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1994 ANNUAL REPORT

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FERMILAB A Department of Energy National Laboratory

FERMILAB IN 1994

Fermi National Accelerator Laboratory is a Department of Energy national laboratory operated by Universities Research Association, Inc. for research in particle physics. At Fermilab, university physicists from across the nation and around the world explore the fundamental nature of matter at the smallest scale, deep within the structure of the atom.

The world's most powerful particle accelerator, Fermilab's Tevatron, accelerates the subatomic particles called protons to high energy. When high-energy protons collide with other particles, the collisions can sometimes reveal the deepest secrets at the heart of matter.

In 1994, the Tevatron created more high-energy collisions than ever before. From the data describing these collisions came the world's first experimental evidence for the top quark, announced at Fermilab on April 26, 1994. During the same year, work progressed at Fermilab to upgrade accelerators and detectors into ever more powerful research tools. Preparations intensified for a new group of experiments beginning in 1996, using Fermilab's unique particle beams.

In 1994, Fermilab confirmed its current role in keeping the U.S. among world leaders in the science of particle physics and strengthened the Laboratory's capabilities for the future.

FERMILAB A Department of Energy National Laboratory

ANNUAL REPORT 1994

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Laboratory Mission

Fermi National Accelerator Laboratory advances the understanding of the fundamental nature of matter and energy by providing leadership and resources for qualified researchers to conduct basic research at the frontiers of high-energy physics and related disciplines. Fermilab fosters and stimulates science education, transfers to industry technologies developed at the laboratory, and conducts operations with the goal of excellence in health, safety and the protection of the environment.

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COLLABORATION

Particle physics has never been a solitary science.

Today, more than ever, it is a partnership—of nations, laboratories, universities, government, industry, and men and women of all ages, races and backgrounds. As a particle physics laboratory, Fermilab, too, is a partnership, a collaboration of people working together in many different ways to achieve a mission of scientific leadership at the frontiers of particle physics research. In the pages that follow, Laboratory employees explain the individual parts they play in Fermilab's collaboration to explore the fundamental nature of matter and energy.

ROBERT WILSON
EMPLOYEE #1

As a young man, I...worked hard to attain that exalted image of scientific purity—the lone scientist in pursuit of truth. But my search for truth led me deep into the nucleus of the atom, and it is almost as hard to reach the nucleus by oneself as it is to get to the moon by oneself. To reach the moon, one must join a large team, and to reach the nucleus, one must also use the help of others.

IMRE GONCZY #4702

For the past 20 years, I have worked as a technician building magnet components for the Fermilab accelerator. I have spent many years winding coil, first for conventional magnets and then superconducting magnets for the Tevatron and the SSC. I have spent the last three years building "pans" containing scintillating tiles and optical fibers for the future upgrade of the Collider Detector at Fermilab.

The work that is done on magnets by myself and other technicians allows the particle accelerators to run. There would be no beam without the Tevatron magnets to keep it on its track. Work on detectors supports the scientific mission even more directly by allowing physicists to see the particle collisions. My work at Fermilab has therefore helped the Lab achieve its goals in different ways. The magnet work allows the particles to collide, and the detector work helps physicists see the results. I believe our contribution will help Fermilab continue to be the leader in particle accelerator technology.

"It is almost as hard to reach the nucleus by oneself as it is to reach the moon by oneself."

Director Emeritus Robert Wilson

REGINA RAMEIKA #5652

I have been deputy head of the Research Division for the past three years. The division head, two associates, and I manage Fermilab's approved experimental program: we determine schedules, budgets, and staffing for the design, construction, installation, and operation of the physics program.

The Lab's mission is to use its facilities to explore the fundamental questions of elementary particle physics. Though the most important ingredients in doing this are intelligent, creative ideas, they can only come to fruition with strong technical

and administrative support. The Research Division supplies the means to get the former and directly provides the latter.

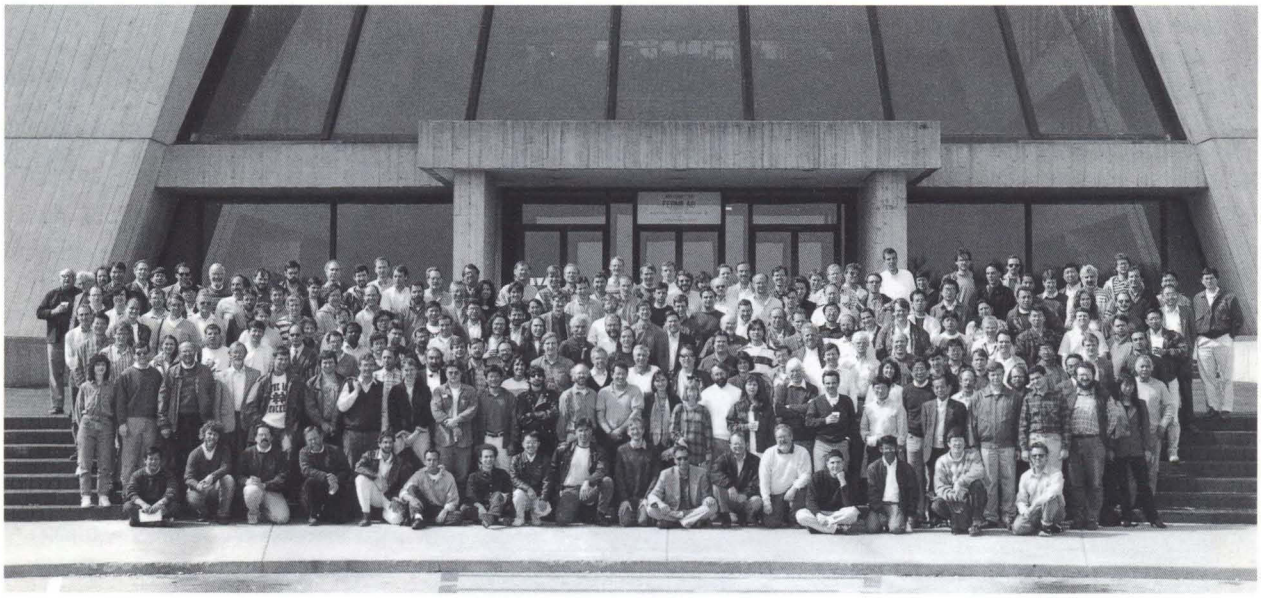
As a scientist, I have also spent the past two years developing the scientific, technical, and management case for an experimental initiative to use protons from the new Main Injector to produce a neutrino beam for experiments to explore the exciting question whether the neutrino has mass.

ED CRUMPLEY #6878

I manage the Facilities Engineering Services Section Engineering Group, responsible for design and construction of new facilities and remodeling of existing ones.

MARCEL DEMARTEAU #10291

I'm a physicist working on one of the two big collider experiments at Fermilab. My research interests go out to the precise measurement of the parameters of the electroweak interaction. A typical day for me consists of analyzing events from the proton-antiproton interactions that contain a *W* or *Z*-boson. Another duty is the coordination of the electroweak analyses within the collaboration.



Members of the Collider Detector Facility at Fermilab assembled on Wilson Hall's front steps. The collaboration had just decided to announce the first direct evidence for the top quark.

DAVE PUSHKA #10239

I'm an engineer working on the new KTeV experiment. I take conceptual, sometimes loosely defined needs of scientists and, with the help of draftsmen, machinists, welders, and technicians, turn them into physical devices.

Scientists at Fermilab do experimental high-energy physics. Part of doing experimental physics is deciding what device designs are best for making desired observations. Besides performance, safety and cost are design inputs to achieve optimum performance at minimum cost with absolute minimum hazards to people or the environment.

My part in supporting Fermilab's scientific mission is to promote teamwork within our engineering group and across other groups in FESS in reaching out to our customers. When I can do this for the teams (and remove administrative and bureaucratic barriers from their paths), they provide the Lab with a facility base from which to run the accelerator and conduct experiments.

I view Fermilab's scientific mission as trying to provide clues and perhaps some answers to aspects of the question: Why is nature the way it is? A particular aspect studied at Fermilab is the structure of the fundamental interactions. My daily work, sifting through the millions of proton-antiproton collisions and trying to make precise measurements of parameters of the electroweak interactions, provides direct insight into their structure.

JOHN PEOPLES #1653

With the help of 2,100 Fermilab employees and nearly 2,000 visiting scientists, most of them from the institutions that sponsor Universities Research Association, I direct Fermilab for the Department of Energy and the scientific community.

Within the framework of the mission established by the Department of Energy and the Congress of the United States, I set the direction for Fermilab's scientific program. As times change, I choose appropriate new scientific directions for our program, since our understanding of the fundamental properties of matter and our views of the origin of the universe do not stay confined in a nice, tidy box, but are forever changing. I give much of my attention to environment, safety and health, since a scientific program without these elements cannot long succeed.

I must assure Universities Research Association, the Department of Energy, and the U.S. Congress that the Laboratory is using public funds for the purpose the government intends. Perhaps most important, and most challenging, is to persuade all of these folks that the pioneering science we do at Fermilab is both exciting and of benefit to the nation.

Members of the DZero collaboration in their detector's Assembly Hall.

KAREN KEPHART #3119

My job is to juggle time, manpower, and space in order to deliver high-quality prototypes and finished detectors to experiments supported by the Fermilab Physics Department. I lead a group of mechanical technicians who specialize in wire chambers, tile and fiber calorimetry, and related prototype and R & D detectors.

Directly, I support the scientific mission by providing hardware for particle detection. Indirectly, I have attempted to create an environment where experimenters can come with anything from vague ideas to concrete approved projects and find both intellectual and physical resources to help them. Our group has come to function as a "clearinghouse" for information on related projects, on who has done what, with what success, to solve similar problems.

"As times change, I choose appropriate new scientific directions for our programs, since our understanding of the fundamental properties of matter and our views of the origin of the universe do not stay confined in a nice, tidy box, but are forever changing."

Director John Peoples

ANGIE VELASQUEZ #2202

We in the cafeteria provide a daily menu for Fermilab employees and users: breakfast, lunch, and snacks. We also provide coffee services, luncheons and dinners for special Laboratory occasions.

I feel that the Cafeteria staff are an important part of Fermilab. We supply coffee and food for many meetings that need to continue without interruption. Most important, for many other employees with busy schedules and deadlines, we provide a friendly atmosphere where they can eat their meals together.

RUTH PORDES #1948

I am responsible for the projects and the people in the Online Systems Department of the Computing Division. As the technical leader of the DART data acquisition project and the production system development coordinator for the Sloan Digital Sky Survey, my jobs are to ensure the success of these projects, and the professional well-being of the people in OLS who work on them. Both these projects are collaborations between technical professionals and scientists.

Professionals in the Computing Division bring technical expertise and experience to bear on the engineering and programming aspects of projects to help scientists do science. In DART, for example, where seven fixed-target experiments are collaborating, our role is to understand the experiments' data acquisitions requirements and find common solutions, to have reliable working systems ready for beam. Progress comes when I look through the glass into the ninth-floor crossover and see groups from E781, E835, KTeV, E831 and OLS working shoulder to shoulder at the test stands, solving their technical problems.

ROBERT JOHNSON #8162

As a purchasing administrator, I do many tasks during the day: I place orders from requisitions; send out quotations to vendors for bidding purposes; return to vendors material that doesn't meet Fermilab specifications; meet with salesmen to hear about new products or new ways of purchasing present products; and answer questions from people in Receiving, Accounting, and throughout the Lab.

Purchasing supports the Fermilab mission by obtaining all the thousands of items that Laboratory operations require, from vacuum pumps and leak detectors, to steel for experiment components, to protective clothing and eye and ear protection.

GREGORY GILBERT #5340

I am a working mechanical foreman in the Facilities Engineering Support Section. I plan, schedule, coordinate, assign, and perform repairs and preventive maintenance. I order parts for jobs in progress and provide documentation and feedback to management and staff.

In my job, I help provide a functional, comfortable, and dependable working and living environment in which the scientific staff and researchers can conduct experiments and accelerator operations. The Mechanical Group performs preventive maintenance and repairs of cooling and heating systems, boilers, pumps, air compressors, cranes, fire hydrants, air handlers, plumbing, low conductivity water systems, domestic water systems, and sewage disposal systems. The way we perform these tasks helps build reliability into the physical plant to maximize scientific operations.

Angie Velasquez, cafeteria supervisor, anticipates the noontime rush in the Fermilab cafeteria.

