FERMI NATIONAL ACCELERATOR LABORATORY 1995

FROM THE DIRECTOR

The discovery of the top quark was the big event at Fermilab in 1995. The top quark at last took its place in the "periodic table" of elementary particles. Fermilab staff and scientists are not resting on their laurels, however. There is much more to learn about the fundamental particles of matter.

The Laboratory's major effort in 1995 was to deliver beam to CDF and DZero, a task the Accelerator Division achieved superbly. As Run Ib ended, CDF and DZero had recorded three times the integrated luminosity recorded in all previous collider runs. It was these data that made the top quark such a clear-cut discovery.

Fermilab's project to make the Tevatron yield even more data made excellent progress in 1995. The Main Injector construction project was approaching the halfway point at the end of 1995, on schedule and on budget for completion in 1999. It will increase Tevatron luminosity fivefold.

The top quark remains largely *terra incognita*. For at least a decade, the Tevatron will be the only facility where scientists can explore this most massive of the quarks. The Main Injector will give the explorers a powerful new research tool. To prepare for running with the Main Injector, the CDF and DZero collaborations have stepped up efforts to improve their detectors substantially.

The end of 1995 also found the Laboratory busily preparing for the last major run of the 800 GeV fixed-target program. Fixed-target physics has been the backbone of the Fermilab program since the first 200 GeV bubble chamber experiments in 1972;

Fermilab Director John Peoples Jr. talks with reporters on March 2,1995, after the announcement that Fermilab scientists had discovered the top quark.

colliding beams began 15 years later in 1987. Sadly, the steady decline in purchasing power of the Laboratory's annual funding has forced the retrenchment of fixed-target programs. Nevertheless, we expect to end the big 800 GeV fixed-target program with a flourish in 1996–1997. Each of the 10 fixed-target experiments addresses a very important aspect of particle physics, as this report explains. One experiment, called DONUT, seeks to observe the interaction of the tau neutrino. If it succeeds, Fermilab can lay claim not only to the discovery of the third generation of quarks, but also to the exploration of third-generation leptons.

Plans for NuMI, "Neutrinos at the Main Injector," moved forward with a HEPAP recommendation that Fermilab and its Main Injector be the site of the U.S. long-baseline neutrino program. Fermilab will point a neutrino beam at the Soudan Mine in northern Minnesota, 730 kilometers away, where there is already a superb facility for an underground laboratory. Perhaps the MINOS or COSMOS experiment will reveal that neutrinos have tiny masses; and perhaps the mass of the tau neutrino will be measured at Fermilab. Such a discovery could change our ideas about the evolution of the universe in its earliest moments.

Despite a declining budget, Fermilab remains exciting, vital and the most productive high-energy laboratory in the U.S. as we approach the millennium. Our plans for the next decade give me confidence that Fermilab will remain at the forefront of particle physics in the 21st century. ■

John Peoples Jr.

FERMILAB 1995

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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.

On January 25, 1996, Deputy Director Kenneth Stanfield made a State of the Laboratory address to the Council of Presidents of URA, the consortium of research universities that operates Fermilab for the Department of Energy.

"Among the most pleasurable of tasks that occasionally fall to me as deputy director is to share with you our experiences at Fermilab in the past year, and our plans for the year to come—as well as our goals, our concerns, and our vision for the years that follow.

As I was thinking about what I wanted to say to you today, I came across a New York Times editorial with the headline "State of the Something." The first sentence caught my eye. It said: "January is the State of the Something season in political circles, when every elected official worth his or her salt wants to make a Big Speech, bragging about past achievements, setting goals for the new year, and making a stab at major-league oratory."

I thought, 'That's it. That's what I want to do.' So, although I don't travel in political circles and, thankfully, I am not an elected official, I want to bring to you today my State of the Laboratory message. I plan to stick to the classic form. I will begin by bragging about past achievements and move on to setting goals for the coming years.

I want to brag about the past year, because it's an easy year to brag about.

Ken Stanfield, Fermilab's deputy director, addresses the Universities Research Association's Council of Presidents meeting in January, 1996.

Fermilab may be unique among national laboratories in having a one-sentence mission statement: 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. How did we do last year in carrying out our mission?

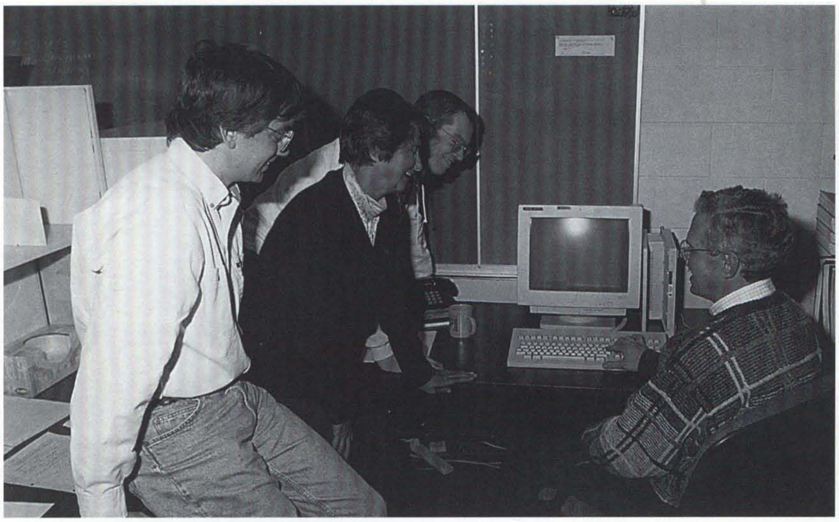
The heart and soul of any particle physics laboratory is its accelerator, and last year Fermilab's accelerator had the best year of its life. Many of us have known the Tevatron since it was barely more than a gleam in Bob Wilson's eye. For us, perhaps, it is a particular pleasure to see this remarkable machine grow up to perform better than anyone thought possible. Last year the Tevatron collider routinely operated at 15 times its design luminosity—that means 15 times as many high-energy particle collisions as it was designed to provide. On May 10, 1995, the Tevatron set a new luminosity record that was five times the highest peak luminosity of Run Ia. Since resuming operations in October, the Tevatron's efficiency, calculated as the actual hours of uptime divided by the scheduled hours of operation, was an outstanding 65 to 85 percent. In Run Ia, the luminosity per store hour reached a high of 17 inverse nanobarns; in Run Ib, the record is 51—up by a factor of three!

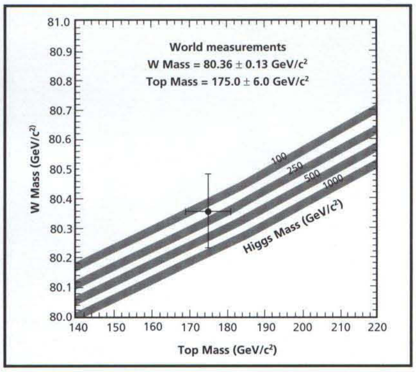
What all these numbers add up to is more data than ever before, delivered from the world's highest-energy particle accelerator to Fermilab's two collider detectors, CDF and DZero. What did they do with these data? On March 2, 1995, the CDF and DZero collaborations, each about 450 strong, announced the discovery of the top quark, the

The Accelerator Division's Christmas tree, seen here in the Main Control Room, is actually a festive Tevatron monitor. The higher the luminosity, the faster the tree's lights blinked on and off. In 1995, the Tevatron collider routinely operated at 15 times its design luminosity.

last remaining undiscovered quark, completing the third generation of matter postulated by the Standard Model. We have photographs of a collaborator from CDF and one from DZero each pushing the return keys on their computers at 11 a.m. Central Standard Time on February 24, simultaneously transmitting to Physical Review D their respective papers describing the top discovery.

Besides the discovery of the top quark, the collider experiments measured top's mass and studied the way it decays, as they opened a new era of top quark physics. They also made the most accurate measurements to date of the mass and width of the force-carrying particle called the *W* boson. The *W* is a particle we really want to understand, because if we





At 11 a.m. on February 24, 1995, members of the CDF collaboration (top) and members of the DZero collaboration (above) simultaneously pushed the "return" keys on their keyboards to submit their collaborations' top quark discovery papers to Physical Review D.

The graphic shows measurements of the *W* boson and top quark masses. Within the Standard Model, precise measurements of the *W* boson mass and top quark mass give information on the mass of the Higgs particle. The Higgs particle is thought to be related to the origin of mass for all particles.

combine what we learn about the *W* with what we learn about top, the combination will tell us things we'd like to know about that Holy Grail of particle physics, the Higgs boson, and the mystery of mass.

Besides collider physics, Fermilab collaborators also do fixed-target physics, and they spent much of 1995 getting ready for a new fixed-target run that will begin next summer.

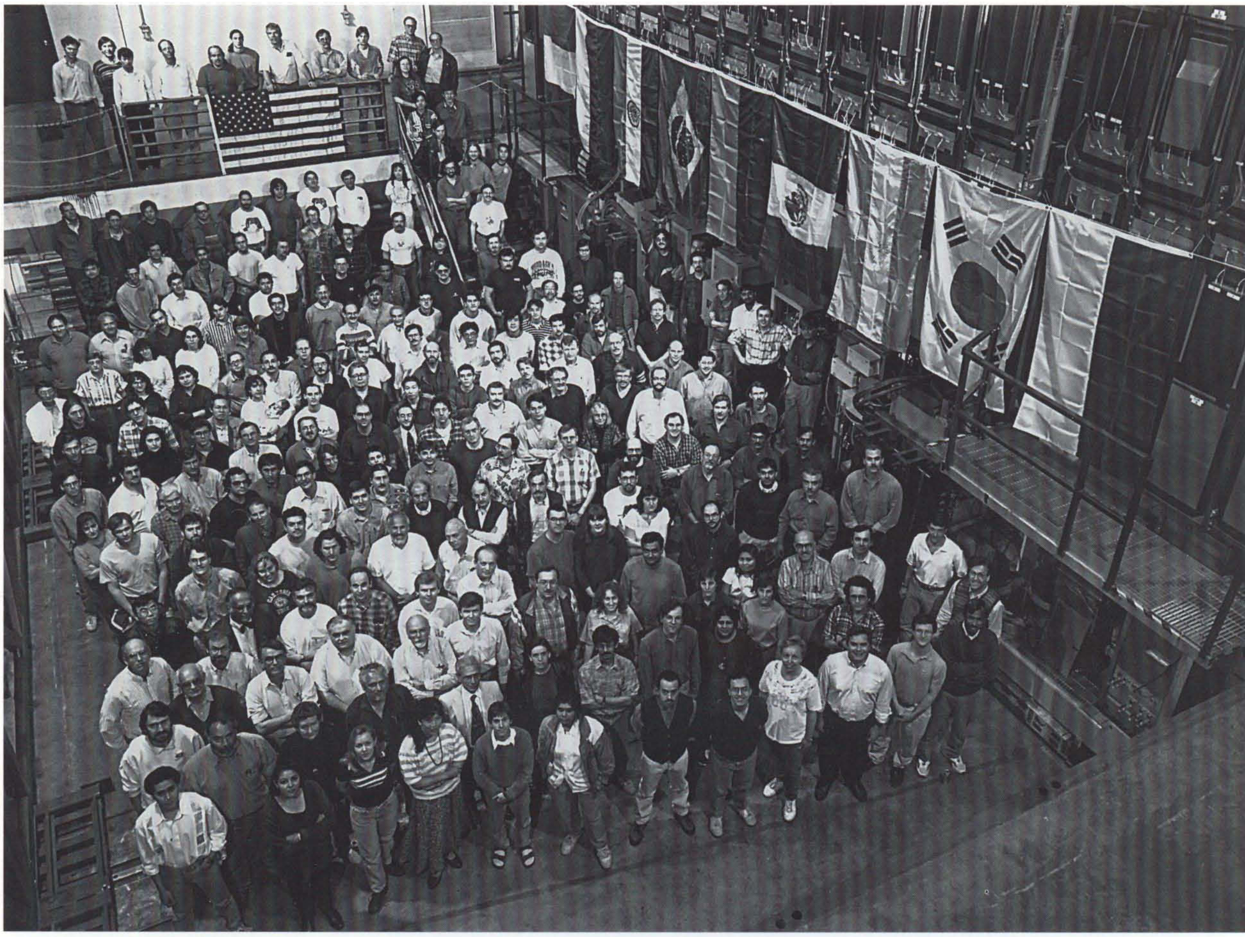
Fermilab had good news in September from the High Energy Physics Advisory Panel. In September, a HEPAP subpanel recommended that DOE support Fermilab's proposal for an experiment using high-intensity neutrino beams from the Main Injector, aimed at a target in a former iron mine in northern Minnesota, in a long-baseline experiment to investigate the question of neutrino mass. The NuMI collaboration now awaits Key Decision Zero from the Department of Energy. It is the milestone decision that will turn NuMI from a Laboratory proposal to a full-fledged DOE initiative.

Last year the Sloan Digital Sky Survey, of which Fermilab is a partner, made major advances toward the goal of beginning to collect data in 1996 for a three-dimensional map of the universe. The Pierre Auger Project, an international proposal for an experiment to discover the origin of very high-energy cosmic rays, held a six-month workshop based at Fermilab. The workshop designed the detectors for the two Rhode-Island-sized detector arrays that the Auger Project proposes to build.

