fermilab report

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FERMILAB-84/8 Fermi National Accelerator Laboratory 0090.01

THE COVER: Excavation of the Booster tunnel and cutting off a stairway to build the Booster Target Station for Tevatron I.
(Photograph by Fermilab Photo Unit)

CONTENTS SEPTEMBER 1984

ACCELERATOR SHUTDOWN WORK

J. R. Orr

A great amount of work is being done on the Main Ring and Tevatron while they are shut down this summer. The largest single job is the modification of the upstream magnet leads supports at the end of all TC Tevatron magnets (see the cover and lead story of the last issue of **Fermilab Report** for a discussion of the problem).

About half the total (199) of the TC magnets must be removed from the ring, all 384 modified, and reinstalled in the ring. Both Magnet Factory and Accelerator Division people have been working very hard on this job. The removal and modification are going smoothly, but the reinstallation is somewhat more difficult than had been expected. The welding and leak checking, particularly of the beam tube, are extremely hard to do properly in the cramped conditions of the tunnel and have had to be redone in some cases. The whole job is slightly behind schedule and almost-heroic efforts are being made to catch up.

The D0 overpass is being installed in the Main Ring this summer. This work is going well. It should be noted that the vertical bend magnets needed to complete the ring will not be finished until November.

When we look forward to the start-up at the end of the year, we can predict, as Wellington said about Waterloo, that it will be "a damned close-run thing."

E-617 A PRECISION STUDY OF CP-NONCONSERVATION IN $K\to2\pi$ DECAYS

Bruce Winstein
Enrico Fermi Institute and the Department of Physics
The University of Chicago

R. Bernstein, G. Bock, D. Carlsmith, D. Coupal, J. W. Cronin, G. Gollin, W. Keling, K. Nishikawa, and H. Norton, The University of Chicago; B. Peyaud, R. Turlay, and A. Zylberstejn, CEN, Saclay

Introduction

This experiment is a study of the rates for the long-lived neutral kaon (K_L) to decay into the $\pi^+\pi^-$ or $\pi^0\pi^0$ final states. The existence of these modes of decay, at the level of 10^{-3} in branching ratio, together with some very general assumptions (such as the CPT theorem) tells us that the weak interaction violates CP and T invariance. Specifically we know that the process $K^0\to\bar{K}^0$ does not occur at the same rate as the "time reversed" process $\bar{K}^0\to K^0$. This is the only known violation of time symmetry. These processes--a particle turning into its own anti-particle--can occur since the only distinction between a K^0 and a $\bar{K}^0$ is two units of strangeness and the weak interaction does not respect strangeness conservation. As a result of this asymmetry the K_L itself is not a CP eigenstate but rather is an unequal mixture of particle and anti-particle:

$$|K_L\rangle \sim (1+\varepsilon)\,|K^0\rangle - (1-\varepsilon)\,|\bar{K}^0\rangle,$$

where the complex parameter ε has been measured to be $|\varepsilon| \approx 2.25 \times 10^{-3}$.

The issue addressed by E-617 was whether the CP or time symmetry violation is confined to a $\Delta S = 2$ interaction, the "superweak" hypothesis. Were this the case, the decay rates for the K_L into $\pi^+\pi^-$ and $\pi^0\pi^0$ would be exactly in the ratio of the CP conserving K_S decay rates to the same modes.

We then define the amplitude ratios

$$\eta_{+-} = \frac{\text{amp }(K_L\to\pi^+\pi^-)}{\text{amp }(K_S\to\pi^+\pi^-)}$$

$$\eta_{00} = \frac{\text{amp }(K_L\to2\pi^0)}{\text{amp }(K_S\to2\pi^0)};$$

the superweak hypothesis would then require that

$$\eta_{00} = \eta_{+-}.$$

Motivation

Recent theoretical ideas have given rise to what can be called a "natural" way of accommodating the time-symmetry violation in the so-called standard model and these in turn have motivated several experiments to detect a $\Delta S = 1$ CP nonconserving interaction. In particular, the Kobayashi-Maskawa (KM) model "allows" for CP non-conservation in the weak interaction in a world of six or more quarks. While this model was proposed in 1973, even before the discovery of the (4th) charm quark, the discovery of the (5th) b quark at Fermilab was an important element in the widespread appreciation of the KM model's potential for "explaining" CP non-conservation. The beauty of the KM model is in part that it unifies two seemingly very disparate questions:

(1) Why do the quarks mix in their weak decays (e.g., a c quark can decay to either an s or a d quark)?
(2) Why is time symmetry violated by the weak interaction?