NANCY GROSSMAN #10429

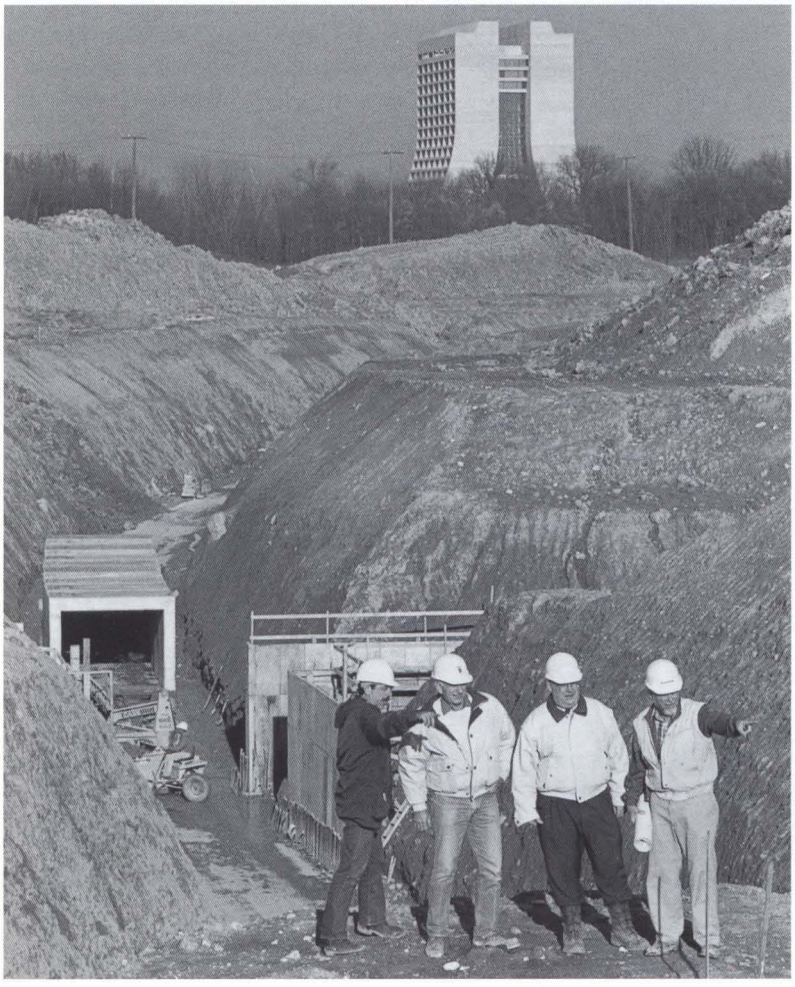
As an applications physicist in the Radiation Physics Group of the ES&H Section, I help make policy and implement orders and regulations for radiation protection at Fermilab. As a member of the DZero collaboration, I work to help improve the detector's signal-to-noise ratio and hence the chances of seeing interesting physics.

For the ES&H Section, I make scientific measurements, such as calculating the muon rates at the site boundary. I help determine the best ways to implement DOE orders, a job we always do with thought for the physics program. As quality assurance manager, I try to find ways to perform jobs more effectively with a view to the Lab as a whole. As a source physicist, I help experimenters determine radioactive source needs for their experiments, provide training, and supply the appropriate radioactive sources to calibrate parts of detectors, determine radiation damage, and test new equipment.

My work in ES&H supports the scientific research community at Fermilab by helping to provide a safe and productive environment. My part in the DZero collaboration gives me a chance to contribute directly to the scientific mission of understanding matter and energy.

"As financial officer for the Main Injector Project, I monitor the financial pulse of the project."

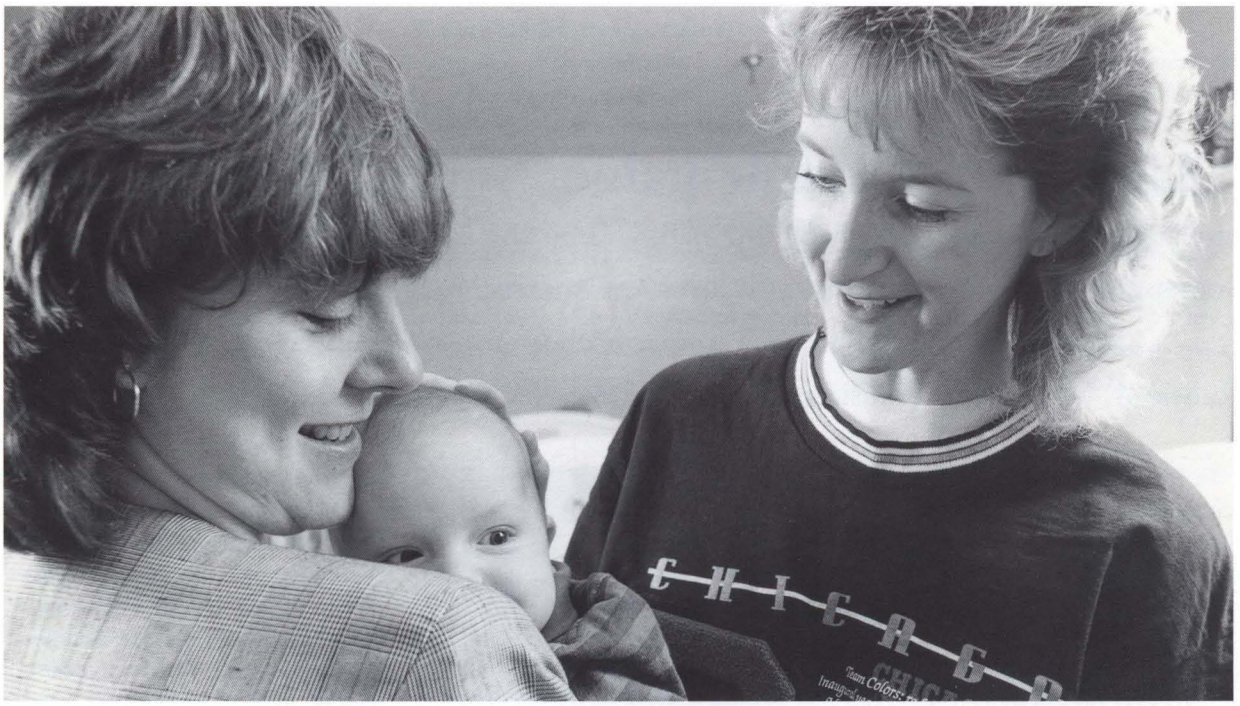
Financial Officer Ann Nestander



Ronald Foutch, from FESS, with Tom Pawlak, Dixon Bogert and Bob Vanecek, all of the Accelerator Division, collaborate on the construction of the Fermilab Main Injector.

ANN NESTANDER #10359

As financial officer for the Main Injector Project, I monitor the financial pulse of the project and provide the Main Injector management team and DOE with information on the financial status of the project. Each month, I review and analyze financial data and prepare a package of financial reports on budgets, obligations, and costs for the project, and on projections for the future. I have also helped develop and implement a Main Injector Project Control System that satisfies DOE and Main Injector management requirements—a particular challenge since the reporting



Robin Dombeck, of the Science Education Center, holding her son Kyle, with Pam Eggleston of the Children's Center staff.

needs of the project differ from those of the Laboratory as whole.

Successful completion of the Main Injector Project is an integral part of Fermilab's vision and strategic objectives. DOE measures our performance in meeting this goal not only from a technical standpoint, but also by whether or not the project is within budget and on schedule.

Annual funding for the Main Injector has consistently fallen short of optimal levels, creating a project schedule that is funding driven. Thus it is extremely important to plan our work so as to use available funds as effectively as possible to advance work on the project. My work gives Main Injector management the information to make informed, responsible decisions about expenditures and scheduling, in turn helping to ensure that we will meet our budget and schedule.

"We support Fermilab's scientific mission by providing a safe, reassuring place for parents to bring their children each day."

Day Care Supervisor Patricia Hedrick

PATRICIA HEDRICK #4702

I supervise the Fermilab Day Care Center, where we provide day care for children from six weeks to six years old, whose parents are employees or users at Fermilab. We teach the children age-appropriate skills and try to meet each child's physical, emotional and social needs.

Our goal at the Day Care Center is twofold. We support Fermilab's scientific mission by providing a safe, reassuring place for parents to bring their children each day. We believe that when parents feel comfortable with their children's care, they are free to work at their greatest capacity. Our work with the children is the second part of our goal—to give every child an opportunity to learn in a loving, safe environment.

"Baseball is a simple game," says the pitcher in the baseball movie *Bull Durham*. "You throw the ball, you hit the ball, you catch the ball. Sometimes you win, sometimes you lose. And sometimes it rains."

Likewise, collider physics is a simple science: You make collisions, you detect collisions, you analyze collisions. And sometimes you make a discovery.

In 1994, the players' strike reminded us that baseball is not such a simple game, and we learned anew that collider physics has its share of complications.

Fermilab's Tevatron collider produces more particle collisions, at higher energy, than any particle accelerator in the world. The two collider detectors, CDF and DZero, record and store the data that describe collision events. The experiment collaborations mine and analyze the data for evidence that may advance our understanding of the elementary particles and forces that determine the fundamental nature of matter. The higher the energy of the collisions, the more likely they are to yield new evidence. The higher the number of collisions, the better the chances of finding a few with the very rare phenomena physicists look for.

During Collider Run Ib, the Tevatron made more collisions than ever before—4.2×10^{12} collisions in one year, and a record of 2.37×10^{11} in one week.

MAKING COLLISIONS—THE TEVATRON IN 1994

Beyond a doubt, the starring role in the remarkable story of collider physics at Fermilab in 1994 belonged to the Tevatron. The story began in September, 1993, with the commissioning of a new linear accelerator, designed to increase the Tevatron's luminosity from $9.22 \times 10^{30} cm^{-2} sec^{-1}$, the record set just before shutdown in Run Ia, to double that level. Run Ib officially got under way on December 14, 1993, after a six-month shutdown to install the new Linac and prepare the rest of the accelerators—the Booster, the Main Ring, the Antiproton Source, and the Tevatron—for the higher beam intensities from the new Linac. The CDF and DZero collaborations had upgraded their detectors to handle improved accelerator luminosities. Plans also called for operation at a record-breaking energy level of 1000 GeV, or 1 TeV—making the Tevatron live up to its name. Hopes were high for the best collider run ever at the Tevatron.

Collider Run Ib Records

Integrated luminosity in one week
$3386\ nb^{-1}$

Luminosity per store hour for one week
$25\ nb^{-1}/hr$

Average initial luminosity for one week
$1.44 \times 10^{31}\ cm^{-2}sec^{-1}$

Store hours per week
138 hours

Single store integrated luminosity
$672\ nb^{-1}$

Antiproton stacking rate for one hour
$6.68 \times 10^{10}/hour$

Average stacking rate for one week
$4.50 \times 10^{10}/hour$

Peak antiproton stack
207×10^{10}

Antiprotons stacked in one week
596×10^{10}

Antiprotons used in one week
582×10^{10}

Quench!

On November 13, 1993, an early attempt to circulate beam in the Tevatron after the shutdown had produced a spectacular—a fateful—quench in a Tevatron quadrupole focusing magnet at the CDF low-beta insertion. A quench occurs when a

superconducting magnet suddenly "goes normal," returning to its non-superconducting state and releasing its stored energy. The Accelerator Division turned off the beam, made repairs, cooled the Tevatron again and resumed operating, reaching for the goal of surpassing an initial peak luminosity of 10^{31} $cm^{-2}sec^{-1}$.

On January 14, 1994, with characteristic optimism, *FermiNews* reported "Run 1B Start-Up Showing Signs of Success." To some in the trenches of the Accelerator Division, however, the signs appeared less promising. Luminosity was not rising as fast as it should. Somewhere, something was wrong; there were many candidates for the problem. To try to identify the difficulty, the Laboratory decided to postpone the attempt to operate at 1000 GeV until the Tevatron had achieved stable operation at 900 GeV, an aim that proved elusive because of the strong coupling of the horizontal and vertical betatron motions. Coupling had always been a problem in the Tevatron, but in the past careful tuning had reduced it to manageable proportions. This time, it took two months to select currents for the Tevatron magnets to allow sufficiently stable operation to study individual sources of the problem in detail.

It must be the Tevatron.

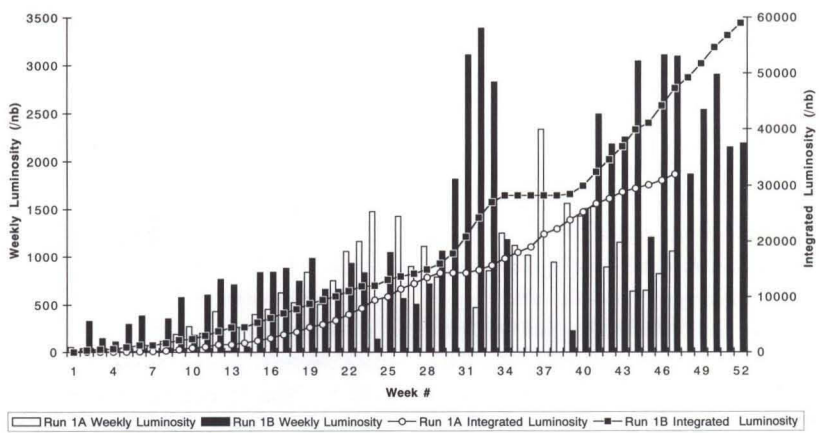
By mid-March, the Tevatron was delivering only about as much luminosity per hour of colliding beams as it had in 1992 and 1993—a disappointing outcome, far from the goal of twice the luminosity per hour. The major modifications to the accelerator complex during the shutdown had clearly improved the performance of the Linac, Booster, Antiproton Source, and Main Ring. The Tevatron itself looked like the source of the problem—a new experience for Fermilab.

April arrived. Although the Tevatron's luminosity was slowly rising, the goal of 25 inverse nanobarns per hour remained well out of reach. To make things worse, the accelerator experienced a plague of equipment problems, including a rash of failures of the aging 13.8 kV electrical power feeders. When a feeder failure causes the Tevatron to expel its inventory of liquid helium, recovery takes three or four days. April turned to May.

