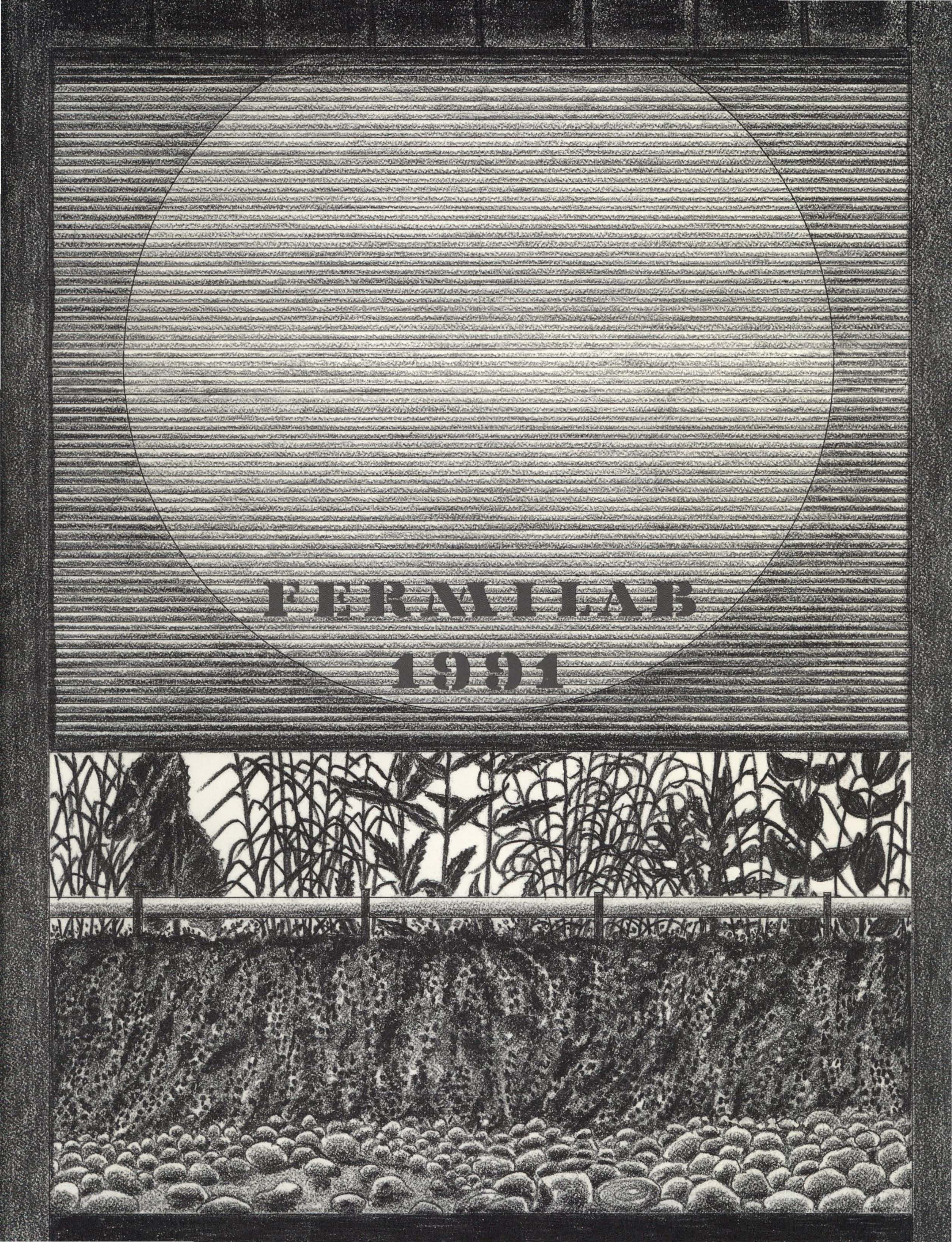

FERMILAB
1991

"There's something awesome about doing experiments in the laboratory at the human scale and then, by the process of creative thought, finding out about the inside of the atom so many, many orders of magnitude beyond human experience. It is equally awesome to find out that the laws which apply to the inside of the atom help to explain the vast reaches of space and time . . . . That man can comprehend the great reaches of inner and outer space and then understand from whence it came moves me to feel reverence and pride in being a human being."

Robert Rathbun Wilson, Founding Director of Fermilab

Fermilab 1991

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

From the Director

Nineteen ninety-one was not the easiest year in Fermilab's history, but as I look back on the challenges we faced, I am proud of the dedication, skill, and determination shown by so many members of the Laboratory community.

No Fermilab employee has ever been involved in a serious accident at the Laboratory except for accidents involving personal automobiles. Nevertheless, when we completed our first comprehensive self-assessment of environment, safety, and health matters in March, we realized that our line management was not putting our policies in these areas into practice uniformly and consistently. In concert with the Department of Energy, Fermilab is actively engaged in charting a new course toward full accountability in the areas of environment, safety, and health.

Accordingly, in July I created the Environment, Safety and Health Policy Advisory Committee (ESHPAC), consisting of senior managers from every division and section. In weekly meetings ESHPAC has made our policies uniform across the Laboratory and ensured that responsibility for seeing that the policies are carried out rests with line management. I am confident that this change will allow us to safeguard our most precious resource — the people of Fermilab — even more effectively. I am also confident that in the traditional Fermilab style, we will demonstrate that we have the energy and commitment required not just to do something, but to do it well.

When we discovered that our radiation shielding did not meet our safety criteria for those unlikely instances in which the beam is inadvertently mis-steered, we chose to correct the deficiency before turning to the scheduled fixed target run. A great many people worked long and hard on this project; with their help, we started up the accelerator by early July.

The run itself was a great success. Physicists from across the country — and from many places around the world — took data that promise a deeper understanding of the properties of charm and strange quarks. In addition, we set a new record for stacking antiprotons: 2.5 x 10^{10} antiprotons per hour were stored during the week between Christmas and New Year's. Because the number of protons per hour that can be accelerated with the Main Ring and then put onto the antiproton target is smaller in the fixed target mode than the collider mode, a simple comparison with the previous record of 2.1 x 10^{10} antiprotons per hour, set during collider operation, robs this achievement of its significance. When the differences are corrected for, this record represents almost a twofold improvement.

Nineteen ninety-one saw much enthusiastic work focused on the future. Each of the three elements of **Fermilab III** is proceeding well: the Accelerator Division staff will have installed the first piece — the beam separation system and the low-beta insertions at BØ and DØ — by the 1992 collider run. The second piece, the Linac upgrade, is nearly ready; the AØ building is full of shiny, newly brazed side-coupled cavities, and the new Linac power supply gallery — empty a year ago — is full of modulators and power supplies. The Main Injector, the very important third piece, received a $15 million appropriation from congress and President Bush and the commitment of the Department of Energy. I expect that in 1997 **Fermilab III** will be ready to fulfill its promise of yielding important physics results.

Much of the technology and expertise now being employed to build the Superconducting Super Collider (SSC) originated or is being developed here. In 1991 we made substantial contributions to the work on 50-mm dipoles, securely rooted in our years of experience with superconducting magnets. In a fine illustration of technology transfer, Fermilab shared this experience and knowledge with General Dynamics. The first of the industrially assembled SSC magnets was tested successfully when 1992 was only a few days old.

The tests and triumphs of 1991 were important ones. We have demonstrated an undiminished enthusiasm for doing science responsibly, creatively, and joyfully that will keep us at the frontiers for many years to come.

John Peoples

Introduction to Fermilab

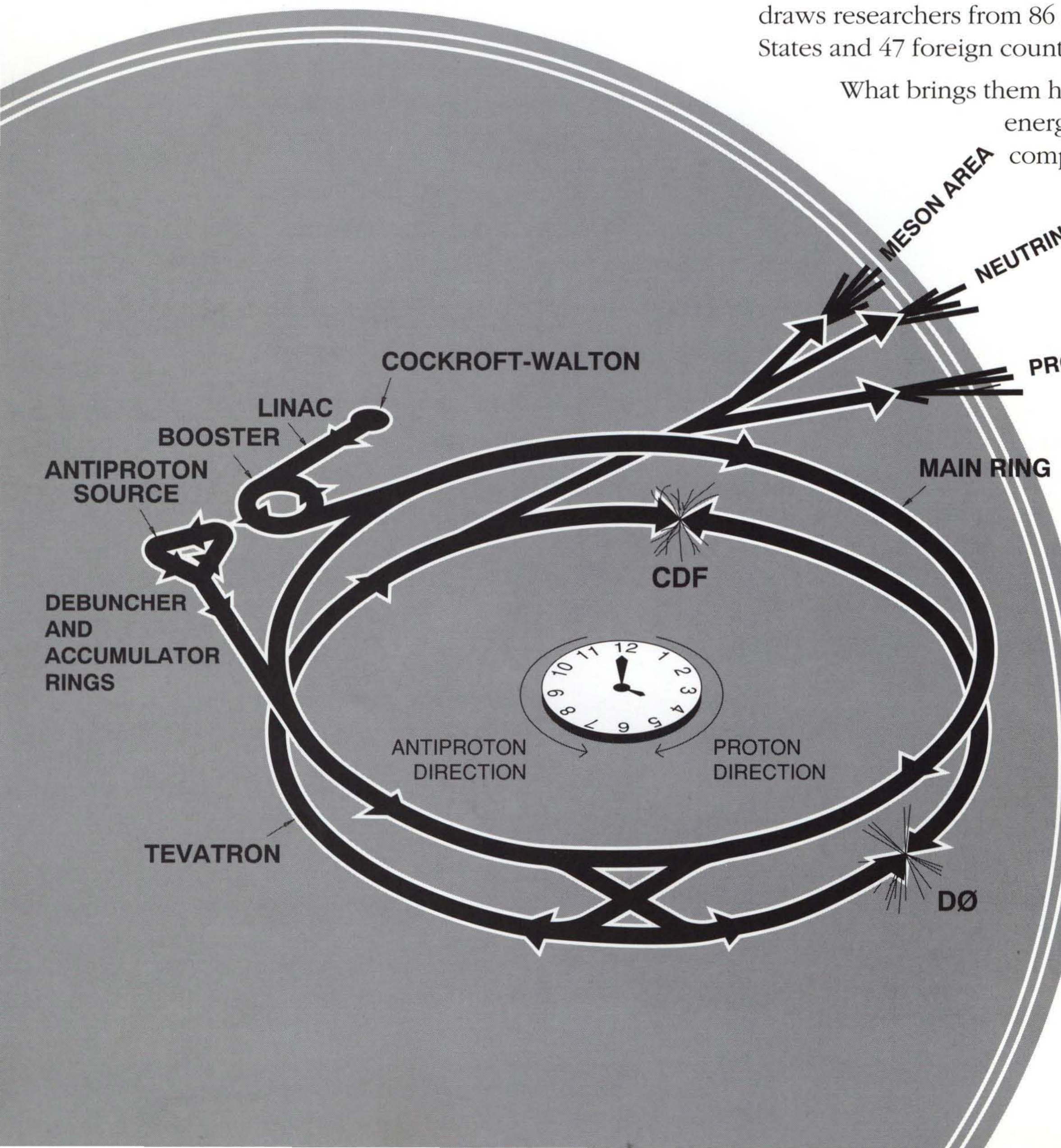
Particles that are tiny compared with the nucleus of an atom hold the key to the laws that govern all physical phenomena. Their behavior shapes the answers to a vast range of questions — from why a book will rest on a tabletop but not on a lake, to how a universe with books and tabletops and lakes and planets and galaxies could emerge from a swirling, almost uniform cloud of subatomic matter.

Fermi National Accelerator Laboratory, known as Fermilab to its friends, is dedicated to the exploration of this realm. Set amid the rippling grasses of the Illinois prairie, about thirty miles west of Chicago, the twenty-four-year-old laboratory is one of the largest centers for high energy physics in the world. Named in honor of Nobel laureate Enrico Fermi, who devoted much of his life to understanding the nucleus of the atom, Fermilab draws researchers from 86 institutions in the United States and 47 foreign countries.

What brings them here? Fermilab has the highest energy accelerator in the world, computing innovations that will be tomorrow's state-of-the-art, and a host of experts in theoretical physics, cosmology, engineering, and a wide range of technologies. In 1991, we employed more than 2300 people, and graduate students from more than 85 American universities conducted research toward their doctoral degrees here.

The Universities Research Association, Inc., a consortium of 79 North American universities, manages Fermilab for the Department of Energy.

Fermilab Accelerator Complex



AROUND THE RING

The centerpiece of Fermilab is the Tevatron, a four-mile-long ring in which bunches of protons — electrically charged particles found in the nuclei of all atoms — are accelerated to the unprecedented energy of nearly a trillion electron volts. The superconducting magnets that bend the protons' path were a milestone in the development of accelerators — and in the evolution of superconductivity from laboratory curiosity to practical tool, useful in magnetic resonance imaging for medical purposes as well as in other accelerators around the world.

The high-energy protons are used to explore matter on the smallest scale now possible. At Fermilab, we can either direct the protons into stationary targets of various materials or bring them into head-on collision with bunches of antiprotons, their antimatter counterparts, which are accelerated in the opposite direction. Sophisticated instruments designed and built by collaborators from many institutions detect and record the outcome of the impact, when the energy of the particles is transformed into new particles. Either kind of experiment provides glimpses of subatomic behavior that are essential for piecing together a comprehensive view of the universe at the most fundamental level.

WHAT WE KNOW

Ordinary matter is composed of atoms, which are in turn made up of electrons orbiting a nucleus of protons and neutrons. Each of these particles can exist without changing for a very long time — which is exactly why they are the constituents of the familiar world. But there are many less stable forms of matter: particles that transform themselves into other particles within a tiny fraction of a second.

Quarks and Leptons in the Standard Model

	ELECTRIC CHARGE (PROTON IS + 1)	*M = MASS IN ENERGY UNITS*		
The Quarks	+2/3	M = 5 MeV **u** **up**	M = 1500 MeV **c** **charm**	M > 91,000 MeV **t** **top** *NOT YET DISCOVERED*
	-1/3	M = 10 MeV **d** **down**	M = 150 MeV **s** **strange**	M > 5000 MeV **b** **bottom** *DISCOVERED at FERMILAB*
The Leptons	0 (neutral)	M = 0 or almost 0 ν_e **electron neutrino**	M = 0 or almost 0 ν_μ **muon neutrino**	M = 0 or almost 0 ν_τ **tau neutrino** *NOT YET OBSERVED DIRECTLY*
	-1	M = 0.511 MeV **e** **electron**	M = 105 MeV μ **muon**	M = 1784 MeV τ **tau**

Experimental results and theoretical insights have led to a surprisingly simple picture of the world of elementary particles and the laws they obey. According to this picture, called the Standard Model, the most fundamental particles are grouped into three categories: the leptons, the quarks, and the gauge bosons. The electrically charged electrons are leptons; so are two unstable particles that are heavier than the electron, and particles known as neutrinos, which are neutral. Two kinds of quarks, called "up" and "down," make up the protons and neutrons, but there are also heavier, less stable quarks. The various forces that govern the behavior of the quarks and leptons are produced by gauge bosons.

WHAT WE KNOW WE DON'T KNOW

So far, the agreement between predictions of the Standard Model and experiment has been spectacular. However, there are areas in which the Standard Model has not been well tested. In addition, there are many compelling questions that the Standard Model alone cannot address, and experimental data are required to determine which — if any — of the competing speculations is the correct picture of nature.

The Forces of Nature

FORCE	RELATIVE STRENGTH	TRANSMITTED BY *(GAUGE BOSON)*	REPRESENTATIVE EFFECTS
Strong	**1**	**Gluons (massless)**	**Bound States of Quarks Stable Atomic Nuclei**
Electromagnetic	**1/100**	**Photons (massless)**	**Light Stable Atoms Chemical Reactions**
Weak	**Varies (actually stronger than electromagnetic at Fermilab energies)**	**Bosons Z^0, W^+, W^- (heavy)**	**Nucleosynthesis Stars Neutrons (unstable)**
Gravitational	**10^{-38}**	**Graviton (massless)**	**Solar Systems Galaxies**

FERMILAB'S FRONTIERS

Because the mass of the new particles that an accelerator can produce depends on the energy available in a collision, Fermilab's position as the highest energy accelerator in the world enables searches for particles that could not be undertaken elsewhere. Fermilab also provides access to the high-intensity frontier, making possible highly precise measurements that are sensitive to new processes and to deviations from predicted values.

1991 at Fermilab

The accelerator is the backbone of the Laboratory. In 1991, the skill and dedication of the Accelerator Division brought the machine smoothly over the hurdles of disturbances caused by new shielding, installation of the Tevatron's new quadrupoles, a fire, and a snake with a fatal sense of curiosity. The average weekly efficiency was 73 percent, one of the best runs in the Lab's history. (See story on p.8)

The run yielded an exciting physics result almost immediately: E760 found a new bound state of charmonium. Large samples of charm quark events were harvested at E687 and E791, opening the way to such previously inaccessible studies as searches for D^0-$\overline{D^0}$ mixing and doubly Cabibbo-suppressed decays. Data from E665, E683, and E706 should help illuminate some areas in the theory of strong interactions that have not yet seen the light of experiment. Some collaborations are also exploring the potential for using the Tevatron to study b physics. (p.10)

Contributions from Fermilab experiments to understanding mechanisms that distinguish matter from antimatter are chronicled in this issue (p.14), including E731's most recent measure of the quantity ε'/ε. This measurement is crucial to determining whether CP-symmetry violation could be the manifestation of a new, barely noticeable force — one of the most compelling questions in particle physics today.

Another well-established family of fixed target experiments at Fermilab was designed to measure the magnetic moments of the hyperons — particles

Silhouetted against an autumn sunset, the prairie grasses inside the Main Ring symbolize Fermilab's long-term commitment to maintaining and enhancing the environment.

Forming large international collaborations, scientists from many nations conduct their research at Fermilab. Flags from around the world, parading in front of Wilson Hall, greet visitors from near and far.

made up of three quarks, at least one of which is strange. This beautiful series of experiments has produced a complete set of extremely precise values that serve as important checks for theoretical models of hadron structure. (p.16)

The essence of science is the interaction between theory and experiment, and at Fermilab we recognize the importance both of gathering information to shape and adjudicate conceptual models and of building theories that shape and inspire the quest for data. The theory that describes the interactions of quarks and gluons, quantum chromodynamics (QCD), demands new computational techniques. QCD calculations can be made more tractable by treating space and time as points separated by empty space on a grid, or lattice. Even this method challenges today's computers, because of the size of the grids and the enormous number of computations required. Fermilab's outstanding computer resources now include an exceptionally powerful parallel computer designed expressly for QCD lattice calculation — the result of a collaboration of the Computing Division and the Theoretical Physics Department. (p.18)

Nothing that we do at Fermilab is more important than ensuring that Laboratory activities cause no harm to people or the environment. We have a long tradition of working toward even more conservative standards than those set by federal and state guidelines. In 1991, people from many parts of the Laboratory, encouraged by the leadership and example of the Department of Energy, joined to carry out a comprehensive and detailed evaluation of our radiation protection and to strengthen our safeguards. (p.28)

What does the future hold? With the world's highest energy particle accelerator, Fermilab is poised to make dramatic contributions to science in the coming years. CDF and DØ are eagerly awaiting the 1992 collider run to track down the tantalizing top quark and to measure precisely the mass and width of the W boson, the better to scrutinize the Standard Model. Hopes are also high that the strange B meson, the B baryon, and the charm B meson will be observed. (p.30)

Further ahead lies the time when the SSC in Texas will be a source of new physics. Fermilab's expertise in both superconducting magnets and the art of doing physics at hadron colliders had been an integral part of preparation for the SSC. This year, the Laboratory's unique superconducting magnet capabilities contributed to the successful tests of the first two SSC magnets with the new 50-mm aperture to be built at Fermilab and to the smooth transfer of assembly techniques to General Dynamics, one of the firms that will bid for the industrial production contract. (p.34) Fermilab is also a leader in the multinational effort to design and build one of the SSC's first detectors, a device that will be a laboratory for exploring some of the most compelling issues in particle physics. (p.36)

Fermilab's education programs represent an even longer-term investment. The first of these, Saturday Morning Physics, is highlighted in this issue. (p.38) This ten-week course for high school students embodies the deep and long-standing commitment of people at the Laboratory to encourage a love of science by conveying the excitement and spirit of adventure that imbues our work.

Of course, people contribute every day to the smooth running of the myriad systems that make up our Laboratory. Even with photographs at the immortal exchange rate of a thousand words each, it is impossible to capture all the smiles, thoughtful gestures, insights, and hard work that make Fermilab an exceptional place. A few are recorded in the Year in Pictures sections — many more in our memories.

The 1991 Fixed Target Run

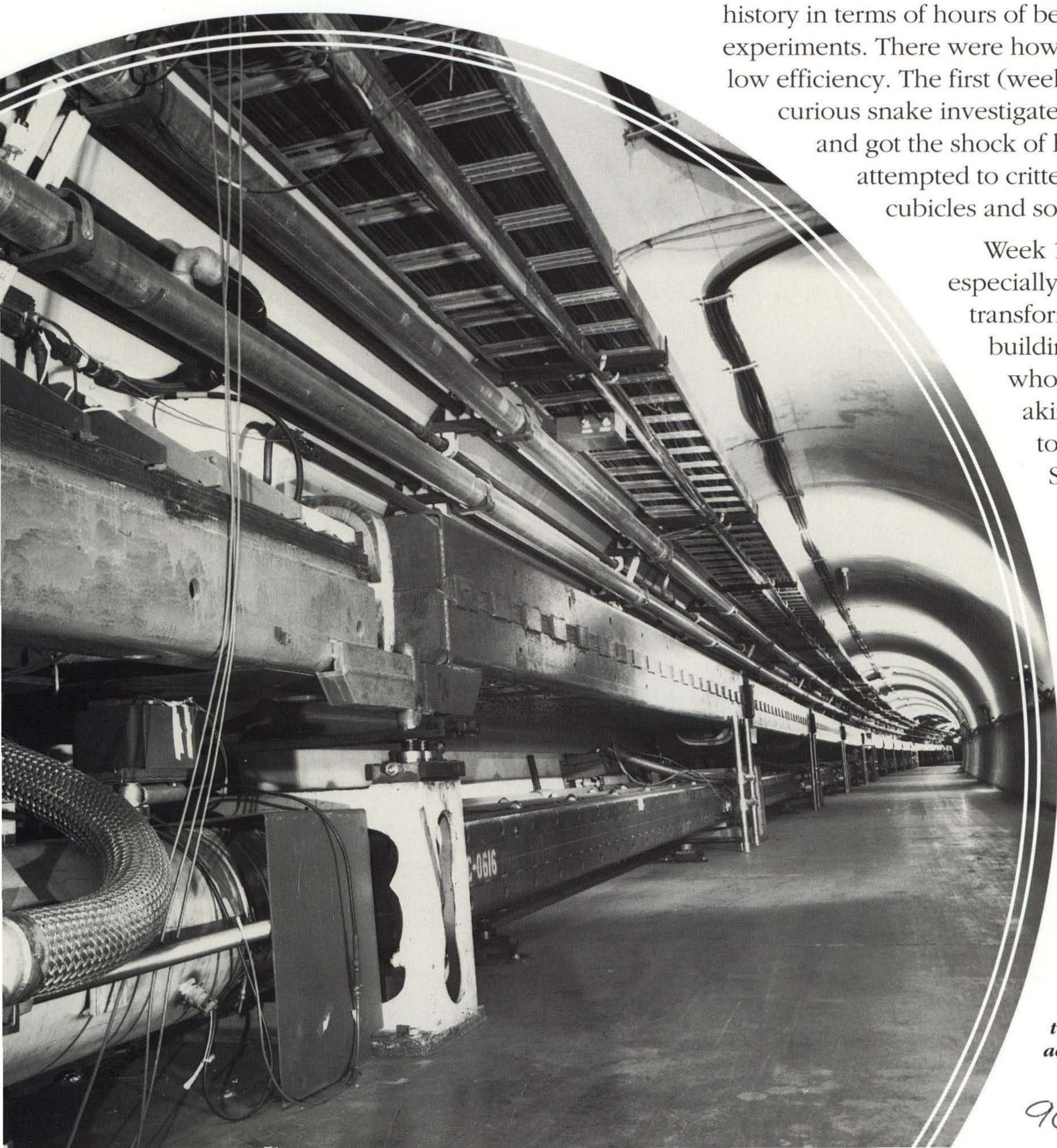
Accelerator Complex Performance

The smooth and steady delivery of over 2×10^{18} protons in the 1991 fixed target run represents another success for the accelerator complex.

