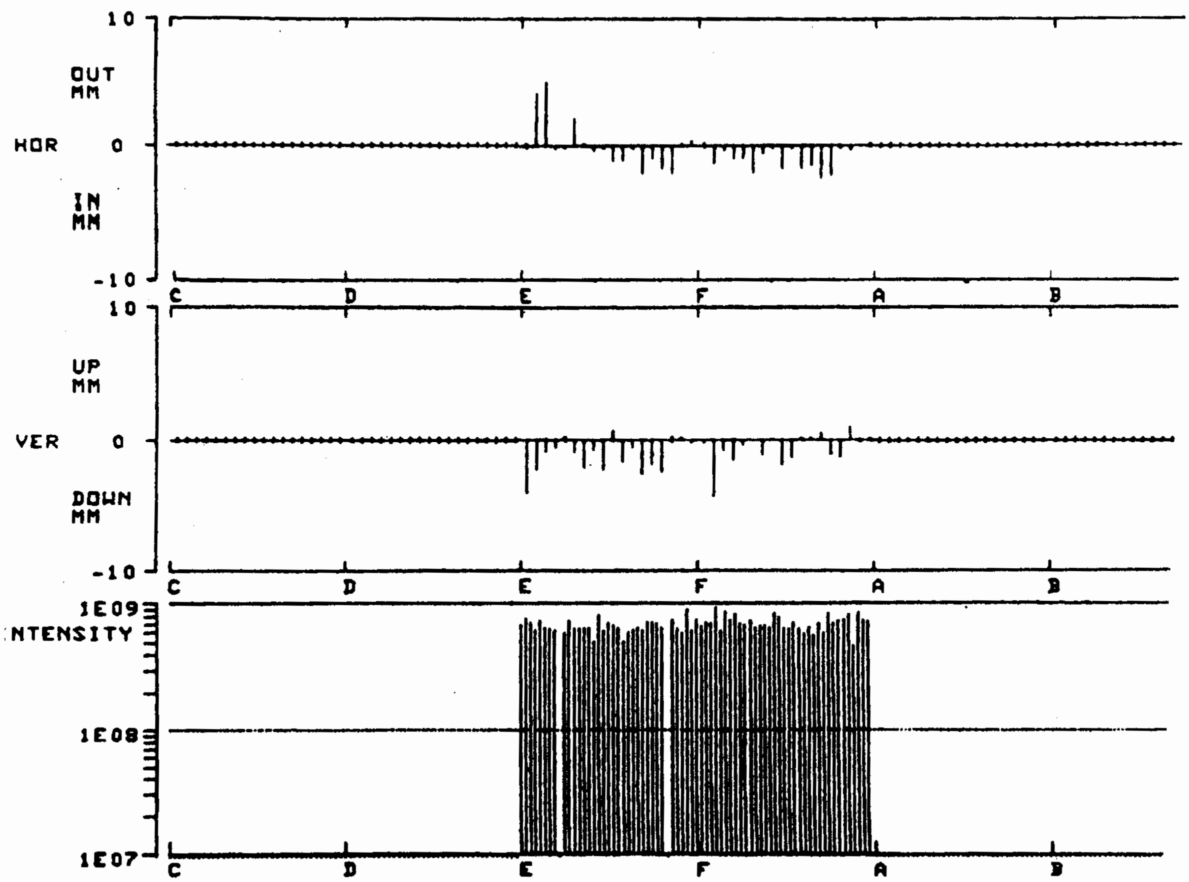
# fermilab report

Fermi National Accelerator Laboratory Monthly Report

May 1983



**fermilab report** is published monthly by the Fermi National Accelerator Laboratory, P. O. Box 500, Batavia, Illinois 60510

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FERMILAB- 83/5 Fermi National Accelerator Laboratory 0090.01

THE COVER: This computer-generated graphics display shows the horizontal and vertical beam orbit measurement made during the injection studies into E and F sectors of the Energy Saver on April 22. The third plot shows the beam intensity measured at each beam position monitor location.

CONTENTS

# ENERGY SAVER/DOUBLER NEARS COMPLETION

Since January of this year, the Saver/Doubler project has remained incredibly well on schedule. Much to the delight of the participants, a number of important milestones have recently been passed as the project heads for completion in early June.

On March 18, the last three superconducting magnets were installed in the ring with an accompanying ceremony (see last month's issue of **Fermilab Report**). On April 9, recommissioning of the Main Ring and commissioning of the Saver began in earnest, with the Main-Ring tunnel secured and interlocked for three-day weekends of around-the-clock power tests. Installation and leak-checking crews were put on four-day work weeks. On April 16, sectors E and F (one-third of the ring) were powered to 2200 amps (equivalent to 500 GeV) for the first time. On the following day, a proton beam in the Main Ring was accelerated to 150 GeV for the first time since last June. This energy is all that is needed for injection from the Main Ring into the Saver.

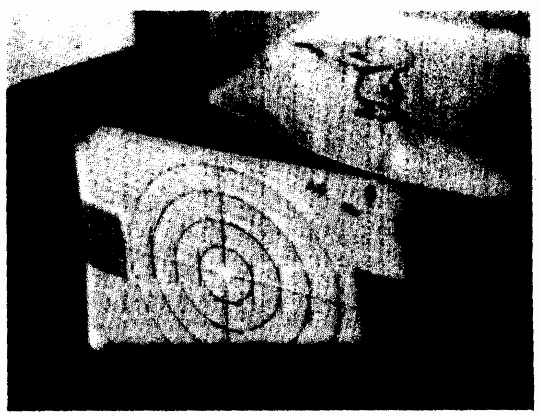
On Friday, April 22, a low-intensity beam was injected from the Main Ring into the Saver at the E0 straight section. There followed 19 hours of tuning the injection line and gradually steering the beam through the early part of E sector with the correction dipoles after which the beam was lost. This tuning led to the realization that the Main Ring and the Saver magnetic fields were mismatched by about 1%, so the current in the Saver bus was raised by 5 amps. After a final adjustment of one correction dipole about one-third of the way into E sector, the beam was suddenly transported all the way to the present end of the line, a makeshift beam dump one-third of the way around the ring in the Transfer Hall. There were no measurable beam losses in E and F sectors and no assistance from any of the correction dipoles other than the first few in E sector. This sudden surprise was of course greeted by applause and elated cheers by the twenty or so people gathered in the Main Control Room at 6:23 p.m. Saturday.

The rest of the weekend and the next were spent fine-tuning the orbit to center it at each quadrupole. The new beam position monitoring and beam loss monitoring systems were tested with beam for the first time and performed beautifully (see next article by Bob Shafer). Dramatic computer-generated color displays showed the location of the beam in the Saver vacuum pipe to a precision of 1 mm over the 2 km distance (see cover). The digital information from the beam position monitors was used to adjust the correction dipoles in a semi-automatic fashion. The beam was also deliberately displaced horizontally and vertically by as much as one inch from the centerline of the magnets to look for aperture limitations or misaligned magnets. As each displacement was made, the beam position monitoring information was read by a new computer program which instantly recalculated the currents in all correction elements necessary to re-center the beam at each position monitor. The ability to displace the beam by these large amounts with no beam losses over the 2 km path demonstrates the precision to which the more than 300 magnets in E and F sectors are aligned.

Progress was so successful that no further Saver beam studies will be conducted until a closed orbit is attempted early in June. This attempt now awaits only the cooldown of sectors A and B and completion of the power system for the same two sectors.

On May 2, the final two cryogenic beam line elements were installed in the ring (two spool pieces at A-47 and A-49), thus physically "closing" the ring. With record speed by the hookup/leak check teams, A-sector was declared leaktight by 2 p.m., May 4. Meanwhile, sectors C and D had been cooled to liquid helium temperatures and their 4000-amp power systems completed. During the weekend of May 7, sectors C and D were operated at 660 amps (Doubler injection energy).