The parameter which controls the $\Delta S = 1$ CP violating interaction in the kaon system is traditionally denoted by ε'. Its relation to the previously defined parameters is given by

$$\frac{\varepsilon'}{\varepsilon} \approx \frac{1 - \left|\frac{\eta_{00}}{\eta_{+-}}\right|^2}{6}.$$

The predictions for ε'/ε depend upon the top quark mass and other parameters of the KM matrix. As a result of constraints on these parameters by a host of experiments, only a limited range of possible values for ε'/ε is allowed. Although the calculations are uncertain, some conclusions emerge:

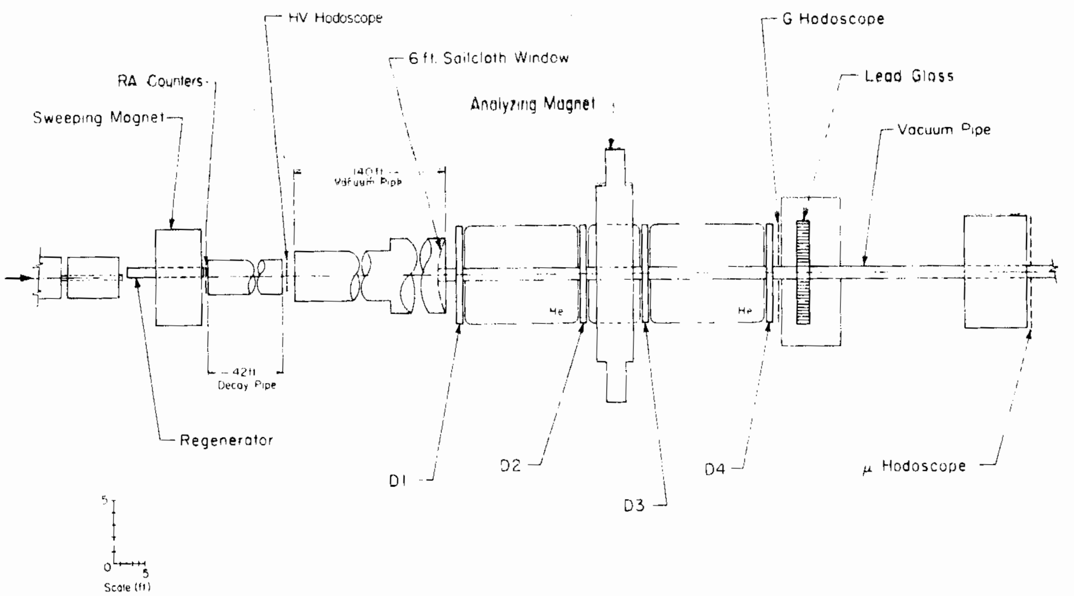
(1) ε'/ε is not equal to zero.
(2) ε'/ε is $\gtrsim 0.005$.

Thus, one should see a departure from unity in the quantity $|\eta_{00}/\eta_{+-}|^2$ of a few per cent.

Experimental Technique

This experiment was performed in the M3 neutral beam line. K_L's were produced at about 5mr using 400-GeV protons; the detector was optimized for $\langle p_K \rangle \approx 100$ GeV/c. This arrangement allowed for a good K_L/n ratio, good K_L flux, and superior resolution for the $K_L \to 2\pi^0$ decay mode.

In order to reduce a major source of systematic uncertainty, two side-by-side and distinct K_L beams entered the region of the detector, shown in the figure that follows.