At first there were a few perturbations to be weathered. Radiation shielding added to the Main Ring (see story, p. 28) caused the magnets near the BØ overpass to settle as much as 4 mm. New radiation monitors shut down operations when they shouldn't have, because a lack of weatherproofing resulted in equipment failures. New quadrupoles in the Tevatron changed the machine's parameters and for a while made it difficult to extract the beam.

Nevertheless, we were able to start the experimental program on schedule with the requisite intensity, and the average weekly efficiency for this run was the same as for the 1990 fixed target run: 73%. These two runs were the smoothest in the Laboratory history in terms of hours of beam delivered to the experiments. There were however several weeks with low efficiency. The first (week 4) came about when a curious snake investigated a high power cubicle and got the shock of his life. We have attempted to critterproof the rest of our cubicles and so far we have succeeded.

Week 10 does not stand out especially, despite a fire in a transformer near the G2 service building. A heroic effort by the whole laboratory complex, akin to the old time response to a barn burning, kept the Switchyard cryogenic systems in a state of readiness even though there was no conventional electrical power or computer controls. Approximately two days of running were saved by the valiant efforts of many groups,



Buried under an earthen berm, the four-mile circular tunnel houses 1000 conventional, copper-coiled magnets (upper ring) and 1000 superconducting magnets (lower ring) which are the final two stages of Fermilab's accelerator complex.

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In the Main Control Room, Fermilab personnel use an array of computer screens to monitor parameters — such as beam current, position, and vacuum — to insure the smooth and efficient operation of the accelerator around the clock.

90-1400-10

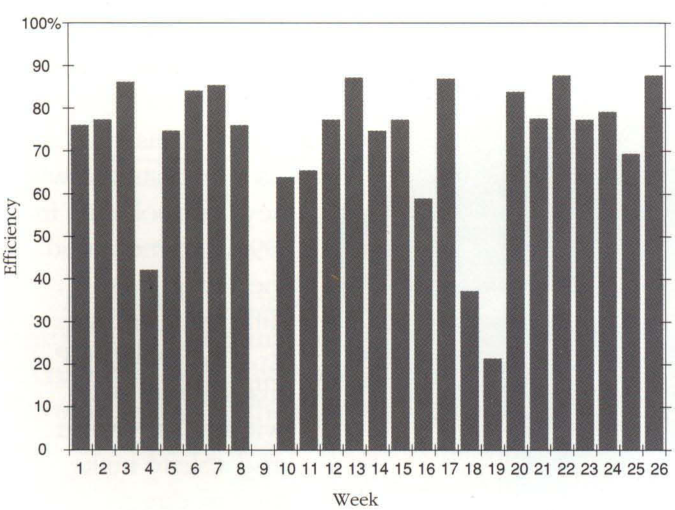
including Facility Engineering Services, the Accelerator Electrical Engineering Support group, the Switchyard group, the Cryogenics group, and especially the Accelerator Operations group. Some of the old time spirit was displayed and it is a pleasure to remember the occasion.

Weeks 18 and 19 show the effects of the one Tevatron dipole failure. A very important contribution to the smoothness of this run was the systematic implementation of improved lead restraints for the Tevatron dipoles prior to the previous run. The efficiency graph shows how multiple failures must have affected previous runs, and the graph of HEP hours, which compares the two most recent runs with the immediately preceding one, highlights the benefit realized by the improvement.

Weekly Operating Efficiency

1991

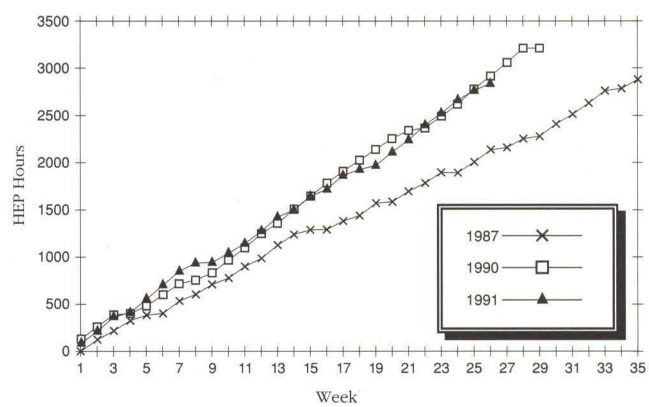
800 GeV Fixed Target Run



Experimenters also desire smooth running on shorter time scales. (This is technically referred to as spill quality.) This run had occasional episodes of intensity-dependent instability in the spill that could not be traced to a simple cause like a ripple in a power supply. The extent of the problem ranged from negligible to bothersome, depending on the details of the experimental apparatus; it was not judged to be serious by the Program Planning office. However, not knowing the cause of the instability was a source of concern for the upcoming collider run and especially

Comparison of
1987, 1990 & 1991
Fixed Target Runs

Integrated HEP Hours



for future fixed target runs with the expected higher intensity from the upcoming upgrades. Finally, near the end of the run Pat Colestock and Gerry Jackson found the culprit in the radio-frequency system.

Having taken the challenges of 1991 in stride, the Accelerator Division looks forward with confidence to the increase in intensity projected for the future fixed target and collider runs.

Glimpses of Physics to Come

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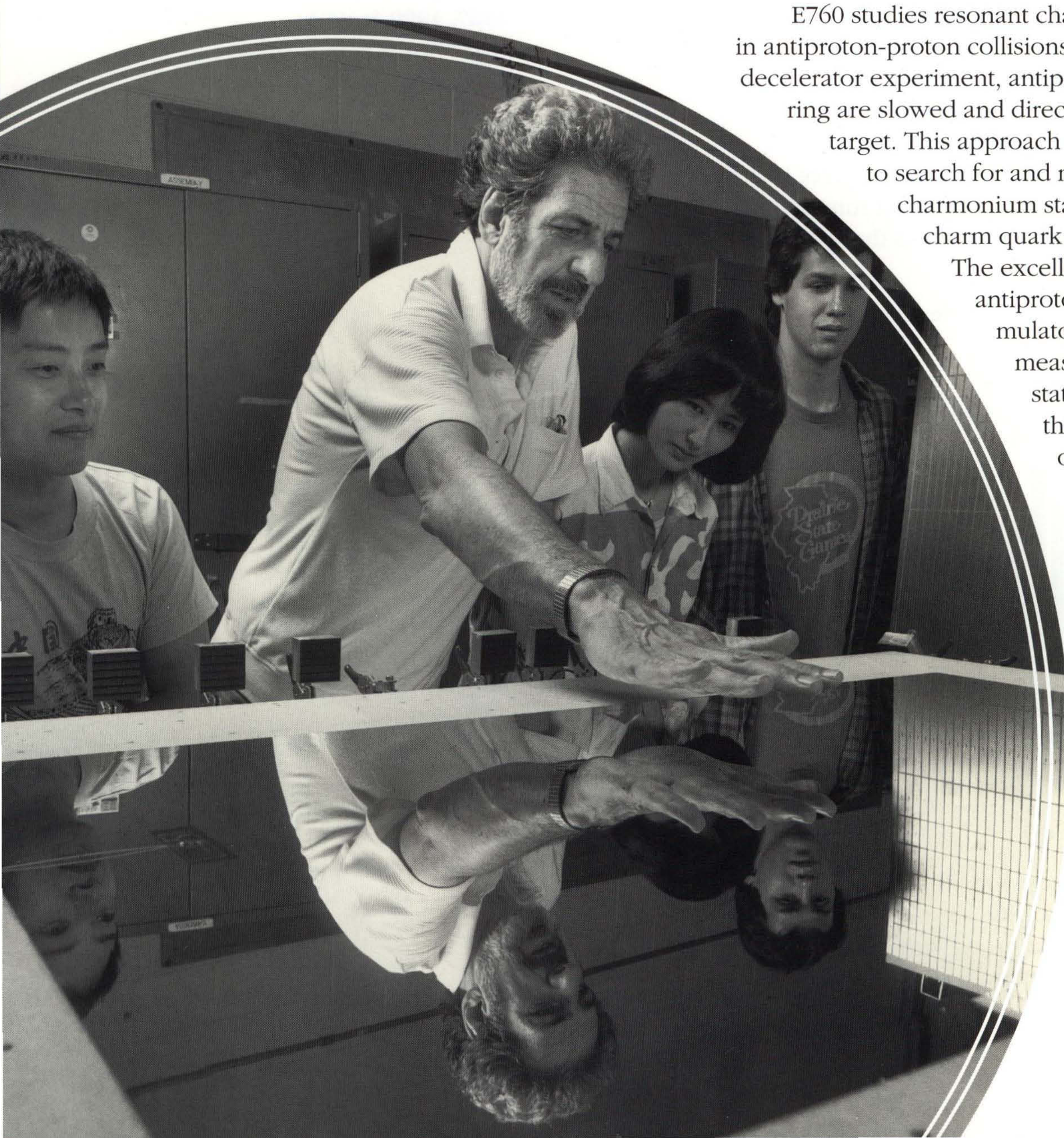
Flanked by students from Northwestern University, Jerome Rosen stretches his hand over the gold foil surface of one of the planes of a proportional wire chambers for E771. From the left, the students are Jack Zhao, Mika Masuzawa, and Daniel Segel.



The 1991 fixed target run brought data to a fruitful and diverse physics program, comprising 13 experiments and many test beam activities. Among the physics topics to be addressed by the fixed target experiments are precision measurements of charmonium states; high-statistics charm physics; bottom production searches; studies of QCD, structure functions, and hadronization; measurement of the Ω^- magnetic moment; CPT tests; and searches for direct CP violation in neutral kaon decays. Although the run did not end until January 8, 1992, some surprises and quick physics results have already emerged.

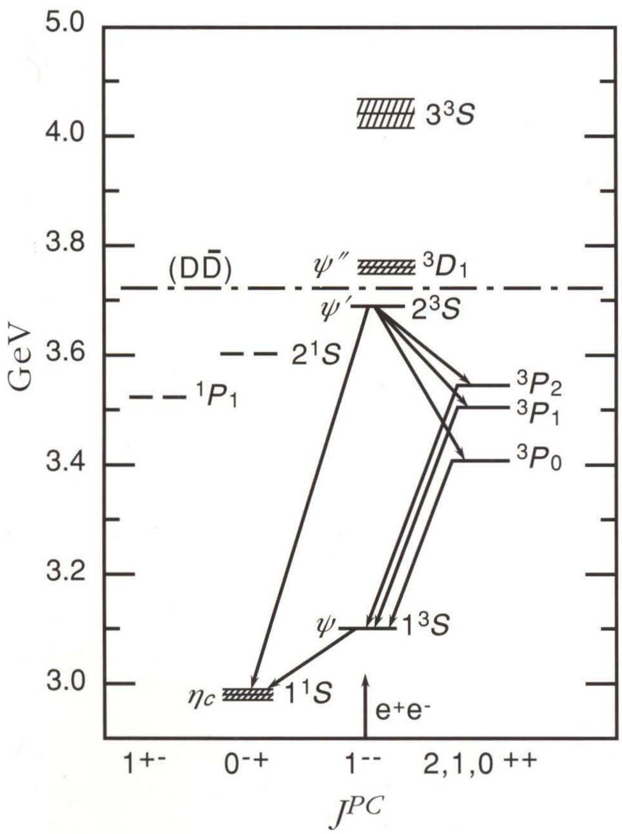
DISCOVERY OF A NEW $^1P_1$ CHARMONIUM STATE FROM E760

E760 studies resonant charmonium production in antiproton-proton collisions. In Fermilab's only decelerator experiment, antiprotons in the accumulator ring are slowed and directed to a hydrogen gas jet target. This approach offers a precision method to search for and measure the spectrum of charmonium states (bound states of a charm quark and a charm antiquark). The excellent definition of the antiproton energy in the accumulator allows a highly accurate measurement of the initial state ($\Delta E_{c.m.} \approx 0.2$ MeV) and thus for a measurement free of any dependence on detector resolution. The success of this approach was demonstrated when they first took data in 1990, and measured the J/ψ-ψ' mass difference and the χ_1 ($^3P_1$) and χ_2 ($^3P_2$) masses and total widths. They were also able to make the first direct measurements of the total width of the J/ψ and the ψ'.

Arthur McManus (left) and Carl Swoboda examine a printed circuit board used in a multi-channel silicon strip detector data acquisition system for E771.

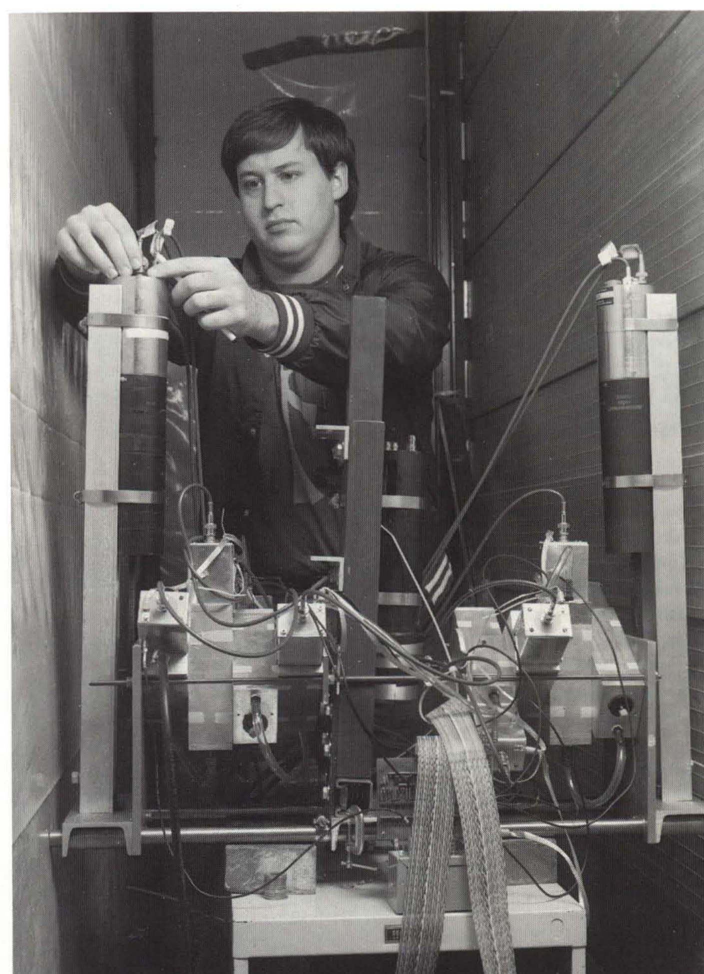
These results all have errors smaller than the previous best measurements made at SLAC and CERN.

The Charmonium Spectrum

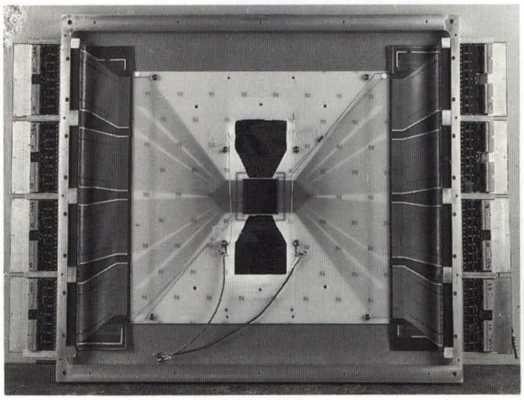


An exciting surprise was the discovery of the $^1P_1$ state ($J^{PC} = 1^{+-}$) at a mass of 3526 MeV, a bound state of charmonium that had never been seen. The $^1P_1$ state was searched for in the mass region between 3520 to 3530 MeV by selecting events containing $J/\psi + \pi^0$ in which $J/\psi \rightarrow e^+e^-$ and $\pi^0 \rightarrow \gamma\gamma$ for a range of antiproton energies. Each run in the scan took about five days to accumulate 1.3 pb^{-1} integrated luminosity. Eight energy points (about 0.5 - 1 MeV apart) were taken before the fixed target run was extended. Two high points hinted at a resonance, but might also have been a statistical fluctuation. An extension of the run revealed the resonance structure of this new state. The measured cross section for the $^1P_1$ state is only about 5 pb, 200 times smaller than the 1 nb cross section of the χ's. During the 1991 run, E760 accumulated 31 pb^{-1}; 20 pb^{-1} were spent on studying the $^1P_1$ state and the rest on $\chi_2 \rightarrow \gamma\gamma$, η_c and a search for the η_c'.

Continued ➤



At the back of E789, William Luebke, a graduate student from Northern Illinois University, checks connections to a trigger counter for the drift tube telescope used to test a proposed optical trigger for the bottom quark.

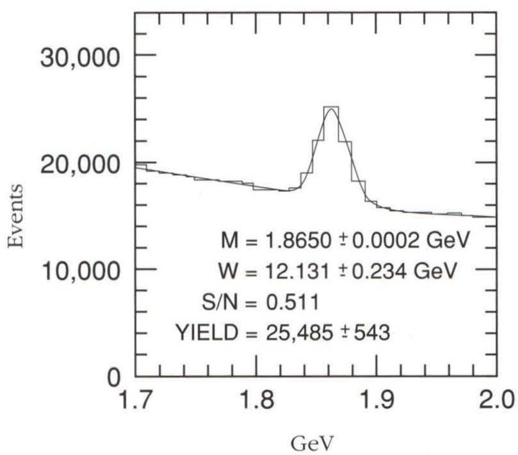


The central square of this silicon microstrip detector contains extremely fine (50 microns) strips of silicon to enable E789 to conduct precise measurements of the B meson decay.

HIGH-STATISTICS CHARM PRODUCTION

The study of heavy quarks has long been an important part of the Fermilab physics program. E687 and E791 take different approaches to the goal of collecting large samples of events containing charm quarks. E791 has used the fastest data acquisition system in the Laboratory to produce 20 billion pion interactions. They hope to reconstruct 200,000 charm decays, 20 times more than the largest existing data set. E687, on the other hand, has chosen to use the world's highest energy photon beam to produce charm quarks at a more modest rate with much less background. From the 500 million interactions collected over the past two fixed target runs, they expect to reconstruct 100,000 charm decays. Because they took data successfully in 1990 and because of their good signal-to-background ratio, E687 has already produced charm signals with

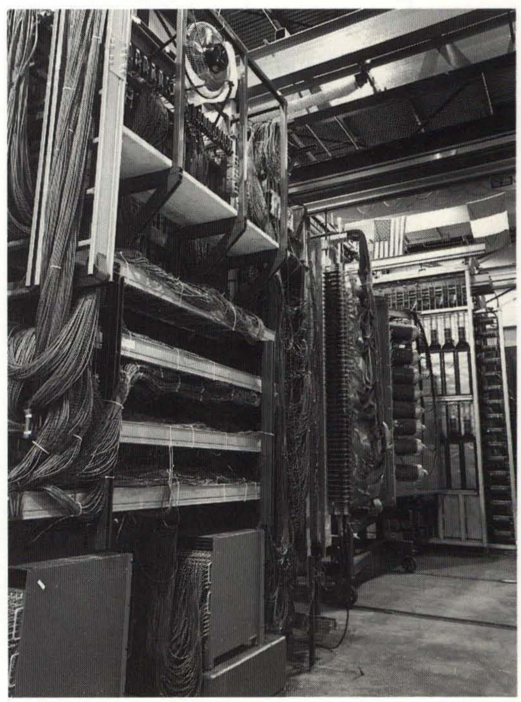
E687 D Meson Signal



higher statistics than any previous experiment. These large data sets open the way to previously inaccessible physics topics such as searches for D^0-$\overline{D^0}$ mixing, doubly Cabibbo-suppressed decays, and other rare charm decays. Both experiments hope to reconstruct events containing bottom quarks.

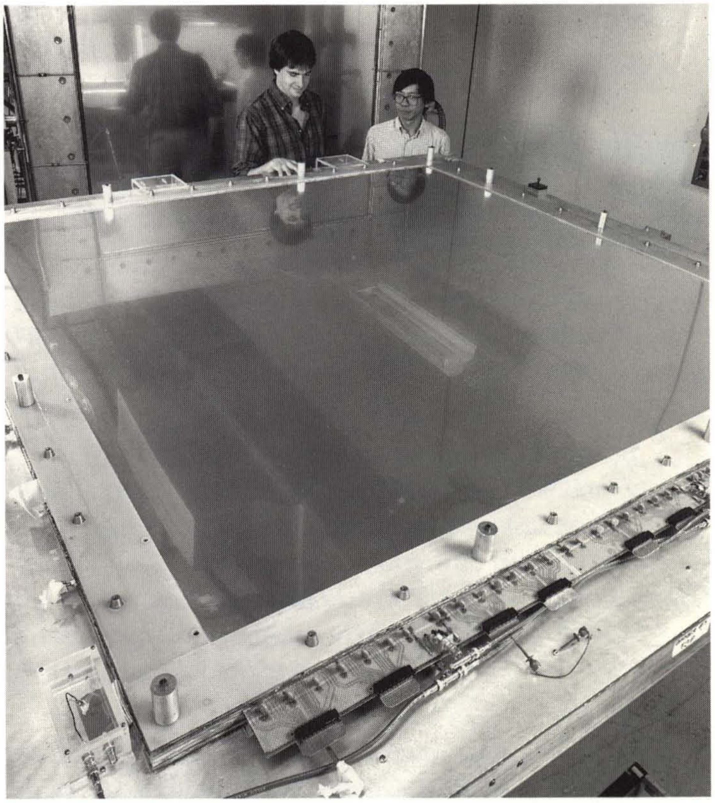
QCD PHYSICS

A number of fixed target experiments concentrated on testing the predictions of QCD. E665 continued to exploit the world's highest energy muon beam to study deep-inelastic scattering processes. E683 used a high-energy photon beam to study high–transverse-momentum jets produced by QCD Compton scattering and quark-gluon fusion processes. E706 used a mixture of pion and proton beams to study direct photon production, which involves the same QCD diagrams as E687 reversed in time. E665 and E706 used the 1991 run to complement their existing data by extending their kinematic ranges and concentrating on light targets. For E683, the 1991 run yielded their first physics data. The data from these three experiments are in many ways complementary and should greatly improve our knowledge of hadronization processes and gluon structure functions. In addition, results will provide tests of second-order QCD calculations over a wide kinematic range.