Progress is not always unaccompanied by stumbling blocks. As this issues goes to press, we are still diagnosing a problem in C sector which prevents the current from being ramped to 660 amps rapidly without quenching the superconducting magnets. Nonetheless, the Accelerator Division is hoping for an attempt at circulating beam early in June.



Beam illuminating fluorescent screen in front of dump at A0.
- Bull's-eye! 6:23 p.m. April 23, 1983

# THE ENERGY SAVER BEAM POSITION MONITORING SYSTEM

Bob Shafer

The Energy Saver requires the simultaneous operation of many control systems in order to run. The systems include Vacuum, Refrigeration, Power Supply, Quench Protection, and Correction Element Systems, as well as the Beam Position Monitor (BPM) and Beam Loss Monitor (BLM) systems. Unlike the other systems, the BPM and BLM systems could not be tested until the Energy Doubler injection studies on April 22.

The BPM detector is a pair of 20 cm long directional couplers mounted inside the main Saver quadrupole at 4°K. There are 216 detectors in all, half vertical and half horizontal. RF signals induced in these striplines are carried to the adjacent Service Building where special NIM modules, using amplitude-to-phase (AM/PM) conversion, generate both analog position and intensity signals with rise times less than 100 nsec.

This combination of directional couplers and the AM/PM module was tested in the Main Ring and found to give position measurements with a precision of ±30 microns at $3\times10^{10}$ ppb (protons per bunch) and ±500 microns at $1\times10^{8}$ ppb, when the accelerator is operating in batch mode (for fixed target physics). In order to make the same circuit operate in collider mode (bunches separated by several microseconds rather than the normal 19 nsec in batch mode) tuned circuits resonant at 53 MHz were included in the AM/PM circuit. The threshold for reliable operation in collider mode is about $1\times10^{9}$ ppb. The natural directivity of the BPM detector allows it to detect antiprotons in the presence of protons and vice versa (the rejection of signals from wrong-way bunches is about 24 db).

Fast comparators (whose threshold is set by the host computer) on the intensity signal trigger fast self-synchronizing sample-and-hold circuits on every position and intensity signal. The self-synchronization is necessary since the detectors coupled to a single processor are spread over about 250 m, and the signals are skewed in time over about 1 microsecond. The intensity signal is amplitude compressed in a logarithmic amplifier (a forward-biased p-n junction is used) and digitized in about 5 microseconds.

Digital processing proceeds in either of two ways. Normally, up to 64 consecutive position digitizations (at the rate of 1 to 4 times per revolution) are averaged to obtain a closed orbit measurement with minimal errors due to coherent betatron oscillations. These measurements are stored in a 5k byte random access memory at specific times to aid in orbit correction calculations, and are also used to initiate a beam abort if the beam strays beyond a position limit. These measurements are also loaded into a 10k byte circular buffer which is stopped whenever any system fires the abort kicker. These measurements can then be used to reconstruct the orbit prior to the abort.

The second digital processing stores the digitized value of both the position and intensity for a single passage of beam. This requires about 300 nsec of $2\times10^8$ ppb (i.e. about $3\times10^9$ protons) which is normally not expected to quench the magnets. Such a beam is very useful in beam tuning. This mode of operation utilizes computer-downloaded gate delays and gate widths which are triggered by encoded timing signals on the 10 MHz Saver clock. Coincidence resolution times between the clock signal and the beam are obtainable with 200 nsec resolution, allowing the following of a single bunch of particles around the ring in collider mode. This processing method is also useful for injection and first turn studies.

The BLM detector is a 110 cc argon-filled sealed-glass ion chamber operated at about 2000 volts. There are about 220 such detectors around the ring. They are coupled to 4-decade logarithmic amplifiers with a 50 msec decay time constant (chosen to match beam induced quench properties of Saver magnets). About 1 nanoamp of dc current is "leaked" into the amplifier to assure a digitizable output even when there are no beam losses. This signal is digitized and stored at 8 msec intervals. Excessive beam losses can also initiate a beam abort.

All of the digital processing is carried out in Multibus. Each system (there are 24) includes three Z80 microprocessors to manage the hardware, the memories, and the link to the Control System. Computer initiated hardware tests are permitted between accelerator cycles and carried out under microprocessor control. These tests include measuring all dc power supply voltages, injecting a dc current into the BPM cables to check cable and detector continuity (the BPM detectors are back terminated), injecting RF into the AM/PM circuits, and ramping the BLM high voltage down and up to induce charge in the current amplifier (the BLM detector interelectrode capacitance is about 2 picofarads). This test thus checks continuity of all cabling and status of the BLM electronics. In addition, all downloaded parameters can be read back for verification. In case of a BPM or BLM failure, their beam abort capability can be defeated by computer control.

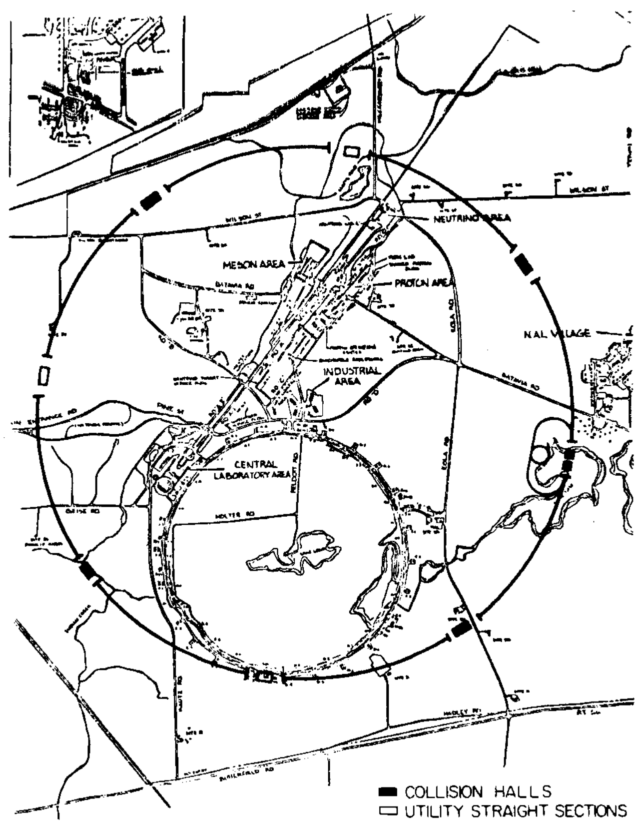
In the Control Room, color displays create linear bar graphs of both horizontal and vertical beam position, as well as logarithmic bar graphs of beam intensities and losses around the entire ring. In addition, any or all of the data stored in the random access memories (a total of 250k bytes) can be read into the host computer data base for beam orbit calcutations. On April 22, orbit correction algorithms applied to the single pass position measurements corrected the orbit to about ±1 mm in about 3 injection cycles. (See the cover illustration on this issue.) Based on the success of these tests, obtaining a closed orbit in the near future appears to be assured.

Many groups at the Lab participated in implementing the BPM and BLM systems. The Magnet Factory provided the BPM detectors, the Accelerator RF Group provided the AM/PM circuits, Controls Group provided the BPM analog processing hardware, Research Services provided the Multibus hardware, Radiation Physics provided the BLM detector and electronics, and Accelerator Operations provided the software applications programs and color graphics displays. So all the Lab can share the credit for the successful operation of the BPM and BLM systems.

