort system, or by kicking the beam into straight sections using the strong dipole corrections, was of great help in finding these problems. There could be no confusion about losses from multiple turns. In the abort straight section C0, we found that an error had been made in the design of some beam pipe, severely limited the aperture. In the A0 extraction straight section, a wad of paper was found at a flange joint where it had been forgotten after modification of the pipe. At station E47 in a cryogenic region, an obstacle was detected which appeared to cover the lower half of the beam pipe. Beam could be steered around it without difficulty. Upon subsequent warmup of the region much later, nothing was found. Once the obstructions were corrected, coasting beam was easily obtained and the rf was turned on and acceleration checked by moving the radial beam position with the rf system.

Once 0.8 sec of good beam to the abort time was established, ramped excitation, first to 250 GeV, then to 512 GeV, began. Beam accelerated with only minor difficulty. Dipole correction coils are automatically scaled with energy and needed little change with excitation.

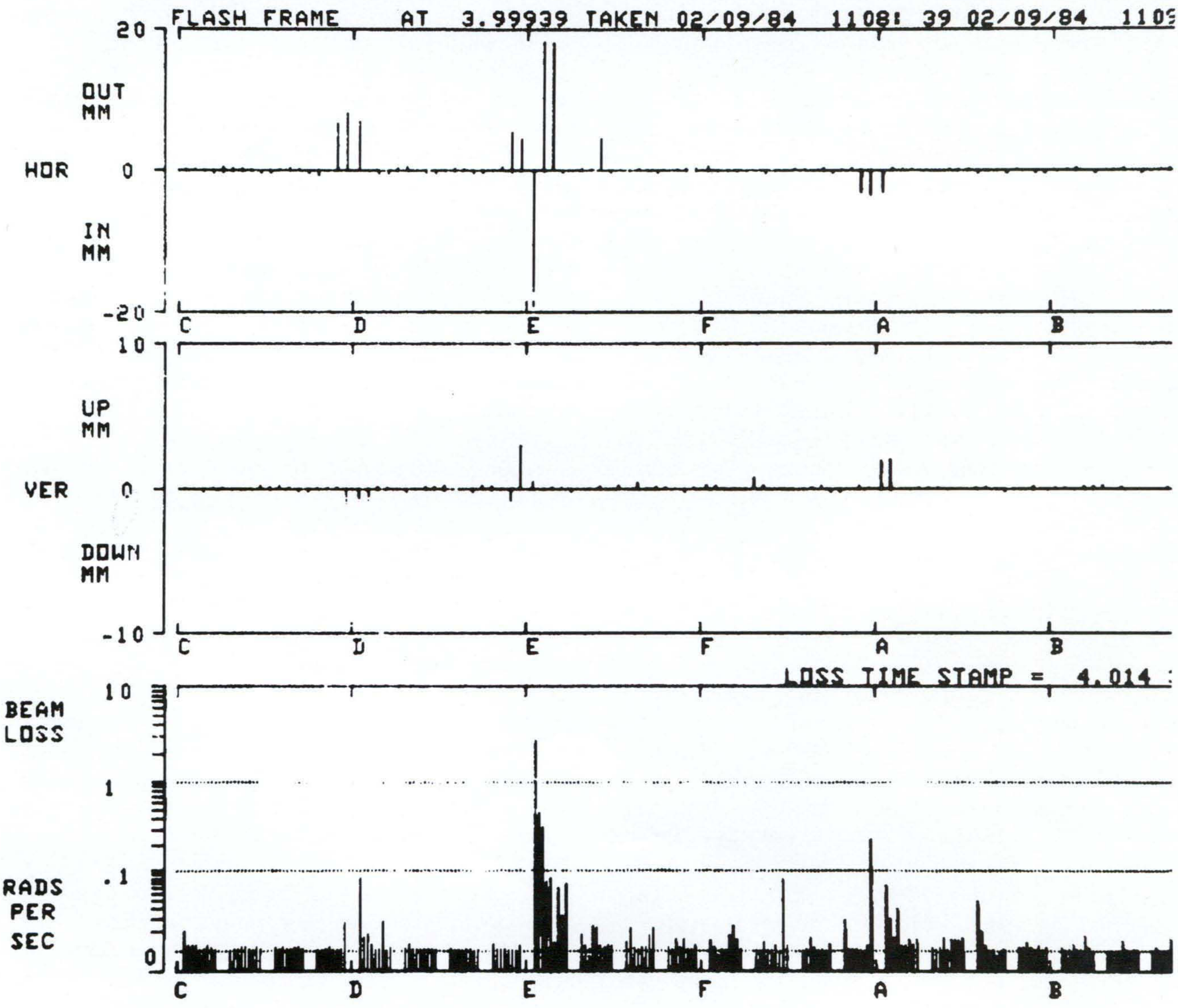
Acceleration to 512 GeV was obtained on July 3, 1983, after about 210 hours of available system uptime and about 20 operating days from the start of full-ring operation.

After beam had been accelerated to 512 GeV, numerous measurements and adjustments at flat top were taken in order to prepare for resonant slow

Beam Measurements and Comparison with Magnetic Measurements

Orbit measurements have been carried out to a level of detail probably somewhat greater at this early stage than any previous accelerator. In addition, the magnetic fields of the magnets were measured before installation in equally great detail. It is therefore possible to compare the results of beam measurements with beam performance expected from the measured magnetic fields and some of this has been done.

There is general agreement, but also some inconsistencies between the two kinds of measurements. The beam measurements predict in several cases multipole errors in the magnetic fields that are larger than those measured. The reasons behind these discrepancies are not yet understood, and they are therefore puzzles, but it should be emphasized that these discrepancies are of the order of a few Gauss at 1-inch radius compared with a total peak field of 45,000 Gauss. At this level, the problems are interesting, but by no means crucial.

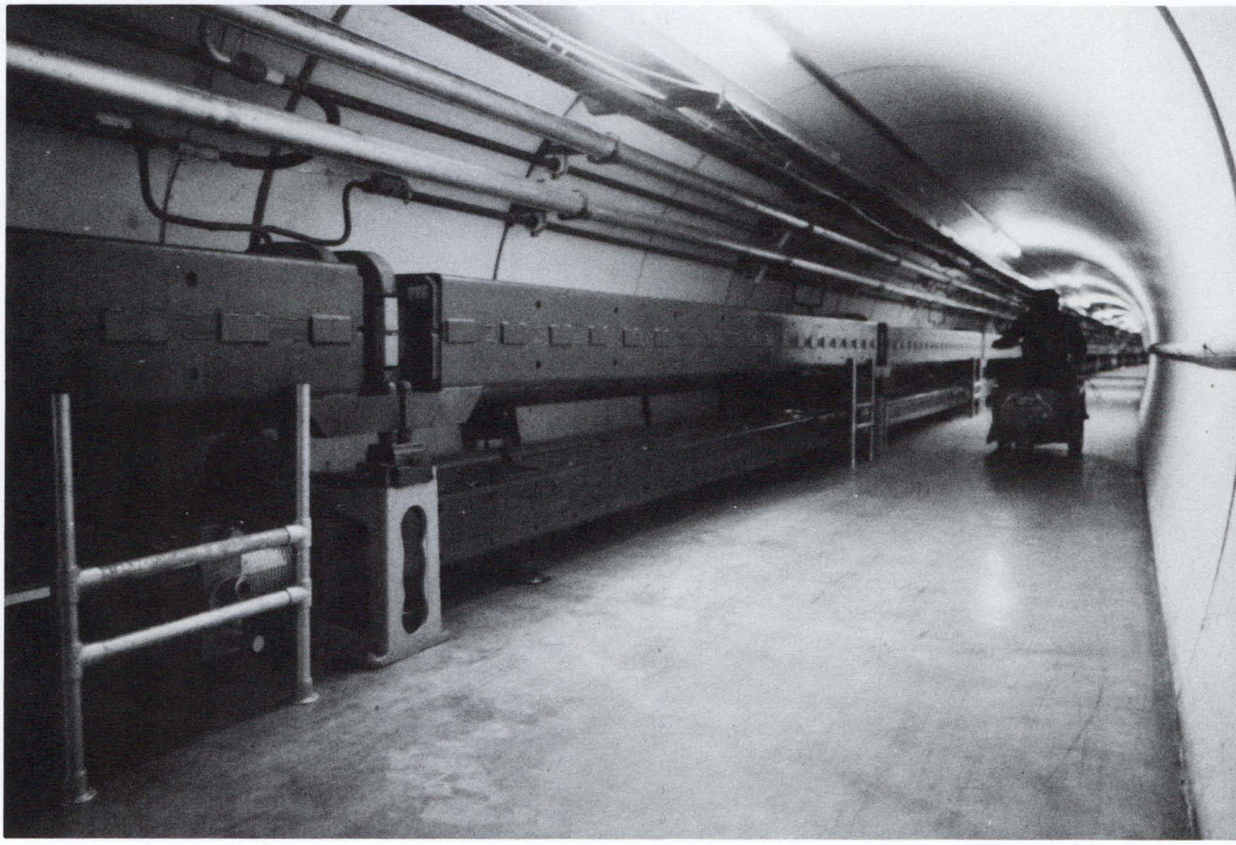


extraction. These measurements included: tune, tune vs. radial position ($\Delta p/p$), and horizontal-vertical coupling. Adjustments of the chromaticity and minimization of the coupling were performed. Higher-order correction magnets were tested and beam resonances explored.

These measurements took about three weeks (165 hours available uptime) with an interruption of one week downtime to change a clogged filter in the Central Helium Liquefier cold box. On August 2, 512-GeV beam was successfully resonantly extracted and transported to the beam dump in the beam switchyard area.

Beam Test and Commissioning.

Available Up Time (Hours)	Event	Date
~-80	--	4/22
	← Start injection at E0	
	First 4 out of 5 horizontal detector reversed polarity	
	← Beam to end of F-sector (A0) 150 GeV dc	**E&F sector tests**
~-50		**Weekend 1**
	Test injection kicker	
	--------------(installation)------------------	4/24-4/29
	Ramp magnets & transport beam	
	Explore aperture	**E&F sector tests**
	Exercise tuning program	**Weekend 2**
0	-----(finish installation & power tests)------	5/1-6/2
	← 1st turn	
	← Possible? 13 turns	100 GeV dc
	------------(fix bad magnet splices)----------	6/4-6/16
	← 20-30 turns	6/18
		150 GeV dc
100	← C0 aperture restriction found	6/22
	← E47 obstacle triangulation	6/25
	← A0 paperwipe wad found	
	← Coasting beam, 200 ms to abort time	6/26
	← 1st turn tune evaluation & skew quad setting	
	RF on - good coasting beam & rf radial position change accomplished	6/28
	← 800 ms beam to abort time	
	--	
	← 250 GeV beam	
200	← 512 GeV beam	7/3
		Ramped
	← Tune vs ΔR & coupling measurements at 512 GeV complete	7/15
	---------(change filter CHL cold box)---------	7/16-7/23
300		
	← Coupling measurement at large orbit distortions	7/24
	← Zero harmonic oct. test tune vs ΔR	
		Ramped
	← 1/2 integer stopband measurement	
	← Completion of 39th harmonic circle study	7/31
375		
	← Beam resonant extraction & transported to SY dump	8/2
400		

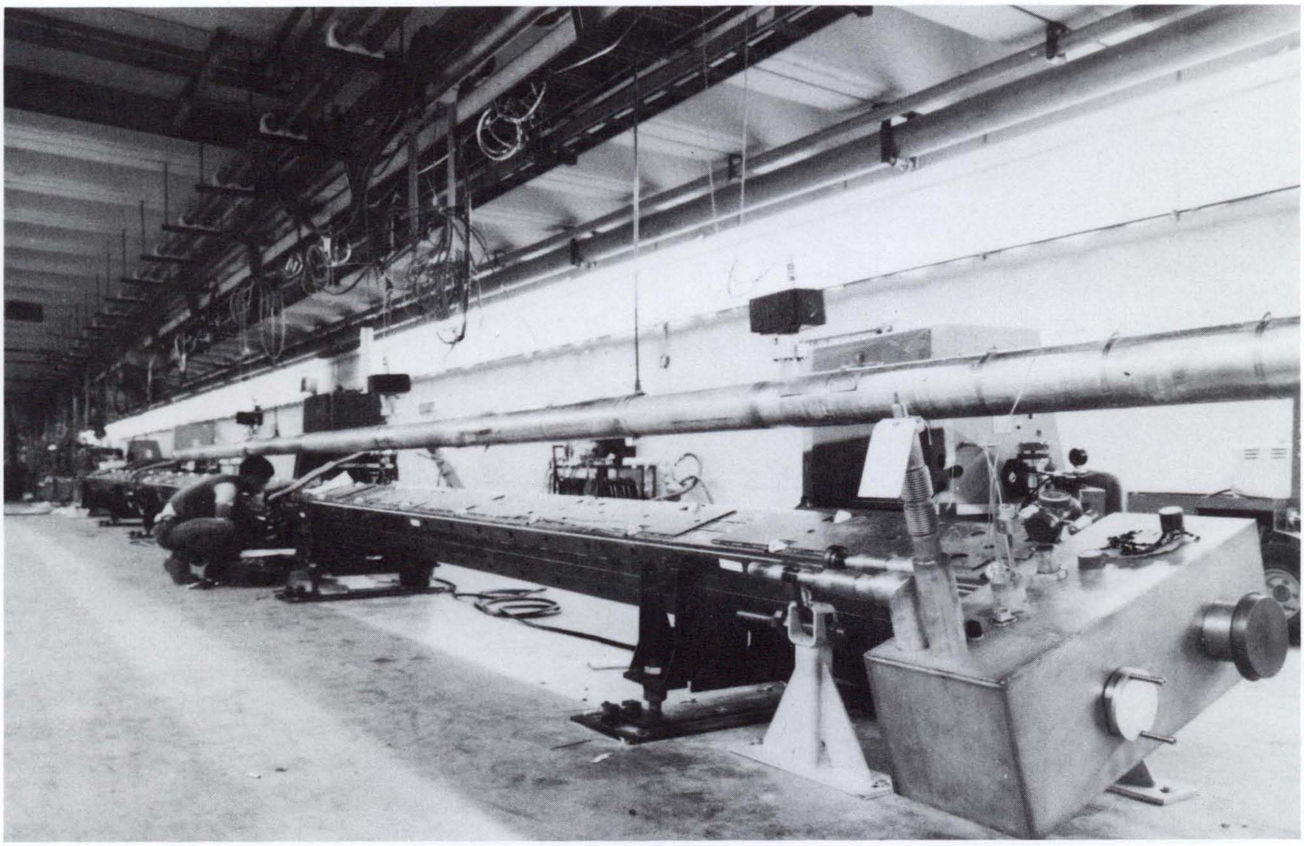


The completed Energy Saver.

Operational Experience and Reliability

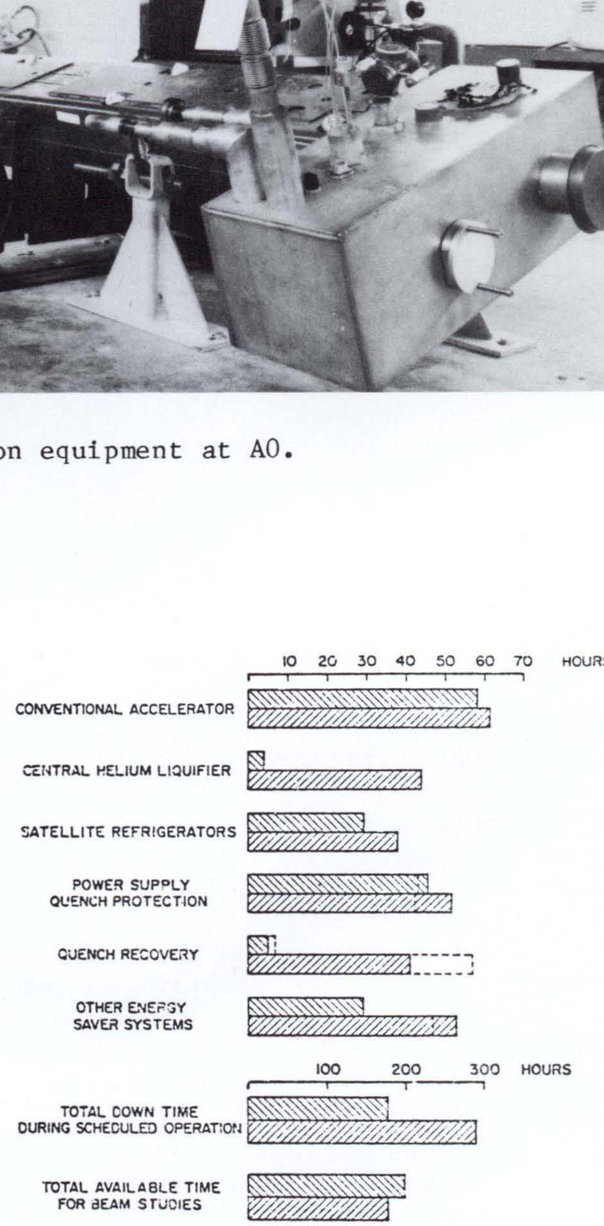
The reliability during the beam commissioning time was very poor, as can be seen by comparing the number of days it took for any phase with the amount of available uptime. (Available uptime is defined as any time when there was not recorded downtime. It does not reflect the inefficiencies of interruptions and confusion when controls do not seem to respond, for example.) Actual usable uptime seemed to the crews to be about half of what is indicated here. Whole shifts would go by with nothing productive accomplished. We have always planned on poor reliablity in initial operation and the data gathering of beam information was very effective in making efficient use of beam when it was available.