In June, the Laboratory was at last able to sustain accelerator operations long enough to search thoroughly for the source of the problems, including the strong coupling. In the last week of July, the source of the strong coupling was traced to the CDF low-beta magnets. A resurvey of all of the magnets in the BZero low-beta insertion revealed that one of the magnets was badly misaligned, rolled to one side, probably as a consequence of the quench of the previous November. Laboratory staff realigned the magnet and retuned the entire Tevatron.

Yes!

Within days, the Tevatron showed a spectacular improvement in luminosity. Fermilab's collective sigh of relief was heard as far away as Glasgow, Scotland, scene of the International High Energy Physics Conference where CDF and DZero collaborators were reporting to the world's high-energy physics community that they had not yet discovered the top quark and would need more data.



The Tevatron's weekly and integrated luminosity in Run Ib, compared to Run Ia.

It was the beginning of a new era in Tevatron operations. Since July 23, the Tevatron has regularly made and broken new performance records, with integrated luminosity per week consistently twice as high as the accelerator had delivered in 1993. A comparison of the luminosity delivered in the 1992–1993 collider run and the 1994 collider run shows the improvement. Data poured into the collider detectors. By December, 1994, the Tevatron had delivered nearly 60 inverse picobarns of integrated luminosity, and luminosity was still going up.

DETECTING COLLISIONS

DZero

Before Run Ib collider operation began, the DZero collaboration made upgrades to the detector and data acquisition system (DAQ), to improve performance and enhance DZero's capability to make the most of higher Tevatron luminosities. DZero ran almost continuously during Run Ib, with an average operating efficiency of 88 percent. DZero logged to tape 32 million events.

Improved DAQ

The instantaneous data rate in Run Ib was predicted to increase by about a factor of two beyond Run Ia's. In 1994, the peak luminosity actually went up by a factor of about 1.6, and DZero's DAQ rate went up by about the same factor. DZero made several improvements to the DAQ system to accommodate the rate increase and to maintain high "live" time for top quark and other searches. Among the improvements: increased readout speed of front-end electronics; hardware improvements to speed up digitizing and read-out electronics; development and use of a new Level 1.5 calorimeter trigger; increases in the Level 2 computing farm memory; replacement of slower processing nodes with faster ones; and a new high-speed data transfer mode from the Level 2 farm to tape.

Besides these changes, the collaboration refined and stabilized the trigger tables that program the DAQ system to collect signal, background, and efficiency measurements, and calibration event samples. As a result, the DZero detector is optimized across the broad range of luminosity conditions presented by Run Ib.

DZero developed successful schemes for triggering on interesting collider signals (including top quark triggers) even in the presence of the Main Ring beam.

The Main Ring passes through the outermost section of DZero's calorimeter. This causes dead time at certain times during the Main Ring antiproton production cycle, when stray particles deposit energy in the DZero detector. The Run Ia experience led to improved instrumentation and ability to detect losses from the Main Ring. After analyzing the losses, we developed successful schemes for triggering on interesting collider signals (including top quark triggers) even in the presence of the Main Ring beam. Not all physics channels can take advantage of this improvement, but many benefit from about 20 percent more luminosity as a result.

Muon detection

Perhaps the most difficult challenges in Run Ib came from the muon detection system. The large area of the detectors makes them susceptible to cosmic ray backgrounds and beam-associated noise that mimic the signature of muons from Tevatron collisions. During Run Ib, we increased cosmic ray rejection by about a factor of 10, by using the precise timing information from the newly installed scintillators that completely cover the upper central muon system.

Early in Run Ia, we noted but did not understand why the detectors in the forward region and other places close to the beam suffered severely from low efficiency. The problem was associated with radiation-induced damage, but the detailed mechanism and magnitude required a multi-faceted effort to understand and, finally, to fix. Significant elements of the solution involved electronics changes to over 200 readout boards on the chambers, and the installation of shield walls to absorb beam halo

"Collaboration between the experimenters and the Accelerator Division has been a dynamic process this run, with good things coming out of it."

DZero Cospokesman Hugh Montgomery

backgrounds that contributed to radiation damage. The most significant finding was that material in the chamber system emitted contaminants into the detector gas, which, when dissociated by radiation, collected to form a sheath on the sense wires. We then found that the coated wire could be cleaned by high-voltage current pulsing, and, further, that the gas contaminant could be removed! This discovery has led to a complete resurrection of almost all the reduced-efficiency muon chambers, and a better life for the physics of muons at DZero.

One byproduct of studies of beam-related background in the muon detectors is the development of a new technique for measuring the accelerator beam parameters at the DZero collision region. This method is useful for independent and precise determinations of the luminosity, and has the potential to improve accelerator performance, since the measurements show that the collider parameters are not as designed.

"Collaboration between the experimenters and the Accelerator Division has been a dynamic process this run, with good things coming out of it," said Hugh Montgomery, DZero cospokesman. "The time spent scraping away beam halo at the beginning of store been reduced dramatically, with a resulting gain in efficiency when the collisions are most intense."

CDF

On December 14, 1993, the Accelerator Division officially opened for business in Collider Run Ib. A month later, on January 19, CDF began taking "good" data—data that might contain evidence for the top quark. The start of data-taking after only one month represents a significant achievement: in Run Ia it took from May until August. Experience made the difference

New DAQ

During the period from February to May, 1994, CDF installed and commissioned a totally new system to record data about particle collisions *while simultaneously running the old system.* The new data acquisition system is the bare-bones version of the system CDF plans to use in Run II, the first collider run with the Main Injector. The new DAQ achieved the goal of taking data twice as fast, to keep up with the luminosity delivered by the Tevatron. CDF also achieved the goal of fewer failures with the newer system. Compared to Run Ia, CDF down time—the amount of time when the detector was out of commission but there was beam in the Tevatron—fell from 7.5 percent to less than 4 percent in Run Ib. As an added benefit, the people who maintain the new DAQ usually get to sleep through the night.

Better triggers

CDF commissioned another improvement during the period from August to November 1994, replacing the old Level 2 processors (specialized computers in the detector's trigger system) with new ones based on the Digital Equipment "Alpha" central processing unit. The old processors, designed in the mid-1980s, used a component no longer on the market; and CDF had scrounged the last one still to be found in the bottom of any engineer's drawer, including the drawers at CERN. The new system proved more reliable. In its first few weeks of operation, CDF had only three hours of downtime from the new system, compared to 34 hours for the old system. Eventually, the new system will also run faster and allow CDF to introduce new triggers.

Competition in the control room

CDF's control room keeps track of the "top ten," the eight-hour shifts with highest total luminosity recorded to tape. The best in Run Ib for 1994 recorded 234 inverse nanobarns

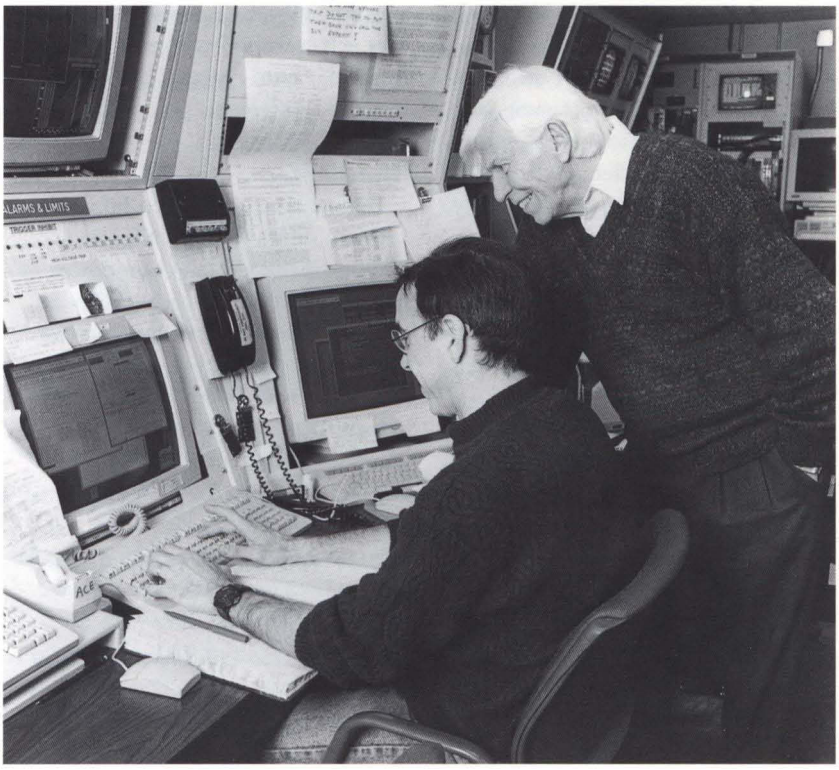
CDF in 1994: Top Ten Shifts

	Date	Shift day starts 0800 eve starts 1600 owl starts 2400	Delivered Luminosity (in nb^{-1})	Luminosity on tape (in nb^{-1})	Efficiency
1.	Aug 22	Eve	274	**230**	84 %
2.	Aug 21	Eve	311	**230**	74 %
3.	Aug 20	Eve	274	**220**	80 %
4.	Dec 23	Owl	246	**212**	86 %
5.	Nov 4	Owl	244	**211**	87 %
6.	Dec 12	Owl	236	**207**	88 %
7.	Dec 12	Eve	259	**204**	79 %
8.	Aug 8	Owl	256	**202**	79 %
9.	Nov 1	Owl	241	**200**	83 %
10.	Dec 9	Owl	223	**193**	87 %

For reference, the 1988-89 run record was 26 nb^{-1} and the Run Ia record was 134 nb^{-1} on tape.

(which translates to about 16.4 billion particle collisions) compared to a best of 134 nb^{-1} (9.4 billion collisions) in Run Ia. Making the top ten is somewhat a matter of luck, but when things are going well a strong sense of excitement pervades the detector control room.

The three top shifts occurred in August, all with substantially the same crew. Alvin Tollestrup was a Consumer Operator on all three shifts. It seemed fitting that one of the people who started it all was there for the CDF detector's best performance.



CDF collaborators Alvin Tollestrup (right) and Joe Incandela in the CDF control room.

ANALYZING COLLISIONS

In the early 1980s, physics experiments at Fermilab were approaching a crisis. High-energy physics analysis used mainframe computers running FORTRAN programs. Physics results lagged behind data-taking by two or three years, due to lack of computing capacity. The need for computing was expected to increase dramatically as the data from experiments increased, and we could no longer afford to buy enough commercial mainframes and minicomputers to keep up. Computing power was limiting the ability to do experiments.

Parallel processing

The Advanced Computing Project set out in search of a solution. They found it by identifying the cheapest, most cost-effective processors capable of solving physics problems and using large numbers of these processors in parallel processing systems. The project required remarkable innovations in hardware and software, and broke ground in computing technology.

The most computing-intensive parts of data analysis at Fermilab are event reconstruction and simulation. Both have a quality called "coarse-grained parallelism;" that is, each event is in principle an independent computing problem. As microprocessors evolved into the basis of the PC industry, market pressures made them the most cost-effective source of computing power. The goal of the ACP project was to develop a system of parallel microprocessors to handle event reconstruction and simulation.

The pieces came together in 1986 when the first generation ACP I systems began analyzing data from fixed target experiments. Future production systems at Fermilab would all be based on the same types of parallel processing farms. The system grew to more than 600 nodes, and was used intensively and successfully by fixed target experiments and by CDF in 1988-89.

Anticipating even greater future needs, the ACP group developed plans for a second-generation system based on a new generation of microprocessors using RISC (reduced instruction set computer) technology. The ACP II systems marked the end of one era and the beginning of another. Commercial vendors had overtaken the ACP engineers, and were now producing commercial workstations harnessing the same RISC technology at extremely competitive prices. Now farms at Fermilab consist entirely of carefully integrated commercial processors.

Farm-fresh computing at Fermilab

The RISC revolution provided new, cost-effective and capable hardware. The computers themselves, as well as the operating systems and compilers, were all provided by the computer manufacturers as part of UNIX workstations, each one a complete computing system. These advances led to fundamental changes in the approach to parallel computing at Fermilab. Now the real effort was integrating workstations into "farms," where many computers worked together to provide large amounts of computing to single jobs using the Cooperative Processes Software tool kit developed at Fermilab. Equally important was providing a comprehensive production environment for experiments, including tape mounts for data input and output, a batch system to allow queuing of jobs, allocation of resources to experiments, and support for the computers and software that ran on the farms.

The UNIX farms started fairly modestly with 25 workstations. Each workstation was a server and had neither screen nor keyboard—access was via the network via ethernet. Twenty-three workstations were mounted in racks on the second floor of the Feynman center. Each node had a connection to the network, a console connection for system management purposes, and a hard disk large enough for the operating system and for swap space. Two workstations were mounted in racks on the first floor of Feynman and had tape drives and other hard disks attached through a SCSI bus. They allowed access to data via the tape drives, provided storage space for programs and log files and control for the farms as a whole.

Once the Computing Division made modifications in the CPS software, it was possible to process entire 8mm tapes (2 GB of data) through reconstruction programs, a big step in the evolution of the farms.

In mid-1991, we added 66 IBM RS6000 nodes to the UNIX farms for a big increase in computing power, and we added a new operating system to the farms. The increased capability motivated us to make many changes in CPS and to the auxiliary tools that provide a complete environment for 24-hour-a-day computing. After a few months of slow improvements, the software, hardware and procedures began to run smoothly, and we were delivering substantial computing power to experiments.

