DØ

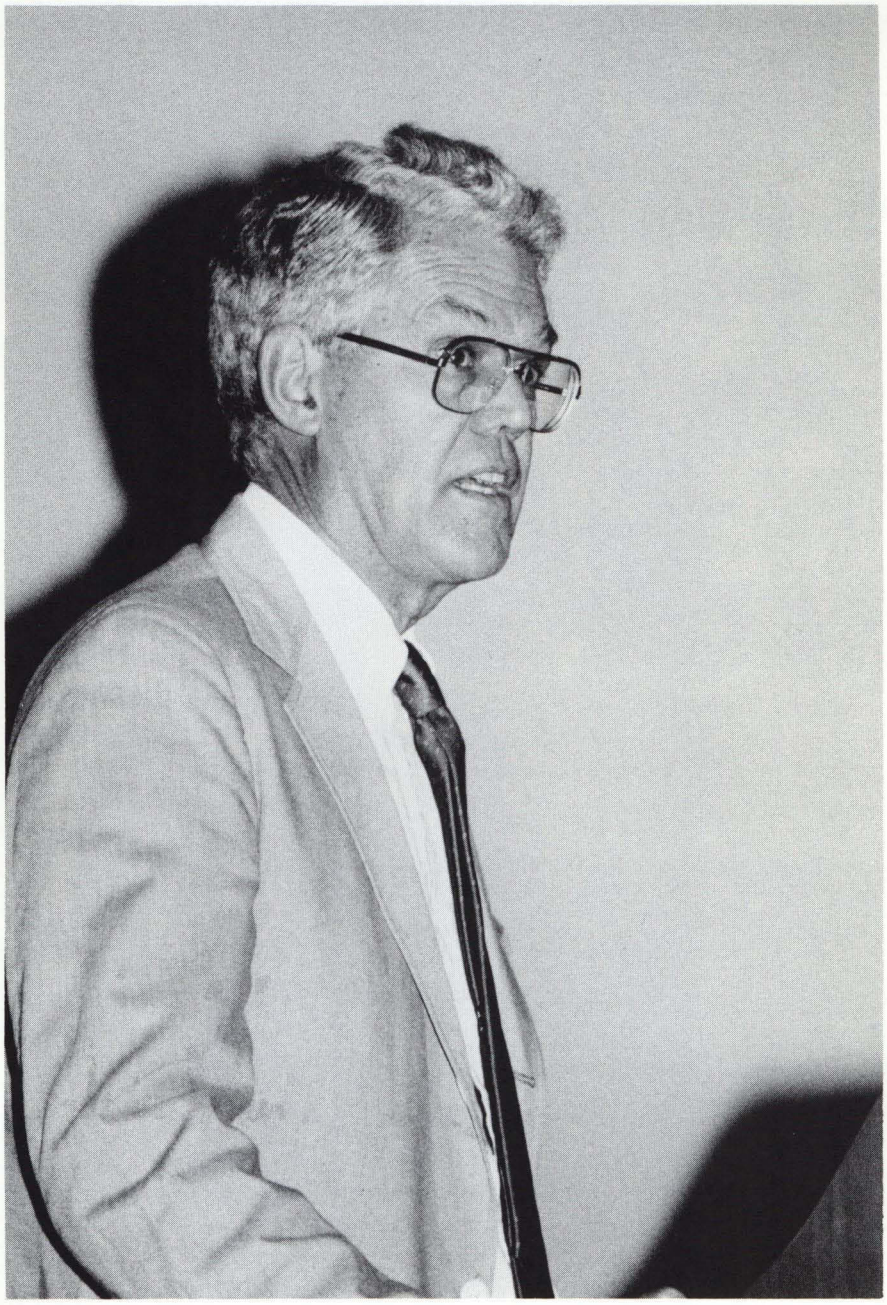
Fermilab 1986

Fermilab 1986

Annual Report of the Fermi National Accelerator Laboratory

Fermi National Accelerator Laboratory
Batavia, Illinois

Operated by Universities Research Association, Inc.
Under Contract with the United States Department of Energy



Edward A. Knapp, President
Universities Research Association, Inc.

UNIVERSITIES RESEARCH ASSOCIATION

1111 19th Street, N.W. Suite 400 Washington, D.C. 20036

(202) 293-1382

November 21, 1986

Dr. Leon Lederman, Director
Fermi National Accelerator Laboratory
P.O. Box 500
Batavia, Illinois 60510

Dear Dr. Lederman,

This year marks the completion of the last phase of construction for the Tevatron systems. With the completion of the last major construction project and the assembly of the overpass systems in the accelerator, Fermi National Accelerator Laboratory is finally ready for long, uninterrupted periods of research and data taking. The Universities Research Association is proud to be the operating contractor for the Department of Energy for this vital and productive enterprise.

It is clear that Fermilab has a bright future ahead, with the commissioning of the TeV I and II, and the development of the detectors and experimental techiques necessary to exploit these major new facilities. Fermilab is also intimately involved in the future of high-energy physics on another front. By operating the world's first superconducting high-energy proton accelerator, it has shown the way to the next generation of instrumentation for this field. Fermilab is also an active participant in the R&D studies directed toward the next major accelerator needed by the field. The effort to pool technical development by participants from the entire high-energy field and industry has been extremely successful over the past year, and Fermilab has been a major contributor and participant in this cooperative venture for American Science.

I see an era of great promise and productivity ahead for high-energy physics. The URA will continue to emphasize the university nature of this science and work with the Department of Energy to keep this most fundamental of the scientific fields productive and vital.

Sincerely,

Edward Knapp

Edward A. Knapp
President

Table of Contents

I. The State of the Laboratory 1
Leon M. Lederman et al.
The Director and his colleagues map the terrain covered in the past year.

Retrospective on Seven Years with the Accelerators 3
J. Richie Orr

The Pbar Source 7
John Peoples

The 8-GeV Booster 10
Stephen D. Holmes

The Main Ring 13
Stanley Pruss

The TEVATRON 16
Rolland Johnson

The Collider Detector at Fermilab 21
Roy Schwitters (Harvard University)

The D0 Experiment 26
Paul Grannis (SUNY/Stony Brook)

Small Collider Experiments 33
Roy Rubinstein

The Research Division 37
Mark Bodnarczuk and Ken Stanfield

The Physics Department 47
Dan Green

The Technical Support Section 51
Paul Mantsch

The Computing Department 61
Hugh Montgomery

The Advanced Computer Program 69
Thomas Nash

The Safety Section 75
Larry Coulson

The Theoretical Physics Department 79
Chris Quigg

Fermiland Astrophysics 83
Rocky Kolb

The Neutron Therapy Facility 87
Arlene Lennox

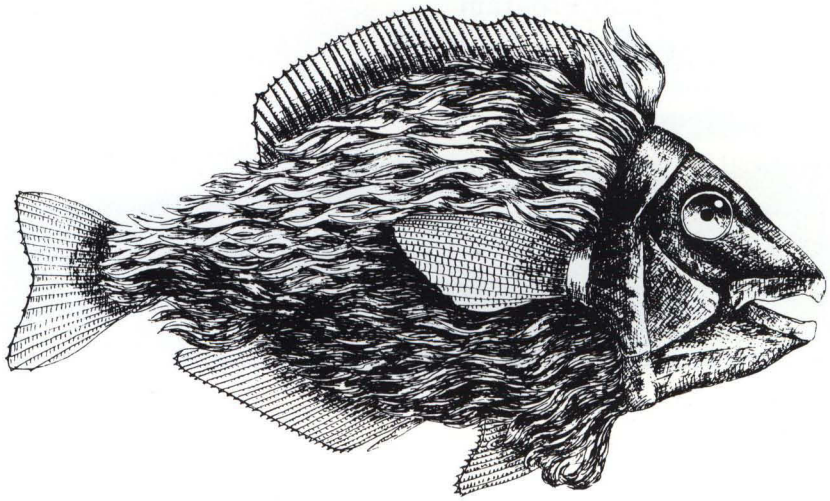
The Medical Accelerator 89
Francis Cole

Technology Transfer 91
Dick Carrigan
The US Particle Accelerator School 95
Mel Month (Brookhaven National Laboratory)

II. Recent Physics Results from the TEVATRON 99
Roger Dixon
The longest run of the TEVATRON produced some spectacular data.

III. The Accelerator Upgrade Program 113
Helen Edwards
The dark and forbidding territory of the TEVATRON must have more illumination!

IV. Appendices
Appendix A: Publications 123
Appendix B: Seminars and Colloquia 145
Appendix C: Approved Experiments in the Fermilab Fixed-Target and Collider Programs 161
Appendix D: Visitors to the Fermilab Theoretical Physics Department 164
Appendix E: Visitors to the Fermilab Theoretical Astrophysics Group 165
Appendix F: Universities Research Association, Inc. 167
Appendix G: Physics Advisory Committee 168
Appendix H: Fermilab Users Executive Committee 168
Appendix I: Fermilab Industrial Affiliates 169



A - Extraction	*G - Booster*	*M - Muon Lab*
B - CDF	*H - Pbar Source*	*N - Erratics*
C - E735	*I - Wilson Hall*	*O - Broken Symmetry*
D - DO	*J - Meson Lab*	*P - Bison Bison*
E - E710	*K - Neutrino Lab*	*Q - Branta Canadensis*
F - RF	*L - Proton Lab*	*R - Fauna Incognita*

I. The State of the Laboratory

The time of writing is January 1987. The procedure we have followed over the past several *Annual Reports* is to beg a selection of Laboratory Leaders to compose annual reports and then for the Director to string them together with homilies, aphorisms, and an occasional insight. Fermilab is a "single purpose" Laboratory devoted to research in particle physics, but so much goes on that a reporter identifies with the mosquito in the nudist colony: where to begin? Being January 1987 one is tempted to start with the TEVATRON COLLIDER and its commissioning for physics, primarily with the CDF (i.e., the Collider Detector at Fermilab) detector in place and more or less complete. As this is being composed, the first collisions since the engineering run of October 1985 are being recorded. We are anticipating the halcyon days of the TEVATRON era and we are suitably humbled by the custodial responsibility for the highest energy accelerator in the world. This applies to both the fixed-target program and the Collider which arranges head-on collisions of protons and anti-protons.

The luminosity begins with a gratifying factor of about 1000 increase over the 1985 test and with a very optimistic objective of reaching 10^{29}cm^{-2} sec^{-1} before the end of this "first physics" run in early spring. The excitement in the CDF control room is palpable as event after event flashes on the computer screen. Some bring oh's and ahh's. Soon, the crowds will thin and the equipment tuning will become routine and painstaking. CDF, reviewed often, is a uniquely complex detector with a history covering a decade and intense and systematic designing, R&D, and construction covering the past five years. Rivalling this effort is the PBAR SOURCE (nee TeV I). Now merged into the Accelerator Division, it appears at this early stage to be a glowing success - as milliamperes of antiprotons (pbars) accumulate and are stored for days. The third element in the chain of necessities is the Accelerator Complex - venerable Main Ring and superconducting TEVATRON which must receive the antiprotons from the Source and do so many things before delivering a compacted bunch of pbars to the collision point in the middle of the CDF detector.

There are other high points seen in January 1987. Evidence of a rather spectacular success of the fixed-target program's good run in 1985 began to appear in the Summer Conferences of 1986 and became clearer as the year wore on. What is emerging is a *qualitatively* more powerful attack on what is called "Standard Model" physics. In experiment after experiment, the quantity of data increases by two or three powers of ten (e.g., a few hundreds of events before becomes 100,000 events after), also the quality of the data changes. Although the fixed-target research has been described as programmatic, such an

←*"Now when I was a little chap I had a passion for maps. I would look for hours. . .and lose myself all in the glories of exploration. At that time there were many blank spaces. . . and when I saw one that looked particularly inviting. . .I would put my finger on it and say 'When I grow up I will go there'." Joseph Conrad,* Heart of Darkness

improvement has historically often lead to important discoveries. Roger Dixon spells this out later in this *Annual Report*. All of this gave a tremendous boost to preparations under way for the 1987 run this spring. Here, the program will be in its mature adolescence as three major new experiments come on line.

Another peak has to do with our venture into a necessity-driven R&D program on parallel microprocessors for data analysis: our Advanced Computer Program (ACP). Started in 1983, in 1986 this device was also a clear success, crunching data, widely in demand, the technology transferred to industry and the glory rolling in . . . also relief that we *will* be able to cope with the computer demands of CDF, D0, and a sophisticated fixed-target program.

In January of 1987, the TEVATRON program, a concept which evolved out of a vision conceived in Fermilab's remote past, is essentially complete. To justify the human and financial investment, science must be done. This naturally leads to a new vision of what we must do in the next five years: we call it the UPGRADE program. What is important about the Upgrade is its necessity. Remember that the major detectors surround the collision point and try to detect everything. CDF (and later D0) will have all the armaments that can be thought of and afforded. They will surely be improved over the next years to increase the *quality* of the data but these will be minor compared to the original construction. The real improvement by far must be a significant increase in the *quantity* of data collected each year, hence: UPGRADE. In hadron colliders where the constituent quarks do the colliding, increasing the collision rate also increases the probability of more energetic quarks colliding, i.e., the effective energy increases. The story is told later on by Helen Edwards.

These are the great peaks. How we got here is the story of this *Annual Report*. Not all the heroes and heroines will get deserved credit, not all the good things we have done will be told; surely we will tell none of the bad things. We begin with the heartland of Fermilab: the accelerators.

Our first reporter is an authentic hero. J. Richie Orr lead the Accelerator Division since its merger with the Energy Saver Division (1981) and headed the E.S.D. since its inception in 1978. He has had a wide assortment of Laboratory responsibilities, all carried out with style and a real concern for people. On January 1, Rich Orr's assignment was changed at his request and so it is appropriate to open this *Annual Report* with Rich's retrospective:

Retrospective on Seven Years with the Accelerators

J. Richie Orr

Although the last seven years have seen a shortage of beam for high-energy physics (HEP), they have also been a time of investment for the future. Rising energy costs, the installation of the TEVATRON, and the construction of four colliding-beams experimental areas and two Main Ring overpasses all conspired to take beam away from our users. My records show that the experimenters received beam about 50% of each year in the peak period from 1975 to 1978. This percentage dropped steadily to a low of 10% in 1983, a year devoted mostly to TEVATRON installation. It rose to almost 55% in 1985 and dropped to zero in 1986, the year of the shutdown for the construction of the C0, D0, and E0 experimental areas and the Main Ring overpass at B0. As one can see, beam time is the price we paid. What we accomplished in the intervals when we were not delivering beam is outlined below:

By the beginning of 1979, the year that the Energy Saver project was authorized, many of the elements for the project were in place. Pilot magnet production runs were underway at the Magnet Facility. The Magnet Test Facility was beginning to function. The cryogenic system had been designed, a prototype satellite refrigerator had been constructed, and the Central Helium Liquefier was being assembled. The control system had been specified and hardware and software work had begun. Parts were beginning to flow from many of the vendors. The quench protection scheme had been tested at the B12 test string. We had installed and tested a string of 20, 22-feet-long superconducting dipoles and four quadrupoles in Sector A of the Main Ring

Rich Orr and Helen Edwards on the morning after the 950-GeV quench test of the TEVATRON's A-Sector in 1982.

tunnel. Although these magnets were later removed because of a change in the dipole magnet length to 21 feet, this exercise allowed us to develop many of the techniques that were used later to install the TEVATRON. We had also extracted 90-GeV beam from the Main Ring and sent it through this string.

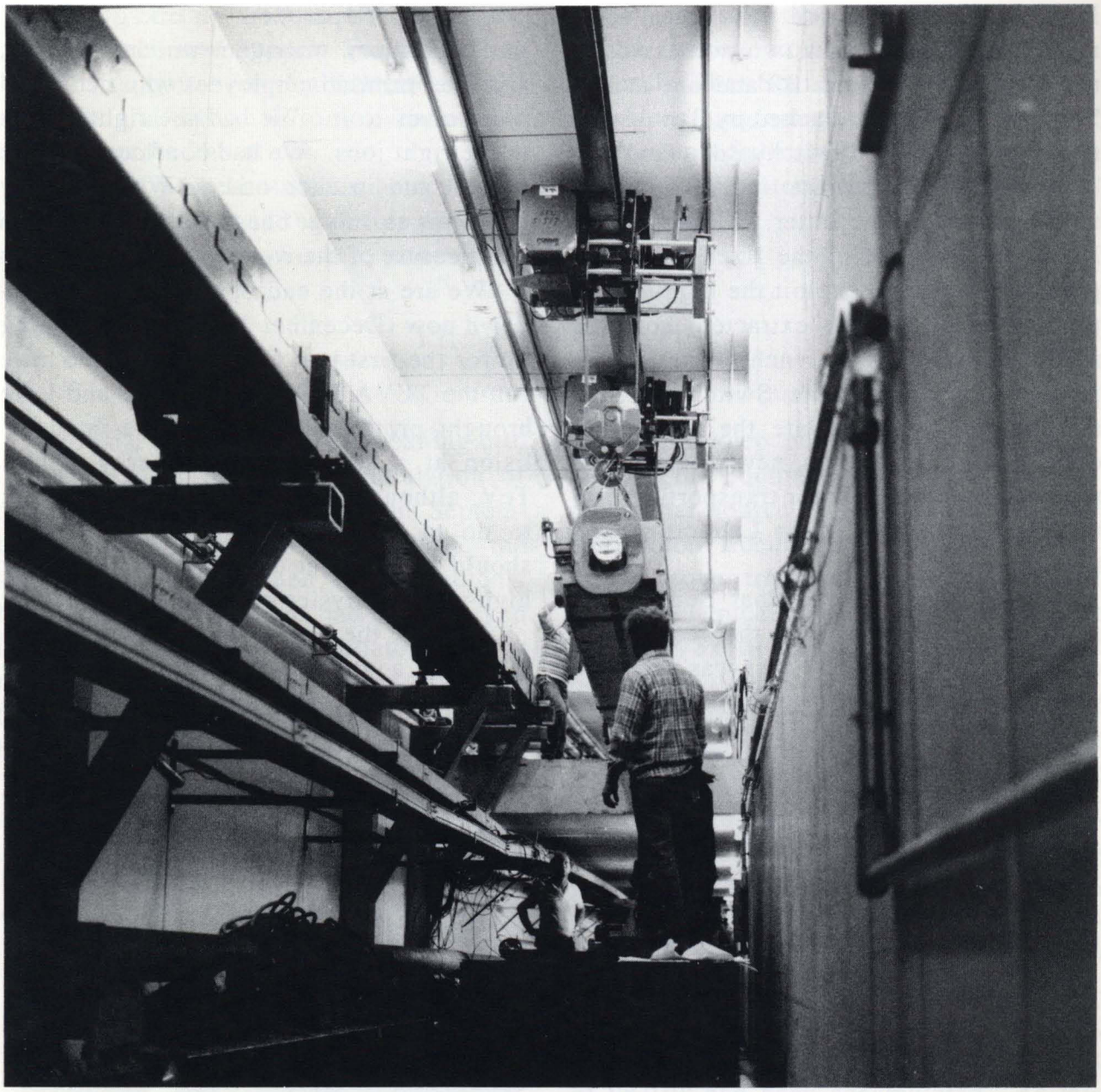
In 1980, we installed a second string of the (now obsolete) 22-ft magnets in Sector A in order to perform more cryogenic tests. This string, located downstream of the first and fed by a second refrigerator, was 30 dipoles and 8 quadrupoles long. Production of the final (21-ft long) dipoles began in earnest. By the end of the year we were turning dipoles out at a rate of more than 15 per month. Quadrupoles and spools (which contain the correction magnets) were coming out at a matching rate. Satellite refrigerators and transfer lines were beginning to appear on top of the Main Ring berm. Components and materials were arriving at Fermilab from as far away as the Pacific Northwest and New England on a regular schedule. People were joining the project from many parts of the Laboratory.

Between the summers of 1981 and 1982 the first significant part of the TEVATRON (3/4 of A-sector) was installed and tested during intervals when we were not running the Main Ring for high-energy physics. We decided to see if the machine was rugged enough to handle the conditions that would be imposed in actual service. We ramped repeatedly to 950 GeV and quenched the entire string at this energy with an extra 1000 volts applied between the magnet coils and ground. We performed pressure tests, quench protection tests, and cryogenic tests under simulated fault conditions. The system took the beating and came up smiling.

The late spring of 1982 saw the end of 400-GeV running with the old Main Ring and the beginning of the final push to install the TEVATRON. Most of the preparation work was complete. Accelerator-quality magnets had been flowing from the Magnet Facility at a rate of more than ten per week for 18 months. The rf, controls, power supply, quench protection, vacuum, correction, injection, and extraction systems were ready (or almost ready) to be installed. Installation crews had been trained and equipped. Contracts had been awarded for the conventional electrical and mechanical work. The massive cryogenic system with its Central Helium Liquefier and 24 satellite refrigerators was mostly in place. We worked around the clock for a little more than a year. On May 31, 1983, the machine was complete and at its operating temperature. We were ready to start the commissioning phase.

The turn-on went swiftly. We reached 512 GeV (a new energy record) by July 3. We were at 700 GeV by August 15. We lowered the energy for the last three months of 1983 to finish the 400-GeV program and then ran the machine at 800 GeV for two successful fixed-target runs in 1984 and 1985.

In parallel with the work on the superconducting machine, the TEVATRON I project had been under construction since 1982. Its centerpiece is the sophisticated Pbar Source itself, with its target station, Debuncher, Accumulator, stochastic cooling, and beam-transfer systems. In addition, this project reached into almost all of our other machines. Because of Tev I there are new beam-extraction and transfer systems from the Booster and Main Ring. There is a special rf system in the Main Ring for coalescing beam bunches. There is a low-beta system in the TEVATRON.



Riggers installing an overpass magnet in the B0 Overpass in the Main Ring.

Most traumatic of all for the older machines, there are now two overpasses in the Main Ring - one at B0 and one at D0. The only systems untouched by Tev I were the Linac and the Switchyard - and the TEVATRON II project included major modifications to the latter. (TEVATRON II was the upgrade of the fixed-target experimental areas to exploit the high-energy protons which can be extracted from the new superconducting synchrotron. As a part of this project, the Switchyard was modified to accommodate the higher energy beams. In addition, new primary proton beams were added for transporting protons to serve a new Muon Laboratory and two test areas.)

By fall of 1985, the Pbar Source was ready to be merged with the rest of the accelerator complex. A test was arranged with the CDF detector in place to observe the results. Proton-antiproton collisions were observed on October 13, 1985. The project was successful.

I think the major reason for the success of this high-risk endeavor was tight communication and cooperation among all of the people who worked on the project, including the Department of Energy people, the Laboratory management, the vendors, and the Fermilab employees who dedicated themselves to it. We had the right people in the right jobs. We had confidence in the project and in each other. We had many problems to solve, but these only added to the pleasure of the work.

We are at the end of the last long shutdown now (December 1986) and are tuning up for the first real Collider test. We have run the TEVATRON at 900 GeV and have brought protons and antiprotons into collision at a center-of-mass energy of 1.8 TeV, although we still have a lot of work to do to increase the luminosity. 1987 should be the first of many rich years for high-energy physics at Fermilab.

For me, the past seven years at Fermilab were a great experience. I felt like Huck Finn riding a raft down the Mississippi. The early years were like drifting on the quiet upper river. As tributaries with names like the Saver, TEVATRON I, and TEVATRON II entered the stream, the current became swift and powerful. With luck, a great discovery will be made in time to reach New Orleans for Mardi Gras.

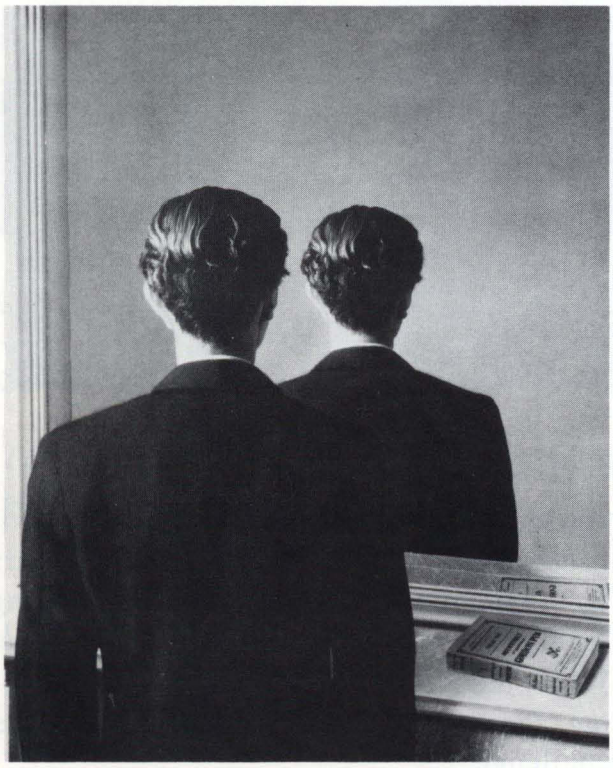
On January 1, Rich Orr joined the Technical Support Section to help support the Laboratory's SSC activities and, as usual, to do whatever he can to keep the Lab afloat.

We turn now to another hero. John Peoples, who managed the design and construction of the Pbar Source, now writes from his new perspective as Deputy Head of the Accelerator Division. He writes about the Pbar Source. Now "pbar" sounds like something out of either A.A. Milne or Gilbert and Sullivan, but it is simply jargon for "antiproton," usually designated as $\bar{p}$, i.e., pbar.

The Pbar Source

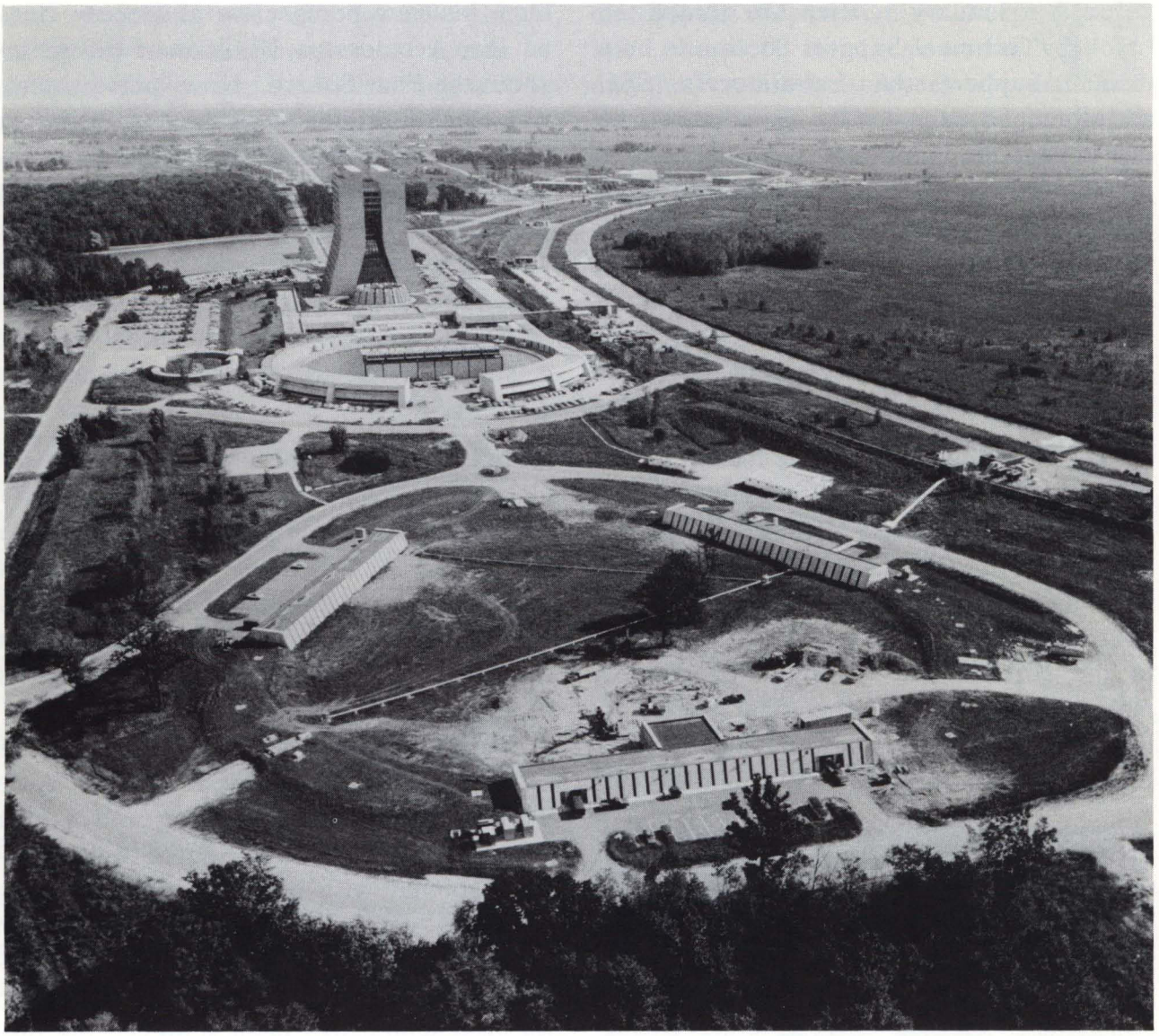
John Peoples

The Pbar Source put some meaning into its name when the first accumulation of antiprotons was accomplished in September of 1985. By October of 1985, the stacking rate had reached 10^9 antiprotons/hour and 10^{10} antiprotons had been stacked in the core of the Accumulator thereby making it the highest flux pbar source in the western hemisphere and the second highest in the solar system. While such statements keep publicists busy, the only meaningful comparison is with the only other pbar source in the solar system, the Antiproton Accumulator at CERN. It is better known to antimatter afficianados as the AA. Typically the accumulation rate at the AA is 5×10^9 antiprotons/hour and stacks of up to 5×10^{11} have been achieved.



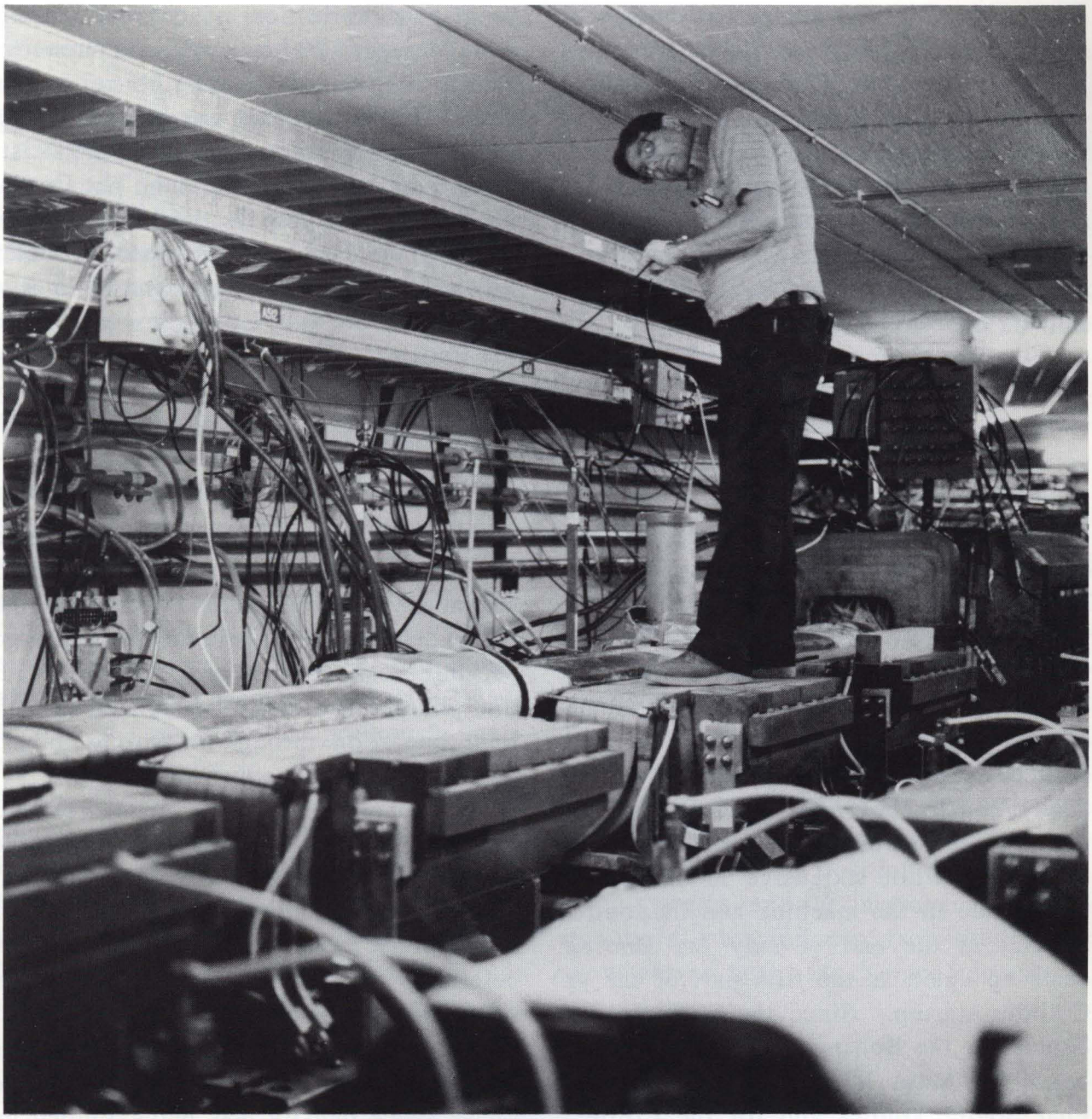
"La Reproduction interdite"

During the October 1985 run, a number of problems were exposed. All of these were either corrected during the 1-year shutdown, or the Pbar Source was modified, so that with patience, the remaining problems can be eliminated. Antiproton stacking resumed in mid-November. Initially the rate was only 10^9/hour, equal to the best which had been achieved the previous year. After several weeks of work, the rate rose to 4×10^9/hour and a peak stack of 9×10^{10} had been accumulated. As this note was submitted for editing, the rate reached 6×10^9/hour. Careful scrutiny of this improved performance will show where further changes will lead to still better performance. Fortunately, an extensive shutdown will not be needed to implement the small changes that are foreseen. Hopefully, by the time readers' eyes pass this line the accumulation rate will be closer to 5×10^{10} antiprotons/hour and stacks of 2×10^{11} antiprotons will have been accum-



A view of the Pbar Source looking north toward Wilson Hall. The recently completed South Booster Laboratories are the two buildings which extend the arc of the Booster Service buildings to Well Pond Road. The addition to service building AP-50 for E-760 can be seen in the foreground.

ulated. While such a prediction may seem optimistic, the optimism is sustained by the fact that the technically most challenging parts of the Source, the stochastic cooling systems and the lithium lens, will reach their design performance with relatively small changes. This gives us folks in the antimatter factory reason to believe that stacking rates approaching 4×10^{11} antiprotons/hour can be achieved in four years by extending collection and cooling technologies as proposed in the Upgrade. While the R&D to do this will be challenging, the scientific goals are well worth the challenge.



T&M electrician Marvin Walling adapts to the situation as he pulls motor-control cable in the Pbar Source Accumulator.

The Director has the advantage of the last word, and what was most impressive about the Pbar Source was the fact that the core stack of pbars, to which we alternatively added via pbar production and subtracted via "shots" to the Accelerator and the hungry CDF experimenters, this core of never less than 3mA circulated in the Accumulator Ring for a January record of 14 days!

The sparkling new TEVATRON rests on a base collection of ancient accelerators, designed 20 years ago, and strenuous efforts are now beginning to rejuvenate these. If we succeed, one could consider using these techniques on older physicists but we are not too optimistic. The first of the "older machines" is the Linac and upgrade plans here are discussed in Helen Edwards' article. Young Steve Holmes, a veteran of the TeV I program, tells about the Booster:

The 8-GeV Booster

Stephen D. Holmes

This has been both a year of change and a year of intense activity for the Booster. During the period of January through April, while the Main Ring and TEVATRON were not operational, machine studies were carried out in the Booster while simultaneously, protons were provided to the Pbar Source for commissioning studies via the newly constructed AP4 line. During the period of May through July the Booster was turned off while extensive modifications were made to the machine and its control system; at the end of July the Booster came up again as the first part of the $\bar{p}p$ Collider startup. Since the beginning of September the Booster has been providing beam for Main Ring, TEVATRON, and Pbar Source studies and for the Collider startup.

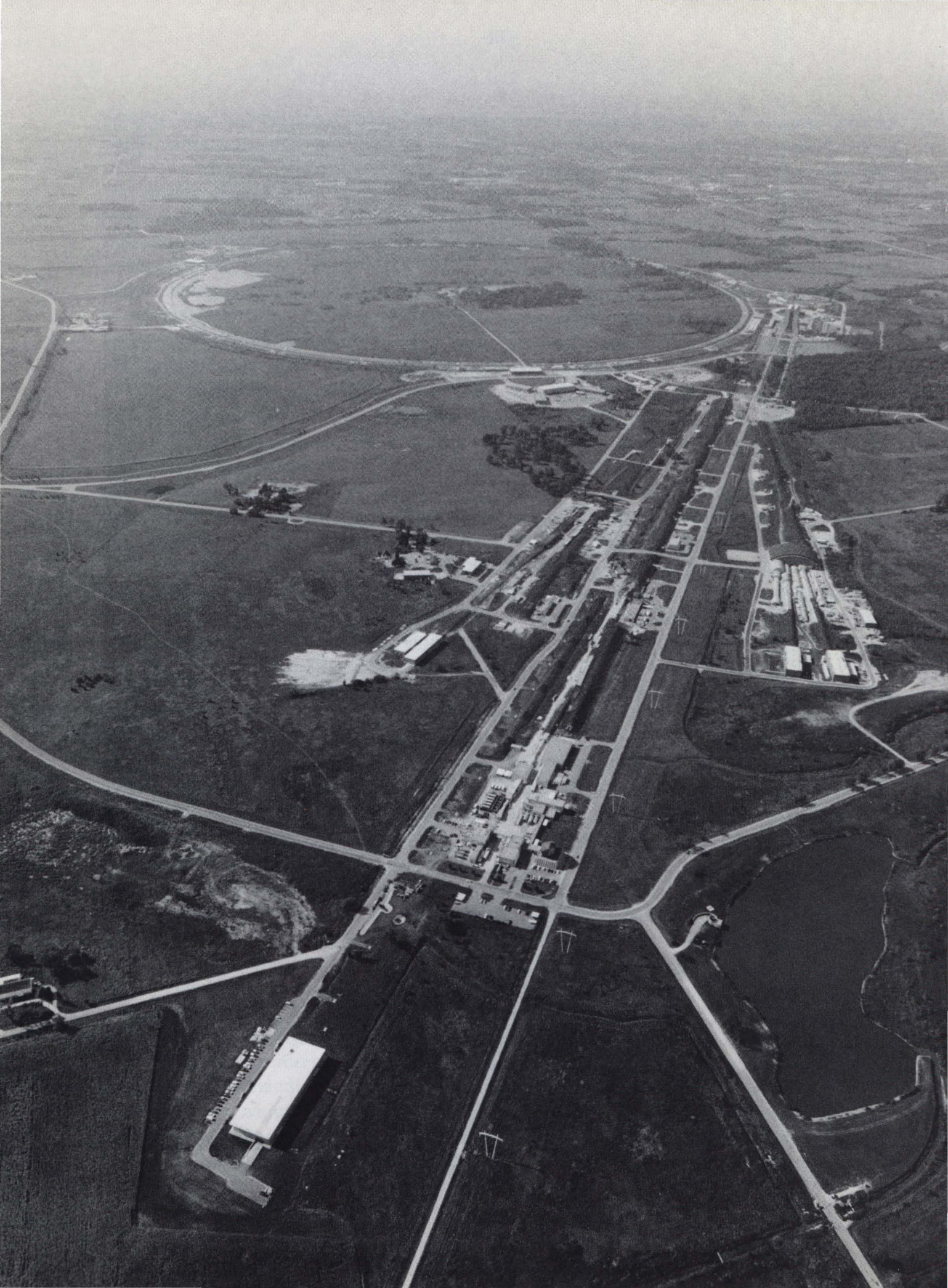
The period January 15 through April 30 was devoted to machine studies in the Booster, free of the burden of supplying beam to the Main Ring. In anticipation of the upcoming Collider run, the studies focused on understanding properties of the Booster beam which directly relate to Collider performance - that is, the achievable beam densities in both transverse and longitudinal phase space. Transverse phase space density translates directly into luminosity in the Collider by virtue of the linear dependence of luminosity on charge per unit cross sectional area. The longitudinal phase space density is related to Collider operation through its strong impact on the antiproton production process.

Documentation of the transverse and longitudinal beam sizes delivered from the Booster as a function of intensity was completed. Measurements of the beam sizes as a function of time during the Booster acceleration cycle were also completed in order to help identify the causes of dilution. As a result of these studies it was strongly suspected that the transverse phase space density was being limited by incoherent space-charge effects at injection time, and that the longitudinal phase space density was being limited by at least three effects: phase noise in the low-level rf (LLRF) system, space charge effects at transition, and a coupled bunch instability which developed shortly after transition. Virtually no effort was invested during this period in improving the overall beam intensity out of the Booster which had, for

several years, been running nearly a factor of two below the historical highs. It was felt we would be better suited to attack this problem following the shutdown.

The Booster shutdown started on May 1 and ended on July 22. During this period extensive modifications were completed. The old Xerox 530-based controls system was eliminated and a new controls system which integrated the Booster into the Accelerator Division network (ACNET) was completed. Beam position pickups (both horizontal and vertical) were installed at 48 locations around the Booster. This system is allowing us, for the first time, to study the Booster orbit throughout the acceleration cycle and should lead ultimately to improved Booster acceptance (and intensity). Installation was begun on a transition jump system. The recent commissioning of this system showed it to be effective in combating the previously mentioned dilution due to space charge at transition. The LLRF system was substantially rebuilt to eliminate phase noise and to allow lower rf voltages at Booster extraction. These modifications have eliminated phase noise as a contribution to longitudinal dilution in the Booster. In addition, half of the PCB capacitors in the Booster were replaced as part of the ongoing program of eliminating these capacitors completely.

The Booster resumed operation on July 23. Booster tuneup and studies occupied the month of August. During this period a Booster batch intensity of 3.3×10^{12} protons was achieved. This was the highest intensity that has been observed in several years and was only slightly below the all-time record of 3.5×10^{12}. The high intensity was attributed to an improved aperture resulting from the removal of a piece of epoxy which was discovered in the ring during installation of the beam position monitoring system. It is expected that operation of the beam position monitoring system will allow us to improve the aperture further and with it the total beam intensity. Starting in September the Booster has been supplying beam to the other accelerators in the Fermilab complex. As a result, study and access time have been limited. The focus during this period has been, and will continue to be, the completion and commissioning of the beam position and transition jump systems, and the improvement of the quality of beam delivered from the Booster by whatever means are deemed necessary.



The Booster injects into the Main Ring; clearly in 1987 this is a misnomer but the force of history wins and Main Ring it will be called until (and if) we replace it as part of the Upgrade. In the 1986 shutdown, we constructed the B0 Overpass. This is the most dramatic departure from planarity in the history of accelerators; the Overpass soars 20 feet out-of-plane in order to avoid the CDF detector. The Overpass is designed to allow continuous pbar production with Main Ring protons while CDF is active in discovering all the new particles. Meanwhile, Stan Pruss has been instructed to love the elderly and now deformed Main Ring:

The Main Ring

Stanley Pruss

The first half of 1986 was spent disassembling the Main Ring. Not only was nearly 10% of the tunnel dug up because of the construction of the B0 Overpass and the D0 Collision Hall, but also most of the correction elements and position detectors were removed for installation of Z/n parts. Z/n is accelerator jargon for smoothing the internal surfaces of the vacuum tube through which the beam passes in order to reduce harmful effects of image currents. Because so many of the Main Ring quadrupoles were disturbed by the construction, it was decided to sieze this opportunity to improve the alignment of about half of the magnets in the ring. In addition to changes in the Main Ring, the beam transport line from the Booster to the Main Ring (the 8-GeV line) was completely rebuilt with new magnets and new optics. All of these and many other minor changes meant we had a very different machine when it came time to start up.

In June, massive re-installation began. By early August, we were able to try beam for the first time in 1986. On the first weekend, August 9-10, beam went over the B0 Overpass, through the new D0 Collision Hall, and circulated around the ring for three turns. Despite our best efforts, beam continued to die after only three or four turns until August 29-30 when obstructions were located in the beam vacuum tubes: a garbage bag was removed from the rf cavities and a plastic pipe-cover was removed from the beam tube. By the following weekend, September 5-7, we had accelerated beam to flat-top. We measured the high-field orbit and found that by moving a few quadrupoles we were able to produce the best high-field orbit since the Main Ring became a TEVATRON injector.

During the next several weeks we learned to control the Overpass supplies to maintain a good closed orbit during acceleration and learned to control the new sextupole supplies to properly control the chromaticity. We also spent considerable time studying the 8-GeV line. By September 20, we found that the vertical bump magnets (VBMP), part of the new 8-GeV line, had an enormous sextupole component. Since they were also somewhat misaligned, this lead to large

←The Fermilab experimental areas and Accelerator Complex.

resonance driving terms which had been contributing to our poor injection and acceleration efficiency. By September 25, the VBMP magnets had been realigned and the intensity went up enough that the Main Ring started delivering beam for pbar production tune-up. In early October, CDF began complaining about the radiation levels in the B0 Collision Hall and the radiation damage this would cause to their detector.

On October 7, the TEVATRON ramped for the first time this year and totally destroyed beam in the Main Ring. This was due to the stray magnetic field of a new TEVATRON bus through the D0 Collision Hall. The following day this problem was fixed with more magnetic shielding and new VBMP's were installed in the 8-GeV line. On October 13 the first beam was sent to the TEVATRON. We then painfully rediscovered the difficulties of run-

VERTICAL DISPERSION, METERS

Updated 24-JUL-86

Lattice Title
F17 DSD D0=WD81 B0
REVISION 1

	E	F	A	B	C	D
VX11	.69	-.56	-.83	3.32	1.6	-.09
VX12	.5	-1.02	-.76	3.42	1.62	.28
VX14	-.79	-.96	.55	.65	-.67	.76
VX16	-1.1	.3	1.18	-2.45	-2.13	-.57
VX18	-.04	1.19	.34	-2.51	-.94	-1.2
VX21	1.07	.6	-.92	-1.35	1.41	-.33
VX23	.85	-.73	-1.04	1.02	2.01	.95
VX25	-.42	-1.15	.13	2.12	.1	1.05
VX27	-1.17	-.13	1.14	.58	-1.93	-.15
VX29	-.46	1.05	.73	-1.68	-1.56	-1.16
VX33	.82	.93	-.59	-1.85	.74	-.72
VX35	1.09	-.34	-1.17	.27	2.13	.61
VX37	0	-1.19	-.29	2.06	.86	1.19
VX39	-1.09	-.55	.95	1.28	-1.48	.28
VX43	-.82	.77	-.88	-1.09	-1.98	-.97
VX45	.46	1.14	-2.09	-2.11	-.02	-1.02
VX47	1.17	.09	-.69	-.5	1.78	.2
VX49	.22	-1.07	3.6	1.78	0	1.12

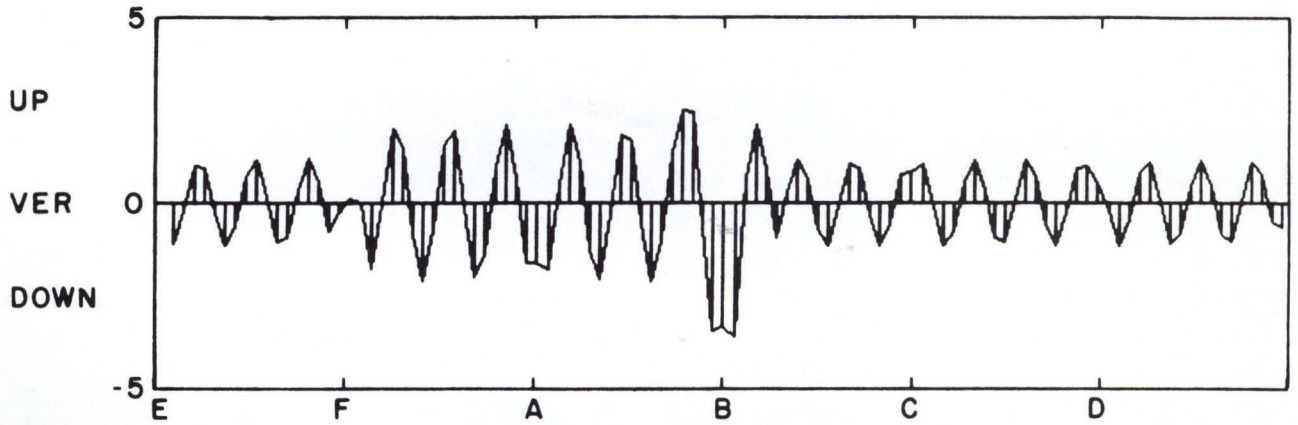


Figure 1. SYNCH-generated calculated beam dispersion function for the Main Ring with both overpasses (B0 and D0) included. The letters (E through D, left to right) represent Main Ring sectors; the numbers in each column in the table indicate the magnitude of the dispersion function and are plotted on the graph.

ning the Main Ring with the TeV ramp and a multi-user mode. The Main Ring had to supply both the TEVATRON and the Pbar Source with beam while continuing its own tune-up. We realized that the B0 radiation and much of the beam loss were caused by the combination of large vertical dispersion due to the new B0 Overpass and a large and varying effective momentum spread of the beam from the Booster. (Figure 1 shows the vertical dispersion with both of the overpasses.) During the last half of October we replaced three of the Main Ring magnets which were vertically limiting the aperture with larger ones. This eliminated the B0 radiation problem.