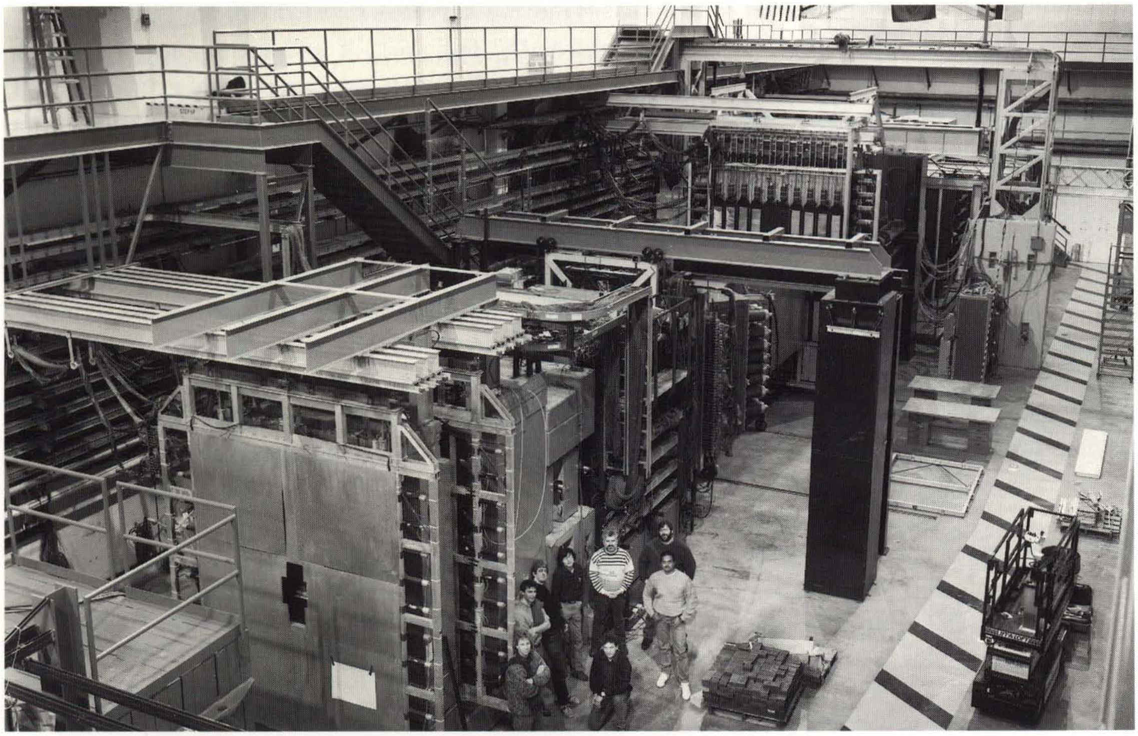
Extensive cabling is required to capture the electronic signals in the hadron calorimeter and inner electromagnetic calorimeter of E687.

Robert Tschirhart (left) and Yau Wai Wah stand beside the 2m x 2m transition radiation detectors used to separate electrons and positrons from pions in E799, an experiment designed to study rare kaon decay.



BOTTOM QUARK PHYSICS

Several fixed target experiments took data during the 1991 run to demonstrate their ability to use silicon microstrip detectors to detect and reconstruct short-lived bottom particles. E789 and E771 looked for bottom decaying via J/ψ with dimuon triggers. Somewhere between ten and a hundred reconstructed B → J/ψ events are expected from this run. E789 ran at a 50-MHz interaction rate to search for the rare non-charm dihadron and dilepton decays of B^0 mesons. These rare decays, if observed, will give important information about the fundamental decay parameters of bottom quarks. If the experiments prove to be successful, the Tevatron may in the future be able to provide the huge number of bottom quarks needed to address some of the most interesting b physics issues.



Experimenters from E687 stand beside their spectrometer, composed of muon chambers, counters, and a muon shield. The experiment is set up in the Wide Band Lab. From the left, Gary Grim, Luca Cinquini, Brian O'Reilly, Kui Young Kim, Selcuk Cihangir, Paul Sheldon, Murali Pisharody. Kneeling, Vittorio Paolone.

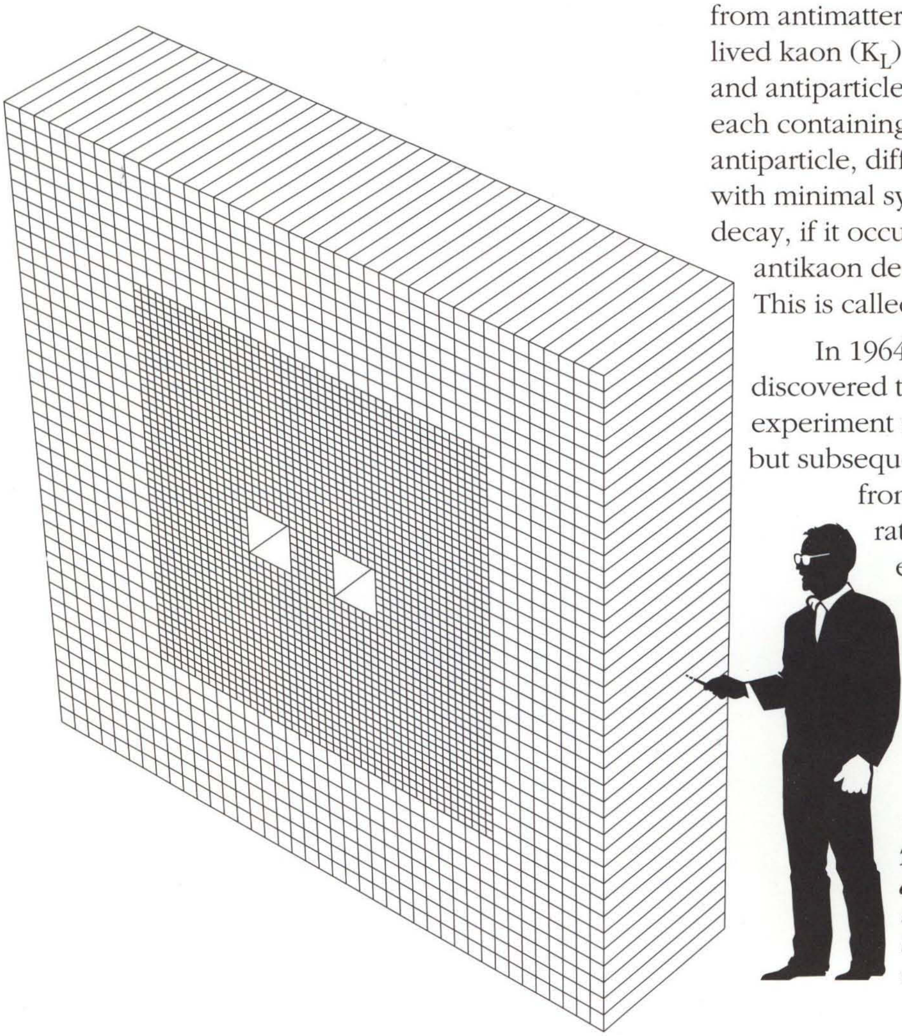
CP Violation

E731

Every particle has a corresponding antiparticle, which has identical mass but opposite values for electric charge and similar quantities. Although particles and antiparticles are produced equally in high-energy particle collisions, there appears to be a dearth of antimatter in every part of the universe we have been able to observe. If our universe began symmetrically, i.e., with baryon number equal to zero at the time of the big bang, then some mechanism operating very early (10^{-35} sec) distinguished matter from antimatter. The crucial distinguishing mechanism involves very heavy particles whose decay rates differ from the corresponding antiparticle decays. The study of CP violation involves an important difference in the behavior of particles and antiparticles.

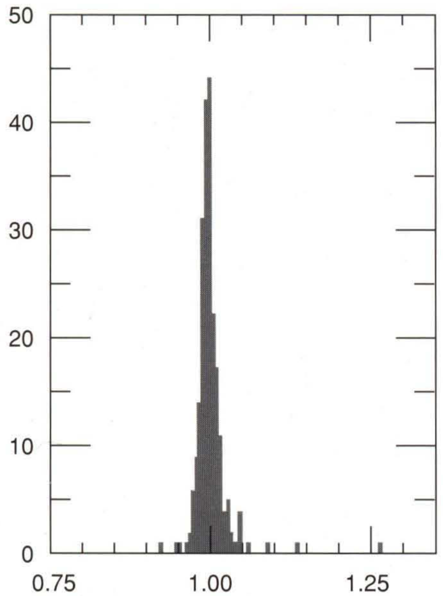
Today we can make antimatter copiously at accelerators. The neutral kaon system is ideal for studying possible mechanisms that distinguish matter from antimatter. Until 1964, physicists thought the long-lived kaon (K_L) was an exactly equal mixture of particle and antiparticle. With a clean beam of these mesons, each containing a (coherent) mixture of particle and antiparticle, differences in decay rates could be studied with minimal systematic uncertainty. The two-pion decay, if it occurred, would show that the kaon and antikaon decayed to two pions with a different rate. This is called "direct" CP violation.

In 1964, Christenson, Cronin, Fitch, and Turlay discovered the two-pion decay of the K_L in an experiment at Brookhaven. This was CP violation, but subsequent studies showed that this was not from a different particle/antiparticle decay rate. Rather, the K_L does not contain an equal mixture of particle and antiparticle. The difference, parameterized by ε, is about 2.3×10^{-3}. This is called "indirect" CP violation because it occurs not in particle decay but in the $K^0 \rightarrow \text{anti}K^0$ transition.



The calorimeter for E832 consists of this array of pure cesium iodide bars. The large bars are 5 cm square and 50 cm long. The smaller bars in the center result in better position resolution.

E/p for CsI Test Array



Exploration of the neutral kaon system has been carried out at Fermilab from the beginning of the Laboratory. Since the early 1980s, the study of CP violation has been a major thrust of our research. E731 completed taking data in early 1988, and the analysis of the complete data set was reported on in summer 1991. This effort had two daughters. The first, E773, completed taking data in late 1991; it focuses on a test of CPT symmetry. The second, E799, is a study of many rare kaon decays.

The main goal of E731 and E832 is determining whether a difference in decay rates over and above the "background" of the indirect process exists. The direct effect is parameterized by ε'. Before E731, we knew that ε'/ε was less than about 0.006. The direct effect is studied by comparing the charged and neutral two-pion decays of the K_L and the K_S through a double ratio of decay rates.

E731 derives its K_S from a regenerator, using two simultaneous beams. Both $2\pi^0$ modes are collected simultaneously, alternating with the taking of both $\pi^+\pi^-$ modes simultaneously. As such, rate effects and detector drifts become negligible. However, one needs to use a Monte Carlo (MC) for the acceptance and this requires excellent understanding of the detector and its properties.

The total correction to the double ratio, after fiducial selection criteria, is 5.5%. The selection criteria are blind to K_S vs K_L, the distinction being made only at the level of background subtraction. In other words, track quality cuts, fiducial cuts, and kinematic reconstruction and selection are done without knowing from which beam the kaon decayed. The lead glass electromagnetic detector has an energy resolution of $1.5\% + 5\%/\sqrt{E}$ and a position resolution of 3.5 mm. The tracking chambers have 100 μm resolution per plane. Statistics for the full data set:

	$\pi^+\pi^-$	$\pi^0\pi^0$
K_L	330,151	223,994
K_S	1,062,319	775,195

The preliminary result for the full E731 data set is $\varepsilon'/\varepsilon = [6.0 \pm 5.8(\text{stat.}) \pm 3.2\ (\text{syst.}) \pm 1.8\ (\text{MC})] \times 10^{-4}$.

This combines to $\varepsilon'/\varepsilon = (6.0 \pm 6.9) \times 10^{-4}$.

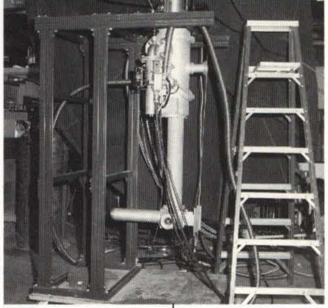
The result is consistent with zero. The error has been reduced by about an order of magnitude. However, the result is not in good agreement with values from recent analyses of the NA31 (CERN) data sets, which average to $(23 \pm 7) \times 10^{-4}$.

The systematic error has various sources and was studied extensively: over 400 fits to the data were performed with varied background subtraction techniques, calibration constants, and distortions in the acceptance calculation. The largest contribution arises from uncertainties in the calibration of the electromagnetic detector.

Although E731 was designed expressly to measure ε'/ε, it has paid a number of interesting dividends. In the 2π modes, the K_S lifetime, the K_L-K_S mass difference, and the phase difference between $2\pi^0$ and $\pi^+\pi^-$ decays have been measured with increased precision. Other processes studied include $K_{L,S}$ to $\pi^0 e^+ e^-$, $\pi^0\gamma\gamma$, $\pi\pi\gamma$, $\pi^0\nu\nu$, $3\pi^0$ (Dalitz plot structure).

At present, the expectations from the Standard Model have large uncertainties. They favor a value in the range of several times 10^{-4}. For the future, major new resources will be brought to bear on CP violation in the neutral kaon system. The effort is called KTEV and should run in the next fixed target run. There are two experiments: a second phase of E799 and a new experiment, E832, which focuses on the two-pion decays. E832's goal is a sensitivity of 1×10^{-4}. The major new piece of equipment is a cesium iodide calorimeter. It offers better resolution and greater radiation resistance than lead glass. The electron response of a small test array is shown above. E799 and E832 should run in 1994; there is every indication that the physics payoff will be rich.

Hyperon Magnetic Moment Story



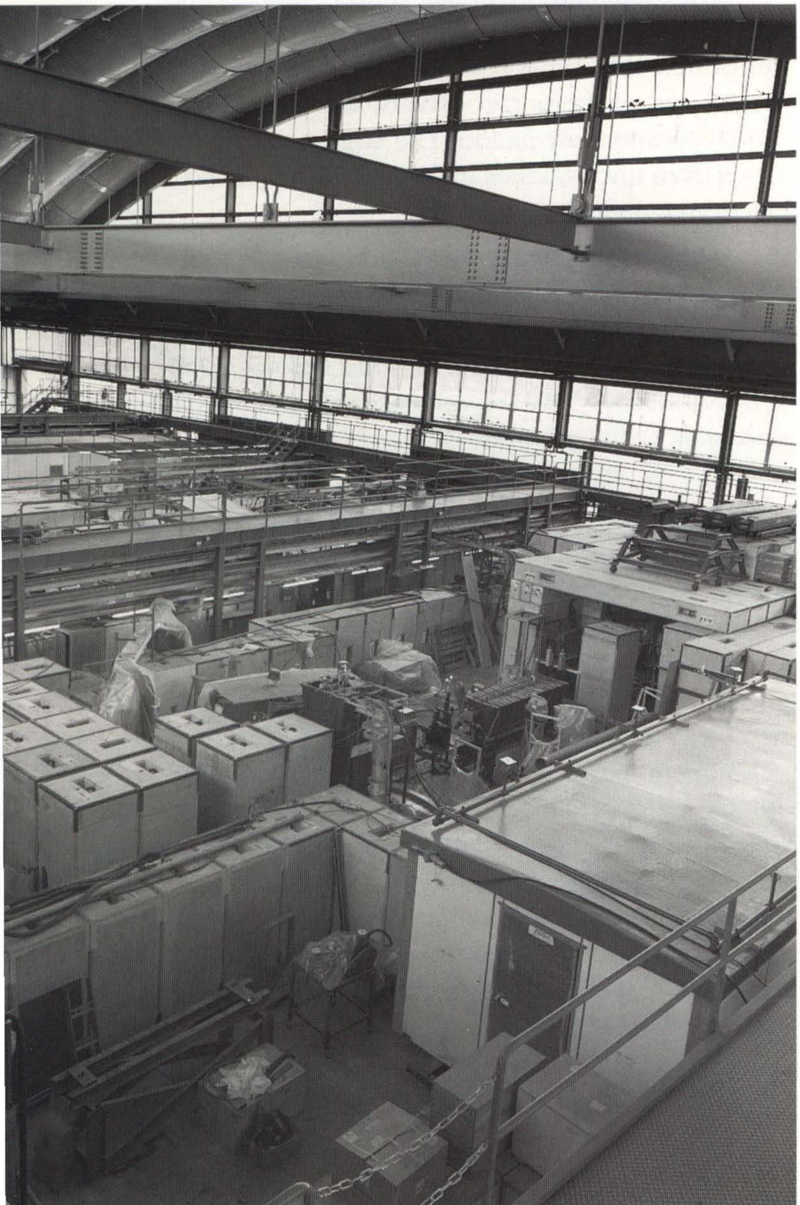
E8	E361	E440	E441
3/22/76	10/29/79	3/22/77	7/2/77
Experiments in a Neutral Hyperon Beam	Precision Measurement of Lambda Beta Decay Parameters	Measurement of the Magnetic Moment of the Lambda Hyperon	Lambda Polarization
B. Edelman P. Skubic P. Martin	J. Dworkin	L. Schachinger	R. Grobel

E8 to E800

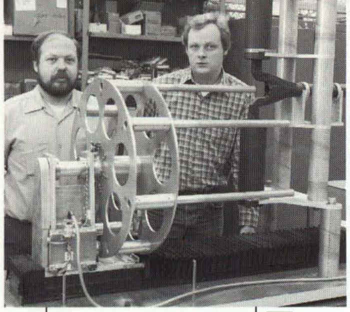
A crucial test for any theoretical model is its ability to arrive at values for experimental parameters that are well known. Feynman said, "If it disagrees with experiment it is wrong. That is all there is to it." Over the past 15 years, a series of experiments at Fermilab has yielded a set of measurements of hyperon magnetic moments. Values that were known only to within 30 or 40 percent are now known to three significant figures. Like other static properties of a particle such as mass or lifetime, the precision measurements of magnetic moments and decays have made it possible to test and compare theoretical models that strive to explain baryon structure from fundamental principles of QCD.

High energy physics has always been a field where discussions of the sociology of doing experiments is often as exciting or thought provoking as a discussion of the experiments themselves. Today, we find ourselves involved in experiments where the collaborations range in size from 50 to 250 persons, and look ahead to an era of even larger enterprises demanded by the complexity of the experiments. For most high energy physicists small groups are a fond memory of "the good old days." The E8 to E800 experimental program is a notable exception to the growth of groups which we have come to expect. While most of the participants in the program have changed through the years the number has remained steady at about 10 ± 4.

The basic experimental set-up has endured for nearly 16 years and been used in 11 experiments. Twenty-four graduate students, including two who went on to become spokespersons for later experiments in the series, obtained their Ph.D. thesis data here. Their names are listed in the time line above.



The Meson Laboratory was home to the experiments in this family through E555. Subsequent experiments were housed in Proton Center.



E495	E555	E619	E620	E621	E756	E800
8/28/78	2/17/82	6/14/82	1/22/80	8/29/85	2/15/88	1/8/92
Cascade Zero Polarization & Magnetic Moment	Cross Sections & Polarization at High Transverse Momentum	Measurement of the Sigma-Zero to Lambda Transition Magnetic Moment	Measurement of the Magnetic Moment of Charged Hyperons	Kaons CP Violation	First Measurement of the Magnetic Moment of the Omega-Minus Hyperon	Precision Measurement of the Magnetic Moment of the Omega-Minus Hyperon
P.T. Cox	B. Lundberg	C. James P. Cushman	R. Rameika C. Wilkinson L. Deck K.B. Luk	P. Border K. Thorne N. Grossman	T. Diehl J. Duryea P.M. Ho A. Ngyuen	G. Guglielmo D. Woods N. Wallace

In 1976, E8, a study of production of neutral strange particles by protons at 300 GeV, revealed that Λ's produced at non-zero production angles were polarized. This unanticipated phenomenon has yet to be accounted for by theory. This first observation of inclusive polarization was made by the Neutral Hyperon Collaboration using the Meson Lab M2 beamline.

With this discovery, it was recognized that the magnetic field used to define the neutral beam, by sweeping away charged particles, also precessed the polarization vector. The precession angle is directly proportional to the intrinsic magnetic moment of the hyperon, μ, and field integral through which the particle passes. At the high energy available at Fermilab, hyperons were copiously produced and had mean flight paths on the order of meters. This implied that large precession angles could be achieved by the use of field length rather than field strength, as had been required for measurements at low energy.

This fact was exploited to make the first precision measurement of the magnetic moment of the Λ. The following year, E440 collected more than three million Λ's and made the definitive measurement of the μ. At the same time the group asked the natural question, "Are other hyperons polarized as well?" By selecting Λ events that did not "target-point," the E440 analysis yielded a sample of 42,000 Ξ^0 events. The non-zero polarization of the Ξ^0's was used to make the first measurement of μ_{Ξ^0}. One year later, E495 collected more than 200,000 fully reconstructed $\Xi^0 \rightarrow \Lambda\, \pi^0$ events and improved the precision in μ_{Ξ^0} by a factor of five.

During 1979-1991, a series of rich and successful experiments in hyperon physics emerged. Following the success of E495, the group tried its hand at charged hyperons, mounting and executing E620, which collected 130,000 Σ^+, 500,000 Σ^-, 200,000 Ξ^-, and 2000 Ω^-. Each data set contributed to the emerging view that polarization was a general feature of hyperon production. Before the end of the 400-GeV era, two Fermilab groups cornered the market on measurements of hyperon polarization and magnetic moments. E555, the last experiment of the E8 group done in the Meson Lab, collected more than 40 million Λ's and made the first high-statistics measurements of the kinematic dependence of polarization. In the Proton Center beam the "other hyperon group" carried out E497, making precision measurements of μ_{Ξ^-}, μ_{Σ^+} and μ_{Σ^-}. A move of the "E8" group to Proton Center, in spring 1982, created competition for beam time, and ensured a high density of physics output for a single experimental area!

In 1985, the increase in energy to 800 GeV, along with the increased duty factor of the Tevatron, moved the hyperon physics program from the excitement of discovery to the beauty and elegance of precision. E756 proposed to measure the polarization of the Ω^- and, if it were non-zero, the first measurement of μ_Ω would follow. The proposal turned out to be non-trivial, since unlike all other hyperons, Ω's were not produced polarized. In the course of learning this, more than four million polarized Ξ^- were produced, as well as 70,000 polarized anti-Ξ^-'s (a real surprise!).

In 1991, E800 collected nearly 400,000 Ω^- events. Using a modification of the neutral beam production mechanism, it was found that an unpolarized neutral beam, incident at a small production angle, could also produce polarized Ω's, and at a rate nearly eight times higher than the spin-transfer method. Nearly 250,000 were collected in this way and should make possible a measurement of the Ω^- magnetic moment to a precision of two percent.

Lattice Gauge Calculations and ACPMAPS

For theories to be fruitful, the precision of theoretical calculations must keep pace with experimental measurements. A new computer, developed at Fermilab to carry out calculations using the grid technique, is breaking new ground in the quest to understand one of the fundamental forces.

