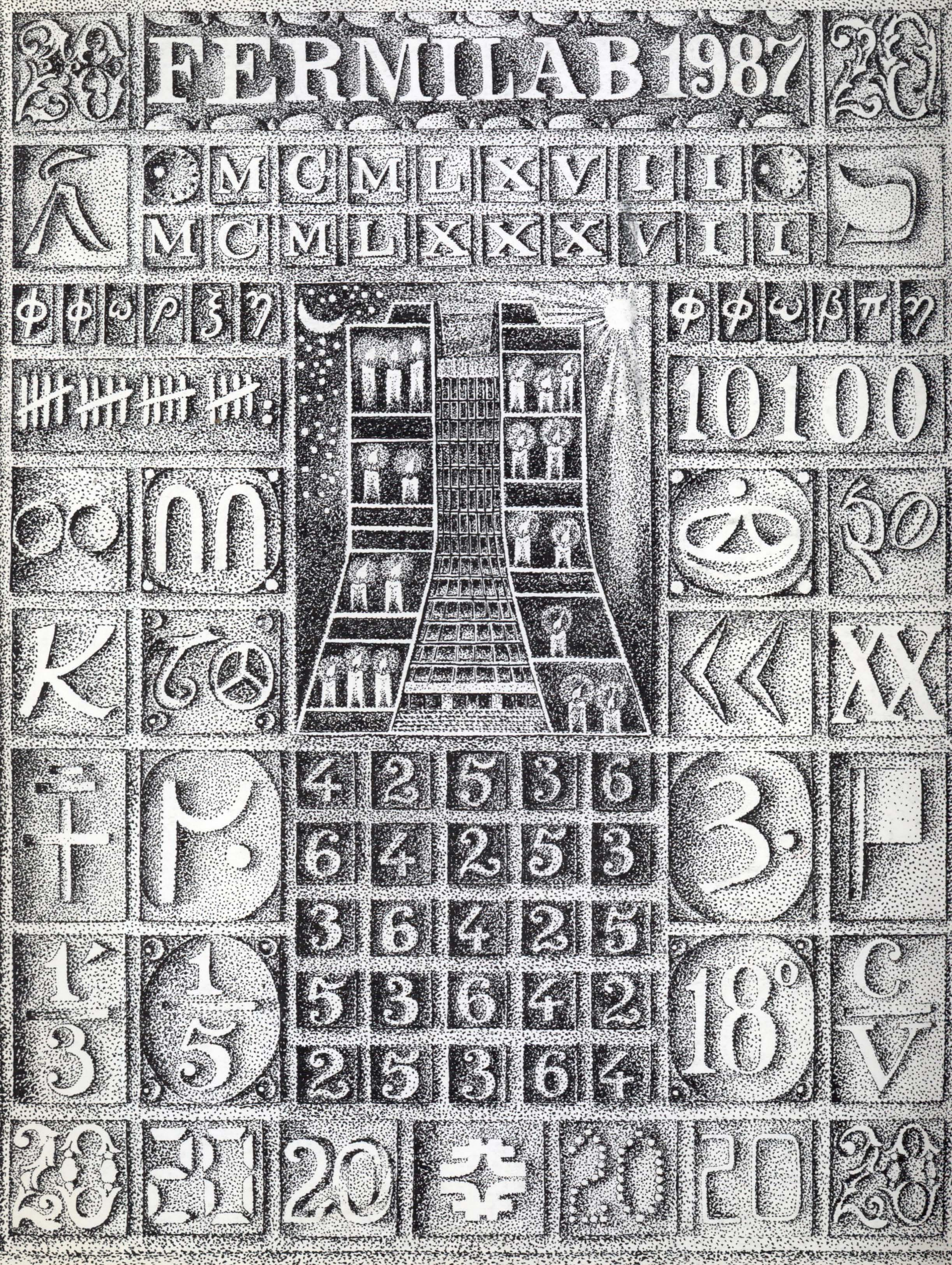
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Fermilab 1987

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

UNIVERSITIES RESEARCH ASSOCIATION

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(202) 293-1382

February 15, 1988

Dr. Leon Lederman
Director
Fermi National Accelerator Laboratory
Batavia, Illinois 60510

Dear Dr. Lederman:

Congratulations on a superb year at Fermilab. The first production runs of the p-pbar collider and an excellent fixed target run mark the first sustained physics experimentation in the TEV energy region ever undertaken. Fermilab is again the highest energy accelerator facility in the world and will be extremely productive in the years ahead. By operating the world's first superconducting high energy proton synchrotron, Fermilab has also pioneered the technology of the next generation of high energy accelerators, and has done so with superior technical success. By participating in the research and development program for the SSC dipole magnet, we are assuring the transfer of this technology to the next generation of large accelerators and to industry.

Universities Research Association is proud to be the operator of Fermilab. We shall continue to emphasize the university-based nature of high energy physics, to work with the Department of Energy to keep this most fundamental of all scientific fields healthy, and to keep Fermilab at the forefront of these activities.

Sincerely,

Edward A. Knapp

Edward A. Knapp
President

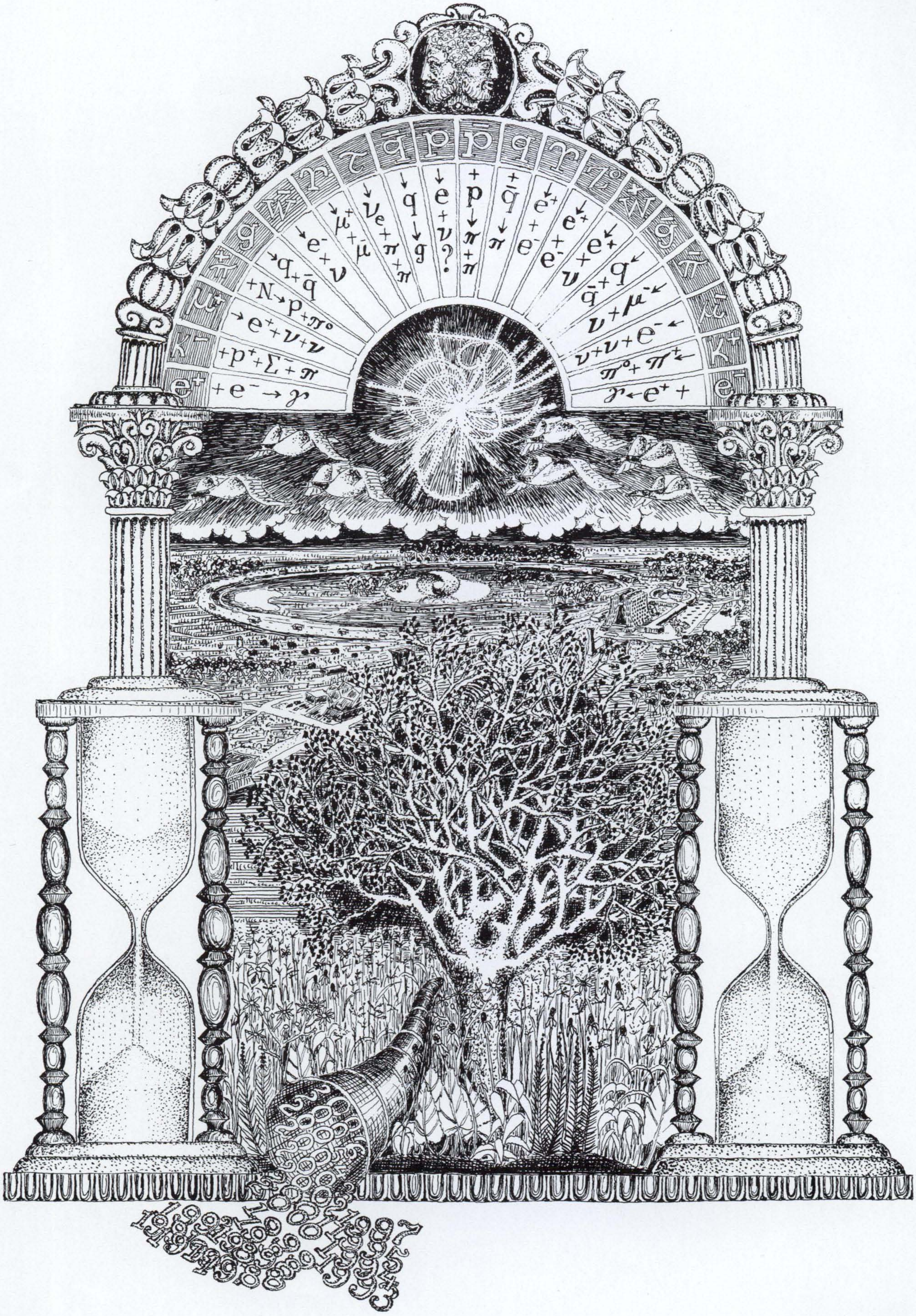

MONDAY, JUNE 1,'87
MEETING AT AO, OPPOSITE
WILSON HALL AT 7:00 A.M.
9TH ANNUAL SLOW
RUN WITH THE DIRECTOR
ANYONE WHO FINISHES
IS INVITED TO A FREE
BREAKFAST IN
CAFETERIA

Table of Contents

Outside the Tomb of Chien Lung

There is a collage of ruins in my head
From rummaging rubble where too many Caesars bled,
Are buried, gained or lost the spoiils of war.
Bits and pieces on the ground. Bits and pieces I have found
And try to remember where it was before.
Seyeste? Monte Alba, say?
Chichen Itza or the long white road of Ephesus?
O! I have swept a hundred streets,
Old courtyards from whence all but guides have fled,
Paestum's temples or among Cervetri's dead,
Cyclopean walls, Persepolis' halls,
- Time's corridors have echoed to my tread.
And now, again, where Emperors lie
I seek a Dragon's Pearl, a Pheonix Eye.

- Jane Wilson



I. The State of the Laboratory

This Annual Report for 1987 is part of what will be the Twentieth Anniversary of the Fermi National Accelerator Laboratory. Thanks to the fuzziness of history, we can extend the celebration from the authorization of the 200-BeV Accelerator, in February 1967, to the occupation of the Batavia site in December 1968. To begin this celebration, we have leavened this report of our 1987 year with a series of Homeric recollections including one Lab Director, one Atomic Energy Commission (AEC) Chairman, one Universities Research Association (URA) President, and one licensed historian. This compilation makes fascinating reading and records a notable event in the history of science. Its relevance to the ongoing saga of the Superconducting Super Collider (SSC) is also clear.

Not that 1987 needs leavening. It is the "Year of the TEVATRON," the first year in which the accumulated visions and labor of the Laboratory came to full fruition. On January 3, 1987, the Accelerator Division began to deliver antiproton-proton collisions to the Collider Detector at Fermilab (CDF) at a total energy of 1800 GeV. The run, described in detail in the CDF and Accelerator Division stories that follow, ended May 11 with a very respectable accumulation of 70 nb^{-1} or, with less jargon, over 100 million head-on collisions being observed by the 4000-ton "Swiss watch" particle detector which surrounded the interaction point in the BZERO collision hall. Three other Collider experiments also took data during the run. And the Antiproton (Pbar) Source went through its paces as one of the most sophisticated examples of accelerator ballet ever choreographed. And it broke records in its debut, records for energy and pbar accumulation rates. Achieving over 10% of the design luminosity in a first run is no small accomplishment as our colleague-competitors at CERN have graciously admitted.

On June 1 we began extraction to the fixed-target areas to continue the program which had its first long run at 800 GeV in 1985. This run had terminated in August '85 in order to make way for a pbar test and one year's worth of final TEVATRON construction. We then had almost two years of work on targeting, new beamlines, and new experiments which are reviewed below by Roger Dixon. As of January 1988, the run is reasonably successful, and we have been in operation for the entire calendar year - a kind of 20-year record.

The decision to operate the Accelerator and the Laboratory for the acquisition of physics data as the single highest priority was made in the fairly gloomy fall of 1986 when the FY87 budget numbers were known to us. In the fishbowl of HEPAP, Department of Energy (DOE) reviews, PAC, URA, etc., this decision was universally applauded. And operate we did, even though the cost to almost all other activities in the Laboratory was major: cancellation of prior approved experiments (the entire prompt

"Antiquities, or remnants of history, are 'Like the planks of a shipwreck': when industrious persons, by an exact and scrupulous diligence and observation, out of monuments, names, words, private records and evidences, fragments of stories. . .do save and recover somewhat from the deluge of time." - Sir Francis Bacon, Advancement of Learning, Second Book

neutrino program), delays in the completion of upcoming research, including the DZERO collider detector (see Paul Grannis' report), deferred maintenance, reduction in spare parts at all levels, a layoff (the first ever) of 50 staff members and a hiring freeze which resulted in a further decrease of about 40, and a slowdown of our efforts to upgrade the Collider. We also incurred the righteous wrath of the DOE by dipping further into our forward financing (GSO) in order not to have to shut down as our funds ran out shortly before the fiscal year. But we did take data!

History will judge whether the decision was correct. What are, incidentally, the criteria for a successful science policy decision? Clearly, important physics data is high on the list. Judgment here will take a few years. However, these are curious times with the Superconducting Super Collider looming and its overpowering influence seeming to complicate the scene. The consensus for proceeding with SSC has never been stronger. The support of the President was crucial, and it is now institutionalized in the DOE. Yet, sensible science policy has it that the TEVATRON, the highest energy accelerator in the world, built at a total cost, including R&D and equipment component, of over $400 million, be exploited to help keep U.S. high-energy physics and its practitioners in the field until the late 1990s. Hence, the anguish of the Laboratory and the menace to our noble purpose: pitfalls, shoals, the need to steer between Scylla and Charybdis, between the rock and the hard place, a Hobson's choice of all-out data taking versus prudent retrenchment and preservation of capability. . .

What else happened in 1987? The success of our investment in the Advanced Computer Program (ACP) is clear in 1987. What would we have done without it? The details are in Tom Nash's understated piece where the growth potential gives glimpses of a major advance in this form of parallel architecture. The responsibility to revive the R&D for this next phase is heavy indeed. Part of our long-range burden of caring for this child of our intellectual fertility may have been lifted by the recent announcement that Big Blue, none other than IBM, is now committed to commercializing the kind of parallel architecture which ACP demonstrated.

The successes of the fixed-target program continued to emerge in 1987 as the analysis of experiments proceeded. In the accompanying chart (Table 1), we list all the currently approved experiments. For each of these we give the date of approval by our Physics Advisory Committee (PAC). One sees a startling fact: From time of conception to completion of data taking now averages almost five years. Add a year or two for analysis and the year or so it took to win approval and we see a significant fraction of one's scientific lifetime going into one fixed-target experiment. Collider experiments are obviously longer. The saving grace to this sociological disaster is that students often don't join the research at its beginning; also, as we head towards ever larger and more sophisticated installations, the second and third generation usage tends to improve the turnaround time. Nevertheless, as we approach an all-collider, SSC-scale community, we must creatively rethink the experience we want to give our graduate students and postdocs. Incidentally, more felicitous funding could probably have reduced the time between proposal and data taking by one to two years.

Table 1
Currently Approved Fermilab Experiments

Fixed Target

Electroweak		Date Approved	
E-632	(Morrison/ Peters)	6/82†	Wide Band Neutrinos in the 15-Ft. Bubble Chamber (16/84)
E-665	(Montgomery)	7/81†	Muon Scattering with Hadron Detection (13/79)
E-733	(Brock)	11/83†	Neutrino Interactions with Quad Triplet Beam (4/26)
E-745	(Kitagaki)	12/83†	Neutrino Physics with Quad Triplet Beam (10/43)
E-770	(Smith)	12/85	Neutrino Physics with Quad Triplet Beam (4/28)
E-782	(Kitagaki)	7/87	Muon Scattering with Tohoku Bubble Chamber (7/33)
Decays and CP			
T-721	(Rosen)	3/84	CP Violation (8/44)
E-731	(Winstein)	7/83†	Measurement of ε'/ε (5/27)
E-756	(Luk)	6/85	Ω^- Magnetic Moment (4/16)
E-761	(Vorobyov)	6/85	Hyperon Radiative Decay (6/16)
E-773	(Gollin)	7/86	Phase Difference Between η_{00} and η_{+-} (4/12)
E-774	(Crisler)	12/86	Electron Beam Dump Particle Search (4/7)
Heavy Quarks			
E-653	(Reay)	7/81†	Hadronic Production of Charm and B (19/79)
E-687	(Butler)	7/81†	Photoproduction of Charm and B (8/58)
E-690	(Knapp)	7/81†	Hadronic Production of Charm and B (5/21)
E-705	(Cox)	12/81†	Charmonium and Direct Photon Production (8/47)
E-760	(Cester)	6/85	Charmonium States (7/59)
E-769	(Appel)	12/85	Pion and Kaon Production of Charm (8/25)
E-771	(Cox)	4/87	Beauty Production by Protons (9/68)

Table 1 continued

Hard Collisions and QCD

E-672	(Zieminski)	7/81†	High PT Jets and High Mass Dimuons (7/28)
E-683	(Corcoran)	12/83†	Photoproduction of Jets (9/33)
E-704	(Yokosawa)	12/81†	Experiments with a Polarized Beam (16/50)
E-706	(Slattery)	12/81†	Direct Photon Production (9/75)
E-711	(Levinthal)	7/83†	Constituent Scattering (3/23)
E-772	(Moss)	7/86	Nuclear Antiquark Structure Functions (9/26)
			Collider
E-710	(Orear/ Rubinstein)	6/82†	Total Cross Section (6/18)
E-713	(Price)	6/82†	Highly Ionizing Particles (2/3)
E-735	(Gutay)	12/83†	Search for Quark Gluon Phase (7/52)
E-740	(Grannis)	2/84	D0 Detector (20/124)
E-741/ E-775	(Schwitters/ Tollestrup)	4/82†	Collider Detector at Fermilab (20/247)
			Others
E-466	(Porile)	3/76	Nuclear Fragments (3/7)
E-754	(Sun)	11/84	Channeling Tests (4/8)
T-755	(Majka/ Slaughter)	11/86	Streamer Chamber Tests (2/10)
E-776	(Baker)	1/87	Nuclear Calibration Cross Sections (3/7)
E-777	(McCaslin)	1/87	Neutron Flux Measurements in the TEVATRON Tunnel (3/9)
E-778	(Edwards)	12/86	Study of SSC Magnet Aperture Criterion (5/15)
E-790	(Sciulli)		Zeus Calorimeter Module Tests (7/?)

Note: E = Experiment, T = Test. Numbers in parentheses denote total number of institutions and physicists, respectively. † indicates approved more than four years ago.

In the second chart (Table 2), we present our pride and joy, the source of our torment and satisfaction, the embodiment of our successes and failures, our users. This is about 50% of the U.S. physics community and about 20% of the world community, assuming high-energy physicists are under-represented among the Eskimos, and Papuans, and residents of Peoria.

Table 2
Demographics of Fermilab Users - 1987

	Ph.D.	G.S.	Total
Collider			
U.S.:	310	92	402
Foreign:	66	22	88
	376	114	490
Fixed Target			
U.S.:	427	207	634
Foreign:	249	52	301
	676	259	935

Note: Some experimenters are participants on both Collider and fixed-target experiments. Below, we eliminate all duplication.

	Ph.D.	G.S.	Total
All approved incomplete exps.			
U.S.:	666	294	960
Foreign:	310	74	384
	976	368	1344

	U.S.	Foreign	Total
Institutions	79	62	141

(Seventeen foreign countries are currently participating in Fermilab research.)

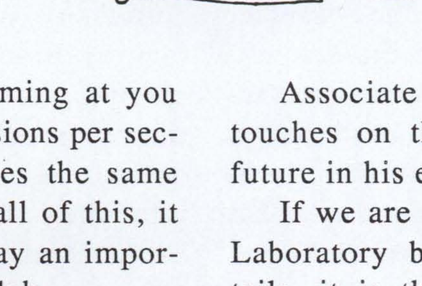
We note that at the last DOE census, there were 2100 U.S. high-energy physics experimentalists (including graduate students). Thus, Fermilab services about 50% of the U.S. users and 10-15% of all foreign (Europe + Japan) users.

Experiment 691, photoproduction of particles containing the charmed quark, continued to dominate the field with its qualitative and quantitative increase in data on the properties of this exotic form of matter. A beautiful CERN CP-violation experiment served to underline E-731 as an experiment whose 1985 results were impressive but whose 1987 run will provide the precision to either confirm or rebut the CERN indication of a finite (3 standard deviations) ε'/ε parameter. The instrumentation of E-691, silicon microvertex detectors and ACP data crunching, constitutes a clear road towards the heaviest known quark, the beauty (b-) quark. In 1987 we learned that particles composed of b-quarks, as seen in the DESY (Hamburg) e^+e^- colliders, promise a splendid harvest of physical data to anyone who can collect a few tens of millions of the "B-mesons," i.e., mesons containing the b-quark. So promising is this field that extensive workshops in Europe, at SLAC, and at Fermilab have been held and "B-FACTORIES" at a cost of hundreds of millions have been proposed. The current situation is as follows: Some few hundred thousands of events containing b-quarks have been collected in the e^+e^- machines, most notably at Cornell and DESY. Whereas production in hadron (pp, πp, $\bar{p}$p) collisions is expected to be thousands of times more prolific, virtually nothing has yet been observed. Backgrounds!

Fermilab has two options for getting into this field. The pbar Collider offers the possibility of generating something like 10^9 $B\bar{B}$ pairs per year. A special detector optimized for B-meson detection is very likely needed. Also, an increase in luminosity is needed so that one can indeed acquire this much data in a reasonable run. The technical problems of acceptance, backgrounds, efficiencies, etc., are formidable and the Laboratory has encouraged the proponents in their plan of detailed "thinking" for a year. The policy problem these proposals raise has to do with space and schedule. Do we create another (smaller) interaction hall at, say, AZERO? This would imply a shutdown of at least six months, something we could not contemplate for another three years or so. The alternative is to have the B-detector go into the CDF hall after two or three exposures. This could come about when CDF was undergoing modernization.

The other option is the fixed-target program where the almost unlimited luminosity creates 10^7 B-mesons every minute! When realistic (?) factors are put in, it is in fact thinkable to acquire some 10^8 $B\bar{B}$ events in a "year" (10^6 sec) run. The background is now over 10^6 irrelevant and, hence, distracting collisions per produced B and the burden on technology is fierce. However, if we take an SSC-like rate of 10^8 collisions per second, one could have a go at 10^8 B-events. Ingenuity, luck, technology, etc., could even increase this, without violating any known law of physics, to 10^{11} or 10^{12}! Today there are several experiments (e.g., E-705 [771], E-687, E-706, and E-605) that have the capability of collecting ~100-1000 B's in the next year. This will be good learning experience. The silicon-ACP technology smells good. When we combine this with the ongoing philosophy of data-driven architecture such as is exemplified by E-690, one begins to see an evolution of the breakthrough achieved by the E-691 collaboration. After all, SSC physics assumes that one can read signatures of new physics at the level of 1 event in 10^{10} collisions, each spewing a hundred or so charged par-

The descending serpent of light at El Castillo, Chichén Itza, Yucatan, Mexico.



ticles in all directions and coming at you with a rate of 100-million collisions per second. The B-program addresses the same issues. It must work! From all of this, it is clear that B-physics will play an important role in the future of Fermilab.

Associate Director James Bjorken touches on this and other aspects of the future in his essay below.

If we are to summarize the State of the Laboratory before proceeding to the details, it is that we have come through a long period (1979-1986) of construction, and in 1987, we have emerged into a phase of operation for research in particle physics. One doesn't turn a construction-driven staff into an operating staff at the click of a toggle switch. There is an ethic involved, a collective state of mind, a habit. The evidence of change is everywhere: Fermilab physicists are running shifts on their experiments, users' requests are taken seriously, and even the most recalcitrant of our detractors have been seen trying to suppress a smile.

What we have to do is finish the D-ZERO detector which will add the essential component to the exploitation of the Collider and, with these two powerful eyes, we have to implement an evolution of the Collider luminosity so as to forage more deeply into the forest of the night. And we must do physics and thereby tend to the postdocs and the graduate students, present and future, many of whom will be the cadres of the SSC era. And we must not neglect the data base of the Standard Model; if this isn't rock solid, reaching for the summit will be a foolish activity, as any mountaineer will attest.

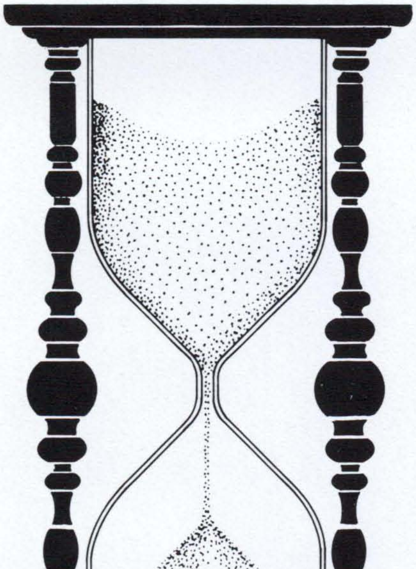
Finally, from time to time the Director sits back and contemplates the entire field which we call High-Energy Physics. Two overwhelming programs dominate all attempts at judgment. One is the SSC, the instigator of more hype than has been generated by science in living memory. But it has brought the subject to an edge - whether it is a precipice or a road to the summit, time will tell. Clearly, the SSC is an instrument essential for progress. There is no other way to adequately address the crucial issues. It is a kind of major miracle that the "Desertron" of Snowmass '82 has progressed to where SSC stands now. Credit goes to scientists and statesmen, bureaucrats and visionaries, Tigners and Trivelpieces. However, it has raised fear and loathing among some of our colleagues in other sciences (this is nothing new), and the DOE has a tremendous responsibility to implement SSC so that we have a scientifically benevolent transition from the pre-SSC to the post-SSC era.

The second program is the Theory of Everything, or Superstrings. Here is an enigma for us earth-bound experimentalists. Our theoretical colleagues are very caught up in this ambitious work. "It is the only game in town," one young theorist proclaimed as he packed his bags and prepared to depart for the Planck Mass. However, one is hard put to recall a time in the history of physics when so many worked so long for so little contact with observation.

One sees a very lively effort in the lattice gauge QCD, in perturbative QCD, certainly in heavy quark phenomenology. But what about Grand Unification and all of its tounge-twisting versions? Where are the prequark, SUSY, and technipion proponents? The obligation to provide new and illuminating data for our deeply troubled theoretical colleagues has never been more pressing.

As this *Annual Report* went to press we learned of the death of I. I. Rabi at age 89. Rabi was an architect of modern American physics. Researcher and teacher, Rabi was a creator of the great period at Columbia University, a founder of our sister laboratory at Brookhaven, an instigator of the creation of CERN, a veteran of the wartime exploits in radar and the atomic bomb, and of the post-war efforts to install rationality into national science policy. Those of us who were graced by his friendship and guidance will long remember his street-wise vision and his unquenchable disrespect for dogma and authority. I know that Rabi felt good about Fermilab, his talk here in 1983 was an electrifying experience, and I close this with a quote from his essay entitled "The Physicist and Physics" (I. I. Rabi, *Science - The Center of Culture*, [World Publishing Co., New York and Cleveland, 1970] p. 1):

> "In the study of natural phenomena, man is a very nearsighted creature, and even the most profound and original man can see but a very short distance. [Science] is a great adventure where close study, patience, intuition, and luck each play a part. It is the last frontier left to the free spirit of man in a crowded world."



James D. Bjorken's towering stature, in theoretical physics *and* among his 5′ 10″ colleagues, ranks him also as one of the nation's leading futurists. It is clearly appropriate to ask him from time to time about the future of Fermilab. We know what the previous 20 years were like, how about. . .

The Next Twenty Years for Fermilab

James D. Bjorken

Twenty years? Out of sight! Twenty years ago there were only fragments of the Standard Model, no superconducting magnets, no Fermilab emergent from the Illinois corn. Could we have imagined then where we are now? No Way.

Even though the task is hopeless, Leon asked me to look into a crystal ball and give it my all. So here goes.

1. *The next 20 years will be even harder than the first 20:*

Extreme austerity is a Fermilab tradition. Especially from this year's view-point, it is hard to see a change for the better. Of course, most everything depends upon the fate of the Superconducting Super Collider. If the SSC does come to Fermilab, the 20-year plan is assured - at least for the new machine and its ancillary facilities. But it is not so for the present research program and its extensions, which will be put under great stress. It will be the #2 project - so try harder, everyone! If, perish the thought, the SSC lands elsewhere, there will be the same situation in spades, with even less personpower and money to support the program. So how to survive? There is one and only one way - by good physics: good experiments carried out by imaginative and talented physicists. I firmly believe that good ideas get good support and that Fermilab's future depends most of all on new, innovative, sound ideas.

2. *Yes, there is a lot of identifiable, excellent physics left for Fermilab to do:*

The experiments now on the floor have, in general, a lot of longevity. But on a 20-year time scale, it is obvious then that they are not enough. To identify now the new ideas which will appear ten years from now is a contradiction in terms. But some of the old ideas may reappear in a new guise. What follows should be only a pale imitation of what will - or ought to - occur:

• *Extensions of the great discoveries of CDF and D0*

The new physics which the Collider experiments uncover will invite exploitation. This can go in two directions - into improvements in the detectors and into upgrades of luminosity. These will put a heavy burden both on experimental groups and the accelerator physicists.

• *New Collider experiments for new scientific goals*

We already see an example in the enthusiasm for a new Collider experiment to look at hadrons containing the fifth (bottom or beauty) quark. The TEVATRON Collider is an especially copious source of bottom-quarks and the ultimate prize is the observation of CP violation in bottom-quark decays.

• *New major fixed-target experiments for heavy-flavor physics*

It is also an attractive possibility to do bottom-quark physics in the fixed-target environment. But to remain competitive in the long run may well require a high-quality, high-rate spectrometer of a scale and complexity comparable to the largest collider detectors. This implies a very large experimental collaboration, something uncommon for the sociology of fixed-target experimentation. Twenty years may be just enough for the necessary social changes to occur.

Charm physics in fixed-target experiments already has accomplished much and has a promising long-range future. It is very hard to project where the ultimate limitations may lie. It may simply be the stamina of those engaged in the experimentation.

• *New directions in neutrino physics*

The present phase of neutrino experimentation is ending. But this subject may revive. There already is a stirring of interest in a tagged-neutrino beam; in addition there is the, at present dormant, program for observation of the tau neutrino. Much may depend upon what happens elsewhere. If, for example, the hints of neutrino oscillations or other exotic phenomena seen at experiments at Brookhaven firm up, there could be a revival of interest in such experiments at Fermilab's higher energies.

• *Experiments with kaon beams*

The splendid experiments which study CP violation in 2-pion and 3-pion decays of neutral kaons invite follow-on measurements of increased sensitivity. Again, whether to go ahead with what clearly are extremely challenging experiments will depend on the results from the present round. This also applies to the study of rare K-decays, where again results from the present round of experiments at Brookhaven may stimulate initiatives at Fermilab. One should remember that the Main Ring can provide not only a copious supply of antiprotons, but also an even more copious supply of kaons (not to mention neutrinos, muons, etc.), more or less "for free" during Collider running. It may be that this source is worth tapping.

• *An antiproton factory?*

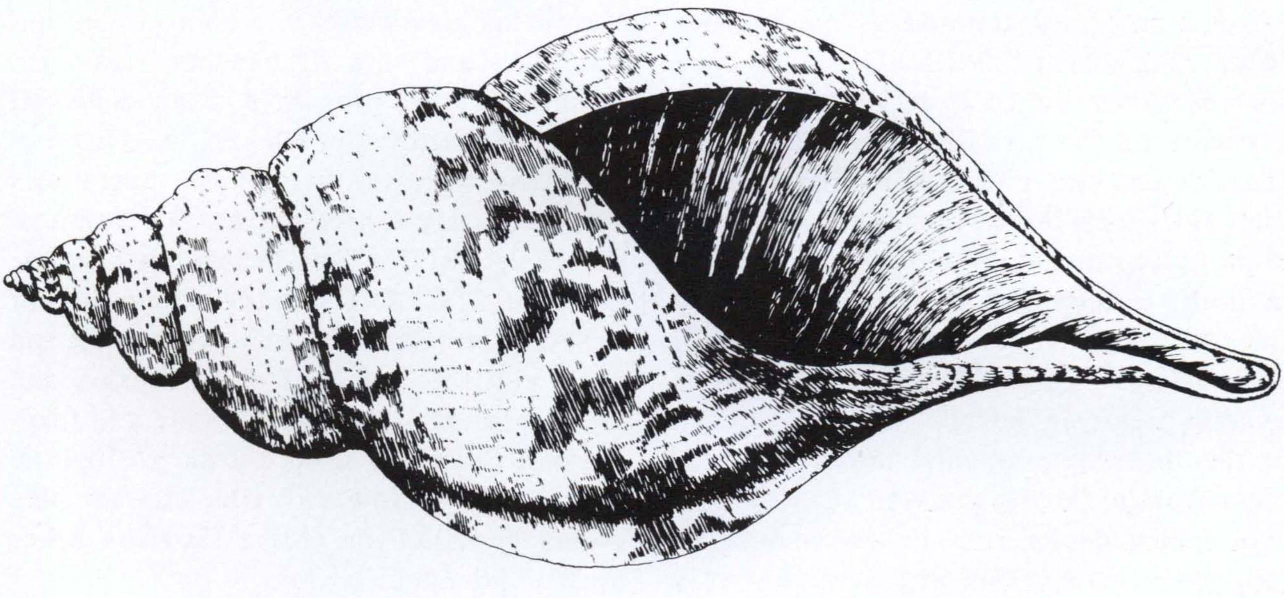
Fermilab is at present the sole U.S. supplier of high-quality antiprotons. There is a lot of interest in creating here a facility similar to the CERN Low Energy Antiproton Ring (LEAR), and the matter is under study by the Laboratory. Everything from CP violation studies to "weighing" the antiproton is accessible in such a facility. Much of the question on whether to go ahead depends on what fraction of this research will already be done by CERN.

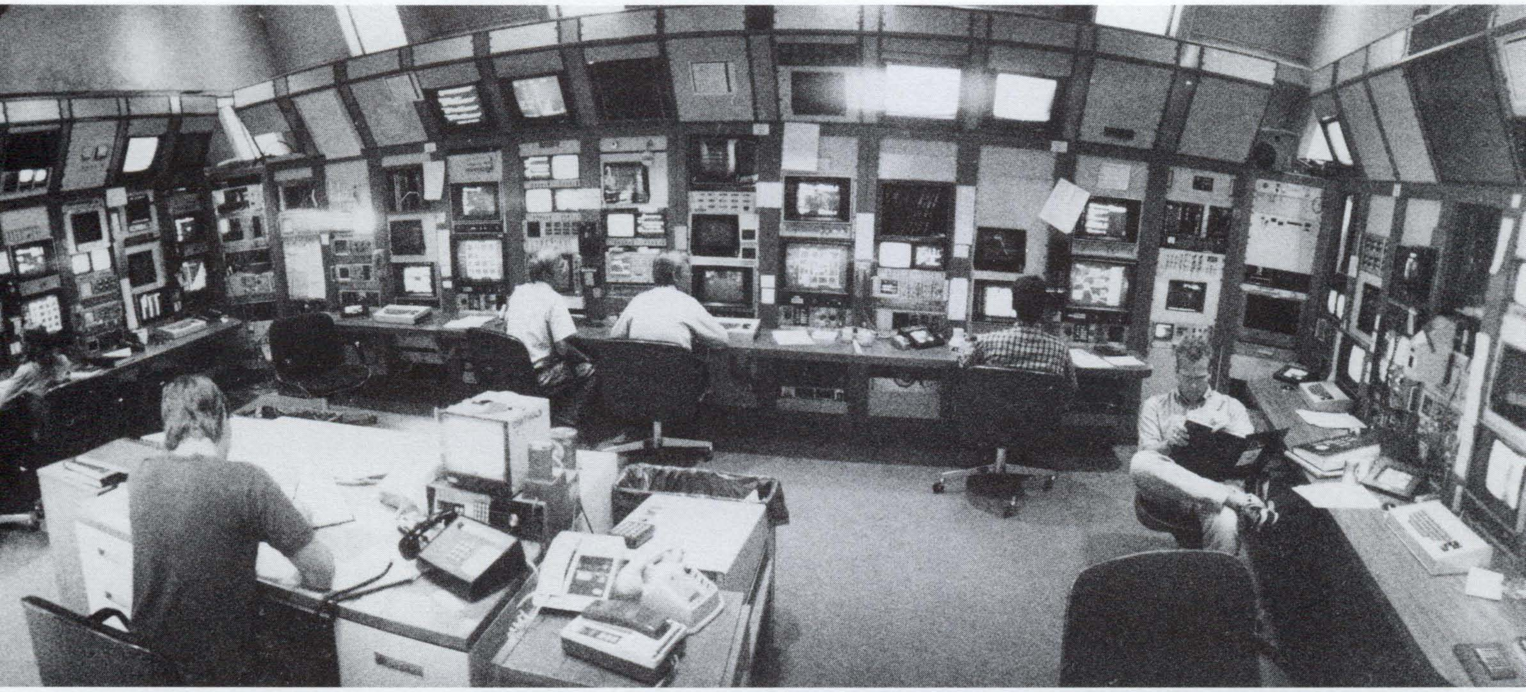
• *Advanced accelerator R&D*

How will we ever achieve proton-proton collisions at energies far beyond the SSC? Circular machines appear to become very impractical, not only because of problems of real estate and cost but also because of the heavy dose of synchrotron radiation emitted by the circulating protons. High-gradient linear accelerators *for protons* need to be developed. If 100-TeV x 100-TeV pp collisions in a reasonable size machine (say 100+100 km) is ever attainable, then a 5-TeV linac fits easily on the Fermilab site. To build any pp linear collider is extraordinarily demanding: millimeter bunch lengths, sub-sub-micron beam sizes, and luminosity large compared to the SSC luminosity will be demanded. But a first step can be much more modest. If, out of 10^{13} TEVATRON protons injected into a prototype linac, one could accelerate 10^7 of them to a few TeV, even with poor beam quality by Collider standards, one could do excellent fixed-target physics with the output. It seems to me such a goal is thinkable - and now is not too soon to start thinking about it.

3. *Yes, Fermilab (minus the SSC) has a long-range scientific future:*

But there are the big question marks. The Laboratory will require the very best ideas put forward most forcefully. It will require strong support from the national high-energy physics community and the government, even in the presence of the SSC. Given the investment and the accomplishments of this Laboratory, I think Fermilab will deserve that support.





A panoramic view of the main control room. The relative calm is deceiving.

The Accelerator Division

The Accelerator Division is under the able leadership of Helen Edwards who honored us all by winning the 1986 E. O. Lawrence Award, given by DOE in recognition of her work on the SAVER. The tasks of the Division are very straightforward: operate the Cockcroft-Walton, Linac, Booster, Main Ring, and TEVATRON with good reliability, keep improving the intensity (the 1987 objective is to touch 2×10^{13} ppp) and quality, organize the Switchyard so as to send precisely defined fractions to each of the three experimental areas, organize the spill structure so that one has a smooth and level intensity over the 20-second flattop, and punctuate this with numerous very short (~1 ms) pings to the Neutrino areas. After six or eight months of this, switch over to Collider operation where now the Main Ring also works as a pbar-production machine, and the Debuncher and Accumulator rings do their thing with all those pbars, etc., etc. Oh yes, the Division must also work on the Collider upgrade, a very necessary ingredient for the future of the TEVATRON. This leaves lots of spare time for SSC R&D studies, operation of the Neutron (Cancer) Therapy Facility, and help with the Loma Linda medical accelerator project as well as the care and feeding of DZERO. It is not too surprising that Helen has no time to write, but her able colleagues pitch in. Mike Harrison heads up the Main Accelerator.

The Main Accelerator

Michael Harrison

This past year witnessed the start of the colliding-beams era in the TEVATRON. In contrast to 1986, which was spent performing major modifications to the Main Accelerator complex, 1987 saw almost continuous operation of the Main Ring and the TEVATRON in both the fixed-target and colliding-beams modes.

The last issue of the *Annual Report* left the reader in a state of great anticipation with the commissioning of the Collider just beginning. We shall pick up the story from there.

The first few days in January were spent tuning up the complex transfer process from the Accumulator through the Main Ring to the TEVATRON by running protons backwards through the pbar transfer lines. The first attempts at transfers using pbars took place on January 11, and two days later pbars were successfully accelerated in the TEVATRON to 900 GeV and squeezed to the required small spot size at the B0 collision region. The rest of the month was spent wrestling with cryogenics, power supplies, and the various subsystems to improve the reliability of the beam storage. Pbar "shots" were taken as often as possible while we learned how to increase the reliability and efficiency of

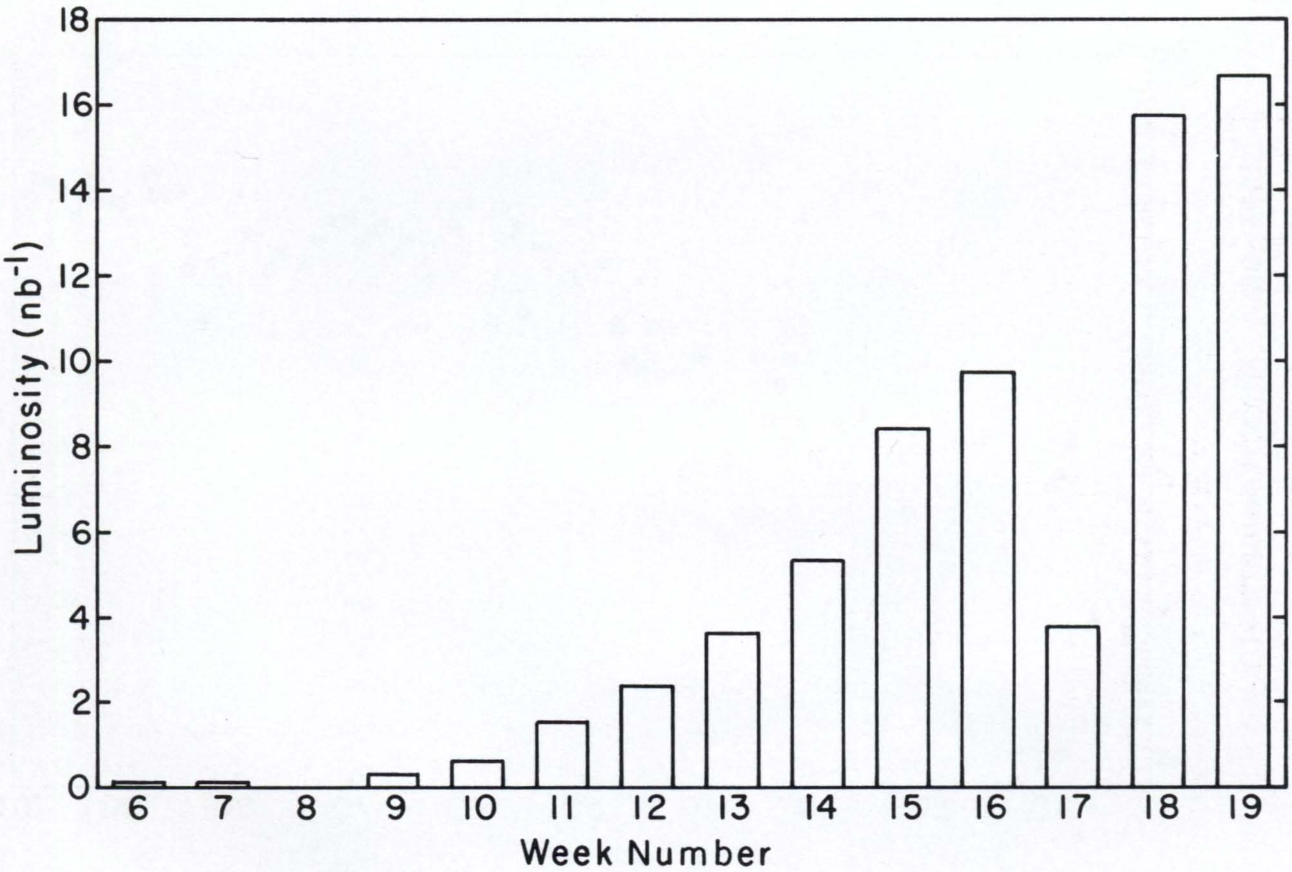


Figure 1. TEVATRON integrated luminosity per week since February 2, 1987.

the transfers. Indeed, the main accelerator control room during the build up to a shot was rumored to be the best show in town, and spectators from as far away as the Director's Office were frequently to be seen enjoying the suspense of the countdown.

The first 24-hour store took place on February 6, but this was closely followed by the failure of a TEVATRON magnet and activities were halted for 10 days while the offending element was replaced. Nevertheless, by the end of February the design operating condition of three proton bunches colliding with three pbar ones was seen for the first time, and the CDF detector started to observe significant numbers of collisions. The champagne flowed on March 11 when the first milestone luminosity of 10^{28} cm^{-2}sec^{-1} was achieved; the transfer efficiencies of pbars from the Accumulator core to high-energy collisions in the TEVATRON exceeded 20% during this period. The run continued into April, and the luminosity continued to rise; the running time at this point was more or less equally divided between accelerator studies to improve the machine performance and CDF data taking. This mode of operation continued until mid-April when the peak luminosity reached 10^{29}, and the decision was taken to switch to full-time collisions for the remainder of the run. The run ended on May 11 after reaching an integrated luminosity of ~70 nanobarns^{-1}, most of which came in the last few weeks (Figs. 1 & 2). This most promising start to the Collider program was anchored by the noteworthy performances of the Pbar Source and the Main Ring. The Source was invariably able to supply pbars on demand, and the Main

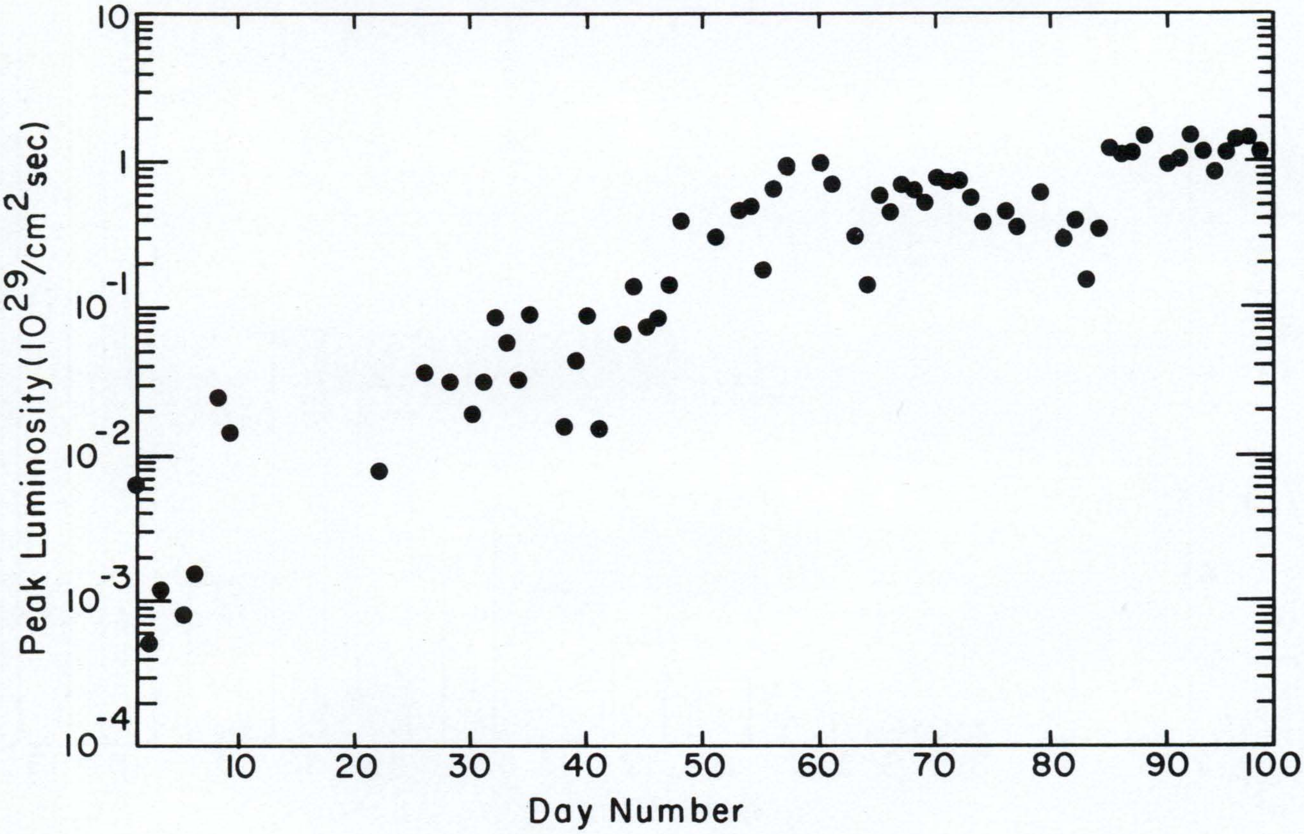


Figure 2. TEVATRON peak luminosity per day since February 2, 1987.

Ring, which was continuously accelerating protons to 120 GeV to make new pbars, achieved a 2.4 s cycle time with an intensity of $\sim 1.4*10^{12}$ ppp.

After a three-week shutdown for SSC studies and to remove the CDF detector, the machine operation was switched to fixed-target running, and the first extracted beams were seen in the Switchyard on June 8. The proton intensity increased steadily during the first 12 weeks of running at which point the first of a series of superconducting-magnet failures occurred. We have experienced six such magnet failures since then which have been due to either vacuum leaks in the cryostat or voltage breakdown in the ends of the magnets. Since it takes six days to replace a TEVATRON magnet, these failures have been a significant disruption to the machine operation. The lead failures, which are aggravated by the constant ramping of fixed-target operation, appear to be confined to a particular subset of the magnets. We are planning to examine and repair damaged leads during the shutdown before the next Collider run. The maximum intensity achieved to date in the fixed-target mode is $\sim 1.7*10^{13}$, the integrated number of protons delivered to the experimental areas are shown in Fig. 3.

Design work continued throughout 1987 on the luminosity upgrade project. This scheme to increase the Collider luminosity to $5*10^{31}$ $cm^{-2}sec^{-1}$ requires many bunches (~100) of protons and pbars coming into collision only at the experimental locations and separating into non-intersecting spiral orbits around the rest of the ring. The beam dynamics of spiral orbits pose complex problems of injection, stability, and lifetime (amongst other things), and work is under way to examine these effects both theoretically and experimentally. A machine lattice incorporating two matched collision regions with space for electrostatic beam separators has been completed.

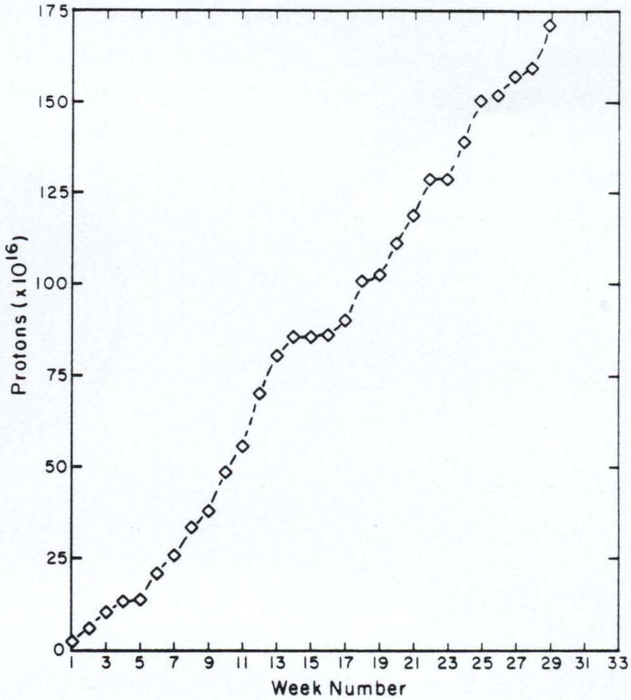
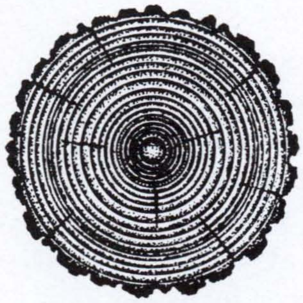


Figure 3. TEVATRON integrated intensity at 800 GeV for fixed-target operation.

On a more immediate time frame, a modification to the D0 overpass in the Main Ring will be completed shortly. This will minimize the effect of the existing overpass regions on the Main Ring performance while at the same time improve the transfer matching between the TEVATRON and the Main Ring.

Other topics covered in the accelerator studies involved the low-energy behavior of the Main Ring, Main Ring performance at 20 GeV, machine aperture limitations, beam-lifetime effects, the generation of single high-intensity bunches from several low-intensity ones, and last but not least, an initial study of SSC-related beam dynamics, which involved intentionally degrading the TEVATRON magnetic field quality to produce conditions similar to those expected in the SSC. The 1988 Collider run will hopefully demonstrate how much we have benefited from the activities of 1987.



Gerry Dugan runs the Pbar Source Department and, as such, he is the proprietor of the world's most prolific source of antiprotons. We are not yet informed on the success of the ACOL group, our colleagial friends and competitors at CERN. Gerry and his group have much to be proud of in 1987, but the thing about colliders is that your encores must be much better every year.

The Pbar Source

Gerald Dugan

The year 1987 saw three significant events in the short history of the Fermilab Antiproton Source: the first extended operation for Collider physics, the first work on an experiment in the bowels of the Source itself (E-760), and the first major efforts at improvements beyond the TeV I design.

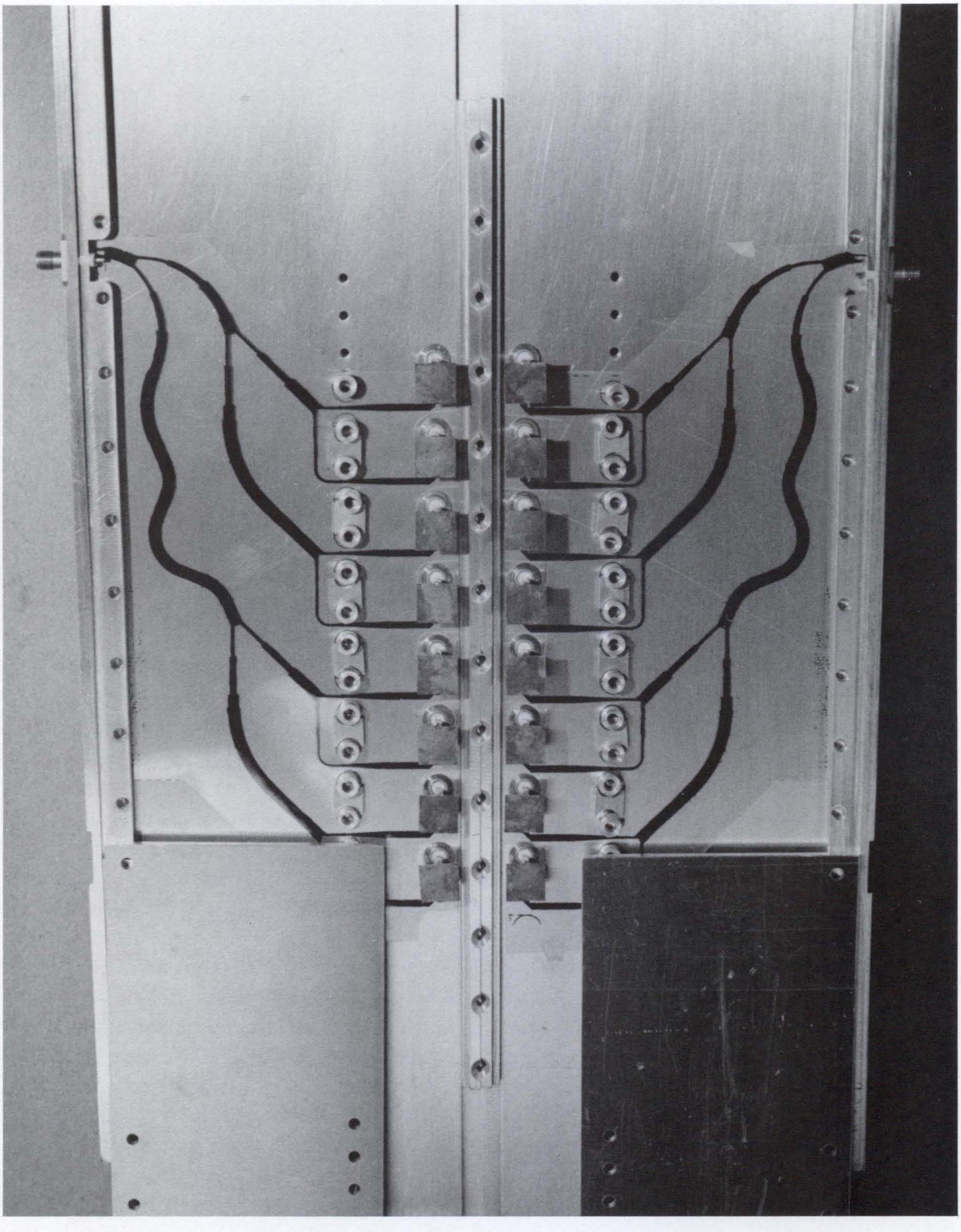
The operational routine during most of the period of Collider operation (January to mid-May) alternated between periods of stacking antiprotons (typically for at least 12 hours) and periods of transferring some fraction of the stored antiproton stack back into the TEVATRON for Collider operation. This latter activity (i.e., the filling of the Collider), was called a "pbar shot." During the periods of antiproton stacking, the Source was operated by the Operations Group, with on-call assistance from staff members of the Pbar Source Department for help with specific problems. Over the 4-1/2 months from January to mid-May, the Pbar Source and Main Accelerator Departments and the Operations Group, working together, made gradual improvements both in the Main Ring operation for pbar production and the efficiency of operation of the Source itself. By April, the efficiency of antiproton production, collection, and storage reached 7×10^{-6} antiprotons stored per 120-GeV proton on target. The maximum rate at which antiprotons were collected reached 1.2×10^{10}/hour during April, exceeding the previous world record held by the CERN AA by almost a factor of two. The peak stored antiproton intensity reached 3.6×10^{11}, a number within 10% of the design intensity of the Accumulator. The excellent operational reliability of the Source was most clearly exemplified by the duration of the periods of continuous operation with a stored antiproton stack. The average duration was 10 days, and the longest period was in excess of 24 days. During the January to May running period, a total of $6x10^{12}$ antiprotons were stacked into the Accumulator core, which corresponds to about 10 picograms of antimatter.

Of course, the antiprotons will not do the TEVATRON Collider much good if they stay in the Pbar Source; thus, equally important to the ability of the Source to collect and store antiprotons is its performance in delivering a high-quality antiproton beam to the Main Ring. The antiproton transfers took place during the pbar shots. During January and February 1987, this activity, which could occur once, twice, or even three times a day, was a highly choreographed cooperative effort of many experts from the Pbar Source and the Main Accelerator departments. It sometimes lasted as long as eight hours. As the run progressed, the duration of the shots decreased, and by late April they had evolved into relatively routine operations in which the Operations Group handled most of the details, with help from the "shot master" physicist and possibly some on-call experts as needed. The quality of the antiproton beam provided by the Source was a crucial determinant of the success or failure of a shot. By late April, in a typical shot, $2\text{-}3x10^{10}$ antiprotons were extracted from the Source and injected into the Main Ring with an injection efficiency of 75-95%. This good performance was the result of hard work by Pbar Source and Main Accelerator department members, working together to understand and optimize the antiproton transfer process.

Before the plans for future improvements to the Source are discussed, it is appropriate to say a few words about the work done for Experiment 760. This experiment intends to collide antiprotons with a hydrogen gas jet in the Accumulator Ring itself, to form and study various charmonium states. It requires deceleration of the antiproton beam from 8.9 GeV/c to momenta in the range of 4 to 6.3 GeV/c; it also requires the installation of a hydrogen gas jet in the Accumulator. This fall, progress was made in both of these areas: Beam deceleration to about 5.5 GeV/c was achieved, with bright prospects for continued progress, and the gas jet was physically installed and operated in the Accumulator. The year 1988 should see further progress on this experiment.

Although the performance of the Pbar Source during this first Collider run was quite good, it is certainly true that there is plenty of room for future improvement. The most obvious area for improvement lies in the stacking rate. Though a world record at $1.2x10^{10}$/hour, it was, nevertheless, a factor of eight below the TeV I design goal. During the spring, summer, and fall of 1987, staff members of the Pbar Source Department developed and started to implement a plan for improving both the stacking rate and the quality of the stored beam in the Accumulator during the next two years. These plans are the first steps in the evolution of the Pbar Source performance to levels adequate to supply the needs of the proposed luminosity upgrade of the TEVATRON Collider.

In the next Collider run, to increase the stacking rate, the Main Ring will operate in the "multi-batch" mode, which requires a shorter cycle period for the Pbar Source. In a test run in October, the Main Ring and the Source were operated in this mode suc-

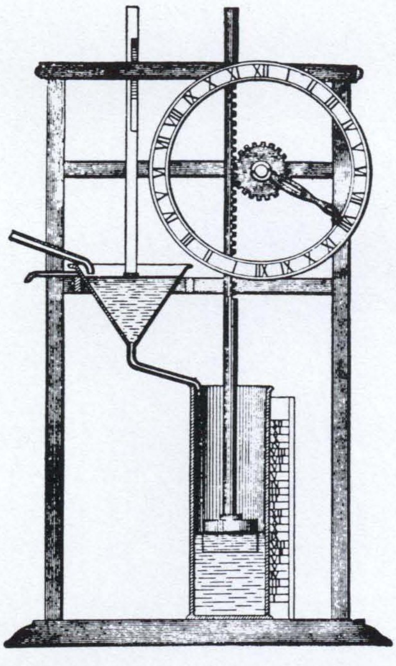


Prototype 4-8GHz pickup array for the Pbar Source. The pickup loop repeat distance is 1 in.

cessfully. Improved performance of the Debuncher fast betatron cooling will be required to cope with the rapid cycle rate, but the installation of an optical notch filter in the system, completed in November, is expected to provide this.

The other major efforts at Source improvements are aimed at the year after next, because of the long lead times for system procurement and development. A major R&D effort to develop a 4-8 GHz stochastic cooling system for the Accumulator core is well under way. This will ultimately result in enhanced quality of the antiproton beam sent to the TEVATRON. Procurement activity was started for further improvements in the Debuncher fast betatron cooling and for increased voltage in the Debuncher rf system, which will increase the number of antiprotons which can be collected. Conceptual design of an upstream pre-focusing lithium lens is in progress; this will reduce the proton spot size on target and further enhance the pbar yield. A plan to increase the Debuncher transverse aperture, also resulting in a larger pbar yield, is under consideration.

The improvement program discussed above is intended to upgrade continuously the capabilities of the Antiproton Source, both in terms of performance and reliability. The year 1987 was a very eventful year for the Source. Nevertheless, the future of the Source, as a crucial operational component of the TEVATRON Collider complex and a pivotal ingredient in its evolution to higher luminosity operation, looks even more exciting.



The Collider Upgrade has been with us almost as long as the Collider. The physics reach of a 1.8-TeV proton-antiproton collision is formidable, extending significantly beyond the 100-GeV domain. However, the reach of an upgraded 2.0-TeV Collider will double the mass domain which can be sensitively explored. The Fermilab Collider, with two complementary and battle-tested detectors, can, in the 1992-1997 period, be a veritable gold mine of new physics. Consistent with our highly biased enthusiasms, we assert that this upgraded facility has by far the greatest potential for changing our view of the microworld of any accelerator now being constructed. Energy (with enough luminosity) has never let us down. Our current and evolving view of some of the needed steps in the upgrade is given by Ernest Malamud, Don Young, and Steve Holmes. This may get a bit technical but can be managed if the reader grips his chair firmly.

The TEVATRON Collider Upgrade

Ernest Malamud

One measure of the efficiency of exploiting the TEVATRON Collider for physics is the number of collisions that occur during a given running period. This number is proportional to the integrated luminosity at each major detector. As the luminosity is raised, the likelihood of detecting collisions of a quark and antiquark which contain large total energy is increased.

If round beams are assumed, the luminosity is approximately inversely proportional to the area of the proton and antiproton beams at the collision point. For a given emittance beam, the transverse beam size can be obtained from the function, β. If β at the intersection point, called β^*, is reduced a factor of two in each plane, the beam size is reduced both horizontally and vertically by $\sqrt{2}$, and a factor of two increase in luminosity is obtained.

The currently installed and successful low-beta insertion at B0 operates at a nominal β^* of 1 m. In fact, during the 1987 run, β^* has been made as low as 70 cm by operating the existing insertion in a "mini-β" mode. There is no low-beta insertion at D0, and one must be constructed for the experimental program in the large detector being built there. At D0 the goal will be to build and install an insertion in time for the first run of the D0 detector that can reach values of $\beta^* < 50$ cm.

β^* can be made smaller by using stronger low-beta quadrupoles or moving them closer to the interaction point. However, the latter approach is limited by the goal of making the detector as hermetic as possible and covering the small angle region where momenta are higher and require more room for particle measurements. As β^* is reduced, the maximum value of the amplitude function, β_{max} increases. It is important that β_{max} not become too large and make a beam admittance restriction that would reduce the lifetime.

A design for the D0 insertion has been made by Tom Collins. This insertion is matched in betatron and momentum space. The matched insertion design can be replicated at other straight sections. The present plan is to do this at B0, replacing the existing insertion, and thus increase the number of collisions per year that the powerful CDF detector can study. The insertions are identical at B0 and D0. The TEVATRON is tuned to (ν_x, ν_y)=(20.58, 20.59) and the beam is squeezed with $\beta_x=\beta_y$ starting from injection values of β=170 cm down to $\beta < 50$ cm.

The insertions being built for D0 and B0 use five pairs of high-current quadrupoles and four high-gradient correctors on either side of the intersection point. The longest quadrupole has a 232-in. magnetic length. The three pairs of quadrupoles bracketing the detector form asymmetric triplet lenses. The elements in the triplet operate at maximum gradients of 1.4 T/cm. This is possible because of significant advances in the current-carrying capability of NbTi superconducting cable over the past few years.

There are two types of high-gradient correctors: In one case, a short two-shell cold-iron quadrupole is coupled to a spool-correction package. In the other type, a 7.5-in. O.D. one-shell quadrupole constructed with "5-in-1" conductor replaces half of the standard spool package.

The inside coil diameter is 3 in., and there is a clear beam aperture of 2.7 in., equal to the horizontal and vertical TEVATRON dipole aperture. The outside of the cold iron is 10.5 in. in diameter. Design and construction of 1-meter-long prototype coils, coil-curing fixtures, coil collars, and collar-assembly tools is nearing completion.

The superconducting cable is woven from .020-in. strand containing 630 filaments, 13 microns in diameter and a copper to superconducting ratio of 1.5:1. It is expected that the NbTi can reach a current density of 3000 A/mm^2 at 4.6° K and 5 T. There are 47 turns per pole in the final two-shell design and 65 turns per pole in the one-shell correctors. The two-shell transfer function is 0.291 T/cm/kA; for the one-shell it is 0.562 T/cm/kA.

The D0 low-beta insertion also requires considerable electrical, cryogenic, and mechanical design and engineering effort. Although the insertion at D0 will be built before the retrofit at B0, an attempt is being made to keep them identical to reduce spares requirements. The innermost quadrupole of the triplet is cantilevered into the collision hall and inserts into the end caps of the major detectors. The CDF detector presents the more restrictive 20-in. square, whereas the constraint at D0 is a 22-in. square. A cryostat design satisfying this constraint has been made. Heat loads have been calculated and a decision made to operate the D0 low-beta quadrupoles on the existing refrigerators in the C4 and D1 service buildings.

The D0 low-beta insertion is mechanically more complex than either the present one at B0 or the retrofit planned for B0. Since the electrostatic septa for extracting the proton beam from the TEVATRON are located at D0, this straight section must be re-configured each time the physics program is switched between fixed-target and Collider mode. Mechanical designs have been made for mounting sets of components on movable girders to make these changeovers efficient and reproducible.

The oppositely charged beams must be kept apart except at the B0 and D0 experiments in order to minimize beam-beam effects. This is accomplished with local electrostatic "three bumps" in each plane. One pair of bumps creates helical orbits from B11 to C49. The other pair of bumps keeps the beams apart from D11 to A49.

One particular choice of separator strengths results in almost round helices when $\beta^*\sim 50$ cm. For a specific assumption of beam properties, the total beam-beam separation in "σ's" can be calculated. For equal normalized transverse emittances, $\varepsilon_H=\varepsilon_v=24\pi$, p=1000 GeV/c, and $\Delta p/p=0.12\times10^{-3}$, in most places the beams are 12 or more σ's apart. If the number of bunches, B=53, there are 106 crossing points spaced 59.3 meters apart, and one collision point at B0 and one at D0. A list of required separators can be developed for this scheme. If 5×10^6 volts/meter can be achieved (e.g. 200 kV on a 4-cm gap), then a "natural" separator module length of about 3 meters is convenient. Eighteen such modules are required.

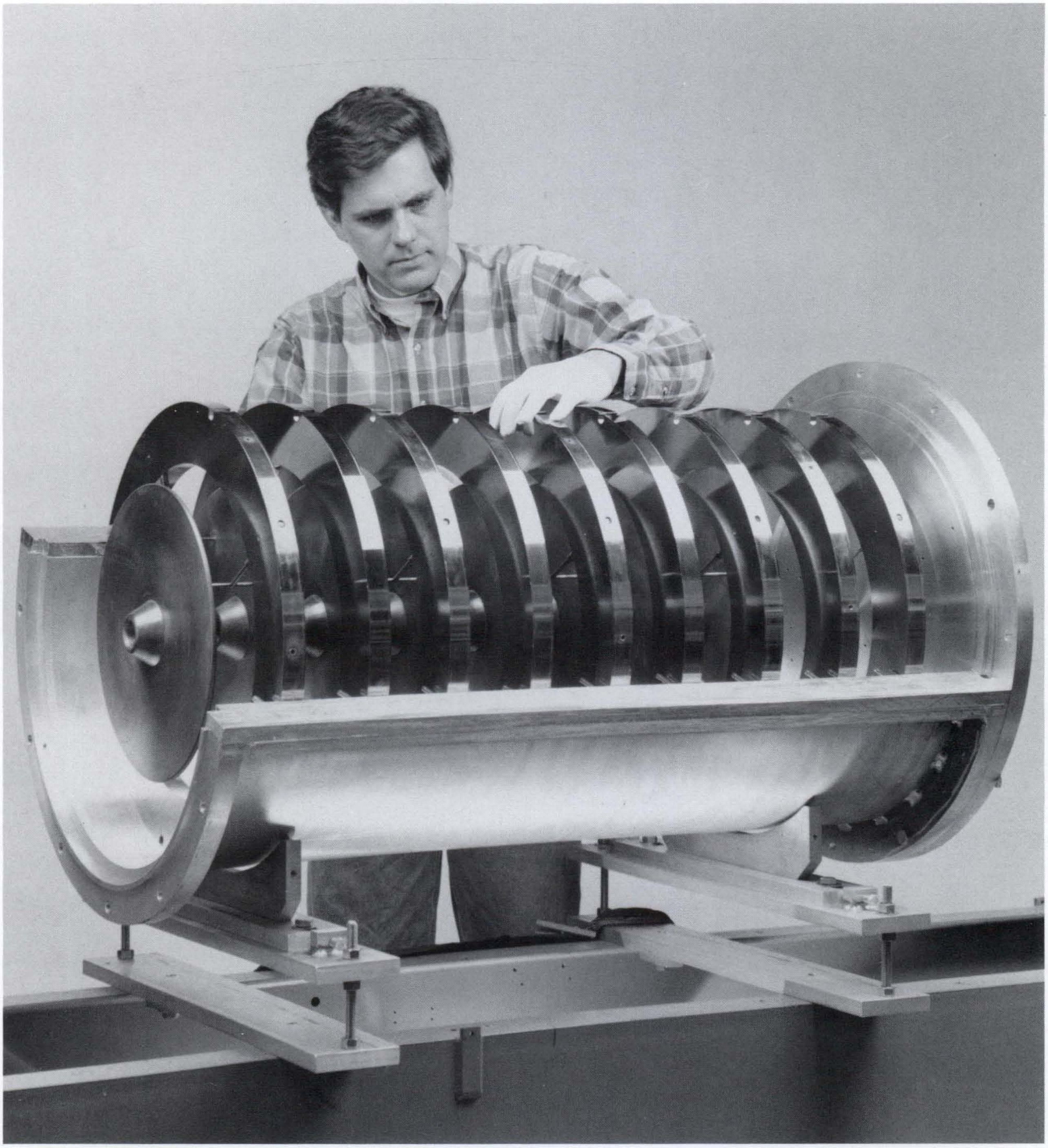
The Linac Upgrade

Donald E. Young

The Fermilab linear accelerator (Linac) was conceived 20 years ago, produced its first 200-MeV beam of accelerated protons on November 30, 1970, and has run without major interruption since that time. Its responsibilities have steadily increased as greater demands have been placed on it by the added complexity of the downstream chain of accelerators and by the increased patient load of the Neutron Therapy Facility. The major improvements during the last 17 years have been the conversion from the acceleration of protons to the acceleration of H^- ions, a new control system, and replacement of the rf control and monitoring system. Minor improvements have resulted in an increase in the reliability so that during 1987 it ran reliably 98.7% of the time. However, as gratifying as the record may seem, the technology for linacs has advanced in the last 17 years to the point where the performance could be vastly improved to the benefit of all systems downstream of the Linac.

During 1987 plans for an upgrade of the Linac became well focused. It is now planned to replace the last four tanks in the present Linac with seven new accelerating modules operating at a higher frequency and higher accelerating fields so as to increase the energy from 200 to 400 MeV. This change can be done in the existing building enclosure with the new sections initially installed adjacent to the old tanks. Only minor modifications will be required in the injection line to the Booster to accommodate the higher energy. The rf power to drive the new modules will be supplied by high-power, 805-MHz klystrons. An expansion of the gallery space will allow the installation of these systems without disruption of the presently operating rf systems. The higher Linac energy will reduce the tune spread due to beam space-charge force at injection in the Booster accelerator thereby improving the ratio of the total number of particles in the accelerator (N_t) to the normalized transverse emittance (ϵ), i.e., N_t/ϵ. At 400 MeV this ratio should be increased by 75% compared to the ratio at 200 MeV.

Another advance in linac technology that has taken place since the Fermilab Linac was constructed is the development of a radio-frequency quadrupole (RFQ) structure to capture, bunch, focus, and accelerate the beam from the ion source into the drift-tube Linac. This is the region where beam space-charge forces are most severe, and even more so for an H^- beam since neutralization by positive ions from the residual gas is slower than for an H^+



Linac Technician Alan Forni making adjustments in a ten-cell, full-scale prototype disk-and-washer accelerating structure fabricated by Fermilab and Science Applications International Corporation for the Linear Accelerator Upgrade.

beam, which depends on electrons. Measurements have shown that the H^- beam emittance grows by a factor of two in the 750-keV beam-transport system and by another factor of two in the first 10-MeV tank of the Linac. By replacing the 750-keV Cockcroft-Walton preaccelerator with an RFQ to an energy of 2 MeV, the emittance growth can be reduced. Replacing the present first tank of the Linac with a new structure from 2 to 10 MeV would have further benefits in preventing the emittance dilution. Emittance improvement at low energy would be transmitted through the Linac to 400 MeV for further enhancement of the N_t/ϵ factor in the Booster.

R&D support of both the low-energy and the high-energy Linac improvements were started in 1987. At low energy, the ion-source test stand was upgraded and a plasma lens (Gabor lens) was fabricated and installed on the test stand. Studies will follow to assess the feasibility of neutralizing and focusing the beam as it emerges from the ion source so as to match the beam into an RFQ. A 750-keV RFQ was borrowed from the University of Frankfurt, Germany, and powered to full voltage. It will be added to the test stand after the plasma lens so that the beam properties emerging at 750-keV can be measured, studied, and compared with the beam from the present online operating system.

High-frequency, high-gradient accelerating structures are being studied for the high-energy Linac upgrade. Models of a few cells of disk-and-washer and side-coupled resonant cavity structures have been built and measured. The fabrication of full length power models to test operation at the design field gradients are in progress. A 1.25-MW, 805-MHz power supply is being fabricated, using a klystron borrowed from Los Alamos National Laboratory to allow the prototype accelerating structures to be tested and operating experience acquired.

The Linac improvement program is structured to take advantage of the progress made in the last 20 years in Linac technology to make a brighter Linac beam at twice the energy. The program should result in another 20 years of exceptional operation for the Linac. This is the first step in the Fermilab Accelerator Upgrade Program intended to provide greater luminosity for the colliding-physics program, greater pbar production rates, and an intensity increase for fixed-target operation.

