fermilab report

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FERMILAB-80/6 Fermi National Accelerator Laboratory 0090.01

THE COVER: Professor P. A. M. Dirac at the History of Particle Physics Symposium in May.
(Photograph by Fermilab Photo Unit)

CONTENTS JUNE 1980

BEAM STORAGE IN THE MAIN RING

James A. MacLachlan

Introduction

Over the years, there have been many studies of stored beam in the Main Ring. The first such study was late in 1971, when the lifetime of 7-GeV beam was measured as a function of vacuum pressure to try to understand the relatively rapid loss of injected beam.

The motivation for these studies changed in later years. In 1976, studies were begun with an eye toward improving beam lifetime for proton-proton or proton-antiproton colliding beams in the Main Ring. A large amount of work was done at that time and was an important part of the 1977 Summer Study on colliding beams.[1,2] More recently, the interest in colliding-beam possibilities has centered on the Tevatron and the motivation of storage studies in the Main Ring has been more toward the understanding of the physical phenomena and as an example to be translated to Tevatron parameters.

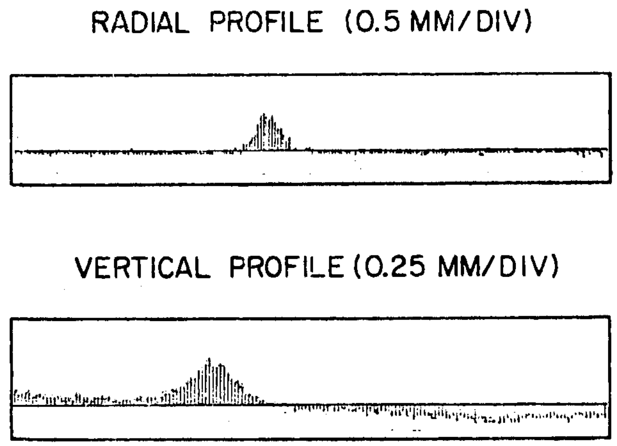
This paper will emphasize the recent studies,[3] with some reference to the earlier work. For the application to colliding beams, both beam lifetime and beam size are important, for they both affect luminosity, and measurement of both will be discussed.

Experimental Methods

Beam is accelerated to the storage energy in the usual way. The ramp is then flat-topped and beam allowed to coast with rf voltage on to keep the particles bunched in buckets. The water-cooling system of the magnets is adequate for dc operation of the Main Ring up to an energy of almost 200 GeV. The quadrupole excitation can be set to fix the **tune** (the numbers of horizontal (ν_x) and vertical (ν_y) betatron oscillations per revolution) to high precision. The "reference" conditions for storage are $\nu_x = 19.441$ and $\nu_y = 19.435$. These conditions are nominal, because coupling between radial and vertical oscillations changes the real tune values slightly and ν_x and ν_y cannot be made exactly equal. The reference tune is chosen to avoid the fifth-order resonances at $\nu_x = 19.4$ and $\nu_y = 19.4$, the seventh-order resonances at 19.429, and the ninth-order resonance at 19.444.

The rf can be used to set the momentum at the center of the aperture with high precision and the beam can be moved in radius by changing this momentum with rf. An important feature is that the tune depends on momentum; the **chromaticities** ξ_x and ξ_y are the rates of change of horizontal and vertical tunes with momentum. The chromaticity can be controlled by use of the correction sextupoles, which are strong enough to reduce the chromaticity to zero up to an energy of approximately 150 GeV. The largest new element in the recent studies is the careful control and investigation of chromaticity and its effects on beam storage.

Two kinds of measurements of the beam are made. The total circulating current is measured with a magnetic toroid surrounding the beam. This measurement is independent of beam size and shape. The transverse size and shape parameters are measured by the Ion Beam Scanner (IBS), which collects secondary electrons produced in collisions of beam particles with the residual gas. The IBS data are processed digitally by the control system to produce readouts like the one in the figure below. The data are



Beam profile data from the IBS.