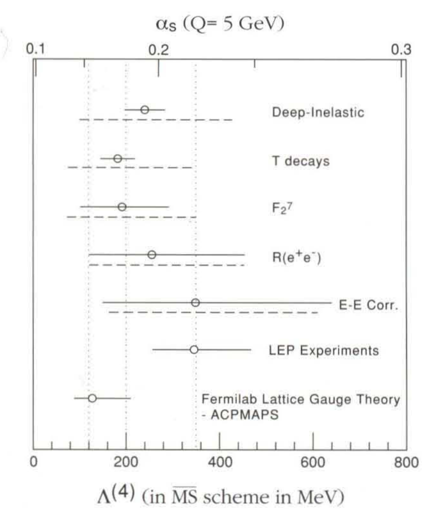
QCD is the theory of the strong force, which confines quarks and gluons inside the protons, neutrons, pions, and the other hadrons. Understanding the forces inside hadrons and the residual interactions of hadrons in the QCD theory requires numerical calculations using Monte Carlo sampling methods within the framework known as lattice gauge theory. Lattice gauge theory is the only existing technique that allows the systematic study of all aspects of QCD. In the lattice approach, physical space and time are approximated by a discrete spacetime grid of finite total volume and nonzero spacing between adjacent sites. The basic properties of QCD are preserved in the lattice gauge formulation. Physical results are recovered as the spacing between adjacent points approaches zero and the volume increases without bound.

Realistic lattice calculations require very large grids and huge numbers of computations at each grid site. The sheer magnitude of the computations and the memory required push the limits of supercomputing technology. Fermilab has developed a grid-oriented parallel computer designed to accommodate the requirements for lattice gauge calculations. This machine, the Advanced Computing Program Multi-Array Processor System (ACPMAPS), is a multiple instruction/multiple data system presently based on 256 processors. It was designed and built jointly by the Computer Research and Development Department of the Computing Division and the Theoretical Physics Department.

David Oyler (left) and Mark Mengel monitor the current status of the IBM farm. Installed in the Feynman Computing Center, the new facility enhances the Laboratory's capabilities to analyze vast amounts of data.

The developers of ACPMAPS flank their computer. Back row, from left to right, Luann O'Boyle, Thinh Pham, Mark Fischler, Donald Husby, Joseph Biel, Gregory Deuerling, Bill Haynes, Ted Zmuda, Karmegan Thayalan, Kristine Davies (visitor) and Thomas Nash. Front row, from left to right, Michael Isely, Sylvia Trevino, Aida El-Khadra, Mingshen Gao, Paul Mackenzie, Estia Eichten, George Hockney and Andreas Kronfeld.

Lattice field theory calculation of α_s using charmonium states



ACPMAPS has three major hardware subsystems:

- The 256 processors using the Weitek XL chip set and having 8 Mbytes of memory on each module.
- A communication backbone with 20 Mbyte/sec/channel bandwidth. The system consists of four planes of nine crates. A typical crate contains eight processors and seven communications modules. All the modules in a single crate can communicate among themselves through a crossbar switch backplane giving an aggregate bandwidth of 160 Mbytes/sec. Any processor can communicate to any other in the system.
- A distributed I/O system capable of storing and retrieving large data sets rapidly. Presently there is a 20 Gbyte disk system and 32 helical scan 2.3 Gbyte 8-mm tape drives.

The software system has two subsystems:

- A software framework that allows users to program this parallel processing system in C, without any consideration of the special nature of the ACPMAPS system. Programming is no more difficult than writing a C program for a workstation.
- A set of software tools for hosting users' jobs on ACPMAPS. In the summer of 1991 this system began running physics at 5 Gflops (peak).

Within the Standard Model, lattice studies can be expected to provide insight into both QCD dynamics and the masses and static properties of hadrons. In addition, to extract the electroweak parameters for quarks from the observations of the mixing and decays of hadrons, the nonperturbative effects of QCD cannot be ignored. There are significant theoretical components to the present errors. Improving these measurements will require large experimental and theoretical efforts. Lattice QCD will be a critical ingredient in the theoretical effort to understand heavy flavor physics.

Initial theoretical studies using the ACPMAPS system look extremely promising. One lattice study allows the calculation of the QCD coupling α_s and the QCD scale parameter $\Lambda_{\overline{MS}}$ from the precisely measured masses of the S and P wave charmonium states. The lattice results, including the estimation of all systematic errors, may be compared with existing estimates of α_s and their associated errors. The power of the lattice approach is evident. Other studies into the spectrum, static properties, and semileptonic decays of charm and bottom mesons are being carried out.

This year, the collaboration of the Theoretical Physics Department and the Computer Research and Development Division led to a new processor module for ACPMAPS that will support all existing user code without modification. This new module, containing two Intel 860 CPUs each running at 80 Mflops (peak) and having 32 Mbytes of DRAM memory, will increase both the peak speed and the total memory of the ACPMAPS system by a factor of ten. With a (peak) speed of 50 Gflops and a total memory of 20 Gbytes, the upgraded system will be one of the most powerful computing machines in the world.

The Year in Pictures - Part I

A mechanical pencil illustrates the tiny scale of the scintillating fibers which are less than a millimeter in diameter.

91-241

Appearing as a shimmering forest of light, more than 2000 of these shining cylinders compose one of the scintillating fiber calorimeters painstakingly built by the Physics Section for the Solenoid Detector Collaboration. The fibers are sandwiched in grooved layers of lead in an array approximately 20 cm square. Packaged in specially designed aluminum boxes, upon completion the calorimeters are shipped to Beijing for radiation damage testing.

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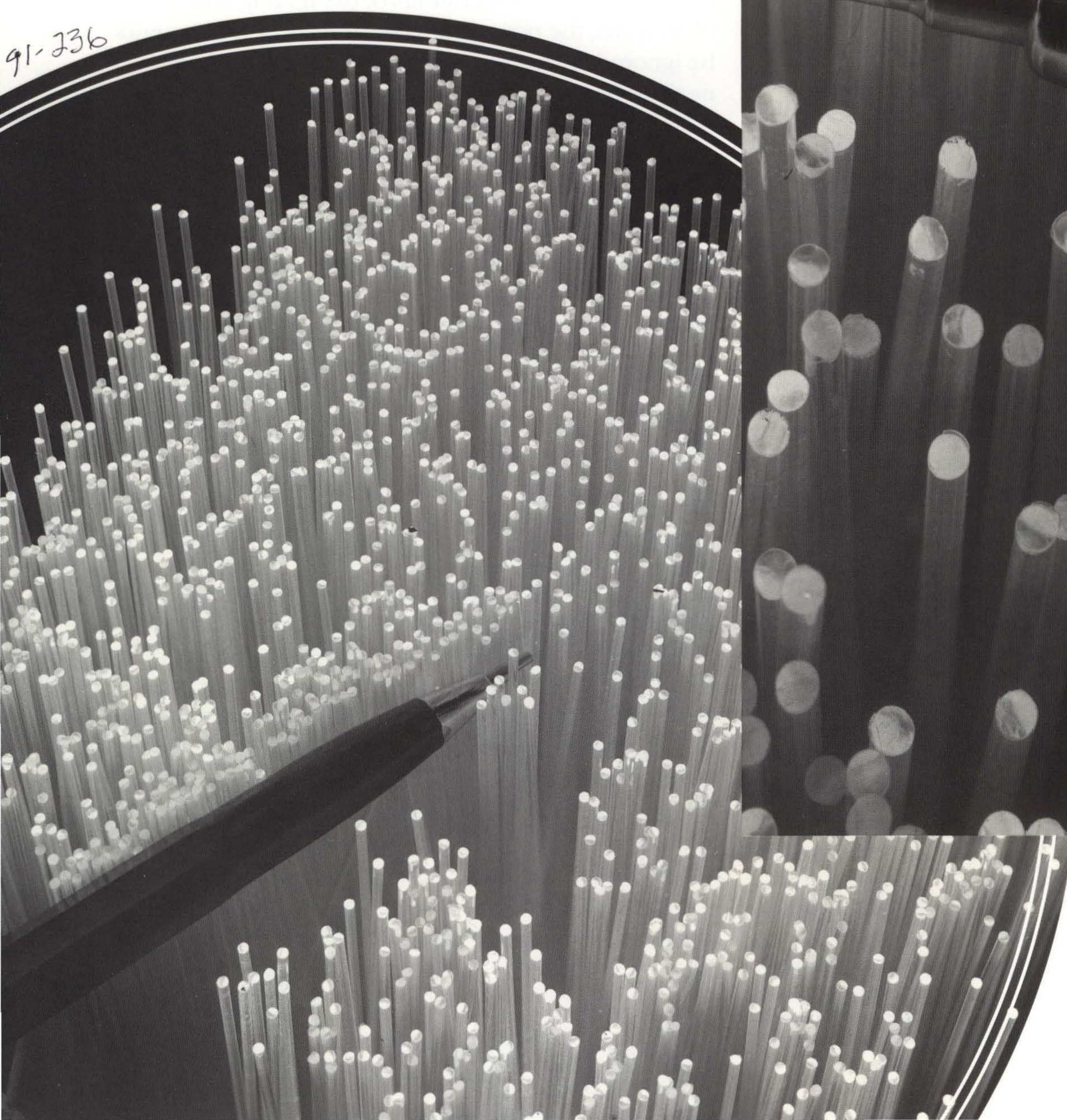
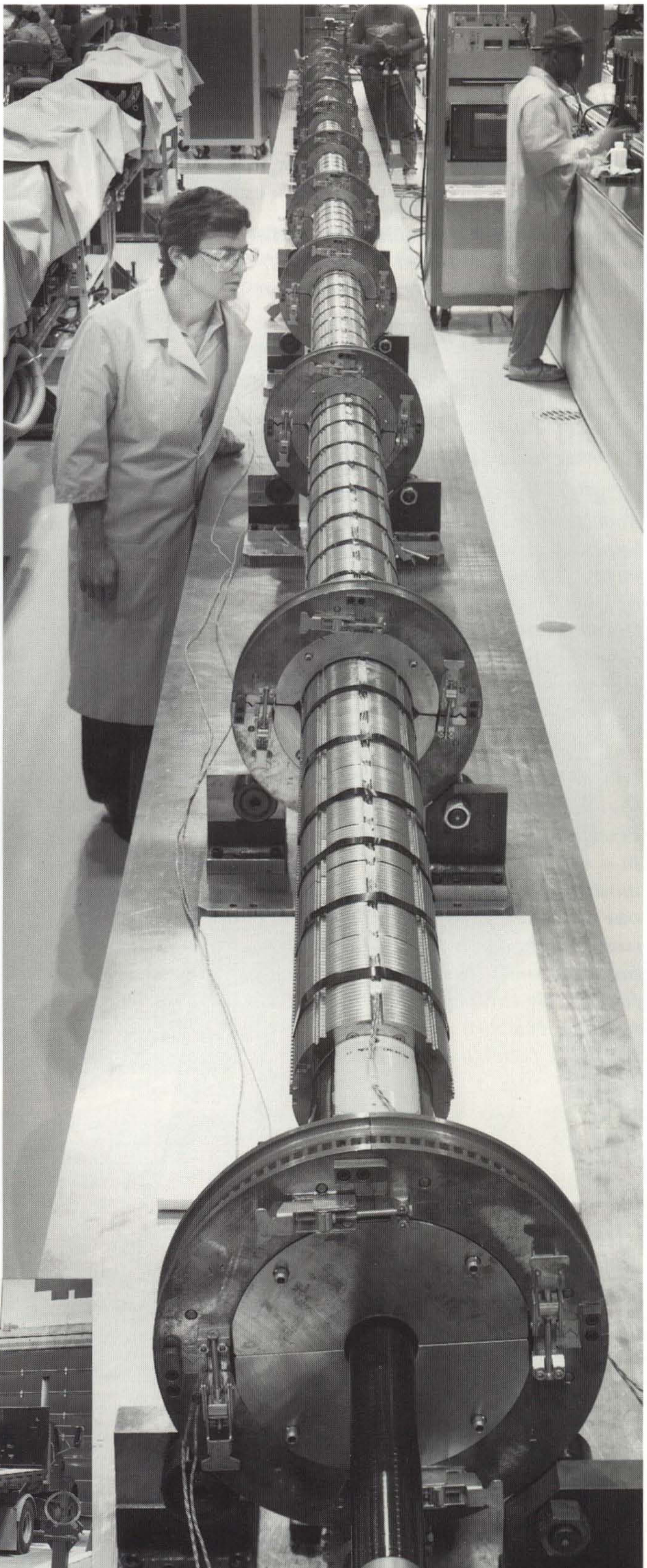
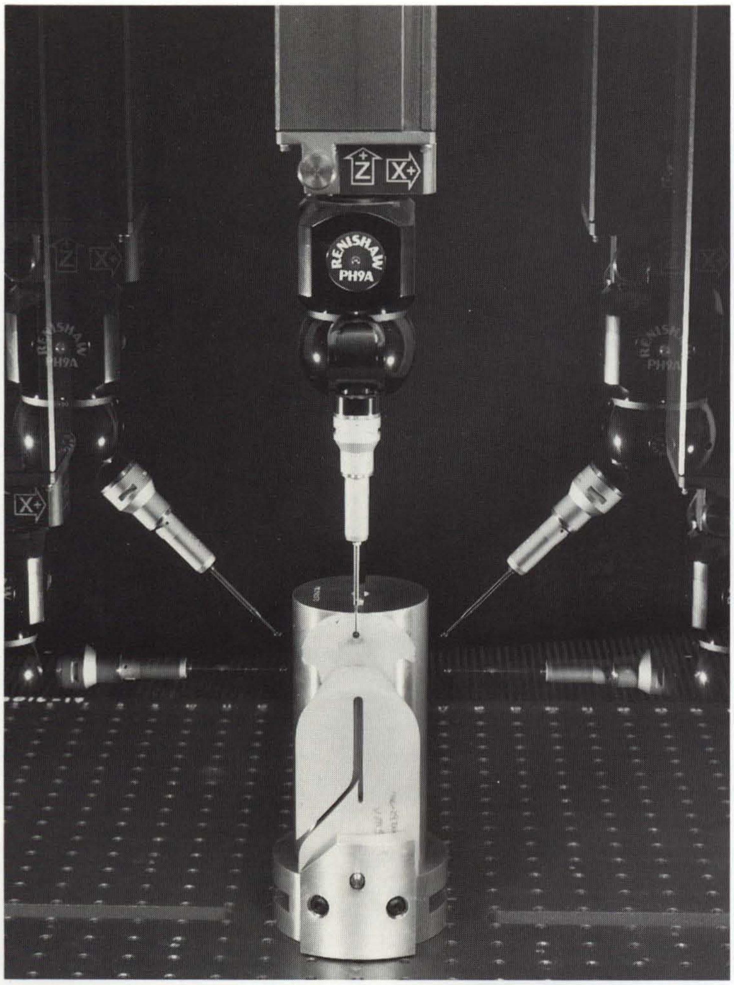


(Right) Guy Harris of Fermilab (right) and Alan Fogerty of SSC work on a full length SSC dipole magnet in the Industrial Center Building. To insure quality control, a "traveler" book accompanying each magnet details assembly procedures and calls for inspections at required intervals so that the completed magnet will operate according to all specifications.

(Below) Technical Support's Quality Control Group uses a coordinate measuring machine to inspect an SSC coil component. Measurement and fabrication with a precision of 0.001 inch are required because of the critical nature of the position of various parts within a magnet.

(Bottom) SSC superconducting dipole magnet DCA 313, the first industrially assembled magnet, stands ready for installation and testing at Fermilab's Magnet Test Facility.

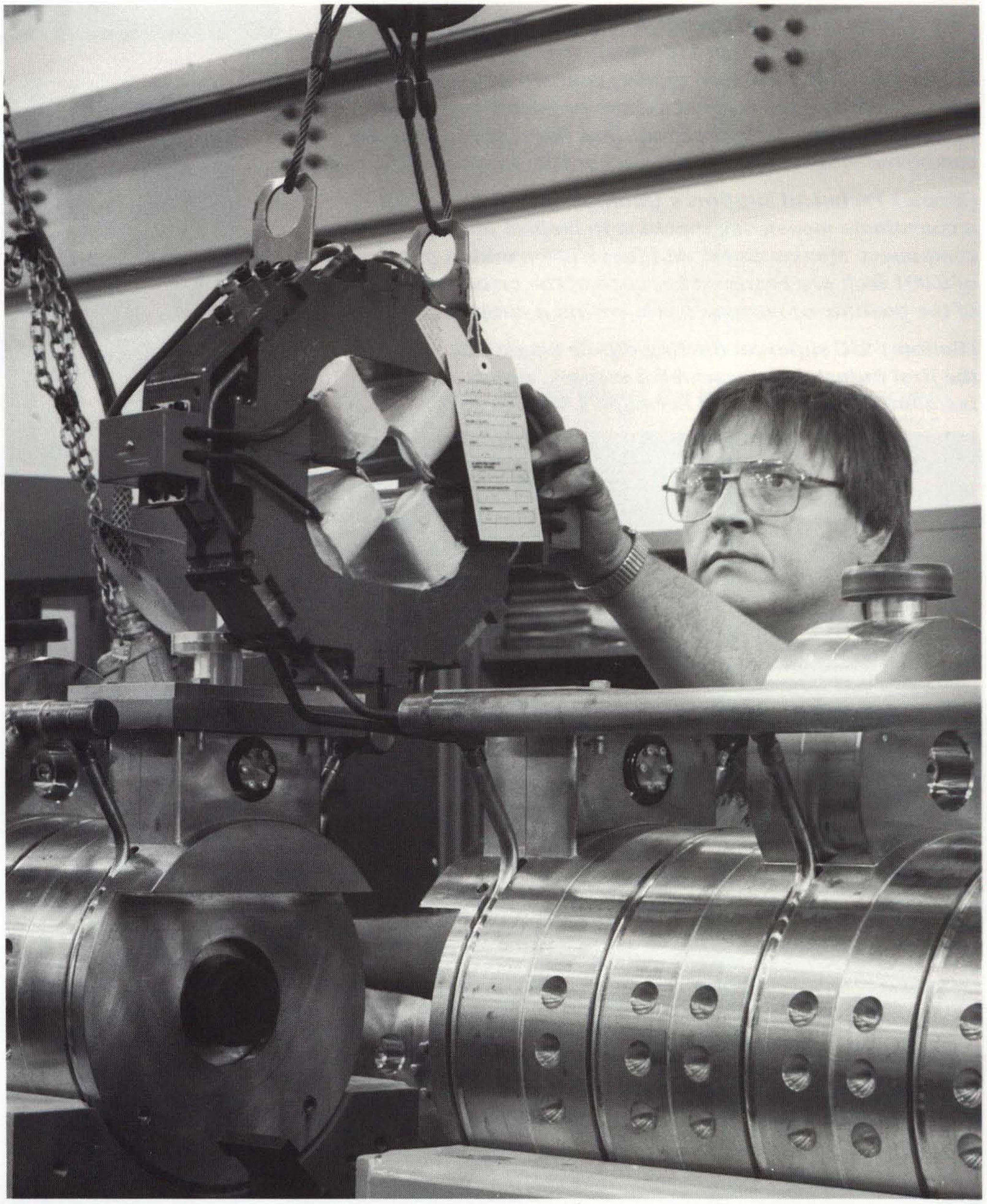


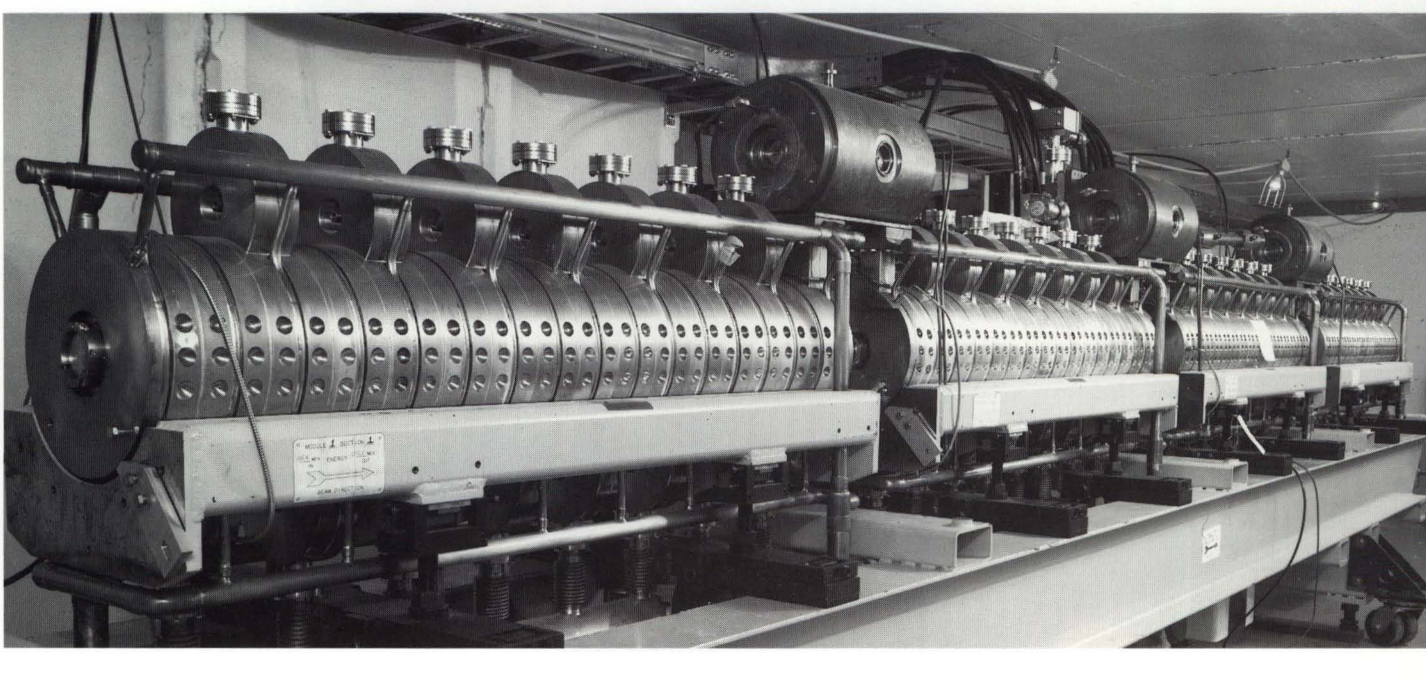


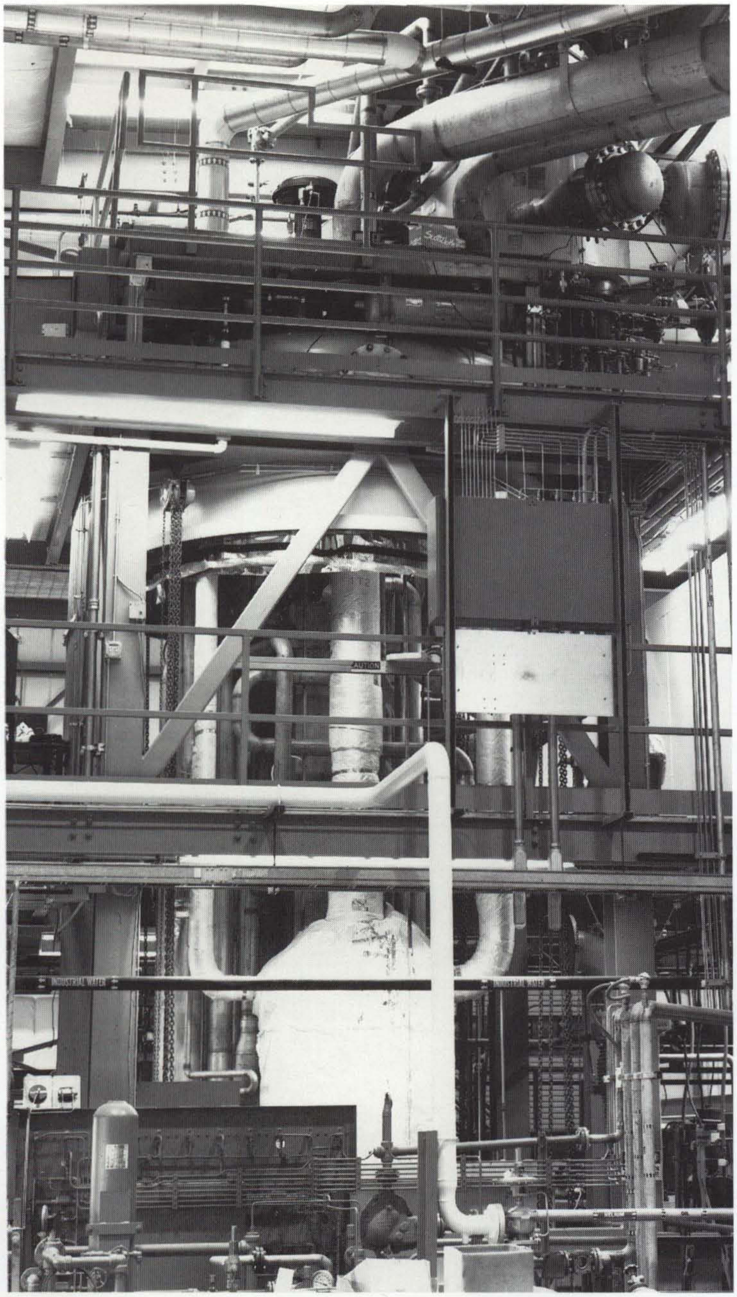
Fermilab has embarked on a project to double the Linac's final beam energy from 200 MeV to 400 MeV. In the Linac upgrade, seven new accelerating modules operating at a higher frequency and higher accelerating fields will replace the last four drift-tube tanks (total 60 meters long) of the nine in the present Linac.

