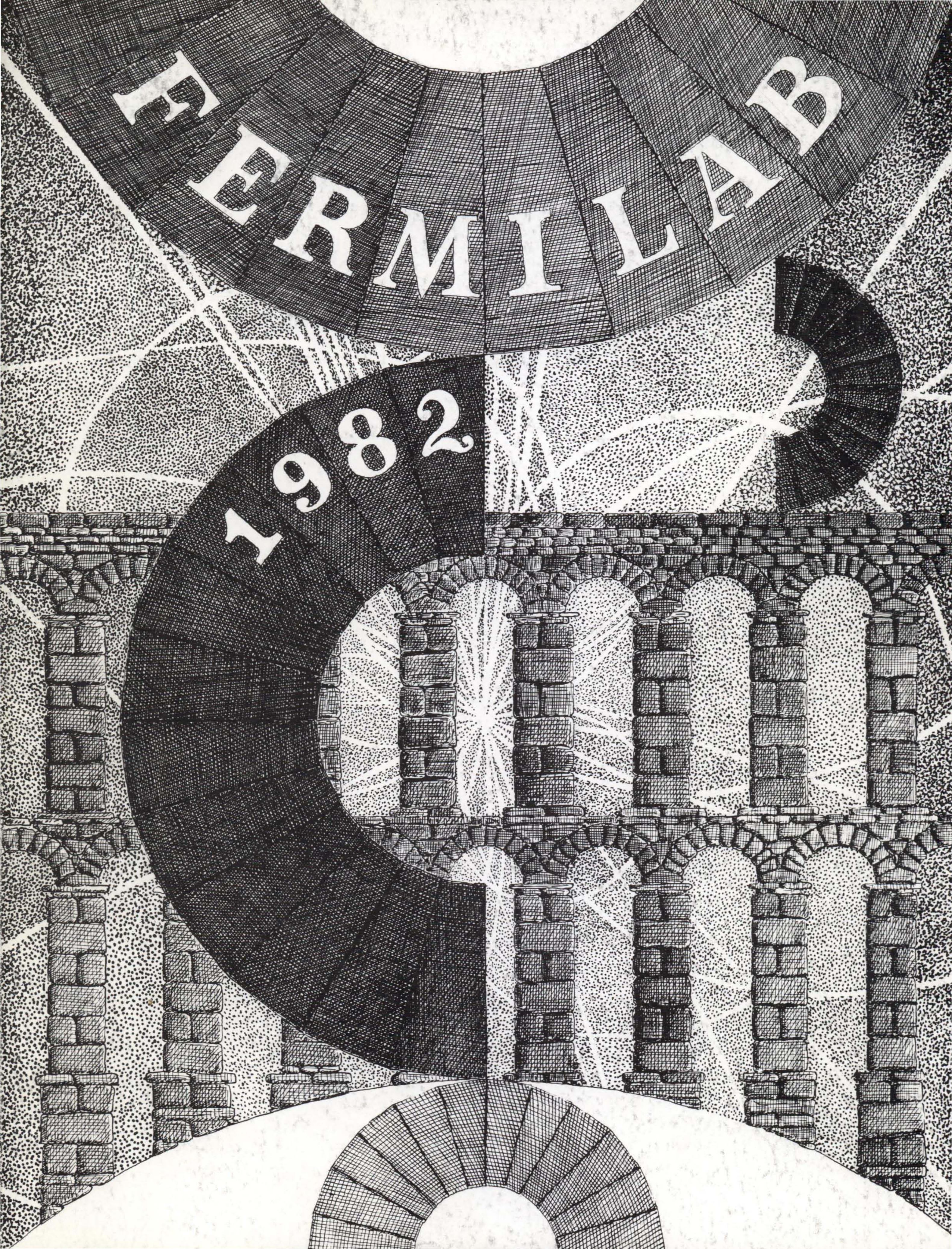
FERMILAB
1982

Fermilab 1982

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

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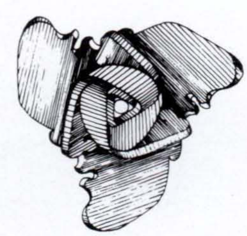


I. State of the Laboratory

Prospice Adspice Respice

This fourth annual report, covering the calendar year 1982, uses a somewhat different format as we strive to present a coherent record of the Laboratory. We are aware that such records are not only useful for communicating with colleagues, policy makers and, generally, with the interested public, but also useful for historians and sociologists. These scholars will place our efforts within the context of world activities, will examine our products, compare with other laboratories and seek to understand the origins of the relative successes and failures. The products are easily judged: publications, citations, peer opinions. The underlying factors are often so much more subtle. Here elements of style, environmental mood, managerial competence, luck and the capability of seizing the opportunities all play a part, together, of course, with funding and the skills it takes to insure that either the resources exist to succeed, or, from the other side, success can be achieved within the resources allocated.

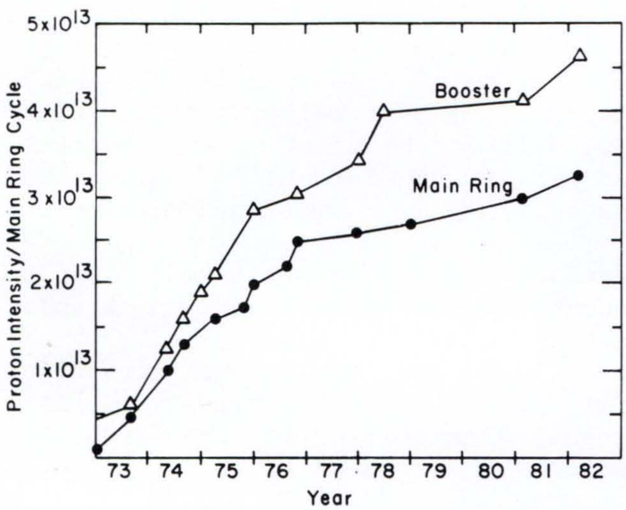
In this review, we will cover the main events of 1982 in a highly subjective and personalized manner, occasionally drifting backward to set the stage and projecting forward to expose our hopes. Since high-energy particle physics is our business, we have reserved considerable space below for an account of where this subject stands, what role we have played in it, and what part our present constructions will permit us to address, as they become operational in the 1983-1986 period.

We note finally that 1982 marks ten years since the start of the experimental program and a review in detail of the results seems appropriate.

The Physics Program: The Accelerator

The High Energy Physics (HEP) program started January 1 and ended June 14, 1982. This run followed a seven-month shutdown which was extended from a planned five-month Saver installation period because of budget constraints. In order to insure an efficient turn-on, accelerator systems were restored and checked during innumerable midnight and weekend shifts beginning back in September of 1981. Because this was to be the last running period of the conventional 400-GeV accelerator, we were intent to have a reliable period of operation. The spread of experiments put great demands on the accelerator: we needed lots of protons delivered to many areas and in a bewildering variety of modes: e.g., 1 msec fast spill, 1.4 and 2 ms fast spills, pings, micro-pings, mini-pings, maxi-pings, and for one user, a 250-GeV 1-ms fast spill. All of this was superimposed on the 400-GeV slow spill for the majority of users. Our geniuses in the control room pretty much satisfied these requirements and managed to set several new operational records: 4.61×10^{13} protons per pulse in the Booster and 3.25×10^{13} protons per pulse in the Main Ring at 400 GeV. (The 1981 record was 3.02×10^{13} ppp.) The accompanying figure illustrates the intensity history of our machine. We record in Table I, some of the data on utilization over these past three years, each suffering from the combination of Saver construction and financial stringency. One should recall that the previous four years had averaged 4200 hours of HEP time and a higher repetition rate than our more recent power bill allocation would allow.

As it turned out, we did better in 1982 than we expected--Victoria's messenger arrived in the nick of time with funds to add two crucial weeks to the run and we managed to eke out the best data of these three lean years.



Intensity in the Main Ring and Booster over the years.

Table I. Summary of Accelerator Operations

	Hours		
	1980	1981	1982
HEP Actual	2401.30	2148.05	2730.30
HEP Scheduled	3055.60	2715.20	3495.00
Actual/Scheduled	79%	79%	78%
Studies Actual	530.30	126.04	176.30
Studies Scheduled	563.50	169.50	206.00
Actual/Scheduled	94%	74%	86%
Start-up Actual	426.20	218.80	0
Start-up Scheduled	360.20	407.50	0
Tuning Actual	23.70	76.12	128.10
Tuning Scheduled	0	0	0
Accelerator Failure	591.60	615.99	587.55
Operations Hours Actual	3973.10	3285.00	3622.65
Operations Hours Scheduled	3979.30	3292.20	3701.00
Shutdown Actual	4801.50	5454.90	5106.60
Shutdown Scheduled	4804.70	5467.80	4693.00
Ad hoc Shutdown Actual	9.40	20.10	30.75
Ad hoc Shutdown Scheduled	0	0	0
Total Hours	8784.00	8760.00	8760.00
Total # of Protons Accel. (10^{17})	114.64	142.57	151.54
Total # of Main Ring Ramps	947,111	848,779	863,603
Total to Meson Area (10^{17})	23.45	16.37	32.32
Total to Neutrino Area (10^{17})	53.36	72.87	81.98
Total to Proton Area (10^{17})	27.62	45.71	26.90

The Physics Program: Experiments

In our 1982 run, some 21 experiments took data. Of these, five were not completed; the rest were defined to be completed in the sense that more than 70% of the commitments to the experiment were delivered. In a better situation, one with a higher assurance of good physics per experiment, beam delivered would have exceeded 100% of commitment. Other statistical factors are that 91 teams from 60 institutions completed experiments which had proposal dates varying from November 1974 to February 1981, the mean being mid-1978, i.e., a four-year interval! See Table II. We leave it to the reader to ponder the implications of this kind of sociology. Of course, at this writing we do not have physics results from these runs. In general, the physics explored covered a wide range of observations. Neutrinos were used to probe quark behavior (E-594, 613, 701) and to determine if neutrinos can oscillate (E-701). Four experiments explored the process in which quarks annihilate with antiquarks (E-326) when protons and pions carry in the constituent quarks and (E-537) when antiprotons carry the quarks. One of these (E-615) probed the validity of the theory of quarks, QCD, in a very sensitive domain of the kinematic variables. One experiment (E-617) studied the phenomenon of CP violation, in an attempt to pin down a crucial constant. Two others involved the observation and measurement of polarization and magnetic moments of hyperons (E-555, 619) as a test of the theory of how quarks fit together to compose these objects. How quarks and gluons emerge from hard collisions and manifest themselves as "jets" was the objective of E-609. A study of the ways in which photons can dissociate into states with the same quantum properties was performed (E-612). Other "classical" experiments in the 30-in. bubble chamber (E-526, 570, 597) concentrated on soft collisions at high energies--on collisions of incident particles with complex nuclei where the observation of details leads to a large variety of special issues.

It is clear that in the above experiments we are concentrating on illuminating the hadronic structure, composed of quarks in strong, weak, and electromagnetic interaction with the incident probes. In another class of research (E-400, 515, 623, 630, 673), searches and measurements are made on the most subtle aspects of the quark theory, the fleeting presence of very massive quarks in nuclear matter, the charm and bottom quarks.

Further details on these experiments may be obtained by consulting the Fermilab Research Program Workbook for 1982 and by watching the physics literature.

Table II. Experiments Run in 1982

Exp.	Title	Institutions	Proposed	Completed
326	Di-muon production by pions	Chicago, Princeton	5/74	4/82
400	Charmed particle production by neutrons	Colorado, Fermilab, Illinois, Milano, Pavia	5/75	In progress
466	Nuclear fragments from proton-nucleus collisions	ANL, Chicago, Illinois Chicago Circle, Purdue	1/76	In progress
515	Charmed particle production in hadronic interactions	Carnegie-Mellon, Fermilab, Northwestern, Notre Dame	10/76	3/82
537	Di-muon production by antiprotons	Athens, Fermilab, McGill, Michigan, Shandong	2/77	2/82
555	Λ^0 production at high P_t	Michigan, Minnesota, Rutgers, Wisconsin	5/77	2/82
565 570	Hadrons in the 30" bubble chamber with plates and down-stream particle spectrometer	Brown, College de France, Fermilab, Indiana, MIT, Nijmegen, Oak Ridge, Rutgers, Stevens, Tel Aviv, Tennessee, Tohoku, Tohoku Gakuin, Yale	6/77	6/82
594	Neutrino interactions in a fine grain detector	Fermilab, IIT, MIT, Michigan State, Northern Illinois	2/78	6/82
597	Hadrons in the 30" bubble chamber with plates and down-stream particle spectrometer	Cambridge, Duke, Fermilab, Kansas, Michigan State, Notre Dame	2/78	5/82
605	Production of leptons and hadrons near the kinematic limit	CERN, Columbia, Fermilab, KEK, Kyoto, Saclay, SUNY Stony Brook, Washington	5/78	In test stage
609	Hadronic jet production	ANL, Fermilab, Lehigh, Pennsylvania, Rice, Wisconsin	10/78	In progress
612	Diffractive photon dissociation on hydrogen	Rockefeller	10/78	4/82
613	Neutrino production in a beam dump	Firenze, Fermilab, Michigan, Ohio State, Wisconsin	10/78	5/82
615	Forward production of massive particles	Chicago, Fermilab, Iowa State, Princeton	11/78	In progress
617	Measurement of $\lvert \eta_{00}/\eta_{+-} \rvert$	Chicago, Saclay	1/79	In progress
619	Σ-Λ transition magnet moment	Michigan, Minnesota, Rutgers, Wisconsin	5/79	6/82

Table II. Experiments Run in 1982 (Cont.)

Exp.	Title	Institutions	Proposed	Completed
623	Particles decaying into $\phi\phi$	Arizona, Fermilab, Florida State, Notre Dame, Tufts, Vanderbilt, VPI	5/79	6/82
630	Study of charmed particles using a high resolution streamer chamber	Fermilab, LBL, Yale	2/80	3/82
660	Channeling in crystals	CERN, Chalk River, Dubna, Fermilab, New Mexico, SUNY Albany, Strasbourg	6/80	6/82
673	χ meson production by hadrons	Fermilab, Illinois, Pennsylvania, Purdue, Tufts	2/81	4/82
701	Neutrino oscillations	Chicago, Columbia, Fermilab, Rochester	2/81	6/82
720	Free quark search	ANL, Fermilab	1/82	10/82

The Physics Program: Theoretical Physics

We should be reminded of the role of theoretical physicists in an accelerator laboratory:

(1) They must provide guidance to the in-house staff.

(2) They must support the users in residence "in loco universitas," both by being available for conversation, and also by providing an Academic Lecture series--especially for the sake of resident graduate students.

(3) They must be available to advise the staff on directions for the Laboratory, i.e., to constantly evaluate the state of the science and direct the future developments so as to best address the open questions. Like the investment counselor of the everyday world, the theorist can lay out the risks and profit possibilities.

(4) Theorists must help evaluate incoming proposals on a more continuous basis than the Physics Advisory Committee.

(5) Finally, theorists must help set the intellectual climate of the Laboratory. By their seminars, colloquia, coffee discussions, by their journal clubs, and attendance at the experimental or accelerator seminars, they accomplish this important task.

Once one embarks on establishing a theory group, it develops its own needs and rationale for achieving size and balance. The group listed on page 6 is still below the level appropriate to the size of the Laboratory, and we are in the course of seeking excellent new prospects.

In a year when so much of the Laboratory's energies and passions are devoted to invention and construction, to the actualization of ideas, it may be appropriate counterpoint to highlight an activity which results in less tangible products. The output of the theory group is to be measured not merely in the span of talk-filled hours or in the number of trees that have given their lives for their preprints, but also in the near ineffables of ambience, inspiration, and intellectual ferment.

I would add to the functions of the theory group the task of seeking to create a milieu in which physics and physicists can flourish.

This broader calling was recognized early in the history of the laboratory by Bob Wilson and Ned Goldwasser. They enlisted the help of distinguished senior theorists, notably Sam Treiman of Princeton and Dave Jackson of Berkeley to oversee the Theory Year Program which provided a theoretical presence until a permanent group could be assembled. When the Laboratory had the great good fortune to attract the late Ben Lee as Department Head, building a staff and a tradition began in earnest. It is Ben Lee's vision that we seek to fulfill today.

Our program has two important components: the development of an outstanding resident theoretical group and the operation of a vigorous visitors program.

In the recent past, the Fermilab group has provided facilities (and in many cases, support) to 150-200 visitors per year. Most visits last for periods of a few days to a month. A number of important benefits are derived from this large flux of visitors. It enriches the theoretical activity at Fermilab, and exposes the Fermilab experimental program to a wide range of theoretical ideas and opinions. Beyond that, it makes a significant contribution to the national theoretical physics program by providing stimulation, both theoretical and experimental, to university physicists. A special effort has been made to include promising young theorists, as well as established senior theorists in the program. Like Fermilab as a whole, the visitors program has a distinctly international flavor.

The Theoretical Physics Department makes key contributions to the intellectual life of the Laboratory. Members of the department organize weekly theoretical seminars and the weekly joint experimental theoretical ("wine and cheese") seminar. A series of academic lectures on current research topics is intended as cultural enrichment for experimental graduate students (and others). Members of the group also are frequently called upon to speak at laboratory workshops and informal soirees on specific physics topics. A few members of the group participate regularly in meeting of the Laboratory's Physics Advisory Committee. Others have become involved with particular proposals or experiments through the godfather program. Of course, informal interaction with experimentalists takes place regularly.

Current research interests of the group can be extracted from the publications listed elsewhere in this Report. Recent activity has covered many of the most timely and important topics in high-energy physics, including applications of quantum chromodynamics (both perturbative and nonperturbative), the study of quarkonium systems, the development of methods for the exact solution of quantum field theories in two models, and grand unification. A few members of the group have taken an interest in accelerator topics or in cosmology. Several members have also developed active collaborations with groups at other laboratories and universities.

Here we note a significant addition: the Fermilab Astrophysics Group, partially funded by a three-year

NASA grant. The rationale is clear: the increasingly fruitful conversation between particle physics and astrophysics continues to be intense; what happened in the early universe and how galaxies were formed provide constraints and ideas for experiments at Fermilab. There seems to be a connection between the width of the Z^0 particle and the helium abundance in the universe. The nature and flux of monopoles and the validity of supersymmetric grand unified theories are closely involved with efforts to model evolution during the first few thousands of a picosecond in the life of the universe.

Recruiting for the new group has progressed very well, and we look forward to this new group stirring up lots of trouble in 1983.

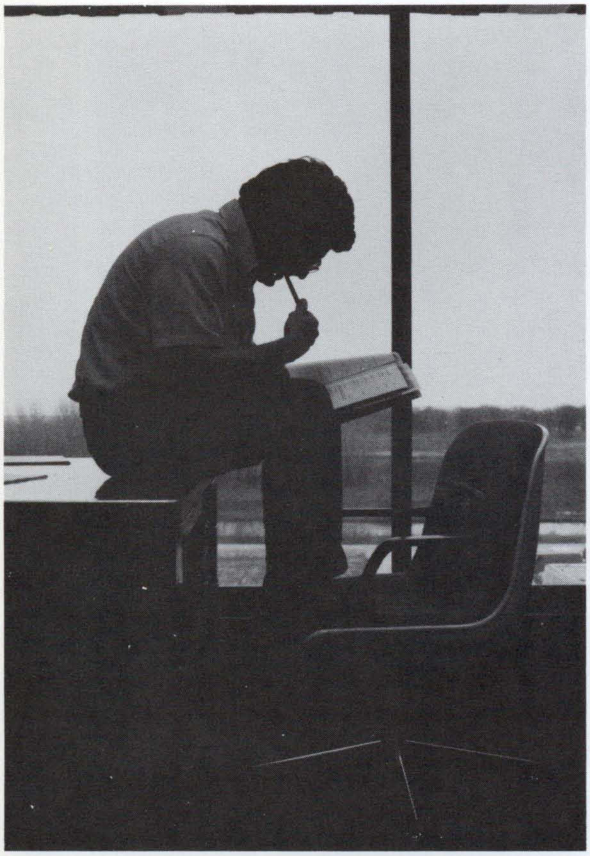
Theoretical Physics Department in 1982

Administrative Support:

E. Moore, P. Oleck, G. Rudd

Physicists:

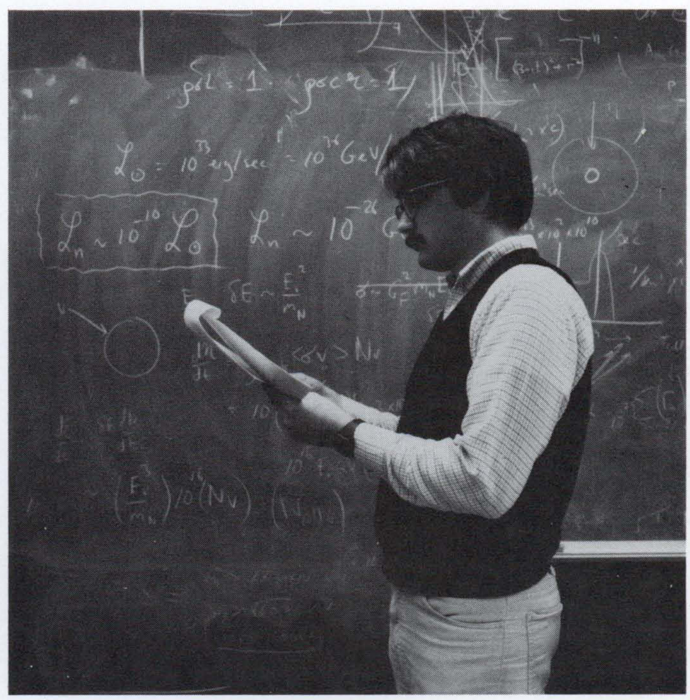
C. Albright (Northern Illinois University),
W. Bardeen,
E. Berger (Argonne National Labortory),
J. Bjorken, S. Dawson,
L. Durand (University of Wisconsin),
E. Eichten, C. Hill,
R. Huerta (CINVESTAV-IPN, Mexico),
J. Lucio (CINVESTAV-IPN, Mexico),
P. Mackenzie,
M. Moshe (Technion-Israel
Institute of Technology),
S. Mtingwa,
R. Oakes (Northwestern University),
J. Oliensis, C. Quigg,
J. Rosner (University of Chicago),
A. Schellekens, J. Schonfeld,
D. Schramm (University of Chicago),
A. Sen, T. Taylor (University of Warsaw)
H. Thacker, W. Tung (IIT, Chicago),
A. White (Argonne National Laboratory),
C. Zachos,
Z. Bang-Rong (China University
of Science and Technology)



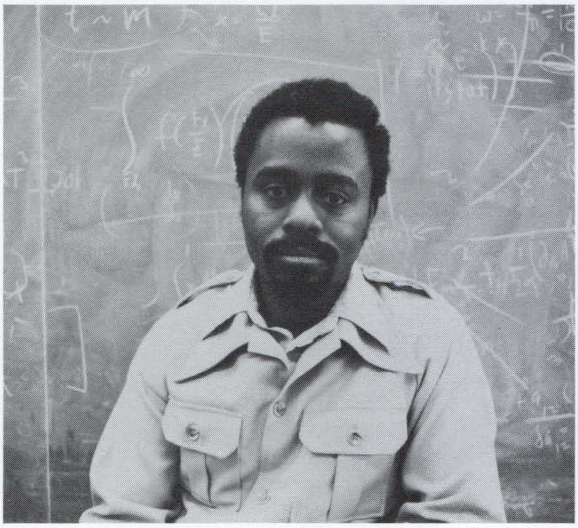
Cosmas Zachos

Chris Quigg

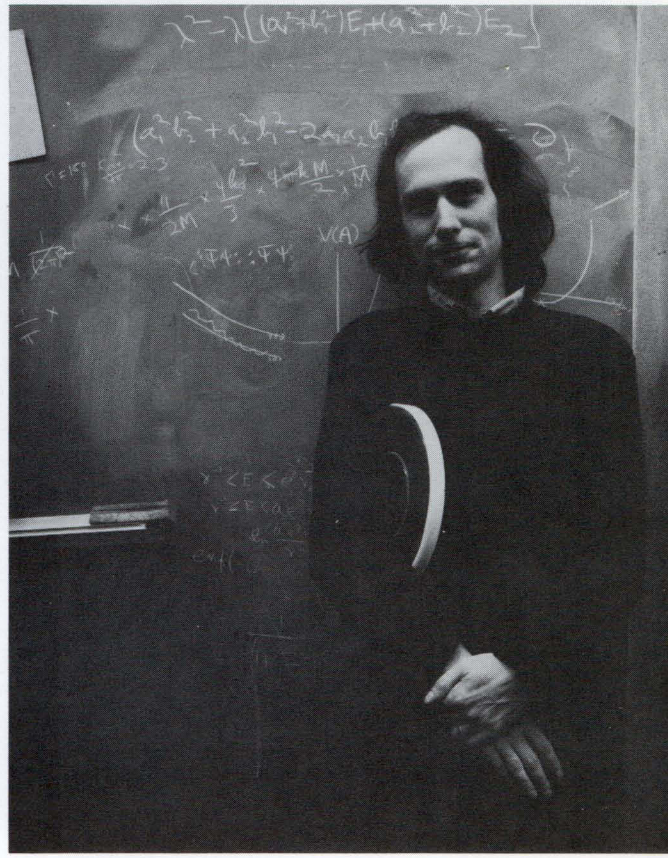
Mary K. Gaillard



Chris Hill

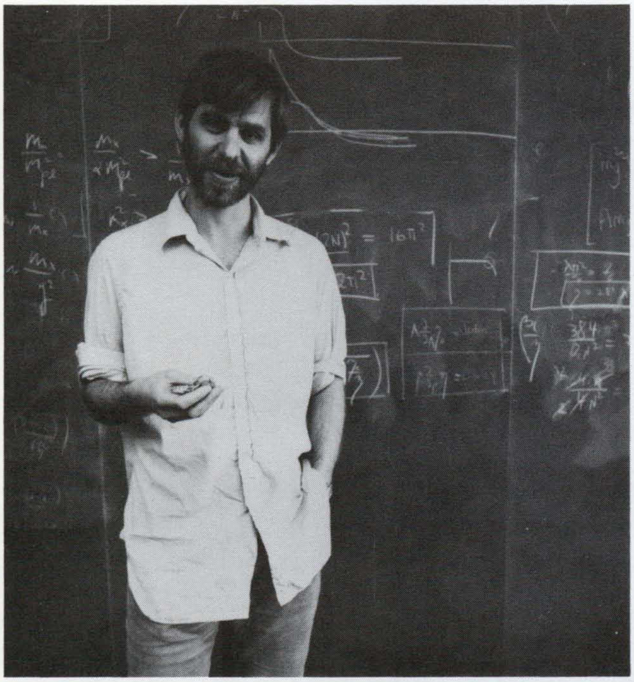


Sekazi Mtingwa

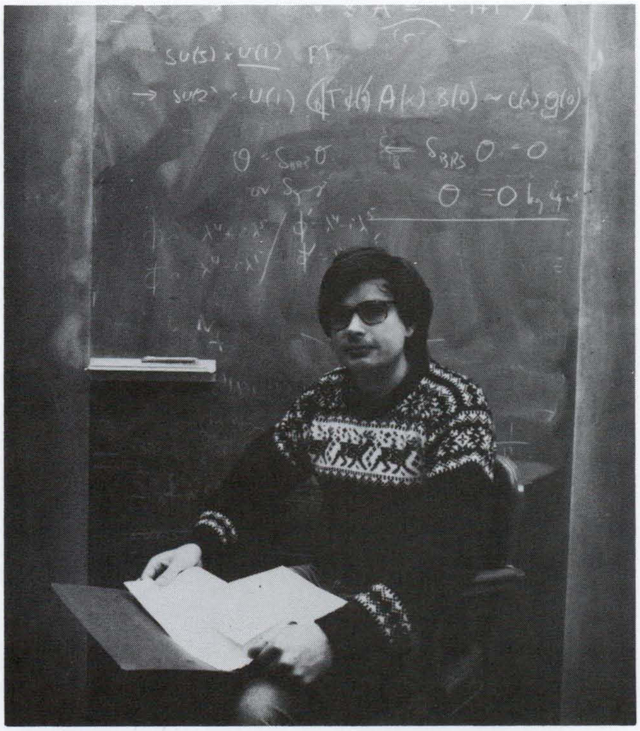


Paul Mackenzie

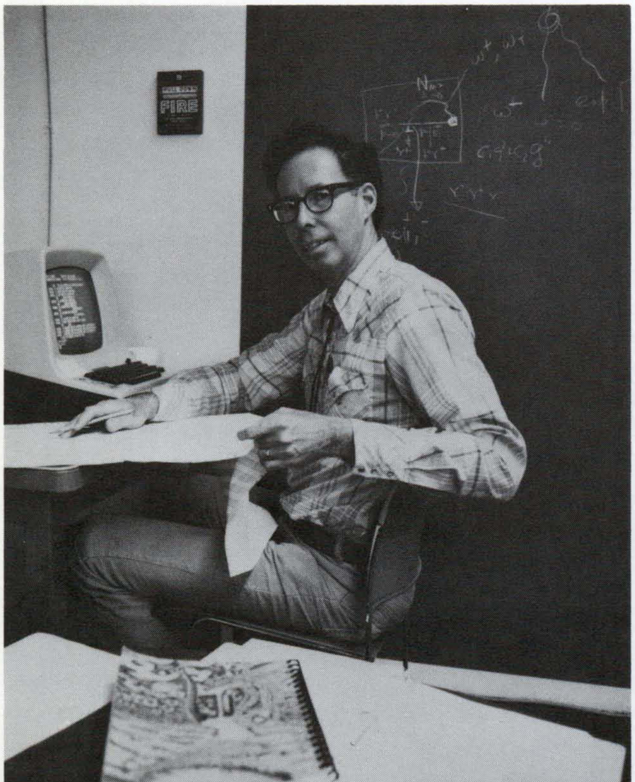
Jonathan Schonfeld



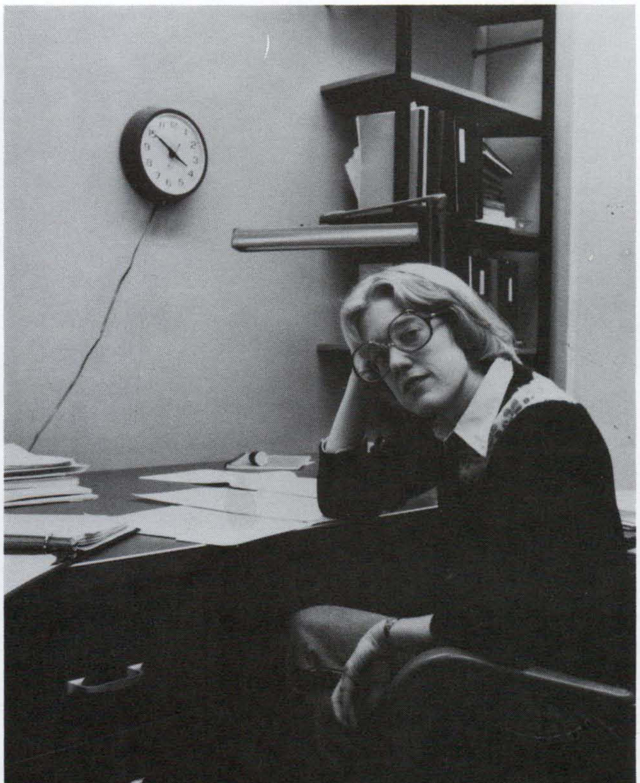
John Oliensis



Tom Taylor



Randy Durand



Sally Dawson

The Construction Projects: Energy Saver

Accelerator Division Staff

Accelerator Operator Crew Chiefs:

R. Angstadt, T. Asher, D. Baddorf, R. Benson, P. Emma, L. Hallahan, B. Hanna, E. Harms, B. Hendricks, M. Henry, D. Johnson, L. Klamp, E. Macheel, J. Mealy, M. Olson, D. Patterson, D. Rohde, G. Royal, J. Smedinghoff, G. Smith, M. Syphers, M. Utes, T. Williams

Administrative Support:

H. Dick, N. Faxon, M. Gleason, L. Hanabarger, M. Harvey, L. Lopez, C. Merkler, M. Paul, N. Poore, M. Richardson, V. Stazak, J. Tinsley C. Vanecek, P. Warfield, E. Williams

Construction Coordinator:
D. Smith

Deputy Head, Neutron Therapy Facility:
L. Cohen

Drafters/Designers:

M. Ackmann, H. Barber, A. Bart, M. Battista, D. Breyne, R. Divelbiss, J. Edwards, R. Gloor, R. Gorge, R. Haring, D. Moline, C. Pallaver, A. Parker, A. Rehbein, D. Schmitt, T. Schmitz, T. Sengmanivong, R. Smith, G. Termansen, S. Wesseln

Engineers:

E. Anderson, R. Andrews, L. Bartelson, D. Beechy, G. Biallas, K. Bourkland, S. Bristol, J. Crisp, J. Dinkel, A. Donaldson, R. Ducar, R. Ferry, J. Fitzgerald, A. Franck, J. Fritz, R. Fuja, R. Hanson, W. Knopf, G. Krafczyk, F. Lange, G. Lee, T. Lincicome, J. Lockwood, J. Makara, D. Martin, M. Martin, M. May, W. Merz, H. Miller, J. Misek, M. Palmer, R. Parry, T. Peterson, H. Pfeffer, S. Reeves, J. Reid, R. Reilly, R. Rihel, C. Rode, J. Ryk, J. Satti, L. Sauer, T. Savord, K. Seino, J. Theilacker, E. Tilles, G. Tool, D. Wolff, J. Zagel

Engineering Physicists:

H. Barton, A. Crawford, R. Flora, J. Gannon, R. Gerig, J. Lackey, S. Lackey, C. McClure, K. Meisner, M. Stone, K. Ueno, R. Webber, P. Yurista

Experimental Area Floor Manager:
D. Mizicko

There were, in 1982, oscillations of better and worse news superposed upon a steady progression towards the endpoint. The start of preparations for the physics program in December 1981 drove the builders out of the tunnel with only three-fourths of the A-sector complete. Still, this represented a substantial advance over our previous experience in operating long strings of superconducting magnets: ninety-four dipoles, twenty-four quadrupoles and twenty-four spool pieces had been made vacuum tight along with specialized cryogenic elements, embellished with monitoring equipment and computer controls. These were cooled to 4K by three satellite refrigerators and the Central Helium Liquefier--scheduled to have its first serious operating test.

This "3/4 A-Sector test" continued through the five months of the 400-GeV run. The tests demonstrated the ability to install, cool down, maintain, and operate an extended cryogenic system under microprocessor control. Remember that there are two sources of potential energy stored in the magnets during operation: the potential expansion of liquid helium to gas and the energy stored in the magnetic field when the windings are energized to 4400 amperes. For a variety of reasons, a superconducting magnet might stop superconducting. It then becomes a matter of intense interest to remove all stored energy before the magnet is destroyed. This is one of the novel challenges faced by our designers.

The system to detect the onset of such "quenches," (the QPM system) the specialized, high-current, fast circuitry to move the electrical energy from the affected magnets (the QBS system) and the positive-control valve system to remove the liquid helium from the affected magnets (the Kautzky valve system) were all tested intensively and extensively during this period.