Early in November we reduced the cycle time to three seconds to increase the pbar production rate. This revealed a problem of the main guide field slowly varying during the first second (or so) after a ramp. By mid-November we were running with the 5-second repetition rate at 1 E12 protons/pulse for pbar production. By late November we started studies with $\bar{p}$'s. By the end of November, $\bar{p}$'s were being injected into the TEVATRON. Parasitic Main Ring studies continued and in early December several more limiting apertures were modified.

At year's end we had reasonable expectations that the Main Ring would give the program at least another year of good service.

Finally, we hear from Rolland (which rhymes with Holland) Johnson about 1986's events related to the world's first superconducting synchrotron, the TEVATRON:

The TEVATRON

Rolland Johnson

Preparations for the TEVATRON's new role as a proton-antiproton collider were the obsession of the Accelerator Division during 1986. While the machines were down for installation of the B0 Overpass and the D0 Collision Hall, many improvements were made which will add to the TEVATRON's ability to provide more useful beams for high-energy physics experiments. The October-November startup, in which reliable storage operation at 900-GeV was quickly established, demonstrated that the preparations were effective and done well.

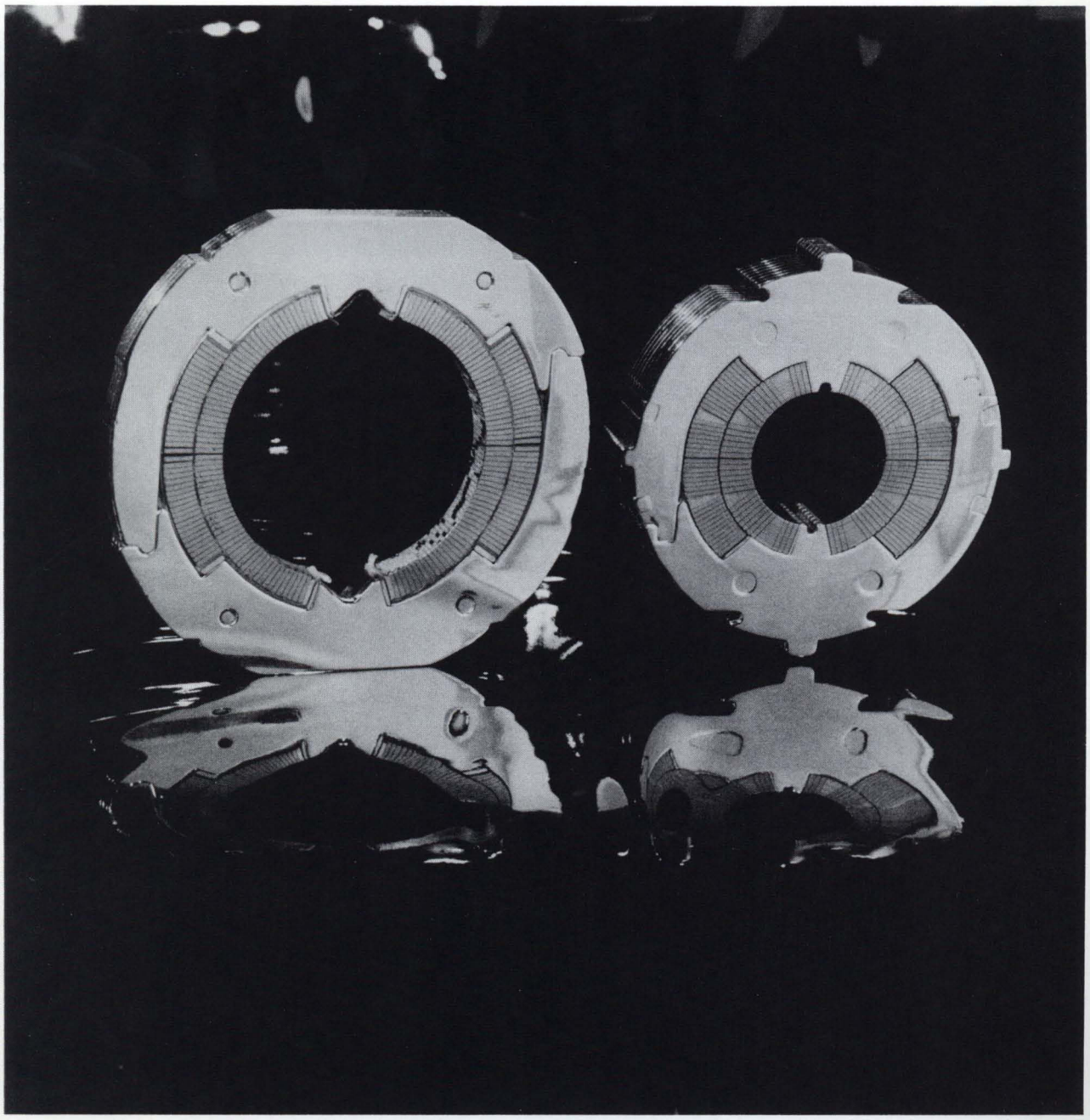
While most people were aware that much of the TEVATRON had to be dismantled and then rebuilt for the various construction projects around the ring, few know about the many devices that were replaced to improve the energy capability and reliability of the machine. Over 40 dipoles and many other superconducting devices which were either an energy limitation or had heat leaks were replaced. All the heater firing units which protect the magnets and which have been a major source of down-time were replaced. Safety leads on all spool pieces were modified. All the expansion engines and screw compressors were overhauled. Twelve new power supply transformers and filters were installed.

One of the major accomplishments of the 1986 shutdown was the development of a luminosity upgrade concept. This included a new double low-beta design and a scheme to use electrostatic separators to achieve a luminosity of 5×10^{31} $cm^{-2}s^{-1}$. More about this later.

While the end of the year did not see the establishment of a real colliding-beams program, there were several signs of imminent success. After a cryogenic cool-down period of two months, the TEVATRON was ready for beam almost exactly one year from when beam was last seen in that machine. Beam was first available from the Main Ring to be injected into the TEVATRON on October 13. By the next day beam had been accelerated to 400 GeV in spite of an incredible number of changes in every major system of the accelerator. One week later the beam had been accelerated to 900 GeV for the first time in its history.

One magnet prevented storing beam for longer than 20 minutes at 900 GeV and the optics maneuvers for the low-beta turn-on had to be done at 875 Gev. By November 26 the weak magnet had been replaced and we learned how to turn on the low-beta optics with no beam losses at 900 GeV. In fact we learned so well that we were able to invert the squeeze procedure and go back and forth between the fixed-target optics and the low-beta optics several times with no degradation of the beam quality.

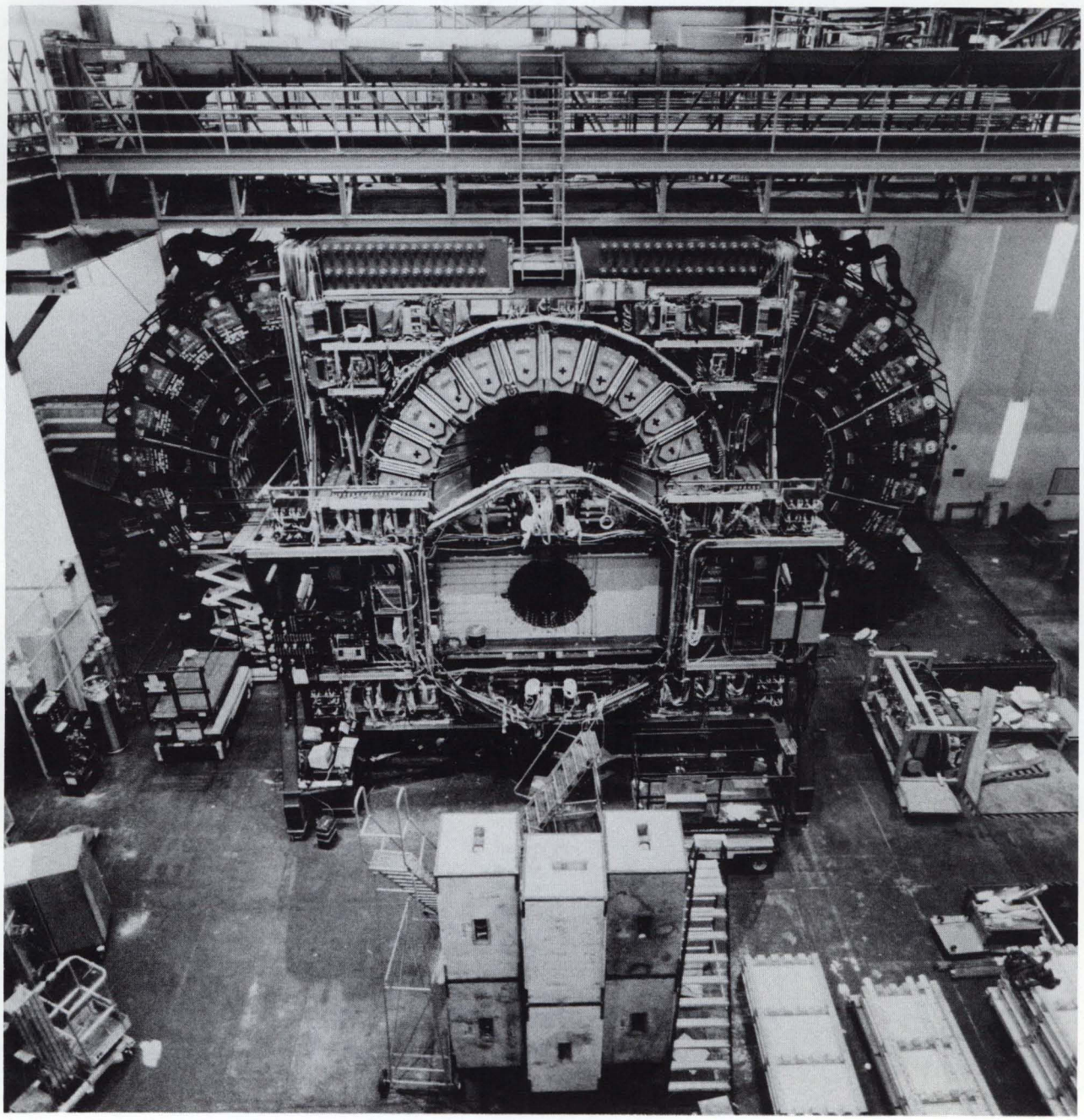
Operation of the TEVATRON in 1986 ended, perhaps appropriately, on December 7 when a dipole magnet failed. An analy-



A section of the TEVATRON collared coil (left) with its linear descendant, the SSC collared coil.

sis of the failure revealed an unsecured lead on a TC-type dipole, the cause of several failures two years ago. No one knows why this particular magnet had not been retrofitted along with the other TC magnets during the previous long shutdown. The installation of the CDF detector precluded machine operation for the rest of the year.

A newly discovered feature of superconducting magnets, namely a time dependence in the field quality of the dipole magnets, has complicated many of the operational procedures needed for beam storage. Nevertheless, storage lifetimes of 10 to 30 hours at 150 GeV and lifetimes of more than 100 hours at 900 GeV have been seen. These numbers are to be compared to the TeV I design which calls for the beams to be replaced every two hours. In one of the two shots of antiprotons into the TEVATRON in 1986, the protons and antiprotons were accelerated to 900 GeV, the low-beta insertion was turned on, and a luminosity of about 10^{26} was estimated. This is some factor of 50 greater than the best attempts of last year. Although it was four orders of magnitude short of the design goal, the fact that it was accomplished so quickly gives us a great deal of optimism for 1987.



The CDF Central Detector in the CDF Assembly Hall being serviced prior to installation in the B0 Collision Hall.

Having given the reader a sense of the efforts in the Accelerator Division, we turn to the great hope of U.S. particle physics, the CDF detector. CDF, incidentally, looks principally to the Research Division for its administrative and technical support although help arrives from all over the Laboratory. The prehistory of CDF goes back to 1978 or so and to early activists like Jim Cronin, Jimmy Walker, and Alvin Tollestrup. CDF has been a unique experience for Fermilab and the U.S., a truly European-size group of about 250 scientists and students supported by an impressive array of engineering talent. The sociology of "Big Science" will be on display here, not only for the scientific harvest but also for the nurturing of the many students and young investigators. Roy Schwitters and Alvin Tollestrup are sensitive leaders and this is reflected in the spirit and enthusiasm of the CDF crowd. Roy tells about 1986:

The Collider Detector at Fermilab

Roy Schwitters (Harvard University)

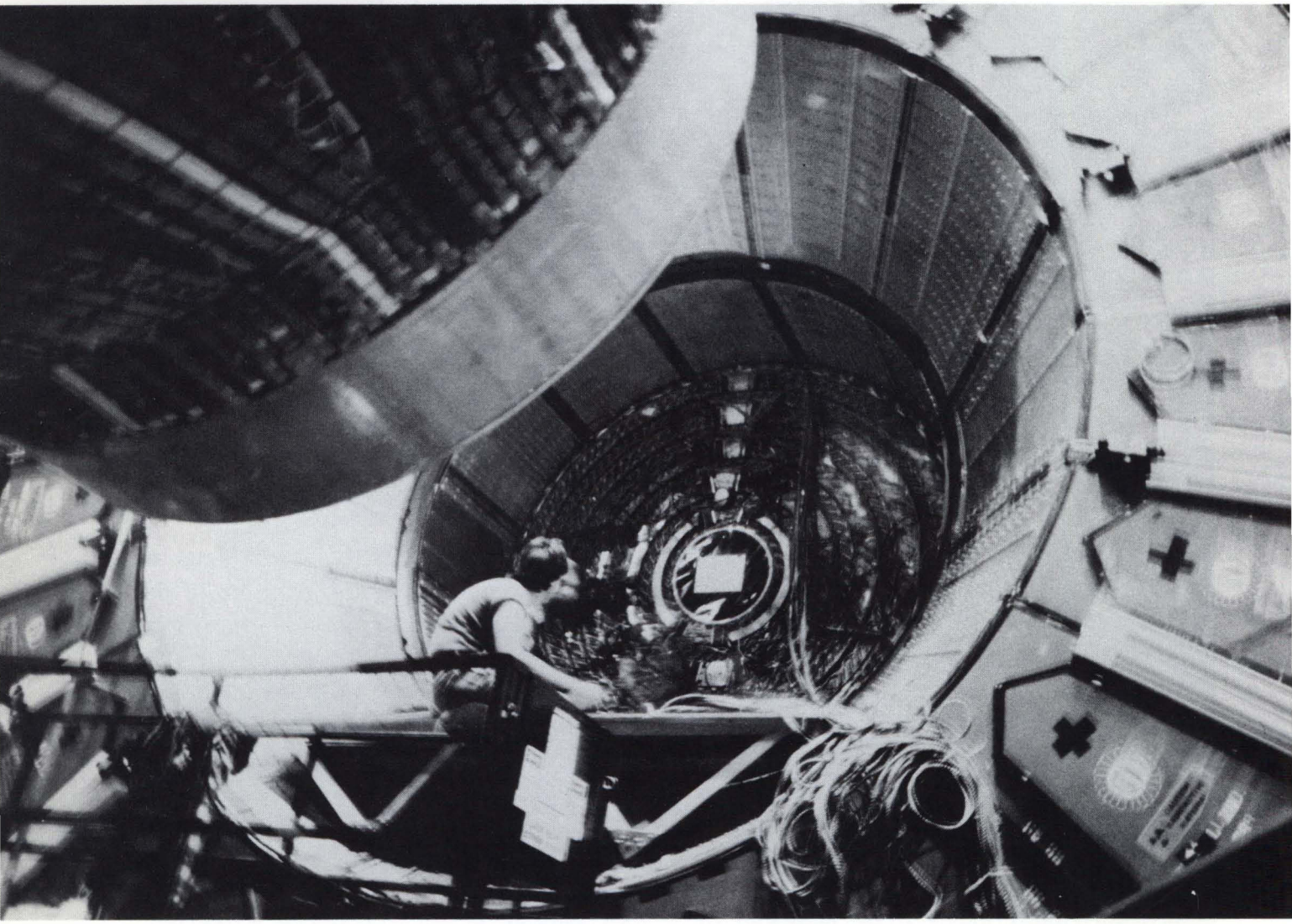
The year 1986 was "in between" for CDF. We were in between the exciting 1985 Collider test run where the first 1.6-TeV $p\bar{p}$ collisions were observed and the first physics run starting New Year's, 1987. We were in between the major detector construction activity that has been going on for several years and the fundamental new physics studies about to begin. We were in between planning for something and actually doing it.

By the beginning of 1986, members of CDF had recovered from the monumental effort required to assemble the interim detector pieces that were used in the October 1985 test run. Lessons from that run had been digested and attention was directed toward final assembly and integration of CDF.

There was great activity in the CDF assembly area, where Bob Mandernack and John Grimson led the effort that completed construction of the large muon toroids, forward/backward calorimeters, and solenoid end plugs, and made final "touches" on the central detector. At the end of the Main Ring Overpass construction in late summer, the forward/backward detector systems were moved onto beamline in the Collision Hall and checkout of these systems commenced. Meanwhile, Don Mizicko and his staff built the elaborate and vital detector gas system, and Bill Wickenberg, Rich Krull, and their groups completed the enormous electrical and cable plant needed for CDF. The scope of these activities is unprecedented in high-energy physics instrumentation.

A crucial, but thankless task in an activity as large and complex as CDF is safety, both for personnel and protection of the equipment. John Elias made major contributions to CDF safety through his design, planning, and checking of safety systems, and the education of physicists and other CDF workers.

Upstairs, in the CDF counting rooms, the Particle Instrumentation Group and the Data Systems Group assembled the vast quantities of state-of-the-art electronics required to register and record the large quantity of physics data detected by CDF. By year's end, the Data Systems Group had completed many of its CDF re-



View into the innards of CDF showing the Central Tracking Chamber before cabling.

sponsibilities, allowing it to take on new responsibilities in the Research Division. Throughout the year, David Quarrie and his Online Computing Group created a prodigious quantity of software that serves as the nerve center of the entire experiment.

A key detector component, the Central Tracking Chamber, was completed and installed in the CDF solenoid coil in 1986. This is one of the most advanced drift-chamber tracking chambers ever built. Its innovative design and highly successful construction was led by Richard Kadel and John O'Meara. Inside the chamber are the Vertical Time Projection Chambers that were used to "see" tracks in the 1985 test run, and a new very-low-mass vacuum chamber made of beryllium. This vacuum chamber, in which the TEVATRON beams pass, is an advance in detector technology. It was designed by the CDF group with substantial assistance from the Accelerator Division Vacuum Group.

In early fall, routine operations of the data acquisition and front-end electronics systems began. This involved, for ex-

View inside the cable mover connecting the CDF Central Detector to the counting rooms.

ample, the calibration and testing of some 40,000 electronics channels on a daily basis. Finally, just before Christmas, all of the components had been brought together and the CDF central detector was rolled into the B0 Collision Hall to join the forward and backward detectors, thus completing the assembly of CDF. Soon after, CDF physicists began to run shifts, 7 physicists to a shift, 24 hours a day, 7 days a week. This will continue until the end of the first Collider run not before the end of spring.

What lies ahead is a tremendous amount of work to test, debug, and understand the detector. When colliding beams become operational, there will be a major CDF impact on the Fermilab Computing Department. Beyond all of this lies a rich and uncharted sea of exciting new physics to be explored.

Any review of CDF must mention the strong commitment of both the Italian and Japanese contingents, both in financial and human terms. Anyone who questions the broader value of this kind of international collaboration should observe the details here, where families from Pisa and Cambridge, from Tsukuba and Urbana make do in the Fermilab Village and the West Chicago schools while physicists do battle, shoulder to shoulder, in the B0 trenches.

As CDF makes the transition to operations, the Laboratory's attention turns increasingly to the Avis of detectors, D0; Avis from the point of view of being second in time but having the advantages of the CERN experience and the official mission of complementing CDF in its design attributes. These have to do with hermiticity (detection of neutrinos!), resolution, segmentation, and complete lepton identification.

A major activity of the Laboratory in 1986 was the construction of the D0 Interaction and Assembly halls. This turned out to be more complex than even B0 but a "Reliable" contractor and the spectacular design efforts of Wayne Nestander's group lead to an anticipated completion on schedule and under budget. What goes into this hall is discussed by Paul Grannis:

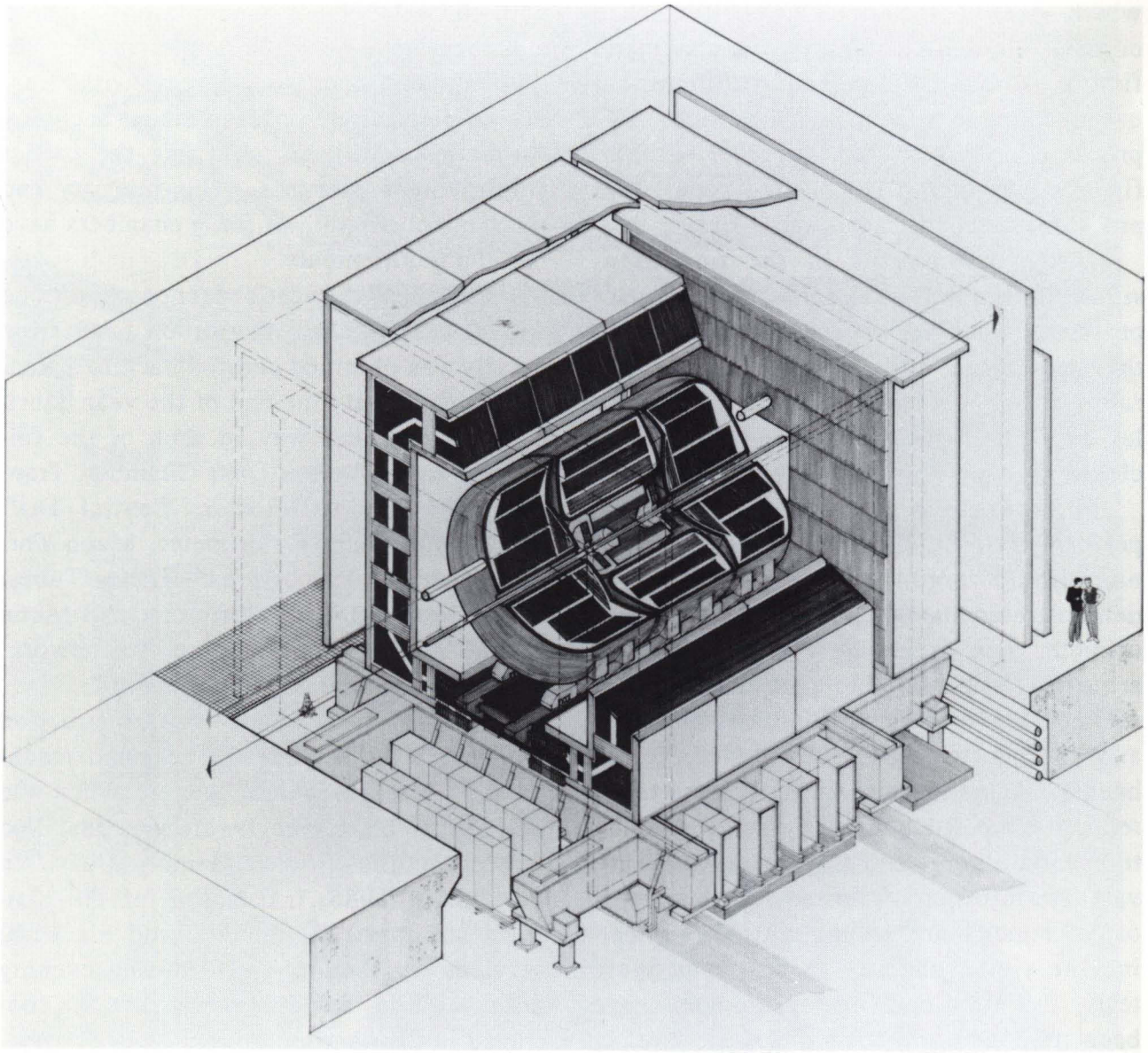
The D0 Experiment

Paul Grannis (SUNY/Stony Brook)

The year 1986 has been a time of intensive work and dramatic change for the D0 experiment. In the previous two years D0 was mainly in the stage of conceptual design and R&D. During 1986, the initial funding for detector construction began with the allocation of about $8M. Gratifying progress has been made in building the elements of the D0 detector and in testing prototypes of the various detector elements.

The main strategy for the design of D0 remains as before: the detection of leptons (electrons and muons), hadron jets, and missing transverse energy are believed to be the key to recognizing new phenomena in the TEVATRON Collider energy domain. The D0 design optimizes detection of these elements. The primary pieces of the experiment are: (a) a chamber system surrounding the interaction region which stresses the identification of electrons, (b) a set of three uranium-liquid argon calorimeters extending to within 1 degree of the beamlines for accurate measurement of particle energies, and (c) a set of magnetized iron magnets with appropriate drift-chamber planes for muon identification and measurement.

Several crucial test programs have confirmed aspects of the D0 design in the past year. Model cells of two of three tracking chamber systems were tested in a beam at Brookhaven National Laboratory (BNL) in late spring. This test was noteworthy in its use of chamber signal readout and digitization electronics which were final prototypes for the experiment. Charge deposited on the chamber electrodes was sampled in successive 10-nanosecond windows so that subsequent analysis was capable of determining both time of arrival and integrated signal size. These analyses have shown position resolution of 35-60 microns (Vertex Chamber) and 150 microns (Central Drift Chamber), both of



Schematic view of the D0 detector on its moving support platform. Large magnetized iron toroids for muon detection surround the three uranium-liquid argon calorimeters. Particle tracks are measured in chambers within the calorimeters. About 100,000 signals from the detector are processed by electronics on the detector before being sent to encoding electronics in the control rooms.

which exceed the detector performance criteria. This same test program also made first use of the D0 data-acquisition system based upon parallel arrays of MicroVAX processors. This system, together with the first version of the D0 on-line acquisition program, performed well under fire.

Test measurements of the final transition radiation detector system were performed at CERN. These results show that pions can be rejected over the full range of angular incidence in D0 at the level of 50:1 while retaining 90% of the electrons.

Final results were obtained from a test, performed during 1985, of a prototype uranium-liquid argon calorimeter. These demonstrated that the response of the calorimeter was exceedingly linear with energy of these incoming particles and that the response of the calorimeter to electrons and photons was just 10% higher than to hadrons. This latter feature is important in reducing the fluctuations seen in missing transverse energy. These tests also gave valuable information on the required depth of calorimetry and on methods for collecting the signal charge. Based upon these tests, the first calorimeter modules have been produced and their mechanical, electrical, and thermal properties were tested. One such module has been placed in operation using cosmic rays and has shown that the expected signal response and noise characteristics are achieved. Small hybrid circuit versions of the calorimeter front-end electronics employed in the test have been designed, fabricated, and tested. These circuits show measured noise and uniformity characteristics which meet specifications.

Full-sized planes of muon chambers have been built (8 feet by 20 feet in area with three layers of wire planes). These chambers have been operated using cosmic rays and radioactive sources with final design electronics. Measurement accuracy for both coordinates confirms the earlier single-wire prototypes. Gas integrity and mechanical strength of these chambers have met the requirements.

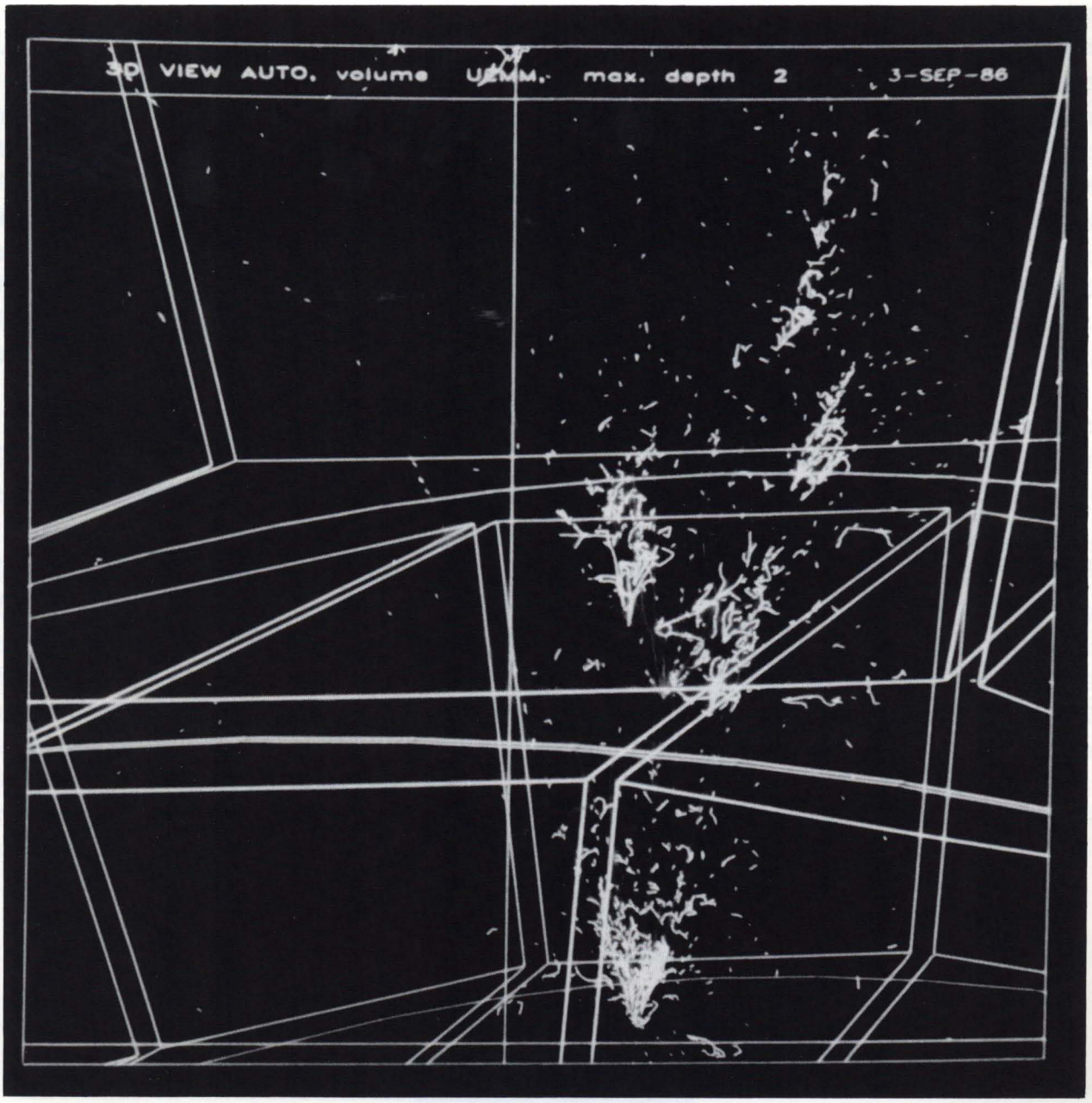
In each of the test sequences described above, valuable information on fabrication details was obtained and fed back to a final design stage. By the end of the year, fabrication was under way in each of the following areas: Vertex Drift Chamber, Transition Radiation Detector, Central Drift Chamber, Central Calorimeter, Muon Toroids, Muon Proportional Drift Tubes, Tracking Chamber, Calorimeter and Muon Chamber Electronics, Trigger Framework, and Data Acquisition Electronics.

The D0 Experimental Area construction progressed throughout the year and reached a milestone in late August when the radiation shield block wall was installed between collision and assembly areas. In the fall of 1986, installation of the platform structure, cryogenics, and electrical services was begun by D0 during evening hours, while building construction continued in the daytime.

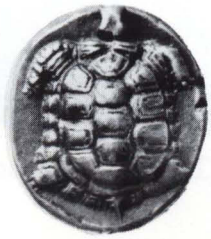
Development of the software required to filter the huge data load, to control and monitor the many pieces of hardware, to present useful displays and summaries of experiment performance, and to analyze the physics information from the experiment presents a formidable task. Good progress has been made in these areas during the year. The software effort has been guided by the use of formal software engineering tools to enhance the consistency and reliability of the code. The many tests of hardware systems were taken as opportunities

The D0 experimental area in late August 1986 during the initial stacking of the concrete shield wall separating the collision area and assembly area. The Main Ring beam pipe is visible behind the wall. Counting rooms for experiment control are along the right wall.

Monte Carlo simulation of an electron shower in the D0 calorimeter. The dense core of ionization extends over several millimeters, with a more dispersed part of the shower extending to a few centimeters.



A Monte Carlo simulation of a hadron shower cascade in the D0 calorimeter. Clumps of ionizing particles are seen near the points of the primary hadron interactions in the cascade.



for successively more complete versions of the software being developed for D0. This evolution will continue with tests planned for next year.

The simulation of the D0 detector has been stressed in this year; modelling of the detector is nearly complete and several valuable conclusions on design strategy were reached through Monte Carlo simulation of experiment performance. Reference files of Monte Carlo physics events have been created, from which further studies of trigger efficiency, experimental resolutions, and reconstruction strategies are being made.

The D0 collaboration has again grown in strength with the addition of new physicists and a larger fraction of full-time effort from collaboration physicists from 19 institutions (14 university groups, 3 U.S. national laboratories, plus groups from France and Brazil) working on the experiment. Administrative and technical support for D0 at Fermilab has also increased. This support comes largely from the Experimental Support Department within the Accelerator Division; the Department is now headed by Eugene Fisk since Peter Koehler's departure from the Laboratory in August 1986.

Given the strides made by the D0 collaboration during 1986, anticipation of a fruitful physics harvest is growing. Technical considerations would enable this experiment to begin its full operation in 1989 though financial constraints may delay this startup. It now appears that the D0 experiment will achieve the promise of its early design; we look forward to its entry on the scene and to the full utilization of the TEVATRON Collider.

Adding the D0 visitors to our Village population brings natives of Gif-sur-Yvette and Rio.

Paul does note that D0 was housed in the Accelerator Division (in contrast to CDF). Here, his close associate Gene Fisk sees to the Fermilab obligations and especially to the Accelerator Division interface. This was not (only) to stimulate collaborative competition but also to spread the work, bring more physicists into the A.D. for future subversion to machine physics, and to increase the contact between Accelerator support groups and the research program. The intimacy of Collider experiments and the machine is another cogent argument. This applies equally to the "small Collider experiments," those proposed for various nooks and crannies but which add significantly to the A.D. tasks. Roy Rubinstein discusses these:

Small Collider Experiments

Roy Rubinstein

Yes, there really are Collider experiments in addition to CDF and D0! Though frequently overlooked due to the understandable attention given their larger and better-known brethren, three small experiments are currently being installed in the Accelerator tunnel. It should be noted that although these experiments are small in comparison to the large general-purpose collider detectors, some are nevertheless of a size typical of fixed-target experiments. All three are aimed at specific areas of physics that are not covered fully (or at all) by the large detectors. In addition, they generally do not require large luminosities, at least initially, and thus can profitably use the lower Collider performance expected in early running.

The three experiments and their locations are as follows:

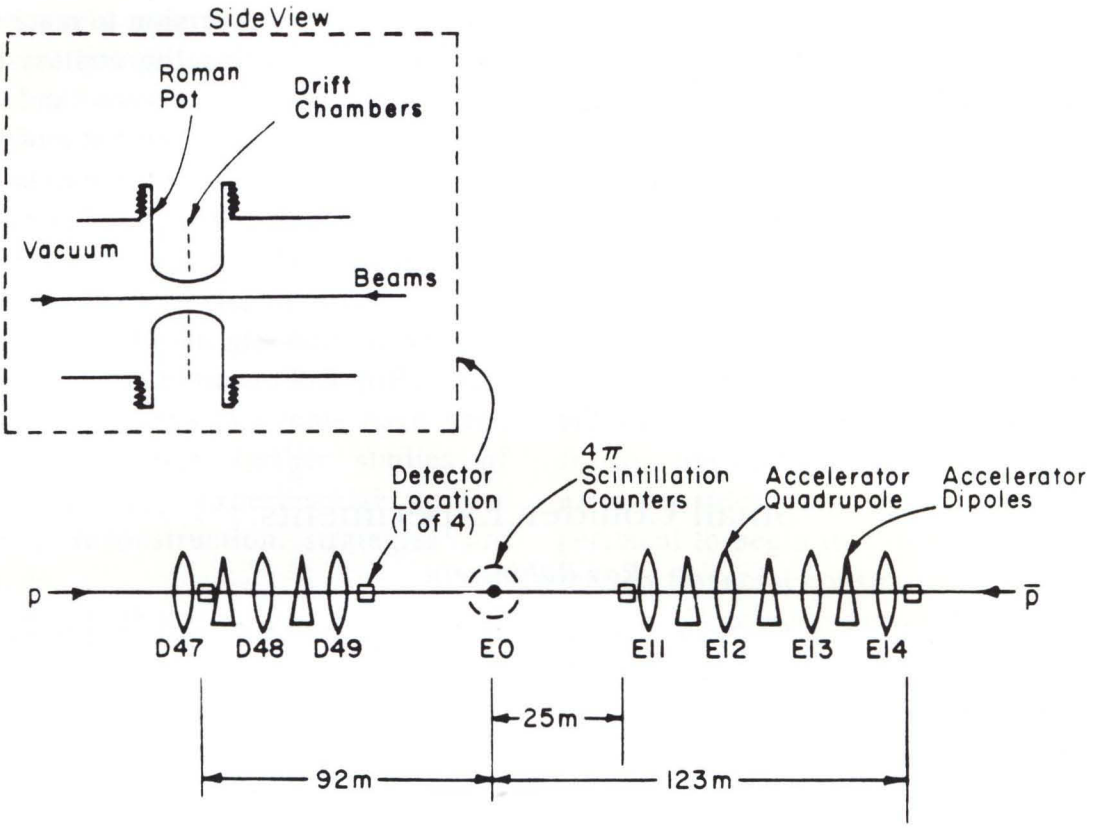
- E-710 (Orear/Rubinstein): Total Cross Sections and Elastic Scattering (Location: E0)

- E-713 (Price): Search for Highly Ionizing Particles (Location: D0)

- E-735 (Gutay): Search for Quark-Gluon Plasma (Location: C0)

(Additionally, the smallest-angle silicon strip detectors of CDF are located in the Accelerator tunnel outside of the B0 Detector Hall. For many purposes, including impact on the Accelerator, this can be considered another small Collider experiment.)

Support for these experiments is coordinated through the Experimental Support Department, which was established in the Accelerator Division for this purpose. All three experiments are in locations in the TEVATRON which are used primarily



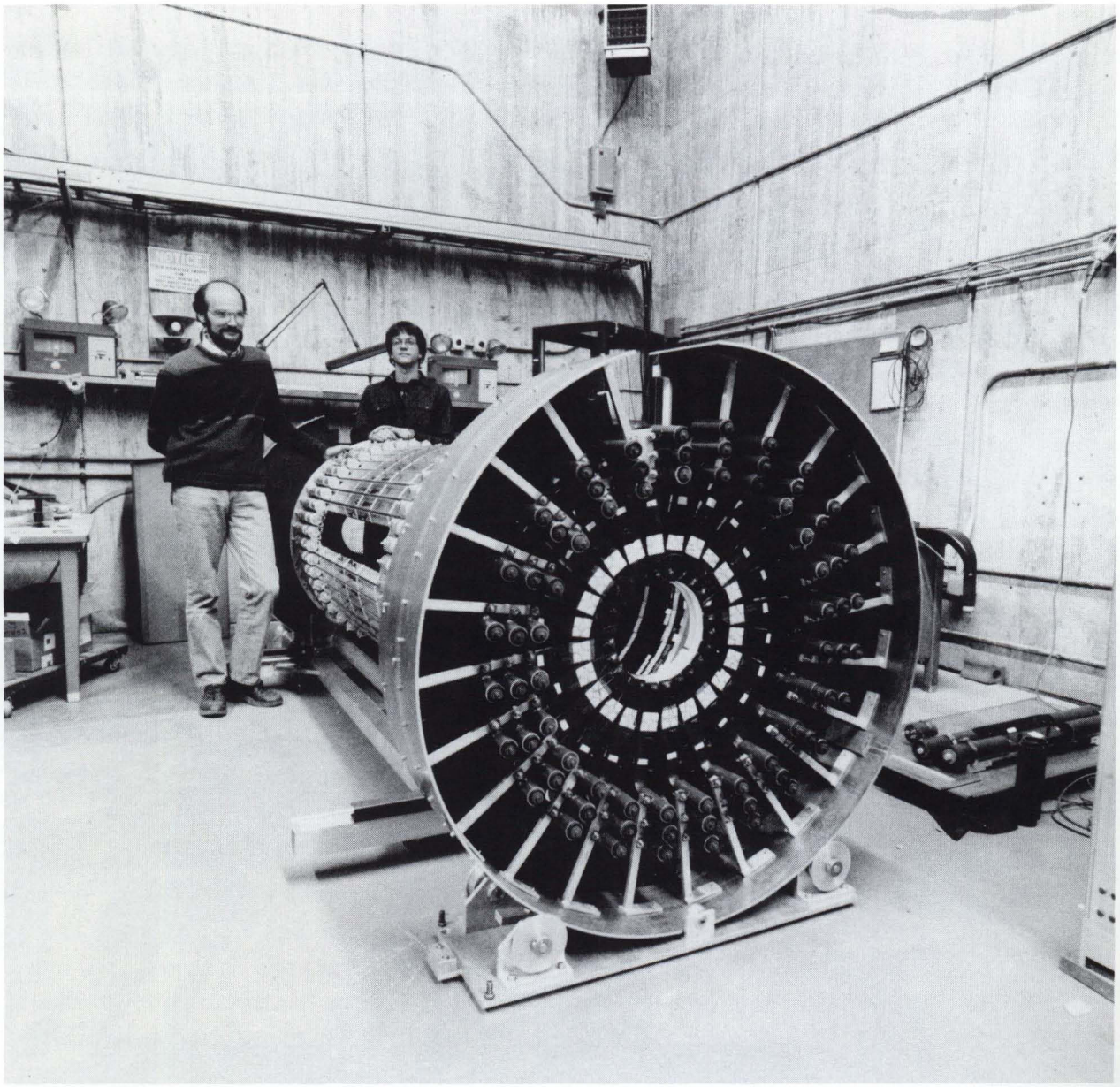
Layout of E-710.

for other purposes, and this has affected their design. C0 is the location of the Main Ring and TEVATRON abort systems; D0 contains extraction septa when the fixed-target program is running, and is being prepared for installation of the D0 detector; E0 is the straight section used for transfer of both protons and antiprotons from the Main Ring to the TEVATRON.

Experiment 710 will measure $\bar{p}p$ total cross sections and elastic scattering over the energy range $\sqrt{s}$ = 300 to 2000 GeV. The apparatus is capable of observing very small scattering angles, allowing measurements into the Coulomb scattering region. It uses detectors (scintillation counters and drift chambers) around the interaction point, as well as detectors which can be placed close to the circulating beams inside "Roman Pots" on either side of the interaction point.

The goal of E-713 is a search for highly ionizing particles; these could include, for example, magnetic monopoles. There are thin arrays of glass detectors inside the vacuum pipe and plastic detectors (CR-39 and Lexan) outside, covering a large fraction of the total solid angle. By etching these detectors after exposure to $p\bar{p}$ collisions, particle tracks become visible, and their ionization can be measured.

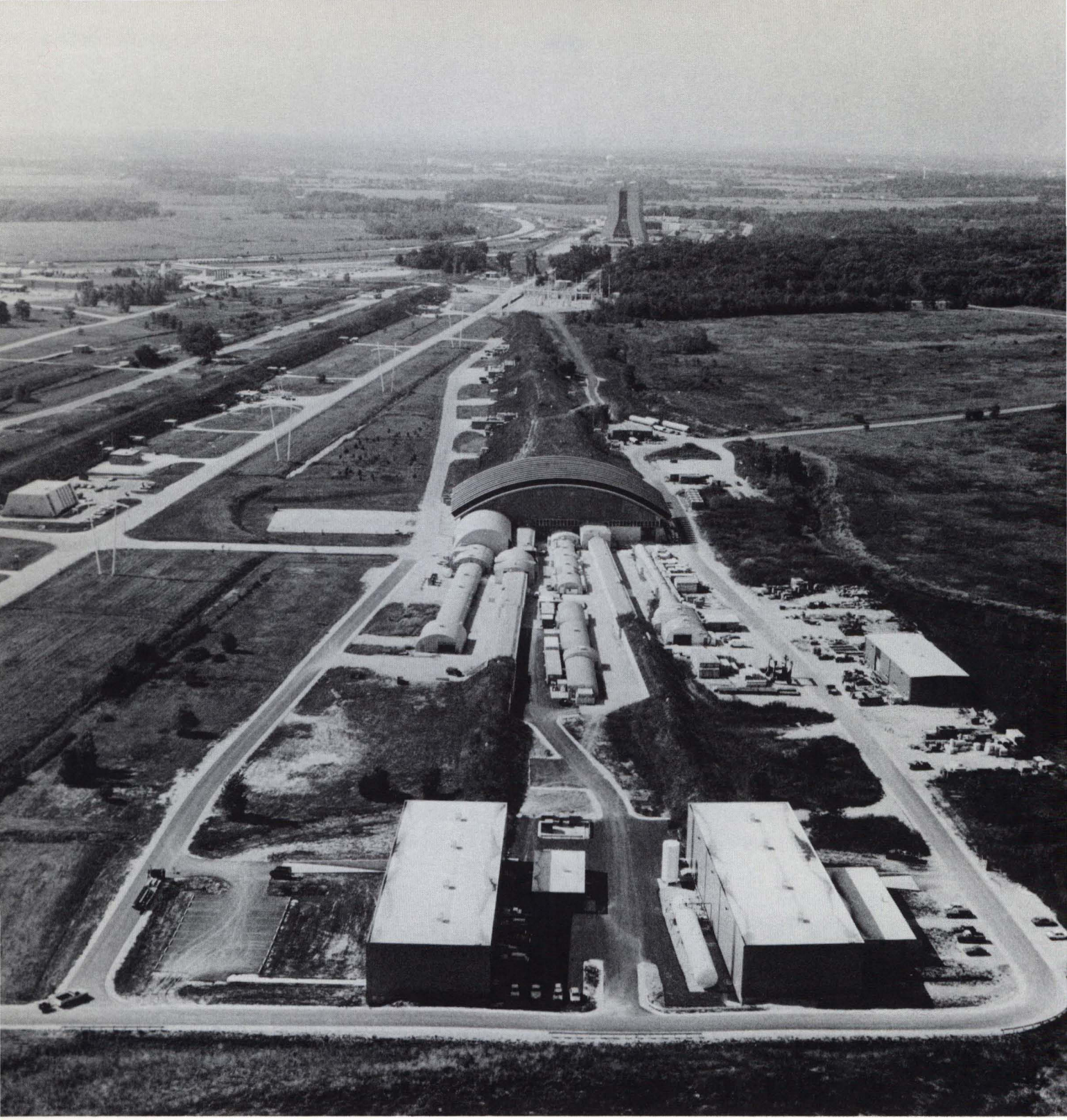
Experiment 735 is a search for a deconfined quark-gluon phase of strongly interacting matter. It uses a central tracking chamber, covering almost 4π around the interaction point, and a magnetic spectrometer off to one side. The spectrometer measures the transverse momentum (up to



Clark Lindsey (Iowa State University), at left, and Ramsey Harcourt (Reed College), with the two End Caps and the Central Barrel Hodoscope for E-735 at C0 in the $\bar{p}p$ Collider.

around 1.4 GeV/c) distribution of centrally produced charged particles of various types as a function of charged particle multiplicity; the spectrometer particles are identified by means of time-of-flight and momentum analysis.

At present, all three experiments are being installed; during the early 1987 Collider run they will have most, or all, of their equipment in place and hope to start data taking.



Aerial view of the Meson Area with the Central Lab in the background. The two rectangular buildings in the foreground are the new M-Polarized (left) and M-West (right) experimental halls. M-Polarized currently houses E-704 and M-West houses the experimental apparatus of E-706. Both buildings were constructed as part of the TeV II project.