Finally, in 1995, you and your colleagues in other universities sent more users to Fermilab than ever before. Sometimes we wonder where we're going to put all our users, but we're very glad to have them. That's what we're here for, and it validates the importance of Fermilab and the Tevatron to the university community working in particle physics.

UPGRADES

Our mission says that Fermilab provides resources for high-energy physics research. Last year, as we do every year, we worked to make those resources better. Remember that in creating a particle physics laboratory, you're never finished. The research will not advance if the tools do not advance. Progress in elementary particle physics critically depends on the continuous improvement of



In 1995, universities sent more users to Fermilab than ever before. Here, members of DZero gather for a collaboration portrait.

accelerators and detectors and of the entire laboratory. It never ends.

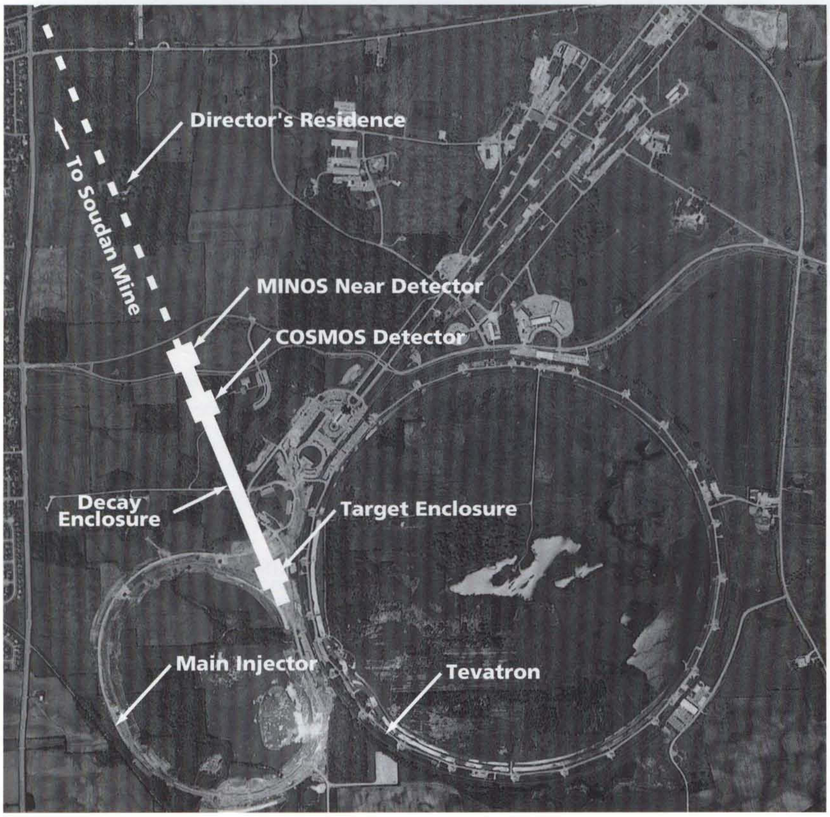
The Main Injector project is the centerpiece of the set of accelerator improvements for the 1990s that we call Fermilab III. When I last checked, the Main Injector was 41 percent complete, on schedule and on budget for completion in 1999. When the Main Injector begins operating in 1999, it will raise the Tevatron's luminosity by a factor of five. The Main Injector will also have the great advantage of making it possible to do collider physics and fixed target physics at the same time at Fermilab.

The two collider detectors must also make major improvements to keep up with the increased luminosity the Main Injector will provide. Both detectors are well along in the program of upgrades that will allow them to make good use of the data the Tevatron, with the Main Injector, will deliver. The problem—and it is a problem of great concern, one that I will return to—is funding. Right now, we don't know where we're going find all the money to complete these detector upgrades in time for the Main Injector.

We and the Department of Energy have also made another kind of improvement at Fermilab. For some time, URA, Fermilab management, and people at DOE have had concerns about a proliferation of orders, rules and regulations that had the effect of micromanaging environment, safety and health functions at the Laboratory. Everyone had the goal of a safe, environmentally sound Laboratory operation. At the same time, many of us both at Fermilab and at DOE realized that the process of achieving this goal had gotten out of hand. This year, as part of the effort to improve management of the labs along the lines suggested by the Galvin panel and others, DOE asked Fermilab to undertake a pilot project in ES&H management. The project, which came to be known as "Necessary and Sufficient," was charged to come up with the smallest set of ES&H regulations that would be both necessary and sufficient to ensure the safe, environmentally sound operation of the Laboratory. DOE and URA accepted the list of standards the group produced, including parts of only three DOE orders. The "Necessary and Sufficient" standards were incorporated into the Fermilab contract, by a few strokes of the pen, on Bastille Day, July 14. We have begun the process of implementing the new standards, a process that will continue for some time.

BUDGETS

What does the funding level for FY1996 mean for the Laboratory? The FY1996 appropriation provides $204.3M in operating and equipment funds, and $52M for Main Injector construction. In FY1995, Fermilab's total authorized expenditures for operating and equipment added up to $208M. Adding three percent annual inflation gives a figure of $214.3M. The actual funding level of $204.3M is thus $10M less than the amount needed to stay even with last year's operating level.



The Fermilab campus from the air, with the NuMI project beamline indicated by a dotted line.

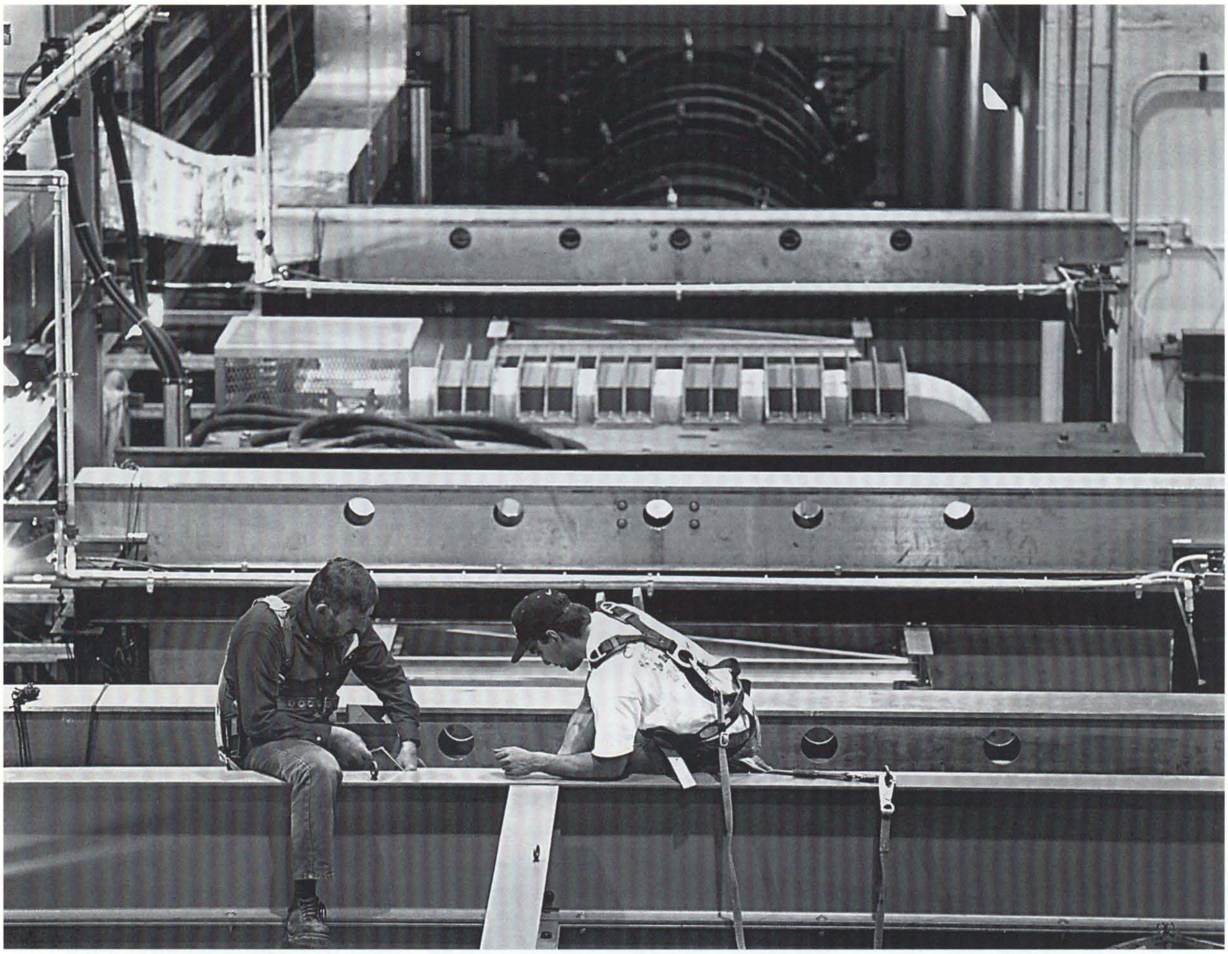
How will Fermilab save $10M in the coming year? The collider detector upgrades cannot proceed as rapidly as planned. We won't make all the improvements we need in our computing capability. R&D for projects like NuMI won't move forward as quickly as we or our university colleagues would like.

Operating budgets for all Fermilab divisions and sections are below last year's levels, and all Laboratory organizations are looking hard to find ways to cut costs without cutting the scientific program.

Meanwhile, the budget process for FY1997 is well underway. Fermilab has submitted its funding proposal to the Department of Energy, and the cycle moves on. If we look at the trend for high-energy physics funding over the past decade and subtract that large bump called the SSC, we see that the direction is slowly but inexorably downward, year by year. I regret that I can think of nothing that would lead us to believe that this trend will spontaneously reverse itself. If our field continues to see constant declines in our budget, eventually we will fall below a viable threshold.

We will not solve here today the problem of how to do the physics we would like to do in the coming decade with the shrinking resources vouchsafed to us. One thing is clear: If we want the U.S. to continue among world leaders in the field of particle physics—indeed, in science and technology—we must all make the case for the benefits it brings to our nation, whenever and however we have the opportunity.

Our most grievous immediate concern at Fermilab is how we will



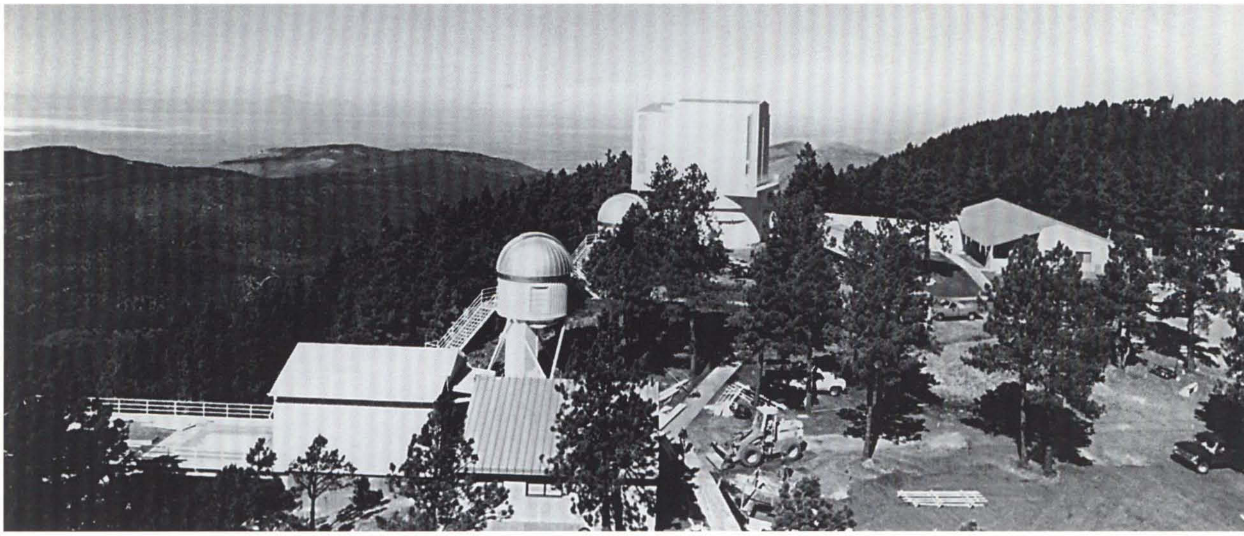
During 1995, the KTeV experiment hall gradually filled with equipment for the study. The KTeV experiment will explore the origin of CP violation, the phenomenon that accounts for the asymmetry between matter and antimatter in the universe.

fund the collider detector upgrades within foreseeable funding profiles. The funding we now project will prevent us from completing the detector upgrades in time to use the new Main Injector. It is not out of the question that we could lose a year or more of experimentation with the Main Injector. Or that both detectors are compromised in a major way. Or that we are forced to start the run with only one detector. Any of these possibilities causes great concern to us and to our users, a concern that we share with you today.

GOALS

Our resources may be stretched at Fermilab, but we still want to do great physics. We have goals and plans to make full use of our vantage point at the energy frontier for the coming year and for the next decade. Beyond that, we plan to do all that we can to make sure that Fermilab will make a leading contribution to the physics of the 21st century.