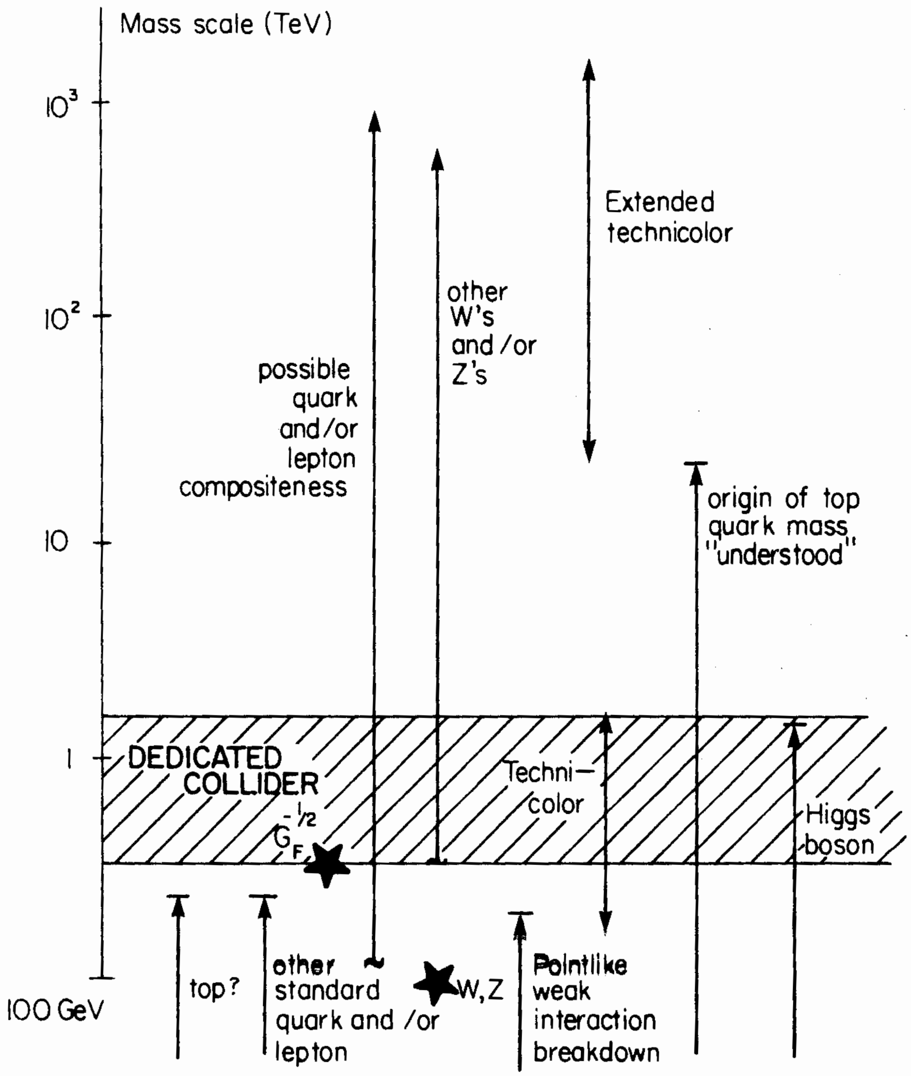
## THE FERMILAB DEDICATED COLLIDER

A **short article in last month's *Fermilab Report* announced that Fermilab is proposing** to the HEPAP Subpanel on Long Range Planning that we build a Dedicated Collider on the Fermilab site. The purpose of this article is to review the proposal in more detail.

The Dedicated Collider (DC) is a $\bar{p}p$ collider operating at a center-of-mass energy of 4 to 5 TeV with four interaction halls and a luminosity of more than $10^{31}$ cm$^{-2}$ sec$^{-1}$. Included is a 10-GeV electron ring with two interaction regions to intersect the 2 to 2.5 TeV proton ring for ep collisions. Construction could begin in October 1985 with the ring complete and cold by April 1989. The accompanying sketch illustrates the proposed ring siting.




Layout of the Dedicated Collider on the Fermilab site.




Energy landmarks.

The Dedicated Collider ring fits gracefully within the present Fermilab site and can make use of the Tevatron as an injector for both protons and antiprotons. It also makes use of existing Fermilab superconducting-magnet and refrigeration-system technology to provide a rapid and economical way to more than double the maximum U.S. and, indeed, world hadron collider energy. This very high energy, good luminosity, and large available running time will increase the potential physics productivity of the U.S. program by orders of magnitude. The ep option is competitive with any existing or planned ep facility and it could be upgraded to a 40 GeV×2 TeV collider which would be unique in the world.

The Dedicated Collider is designed to have a total of six experimental areas, four major experimental areas for $p\bar{p}$ collisions and two for ep collisions. Further, the Tevatron fixed-target program will no longer share the accelerator with the TeV I collider and can therefore operate at full efficiency. The $p\bar{p}$ luminosity is in excess of $10^{31}cm^{-2}sec^{-1}$ and the ep luminosity is $6\times10^{31}cm^{-2}sec^{-1}$. The first stage of this project can be chosen to emphasize either the ep option or the $p\bar{p}$ option, depending upon the scientific priorities perceived to exist at the time of decision (approximately 1986). No matter which option is chosen, it will be Laboratory policy that the fixed-target Tevatron II physics program will not be compromised either in support or in operation by the construction program for the Dedicated Collider.

Decoupling the Collider physics from TeV II results in a substantial gain in productivity for the fixed-target program. This will increase utilization by considerably more than a factor of two by the elimination of end effects in switching between programs. More importantly, experiments will be permitted longer dwell times in beam lines, a process that is well know to increase greatly the productivity of this kind of research.

## Physics

The high energy and good luminosity of the DC suffices to address the physics issues in this 500 to 1000 GeV effective-mass domain. This is exemplified by the table at the top of the next page which shows the attainable mass scale for many hypothetical particles. Theoretical high-energy physics is at an impasse after a decade of remarkable progress. An impressive representation of theorists have publicly pleaded for experimental illumination, especially in the effective mass range well "beyond the W." There is now a proliferation of speculations as to how to extend the standard model. The graph on page 7 illustrates this and emphasizes the 1-TeV mass range as particularly rich in candidates for refining our view of the physical world. In the context of world physics, we note the attention being given to the effective-mass region near 100 GeV by LEP and SLC in $e^+e^-$ collisions, by the CERN collider in $p\bar{p}$ collisions, and possibly HERA in ep collisions. There is much to be learned in this energy domain, but it seems clear that by the end of the decade there will be an urgent need to look well beyond that mass scale.

Mass limits attainable in the DC for production of 100 events at $\int dtL = 10^{38} cm^{-2}$. The two columns correspond to different assumed parton distribution functions. The "gluon-poor" distributions are those of Owens, Reya, and Duke. The "gluon-rich" distributions are those of Baier et al. (as used at the 1982 Snowmass study).

| Particle | Mass limit GeV/$c^2$ "Gluon-poor" | Mass limit GeV/$c^2$ "Gluon-rich" |
|---|---|---|
| Standard model: | | |
| Higgs scalar | 135-220 | 170-340 |
| Heavy fermion | 320 | 395 |
| Jet pair mass | >700 | >1000 |
| New gauge bosons: | | |
| W' or Z' | 1200 | 1200 |
| Supersymmetric partners: | | |
| squark | 215 | 300 |
| gluino | 400 | 500 |
| Techniparticles: | | |
| octet | 345 | 500 |
| sextet | 330 | 500 |
| triplet | 260 | 340 |
| Higgs-like scalars: | | |
| $P_8$ | 640 | 1400 |
| $P_0$ | 400 | 960 |
| Compositeness (hadron jets): | | |
| LH scale | 3000 | 2200 |
| RH scale | 2500 | 1800 |

The Tevatron I collider provides the first step in this exploration. In reaching the mass range 200-400 GeV, TeV I will provide a major stimulus to go further. The DC covers the 500 to 1000 GeV range. This mass range, while only a factor 2-3 above TeV I, may well be an especially rich one. It is very arguable that this is the natural mass scale needed to understand the "Higgs sector" of electroweak physics.