Over the next year and a half the farms rapidly expanded. During this time both DZero and CDF began to use the farms for the off-line processing of data from Collider Runs Ia and Ib. All the features required to handle the data were available: CPU power, software for parallel processing, and the systems required to handle the tape mounts and other services required of a production system. Nevertheless, it required much more work by the experimenters and the Computing Division to improve the systems to the point where they could handle the data from the Collider.

In the end, both DZero and CDF could reconstruct all of their data from Run Ia quickly enough to analyze it in essentially real time. DZero and CDF were both able to reprocess all or part of their data using improved programs after Run Ia ended and before Run Ib began.

As the luminosity of Run Ib increased, we allocated more and more farms to DZero and CDF (and away from fixed-target experiments) until 2/3 of the farms were dedicated to the colliders. Each collider experiment could now keep up with the data being taken—enough data to provide the first experimental evidence for the top quark.

The long R&D efforts in computing have provided spectacular increases in computing capabilities for the experimental program at Fermilab.

The long R&D efforts in computing have provided spectacular increases in computing capabilities for the experimental program at Fermilab. The computing capability goes hand in hand with better detectors, higher intensities, and larger datasets written to tape. Rapid changes will lead to even more innovation and opportunities in the future.

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NEWS RELEASE

For Release 2:00 p.m. CDT April 26, 1994

NEW EVIDENCE IN THE SEARCH FOR THE TOP QUARK

Batavia, IL—Physicists at the U.S. Department of Energy's Fermi National Accelerator Laboratory today (April 26) announced new results in the search for the top quark. The Collider Detector at Fermilab collaboration presented the first direct experimental evidence for the top quark, a subatomic particle that is the last undiscovered quark of the six predicted by current scientific theory. Scientists worldwide have sought experimental evidence for the top quark since the discovery of the bottom quark at Fermilab in 1977.

A research paper, submitted Friday, April 22, to The Physical Review by the 440-member CDF collaboration, presents evidence for the production of top quarks in world-record high-energy collisions between protons and antiprotons, their antimatter counterparts, at Fermilab's Tevatron particle accelerator. The CDF collaboration presented its results at a scientific colloquium held April 26 at Fermilab.

CDF researchers stopped short of claiming discovery of the top quark, however. "We have not yet observed enough examples of top quark production to establish the particle's existence beyond question," said CDF cospokesperson Melvyn Shochet. "Nevertheless, this new evidence points strongly to the existence of the sixth and final quark that we have been seeking for so long."

Shochet added that the collaboration expects data from the collider run now underway at Fermilab to yield enough additional top quark events in the next few months to confirm the particle's existence and to improve the precision of measurements of its mass. The Tevatron is the world's highest energy accelerator, the only one capable of producing the top quark.

"I share the excitement of the scientists at Fermilab and around the world who have contributed to this success," said U.S. Secretary of Energy Hazel R. O'Leary. "These results give new impetus to Fermilab's compelling work exploring the frontiers of particle physics."

Scientists are eager to find and study the top quark, because its discovery would strongly support the Standard Model, the prevailing theory of the particles and forces that determine the fundamental nature of matter and energy. Despite intensive searches at accelerator laboratories in Europe, Japan, and the United States, the top quark has eluded discovery because of its apparent large mass in comparison to other subatomic particles. The more massive a subatomic particle, the more energy is required to produce it in collisions, and the more difficult it is to find.

The Laboratory's DZero collaboration also presented analyses of their top search experiments, providing information beyond recently published results. DZero's preliminary analyses currently show no significant signal for the top quark. "More data are likely needed to reach a definitive conclusion," said DZero cospokesperson Hugh Montgomery.

CDF's particle detector, the heart of the collaboration's experiment, was constructed with funds provided by the U.S. Department of Energy, the Japanese Ministry of Education, Science and Culture (MONBUSHO), and the Italian Institute for Nuclear Physics (INFN), and the National Science Foundation. Besides U.S. scientists, CDF includes physicists from Italy and Japan, as well as Canadian and Taiwanese experimenters. The DZero collaboration includes many U.S. institutions and groups from Brazil, Colombia, France, India, Korea, Mexico, and Russia. Funds for DZero's detector came from DOE, NSF, Russia, and France.

"It is gratifying that after more than a decade of intensive searching," said Fermilab Director John Peoples, "we are beginning to observe direct evidence of the top quark. As our research tools improve, the experimenters will find still more evidence for its existence. The top quark, a subatomic particle that appears to be as heavy as an entire gold atom, may well unlock some of nature's best-kept secrets."

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Operated by Universities Research Association, Inc. for the U.S. Department of Energy

The top quark got the headlines in physics news

at Fermilab in 1994. On April 26, the CDF collaboration announced the first experimental evidence for the long-sought sixth quark of the Standard Model. CDF and DZero spent much of the rest of 1994 in the effort to turn "evidence for" into "discovery of" the top quark.

Besides top quark physics, the collaborations made measurements of *B* meson production, masses and lifetimes and precision measurement of *W* mass and width.

B PHYSICS

The study of *b* quarks tests the theory of perturbative quantum chromodynamics that describes interactions between quarks. The *b* quark will also be of interest for future investigations of the way fundamental symmetry principles are violated in the *b*-quark system. In 1994, DZero focused *b*-physics studies on measuring the effective geometric area of *b* quarks to quantify their probability of interaction with other particles, determining the mechanisms for producing different states of the *b* quark, and investigating the relationship of *b*'s and their antiparticle counterparts. CDF concentrated on measuring the lifetimes of *b*-quark events and searching for rare events.

CDF collaborator G.P. Yeh talks with reporters following the April 26 press conference at Fermilab.

Director John Peoples explains the significance of the new Main Injector for the future of physics at Fermilab.

W MASS AND WIDTH

The determination of the mass of the *W* boson, a particle that carries the weak force, is one of the critical measurements for hadron collider experiments. The *W* lives for a very short time, which means that its energy is intrinsically spread over a range of possible values, a range referred to as the particle's width. Both DZero and CDF measured the mass and width of the W, improving the precision of these measurements over previous attempts.

CHARM PARTICLE SYSTEMATICS

In 1994 the collaborations studying charm meson particles advanced our understanding of how charm mesons decay, or transform into secondary particles. Experiments this year confirmed results from the CLEO detector at Cornell and improved the level of confidence reported earlier in other studies at Fermilab. In 1994, physicists at Fermilab made the first use of a new hadron calorimeter to verify the direction and energy of particles emerging from a decay event; this ability to reconstruct one of the products of the decay allowed the initial observation of a new decay mode.

EXPERIMENTAL ASTROPHYSICS

The Sloan Digital Sky Survey, which will map stars and galaxies to a greater depth than previous surveys, comes within the purview of the Experimental Astrophysics group of the Fermilab Computing Division.

In 1994 the consortium managing the sky survey grew with the addition of the United States Naval Observatory and the University of Washington as collaborating institutions. In August, 1994, the collaboration met to plan the survey, which is to begin data-taking in 1996. SDSS group members deployed the Monitor Telescope at Apache Point Observatory in New Mexico, and began testing calibration methods for the SDSS. The Fermilab Drift Scan camera was also installed and gathered data for a number of projects.

Sloan Digital Sky Survey members deployed the Monitor Telescope at Apache Point Observatory in New Mexico and began testing calibration methods.

The Theoretical Physics Department supports a spectrum of research in theoretical elementary particle physics. Members of the Theory group collaborated with members of the Computer Research and Development Group in the Computing Division to create a large-scale highly parallel supercomputer for lattice gauge theory calculations. The system was operational in 1994 with a peak computing power of approximately 50 Gflops and 20 Gbytes of memory.

In the Theoretical Astrophysics Group, a core of theoretical astrophysicists, expert in both astrophysics and particle physics, conduct research at the confluence of astrophysics, cosmology, and particle physics. They study the very early universe, galaxy formation and dark matter, ultra-high energy cosmic rays, cosmic strings, and the astrophysical implications of new particles. Research topics in 1994 included the origin of density inhomogeneities, primordial nucleosynthesis, supernovae and neutrino properties, solar neutrinos, and the implications of observational results on the cosmic microwave background emission.

Papers Published in 1994

In 1994, scientists and engineers at Fermilab published over 400 articles. The following list includes published journal articles, but not conference proceedings or unpublished reports filed in the Fermilab library as Physics Notes or Technical Memos.

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SEARCH FOR CP VIOLATION IN CHARM MESON DECAY. By E687 Collaboration (P.L. Frabetti et al.). Phys.Rev.D **50** 2953-2956 (1994).

DECAYING LAMBDA COSMOLOGIES AND POWER SPECTRUM. By V. Silveira and I. Waga. Phys.Rev.D **50** 4890-4894 (1994).

GLUON FRAGMENTATION INTO P WAVE HEAVY QUARKONIUM. By E. Braaten and T. C. Yuan. Phys.Rev.D **50** 3176-3180 (1994).

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Progress in elementary particle physics critically

depends on the continuous improvement of accelerators and detectors, and of the entire Laboratory. In 1994, Fermilab made many improvements, including significant progress on the Main Injector project, upgrades of the CDF and DZero collider detectors, and an overhaul of customer service in the Facilities Engineering Services Section.

FERMILAB MAIN INJECTOR

Fermilab physicist and Main Injector Project Manager Steve Holmes describes progress on the Main Injector, a major upgrade in Fermilab's research capability:

The Fermilab Main Injector project is the centerpiece of Fermilab's initiative for the 1990s, Fermilab III. The Main Injector is a new 150-GeV accelerator that will replace and extend the capabilities of the Main Ring. The goals for the Fermilab accelerator complex following completion of the Main Injector project include a luminosity greater than $5x10^{31}$ $cm^{-2}sec^{-1}$, at a center-of-mass energy of 2000 GeV in the Tevatron $\bar{p}$-p Collider, simultaneous with 120 GeV fixed target operation of the Main Injector.

Main Injector Benefits

We are constructing the Main Injector tangent to the Tevatron on the southwest corner of the site. It will be roughly half the size of the existing Main Ring, yet will boast greatly improved performance. The Main Injector will support an antiproton production rate approximately three times the rate we can now achieve and will allow the injection of many more protons and antiprotons into the Tevatron—the key to higher luminosity.

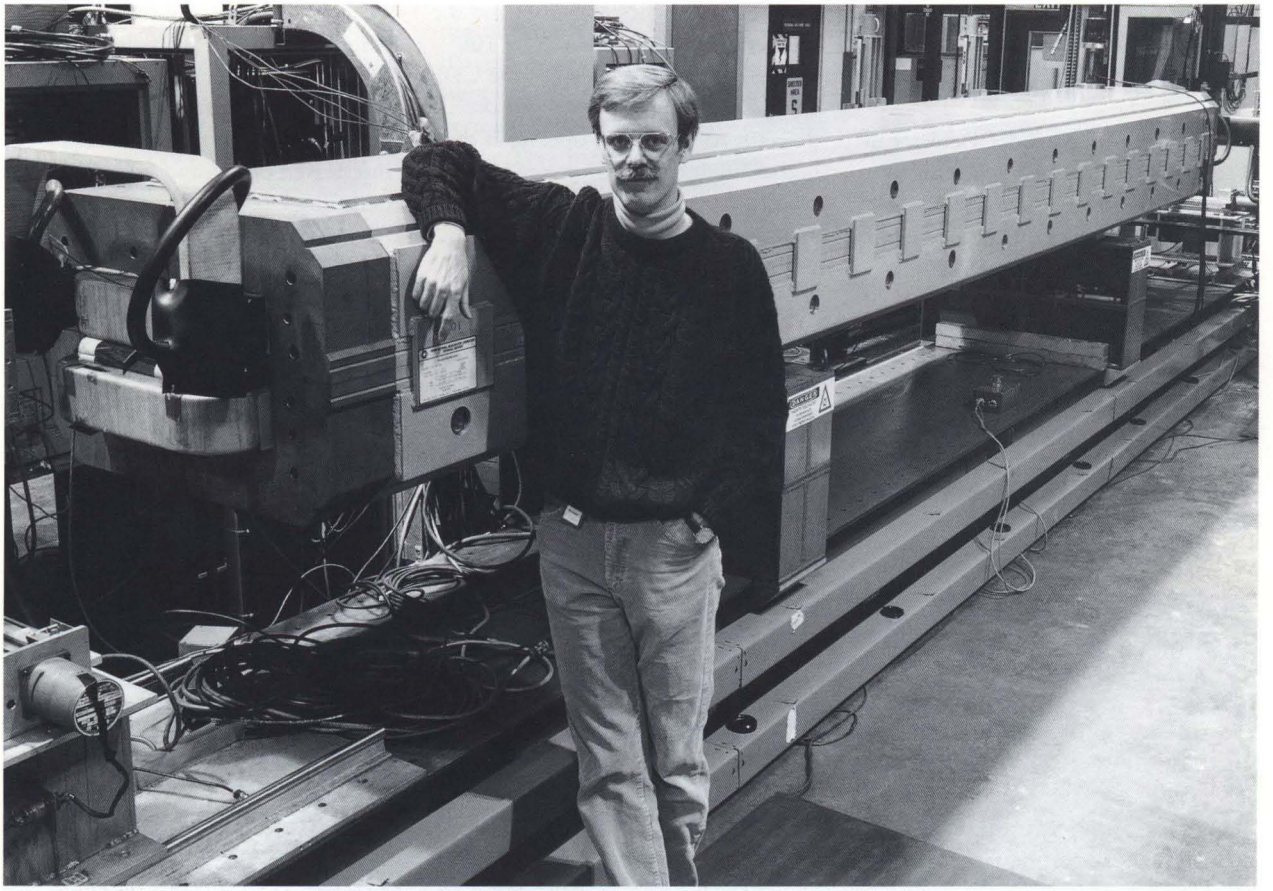
The Main Injector will support the delivery of intense proton beams for use in state-of-the-art studies of the mysterious physical phenomenon called CP violation, and for experiments to search for transmutation among different neutrino generations. Low intensity proton beams from the Main Injector will support calibration and test beams for the development of new experimental detectors for Fermilab and other high-energy hadron colliders.