The Research Division is the mainstay of the fixed-target program, that complex of activities that provides the beams and helps with the construction and installation of experiments out to the north. Divided historically into Meson, Neutrino, and Proton areas, there are now 14 upgraded and redesigned beamlines, all constructed in harmony with "TEVATRON II," a project brought to completion on schedule and budget by Tom Kirk with a staff of 3.6 able bodies and the help, mostly of the Research Division, but also of most of the Laboratory. As we see, the Research Division also provides the base for the Computing Department, the Advanced Computer Program, the Theory Department, the Astrophysics Group, and CDF, although these are functionally autonomous. In the organization-chart boggling managerial style of Fermilab, all of this seems to work largely because if we must have boxes, we'd rather put them around people than put people in boxes. Now hear this:

The Research Division

Mark Bodnarczuk and Ken Stanfield

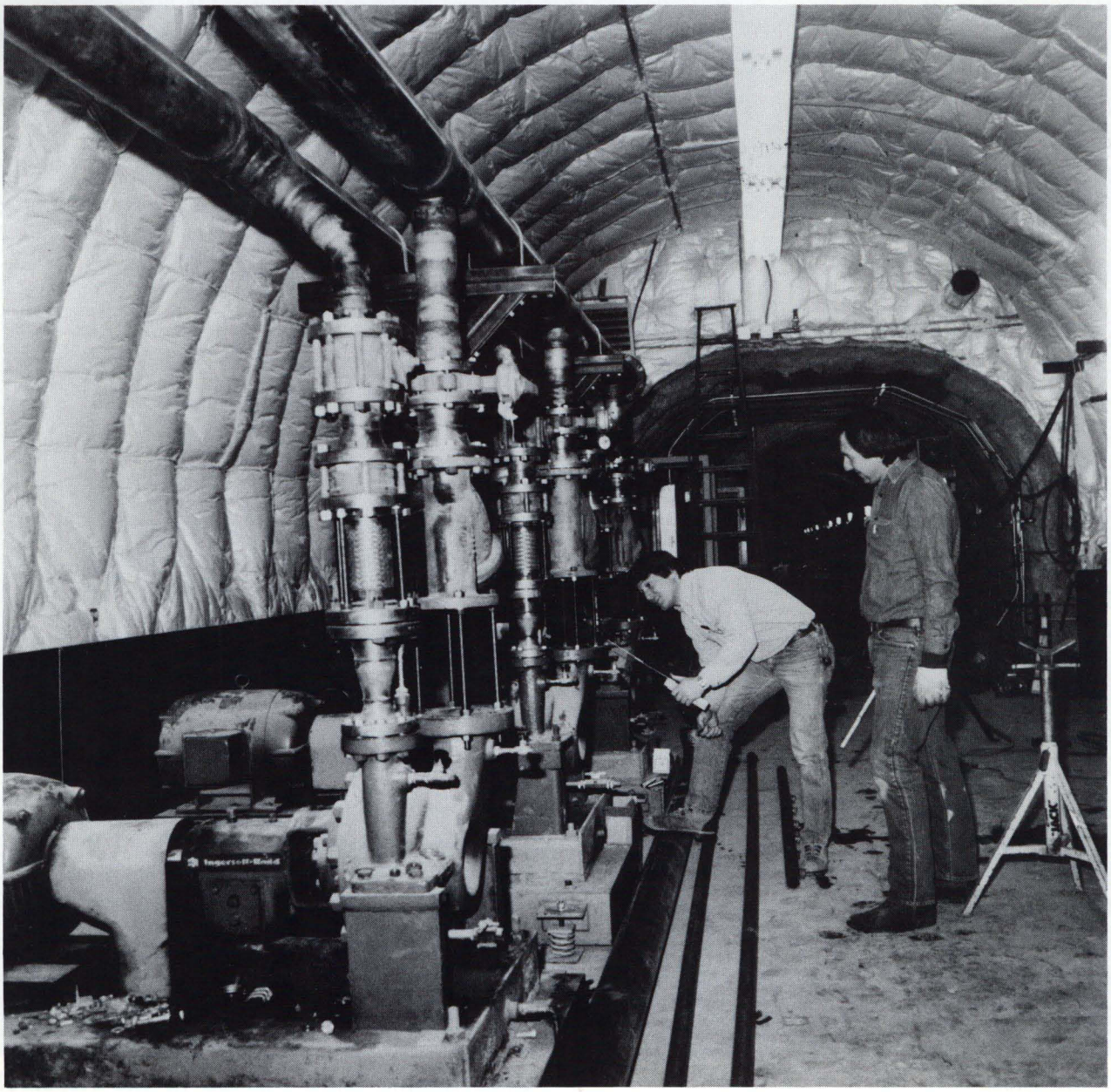
General Highlights

The fiscal year which ended September 30, 1986 (FY85), saw the end of the TEVATRON II (TeV II) construction project. This project provided the Plant funds necessary for upgrading extraction and the primary proton beams as well as the conventional construction necessary to house secondary beamlines and experiments. The Research Division Support Departments played a very important role in the successful and timely completion of this project. As activities associated directly with the TeV II project came to an end, an ever-increasing effort was expended toward the completion of the installation of the secondary beamline components and the detectors which were approved for these new beamlines.

The last fixed-target run, which was perhaps one of the most productive runs at this Laboratory, was nonetheless limited to previously existing detectors and beamlines upgraded from the previous era of 200- to 400-GeV operation. The Research Division Support Departments, working with the fixed-target users, expended a very large effort over this past year preparing for the first physics run with the all-new beams and detectors designed for 1-TeV operation. This includes the world's highest energy photon, muon, pion, and polarized proton beams. As a result of this effort we can look forward to the next fixed-target run in the spring of 1987 with 14 high-energy beamlines and 16 experiments in operation. This will be the realization of plans undertaken as early as September 1979 when requests for TEVATRON II experimental proposals were first announced to the high-energy physics community.

Effective May 1986, two new support departments were formed in the Research Division. The first is the new Research Facilities Department, and the second is the Site-Operations Department. Both departments are consolidations. The Research Facilities Department is composed of the old Research Division Beams Group and

the Facilities Support Department, while the Site-Operations Department is made up of the previously existing Operations Department and the Experimental Areas Support Department. The activities of each department are described below.

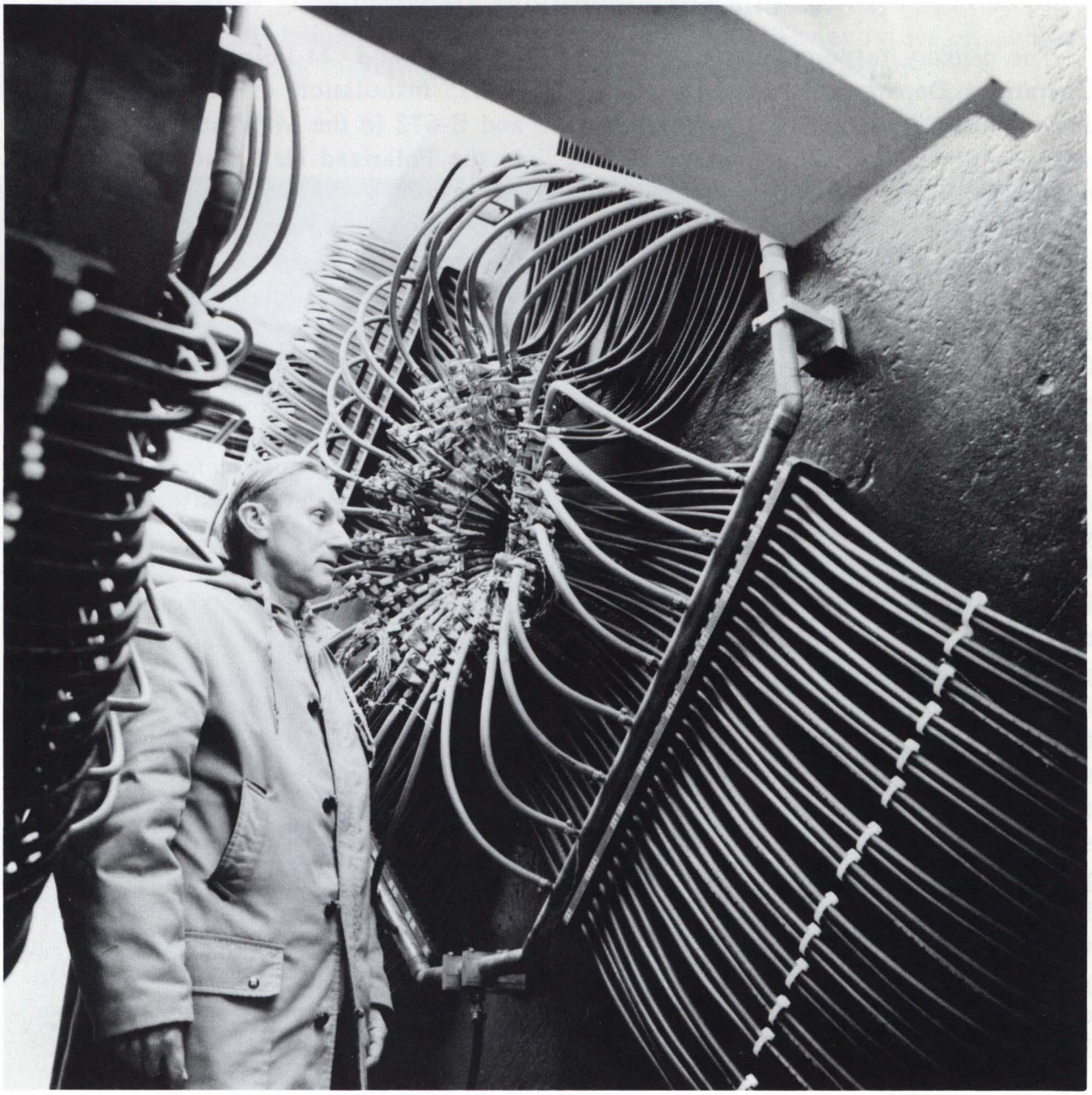


Pipe fitters at work on the new industrial chilled water (ICW) system in MS6 of the Meson Area. Similar systems were installed at Lab D in the Neutrino Area and the High Intensity Lab in the Proton Area. The Neutrino and Proton Area installations are part of an energy management plan which will replace low conductivity water cooling towers by pumping ICW from Casey's Pond. The conversion to ICW will save on power costs, having about a 4-year pay-back period.

The Site-Operations Department

The primary responsibility of the Site-Operations Department is the installation and support of the fixed-target experiments and beamlines, and the operation of the beamlines for the experiments. The department consists of five groups: the Mechanical Group, the Electrical Group, the Alignment Group, the Experimental Coordination and Engineering Group, and the Operations Group. [*Note: For a definition of the experiments referred to below by "E" numbers, see Roger Dixon's review of the fixed-target experimental program later in this* Annual Report.] A few highlights for this year include: installation of experiment E-687 in the new Wide Band Experimental Hall; conversion of the P-East beam from a tagged-photon beam to a hadron beam in preparation for E-769; installation of a new hyperon beam in P-Center in preparation for E-756; completion of the final stages of the new Muon beamline which involved (among other things) the installation of spoiler magnets; installation of the experimental apparatus for E-665 in the new Muon Experimental Hall; conversion of the N-East beam to a pion beam in anticipation of experiments E-711 and E-653; completion of the new M-West and M-Polarized beamlines that lead to the new M-West and M-Polarized Experimental Halls; installation of experiments E-706 and E-672 in the M-West Hall, and E-704 in the Polarized Hall; and finally, the installation of the M-Test beam that will serve as a test beam for CDF in the upcoming fixed-target run. In addition, the Site-Operations Department carried out a major revision and overhaul of the entire vacuum system, and an upgrade of the low-conductivity water systems, converting to new standard radioactive water systems. The department also designed and installed a centralized gas distribution system which will provide gas to a variety of devices like segmented wire ionization chambers (SWIC) throughout the experimental areas.

A major undertaking of the Alignment Group was the alignment of all stages of the TEVATRON accelerator complex, including the Switchyard, which they will complete with the alignment of the experimental areas. The above steps are all preparatory to the upcoming physics run, at which time the Operations Group will operate the 14 beams, feeding 16 experiments and 2 test beams, and also provide operations support for CDF during their running period.



Age Visser of the Research Division checks the physical manifestation of his design of the hybrid coil windings at the connections between the water-cooled center conductors and the outer cables on the 120 in.-diameter steel toroid for E-665 in the NMO enclosure in the Neutrino beamline.

The Mechanical Department

The Mechanical Department assumes responsibility for essentially all the mechanical workings of the experimental areas, including all the beamlines and experimental facilities. New projects are generally initiated in the department, including concept design, design engineering, fabrication, and assembly. In addition, the department supports other groups by maintenance operations. To a great extent, the target areas for all beamlines are designed, built, and maintained by the Department. Radioactive handling is a departmental responsibility and is carried out in a facility called the Target Service Building, the only dedicated radioactive handling facility at the Laboratory.

Some departmental highlights during the past year were the installation of the new M-West beamline; the installation of the analysis magnet, and continuing work on the liquid argon calorimeter, for E-706; the on-going installation of E-672 and the M-Test beamline which will service CDF in the up-coming fixed-target run; the installation of E-772; installation of the new M-Polarized beamline and the N-West test beam which will be used as a calibration beam for D0; the modification of the N-Center beam with the Quad Triplet Train being readied for installation; the completion of the new Muon beamline with the installation of spoiler magnets; the completion of the M-Polarized target pile; the modification of the P-East beam for E-769; and finally, the completion of the new Wide Band beamline.

The Research Facilities Department

The Research Facilities Department is organized into three groups: the Beams Group, the Facilities Support Group, and the Particle Detector Group. In general, the first two groups are responsible for achieving a successful fixed-target program, while the Particle Detector Group is charged with the design and development of new techniques for high-energy physics research.

Highlights for this year include the addition of the CERN Disc Cerenkov Counter and Transition Radiation Detector to the Tagged Photon Spectrometer system, allowing pion, kaon, and proton separation for E-769; the construction of the beam-tagging system and gas systems for the wire chambers and Ring Imaging Cerenkov Counter for E-665; upgrades of the detectors at the 15-ft Bubble Chamber, especially the construction of a monitoring system for the laser holographics and modifications of the external muon identifier; support for the construction of the Liquid Argon Calorimeter and associated devices for experiments E-706 and E-672 in the new M-West Experimental Hall, and for the upgrade of the spectrometer for E-653; support for the installation of E-687's cabling; upgrade of the spectrometer chambers for E-711; and finally, a service provided for all the fixedtarget users, the operation of the Ziptrack, i.e., the device which measures and maps the spectrometer magnetic fields. Because the department acts as the source of beamline and liason physicists, it provided physics support to all experiments throughout the year,

helping in beam design and research, and developing a wide variety of software tools that are used by other Research Division departments. Also, the Small Electronics Group built multi-purpose modules for experiments as well as servicing major facilities. Finally, the Particle Detector Group continued its work on Barium Fluoride Calorimeters and studies on doping of liquid argon calorimeters.

The Electronics/Electrical Department

The Electronics/Electrical Department has the responsibility for the design, development, implementation, and maintenance for the majority of the electronic and electrical devices necessary for the utilization of beams in the experimental areas. This includes beamline magnet power supplies, controls, radiation and electrical interlock systems, beamline instrumentation (such as SWIC's, beam loss monitors, etc.), and other devices. This year's highlights include major upgrades to the EPICS beamline controls software and on-going progress on the new EPICURE replacement system; the relocation of the PDP-11 controls computers to the Experimental Areas Operations Center; continuing progress on a new VME-based system (hardware and software) for the cryogenics control system, the completion of the video data acquisition system for E-687's fiber-optic target; new electronics for laser pulse stretching for the holographics at the 15-ft Bubble Chamber; the completion of major design work for the front-end electronics utilizing surface mount technology; the commissioning of the electronics associated with the CERN Vertex Magnet, the Chicago Cyclotron Magnet, and the CDF magnet; installation of an oxygen deficiency hazard system in all the experimental areas where cryogens are found; and finally, the installation and commissioning of a micro-electronics development lab and a wire bonder which also has a micro-electronics probe station.

The Cryogenics Department

The Cryogenics Department is responsible for all aspects of cryogenic systems in the Research Division. Highlights of this year's activities include the installation and commissioning of the cryogenic plant for E-665 that will service the CERN Vertex Magnet and the Chicago Cyclotron Magnet, both of which are superconducting; the completion of beamline cryogenic plants at service buildings PS1, PS4, and Meson Cryo Central; both cryogenic and holographic upgrades at the 15-ft Bubble Chamber; the installation of piping and venting systems for E-706's Liquid Argon Calorimeter, the modification of the magnet iron of the Tohoku Bubble Chamber yoke to accommodate the new enlarged chamber and the repositioning of the superconducting coil to reduce the magnetic forces; the installation of a venting system in PW8 for E-705; and finally, R&D efforts aimed at reducing the stress on the windows of liquid hydrogen targets, and the operation of the CDF cryogenic solenoid. Also, a small R&D effort on the effectiveness of various numbers of layers of superinsulation against radiative heat losses in magnets should be quite interesting to the designers of superconducting magnets.

Jerry Morris and Ed Justice (R/D Cryogenics Department) work on part of the cryogenics system of the new Wide Band beamline.

The Safety Group

The Safety Group monitors and implements unified safety policies developed in harmony with requirements of the rapidly changing experimental conditions. There is considerable interaction of safety personnel with the rest of the departments in the Research Division when planning present and future experimental operations. Highlights of this year's activities include the initiation of a new program of hazard communication to make employees more aware of proper methods of using hazardous materials; providing support to the Electronics/Electrical Department's Interlock Group for the designing and documenting of interlock systems for the upcoming high-energy physics run; a major effort aimed at the design of shielding for the upcoming fixed-target physics run; extensive surveys and inspections to improve safety performance throughout the Division; and finally, an across-the-board safety training program for all personnel in the Research Division.

The Administrative Support Group

The Administrative Support Group is comprised of the Secretaries and Administrative Assistants who serve all of the departments in the Research Division. The group provides secretarial and administrative support for department heads, physicists, engineers, and other members of each department, and, in some cases, users. The group was reorganized this year to provide more appropriate secretarial support to Research Division Departments. Also, all members of the group were trained to use a standard word-processing software package called MASS-11.

Having established the frenetic accomplishments of the Research Division for the archives, we turn to that unique organization charged with the research activities of Fermilab's oppressed physicists and also our post-doc program. The post-docs are the Fort Knox of the Laboratory - no, the entire field! It's important that they don't find this out because of the long hours and low pay that are the traditional rewards of post-doctorism. The Physics Department, by its nature, is also involved with CDF, D0, and a large fraction of the fixed-target experiments. It can only be led by an extraordinary person. The Chairman writes:

The Physics Department

Dan Green

During 1986, the Physics Department continued feverishly preparing for the 1987 Collider and fixed-target runs. These provide the initial realization of the TeV I and TeV II investments of the last several years. The extremely diverse program supported by the Physics Department consists of 16 fixed-target experiments, two special purpose collider detectors (C0, E0), one general purpose collider detector (D0) and one $\bar{p}$ Accumulator experiment (E-760).

The roughly 100 people in the Physics Department have as their mission the support of this program. Just about half of our people are professional physicists or engineers. Of that half, about 25 are Post-doctoral Fellows or Wilson Fellows who stay in the Department for four years on average. They are recruited from around the country out of the pool of recent Ph.D. recipients in high-energy physics. During their stay at Fermilab, they work on an experiment of their choice.

The mission of the staff of the Physics Department is to provide necessary services for Fermilab physicists who are doing HEP research. Office space for experimenters and Guest Scientists is provided on the 10th floor of Wilson Hall. During 1986, a terminal cluster was installed consisting of terminals, stand-alone PC's, software, and laser printers. The departmental staff also provides secretarial services and figure drafting for aid in publication of papers. Travel funds for conferences, workshops, and group meetings are provided by the Physics Department.

Laboratory space has been set aside for experimenters on both the 9th and 10th floors of Wilson Hall. In addition, an open assembly area, a light machine shop, and a special stock area are maintained. These facilities allow experimenters to do their research and development in the Physics Department. This geographical layout helps to establish a close rapport between users and the Electrical and Mechanical Support groups.

During 1986, the capabilities of both the Electrical and Mechanical Support groups were expanded. The Electrical Group acquired and augmented the hardware and software to test both CAMAC and VME modules. The group also acquired programmable array logic (PAL) and computer-aided design (CAD) capability. The Mechanical Group doubled its number of CAD terminals. These acquisitions will aid these support groups in designing and fabricating experimental equipment.

This year the Film Analysis Facility converted to CAMAC-based operation with a new VAX system as host computer. These improvements were made in anticipation of the flood of new fixed-target data and in recognition of the fact that Fermilab now supports one of the most active scanning and measuring operations in the United States.

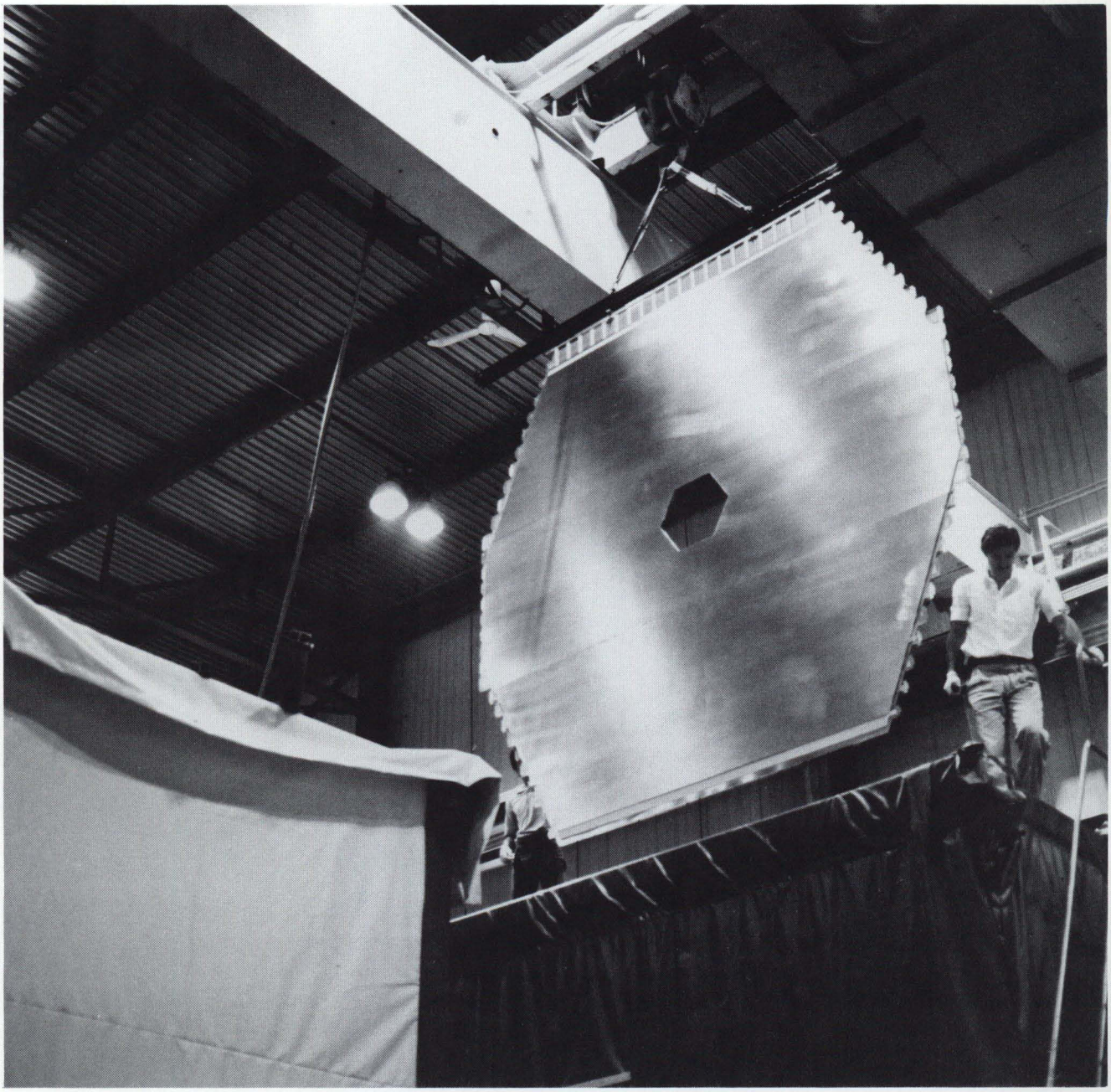
The Physics Department also operates several detector construction facilities. We make scintillation counters in the Wilson Hall basement, and this year we have inaugurated a vacuum-deposition facility. This facility allows users to overcoat photomultiplier tubes, aluminize mirrors, and test their ultraviolet reflectance. Detector assembly areas were also freed up to users by moving a detector factory out to Lab 5 in the Fermilab Village. The D0 experiment has begun to mount major tests of both calorimetry and muon detection in these areas.

The major departmental chamber construction area continues to be Lab 6 in the Village. During 1986, detectors for E-665, E-687, and E-706 were completed. Lab 6 also serves as a chamber repair station. Lab 8 houses the apparatus to construct large copper-clad G-10 boards. All departmental chamber substrate now originates in Lab 8. For example, a new E-711 PWC and the Ring-Imaging Counter artwork for E-665 and E-756 were made in 1986. An additional machine which arrived this year will allow us to expand operations in order to meet the calorimeter board needs of the D0 experiment.

Besides construction of new equipment, the Physics Department supplies the "lead technicians" who install that equipment, and maintain and repair existing experiments. This small but dedicated group is rather hard pressed to meet the expanded menu of experiments arrayed for the 1987 run; however, their enthusiasm should carry them through this crisis.

High-energy physicists (even experimentalists) do not live by detectors alone, but also by the contemplation of physics. To that end, the Physics Department sponsors the Wednesday Colloquium. In addition, Academic Lectures are organized by the Physics Department. In a more informal atmosphere, the Physics Department conducts a monthly "Food for Thought" dinner which gives the hard-working postdocs a spot of relaxation. These same postdocs aid in the highly successful Saturday Morning Physics Program for high school students.

In summary, 1986 was largely a year of preparation. We hope that the expanded facilities and services provided by the Physics Department will contribute to a successful 1987 Collider and fixed-target run.



George Fanourakis (right) and Takahiro Yasuda (partially hidden, left) of E-706 guide a freshly minted "cookie" for the hadron section of the experiment's Liquid Argon Calorimeter. The calorimeter consists of 53 such detector planes, each separated by 1 in. of stainless steel. Each cookie contains two detector gaps in a tessalated geometry, and they were made using a computer-controlled routing table designed at Fermilab.

Once upon a time Fermilab engineered, and contracted for parts, and assembled over 1000 superconducting magnets. The engineering and assembly capability, thinned considerably, was reorganized into the Technical Support Section (TSS). Its job is to make things. It keeps our apparatus modern, continuously upgrading our capability to respond to the absurd requests generated by research at the frontier. Advanced concepts, be they in CAD/CAM, superconducting materials, SSC gizmos - you name it, TSS will make it. Its activities are described by Section Head Paul Mantsch:

The Technical Support Section

Paul Mantsch

The Technical Support Section provides a broad range of mechanical services with emphasis on magnets and related hardware. Groups within the section are the Magnet Facility; the Magnet Test Facility; Mechanical Drafting, Design and Engineering groups; and the machine shops. Current activities include production of new magnets and spares for the Accelerator and experiments, fabrication of components for the D0 collider detector, SSC magnet R&D, as well as a broad range of mechanical services.

Accelerator Support

The Magnet Facility and Magnet Test Facility provide basic support to the Fermilab accelerators. An ongoing program provides basic spare magnets of all kinds, both superconducting and conventional, including dipoles, quadrupoles, and correctors for the Main Ring, TEVATRON, and Pbar Source. A variety of special magnets, or modifications to existing magnets, also requires the effort of the Magnet Facility.

Plans for an upgrade to the Accelerator to achieve high luminosity present challenging tasks. These tasks include a very-high-gradient quadrupole (2 tesla/cm) and a modified high-field TEVATRON dipole with a 6-tesla field. The design of these high-performance magnets, now underway, will take advantage of the recent enormous increase in the performance of superconducting wire. The fields required of these magnets may also require them to operate in superfluid helium at 1.8 K. The high field energies, magnetic forces, and tricky cryostats implied by these magnets will certainly challenge our skills.

The Magnet Facility will fabricate the magnets for the 250-MeV medical proton-synchrotron program. The medical accelerator is a collaborative effort between Loma Linda Medical Center and Fermilab.

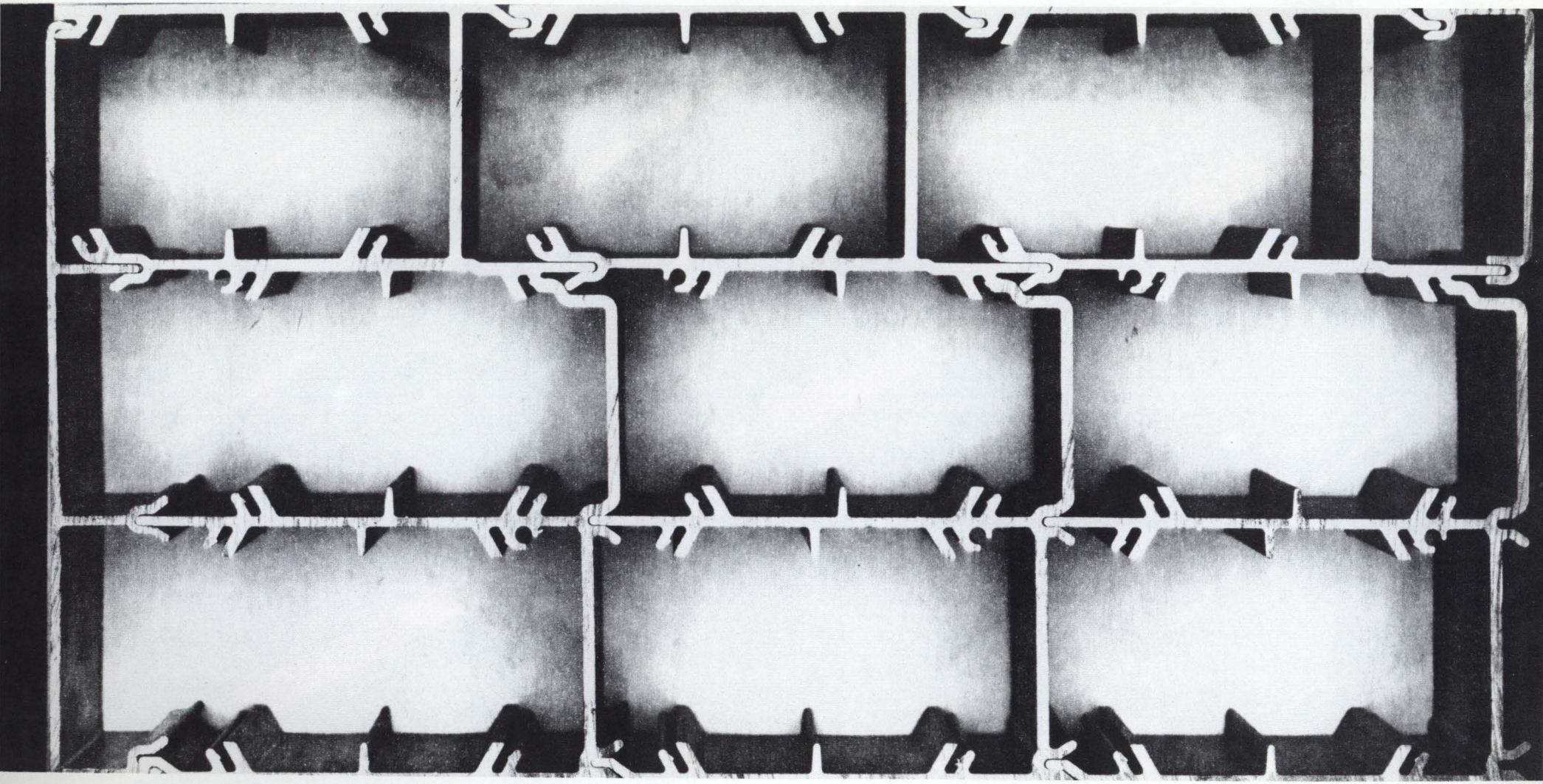
The D0 Collider Detector

The facilities within the Technical Support Section that were built up during the construction of the TEVATRON and the Collider are being brought to bear on the fabrication of components for the collider detector at D0.

The D0 detector includes large magnetized iron toroids for measuring muon momentum. A critical task in making the necessary magnet coils is in applying the insulation to the conductor. So far 20 coils, each weighing about 4000 lbs., have been made by industry and delivered to the Conventional Magnet Facility for insulation An additional 16 coils will be insulated to complete the toroids.

Technical Support is also helping with the assembly of muon detectors and end-cap calorimeters for the D0 detector.

The services of the shops, fabrication task order operation, Drafting and Design Group, inspection lab, and materials lab also contribute to the fabrication needs of the D0 detector.



The Superconducting Super Collider

The Fermilab Technical Support Section plays an important role in the development of the ring magnets for the proposed Superconducting Super Collider. These superconducting magnets account for a third of the SSC cost and are the components most critical to the success of the SSC.

The magnet R&D program is a collaboration of four laboratories: Brookhaven National Laboratory (BNL), Lawrence Berkeley Laboratory (LBL), the Texas Accelerator Center, and Fermilab. The responsibility of Fermilab has been the design of the magnet cryostats, assembly of the dipole magnets incorporating the coils provided by BNL, and testing of the completed magnets.

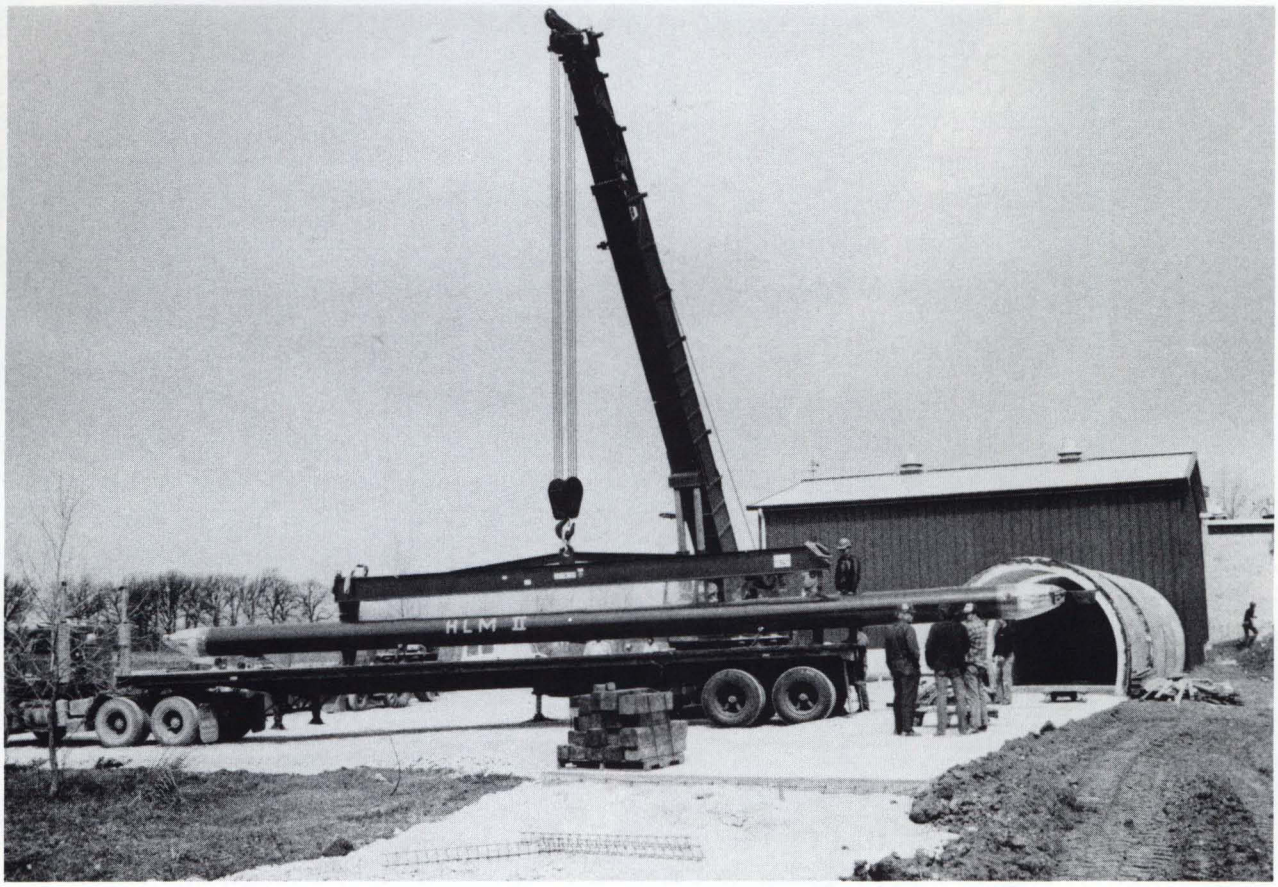
A major accomplishment of the SSC program was the issuing of the Conceptual Design Report (CDR) in March of 1985. This highly detailed technical description and cost breakdown was based largely on the R&D program of the previous two years. Fermilab contributed to the CDR in many areas. Technical Support provided the cryostat design, as well as assembly, testing, and installation procedures. Underlying nearly every part of the design report was experience gained from the Fermilab TEVATRON. The cost data in particular, accumulated during the construction of the TEVATRON and contained in the extensive fabrication and purchasing records within Technical Support, was vital to the quality of the SSC cost breakdown.

Major technical achievements at Fermilab also contributed significantly to the SSC effort. A full-scale SSC prototype cryostat was constructed and extensively tested to exercise the magnet assembly tooling and procedures, and to make a heat leak measurement. The heat leak model (HLM II) demonstrated that the very low heat leak, vital to the success of the SSC, can be achieved with the Fermilab cryostat design. The heat leak of the magnets will largely determine the ultimate operating cost of the SSC.

Two complete prototype magnets were assembled using coils supplied by BNL. A program to test these two magnets is underway at the Technical Support Magnet Test Facility.

Ongoing design studies continue to improve the quality of cryostats, magnet interconnects, and assembly tooling. Work has also begun on the standard SSC quadrupole. Initial quadrupole coil design work has been carried out at LBL, while the

←Photo micrograph of NbTi filaments that have a diffusion barrier which does not allow the formation of TiCu intermetallic. Notice the uniformity of the cross section. TiCu intermetallic can cause filament distortions during the cold drawing process leading to premature voltages in the transport of supercurrent. This sample will have a very sharp transition (superconducting to normal).



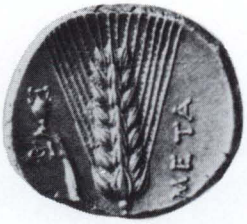
SSC heat leak model being installed for tests at the SSC String-Test Facility. The heat leak model is a full-scale SSC cryostat with a dummy collared coil used for cryogenic heat leak measurements.

actual fabrication of the coil and cryostat assembly will take place at Fermilab.

As part of the early coil development work at Fermilab, a machine was conceived to make a continuous on-line measurement of the cable used in the magnet coils. The result was a remarkably successful device that can measure the thickness of cable to a precision of 0.0001 of an inch. Being able to measure the cable in detail for the first time should contribute significantly to the quality of future coils.

Future plans include the fabrication of more prototype dipoles, quadrupoles, and spool pieces, and their test in a string for development of magnet-related systems.

The outer vacuum shell of an SSC cryostat at the Industrial Center Building. In the distance is an SSC magnet inside a cryostat, ready for testing.



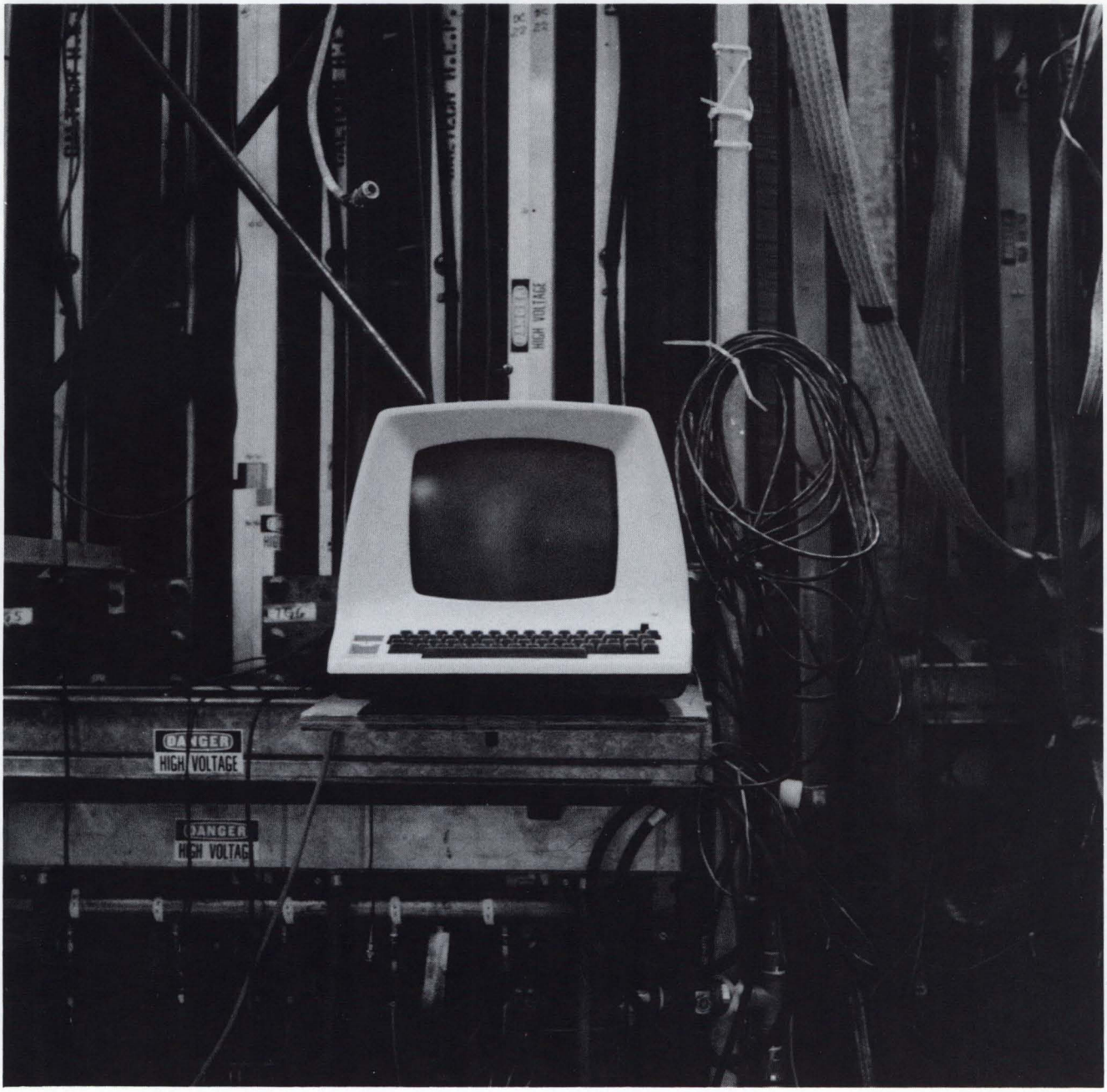
Services

The mission of Fermilab machine shops is to provide unique capabilities and services not available outside the Laboratory. These special capabilities include state-of-the-art machining techniques, fabrication knowledge of exotic materials, high precision, close interaction with customers, and rapid turn around. In order to keep these capabilities vital, a program of continued improvement both in training and in quality of machine tools is underway. The large fraction of the Fermilab machinists have now had formal training in computer-aided machining.

A computer numerical control (CNC) turning center (lathe) and a second CNC mill have been added to the shop resources. The NC and CNC machines have been interfaced to the Laboratory CAD system via the Fermilab computer system. The enthusiasm of the machinists to learn CNC skills, together with the support of local design and computer experts, has made the Fermilab shops on a par with the best to be found anywhere and especially honed to the research environment.

A successful program of physics research demands rapid responsiveness in the fabrication of parts for the Accelerator and detectors. In the past year a fabrication task order effort was set up to speed procurement of small fabricated parts. Under this system more than 60 outside shops are under contract to respond to a job within 24 hours of receipt of the order. These shops cover a broad range of specialties. This system has proven a success. Not only can fabricated parts be obtained rapidly, but the backlog of the Fermilab shop can be held to a few days enabling them to respond to their special tasks.

Mechanical computer-aided design continues to progress at Fermilab, encompassing new equipment and more extensive training. With the prospect of the imminent departure of the CDC CYBER computer system, plans are being made for a major upgrade in the CAD system. A group with representatives from across the Laboratory has been evaluating new systems that will meet Fermilab's needs over the next several years.


DANGER
HIGH VOLTAGE
DANGER
HIGH VOLTAGE
DANGER
HIGH VOLTAGE

The physics output of the Laboratory is almost wholly dependent on the Computing Department's capabilities. All experiments based on Fermilab accelerators to an increasing degree use these facilities; very few depend on campus computers. In 1983, we called upon an outside committee (Ballam Committee) to advise us, and its report has been a blueprint for the evolution of these facilities to meet the severe challenges of the TEVATRON era. Not only does the group acquire and manage the central facilities, but it allocates computers and computer-related hardware, including commercial electronics modules, to the experimenters. Department Chairman Hugh Montgomery reviews the process:

The Computing Department

Hugh Montgomery

In a year without an Accelerator run there is perhaps a temptation to relax; if such a temptation touched the minds of those in the Computing Department it was but fleetingly.

The volume of data accumulated during the 1985 TEVATRON fixed-target run exceeded expectations for several experiments, especially those able to exploit the large duty factor of the Accelerator. In one case, close to 100-million events were accumulated and production analysis had already started before the end of 1985. Such data sets have kept the complex of a 2-CPU CYBER875 and three CYBER175 CPU's fully occupied. Recently, the system set new records by delivering just over 160 CYBER175-equivalent CPU-hours-per-day during the months of September and October. The evolution of this performance measured over the last two years is shown in Fig. 2.

A new element of raw data-crunching power was introduced in July when the Ad-

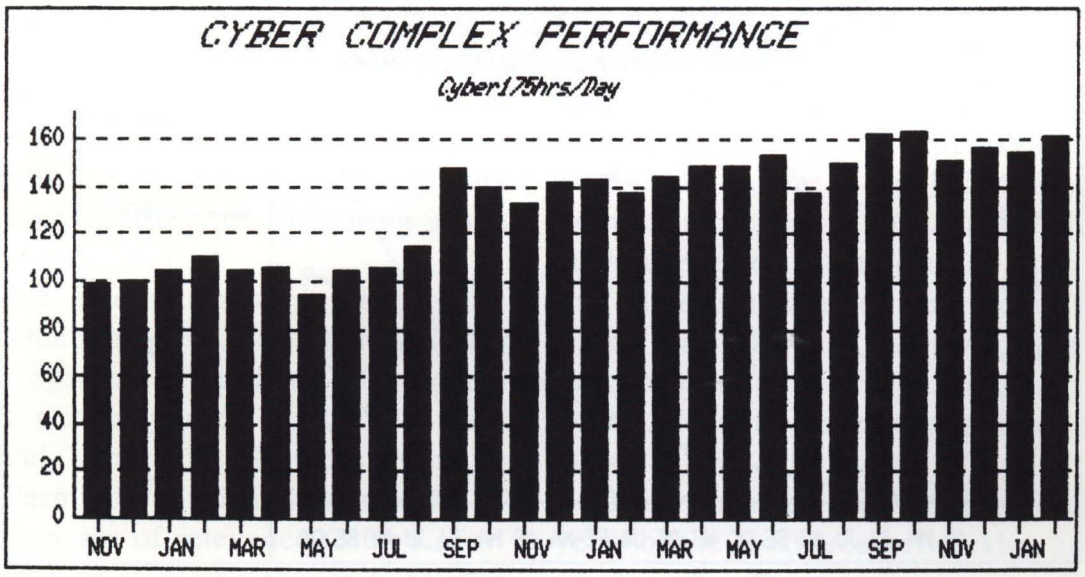


Figure 2. CYBER 175 CPU hours per day for the last two years, averaged monthly as a function of time.

vanced Computer Program Group presented us with the fruits of its labors (see Tom Nash's report on the Advanced Computer Program [ACP], immediately following). A system of about 50 processor nodes was put into production running, integrated with the Computing Center VAX Cluster. Operations adopted the new chick (albeit a cuckoo) into the nest and started feeding it tapes in large numbers. Since then the system has run with few problems and its impact can be gauged from Fig. 3 which shows the cumulative computing on both the CYBER and ACP systems used by E-691. The current total of about 30,000 CYBER175 equivalent hours (about 200,000 VAX780-equivalent hours) is perhaps the biggest total ever delivered to any single experiment in a comparable period.

This success has whetted the appetites of other experiments which are now prepared to request computing at the level of 10^5 CYBER-equivalent hours for a single Accelerator run. The onus is, and will be, on all to port applications and utilities to these systems. An unoptimized version of the CERN Library utilities is available and work has started on some of the more complex utilities.

The third component of scientific computing is the VAX Cluster which has come under enormous pressure and has been expanded accordingly. During the month of September the two VAX8600 machines were upgraded to VAX8650s, an increase of about 1.5 in CPU power, and their memories were increased to 44 and 48 megabytes each. In October a third VAX8600 was installed after an eventful trip around the world. This machine was purchased by the Istituto Nazionale di Fisica Nucleare and incorporated in the central VAX cluster because of the large participation by Italian physicists in many Fermilab experiments, i.e., CDF, E-687, E-704, E-710, and E-760. It is interesting to note that while the number of persons interactively using the VAX Cluster simultaneously during the day now often exceeds 150, there has not been a cor-

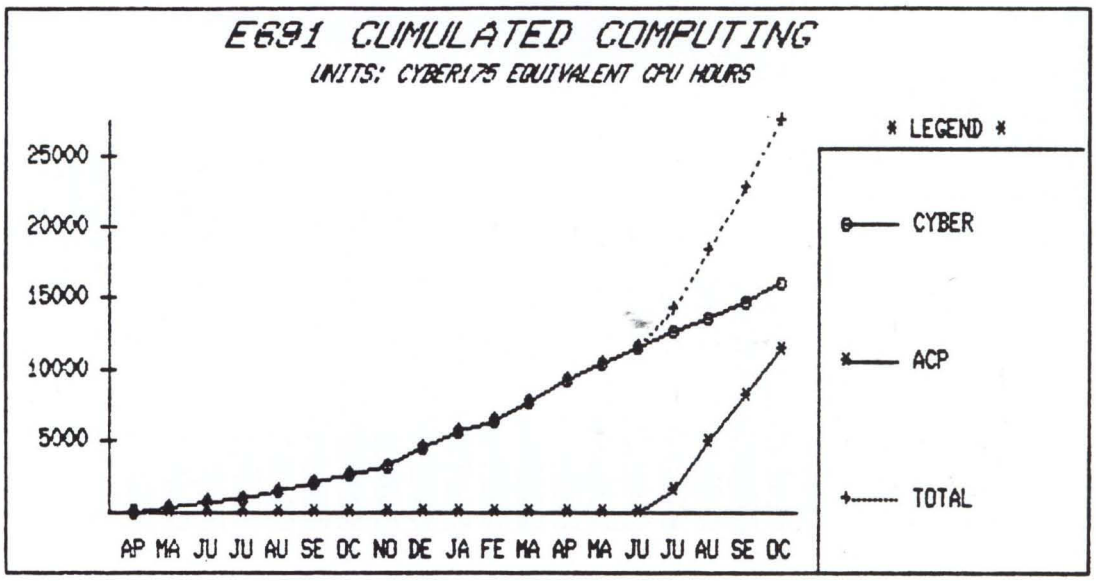


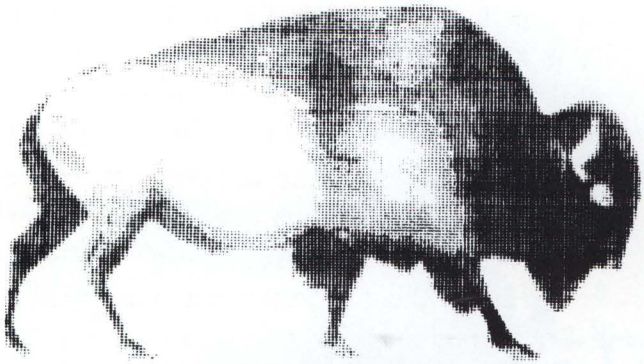
Figure 3. Experiment 691's cumulative computing on both the CYBER and ACP systems.