The Collider Upgrade: 20-GeV Rings

Stephen D. Holmes

During 1987, the Accelerator Division undertook a study of the need for and feasibility of constructing new accelerators at Fermilab in support of the proposed Collider upgrade to 5×10^{31} cm^{-2}sec^{-1} luminosity. The primary needs for new rings were identified as being associated with the large number ($\sim 4 \times 10^{12}$) of antiprotons needed to produce the desired luminosity, and with the need to improve the performance of the Main Ring in terms of transmission, emittance preservation, and beam losses at B0 and D0. Several scenarios which met these needs were examined including, in various combinations, the construction of a new Antiproton Ring, a new Booster, a new Post-Booster, and a new Main Ring. The option deemed most attractive from the technical and operational point of view was the construction of a new antiproton storage ring, called the Antiproton Depository, and a new Post-Booster. The Accelerator Division is currently preparing a Fiscal Year 1990 construction project data sheet (Schedule 44) and conceptual design report for these rings.

Although the two rings have circumferences similar to the existing Antiproton Accumulator and 8-GeV Booster, both are capable of accelerating beams to 20 GeV/c. This will allow the injection of protons and antiprotons into the existing Main Ring above transition (Main Ring transition is at about 17.5 GeV/c). Enhanced Main Ring performance is expected to result from this mode of operation. This expectation is based on machine studies carried out during 1987 which show a 100-fold increase in the beam lifetime at 20 GeV/c (as compared to the present 8.9 GeV/c) accompanied by an improvement in magnetic field quality at injection. The new rings will be situated concentrically in separate tunnels. Parameters of the two new rings are given in Tables 3 and 4.

The Antiproton Depository is designed to provide the capability of storing 4×10^{12} antiprotons in one place. The existing Antiproton Accumulator does not have this capability nor is it thought to be possible to upgrade the existing machine to meet this specification. In any case, it is totally impossible to contemplate raising the energy to the existing Accumulator. The Depository looks very similar to the Accumulator except that it lacks a stack-tail stochastic cooling system. A stack-tail system is not needed in this ring since it will be required to accept antiprotons only rarely (every hour or so) from the Accumulator. In contrast, the existing Accumulator must accept antiprotons every two seconds from the Debuncher Ring. The lack of need for a stack-tail system in this ring is the primary reason for improved storage and peak energy capability in the Depository relative to the Accumulator. The Depository is also designed to accept antiprotons recovered from the Collider (at 20 GeV/c) for re-cooling.

The primary function of the Post-Booster is to provide protons for injection into the Main Ring above transition. It accepts protons from the existing 8-GeV Booster at 8.9 GeV/c and accelerates them to 20 GeV/c. Since this accelerator will participate in antiproton production and fixed-target operations as well as Collider loading, it is designed to have a rapid cycling rate of 5 Hz. The Post-Booster will be constructed as a separated function machine allowing it to attain an energy of 20 GeV in a circumference only 25% larger than the existing 8-GeV Booster.

It is anticipated that the construction of the two new rings could be completed by the end of CY 1992.

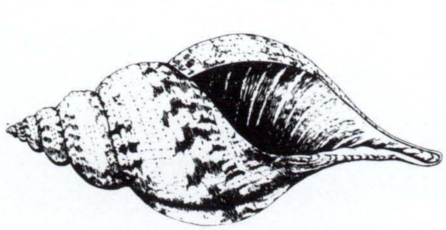
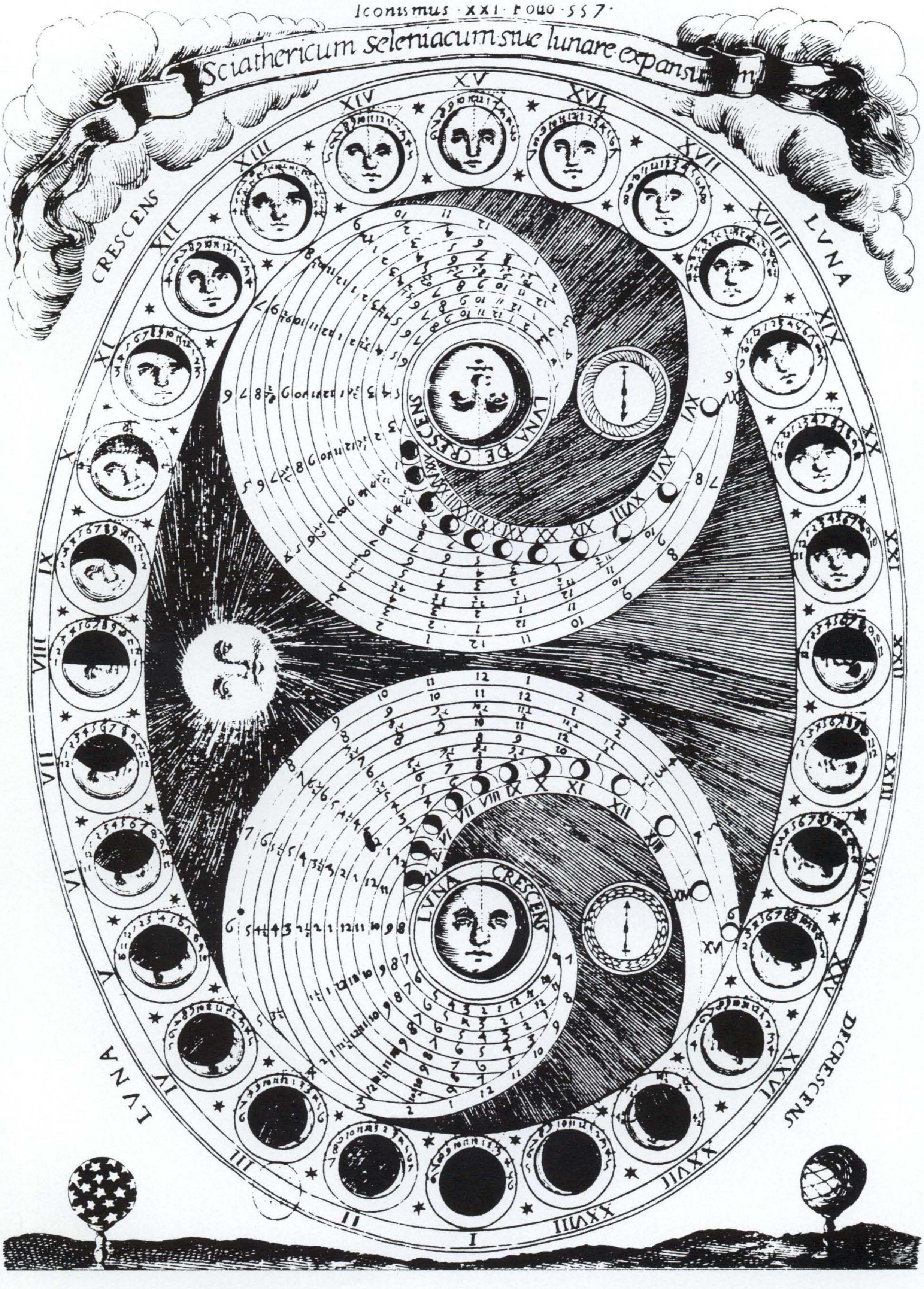


Table 3
Antiproton Depository Machine Parameters

Circumference	513.72 meters
Accumulation Energy	8.9 GeV
Peak Energy	20.0 GeV
Harmonic Number (@53 MHz)	91
Horizontal Tune	6.61
Vertical Tune	6.61
Transition Gamma	7.0
η @ Low Energy	.009
η @ Peak Energy	.018
Maximum No. of Antiprotons	4×10^{12}
Transverse Emittance (Normalized)	10π mm-mr
Full Momentum Spread	20 MeV
Longitudinal Emittance	30 eV-sec
Cooling System Bandwidth	8-16 GHz
Transverse Acceptance (Unnormalized)	8π mm-mr
Momentum Acceptance	1.7%
Number of Straight Sections	6
Length of Zero Dispersion SS	10.7 meters
Length of High Dispersion SS	7.7 meters
Number of Dipoles	84
Dipole Length	3.1 meters
Dipole Field (Max)	15.9 kGauss
Number of Quadrupoles	72
Magnet Style	TeV I

Table 4
Post-Booster Machine Parameters

Circumference	592.76 meters
Injection Energy	8.9 GeV
Peak Energy	20.0 GeV
Cycle Time	0.2 sec
Harmonic Number (@ 53 MHz)	105
Horizontal Tune	7.41
Vertical Tune	7.41
Transition Gamma	6.8
Number of Bunches	84
Protons/Bunch	8.6×10^9
Transverse Emittance (Normalized)	8π mm-mr
Longitudinal Emmitance/Bunch	0.09 eV-sec
Momentum Spread (Max, full width)	0.3%
Transverse Acceptance (Unnormalized)	8π mm-mr
Momentum Acceptance	0.6%
β_{max} (Arcs)	23 meters
β_{max} (Straights)	30 meters
Maximum Dispersion	3.4 meters
Number of Straight Sections	18
Total Length in Straight Sections	103 meters
RF Frequency (Injection)	52.8 MHz
RF Frequency (Extraction)	53.0 MHz
RF Voltage	540 KV
Synchronous Phase (Max)	33 degrees
Number of Dipoles	72
Dipole Length	4.4 meters
Dipole Field (Max)	13.1 kGauss
Number of Quadrupoles	90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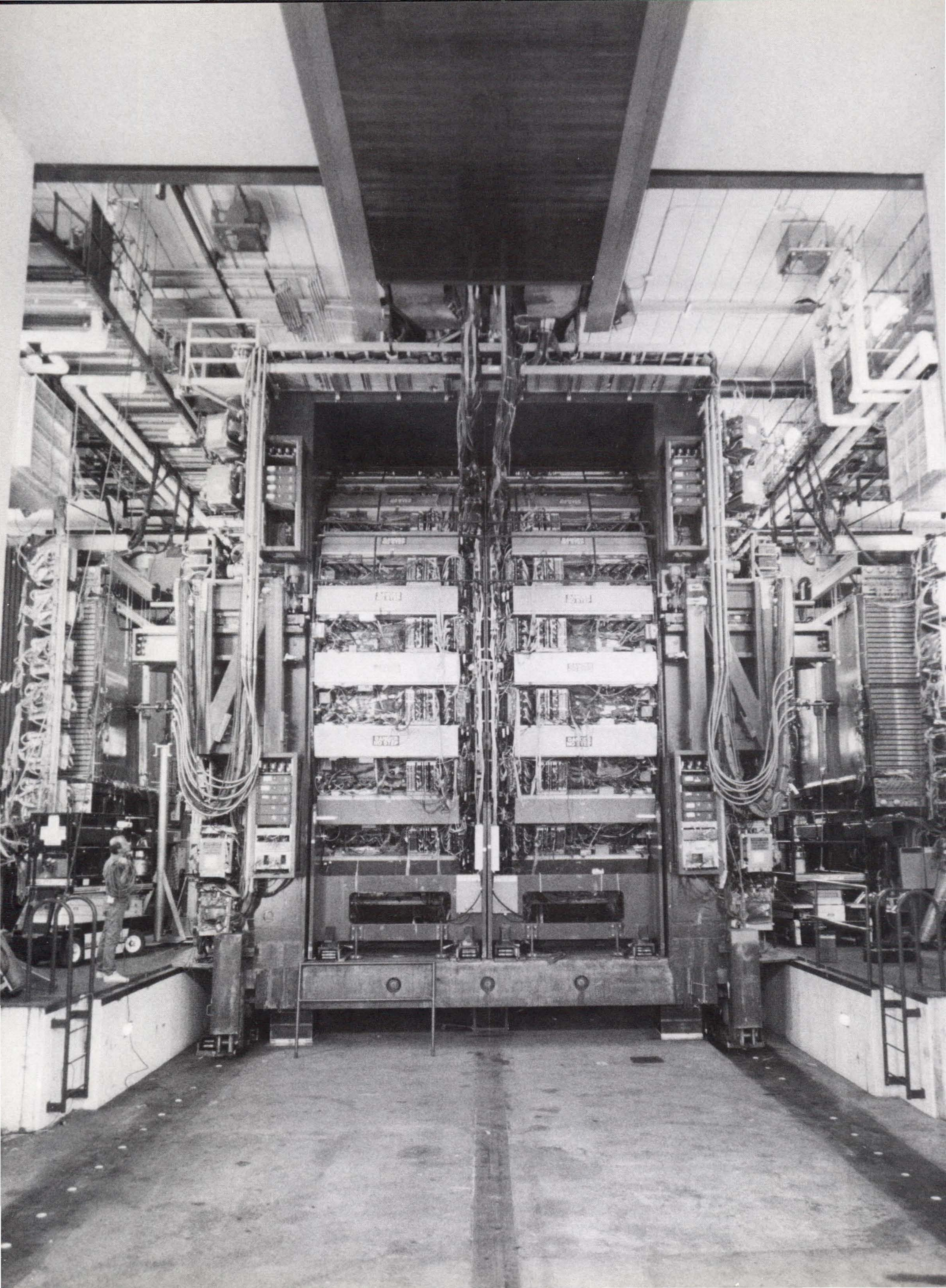


In justifying the prodigious effort to construct the TEVATRON complex, one research thrust has, from the beginning, been put forward as the crown jewel of the program - the observation of 2000-GeV collisions of protons and antiprotons by the CDF detector. The past year is described by Roy Schwitters while co-manager Alvin Tollestrup whispers to me of the vast treasures that will be exposed in the 1988 run *if only* we can deliver 1000 nb^{-1}, i.e., 20 times the total number of collisions seen in 1987. This will indeed be an exposure to a domain where, in the immortal words of an unnamed graduate student, ". . .no human eye-ball has ever set foot."

The Collider Detector at Fermilab

Roy Schwitters

On March 29, 1987, a computer printout of a curious-looking event was passed around the CDF control room. Found by Kiyoshi Yasuoka in a preliminary analysis of CDF data taken a few days before, the event was distinguished by what appeared to be a single, very-high-energy electron accompanied by a few low-energy particles. Physicists on shift that evening quickly recognized the importance of the find and began additional studies, some on the computer and some using such old-fashioned methods as pencil and graph paper, to determine the origin of the event. Within hours, there was general agreement: CDF had found the first "new world" W particle.

The W boson has a long history in theoretical physics, but was first observed experimentally at CERN in 1983 by the UA1 and UA2 groups. A key ingredient in the Standard Model of particle physics, its discovery garnered the 1984 Nobel Prize in Physics for Carlo Rubbia and Simon van der Meer. Its detection at Fermilab signaled that CDF had "joined the club" along with UA1 and UA2, and was poised to search for new physics in the considerably higher energy collisions provided by the TEVATRON.

1987 began with the full CDF central detector positioned on the TEVATRON beam along with the newly completed forward/backward detector systems. Following the very brief 1985 run where first collisions in the TEVATRON were detected, CDF and the B0 collision hall underwent major construction efforts to complete them for initial physics studies. On January 5th, around-the-clock operations began with a staggering amount of testing, programming, and learning to be done before CDF could seriously contemplate doing physics.

For several years, CDF components were being built all over the world, in specialized shops at physics institutes in Italy, in major Japanese factories, and in physics-department facilities across the United States. Suddenly, it seemed in early 1987 everything was focused at B0 where an extraordinary number of pieces had to be made to function together as a system for the first time. Systems studies were the

← Final installation of the CDF detectors in the B0 straight section of the TEVATRON. The passageway shown will be plugged with a 1200-ton shielding door.

principal activity for CDF during winter 1987; many problems were revealed and resolved during this time.

A complex instrument like CDF does not come with an instruction manual. The collaboration had to learn how to operate it, which required a combination of trial-and-error and teaching each other. A highly successful means of assigning and distributing shift responsibilities across the collaboration was developed. While senior professors were often assigned the role of "shift captain," the success of a crew usually depended on the youngest members who, being agile with the computers, were designated "ace!"

By March, TEVATRON operations were making excellent progress, and CDF was able to begin recording interesting data. Some spectacular events, which are also relatively common, consist of two dense clusters of energetic particles observed on opposite sides of the apparatus. These clusters are called "jets." They are formed when billiard-ball-like collisions take place among the constituents of the beam particles. In such collisions, quarks and gluons scatter at large angles from the beam direction with very high energies. They emerge as the jets of particles that are detected. These events seen by CDF offer some of the clearest evidence for the underlying quark structure of nuclear matter.

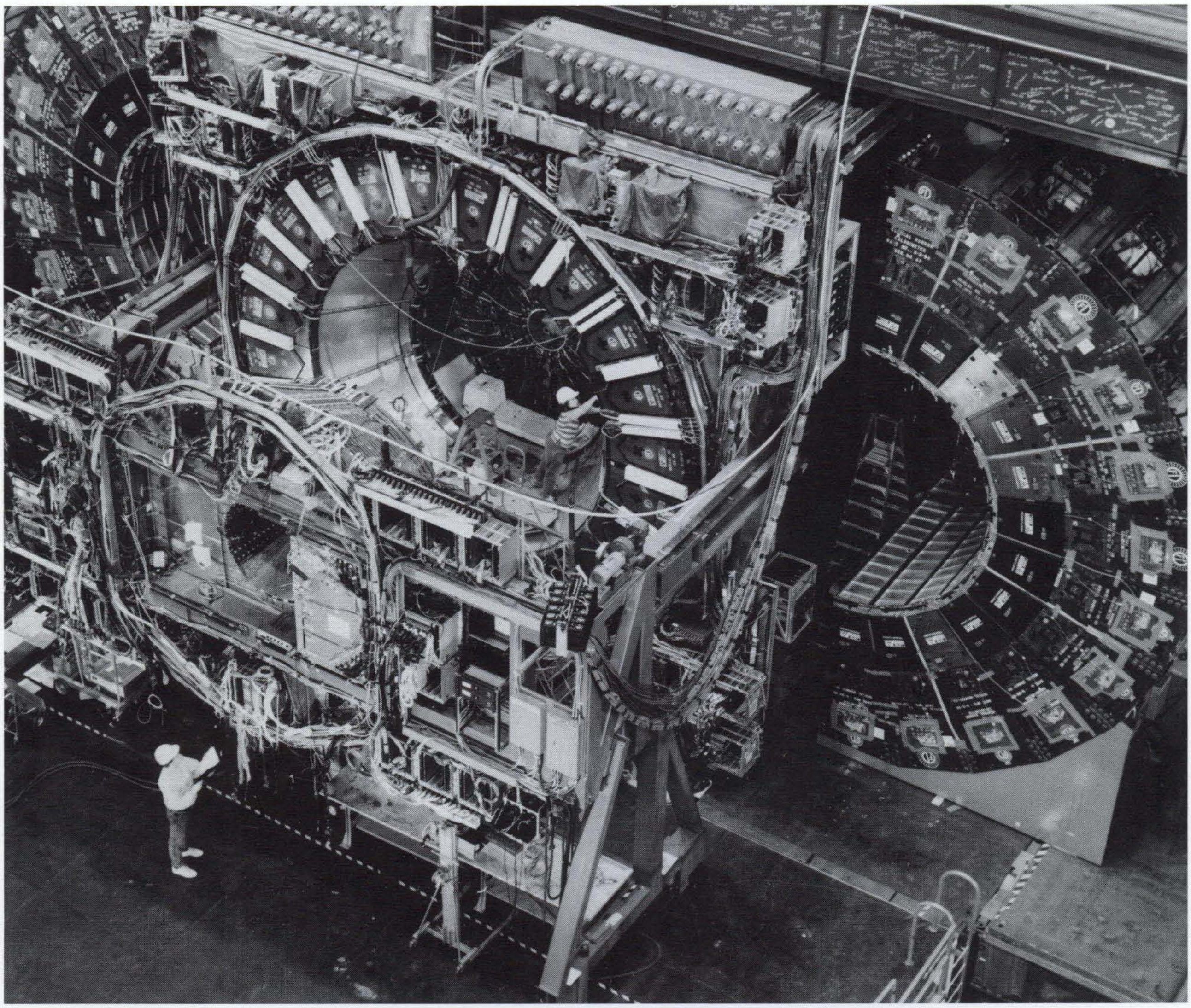
The CDF control room was a most dramatic place to visit during the Collider run. With its TV monitors and computer consoles, it can compete with the best that Hollywood has to offer. When the countdown begins for a fresh refill of protons and antiprotons, the intensity rivals a NASA launch. The excitement of seeing, as they are occurring, displays of collision events from an unexplored physical realm is unique.

On May 11, the Collider run terminated and much effort was turned toward the computer programs necessary to analyze the vast quantity of data recorded. New challenges had to be faced. These included developing the analysis algorithms, management of software across our international consortium, running efficiently large numbers of data tapes through the offline computers, and actual analysis of detector performance and physics.

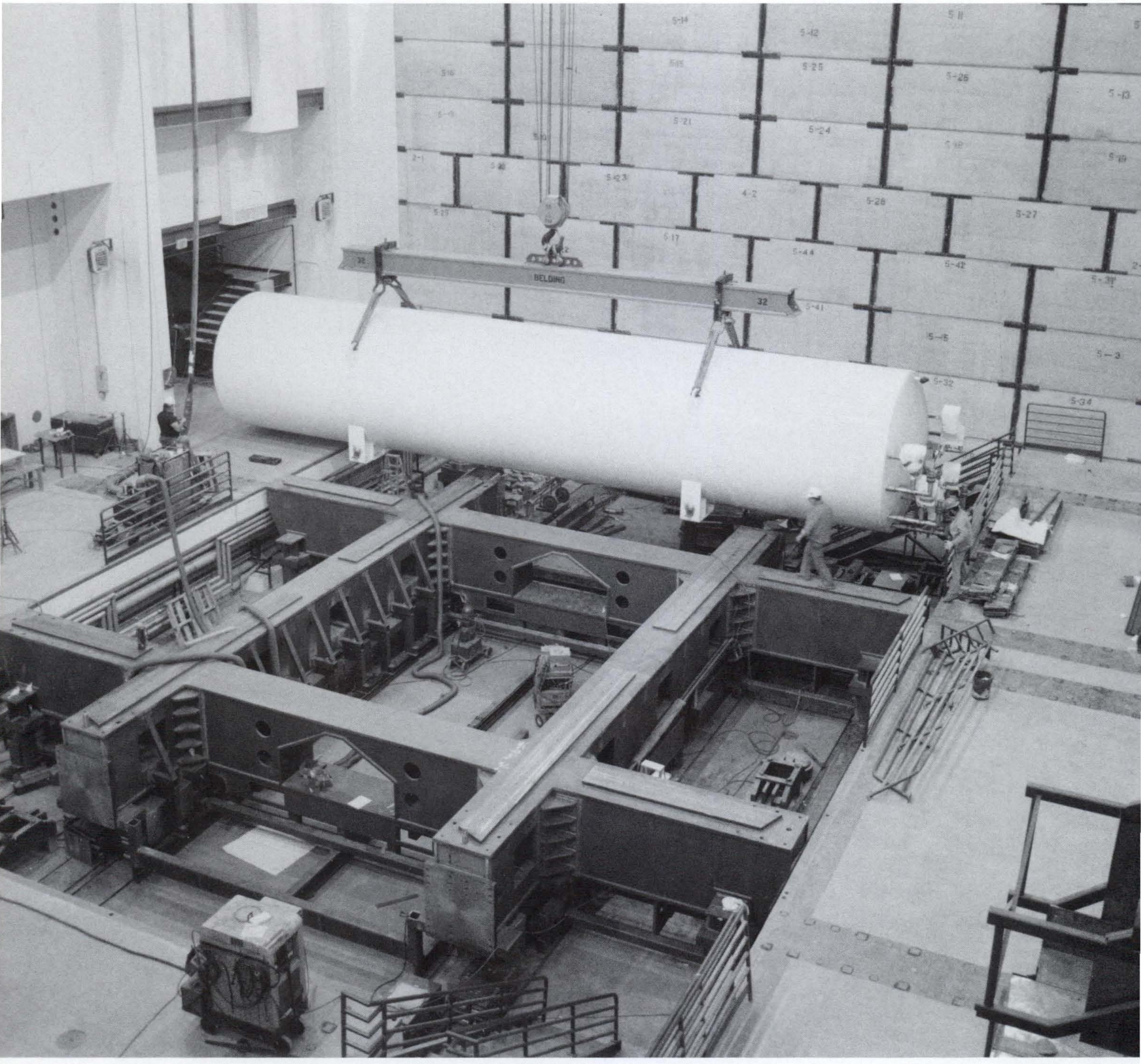
Over the summer, the full set of data tapes was processed, giving reconstructed event information that could be used by CDF physicists to begin to look at new physics. This effort demanded a major fraction of the Fermilab Computer Center's VAX resources. By early fall, it was clear that the Collider run, in addition to being a very successful engineering run for understanding the apparatus, would provide publishable physics results and enough data for approximately 20 Ph.D. dissertations. Among the roughly one-million events recorded, there were found about 30 W events, a half-dozen Z particles (the relative of the photon and W), and thousands of jet events, some of which are more energetic than ever before detected. In December, a full collaboration meeting was held to discuss physics analyses in progress. It more resembled an international conference with many new and interesting results presented. Groups have been formed to move toward publishing these results as quickly as possible.

The data collected during 1987 gave us a taste of physics, but are not enough to address the most important current physics issues. Thus, we look forward to 1988 when we hope to accumulate 30 times the data. This will give us a chance for real discoveries, such as the long-sought top quark or physics beyond the Standard Model.

In preparation for the next run and to do the necessary R&D for upgrades to the CDF detector, a major effort in the fall was devoted to developing a new test beam in the Meson Area. With considerable assistance from the Research Division, this beam was commissioned and is being used for calibrations and other studies. Finally, as we began 1987, so we end it with systems tests and preparations for the next Collider run, which we hope will be one of new discoveries.



Preparing the CDF central detector for a Collider run. The end plugs and the side arches are retracted to allow access for service and calibration.



Installation of the D0 40,000-gallon liquid-argon dewar. Its final location is in the alcove on the left. The platform on which the detector is built is shown in the foreground.

In 1987, CDF had its baptism of fire and, sitting in the CDF control room, breathing in the lessons, the goofs, the things-that-didn't-work-too-good, dressed in an unobtrusive Burberry rain coat and slouch hat, holding up an old copy of the *Batavia Chronicle* with a hole in the middle, was an officially sanctioned spy from across the Main Ring at D0. This space-age detector is jointly managed by Paul Grannis of SUNY/Stony Brook and Gene Fisk of the Experimental Support Group in the Accelerator Division, which is charged with the in-house responsibilities of administration, safety, etc. D0, originally scheduled to be complete in 1989 concurrently with the third CDF run, was designed with much of the CERN experience at hand and with special attention to issues of hermiticity, lepton detection, and hadron resolution. Like other sections of the Lab, D0 also has its funding problems, but they decided to submit their contribution anyway.

The D0 Experiment

Paul D. Grannis

For four years, D0 has been separately the name of the new collider detector and an address within the circumference of the TEVATRON. In 1987, name and address became merged when the detector began to take up residence in its new hall, even while contractors complete the amenities needed for operating the D0 experiment. The visible growth of the D0 detector, together with vigorous activity building components within each of the 21 collaboration groups, constitutes a large step toward reaching full utilization of the power of the TEVATRON.

The year 1987 has, at the same time, been a period of cottage industry operation and large-scale assembly plant work. The small-scale operations have been tuned to produce detector pieces and electronics components which flow to the large assembly lines or toward installation in the D0 hall. University groups are turning out such varied parts as microprocessor trigger nodes, signal digitizers, tools for quality control in production, calibration software, calorimeter signal boards, liquid-argon monitors, delay lines for tracking chambers, and feed-through boards which transform the chaotic patterns of signals delivered by hardware into an orderly arrangement for analysis.

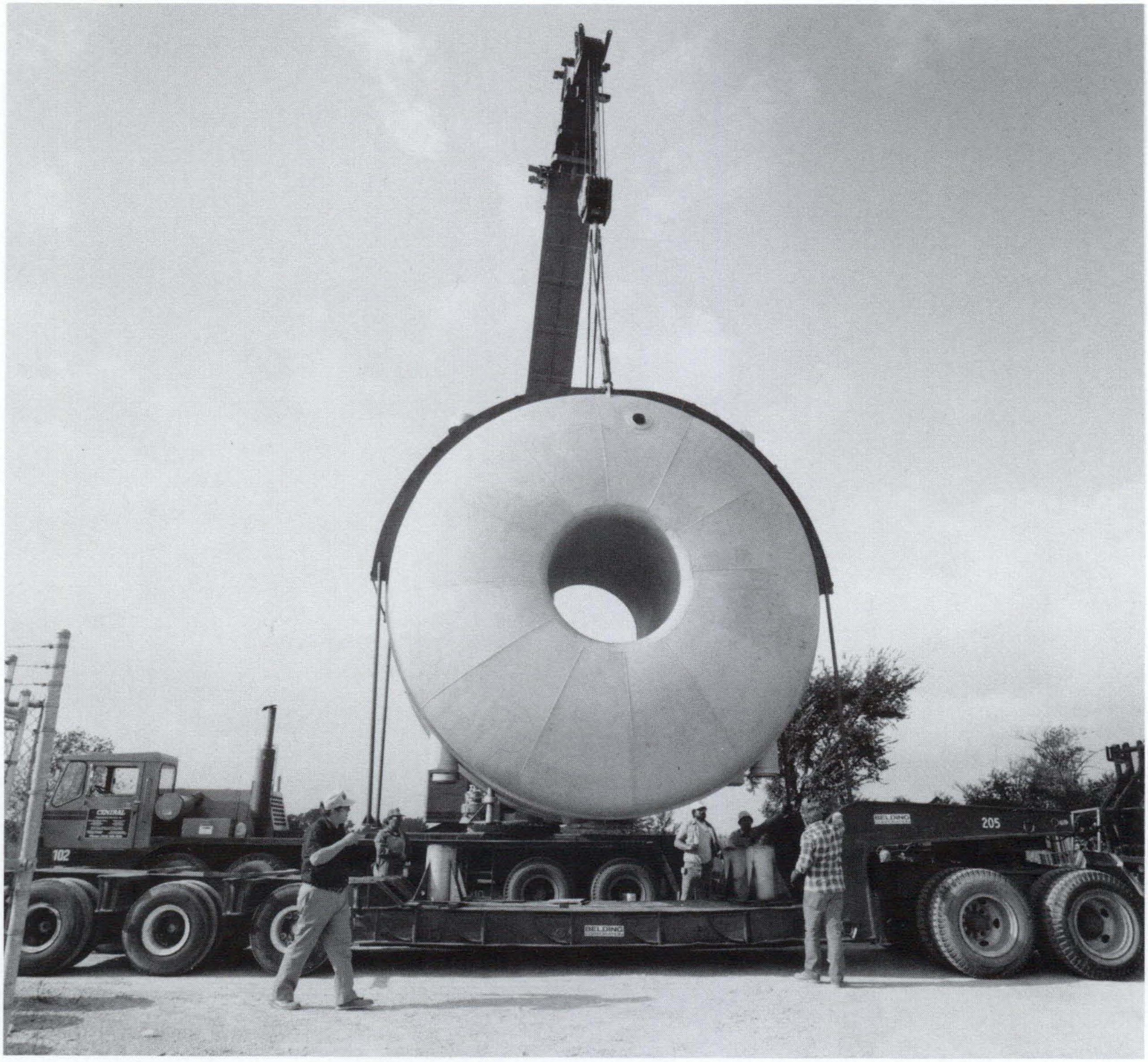
This large array of components is being assembled into the main detector elements which comprise D0. The three distinct tracking chambers are being assembled in separate laboratories spanning the continent. These three devices will be assembled around the transition radiation detector under construction in France. Facilities for assembling the liquid-argon calorimeters have been set at four national laboratories. These large operations (at Serpukhov, U.S.S.R.: end coarse calorimeters; Brookhaven National Laboratory: central calorimeters; Fermilab: end fine calorimeters; and Lawrence Berkeley Laboratory: end electromagnetic calorimeter) rely on the university groups' manpower and components. The large panels of muon chambers are being produced in a network of facilities at Fermilab, again with help from a group of university physicists and technicians. Electronics for signal processing and triggering are being developed, packaged, and tested at about a dozen different sites.

One interesting phenomenon which has occurred through the process of setting up these parallel pipelines for D0 detectors, has been the partial breakdown of traditional user-group boundaries. At the simplest level, the D0 detector consists of just three major detection systems (tracking TRD, calorimetry, and muon detection). These systems are each too large for a single institution to undertake, so collaboration at the system level is required. In D0 the pattern has emerged in which a particular group divides its effort; a portion of the group might work on tracking chambers while a second part is involved with calorimeter production. This pattern of involvement produces a new and healthy set of dependences which is orthogonal to the traditional group structure. In a project as large as D0, this enlargement of connectivity serves well to keep the overall project needs and priorities harmonized over the full collaboration.

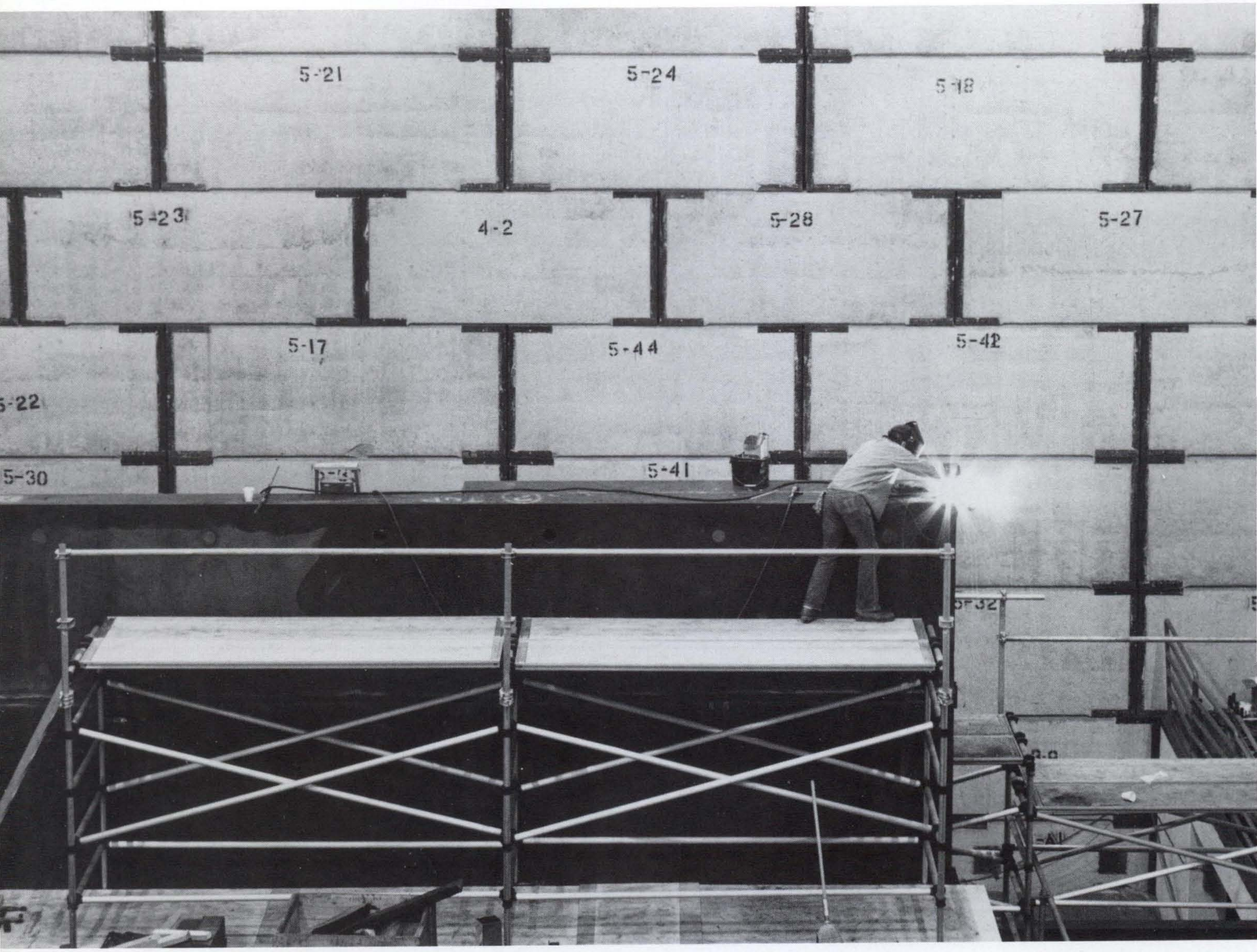
Given the dispersal of activities this year in building D0, it is obvious that careful attention must be given to harnessing the pieces into a whole. A major focus for this is the D0 Experiment Department in the Accelerator Division. The important functions of planning, safety, reviewing, accelerator liaison, monitoring, and installation are all carried out through the Accelerator Division/D0 Experiment Department. During 1987, one of the most visible of these activities has been the installation of major detector systems in the D0 hall. Following completion of Phase 1 construction late last year, the platform on which the detector will ride has been constructed. Through the year, this platform has been augmented with water, cryogenics and power distribution systems, electronics racks and the cable bridge which carries signal cables to the safe area, and the moving counting house at the other end of the bridge where digitization of signals will occur. The storage dewar for liquid argon is now in place. The outline of the detector itself is presently emerging as the three large iron toroids for bending muons and supporting all remaining detectors are being erected on the platform.

A second crucial unifying focus for D0 has been the test-beam operation in the NWA beamline. This test, involving physicists from two-thirds of the collaborating institutions, has several goals. First, the performance of production detector elements must be measured; central calorimeter, end calorimeter, vertex chamber, forward drift chamber, and central drift chamber are all included in this program. In each case, signal collection is being done using final versions of the D0 shaping and digitizing electronics. Triggering and data acquisition also use systems built for the experiment. Thus, an important component of the test has been identifying and solving the system and interconnection problems before they occur in the full experiment. Included in this global integration is the use of D0's online, monitoring, calibration, and display software. This test has been an essential guide for the evolution of D0 software into a battle-tried system.

The test-beam experiment is an operation which is comparable in size to many fixed-target experiments. Already, it has given encouraging results on calorimeter energy resolution and overall electronics noise contributions. Many of the hurdles encountered in melding the diffuse parts of the experiments into a whole have been cleared; this experience in working with the full D0 detector should stand the collaboration in good stead to make a rapid turn-on of the experiment when installed at the Collider. A final benefit of this test



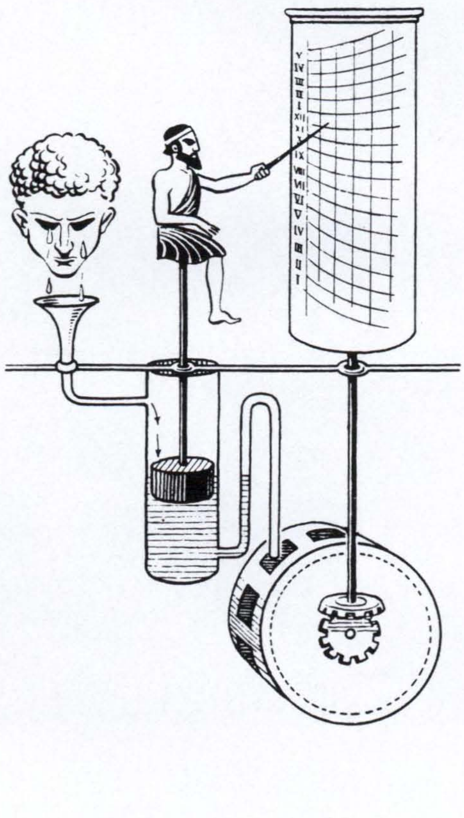
The cryostat for the D0 central calorimeter being off-loaded at delivery in August. The doughnut-shaped vessel (5.2 m in diameter and 3 m long, with an inner-hole diameter of 1.5 m) has since been vacuum- and cold-tested and prepared to accept its load of 64 individual calorimeter modules.

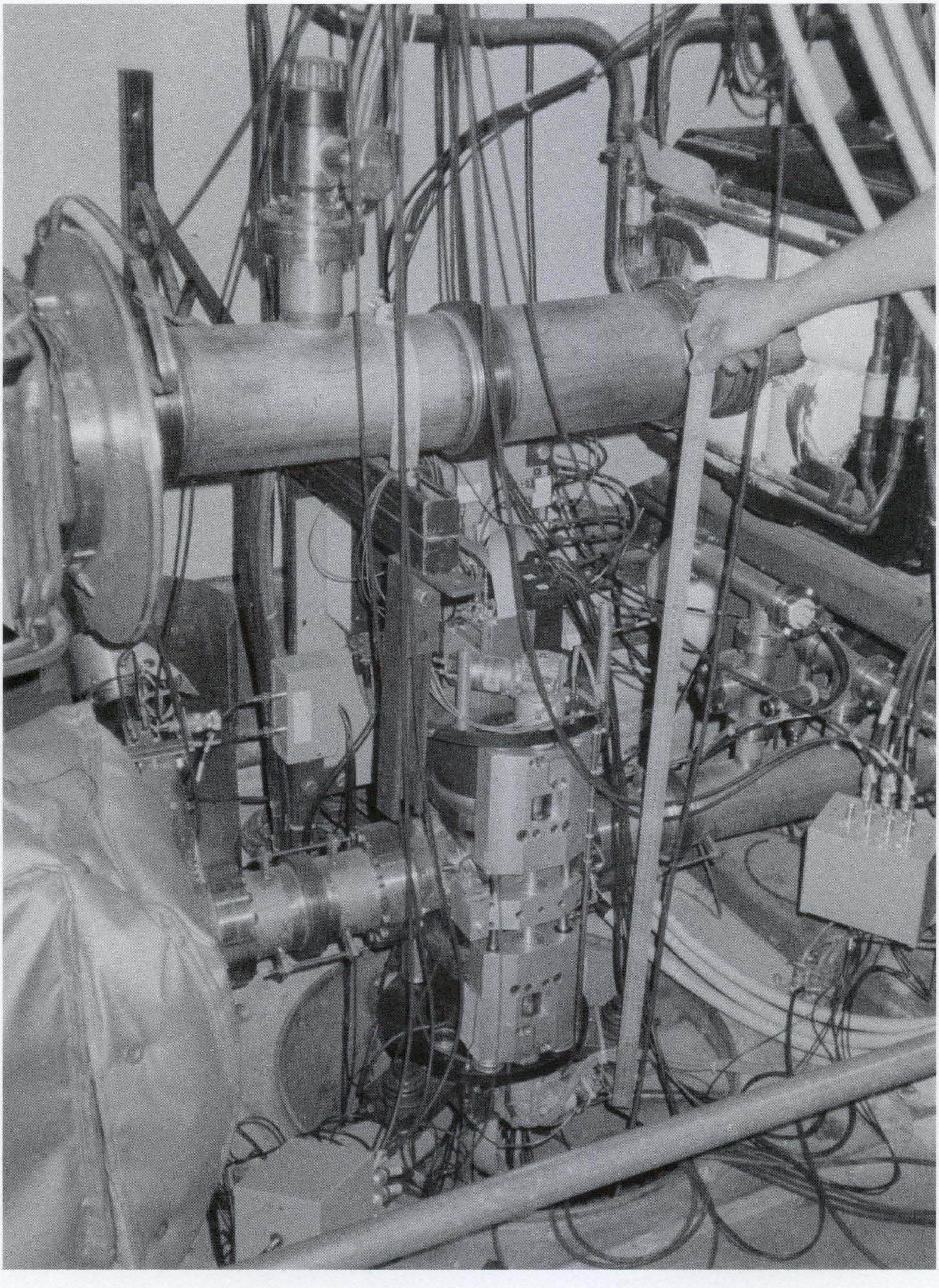


A welder at work on the D0 central iron torroid against the backdrop of the shielding wall that separates the assembly and collision halls.

comes from the opportunity for many of the collaborating physicists to work together effectively on detailed problems and with shared triumphs.

A look to the future with D0 has several components. On the immediate horizon we hope to see the completion of the detector components. With much of the intellectual effort of design and prototyping finished, this effort requires organization, manpower, and sufficient funds. Plans are now being drawn in detail for installation and commissioning D0. Monte Carlo simulation of the detector continues to be a tool both for understanding detailed performance questions and for developing the pattern recognition and reconstruction software needed to produce physics. This activity, often delayed until an experiment is running, is important for D0 if it is to join CDF in producing physics as soon as the detector is commissioned. Finally, the D0 collaboration looks further ahead to plan for the continuing evolution of the detector capabilities to track developments in machine luminosity and new physics opportunities. In this regard, the D0 collaboration has already modified its trigger architecture for early adaptation to high rates: Augmentations for improving transverse energy measurements are being implemented. Studies are under way for extending the reach of physics at D0 and pushing muon detection to the small-angle regions.





Human ingenuity knows no bounds. When we designed the Collider, it was to be at B0. It was noted in the 1979 design report that D0 was also a possibility. But see what happened! Three intrepid groups came to us and pointed out that there were all sorts of nooks and crannies where 2-TeV research of significance could be done. Others noted that the Collider could provide valuable studies of accelerator properties. These are the "Small Collider Experiments," and Roy Rubinstein describes what they are and what they did.

Small Collider Experiments

Roy Rubinstein

Because of all the understandable attention given to CDF, it may be hard for the reader to believe that, yes, there really were other experiments taking data during the 1987 TEVATRON Collider run! Nevertheless, there were several, and we will discuss their progress and available results here. Some were high-energy physics experiments, while others were studies of accelerator properties. We will cover the three high-energy physics ones first; their general characteristic is that they address well-focused, specific physics topics to which the large, general-purpose detectors are not ideally suited. Generally the experiments are "small," although this is relative only to (the gargantuan?) CDF; some, in fact, are of a size of a typical fixed-target experiment. They are all located in interaction regions where the luminosity is typically a factor of about 80 lower than CDF. (For many purposes, including impact on the Accelerator, the smallest-angle detectors of CDF can be considered a "small Collider experiment"; they are located in the accelerator tunnel outside of the B0 detector hall. However, we will not discuss them here.)

E-710

The goal of this experiment is to measure the proton-antiproton total cross section, the slope of the elastic scattering distribution, and ρ (the ratio of the real to imaginary part of the forward scattering amplitude) at energies from $\sqrt{s}$ = 300 to 2000 GeV. The experiment is located around the E0 $\bar{p}p$ interaction point. Detectors for measuring small-angle elastic scattering are drift chambers and scintillation counters housed in "Roman Pots," which can be placed very close to the circulating beams of the TEVATRON. There are four pairs of these pots - one each at the two ends of the E0 straight section, and the others located about 100 meters from E0 at the D47 and E14 locations in the TEVATRON lattice. Focusing by the Accelerator quadrupole magnets makes the effective distance to these latter detectors about 80 meters; this

← Part of a small Collider experiment: One of the assemblies (lower center in the photograph) containing two "Roman Pots" for the detectors of Experiment 710, installed at the E11 TEVATRON location. The TEVATRON beam pipe is attached to the assembly, while above it is the Main Ring beam pipe.

large distance enables scattering at very small angles to be detected. Located around the interaction point are scintillation counters and drift chambers to measure the total inelastic counting rate.

During the 1987 run, many studies were made of the detector characteristics, and of the effect of varying accelerator conditions. The experimenters found that detectors could be placed within 5 mm of the circulating beams after only small effort to reduce beam tails by scraping. It was observed that the large amount of magnetic bending between the interaction point and the detectors in the lattice swept away most backgrounds, giving very clean data.

Analysis of the data is under way, and indicates that the experiment will be successful in achieving its goals. Shown in Fig. 4 is a preliminary elastic scattering distribution from one six-hour run. The exponential slope parameter obtained is 16.4 ±1.1, which is in good agreement with extrapolations from lower energy data.

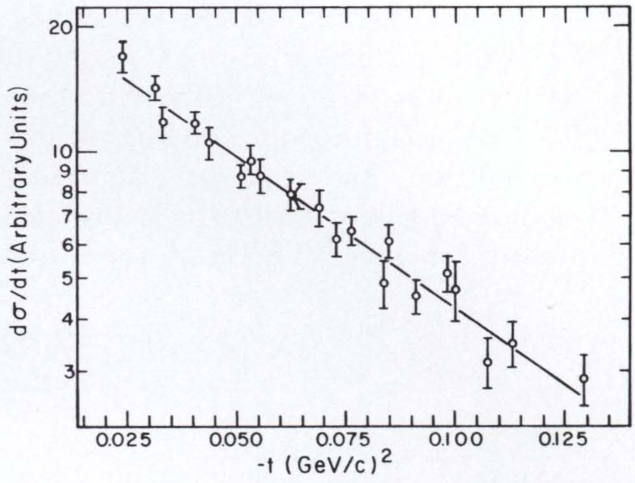
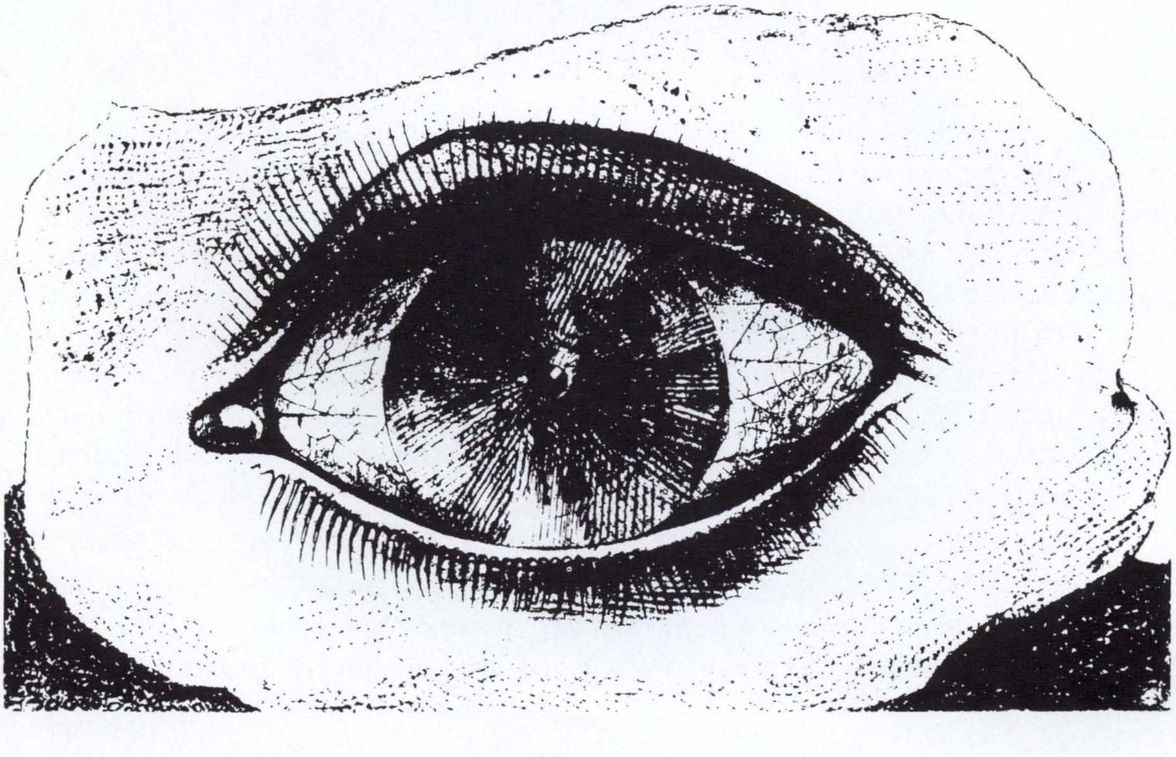


Figure 4. Preliminary results on $\bar{p}p$ elastic scattering at $\sqrt{s}$=1800 GeV from E-710.

For the next run, a number of improvements are planned; these include improved beam scraping to allow measurements to smaller angles in the Coulomb scattering region; movement of some TEVATRON Lambertson magnets to allow measurements to larger angles, and various small modifications of the experimental apparatus.



E-713

Whenever a previously unattainable energy range is opened up by operation of a new accelerator, it is an opportunity to look for hypothesized particles not previously observed at lower energy machines. One such particle, long the subject of theoretical discussion and experimental searches, is the magnetic monopole; E-713 undertook a search for this particle at the TEVATRON Collider. Three types of track-etch detectors (glass, CR-39, and Rodyne polycarbonate) were placed around the D0 interaction region, and remained there throughout the run.

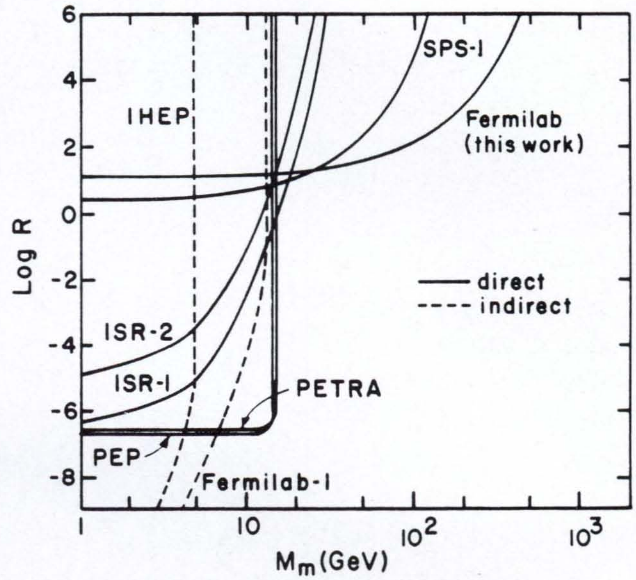


Figure 5. Results from E-713 ("this work") and previous experiments on monopole searches. Upper limits are shown for the dimensionless parameters R (see text) as a function of monople mass.

After the run ended, the detectors were removed, etched, and the tracks revealed in the etching were studied. Unfortunately, no monopoles were found (otherwise you would have already read about it on the *New York Times* front page!). Results for upper limits on the monopole production cross section from this and earlier experiments are shown in Fig. 5. In order to better compare experiments from hadron and lepton colliders, the results are shown as limits on the dimensionless parameter R, the ratio of monopole production to muon pair production; E-713 provides the best cross section limits for monopole mass greater than 20 GeV. The experiment hopes to push the limits a further factor of 20 lower in the next Collider run.

E-735

This experiment, a search for evidence of a transition to quark-gluon plasma in hadronic matter, was partially installed and collected data at the C0 interaction region during the first Collider run. The spectrometer, time-of-flight system, multiplicity hodoscope, and trigger processor were all installed and operational. A total of five-million triggers was collected on tape for analysis, with an estimated integrated luminosity of the order of 0.35 nb^{-1}. Analysis of the data is still in progress, and all data collected have been already processed into data summary tapes. A number of physics topics are being studied.

The transverse momentum spectra of centrally produced non-diffractive secondaries has been obtained up to 3.0 GeV/c. The event-by-event associated multiplicity is also available from the multiplicity hodoscope. Figure 6 shows the mean transverse momentum as a function of multiplicity. Work is progressing on the understanding of backgrounds, especially in the multi-

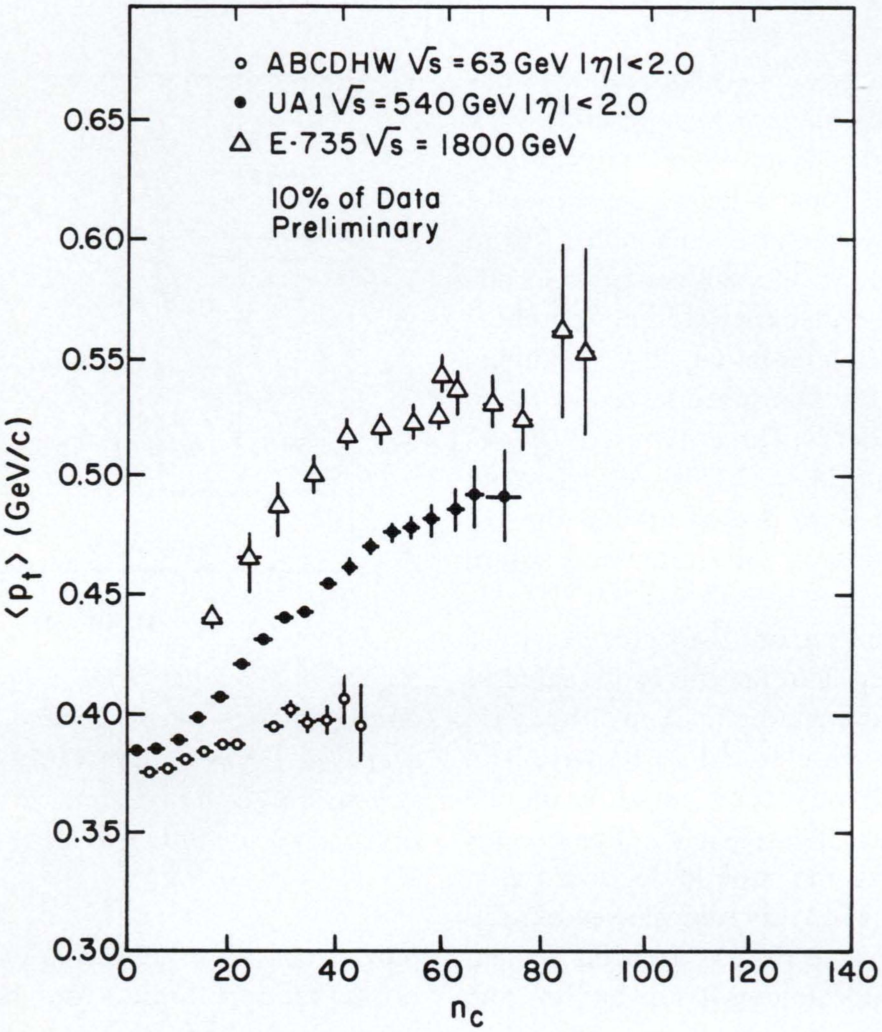


Figure 6. Mean transverse momentum as a function of multiplicity obtained by E-735 and previous experiments.

plicity, since the secondary interactions and photon conversion in the beam pipe tend to produce an apparent larger multiplicity. For the next Collider run, the central tracking chamber, end cap chambers, and a beryllium beam pipe will produce a cleaner determination of the charged multiplicity. The observed transverse momentum spectrum is in agreement with that obtained by other experiments at lower energies, and it also flattens with increasing multiplicity.

Analysis is advancing on particle identification by time-of-flight, to be used in conjunction with the transverse momentum analysis mentioned above. The resolution of 200 picoseconds presently achieved should allow the experimenters to achieve proton/kaon separation to beyond 1.0 GeV/c. Transverse mass spectra have already been produced, and the evaluation of backgrounds continues.

E-777

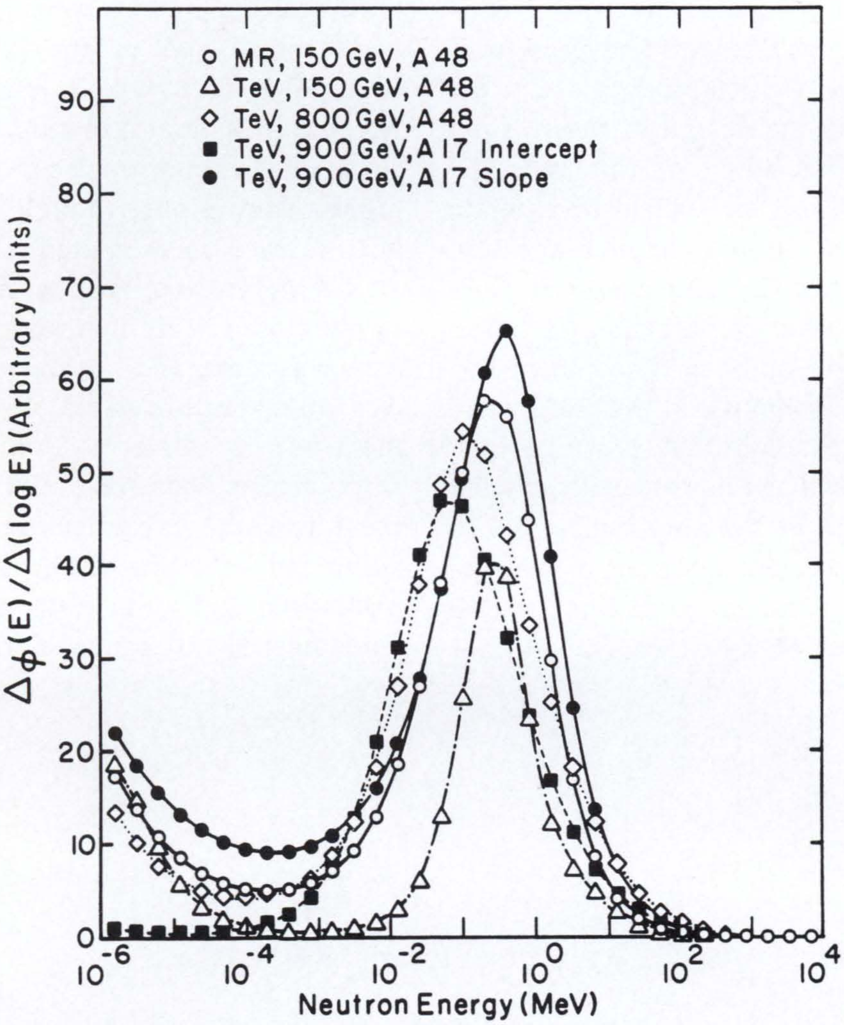


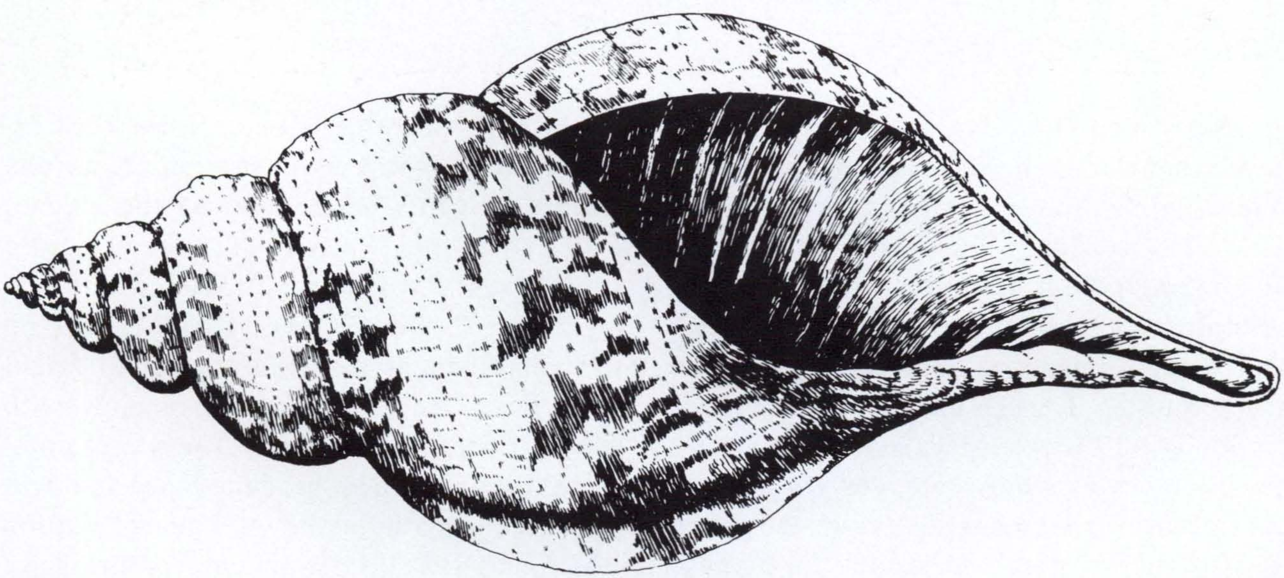
Figure 7. Typical results on neutron fluences taken under various conditions by E-777.

Experiment 777 had, as its purpose, the measurement of neutron energy spectra, fluence distributions, and rates near the TEVATRON ring. This work is relevant to understanding radiation damage to accelerator components, electronics, and research equipment at high-energy proton accelerators. The 12-meter warm straight section at A17 was used as a source of beam-gas interactions whose rate was varied by a controlled nitrogen gas leak over the range of 10^{-8} to 10^{-5} torr. Cascades from these interactions were developed in the first dipole following the warm section. Neutrons from the events, moderated by the magnet iron and tunnel walls, were detected by a Bonner multi-sphere spectrometer.

Figure 7 shows some typical results on neutron fluences for a number of different conditions. Results show consistency with Monte Carlo simulations. The direct component of neutrons produced per incident 900-GeV proton in the A17 warm section was found to be 13 per gm cm^{-2} of nitrogen.

E-778

Since the only superconducting synchrotron operating in the world at present is the TEVATRON, it is natural to use it for studies needed in the design of future such accelerators. One study of this type, E-778, was carried out in 1987 to investigate effects important in the magnet aperture criterion for the SSC. The magnetic field quality specification for the SSC is based on the imposition of bounds to the departure from linear behavior in the oscillation of single particles about their closed orbits. "Smear" quantifies the nonlinearities as the fractional change of the amplitude. E-778 attempted to answer the questions of whether smear can be predicted and what is the operationally acceptable lowest bound for the smear. In the experiments, nonlinearities were introduced in the TEVATRON by sextupoles, and an excellent agreement between experiment and calculation at lower sextupole excitation was observed. At higher excitations, though, the smear did not increase as predicted. However, even at the highest excitations, no deterioration in the closed orbit or in the injection trajectory was observed. Measurements of the dynamic aperture were in general agreement with prediction. Particles trapped in resonance islands were easily detected. In the future the experimenters expect to resolve the behavior of the smear at higher excitations and to make the first direct measurements of resonance island widths.

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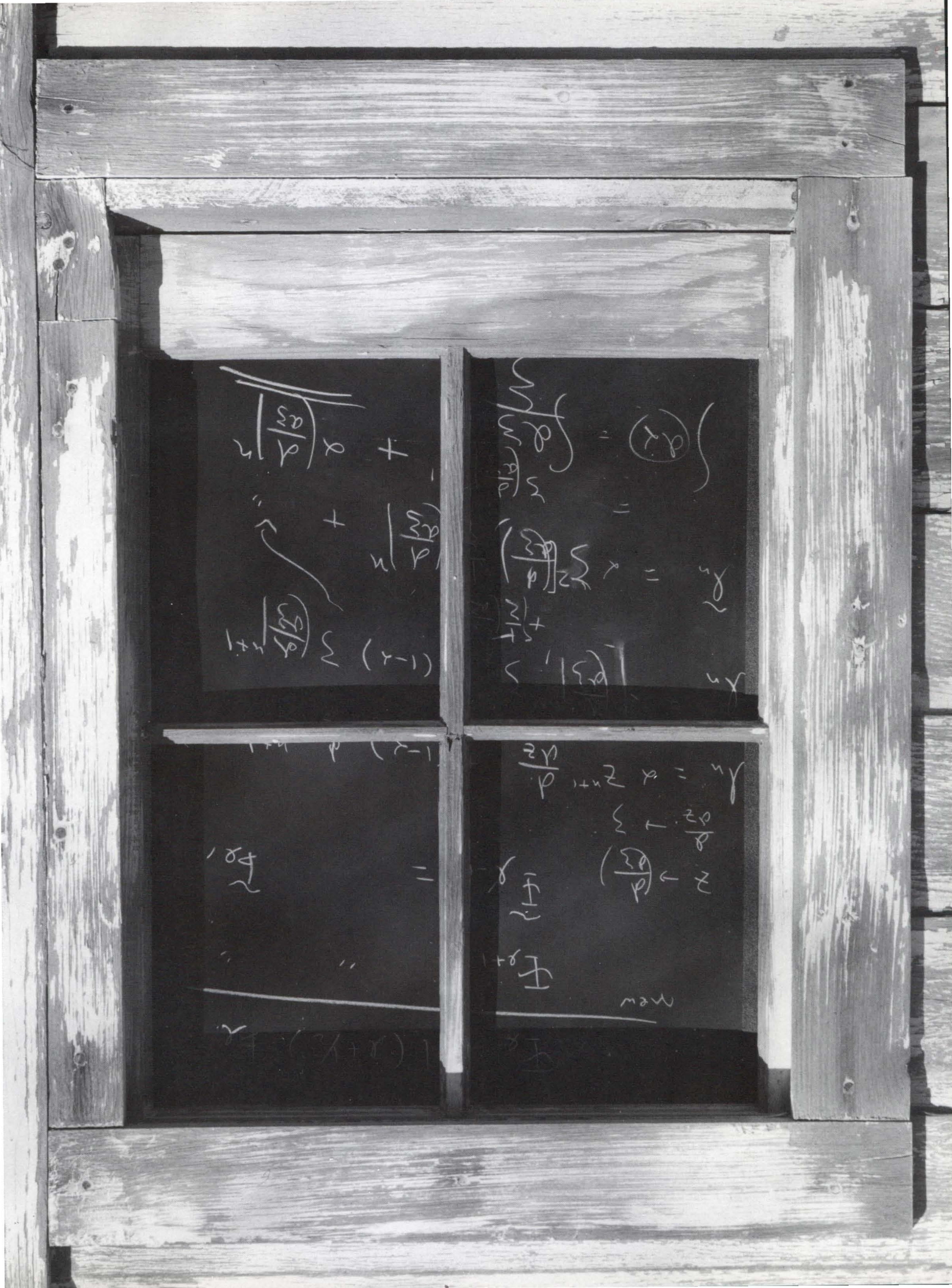


The 20-year history of Theory at Fermilab will be told elsewhere but will surely include the key contribution to modern-day superstring theory by Pierre Raymond, working in the Village in the early seventies. Since then, Theoretical Physics has flourished in the prairie and the group has had a very high order of productivity in 1987 across a very broad spectrum of topics, leaning (more or less) toward the high-energy phenomenology appropriate to an accelerator laboratory. In fact, the Director reluctantly must confirm the reports emanating from the third floor of Wilson Hall that this is one of the very best theoretical physics groups in the world, devoted to particles and fields. For example, if the SSC would come to Fermilab, as our Governor insists, it is possible that, unlike all other parts of the Laboratory, Theory can handle the factor of 20 with no sweat. Two major happenings are described below: the defection of Chairman Chris Quigg to the SSC Central Design Group and his replacement by Bill Bardeen, and the formation of a joint venture of Theory and the ACP to build a Theory Engine.

What is a Theory Engine? Does it replace theorists? Is it a theorist with humility? Is that a contradiction in terms? Tune in to Bardeen's report:

The Theoretical Physics Department

William A. Bardeen

This year has been a time of transition for the Theoretical Physics Department. Chris Quigg has provided the leadership for the Theory Department for the past ten years since the death of Ben Lee, the first permanent Head of the Department. Quigg has now gone on leave from Fermilab to assume the challenge of the Superconducting Super Collider project as an Associate Director of the Central Design Group in Berkeley. His contributions to all aspects of the Laboratory will be missed during his absence. Bill Bardeen has been named as the new Head of the Theory Department.

The Theoretical Physics Department plays an essential role in the intellectual life of the Laboratory. Its members have contributed to a broad spectrum of elementary particle physics research from the practical to the esoteric. The group now consists of seven permanent members, four Associate Scientists with five-year appointments, and eight postdoctoral Research Associates. Fermilab provides a focus for the research of several faculty members from surrounding universities as well as a number of long-term visitors from universities and institutes around the world. In addition, Fermilab has its traditional theory visitor's program operating throughout the year which provides hospitality and support for a large number of physicists from the local, national, and international physics communities. This program makes Fermilab a central crossroads for the exchange of new theoretical developments. It also provides an opportunity for useful interaction between the theoretical community and the many experimental physicists who find Fermilab the focus of their research.

The Theoretical Physics Department organizes the weekly Theoretical Physics and Joint Experimental-Theoretical Physics Seminars. The group also organizes an annual winter workshop for the study of new theoretical developments of mutual interest.

For this past winter, the topics included conformal symmetry, conformal field theory, and orbifold compactification in string theories. Members of the group contribute to the Fermilab Academic Lecture Series which is addressed to the broader physics community at Fermilab.

The successful running of the Fermilab TEVATRON program in both the fixed-target and the Collider modes has emphasized the need for accurate calculations of processes which contribute to this new range of physical phenomena. The stage for this physics was set by the work of Quigg and Eichten in their analysis of the expectations for physical processes from TEVATRON energies to those of the SSC. A particular interest at Fermilab has been the study of hadroproduction and photoproduction of heavy flavors from charm and bottom to top quarks. The expectations for heavy quark production were analyzed by Quigg and Ellis. . Recently, Ellis has extended the analysis of these processes to include the first nonleading QCD (quantum chromodynamics) corrections. He has found that these corrections will have a significant effect on the observable cross sections. Possible mechanisms for the discovery of the elusive Higgs boson have been analyzed by Ellis, Hinchliffe, Soldate, and van der Bij. Mangano, Parke, and Xu have adapted known string amplitudes to the calculation of QCD parton cross sections for the production of gluons and quarks which could have important phenomenological applications as well as revealing new insights on the structure of QCD.

Strong-interaction physics also plays a role in using experimental information on weak processes to determine the fundamental parameters of the electroweak theory. Bardeen has used the large N_c (string) limit of QCD to compute the weak matrix elements needed to understand the $\Delta I=1/2$ rule in kaon decays and the B parameter of K^0-$\overline{K}^0$ mixing. This physics is also the focus of QCD calculations using lattice methods.

During the past year, the Theory Group and the Fermilab Advanced Computer Program have formed a collaboration to create a large-scale, highly parallel supercomputer for lattice gauge theory calculations. This effort emphasizes the programming flexibility needed for algorithm development and a wide variety of physics applications. Eichten, Thacker, Mackenzie, and Hockney have all contributed to the Theory Group's participation in this project. With the proper support, Fermilab can be expected to provide essential leadership for the development and application of numerical methods to physical problems. At present, the VAX facilities at Fermilab have been exploited by Thacker, Eichten, and Sexton for using lattice gauge theory methods to analyze the structure of heavy quark systems, baryon potentials, and the heavy-light systems relevant to B-meson physics.

More formal aspects of current research have involved a variety of problems associated with the fundamental string theories. Taylor and Itoyama have studied nonsupersymmetric, four-dimensional string theories where the cosmological constant is dynamically suppressed. Taylor has developed new mechanisms for supersymmetry breaking in asymmetric orbifold models which lead to chiral string theories with vanishing cosmological constant. Itoyama has studied multiparticle amplitudes in superstring theories and has developed a picture of string field theory using a Bogoliubov transformation approach. He and Thacker have discovered a lattice Virosoro algebra in certain two-dimensional integrable lattice systems which may be related to the application of conformal field theory to strings. Two-dimensional critical systems have also been explored by Arnold and Mattis with an emphasis on the structure of the Green's functions of the theory. Mangano has worked with others to develop the connection between strings and index theory on infinite dimensional manifolds by analogy to Atiyah-Singer index theorems used in conventional field theory.

The interface between astrophysics, cosmology, and particle physics has been a productive area of research particularly at Fermilab with the proximity of the Theoretical Astrophysics Group. Hill has focused his research on the physical properties of superconducting cosmic strings which may arise in grand unified theories. His collaborations with Hodges, Lee, Schramm, Turner, Walker, and Widrow have led to proposals for several new observational signatures of cosmic strings as well as clarifications of issues related to the fundamental dynamics of these objects. Hill has also continued his research on quantum field theory in curved space-time. McLerran and Arnold have studied the physics of baryon number violating processes using sphalerons which may occur at temperatures in the early Universe of only a few TeV. They have also collaborated on possible mechanisms to explain Cygnus X-3 air-shower events. McLerran has studied the chiral phase transition in QCD with its implications for nucleosynthesis as well as a variety of issues related to heavy-ion collisions. Reno and Quigg have studied ultrahigh-energy neutrinos and their possible detection on Earth. Reno and Seckel have completed an extensive study of the effects of injecting hadrons during primordial nucleosynthesis. The complete phenomenology of the effects of resonant neutrino oscillations in the sun was analyzed by Parke and Walker with predictions for both the chlorine and gallium experiments.

The future research of the Theoretical Physics Department will continue to involve a broad spectrum of physics issues from questions of direct phenomenological interest to the more formal aspects of quantum field theory and superstrings.

Almost every thinking person has, at some time, stared at the night sky and asked the age-old questions: What is out there? How did it all come about? Where are we going? Very few have stared at a table of particles and asked the equivalent questions. Yet the two activities are now so intimately joined that it is natural for particle physicists to lay claim to the night sky in order to explain their work to their in-laws, the general public, congressional visitors, etc. The institutionalized particle-cosmology interface is represented by the Fermilab Theoretical Astrophysics Group, headed by Edward (Rocky) Kolb and Michael Turner, co-founders of the Warrenville Astrophysical Society. Rocky Kolb, an expert on the structure of the Universe before there was a Universe, tells his story here. It was about Rocky that Lucretius wrote (99-55 B.C., in *The Nature of the Universe*):

> "He has ventured far beyond the flaming ramparts of the world and in mind and spirit traversed the boundless universe."

Venture beyond, Dr. Kolb:

The Theoretical Astrophysics Group

Edward W. Kolb

During 1987, members of the Fermilab Astrophysics Group have contributed to a broad range of topics at the interface of elementary particle physics and astrophysics. The group has grown in 1987. Andy Albrecht from Los Alamos National Laboratory and Neil Turok from Imperial College (London) have joined as Associate Scientists. New postdocs are Ed Copeland (also from Imperial College) and Angela Olinto (from Massachusetts Institute of Technology). Phillipe Jetzer was awarded a Swiss National Science Foundation fellowship to study abroad and has chosen to spend the year visiting our group. He joins our other foreign fellows, Sirley Marques, supported by a Brazilian CNPq fellowship, and Frederique Grassi, supported by a French CNRS fellowship. Together with permanent staff Kolb and Turner, frequent visitor David Schramm from the University of Chicago, four continuing postdocs (David Bennett, Albert Stebbins, Jamie Stein-Schabes, and Marcelo Gleiser), and the continued collaboration with the Theoretical Physics Group, Fermilab now boasts one of the most active (and best!) groups working at the interface of high-energy physics and cosmology.