No one has yet built an ep colliding-beam facility. Electron-proton collisions, which have yielded so much insight into hadron structure in the past, have no less promise for the future. Even setting aside production of new states in ep collisions, the study of "conventional" phenomena such as QCD jets or weak-interaction form factors should be especially fruitful. ep collisions share many of the features of simplicity possessed by

$e^+e^-$ collisions, as well as having some of the richness and higher energy of the phenomena seen in hadron-hadron colliders. If the $p\bar{p}$ phenomena differ in any essential way from $e^+e^-$ collider phenomena, then it is important to have means of interpolating between the extremes. ep collisions provide that interpolation.

## Energy

The bulk of the proposal addresses the design and physics of a 4 TeV collider (2 TeV against 2 TeV), but there do exist options which give us considerable confidence that we can actually achieve close to 5 TeV at little or no cost increase. These include increased magnet "packing," higher magnetic field, and larger radius.

## The Colliders

In order to attain the design luminosity of $(1\text{-}4)\times10^{31}$ $cm^{-2}sec^{-1}$, the $p\bar{p}$ collider stores 44 bunches each of protons and antiprotons ($10^{11}$/bunch) with electrostatic deflectors used to separate the bunches between collision points. The TeV I system of $\bar{p}$ accumulation is used, with injection into the DC at E0 at 1 TeV. The ep collider has 80% beam polarization with spin rotators to provide longitudinally polarized beam at the collision points. The electron ring is of appropriate energy to serve as injector into a Stage II 40-GeV electron ring concentric with the DC ring.

## Costs

The project is being proposed in the most conservative way, following Saver experience in great detail. In this way, the costs must be overestimated, since experience usually results in improvement. Fermilab has ten years of experience in superconducting-magnet R&D. This engenders a sharp discrimination between changes that may require extensive R&D and those that may be undertaken with confidence. The construction cost is $362M for the $\bar{p}p$ option, with an incremental cost of $60M to acquire ep physics. Alternatively, we estimate a cost of $396M for the ep option, with an incremental cost of $25M for adding $\bar{p}p$ physics. To this should be added approximately $10M in PE&D and R&D costs. The choice of ep vs $\bar{p}p$ as first priority need not be made until 1986. Although detectors have not been considered in any detail, a plausible allocation for detector costs is $120M for the $p\bar{p}$ option and $50M for the ep option.

## Schedule and Manpower

Crucial dates are the following:

| | |
|---|---|
| August 1983 | Refined conceptual design and request for FY85 construction funding at the level of $10M. |

| | |
|---|---|
| July 1984 | Final design after review by DOE for FY86 budget cycle. Completion of all R&D essential to achieving the design. |
| October 1984 | Beginning of procurement of long lead-time items, tooling, and so forth. Begin A&E work, some site preparation. |
| October 1985 | Beginning of assembly of magnets, refrigeration. Begin civil construction. |
| April 1989 | Cooldown of entire ring and beginning of commissioning. |
| September 1989 | Physics. |

Allocation of manpower to this task will largely come from people now involved in Saver, TeV I, and TeV II construction activities. Meticulous attention has been paid to giving the Tevatron program enough support to be able to operate and improve the Saver, beam lines, and TeV I reliability and intensity. The Laboratory manpower growth is minimal (~5%), but there will be problems of matching skills between what we have and what we need.

## Conclusion

The 1981 Subpanel on Long Range Planning chaired by George Trilling, recommended "a start by the mid 1980's on a new high-energy construction project...". Examples of such a new facility cited in that report are "an electron-proton collider or a less-expensive high-luminosity ($L \sim 10^{33} cm^{-2} sec^{-1}$) hadron-hadron collider built in the ISABELLE tunnel; a second proton collider ring at Fermilab dedicated to $p\bar{p}$, pp, and/or ep collisions, an $e^+e^-$ collider using superconducting cavities (as proposed for CESR II), or a combination of smaller facilities, one of which might be a major non-accelerator facility."

The Fermilab Dedicated Collider provides an excellent, practical solution to this perceived need for a new facility. But most important, it will produce the first-class science that is required by the rapid evolution of the field. By 1989, there will be great pressure to explore physics at multi-TeV energies beyond TeV I.

The basic philosophy underlying the design is to minimize research and development and capitalize on the large and successful Fermilab R&D programs of the past several years. In this way, the Dedicated Collider can be built rapidly, using designs and estimates of costs and schedules based on actual experience.

Finally we note that the Dedicated Collider is an evolution of the Fermilab Site Filler which has been part of the Laboratory's long-range planning since 1972. In 1974, Robert Wilson wrote in **Scientific American** (230, 72, 1974):

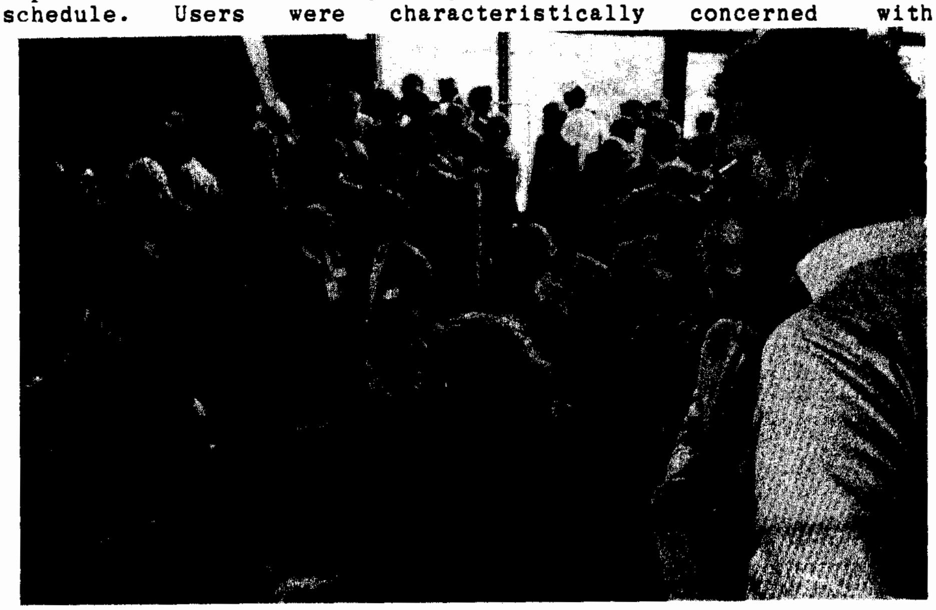
"The largest superconducting ring we could build within our present boundaries would have a circumference of about 10 miles. If the facility were designed as an intersecting-storage-ring system, it might enable us to reach collision energies of several million GeV. If the experiments we are now capable of doing do not yield the knowledge we desire, or, what is more likely, if the new knowledge makes it irresistible to discover what happens at very much higher energies, we are confident those energies can be achieved at our laboratory on the Illinois plain."