Fermilab Director Leon Lederman (center) leads the ground-breaking efforts for the new Central Computer Facility on July 1, 1986. Helping are (left to right) Gordon Charlton (DOE), Dave Mondo (Barcon Corp.), Ed Temple (DOE), and Jeffrey Appel (Fermilab), while Rich Farritor (far left) of the Contracts Department watches for rain.

responding drop in CYBER users; one can only conclude that this reflects the improving accessibility of this type of computing and the increased role of computing in the everyday work of all.

A piece of our computing at the Laboratory which often escapes attention is the Business System. This is an IBM system which is primarily used by the Business Office and Laboratory Services components of Fermilab. Since it is the home of many data bases of relevance to the Laboratory operation as a whole, it is becoming more widely visible and it is not unusual for it to support more than 60 simultaneous users. During the course of 1986 the system underwent an upgrade from an IBM4341 system to an IBM4381 system with memory and disk increase to make such a level of use tractable. It is hoped that there is a base for future development which will allow the business functions to benefit from the improvement in computing evident in other aspects of the Laboratory mission.

The expansion over the last couple of years of the local area networking has been staggering. There are now more than 50 machines on site owned by the Lab or its users, which are nodes of the nationwide



Fermilab Computing Department Newsletter

high-energy physics DECnet. Indeed, during the last year access to Europe by this means was also opened up. The network has permitted an interesting extension of our central computing facilities to include some of the many machines around the site. With the cooperation of the individual systems managers on the different experiments and Accelerator VAXs, a procedure has been set up to allow users to submit jobs to a queue on the VAX Cluster for execution on any available CPU. The system takes charge, transmits what is necessary to the local VAX, executes the job at lowest priority so as not to impact local usage, and returns the results to the user on the Cluster. Other usages of the network include remote software distribution, and installation and trouble shooting by the online support groups. Many aspects of the Fermilab participation in the wide world of national and international networking were discussed in a two-day Networkshop in October, which was jointly organized by the Computing Department and the Computer Coordinating Committee.

While it is difficult to keep pace with hardware needs, it is even more difficult in the software arena. Resources have been tested to the limits in supporting all manner of office automation, CAD/CAE/CAM, enhanced graphics facilities, and the increasing number of laser printers throughout the Laboratory, beyond the traditional support for physicists. The approach taken has been to try and increase dramatically the level of user education provided. There is an increased number of courses and seminars sponsored by the User Support Group which are either given by group members or by the appropriate vendors. Modern commercial software has so much more capability, and the resulting options are often so numerous, that the casual user needs much initial guidance to get him or her productive quickly, and to maintain currency. An example of a product which was introduced in 1985, but which has bloomed across the spectrum of use from off line to data acquisiton in 1986, is the DI3000 graphics package. This is a commerical product whose utility comes from its rather well-defined structure and the ability to support a wide range of output devices including those with inherent three-dimensional capabilities.

In addition to the general Newsletter which appears every two months, two other publications have been introduced. The PC/CAD newsletter appears monthly and the Office Computing Newsletter bimonthly. Information dissemination associated with these activities, and those of other groups in the department, is the responsibility of the Computing Department Library and the scale of its task can be gauged by the volume of paper which it has dis-

tributed: exceeding 200 cubic feet for the year.

Also in the field of physics software, the products available are much bigger and have more capability. An example of a very powerful package which is enjoying much popularity is the GEANT3 Monte Carlo package from CERN which has facilities for many facets of detector design and simulation. As in commercial packages however, there is "sufficient rope for the physicists to hang themselves," and lots of effort is being put into consulting and guidance for users of such packages. Finally, we have recently taken a toddler's first step in the direction of exploiting non-scalar architectures with a small project to try and understand the conflicting opinions as to the enhanced return available from recasting event analysis algorithms for vector machines.

Front end data-acquisition software provided by the Data Acquisition Software Group supports a range of systems including RT11 and RSX on the venerable PDP-11 machines, and FASTBUS for which significant improvement has been made in the support of the Lecroy 1821 interface. The scheme provides for parallelism and buffering at this level, thereby reducing readout times and exploiting the Accelerator spill structure. The VAXOnline system, originally introduced in rudimentary form towards the end of the 1985 TEVATRON run, accepts data from these various sources and concatenates various sub-events in a microVAX or VAX780. The complete events are then made available, in a pool, to other software components which may be standard, furnished tasks for logging to tape or distribution to other machines in the system, or may be physicist-generated consumer tasks for monitoring and checking the data. An interactive display facility is also provided. The coherence of this total system has met with approval from the experiments and a majority of the newer experiments has adopted its framework. This success has led to an increased pressure on the Data Acquisition Software Group since their products are perceived as critical elements for the Laboratory's experimental program.

During the past year the Computing Department has collaborated with several other departments in the Research Division, as well as with the Physics Department, to generate a prototype readout and data-acquisition system which will be used first for E-769. A smart CAMAC crate controller is used to execute a list of instructions and pump data into buffer memories resident in a VME crate. These buffers are read into several ACP processors which can then analyze and format the data before it is written directly from the VME crate to tape. The system enhances the CAMAC readout by introducing as much parallelism as desired and by executing at full CAMAC speeds. The system is currently in an advanced state of testing in the experiment.

This represents only one of the possible future directions for data acquisition. Another project, somewhat less radical, is also in hand to incorporate systems of processors within the VAXOnline data stream, again to provide data filtering capability far in excess of that available from conventional hosts.

The introduction of new systems, the advent of VME and ACP processors, and newer and faster terminals and MicroVAXs and more FASTBUS has kept the members of the Physics Research Equipment Pool and the Data Acquisition Hard-

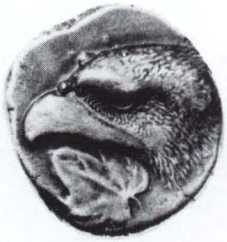
ware Maintenance groups on their toes. In addition, support for board level exchange and repair for Laboratory IBM PC and Apple Macintosh personal computers has been provided since the spring, giving yet another new aspect to their efforts.

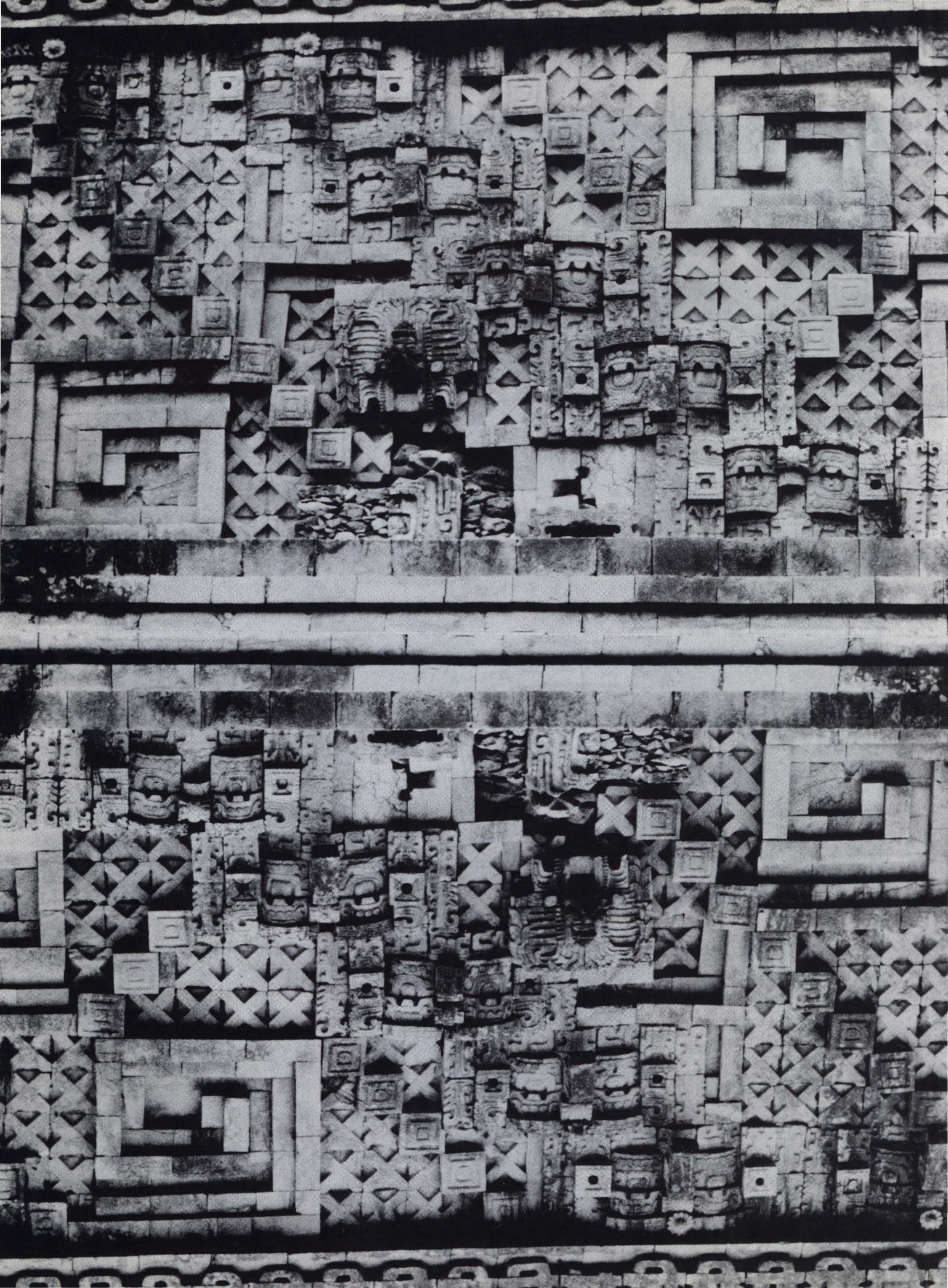
As the time for the new Accelerator runs approach (with all the subtlety of a runaway train), it is hoped that the efforts of this "shutdown year" have really resulted in the experiments being ready to run. (IF THEY CAN ONLY HAVE ONE LAST CAMAC AND FASTBUS MODULE AND THIS ONE LAST FINAL INCREASE IN DATA-ACQUISITION COMPUTER DISK SPACE!!)

A prosperous future is usually based on a solid foundation and this we hope will hold true for the future computing at the Laboratory. Hope was expressed a year ago that the efforts associated with the Central Computing Upgrade Project would be visible to the eye. The fulfillment of this hope began with the ground breaking ceremony on July 1, 1986, and has been extended by the visibility of the foundations of the new building near the intersection between Roads B and D near the Central Helium Liquefier plant. The foundations are now complete and we hope to proceed to the next phase which is the construction of the building proper. The building will be three floors high and will be annular in shape and is intended to continue Fermilab's commitment to a tradition of interesting architecture.

The architecture of the computing which the building houses will not be so evident until construction is complete. However, as a result of joint efforts by the Next Acquisition Committee and the Computing Department, Department of Energy approval for the acquisition plans is in hand. Benchmarks have been prepared and the procurement process will start in earnest very soon. We hope to have delivery of the very first components within a short time of this writing; these will have to be housed in the already very crowded space in Wilson Hall. The pacing of the acquisition and the building schedule is a complicated process made more so by Fiscal 1987 constraints. Every effort is being made to accomplish these aims in a rational manner while furnishing the computing to respond to what we hope will be an onslaught of data from both Collider and fixed-target experiments during 1987.

Aerial view of the foundations and caissons for the new Computer Center shows the annular shape of the building. In the background is the Central Helium Liquefier and the Industrial Complex.





Closely related to the Computing Department and already cited as a highlight is the Advanced Computer Program, and its mover and shaker, Tom Nash, writes about it and fearlessly exposes his vision of even greater achievements to come:

The Advanced Computer Program

Thomas Nash

The Advanced Computer Program turned over the first of its ACP Multi-microprocessor Systems for Computer Center operation in July and it has run trouble free since then. For the first five months, less than half the processors of the system were installed. Nonetheless, during this period the ACP system's performance nearly matched the full capacity of the Computer Center's large mainframes which have traditionally been applied to grinding out the reconstruction of Fermilab's huge amounts of experiment data. The construction cost of the ACP system was more than two orders of magnitude cheaper than the 20 or so million dollars originally spent on the Center's big computers.

Surprising only because of the natural skepticism of physicists who had frequently heard outrageous claims before, the ACP system has exceeded its proponents' promises for performance, cost, reliability, and ease of use. Most important has been the quick and painless incorporation of this new architecture into the Computer Center. This, and, of course, the extraordinary cost effectiveness, has made believers of the Computing Department bosses (see Hugh Montgomery's piece in these pages). A naturally conservative bunch, they see the ACP Multiprocessor as an essential component of their plans for meeting the long term number-crunching demand of the Laboratory, which sometimes seems to grow without finite limit while the computing budget is at least constrained by the GNP.

Almost as big an honor as the benediction of the Computing Department was the IR-100 Award presented to Fermilab by *Research and Development Magazine* for the ACP Multiprocessor as one of the 100 most significant technical products of 1986.

Success brings with it popularity, and in this context that means more and more users of the system with varying (and sometimes surprising) requirements. If this were a money making business, we would call users, with perhaps more politeness, customers. Their support, "user support," is now a major concern of both the ACP and the Computing Department. The ACP Multiprocessor software was always designed to make it easy to bring up new and old programs on the parallel system. A significant and successful aspect of this was the design decision to incorporate the "front end," where most of the user time is spent, into the familiar VAX VMS environment. A full simulator is available on the VAX Cluster in the Computer Center to allow the conversion of user code (and, not incidentally, the user's mentality) from the conventional uniprocessor world to a parallel processor. An ACP user software development station, also accessible from the Cluster, consists of several mini-ACP systems to compile and debug FORTRAN 77

programs on real ACP CPU's preparatory to running on a full production system.

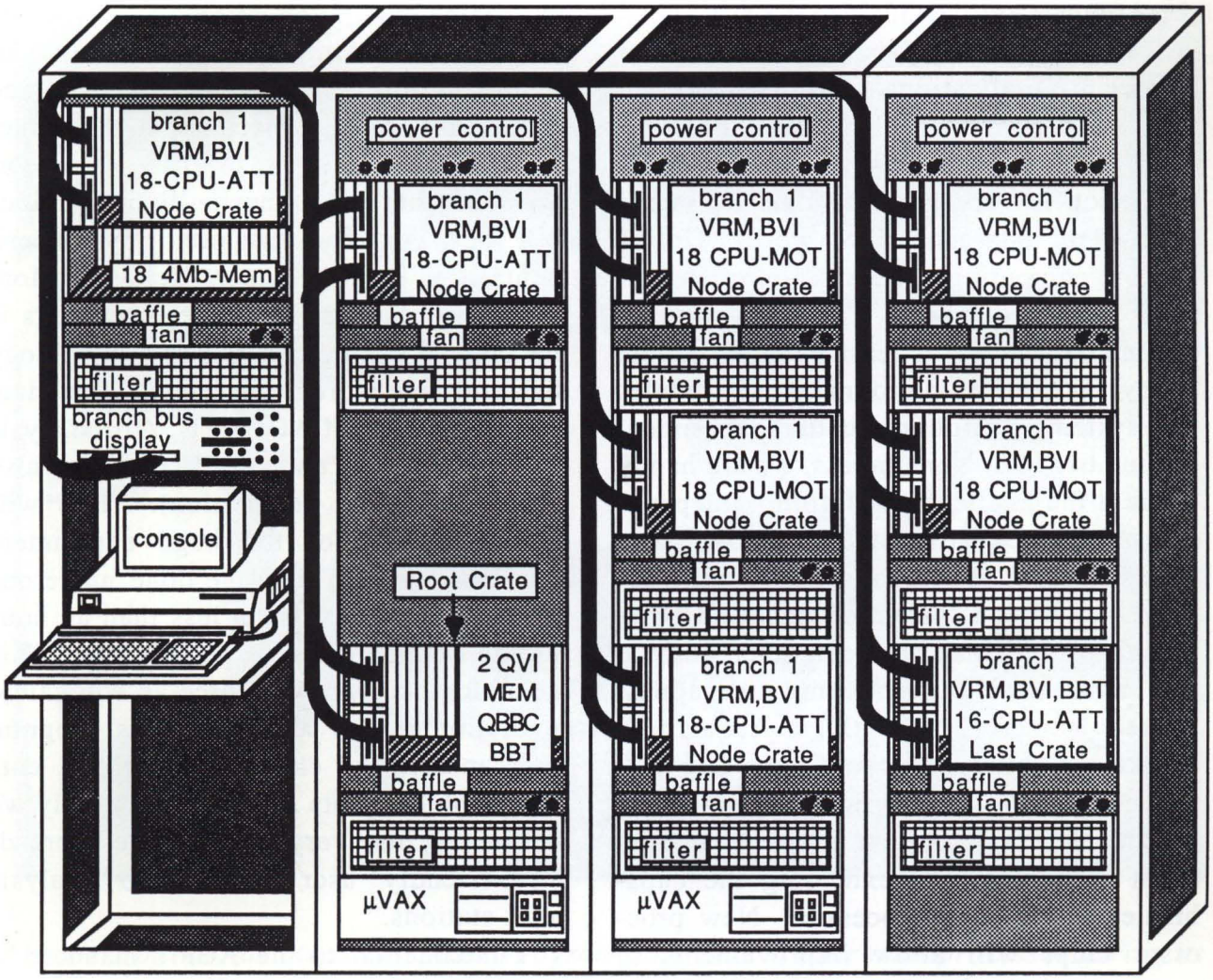
The fundamental ease of use of the ACP system was demonstrated recently by a visitor from Europe who had no previous exposure to the ACP software or its documentation. In about one working day during a short stay at Fermilab, he had the Lund Monte Carlo (an important and standard theoretical simulation of the strong interactions) running on the ACP system. This "typical" example is, in truth, only typical of programs like this one which are prepared with the intention that they be readily portable. Retrofitting major experimental code which has been developed for a single specific computer family (for example, the 60-bit CYBER computers at Fermilab), takes more time. Much of that time is spent in a first step: converting to run on the VAX. The intellectually interesting problem, the subject of much discussion in the computer science world, of breaking up a program into appropriately parallel pieces, has proven to consume very little time and not be particularly challenging.

High-energy physics FORTRAN programs have a way of exercising all the hidden corners that a microprocessor compiler must cover. The ACP acts as an "alpha" or "beta test site" for several commercial compiler developers, and with our help they are reaching the "reasonably" bug-free stage. A user program that sticks strictly to the portable FORTRAN 77 standard (plus allowed extensions) rarely encounters microprocessor compiler difficulties these days.

Thus, a clearly important ACP activity at this stage is support of its user customers in several areas along the front, most in collaboration with the Computing Department. These are: adequate development tools, powerful error handling, software verification and debugging, compiler improvements, support of major libraries (e.g., CERN Lib), and education of users through meetings, documentation, and consultants.

The first 140-CPU ACP system has been built under the supervision of the ACP. Fermilab is not, and should not be, set up to mass produce electronic modules for its, or other institutions', needs once development is complete. Arrangements were made for a local company, which specializes in such products, to take over this role. Omnibyte Corp. of West Chicago has delivered over 100 ACP-designed CPU's and has orders for many more, the majority from outside Fermilab. [*In other places this is called Technology Transfer.*] They are delivering all the interface and control modules that make up the full ACP Multiprocessor System. Systems are now running, being installed, or on order for, among others, Yale, Los Alamos National Laboratory, Montreal, Toronto, Rutgers, Antwerp, SIN (Swiss National Lab), Saclay (French National Lab), and Brookhaven. The benefit to Fermilab of all this outside activity is an expanded user community and a resulting larger base of software (and, perhaps someday, hardware) which can be exchanged.

When triggers programmable in high-level languages are conceived for large experiments, the distinction between on line and off line becomes fuzzy. After all, it makes little difference to the computing engine whether its data comes from an on-line buffer in real time or from a data tape sometime later. Since triggering requirements are becoming more and more severe (for experiments on an SSC-scale accel-



A Macintosh-generated rack layout of the ACP Multiprocessor System prepared prior to installation of the ACP in the Computing Center where it now productively resides.

erator the matter will be a major technological challenge), such high-level triggers are very much in fashion. The ACP system was designed to be able to accept extraordinarily high data rates (well over 100 megabytes/second) so that it would be able to function in any foreseen high-level trigger. Two large experiments have chosen to incorporate the ACP multiprocessor into their FASTBUS data-acquisition systems: CDF at Fermilab and the MEGA experiment at Los Alamos. A FASTBUS interface to the ACP Branchbus has been developed with the CDF people. It has been tested with an unbelievable zero error rate for 48 hours at a full spec 20 megabytes/second data transfer rate into one ACP branch. With a switch presently in ACP design, multiple parallel branches, and even higher rates, will be possible in such applications. A first live test of the "Level 3" trigger based on the ACP Multiprocessor is expected during the winter 1987 CDF run.

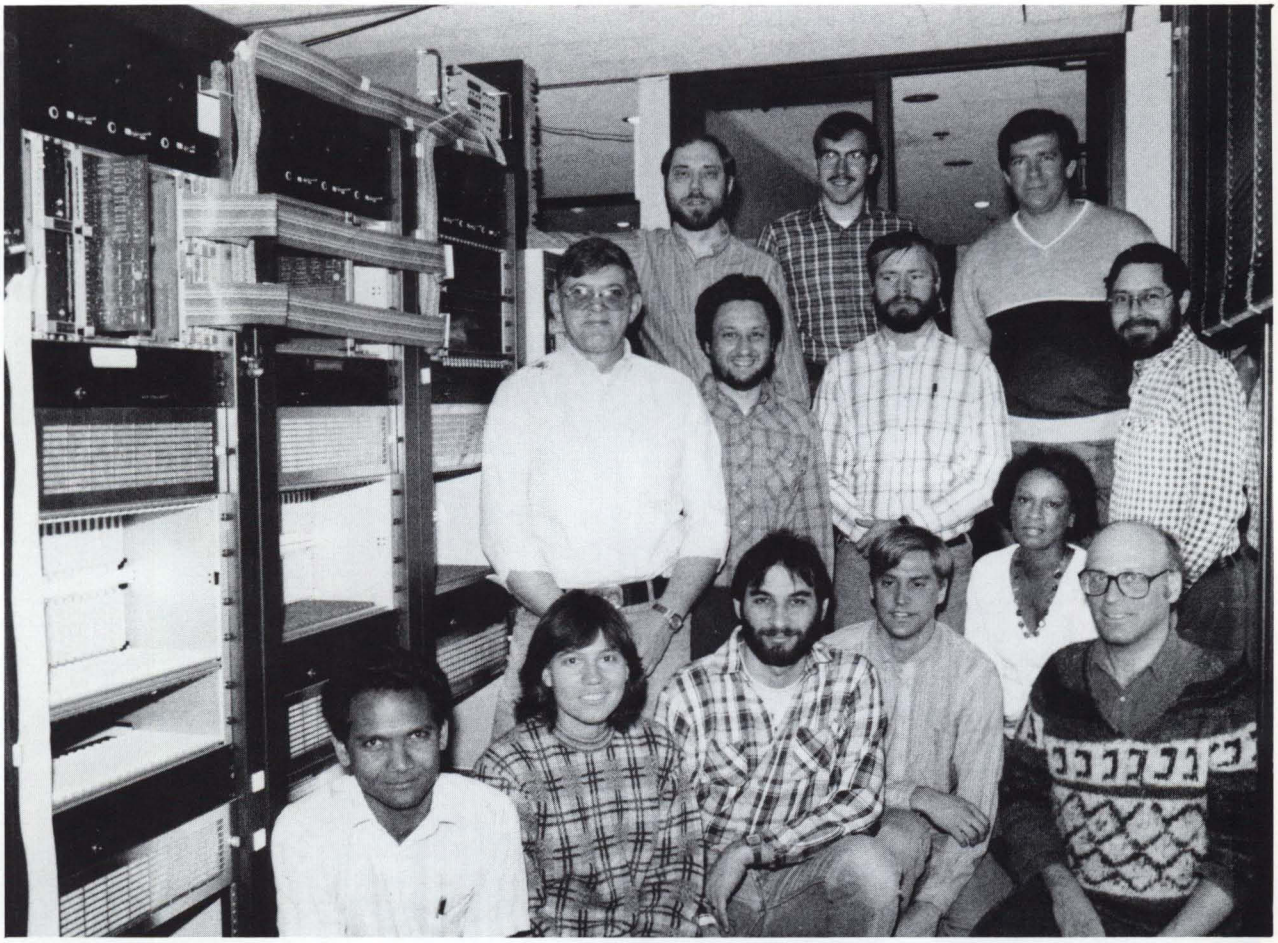
Another module presently being designed in the ACP will allow mastership of

the ACP system's Branchbus from a standard VME system. This has a number of important applications, not the least of which is for high-level triggers in VME-based experiments. Unfortunately, standardization is very hard to come by in the experiment data-acquisition world. Unlike off-line computing, it seems almost impossible to come up with a defined solution that makes all, or at least enough, people happy. We are trying to make our modules and systems useful in smaller experiment on-line triggers. Nonetheless, we are happy to yield the challenge of turning independent minded experimentalists into a contented herd of sheep following a well defined acquisition system of ACP and other modules. This task has been taken on by a new Research Division committee appropriately named DAWG (Data Acquisition Working Group) and the Computing Department's Data Acquisition Group.

The ACP's next year or more will be spent exploiting and extending the capabilities of the multiprocessor. New processor chips will allow improvements in cost performance of 5-10 in new CPU modules on the time scale of a year or so. The multiprocessor's architecture, with a new Branchbus boss VME module (referred to earlier) and software that allows efficient CPU "node to node" communication, is ideal for lattice gauge calculations. This is particularly true in light of the new realization that these important calculations of the strong forces will benefit from non-local communication. The ACP people, the processor, and several members of the Theory Department with strong interest are teaming up to be a powerful force in this very important field.

We expect to develop a single board array processor to couple with a natural and immediate application in the lattice gauge work. Although experiment event reconstruction is at present too ill defined to promise quick benefit from the rather constraining power of an array processor, we hope that the opportunity it provides will be seen and exploited by experimentalists without much delay. More obviously of benefit to experimentalists is our plan to couple cheap video technology disk and tape storage devices to individual or small groups of ACP CPU's for analysis of reconstructed data (and, perhaps, also on-line raw data acquisition). This will allow scanning of the huge experiment data bases, which must be done numerous times during analysis, in less than an hour instead of the present several weeks. This technological leap will force an equivalent revolution in the way physicists program their analysis to choose kinematical cuts and graphical plots of data. Inevitably we will move into very easy to use "spreadsheet friendly" user interfaces to "analysis work stations."

Fundamental to the ACP's mandate to react quickly to new technology in the interests of particle physics is the ability to turn new designs around rapidly. In order to improve the situation in this regard, the ACP conducted an evaluation of computer-aided engineering and design tools. The result was the procurement of Fermilab's first major electronic CAE/CAD system that allows highly efficient "soup to nuts" design. A design will proceed from schematic entry through full-functional and worst-case timing simulation to multilayer PC board layout without seeing the light of day. No more debugging of irrelevant timing problems and loose connections on a wire-wrapped prototype board! ACP designs will now go straight to the final PC



Members of the Advanced Computer Program pose next to their multiprocessor during its construction. First row, left to right, are Hari Areti, Carla DeBarros, Bob Atac, Don Husby, Claudia Foster, and Tom Nash; second row, left to right, Art Cook, Mark Fischler, Rick Hance, and Irwin Gaines; and third row, left to right, Joe Biel, Glenn Case, and Ted Zmuda.

board testing (with hopefully few errors because of extensive simulation). The system has proven so attractive that it is being extended to support some of the needs of the Electronics/Electrical Department in the Research Division. It is pleasing that even in this indirect way the ACP is realizing one of the Director's original goals in forming it: to help raise the general level of electronics and computing at the Lab.

Fermilab Director Leon Lederman signs the Safety Analysis Report for the Tev I project. Looking on are (left to right) Safety Section Head Larry Coulson, Radiation Safety Group Leader Bill Freeman, and Associate Director Dick Lundy.

Nothing can more demoralize a laboratory, nor more signify demoralization, than a poor safety record. The effort to find a balance between safety and economy, between safety and bureacracy, is an all-consuming one. Here is Larry Coulson, Head of the Safety Section:

The Safety Section

Larry Coulson

The Safety Section monitors the carrying out of safety procedures and institutes activities in a wide variety of areas including radiation safety, cryogenic safety, mechanical safety, pressurized and flammable gas safety, chemical safety, and environmental protection. Some of these activities during the past year are detailed below.

In 1986, personnel radiation exposures continued the trend toward reduction with the total person-rem value slightly lower than in 1985. At the same time, occupational accident statistics increased significantly. There were, for example, four times as many lost work days due to accidents and injuries than in the previous year. Analysis has indicated that about 80% were due to typical occupational hazards - slips, trips, falls, objects falling on people, back injuries from material handling, inadequate eye and skin protection - and not from hazards associated with the advanced technology at the Laboratory. In order to reverse this trend, proposals that include monthly hazard inspection and follow-up by upper management personnel, the training of safety officers in accident investigation, and the training of people who hold back injury-risk jobs have been implemented, with Laboratory-wide support.

Additional success has been achieved in meeting the challenge of both chemical and radioactive waste handling. A volume-toxicity waste reduction program that involves, among other things, the recycling of petroleum-based solvents and stricter controls on waste oil has led to a significant reduction in the number of gallons of chemical waste The sorting and screening activities of the radioactive waste program have also been effective in reducing the total volume of such waste and increasing the efficiency of the compacting facility.

In the area of industrial hygiene, the program on chemical hazard identification, started in 1985, was implemented during 1986. Its function, through an extensive computer base, is to provide the user with hazard information, handling procedures, and training. There has also been improvement in laser safety through inventory, training, and medical surveillance programs. Safety Section monitoring of the work involved with the development of the D0 uranium calorimeter prototype has led to a large amount of information on both conventional industrial hygiene and health physics aspects of the hazards to be expected in the fabrication of the full-scale modules.

During 1986, Fermilab was honored by being selected as the lead accelerator health physics laboratory. The function of the "Lead Lab" is to provide leadership via the head of the Safety Section for applied research in accelerator health physics at various Department of Energy installations. Near-term tasks are to formulate plans to

support efforts to characterize neutron and muon fields at DOE accelerators, to determine test standards in support of personnel dosimetry performance testing programs, to coordinate arrangements for technical workshops, and to solicit input and technical proposals for needed health physics technology development.

The program to characterize neutron radiation fields at Fermilab continued during 1986 with the analysis of measurements performed in the Accelerator tunnel in late 1985 in a collaborative effort between the Fermilab Safety Section and Accelerator Division, and LBL scientists. The radiation environment was studied by determining the neutron fluence as a function of energy using a multisphere ^{6}LiI scintillation spectrometer at a location about 15 meters downstream from the A48 warm section. The surprising result from these studies was that high-energy neutrons are relatively unimportant compared to those of lower energy. The spectra were quite soft with prominent peaks at about 0.2 MeV and thermal neutron energies, independent of TEVATRON or Main Ring operating conditions. Further measurements, which could provide important information for SSC planning, have been proposed to directly relate neutron fluence to beam loss and thus more uniquely define the primary source of neutrons in the tunnel.

The usual Safety Section environmental monitoring functions (penetrating radiation at the site boundary, and off-site release of radioactive effluents) were broadened during the past year by the need to meet the challenge of escalating DOE regulation. Because of provisions of the National Environmental Policy Act (NEPA) it is now necessary to evaluate projects as to environmental impact. To this end:

- The services of an archaeologist were enlisted to update work done in the early 1970s to discover and protect Laboratory archaeological sites.

- The Natural History Survey of the State of Illinois has studied potential habitats of threatened and endangered species on site, and a small number of such species of prairie plants and a rookery (20 nests) of the Great Blue Heron have been identified.

- Corn tract licenses are now required to leave a 50% crop residue on the land to reduce soil erosion due primarily to rain water.

- The Fermilab Village water and sewer systems are being upgraded by connection to those of the City of Warrenville in order to meet today's new standard.

Furthermore, an environmental advisory committee with expertise in grasslands has been appointed to evaluate proposals for environmental research projects at Fermilab. The foundation for such studies is the prairie restoration project in place at the Laboratory for the last ten years. It is expected that the Laboratory will be designated a National Environmental Research Park (NERP), with the specific mandate to promote prairie research programs.

LIQUID

In earlier *Annual Reports*, we laid emphasis on the atmospherics of great research institutions and invoked the spirit of Copenhagen, Cambridge, and Capistrana. . .what was wrought there, we said, can also be wrought in Batavia, we said. The needed ingredient, the sauce in our pot roast, the bouquet in our porridge, the ambrosia in our *beouf hache*, are provided by our theoretical physicists and our astrophysics introverts. They sing herein:

The Theoretical Physics Department

Chris Quigg

During 1986, members of the Theoretical Physics Department have contributed to a broad range of problems in the theory of elementary particles, and have continued to play a central role in the intellectual life of the Laboratory. The group has grown to include eight permanent members, four associate scientists with five-year appointments, as well as eight postdoctoral fellows. Several faculty members from nearby universities make Fermilab the focus of their research, and the traditional visitors' program continues to provide hospitality and support for nearly 200 theorists each year. This brings new ideas to Fermilab, and makes the stimulating environment of the Laboratory - the experimental program and the (mostly intellectual) ferment of the third floor of Wilson Hall - available to many of our colleagues in other institutions.

The organized activities of the group include the weekly Theoretical Physics and Joint Experimental-Theoretical Seminars. Each year, members of the group devote two sessions a week during the cruelest months to a Winter Workshop, a cooperative exercise in self-education intended to make all participants literate in some topical subject. Past Winter Workshops have concerned Lattice Gauge Theories; Supersymmetry and Gravity; and Anomalies, Geometry, and Topology. The 1986 Winter Workshop dealt with Superstring Theories, bringing to Fermilab some of the String Fever that is pandemic in the theoretical world.

Research highlights in 1986 range from supercollider phenomenology to the fundamental problems in field theory. One particularly active area has been perturbative calculations in quantum chromodynamics (QCD), the gauge theory of the strong interactions. Keith Ellis and collaborators have launched an assault on the production of heavy flavors, with particular emphasis on forward production and the role of two-to-three processes. Stephen Parke and Tom Taylor, and others, have made further progress toward understanding multijet production, and have continued to hone new calculational tools.

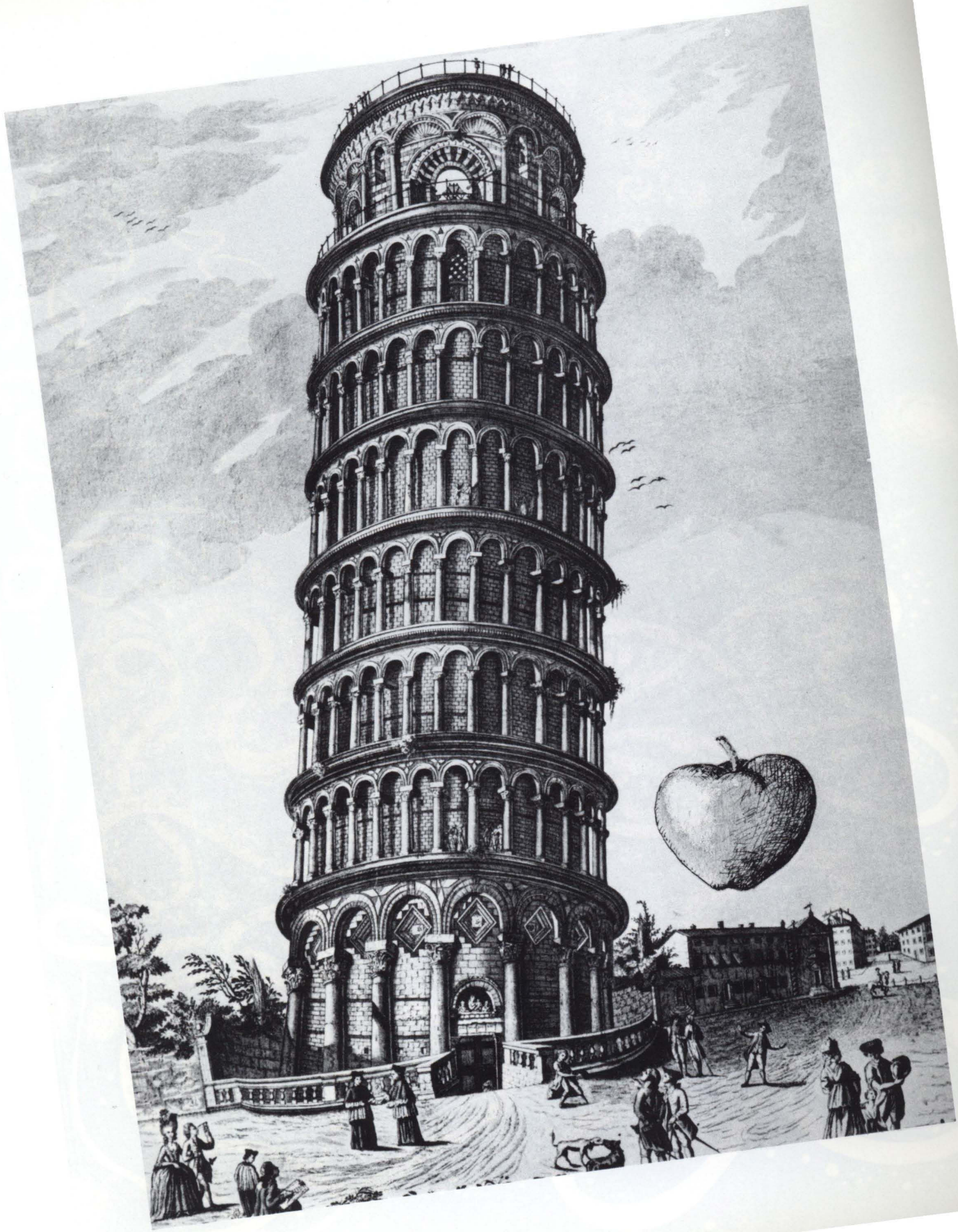
On the electroweak front, Parke and Terry Walker, a student in the Theoretical Astrophysics Group, have made an extensive study of the implications of the conjectured resonant neutrino oscillation mechanism for a variety of experiments to measure the flux of solar neutrinos.

A growing group of lattice practitioners, including Estia Eichten, Paul Mackenzie, and Hank Thacker, have martialled the varied computing resources of the Laboratory (the VAX Cluster, VAXs in the experimental areas, and the FPS-164 Array Processor) together with the MFE

Cray-XMP machine at Livermore for their numerical simulations of the nonperturbative properties of quantum field theories. The Fermilab Computing Department has provided excellent support for gracefully harnessing idle cycles of the Experimental Area VAXs. These machines are now gainfully employed at theoretical physics whenever (because of pauses in the experimental program) there are no more pressing tasks for them. Work during 1986 has addressed the phenomenological issues of the baryon potential and the scaling behavior of the QCD deconfinement temperature on asymmetric lattices. A collaboration has been initiated with the Advanced Computer Program team to understand how the ACP hardware can be made a highly efficient engine for Monte Carlo simulations of large lattices.

Among more formal efforts carried out within the group, it is appropriate to take note of Chris Hill's studies of quantum field theory in classical background gravity, including the effects of horizons. Hiroshi Itoyama, Larry McLerran, Tom Taylor, and Jochum van der Bij have studied the properties of the graviphoton, a particle whose exchanges may give rise to extremely feeble, finite range antigravitational forces, in N=2 extended supergravity.

The other subjects which have occupied the attention of Fermilab theorists are indicated by the seminar titles and list of publications included elsewhere in the Appendices to this *Annual Report*.



There are precious few of us that adore quarks and leptons and the electroweak force but all of us are awed by the heavens and drawn by their mystery. TEVATRON has a role in this too, and to teach us about this we have the Astro group:

Fermiland Astrophysics

Rocky Kolb

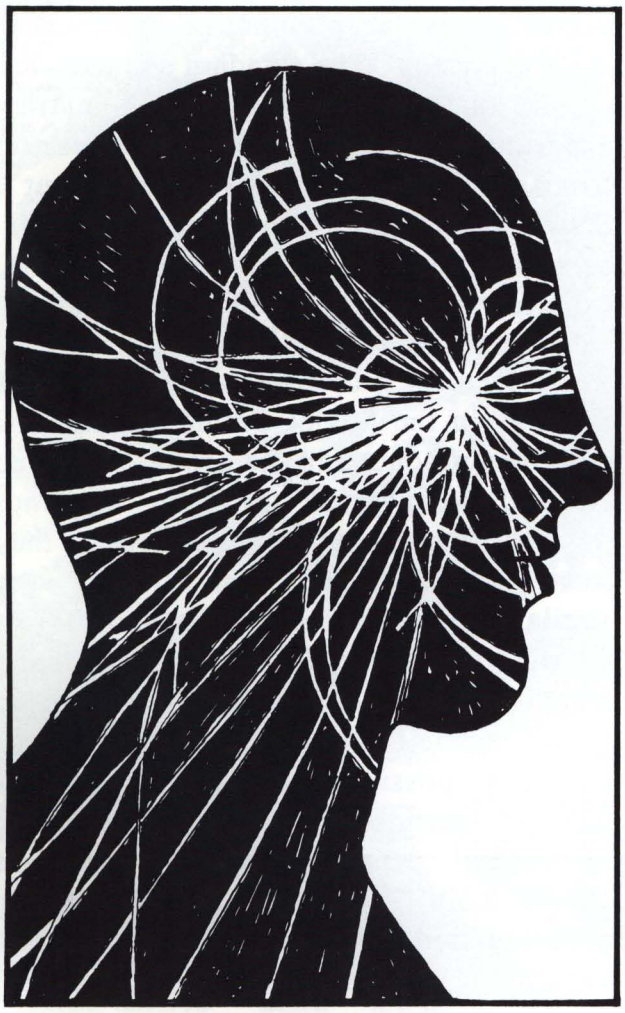
The end of 1986 marks the fourth year of the Fermiland Theoretical Astrophysics Group. The group is jointly funded by a grant from the Innovative Research Program of the National Aeronautics and Space Administration and by Fermilab. At the end of 1986 the group consists of Rocky Kolb and Michael Turner as permanent staff members, and Rich (Marshall) Holman, Jamie Stein-Schabes, Albert Stebbins, Marcelo Gleiser, and Dave Bennett as post-docs. The group also is host to many visitors in astronomy, astrophysics, and early Universe cosmology. Early in 1987, Andy Albrecht will join the group as an Associate Scientist.

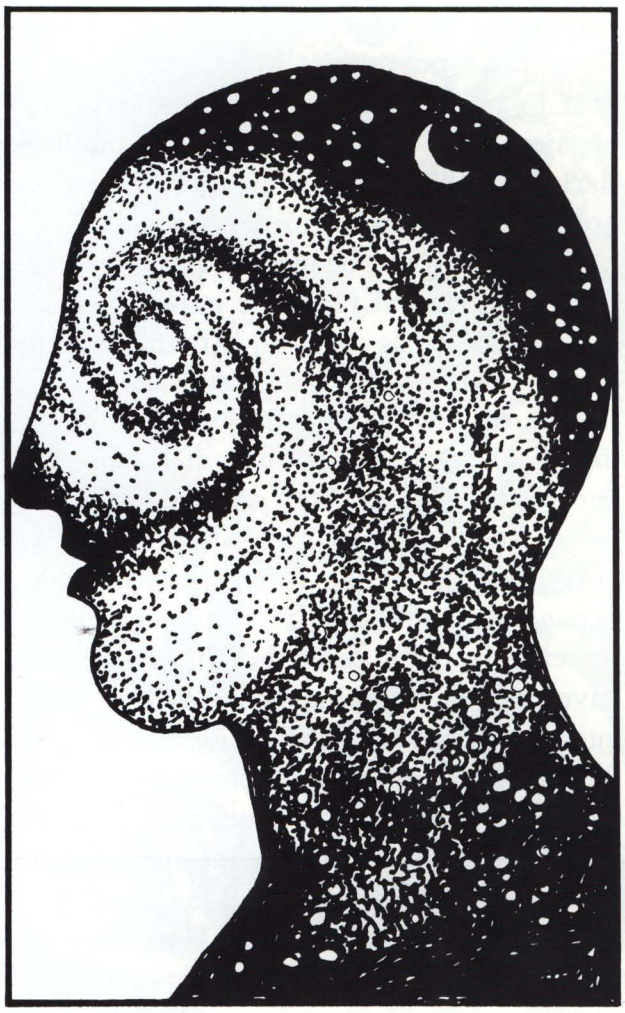
The group has been very active over the year, as apparent from the papers listed in the Publications section of this *Annual Report*. One of the most active areas of research of the group continues to be the theory of cosmic inflation. It is now well known that if the energy density of the Universe was ever dominated by vacuum energy, the size of the Universe would have expanded exponentially. This tremendous increase in the size of the Universe would have dramatic implications for the subsequent evolution of the Universe. In 1986 the Fermilab group concentrated in elucidating the conditions necessary for the Universe to enter the inflationary phase. Would every set of possible initial conditions (i.e. every possible Universe) end up going through inflation? This important question was studied in a series of papers by Turner and Larry Widrow (University of Chicago) and by Stein-Schabes and Lars Jensen (Jensen was a Fermilab post-doc - he is now at CERN). They find that a very wide class of initial models of the Universe will go through the inflationary phase, and they have developed a formalism that can be applied to study the general case.

One of the outstanding problems in astrophysics is the problem of the missing solar neutrinos. The standard solar models predict that the Homestake solar neutrino experiment should detect electron neutrinos from the sun at a level of about 7 SNU's (a SNU is a convenient unit to express the neutrino flux). Years of careful experiment have resulted in a measured solar neutrino flux of about 2 SNU's. It was recently proposed by Mikhev and Smirnov in the Soviet Union that electron neutrinos produced in the center of the sun could be converted to muon neutrinos through interactions with electrons as they travel out of the sun. The effect is very similar to neutrino oscillation, but the oscillation parameters (oscillation length and magnitude) are modified from their vacuum values by the effect of the electrons in the sun. The possibility of using the matter-induced neutrino oscillations was a subject of several papers in the Astrophysics Group. Kolb, Turner, and Terry Walker (a graduate student from Indiana studying at Fermilab) studied the values of the

neutrino masses and mixing angles that could solve the solar neutrino problem, and the effect of oscillation on the Gallium solar neutrino experiment under construction at the Gran Sasso Laboratory in Italy. Steven Parke of the Fermilab Theory Department pointed out that the probability of conversion of the electron neutrino can be analytically estimated in many cases, and used this result in a further collaboration with Walker to make a systematic study of the conversion probability.

One of the hottest topics in cosmology is Cosmic Strings. Cosmic Strings are topologically stable flux tubes of false vacuum that were produced in a phase transition associated with spontaneous symmetry breaking. Cosmic Strings are predicted to have a multitude of astrophysical and cosmological effects. The year ended with a workshop at Fermiland on Cosmic Strings. The workshop was hosted by the Fermiland Astrophysics Group and brought together just about all the world's experts in Cosmic Strings. Two of the new astro postdocs (Bennett and Stebbins) are working on Cosmic Strings, and Albrecht will strengthen our Cosmic String effort when he joins us in 1987. It is still too early to tell if Cosmic Strings will provide all (or any) of the answers, but they will be a subject of a lot of work in the Astro group for the next year. Tune in to the *1987 Annual Report* to find out if strings are the thing!