Results from these tests were used to methodically improve the hardware and software for the system. By the time the 3/4 A-Sector Test was terminated in June, the 142-magnet ensemble was pulsing routinely at the 900-GeV level using the planned Tevatron duty cycle.

Under these conditions, the system was subjected to maximum stresses in all the accessible parameters without damage.

Starting with the termination of the 400-GeV physics run in June, when the Main-Ring tunnel was once more accessible, the Saver project has been focused on completing the entire installation. An intermediate goal was to bring on and test two more sectors, E and F, incorporating all the results of the A-Sector tests. Installation and debugging of all the necessary systems were completed by mid-November, and the cool-down of the magnets was initiated. This test involves a third of the full ring and makes use of the more sophisticated VAX-PDP 11/34 control computer network. The front end of the system involves 500 microprocessors communicating with the VAX through the front end PDP 11/34. (The 3/4 A-Sector Test still used the older Xerox 530 computer system.) As installation is completed successively in D-, C-, and B-sectors, they will be cooled down and brought on line so that a smooth transition will be made from installation to Saver commissioning with beam when the integrity of the Main Ring is restored in the spring by completion of the Collider Detector Facility Collision Hall.

As of year's end, bottlenecks to a completely cold and leak-tight ring appear in many of the required systems. Throughout '82, this dubious honor had jumped from system to system. The story is a continuum of crises and response to crises. However, it does appear plausible that spring will find us close to trying to trace the first

Fabrication Specialist:
G. Jugenitz

Head, Neutron Therapy Facility:
F. Hendrickson

Nurse:
B. Deke

Operations Specialists:

L. Allen, B. Barnes, J. Crawford, J. Engelbrecht, J. Hogan, W. Kissel, R. Kolar, F. Krzich, R. Mau, D. Plant, S. Tawzer, A. Thomas, R. Vanecek, J. Ziober

Programmers/Systems Analysts:

C. Briegel, K. Cahill, L. Chapman, J. Firebaugh, M. Glass, R. Goodwin, G. Johnson, C. Lee, W. Marsh, R. McLin, S. Morris, F. Sample, M. Storm, A. Waller, T. Watts, L. Winterowd

Radiation Oncology Clinical Research Coordinator:
J. Mansell

Safety Engineers/Officers:
C. Bonham, H. Casebolt

Scientists:

C. Ankenbrandt, M. Awschalom, F. Beck, V. Bogert, S. Childress, C. Curtis, A. DeLucio, R. Dixon, D. Edwards, H. Edwards, D. Finley, W. Fowler, M. Gormley, T. Groves, M. Harrison, R. Huson, R. Johnson, H. Jostlein, Q. Kerns, K. Koepke, P. Kurup, P. Limon, P. Martin, L. Michelotti, C. Moore, G. Mulholland, T. Murphy, F. Nagy, D. Neuffer, K. Ng, S. Ohnuma, J. Orr, C. Owen, S. Pruss, F. Rad, R. Raja, R. Rice, I. Rosenberg, A. Russell, C. Schmidt, S. Segler, M. Shea, S. Snowdon, L. Teng, R. TenHaken, T. Toohig, E. Treadwell, A. VanGinneken, R. Walker, J. Walton, D. Wildman

Technicians:

M. Adamus, P. Adderley, R. Afanador, M. Albertus, J. Anderson, L. Anderson, A. Anello, R. Applegate, G. Athanasiou, D. Augustine, M. Augustine, B. Bennett, L. Benson, L. Berry, A. Beutler, J. Biggs, B. Billenstein, S. Bjerklie, D. Black, R. Books, R. Bossert, L. Bradley, R. Brazzale, R. Brooker, J. Brown, J. Brown, L. Brown, N. Brown, W. Carl, A. Casperson R. Cassidy, D. Chasco, B. Chase, H. Christ, M. Cichon, B. Claypool, P. Cliff, M. Coburn, J. Colvin, S. Conlon, whiffs of 150 GeV (injection energy) protons around the superconducting ring.

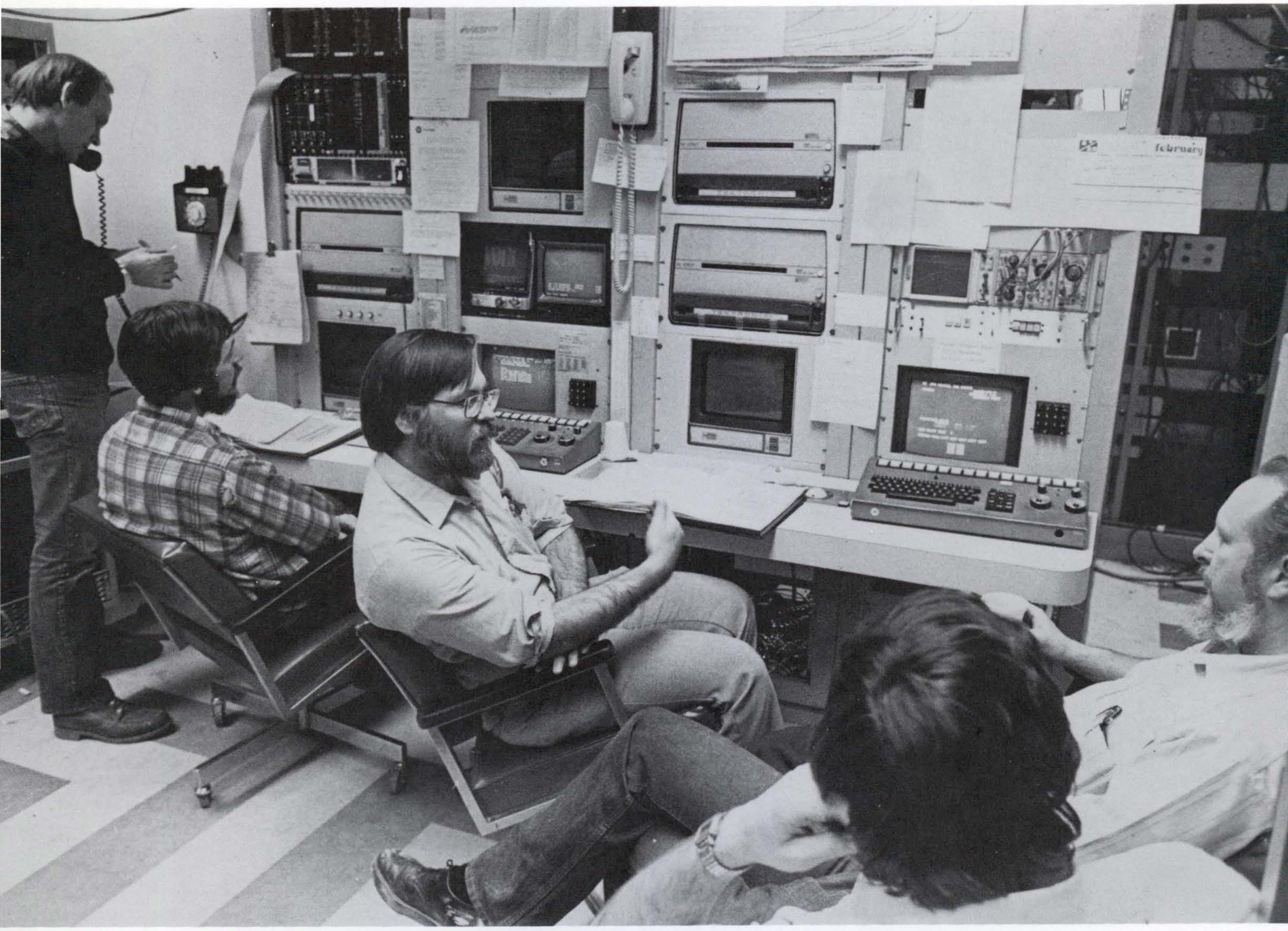
Consider that there will be 1400 superconducting elements, 24 satellite refrigerators, and a vastly increased load on the Central Helium Refrigerator, consider a new and sophisticated controls system, consider the need to explore the useful aperture around the 6.3-km circuit and consider that we must learn the acceleration, storage, and extraction techniques. It is not overly conservative to project the onset of HEP for October, 1983. Very little overconfidence here.

Technicians (Cont.):

D. Connolly, H. Cranor, C. Crose, T. Cross, W. Cross, R. Crouch, J. DeLao, S. DeMarco, R. Dice, C. Dickey, R. Diehl, E. Dijak, G. Disandro, S. Dochwat, D. Douglas, K. Dragstrem, D. DuPuis, D. Durham, J. Elseth, K. Ermsting, E. Faught, P. Feyereisen, J. Flores, R. Florian, A. Forni, W. Franklin, D. Freeman, W. Ganger, E. Gendvilas, J. Geralds, H. Gerzevske, P. Gibbs, T. Gierhart, G. Giese, R. Glavin, J. Gomilar, C. Gonzalez, R. Gonzalez, M. Gordon, T. Gordon, M. Gorecki, R. Gould, R. Gutierrez, D. Hanabarger, E. Hanson, J. Harder, C. Hardrick, M. Hartman, E. Haun, S. Hays, D. Hellberg, T. Hendricks, M. Hentges, M. Hentges, R. Hively, G. Hodge, J. Hoover, D. Howard, R. Hren, D. Huffman, J. Irvin, L. Jackson, R. Janes, E. Joerg, S. Johnson, A. Jones, K. Jordan, F. Juravic, E. Kessler, D. Kindelberger, R. Klecka, L. Klein, B. Kling,

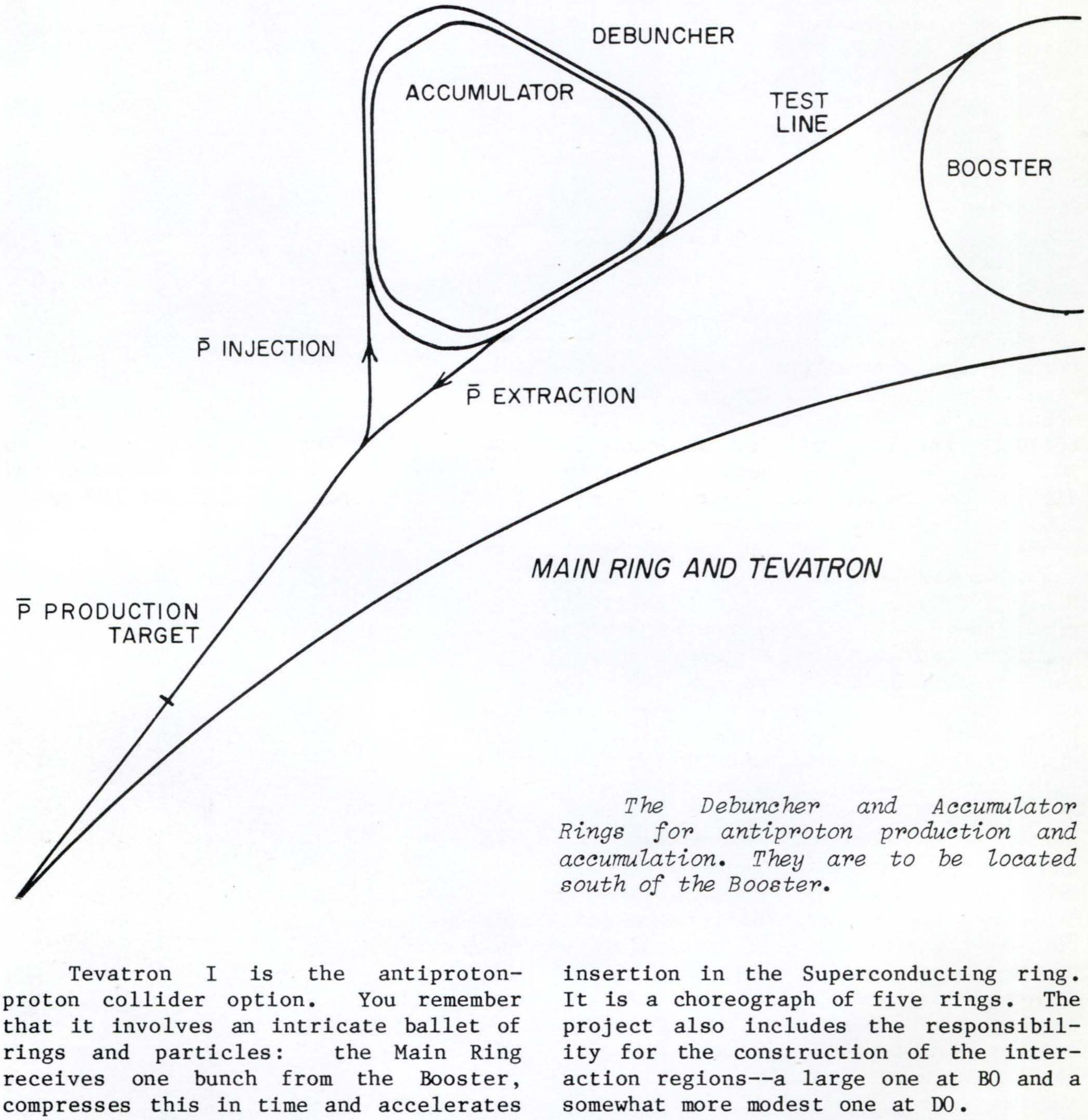
M. Koenig, H. Landers, T. Larson, T. Lassiter, A. Lathrop, G. Lawrence, J. Lazzara, H. Le, R. LeBeau, N. Leja, F. Linton, K. Lockhart, M. Long, J. Loskot, E. Mabeus, R. Mahler, C. Maier, R. Marquardt, W. Martin, D. McCormick, J. McDowell, C. Meade, R. Meadowcroft, F. Mehring, J. Meisner, K. Mellott, G. Meyer, L. Middlebrooks, M. Mills, H. Mong-Phung, R. Morrison, T. Morrison, R. Mraz, D. Musser, R. Muth, W. Noe, R. Norton, M. Nurczyk, B. Ogert, W. Olach, K. Olesen, G. Opperman, D. Ostrowski, R. Padilla, N. Pastore, P. Paul, M. Petkus, B. Pientak, E. Podschweit, M. Popp, D. Quintero, A. Rader, D. Rame, E. Ramirez, J. Ranson, M. Raphael, L. Ray, D. Rice, T. Richer, L. Rolih, J. Ruffin, A. Runde, J. Sabo, G. Saewert, H. Satter, J. Savignano, R. Scala, F. Schneider, K. Schuh, L. Senders,

J. Seraphin, J. Sheley, L. Shepard, R. Shores, K. Sievert, D. Slimmer, J. Smith, T. Smith, J. Smolucha, G. Sorenson, W. South, J. Spender, E. Stitts, J. Stockton, T. Svejda, A. Tanner, K. Taylor, R. Thomas, T. Thomas, J. Thompson, J. Ticku, D. Tinsley, D. Tinsley, M. Urso, M. VanDensen, P. Vierig, D. Villarreal, C. Voit, B. Vollmer, D. Voy, L. Wahl, W. Waitkoss, D. Wallace, F. Walters, D. Warner, J. Wendt, S. Whelchel, C. White, J. Wildenradt, M. Wilks, R. Williams, D. Wilself, G. Wilself, D. Yardley, J. Zeilinga, R. Zifko, M. Ziomek, J. Zuk



The Fermilab Main Control Room during the A-sector test (left to right) Rich Andrews, Mike Hentges, Phil Martin, Dan Wolff, and Gerry Tool.

The Construction Projects: Tevatron I



The Debuncher and Accumulator Rings for antiproton production and accumulation. They are to be located south of the Booster.

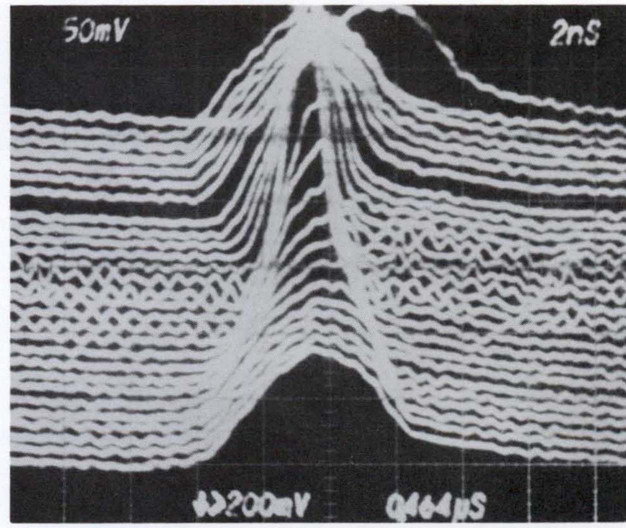
Tevatron I is the antiproton-proton collider option. You remember that it involves an intricate ballet of rings and particles: the Main Ring receives one bunch from the Booster, compresses this in time and accelerates to 120 GeV where it is extracted onto a target. Antiprotons are collected and transported to a Debuncher ring (that's 3) where they are cooled and decompressed in order to transfer to an Accumulator ring. Four hours should be enough to cook the batch (uncook, really) and ship them back to the Main Ring for acceleration to 150 GeV and insertion in the Superconducting ring. It is a choreograph of five rings. The project also includes the responsibility for the construction of the interaction regions--a large one at B0 and a somewhat more modest one at D0.

Whereas 1981 was a year of decision to go for maximum luminosity, the past year has developed the detailed designs of Debuncher and Accumulator. These are Booster-sized storage rings with a variety of magnets and acceleration systems plus advanced systems for stochastic cooling. The TeV I group is deeply engaged in building models and prototypes and has been aided by our collaboration with Argonne National Laboratory, University of Wisconsin, Lawrence Berkeley Laboratory, and the Institute of Nuclear Physics at Novosibirsk. More informally, we have been in close communication with the CERN group whose own $\bar{p}p$ collider project is well into their physics program.

Part of our work has been to develop cost estimates for our new design. A momentous time was reached in May when it was agreed by all concerned that the design and cost estimates had become firm enough that we should start the construction of the building for the Collider Detector at B0. That construction began in June by digging the deepest hole ever at Fermilab and breaking open the Main Ring tunnel at B0. By the end of the year, the hole had been filled with concrete. Vehicle bypass and transition sectors were turned over by the contractor to Fermilab in December, thereby allowing the completion of the Energy Saver to proceed. The Collision Hall roof has been completed, thereby enclosing the space. It is expected that by the time this is read, all of the Collision Hall shielding will be in place, thereby allowing accelerator operations to resume in the Main-Ring tunnel.

The production of antiprotons for $\bar{p}p$ collisions will require manipulation of the beam in the Main Ring before targeting in order to produce tightly bunched antiprotons. Regrouping into a smaller number of bunches is also needed at a later stage. Just before the long shutdown began in June, a series of important accelerator experiments was carried out to show the feasibility of this rebunching. We can now confidently plan on these exotic manipulations of beam to carry out our antiproton accumulation.

The schedule for $\bar{p}p$ physics is somewhat discouraging. As we read the



Rotation of a mismatched rf bunch following sudden increase in rf voltage to 1 MV. Time progresses downward and traces are separated by about 100 msec. The displaced top trace is a mistrigger.

Werner Sax at work on the prototype lithium lens.

exciting results coming out of CERN's 540-GeV $\bar{p}p$ research, we must look to 1986 before we will be able to examine our 2000-GeV collisions. Of course it is worth waiting for--with all the benefits of CERN's detector experience, with a design that will yield higher luminosity at much high energy, the physics potential is enormous.

Tevatron I Staff

Administrative Support:

H. Casebolt, R. Craven, G. Dean, D. DeLeon, P. Dreher, T. Martin, A. Riddiford, R. Wendt

Physicists:

A. Ando, F. Cole, T. Collins,** G. Dugan, J. Griffin, D. Harding, C. Hojvat, D. Johnson, W. Kells, M. Kuchnir, A. Lennox, J. MacLachlan, E. Malamud, J. Marriner, F. Mills, S. Mtingwa, S. Ohnuma,** L. Oleksiuk, J. Peoples, R. Peters, A. Ruggiero, R. Shafer, J. Simpson,* K. Takayama,* D. Young, Q. Zubao*

Engineers:

L. Bartozsek, F. Cilyo, R. Hanson, B. Hyslop, F. Lange, J. McCarthy, A. Moretti, R. Pasquinelli, J. Petter, W. Sax

Technicians:

R. Barner, M. Kucera, L. McMath, R. Meeks, W. Mueller, D. Paddock, D. Poll, T. Rathbun, M. Rubuehr, P. Seifrid, R. Vargo

Drafters/Designers:

*C. Costanzo, P. Dermott, R. Firchau, S. Meredith,** C. Nila, L. Sobocki*

Engineering Physicists:
T. Ellison, J. Fitch

Experimental Area Floor Manager:
J. Klen

Operations Specialist:
R. Oberholtzer

* *denotes Visiting Scientist status*
** *denotes On Loan from another division at the Laboratory*

The Construction Projects: Collider Detector at Fermilab

Two major happenings in 1982 dominated the mood of the CDF group. The first was the onset of civil construction of the collision hall and CDF assembly area at B0. The second was the report of a very successful run of our CERN colleagues where 270 GeV protons and antiprotons began colliding for the first significant phyics run in September. Preliminary results of the CERN $\bar{p}p$ collider had already been presented at the biannual assembly of particle physicists in July in Paris (sigh!). The clear observation of "needle-like" jets emerging from these collisions is a virtual demonstration of the reality of quarks as the primary objects in the scattering. The new run established new records of luminosity and the first rumors of W-like events. It was enough to stir the blood and quicken the pulse.

One member of the group was assigned to spend four months with one of the CERN experiments. The rest buckled down to work.

CDF reorganized a bit and passed a combined internal-DOE review with good marks. Much work was done in the test beam with prototypes of the calorimeters. Production lines have been set up for cutting and shaping scintillator and waveshifter pieces and a very impressive (~30 ft high) arch consisting of twelve central calorimeter wedges was assembled.

The mammoth superconducting solenoid (3 meter diameter, 5 meter long) made progress and much effort went into the front-end electronics. All in all, progress was made on all fronts.

The DOE review, the CERN detector experiences, and periodic internal examinations, these all lead us to the conclusion that we are building a powerful and well-designed detector for 2000-GeV $\bar{p}p$ collisions. It is a very complex array of large systems and it will be far from trivial to get physics out of this at the earliest date.

Collider Detector Group

Administrative Support:

D. Carlson, B. Perington, C. Picciolo, J. Robb

Physicists:

M. Atac, T. Collins, J. Elias, J. Freeman, I. Gaines, H. Jensen, R. Kadel, R. Kephart, S. Mikamo, M. Mishina, H. Miyata, A. Murakami, M. Ono, J. Patrick, D. Quarrie, R. Schwitters, Y. Takaiwa, D. Theriot, A. Tollestrup, R. Yamada, K. Yasuoka, J. Yoh

Enginering Physicist:
D. Hanssen

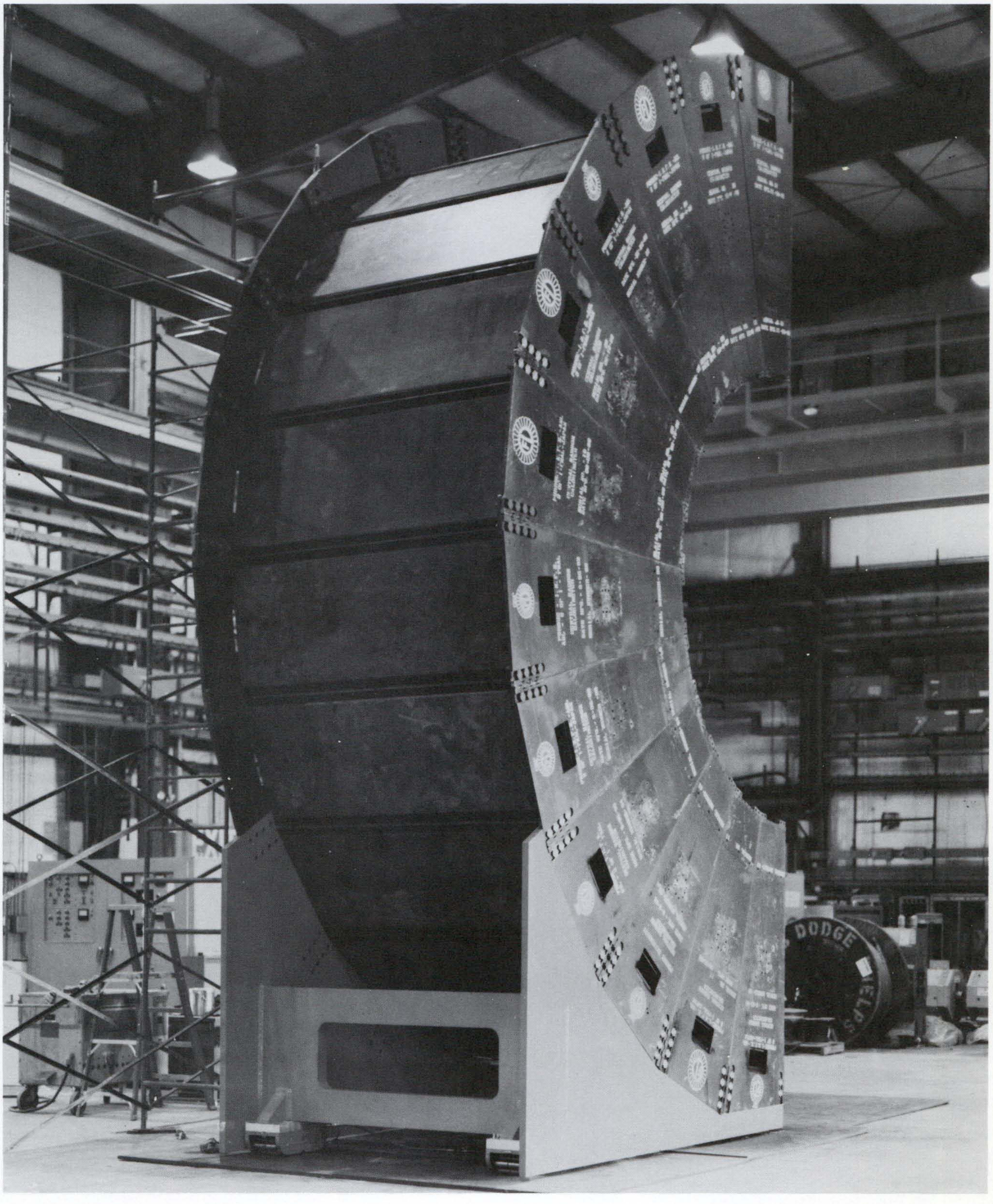
Engineers:

J. Grimson, H. Kautzky, M. Leininger, Y. Ofek, J. O'Meara, C. Swoboda

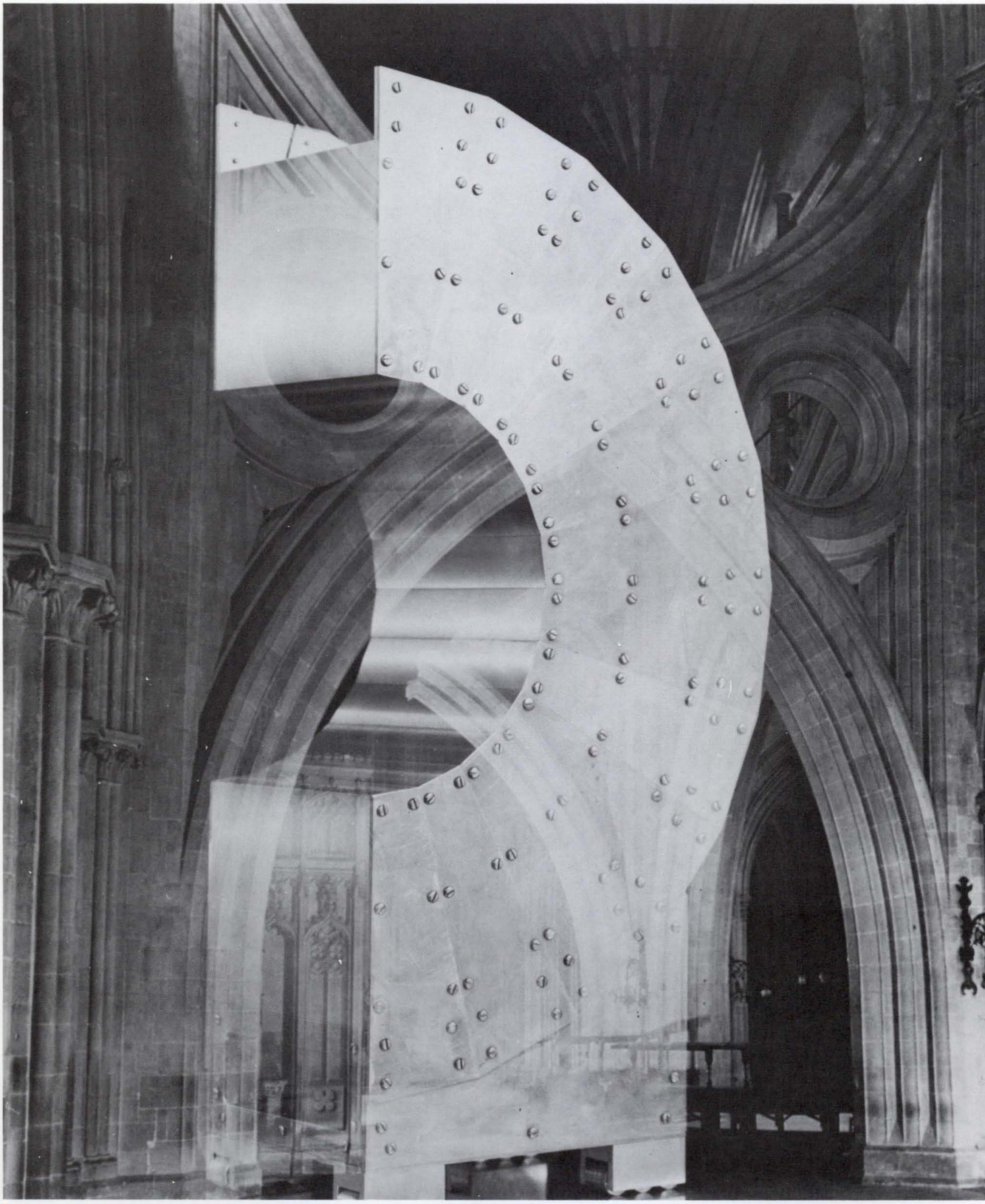
Technicians:

W. Coleman, M. Hrycyk, M. Knapp, R. Krull, R. Mandermack, G. Moore, J. Urish, B. Wickenberg

Drafter:
J. Catalanello

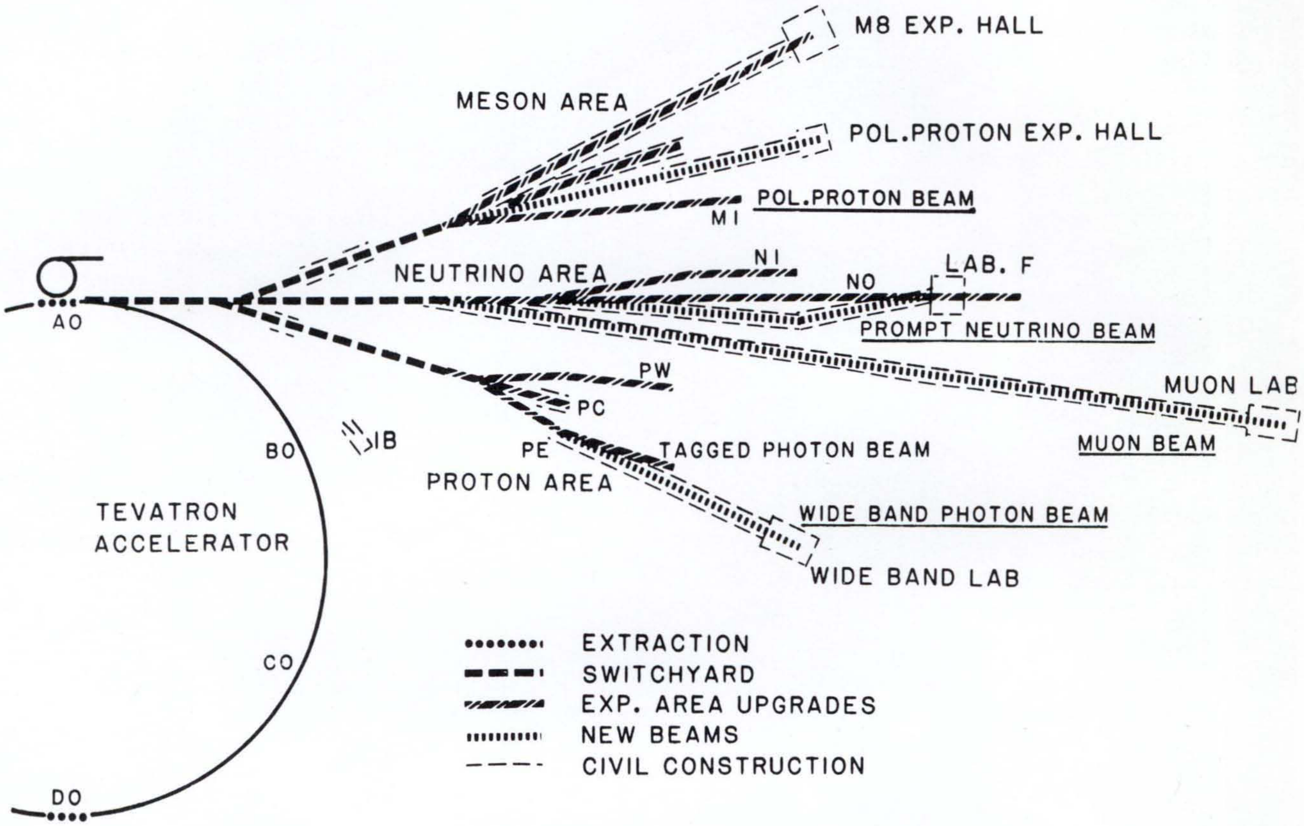


The central calorimeter of the Collider Detector.



A model of the calorimeter.

The Construction Projects: Tevatron II



Tevatron II converts the fixed-target experimental areas to 1000-GeV capability. It adds new beam lines to replace old beam lines. Many bends are replaced by superconducting magnets. The upgrades are scheduled to fit into the planned running program and will not be complete until late in calendar 1985. The long 1982 shutdown provided the first sustained TeV II construction activity. The project head writes:

> "The intensive planning and preliminary design activities of prior years began to be accompanied by the clanking of bulldozers, the bashing of punch presses, and the hissing of arc welders. Sketches and rough estimates were supplanted by sets of blueprints and detailed computer output. The upgrade was underway!"

Yes, well...

In functional terms, the TeV II upgrade has been structured in three successive one-year phases, roughly corresponding to the three and one-half calendar-year span of the project. The first phase consisted of fabricating and installing the extraction system for bringing slow-spill proton beam out of the Saver ring and transporting it through a rebuilt and upgraded beam switchyard to primary beam targets in the Meson, Neutrino, and Proton experimental areas. This phase also involves a significant amount of civil construction in the primary beam areas to accommodate new beam transport elements and to establish proton beam lines in each of the three experimental areas. These lines will serve new secondary beams to be developed in phase three of the project.