# THE FERMILAB ANNUAL USERS MEETING APRIL 22-23, 1983

Maris Abolins
Michigan State University

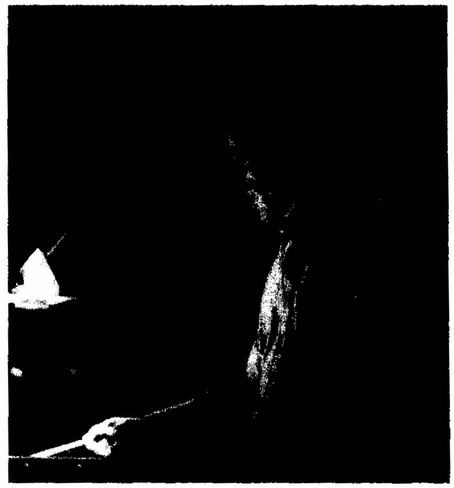
In an atmosphere pregnant with promise, a record 370 users met at Fermilab on April 22 and 23 for the 15th Annual Users Meeting. The gathering took place in the midst of activities to bring beam through one third of the Energy Saver. In detailed reports, Leon Lederman and his staff showed that the ring was nearing completion and that there could be circulating beam as early as June. The ebullience of the moment was stimulated by an awareness of the astonishing successes in Europe and by the realization that pivotal decisions would have to be made for the United States to regain a leading position in the field.

The two-day program included talks by Leon Lederman, Universities Research Association president Guy Stever, and the Director for Energy Research at the U.S. Department of Energy, Alvin Trivelpiece. Of particular interest to users were presentations by Fermilab personnel on the status of Laboratory facilities for the upcoming fixed-target program. Particularly lively discussion ensued after presentations by Ken Stanfield on the Experimental Areas and by Taiji Yamanouchi about the putative schedule. Users were characteristically concerned with



**Afternoon coffee break during the Annual Users Meeting.**
(Photograph by Fermilab Photo Unit)

Alvin Trivelpiece, Director of Energy Research for DOE.



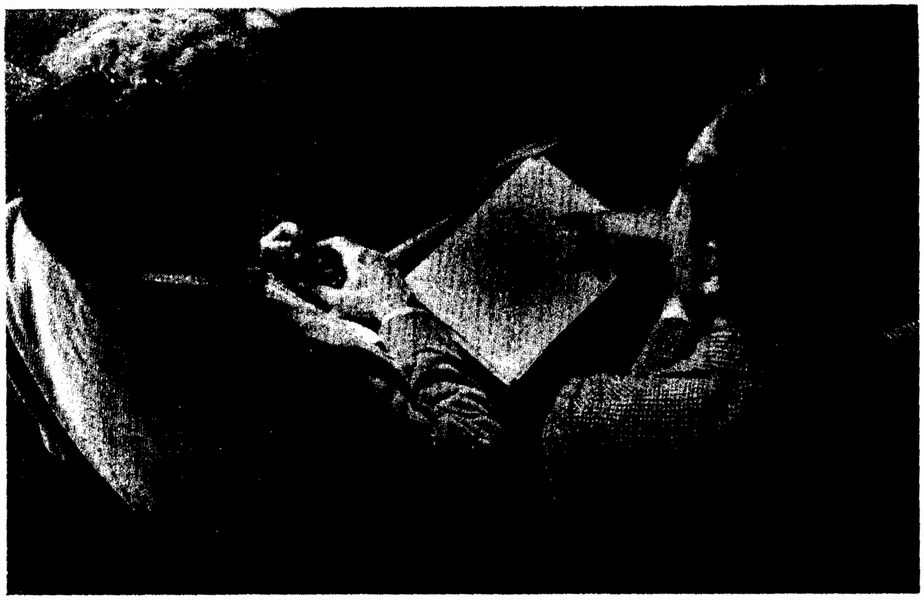
Stan Wojcicki, Chairman of The Woods Hole Subpanel.

seeming delays in schedules that prevented their resumption of an active experimental program at the earliest possible moment.

The situation with TeV I, the proton-antiproton collider program at Fermilab, was aired in talks by John Peoples who described the design and projected construction schedules for the antiproton source, by Alvin Tollestrup who presented a status report on the CDF flagship detector for TeV I and by Dave Johnson who outlined the possibilities for the other interaction region in DO. The inevitable comparisons with the CERN program had to be made. Reasons for optimism emerged based on higher energy (2 TeV vs 0.54 TeV) and higher anticipated luminosity, permitting the exploration with higher statistics of "known" phenomena such as $Z^0$'s, and W's, and perhaps opening thresholds to new and unexpected physics.

Al Brenner reported on the Computing Facility and described the present saturated state of the Cyber system. He outlined the schedule for the acquisition of an upgraded system which calls for at least a factor of two more computing power to be installed by Christmas 1983. This new system will take care of the computer needs for only the next two to three years. Brenner emphasized that a new architecture is really needed to accommodate the long-term computing requirements at Fermilab.

A highlight of the meeting was a Friday afternoon session devoted to a discussion of Fermilab options presented to the HEPAP subcommittee on New Facilities (Woods Hole Panel). In a brilliant introductory statement Stanley Wojcicki, the



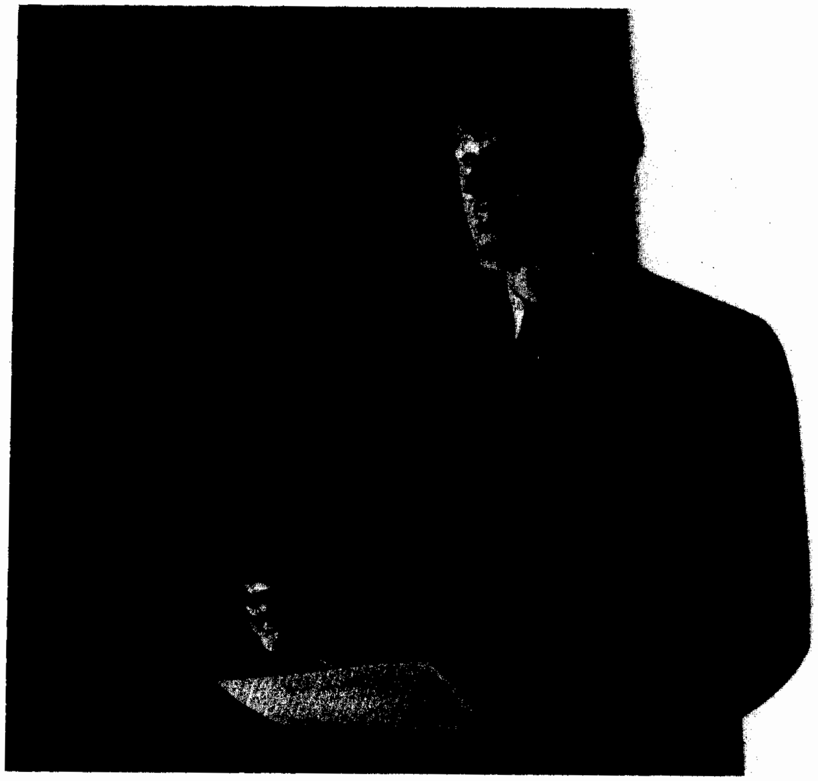
Jerome Rosen (left) of Northwestern University and Al Abashian of Virginia Polytechnic Institute and State University converse at the Annual Users Meeting.
(Photograph by Fermilab Photo Unit)

chairman of the panel, outlined the charge to the panel, the method by which it hoped to arrive at its recommendations, and the good news and bad news confronting U.S. particle physics. J. D. Bjorken gave a short summary of the Fermilab proposal for a 2 TeV × 2 TeV Dedicated Collider (DC) and Maury Tigner summarized the results of a Cornell workshop on a 20 TeV × 20 TeV pp collider, the so-called "Desertron." [Editors' Note: See separate articles on these in this issue.] A lively "Town Meeting" discussion followed involving the users, the speakers, panel members, and Laboratory personnel debating the pros and cons of the various options. A feeling of optimism for the future could be sensed in the animated discussions which continued throughout the dinner hour at the Users Center.

In his talk on Saturday regarding DOE's FY84 Science Budget, Alvin Trivelpiece said nothing to dispel that optimism by pointing out that the climate for basic research in Washington is good, both major parties would identify themselves as friends of basic research, and the administration is open to suggestions for major new initiatives in science.