At the end of 1986 the group sponsored a three-day workshop on cosmic strings. Following the cosmic-string workshop, the group was active in organizing the 13th Texas Symposium on Relativistic Astrophysics held in Chicago. In April 1987, the group sponsored another small workshop on Quantum Cosmology (organized in collaboration with Chris Hill of the Theory Group). The workshop brought together a remarkable array of talent to study the quantum origin of the Universe. Murray Gell-Mann from Caltech, Stephen

← Two Galaxies and Snail Landscape, *acrylic painting by Nancy Peoples, 1987.*

Hawking from the University of Cambridge, and Yakov Zel'dovich and Alexi Starobinskii from the Soviet Union were but a few of the people in attendance. The Astrophysics Group intends to continue to hold small informal workshops on topics in particle cosmology.

The Astrophysics Group has a very active visitor program. Over 40 cosmologists from throughout the world visited Fermilab to give seminars and colloquia, collaborate with members of the group, etc. In November we were fortunate to be able to host the visit of Andrei Linde of the Lebedev Institute in Moscow. Linde gave several seminars and a colloquium during his brief visit.

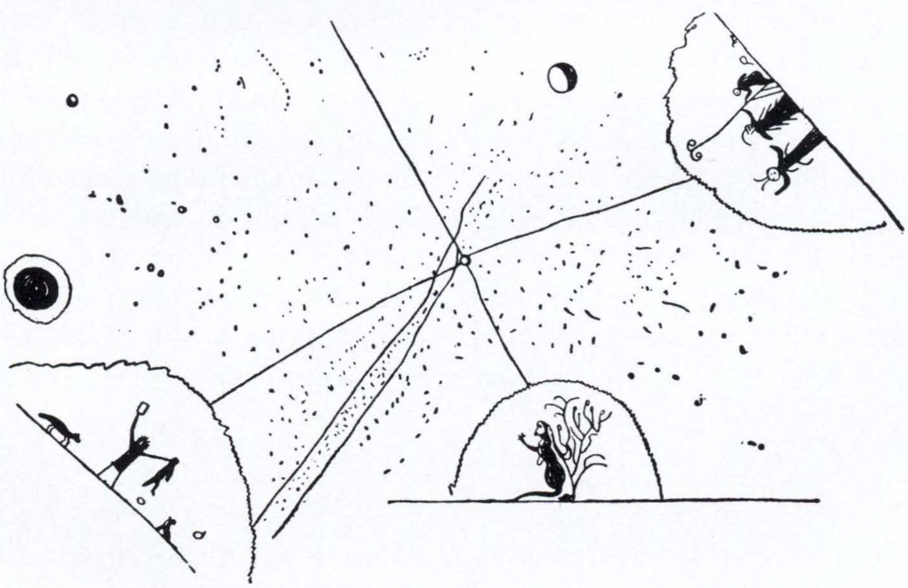
During the year the symbiotic relationship of the Astrophysics and Theoretical Physics Groups continued to grow. Chris Hill of the Theory Group collaborated with Michael Turner and students on a series of papers on superconducting cosmic strings. Kimyeong Lee, a postdoc in the Theory Group, participated with Kolb and Holman in a study of Wilson-loop instantons. Van der Bij (also a postdoc in the Theory Group) worked with Gleiser on boson stars. Mark Rubin (another Theory postdoc) studied vacuum energies with Gleiser and Jetzer. The combination of the two groups creates an intellectual ferment that pervades the third floor and, hopefully, leaks out to the rest of the Laboratory.

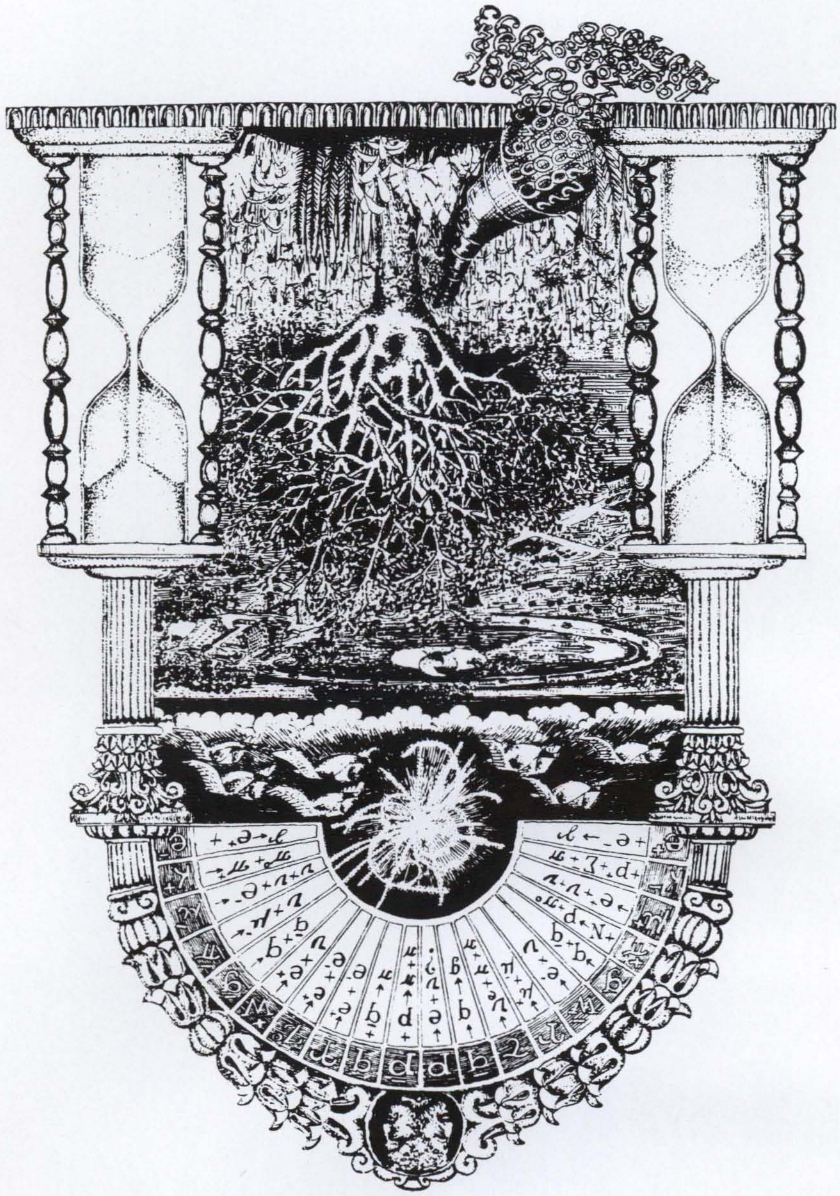
Cosmic strings, inflation, dark matter, and extra dimensions all continue to be active areas of research of the group. In addition to these areas, members of our group have worked on the implications of the celestial star of the year, Supernova 1987A.

Note: As this report was going to press, we learned of two occurrences, one occasion for rejoicing, the other for sorrow, that relate to the Fermilab astrophysics program.

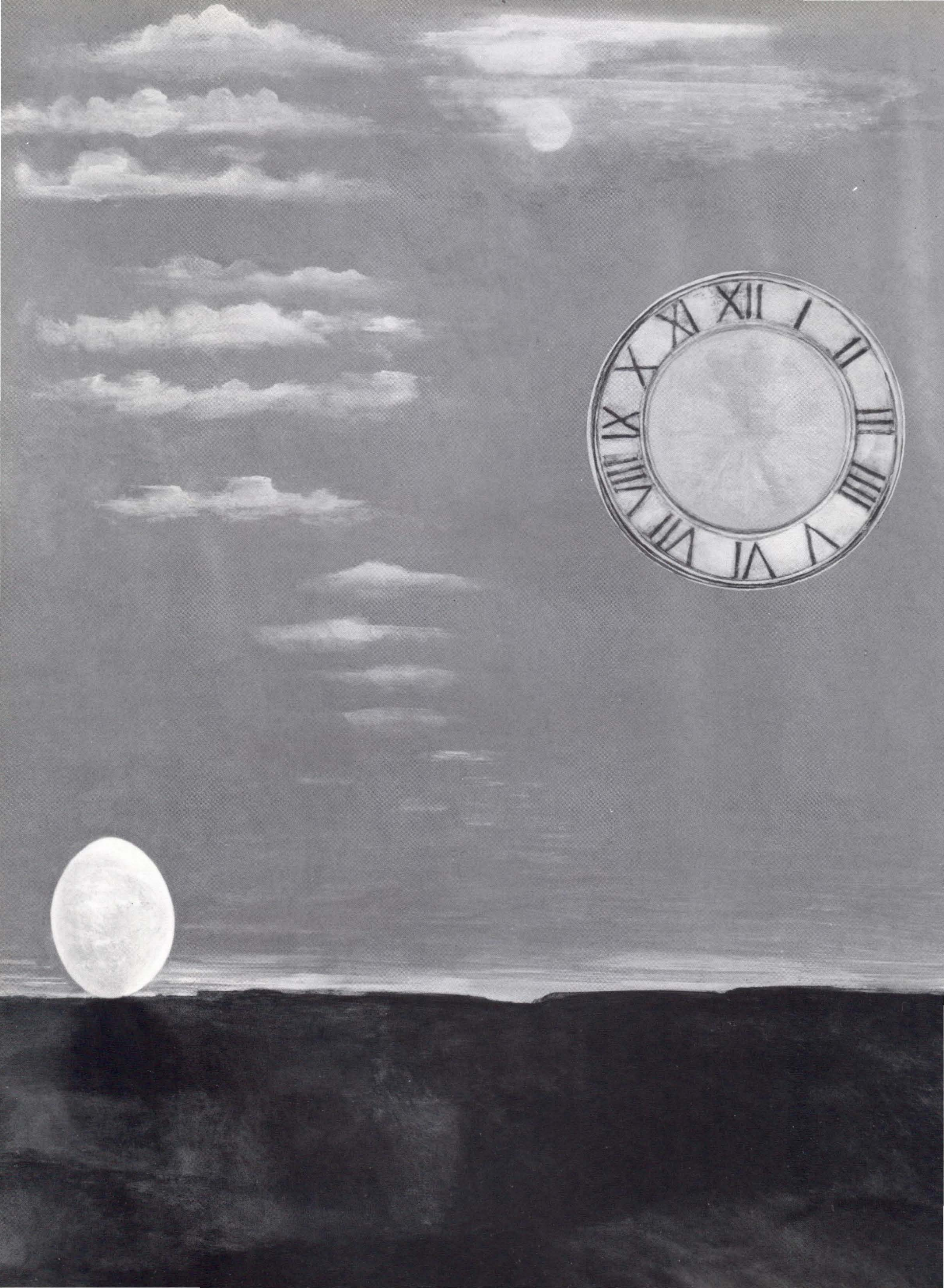
The good news is that Fermilab was awarded a three-year grant from NASA as part of the Astrophysics Theory Program from the Office of Space Science and Applications.

Our sorrow springs from the news that the visit by Yakov B. Zel'dovich to Fermilab last May will be his last. The sudden death of Zel'dovich on December 2, 1987, is a tragic loss to physics and astrophysics. We at Fermilab are fortunate to have been witness to his love for physics and life.





← The sky and the four inferior worlds. Tschutetschi drawing from east Siberia. Recognizable are the Pleiades (top), the Milky Way (below), and the crescent of Venus (left, top) which cannot be observed by average eyesight.



A Table of Organization of Fermilab is a thing of marvelous simplicity. There is, of course, the Directorate and there are two operating divisions, plus the viscera and connective tissue of the support and administrative sections. We have heard from the Accelerator Division. Ken Stanfield manages the largest group, the Research Division (RD). The RD simply runs the fixed-target program with its 14 beamlines. Well, it also houses the CDF detector. Oh, and the Central Computer and its ACP partner. Yes, it also manages (haw!) the theorists and interacts with the 1300 or so users who look to it to supplement poverty-stricken university contracts. That's all, except the particle-detector grouplet, PREP, and a variety of specialized fabrication facilities. A highly selected résumé follows.

The Research Division

Fixed-Target Activities and Research Division Support Departments

Introduction

Peter H. Garbincius and
Kenneth C. Stanfield

In addition to providing a home for CDF, Theory, the Computing Department, ACP, and some direct support for all Collider experiments, the Research Division provides the resources for the installation and operation of the fixed-target facilities. In 1987, a major activity of the Division was to assist the fixed-target users to achieve maximum utilization of the TEVATRON and its new fixed-target facilities. The 1985 run, which was perhaps one of the Laboratory's most successful fixed-target runs ever, did not have the benefit of the full complement of beams including the Wide Band Photon beam, the New Muon beam, the MWest Pion beam, or the MP Polarized beam. A very large effort was expended by the Research Division in preparing all beams and detectors for the 1987 run which began successfully in the early summer months.

Perhaps the best way to get a measure of the progress is to examine the fixed-target program before and after the completion of the TEV II project. Upon recalling the fixed-target program in the days before the TEV II project, one is struck by the contrast with today's beams and detectors as well as the improved level of support. While there were 17 detectors on the floor in 1979 and 16 in 1987, the sophistication and size of today's detectors has grown enormously as is required by the difficulty and scope of the experiments undertaken. Only one measure of this is that the PREP inventory alone as risen from 8000 items to 30,000 items over this period.

The complexity and capabilities of the beamlines have also increased dramatically. In order to transport 1-TeV beams, 50 superconducting magnets in 10 bend strings have been installed. Overall, there are

← Equinox, *acrylic painting by Nancy Peoples, 1983.*

nine liquid-helium refrigeration systems in operation in the experimental areas. In addition, the number of conventional components in beamlines have increased by 25%, so that there are now 623 conventional magnets and 371 55-kW, 150-kW, 240-kW, and 500-kW power supplies. The number of slow-spill primary beams has risen from 6 to 10, and the number of high-intensity target stations from 6 to 11. All of this has been accomplished by the Research Division Support Departments in collaboration with the fixed-target users with the same number of people as were available in 1979 for the support of a much smaller program. For this, the leadership and membership of each of these departments deserves congratulations.

An ingredient too often omitted from an analysis of scientific progress is the important role that the non-scientists (craftsmen, engineers, secretaries, technicians, etc.) play. In what follows, this role becomes clear as each of the department heads gives his own perspective on the accomplishments and events of the year.

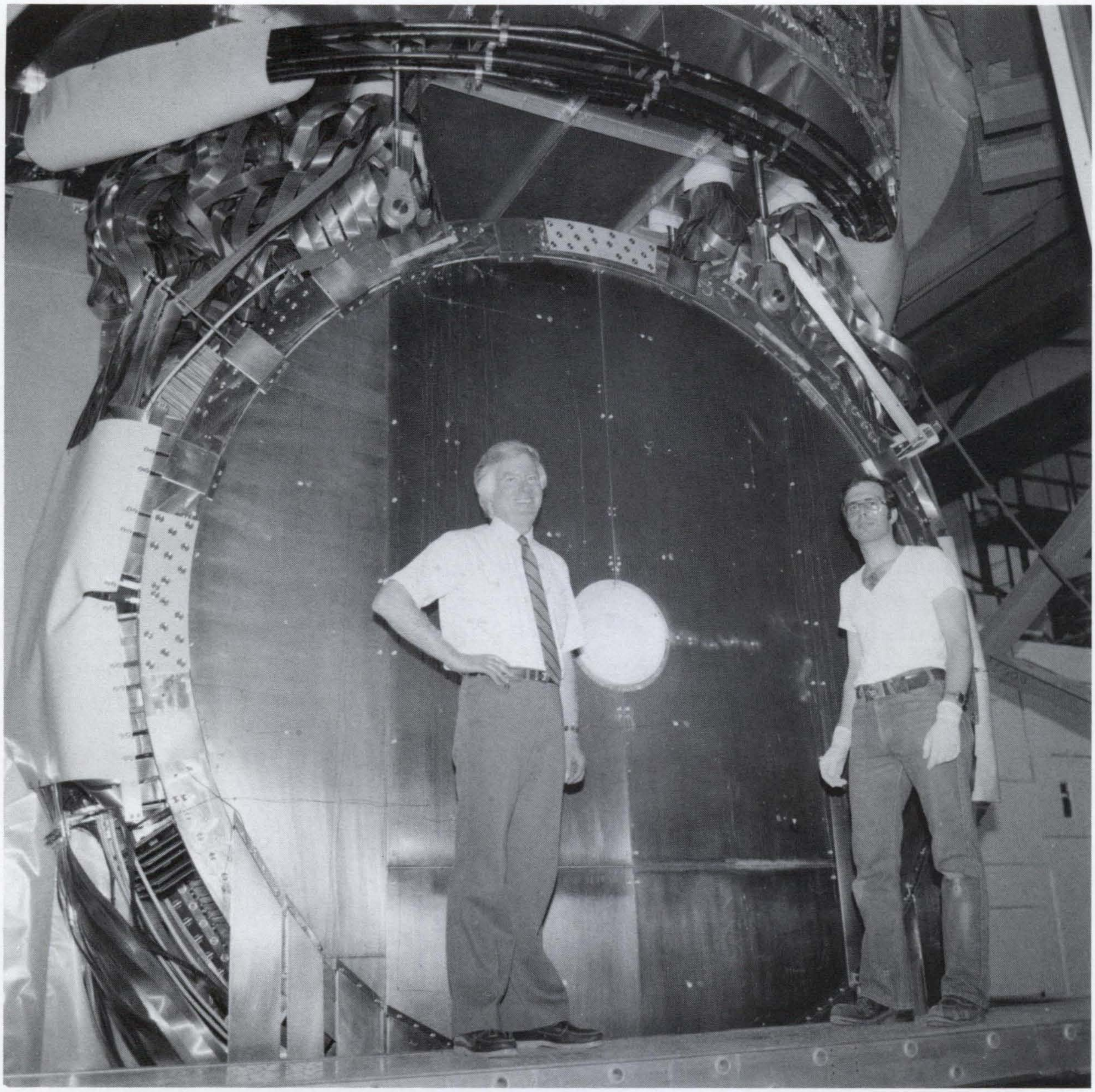
The Research Facilities Department

David F. Anderson, Stephen Pordes, and Raymond Stefanski

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

The Beams Group has devoted much of the year to turning on new beamlines and experiments during the fixed-target run. In particular, a new test beam was commissioned in the Meson Area to be used by CDF and T-775. The M-West primary and secondary beams were brought up for the first time for use by experiments 706 and 672. The M-Polarized beamline was also run for the first time and served as a calibration and test beam for E-704. In the Neutrino Area, a new pion beam was commissioned and ran at 600 GeV for E-653. In the Proton Area, the new P-Center primary beam was run for E-756. Also, the N-Muon beam and PB (Wideband Photon beam) were brought up for the first data runs. (These beams were commissioned in the 1985 run for initial turn-on runs.) In addition, the group was responsible for the initial startup of the well-established beamlines such as the M-Center neutral beam, the neutrino beams, the P-East and P-West beams and other test beams.

The Beams Group was also involved in the design of beam upgrades for P-West (to transport machine-intensity protons to the enclosure PW8), and the development of a muon beam in N-East for P-782. For the far future, calculations were carried out for the development of new ideas for very-high-yield B-physics experiments and beams. Members of the Beams Group have taken major roles in the development of software systems for the cryogenic control system, the applications programs for the beamline control systems, and for support software for the Alignment Group.



Paul Slattery (left) and George Ginther, of the University of Rochester, in front of the detector for the E-706 liquid-argon calorimeter.

The Group also maintains and improves the beamline design software packages called TRANSPORT, TURTLE, and HALO.

A new group has been organized in collaboration with the Electronics/Electrical Department that will provide specifications for custom integrated circuit design. This group will develop front-end electronics for E-771 which should have its first run in the P-West beamline in 1989. This group is also involved in the development of new absolute beam-intensity monitors, remotely digitized visual beam detectors, and other beam-detectors development work.

The Facilities Support Group is responsible for the operation of experimental facilities within the Research Division. These include the Ziptrack magnet field measurement apparatus, the EMI detector at the 15-ft Bubble Chamber, and the Tagged Photon Lab Spectrometer. The group also provides mechanical support to experiments with the staff in Lab 6. During the year a new design of the Ziptrack was implemented to improve data collection and reliability. A CCD (charge-coupled device) camera-based system was installed at the 15-ft Bubble Chamber to monitor the laser beam for holographic photography. The group also assembled the beam-momentum tagging system for CDF in the M-Test beam and provided electronics support of various specialized NIM and CAMAC modules to experiments. The Facilities Support Group supplied construction and operational support for the spectrometer systems at the M-West experimental hall, and for the E-706 liquid-argon calorimeter. In addition, they built chamber and counter gas systems for several experiments and were substantially involved in the installation of E-760 in the Pbar Experimental Hall at A0.

The Particle Detector Group develops new particle detection techniques that will be used in future high-energy physics (HEP) experiments. The work this year includes the development of new scintillating plastics, measurement of the light yield from BaF_2 that would be used for calorimetry, the development of a low-pressure photosensitive wire-chamber readout, work on electrostatic imaging, and the measurement of high-rate effects in warm liquids. A study of the effect of doping liquid argon was also carried out.

The Cryogenics Department

C. Thornton Murphy

The Cryogenics Department is responsible for all aspects of cryogenic systems in the Research Division. This includes all superconducting magnets, liquid-hydrogen targets, liquid-argon calorimeters, and the hydrogen-neon bubble chamber.

Highlights of this year were a roughly equal measure of commissioning new systems and successfully operating old systems. The new systems commissioned this year were the E-706 liquid argon calorimeter (in collaboration with the experimenters), the Tohoku Bubble Chamber CRl 1400 helium refrigerator for the superconducting coil, a much improved holographics optics system for the 15-ft Bubble Chamber, and liquid-deuterium targets for E-772 and E-665. The E-665 target had unique technical and safety aspects necessary to allow it to operate in the middle of the very high electrical field of a streamer chamber. The old systems, which had many months of operations, were the two superconducting analysis magnets in the Muon Laboratory for E-665, the 15-ft hydrogen-neon bubble chamber, and three liquid-helium plants which cool nine independent strings of superconducting beamline magnets. The CDF superconducting solenoid and associated helium refrigerator operated very reliably during the 1987 Collider run. The cryogenics systems for both the Collider and the fixed-target runs were remarkably more reliable than in 1986, with significantly less beam time lost to experimenters. Planning and design was begun on several future projects, including the installation of the Big Test Beam Calorimeter for the D0 experiment, modifications of test stands for SSC prototype superconducting magnets, and conceptual design of a large superconducting solenoid for SSC experiments. A major upgrade of computer controls for cryogenic systems was begun. When the system is fully implemented in 1988, this should greatly improve reliability of the systems. Various other operational and safety improvements to the CDF and beamline systems were begun and, in some cases, implemented. Finally, the small R&D effort on the effectiveness of various numbers of layers of superinsulation was extended from liquid-nitrogen temperature to liquid-helium temperature and brought to a conclusion.

The Electronics/Electrical Department

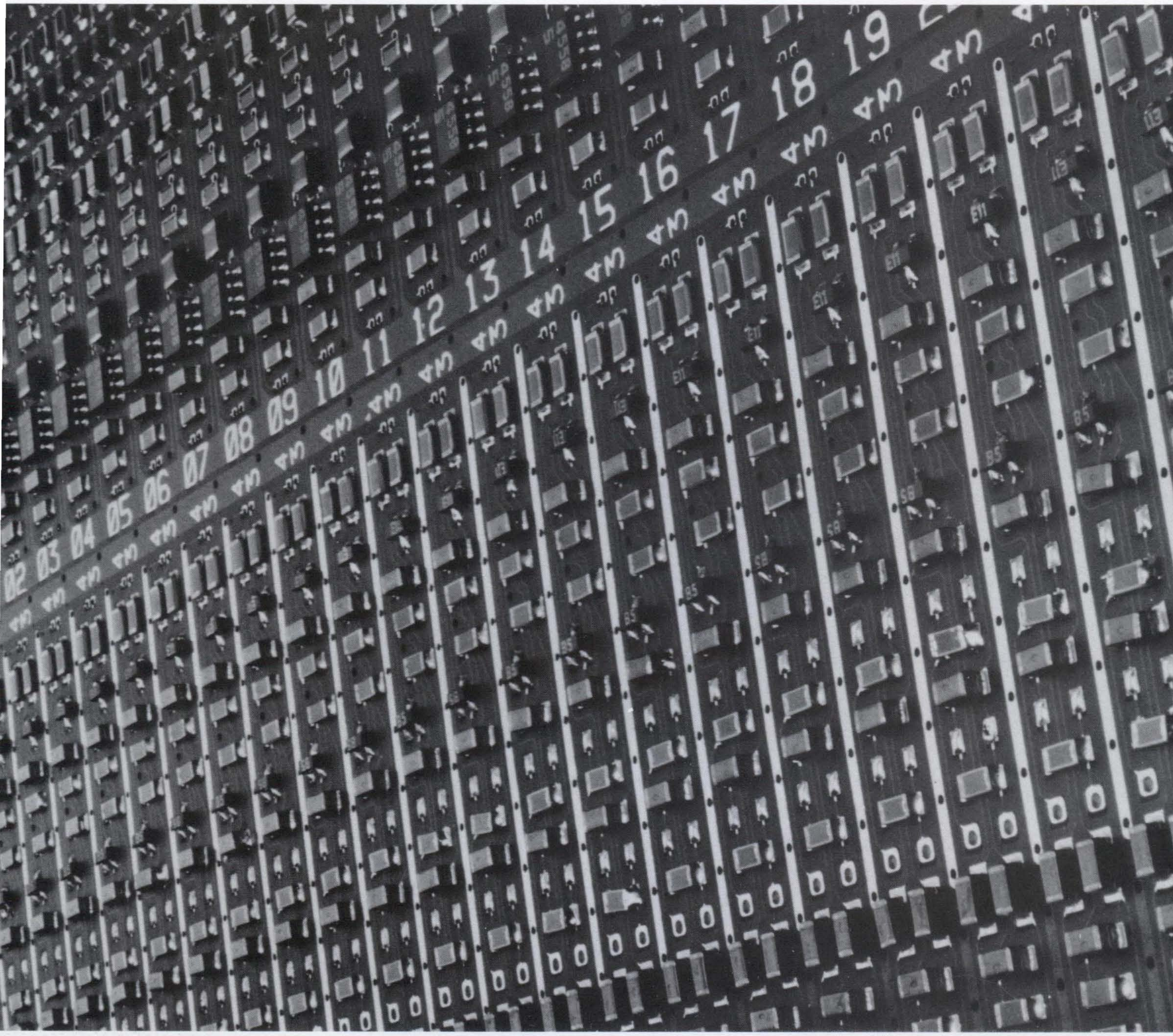
Robert C. Trendler

The Electronics/Electrical (E/E) Department is responsible for much of the design, development, implementation, and maintenance of the electronic and electrical devices used to bring beams to the experiments. These include beamline controls, radiation and electrical interlocks, power supplies, beam instrumentation, and safety electronics (oxygen-deficiency hazard [ODH] and temperature monitoring). Additionally, considerable direct support to the experimental groups is provided. Some examples are: the E-687 calorimeter position control, and "quiet" power designs for E-687, E-665 and others. Other examples include the E-705 "cluster finder" modifications, and the E-772 hydrogen target position controller.

As a result of this broad responsibility, the E/E Department also actively supports most of the other departments in the Research Division. Controls for the Cryogenics Department, motor controls and position readouts for the Mechanical Department, electrical design for the Site-Operations Department, FASTBUS design and maintenance support to the CDF Department, and engineering design support for the Research Facilities Department are but a few examples of this type of activity. Also, the E/E Department is responsible for the hardware development component of the data acquisition collaboration with the Computing Department.

To accomplish its mission, the E/E Department is organized into four groups: the Power Systems and Interlock Group, the Data Systems Group, the Electronics and Instrumentation Development Group, and the Controls Group. There are both design and maintenance components associated with each group's work. Also, each of the groups have access to several commercially procured computer-aided design systems to assist them.

The skills and tools engineers need have been rapidly changing for some years. In particular, computer-assisted design tools are now essential for our engineers to do their work. The complex circuits required by the high-energy physics program must be simulated by computer to prove the design. Printed circuit-board layouts are now completed on specialized computer-



A portion of a typical multichannel amplifier-shaper-discriminator circuit board like those used in the Collider Detector at Fermilab. Surface-mount technology advanced by the Electronics/Electrical Department of the Fermilab Research Division was used to place the 220 components on the board's surface.

assisted work stations featuring autorouting capability. Application-specific integrated circuits (ASIC) are now part of the arsenal of engineering tools. The E/E Department is working closely with Fermilab physicists, vendors, other laboratories, and various university groups to continue to develop this capability.

The major activity for the E/E Department this year was our contribution to the enormous Research Division effort required to bring the fixed-target beamlines and the experiments into successful operation. Virtually every person in the E/E Department was totally involved in preparing their systems for operation. The effort was well worthwhile; the experimental area start-up was very successful, and subsequent operation has been very reliable. Even now, well into the run, considerable effort is still required to meet the changing needs of the experiments. Other highlights for this year include: significant progress on the electronics for the muon detector for the D0 colliding-beams experiment, commissioning of ODH monitoring in designated areas; completion of a stepping motor controller that has commercial promise; the integration of the cryogenic control system with the EPICURE control system upgrade; evaluation and characterization of several CMOS silicon-strip detector integrated circuit chips for the CDF Department; completion of several FASTBUS interface boards for CDF; the use of the Video Data Acquisition System for experiment E-687 and to make observations of Halley's comet with University of Notre Dame physicists; the completion of the installation of new radiation safety systems in high-priority areas; and finally, electrical design for the Loma Linda medical accelerator project.

The Mechanical Department

John F. Lindberg

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

Some highlights during the past year were the installation of the new M-West beamline. Downstream in the new M-West Experimental Hall, the Mechanical Department completed the installation of the analysis magnet and liquid argon calorimeter for E-706 as well as the installation of experiment E-672, which is also located in the M-West Hall and runs simultaneously with E-706. The M-Test beamline was installed and is currently serving as a test beam for CDF and the T-755 streamer chamber tests. Also in the Meson Area, the new M-Polarized beam is now operational, and the first experiment scheduled to use this new beam, Experiment 704, will be commissioned at the end of this current running period.

In the Neutrino Area, the N-West test beam was modified and is being used to calibrate equipment from the collider at D0. Modifications to the N-Center beam, the Quad Triplet Train, were completed, and the beam is currently being operated. A major new beamline, the New Muon beamline, was also completed this year.

All beamlines in the Proton Area are now completed including the new Wide-band Photon beam which services E-687, the first experiment to use this new facility. All other beams in the Proton Area are currently operating for this fixed-target run.

The Site-Operations Department

William J. Spalding

The various groups of the Site-Operations Department are responsible for the installation and support of the fixed-target experiments and beamlines along with the operation of those beamlines. One of the groups, (the Alignment Group) has a wider sphere of responsibility, providing alignment services for all Divisions and Sections of the Laboratory. At the beginning of this year, the Alignment Group completed the alignment of the accelerator complex, the CDF detector, and the apparatus of the smaller colliding-beams experiments in preparation for the Collider run early in the year. Meanwhile, preparations continued for the fixed-target run to follow. Fifteen beamlines and 19 experiments and test-beam users were installed for this run. Several of these were major mechanical and electrical installation projects and all included extensive modifications and upgrades. The new centralized gas-distribution system for beamline instrumentation, and the 18 LCW and 8 RAW systems were brought online, and the vacuum systems (10.5 miles of vacuum pipe total!) readied.

The Operations Group, along with the beamline physicists of the Research Facilities Department and with the assistance of the various support groups from all departments, commissioned the beamlines to prepare for the fixed-target run. In addition, this group provided help to the Accelerator Division Operations Group and the Collider experiments during the Collider run. When the fixed-target run started in June, most beamlines were fully operational and the others were soon up and running. During the previous fixed-target shutdown, the Operations Group had improved their monitoring and data-logging capabilities, and the documentation system for emergency and safety information and for the documentation on various systems in the beamlines. In addition, a computer-based log-book and information system was developed. The use of this system has improved the flow of information between operating crews and has made up-to-date information on running conditions and problems available to all interested parties, allowing better preparation and follow up for repair and maintenance.

The Safety Group

Donald J. Cossairt

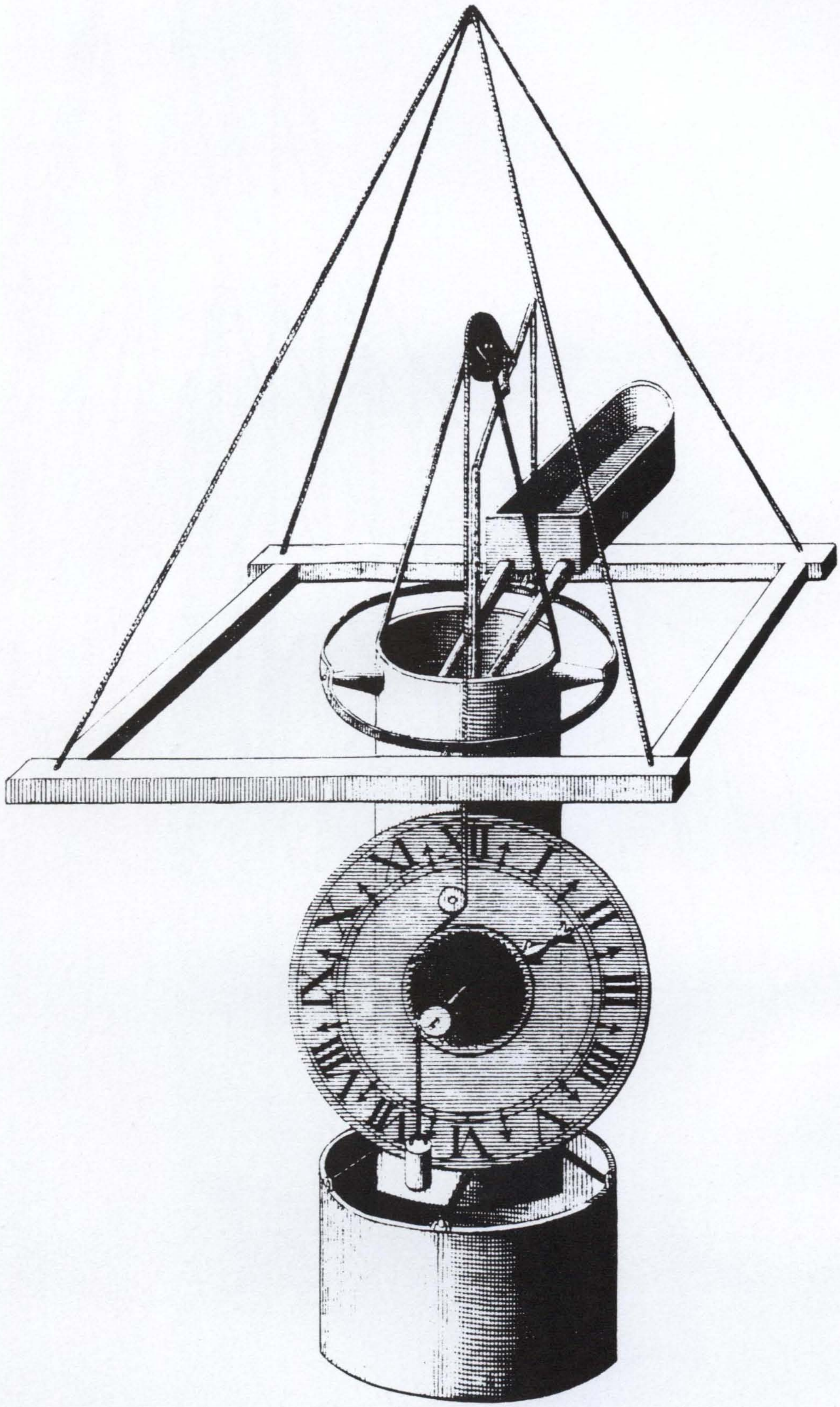
The Safety Group monitors and implements unified safety policies developed in harmony with requirements of the rapidly changing experimental conditions. There is considerable interaction of safety personnel with the rest of the departments in the Research Division when planning present and future experimental operations. One highlight of this year's activities was the development of improved emergency response procedures in the experimental areas. The procedures were designed for complex problems which are caused by a multiplicity of potential hazards within a single building. For example, several of the buildings under Research Division activities contain oxygen-deficiency and radiation hazards, as well as potential hazards resulting from flammable gases.

Also this year, the Safety Group has continued to provide support to the Electronics/Electrical Department's Interlock Group for designing and documenting the radiation interlock systems for this year's high-energy physics run with all interlock test procedures now being developed by the Safety Group. During this year's fixed-target physics run, the Safety Group provided extensive operations support to the Research Division Site-Operations Department through various beam-on and residual radiation surveys. The group also provided support through a radiation-detection tagging system which provides an online readout of detectors that have tripped. The Safety Group also provided extensive surveys and inspections to improve safety performance throughout the Division and an across-the-board safety training program for all Research Division personnel and users.

The Administrative Support Group

Barbara K. Edmonson

The Administrative Support Group (ASG) is comprised of the secretaries and administrative assistants who serve each of the departments in the Research Division. Standardized training in computer skills and office procedures are provided to group members. Group members are, therefore, able to function in any ASG position throughout the Research Division if necessary in order to assist or replace another member of the group. The resulting flexibility also allows the group to provide coordinated, standardized documentation on Division-wide projects. This year the ASG worked with other Research Division Personnel in an orchestrated attempt to provide the high caliber of administrative support necessary to running a large and complicated colliding-beams and fixed-target physics program.



Twenty years ago, physicists armed with slide rules and packing Marchand adding machines, invaded the peaceful farm community of Batavia. Today, the international language of science, understood in every city on the planet large enough to boast a Burger King and a Computerland, is broken FORTAN.

In 1987, Hugh Montgomery counted on his fingers to three, shook them under the Director's nose, and, with his funny accent, said, "That's how long I've been head of the Computing Department. I want to do RESEARCH!!" They don't make Al Brenners anymore, so Jeff Appel took over the Department in mid-stream, so to speak. The gyrations involving transition to TEVATRON-era computing at Fermilab are in mid-course with the new and splendid Wilson-designed Computer Building, the mainframe acquisition, and ACP bubbling up everywhere. Jeff Appel gives the details.

The Computing Department

Jeffrey A. Appel

New architectures dominated the thinking and actions of the Computing Department in 1987. The first ACP system, a new multiprocessor architecture providing a specialized data-crunching facility, moved from the experimental to an operational stage in the Central Computing Facility. Secondly, benchmarking and other activities necessary for the acquisition of a new large-scale, general-purpose scientific computer to replace the old architecture CDC CYBER computers became a major focus for department personnel. At the opposite end of the spectrum, the department took over responsibility for maintenance of personal computers at the Laboratory and also expanded its software consulting in this area. In the experiment data-acquisition area, the FASTBUS capability was extended, and a new architecture involving more parallel readout of the CAMAC electronics and incorporation of VME components was begun. Finally, the stimulating architecture of a nearly complete new building to house many activities of the department excited interest as it rose in the shadow of Wilson Hall. In fact, this new facility is architecturally interesting in its own right.

Much of the new architecture is associated with the Central Computing Upgrade Project, a $25-million Congressional Line Item stretching over four fiscal years. This project is a source of major funding for an upgrade to the Central Computing Facility in support of the high-energy physics program at the Laboratory. It provides funds for a new 74,000-sq-ft building and for the Laboratory's three-prong attack on the scientific computing needs of the research program. These three prongs include the innovative parallel-processing ACP system, the large-scale, general-purpose scientific computer, and an expansion of the heavily interactive front-end system. The bulk of the funds available for 1987 were used for construction of the new building.

The year 1987 saw a change in the quantity and quality of use and support for

← *The "dark side" of the new Central Computing Facility Building.*

the parallel-processing ACP systems in the Computing Department. The number of systems supported in the Department increased from one to four, and the total number of nodes increased from 100 to 215. In place of a single experiment (E-691) making use of the facility, there are now five experiments (E-400, E-687, E-731, E-769, and CDF) vying for use on the various development and production systems. With the growing cluster of ACP elements, the Department has taken an increasing role in the configuration, maintenance, and support for these systems. Their growing use at the Laboratory is confirmation of the wisdom of their inclusion as one of the major facets of computing in the future at Fermilab.

While the ACP systems have a major role to play, it is still limited to the production processing of raw physics data. The major needs for code development, communications, engineering support, physics analysis, and other functions still require major front-end and more general-purpose computing capability. To this end, a VAX 8800 was added to the VAX Cluster front end early in the fiscal year. A much larger effort went into preparing the specifications for the new large-scale scientific computer system, to evaluating vendor responses to these specifications, and in benchmarking the qualified vendor proposals. At the end of the year, the Laboratory was prepared to contract with Systemhouse, Inc., the winning bidder, for an Amdahl 5890/600E-based system. This system includes 4 central processors, 192 Mbytes of memory, 40 Gbytes of disk storage, 16 tape drives, 8 cassette tape drives, printers, and communications. Delivery of the system can begin in the spring, at the time of the completion of the new Central Computing Facility Building.

The Department's responsibility for supporting the administrative IBM computer hardware and system software not only continued unabated, but expanded to include code migration efforts by CDF and development of emulator processor code for another experiment.

New architectures dominated the data-acquisition area of the Computing Department also. The new architecture domination is both in the smaller steps taken for some of the fixed-target experiments running this year and in studies and tests for extending these into the future. Fermilab now supports increased parallelism of both computers and front-end readout. The VAXONLINE software suite was enhanced with more complete coordination of multiple front-end microVAX and PDP-11 computers, and parts or all of the programs were used in over 15 experiments. Four of the fixed-target experiments (E-653, E-705, E-731, and E-769) are also gaining more parallelism in their CAMAC readout by incorporating the Smart Crate Controller which was picked up from one experiment and extended with new Laboratory engineering and software. Some of these experiments read their data into VME-based architectures and others into FASTBUS. Both of these architectures were evaluated during the year for extending the data acquisition capabilities of Fermilab experiments. The Development and Evaluation Group continued to enhance the testing capability with new test stands and software during the year. They also tested VME capabilities in the tape writing, multiple crate, and block data transfer areas. All together, this first year with the full TEVATRON II experimental program installed saw both continued use of the tried systems, installation and use (actually use under fire!) of the enhanced capabilities of the mainline data acquisition effort, and extended use of new architectures.

Communications at the Laboratory, linking the various architectures from Data Acquisition to Central Facility to the remote user community, continued to expand at a very fast rate during 1987. This year's local-area network activities included extension of Ferminet, use of "mini-port selectors" and Ethernet bridging. The extension of Ferminet (Fermilab's broad-band communications backbone) now serves the new experimental areas around the Main Ring and into the Village. Micom miniport selectors were located at experiments to provide local service as well as two-way access to the Central Computing systems and off-site collaborators. The potential capacity of the central port selectors was also increased by 50% in anticipation of the new large-scale scientific computer system. Finally, bridging of all the experimental areas Ethernets was the first step in creating a Lab-wide Ethernet communications backbone.

Fermilab's wide-area networking activities were centered around a large expansion of DECnet to universities and laboratories across the U.S.A. and into Europe. Currently, Fermilab hosts network connections to 19 universities and 6 laboratories of which 24 are running DECnet. DECnet connectivity is approaching world-wide proportions with DECnet connections to Europe via Fermilab to INFN in Bologna, Italy, and CERN via MIT and Asia via LBL to KEK in Japan. To help manage the DECnet activities, a network management system has been installed. It monitors the conditions of the various leased lines and gathers statistics on utilization and errors.

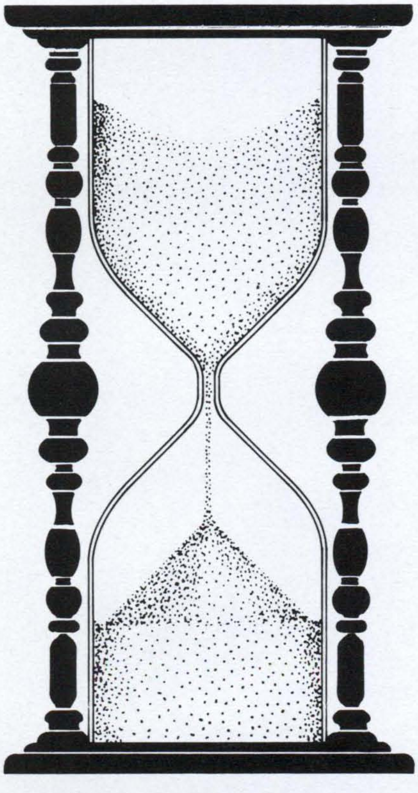
Not only is the distributed processing architecture described above becoming ever more visible, but distributed output is a part of the emerging architectural scene. Remote printing has finally reduced the amount of paper coming through the Central Facility. The remote printing leads to faster turn-around for users and greater user satisfaction.

With all the new architectures in the Department, even the on-going support activities have taken on a new sparkle. The Department has organized 28 courses and 25 Computing Techniques Seminars during the year covering the whole spectrum of Department activities from PC's to data acquisition systems manager training to specialized software packages on the mainframes. The number of papers submitted to conferences is significantly up, and one of the papers was even recognized as one of the three best papers at its conference. Sharing of our software beyond Fermilab is also increasingly important. DOE efforts to encourage technology transfer resulted in the Department sending 15 separate software packages to the National Energy Software Center this year.

Users now have online access to the Fermilab stockroom catalog and telephone directory. Additional new products completed during the year include ZIPMAP for analysis of data taken with the Research Facilities Department's ZIPTRACK magnetic field-mapping apparatus. Work in the Physics Projects Group also included a study of using vector architecture computing for the track reconstruction problem. This study measured the relative effectiveness of a number of supercomputer mainframes to the kind of high-powered scalar machines in wide use today. Finally, a start was made on joint software efforts with CERN on the so-called Physics Analysis Workstation Project.

The major new facilities associated with the TEV II program led to large increases in the Physics Research Equipment Pool (PREP). It grew by approximately 15% in value in 1987. The new FASTBUS hardware now comprises 6% of the electronic modules in the pool, and 12% of its value. Of the 12,000 items which cycled through the Instrument Repair Group this year, 3000 were new items.

In the face of all the new architecture emphasis in 1987, the Computing Department continued to sustain a very large continuing computing load. This load was heavy in both the batch processing and interactive modes. New records were set for interactive computing on the VAX Cluster (210 users during peak hours) and on the IBM system (75 users in peak hours). While the CYBERs finally have seen a drop in interactive use (typically 80 users in peak hours), there were also surges back to the former peak values of 160 users. The 1985 fixed-target experiments were deep in analysis of results during the entire year. Physics publications resulting from this analysis of the run are now in full swing with no immediate letup in sight. The first CDF data run was followed by the completion of the first pass on all the data and first results. The 1987 run of the fixed-target program saw several experiments planning on taking greater than 100 million events each. With the enormous growth in the computing load associated with preparing for and executing the new experiments, it is clear that new architectural approaches are required. Fermilab is making commitments of just this kind to meet these new challenges.



Give a physicist a centimeter and he'll take a kilometer. The Advanced Computer Program is no exception. Just because it has achieved a modicum of success and is being ordered by such labs as Brookhaven, Los Alamos, Oak Ridge, SIN (Switzerland), and SACLAY (France), there follows here delusions of grandeur as our perennial ACP reporter, Tom Nash, soars on wings of imagination. . . or is it? Let the reader not be lulled into the dream world of instant gratification !

The Advanced Computer Program

E. Thomas Nash

At the time, it seemed an awful lot of data: almost 20-million events, each requiring a couple of seconds on Fermilab's big CYBER 175 mainframe. Processing took more than two years, at several big computer centers. The time and effort was an overwhelming obstacle to producing physics. The data came from E-516, the inaugural run on the Tagged Photon Spectrometer, the first of a new generation of high-rate, large solid angle multiparticle spectrometers. These detectors, which now include both fixed-target and high-luminosity colliding-beams experiments, were conceived to study the "new physics" of heavy quarks, gauge bosons, and other high-mass particle states that decay rapidly into many particles. The high multiplicity of particles in new-physics events and their rare occurrence, which necessitates taking huge numbers of events, implied a new scale in the computing required to process them.

The experience with E-516's data made it clear that the new large-detector, open-geometry attack on rare heavy particles required a conceptual change in how computing was to be done. In spring 1982, the Director looked kindly on suggestions for formation of an effort to be known as the Advanced Computer Program. The resulting ACP Multiprocessor has been described extensively in the last three editions of Fermilab's *Annual Report*. "ACP's" are so ubiquitous at Fermilab these days that even the meek are heard suggesting experiments that will take over 10^9 events. Yes, "billions and billions" of them. Experiment 516's 20-million events, which started it all, just don't seem so bad anymore.

The suggestions for billion-event experiments are not frivolous. Experiments have always been conceived when new technology opens up opportunities. Nature yields secrets to good instruments, i.e., ideas and technology. The new computing power represented by ACP Multiprocessors suggests a world of new possibilities if still more computational power is offered. The science has been severely constrained for many years by available computing. It is no wonder that opening the lid a crack releases pressure for more and more processing.

With the certainty that high-energy experiments would effectively apply another large step in computing power, what can we deliver? In the next year or so, an order of magnitude jump in processing cost effectiveness seems assured. This confidence is based on the existence in production of several new so-called RISC (for Reduced Instruction Set Computer) microprocessors. These designs focus on the large fraction of simple instructions that can be executed typically in one 50-60 nanosecond cycle. The complex instructions, which bogged down earlier computers, have been found to be rarely used. In RISC, they are left to software. Simple instructions also make it easier to write highly optimizing compilers. The result: chips with nearly a factor of ten performance improvement in FORTRAN, compared to existing high-performance microprocessors. The ACP is now designing a new CPU model based on the MIPS Computer Systems R2000 RISC chips. If promising, these will be supported by ACP system software, allowing direct procurement competition on a performance-divided-by-cost basis for Fermilab and other high-energy physics needs.

The extraordinary performance of the new designs carries with it the serious problem of getting data in and out of the processors quickly enough. This will not be a difficulty for new CPU's in existing smaller systems or for larger systems running programs like Monte Carlo simulations that require little input data. However, conventional tape drives (and the present host MicroVAX computer) will not be able to feed enough data to systems of more then 10 or 20 new processors running a typical experiment's reconstruction code.

Just as parallel processing was the answer to the processing bottleneck, parallel I/O (Input/Output) seems to be the answer to the new I/O bottleneck. Farms of traditional reel-tape systems, costing $10,000 or so each, however, may not be the best approach. Most promising are the new 8-mm video technology digital tape units which cost about $2000 each and hold the equivalent of a dozen 10-in., 6250 BPI reels on a single 2.5 in. x 3.75 in., $10.00 cassette. Each of these compact devices transfers data at about the same speed as a big tape drive, but the low cost allows us to use many of them in parallel. Beyond the ACP interest in using them for offline reconstruction and analysis processing, these video drives are exciting to experimenters as a particularly convenient way to record data in parallel at improved rates.

New (or upgraded) ACP Multiprocessor configurations will support parallel I/O. The video devices are expected to be driven directly by input and output ranks of ACP CPU's, which should ultimately take over as host from the MicroVAX. New ACP bus interface modules and a high-speed, 16-fold bus crossbar switch will soon be available to interconnect these I/O ranks of CPU's with the processing ranks. A new generation of system software is being designed to support the upgraded ACP Multiprocessor architecture. In due course, it is a goal to incorporate into this software a particularly friendly, graphic human-interface, with histrogramming and statistical tools. This will run on work stations such as those from Sun Microsystems or in the Apple Macintosh series. In this way, the ACP processors will become easily accessible for what consumes so much physicist effort, the actual analysis of reconstructed data.

As the data in a high-energy physics experiment moves from the digitizers to published results, intensive computing is required at each major stop. ACP developments for online triggers, offline reconstruction, and analysis, at first glance, might seem to cover everything. But there is one more essential duty for an experiment: comparison of experimental results with theoretical predictions. Probably the most important new ACP activity in the past year has been aimed at theoretical computing. This is the development of a new Multi Array Processor System (ACP

MAPS) in a collaboration with Fermilab's Theoretical Physics Department.

Until recently, theorists did not require unusual amounts of computing to prepare quantitative predictions from the abstract mathematics of theory. That situation has changed, and it has changed dramatically. Much experimentation these days involves direct measurements of strong interaction effects (tests of quantum chromodynamics, QCD, and mass spectroscopy) or detailed studies of parameters of the electroweak force. Both types of experiment require precise calculations of the theory of the strong forces, QCD. The first, because that is what is being directly measured. The second, because the strong interaction binds quarks and gluons into detectable particles and, thereby, has a significant effect on the electroweak parameters extracted from measurements. The seriousness of this latter problem is demonstrated by measurements of the Kobayashi-Maskawa (K-M) matrix parameters for the electroweak interaction. These are fundamental and critical measurements that are the focus of many heavy-quark experiments. Yet, the uncertainty in these measurements is now dominated in most, if not all, cases by theoretical calculation of strong interaction effects.

Virtually all physicists believe QCD is most likely the correct theory of the strong interactions. Unfortunately, because of the strength of this interaction, the traditional perturbation approximation tools, which have been used so successfully in calculating electromagnetism, cannot be applied to much of what is interesting about QCD. The only alternative appears to be an approach that maps the space-time coordinates of the world within a nucleon onto a mathematical lattice of points. On this lattice it is possible to use a computer to simulate the activities of quarks and gluons following the microscopic laws of QCD. In principle, arbitrarily precise predictions can be obtained. In practice, even rough calculations require colossal amounts of computing. (The reader must have known *this* was coming.) Desperate estimates like "70,000 Cray-years" have been heard, and, for precise calculations, they are true, unless new algorithms are found.

The ACP MAPS project has been driven both by the recognition of this critical need to be able to develop new algorithms and by the traditional hunger for raw, maximally cost-effective, floating-point calculational power. Without sacrificing performance, the processor is flexible and convenient enough to allow algorithm development. It is programmable in high-level languages like FORTRAN and C, though key routines will be microcoded to reach the highest performance levels. Unlike other processors aimed at the lattice gauge problem, the architecture of this one (Fig. 8) allows for flexible non-local communication among the local memory CPU's while they operate in a truly parallel asynchronous array. Each CPU is based on the Weitek XL floating-point chip set and has 10 megabytes of memory. At a cost of about $3000 each in production, they will have a peak performance of 20-million floating-point operations per second. This is nearly two orders of magnitude better than the present cost/performance of the Cray 2 supercomputer.

The theorist-interface software, which allows efficient programs to be prepared quickly, is called CANOPY. It has been developed by the Theoretical Physics Department and the ACP. The architecture of the computer is hidden. The user designs the program in terms of lattice "sites" and "field" variables, not processing nodes.

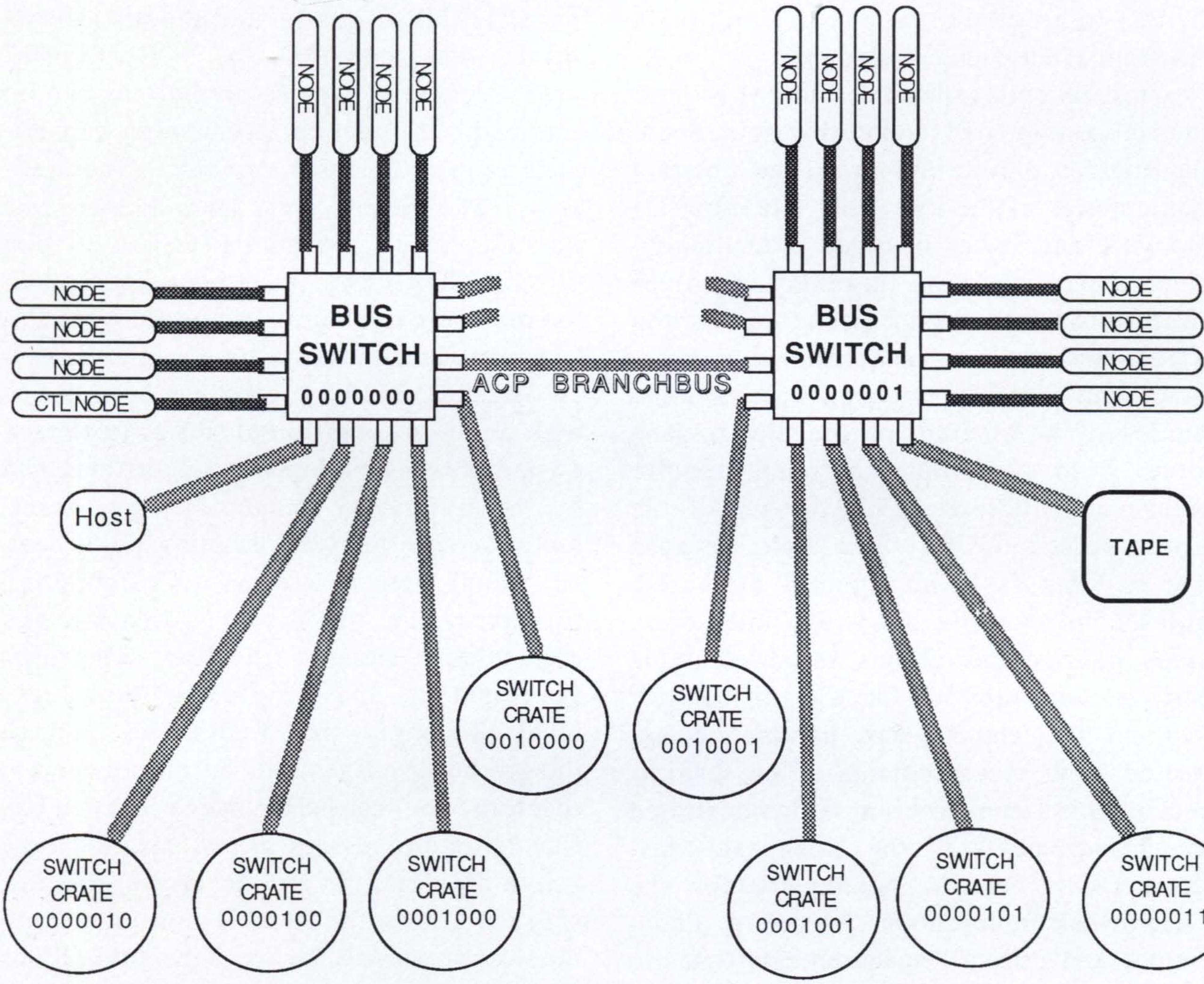


Figure 8. A computer rendering of the ACP Multi Array Processor System (ACP MAPS) 256-node configuration.

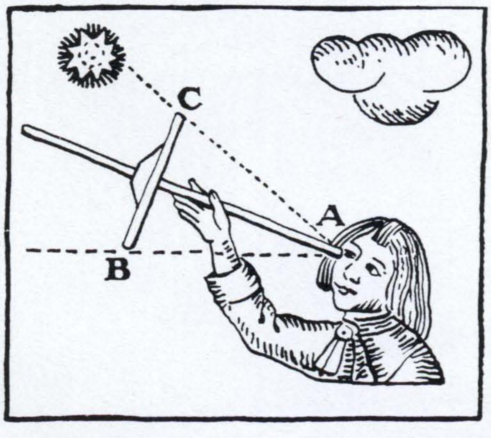
CANOPY automatically allocates sites to nodes following site connectivity instructions provided by the user. Access to variables on other sites (even those on a physically different CPU) is handled automatically when the application program makes requests like GET_FIELD and PUT_FIELD. Most of the basic system routines will be microcoded, as will certain heavily used physics activities, like SU3_MULTIPLY. In this way, it is hoped, the theorist can operate entirely from a flexible and readable high-level programming language platform and still obtain nearly all the raw computer performance that technology can deliver.

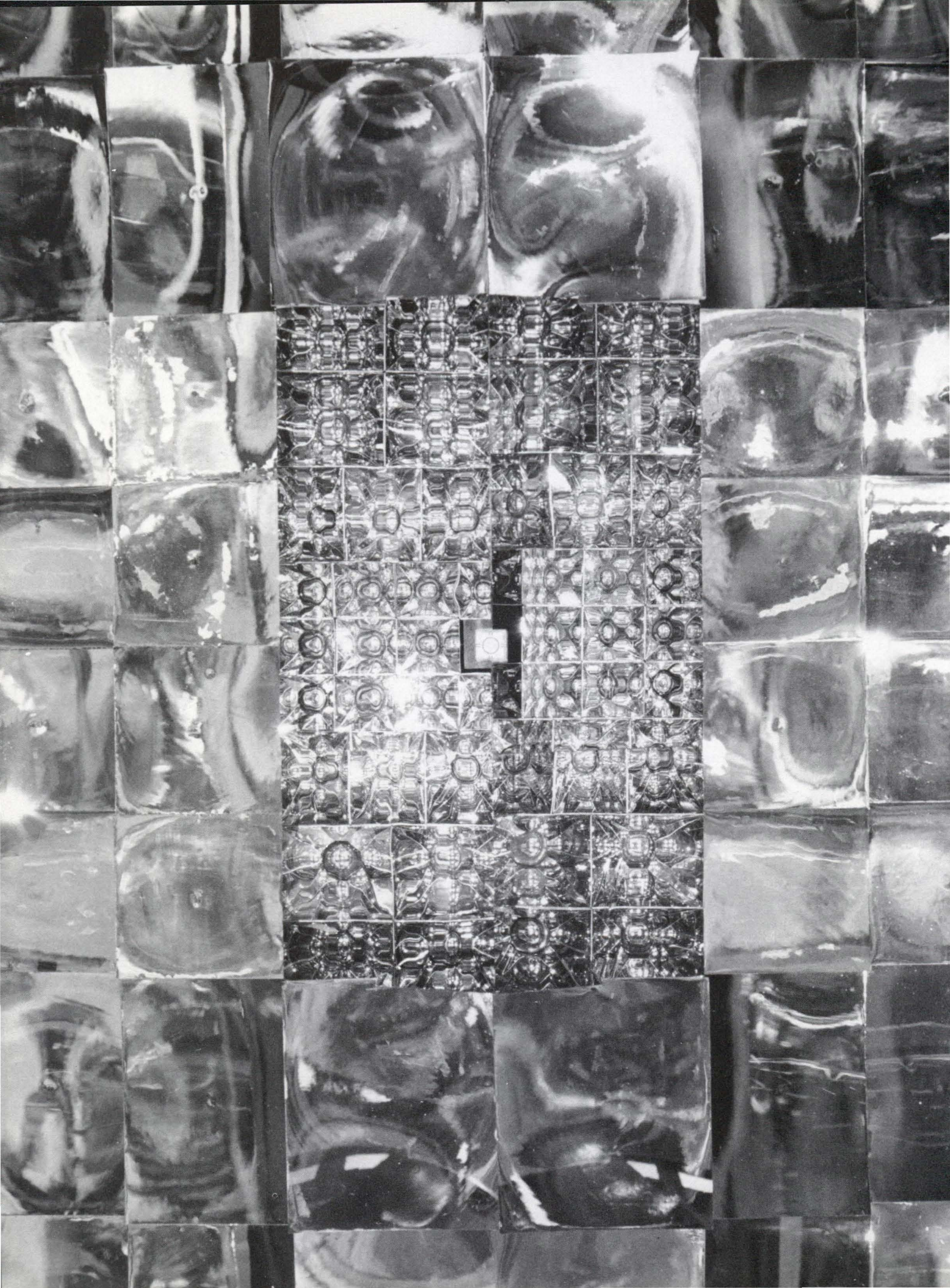
Although aimed primarily at the high-energy physics lattice gauge problem, CANOPY and, to an even larger extent, the ACP MAPS hardware will be very attractive to a broad range of scientific problems with heavy computing needs. Just as the experimentalists' ACP Multiprocessor System was commercialized by Omnibyte, Inc., the new theorists' engine will be available for technology transfer to industry.

The work on the lattice gauge problem follows the ACP's historical themes: maximal computing cost effectiveness for critical problems, convenient user interfaces, and local memory multiprocessors based on the latest VLSI developments from industry. This emphasis has proven to be productive, and one should ask if this will continue. Present estimates for offline computing are about 1500 VAX equivalents for each large experiment at the future Superconducting Super Collider. If correct, these needs can readily be met by the present developments in ACP Multiprocessors - and at a small fraction of the anticipated cost. So, why pursue the probable additional factor-of-five performance obtainable with RISC processors in the next few years, or the opportunities to incorporate vector instructions, and resulting speedups, that are starting to appear on the VLSI technological horizon?

Six years ago, the expected processing needs of the Collider Detector at Fermilab were stated to be less than 10 VAX-years per run. In the light of experience with real data and real programs, some 200 equivalent VAXes worth of ACP Multiprocessors are now being assigned to CDF online and offline computing. This history suggests how SSC experiment computing requirements will, in reality, compare to the early design estimates. And this is only applying our present-day ideas of computing to experiments. When we remember how rapidly new levels of available computing increase our opportunity to do new physics, we realize how important a continuing, coherent R&D effort, like the ACP, will be to the long-range future of experiments at Fermilab, SSC, and, in fact, all accelerators over the next decade. Similar motivations suggest a focused R&D effort on data acquisition, directed with a long-range view and coordinated with computing R&D, to which it is closely related.

Perhaps it is the very discouraging budget environment that faces us at the end of 1987, but it has seemed important to emphasize how important R&D efforts like the ACP are (and could be in related areas) to the future of the field. Long-term R&D frequently finds itself in difficulty competing for attention with immediate operational concerns. Certainly, this problem is exacerbated at times of funding drought. Nonetheless, it is pleasing to end this report by noting that Fermilab has, in fact, found a way to nurture the Advanced Computer Program past its fifth birthday this year, and it was the year in which ACP developments met with widespread acceptance.





Our URA parent organization, in its early deliberations, was concerned that Fermilab physicists not dominate the research program at this "truly" national laboratory. A limit of 25% of the research activity was set for the in-house staff, although no one really defined the number. If we take a most generous allowance, we know that during the heavy years of TEVATRON construction this number never exceeded 10% and is at last creeping up. The mechanism for carrying out in-house physics is through the Physics Department. Dan Green is Chairman.

The Physics Department

Daniel R. Green

> "My center gives way, my right wing is folding up. Situation excellent. I attack tomorrow."
>
> - Foch to Joffre
> First Battle of the Marne
> September 8, 1914

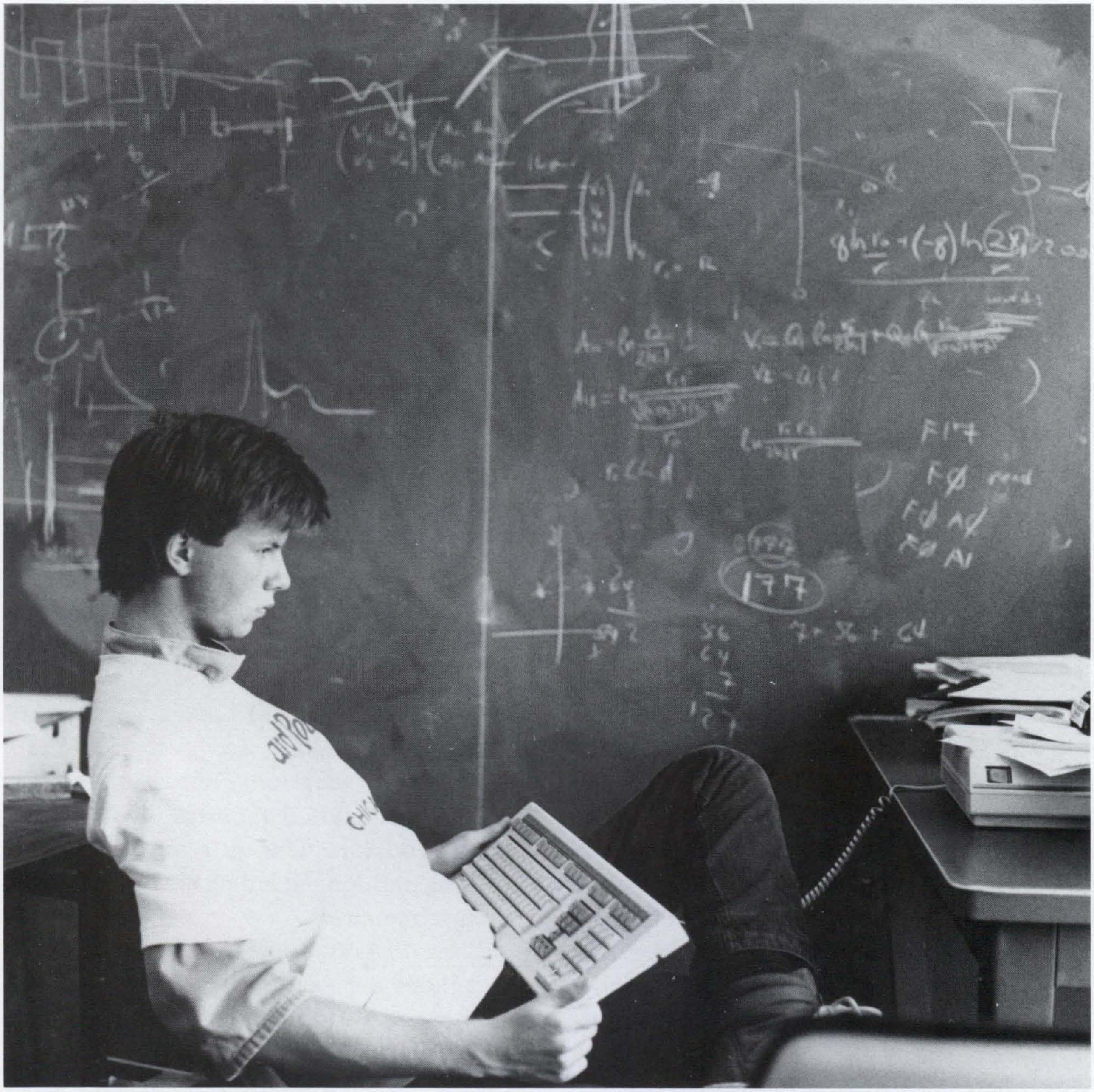
Sometimes it felt like that kind of year. We had austerities and had to reduce the size of the Department by 10% due to the Gramm-Rudman budget cuts. The bottom line was to finally begin to realize the physics potential of the TEVATRON. We drew our inspiration from Leon who was often heard to say, "The future is now." We may be poor, and the stockroom cupboards may be bare, but we did physics all year. No other national laboratory can make that statement.

The Collider started up last winter (1987) and ran from early January to early May. The Accelerator Division delivered enough luminosity to enable experiments 710 (elastic scattering), 735 (quark-gluon plasma), and 741 (CDF) to get physics results of a preliminary nature. The Physics Department had major construction and installation responsibilities for E-710 and E-735. These three experiments immediately went into data analysis mode following the end of the run.

With a short rest, the Laboratory switched to fixed-target mode and delivered beam from June to (we hope) February to 15 distinct experiments supported by the Research Division. This is a very solid run, fulfilling the long-standing needs of a host of experimenters.

The Physics Department continued throughout the year in its normal mode of supporting Fermilab staff physicists in their research efforts. Although we had a hiring freeze late in 1986, during 1987 we again began to recruit the best new Ph.D. physicists to replace our "graduates." The number of postdocs and Wilson Fellows has leveled off at about 30. This infusion of new blood is crucial to the health of the Laboratory and is perhaps the top priority

← A beam's-eye view of the reflection of the photomultiplier detector planes for one of three multi-particle Cerenkov counters of E-687. This particular Cerenkov counter was provided by collaborators from the University of Illinois.



The 1000-yard stare, a by-product of physics and computers.

of the Department. After an average of four years, our postdocs move on to university or Fermilab staff jobs.

The other 70 people in the Physics Department - engineers, technicians, draftspersons, and scanners - are more permanent. They have as their mission the direct support of physics research at Fermilab. Each experiment has assigned to it a "lead technician" whose job is to expedite the installation, running, and repair of that experiment. These people are our front line - right in the trenches. Directly behind that "thin red line" are the Physics Department "factories" in Lab 6 (chambers) and Lab 8 (calorimeters). They continued at full throttle in 1987 as did the scintillation-counter shop and the vacuum-deposition facility.

Somewhat behind the front lines, is the rear echelon of electrical and mechanical support groups. They supply the engineering, design, and construction of experimental apparatus. During 1987 the number of engineers in the Department was increased. This expansion was necessary given the increasing sophistication of the detectors which are being constructed for high-energy physics experiments.

In 1987 those support groups helped finish a complete set of fixed-target experiments. That level of activity will probably never occur again. In the future, it is expected that only a few new experiments need to be mounted per running cycle. This year we could already see a shift in emphasis from merely getting experiments ready to analyzing the flood of new data. The center of gravity of the Department will undoubtedly shift towards analysis during the next year.

As they say, the proof of the pudding is in the publishing. All the sacrifices made in 1987 just to run the machine will be wasted unless the data is analyzed and put into publishable form. To aid in achieving that end, the Film Analysis Group was reorganized in 1987 to form the Data Analysis Group. In addition to performing their traditional role of film scanning and measuring, this group will now attempt to supply data aides. The role of these aides is conceived to be to submit analysis jobs, organize tapes, and keep statistics. The paradigm is the success of the E-691 data analysis efforts. As an historical note, the first major task of the Physics Department in 1969 was bubble-chamber film analysis. In 1987 we're still analyzing film, and our scanners are now studying visual displays for CDF, the most modern detector presently at the Laboratory. Such are the ironies of history.

As further inducements to finishing an experiment, office space for experimenters and Guest Scientists is provided on the 9th and 10th floors of Wilson Hall. Other analysis tools which are supplied are terminals, stand-alone PC's, software, and laser printers. The staff contributes secretarial services and figure drafting for aid in publication of papers. Travel funds for conferences, workshops, and group meetings are also provided.

When not standing shifts on experiments or computing, staff physicists occasionally do think about physics. To further that end, the Physics Department sponsors the Wednesday Colloquium. In addition, Academic Lectures are organized by the Physics Department. In a more informal atmosphere, the Physics Department organizes a monthly "Food for Thought" dinner which gives the shell-shocked postdoc a spot of R and R. These same postdocs aid in the highly successful Saturday Morning Physics Program for high-school students. In 1987, a preprint and journal "reading room" was established on the 10th floor of Wilson Hall to encourage experimentalists to keep up with the literature.

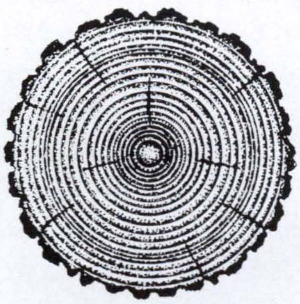
In summary, 1987 was a year of taking data to cash in on the long-standing investments made in the TEVATRON. We will strive to help make 1988 the year of the publication.

"It was twenty years ago today. . ."

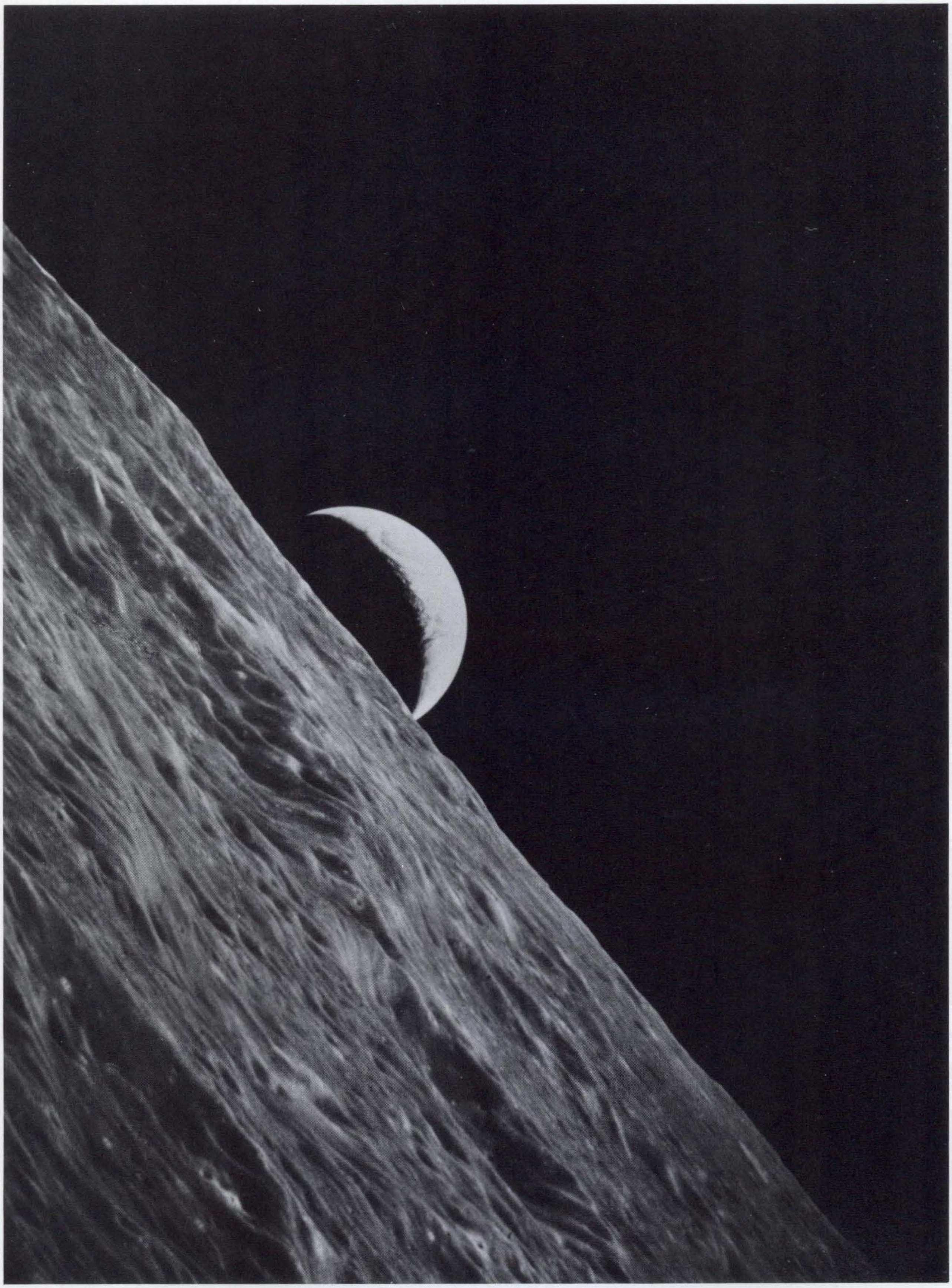
It's hard to realize that a young place like Fermilab actually began 20 years ago. Perhaps this is because there is a continuity to design at Fermilab. Going back and reading a seminal paper by R. R. Wilson (NAL-6, "Some Aspects of the 200-GeV Accelerator," September 12, 1967) really gives one shivers at its vision and prescience. Even the design of a "TEVATRON" was present at the creation.