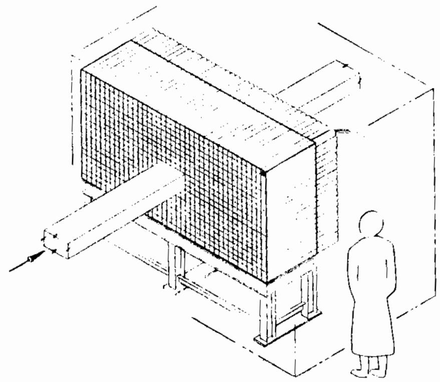


Schematic of the Chicago-Saclay detector

In one of the beams a regenerator, consisting of 1 m carbon and 1/2 in. Pb, was placed to provide a K_S component. K^0 decays were accepted within a 14 m evacuated decay pipe following the regenerator. The data were collected in two phases: the charged and neutral modes. For the charged mode ($\pi^+\pi^-$) running, the trigger required a two particle signature. The tracks were momentum analyzed via a drift chamber spectrometer; thus the invariant mass of the two candidate pions could be reconstructed as well as the decay point which is crucial in determining from which beam the event originated.

This dual beam arrangement has several advantages: no monitor is required as K_L and (the normalizing) K_S decays are collected simultaneously; the detector is equally busy for both K_L and K_S decays; extra "background" tracks produced by the thick regenerator could result in a small loss of events which, however, will be equal for K_L and K_S decays; the roles of the beams are intercharged every pulse by alternation of the regenerator so that any small asymmetries in the detector response are of no consequence.

For the neutral mode ($\pi^0\pi^0$) running, only one change was made to the detector. A thin anti-counter and 0.1 rl lead converter were added immediately upstream of the triggering hodoscope that defined the end of the decay region. By means of this converter, one and only one photon was required to convert; the resultant e^+e^- pair was tracked with the spectrometer, and the pair, together with the remaining three gammas, were then observed in an 804 element lead glass block array as shown in the figure on the next page.



The lead glass array of the Chicago-Saclay experiment

Operation of the Experiment

E-617 was proposed in January, 1979, approved in April, had a brief test run in May, 1981, and a final data taking run between January and June of 1982. The majority of the data came during a 10 week period during which we had primary control over the meson targeting. A major activity during the run was the monitoring of the lead glass array, whose performance was crucial for the $\pi^0\pi^0$ reconstruction. In fact, over the course of the run, only four or five tubes of the 800 ever needed replacement.

Throughout the experiment the drift chambers gave about 200μ resolution while in the lead glass, photon showers could be determined with a (projected) position resolution of about 3 mm and an energy resolution of

$$\frac{\sigma_E}{E} \approx 2\% + 6\%/\sqrt{E}.$$

Analysis

The analysis of this experiment has taken about two years to complete. The primary difficulty was the reconstruction of the rare $K_L \rightarrow 2\pi^0$ mode for which there is copious background. The major steps in the analysis were

(a) the isolation and identification of photon clusters, i.e., patterns of energy deposits in the lead glass which correspond to photons;

(b) the assignment of an energy to each photon. This included correcting for a time dependence in the response of each block and as well for non-linearity;
(c) the reconstruction of the 3-momentum and invariant mass of the candidate kaon from which one could distinguish the two beams;
(d) the understanding, simulation, and subtraction backgrounds;
(e) the simulation of the detector response via Monte Carlo.

The event totals, after subtractions, are given in the table below.

Event Totals for the Chicago-Saclay Experiment

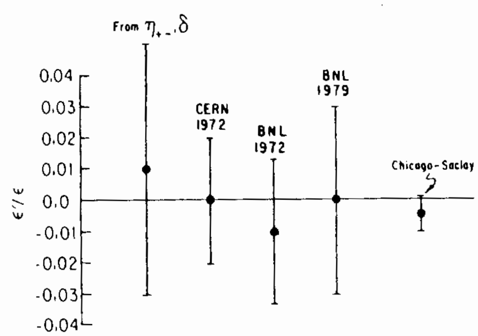
Mode	Events
$K_L \to 2\pi^0$	3142
$K_S \to 2\pi^0$	5663
$K_L \to \pi^+\pi^-$	10676
$K_S \to \pi^+\pi^-$	25752

For comparison, the two most precise previous experiments collected a total of only about 300 $K_L \to 2\pi^0$ events.