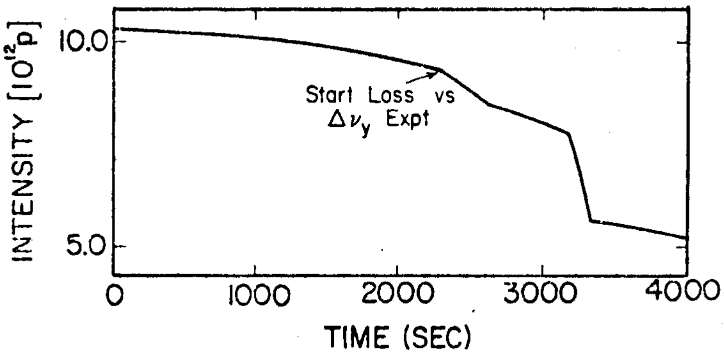
logged by the control system and are available for off-line study and analysis. The measurements discussed here deal with intensity and transverse growth, but some qualitative observations have been made of longitudinal growth using a wide-band beam detector.

The average vacuum pressure is measured from the current readings of the small ion pumps attached to the dipoles. These pumps have been refurbished and augmented in the last few years and their readouts have been modified to give response at lower pressure. The pressure can also be derived from the lifetime and beam-size measurements, as discussed below.

Experimental Results

The lifetime of stored beam can be varied over several orders of magnitude by detailed tuning. If the tune is close to a nonlinear resonance, other effects discussed below will drive the beam through the resonance and increase beam size.

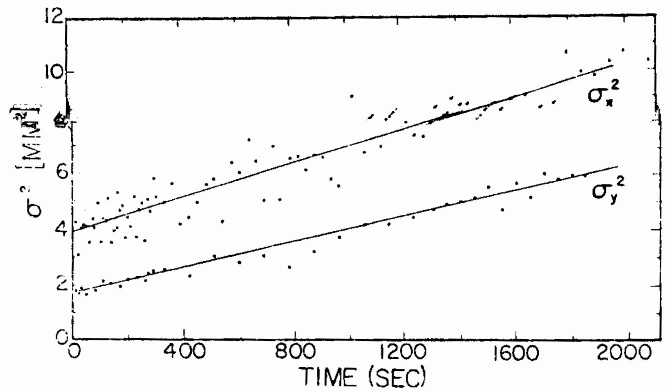
The earlier studies had occasions of rapid early loss. The present studies have not as a rule found such rapid early losses. Instead, the loss patterns appear to have two parts. First, there is a slow early loss in which the intensity decreases linearly with time. By approximately 500 to 1000 seconds, the loss has settled into a pattern of exponential decay. These two regimes are seen roughly in the plot below, in which other experiments are also done after the first 2000 seconds.



Beam intensity vs time 100 GeV.

The early linear beam loss is interpreted as caused by nuclear scattering by the residual gas. A single nuclear scattering can change the orbit of a proton enough to make it leave the vacuum chamber. But a single Coulomb scattering by the electric charge of the residual gas nuclei will not make a large enough change in the proton orbit to make it leave. Instead, multiple Coulomb scatterings make the beam grow gradually in size. There is some amplitude beyond which the motion is unstable and particles grow to this amplitude, then leave the chamber. This multiple Coulomb scattering is responsible for the long-time exponential beam loss. This interpretation is reinforced by rough agreement of the pressure calculated from the multiple-scattering lifetime with the measured pressure. The data indicate that the composition of the residual gas is largely lighter molecules, which is in agreement with compositions measured in low-pressure regions. This composition is what one expects from outgassing of an unbaked stainless-steel chamber. The average pressure around the ring is approximately 6×10^{-8} Torr.

The multiple Coulomb scattering interpretation of transverse beam growth predicts a linear growth with time of the mean-square beam size σ^2 and this growth is observed, as can be seen in the figure on the following page, showing IBS data. The pressure can



Beam width σ^2 vs time at 100 GeV.

be calculated from the measured growth rate of beam size. The pressures calculated from beam-size growth are larger than those calculated from beam survival data. This discrepancy is not fully understood, but the evidence suggests that the overestimate may be an instrumentation effect of the IBS.