(Right) Michael Ziomek of the Accelerator Division's Mechanical Support group installs a quadrupole magnet between sections of the accelerating module for the Linac upgrade. In each module, there are four quadrupoles to provide beam focusing.

(Below) The basic fabrication unit for the new Linac is a set of coupled resonant cavities brazed together into a 16-cavity section. Four such sections are connected in a series to form an accelerator module, which is then powered by one klystron. Once assembled, the unit undergoes high voltage testing and conditioning at the AØ test facility. By the end of 1991, four of the seven units had been successfully fabricated and tested.



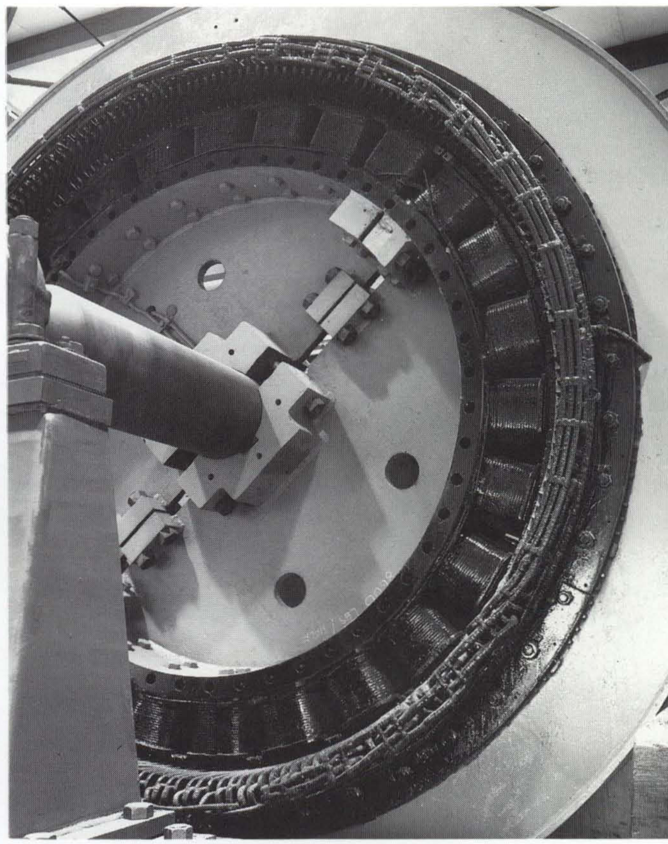


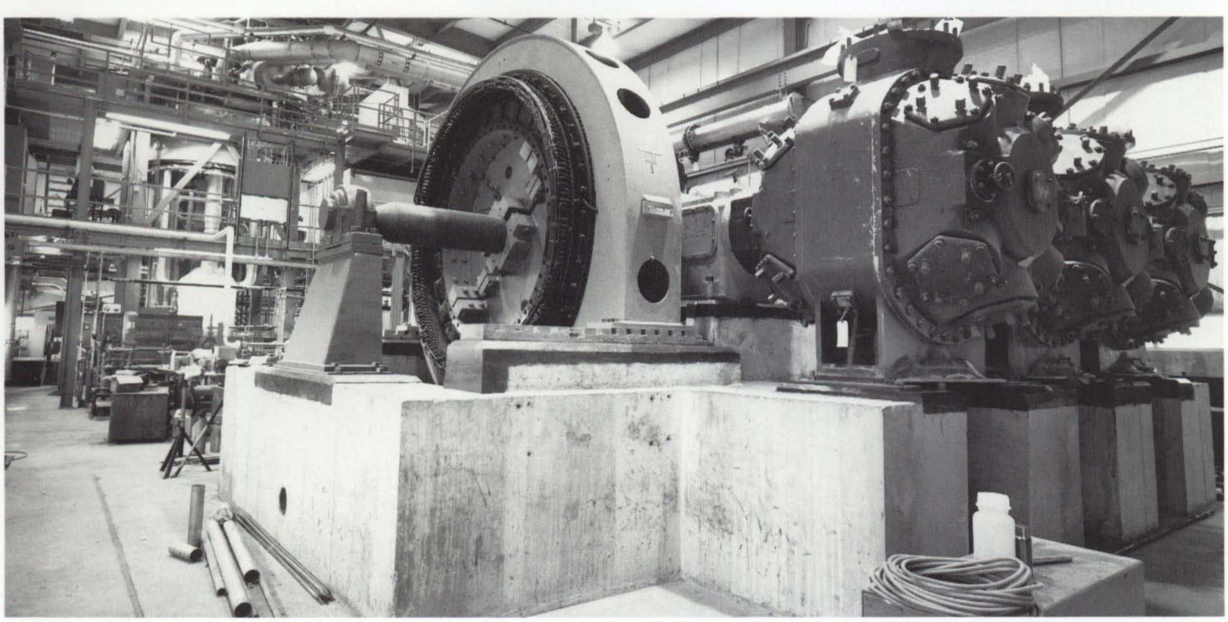


(Left) Commissioned in December 1991, the Cold Box II upgrade to the Central Helium Liquefier (CHL) will increase the capacity of liquid helium delivered to the Tevatron by 35%. The new system is also crucial to the low-temperature–high-energy Tevatron upgrade which will result in minimum temperatures of 3.5°K compared to the current 4.5°K.

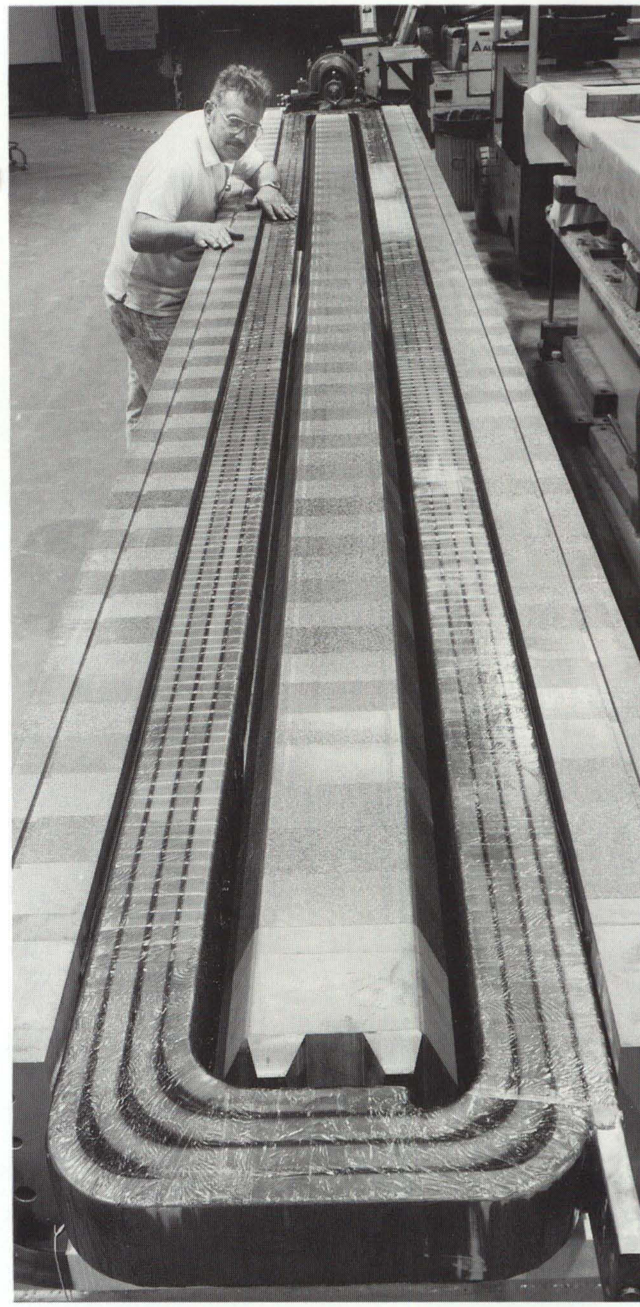
(Below) The 4000-horsepower motor of the new compressor for Cold Box II has a diameter of three meters.

(Bottom) This new compressor unit was constructed to provide the necessary redundancy in the CHL upgrade. The largest piston is one meter in diameter.





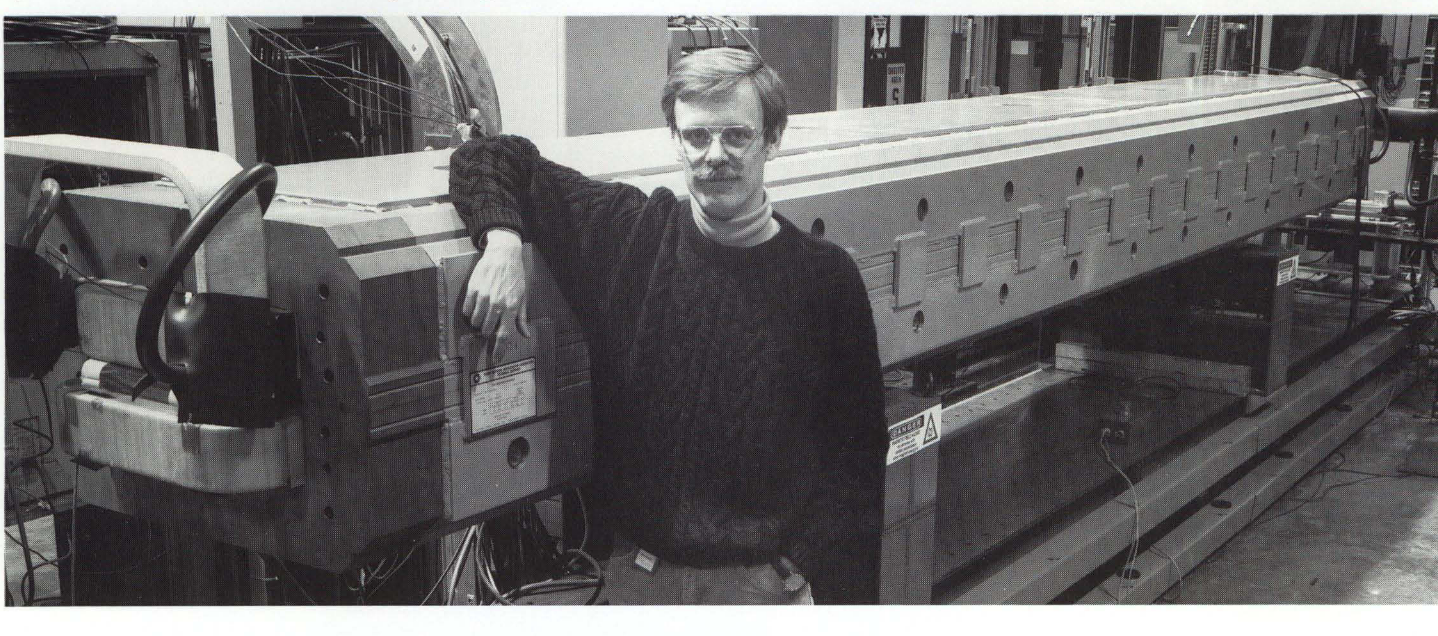

Fermilab III
THE MAIN INJECTOR



FERMILAB III is a series of improvements that will allow the frequency of proton-antiproton collisions in the Tevatron to be increased more that fifty-fold. The centerpiece of FERMILAB III is the Main Injector, a 150-GeV accelerator that will replace the Main Ring, the original accelerator built at Fermilab twenty years ago. The new accelerator, 3.3 km in circumference, will be tangent to the Tevatron in the southwest corner of the site. Thanks to the substantial and sustained support of the entire Illinois congressional delegation, funding for the Main Injector is proceeding nicely.

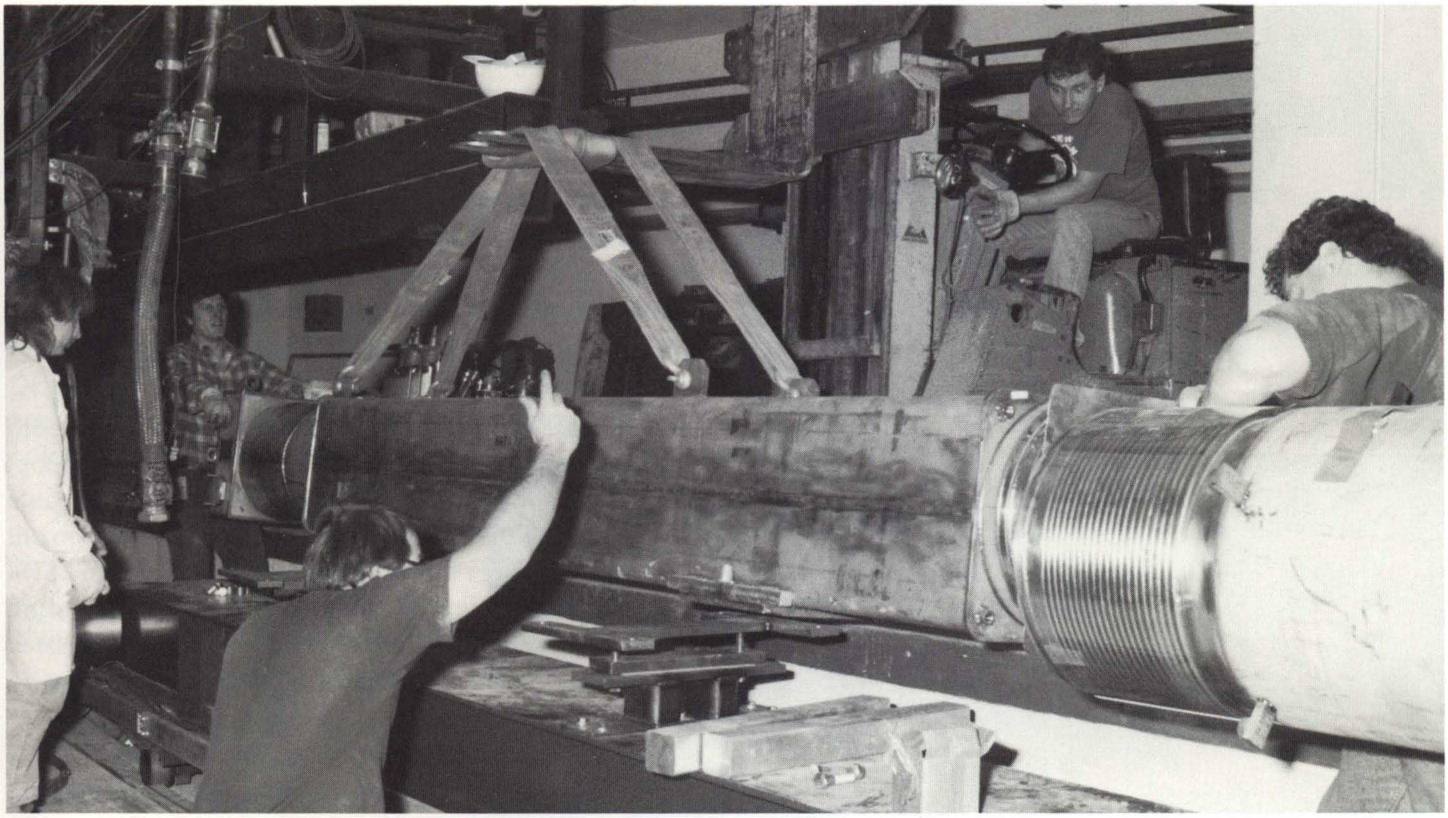
(Right) Warren Classert of Technical Support's Conventional Magnet Facility examines the coil placement in the half core of a prototype dipole magnet for the Main Injector. A specially designed slip plane between the core and the coil allows the magnet ends to expand and contract longitudinally with thermal changes due to accelerator start-up and shut-down.

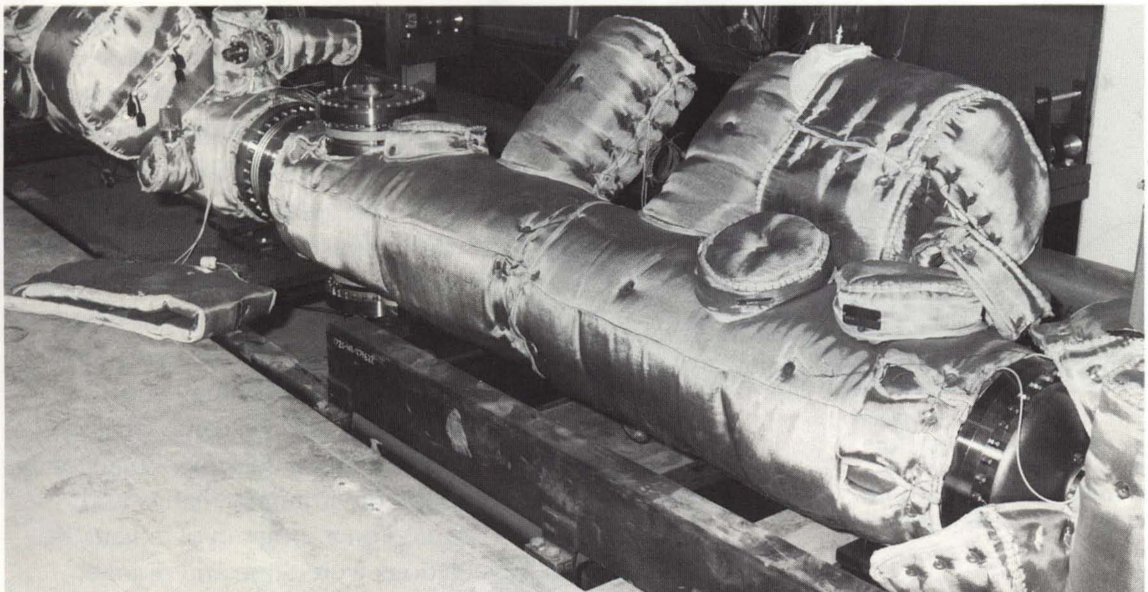
(Below) Stephen Holmes, Accelerator Division Head and Main Injector Project Manager, stands beside a completed prototype Main Injector magnet. The project calls for a total of 344 of these conventional iron-core dipole magnets.



(Below) Technicians prepare to install a quadrupole magnet in the low-beta section of the DØ detector. Pictured left to right are: Scott Adner, David Augustine, Roger Thomas, Douglas Howard, and John Seidelman.

(Bottom) Electrostatic separators are used to separate proton and antiproton beams in the Tevatron. The separator is snugly wrapped in a set of custom-made blankets used for the high temperature bakeout which allows it to achieve an ultrahigh vacuum and to sustain the high electrostatic fields required to maintain an acceptable beam separation.





Assessment and Improvement

Although Fermilab is dedicated to elucidating the fundamental laws that shape the universe, that is not our sole focus. We are committed to maintaining a healthy environment on the site and to protecting our staff, our visitors, and our neighbors from any adverse effects due to Laboratory activities. In 1991, Fermilab joined other Department of Energy facilities in a renewed and redoubled attention to issues related to the environment, safety, and health.

As part of this concern, Fermilab has always had exacting standards for radiation safety and carefully monitored environmental conditions. We have felt it prudent to periodically review these standards. (Although the Laboratory is legally compelled to meet all applicable federal and state radiation regulations, we have a long tradition of working toward even more exacting standards than those imposed.) Our Radiation Safety Guide sets standards for both normal operations and accidents. There are (and can be) few questions regarding conditions associated with normal operations. A more conservative definition of an accident at our accelerator complex, however, has been adopted as consistent with the very cautious approach to radiological exposure that now reflects society's attitude generally.

In the summer of 1991, a team from the Research Division designed a device to locate and then repair a water leak in a section of the vacuum tube in the proton beam line. From the left, Cary Kendziora, Ronald Davis, Willie Stitts, and John Barilla load the Internal Pipe Repair Apparatus into a simulated beam pipe.

A year ago, following some tests related to the future Main Injector accelerator, doubts were raised as to whether certain portions of our radiation shielding were sufficient to meet these new standards. The Laboratory response was immediate, wide-ranging, and impressive, even to the participants.

The initial tests were made in the region of the Switchyard where beams to the different experimental areas are redirected as they leave the accelerator. In that area the roads would eventually be recontoured. The Accelerator and Research Divisions, in concert with the Directorate, the Facility Engineering Services Section, and the Environment, Safety and Health Section embarked on a program of exhaustive investigation. Calculations were done and redone,

On the berm to the south of CDF, John Grimson checks out the earth coverage over the pieces of iron designed to give additional shielding in the BØ region.

measurements made and checked, worst-case scenarios explored and resolved. Miles of accelerator, miles of beamline, acres of coverage were examined with a precision of a few inches in earth equivalent depth. Aerial surveys of the site played a vital role but so also did the measuring stick and drawing board. Monte Carlo calculations of neutron flux and fluence were compared with experimental data. The mighty Tevatron complex was operated mainly at 8 GeV to investigate some of the more esoteric possibilities.

The results of this vigorous introspection was a program of remedial action. We added earth coverage, recontoured berms, and reinforced weak spots. The electronic shield of radiation monitors, which cuts off the operation of accelerator or beam when anomalous levels are detected, was reinforced. Perhaps most important, the entire Fermilab community refreshed its knowledge of the complexities of the parameters on which we depend for safety and health issues.

In the eight months from December 15, 1990 to July 15, 1991, the Laboratory as a whole paused, examined, reflected, corrected where necessary, and reset our course toward discoveries. The whole Laboratory played a role. To be sure, students close to their doctorates were impatient, and senior physicists who had planned happy family events for after the fixed target physics run now found the happy event occurring in mid-run instead. In the end, however, this will be remembered as just one more occasion when the Fermilab community came together and worked hard on behalf of the people and the environment around us.