Our goal in 1996 is to finish the Collider Run, which we plan to do in the third week in February, and to begin running fixed-target experiments about July 1. Fermilab provides the high-energy community with the highest-energy fixed-target beams to be found anywhere. They come in eight varieties, created from 800 GeV proton beams extracted from the Tevatron. Each of the 10 experiments now preparing to run will emphasize precision measurements of key parameters for our understanding of the Standard Model. Each experiment is a kind of specialized laboratory for the study of a physics question not



Apache Point Observatory in New Mexico, the site of the Sloan Digital Sky Survey. The survey will create a three-dimensional map of the universe.

easily accessible in the collider environment.

We will devote all the resources we can to Main Injector construction in 1996. By this time next year, we plan to be on the home stretch for that project.

In 1996 we will also build on the start we made with the Necessary and Sufficient pilot project for ES&H. We are currently in the midst of a Business Pilot Project with DOE to bring the same kinds of improvement to procurement, payroll, salary administration, and travel audit functions at the Laboratory.

In about 2005, a watershed event will take place in the world of particle physics. In that year, the Large Hadron Collider at CERN will turn on. I should perhaps say that it will probably turn on. I don't have to tell anyone in this room that when it comes to building big new accelerators, it ain't over 'til it's over. Nevertheless, we believe that 2005 will probably be the year when the LHC replaces the Tevatron at the energy frontier. We can use the year 2005 as a reference point in talking about our Fermilab goals.

From now until 2005 will be a great decade for Fermilab. Our goal is to make the very best use we can of our wonderful facilities at the energy frontier, to advance the understanding of matter, both within the framework of the Standard Model, and beyond. We will use this decade to address the most important questions of particle physics today:

- Why do quarks have mass? Why, for example, is the top quark so heavy?
- Why is there more matter than antimatter in the universe?
- Do neutrinos have mass?
- What lies beyond the Standard Model of elementary particles?

In the next decade, Fermilab will provide the resources for users to do collider physics at unprecedented luminosity and energy. We will build and operate the NuMI experiment, cultivating a whole new acquaintance with northern Minnesota—and, we hope, with the neutrino. Users will do fixed-target experiments that take advantage of the new capabilities conferred by the beams from the Main Injector. We also hope to contribute to building the LHC, both to the accelerator and one of the detectors. Research at the confluence of particle physics, astronomy, and cosmology will likely play an important role in our search for an understanding of matter and the origin of the universe.

After about the year 2010, the Fermilab community is committed to have a new international accelerator at the energy frontier and at Fermilab. The accelerator might be a hadron collider, a muon-muon collider, or even an $e+e-$ machine, but we are determined to make the United States a major contributor to the physics of the next century.

To make this happen, we must make investments now—investments in research in accelerator physics and in the underlying technology that moves accelerator physics forward. Only by constantly improving our accelerator-building capabilities and the technologies supporting them will we be in the position we want to be in 15 years from now.

I have told you of Fermilab's goals for the next ten years, and of our goals for the years after 2010. How will we make good use of Fermilab during those years when we have relinquished the energy frontier and haven't yet begun to recapture it? We will focus on areas where Fermilab, has unique physics capabilities. We are currently evaluating proposals to raise the Tevatron's luminosity even higher, to 10^{33}, and to exploit our fixed-target capabilities. It will be a time when we focus on unique precision measurements that only the Tevatron can do—or can do better than any other laboratory.

THE POINT OF IT ALL

When I started my academic career as an undergraduate at the University of Texas several years ago, I considered studying chemistry. I soon decided on physics, however, because chemistry was too hard. You had to remember lots of formulas and a large table of elements. Physics was much easier for me. It was essentially about billiard balls and what happens when they roll down an inclined plane or whack into each other on a frictionless surface.

We often use the billiard-ball metaphor when we talk about particle physics to people who aren't physicists. We use billiard balls to explain concepts like the conservation of energy and momentum in particle collisions, and the relation between energy and mass.

It occurs to me that particle physics and pool may have more in common than just energy conservation. They both, for example, involve hustling, in the best sense of that word, and the exchange of large sums of money. Success at the pool table takes patience, concentration, dedication, skill, stamina, and luck—the same things you need for success at particle physics.

I am reading a book, "Playing Off the Rail, A Pool Hustler's Journey," by David McCumber, that confirms my view of particle physics and pool. In this true story, the author, a reporter with a lifelong fascination for pool, quits his job and stakes a pool hustler named Anthony Annigoni on a pool-hustling trip across America. The author puts together a stake of about $27,000, straps it to his leg, and off they go.

In many respects, it's a disappointing journey. Poolrooms today are not what they once were, and the subculture of pool is far from glamorous. They stay in seedy motels, they eat bad food, and of course pool hustling turns out to be very hard work. But the game is still the game, and Mr. Annigoni can really play it, as the author observes one evening. "As he made the shots, I was overpowered by the beauty of this game, at once immutably logical, governed by physical inevitabilities, and at the same time infinitely poetic and varied."

I think it's easy for us to get caught up in the high-stakes hustle of particle physics, with its fascination and its demands, and to lose sight, occasionally, of the real reason why we're all here; of the real reason for URA and for Fermilab, and for the long, strong partnership we have forged with DOE; of the real reason for all the budgets, and all of the planning. We do it all for one reason: to discover the immutable logic that prevails in the universe, that is "governed by physical inevitabilities, and at the same time infinitely poetic and varied." ■

Students play "particle pool" at the Lederman Science Center to learn about particle interactions.

NEW PHYSICS

On March 2, 1995, the Laboratory's two collider-detector collaborations, CDF and DZero, simultaneously announced the long-awaited discovery of the top quark. The top was the last undiscovered quark of the six postulated by the Standard Model, the theory of the fundamental particles and interactions. The two collaborations announced the discovery at a packed colloquium in Fermilab's Ramsey Auditorium. Next day, news media around the world proclaimed that the elusive top quark had at last been found, with a surprisingly large mass, roughly equal to that of an atom of gold.

Operating as a collider, the Tevatron achieved record luminosities, resulting in more high-energy particle collisions than ever before. The harvest of data was rich for the detector collaborations, each with about 450 members from universities and laboratories across the nation and throughout the world.

Experimenters also continued to publish results from the accelerator's 1990-91 run in fixed-target mode. At Fermilab, new physics results for 1995 fall into several categories: top quark, bottom or *b* quark, electroweak interactions, quantum chromodynamics, studies of the charm and strange quarks, hyperons, and the search for new phenomena.

COLLIDER EXPERIMENTS

Top quark physics

From proton-antiproton collision data accumulated through the end of 1995, experimenters sought to pin down two numbers: the rate at which *t* quarks are created, the production cross section, and the mass of the *t*. To help identify the events they observe in the detectors, they search for pair production of *t* quarks (a top and its antiparticle occur together) with Standard Model decays. For those top quark events that begin as a *t* and anti-*t*, with decays into two *W* bosons, a *b* quark, and an anti-*b*, experimenters classify events according to how the *W* bosons decay. *W*s may decay either leptonically (to an electron or muon and a neutrino) or hadronically (to two quarks that are detected as two jets). "Lepton plus jets" events include a well-identified lepton, missing energy signaling a neutrino, and at least three jets. For events of this kind, experimenters either try to tag, or identify, at least one of the *b* quarks, or use the fact that these events have a profile that is quite different from non-top events. "Dilepton" events have two well-identified leptons, missing transverse energy, and at least two jets.

Experimenters used "leptons plus jets" data to reconstruct the mass of the top. In 1995, CDF inferred a *t* mass of 176 ± 13 GeV/c^2, and DZero measured a value (refined in 1996) of 170 ± 18 GeV/c^2. DZero also presented a measurement of the top mass, using dilepton events, of 158 ± 27 GeV/c^2.

The cross section for producing *t* is derived from the data using an accepted value for the mass of the particle. DZero found a cross section of 5.2 ± 1.8 picobarns for their measured mass. At CDF, experimenters determined a cross section of $7.6\ {+2.4}/{-2.0}$ pb, for a *t* mass of 176 GeV/c^2.

In addition to calculating the mass and cross section for production of the top, CDF experimenters began a number of studies of the particle's decay properties. The V_{tb} parameter describes the interaction, via the weak force, of the top and bottom quarks, and can be determined from the rate at which *t* quarks decay to a *W* particle and a *b* quark. Rare decays are also interesting: both collider collaborations started searching for decays such as a *t* decaying to a *Z* boson and a *c* quark, or a *t* decaying to a photon plus either a *u* or *c* quark. Standard Model predictions for these decays are for one event in around 10^{10}, so observing any signal would be evidence for physics beyond the Standard Model.

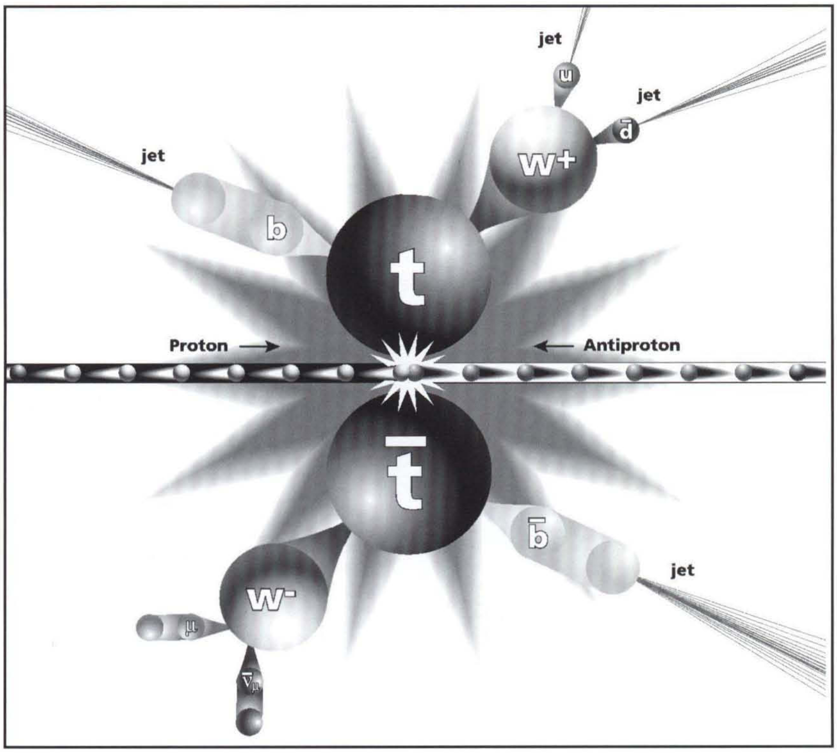
Electroweak Physics

Collider data yielded the best measurements so far on the mass of the *W* boson, a carrier of the weak force. From DZero, the final value for the mass of the *W* in 1995 was 80.33 ± 0.27 GeV/c^2. CDF measured the mass as 80.41 ± 0.18 GeV/c^2. The uncertainties are half those of previous measurements. Because the *W* is very short-lived, it has an intrinsic range in energy, known as its width. Both collaborations measured the width of the *W* by indirect methods, and CDF made direct measurements as well.

As part of their program in electroweak physics the DZero and CDF collaborations studied the "trilinear couplings of the electroweak gauge bosons"—that is, the interactions among *W* particles themselves, as well as couplings of *W* and *Z* particles with photons. The collaborations studied differences in the structure of quarks in protons and antiprotons. They also searched for new heavy vector bosons outside the Standard Model.

B Physics

CDF physicists continued to study a wide range of bottom-quark topics in the data set available in 1995. Experimenters reduced the uncertainties on the lifetimes of the *B* mesons (*b* quarks paired with an anti-quark), and investigated *b* production, decays and branching ratios. They measured the mass of the Lambda-*b* baryon (consisting of *u*, *d*, and *b* quarks) at 5623 MeV/c^2, and confirmed that the lifetime is significantly shorter than those of the *B* mesons. This measurement is significant because it calls into question the so-called factorization theory that describes the interaction of quarks within a hadron.

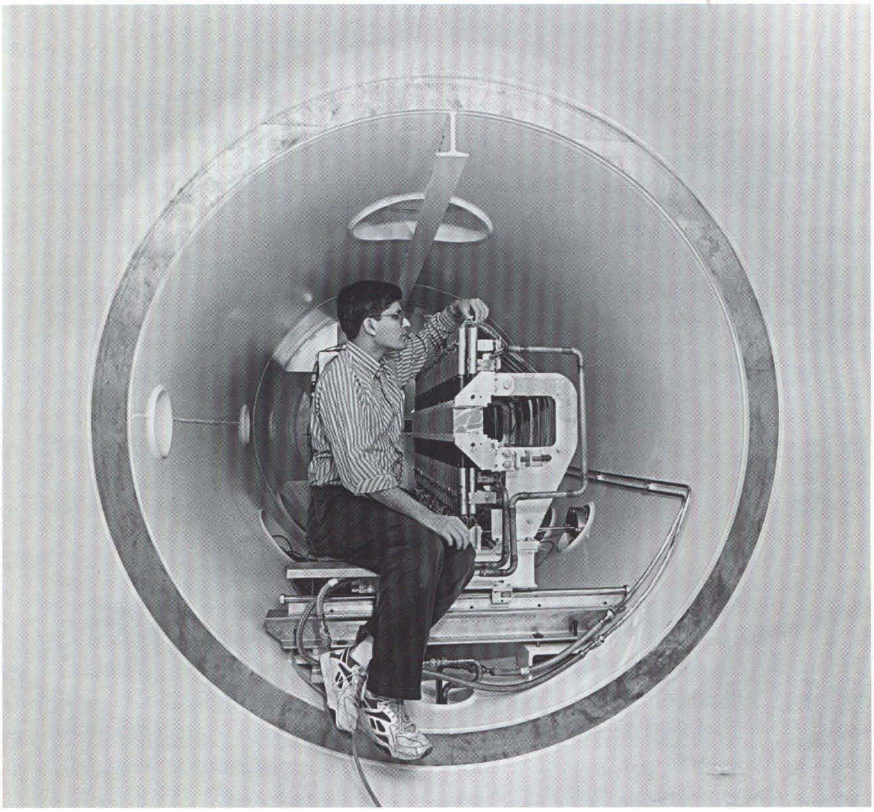


In this artist's representation of a particle collision, a proton and antiproton collide at high-energy to produce top and antitop quarks.