In contrast to the present configuration at Fermilab, simultaneous antiproton production and Main Injector slow-spill operation to fixed targets will be possible under normal circumstances. We expect Main Injector operations to begin in 1999.

Year of Progress

The Fermilab Main Injector Project entered its third year of funding in 1994 with a $25M appropriation from Congress. In October, Congress appropriated $43M for the 1995 fiscal year. The increased funding has allowed construction activities to proceed on a broad front. In summer 1994, we completed construction of the MI-60 service building and the site preparation work, begun in 1993. By the end of 1994, the project architectural/engineering firm had delivered bid drawings and specifications for all project civil construction packages, with the exception of the 8 GeV/Booster connection work scheduled for 1998. Physical construction of the two-mile long accelerator underground enclosure began in April 1994. This construction was approximately 35 percent complete at the

The Main Injector will allow the injection of many more protons and antiprotons into the Tevatron.



Fermilab physicist and Main Injector Project Manager Steve Holmes stands with prototype Main Injector magnet in the Technical Support Section's magnet test facility.

end of 1994 and should be complete in January 1996.

Work has also proceeded on the technical components of the Main Injector accelerator. We completed the magnet R&D program in January 1994. We devoted most of the spring to managing the transition from R&D to production, both at Fermilab and at the dipole magnet production vendors. By August, dipole magnet production was underway, and by year's end, we had achieved the full production rate of 10 dipoles per month. Quadrupole and sextupole magnet production began before the end of the year.

1994 also saw the successful completion and testing of the prototype dipole power supply. Twelve units, at 1000V/10,000A each, will drive the Main Injector dipole magnet circuit. We operated the prototype unit through several million ramps into a several-magnet string during the fall. Late in the year, we procured a dry (oil-free) transformer for the evaluation on the first preproduction supply.

Three 200 kW power amplifiers required for beam acceleration at 240 GeV/sec were completed in 1994. The associated modulators were nearly complete at the end of the year. We installed one unit on a Main Ring rf station and accumulated several thousand hours of problem-free operations by the end of 1994.

We expect construction activities in FY1995 to encompass nearly all components required for the project. An FY1996 appropriation of $52M will keep the project on schedule for 1999 completion.

CDF UPGRADE

To keep up with increased luminosity in the Main Injector era, both Fermilab collider collaborations must improve their detectors. Fermilab physicists and CDF

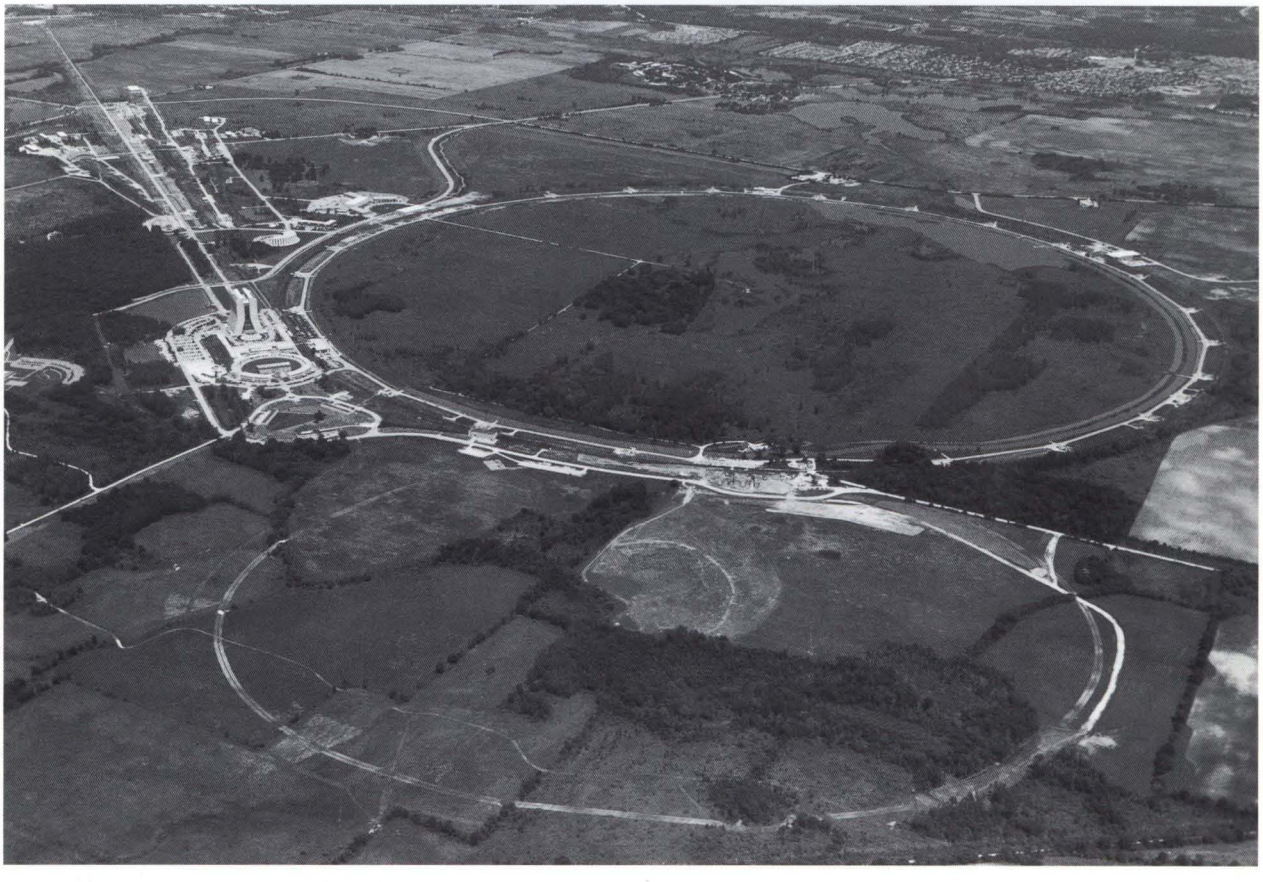
collaborators Cathy Newman-Holmes and Brenda Flaugher describe the changes at CDF:

Most of the Collider Detector at Fermilab was designed and built by 1985, when physicists observed the first proton-antiproton collisions at the Tevatron. At that time the projected Tevatron luminosity was about 10^{30} $cm^{-2}sec^{-1}$ with six proton bunches and six antiproton bunches colliding in the ring, and 3500 nanoseconds between collisions. When the Main Injector begins operating, the luminosity will be about 10^{32} $cm^{-2}sec^{-1}$; there will be at least 36 proton and antiproton bunches colliding; and the time between collisions will be 100-400 ns. The primary goal of the CDF Upgrade Project is to improve the detector so that it can operate at the higher luminosity, with many more collisions per second, and with the shorter time between the bunches.

The End-Plug

We are building new calorimeters to replace existing detectors in the plug and forward regions of CDF. The current detectors are too slow for the 100-400 ns bunch spacing and would have trouble operating at the high beam intensities of the Main Injector. The new calorimeter design features scintillating plastic tiles read out by optical fibers and photomultiplier tubes. Each new end-plug module will have two parts: one made of interleaved plastic and lead sheets, for detecting electromagnetic energy (electrons and photons); and one made of interleaved steel and plastic sheets, for detecting hadronic energy (from pions and other particles). The steel in the current plug hadronic calorimeter will be used in the new plug calorimeter.

The project is an international effort. A group in Japan is building the electromagnetic part of the



An aerial photograph of Fermilab shows the Main Ring/Tevatron in the background and the future Main Injector in the foreground.

calorimeter, while the hadronic part is being built at Fermilab. A group from Italy is working on the high voltage system and the photomultiplier tubes.

During 1994, construction of the new plug calorimeter proceeded on schedule. Collaborators are assembling a module for study in a test beam during the next fixed target run. We will test the electromagnetic calorimeters with cosmic rays late in 1995.

SVX II

CDF has had great success using silicon vertex detectors to identify *b* quarks. These quarks live for a short time before decaying, and their decays thus appear to come from a point slightly displaced from the location of the primary proton-antiproton collision. Silicon vertex detectors locate charged particle tracks very close to the interaction point. CDF is building a new silicon vertex detector, SVX II, because the electronics used by the current one will not stand up to the higher luminosities of Run II. The goal of SVX II is to increase the number of events identified as having *b* quarks. The presence of *b* quarks is critical in identification of top quarks, and physics with *b* quarks is interesting in its own right.

The current SVX covers only about half the region where the protons and antiprotons collide. The SVX II will cover 95 percent of the collision region and have much-improved track identification capability. SVX II will use double-sided detectors to allow particle track reconstruction in three dimensions.

The SVX II project is an international effort, including physicists from Italy, Japan, Taiwan and the U.S. In 1994 much progress was made on the mechanical designs. Prototype silicon detectors were obtained from a number of vendors for testing. The silicon vertex detectors are located very close to the Tevatron beam and thus receive a large radiation dose.

The primary goal of the CDF Upgrade Project is to improve the detector so that it can operate at the higher luminosity, with many more collisions per second, and with the shorter time between the bunches.

Progress was also made on a readout chip being developed jointly with DZero.

Muon Detection

The presence of muons is an important signature for top quark physics. Upgrades of the CDF muon systems include adding more chambers and increasing the speed of the electronics. During 1994, CDF set up a facility for final chamber assembly in the CDF assembly hall, and collaborators constructed a test stand for prototypes at the University of Illinois.

Electronics and Trigger Upgrades

Because of the shortened time between collisions for Run II, virtually all of the electronics systems used to read out the detector will need replacement. In addition, the specialized electronic system used to decide whether or not to study each collision (the "trigger") must be rebuilt to make decisions in much less time. CDF will also add a new processor to help identify *b* quarks at the trigger level. Groups at many CDF institutions are designing and building the electronics/trigger upgrades.

In addition, the data acquisition system must be upgraded to handle higher rates. CDF has already done much of this upgrade for Collider Run Ib, and the new system has functioned well.

THE DZERO UPGRADE

Fermilab physicist and DZero collaborator John Womersley describes improvements to the DZero detector:

The DZero detector has proved to be powerful instrument for the study of the Standard Model. The detector's finely segmented calorimeter, which measures the energy of particles produced in proton-antiproton collisions, and the large angle of coverage for measuring and identifying electrons and muons, have enabled the DZero collaboration to address a wide range of physics.

The goals of the DZero detector upgrade are to maintain the detector's excellent performance in the Main Injector era, when the collision rate in

the Tevatron will increase by a factor of 10, and to extend the detector's capabilities. In particular, the upgrade will improve identification of top quarks by identifying the *b*-quarks into which tops decay. The physics goals for the upgraded DZero detector include making precise measurements of the top quark's mass and decays, measuring the mass of the *W* boson to one part in 2000, and exploring production and decay of particles containing *b*-quarks.

New magnet

The upgrade involves a major addition to DZero: a superconducting solenoid magnet giving a 2 tesla magnetic field. As charged particles from the collisions bend in the field, the detector will measure their momentum using an entirely new tracking system. The system consists of a silicon vertex detector for precise measurement of tracks very close to the interaction point (to identify *b*-quarks) and a set of four scintillating fiber barrels to trigger on and measure charged particle trajectories.

Between the magnet and the calorimeter is another new detector: a scintillator strip preshower detector to improve DZero's ability to identify electrons close to jets of other particles. Experimenters will read out the data from the scintillator detectors using visible light photon counters (VLPCs)—a new type of solid state light detector that operates at liquid helium temperatures.

New electronics

DZero will retain the detector's existing calorimeter system but equip it with new front-end electronics with a faster readout time and lower noise, a requirement for handling the reduced time between collisions in the Main Injector era. The collaboration will rebuild the intercryostat detector, which measures energy lost between the central and end calorimeters in the forward region. A new preshower detector will augment existing calorimeters. The DZero muon system will also receive new electronics. The collaboration will add additional fast detectors to allow unambiguous association of muons with a given beam crossing, and to reduce false triggers from backscattered particles. We will rework the fast electronics that determine when an event is sufficiently interesting to be saved and the data acquisition system to handle the increased data rates.

The goals of the DZero upgrade are to maintain the detector's excellent performance in the future Main Injector era, when the collision rate in the Tevatron will increase by a factor of 10 from today, and to extend significantly the detector's capabilities.

Moving forward

Over the last year, the DZero upgrade project moved significantly forward. The contract to build the solenoid magnet has been awarded, and delivery is expected in late 1996. We completed the detailed design of the silicon detector and ordered the first detector elements. The scintillating fiber detector design with its new VLPC readout has been extensively tested using cosmic rays. Each layer of fibers is 99.6 percent efficient. The latest VLPC design has a dramatically reduced noise level, and is stable for many months. The preshower detector design is being tested, with construction to start next year. The new calorimeter electronics design is complete, and we are buying components.