The accompanying graph illustrates the amount of downtime caused by various systems in the Energy Saver and caused by the conventional accelerator (Linac-Main Ring). Down-time increased substantially when ramping of the superconducting magnets was initiated and proper cooling required full Central Helium Liquefier output. Quench recovery, which was not a problem at 150-GeV dc operation, took considerably longer when quenches occurred at higher excitation. Failure of a number of devices could cause quenches that took much longer to



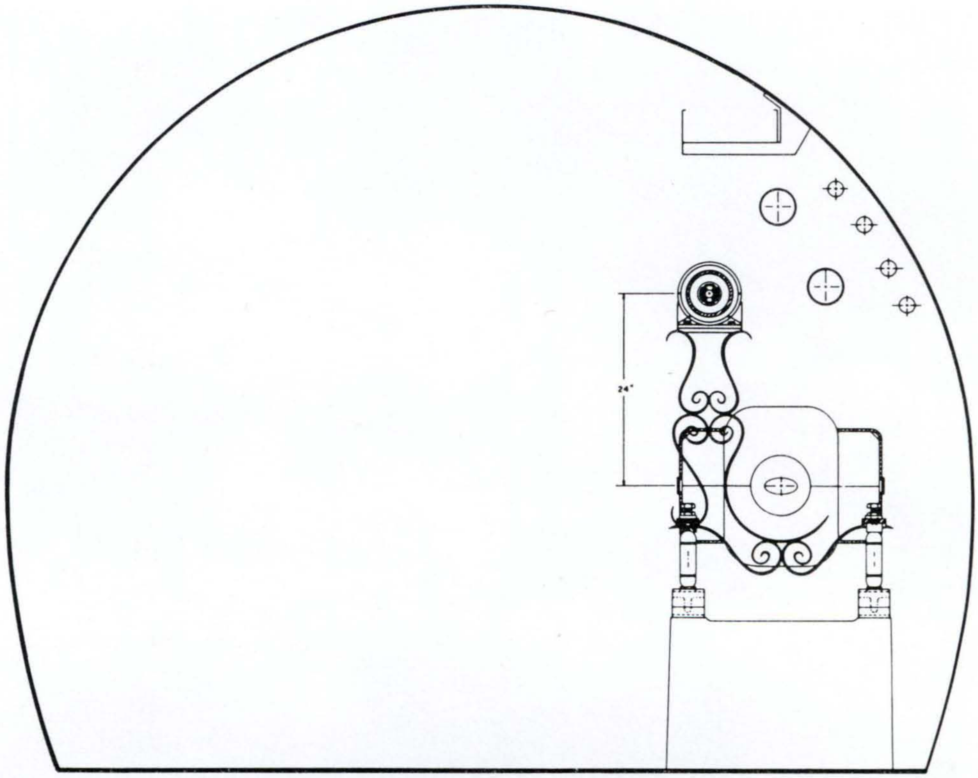
1-TeV beam extraction equipment at A0.

recover from than the adjustment or repair of the original problem. The refrigeration system was more reliable than expected, probably because of the reasonably long time (3 months) over half the system had been in operation before beam time. On the other hand, the power-supply quench-protection system had little operating time before beam startup.



DOWNTIME DURING SCHEDULED OPERATION BY SYSTEM OR CATAGORY

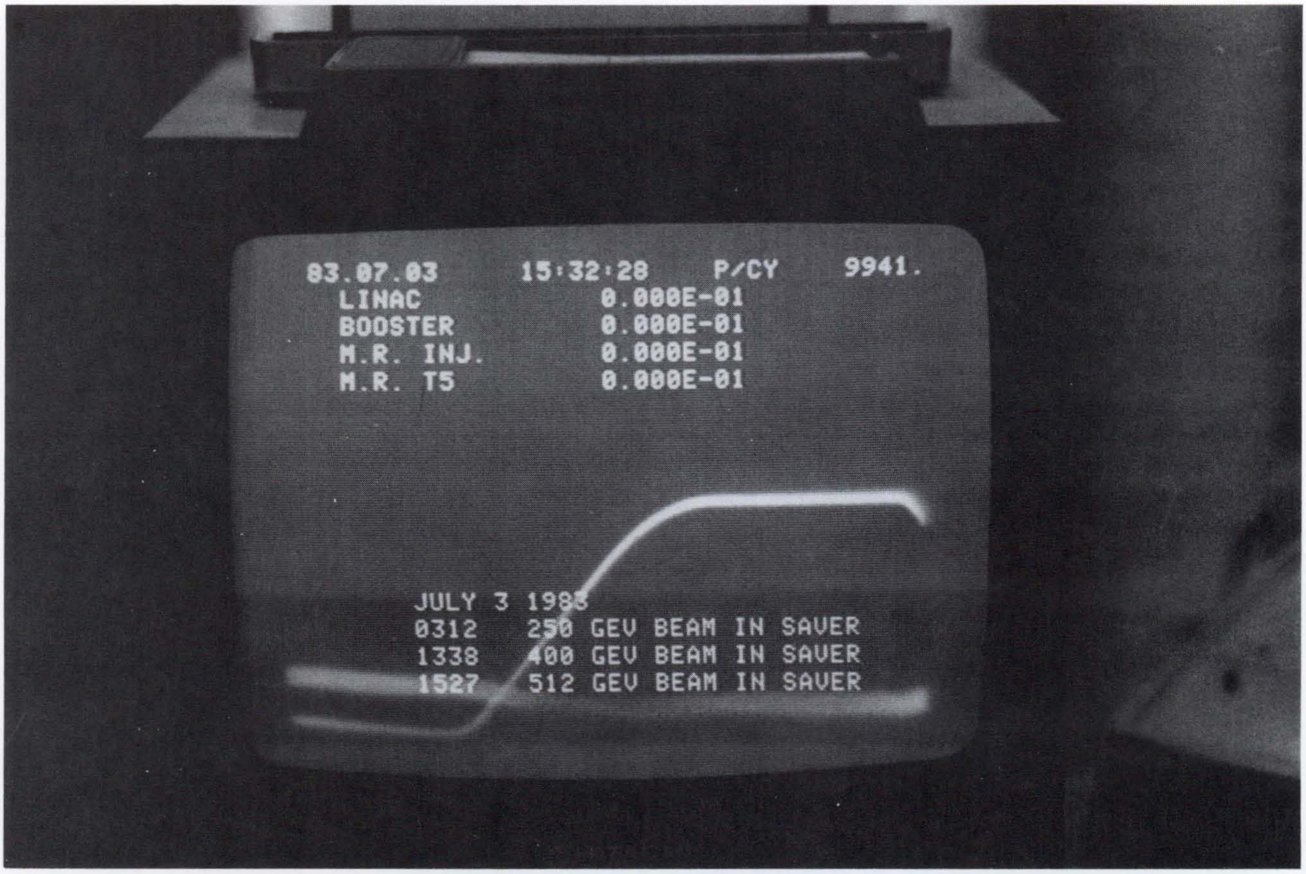
- 6/2/83 - 7/2/83 DC INJECTION EXCITATION
- 7/3/83 - 8/2/83 RAMPED (512 GeV) EXCITATION
- OTHER SYSTEM FAILURE LEADING TO QUENCH RECOVERY



One of the first designs for the Energy Saver with respect to its position in the Main-Ring tunnel.

Energy Saver Chronology

67-70	Discussions of adding superconducting magnets to ring.
3-71	RRW announces intention to request authorization to build Energy Doubler.
7-71	Carrigan suggests using Doubler for colliding beams (FN-233).
	FN-235 reports first small model quadrupole (Sheldon, Strauss).
9-72	Working group established.
1-73	R&D started.
4-73	First magnet tested.
5-73	First preliminary design report (TM-421).
1-74	Energy Doubler Design Study Progress Report.
5-75	Beam transported through one 3-ft magnet at B12. Magnet hung on tunnel ceiling.
7-75	Central Helium Liquefier Satellite concept developed.
8-75	Beam quench studies on early superconducting magnet in A0 extraction line.



Energy Saver Chronology

12-75	External collar concept developed.
2-76	B12 above-ground test area started.
1976	About ten 22-ft magnets made.
1977	B12 test area-four magnet string test started < 2000 A.
12-78	Beam transported A0 to A17, 22-ft magnet (20 dipoles, 3 quads).
5-79	Final design report-change magnet design length to 21 ft.
6-79	B12 test area-16 22-ft magnets, 4 quads installed.
7-79	Start of construction.
12-80	Start installation of A-sector.
1-81	B12 test area-16 21-ft magnets, 4 quads, installation starts.
3-81	B12 test area-start tests on final magnets.
5-81 } 12-81	Installation of 3/4 A-sector.

Leon Lederman and Linda Klamp celebrate 512 GeV.

Energy Saver Chronology

1-82 – 6-82	3/4 A-sector test to 4200 A	Cryogenics Power Voltage-to-ground Quench Protection Pressure Tests

6-82 400 GeV program terminated.

3-83 Magnet installation complete.

5-83 Entire accelerator cooled to liquid helium.

6-2-83 First full turn.

6-26-83 Many turns: coasting beam.

7-3-83 Beam accelerated to 512 GeV.

8-2-83 Extraction to Experimental Areas.

8-15-83 Beam accelerated to 700 GeV.

10-1-83 Experimental program starts.

1-10-83 Beam physics program; storage for over 30 hours.

Conclusion

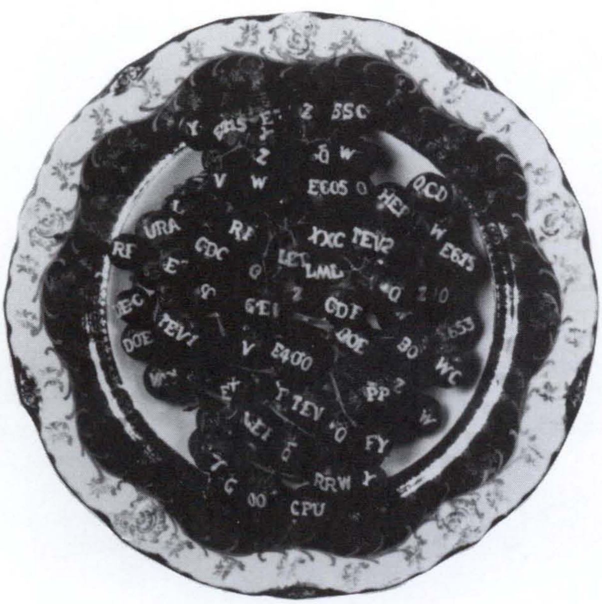
The Energy Doubler gives every indication of being a very stable, rational accelerator with no particular aperture problem and with classical optical properties. It still must get to design intensity and energy. Problems that occurred during installation and commissioning were sufficiently small as to allow enumeration. None seem fundamental at this time. The long, careful test program was probably instrumental in making for a rather rapid turn-on period.

On August 15, 1983, beam was accelerated to 700 GeV and on August 19, a test of the controls for beam storage was attempted. Beam was held for about 13 minutes before being aborted on command. Beam attenuation during this time was less than 3-4%, even though all 12 power supplies were on and no attempt was made to select any particular tune value. The major technical goals of a superconducting accelerator have been achieved.

The conception of the Energy Doubler is due to the imagination, determination, and foresight of R. R. Wilson. The success of the magnet program has its foundation in the work of Alvin Tollestrup. The environment for success has been generated under the direction of Leon Lederman who made this project the number one priority of the Laboratory.

The professionalism, desire for excellence, and commitment of the Fermilab employees to schedule and performance have brought this project to realization.

Helen T Edwards



近藤、宮下様

本日、三品さんと福井君と僕の3人で、glueing 及び gas vessel への assembly について議論した結果を報告します。

1. 位置決めの精度

a) pattern の位置決めの精度は ±1mm であること。

b) 90° の直線は、ケガキ線の外へはみ出すとしても +0.5mm 以下であること。

c) 内側の円弧の部分は本来の位置より 1.3mm 以上でてはいけない。

以上の a) b) c) の規格のうち、c) は a) が満たされれば自動的に満たされる。

2. Glueing (4頁目の絵を参考にして下さい。)

鉛とチェンバーとの貼り合わせは、以下の手順で行ないます。

a) チェンバーの 45° の 30mm巾穴の部分に真チュウのスペーサーを入れ、ロッドに通す。ロッドの直径は 28mm で、スペーサーに開いた穴は直径 28.1mm です。glue を塗った後、鉛板をロッドに通す。これを 4回(あるいは 5回)繰返す。

(鉛板の上に glue を塗る。)

III. CDF, The Collider Detector at Fermilab

Introduction

By now, almost everyone who visits or works at Fermilab has passed by the large orange building on Road D between Batavia Road and the Central Laboratory. This building, known as the B0 Collision Hall and Assembly Area, is the home for a large experiment being built to measure what happens when beams of protons and antiprotons, counter-rotating in the Tevatron, collide head-on.

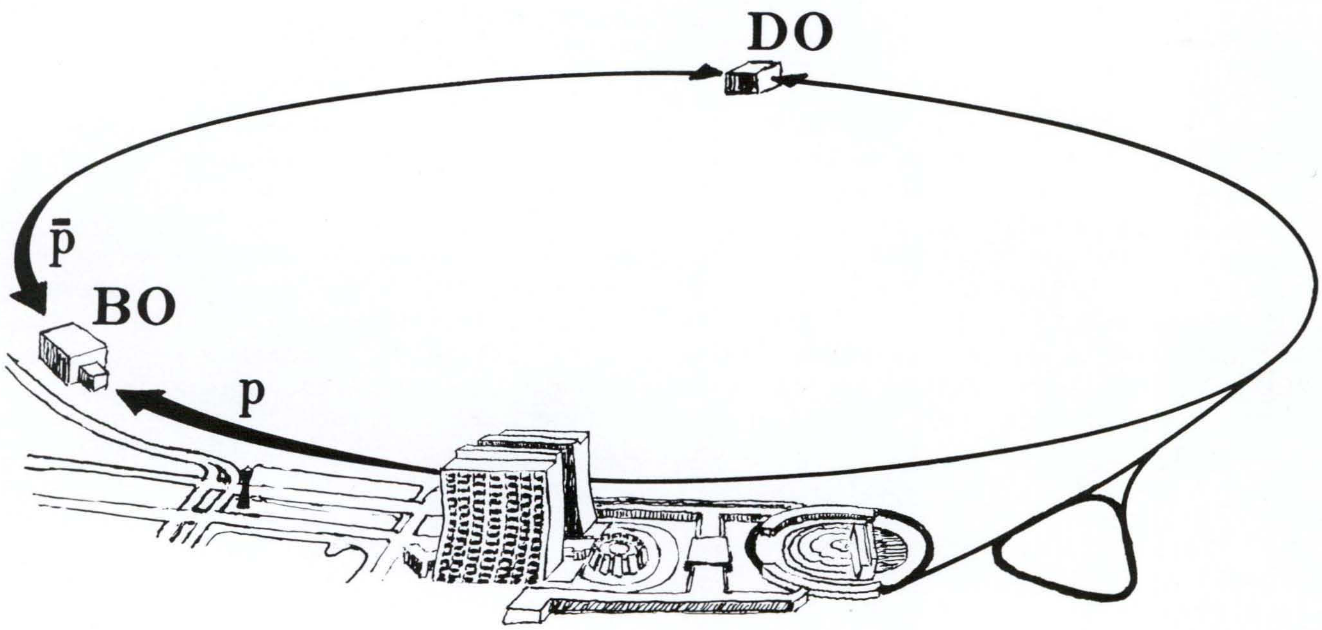
The apparatus for this experiment is called CDF, the Collider Detector at Fermilab. When experiments using CDF begin in 1985-1986, they will be observing the highest-energy collisions ever produced in a laboratory, some three to four times the highest available now at the CERN laboratory in Geneva, Switzerland. These very high energies allow physicists to probe much deeper into the structure of matter than heretofore possible. We are not sure what will be found with CDF--that is the excitement of high-energy physics--but we do know that it will make significant contributions to our knowledge of the subnuclear world where current understanding is incomplete.

This article will look at some of the kinds of physics questions that can be addressed by a detector such as CDF; these considerations are what led to the basic design of CDF. The hardware being constructed for CDF will be described. Finally, some of the plans for using CDF will be mentioned.

A major high-energy physics enterprise such as this one is really a form of high adventure, much like the Spanish voyages of discovery or an Himalayan climbing expedition. To succeed, these enterprises demand the talent, dedication, and hard work of a large number of individuals. In the case of CDF, physicists and secretaries, engineers and technicians, draftsmen and machinists, students and business managers are all part of the enterprise. All told, there are 200 people all over the world working directly on CDF. They come from ten U.S. universities (Brandeis, Chicago, Harvard, Illinois, Pennsylvania, Purdue, Rockefeller, Rutgers, Texas A&M, and Wisconsin), three U.S. national laboratories (Argonne, Fermilab, and Lawrence Berkeley) and two foreign countries, Italy (Italy--University of Pisa and Frascati National Laboratory) and Japan (Japan--KEK National Laboratory for High Energy Physics, Fukui University, Saga University, and Tsukuba University).

Like other great adventures, CDF also needs its ships and supplies. The major funding for CDF comes from the U.S. Department of Energy. The DOE equipment funds are managed by the CDF Department at Fermilab and are distributed to the U.S. university and laboratory groups. The U.S. National Science Foundation supports CDF principally through two of the collaborating university groups. The second largest source of funds for CDF is the Japanese Ministry of Education through the joint U.S./Japan Accord program for high-energy physics. The Japanese MOE also provided important support for the superconducting solenoid coil through a special program with Tsukuba University. Significant support for CDF is being provided by the Italian government through INFN.