The second phase, into which the project will move this spring, involves the construction of a new experimental hall at the end of each of the four new secondary beam lines included in the 1-TeV upgrade. The third and final project phase consists of building appropriate civil structures, vacuum beam pipes, earth shielding, and utilities to complete the new secondary beam lines. This work will take place in late 1984 and 1985.

Some project highlights include a new and completely revised Meson Laboratory with three separate targets supplying their own secondary beam lines (the old Meson Lab had one target and six beam lines). A dramatic improvement has been made in the fabrication of electrostatic wire septa which are used for nudging proton beams into new orbits suitable for extraction and to split proton beams. These are very tricky devices designed to withstand high voltages and high radiation levels. Another highlight of 1982 is the improved design of the flux collection stage of the new muon beam, which saved more than half a million dollars and performed better. The project head writes more:

> "... and we look forward to 1983 with a reasonably well-trimmed ship and a steady breeze astern."

Obviously he trained under an ONR contract.

The immediate goal of TeV II is to be ready for the experimental program by October 1. Limitations in manpower and cash flow and the sheer number of things to do make this a tight schedule.

Tevatron II Staff

Tom Kirk, Roger Dixon

Department Office:

E. Brown, E. Duty, B. Edmonson,
B. Forester, C. Foster,
P. Mascione, N. McDonough, K. Stanfield

Safety Group:

S. Benesch, S. Butala, D. Cossairt,
A. Coveleski, M. Gerardi, K. McDonough,
J. Richardson, T. Sarlina

Liaison Physicists:

W. Baker, C. Brown, J. Butler, R. Coleman,
D. Green, H. Haggerty, J. Hawkins,
J. Lach, J. Morfin,
M. Mugge, S. Pordes, L. Read,
W. Smart, K. Stanfield, L. Stutte, R. Tokarek

Experimental Areas Support:

M. Alling, D. Byrd, R. Doyle, J. Featherston,
A. Guthke, A. Jonckheere, C. Kendziora,
M. Mascione, D. Miller, E. Mottys,
T. Prosapio, D. Rieth,
F. Rittgarn, C. Rogers, P. Simon, G. Smith,
W. Stitts, L. Torres, D. Worland

Tevatron II Staff (Cont.):

Facilities Support:

R. Cantal, H. Fenker, V. Frohne, D. Green, G. Gillespie, J. Guerra, H. Haggerty, S. Hansen, G. Koizumi, C. Mangene, C. Needles, S. Pordes, H. Schram, J. Spaulding, L. Stutte, H. White

Mechanical Support:

N. Bosek, D. Brinegar, D. Carpenter, R. Currier, R. Davis, D. Eartly, J. Gran, D. Hoffman, L. Indykiewicz, V. Jacobsen, E. LaVallie, J. Lindberg, J. Morris, D. Nelson, W. Noe, Jr., T. Olszanowski, M. O'Malley, R. Oudt, A. Passi, R. Roth, B. Smith, G. Smith, S. Sobczynski, M. Solis, H. Stredde, W. Strickland, W. Thomas, E. Villegas, T. Waldrop, M. Walega, R. Williams, T. Zolli

Operations:

G. Bock, M. Bodnarczuk, D. Carey, R. Coleman, H. Fenker, T. Fink, R. Flood, J. Hawkins, S. Heyden, W. Higgins, D. Johnson, G. Koizumi, J. Lentz, A. Malensek, C. McGuire, D. Miller, M. Mugge, R. Schailey, R. Sood, L. Spires, G. Tassotto, R. Tokarek, R. Zimmermann

Construction Planning and Coordination:

W. Baker, C. Brown, F. Browning, J. Butler, R. Coleman, D. Eartly, H. Ferguson, V. Frohne, P. Garbincius, A. Glowacki, D. Green, H. Haggerty, J. Hawkins, D. Johnson, L. Kula, J. Lach, J. Morfin, M. Mugge, S. Orr, S. Pordes, R. Shovan, A. Skraboly, K. Stanfield, R. Stefanski, L. Stutte, J. Walker

Cryogenics:

E. Beck, F. Bellinger, D. Burke, J. Bywater, J. Caffey, H. Carter, J. Clark, R. Coots, W. Cyko, E. Desavouret, K. Dixon, J. Ellermeier, J. Foglesong, P. Garbincius, M. Gonzalez, K. Graham, C. Grayson, P. Healey, E. Justice, O. Keefer, J. Kilmer, H. Koecher, T. Kovarik, K. Krempetz B. Lambin, D. Lipke, D. Markley, P. Mazur, C. McNeal, J. Morris, T. Neustadt, J. Norris, T. O'Brien, R. Pighetti, J. Probst, R. Pucci, J. Sasek, A. Schoeberlein, G. Simon, W. Smart, R. Stanek, H. Stapay, S. Stoy, R. Thompson, P. Thorkelsen, J. Urbin, G. Zielbauer

Electrical Support:

P. Allcorn, J. Becker, J. Bell, L. Beverly, J. Burt, J. Butler, N. Cuny, P. Czarapata, G. Dychakowsky, G. Federwitz, R. Gibbons, M. Herren, R. Innes, D. Jakubek, W. Jaskierny, S. Johnston, A. Legan, P. Liston, C. Lundberg, C. Mangene, F. McIntosh, R. Moore, C. Needles, S. Orr, M. Oslin, M. Pauley, A. Rogers, G. Ross, G. Samojluk, J. Schmidt, D. Schoo, D. Sorensen, G. Tassotto, R. Trendler, K. Tye, R. Vidal, A. Visser, D. Walsh, W. Williams, C. Worel, G. Wyatt, D. Zafiropoulos

Research Division

The Research Division single-mindedly carried on a number of different activities during 1982, so many that they sometimes were like jugglers keeping many objects in the air at once.

The most important effort of the first half of the year was the 400-GeV run from January to June. From the experiments' end of the action, it was a solid run with exceptional intensity and reliability, even some new features like the novel beam operated in the Neutrino Area. Only the M6 beam in Meson failed to live up to its advertising.

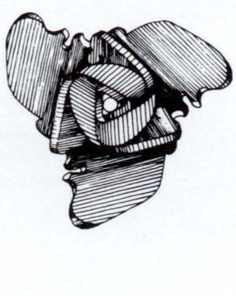
We have had a considerable amount of discussion and thinking about the organization of the Research Division. After the completion of the 400-GeV run, the Division was reorganized to group the traditional Meson, Neutrino, and Proton Areas into a single Experimental Areas Department. The cross-fertilization of ideas, skills and experience has exceeded our fondest hopes. Many problems in each area had previously been solved in one of the other areas. Knowing about these solutions has saved money and enabled us to do a better job.

The Research Division's primary mission after the 400-GeV run was to provide a home and resource base for TeV II and for CDF, both of which have been described above.

The other parts of the Research Division have been actively helping these and other Laboratory efforts. Research Services is building a superconducting solenoid for the Collider Detector with our collaborators from Japan. In addition, they are building all the front-end electronics and the FASTBUS system for the Collider Detector. Another electronics group in Research Services has helped the Energy Saver, building correction magnets, spool pieces, correction-magnet power supplies, and beam-position processors. Research Services is building the beam-dump magnets for the prompt-neutrino beam and many other systems for Tevatron II.

In the Computer Department, maintenance of all the on-bus computers of the Laboratory has been taken over and made successful. PREP (Physics Research Equipment Pool) is working on large electronic systems for Tevatron II. The central computing facilities have brought a remote-control automatic tape library into operation this year. Our central computing facilities are so popular that they are used to saturation and we have begun to plan for a much-needed improvement of the system in the future.

Here is where the Director feels maximum insecurity. It seems intuitively clear that the key to getting physics out of TeV I and II will be access to powerful computing capability. Our resources are up to doubling or trebling the capability of the central computer. We feel that by 1985 we may wish we had ten times this. What to do? A small start was made by forming a group to look at hardware processing of that ubiquitous task: track reconstruction. Beyond that, we could think of nothing more than forming a committee. Tune in next year.



Short Range Planning: The Tevatron Program

At the end of this year, this institution, and its people look to the program of science set out for us by our selection committees. We are awed by the potential of the machines we are making and weighed by an overwhelming sense of responsibility: to the physicists in their university labs, investing significant fractions of their scientific life in preparing to do their science here and to the heritage of legions of investigators who have brought both the science and the technology to the point where we can manipulate the one in order to advance the other. Our forthcoming schedule calls for supplying beams of near 1000 GeV protons to the experiments listed in Table III. Each experiment represents many institutions, an average of 29.4 scientists (ugh!) and the labor and investment of many times that number. The science can only be suggested by the experiment titles. Suffice it to say, the major thrust is programmatic--to sharpen the observation of the substructure of particles, to study the details of the strong and electroweak interactions in a new domain of parameters, to confront the standard model in a variety of ways in order to find clues, however subtle, to what lies beyond.

This is the major U.S. program, occupying almost half of the experimental high-energy physicists in this country supplemented by about 15% of our foreign colleagues. It must work well.

Table III. Tevatron Experimental Program

Beam Lines	Approved Experiments	
M-East (p, π)	E-605 (Brown)	Leptons and Hadrons near Kinematic Limits
M-Polarized (p)	E-704 (Yokosawa)	Polarized Beam Experiments
M-Center (n, K^0)	E-617 (Winstein)	Precision Measurement of $\|\eta_{00}/\eta_{+-}\|$
M-West (p, π)	E-557 (Zieminsky)	Hadron Jets with the Multiparticle Spectrometer
	E-609 (Selove)	High p_T Hadronic Jets
	E-672 (Dzierba)	High p_T Jets and High Mass Dimuons
	E-706 (Slattery)	Direct Photons
N-0 (ν)	E-632 (Morrison)	Neutrino Experiment in the 15-ft bubble chamber with Ne/H_2 Fill
	E-649 (Taylor)	Neutrino Experiment with Lab C Detector
	E-652 (Sciulli)	Neutrino Experiment with Lab E Detector
Prompt Neutrino	E-636 (Pless)	Beam Dump Experiment with 32-in. holographic bubble chamber
	E-646 (Baltay)	Beam Dump Experiment with 15-ft bubble chamber
Muon	E-640 (Loken)	Muon Scattering with Berkeley/Princeton Multimuon Spectrometer
	E-665 (Kirk)	Open Geometry Muon Scattering Experiment
N-3 (p)	E-653 (Reay)	Hadronic Production of Charm and Beauty in Hybrid Emulsion Spectrometer
	E-690 (Knapp)	Hadronic Production of Charm and Beauty
P-Center (K^0, $Y^{\pm}$)	E-621 (Thomson)	Measurement of η_{+-0}
	E-715 (Cooper)	Σ β-decay

One of my favorites, Joseph Bronowski, wrote in his Ascent of Man :

> ...And we are really here on a wonderful threshold of knowledge. The ascent of man is always teetering in the balance. There is always a sense of uncertainty...And what is ahead for us?...we are all afraid--for our confidence, for the future, for the world.

To which we add: "Yes, that too."

Looking even further ahead we see the collisions of proton and antiprotons. We have described CDF at B0. In 1983, we will select another experiment in D0. As we anticipate the imminent discovery of the W-boson we note with satisfaction that our program is aimed at the domain "beyond the W" where theoretical prediction is far less incisive and where opportunity for really profound discovery abounds.

Our higher energy will clearly be important. Here again the investment is tremendous and this Laboratory must apply all of the resources required to see this through and with as abbreviated a schedule as we can possibly manage.

Long Range Planning and the Future of HEP

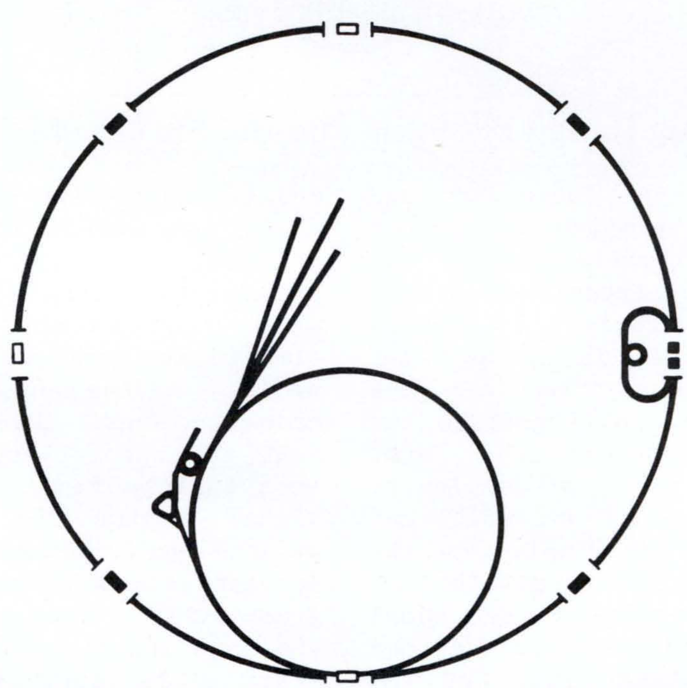
It is clear to all observers and especially to the Fermilab management that our sacred obligation is to exploit the physics opportunities provided by the vast construction activities described above. This is by no means simply a matter of getting all the machinery working and leaving it to the operators, skillful though they are. There is here a new level of complexity matched to a new level of technological sophistication made available by the continuing solid-state revolution. This machine will require a great deal of attention before we can achieve confident operation near 1000 GeV and with enough protons to satisfy the fixed-target program (now estimated to be in excess of 4×10^{13} ppp). The antiproton source again will require continuous attention in order to fulfill its design luminosity goal of greater than $10^{30}\,cm^{-2}sec^{-1}$. These requirements will occupy the best and the brightest in the laboratory until at least 1985. So what is the purpose of long range planning? The answer is well known to the professionals--lead time to the accomplishment of any major project is measured in years or decades. There is a clear perception that the theoretical state of our science will in fact require substantially higher energy than is now available. By the end of the decade, the major scientific results of the Tevatron program will probably be known; neither the Laboratory nor the science can tolerate a lapse of five years for new construction.

At this writing (January 1, 1983) we can only contemplate with awe and envy the program of our European colleagues. The LEP program is a very bold initiative to provide more than

100 GeV e^+e^- collider physics. The program will be heavily instrumented with four groups of at least 200 physicists in each group, building detectors in the CDF or bigger category. To sustain the waiting period, there is superposed on a well-instrumented SPS program, the $\bar{p}p$ collider, now digesting their first serious run but already designing an improved luminosity $\bar{p}$ source which may well be ready by 1986. LEAR is an interesting new facility which studies low-energy $\bar{p}p$ interactions with novel intensities. PETRA, at DESY, is close to a new energy range--one which may uncover the top quark and open a new domain of quark atom spectroscopy while DORIS has completed an upgrade in order to compete more effectively with Cornell's CESR. There seems to be increasing confidence that HERA, the DESY plan for e-p collisions will be authorized soon. This overall program sets a new scale by which the pace for U.S. physics may be judged.

What can we at Fermilab do? We are working on higher-field superconducting magnets--indeed, we have a program in collaboration with the Japanese laboratory KEK, to develop magnets near 10T. Equivalent quadrupoles would have immediate applications to our $\bar{p}p$ collider and provide a short-range focus to this work. A new crowd: the Group for Long Range Planning (GLRP!) has been examining options for the '90's. It is a low-priority operation but, after a wide ranging consideration of options, this group has narrowed the issues to two approaches:

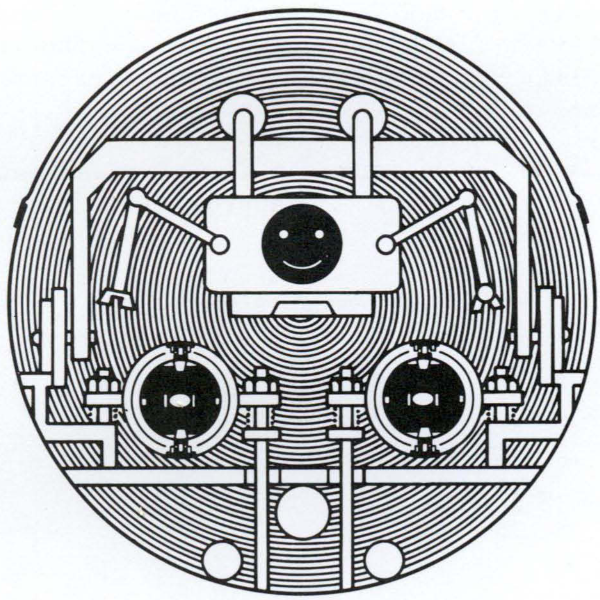
1. The Dedicated Collider Option



We are involved in a transient dream about building a dedicated collider--it is an evolution and modification of the old Fermilab idea of a site filler which has heretofore appeared in all our projections. The dedicated collider would use Saver magnets with improved superconducting wire to reach 5T. We could then comfortably site a 2-TeV ring to be fed by the Energy Saver with protons and antiprotons to create a 4-TeV $p\bar{p}$ facility.

With freedom from the constraints of the old tunnel, a special lattice can be designed to hold about 40 bunches of $\bar{p}$'s (instead of 3) and to store for a long time. This frees the fixed-target (TeV II) program from the burden of sharing time with the collider option and provides about 50 times the integrated luminosity in the collider physics: four interaction regions become possible instead of two; we run all year and we may get 10 times the luminosity of TeV I. There is more. The dedicated collider could take an electron ring for ep physics (we talk about 10-20 GeV against 2000 GeV). Our Physics Advisory Committee just loved this plan and has encouraged us to submit this to the DOE. We are at this writing studying costs, schedules, etc.

2. The "Desertron" Option

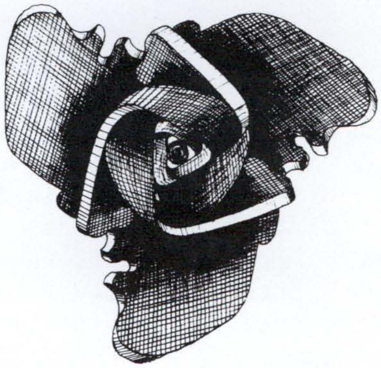


Assessing the state of the science, and the pace of European activity, we are lead to consider the next higher energy regime. Many workshops have considered the 10 TeV × 10 TeV collider (or 20 TeV × 20 TeV). The standard price is \$3B and this was the rationale for ICFA--the International Committee on Future Accelerators--charged with the task of studying a world laboratory solution to the cost problem. A Division of Particles and Fields workshop took place in Snowmass, Colorado in the summer of 1982. The 20 TeV accelerator was much discussed. More recently a subset of GLRP has been looking at the possibility that one can reduce the cost of a 10 × 10 accelerator to under \$1B, including injector, site establishment, etc. This is clearly a very challenging field and we are irresistibly tempted to pursue these ideas until they are proven wrong. This must be done in collaboration with experts wherever they may be found. It may be that the results of such a study will have a profound influence on the future of this Laboratory.

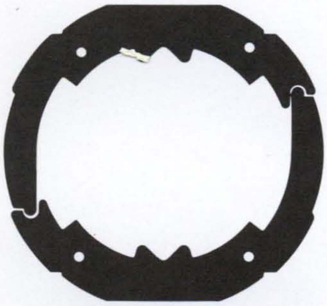
Leon M Lederman

Acknowledgment

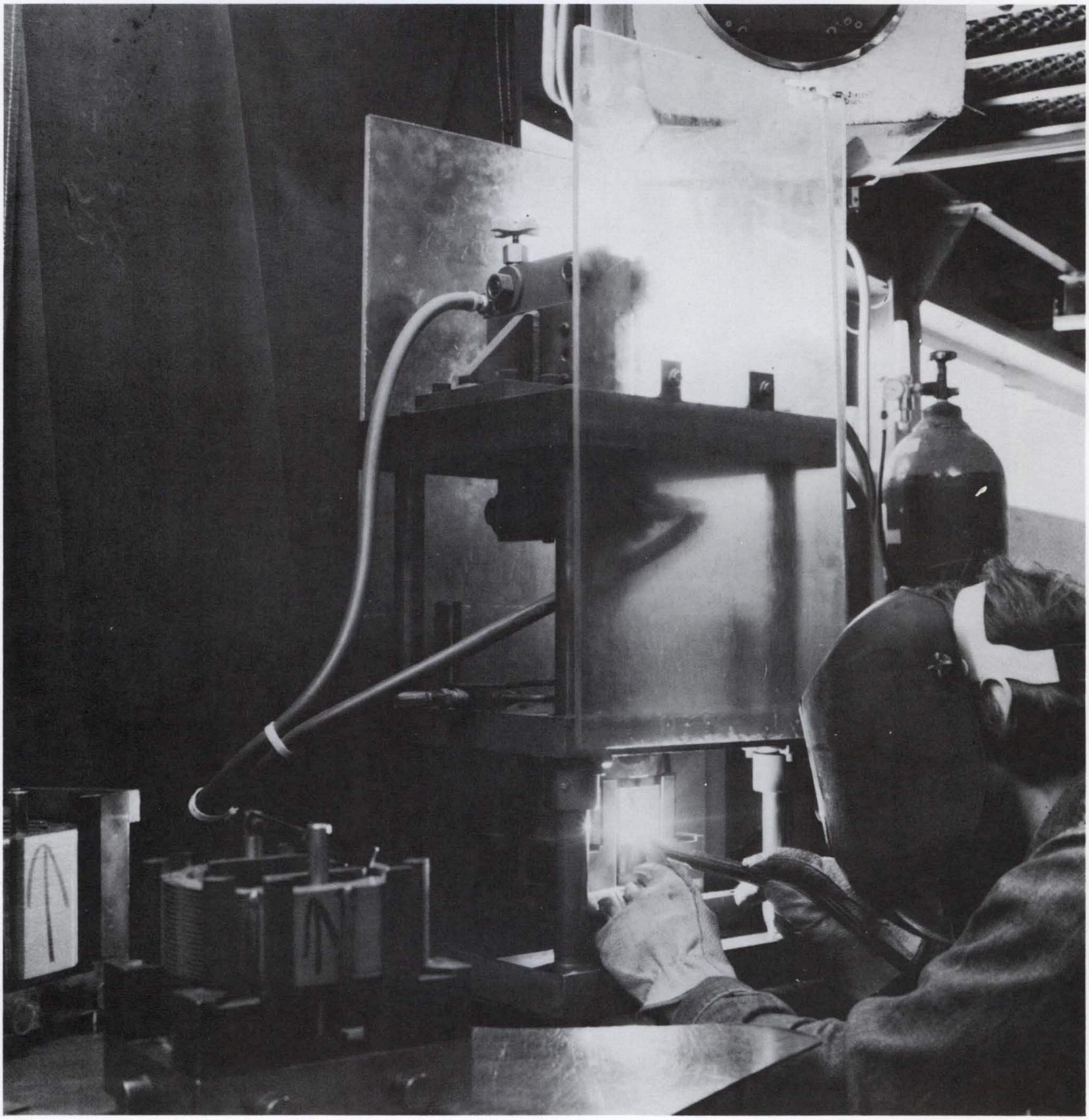
We have, in this Annual Report, decided to restrict the subjects discussed. Perhaps next year we will pay more attention to the many crucial elements in this Laboratory, e.g., the shops and the services, from business to personnel, to the people who keep us safe and out of trouble. We should devote some time to those individuals in the DOE and the Scientific Establishment in "This Town" who make our lives tolerable and our activities possible, and to the people who maintain and enhance the esthetic quality of our work space. Perhaps next year...



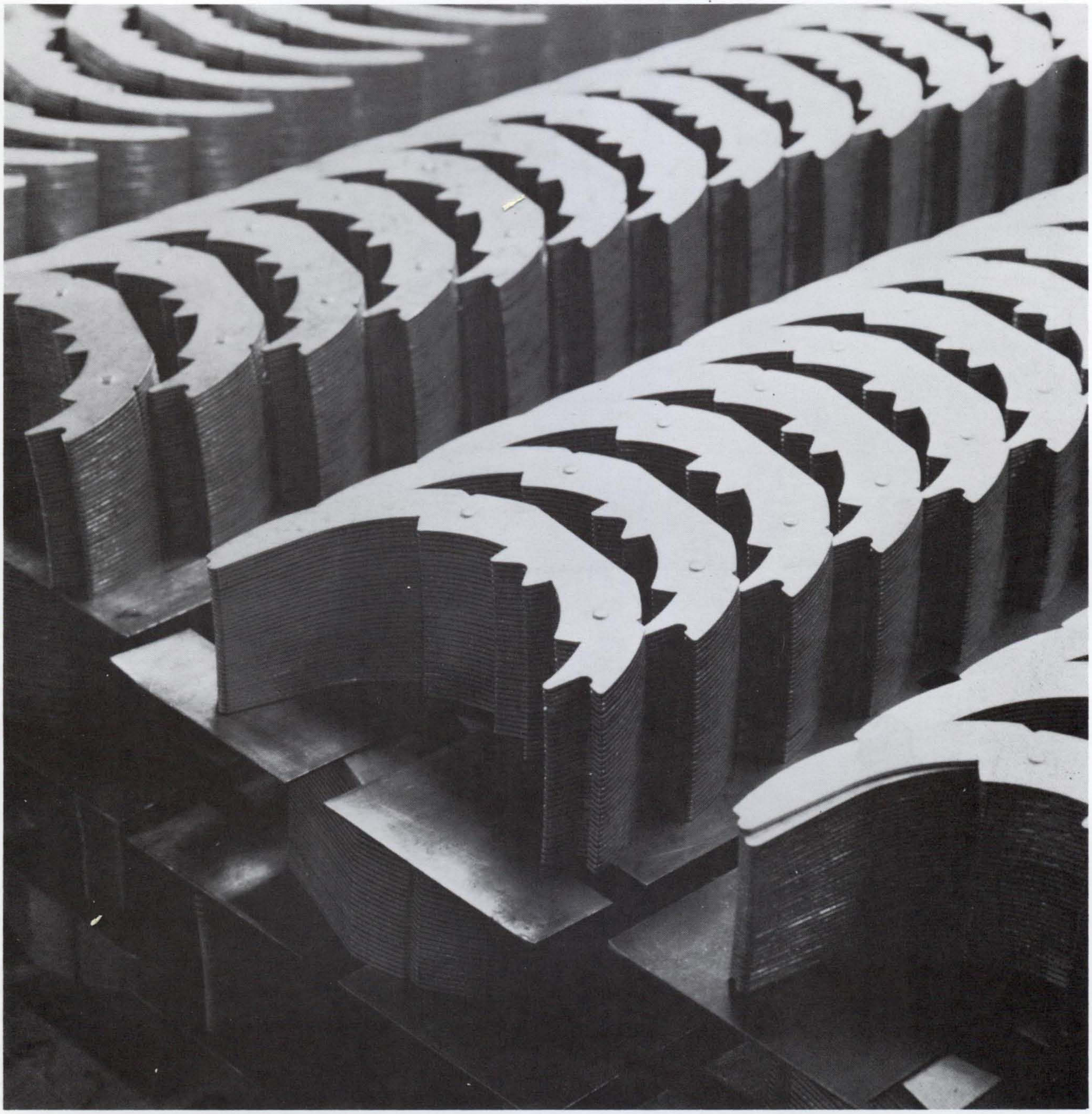
II. Fabricating Energy Saver Superconducting Magnets



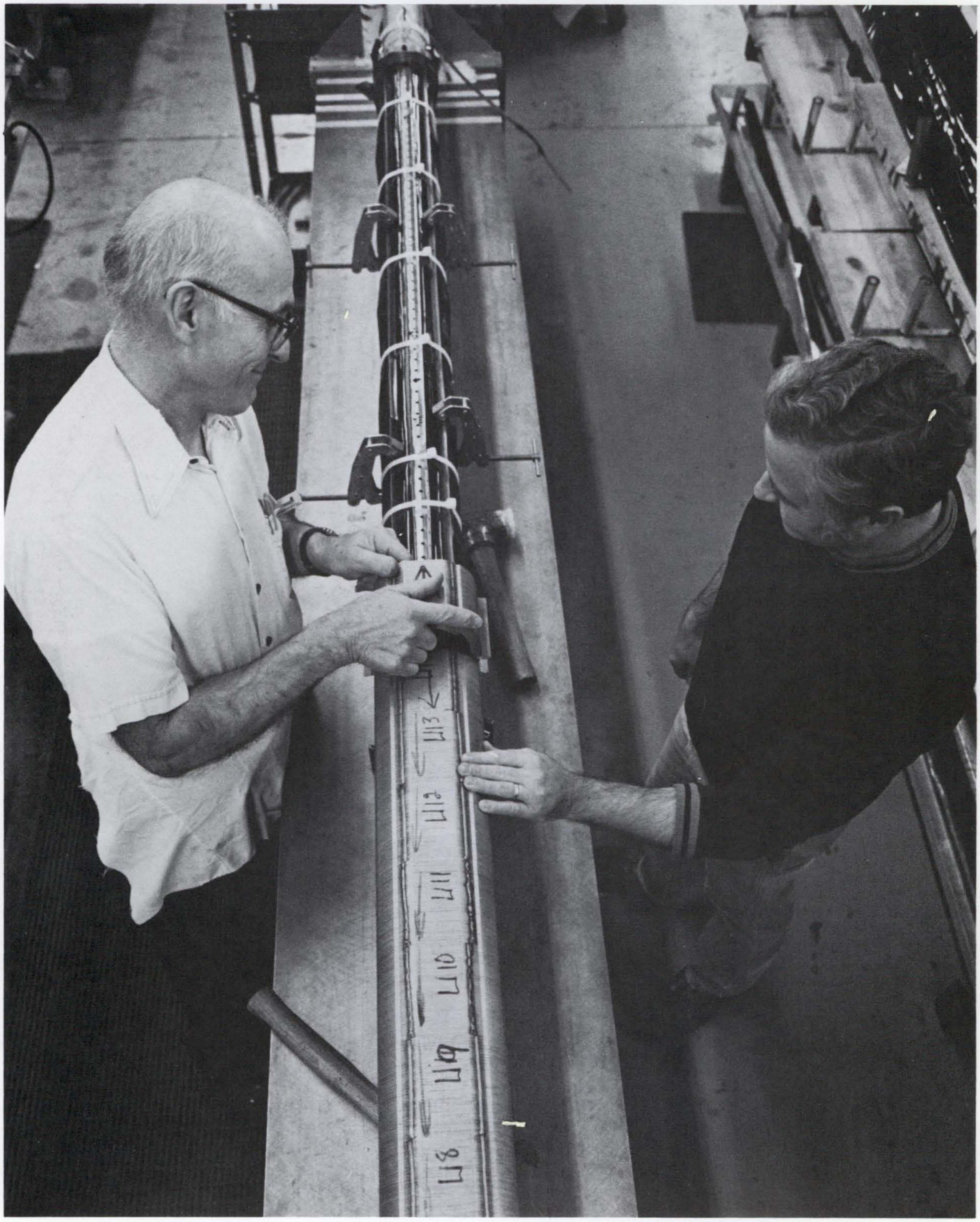
The fabrication of a superconducting magnet starts with winding the coils. The superconducting cable is unwound from the reel on which it is sent by the manufacturer and precisely tapped into place in the coil form by Pamela Greenwood. In the background, Darlene Mindar guides the motion of the cable reel and the unwinding of the cable. The inner coil shown here is wound flat then pressed around a cylinder. The outer coil is then wound on the inner coil.



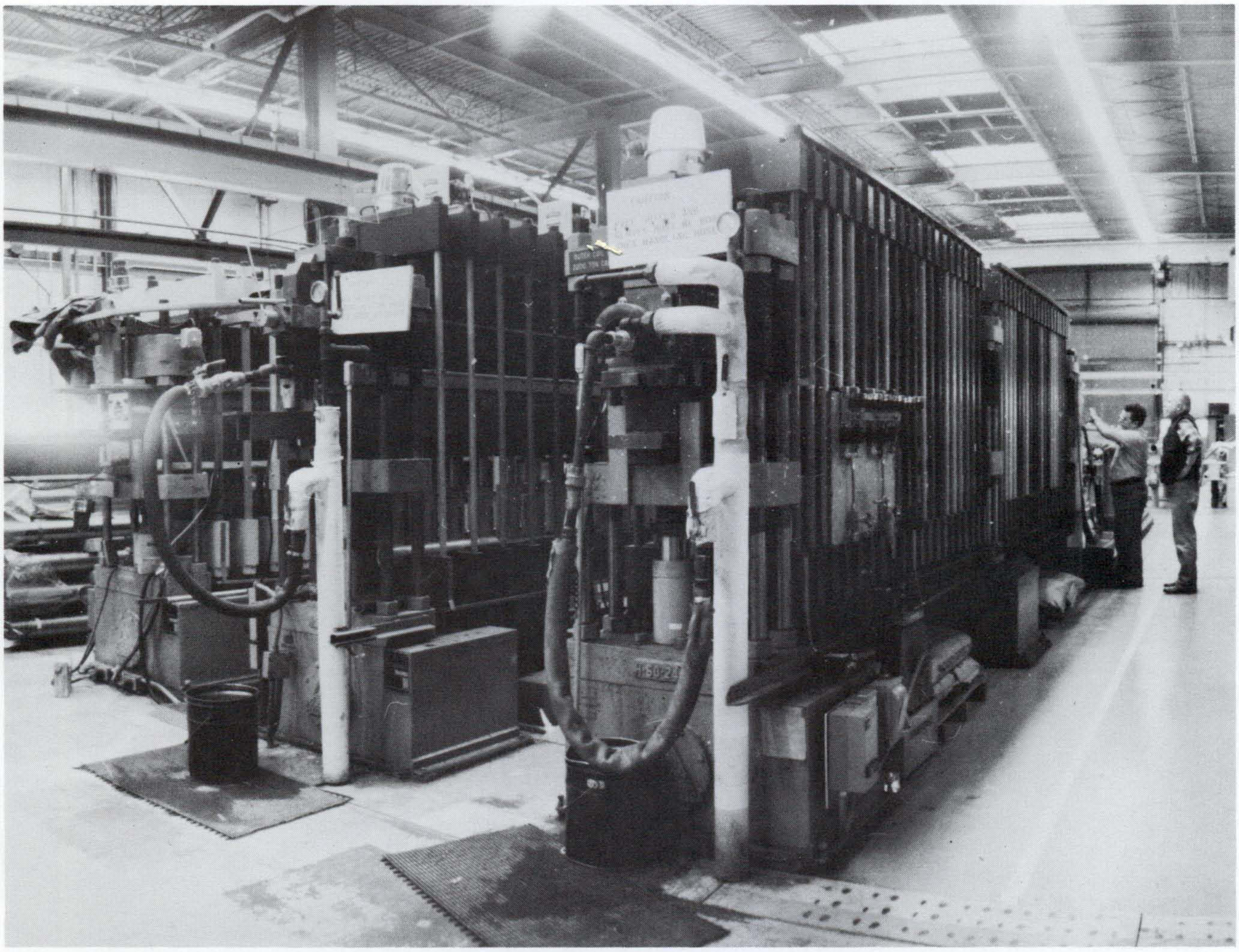
The superconducting coils are held in place by laminated stainless-steel collars. Here a pack of laminations is preassembled.



The stampings from which lamination packs are made. The inner and outer coils fit snugly into the grooves inside the laminations.