The result of the experiment is then

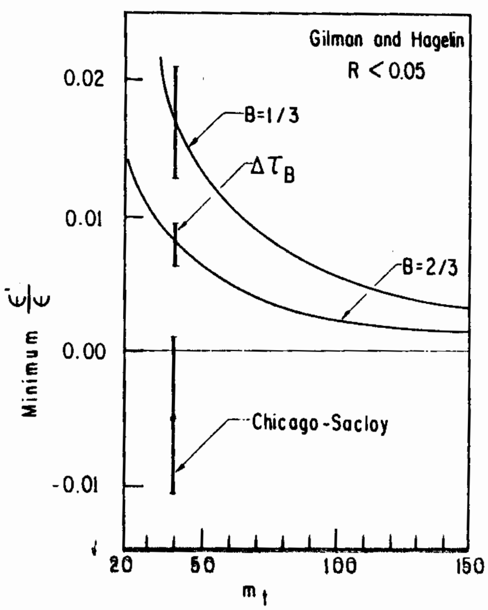
$$\epsilon'/\epsilon = -0.0046 \pm 0.0053 \text{ (statistical)} \pm 0.0024 \text{ (systematic)}.$$

The systematic error is primarily a result of uncertainty in the various background subtractions. The result has been checked by a variety of methods which all give a consistent answer: ϵ'/ϵ is still consistent with zero and is probably not as large as predicted by the KM model.



The Chicago-Saclay result in comparison to previous determinations of ϵ'/ϵ.

In the preceeding figure we show our result in comparison with three previous efforts (and with a determination using a measurement of the K_L semileptonic charge asymmetry, δ). The figure that follows shows our result compared to recent predictions based upon the KM model. The predicted lower bound for



The Chicago-Saclay result in comparison to the lower-bound predictions of Gilman and Hagelin. The dependences of these predictions on the "Bag Factor," B, and upon the experimental error on the lifetime of the bottom quark, τ_B, are shown.

ε'/ε is plotted against the mass of the top quark and we have plotted our point at 40 GeV, the value favored by the $Sp\bar{p}S$ results. The agreement is not good and this could signal a new mechanism for CP nonconservation. However, it is clear that an even more precise measurement is called for, and better calculations are needed.

The Future

Several of us, together with some new collaborators (including a Fermilab group) are attempting to measure ε'/ε about five times more accurately than did E-617. That experiment (E-731) which takes advantage of a new Tevatron beam (MC) together with a superior apparatus, should see its first beam in early 1985.

Final Remark

We are happy to here acknowledge the enthusiastic support of the Meson Department, the Computing Department, the Research Division, the Accelerator Division, and the Directorate throughout the course of the experiment which greatly contributed to its success.

An aerial view of the RF Building at F0, showing construction work on the new addition for antiproton-acceleration equipment.

(Photograph by Fermilab Photo Unit)

1984 FERMILAB ACCELERATOR SUMMER SCHOOL

Frank Turkot

Fermilab once again hosted the U.S. Summer School on High Energy Particle Accelerators during the two-week period from August 13-24. It was the fourth in an annual series of schools on accelerator science that was initiated at Fermilab in 1981. Melvin Month of Brookhaven National Laboratory and Frank Turkot of Fermilab organized this year's School. Stimulated in part by the recent discussions of the Superconducting Super Collider (SSC), school attendance was 225, a 50% increase over the 1981 school.

The central theme of this year's school was the conceptual design of large accelerators utilizing colliding beams to achieve particle collision energies 1000 times larger than that available with current fixed-target experiments using the Tevatron beam. Nearly two-thirds of the lectures were devoted to collider accelerators and related topics.

In a special symposium entitled "Accelerators for the 1990's" on Monday, August 20, three proposals to achieve these ultra-high energies were presented. Boyce McDaniel of Cornell University reviewed the SSC, the U.S. proposal for a 20-mile diameter circular accelerator colliding protons on protons, and Roy Billinge of CERN presented a design study of a similar machine (Large Hadron Collider, LHC) to be placed in the 6-mile diameter LEP tunnel now under construction at CERN. Burt Richter of SLAC outlined an alternative proposal to achieve the same result with electron-positron collisions using a 30-mile long linear accelerator. A study completed in June estimated the construction cost of an SSC to be approximately three billion dollars.