In situ tests in the present DZero detector are underway for the new muon trigger detectors. A major effort to understand how we will trigger the upgraded detector has begun.

Project management for the upgrade is also in place. DZero has made a grounds-up cost estimate and compiled a detailed schedule for fabrication and installation. It shows the upgraded detector ready to roll into the collision hall in January 1999—and to advance still further DZero's goal of producing first-rate physics at the world's highest energy accelerator.

FESS GETS A NEW MISSION

Section Head David Nevin describes changes in the Facilities Engineering Services Section designed to help keep the data flowing at Fermilab.

In 1994, the Facilities Engineering Services Section adopted a new mission statement: To establish and maintain a dependable base from which high energy physics and other Fermilab programs can be accomplished without interruption.

The new mission set the stage for internal changes in the way FESS conducts our day-to-day business. We began by focusing on what our customers want and expect from FESS. We conducted a survey of our internal and external customers, and determined what areas needed improvement. We established measurements to help us detect change as we set about to improve in those areas. We set up monthly meetings with customers in order to improve communications and speed up response time. We set up a new computerized maintenance management system (CMMS) to strengthen corrective and preventive maintenance, allowing us to leverage our resources better and be ready to act whenever the opportunity to work on mission-critical equipment arises.

On the Engineering side, we reorganized into a matrix-based system, allowing project engineers to form multidisciplinary teams, as needed, to solve complex problems presented by our customers. In the field, supported by our environmental and safety professionals, our engineers continued to provide safe and effective oversight for the many projects and tasks assigned them.

Sitewide, FESS continued its effective stewardship of the Fermilab prairie, bison herd and property, enhancing the overall appearance of the site and providing inviting surroundings for use by employees, users and visitors.

Facilities Engineering Services Section Head David Nevin. The section adopted a new mission statement: "To establish and maintain a dependable base from which high energy physics and other Fermilab programs can be accomplished without interruption."

GETTING READY TO RUN

In 1994, a double handful of Fermilab experiments

stepped up preparations for the next fixed-target run at the Tevatron in 1996 and 1997. Fermilab has become a center for the study of the heavy quarks discovered over the past two decades. Some of the first indications for charm, and many of the best studies of charmed particles, including elegant measurements of their lifetimes, have come from Fermilab experiments. The fifth (*b*) quark was discovered at Fermilab in 1977, with the observation of the upsilon particles. Study of the spectrum of those particles established the universality of the force that acts between quarks.

The existence of a third generation of quarks, the *b* and the *t* (for which Fermilab announced the first experimental evidence in April 1994), may provide the key to understanding the tiny flaw in nature's mirror known as CP violation, an essential ingredient in producing the observed excess of matter over antimatter in the universe. Fermilab has become one of the world's centers for the study of *b*-quarks and is the only place on the planet to study top quarks.

The Fermilab fixed target experiments that will begin running in the spring of 1996 will continue these studies. Each major experiment will emphasize precision measurements of parameters revealed in the past decade as key to our understanding of the Standard Model of particles and interactions. Each experiment constitutes a kind of specialized "laboratory" for the study of a question not easily accessible in the collider environment. If we think of collider experiments as power tools for attacking the questions of particle physics, we might think of the fixed-target experiments as a set of surgical scalpels for their dissection.

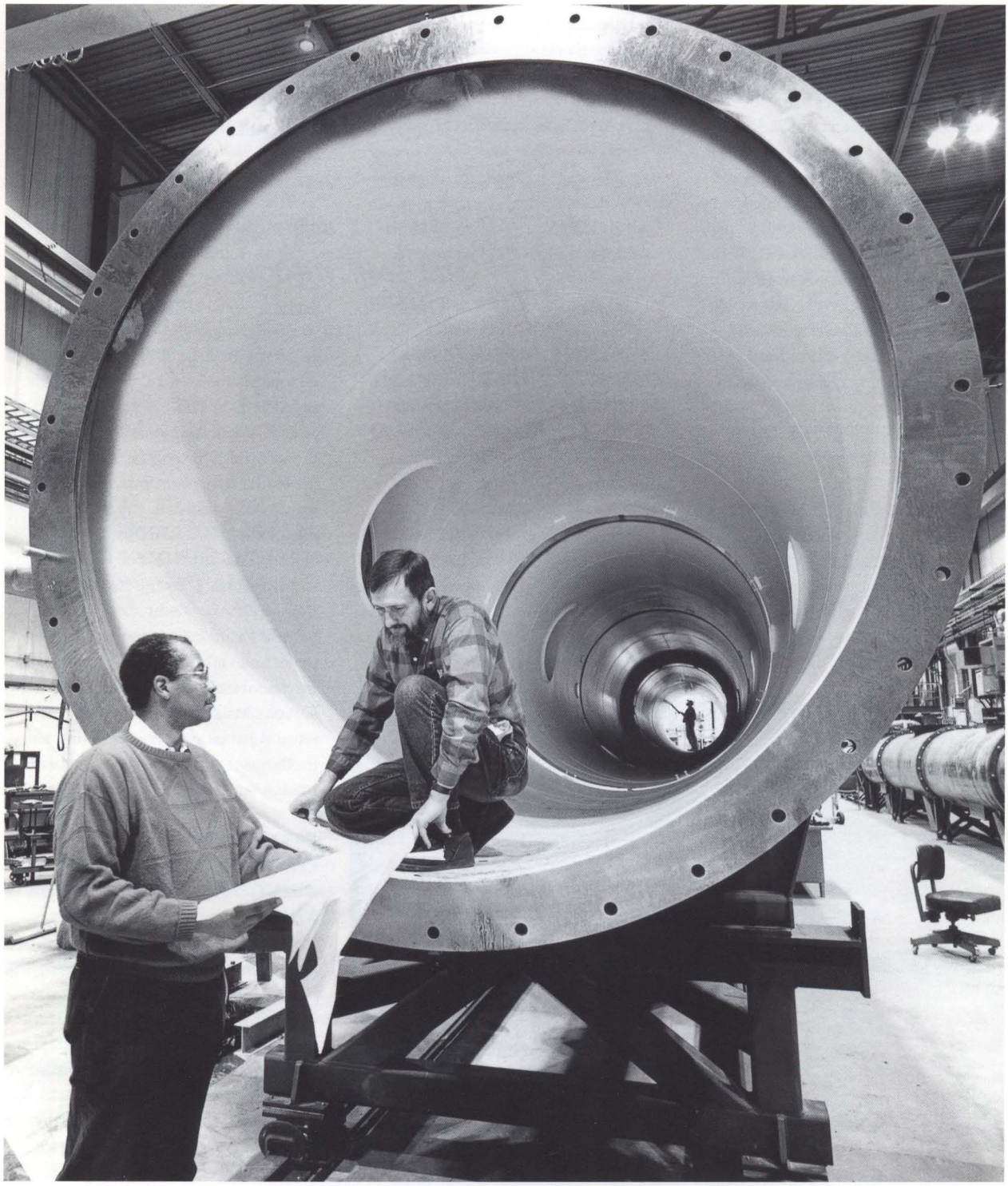
E781 "STUDY OF CHARM BARYON PHYSICS"

E781 has the goal of creating and precisely measuring a new state of matter containing charm and strange quarks. The experiment will use a hyperon beam to enhance production of charm-strange particles. Scientists will design the detector to look at this area of physics under a different lamppost from earlier experiments.

If we think of collider experiments as power tools for attacking the questions of particle physics, we might think of fixed target experiments as a set of surgical scalpels for their dissection.

E815 "PRECISION MEASUREMENTS OF NEUTRAL CURRENT INTERACTIONS"

Research in particle physics over the past sixty years has produced a remarkably successful theoretical picture describing matter and energy as built of certain constituents, interacting through specific forces according to known physical laws. Yet despite its success, this picture also raises profound questions that present opportunities for discovery. Physicists test the Standard Model by doing high-energy physics experiments designed to measure the properties of the particles an fields of the model and to probe the way the pieces interact. E815, "Precision Measurements of Neutral Current Interactions" is an experiment designed to make very precise measurements of certain parameters of the Standard Model. Within the context of the Standard Model, these parameters can be transformed into measurements of the masses of the *W* and *Z* bosons, the carriers of the weak



KTeV collaborator Herman White (left) with Henry Koecher of the Research Division with a vacuum chamber for the KTeV experiment.

force. E815's measurements of the *W* mass will be competitive with direct measurements made by CDF and DZero in collider runs. Combining the direct and indirect measurements will provide a precise test of our understanding of the Standard Model. E815 will also measure the ρ ("rho") parameter, equal to one in the Standard Model. If the experiment finds a deviation from one in this parameter, the finding would indicate a correction to the Standard Model and might point toward possible signatures of the Higgs boson.

E831 "HIGH STATISTICS STUDY OF HEAVY QUARK STATES"

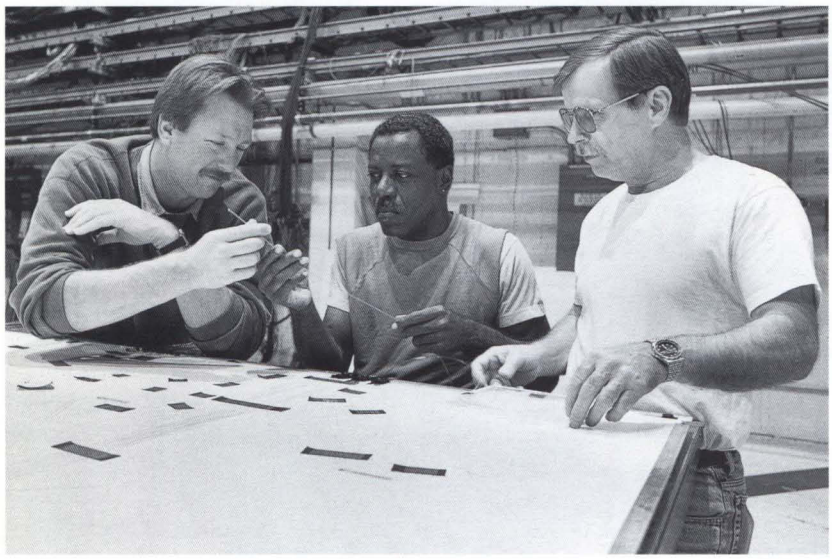
E831 will produce states of matter combining one or more charm quarks with light quarks (strange, up, down). The experiment aims to create 10 times as many such particles as in previous experiments and to observe rare phenomena that may shed light on the fundamental interactions of the strong and electroweak forces.

KTeV will be the most ambitious of the fixed-target experiments for the coming run.

E799/E832 (KTEV) "SEARCH FOR DIRECT CP VIOLATION IN THE 2Π DECAYS OF K0"

How did the universe come to contain more matter than antimatter? Fermilab's KTeV experiment may help scientists understand CP violation. Fermilab experiments have contributed much of the most precise knowledge about the phenomenon of CP-violation, first observed 30 years ago as a slight asymmetry in the behavior of matter and antimatter—an asymmetry that permits the existence of a universe made of matter.

KTeV will be the most ambitious of the fixed-target experiments for the coming run. The KTeV experiment returns to the one place besides the universe as a whole where we have seen CP violation—the particle called the neutral K meson, or kaon. The neutral kaon system provides an experimental thread, the only dangling thread found so far that we can tug to try to unravel the mystery of CP violation. Like the formation of the universe as a whole, the decay of neutral kaons into other subatomic particles exhibits an asymmetry in the ways in which matter and antimatter behave. Studying this asymmetry in neutral kaons may provide clues to the larger asymmetry that surrounds us.



Steve Gourlay (left) of the Technical Support Section, with Roy Justice (middle) and Ken Gray of the Physics Department at work on the detector for Experiment 831.

E835 "FORMATION OF CHARMONIUM STATES USING THE ACCUMULATOR RING"

When a particle of matter encounters its antimatter counterpart, the two particles annihilate, producing energy, which turns into a corresponding amount of mass in the form of secondary particles. It is possible to control the energy of proton-antiproton annihilation, tuning it to a precise level corresponding to an equivalent particle mass. By controlling the energy of annihilation, experimenters

can sometimes produce new forms of matter, predicted but never previously observed.

E835 is the latest in a series of Fermilab experiments using beams of antiprotons to create a new form of matter. "Formation of Charmonium States Using the Accumulator Ring" will use the controlled energy of proton-antiproton annihilation to produce charmonium, a new form of matter containing charm and anticharm quarks, and will measure its properties. These experiments with the bound states of charm quarks help to define, in a well-defined, clean system, the fundamental forces that act between quarks within the proton and neutron.

E862 "FORMATION AND DETECTION OF RELATIVISTIC ANTIHYDROGEN ATOMS"

Star Trek viewers know about antimatter; it's the fuel for the Starship Enterprise, powering that intrepid vessel's efforts to boldly go where no one has gone before. Fermilab also uses antimatter, in the Laboratory's scientific voyage of exploration into the deepest substructure of the atom, where no one has gone before.

Every particle of matter—electron, neutrino, quark and so on—has an antimatter counterpart. Antimatter electrons are called positrons; each quark has its antiquark; each lepton its antilepton. Fermilab's accelerator complex produces the world's largest supply of antimatter, in the form of antiprotons. Antiprotons are particles with the same properties as protons, but with an opposite, negative, charge. Fermilab's Tevatron accelerates beams of protons and antiprotons in opposite directions around a ring to create high-energy collisions that probe the ultimate underlying structure of matter.