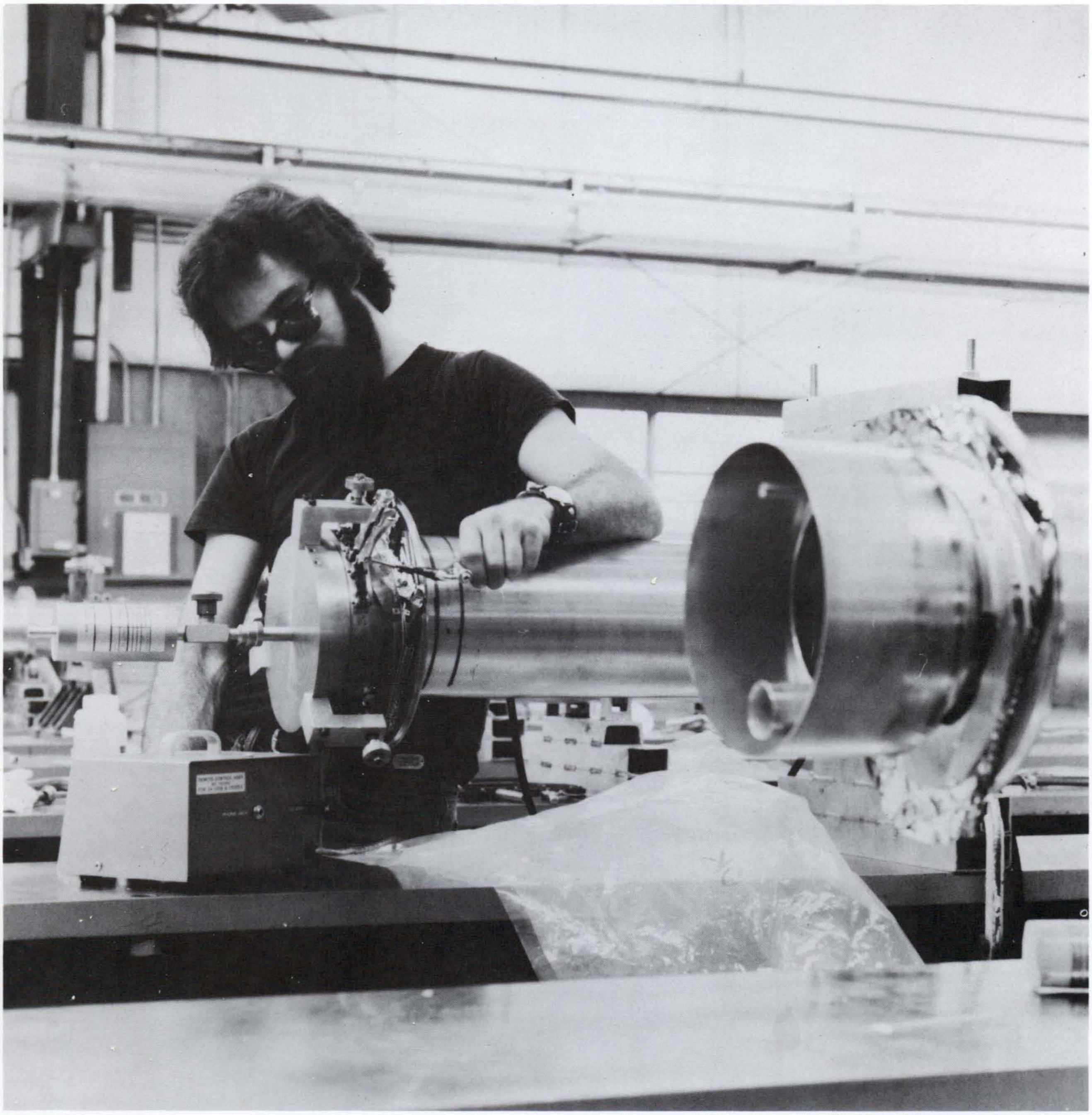


Using shims to keep the dimensions precise, the lamination packs are assembled over the coils by (left) Emery Konop and Tom Fritz.

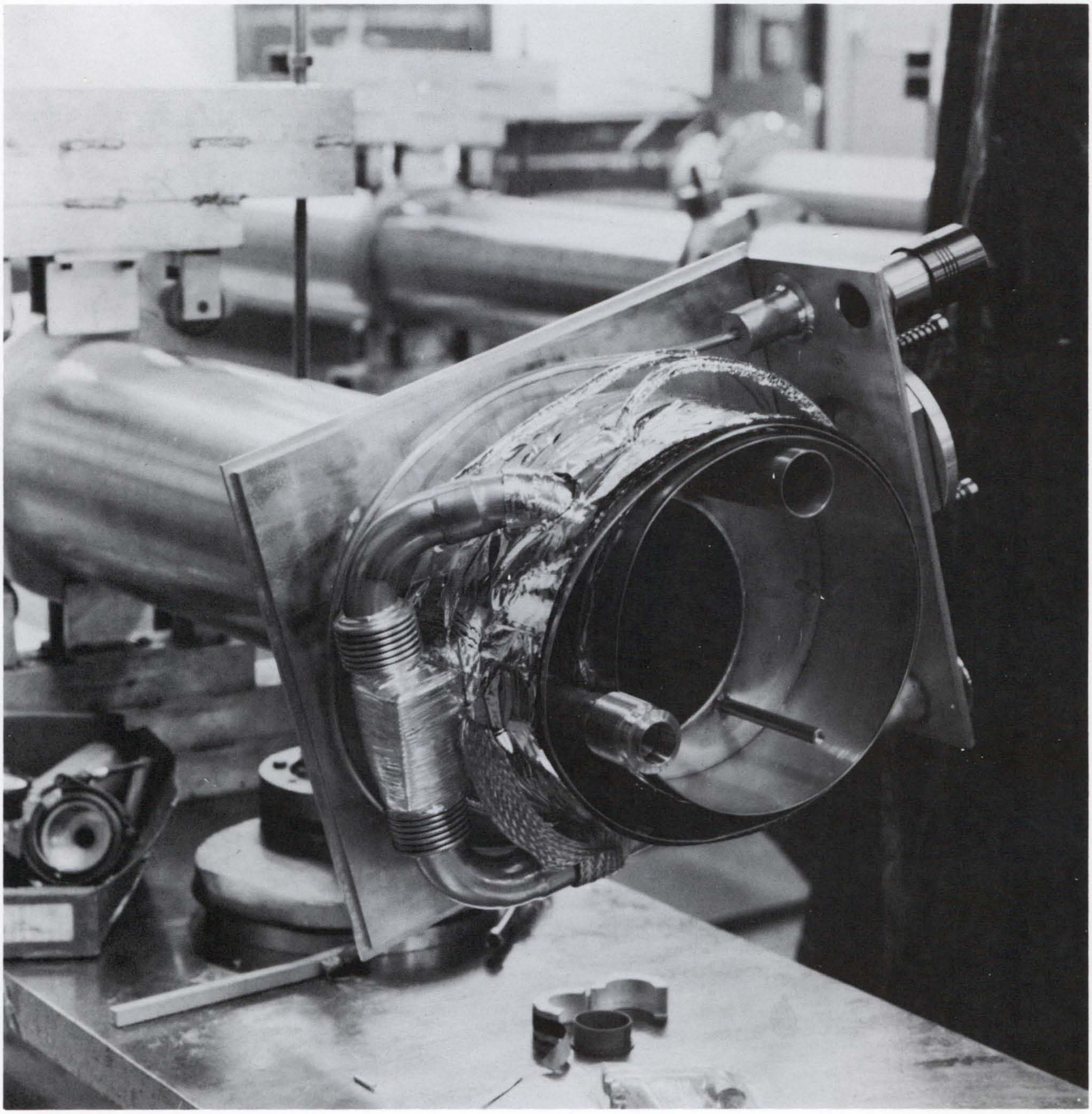


The coils and collared coils are pressed into shape and assembled in large presses.

The coils will be mounted in a cryostat where they are kept cold. Here a welder is working on the mounting holes for anchor supports. These anchor supports hold the coil suspended inside the cryostat.

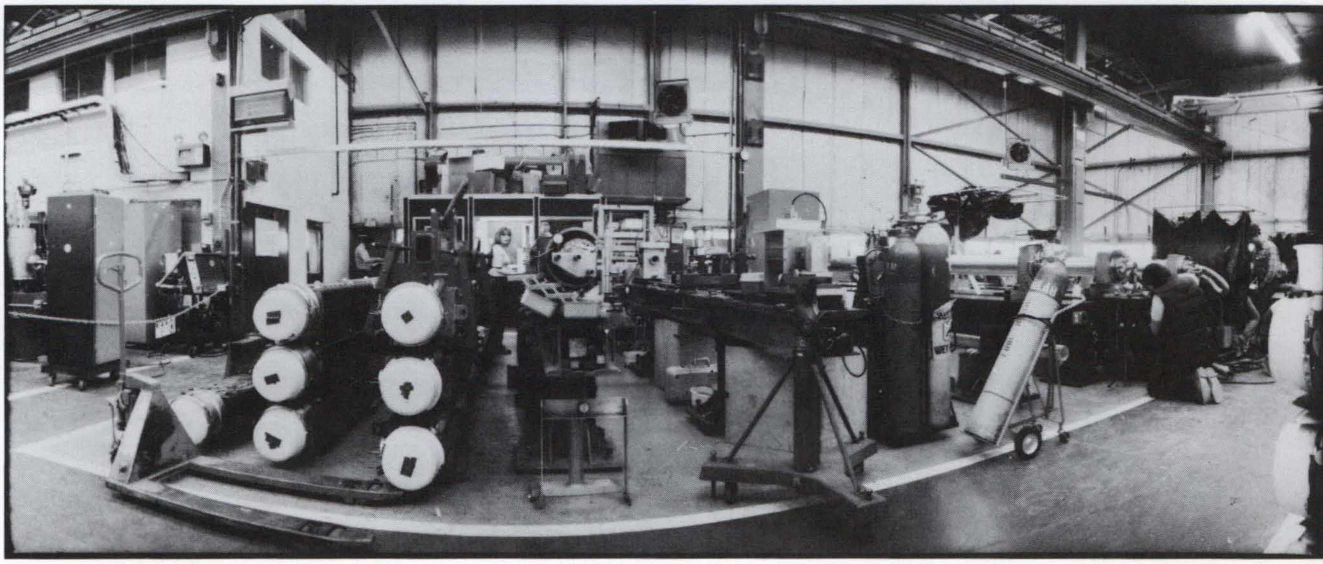


Final tests on the cryostats prior to "pushing" the collared coils inside them.



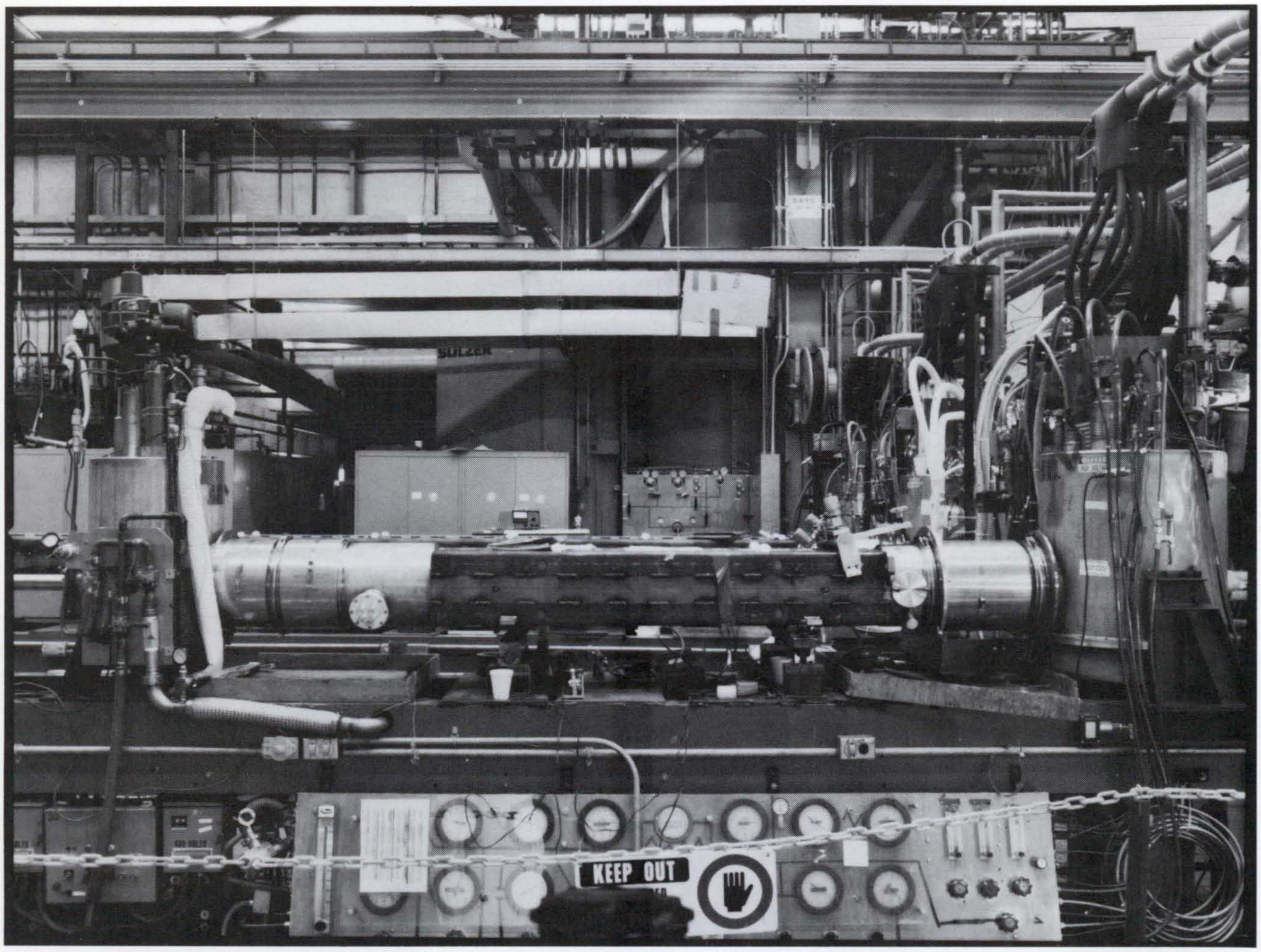
Partly completed cryostat end with some of the tubing in place.

Final assembly of the end of a cryostat. The liquid nitrogen and two-phase helium tubes are just above Jerry Kucera's hands. The coil end can be seen inside the collared coil while the coil lead goes out over Jerry's shoulder.



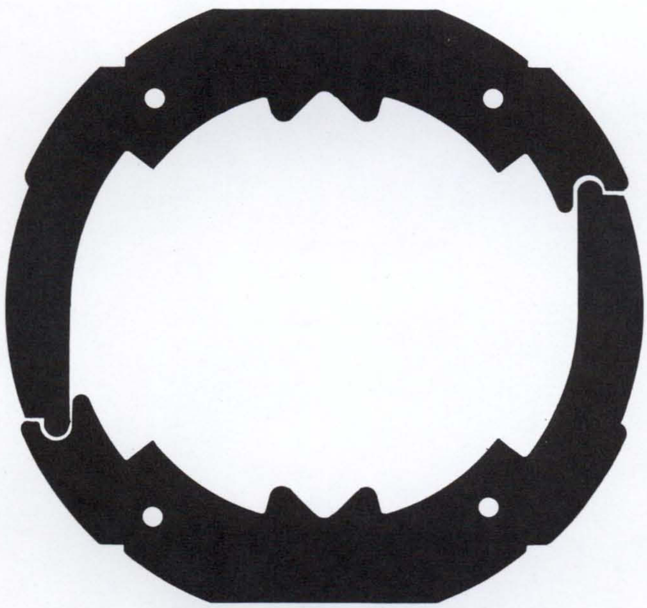
Final assembly takes place inside Industrial Building 1. At the right, cryostats are being vacuum checked. At the left are completed magnets awaiting magnetic measurements.

Inside Industrial Building 1. In right foreground is the quadrupole assembly line. In the background is the assembly area where magnet yokes are fitted onto the completed cryostats and coils. To the left is the Magnet Test Facility.



A quadrupole magnet on test stand 3. The refrigerator is in the background and the helium and nitrogen distribution system is at the right. Note the frost that builds up on any exposed line. Each magnet spends at least a day being given numerous magnetic tests.

Completed, accepted Energy Saver magnets in Industrial Building 4 awaiting tunnel installation.



III. The State of the Science

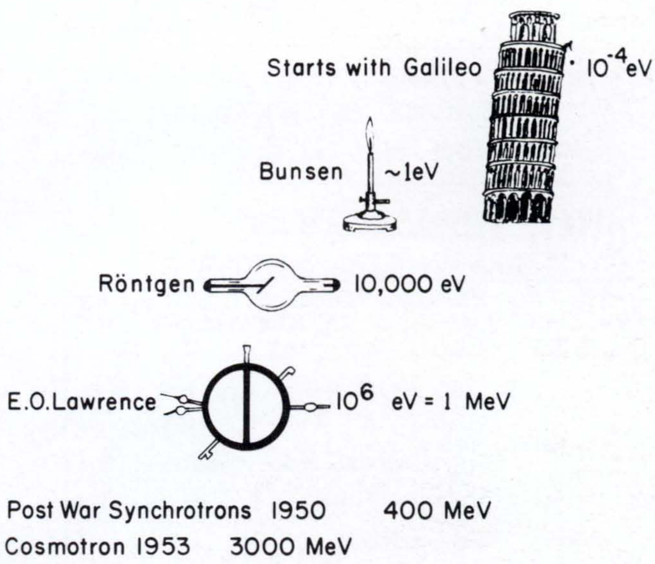
What is the current state of our subject, and what are our dreams and aspirations for its further evolution? In this section, we essay a brief description of where we are in our study of the fundamental constituents of matter and the interactions among them. We shall evoke some of the decisive experimental observations and influential theoretical ideas which have brought us to our present understanding, but the principal interest of this article is with the future. What developments may we anticipate? What are the great issues before us? What are the new programs and new instruments that our curiosity requires? What new technologies must we therefore invent or master?

High-energy physics continues in a period of remarkable excitement, progress, and promise. Over the past fifteen years, our world-view has changed in several dramatic and important ways. As a result, we have come to an understanding of the microworld that is both more orderly and more fundamental than the picture it replaces. Scientific explanation is always tentative, in the sense that it may be overturned by an unexpected discovery, or may be simplified and extended by a new insight. A great strength of our current theoretical framework--built as it is on the foundation of experimental regularities--is that it suggests lines of further thought and experimental research, creating new experience to support a grander edifice in the future.

The idea that matter in its ultimate structure is discrete, rather than infinitely divisible, has been part of scientific thought for 2500 years, but is was only at the beginning of the last century that a quantitative science of chemistry made possible an experimental verification of the atomic hypothesis. The laws of chemical combination formulated then are still

ARISTOTLE
DEMOCRITUS
EMPEDOCLES
LUCRETIUS
COPERNICUS
GALILEO
BRAHE
KEPLER
NEWTON
DALTON
CAVENDISH
OERSTED
AMPERE
VOLTA
FRESNEL
FARADAY
MAXWELL
HERTZ
CURIE
THOMSON
RUTHERFORD
EINSTEIN
BOHR
HEISENBERG
SCHRODINGI
FERMI
DIRAC
SCHWIN
LEE
YANG
GELI

The history of particle physics is a history of the invention of a series of accelerators of increasing energy and of instruments of detection.



Post War Synchrotrons 1950 400 MeV
Cosmotron 1953 3000 MeV
Bevatron
AGS
SLAC
Fermilab 1973 400 GeV (Billion Volts)
Fermilab 1983 1000 GeV

World HEP

Machine	What Collides	When	Effective Energy In GeV	Luminosity (Related to Number of Collisions)
CERN $\bar{p}p$	$\bar{p}p$	1981	540-600	$\geq 10^{29}$
DORIS Upgrade	e^+e^-	1982	10 upsilon	$>10^{31}$
PETRA Upgrade	e^+e^-	1982/3	→43	10^{31}
*Fermilab TeV II	pT^+	1983-85	42 (F.T.)	10^{36}
*Fermilab TeV I	$\bar{p}p$	1985	2000	$>10^{30}$
*SLAC SLC	e^+e^-	1986	100	10^{30-1}
Japan (TRISTAN)	e^+e^-	1987	50	10^{32}
CERN LEP	e^+e^-	1988	100-140	10^{32}
DESI HERA ?	e^+p	1988	300	10^{32}
TRISTAN II	e^-p	1989	200	10^{32}
*BNL ISABELLE?	pp	1989	800	$\geq 10^{33}$
USSR UNK	pT^+	1990	70 (F.T.)	10^{36}
SC‡ in LEP Tunnel	$\bar{p}p$	1990	~10,000	10^{30}
USSR UNK Coll.	$\bar{p}p$	1993	6000	10^{30}
VBA (World Lab)	?	2001	20,000	

* US Machines T^+ Fixed Target   ‡ Super Conducting Magnets

MORE HISTORY

IN ~500 BC THE STANDARD MODEL HAD 4 PARTICLES AND 2 FORCES:

THINGS: AIR • EARTH • FIRE • WATER

FORCES: "LOVE" + "STRIFE" EMPEDOCLES

IN ~1800 AD: PROUT'S LAW - ALL THINGS WERE MADE OF HYDROGEN
O.K. FOR H, C, N, O but Chlorin?

~1869 STANDARD PICTURE
7 COLUMN PERIODIC TABLE BUT ARGON
CORRECTED PERIODIC TABLE SUGGESTED CYCLIC STRUCTURE → SHELLS OF ELECTRONS

~1920 TWO PARTICLES e, p
TWO FORCES Gravity, Electromagnetic

BUT: N^{14} (needed two varieties of e - e_{INSIDE} + $e_{OUTSIDE}$)

also: Radioactivity, Sunshine } puzzles - facts which did not fit.

BUT OTHERWISE AN ELEGANT STANDARD PICTURE

obeyed by chemicals and learned by students today. At the end of the nineteenth century came the first hint that atoms were themselves composite and could be dismantled. In 1897 J. J. Thomson's discovery of the electron--which we still regard today as one of the fundamental constituents of matter--also posed the question of what else lies inside the atom. By 1931, Ernest Rutherford and his co-workers had provided the answer: an atom is composed of electrons and a small, dense nucleus. The nucleus is itself a composite of more elementary protons and neutrons. It then appeared that all of matter could be composed of three fundamental particles: the electron, proton, and neutron. If the interactions of the neutron and proton could be understood, the diversity of the forms of matter would be explained.

One way to investigate the nuclear force is to try to knock nuclei apart, by bombarding them with energetic particles such as neutrons or protons or electrons. To accelerate these particle projectiles to extremely high energies, larger and larger machines were built. These early "atom smashers" were the ancestors of Fermilab's five accelerators. In the course of these studies it was found that nuclear binding could be understood if another elementary particle, called the pion, were postulated. Shortly after the Second World War, the pion was found, first in cosmic-ray interactions and then in accelerator studies. The nuclear force was essentially understood.

Over the course of the next twenty years, hundreds of other subnuclear particles were discovered. All had their corresponding antiparticles--small bits of antimatter. It became clear that none of them, including the proton and neutron, could be considered more fundamental than any other. All of them were extended objects, had internal structure, and could be considered composite.

Composites of what? We now believe that subnuclear particles are made up of basic entities called quarks. The first clues to the existence and nature of the quarks came from the family relations among the subnuclear particles. For example, three quarks are contained within each proton or neutron. Indeed, all the hundreds of particles with nuclear interactions discovered until 1974 can be understood as composites of three distinct kinds (or flavors) of quarks, combined according to two simple rules: Particles like the proton are composed of three quarks, while those like the pion are made up of one quark and one antiquark. From these simple ideas emerge the rich and varied spectroscopy of the subnuclear particles.

We have not succeeded in dismantling the proton and extracting the quarks within. Yet we use the simple quark model to derive a multitude of physical results. How do we justify our bold assertions about what goes on in the interior of the proton? By experiment. Experiments of a type pioneered at the Stanford Linear Accelerator Center and extended at Fermilab and elsewhere show that the proton indeed behaves as a collection of structureless constituents that have all the properties earlier ascribed to quarks. Other experiments carried out at Fermilab and at CERN have shown the possibility of studying individual quark-quark collisions. All of this evidence is circumstantial, but it is overwhelming.

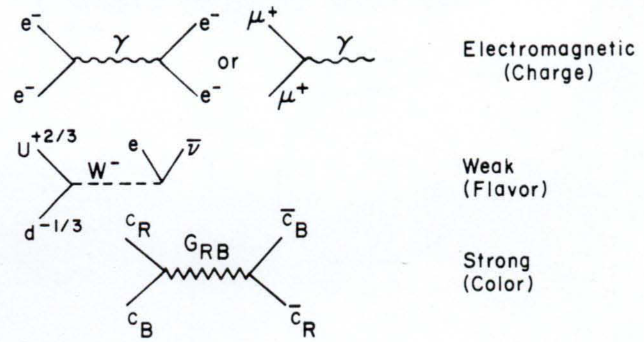
Two new quark flavors have been discovered in rapid succession: the charmed quark found in 1974 at SLAC and Brookhaven, and the b (for beauty or bottom) quark sighted at Fermilab in 1977. Like the older quark flavors, these have not been seen in isolation, but are inferred from new forms of matter.

A similar proliferation of flavors has occurred for fundamental particles

STANDARD PICTURE (1982)

I	II	III	IV	
$u_R\ u_B\ u_G$	$c_R\ c_B\ c_G$	$t_R\ t_B\ t_G$	?	Quarks (36)
$d_R\ d_B\ d_G$	$s_R\ s_B\ s_G$	$b_R\ b_B\ b_G$		
e	μ	τ		Leptons (12)
ν_e	ν_μ	ν_τ		

γ, $W^\pm$ Z°	} electroweak	Gauge Bosons (12)
8g(RB,GR···)	} gluonic strong	
[Higgs]	≥1 higgs	



Gell-Mann's Chart

Name	Mass	Charge	Baryon No.
up	2	+ 2/3	1/3
down	2	- 1/3	1/3
strange	550	- 1/3	1/3

Some Composite Hadrons

			Quark Structure
Proton	1000	+ 1	u u d
Neutron	1000	0	u d d
Lambda	1150	0	u d s
Pion π^+	150	+ 1	$u\bar{d}$
π^-	150	- 1	$d\bar{u}$
π°	150	0	$(u\bar{u}+d\bar{d})$
Antiproton	1000	- 1	$\bar{u}\bar{u}\bar{d}$

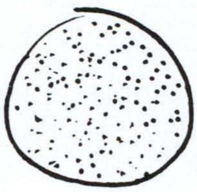
All Hadrons (1973) Could be Fitted

The Forces of Nature

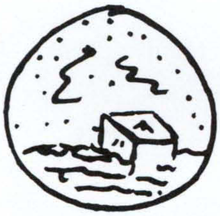
Force	Strength	Range	Carrier
Gravity	10^{-39}	Infinite	Graviton
Electromagnetic	10^{-2}	Infinite	Photon
Weak	10^{-12}	10^{-17} cm	W^+, W^-, Z°
Strong	0.2	10^{-13} cm	Gluons

THE TRUE SYMMETRY (SIMPLICITY) OF THE LAWS OF NATURE IS HIDDEN (BROKEN) BECAUSE OUR EXPERIENCES ARE AT VERY LOW ENERGY (TEMP.)

ANALOGY

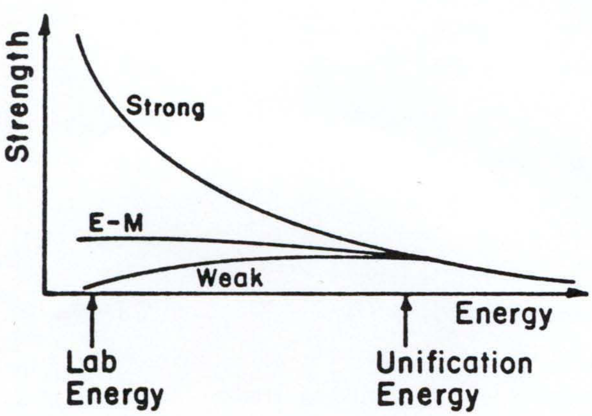


T >> 400°K



T << 300°K

At high enough temperatures — perfect symmetry is restored
GENERATION GAP ALSO CLOSES.



like the electron, which do not experience the strong, or nuclear, interaction. The electron's neutrino, postulated in the 1930's, was observed by means of its interactions in the early 1950's. A "heavy electron" called the muon was observed in the 1940's. A classic experiment in the early 1960's showed that the muon has its own distinct neutrino partner. Meticulous detective work in the mid-seventies at SLAC uncovered yet another kind of heavy electron, named the tau. We expect that it too has a neutrino partner, and Tevatron experiments are planned to complete the demonstration that the tau's neutrino exists.

The acceleration of history embodied in the swift development of the notion of elementary particles or fundamental constituents has been matched by the progress toward an understanding of the forces of Nature. To the layman, the forces of everyday experience are imposing in their diversity and numbers. We speak of the force of the wind, of friction, tidal forces, and many more. To the physicist, all the known interactions are manifestations of four fundamental forces: gravitation, electromagnetism, the weak interaction responsible for radioactive decay and starlight, and the strong interaction which binds the nucleus together.

Although gravity is the most familiar in everyday life, it was not given a precise theoretical foundation until the work of Newton at the end of the seventeenth century. A deeper understanding was provided by Einstein in 1915, but there are still puzzles associated with the behavior of the gravitational force at microscopic distances or at extremely high energies.

In common experience, electricity and magnetism seem as disparate as a bolt of lightning and the gentle swing of a compass needle. A series of brilliant nineteenth century experiments set the stage for Maxwell's unification of electromagnetism in a set of four equations that embody all the macroscopic phenomena.

More recently, we have learned how to construct Maxwell's theory of electromagnetism beginning from a symmetry principle. This is of special interest not only because it provides us with a more profound understanding of electromagnetic phenomena, but also because it serves as a model for the creation of new theories of the other fundamental interactions. The new strategy which underlies current theories is called, for historical reasons, a gauge principle. It is rather easy to invent a theory. One reason that theoretical physics is difficult is that it is so easy to invent theories which are wrong. We rely on experiment to tell us which theories are wrong, and we exploit great principles to help us guess which theories have a chance of being right. In general terms, the idea of gauge symmetry is that we should take very seriously indeed the patterns suggested by experiment such as the apparent family relationships among the quarks and the leptons. Theories that incorporate these patterns are rather severely constrained and have little room for arbitrary ingredients. If the gauge principle is correct, and if we are skillful at spotting real patterns--as opposed to illusory ones--in experimental results, we may be able to describe the fundamental interactions without any important ambiguity.

This appealing and ambitious program of deducing interactions from symmetries has been implemented in several important cases. We do not know yet whether the resulting theories are entirely correct. They do, however, seem to incorporate most elegantly all the experimental systematics built up over many years. What is more, they make extremely interesting new predictions that may soon be subjected to experimental tests. It is

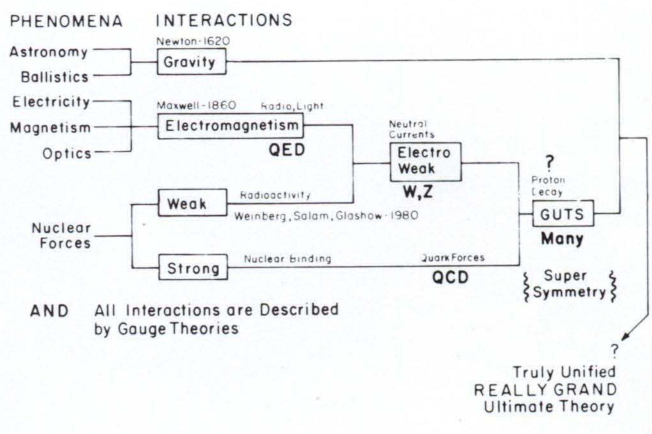
UNIFICATION OF SUCH APPARENTLY DIVERSE FORCES WAS TREATED SKEPTICALLY BY MANY:

W. PAULI:
"WHAT GOD HATH PUT ASUNDER — NO MAN SHALL EVER JOIN."

OR

"THE ··· SYMMETRY OF FORCES ··· IN WHICH ONE DOES SOMETHING TO SOMETHING AND THEN COMPARES THE RESULT WITH THE RESULT OBTAINED FROM DOING THE SAME THING TO SOMETHING ELSE OR SOMETHING ELSE TO THE SAME THING" — JAMES NEWMAN OR TOM LEHRER

CLEAR?



THE ASTROPHYSICS CONNECTION

"THE EARLY UNIVERSE IS A HIGH ENERGY LABORATORY WITH A TOTALLY UNCONSTRAINED BUDGET"

Examples

1. Neutrino mass, the identification of "dark mass" and the question of open or closed universe
Fermilab exp E-613, E-701: ν-osc + Theoretical work on Rt handed ν in early universe

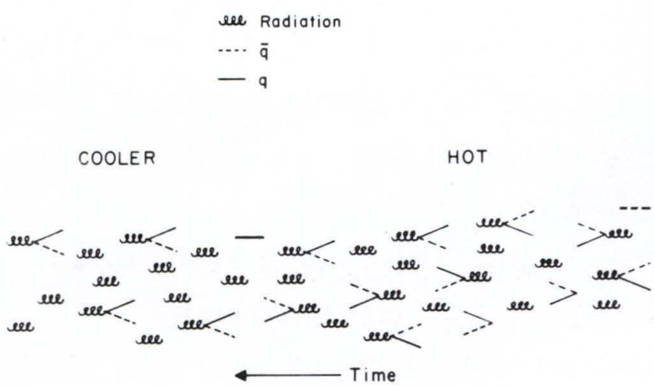
2. GUTs has direct application on modeling the quark-lepton soup – Baryon stability – ratio of photons to baryons – antimatter abund.
NEW OBJECTS: MONOPOLES, X things ....

3 Axions : astrophysical constraints being tested by SLAC-Fermilab expt

4. Transition phase & quarks → hadrons in early universe (Bardeen, Bj)

5. Monopoles E-690 $\boxed{\text{TEV I} \rightarrow 10^{-14}\,\text{sec}}$
etc, etc

⇒ FERMILAB ASTROPHYSICS GROUP



appropriate that we mention a few of these predictions which are under intensive study.

In quantum field theory, interactions are mediated by the exchange of "force particles." The best known of these is the photon, the quantum or particle of light, which carries the electromagnetic interaction. The existence of the photon was suggested by experiments on the photoelectric effect at the beginning of this century, and was rendered inescapable by A. H. Compton's measurements in 1923 which showed that X rays scattered as if they were billiard balls.

Gauge theories attribute definite properties to the mediators of the fundamental forces. The carrier of the weak interactions, the so-called intermediate vector boson (denoted $W^{\pm}$ for weak) has been the object of speculation for forty years. According to the unified theory of weak and electromagnetic interactions, the W-boson should weigh about 85 times as much as the proton. We have just received the first highly suggestive evidence for the existence of this particle from experiments at the CERN proton-antiproton collider. With luck, confirmation of this inference as well as evidence for the somewhat heavier mediator of the neutral current weak interactions, the Z^0, will soon be forthcoming.