QCD Physics

CDF physicists submitted a manuscript to Physical Review Letters (now published) describing intriguing results in the study of high transverse-energy jets. The jets consist of secondary particles from high-energy quark collisions, and have a large component of momentum transverse to the proton-antiproton beam. Perturbative QCD predictions made in 1995 underestimate the jet rate CDF observes at transverse energies above 200 GeV. The next-to-leading-order perturbative QCD calculation may require higher-order corrections, or we may have to revise our understanding of the way momentum is distributed among the quarks and gluons in a proton, or we may be seeing hints of new physics. DZero's systematic errors are large enough that they find their results are consistent with both CDF and theoretical predictions.

Experimenters measured the strong coupling constant α_s and its "running," or variation with energy. Statistical errors in the 1995 measurements were the world's best, and for the first time, a single experiment probed the running of the



Experimenters searched for evidence of supersymmetry—particles that form symmetric pairs with those we already know, but at higher energies—with several signatures.

Amitabh Lath, a user from Rutgers University, checks phototubes on the regenerator at KTeV.

coupling constant over a wide range of energies.

In 1995 QCD specialists also began to examine low energy scales where evidence of new states of strongly coupled matter may appear. Glancing-incidence or soft collisions, which nevertheless break up a proton, provide insight into the structure of the proton.

Exotic Physics

Experimenters searched for evidence of supersymmetry—particles that form symmetric pairs with those we already know, but at higher energies—with several signatures. They completed a search in Run Ia data for a charged Higgs particle from a top quark decay, with the Higgs decaying to a tau lepton with a subsequent hadronic tau decay. They are also searching for third-generation leptoquarks: particles carrying a force that would convert a quark into a lepton.

FIXED-TARGET EXPERIMENTS

In 1995, Fermilab physicists and users continued to publish results from the 1990-1991 fixed-target run. These included limits on rare charm and kaon decays, strange quark structure functions from neutrino scattering, and studies of the quark structure of nucleons. Experimenters also began preparations for the 1996 fixed-target run.

Hyperons and Polarization

Several experiments examined hyperons and their magnetic moments and spin polarization vectors. Hyperons are stable particles consisting of three quarks, and are heavier than a proton or neutron, because their constituents are other than all up and down quarks. E800 measured the magnetic moment of the Omega-minus hyperon as part of an effort to test models of baryon magnetic moments. The "static quark" model, which successfully accounts for the other measured baryonic magnetic moments, predicts a value for the Omega-minus that is relatively far from the measured value. The *sss* content and 3/2 spin of the Omega-minus make it a unique laboratory for the testing of such theoretical models.

E761 re-checked the apparent discrepancy between experiment and the theory that predicts SU(3) symmetry in the decay of the Sigma-plus hyperon (quark content *uus*) to a proton and photon. SU(3) says that mesons and baryons of the same total spin form groups with symmetric properties. The alignment of the Sigma-plus particle's spin vector varied in a more complex way than expected as a function of the transverse momentum of the hyperon.

E704 reported on the left-right production asymmetry for Lambda-zero hyperons (quark content *uds*) produced with a vertically polarized proton beam. The effect challenges non-perturbative QCD theory.

Inelastic muon scattering

E665 continued its study of the quark structure of protons and neutrons, with a view to understanding the possible importance of sea quarks relative to valence quarks. The sea quarks are virtual particles that exist only fleetingly within a hadron, and may play a part in interactions with oncoming projectile particles. The experiment uses muons as a probe of the nuclear target. Results are consistent with models that include nuclear shadowing in the deuteron; the difference in muon scattering between proton and deuteron targets appears to be due to shadowing and does not require flavor asymmetry for the sea-quark distributions within the nucleon.

Kaon physics

E773 made an improved measurement of CP violation in the decay of the so-called K-long meson. CP conservation means that the K-long normally decays to three pions; E773 researchers studied the CP-violating decays to two pions plus a gamma ray. The experiment more than doubled the sum of similar events previously studied in both Fermilab and Brookhaven experiments. Their results indicate that any direct CP violation in this particular decay process is small. The alternative explanation is indirect CP violation, which interprets the K-long meson as a combination of two components with different CP states. This experiment is a predecessor to KTeV, one of Fermilab's most complex fixed-target experiments operating in the 1996 run.

E773's primary goal was a test of CPT invariance, checking the Brookhaven result that CPT is not conserved. E731 found CPT is, indeed, conserved.

c-quark physics

E760 studied charmonium, mesons consisting of a *c* and anti-*c* quark in various spin and angular momentum states, as a way of testing theories of the strong force. In 1995 the experiment reported new and more precise measurements of the mass of the eta-c meson, which decays into two photons, and the mass and width of excited states of this meson. The mass of the excited state of eta-c was not at or near the theoretically predicted values, which motivates experimenters to carry out follow-up measurements in E835.

E687 reported on rare decays of the D^0 meson (consisting of a *c* and anti-*u* quark pair), including the decay D^0 to $K^- K^+ K^- \pi^+$. This experiment also verified a definite inconsistency between theoretical and observed rates for the ratio [D—> (K*) (lepton) (neutrino) / D —> (K) (lepton) (neutrino)].

Charm baryons, consisting of three quarks, are harder to produce and study.

E687 produced the first measurement of the lifetime of the Omega-c-zero baryon. E687 published the first measurement of the lifetime of the Omega-c-zero charm baryon to be 89 ± 37 femtosec, which makes it the shortest-lived particle observed by its decay path.

b-physics

Although *b* quarks are produced at a low rate at fixed-target energies, both E672/706 and E789 have measured the *b* anti-*b* production cross sections for pion and proton beams, respectively.

New phenomena

E774 and E770 set limits on neutrino oscillations. If neutrinos have mass, they may oscillate between the electron, muon, and tau neutrino varieties. Neutrino oscillation would account for observed deficits of solar and atmospheric neutrinos, and perhaps help solve the mystery of "dark matter" in the universe.

E733, which completed data taking in January 1988, recently published a search for Weakly Interacting Massive Particles. Such objects, called WIMPS by the astrophysics community, are candidates for gravitationally closing the universe. E733 has substantially increased the search limits for WIMPS either decaying or interacting in their detector, but did not find any. ■

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RUN I

Fermilab's Collider Run I entered the history books at 0800 on Tuesday, February 20, 1996. Run I set luminosity records, flushed the top quark from its hiding place at the high end of the mass scale, and took us all into unexplored territory where no high-energy physicists had gone before. In one way or another, everyone at Fermilab had a hand in Run I, and, when it was over, the spokesmen of the two collider detectors expressed their thanks to the entire Laboratory.

It began on a hot day in August, 1991, and by the time it ended on a cold morning in February, 1996, Collider Run I at Fermilab had changed our understanding of the natural universe. It had delivered the astonishing number of 179.67 inverse picobarns of luminosity, or 12,572,000,000,000 high-energy proton-antiproton collisions, to Fermilab's two collider detectors, CDF and DZero. "It was like winning the data lottery," said CDF Department Head John Cooper.

Those Run I data held the evidence for new physics. "Physicists Track Down an Elusive Atomic Particle," said the front-page story in The New York Times on March 3, 1995. "Culminating nearly a decade of intense effort, two rival groups of physicists announced today that they had found the elusive top quark—an ephemeral building block of matter that probably holds clues to some of the ultimate riddles of existence.

"The announcement brought sustained applause and a barrage of questions from an overflow audience of physicists at the Fermi National Accelerator Laboratory, where the work was done. Fermilab has the world's most powerful particle accelerator."

"YOU HELPED MAKE IT POSSIBLE."

A few days later, the 475 members of the division that operates that accelerator received a letter from Division Head Dave Finley. "We make them," he wrote. "They find them. And together we have discovered the top quark. And that's a scientific fact...What you have heard over the last few years, from 'prediction,' to 'evidence,' to the 'discovery,' was science history in the making. And you helped make it possible.

"Some might tell you that it was inevitable that Fermilab would discover the top quark. It wasn't. It took talent and dedication. A few of you know what it takes to keep this accelerator complex running. It took two decades populated with dreamers, doubters and doers...

"All together we've made about 1000 top pairs. That means each of us in the Accelerator Division has had a top quark pair made at CDF and one at DZero with our name on it."

The Computing Division helped as well. For the first time in Fermilab history, the most intensive processing of the data, which must be done before the analysis leading to the physics results, was complete within days of the data's creation. An array of computers provided the computing power to extract the essential physics results, check and recheck them, and eventually declare the discovery of the top quark.

Beyond discovering the top quark, experimenters measured the particle's mass and studied its decay modes, opening a new era of top quark physics. They also made the most accurate measurements to date of the mass and width of the force-carrying particle called the *W* boson. Combining the precisely measured characteristics of the *W* with precise top quark data will provide insight into the nature of the Higgs boson and the mystery of mass.

When Run I ended, the spokesmen for the two collider experiments wrote to Fermilab Director John Peoples to thank the Fermilab community.

COLLIDER DETECTOR AT FERMILAB

John Peoples
Director
Fermilab

February 20, 1996

Dear John,

We wish to convey to you our heartfelt thanks for an incredibly successful Run I.

Please pass on our thanks to everyone at the laboratory. We are sure that sometime between the end of the "88-89 Run" in June, 1989, to the end of Run I today, everyone at the lab helped us in some way - in the design, building, installation, running, or processing of the data. They all have a share in CDF's discoveries and measurements.

We look forward with relish to Run II and the continued joint venture with the laboratory in the exploration of the high energy physics frontier at 2 TeV.

Giorgio Bellettini

Bill Carithers

Fermilab

Fermi National Accelerator Laboratory
P.O. Box 500 • Batavia, Illinois • 60510

February 20, 1996

John Peoples, Jr.
Director
Fermilab
P. O. Box 500
Batavia, IL 60510

Dear John,

This morning saw the official end of Run 1 for high energy physics and in some senses the end of an era.

Many people who were young when D0 was started are now mature, students have become post-docs and professors and some of us not involved with D0 have now joined and one or two professors even retired.

On behalf of all those members of D0, past and present we would like to express our appreciation to the Laboratory, its staff and its efforts to provide the wherewithal for us to execute such a marvellous program of physics research.

We trust that you will transmit our best wishes to all at the Laboratory and hope that a similar triumph awaits us and them in a few years time.

Sincerely,

Paul Grannis and Hugh Montgomery

MAGNETS, NITROGEN, AND CHERRY TREES

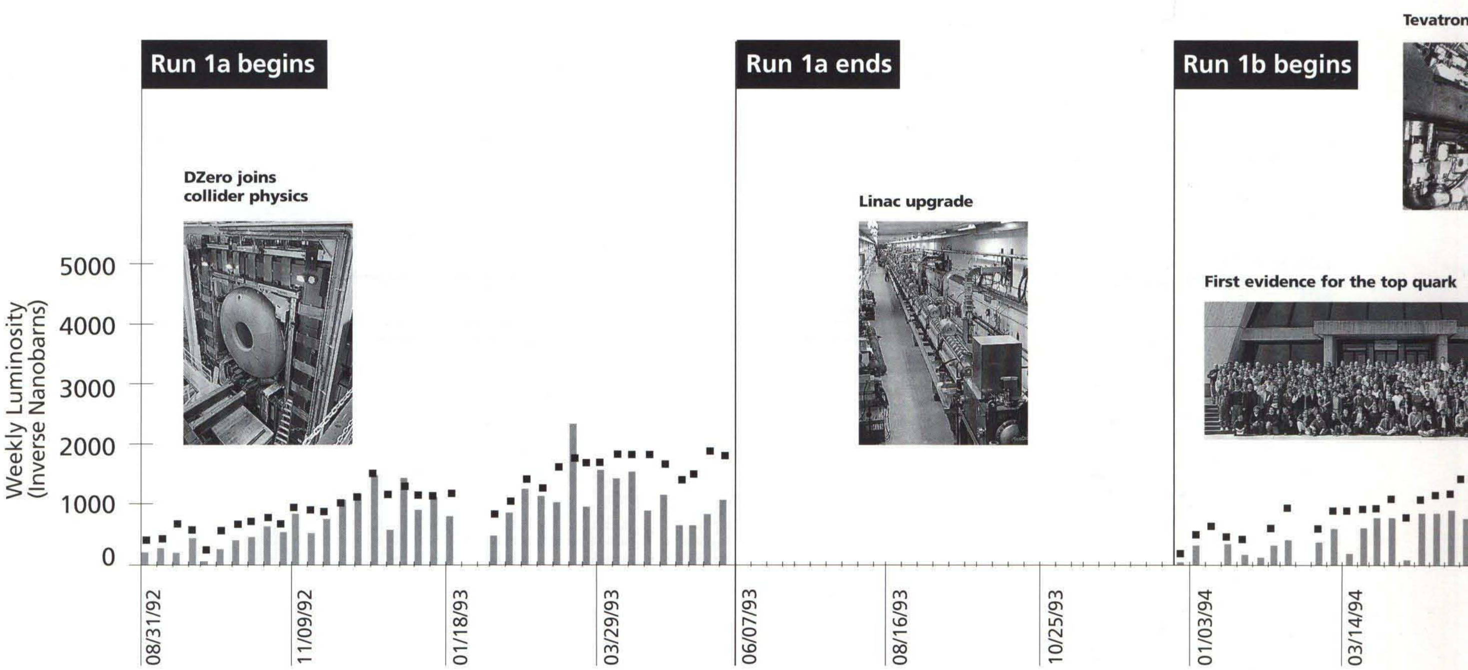
Run I was exhilarating, but it was no romp through the roses. Most vexing of Run I's headaches was the failure of the Tevatron's luminosity to rise after a 1993 shutdown for the installation and commissioning of a new 400 MeV linear accelerator, expected to double the luminosity from pre-shutdown levels. But when operations resumed, luminosity obstinately refused to rise, barely attaining the previous levels. For months, Laboratory staff searched in vain for the bottleneck. At last, in the final week of July, 1994, the problem was traced to a Tevatron magnet that had moved out of alignment. Workers realigned the magnet and luminosity instantly shot up, to universal relief.