Bruce Squires examines the reinstallation of the cryogenic relief valves on the Meson berm. During the 1991 shielding project, the valves, which vent gaseous helium and nitrogen in the event of a magnet quench, were heightened and offset in order to reduce radiation danger in the event of an accident in the beam directly below.

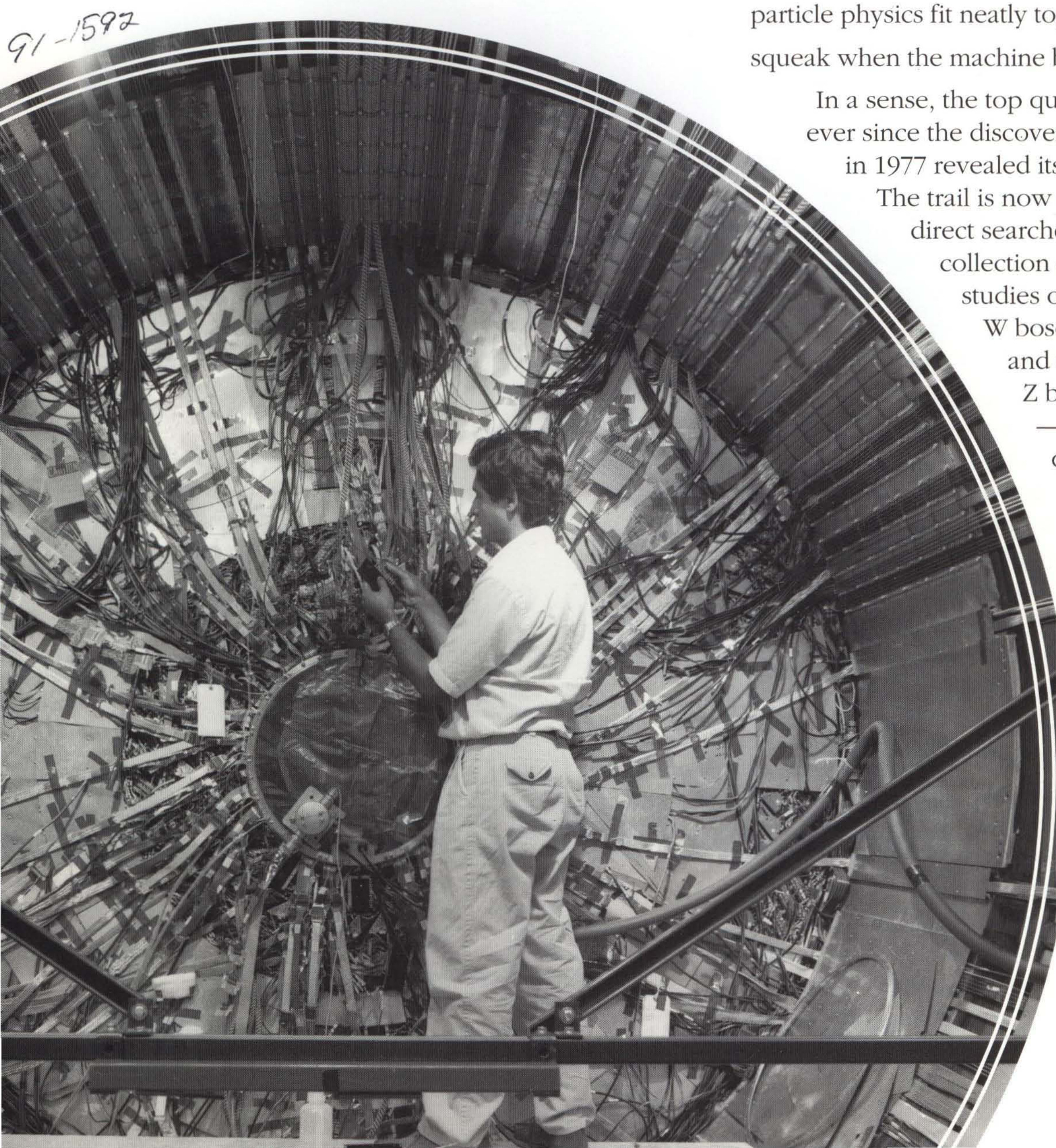
The Outlook for Physics

Fermilab's Experimental Program

91-1592

As the highest energy laboratory for particle physics in the world, Fermilab is poised to make dramatic contributions to science and technology in the years ahead. The Fermilab community — with the entire world of particle physics — eagerly awaits the start in the spring of 1992 of a collider run that will renew the search for the top quark. Top is the one known quark remaining to be found, and, because top will be the heaviest particle ever found, some believe it holds the key to the pattern of the other quarks. Once we know the top-quark mass, we can test our understanding of the masses of the W and Z bosons, the carriers of the weak interactions. We will see whether all the gears of the theoretical machine we call the Standard Model of particle physics fit neatly together, and whether they squeak when the machine begins to turn.

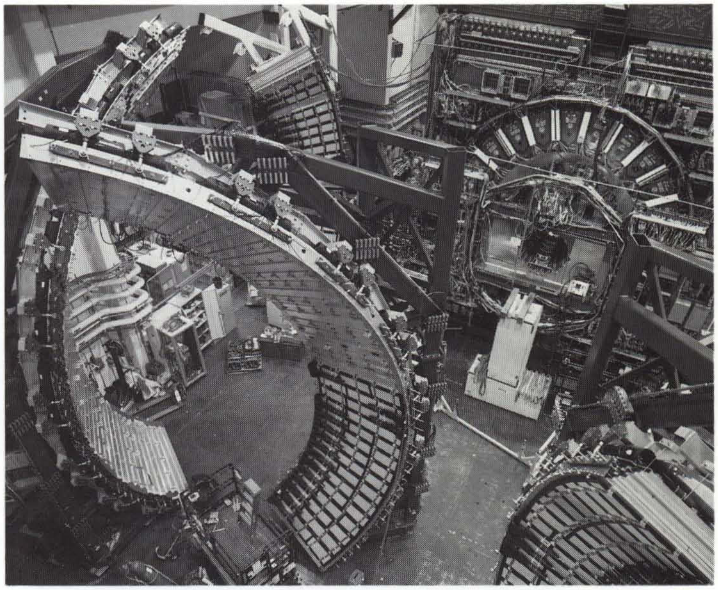
In a sense, the top quark has been on our minds ever since the discovery of the upsilon at Fermilab in 1977 revealed its partner, the bottom quark. The trail is now particularly hot because the direct searches at Fermilab and a vast collection of indirect hints — from studies of neutrino scattering and the W boson at Fermilab and CERN and the remarkable studies of the Z boson at CERN's LEP collider — are closing in on the top-quark mass like two jaws of a vise. CDF's 1989 data show that the top-quark mass must exceed 91 GeV/c^2, while the indirect measurements are inconsistent — if we can trust the Standard Model — with a mass greater than about 220 GeV/c^2. The oddsmakers' favorite value is around



During the 1991 upgrades to CDF, Aseet Mukherjee connects high voltage leads to the central tracking chamber. In anticipation of the expected increased luminosity, the electronics were modified to reduce amplifier noise thus increasing the detector's useful life.

91-612-2

Inside the bore of the central tracking chamber of CDF, Michael Nurczyk performs alignment work on the ladder-like master fixture which is used to install supports for the vertex time projection chambers and the silicon vertex chambers.



The curved arches of the muon chambers dominate this view of the CDF assembly building just prior to the detector's movement into the collision hall. 92-22

Dwarfed by the mammoth arch of completed chambers, Stephen Kuhlmann prepares to install another of the central preradiator chambers which sit behind the 1.0 radiation length CDF coil/cryostat.

120 GeV/c^2, close to the limit of sensitivity achievable in the 1992-1993 run.

That sensitivity, measured by the number of collisions studied, will increase twentyfold, thanks to impressive enhancements to Fermilab's accelerator complex. During the first part of the run, the event rate will benefit from electrostatic separators in the Tevatron and improvements to the antiproton source, which made possible the world-record rate of antiproton accumulation achieved near the end of the 1991 fixed target run. The upgraded Linac, which will inject brighter beams into the Booster, will be commissioned during a brief pause in the middle of the run. Low-beta quadrupoles installed in the interaction regions to focus the proton and antiproton beams more sharply will also contribute to higher luminosity at the two detectors. In later runs, the Tevatron energy will be increased to 1 TeV per beam by lowering the temperature of the superconducting magnets. The rate of production of massive particles such as top quarks is sensitive to collision energy. Increasing the Tevatron energy is another way to improve the odds that top will be discovered at Fermilab. Farther in the future, the Main Injector will increase the collision rate by another factor of five.

The search for top will be carried out by two superb international teams. CDF, greatly enhanced by the addition of a large-scale silicon vertex detector and new muon counters, will be joined in this run by DØ, a nonmagnetic detector that emphasizes high-quality calorimetry. Both the Tevatron veterans of CDF and the DØ collaborators eager to record their first proton-antiproton interaction bring years of preparation and a determined enthusiasm to the hunt.

Complementing the search for rare events will be precise measurements of the mass and width of the W boson, crucial parameters for the Standard Model. Quantum chromodynamics, the theory of the strong

Continued ➤

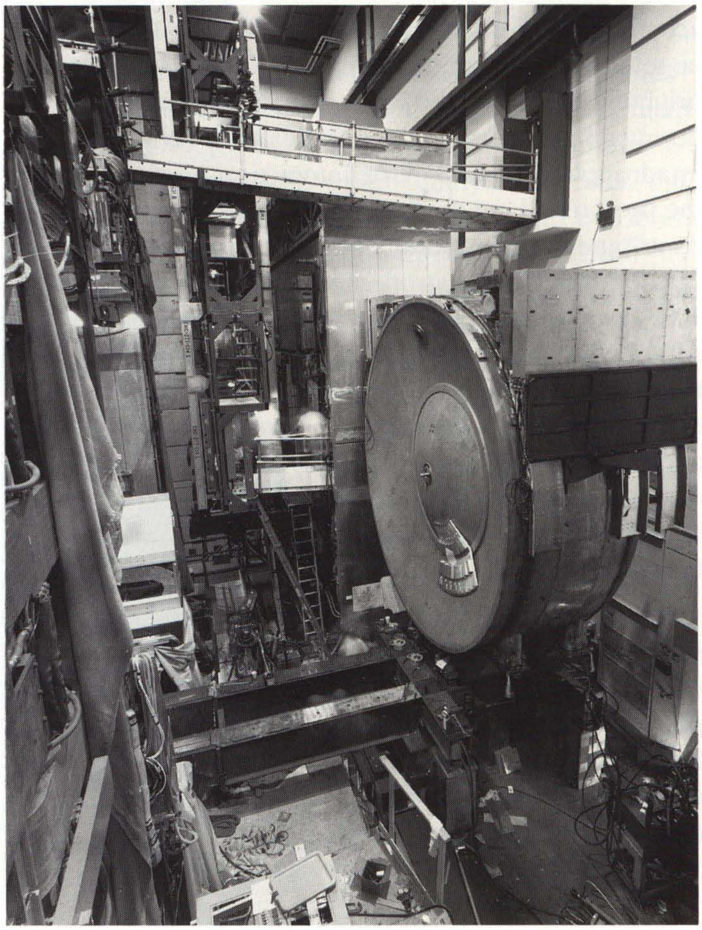
In the DØ control room, the electronic survey system is being calibrated. During the summer of 1991, cosmic rays were used to test and calibrate the equipment. Clockwise from the front right, Andrew Lathrop, Charles Murphy, Sandor Lokas, Jra Li, and Herbert Greenlee.

interaction, will be tested in the study of hadron jets produced in violent collisions of the quarks and gluons that compose protons and antiprotons, and in the events containing W and Z bosons. One important aspect of the jet studies will be a search for structure within the quarks, the elementary particles of the Standard Model.

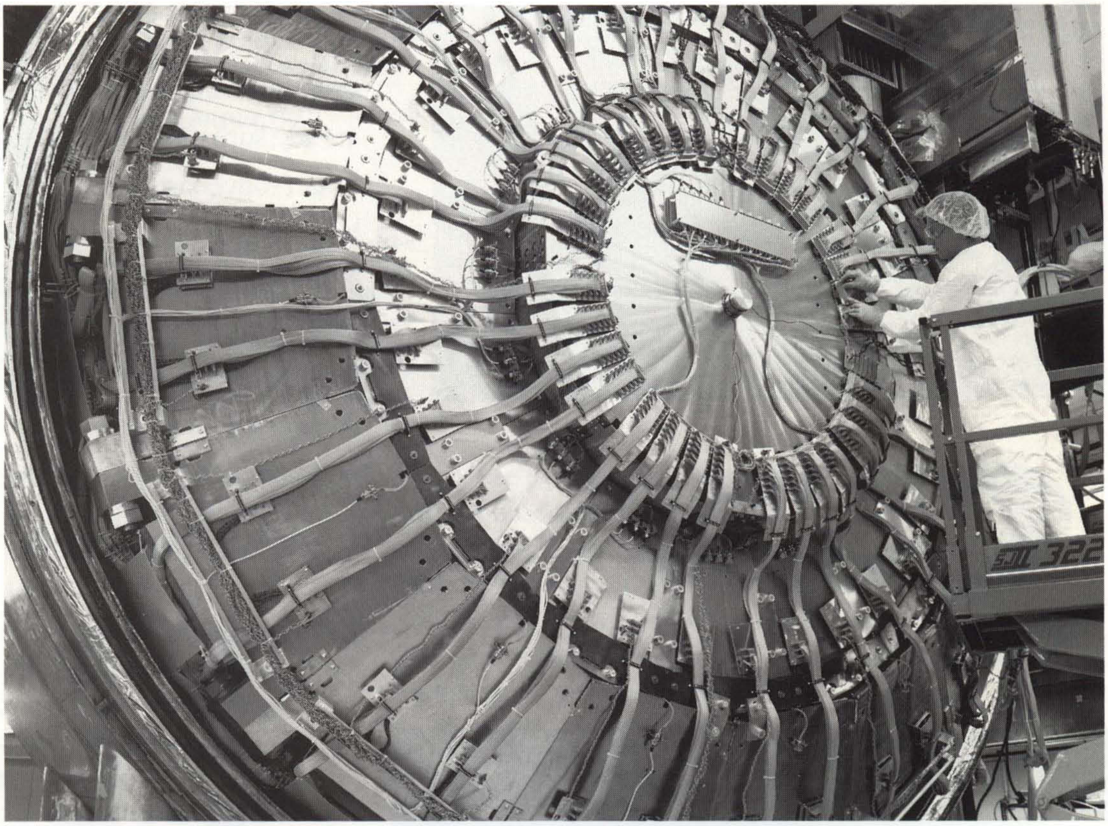
In addition to exploring phenomena at the highest attainable energies, a promising second frontier was opened by the CDF collaboration's observation of the charged and neutral B mesons decaying into J/ψ plus a kaon or K* meson. These 5 GeV/c^2 particles are produced in enormous numbers at the Tevatron; about 10^9 B particles will be produced in each detector during this run. The question is, how many can be detected? The experimental challenge is a more taxing version of the problem overcome in detecting great numbers of charm particles in fixed target experiments. Hopes are high that the strange B meson, the B baryon, and possibly the exotic charm B meson can be observed at the Tevatron collider in 1992. The observation of CP violation in decays of B particles is one of the prime objects of desire for particle physics in the next decade. The quest will be an important element in Fermilab's long-term program.

No look at Fermilab's future would be complete without a mention of the exciting program of well-chosen fixed target experiments. For the foreseeable future, Fermilab will retain the distinction of providing the highest-energy extracted and secondary beams in the world. Over the next five years, it should be possible to harvest a million reconstructed charm particles. New measurements of high-energy neutrino scattering are required to keep pace with the LEP studies of the electroweak interaction. A new round of neutral kaon experiments promises to close in on the nature of CP violation. Data from the run just concluded will help us to judge how fixed target experiments can contribute to b physics. Once the Main Injector comes into operation, its 120-GeV protons will produce the world's most intense beams of neutrinos and neutral kaons, complementing the high-energy beams from the Tevatron. Imaginative proposals to study kaon decays and neutrino oscillations show the promise of the high-intensity frontier.

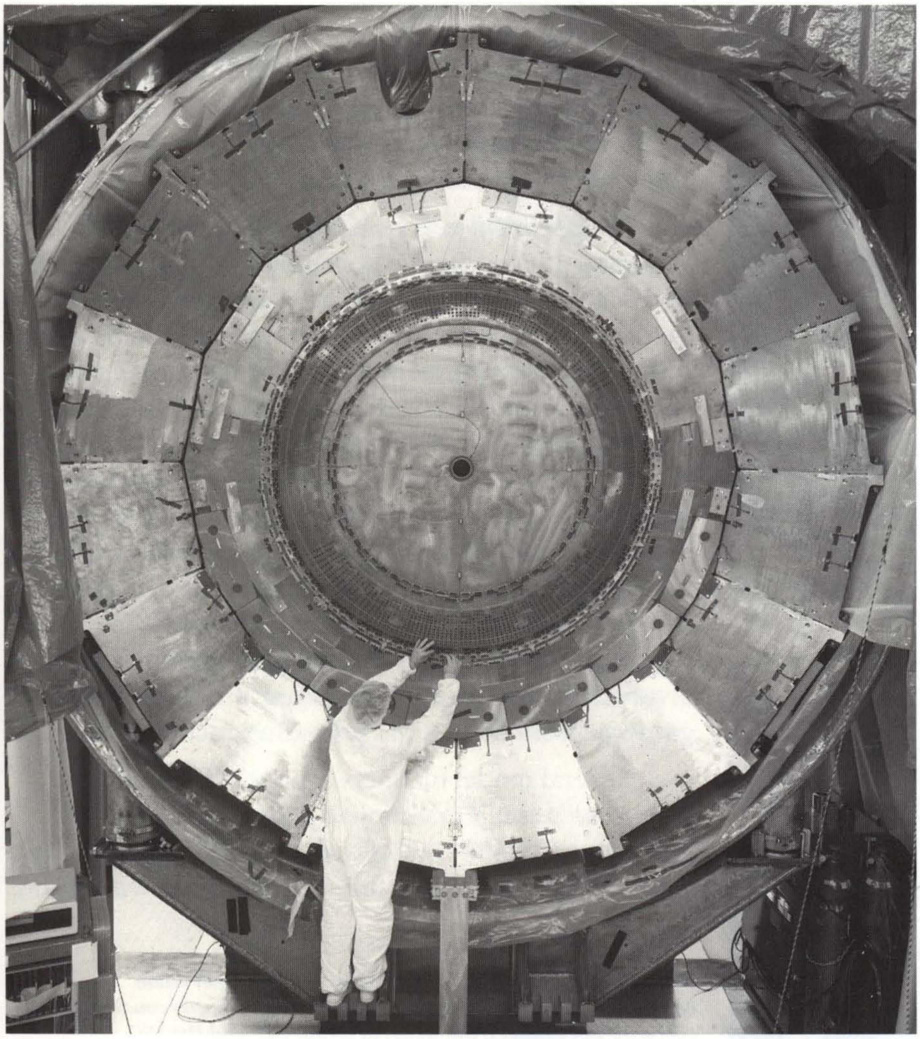
Fermilab's best is yet to come!



The north end calorimeter of DØ stands ready to be placed on the center beam. Once in position, it will be filled with liquid argon and used in the measurement of hadrons and electrons.



Wedged-shaped hadronic modules ring DØ's electromagnetic calorimeter in the central circular area. In order to avoid unnecessary contamination of the highly sensitive equipment, the detector was assembled in a "clean room" requiring technicians to wear special clothing.



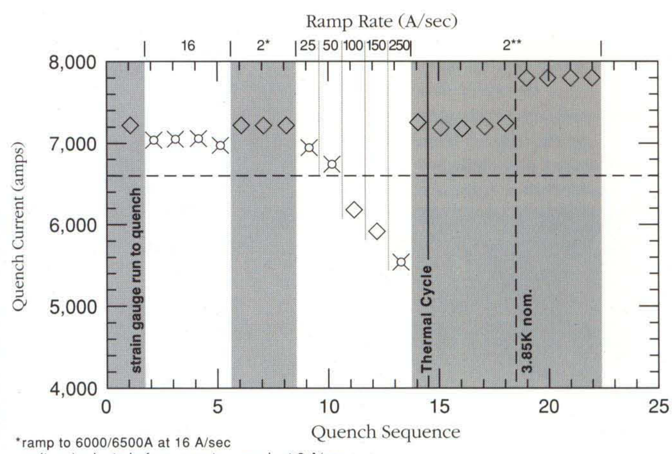
A technician hooks up the signal cables which feed electronic data from the detector to the preamplifiers to the computers in the counting room.

Cooperation between Fermilab and the SSC Laboratory

SSC Magnet Program

Among the most important components for the SSC are the superconducting dipole magnets for the collider ring. From coast to coast, with Illinois and Texas in between, Department of Energy facilities have cooperated closely in this important endeavor of producing prototype SSC magnets. Fermilab, where superconducting accelerator magnets were first developed, has applied its expertise in designing, building, and testing SSC magnets.

SSCL Collider Dipole DCA311 Current at Quench



*ramp to 6000/6500A at 16 A/sec
wait>= 1 minute before ramp to quench at 2 A/sec

**wait -10 min at 6500A
ramp to quench at 2 A/sec

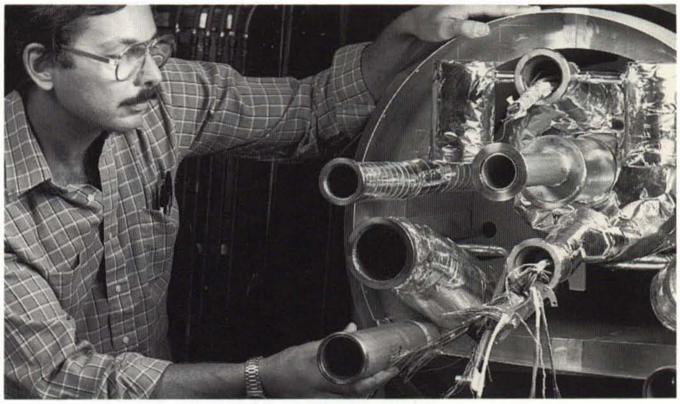
After a multi-year collaboration with the SSC Laboratory, its predecessor, the Central Design Group, Brookhaven National Laboratory, and Lawrence Berkeley Laboratory, Fermilab completed the 40-mm collider dipole magnet program during 1991 with the successful fabrication and testing of two full-length, Fermilab-designed magnets. The 40-mm program provided us with personnel training and experience in fabrication techniques, tooling, material control, quality assurance, traveler development, and testing. Our focus then turned entirely to completing the design, begun in 1990, of the 50-mm magnets which meet the new requirements of the SSC. Although the new aperture involved some non-trivial changes, the experience garnered from the 40-mm program proved invaluable.

Several model magnets (one-tenth the design length) were built to establish detailed assembly methods and to test the new design. The first two of a series of thirteen 50-mm full-length dipoles were also

In a prime illustration of technology transfer, Fermilab employees share their expertise in winding a superconducting coil with personnel from General Dynamics and the SSC.

In this tunnel, a 275-foot long string of five 40-mm superconducting dipole magnets was successfully tested in August 1991.

Thomas Wokas examines the end of one of the test stands in the Magnet Test Facility. Extensive adaptation of the coupling was required so that the performance of the 50-mm magnets could be tested.



successfully built and tested, in an excellent collaboration among several hundred Fermilab people, close to 40 SSC employees, and approximately 30 General Dynamics employees stationed at Fermilab.