Wilson was appointed Fermilab Director on March 7, 1967. One year later the Lab had 200 employees, including 54 scientists and engineers. One finds that the seed of the present experimental areas was sown early. Staff physicists were initially preoccupied with experimental beamlines (sounds familiar, doesn't it?) which were thought to be "nine real beams issuing from two external targets."

Somewhat later, on November 1, 1968, a separate Physics Research Section was formed under Ned Goldwasser, which was to "serve as a focus for experimental particle-physics research by laboratory staff members." Clearly this was the precursor of the present Physics Department. Its beginnings were modest. On May 31, 1969, Frank Cole reported that "particle-physics experiments are to be carried out by laboratory physicists through the Physics Research Section. This section now has no members" - and so it goes. . .



Earthrise as seen from the Moon. →



One of Associate Director Richard Lundy's responsibilities is "technology," a catch-all title for Fermilab's concern with high-quality engineering. The line organization most relevant to this is the Technical Support Section (TSS). Here, in a charge-back operation, are the skills and experience that have been acquired in the course of assembling the original Main Ring magnets (20 years ago), the wide variety of conventional spectrometer and beamline magnets, and, in the 1978-1983 period, some 1400 superconducting things: dipoles, quads, correction elements, spool pieces, and turn-around boxes.

Some of these engineering and technical skills have, since 1985, been exported to other parts of the Laboratory or, sadly, have been lost to budget stringencies, but out of the debris of the Energy Saver Magnet Facility has arisen a leaner and meaner TSS. The entire Laboratory looks to TSS to keep the Lab on the cutting edge of magnet fabrication technology. Technical Support's leader, Paul Mantsch, talks about 1987.

The Technical Support Section

Paul M. Mantsch

Introduction

The magnet facility and the service groups which make up the Technical Support Section have participated in several major Laboratory projects and are an important part of the R&D activity on the Superconducting Super Collider. Major Laboratory projects include new high-performance magnets for the TEVATRON upgrade and fabrication of components for the D0 collider detector. Effort in support of the SSC includes assembling magnets with coils supplied by Brookhaven National Laboratory and the start of work on a complete dipole-magnet production facility. Another significant task is the fabrication of magnets for a 250-MeV proton synchrotron for medical therapy. All of these activities and more are supported by the ever-improving engineering, design, machining, and testing facilities of the Technical Support Section.

The TEVATRON Upgrade

Although support of the accelerators includes a steady stream of new and repaired components, the currently most challenging task is to provide magnets of new design to be used in the luminosity upgrade of the TEVATRON Collider. Thirty low-beta quadrupoles of various lengths and 14 quadrupole correctors are required for the magnet lattice. The designs for the required 1.4-T/cm cold-iron low-beta quadrupole and 0.75-T/cm single-shell quad correctors are now nearly complete. Tooling is being received and winding will soon begin. The cryostat to be used for the low-beta quadrupoles uses many advanced design features from the SSC cryostat.

These new magnets take maximum advantage of dramatic improvements in conductor current density. In collaboration

High-tech devices require high-tech tools: A computer-controlled numerical turning center in the Fermilab Main Machine Shop.

with the University of Wisconsin and our vendors, new records for current density with NbTi multifilament conductor have been reached. For example, the cable developed for the D0 low-beta quadrupoles has almost double the current-carrying ability of the TEVATRON conductor.

Another important project to upgrade TEVATRON performance is the study of the time variation in the shape of the field in the TEVATRON magnets. These measurements, being carried out at the Magnet Development and Test Facility, are expected to contribute to the improved performance of our machine and should be of interest to those working on its progeny (HERA, UNK, RHIC, and the SSC).

The Superconducting Super Collider

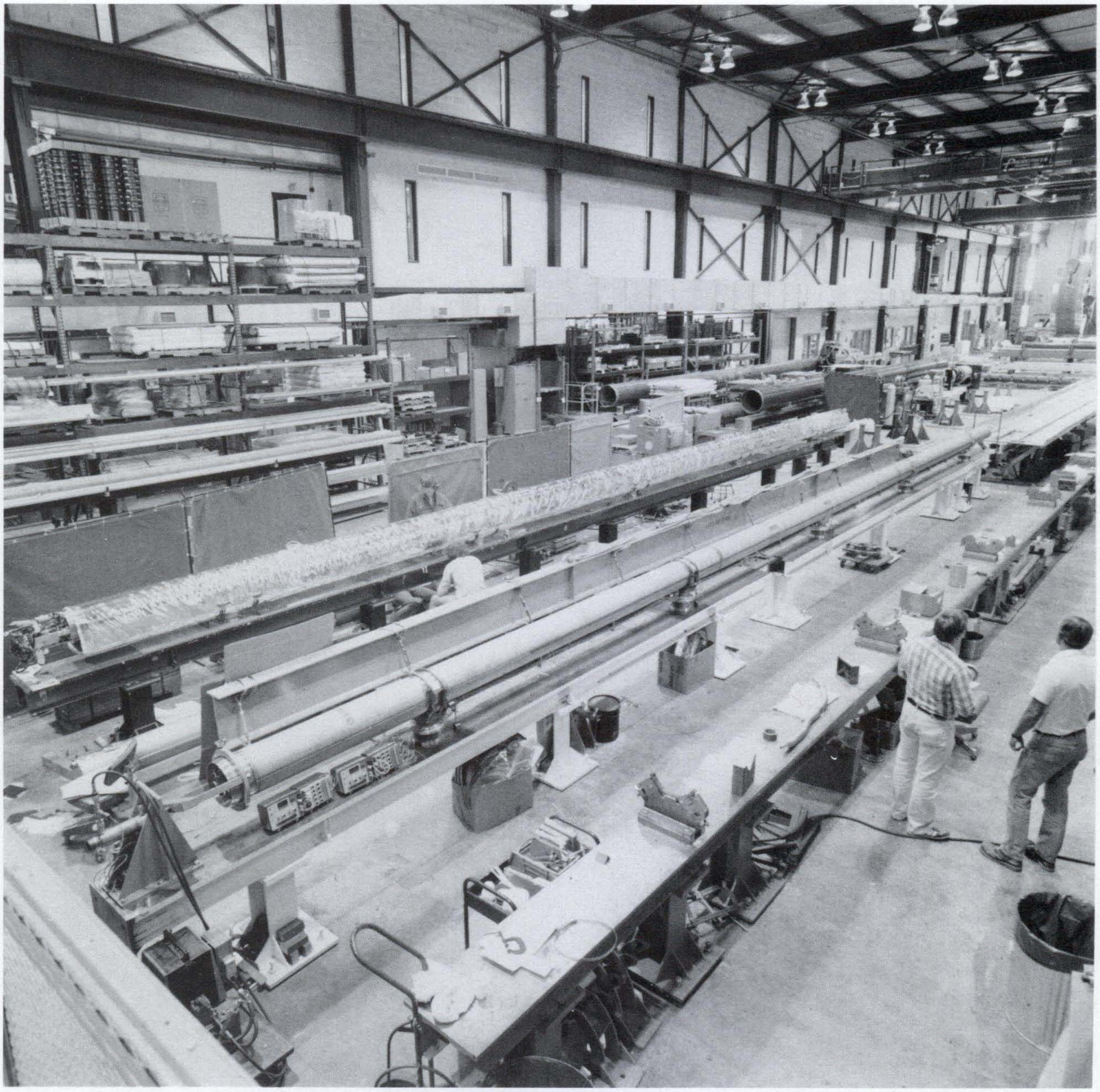
The SSC program under the guidance of the SSC Central Design Group makes use of development and fabrication resources of the national laboratories: Brookhaven National Laboratory, Lawrence Berkeley Laboratory, and Fermilab. Several full-scale dipole magnet models have been assembled and tested. The magnet coils are wound at Brookhaven. The coil/ cool mass is then transported to Fermilab where the magnet is assembled using the Fermilab-designed cryostat. Once assembled, the magnets are tested in the Fermilab Magnet Test Facility. A program has recently been initiated to develop tooling for SSC coil fabrication at Fermilab. The objective of this program is to develop a pilot production facility for complete dipoles.

Within the past year three SSC dipoles have been completed. Two of these have been tested. The data derived from these tests are analyzed in detail to understand magnet performance and thereby improve later designs. These tests are far from routine. Each magnet has special instrumentation and its own set of test requirements. In order to keep pace with the SSC magnet program, a second test stand is being assembled. This stand is expected to become operational in January, just in time to match the increased rate of magnet delivery. The new test stand will have the additional capability of reducing the magnet temperature to 1.8° K. Energizing magnets at low temperature to high currents has been demonstrated to make them operate more stably at normal operating temperatures. Low temperature will also enable testing of the structural performance of the magnets by taking them to much higher currents.

Since the operating cost of the SSC depends strongly on the cryogenic performance of the magnets, considerable effort at Fermilab has been devoted to cryostat design. Significant refinements have been made to the cryostat during the past year. These improvements, including a better suspension system, insulation, and magnet interconnection, will be incorporated in future magnets, making the cryostat simpler and more efficient.

The program to build a pilot dipole-production facility was begun in the summer of 1987 as the result of a special agreement with the SSC Central Design Group. The objective is to draw on the production experience gained in the TEVATRON project to develop new full-length coil tooling. The first 1-meter models for tooling qualification are expected to be wound and cured in early 1988. Winding of the first 16.6-m coil will begin in July 1988. As experience is gained with the tooling, the dipole production rate is expected to reach an eventual level of 2-1/2 complete magnets per month. This pre-production facility will provide magnets to the string test and accelerated life test and will also demonstrate fabrication techniques to potential magnet vendors.

Additional projects completed for the SSC this year include the development of a dipole vertical plane measurement device, measurement of the heat transfer properties of some of the materials used in the magnet, and the design, fabrication, and calibration of a significant fraction of the instrumentation required for the magnet test program.



Assembling prototype SSC magnets for testing at the Fermilab Magnet Development and Test Facility.

Installation of an SSC R&D magnet into the tunnel mock-up at Fermilab for system tests.

The D0 Collider Detector

Skills developed in making the cryostats for the TEVATRON superconducting magnets helped in the production of the 20-ft x 8-ft muon chambers for the D0 detector. Over 50 of the chambers have now been completed.

The services of the shops, fabrication task order operation, drafting and design group, and inspection and materials lab are contributing to the needs of the D0 detector effort.

High-Gradient Quadrupoles for the Stanford Linear Collider

Each arm of the SLAC Linear Collider will terminate in a superconducting quadrupole triplet lens. The magnets for these lenses are being fabricated and measured by Fermilab. Half of the order for 12 quadrupoles (including spares) is complete.

The Loma Linda Medical Accelerator

The Technical Support Section is fabricating magnets as part of a cooperative effort with the Loma Linda Medical Center to develop a 250-MeV proton synchrotron for medical therapy. The complete project requires a total of 156 conventional magnets of various types. Eight accelerator dipoles have been completed. The magnets are built on a 63-in. radius and weigh 6800 pounds. These dipoles have curved, laminated, "wet layup" cores with removable bolt-on lamination end packs (a special expertise of the Magnet Facility). The end packs can be removed and re-machined for final field shaping. The development of these magnets depends on detailed measurement of the prototype dipole field in order to determine the shape of the pole tips. These magnets required special magnetic measurement probes because they are so highly curved.

The design of Loma Linda beam transport, extraction, and trim magnets is under way.

Computerized Engineering Analysis, Design, Machining, and Inspection

The mechanical services provided by the Technical Support Section to the Laboratory are of a breadth and quality that ensures that Laboratory projects can be accomplished in an effective and timely way. Computers have greatly expanded our ability to design and fabricate a large variety of specialized parts and assemblies needed to carry out the research program at Fermilab. The Engineering Group, the Machine Shops, and the Material Inspection Group are being equipped and trained to take maximum advantage of these advanced techniques. Indeed, it has often been necessary to press the state of the art to meet the needs of our programs. Not only has our thrust into computer-aided fabrication methods made unique capabilities possible, the design and fabrication of ordinary parts has become demonstrably more efficient.

Engineering analysis capability has been enhanced during the past year by the addition of a new "pre-processor" for the finite element structural analysis codes. Formatting structural problems by defining the mesh of elements has been difficult and time consuming. The more powerful user-friendly mesh generators make problem definition quicker while reducing the training time necessary to effectively use these tools. This type of analysis has been used extensively during the past year in cold-mass support systems for the SSC dipoles and the low-beta quadrupoles for the TEVATRON upgrade.

The acquisition of 20 high-resolution graphics terminals has made access to the computer-aided design (CAD) system possible by almost everyone in the section who is trained to use it. The value of computer-aided design is becoming widely recognized, particularly where project participants are based all across the country. Large projects such as the SSC and the D0 detector, for example, want all drawings to be CAD based. In addition to having the largest group of designers and greatest commitment to CAD, the Technical Support Section offers local training for CAD users Lab-wide. So far nearly 20 draftsmen and designers have been trained in these CAD classes.

An effort is under way to select a new CAD software system that will be compatible with the Laboratory computing system which will shortly be reconfigured. This includes an attempt to standardize the Laboratory CAD systems and to make them compatible with machine shop CAM (computer-aided machining) and computer-aided inspection.

The Fermilab Machine Shop is engaged in an ongoing program to modernize its equipment with particular emphasis on computer numerical control (CNC) machine tools. During the past year, a CNC wire EDM (electric discharge machining) was acquired. Experience has shown that the several CNC machines now in operation not only are able to form unique new kinds of parts but are also faster and cost effective in more normal jobs.

The influx of CNC equipment into the Machine Shop has spurred new interest in training. There are now two classrooms and five terminals dedicated to CAD/CAM training. Shop personnel have access to the training area before work, during lunch, after work, and on weekends. Many machinists have taken advantage of this opportunity to build their skills in CAD/CAM. Several special seminars are sponsored by the machine shop to help draftsmen, designers, and engineers from around the Laboratory familiarize themselves with NC/CNC terminology and concepts. These seminars have been very successful both in training designers in how to make drawings of parts that can be transferred to CNC machines and in alerting designers to the range of new machining possibilities with CNC machines.

The specialized needs and occasional high volume of parts needed at Fermilab requires a well-equipped inspection lab. The fabrication of both conventional and superconducting magnets, for example, needs precision measurements of many of these parts. During the past year a computer-driven Contour Projection Machine with automatic edge finder has been installed. In the measurements of laminations such as those used in magnet tooling, as well as yoke and support collars, repeatability and accuracy is ±.0001 in. This machine is complementary to our Coordinate Measuring Machine. Some special parts like laminations can be measured, more error-free, ten times faster on the new machine than on the Coordinate Measuring Machine.

The superconducting-cable-measuring machines developed in the Magnet Facility last year are now installed at both cabling facilities used to make cable for the SSC. By being able to measure cable dimensions to better than ±0.0001 in. online, these machines allow the manufacture of cable precise to ±.0002 in. as compared to allowed past tolerances of ±.0010 in.

The objective in all of these activities is to help ensure a vigorous Fermilab research program by providing high-quality, state-of-the-art engineering and mechanical support.

4	2	5	3	6
6	4	2	5	3
3	6	4	2	5
5	3	6	4	2
2	5	3	6	4

Radiation, heavy loads, overhead cranes, high voltages, explosive gases, and PCB's are just a few of the scare words that haunt the dreams of all Lab directors. . . sometimes even rivaling the steady-state nightmare of insufficient operating budgets. At Fermilab, these nocturnal tortures are strongly moderated by a superb Safety Section under Larry Coulson.

The Safety Section

Larry Coulson

There is good news and bad news to report on safety-related events which occurred in the past year. First, the good news:

"Excellent" is the adjective used by the DOE in rating our health physics, industrial hygiene, occupational medicine, and emergency preparedness safety programs. The same adjective was used by the Safety Management Appraisal Team to describe safety management by the Lab. This is the best set of grades we have ever received.

The DOE conducted an environmental survey of Fermilab on September 14-25. These surveys are being conducted at all DOE sites as part of the agency's response to environmental problems resulting from operations at some of their older sites. There were no Category I or II findings - categories requiring immediate response. However, there were five Category III findings which are concerned with long-term potential problems. These require further investigation to see if there is any need for future action. In the remaining category, Category IV, there were nine findings which dealt with minor improvements in spill control, quality assurance, and administrative regulatory compliance. The total number of findings was fewer than that encountered at other national laboratories. Our excellent showing may partly be because Fermilab is younger than its sister labs and many of the regulations

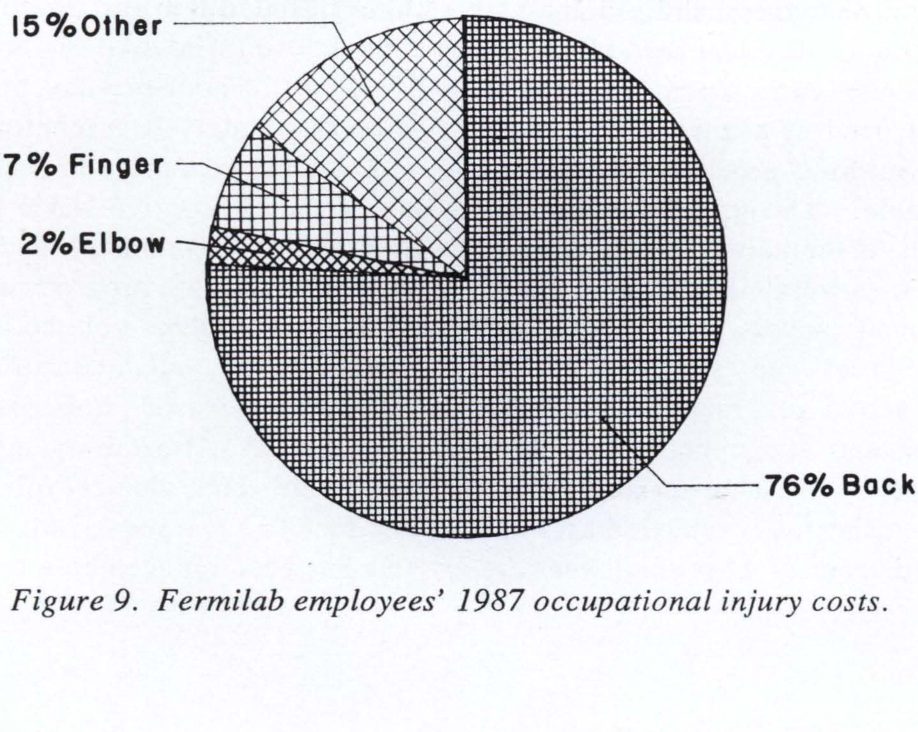


Figure 9. Fermilab employees' 1987 occupational injury costs.

were already in place before operations began. But this is also indicative of the Laboratory's commitment to protect and enhance the environment.

Under the auspices of the Lead DOE Laboratory for Accelerator Health Physics Research, two contractor meetings were organized in conjunction with Health Physics Society meetings held in Reno, Nevada, and Salt Lake City, Utah. In addition, 11 DOE accelerator laboratories were visited as part of the program to characterize their accelerator health physics programs and solicit ideas for areas of research. A report is being prepared which outlines accelerator health physics research needs and priorities.

Back injury prevention and asbestos control are two areas in which Fermilab has launched new initiatives. "My aching back" describes the major source of injury costs at Fermilab (see Fig. 9). The fraction of costs due to back injuries has increased - but we believe this is due to our success at reducing other injuries. Nevertheless, in recognition of the importance of back injuries, Fermilab adopted an aggressive program of improved medical screening, as well as extensive training and job analysis by a subcontracted physical therapist.

Some of the earliest construction at Fermilab occurred at a time when the use of asbestos building products was considered acceptable. The greatest volume of this material is contained in sprayed-on insulation in several buildings, though asbestos-cement panels are occasionally found throughout the site. We have adopted an active program of monitoring the condition and atmospheric contamination produced by these materials. Where practical, the asbestos is removed by a specially trained team of Lab employees (referred to as the A-Team!). In 1987, asbestos materials were removed from the outside of a dormitory farm house, exhaust ducts from an emergency generator, as well as other locations.

In the area of ionizing radiation, personnel exposures increased only slightly (see Fig. 10). This is not unexpected - more accelerated protons means high residual radiation levels, which inevitably leads to higher personnel exposures. An increase in beta dose was also seen for the first time due to greater handling of depleted uranium associated with the construction of the uranium-liquid argon calorimeter for E-740 [D0].

Extensive measurements were made of muon distributions downstream of the fixed-target experiments since these are the dominant source of off-site radiation dose. Particular attention was paid to the new muon beamline for E-665. Comparisons with calculations using the latest version of the Monte Carlo program CASIM showed relatively good agreement with the measured fluence distributions from this beamline, but rather serious disagreement with another commonly used code, HALO. It is estimated that the maximum fenceline annual dose (primarily due to these muons) based on 24-hour-per-day occupancy will be approximately 10 mrem for CY87.

Over the years, the unit cost of disposing of the radioactive waste has continued to escalate. Toward the end of 1986, we conducted a pilot program of sorting and screening to reduce volume. Beginning in January 1987, all material collected in radioactive "waste" containers has been checked for radioactivity and sorted into recyclable and non-recyclable material. The results have been gratifying. The volume has been reduced by a factor of 20.

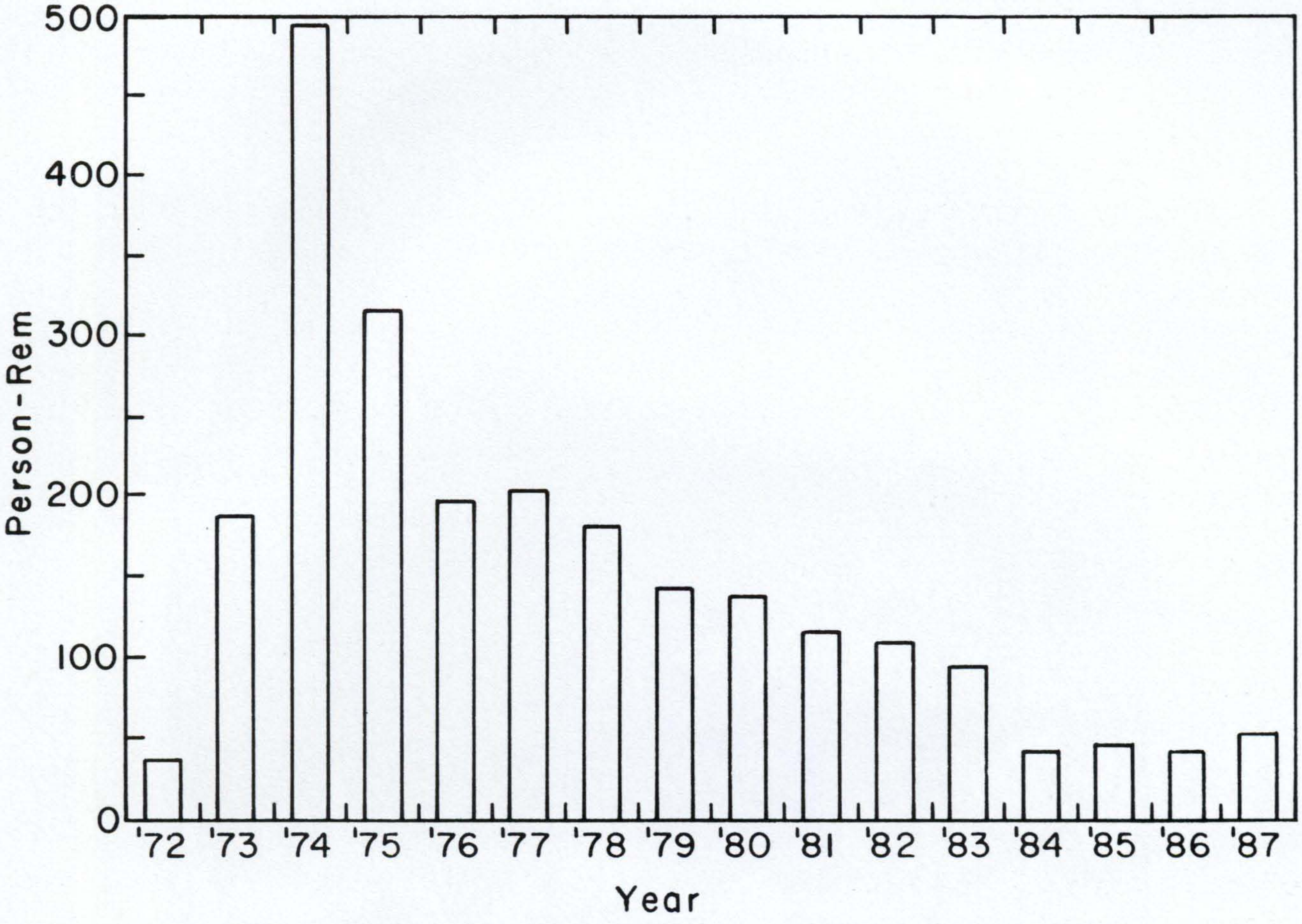


Figure 10. Fermilab whole-body radiation dose in person-rem by year since 1972.

Because of the nationwide concern over radon gas in houses, a radon survey was conducted on site to determine whether any Village residents were exposed to radon in excess of the Environmental Protection Agency (EPA) standard. The program was later expanded to measure radon in tunnels and other work areas. None of the residential living areas showed concentrations of radon greater than the EPA standard of 4 pCi/1. The worst-case occupational exposure was 3% of the maximum permissible concentration for workers.

Now the bad news:

In October the most significant fire loss in Fermilab's history occurred. A fire in the Wide Band Hall completely destroyed a large calorimeter. However, the sprinkler system confined the fire until the Fermilab Fire Department could extinguish it. Fire detection has now been installed in this experimental hall.

In addition to heightening awareness about the electrical fire hazards associated with experiments, the Wide Band Lab fire underscored the value of early fire detection, effective sprinkler systems, and adequate smoke venting. As a result, plans are in progress to upgrade experimental halls in these respects.

There are a collection of crucial Laboratory activities coloquially known as the "G&A" sections. Under the general supervision of Associate Director Bruce Chrisman, these span a humongous variety of activities including Library, Audit, Budget Control. . . The following terse descriptions from Jim Finks, Business Manager, and Chuck Marofske, Head of Personnel Services, belie the real effort and contribution of these groups to the success of the Laboratory. In another context we have presented the accomplishments simply in terms of services applied to an increasing work load, an increasing number of requisitions processed, square footage cleaned, miles of things maintained, personnel actions accomplished, meals served, apartments refurbished, tons received. . . and we have noted that all this was done with style, efficiency, *esprit*, and a constantly dwindling work force. This obviously cannot continue; however, the ticking of the time bomb is well concealed in these reports.

The Business Services Section

James E. Finks, Jr.

Talk about mighty trees from tiny acorns. . .

The Business Services Section traces its roots back to the National Accelerator Laboratory's first offices at (appropriately) Oak Brook, where one person manually processed both vendor and payroll checks. Later the group branched out and moved onto the Weston site where employees worked in a kitchen, a living room, and the bedrooms of a Village house, and check processing advanced to a Burroughs bookkeeping machine.

Prayers for more space were answered, and the group migrated to a former church on Wilson Road, which also hosted another technological leap to an IBM 360-50 computer. Finally, the wanderings ceased as the (now) Department left the wilderness and settled into the Central Lab (now Wilson Hall) as one of the first tenants.

The Materials Department, which had joined the flock, eventually moved from a "stow it where you can" operation in a 100-year-old warehouse along the Fox River, to a computerized, paperless receiving operation housed in two giant warehouses located on site; from a stores inventory completely contained in a Village house to a volume now requiring half a warehouse; from a purchasing operation conducted largely by begging vendors to sell to an organization that lacked both purchasing forms and credit references, to a 5000-vendor data base that is used to assure cost-saving competition; from a property system handwritten in a log book to an automated, bar-coded inventory system; and from a fleet of vehicles considered scrap by the Joliet Army Arsenal to a modern, well-maintained, 260-vehicle fleet.

In the ensuing years, the Business Services Section has expanded its responsibilities to include Accounting, Contracts, Purchasing, Support Services, Information Systems, the Legal Office, Business Safety, Facilities Management, T & M Operations, Emergency Services Coordination and Operations, Facility Engineering, and Facility Operations.

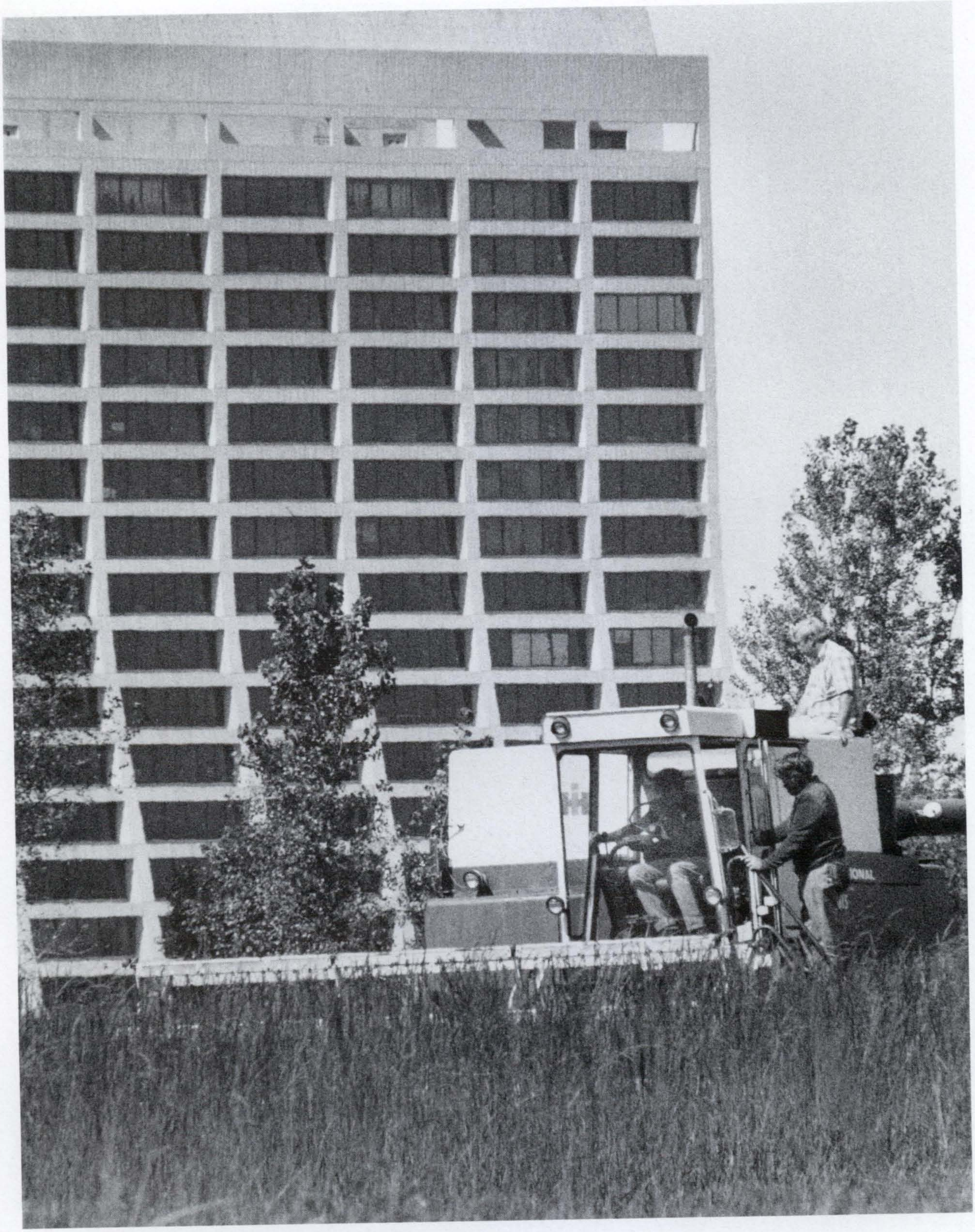
1987 saw the design and construction for the new Roads and Grounds building which will improve the efficiency and morale of this group of dedicated people.

Another step in the program to improve our cooling/fire protection water supply was realized with the completion of a pipeline section from the Fox River to Casey's Pond. This will assure that more water reaches Casey's by eliminating seepage and evaporation.

A new Auditorium sound system was installed, a new telephone switch was activated, and replacement transformers for the failed 100-MVA transformer arrived. Warrenville now supplies domestic water to, and accepts sewage from, the Fermilab Village.

The Business Services Safety Office worked closely in 1987 with other Laboratory safety groups to pioneer the prototype of the Lab's "Right to Know" Hazard Communication Program. The Safety Office also updated the Laboratory's Emergency Preparedness Plan and set up documentation books for all Divisions and Sections.

The first bar-code application was completed in FY87. The projected applications were delivery tickets generated from the Receiving System, property identification, and I.D. cards. The projects were completed in FY87, but due to vendor delays in equipment deliveries, only the delivery tickets generated from the Receiving System application was installed. During the first quarter of FY88, the remaining applications will be completed.



Work on the Prairie Restoration Project continues. Roughly 700 acres on the Fermilab site are now devoted to this recreation of the original prairie flora.

The first contingent of Fermilab 20-year veterans. First row, left to right: Jean Plese (Fermilab I.D. #57), Quentin Kerns (#32), Frank Cole (#13), Reid Rihel (#29), Barb Kristen (#59), and Carolyn Hines (#47); second row, left to right: Art Skraboly (#49), Gerry Tool (#34), Stan Snowdon [retired] (#51), Don Young (#2), Angela Gonzales (#11), and Jan Wildenradt (#62); third row, left to right: Tony Frelo (#9), Curt Owen (#17), Lincoln Read (#5), Glenn Lee (#15), and Phil Livdahl [retired] (#40). Director Leon Lederman (at right, #3682) offered congratulations on behalf of the Laboratory. Chuck Marofske (#54) and Lee Teng (#22), also 20-year veterans, are not pictured.

The Laboratory Services Section

Charles F. Marofske

Since the Laboratory formally opened in 1967, almost 8000 individuals have worked on the Fermilab payroll. During the ensuing years, there have been over 200 employee retirements, and the current work force is slightly over 2000. This year the agreement between URA and DOE for operation of the Laboratory was renewed with an extension through 1991. Laboratory Services worked on numerous aspects of the contract modification. During 1987, 19 employees reached the 20-year service mark. The original group of 1967 hires totaled 61.

Onsite housing has available 96 dorm rooms and 61 houses/apartments. In FY 87 there was a 95% overall occupancy rate with a total of 3500 rental transactions. Food Services provided over 20,000 meals and additionally catered functions for meetings and conferences at a rate of more than one event per day. Day Care had an average enrollment of 65 children.

Total regular employment dropped by 110 persons through the year. This was partially the result of about 50 layoffs necessitated by budgetary concerns and project completions. We also had 40 retirements, an all-time annual high for the Laboratory. There were 125 regular employment vacancies filled during the year and over 7000 applications received.

Almost 200 persons were employed for the summer. Among these were the participants in the 17th Summer Program for Minority Students managed by the Fermilab Equal Opportunity Office. With financial assistance from Friends of Fermilab, this office also conducted a summer enrichment program in science and engineering for high school students.

A series of better health programs, called "Wellness Works," was initiated. Employee interest in health maintenance programs remained high during the annual open enrollment. We had well over 200 employees participating in the tuition reimbursement program. Labor agreements were re-negotiated with a number of bargaining units.

Effort was directed at bringing benefit plans up to date with recent legislation. Over 100 pre-employment exams were performed, and 885 employees were examined as part of the physical checkup program. The Medical Office staff was active on "wellness" projects and safety awareness.

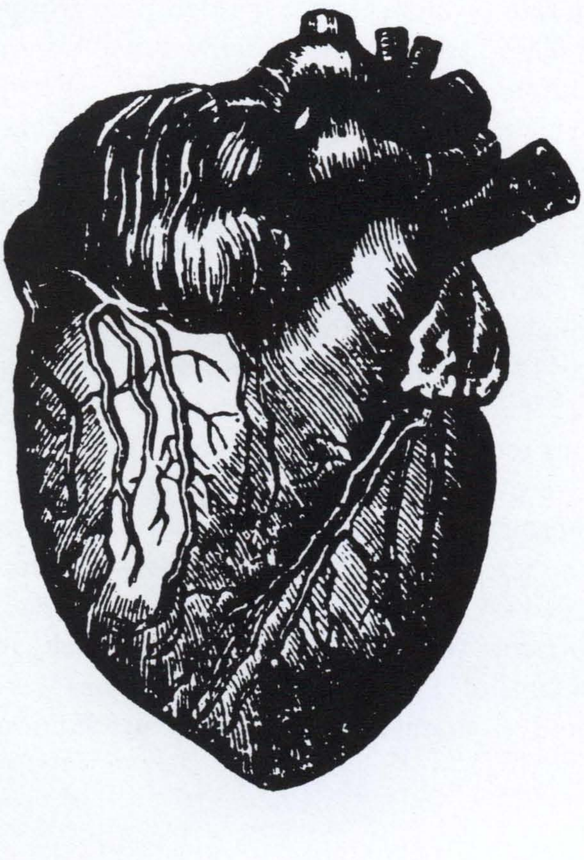
Over 40,000 people visited the Laboratory including more than 9500 through guided tour groups such as senior citizens' clubs as well as college physics classes from five states. Fermilab continues to receive wide press coverage, and writers for major science publications and other media representatives are frequent callers.

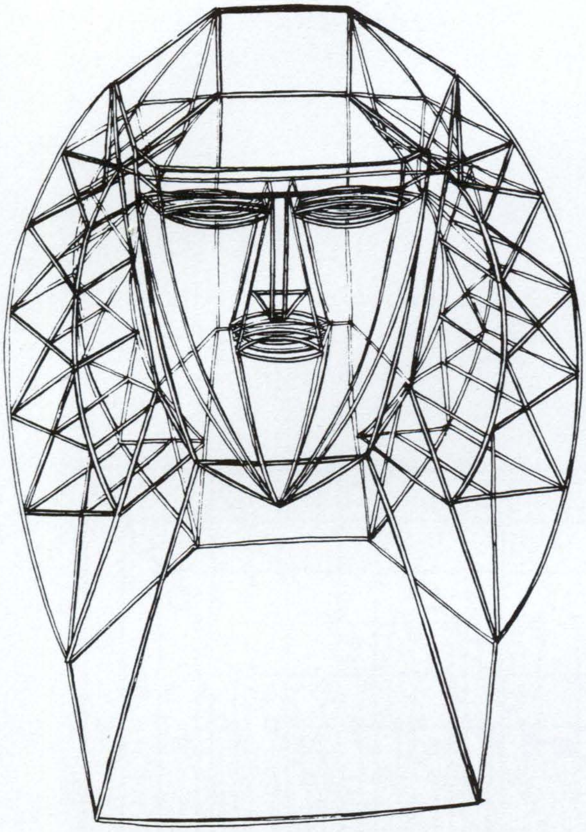
Our Publications Office continued to publish *FermiNews*, *Fermilab Report*, and this *Annual Report*, along with *FermiTech*, produced in conjunction with the Office of Research and Technology Applications and highlighting recent technology advances at Fermilab. The heightened HEP activity at the Lab is reflected by an increase in technical reports, especially preprints, handled by Publications during the year. Equipment and computer access used in preparing publications were upgraded to facilitate timely production, and a database was established cataloguing all Fermilab technical publications for easy referencing on the VAX Cluster and DECnet.

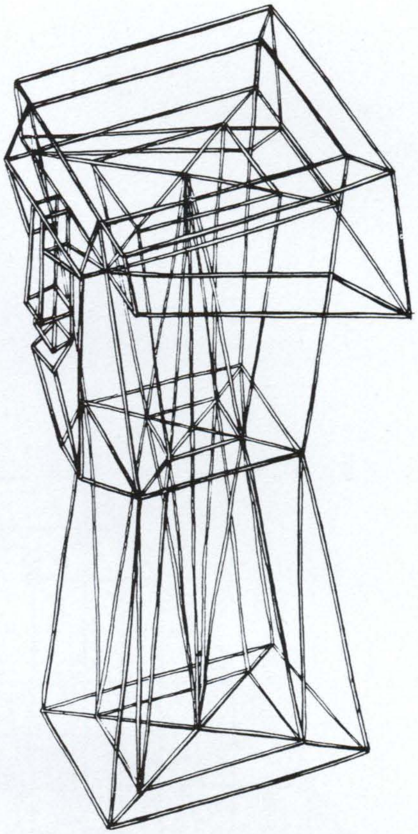
In the Library, steps were taken to enhance our collection of resources and develop automated access to our catalog. Most HEP preprints can now be searched using the SPIRES data base.

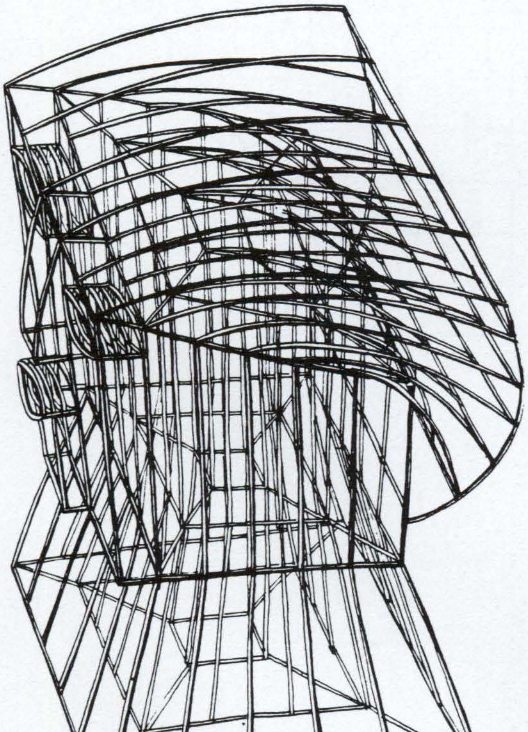
A Visual Media Services unit was formed merging the photography, duplicating, and video offices. A more effective utilization of the creative talents involved is the objective. The video inventory now lists over 200 programs on Laboratory subjects, and the photo unit has available a pictorial history of Fermilab, having shot more than 20,000 rolls of film during the years of Fermilab operation.

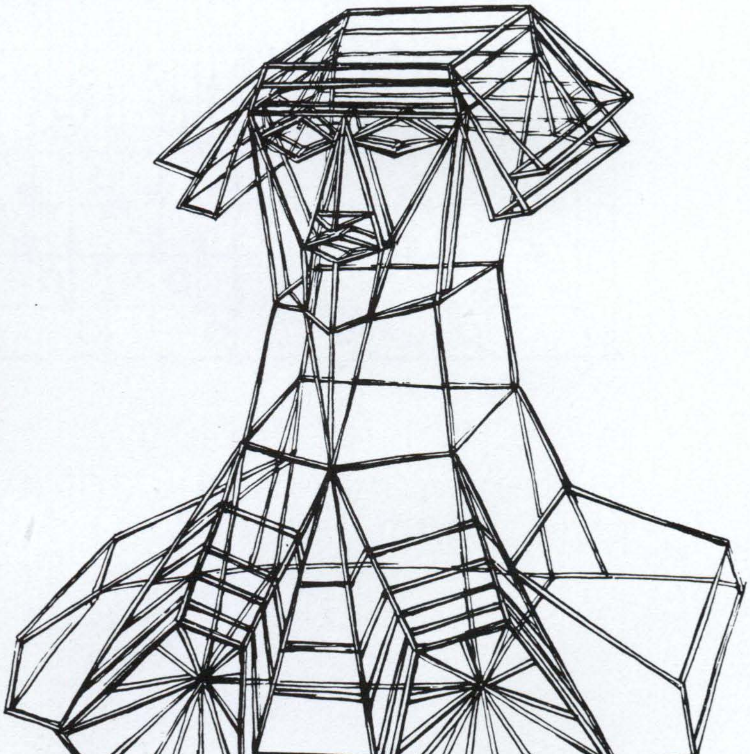
The Laboratory has always had an active recreational program for employees and users. Club functions, athletic leagues, recreation centers and the Users Center gourmet restaurant continue to flourish. This past year, programs utilizing the gymnasium were expanded, and extensive renovations to the Users Center got under way.



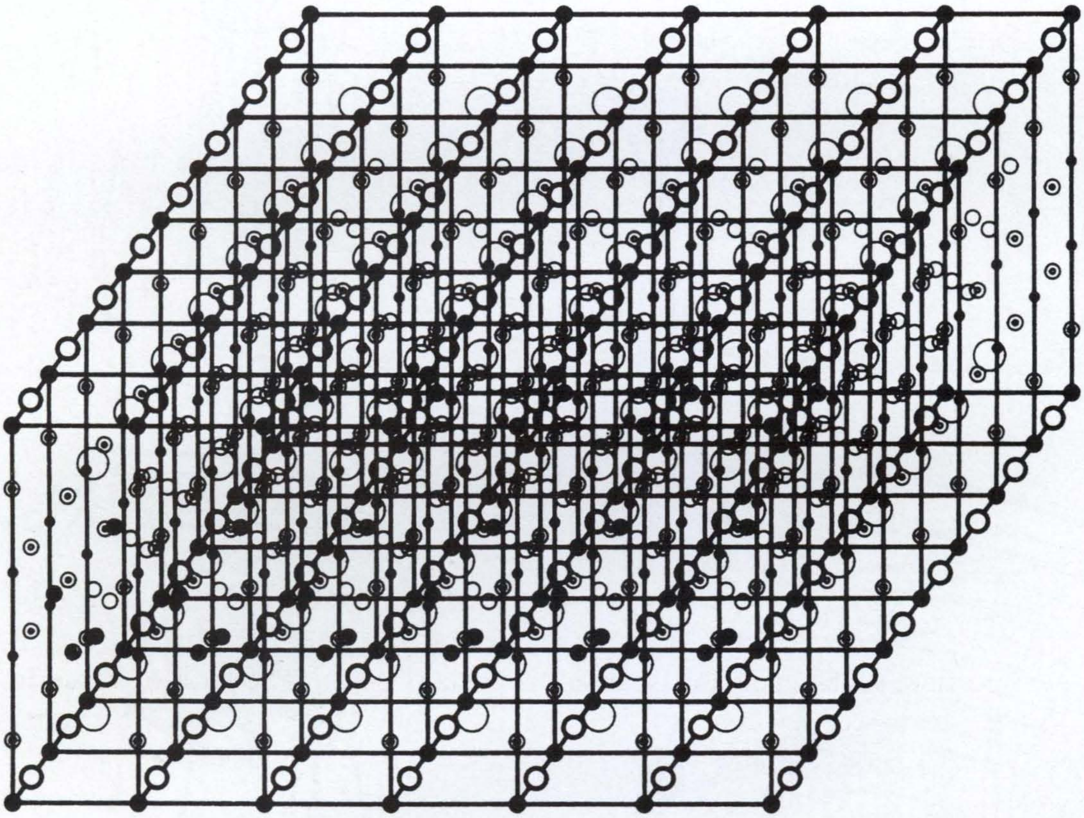








Fermilab
Industrial Affiliates
Roundtable
On



Research Technology
In the Twenty-First Century
May, 1987

Technology transfer is a current buzz-word, but it reflects a serious concern for a place like Fermilab. One does not build a research laboratory in order to generate spin-offs, transfer technology, and advance the economic competitiveness of the nation. We like to think Fermilab exists to help our understanding of the Universe and in so doing, to enhance our culture. But there is spin-off, there is technology transfer, and contributions to the advance of our technological capability are not negligible. It clearly makes sense to pay attention to these things and we do it formally through the Office of Research and Technology Applications (ORTA). CARRIGAN, who is charged with this task, has to wheedle nuggets of potential commercial gold without unduly distracting the creative engineers and physicists. He does almost as good a job as he ORTA.

The Office of Research and Technology Applications

Richard A. Carrigan, Jr.

At Fermilab there was good progress in the tantalizing task of transferring technology in 1987. This included great strides on the Loma Linda medical accelerator and the ACP project. Both programs have important implications for technology transfer. Years of effort on the formal side of technology transfer also started to pay off as URA received the rights to Fermilab inventions and began to license them. Finally, the discovery of new superconductors brought wide notice of the importance of the technology developed for the TEVATRON.

High-temperature superconductors sparked interest around the world in 1987. The Cryogenic Engineering Conference and the International Cryogenic Material Conference in June served as an important forum for discussions of these new materials. The joint conferences, held in St. Charles, Illinois, were co-sponsored by Fermilab. When the media looked back for applications of superconductivity, they found that Fermilab's TEVATRON was the largest superconducting project ever built. The other major application that received extensive exposure was medical resonance imaging (MRI). Some of the wire and magnet makers for MRI had cut their teeth on the TEVATRON. In July, 1987, *High Technology* magazine reported on the new superconducting revolution. The article brought home just how significant the TEVATRON had been for industrial-scale superconducting technology. Many of the companies mentioned were either Fermilab Industrial Affiliates, had direct experience in the construction of the TEVATRON, or both.

Two major programs at Fermilab currently have technology transfer as an important goal. The first of these is the project to build a Proton Accelerator for Medicine for Loma Linda University Medical Center in California. Loma Linda asked Fermilab to design and construct a prototype accelerator because of the experience in accelerator physics at the Laboratory. The medical radiation community also knew Fermilab as a result of the neutron therapy project here.

Loma Linda's involvement with Fermilab grew out of the establishment of the Proton Therapy Co-Operative Group, or PTCOG, at Fermilab. PTCOG explored ways of providing proton therapy for hospitals using modern accelerator construction techniques.

An important part of the Loma Linda technology transfer plan is the participation of an industrial partner. The partner's responsibility is to handle downstream commercialization and service of later versions of the accelerator and ancillary facilities. The partner is SAIC, a Fermilab Industrial Affiliate.

Last year saw the completion of the Loma Linda design. Construction of the accelerator bounded ahead. Meanwhile, the PTCOG group has continued to interact with the project. That has helped to develop innovative devices such as a patient treatment gantry. It also stimulated interest at other medical centers in the possibilities of proton therapy.

A second major Fermilab project with a strong technology transfer component is the Advanced Computer Program. That project has involved the construction of a loosely-parallel supercomputer using commercially available, 32-bit microprocessor chips ganged together. A system now running with 100 microprocessors analyzes events at about the same speed as the Fermilab Central Computing Facility. The Central Computing Facility costs roughly 50 times more than the ACP.

Currently, a nearby electronics firm, Omnibyte (also an Industrial Affiliate), is supplying boards for the ACP.

In addition to the inexpensive hardware, the ACP also has very flexible software. That flexibility has already led to the use of the ACP outside the particle physics community.

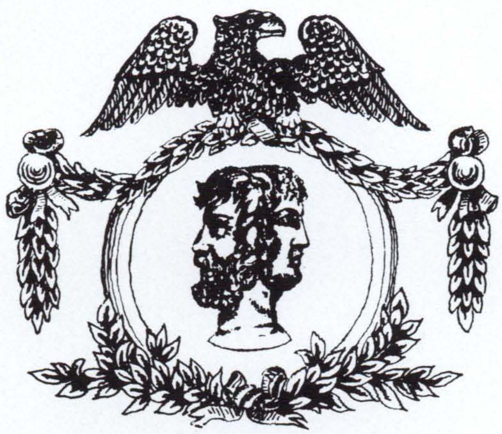
Technology is the first and most important ingredient for good technology transfer. It is also important to have a way to transfer that technology. The Fermilab Industrial Affiliate program is Fermilab's most effective means for technology transfer and for relating to industry. There are now approximately 40 Affiliates. The Appendix to this report contains a list of the current Affiliates. Affiliates receive regular information about the Laboratory as well as early news concerning licensing possibilities and new technology at Fermilab.

The annual Affiliates meeting this year had as its theme "Research Technology in the Twenty-First Century." The keynote speaker was Lloyd Thorndyke, president of ETA Systems, Inc., a new supercomputer company in Minneapolis. Other participants in the Roundtable included Ted Geballe, Stanford University; Wilmot Hess, DOE; Tom Nash of Fermilab; and Andy Sessler, Lawrence Berkeley Laboratory. Geballe, and Peter Limon of the SSC Central Design Group, also discussed some of the possibilities and problems associated with high-temperature superconductors.

The last year has seen important strides in the area of marketing Fermilab technology. The new DOE-URA prime contract signed in early 1987 gives URA rights to patents developed at Fermilab. This is an outgrowth of the Dole-Bayh law. As a result of this new potential, the Laboratory developed increased marketing capability and retained outside patent counsel. For the first time there is a person at the Laboratory responsible for licensing. The Laboratory also instituted a system of royalty sharing with inventors.

The Fermilab Office of Research and Technology Applications assesses every new technology developed at the Laboratory. Then the Laboratory Patent Advisory Group reviews them. For a promising technology, URA files a patent and starts a licensing campaign. If a patent is not appropriate, there are other mechanisms for transferring the technology. A recent addition is *FermiTech*, a monthly technology status sheet distributed to Affiliates and other interested parties.

This year the Laboratory has continued to operate a technology Information Transfer Center with the State of Illinois. Unfortunately, the state substantially reduced their contribution from last year. This state center offers the Laboratory a good opportunity to forge new relationships at the local level.



Among the more gratifying of our socially redeeming activities is the now 12-year-old Neutron Therapy Facility (NTF), a joint venture between Fermilab, represented by Arlene Lennox, and the Midwest Institute for Neutron Therapy (MINT), the consortium of medical doctors who care for the patients. Arlene gives a status report enriched by a look back at NTF's successes over the years.

The Neutron Therapy Facility

Arlene J. Lennox

When the Neutron Therapy Facility began treating patients in 1976, emphasis was placed on inoperable tumors which were also considered to be radioresistant because they could not be controlled by conventional photon radiation therapy. Because of the mechanisms by which neutrons transmit energy to tissue, they induce irreparable changes in chromosome structure independent of the metabolic or biochemical state of the cells. It was hoped that the neutrons would be able to control tumors which had heretofore been classified as radioresistant. As a result of dose-searching and fractionation research at Fermilab and a number of other neutron facilities in the United States, Europe, and Japan, it is now known that certain radioresistant tumors will respond to treatment with neutrons. Table 5 lists the control rate for these tumors (source: Lionel Cohen and Frank Hendrickson, "External Neutron Beam Therapy," *Illinois Medical Journal*, Vol. 171:4, April 1987, p. 235).

Table 5
Control Rates for Tumors
Treated with Neutrons

Tumor Type	Control Rate
Salivary Tumors	74%
Sarcoma of Bone	59%
Soft Tissue Sarcoma	58%
Melanoma	71%
Rectosigmoid Cancer	52%
Bladder Cancer	50%

In addition, it was found that freedom from locally recurrent prostate cancer is 62% for patients receiving combined photon and neutron therapy compared to 35% for patients receiving only photons (source: George E. Laramore, et al., "Fast Neutron Radiotherapy for Locally Advanced Prostate Cancer: Results of an RTOG Randomized Study," *International Journal of Radiation Oncology Biology Physics*, Vol. 11, pp. 1626-1627). At present Fermilab is participating in a study (Illinois Cancer Council Protocol #86U1 - Randomized Study to Compare Three Modes of Radiation Therapy in the Treatment of Clinical Stage C Adenocarcinoma of the Prostate) comparing the results of this combined therapy with using only neutrons to treat advanced prostate cancer.

As of December 1987, we have evaluated 1841 cases and have accepted 1582 patients for treatment. A summary of the tumor types treated here is given in Table 6. About 80% of our patients come from within 200 miles of the Laboratory though we have had patients from as far away as New York, Florida, India, Alaska, and the Philippines.

Neutron therapy is now gaining recognition as a medically accepted, standard method of cancer treatment. Fermilab has played a significant role in making neutron therapy the treatment of choice for certain types of tumors.

Table 6
Summary of Tumor Types
Treated at Fermilab Since 1987

Tumor Type	Number Evaluated	Number Treated
Brain	220	193
Head & Neck	770	668
Thorax	162	125
Abdomen	191	163
Pelvis	205	161
Sarcoma, melanoma and other	256	225
More than one course of neutrons	47	47

Fermilab Deputy Director Philip V. Livdahl (retired).

Philip V. Livdahl came to Fermilab in 1967 and for the next 20 years he served in a variety of roles starting with construction and commissioning of the Linac and progressing through co-manager of the Main Ring construction, Deputy Head of the Accelerator Division, Acting Director, and finally Deputy Director in 1984.

Phil Livdahl retired from the Laboratory in September of 1987 in order to give his full attention to the Loma Linda project, which of course just happens to be located in a beautiful part of sunny California. His loyal, able service to the Laboratory over these years is appreciated by all of us and, in a series of parties and receptions, his friends assured him of their affection and best wishes. Phil will continue to be associated with the Lab through the Loma Linda project, the subject of the following brief status report by Phil and co-author Frank Cole.

The Loma Linda Medical Accelerator

Francis T. Cole and
Philip V. Livdahl (retired)

Fermilab has had a long-standing interest in the use of accelerators in medicine. Robert Wilson, our founding Director, first proposed the use of protons or other heavy-charged particles in cancer therapy. His 1946 proposal was centered on the concept, still as valid today as it was then, that the strong peaking of energy loss along the path of a proton in matter, the Bragg peak, and its small transverse scattering, could be used to localize the radiation. Thus, a tumor site can be irradiated to kill cancer cells while sparing the healthy tissue around it. Damage to healthy tissue causes the side effects of weakness and nausea that limit radiation therapy with X-rays.

After the Fermilab accelerator went into operation in 1972, serious study was given to using the 200-MeV proton beam for therapy during the idle time between injection pulses. But modern methods to locate tumors precisely, such as CT scanning, magnetic resonance imaging, and positron emission tomography, were not available at that time. At the urging of the Chicago medical community, a neutron therapy facility was built instead. Donald Young, Miguel Awschalom, and Arlene Lennox have been among the Fermilab people active in building and operating the Neutron Therapy Facility.

But the localization available with protons is still superior to that with neutrons. Pioneering work has been done at Harvard, using a cyclotron built by Wilson. This and work at Lawrence Berkeley Laboratory and a number of accelerators abroad (all converted from physics research) and the development of imaging methods have made the time ripe for an accelerator designed and built for proton therapy.

The Loma Linda University Medical Center in Loma Linda, California, has asked Fermilab to design and build such an accelerator, and work toward that goal has gone on since May 1986. As 1987 ends, the accelerator, a 250-MeV proton synchrotron, is nearing completion. The magnets are almost done, and the acceleration, controls, and extraction systems are not far behind. The longest lead-time system, the injector, a 2-MeV radio frequency quadrupole linear accelerator, is being built by a private company and should be ready to use sometime in April of 1988. The accelerator is being assembled in an area in Industrial Building I.

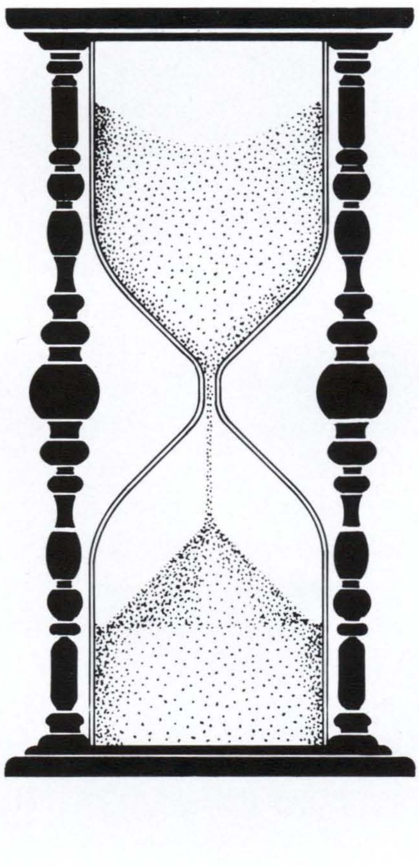
We plan to operate the accelerator here at Fermilab until the summer of 1989, when the new building for it is ready at Loma Linda. The time will not be wasted; we will commission the accelerator, testing all its systems and components, then carry out shielding, microdosimetry, and radiobiology studies in collaboration with medical physicists from several universities.

We are also working to transfer the technology to industry so that more proton therapy accelerators can be built. Loma Linda University Medical Center has chosen Science Applications International Corporation as an industrial partner, and they are working closely with us on design and fabrication.

The medical accelerator is a sideline to Fermilab's work in particle physics. But we are able to apply particle physics technology to a humanitarian end and this is a positive endeavor for us and for Fermilab.

And, with this, the report of our 20th year with its theme of time, finally closes.

Leon M. Lederman

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II. 1987 Physics Results at the TEVATRON

Introduction

During 1987 the TEVATRON physics program began to fulfill its potential as the first major run of the Collider unfolded and the fixed-target program came up to record strength. The first serious look at 1.8-TeV $\bar{p}p$ interactions began in February following a three month commissioning period for the Collider. One major detector (CDF) and three relatively small detectors took advantage of the new mode of TEVATRON operation. Much data was written on tape, and physics results will follow soon (see the articles by Roy Schwitters on CDF and Roy Rubinstein on small Collider experiments in the State of the Laboratory); however, these successes are only indicative of things to come. The world eagerly awaits the next run of the Collider which will produce enough integrated luminosity to have a significant impact on the world of physics. The elusive top quark, supersymmetry, or perhaps something totally unexpected are some of the possibilities that stir imaginations.

The Collider run ended in May with the Accelerator delivering a total integrated luminosity of 71 nb^{-1} of which about 30 nb^{-1} was recorded on tape by CDF. After a three-week shutdown to change operating modes of the Accelerator, the fixed-target run began in June. During the period of June to December, all scheduled experiments achieved data taking and several tests for future experiments were successfully carried out. The run continued into 1988 and the total duration will be greater than eight months. The program includes four large new detectors with new beamlines that were constructed as part of the TeV II program. One of the detectors was scheduled only for testing, but the other three were all taking data by December 1. In addition, the program included three new experiments using pre-existing beamlines and significant parts of existing spectrometers, as well as eight experiments that were carried over from the 1985 fixed-target run. One experiment being installed in the Accumulator Ring of the Pbar Source also began testing during the 1987 run. Other activities occurring during the run include CDF and D0 test-beam running. Literally thousands of data tapes have been written during the past few months, and their impact on physics can only be a subject of speculation at this point.

Physics results from the 1987 Collider and fixed-target runs will not be out for some time as much analysis must be undertaken first. However, a number of results have been published during the year from past fixed-target runs. For example, last year on the pages of this *Annual Report* were some preliminary results from the 1985 run of the tagged-photon spectrometer in the Proton Area. It was clear at the time that important new measurements of charmed particle lifetimes had been made, even though only a small part of the data had been analyzed. This year the results of a year's worth of analyses on those data will be reviewed. Other results from last year that will be updated here include those from E-731, the measurements of ϵ'/ϵ. Final numbers are not available yet as the experiment is still running. This article will discuss these and several other results from past experiments and attempt to highlight some of the expectations of the 1987 run.

Physics at Hand

E-691 gathered data during the 1985 fixed-target run using the tagged-photon beam in the Proton Laboratory. The spectrometer and beam had been used once before for E-516 during the days of 400-GeV physics. It had matured and was ripe to produce some spectacular results. Silicon microstrip detectors (SMD) had been added since the previous run, and a number of other improvements had been made. The experiment was designed as a high-statistics study of charmed particle production by a photon beam. The photons were produced by a 260-GeV electron beam; the average photon energy was 145 GeV. The spectrometer consisted of a two-stage magnet spectrometer with large-acceptance drift chambers, Cerenkov counters for particle identification, and electromagnetic and hadronic calorimetry.

Approximately one-half of the secondary vertices from charm decay could be identified with the SMD. Data taking was triggered by >2.5-GeV energy deposition in the calorimetry. The trigger was 80% efficient for charm events and suppressed the hadronic background by a factor of 2.5. Cuts of SMD information applied offline reduced the background by another factor of 300. A total of 100 million triggers were recorded during the run.

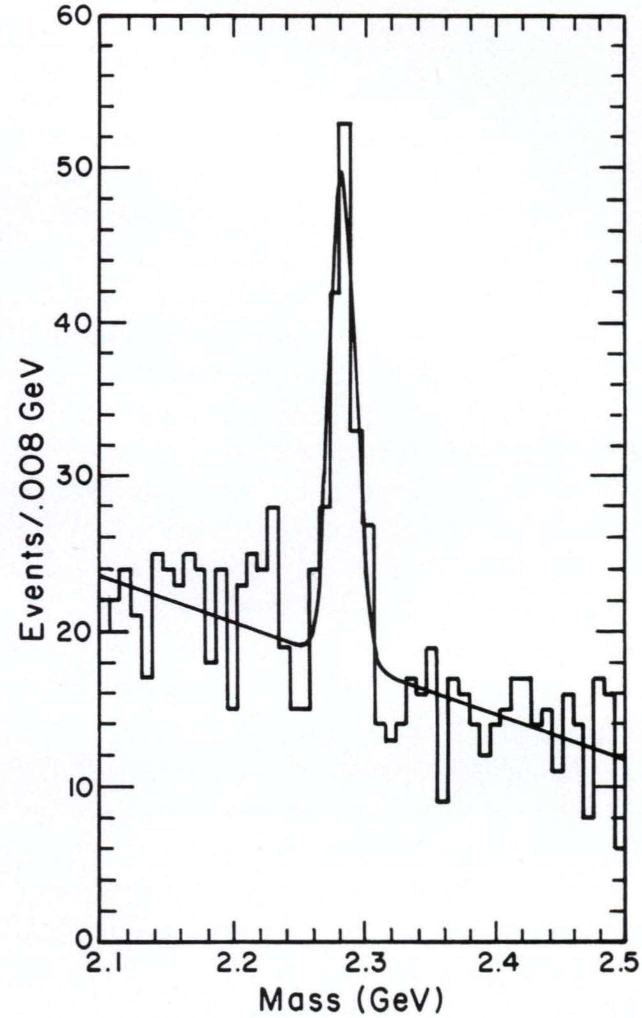


Figure 1. Λ_c signal in mass spectrum of $PK\pi$ from E-691.

Last year at this time a sample of very clean charm signals containing D^0's, D^+'s, and D_f's had been shown. There were also preliminary lifetimes for these particles based on approximately 30% of the data, and these lifetimes were already more accurate than those published by any other experimental group. During the past year the analysis has continued at a rapid pace using the Laboratory's ACP system, and all of the data have now been included in the lifetime results. A search for additional charmed particles has yielded a Λ_c signal containing approximately 100 events (see Fig. 1) and a lifetime determination has been made. A compilation of charmed particles including the E-691 results are shown in Figures 2, 3, and 4. It is clear that E-691 has made a dramatic contribution to the charmed lifetime business.

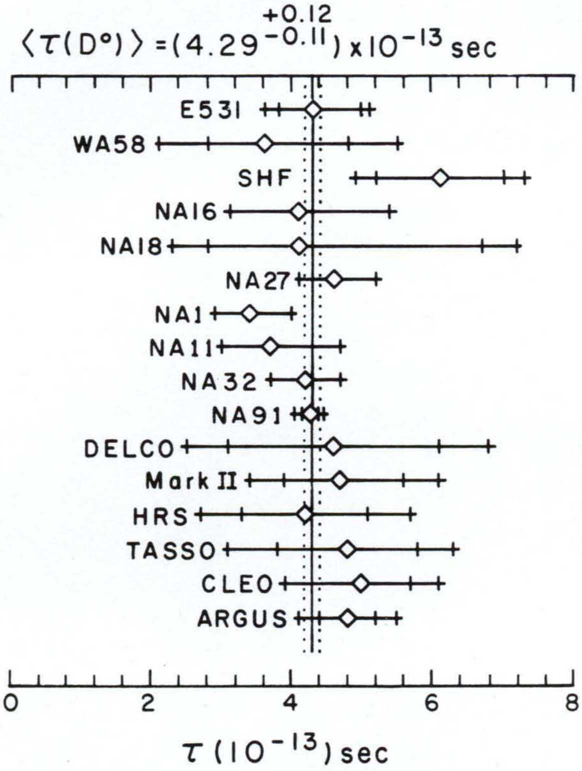


Figure 2. Summary of D^0 lifetime results.

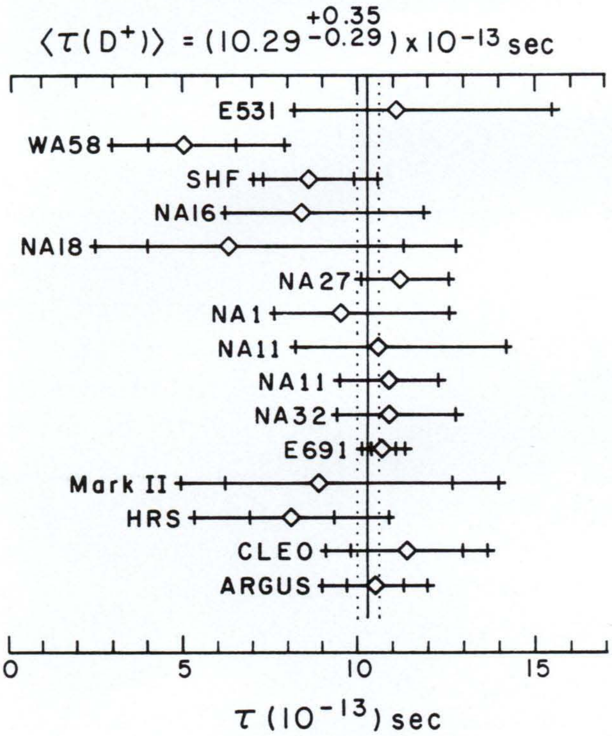
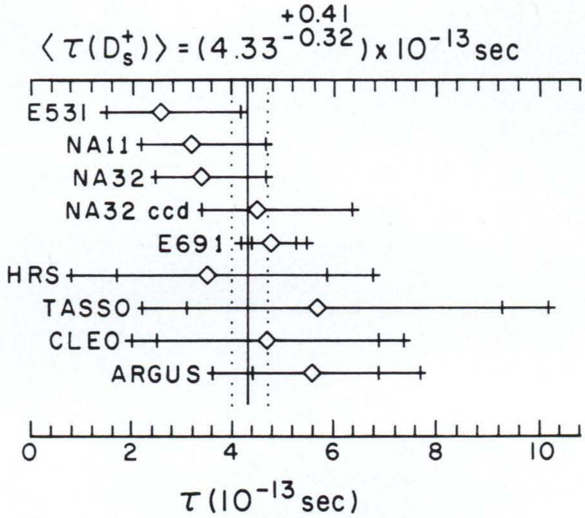


Figure 3. Summary of D^+ lifetime results.



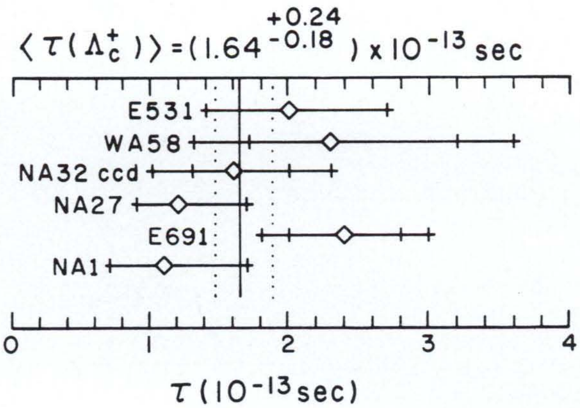


Figure 4. Summary of D_s and Λ_c lifetime results.

However, their impact has not been confined to charmed particle lifetimes. The group has recently published a paper on D^0 - $\overline{D}^0$ mixing. There had been some experimental indication that the mixing might be as large as 1%, a number much larger than theory predicts. E-691 was able to make two independent determinations of the mixing with the following results:

$$r_m < .0037$$

and

$$r_m = .005 \pm .002$$

where $r_m = B(D^0 \to \overline{f})/B(\overline{D}^0 \to f)$.

The combination of photoproduction and the use of the silicon vertex detectors has proven to be a very powerful technique for the study of charm. Many important results are still coming out of E-691 on the topics of charm spectroscopy and non-charm spectroscopy. Other experiments at Fermilab and CERN are assimilating this technique and improving upon it, hoping to push back the frontiers of heavy-flavor production in future years. E-687 is an example of an experiment that should open the door to b production using a similar technique.

Another experiment discussed in the future tense on the pages of last year's *Annual Report* was E-731 in the Meson Laboratory. The experiment is situated in a double neutral beam studying neutral kaon decays in an attempt to make the most accurate measurement to date of the CP violating parameter ϵ'/ϵ. The detector observes decays of both K short and K long simultaneously by alternately placing a regenerator in one beamline and then the other. Both charged and neutral two-body decays of the kaons are recorded. The charged decays are measured by a magnetic spectrometer, and the neutral decays are detected using a pb-glass calorimeter. The competition from CERN's NA31 is fierce, but if the two experiments agree that the value of this parameter is nonzero, they will have captured the attention of the theorists.

During the 1985 fixed-target run, E-731 recorded 43,000 K long --> 2 π events; they have produced a preliminary result for ϵ'/ϵ of .0035 ±.003 (stat.) ±.002 (systematic). This value agrees with the number reported by the CERN group based on a larger number of decays and with errors almost a factor of 10 smaller. The E-731 group expects to finish the 1987 run with a total of 350,000 K long --> $\pi^+ \pi^-$ decays and about 250,000 K long --> 2 π^0 decays. This would make their present statistical error <.0006. They have promised a preliminary result in the near future. The CERN group plans another run in 1988 with an improved detector and beam, hoping to significantly reduce their systematic error.

Another experiment which measures a CP violating parameter is E-621. This experiment attempts to measure η_{+-0}; it also ran during 1985 and was completed at that time. During the summer of 1986 the group reported preliminary results of their measurement at the Berkeley conference based on about 1/30th of their total data sample which contains approximately 3 million neutral kaon decays. They obtained an absolute value of η_{+-0} = .04 ± .035. The group hopes to have a new value in the spring of 1988 based on about one-quarter of the total data sample yielding an error of ± .01. In the meantime, they have not been idle. During the past year they have published a result on the K short lifetime as a function of the momentum of the decaying kaon. Fifth-force scenarios had predicted that the lifetime would vary with momentum. Their measurement indicates a constant lifetime.

Two other 1985 experiments that had preliminary results last year are still working on the analysis of their data and should be producing physics soon. They are E-743, which measured the charm production cross section for pp interactions at 800 GeV, and E-605, which measured single- and double-particle production at large transverse momentum. E-743 plans to have a preliminary result on the X_f distribution for charm production within a few months, and E-605 will also publish their 1985 800-GeV data soon.

Promise for the Future

Table I lists all of the fixed-target experiments that ran during 1987 along with a brief description of their physics goals. Most of the running experiments will produce some physics results from the data they are taking now.

E-687 is situated in the new Wide Band Photon beam in the Proton Area. The photons are produced by an electron beam that ranges in energy up to 600 GeV with reasonable fluxes. The detector consists of a powerful two-stage spectrometer that includes a vertex detection system consisting of silicon microstrip detectors, four conventional Cerenkov counters to provide particle identification, electromagnetic and hadronic calorimetry, and muon detection. Tests of a scintillating-fiber active target are also planned during the present run. The experiment has incorporated all of the design features that made E-691 so successful and then improved on them. The photon beam provides a very clean mechanism for charm production and, perhaps, even some b production.