Tevatron performance soared until the end of August, 1994, when trouble struck again. The 5000.3B "Occurrence Report" to DOE told the tale: "On Friday, August 26, 1994, the outside vendor contracted by Fermilab to provide liquid nitrogen (LN2) to the Accelerator Division's Central Helium Liquefier (CHL) for use in operation of the Tevatron accelerator ceased their scheduled deliveries of LN2. Laboratory personnel were notified by a representative of the vendor at approximately 0800 hours on 8/26/94 that there would be no more deliveries to CHL in the immediate future beyond the one just then completed.

"CHL is the source of the LN2 used...in the process of achieving and maintaining the superconducting temperatures in Tevatron components necessary for Tevatron operation. Onsite inventories and reliquefaction capability are insufficient to maintain operating cryogenic temperatures in the Tevatron without daily deliveries of LN2 from an outside vendor."

Fermilab used the "nitrogen drought" to carry out a planned accelerator maintenance program—and to make arrangements for a more reliable future nitrogen supply.

On May 10, 1995, the Tevatron set the peak luminosity record for Run I. And on June 22, the lights went out. "Blackout disrupts Fermilab operations," reported the Aurora Beacon-News. "Power was cut off for more than four hours to Fermilab here Thursday, but it could take much longer than that for normal operations to resume at the site of the world's high-energy producing accelerator. The outage occurred at about 10:20 a.m., when a [cherry] tree made contact with the 345-kilovolt electrical line that supplies power to the laboratory and created a short..." Recovery took a couple of weeks.



Collider Run 1: Weekly and Peak Luminosity Bars represent weekly luminosity and

GOOD-BYE RUN I, HELLO RUN II

Following a summer 1995 shutdown to allow progress on constructing Fermilab's new Main Injector, Run I ended with a dazzling flourish of high luminosity.

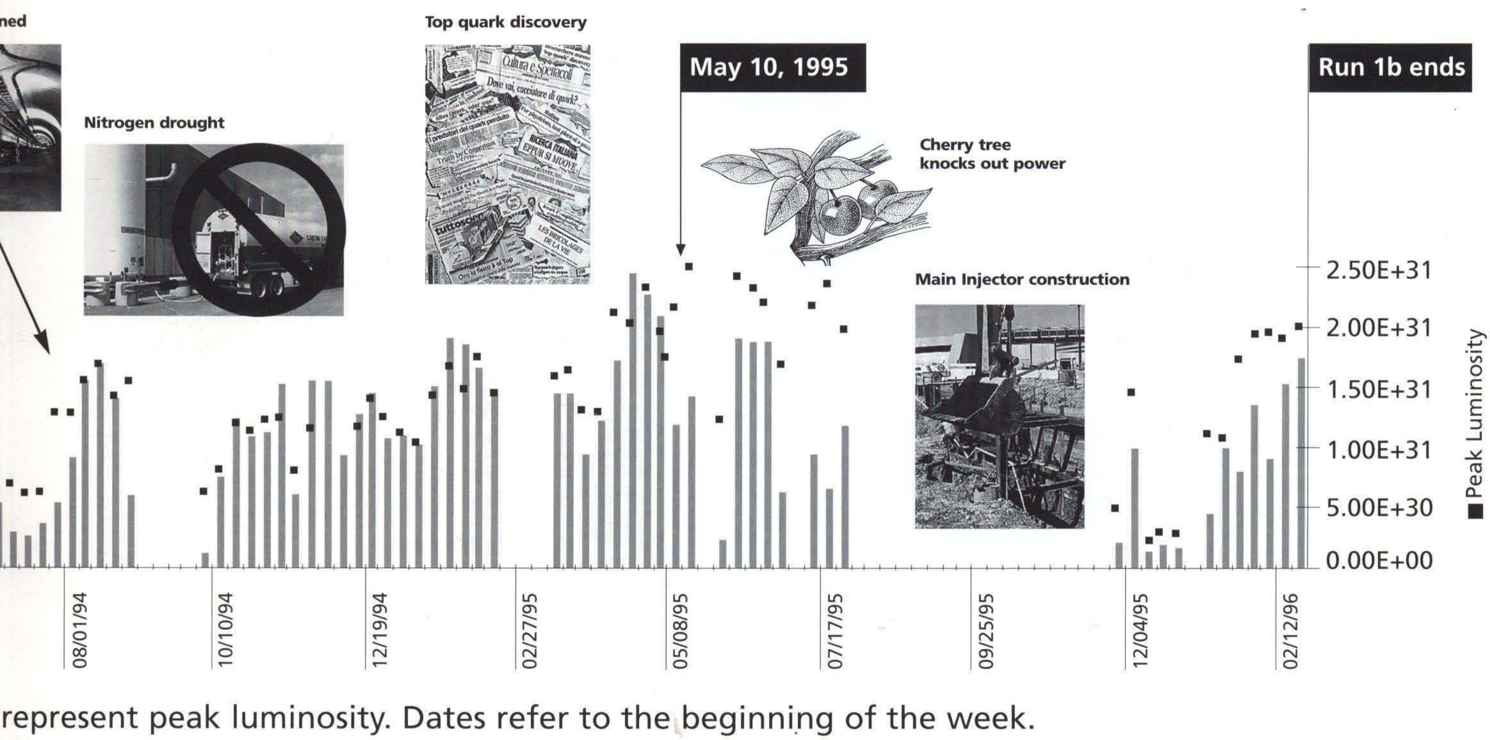
Researchers greeted the end of Run I with mingled pride, regret, and relief. "The original 1981 CDF design report talked about a luminosity on the scale of $1pb^{-1}$," said CDF cospokesman Bill Carithers, "It discussed the likelihood of discovering the top quark if its mass was less than 25 GeV!" In fact, CDF recorded 129 pb^{-1} of data in Run I, and the top weighed in at something near 180 GeV.

Run I was the first Fermilab collider run with two detectors, as DZero joined CDF, across the accelerator ring. "When DZero started out, the feeling was that Run I would be an 'engineering run' to get the kinks out of our detector," said DZero cospokesman Paul Grannis. "Of course, it turned out to be nothing of the sort. I am very pleased at our ability to search for new physics in areas far beyond what had been done before."

As they continued to analyze Run I data, the collaborations moved on to upgrading the detectors for Run II, the first run with the Main Injector. "We expect that many more physics milestones await us as we continue to exploit our goldmine of data," wrote CDF spokesmen Bill Carithers and Giorgio Bellettini to their colleagues. "However this occasion also defines a transition as we begin to turn our attention to preparing for Run II. Upgrading the detector poses a great challenge to the collaboration, but Run I has proven that we have an excellent record for meeting and exceeding challenges and we have every reason to be very optimistic about a bright future."

In March 1996, the two 5,000-ton detectors rolled slowly out of the collision halls and into view for the first time in over three years. "It is a pleasure to see our old friend, our long-lost friend again," Grannis said, "and to kick its tires and crawl around inside it. I'm really delighted to be seeing it again....

"People may sing doom and gloom for particle physics, but Fermilab is truly confronting forefront physics issues. There are hints of truly exciting things to come." ■



represent peak luminosity. Dates refer to the beginning of the week.

COLLABORATION

One cannot traverse the high-energy physics frontier alone. More than 2,300 scientists from nearly 200 institutions use Fermilab's facilities to conduct particle physics research. These "users" generally work together in large research collaborations. But the teamwork for basic research doesn't stop in the experimental halls. Fermilab depends on its engineers, conference coordinators, roads and grounds crew and a multitude of other positions and personalities to carry out the mission of expanding the world's knowledge of the fundamental constituents of nature.

CHARLES MATTHEWS, #802

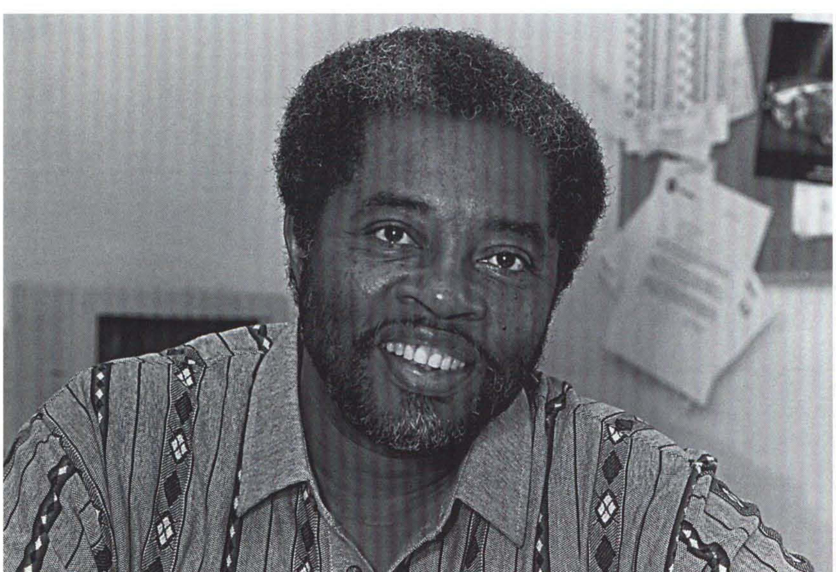
Charles Matthews builds things.

As superintendent of Fermilab's Machine Shop in the Technical Support Section, Matthews directs the welding, machining and development of experimental apparatus for Laboratory projects.

"Sometimes you look at something and wonder what in the heck it's going to be used for," Matthews says. "But when you build this thing and the guy goes off and does his thing and gets his results and he's happy, then we're happy that we had some effort in helping him achieve that goal. It's great to be a builder."

One of the most satisfying aspects of his job comes from working with scientists, Matthews says.

"I've been here 25 years and it's always interesting," he notes. "They're so down to earth, and yet they're thinking so far ahead. It's a joy to get some of these things and build them because it kind of makes you feel that you are adding a little bit to their effort."



Charles Matthews of the Technical Support Section

At 802, with only three digits, Matthews' employee number reflects the length of his 25-year tenure at the Lab.

"In 25 years I can't remember having a day when I didn't want to be here," he says with a smile. The attraction for Matthews comes from the Laboratory's atmosphere. He gestures to the window and speaks of rabbits playing in the grass and deer walking across the prairies. Scenes like these draw him to this place.

Keeping a capable work force challenges Matthews. "We spend a lot of money on training and a lot of people are recruited away from us," he says. "We are constantly developing skills over and over again."

BRENNA FLAUGHER #8987

Brenna Flaugher came to Fermilab ten years ago as a graduate student, and stayed on to make a career of QCD, the study of the quark interactions. Flaugher, who is now an Associate Scientist in the Research

Division, has kept to one line of research: "I've always been with CDF, and I've always worked on QCD. CDF is big enough that you can work on different things within the same experiment; the part I work on is jet physics. Jets are produced when quarks collide."

Flaugher says the attraction of working at Fermilab is the possibility of finding something new. "The Tevatron is the world's highest energy machine, so it has the greatest discovery potential. In QCD, energy is the key to finding anything new. In other areas, precision is the key."

Aside from the CDF detector, which she is helping to upgrade for the next collider run in 1999, Flaugher's favorite aspect of the Lab is the outdoors. "I like all the open space that you can go walk around—I take my dogs for walks there—and the area's nice bike paths, and the Fermilab pool...."

Barbara Edmonson, DZero

BARBARA EDMONSON #4431

While DZero takes data, Barb Edmonson takes care of DZero.

"I provide office support for DZero employees, information concerning the Laboratory, and assistance to collaborators and other visitors," says Edmonson, staff assistant to the DZero collider experiment.

Beyond the DZero collision hall, Edmonson's job brings her into contact with many Fermilab offices, including the Directorate, Accounting and Travel and Receiving.

"I have rarely dealt with anyone who is not willing to go out of his or her way to provide information and assistance," Edmonson says.

She believes that attitude fosters the community spirit many Fermilab employees share with one another.