A major objective for the entire program has been the transfer of superconducting magnet technology to General Dynamics, the lead industrial contractor responsible for the design and production of up to 8000 collider dipoles. To this end, General Dynamics personnel are being trained at Fermilab and will assemble seven magnets here. Five of those magnets will be joined together in a "string" test to be conducted at the SSC near Dallas in 1992. For all of these dipoles, Fermilab staff provided procurement and material control services and operated and maintained the major tooling devices. Fermilab is also assisting General Dynamics with their magnet design for mass production.

In November, the first complete full-length 50-mm magnet (DCA311) was successfully tested. Its quench data are shown at the left. This magnet, which was built by Fermilab personnel, exceeded the operating current by approximately a 600 ampere margin and exhibited no training. (Quenches below the 7200 ampere plateau result from higher ramp rate operation.) The magnet was operated at three different temperatures and reached the limit of the conductor at each temperature. DCA312, a magnet built by Fermilab and General Dynamics people working side by side, was tested in December with similar results. Detailed measurements of the mechanical behavior of both magnets indicate that they behave according to design. Magnet testing at Fermilab's Magnet Test Facility was a collaboration of SSC and Fermilab.

The first industrially assembled magnet, DCA313, was completed and installed in the Magnet Test Facility in December.

Due to small changes in the dimensions of the superconducting cable between the time the electromagnetic design was complete and magnet assembly began, it was expected that the higher order "allowed" magnetic field harmonics would not meet the current SSC specifications. Based on the room-temperature measurements of the first magnets, the values of the harmonics are close to the calculated values expected from the actual cable dimensions. Equally important, the measured magnet-to-magnet variations in all specified harmonics are considerably smaller than the RMS variation allowed for the SSC collider. Thus, only small changes in the final General Dynamic's electromagnetic design are required to bring the field quality into specification.

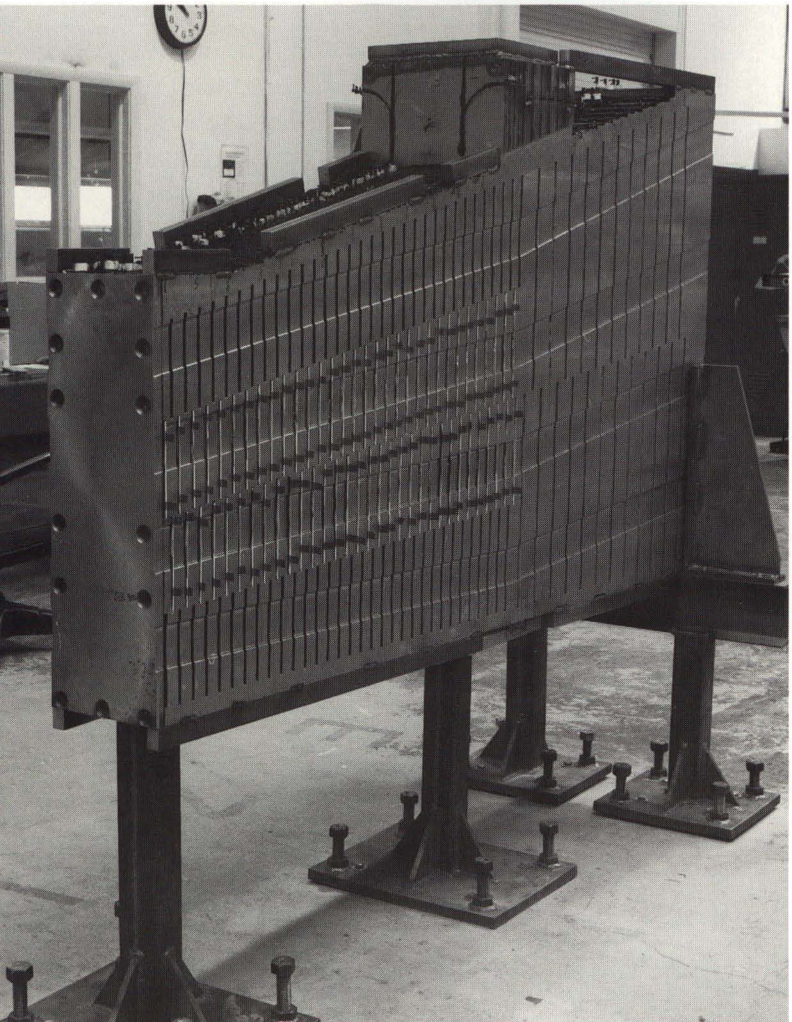
There were two major achievements in the area of cryostat development during 1991: measurement of the performance of the multi-layer insulation below 80°K, and the development of a single tube non-reentrant support using fiberglass and graphite composite tubes.

The success of the 1991 magnet program is due in large part to excellent cooperation between Fermilab, SSC and General Dynamics. This cooperation involved not only the design and assembly, but also the development of the requirements and specifications which were to be met in the production of the SSC dipoles. Technology transfer — the movement of technological expertise from the laboratory to industry — is one of the Department of Energy's top priorities. The SSC magnet development program thus stands as a prime example of technology transfer.

Solenoid Detector Collaboration at Fermilab

The Solenoid Detector Collaboration (SDC) is an international group of over 700 physicists who are collaborating on one of the first detectors for the SSC. This instrument will in essence be a laboratory for carrying out a variety of experiments designed to probe such fundamental questions as how the masses of the particles are created. A detector such as SDC is indispensable for the incisive confrontation of the outstanding questions of particle physics. Fermilab operates the only hadronic collider detectors in the United States, and physicists here have amassed immense experience in operating, triggering, and analyzing data from these detectors. Since SDC is the logical extrapolation of CDF and DØ, Fermilab physicists naturally take a central role in SDC. Over the next decade it is expected that many physicists currently working on CDF and DØ, as well as elsewhere, will join the SDC collaboration.

The Technical Support Section built this wedged-shaped prototype detector module for SDC. Approximately six feet long, the body is made of steel plates plug-welded together. Scintillator tiles are placed in the alternate spaces appearing as vertical lines in the photograph.

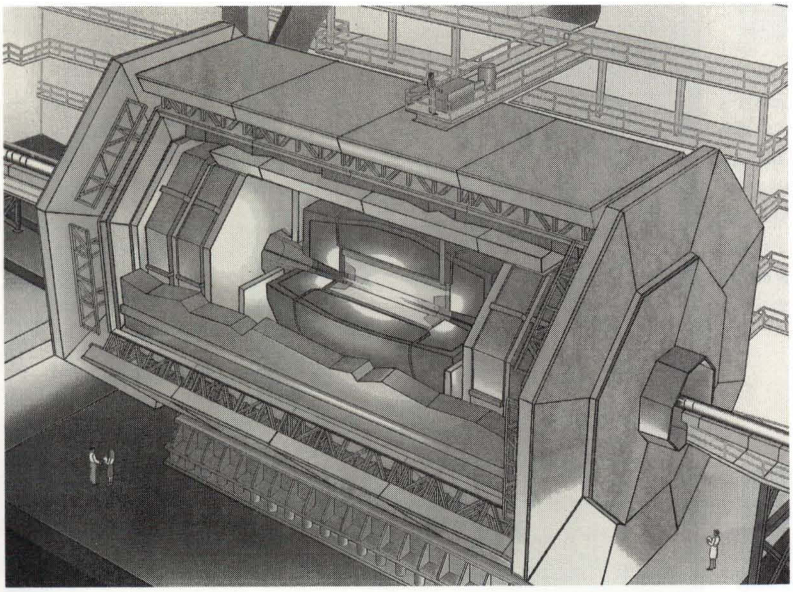


SDC was born at the Breckenridge Workshop in the summer of 1989. The immediate goal of the SDC collaboration is to create a fully engineered Technical Design Report by April, 1992. The Fermilab group contributes directly to this effort utilizing the Laboratory's resident engineering support groups, especially in the Technical Support Section. Industrial partners, for example Westinghouse Science and Technology Center, are also used.

Another important aim is to determine which detection system options offer the best performance for the least cost. The SDC group is actively engaged in R&D for the detector: both general R&D and specific work with the Fermilab test beams.

It is intended that SDC R&D dovetail with the existing Fermilab program to the extent possible. In the case of CDF, the scintillation tile/fiber calorimetry used in the "plug upgrade" has been adopted by SDC for the central calorimeters. The DØ option of scintillating fiber tracking for the outer tracking chamber is very similar to an option being explored by the SDC. In general, there is also a loose connection to the Fermilab program of high-rate triggering and data acquisition.

This year, the SDC group moved into office space on the seventh floor of Wilson Hall and into laboratory space in the Village. The group is presently small, and uses existing support groups in the divisions/sections as they become available for R&D on fiber tracking, fibers,



As this schematic rendition shows, the SDC detector, 40 meters in length, has a large cylindrical volume, concentric with the beam. The system is designed to measure particles emitted from the collision point with an angular acceptance ranging from 10 to 170 degrees relative to the beam.

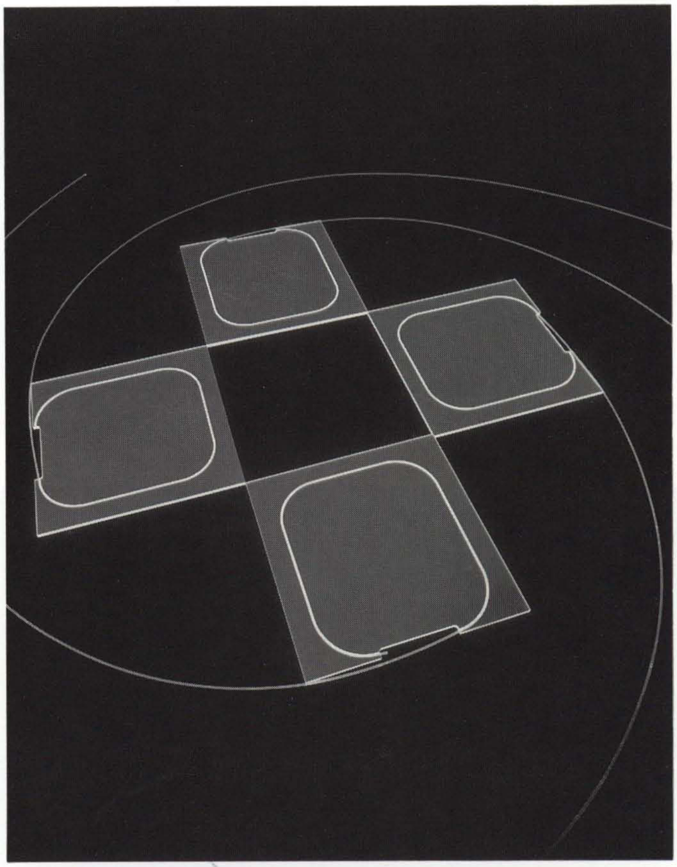
transducers, and electronics for front ends and triggers. There is a very active effort on solenoid magnet design. Tile/fiber calorimetry has the broadest program of R&D. There are test beam efforts in the MP beam (hadron "wedge") and in the MT beam ("hanging file").

The high radiation environment of the SSC is a serious challenge for experiments. Modules built to study the problem have been shipped to Beijing (China), Saclay (France), and KEK (Japan) to be irradiated and monitored using the SDC prototype calibration system. Several industrial partners are involved in the search for scintillating plastics which are radiation resistant.

We also are working on integrated circuit design (Application Specific Integrated Circuits) for front ends, pipelines, triggers, and data acquisition. This work is a natural extension of the existing Fermilab R&D program given the similar aims of selective triggering and high-luminosity data logging. (SSC and Fermilab radiofrequency bunch spacings are very similar.)

In addition to Fermilab SDC interests, many other SDC groups are active in the use of Fermilab test beams for R&D. A silicon pixel group, a fiber tracking group, and several muon tracking prototype groups have worked in beam NMU. Studies of neutron backgrounds, prototype scintillation based calorimetry, and warm liquid calorimetry have been made in the NWA, MP, and MT beam lines respectively.

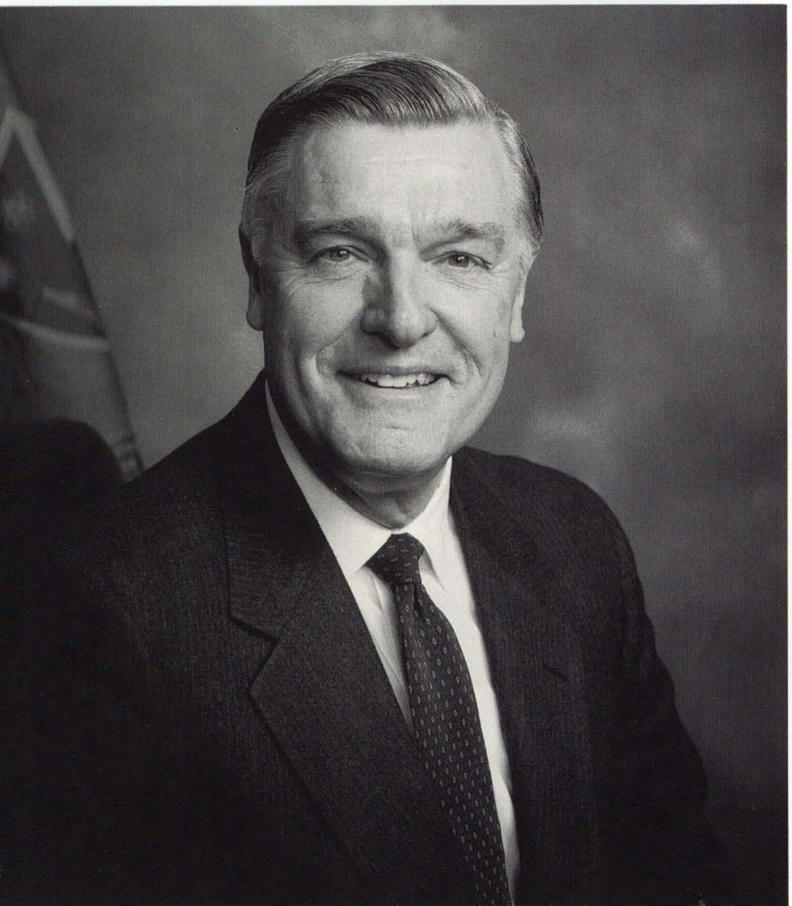
We anticipate that SDC will be approved for construction some time in 1992. The Fermilab SDC group will then shift from R&D to actually building elements of the detector, which will begin to run at the SSC in the year 2000.



Crucial to detecting the presence of charged particles, these scintillating tiles will be used in the SDC calorimeter. Made of polystyrene with a special fluourescent dye, the tiles are 10 cm x 10 cm and 4 mm thick. The fiber has a diameter of 1 mm. 91 - 1343

Saturday Morning Physics

> ***"As we live through these times of great change, the tremendous value of a well educated, scientifically literate population becomes increasingly clear. The education of America's next generation is one of our most important challenges. There is no question that the quality of math and science teaching and learning will closely determine the quality of life in the United States."***
>
> James Watkins - Secretary of Energy



Since the fall of 1980, 30 times a year a wonderful event takes place at Fermilab. Early on a Saturday morning, nearly a hundred young people arrive at the front steps of Wilson Hall, in groups or individually, driving themselves or dropped off by their parents, and assemble in a lecture hall for another session of Saturday Morning Physics. They come to learn about quarks and linacs and what Fermilab is all about.

When Leon Lederman became Director, he recognized the pressing need to stimulate and motivate our youth towards careers in science and technology. Saturday Morning Physics was born. On October 4, 1980, he gave the first lecture — "What is an Elementary Particle? From Molecules to Quarks with a Pause at the Hydrogen Atom." This lecture was both inspirational and informative. Other "charter" lecturers in the first series were James Bjorken, Charles Brown, Frank Cole, Mark Fischler, Irwin Gaines, Christopher Hill, Ernest Malamud, Chris Quigg, and Alvin Tollestrup.

Professor Lederman believed so strongly in the aims of this course that he took time out from his busy schedule to give this introductory lecture as often as possible, and to preside over the graduation ceremony following the tenth and last lecture in each course.

Fermilab provides Saturday Morning Physics as a community service at no cost to the participants. The course furthers the understanding and appreciation of modern physics among high school juniors and seniors. Most who attend are college bound and have shown strong interest and ability in mathematics and science. The ten-week course is repeated three times each school year. Each session consists of two hours of lecture and discussion followed by tours of the Laboratory. Students see the interface of experiments, theory, and technology: the world's highest energy accelerator, ultra-modern computers, advanced technology for building superconducting magnets for Fermilab and the future SSC, and several collider and fixed target experiments.

Fermilab scientists and engineers volunteer as lecturers and group leaders for the program. The ten different lecturers present material in their own style, a style often more motivational and anecdotal than in the typical classroom. After the lecture, the class is divided into four groups, each conducted by an Associate Lecturer, usually a Physics Section Research Associate, who runs a discussion group, answers questions, and conducts that day's tour. The program

Another education program that Fermilab particpates in is the Department of Energy's High School Honors Research Program in Particle Physics. Gifted students (one from each state and several from foreign countries) come to the Laboratory for two weeks. Erik Gross representing Alaska visited experiments, attended lectures and tutorial sessions, and experienced physics research first hand. Director John Peoples signs his autograph during the 1991 closing ceremony.

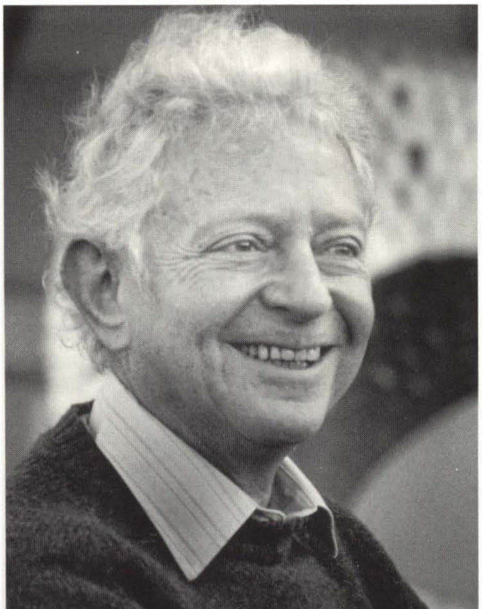
has been directed with dedication, creativity, and humor by Fermilab physicist Drasko Jovanovic for most of its twelve-year history.

The course ranges from quarks to quasars. Students learn about the apparatus we use to make particles (accelerators) and the devices that extend our range of perception to see particles (detectors). They learn about the Standard Model, about conservation laws and symmetry principles, about left-handedness and right-handedness, time and its connection to anti-matter, special relativity, quantum theory, the early Universe, and the spin-offs and technology transfer from particle physics research. They learn that many different kinds of people become physicists and engineers. They learn to discard the stereotype of the white male scientist in horn-rimmed glasses and white lab coat.

Facing the United States is the problem of assuring an adequate number of scientists and engineers in the next century. In addition, a scientifically literate public capable of making intelligent choices on controversial topics is of paramount importance. The "pipeline" to science careers starts as a broad stream in the early grades and then becomes successively narrower as people proceeding through the educational system drop away from science and mathematics learning at various stages. One crucial narrowing of the pipeline occurs in high school when career choices are beginning to be made. It is at this point in time that Saturday Morning Physics aims to influence students — particularly those who are undecided — to pursue careers in scientific or engineering disciplines.

Students are selected by their principals from the public, private, and parochial school community of over 200,000 high school students. Many students come from Chicago. Groups traditionally underrepresented in science and engineering are reached. From the 34 courses run through the end of 1991, almost 4000 have graduated from Saturday Morning Physics. The continuing high rate of applicants, the interest of the participating schools and their principals, and the enthusiasm of students and their families give evidence to the popularity of the program.

Saturday Morning Physics was the first of many educational programs at Fermilab. Its success has inspired dozens of other pre-college programs at the Laboratory and has been a strong motivating factor for several other endeavors with similar goals outside the Laboratory.



Professor Leon Lederman, Fermilab Director 1979 - 1989, founded the highly successful Saturday Morning Physics program.

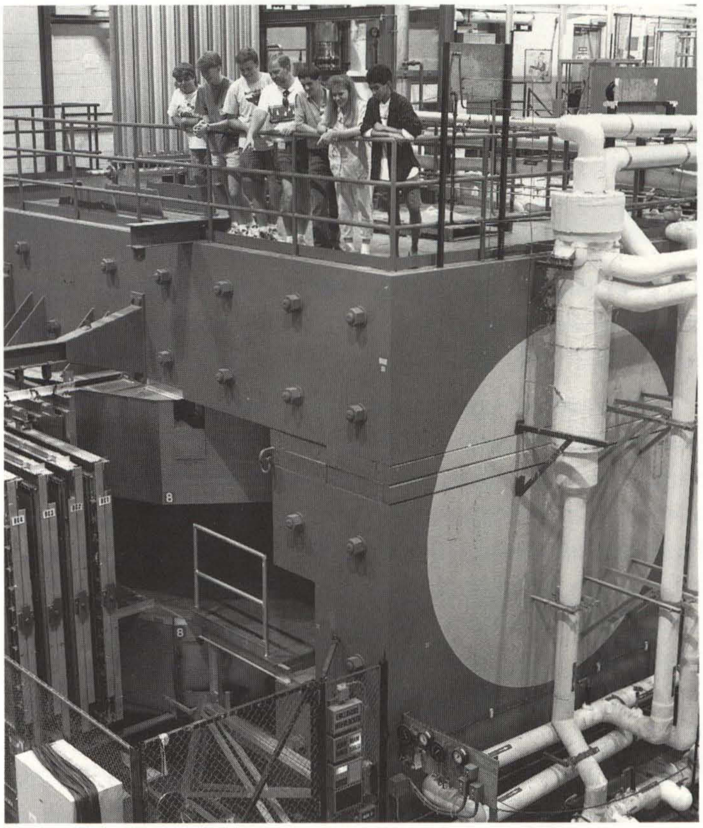
The Year in Pictures - Part II

(Above) In a meadow west of Wilson Hall, an exciting new building gradually took shape in 1991. The Science Education Center will house the Laboratory's pre-college education programs.

(Right) Participants in the Department of Energy's High School Honors Research Program in Particle Physics view a fixed target experiment from atop the Chicago cyclotron magnet in the Muon Lab.

(Bottom) The Fermilab-Educational Assistance Ltd. Summer Science experience is designed to encourage economically disadvantaged students to continue their study of mathematics and science and to enroll in college. Ward Haselhorst (right) demonstrates the measurement of the wavelength of microwaves to an intensely interested group of students.