Experiment 687's run during 1987 was interrupted by a fire in one of the calorimeters which terminated data taking for more than a month. Before the fire, 15 million triggers were recorded with an electron-beam energy of 250 GeV. When data taking resumed, the energy was increased to 350 GeV and, as of this writing, an additional 25 million triggers have been

Table 1
1987 Fixed-Target Experiments

Electroweak

E-632: Wide-band neutrinos in the 15-ft bubble chamber
E-665: Muon scattering with hadron detection
E-733: Neutrino interactions with the Quad Triplet Beam
E-745: Neutrino interactions in the Tohoku Bubble Chamber
E-770: Neutrino interactions with the Quad Triplet Beam

Decays and CP

E-731: Measurement of epsilon prime/epsilon
E-756: Omega-minus magnet moment

Heavy Quarks

E-653: Hadronic production of charm and b
E-687: Photoproduction of charm and b
E-705: Charmonium and direct photon production
E-769: Pion and kaon production of charm
E-672: Hadronic states in conjunction with high-mass dimuons
E-706: Direct photon production
E-711: Constituent scattering
E-772: Nuclear anti-quark structure function

recorded on tape. With good luck the experiment could accumulate a data sample comparable to the total E-691 sample.

The 1987 run also found a new muon beam in the new Muon Laboratory where E-665 eagerly began the shakedown of a large new detector that will be used to make a detailed examination of deep inelastic scattering of muons. A detailed investigation of the break up of the nucleus as the muon is scattered is the main goal. The group intends to measure A dependences, parton fragmentation, and nucleon structure functions among other things.

As is common in these second-generation detectors, the spectrometer is a two-stage magnetic device. In this case, the aperture of the magnets is very large, giving the detector a large acceptance for the nuclear breakup. The first magnet is a cryogenic magnet borrowed from CERN. It contains the experimental target as well as a streamer chamber, which is triggered to look at a small fraction of the events. Behind the CERN Vertex Magnet is an array of drift chambers and Cereknov counters followed by the Chicago Cyclotron Magnet (CCM), which provides the second stage of the magnetic bending. Following the CCM there is a large Ring Imagining Cerenkov Counter surrounded by more drift chambers, and finally, a muon detection system.

During the 1987 run the group took data with two different triggers and three targets. They have used a large-angle trigger (>3.7 mrad) and a small-angle trigger (<.5 mrad) and they have accumulated several hundred thousand deep inelastic scatters with each. The targets used were deuterium, hydrogen, and Xenon.

The third large new detector to achieve data taking during the 1987 run was in the Meson West pion beam, which is capable of delivering pions up to 600 GeV. It can also deliver protons, kaons, and antiprotons. As with the other new beams, commissioning occurred during the early part of the run.

The experiment is E-706/E-672, an amalgamation of two experiments and two groups with combined interests. The first group conceived a detector with the primary feature being a large liquid-argon calorimeter (LAC) to look at direct photon production. The E-672 collaboration proposed an investigation of hadronic states produced in conjunction with high-mass dimuons. It was a marriage made in heaven.

Full data taking did not get under way until early November of 1987 due to the large amount of effort required to commission the LAC. In spite of the delay, E-672 did manage to start accumulating dimuon events as early as July. Since that time, they have produced a J/Ψ signal which is shown in Fig. 5. In November the LAC was ready for data taking as evidenced in Fig. 6, which shows a π^0 signal in the two-photon mass spectrum recorded by the LAC. All in all, it has been a successful initial run for the E-706/E-672 groups and there will be some data for an initial look at the physics.

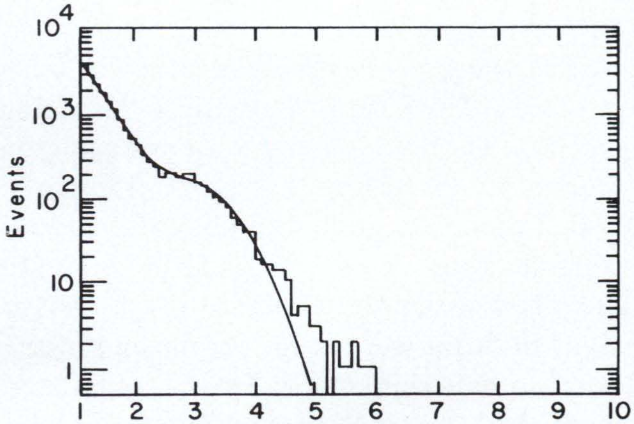


Figure 5. J/ψ signal in the μ^+ μ^- mass spectrum from E-672.

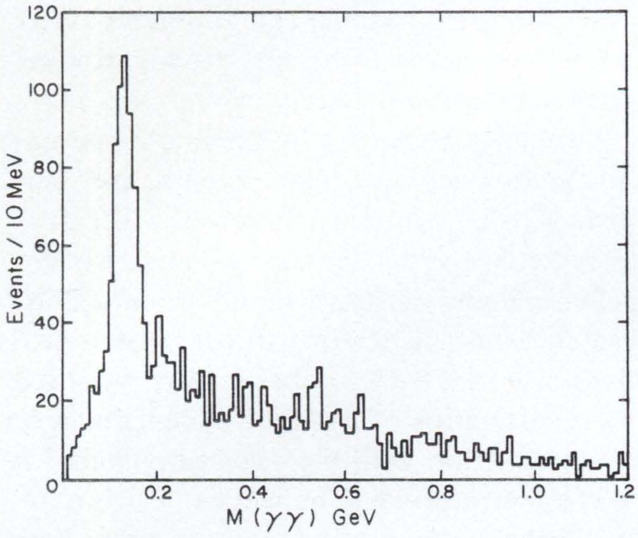


Figure 6. $\pi^0 \to \gamma\gamma$ *signal as measured in the E-706 LAC.*

The detector itself was improved by the addition of more silicon strips to the SMD, both upstream and downstream of the target. The data acquisition system was also upgraded through the addition of ACP boards which allow large numbers of events to be buffered during a spill, leading to data rates of over 400 events per second.

Preliminary offline analysis of a small amount of the data has already produced a charm signal which is shown in Fig. 7. This is quite an impressive result. The high rate and beam tagging should provide answers to many of the remaining questions about charm production at these energies.

Experiment 769, which is running in the Tagged Photon Laboratory of the Proton Area, is an experiment that is building on successes of the past. It uses the Tagged Photon Spectrometer (TPS), the detector so fruitfully employed by E-691 for charm studies. Spurred by the recent reports of the ACCMOR group at CERN that charm production can vary greatly depending upon beam particle type, E-769 brought a 250-GeV tagged-hadron beam to the TPS. The tagging was done by a DISC Cerenkov counter brought to the Laboratory from CERN many years ago, and a newly constructed Transition Radiation Detector (TRD). The DISC counter was capable of uniquely identifying kaons at 250 GeV with a pion background of about 5% at reasonable kaon rates. The TRD uniquely identifies a sample of pions. Both charge signs of beam were used. At the end of the run, the experiment will have accumulated more than 200 million negative beam triggers and more than 100 million with positive beam.

Figure 7. D^0 *signal in the* $K\pi$ *mass spectrum from* $D^* \to D^0\pi$ *in E-769.*

Nowhere is the power of the TEVATRON fixed-target facility demonstrated more clearly than in E-756. This experiment set out to measure the magnetic moment of the Ω^- hyperon in the P Center area of the Proton Laboratory. However, in order to accomplish the goal, Mother Nature had to smile upon the experimenters: she was required to provide a polarized Ω^-.

For the initial attempt, the Ω's were produced using a proton beam and the polarization was measured. A spin-off of the measurement was the determination of the polarization of the Ξ^-. A sample of 60,000 Ω^-'s were collected and the results indicated little or no polarization. The experimenters were determined to seize Mother Nature's secret away from her: they modified the beam so that the Ω's were produced by a neutral Λ/Ξ beam. To date, 11,000 Ω's have been collected, and a non-zero polarization has been measured. By the end of the run the experimenters expect to collect on the order of 20,000 Ω's which will be enough for a preliminary measurement of the magnetic moment. The group collected thousands of such exotic particles as the $\overline{\Omega}^-$ and the $\overline{\Xi}^-$, which are, of course, positive (see Figs. 8, 9, and 10).

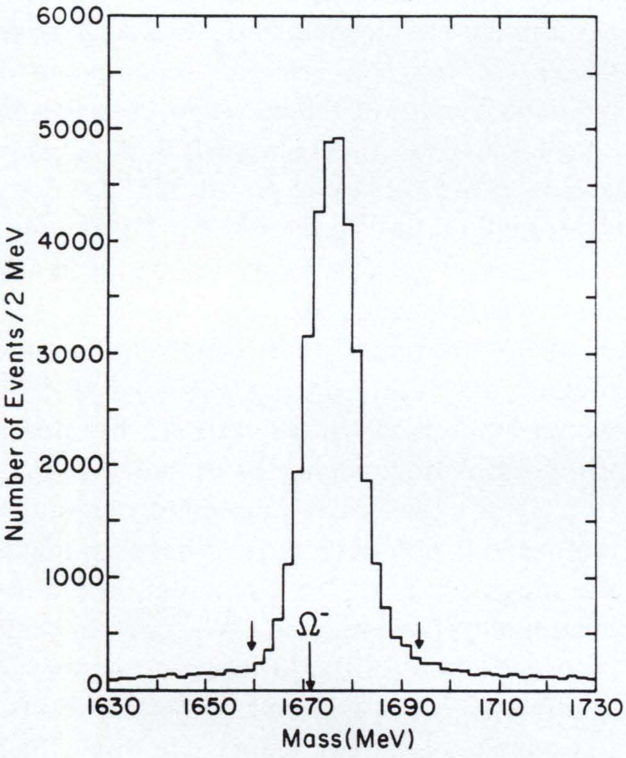


Figure 8. Ω^- signal using one-half of the total sample. It contains approximately 28,000 Ω^-'s with σ=5 MeV.

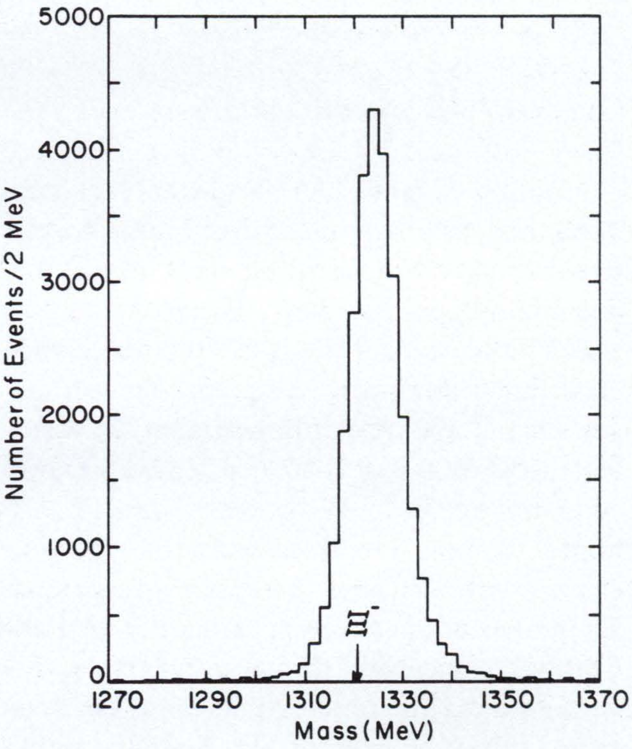


Figure 9. Ξ^- signal seen using .3% of the total data sample.

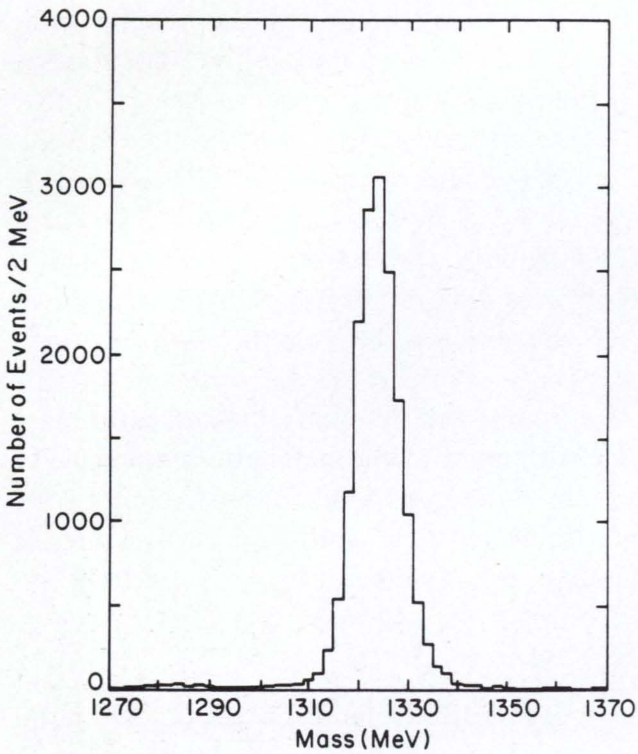


Figure 10. Ξ^- *signal containing ~ 18,000 events.*

In Lab C and Lab E of the Neutrino Area, the two big electronic neutrino detectors will close out their data taking forever with the 1987 run. Experiments 733 and 770 have each doubled their statistics by accumulating 4.5 x 10^{17} protons on target during the run. Experiment 733 collected 115,000 and E-770 collected 800,000 neutrino events. With these data E-770 hopes to have the final word on neutrino cross sections and structure functions. They also collected approximately 100 additional same-sign dimuon events to investigate earlier reports that an anomalous signal might be present. Preliminary analysis of their 1985 data indicated that the signal was consistent with the expected background. The present run uses a detector improved by the addition of flash ADC's and a significant amount of calibration in order to understand the same-sign background produced by the decay of hadrons. The data will put the question permanently to rest (unless it comes up again - just kidding).

The E-733 group, in addition to the structure function studies and $\sin^2 \theta_w$ determination, will search their data for weakly interacting massive particles (WIMPS). For this purpose they added a number of large scintillation counters interleaved between the planes of their detector to look for objects arriving out of synchronization with the beam's rf structure. Real men everywhere hope they find nothing.

Both of the bubble chambers in the Neutrino Area also took beam in the 1987 run. The 15-ft Bubble Chamber has taken 230,000 conventional pictures during the run and more than 2000 "good" holograms containing visible neutrino events. About 45,000 of the conventional pictures have neutrino events in them. Also present for data taking was the Tohoku Bubble Chamber of E-745. They exposed 345,000 conventional pictures and 61,000 holograms. Their analysis has already yielded a handful of charm events.

An experiment that began and completed data taking during 1987 was E-772 which studied the anti-quark sea by measuring the A-dependence of dimuon production. The experiment employed the much exploited E-605 detector and beam to make the measurement. Iron, calcium, and deuterium targets were used. All together they recorded about 350,000 dimuon events including 10,000 J/ψ's and 15,000 upsilons. Estimated statistical errors are less than 1% for the ratio of the Drell-Yan cross sections for Ca/LD2 and Fe/LD2 with target X less than about .2, making for a very successful run.

Three other experiments took data during the run, and one other experiment, E-

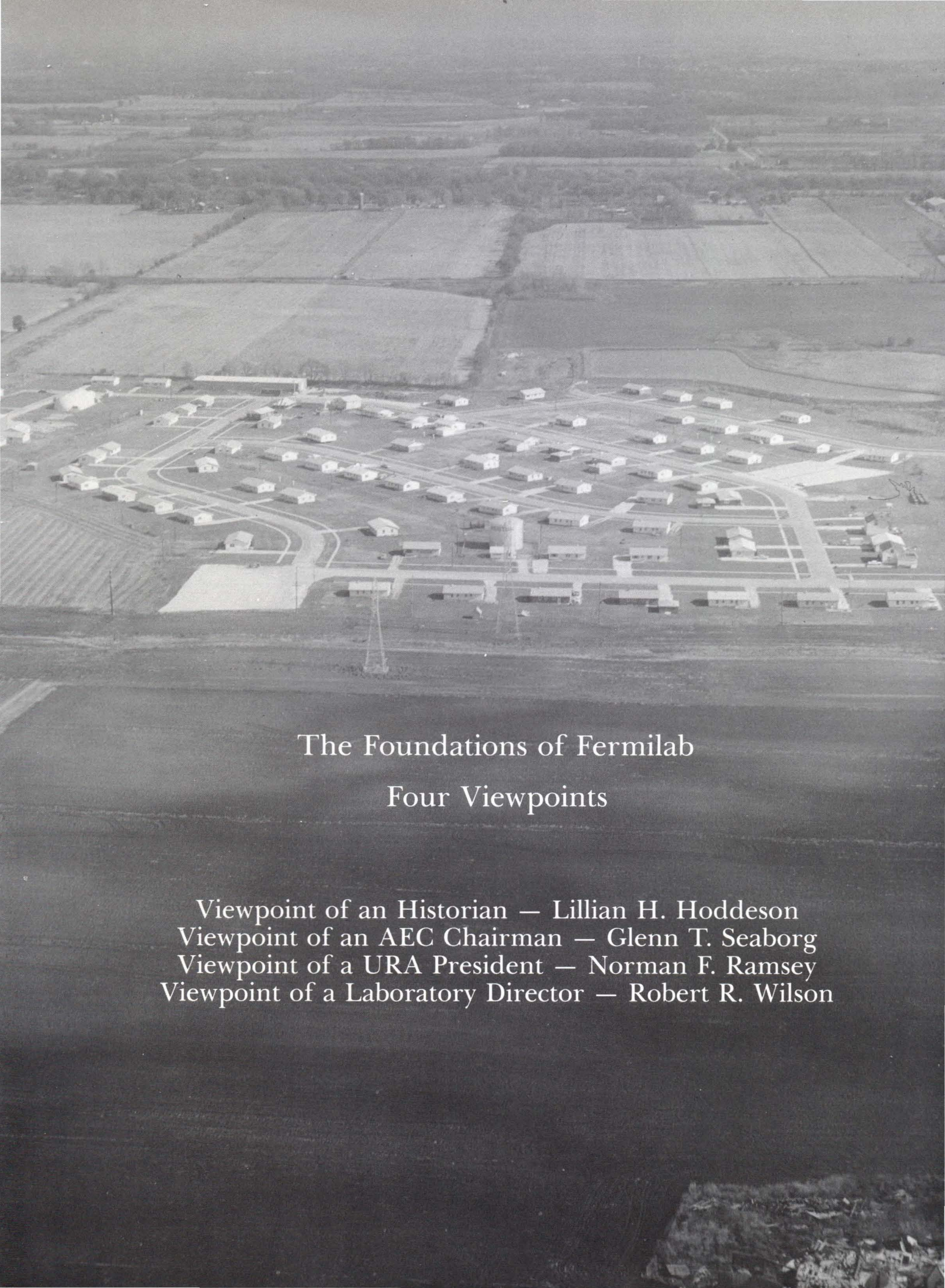
35,000 tapes!

704 in the polarized proton beam, began testing during the period. The three additional experiments are E-653, E-711, and E-705. Experiment 653 is a heavy-quark production experiment that consists of an emulsion followed by a spectrometer. It had its first run in 1985. A charm signal has been reported, but further results await the time consuming examination of the emulsions. Experiment 711 had to time-share a beam with E-653 and, as a consequence, did not begin real data taking until late in the run. A measurement of the energy, angle, and flavor dependence of constituent scattering is the goal of the experiment. Experiment 705 was also running for the second time and is looking at charmonium states and direct photon production.

Conclusion

The two 1987 runs of the TEVATRON have realized the first steps in achieving the full physics potential Laboratory. The first run of the Collider has stirred imaginations wondering what nature might reveal in the next run. The fixed-target program is finally at full strength as the Laboratory successfully ran its largest-ever complement of experiments. Physics from previous runs only whets the appetite to feast on what has been written onto data tapes during the past few months. Charm production experiments have, in two runs, reached a mature state. Similar progress for beauty production could be just around the corner. Ah, we live in exciting times.

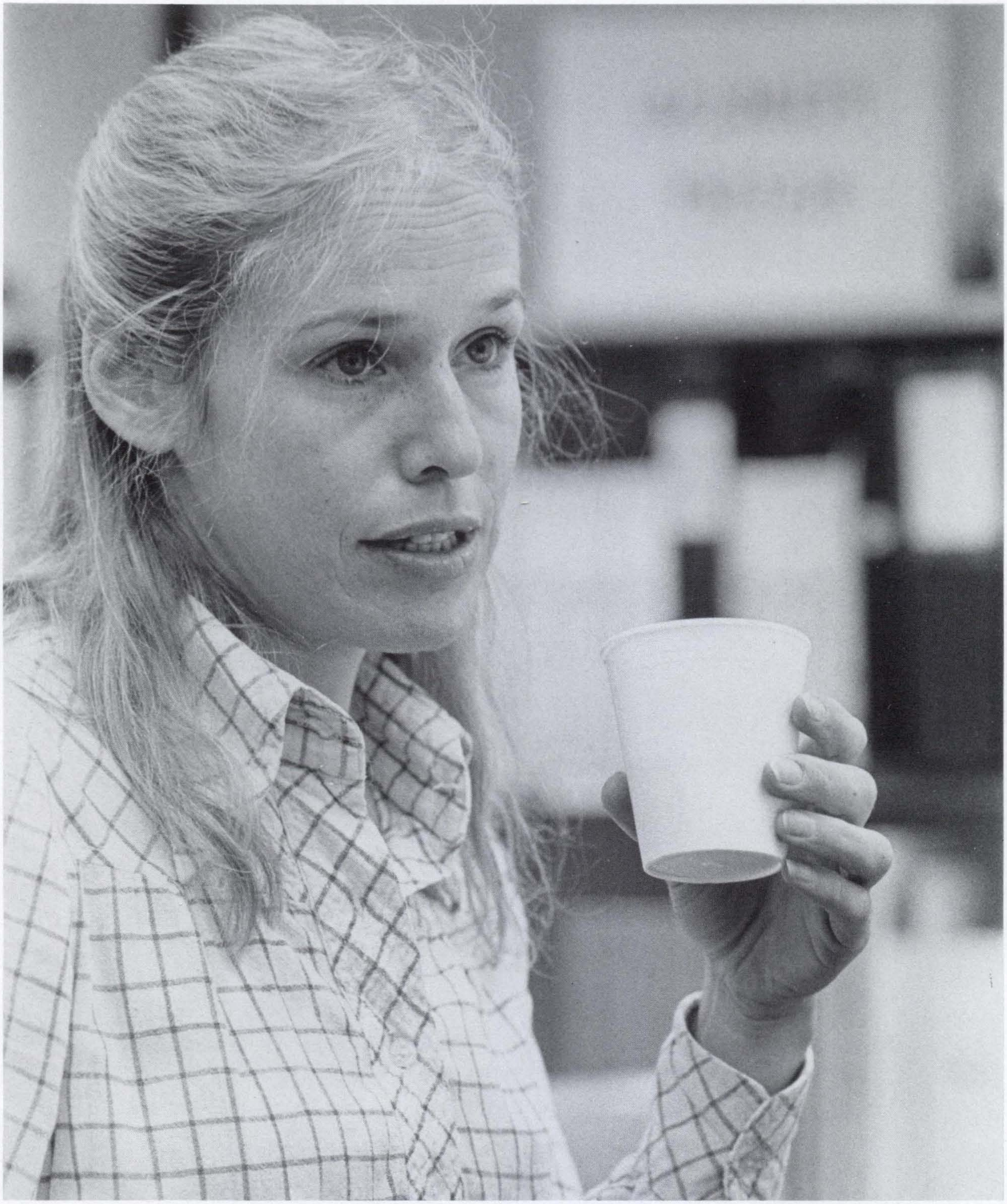
Roger L. Dixon



The Foundations of Fermilab

Four Viewpoints

Viewpoint of an Historian — Lillian H. Hoddeson
Viewpoint of an AEC Chairman — Glenn T. Seaborg
Viewpoint of a URA President — Norman F. Ramsey
Viewpoint of a Laboratory Director — Robert R. Wilson



Fermilab Historian Lillian H. Hoddeson.

III. The Foundations of Fermilab

The Beginnings of Fermilab

Viewpoint of an Historian

Lillian H. Hoddeson

In the wake of technical and institutional developments spawned by the Second World War, the art and science of accelerator building was blossoming into a strongly competitive, independent branch of physics. Innovations appeared by the dozens. To list but a few of the more important ones: phase stability; alternating gradient (AG) or "strong" focusing; separated-function magnets; beam stacking; colliding beams; the rapid-cycling high-intensity synchrotron; and the fixed-field alternating gradient (FFAG) accelerator.

In the early 1950s, the principle American accelerator efforts were still localized on the East and West coasts; the Brookhaven Cosmotron and Berkeley Bevatron, both proton synchrotrons, were the largest accelerators in the world, as well as the first to be funded by the U.S. Atomic Energy Commission (AEC). A pioneering 32-MeV proton linear accelerator - the prototype for a generation of subsequent linear accelerators - was built at Berkeley, using wartime surplus radar. By the middle of the decade, however, these East and West coast efforts were being challenged by accelerator developments elsewhere in the country, for example by those of the Midwestern Universities Research Association (MURA), formed soon after the Cosmotron had been completed in 1952, which hoped to design the next large United States accelerator facility. Reasonably, they felt, this next accelerator should be located in the Midwest. By this time, the various American accelerator schools were differentiating one from another in their approach to design.

The Fermilab machine's conceptual root grew out of the discussions at a MURA summer study meeting in 1959, a meeting aimed at generating support for MURA and reconsidering the FFAG design in relation to all the existing schemes of achieving high energy or high intensity. At that time it was generally felt that the only practical way to produce energies in the several-hundred-GeV range was by colliding accelerated beams. Furthermore, it was believed that fixed-target machines of very high energy would be exorbitantly expensive (if even feasible technically) - and perhaps not useful for physics anyway, because above approximately 5 GeV all the existing schemes for identifying particles were suspect. (The fear was that all particles would look alike, being confined to a narrow forward-moving cone.) At that meeting, Matthew Sands, an iconoclastic participant from the California Institute of Technology (Caltech), became challenged by the problem of designing a reasonable cost fixed-target machine aimed at approximately 300 GeV. He reinvented the concept, suggested several years earlier by Robert R. Wilson and others (including F. Heynman and Lee Teng), of forming a cascade of accelerators, injecting an accelerated beam from one machine to another. By first accelerating the particles up to a high energy in a "booster" synchrotron and then, with a reasonably high injection field, feeding the beam into a main synchrotron, Sands hoped to avoid the use of very large (and, therefore, very costly) magnets in the highest energy machine. Beams of particles occupy increasingly smaller transverse space as they experience acceleration. By cascading accelerators, the final and largest ring would then require smaller transverse dimensions.

Although it was thought then that one could not control such a large system or use magnets as small as Sands specified, working out details with a subgroup of the MURA study (which included Courant and M. Hildred Blewett from Brookhaven, and Alvin Tollestrup from Caltech), Sands showed mathematically that the magnet aperture in the main ring could be but a few square centimeters in size. Optimization of parameters gave the result that to achieve 300 GeV most efficiently, one should inject into the main ring from a 10-GeV range "rapid cycling," booster synchrotron. The high repetition rate of such a booster would enable a high intensity to be achieved.

Most of the participants at the MURA summer study did not take Sands' proposal seriously, but he and Tollestrup continued to work on the idea at Caltech, also involving Robert Walker in the project. Since Caltech judged building such a machine to be a project too large for them to support alone, a sponsoring group was formed, the Western Accelerator Group (WAG), which included physicists from Caltech, the University of California at both Los Angeles and San Diego, and the University of Southern California. Berkeley declined the offer to join WAG, for in the late fifties, researchers there (for instance, David Judd and Lloyd Smith) had been working on their own concept for a very-high-energy machine based on a proposal of Nicholas Christofilos. In April 1961, WAG submitted its proposal to the AEC. One of those who appreciated WAG's design was Wilson at Cornell, whose earlier suggestion of cascade injection had stimulated the Sands design. Several years later Wilson would build Fermilab on this model. Presciently, he wrote to Sands on April 25, 1961: "I have been watching your efforts with the 300-GeV machine with open-mouthed admiration. It seems to me that you are working on the right problem and at the right time, and I am sure something will come of it all."

Meanwhile, interest in a several-hundred-GeV machine had been mounting in other parts of the U.S. In August 1960, Wilson organized an unofficial conference in Rochester, New York, at which approximately 30 physicists who were attending the concurrent Rochester Conference on High Energy Physics, took part in "intensive discussion of. . . the desirability of super energy from the point of the theory of particles. . . [and] the experimental practicability of constructing and using ultra-high-energy machines." As Wilson summarized in his own style:

"It was generally agreed that for, say, \$100 million - or at most \$200 million - it would be feasible to push the design of a conventional alternating-gradient proton synchrotron to 100 GeV or even higher and that this might also cover the first round of experiments. With the same reasoning, but pushing the kind of tolerances that must be held, we could even think of attaining 1000 GeV and at a cost of less than \$1 billion - really a bargain, of course."

Further support for such projections came at a meeting in September 1960 at the American Institute of Physics in New York, and at the 1961 International Particle Accelerator Conference at Brookhaven. In February 1962, Brookhaven submitted a proposal to the AEC for a 300- to 1000-GeV design study. In February and December of 1962, Berkeley submitted proposals for study of machines in the 100- to 300-GeV range. WAG's 300-GeV proposal was now in serious competition with proposals from the established accelerator laboratories.

The AEC, having also to evaluate proposals for other large machines, including one by Cornell to upgrade its machine and one by MURA to build a 10-GeV FFAG, found itself in need of advice. For the first time in its history, the funding was insufficient to support all pending accelerator proposals. From this point on, American high-energy physicists would be spending more and more time on panels to discuss funding. Extensive participation by the U.S. Congress had recently begun with hearings in 1959-60 over the issue of supporting Stanford's linear accelerator, the first machine with a budget in the \$100-million range.

Most influential of the American accelerator panels in this period was that headed by Norman Ramsey during 1962 and 1963. After extended discussion, this panel ranked the proposals and, in a report in April 1963, suggested 13 steps to be taken in order. The first was that Berkeley, rather than Brookhaven or Caltech, construct a proton accelerator of approximately 200 GeV. This machine eventually became Fermilab. The next three steps were: that Brookhaven construct storage rings "after a suitable study"; that design studies be conducted at Brookhaven for a 600- to 1000-GeV national accelerator; and that MURA, in fiscal year 1965, construct "a super-current accelerator without permitting this to delay the steps toward high energy . . ." WAGS's proposal was not mentioned. Brookhaven and Berkeley were favored for the very-high-energy machines because they were the most experienced accelerator laboratories. By ranking the MURA machine fourth, the panel effectively phased out this machine, a move that would later enter into the selection of the site of the 200-GeV accelerator.

Two other features of the Ramsey Panel's report are notable. First, the recommendation emphasized that studies for new high-energy facilities "should be permitted to proceed to greater detail with explicit authorization so that ideas can be explored conclusively without implying any commitment to proceed." Thus, accelerator development advanced into the era of the "design study," in which groups of physicists would be authorized to prepare detailed designs over a period of several years, without any commitment to build. Secondly, the panel stressed that future high-energy laboratories be nationwide rather than regional facilities, having a strong users' representation as well as in-house research staff.

An informal but influential paper, prepared in June 1963 by Leon Lederman of Columbia University, then participating in the committee headed by M. L. Good and appointed to review the Ramsey Panel's report, defined the concept of the "Truly National Laboratory," or TNL - a laboratory whose ultimate governing body, to which even the director would be responsible, would be a nationally represented committee. The users' group at the TNL would be "at home and loved." Not only, Lederman argued, should users have the right of access to the machine, ancillary equipment, and any specialized services that are offered, but also (1) laboratory and office space on site; (2) a "substantial" support budget to supplement their own grants; (3) strong representation on the scheduling committee; and (4) an active users' advisory committee. He suggested that the site be selected with a view towards "ease in airport-to-site transportation, housing and school facilities, and general pleasantness." This TNL concept would be put into operation four years later in the design of Fermilab.

After the Good Committee endorsed the Ramsey Panel's recommendations, the AEC appropriated money for Berkeley, under the direction of Edward Lofgren, to conduct a detailed study to design a 200-GeV accelerator. And two years later, in June 1965, the design study appeared. It described, in two thick blue books, a four-accelerator cascade in the spirit of the Sands proposal, but differing substantially from Sands' concept in technical features, most notably its size. In the Berkeley design, the magnet apertures were comparatively huge, contributing to the total budget of over $340 million.

It was a poor time for Berkeley to present such an expensive proposal, for Congress was just then beginning to feel that high-energy physics was over-supported, and that too large a proportion of funds was going to California. Furthermore, non-Berkeley physicists were complaining that in the past they had not been granted adequate access to Berkeley's machines. In this context, in the fall and winter of 1965, Wilson dramatically entered the story of the 200-GeV accelerator. He had had an opportunity during the previous summer to study the Berkeley design, as presented by McMillan at a meeting in Frascati, Italy. Feeling strongly that the Berkeley design was too conservative, and thus much too expensive, Wilson wrote a series of critical papers. By December, he had drawn up an alternative proposal for a 200-GeV machine at a cost of only $50 million, estimating only $100 million to achieve 600 to 1000 GeV. He based his estimates on economizing features used in the Cornell electron synchrotron - for example, small magnets and austere experimental facilities. Another alternative, suggested by Samuel Devons of Columbia University, was to add a further level of acceleration to the Brookhaven machine, using the AGS as injector. While the Berkeley physicists tended to dismiss the economizing suggestions of both Wilson and Devons, the AEC did not, and announced a cost ceiling of $240 million, so that Berkeley had to prepare a "reduced scope" design.

The debates in 1965 further focused on the location of the new laboratory. While Berkeley had assumed throughout that the site would be in California, physicists and politicians in other states actively began to question this assumption. In April 1965, after receiving Colorado's independent site proposal, the AEC advertised for other proposals. One hundred and twenty-six were received, suggesting over 200 sites, with one or more from each of 46 states. By September 1965, the AEC had reduced the number of proposals to 85, and in March 1966, with the help of a National Academy of Sciences site evaluation committee headed by Emanual Piore of IBM, only six remained. It is widely believed that political agreements entered into the final selection of the site at Weston, Illinois, about 30 miles west of the center of Chicago, a choice made in December 1966. With this choice, President Lyndon Johnson could repay a debt to the Midwest incurred by the closing of MURA in 1965, at the same time obligating the Illinois senator Everett Dirksen to support Civil Rights legislation. This plausible conjecture has been contradicted by, among others, Glenn Seaborg, the Chairman of the AEC.

Somewhat earlier, Frederick Seitz, President of the National Academy of Sciences, had taken the initiative of organizing a national university-supported organization, modeled after Brookhaven's AUI, and named the Universities Research Association (URA), to build and operate the new accelerator laboratory. In June 1965, the URA consortium, composed originally of 34, and later of over 50 and then more than 60, universities broadly distributed throughout the United States and later Canada, was incorporated. Ramsey was selected as its President. The URA's first job was to choose a director for the new laboratory. It was initially intended to have the position divided into a physics and an accelerator director. The first offer, that of accelerator director, went to Lofgren, who had been head of the Berkeley design project. But Lofgren, apparently supporting Berkeley's hope that the laboratory be in California, turned the offer down on the grounds that the Illinois site was unsuitable and the $240-million budget impossibly low. Then on February 6, 1967, the URA formally offered Wilson the combined position of accelerator and laboratory director. Wilson was appointed on March 7, 1967.

Operating from his home base in Cornell, Wilson spent the remainder of the academic year 1966-67 on staffing, designing, planning conferences, and arranging for an engineering firm to take on the construction. Staffing was somewhat hindered by the fact that the Illinois site - 6800 acres of totally flat cornfield - seemed an unappealing place to live. Staffing was aided, however, by the fact that MURA and the Cambridge Electron Accelerator were then both at the point of closing down. To emphasize his intention to make the facility "truly national," as discussed by Lederman, Wilson named it "The National Accelerator Laboratory," NAL. Seven years later, in May 1974, NAL would be formally renamed Fermi National Accelerator Laboratory, or Fermilab for short, in honor of Enrico Fermi.

Wilson made effective use of the centrality of the Illinois site, bringing in people from both coasts in an almost continuous series of meetings in order to build consensus and confidence within the physicists' community as well as with the AEC and the contractors. Since Illinois was having local difficulties buying the land that was to be turned over to the Federal government, the new laboratory was not able to move to Weston until fall 1968. The workshops Wilson held in the summer of 1967 to design the laboratory, attended by participants from various parts of the U.S., supported by their home institutions, were held in temporary offices in Oak Brook, a suburb of Chicago. The conferees at Oak Brook chose basic parameters, such as the radius of the main synchrotron ring, and decided where on the site to place particular components. The workshops also gave Wilson and the conferees a chance to look each other over as potential staff and boss. At the end of the summer, approximately half those attending the workshop joined Wilson's staff.

At the Oak Brook meetings, some of the physicists argued that an added ring of superconducting magnets, installed in the Main Ring tunnel, could be used as a beam stretcher, to lengthen the time over which beam feeds out to experiments, or to store the accelerated particles that could then collide against other particles emerging from the primary ring. But most of those who met at Oak Brook considered these concepts to be beyond immediate technological feasibility; designing and building a 200-GeV non-superconducting machine was the immediate job at hand. Following these meetings, Wilson issued an informal edict prohibiting active work on a superconducting accelerator until the main accelerator was functioning. Nevertheless, he insisted that a space "be left free just below the magnets of the NAL proton synchrotron so that a second ring of superconducting magnets could be installed . . . then the energy of the protons that have been accelerated in the ring will be doubled to 1000 BeV." Richard Lundy, who worked on building the Main Ring magnets, recalls that "Bob [Wilson] did enforce the idea that space be left clear . . . [although] it was never exactly obvious what would go in there."

The design report for NAL, completed during the fall of 1967 and issued in January 1968, described a cascade machine quite similar to that proposed by Sands in 1959, but with some features of the Berkeley design. Many innovations reduced costs: small "H-design" magnets with minimal enclosures and a relatively small Main Ring tunnel, separated-function magnets for bending and focusing in the Main Ring, modular equipment in the Main Ring, a single emergent beam split after extraction, newly developed solid-state rectifiers (instead of traditional flywheel generators) tying the magnets directly to AC power lines, an electrostatic septum, a Main Ring tunnel built directly on glacial clay, and simple stands rather than expensive girder supports for the magnets. The design also included a built-in option to raise the energy of the conventional machine to 400 GeV. By mid-April, Congress had passed, and Johnson had signed, the bill authorizing the project at $250 million.

The Linac group was the first to begin work at Weston in 1967-68. The rest of the staff moved there in October 1968. Then a frantic three-year period of actual construction began in December 1968 with the Linac ground-breaking. The emphasis in this period was on economy and speed; Wilson and his Deputy Director, Edwin Goldwasser, kept setting tight schedules and trying to motivate the staff to beat theses schedules in order to save labor costs. Experimental facilities (including a Meson area, a Neutrino area, and a Proton area) were planned by a national group at summer studies held in 1968 and 1969 in Aspen, Colorado, and in 1970 at NAL. When the first 200-GeV beam passed through the Main Ring in March 1972, the NAL accelerator was the highest energy accelerator in the world.

One year earlier, in March 1971, Wilson had begun his campaign to reserve this distinction for Fermilab during the 1980s. He explained to the Joint Committee on Atomic Energy how, using superconducting magnets, the energy of the NAL machine could be doubled - the accelerating scheme that would later be called the Energy Doubler, or TEVATRON: "The idea is to take the protons out of the present magnet ring and then inject them into the new ring of superconducting magnets - piggy back upon the other." He fantasized on the implications: "One could install one of these rings after another, taking the beam from one to the next, doubling the energy each time." A short proposal in February 1972, by William Fowler and Paul Reardon, set the project in motion. Initially a poorly supported, loosely organized, back-burner effort of a handful of researchers surrounding Wilson, this project would grow over the next ten years into a well-funded, well-orchestrated, large-scale effort, Fermilab's first priority. The lack of adequate funding for the Doubler was the immediate reason for Wilson's resignation in 1978; the machine would be completed during the tenure of Fermilab's second director, Leon Lederman, after many financial and technical hurdles had been overcome. On July 3, 1983, the milestone was met of achieving the first acceleration of beam in the Doubler to 512 GeV. As J. Richie Orr, then Head of the Fermilab Accelerator Division, recalls, the event was "a pleasant surprise. The machine was a lot better than we thought it would be. . ." Experiments using the Doubler began in October and a record of 900 GeV was reached on February 16, 1984. The Fermilab Accelerator - now the Doubler - was again the highest energy accelerator in the world.

Robert R. Wilson and Glenn T. Seaborg at the ground breaking for the National Accelerator Laboratory on December 1, 1968.

The Fermilab Story

Viewpoint of the Chairman of the Atomic Energy Commission (1961-1971)

Glenn T. Seaborg

A good place to begin this short narrative is by reference to the third and final report by the President's Scientific Advisory Committee and the General Advisory Committee (PSAC/GAC) Panel, issued in May of 1963, as a result of which the Atomic Energy Commission initiated direct action toward realization of a multi-hundred-BeV (the designation used at that time) particle accelerator by authorizing the Lawrence Radiation Laboratory at Berkeley, California, to proceed with an advanced engineering study of a proton accelerator in the 200-BeV energy range. The third PSAC/GAC Panel, following two earlier reports by the Piore Panel (named after its Chairman, Dr. Emanuel R. Piore), was generally referred to as the Ramsey Panel after Dr. Norman F. Ramsey, who chaired the Panel.

The Panel specifically advised that the Federal Government authorize, at the earliest possible date, the construction of a high-energy proton accelerator at an approximate energy level of 200 BeV. It emphasized, too, the very positive impact of the national high-energy physics program on education in the country, saying that the impact of the program on education went deeper than the important training of graduate and postdoctoral students, since many of the most active scientists in high-energy physics had strong influence on education at all levels and that this was essential to the teaching function of any strong university physics department. Also, and among other things, this third PSAC/GAC Panel stressed the international character of high-energy physics. During this time period, the importance of the pursuit of high-energy physics was receiving increased recognition and support abroad. In Europe, the CERN 28-BeV Alternating Gradient Proton Synchrotron was in full operation and was yielding important new scientific data.

During the course of AEC's FY 1965 Authorization Hearings before the Joint Committee on Atomic Energy, Vice Chairman Chet Holifield discussed the essential relationship between the nation's research and development programs. In doing so, he noted that no definite technological achievements can be predicted from high-energy physics but, nonetheless, he believed that the field should be supported and that it was imperative to develop a national policy for high-energy physics (similar to that which existed for the space program) for the guidance of the Congress. Holifield said, "It is also important to obtain the acquiescence of the President in general to this, if it is possible to get it. Otherwise, we are going to find ourselves in trouble in the Congress in getting this projected program authorized and funded."

As a consequence of the Joint Committee's earnest concern, of the AEC's obvious interest and activity, and of cooperation within the scientific community, on January 25, 1965, I forwarded to the President of the United States a report, entitled "Policy for National Action in the Field of High-Energy Physics," that had been requested by Vice Chairman Holifield. This document summarized the status of the national and international efforts in high-energy physics, and presented among its specific plans the proposed construction of a high-energy proton accelerator of about 200 BeV. The President subsequently transmitted the policy document to Holifield, stating in the transmittal letter, "I commend the Commission and its staff for their efforts in working out a well-considered program. . . The fundamental nature of high-energy physics makes it one of the most important fields of basic science. We must continue to explore it vigorously and to maintain our national leadership." The President went on to say, "I believe that the AEC report provides a useful guideline for decision-making in the development of high-energy physics."

In this same time period other activities were transpiring that would later directly concern the weighty problems of successfully and equitably managing the huge new national research facility.

AEC Commissioner Gerald Tape and I met on December 11, 1964, with Dr. Frederick Seitz, President of the National Academy of Sciences, to discuss AEC participation in an upcoming meeting of a group of university presidents. The meeting of the university presidents was called by Seitz for the purpose of discussing the management of future high-energy accelerators, and the possibility of forming a new national corporation for this purpose. It was realized that any new organization that might be formed to manage such a new facility would require the full backing of the universities and of the scientific community most directly participating in high-energy physics. It was also recognized that the AEC, representing the government, must be assured that any organization formed to carry out such a mission would be properly constituted so as to ensure the initial and continued success of the enterprise. The National Academy of Sciences had a potential for playing an important role in getting together representatives of institutions most likely to be involved in setting up such an organization. (This move was, understandably, vigorously opposed by Ed McMillan, Director of the Lawrence Radiation Laboratory in Berkeley, where the design work on the 200-BeV accelerator was taking place, and his colleagues, including Ed Lofgren, who was in charge of the preliminary design effort.)

On January 17, 1965, at the invitation of Seitz, 25 university presidents met at the National Academy of Sciences in Washington to consider the management and administration of possible future high-energy accelerators. Due to the cost of the 200-BeV machine, there would be only one such facility in the United States. It was very important that this national facility be accessible to all qualified high-energy physics experimentalists and that all prospective participants be satisfied that this would indeed be true. This meeting of university presidents initiated a train of events that culminated in the formation of the Universities Research Association that was to be under contract with the AEC to construct and operate the 200-BeV accelerator facility. In a "Summary of Conclusions" circulated after the meeting, the participants agreed, among other things, that, "There should be a body, meeting perhaps once a year, on which the university presidents would serve. In this capacity they could not only discuss the problems of the association from time to time, but could also review broader problems bearing on the administration of science in universities when collective use of facilities is necessary." They agreed, too, that, "There should be a second body, composed both of administrators and of senior scientists, competent to formulate policies governing the operation of the high-energy laboratory. The members of the second body should, from the start, adopt the view that they represent the interests of the association and the laboratory and not their home institutions." Until this association of universities had actually been organized and established in its own quarters, office space and supporting staff and facilities would be provided by the National Academy of Sciences.

This and other factors led to the concept that we should have a national competition for the choice of the accelerator site. One result of this was the sought-after shift, as a result of the nationwide competition for the accelerator, from the question of *whether* we should build such an accelerator to the question of *where* we should build it. Among the most significant activities associated with selecting a site for the National Accelerator Laboratory project was the formulation of appropriate criteria by which the many sites yet to be proposed would be evaluated. On March 2, 1965, I sent a letter to Seitz at the National Academy of Sciences listing several general criteria that became the nucleus around which subsequent lists were formulated. In my letter, I noted that the general list had evolved over a number of years in connection with studies and discussions on the location and use of large accelerators. The list included the following: 1) Suitable geology. 2) Availability of sufficient power and water with consideration being given to the economics of both, especially during the operating phase. 3) Sufficient acreage, including both initial and long-term expansion requirements. (Initial need for an accelerator in the 200-BeV range was deemed to be approximately 2000 acres, with a long-term requirement for up to another 2000 acres for additional experimental areas and possible storage rings.) 4) Proximity to a major airport and transportation center. 5) Proximity to a cultural center that included both a large university and a well-developed research and development base. 6) Ability to mobilize the necessary staff at the proposed site. 7) Regional cost variations, during both construction and operation.

In my letter of March 2, 1965, I also proposed to Seitz that the National Academy of Sciences, by contract to the AEC, study in considerable detail the problems associated with selecting a site. At the conclusion of such a study, the Academy might make its recommendations to the AEC for the most appropriate location or locations available for the new national accelerator facility. It was also noted that several potential locations had already been brought to AEC's attention. These were: Camp Parks, California; Hanford, Washington; Denver, Colorado; and St. Louis, Missouri.

Prior to the actual execution of a contract between AEC and the National Academy of Sciences, the Subcommittee on Research, Development and Radiation of the Joint Committee on Atomic Energy held a four-day session of very extensive hearings on the high-energy physics research program. During these hearings, testimony was heard from government officials, including Commissioner Tape and me, other representatives of the AEC, Seitz, and Donald F. Hornig (the Director of the Office of Science and Technology), Leland J. Haworth (Director of the National Science Foundation), and from a large number of practicing high-energy physicists. As stated by Subcommittee Chairman Melvin

Price at the opening of the hearings, discussion generally centered in the following areas: the purpose, objectives, and tools required in high-energy physics; achievements in the U.S. and other countries; the place of high-energy physics in the context of the total U.S. effort; the recommendations of the National Policy Report (including the recommendation to construct a new accelerator in the 200-BeV range); and the organization for management of such a large new facility (such as the corporation of universities).

At the time of the hearings, no commitments had been made by AEC concerning the future location of the new accelerator facility. As has been mentioned, the Lawrence Radiation Laboratory had been preparing preliminary design work on such a facility. Associated with that work, the Laboratory had done some exploratory geographic and geologic investigations at sites near Camp Parks and Sacramento, California, in order to better understand the requirements of the project. It was clear that this kind of information was required before proceeding with more detailed site criteria and site surveys.

The hearings before the Subcommittee on Research, Development and Radiation undoubtedly performed a vital service to Congress, to executive agencies, to the scientific community, and to the general public in airing the achievements and future requirements of the nation's high-energy physics program.

On April 7, 1965, a site evaluation task group was established within the AEC for the following purposes: 1) To obtain preliminary information on specific sites, 2) to conduct a preliminary screening operation, and 3) to recommend to the AEC General Manager those sites that should be referred to the National Academy of Sciences for its consideration and evaluation. In addition, the group was to establish minimum criteria to be given prospective site proposers, and to arrange for a survey by the General Services Administration of excess government-owned lands that might meet the minimum site criteria. The task group was to work under Paul W. McDaniel, Director of the Division of Research.

Soon thereafter, on April 28, 1965, the AEC issued a press release announcing that it was receiving specific site proposals, and stating that AEC and the National Academy of Sciences had entered an agreement (April 19, 1965) whereunder the National Academy of Sciences would evaluate, for the AEC, sites proposed for the 200-BeV accelerator project. This press release was, in effect, an invitation for proposals since it stated that AEC would furnish, upon request, guidelines for the preparation of preliminary site proposals for the proposed new national accelerator laboratory. In addition, there was attached to this press announcement a statement of the general considerations involved in siting a major new accelerator.

During this period, there was a need to develop more definitive project scope and cost information so that AEC would be prepared to speak in more detail when the time came to request congressional authorization and funding of the 200-BeV accelerator project. To serve this need, on May 6, 1965, the AEC selected a joint venture of four firms to perform advance architectural and engineering services associated with the project. The joint venture (DUSAF) included the following firms: Daniel, Mann, Johnson, and Mendenhall, Los Angeles; the Office of Max O. Urbahn, New York; Seelye, Stevenson, Value, and Knecht, Inc., New York; and the George A. Fuller Company, New York.

Also, by early May of 1965, the National Academy of Sciences had formally organized its Site Evaluation Committee, and was then prepared to undertake, on behalf of the AEC, evaluation studies of proposed sites referred to it by the AEC. The group was chaired by Dr. Emanuel R. Piore, Vice President and Chief Scientist of the International Business Machines Corporation. Other members of the group were: Professor Robert Bacher, California Institute of Technology; Professor Harvey Brooks, Harvard University; Dr. John W. Gardner, President, Carnegie Corporation; Professor Edwin L. Goldwasser, University of Illinois; Dr. G. Kenneth Green, Brookhaven National Laboratory; Dr. Crawford H. Greenewalt, E. I. DuPont de Nemours & Co., Inc.; Professor Val L. Fitch, Princeton University; Professor William B. Fretter, University of California, Berkeley; Professor William F. Fry, University of Wisconsin; and Dr. Herbert E. Longenecker, President, Tulane University.

The mechanism for selection of the most appropriate site for the new national accelerator laboratory facility was now firmly established and organized. The AEC had established a list of general considerations and criteria for locating the project, had made these public, and was receiving site proposals from any and all interested parties. Within the AEC, there was a Site Evaluation Task Group with responsibility for obtaining information, performing a screening operation on the sites proposed, recommending the better sites for referral to the National Academy of Sciences, and providing a liaison function to the Academy's own site evaluation advisory group.

It was doubtful that one particular site would quickly emerge as being greatly superior to the others, and within the AEC it was expected that the Academy's evaluation group would probably recommend several of the most promising locations to the Commission. The Commission itself would then need to identify the one site possessing, on balance, the most favorable attributes expected to contribute toward the total success of the new national laboratory facility.

Soon after the public announcement that the AEC was searching for the most appropriate location for the project, dozens of site proposals began to arrive in the Division of Research, the staff unit within AEC directly responsible for initial handling of the proposals. Detailed procedures had been established earlier by the Division to ensure systematic and equitable screening by the site evaluation task group of each of the locations proposed, and the screening operation began upon receipt of the first proposed packages. Two sets of criteria were being used by the group. The first set contained the minimum or basic criteria, each of which had to be met by any proposed site in order to qualify for further and detailed evaluation. An example would be the minimum land requirement of 3000 acres. The second set included more detailed technical and other considerations.

It is illustrative of the size of the task involved that during the July-December 1965 time period, the AEC Commissioners considered the 200-BeV site selection matter at 49 of their meetings. In addition, the Commissioners held numerous meetings with congressional, state, and local representatives, and conferred twice with the Academy's Site Evaluation Committee. Most of the meetings focused upon screening procedures, the various economic and other factors relating to site selection, and reports by data-gathering teams that visited all of the sites that met the basic criteria.

The AEC Site Evaluation Task Group had, by early July 1965, performed enough of its reviewing and screening activities to permit the Commission to initiate an in-depth review of the group's initial evaluations and its enumeration of those that met or failed to meet their minimum site criteria. Noting that the Commissioners had not yet completed their review of the AEC Task Group's work and that some changes could, therefore, be expected, on July 15, 1965, I transmitted to Seitz 25 site proposals for detailed evaluation by the Academy's Site Evaluation Committee. Then on August 24, 1965, by letter from me to Seitz, the AEC modified somewhat its listing of locations identified for detailed evaluation by the Academy's Committee. I cautioned that, while the criteria used by AEC's task group were adequate for initial screening purposes, the criteria would require further review and refinement for purposes of detailed site evaluation.

At the end of August 1965, I addressed a letter to the President informing him that the AEC had completed its screening of the 126 site proposal packages (containing over 200 potential locations and representing sites in 46 states - Delaware and Vermont did not submit proposals; Alaska and Hawaii were excluded by the criteria). The letter noted that the Commission's preliminary review and screening of the many proposals resulted in the designation of 34 locations and five alternates for detailed consideration by the National Academy of Sciences' Site Evaluation Advisory Committee. Attached to this letter was a list of all the site proposals, along with a list of those designated for further detailed study. Observation was made in the letter that the shorter list did not include several sites that had been the subject of extensive congressional interest, such as the Little Rock, Arkansas, and Arlee, Montana, locations. A schedule for publicly announcing the then-current status of site selection activities was also included in this letter.

In a continuing effort to keep the White House informed of the activities, a memorandum was sent on August 28, 1965, to Lawrence F. O'Brien (Special Assistant to the President) from Dwight A. Ink of the AEC staff. This memorandum provided detailed information concerning the locations and congressional interest in the various sites proposed. It was noted that the 39 locations that had been identified for further study represented 33 states and about 119 congressional districts, and that approximately 80 districts were associated with the proposals not so identified. This memorandum also stated that any forthcoming press announcements associated with site selection activities would be closely coordinated with Bill D. Moyers, Press Secretary to the President.

The next major development in the site selection process occurred during a discussion that I had with W. Marvin Watson, Special Assistant to the President, at the White House, on September 1, 1965. Watson explained that the President believed the time was inappropriate for announcing a major cutback in the number of site proposals still under consideration. The President took this position since it was felt that several of the Administration's very important legislative proposals could be prejudiced by such an announcement at that time. He was also disappointed that the Austin, Texas, site was not in the list of 39 sites; he didn't expect this site to be the winner, but it was embarrassing to him to have it eliminated in the first cut. (Later, the President told me he didn't think the accelerator should be located in Texas.) The AEC, therefore, postponed the press announcement it had planned for September 2nd. Subsequently, however, it developed that what at first had appeared to be an unfortunate coincidental untimeliness turned out to be a fortuitous circumstance. The list was actually too restrictive for that time. The Commission decided, following detailed considerations of the many problems associated with the review, to extend the list of locations designated for consideration by the Academy's committee. In a letter to Seitz on September 13th, it was noted that the proposers of 85 sites had submitted sufficient data to indicate that, upon a first screening, their proposed locations met the criteria applicable to the 200-BeV accelerator facility.

Also on September 13th, I sent a letter to the Vice President advising him of the extension of the list of proposed sites to be considered by the Academy's Committee and noting that the Commission planned to issue a press release to that effect on September 15th. A listing of the 85 sites was attached, and copies of the letter with its attachment were sent to the following: Lawrence F. O'Brien, Special Assistant to the President, The White House; Charles L. Schultze, Director, Bureau of the Budget; Donald F. Hornig, Special Assistant to the President for Science and Technology, Executive Office Building; Senator Michael J. Mansfield, Senate Majority Leader, United States Senate; and Representative John W. McCormack, Speaker of the House, United States Congress. On the following day, September 14, 1965, informational letters were sent to the Joint Committee on Atomic Energy, and to Desautels, Moyers, and Laitin (Assistant Press Secretary), at the White House. The AEC was planning to release a press announcement on September 15th stating that the National Academy of Sciences Site Evaluation Advisory Committee had been asked to evaluate the locations contained in 85 of the site proposals. By letter to Chairman Holifield, I explained the then-current status of the site selection activities to the Joint Committee and provided a listing of the 85 proposal packages yet under review. It was also pointed out that a number of site visits would probably be necessary to the data-gathering task and that the Joint Committee would be kept informed in that matter.

At 1:00 p.m. (EDT) on Wednesday, September 15, 1965, the AEC released the press announcement identifying the 85 site proposal packages that had been transmitted to the National Academy of Sciences two days earlier. Letters to all 126 proposers were placed in the mail somewhat earlier, advising them of the new development, and members of Congress were notified directly concerning the status of sites receiving their support. The announcement stated that there was sufficient data on sites contained in each of the 85 proposals to indicate the sites met the basic criteria established for location of the 200-BeV accelerator facility. It noted that the AEC and the Academy were still seeking further specific information on certain proposed locations, but that the AEC was no longer accepting any new proposals.

Following up on the necessity to obtain further specific data on the sites, and after the Commission had discussed the matter with members of the Academy's Site Evaluation Advisory Committee (October 9-10, 1965), the AEC formed (on October 20, 1965) eight site-visit teams for the purpose of actually seeing the proposed locations first hand. Among them, the teams would visit each of the locations contained in the 85 proposals still under evaluation. Their mission was to supplement and verify the information that had been received, and to gain visual impressions of the proposed sites and their environments. These teams were, therefore, data-gathering groups that were to obtain information by observation, questions, and discussion for the purpose of substantiating and augmenting the various proposers' responses concerning the AEC's site criteria. With the great mass of information available, there was also the need to ensure that data submitted on particular questions by the various proposers was developed under comparable assumptions. On October 26, 1965, I informed Chairman Holifield of the decision to visit each of the sites and explained the necessity to do so; and on November 6 and 7, 1965, Commissioner Tape attended meetings of the Academy's Site Evaluation Committee during which the on-site visit schedule was discussed.

Each of the eight four-member site-visit teams was comprised of a senior AEC staff member, a member of the AEC's Site Evaluation Task Group, a construction engineer, and a practicing high-energy physicist from one of the AEC-supported laboratories or universities. The team members spent considerable time studying and familiarizing themselves with the several locations assigned to them prior to initiation of the visits. The actual site-visits were begun on October 28, 1965, were conducted during November and December of 1965 and were concluded on December 9th.

In another development, by letter of November 17, 1965, Gaylord P. Harnwell (Chairman of the Council of Presidents, the Universities Research Association, Inc.), formally tendered its services to the AEC "as the contracting agency for the construction and operation of the high-energy particle accelerator which is under contemplation by the Atomic Energy Commission." Chairman Harnwell also stated that the Universities Research Association would support the government's selection of a site for the project. In my reply dated December 3, 1965, I noted the Commission's great interest in the plan and stated, "Considerations relating to the role which URA could play in the construction and operation of the High-Energy Accelerator Laboratory can, more beneficially, be discussed at a later date, when some of the uncertainties in location and schedule have been resolved." I also noted, with pleasure, that URA would support the government's selection of a site.

During meetings of the Academy's Site Evaluation Committee, held on November 21 and 22, 1965, progress reports concerning the on-going site-visits were discussed; and Piore (Chairman of the Committee) stated the aim of the Committee as identifying the best six or so individual sites from the 85 under review. In a meeting held on December 13, 1965, the Academy's Committee met with the AEC site-visiting team captains for discussions of additional information obtained during the visits, and on December 18 and 19, 1965, the site reports were formally submitted to the Committee. On those days, the Commission met with members of the Committee to review the status of site selection activities, to review appropriate public announcement procedures, and to discuss other related matters.

Meanwhile, design work was going on at the Lawrence Radiation Laboratory, but continuation was placed in jeopardy because Bureau of the Budget Director Charles Schultze refused to include our request of $4 million for architects' and engineers' work in the budget for Fiscal Year 1967. On Friday, December 10, 1965, I flew to

Texas, as I did every year at about this time, to try to get President Johnson to overrule this budget decision (among a number of other adverse decisions). President Johnson ruled in my favor and, thus, we were able to proceed with the design of the 200-BeV accelerator. This represented a turning point because, from this point on, the funding process in the Executive Branch proceeded on a schedule pretty much in tune with our requirements.

In another aspect of the site selection activities, on December 29, 1965, I responded to a letter, dated December 16, 1965, from James Farmer, National Director of the Congress of Racial Equality, regarding the selection process in general and the Louisiana site proposal in particular. In my reply I noted that appropriate commitments would be secured and measures taken, in an effort to prevent discrimination in community facilities and services, when the number of potential sites was reduced to a final few.

To further illustrate the size of the task involved in finally identifying the most appropriate location for the 200-BeV accelerator project, during the January through June 1966 period, the Commissioners considered related questions at a total of 39 of their meetings. Matters of primary concern during this period involved evaluating the Academy's Site Evaluation Committee Report, foundation requirements, construction cost evaluations, and the on-site visits to be undertaken by the Commissioners. Furthermore, during the months of July through December 1966, the Commissioners considered site selection matters at another 18 of their meetings. During this period, prime considerations included electrical power supply and civil rights.

In a report dated January 1966, DUSAF, the combine of architect-engineering firms chosen earlier by the AEC to make an independent cost estimate of the 200-BeV accelerator project, indicated a preliminary cost estimate of $368,276,000 (excluding the bubble chamber, but including $40,940,000 for research equipment). This estimate was approximately 6% above the estimate contained in the initial Lawrence Radiation Laboratory Design Study Report of June 1965.

During this period, on February 25 and March 7, 1966, the Commissioners discussed at length the site selection factors that could not be easily evaluated by costs but rather had to be evaluated primarily on the basis of subjective judgment. These criteria were referred to as the "soft criteria" and included such items as community environment, transportation facilities, availability of adequate housing, cultural amenities, proximity of one or more major universities, civil rights, equal employment opportunities, economically depressed areas, international considerations, and others. AEC Authorization Hearings for FY 1967 were held by the Joint Committee on Atomic Energy during February and March of 1966. During these hearings, on March 10, 1965, Commissioner Tape testified that a Commission decision on a final site would require approximately three to six months following AEC's receipt of the Academy Committee's Report. Commissioner Tape also pointed out that the President's budget included the statement that if the site was selected early enough, the AEC would submit a request for supplemental authorization of funds in FY 1967 to permit initiation of a definitive design for the 200-BeV accelerator project.

The Report of the Academy's Site Evaluation Committee was received by the AEC on March 21, 1966. Upon receipt of the Report, the Commission initiated a comprehensive review of the document. In its report the Committee identified six sites that it believed were, on balance, clearly superior to the others. These were located at Ann Arbor, Michigan; Brookhaven National Laboratory, New York; Denver, Colorado; Madison, Wisconsin; the Sierra Foothills near Sacramento, California; and South Barrington (or Weston), near Chicago, Illinois. The two alternative sites in Illinois were subsequently reduced to one (Weston) when community opposition from the South Barrington area became sufficiently severe that the site was withdrawn as a potential location for the project by the State of Illinois on April 5, 1966. In a letter dated June 9, 1966, to John T. Conway, Executive Director of the Joint Committee on Atomic Energy, General Manger Robert Hollingsworth explained this situation and noted that AEC had received a petition opposing selection of the Weston site, and another endorsing the same site and containing 6727 signatures. The Academy Committee's Report noted further that while none of the six recommended sites was ideal, each was "excellent in at least one of the most important features and within acceptable limits with respect to others."

The following day, March 22, 1966, AEC announced in a press release that the Commission had received the report in the form of a recommendation, and noted that the Academy Committee's role had been advisory in nature. By a letter of the same date, I informed the Joint Committee on Atomic Energy of the Committee's recommendation. I tried to send a copy of the report to the President the night before but received word that the President wanted no advance notice so that it would be clear the decision was made entirely by the AEC.

Soon thereafter, on March 28, 1966, Professor Henry D. Smyth, Chairman of the Board of Trustees of the Universities Research Association, reported to the Commission on the views of URA members and other members of the scientific community with regard to the site selection. In general, the views were positive and supported the selection activities as they had progressed to date. In the remaining days of March 1966, the Commission reviewed a staff study of 11 proposed sites, in addition to the recommended six, to determine whether any of them should be added to the list from which the final selection would be made. The Commission concluded that sufficient basis did not exist upon which to add additional sites to the list. During late March the Commission also reviewed staff efforts to develop cost differentials for the six finalist locations, thoroughly discussed the Academy Committee's Report, and considered the possible advantages of existing AEC sites as well as the desirability of selecting the site most attractive to high-energy physicists. Also discussed among the Commissioners was the probable desirability of visits by the Commissioners to the six finalist sites.

By press announcement of March 30, 1966, the Commission formally announced its decision to select the location for the 200-BeV accelerator project from among the six sites recommended as being superior by the Academy's Committee. The announcement noted that the Commission had come to this decision after conducting an exhaustive review not only of the Committee's Report, but also of the great mass of information independently collected by the AEC. Further, the announcement quoted me as saying the Commission would proceed then with whatever studies were necessary to make a final selection. Immediately following, on April 1, 1966, another press announcement was issued stating that a group of Atomic Energy Commission officials - headed by me - would make a personal inspection of the possible locations for the project. The inspection trip was to take three days. Prior to initiation of the trip, the Commissioners reviewed plans for the site visits, noting that among the primary subjects for discussion with the various site proposers and supporters were the matters of power costs and equal opportunity. It was agreed that with respect to equal opportunity, specified assurances and commitments would be required from local authorities and other groups. In fulfillment of this commitment, the Commissioners visited the six sites.

During the remainder of April 1966, two other significant occurrences transpired. Letters were sent, during the period April 12th-19th, to the applicable power company officials in the six site areas requesting assurances on their power cost statements contained in the site proposal documents. Also, on April 27th, the Commission discussed an appropriate response to a letter received from Charles L. Schultze, Director of the Bureau of the Budget. Schultze had observed that while costs were not the only consideration in selecting a site for the project, they were nevertheless an important factor. He then requested that the Commission "identify with some precision the construction and operating cost differences resulting from 'possible changes in design intensity,' and evaluation of 'the differences in benefits against differences in costs.'" My response, dated May 12, 1966, indicated that the Commission was indeed giving consideration to the relative construction and operating costs associated with the various sites yet under review. In my discussion of the issues involved in preparing a cost-benefit kind of analysis of the 200-BeV project, I noted that in addition to such factors as construction cost indices, foundation design requirements, power and other costs, there was another critical determinant of the ultimate cost and scientific output of the new laboratory. This was the quality and capability of the scientists and engineers that could be attracted to a given location to design, construct, operate, and utilize the new facility.

Many varied matters were reviewed by the Commission during the May-July 1966 period. Principal among these were methods of evaluating construction costs, commitments by the six site proposers that no payments in lieu of taxes would be expected by the Atomic Energy Commission, summaries of civil rights and equal opportunity aspects as related to the finalist sites, and the "soft criteria." Among the soft criteria considered were domestic and international air accessibility, colleges and universities in the various site areas, projected growth patterns for these schools including plans for establishment of night schools and extension courses, probable university involvement with the accelerator facility, and the general effect of the facility on the surrounding region. In addition, on July 1, 1966, letters were sent to six Federal agencies soliciting information concerning the status of civil rights in each of the six site locations under consideration. Replies were received from the Commission on Civil Rights, the Equal Employment Opportunity Commission, the Department of Housing and Urban Development, the Department of Justice Community Relations Service, the Department of Labor, and the Office of Federal Contract Compliance. In addition, the Civil Service Commission forwarded community reviews for each of the six site areas. Each of the replies was considered by the AEC in its deliberations.

In early August it was decided by the Commission that formal letters should be sent to the governors of the six states where sites were still under study. The purposes of the letters were to provide summaries of plans and commitments (excluding information relating to civil rights and power supply) as understood by the Atomic Energy Commission, and to request the governors to examine the summaries for accuracy and completeness and to provide any necessary clarification. Replies were received from each of the governors later in the month. These were duly examined and reviewed by AEC staff and the Commissioners.

During late August 1966, the Atomic Energy Commission sent to the General Accounting Office (GAO) copies of the six finalist proposal documents, the project cost-estimate formulated by DUSAF, the cost study performed by the Lawrence Radiation Laboratory, the Academy Committee's Report, and the AEC site team reports. This was done at the request of Senator Edward V. Long (D-Missouri) who was questioning whether the Academy Committee had adequately considered the AEC site criteria prior to making its recommendation to the Commission, as well as the adequacy of the AEC's review procedure. The GAO was specifically requested to review informally the material and report whether the AEC was considering operating and construction costs at the six sites. Subsequently, the GAO informed Senator Long that it was convinced of the adequacy of AEC's review procedures.

In another letter, dated September 15, 1966, to each of the six governors with finalist sites located in their respective states, I addressed the subjects of power supply and civil rights. I noted that the Commission had decided to engage the services of several power experts as consultants, and that the consultants and AEC staff would probably want to contact representatives of the power companies involved as part of the continuing study of power proposals. In addition, the Commission would seek appropriate civil rights commitments such as those suggested by William L. Taylor, Staff Director of the U.S. Commission on Civil Rights, in his letter to me of July 20, 1966. A copy of Taylor's letter was sent to each of the governors. The general areas of Taylor's suggestions included the matters of employment, housing, education, municipal and community facilities, and police-community relations.

During the three months left prior to final selection of a site for the project, the Commission spent considerable time studying associated civil rights and power matters. A large volume of civil rights and equal-opportunity information was received by the Commission and considerable time was required to sort, digest, and study the data in detail. Concerning project power requirements, Commission and Lawrence Radiation Laboratory staff briefed (September 28th) the power consultants on the schedule of power demands and the consultants were requested to review the various power proposals in detail.

During the week of October 10, 1966, the power consultants and AEC staff met with each of the utilities representing the six remaining sites. The latter were requested to provide confirmation of verbal information that they had previously presented. Then, on October 26, 1966, the power consultants reported to the Commissioners on the adequacy, quality, and reliability of the various power supplies under view. This was followed, on November 16th, by another report from the consultants on each proposers' power costs, rates, and the terms and conditions involved.

Following final deliberations in late November and early December 1966, the Commission selected the Weston site, near Chicago, Illinois, for location of the project. (The Madison, Wisconsin, site was the runner-up, and the Denver, Colorado, site was a strong contender.) The following day, December 16th, the final selection was publicly announced. The announcement included my statement as follows: "All six sites would have been suitable locations for this project. Each proposal had many strong points making the selection of one site an extremely difficult task. However, after weighing all factors the Commission unanimously decided that the Weston site, which is near Chicago and also near the Argonne National Laboratory, is the most suitable location for this large project. The AEC has received excellent cooperation from all six proposers, and they have no doubt that the information developed for these proposals will be a help to the communities in attracting other industry or government projects."

Notifications regarding the final site selection, of course, involved considerably more than the issuance of a public announcement. I sent word to the President in the days before the announcement, informing him that the announcement was imminent and asking him how much in advance he wished to be informed. First the word came back that he wished to be informed the night before the announcement, and then I learned he wanted to be informed at the same time as the others were informed and not any earlier. (Contrary to rumors that have circulated, the President didn't exert any pressure on the AEC and left the choice of the site from among the six finalists entirely to our discretion.)

Thus, by a letter dated December 16, 1966, I formally notified the President of the Commission's decision. I stated, "Although each of these six sites has great potential as the location for the project, the Commission finds that, on balance, the Chicago (Weston) site possesses in greatest measure the attributes that we consider will best ensure the overall success of the project. In arriving at this finding the Commission has spent considerable time during the past several months in evaluating each of the sites against the complex and unique requirements of the facility." Enclosed with the letter were copies of the Commission's news release and a detailed description of the Weston site. I notified the Vice President on the same date, as well as the following individuals: Bill Moyers, the President's Press Secretary; Henry Wilson, Administrative Assistant to the President; Joseph A. Califano, Jr., Special Assistant to the President; Charles Johnson, Special Assistant to the President; and Charles L. Schultze, Director of the Bureau of the Budget. In addition, congressional leaders were informed of the decision, as were all Representatives and Senators that had indicated interest in the finalist sites. When requested by various congressional offices, special information was provided.

Following selection of the Illinois site for location of the laboratory, the AEC immediately began activities to expedite actual acquisition of the 6800 acres involved, in order to move ahead with the project as rapidly as possible. I exchanged correspondence with Illinois Governor Otto Kerner concerning the commitment to the project by the State of Illinois, and on December 21, 1966, Commissioners Johnson, Nabrit, Ramey, Tape, and I, the General Manager, and other AEC representatives met with Governor Kerner and his staff for discussion concerning the status and immediate future of the project. In addition to State commitments concerning acquisition and transfer to the AEC of the site and other obligations undertaken by the State, the matter of equal opportunity and nondiscrimination was discussed in considerable detail. Following this meeting, another was held with Mayor Richard J. Daley of Chicago. Both meetings were designed to coordinate the thinking and activities of the many groups and individuals associated with the project, and to focus attention on the mutual goal of bringing the National Accelerator Laboratory to fruition.

After the site selection was made, the Universities Research Association also moved forward toward the monumental task of constructing the new laboratory. On March 7, 1967, Robert R. Wilson was named Laboratory Director. Temporary quarters were leased in Oak Brook, Illinois, in order that the early work would proceed pior to actual occupancy of the selected tract.

On April 12, 1967, Commissioners Ramey, Tape, Nabrit, and I met at the invitation of Governor Kerner with the mayors of local communities in the site area. At this meeting, which preceded issuance of the Joint Committee on Atomic Energy's Authorization Report for Fiscal Year 1968, I delivered a strong statement concerning the availability of housing in the area. Among other things, I said, "We have come here today because we believe that authorization and appropriation of the design monies for the 200-BeV project by the Congress this year and the construction authorization and appropriation of money for the project next spring are endangered by discrimination in housing in the site area and by the absence of legal means at either the state or local level to deal with the situation effectively. If this issue could be eliminated, we believe that the chances of obtaining the authorization and attendant confirmation of Weston as the site for the project would be greatly enhanced." Rhode Island Senator John Pastore of the Joint Committee on Atomic Energy was particularly insistent that laws outlawing discrimination in housing be enacted, and fortunately, we succeeded in convincing the authorities in Illinois to do this.

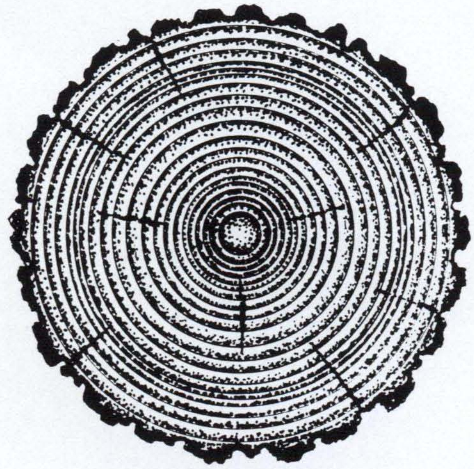
Prior to this time the Bureau of the Budget had asked the AEC to consider the cost and other implications of constructing a 200-BeV accelerator of lesser scope than had initially been conceived. This matter was discussed during the Congressional Authorization Hearings. On April 19, 1967, the Joint Committee on Atomic Energy issued the Report of its Subcommittee on Research and Development. This report recommended that in constructing the 200-BeV accelerator, the early design intensity of approximately $3x10^{13}$ protons per pulse should not be reduced. It also recommended that, since the facility was intended to promote high-energy physics research on a national basis, the initial design should at least include provision for establishing additional experimental areas at a later time.

In the months following, the Laboratory Director assembled an excellent staff at the temporary Oak Brook quarters, project designs and schedules became more definitive, and the State of Illinois proceeded with acquiring the site area. By October 1, 1968, the temporary quarters had been relinquished and all of the Laboratory staff had been moved onto the site. The staff was housed in the small residences that had formerly comprised the Village of Weston.

On December 1, 1968, on a wintry cold day in Chicago, with approximately 1000 people in attendance, Bob Wilson and I broke ground for the project. I gave the principal address; other speakers included Representative Melvin Price, Commissioners Ramey and Tape, Professor Norman Ramsey of the Universities Research Association, and Wilson. On this occasion I stated, "Symbolically, we could say that the spade that breaks ground on this site today begins our deepest penetration yet into the mysteries of the physical forces that comprise our universe."

On April 29, 1969, I announced that the Commission would name the National Accelerator Laboratory in honor of the late Dr. Enrico Fermi. Illinois Congressman Frank Annunzio had been among those who had urged us to honor Enrico Fermi in this manner.