The Director's report now veers toward some (by no means all) of our socially redeeming activities. These are contiguous to our main mission of seeking for the Fundamental Laws of Nature but are morally mandated by the relative ease of applying our expertise. We begin with the medical work - something old and something new:

The Neutron Therapy Facility

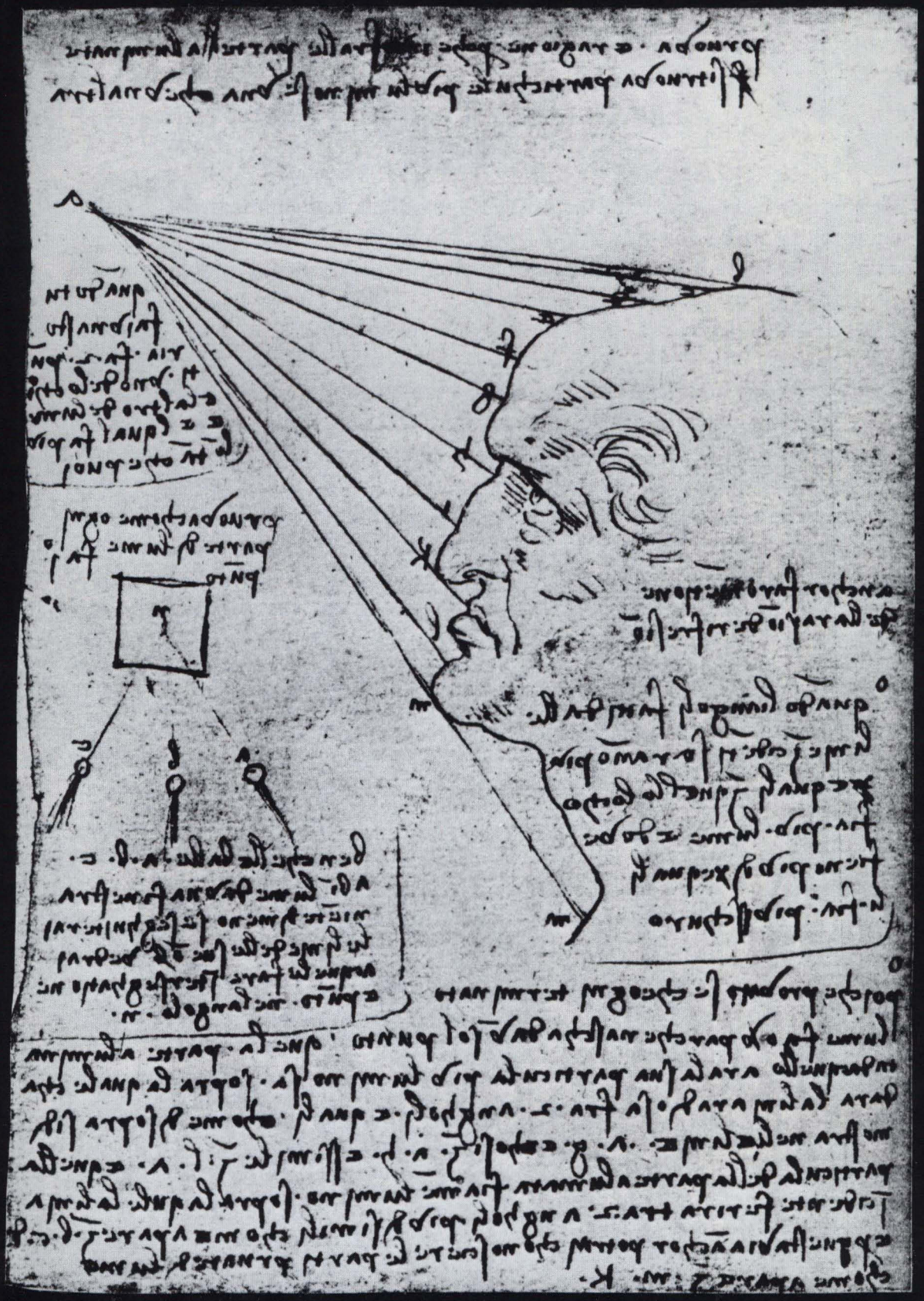
Arlene Lennox

The Neutron Therapy Facility (NTF) has successfully made the transition from operation under a grant from the National Cancer Institute to operation under a contract with the Midwest Institute for Neutron Therapy. In 1986, NTF treated over 100 patients and saw nearly 500 follow-up patients. In addition, patients who could not come for a follow-up visit were contacted by telephone. There is no charge for follow-up visits because the staff continues to be interested in the long-term effects of the treatment. Community volunteers, including members of Make Today Count and the American Cancer Society, as well as private individuals, continue to offer their services to patients who have special needs. Most of the staff have acquired additional training to compensate for the positions that were eliminated when the grant terminated. The Facility continues publishing its results in medical and medical physics journals. In September 1986, we celebrated our tenth anniversary of treating patients.

This year we also began a systematic evaluation and upgrade of the NTF controls system. The ten-year-old beamline microprocessor was replaced by a new VMEbus/68000 microprocessor system. New integrators and digitizers were installed and the hardware safety interlock system has been rebuilt. The most obvious improvement was the upgrading of the 58° dipole power supply enabling it to ramp the magnet fast enough to accommodate the requirements of the Pbar Source. All these improvements were made without interrupting our treatment schedule. Thanks to many dedicated individuals in the Accelerator Division (and especially the Linac Group) Fermilab's Neutron Therapy Facility continues to provide the most reliable neutron therapy beam in the country.

←"Electricity, the harbinger of hope for the sick. The glass ball fastened to a shaft is part of a spark generator. It is surrounded by a corona symbolizing the omnipotent electric force." 18th century engraving; the quote is translated from the original German.

Design of a Proton Therapy Synchrotron



June, 1986

The Medical Accelerator

Francis Cole

The objective of treating cancer patients with protons has been advanced greatly by Fermilab work in the last two years. A conceptual design of a proton accelerator designed specifically for therapy has been completed. Work on modelling components of the accelerator has begun. It is planned that construction of the accelerator will take place in 1987 and that it will be tested at Fermilab through 1988. The accelerator energy is chosen to be 250 MeV in order to irradiate the deepest tumors from any angle. The intensity is modest in Fermilab terms, but in such a small accelerator, the goal of irradiation of the largest possible tumor in two minutes stretches the design considerably. The accelerator is approximately 20 feet in diameter, but the beam-transport and beam-delivery systems that carry the beams to patients are considerably larger and offer difficult design problems in themselves.

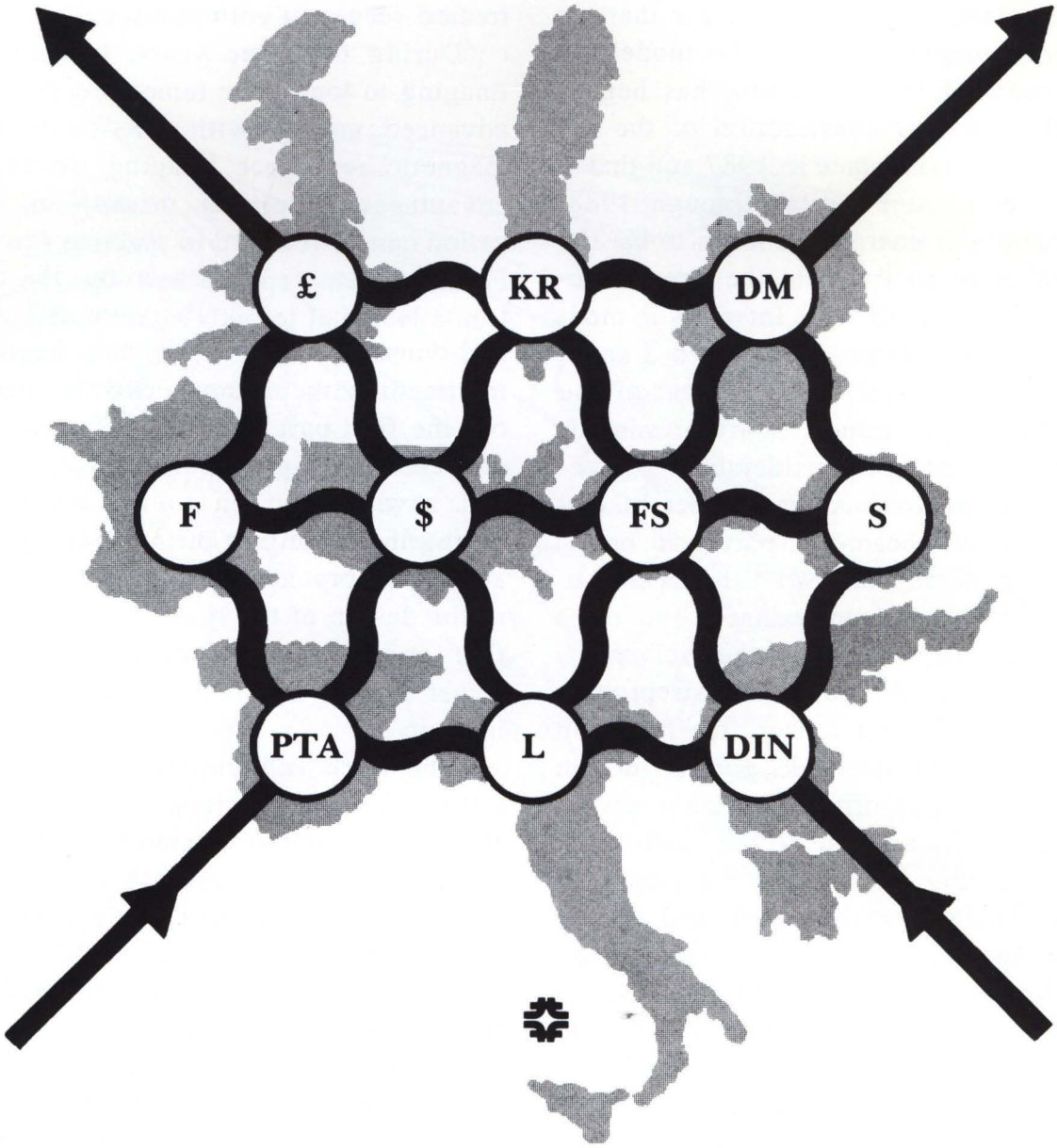
The original proposal to use protons was made by Robert Wilson, the founding director of Fermilab. He pointed out in 1946 that protons offer significant advantages in localizing dose to the tumor site, sparing healthy tissue, and reducing side effects. Since his original proposal, proton therapy has been carried out clinically on several thousand patients at Harvard, in Sweden, the U.S.S.R., Switzerland, and Japan, with good results. All the accelerators used were originally built for other purposes and have been adapted for therapy with great labor and ingenuity. The clinical work has been limited by available beam energies, but has shown that eye melanomas, brain tumors, Hodgkin's disease, and many other tumors can be treated with proton beams. In addition, non-cancerous diseases such as arterio-venal malformations and Cushing's disease can be treated very well with protons.

During the same years, techniques of imaging to locate the tumor precisely have advanced greatly with CT scanning and magnetic resonance imaging, so that the advantages of proton therapy in localization can be realized in practice. In 1985, Fermilab was approached by the Loma Linda Hospital to collaborate on the design and construction of a complete facility for treatment with protons. We have carried out the first part of the work, producing a conceptual design report in May of 1986 and have moved on to the final design during the latter part of the year. We have also collaborated with Loma Linda people in the design of the beam-delivery systems that spread the beam for treatment of larger tumors and monitor its location and intensity.

The work at Fermilab is being carried out under the provisions of the Stevenson-Wydler Act and is a model for DOE. Interest has been expressed by several other hospitals in accelerators like this one. It is not Fermilab's mission to build many accelerators in competition with private industry and we are therefore working with Loma Linda to develop industrial participants so that we can turn the work over to private industry. It is our hope that in the 1990s and beyond, some company will build many such accelerators for medical treatment all over the world.

Fermilab Industrial Affiliates Roundtable on Science, Economics and Public Policy

1986



Technology Transfer

Dick Carrigan

The Fermilab Industrial Affiliates program continues to be one of the Laboratory's most effective means for technology transfer and for relating to industry. The organization membership hovers between 35 and 40 companies. Over the years the roster of member companies has become better coupled to technology at the Laboratory. As a result there is more and more direct contact with individual Affiliates. For example, both the Advanced Computer Program and the Proton Accelerator for Medicine have involved interactions with Affiliates. We have had visiting engineers from Air Products - a large cryogenics firm interested in collaborating on advanced R&D. Our annual meeting this year had as its theme "Science, Economics, and Public Policy," an exploration of the interaction, short- and long-range, of basic research and economic competitiveness (to use a catchword). The principal address was given by Dr. George Pake, Vice President for Research of Xerox, recently retired. To some extent the meeting addressed the econometric study of the benefits of particle physics. Indeed, W. Steinmueller of Stanford University, who with David Mowery of Carnegie-Mellon University has been working on this question, was one of our panelists. Publication of that Roundtable is expected early in 1987.

The new laws and regulations vesting Fermilab patents with our parent contracting organization, the Universities Research Association (URA), will have a serious impact on technology transfer at Fermilab. On the one hand there is now a possibility of developing sound license protection for some of the inventions at the Laboratory. Many believe that this will make it easier for private industry to exploit these inventions. In principle, this could lead to a modest source of funds for both Fermilab and URA. On the other hand, Fermilab will now have to support some phases of these activities out of license revenue. Will this result in a net gain? Some of us are quite skeptical and worried about the overlay of encumbering regulations. Nevertheless we remain convinced of the importance of technology transfer from high-energy and accelerator physics, and intend to make a conscientious effort to exploit the new regulations to facilitate this transfer.

Several changes are already under way to accomplish this. The Laboratory patent survey group has been reconstituted to serve as a sounding board on commercialization. Independent counsel has been retained to help in patent matters. In the near future a new inventor reward system will be implemented, pending approval of URA. This will return a significant portion of any license royalties to individual inventors on the Laboratory staff. The policy will be in line with practices at many universities.

This year has seen a more active involvement with the State of Illinois on technology transfer activities. While this interaction is often complex it still offers the Laboratory a splendid opportunity to forge new relationships at the local level. Leon Lederman and Frank Cole serve as members of the Governor's Commission on Science and Technology. One of that commission's responsibilities is to im-

prove technology transfer in this state. Last February the Laboratory participated in an exhibition for industry with NASA and the three other federal laboratories in the state at the Museum of Science and Industry in Chicago.

The following two items have already been mentioned in this *Annual Report* but are repeated here for completeness:

The Advanced Computer Program project has been directed at developing a parallel-processor computer system utilizing large numbers of commerical microprocessors. A significant feature of the system is that it is expandable and reconfigurable. The need for technology transfer has been an important part of the program from the start. A private company, Omnibyte, is now marketing parts of the system, as noted by Tom Nash in his article on the ACP earlier in these pages. University groups are already assembling systems with these modules. The Fermilab ACP may have applications in robotics, process simulation, and animation.

The Advanced Computer Program was awarded one of the two IR-100 prizes Fermilab received in 1986. The other was given for the Video Data Acquisition System (VDAS), developed jointly with Notre Dame University and orginally designed to record and store the extremely faint and fast light signals from particle tracks in scintillators. In essence the system can take and analyze flash video pictures. During 1986, VDAS was used to take real-time video tapes of Halley's comet looking for fluctuations in the comet's tail in a period of minutes.

During 1986 Fermilab entered into an agreement to build a proton accelerator for medicine for the Loma Linda Medical Center in California. That project is now well under way with a model magnet and an ion source being constructed at Fermilab and an RFQ being designed at LBL.

This project has been structured from the start to include technology transfer and the possibility of commercialization. An important consideration for the possibility of rapid commercialization was the fact that the work is being done under a "work-for-others" agreement. This permits a private organization to rapidly exploit the technology. In addition a serious attempt is being made to find an industrial partner for the project. This has involved both discussions on a national level and with the Illinois Manufacturers Association. The State of Illinois has established a Technology Commercialization Center at the Laboratory to attempt to exploit this technology. As one part of that effort we have had discussions with some of the medical schools in the state about a second machine.

The more formal mechanisms described above often obscure the equally important technology transfer activites that go on without all the orchestration, the so-called "normal" technology transfer mechanisms. These include the ebb and flow of scientific talks and publication (it is essential not to restrict that), people from high-energy physics going to work in other areas, and the challenge to our industrial suppliers of meeting technological problems on the cutting edge. The open nature of Fermilab, the competitive character of high-energy physics, and the excellent staff and facilities all help to further these natural mechanisms.

A 16th-century mint.

Joint US — CERN School on Particle Accelerators

Topical Course On

Frontiers Of Particle Beams

October 23-29, 1986 South Padre Island, Texas

Specialized Topics in Particle Accelerators

Mathematical Physics

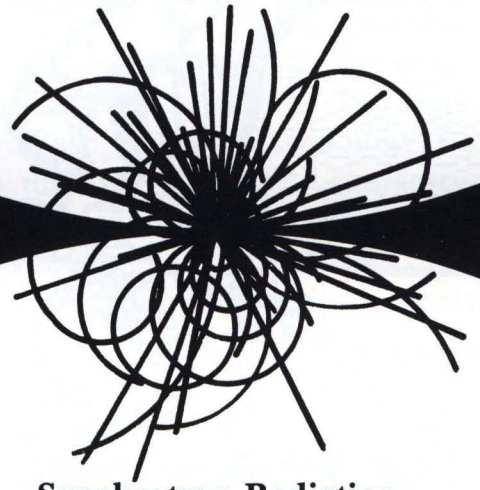
Electromagnetic Fields • Phase Space Dynamics
Multiparticle Dynamics • Beam Simulation

Linear Colliders

Optimization • Beam Damping
Beamsstrahlung and Disruption

Particle Beam Behavior

Instabilities • Intense Beams
Beam Breakup • Beam Cooling



Synchrotron Radiation

Single Particle Theory
Coherent Radiation

Acceleration Concepts

High Gradient Fields • rf Power
Acceleration Mechanisms

Seminar Series on Accelerator Perspectives and Advanced Ideas

For application forms write to:

US Particle Accelerator School
%Marilyn Paul • Fermilab • MS 125
P.O. Box 500 • Batavia, Illinois 60510

Or

CERN Accelerator School
%Suzanne von Wartburg • CERN/LEP Division
CH-1211 Geneva 23 • Switzerland

Application Deadline July 1, 1986

The School is organized jointly by the CERN Accelerator School (Director P. Bryant) and the United States Particle Accelerator School (Director M. Month), is hosted by the Texas Accelerator Center (Director F. R. Huson), and receives support from the United States Department of Energy and the National Science Foundation.

The US Particle Accelerator School

Mel Month
(Brookhaven National Laboratory)

The US Particle Accelerator School began operation in 1981 following a recommendation made by a subpanel of the High Energy Physics Advisory Panel that convened in 1979-1980 to study the state of accelerator R&D. With the school changing its location from year to year, a central school office was established at Fermilab in 1984.

In 1986, the school organization was strengthened with the introduction of a Steering Committee chaired by Burton Richter, Director of SLAC, and includes as members Marty Blume, Deputy Director of BNL; Helen Edwards, Head of the Fermilab Accelerator Division; Hermann Grunder, Director of the Continuous Electron Beam Accelerator Facility; and Boyce McDaniel, former Director of Cornell University's Laboratory for Nuclear Studies.

The school program in 1986 was highlighted by the following:

- The 2nd Joint US-CERN Topical Course on Particle Accelerators, "Frontiers of Particle Beams," was held at South Padre Island, Texas, in late October. The first such international collaboration between the US Particle Accelerator School and the CERN Accelerator School took place in Sardinia in early February 1985 on the subject, "Nonlinear Dynamics." The third joint school will be held in Europe in 1988.
- The combined text for the 1984 and 1985 summer schools was completed, and includes 36 articles in a 2-volume, 1800-page edition with subjects ranging from magnets, rf, and ground motion, to basic accelerator theory and nonlinear behavior.
- The 1986 Prizes for Achievement in Accelerator Physics and Technology were awarded to Thomas Weiland of DESY "for the development of novel methods for calculating electromagnetic fields in complex structures," and to Helmut Piel of the University of Wuppertal and Maury Tigner of URA/SSC "for their contributions to making rf superconductivity a practical reality."
- Plans were initiated for a four-week school in association with the University of Chicago to be held at Fermilab July 20-August 14, 1987, with the first two weeks devoted to three university-style (25 hours of lecture) courses each carrying three credits (transferable) from the University of Chicago.
- Work continued on the American Physical Society Topical Group on Particle Beam Physics, and concentrated on finding ways to enhance scholarly publication in accelerator physics. To this end, an agreement was reached with *Physical Review* to set aside a part of *Physical Review D* for accelerator physics and to establish an Editorial Committee on Accelerator Physics to help in the allocation and refereeing of papers.

The student population for the annual two-week school has more than doubled from its initial attendance of 120 in 1981. This very large growth in demand reflects a deep interest in the use of particle beams and is undoubtedly related to the continued expansion of accelerator use in accelerator-based sciences as well as in industry, medicine, and defense.

There are so many other things that could be listed. Our Ph.D. program for accelerator physicists (in collusion with the degree-granting universities) is thriving. Our multitude of pre-college educational activities, which stars Saturday Morning Physics and the projects of Friends of Fermilab Association, continue to expand, impact positively upon our locality, and, most important, be widely copied around the country. Fermilab staffers have been most prominent in carrying the message of our subject to the public and to science groups far and wide. The rationale for the SSC is one of our favorite themes even though our 1986 15-Year Plan details the specific dilemmas that SSC will bring to the TEVATRON program. Consistent with our policy of varying the emphasis of these *Annual Reports*, we give short shrift to these and many other activities and proceed to the signed articles which emphasize, on the one hand, the future of our Collider and, on the other, the status of the fixed-target physics.

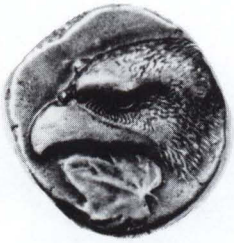
In our penultimate paragraph for 1986, what can we say about our subject? We have, on the one hand, our theorists, in a collective state of euphoria about Superstrings, but the symmetry is quickly broken and we hear the shards: Supersymmetry, Technicolor, Constituents, the Higgs Enigma . . . and we are reminded (by a contemporary) of a remark by Edward Gibbon in *The Decline and Fall of the Roman Empire*:

> "The various modes of worship which prevailed in the Roman world were all considered by the people as equally true, by the philosophers as equally false, and by the magistrates as equally useful."

The quality of metaphor is strained!

Leon M Lederman

Goldwasser Grove.



II. Recent Physics Results from the TEVATRON

The ultimate product of any laboratory engaged in basic research is not a product that you can see and count, rather it is a deeper understanding of our Universe and perhaps of the Universe next door. At Fermilab, output is measured by the number and quality of physics results produced. Some of the by-products manifest themselves first as new experimental techniques. By these measures the 1985 fixed-target run (the second run of the TEVATRON era) was an enormous success. Thirteen major experiments were in the data-taking mode when the run ended in August 1985. Of the 13, four completed their data taking during the successful eight-month run and all four have produced physics results during the past year. The other nine experiments plan to continue their data taking in the next fixed-target run which is scheduled for the spring of 1987. (For a complete listing of approved Fermilab fixed-target and Collider experiments see Appendix C.) Some of them have also produced, or are in the process of producing, preliminary results. This article will concentrate on the early results of the four experiments that completed their data taking during the 1985 run and highlight some of the results that are expected to come from the other experiments that took data during the run. In addition, several other groups have published results from previous runs during the year. Some of these results will also be discussed.

E-691

Some of the most spectacular results to come from the TEVATRON were produced by E-691 using the tagged-photon beam in the Proton Area. This was the second experiment to use the Tagged Photon Spectrometer (TPS), the first being E-516. It is clear from the preliminary E-691 results that the detector has matured to the point of routinely producing good physics.

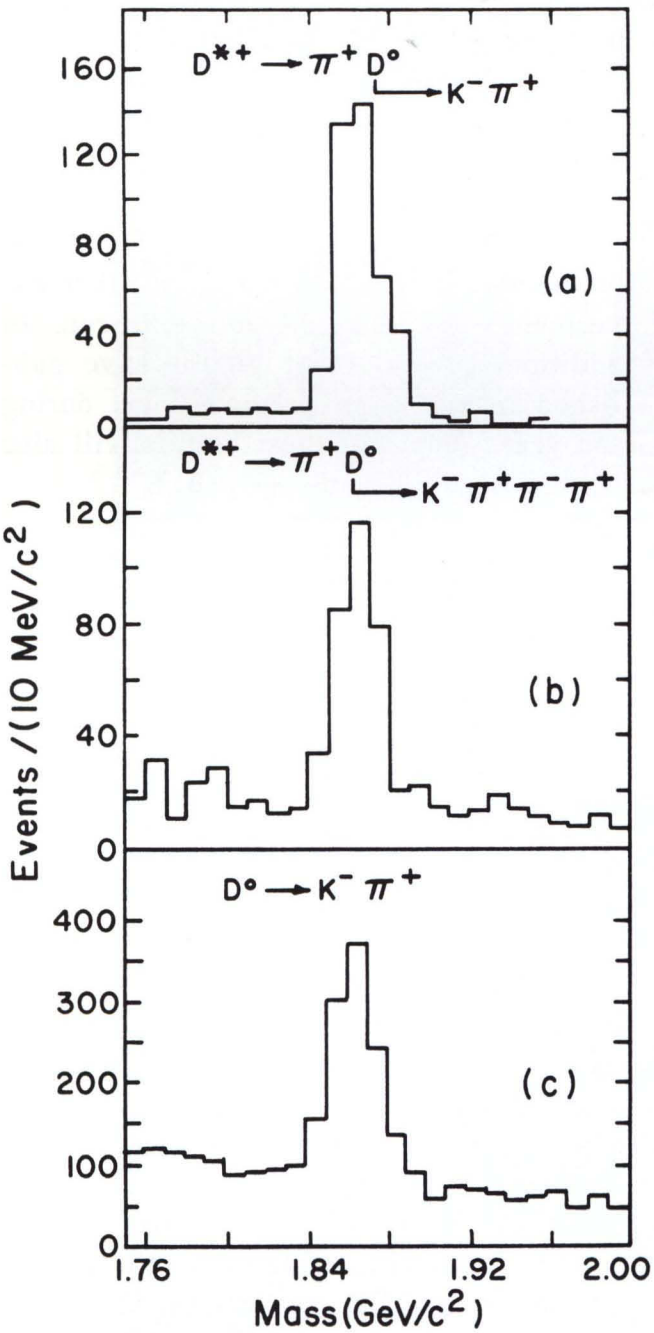


Figure 1. Three independent D^0 samples from E-691.

The experiment was designed as a high-statistics study of charmed particles produced by a photon beam. The beam energy averaged 125 GeV and ranged from 100 GeV to 260 GeV. It is a two-magnet spectrometer with large acceptance, drift chambers, Cerenkov counters, and electromagnetic and hadronic calorimetry. The detector was modified for the E-691 run primarily through the addition of nine silicon micro-strip detectors (SMD). Additional improvements were made to the Cerenkov counters and tracking system. The SMD provides enough precision to identify approximately one half of the secondary charm vertices. Data taking was triggered by a large transverse energy (>2.5 GeV) signal in the calorimetry. This trigger was 80% efficient for charm events and suppressed hadronic production by a factor of 2.5. A total of one hundred million triggers were recorded, 10% without the large transverse energy requirement. Cuts on SMD information were applied in the off-line analysis and resulted in up to a factor of 300 in background reduction. As testament to the success of the technique, Fig. 1 shows clear D* and D mass peaks for 30% of the data. There is little background under the signals, and the statistics are impressive. Lifetimes are accurately and easily determined from the data. Figure 2 shows the E-691 lifetime results along with results from many other experiments for the D's. The E-691 result, with only 25% of the data analyzed, has error bars comparable to the world average value and is superior to any other single experiment.

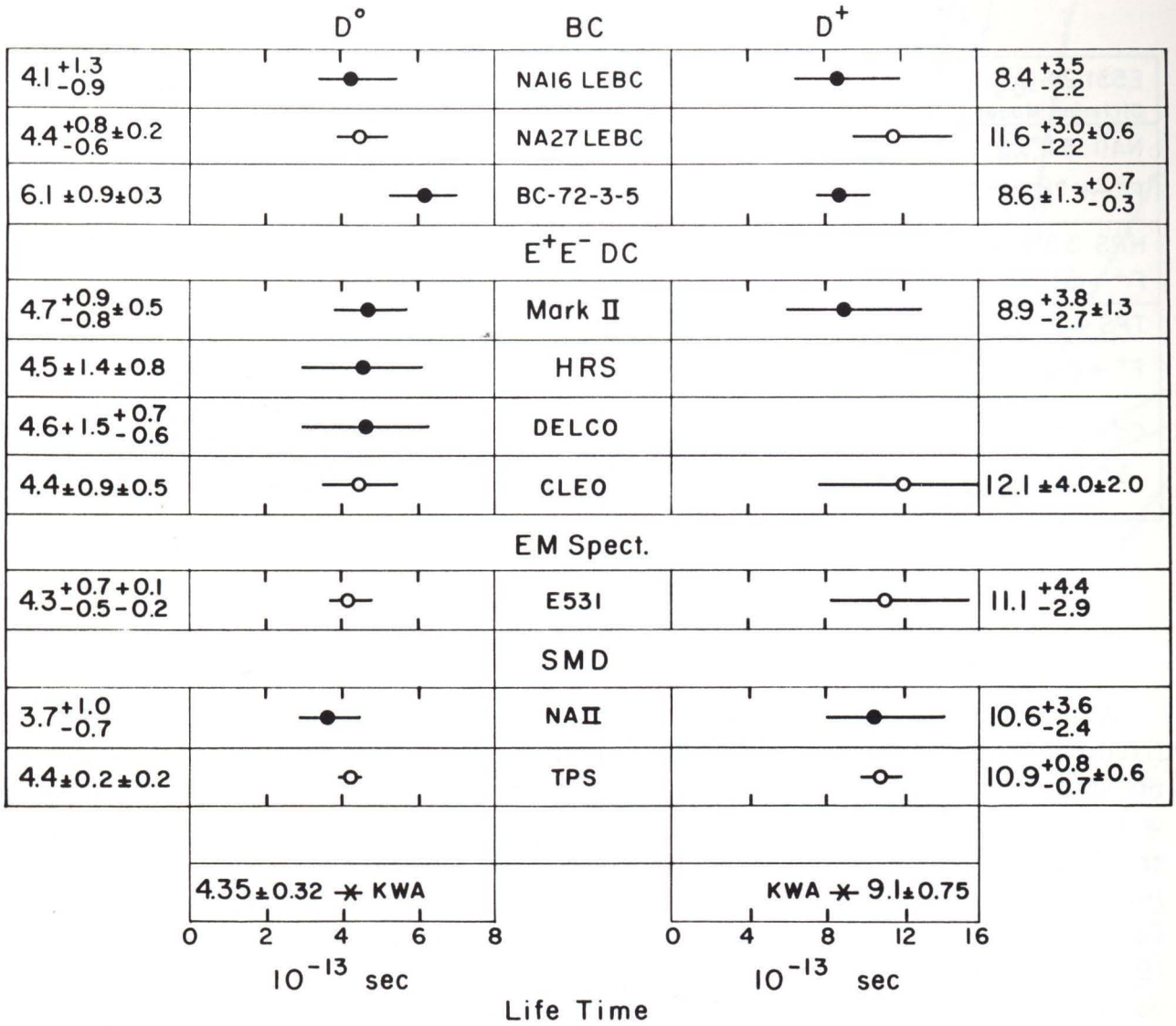
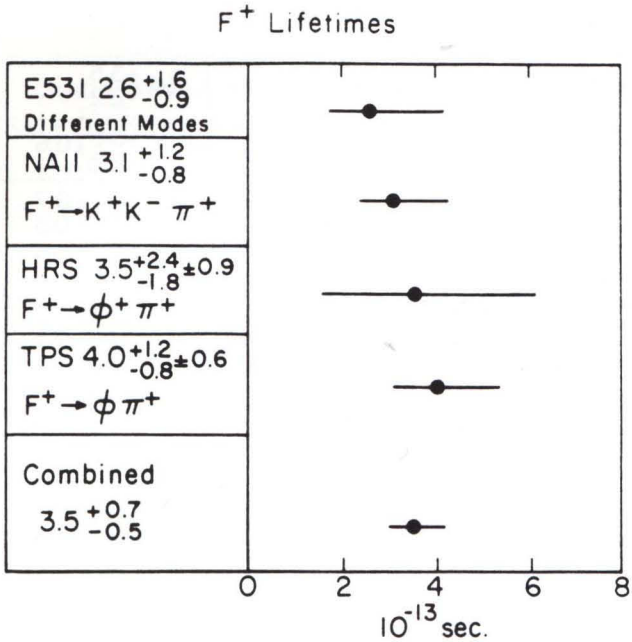


Figure 2. Summary of D^0 and D^+ lifetimes.

Similar results with 30% of the data have been obtained for $F^+ \rightarrow \Phi\pi$ and $F^+ \rightarrow K^*K$. Figure 3 shows the preliminary F lifetime as determined by E-691. The result is in good agreement with the existing world data and provides a substantial improvement in accuracy.

In addition to refinements of the results discussed above, a wealth of other physics is expected to come out of the experiment. The number of charmed particles expected in the full sample is overwhelming. For example, a total of some 8000 neutral D's are expected along with about 125 F's. A good number of charmed baryons should also be present in the data. Analysis has just begun to explore the possibilities of the large statistics available. A preview of some of the anticipated results includes production studies which will allow comparison with QCD predictions, studies of charmed baryon production and decays, neutral D mixing, and the study of semileptonic D decays. In addition, one might



expect a detailed study of Cabbibo suppressed decays of the D's and perhaps the observation of a few Bottom events. Another result that has come out of the experiment is the measurement of the A-dependence of J/Ψ production. These results are expected to be published soon.

←*Figure 3. Summary of F^+ lifetimes.*

E-743

A second experiment from the 1985 fixed-target run to produce an impact in the study of charmed particles was E-743 which measured the total charm production cross section in a high-resolution Lexan Bubble Chamber (LEBC) using the Fermilab Multiparticle Spectrometer (FMPS) for momentum determination and particle identification. The goal of the experiment was to tie the lower energy ($\sqrt{s}$ = 27 GeV) SPS measurements of the charm cross section, which had used LEBC in conjunction with the CERN EHS spectrometer, to the relatively high energy ISR results ($\sqrt{s}$ = 50 to 60 GeV). The ISR results had indicated that the charm cross section increases by something like a factor of 10 over the lower energy points. This large increase was not predicted by QCD theory, therefore it was of much interest to get another data point in between the two previous measurements.

The experiment was done at Fermilab using 800-GeV primary protons incident on the hydrogen filled bubble chamber, giving a $\sqrt{s}$ value of 39 GeV. The bubble chamber technique has the advantage that it uses a hydrogen target and avoids the complications of measuring cross sections using heavy targets and attempting to extrapolate the results to hydrogen. Another advantage is that the bubble chamber/spectrometer combination has a large acceptance. The bubble chamber has a 20-micron bubble size with 2-micron spatial resolution. This yields a vertex resolution of about 7 microns which means that the secondary vertices from charm decays are easily resolved. All of these factors conspire to give a small correction factor, and hence a highly reliable charm cross section.

Normal picture taking was instigated by an interaction trigger which required a beam particle and three or more charged particles downstream of the bubble chamber. In addition, 80,000 pictures were taken with a beam trigger which only required that 12 to 20 good beam particles enter the

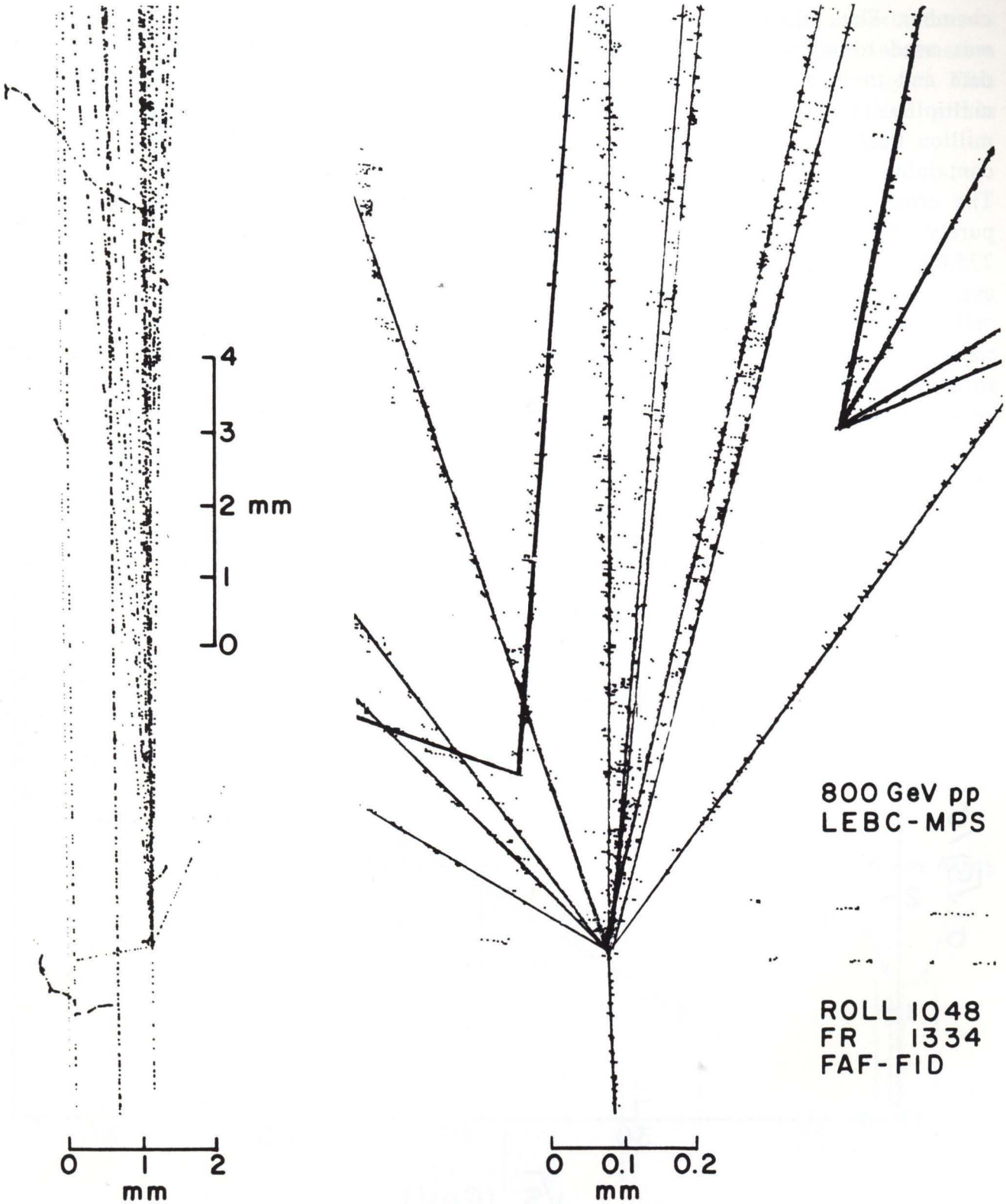


Figure 4. LEBC event showing a V2 and a V4. The picture on the left is from the bubble chamber film. The picture on the right has a factor of 10 expansion in the horizontal plane.

chamber. Data taken with the beam trigger was used to normalize the cross section data and to measure the charged particle multiplicities. The two triggers yielded 1.2 million bubble chamber pictures, 500,000 containing interactions in the hydrogen. The cross sections published so far are purely topological based on the analysis of 275,000 pictures; i.e., they do not make use of spectrometer information. The result is based only on secondary decays where a single charged particle is observed to decay into three charged tracks (C3's) and neutral decays into four charged tracks (V4's). This sample should contain most of the charm events. Figure 4 is an event containing a V2 and a V4.

The data sample contains 21 C3's and 4 V4's after all cuts have been made. These events yield a total cross section of $59 \pm \frac{22}{15}$ microbarns for all Feynman X. The comparable result obtained at CERN for $\sqrt{s}$ = 27 GeV is 34.4 ± 4.2 microbarns. This yields a ratio between the cross sections of 1.7 which agrees quite well with gluon fusion model predictions. The result is shown graphically in Fig. 5. The shaded region in the figure represents the bounds of the gluon fusion model predictions which depend on the quark mass used, the production threshold, and the scale parameter Λ. The data has been normalized to the $\sqrt{s}$ = 27 GeV point.

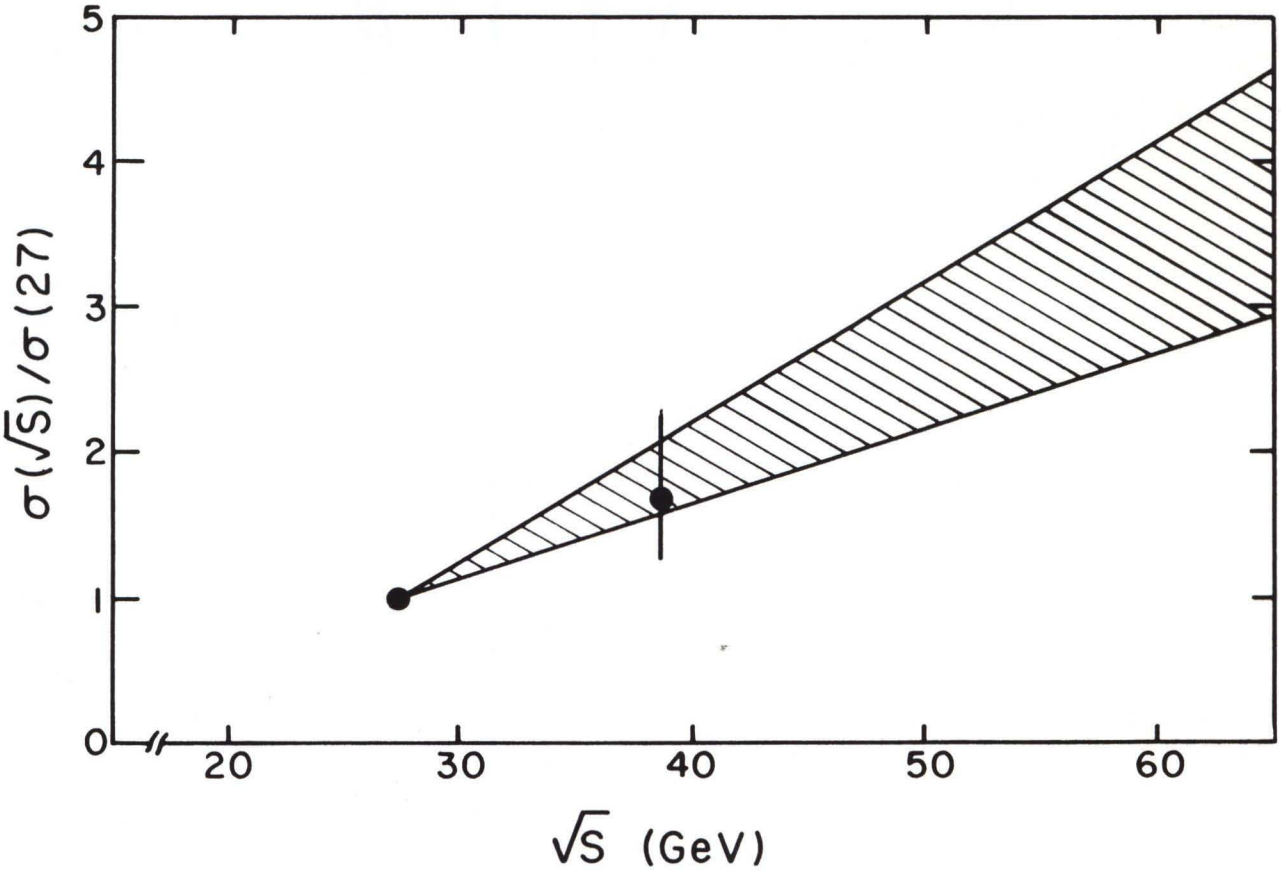


Figure 5. Charm cross section measured in E-743 at $\sqrt{s}$ = 38 GeV normalized to cross section measured at CERN in the LEBC at $\sqrt{s}$ = 27 GeV. The shaded region encompasses the bounds of the gluon fusion model predictions for the cross section.

LEBC has also produced multiplicity distributions for 800 GeV pp interactions. The future promise of E-743 lies in a more accurate cross section determination as the statistics improve and a comparison of the production and decay of the various charm states as the spectrometer information is combined with the topological information from the bubble chamber pictures. This work is expected to be completed within the next year.

E-621

Another experiment to produce new results during the past year is E-621. The experiment had its initial run in 1984 and completed data taking in 1985. It was designed to measure the CP violating parameter η_{+-0} which is the ratio of amplitudes for K short decaying to π^+, π^-, π^0 to K long decaying to three pions. Previous measurements indicated that the ratio was something less than .35 and were based on a sample of some 500 decays. E-621 set out to measure the ratio to an accuracy of .003. To achieve this goal a total of 3.2 million decays were accumulated. The results presented this year only make use of 101,000 events.

The experiment was carried out using the PC beamline of the Proton Area. Figure 6 shows a layout of the apparatus. To measure η_{+-0}, the time dependence of the interference between the K long and K short decays was measured. To accomplish this, two beams were directed at the detector, each with two targets. One of the targets in each beamline was 24 meters upstream of the other. This allowed the acceptance for the K long decays to be accurately measured, and the two beams allowed for an accurate elimination of systematic effects. Both of the beams were run simultaneously, each with only one of the targets in place. Running in

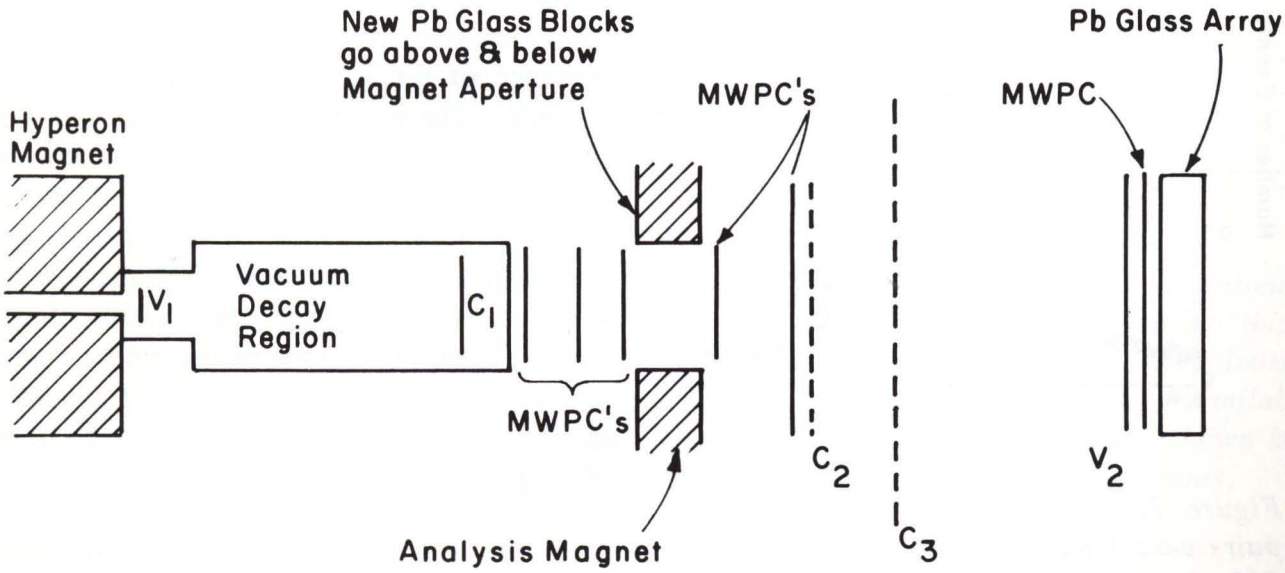


Figure 6. Layout of the E-621 detector.

each beam was alternated between the upstream and downstream targets. The decay products of the kaons were observed in the magnetic spectrometer downstream of the hyperon magnet. Neutral pions were reconstructed using the lead-glass calorimeter at the downstream end of the spectrometer. The invariant mass of the 2-track plus π^0 events was calculated and those events falling into the kaon mass peak were used in the analysis.

The result, based on 101,000 events, is that η_{+-0} is .04 ±.03. This is based on 1/30 of the data. Much better accuracy will be achieved when the complete data sample is used in the analysis. The experiment also measures the phase of η_{+-0} and finds it to be 20 degrees ±90 degrees.

E-605

The final experiment to be discussed that completed data taking during the 1985 run is E-605. The experiment was designed to study large transverse momentum production of di-hadrons, di-electrons, and di-muons. The detector consisted of a large two-magnet spectrometer, a Ring Imaging Cerenkov Counter, hadronic and electromagnetic calorimetry, and muon detection. A high-intensity primary proton beam was incident on the nuclear target and subsequently dumped in the first long spectrometer magnet. During the 1985 run a lead wall was added just downstream of the first magnet to filter out soft photons produced in the target and the dump, and data taking concentrated on di-muons. Addition of the lead wall made it possible for the experiment to take up to 5 E12 protons per pulse while not significantly affecting the high resolution of the spectrometer.

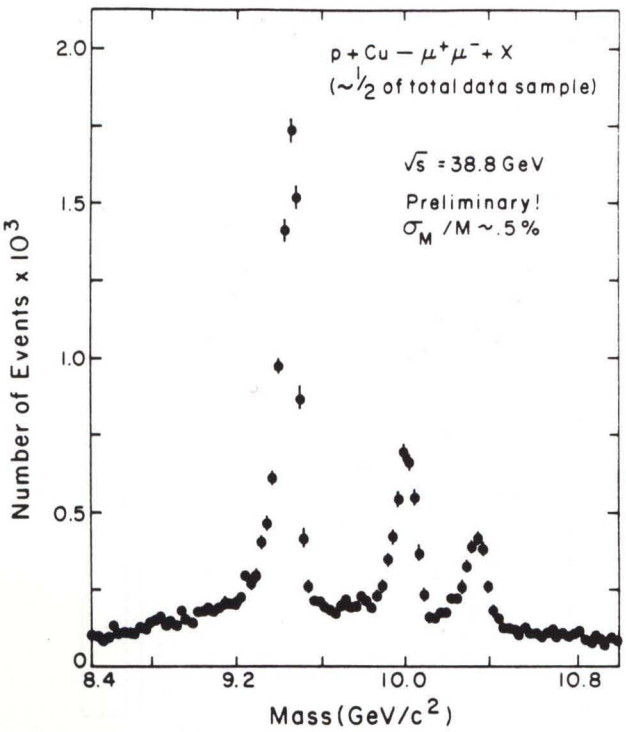


Figure 7. Yield of opposite-sign muon pairs versus mass in the upsilon region at 800 GeV off Cu for 1/2 of the closed aperture data.

Figure 7 shows the di-muon mass distribution in the vicinity of the upsilon. The order of 20K upsilons were accumulated with a mass resolution of .25% and an acceptance of the order of 1% optimized at 10 GeV. The region in mass from about 8 GeV to 15 GeV was searched for resonances. Figure 8 shows the 95% confidence level limits established by E-605 for the various types of di-muon resonances that might be imagined to lie in this mass range. The Drell-Yan production of the di-muon continuum is also being investigated. The results will be used to test QCD predictions of the standard model. Results are also expected from earlier runs in which di-hadrons and di-electrons at high transverse momentum were accumu-

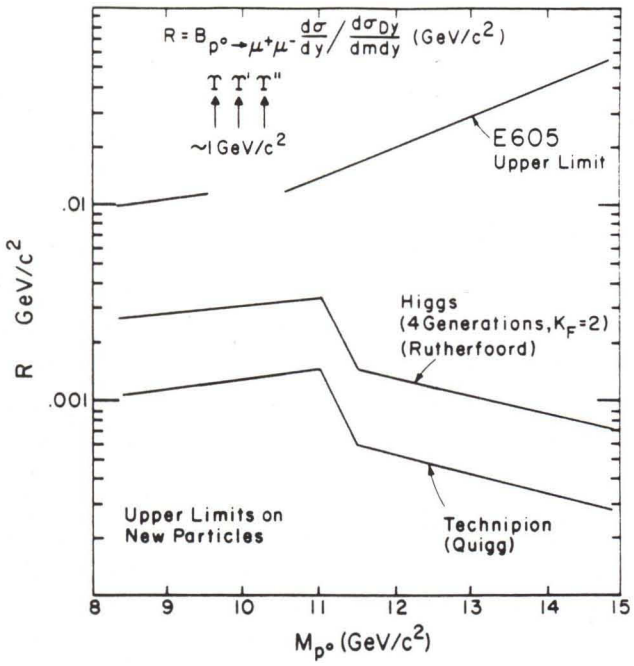


Figure 8. Ninety-five per cent confidence level upper limit versus mass for dimuon resonance production cross section times branching ratio normalized to the Drell-Yan cross section, and compared to predicted cross sections for the Higgs and Technipion.

lated. The experiment also measures the A-dependence of di-particle production; results from an early 400-GeV run have recently been published.

