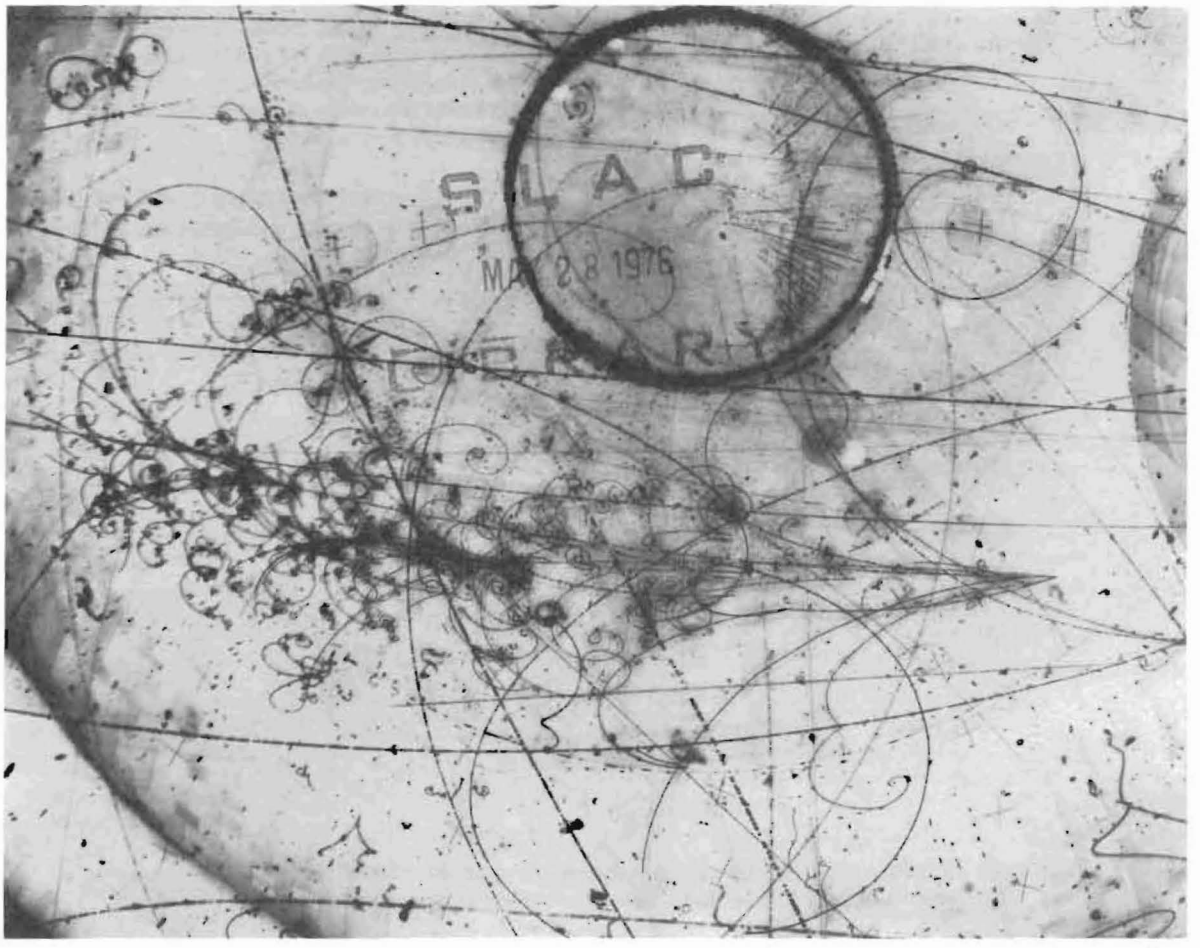
NALREP



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lonthly Report of the Fermi National Accelerator Laboratory

May 1976

Fermi National Accelerator Laboratory

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THE COVER: Fifteen-foot bubble-chamber picture of a neutrino interaction. The bubble chamber was filled with a neon-hydrogen mixture.