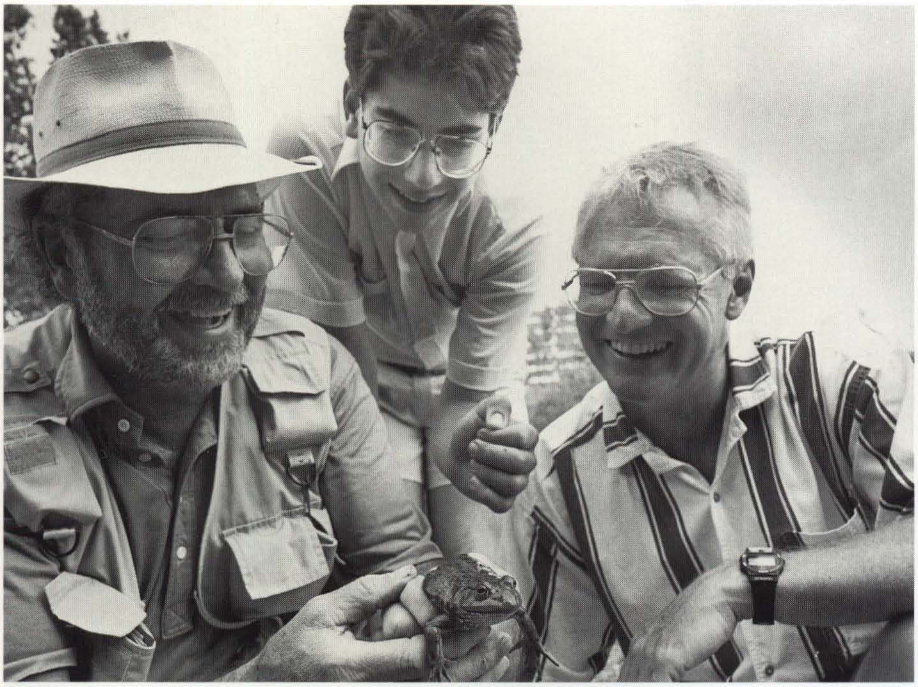
(Bottom of next page) A student demonstrates an interactive video under the watchful eye of its developer, Elizabeth Quigg, during a corporate-media visit, sponsored by the Department of Energy, to the Laboratory's various educational programs.



(Below) Participating in a project on wetlands funded by the Department of Energy, Fermilab's Rudolph Dorner (left) shows a frog captured in Indian Creek, which runs between Wilson Hall and the Science Education Center, to a delighted student (David Rode, center) and teacher (Arthur Hammon, right) from New Hampshire.

(Below right) In the spring and summer of 1991, Fermilab hosted a sculpture display sponsored by the Central Time Zone Organization. Works in a variety of media — bronzes, wildflowers, stone, clay and latex, ceramic — sprung up at various sites both indoors and out. Triangles made of mirrors and stainless steel float in the reflecting pond in front of Wilson Hall while a Mirror Man (bottom) strides on the stones next to Ramsey Auditorium.

(Above) The Teacher Resource Center will be an important part of the Science Education Center. This specialized library will serve as a clearinghouse for ideas, materials, and resources for local educators.

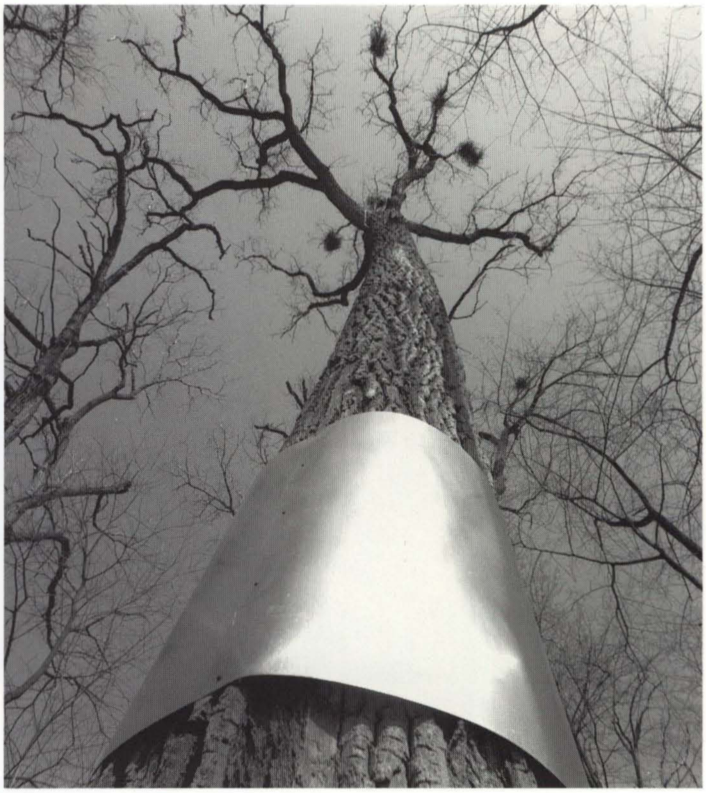


(Below) The Roads and Grounds crew collects more than 6000 bales of hay each year for Fermilab's herd of buffalo. Clarence Winders drives the tractor, while Robert Lootens (center) and Michael Becker stack the bales on the hay wagon.

(Below right) Since 1985, the great blue heron has found comfortable nesting grounds at Fermilab. Prior to the 1991 breeding season, at the recommendation of an ornithologist, predator shields were placed around trees in the heron rookery to protect the nests from attack by ground animals.

(Bottom) On Arbor Day, an annual event demonstrating Fermilab's long-time commitment to the environment, Richard Cantal (left) and James Shultz (right) carefully position one of the 1000 saplings planted south of Wilson Road.

(Above) A science laboratory with stations for 40 students, a classroom and office space are included in the Science Education Center.



(Below) A specially designed and stocked high-cube van became the moving "office" for Fermilab's locksmith Earl Shaffer in 1991. With supplies readily available, the new vehicle allows for increased productivity and expanded operation. The maintenance of hinged fire doors as required by OSHA standards has been a major emphasis in 1991.

(Right) In 1991, the Publications Office processed more than 400 technical papers on various aspects of Fermilab's research. Cynthia Crego (right) double-checks a listing with Susan Hanson while Elizabeth Gonzalez types a title page in the background.

(Bottom) Members of the Alignment Crew, Richard Graff (left) and Charles Wilson, use the three dimensional triangulation measuring system to record the position of various components in the CDF upgrade. Hard hats are a safety measure.

(Above) The Science Education Center is a low profile, one-story structure in the Prairie School style. Accentuated by its placement on an earthen mound, the building is surrounded by both woods and prairie to provide outdoor laboratories for visiting students.

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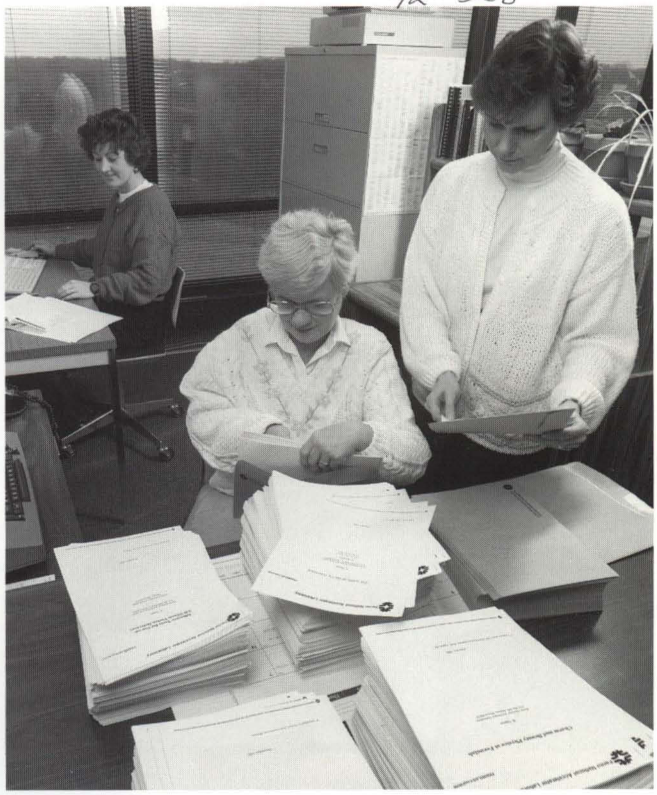


(Below left) In 1991, Rod Walton, coordinator of Fermilab's Environmental Research Park, installed a comprehensive, solar powered weather station to gather, more precisely and efficiently, meteorological data for the Laboratory.

(Below right) Alex Elwyn of the ES&H Section adjusts the antenna on the Mobile Environmental Radiation Laboratory (MERL) whose telemetry system provides information on the intensity of the primary proton beam. MERL monitors doses due to penetrating radiation to ensure that they remain within the limits specified by the Department of Energy.

(Bottom) The Environment, Safety and Health Policy Advisory Committee (ESHPAC) has formulated policy, produced an action plan for the Fermilab internal assessment, developed an ongoing self-assessment plan, and reviewed training procedures, current documents, and Department of Energy orders.

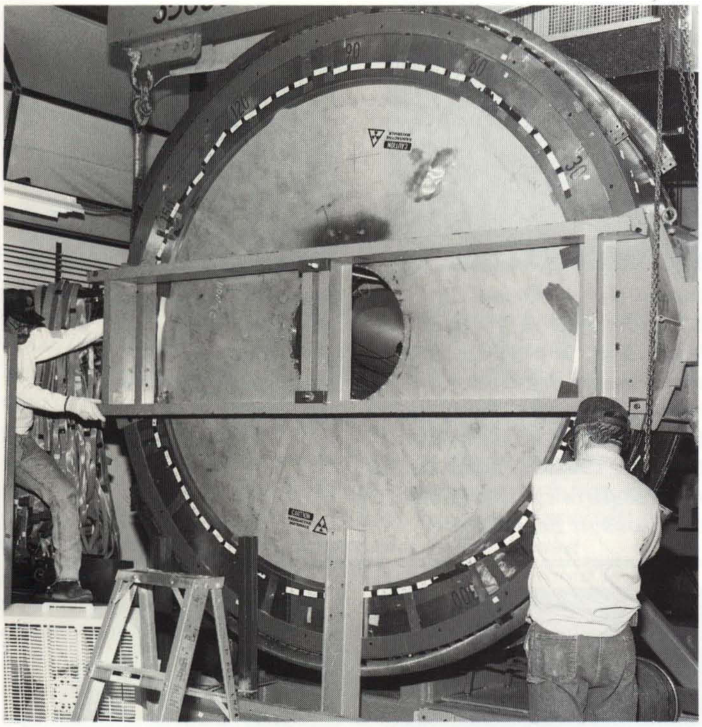
(Above) Quarks to Quasars, a series of interactive teaching stations, will encourage informal science learning through hands-on activities and intriguing displays. The topics covered include accelerators, detectors, collisions and scattering, colliding beams, and the structure of matter.

(Above) In the years ahead, the Science Education Center will provide students, teachers, and visitors of all ages an exciting look at some of the significant scientific achievements of our time.

(Below left) At the Meson Test Beam, Lawrence Harris (left) and Richard Brown install the plug electromagnetic calorimeter, designed to reduce sporadic electrostatic discharges, on the test fixture.

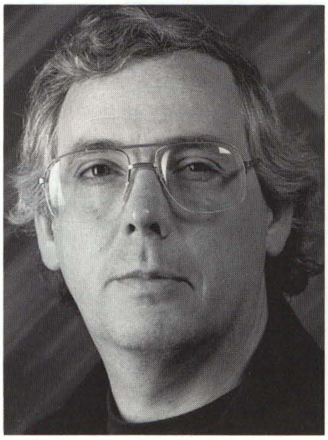
(Below right) Robin Denham of the Physics Department prepares to test the electronics for one of the 164 proportional drift tube chambers for muon identification built for DØ.

(Bottom) Dale Robinson welds the segment frames for the Conical Muon Extension Chambers, part of the CDF upgrade.

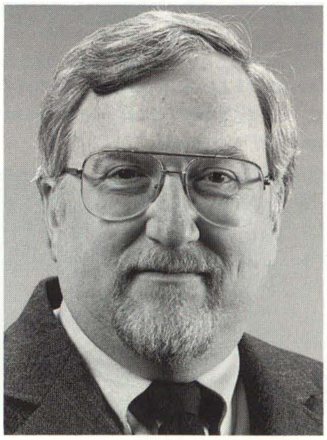


Honors and Awards

The American Physical Society (APS) designates for Fellowship those members who have contributed to the advancement of physics by independent, original research, or who have rendered some other special service to the cause of science. Election to the highly prestigious fellowship is limited to no more than one half of one percent of membership of the APS's Division of Particles and Fields.

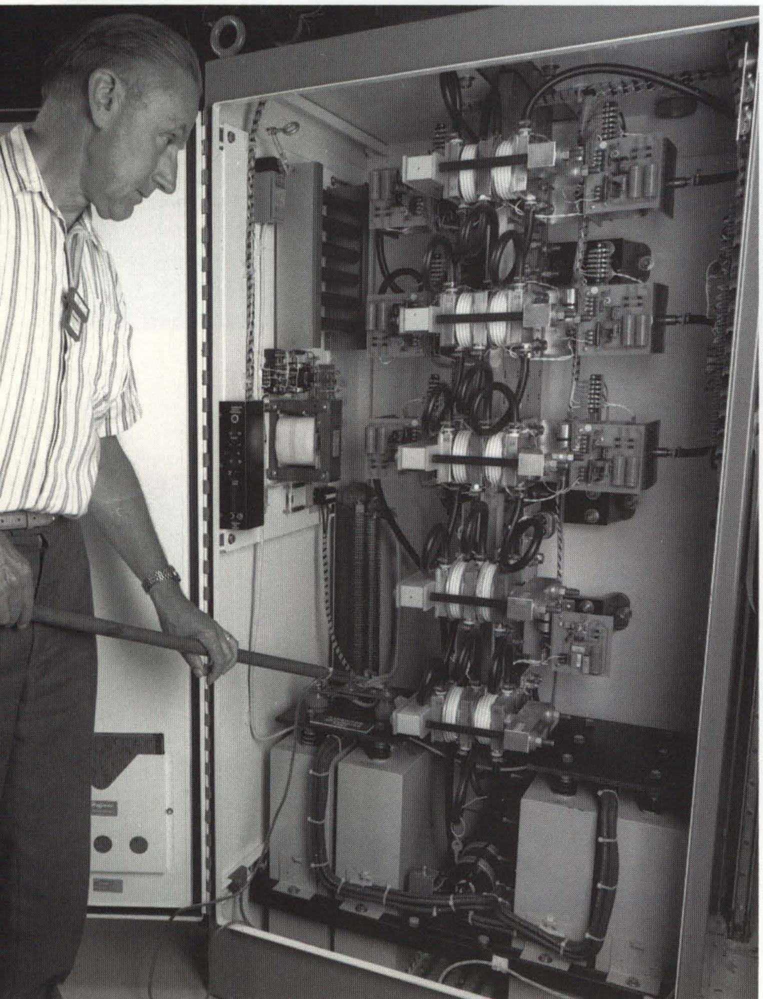


Daniel Green, Research Division, elected "for his leadership in particle physics experiments including the muon system for the Fermilab DØ detector, the SSC Solenoid Detector Collaboration and in several physics administrative positions at Fermilab."

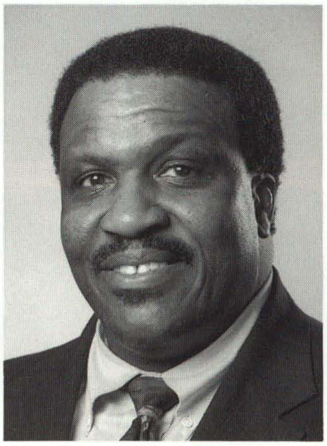


Dennis Theriot, Associate Director, elected "for his crucial leadership in the construction of the CDF detector."

(Below) In 1991, Fermilab was named one of the recipients of the esteemed R&D 100 AWARD for the High-Amperage Solid State Switch (HASSS). Developed by electrical engineer Age Visser, HASSS can continuously carry direct currents as high as 10,000 amperes and switch them off in less than 150 microseconds. In the design and successful operation of the superconducting magnet test program, it is crucial to have a device such as the HASSS to switch the stored energy to an external resistor when a fault is detected. The HASSS accomplishes this task in a reliable, elegant, and cost-efficient manner. Unlike conventional circuit breakers which have a limited lifetime, the HASSS has no mechanical parts and can be used over and over again in any application where high-current, high-voltage, high-speed dc switching is required. With this annual award, the publishers of R&D Magazine recognize the achievement of significant new technology. This year Department of Energy laboratories won over one-third of the awards.



In January 1991, Richard Auskalnis, Business Services, was named president-elect of the 34,000 member National Association of Purchasing Management, Inc. (NAPM), a not-for-profit organization which provides national and international leadership in purchasing and material management research and education. NAPM provides its 169 affiliated associations with opportunities to expand their professional skills and knowledge.



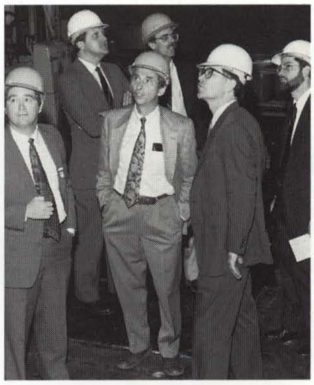
This year the Laboratory won the Creative Excellence Advertising Award for Best in Category for College Recruitment. The Employment Management Association, a national network of employment and human resource professionals, presented the award to Jordan Tamraz Caruso Advertising. James Thompson, Laboratory Services, accepted on behalf of Fermilab.

Notable Events

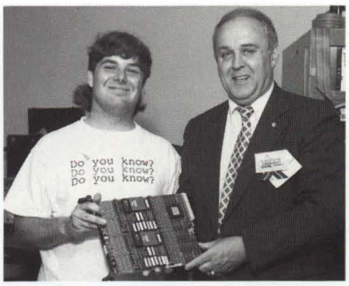
In August 1991, Fermilab and IBM, Inc. dedicated a powerful new computing facility that sets the standards for cost-effective, high-performance computing. The system, consisting of a farm of 68 IBM RISC SYSTEM/6000 workstations, enables individual processors to cooperate on parallel solutions of demanding computer problems. Present at the dedication were, from the left, Director John Peoples, John Armstrong, IBM Vice President for Science and Technology, and Thomas Nash, Head of Fermilab's Computing Division. The computing farm was dedicated to the memory of former Fermilab employee Charles Kaliber.

At the invitation of Illinois Congressman Dennis Hastert, whose 14th congressional district includes Fermilab, four congressmen from key House committees visited on June 17. During their tour, the delegation visited the 15th floor exhibit and observation area, the ACPMAPS supercomputer, the Education Office and CDF. In addition, the Congressmen posed with students from their states participating in DOE's High School Honors Research Program.

From the left, Director John Peoples describes the Main Injector location for Congressmen John Rhodes (Arizona) and Dean Gallo (New Jersey).



Congressmen and Fermilab staff marvel at the huge size of CDF. Congressman David Skaggs (Colorado) is on the right foreground.

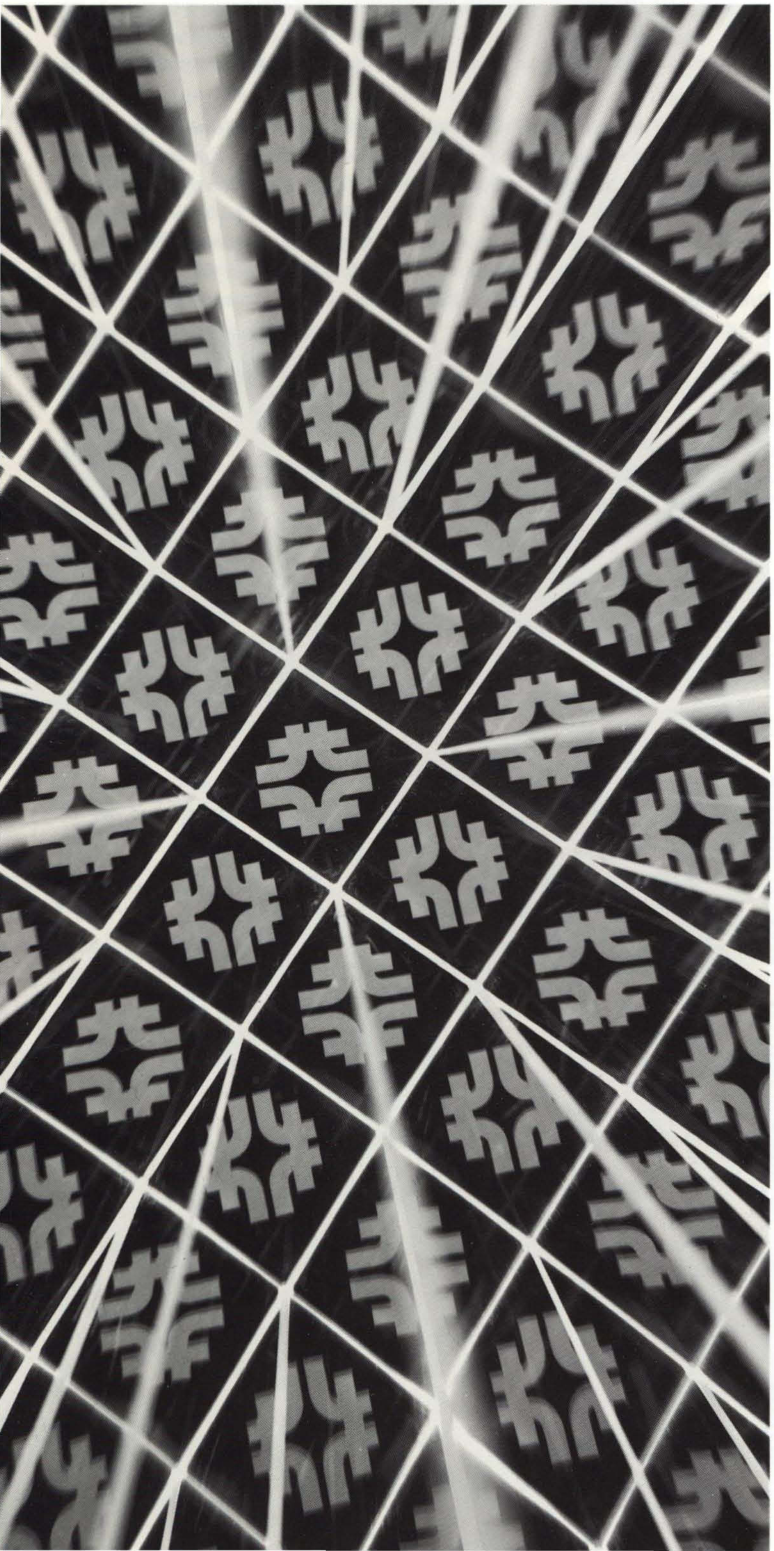


Congressman Carl Pursell (Michigan) hands a computer board to DOE Honors student John Scholten, also from Michigan.

Congressman Dennis Hastert (center) of Illinois discusses the summer educational program with a student as John Peoples (left) listens.

(Below) On December 30, 1991 the Department of Energy (DOE) extended its contract with the Universities Research Association, Inc. (URA) for the continued operation of Fermilab. The five year contract will be in effect through December 30, 1996. The Department of Energy and its predecessor agencies have funded the construction, operation, and continuing research program at Fermilab since 1967. Universities Research Association, Inc. is a consortium of 79 major research-oriented universities in the United States and Canada. Seated in the Art Gallery on the second-floor crossover for the signing ceremony are John Toll, President of URA, (left) and John Kennedy, Acting Deputy Manager, DOE Field Office, Chicago. Standing, Fermilab Director John Peoples (left) and Andrew Mravca, Manager of DOE's Batavia Area Office, witness the signing.

Acknowledgements



We want to thank most warmly each and everyone of the contributors to the *1991 Annual Report*. They have recorded for posterity the many Fermilab accomplishments of 1991. We apologize, if, in the editing process, we have introduced an inaccuracy or removed some subtle intention.

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(Universities Research Association, Inc.)

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University of Alabama, Tuscaloosa

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Arizona State University

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University of California, Irvine
University of California, Los Angeles
University of California, Riverside
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