A second prediction of our current theories is that quarks and the carriers of the strong interactions, the gluons, cannot be isolated but must be permanently imprisoned within particles like the proton and pion. While this theoretical expectation has not quite been proved, it seems unavoidable and is most important to test and retest experimentally. We look to the Tevatron I Collider experiments to batter protons and antiprotons more forcefully than before, giving the constituents a new (but we expect, still vain) opportunity to escape. More generally, the time-honored study of hadron spectroscopy becomes still more interesting as we come closer to a predictive theory of how quarks combine. In particular, the theory of quantum chromodynamics (QCD) suggests the existence of quarkless states composed entirely of glue. A few provocative sightings have been reported, but more--and different--experimental methods are required. The proton-antiproton collider again suggests techniques hitherto unavailable.

With respect to the properties of the allowed configurations of quarks and antiquarks, we are in the novel position of having a plausible theory of the strong interactions which we have not yet been able to exploit in full. Quantum physicists are adept with a method known as perturbation theory, which provides reliable approximate results in the case of feeble interactions. To "solve" the spectrum of the strong interactions requires the invention of new mathematical techniques. One promising approach is the method known as lattice gauge theories, in which space-time is provisionally regarded as a crystalline structure, and the consequences of the theory emerge statistically from large-scale computer simulations of the interaction. Thanks to the extensive computer resources available at Fermilab, it has been possible to begin some work in this direction. However, future progress is almost sure to depend on finding ways to increase computational power, either by incorporating special-purpose processors or by exploiting new architecture. This is a field in which theorists may have to learn to build their own equipment. In any case, it seems desirable that Fermilab--with its diverse hardware, human resources, and keen interest in the physics outcome--play an increasingly important part in the development of this subject.

Another promising way to investigate the strong interactions is by observing the violent collisions among quarks and gluons that occur when high-

CONTEMPLATE THE MAGNITUDES AND VARIETY OF THINGS!

SPACE FROM BILLIONS OF LIGHT YEARS DOWN TO $\frac{1}{1,000,000,000,000,000}$ of an inch

TIME FROM 20 Billion Years (Age of Univ.) to $\frac{1}{1,000,000,000,000,000,000,000,000,000,000,000,000,000,000}$ of a second

ENERGY (TEMP) FROM .001 eV (3° ABOVE ABSOLUTE ZERO) to 1,000,000,000,000,000,000 GeV (very hot!)

NOT MUCH HUMILITY HERE!

BUT, FOR EXAMPLE, THERE ARE AT LEAST TWO DRAMATIC "SUCCESSES" OF CURRENT THEORY IN COSMOLOGY -

(1) Where is the Anti-matter?

It was used up in collisions with matter in the first 10^{-30} sec. A small surplus of matter, generated by CP-violating X decays, supplied the material for all of the galaxies in the Universe.

(2) How will the Universe End?

It depends on the "missing mass" which may be contained in neutrinos.

- Examples of the ever increasing synergy of PARTICLE PHYSICS AND COSMOLOGY

"THE EARLY UNIVERSE IS A HIGH ENERGY LAB WITH A (SIGH!) UNLIMITED BUDGET"

Neutrinos + the END OF THE UNIVERSE

① EXPANSION

② CLOSED vs OPEN UNIVERSES

③ Mass Density ?

④ ν_e, ν_μ, ν_τ

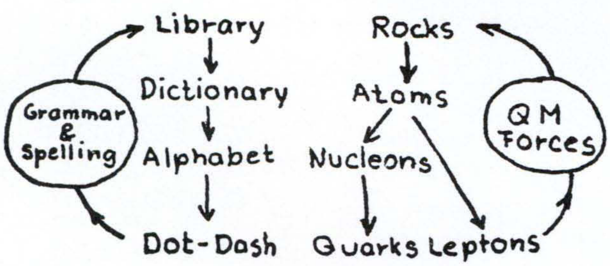
Mass $\nu_e \leq 100$ e.v.

$m_e = 500{,}000$ e.v.

IF $\left\langle \frac{m_e^\nu + m_\mu^\nu + m_\tau^\nu}{3} \right\rangle \geq 30$ e.v. ?

"Portacamp" discovery ?

△ The Parable* of St. Leon Di Batavia (circa XX^th cent. AD)



* Parable: an archaic term meaning paradigm.

Notes prepared by Leon Lederman to be used to illustrate various public lectures.

△ *Note by K. Gottfried, a parody on the Leon Lederman notes, and also used in one of the above-mentioned public lectures.*

energy protons and antiprotons collide. Early work at the CERN collider has shown that these rare but interesting events have a characteristic topology which means they can readily be selected from more routine occurrences. The Fermilab Collider will have much to contribute to the study of simple collisions among constituents. By virtue of its high energy, there is a great richness of event types to be anticipated.

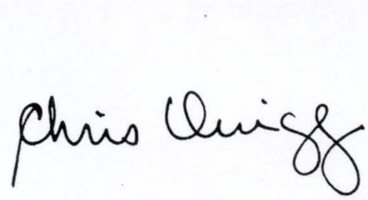
The proton is among the most stable of the observed particles, with a lifetime many orders of magnitude greater than the age of the universe--if indeed it decays at all. However this great stability is neither explained nor required by any of our grand principles. Indeed, within the framework of unified theories of the fundamental interactions, it seems likely that the proton should be mortal. In such theories, the quark families and lepton families are merged into extended families that reflect a more complete underlying symmetry. This is suggested by the pronounced similarities between quarks and leptons. In gauge theories there are interactions that can transform any member of a multiplet, or extended family, into any other. Some of the new possibilities that arise when quarks and leptons are unified induce disintegrations of the proton.

A number of imaginative experiments have been mounted to search for proton instability up to lifetimes of about 10^{32} years. The state of theory is such that finding strong evidence either for or against proton decay at this level would have profound consequences. The interaction responsible for proton decay is far too feeble to have direct implications for accelerator experiments, except insofar as it may be responsible (on the cosmic scale) for our existence and it is we who have built the accelerators. A number of the contending theories do, however, imply phenomena in the new territory opened by the fixed-target Tevatron, the Collider, and the machines of our dreams. All this speaks to the ultimate fate of the Universe.

To dream of new machines before our colleagues have completed the Tevatron may seem an act of infidelity. Not so! It is, in fact, the progress in accelerator technology that the Tevatron represents that stirs our imagination. The state-of-the-art techniques embodied in the Tevatron magnets, for example, now provide a baseline from which new developments can be measured. How can we reach still higher energies--two or five or ten times Tevatron scale--to probe more deeply into the regime where theories are more equivocal (and theorists less smug)? Surely we must continue the domestication of superconductivity by striving for magnets of higher performance and greater simplicity. Can we also exploit innovations in automation by devising robots to build magnets or even entire accelerators? Research into the mechanics of acceleration holds clear promise for reducing the size and cost of future machines. Fundamental investigations into beam dynamics may also lead to new concepts of practical importance. The history of our science has been the history of accelerator technology. New inventions hold the key to progress in the future.

High-energy physics is not a finished subject, so it may be appropriate to close this informal survey with some unalloyed speculation. We may divide the fundamental particles into two broad classes: the constituents and the force particles. The constituents are the quarks and leptons, which carry spin -1/2. The force particles include the photon, the gluons, and the intermediate bosons, which are particles with integer spin. We have not yet discerned the origin of the observed pattern of constituents, but the force particles are prescribed by gauge symmetry principles. In a sense that can be given a precise meaning in quantum theory, the constituents are solitary, whereas the particles with integer spin are gregarious. Would it not represent progress to relate the one class to the other, and thus to increase the power of the gauge principle while reducing the arbitrariness of our theories? So it would seem. Remarkably, a mathematical formalism has been developed which would do precisely that. Supersymmetry, as it is called, relates particles of different spins and severely constrains the possibilities for model-building. It is likely that a realistic unified theory will require the inclusion of gravity with the three forces: strong, weak, and electromagnetic, already joined in present-day theories. Theorists seem unable to resist the blandishments of supersymmetry. It remains to discover whether Nature is similarly smitten.

This is the place to which our explorations have brought us. Some new landmarks are already in sight. Others lie just around the next bend, if our charts can be trusted. While seeking to answer the questions before us, we shall keep our eyes peeled for surprises.



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IV. A Decade of Experimental Physics

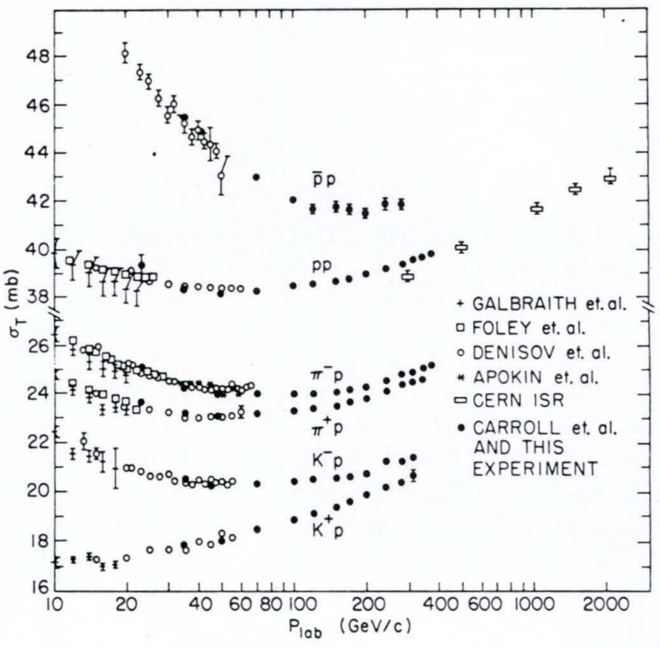
The Fermilab accelerator came into operation in 1972. During ten years of operation at beam energies between 200 and 500 GeV, experiments have investigated a broad range of phenomena. Experiments have been of the survey, search, discovery, and measurement varieties and have been devoted both to traditional concerns and to new areas of interest. A few experiments change physics with dramatic observations; many others contribute to the body of information we seek to understand, and enable us to extract systematic patterns. This conspectus is intended to indicate the breadth of experimental activity at Fermilab and to highlight a few notable experiments of each genre.* At the end of this overview is a section that evaluates several of our recent experiments from a vantage point of a more current perspective. The general remarks are organized around particular physics topics. If some of these descriptions appear more technical than is appropriate for the esteemed lay reader, we apologize and plead the necessity of a lasting record. A summary of highlights is given at the end of this section.

1. Hadron Collisions at Low Momentum Transfer

As the first fixed-target accelerator in a new energy range, Fermilab carried out a large number of survey experiments and archival measurements. Taken together, these constitute a coherent picture of hadronic interactions at high energies. Let us examine some representative topics, in order of increasing complexity.

A brief document must be more evocative than explicit. Further details of the experimental program may be traced using "Publications from Fermilab Experiments," and "Theses from Fermilab Experiments," both issued in April 1979, by the Program Planning Office. The status of current and future experiments is reported annually in the "Fermilab Research Program Workbook." Early Meson Area experiments are reviewed in A. L. Read, "A Summary of Research Activities in the Meson Lab (1972-1977)." Other reviews of classes of Fermilab experiments include J. Whitmore, Phys. Rep.* ***10C,* *173 (1974);* ***27C,*** *186 (1976) [30-in. bubble chamber]; G. Giacomelli, Phys. Rep.* ***23C,*** *123 (1976) [elastic and total cross sections]; B. C. Barish, Phys. Rep.* ***39C,*** *279 (1978] [neutrino physics]; A. C. Melissinos and S. L. Olsen, Phys. Rep.* ***17C,*** *77 (1975) [gas jet experiments].*

E4: Lawrence Berkeley Laboratory (LBL), U. of Michigan; E8: U. of Michigan, Rutgers U., U. of Wisconsin; E25A: U. of California (UC)-Santa Barbara, Fermi National Accelerator Laboratory (Fermilab), Lebedev Physical Institute-Moscow (USSR), U. of Toronto (Canada); E27A: Fermilab, U. of Massachusetts, Northwestern U., U. of Rochester; E104: Brookhaven National Laboratory (BNL), Fermilab, Max Planck Institute-Munich (Germany), Rockefeller U., U. of Washington; E486: U. of Chicago, LHE-ETH Honggerberg-Zurich (Switzerland), U. of Wisconsin.



E82: UC-San Diego, U. of Chicago, Stanford Linear Accelerator Center (SLAC), U. of Wisconsin; E111: California Institute of Technology (Caltech), LBL; E425: UC-San Diego, U. of Chicago, LHE-ETH-Honggerberg-Zurich (Switz.), SLAC, U. of Wisconsin; E486: U. of Chicago, LHE-ETH Honggerberg-Zurich (Switz.), U. of Wisconsin; E585: UC-Davis, UC-San Diego, Carleton U. (Canada), Michigan State U.

E99: Argonne National Laboratory (ANL), Fermilab, SLAC, Stanford U.

E7: ANL, Fermilab, Indiana U., U. of Michigan; E36A: Fermilab, Joint Institute for Nuclear Research-Dubna (JINR) (USSR), U. of Rochester, Rockefeller U.; E69A: Fermilab, Rutherford High Energy Laboratory (Great Britain), Yale U.; E96: ANL, U. of Bari (Italy), Brown U., CERN, Cornell U., Fermilab, Massachusetts Institute of Technology (MIT), Northeastern U., Stanford U.; E186: Fermilab, JINR-Dubna, U. of Rochester, Rockefeller U.; E198A: Imperial College-London (Great Britain), U. of Rochester, Rutgers U.; E248: U. of Michigan.

A number of experiments have undertaken the measurements of $\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$, n, Λ, and γ total cross sections on a variety of targets including hydrogen, deuterium, and complex nuclei. The results confirm and extend the observations of rising total cross sections made earlier at Serpukhov for K^+p and at the CERN ISR for pp. Using the data on meson-baryon scattering, one could calculate a Pomeranchuk singularity contribution with an effective Regge intercept above unity. This encouraged the development of Reggeon calculus techniques, which in turn suggest the onset of new and more complicated phenomena at collider energies. The few mb differences between πN and KN total cross sections persists at high energies. Does this have a fundamental explanation? We do not know yet.

Differences of total cross sections permit the isolation of quantum-number-exchange contributions. These are found to be Regge-behaved, and invite comparison with the meson Regge intercepts found at lower energies. The classical Regge-pole reactions $\pi^-p \rightarrow \pi^0n$ (ρ-exchange), $\pi^-p \rightarrow \eta^0n$ (A_2- exchange), $K^+n \rightarrow K^0p$, $K^-p \rightarrow K^0n$ (ρ, A_2 exchange), $\pi^-p \rightarrow \omega^0n$ (ρ exchange), and $K_LN \rightarrow K_SN$ (ρ, ω exchange) have also been studied in Meson Area experiments. The results are beautifully consistent with the total cross section data and demonstrate the utility of the simple Regge pole language in this energy regime. In later experiments, associated production reactions have also been studied.

Other experiments in the Meson Laboratory and the Internal Target Area have made extensive measurements of $\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$, n, and Λ elastic scattering on nucleons. The ratio of elastic to total cross sections is found to be approximately constant at Fermilab energies and equal to 1/5 for baryon-baryon and to 1/7 for meson-baryon scattering. Early measurements in the Meson Lab and later extensive measurements with the internal gas jet target showed that a diffractive minimum in pp scatterings develops over the Fermilab energy region. Much later, detailed experiments, again in the Meson Laboratory beams, showed that a similar diffraction minimum occurs in pion proton scattering, but at a much higher momentum transfer of $t = -4.0\ (\mathrm{GeV}/c)^2$.

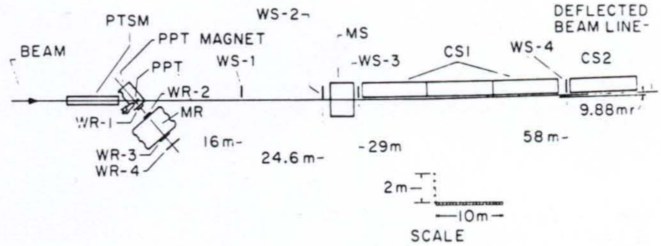
***E577:** U. of Arizona, UC-San Diego, Cornell U., Fermilab.*

Still other experiments have measured the real parts of the forward elastic-scattering amplitude by Coulomb-nuclear interference. The real-part measurements support the behavior of the total cross sections through their consistency with forward dispersion relations.

***E36A:** Fermilab, JINR-Dubna, U. of Rochester, Rockefeller U.; **E69A:** Fermilab, Rutherford High Energy Laboratory (Great Britain), Yale U.; **E381:** U. of Arizona, Fermilab, JINR-Dubna, U. of Rochester. **E12:** Carleton U., Michigan State U., Ohio State U.*

Pion exchange has been investigated both in nondiffractive (np charge exchange) and diffractive (Deck process) reactions. In the latter case, detailed measurements of the reaction $np \to pp\pi^-$ yielded convincing evidence for the presence of both baryon and pion exchange in the non-Pomeron leg of double-peripheral diagrams. This high-statistics, broad acceptance work moved the Deck effect from the realm of artistry (an assertion of truth) to that of science (a search for truth)!

***E27A:** Fermilab, U. of Massachusetts, Northwestern U., U. of Rochester; **E305:** Fermilab, Northwestern U., U. of Rochester, SLAC.*



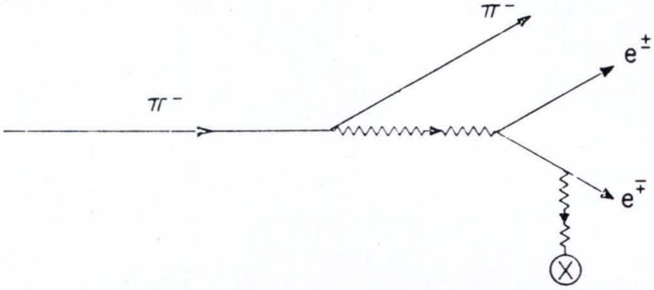
High-precision measurements of the polarization in pp and π^+p elastic scattering have manifested the behavior expected on the basis of Regge-pole extrapolations from lower energies, and revealed no surprises in spin structure.

***E61:** ANL, Fermilab, Harvard U., LBL, Suffolk U., Yale U.; **E313:** Indiana U.*

The surveys of multiple production carried out using the 30-in. bubble chamber played a dominant role in establishing the character of soft inelastic reactions (the bulk of the total cross section) at energies above 60 GeV. From these studies we learned that multiple production is dominantly a short-range (in rapidity) correlation phenomenon, in general accord with a multiperipheral description, and decidedly unlike the isobar model and its descendants. Comparison of the inclusive cross sections produced in

***E2B:** Duke U., Fermilab, Iowa State U., U. of Maryland, Michigan State U., U. of Notre Dame, Purdue U., U. of Toronto (Canada), U. of Wisconsin; **E37A:** Caltech, UC-Los Angeles, Fermilab, Indiana U.; **E121A:** UC-Davis, LBL, **E125:** CERN; **E137:** UC-Berkeley, Fermilab, LBL; **E138:** U. of Michigan, U. of Rochester; **E141A:** ANL, Fermilab, Iowa State U., U. of Maryland, Michigan State U.; **E154:** Brown U., Fermilab, Illinois Institute of Technology (IIT), U. of Illinois, Indiana U., Johns Hopkins U., MIT, Oak Ridge National Laboratory, Rutgers U., Stevens Institute of Technology, U. of Tennessee, Yale U.; **E161:** U. of Wisconsin; **E163A:** Duke U., U. of North Carolina; **E194:** Carnegie-Mellon U., Fermilab, U. of Michigan, State U. of New York-Stony Brook; **E209:** Caltech, Iowa State U., Tufts U., Vanderbilt U.; **E218:** UC-Davis, Institute of Nuclear Physics-Cracow (Poland), Warsaw U.-INS (Poland), U. of Washington; **E228:** U. of Michigan, U. of Rochester; **E234:** Fermilab, Florida State U.; **E252:** U. of Michigan, U. of Rochester; **E280:** ANL, Canadian Institute of Particle Physics-Montreal (Canada), JINR-Dubna, Moscow U.-Moscow*

(USSR); ***E281:*** *Iowa State U., U. of Maryland, Michigan State U., U. of Notre Dame;* ***E295:*** *Centre de Recherches Nucleaires-Strasbourg (France), Fermilab, Weizmann Institute of Science-Rehovot (Israel);* ***E299:*** *Brown U., Fermilab, IIT, U. of Illinois, Indiana U., Johns Hopkins U., MIT, State U. of New York-Albany, Nijmegen U.-Nijmegen (Netherlands), Oak Ridge National Laboratory, Rutgers U., Stevens Institute of Technology, U. of Tennessee, Universite de L'Etat-Mons (Belgium), U. of Cambridge (Great Britain), Yale U.;* ***E311:*** *Fermilab, Michigan State U., U. of Cambridge,* ***E338:*** *UC-Davis, Institute of Nuclear Physics-Cracow, Warsaw U.-INS (Poland), U. of Washington;* ***E341:*** *UC-Davis, LBL;* ***E343:*** *ANL, U. of Kansas, State U. of New York-Stony Brook, Tufts U.*



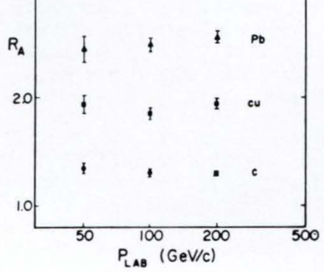
E14A: *Columbia U., State U. of New York-Stony Brook;* ***E36A:*** *Fermilab, JINR-Dubna, U. of Rochester, Rockefeller U.;* ***E67A:*** *Florida State U., Rutgers U., Upsala College;* ***E96:*** *ANL, U. of Bari, Brown U., CERN, Cornell U., Fermilab, MIT, Northeastern U., Stanford U.;* ***E118A:*** *U. of Bari, Brown U., Fermilab, MIT;* ***E186:*** *Fermilab, JINR-Dubna, U. of Rochester, Rockefeller U.;* ***E188:*** *U. of Illinois-Chicago Circle, Imperial College-London (Great Britain), Rutgers U., Upsala College;* ***E221:*** *Columbia U., State U. of New York-Stony Brook;* ***E317:*** *U. of Arizona, Fermilab, JINR-Dubna, U. of Rochester, Rockefeller U.;* ***E321:*** *Columbia U., State U. of New York-Stony Brook;* ***E350:*** *BNL, Caltech, LBL.*

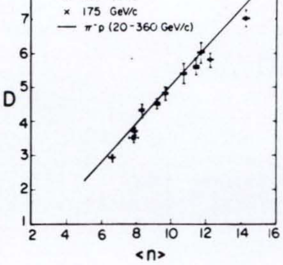
TABLE IV. The asymptotic ratios of particle and antiparticle induced cross sections. The cross-section limits A_+ and A_- are taken from Table II for the production of $\pi^\pm$ by $\pi^\pm$ and p, and from Table III for the other reactions.

Cross-section ratio	$c = \pi^-$	$c = \pi^+$	$c = K^+$	$c = p$
$(\pi^+ p \to c)/(\pi^- p \to c)$	0.88 ± 0.06	1.04 ± 0.07	0.96 ± 0.04	0.97 ± 0.07
$(K^+ p \to c)/(K^- p \to c)$	1.35 ± 0.28	0.96 ± 0.17	...	1.86 ± 0.42
$(pp \to c)/(\bar{p}p \to c)$	1.10 ± 0.23	0.96 ± 0.13	...	0.99 ± 0.17

E324: *U. of Pennsylvania.*

E178: *Carleton U., Fermilab, MIT.*





$\pi^\pm p$, $K^\pm p$, pp, and $\bar{p}p$ collisions revealed that particle production in the central region is largely independent of the nature of the colliding particles, and therefore is characteristic of the interaction, as the short-range-correlation picture requires. Together with experiments at the CERN ISR and at the Internal Target Area, the 30-in. chamber studies demonstrated the existence of high-mass diffraction dissociation, and thus influenced the development of the two-component (short-range-correlation plus diffraction) description of multiple production. The bubble-chamber experiments also indicated a striking similarity between the diffractive excitation of pions and of protons. Experiments in the Internal Target Area, the Single Arm Spectrometer, and elsewhere have focused on the quantitative aspects of inclusive diffraction scattering as expressed in the language of triple-Regge analysis and finite missing-mass sum rules. By studying the structure of diffractive events (labeled by large rapidity gaps), the bubble chamber physicists showed that Pomeron-proton collisions are, except for the absence of a "leading Pomeron" effect, profoundly similar to ordinary hadron-hadron collisions. High-precision electronic measurements of inclusive cross sections in the fragmentation region over a wide range of energies have shown the continued utility of the Mueller-Regge analysis. Simple and elegant studies of particle production in nuclear targets called attention to the long time scales and hence large longitudinal distances involved in the particle-production process. The full potential of nuclear targets as probes of hadronic interactions should be more nearly realized at still higher energies.

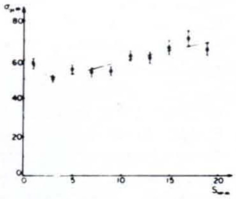
2. Properties of Light Hadrons

Although light-hadron spectroscopy is only beginning to be assaulted in Fermilab experiments, a number of important measurements of the properties of hadrons that are stable against strong decay have been carried out. Hadron-electron scattering provides information on the electric charge radius of the hadrons. This process has been studied at Fermilab for the charged pion and for charged and neutral kaons. The charge radii inferred from these measurements are in general accord with the vector-meson-dominance picture and the simple quark model. An extended program in the Meson Laboratory Hyperon Facility has exploited newly discovered polarization of the produced hyperons to make high-quality measurements of the magnetic moments of Λ^0, Ξ^0, Ξ^-, Σ^+, and Σ^-. The measured moments are in general acccord with the expectations of the quark model, but point to some quantitative shortcomings of the model in its simplest form. A measurement of the Λ^0-Σ^0 transition moment and thus of the Σ^0 lifetime has also been carried out. Still at small momentum transfer is a study of Coulomb dissociation of π^+ and K^+, which leads to measurements of the photonic decay widths of ρ, K^*, and other mesons. This information also confronts specific predictions of SU(3) and the quark model.

Experiments on the continuum production of massive dilepton pairs and the interpretation of these results in terms of the Drell-Yan model provide a new means for determining the structure functions of hadrons. This technique resulted in significantly improved determinations of the sea-quark distribution of the proton and the first measurement of the structure function of the pion.

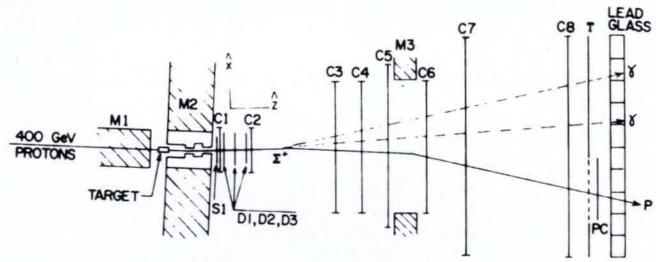
3. Hard Collisions of Hadrons

Many Fermilab experiments have investigated the deep scattering of hadrons. Measurements of pp and π^-p elastic scattering out to momentum transfers of $t \simeq -14$ (GeV/c)^2 confronted the structure of diffraction minima and maxima expected in optical-model descriptions. No secondary minimum was found. Fermilab experi-



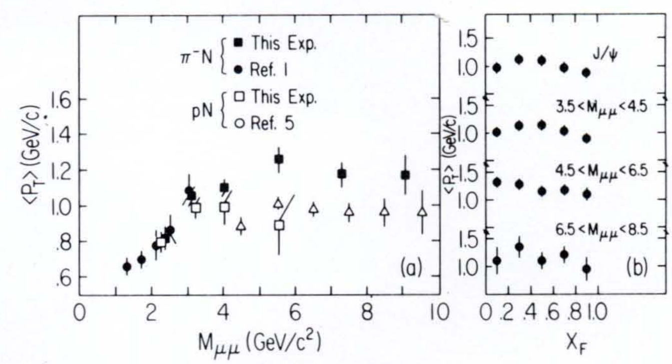
E216: UC-Los Angeles, Fermilab, JINR-Dubna, U. of Notre Dame, U. of Pittsburg; ***E226:*** *U. of Chicago, LHE-ETH Hongerberg-Zurich (Switz.), U. of Wisconsin;* ***E456:*** *UC-Los Angeles, Fermilab, JINR-Dubna, U. of Notre Dame, U. of Pittsburg.*

E8: U. of Michigan, Rutgers U., U. of Wisconsin; ***E440:*** *U. of Michigan, Rutgers U., U. of Wisconsin;* ***E495:*** *BNL, U. of Michigan, Rutgers U., U. of Wisconsin;* ***E619:*** *U. of Michigan, U. of Minnesota, Rutgers U., U. of Wisconsin;* ***E620:*** *U. of Michigan, U. of Minnesota, Rutgers U., U. of Wisconsin.*



E272: BNL, Fermilab, U. of Minnesota, U. of Rochester.

E288: Columbia U., Fermilab, State U. of New York-Stony Brook; ***E444:*** *U. of Chicago, Princeton U.*



E177A: Cornell U., Lebedev Physical Institute-Moscow (USSR), McGill U. (Canada), Northeastern U.; ***E577:*** *U. of Arizona, UC-San Diego, Cornell U., Fermilab.*

E70: Columbia U., Fermilab; ***E100A:*** *U. of Chicago, Princeton U.*

Ratio	n	b	X^2/DOF
p/π^+	n = 3.62 ± 1.5	b = -1.67 ± 1.0	5.3/7
$\bar{p}/\pi^-$	n = 0.27 ± 1.7	b = 4.29 ± 1.9	3.1/4
K^+/π^+	n = 0.20 ± 0.5	b = -0.68 ± 0.4	15.1/7
K^-/π^-	n = 1.58 ± 1.4	b = 1.59 ± 1.2	9.0/6

E268: *BNL, Caltech, LBL.*

E100A: *U. of Chicago, Princeton U.;* ***E300:*** *U. of Chicago, Princeton U.*

E236A: *Fermilab, Tufts U., U. of Washington;* ***E260:*** *Caltech, UC-Los Angeles, Fermilab, U. of Illinois-Chicago Circle, Indiana U., Max Planck Institute-Munich;* ***E395:*** *Lehigh U., U. of Pennsylvania, U. of Wisconsin.*

E258: *U. of Chicago, Princeton U.*

E494: *Columbia U., Fermilab, State U. of New York-Stony Brook.*

E100A: *U. of Chicago, Princeton U.;* ***E300:*** *U. of Chicago, Princeton U.*

E63A: *Fermilab, U. of Hawaii, Northern Illinois U.;* ***E284:*** *Fermilab, Northeastern U., Northern Illinois U.*

E70: *Columbia U., Fermilab;* ***E100A:*** *U. of Chicago, Princeton U.*

E48: *BNL, Fermilab, Yale U.;* ***E331:*** *U. of Chicago, Princeton U.;* ***E435:*** *BNL, Fermilab, Yale U.;* ***E436:*** *BNL, Fermilab, Yale U.;* ***E444:*** *U. of Chicago, Princeton U.*

ments were among the first to establish that large-transverse-momentum hadron production is copious enough to be studied extensively. Subsequent investigations have revealed that inclusive cross sections behave as $d\sigma/(d^3p/E) = p_\perp^{-8} f(p_\perp/\sqrt{s})$ at the energies and transverse momenta currently accessible. This suggests that present-day "high-$p_\perp$" is not high enough to isolate elementary parton-parton scattering, with its expected $p_\perp^{-4}$ behavior. It has also been found that pion beams are more efficient than hadron beams for the production of large -$p_\perp$ hadrons. The relative rate of heavy - particle (K, η, p, $\bar{p}$) production is found to increase significantly at large-$p_\perp$.

Although the study of hadron jets is somewhat frustrating below about 400 GeV, there is good evidence for the idea that the inclusive cross section for jet production is two orders of magnitude greater than that for single-particle production. Recent experiments on the production of $\pi^\pm$, $K^\pm$, $p^\pm$, in $\pi^- p$ collisions convincingly show the absence of dominant "leading-particle" effect for π^- production at large $p_\perp$. Other details of the hard collision process are supplied by dihadron correlation studies. An anomalous and species-dependent A-dependence ($\sigma \propto A^n$, $n > 1$) observed in production from complex nuclei has not yet found a satisfactory understanding. Finally, comparison of inclusive measurements carried out at Fermilab over a wide range of Feynman-x and $p_\perp$ has provided evidence for "radial scaling" as a useful empirical parametrization.

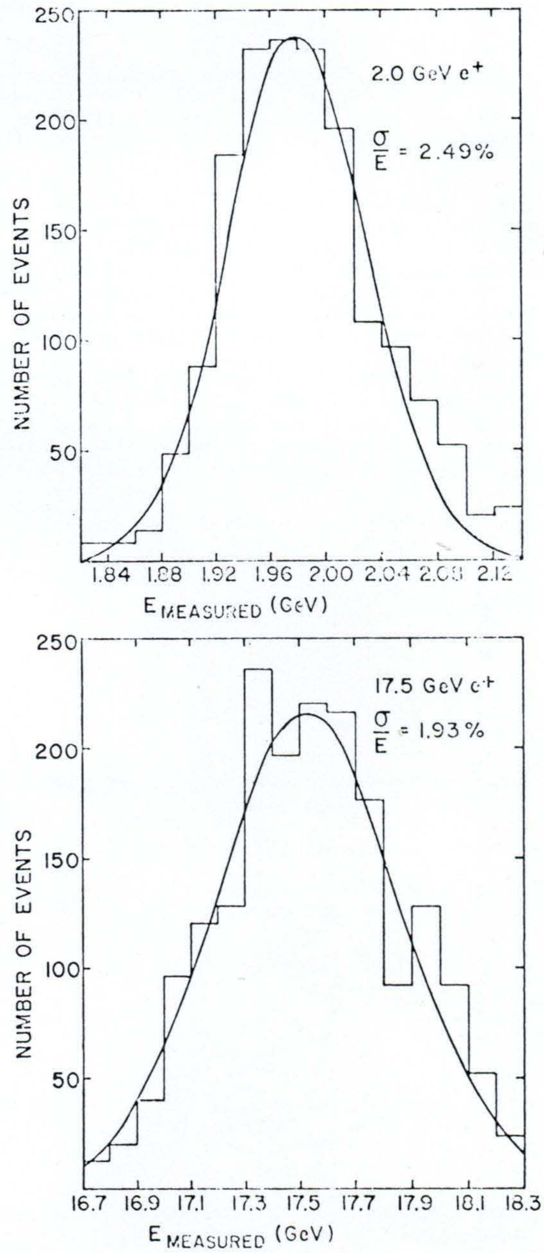
The significant ratio of prompt lepton to pion production $\ell/\pi \sim 10^{-4}$) found in early single-arm experiments at Fermilab was a cryptic indication of new phenomena. Subsequent experiments have shown that most prompt leptons are pair-produced electromagnetically (approximately 70%) with important contributions from ψ decay (approximately 30%) and from a low-mass continuum that is still only dimly understood. Single prompt leptons accompanied by missing energy are consistent with a charmed-particle origin.

E331: U. of Chicago, Princeton U.; E444: U. of Chicago, Princeton U.

Continuum studies of dilepton production have been an important element of the Fermilab program. Experiments have established the approximate validity of Drell-Yan scaling and confirmed the expected A^1-dependence of pair production from complex nuclei. The experiments go on to measure the structure functions of quarks in the nucleon. Since these are independently determined by lepton scattering experiments, an important confrontation of the Drell-Yan model is available. The model has in the meantime evolved into a QCD theory and higher-order corrections seem more in line with the data than the simple model.