Earlier studies had given larger scattering rates. The studies discussed here give smaller diffusion rates and improvements in lifetime longer than could be expected from the improvement in pressure. It is believed that the larger diffusion rate in the earlier studies came from multiple crossing of nonlinear resonances. The tune can shift from real changes in momentum arising from longitudinal synchrotron oscillations or from apparent changes in momentum arising from magnet current ripple. In the recent studies, these tune changes can be made much smaller because the chromaticity can be corrected. We have investigated the effect of chromaticity correction in some detail. Our data show that we can double the lifetime of the beam by proper chromaticity correction. This lends credence to the interpretation of nonlinear resonance crossing as the cause of increased diffusion.

Conclusions and Future Studies

The results of chromaticity correction and the qualitative agreement of the scattering picture make it possible to take a reasonably optimistic view of possible colliding-beam lifetimes in the Tevatron. Lifetimes of more than two hours have been achieved in the Main Ring. At the same time, the quantitative agreement certainly needs more study and some new instrumentation is being prepared for this work.

There are also other phenomena. We have observed beam-bunch lengthening during our transverse studies and this effect is connected with the differences observed in horizontal and vertical growth rates. RF noise is believed to be an important factor in this phenomenon. Bunch lengthening and its effects on luminosity are being studied.

References

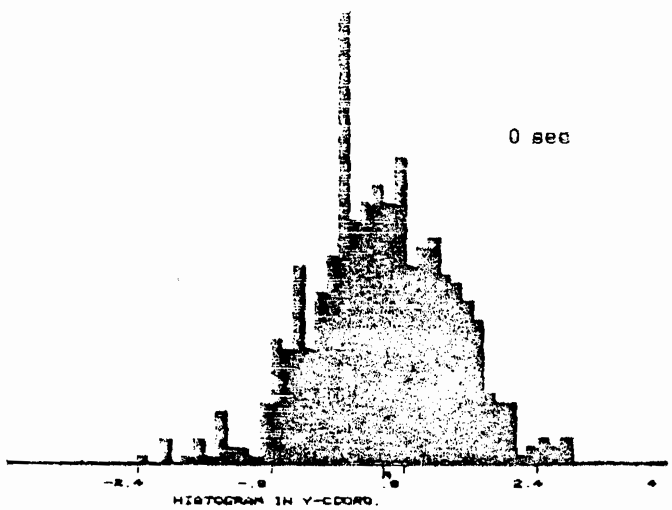
1. C. M. Ankenbrandt et al., Beam Storage in the Main Ring at High Energies, IEEE Trans. Nucl. Sci. **NS-24**, June, 1977, p. 1872.
2. Colliding Beams at Fermilab, 1977 Summer Study, Fermi National Accelerator Laboratory, p. 97-243.
3. J. A. MacLachlan, The Lifetime of Bunched Beam Stored in the Main Ring at 100 and 150 GeV, Fermilab Report FN-324, April 14, 1980.

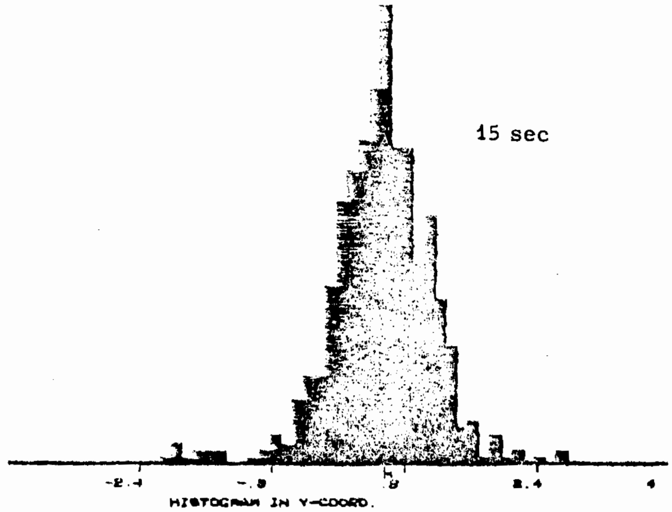
TRANSVERSE STOCHASTIC COOLING

On May 1[illegible], the vertical motion of a [illegible]-MeV proton beam was sucessfully cooled stochastically, as can be seen in the sequence of beam profiles below. Vertical emmitance was reduced by a factor of four.

The equipment was built and the experiments carried out by a group from the Lawrence Berkeley Laboratory. Combination of vertical and longitudinal cooling gave a very long beam lifetime. There appeared to be little interaction between the vertical and longitudinal cooling.