Another essential ingredient in the experiments planned for CDF is the source of antiprotons being built by the Tevatron I group at Fermilab. This is an extremely challenging and interesting project in its own right, but space does not permit an adequate description here. It will simply be assumed that the antiproton source provides intense bunches of antiprotons



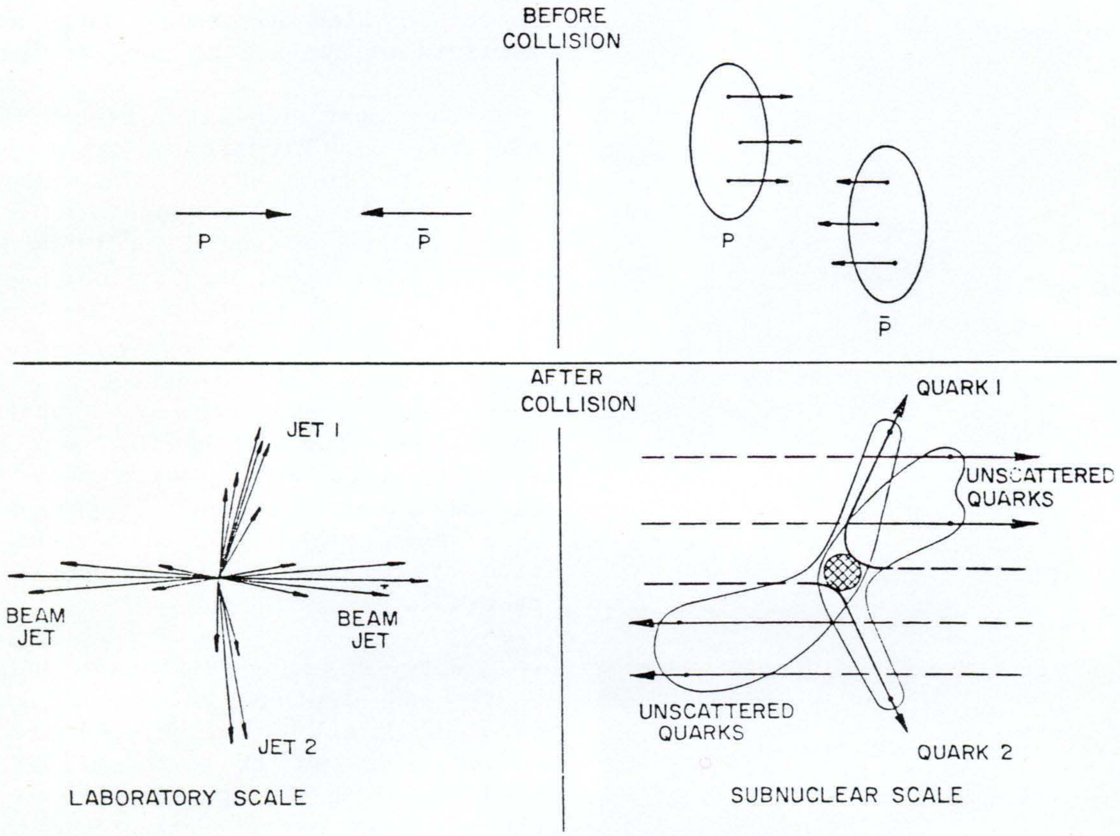
The Fermilab ring and the collision points at BO and DO.

that are stored and circulate in the Tevatron. Since antiprotons have the opposite electric charge as protons, they will circulate in the opposite direction to protons, but on the same path. Both the protons and antiprotons will be confined to sausage-like bunches, approximately 1 meter long and less than a millimeter in diameter. It is expected that there will be three such bunches of protons and three bunches of antiprotons, each set being equally spaced around the Tevatron. There they travel at very nearly the speed of light for periods of several hours while the experiments are in progress. Collisions between the bunches of protons and antiprotons will actually take place at six points around the Tevatron. CDF will observe the collisions that take place in the BO straight section; another experiment now just beginning to be organized will operate at a second region called DO.

No attempt will be made here to identify all of the specific contributions being made to CDF by individuals or collaborating institutions; this is simply too large a task. The problem of coordinating the construction of complicated detector components that are being built all over the world is an interesting one, however, and some of these coordinating efforts will be described.

Physics

The past fifteen years have been a revolutionary period in the understanding of the basic constituents of matter and the forces between them. Physicists immodestly include everything in the universe when they talk about matter. Their hope is to gain an understanding of all the diverse behavior of all the matter around us by trying to break matter into smaller and smaller

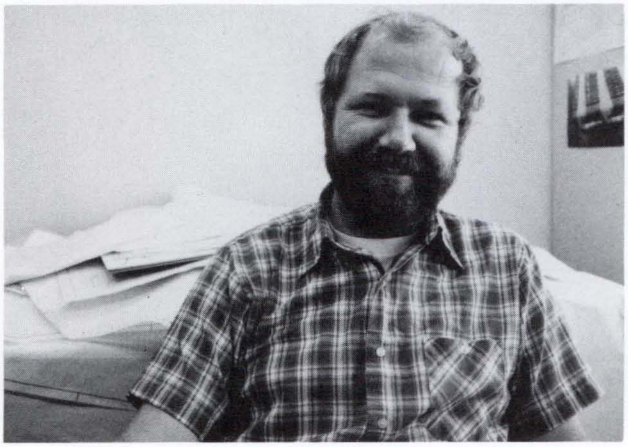


pieces and discovering the force laws that govern the interactions of all the pieces. It is very much an open question whether this process will ever end, but most physicists would like to find a basic or fundamental set of building blocks out of which everything is made.

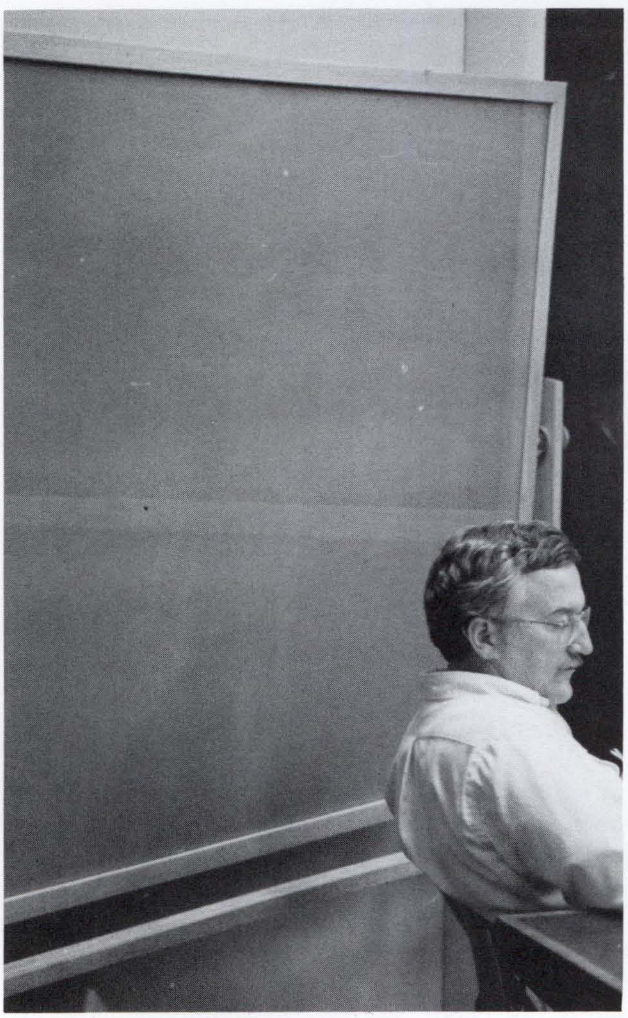
The essential fact that has emerged over the past few years is that all matter is made out of just two classes of elementary building blocks or constituents. The particles that make up one of the classes are called "quarks"; members of the second class go by the name of "leptons." For each quark or lepton, there is a kind of mirror partner known as an antiquark or antilepton. The antimatter that is made from antiquarks and antileptons is not found under normal conditions, but it is routinely produced at high-energy particle accelerators such as Fermilab.

Five different kinds of quarks are now known; most physicists fully expect that a sixth will be found in the relatively near future. The main reason behind this confidence is that six leptons are also known to exist and there are deep reasons to believe the two families of particles may have exactly the same number of members.

The great achievement of the past 20 years has been the realization that quarks are the basic building blocks of atomic nuclei, even though they appear to be so tightly bound into nuclei that individual quarks have never been broken free and isolated in the laboratory. Nevertheless, by scattering particles off nuclei and other kinds of high-energy physics experiments, the picture of the internal structure provided by the quarks has become incontrovertible. Quarks are bound into nuclei and other subatomic particles by



Hans Jensen



Dennis Theriot

objects called gluons. These are the carriers of the strong nuclear force.

The most familiar lepton is the electron. Electrons orbit around nuclei to form atoms and molecules. They are largely responsible for the chemical properties of ordinary matter and for electrical conduction.

It is interesting to note that essentially all matter normally encountered on earth is composed of only the two lightest quarks and involves interactions with only two of the six known leptons. To paraphrase a well-known physicist, when this question first arose, "Who ordered all the others?!."

With so many different kinds of quarks and leptons, a natural question is whether all these objects are themselves made out of even smaller, more fundamental building blocks. As yet, there is no experimental evidence for such things, but they will certainly be sought in the Tevatron experiments.

The basic strategy in the CDF experiments on the Tevatron is to see what happens when quarks and antiquarks collide at very high energies. Because it is impossible to make beams of quarks, we plan to use the quarks that are normally bound in protons (the nucleus of hydrogen) and collide them with the antiquarks in antiprotons. Of course, what is actually done is to collide beams of protons and antiprotons that are stored in the Tevatron, circulating in opposite directions.

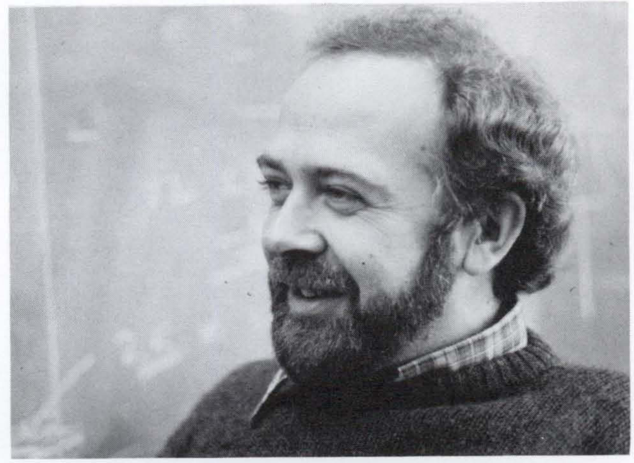
Most of the time, the protons and antiprotons will miss, but on rare occasion, the two beam particles will pass so close to one another that a quark in the proton will have a very violent collision with an antiquark in the antiproton. When that happens, various results are possible. In the simplest case, the quark and antiquark will bounce off one another much like billiard balls. If they scatter at large angles from the original beam direction, the quark and antiquark "billiard balls" will move away from their companion quarks in the original proton and antiproton.

The gluons that bind quarks in nuclei prevent the quarks from traveling too far (about the diameter of a proton or roughly 10^{-13}cm) before they are transformed into a narrow cluster of several energetic subatomic particles, built out of more quarks and antiquarks. These clusters are called "jets"; the particles in jets are the objects actually observed in experiments such as CDF. The gluons can also collide with quarks or other gluons, giving rise to jets very similar to the quark jets.

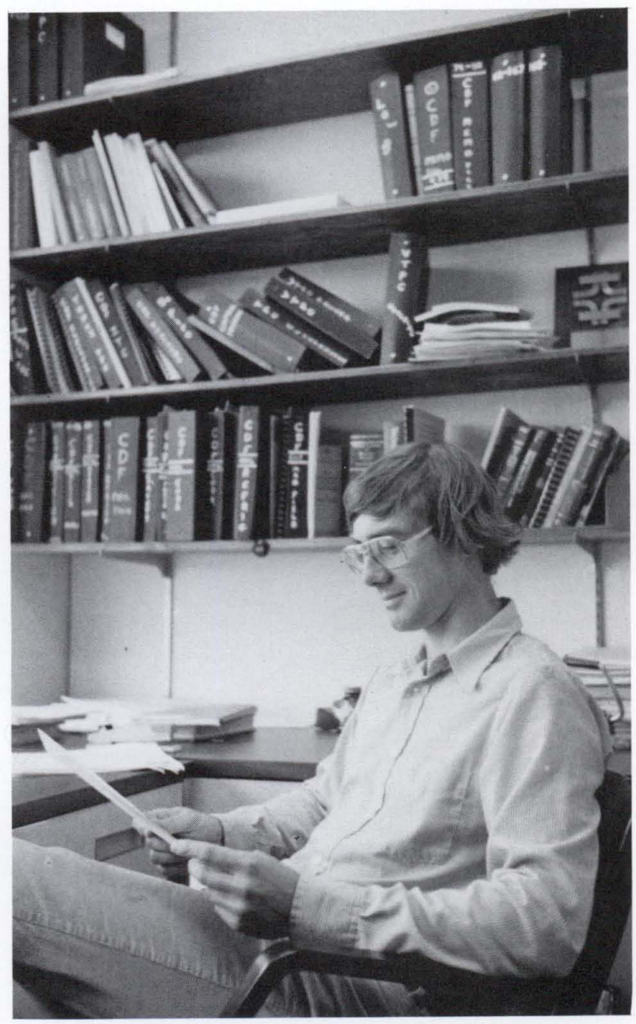
The other quarks in the original proton that did not collide continue in the beam direction and also are manifested as jets of subatomic particles. These are called "beam jets"; they usually travel along the original beam direction and are ignored as much as possible in experiments. A schematic representation of this quark-antiquark collision process is shown on page 61.

A billiard ball-like collision is not the only thing that can happen; the other possibilities are what make these experiments so interesting. For example, in the recent experiments at the CERN collider, it was found that occasionally the collision energy was transformed into new kinds of particles, called W and Z bosons. These particles were then observed to decay into leptons which were detected in the experiments. The original quark and antiquark actually disappeared to make the new particles. This was the first time W and Z particles had been seen and their observation provided a crucial confirmation of the theory of the forces between leptons and quarks, which predicted the existence of the new particles.

The CERN experiments succeeded in



Roy Schwitters



Bob Kephart

Hans Kautzky

Cathy van Ingen

finding the W and Z particles because of the very high collision energy provided by their proton-antiproton collider. No other existing accelerators could produce such high masses. The Fermilab Tevatron collider can reach energies several times higher than CERN, which puts it in position to find even higher-mass particles if they exist. The goal for CDF is to detect jets and leptons coming from collisions in the Tevatron and infer whether they arise from billiard-like collisions, W or Z particles, new and heavier particles, or completely new, unexpected phenomena.

The Detector

Given these physics goals, the challenge to the detector builders is to find practical ways to observe all of the particles created in the proton-antiproton collisions, the jets and lepton, and to interpret these in terms of the underlying quarks, leptons, and new particles such as the W's and Z's.

An isometric drawing of CDF is shown on page 70. CDF consists of a 2000-ton central detector surrounding the intersection region of the beams, and two large forward/backward detectors to measure particles produced at small angles with respect to the beam direction. Not shown in the figure is a complex system of special electronics and computers that collect and process information from the detectors yielding digital "images" of the collision events that can be studied by physicists. What are all the parts of CDF and how do they work?

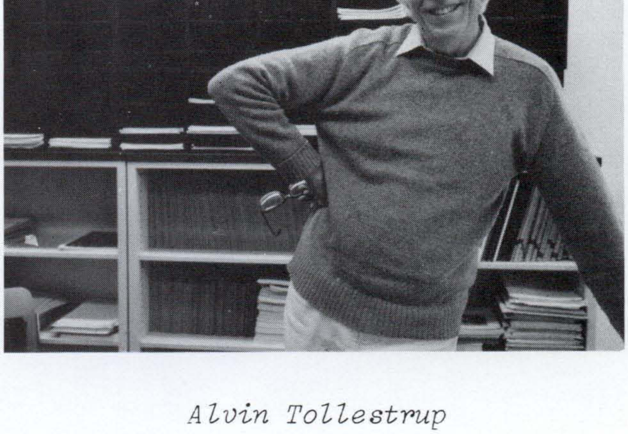
The essential fact that is exploited by all detectors in high-energy physics is that when charged particles pass through matter, they ionize atoms along their path. By detecting the ionization, we can follow the particle much like a high-flying jet airplane can be followed by its vapor trail even though one cannot actually see the aircraft. This ionization is measured in several ways. In certain gases, the electrons liberated by ionization of the gas can be collected on wires and amplified by sensitive electronic circuits. The position of the wires and the electric charge collected then tell where the particle went and how much ionization it left behind. In plastic materials doped with special chemicals, the ionization produces small flashes of light that are detected by sensitive photomultiplier tubes that convert the light to electrical impulses.

Different kinds of particles interact differently when they pass through matter. One of the leptons, the muon, has essentially no interactions except for ionization and is capable of penetrating great distances through heavy materials such as steel. High-energy electrons interact in a few millimeters in heavy materials such as lead, giving rise to what is called a shower of more electrons and their antiparticles, called positrons. By the time the shower penetrates several centimeters of lead, essentially all of the energy of the original electron is converted into hundreds or thousands of particles in the shower and the shower dies out.