E288: Columbia U., Fermilab, State U. of New York-Stony Brook; E325: U. of Chicago, Princeton U.; E326: U. of Chicago, Princeton U.; E358: Columbia U., Cornell U., Fermilab, U. of Hawaii, U. of Illinois. E537: U. of Athens (Greece), Fermilab, McGill U., U. of Michigan, Shandong U. (PRC).

The same data provided new evidence for the primordial (binding) motion of quarks imprisoned in the colliding hadrons. This was observed via the $p_\perp$ behavior of dileptons, which achieved fairly detailed explanation. Only quark-gluon effects were included in the calculations. Comparison of $\pi^\pm C \to (\mu^+\mu^-)$ + anything indicated a substantial isospin violation, as expected for an electromagnetic process, and verified that the virtual photons were produced in the annihilation of quarks with average charges of $|2/3|$ and $|1/3|$. Measurements of the decay angular distributions of muon pairs produced in $\pi^- N$ collisions are in agreement with the parton-model description except near x = 1, where a change in the virtual-photon density matrix may reflect the influence of hadron wave-function (confinement) effects.



4. Lepton Scattering

The expectation that neutrino and muon scattering in a new energy regime would yield important discoveries encouraged wide participation in Neutrino Area experiments. The field has indeed turned out to be rich and exciting, and

Fermilab experiments have made significant contributions to its development.

E1A: Fermilab, Harvard U., U. of Pennsylvania, U. of Wisconsin; E21A: Caltech, Fermilab.

Electronic experiments at Fermilab were an important adjunct to the discovery of weak neutral currents in deep-inelastic neutrino scattering. Subsequent measurements using electronic detectors and the 15-ft bubble chamber determined the rates of neutral-current to charged current interactions in neutrino and antineutrino scattering and helped to elaborate the isospin structure of the neutral current. A bubble chamber and an electronic measurement of the cross section for $\nu_\mu e$ elastic scattering provide the best available information on this reaction, which is a particularly clean test of neutral current models.

E31A: ANL, Carnegie-Mellon U., Purdue U.; E45A: Fermilab, U. of Hawaii, LBL, U. of Michigan; E172: UC-Berkeley, U. of Hawaii, LBL, U. of Washington; E180: Fermilab, ITEP-Moscow (USSR), Institute of High Energy Physics-Serpukhov (USSR), U. of Michigan; E262: Caltech, Fermilab; E310: Fermilab, Harvard U., U. of Pennsylvania, Rutgers U., U. of Wisconsin; E320: Caltech, Fermilab; E380: BNL, Columbia U.; E454: Harvard U., HEPL-Stanford U., Rice U., Yerevan Physics Institute-Armenia (USSR).

E53A: BNL, Columbia U.; E253: Academia Sinica-IHEP-Beijing (PRC), U. of Maryland, National Science Foundation, U. of Oxford (Great Britain), Virginia Polytechnic Institute & State U.

In single-muon final states, precise measurements of the total νN and $\bar{\nu} N$ cross sections have been carried out. Published results extend to 280 GeV for neutrinos and 200 GeV for antineutrinos. Both show the expected linear dependence upon neutrino energy, and imply a lower bound of about 30 GeV/c^2 on the mass of the charged intermediate boson. Extensive measurements of nucleon structure functions confirm the general validity of the parton-model description. Bubble-chamber experiments have studied particle production in neutrino reactions with special attention to the dressing of quarks into jets of hadrons. In first approximation, these jets are similar to those observed in e^+e^- annihilations, but suggestive differences are just now beginning to emerge.

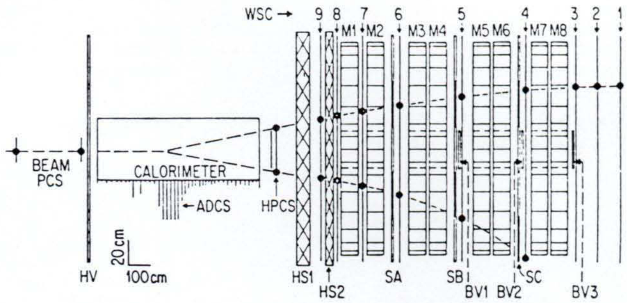
E1A: Fermilab, Harvard U., U. of Pennsylvania, U. of Wisconsin; E21A: Caltech, Fermilab; E31A: ANL, Carnegie-Mellon U., Purdue U.; E45A: Fermilab, U. of Hawaii, LBL, U. of Michigan; E53A: BNL, Columbia U.; E172: UC-Berkeley, U. of Hawaii, LBL, U. of Washington; E180: Fermilab, ITEP-Moscow, IHEP-Serpukov (USSR), U. of Michigan; E254: BNL, Caltech, Fermilab, Purdue U.; E310: Fermilab, Harvard U., U. of Pennsylvania, Rutgers U., U. of Wisconsin; E356: Caltech, Fermilab, U. of Rochester, Rockefeller U.; E380: BNL, Columbia U.; E388: Fermilab, U. of Hawaii, LBL; E545: IIT, U. of Maryland, State U. of New York-Stony Brook, Tohoku U. (Japan), Tufts U.; E616: Caltech, Columbia U., Fermilab, U. of Rochester, Rockefeller U.

E546: UC-Berkeley, Fermilab, U. of Hawaii, LBL, U. of Washington, U. of Wisconsin.

Neutrino-induced dimuon events, discovered at Fermilab, were perhaps the first experimental indications for charm. Bubble-chamber experiments established the association of dilepton events with strange particles. Subsequent extensive measurements are in complete accord with the charm interpretation. These give the first indication of the Cabibbo-suppressed $c \rightarrow d$

E1A: Fermilab, Harvard U., U. of Pennsylvania, U. of Wisconsin; E21A: Caltech, Fermilab; E310: Fermilab, Harvard U., U. of Pennsylvania, Rutgers U., U. of Wisconsin. E28A: CERN, U. of Hawaii, LBL; E53A: BNL, Columbia U.; E172: UC-Berkeley, U. of Hawaii, LBL, U. of Washington; E546: UC-Berkeley, Fermilab, U. of Hawaii, LBL, U. of Washington, U. of Wisconsin.

transition and the only evidence so far for the handedness of the charm-changing charged current. Still unexplained and of potential significance are the "like-sign" dimuon events.

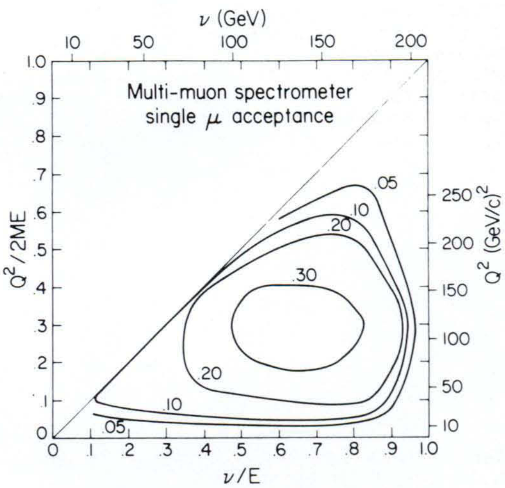


E26: UC-San Diego, Cornell U., LBL, Michigan State U.; E98: U. of Chicago, Harvard U., U. of Illinois, U. of Oxford.

E203A: UC-Berkeley, Fermilab, LBL, Princeton U.; E319: Fermilab, Michigan State U.; E398: U. of Chicago, Harvard U., U. of Illinois, U. of Oxford, Virginia Polytechnic Institute & State U.

First-generation muon scattering experiments at Fermilab made the original discovery of violations of Bjorken scaling, an important indicator of the relevance of QCD. Subsequent measurements have confirmed and extended these observations and made possible new determinations of the quark and gluon distributions within the nucleon. The study of final states in μN scattering has led to further understanding of the structure of muon-initiated events and of quark jets. An experiment in the multimuon spectrometer has provided measurements of the charm production cross section in virtual photoproduction and has studied the virtual photoproduction of ψ in considerable detail. Such investigations complement the real photoproduction experiments, past and present, and stringently test the extension of perturbative QCD to reactions that do not take place at very short distances. The charm contribution to the μN cross section also has potentially important implications for the quantitative study of scaling violations.

E203A: UC-Berkeley, Fermilab, LBL, Princeton U.



5. New-Particle Physics

Since the discovery of the ψ/J in 1974, a great number of Fermilab experiments have turned their attention to the physics of new quark flavors. Immediately after the discovery, the observation of ψ photoproduction gave a measure of the ψN total cross section and supported the idea that ψ was a hadron. Later photoproduction studies have observed the ψ' and the charmed particles D^0, D^*, and C_0^+, and provided estimates of the charm contribution to the photon-nucleon total cross section. The dynamics of ψ and ψ' production have been studied in pN and πN collisions as well. The pion is found to be

E25A: UC-Santa Barbara, Fermilab, Lebedev Physical Institute-Moscow (USSR), U. of Toronto (Canada); E87A: Columbia U., Fermilab, U. of Hawaii, U. of Illinois.

E87A: Columbia U., Fermilab, U. of Hawaii, U. of Illinois; E401: Fermilab, U. of Illinois.

a superior source of large-x psions, as expected in a variety of models.

E288: Columbia U., Fermilab, State U. of New York-Stony Brook; E331: U. of Chicago, Princeton U.; E365: Northeastern U.; E444: U. of Chicago, Princeton U.

E369: Fermilab, Harvard U., U. of Illinois, Max Planck Institute-Munich, Tufts U.

Indications that a substantial fraction of ψ's are produced in the cascade decay of χ's have been found and are being pursued. Studies of multimuon final states have shown that ψ's are not appreciably produced in association with charmed particles. This is evidence against a model in which charmed quarks from the hadron's sea fuse to make the psions.

E610: Fermilab, Howard U., U. of Illinois, U. of Pennsylvania, Purdue U., Tufts U.; E673: Fermilab, U. of Illinois, U. of Pennsylvania, Purdue U., Tufts U.

E358: Columbia U., Cornell U., Fermilab, U. of Hawaii, U. of Illinois; E444: U. of Chicago, Princeton U.

The upsilon family was discovered in pN collisions at Fermilab, and extensive measurements gave evidence for three states below flavor threshold. The production characteristics of ϒ have also been studied in a large-acceptance magnetized-iron detector. Many experiments have been devoted to the search for charm in hadron collisions. A calorimeter experiment in which muons and total energy are measured has made the best measurement extant of the charm production cross section: 20 μb in 400 GeV/c pN collisions. The same experiment has placed an upper limit of 50 nb on the cross section for $b\bar{b}$ production, and has begun to make detailed studies of charm production dynamics. Another experiment reports $\sigma(b\bar{b}) < 8$ nb in 225 GeV/c $\pi^{-}N$ collisions. A high-pressure, high-resolution streamer-chamber experiment has observed short tracks characteristic of charm decay and given a preliminary estimate of the charm lifetime.

E288: Columbia U., Fermilab, State U. of New York-Stony Brook.

E439: U. of Michigan, Northeastern U., Tufts U., U. of Washington.

E515: Carnegie-Mellon U., Fermilab, Northwestern U., U. of Notre Dame. E567: BNL, Centre de Recherches Nucleaires de Saclay (France), Fermilab, Princeton U., Universita di Torino (Italy);

E379: Caltech, U. of Rochester, Stanford U.; E595: Caltech, U. of Chicago, Fermilab, U. of Rochester, Stanford U.

E444: U. of Chicago, Princeton U.

E490: Fermilab, LBL, Yale U.

Perhaps the best information on the absolute lifetimes of charmed particles comes from a hybrid neutrino spectrometer experiment in which photographic emulsion serves as the target. So far about eighty examples of short-lived particles have been found. On the basis of this sample, it appears that the lifetime of D^0 is approximately 10^{-13} sec and that the D^+ lifetime may be a factor of two longer. A few examples of short tracks have also been found in neutrino bubble-

E531: Aichi U. of Education-Kariya (Japan), Fermilab, Kobe U. (Japan), Korea U.-Seoul (S. Korea), McGill U., Nagoya U.-Nagoya (Japan), Ohio State U., Okayama U.-Okayama (Japan), Osaka City U. (Japan), Osaka Prefecture-Science Education Institute (Japan), Universite d'Ottawa (Canada), U. of Tokyo-Cosmic Ray Laboratory (Japan), U. of Toronto (Canada), Virginia Polytechnic Institute & State U., Yokohama National U.-Yokohama (Japan); E553: Cornell U., U. of Lund (Sweden), U. of Oklahoma, U. of Padova (Italy), U. of Pittsburg, U. of Rome (Italy), U. of Sydney (Australia), Universita di Torino, Universite Libre de Brussels (Belgium), York U. (Canada); E564: Fermilab, IIT, ITEP-Moscow, IHEP-Serpukov, Institute of Nuclear Physics-Cracow, JINR-Dubna, U. of Kansas, U. of Sydney, U. of Nuclear Physics-Sofia (Bulgaria), U. of Washington.

chamber experiments. The bubble-chamber experiments also have found evidence for nonleptonic charm decays in effective mass distributions and have provided some information on branching ratios. On the subject of a new lepton flavor, bubble-chamber observations have ruled out the possibiltity that ν_τ is identical to ν_μ.

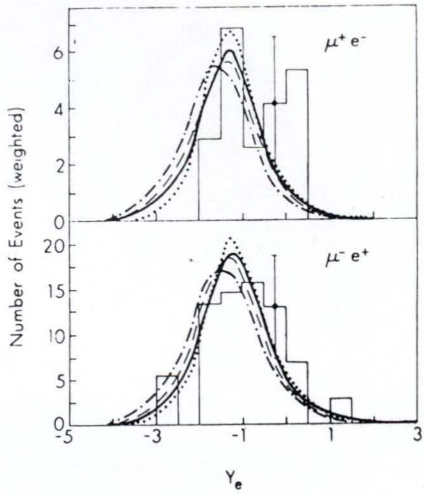
The last three years of the Fermilab 400-GeV program show a departure from the early part of the program. Survey and archival hadron interaction experiments, total cross sections and elastic scattering gave way to experiments more closely related to the thrust of the standard model. The Drell-Yan process has been pursued in all channels accessible to experimentation. A comparison of $\bar{p}p$- and pp-produced muon pairs has been made. The A-dependence and the high-x scaling variable region were explored and serious confrontation with QCD is in progress, indicating the presence of significant QCD corrections in the Drell-Yan process. A greatly refined successor to the original experiment that discovered ϒ is now mounted in the Meson Laboratory with the aim of extending the observation to several orders of magnitude smaller cross sections.

6. Particle Searches, Etc.

A number of conjectured particles have not been found in Fermilab experiments. These include:

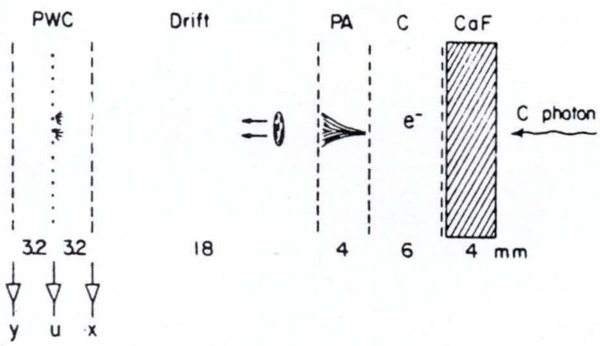
i)	free quarks	72, 75
ii)	monopoles	3, 76
iii)	intermediate bosons	21A
iv)	tachyon monopoles	202
v)	heavy stable particles	199, 330, 468, 469, 596, 580
vi)	heavy muons	21A, 53A

E53A: *BNL, Columbia U.;* ***E546:*** *UC-Berkeley, Fermilab, U. of Hawaii, LBL, U. of Washington, U. of Wisconsin.*



E537: *U. of Athens, Fermilab, McGill U., U. of Michigan, Shangdong U. (PRC)*

E605: *Centre de Recherches Nucleaires de Saclay (France), CERN, Columbia U., Fermilab, Kyoto U. (Japan), (KEK)-Tsukuba (Japan), State U. of New York-Stony Brook, U. of Washington.*



E72: *BNL, Yale U.;* ***E75:*** *Fermilab, New York U.*

E3: *LBL;* ***E76:*** *Fermilab.*

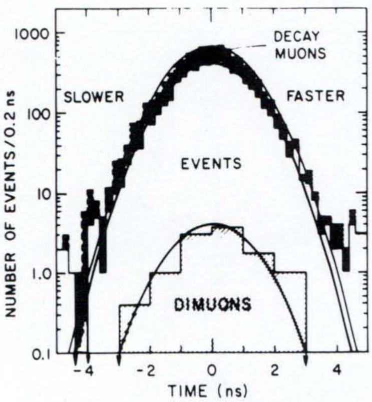
E21A: *Caltech, Fermilab.*

E202: *U. of Colorado, Princeton U.*

E199: *Fermilab, U. of Pennsylvania;* ***E330:*** *U. of Michigan;* ***E468:*** *U. of Maryland,* ***E469:*** *U. of Bari, Brown U., CERN, Fermilab, MIT;* ***E580:*** *U. of Arizona, Fermilab, Florida State U., U. of Notre Dame, Tufts U., Vanderbilt U., Virginia Polytechnic Institute & State U.;* ***E596:*** *Columbia U., Fermilab, State U. of New York-Stony Brook.*

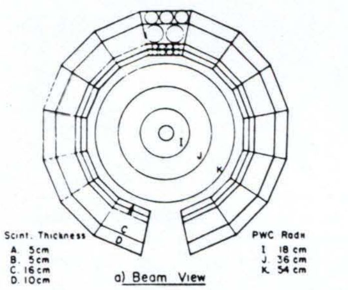
E21A: *Caltech, Fermilab;* ***E53A:*** *BNL, Columbia U.*

E21A: Caltech, Fermilab.

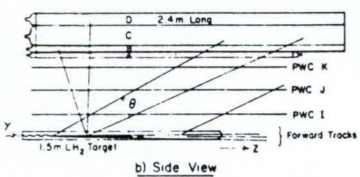


E22: BNL, Virginia Polytechnic Institute & State U.

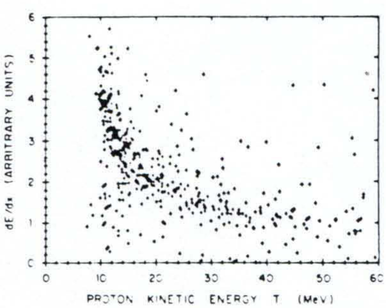
E533: U. of Chicago, Stanford U., U. of Wisconsin.



E516: UC-Santa Barbara, Carleton U., U. of Colorado, Fermilab, National Research Council of Canada (Canada), U. of Oklahoma, U. of Toronto (Canada).



E612: Rockefeller U.



E95A: Fermilab, Johns Hopkins U.

vii) Georgi-Glashow O(3)
model heavy leptons 21A

The nonobservation of free quarks reinforces the current theology of color confinement. The absence of 5 GeV/c^2 particles with lifetimes exceeding 5×10^{-8} sec was the first evidence that the b-quark is not inert with respect to the weak interactions.

An experiment mounted to study the multiphoton phenomenon observed in cosmic-ray experiments (Schein events) found no evidence that they exist.

An experiment on the rate of formation of $\pi\mu$ atoms found about 300 such atoms; this experiment is sensitive to delicate features of the π-μ interaction.

The photoproduction of charmed particles was noted earlier and is being pursued with vigor in the Tagged-Photon Laboratory. A massive and intricate electronic experiment was completed in early 1981 with the data digestion now nearing completion. The twenty million triggers recorded is expected to yield upwards of a hundred thousand charmed and charmed-strange events. This is hoped to be the world's largest sample, allowing the investigation of some of the rare modes of the D-meson decays.

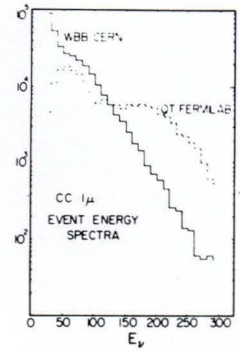
In the same laboratory, the Tagged Photon beam was used in a novel experimental setup, exploiting a hydrogen TPC both as a target and detector; low momentum-transfer states having the quantum numbers of the incident photon were explored.

Direct photon production in hadronic collisions is direct evidence for pointlike particles inside nucleons undergoing bremsstrahlung radiation. In particular, a process called Inverse QCD Compton Effect (quark + gluon → quark + photon) is directly calculable by QCD apparatus. A pioneering early Fermilab experiment showed evidence of direct photon production; further studies have recently been carried out.

The neutrino program has received considerable attention in the past years with the aim of augmenting and refining our knowledge of the structure functions, their evolutions with q^2, and possible non-QCD corrections (higher twist terms, etc.). The ratio of longitudinal to transverse quark momentum distribution, the R parameter, was an objective of a very large neutrino exposure for an electronic experiment. Data analysis is almost completed and offers strong evidence for the Standard Model. At the same time, a bubble chamber filled with deuterium offered a target to neutrinos in which subtle isospin tests could be separately studied and confronted with the QCD predictions. Neutral-current structure functions have so far eluded experimental measurement. The task is complicated by having a hadronic shower and a neutrino (undetectable) in the final state. Bubble chambers suffer from small mass and limited interaction depth, while electronic measurements usually exploit large-mass steel calorimeters. A new electronic detector with high mass was built to take care of this problem. A significant amount of data was recently taken.

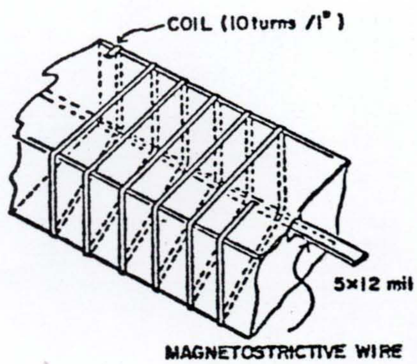
The interesting suggestion that the three neutrinos, ν_e, ν_μ, and ν_τ may have a non-zero mass was made a long time ago. The renewed interest was sparked by the measurement of a USSR group, Ljubinov et al., which reported a finite result for m_{ν_e}) = 30 eV. Interest in this topic is also generated by astrophysical considerations making it "desirable" for neutrinos to have masses in the range of 10-50 eV to account for the puzzle of "missing mass" in the universe. Were it the case that the neutrinos have masses of this magnitude, with their number density as predicted by the Big Bang model, there would be enough total mass to preclude the possibility of the

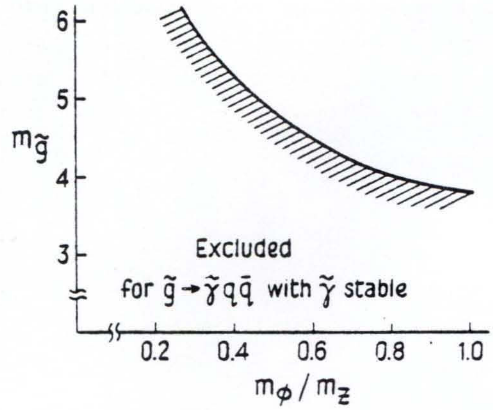
E629: *Fermilab, Michigan State U., U. of Minnesota, Northeastern U., U. of Rochester, Texas A & M U.*



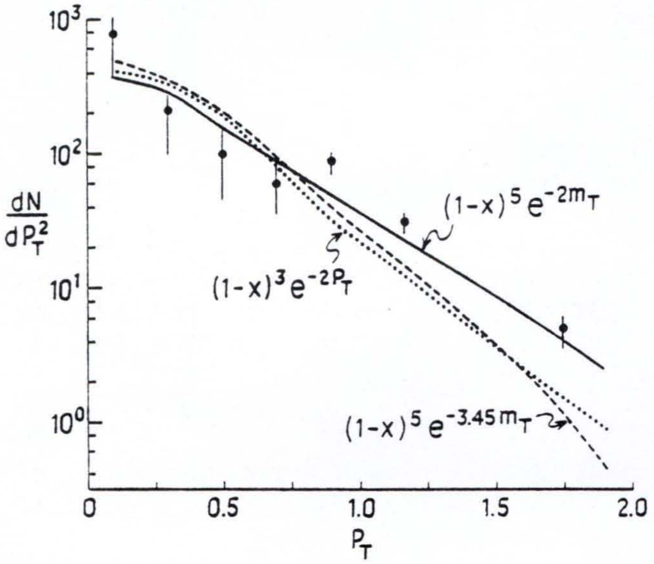
E616: *Caltech, Columbia U., Fermilab, U. of Rochester, Rockefeller U.*

E594: *Fermilab, IIT, MIT, Michigan State U., Northern Illinois U.*

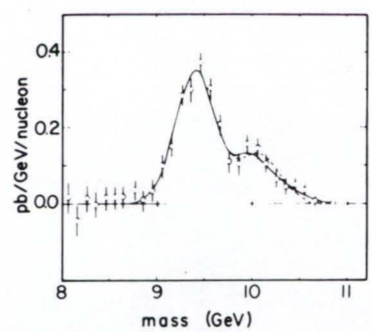




E701: U. of Chicago, Columbia U., Fermilab, U. of Rochester.



E613: Universita di Firenze-Firenze (Italy), U. of Michigan, Ohio State U., U. of Wisconsin.



E288: Columbia U., Fermilab, State U. of New York-Stony Brook

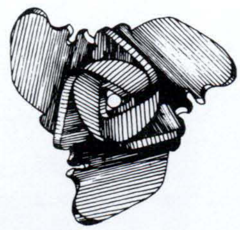
universe expanding forever. Direct experiments that measure neutrino mass, mostly of electron neutrinos, are very difficult and are being undertaken at several U.S. and other laboratories.

Another method of establishing that the neutrinos are massive is to observe the phenomenon of neutrino oscillations. This quantum-mechanical phenomenon, resembling the mixing observed in the neutral-kaon system, supposes that the three kinds of neutrinos, if coupled in a way similar to the coupling (mixing) of quarks, will undergo transformations into each other along their paths of travel. A bias-free experiment on neutrino oscillations, using simultaneously two neutrino detectors at different distances along the neutrino flight path was completed in the summer of 1982. The data are being analyzed.

Associated with the phenomenon of the neutrino oscillations in the observation made elsewhere that there is an anomalous inequality of electron and muon events produced in a beam associated with the prompt-neutrino source. Such a source, called a "dump target," absorbs longer-lived hadrons, pions, kaons, lambdas, etc., before they have a significant probability to decay. Hence, the neutrino flux from such a target should be dominated by the decay of much shorter lived D-mesons and F-mesons, or even heavier flavors. Apart from the interest in studying this flux per se, an experiment in the Meson Lab established the absence of this anomaly at the energy range above 30 GeV.

Conclusion

Ten of the experiments mentioned in this review have greatly contributed to the evolutions of our current ideas, and a few have had a keystone significance. Foremost in this last category is the hadroproduction of Υ. What was a very significant discovery in the year 1977, the upsilon family, together with τ-lepton is now a foundation for the postulate of the three particle families of quarks and leptons. Careful measurement of quarkonia states at Fermilab and elsewhere firmed our notion of the existence of quarks. QCD became the operative theory of hadrons and the very recent experimental hints of the W-boson existence all but set the stage for full acceptance of the Standard Model. Of course, ν_τ and the t quark still have to observed, but "everybody" expects them to be found.



Highlights of the Experimental Program

Precise measurements of elastic and diffractive scattering and polarization effects in the collisions of π's, K's, p's, anti-p's, γ's, neutrons with target nucleons.
1972-1978

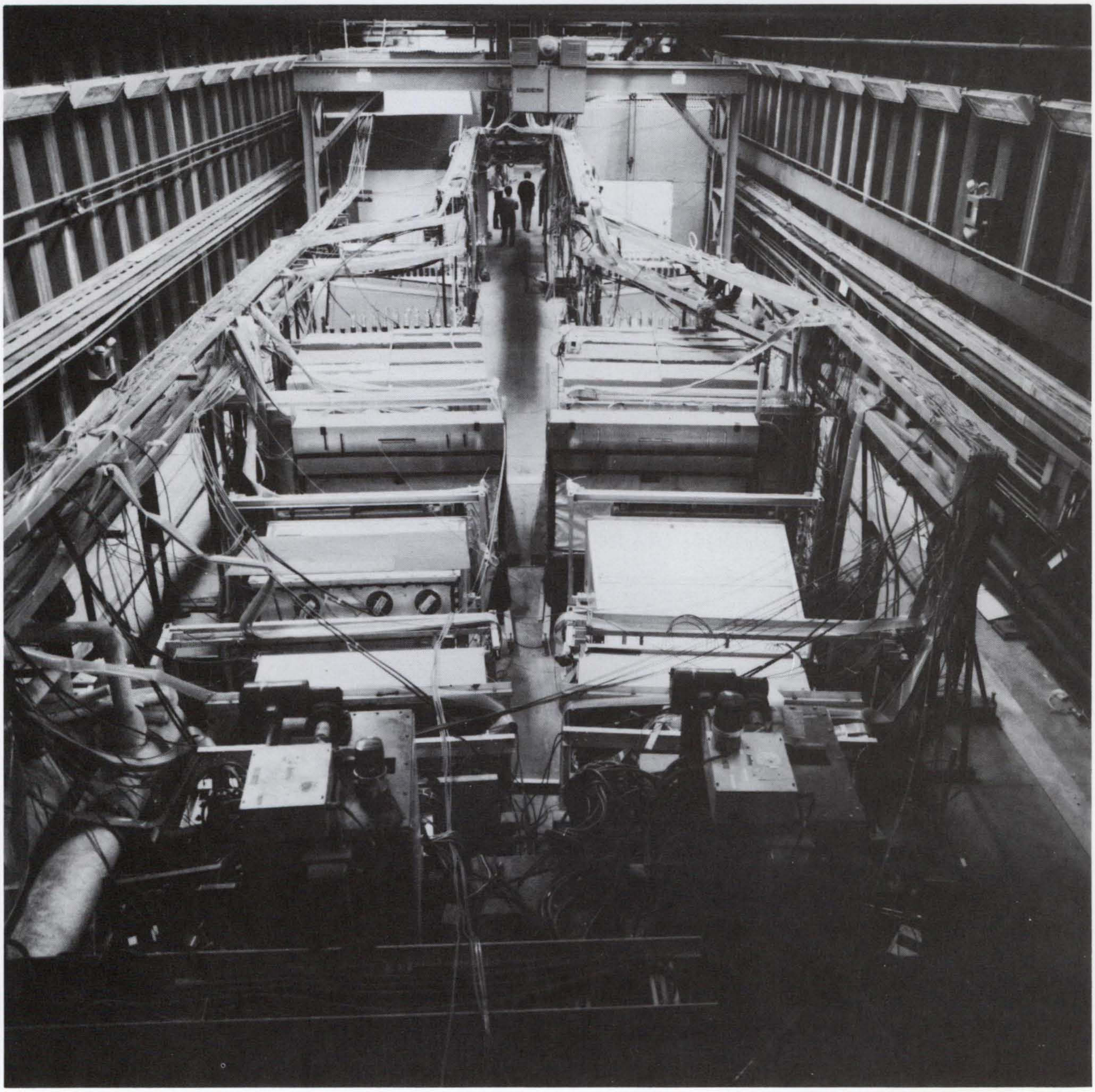
Precision measurements of magnetic moments of the unstable hyperons Λ^0, Ξ^0, Ξ^-, Σ^+ and Σ^- and the transition moments $\Lambda^0 - \Sigma^0$.
1974-1982

Continuum precision studies of dilepton production in hadronic collisions and application to hadronic structure functions and higher order QCD calculations.
1977-1981

Observation of neutral currents in weak interactions of neutrinos were an important verification of the earlier CERN reports establishing this crucial effect.

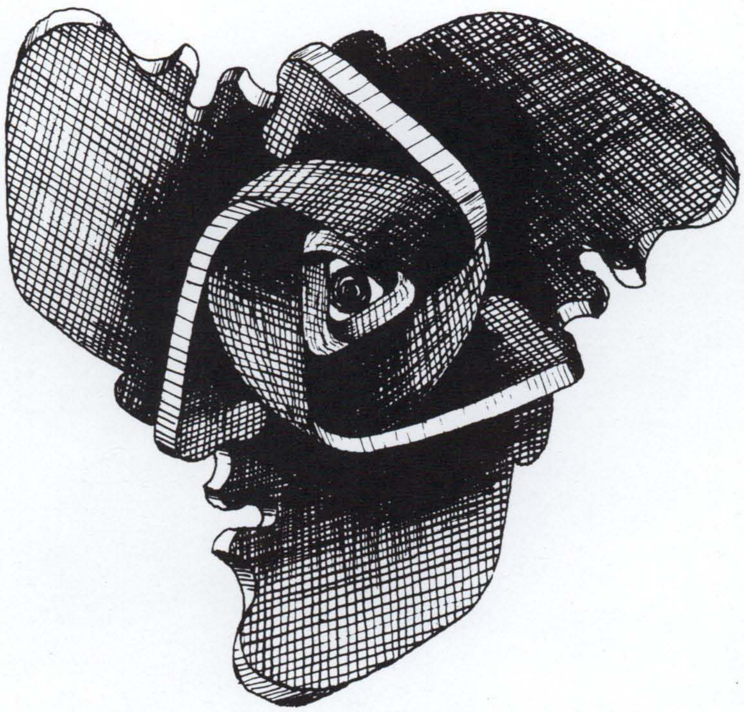
First observation of the violation of Bjorken scaling in muon inelastic scattering.
1975

Discovery of the Upsilon family of three closely spaced resonances establishing the existence of a fifth quark, b- and the first data on the properties of the heavy $\bar{b}$ system.
1977-1979



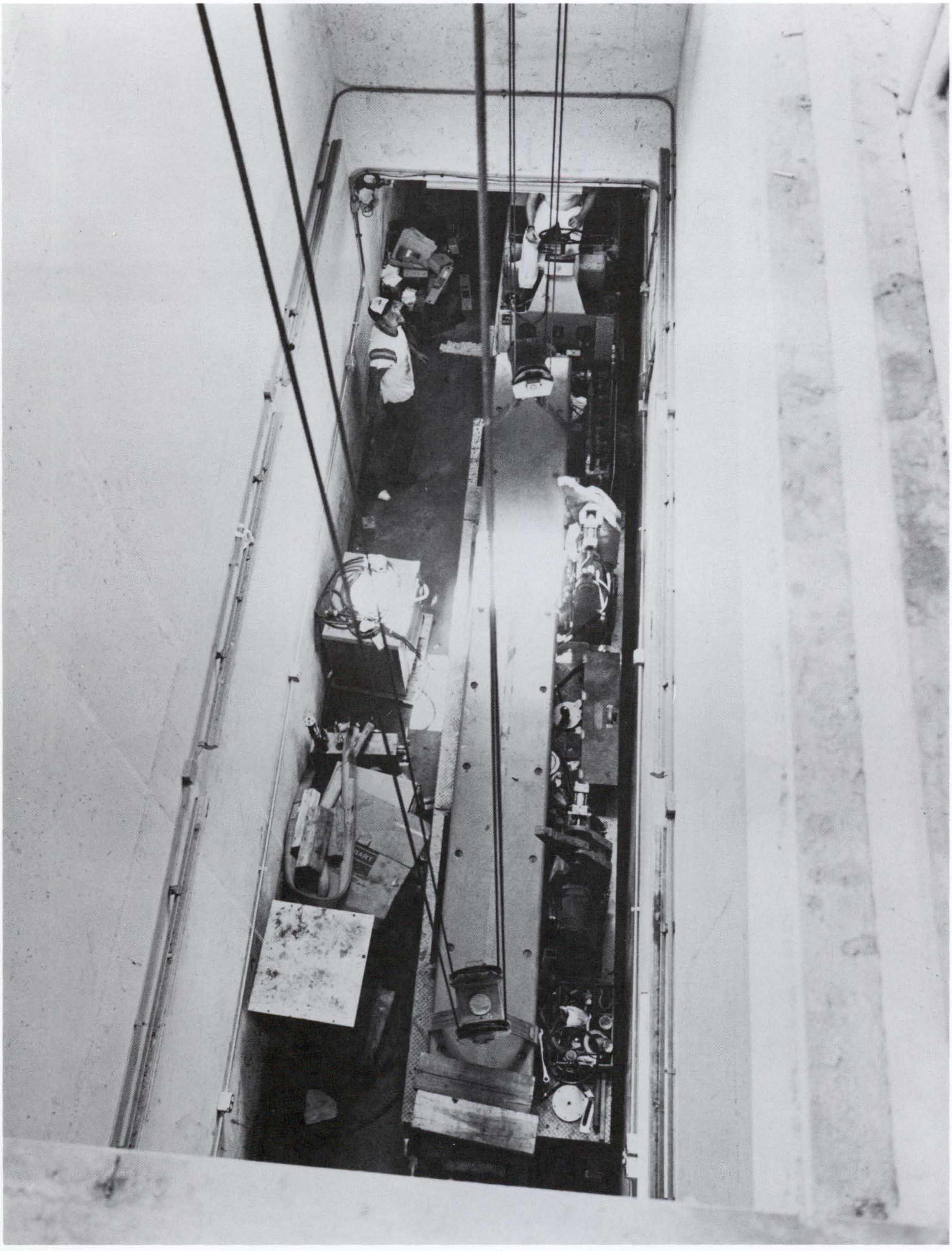
Muon spectrometers for Experiment 288 in the Proton Center experimental pit.