The 1990's Symposium was followed by an evening round-table discussion addressing the subject, "The World-Wide Growth of High Energy Physics--Competition or Collaboration?" The speakers above were joined by Martinus Veltman, University of Michigan, Stan Wojcicki, Stanford University, and Leon Lederman. In the lively exchange that ensued, it was argued that (a) the costs of the new machines rule out the duplication of accelerator facilities that has occurred in the past; (b) the construction of the SSC and LHC would be a duplication of facilities; (c) the interested governments are encouraging an international collaboration as a means to reduce the financial burden to any individual country; (d) at present there is no mechanism to build a world-wide consensus; (e) there do exist many examples of international collaboration on R&D for accelerator components and detectors.

A second symposium on "Accelerators of the 1980's" held on Thursday, August 23, reviewed the status and time schedules for the five new high-energy accelerators under construction in the western world. All five are colliders; they include TeV I at Fermilab (completion in 1986), SLC at SLAC (1986), TRISTAN at KEK Laboratory in Japan (1986), LEP at CERN (1988), and HERA at DESY in Germany (1990). Recent experimental discoveries and advances in particle theory lead to great expectations from these new facilities.

All told, there were 63 lectures delivered at the school by 51 lecturers, who represented a broad crosss section of leading researchers from high-energy laboratories and universities around the world. Twelve Fermilab staff were among this group. Many of the students commented on the uniformly high quality of the lectures and the informative site tour which included the accelerator, magnet production facilities, and the B0 detector complex.

Summer School organizers (left) Frank Turkot and Mel Month.
(Photograph by Fermilab Photo Unit)

Roy Billinge, CERN, addresses the summer school on the design and operation of the Sp$\bar{p}$S Collider.
(Photograph by Fermilab Photo Unit)

Round Table Committee members (left to right) Roy Billinge, CERN; Burton Richter, SLAC; Stanley Wojcicki, SLAC; Leon Lederman, Fermilab; Boyce McDaniel, Cornell, and Martinus Veltman, University of Michigan.
(Photograph by Fermilab Photo Unit)

Richard Lundy, Fermilab, illustrates the scale of the LEP collider during his lecture.

(Photograph by Fermilab Photo Unit)

Ian Hinchliffe, LBL, discusses exotic collisions.
(Photograph by Fermilab Photo Unit)

Bill Ng of Fermilab talking with Simon van der Meer of CERN at a break in the accelerator school. Bill Cooper of Fermilab is in the background.

(Photograph by Fermilab Photo Unit)

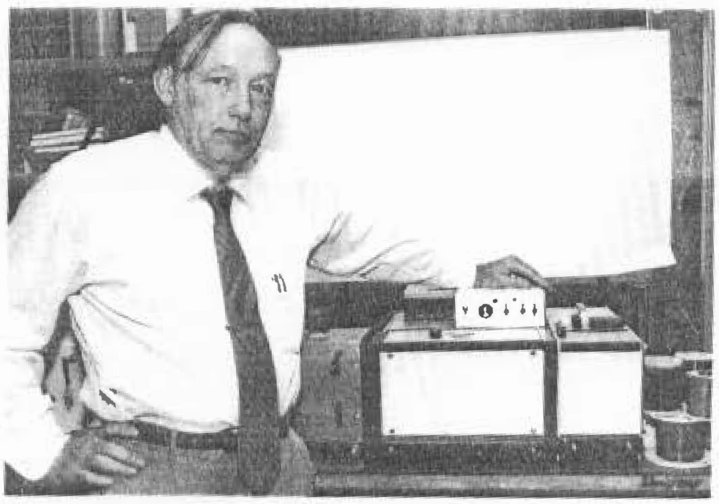
I-R 100 AWARD

A Spectrographic Nitrogen Detector developed at Fermilab by Ronald Walker, who heads Fermilab's Central Helium Liquefier, has been named one of the outstanding technological developments of 1984 in the I-R 100 competition sponsored by **Research and Development** Magazine. The detector was created to improve reliability of the Liquefier's operation.

The Central Helium Liquefier is an important component of Fermilab's superconducting accelerator. Some 5,000 liters of liquid helium are needed each hour to cool the magnets, and the helium must be free of the contamination frequently encountered in such large systems.