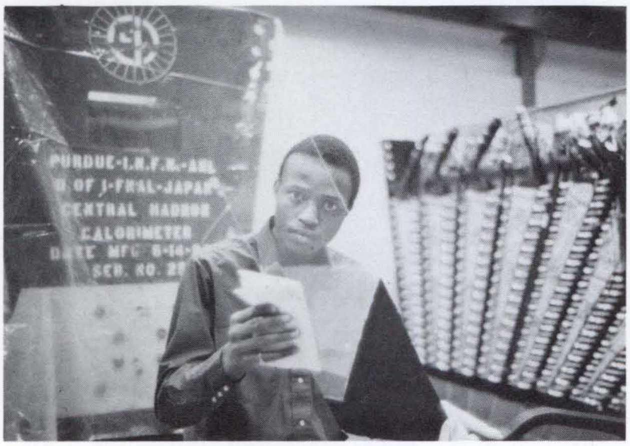
The particles that make up jets, collectively known as hadrons, have interactions in ordinary matter somewhat intermediate between muons and electrons. They can travel several centimeters through iron or lead before new particles are created and a shower starts to form. The shower tends to stretch out over a meter or so of iron before it dies out. The transverse size of a hadron shower is several centimeters; that of electron showers is about one centimeter in lead. In both kinds of showers, a measurement of the total ionization gives the energy of the incident particle.

Electrically neutral particles don't ionize, but they can nevertheless

Masa Mishina



Alvin Tollestrup

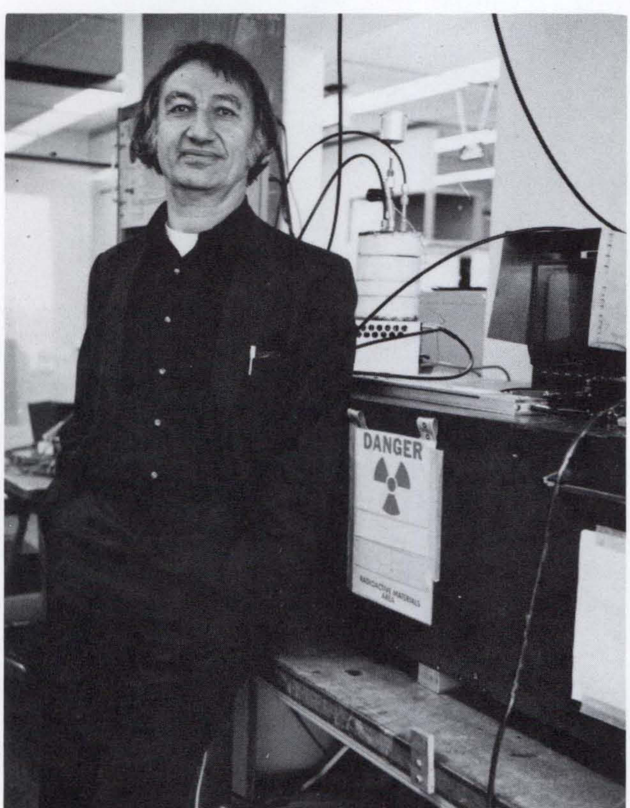


Dave Sanders

be detected. The most commonly encountered neutral particles are high-energy photons or gamma rays. When they enter heavy matter, they start a shower much like electrons. Therefore a signal for photons is no track in a gas-filled detector, followed by a small dense shower in a lead-filled detector (usually called a shower counter). Neutral hadrons exist and they usually produce large, spread-out showers in lead and iron, much like charged hadrons. Neutral leptons, known as neutrinos, don't ionize and interact so weakly that they penetrate any practical detector leaving no signal of their presence, except for the missing energy and momentum they carry away.

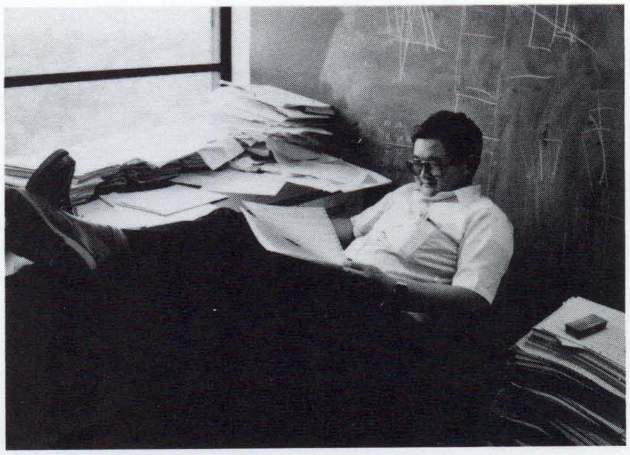
Equipped with these tools of the detector builder's trade, we can understand what goes into CDF. Let us follow a particle created in a collision at the intersection of the beams. It first travels through vacuum until it passes through the 3-inch diameter vacuum pipe that carries the beams. Next, the particle encounters gas-filled tracking chambers that measure trajectories of charged particles. There is a strong magnetic field in this region of the detector produced by a 3 meter diameter by 5 meter long superconducting solenoid coil. Charged particles bend in this field, the amount of bend is related to their momentum. By measuring trajectories in the tracking chambers, we know where charged particles are going, and we can measure their momenta.

Next, the particle encounters shower counters. Depending on the production angle, different types of shower counters are used. For angles between 2 and 10 degrees with respect to the beam line, particles exit the hole in the end of the magnet and travel to the forward or backward shower counters that are made with thin lead sheets, separated by gas-filled chambers to measure ionization in the showers. For angles between 10 and 30 degrees, particles hit shower counters



Muzafer Atac

mounted on the end caps of the magnet; these are also made from lead sheets and gas-filled chambers. At larger angles, particles must penetrate the solenoid coil before entering the central shower counters which are made from sheets of lead sandwiched with sheets of scintillating plastic.

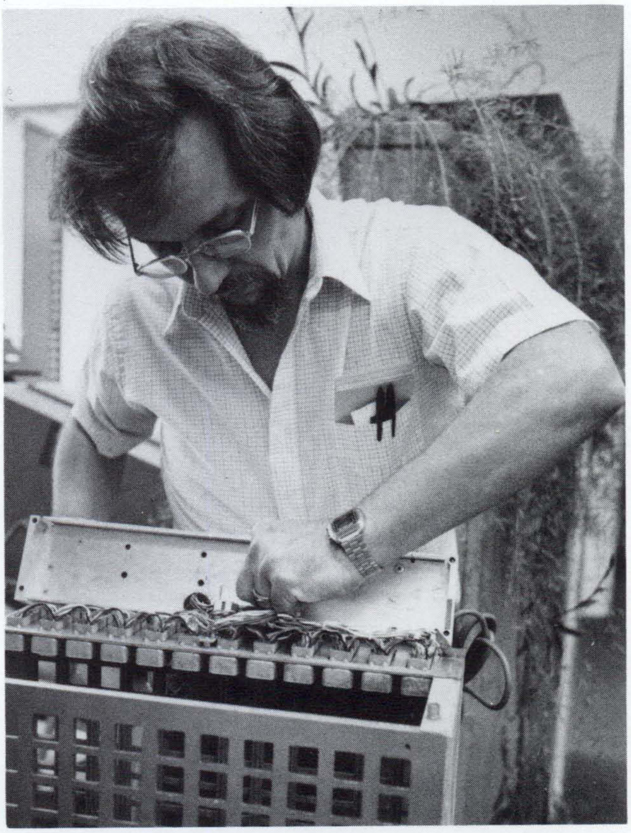


John Yoh

Outside all the shower counters are hadron calorimeters made of plates of steel separated by ionization detectors, either gas-filled chambers or more scintillating plastic. The plates are typically one or two inches thick depending on the region of the detector and have enough plates to give at least a meter of iron total thickness.

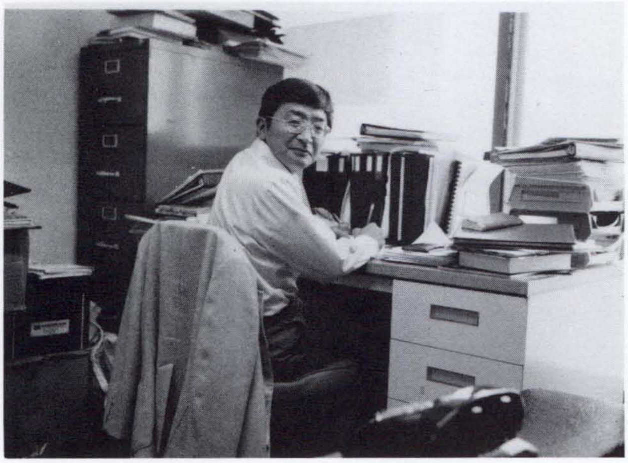
Ionization deposited in the various shower counters and hadron calorimeters is collected in cells called "towers" that point back to the intersection region of the beams. These towers can be thought of as forming a compound eye to look at the proton-antiproton collisions. The sizes and locations of the towers are carefully chosen to match the kinds of physics measurements we hope to make.

There are approximately 4000 towers in both the shower counters and hadron calorimeters. A single electron will usually show up in only one shower-counter cell; a typical jet of hadrons will deposit most of its ionization in 5 to 10 adjacent shower-counter and hadron-calorimeter cells. In an average event, 50 to 100 charged tracks will be seen in the gas-filled tracking chambers; many of these are uninteresting debris from the beam jets and others will be clustered in the jets of interest or will be isolated leptons.

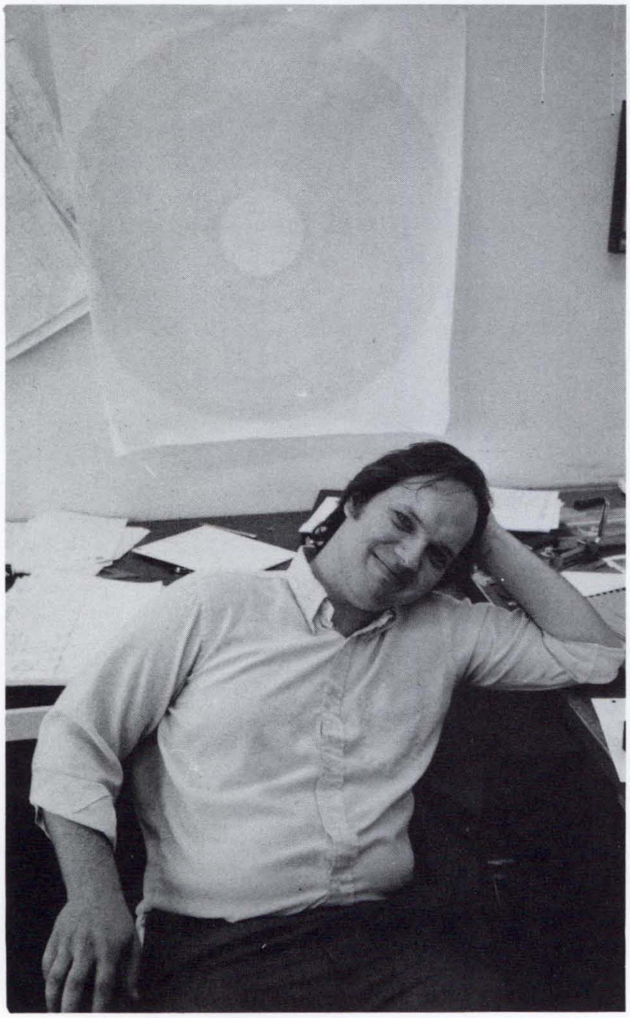


John Elias

Finally, outside all of this iron and lead we place more tracking chambers to measure the tracks of any muons that penetrate the entire detector. In the forward and backward regions, there are additional iron toroids that are magnetized to provide a measurement of



Ryuji Yamada



Richard Kadel

the momentum of muons produced at these small angles where the solenoid measurement is less effective.

A great deal of mechanical engineering effort has gone into holding up the several thousand tons of detectors in CDF. The requirement that we minimize any dead regions, not sensitive to the particles we need to measure, makes the mechanical problems especially difficult.

One interesting solution is the use of "Roman arches" that are built out of the shower counters and hadron calorimeters that detect particles in the central region of angles. A total of four Roman arches will be built for CDF.

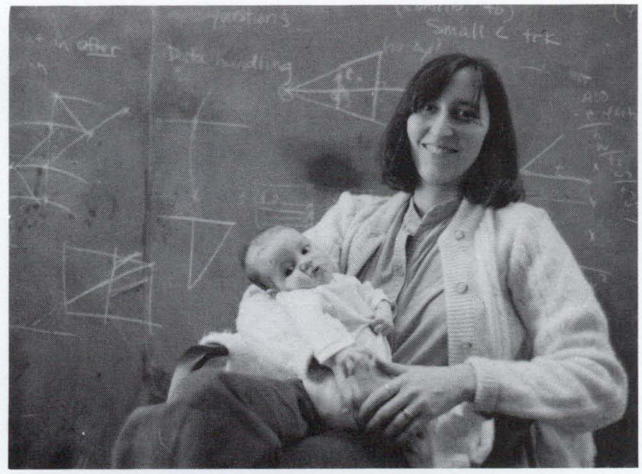
Other innovative designs provide for moving the entire detector in and out of the B0 collision hall rapidly when the Tevatron switches between colliding beam and fixed-target running. The main structure for moving the detector and supporting the Roman arches is the 1200-ton iron return yoke of the solenoid magnet.

The detector and mechanical components are only a part of CDF. We must also extract signals from the detectors and make sense out of them. There are more than 50,000 channels of information to be processed on any given collision event. Most of these have no signals in them, but every detector element struck by a particle provides analog or timing information that must be digitized and recorded for analysis. This is the job of the "front-end electronics" and the "data-acquisition electronics."

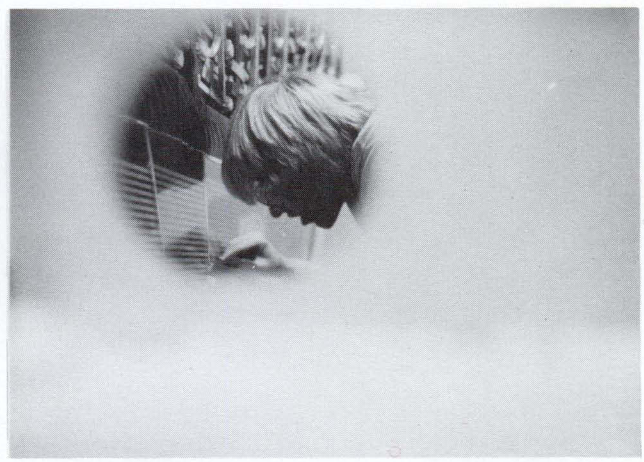
Front-end electronics consists of sensitive amplifiers, analog-to-digital converters, fast timing circuits, and so on, connected to the detector components. We are planning to mount much of this electronics right on the detector to minimize cable runs, thus improving signal quality. After the front-end electronics digitizes the signals and ignores channels that were not hit by particles, the data-acquisition electronics must bring all of the data together into computers for further analysis and storage. Because of the special demands made by a detector such as CDF, much of this electronics is state-of-the-art and must be designed specifically for CDF.

From the design intensity of the Tevatron collider and extrapolations of experience at lower energies, we estimate that the rate for producing events giving signals in CDF will be about 50,000 per second. This is much too high for our data acquisition and computer systems to handle. Most of these collisions are uninteresting from a physics standpoint because the quarks pass too far from one another to have the very hard collisions we want to study. The rate of events we want to study is probably less than one per second. Therefore, we need a trigger system that keeps the interesting events and rejects all the others. This is done in CDF by a special electronics system that interrogates signals coming out of the detector components and makes fast decisions to save or reject the event. Physicists will be able to program into the trigger system patterns of events they want to keep. For example, to select events containing jets, the trigger is programmed to respond when an energetic cluster of shower counter and hadron calorimeter towers is found.