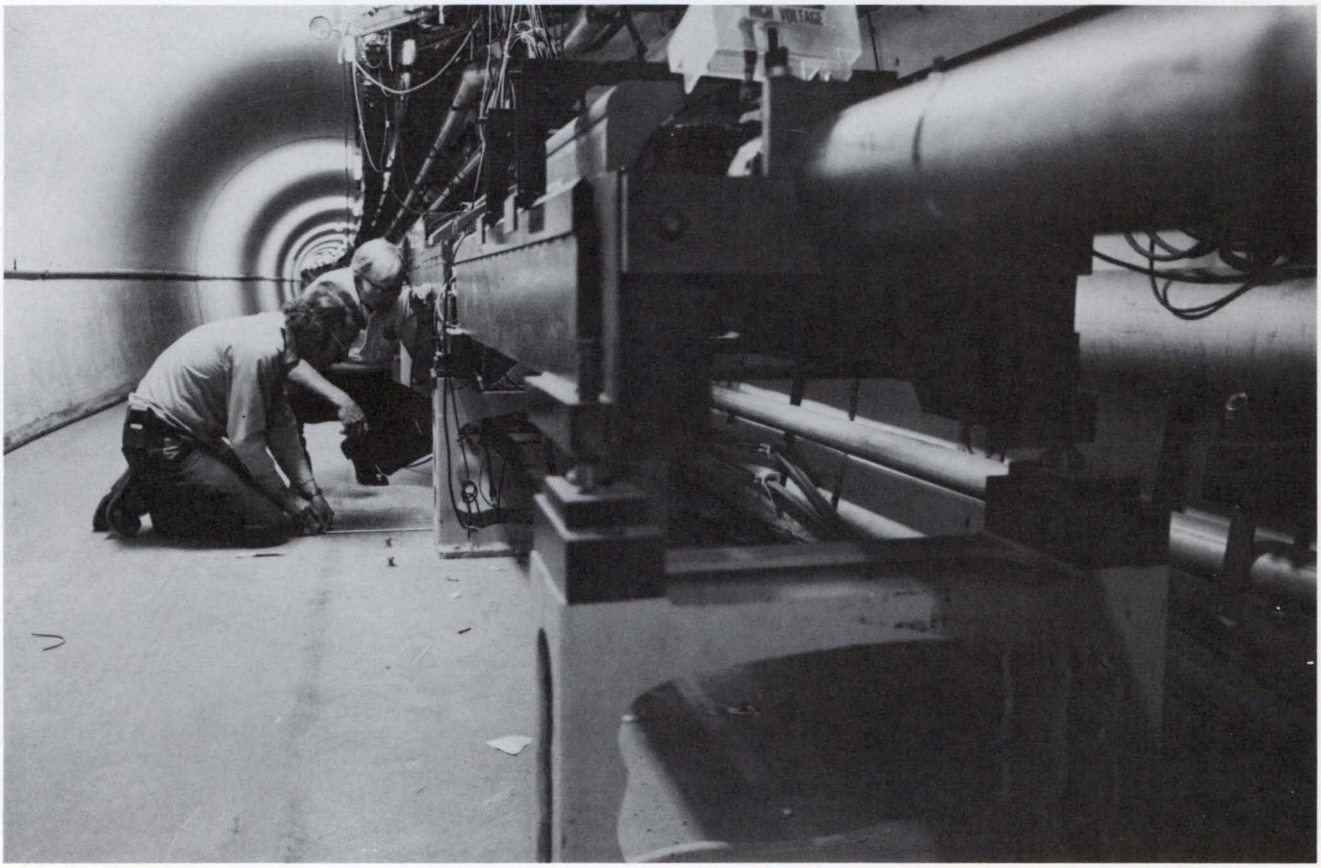
V. Work in the Main-Ring Tunnel



Harry Krider, a Belding employee, unloads Energy Saver magnets at D0 prior to being lowered into the tunnel for installation.

A Main-Ring dipole magnet is lowered onto the Main-Ring moving vehicle for reinstallation in the tunnel. →





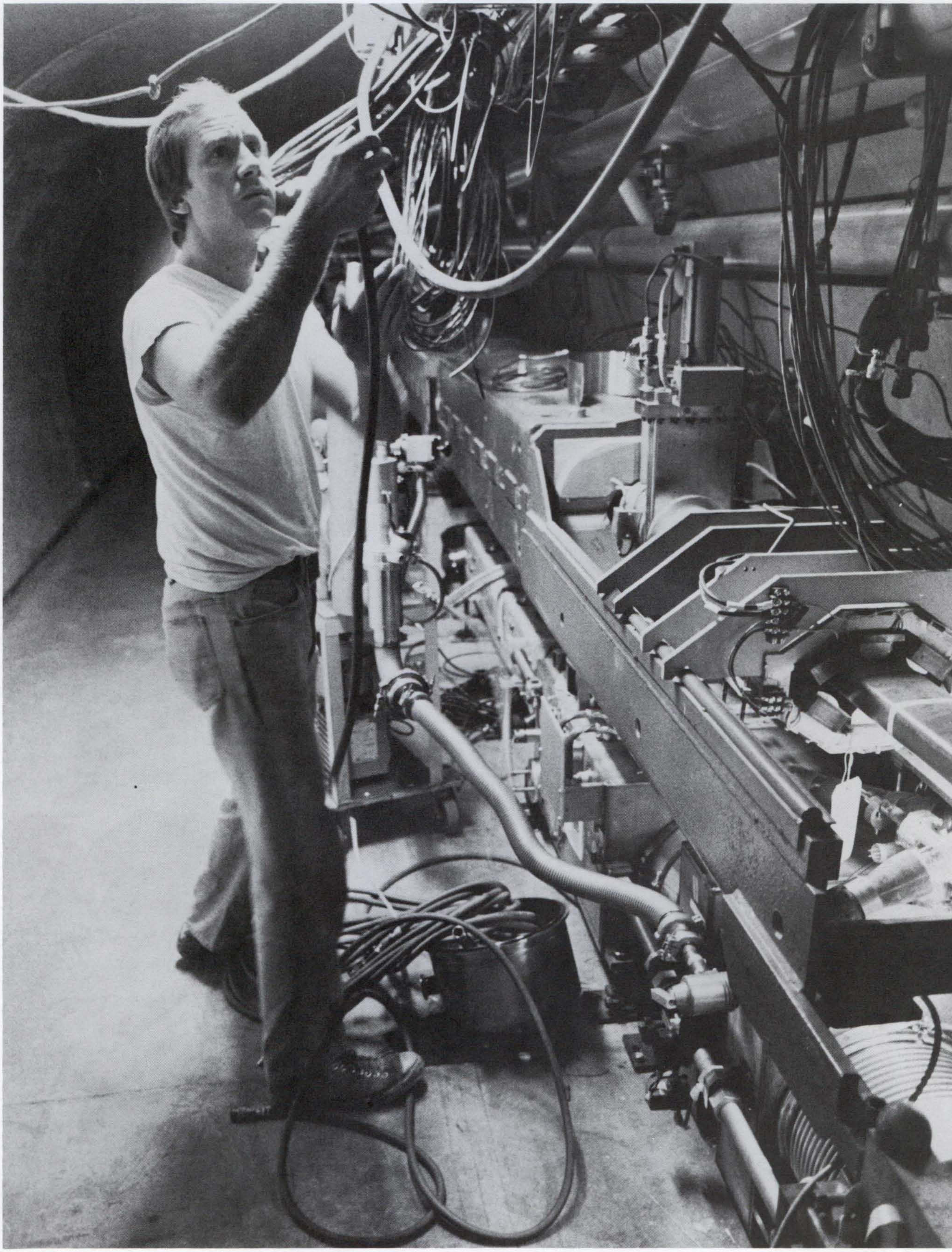
Thornton Murphy (left) and Max Palmer make measurements to determine how to insert a power spool piece for the Energy Saver under the existing Main-Ring magnets.

Belding Corp. employees Clay Horton (left), Ken Meissner, and Rine DeKing, and Merrill Albertus, Fermilab, off load a spool piece from a trailer prior to inserting it in the Energy Saver beam line, visible at the far right of the photograph.

→

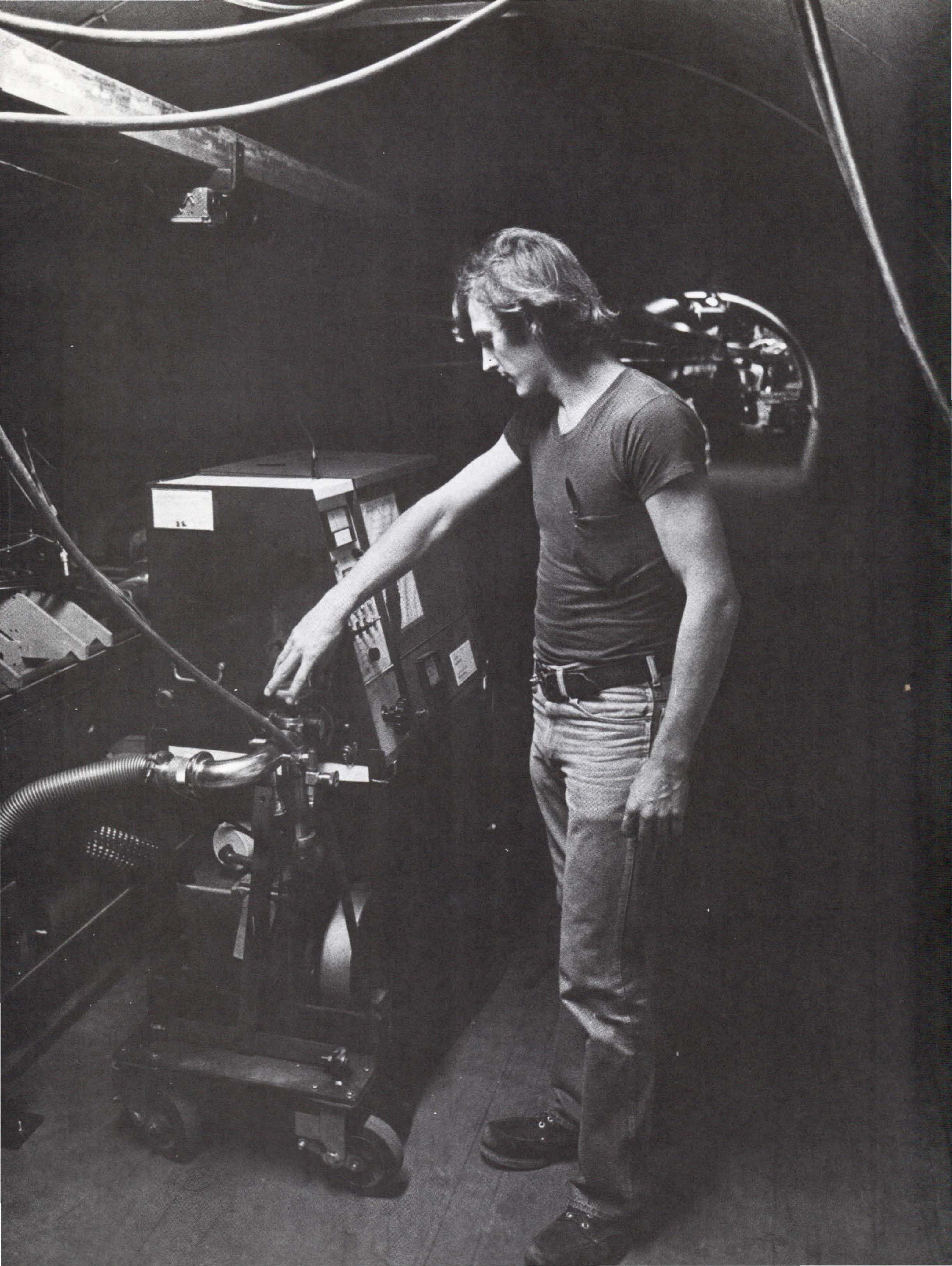
Gary Capola (kneeling) and Terry Guthke use surveying techniques to align a Saver magnet to within a few thousandths of an inch.

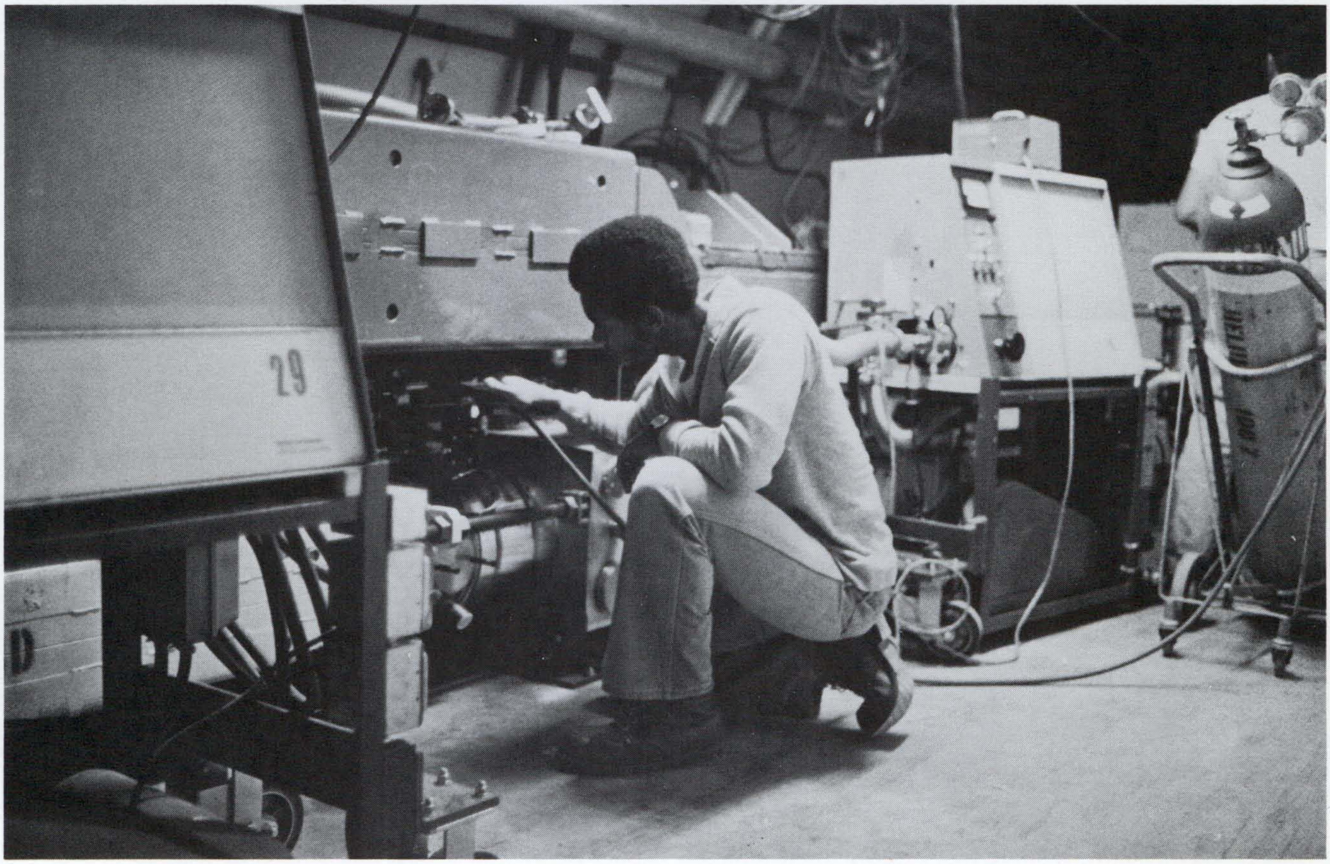
Russ Harrison connects cryogenic lines between magnets. →



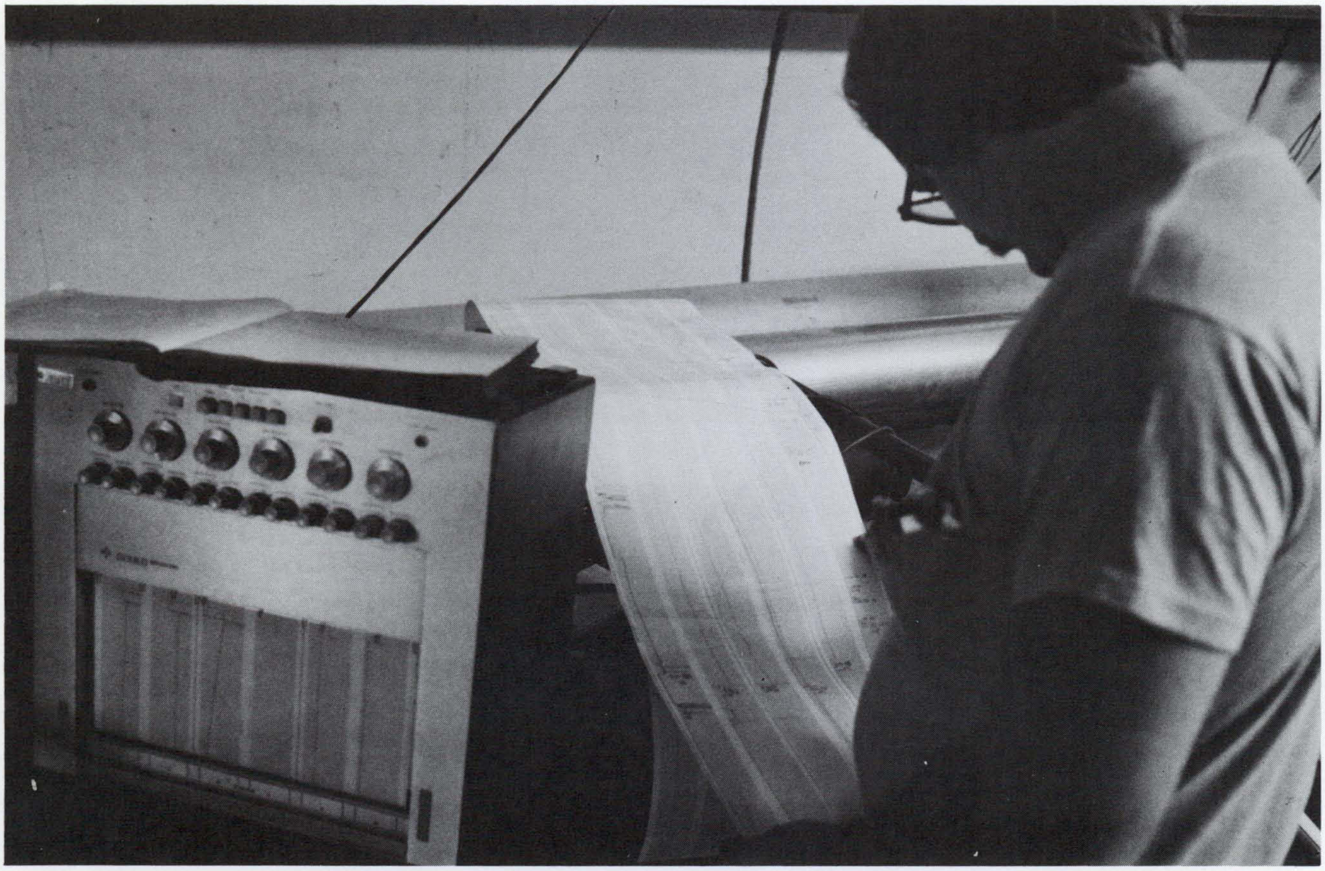
Bruce Kling purges the pneumatic control system in the Main-Ring tunnel.

Dave Augustine adjusts a leak detector used to test Energy Saver magnets. ⟶



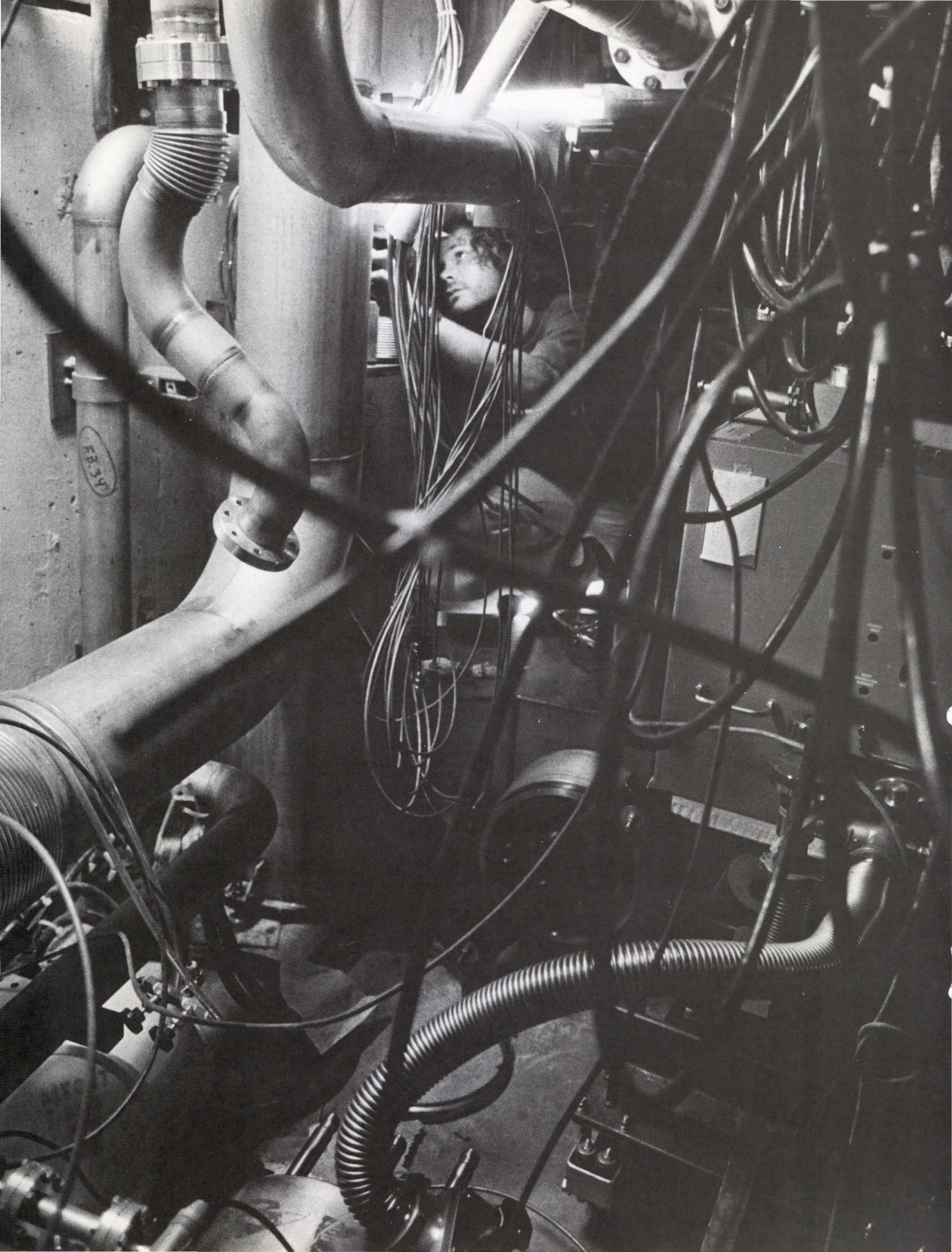


Rodney Shores sprays helium on a magnet interface to check for leaks.



Using a chart recorder, Roger Thomas reads output from six leak detectors spaced 100 feet apart.

Dale Durham fits pipes for the Energy Saver in the Main-Ring tunnel. This photograph shows the often cramped conditions that are typical of many jobs performed in the close confines of the tunnel. →

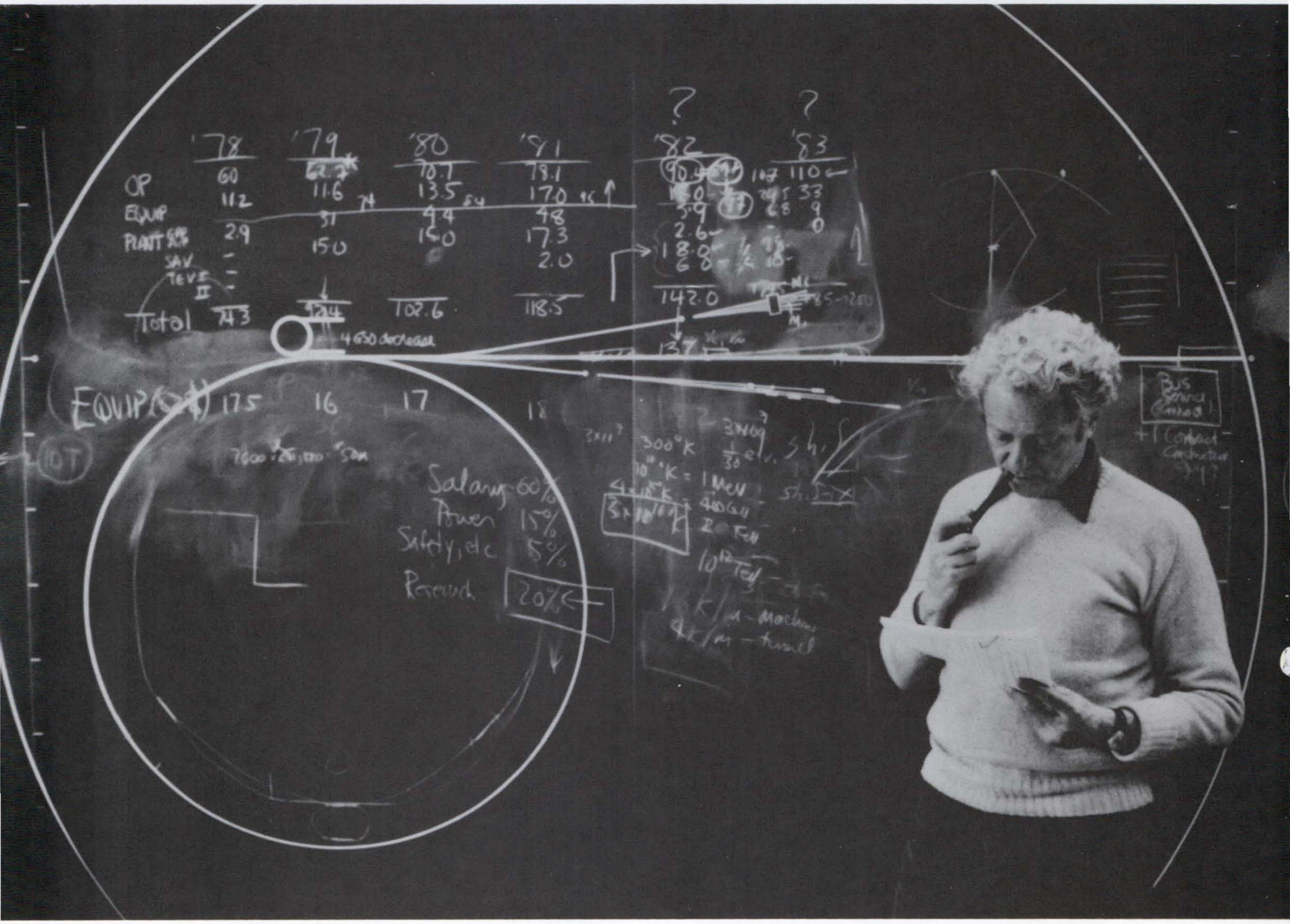


Laif Spencer of Park Associates welds together a stainless-steel pipe assembly prior to welding it into the low pressure helium header behind the Main-Ring magnets.

←

A National Heat and Power Corp. welder's helper practices welding a piece of pipe while sitting on the final section of the four-mile liquid helium transfer line. The transfer line went into operation in December, 1982.

Ken Olesen (left) readies a temporary blankoff plunger while Jay Theilacker removes a malfunctioning liquid helium relief valve from an Energy Saver dipole magnet.


'78
'79
'80
'81
'82
'83
OP
EQUIP
Total
Power 15%
20%

VI. Publications

HIGH ENERGY PHYSICS PROGRAM EXPERIMENTAL PUBLICATIONS*

15-Foot Antineutrino/H_2 #31A

STRANGE-PARTICLE PRODUCTION IN HIGH-ENERGY $\bar{\nu}$ AND ν CHARGED-CURRENT INTERACTIONS ON PROTONS. R. Brock et al., Phys. Rev. **D25**, 1753 (1982).

MULTIPLICITY DISTRIBUTIONS IN $\bar{\nu}_\mu p$ INTERACTIONS. M. Derrick et al., Phys. Rev. **D25**, 624 (1982).

MEASUREMENT OF QUARK MOMENTUM DISTRIBUTIONS IN THE PROTON USING AN ANTINEUTRINO PROBE. V. E. Barnes et al., Phys. Rev. **D25**, 1 (1982).

MEASUREMENT OF THE NEUTRAL-CURRENT-TO-CHARGED-CURRENT CROSS-SECTION RATIO FOR ANTINEUTRINO-PROTON INCLUSIVE SCATTERING. D. D. Carmony et al., Phys. Rev. **D26**, 2965 (1982).

K^0 Regeneration #82

DETERMINATION OF THE FUNDAMENTAL PARAMETERS OF THE K^0-$\overline{K^0}$ SYSTEM IN THE ENERGY RANGE 30 GeV-110 GeV. S. H. Aronson et al., Phys. Rev. Lett. **48**, 1306 (1982).

Muon #98

DIFFRACTIVE PRODUCTION OF VECTOR MESONS IN MUON-PROTON SCATTERING AT 150 AND 100 GeV. W. D. Shambroom et al., Phys. Rev. **D26**, 1 (1982).

Emulsion/Protons @ 200/400 GeV/c #105/385

RAPIDITY-GAP CORRELATION IN PROTON NUCLEUS INTERACTIONS AT 200 AND 400 GeV/c. M. M. Aggarwal et al., J. Phys. Soc. Japan **51**, 353 (1982).

Multiparticle #110

PION-PION DECAY DISTRIBUTIONS FOR $\pi^- p \rightarrow \pi^+ \pi^- n$ AT 100 AND 175 GeV/c. S. R. Stampke, Ph.D. Thesis, California Institute of Technology, 1982.

Inclusive Scattering #118

EXPERIMENTAL STUDY OF SINGLE-PARTICLE INCLUSIVE HADRON SCATTERING AND ASSOCIATED MULTIPLICITIES. A. E. Brenner et al., Phys. Rev. **D26**, 1497 (1982).

30-In. $\pi^- p$ @ 200 GeV/c #137

STUDY OF CHARGE-DEPENDENT BEHAVIOR OF FINAL-STATE PARTICLES IN $\pi^- p$ INTERACTIONS AT 205 GeV/c. G. P. Yost et al., Phys. Rev. **D25**, 1181 (1982).

30-In. Hybrid #154/299

COMPARISON OF 147 GeV/c $\pi^- p$ LOW TRANSVERSE MOMENTUM HADRON PRODUCTION WITH DEEP-INELASTIC LEPTOPRODUCTION. D. Brick et al., Z. Phys. **C11**, 335 (1982).

APPROACH TO SCALING IN INCLUSIVE $\pi^+\pi^-$ RATIOS AT 147 GeV/c. D. Brick et al., Z. Phys. **C13**, 11 (1982).

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*This list was compiled using 1981 (not in **Fermilab 1981**) and 1982 journal articles, theses, and conference papers. Some conference papers were submitted to a conference earlier and were not published until 1982. If there are changes, omissions, or comments, please notify the Publications Office.

30-In. π^-p & Ne @ 200 GeV/c #163

NEUTRAL-PION PRODUCTION AND DIFFRACTION DISSOCIATION IN HIGH-ENERGY π^--NUCLEON COLLISIONS. H. R. Band et al., Phys. Rev. **D26**, 1013 (1982).

15-Ft ν/H_2 & Ne #180

QUARK JETS FROM ANTINEUTRINO INTERACTIONS (I). NET CHARGE AND FACTORIZATION IN THE QUARK JETS. J. P. Berge et al., Nucl. Phys. **B184**, 13 (1981).

QUARK JETS FROM ANTINEUTRINO INTERACTIONS (II). INCLUSIVE PARTICLE SPECTRA AND MULTIPLICITIES IN THE QUARK JETS. J. P. Berge et al., Nucl. Phys. **B203**, 1 (1982).

QUARK JETS FROM ANTINEUTRINO INTERACTIONS (III). TRANSVERSE STRUCTURE OF THE QUARK JETS. J. P. Berge et al., Nucl. Phys. **B203**, 16 (1982).

QUARK JETS FROM DEEPLY INELASTIC LEPTON SCATTERING. R. Orava, Physica Scripta **25**, 159 (1982).

INCLUSIVE CHARGED-CURRENT ANTINEUTRINO-NUCLEON INTERACTIONS AT HIGH ENERGIES. V. V. Ammosov et al., Nucl. Phys. **B199**, 399 (1982).

Muon #203/391

STUDY OF RARE PROCESSES INDUCED BY 209-GeV MUONS. W. H. Smith et al., Phys. Rev. **D25**, 2762 (1982).

Form Factor #216

ELASTIC-SCATTERING MEASUREMENT OF THE NEGATIVE-PION RADIUS. E. B. Dally et al., Phys. Rev. Lett. **48**, 375 (1982).