An unexpected spin-off from the experiment was a new limit set on axion production in 800-GeV hadronic showers. Possible observation of a particle in heavy ion collisions coupling to e^+e^- with a mass of 1.8 MeV had been reported by a Darmstadt group. The detector was used to search for a weakly interacting particle which couples to e^+e^-. To look for a signal, electron pairs coming from the downstream end of the beam dump were investigated. Observation of such pairs could result from the decay of the weakly interacting neutral axion. In fact, many muon pairs and 74 electron pairs were observed to emerge from the dump. The electrons were consistent with zero mass pair production in the last radiation length of the dump. The trigger required an energy deposition of greater than 150 GeV in the electromagnetic calorimeter.

Figure 9 shows the 90% confidence level limit established by E-605 along with the limits established by several other experiments for the existence of such a particle. The plot is for 4 E13 proton incident on the dump. Of major interest is the fact that a 1.8-MeV particle coupling to e^+e^- is completely ruled out on the plot.

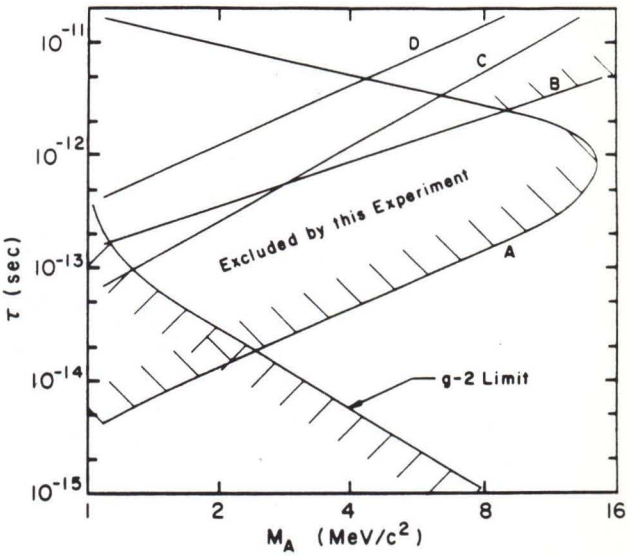


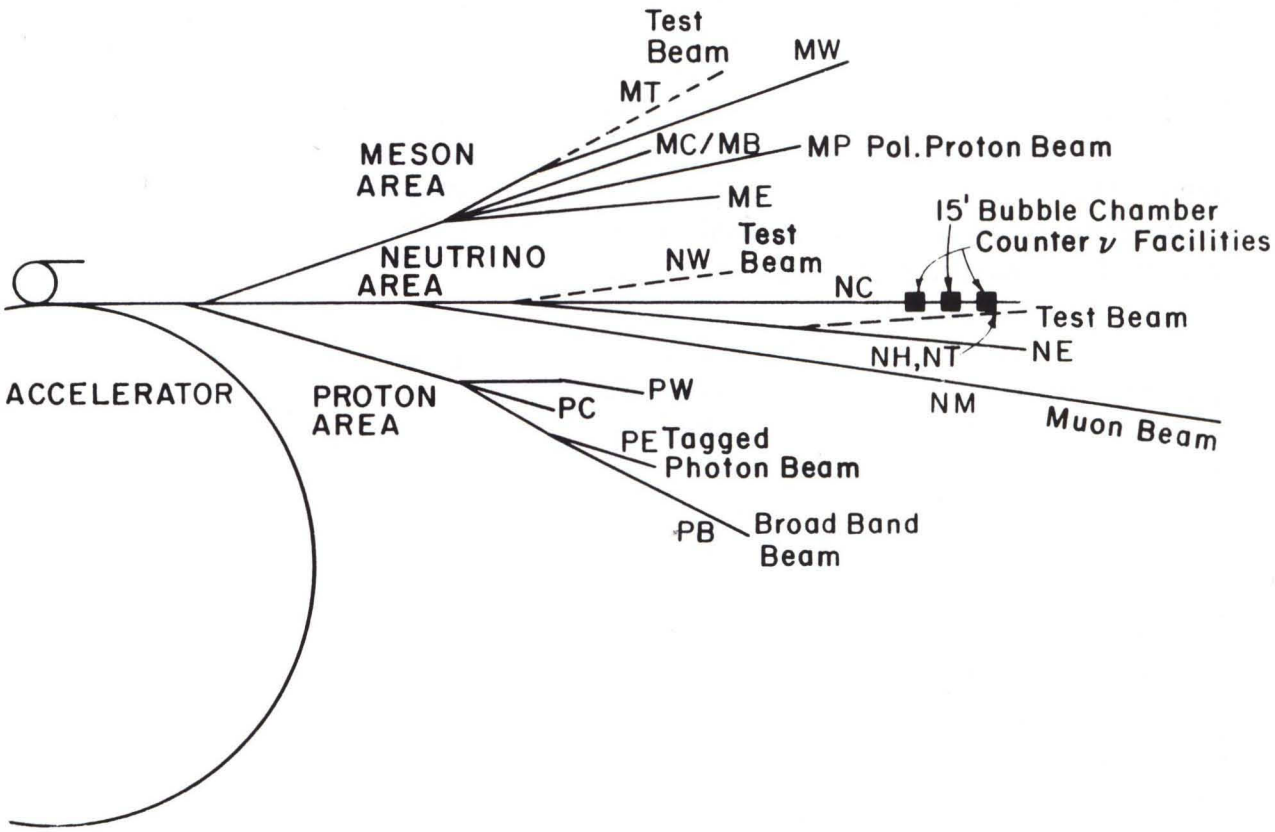
Figure 9. Limits on the mass and lifetime of an axion-like particle from a) this experiment, and previously published limits from b) KEK, Konaka et al., c) Fermilab E-613, and d) SLAC E-56. Also shown is the lower limit from g-2 measurements.

Other Results

Many other experiments took data during the 1985 fixed-target run and several of them are close to producing preliminary physics results which are eagerly awaited by the high-energy physics community. In this class are the results from the two large neutrino detectors in Lab C and Lab E. They both took data during the 1985 run of the wide-band neutrino beam and both are expected to make a contribution to our understanding of same sign di-muon events. The result will either be consistent with the well-understood backgrounds or will be evidence for some other process that has yet to be directly observed.

Also in the class of eagerly anticipated results is the measurement of CP violating parameter ε' by E-731. Indications from the earlier ε' experiments are that ε' is very close to 0. However, more accuracy is needed to further constrain the various theoretical models. Towards this end, 43,000 K long to 2-π events were collected in the 1985 run. These data should give a result that has twice the statistical precision of a previous Fermilab experiment, E-617, which had made the most accurate determination of ε' to date. E-731 hopes to collect 150,000 K long to 2-π decays which will severely test the superweak theory which predicts an ε' value of 0.

A significant result that was published this year came from the first run of the TEVATRON in 1983 and 1984. It came



Layout of Fermilab fixed-target beams; all will be in operation during 1987.

from E-715, which was done in the Proton Area. The experiment measured the asymmetry of $\Sigma^-\beta$ decay. Before the experiment was performed, only a handful of $\Sigma^-\beta$ decay events had been observed in the world. Early indications were that the theory was having trouble predicting the decay asymmetry properly. E-715 collected 80,000 such events and established once and for all that the theory is correct.

Another experiment that ran in the first year of the TEVATRON is also publishing new results this year. It is E-615 which was also run in the Proton Area. This experiment studied the production of massive muon pairs in the forward direction with a closed-geometry spectrometer.

A number of other experiments also took data during the 1985 run and are expected to have significant results in the future. They are all continuing to run during the next fixed-target run. Included in this group is E-653, which is studying heavy quark production; E-711, which is studying constituent scattering; E-632 and E-745, which are looking at neutrino interactions in the 15-ft and 1-m bubble chambers respectively; and E-705, which is a high-resolution study of χ-state production in the Proton Area. In addition to the many experiments that are continuing their data taking into the next run, there are a number of large new experiments that will come on-line. They are discussed elsewhere in this *Annual Report*.

All in all, the last fixed-target run of the TEVATRON was a smashing success. The high energy of the TEVATRON provides a significant advantage in event rates over the lower energy fixed-target machines. These advantages and others are illustrated in Table I which summarizes total event rates for several recent experiments. Results are just beginning to be

Table I.

Experiment	Previous Data	This Experiment
E-605	<10K events in the Υ region (E-288)	~50K events at 10 times better resolution
E-621	1223 events, all previous experiments	3×10^6 total for this experiment
E-691	<1000 D's from all sources suitable for lifetime determinations	~10K very clean D's expected from this experiment
E-715	352 total $\Sigma^-\beta$ decay events	80K events
E-731	24K events from two previous experiments	150K $K_L\rightarrow2\pi$ total expected for E-731

published and have already impacted on the thinking of the high-energy physics community. Not only have we accumulated exciting new data, but experimental techniques such as the use of silicon micro-strip detectors came of age during the run. In addition, new frontiers in computing are being explored as the Laboratory's Advanced Computer Program system comes into use as a data analysis tool for many of the experiments that took data during 1985. Future experiments will depend more and more on these new developments. The success of 1985 yields much promise for future fixed-target runs.

Roger L. Dixon

U M

III. The Accelerator Upgrade Program

In order to maintain a vital long-range colliding-beams physics program, it is necessary that the luminosity increase significantly each running period so that effectively higher energy constituent collisions can be explored. A rule of thumb adopted by the experimental physicists is that with each yearly run the cumulative integrated luminosity should double in order that new physics can be effectively explored. It seems probable that the Fermilab Collider luminosity will reach saturation in 1990-1991. A substantial upgrade should be undertaken for completion by 1992. Intermediate steps, such as the low-β quad design and a Linac energy upgrade, should benefit Collider and fixed-target physics on a shorter time scale.

Thus, it is appropriate at this time to consider what potential luminosity improvements beyond the TeV I design are possible and to begin design study and R&D toward that goal. It is, of course, symptomatic of the optimism, arrogance, and downright greed of high-energy and accelerator physicists that we should be contemplating an upgrade at this time, even as we are trying to get first $p\bar{p}$ collisions after a one-year shutdown. But after all, we only need a factor of a million increase in luminosity from last year's commissioning run to reach the TeV I design specification. So on that scale of things, what is a factor of 50 more, which is the goal of the Upgrade?

The Upgrade Program presently under evaluation has three goals:

a) Luminosity to 5×10^{31} cm^{-2} sec^{-1}.
b) Pbar production rates to 4×10^{11} pbar/hr.
c) Intensity increase for fixed-target operation.

All areas of the Accelerator are impacted and work has begun in some areas like the 8-GeV line, and Main Ring Z/n modifications. The Injector and Main Ring are being analyzed to determine an appropriate emittance improvement program. The Pbar Source is being evaluated to determine the optimum plan for increased pbar production, and the feasibility of many-bunch operation in the TEVATRON is being evaluated in order to reach the luminosity goal.

6 factors of 2 is a factor of 50 increase in luminosity over the TeV I design with a little to spare. So let us consider where they might be available.

The luminosity is proportional to the number of bunches of each beam, B, and the number of particles of each type, p or pbar, in a bunch, $N_{p,\bar{p}}$. It is inversely proportional to the beam transverse normalized emittance, ε_N (assumed here the same for protons and pbars), and to the interaction point amplitude function β^*.

$$\mathcal{L} \propto \frac{BN_{\bar{p}}}{\beta^*} \frac{N_p}{\varepsilon_N}$$

Other factors enter in if you are going to consider changing the ring radius. We are not planning to do this. So this is pretty simple - there are not many choices to consider. $BN_{\bar{p}}$ is the total number of pbars in a store, and must be equal to the number produced over the average store duration

$$BN_{\bar{p}} = R_{\bar{p}}\, Ts$$

where $R_{\bar{p}}$ is the rate accumulated per hour and T_s is the store duration. The TeV I design calls for a rate of $R_{\bar{p}} = 10^{11}$/hr. With three bunches of 6×10^{10}/bunch, it should take about two hours to make

enough pbars. A store could be replenished that often.

So $BN_{\bar{p}}$ can be increased by increasing $R_{\bar{p}}$, the production rate, to T_s, the store time. The trouble with increasing the T_s is that the beam quality (emittance) and intensity degrade with time so that the average luminosity ends up considerably below the peak obtained at the beginning of a store. Longer store times also require higher reliability of the Storage Ring operation. Because of the limited production rate and the emittance deterioration with storage time, it is very appealing to consider some way of saving and recooling antiprotons at the end of a store instead of throwing them away in the beam abort.

The total luminosity is independent of the number of bunches, B, in a pbar-p ring as long as the pbar production budget is the limiting factor. B can be selected at the convenience of the experimenter (event probability per crossing ≤ 1) and the accelerator designer (total head-on beam-beam tune shift ≤ 0.02; $\Delta\nu_{\bar{p}, p}$ per crossing $\propto N_{p, \bar{p}}/\varepsilon_N$). Since both the beam-beam tune shift and the depletion of the beam through collisions scales with the number of collision points, it is important to minimize the total number of these points not used by experiments. Thus, for any but a small number of bunches it is desirable to separate the proton and antiproton beams so that they snake around one another throughout most of the magnet ring and collide only where necessary at and adjacent to the detector locations. This beam separation can be provided by electrostatic deflectors or "separators."

As long as the total head-on beam-beam tune shift for either beam is below the tolerable threshold, it is desirable to maximize N_p/ε_N. Note that there is no proton economy issue, the total number of protons are free, so the goal is to get into single bunches as dense a population as possible. Operationally N/ε_N does saturate, beam tune spreads increase, and instability thresholds become lower as this ratio is increased.

The only other parameter is the interaction point amplitude function β^*. This can be made smaller by using stronger low-β quads or moving them closer to the interaction point. Here the thing to watch out for is that the amplitude function in the quadrupoles does not get too large and make a beam admittance restriction that would reduce the lifetime. The β^* can probably be reduced by a factor of 2 to 4 with present superconducting cable, but to make use of this improvement the beam bunch length must be kept short because β grows along the beam direction about the interaction point; $\beta(z)= \beta^*+z^2/\beta^*$. If the bunch length σ_ℓ is equal to β^*, the integrated luminosity is 3/4 of that which you would get for a very short bunch. Alternatively if σ_ℓ = 1/2m the luminosity ratio in going from β^*=1:1/2:1/4m is 1:1.7:2.1. If you are going to benefit a lot from the β^* improvement you have to make the bunch length short.

In summary, we want:

a) a high $\bar{p}$ production rate,
b) a long storage time,
c) dense beams in transverse phase space N_p large, ε_n (p and pbar) small,
d) β^* small - and to realize its potential -
e) bunch length, σ_ℓ, short.

The problem with b), c), and e) is that the beam diffuses to larger emittances, both transverse and longitudinal, through intrabeam scattering (coulomb scattering amongst particles in a bunch). This process is accelerated as the phase space den-

sity is increased. Thus, longer storage times and smaller emittances will lead to greater reduction of average to peak luminosity. Protons can be replaced as often as required but antiprotons are limited. That is why it would be great if schemes could be developed either to cool antiprotons in the TEVATRON or to recover and cool them in a separate ring so that they can be recycled. Operationally what you really need is enough pbars one way or another so that you aren't afraid to go through the required accelerator manipulations efficiently - and allow for an occasional mistake.

So, back to the factor of 50-6 factors of 2. Let's write down TeV I design parameters and an Upgrade budget goal to see from where these factors might come. Table I gives a set of tentative parameters, each of which will have to be studied to see if it is feasible, or for that matter, makes any sense at all. Only after some real design effort will we be able to judge how much of the 50 factor may be possible.

Table I.
Comparison of Tentative Upgrade Parameters with TeV I Design and Potential Improvement Factors

	TeV I	Upgrade	Ratio	$\mathcal{L}$ Factor
N_p (10^{10})	6	5-6	5/6	$2^{-0.3}$
$N_{\bar{p}}$ (10^{10})	6	$2\frac{1}{2}$ - 3	5/12	
B	3	144	48	
$BN_{\bar{p}}$ (10^{11})	1.8	36	20	$[2^{4.3}]^1$
$\varepsilon N/\pi$ $(10^{-6}m)$	24	12	1/2	2
β^* (m)	1	$\frac{1}{2}$ - $\frac{1}{4}$	1/2	2
L/hit $(10^{25}\ cm^{-2})$	0.72	1	1.39	
$R_{\bar{p}}$ $(10^{11}/hr)$	1	4	4	2^2
T_s (hr)	2	10	5	$2^{2.3}$
$\mathcal{L}$ $(10^{30}cm^{-2}sec^{-1})$	1	67 (=50)	50	2^6

[1]Made up of $R_{\bar{p}}$, T_s.

Now let's ask what the $\mathcal{L}$ factors imply for the potential improvements.

In the TEVATRON, D0 needs a low-β quadrupole system operating by 1989. This will be designed for possible 1/4m β^* operation. A beam separator design should be worked out as soon as possible, probably first for 6x6 operation (separation in one plane). Then the more complicated two-dimensional spiral separation for any number of bunches will be developed. The 6x6 operation would be used for the first few D0 runs prior to detector upgrades at B0 and D0. However, once the two-dimensional separation works, one could consider trying it for 10-hour storage times

with 20-40 bunches and a peak (not average) luminosity factor of 10 over TeV I.

The development effort here is all in the TEVATRON low-β, separator, and injection design. How do we fit the separators in? Do we need to make space by using some higher strength dipoles? Is there enough good-field aperture for the separated beams? Is the long-range beam-beam tune shift a problem? How do we get the two beams into and out of the TEVATRON and abort them safely? What do the kickers look like? These are just a few of the questions.

In the Pbar Source, optimists believe the accumulation rate can be increased by up to a factor of 4. Obviously a factor of 20 would be nice, but short of building more source rings, this looks tough. The accumulation rate will be increased by increasing the targeting cycle rate and pbar collection efficiency per cycle. Cooling rates must be increased a factor of 4 with higher frequency cooling systems.

Going further back in the accelerator chain, we believe that if we are careful with the transfers of beam from one accelerator to the next, that ultimately the transverse emittance is set by the space charge beam tune shift at injection time in the Booster. This could be substantially improved by injecting from the Linac at a higher energy. Replacing the second half of the Linac with modern, higher-frequency sections would increase the energy to 400 MeV and thus improve the emittance by a factor of about 2. The real question here is whether that improvement would be realized in the TEVATRON at 1 TeV. The emittance improvements should help Collider luminosity, the proton beam intensity for pbar production and for fixed-target operation. It would be nice to replace the front end of the Linac as well; it is becoming obsolete.

Remaining to be discussed are two areas: improved performance of the Main Accelerator, and the issue of pbar economy and emittance dilution during storage by intrabeam scattering. Obviously the Upgrade design is not nearly as conservative as TeV I in regard to having enough pbars. As mentioned before, to recover that safety factor we should consider either bunch beam cooling in the TEVATRON or recycling pbars to a recovery ring where they are recooled to the desired emittance and then reinjected into the TEVATRON. One possibility might be to build a ring at 20 GeV, above Main Ring transition energy, where the Main Ring operates efficiently without loss. At the same time one might build a proton post-Booster accelerator so that Main Ring injection could be raised to 20 GeV for all processes. Two rings like this might cost $80M, but might make up the difference between an upgrade that operated reliably at its goal and one that does not.

It is clear that a plan like the Upgrade can be realized in steps, but that design work must go on in many areas and should start as soon as possible. There is a lot of R&D required. With a little effort it will probably become much clearer what is really possible and how to optimize the cost/benefit. During this evaluation we will not lose track of the possibility of going to higher energy as well.

Some Details on the Upgrade

The preceding discussion has been an introduction to some of the thoughts for the Upgrade. What follows is a more detailed description of some aspects, and a summary of work done by members of the Accelerator Division and Technical Support Section during the past summer.

The Injector and Main Ring Upgrade

The Injector and Main Ring Upgrade Program is focused on improvement of the beam quality, i.e., lower emittance for present intensities, or increased intensity for presently obtained emittances. These goals should help both fixed-target and Collider operation.

The Booster Space Charge Limit

It is believed that the transverse beam emittance is set by the space charge tune spread limit in the Booster at the start of acceleration after the beam has been bunched. The space charge tune spread

$$\Delta\upsilon \propto \frac{R}{\beta\gamma^2}\,\frac{1}{\sigma_\ell}\,\frac{N_p}{\varepsilon_N}$$

where R is the accelerator radius, $\beta\gamma^2$ is the relativistic factor, and σ_ℓ the bunch length σ.

The tune spread for a given bunch intensity divided by normalized emittance can be reduced by increasing the beam energy or decreasing the accelerator radius. After some consideration, it has been decided to pursue an upgrade of the energy of the Linac rather than the construction of an additional pre-Booster ring. A pre-Booster at, say, 1/3 the radius of the Booster, would require three times the length of time to fill the Main Ring and add one more accelerator in an already complicated chain. A Linac upgrade, especially if it can be done in stages, can benefit the program over a relatively short time period and in the long run lead to the total replacement of dated equipment.

The Linac Upgrade

This phase can proceed in stages. Most important is the initial step of replacing the last half of the 200-MHz Alvarez accelerating tanks with 800-MHz side-coupled structures for an increase in kinetic energy from 200 MeV to about 400 MeV. This change can be done in the existing building and without extensive modification to the injection line to the Booster. Sections of the side-coupled structure can be installed during normal maintenance and development periods with a somewhat longer period (six weeks) for the final conversion. A change in $\beta\gamma^2$ from 0.83 to 1.45 would predict an increase in N/ε_N of 1.75 based on tune shift depression due to space charge.

The second step would call for replacement of the preaccelerator with an RFQ and the replacement of the lower energy 200-MHz tanks and rf power supplies with a 400-MHz system and an improved rf power source. The higher gradients achiev-

able with the 400-MHz system would allow the side-coupled structure to be moved upstream. Additional side-coupled cavities could then be added to make a 600-MeV Linac of about the same length as the present 200-MeV Linac. The transverse emittance would be 3π normalized (90%), or about one half the present value. This step would require considerable rework of the Booster injection line. Consequently, it may be more desirable just to replace the preaccelerator and first Linac tank with an RFQ and modified Tank I. This change would give the benefit of the smaller emittance without the added complexity of a new Booster injection line.

The Pbar Source Upgrade

The Pbar Source Upgrade Program has a goal of increasing the production rate by a factor of 4 from 1×10^{11}/hr to 4×10^{11}/hr. In order to achieve this, the source targeting cycle rate would be increased a factor of 2, to 1-Hz average, and the number of pbar's entering the Debuncher would also have to be increased a factor of 2.

Main Ring repetition rate improvements can be achieved by multiple Booster batch acceleration and single batch extraction to the pbar production target. If six batches were accelerated together and extracted on flattop every 0.7 sec, an average of 1 Hz could be obtained.

The Pbar Production Target and Lithium Lens

At the pbar production target, higher yields can be obtained if either the proton beam size is reduced or the beam current increased. In both cases the peak energy density will increase beyond allowable limits unless the beam is swept across the target such that the peak energy density is no larger than the current rate. While such an approach is in principle feasible, it is technically quite difficult. If pbars can be removed from the TEVATRON and recooled in a recovery ring, this might be a way of supplementing the $\bar{p}$ production. If 50% of the pbars could be recovered and recooled, there would be no need to demand more from the target system aside from the higher repetition rate.

The lithium lens cycle time can be increased from 0.5 Hz to 1.4 Hz without reduced efficiency if the lens radius, R_0, is reduced while the gradient is increased such that magnetic field at R_0 is unchanged.

Cooling Systems

Cooling times in both the Debuncher and Accumulator will be reduced by the development of higher bandwidth systems (4-8 GHz or 8-16 GHz instead of 1-2 or 2-4 GHz). In addition, cooling power requirements in the Debuncher and Accumulator can be reduced by changing the gap of the pickups and kickers as the transverse beam emittance shrinks. The Debuncher transverse cooling rate is given by

$$\frac{1}{\tau_\varepsilon} = \frac{2\omega^2 |\eta| \Delta p/p}{N_{\bar{p}} f_0}$$

where ω is the bandwidth, f_0 is the revolution frequency, and $\eta=1/\gamma_t 2-1/\gamma^2$. The cooling can be increased by increasing η

1.5 times. This can be accomplished with a γ_t jump scheme that would preserve the present η and the rf voltage requirement at injection time.

In the Accumulator, $\eta\Delta p/p$ must be reduced by a factor of 4 so that Schottky bands at the revolution harmonic will not overlap in the bandwidth of the cooling system. This condition is given by

$$\frac{2\omega\eta}{f_0}\frac{\Delta p}{p} < \frac{2}{3}$$

Since the bandwidth of the cooling system must increase by 4 to accommodate the faster stacking rate, $\eta\Delta p/p$ must be reduced by this amount. Here η can be reduced a factor of 2 by using different gradients in the lattice quadrupoles. Reduction of $\Delta p/p$ of the stack by a factor of 2 is feasible although it will require precooling of the injected beam. Here again pickup gap sizes need to be reduced by a factor of roughly 2 in order to obtain an acceptable Schottky beam signal-to-electronic-noise ratio. Kicker gap sizes need to be reduced in order to reduce the microwave output power requirements.

Accumulation rates of 4×10^{11}/hr will build up to the design instability threshold of 10^{12} particles in about two hours. Thus, fills should be transferred from the Accmulator to the TEVATRON (or a high-quality storage ring) at about this time interval. It is planned that the beam will be unstacked and extracted in two loads of 12 bunches spaced at the 7th subharmonic of 53 MHz. Each bunch will contain 3×10^{12} particles or a total of 0.7×10^{12} particles per fill.

Loading the TEVATRON: Operating Scenario

A fill sequence will take place about once every two hours and consists of replacing all of the protons and 1/6 of the antiprotons. First, the TEVATRON beams will be decelerated to injection energy and protons and 1/6 of the pbar's removed. Then two loads from the Pbar Source will be transferred from the Accumulator through the Main Ring without coalescing and injected into the TEVATRON. A full ring of proton bunches will be coalesced in the Main Ring on harmonic h=159 and transferred to the TEVATRON. Coalescing of no more than three bunches into one will be sufficient to achieve the required proton bunch intensity of $5\text{-}6\times10^{10}$.

In order that a full ring of protons can be injected into the TEVATRON while pbar's are circulating, the beams must be separated by electrostatic separators, and a proton injection kicker must be developed which has a shuttered septum between the two beams to shield the pbar beam from the kick. Aperture requirements for the two beams during the injection process must be studied in detail.

Kicker rise and fall times require some missing bunches. The pattern chosen at this time is that every 1/7 53-MHz bucket will be full (132-ns bunch spacing), except that each 13th bunch will be missing and after 4x13 bunches (1/3 of the ring) an additional bunch will be missing. This pattern can be written

$$3(4(12b+1)+1) = 1113/7=159,$$

where h=1113 is the harmonic number of the 53-MHz rf system. Pbar kicker rise and fall times must be less than 245ns and proton kicker times less than 377ns. An abort system that meets these requirements has not been worked out at present.

The TEVATRON Collider Upgrade

The Collider Upgrade has a goal of 5×10^{31} cm^{-2} sec^{-1} luminosity. Table II lists the tentative parameters. The main features of the design are as follows:

- Low β^* of 1/2 meter or less. High-gradient 20-kG/cm quadrupoles will be designed with a 3-inch inside diameter. Research on NbTi superconductor with ternary tantalum (Ta) will be done. The quadrupoles will be designed to operate at 2K with a fall back to 14 kG/cm at 4.2K. The appropriate cryostat and refrigeration system must be developed. If β^* of less than 1/2m can be obtained this will reduce requirements on pbar production.
- Electrostatic separators, on either side of each interaction region (IR), must be used to reduce the number of collision points and the head-on beam-beam tune shift. The separators might be placed in the region of the low-β quads, but even so there will be three collisions at each IR, one at β^* with two adjacent satellites. Separation will be in both planes, producing a "Double Helix" of counter-rotating beams spiraling about one another. The

Table II.
Tentative Upgrade Parameters

N_p	5×10^{10}
$N_{\bar{p}}$	$2\frac{1}{2} \times 10^{10}$
ε_T (95%)	$12\pi \times 10^{-6}$m with growth to 20π
ε_L	0.5-1.0 eV-s with growth to 3 eV sec
σ_ℓ	20-30 cm with growth to 60 cm
Bunches B	144
β^*	1/2-1/4 m
L/hit (10^{25} cm^{-2})	1 maximum reduction with growth
$\mathcal{L}$ (10^{30} cm^{-2} sec^{-1})	67 maximum reduction with growth
Design goal $\mathcal{L}$ (10^{30})	50
Bunch spacing	132 ns
Harmonic number	1113/7=159
BNp (10^{13})	0.7
BNpbars (10^{13})	0.35
$\bar{p}$ accumulation rate	4×10^{11}/hr
$\bar{p}$ accumulation time to refill	10 hr minimum
Accumulator intensity	10^{12} max
Fill interval	~2 hr (24 pbar bunches)
Beam-beam tune shift head-on 3 crossings per IR	0.018

long-range beam-beam tune shift and multipole fields produced by the coulomb field must be evaluated. The tune shift term is partially cancelled because the beams are separated in both x and y planes.

• Intra-beam scattering growth time will be important. Both horizontal and longitudinal emittance will grow and cause a reduction in luminosity with time. The horizontal growth affects the luminosity to first order, whereas the longitudinal growth is a second order effect which becomes important as the bunch σ_ℓ become comparable with β^*. The bunch length growth especially is expected to be rapid. One feature of the parameters chosen is the unequal proton and antiproton bunch intensities and the plan that all protons will be replaced every fill cycle (~2 hours), whereas pbars must last for six cycles. Thus, though protons are twice as intense, they should suffer less degradation. The potential of a pbar recovery ring or bunch beam cooling must be evaluated.

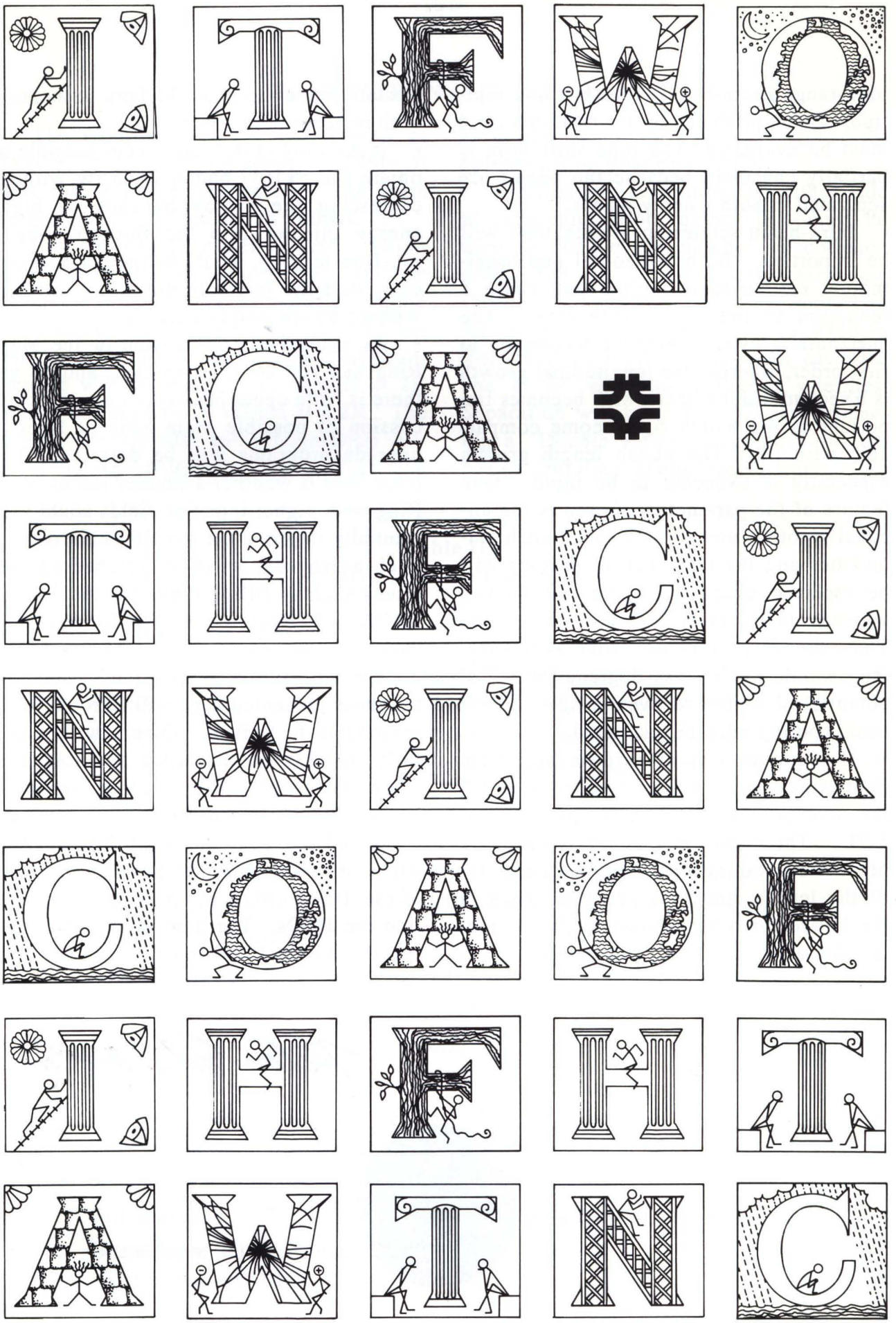
• If required, special purpose high-field dipoles can be developed to operate at 4/3 the Energy Doubler dipole strength, or 5.9T. These magnets could replace the present ones in specific regions using 3/4 of the length, and thus generate space in the lattice for other devices such as quadrupoles associated with the low-β's, electrostatic separators, or kickers associated with injection and abort.

• It does not at this time seem possible to obtain the 5×10^{10} bunch intensity without coalescing the proton bunches. A high-energy injector into the Booster, like a pre-Booster ring, would be required. However, half the intensity might be achieved without bunch coalescence.

• As extensive modification of the Main Ring has just been completed, and as yet there is little operating experience, any discussion of possible Main Ring or Booster upgrade programs will be deferred. The issue here is whether a smaller radius Main Ring with higher injection fields could substantially improve the overall performance. Such a proposal must be weighed against issues such as filling times for the TEVATRON and targeting rep rates for pbar production. An alternative might be a fast-

The Upgrade is in its infancy; some of the ideas presented here will turn out to be reasonable to pursue. Others will, hopefully, quickly be discarded and forgotten when their problems become apparent. What is left may not be a luminosity increase of the goal factor of 50, but may adequately augment the physics potential of the TEVATRON in upcoming years and into the 1990s. The hard work and fun of real design must now begin.

Helen Edwards


ITFWO
ANINH
FCA W
THFCI
NWINA
COAOF
IHFHT
AWTNC

IV. Appendices

Appendix A
Publications

Experimental Publications

15-ft Neutrino/H2&NE E-53A

STRANGE PARTICLE PRODUCTION IN NEUTRINO - NEON CHARGED CURRENT INTERACTIONS. N.J. Baker et al., Phys. Rev. **D34**, 1251 (1986)

EVIDENCE FOR COHERENT NEUTRAL-PION PRODUCTION BY HIGH-ENERGY NEUTRINOS. C. Baltay et al., Phys. Rev. Lett. **57**, 2629, (1986)

Muon E-203A

MEASUREMENT OF THE NUCLEON STRUCTURE FUNCTION USING HIGH ENERGY MUONS. P.D. Meyers, Ph.D. Thesis, Lawrence Berkeley Laboratory, University of California, Berkeley, December 1983.

MEASUREMENT OF THE NUCLEON STRUCTURE FUNCTION IN IRON USING 215- AND 93-GeV MUONS. P.D. Meyers, et al., Phys. Rev. D. **34**, 1265 (1986)

Hadron Dissociation E-272

MEASUREMENT OF THE RESONANCE PARAMETERS AND RADIATIVE WIDTH OF THE ρ^+. J. Huston et al., Phys. Rev. D. **33**, 3199 (1986)

30-in. Hybrid E-299

SCALING IN SOFT HADROPRODUCTION BY POSITIVE PROJECTILES IN THE RANGE OF 32-GeV/c - 147-GeV/c. D.H. Brick et al., Z. Phys. **C31,** 59 (1986)

Lambda-Beta Decay E-361

ELECTRON IDENTIFICATION USING A SYNCHROTRON RADIATION DETECTOR. J.S. Dworkin et al., Nucl. Instrum. Meth. **A247**, 412 (1986)

Xi-Zero Production E-495

PRODUCTION OF Ξ^0 AND $\bar{\Xi}^0$ HYPERONS BY 400-GeV PROTONS. A. Beretvas et al., Phys. Rev. D. **34**, 53 (1986)

Photoproduction E-516

HADRON CALORIMETRY AT THE FERMILAB TAGGED PHOTON SPECTROMETER FACILITY. J.A. Appel et al., Nucl. Instrum. Meth. **A243**, 361 (1986)

Neutrino E-531

LIFETIMES OF THE CHARMED PARTICLES $D^{\pm}$, $F^{\pm}$, AND Λ_c^+ PRODUCED BY NEUTRINOS. N. Ushida et al., Phys. Rev. Lett. **56**, 1767 (1986)

LIFETIME OF D^0 CHARMED MESONS PRODUCED IN NEUTRINO INTERACTIONS. N. Ushida et al., Phys. Rev. Lett. **56**, 1771 (1986)

LIMITS TO ν_μ, $\nu_e \rightarrow \nu_\tau$ OSCILLATIONS AND ν_μ, $\nu_e \rightarrow \tau^-$ DIRECT COUPLING. N. Ushida et al., Phys. Rev. Lett. **57**, 23 (1986)

Pi-Mu Atoms E-533

MEASUREMENT OF THE RATE OF FORMATION OF PI-MU ATOMS IN K_L^0 DECAY. S.H. Aronson et al., Phys. Rev. D. **33**, 3180 (1986)

Di-Muon E-537

A LARGE APERTURE SPECTROMETER AT FERMILAB TO STUDY HIGH MASS DIMUONS. E. Anassontzis et al., Nucl. Instrum. Meth. **A242**, 215 (1986)

Neutral Hyperon E-555

A HIGH STATISTICS STUDY OF LAMBDA BETA DECAY. J.S. Dworkin, Ph.D. Thesis, University of Michigan, Ann Arbor, Michigan, 1983.

NEUTRAL STRANGE PARTICLE PRODUCTION AND POLARIZATIONS AT LARGE p_T. B.G. Lundberg, Ph.D. Thesis, University of Wisconsin, Madison, Wisconsin, 1984.

Hadron Jets E-557

BEAM JET STRUCTURES IN SOFT AND HARD PROTON-PROTON COLLISIONS AT S=27.4 GeV. S.-C. Ahn, Ph.D. Thesis, Rutgers, the State University of New Jersey, Piscataway, New Jersey, October 1986.

VALENCE QUARK EFFECTS IN BEAM REMNANTS IN HIGH E_t PROTON-PROTON COLLISIONS AT $\sqrt{s}$ = 27.4 GeV. S. Ahn et al., Phys. Lett. **B177**, 233 (1986)

15-ft & Emulsion/Neutrino E-564

NEUTRINO INTERACTIONS IN EMULSION STACKS INSIDE THE FERMILAB 15-FOOT BUBBLE CHAMBER. W. Smart et al., Acta Phys. Pol., **B17** 4 (1986).

Particle Search E-580

INCLUSIVE STRANGE-PARTICLE PRODUCTION IN SINGLE-VEE EVENTS IN 200-GeV/c π^-N INTERACTIONS. S. Mikocki et al., Phys. Rev. D. **34**, 42 (1986)

Particle Search E-591

ACCELERATOR INTERNAL TARGET EXPERIMENTS USING A SUPERSONIC GAS JET. B.C. Stringfellow et al., Nucl. Instrum. Meth. **A251**, 242 (1986)

Neutrino E-594

AZIMUTHAL ENERGY FLOW IN DEEP INELASTIC NEUTRINO SCATTERING. A. Mukherjee, Ph.D. Thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, March, 1986.

30-in. Hybrid E-597

OBSERVATION OF A DEPENDENCE IN KOBA-NIELSEN-OLESEN SCALING DISTRIBUTIONS FOR HIGH-ENERGY HADRON-NUCLEUS INTERACTIONS. N.N. Biswas et al., Phys. Rev. D. **33**, 3167 (1986)

High Mass Pairs E-605

A NEW LIMIT ON AXION PRODUCTION IN 800-GeV HADRONIC SHOWERS. C.N. Brown et al., Phys. Rev. Lett. **57**, 2101 (1986)

INCLUSIVE HADRONIC PRODUCTION CROSS SECTIONS MEASURED IN 400 GeV PROTON-NUCLEUS COLLISIONS. J.A. Crittenden, Ph.D. Thesis, Columbia University, New York, New York, January 1986.

INCLUSIVE HADRONIC PRODUCTION CROSS SECTIONS MEASURED IN PROTON-NUCLEUS COLLISIONS AT $\sqrt{s}$ = 27.4 GeV. J.A. Crittenden et al., Phys. Rev. D. **34**, 2584 (1986)

IDENTIFICATION OF LARGE-TRANSVERSE-MOMENTUM HADRONS USING A RING-IMAGING CHERENKOV COUNTER. R. McCarthy et al., Nucl. Instrum. Meth. **A248**, 69 (1986)

Hadron Jets E-609

EVIDENCE FOR HIGHER-TWIST EFFECTS IN HARD πp COLLISIONS AT 200 GeV/c. C. Naudet et al., Phys. Rev. Lett. **56**, 808 (1986)

Beam Dump E-613

CHARACTERISTICS OF CHARM PRODUCTION BY 400-GeV PROTONS. M.E. Duffy et al., Phys. Rev. Lett. **57**, 1522 (1986)

Transition Magnetic Moment E-619

ON PRIMAKOFF PRODUCTION OF Σ^0 HYPERONS. T. Devlin et al., Phys. Rev. D., **34**, 1625 (1986)

MEASUREMENT OF THE Σ^0-Λ TRANSITION MAGNETIC MOMENT. P.C. Petersen et al., Phys. Rev. Lett. **57**, 949 (1986)

THE SIGMA-LAMBDA TRANSITION MAGNETIC MOMENT. P.C. Petersen, Ph.D. Thesis, Rutgers, the State University of New Jersey, Piscataway, New Jersey, October 1985.

Charged Hyperon Magnetic Moment E-620

MEASUREMENTS OF PRODUCTION POLARIZATION AND DECAY ASYMMETRY FOR Ξ^- HYPERONS. R. Rameika et al., Phys. Rev. D. **33**, 3172 (1986)

Particle Search E-623

OBSERVATION OF DOUBLE PHI-MESON PRODUCTION IN 400-GeV/c PROTON-NUCLEON INTERACTIONS. T.F. Davenport et al., Phys. Rev. D. **33**, 2519 (1986)

OBSERVATION OF A NARROW ENHANCEMENT IN ϕKK and $\phi\pi\pi$ FINAL STATES PRODUCED IN 400-GeV p-N INTERACTIONS. D.R. Green et al., Phys. Rev. Lett. **56**, 1639 (1986)

OBSERVATION OF $\phi K\pi$ DECAY OF THE $K^{*0}(2060)$. S. Torres et al., Phys. Rev. D. **34**, 707 (1986)

Charm Particle E-630

A STUDY OF THE PROPERTIES OF MUONS PRODUCED IN THE DECAYS OF CHARMED PARTICLES. P.L. McBride, Ph.D. Thesis, Yale University, New Haven, Connecticut, 1984.

MEASUREMENT OF THE HADRONIC CHARM PRODUCTION CROSS SECTION IN A HIGH RESOLUTION STREAMER CHAMBER EXPERIMENT. L. Tzeng, Ph.D. Thesis, Yale University, New Haven, Connecticut, 1984.

15-ft Neutrino/H2&NE E-632

HOLOGRAPHY IN 15-FOOT BUBBLE CHAMBER AT FERMILAB. H. Akbari and H.I. Bjelkhagen, SPIE "Practical Holography" **615**, 7 (1986)

PULSE STRETCHING IN A Q-SWITCHED RUBY LASER FOR BUBBLE CHAMBER HOLOGRAPHY. G. Harigel et al., Applied Optics **25**, 4102 (1986)

Particle Search E-650

SEARCH FOR D^* PRODUCTION IN PION-NUCLEON INTERACTIONS. V.L. Fitch et al., Phys. Rev. D. **33**, 1486 (1986)

Channeling E-660

DEFLECTION OF AN 800 GeV PARTICLE BEAM USING CHANNELING. S.I. Baker et al., Nucl. Instrum. Meth. **A248**, 301 (1986)

Lambda Polarization E-663

POLARIZATION OF Λ'S AND $\overline{\Lambda}$'S IN pp, $\bar{p}p$, and K^- p INTERACTIONS AT 176-GeV/c. S.A. Gourlay et al., Phys. Rev. Lett. **56**, 2244 (1986)

TEVATRON Muon E-665

RING IMAGING CHERENKOV DETECTOR PROTOTYPE RESULTS FOR E665 AT FERMILAB. G. B. Coutrakon et al., IEEE Trans. Nucl. Sci., **33** (1), p. 205 (1986).

Tagged Photon E-691

AN EXPERIMENTAL STUDY OF THE A-DEPENDENCE OF J/ψ PHOTOPRODUCTION. M.D. Sokoloff et al., Phys. Rev. Let. **57**, 3003 (1986)

Chi Meson E-705

E-705 ELECTROMAGNETIC SHOWER POSITION DETECTOR. C.M. Jenkins et al., Proceedings of the Gas Sampling Calorimetry Workshop II, Fermilab, Batavia, Illinois, October 31-November 1, 1985, Eds. M. Atac et al. p. 201 (1986).

Total Cross-Section E-710

DRIFT-POTS FOR SMALL ANGLE ELASTIC SCATTERING AT THE FERMILAB COLLIDER. N. Amos et al., Nucl. Instrum. Meth. **A252**, 263 (1986)

Sigma Beta Decay E-715

SIGMA MINUS BETA DECAY AND MAGNETIC MOMENT. J. Marriner, Proceedings of the International Europhysics Conference on High-Energy Physics, Bari, Italy, July 18-24, 1985, Eds. L. Nitti and G. Preparata, European Physical Society, p. 245 (1985)

MEASUREMENT OF THE Σ^- MAGNETIC MOMENT USING THE $\Sigma^- \rightarrow ne^- \bar{\nu}$ AND $\Sigma^- \rightarrow n\pi^-$ DECAY MODES. G. Zapalac, et al., Phys. Rev. Lett. **57**, 1526 (1986)

Gravitational Detector E-723

SEARCH FOR LONG RANGE INTERACTIONS AT HIGHLY RELATIVISTIC VELOCITIES. P. Reiner et al., Phys. Lett. **B176**, 233 (1986)

Neutrino Interactions E-733

HADRON CALORIMETRY WITH PROPORTIONAL TUBES IN E-733 AT FERMILAB. M. Tartaglia et al., Proceedings of the Gas Sampling Calorimetry Workshop II, Fermilab, Batavia, Illinois, October 31-November 1, 1985, Eds. M. Atac et al. p. 259 (1986)

D0 Detector E-740

THE D0 DETECTOR AT THE TEVATRON COLLIDER. M.A. Abolins, First Aspen Winter Physics Conference, Aspen Center for Physics, Aspen, Colorado, January 6-19, 1985, Ed. M.M. Block, Annals of the New York Academy of Sciences, Vol. 461, New York Academy of Sciences, p. 63 (1986)

THE PROPOSED MONITORING SYSTEM FOR THE FERMILAB D0 COLLIDING BEAMS DETECTOR. R. Goodwin et al., Nucl. Instrum. Meth. **A247**, 107 (1986)

HADRON SHOWERS AND MUON TRAJECTORIES IN THICK ABSORBER FROM 25 TO 150 GeV/c. D. Green et al., Nucl. Instrum. Meth. **A244**, 356 (1986)

Collider Detector E-741

LEVEL 3 FILTERS AT CDF. J.T. Carroll, Proceedings of the Workshop on Triggering, Data Acquisition and Computing for High Energy/High Luminosity Hadron-Hadron Colliders, Fermilab, Batavia, Illinois, November 11-14, 1985, Eds. B. Cox et al., p. 254 (1986).

CDF AT FERMILAB: A PROGRESS REPORT. A.V. Tollestrup, First Aspen Winter Physics Conference, Aspen Center for Physics, Aspen, Colorado, January 6-19, 1985, Ed. M.M. Block, Annals of the New York Academy of Sciences, Vol. 461, New York Academy of Sciences, p. 56 (1986)

Charm Production E-743

MULTIPLICITY OF CHARGED PARTICLES IN 800 GeV p-p INTERACTIONS. R. Ammar et al, Phys. Lett. B, **178**, 124 (1986).