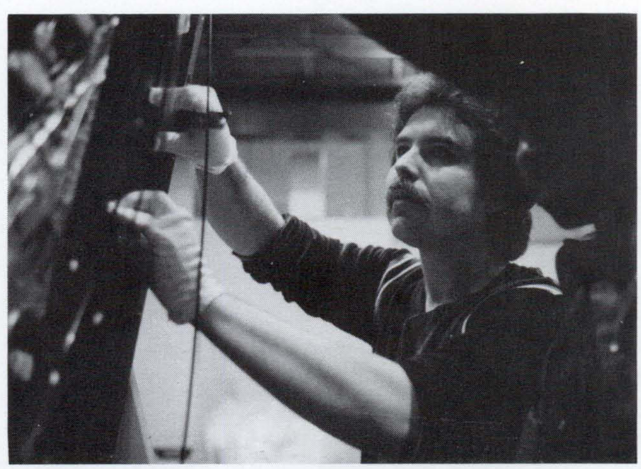
An elaborate on-line computer system involving several VAX computers is being developed to control the apparatus, trouble shoot, and record data. This in itself is a major effort, requiring many man-years of programming effort. The on-line computers will become the community center for the CDF collaboration when we run on the Tevatron. They tell the physicists how well the apparatus is working and special displays will give us a first look at the physics coming out



Cathy Holmes



Jeff Gordon



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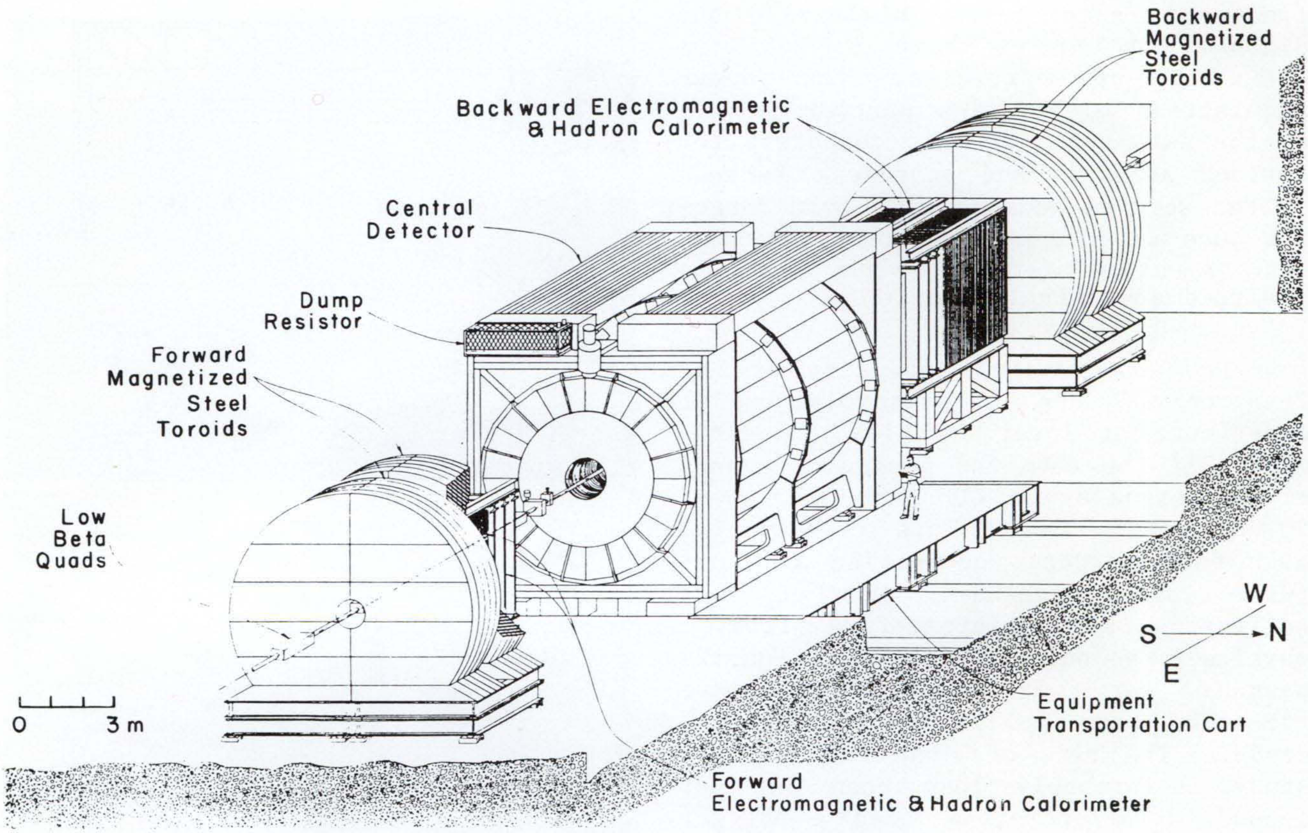
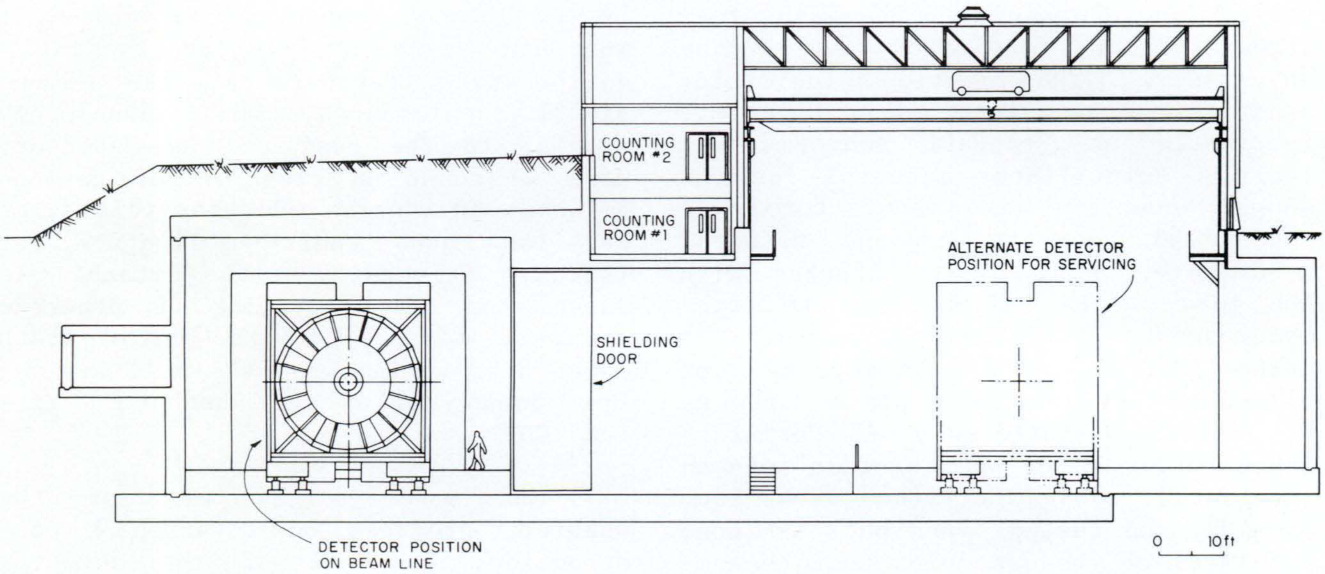


Isometric drawing of CDF.

from these experiments. The on-line computers and trigger electronics will be situated in control rooms above the BO assembly area.

The recording of interesting events at the rate of about one a second may be the end product of the overall detector system, but it is just the beginning of the physics analysis. An off-line analysis system takes over and is programmed to reconstruct as accurately as possible the original patterns of particles in the events. Responses in the various detector elements are correlated to try to find leptons, jets, and the other particles created in these collisions. Trajectories of charged particles measured by the tracking chambers in the magnetic field will be reconstructed to determine their momenta. Physicists then will pore over these data and try to interpret them in terms of existing theories while looking for new and unexpected phenomena. While most of the data collection and analysis will be centered at Fermilab, collaborators will take summary data back to their home institutions for further analysis. Data accumulated over a few months will probably take years to digest completely.

What might we hope to see in these data? We will certainly collect events with very high energy jets. These may shed light on whether quarks have a substructure. The W and Z particles found at CERN should be produced in CDF at ten times the CERN rate. Many of their properties will be measured. A few rare events may be found where pairs of W's or Z's are produced.



Cross section of CDF through BO Collision and Assembly Hall.

These should provide sensitive tests of theories of W and Z particles. It is possible that exotic, very heavy particles will be found that decay to pairs of W's and Z's. An obscure particle, the Higgs particle, central to current theories, but as yet undetected, may be found, but its mass is not predicted. The very high energy of the Tevatron makes CDF one of the better bets for finding the Higgs. Of course, the most interesting physics to be done with CDF may not even be thought of yet.

Current Activities and Future Plans

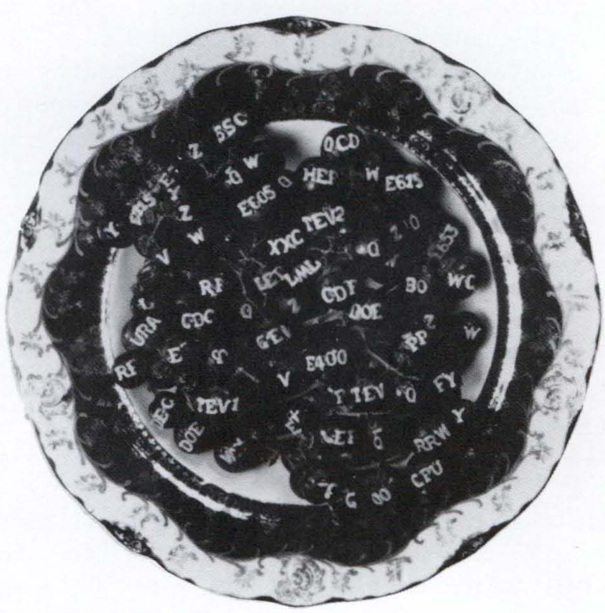
The many pieces that go into CDF are in various stages of final design, prototyping, construction, and calibration. These activities are taking place all over the world at the institutions participating in CDF. Construction of the BO collision hall is complete and assembly of the major detector components is beginning in the BO assembly area. We expect to have a preliminary checkout run in May 1985. Full data-taking runs involving the entire detector will begin in early 1986.

With so many components being built at so many different places, the CDF group finds itself facing many interesting coordination problems. An example of this is the final assembly of the central shower counter-hadron calorimeter modules. These are the so-called "wedge" modules. The main steel structure is fabricated at Purdue University. The plastic scintillator material and associated light pipes are fabricated at Frascati and Pisa in Italy. Scintillator material for the shower counters is manufactured in Japan and sent to Argonne National Laboratory, where it is stacked with the lead sheets and machined to tight tolerances. Muon tracking chambers are assembled at the University of Illinois. All of these pieces show up at Industrial Building 4 at Fermilab, where they must be put together into an integrated module, outfitted with electronics, and tested. And not just one, but fifty of these modules must be completed over the next year and a half. Needless to say, it takes the hard work and a good sense of humor by many people to make this happen.

Another interesting problem in international detector-building logistics is the construction of the solenoid coil. It is being fabricated by the Hitachi Company in Japan, yet it must use standard Fermilab cryogenics equipment. Furthermore, its dimensional tolerances are absolutely crucial to the rest of the detector. Here we count on close communications between engineers and physicists at Fermilab and their colleagues at Tsukuba University and Hitachi in Japan. So far everything has progressed very well, but the moment of truth comes next spring when the coil arrives from Japan and we see whether it fits into CDF!

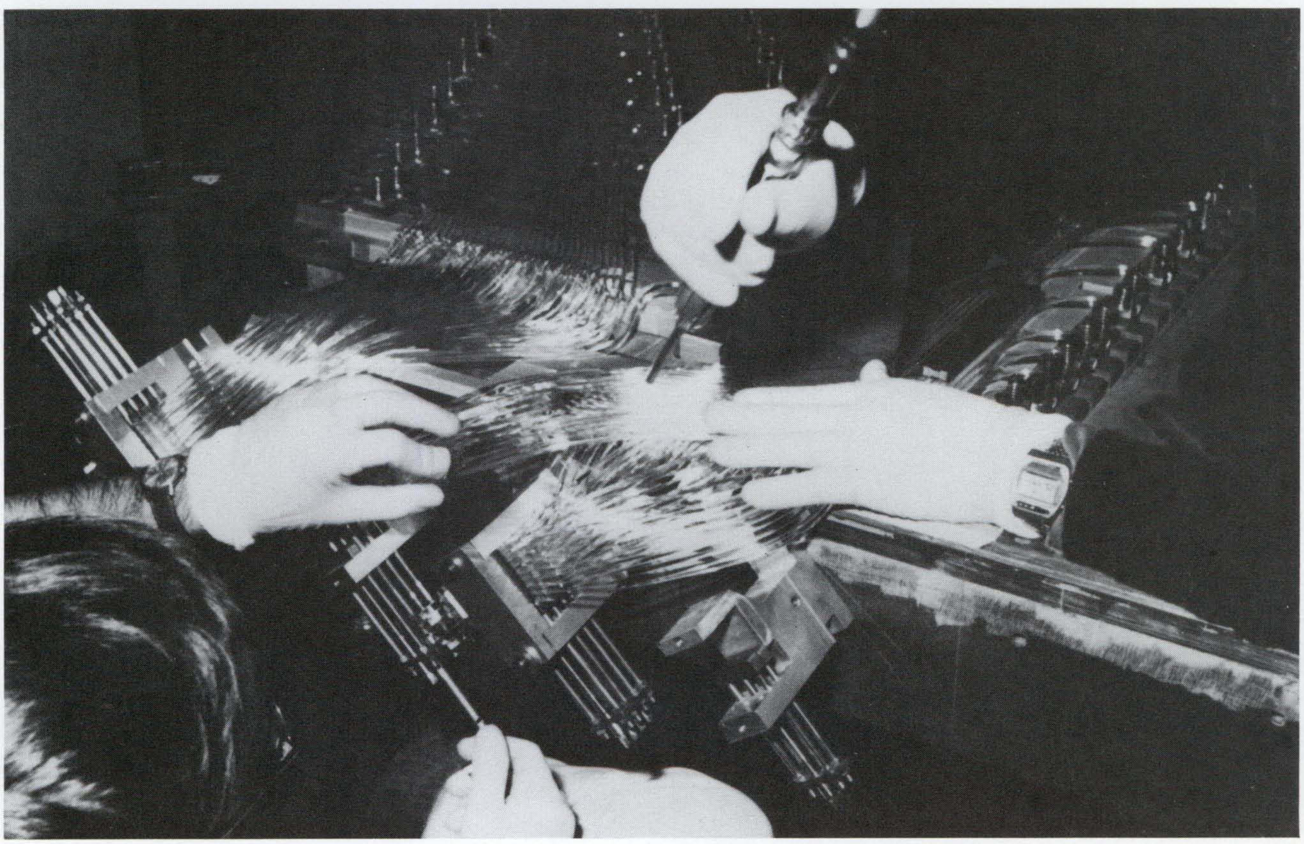
The wonderful success of the Doubler, progress on Tevatron I construction, and all of the detector pieces coming together make this a very exciting time for everyone working on CDF. Given a little luck, we should see the first proton-antiproton collisions within two years. Three years from now, the physicists of CDF will begin charting a new world of very high energy quark and lepton physics.

Roy F. Schwitters



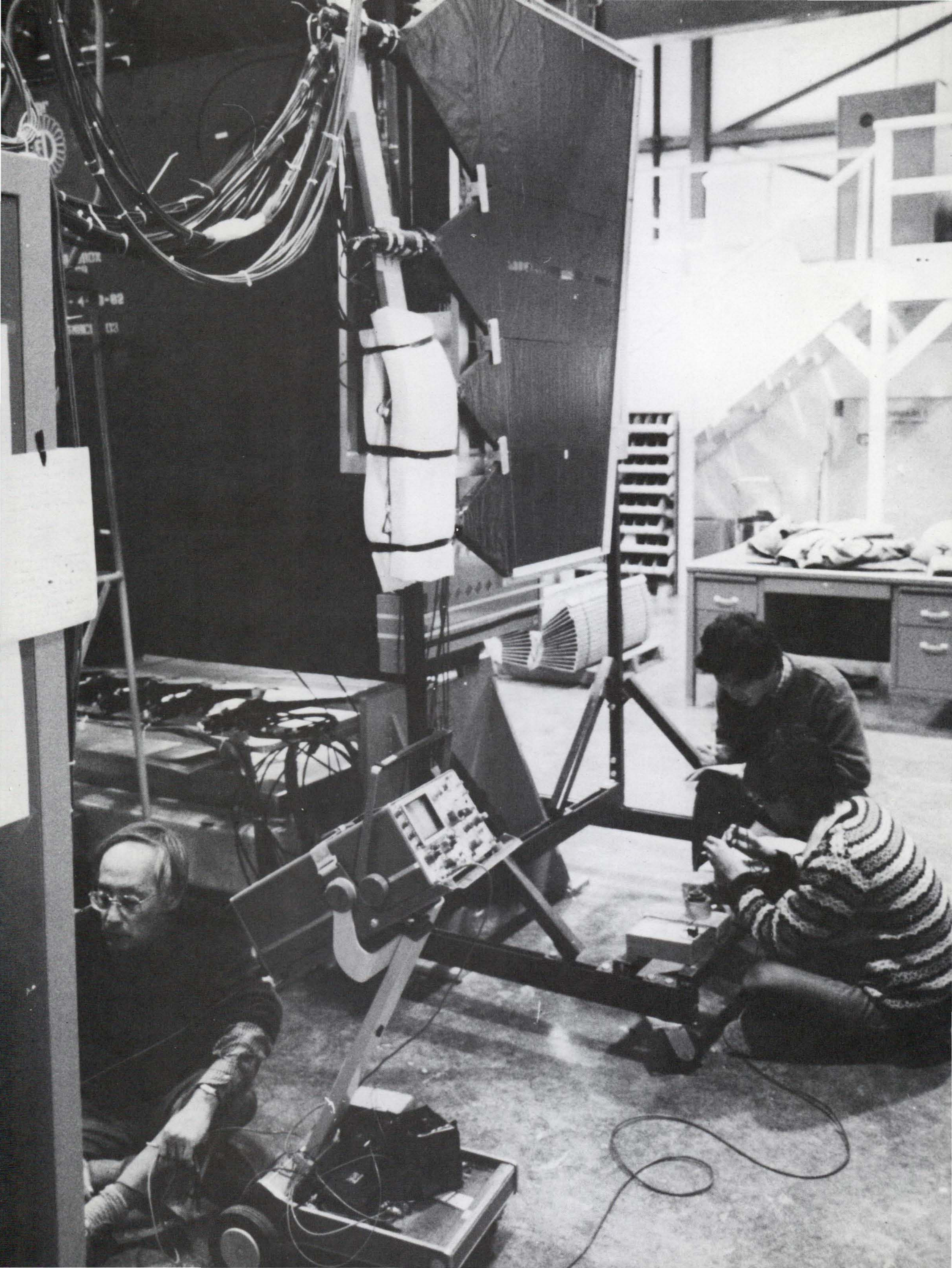
CDF wedge calorimeter assembly line in Industrial Building 4.

Alessandro Di Virgilio, Massimo Santoni, and Andrea Sansoni assemble light pipes in Frascati, Italy.