Martin Perl of SLAC, co-recipient of the prestigious Wolf Foundation prize in physics with Leon Lederman earlier this year, discusses the history and possibilities for future lepton searches and urged Fermilab users attending the Annual Meeting to "enlarge your ways of thinking about heavy leptons."
(Photograph by Fermilab Photo Unit)

Some of the new physics that may be studied with the new machines was summarized by Martin Perl of SLAC who gave a talk entitled "The Status of Lepton Searches," a specialty of his for which he received the 1982 Wolf Prize for physics, an honor he shared with Fermilab Director Leon Lederman. The conference ended with an interesting discourse on computing and its ramifications by 1982 Nobel Laureate Ken Wilson of Cornell University. He argued persuasively that we must look to the revolution in microprocessors to provide the basis of an industrial recovery. Moreover, he presented a scenario whereby the funding of the "Desertron" could be effectively obtained from computer and electronics companies without having to look to the federal government. On this euphoric note the attendees dispersed to continue their preparations for the imminent Tevatron era.



Maris Abolins of Michigan State University and Chairman of the Users Executive Committee at the Users Meeting last month.
(Photograph by Fermilab Photo Unit)

# 20-TeV HADRON COLLIDER WORKSHOP

**Maury Tigner**
Cornell University

## Introduction

The general subject of proton colliders in the 20 TeV range has been discussed by the world community of particle physicists for some time. Two ICFA workshops, one in 1978 at Fermilab and one in 1979 at CERN, considered this type of accelerator among other potential candidates for truly frontier instruments in high-energy physics. At these workshops general techniques and schemes for reaching very high energies were discussed while costs and engineering details were left for the future. In the intervening four years, magnet and colliding-beam technologies germane to hadron colliders have made substantial advances.

Inspired by these technical advances and the enormous scientific opportunities that would be opened up by a 20-TeV hadron collider, leaders in the field of elementary particle physics have suggested that we exploit the new technology and begin construction of such an accelerator at the earliest possible date. An examination of this suggestion by the U.S. HEP community was begun as part of the 1982 summer study of the Division of Particles and Fields of the American Physical Society held at Snowmass, Colorado.

Building on the Snowmass findings[1,2] and encouraged by the administrations of the U.S. laboratories engaged in particle physics as well as by the U.S. Federal Administration and many scientists in the field, this workshop was convened to consider further the technical issues pertaining to a 20-TeV collider facility.

Forty U.S. and European experts in accelerator science and accelerator and construction technology met March 28 through April 2, 1983, the issue of which is a report to the U.S. HEP community. In it we attempt to offer the best technical advice we can give today with regard to the feasibility and appropriate time scale for a 20-TeV class hadron collider.

In particular, we have tried to answer the questions:

- What, if any, are the interesting technical options for a 20-TeV hadron collider in the luminosity range $10^{31}$ to $10^{33}$ $cm^{-2}sec^{-1}$?
- If such options exist, what engineering and technological developments are needed before we start to build?
- How long might the preparations take?
- What might be the economics of such a facility?

In carrying out this examination we divided ourselves into four task groups, each coordinated by a secretary. The task groups and their secretaries were:

- Accelerator Physics — D. A. Edwards
- Magnets and Cryogenics — C. Taylor
- Systems Engineering — B. D. McDaniel
- Sources and Injectors — R. Martin

Under the rubric of Systems we have subsumed civil construction, accelerator assembly, auxiliary systems, facilities, shielding, etc.

## Accelerator Physics

This task group was concerned with interaction region optics, good field aperture requirements, extra aperture required for $\bar{p}p$ operation, single-beam stability requirements, intra-beam scattering and synchrotron-radiation effects. Although all of these issues will need to be addressed again in detail if a serious design study is launched, none of them seem to present major difficulties. Existence proof level solutions for needed optics were found and are displayed in the report. Evidently an aperture of about 1 inch will be adequate from both beam-containment and stability points of view. Configurations permitting both head-on collisions of bunched beams and collisions of continuous beams crossing at a small angle were considered. Luminosities up to $10^{33}$ appear to be feasible.

## Magnets and Cryogenics

Costs and technical feasibility for five possible magnet systems were discussed: i) direct use of Saver magnets, ii) use of "superferric" magnets at 2.5 to 3 Tesla, iii) use of a small-aperture version of Saver or CBA magnets at 4-6 Tesla, iv) use of improved Nb-Ti conductor at 2 Kelvin with or without iron and, v) use of $Nb_3Sn$ with field up to 10T and operating temperature above 4K. Portions of the various systems contributed to a lively debate. Although many specifics remain to be thrashed out, it was generally agreed that more than one of the proposed systems could be viable candidates for a 20-TeV ring.

## Systems Engineering

This task group considered the accelerator system and associated facilities as a whole, including construction and accelerator assembly methodologies, shielding and utility requirements, etc. Fortunately a wide range of possible construction technologies exist. In studying optimization of an integrated collider facility based on the various possible magnet systems and at various possible sites, many of these construction methods will need to be considered in detail. No matter what system may ultimately be adopted, the application of mechanization to most aspects of accelerator construction, installation and maintenance will be crucial.

Shielding requirements, at least for luminosities up to $10^{33}$, with head-on collisions of bunched beams, will be easy to meet. Six meters of earth cover or substantially less under some circumstances will be entirely sufficient.

Surprisingly, the utility requirements will be relatively modest. At full operation, it is expected that about 75 MW of electric power may be required.

### Sources and Injectors

The fact that the injector system for a 20-TeV collider will, in many aspects of performance, be the equivalent of the largest accelerator complexes in operation today shows the magnitude of the project envisioned. The existence of these complexes shows the technical feasibility of the requisite injector system, but application of the technology to be used for the main collider will be needed to control the cost. Technology for producing antiprotons sufficient for luminosities of $10^{31}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ will be in hand shortly. Technology for producing proton beams of the intensity and the phase space density needed for luminosities up to $10^{33}$ is in hand today.

### Cost Estimate

Even with assured technical feasibility, cost considerations for a 20-TeV ring will dominate. For this reason, the workshop participants spent considerable effort in attempting to make conservative estimates and to identify areas of important cost uncertainty. Cost estimate breakdowns and uncertainty assignments are given in the workshop report in tabular and graphical form. Briefly, we concluded that if we started today, using Saver magnets, we could build a 20 TeV on 20 TeV $p\bar{p}$ collider with luminosity $\sim 10^{31}$ for a cost somewhere between 2.4 and 3 (G$). After three or four years of engineering development, we might reasonably expect to be able to build a 20 TeV on 20 TeV pp collider with luminosity $\sim 10^{33}$ for a cost somewhere between 1.3 and 2 (G$) including the cost of a new lab. By lowering the beam energy to 10 TeV, at least 25% of the cost could be saved and probably more.

## Summary of Findings and Recommendations for Further Study

We see no fundmental accelerator physics reasons which would prevent the successful operation of a 20-TeV collider at high luminosity.

More or less standard solutions to collision optics are feasible at these energies using existing magnet technology.

A cost effective hadron collider in the 20-TeV class must be based on superconducting magnet technology.

A $\bar{p}p$ collider based on magnets now in production could be built immediately, but would be unnecessarily costly.

Moderate R/D of an engineering nature, utilizing superconductor now in commercial mass production could produce cost effective magnets in the 2.5 to 6 Tesla range.

R/D of an engineering nature, utilizing advanced conductor now in the commercial pilot production stage, could produce an economically attractive magnet in the 6 to 8 Tesla range.

The low heat losses for projected designs indicate that the refrigeration requirements for a 20-TeV machine can be met with existing technology.