Charged Interactions E-744

FLASH ADC READOUT OF HADRON SHOWERS IN DRIFT CHAMBERS. K.T. Bachmann et al., Proceedings of the Gas Sampling Calorimetry Workshop II, Fermilab, Batavia, Illinois, October 31-November 1, 1985, Eds. M. Atac et al. p. 291 (1986)

HADRON SHOWER PUNCHTHROUGH FOR INCIDENT HADRONS OF MOMENTUM 15, 25, 50, 100, 200 AND 300 GeV/c. F.S. Merritt et al., Nucl. Instrum. Meth. **A245**, 27 (1986)

Charmonium States E-760

THE FERMILAB ANTIPROTON SOURCE: PROSPECTS FOR $p\bar{p}$ EXPERIMENTS. P.A. Rapidis, Proceedings of the First Workshop on Antimatter Physics at Low Energy, Batavia, Illinois, April 10-12, 1986, Eds. B.E. Bonner and L.S. Pinsky, p. 83 (1986).

Theoretical Physics Publications

MIRROR-LEPTON PHENOMENOLOGY IN A LEFT-RIGHT MODEL WITH ULTRALIGHT DIRAC NEUTRINOS. C.H. Albright and J. Oliensis, Phys. Rev. D. **33**, 2602 (1986)

PROSPECTS FOR SUPERSYMMETRY AT THE FERMILAB COLLIDER. H. Baer and E.L. Berger, Phys. Rev. D. **34**, 1361 (1986)

GAUGE ANOMALIES, GRAVITATIONAL ANOMALIES AND SUPERSTRINGS. W.A. Bardeen, Proceedings of the 1985 INS International Symposium on Composite Models of Quarks and Leptons, Tokyo, Japan, August 13-15, 1985, Eds. H. Terazawa and M. Yasue, Institute for Nuclear Study (INS) University of Tokyo, p. 336 (1986)

COMMENT ON SPINOR ANOMALIES. W.A. Bardeen and N. Deo, Nucl. Phys. **B264**, 364 (1986)

DILATON AND CHIRAL-SYMMETRY BREAKING. W.A. Bardeen et al., Phys. Rev. Lett. **56**, 1230 (1986)

CONSTRAINTS ON VARIANT AXION MODELS. W.A. Bardeen et al., Nucl. Phys. **B279**, 401 (1986)

THE $\Delta I = 1/2$ RULE IN THE LARGE-N LIMIT. W.A. Bardeen et al., Phys. Lett. B. **180**, 133 (1986)

COMMENT ON THE FINITE-TEMPERATURE BEHAVIOR OF $\lambda(\vec{\Phi}^2)^2_4$THEORY. W.A. Bardeen and M. Moshe, Phys. Rev. D **34**, 1229 (1986)

JETS IN EXPANDING QUARK-GLUON PLASMAS. J.P. Blaizot and L.D. McLerran, Phys. Rev. D **34**, 2739 (1986)

STATIC POTENTIAL FOR SMOOTH STRINGS. E. Braaten et al., Phys. Rev. Lett. **58**, 93 (1986)

ENERGY-DENSITY FLUCTUATIONS IN DE SITTER SPACE. R.H. Brandenberger and C.T. Hill, Phys. Lett. B. **179**, 30 (1986)

LASER INDUCED AXION PHOTOPRODUCTION. S.J. Brodsky et al., Phys. Rev. Lett. **56**, 1763 (1986)

CALCULATING HEAVY QUARK DISTRIBUTIONS. J.C. Collins and W.-K. Tung, Nucl. Phys. **B278**, 934 (1986)

PATH-INTEGRAL SOLUBILITY OF TWO-DIMENSIONAL MODELS. A. Das and V.S. Mathur, Phys. Rev. D. **33**, 489 (1986)

BRST GHOSTS AS WORLDSHEET PARAMETERS IN GAUGE-INVARIANT STRING FIELD THEORY. S.R. Das and M.A. Rubin, Phys. Lett. **B181**, 81 (1986)

A TOMONAGA-SCHWINGER-DIRAC FORMULATION FOR STRING THEORIES. S.R. Das and M.A. Rubin, Phys. Lett. **169B**, 182 (1986)

THE DECONFINEMENT TRANSITION IN SU(2) GAUGE THEORY: A FINITE-SIZE ANALYSIS. S. Das and J.B. Kogut, Nucl. Phys. **B265**, 303 (1986)

SIGNATURES FOR TECHNICOLOR. E. Eichten et al., Phys. Rev. **D34**, 1547 (1986)

CHIRAL GAUGE THEORIES IN THE 1/N EXPANSION. E. Eichten et al., Nucl. Phys. **B268**, 161 (1986)

CHIRAL GAUGE THEORIES ON THE LATTICE. E. Eichten and J. Preskill, Nucl. Phys. **B268**, 179 (1986)

NEW RESULTS IN PERTURBATIVE QCD. R.K. Ellis, Proceedings of the Oregon Workshop on Super High Energy Physics, **Supercollider Physics**, Ed. D.E. Soper, World Scientific, p. 77 (1986)

TOPICS IN PERTURBATIVE QCD AT COLLIDER ENERGIES. R.K. Ellis, Proceedings of the UCLA Workshop: Observable Standard Model Physics at the SSC: **Monte Carlo Simulation and Detector Capabilities**, January 15-24, 1986, Eds. H.-U. Bengtsson et al., World Scientific, p. 167 (1986)

COMPACT COVARIANT CROSS SECTIONS FOR VECTOR BOSON PRODUCTION. R.K. Ellis and R.J. Gonsalves, Proceedings of the Oregon Workshop on Super High Energy Physics, **Supercollider Physics**, Ed. D.E. Soper, World Scientific, p. 287 (1986)

QCD RADIATIVE CORRECTIONS TO PARTON-PARTON SCATTERING. R.K. Ellis and J.C. Sexton, Nucl. Phys. **B269**, 445 (1986)

NONPERTURBATIVE QCD CORRECTIONS TO R = σ_L/σ_T, S. Fajfer and R.J. Oakes, Phys. Lett. B. **176**, 473 (1986)

HADRONIC COUPLING CONSTANTS IN LATTICE GAUGE THEORY. S. Gottlieb et al., Nucl. Phys. **B263**, 704 (1986)

DETECTING THE HIGGS IN PURELY LEPTONIC DECAY MODES. J.F. Gunion and M. Soldate, Proceedings of the Workshop on Triggering, Data Acquisition and Computing for High Energy/High Luminosity Hadron-Hadron Colliders, Fermilab, Batavia, Illinois, November 11-14, 1985, Eds. B. Cox et al., Fermilab, p. 79 (1986).

OVERCOMING A CRITICAL BACKGROUND TO HIGGS-BOSON DETECTION. J.F. Gunion and M. Soldate, Phys. Rev. D **34**, 826 (1986)

SIGNATURES OF HEAVY-NEUTRINO PRODUCTION AT THE CERN COLLIDER. H.E. Haber and M. Hall Reno, Phys. Rev. D **34**, 2732 (1986)

ONE-LOOP OPERATOR MATRIX ELEMENTS IN THE UNRUH VACUUM. C.T. Hill, Nucl. Phys. **B277**, 547 (1986)

SUPERSYMMETRY AND ZERO-MOMENTUM MODES. H. Itoyama, Phys. Rev. D. **33**, 3060 (1986)

SOME QUANTUM CORRECTIONS TO CALABI-YAU COMPACTIFICATION. H. Itoyama and J. Leon, Phys. Rev. Lett. **56**, 2352 (1986)

N = 2 NO-SCALE SUPERGRAVITY. H. Itoyama et al., Nucl. Phys. **B279**, 380 (1986)

SUPERSYMMETRY ANOMALIES: FURTHER RESULTS. H. Itoyama et al., Phys. Lett. **168B**, 78 (1986)

DILEPTON EMISSION AND THE QCD PHASE TRANSITION IN ULTRARELATIVISTIC NUCLEAR COLLISIONS. K. Kajantie et al., Phys. Rev. D **34**, 2746 (1986)

STUDIES OF THE HYDRODYNAMIC EVOLUTION OF MATTER PRODUCED IN FLUCTUATIONS IN $\bar{p}p$ COLLISIONS AND IN ULTRARELATIVISTIC NUCLEAR COLLISIONS. II. TRANSVERSE-MOMENTUM DISTRIBUTIONS. M. Kataja et al., Phys. Rev. D **34**, 2755 (1986)

TRANSVERSE FLOW EFFECTS IN DILEPTON EMISSION. K. Kajantie et al., Phys. Rev. **D34**, 811 (1986)

STRANGENESS PRODUCTION IN ULTRARELATIVISTIC HEAVY-ION COLLISIONS. I. CHEMICAL KINETICS IN THE QUARK-GLUON PLASMA. T. Matsui et al., Phys. Rev. D. **34**, 783 (1986)

STRANGENESS PRODUCTION IN ULTRARELATIVISTIC HEAVY-ION COLLISIONS. II. EVOLUTION OF FLAVOR COMPOSITION IN SCALING HYDRODYNAMICS. T. Matsui et al., Phys. Rev. D **34**, 2047 (1986)

INTEGRAL EQUATION FOR MULTIPLICITY DISTRIBUTION. T. Munehisa and K. Tesima, Nucl. Phys. **B277**, 575 (1986)

PROBING THE TRI-BOSON COUPLING IN HIGH-ENERGY VECTOR-BOSON PAIR PRODUCTION. F. Olness and W.-K. Tung, Phys. Lett. B. **179**, 269 (1986)

NONADIABATIC LEVEL CROSSING IN RESONANT NEUTRINO OSCILLATIONS. S.J. Parke, Phys. Rev. Lett. **57**, 1275 (1986)

AMPLITUDE FOR n-GLUON SCATTERING. S.J. Parke and T.R. Taylor, Phys. Rev. Lett. **56**, 2459 (1986)

THE CROSS SECTION FOR FOUR-GLUON PRODUCTION BY GLUON-GLUON FUSION. S.J. Parke and T.R. Taylor, Nucl. Phys. **B269** 410 (1986)

FIELD THEORY OF PATHS WITH A CURVATURE-DEPENDENT TERM. R.D. Pisarski, Phys. Rev. **D34**, 670 (1986)

MAGNETIC MONOPOLES IN TOPOLOGICALLY MASSIVE GAUGE THEORIES. R.D. Pisarski, Phys. Rev. D **34**, 3851 (1986)

INTERACTIONS OF ULTRAHIGH-ENERGY NEUTRINOS. C. Quigg et al., Phys. Rev. Lett. **57**, 774 (1986)

QUANTUM CHROMODYNAMICS NEAR THE CONFINEMENT LIMIT. C. Quigg, Lecture Notes in Physics, **Quarks and Leptons**, Proceedings of the Fourth South African Summer School in Theoretical Physics, University of Stellenbosch, January 21-February 1, 1985, Ed. C.A. Engelbrecht, p. 247 (1986)

PARITY ANOMALIES IN GAUGE THEORIES IN (2+1)-DIMENSIONS. S. Rao, Phys. Lett. **B172**, 227 (1986)

DYNAMICAL BREAKDOWN OF SYMMETRIES IN THREE-DIMENSIONAL QED. S. Rao and R. Yahalom, Phys. Rev. D **34**, 1194 (1986)

PATH INTEGRAL MEASURES FOR TWO-DIMENSIONAL FERMION THEORIES. M. A. Rubin, J. Phys. **19**, 2105 (1986)

TEST OF COHERENT VERSUS INCOHERENT SHOWER DEVELOPMENT. T. Sjostrand and D.E. Soper, Proceedings of the Oregon Workshop on Super High Energy Physics, **Supercollider Physics**, Ed. D.E. Soper, World Scientific, p. 283 (1986)

NONABELIAN FAMILY SYMMETRY AND THE ORIGIN OF FERMION MASSES AND MIXING ANGLES. M. Soldate et al., Phys. Lett. **B179**, 95 (1986)

CORNER TRANSFER MATRICES AND LORENTZ INVARIANCE ON A LATTICE. H. B. Thacker, Physica **18D**, 348 (1986)

INSTABILITY OF DE SITTER SPACE ON SHORT TIME SCALES. J. Traschen and C.T. Hill, Phys. Rev. **D33**, 3519 (1986)

DOES LOW-ENERGY PHYSICS DEPEND ON THE POTENTIAL OF A HEAVY HIGGS PARTICLE? J.J. van der Bij, Nucl. Phys. **B267** 557 (1986)

TOPOLOGICAL MASS TERM FOR GRAVITY INDUCED BY MATTER. J.J. van der Bij et al., Phys. Lett. **B179**, 87 (1986)

STUDIES OF THE HYDRODYNAMIC EVOLUTION OF MATTER PRODUCED IN FLUCTUATIONS IN $\bar{p}p$ COLLISIONS AND IN ULTRARELATIVISTIC NUCLEAR COLLISIONS. H. von Gersdorff et al., Phys. Rev. D **34**, 794 (1986)

Theoretical Astrophysics Publications

FINITE-TEMPERATURE INSTABILITY FOR COMPACTIFICATION. F.S. Accetta and E.W. Kolb, Phys. Rev. D. **34**, 1798 (1986)

TOWARD STABLE COMPACTIFICATIONS. F.S. Accetta et al., Nucl. Phys. **B276**, 501 (1986)

EFFECTIVE POTENTIAL FOR THE 0(N)-SYMMETRIC MODEL IN STATIC HOMOGENEOUS SPACETIMES. P.R. Anderson and R. Holman, Phys. Rev. D. **34** 2277 (1986)

NEW AND OLD ACCELERATORS: WHAT CAN THEY DO FOR ASTROPHYSICS? J.D. Bjorken, Proceedings of the Inner Space/Outer Space Conference, **The Interface Between Cosmology and Particle Physics**, Fermilab, Batavia, Illinois, May 5, 1984, Eds. E.W. Kolb et al., The University of Chicago Press, p. 613 (1986)

PERCOLATION OF EXPLOSIVE GALAXY FORMATION. J.C. Charlton and D.N. Schramm, Ap. J. **310**, 26 (1986)

ASTROPHYSICAL CONSTRAINTS ON THE COUPLINGS OF AXIONS, MAJORONS, AND FAMILONS. D.S.P. Dearborn et al., Phys. Rev. Lett. **56** 26 (1986)

CLASSICAL COSMOLOGIES FROM TEN-DIMENSIONAL SUPERGRAVITY. M. Gleiser and J.A. Stein-Schabes, Phys. Rev. D. **34**, 1739 (1986)

TIME VARIATION OF COUPLING CONSTANTS IN KALUZA-KLEIN COSMOLOGIES REEXAMINED. M. Gleiser and J.G. Taylor, Phys. Rev. D. **33**, 570 (1986)

IMPLICATIONS OF THE ULTRAHIGH-ENERGY COSMIC-RAY SPECTRUM OBSERVED BY THE FLY'S EYE DETECTOR. C.T. Hill et al., Phys. Rev. D. **34**, 1622 (1986)

NEUTRINOS IN HIGH-ENERGY ASTROPHYSICS. C. Hill et al., Festschrift, Eds. K. Sakurai and J. Aratune, Tokyo: Reidel (1986)

AXION COSMOLOGY IN AUTOMATIC E_6xU(1) MODELS. R. Holman and T.W. Kephart, Phys. Lett. **167B**, 169 (1986)

GLOBAL ANOMALIES IN YANG-MILLS THEORIES IN HIGHER DIMENSIONS. R. Holman and T.W. Kephart, Phys. Lett. **167B**, 417 (1986)

FERMION MASSES AND PHENOMENOLOGY IN SO(10) OR SU(5) SUPERSTRING COMPACTIFICATIONS. R. Holman and D.B. Reiss, Phys. Lett. B. **176**, 74 (1986)

FERMION MASSES IN E_8xE_8' SUPERSTRING THEORIES. R. Holman and D.B. Reiss, Phys. Lett. **166B**, 305 (1986)

EFFECT OF INFLATION ON ANISOTROPIC COSMOLOGIES. L.G. Jensen and J.A. Stein-Schabes, Phys. Rev. D. **34**, 931 (1986)

IS INFLATION NATURAL? L.G. Jensen and J.A. Stein-Schabes, Phys. Rev. D. **35** (1986)

LECTURES ON PARTICLE PHYSICS AND COSMOLOGY. E.W. Kolb, **Superstrings, Supergravity and Unified Theories**, Proceedings of the Summer Workshop in High Energy Physics and Cosmology, Trieste, Italy, June 10-July 19, 1985, Eds. G. Furlan et al., p. 444 (1986)

SEARCHING FOR CYGNETS. E.W. Kolb, **Particles and the Universe**, Proceedings of the International Symposium on Particles and the Universe, Eds. G. Lazarides and Q. Shafi, Thessaloniki, Greece, June 24-29, 1985, p. 247 (1986)

LEE-WEINBERG BOUND REEXAMINED. E.W. Kolb and K.A. Olive, Phys. Rev. D. **33**, 1202 (1986)

EFFECT OF INTERACTING PARTICLES ON PRIMORDIAL NUCLEOSYNTHESIS. E. W. Kolb et al., Phys. Rev. D. **34**, 2197 (1986)

FUTURE DIRECTIONS AT THE PARTICLE PHYSICS-COSMOLOGY INTERFACE. E.W. Kolb et al., Proceedings of the Inner Space/Outer Space Conference, **The Interface Between Cosmology and Particle Physics**, Fermilab, Batavia, Illinois, May 5, 1984, Eds. E.W. Kolb et al., The University of Chicago Press, p. 622 (1986)

MICROWAVE-BACKGROUND ANISOTROPY AND DECAYING-COLD-PARTICLE SCENARIOS. E.W. Kolb et al., Phys. Rev. D. **34**, 940 (1986)

TIME VARIATION OF FUNDAMENTAL CONSTANTS, PRIMORDIAL NUCLEOSYNTHESIS, AND THE SIZE OF EXTRA DIMENSIONS. E.W. Kolb et al., Phys. Rev. D. **33**, 869 (1986)

YET ANOTHER POSSIBLE EXPLANATION OF THE SOLAR-NEUTRINO PUZZLE. E.W. Kolb et al., Phys. Lett. B**175**, 478 (1986)

HADRONIC DECAYS OF COSMOLOGICAL GRAVITINOS. D. Lindley, Phys. Lett. B.**171** 235 (1986)

MORE DIMENSIONS - LESS INFLATION. D. Lindley, Proceedings of the Inner Space/ Outer Space Conference, **The Interface Between Cosmology and Particle Physics**, Fermilab, Batavia, Illinois, May 5, 1984, Eds. E.W. Kolb et al., The University of Chicago Press, p. 593 (1986)

GENERAL CONSTRAINTS ON THE AGE AND CHEMICAL EVOLUTION OF THE GALAXY. B.S. Meyer and D.N. Schramm, Ap. J. **311**, 406 (1986)

ARE BARYONIC GALACTIC HALOS POSSIBLE? K.A. Olive and D.J. Hegyi, Proceedings of the Inner Space/Outer Space Conference, **The Interface Between Cosmology and Particle Physics**, Fermilab, Batavia, Illinois, May 5, 1984, Eds. E.W. Kolb et al., The University of Chicago Press, p. 112 (1986)

LARGE-SCALE MICROWAVE BACKGROUND FLUCTUATIONS: GAUGE-INVARIANT FORMALISM. M. Panek, Phys. Rev. D. **34**, 416 (1986)

RESONANT-SOLAR-NEUTRINO-OSCILLATION EXPERIMENTS. S.J. Parke and T.P. Walker, Phys. Rev. Lett. **57**, 18 (1986)

ON THE RELIC, COSMIC ABUNDANCE OF STABLE, WEAKLY INTERACTING MASSIVE PARTICLES. R.J. Scherrer and M.S. Turner, Phys. Rev. D. **33**, 1585 (1986)

HE RESURRECTION OF NEUTRINOS AS DARK MATTER. D.N. Schramm, Proceedings of the Sixth Moriond Workshop, January 25-February 1, 1986, **'86 Massive Neutrinos in Astrophysics and in Particle Physics**, Eds. O. Fackler and J. Tran Thanh Van, p. 75 (1986)

MATTER DOMINATION - RECOMBINATION: COINCIDENCE OR CONSEQUENCE? D.N. Schramm and E. Vishniac, Comments Nucl. Part. Phys. **16**, 51 (1986)

INFLATION IN A WALL DOMINATED UNIVERSE. D. Seckel, Proceedings of the Inner Space/Outer Space Conference, **The Interface Between Cosmology and Particle Physics**, Fermilab, Batavia, Illinois, May 5, 1984, Eds. E.W. Kolb et al., The University of Chicago Press, p. 367 (1986)

A REEXAMINATION OF THE COSMOLOGICAL BOUND TO THE NUMBER OF NEUTRINO FLAVORS. G. Steigman et al., Phys. Lett. B. **176**, 33 (1986)

NONSTATIC VACUUM STRINGS: EXTERIOR AND INTERIOR SOLUTIONS. J.A. Stein-Schabes, Phys. Rev. D. **33**, 3545 (1986)

EINSTEIN-KALB-RAMOND COSMOLOGY. J.A. Stein-Schabes and M. Gleiser, Phys. Rev. D. **34**, 3242 (1986)

COSMIC AND LOCAL MASS DENSITY OF "INVISIBLE" AXIONS. M.S. Turner, Phys. Rev. D. **33**, 889 (1986)

HOMOGENEOUS COSMOLOGICAL MODELS AND NEW INFLATION. M.S. Turner and L. Widrow, Phys. Rev. Lett. **57**, 2237 (1986)

MONOPOLES, COSMOLOGY, AND ASTROPHYSICS--UPDATE 1985. M.S. Turner, First Aspen Winter Physics Conference, Aspen Center for Physics, Aspen, Colorado, January 6-19, 1985, Ed. M.M. Block, Annals of the New York Academy of Sciences, Vol. 461, New York Academy of Sciences, p. 652 (1986)

PROBING THE STRUCTURE OF THE GALACTIC HALO WITH GAMMA RAYS PRODUCED BY ANNIHILATIONS OF WEAKLY INTERACTING MASSIVE PARTICLES. M.S. Turner, Phys. Rev. D. **34**, 1921 (1986)

General Publications

REPORT OF THE HIGH LEVEL TRIGGER GROUP. M. Abolins et al., Proceedings of the Workshop on Triggering, Data Acquisition and Computing for High Energy/High Luminosity Hadron-Hadron Colliders, Fermilab, Batavia, Illinois, November 11-14, 1985, Eds. B. Cox et al., Fermilab, p. 131 (1986).

REGULATING THE WASTE GENERATOR. R. L. Allen and S. I. Baker, **Professional Safety**, 34 (1986).

THE TRIGGER SYSTEM FOR THE COLLIDER DETECTOR FACILITY. D. Amidei et al., IEEE Trans. Nucl. Sci., **33** (1), p. 63 (1986).

PHOTOSENSITIVE DOPANTS FOR LIQUID ARGON. D.F. Anderson, Nucl. Instrum. Meth. **A242**, 254 (1986)

NEW PHOTOSENSITIVE DOPANTS FOR LIQUID ARGON. D.F. Anderson, Nucl. Instrum. Meth. **A245**, 361 (1986)

OFFLINE COMPUTING AND NETWORKING. J.A. Appel et al., Proceedings of the Workshop on Triggering, Data Acquisition and Computing for High Energy/High Luminosity Hadron-Hadron Colliders, Fermilab, Batavia, Illinois, November 11-14, 1985, Eds. B. Cox et al., Fermilab, p. 269 (1986).

SOFTWARE DEVELOPMENT FOR THE SSC. J.A. Appel et al., Proceedings of the Workshop on Triggering, Data Acquisition and Computing for High Energy/High Luminosity Hadron-Hadron Colliders, Fermilab, Batavia, Illinois, November 11-14, 1985, Eds. B. Cox et al., Fermilab, p. 315 (1986).

WIRE CHAMBER AGING. M. Atac, Proceedings of the Workshop on Radiation Damage to Wire Chambers, Lawrence Berkeley Laboratory, Berkeley, California, January 16-17, 1986, p. 55 (1986)

RADIAL WIRE DRIFT CHAMBERS FOR CDF FORWARD TRACKING. M. Atac and T. Hessing, IEEE Trans. Nucl. Sci., **33** (1), p. 189 (1986).

AN OPERATOR'S VIEWS ON FERMILAB'S CONTROL SYSTEM. D.S. Baddorf, Nucl. Instrum. Meth. **A247**, 176 (1986)

DEFLECTION OF AN 800 GeV PARTICLE BEAM USING CHANNELING. S.I. Baker et al., Nucl. Instrum. Meth. **A248**, 301 (1986)

OPERATIONAL HISTORY OF FERMILAB'S 1500 W REFRIGERATOR USED FOR ENERGY SAVER MAGNET PRODUCTION TESTING. R.K. Barger et al., 1985 Cryogenic Engineering Conference, "Advances in Cryogenic Engineering," Plenum Press, New York, **31**, p. 645 (1986).

A REAL TIME DATA COMPACTOR (SPARSIFIER) AND 8 MEGABYTE HIGH SPEED FIFO FOR HEP. A. E. Baumbaugh et al., IEEE Trans. Nucl. Sci., **33** (1), p. 903 (1986).

A SILICON VERTEX DETECTOR FOR CDF. F. Bedeschi et al., IEEE Trans. Nucl. Sci., **33** (1), p. 140 (1986).

TIME AND DATA DISTRIBUTION SYSTEMS AT THE FERMILAB ACCELERATOR. D.G. Beechy and R.J. Ducar, Nucl. Instrum. Meth. **A247**, 231 (1986)

PHYSICS AT THE TEVATRON COLLIDER. G. Bellettini, First Aspen Winter Physics Conference, Aspen Center for Physics, Aspen, Colorado, January 6-19, 1985, Ed. M.M. Block, Annals of the New York Academy of Sciences, Vol. 461, New York Academy of Sciences, p. 161 (1986)

ELECTROPRODUCTION AT VERY SMALL VALUES OF THE SCALING VARIABLE. J. D. Bjorken, **Particles and Detectors**, Festschrift for Jack Steinberger, Eds. K. Kleinknecht and T. D. Lee, p. 17 (1986).

FORWARD SPECTROMETERS AT THE SSC. J.D. Bjorken, Proceedings of the Workshop on Triggering, Data Acquisition and Computing for High Energy/High Luminosity Hadron-Hadron Colliders, Fermilab, Batavia, Illinois, November 11-14, 1985, Eds. B. Cox et al., Fermilab, p. 363 (1986).

WILL THE NEXT FIFTEEN YEARS OF HIGH ENERGY PHYSICS MATCH THE LAST FIFTEEN? J. D. Bjorken, Proceedings of the 10th Hawaii Topical Conference in High Energy Physics, Honolulu, Hawaii, August 26-31, 1985, Eds. F.A. Harris et al., University of Hawaii Press, p. 627 (1986).

SUMMARY REPORT FOR THE SPECIAL TRIGGERS GROUP. J.D. Bjorken and A.J. Slaughter, Proceedings of the Workshop on Triggering, Data Acquisition and Computing for High Energy/High Luminosity Hadron-Hadron Colliders, Fermilab, Batavia, Illinois, November 11-14, 1985, Eds. B. Cox et al., Fermilab, p. 359 (1986).

THE FERMILAB ACCELERATOR CONTROL SYSTEM. D. Bogert, Nucl. Instrum. Meth. **A247**, 8 (1986)

FIRUS; THE FNAL SITE-WIDE FIRE AND UTILITY MONITORING SYSTEM. C. Briegel et al., Nucl. Instrum. Meth. **A247**, 85 (1986)

LASER-INDUCED AXION PHOTOPRODUCTION. S. J. Brodsky et al., Phys. Rev. Lett., **56** p. 1763 (1986).

COMMENT ON THE IMPACT OF VERTEX DETECTORS ON TRIGGERING AND DATA ACQUISITION IN THE GENERAL PURPOSE 4π DETECTOR. A. Bross and J. Slaughter, Proceedings of the Workshop on Triggering, Data Acquisition and Computing for High Energy/High Luminosity Hadron-Hadron Colliders, Fermilab, Batavia, Illinois, November 11-14, 1985, Eds. B. Cox et al., Fermilab, p. 390 (1986).

THE SSC CRYOGENIC SYSTEM. D. P. Brown et al., 1985 Cryogenic Engineering Conference, "Advances in Cryogenic Engineering," Plenum Press, New York, **31**, p. 57 (1986).

RADIATION DAMAGE STUDIES ON BAF_2 AND BGO SCINTILLATOR MATERIALS. A. J. Caffrey et al., IEEE Trans. Nucl. Sci., **33** (1) p. 230 (1986).

SEVENTH IEEE SYMPOSIUM ON MASS STORAGE SYSTEMS. C. V. Canada, Proceedings of the Workshop on Triggering, Data Acquisition and Computing for High Energy/High Luminosity Hadron-Hadron Colliders, Fermilab, Batavia, Illinois, November 11-14, 1985, Eds. B. Cox et al., Fermilab, p. 289 (1986).

FUTURE COMPUTER NETWORKING FACILITIES FOR REMOTE ACCESS OF SSC DATA. G. Chartrand, Proceedings of the Workshop on Triggering, Data Acquisition and Computing for High Energy/High Luminosity Hadron-Hadron Colliders, Fermilab, Batavia, Illinois, November 11-14, 1985, Eds. B. Cox et al., Fermilab, p. 283 (1986).

HIGH ENERGY ELECTROWEAK PARAMETERS AND EXPERIMENTAL DATA FROM $p\bar{p}$ COLLIDER RUNS. D.B. Cline, First Aspen Winter Physics Conference, Aspen Center for Physics, Aspen, Colorado, January 6-19, 1985, Ed. M.M. Block, Annals of the New York Academy of Sciences, Vol. 461, New York Academy of Sciences, p. 487 (1986)

CALCULATION OF CLINICAL R.B.E. VALUES FOR NEUTRONS. L. Cohen, Int. J. Radiat. Biol., 50 (1), 147-154 (1986).

SUMMARY OF THE WORKSHOP ON TRIGGERING, DATA ACQUISITION AND OFFLINE COMPUTING AT HIGH ENERGY, HIGH LUMINOSITY HADRON-HADRON COLLIDERS. B. Cox, Proceedings of the UCLA Workshop, "Observable Standard Model Physics at the SSC: **Monte Carlo Simulation and Detector Capabilities**," Eds. H.-U. Bengtsson et al., January 15-24, 1986, p. 239.

SSC EVENT CHARACTERISTICS AND IMPLICATIONS FOR DETECTOR DESIGN. B. Cox et al., Proceedings of the Oregon Workshop on Super High Energy Physics, **Supercollider Physics**, Ed. D.E. Soper, World Scientific, p. 120 (1986)

TEST RESULTS AND DESIGN DETAILS OF THE TOHOKU BUBBLE CHAMBER MAGNET. W. Craddock et al., 1985 Cryogenic Engineering Conference, "Advances in Cryogenic Engineering," Plenum Press, New York, **31**, p. 191 (1986).

SUMMARY OF WORKING GROUP V, DATA ACQUISITION AND FILTERING SUB-GROUPS B (MODELS) AND C (SOFTWARE). D. Cutts et al., Proceedings of the Workshop on Triggering, Data Acquisition and Computing for High Energy/High Luminosity Hadron-Hadron Colliders, Fermilab, Batavia, Illinois, November 11-14, 1985, Eds. B. Cox et al., Fermilab, p. 211 (1986).

MODELLING MICROPROCESSOR FARMS FOR SSC DATA ACQUISITION. D. Cutts and C. van Ingen, Proceedings of the Workshop on Triggering, Data Acquisition and Computing for High Energy/High Luminosity Hadron-Hadron Colliders, Fermilab, Batavia, Illinois, November 11-14, 1985, Eds. B. Cox et al., Fermilab, p. 216 (1986).

THE RABBIT SYSTEM: LOW COST, HIGH RELIABILITY FRONT END ELECTRONICS FEATURING 16 BIT DYNAMIC RANGE. G. Drake et al., IEEE Trans. Nucl. Sci., **33** (1), p. 92 (1986).

A LARGE DYNAMIC RANGE CHARGE AMPLIFIER ADC FOR THE FERMILAB COLLIDER DETECTOR FACILITY. G. Drake et al., IEEE Trans. Nucl. Sci., **33** (1), p. 893 (1986).

TESTING OF THE SUPERCONDUCTING SOLENOID FOR THE FERMILAB COLLIDER DETECTOR. R.W. Fast et al., 1985 Cryogenic Engineering Conference, "Advances in Cryogenic Engineering," Plenum Press, New York, **31**, p. 181 (1986).

FIRST CAPTURE OF ANTIPROTONS IN A PENNING TRAP: A KILOELECTRON-VOLT SOURCE. G. Gabrielse et al., Phys. Rev. Lett. **57**, 2504 (1986)

PROSPECTS FOR EXPERIMENTS WITH TRAPPED ANTIPROTONS. G. Gabrielse et al., Proceedings of the First Workshop on Antimatter Physics at Low Energy, Fermilab, Batavia, Illinois, April 10-12, 1986, Eds. B.E. Bonner and L.S. Pinsky, p. 211 (1986).

SIGNAL FROM THE NATURAL RADIOACTIVITY OF DEPLETED URANIUM IN LIQUID ARGON. N.D. Giokaris et al., Nucl. Instrum. Meth. **A248**, 389 (1986)

THE MEETING OF TWO REALMS: LESSONS FROM THE TEVATRON FRONT END. M. Glass, Nucl. Instrum. Meth. **A247**, 133 (1986)

HEAT LEAK MEASUREMENT FACILITY. J.D. Gonczy et al., 1985 Cryogenic Engineering Conference, "Advances in Cryogenic Engineering," Plenum Press, New York, **31**, p. 1279 (1986).

THE PROPOSED MONITORING SYSTEM FOR THE FERMILAB D0 COLLIDING BEAMS DETECTOR. R. Goodwin et al., Nucl. Instrum. Meth. **A247**, 107 (1986)

FUTURE DETECTOR NEEDS FOR HIGH ENERGY PHYSICS. D. Green, IEEE Trans. Nucl. Sci., **33** (1), p. 60 (1986).

MUON TRIGGERING AT SMALL ANGLES. D. Green, Proceedings of the Workshop on Triggering, Data Acquisition and Computing for High Energy/High Luminosity Hadron-Hadron Colliders, Fermilab, Batavia, Illinois, November 11-14, 1985, Eds. B. Cox et al., p. 402 (1986).

FASTBUS RACK ALARMS AND LIMITS. M. Haldeman and S. Zimmerman, IEEE Trans. Nucl. Sci., **33** (1), p. 838 (1986).

FASTBUS COOLING. M. Haldeman et al., IEEE Trans. Nucl. Sci., **33** (1), p. 825 (1986).

FIRST RESULTS FROM A 1.1-m-DIAMETER SUPERCONDUCTING MONOPOLE DETECTOR. J. Incandela et al., Phys. Rev. D. **34**, 2637 (1986)

THE COLLIDER DETECTOR AT FERMILAB (CDF). The CDF Collaboration, H. B. Jensen (presentor), IEEE Trans. Nucl. Sci., **33** (1), p. 40 (1986).

SSC PHYSICS SIGNATURES AND TRIGGER REQUIREMENTS. G. Kane et al., Proceedings of the Workshop on Triggering, Data Acquisition and Computing for High Energy/High Luminosity Hadron-Hadron Colliders, Fermilab, Batavia, Illinois, November 11-14, 1985, Eds. B. Cox et al., Fermilab, p. 1 (1986).

A MULTIWIRE SECONDARY EMISSION BEAM PROFILE MONITOR WITH 20 μm RESOLUTION. J. Krider and C. Hojvat, Nucl. Instrum. Meth. **A247**, 304 (1986)

MEASURING HEAT LEAK WITH A HEATMETER. M. Kuchnir et al., 1985 Cryogenic Engineering Conference, "Advances in Cryogenic Engineering," Plenum Press, New York, **31**, p. 1273 (1986).

MINIMUM BIAS EVENT MULTIPLICITIES. J. Lach, Proceedings of the Oregon Workshop on Super High Energy Physics, **Supercollider Physics**, Ed. D.E. Soper, World Scientific, p. 276 (1986)

FAST NEUTRON AND MIXED BEAM RADIOTHERAPY FOR INOPERABLE NON-SMALL CELL CARCINOMA OF THE LUNG: RESULTS OF AN RTOG RANDOMIZED STUDY. G. E. Laramore et al., Am. J. Clin. Oncol., (CCT), 9 (3), 233-243 (1986).

EXPERIMENTAL FUTURE: SOME SOCIOLOGICAL COMMENTS ON HIGH ENERGY PHYSICS. L.M. Lederman, First Aspen Winter Physics Conference, Aspen Center for Physics, Aspen, Colorado, January 6-19, 1985, Ed. M.M. Block, Annals of the New York Academy of Sciences, Vol. 461, New York Academy of Sciences, p. 1 (1986)

INNER SPACE/OUTER SPACE. L. M. Lederman, Proceedings of the 10th Hawaii Topical Conference in High Energy Physics, August 26-31, 1985, Honolulu, Hawaii, Eds. F.A. Harris et al., University of Hawaii Press, p. 235 (1986).

PHYSICS WITH THE TEVATRON. L.M. Lederman, **Particles and Detectors**, Festschrift for Jack Steinberger, Eds. K. Kleinknecht and T.D. Lee, p. 165 (1986)

1986 RICHTMYER LECTURE: UNIFICATION, GRAND UNIFICATION, AND THE UNITY OF PHYSICS. L. M. Lederman, Am. J. of Phys., **54** (7), 594 (1986).

SCIENCE MUST GROW. L. M. Lederman, Science, May 30, 1986, Vol. 232, p. 1096.

SERMON FOR SCIENCE TEACHERS. L. M. Lederman, The Physics Teacher, September, 1986.

EVALUATION OF A NEUTRON BOOST IN HEAD AND NECK CANCER: RESULTS OF THE RANDOMIZED RTOG TRIAL 78-08. M. H. Maor, et al., Am. J. Clin. Oncol., 9 (1), 61-66 (1986).

CRYOGENIC COMPRESSIVE PROPERTIES OF BASIC EPOXY RESIN SYSTEMS. F.W. Markley et al., Advances in Cryogenic Engineering Materials, Plenum Press, New York, Eds. R.P. Reed and A.F. Clark, **32**, p. 119 (1986)

5-cm, NO IRON SSC 6-m DIPOLE TEST PROGRAM. P.O. Mazur et al., 1985 Cryogenic Engineering Conference, "Advances in Cryogenic Engineering," Plenum Press, New York, **31**, p. 37 (1986).

A SHORT REVIEW OF MONTE CARLO HADRONIC CASCADE CALCULATIONS IN THE MULTI-TeV ENERGY REGION. N.V. Mokhov and J.D. Cossairt, Nucl. Instrum. Meth. **A244**, 349 (1986)

HADRON SHOWERS IN IRON AND MUON IDENTIFICATION. T. Murphy et al., Nucl. Instrum. Meth. **A251**, 478 (1986)

THE FERMILAB ACCELERATOR CONTROLS NETWORKING SYSTEM. F.J. Nagy, Nucl. Instrum. Meth. **A247**, 208 (1986)

THE FERMILAB ADVANCED COMPUTER PROGRAM MULTI-MICROPROCESSOR PROJECT. T. Nash et al., Proceedings of Computing in High Energy Physics, Amsterdam, The Netherlands, June 25-28, 1985, Eds. L.O. Hertzberger and W. Hoogland, p. 375 (1986).

THERMAL SHIELD BOWING IN LONG SUPERCONDUCTING MAGNETS. T.H. Nicol et al., 1985 Cryogenic Engineering Conference, "Advances in Cryogenic Engineering," Plenum Press, New York, **31**, p. 81 (1986).

THE CRYOSTAT FOR THE SSC 6 T MAGNET OPTION. R.C. Niemann et al., 1985 Cryogenic Engineering Conference, "Advances in Cryogenic Engineering," Plenum Press, New York, **31**, p. 63 (1986).

DESIGN, CONSTRUCTION AND PERFORMANCE OF A POST TYPE CRYOGENIC SUPPORT. R.C. Niemann et al., 1985 Cryogenic Engineering Conference, "Advances in Cryogenic Engineering," Plenum Press, New York, **31**, p. 73 (1986).

REQUIREMENTS FOR SSC CENTRAL COMPUTING STAFFING (CONCEPTUAL). J. Pfister, Proceedings of the Workshop on Triggering, Data Acquisition and Computing for High Energy/High Luminosity Hadron-Hadron Colliders, Fermilab, Batavia, Illinois, November 11-14, 1985, Eds. B. Cox et al., Fermilab, p. 321 (1986).

THE CDF DATA ACQUISITION SYSTEM. D.R. Quarrie, IEEE Trans. Nucl. Sci. **32**, 1467 (1985)

ELEMENTARY PARTICLE PHYSICS AND THE SUPERCONDUCTING SUPER COLLIDER. C. Quigg and R. F. Schwitters, Science, **231**, 1522 (1986).

THE TEVATRON ORBIT PROGRAM. R. Raja et al., Nucl. Instrum. Meth. **A242**, 15 (1986)

NEUTRON DOSIMETRY WITH SILICON DIODES. C. Reft et al., (abstract), Medical Physics, 13 (4), p. 578 (July/Aug. 1986).

A CERIUM GLASS FIBER-OPTIC ACTIVE TARGET FOR HIGH ENERGY PHYSICS EXPERIMENTS. R. Ruchti et al., IEEE Trans. Nucl. Sci., **33** (1), p. 151 (1986).

AN INTELLIGENT CAMAC MODULE FOR ACNET TO GPIB INTERFACE. K. Seino et al., Nucl. Instrum. Meth. **A247**, 215 (1986)

AN EXPERIMENTAL STUDY OF HEAT TRANSFER IN MULTILAYER INSULATION SYSTEMS FROM ROOM TEMPERATURE TO 77 K. Q.S. Shu et al., 1985 Cryogenic Engineering Conference, "Advances in Cryogenic Engineering," Plenum Press, New York, **31**, p. 455 (1986).

NOISE THERMOMETRY WITH COMMERCIAL SQUIDS. Q.S. Shu et al., 1985 Cryogenic Engineering Conference, "Advances in Cryogenic Engineering," Plenum Press, New York, **31**, p. 1251 (1986).

THE FERMILAB ACCELERATOR CONTROL SYSTEM PARAMETER PROGRAM AND PLOTTING FACILITIES. J. G. Smedinghoff, Nucl. Instrum. Meth. **A247**, 172 (1986)

AN EDITING AND REPORTING SYSTEM FOR FERMILAB'S ACCELERATOR CONTROLS SYSTEM DATABASE. S. Sommers et al., Nucl. Instrum. Meth. **A247**, 259 (1986)

ACCELERATOR COMPUTER CONTROLS: PAST, PRESENT, AND FUTURE. M.R. Storm, Nucl. Instrum. Meth. **A247**, 1 (1986)

QUASIELASTIC NUCLEON TRANSFER AND THE HEAVY-ION INTERACTION POTENTIAL. A.M. van den Berg et al., Phys. Rev. Lett. **56**, 572 (1986)

ENERGY LOSS AND ANGULAR CHARACTERISTICS OF HIGH ENERGY ELECTROMAGNETIC PROCESSES. A. Van Ginneken, Nucl. Instrum. Meth. **A251**, 21 (1986)

RECENT OPERATING EXPERIENCE WITH THE FERMILAB CENTRAL HELIUM LIQUEFIER. R.J. Walker et al., 1985 Cryogenic Engineering Conference, "Advances in Cryogenic Engineering," Plenum Press, New York, **31**, p. 635 (1986).

THE FERMILAB ACCELERATOR CONTROL SYSTEM DATABASE. A.M. Waller, Nucl. Instrum. Meth. **A247**, 251 (1986)

FASTBUS REVIEW 1985. H.V. Walz and E. J. Barsotti, IEEE Trans. Nucl. Sci., **33** (1), p. 768 (1986).

A SURFACE MOUNT AMPLIFIER-SHAPER-DISCRIMINATOR AND PREAMPLIFIER FOR THE FERMILAB CDF TRACKING CHAMBERS. R.J. Yarema et al., IEEE Trans. Nucl. Sci., **33** (1), p. 933 (1986).

DESIGNING AND CONSTRUCTION OF A 11-T SUPERCONDUCTING MAGNET SYSTEM WITH A 30 mm DIAMETER 4.2-400 K BORE. K. Yu et al., 1985 Cryogenic Engineering Conference, "Advances in Cryogenic Engineering," Plenum Press, New York, **31**, p. 209 (1986).