The Accelerator was constructed on schedule, well within the cost estimate, and the design parameters for beam energy and intensity were met and exceeded due to the seminal contributions of the Lawrence Radiation Laboratory, the competent leadership of Fermilab Director Robert W. Wilson, and the excellent performance of the outstanding group of scientists that he assembled. Operation began with the attainment of the first beam of 200-BeV protons on March 1, 1972. The success of this objective was also, in my opinion, following the initial contributions of the Piore and Ramsey panels, a result of the skillful execution of the game plan, including the national competition in the site selection procedure, and the cooperation with President Johnson and White House staff, the National Academy of Sciences, and many members of Congress, by the AEC Commissioners and their competent and experienced staff.



Then URA President Norman F. Ramsey at the NAL groundbreaking, December 1, 1968.

The Early History of URA and Fermilab

Viewpoint of a URA President (1966-1981)

Norman F. Ramsey

The beginnings of URA and Fermilab were rooted in the interest aroused by the fundamental discoveries made with the Brookhaven Cosmotron and the Lawrence Radiation Laboratory (LRL) Bevatron, and by the successes of the alternate gradient focusing principle as applied to the Brookhaven 33-GeV AGS and the similar accelerator at CERN. The agreement between design expectations and performance for these two accelerators encouraged designers to believe that much larger and less conservatively designed accelerators were feasible. As a result, a number of independent and interrelated design studies for new accelerators were in progress by 1960 at Caltech, LRL, Brookhaven, Wisconsin, Cornell, Yale, and a number of other universities and research centers. Among the most active participants in these studies were John and Hildred Blewett, Ernest Courant, Leon Lederman, Edward Lofgren, Edwin McMillan, Kenneth Robinson, Matthew Sands, Alvin Tollestrup, Robert Wilson, and Luke Yuan.

By late 1962, the AEC was confronted with more than a dozen proposals for accelerators at energies ranging from 10 to 1000 GeV. As a result, the President's Scientific Advisory Committee and the General Advisory Committee of the AEC appointed a joint PSAC/GAC Panel on High Energy, which I chaired, to "assess the future needs in high-energy accelerator physics." In May of 1963, this panel recommended: (1) prompt construction of a 200-GeV proton accelerator by LRL, (2) construction of colliding-beams storage rings at Brookhaven, (3) design studies at Brookhaven for a proton accelerator in the 600 to 1000-GeV range, (4) construction of a high-intensity 12.5-GeV proton accelerator by MURA "without permitting this to delay the steps toward higher energy," and (5) development and construction of electron-positron colliding-beams storage rings at Stanford. The Panel also recommended that "the larger accelerator installations should incorporate an administrative structure with national representation to assure that all proposals from qualified scientists be considered on equal footing."

Soon after the panel report was made public, PSAC convened a committee of accelerator users chaired by Myron Good, to review the Ramsey Panel recommendations. The Good Committee endorsed the Panel recommendations but stressed even more the need for national representation and that "outside groups should have a voice and responsibility in certain aspects of laboratory management." Further reviews with similar conclusions were made by a National Research Council Panel chaired by Robert Walker and in a 1965 Report on National Policy prepared by the AEC staff.

As a result of the disappointment in the Midwest with President Johnson's decision not to support the MURA proposal, and of continuing disagreements between the LRL management and its Advisory Committee on the extent to which the management of the new accelerator should have a national character, both the site and management questions were reopened.

The AEC then invited all states to submit site proposals for the accelerator and a total of 125 proposals were received from all but two states. During 1965 the Atomic Energy Commission reduced the number of qualified sites to 85 and passed these on to a panel of the National Academy of Sciences chaired by Emanuel Piore. Originally the panel was to select a single site, but at the urging of the Joint Committee on Atomic Energy, the panel was asked to recommend the six best sites with the final choice to be made by the Atomic Energy Commission. In March of 1966, the Piore panel announced their selection of six possible sites in California, Colorado, Illinois, Michigan, New York, and Wisconsin.

With the opening of the site issue, Frederick Seitz, the President of the National Academy of Sciences, felt there should be some truly national organization available to construct and operate the accelerator at whatever site was finally selected. He called 25 university presidents to a meeting on January 17, 1965, to discuss the management of the 200-GeV accelerator. At this meeting, it was decided to establish a new organization, Universities Research Association, Inc., and to offer its services to manage the proposed accelerator wherever it might be located. In June of 1965, 34 presidents met to establish URA, which was incorporated on June 21, 1965, with two governing boards - a Council of Presidents representing each of the member universities, and a Board of Trustees actively responsible for the management of URA including the responsibility to elect the President and the Director. The Council of Presidents, at a meeting in November of 1965, elected Gaylord Harnwell to be the first Chairman of the Council of Presidents, elected one of its own members, Jacob Warner, to be interim President and completed the election process for members of the URA Board of Trustees. At that meeting the Council also "Resolved that the members of the Council declare themselves ready to support the decision of a site for the 200 GeV accelerator, upon the making and announcement of such decision by the Atomic Energy Commission."

The first regular meeting of the Board of Trustees of URA was held on December 12, 1965, and Henry D. Smyth was elected Chairman of the Board. At a later meeting in July of 1966, I was elected President of URA.

Because of the urging by the Joint Committee that the Atomic Energy Commission and not the scientists should make the final site selection, the AEC indicated they did not wish to make any contract or have any formal relation with URA until after the site was announced and requested that the URA staff refrain from expressing site preferences to anyone.

Until the site was selected, URA Trustees could do only limited specific tasks. The available time enabled the URA Trustees to carefully discuss plans and policies, such as a decision that the laboratory management should be a strong one with considerable independence, and that to encourage this policy the headquarters of URA should be in Washington rather than at any laboratory site. The Trustees also prepared for rapid action once the site was selected; for example, a list of 44 possible directors was compiled and extensively discussed, and draft proposals for a design-study contract were prepared. The possibility of modifying the accelerator proposal to permit a later increase in energy beyond 200 GeV was discussed with Glenn Seaborg, the AEC Chairman, who advised strongly against such a change for fear of jeopardizing the entire project.

Since URA could produce few publicly visible accomplishments prior to the selection of the site, many accelerator builders were very worried about the organization. Some feared that URA might never be able to accomplish anything, while others feared that the URA Trustees by themselves were secretly designing an accelerator and were not exposing it to public criticism.

As it became apparent that the Commissioners would soon select a site, the regional rivalry became intense, and there was a real threat that the accelerator might never exist, since the disappointed regions could easily kill the project by their protests. To prevent this, I, as President of URA, arranged to speak to all Users Meetings to point out that it would be easy for any regional group to prevent the accelerator from going to the selected site, but it would be impossible to get it transferred to a different region. Most of these talks were given to Users Groups shortly before the site decision and were welcomed by the groups, since all hoped that the site might go their way. Unfortunately, due to the scheduling of the Users Meeting, the talk at Berkeley could not occur until shortly after the site had been selected at which time the disappointment in Berkeley was at its peak and the audience was inevitably unfriendly.

On December 16, 1966, the AEC announced that the site had been selected on a 6800-acre plot to be provided by the State of Illinois incorporating the town of Weston. After the site selection, URA moved into action rapidly with a meeting on December 19 followed in short order by three other meetings in less than two months. On December 19, Ed Lofgren, who had directed the previous Berkeley Design Studies, was asked to be Director of the URA Design Studies, which he declined three weeks later. On December 23, URA submitted to the AEC a proposal for a Design Study Contract with $200,000 initially requested. On January 5, 1967, a letter contract from the AEC was signed. Since December 16 was the earliest possible date for a proposal, this letter must come close to setting a U.S. government record for minimum time between the earliest possible proposal date and the signature on a letter contract.

At a Trustees meeting on January 15, the position of Director was offered to Robert Rathbun Wilson, whose new Cornell synchrotron had just been completed one year ahead of schedule. Although Bob Wilson indicated almost immediately that he was interested and would probably accept, he withheld his formal acceptance until the Atomic Energy Commission assured him that it would satisfy conditions which would enable the project to move rapidly and to be scientifically exciting. These agreements later proved to be of immense value to the project, but they did delay Bob's formal acceptance of the post until March 7 and caused some people to worry that URA would never be able to get started.

As a result of the delay in the Director's formal acceptance, he was not available for the critical hearings of the Joint Committee on Atomic Energy in February 1967, so URA was represented by Kenneth Pitzer (Chairman of the Council of Presidents), Robert Bacher (Vice Chairman of URA), and by me. These hearings produced some pleasant as well as unpleasant surprises. Congressman Bates of Massachusetts, on his own initiative, was quite critical of the choice of energy and urged that the design be such as to permit a later increase to higher energy. His comments in the Joint Committee Report opened up the possibility of this highly desirable increase in energy which was already favored by the URA Trustees. There were also vigorous criticisms in the hearings of the decision by the Office of Management and Budget to reduce the scope of the project from $350 million to $250 million, but these criticisms led to no increase in funds.

An unexpected objection to the location of the accelerator in a state which did not have open housing laws was raised at the hearings by Clarence Mitchell of the NAACP. In the long run, this criticism proved to be of great value to the National Accelerator Laboratory, since it made it possible for the Laboratory to develop much more imaginative programs for the training of minority employees. One year later the same NAACP representative strongly supported the Laboratory. At the 1967 hearings, vigorous criticisms of the location and proposed management were expressed by representatives of the regions which had lost out in the site selection, particularly by those from California. Congressman Hosmer stated at one point, "I understand they [URA] operate at the end of a telephone line in a borrowed room at 2101 Constitution Avenue." There was more validity to this criticism than even Congressman Hosmer knew: The National Academy was so tightly pressed for space that URA had just been moved from a borrowed room to a borrowed corridor. Despite the criticisms raised in the Joint Committee hearing, authorization for design and engineering for the project was achieved during that session of Congress and $7.33 million was appropriated even though this was later reduced by executive order to $4.83 million. The appropriation of these first funds was in accordance with the philosophy on congressional relations that it is better to be criticized by a committee and get the money than to be praised and receive nothing. The open-housing issue had the effect that, in the most critical vote for the start of the project, many of the congressional supporters of the accelerator voted against it, and many of those who would normally have voted against it voted in favor.

On March 7, 1967, Robert Wilson was appointed Director of the National Accelerator Laboratory. In April of that year, URA sponsored a meeting of potential users to discuss physics at 200 GeV and to initiate the formation of a Users Organization which held its first regular meeting on December 9, 1967. In November of 1967, the AEC announced that DUSAF, which had worked with the Berkeley group, was selected to be architect-engineers for the 200-GeV project under a subcontract to URA.

During the spring of 1967, planning and designing were done at Cornell by Bob Wilson and consultants whom he assembled there, and on June 15 a group of staff members and consultants assembled in otherwise empty rooms at Oak Brook, Illinois, to begin intensive designs on the accelerator.

Design work on the accelerator proceeded rapidly during the summer and early fall of 1967. Many basic policy decisions were made including those to cut costs extensively, even at the risk of failure of some components and with the expectation of having to rectify the failures later. It was believed that this procedure would, in the long run, save much money and that it offered the best means for producing an accelerator with exciting scientific potentialities within the restricted budget. The magnet aperture was greatly reduced, piles under the magnets were eliminated, and the tunnel cross section was markedly diminished.

Other decisions at that time were to design the accelerator primarily for 200 GeV, but with the possibility of later expansion to 400-500 GeV and to pursue a much more rapid schedule than originally contemplated, with the first beam planned for July 1972 instead of July 1974, which would have been more in accord with previous plans. These plans were considered irresponsible by many in the field and were the source of vigorous criticisms and conflicts which were aired in many places including a meeting for this purpose at Oak Brook. As a result of these criticisms, the Laboratory proposals were considered with particular care by the Scientific Committee of the URA Trustees; and at a special meeting on October 12, 1967, the Trustees authorized the Director to submit the proposal. The first design reports were available on December 15. During this interval it was also decided that to save money, the project should move as rapidly as possible to the Weston site. Since no AEC funds were available for construction, URA expended several thousand dollars of its own funds for on-site buildings with the hope, which later proved valid, that URA could later be reimbursed once the construction project was approved.

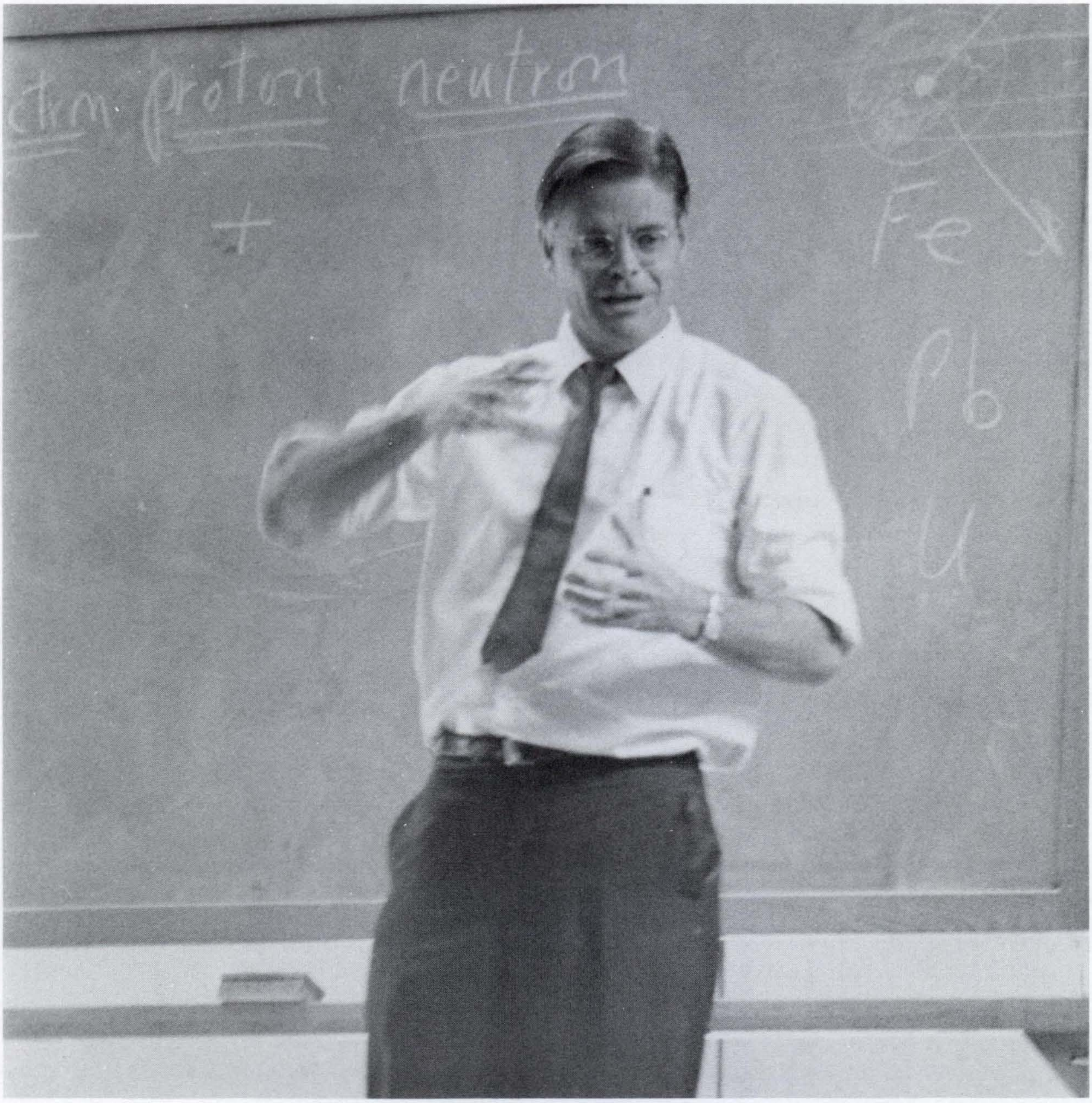
During 1967, the staff of the accelerator design project grew rapidly; at the beginning of the year there were no staff members, but by the end of the year there were 52 staff members including the Director and the Deputy Director, Ned Goldwasser. By that time the DUSAF staff had grown to 26. During this same period, the Laboratory established a strong minority program including the sponsorship of training programs to provide the possibility for contractors to hire qualified minority employees.

On January 23, 1968, the first regular contract for construction was signed between URA and the Atomic Energy Commission. The funds appropriated during 1968 proved to be a severe disappointment, with the Laboratory having requested $75 million which was later reduced in the President's budget to $25 million and with a further reduction to a final appropriation of $12.074 million plus authority to spend $2.5 million, expenditure of which had been prevented by the Executive restrictions on allocations the preceding year. Also, unfortunately the funds initially were restricted to engineering and design, and only after vigorous appeals to the Commission, which in turn appealed to Congress, was the Laboratory permitted to do limited construction on designated projects, including the Linac building.

As part of the planning for the future, there was a study in 1968 of the feasibility and desirability of colliding-beams storage rings at NAL. During the summer of 1968 the first Users Summer Study at Aspen was held and proved to be of immense value in the planning for the accelerator.

On July 11, 1968, the authorization for the full $250 million accelerator project was signed by the President. That year the first really large appropriation was obtained even though it was smaller than desired. The Laboratory had hoped for $102 million of construction funds, but this was reduced by OMB to $96 million and $70 million was finally appropriated. During 1969, construction work proceeded rapidly and successfully. That year the Program Committee to select experiments for the accelerator was established.

With Congressional authorization of the accelerator, with the appropriation of significant construction funds, and with successful initial operation and management, the future of the National Accelerator Laboratory was assured and its basic modes of operation were determined, so 1969 is an appropriate year in which to bring to an end this *Early* History.



Fermilab's founding Director, Robert R. Wilson.

Starting Fermilab

Some Personal Viewpoints of a Laboratory Director (1967-1978)

Robert R. Wilson

"When to the sessions of sweet silent thought
I summon up remembrance of things past. . ."

It wasn't the taste of the madeleine soaked in tea which evoked these memories of things past, but rather the request of Leon Lederman to help mark the twentieth anniversary of Fermilab.[1] Ah, memories, how conveniently we forget the disagreeable, how adeptly we rearrange the actuality, how warm and pleasant it all becomes - in memory! My coverage will be incomplete and very personal - a stream-of-conscious view of starting Fermilab.

I shan't dwell on how it happened that a proton synchrotron designed at the University of California, Berkeley (UCB), to give 200 BeV came to be built in Illinois instead of in California and how I, then a carefree professor at Cornell University, was chosen *faute de mieux* to head the construction of what eventually would be named Fermi National Accelerator Laboratory. I shall also gently elide my first months in an unreal world in which I was the lone employee, wondering who, if anyone, would come to help me turn that cornfield into a physics laboratory. Eventually, brave physicists and engineers *did* come, but the hiatus gave me time to meditate about and discuss with others the kind of laboratory I hoped it would become.

The result of my meditations was that the designed proton energy, 200 GeV, was too small for the physics opportunities, too small for the size of the site, and too small for the amount of money available. I also felt that the best technical people would come (and I hope this was panache and not hubris), only if challenged by something hard to do. Accordingly, I announced that 400, or even 500, GeV would be our goal. That worked. All sorts of superb people identified themselves as eager to do just that. Similarly, I let it be known that we would try to return to the same number of experimental facilities as had been originally designed and to the full intensity of proton current - not that of the "reduced scope." And so that no one could charge me with "not being crazy enough," I put the UCB construction schedule of about seven years ahead to about five years.

The powers-that-be in the Atomic Energy Commission looked benignly on all this madness, but pointed out that I had signed in blood not to exceed the authorized level of $250 million as "reduced" from the UCB budget of $340 million, and that I would rot in Hell if I did. Nevertheless, from Glenn Seaborg, the AEC Head Commissioner, on, the AEC functionaries

[1] Lillian Hoddeson will have written more authoritatively on the subject in her Viewpoint elsewhere in this report. Catherine Westfall has prepared an excellent account of the early days of Fermilab in her Ph.D. thesis, "The First 'Truly National Laboratory': the Birth of Fermilab History," (Michigan State University, 1988 [unpublished]). Norman Ramsey produced a lively historical note for the Fermilab Users Meeting in May of 1975. Phil Livdahl has prepared an informative note (Fermilab TM-1222, November 1983) on "Staffing Levels."

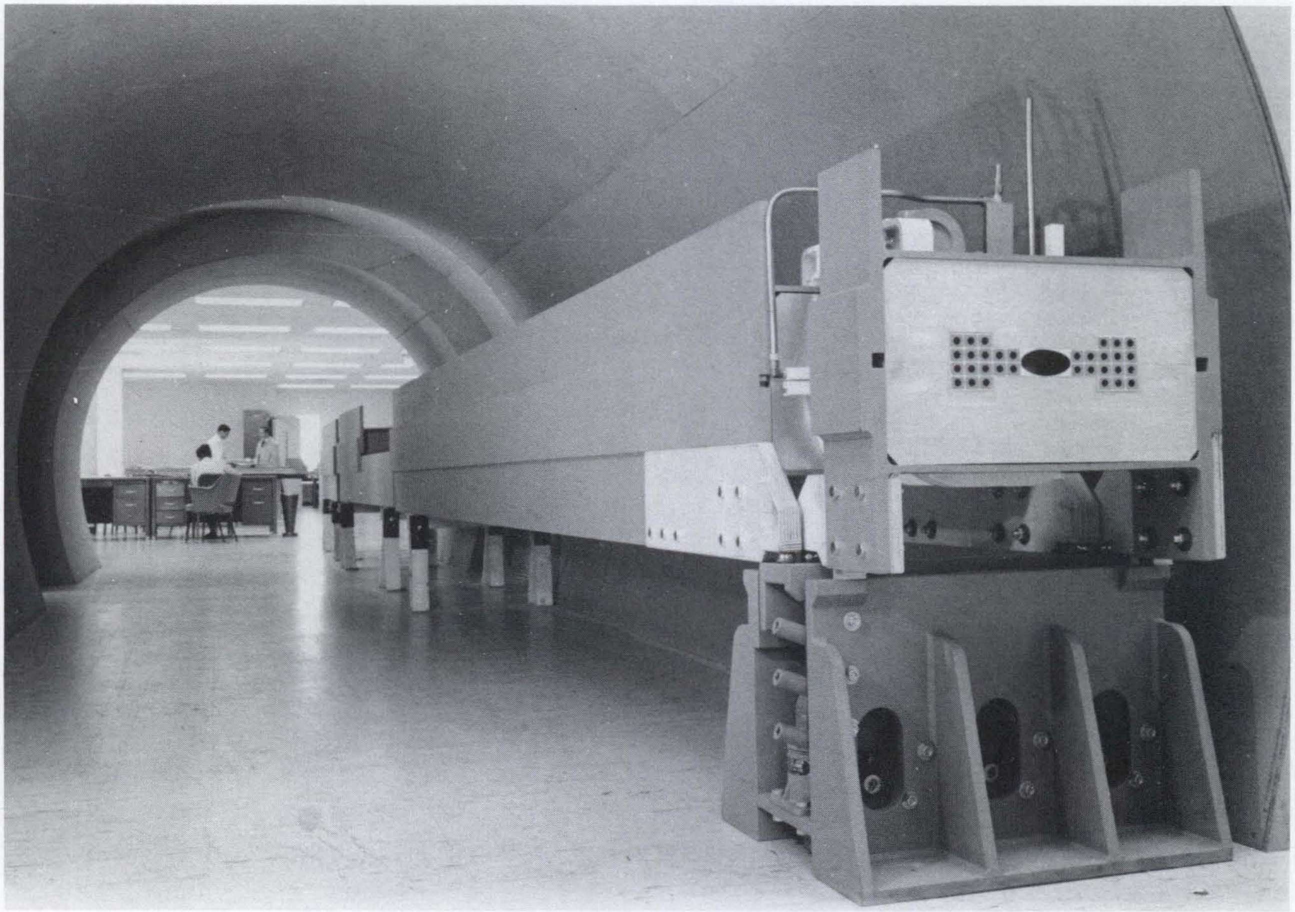
Then Deputy Director Ned Goldwasser traverses the Village in 1968.

were romantics at heart. Without their enthusiasm and commitment and more-than-willing cooperation, nothing would have happened. The enthusiasm of the congressmen and senators in the Joint Committee for Atomic Energy (JCAE) was unexpected and also a vital ingredient in how we fared.

I seemed to have a boss in every direction, not only the AEC and the JCAE, but more directly: the Universities Research Association and the physics community itself. Harry Smyth, one of my early mentors, was Chairman of the URA Board of Trustees. A "typical" member of the Board was that *eminence gris*, Leon Lederman, who had had the original vision of a "truly national laboratory" built and operated for and by *all* of the particle physics people, where they would be "at home and loved." Well, they all helped, but it was Norman Ramsey, President of URA, who throughout my tenure as Director was my greatest source of strength. We complimented each other in many ways. Norman has a quick and logical mind, and in our frequent discussions about all aspects of the Laboratory, my ideas, largely intuitive, were tested against his good sense - and not infrequently abandoned. We had been friends before, but our friendship deepened in the adventure of Fermilab.

How does one gather an instant administration and staff? That was an even more severe problem than re-designing the accelerator, but of course the problems were coupled. Bringing a staff of physicists and engineers together was straightforward; one tried for the best. But my fellow administrators would be different in that they had to be loyal to me and to my commitment, yet I needed independent minds to supplement my own talents and to keep me from making unwise decisions and policies. One couldn't just try somebody and then, if things did not work out, look for someone else; for one thing, there wasn't enough time for that, and for another, to get a good person required a commitment - like a marriage.

My most critical need was for a deputy director and I chose Ned Goldwasser, not only for his obvious competence, but because he supplemented my own experience. Then, too, anyone who knows Ned would know that he would be very strong in any disagreement, certainly no "yes" man. Ned was a godsend. Indefatigable, warmhearted, sophisticated, there was no job that needed doing that he would not and did not tackle. He was particularly active with the physics programs and relations with our user physicists, but every facet of the Lab came into his purview - especially problems involving sensitivity

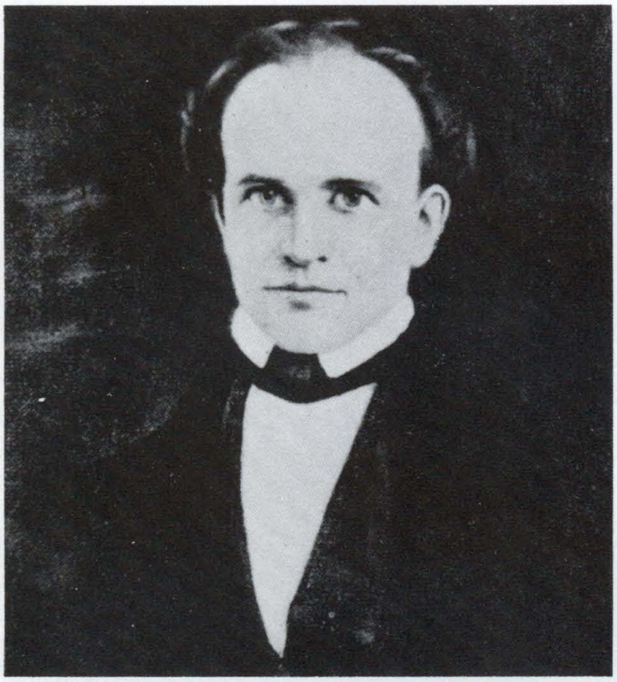


The full-scale, cardboard model of the Main Ring tunnel, magnets, and magnet stands at the Oak Brook offices.

and humanness. What a lucky day for me, and the Lab, when early on he signed up.[2]

Those early meditations of mine were often a kind of a fantasy in which I envisaged the Laboratory as a utopian place where physicists coming from all parts of the country - and from all countries - would be doing their creative thing in an ambiance of well-functioning and yet beautiful instruments, structures, and surroundings that would reflect the aesthetic magnificence of their discoveries and theories. All this to be done in a scientific climate of mutual respect and responsibility; it would be a place where, according to the Chinese ideal, "All would be happy to do what they had to do, and would have to do what they were happy to do."

[2] I cannot make this a recital of names, nor can I ignore those colleagues who have randomly floated in and out of my remembrance. I propose to put nearly all of the remaining references to people in footnotes, thus the early administration consisted of Stan Livingston and Tom Collins as associate directors, Don Getz as Assistant Director, and Frank Cole as Assistant Director for Information. Don Getz, a hero of those days, knows most about what actually happened and has written an unpublished memoir in 1977 that captures the spirit of those early times. Frank Cole was in charge of putting out the *NAL Monthly Report*, which is still the definitive source of what happened and when.



John G. Fee (see footnote 3).

My fantasy of a utopian laboratory clearly required a setting of environmental beauty, of architectural grandeur, of cultural splendor, but therein lay the rub: money. A rule of thumb of large technical projects is that about half the costs go to technical things and the other half to conventional construction such as buildings, utilities, roads, and site development. This rule seemed to hold for the carefully-made cost analysis of the UCB study for the 200-BeV project. Roughly speaking, if we were to build to twice the energy, and hold to the reduced-scope budget of $250 million, would anything be left over for the architectural costs? Put differently, the conventional construction might be little affected by the reduction in scope of the project and hence might cost half of the UCB $340 million, leaving about $80 million for the accelerator. My conclusion from this was that I had better pay close attention to the architecture of the project for I was determined that it be significant, yet affordable. When I announced my ambitions for architectural significance to my scientific friends, some of them became angry with me, for they correctly reasoned that each dollar going to architecture would not go into physics. My justification was that if we produced a dowdy site with shabby buildings, then the technical people we wanted to work with us would not come and the statesmen, who might judge us in part by appearances, would not, in the long run, give us the funds we would need for our physics. There were other serious problems, a gathering storm of civil rights for one.[3]

Let us take the beginning of the Lab to be June 15, 1967, when a small group of determined people showed up at the Executive Plaza Office Building at Oak Brook, Illinois. We occupied the vacant floor at the top, and were soon busily marking out on the unpartitioned floor where we would work until we had access to the site about two years later on. A pretty good plan

[3] I take pride in being a descendent of John G. Fee, an Abolitionist preacher who founded Berea College for blacks and whites in pre-Civil War Kentucky. It was a family obligation to be involved in the Civil Rights Movement of the sixties, and becoming Director of Fermilab offered an opportunity for me, as well as for my comrades, to do something other than just talk.

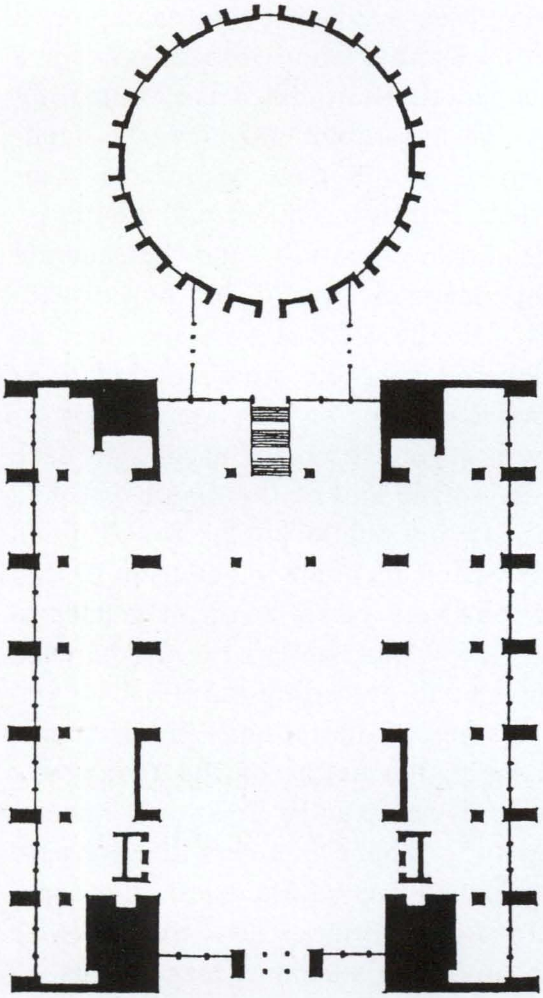
It was Kenneth Williams, born in Chicago's inner city, who was our "godsend" in making the Laboratory effective in this respect. Ned Goldwasser bore the administrative responsibility and he has told the story in *Bulletin of the Atomic Scientists*, (Vol. XXV, No. 8, October 1969, pp. 7-10; see also: *Science*, [1185, June 1970]) of how we helped with open housing, with training and hiring programs, and with the use of minority businesses. I am still proud of our policy statement: "In any conflict between technical expediency and human rights, we shall stand firmly on the side of human rights" - and we did.

evolved more or less by chance: There was a large, central, common area (the Bull Pit) and all around offices at the windows opened into it. A spontaneous discussion would start at about 8:00 a.m. and continue until about 6:00 p.m. One could choose to join the general debate, or retreat to an office for reflection and calculation. Every so often, I would ask a secretary[4] to ring a school bell to announce that a decision on some particular facet of the project would be made. The drama of the situation just then was that we really had to race in order to qualify for funds for FY69 (at that time the federal year extended from July 1968 through June 1969). This meant that we had to re-design the whole project for the new site and for our new goals, and this full authorization report had to be done by October 1967. Otherwise we would lose at least a year.

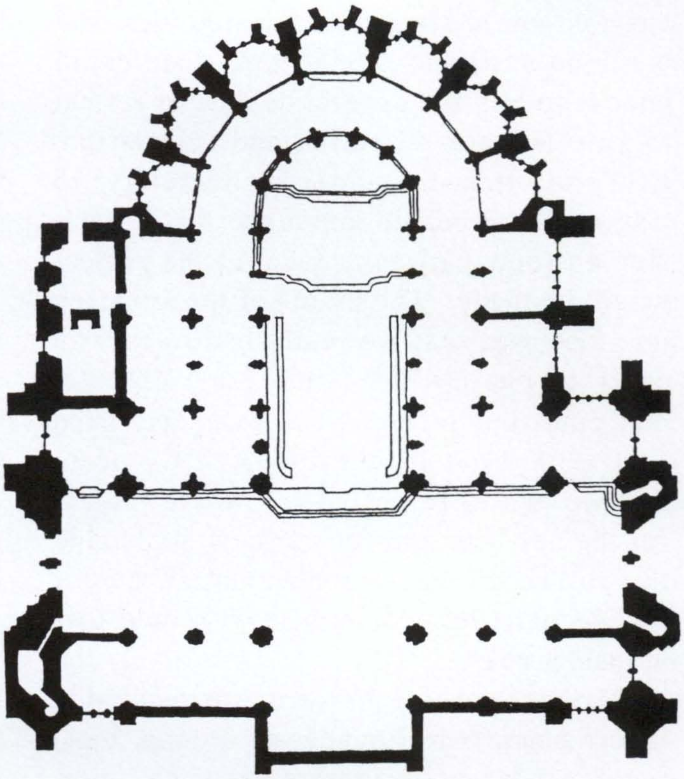
Rather than just go for it, we decided to invest a month in floundering around, looking at all kinds of alternatives such as superconducting magnets (the technology wasn't ready yet) or colliding beams (again, not within either our reach or grasp). We hoped for an important invention. All sorts of people came by to participate in the excitement, and all sorts of ideas were explored. The Berkeley people were especially generous in explaining what had gone into the UCB report and why. I thought the most promising idea was that being championed by Gordon Danby, from Brookhaven, for a separate function lattice for the Main Ring magnet. In this rather old idea, the bending magnets would have a uniform magnetic field, meaning that they would go into saturation gracefully, and the separate focusing magnets would be pure quadrupoles. In the UCB design the bending and focusing magnets were combined by appropriate shaping of the magnet poles.

It was a good time for us to size each other up. At the end of the month (we had all been staying at a local Oak Brook motel and we varied in number between 10 and 100), I found myself on an airplane back to Ithaca, New York, reviewing all that had gone on in the preceding month. A number of design considerations fell into place, for example, the radius of the accelerator ring would be exactly 1 km (I have a propensity for round numbers that are hard to forget) and we would adopt the separated function lattice. The trouble with that was in Danby's bending magnets, which I thought were much too huge. They were a "window frame" design with all the coils uniformly distributed in the gap between the poles of the magnets. This implied a width of about 1 m. Before the airplane had come down, a new kind of magnet occurred to me in which some of the coil was put in the magnet gap and some of the coil

[4] That was usually Cynthia Sazama, the first permanent secretary, who is still at Fermilab, in charge of housing. A crucial concern for any director is his office support. In that matter I was exceedingly fortunate. Rose Bethe was the first secretary for the pre-Lab phase at Cornell. Priscilla Duffield, whom I had known first as Ernest Lawrence's secretary, then at Los Alamos as Robert Oppenheimer's secretary, worked with me as secretary (really as an Assistant Director, but she insisted on the title "secretary"), from late 1967. When Priscilla left, it was my great fortune to have Judy Ward (now Schramm) show up. Then there was a host on the second floor of the Central Lab: Jean Plese, Jackie Gifford (now Coleman), Doris Ferrell (now Bart), Anne Burwell, Barbara Rozic (now Kristen), Helen Peterson, to mention a few. Not typical is the irrepressible Sammy Rumple, who helped organize the Riding Club and who moved from the Travel Office to the Users Center, went on to become a technician, and then left to found her own business for technical support for the Lab.



Wilson Hall

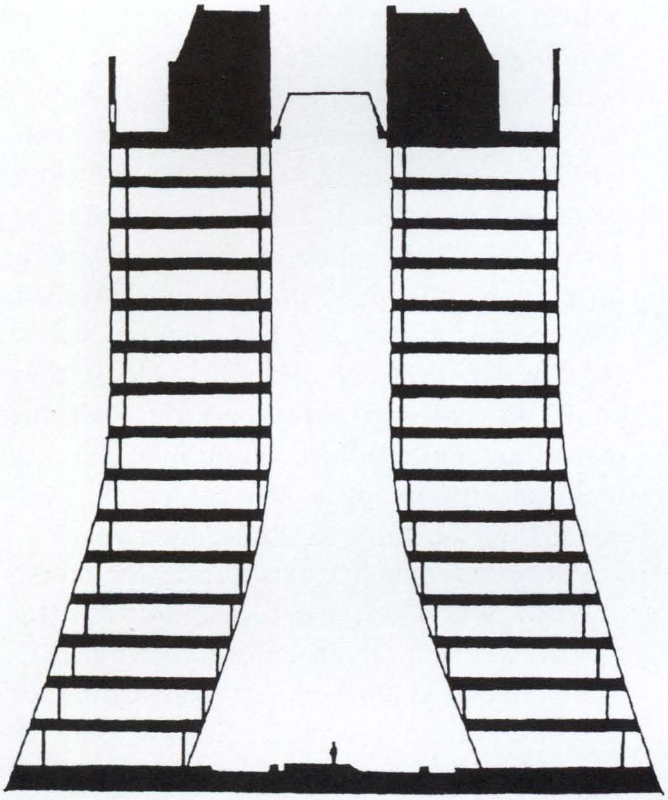


Beauvais Cathedral

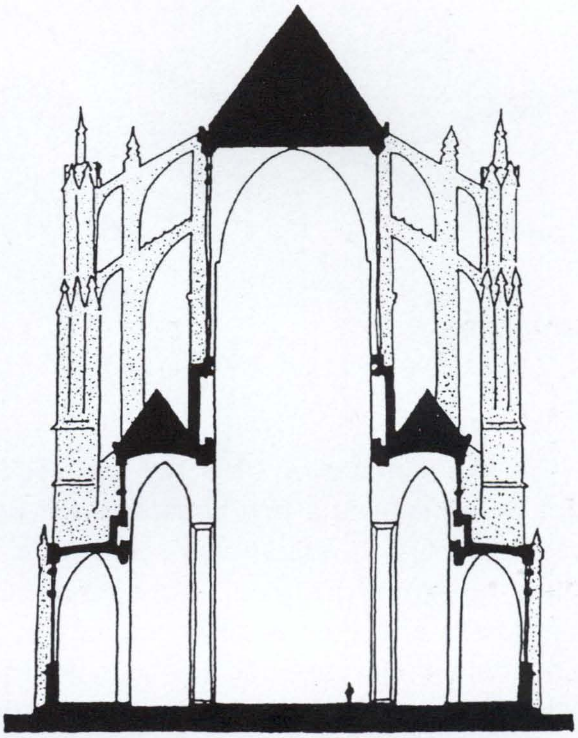
Influenced by Wilson's interest in cathedrals, the architect modeled these drawings of the Central Lab on those of the cathedral at Beauvais. That choice led Wilson away from Chartres, and to Beauvais, as a model for the Central Lab Building.

was consolidated in a larger opening outside the gap. This implied a better aspect ratio of the width and height of the magnet which made it about half as big. That was perhaps my only real invention of the whole project, yet I was proud of it, for the Main Ring magnets were the single most expensive item. An incidental feature of this design was that the magnets, because of the compensation of an edge effect and a magnetic-potential drop, would be able to reach a field of 22.5 kg (compared with the 15 kg of the UCB magnets) and that meant we might reach the fantasy goal of 500-GeV protons. Other results of the design month were decisions to use a small tunnel to eliminate elaborate magnet supports going down 100 ft to bedrock, and to use solid-state rectifiers rather than the ubiquitous and fallible and expensive rotating generators in general use then.

My main concern was to get a complete laboratory in business at the earliest time, that is, one doing experiments. This meant



Wilson Hall



Beauvais Cathedral

Beauvais Cathedral (A.D. 1225-1568) "was never completed westward of the choir and transepts, and the site of the proposed nave is partly occupied by the Romanesque church known as the 'Basse Œuvre.' The roof fell (A.D. 1284); the choir was reconstructed and strengthened by additional piers (A.D. 1337-47), and in the 16th century the transepts were built. The building is of extreme height, 157 ft 6 ins. to the vault - the loftiest in Europe - and about three and a half times its span. This soaring pile is perhaps the most daring achievement in Gothic architecture, and has been regarded as one of the wonders of Medieval France. The structure is held together internally only by a network of iron tie-rods, which suggest that these ambitious builders had attempted more than they could achieve."

that the accelerator, the experimental areas, and the experiments themselves should all be planned together. In some measure that's what we did. But obviously, it was the accelerator that would need the greatest emphasis. Without it in actual operation, the experimenters would find it difficult to make their plans - their commitments. I didn't want time and money to be wasted by an over-design of the machine, yet it had to work, and work reliably, or we would be nowhere. I felt that inevitably we would make mistakes and part of my compulsion to proceed rapidly was so that we could recognize those mistakes and have the time to correct them.

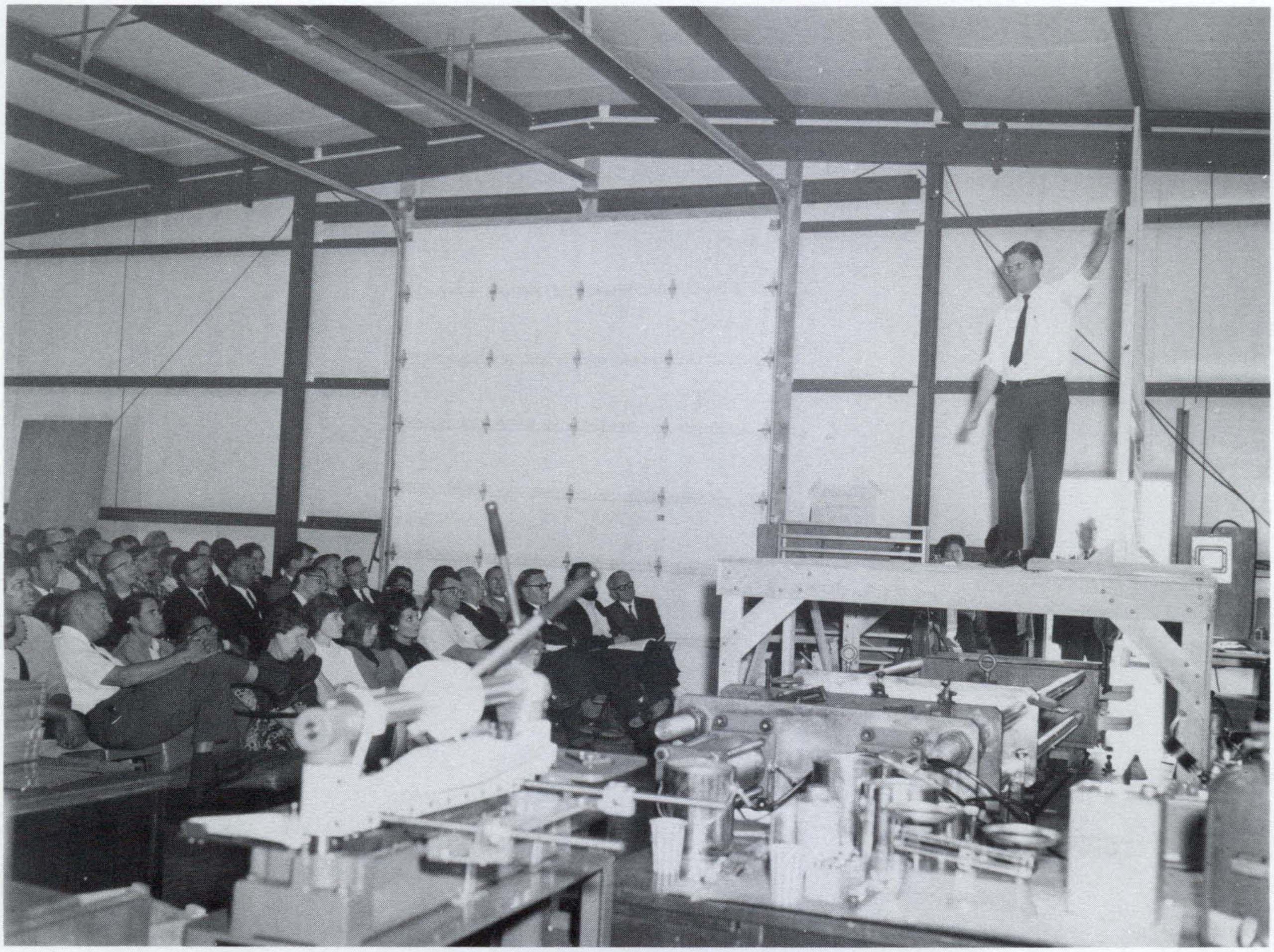
The first accelerator in the chain of accelerators would be a 200-MeV linac. Its progress would be important in achieving a fast pace. We decided to copy a linac then being built at Brookhaven; it was well designed and we hoped to save time, effort, and money by just duplicating their orders.

In the summer of 1968, we managed to get possession of a few houses in the little town of Weston, which was on the site. A gung-ho group[5] had been gathered to build the Linac and they eagerly moved in, announcing their presence in the wilderness with a sign, Fort Fortitude, from which, ominously, a real arrow protruded. The URA put up its own money so we could erect a temporary building adjoining and connecting the houses (it's still there, as are several other such buildings). By January 1969, the group had accelerated a beam of 60-KeV protons using parts largely borrowed from the Argonne National Laboratory, and were furiously designing and building the first 10-MeV section, the most complicated and critical part of the 200-MeV Linac. By dint of a heroic push, which involved even secretaries and AEC personnel doing such things as wiring, by June of 1968 they had the device working to give its 10-MeV protons as designed. This nearly miraculous achievement was a shot in the arm for all of us, for if they could do that on the lone prairie, then the rest of us could build a whole laboratory at the same timely pace. To celebrate, I advanced our building schedule by a year!

Once the intensive summer design month of 1967 was over, we turned to architecture as a relief. Even before coming to Illinois, we had chosen the consortium of architectural-engineering firms, DUSAF (Daniel, Urbahn, Seeleye, and Fuller). It hadn't been easy to come to that choice, for they had been the same group who had worked for the group at the Lawrence Berkeley Laboratory (LBL), and I thought they had overdone the buildings - made them too expensive. Furthermore, as good people will, they had become very loyal to the LBL group and found it difficult to

[5] Don Young, as well as several other physicists from the MURA project in Madison, Wisconsin, were the first to join the Laboratory. Phil Livdahl came from Argonne National Laboratory to join them. The group has been in the thick of things at the Lab ever since.

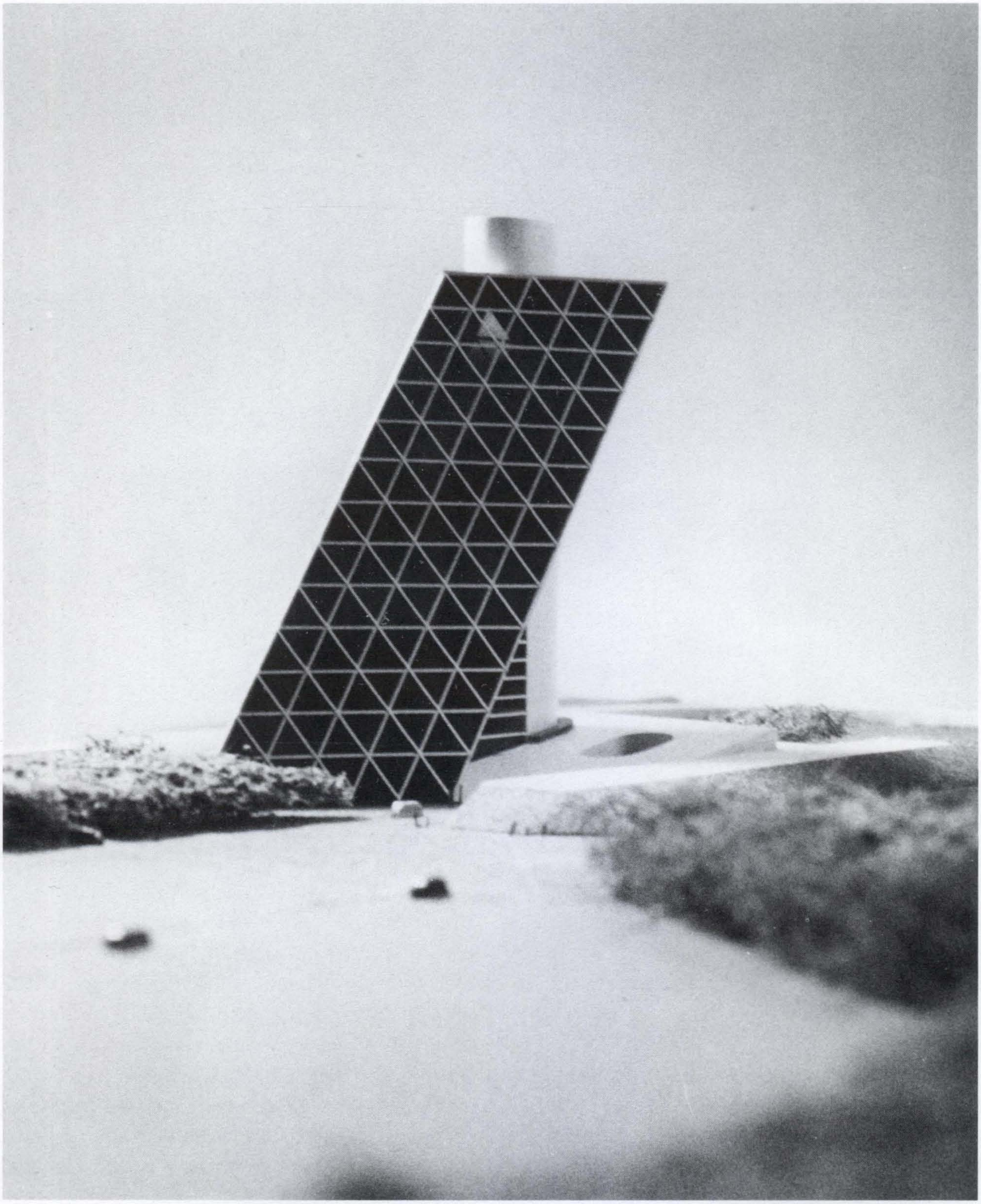
One of my policies at Fermilab, of which I am most proud and for which I was roundly criticized, was to move people in and out of various responsibilities at roughly yearly intervals (I disliked the "empires" which just naturally had grown up at other laboratories). Phil Livdahl exemplifies this. After the Linac was finished he moved on to help direct the commissioning of the Main Ring, became head of Accelerator Division and played an important role in the TEVATRON project, became Acting Director of the project, and finally Deputy Director. He retired in 1987 to devote his full energies to the Loma Linda medical accelerator. Paul Reardon went through similar changes: Head of the Booster, Business Manager, Head of the Accelerator Division, and exceedingly important in the development of the TEVATRON magnets. Indeed, a whole generation of similar physicists at the Laboratory became superb administrators in that game of musical chairs: Rich Orr, Dick Lundy, John Peoples, Bill Fowler, Helen Edwards, Russ Huson, Drasko Jovanovic, and many, many others. Then there was the host of anonymous physicists, engineers, and technicians performing prodigies of construction. Ryuji Yamada was typical, he worked devotedly and with great effort on nearly every aspect of the accelerator.



Robert Wilson addresses the first meeting of the assembled National Accelerator Laboratory staff in the newly-constructed RF Building in 1968.

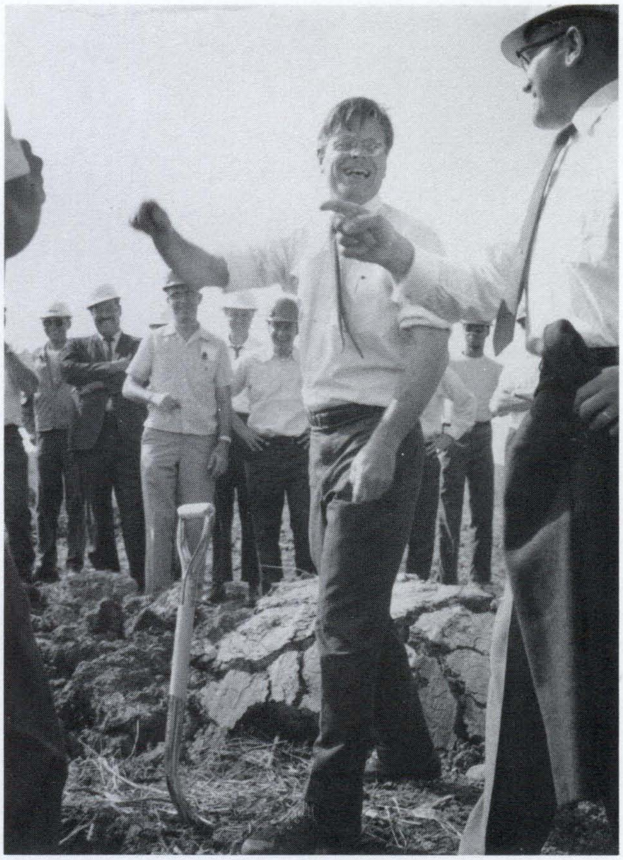
imagine how I might in a short time shape up a laboratory that could ever compare with the great Radiation Laboratory. I must confess to some trepidation in that regard myself.

Only days after I had been named Director, a group from DUSAF had visited me at Cornell University with an offer to build the whole project, including the accelerator, as a turn-key operation. Offended, I offered to let them design a few out-buildings, and I meant, literally, outhouses. Not an auspicious start, I thought, as they clumped off in anger. Yet their President, Colonel William Alexander, a true Virginia gentleman, got right back to me with assurances that they were in the architecture/engineering business, and could and would adapt to my style for whatever part of the project I might choose. Something about him convinced me that he would do just that, so after Norman Ramsey and I had checked more thoroughly, the Colonel and I shook hands on it. Not for a moment did I ever regret that handshake. He appointed Parke Rohrer as general manager at the site, and Parke was perfect.



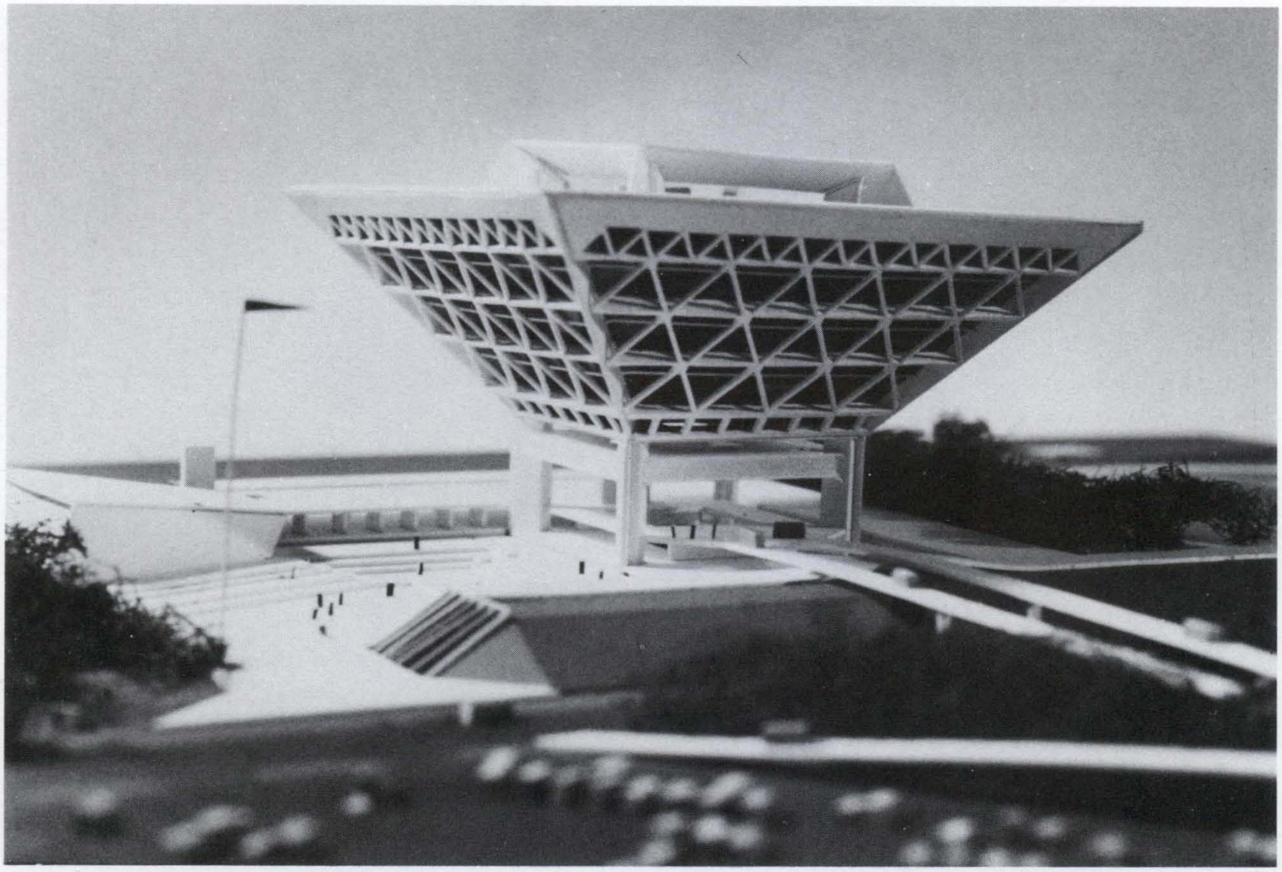
The Leaning Tower of Pisa was the inspiration for this Central Lab Building design.

The first task was to locate the synchrotron and its experimental areas on the site plan. This was done mostly to maximize the length and number of experimental areas, but ecological considerations for the site - trees and such - were given due regard. My own sentiment then was to have just one big building located at the injection and ejection point on the Main Ring, and to have as much as possible of the injection accelerator and utilities placed in the lower floors, the offices and laboratories to be above. I hated the clutter and bad communication that results from having a multitude of small buildings. To decide how high the "Lab" building ought to be, I went up in a helicopter and had the pilot hover at various altitudes as I plotted an "aesthetic factor" as a function of height. The curve rose sharply to about 75 ft where it began to flatten as the Fox River Valley came into view. The sky, the sunsets, the Illinois landscape, all looked better at the higher levels, as it had from the tenth floor of the Oak Brook office building. I concluded that the building should be at least 200 ft tall, and taller if possible (it turned out to be 250 ft).



Robert Wilson and Parke Rohrer (right) at the Main Ring ground-breaking ceremonies on October 3, 1969.

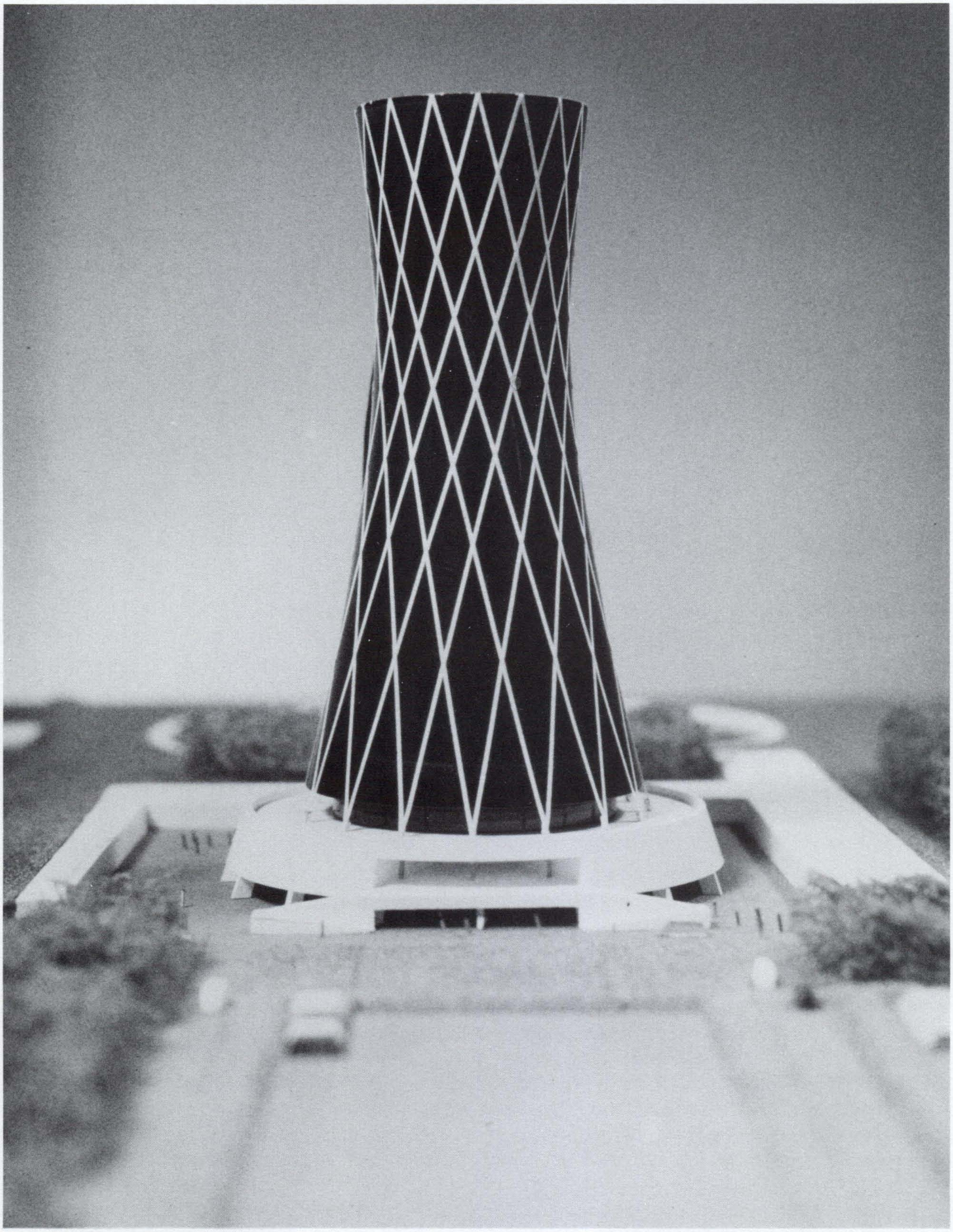
Years earlier, I had been delightfully involved with the question of height while driving from Paris, France, to see Chartres Cathedral. As you go along, at first you see it, then you don't, then it seems to flirt with you, and finally bursts out in all its radiant splendor. Perhaps it was hubris to hope for a similar effect on approaching Fermilab. Ultimately, it was not Chartres, but Beauvais Cathedral that was to have a closer resemblance to the Central Lab. When asked by the architects if I had any predilections concerning the style of the building, I responded that the Ford Foundation Building in New York City, with its handsome atrium, appealed to me, except that it had been one of the most expensive structures ever built. Could they not do a similar building - but inexpensively? They took up that challenge. A competition developed in which each of the firms comprising DUSAF, except for the Fuller Construction Co., designated a group to make a design. We announced a date when all the designs would be presented. I would then choose one of them for further development. We all gathered around on the designated day for the dramatic moment. There was a leaning building of triangular cross section, a narrow but high circular building (a Prell shampoo bottle had been used for the model), a far-out upside-down



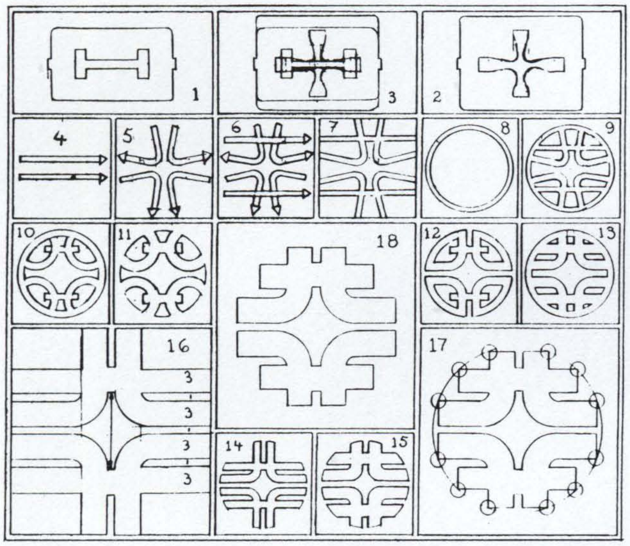
The "far-out" inverted pyramid design for the Central Lab Building, submitted by Max Urbahn and his associates.

pyramidal structure presented by Max Urbahn and his associates, our official *beaux arts* firm, and finally, a dark-horse entry by George Adams, a young architect hired by Parke Rohrer "off the street." His building was a truncated cone with a domed atrium. A cost estimate as well as a model had been made for each entry. After discussing the merits of each of the buildings with the National Accelerator Laboratory staff, to Urbahn's disgust (his building had been architecturally most significant), I chose Adams' entry as coming closest to satisfying our technical and aesthetic needs, and for being substantially lower in cost. By that time, I had realized how slowly our money would be appropriated, so I announced that the accelerator would come first and the Central Lab last. Still, we had learned a lot from the exercise - we had also enjoyed it tremendously and Adams' building did eventually metamorphose into the Central Lab, which was principally the design of Alan Ryder.

The architects didn't quite know what to make of me. I was their client who would choose what they would design and then decide whether to approve it or not (of course, the AEC had a voice in that), but I would not hesitate, as a sculptor, to criticize their aesthetic forms, nor would I, as a physicist, refrain from calculating strengths of beams or flows in pipes. Should some structure come in for more



The clean lines of a Prell shampoo bottle are reflected in this proposed Central Lab Building.

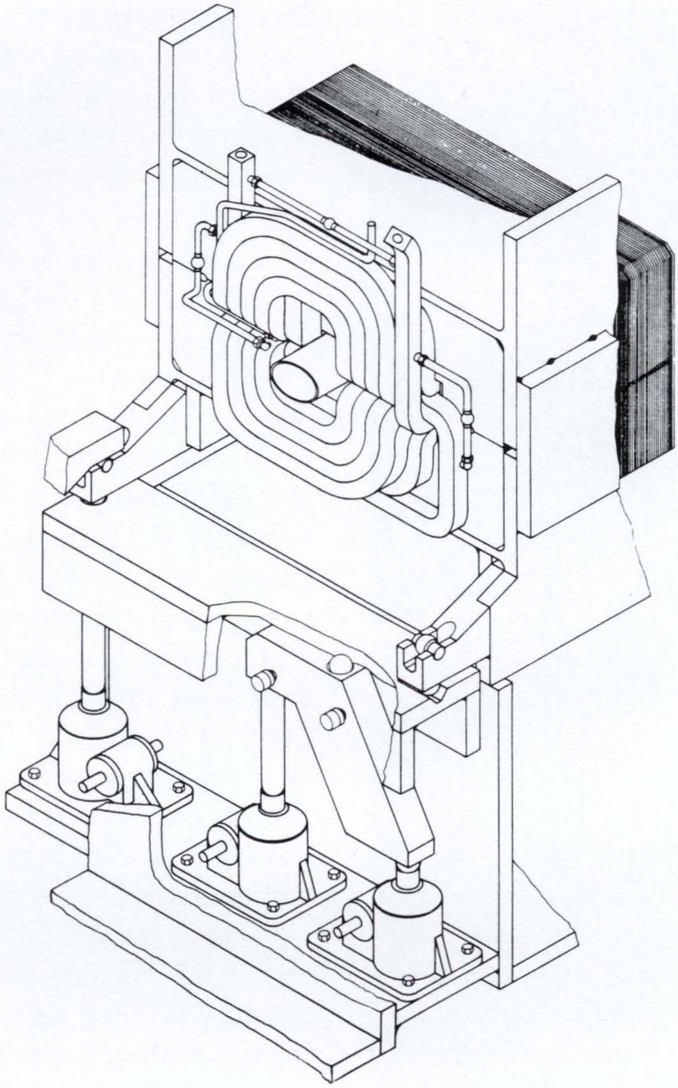


The Evolution of a Logo: ***1.*** *Bending-magnet lamination.* ***2.*** *Quadrupole-magnet lamination.* ***3.*** *Both laminations combined.* ***4.*** *Bending-magnet aperture configuration.* ***5.*** *Quadrupole-magnet aperture configuration.* ***6.-7.*** *Lines combined, representing a chalk drawing by R. R. Wilson on his blackboard, summer 1967.* ***8.*** *Decision to confine the design in a circle.* ***9.-15.*** *Rejected solutions.* ***16.*** *Drawing to determine proportions of white and black areas: 1:3.* ***17.*** *Drawing to confine the design in a circle; the small circles indicate points where design intersects circle.* ***18.*** *Final version.*

cost than I had budgeted, I found a simple show of anger quite effective - as long as I did not really lose my temper. Tearing up the plans and then jumping up and down on them seemed to help get my point across. I think that they were pleased that their client really cared. I respected them, for they were exceedingly competent architects and engineers, and despite my bluster and show of artistic temperament, we all got to be great friends.[6]

In order to get our buildings done on time and within budget - and this was crucial for keeping to our fast schedule - we followed an effective procedure. First, the design would be made for a schedule that optimized cost, then we would go out for bids on that basis. Once the lowest bidder had been chosen, Parke Rohrer would sit down for a heart-to-heart talk at which Parke would offer a certain amount of money extra for each day the contractor would finish his building ahead of schedule. Of course we would have in mind the date necessary for us to keep our schedule, so the premium per day would go up as that day ap-

[6] Tom Collins came to us from the Harvard-MIT electron synchrotron laboratory. Tom had been the physicist most responsible for designing and building the 8-GeV synchrotron at Harvard and had made all sorts of accelerator inventions. The one that affected us most was to provide long straight sections in a strong focusing lattice; we had eight in our Main Ring. In addition to the arcane features of synchrotrons, Tom has an exceedingly good understanding of the nitty-gritty of accelerators: the utilities, and power supplies, and vacuum, etc., where most of the money would be spent. Tom, as Associate Director for Accelerators, was not only of importance in the design and construction of the Main Ring, but he was also close to me in all architectural matters. He ran a once-a-week meeting at which all architectural questions were discussed and at which most of the vital decisions about building schedules, etc., were made. I sometimes think that Tom's lifeblood flows through the magnets of the synchrotrons. He still is going just as strong with the TEVATRON - a true Fermilab hero.



Artist's conception of the Main Ring bending magnet and support system from the January 1968 Design Report.

proached. On the last day the extra payment would become significantly greater. It became a game for the contractor to get the prize money - and a point of pride - and usually they would make it into the "big money." Yet the total of the premium would be but a few thousand dollars out of millions - and it was worth much more to us to keep things on schedule. Cost penalties usually do not work because the builders' lawyers can always find an excuse for a delay without penalty.[7]

[7] We did not have a construction division in the Laboratory as did most labs. Instead, I made Parke Rohrer the Fermilab Associate Director for Construction, responsible to me. Parke is an exceptionally gifted person who could, and did, serve both DUSAF and Fermilab. If we moved rapidly and produced workable and attractive structures, it was because Parke Rohrer and his associates cared so much - and indeed we had all sorts of people at the lab *just like him*.

Kennedy C. (Casey) Brooks.

In the House-Senate Joint Committee hearing in 1967, it was recommended that the AEC take direct responsibility for all civil construction because of the magnitude of the project. This made my blood run cold, for it was bruited about in Washington that AEC buildings "did not have to be cheap, they just had to look cheap." John Erlewine, director of construction for the AEC, informed me that his division was ready to take on that responsibility. He listened sympathetically to my arguments to the contrary and then replied that if I could demonstrate responsibility, he would stay out of it. In the event, that's how it worked out. That implied a local office (for other reasons as well) and one of the AEC's greatest gifts to us was the Office Manager, the beloved Kennedy C. Brooks, or Casey as he was known to all. Casey, with a lifetime of construction experience, mostly with the AEC, had a beautifully light touch and he guided us through the labyrinthine procedures of the AEC.[8] Support in great depth is what we got from the AEC in every respect - they became more than a source of government funding, they became partners and comrades.

I have always felt that science, technology, and art are importantly connected, indeed, science and technology seem to many scholars to have grown out of art. In any case, in designing an accelerator I proceed very much as I do in making a sculpture. I felt that just as a theory is beautiful, so, too, is a scientific instrument - or that it should be. The lines should be graceful, the volumes balanced. I hoped that the chain of accelerators, the experiments, too, and the utilities would all be strongly but simply expressed as objects of intrinsic beauty. Aesthetics is partly a matter of communication, and with so many people

[8] The people in Casey's office, from Fred Mattmueller to Minerva Sanders, his secretary, were also *sympatico* and models of efficiency. Andy Mravca performed bureaucratic and technical marvels. He worked so closely with our people that he sometimes knew more than we did about our plans. He boasted that he would have things lined up in Washington so that not more than one day, rather than three months, would be required to obtain the necessary AEC approvals - he invariably came through in just that way - and still does!