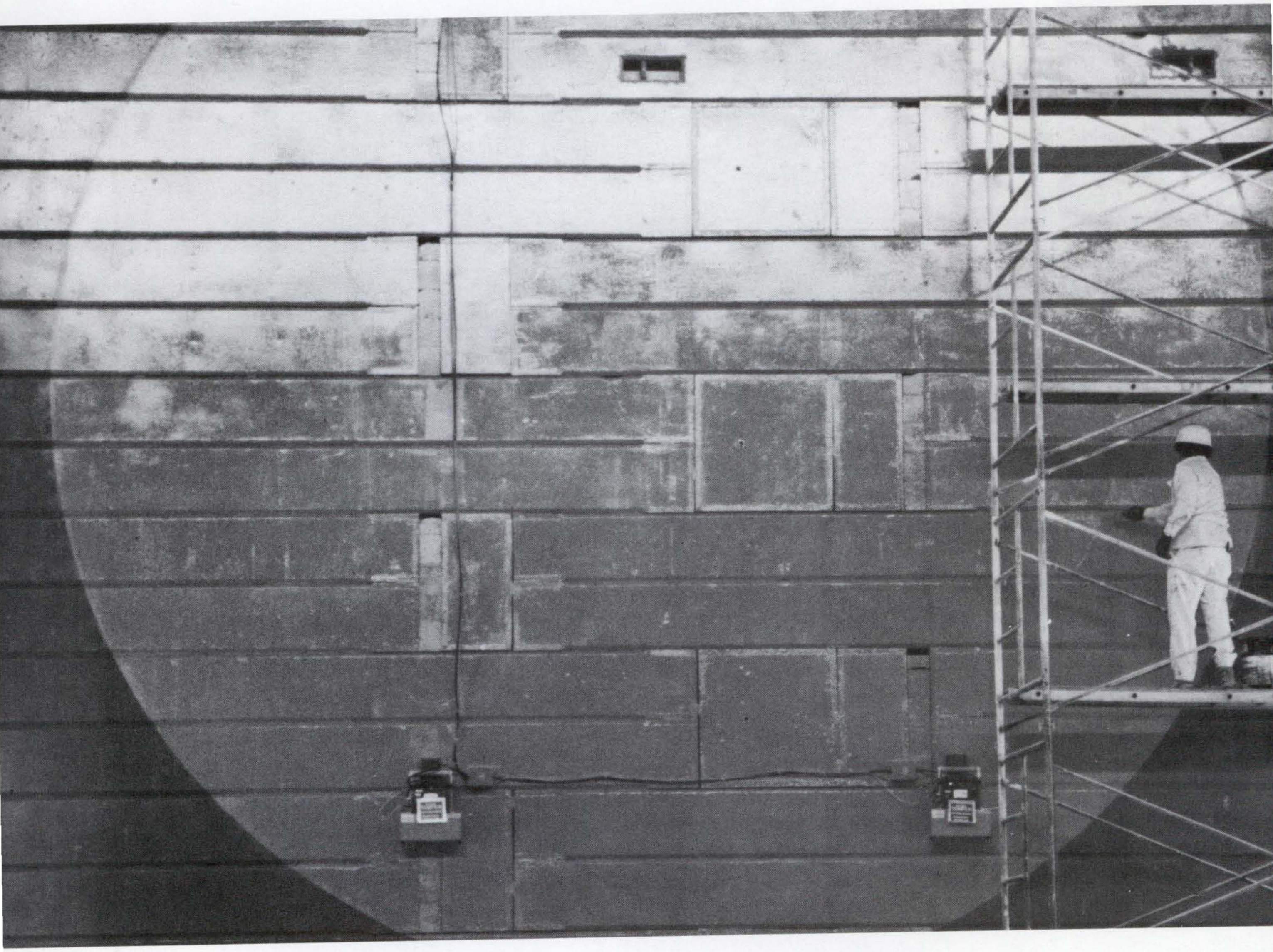


Closeup of light pipes in a CDF wedge calorimeter.

Japanese collaborators (left ro right Shoji Mikamo, Kiyoshi Yasuoka, and Akihiro Yamashita) set up cosmic-ray test stand for wedge calorimeter. ⟶

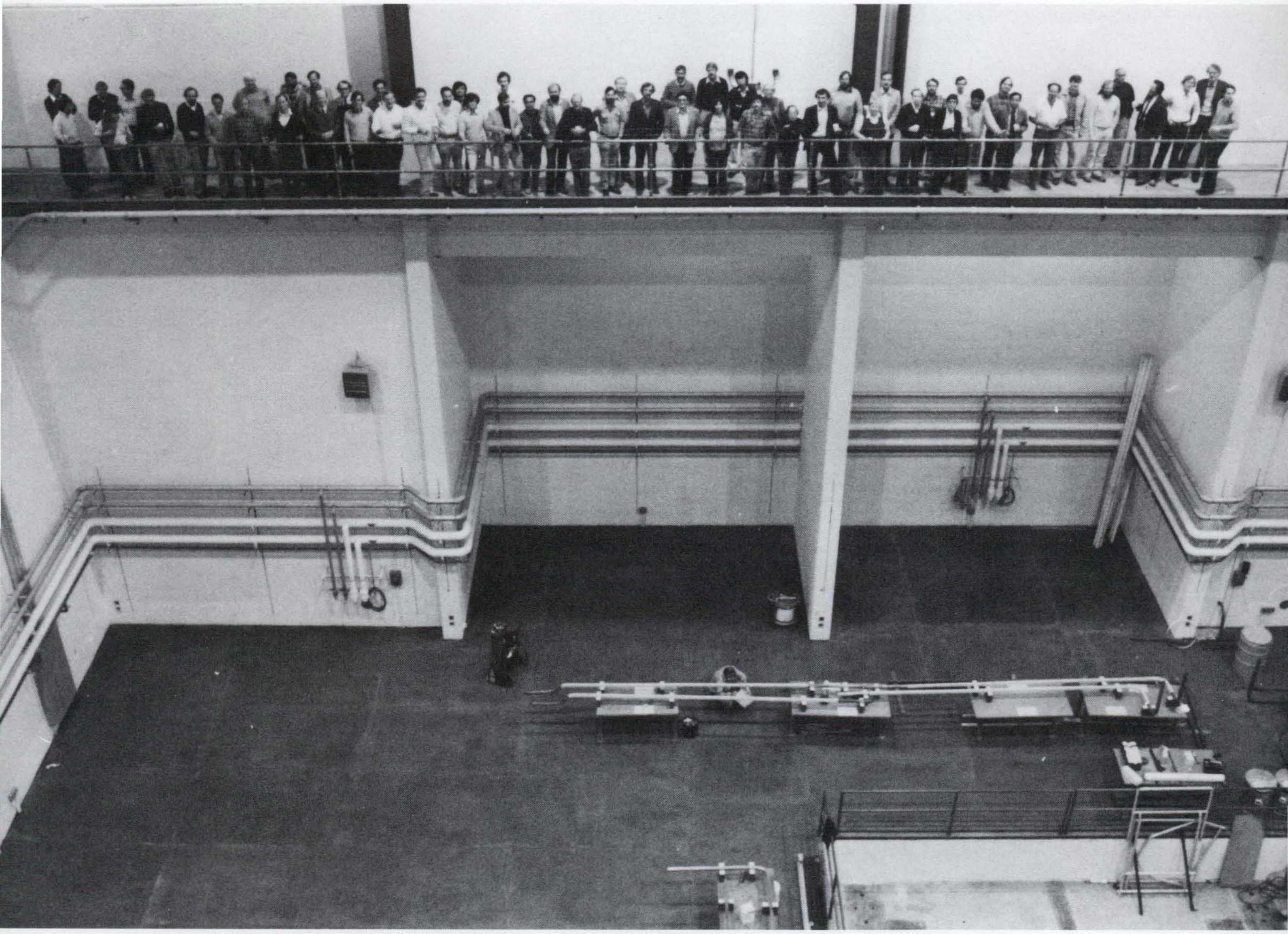


Rich Krull (left) and Don Tinsley assemble a central calorimeter wedge module.



Painting the rolling door at the B0 collision hall.

← Closeup of light pipes and phototubes on a CDF wedge calorimeter.



CDF collaborators in BO Assembly Hall during a workshop meeting on early CDF runs.


Fermi National Accelerator Laboratory
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IV. Publications

HIGH ENERGY PHYSICS PROGRAM EXPERIMENTAL PUBLICATIONS*

15-Ft Neutrino/H_2& Ne #28

CHARACTERISTICS OF NEUTRAL-CURRENT INTERACTIONS INDUCED BY NEUTRINOS. J. Marriner et al., Phys. Rev. **D27**, 2569 (1983).

Multiparticle #110

STUDY OF A_2 PRODUCTION IN THE REACTION $\pi^- p \rightarrow K^0 K^- p$ AT 50, 100, AND 175 GeV/c. C. Bromberg et al., Phys. Rev. **D27**, 1 (1983).

Photoproduction #152

A LARGE-SOLID-ANGLE SPECTROMETER FOR HIGH-ENERGY ELECTRONS AND PHOTONS. A. M. Breakstone et al., Nucl. Instrum. Methods **211**, 73 (1983).

Muon #203/391

MEASUREMENT OF THE NUCLEON STRUCTURE FUNCTION IN IRON USING 215- AND 93-GeV MUONS. A. R. Clark et al., Phys. Rev. Lett. **51**, 1826 (1983).

Emulsion/Protons @ 300 GeV/c #232

DELAYED CASCADES. D. T. King. Phys. Rev. **D27**, 647 (1983).

Hadron Jets #236

A MEASUREMENT OF HIGH-p_T CORRELATIONS IN 340 GeV/c pp AND 280 GeV/c $\pi^- p$ REACTIONS. W. P. Oliver et al., Nucl. Phys. **B228**, 439 (1983).

Pion Inclusive #258

INCLUSIVE PRODUCTION OF HADRONS AT HIGH P_T IN 200 AND 300 GeV $\pi^- p$ AND π^--NUCLEUS COLLISIONS. H. J. Frisch et al., Phys. Rev. **D27**, 1001 (1983).

Hadron Dissociation #272

MEASUREMENT OF THE RADIATIVE WIDTH OF THE K^{*+} (890). C. Chandlee et al., Phys. Rev. Lett. **51**, 168 (1983).

CALIBRATION AND PERFORMANCE OF A DRIFT CHAMBER SPECTROMETER. C. Chandlee et al., Nucl. Instrum. Methods **215**, 369 (1983).

THREE PION PRODUCTION ON NUCLEI AT 200 GeV. M. Zielinski et al., Z. Phys. **C16**, 197 (1983).

RADIATIVE DECAY WIDTH OF THE ρ^- MESON. T. Jensen et al., Phys. Rev. **D27**, 26 (1983).

Backward Scattering #290

PION-PROTON BACKWARD ELASTIC SCATTERING BETWEEN 30 AND 90 GeV/c. W. F. Baker et al., Phys. Rev. **D27**, 1999 (1983).

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*This list was compiled using 1982 (not in **Fermilab 1982**) and 1983 journal articles, theses, and conference papers. Some conference papers were submitted to a conference prior to 1983 but were not published until 1983. If there are changes, omissions, or comments, please notify the Publications Office.

30-In. Hybrid #299

THE REACTIONS $pp \to pp\pi^+\pi^-$, $K^+p \to K^+p\pi^+\pi^-$, $\pi^+p \to \pi^+p\pi^+\pi^-$ AND $\pi^-p \to \pi^-p\pi^+\pi^-$ AT 147 GeV/c. D. H. Brick et al., Z. Phys. **C19**, 1 (1983).

Emulsion/Protons @ 400 GeV/c #385

MULTIPLICITY DISTRIBUTIONS IN PROTON-NEUTRON INTERACTIONS AT 400 GeV/c. D. K. Bhattacharjee et al., Can. J. Phys. **61**, 523 (1983).

TARGET NUCLEUS EXCITATION DEPENDENCE OF CORRELATION IN THE MULTIPLE PRODUCTION ON NUCLEI AT 400 GeV AND THE ADDITIVE QUARK MODEL. D. Ghosh et al., Can. J. Phys. **61**, 1308 (1983).

15-Ft Antineutrino/H_2 & Ne #388

$\bar{\nu}_\mu$ NUCLEON CHARGED-CURRENT TOTAL CROSS SECTION FOR 5-250 GeV. G. N. Taylor et al., Phys. Rev. Lett. **51**, 739 (1983).

LIMITS ON THE NEUTRINO OSCILLATIONS $\bar{\nu}_\mu \to \bar{\nu}_e$ AND $\bar{\nu}_\mu \to \bar{\nu}_\tau$ USING A NARROW-BAND BEAM. G. N. Taylor et al., Phys. Rev. **D28**, 2705 (1983).

Photoproduction #401

ψ' PHOTOPRODUCTION AT A MEAN ENERGY OF 150 GEV. M. Binkley et al., Phys. Rev. Lett. **50**, 302 (1983).

Inclusive Scattering #451

EXPERIMENTAL STUDY OF THE A DEPENDENCE OF INCLUSIVE HADRON FRAGMENTATION. D. S. Barton et al., Phys. Rev. **D27**, 2580 (1983).

Charged Hyperon #497

PRECISE MEASUREMENT OF THE Σ^+ MAGNETIC MOMENT. C. Ankenbrandt et al., Phys. Rev. Letters **51**, 863 (1983).

Neutrino #531

CHARMED HADRON PRODUCTION BY NEUTRINOS. N. Ushida et al., Phys. Lett. **121B**, 292 (1983).

CROSS SECTIONS FOR CHARM PRODUCTION BY NEUTRINOS. N. Ushida et al., **121B**, 287 (1983).

Di-Muon #537

A FAST PROCESSOR FOR DILEPTON TRIGGERS. H. Areti et al., Nucl. Instrum. Methods **212**, 135 (1983).

15-Ft Neutrino/D_2 & Hiz #545

CHARGED-PARTICLE MULTIPLICITY DISTRIBUTIONS IN νn AND νp CHARGED-CURRENT INTERACTIONS. D. Zieminska et al., Phys. Rev. **D27**, 47 (1983).

QUASIELASTIC CHARMED-BARYON PRODUCTION AND EXCLUSIVE STRANGE-PARTICLE PRODUCTION BY HIGH-ENERGY NEUTRINOS. D. Son et al., Phys. Rev. **D28**, 2129 (1983).

STUDY OF DIQUARK FRAGMENTATION INTO Λ AND Y^{*+} IN νn AND νp INTERACTIONS. C. C. Chang et al., Phys. Rev. **D27**, 2776 (1983).

HIGH-ENERGY QUASIELASTIC $\nu_\mu n \to \mu^- p$ SCATTERING IN DEUTERIUM. T. Kitagaki et al., Phys. Rev. **D28**, 436 (1983).

15-Ft Neutrino/H_2 & Ne #546

OBSERVATION OF MUON INNER BREMSSTRAHLUNG IN DEEP-INELASTIC NEUTRINO SCATTERING. H. C. Ballagh et al., Phys. Rev. Lett. **50**, 1963 (1983).

EVIDENCE FOR HARD GLUON BREMSSTRAHLUNG IN A NEUTRINO EXPERIMENT. M. D. Sokoloff, Ph.D. Thesis, University of California, Berkeley, May 1983.

Hadron Jets #557

PRODUCTION OF HIGH-TRANSVERSE-ENERGY EVENTS IN p-NUCLEUS COLLISIONS AT 400 GeV/c. B. Brown et al., Phys. Rev. Lett. **50**, 11 (1983).

Elastic Scattering #577

ELASTIC SCATTERING OF $\pi^\pm$ AND $K^\pm$ ON PROTONS AT 100 AND 200 GeV/c. R. M. Kalbach et al., Phys. Rev. **D27**, 2752 (1983).

Particle Search #580

DIFFRACTIVE PRODUCTION OF $K_S^0 K_S^0 \pi^-$ IN $\pi^- N$ INTERACTIONS AT 200 GeV/c. T. Y. Chen et al., Phys. Rev. **D28**, 2304 (1983).

Particle Search #595

FORWARD PRODUCTION OF CHARM STATES AND PROMPT SINGLE MUONS IN 350 GeV p-Fe INTERACTIONS. J. L. Ritchie et al., Phys. Lett. **126B**, 499 (1983).

A STUDY OF THE FORWARD PRODUCTION OF CHARM PARTICLE PAIRS IN p-Fe AND π^--Fe INTERACTIONS. A. Bodek et al., Phys. Lett. **113B**, 77 (1982).

Neutrino #602

A MONTE CARLO SIMULATION OF AN ACTUAL SEGMENTED CALORIMETER: A STUDY OF CALORIMETER PERFORMANCE AT HIGH ENERGIES. T. A. Gabriel et al., Nucl. Instrum. Methods **195**, 461 (1982).

High Mass Pairs #605

PROGRESS IN CHERENKOV RING IMAGING. PART 2: IDENTIFICATION OF CHARGED HADRONS AT 200 GeV/c. Ph. Mangeot et al., Nucl. Instrum. Methods **216**, 79 (1983).

Particle Search #610

STRANGE-QUARK SUPPRESSION IN 225-GeV/c π^- Be INTERACTIONS. P. Schoessow et al., Phys. Rev. **D28**, 1773 (1983).

Neutrino #616

MEASUREMENT OF THE RATE OF INCREASE OF NEUTRINO CROSS SECTIONS WITH ENERGY. R. Blair et al., Phys. Rev. Lett. **51**, 343 (1983).

Charged Hyperon Magnetic Moment #620

A STUDY OF THE OMEGA MINUS HYPERON. Kam-Biu Luk, Ph.D. Thesis, The State University of New Jersey, New Brunswick, February 1983.