"I believe it is this positive attitude, more than anything else, that makes Fermilab work," Edmonson says. "Each of us contributes to it and in doing so we contribute to our own departments or groups and to Fermilab as a whole."

ANDREAS KRONFELD #8170

A theoretical physicist at Fermilab for the past eight years, Andreas Kronfeld makes a living thinking about things in the abstract.

Kronfeld specializes in so-called lattice calculations of QCD, the theory of the strong interactions that bind quarks in a proton. "We don't know how to make progress on all the interesting questions in QCD using a pencil and paper. So what people in the Computing Division do, with cooperation from the theory group, is to design a computer to do calculations," he says.

Contrary to the stereotypes of theoretical physicists, its practitioners do, in fact, often meet up with reality. "The calculations that we do are almost always relevant to the experiments that are going on at Fermilab," Kronfeld adds.

He thinks theory and experiment can work together profitably.

"Physics, more than other sciences, relies on a strong interplay between theorists, who work mostly with mathematics, and experimentalists, who work mostly with detector apparatus, to find out whether we really know what's going on," Kronfeld says. "The whole enterprise is based on having people who attack questions from both points of view."

But he noted that Fermilab theorists do seem more in touch with experimentalists than some theorists.

"At some universities and some other labs, a lot of theoretical physicists do things that are more mathematically abstract," Kronfeld says. "Theoretical physics bridges the whole range from experimental physics to pure mathematics. At Fermilab we're closer to experimental physics."

CELE BRUCE #10570

Cele Bruce, of the Computing Division, doesn't need to reference Fermilab's mission statement when speaking of her role at the Lab. Her motivation is clear and her impact is real.

"Support for the physicists," she says. "For what they do out there, we have to have the computing power to back them up."

Bruce, an administrative assistant for the Computing Division, has worked at Fermilab for three years. She handles electronic mail problems for the administrative staff and maintains the Computing Division's phone lists, organization chart and conference databases. In addition, she organizes the e–mail distribution lists and answers questions about software used by the Division's administrative group.

She started work at the Lab as an administrative assistant, but slowly took on computer–related tasks. Recently she moved to working full–time on the WWW computer applications, and, although her impact on the experimentalists' work comes farther down the line, she says she still feels a direct connection to basic research.

"We are helping the experimenters with computing, who are, in turn, working directly with the experimenters in other parts of the Lab," says Bruce.

DIXON BOGERT #1239

Dixon Bogert talks fast.

That's not surprising, because as deputy project manager for the Main Injector, he has an ambitious project to complete by 1999.

"I look after the civil and several of the business–oriented problems of the project," he says. "I have been associated with the Main Injector, in one way or another, almost since people stopped batting the idea about as a physics proposal and began wanting cost figures."

In his 26th year at the Lab, Bogert has done a little bit of everything. "Because I'm a physicist by trade, I've worked on a number of physics experiments. But as a scientist I did not have a civil construction or engineering background, so I have enjoyed learning those things for this project. It's an area that I find interesting because it's an intellectual exercise...Naturally I enjoy the work—you'd be crazy to be in this business if you didn't enjoy it," he says.

Having worked at the Lab since its early days, Bogert has developed an appreciation for its continual development, and has a sense of pride when he reflects on its accomplishments.

"Fermilab has evolved from the beginning," Bogert observes. "One of the nicest features of the Lab is that many of its characteristics that were instilled from the beginning are still present. The Lab hasn't intellectually ossified, and there are still many younger people coming on board who easily adapt to the general nature of the facility."

SERGEI SHARONOV #10807

Look in the Fermilab telephone directory under "S" and you will find no John Smiths. You will, however, find two Sergei Sharonovs.

Such is life at high-energy physics labs, which foster international collaboration more than most fields of endeavor.

Originally an electrical engineer, this particular Sergei Sharonov now does electrical design and software and system integration.

"We try to buy electronics modules as much as possible, so a big part of my work is system integration," Sharonov says. "I take some electronic modules, put them together, connect them with cables, write some software and make them talk to each other."

Sharonov toils in his office, surrounded by electronics. Working at a research institution, he seems to have a different challenge every day. He wouldn't have it any other way.

Sharonov enjoys the challenge of working on instruments that can measure to precisions that satisfy particle physicists.

"Here, there is much more interesting work to do," he says. "There is more work here than you can actually do so you can get a little bit choosy. It has the same deadlines as an industry, but in general the work is more challenging. I cannot imagine sitting in a private company doing some job. I like doing something different all of the time."

CYNTHIA SAZAMA #12

For Cynthia Sazama, it's the details that matter.

"I am the coordinator of conferences for Fermilab," the Physics Department assistant says. "Theoretically, I am a one-person office, and I am supposed to help with or handle all of the small workshops. For these functions I get involved in the logistical planning, space, food and transportation."

Though not responsible for scientific planning, she handles everything else. She has organized conferences with as many as 1,000 attendees, and enjoys working with the physicists. She has noticed that after they have helped her put on a conference, they are more appreciative at later functions. Sazama says they often simply don't realize how much work goes into running a conference. That's where her 25 years of expertise come in.

"I act as a service organization, bringing a lot of physicists' international groups together here at Fermilab," Sazama says. "The physics community, because it's a fairly small community, find that the conferences and workshops are one good way of getting people together."

TJ SARLINA #4129

It must not be much fun to go into a haunted house with TJ Sarlina. As head of the Research Division's ES&H Department, he spends most of his time identifying potential hazards and taking precautions against them.

"We try to provide safety and environmental oversight for the Division," Sarlina says. "It runs from the routine things, like where we need sprinklers, to somebody wanting to use an exotic chemical or substance in a detector."

Sarlina has worked at the Laboratory for 17 years. During those years he has seen the Laboratory grow and take a more aggressive attitude toward safety.

The goal, of course, remains taking particle physics to greater heights. But as experimenters work with new equipment and chemicals, Sarlina and his colleagues seek to identify and neutralize any new risks.

"We like to think that whatever experimenters think they need...to help them advance the high-energy physics program, that we can come up with a set of precautions that will allow them to use that material safely," he says. ■

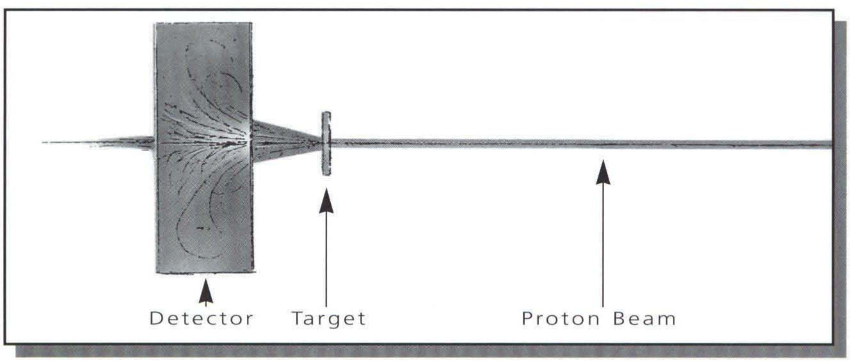
TJ Sarlina, Research Division, ES&H Department

FIXED-TARGET PHYSICS

In 1911, New Zealand-born physicist Ernest Rutherford announced that he had used beams of alpha particles (ionized helium atoms) from the decay of radium to discover the extremely small, dense core of particles that is the atomic nucleus. Rutherford's study of particles scattering off a foil target is a prototype of many of today's "fixed-target" experiments. At Fermilab, fixed-target experiments use high-energy protons from the Tevatron to hit targets and create secondary particles at experimental halls. Experimenters then use magnets and other devices to create specialized beams of particles for further study.

From the late 1930's through the early 1970's, the particle accelerator governed both nuclear and particle physics experiments. Today we would call these experiments fixed-target experiments: accelerated particles hit internal or external targets. At the time, however, they were just called "physics."

In the early 1970's a new method of studying fundamental phenomena came into wide use, in which counter-rotating beams of particles produced head-on collisions. To distinguish between the two different types of experiments, someone coined the terms "collider" and "fixed-target" physics.



The main advantage of colliding beams is that the total energy of the two beams is available for producing new particles, while in fixed-target experiments, much of the energy goes toward moving forward the particles that result from the impact with the target. Thus, colliding beams represent the high-energy frontier—up to 1800 GeV in the last Fermilab collider run. In the current fixed-target run, the energy available for production of particles is considerably less than in the Tevatron, up to a maximum of 39 GeV. Therefore the production of massive particles like the *W* and *Z* bosons and the top quark is possible only with colliders, and even the much lighter bottom quarks are less copious than in the colliding beam mode.

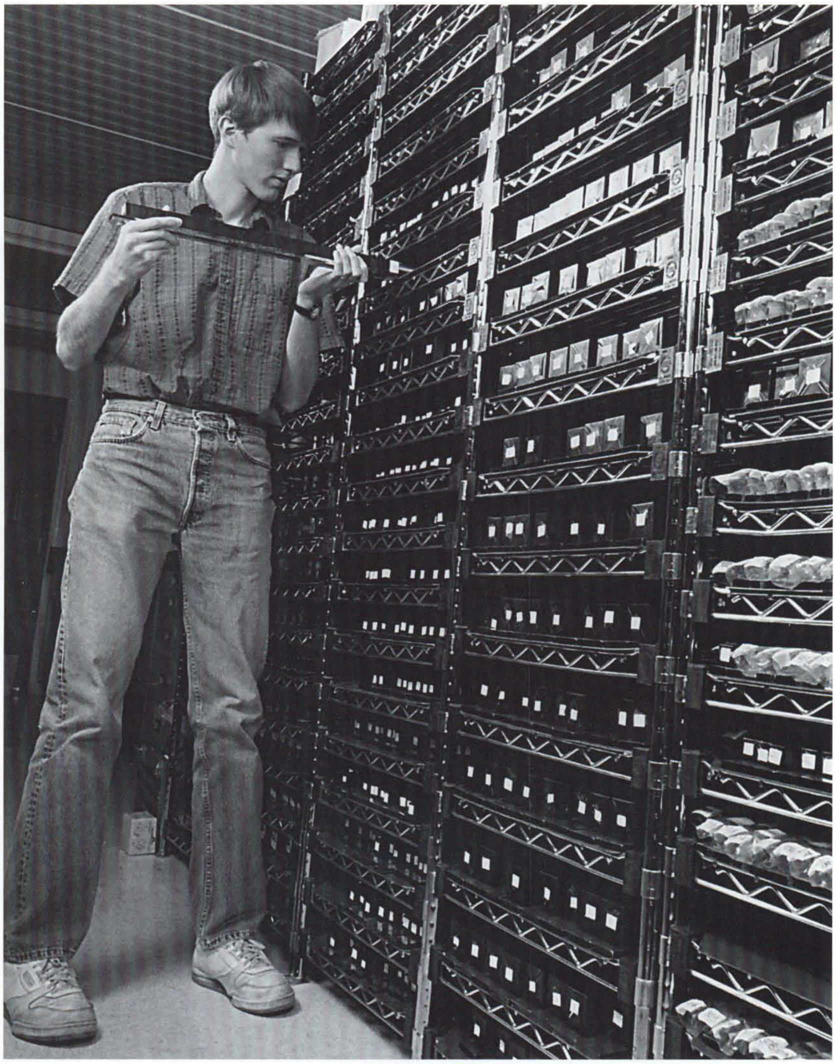
Colliding beams are impressive, but we shouldn't sell fixed-target physics short. In the fixed-target mode, we can use the protons from the accelerator directly, or we can form secondary beams consisting of a combination of other quarks, leptons, and photons. Like a chemist concentrating and purifying a sample before beginning a measurement, fixed-target experimenters can prepare beams enriched in the specific particles or quarks of interest. This allows them to study their interactions or decays relatively cleanly, free from backgrounds of less interesting particles.

Former Director Leon Lederman often spoke proudly of Fermilab's beams of hot and cold running protons, neutrons, electrons, photons, muons, neutrinos, pions, kaons and all the hyperons, up through the Omega, and, of course, their associated antiparticles. With these beams of quark composites, we can study a number of different quark interactions and decays. Variety is the spice of experimental physics!

Furthermore, fixed-target experiments make use of a higher luminosity, or rate of interactions. The collider run that ended in early 1996 attained a world record proton-antiproton luminosity of 2.5×10^{31} cm^{-2}/sec^{-1}. In the fixed-target realm, beam luminosities far surpass that number every day. For example E288, in which Leon Lederman and his collaborators discovered the upsilon particle, used an average luminosity of 5×10^{34} cm^{-2}/sec^{-1}, a factor of 2,000 over the collider record! That experiment required a specialized set-up to make use of such high luminosity, but it yielded a special discovery—the bottom quark.

In summary, collider and fixed-target physics approaches are complementary and allow physicists to study the universe from different viewpoints with different tools. When we require the maximum energy, colliding beams are the only choice. However, in those cases where sheer energy is not the highest consideration, for more controlled environments, for precision experiments, and for searches for and studies of rare phenomena, the fixed-target approach is often better.

In 1995, Fermilab users and staff continued the work of bringing the new fixed-target experiments online. The following pages give a summary of each of the new studies, including their goals and configurations.



Peter Shawhan, from the University of Chicago, works on KTeV hardware.