Emulsion/Protons @ 300 GeV/c #232

INITIAL BREMSSTRAHLUNG CONVERSION. D. T. King, Phys. Rev. **D24**, 555 (1981).

15-Foot Engineering Run #234

INCLUSIVE π^0 PRODUCTION IN 250-GeV/c π^-p INTERACTIONS. R. N. Diamond et al., Phys. Rev. **D25**, 41 (1982).

Neutrino #253

THE TOTAL CROSS SECTION FOR ν_μe ELASTIC SCATTERING. K. A. Lefler, Ph.D. Thesis, University of Maryland, 1981.

30-In. Hybrid #299

INCLUSIVE STRANGE-RESONANCE PRODUCTION IN pp, π^+p, AND K^+p INTERACTIONS AT 147 GeV/c. D. Brick et al., Phys. Rev. **D25**, 2248 (1982).

INCLUSIVE AND SEMI-INCLUSIVE ρ^0 PRODUCTION IN $\pi^+/\pi^-/K^+$/pp INTERACTIONS AT 147 GeV/c. M. Schouten et al., Z. Phys. **C9**, 93 (1981).

TOPOLOGICAL, TOTAL, AND ELASTIC CROSS SECTIONS FOR K^+p, π^+p, AND pp INTERACTIONS AT 147 GeV/c. D. Brick et al., Phys. Rev. **D25**, 2794 (1982).

Di-Muon #326

ATOMIC-WEIGHT DEPENDENCE OF MUON-PAIR PRODUCTION IN 225-GeV/c π^- NUCLEUS INTERACTIONS. H. J. Frisch et al., Phys. Rev. **D25**, 2000 (1982).

Emulsion/π^- @ 200 GeV/c #328

INVESTIGATION OF DIFFRACTIVE DISSOCIATION OF π^- MESONS ON NUCLEONS AND NUCLEI AT 200 GeV/c. S. A. Azimov et al., Yad. Fiz. **35**, 950 (1982).

CHARGED AND NEUTRAL PARTICLES OF LEADING ENERGIES IN INTERACTIONS OF π^- MESONS WITH PHOTOEMULSION NUCLEI AT ENERGIES OF 50 AND 200 GeV. G. I. Orlova et al., Yad. Fiz. **35**, 706 (1982).

Inclusive Neutral Meson #350

AN SU(3)-BASED COMPARISON BETWEEN INCLUSIVE KAON AND PION CHARGE EXCHANGE SCATTERING IN THE TRIPLE REGGE REGION. A. V. Barnes et al., Nucl. Phys. **B206**, 173 (1982).

Emulsion/Protons @ 400 GeV/c #385

RAPIDITY-GAP AND RAPIDITY-CORRELATION STUDY IN 400-GeV/c PROTON-NUCLEUS INTERACTIONS. D. Ghosh et al., Phys. Rev. **D26**, 2983 (1982).

CHARM PRODUCTION IN 400 GeV/c PROTON-EMULSION INTERACTIONS. T. Aziz et al., Nucl. Phys. **B199**, 424 (1982).

Hadron Dissociation #396

CHARGED MULTIPLICITIES OF HIGH-MASS DIFFRACTIVE $\pi^\pm$, $K^\pm$, and $p^\mp$ STATES. R. L. Cool et al., Phys. Rev. Lett. **48**, 1451 (1982).

UNIVERSALITY OF CHARGED MULTIPLICITY DISTRIBUTIONS. K. Goulianos et al., Phys. Rev. Lett. **48**, 1454 (1982).

Photoproduction #401

J/ψ PHOTOPRODUCTION FROM 60 TO 300 GeV/c. M. Binkley et al., Phys. Rev. Lett. **48**, 73 (1982).

Form Factor #456

ELASTIC-SCATTERING MEASUREMENT OF THE NEGATIVE-PION RADIUS. E. B. Dally et al., Phys. Rev. Lett. **48**, 375 (1982).

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RECOIL PROPERTIES OF FRAGMENTS EMITTED IN THE INTERACTION OF COMPLEX NUCLEI WITH RELATIVISTIC ^{12}C IONS AND PROTONS. G. D. Cole and N. T. Porile, Phys. Rev. **C25**, 244 (1982).

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THE MAGNETIC MOMENT OF THE CASCADE-ZERO HYPERON. P. T. Cox, Ph.D. Thesis, The University of Michigan, 1980.

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Monopole #502

SEARCH FOR COSMIC-RAY-RELATED MAGNETIC MONOPOLES AT GROUND LEVEL. D. F. Bartlett et al., Phys. Rev. **D24**, 612 (1981).

High Energy Channeling #507/660

POSSIBLE APPLICATIONS OF THE STEERING OF CHARGED PARTICLES BY BENT SINGLE CRYSTALS. R. A. Carrigan, Jr., et al., Nucl. Instrum. Methods **194**, 205 (1982).

RADIATION FROM THE CHANNELING OF 10-GeV POSITRONS BY SILICON SINGLE CRYSTALS. N. A. Filatova et al., Phys. Rev. Lett. **48**, 488 (1982).

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Neutrino #531

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π-μ Atoms #533

MEASUREMENT OF THE RATE OF FORMATION OF PI-MU ATOMS IN K_L^0 DECAY. S. H. Aronson et al., Phys. Rev. Lett. **48**, 1078 (1982).

15-Ft Neutrino/D_2 & Hiz #545

NEUTRAL-CURRENT $\nu_\mu n$ AND $\nu_\mu p$ CROSS SECTIONS FROM HIGH-ENERGY NEUTRINO INTERACTIONS IN DEUTERIUM. T. Kafka et al., Phys. Rev. Lett. **48**, 910 (1982).

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CHARMED-BARYON PRODUCTION IN $\nu d \rightarrow \mu^- \Lambda X$ REACTIONS. D. Son et al., Phys. Rev. Lett. **49**, 1128 (1982).

15-Ft Neutrino/H_2 & Ne #546

A MOMENTUM CALCULATION FOR CHARGED TRACKS WITH MINUTE CURVATURE. E. Treadwell, Nucl. Instrum. Methods **198**, 337 (1982).

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30-In. Hybrid #565/570

CRISIS DETECTOR: CHARACTERISTICS AND PERFORMANCE. A. M. Shapiro et al., Rev. Sci. Instrum. **53**, 393 (1982).

MEASUREMENT OF THE MULTIPLICITIES IN THE COLLISION OF HADRONS WITH HEAVY NUCLEI AT 200 GeV/c. D. H. Brick et al., Nucl. Phys. **B201**, 189 (1982).

Elastic Scattering #577

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CRITICAL PHENOMENA IN HADRONIC MATTER AND EXPERIMENTAL ISOTOPIC YIELDS IN HIGH ENERGY PROTON-NUCLEUS COLLISIONS. R. W. Minich et al., Phys. Lett. **118B**, 458 (1982).

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THE FERMILAB COLLIDER DETECTOR FACILITY DATA ACQUISITION SYSTEM. A. E. Brenner et al., IEEE Trans. Nucl. Sci. **NS-29**, 105 (1982).

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RECENT WORK ON COLLECTIVE ACCELERATORS. F. T. Cole, Proc. of the 1981 Linear Accelerator Conference, October 19-23, 1981, Santa Fe, New Mexico, p. 225.

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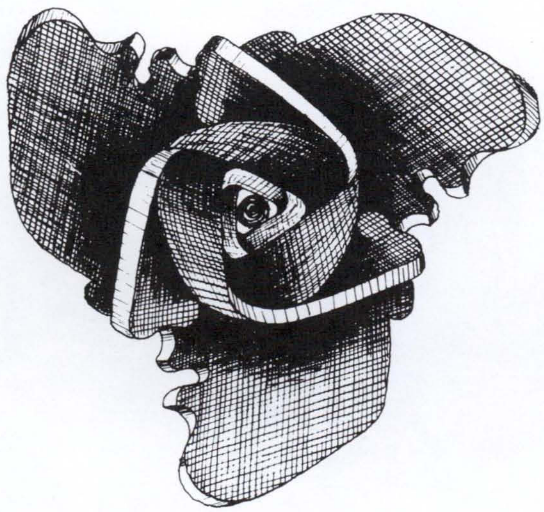


VII. 1982 Workshop and Seminar Series

Arms Control and International Security Seminar Series

Dr. Wolfgang Panofsky, Stanford Linear Accelerator Center: "Arms Control: Successes and Failures," September 24, 1981

Dr. George Rathjens, Massachusetts Institute of Technology: "Nuclear Weapons Proliferation and Its Relation to Nuclear Power," October 14, 1981

Dr. William Perry, Former Undersecretary of Defense for Research and Engineering: "Strategic Modernization and Arms Control," December 10, 1981

Dr. Frank von Hippel, Center for Environmental Studies, Princeton Unviersity, and, Dr. Richard Gardiner, Director of Gastrointestinal Radiology, Rush-Presbyterian St. Luke Medical Center, Chicago, Illinois and Chairman of the Chicago Chapter of Social Physicians for Responsibility: "The Probability and Consequences of 'Limited' Nuclear War," January 29, 1982

Dr. J. Carson Mark, Los Alamos National Laboratory: "The Consequences of Large Scale Nuclear War," February 18, 1982

Dr. Edward Teller, Hoover Institute of War, Peace, and Revolution, Stanford University: "Mutual Assured Destruction or Mutual Assured Survival," March 17, 1982

Dr. Richard Garwin, IBM: "Submarines in Strategic and Tactical Roles," April 22, 1982

Dr. John Steinbruner, The Brookings Institute: "Command, Control, and Communications Vulnerability," May 12, 1982

Admiral Bobby R. Inman, U.S.N. (Ret.): "The State of U.S. Intelligence," August 11, 1982

Astrophysics Seminar Series

Dr. James Fry, University of Chicago: "Large Scale Inhomogeneities in the Universe," October 12, 1982

Dr. J. Ostriker, Princeton University: "Statistics of Gravitational Lenses," October 26, 1982

Dr. Brad Filapone, Argonne National Laboratory: "Nuclear Physics and Solar Neutrinos," November 5, 1982

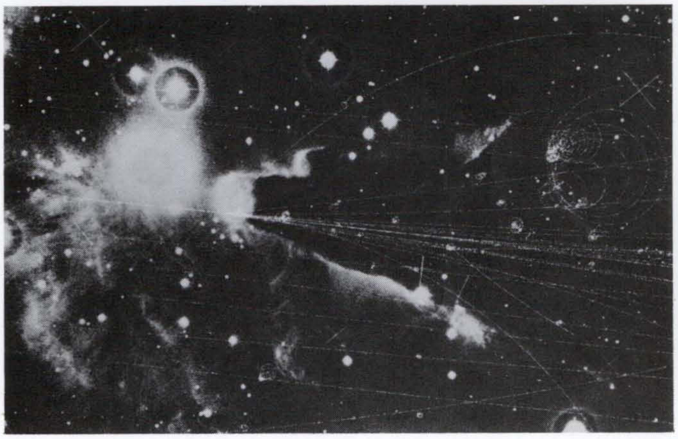
Dr. Michael Turner, University of Chicago: "The Inflationary Universe - Birth, Death, Transfiguration," November 12, 1982

Dr. David Lindley, University of Cambridge: "Primordial Black Holes and Baryon Production," November 23, 1982

Dr. Edward Anders, Enrico Fermi Institute: "Isotopic Anomalies in Meteorites; Evidence for Presolar Matter," December 3, 1982

Dr. Roger Hildebrand, University of Chicago: "The Polarization of the Dusty Universe," December 10, 1982

Dr. James Hartle, University of Chicago: "Quantum Dynamics of the Early Universe," January 7, 1983



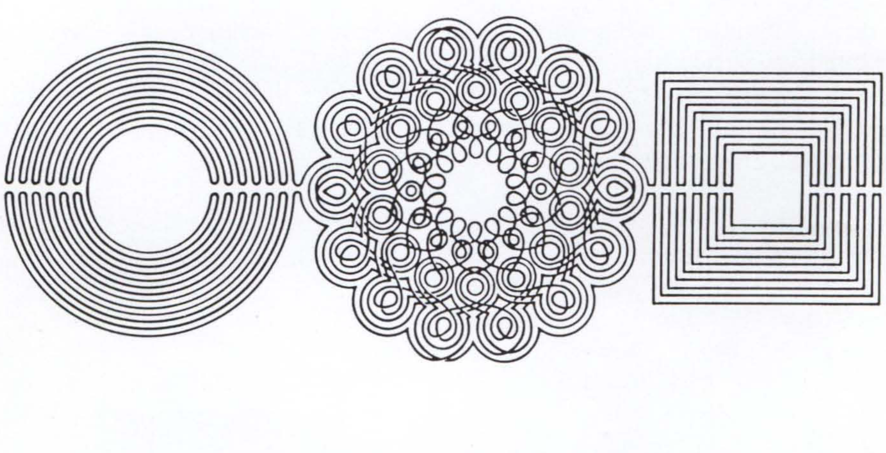
Advanced Computer Seminar Series

Dr. Jack Schwartz, New York University: "The NYU Ultracomputer--A Large Scale Parallel Architecture," September 22, 1982

Dr. Jack Dennis, Laboratory for Computer Science, Massachusetts Institute of Technology: "Data Flow Computer Architecture," October 28, 1982

Dr. David Kuck, University of Illinois: "Compilation for the Supercomputers of Today and Tomorrow," November 11, 1982

Mr. William Sippach, Nevis Laboratories: "Data Driven Processing," December 9, 1982



Fermilab Colloquia Series

Dr. Hank Thacker, Fermilab: "Nonperturbative QCD," January 6, 1982

Dr. Robert Richardson, Cornell University: "Liquid ^{3}He: The Magnetic Superconductor Without Charge," January 20, 1982

Dr. Roland Winston, University of Chicago: "Evolution of Stationary Solar Concentrators," January 27, 1982

Dr. Scott Tremaine, Massachusetts Institute of Technology: "The Dynamics of Planetary Rings," February 10, 1982

Dr. Charles Baker, Argonne National Laboratory: "Fusion Energy Programs in the U.S....Status and Future," February 17, 1982

Dr. Richard Briggs, Lawrence Livermore National Laboratory: "High Intensity Electron Accelerators and Their Applications," March 3, 1982

Dr. Marc Gorenstein, Massachusetts Institute of Technology: "Looking Through a Gravitational Lens: Radio Maps of the Twin Quasars," April 14, 1982

Dr. Carleen Hutchins, Catgut Acoustical Society, Inc.: "Technical Problems and Violin Research," April 21, 1982

Dr. Kenneth Wilson, Cornell University: "Universities and the Future of Computer Technology," April 21, 1982

Dr. T. H. Fleisch, Amoco Research Center: "Surface Science--Applications in a Petroleum Company," May 5, 1982

Dr. Kirk McDonald, Princeton University: "Does Quantum Mechanics Require Superluminal Connections?" May 12, 1982

Dr. Boris Kayser, National Science Foundation: "Quantum Mechanics of Neutrino Oscillation," May 19, 1982

Dr. Kosta Tsipis, Massachusetts Institute of Technology: "Directed Energy Weapons," May 26, 1982

Dr. Robin Giffard, Hewlett-Packard Company: "The Josephson Effect, Superconducting Quantum Interference Devices (SQUIDs) and the Detection of Unusual Magnetic Signals," June 2, 1982

Dr. H. T. Kung, Carnegie Mellon University: "Silicon Subroutines: An Emerging Opportunity From Very Large Scale Integrated Circuits (VLSI)," July 1, 1982

Dr. Eric Drexler, Massachusetts Institute of Technology: "Sailing in Space," July 7, 1982

Dr. Haim Harari, Weizmann Institute of Science: "Composite Quarks and Leptons?" August 30, 1982

Dr. Jim Potter, Los Alamos National Laboratory: "Radio Frequency Quadrupole Development at Los Alamos National Laboratory," September 8, 1982

Dr. Jerry Nelson, Lawrence Berkeley Laboratory: "The University of California Ten Meter Telescope," September 15, 1982

Dr. Robert Laughlin, Lawrence Livermore National Laboratory: "Two-Dimensional Electrons in Strong Magnetic Fields: The Quantized Hall Effect," September 29, 1982

Dr. C. K. N. Patel, Bell Laboratories: "Fascinating Science and Spectroscopy of Highly Transparent Solids and Liquids," October 6, 1982

Dr. E. (Rocky) Kolb, Los Alamos National Laboratory: "Monopole Catalyzed Nucleon Decay in Neutron Stars," October 13, 1982

Dr. Albert Libchaber, Ecole Normale Superieure: "Routes to Chaos in Dissipative Dynamical Systems," October 20, 1982

Dr. Thomas J. Greytak, Massachusetts Institute of Technology: "Spin-Polarized Atomic Hydrogen," November 3, 1982

Dr. Claudio Rebbi, Brookhaven National Laboratory: "Monte Carlo Computations for Lattice Gauge Theories," November 10, 1982

Dr. Al Clark, National Bureau of Standards: "Future of Superconductivity," November 17, 1982

Dr. John G. Bollinger, University of Wisconsin, Madison: "Robotics and Tactile Sensing," December 1, 1982

Dr. H. J. Lubatti, University of Washington: "Rare Decays of Kaons--Beyond the Standard Model," December 8, 1982

Dr. Thomas D. Rossing, Northern Illinois University: "The Physics of Drums," December 15, 1982

colloquium

Research Technique Seminars

Dr. G. Poelz, DESY: "Preparation of Silica Aerogel and Its Application in the TASSO Cherenkov Counters," February 26, 1982

Dr. M. Atac and H. Jensen, Fermilab: "Highlights of the International Conference on Instrumentation for Colliding Beam Physics," March 11, 1982

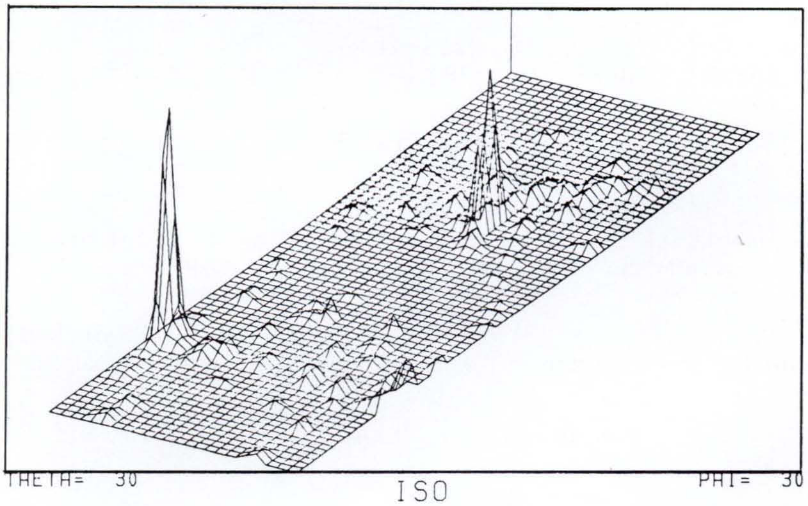
Dr. K. Kuroda, Annecy, France: "A Position-Sensitive Photomultiplier," April 22, 1982

Dr. D. Mueller, University of Chicago: "Transition Radiation Detectors for High Energy Cosmic Rays," June 24, 1982

Dr. F. James, CERN: "Experience with Fitting Tracks in MWPC Using the Chebyshev Norm Instead of Least Squares," July 15, 1982

Dr. F. Pouyat, and W. Seidl, CERN: "Holographic Optics, Tests and Plans for the Big European Bubble Chamber," September 23, 1982

Dr. C. Baltay, Columbia University: "Wide Angle Straight Through Holography for Large Bubble Chambers," December 2, 1982



Joint Experimental-Theoretical Physics Seminars

Dr. Roger Ericson, Stanford Linear Accelerator Center: "Charm Production with the SLAC Back-Scattered Laser Beam," January 15, 1982

Dr. Don Reeder, University of Wisconsin: "A New Measurement of the Prompt Neutrino Flux from Hadronic Collisions" (Results from E-613), January 22, 1982

Dr. Dick Slansky, Los Alamos National Laboratory: "Fractional Electric Charge in Broken QCD," January 29, 1982

Dr. Tom Devlin, Rutgers University: "Polarization and Magnetic Moment of the Σ^- Hyperon," February 5, 1982

Dr. K. Goulianos, (E-612): "Diffraction Dissociation of Hadrons and Photons," February 12, 1982

Dr. Juha Lindfors, University of Helsinki: "QCD Effects in $W^{\pm}$ and Z^0 Production," February 19, 1982

Dr. Risto Orava, Fermilab: "Jet Structure and the Magic of the Moments," February 26, 1982

Dr. John Linsley, University of New Mexico: "Particle Physics in Cosmic Ray Air Showers," March 5, 1982

Dr. Clive Halliwell, University of Illinois, Chicago Circle: "Properties of Events Produced with High Transverse Momentum in pp and pA Collisions," March 13, 1982

Dr. Dave Bailey, McGill University: "Production of Charm by Neutrinos," March 19, 1982

Dr. William Francis, University of California, San Diego: "An SU(3) Based Comparison Between Inclusive Kaon and Pion Charge Exchange Scattering in the Triple Regge Region" (E-383, E-350), March 26, 1982

Dr. Jean Cleymans, University of Bielefeld: "Production of Heavy Resonances ($J/\psi, \Upsilon$) with Muon Beams," April 16, 1982

Dr. Hans Jensen, Fermilab: "What Physics Do We Expect to Learn with the CDF?" April 23, 1982

Dr. N. Yamdagni, Institute of Physics, University of Stockholm, Sweden: "Search for Centauro Phenomena at the SPS Collider," May 3, 1982

Dr. Dennis Duke, University of Florida, Tallahassee: "How Well Can We Extract Λ_{QCD} from Experimental Data?" May 7, 1982

Dr. S. Meshkov, National Bureau of Standards: "Glueballs and Oddballs," May 14, 1982

Dr. Marvin Marshak, University of Minnesota: "The Soudan Mine Proton Decay Experiment," May 21, 1982

Dr. C. Nelson, Fermilab: "Direct Photon Production at 200 GeV/c," May 28, 1982

Dr. C. Baltay, Columbia University: "Bubble Chamber Measurements of the Total Neutrino Cross Section," June 2, 1982

Dr. Bob Wagner, Fermilab: "Antiproton Production of Dimuons" (E-537), June 4, 1982

Dr. Ray Hagstrom, Argonne National Laboratory: "Fundamental Research at Argonne Without the Use of Accelerators," June 11, 1982

Dr. Geoffrey Taylor, University of Hawaii: "The Mu-Anti-Neutrino Charged Current Total Cross Section," June 18, 1982

Dr. Chris Maxwell, Rutherford Appleton Laboratory: "QCD-Sensitive Features of Large Pt Scattering," June 25, 1982

Dr. Francois Vannucci, CERN: "Neutrino Oscillations from Mountain Peaks to Ocean Depths," July 9, 1982

Dr. D. Weingarten, Indiana University: "Hadron Masses from Lattice QCD," July 23, 1982

Dr. M. K. Gaillard, University of California, Berkeley: "Susy GUTs and Super GUTs," August 6, 1982

Dr. Gad Eilam, Israel Institute of Technology: "Searching for the Top Quark in Flavor Changing Neutral Transitions (B-decays, etc...)" August 13, 1982

Dr. H. Lipkin, Weizmann Institute, Israel: "The Constituent Quark Model Revisited Success for Hadrons; Failures for Multiquark States, New Insight from Hyperon Beams," August 20, 1982

Dr. Holgar Lierl, Max Planck Institute: "Recent Results from CELLO Detector at PETRA," September 3, 1982

Dr. Jean Ernwein, Saclay: "The Fréjus Tunnel Proton Decay Experiment," September 10, 1982

Dr. Melissa Franklin, Stanford Linear Accelerator Center: "Selected Studies of Charmonium Decay (Mark II)" September 10, 1982

Dr. Gösta Gustafson, University of Lund, Sweden: "Status of the Lund Model," September 24, 1982

Dr. A. Brenner, C. Brown, B. Cox, T. Kirk, L. Lederman, P. Limon, P. Malhotra, and J. Peoples, Fermilab: "The Paris Conference: A Panel Discussion," October 1, 1982

Dr. Robert Marshak, Virginia Polytechnic Institute: "Preon Model of Quarks and Leptons and the Generation Problem," October 8, 1982

Dr. Giorgio Giacomelli, University of Bologna, Italy: "Comparison of $\bar{p}p$ and pp Collisions at the ISR," October 12, 1982

Dr. Rick Field, University of Florida, Gainesville: "Jet Formation in QCD," October 22, 1982

Dr. Yau Wah, Yale University: "Σ^+ Polarization and Magnetic Moment," October 29, 1982

Dr. Rafe Schindler, Caltech: "The Emergence of Jet Structure at $\sqrt{s}$ = 63 GeV" (ISR Axial Field Spectrometer), November 5, 1982

Dr. Petros A. Rapidis, Fermilab: "Results from E-616: Neutrino Cross Sections and Nucleon Structure Functions," November 12, 1982

Dr. Chih-Yung Chien, John Hopkins University: "A First Look at Physics with PEP-4 (TPC)" December 3, 1982

Dr. Roger Hildebrand, University of Chicago: "The Polarization of the Dusty Universe," December 10, 1982

Dr. B. Gittelman and B. Siemann, Cornell University: "A Z^0-Factory for the Fermilab Site?" December 16, 1982

Theoretical Physics Seminars

Dr. Bert Schellekens, Fermilab: "Preon Models with Dynamical Symmetry Breaking," January 5, 1982

Dr. J. Polchinski, Stanford Linear Accelerator Center: "Supersymmetry on the Lattice," January 11, 1982

Dr. Barry Freedman, Indiana University: "Solving ϕ^4 with Monte Carlo," January 12, 1982

Dr. Sally Dawson, Fermilab: "Phenomenology of 'Glow' Models," January 19, 1982

Dr. G. Peter LePage, Cornell University: "Initial State Interactions in the Drell-Yan Process," January 26, 1982

Dr. Y. E. Keung, Brookhaven National Laboratory: "Lepton Number Nonconservation," February 2, 1982

Dr. Poul Damgaard, Cornell University: "Exclusive Two Photon Processes with Baryons," February 9, 1982

Dr. Estia Eichten, Fermilab: "Chiral Fermions on the Lattice?" February 16, 1982

Dr. A. Duncan, University of Pittsburgh: "Monte Carlo Evidence for Long Range Chiral Structure in QCD," February 23, 1982

Dr. A. White, Fermilab: "Confinement Through Regge-Limit Infrared Analysis of QCD," March 9, 1982

Dr. V. Baluni, University of Michigan: "Masses of Composite Pseudogoldstone Bosons," March 16, 1982

Dr. S. Raby, Los Alamos National Laboratory: "Supersymmetric Unified Model," March 23, 1982

Dr. S. F. Tuan, University of Wisconsin: "Where is the Top-Quark?" March 24, 1982

Dr. Michael Peskin, Cornell University: "A Subgroup Alignment Paradox in Two Dimensions," March 30, 1982

Dr. Lawrence Krauss, Massachusetts Institute of Technology: "Was the Big Bang a Phase Transition?" April 6, 1982

Dr. R. W. Brown, Fermilab/Case Western Reserve University: "Gauge Zeros: Their Explanation and Proliferation," April 7, 1982

Dr. E. Weinberg, Columbia University: "Fundamental Composite and Deformable Monopoles," April 13, 1982

Dr. D. Callaway, Argonne National Laboratory: "The Microcanonical Ensemble: A New Formulation of Lattice Gauge Theory," April 15, 1982

Dr. Qaisar Shafi, University of Maryland/ICTP-Trieste: "Strings in Unified Gauge Theories," April 20, 1982

Dr. L. Dolan, Rockefeller University: "Exact Integrability and Kac-Moody Algebra," April 27, 1982

Dr. J. Schonfeld, Fermilab: "Anomalies in Soliton-Antisoliton Scattering," May 4, 1982

Dr. R. Michael Barnett, Stanford Linear Accelerator Center: "Possible Evidence for Substantial Nonperturbative QCD Effects in Deep-Inelastic Scattering," May 6, 1982

Dr. S. Shenker, University of Chicago: "The Scales of Chiral Symmetry Breaking," May 11, 1982

Dr. Zhou Bang-Rong, Fermilab: "Constraints from Unification of Interactions in a Class of Composite Models," May 18, 1982

Dr. Peter Zerwas, R.W.T.H. Aachen, Germany: "Testing the 3 Gluon Coupling in Jet Distributions," May 25, 1982

Dr. Sherwin Love, Max Planck Institute, Munich, Germany: "Chiral Symmetry and Supersymmetry," May 27, 1982

Dr. Antti Niemi, Massachusetts Institute of Technology: "Superspace Negative Dimensions and Quantum Field Theories," June 1, 1982

Dr. K. Bitar, Fermilab: "Phase Structure and Renormalization Trajectories of Lattice SU(2) Gauge Theory," June 8, 1982

Dr. Peter Freund, University of Chicago: "Topics in Dimensional Reduction," June 15, 1982

Dr. V. Baluni, University of Michigan: "The Standard Model on the Lattice," June 22, 1982

Dr. J. Van der Bij, University of Michigan: "Supersymmetry and the Gauge Hierarchy Problem," June 29, 1982

Dr. T. Curtright, University of Florida, Gainesville: "Liouville Field Theory--No Strings Attached," July 7, 1982

Dr. A. Mueller, Columbia University: "Soft Hadron Production in QCD Jets," July 20, 1982

Dr. B. Zumino, University of California, Berkeley: "Spontaneous Breaking of Supersymmetry," July 27, 1982

Dr. D. Weingarten, Indiana University: "Quantum Gravity on the Lattice," August 3, 1982

Dr. D. Pottinger, Glasgow University, U. K.: "Gluon Condensation and Nonlinear QCD Effects," August 5, 1982

Dr. Max Dresden, SUNY, Stony Brook: "The Use (Misuse) of Statistical Concepts in GUTs," August 9, 1982

Dr. Alan Guth, Massachusetts Institute of Technology: "Fluctuations in the New Inflationary Universe," August 12, 1982

Dr. M. Olsson, University of Wisconsin, Madison: "Quarkonia--Spin Independent and Spin Dependent Effects," August 17, 1982

Dr. Tepper Gill, Howard University, Washington, D. C.: "Analytic Factorization of the Square Root Operator and the Question of Proper Time in Relativistic Quantum Mechanics," August 24, 1982

Dr. J. D. Bjorken, Fermilab: "Production of Quark-Gluon Plasma in High Energy Ion-Ion and Nucleon-Nucleon Collisions," August 31, 1982

Dr. S. Nandi, University of Texas, Austin: "Proton Decay in GUTs and SUSYGUTs," September 7, 1982

Dr. N. Deshpande, University of Oregon: "Electric Dipole Moment of the Neutron in Gauge Theories," September 14, 1982

Dr. H. Rubinstein, Weizmann Institute: "Baryons, Three Point Functions, and Chiral Parameters," September 23, 1982

Dr. W. M. Geist, CERN: "Quark and Gluon Jets from the Split Field Magnet Detector at the ISR," September 27, 1982

Dr. A. Gonzalez-Arroyo, University of Madrid/Brookhaven: "The Twisted Eguchi-Kawai Model as a Reduction of Large N Gauge Theories," September 28, 1982

Dr. T. Taylor, University of Warsaw/Fermilab: "Supersymmetric Effective Lagrangians," September 30, 1982

Dr. Neil Craigie, ICTP, Trieste: "What Can One Learn from Spin Physics at Short Distances?" October 5, 1982

Dr. J. Oliensis, Fermilab: "Two Loop Predictions of $M_b/M_{\cong}$ and Heavy Fermion Masses in SU(5)," October 7, 1982

Dr. D. Olive, Imperial College, U.K.: "Strings in Some Grand Unified Theories," October 12, 1982

Dr. A. Sen, Fermilab: "Asymptotic Behavior of the Sudakov Form Factor in QCD," October 14, 1982

Dr. J. Preskill, Harvard University: "Cosmology of the Invisible Axion," October 19, 1982

Dr. Steven Parke, Stanford Linear Accelerator Center: "Excitation of Atoms by Slow Moving Monopoles," October 21, 1982

Dr. J. Bagger, Princeton University: "Coupling the Gauge Invariant Nonlinear Supersymmetric Sigma Model to Supergravity," October 26, 1982

Dr. I. Bars, Yale University: "Structure of Quarks and Leptons," November 2, 1982

Dr. H. E. Montgomery, CERN: "Recent Results in Muon Scattering from the European Muon Collaboration," November 4, 1982

Dr. Mark Bowick, University of Florida, Gainesville: "The Possibility of Fermions with $\Delta I=0$ Mass," November 9, 1982

Dr. L. Durand, University of Wisconsin, Madison/Fermilab: "Why the SVZ Moments Method Works (Or Doesn't Work)" November 16, 1982

Dr. David Politzer, California Institute of Technology: "Soft Pions and Hard Quarks," November 18, 1982

Dr. J. Harvey, Princeton University: "Supersymmetry Breaking in 2+1 Dimensions," November 23, 1982

Dr. C. Hill, Fermilab: "Monopolonium," December 2, 1982

Dr. Minh Tran, Brookhaven National Laboratory: "Updated K-M Matrix Phenomenology," December 7, 1982

Dr. S. Mandelstam, University of California, Berkeley: "Light-Cone Superspace and the Finiteness of the N=4 Model," December 14, 1982

Dr. Ken Lane, Ohio State University: "New Tests for Quark and Lepton Substructure," December 9, 1982

Dr. F. Klinkhamer, University of Leyden: "Lattice Gauge Theory at Finite Temperature," December 21, 1982

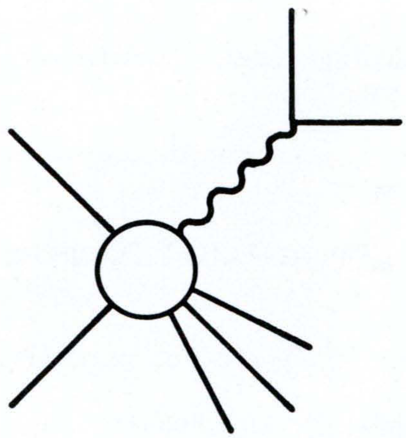
Workshops

Drell-Yan Workshop
October 7-8, 1982

Gas Sampling Calorimeter Workshop
October 28-29, 1982

Workshop on D0 Physics Opportunities
November 9-20, 1982

Tevatron Neutrino Beam Workshop
November 30, 1982



Other

Fermilab Industrial Affiliates Annual Meeting
May 20-21, 1982

Fermilab Users Annual Meeting
April 30, May 1, 1982

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Acknowledgment

Inside Front Cover: Almost completed floor for the 706 ft level of the B0 Experimental Area. When completed, the Fermilab Collider Detector will stand at this level on the right side of the photograph. The exposed accelerator tunnel is in the upper left quadrant of the photo.

Frontispiece: Setting reinforcing bar for the floor of the B0 Experimental Area. The exposed accelerator tunnel is visible in the upper right.

Page 84: Leon Lederman
(Photograph by Mark Godfrey, National Geographic Society)

Page 107: Setting reinforcing bar for the wall of the B0 Experimental Area.

Inside Back Cover: Pouring concrete for the floor of the B0 Experimental Area. The concrete is being transported by a conveyor belt system called a "Creeter Crane."

Photography in this report was done by the Fermilab Photo Unit