Longitudinal stochastic cooling is to be used in the Precooler ring to be built as part of the proton-antiproton colliding beams system at Fermilab. Transverse stochastic cooling is a possible option for the future in the collider.

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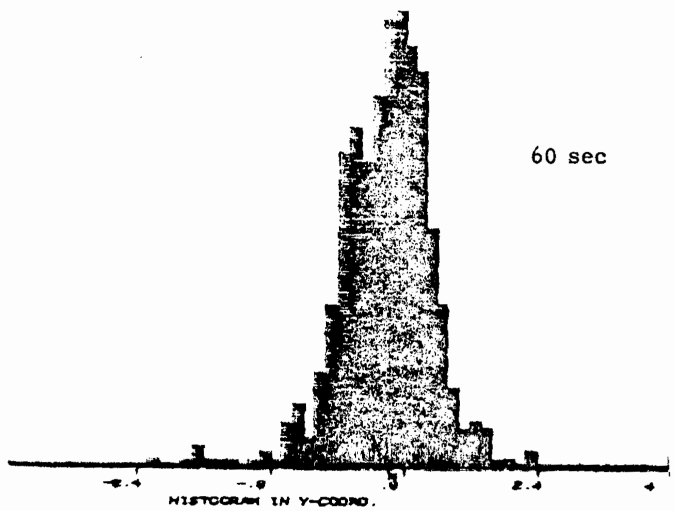
HISTOGRAM IN Y-COORD.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HISTOGRAM IN Y-COORD.

SUMMARY OF OPERATIONS - MAY 1980

Program Planning Office

The high-energy physics program continued 350-GeV operation during the month of May. The Main Ring accelerated a nominal 1.7×10^{13} protons/pulse spilling them out of the proton synchrotron during a one and one-half second flattop. After two relatively smooth startups following the first two weekly maintenance periods, over 34 hours of down time were recorded during the startup after the third week's maintenance period. The chief problem was a twice-undetected closed valve in the Main-Ring cooling system at E2, which ultimately resulted in the flooding of the E2 service building. By comparison, the fourth week's startup was perfect.

Two major changes occurred in the experimental areas during May. Dimuon #326 finished their run for this operating period and relinquished the Proton-West beam line to Dimuon #537. After an initial phase of experimental apparatus check out, Experiment #537 began doing $\bar{p}$ flux measurements. In the M6 beam line, Elastic Scattering #577 replaced Particle Search #580 and, after a brief setup period, began taking data. In addition, two other experiments, Particle Search #610 (N1) and Kaon Charge Exchange #585 (M4), began taking data. This makes a grand total of seven experiments taking data.

Three experiments are in test mode in anticipation of future running. Beam Dump #613 finished their radiation measurements and began investigating muon contamination in their detector. Charged Hyperon #497 has been learning to tune the Proton-Center beam line and measuring hyperon rates. Neutrino #594 has been plagued by problems with its flash chamber pulse-forming networks, but, by the end of the month, were able to write neutrino events on tape.