EXPERIMENT 799/832, KTEV, THE ORIGINS OF CP VIOLATION

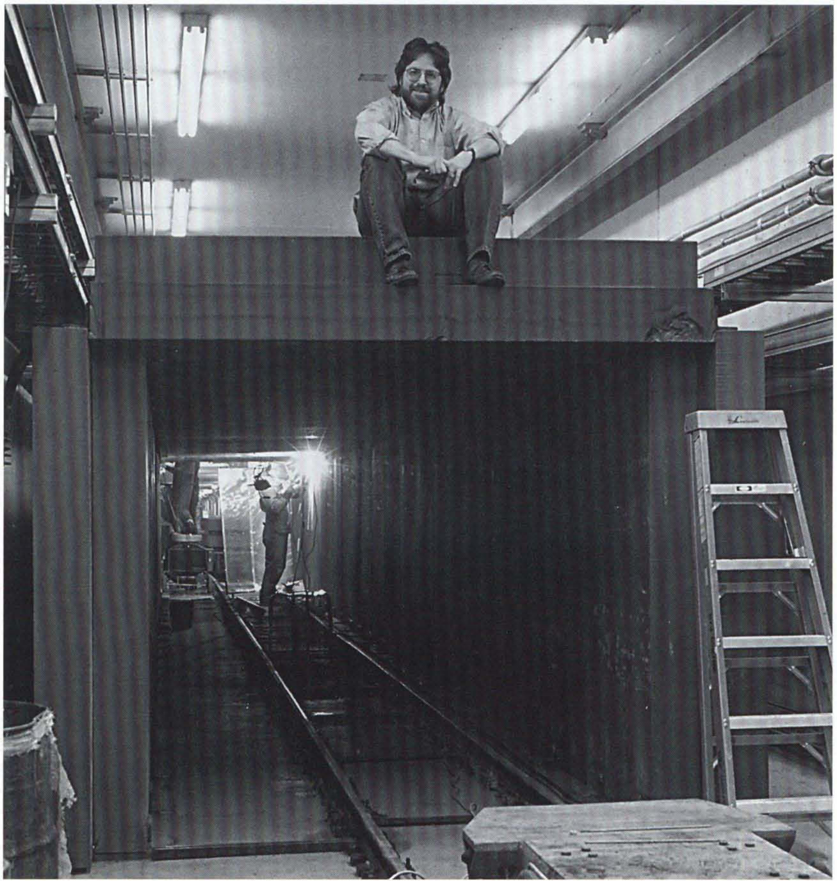
Experimenters in the KTeV (Kaons at the Tevatron) program will focus on the particle interactions that lead to the observed predominance of matter over antimatter in the universe. The asymmetry between matter and antimatter—the fact that our world seems to be made mostly of matter, despite the fact that antimatter particles pop up routinely in experiments—may hinge on a phenomenon called CP violation. A process that violates the rule of CP conservation is one of several conditions that make it possible for particles to outnumber antiparticles in the universe. Experimenters are pursuing the origins of CP violation in the decay of kaon particles. KTeV comprises two experiments working in parallel but studying two different facets of CP violation.

E832 aims to repeat earlier CP violation experiments six times more accurately. Phase II of E799 will study rare kaon decays and provide new high-precision hyperon beta decay data.

One experimenter said if they should find that direct CP violation in the decays in E832 is still compatible with zero at a high precision, then, at that point, one doesn't know whether there is a problem with the Standard Model or the parameters in the Standard Model conspire to give you a small direct CP violation. In that case, further study of the rare decays in E799 becomes crucial.

EXPERIMENT 815, NUTEV

The 40–member collaboration will use a beam of neutrinos to make precision measurements of neutral current interactions, providing a test of our understanding of aspects of the Standard Model. The scientists will measure the weak mixing angle, which describes how the photon and *W* and *Z* bosons are related. (The *W* and *Z* particles are carriers of the weak force.) The collaborators will also study the strong force and attempt to determine whether the strong coupling—the strength of the interaction that binds the nucleus together—behaves in accordance with the theory of the strong interactions, called QCD. To shed light on these questions, E815 will use a "fast spill" of the beam from the accelerator. Because neutrinos interact so rarely, the experiment needs the fast delivery of many particles at once to distinguish the beam signal from cosmic ray background.



Bob Bernstein, a Fermilab physicist and cospokesman for E815, sits in the NuTeV experiment hall during construction in 1995.

EXPERIMENT 872, SEARCH FOR THE TAU NEUTRINO

E872 is the direct search for the tau neutrino. Researchers hope to find the particle and better understand its properties. Since the discovery of the top quark, UC Davis physicist Vittorio Paolone, cospokesman for E872, said news reports often state that scientists have observed all of the fundamental particles in the Standard Model.

"It's just not true," he said. "There is a lot of indirect evidence, but [the tau neutrino] has never been directly observed, like the electron and muon neutrinos."

The neutrino search is a precursor to the Neutrinos at the Main Injector (NuMI) project, the search for neutrino mass. Paolone says it is important that researchers first directly observe the tau neutrino, and understand its properties, before they embark on the quest to see if it and the other two neutrino flavors have mass.

EXPERIMENT 868, SEARCH FOR ANTIPROTON DECAY

E868, known as the APEX experiment, is the search for antiproton decay. The study ran from April to June 1995 during Run Ib collider operations. Although the

Fermilab physicist Steve Geer, spokesman for E868, working on equipment for his experiment, the search for antiproton decay.

experiment is small, its goals are ambitious: to improve the sensitivity of previous searches for antiproton decay by a factor of 1,000, and to test a fundamental theorem in high-energy physics requiring that antiparticles (e.g. antiprotons) live just as long as their particle cousins (in this case, protons). Observation of antiproton decays with lifetimes shorter than their proton counterparts "would be revolutionary," said Steve Geer, the experiment's spokesman and a Fermilab physicist. Researchers had some preliminary results at the end of the year, and Geer expects them to have more in the months ahead.

EXPERIMENT 871, HyperCP

CP violation has only been observed in the kaon system. KTeV, mentioned earlier, will continue a long line of kaon experiments.

Another fixed-target study, E871, will attempt to observe CP violation using decays outside the kaon world. Experimenters will study the decay of the lambda hyperon and the cascade particle (or Xi), and their antimatter counterparts.

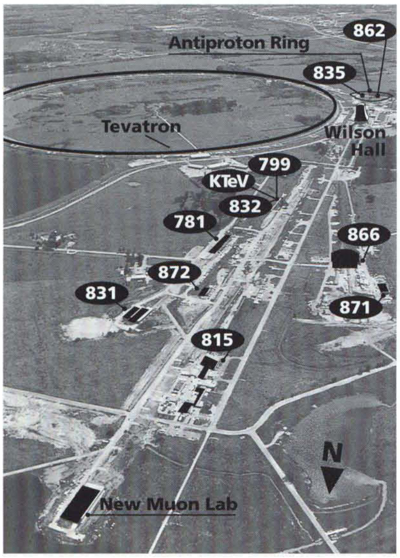
Craig Dukes, professor at the University of Virginia and cospokesman for E871, said researchers are looking for any difference in the decays of the particles and their antiparticles as evidence for CP violation. He added that any observed difference in the lambda hyperon decay and the decay of its antiparticle would be profound on two levels, signifying CP violation outside the kaon system and offering evidence for "direct" CP violation. He said if CP violation is present but unexpectedly small, experimenters may not see it.

EXPERIMENT 781, A CHARMED STUDY

Simply put, E781 aims for charm. The collaboration is looking for charm particles, in general, and baryons, in particular. Baryons are particles consisting of three quarks, as opposed to mesons, which consist of a quark–antiquark pair.

"We expect to increase the present world sample of charm baryons by a factor of 10 to 10,000," said experiment spokesman James Russ.

The 110 experimenters from nine countries will use a hyperon beam to enhance the production of charm–strange particles. E781's detector system can differentiate between pions and kaons—two families of mesons—up to an energy of 250 GeV, an accuracy that Russ describes as potentially a "world record." The extensive system—one component of which contains about 60,000 active strips of silicon—will pinpoint the decays of the specific particles the experimenters are seeking. The experiment has the potential to address three areas of particle physics theory: weak-decay physics, spectroscopy of excited states and charm–production physics. The last intrigues Russ most. Charm particles have many different colors but *b* quarks have only three colors. No experiment to date has been able to explain this incongruity.



"The biggest challenge of this experiment is to understand 'color bleaching,'" Russ said. "...We hope to understand this puzzle."

EXPERIMENT 866, INSIDE THE PROTON

All nuclei contain a sea of quark–antiquark pairs. The two lightest—the up quark and down quark—were always thought to occur in equal numbers. However, there is now circumstantial evidence that an asymmetry exists between the distribution of anti-up and anti-down quarks in the nucleon at about a 10 percent level. The measurements from E866 should provide the world's first detailed and accurate measurement of the asymmetry. This study is an integral part of ongoing experimental and theoretical efforts to understand the precise structure of protons and neutrons and the small differences between them, potentially leading to a clearer picture of how nuclei are assembled.

EXPERIMENT 835, CHARMONIUM STATES

Scientists will attempt to produce new states of charmonium, a form of matter containing charm and anti-charm quarks.

Collaborators will force protons to collide with antiprotons at a 90 degree angle in the Antiproton Accumulator. By precisely tuning the antiproton beam's energy, the experimenters will get charmonium in a small fraction of the interactions. The scientists will look for high-energy electrons and positrons, signaling charmonium decay.

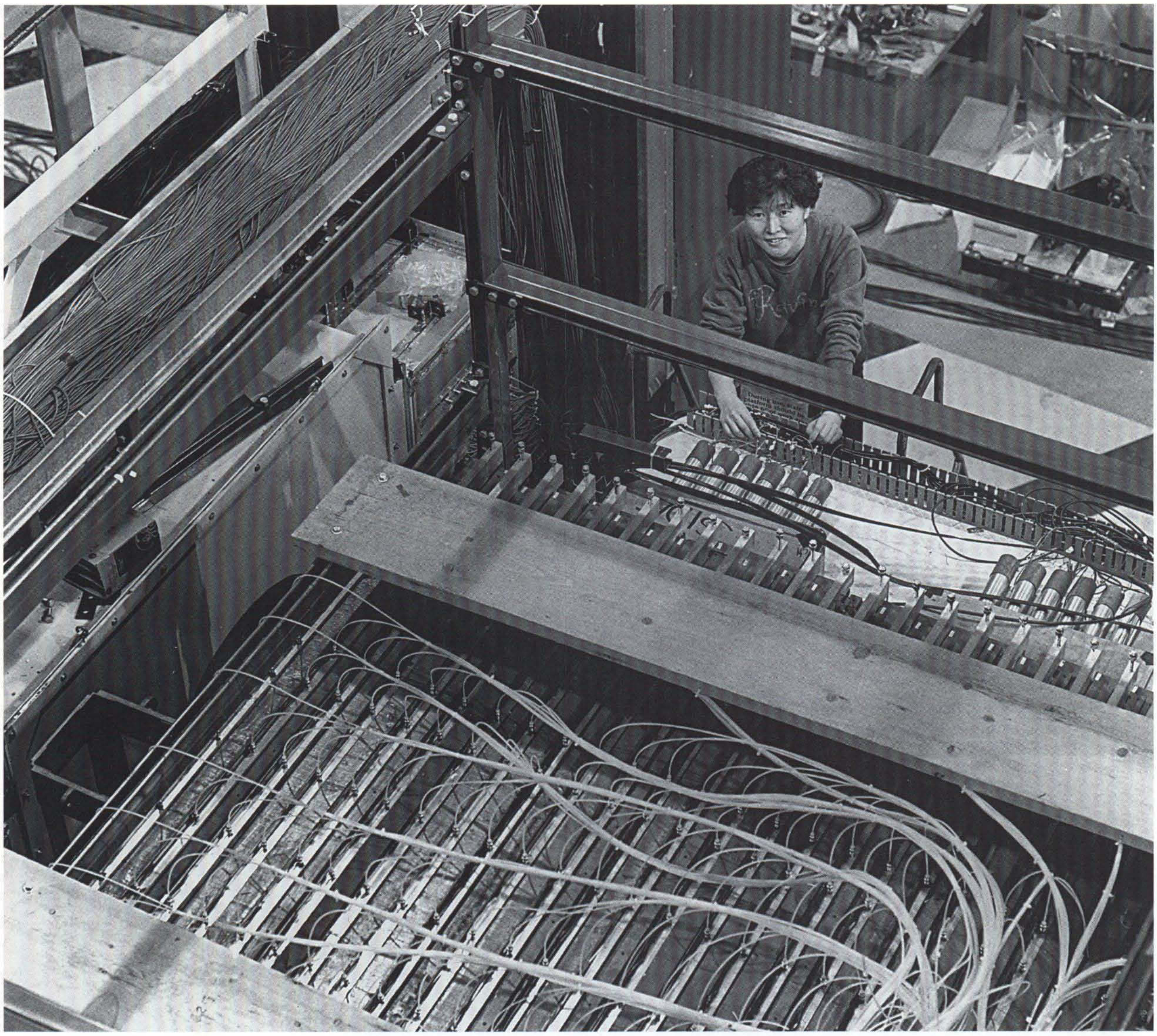
Experimenters plan to study charmonium to learn more about the strong interactions between the quarks. Fermilab physicist Stephen Pordes said previous similar experiments used electron–positron collisions, but such collisions can produce only a few charmonium states. Proton–antiproton collisions can produce a much wider array.