Direct Photon Production #629

OPERATIONAL PERFORMANCE OF A LARGE LIQUID ARGON PHOTON CALORIMETER. C. Nelson et al., Nucl. Instrum. Methods **216**, 381 (1983).

INCLUSIVE PRODUCTION OF DIRECT PHOTONS IN 200-GeV/c COLLISIONS. M. McLaughlin et al., Phys. Rev. Lett. **51**, 971 (1983).

NUCLEAR ENHANCEMENT OF π^0 AND η MESONS PRODUCED AT LARGE TRANSVERSE MOMENTA. J. Povlis et al., Phys. Rev. Lett. **51**, 967 (1983).

Collider Detector at D0 Area #740

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A CLASS OF SUSY COMPOSITE MODELS BASED ON $SU_H(N)$. B.-R. Zhou and J. L. Lucio M., Phys. Lett. **132B**, 83 (1983).

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BANG-MODEL ANALYSES OF PROTON-ANTIPROTON SCATTERING AND ATOMIC BOUND STATES. M. A. Alberg et al., Phys. Rev. **D27**, 536 (1983).

DEVELOPMENT OF AXION PERTURBATIONS IN AN AXION-DOMINATED UNIVERSE. M. Axenides et al., Phys. Lett. **126B**, 178 (1983).

MORE ABOUT BARYON NUMBER VIOLATION CATALYZED BY GRAND UNIFIED MONOPOLES. F. A. Baizs et al., Nucl. Phys. **B219**, 189 (1983).

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PRIMORDIAL SUPERSYMMETRIC INFLATION. J. Ellis et al., Nucl. Phys. **B221**, 524 (1983).

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GRAND UNIFIED THEORIES AND THE ORIGIN OF THE BARYON ASYMMETRY. E. Kolb and M. S. Turner, Ann. Rev. Nucl. Part. Sci. **33**, (1983).

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MONOPOLE HEAT. M. S. Turner, Nature **302**, 804 (1983).

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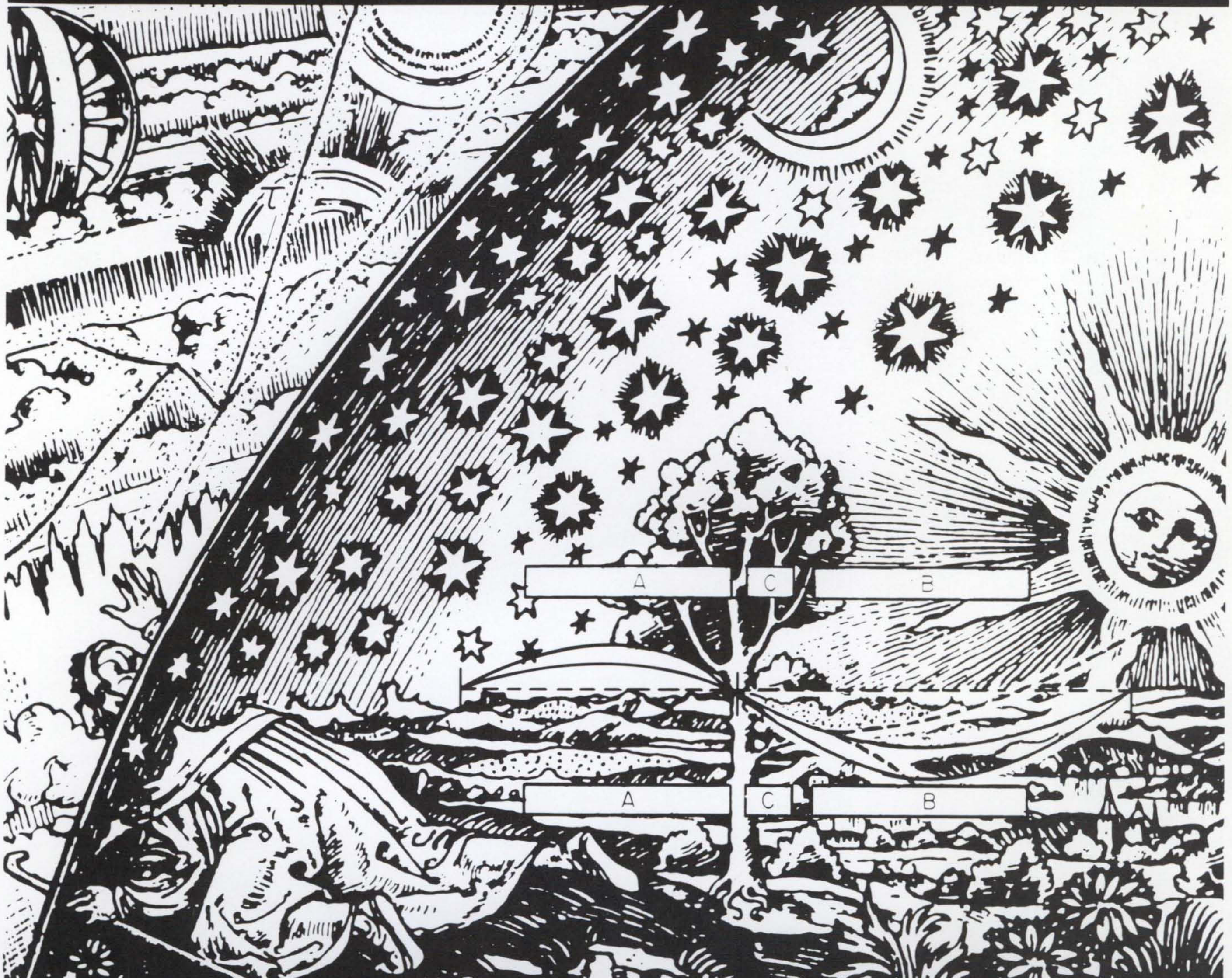
COHERENT SCALAR FIELD OSCILLATIONS IN AN EXPANDING UNIVERSE. M. S. Turner, Phys. Rev. **D28**, 1243 (1983).

THE END MAY BE HASTENED BY MAGNETIC MONOPOLES. M. S. Turner, Nature **306**, 161 (1983).

Colloquium

I. I. Rabi

Professor Emeritus
Columbia University
Nobel Laureate - 1944



Physics at Mid-Century
1933 - 1967

Norman Ramsey Auditorium
Fermi National Accelerator Laboratory
Wednesday, May 25, 1983, 4:00 P. M.

V. 1983 Workshop and Seminar Series

Joint Experimental—Theoretical Physics Seminars

Reiner Wilcke, Cornell University, "Decays the b-Quark"(CLEO Collaboration), January 28, 1983

Peter Igo-Kemenes, Columbia University, "Measurements of Hyperon β-Decays at CERN," February 11, 1983

Milind Purohit, CALTECH, "Structure Functions, R, and QCD Results from the CCFR Experiment," February 18, 1983

Marvin Marshak, University of Minnesota, "Multiple Muon Events at Soudan Mine," February 18, 1983

George Sterman, SUNY-Stony Brook, "The Shape of the KNO Scaling Function in QCD," February 25, 1983

Cathy Newman, Princeton University, "Recent Results on J/ψ Radiative Decays," February 21, 1983

Harry Weerts, Fermilab, "Limits on Neutrino Oscillations from E594," March 4, 1983

Jim Linneman, CERN, "High p_T Trigger EM Calorimeter at ISR," March 10, 1983

K. B. Luk, Rugters University, "Almost Everything You Ever Wanted to Know About the Ω^-," (E620), March 11, 1983

Milind Purohit, Caltech, "Stucture Functions, R and QCD Results from the CCFR Experiment," March 18, 1983

Michael Crisler, Ohio State University, "Resent Results from E613," April 1, 1983

Peter Weilhammer, CERN, "Measurement of Charged Particle Production Hadron Interactions at the CERN SPS," April 22 1983

Scott Whitker, MIT, "Latest Results from a Flash Chamber Proportional Tube ν Detector at Fermilab," April 15, 1983

Art Rich, University of Michigan, "New Tests of the Weak Interactions and QED Using Positrons and Positronium," May 6, 1983

Fred Lopez, University of Illinois (Chicago), "Can a Fixed Target Calorimeter Experiment Observe Hard Scattering Effects?" (E-537), May 13, 1983

John Hagelin, SLAC, "Discovering Supersymmetry with Today's Accelerators," May 13, 1983

Peter McIntyre, Texas A&M University, "A 10 TeV $\times$ 10 TeV to 50 Tev $\times$ 50 TeV Collider for $200 to $500 Million Now!" May 17, 1983

Gikas Mageras, Max Planck Institute, "Transitions of the Υ Systems," May 20, 1983

M. Shaevitz, Columbia University, "Results from the E701 Neutrino Oscillation Experiment," May 27, 1983

Kristos Sliwa, Fermilab, "First Results from the Tagged γ Spectrometer," June 10, 1983

Byron Lundberg, University of Wisconsin, "Inclusive Λ Polarization at Large p_T," June 17, 1983

Mike Arenton, Argonne National Laboratory, "Hadron Jets at Fermilab; Results from E609," June 24, 1983

Norman McCubbin, CERN, "Jet Physics From R807 at the ISR," June 30, 1983

Andre Rousserie, Saclay, "New Results of the UA2 Experiment," June 30, 1983

Helfried Burckhardt, Heidelberg University/CERN, "Observation of a Narrow Resonance at 2.46 GeV - A Candidate for the Charmed-Strange Baryon A^+," June 30, 1983

R. Castaldi, CERN, "The UA4 Collider Experiment on $\bar{p}p$ Elastic and Total Cross Section," July 8, 1983

Walter Wagner, University of Aachen, Germany, "Structure Functions Measurements in Two Photon Physics," July 15, 1983

S. Lokanathan, Jaipur University, India, "The Experimental Status of Anomalons," July 29, 1983

Jean-Paul Repellin, CERN, "Observation of W and Z^0 Decays into Electrons and Neutrinos in the UA2 Experiment," August 1, 1983

G. Preparata, Universita di Bari, "Partons vs. Hadrons: A Physical Theory of Fragmentation," August 10, 1983

T. Curtright, University of Florida, "Weak-Coupling Limit of Liouville Field Theories," August 12, 1983

C. Quiqq, Fermilab, "Auguries and Portents," October 14, 1983

M. Nelson, Lawrence Berkeley Laboratory, "Lifetimes of Heavy Quarks and Leptons--Mark II," October 28, 1983

S. Errede, University of Michigan, "IMB Update," October 28, 1983

W. Smith, Nevis Labs, "Neutrino Production of Dimuons," November 4, 1983

D. Hitlin, CALTECH, "Mark III Results on ψ Radiative Decays and Review of Glueball Candidates," November 11, 1983

F. Pauss, CERN, "Recent Results from UA-1 On $W^{\pm}$ and Z^0," November 9, 1983

D. Noop, CALTECH, "Prompt Electrons from Delco," December 2, 1983

M. Kuchnir, Fermilab, "Chicago-Fermilab Monopole Search," December 9, 1983

L. McLerran, University of Washington, "The Quark-Gluon Plasma," December 16, 1983

R. Zhu, Massachusetts Institute of Technology, "Latest Results of the Mark-J Experiment," December 16, 1983

Theoretical—Astrophysics Seminars

James Hartle, University of Chicago, "Quantum Dynamic of the Early Universe," January 7, 1983

George Fuller, University of Chicago, "Evolution of Supermassive Stars," January 14, 1983

Richard Kron, University of Chicago, "Evolution of Distant Galaxies and Quasars," January 21, 1983

Don York, University of Chicago, "Measuring Big Bang Artifacts: D, ^{3}He, ^{4}He," Janurary 28, 1983

Katherine Freese, University of Chicago, Cosmological Constraints on Neutrino Masses," February 11, 1983

Joan Centrella, University of Illinois, "The Large-Scale Structure of the Universe," February 14, 1983

Robert Kirshner, University of Michigan, "The Texture of the Universe," February 18, 1983

Marc Davis, University of California, Berkeley, "The Structure of the Universe," February 25, 1983

Peter Meyer, Enrico Fermi Institute, "A Space Experiment: Cosmic Ray Composition at Very High Energies," March 4, 1983

Joe Taylor, Princeton University, "Pulsars," April 1, 1983

John Ellis, SLAC/CERN, "Supersymmetry, Cosmology and Inflation," April 8, 1983

David T. Wilkinson, Princeton University, "Anisotropies in the Background Radiation," April 15, 1983

Jon Arons, University of California - Berkeley, "The Fast Pulsar," April 29, 1983

Pat Palmer, University of Chicago, "Interstellar Molecule," May 6, 1983

Eugene Loh, University of Utah, "The Fly's Eye," May 13, 1983

David S. P. Dearborn, University of Arizona, "Astronomy of the Incas," May 20, 1983

G. Steigman, Bartol Res. Found./University of Chicago, "Messengers from the Big Bang," May 17, 1983

Myron L. Good, Stonybrook, "Self-Consistent Solution for a Pulsar Magnetosphere," September 15, 1983

J. Hawley, University of Illinois/Champaign-Urbana, "2-D Black Hole Accretion and Thick Disks--A Numerical Approach," September 29, 1983

Piero Galeotti, University of Torino, "Report on the Mont Blanc Proton-Decay and Neutrino-Astronomy Detector," October 10, 1983

A. Melott, University of Chicago, "The Connection between Elementary Particles and the Formation of Superclusters of Galaxies," October 13, 1983

L. Krauss, Harvard University, "Neutrinos from Heaven to Earth," October 20, 1983

Willy Fischler, University of Texas, "The Entropy Crisis of Supersymmetric Theories," October 27, 1983

Piet Hut, Princeton, "3-Body Scattering Experiments: Binaries as an Energy Source in Stellar Dynamics," November 3, 1983

Demosthenes Kazanas, NASA, "A Model for Active Galactic Nuclei," November 10, 1983

Dennis Hegyi, Michigan, "Problems with Baryonic Galactic Halos," November 17, 1983

Stirling Colgate, Los Alamos National Laboratory, "Gamma Ray Bursts," November 30, 1983

R. Epstein, Los Alamos National Laboratory, "An Extremely Simple Model of Galaxy Formation," December 1, 1983

Robert Brandenberger, ITP-U, University of California, Santa Barbara, "Density Fluctuations in Inflationary Universe Models," December 8, 1983

Joe Silk, University of California, Berkeley, "From Particles to Pancakes: The Large Scale Structure of the Universe," December 15, 1983

Theoretical Physics Seminars

Nina Byers, University of California, Los Angeles, "ϒ Spectroscopy," February 8, 1983

Daniel Caldi, Lawrence Berkeley Laboratory, "Can a Gambler Tell the Difference Between 1 and 2?--A Monte Carlo Analysis of U (1) Gauge Theory," February 15, 1983

L. Hall, Lawrence Berkeley Laboratory, "Two-Sector Models in N=1 Supergravity," February 17, 1983

E. Tomboulis, Princeton University, "Permanent Confinement in Four Dimensions," February 22, 1983

W. van Neerven, NIKHEF, Amsterdam, "How Reliable is the Drell-Yan Mechanism for W Production?" March 1, 1983

R. Gupta, Northeastern University, "Calculation of Hadron Spectrum in Lattice QCD," March 8, 1983

Sinan Kaptanoglu, SUNY - Stony Brook, "A Class of Gauge Theories which Remain Renormalizable in the Infinite Coupling Constant Limit," March 10, 1983

Carl Albright, Northern Illinois University/Fermilab, "Preon models of Composite Quarks and Leptons," March 15, 1983

John Ralston, Argonne National Laboratory, "High Energy Phase Evolution and Interference In Perturbative QCD," March 22, 1983

Y. Zazama, Kyoto Univeristy, Japan, "More About Monopole-Fermion Dynamic: Subtleties of the Boundary Conditions," March 17, 1983

M. Bander, University of California - Irvine, "Quark-Antiquark Bound States," March 24, 2983

J. Polchinski, Harvard University, "Low Energy Supergravity," March 29, 1983

P. Goddard, University of Cambridge, "Monopole Solutions to Gauge Theories," April 5, 1983

K. Sibold, CERN, "On the Off-Shell Infrared Problem of Supersymmetric Gauge Theories," April 12, 1983

J. Kim, Caltech, "General Method for Minimizing Group Invariant Scalar Potentials," April 18, 1983

G. Farrar, Rutgers University, "Exclusive Hadron Scattering," April 19, 1983

W. Celmaster, Northeastern University, "Gauge Theories on a Body Centered Tesseract," April 26, 1983

A. Duncan, University of Pittsburgh, "Stieltjes Spectral Analysis of Hamiltonian Lattice Field Theories," May 3, 1983

J. Schwarz, CALTECH, "Supergravity and Superstrings," May 10, 1983

G. Martinelli, INFN Frascati, "Monte Carlo Simulation of QCD on a $10^3 \times 20$ Lattice: Results for Hadron Spectroscopy," May 16, 1983