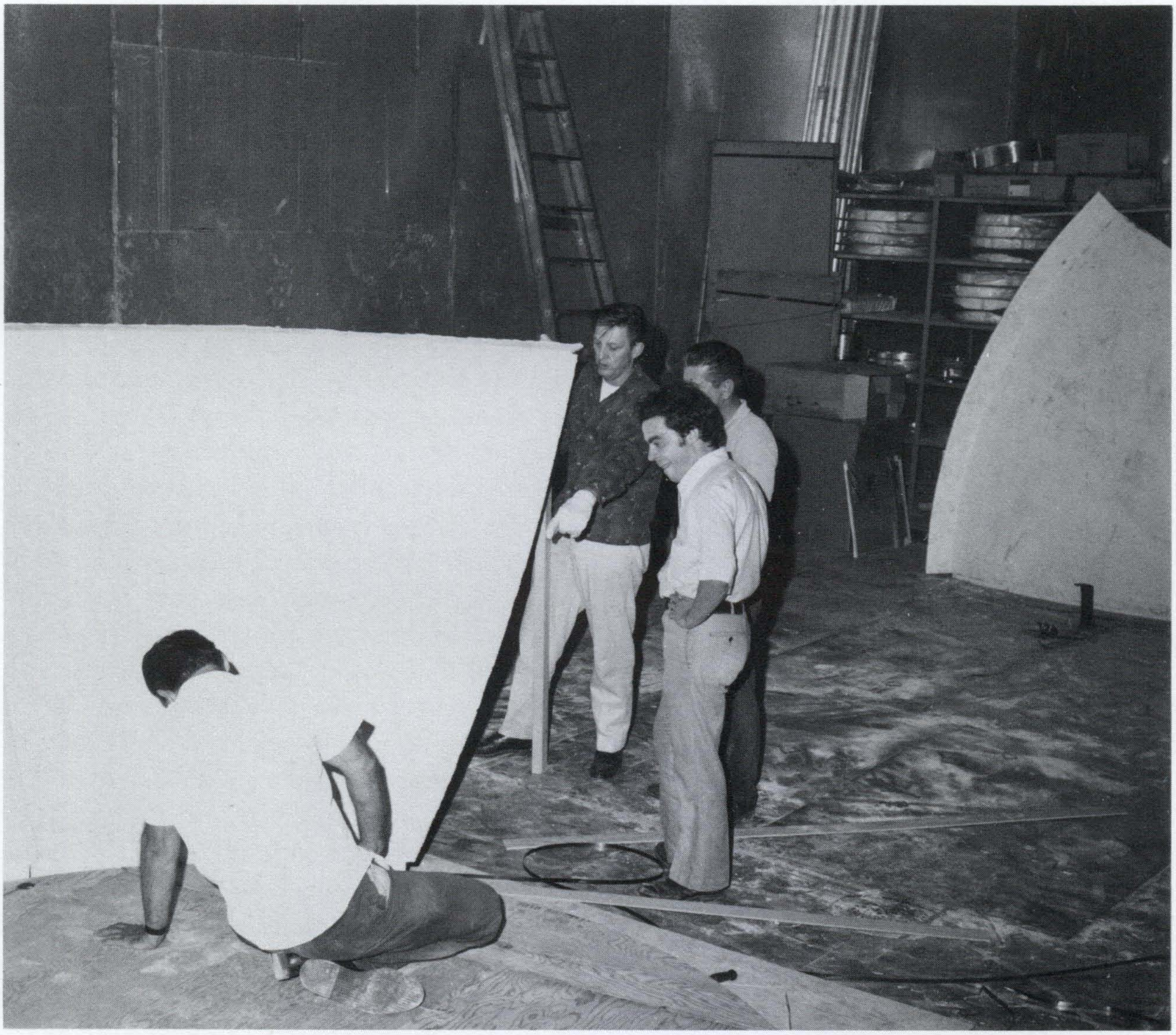
involved, I felt that everyone would appreciate the economy of good design and would keep their designs equally clean and *understood*.[9]

The first product to appear almost at once at the Oak Brook offices was a full-size (in cross section) cardboard model of how big I thought the Main Ring tunnel should be, namely about 10 ft in diameter, and how large the magnets in it should be, about 25 in. by 14 in. This raised more than a few eyebrows, but that was how it was built. Models. I tried to have models built of every building and every component of the machine. It enabled me to visualize where drawings would confuse.[10]

Let me return to the excitement of designing the accelerator. Imagine the hysteria of those months at Oak Brook as we raced toward our deadline to have a credible design and cost estimate (a Schedule 44 for the *cognescenti*) in order to get funds to keep us on schedule. The DUSAF people were old pros, for they had traveled the same road at Berkeley during the preparation of the 200-BeV report. We just had to be Procrustean and have them change their designs to fit our financially limited beds. They had separate designers and cost estimators, but the accelerator part was more difficult because we, of course, did not have the technical resources of the Berkeley laboratory at all. In order to get reliable accelerator cost estimates, I called on my good friend Bill Brobeck. Bill, a master engineer, had been an exemplar of mine when I was a student in the old Radiation Laboratory. I tried to emulate him as much as possible in what I later did by way of design and engineering at Cornell where, with satisfaction, we had used the services of his company in the construction of the 10-GeV electron synchrotron. William M. Brobeck and Associates had a reputation for making high cost estimates, a practice that would counterbalance my own reputation for making low estimates. What we would do was to design various parts of the accelerator complex with our own few physicists and engineers and then Brobeck's people would make a cost estimate based on our design. DUSAF would make parallel cost estimates for the buildings and utilities. If the total estimate exceeded

[9] Angela Gonzales, a draftsman at Cornell and a talented painter, had worked closely with me during the design of the Cornell synchrotron. She understood well what I was trying to get at, and was useful in her criticisms of the balance of my lines and forms. I was delighted when she agreed to come to the project, for she embodied to a degree what I wanted with regard to the aesthetics of the project. Her influence can be seen everywhere at the Lab, from the colors and forms of the buildings and accelerator to the highly original drawings on the covers of reports and the illustrations within. The Auditorium lecture program and concert series, and the art exhibits on the mezzanine of the Central Lab Building, originally directed by Janice Roberts, were another manifestation at the Lab of the unity of art and science and the general culture. This may be an appropriate place to discuss wives. My wife, Jane, was enormously important to the Lab both socially and in initiating the lectures program. I felt, too, that my colleagues were blessed in the great wives who accompanied them to the Lab. Many had jobs in the Lab, but all contributed importantly to the social ambience. Indeed, NALWO was formed by them so they could be more effective in their endeavors.

[10] Jose Poces, who ran our superb Model Shop, contributed importantly to our architecture by his creative suggestions in the process of making the models. Even better, he would brook no nonsense from me, he was devastatingly honest, but very useful in his candid criticism.



Jose Poces (third from left, hands on hips) overseeing the casting process for the full-size model of the Bubble Chamber at the Model Shop.

$250 million, we would go back and make inventions and more imaginative designs until our architectural and technical costs had come down to the level of our financial resources.

It wasn't easy, still it was a happy, triumphant group that turned in a $250-million design on October 1. I think I got decision-happy during that period, for there were thousands of decisions to be made. I learned to spew out decisions at a great rate: I would spout them off walking down the corridor as a Pope does benedictions. I came to understand that a poor decision was usually better than no decision at all, for if a necessary decision was not made, then the whole effort would just wallow - and, after all, a bad decision could be corrected later on. Making decisions is heady stuff, it's the Director's *raison d'etre*, but I doubt that it is very good for a scientist's mind. I recall that in making im-

portant decisions, I would inform myself as much as possible before a meeting, i.e., get "psyched up," then listen as carefully as I could to the pros and cons, then rear back and deliver the goods - usually from my subconscious. As I would walk away from such a session, I could feel the knowledge oozing out of me. Ten minutes later, confronting a new problem, I could not remember the earlier problem nor the decision. I seemed to have become a decision machine, far different from the reflective scholar who had come from Cornell University.[11]

It was not roses, roses, all the way. Tragedy began to strike as our numbers grew - disease, even death. Nowhere in the annals of physics are such things mentioned, nor had my previous experience prepared me to cope with them. Yet coping was part of the job. I soon found that Tim Toohig, a cracking good physicist at

[11] Teamwork is of the essence in the operation of a large laboratory, yet individualism and some tranquillity were an absolute necessity for my sanity. Thus, at lunch time or late at night, I would find myself getting rid of my aggressions by hammering at a piece of marble - take that, and that, and that! - and doing what I did exactly as I wanted, no explanations, no committees. I was never so active a sculptor as I was at Fermilab.

the Lab, as well as a Jesuit priest, would appear on such occasions full of compassionate sympathy and understanding. Despite a difference in our religious beliefs, we became close friends and the difference narrowed as my respect for Tim grew. He became the spiritual counsel for the project.

There are so many stories to tell about the early days: getting access to the site; fighting for adequate funding; building the Linac, the Booster,[12] the Main Ring,[13] and the experimental areas;[14] extracting the protons and switching them to the experimental areas;[15] getting the whole complex to work at all and then to work reliably and with high enough proton intensity. Appendix A gives an optimistic picture of the project as presented in my testimony of March of 1971 before the House-Senate Joint Committee on Atomic Energy. However, just after that report was given, all hell broke loose; it seemed that whatever could fail, did fail. But these stories are not for the telling here. Perhaps the illustrations will speak where words and memories now fail. More frustrating is that I have not addressed the major theme, indeed the only theme of the project, Physics, the planning of which started in the times covered here.

In retrospect, I suppose, my most serious problems had been with my colleagues. For exemplary reasons they felt impelled to do the best job of which they were capa-

[12] The Booster was largely under the leadership, first of Arie Van Steenbergen, then of Paul Reardon, and then of Roy Bilinge and Helen Edwards. The latter two not only completed it, but brought it into successful operation.

[13] John DeWire, and then Frank Shoemaker, contributed seminally in the early months. Ernie Malamud took over from them when they returned to their universities. Ernie was typical of the Fermilab physicist: utterly dedicated and utterly tireless. He took on all the hard problems from civil rights to union disputes. His was a romantic idealism, and while he was doing everything else, he was also arranging a collaboration with the Russians to do the first experiment. Ernie has written an unpublished account, "Early History of the Main Ring," October 20, 1983, which is the most authoritative description of the Main Ring effort. Two really great engineers made significant contributions: Dick Cassel and Hank Hinterberger. Quentin Kerns came from UCB with almost complete plans for the radio-frequency cavities. Don Edwards and Lee Teng were the theoretical gurus of the Main Ring.

[14] Jim Sanford, a visitor from Brookhaven during our summer of design, plotted out an idea to have but one beam extraction point and but one long external proton beam from which secondary beams diverged. It was a good idea and he was so enthralled that he later returned to the Lab to become the major-domo for the beams and an associate director for program planning. The first summer study at Aspen in 1968 was exceedingly valuable in designing the experimental areas to correspond to the anticipated experiments.

[15] Al Maschke, head of our Beam Transfer Group, was one of the first physicists to come to the project. He is an exceedingly imaginative and competent physicist and many of his ideas were crucial to the success of the project. Most important was his concept of extracting the beam with an efficiency of 99% - up 'til then, 60% was considered quite good. Al was something of a character, to put it mildly. He did not get along with everyone, but our relationship was excellent - perhaps because I respected his physics so much. However, we disagreed just once, and it was serious because Al walked away angrily and did not come back. Helen Edwards filled the void he left. Years later we made up - but it was a tragedy for me when he left.

"I was never so active a sculptor as I was at Fermilab." Wilson at work, in 1978, on Acqua alle Funi, *the obelisk that now graces the Wilson Hall reflecting pond. The title translates as "Water to the ropes." In 1586, Pope Sixtus V decided to move a 92-ft, 240-ton obelisk 275 yards to the square in front of St. Peter's Cathedral in Rome. The architect, Domenico Fontana, was given supervision of the project. Fontana had calculated the exact thickness and length of the ropes needed to lower and then lift the monument. Each coil of rope was wound around a capstan sunk in the ground. Nine hundred men and 74 horses labored to move the structure. At one point, the ropes began slacking due to the hot, dry weather. In spite of an edict forbidding the onlookers to speak on pain of death, a bystander cried out "Water to the ropes!" thereby saving the project.*

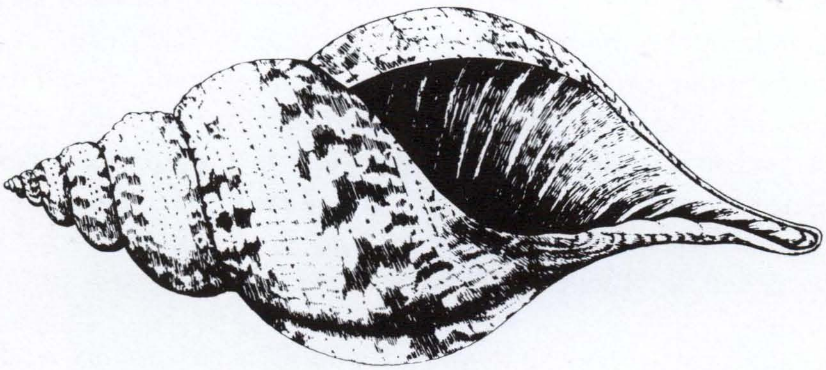
ble and to minimize the probability of failure. I, on the other hand, was asking them to work at the edge of failure in order to save time and money, hoping to correct our mistakes as they arose. In many cases this understandably led to a real conflict, and to resolve the conflict, and in order to stay within budget and on schedule, I found it necessary to be firm, sometimes dictatorial. But that was exactly contrary to my own sense of how a good scientific laboratory should operate. Thus, my success as Director would hinge on how fast my strong-man regime would "wither," how soon I would become superfluous.

Originally I had hoped to return to the scholarly life at Cornell in five years, the duration of my leave. That, of course, was naive, but by the end of eight years I had indeed become superfluous, for a wonderfully competent group of colleagues had taken over all phases of the operation of the Lab. My obsession had become the TEVATRON, but when the funds to operate the Lab had become patently inadequate, and when the funds for the TEVATRON had essentially dried up, it was time for me to leave, time for a younger director, time for Leon Lederman to take over. Leon managed to turn that dismal prospect around and under his regime the Lab has flourished.

Remembrance of things past; these inchoate memories float into and out of my consciousness like isolated clouds on a summer day. Perhaps, even if only partial, they may give some of the flavor of starting the Laboratory. Still to be told is the major story, a story of high adventure, hard work, occasional success, occasional failure, and always soaring spirits. To find out how it all turned out, tune in on the thirtieth anniversary.

Goethals was once asked what was the most important factor in building the Panama Canal. "It was the pride *everyone* felt in the work," he replied.

"But if the while I think on thee, dear friend
All losses are restored, and sorrows end"



Fermilab

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

Directors Office

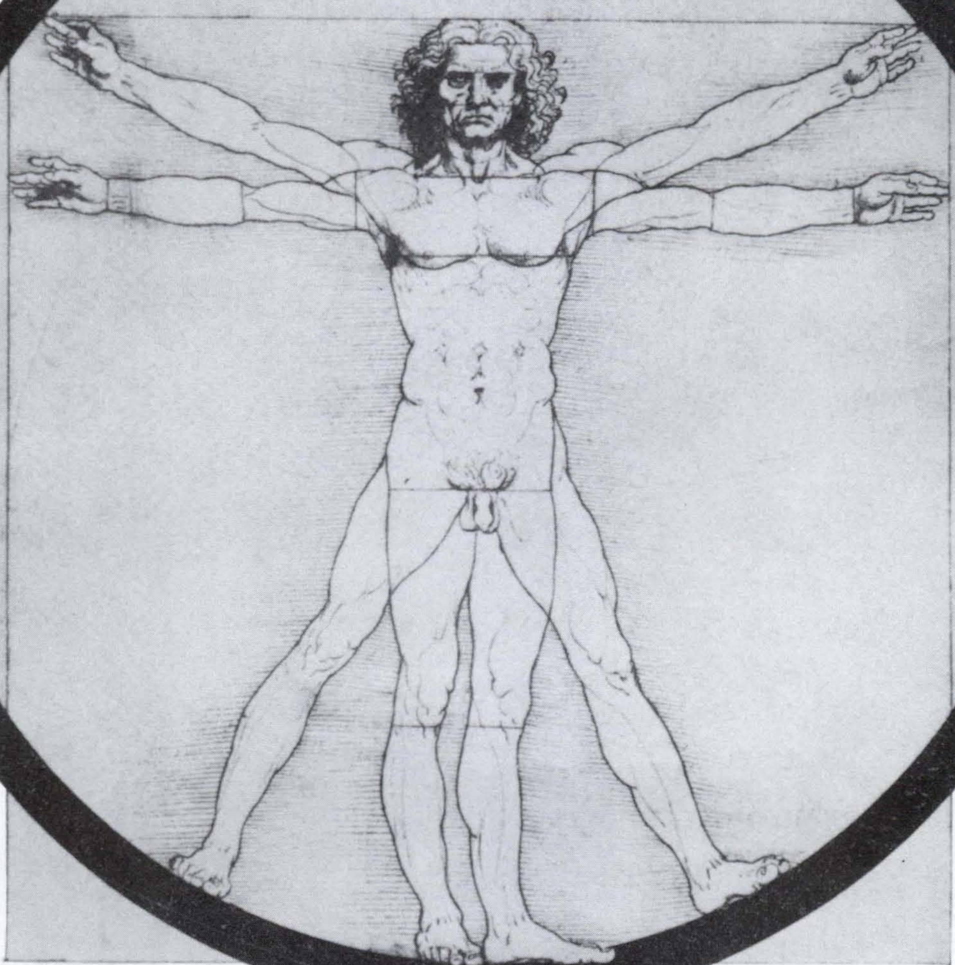
Dear colleague, May 5

An all too common failing of large institutions is to fall into the bureaucratic morass — complicated procedures, red-tape, and all that. That's terrible.

Lets try hard to keep the good old can-do informal spirit of Fermilab alive!

I ask each of you to be intolerant of creeping bureaucracy

Bob Wilson



design report

national accelerator laboratory

V. Appendices

Appendix A
Statement by Robert R. Wilson, Director, National Accelerator Laboratory, to the Joint Committee on Atomic Energy March 9, 1971

Fortune has smiled on us at the National Accelerator Laboratory since our ground breaking on December 1, 1968. Our costs have been low enough and our construction has been rapid enough that a larger fraction of the machine is under way, or actually finished, than might otherwise have been expected. Indeed, it appears possible now that the accelerator might be in operation this coming summer.

May I remind you that the accelerator consists of three different sub-accelerators: A Linac that produces a proton beam having an energy of 200 MeV; a Booster synchrotron in which this energy is raised to 8 BeV; and then the Main-Ring Accelerator where the energy is raised from 8 BeV to 200 BeV or higher. The Linac was finished and working on December 1, 1970, exactly two years after the ground breaking. It works magnificently. The Booster construction is also finished, and we are now in the testing phase of that accelerator. It has already produced a beam of 1 BeV protons, and we are confident that it will go on up to its design energy of 8 BeV in the coming months. The construction of the four-mile long Main-Ring tunnel is completed and about half of the roughly 1000 magnets of which the Main Ring is to be comprised have been fabricated and are installed in the tunnel. In fact, 1 BeV protons that are being accelerated in the Booster have been extracted and then injected into the first part of the Main Ring where studies of the orbits of these protons are now in process.

Let me now turn to the business end of the accelerator - the experimental facilities. These are just as complex, and just as expensive, as the accelerator itself. Two of these facilities, one called the Meson Laboratory, the other called the Neutrino Laboratory, have been designed and are under construction. Another facility, the Proton Laboratory, is still being designed. I hope that some part of these facilities will be ready to use this summer in crude form as soon as the first beam of protons is produced, so that a few important experiments can get started. For example, in one such experiment a search will be made of the quark - the hypothesized particle which may be the long-sought simple and ultimate "atom" of which the many presently known "elementary particles" are composed. Other experimenters will seek the magnetic monopole - the lost chord of electricity. Another of the first experiments is designed to study the so-called weak force, the force that comes into play when the evanescent neutrino interacts with matter. Here the experimenters will be searching for another new particle, the W-boson, which is expected to play - in the weak interaction - the same role that the photon plays in electric interactions. In our initial experiments we will also start the exploration of the deepest regions of the proton and the neutron - regions that will be accessible to us for the first time because of the very high energy that will be made available by our new accelerator.

Although the construction is going well enough that we may see initial operation this summer, this does not imply that the construction of the entire Laboratory will be completed by then. The appropriations have been much lower than originally anticipated, and in general, we have accommodated to this situation by doing that which has been absolutely necessary for the accelerator and by putting back in time such things as site developments, utilities, or buildings that were not essential for initial operation. Thus, the badly needed central laboratory building, for example, has been delayed year by year by the insufficiency of construction funds so that only now is the foundation of that building under construction. We have allocated money so far only for the basement level of that sixteen story structure. In another instance, instead of building an expensive water treatment plant, as originally proposed, we have been able to improvise and to invent new methods of treating the water.

As you know, we originally designed the NAL accelerator to start operation at an energy of 200 BeV, but also to have the capability eventually of going to a higher energy. A year ago we found that due to advances in solid state devices we would be able to build larger supplies than we had originally contemplated, and at a cost which would still be less than that which we had originally estimated. We also found by actual test that our magnets were capable of going to very high fields. Thus it has turned out that our magnet system will have the capability to provide 500 BeV pulses right from the start.

The water cooling that will be installed has been designed for the 200 BeV level only and will limit the pulse rate, depending on the outside temperature. Furthermore, any operation above 200 BeV will depend on the effects of our electrical load on the power line and will be only by mutual agreement with Commonwealth Edison. Full operation at 500 BeV would mean an increased power consumption and hence an increased operating cost. Now this eventuality of going to 500 BeV came about, you will remember, because of the recommendation in 1968 of the JCAE Subcommittee on Research, Development and Radiation that we try for a higher energy. They also had advised a continued study of the possibility of achieving a higher energy by the use of superconductivity. It appears now that such a possibility may become feasible in the concept of what I like to call an "energy doubler." It is a small-bore superconducting magnet that can be mounted "pickaback" on the present main ring magnet. If successful, it should be of modest cost and should enable us to achieve higher energies - as much as 1000 BeV. Just as important, though, is that operation above the 200 BeV level would cost much less using the superconducting magnet than it would using our present copper and iron magnets. In fact, a considerable fraction of the cost of the energy doubler might be recovered in the first years by savings in operating costs. It might also forestall the necessity of installing additional water cooling or of installing devices to smooth out our electrical loads on the power lines.

Let me try to give a rough idea of how the energy doubler might work. It would consist of a very small bore superconducting magnet that would be placed just above the main-ring magnets. . . It would also have the same configuration as the main-ring magnets; that is, wherever a main-ring bending or focusing magnet is located, then just above it would be found the same kind of superconducting magnet. The protons, after being accelerated to a particular energy in the Main-Ring, would be transferred to the superconducting ring which would have at that time exactly the same magnetic field as the Main-Ring. Then the field in the superconducting ring would be raised to twice its initial value, and because the protons would be accelerated by an oscillating electric field as the magnetic field increased, the energy would be doubled. In a sense, the old Main-Ring would become a Booster Accelerator for the New Main-Ring, now made of superconductors. The electrical energy for the new ring might also come from the old one. The only thing novel about all this is that the injection field of the new magnet would be very high so that most of the problems encountered up till now in trying to make an accelerator using superconductivity are avoided. In other words, it is only because we have the conventional Main-Ring magnet made of copper and steel that we can consider the use of a superconducting magnet at this time.

Because the bore of the new magnets would be so small, because no new tunnel or buildings would have to be constructed, we can hope to be able to build such a device for less than \$20 million, possibly even less than \$10 million. All of these considerations, it must be emphasized, are based only on the most preliminary of studies.

Turning back to our experimental program, when it became evident last year that the accelerator might come into operation a year earlier than we had originally projected, we sent out a call for proposals for experiments. As a result, over 100 excellent experiments have now been proposed by physicists from all over the country. We have been aided by a distinguished and hard-working Program Advisory Committee* in selecting from the array of proposals those experiments which will be started in the first year or two. It is interesting to note that these proposals have been made by some 500 physicists, which is roughly one-half of the physicists who do high-energy physics experiments. It is now clear that the demand for experimental space will far exceed that which is planned for the immediate future. Something like two-and-a-half areas should be completed within the next year, but these can only accommodate a small fraction of the experiments that have been proposed. As experience is gained with these areas, we will design new facilities for experiments.

Now, it is painfully evident that the funding of the project is at a slower rate than we had expected. Thus, we have so far received only \$150 million of our projected \$250 million construction funds. Of the \$60 million that had been anticipated for equipment funds, we have received only about \$13 million. Next year the President's Budget provides for \$48 million for construction funds, \$11.9 million for operating funds, and \$8 million for equipment. We have been responding to this low rate of funding by doing only the most urgent construction, by making sure that no contingencies arise, by keeping the number of employees to an absolute minimum, by exploring technical innovations, such as the energy doubler, to keep down operating costs, and by scrounging used and old-fashioned equipment to bolster our meager equipment funds.

The experimenters, who came to us from universities and from other national laboratories the funds of which have also been most seriously curtailed, have entered into the spirit of making the best of doing physics with little money. It is gratifying to see them go to extreme limits of improvisation by the use of old equipment or by devising novel solutions to getting on with their experiments. Their enthusiasm is contagious, and we have been inspired to make extra efforts by the presence of so many excellent physicists at our site as they plan and scheme how best to use our facility. However, the shortage of money in this field will have a very serious effect on how much can be done at all. A very large amount of government money has been invested in this great facility as well as in the training of these physicists. Is it being short-sighted, not adequately to exploit that investment? Will we miss important scientific discoveries because of inadequate support, and may this great country not miss a generation of physicists because of lack of training and motivation?

If we have done at all well at the NAL, it is in part a reflection of the interest, the eagerness, the ability, the determination of the physicists of this country to explore this exciting frontier of knowledge. I would hope that the JCAE, which has done so much to initiate this project, to bring it to this point of reality, to inspire it to over-reach the initial goal, will help it to reach an operational level that will justify what they have accomplished thus far. I would hope, too, that in living up to my commitment to the Committee not to exceed $250,000,000 for construction, the Committee will challenge me to build as much experimental facilities and attain as high an energy as is possible without exceeding the Congressional authorization of $250,000,000.

*The NAL Program Advisory Committee consists of:

Owen Chamberlain, University of California, Berkeley

Thomas H. Fields, Argonne National Laboratory

Val. L. Fitch, Princeton University

Murray Gell-Mann, California Institute of Technology

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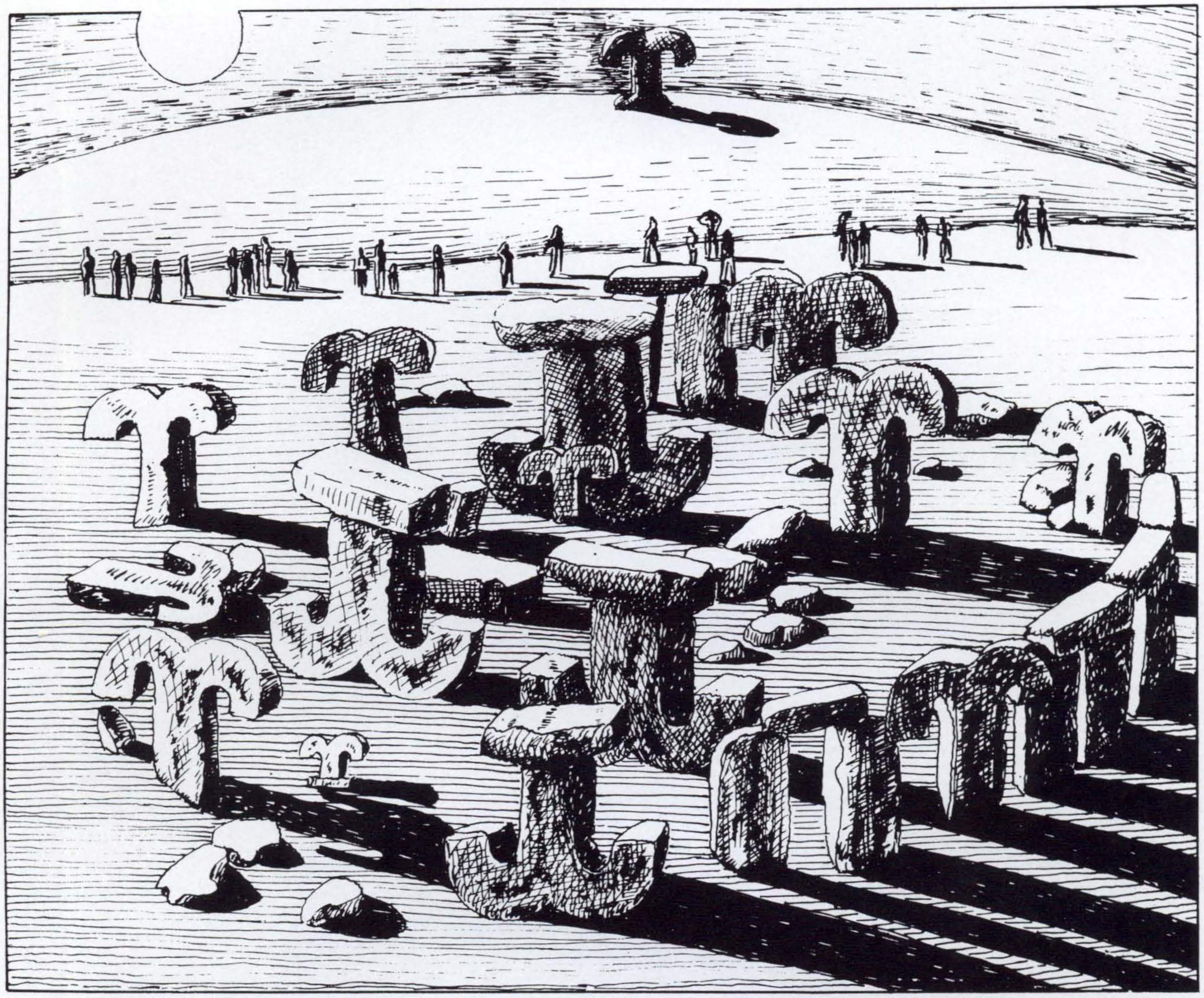
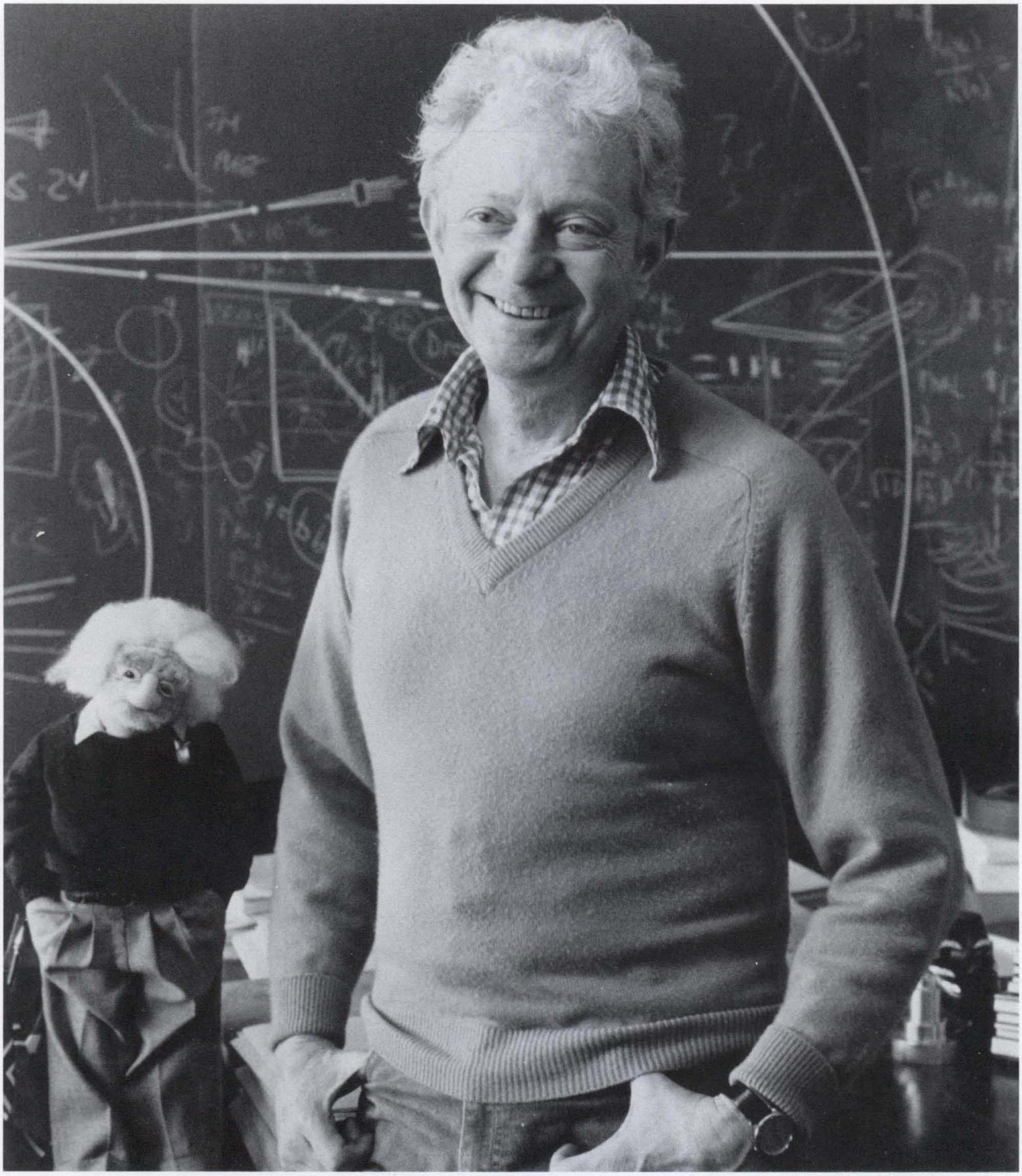




Fermilab Director Leon M. Lederman

Appendix B
Publications

Experimental Publications

Photoproduction E-87A

HIGH-ENERGY DIFFRACTION DISSOCIATION OF K_L^0 INTO EXCLUSIVE FINAL STATES. M. J. Lamm et al., Phys. Rev. D **36**, 3341 (1987).

Particle Search E-400

MEASUREMENT OF THE $\Sigma_c^0 - \Lambda_c^+$ and $\Sigma_c^{++} - \Sigma_c^+$ MASS DIFFERENCES. M. Diesburg et al., Phys. Rev. Lett. **59**, 2711 (1987).

HADROPRODUCTION OF $\Lambda_c \to pK\pi$. J. E. Filaseta, Ph.D. Thesis, University of Illinois, Champaign-Urbana, Illinois (1987).

Particle Search E-515

SEARCH FOR CHARMED MESONS PRODUCED IN HADRONIC INTERACTIONS. G. Ginther et al., Phys. Rev. D **35**, 1541 (1987).

Photoproduction E-516

A COMPARISON OF DIFFRACTIVE Λ AND Ξ PHOTOPRODUCTION. R. G. Kennett et al., Nucl. Phys. B **282**, 626 (1987).

Hadron Jets E-557

SCALING AND FRAGMENTATION DISTRIBUTIONS OF BEAM REMNANTS IN HIGH E_t PROTON-PROTON COLLISIONS AT $\sqrt{s} = 27.4$ GeV. S. Ahn et al. Phys. Lett. B **183**, 115 (1987).

Neutrino E-594

LIMITS ON $\nu_\mu \to \nu_t$ and $\nu_\mu \to \nu_e$ OSCILLATIONS. J. Bofill et al., Phys. Rev. D **36**, 3309 (1987).

COMPARISON OF CHARGED AND NEUTRAL CURRENT STRUCTURE FUNCTIONS. T. S. Mattison, Ph.D. Thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, December 15, 1987.

Particle Search E-595

SEARCH FOR NEUTRAL HEAVY LEPTONS FROM ν-N SCATTERING. S. R. Mishra et al., Phys. Rev. Lett. **59**, 1397 (1987).

Hadron Jets E-609

INVARIANT CROSS SECTION AT $\sqrt{s}$ = 28 GeV FOR COPLANAR HIGH P_t CLUSTERS SELECTED BY A HARDWARE TRIGGER. K. S. Nelson et al., Nucl. Phys. B **294**, 1022 (1987).

Forward Search E-615

J/ψ LONGITUDINAL POLARIZATION FROM πN INTERACTIONS. C. Biino et al., Phys. Rev. Lett. **58**, 2523 (1987).

CP Violation E-617

LIMIT ON THE RADIATIVE WIDTH OF THE K^{0*}(1430). D. Carlsmith et al., Phys. Rev. D **36**, 3502 (1987).

CP Violation E-621

MEASUREMENT OF THE LIFETIME OF K_s^0 MESONS IN THE MOMENTUM RANGE 100 TO 350 GeV/C. N. Grossman et al., Phys. Rev. Lett. **59**, 18 (1987).

15-ft Neutrino/H2 & NE E-632

HOLOGRAPHY IN THE FERMILAB 15-FOOT BUBBLE CHAMBER. G. G. Harigel, Nucl. Instrum. Methods A **257**, 614 (1987).

Photoproduction E-687

HIGH SPEED VIDEO DATA ACQUISITION SYSTEM (VDAS) FOR H.E.P., INCLUDING REFERENCE FRAME SUBTRACTOR, DATA COMPACTOR AND 16 MEGABYTE FIFO. K. L. Knickerbocker et al., IEEE Trans. Nucl. Sci. **34**, p. 245 (1987).

A SCINTILLATING GLASS FIBER-OPTIC ACTIVE TARGET FOR VERTEX DETECTION AND TRACKING APPLICATIONS IN HIGH ENERGY PHYSICS EXPERIMENTS. R. Ruchti et al., IEEE Trans. Nucl. Sci. **34**, p. 544 (1987).

Tagged Photon E-691

MEASUREMENT OF THE D^+ and D^0 LIFETIMES. J. C. Anjos et al., Phys. Rev. Lett. **58**, 311 (1987).

MEASUREMENT OF THE D_s^+ LIFETIME. J.C. Anjos et al., Phys. Rev. Lett. **58**, 1818 (1987).

CHARM PHOTOPRODUCTION RESULTS FROM THE FERMILAB TAGGED PHOTON SPECTROMETER. J. C. Anjos et al., *DPF '87: 13th Annual Meeting of the Division of Particles and Fields of the APS, The Salt Lake City Meeting*, eds. C. DeTar and J. Ball, (World Scientific Publishing, Singapore, 1987), M. Purohit presenter, p. 505.

PERFORMANCE OF THE CHERENKOV COUNTERS IN THE FERMILAB TAGGED PHOTON SPECTROMETER FACILITY. D. Bartlett et al., Nucl. Instrum. Methods A **260**, 55 (1987).

STUDY OF CHARM PRODUCTION MECHANISMS AT THE FERMILAB TAGGED PHOTON SPECTROMETER: $\gamma Be \to D\overline{D}$ x and $\gamma A \to \psi x$. T. Nash et al., *Hadrons, Quarks, and Gluons: Proceedings of the Hadronic Session of the 22nd Rencontre de Moriond,* Les Arcs, France, March 15-21, 1987, ed. J. Tran Thanh Van (Editions Frontieres, Gif-sur-Yvette, France, 1987), p. 197.

LIFETIME MEASUREMENTS OF THE THREE CHARMED PSEUDOSCALAR D-MESONS. J. R. Raab, Ph.D. Thesis, University of California, Santa Barbara, California, April 1987.

Total Cross Section E-710

SMALL t PHYSICS AT THE TEVATRON COLLIDER. M. Bertani et al., Int. J. Mod. Phys. A **2**, 891 (1987).

Constituent Scattering E-711

A VECTORIZED TRACK FINDING AND FITTING ALGORITHM IN EXPERIMENTAL HIGH ENERGY PHYSICS USING A CYBER-205. C. H. Georgiopoulos et al., Nucl. Instrum. Methods A **261**, 493 (1987).

Particle Search E-735

DEGRADATION OF PLASTIC SCINTILLATOR EXPOSED TO TEVATRON TUNNEL BACKGROUND RADIATION. C. S. Lindsey et al., Nucl. Instrum. Methods A **254**, 212 (1987).

D0 Detector E-740

TEST RESULTS FROM A PRECISION DRIFT CHAMBER VERTEX DETECTOR PROTOTYPE USING DIMETHYL ETHER. A. R. Clark et al., Nucl. Instrum. Methods A **261**, 420 (1987).

100 MBS, 8 BIT DATA ACQUISITION AND ZERO SUPPRESSION SYSTEM FOR THE D0 DETECTOR. M. I. Martin et al., IEEE Trans. Nucl. Sci. **34**, p. 258 (1987).

Collider Detector E-741

THE CDF EVENT-BUILDER. A. W. Booth et al., IEEE Trans. Nucl. Sci. **34**, p. 790 (1987).

FBEXPERT - AN INTELLIGENT ASSISTANT TO DIAGNOSE FASTBUS. A. W. Booth et al., IEEE Trans. Nucl. Sci. **34**, p. 987 (1987).

LEVEL 3 SYSTEM AT CDF. J. T. Carroll et al., Nucl. Instrum. Methods A **263**, 199 (1987).

INTEGRATION OF THE ACP MULTIPROCESSOR FARM WITH THE CDF FASTBUS DATA ACQUISITION SYSTEM. B. Flaugher et al., IEEE Trans. Nucl. Sci. **34**, p. 865 (1987).

Charm Production E-743

INCLUSIVE CHARM CROSS SECTIONS IN 800 GeV/c p-p INTERACTIONS. R. Ammar et al., Phys. Lett. B **183**, 110 (1987).

Charged Interaction E-744

MEASUREMENT OF SAME SIGN DIMUON PRODUCTION IN HIGH-ENERGY NEUTRINO INTERACTIONS. F. S. Merritt et al., *Proceedings of the Lake Louise Winter Institute, "Selected Topics in Electroweak Interactions"*, Lake Louise, Canada, February 15-21, 1987, eds. J. M. Cameron, B. A. Campbell, A. Kamnal, F. Khanna, J. Ng, J. Poutissou, (World Scientific Publishing Co., Singapore, 1987), p. 455.

NEUTRINO PRODUCTION OF SAME SIGN DIMUONS AT THE TEVATRON. F. S. Merritt et al., *Proceedings of the Leptonic Session of the Twenty-Second Rencontre de Moriond, Vol. 1, "The Standard Model - The Supernova 1987A,"* ed. J. Tran Thanh Van (Editions Frontieres, Gif-Sur-Yvette, France, 1987), p. 285.

PRODUCTION OF SAME SIGN DIMUONS BY 0-GeV TO 800-GeV NEUTRINOS AND ANTI-NEUTRINOS. F. S. Merritt et al., *DPF '87: 13th Annual Meeting of the Division of Particles and Fields of the APS, The Salt Lake City Meeting*, eds. C. DeTar and J. Ball, (World Scientific Publishing, Singapore, 1987), p. 532.

Theoretical Physics Publications

TESTING THE FRITZSCH QUARK MASS MATRICES WITH THE INVARIANT FUNCTION APPROACH. C. H. Albright et al., Phys. Lett. B **199**, 553 (1987).

STRING THEORY AND LOOP SPACE INDEX THEOREMS. O. Alvarez et al., Commun. Math. Phys. **111**, 1 (1987).

SPHALERONS, SMALL FLUCTUATIONS, AND BARYON-NUMBER VIOLATION IN ELECTROWEAK THEORY. P. Arnold and L. McLerran, Phys. Rev. D **36**, 581 (1987).

HORIZONTAL SYMMETRY AND THE FOURTH GENERATION. K. S. Babu and X.-G. He, Phys. Rev. D **36**, 3484 (1987).

CONSTRAINTS ON VARIANT AXION MODELS. W. A. Bardeen et al., Nucl. Phys. **B279**, 401 (1987).

THE K $\rightarrow \pi\,\pi$ DECAYS IN THE LARGE-N LIMIT; QUARK EVOLUTION. W. A. Bardeen et al., Nucl. Phys. **B293**, 787 (1987).

WEAK MATRIX ELEMENTS IN QCD: LARGE N_c EXPANSIONS. W. A. Bardeen, *Proceedings of the Leptonic Session of the Twenty-Second Rencontre de Moriond, Vol. 1, "The Standard Model - The Supernova 1987A,"* ed. J. Tran Thanh Van (Editions Frontieres, Gif-Sur-Yvette, France, 1987), p. 207.

HEAVY VECTOR LEPTONS AT THE SSC. V. Barger et al., *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 221.

EXCITED QUARK PRODUCTION AT HADRON COLLIDERS. U. Baur et al., Int. J. Mod. Phys. A **2**, 1285 (1987).

EXCITED WEAK VECTOR BOSONS FACING THE HIGH ENERGY AND HIGH PRECISION FRONTIER. U. Baur et al., Phys. Lett. B **193,** 110 (1987).

ISOSCALAR WEAK VECTOR BOSONS AT $e^+ e^-$ COLLIDERS IN THE TeV REGION. U. Baur et al., *Proceedings of Workshop on Physics at Future Accelerators*, La Thuile, Italy, and Geneva, Switzerland, January 7-13, 1987, (CERN, Geneva, Switzerland, 1987), p. 352.

TESTING THE STANDARD MODEL VERSUS A COMPOSITE STRUCTURE OF WEAK INTERACTIONS IN HIGH PRECISION EXPERIMENTS AT LEP AND SLC. U. Baur et al., Nucl. Phys. B **291,** 1 (1987).

THE FIFTH FORCE. J. D. Bjorken, *Proceedings of the Seventh Moriond Workshop, "New and Exotic Phenomena,"* Les Arcs - Savoie, France, January 24-31, 1987, eds. O. Fackler and J. Tran Thanh Van, (Editions Frontieres, Gif-sur-Yvette, France, 1987).

THE FUTURE OF HIGH ENERGY ELECTRON BEAM PHYSICS. J. D. Bjorken, *AIP Conference Proceedings 161, "Electron Scattering in Nuclear and Particle Science,"* eds. C. N. Papanicolas, L. S. Cardman, and R. A. Eisenstein, (American Institute of Physics, New York, 1987), p. 206.

OUR CHANGING VIEW OF HADRON STRUCTURE. J. D. Bjorken, *Proceedings of the Summer Institute on Particle Physics - Probing the Standard Model*, July 28-August 8, 1986, Stanford, California, ed. E. C. Brennan, (Stanford Linear Accelerator Center, 1987), p. 703.

RECENT AXION SEARCHES. J. D. Bjorken, *Proceedings of the Summer Institute on Particle Physics - Probing the Standard Model*, July 28-August 8, 1986, Stanford, California, ed. E. C. Brennan, (Stanford Linear Accelerator Center, 1987), p. 633.

REPHASING-INVARIANT PARAMETRIZATIONS OF GENERALIZED KOBAYASHI-MASKAWA MATRICES. J. D. Bjorken and I. Dunietz, Phys. Rev. D **36**, 2109 (1987).

STATIC POTENTIAL FOR SMOOTH STRINGS. E. Braaten et al., Phys. Rev. Lett. **58**, 93 (1987).

HEAVY QUARK CONTRIBUTIONS TO W PAIR PRODUCTION AT HADRON COLLIDERS. C. Chang and S.-C. Lee, Phys. Lett. B **197**, 220 (1987).

KAHLER MANIFOLDS WITH VANISHING CHIRAL POTENTIAL. N.-P. Chang et al., Phys. Rev. Lett. **58**, 1505 (1987).

SOME ASPECTS OF LARGE N THEORIES. S. Das, Rev. Mod. Phys. **59**, 235 (1987).

SIGNALS OF HORIZONTAL SYMMETRIES AT THE SSC. N. G. Deshpande et al., *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 250.

EXPLICIT FORMULAE FOR HEAVY FLAVOUR PRODUCTION. R. K. Ellis and J. C. Sexton, Nucl. Phys. B282, 642 (1987).

HEAVY FLAVOR PRODUCTION AND COLOR COHERENCE IN HADRONIC SCATTERING. R. K. Ellis, *Proceedings of Les Rencontres de Physique de la Vallee D'Aoste: "Results and Perspectives in Particle Physics,"* ed. M. Greco, La Thuile, Italy, March 1-7, 1987, (Editions Frontieres, Gif-sur-Yvette, France, 1987), **2,** p. 187.

SOFT RADIATION IN PARTON-PARTON SCATTERING. R. K. Ellis et al., Nucl. Phys. **B286**, 643 (1987).

NONLINEAR EVOLUTION OF YUKAWA COUPLINGS IN THE DOUBLE HIGGS AND SUPERSYMMETRIC EXTENSIONS OF THE STANDARD MODEL. B. Grzadkowski et al., Phys. Lett. B **198**, 64 (1987).

STRONGLY INTERACTING SINGLET-DOUBLET HIGGS MODEL. A. Hill and J. J. van der Bij, Phys. Rev. D **36**, 3463 (1987).

FACTORIZATION AND ZERO-SLOPE LIMIT OF STRINGS. H. Itoyama, Phys. Rev. D **36**, 480 (1987).

N=2 NO-SCALE SUPERGRAVITY. H. Itoyama et al., Nucl. Phys. **B279**, 380 (1987).

MULTIPARTICLE SUPERSTRING TREE AMPLITUDES. H. Itoyama and P. Moxhay, Nucl. Phys. **B293**, 685 (1987).

SUPERSYMMETRY RESTORATION IN THE COMPACTIFIED $O(16)\otimes O(16)'$ HETEROTIC STRING THEORY. H. Itoyama and T. R. Taylor, Phys. Lett. B **186**, 129 (1987).

LATTICE VIRASORO ALGEBRA AND CORNER TRANSFER MATRICES IN THE BAXTER EIGHT-VERTEX MODEL. H. Itoyama and H. B. Thacker, Phys. Rev. Lett. **58**, 1395 (1987).

PROBES OF THE QUARK-GLUON PLASMA IN HIGH ENERGY COLLISIONS. K. Kajantie and L. McLerran, Ann. Rev. Nucl. Part. Sci. **37**, 293 (1987).

HEAVY-QUARK SYSTEMS. W. Kwong, et al., Ann. Rev. Nucl. Part. Sci. **37**, 325 (1987).

TEST OF COMPOSITENESS: $Z\gamma$ PROCESSES AT THE $\bar{p}p$ TeV COLLIDERS. J. L. Kneur, Phys. Lett. B **194**, 147 (1987).

DECAY OF THE TRUE VACUUM IN CURVED SPACE-TIME. K. Lee and E. J. Weinberg, Phys. Rev. D **36**, 1088 (1987).

TOPOLOGICAL MASS TERMS ON AXION DOMAIN WALL. K. Lee, Phys. Rev. D **35**, 3286 (1987).

TUNNELING WITHOUT BARRIERS IN CURVED SPACE-TIME. K. Lee, Nucl. Phys. **B282**, 509 (1987).

POLARIZATION DENSITY MATRIX FOR HEAVY $Q\overline{Q}$ PRODUCTION IN HADRON COLLIDERS. S.-C. Lee, Phys. Lett. B **189**, 461 (1987).

DUAL AMPLITUDES AND MULTI-GLUON PROCESSES. M. Mangano et al., *Proceedings of Les Rencontres de Physique de la Vallee D'Aoste: "Results and Perspectives in Particle Physics,"* ed. M. Greco, La Thuile, Italy, March 1-7, 1987, (Editions Frontieres, Gif-sur-Yvette, France, 1987), p. 513.

CHIRAL-SYMMETRY ORDER PARAMETER, THE LATTICE, AND NUCLEOSYNTHESIS. L. McLerran, Phys. Rev. D **36**, 3291 (1987).

AN INTRODUCTION TO QUARK-GLUON PLASMA AND HIGH ENERGY HEAVY ION COLLISIONS. L. McLerran, *Proceedings of the Hadronic Session of the Twenty-Second Rencontre de Moriond, Vol. 2, "Hadrons, Quarks and Gluons,"*, March 15-21, 1987, ed. J. Tran Thanh Van (Editions Frontieres, Gif-Sur-Yvette, France, 1987), p. 399.

MAKING A QUARK PLASMA. L. McLerran and B. Svetitsky, Am. Sci. **75**, 490 (1987).

A SIGNATURE OF ISOLATED HARD PHOTONS FROM PHOTINO DECAY AT THE SSC. S. Mikamo and A. Yamashita, *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 278.

MULTILEPTON SIGNAL FROM A NEW Z BOSON AT SSC. S. Nandi, Int. J. Mod. Phys. A **2**, 1161 (1987).

WEAK NEUTRALINO DECAYS OF AN EXTRA Z BOSON. S. Nandi, Phys. Lett. B **197**, 144 (1987).

SUPERSTRING CANDIDATES FOR DARK MATTER. K. Olive, *Proceedings of the Theoretical Workshop on Cosmology and Particle Physics*, ed. I. Hinchliffe, Lawrence Berkeley Laboratory, Berkeley, California, July 28-August 12, 1986, (World Scientific Publishing, Singapore, 1987), p. 133.

ON THE PRESENT MASS DENSITY OF RELIC PHOTINOS. K. Olive et al., *Proceedings of the Theoretical Workshop on Cosmology and Particle Physics*, ed. I. Hinchliffe, Lawrence Berkeley Laboratory, Berkeley, California, July 28-August 12, 1986, (World Scientific Publishing, Singapore, 1987), p. 148.

THE EFFECTS OF RESONANT NEUTRINO OSCILLATIONS ON THE SOLAR NEUTRINO EXPERIMENTS. S. Parke, *Proceedings of the Theoretical Workshop on Cosmology and Particle Physics*, ed. I. Hinchliffe, Lawrence Berkeley Laboratory, Berkeley, California, July 28-August 12, 1986, (World Scientific Publishing, Singapore, 1987), p. 153.

CROSS SECTION FOR HARD PROCESSES INVOLVING TWO QUARKS AND FOUR GLUONS. S. J. Parke and T. R. Taylor, Phys. Rev. D **35**, 313 (1987).

HEAVY AND SMOOTH STRINGS IN QCD. R. D. Pisarski, *Proceedings of the Paris - Meudon Colloquium, 22-26 September, 1986, "String Theory, Quantum Gravity and Quantum Cosmology (Integrable and Conformal Invariant Theories)"*, eds. H. J. de Vega and N. Sanchez (World Scientific Publishing Company, Singapore, 1987), p. 334.

PERTURBATIVE STABILITY OF SMOOTH STRINGS. R. D. Pisarksi, Phys. Rev. Lett. **58**, 1300 (1987).

SPIN DEPENDENT POTENTIAL FOR HEAVY FERMIONS ON THE ENDS OF A STRING. R. D. Pisarksi and J. D. Stack, Nucl. Phys. **B286**, 657 (1987).

TOPOLOGICALLY MASSIVE CHROMODYNAMICS AT FINITE TEMPERATURE. R. D. Pisarski, Phys. Rev. D **35**, 664 (1987).

CRITICAL SURFACES AND FLAT DIRECTIONS IN A FINITE THEORY. E. Rabinovici et al., Phys. Rev. D **36**, 562 (1987).

A NEW APPROACH TO DYNAMIC APERTURE PROBLEMS. J. F. Schonfeld, Part. Accel. **20**, 121 (1986).

COMMENTS ON "BURNING OF BARYON-RICH QUARK-GLUON PLASMAS." D. Seibert, Phys. Rev. D **35**, 1078 (1987).

DYNAMICAL HADRONIZATION TRANSITION AND HYDRODYNAMICAL STABILITY. II. MIXED PHASE. D. Seibert, Phys. Rev. D **35**, 2013 (1987).

PARTIAL-WAVE UNITARITY AND CLOSED-STRING AMPLITUDES. M. Soldate, Phys. Lett. B **186**, 321 (1987).

PARTON DISTRIBUTION FUNCTIONS AND THE QCD IMPROVED PARTON MODEL; AN OVERVIEW. W.-U. Tung, Int. J. Mod. Phys. A **2**, 1369 (1987).

DETECTION OF SUPERSYMMETRIC CHARGED GAUGE BOSON THROUGH ITS LEPTONIC DECAY MODE AT THE SSC. F. Ukegawa et al., *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 276.

NEW BOUND ON THE ANOMALOUS MAGNETIC MOMENT OF THE W BOSON. J. J. van der Bij, Phys. Rev. D **35**, 1088 (1987).

TWO-LOOP CORRECTION TO WEAK-INTERACTION PARAMETERS DUE TO A HEAVY FERMION DOUBLET. J. J. van der Bij and F. Hoogeveen, Nucl. Phys. **B283**, 477 (1987).

Theoretical Astrophysics Publications

THERMODYNAMICS OF HIGHER DIMENSIONAL BLACK HOLES. F. Accetta and M. Gleiser, Ann. Phys. **176**, 278 (1987).

INSTABILITIES OF HIGHER DIMENSIONAL COMPACTIFICATIONS. F. S. Accetta, *Proceedings of the 13th Texas Symposium on Relativistic Astrophysics*, December 14-19, 1986, Chicago, Illinois, ed. M. P. Ulmer, (World Scientific Publishing, Singapore, 1987), p. 74.

INFLATION WITH GENERALIZED INITIAL CONDITIONS. A. Albrecht and R. Brandenberger, Phys. Rev. D **35**, 429 (1987).

COSMIC STRINGS AND COSMIC STRUCTURE. A. Albrecht et al., New Sci. **114**, 40 (1987).

KINEMATIC TESTS OF EXOTIC FLAT COSMOLOGICAL MODELS. J. C. Charlton and M. S. Turner, Astrophys. J. **313**, 495 (1987).

NEUTRINO FAMILIES: THE EARLY UNIVERSE MEETS ELEMENTARY PARTICLE ACCELERATOR PHYSICS. D. B. Cline et al., Comm. Nucl. Part. Phys. **A17**, 145 (1987).

CHAOTIC UNIVERSE DYNAMICS USING A FOKKER-PLANCK EQUATION. D. Coule and K. Olynyk, Mod. Phys. Lett. A **2**, 811 (1987).

AXIONS AND STARS. J. A. Frieman et al., Phys. Rev. D **36**, 2201 (1987).

LEPTONIC AND HADRONIC MASS SCALES - A COSMIC CONNECTION? H. Fritzsch and D. N. Schramm, Comm. Nucl. Part. Phys. A **17**, 129 (1987).

COSMOLOGICAL STABILITY OF QUANTUM COMPACTIFICATION. M. Gleiser, *Proceedings of the 13th Texas Symposium on Relativistic Astrophysics*, December 14-19, 1986, Chicago, Illinois, ed. M. P. Ulmer, (World Scientific Publishing, Singapore, 1987), p. 67.

FIRST ORDER FORMALISM FOR QUANTUM GRAVITY. M. Gleiser et al., Nucl. Phys. **B294**, 1164 (1987).

VACUUM ENERGY OF $M^4 \times S^M \times S^N$ IN EVEN DIMENSIONS. M. Gleiser et al., Phys. Rev. D **36**, 2429 (1987).

SUPERCONDUCTING COSMIC STRINGS WITH MASSIVE FERMIONS. C. T. Hill and L. M. Widrow, Phys. Lett. B **189**, 17 (1987).

VARIATIONAL STUDY OF ORDINARY SUPERCONDUCTING COSMIC STRINGS. C. T. Hill et al., Phys. Rev. Lett. **59**, 2493 (1987).

ULTRA-HIGH-ENERGY COSMIC RAYS FROM SUPERCONDUCTING COSMIC STRINGS. C. T. Hill et al., Phys. Rev. D **36**, 1007 (1987).

PARKER LIMIT FOR MONOPOLES WITH LARGE MAGNETIC CHARGE. H. M. Hodges et al., Phys. Rev. D **35**, 2024 (1987).

THE FATE OF THE M_b/M_r MASS RELATION IN SUPERSTRING THEORIES. R. Holman and D. B. Reiss, Nucl. Phys. **B288**, 152 (1987).

WILSON-LOOP INSTANTON. R. Holman et al., Phys. Rev. Lett. **59**, 1069 (1987).

THE CRITICAL DIMENSION FOR CHAOTIC COSMOLOGY. A. Hosoya et al., Nucl. Phys. **B283**, 657 (1987)

IS INFLATION NATURAL? L. G. Jensen and J. A. Stein-Schabes, Phys. Rev. D **35**, 1146 (1987).

COSMOLOGICAL PHASE TRANSITIONS. E. W. Kolb, *Proceedings of a NATO Advanced Study Institute on Gravitation in Astrophysics, "Gravitation in Astrophysics,"* Cargese, France, July 15-31, 1986, eds. B. Carter and J. B. Hartle, (Plenum Press, New York, 1987), p. 307.

COSMOLOGY AND EXTRA DIMENSIONS. E. W. Kolb, *Cosmology and Particle Physics*, eds. E. Alvare, R. Dominguez Tenreiro, J. M. Ibanez Cabanell, and M. Quiros, (World Scientific Publishing, Singapore, 1987), p. 243.

PARTICLE PHYSICS AND COSMOLOGY. E. W. Kolb, *Proceedings of the Theoretical Advanced Study Institute in Elementary Particle Physics, "From the Planck Scale to the Weak Scale: Toward a Theory of the Universe,"* Santa Cruz, California, June 23 to July 18, 1986, ed. H. E. Haber, (World Scientific Publishing, Singapore, 1987), p. 673.

ELECTROWEAK ANOMALY AND LEPTON ASYMMETRY. E. W. Kolb and M. S. Turner, Mod. Phys. Lett. A **2**, 285 (1987).

SUPERNOVA 1987A AND THE SECRET INTERACTIONS OF NEUTRINOS. E. W. Kolb and M. S. Turner, Phys. Rev. D **36**, 2895 (1987).

HOW RELIABLE ARE NEUTRINO MASS LIMITS DERIVED FROM SN 1987A? E. W. Kolb et al., Phys. Rev. D **35**, 3598 (1987).

GEOMETRICAL PROPERTIES OF AN INTERNAL LOCAL OCTONIONIC SPACE IN CURVED SPACE-TIME. S. Marques and C. G. Oliveria, Phys. Rev. D **36**, 1716 (1987).

CAN BULK VISCOSITY DRIVE INFLATION? T. Pacher et al., Phys. Rev. D **36**, 1603 (1987).

NEUTRINO EMISSION BY THE PAIR, PLASMA, AND PHOTO PROCESSES IN THE WEINBERG-SALAM MODEL. P. J. Schinder et al., Astrophys. J. **313**, 531 (1987).

THE CONSISTENCY PROBLEMS OF LARGE SCALE STRUCTURE. D. N. Schramm, *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 627.

NEUTRINOS FROM SUPERNOVA 1987A. D. N. Schramm, Comm. Nucl. Part. Phys. A **17**, 239 (1987).

NONCOMMUTATIVE-GEOMETRY MODEL FOR CLOSED BOSONIC STRINGS. S. Sen and R. Holman, Phys. Rev. Lett. **58**, 1304 (1987).

DOUBLE INFLATION. J. Silk and M. S. Turner, Phys. Rev. D **35**, 419 (1987).

COSMIC STRING WAKES. A. Stebbins et al., Astrophys. J. **322**, 1 (1987).

INFLATION IN SPHERICALLY SYMMETRIC INHOMOGENEOUS MODELS. J. A. Stein-Schabes, Phys. Rev. D **35**, 2345 (1987).

INFLATION IN TULMAN-BONDI COSMOLOGICAL MODELS. J. Stein-Schabes, *DPF '87: 13th Annual Meeting of the Division of Particles and Fields of the APS, The Salt Lake City Meeting*, eds. C. DeTar and J. Ball, Salt Lake City, Utah, January 14-17, 1987, (World Scientific Publishing, Singapore, 1987), p. 370.

A COSMOLOGIST'S TOUR THROUGH THE NEW PARTICLE ZOO (CANDY SHOP?). M. S. Turner, *Dark Matter in the Universe*, eds. J. Knapp and J. Kormendy, (Riedel, Dordrecht, 1987), p. 445.

COSMOLOGY AND PARTICLE PHYSICS. M. S. Turner, *Proceedings of 1985 Les Houches Summer School in Theoretical Physics, Session 44: Architecture of Fundamental Interactions at Short Distances*, Les Houches, France, July 1-August 8, 1985, eds. P. Ramond and R. Stora (North-Holland, Amsterdam, 1987), p. 513.

EARLY-UNIVERSE THERMAL PRODUCTION OF NOT-SO-INVISIBLE AXIONS. M. S. Turner, Phys. Rev. Lett. **59**, 2489 (1987).

INFLATION IN THE UNIVERSE. M. S. Turner, *Proceedings of the International Workshop on Superstrings, Composite Structures, and Cosmology*, eds. S. J. Gates and R. N. Mohapatra, (World Scientific Publishing Company, Singapore, 1987).

INFLATION IN THE UNIVERSE, CIRCA 1986. M. S. Turner, *Proceedings of the 11th International Conference on General Relativity and Gravitation, Stockholm, July 6-12, 1986, "General Relativity and Gravitation,"* Stockholm, Sweden, July 6-12, 1986, ed. M. A. H. MacCallum, (Cambridge University Press, 1987), p. 223.

WHY SHOULD BARYONS AND EXOTIC RELIC PARTICLES HAVE COMPARABLE DENSITIES? M. S. Turner, Mod. Phys. Lett. A **2**, 1 (1987).

OLD INFLATION AND ANISOTROPY. M. S. Turner and L. M. Widrow, Nature **326**, 206 (1987).

POSSIBLE SIGNIFICANCE OF A NEW DIMENSIONLESS RATIO IN COSMOLOGY. M. S. Turner and B. J. Carr, Mod. Phys. Lett. A **2**, 1 (1987).

TOWARD THE INFLATIONARY PARADIGM: LECTURES ON INFLATIONARY COSMOLOGY. M. S. Turner, Acta Phys. Pol. B **18**, 813 (1987).

NEUTRINO COUNTING WITH THE SUPERNOVA AND THE BIG BANG. D. N. Schramm, *Proceedings of the Leptonic Session of the Twenty-Second Rencontre de Moriond, Vol. 1, "The Standard Model - The Supernova 1987A,"* ed. J. Tran Thanh Van (Editions Frontieres, Gif-Sur-Yvette, France, 1987), p. 125.

STARS OF BOSONS WITH NON-MINIMAL ENERGY-MOMENTUM TENSOR. J. J. van der Bij and M. Gleiser, Phys. Lett. B **194**, 482 (1987).

THE LARGE-SCALE PECULIAR VELOCITY FIELD IN FLAT MODELS OF THE UNIVERSE. N. Vittorio and M. Turner, Astrophys. J. **316**, 475 1987).

RESONANT NEUTRINO OSCILLATIONS AND THE NEUTRINO SIGNATURE OF SUPERNOVAE. T. P. Walker and D. N. Schramm, Phys. Lett. B **195**, 331 (1987).

General Publications

DETECTING W/Z PAIRS AND HIGGS AT HIGH ENERGY PP COLLIDERS: MAIN EXPERIMENTAL ISSUES. G. Alverson et al. *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 114.

EXPERIMENTAL SEARCH FOR W/Z PAIRS AND HIGGS BOSONS AT VERY HIGH ENERGIES. G. Alverson et al., *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 93.

LIQUID IONIZATION CHAMBERS WITH ELECTRON EXTRACTION AND MULTIPLICATION IN THE GASEOUS PHASE. D. F. Anderson et al., Nucl. Instrum. Methods **A261**, 445 (1987).

THE IMPORTANCE OF SURFACE TREATMENT ON THE AMOUNT OF LIGHT DETECTED FROM BaF_2. D. F. Anderson and D. C. Lamb, Nucl. Instrum Methods **A260**, 377 (1987).

HIGH RATE OPERATION OF WARM-LIQUID IONIZATION CHAMBERS. D. F. Anderson and R. A. Holroyd, Nucl. Instrum. Methods **A260**, 343 (1987).

A MEASUREMENT OF THE INCLUSIVE π^0 and η PRODUCTION CROSS SECTIONS AT HIGH p_T IN $\bar{p}p$ AND pp COLLISIONS AT $\sqrt{s} = 24.3$ GEV. J. Antille et al., Phys. Lett. B **194**, 568 (1987)

WIRE CHAMBER AGING AND WIRE MATERIAL. M. Atac, IEEE Trans. Nucl. Sci. **34**, p. 476 (1987).

RADIATION DAMAGE EFFECTS IN CHANNELING APPLICATIONS. S. Baker, *Relativistic Channeling,* eds. R. A. Carrigan, Jr., and J. A. Ellison, (Plenum Press, New York), p. 391 (1987).

SOFTWARE FOR THE FERMILAB SMART CRATE CONTROLLER. M. Bernett et al., IEEE Trans. Nucl. Sci. **34**, p. 1047 (1987).

SOFTWARE FOR THE ACP MULTIPROCESSOR SYSTEM. J. Biel et al., Comput. Phys. Commun., p. 45 (1987).

OBSERVATION OF A NEUTRINO BURST IN COINCIDENCE WITH SUPERNOVA 1987A IN THE LARGE MAGELLANIC CLOUD. R. M. Bionta et al., Phys. Rev. Lett **58**, 1494 (1987).

UNDERGROUND SEARCH FOR MUONS CORRELATED WITH CYGNUS X-3. R. M. Bionta et al., Phys. Rev. D **36**, 30 (1987).

GENERALIZING THE SSC DECISION. J. D. Bjorken, Physics Today, **40**, p. 136 (1987).

A TECHNIQUE TO PRODUCE COHERENT X-RAY RADIATION VIA LASER PUMPING OF A RELATIVISTIC ION BEAM. S. A. Bogacz and J. B. Ketterson, Nucl. Instrum. Methods **B22**, 40 (1987).

NONLINEAR SATURATION OF THE LONGITUDINAL MODES OF THE COASTING BEAM IN A STORAGE RING. S. A. Bogacz and K.-Y. Ng, Phys. Rev. D **36**, 1538 (1987).

THE CONTROL SYSTEM FOR THE FERMILAB ACCELERATORS. D. Bogert, *Proceedings of the XIII International Conference on High Energy Accelerators*, Novosibirsk, U.S.S.R., August 7-11, 1986, ed. A. N. Skrinsky (Novosibirsk Publishing, Siberian Division, 1987), Vol. 2, p. 198.

AN INVESTIGATION INTO THE USE OF "EXPERT SYSTEMS" FOR SYSTEM-WIDE DIAGNOSTICS. A. W. Booth and J. T. Carroll, IEEE Trans. Nucl. Sci. **34**, p. 151 (1987).

IDENTIFICATION OF ELECTRONS AT THE SSC. G. Brandenburg et al., *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 420.

REAL TIME CONTROL OF THE SSC STRING MAGNETS. O. Calvo et al., IEEE Trans. Nucl. Sci. **34**, p. 760 (1987).

SSC MUON DETECTOR GROUP REPORT. D. Carlsmith et al., *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 405.

THE APPLICATION OF CHANNELING IN BENT CRYSTALS TO CHARGED PARTICLE BEAMS. R. A. Carrigan, Jr., *Relativistic Channeling*, eds. R. A. Carrigan, Jr., and J. A. Ellison (Plenum Press, New York, 1987), p. 339.

CRYSTAL SEPTA FOR SLOW PARASITIC EXTRAPOLATION, AN UPDATE. R. A. Carrigan et al., *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 752.

A TECHNIQUE FOR EPOXY FREE WINDING AND ASSEMBLY OF COS θ COILS FOR ACCELERATOR MAGNETS. J. A. Carson and R. Bossert, IEEE Trans. Magn. **23**, p. 1244 (1987).

ELECTROSTATIC IMAGING OF CHARGES LIBERATED IN DIELECTRIC LIQUIDS BY IONIZING RADIATION. G. Charpak et al., Nucl. Instrum. Methods **A260**, 365 (1987).

A WAVESHIFTER LIGHT COLLECTOR FOR A WATER CHERENKOV DETECTOR. R. Claus et al., Nucl. Instrum. Methods **A261**, 540 (1987).

TUNABLE TWO FREQUENCY FREE ELECTRON LASER USING A PELLETRON AS A DRIVER FOR A PLASMA BEATWAVE ACCELERATOR. D. B. Cline et al., Nucl. Instrum. Methods **A259**, 275 (1987).

EXTERNAL NEUTRON BEAM THERAPY. L. Cohen and F. R. Hendrickson, Illinois Medical Journal **171**, p. 231 (1987).

OBITUARY OF STAN LIVINGSTON. F. T. Cole, Part. Accel. **21**, 3 (1987).

SUMMARY REPORT OF THE IR WORKING GROUP. E. D. Courant et al., *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 503.

THE J/ψ TRIGGER-TAG FOR STUDY OF WEAK BEAUTY QUARK DECAYS AT THE SSC. B. Cox and D. E. Wagoner, *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 83.

HEAVY FLAVORS. B. Cox and A. Soni, Int. J. Mod. Phys. A **2**, 1221 (1987).

THREE-DIMENSIONAL SEISMIC SUPER-ATTENUATOR FOR LOW FREQUENCY GRAVITATIONAL WAVE DETECTOR. R. Del Fabbro et al., Phys. Lett. A **124**, 253 (1987).

LIMITS ON THE ABUNDANCE AND COUPLING OF COSMIC AXIONS AT $4.5 < m_a < 5.0$ μeV. S. DePanfilis et al., Phys. Rev. Lett. **59**, 839 (1987).

LIST PROCESSING SOFTWARE FOR THE LECROY 1821 SEGMENT MANAGER INTERFACE. T. Dorries et al., IEEE Trans. Nucl. Sci. **34**, p. 1000 (1987).

VMS SOFTWARE FOR THE JORWAY-411 INTERFACE. T. Dorries et al., IEEE Trans. Nucl. Sci. **34**, p. 945 (1987).

PBAR PRODUCTION AND COLLECTION AT THE FNAL ANTIPROTON SOURCE. G. Dugan, *Proceedings of the XIII International Conference on High Energy Accelerators*, Novosibirsk, U.S.S.R., August 7-11, 1986, ed. A. N. Skrinsky (Novosibirsk Publishing, Siberian Division, 1987), Vol. 2, p. 265.

THE FERMILAB TEVATRON AND PBAR SOURCE STATUS REPORT. H. Edwards, *Proceedings of the XIII International Conference on High Energy Accelerators*, Novosibirsk, U.S.S.R., August 7-11, 1986, ed. A. N. Skrinsky (Novosibirsk Publishing, Siberian Division, 1987), Vol. 2, p. 20.

QCD JET BROADENING IN HADRON-HADRON COLLISIONS. R. K. Ellis and B. R. Webber, *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 74.

SUPERCONDUCTING MAGNETS. H. E. Fisk, *Proceedings of the XIII International Conference on High Energy Accelerators*, Novosibirsk, U.S.S.R., August 7-11, 1986, ed. A. N. Skrinsky (Novosibirsk Publishing, Siberian Division, 1987), Vol. 2, p. 15.

A SHORT REVIEW OF THE CDF ELECTROMAGNETIC AND HADRONIC SHOWER SIMULATION. J. Freeman and A. Beretvas, *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 482.

e/π SEPARATION IN THE CDF END PLUG EM AND HADRON CALORIMETERS. Y. Fukui et al., *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 417.

USE OF NEW COMPUTER TECHNOLOGIES IN ELEMENTARY PARTICLE PHYSICS. I. Gaines and T. Nash, Ann. Rev. Nucl. Part. Phys. **37**, 177 (1987).

THE ACP MULTIPROCESSOR SYSTEM AT FERMILAB. I. Gaines et al., Comput. Phys. Commun. p 45 (1987).

ACCURATE 2 DIMENSIONAL DRIFT TUBE READOUT USING TIME DIVISION AND VERNIER PADS. D. Green, et al., Nucl. Instrum. Methods **A256**, 305 (1987).

ASTROMAG: A SUPERCONDUCTING PARTICLE ASTROPHYSICS MAGNET FACILITY FOR THE SPACE STATION. M. A. Green et al., IEEE Trans. Magn. **23**, p. 1240 (1987).

THE ACP BRANCH BUS AND REAL TIME APPLICATIONS OF THE ACP MULTIPROCESSOR SYSTEM. R. Hance et al., IEEE Trans. Nucl. Sci. **34**, p. 878 (1987).

FERMILAB SMART CAMAC CONTROLLER. S. Hansen et al., IEEE Trans. Nucl. Sci. **34**, p. 1003 (1987).

A MULTIPLE NODE SOFTWARE DEVELOPMENT ENVIRONMENT. P. Heinicke et al., IEEE Trans. Nucl. Sci. **34**, p. 884 (1987).

PRINCIPLES AND CLINICAL RESULTS OF NEUTRON THERAPY OF THE HEAD AND NECK. F. R. Hendrickson et al., *Head and Neck Cancer: Scientific Perspectives in Management and Strategies for Cure*, (Elsevier Science Publishing Co., Inc., 1987), p. 303.

NULLJOB PRODUCT. N. Hughart and D. Ritchie, IEEE Trans. Nucl. Sci. **34**, p. 914 (1987).

HERMETICITY STUDIES IN SSC TYPE CALORIMETERS. H. Iwasaki et al., *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 371.

HIGH-LUMINOSITY INSERTION SCALING. D. E. Johnson, *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 519.

A POSSIBLE BEAM BYPASS FOR THE SSC CLUSTERED IR REGION. D. E. Johnson, *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 515.

HARDWARE PROCESSOR FOR TRACKING PARTICLES IN AN ALTERNATING-GRADIENT SYNCHROTRON. M. Johnson and C. Avilez, Part. Accel. **22**, 231 (1987).

A PRECISE FORMULATION OF THE EFFECTIVE-VECTOR-BOSON METHOD FOR HIGH ENERGY COLLISIONS. P. W. Johnson et al, *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 164.

PRODUCING AND SUPPORTING SHARABLE SOFTWARE. H. Johnstad and J. Nicholls, Comput. Phys. Commun. **45**, p 473 (1987).

TEST BEAMS FROM THE HEB. T. Kirk, *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 526.

TRANSVERSE QUENCH PROPAGATION MEASUREMENT. M. Kuchnir et al., IEEE Trans. Magn. **23**, p. 503 (1987).

FAST NEUTRON THERAPY FOR MALIGNANT ASTROCYTOMAS, A REVIEW. P. D. Kurup et al., Journal of Neuro-Oncology **4**, p. 123, (1986).

GIVE UNITED STATES FELLOWSHIPS TO LATIN AMERICANS. L. M. Lederman, Scientist, **V1**, N24, 1987.

A "ONE LAB" SSC CONFIGURATION. L. M. Lederman, *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 83.

THE SSC DESERVES BETTER CRITICISM. L. M. Lederman, Scientist, **V1**, N20, 1987.

THE TEVATRON. L. M. Lederman, *Year Book of Science and Technology*, (McGraw Hill, New York), 1987.

STOCHASTIC COOLING AT FERMILAB. J. Marriner, *Proceedings of the XIII International Conference on High Energy Accelerators*, Novosibirsk, U.S.S.R., August 7-11, 1986, ed. A. N. Skrinsky, (Novosibirsk Publishing, Siberian Division, 1987), Vol. 2, p. 323.

STATUS OF THE TEVATRON I COLLIDER. P. S. Martin, *DPF '87: 13th Annual Meeting of the Division of Particles and Fields of the APS, The Salt Lake City Meeting*, eds. C. DeTar and J. Ball, (World Scientific Publishing, Singapore, 1987), p. 605.

THE 5cm APERTURE DIPOLE STUDIES. A. D. McInturff et al., IEEE Trans. Magn. **23**, p. 528 (1987).

COOLED ION BEAMS FOR PHYSICS EXPERIMENTS. F. E. Mills, Nucl. Instrum. Methods **B24/25**, 38 (1987).

STATUS OF (U.S.) HIGH-ENERGY PHYSICS NETWORKING. H. E. Montgomery, Comput. Phys. Commun., p. 45 (1987).

A SPACE-TIME ANALYSIS OF MUO-PRODUCED HADRONIC SHOWERS. J. G. Morfin, *Proceedings of the Workshop on Electronuclear Physics with Internal Targets*, Stanford Linear Accelerator Center, Stanford, California, January 5-8, 1987, eds. R. G. Arnold and R. C. Minehart, (Stanford Linear Accelerator Center, 1987), p. 18.