The assembly, civil works, and bringing into operation of a 20-TeV collider facility will be challenging, but not overwhelmingly so. Technologies for surmounting the challenges appear to be available.

There seem to be no unusually difficult requirements for standard accelerator components such as control, rf, vacuum, and beam manipulation.

Existing source and injector technology is adequate for $\bar{p}p$ mode operation at luminosities at least up to $10^{31}cm^{-2}sec^{-1}$. Higher luminosities in this mode will require substantial technology development.

For luminosities up to $10^{33}cm^{-2}sec^{-1}$ we foresee no unusually difficult shielding requirements even for the most extreme cases of sudden beam loss.

We believe that, if the necessary effort could be mounted, that within a period of four years or less an appropriate magnet system could be in prduction with plans for an integrated accelerator facility in a state of construction readiness.

## Summary of Recommendations for Further Study

In the report a number of recommendations for further study are put forward. Here we present their sum effect rather then a detailed recounting.

While the general near term technical and economic feasibility of a 20-TeV class hadron collider seems not to be in doubt, it is clear that the optimum overall system choice must rest on detailed design studies for a number of comparable, integrated accelerator system possibilities. Thus the central focus of further studies should be in the outlining and detail of integrated systems including the magnet system with refrigerator and its assembly, housing and installation in place as well as of the needed ancillary facilities. One way of accomplishing this would be to make three integrated system designs centered around 2.5-3T magnets, 5-6T magnets, and 8T (or higher) magnets. Once in possession of these more-or-less detailed designs, including siting requirements, an objective choice among them could be made and final design begun. In the meantime, we hope that at the various laboratories magnet development efforts, focused on magnets suitable for a 20-TeV accelerator, can intensify and that the extensive/numerical tracking calculations needed to define magnet quality can go forward at an early date.

# BERKELEY WORKSHOP ON COLLIDER DETECTORS

Peter Nemethy
Lawrence Berkeley Laboratory

The "Workshop on Collider Detectors: Present Capabilities and Future Possibilities" was sponsored by the Division of Particles and Fields of the APS and hosted by Lawrence Berkeley Laboratory. It was held at LBL from February 28 to March 4, 1983. The Workshop focused on the problems posed by high luminosities at hadron colliders, considering luminosities on a continuous range from $10^{29}$ to $10^{34}$ $cm^{-2}$ $sec^{-1}$ and picking two specific center-of-mass energies, 1 TeV and 20 TeV.

Of the 94 participants 18 were local (UCB and LBL), 30 came from the national laboratories and industry, 35 from U. S. universities, and 11 from Europe. The participants divided into the five working groups tabulated below:

| Working Group | Group Leader | Scientific Secretary |
|---|---|---|
| Tracking Detectors | Don Hartill | David Herrup |
| Calorimetry | Bernie Pope | Melissa Franklin |
| Triggers | Mel Shochet | Mike Ronan |
| Particle Identification | Dave Nygren | Rem Van Tyen |
| Detector Systems | Barry Barish | Mark Nelson |

In order to keep the Workshop from becoming a conference, there were no general lectures except for three invited talks on collider experience at the ISR and SPS $p\bar{p}$ Collider by Bill Willis, Carlo Rubbia, and Marcel Banner. Other invaluable input consisted of theoretical estimates of relevant cross sections by Bob Cahn and of high $p_T$ jet behavior by Frank Paige.

The working group on Tracking Detectors concluded that tracking at luminosities of $10^{33}$ $cm^{-2}$ $sec^{-1}$ is hard but possible. It requires high wire density drift chambers. With 2 mm wire spacing the particle flux can be kept to less than 2 $MH_2$/wire and $\bar{n}$(events)/picture = 2 because the drift time is of order 40 ns. Multiple sampling is essential to sort out events. For a $4\pi$ coverage detector, the number of elements is of order $10^5$. Vertex detectors appear practical only at luminosities of $10^{32}$ or less.

The working group on Calorimetry examined a variety of calorimeters. It concluded that scintillation sampling calorimeters can be made quite fast, with time windows as short as 20 ns leading to very little event overlap at $10^{33}$ luminosity: [$\bar{n}$ (events)/gate = 1]. For hadron calorimeters there will be some resolution loss with such short gates. Radiation damage is a concern and tower geometry is essential.

The Particle Identification group, examining a variety of methods (Cherenkov, transition radiation, dE/dx, TOF, synchrotron radiation) found that $10^{33}$ could be dealt with, with segmentation dictated as much by jet multiplicity as by event overlap. Even as unlikely a technique as time-of-flight identification of heavy stable particles appears possible at high luminosity.

The working group on Triggers and Processors did not come up with "no event overlap" as the top of its wish list. Event overlaps of $\bar{n}$(events)/gate as much as 5 force only a moderate rise in thresholds in a well-designed calorimetric trigger. With an analogue storage dead-time-less first layer, a multiple-level-CDF-type trigger system can handle $10^{33}$ but will write tapes at 10 events/sec.

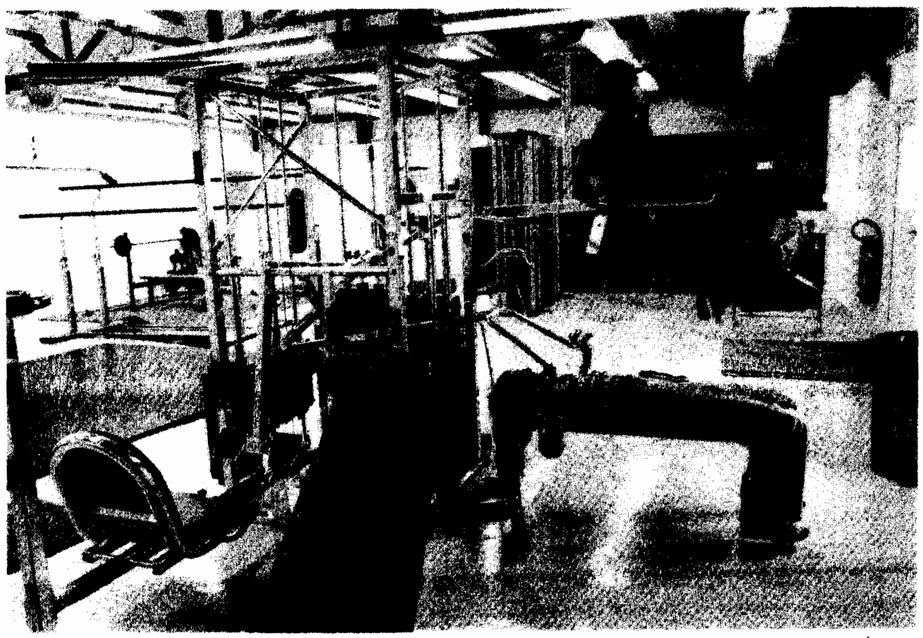
The systems group tackled many subjects. It examined 20 TeV detectors and concluded that they would not be "monsters," would not in fact be much different from 1 TeV ones. In fact, some problems become easier at 20 TeV. The achieved "state of the art" in luminosity defined by published physics, appears to be $10^{31}$. For $4\pi$ detectors, costs will be very large; a simple scaling exercise came up with 3-4 CDF units for a $4\pi$ do-everything detector for $10^{33}$. Computing loads also grow quite seriously.

The Workshop conclusion appears to be that there are technical solutions for $10^{33}$ luminosity, but everything is difficult. Both high luminosity and jet multiplicity push us to very high segmentation and therefore large costs. For the future, all groups agreed that we need much R&D for new solutions, rather than scaling up present detectors to more channels.