J. Rabin, Yale University, "Supersymmetry on a Super-Lattice," May 17, 1983

D. Wallace, Edinburgh University, "Numerical Simulation on the LCL Distributed Array Processor," May 20, 1983

P. Orland, Imperial College, "Actions for Chromoelectric Superconductors," May 24, 1983

K. Ellis, INFN-Rome, "Unravelling Higher Twists," May 31, 1983

D. Wilkinson, Schlumberger-Doll Research, "Percolation Theory and Two-Phase Flow in Porous Media," June 7, 1983

B. Zumino, University of California, Berkeley, "Supersymmetry and Topology," June 14, 1983

N. Seiberg, Institute for Advanced Study, "The Massless Limit of Supersymmetric QCD," June 21, 1983

M. K. Gaillard, University of California, Berkeley, "Scalar Masses in Locally Supersymmetric Theories," June 23, 1983

H. M. Nussenzveig, University of Sao Paulo, "Rainbow and Glory Scattering," June 27, 1983

M. Moshe, FERMILAB/Technion, "Ground State Stability in Large N Field Theory," June 28, 1983

J. Rosner, Enrico Fermi Institute, "Heavy Neutral Leptons," July 5, 1983

T. Barnes, Rutherford Laboratory, "Hermaphrodites--Mixed States of Quarks and Gluons," July 12, 1983

D. Horn, Tel Aviv University, "Variational Calculation of the Vacuum Mean Field and Beyond," July 18, 1983

P. Mackenzie, Fermilab, "Rho Goes to Pi-Pi on the Lattice," July 19, 1983

R. Barbieri, University of Pisa, "Composite Quarks and Leptons," July 21, 1983

R. Barbieri, University of Pisa, "Supersymmetry, Supergravity and Their Phenomenological Implications," July 25, 1983

P. Landshofff, Cambridge University, "P-P and $\bar{P}$-P Elastic Scattering," July 26, 1983

B. Ovrut, Rockefeller University, "The Locally Supersymmetric Geometrical Hierarchy Model," July 28, 1983

Y. Hosotani, University of Pennsylvania, "Dynamical Gauge Symmetry Breaking and Left-Right Assymmetry in Higher Dimensional Theories," August 2, 1983

E. Rabinovici, Hebrew University, "Monte Carlo Studies of the Liouville Model," August 23, 1983

T. Muta, Hiroshima University, "Higher-Order Effects in Electroweak Theory," August 30, 1983

A. Zepeda, CINVESTAV, Mexico, "Flavor Diagonal Neutral Currents From Extended Hypercolor," September 6, 1983

J. H. Kuhn, ITP-Aachen, "Radiative Quarkonium Decays," September 13, 1983

C. Bender, Washington University, "New Quantum Theory on a Lattice," September 20, 1983

A. Khare, Bhubaneswar, "Dynamical Breaking of Supersymmetry in Quantum Mechanics," September 22, 1983

D. Friedan, University of Chicago, "Applications of the Virasoro Algebra in Two-Dimensional Physics (String Theory and Statistical Mechanics)," September 27, 1983

H. Lipkin, Fermilab/Weizmann, "Is the Iota a Giant Quarkonium Resonance?" September 29, 1983

B. Grossman, Rockefeller University, "Magnetic Monopole Regarded as an Impurity in the Dirac Sea," October 4, 1983

I. Bigi, Aachen/Fermilab, "On CP Violation and KM Angles," October 6, 1983

C. Nappi, Princeton University, "Soliton Model of Baryons," October 11, 1983

S. Raby, Los Alamos National Laboratory, "Neutrinos Around Us," October 18, 1983

M. Dine, IAS - Princeton, "Supersymmetry Breaking by Instantons," October 25, 1983

J. Polonyi, University of Illinois, "Microcanonical Simulation of Fermions," November 1, 1983

Marc Sher, University of California, Irvine, "Effective Potentials and the Renormalization Group: From the Standard Model to Inflation," November 15, 1983

Michael Peskin, SLAC, "Ineffective Lagrangians?" November 17, 1983

A. Sen, Fermilab, "Supersymmetric SU(6) as a Solution to the Fine Tuning and the Strong CP Problems," November 22, 1983

H. Haber, University of California, Santa Cruz, "Unusual Gluino Signatures," November 29, 1983

R. Sugar, University of California, Santa Barbara, "Numerical Simulation of Fermion Systems," December 6, 1983

H. Lipkin, Weizmann/Fermilab, "Iota-Glueball or Quarkonium Resonance," December 13, 1983

Advanced Computer Seminar Series

B. Smith, Denelcor, Inc., "Design of the HEP," January 27, 1983

H. Walsh & F. Ris, IBM, "Scientific Computers," February 3, 1983

J. Abraham, University of Illinois, "VSLI Design," March 3, 1983

G. Fox, CALTECH, "Microprocessor Arrays for Physics," February 11, 1983

S. Fernbach, Control Data Corporation, "Supercomputers, Past, Present, and Future," May 12, 1983

D. Lowendorf, Duke University, "Development and Use of an Asynchronous MIMD Computer for Finite Element Analysis," April 21, 1983

P. Cannon, Star Technology, "The Origins of a 100 Megaflop Array Processor--The Star Technology ST-100," April 28, 1983

T. Agerwalla, IBM, "How Fast Can a Single Instruction Counter Machine Execute?" July 6, 1983

S. Boutin, National Semiconductor, Chicago, "NS 16032 and Related Products," October 12, 1983

D. Gajski, University of Illinois, "CEDAR Supercomputer," October 26, 1983

Fermilab Colloquia

Dr. J. Willemsen, Schlumberger-Doll Research, "Geometric Criticality and Paths of Least Resistance," January 5, 1983

Dr. L. Eisenstein, University of Illinois, "Photon-Induced Reactions in Biomolecules: Bacteriorhodopson and Visual Pigments," January 12, 1983

Dr. M. Furth, Memorial Sloan-Kettering Institute, "Oncogenes in Viruses and in Tumors," January 19, 1983

Dr. S. Rice, University of Chicago, "The Structure of the Metal Liquid-Vapor Interface," January 26, 1983

Dr. R. Haselkorn, University of Chicago, "Genetic Engineering for Fun and Profit," February 2, 1983

Dr. A. Mueller, Columbia University, "Perturbative QCD," February 9, 1983

Dr. P. Galison, Harvard University, "How the First Neutral Current Experiments Ended," February 16, 1983

Dr. J. Vick, Exxon, "Development of the Exxon Donor Solvent (EDS) Coal Liquefaction Process," February 23, 1983

Dr. C. Will, Washington University, "General Relativity Confronts Experiment," March 9, 1983

Dr. S. Kirkpatrick, IBM, New York, "Statistical Mechanics and the Travelling Salesman," March 16, 1983

Dr. Yosef Sheffi, MIT, "Modelling Transportation Network Evacuation," March 23, 1983

Dr. P. Steinhardt, Pennsylvania University, "The New Cosmology," March 30, 1983

Dr. M. Lampton, University of California, Berkeley, "The Space Lab One Mission," April 6, 1983

Dr. S. Wolfram, The Institute for Advanced Study, "Cellular Automata and Universality in Self-Organizing Systems," April 13, 1983

Dr. J. D. Cowan, University of Chicago, "Spontaneous Symmetry Breaking in Large Scale Brain Activity--With Applications to Epilepsy and Drug Induced Visual Hallucination Patterns," April 20, 1983

Dr. L. Kirkegaard, Kirkegaard Assoc., "Architectural Acoustics," April 27, 1983

Dr. T. Oka, University of Chicago, "$H3^+$ Ion in Astrophysics," May 4, 1983

Dr. L. Frank, University of Iowa, "Imaging the Faint Lights of Earth," May 11, 1983

Dr. B. Mandelbrot, IBM Thomas J. Watson Research Center, "Now That It Is Agreed That Many Shapes of Physics are Fractal; The Question is Why?" May 18, 1983

Dr. I. I. Rabi, Columbia University, "Physics at Mid-Century 1933-67," May 25, 1983

Dr. M. Dresden, SUNY, Stony Brook, "The Lingering Effects of an Incorrect Theory: The Bohr-Kramers-Slater Considerations," June 1, 1983

Dr. B. McKee, "Nonstandard Automobiles," June 8, 1983

Dr. S. Buchsbaum, Bell Labs, "TBA," June 15, 1983

Dr. D. Held, JPL, "Synthetic Aperture Imaging Radar," June 22, 1983

Dr. M. L. Good, SUNY, Stony Brook, "Why Do Pulsars Pulse?" September 14, 1983

Dr. C. Smorynski, San Jose State University, "New Practical Applications of Gödel's Imcompleteness Theorems," September 21, 1983

Dr. R. York, University of Virginia, "Status Report on the National Electron Accelerator Laboratory (NEAL)," September 28, 1983

Mr. G. Ruffa, Westar Glenwood Earth Station, "A Tower Thrice as Tall as the World," October 5, 1983

Dr. C. Bennett, IBM, "Thermodynamics of Computation," October 12, 1983

Mr. J. Randi, "Science and the Chimera," October 17, 1983

Drs. J. Bartholdi & L. Platzman, Georgia Institute of Technology, "A Minimal Technology Routing System," October 26, 1983

Dr. D. Langenberg, University of Illinois, Chicago Circle, "Science and Government: The Ambivalent Relationship," November 2, 1983

Dr. G. Chanan, Columbia University, "X-Ray Quasars," November 9, 1983

Dr. M. Lacker, Courant Institute Mathematics, "Mathematics of the Menstrual Cycle," November 16, 1983

Dr. S. A. Colgate, Los Alamos National Laboratory, "Gamma Ray Bursts and Nonequilibrium Phenomena," November 30, 1983

Dr. S. Bloch, University of Chicago, "Great Moments in Mathematics: The Proof of the Mordell Conjecture," December 7, 1983

Dr. H. Stormer, Bell Laboratories, "Fractional Quantization of the Hall Effect," December 14, 1983

Research Technique Seminars

P. Olivier, Yale University/CERN; J. Sandweiss, Yale University, "Parked Electrons, Non-Ionizing Track Storage, and Other Aspects of the SSC (Super Streamer Chamber) Development Program," March 10, 1983

H. J. Seebrunner, Max-Planck Institute, "Silicon Strip Detector with High Spatial Resolution," April 12, 1983

S. Majewski, CERN, "The Ring Cherenkov Technique," September 22, 1983

D. Anderson, CERN, "BaF_2 Coupled to a Low Pressure Wire Chamber: More Than a Calorimeter," September 22, 1983

J. Crittenden, Nevis Laboratory, "Data Acquisition System for Experiment 605," October 27, 1983

S. Dhawan, Yale University, "New Developments on Flash ADC's," November 3, 1983

A. Kusumegi, KEK, "Present Status of Heavy Liquid Counter (HELICON)," November 8, 1983

A. Kreymer, Fermilab, "High Speed, High Resolution Particle Imaging Using Scintillating-Glass Fiber-Optic Plates," November 17, 1983

Arms Control and International Security Seminar Series

Ruth Adams, Bulletin of the Atomic Scientists, "The Political Realities of Arms Control," November 10, 1983

Congressman P. Simon, Candidate for U. S. Senate in Illinois, "Arms Control Issues in 1984," December 15, 1983

Workshops

Calorimeter Calibration Workshop
April 29-30, 1983

Other

Fermilab Annual Users Organization Meeting
April 22-23, 1983

Fermilab Industrial Affiliates Annual Meeting
May 19-20, 1983

12th International Conference on High-Energy Accelerators
August 11-16, 1983

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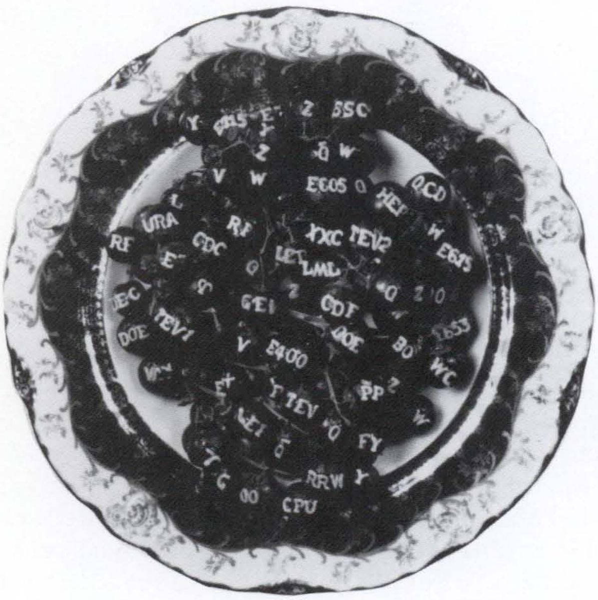


Acknowledgment

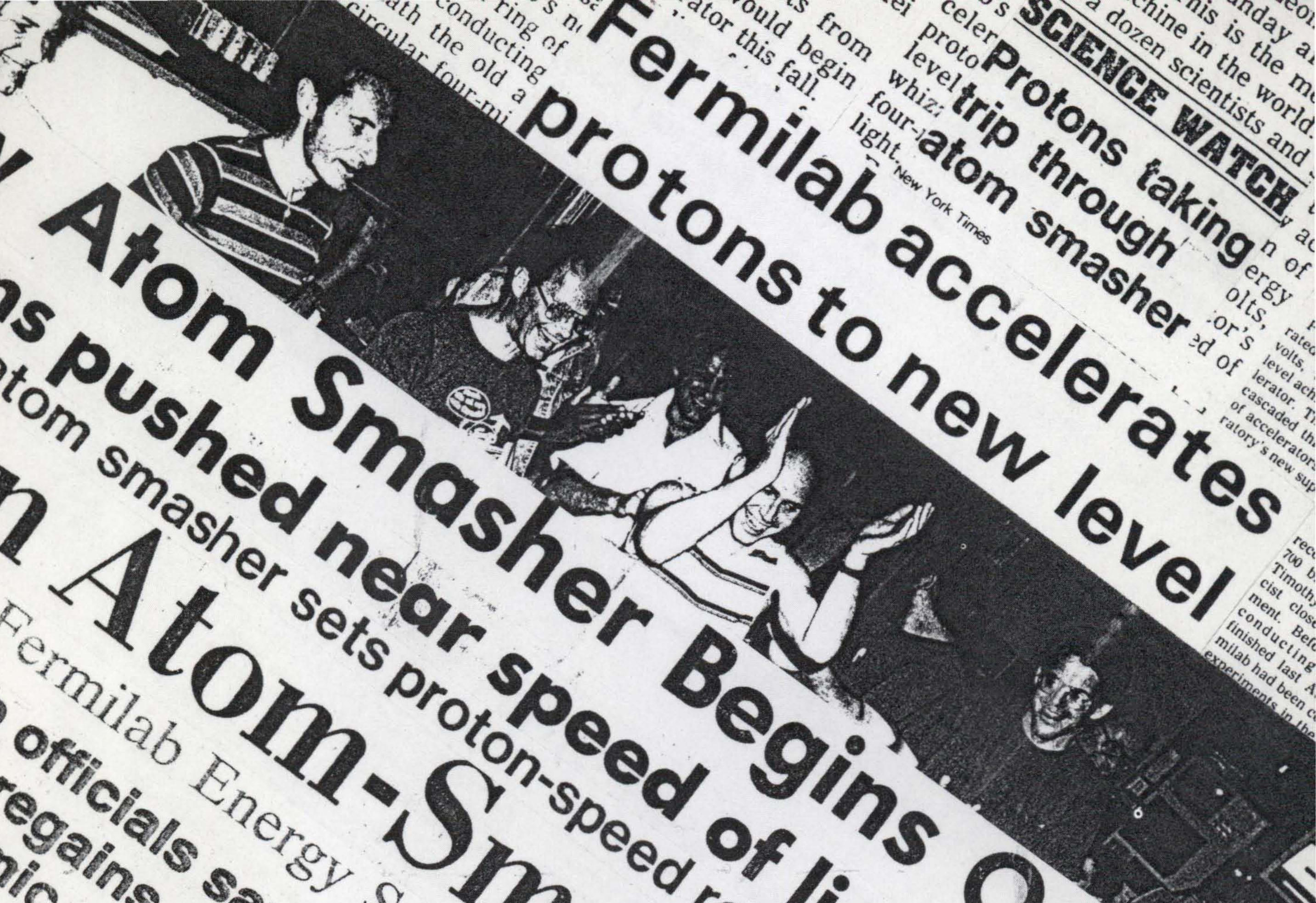
Photographs facing page 1, 35, and vignettes: Olivia Gonzales

Photographs pages 24 and 32: Anthony R. Donaldson

Page 33: Bruegel, "Tower of Babylon"

Page 58: Instructions for glueing the CDF end plug shower counter together.

Photography in this report was done by the Fermilab Photo Unit.



SCIENCE WATCH

Protons taking trip through atom smasher

New York Times

Fermilab accelerates protons to new level

New Atom Smasher Begins Operation

Atoms pushed near speed of light

U.S. atom smasher sets proton-speed record, takes research lead

Engineers had to develop new technology to build that "Thermos bottle," and their efforts are having ...

An Atom-Smashing Giant

Fermilab Energy Saver Hits 500 GeV

BRIGHTON EVENING 9th AUG

Bashing atoms to solve a mystery

Lab officials say U.S. regains edge in atomic studies

BATAVIA, Ill. (AP) — A successful test of the world's most powerful "atom smasher" ... Fermi National Accelerator Laboratory recaptured a lead in high-energy particle research for the United States, officials say.

"... something more to civilization than a toothbrush," Fermilab Director ... said after Sunday ... "This is the most ... the world."

... scientists and spectators ... the lab's control ... operator pushed a ... world record ... electron volts ... four-mi...

Bigger Mini-Bangs for the Buck

A powerful new machine accelerates U.S. high-energy physics

... opening the door to humanity's ... forces of nature.

Once eminent in the field, U.S. physicists recently ... mastery over ...

Scientists Hope To Pry Loose Nature's Secrets

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By RONALD KOTULAK
Chicago Tribune

CHICAGO — At 3:27 p.m. on July 3, the ... buried under old cornfields west of Chi... to life, and physicists throughout Am... Its veins were filled with liqui... temperature stable at 450 deg... zero. Its heartbeat was a ... around its 4-mile circula... light — 186,000 mile... Like any newb... expected ...

'There is something more to civilization than an electric toothbrush. This is the most complicated machine in the world.'
— Leon Lederman Fermilab director