E862, "Formation and Detection of Relativistic Antihydrogen Atoms," will search for antihydrogen atoms, each containing an antiproton and a positron. In a world of matter, creating and containing antimatter is a scientific challenge.

E866 "MEASUREMENT OF $\bar{d}(x)/\bar{u}(x)$ IN THE PROTON"

E866 is designed to reveal more about the structure of the proton by measuring its antiquark content. Ordinary matter contains the valence quarks within a "sea" of quark-antiquark pairs. With its expected very low statistical and systematic errors, E866 should be able to confront the usually assumed flavor symmetry of the quark sea, providing new insight into the structure of the proton.

E868 "ANTIPROTON DECAY"

E868 is a small experiment in the Antiproton Accumulator that will search for antiproton decay, a phenomenon never previously observed. We know that the lifetime of protons is greater than 10^{32} years. Antiproton lifetimes should be the same. But are they? This experiment will attempt to shed light on that question.

E871 "CP VIOLATION IN THE DECAYS OF Ξ^-/Ξ^+ AND $\Lambda^0/\bar{\Lambda}$"

The KTeV experiment, described earlier, will measure the phenomenon of CP violation ("the tiny flaw in nature's mirror") in the decays of the neutral kaon, the only place, besides the universe as a whole, where it has so far been directly observed. E871, "CP Violation in the Decays of Ξ^-/Ξ^+ and $\Lambda^0/\bar{\Lambda}$," will try to find CP violation in the decay of other particles besides the kaon, to look for another way to explore this phenomenon.

We know that the lifetime of protons is greater than 10^{32} years. Antiproton lifetimes should be the same. But are they?

E872 "MEASUREMENT OF τ LEPTON PRODUCTION FROM THE PROCESS $\nu_\tau + N \rightarrow \tau + X$"

The tau neutrino pretty much has to exist. We have abundant, convincing indirect evidence that it does. And yet, no one has observed it directly. E872, "Measurement of τ Lepton Production from the Process $\nu_\tau + N \rightarrow \tau + X$," will try to go beyond indirect evidence and spot the tau neutrino using an emulsion target.

In particle physics, the strong interactions are those that define the interactions between the quarks. In 1994, besides our interactions with the quarks, Fermilab had strong interactions with the university community, with students and teachers in elementary and high schools, with industry, and with many others in the world beyond the interior of the proton.

EDUCATION

Fermilab science education programs serve students at all levels, giving special emphasis to under-represented groups. The Laboratory's precollege programs seek to enhance teaching and learning in mathematics and science, while university-level objectives deal with particle and accelerator physics and related fields. On the undergraduate level, summer employment and internships are available. The Laboratory also sponsors graduate and post-graduate fellowships, participates in a joint University-Fermilab Doctoral Program in Accelerator Physics, and, in collaboration with other laboratories and U.S. universities, helps sponsor the U.S. Particle Accelerator School.

Fermilab offers and supports many precollege programs for teachers, students and families. The comprehensive program of K-12 teacher development opportunities, along with the materials and services available through the Teacher Resource Center, effect change throughout departments, schools, districts, states, regions and the nation. In some programs, Fermilab collaborates with a school district to provide in-service opportunities for teachers and science experiences for students. Over 4,500 precollege teachers nationwide have participated in Fermilab institutes and workshops to enhance their skills to teach physical science and physics, particularly modern physics.

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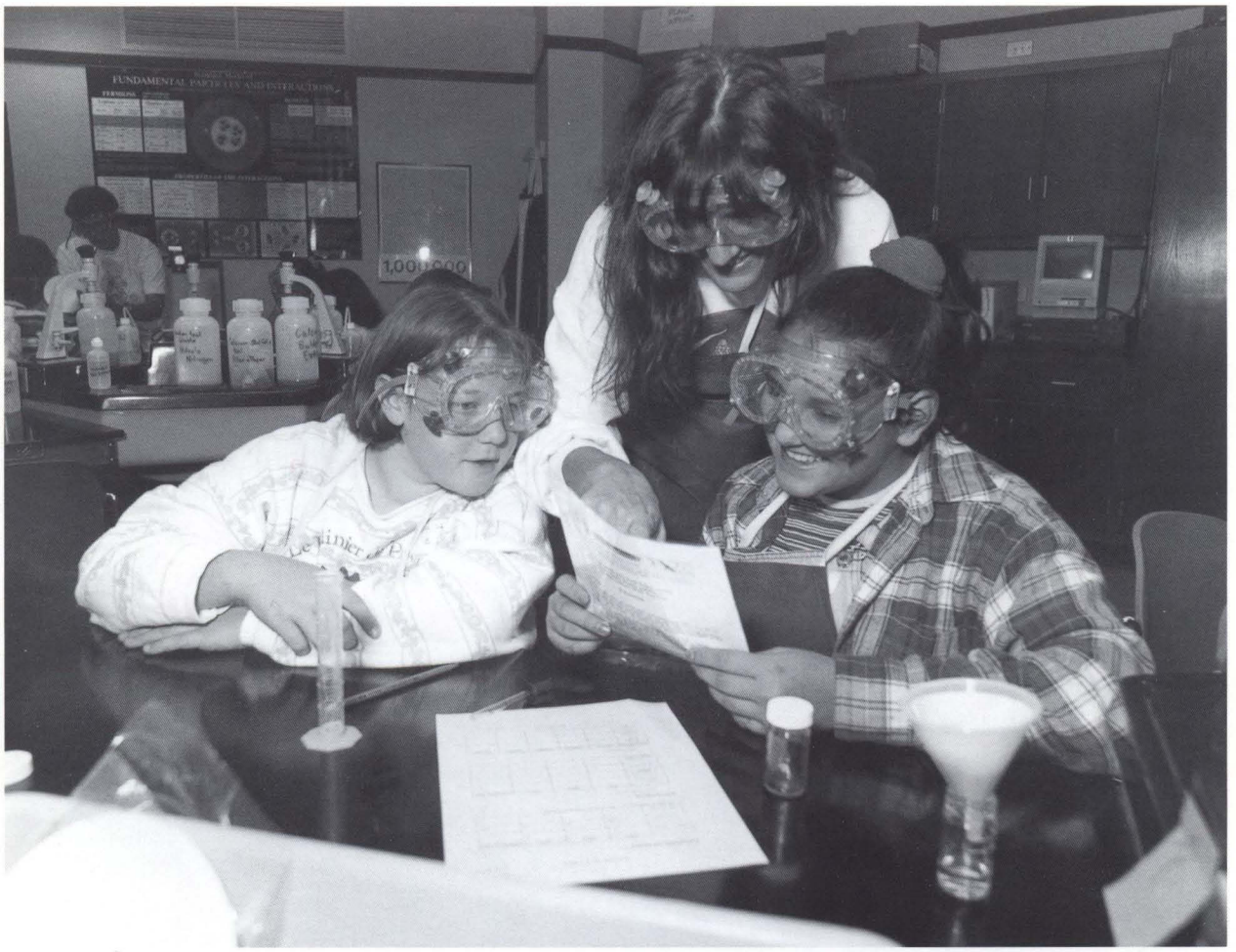
The numbers

Although statistics don't tell the whole story, they do give a glimpse of the number of students and teachers who benefit from Fermilab's education efforts. A look at some precollege education statistics for fiscal year 1994:

- 15,996 teachers, 25,771 students and 4,190 family members and members of the public participated in 50 Fermilab-sponsored educational activities.
- 494 teachers, 10,230 students and 1,500 family members and members of the public participated in programs at Fermilab.
- 107 educators taught in the programs, and 230 scientists, engineers and technicians from Fermilab also participated in education efforts.



Students from an area school test chemical properties of different types of soil and compare them with soil from Fermilab's prairies at the Leon Lederman Science Education Center.

Beyond the numbers

Individual success stories and comments from participants in education programs illustrate the impact of Fermilab's support:

"The most significant indicator of the benefit our students receive from this partnership is reflected in our school report cards (Illinois Goal Assessment Program). At the 4th grade level, our students earned a score of 261 in science compared to 249 for a district average and 246 for the state. I am convinced that Fermi's efforts significantly helped our students succeed."

— *Principal from Gary School in West Chicago, IL*

"Thank you for giving us a once-in-a-lifetime experience. One of the interesting things was in the Lederman Science Center where we could find the motion of an object by its tracks...We thank you very much for increasing our knowledge about the Fermilab center."

— *8th grade students from Springfield, IL*

"I believe that the [Fermilab] program has helped me grow professionally and made me more aware of my potential as a scientist. As a teacher, I know the value that I have to the society in which I live... Knowing that I have contributed to the research taking place at Fermilab

makes it easier for me to stay in teaching. There is a saying, 'Those who can, do. Those who can't, teach.' I now respond confidently to such unenlightened critics of the teaching profession with the statement, 'I can do, and choose to teach too.'"

—*Science teacher from Oakland, NE*

THE ENVIRONMENT

For more than 20 years, Fermilab has maintained a strong dedication to the environment. At the end of 1994, the Laboratory had 36 buffalo, and 960 acres of prairie in various stages of restoration. The native American grasslands are thriving communities rich with plant and animal life, all interrelating in a complex ecosystem. Tall grass prairies once blanketed northern Illinois, "The Prairie State." However, during the area's settlement in the 19th century, agriculture consumed all but a tiny remnant of the native grasslands.

Fermilab employees are steadily enriching existing prairie tracts and planting new ones. A very popular public event at Fermilab is the annual prairie seed harvest. Volunteers from the community come out to the prairie, and Fermilab staff teach them how to recognize particular plants and then clip the ripe flower heads for the seeds. 1994 was a breakthrough year for the harvest, attracting about 150 people, including many families, scout troops and school classes. Fermilab prairie experts give away some of the seeds to other environmental groups seeking to enrich existing prairies or plant new ones in the area.

Although the buffalo and prairie are the most visible and popular environmental attractions at Fermilab, there are other important ecological projects. For instance, the Laboratory has savannahs, woodlands and wetlands on the grounds. Along with the prairie, these areas make up a diverse ecosystem, providing a home to many wild creatures. Fermilab also has several thousand acres of agricultural tracts. Area farmers sign contracts to manage the land, which consists mostly of corn and soybean fields.

1994 was a breakthrough year for the [Fermilab prairie] harvest, attracting about 150 people, including many families, scout troops and school classes.

AWARDS

Fermilab employees won their fair share of awards in 1994:

- The American Association for the Advancement of Science announced the election of Fermilab Director John Peoples to the rank of Fellow. Peoples' AAAS peers elected him.
- The American Physical Society announced the election of the following Fermilab staff members to the rank of Fellow: Lillian Hoddeson (Directorate), Stephen Holmes (Accelerator Division), Joe Lach (Research Division), Ernest Malamud (Directorate), Catherine Newman-Holmes (Research Division)
- Fermilab received the DOE In-House Energy Management Award for Best Laboratory.
- James Davenport, on-site coordinator of Fermilab's Summer Internship in Science and Technology program, was selected as a 1994 Outstanding Faculty Award recipient from the Commonwealth of Virginia Council of Higher Education.
- The American Physical Society Division of Physics of Beams and the Division of Particles and Fields named Thomas Collins, formerly of Fermilab, and Gustav-Adolph Voss of Deutsches Electron Synchrotron Laboratory in Hamburg, Germany the combined winners of the 1994 APS R.R. Wilson Prize.
- The American Physical Society Division of Particles and Fields awarded Fermilab experimenters Thomas Devlin and Lee Pondrom the W.K.H. Panofsky prize.
- DOE expressed its appreciation to Environment, Safety and Health Section Head Don Cossairt and Jonathan Cooper of DOE's Batavia Area Office for serving as regulatory response leads and for commenting on proposed federal rulemaking that may affect Fermilab operations.
- Members of two Illinois police departments issued a citation of appreciation to Fermilab Security Department member Donald Foster in recognition of the department's participation in the second annual D.A.R.E. (Drug Abuse Resistance Education) 5K Family Challenge run.

Mike Becker of Roads and Grounds and Wheaton volunteer
Candice Taylor harvest seed during the 1994 Fermilab prairie harvest.

WORKING WITH INDUSTRY

Although Fermilab is a basic science research laboratory, opportunities sometimes arise to transfer Laboratory-developed innovations to industry.

During 1994, Fermilab's Office of Research and Technology Application completed negotiations on six Cooperative Research and Development Agreements; CRADAs provide a means to combine technology resources of national laboratories and industry in joint development projects. Two of the six CRADAs were canceled because the partner companies' grant proposals were not funded.

One of the CRADAs evolved when the Laboratory identified a need for an affordable, prefabricated, above-ground tornado shelter. Fermilab and Chicago Precast Products Co., a division of North Star Chicago Precast, developed the shelter jointly. Experience with tunnel construction for particle accelerators had given the Laboratory expertise in precast concrete construction technology. Fermilab held a dedication ceremony for the prototype shelter on Nov. 11, 1994.

Although Fermilab is a basic science research laboratory, opportunities sometimes arise to transfer Laboratory-developed innovations to industry.

Installation of the off-the-shelf tornado shelter, developed jointly by Fermilab and Chicago Precast Products Co., in the Village near Lab 8.