FERMI NATIONAL ACCELERATOR LABORATORY
MONTHLY OPERATIONS HISTORY
MAY 1980

Date	Accelerator	Internal Target Area	Proton Area	Neutrino Area	Meson Area
Thu. 5/1	Accelerator Maintenance & Startup (Align ES38)				
Fri. 5/2 Sat. 5/3 Sun. 5/4 Mon. 5/5 Tue. 5/6	$1.5x10^{13}$ppp @350 GeV 1.5 sec flattop ~~MR Computer-N.R.~~ ~~MR Quad-Insulator~~	591	326 (PW) 516 (PE) 497 Tests (PC)	595 (N5) 610 (N1)	580 (M6) 515 (M1) 585 (M4) M2 Tests OFF (M3)
Wed. 5/7	Accelerator M & D				
Thu. 5/8 Fri. 5/9 Sat. 5/10 Sun. 5/11 Mon. 5/12 Tue. 5/13 Wed. 5/14	>$1.5x10^{13}$ppp @350 GeV ~~MR Mag. Repl.~~ 1.5 sec flattop ~~MR&EG Linac RF~~ ~~Necessary Repairs~~ ~$1.5x10^{13}$ppp @350 GeV 1.5 sec flattop	591	516 (PE) 537 (PW) 497 Tests (PC)	595 (N5) 610 (N1)	515 (M1) 585 (M4) 577 (M6) M2 Tests (M2) OFF (M3)
Thu. 5/15	Accelerator M & D				
Fri. 5/16 Sat. 5/17 Sun. 5/18 Mon. 5/19 Tue. 5/20	~$2.0x10^{13}$ppp @350 GeV 1.5 sec flattop ~~MR Water Leak~~ ~$2.0x10^{13}$ppp @350 GeV 1.5 sec flattop	591	516 (PE) 537 (PW) 497 Tests (PC)	595 (N5) 610 (N1) 594 Tests (NO)	515 (M1) 577 (M6) 585 (M4) M2 Tests (M2) OFF (M3)
Wed. 5/21	Accelerator M & D				
Thu. 5/22 Fri. 5/23	Water Leaks & "Obstacle"	Start-up For HEP			
Sat. 5/24 Sun. 5/25 Mon. (H) 5/26 Tue. 5/27	~~Booster Quad P.S.~~ ~$2.0x10^{13}$ppp @350 GeV 1.5 sec flattop	591	516 (PE) 537 (PW) 497 Tests (PC)	595 (N5) 610 (N1) 594 Tests (NO)	515 (M1) 577 (M6) 585 (M4) 613 Tests (M2) OFF (M3)
Wed. 5/28	Accelerator M & D				
Thu. 5/29 Fri. 5/30 Sat. 5/31	~$2.0x10^{13}$ppp [illegible] @350 GeV 1.5 sec flattop	591	516 (PE) 537 (PW) 497 Tests (PC)	595 (N5) 610 (N1) 594 Tests (NO)	515 (M1) 577 (M6) 585 (M4) 613 Tests (M2) OFF (M3)

BEAM UTILIZATION BY EXPERIMENTAL ACTIVITY - MAY 1980

	Beam	Hours	Activities
PROTON AREA			
Dimuon #326	PW	70	data; A-dependence and trigger rate studies
Charged Hyperon #497	PC	450	startup and test; hyperon flux measurements
Photoproduction #516	PE	330	tuneup and check-out; preliminary test data
Dimuon #537	PW	350	startup; equipment checkout and $\bar{p}$ flux measurements
NEUTRINO AREA			
Neutrino #594	NO	140	startup and test; checkout of flash chambers and setup of test of PWC trigger
Particle Search #595	N5	340	data; switched from diffracted protons to π^- beam at -275 GeV/c
Particle Search #610	N1	430	tuneup and data; trigger studies and drift chamber characterization
MESON AREA			
Particle Search #515	M1	340	data; ~ 15 triggers/pulses with 4×10^{12} protons on target
Elastic Scattering #577	M6	290	data at -200 GeV/c
Particle Search #580	M6	80	data at -200 GeV/c
Kaon Charge Exchange #585	M4	420	tuneup and data; checkout of chambers and fix hydrogen target
Beam Dump #613	M2	40	test; radiation measurements and investigation of muon contamination
INTERNAL TARGET AREA			
Particle Search #591	ITA	350	data with various gas mixtures
TOTAL HOURS FOR HIGH ENERGY PHYSICS		3630	

FACILITY UTILIZATION SUMMARY - MAY 1980

I. Summary of Accelerator Operations

		Hours	
A. Accelerator use for physics research			
High energy physics research		446.2	
Accelerator physics research		33.4	
	Subtotal		479.6
B. Other Activities			
Program interruption		89.0	
Accelerator setup and tuning to experimental areas		62.1	
	Subtotal		151.1
C. Unscheduled interruption			113.3
D. Unmanned time			-
Total			744.0

II. Summaries of High Energy Physics Research Use

	# of Expts.	Hours	Results
A. Counter experiments	14	3630	
B. Bubble chamber experiments	-	-	
C. Emulsion experiments	-	-	
D. Special target experiments	-	-	
E. Test experiments	1	40	
F. Engineering studies and tests	-	-	
G. Other Beam Use	-	-	
Totals	15	3670	