ASILOMAR CONFERENCE ON MANAGING COMPLEXITY IN HIGH-ENERGY PHYSICS; A SUMMARY AND RENAMING OF THE CONFERENCE. T. Nash, Asilomar Computing H.E. Phys. 1987, p. 9 (1987).

COMMENTS ON THE IMPEDANCES OF THE SSC SHIELDED BELLOWS AT LOW FREQUENCIES DUE TO THE TRUNCATION OF THE WAKE POTENTIALS. K.-Y. Ng, *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 592.

IMPEDANCES OF CORRUGATED BEAM PIPE IN THE SSC INTERACTION REGIONS. K.-Y. Ng, *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 596.

MICROWAVE INSTABILITY LIMITS WHEN DRIVEN BY NARROW RESONANCES. K.-Y. Ng, *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 590.

REPORT OF TEST BEAM SUBGROUP. L. Nodulman et al., *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 523.

THE STATUS OF THE TEVATRON COLLIDER. J. Peoples, *Proceedings of the 6th International Conference on Physics in Collisions, "Physics in Collisions 6,"* September 3-5, 1986, Chicago, Illinois, ed. M. Derrick, (World Scientific Publishing Company, Singapore, 1987), p. 493.

A MULTI-PROCESS USER INTERFACE. D. Petravick et al., IEEE Trans. Nucl. Sci. **34**, p. 937 (1987).

REVIEW OF THE STATUS OF THE FASTBUS STANDARD ROUTINE SPECIFICATION. R. Pordes, IEEE Trans. Nucl. Sci. **34**, p. 162 (1987).

CHARACTERISTICS OF INELASTIC INTERACTIONS OF HIGH ENERGY HADRONS WITH ATOMIC ELECTRONS. S. Qian and A. Van Ginneken, Nucl. Instrum. Methods **A256**, 285 (1987).

PERSONAL COMPUTERS IN HIGH ENERGY PHYSICS. D. R. Quarrie, Comp. Phys. Comm. **45**, 175 (1987).

SEARCH FOR SHORT-LIVED AXIONS IN AN ELECTRON-BEAM-DUMP EXPERIMENT. E. M. Riordan, et al., Phys. Rev. Lett. **59**, 755 (1987).

NEW SCINTILLATING GLASSES FOR HIGH-ENERGY PHYSICS APPLICATIONS. A. Rogers, et al., IEEE Trans. Nucl. Sci. **34**, p. 541 (1987).

AN UPDATE ON MALIGNANT SALIVARY GLAND TUMORS TREATED WITH NEUTRONS AT FERMILAB. K. R. Saroja et al., Int. J. Radiat. Oncol. Biol. Phys. **13**, p. 1319 (1987).

FULL LENGTH PROTOTYPE SSC DIPOLE TEST RESULTS. J. Strait et al., IEEE Trans. Magn. **23**, p. 1208 (1987).

AN IMPROVED 8 GeV BEAM TRANSPORT SYSTEM FOR THE FERMI NATIONAL ACCELERATOR LABORATORY. M. J. Syphers, Ph.D. Thesis, University of Illinois at Chicago, Chicago, Illinois, April 23, 1987.

DOSE TO RADIOTHERAPY TECHNOLOGISTS FROM ACTIVATION OF PATIENTS AT A FAST NEUTRON THERAPY FACILITY. M. Tatcher et al., Health Phys. **53**, 311 (1987).

4π DETECTORS. D. Theriot et al., *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 351.

PARTON LUMINOSITIES AND SMALL X PHYSICS. W.-K. Tung, *Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider*, June 23-July 11, 1986, Snowmass, Colorado, eds. R. Donaldson and J. Marx, (1987), p. 70.

FERMILAB FAST PARALLEL READOUT SYSTEM FOR DATA ACQUISITION. R. Vignoni et al., IEEE Trans. Nucl. Sci. **34**, p. 756 (1987).

THE VAXONLINE SOFTWARE SYSTEM AT FERMILAB. V. White et al., IEEE Trans. Nucl. Sci. **34**, p. 763 (1987).

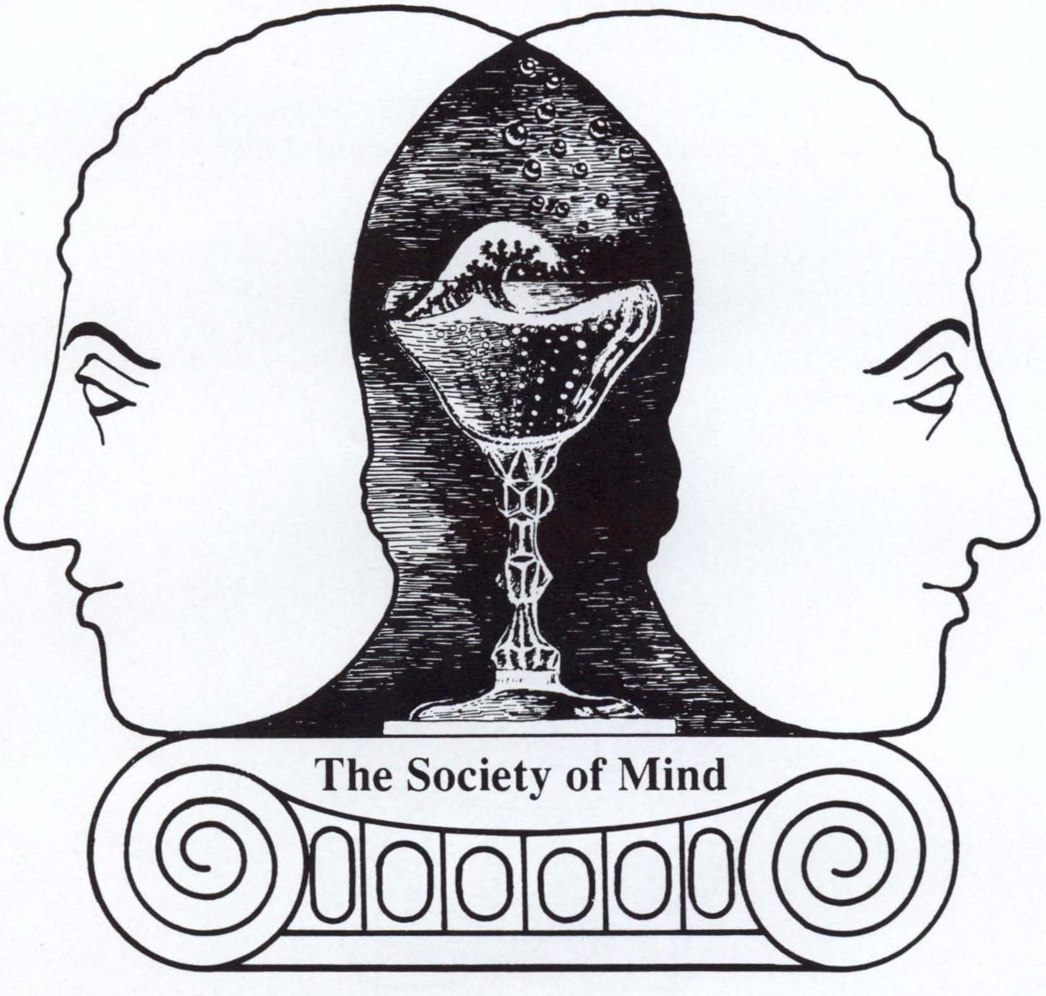
FERMILAB

Special Colloquium

Marvin Minsky

MIT

Professor Minsky is a founder and seminal thinker in the field of artificial intelligence



Fermi National Accelerator Laboratory
Ramsey Auditorium
Friday*, February 13, 1987, 4:00 p.m.

***Note Special Day!**

Appendix C
1987 Colloquia, Seminars, and Workshops

Fermilab Colloquia

J. Audouze, Institut d'Astrophysique, Paris: "Early Nucleosynthesis and Particle Physics," January 7.

P. G. Marston, Massachusetts Institute of Technology Plasma Fusion Center: "The Crisis in Public Education and Effective Individual Initiatives," January 14.

R. Wilson, Mallinckrodt Professor of Physics, Harvard University: "Reactor Safety and the Chernobyl Accident," January 21.

R. M. Tromp, IBM Thomas J. Watson Research Center: "Electron States, Surface Structure, and the Scanning Tunneling Microscope," February 4.

J. L. Rosner, Enrico Fermi Institute and the University of Chicago: "Fundamental Particle Physics Without Accelerators," February 11.

N. Turok, Imperial College of Science and Technology, London: "Cosmic Strings," February 25.

H. Georgi, Harvard University: "Effective Field Theories," March 4.

C. Kisslinger, Professor of Geological Sciences, University of Colorado: "Earthquake Physics and Prediction," March 11.

V. L. Teplitz, U.S. Arms Control and Disarmament Agency: "Bilateral Strategic Arms Control," March 18.

H. J. Kimble, University of Texas, Austin: "Squeezing Light," March 25.

M. Goitein, Massachusetts General Hospital: "Cancer Therapy with Proton Beams," April 8.

D. Black, Chief Scientist, U.S. Space Station, National Aeronautics and Space Administration (NASA): "The Search for Other Planetary Systems," April 22.

D. C. Larbalestier, Applied Superconductivity Center and Department of Metallurgical Engineering, University of Wisconsin-Madison: "Hot, New Superconductors: Layered Perovskite Oxides," April 29.

K. Sliwa, Fermilab: "Decays of Charmed Particles," May 6.

J. T. Seeman, Stanford Linear Accelerator Center (SLAC): "Accelerator and Collider Issues of the Stanford Linear Collider (SLC)," May 13.

T. Bowles, Los Alamos National Laboratory (LANL): "Review of Neutrino Mass Measurements," May 20.

J. D. Sulivan, Professor of Physics and Director, Program in Arms Control, Disarmament, and International Security, University of Illinois at Urbana-Champaign: "Science and Technology of Directed Energy Weapons: Report of the APS Study Group," May 27.

J. Bahcall, Institute for Advanced Study: "Solar Neutrinos," October 28.

A. D. Linde, Lebedev Physical Institute, Moscow: "The Self-Reproducing Universe," November 4.

D. Richstone, University of Michigan: "Search for Massive Black Holes in Nearby Galaxies," November 11.

D. Arnett, University of Chicago: "Supernova 1987A," November 18.

H. Gutbrod, GSI and CERN: "Recent Results from the Heavy Ion Program at CERN and BNL," December 2.

P. Boynton, University of Washington: "Experimental Search for a 5th Force," December 16.

Special Fermilab Colloquia

D. Gross, Princeton University: "The Heterotic String - The Theory of Everything," March 17.

Special Colloquia

J. Ellis, CERN: "Is There Life After LEP?" March 23.

C. J. Pellerin, Jr., Director, Astrophysics Division, NASA: "Great Observations for Space Astrophysics," April 1.

Joint Experimental-Theoretical Physics Seminars

F. S. Merritt, University of Chicago/CCFR Collaboration: "Measurement of Same-Sign Dimuon Production in the TEVATRON Neutrino Beam," January 9.

M. Woods, University of Chicago: "First Results from E-731: A Measurement of ϵ'/ϵ," January 16.

M. Albrow, Rutherford Laboratory: "Have We Found the Lightest Scalar Glueball?" January 23.

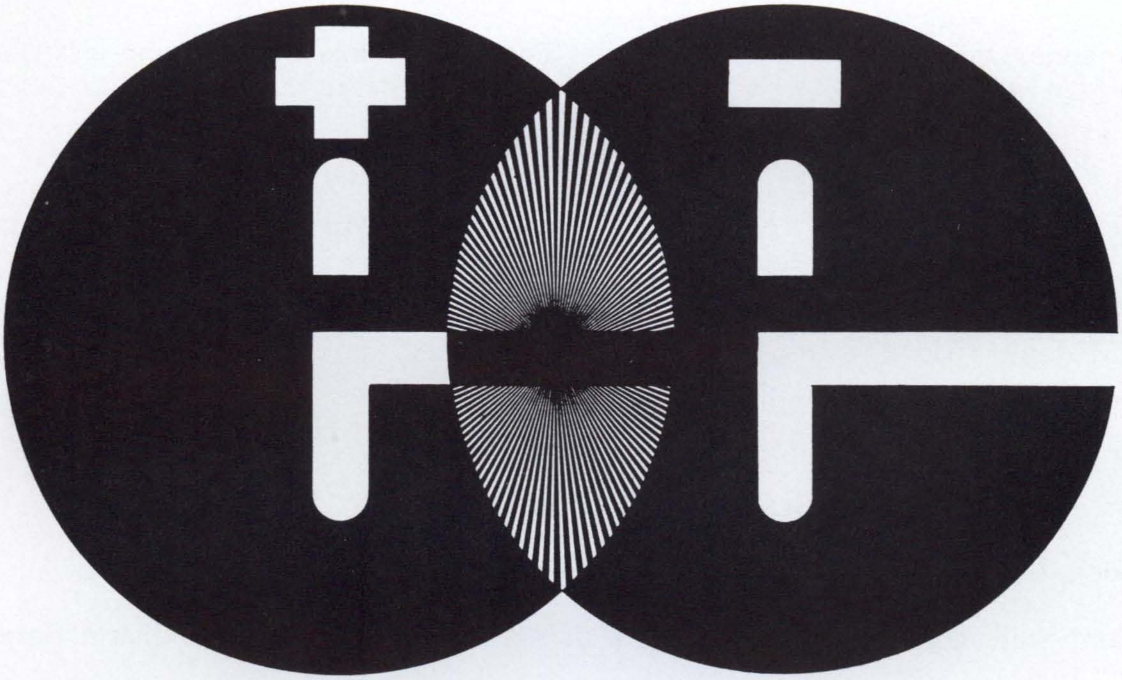
M. Sokoloff, Fermilab: "An Experimental Study of the A-Dependence of J/ψ Photoproduction (E-691)," January 30.

M. Tuts, Columbia University: "Upsilon Physics with the CUSB II Detector," February 6.

Joint Experimental and Theoretical Physics Seminar

Sau Lan Wu

University of Wisconsin



New Results from e^+e^- Interactions at High Energy

Fermi National Accelerator Laboratory
Wilson Hall
Friday, August 21, 1987, 4:00 p.m.

Wine and cheese will be served at 3:45 p.m.

R. Handler, University of Wisconsin-Madison: "A High Statistics Study of Lambda B-Decay (E-361)," February 13.

R. Handler, University of Wisconsin-Madison: A High-Statistics Study of Lambda β-Decay (E-361)," February 20.

P. Border, University of Michigan: "The Measurement of n_{+-o} in E-621," February 27.

Y. Arai, KEK: "The Present Status of TRISTAN Experiments," March 6.

P. Kooijman, Argonne National Laboratory (ANL): "Evidence for the Decay $\tau \rightarrow \pi\eta\upsilon$," March 13.

F. Avignone, University of South Carolina: "Possible Evidence of Neutrino-less Double β Decay . . ." March 20.

J. Ellis, CERN: "Superstring Phenomenology," March 27.

D. Macfarlane, University of Toronto: "Evidence for B_d-$\overline{B}_d$ Mixing from ARGUS," April 3.

D. Summers, Fermilab: "Beauty Production and Evidence for B^0-$\overline{B}^0$ Mixing at UA1," April 10.

S. Nurushev, Institute of High Energy Physics, Serpukhov: "Polarization Measurements at Serpukhov," April 24.

J. Wiss, University of Illinois: "Recent Results from E-400," May 22.

A. Bodek, University of Rochester: "Precision Measurement of σ_L/σ_T," June 5.

S. Alam, State University of New York at Albany: "Production of Charm Baryons at CESR," June 12.

J. Raab, University of California, Santa Barbara: "Measurements of D Lifetimes and D_s^+ Decays by E-691," June 26.

S. L. Wu, University of Wisconsin: "New Results from e^+e^- Interactions at High Energy," August 21.

J. P. Revol, Massachusetts Institute of Technology: "The Study of Heavy Flavors at UA1," August 29.

T. Nakada, Swiss Institute of Nuclear Research, Villigen, Switzerland: "The Proposed SIN B-Factory," September 11.

Z. Kunszt, Fermilab/Eidgenossische Technische Hochschule, Zurich, Switzerland: "Multi-Jet Production at Hadron Colliders," September 25.

C. Brown, G. Dugan, H. Montgomery, J. Spalding, and R. Stefanski, Fermilab: "Report From the Conferences at Hamburg and Stanford," October 2.

V. Hughes, Yale University: "The Muon Anomalous Magnetic Moment," October 9.

S. Stone, Cornell University: "Experimental Status of the K-M Matrix," October 16.

A. Bodek, University of Rochester: "Results from AMY at the Tristan e^+e^- Storage Ring," October 23.

P. Schuler, Yale University: "The Measurement of the Spin Dependent Structure Function in Muon Scattering by the EMC Collaboration," October 30.

P. Cooper, Yale University: "Search for Non-Conservation of Lepton Number $K^+ \rightarrow \pi^+ \mu^+ e^-$," November 20.

K. Ellis, Fermilab: "Production of Top and Bottom Quarks at Collider Energies," December 4.

T. Browder, University of California, Santa Barbara: "D-D Mixing and Doubly Suppresed Cabibbo Decays from E-691," December 11.

M. Chanowitz, Lawrence Berkeley Laboratory (LBL): "Probing Electroweak Symmetry Breaking at the SSC," December 18.

Special Joint Experimental-Theoretical Physics Seminar

H. Albrecht, DESY: "Observation of Charmless B-Meson Decays," August 27.

Theoretical Physics Seminars

A. Gocksch, University of California, San Diego: "Finite Temperature Phase Transition in Lattice QCD," January 15.

R. Gupta, LANL: "Status Report of Lattice QCD from the Los Alamos Group," January 22.

M. Bowick, Massachusetts Institute of Technology: "String Theory as the Geometry of Loop Space," January 29.

U. Heller, ITP/Santa Barbara: "Fundamental SU(2) Higgs Model at Finite Temperature," February 5.

H. Kawai, Cornell University: "Construction of Four Dimensional Strings," February 12.

J. Hartle, University of California, Santa Barbara: "Prediction in Quantum Cosmology," February 16.

K. Pohlmeyer, Freiburg University: "Invariant Charges of the Nambu-Goto String," February 19.

E. Martinec, University of Chicago: "Renormalization Group Approach to String Theory," February 26.

F. Grassi, Fermilab: "Phenomenological Quark Matter Equations of State," March 2.

R. Akhoury, University of Michigan: "String Unitarity in Background Fields," March 5.

C. Vafa, Harvard University: "Topics in Orbifold Compactification," March 12.

J. Ellis, CERN: "Strings in Four Dimensions," March 26.

A. Masiero, New York University: "Low-Energy Tests of Supersymmetry," April 2.

L. Donlan, Rockefeller University: "Compactification of Type II Superstrings," April 9.

D. Nanopoulos, University of Wisconsin: "Low-Energy Physics and Superstrings," April 23.

C. Thorn, Institute for Advanced Study and University of Florida: "Closed from Open String Field Theory," May 21.

A. Sen, SLAC: "Fayet-Iliopoulos D-Terms in String Theory," May 28.

M. Stone, University of Illinois, Urbana-Champaign: "Superconductivity and the Schwinger Model," June 4.

S. Parke, Fermilab: "Duality and Multi-Gluon Scattering," June 18.

A. Billoire, Saclay: "Lattice Glueballs," July 2.

S. Nandi, Oklahoma State University: "Phenomenology of an Extra Z Boson," July 23.

S. Pokorski, Warsaw University: "Strongly Coupled Charged Scalars in b and t Decays," August 6.

A. Bartl, University of Vienna, Austria: "Production of Supersymmetric Particles in e^+ - e^- Annihilation," August 13.

E. Onofri, Trento University, Trento, Italy: "Computing Feynman Path Inegrals in Real Time," August 20.

Z. Kunszt, Zurich: "Heavy Higgs Production and the Effective W Approximation," September 17.

D. Zeppenfeld, University of Wisconsin, Madison: "Probing the ZWW Vertex at a Hadron Collider," September 24.

M. Mattis, University of Chicago: "A Distorted View of High-T_c Superconductivity," October 1.

T. Taylor, Fermilab: "Orbifolds Without Supersymmetry," October 8.

B. Peterson, Bielefeld University, Germany: "Recent Results in Finite Temperature QCD," October 15.

M. Lindner, Fermilab: "Nonlinear Evolution of Yukawa Coupling Matrices," October 22.

S. Dimopoulos, Stanford University: "MeV Baryogenesis," October 29.

S. Rudaz, University of Minnesota: "What Recent Measurements of B_0 Mixing and e'/e Tell Us," November 5.

S. Rajeev, University of Rochester: "Matrix Model for Gauge Theory," November 19.

L. Yaffe, Princeton University: "Classical Solutions in the Weak Interactions," December 3.

S. Willenbrock, University of Wisconsin-Madison: "Radiative Corrections to Heavy Higgs Production," December 17.

Special Theoretical Physics Seminars

P. van Baal, State University of New York at Stony Brook: "QCD on a Torus and Its Connection to the Lattice," January 20.

A. A. Anselm, Leningrad Nuclear Physics Institute: "SUSY GUT with Automatic Hierarchy," February 18.

N. Marcus, University of California, Berkeley: "Group Theory of Open Strings," February 24.

H. Georgi, Harvard University: "GIM Mechanism for Technicolor," March 4.

S. Sen, Trinity College, Dublin: "An Application of Seeley's in 2 Dimensions," March 10.

D. Gross, Princeton University: "Topics in String Theory I," March 18.

D. Gross, Princeton University: "Topics in String Theory II," March 19.

D. Toussaint, University of California, San Diego: "Chiral Symmetry Breaking with Two Species of Staggered Fermions," March 24.

B. Grossman, Rockefeller University: "P-adic Approximations in Physics," September 8.

A. Donnachie, University of Manchester, England: "Hard Diffraction and the Pomeron," October 13.

Special Colloquium

Dr. Charles J. Pellerin, Jr.

Director, Astrophysics Division
National Aeronautics and Space Administration

Great Observatories for Space Astrophysics

Fermi National Accelerator Laboratory
Ramsey Auditorium
Wednesday, April 1, 1987, 4:00 p.m.

J. Harvey, Princeton University: "String Compactification and Quasi-Crystals," November 6.

Y. Khodjamirian, Yerevan Physics Institute, Armenia, U. S. S. R.: "QCD Sum Rules for Quarkonium Radiative Decays," December 1.

Theoretical Astrophysics Seminars

M. Mijic, California Institute of Technology: "Quantum Cosmology and Chaotic Inflation," January 5.

W. M. Suen, University of Florida, Gainesville: "Why Was the Universe So Hot?" January 19.

M. Ruiz-Altaba, University of Florida: "Supersymmetric Inflationary Cosmology," January 26.

S. Blau, University of Texas: "The Dynamics of False Vacuum Bubbles," February 2.

D. Spergel, Institute for Advanced Study: "Superconducting Cosmic Strings," February 9.

J. Hartle, University of California, Santa Barbara: "Prediction in Quantum Cosmology," February 16.

P. Laguna, University of Texas, Austin: "Cosmological Applications of Singular Layers in General Relativity," February 23.

P. Mazur, University of Syracuse: "Gravitational Scattering from Spinning Cosmic Strings," March 9.

M. Gleiser, Fermilab: "Boson Stars (?)," March 30.

G. Fuller, LANL: "The Quark Hadron Phase Transition and Primordial Nucleosynthesis," April 6.

N. Neto, CBPF, Brazil/Fermilab: "First Order Formalism for Quantum Gravity," April 27.

J. Faulkner, University of California, Santa Cruz: "WIMPS, Solar Neutrinos, and Solar Oscillations," May 18.

R. Myers, Institute of Theoretical Physics, Santa Barbara: "Black Holes in String Theories," June 1.

T. Vachaspati, Bartol Research Institute: "Gravity of Cosmic Loops," June 8.

L. Cowie, University of Hawaii: "Searching for Forming Galaxies, Strings, and Other Cosmological Signposts," September 14.

S. Veeraraghavan, University of California, Berkeley: "Large Scale Gravitational Fields of Cosmic Strings," September 21.

J. Frieman, Stanford University: "New Topological Dark Matter Candidates," October 12.

B. Jantzen, Villanova University: "What Time Is It? (In Cosmological Dynamics)," October 19.

F. Bouchet, LBL/University of California, Berkeley: "Simulations of the Evolution of a Cosmic String Network," October 26.

A. D. Linde, Lebedev Physical Institute, Moscow: "Initial Conditions for Inflation," November 2.

K. Maeda, University of Tokyo: "The Use of Conformal Transformation into the Einstein-Hilbert Action," November 9.

M. Gleiser, Fermilab: "Generalities on Non-Topological Solitons," November 16.

C. Thompson, Princeton University: "Cosmological Effects of Superconducting Cosmic Strings," November 23.

S. Raby, LANL: "Particle Physics Candidates for the Wimp/Cosmyon Solution to the Solar Neutrino Problem," November 30.

A. Szalay, Eötvös University/Johns Hopkins University: "General Aspects of Biased Galaxy Formation," December 7.

E. Bertschinger, Massachusetts Institute of Technology: "Monte Carlo Simulations of Large-Scale Streaming Velocities," December 14.

Special Theoretical Astrophysics Seminars

J. Primack, University of California, Santa Cruz: "Can Cold Dark Matter Be Reconciled with Cluster Correlations and Supercluster Drift?" February 13.

J. Goodman, University of Maryland: "New and Preliminary Results on Hercules X-1 and Cygnus X-3," April 21.

A Special Performance by the Theoretical Astrophysics Group
- Supernova Shuffle -

E. Kolb, Fermilab: "Overview of Type I and Type II Supernova," April 20.

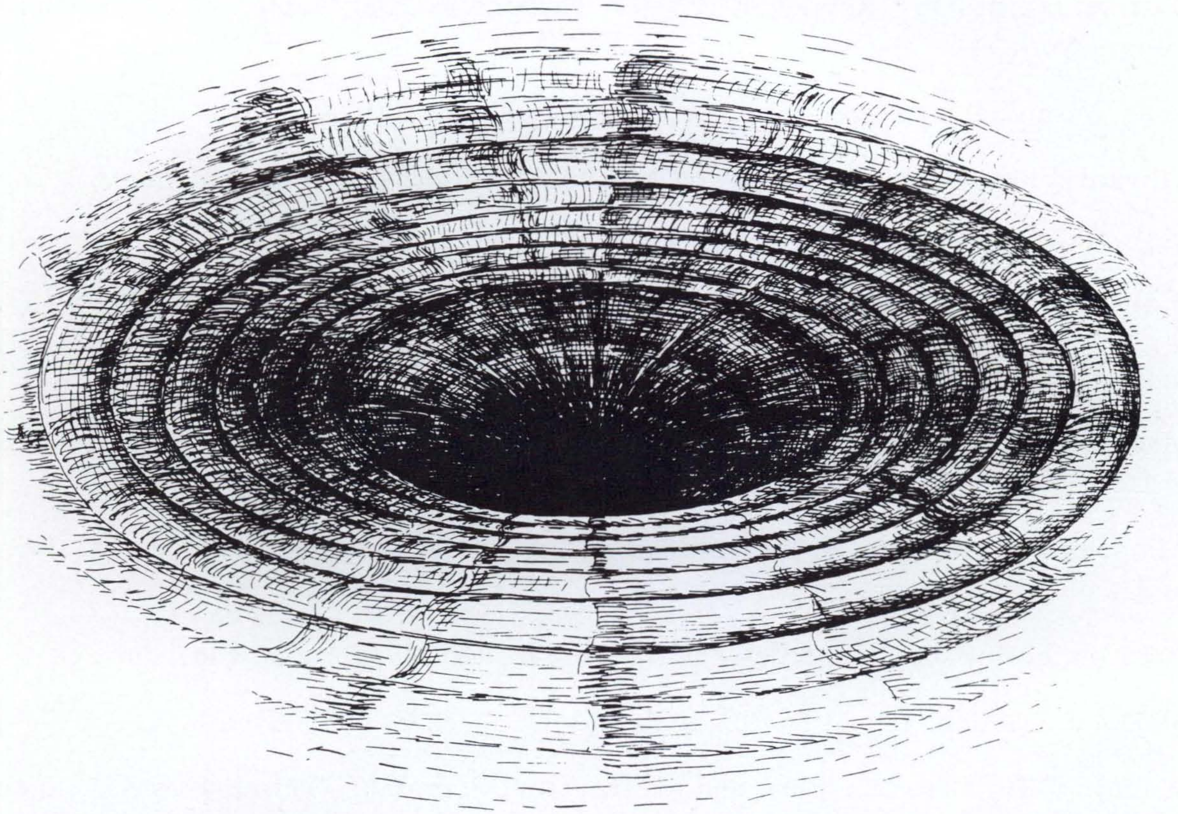
M. Turner, Fermilab: "Supernova Shelton, Gravity Waves," April 20.

A. Stebbins, Fermilab: "Limits on Particle Properties," April 20.

Joint Astrophysics-Particle Physics Seminar

T.D. Lee

University Professor
Columbia University



Soliton Stars and Black Holes

Fermi National Accelerator Laboratory
Ramsey Auditorium
Thursday, May 7, 1987, 2:30 p.m.

L. Widrow, Fermilab: "Cosmic Rays from Supernova Shelton," April 20.

A. Stebbins, Fermilab: "The Remnant," April 20.

Joint Particle/Astrophysics Seminar

T. D. Lee, Columbia University: "Soliton Stars and Black Holes," May 7.

Accelerator Division Seminars

J. Marriner, Fermilab: "Review of Physics, Technology, and Practice of Stochastic Beam Cooling," April 21.

L. Teng, Fermilab: "Accelerator Projects Worldwide," April 28.

H. Edwards et al., Fermilab: "Division News and Collider Performance," May 12.

A. Van Ginneken, Fermilab: "SSC Site Selection: Radiation Safety Criteria," May 19.

T. Collins, Fermilab: "Two Low-Beta Insertions for the TEVATRON Collider," May 26.

D. Wildman, Fermilab: "Bunch Coalescing in the Main Ring," June 9

J. MacLachlan, Fermilab: "ESME Unveiled: Principles and Practice of rf Simulation," June 16.

L. Michelotti, Fermilab: "Problem Solving with Interactive Graphics: a Personal View," June 23.

R. Johnson, Fermilab: "Some Lessons from the Recent '87 Collider Run," June 30.

J. Dinkel, J. Gannon, and G. Krafczyk, Fermilab: "Kickers and Pulsed Magnets," July 7.

D. Young, S. Holmes, D. Finley, and M. Harrison, Fermilab: "Fermilab as SSC Injector," July 21.

D. Larson, University of Wisconsin: "Intermediate Energy Electron Cooling for Antiproton Sources," July 28.

W. Scandale, CERN: "Recent Studies of the Large Hadron Collider in the LEP Tunnel," August 18.

F. Nezrick, Fermilab: "Overview of Lilliputian TEVATRON Collider Experiments," August 25.

M. Harrison, Fermilab: "Accelerator Status and Future Plans," September 1.

G. Jackson, Fermilab: "CESR Luminosity Performance and the Beam-Beam Interaction," September 8.

C. Laughton, CERN: "Informal Discussion of LEP Tunnel Construction and LEP Geology," September 15.

S. Mane, Fermilab: "The Michigan/IUCF Siberian Snake Test," September 22.

D. Larson, University of Wisconsin: "Intermediate Energy Electron Cooling," September 29.

P. Martin, D. Trbojevic, and R. Gerig, Fermilab: "Coalescing Improvements and Main Ring Vertical Dispersion Reduction," October 6.

J. Strait, Fermilab: "SSC Magnet R&D Program," October 13.

D. Edwards, Fermilab: "Progress Report on 'E-778' - Test of SSC Aperture Criterion," October 20.

M. Harrison and A. Van Ginneken, Fermilab: "Beam Scraping in the TEVATRON: Principles and Observations," October 27.

H. Edwards, Fermilab: "FY88 R&D and Improvement Projects; Long-Term Luminosity Upgrade and the Need for More Intensity," November 3.

V. Bharadwaj, Fermilab: "Deceleration in the Accumulator," November 3.

D. Neuffer, LANL: "Lumped Correction of Dipole Multipole Content for Large Synchrotrons," November 10.

S. Holmes, Fermilab: "Plans for Improved Performance of the Fermilab Booster," November 17.

L. Hoddeson, University of Illinois at Urbana-Champaign/Fermilab: "The Underground History of the Doubler," November 24.

S. Saritepe, Oklahoma State University: "Dirac Electron in a Helical Wiggler Field: Solutions and Applications to Free Electron Laser (FEL)," December 1.

M. Harrison, Fermilab: "Fixed-Target Performance Limitations," December 8.

M. Syphers, Fermilab: "Main Ring Performance at 8 and 20 GeV," December 8.

G. P. Goderre, University of Houston: "Computer Simulation of Power Supply Ripple (tune modulation) and Beam-Beam Interactions in the SSC," December 15.

Special Accelerator Division Seminar

M. Knott, ANL: "An Overview of the Argonne Advance Photon Source and Control System Design for That Machine," November 17.

Accelerator Seminars

M. Cornacchia, Lawrence Berkeley Laboratory (LBL)/Fermilab: "The Berkeley 1-2 GeV Synchrotron Radiation Source," January 13.

R. Meller, LBL: "Theory About Bunch Lengthening," January 20.

S. Mane, University of Michigan: "Electron Spin Polarization in High-Energy Storage Rings," January 27.

J. Griffin and L. Teng, Fermilab: "High Intensity Hadron Facilities," February 17.

F. Willeke, DESY: "Sextupole Corrections for the Electron Ring of HERA," February 10.

S. Holmes and R. Noble, Fermilab: "The 400-MeV Linac Upgrade: Design and Expected Impact," February 24.

M. Berz, LANL: "Description of Beam Dynamics to 5th and Higher Orders," March 3.

D. Finley, R. Gerig, V. Bharadwaj, and M. Gormley, Fermilab: "Collider Status Report," March 10.

J. Welch, SLAC: "The SLAC Lasertron, a New Kind of High-Power rf Source," March 31.

S. Herb, Cornell University: "Permanent Magnet Quadrupoles," April 14.

M. Syphers, Fermilab: "Transverse Phase Space Dilution Due to Injection Mismatches," May 5.

Research Division Seminars

R. Ruchti, University of Notre Dame: "Active Target Development for E-687," January 20.

L. Gustafsson, Fermilab: "FASTBUS to VME Interfacing at CERN," February 3.

J. Butler, Fermilab: "Survey of Photoproduction," February 10.

J. Lach, Fermilab: "Status of SSC Siting," February 19.

S. Bracker, University of Toronto: "E-769 VME-Based Data Acquisition System," March 3.

S. Hansen and M. Bernett, Fermilab: "Fermilab Smart Crate Controller," March 17.

P. Drell, LBL: "MARK II at SLC," March 26.

J. Elias, Fermilab: "Experience Designing and Operating the CDF Flammable Gas System," April 7.

L. Roberts, Fermilab: "Evaluation of the FPS 164 Computer for High-Energy Physics Pattern Recognition Problems," April 21.

U. Mallik, SLAC: "J/ψ Spectroscopy from Mark III," April 23.

H. Bichsel, Seattle, Washington: "Energy Loss in Thin Si Detectors," May 7.

P. Avery, Florida State University: "Review of B Meson Decays," May 14.

C. Salgado, Michigan State University: "A Study of Direct Photons at the ISR," May 21.

J. Elias, Fermilab: "Design and Operation of CDF Gas System," June 9.

G. Bock, Fermilab: "Survey of Kaon Physics," September 10.

D. Christian, S. Hansen, and R. Yarema, Fermilab: "Some Initiatives in Front-End Electronics at Fermilab," September 17.

R. Stefanski, Fermilab: "Rap Session on Heavy Flavor Symposium at Stanford and B Workshop at SLAC, September 1-9, 1987," September 23.

O. Sasaki, KEK: "High Resolution TDC's for TRISTAN Experiments," October 29.

R. Wigmans, CERN: "Calorimetry at Supercollider," November 5.

G. Coutrakon, Fermilab/Loma Linda University Medical Center: "The E-665 RICH Detector," December 3.

Special Research Division Seminar

R. Quared, University of Paris: "Charm Physics at NA 27," August 27.

Computing Department Seminar

D. Rohde, Fermilab: "LaTeX and Graphics," January 21.

Computing Techniques Seminars

R. Brun, CERN: "Detector Simulation Developments at CERN," February 11.

J. Tverdik, Fermilab: "Data Bases in the Technical Environment," February 24.

T. Nash, Fermilab: "Summary Talk, Conference on Computing in HEP," March 4.

J. Pfister, Fermilab: "Personal Computer: Acquisition, Care, and Feeding," March 10.

D. Sachs, Fermilab: "Scientific Word Processing with Microsoft Word on the Macintosh," March 17.

R. Thatcher, Fermilab: "Using the VAX Language Sensitive Editor," March 24.

G. Chartrand, Fermilab: "Basic Tutorial on Electronic Mail," April 14.

D. Ritchie, Fermilab: "Getting the Most Out of the VAX - Using the NULLJOB Product to Process Long-Running Batch Jobs," April 28.

A. Thomas and F. Nagy, Fermilab: "EPICURE," May 12.

M. Leininger, Fermilab: "Introduction to VAX Interactive Debugger for FORTRAN Programmers," May 26.

T. Carroll, Fermilab: "Expert System for FASTBUS Network Diagnostics," June 9.

B. Smith, Argonne: "Status of FORTRAN 8X," June 23.

K. Kothera and T. Virgo, Fermilab: "Talaris Laser Printers - What Can They Do?" July 14.

M. Leininger, Fermilab: "Computer-Aided Design/Engineering/Manufacturing: Current Status and Future Direction," July 28.

J. Pfister, Fermilab: "Repeat Presentation: Personal Computers: Acquisition, Care, and Feeding," August 25.

P. Heinicke, Fermilab: "CMS: DEC's Code Management System and How To Use It," September 8.

T. Nicinski, Fermilab: "What is DEC-MMS and How To Use It?" September 22.

H. Johnstad, Fermilab: "ZEBRA Data Structures," October 13.

D. Ritchie, Fermilab: "Conferencing by Computer - What, Why, When, and How," October 27.

F. Bartlett, Fermilab: "Structured Analysis Structured Design Principles and Tools," November 10.

H. Johnstad and R. Thatcher, Fermilab: "FORTRAN 8X, Who's for it, who's against it, and why," November 17.

L. Loebel, Fermilab: "CLI - The Command Language Interpreter - How to Make Your Programs Look Like DCL Commands," November 24.

M. Leininger and G. Tool, Fermilab: "DOE CAD/CAM Conference Report," December 8.

J. Hoftun, Brown University: "MicroVAX Farms," December 15.

Nonlinear Dynamics Seminars

W. Reinhardt, University of Pennsylvania: "Adiabatic Switching as a Probe of Chaotic Classical Dynamics," January 16.

M. Davis, ANL: "The Role of Cantori and Separatrices in Relaxation and Reaction," April 3.

Special Seminars

M. Witherell, University of California, Santa Barbara: "Double Beta-Decay Majorons," February 17.

T. Geballe, Stanford University: "High-Temperature Superconducting Perovskites - Science and Technology," May 21.

H. Wahl, CERN: "Precision Measurememt e′/e in CP Violating K_0 Decays," August 18.

S. Hasegawa, Weseda University, Japan: "High Energy Cosmic Ray Phenomena and Their Implications to TEVATRON Experiments," September 10.

Special Experimental Seminar

T. Ohshima, University of Tokyo: "An Experimental Measurement of the Neutrino Mass in Tritium Beta Decay," January 20.

Safety Development Seminar

S. Baker and J. Grimson, Fermilab: "Crane Safety," June 8.

Fermilab Academic Lecture Series

D. Green, Fermilab: "Gravity for Beginners," January 12, 14, 19, 21, 26, 28.

A. Albrecht, Fermilab: "Cosmic Strings: Possible Seeds for the Galaxies," March 23, 25.

H. Harari, SLAC and the Weizmann Institute: "Quarks and Leptons: The Third Generation and Beyond," June 15, 17, 22, 24.

Summer Lecture Series for College Students

D. Green, Fermilab: "Wire Chambers," June 30.

E. Kolb, Fermilab: "Everything About the Universe," July 7,

D. Jovanovic, Fermilab: "All About Quarks," July 14.

D. Ritchie, Fermilab: "Computers at Fermilab," July 21.

C. Hill, Fermilab: "Introduction to Theory," July 28.

Workshops

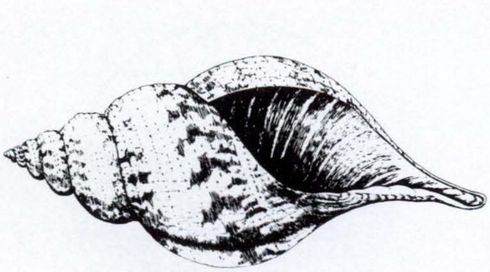
Quantum Cosmology Workshop
May 1, 2, 3

Beauty Physics Workshop
November 11, 12, 13, 14

Other

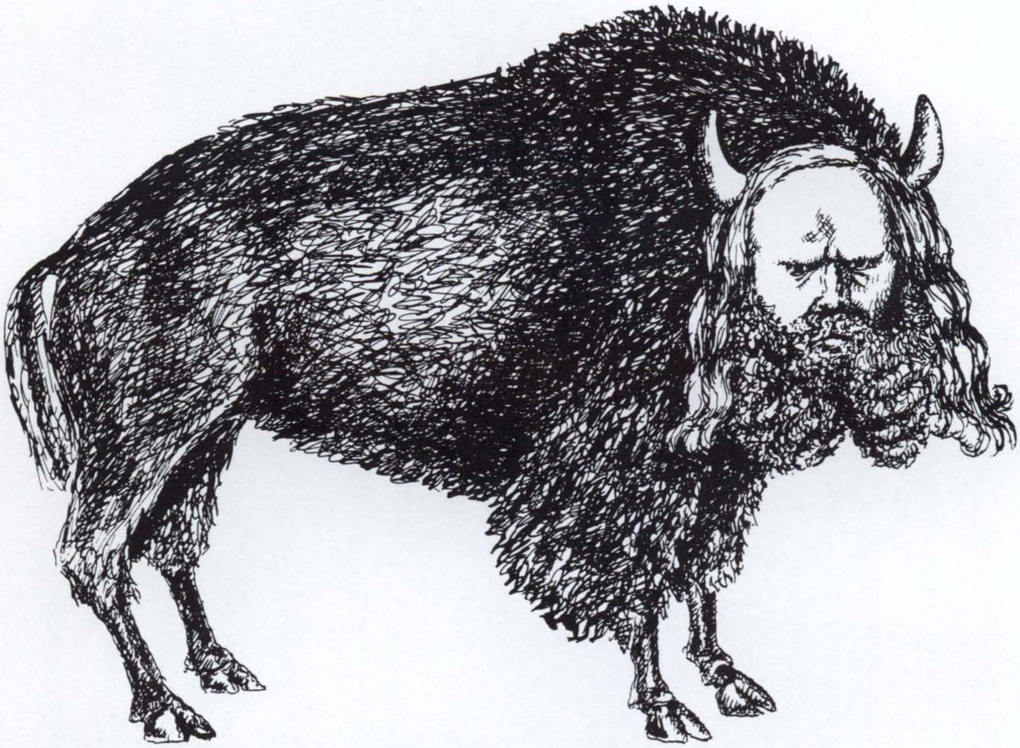
Annual Users Meeting
May 8 and 9

Fermilab Industrial Affiliates Seventh Annual Meeting
May 21, 22



Special Colloquium

John Ellis
CERN



Is There Life After LEP?

Fermi National Accelerator Laboratory
Ramsey Auditorium
Monday*, March 23, 1987, 4:00 p.m.

*Note Special Day

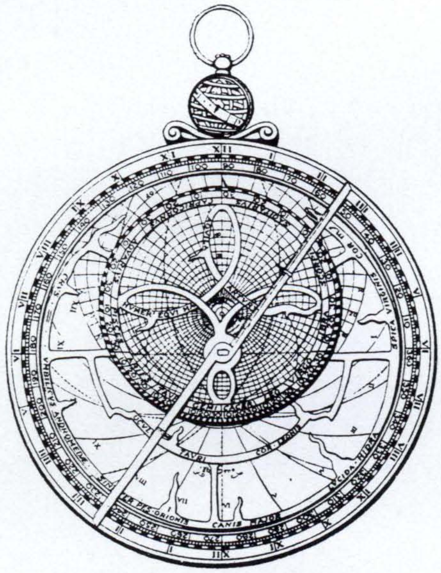
Appendix D
Visitors to Fermilab Theoretical Physics and Astrophysics — 1987

Theoretical Physics Department Visitors - 1987

C. A. Alcalde, University of California , Los Angeles • F. Alonso-Sanchez, Lyman Laboratory of Physics, Harvard University • A. Anselm, Leningrad Nuclear Physics Institute, U.S.S.R. • P. Aurenche, LAPP, France • K. S. Babu, University of Rochester • V. N. Baier, Institute of Nuclear Physics, Novosibirsk, U.S.S.R. • A. Bartl, Universitat Wien, Vienna, Austria • C. Bernard, University of California, Los Angeles • A. Billoire, Florida State University • J. Collins, Illinois Institute of Technology • S. Das, California Institute of Technology • D. Duke, Florida State University • J. Fischer, Czechoslovak Academy of Sciences, Prague, Czechoslovakia • B. Gato , Massachusetts Institute of Technology • S. S. Gershtein, Institute for High Energy Physics, Serpukhov, U.S.S.R. • H. Harari, Stanford Linear Accelerator Center • I. Hinchliffe, Lawrence Berkeley Laboratory • A. Hodjamiryan, ERPI, Yerevan, U.S.S.R. • P. Q. Hung, University of Virginia • J. Iliopoulos, Ecole Normale Superieure, Paris, France • C. Jarlskog, University of Stockholm, Sweden • R. Johnson, Iowa State University • A. Kaidalov, ITEP, Moscow, U.S.S.R. • B. Kayser, National Science Foundation • Z. Kunszt, Eidgenossische Technische Hochschule, Zurich, Switzerland • B. Lampe, ITP, Universitat Hannover, West Germany • A. Linde, Lebedev Institute, Moscow, U.S.S.R. • S. Matinyan, Yerevan Physics Institute, Armenia • A. N. Mitra, University of Illinois at Chicago • S. Mohan, University of Virginia • S. Nandi, Oklahoma State University • D. Nash, St. Patrick's College, Maynooth, Ireland • P. Nason, Brookhaven National Laboratory • A. Niemi, Lawrence Berkeley Laboratory • R. Oakes, Northwestern University • E. Onofri, Universita de Parma, Italy • V. A. Petrov, Institute for High Energy Physics, Serpukhov, U.S.S.R. • S. Pokorski, University of Warsaw, Poland • J. Pulido, Centro de Fisica da Materia Condensada, Lisbon, Portugal • J. P. Ralston, University of Kansas • V. A. Rubakov, Institute of Nuclear Research, Moscow, U.S.S.R. • K. V. L. Sarma, Tata Institute of Fundamental Research, Bombay, India • G. Semenoff, University of British Columbia, Canada • S. Sen, Trinity College, University of Dublin, Ireland • J. Sexton, Institute for Advanced Study • N. Tyurin, Institute for High Energy Physics, Serpukhov, U.S.S.R. • B. Voitsekhovskii, INP, Novosibirsk, U.S.S.R. • E. Weinberg, Columbia University • K. Yamawaki, Nagoya University, Japan • V. Zakharov, Institute of Theoretical and Experimental Physics, Moscow, U.S.S.R. •

Theoretical Astrophysics Group Visitors - 1987

Short-Term Visitors: J. Bahcall, Institute for Advanced Study • E. Bertschinger, Massachusetts Institute of Technology • S. Blau, University of Texas at Austin • F. Bouchet, University of California, Berkeley • L. Cowie, University of Hawaii • O. Eboli, Massachusetts Institute of Technology • A. Erlykin, Lebedev Physical Institute, Moscow, U.S.S.R. • J. Faulkner, University of California, Santa Cruz • J. Frieman, Stanford Linear Accelerator Center • G. Fuller, Lawrence Livermore National Laboratory • J. Goodman, University of Maryland • J. Hartle, University of California, Santa Barbara • R. Jantzen, Villanova University • R. Juszkiewicz, University of California, Berkeley • P. Laguna, University of Texas at Austin • T. D. Lee, Columbia University • A. Linde, Lebedev Physical Institute, Moscow, U.S.S.R. • P. Mazur, University of Syracuse • R. Meyers, Institute of Theoretical Physics, Santa Barbara • M. Mijić, California Institute of Technology • J. Primack, University of California, Santa Cruz • S. Raby, Los Alamos National Laboratory • M. Ruiz-Altaben, University of Florida • M. Sher, Washington University • S. Slavatinsky, Lebedev Physical Institute, Moscow, U.S.S.R. • D. Spergel, Institue for Advanced Study • W. M. Suen, University of Florida, Gainesville • A. Szalay, Johns Hopkins University/Eötvös University, Budapest, Hungary • C. Thompson, Princeton University • T. Vachaspati, Bartol Research Foundation • S. Veeraraghavan, University of California, Berkeley • *Long-Term Visitors:* D. Coule, University of Florida • F. Grassi, Observatoire de Paris, France • D. Haws, Imperial College, London, England • P. Jetzer, University of Geneva, Switzerland • K. Maeda, University of Tokyo, Japan • S. Marques, University of Brazil • D. Mitchell, Imperial College, London, England • N. Neto, CBPF, Brazil • T. Pacher, Institute for Theoretical Physics, Heidelberg • J. Song, Rome University



Appendix E
Universities Research Association, Inc.

Universities Research Association, Inc., Board of Trustees

Regional Trustees (URA University Presidents)

Region 1: Henry Koffler, University of Arizona • *Region 2:* Hanna Holborn Gray, University of Chicago • *Region 3:* Bernard Sliger, Florida State University • *Region 4:* Wesley Posvar, University of Pittsburgh • *Region 5:* Joe B. Wyatt, Vanderbilt University • *Region 6:* Harold Shapiro, Princeton University • *Region 7:* John Marburger, State University of New York at Stony Brook

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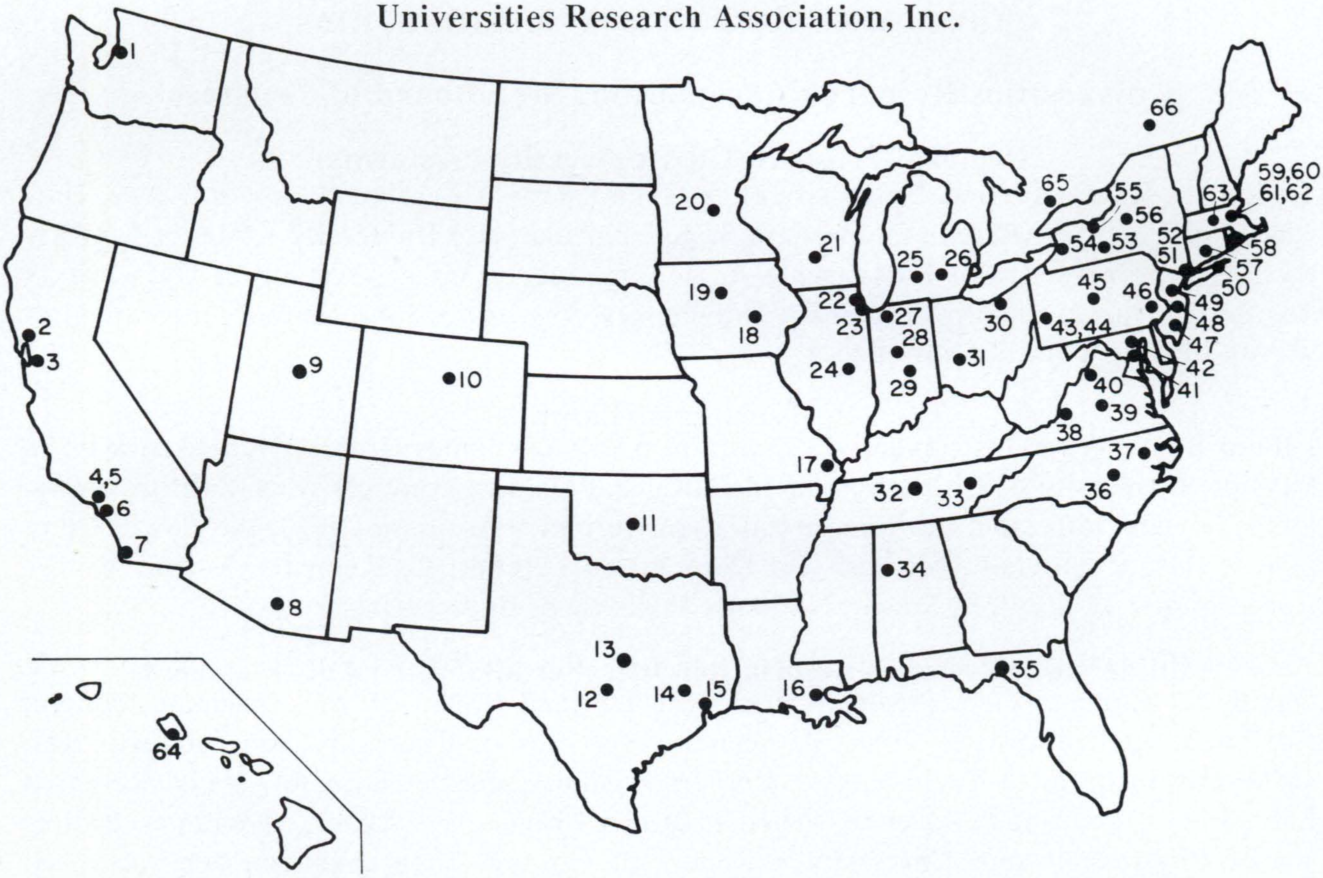
Universities Research Association, Inc., Fermilab Board of Overseers

David H. Cohen, Vice President for Research and Dean of the Graduate School, Northwestern University • John M. Deutch, Professor of Chemistry and Provost, Massachusetts Institute of Technology • Herbert Friedman, former Director, Naval Research Laboratory • Maurice Glicksman, Provost, Brown University • Alan L. Goodman, Professor of Physics, Tulane University • Robert E. Gordon, Vice President for Advanced Studies, Notre Dame University • Kenneth Heller, Professor of Physics, University of Minnesota • Jack M. Hollander, Vice President for Research and Graduate Studies, Ohio State University • William H. Kelly, Dean, College of Sciences and Humanities, Iowa State University • Edward A. Knapp, President, Universities Research Association, Inc. • William L. Kraushaar, Professor of Physics, University of Wisconsin • Joseph E. Lannutti, Professor of Physics, Florida State University • Robert Panvini, Department of Physics and Astronomy, Vanderbilt University • Vincent Peterson, Professor of Physics, University of Hawaii • Alexander Pond, Executive Vice President, Rutgers, The State University of New Jersey • Harrison Shull, Professor of Chemistry, University of Colorado at Boulder • Albert Silverman, Professor of Physics, Cornell University • H. Guyford Stever, Foreign Secretary, National Academy of Engineering • Harold K. Ticho, Vice Chancellor for Academic Affairs, University of California, San Diego • Robert R. Wilson, Professor Emeritus, Cornell University • Harry Woolf, Professor, Institute for Advanced Study

Universities Research Association, Inc., Visiting Committee - 1987

Robert K. Adair, Yale University • Joseph Ballam, Stanford Linear Accelerator Center • James H. Christenson, New York University • Thomas J. Devlin, Rutgers University • Jerome I. Friedman, Massachusetts Institute of Technology • Robert Gluckstern, University of Maryland • Lawrence W. Jones, University of Michigan • Kenneth D. Lane, Ohio State University • Robert L. McCarthy, State University of New York at Stony Brook • Joseph F. Owens, Florida State University • Frank C. Shoemaker, Princeton University • Albert Silverman, Cornell University

Member Institutions
Universities Research Association, Inc.



Locations of member institutions of Universities Research Association, Inc.,
which operates Fermi National Accelerator Laboratory
and the Superconducting Super Collider Central Design Group
as a contractor for the U. S. Department of Energy

Washington
1. University of Washington

California
2. University of California, Berkeley
3. Stanford University
4. California Institute of Technology
5. University of California, Los Angeles
6. University of California, Irvine
7. University of California, San Diego

Arizona
8. University of Arizona

Utah
9. University of Utah

Colorado
10. University of Colorado

Oklahoma
11. University of Oklahoma

Texas
12. University of Texas at Austin
13. Texas A&M University
14. University of Houston
15. Rice University

Louisiana
16. Tulane University

Missouri
17. Washington University

Iowa
18. University of Iowa
19. Iowa State University

Minnesota
20. University of Minnesota

Wisconsin
21. University of Wisconsin

Illinois
22. Northwestern University
23. University of Chicago
24. University of Illinois

Michigan
25. Michigan State University
26. University of Michigan

Indiana
27. Notre Dame University
28. Purdue University
29. Indiana University

Ohio
30. Case Western Reserve University
31. Ohio State University

Tennessee
32. Vanderbilt University
33. University of Tennessee, Knoxville

Alabama
34. University of Alabama, Tuscaloosa

Florida
35. Florida State University

North Carolina
36. Duke University
37. University of North Carolina

Virginia
38. Virginia Polytechnic Institute
39. University of Virginia
40. College of William and Mary

Maryland
41. University of Maryland
42. Johns Hopkins University

Pennsylvania
43. University of Pittsburgh
44. Carnegie-Mellon University
45. Pennsylvania State University
46. University of Pennsylvania

New Jersey
47. Princeton University
48. Rutgers University
49. Stevens Institute of Technology

New York
50. State University of New York at Stony Brook
51. Columbia University
52. Rockefeller University
53. Cornell University
54. State University of New York at Buffalo
55. University of Rochester
56. Syracuse University

Connecticut
57. Yale University

Rhode Island
58. Brown University

Massachusetts
59. Massachusetts Institute of Technology
60. Boston University
61. Harvard University
62. Northeastern University
63. Tufts University

Hawaii
64. University of Hawaii at Manoa

Canada
65. University of Toronto
66. McGill University

Appendix F
Physics Advisory Committee — 1987

Michael Witherell, University of California, *(Chairperson)* • Richard D. Field, University of Florida • Mary Kay Gaillard, Lawrence Berkeley Laboratory • Howard A. Gordon, Brookhaven National Laboratory • Anne Kernan, University of California, Riverside • William J. Marciano, Brookhaven National Laboratory • Francis M. Pipkin, Harvard University • Richard Prepost, University of Wisconsin-Madison • John P. Rutherfoord, University of Washington • Melvin Jay Shochet, Enrico Fermi Institute, University of Chicago • Mark W. Strovink, Lawrence Berkeley Laboratory • Lincoln Wolfenstein, Carnegie-Mellon University

Appendix G
Fermilab Users Executive Committee — 1987

Anna Jean Slaughter, Yale University, *Chairperson* • Stephen Holmes, Fermilab, *Secretary* • Rosanna Cester, Instituto di Fisica, Torino, Italy • Marjorie Corcoran, Rice University • Eugene Engels, Jr., University of Pittsburgh • Steven Errede, University of Illinois • Thomas Ferbel, University of Rochester • Melissa Franklin, Harvard University • Arthur Garfinkel, Purdue University • Hugh Montgomery, Fermilab • James Siegrist, Lawrence Berkeley Laboratory • Bruce Winstein, University of Chicago, Enrico Fermi Institute

Appendix H
Fermilab Industrial Affiliates — 1987

AT&T Bell Laboratories
Air Products and Chemicals, Inc.
Ameritech Development Corporation
Amoco Corporation
Babcock & Wilcox
CBI Services, Inc.
Commonwealth Edison Company
Cray Research, Inc.
CVI, Inc.
Digital Equipment Corporation
Digital Pathways, Inc.
Eaton Corporation
Environmental Monitoring Laboratories, Inc.
(Waste Management, Inc.)
General Electric Company
GTE Laboratories
W.W. Grainger, Inc.
Harza Engineering Company
Hewlett-Packard Company
IBM
State of Illinois
Inland Steel Company
Intermagnetics General Corporation
Kinetic Systems Corporation
Litton Industries, Inc.
Major Tool & Machine, Inc.
NALCO Chemical Company
New England Electric Wire Corporation
NYCB Real-Time Computing, Inc.
R. Olson Manufacturing Company, Inc.
Omnibyte Corporation
Oxford Superconducting Technology
Plainfield Tool and Engineering, Inc.
Schlumberger-Doll Research
Science Applications International Corporation
Sulzer Brothers
Swagelok Companies
Union Carbide Corporation
Varian Associates, Inc.
Westinghouse Electric Corporation

Audited Financial Statements

Fermi National Accelerator Laboratory - Universities Research Association, Inc.

September 30, 1987 and 1986

Ernst & Whinney

Appendix I
Audited Financial Statements
Fermi National Accelerator Laboratory — Universities Research Association, Inc.
September 30, 1987 and 1986

FERMI NATIONAL ACCELERATOR LABORATORY -
UNIVERSITIES RESEARCH ASSOCIATION, INC.

September 30, 1987 and 1986

Ernst & Whinney

150 South Wacker Drive
Chicago, Illinois 60606
312/368-1800

Board of Trustees
Universities Research Association, Inc.
Washington, D.C.

We have examined the balance sheets of Fermi National Accelerator Laboratory - Universities Research Association, Inc. as of September 30, 1987 and 1986, and the related statements of revenues and program costs and changes in fund balance, funded operating expenses and cash flows for the years then ended. Our examinations were made in accordance with generally accepted auditing standards and, accordingly, included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

As more fully described in Note B, in 1986 the Laboratory, in accordance with United States Department of Energy accounting regulations, capitalized a portion of prior years' research and development expenses and reduced program costs in the amount of $17,531,000. In our opinion, this capitalization is not in conformity with generally accepted accounting principles.

In our opinion, except for the effects of capitalization of prior years' research and development expenses on 1986 program costs, as discussed in the preceding paragraph, the financial statements referred to above present fairly the financial position of Fermi National Accelerator Laboratory - Universities Research Association, Inc. at September 30, 1987 and 1986, and the results of its financial transactions and cash flows for the years then ended, in conformity with generally accepted accounting principles consistently applied during the period except for the 1986 change, with which we concur, in property and equipment capitalization policy as described in Note C to the financial statements.

Ernst & Whinney

Chicago, Illinois
December 1, 1987

BALANCE SHEETS

FERMI NATIONAL ACCELERATOR LABORATORY -
UNIVERSITIES RESEARCH ASSOCIATION, INC.

	September 30 1987	September 30 1986
ASSETS		
Cash	$ 331,863	$ 318,598
Miscellaneous receivables	2,650,267	1,819,860
Due from Universities Research Association, Inc.	113,505	151,595
Inventories	21,680,072	19,152,604
Property and equipment--Notes B and C:		
Construction in progress	32,910,087	59,322,621
Equipment and buildings	771,689,527	705,579,497
	804,599,614	764,902,118
Less allowances for depreciation	342,635,848	306,606,676
	461,963,766	458,295,442
	$486,739,473	$479,738,099
LIABILITIES AND FUND BALANCE		
Liabilities:		
Accounts payable	$ 12,526,406	$ 13,351,064
Employee compensation	8,888,662	8,395,178
Contract retentions	485,270	649,268
Deferred credits	1,999,442	3,476,956
	23,899,780	25,872,466
Fund balance	462,839,693	453,865,633
Commitments--Note D		
	$486,739,473	$479,738,099

See auditors' report and notes to financial statements.

STATEMENTS OF REVENUES AND PROGRAM COSTS AND CHANGES IN FUND BALANCE

FERMI NATIONAL ACCELERATOR LABORATORY - UNIVERSITIES RESEARCH ASSOCIATION, INC.

	Year Ended September 30 1987	1986
Revenue:		
Transfers from United States Department of Energy	$184,358,804	$174,000,353
Program costs (credits):		
Funded operating expenses	135,888,087	117,546,406
Other program costs which did not require the use of contract funds:		
Provisions for depreciation	40,333,080	36,049,067
Capitalization of prior years' Tevatron Accumulator costs--Note B	-	(17,531,320)
Other adjustments to property and equipment accounts which did not require the use of contract funds	(848,570)	(380,130)
TOTAL PROGRAM COSTS	175,372,597	135,684,023
REVENUE IN EXCESS OF PROGRAM COSTS BEFORE CUMULATIVE EFFECT OF CHANGE IN CAPITALIZATION POLICY	8,986,207	38,316,330
Cumulative effect to September 30, 1985 of change in capitalization policy--Note C	-	14,621,160
REVENUE IN EXCESS OF PROGRAM COSTS	8,986,207	23,695,170
Net transfers to other federal agencies	(12,147)	(11,361)
Fund balance at beginning of year	453,865,633	430,181,824
FUND BALANCE AT END OF YEAR	$462,839,693	$453,865,633

See auditors' report and notes to financial statements.

STATEMENTS OF FUNDED OPERATING EXPENSES

FERMI NATIONAL ACCELERATOR LABORATORY -
UNIVERSITIES RESEARCH ASSOCIATION, INC.

	Year Ended September 30 1987	1986
Salaries, wages and related costs	$ 79,342,866	$ 79,372,643
Communications	1,722,231	1,760,232
Data processing	1,906,402	1,812,809
Freight	298,614	311,104
Inventory usage and adjustments	7,171,957	6,549,318
Management allowance	1,015,200	1,180,300
Materials and supplies	18,473,281	13,637,718
Low dollar value capital equipment	1,855,904	2,188,257
Relocation costs	182,272	179,736
Rent	334,541	278,067
Subcontracts and purchased services	9,678,339	9,687,077
Travel and other employee expense allowances	2,248,670	2,172,657
Electric power	20,008,449	8,527,676
Miscellaneous revenues, principally from universities and cafeteria and housing operations	(2,435,910)	(2,819,587)
TOTAL	141,802,816	124,838,007
Less portion of operating expenses redistributed to other fund types	5,914,729	7,291,601
TOTAL	$135,888,087	$117,546,406

See auditors' report and notes to financial statements.

STATEMENTS OF CASH FLOWS

FERMI NATIONAL ACCELERATOR LABORATORY -
UNIVERSITIES RESEARCH ASSOCIATION, INC.

	Year Ended September 30 1987	1986
Cash flows from operating activities:		
Revenue in excess of program costs	$ 8,986,207	$23,695,170
Adjustments to reconcile revenue in excess of program costs to net cash provided by operating activities:		
Provision for depreciation	40,333,080	36,049,067
Change in assets and liabilities other than cash:		
Miscellaneous receivables	(830,407)	725,012
Due from Universities Research Association, Inc.	38,090	174,920
Inventories	(2,527,468)	(2,187,101)
Accounts payable	(824,658)	1,940,759
Employee compensation	493,484	538,245
Contract retentions	(163,998)	289,275
Deferred credits	(1,477,514)	(970,722)
Adjustments to property and equipment accounts not affecting cash	356,267	(513,658)
Capitalization of prior years Tevatron Accumulator costs--Note B	-	(17,531,320)
Cumulative effect of change in capitalization policy--Note C	-	14,621,160
Net transfers to other federal agencies	(12,147)	(11,361)
NET CASH PROVIDED BY OPERATING ACTIVITIES	44,370,936	56,819,446
Additions to property and equipment	(44,357,671)	(56,759,672)
NET INCREASE IN CASH	13,265	59,774
Cash at beginning of year	318,598	258,824
CASH AT END OF YEAR	$ 331,863	$ 318,598

See auditor's report and notes to financial statements.

NOTES TO FINANCIAL STATEMENTS

FERMI NATIONAL ACCELERATOR LABORATORY -
UNIVERSITIES RESEARCH ASSOCIATION, INC.

September 30, 1987 and 1986

NOTE A--ACCOUNTING ENTITY AND SUMMARY OF ACCOUNTING POLICIES

Under the terms of a contract between Universities Research Association, Inc. (the Association) and the United States Department of Energy (DOE), the Association has undertaken to organize, design, construct and operate Fermi National Accelerator Laboratory (Fermilab) at Batavia, Illinois. These financial statements include the accounts pertaining to Fermilab which are maintained at the Association's office at Batavia, Illinois. Other financial transactions, which are recorded in the corporate accounts of the Association maintained in its Washington, D.C. office, are reported separately and are not reflected herein.

Property and Equipment: The contract provides that assets acquired to carry out the contract become the property of the United States Government, although Fermilab has their use and custody. Certain equipment and buildings at the construction site have been furnished directly by the Government and have been included in the financial statements at cost less allowances for depreciation, as determined by the DOE or other federal agencies. The balance sheets set forth such assets, related liabilities and equity of the funding agency, the DOE, in Fermilab.

Property and equipment are stated on the basis of cost. Provisions for depreciation of equipment and buildings are computed principally on the straight-line method. Fermilab follows the DOE policy of capitalizing all equipment items costing more than $5,000--see Note C.

Inventories: Inventories consist principally of replacement and repair parts and supplies which are valued at cost using the first-in, first-out (FIFO) method.

Vacation Pay: Vacation pay is accrued as it is earned by the employees.

NOTE B--RESEARCH AND DEVELOPMENT

In years prior to 1986, significant amounts were charged to operations in connection with the research and development of the Tevatron Accumulator. During the year ended September 30, 1986, the Accumulator was commissioned. In accordance with United States Department of Energy accounting regulations, the Laboratory capitalized approximately $17,531,000, representing that portion of Accumulator costs which had originally been expensed as research and development expenses.

NOTES TO FINANCIAL STATEMENTS--Continued

FERMI NATIONAL ACCELERATOR LABORATORY -
UNIVERSITIES RESEARCH ASSOCIATION, INC.

NOTE C--CHANGE IN CAPITALIZATION POLICY

Effective October 1, 1985, the Laboratory modified its capitalization policy to comply with a change in United States Department of Energy accounting requirements and to reduce the record keeping burden and costs required to maintain detailed accounting records for immaterial items of plant and equipment. As a result, the capitalization threshold for individual plant and equipment items was increased from $1,000 to $5,000 and was retroactively applied. The effect of this change on prior years was a $14,621,000 increase in program costs and decreases in plant and equipment cost and accumulated depreciation of $33,020,000 and $18,399,000, respectively.

NOTE D--COMMITMENTS AND CONTINGENCIES

At September 30, 1987, Fermilab had issued purchase orders and other contracts for the procurement of goods and services. The noncancelable portion of these commitments pertain to various activities as follows:

Inventories	$ 1,172,000
Equipment	4,645,000
Plant	5,234,000
Operations	2,533,000
	$13,584,000

The Laboratory is involved in certain legal actions for which liability insurance exists. Management, after taking into consideration legal counsel's evaluation of such action and existing insurance coverage, is of the opinion that the outcome thereof will not have a material adverse effect on the financial position of the Laboratory.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Acknowledgments

As always, we are most grateful to all the Fermilab authors who contributed to this *Annual Report*. This year, we are especially grateful to Lillian Hoddeson, Norman Ramsey, Glenn Seaborg, and Robert Wilson for making their research and reminscences available to us for this twentieth-anniversary volume.

The talents of Fermilab Artist Angela Gonzales make these reports unique amongst their kind, and this year her artistry and effort are evident on the front and back covers, unnumbered page vi (the commemorative urn), the frontispiece to "The State of the Laboratory," and the artwork on pages 57, 113, 118, 168, 169, 176, 186, 191, 211, 212, 214, 215, 220, 223, and 231. A diagram of the front cover is on page 252. The back cover design is comprised of one mark for each day between March 7, 1967, (when NAL employee #1, Robert Wilson, began as Director), to December 31, 1987, leap years included. The vignettes scattered throughout the book are various symbols and devices used to measure time. They date from 300,000,000 years ago (the sea shell) to the present time. The illustrations on pages 98, 117, 232, and 250 are astrological calendars from the *Tres Riches Heures du Duc de Berry*; page 98 represents the phases of Sagittarius/Capricorn, 117 is Gemini/Cancer, 232 is Aries/Taurus, and 250 is Aquarius/Pices.

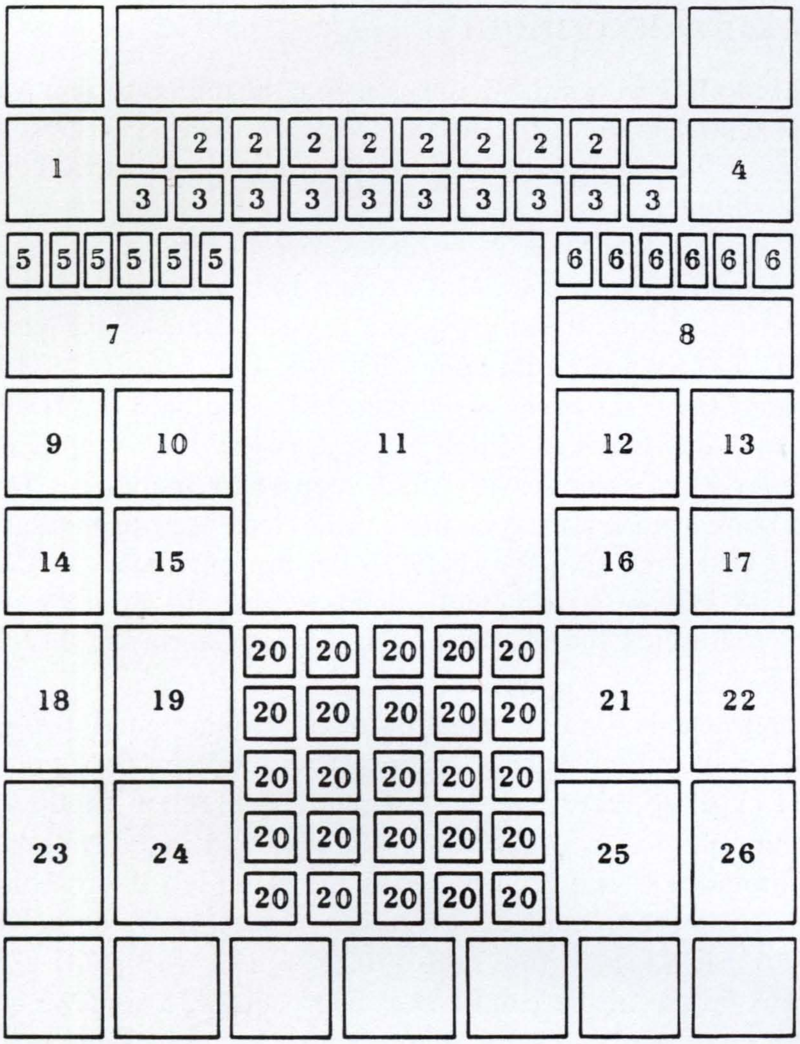
The photography in this report represents a minute fraction of the extant visual history of Fermilab compiled by a succession of photographers, among them those from Argonne National Laboratory who lent their skills to recording the National Accelerator Laboratory's first days, as shown in the photographs on pages 131, 140, 156, and 166. Anthony Frelo, Fermilab's first official photographer and Supervisor of the Fermilab Photo Unit, has exposed thousands of frames of film that record the evolution of the Laboratory. His work is represented on pages 32, 36, 61, 82, 162, 164, 165, 170, 171, 172, 173, 174, 175, 178, 180, and 181. The photographs on the inside front cover, and pages 132 and 183 are by Richard Fenner, formerly of the Photo Unit. The photographs on unnumbered page iv (facing the letter from URA President Edward Knapp), page 84, and the inside back cover are by Olivia Gonzales, a summer photography intern to the Physics Department in 1986. The photographs on pages 20, 26, 35, 39, 40, 50, 70, 74, 76, 91, 101, 102, 110, 114, and 129 are by Reidar Hahn, audio/visual specialist with Fermilab Visual Media Services.

The photograph of Leon Lederman on page 192 is courtesy of WQED/Pittsburgh, and was taken in conjunction with the PBS program, "The Infinite Voyage."

The illustration on page 31 is a table of moon phases from a 17th-century German engraving. The eye on page 44 is by Max Ernst from his "Frottages." The engraving on page 49 was done by a contemporary of Pieter Bruegel after the original by Hiëronymus Bosch. The comet on page 65 is from an 18th-century Swiss engraving. The design on page 106 is the CAD/CAM work of Ayfer Atac of the Technical Support Section, and represents the crystal structure of one of the new superconducting materials. Four drawings for wire sculptures by Hans Uhlmann grace page 105. We wish to thank Nancy Peoples for permission to reproduce her paintings which appear on pages 54 and 58.

Invaluable assistance in the preparation of this report was provided by Constance J.Kania of the Fermilab Publications Office.

- Richard Fenner
Editor, Fermilab Publications Office



1. Hieratic 20
2. Roman 1967
3. Roman 1987
4. Hebrew 20
5. Greek 1967
6. Greek 1987
7. Counting/Year
8. Binary 20
9. Sumerian 20
10. Egyptian Hieroglyphic 20
11. Wilson Hall, 20 Candles
12. Mayan 20
13. Sanskrit 20
14. Greek 20
15. Hindu Arabic 20
16. Cuneiform 20
17. Roman 20
18. Chinese 20
19. Arab 20
20. Magic Square
21. Kashmir 20
22. Aztec 20
23. 20 Seconds
24. 1/5 of 100
25. 1/20 of a Circle in Degrees
26. Roman 100/5

Explanatory diagram for front-cover illustration.