SMARTER SYSTEMS/SMARTER DIAGNOSTICS. J.R. Zagel and L.J. Chapman, Nucl. Instrum. Meth. **A247**, 167 (1986)

First Workshop On
Antimatter Physics at Low Energy

Fermi National Accelerator Laboratory **April 10-12, 1986**

Scope

The goal of this workshop is to gauge the interest in physics that would be accessible by addin variable-energy antiprotion storage and cooling ring to the existing Accumulator at Fermilab The range of possibilities include provision for an internal gas jet, extracted beams, trappin and cooling $\bar{p}$'s as well as a $\bar{p}p$ collider-mode spanning center-of- mass energies through bottomonium. This workshop will bring together the interested physics community, accelerator physicists, Fermilab staff and management, and representatives of the fundi agencies for discussion of these physics possibilities. The anticipated result of the workshop is a clear view of the physics arguments for proceeding with a formal desig study and eventually a proposal for an intermediate-energy antiproton ring at Fermi

Topics

Charmonium and Bottomonium • Low Temperature PBars and Tr
Polarized Antiprotons • Interdisciplinary Applications • Exoti
Invariance Principle Tests • Nuclei as a Laboratory
Color Chemistry • PBar Atoms

Speakers

S. Brodsky, SLAC • M. Chanowitz, LBL • C. Dover, BNL
M. Hynes, LANL • K. Kilian, Julich
E. Steffens, Heidelberg and others

Organizing Committee

B. Bonner, Rice University, Co-Chair
L. Pinsky, Houston, Co-Chair
V. Bharadwaj, Fermilab
S. Brodsky, Stanford-UCSB
C. Dover, BNL
C. Hojvat, Fermilab
M. Hynes, LANL
W. Kells, Fermilab
K. Kilian, CERN/Julich
K. Meshkov, NBS
M. Nieto, LASL/NB Copenhagen
M. Olsson, Wisconsin
J. Peoples, Fermilab
P. Rapids, Fermilab
J. Rosner, Chicago
M. Sakitt, BNL
L. Teng, Fermilab

For Information Contact:

Phyllis Hale
Fermilab Users Office
P.O. Box 500, M.S. No.
Batavia, Illinois 60
Telephone:
312-840-3111
FTS: 370-31

Color Chemistry • PBar Atoms
Invariance Principle Tests • Nuclei as a Laboratory
Polarized Antiprotons • Interdisciplinary Applications • Exotica
Charmonium and Bottomonium • Low Temperature PBars and Traps
Topics
study and eventually a proposal for an intermediate-energy antiproton ring at Fermilab.
workshop is a clear view of the physics arguments for proceeding with a formal design
agencies for discussion of these physics possibilities. The anticipated result of the
accelerator physicists, Fermilab staff and management, and representatives of the funding
bottomonium. This workshop will bring together the interested physics community,
and cooling $\bar{p}$'s as well as a $\bar{p}p$ collider-mode spanning center-of- mass energies through
The range of possibilities include provision for an internal gas jet, extracted beams, trapping
variable-energy antiprotion storage and cooling ring to the existing Accumulator at Fermilab.
The goal of this workshop is to gauge the interest in physics that would be accessible by adding a
Scope
Fermi National Accelerator Laboratory April 10-12, 1986
Antimatter Physics at Low Energy
First Workshop On

Appendix B
1986 Workshops, Seminars, and Colloquia

Director's Special Colloquia on Topics in High-Energy Physics

E. Witten, Princeton University: "Superstring Theory," January 23, 1986

V. Fitch, Princeton University: "Strange Matter," February 14, 1986

J. Peoples, Fermilab: "The Antiproton-Proton Collider," March 6, 1986

A. Sessler, Lawrence Berkeley Laboratory: "Accelerators of the Future," March 13, 1986

J. Cronin, The University of Chicago: "CP: Past, Present & Future," March 20, & May 1, 1986

B. Richter, Stanford Linear Accelerator Center: "Linear Colliders," April 3, 1986

I. Singer, Massachusetts Institute of Technology: "The Mathematics of String Theory," April 10, 1986

Director's Review of Accelerator Status and Upgrade Program

K. Ng, J. Reid, J. Crisp, P. Lucas, P. Martin, and D. Wildman, Fermilab: "Coherent Instabilities and Impedance," May 5, 1986

G. Fisk, A. Tollestrup, L. Michelotti, R. Gerig, N. Gelfand, and D. Edwards, Fermilab: "Magnets, Field Quality, and Tracking - The Main Ring," May 10, 1986

M. Gormley, G. Dugan, V. Bharadwaj, J. Peoples, J. Marriner, R. Pasquinelli, J. McCarthy, and J. Griffin, Fermilab: "Status Report on a Proposal to Increase the $\bar{p}$ Source Accumulation Rate to 4×10^{11}/hr," May 20, 1986

C. Ankenbrandt, C. Curtis, D. Young, S. Ohnuma, A. Moretti, and S. Holmes, Fermilab: "Space Charge in the Booster - Proposals for Improvement - Linac Upgrade," June 14, 1986

D. Finley, R. Johnson, Q. Kerns, F. Mills, R. Shafer, P. Mantsch, T. Peterson, and D. Edwards, Fermilab: "Energy Doubler Low-β and Possible Upgrades," July 3, 1986

A. Tollestrup, P. Koehler, P. Grannis, and D. Nygren, Fermilab: "Experimenters' Reaction - Loose Ends," July 14, 1986

Special Fermilab Colloquium

Yamaguchi, University of Tokyo, Japan: "The Nucleus as Seen from Hadron Physics," January 21, 1986

Fermilab Colloquia

L. Davis, University of Maryland: "A Visual Navigation System for Autonomous Lead Vehicles," January 8, 1986

D. McCarthy, Jr., University of Arizona: "Infrared Imaging and the Search for Other Planetary Systems," January 15, 1986

D. Gordon, University of Illinois-Medical Center: "Noise in the Heart," February 5, 1986

J. Ormes, NASA Goddard Space Flight Center: "The Particle Astrophysics Magnet Spectrometer: A Facility for a Space Station," February 12, 1986

R. Terrile, Jet Propulsion Laboratory: "Latest Results of the Voyager Encounter with Uranus," February 26, 1986

P. Theuer, U.S. Army Construction Engineering Research Laboratory: "Technology Transfer Opportunities from a Construction-Management Oriented Lab," March 12, 1986

B. Sodoulet, University of California, Berkeley: "Prospects for the Detection of Dark Matter from the Halo of Our Galaxy," March 26, 1986

C. O. Qualset, University of California, Davis: "Biological Diversity and its Conservation," April 16, 1986

A. Stockton, University of Hawaii: "Emission - Line Regions Around Quasi-Stellar Objects," May 1, 1986

D. Kocian, Armstrong Aerospace Medical Research Laboratory: "Visually-Coupled System Technology," May 21, 1986

D. Rennie, Rush Medical College: "Thin, Cold Air: The Physiology of High Altitudes," September 12, 1986

P. Steinhardt, University of Pennsylvania: "Quasicrystals - A New Form of Matter," October 1, 1986

A. DeRujula, CERN and Boston University: "The Sixth or Seventh Force," October 15, 1986

R. Britten, California Institute of Technology: "DNA Sequence Comparison and the Process of Evolution," October 22, 1986

P. Limon, SSC Central Design Group and Fermilab: "Current SSC Research and Development," October 29, 1986

A. Ashkin, AT&T Bell Labs: "Optical Molasses," November 7, 1986

W. Klemperer, University of Illinois Champaign-Urbana: "A Molecular Building Block Approach to the Synthesis of Ceramic Materials," November 19, 1986

E. Stone, Jr., California Institute of Technology: "The Voyager II Encounter with Uranus," December 3, 1986

R. Siemann, Cornell University: "Advanced Accelerator Techniques," December 10, 1986

D. Hitlin, California Institute of Technology: "Weak Decays of Heavy Quarks," December 17, 1986

Accelerator Seminars

B. Siemann, Cornell University/Fermilab: "The Operation of CESR," November 4, 1986

F. Mills et al., Fermilab: "Report on the Conference on the Application of Accelerators in Research and Industry," November 18, 1986

A. McInturff, Fermilab: "Modern Conductor Development for the SSC Magnet," December 9, 1986

Advanced Computer R&D Seminars

P. LePage, Cornell University: "GIBBS - A Programming Environment and Work Station for Scientists," February 17, 1986

Beams Group Seminars

R. Stefanski, Fermilab: "The N-East Beamline," January 16, 1986

S. Childress, Fermilab: "Switchyard for the Next Run," February 13, 1986

Computing Technique Seminars

E. Futo, CERN/DD: "Experience with the ADA Language," October 17, 1986

P. Bono, ANSI X3H3 Chairman: "Computer Graphics Standards," October 21, 1986

Engineering Seminars

L. Adams and R. Templeton, Texas Instruments: "Silicon Connection to the IBM Token Ring Lan," January 21, 1986

A. Baumbaugh, Fermilab: "Video Tape of Halley's Comet, Enhanced through Use of the Video Data Acquisition System," February 13, 1986

R. Karklys, Dytec Central: "Tutorial on Use of PERSONAL CAD Schematic Capture and PCB Layout System," February 14, 1986

Nonlinear Dynamics Seminars

*H. Ralph Lewis, Los Alamos National Laboratory: "Exact Invariants for One Degree of Freedom Systems with Time Dependent Potentials," October 11, 1985

*C. Robinson, Northwestern University: "Melnikov Method for Showing Nonintegrability of Perturbations of Hamiltonian Systems," October 25, 1985

*P. J. Holmes, Cornell University: "Rigorous Results for Perturbed Hamiltonians," November 8, 1985

*J. Niederer, Brookhaven National Laboratory: "A Tool Kit for Nonlinear Orbit Studies," November 22, 1985

*H. B. Stewart, Brookhaven National Laboratory: "The Lorenz System and Catastrophic Bifurcation," December 20, 1985

*J. Crutchfield, University of California, Berkeley: "Quantifying Chaos," December 6, 1985

G. Mayer-Kress, Los Alamos National Laboratory: "Methods and Problems in Analyzing Chaotic Data," January 31, 1986

T. Y. Li, Michigan State University: "Continuation Methods for Nonlinear Equations," February 7, 1986

J. Wisdom, Massachusetts Institute of Technology: "Chaotic Behavior in the Solar System," February 21, 1986

J. A. Ellison, University of New Mexico: "The Method of Averaging and its Application to Particle Channeling in Crystals," March 7, 1986

R. McGehee, University of Minnesota: "Singularities in Classical Celestial Mechanics," March 21, 1986

R. Warnock, Lawrence Berkeley Laboratory: "Computation of Invariant Surfaces in Phase Space by the Hamilton-Jacobi Method," October 10, 1986

R. Ruth, Stanford Linear Accelerator Center: "Renormalization: The Route to Chaos in a Hamiltonian System," November 21, 1986

R. Williams, Northwestern University: "Knots in Dynamical Systems: How They Occur and How They are Used," December 12, 1986
**Omitted from the Fermilab 1985 Annual Report*

Research Division Seminars

P. Garbincius, Fermilab: "Status of the Fixed-Target Program," July 10, 1986

D. Anderson, Fermilab: "The Physics and Chemistry of Liquid Ionization Chambers," September 11, 1986

E. Futo, CERN: "WRAP4 Program for Use in the Design and Manufacture of Prototype Wire-Wrap Boards," September 18, 1986

P. Lebrun, Fermilab: "Pattern Recognition in Charged Particle Detectors," September 25, 1986

B. Cox, Fermilab: "Heavy Flavor Physics at the SSC," October 2, 1986

E. Futo, CERN: "State of the Art in Automatic Wire-Wrap Machines at CERN," October 16, 1986

J. Eades, CERN: "Results from the Omega RICH Detector," November 6, 1986

J. Morfín, Fermilab: "Survey of Muon Physics," November 13, 1986

T. Nash, Fermilab: "ACP," November 20, 1986

K. Dixon and R. Stanek, Fermilab: "Report on Cryogenic Symposium at Miami on November 2-7, 1986," December 4, 1986

J. Morfín, Fermilab: "Study of Hadron Showers from Muoproduction," December 18, 1986

Special Research Division Seminars

V. Radeka, Brookhaven National Laboratory: "Signal Formation in Detectors, Noise: Origin and Properties, Lecture I," September 30, 1986

V. Radeka, Brookhaven National Laboratory: "Physical Source of Noise, Charge Amplification and Related Noise, Filtering, Amplitude, Time and Waveform Measurements, Some Circuit Considerations, Lecture II," September 30, 1986

V. Radeka, Brookhaven National Laboratory: "Position Sensing Methods: Delay Line Sensing, Charge Division, Centroid Finding Methods, Lecture III," October 1, 1986

V. Radeka, Brookhaven National Laboratory: "Drift Chambers and Proportional Detectors for Very High Counting Rates, TPC's and 'pad' Detectors, Semiconductor Detectors, Ionization Chamber Calorimeters, Lecture IV," October 1, 1986

W. Smart, Fermilab: "Holography in Bubble Chamber Physics; Especially the 15'," October 21, 1986

P. Mine, CERN: "Operation of a BaF2-TMAE Calorimeter," November 3, 1986

G. Charpak, CERN-EP: "Research on Particle Detectors - Goals and Results," November 24, 1986

Research Technique Seminars

B. Wagner, M. Atac, and D. Christian, Fermilab: "Some Results from the Workshop on Aging in Wire Chambers," February 6 & 20, 1986

M. Johnson, Fermilab: "Data Acquisition System for D0," February 27, 1986

H. Johnstad, Fermilab: "Data Structure and Memory Management in FORTRAN," March 6, 1986

T. Ypsilantis, College de France and University of California, Los Angeles: "Advances in Cherenkov Ring Imaging Detectors," March 13, 1986

T. Ypsilantis, College de France and University of California, Los Angeles: "Particle Identification at the SSC," March 14, 1986

T. Taniguchi, KEK: "A FADC System for TPC Detectors," March 20, 1986

G. Fanourakis, University of Rochester: "Highlights from the Vienna Wire Chamber Conference," April 3, 1986

G. Parrini, University of Firenze, Italy: "CCD's as HEP Detectors at Room Temperature: Practical Use and Test Results on Particle Beams," April 9, 1986

E. Siskind, NYCB Real-Time Computing, Inc.: "A MicrovaxII/FASTBUS Intelligent Interface," May 27, 1986

E. Siskind, NYCB Real-Time Computing, Inc.: "High Bandwidth Front End Digital Signal Processing for Drift Chambers," June 3, 1986

T. Carroll, R. Kephart, A. Menzione, and M. Sheaff, Fermilab: "Highlights of the 2nd San Miniato Conference on Experimental Apparatus," July 10, 1986

Special Seminars

S. Durkin, University of Pennsylvania: "A Precision Measurement of the Weak Neutral Current," February 14, 1986

C. Daum, NIKHEF, Amsterdam: "New Charm Lifetime Results from NA32 (ACCMOR)," May 19, 1986

Yu-Chiu Chao, University of Michigan: "Effective Langrangians for General Chiral Theories," June 5, 1986

J. Milutinovic, Carnegie-Mellon University: "Particle Tracking Using Lie Algebraic Methods," June 12, 1986

A. Clark, CERN: "Recent Results from UA2," June 25, 1986

T. Fujii, Kobe University, Japan: "TRISTAN Project," July 28, 1986

S. C. Cooper, Stanford Linear Accelerator Center: "Hadron Spectroscopy with the Crystal Ball and Others," October 3, 1986

N. Cabibbo, INFN and University of Rome, Italy: "The Gran Sasso Underground Laboratory," October 9, 1986

R. Wigmans, CERN/Amsterdam: "Compensation Mechanisms in Hadron Calorimeters," November 26, 1986

R. Weiss, Massachusetts Institute of Technology: "Search for Gravitational Waves," December 3, 1986

S. C. C. Ting, Massachusetts Institute of Technology: "Photons, Leptons, Quarks, Gluons, and Others," December 16, 1986

Theoretical Physics Seminars

V. Kaplunovsky, Princeton University: "Mass Scales in Superstring Theories," January 15, 1986

M. Rubin, Fermilab: "Tomonaga-Schwinger-Dirac Formalism for String Theory," January 21, 1986

M. Peskin, Stanford Linear Accelerator Center: "Gauge Invariant Strings and Superstrings," January 28, 1986

G. Semenoff, University of British Columbia, Canada: "Berry's Phase and the Quantization of Chiral Gauge Theories," January 30, 1986

R. Nepomechie, University of Washington: "Chern-Simons Term, Kaluza-Klein Theory, and Strings," February 4, 1986

S. Sharpe, Harvard University: "Lattice QCD: Beyond the Mass Spectrum," February 6, 1986

D. Boyanovsky, Stanford Linear Accelerator Center: "New Results in Three Dimensional Gauge Theories," February 11, 1986

Y. Kitizawa, The University of Chicago: "Lepton-Lepton and Lepton-Jet Correlations Up to the Z^0 Resonance," February 18, 1986

P. Pal, University of Maryland: "Spontaneous Parity Violation as the Origin of Isospin Breaking," February 20, 1986

H.Y. Cheng, Indiana University: "Non-Leptonic Decays of Charmed Mesons," February 25, 1986

V. Baluni, CERN: "Dynamical Symmetry Breaking Beyond MAC," March 3, 1986

I. Bigi, Stanford Linear Accelerator Center: "Mixing and CP Violation: Subtle Effects in Heavy Flavor Decays," March 4, 1986

L. Dolan, Rockefeller University: "Kac-Moody Algebras for Compactified Strings I," March 10, 1986

L. Dolan, Rockefeller University: "Kac-Moody Algebras for Compactified Strings II," March 11, 1986

L. Dolan, Rockefeller University: "Modular Subgroup Invariance in a Four-Dimensional String," March 11, 1986

A. Hosoya, Fermilab: "Ginzburg-Landau Type Effective Theory for the Chiral and Deconfinement Transition," March 18, 1986

J. Sexton, Fermilab: "QCD Radiative Corrections to Parton-Parton Scattering," March 25, 1986

J. Polony, Massachusetts Institute of Technology: "Boundary Conditions and Radiative Breakdown of Color Symmetry," April 1, 1986

E. d'Hoker, Columbia University: "Multi-loop Amplitudes in String Theory," April 2, 1986

B.-A. Li, Institute for High Energy Physics, Beijing, People's Republic of China: "The Skyrmion Equation and EM Mass Shift of Proton and Neutron," April 8, 1986

J. Zhang, Shahxi University, People's Republic of China: "Singularities and Spectrum of the System of Fermion-Dirac...," April 9, 1986

M. Wise, California Institute of Technology: "Is the Universe Trivial?" April 15, 1986

B. Ovrut, University of Pennsylvania: "Splitting the Superstring Vacuum Degeneracy," April 22, 1986

L. Alvarez-Gaume, Harvard University: "0(16)x0(16) Heterotic String, or, Yet Another Theory of the Universe," April 29, 1986

A. Nelson, Harvard University: "Strange Goings-on in Neutron Start, or, the Effects of Kaon Condensates (Like Pion Condensates) in Finite Density Nuclear Matter," May 6, 1986

O. Martin, University of Illinois, Champaign-Urbana: "Exact Strong Coupling Spectrum with SLAC Fermions, or, Why Even with an Arbitrary Bare Mass, the SLAC Derivative Gives a Sick Spectrum," May 13, 1986

M. Karliner, Stanford Linear Accelerator Center: "Meson-Baryon Scattering: from QCD Via Skyrmions to Experiment," May 22, 1986

L. Dixon, Princeton University: "Scattering Amplitudes for Strings on Orbifolds," May 27, 1986

F. Karsch, University of Illinois, Champaign-Urbana: "Problems with Finite Density Simulations of Lattice QCD," June 5, 1986

G. Marchesini, University of Parma, Italy: "The IR Problem in QCD: Theoretical and Phenomenological Relevance," June 12, 1986

P. Ginsparg, Harvard University: "Compactifications of Various String Theories," June 19, 1986

G. Hou, University of Pittsburgh: "CP Violation in W and Z Decays," June 26, 1986

C. Albright, Northern Illinois University: "Search for a Solution of the E_6 Superstring Neutrino Mass...," July 3, 1986

A. Georges, P. Le Doussal, Ecole Normale, Paris: "A Sizeable Low-Energy Effect of Supersymmetry...,"July 8, 1986

E. S. Velasco, Cornell University: "Elementary Scalar Particles: Is There Any Hope?" July 17, 1986

T. Matsuki, Louisiana State University: "New Effective Potential for Chiral Symmetry Breaking," July 24, 1986

K. Bitar, Florida State University and American University of Beirut, Lebanon: "A New Method for MCRG on the Lattice," July 31, 1986

W. Zakrzewski, University of Durham, England: "Extended Structures Based on Sigma Models," August 5, 1986

A. Khare, The University of Illinois at Chicago and Institute of Physics at Bhubhaneswhar, India: "Charged Vortices in Topologically Massive Gauge Theories," August 7, 1986

M. Voloshin, ITEP, Moscow: "Neutrino Magnetic Moment and Time Variation Over the Solar Neutrino Flux," August 11, 1986

M. Mueller, Institute for Advanced Study: "Twisted Narain Compactifications of the Hecterotic String," August 14, 1986

J. Kodaira, Hiroshima University: "Renormalization of $(\theta^3)6$ Theory in Curved Space," August 21, 1986

S. Glazek, Institute of Theoretical Physics, Warsaw University, Poland: "Structure of Hadrons and QCD Condensates on the Light Front," August 28, 1986

R. Jackiw, Massachusetts Institute of Technology: "Representing Conformal Transforms and Particle Production," September 4, 1986

M. Mattis, The University of Chicago: "2-D Conformal Green's Functions Made Easy," September 11, 1986

M. Bander, University of California, Irvine: "Hamiltonian Formulation of Lattice Gravity," September 16, 1986

D. Lust, California Institute of Technology: "Covariant Heterotic String and Odd Self-Dual Lattices," September 18, 1986

M. Mangano, Fermilab: "Status of String Theory," September 25, 1986

K. Lee, Fermilab: "Tunnelling Without Barriers," October 2, 1986

Y. Hosotani, University of Minnesota: "Theory of Line Functionals and String Dynamics," October 9, 1986

P. Arnold, Fermilab: "Signatures of Extended Technicolor at the SSC," October 16, 1986

V. Novikov, ITEP, Moscow: "Superinstantons," October 23, 1986

H. B. Nielsen, Niels Bohr Institute, Denmark: "Gauge Glass: A Random Gauge Theory," October 30, 1986

U. Baur, Fermilab: "Limits on Composite Isoscalar Vector Bosons from Future e^+ - e^- Colliders," November 4, 1986

T. Appelquist, Yale University: "Chiral Hierarchies and Technicolor," November 6, 1986

D. Richards, Argonne National Laboratory: "Lattice Gauge Theory Calculations of Proton Decay Matrix Elements," November 12, 1986

F. Gilman, SLAC: "Physics at the Z^0," November 13, 1986

H. Fritzsch, Max Planck Institute, Germany: "Internal Symmetries of the Quark Mass Matrix: Signals of Substructure," November 17, 1986

P. Ramond, University of Florida, Gainesville: "Some Issues in the Quantum Field Theory of Strings," November 20, 1986

K. Stelle, Institute for Advanced Study and Imperial College, England: "Effective Field Theory for Superstrings," December 4, 1986

W. Zimmerman, Max Planck Institute, Germany: "Applications of the Reduction Method to the Standard Model," December 9, 1986

N. Cabibbo, University of Rome, Italy: "APE - A Supercomputer for Lattice Gauge Theory," December 10, 1986

O. Alvarez, University of California, Berkeley: "Geometrical Aspects of Conformal Field Theory," December 11, 1986

Joint Experimental-Theoretical Physics Seminars

A. Chodos, Yale University: "Is There a New Neutral Particle Below 2 MeV?" January 10, 1986

C. James, University of Minnesota: "The Measurement of the Branching Ratio $\Xi^0 \rightarrow \Delta\gamma$ (E619)," January 24, 1986

J. Wotschack, CERN: "High Precision Measurement of Sin θ_W," January 31, 1986

C. A. Heusch, University of California, Santa Cruz: "Testing Lepton Number Conservation at High Q^2," February 7, 1986

A. Mukherjee, Massachusetts Institute of Technology: "Azimuthal Asymmetry in Deep Inelastic Neutrino Scattering," February 28, 1986

R. Baier, University of Bielefeld, Germany: "Prompt Photon Production and Perturbative QCD (Beyond the Leading Order)," March 14, 1986

G. E. Forden, Rutherford Laboratory: "Heavy Flavor Lifetime Measurements by TASSO," March 31, 1986

M. Derrick, Argonne National Laboratory: "Multiplicities in e^+e^- Annihilation and the Nature of Hadronic Interactions," April 4, 1986

L. O'Raifeartaigh, University College, Dublin, Ireland "The U(1) Anomaly and the Bohm-Aharanov Phase Shift," April 4, 1986

K. Pretzl, Max Planck Institute, Germany: "Direct Photon Production - NA24," April 11, 1986

C. Wright, The University of Chicago: "Flavor Change in μ Decay?" April 18, 1986

H. Melanson, Fermilab: "Polarization of Λ and $\overline{\Lambda}$ Produced by Protons, Anti-Protons, and Kaons," April 25, 1986

J. Spalding, Fermilab: "First Results from E-691 - Charmed Particle Photoproduction," May 9, 1986

J. Cronin, The University of Chicago: "A Proposal for Ultra High Energy γ-Ray Astronomy," May 16, 1986

U. Schneekloth, University of Hamburg, Germany: "Jade Results on τ-Leptons," May 23, 1986

H. Fenker, Fermilab: "Charm Cross-Sections and Charged Multiplicities in pp Collisions at $\sqrt{s} = 38{\cdot}8$ GeV (E743)," May 30, 1986

H. Ogren, Indiana University: "Lifetime Measurements with HRS at PEP," June 20, 1986

P. Oddone, Lawrence Berkeley Laboratory: "Recent Results from TPC," June 27, 1986

A. Blondel, CERN: "Recent Measurement of $\sin^2\theta w$ from CDHS at CERN," July 9, 1986

R. Erickson, Stanford Linear Accelerator Center: "The SLAC Linear Collider - The First of a New Generation," July 11, 1986

P. Charpentier, SACLAY: "Latest Results from NA3," July 25, 1986

A. R. Weidberg, CERN: "New Results from UA2," August 1, 1986

R. Szwed, University of Warsaw, Poland: "KNO Scaling, Negative Binomial Distribution and Multiplicities at the Supercollider," July 30, 1986

H. Schellman and co-speaker, The University of Chicago: "Report on the Berkeley Conference," August 8, 1986

S. Parke, Fermilab: "Resonant Neutrino Oscillations and the Solar Neutrino Experiments," September 5, 1986

S. Ellis, University of Washington: "The Standard Model (and More?) at Hadron Colliders," September 12, 1986

T. Mattison, Massachusetts Institute of Technology: "Neutral Current Structure Functions from E-594," September 26, 1986

I. Bigi, Stanford Linear Accelerator Center: "Ultra-Heavy Quarks; Production and Decay at e^+e^- Machines and Hadron Colliders," October 3, 1986

J. J. van der Bij, Fermilab: "Experimental Constraints on Deviations from the Standard Model," October 10, 1986

J. F. Owens, Florida State University: "Direct Photon Production: A Review of Recent Results," October 17, 1986

M. Quiros, CERN: "New Z Bosons from E_6 in Hadron Collider," October 17, 1986

J. L. Rosen, Northwestern University: "Some Re-interpretations of Heavy Quark Bound States Including X(2.2), $c\bar{c}$ and bb Systems," October 28, 1986

J. Wilkerson, Los Alamos National Laboratory: "Limits on the Electron Anti-Neutrino Mass from Tritium Beta Decay Measurements," November 21, 1986

J. Prentice, University of Toronto, Canada: "Recent Results from Argus," December 5, 1986

B. Straub, University of Washington: "Particle Ratios and A-Dependence of High P_T Hadrons," December 19, 1986

Theoretical Astrophysics Seminars

K. Olynyk, Fermilab: "Is Inflation a Stochastic Process?" January 20, 1986

N. Turok, Imperial College, England: "Can One Avoid a Void Problem?" January 29, 1986

D. Page, Pennsylvania State University: "Inflation, Flatness, and Entropy in Hawking's State of the Universe," February 10, 1986

E. Farhi, Massachusetts Institute of Technology: "Strange Matter in the Universe," February 17, 1986

M. Haugan, Purdue University: "Local Lorentz Invariance: Significant New Atomic Physics Tests," February 24, 1986

L. Parker, University of Wisconsin at Milwaukee: "Curvature Induced Asymptotic Freedom," March 10, 1986

D. Bennett, Stanford Linear Accelerator Center: "Evolution of Cosmic Strings," March 17, 1986

B.L. Hu, University of Maryland: "Quantum Geometric Effects in Inflationary Cosmologies," March 24, 1986

R. Flores, Brandeis University: "Is the Universe Radiation Dominated?" March 31, 1986

R. Brandenberger, Cambridge University, England: "Gravitational Radiation from Cosmic Strings," April 4, 1986

F. Stecker, NASA/Goddard Space Flight Center: "Cosmic Ray Antiprotons; What Are They Telling Us?" April 7, 1986

A. Albrecht, Los Alamos National Laboratory: "Evolution of Cosmic Strings - Possible Seeds for Galaxies," April 14, 1986

M.S. Turner, Fermilab and The University of Chicago: "Double Inflation," April 21, 1986

R.V. Wagoner, Stanford: "Lensing of Supernovae by Dark Matter Candidates," April 25, 1986

F. Li Zhi, Institute for Advanced Study: "Observational Cosmology of the Global Topology of the Universe," April 28, 1986

J. Frieman, Stanford Linear Accelerator Center: "Axions and Stars," May 5, 1986

S.-Y. Pi, Boston University: "Quantum Mechanics of a Slow Rollover Transition," September 8, 1986

A. Burd, Sussex University, England: "Three Dimensional General Relativity," September 15, 1986

A. Olinto, Massachusetts Institute of Technology: "Strange Matter in the Universe," September 22, 1986

F. Tipler, Tulane University: "Classical Inflation Versus Quantum Inflation," September 29, 1986

M. Quiros, CERN: "Inflation and Supersymmetry Breaking in Low Energy Superstring Theories," October 6, 1986

J. Stein-Schabes, Fermilab: "Is Inflation Natural?" October 20, 1986

L. Ford, Tufts University: "Gravitational Particle Creation and Inflation," October 27, 1986

D. Lamb, The University of Chicago: "The Physics of γ-Ray Bursts," November 3, 1986

B. Grinstein, California Institute of Technology: "Interpretation of Large-Scale Deviations from the Hubble Flow," November 10, 1986

P. Sikivie, University of Florida: "Estimates of the Density of Dark Matter Near the Center of the Galaxy," December 1, 1986

P. Shellard, DAMTP, Cambridge, England: "Intercommuting Properties of Cosmic Strings," December 8, 1986

Workshops

First Workshop on Antimatter Physics at Low Energy
April 10 - 12

Workshop on Networking
October 23 - 24

Cosmic String Workshop
December 11 - 13

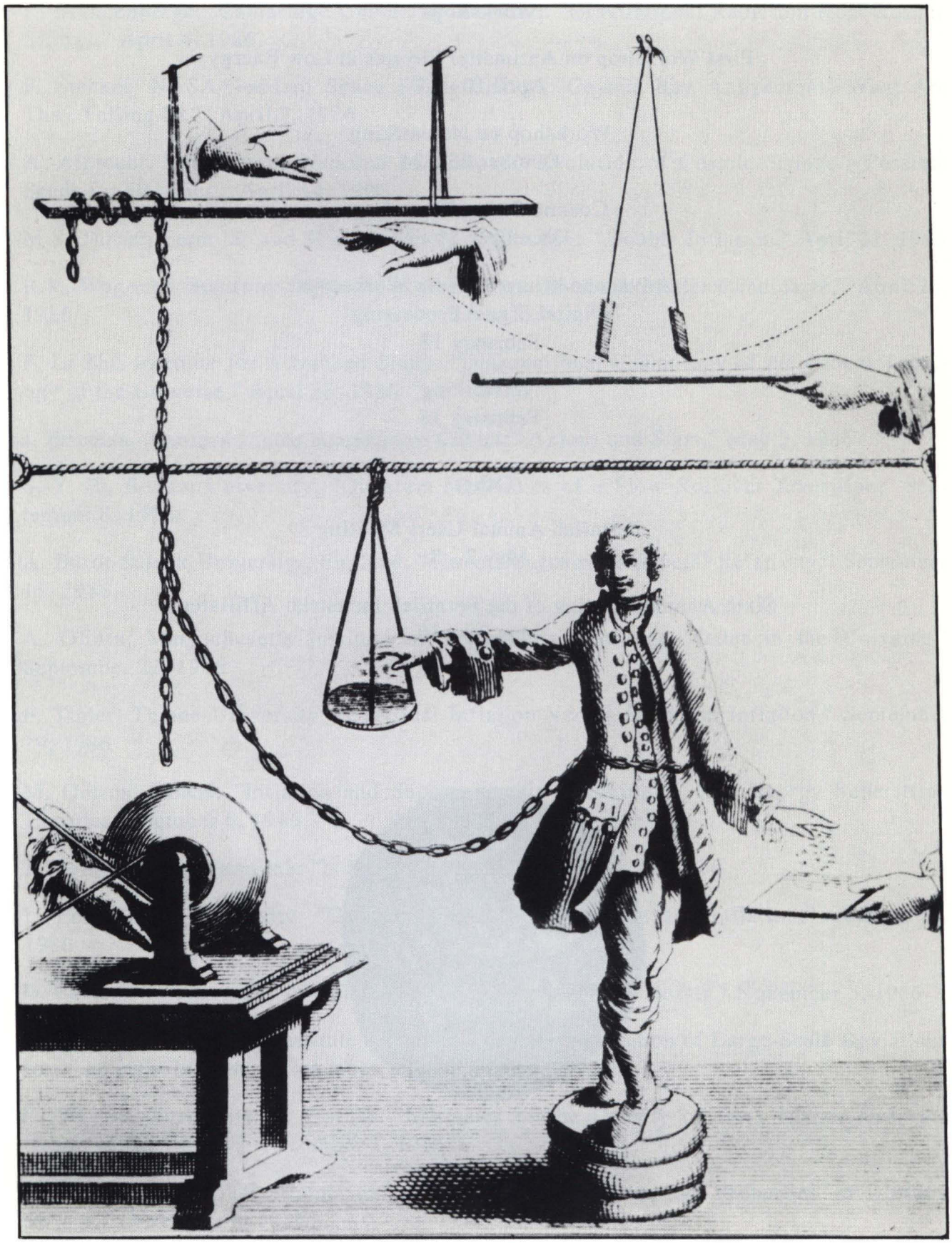
Advanced Micro Devices Workshops:
"Digital Signal Processing"
February 18

"Networking"
February 18

Other

Fermilab Annual Users Meeting
May 2 - 3

Sixth Annual Meeting of the Fermilab Industrial Affiliates
May 29 - 30



Appendix C
Approved Experiments in the Fermilab Fixed-Target and Collider Programs

Fixed Target

Electroweak

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

E-635 LONG-LIVED NEUTRAL PARTICLES (Fermilab, Virginia Polytech)

E-636 BEAM DUMP NEUTRINOS IN 1-METER CHAMBER (Beijing, Brown, Fermilab, Haifa, Indiana, MIT, Oak Ridge, Tel-Aviv, Tennessee, Tohoku, Tohoku Gakuin)

E-646 BEAM DUMP NEUTRINOS IN 15-FT CHAMBER (UC/Berkeley, Fermilab, Hawaii, IIT, Rutgers, Stevens, Tufts)

E-652 NEUTRINO PHYSICS WITH DICHROMATIC BEAM (Chicago, Columbia, Fermilab, Rochester)

E-665 MUON SCATTERING WITH HADRON DETECTION (Argonne, Cracow, Fermilab, Freiburg, Harvard, Illinois/Chicago, Maryland, MIT, Munich, San Diego, Washington, Wuppertal, Yale)

E-733 NEUTRINO INTERACTIONS WITH QUAD TRIPLET BEAM (Fermilab, Florida, MIT, Michigan State)

E-745 NEUTRINO PHYSICS WITH QUAD TRIPLET BEAM (Beijing, Brown, Fermilab, Haifa, Indiana, MIT, Nagoya, Oak Ridge, Tel-Aviv, Tennessee, Tohoku, Tohoku Gakuin)

E-770 NEUTRINO PHYSICS WITH QUAD TRIPLET BEAM (Chicago, Columbia, Fermilab, Rochester)

Decays and CP

E-721 CP VIOLATION (Arizona, Athens, Duke, Fermilab, McGill, Northwestern, Shandong)

E-731 MEASUREMENT OF ε'/ε (Chicago, Elmhurst, Fermilab, Princeton, Saclay)

E-756 Ω^- MAGNETIC MOMENT (Fermilab, Michigan, Minnesota, Rutgers)

E-761 HYPERON RADIATIVE DECAY (Fermilab, Iowa, Leningrad, Sao Paulo, Yale)

E-773 PHASE DIFFERENCE BETWEEN η_{oo} AND η_{+-} (Chicago, Elmhurst, Fermilab, Princeton)

E-774 ELECTRON BEAM DUMP PARTICLE SEARCH (Fermilab, Illinois, Northeastern, Rochester)

Heavy Quarks

E-653 HADRONIC PRODUCTION OF CHARM AND B (Aichi, UC/Davis, Carnegie-Mellon, Chonnam, Fermilab, Gifu, Gyeongsang, Jeonbug, Kobe, Korea, Nagoya Institute of Technology, Nagoya, Ohio State, Okayama, Oklahoma, Osaka City, Osaka Science, Sookmyong Womans, Toho, Utsunomiya, Won Kwang, Yokohama)

E-687 PHOTOPRODUCTION OF CHARM AND B (Colorado, Fermilab, Frascati, Illinois, Milano, Northwestern, Notre Dame)

E-690 HADRONIC PRODUCTION OF CHARM AND B (Columbia, Fermilab, Massachusetts, Mexico, Texas A&M)

E-705 CHARMONIUM AND DIRECT PHOTON PRODUCTION (Arizona, Athens, Duke, Fermilab, Florida A&M, McGill, Northwestern, Shandong)

E-760 CHARMONIUM STATES (UC/Irvine, Fermilab, Ferrara, Genova, Northwestern, Pennsylvania State, Torino)

E-769 PION AND KAON PRODUCTION OF CHARM (Brazil, Colorado, Fermilab, Northeastern, Toronto, Tufts, Wisconsin, Yale)

Hard Collisions and QCD

E-672 HIGH P_T JETS AND HIGH MASS DIMUONS (Arizona, Caltech, Fermilab, Florida State, George Mason, Illinois/Chicago, Indiana, Maryland, Michigan, Rutgers, Serpukhov)

E-683 PHOTOPRODUCTION OF JETS (Arizona, Fermilab, Lehigh, Rice, Vanderbilt, Wisconsin)

E-704 EXPERIMENTS WITH A POLARIZED BEAM (Annecy, Argonne, Fermilab, Hiroshima University, KEK, Kita-Kyushu, Kyoto, Kyoto Sangyo, Kyoto Education, Los Alamos, Northwestern, Rice, Saclay, Serpukhov, Texas/Austin, Trieste)

E-706 DIRECT PHOTON PRODUCTION (Delhi, Fermilab, Michigan State, Minnesota, Northeastern, Pennsylvania, Pittsburgh, Rajasthan, Rochester)

E-711 CONSTITUENT SCATTERING (UC/Davis, Fermilab, Florida State, Michigan)

E-772 NUCLEAR ANTIQUARK STRUCTURE FUNCTIONS (Fermilab, Illinois/Chicago, Los Alamos, SUNY/Stony Brook)

Collider

E-710 TOTAL CROSS SECTION (Bologna, Cornell, Fermilab, George Mason, Maryland, Northwestern)

E-713 HIGHLY IONIZING PARTICLES (UC/Berkeley, Harvard)

E-735 SEARCH FOR QUARK GLUON PHASE (Duke, Fermilab, Iowa State, LLL, Notre Dame, Purdue, Wisconsin)

E-740 D0 DETECTOR (Brazil, BNL, Brown, UC/Riverside, Columbia, Fermilab, Florida State, Florida, Indiana, LBL, Maryland, Michigan State, NYU, Northern Illinois, Northwestern, Pennsylvania, Rochester, Saclay, SUNY/Stony Brook, Yale)

E-741 COLLIDER DETECTOR AT FERMILAB (Argonne, Brandeis, Chicago, Fermilab, Frascati, Harvard, Illinois, KEK, LBL, Pennsylvania, Pisa, Purdue, Rockefeller, Rutgers, Texas A&M, Tsukuba, Wisconsin)

Other

E-466 NUCLEAR FRAGMENTS (Argonne, Chicago, Purdue)

E-754 CRYSTAL CHANNELING (Case Western, Fermilab, General Electric, SUNY/Albany, Sandia)

T-755 STREAMER CHAMBER TESTS (Fermilab, Brussels, Yale)

E-776 NUCLEAR CALIBRATION CROSS SECTIONS (BNL, CERN, Fermilab)

E-777 NEUTRON FLUX MEASUREMENTS IN THE TEVATRON TUNNEL (Fermilab, LBL, SSC-CDG)

E-778 STUDY OF SSC MAGNET APERTURE CRITERION (Cornell, Fermilab, LBL, SLAC, SSC-CDG)

Appendix D
Visitors to the Fermilab Theoretical Physics Department - 1986

I. Bigi, Stanford Linear Accelerator Center • K. Bitar, Florida State University • C.-H. Chang, Academia Sinica, The People's Republic of China • D. Chang, Northwestern University • J. Collins, Illinois Institute of Technology • S. Das, California Institute of Technology • D. Duke, Florida State University • A. Georges, Ecole Normale Supérieure, France • S. Glazek, Warsaw University, Poland • R. Gonsalves, State University of New York at Stony Brook • G. Hou, University of Pittsburgh • P.-Q. Hung, University of Virginia • K. Igi, University of Tokyo • R. Jackiw, Massachusetts Institute of Technology • M. Jacob, CERN • S. Kalara, Los Alamos National Laboratory • T. Kephart, Vanderbilt University • J. Kodaira, Hiroshima University, Japan • C. Kuang-Ta, Brown University • P. Le Doussal, Ecole Normale Supérieure, France • K. Lee, Columbia University • S.-C. Lee, Academia Sinica, People's Republic of China • J. Maharana, Saheed Nagar, India • G. Marchesini, Universita di Parma, Italy • T. Matsuki, Massachusetts Institute of Technology • M. Mattis, Stanford Linear Accelerator Center • D. McKay, University of Kansas • P. Moxhay, Indiana University • M. Mueller, Princeton University • P. Nason, Columbia University • C. A. Nelson, State University of New York at Binghamton • V. Novikov, Institute for Theoretical and Experimental Physics, U.S.S.R. • R. J. Oakes, Northwestern University • N. Paver, International Center for Theoretical Physics, Trieste, Italy • W. Roberts, University of Guelph, Canada • C. Savoy, University of Strasbourg, France • D. Sen, Carnegie-Mellon University • S. Sen, Brookhaven National Laboratory • T. Sjöstrand, University of Lund, Sweden • A. Soni, University of California, Los Angeles • D. E. Soper, University of Oregon • J. Stack, University of Illinois at Urbana-Champaign • T. Thanh Van, Université Paris SUD, France • Z. E. S. Uy, Millersville University • E. Velasco, State University of New York at Stony Brook • V. Visnic, University of Crete, Greece • B. R. Webber, University of Cambridge, England • K. Wu, City College, City University of New York • Z. Xu, Tsinghua University, People's Republic of China • P.-Y. Xue, Academia Sinica, People's Republic of China • W. Zakrzewski, University of Durham, England

Appendix E
Visitors to the Fermilab Theoretical Astrophysics Group - 1986

A. Albrecht, Los Alamos National Laboratory • D. Bennett, Stanford Linear Accelerator Center • R. Brandenberger, Cambridge University, England • A. Burd, Sussex University, England • E. Copeland, Imperial College, England • E. Farhi, Massachusetts Institute of Technology • R. Flores, Brandeis University • L. Ford, Tufts University • J. Frieman, Stanford Linear Accelerator Center • B. Grinstein, California Institute of Technology • M. Haugan, Purdue University • P. Jetzer, University of Geneva, Switzerland • D. Q. Lamb, Jr., The University of Chicago • F. Li Zhi, Institute for Advanced Study • A. Olinto, Massachusetts Institute of Technology • S.-Y. Pi, Boston University • M. Quiros, CERN • D. Reiss, University of Minnesota • A. Ringwald, Institute Theoretical Physics, Heidelberg, Germany • S. P. Rosen, Los Alamos National Laboratory • P. Shellard, Cambridge University, England • P. Sikivie, University of Florida • F. Tipler, Tulane University • N. Turok, Imperial College, England • R. Wagoner, Stanford University

Appendix F
Universities Research Association, Inc.

Trustees

Harry Woolf *Chairman* • William B. Fretter *Vice Chairman* • Barry C. Barish • John M. Deutch • Herbert Friedman • Maurice Glicksman • Edwin L. Goldwasser • Alan L. Goodman • Robert E. Gordon • Kenneth Heller • Lawrence W. Jones • William H. Kelley • Edward A. Knapp • William L. Kraushaar • Joseph E. Lannutti • Homer A. Neal • Robert Panvini • Alexander Pond • Harrison Shull • Albert Silverman • H. Guyford Stever • Robert R. Wilson

Officers

Edward A. Knapp *President* • Ezra Heitowit *Vice-President/Secretary* • Kenneth Shirley *Treasurer/Controller* • Leon M. Lederman *Laboratory Director.*

Universities Research Association, Inc., Visiting Committee - 1986

Joseph Ballam *Chairman* • Robert K. Adair • James H. Christenson • Thomas J. Devlin • Jerome Friedman • Robert Gluckstern • Lawrence W. Jones • Kenneth Lane • Robert L. McCarthy • Joseph F. Owens • Frank C. Shoemaker • Albert Silverman

Member Institutions

The University of Arizona • Brown University • California Institute of Technology • University of California, Berkeley • University of California, Los Angeles • University of California, San Diego • Carnegie-Mellon University • Case Western Reserve University • The University of Chicago • University of Colorado • Columbia University • Cornell University • Duke University • The Florida State University • Harvard University • University of Hawaii at Honolulu • University of Houston • University of Illinois • Indiana University • The Iowa State University • University of Iowa • The Johns Hopkins University • University of Maryland • Massachusetts Institute of Technology • Michigan State University • The University of Michigan • University of Minnesota • University of North Carolina • Northeastern University • Northwestern University • University of Notre Dame • The Ohio State University • University of Pennsylvania • Princeton University • Purdue University • Rice University • The University of Rochester • The Rockefeller University • Rutgers-The State University • Stanford University • State University of New York at Buffalo • State University of New York at Stony Brook • Stevens Institute of Technology • Syracuse University • The University of Texas at Austin • University of Toronto • Tufts University • Tulane University • University of Utah • Vanderbilt University • University of Virginia • Virginia Polytechnic Institute and State University • University of Washington • Washington University • University of Wisconsin-Madison • Yale University

Appendix G
Physics Advisory Committee - 1986

Michael Witherell, University of California, Santa Barbara *Chairperson* • Richard Field, University of Florida • Mary Kay Gaillard, University of California, Berkeley • Howard Gordon, Brookhaven National Laboratory • David Hitlin, California Institute of Technology • Anne Kernan, University of California, Riverside • Alfred Mueller, Columbia University • Francis Pipkin, Harvard University • Richard Prepost, University of Wisconsin-Madison • Melvyn Shochet, The University of Chicago, Enrico Fermi Institute • Mark Strovink, Lawrence Berkeley Laboratory • Martinus Veltman, University of Michigan

Appendix H
Fermilab Users Executive Committee - 1986

Thomas Ferbel, The University of Rochester *Chairman* • Hugh E. Montgomery, Fermi National Accelerator Laboratory *Secretary* • David Buchholz, Northwestern University • Thompson H. Burnett, University of Washington • Rosanna Cester, Istituto di Fisica • Melissa Franklin, University of Illinois • Daniel Green, Fermi National Accelerator Laboratory • Neville W. Reay, The Ohio State University • Angelo Scribano, INFN-Pisa • Marjorie Shapiro, Harvard University • Anna Jean Slaughter, Yale University • Bruce D. Winstein, The University of Chicago, Enrico Fermi Institute • James Wiss, University of Illinois

Appendix I
Fermilab Industrial Affiliates - 1986

AT&T Bell Laboratories • Air Products and Chemicals, Inc. • Ameritech Development Corporation • CBI Services, Inc. • Commonwealth Edison Company • Control Data Corporation • Convair - General Dynamics • Cray Research, Inc. • CVI, Inc. • Digital Equipment • Digital Pathways • Eaton Corporation • General Electric • W. W. Grainger, Inc. • Harza Engineering Co. • Hewlett-Packard Company • IBM • State of Illinois • Intermagnetics General Corporation • Kinetic Systems Corporation • Litton Industries, Inc. • Major Tool & Machine, Inc. • NALCO Chemical Company • New England Electric Wire Corporation • Nuclear Data, Inc. • NYCB Real-Time Computing, Inc. • Omnibyte Corporation • Oxford Airco • Plainfield Tool and Engineering, Inc. • Science Applications International Corporation • Signal UOP Research • Standard Oil Company (Indiana) • Sulzer Brothers • Sunbeam Appliance Company • Union Carbide Corporation • Varian Associates, Inc. • Westinghouse Electric Corporation

Acknowledgements

The *Fermilab 1986 Annual Report* was designed by Angela Gonzales, who also created the front and back covers, the map introducing "The State of the Laboratory," the illustrations on pages 53, 82, 84, 88, 90, 94, 132, and 144, enhanced an 18th century print for the illustration on page 97, and created the collage on page 98 using photographs of the Cathedral of Saint-Eustache in Paris and Wilson Hall at Fermilab. Technical assistance with production of the front and back covers was provided by Ayfer Atac, Hans Kautzky, and the Fermilab Machine Shop.

The illuminated letters introducing the Director's comments in "The State of the Laboratory," and displayed collectively on page 122, were designed by Leon Lederman.

The coins of the realms of antiquity serve as some of the vignettes on these pages, and as the inspiration for the more contemporary "coins" (created by Angela Gonzales and photographed by Ellen Lederman) also used as vignettes.

The illustration on page 7 is from the painting, *La Reproduction interdite (Not to be reproduced)* by Rene′ Magritte.

The illustration on page 78 is a detail from the artwork, *Landscape in Kueilin* by Shu Jia Ding, a master teacher of ink and brush technique in Osaka and Kobe, Japan, whose work was exhibited in the Fermilab Gallery in 1987.

The computer-generated rack layout of the ACP Multiprocessor System on page 71 is by Robert Atac of the ACP Group.

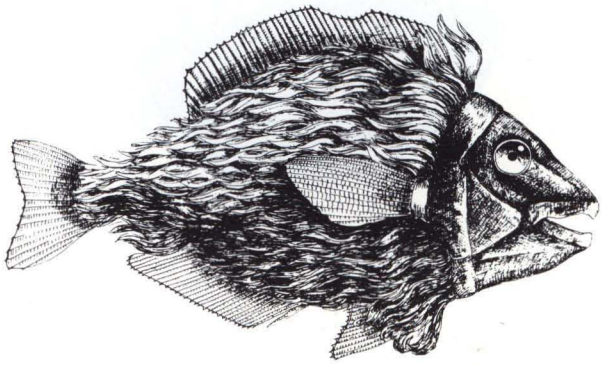
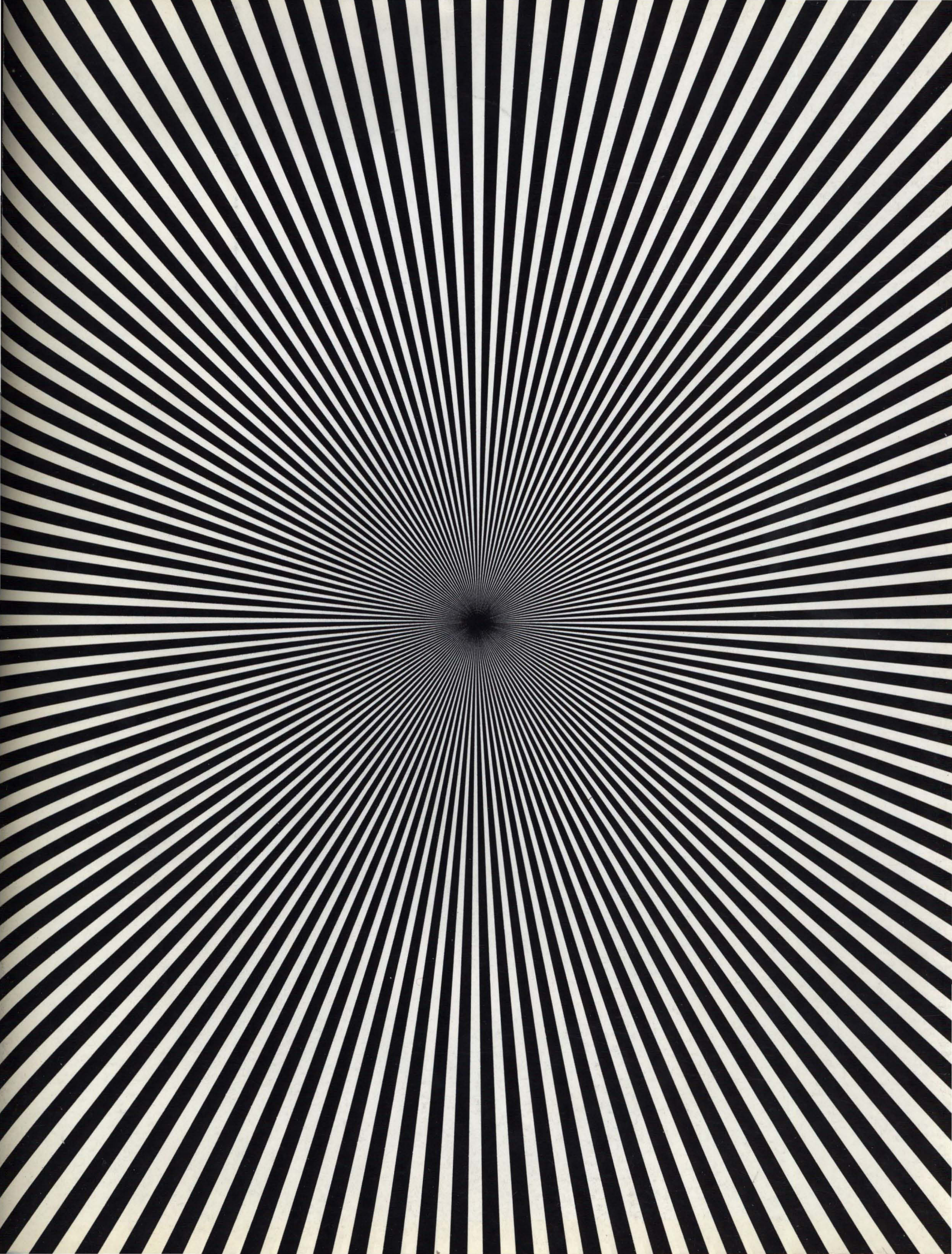
Photography by the Fermilab Photo Unit except where noted below.

The photographs on pages 9, 45, 46, 49, 57, 59, 60, and 85 are by Olivia Gonzales.

The photograph on page 68 was taken at the Mayan Palace of the Governors, Uxmal, Yucatan, Mexico, by Thomas Nash, Head of the ACP Group.

Assistance in the preparation of this *Annual Report* was provided by Susan Winchester of the Fermilab Technical Publications Office. Our thanks to the many authors who contributed.

So Geographers, in Afric-maps,
With savage-pictures fill their gaps;
And o'er unhabitable downs
Place elephants for want of towns.
- Jonathan Swift



QCD·QED·IOE·
GUIS·DOEABC
ΜΕΤΑ
ΜΕΤΑ
ΑΡΕΑ