III. Number of Protons Accelerated and Delivered ($\times 10^{18}$) at 350 GeV

A. Beam accelerated in Main Ring	1.89
B. Beam delivered to experimental areas	1.69
Proton Area	0.27
Neutrino Area	
Slow Spill	0.56
Fast Spill	0.15
Meson Area	0.71

JAPAN - U.S. AGREEMENT

An agreement was signed on May 20 for continued collaboration between Japan and the United States in high-energy physics experiments and research and development on detectors and new accelerators. The agreement covers work in fiscal year 1981 and follows a year of successful collaboration. T. Nishikawa, Director-General of KEK the National Laboratory for High-Energy Physics signed for Japan and J. E. Leiss, Associate Director, Office of Energy Research, High Energy and Nuclear Physics, Department of Energy, signed for the United States.

Fermilab is taking a part in this work, together with other U. S. laboratories. The work at Fermilab will include participation in Experiment 605 (leptons and hadrons near kinematic limits), participation in the building of the detector for the $\bar{p}p$ collider, support of bubble-chamber work, and participation in superconducting-magnet development. This magnet work is to develop second-generation superconducting accelerator magnets, designed to reach bending fields of 10 Tesla (more than twice the fields of the Energy Saver magnets). Magnets of this strength are of interest in Japan for the TRISTAN project and at Fermilab for the PENTAVAC 5-TeV site-filling ring (for which the site boundaries were chosen in 1967).

Lillian Hoddeson, principal organizer of the History of Particle Physics Symposium held last month at Fermilab.
(Photograph by Fermilab Photo Unit)

Satio Hayakawa speaking at the History Symposium.
(Photograph by Fermilab Photo Unit)

Herbert Anderson speaking at the Symposium.
(Photograph by Fermilab Photo Unit)

Gilberto Bernadini at the Symposium.
(Photograph by Fermilab Photo Unit)

MANUSCRIPTS AND NOTES PREPARED
FROM APRIL 11 TO JUNE 11, 1980

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.

Experimental Physics

W. Aitkenhead et al. Experiment #118	A Determination of the Pion and Kaon Structure Functions (FERMILAB-Pub-80/32-EXP; submitted to Phys. Rev. Lett.)
W. Aitkenhead et al. Experiment #118	Multiplicity Measurements in Hadron Reactions at 100 and 175 GeV (FERMILAB-Conf-80/48-EXP; submitted to the XX International Conf. on High Energy Physics, Madison, July, 1980)
V. V. Ammosov et al. Experiment #180	Charged Current Events with Neutral Strange Particles in High Energy Antineutrino Interactions (FERMILAB-Pub-80/44-EXP; submitted to Nucl. Phys. B)
R. W. Stanek Experiment #260	Correlations Between High Transverse Momentum Hadrons in $\pi^{\pm}p$, $K^{-}p$, and pp Collisions at 200 GeV/c (Ph.D. Thesis, University of Illinois at Chicago Circle)
R. C. Ball et al. Experiment #319	Further Measurement of Nucleon Structure Function in High Energy Muon-Iron Interactions (Submitted to Phys. Rev. Lett.)
A. E. Brenner et al. Experiment #451	A-Dependence of Inclusive Hadron Scattering at 100 GeV (FERMILAB-Conf-80/47-EXP; submitted to the XX International Conf. on High Energy Physics, Madison, July, 1980)
E. B. Dally et al. Experiment #456	Direct Measurement of the Negative Kaon Form Factor

R. A. Carrigan, Jr. Experiment #507	On the Possible Applications of the Steering of Charged Particles by Bent Single Crystals, Including the Possibility of Separated Charm Particle Beams (FERMILAB-Pub-80/45-EXP; submitted to Applications of Nucl. Sci.)
R. Ammar et al. Experiment #564	Production and Decay of F^+ (2030) Observed in ν_μ Interactions in Emulsion (FERMILAB-Pub-80/39-EXP; submitted to Phys. Lett.)
A. E. Brenner et al. No Experiment #	DUMAND Data Acquisition with Triggering (FERMILAB-Conf-80/40-EXP; submitted to the Workshop on DUMAND Signal Processing, University of Hawaii, Honolulu, February 11-16, 1980)