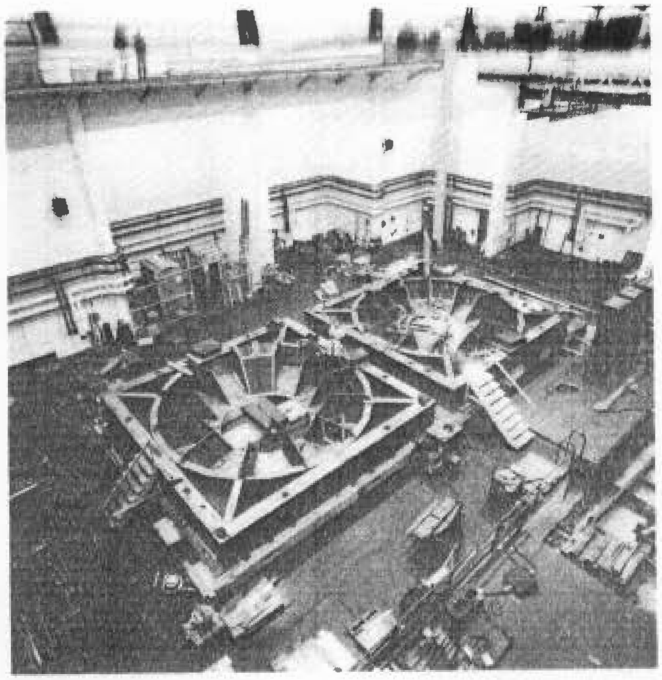
Walker's Spectrographic Nitrogen Detector records nitrogen contamination in helium gas by establishing a low-current electrical discharge in a sample cell. The light from the discharge is focused on the entrance slit of a high resolution monochromator. The monochromator is set to identify light from nitrogen and not from helium. A photomultiplier placed at the exit slit transmits a signal equal to the amount of nitrogen contamination present. Walker calls the detector "very sensitive, stable, and easy to operate and maintain."

"The Spectrographic Nitrogen Detector has been used with excellent results on water and hydrocarbon contamination, and undoubtedly can be used with many other gases," Walker states. This could be important in gas liquefication plants, very critical manufacturing operations, and gas analysis in general, according to Walker.



Moving the helium transfer line at D0 to make space for the D0 colliding-beams area.

(Photograph by Fermilab Photo Unit)



The Collider Detector magnet taking shape.
(Photograph by Fermilab Photo Unit)

MANUSCRIPTS, NOTES, LECTURES, AND COLLOQUIA PREPARED
OR PRESENTED FROM FROM JULY 29, 1984 TO SEPTEMBER 16, 1984

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

Experimental Physics

B. D. Collick Experiment #272	A Measurement of the Mass, Full Width, and Radiative Width of the $B^+(1237)$ Meson (Ph.D. Thesis, University of Minnesota, 1984)
D. Brick et al. Experiment #299	Search for Long-Lived Charge +2 Hadrons (Submitted to Phys. Rev. Rapid Communications)
B. H. Denby Experiment #516	Inelastic and Elastic Photoproduction of $J/\psi(3097)$ (Ph.D. Thesis, University of California, Santa Barbara, 1983)
D. J. Summers Experiment #516	A Study of the Decay $D^0 \rightarrow K^-\pi^+\pi^0$ in High Energy Photoproduction (Ph.D. Thesis, University of California, Santa Barbara, 1984)
M. A. Tartaglia Experiment #594	A Measurement of the Elastic Scattering Cross Section $\nu_\mu + e^- \rightarrow \nu_\mu + e^-$ (Ph.D. Thesis, MIT, 1984)
R. Rameika et al. Experiment #620	Measurement of the Ξ^- Magnetic Moment [Phys. Rev. Lett. **52**, 581 (1984)]
J. D. Povlis Experiment #629	A Measurement of Neutral Meson and Direct Photon Production at Large Transverse Momentum (Ph.D. Thesis, University of Minnesota, 1984)

Theoretical Physics

J. D. Bjorken and L. McLerran	Coherent Photon Radiation from Nuclei as a Probe of Impact Parameter and Nucleon Velocity Distribution in Ultra-Relativistic Nuclear Collisions (FERMILAB-Pub-84/35-T; submitted to Phys. Rev. D)