Another CRADA, signed in 1994 with the University of Michigan, will develop a Multiple Element Amorphous Silicon Detector Array for use in real-time radiotherapy treatment verification. Such an "imager" will be enormously significant in x-ray cancer therapy and should result in commercialization opportunities in medical imaging equipment in the next few years.

Fermilab's Computing Division and Cray Research, Inc. are to extend the use of parallel computing software developed at Fermilab to a commercially available Massively Parallel Processor.

The Extrude Hone Corporation and Fermilab initiated a CRADA in 1994 to develop and commercialize Fermilab technology for automatically calibrating coordinate measuring machines.

At the end of 1994, Fermilab's Computing Division and IBM Corp. had nearly finished negotiations on an agreement to explore and demonstrate systems and tools for data mining and analysis in a parallel computing environment. By implementing and evaluating a prototype system for the fast and reliable delivery of stored data containing tens of terabytes of high energy physics information, the project can determine the feasibility of such a system for commercial data mining.

Fred Bernthal (above) was selected president of Universities Research Association, Inc. in 1994.

Director Emeritus Robert Wilson (left) at the symposium and tribute in honor of his 80th birthday. The day-long event, held March 4, featured talks and reflections by many of Wilson's colleagues and friends.

COMMUNICATING IN THE 20TH CENTURY

Fermilab held various press gatherings in 1994, including the April 26 press conference to announce the evidence of the top quark, which was published worldwide. The local media widely covered the prairie harvest and burns again.

Fermilab unveiled its home page for the World Wide Web on April 26th in conjunction with the top quark evidence. Fermilab staff improved the home page over the course of the year, and continue to update it daily.

TERMINATING THE SSC

The Universities Research Association, Inc. called upon John Peoples, Fermilab director, to manage the termination of the Superconducting Super Collider project planned for Texas. Dr. Peoples began that assignment in November 1993, and it continued to June 1994; Fermilab Deputy Director Ken Stanfield served as acting director during that period.

PAYING OUR RESPECTS

The following members of Fermilab's family passed away in 1994:

• **Richard Dibler**, a former Fermilab employee, died June 11. Dibler retired from Fermilab on October 7, 1991. He worked as an Instrument Welder for the TS/Machine Shop after joining the Lab in August 1979.

• **Terry Lachance** of the AD/CHL Department passed away January 31. Lachance started working at the lab in March 1983 in the RD/Cryogenics Department. After joining the Accelerator Division, he worked as a technical specialist in CHL.

• **John (Jack) F. Lindberg**, a former Fermilab employee, passed away March 26. Lindberg retired from Fermilab in March 1990. He worked as an engineer in the Research Division after joining the Lab in July 1969.

• **Carl Swoboda** of the Computing Division office died July 31. Swoboda started working at the lab in 1983 as an engineer.

CREDITS

Photographs: Fermilab Visual Media Services.
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Fermilab serves university scientists. Fermilab's mission is to advance "the understanding of the fundamental nature of matter by providing leadership and resources for qualified researchers to conduct basic research at the frontiers of high-energy physics and related disciplines." In 1994, physicists from many national and international institutions—178 to be exact, 82 foreign and 96 national—used Fermilab for their research. They are listed in alphabetical order:

FOREIGN INSTITUTIONS

IHEP, ACADEMIA SINICA (TAIWAN) • AICHI UNIVERSITY OF EDUCATION (JAPAN) • UNIVERSIDAD DE LOS ANDES(COLOMBIA) • UNIVERSITY OF ATHENS (GREECE) • IHEP, BEIJING (PRC) • UNIVERSITY OF BOLOGNA (ITALY) • UNIVERSITY OF BRISTOL (ENGLAND) • CIPP (CANADA) • CBPF (BRAZIL) • CEN-SACLAY (FRANCE) • CERN (SWITZERLAND) • CHONNAM NATIONAL UNIVERSITY (KOREA) • CINVESTAV-IPN (MEXICO) • DELHI UNIVERSITY (INDIA) • UNIVERSITY OF FERRARA (ITALY) • INFN, FRASCATI (ITALY) • FREIBURG UNIVERSITY (GERMANY) • INFN, GENOVA (ITALY) • GIFU UNIVERSITY (JAPAN) • UNIVERSITY OF GUANAJUATO (MEXICO) • GYEONGSANG NATIONAL UNIVERSITY (KOREA) • HIROSAKI UNIVERSITY (JAPAN) • HIROSHIMA UNIVERSITY (JAPAN) • JINR,DUBNA (RUSSIA) • KEK (JAPAN) • KINKI UNIVERSITY (JAPAN) • KOBE UNIVERSITY (JAPAN) • KOREA ADVANCED INSTITUTE OF SCIENCE (KOREA) • KOREA UNIVERSITY, SEOUL (KOREA) • INP, KRAKOW (POLAND) • KYOTO SANGYO UNIVERSITY (JAPAN) • KYOTO UNIVERSITY (JAPAN) • KYOTO UNIVERSITY OF EDUCATION (JAPAN) • KYUNGSUNG UNIVERSITY, PUSAN (KOREA) • LAPP, D'ANNECY-LE-VIEUX (FRANCE) • LEBEDEV PHYSICAL INSTITUTE (RUSSIA) • UNIVERSITY OF LECCE (ITALY) • MAX-PLANCK INST • TUTE (GERMANY) • MCGILL UNIVERSITY (CANADA) • INFN, MILANO (ITALY) • UNIVERSITY OF MILANO (ITALY) • MOSCOW PHYSICAL ENGINEERING INSTITUTE (RUSSIA) • MOSCOW STATE UNIVERSITY (RUSSIA) • ITEP, MOSCOW (RUSSIA) • NAGOYA INSTITUTE OF TECHNOLOGY (JAPAN) • NAGOYA UNIVERSITY (JAPAN) • NANJING UNIVERSITY (PRC) • UNIVERSITY OF OCCUPATIONAL & ENVIRONMENTAL HEALTH (JAPAN) • OKAYAMA UNIVERSITY (JAPAN) • OSAKA CITY UNIVERSITY (JAPAN) • OSAKA SCIENCE EDCATION INSTITUTE (JAPAN) • OSAKA UNIVERSITY (JAPAN) • OSAKA UNIVERSITY OF COMMERCE (JAPAN) • UNIVERSITY OF PADOVA (ITALY) • PANJAB UNIVERSITY (INDIA) • UNIVERSITY FEDERAL DO PARAIBA (BRAZIL) • UNIVERSITY OF PAVIA (ITALY) • INFN, PISA (ITALY) • IHEP, PROTVINO (SERPUKHOV) (RUSSIA) • UNIVERSITYAUTONOMA DE PUEBLA (MEXICO) • UNIVERSITY OF PUERTO RICO (PUERTO RICO) • UNIVERSITY OF PUERTO RICO - MAYAGUEZ (PUERTO RICO) • UNIVERSITY FEDERAL DO RIO DE JANEIRO (BRAZIL) • UNIVERSITY AUTONOMA DE SAN LUIS POTOSI (MEXICO) • UNIVERSITY OF SAO PAULO (BRAZIL) • SEOUL NATIONAL UNIVERSITY (KOREA) • SHANDONG UNIVERSITY (PRC) • SOAI UNIVERSITY (JAPAN) • NPI, ST. PETERSBURG (RUSSIA) • TATA INSTITUTE (INDIA) • TECHNION-ISRAEL INSTITUTE (ISRAEL) • UNIVERSITY OF TEL-AVIV (ISRAEL) • TOHO UNIVERSITY (JAPAN) • UNIVERSITY OF TORINO (ITALY) • UNIVERSITY OF TORONTO (CANADA) • UNIVERSITY DI TRIESTE (ITALY) • UNIVERSITY OF TSUKUBA (JAPAN) • UNIVERSITY OF UDINE (ITALY) • UTSUNOMIYA UNIVERSITY (JAPAN) • VANIER COLLEGE (CANADA) • UNIVERSITY OF • WUPPERTAL (GERMANY) • YOKOHAMA NATIONAL UNIVERSITY (JAPAN)

U.S. INSTITUTIONS

ABILENE CHRISTIAN UNIVERSITY • ADELPHI UNIVERSITY • UNIVERSITY OF SOUTH ALABAMA • ARGONNE NATIONAL LABORATORY • UNIVERSITY OF ARIZONA • BALL STATE UNIVERSITY • BOSTON COLLEGE • BRANDEIS UNIVERSITY • BROOKHAVEN NATIONAL LABORATORY • BROWN UNIVERSITY • CALIFORNIA INSTITUTE OF TECHNOLOGY • UNIVERSITY OF CALIFORNIA, BERKELEY • UNIVERSITY OF CALIFORNIA, DAVIS • UNIVERSITY OF CALIFORNIA, IRVINE • UNIVERSITY OF CALIFORNIA, LOS ANGELES • UNIVERSITY OF CALIFORNIA, RIVERSIDE • UNIVERSITY OF CALIFORNIA, SAN DIEGO • UNIVERSITY OF CALIFORNIA, SANTA CRUZ • CARNEGIE-MELLON UNIVERSITY • CASE WESTERN RESERVE UNIVERSITY • UNIVERSITY OF CHICAGO • UNIVERSITY OF CINCINNATI • UNIVERSITY OF COLORADO AT BOULDER • COLUMBIA UNIVERSITY • CEBAF • CORNELL UNIVERSITY • DEPAUW UNIVERSITY • DUKE UNIVERSITY • ELMHURST COLLEGE • FERMILAB • FLORIDA STATE UNIVERSITY • GEORGIA STATE UNIVERSITY • HARVARD UNIVERSITY • UNIVERSITY OF HAWAII AT MANOA • UNIVERSITY OF HOUSTON • UNIVERSITY OF ILLINOIS, CHICAGO CIRCLE • ILLINOIS INSTITUTE OF TECHNOLOGY • UNIVERSITY OF ILLINOIS, CHAMPAIGN • INDIANA UNIVERSITY • IOWA STATE UNIVERSITY • UNIVERSITY OF IOWA • JOHNS HOPKINS UNIVERSITY • KANSAS STATE UNIVERSITY • LAWRENCE BERKELEY LABORATORY • LAWRENCE LIVERMORE LABORATORY • LEHIGH UNIVERSITY • LOS ALAMOS NATIONAL LABORATORY • LOUISIANA STATE UNIVERSITY • UNIVERSITY OF LOUISVILLE • UNIVERSITY OF MARYLAND • UNIVERSITY OF MASSACHUSETTS • MASSACHUSETTS INSTITUTE OF TECHNOLOGY • MICHIGAN STATE UNIVERSITY • UNIVERSITY OF MICHIGAN • UNIVERSITY OF MINNESOTA • UNIVERSITY OF MISSISSIPPI • UNIVERSITY OF NEBRASKA • NEW MEXICO STATE UNIVERSITY • UNIVERSITY OF NEW MEXICO • SUNY AT ALBANY • SUNY AT STONY BROOK • NEW YORK UNIVERSITY • UNIVERSITY OF NORTH CAROLINA • NORTHEASTERN UNIVERSITY • NORTHERN ILLINOIS UNIVERSITY • NORTHWESTERN UNIVERSITY • NOTRE DAME UNIVERSITY • OAK RIDGE NATIONAL LABORATORY • OHIO STATE UNIVERSITY • OHIO UNIVERSITY • UNIVERSITY OF OKLAHOMA • UNIVERSITY OF OREGON • PENNSYLVANIA STATE UNIVERSITY • UNIVERSITY OF PENNSYLVANIA • UNIVERSITY OF PITTSBURGH • PRAIRIE VIEW A&M UNIVERSITY • PRINCETON UNIVERSITY • PURDUE UNIVERSITY • RICE UNIVERSITY • UNIVERSITY OF ROCHESTER • ROCKEFELLER UNIVERSITY • RUTGERS UNIVERSITY • UNIVERSITY OF SOUTH CAROLINA • SLAC • UNIVERSITY OF TENNESSEE, KNOXVILLE • TEXAS A&M UNIVERSITY • UNIVERSITY OF TEXAS AT ARLINGTON • UNIVERSITY OF TEXAS AT AUSTIN • TUFTS UNIVERSITY • VALPARAISO UNIVERSITY • VANDERBILT UNIVERSITY • UNIVERSITY OF VIRGINIA • UNIVERSITY OF WASHINGTON • UNIVERSITY OF WISCONSIN-MADISON • XAVIER UNIVERSITY • YALE UNIVERSITY.

FINANCES 1994

FERMI NATIONAL ACCELERATOR LABORATORY

Operated by UNIVERSITIES RESEARCH ASSOCIATION, INC.
under a contract with the U. S. Department of Energy

Laboratory Funding and Personnel Summary
For the Year Ended September 30, 1994

OPERATING AND EQUIPMENT:

Fermilab Operating	$167,200,000
Work for Others	600,000
Total Operating	167,800,000
Capital Equipment	27,700,000

PROGRAM CONSTRUCTION:

Main Injector	$25,000,000
AIP/GPP(KA)	10,000,000
Low Level Radiation Waste Handling Building	1,000,000
In-House Energy Management	900,000
Subtotal	**$36,900,000**
Total Laboratory Funding	**$232,400,000**

LABORATORY PERSONNEL SUMMARY

Direct	1,704
Indirect	570
Total Laboratory Personnel	**2,274**

FERMILAB A Department of Energy National Laboratory

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