NEW VILLAGE GYMNASIUM TO OPEN IN MAY

For many years, employees and the user community have suggested the need for an indoor gymnasium. Early in 1979, the Fermilab Recreation Committee prepared the first proposal for a complete gymnasium facility which was very ambitious in its scope. This proposal was presented to the Laboratory but was not accepted because of the great expense. Although the Laboratory was favorable to the project, the money required wasn't available.

With the formation of the Quality of Life Committee, another group of interested people again pursued the possibility of such a facility. In 1980, members began determining the miniumum requirements for a gymnasium complex, keeping in mind both the needs of athletes at Fermilab and the need for keeping costs down. They determined that the primary requirement was a building with a full-scale basketball court, in which both tennis and volleyball courts could be accommodated. They also felt that locker rooms were of utmost importance. The final plan accepted

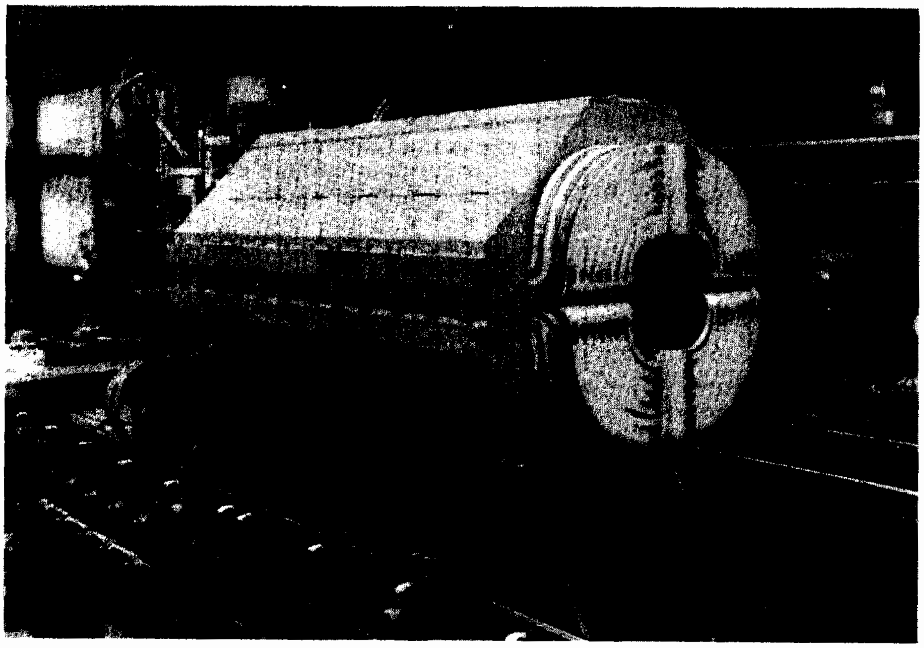


Carol Wilkinson of the University of Wisconsin and Glenn Smith of Fermilab try out the Universal weight machine in the refurbished exercise room in the Recreation Complex.
(Phoograph by Fermilab Photo Unit)

by the Laboratory proposed a very basic shell building erected next to the existing exercise facility in the Village. Appeals for funding to various outside orgnizations were unsuccessful until the Universities Research Association agreed to provide funding for a minimal facility.

The newly completed complex contains the main gymnasium and an expanded exercise room. Locker rooms and showers will be added and be ready for use by fall. The gymnasium is large enough for a collegiate-size basketball court, but can be converted to a tennis or volleyball court by setting up poles and nets. The exercise room has been refurbished and has new equipment, including a weight machine, free weights, and an exercise bike. Additional space has been provided with exercise mats suitable for gymnastics, aerobics, or martial arts practice. Plans for scheduling open recreation time and specific activities are being based on interest groups and their desire to use the new facilities. Requests for use of time and space will be accepted by the Recreation Office.

Use of the Fermilab Recreation Complex will be limited to members only. Membership is open to Fermilab employees, users, contractors, and members of their immediate families. A nominal yearly fee will be charged to pay for a membership key and to help pay for maintenance. Memberships may by purchased in the Recreation Office in Wilson Hall after May 23.



**The first prototype quadrupole for the Tevatron I project.**
(Photograph by Fermilab Photo Unit)

## MANUSCRIPTS, NOTES, LECTURES, AND COLLOQUIA PREPARED OR PRESENTED FROM APRIL 18, 1983 TO MAY 15, 1983

Copies of preprints with Fermilab publication numbers can be obtained from the Publications Office or Theoretical Physics Department, 3rd floor east, Central Laboratory. Copies of some articles listed are on the reference shelf in the Fermilab Library.

### Theoretical Physics

Z. Bang-Rong and C. Chao-Hsi — Family Gauge Symmetry From a Composite Model (FERMILAB-Pub-83/33-THY; submitted to Phys. Rev. D)

S. Fajfer and R. J. Oakes — Twist-Four Effects in Electroproduction: Model Dependence (FERMILAB-Pub-83/37-THY; submitted to Phys. Lett.)

S. J. Brodsky et al. — On the Elimination of Scale Ambiguities in Perturbative Quantum Chromodynamics (FERMILAB-Pub-83/40-THY; submitted to Phys. Rev. D)

J. F. Schonfeld — A New Soluble Approximation to Fokker-Planck Equations (FERMILAB-Conf-83/45-THY; talk delivered at the 49th Semi-Annual Statistical Mechanics Meeting, May 12-13, 1983, Rutgers University, Piscataway, New Jersey)

### General

S. I. Baker — Environmental Monitoring Report for Calendar Year 1982 (FERMILAB-83/29)

R. A. Carrigan, Jr. and W. P. Trower — Magnetic Monopoles: A Status Report (FERMILAB-83/31)

### Physics Notes

T. Nash et al. — Fermilab's Advanced Computer R&D Program (FN-383; invited paper to be published in the Proceedings of Three Day In-Depth Review on the Impact of Specialized Processors in Elementary Particle Physics, Padova, Italy, March 23-25, 1983)

**Colloquia, Lectures, and Seminars**

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|---|---|
| J. Griffin | "Introduction to Longitudinal Phase Space" (Fermilab, April 18, 1983) |
| J. D. Bjorken | "The Fermilab Dedicated Collider" (Fermilab, April 19, 1983) |
| J. Griffin | "RF Manipulation of Beams in the TeV I Project" (Fermilab, April 20, 1983) |
| J. Peoples | "Principles of Stochastic Cooling" (Fermilab, April 25, 1983) |
| R. Shafer | "Implementation of Stochastic Cooling" (Fermilab, May 2, 1983) |
| D. Bogert | "Overview of the Accelerator Control System and Application to TeV I" (Fermilab, May 4, 1983) |
| J. McCarthy | "Extraction and Injection of Beams in TeV I" (Fermilab, May 9, 1982) |
| J. Marriner | "Recent Developments at the CERN AA" (Fermilab, May 10, 1983) |
| C. Hojvat | "Production and Focusing of $\overline{p}$" (Fermilab, May 11, 1983) |

Rich Orr, left, shows Cardinal Joseph Bernardin one of the magnets in the Main-Ring tunnel on his recent visit to Fermilab. Behind Rich Orr (left to right) are Father Jim Roache, Administrative Assistant to the Cardinal, Leon Lederman, and Father Tim Toohig.

(Photograph by Fermilab Photo Unit)

## DATES TO REMEMBER

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|---|---|
| May 30, 1983 | As part of the AAAS Meeting (May 26-31), Detroit, Michigan, a symposium on High Energy Physics will be chaired by Robert G. Sachs, University of Chicago, and moderated by Leon Lederman. Other speakers include Professer Martinus J. Veltman, University of Michigan; Professor Lee G. Pondrom, University of Wisconsin, Madison; and Professor Robert R. Wilson, Columbia University. |
| June 18-24, 1983 | PAC Extended Summer Meeting |