A. Sen	Addendum to Monopole Induced Baryon Number Violation Due to Weak Anomaly V. Effect of Higher Generation Fermions (FERMILAB-Pub-84/42-T; submitted to Nucl. Phys.)
S. R. Das	Spontaneous Compactifaction of Generalized Kaluza-Klein Theories on Twisted Tori (FERMILAB-Pub-84/52-T; submitted to Phys. Lett. B)
C. N. Leung and S. T. Petcov	On the Possibility of Destructive Interference Between Light and Heavy Majorana Neutrinos in Neutrinoless Double Beta Decay (FERMILAB-Pub-84/56-T; submitted to Phys. Lett. B)
S. Kivelson et al.	Effect of Interactions Between Electrons of Like Spin in Conducting Polymers (FERMILAB-Pub-84/57-T; submitted to Phys. Rev. D)
K. A. Olive	Cosmology and GUTs (FERMILAB-Conf-84/59-A; to be published in Grand Unification With and Without Supersymmetry and Cosmological Implications, International School of Advanced Studies Lecture Series No. 2, Trieste, Italy, 1983)
M. S. Turner	Cosmology and Particle Physics (FERMILAB-Conf-84/60-A; lectures given at the NATO Advanced Study Institute on Quarks and Leptons, Max Planck Institute, Munich, September 1983)
W. Bardeen et al.	Spontaneous Breaking of Scale Invariance in a Supersymmetric Model (FERMILAB-Pub-84/62-T; submitted to Nucl. Phys. B)
E. W. Kolb	Remnants from Compactification (FERMILAB-Conf-84/65-A; to be published in the Proceedings of the VII Johns Hopkins Workshop on Current Problems in Particle Physics, June 1984)
H. J. Lipkin	Clues to QCD Dynamics from Flavor Dependence of Nucleon Spin-Flip Transitions (FERMILAB-Pub-84/66-T; submitted to Phys. Rev. Lett.)

A. Sen — Sliding Singlet Mechanism in N=1 Supergravity GUT (FERMILAB-Pub-84/67-T; submitted to Phys. Lett.)

General

I. Gaines et al. — The Fermilab ACP Multi-Microprocessor Project (FERMILAB-Conf-84/63; presented at the Symposium on Recent Developments in Computing, Processor, and Software Research for High-Energy Physics, Guanajuato, Mexico, May 8-11, 1984)

M. Fischler et al. — Software for Event Oriented Processing on Multiprocessor Systems (FERMILAB-Conf-84/64; presented at the Symposium on Recent Developments in Computing, Processor, and Software Research for High-Energy Physics, Guanajuato, Mexico, May 8-11, 1984)

W. Kells et al. — On Achieving Cold Antiprotons in a Penning Trap (FERMILAB-Conf-84/68-E; presented at the IX International Conference on Atomic Physics, Seattle, Washington, July 23-27, 1984)

C. H. Rode — Cryogenic System for a 100 km Superconducting Collider (Presented at the 10 International Cryogenic Conference, Espoo, Finland, July 31-August 3, 1984)

R. W. Fast et al. — Fabrication and Testing of a 3-m Diameter Superconducting Solenoid for the Fermilab Collider Detector (Presented at the 10th International Cryogenic Conference, Espoo, Finland, July 31-August 3, 1984)

R. W. Fast et al. — Refrigeration Tests of the Cryogenic System and Solenoid for the Fermilab Collider Detector (Presented at the 10th International Cryogenic Conference, Espoo, Finland, July 31-August 3, 1984)

Physics Notes

J. Freeman et al.	Transverse Energy Physics with the CDF Calorimeter (FN-399; presented at the 4th Topical Workshop on $p\bar{p}$ Collider Physics, Bern, Switzerland, March 5-8, 1984)
J. A. Appel et al.	Hadron Calorimetry at the Fermilab Tagged Photon Spectrometer Facility (FN-405)
J. D. Cossairt et al.	Radiation Measurements in a Labyrinth Penetration at a High Energy Proton Accelerator (FN-406; submitted to Health Physics)
L. Cohen et al.	Response of Sarcomas of Bone and of Soft Tissue to Neutron Beam Therapy (FN-407)