EXPERIMENT 862, ANTIHYDROGEN

Hydrogen is the simplest stable atomic structure, with one electron bound to one proton. E862 collaborators will attempt to create antihydrogen—a piece of nature that scientists believe is very rare, if it exists at all, in the universe. Antihydrogen is a positron (antielectron) bound to an antiproton. Experimenters plan to measure the antihydrogen production rate in interactions of the Fermilab Accumulator Antiproton beam in the E835 gas jet target.

EXPERIMENT 831, FOCUS

Like submariners who go from looking through a periscope to standing atop the sub's deck, FOCUS experimenters will have a wider field of view during the fixed-target run when they capture one million fully reconstructed charm particles, which would be the world's largest sample. Presently, there are competing models explaining exactly how charm particles decay; this experiment will help determine which is the correct model. To attack this discrepancy,



Seong Sook Myung, a scientist from the University of Korea, working in the E831 experimental hall at Fermilab.

experimenters will use the highest-energy photons in the world. When a photon interacts with a target, there is almost zero background debris, which provides a clear signal to study the charm. A proton interaction, by contrast, has much more background debris.

E831 will use a similar spectrometer to one used in a previous charm experiment, which carried out detailed studies of the decay channels of charm mesons and baryons. Experimenters will boost their yield of charm particles by a factor of 10 by using a more efficient detector and increased beam intensity.

By producing many decay channels of the baryons and mesons, the sheer number of events produced will give experimenters good looks at some of the more interesting decay channels. ■

STRONG INTERACTIONS

Inside the proton are quarks, held together by the strong interaction. In 1995, Fermilab worked to keep interactions with the university community, students, teachers, its neighbors and the environment as strong and vital as ever. Fermilab's high-energy physics mission defines our relationships with institutions and people—both near and far—as a science laboratory, a good neighbor, educator and environmental steward.

EDUCATION

Fermilab has many forms of outreach, building bridges between the Laboratory and the community. Among the most significant are the education programs at the Lab. Fermilab science education programs serve students at all levels, giving special emphasis to underrepresented 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. Fermilab's "Target" program, for example, is a precollege science and engineering curriculum that began in 1980. Target identifies and encourages scientific and engineering research ability among members of underrepresented minority groups, with the goal of increasing their representation in the sciences and engineering.

Summer employment and internships provide opportunities for undergraduates. 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.

However, teaching doesn't stop with students. Fermilab also offers and supports many precollege programs for educators. 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. By enhancing teachers' science and mathematics skills, Fermilab reaches even more students from all over the nation and the world.

A sampling of programs:

• A grant from the Illinois State Board of Education sponsors a course at Fermilab that instructs teachers how to integrate Internet resources into their curriculum.

• Fermilab's "Prairie Science Experience" offers methods for educators to enhance their curriculum with prairie field studies. An Eisenhower National Clearinghouse publication, distributed nationwide to educators, highlighted the program in its Fall 1995 issue—one of only about 15 programs that the publication promoted.

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 1995:

• 4,647 teachers and 26,637 students participated in 30 Fermilab-sponsored educational activities.

• Thirty–six educators were Program Leaders, and 150 scientists, engineers and technicians from Fermilab also participated in education efforts.

• 57 students received their Ph.D.'s with thesis work at Fermilab.

Beyond the numbers

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

DOE honors students get some hands–on experience at Fermilab in 1995. The program, which served high-school students, was canceled for 1996 due to budget cuts.

"This past week I had the pleasure of bringing twenty-two school administrators to the Science Education Center for Internet staff development. This workshop was one part of our district-wide staff development plan to train all 303 staff members in the use of this wonderful resource called the Internet. The plan was developed by six of our teachers who had the opportunity to participate in the LINC class this past spring. We are also fortunate to have four more staff members be a part of LINC this summer. All of these people will become trainers in our district. So, by the end of the '96-'97 school year, your facility and initial training will have an impact on all 10,000 students in our district. We are so fortunate to have this type of facility and the expertise of staff members to help make a real impact on the technology needs of public education."

—District Director of Media and Technology, St. Charles, Illinois

"(My son) is a 'gifted' student and I often find it difficult to keep him challenged and interested in school. Science and math are his subjects of choice, but what was apparent this week was true enthusiasm and the delight of discovery from your well-conceived program."

—Mother of a Summer Science Camper

THE ENVIRONMENT

Although science is first in Fermilab's heart, many visitors' first impression of the Laboratory comes from its environment. Whether it's the buffalo, or the tall-grass prairie standing well over six-feet tall, Fermilab's environment is an important and beautiful attraction. For all of its nearly 30 years, the Laboratory has maintained a strong dedication to nature, and 1995 continued the tradition.

During the year, Fermilab maintained 35–64 buffalo in its herd. Fermilab prairie keepers added 35 acres of prairie during 1995, bringing the total to more than 1,000 acres. Fermilab also held its popular prairie seed harvest on two Saturdays in the fall. More than 150 volunteers from the community, including families and school classes, came out to the prairie, where Fermilab staff taught them how to recognize particular plants and then clip the ripe flower heads for the seeds.

Black-eyed Susan flowers, one of many plant species in Fermilab's prairie.

Although the buffalo and prairie are the most visible environmental features at Fermilab, there are other important ecological projects. Fermilab has savannahs, woodlands, agricultural tracts and wetlands on the grounds. On May 8, 1995, Fermilab received the Department of Energy's 1995 Office of Energy Research NEPA Compliance Officer Quality Award for Environmental Planning, for the Main Injector project's wetlands mitigation efforts. The Lab built 8.55 acres of wetlands to replace 5.7 acres lost to construction of the Main Injector.

Fermilab is also designated as a National Environmental Research Park (NERP), a program designed to make DOE sites centers for environmental studies. Fermilab's NERP program lost funding in 1992, but research still continues at the Lab, mainly through university groups doing studies on Fermilab's unique environment. In 1995, four major projects began work:

• A University of California–Irvine team studied the evolution of herbivore resistance in goldenrod, a prairie plant.

• A researcher from the University of Illinois at Chicago built models of plant succession in restored prairies.

• A group from Northern Illinois University in nearby DeKalb, IL

Science teacher Maryon Tilley with some of her students from Morton West High School in Berwyn at the 1995 prairie harvest.

studied predator–prey population dynamics of small mammals.

• Two researchers from Argonne National Laboratory studied soil dynamics of restored tall-grass prairies.

REORGANIZATION

In a continuing effort to address the needs of the Laboratory and improve workforce efficiency, Fermilab reorganized its staff and added two new departments in 1995.

In February, Fermilab formed the Emergency Management Department within the Environmental, Safety and Health Section. The new department comprises the Fire Department, Security, Communications, Keys and ID, the Lock Shop and the Office of Emergency Planning. Emergency Management, under the direction of Romesh Sood, ensures the safety and health of workers, users and the public at the Laboratory. They also are prepared to respond to any emergency that may arise.

In May, the Public Affairs Office was born and placed under the Directorate. Fermilab Director John Peoples tapped Judy Jackson to run the office, which includes two editors and an administrative assistant. The team is responsible for all nontechnical publications, including the Annual Report, Institutional Plan and *FermiNews*, the bi-weekly newsletter of the Lab. The office also works with the press and public, and serves as the Lab's webmaster, updating Fermilab's World Wide Web site. Public Affairs staff members also support employees and users with communication efforts, produce informational materials and plan special events.

SITE ACCESS CHANGE

For 27 years, residents of neighboring communities used the privilege of driving freely through a national research laboratory. Fermilab's roads became popular avenues to bypass traffic on nearby streets. But in 1995, Fermilab made the decision to restrict drive-through traffic. As the Fox Valley population exploded, traffic volume rose at the Lab due to drive-through commuting, interfering with Laboratory operations. Drive-through traffic also exposed Fermilab to regulatory requirements of the U.S. Department of Transportation.

Fermilab is still open to the public seven days a week, but now requires all public motor vehicle traffic to use only the Lab's main entrance at Pine Street for entry and exit. The Lab remains open to visitors for tours and recreational use.

ON-SITE REVIEW

A Department of Energy delegation, headed by Energy Research Director Martha Krebs, conducted an extensive on-site review of Fermilab on September 28, 1995, hearing detailed reports of the Laboratory's past accomplishments, current work, education efforts and future goals.

For at least the next 10 years, Fermilab's planned research and direction will keep it at the "energy frontier of particle physics," said Deputy Director Ken Stanfield; however, efforts will not stop there. A vigorous planning process will keep the Laboratory among the world leaders of high-energy physics research beyond the next decade and the projected 2005 start-up of the Large Hadron Collider at CERN, according to Stanfield.

"I can see that...[Fermilab employees] have a vision, that there is the capability beyond the turning–on of the LHC..." said Krebs. "Now, clearly that vision has to be validated in some way by the larger community. But, it at least puts me in a position of defending [Fermilab's future] inside DOE, with OMB [the Office of Management and Budget] and with Congress."

Other members of the delegation, which included DOE staff from the Fermi group, the Chicago Operations office and Washington, D.C., agreed with that assessment. The DOE staff members heard reports on administration, education, diversity efforts and the Lab's physics goals, as well as an address by Director John Peoples.

Fermilab review participants "have done a lot to establish that there is a future here beyond 10 years," said John O'Fallon, director of the High–Energy Physics Division for DOE.

Steve Holmes, Main Injector project manager, talks with Martha Krebs, DOE Energy Research director, in the Main Injector tunnel during the on-site review.

Physicist William Fowler conveys wetlands award to Director John Peoples in the award-winning wetland.

AWARDS

A look at the awards won by Fermilab and Fermilab employees in 1995:

• Fermilab's Office of Research and Technology Applications recognized 37 Fermilab inventors for filing Records of Inventions during 1994. Each inventor received a certificate and a cash award.

• Fermilab received the Department of Energy's 1995 Office of Energy Research NEPA Compliance Officer Quality Award for Environmental Planning, for the Main Injector project's wetlands mitigation efforts.

• Fermilab's Education Office received a DuKane Valley Council award for its innovative problem-solving programs at the Leon Lederman Science Education Center.

• Rich Kron, head of the Computing Division's Experimental Astrophysics group, was awarded the Llewellyn John and Harriet Manchester Quantrell Award for Excellence in Undergraduate Teaching from the University of Chicago.

• The Feynman Computing Center was chosen as one of 52 Federal Showcase Facilities.

• Martha Krebs, Energy Research director for the U.S. Department of Energy, presented the DOE's Distinguished Associate Award to Laboratory Director John Peoples, for his major scientific and managerial accomplishments at Fermilab and for directing the phase-out of the Superconducting Super Collider.

• Peoples was also awarded the Distinguished Alumni Award from the Staten Island Academy.

• Ron Fast was presented with the Samuel C. Collins Award for outstanding contributions to cryogenic technologies. Fast retired from Fermilab in 1994, after 25 years of service.

• Venkat Kumar, Fermilab engineer, was honored by the Association of Energy Engineers, Iliana Chapter, as the Association's Energy Manager of the Year. Fermilab was also honored by the Association's Chicago Charter Chapter, for "Environmental Projects" including lighting and heating retrofits.

• Don Cossairt was elected a member of the National Council on Radiation Protection and Measurements.

PAYING OUR RESPECTS

The following members of Fermilab's family passed away in 1995:

- Charles Galauner, an instrument maker in the Technical Support Section's Machine Shop, died January 8.
- Richard Hunckler, a Senior Technical Aide in the Research Division's Site Operations office, died August 20.
- Wilbur Meeks Jr., a DZero technician, died on August 8.
- Emma Visor, a food attendant for Laboratory Services, died August 18.
- Eugene Beck, a Senior Technical Aide in the Physics Section, died September 24.
- Arcilla Magee, a Maintenance Electrician for the Facilities Engineering Services Section, died April 27.
- Richard Scherer, an Expediting Administrator for Business Services, died August 29.
- William Jones, a Machine Shop Superintendent for Technical Support, died July 16.
- Norbert Ambrose, a Maintenance Mechanic in Business Services, died December 26.
- Barbara Lach, Public Relations Manager for Laboratory Services, died March 31.

CREDITS

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Design: Weed Advertising

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 1995, over 2,300 physicists from many national and international institutions—186 to be exact, 86 foreign and 100 national—used Fermilab. They are listed in alphabetical order:

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U.S. INSTITUTIONS (100)

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FINANCES 1995

FERMI NATIONAL ACCELERATOR LABORATORY

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Laboratory Funding and Personnel Summary
For the Year Ended September 30, 1995

OPERATING AND EQUIPMENT:

Fermilab Operating	$168,400,000
Secondary Projects	
• Waste management	1,898,000
• Education	1,256,000
• PET	1,050,000
• Work for others	270,000
• Tech transfer	160,000
• IHEM operating	135,000
Subtotal Secondary	4,769,000
Total Operating	**173,169,000**
Capital Equipment	**27,545,000**

PROGRAM CONSTRUCTION:

Main Injector	$43,000,000
AIP/GPP(KA)	9,720,000
Low Level Radiation Waste Handling Building	2,500,000
In-House Energy Management	2, 390,000
Subtotal	**$57,610,000**
Total Laboratory Funding	**$258,324,000**

LABORATORY PERSONNEL SUMMARY

Direct	1,658
Indirect	566
Total Laboratory Personnel	**2,224**

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