Theoretical Physics

P. Q. Hung and C. Quigg	Intermediate Bosons: Weak Interaction Couriers (FERMILAB-Pub-80/24-THY; submited to Science)
H. Minakata	Space-Time Structure of Jet Hadronization (FERMILAB-Pub-80/28-THY; submitted to Phys. Rev. Lett.)
V. Visnjic-Trantafillou	A Natural Composite Model for Quarks and Leptons (FERMILAB-Pub-80/34-THY; submitted to Phys. Rev. Lett.)
K. Kamada	Semileptonic Decay of Charmed Particles and Weak Form Factors (FERMILAB-Pub-80/36-THY; submitted to Phys. Rev. D)

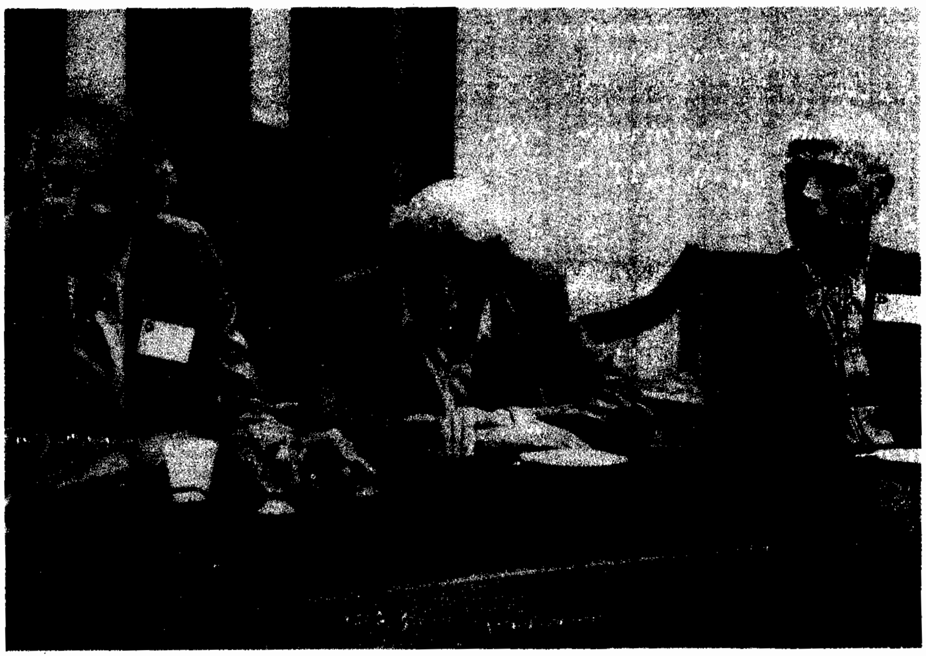
Physics Notes

J. A. MacLachlan	The Lifetime of Bunched Beam Stored in the Main Ring at 100- and 150-GeV (FN-324)

[illegible]

M. Haldeman et al.	A Hardware Device that Aids Performance Monitoring of the PDP-11 (Submitted to the DECUS U. S. Symposium, Chicago, April 22-25, 1980)
M. Wake et al.	Quench Characteristics of Energy Doubler Magnets (Submitted to the 8th International Cryogenic Engineering Conf., Genova, Italy, June, 1980)
M. Wake and R. Yamada	Higher Harmonics and Field Homogeneity in Two-Shell-Type Superconducting Dipole Magnet (Submitted to the 8th International Cryogenic Engineering Conf., Genova, Italy, June, 1980)

Satio Hayakawa, Abraham Pais, and Robert Marshak (left to right) in a roundtable discussion at the Symposium.
(Photograph by Fermilab Photo Unit)



Robert Marshak, Paul Dirac, and Willis Lamb (left to right) at a roundtable.

(Photograph by Fermilab Photo Unit)

Willis Lamb, Robert Serber, and Victor Weiskopf (left to right) at a roundtable during the Symposium.
Photograph by Fermilab Photo Unit)

DATES TO REMEMBER

July 24-25, 1980	**Fixed Target Workshop** (contact Program Planning Office for details).
July 28-August 1, 1980	

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MESON DEPARTMENT, MS #221
FERMILAB