Colloquia, Lectures, and Seminars

D. Carey	"Statistics and Data Evaluation" (Fermilab, July 30, 1984)
D. Lindley	"Particle Physics and Cosmology" (Fermilab, August 1, 1984)
D. Seckel	"The Cosmic Distance Ladder" (Fermilab, August 3, 1984)
W. Cooper and G. Mulholland	"Cryogenics Standards Development Seminar" (Fermilab, August 6, 1984)
H. B. White	"Topics in Particle Physics" (Fermilab, August 10, 1984)
R. Ferry	"Status of Cryogenic Systems for the Antiproton Source, F0 and F18" (Fermilab, August 16, 1984)
M. Notarus	"Booster Office Buildings--Out of the Portakamps and into the Palace" (Fermilab, August 16, 1984)
D. Lindley	"The Distribution of Matter in the Universe" (Fermilab, August 17, 1984)

P. Martin	"Summary of What Was Accomplished in the Main Ring Studies in FY84 and Plans for FY85" (Fermilab, August 30, 1984)
R. Orr	"Accelerator Division Information Meeting" (Fermilab, Sepember 4, 1984)
P. Rapidis	"Description of the Diagnostics Which Will Be Available at the Start of the $\overline{p}$ Source Commissioning" (Fermilab, September 6, 1984)
E. Malamud	"Update on the XMR Timing System" (Fermilab, September 6, 1984)
S. Mtingwa	"Quality Assurance Tests to Measure Pickup and Kickers" (Fermilab, September 6, 1984)

Clincy Latimer, a summer student from Hampton Institute, at work.

(Photograph by Fermilab Photo Unit)

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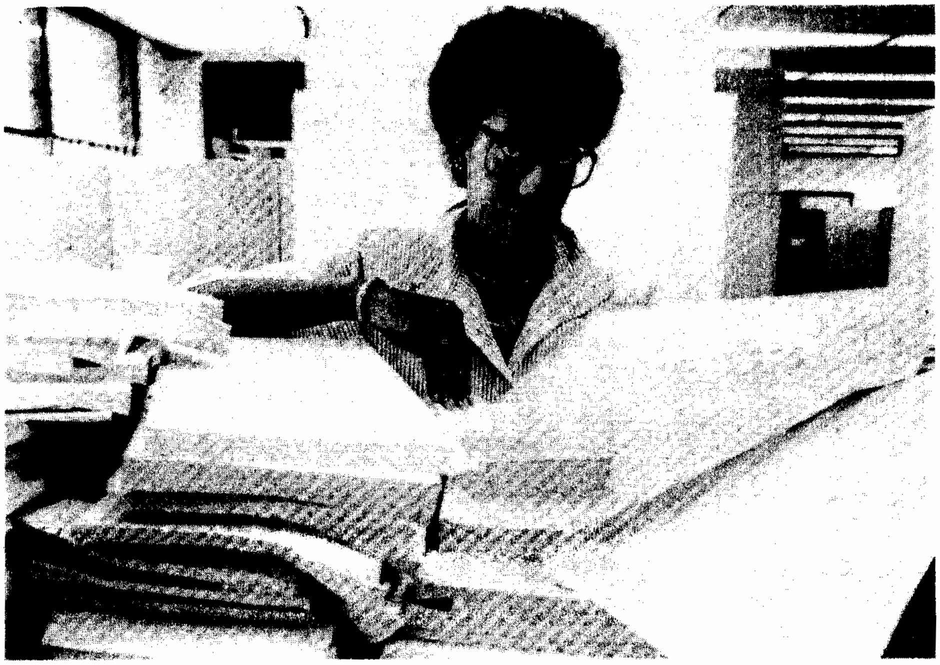

Allora Goode, a summer student from Virginia State University, working on simulation of particle channeling.
(Photograph by Fermilab Photo Unit)

DATES TO REMEMBER

September 21-22, 1984	Vertex Detectors: Charm and Beauty I (for more information, contact Phyllis Hale, Users Office, 840-3111)
October 1, 1984	Deadline for submission of material for November Physics Advisory Committee Meeting
October 12, 1984	Direct Neutral Lepton Facility Workshop (replaces the Prompt Neutrino Facility Workshop previously scheduled for Oct. 12). For more information, contact Phyllis Hale, Users Office, 840-3111
November 8-9, 1984	Physics Advisory Committee Meeting