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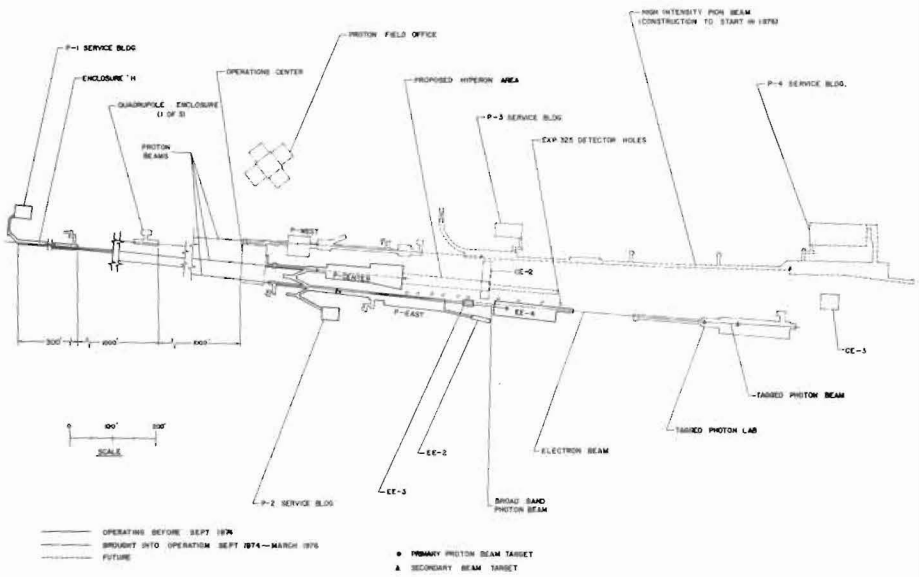
THE PROTON AREA: SEPTEMBER 1974 TO MARCH 1976
(When You're No. 3, You Try Even Harder)

Reported by Roy Rubinstein

The design criteria and the early construction of the Proton Area were described in a November 1974 NALREP article by John Peoples. That report discussed the state of the area in September 1974, at which time two experiments had been completed and another two experiments were set up. The major characteristics of the area at that time were earthmoving equipment, mud, and irregular operation for experiments because of the need for installation time for beam and experimental equipment.

In the past 18 months, the area as originally planned has been completed and the major effort has changed from construction to steady operation for an increasing number of experiments, several of which have already produced important physics results. At the same time, planning has proceeded on the design of further beams and facilities, and construction of some of these is scheduled to start in the near future.

In this report we will first describe the changes in the area in the past 18 months, then the physics research carried out or under way, and, finally, the future plans. The figure on the next page shows a layout of the enclosures in the Proton Area, indicating the status of various parts in September 1974, March 1976, and what is planned for the future. The facilities stretch for close to three-fourths of a mile, with the beam lines about 12 feet below ground level in order to use the earth for shielding.



Layout of the Proton-Area enclosures indicating the status of various parts in September 1974, March 1976, and what is planned for the future.

Construction Efforts

The time period under discussion began with characteristic major changes in September, 1974, when the control room for the whole area was moved from a very temporary location in Portakamps to a partially temporary location in the newly occupied Operations Center basement. This involved cutting and then reconnecting every control cable in the area and it was gratifying that the area functioned again in a very short time afterwards! While this was going on, the first half of the electron beam was being installed. To form the electron beam, the proton beam in P-East strikes a beryllium target to produce a 0° neutral beam whose useful component is

photons. These photons in turn strike a lead converter 40 feet from the primary target, producing electrons that are transported in a conventional two-stage beam. In the first run, electrons were taken to the partially completed Tagged Photon Laboratory; the properties of the beam, both at this time and later when the complete beam was tested, were impressively close to those predicted. Much credit for the design and construction is due to Tom Nash.

The last two months of 1974 saw the start of construction of the P-West quadrupole enclosures, the completion of Experiment #70 in Proton Center (both described later), and the start of the first of two long data-taking periods for Experiment #'s 87 and 358 in P-East. These latter experiments used the broad-band photon beam in P-East. A 0° neutral beam produced by protons on a beryllium target is passed through 103 feet of liquid deuterium placed in a cryostat that is between the pole tips of a series of magnets. Neutrons are preferentially absorbed by the deuterium, leaving a nearly pure photon beam with a broad spectrum of momenta. With the deuterium removed, the beam is effectively pure neutrons. The successful operation of the crucial deuterium cryostat owes much to the hard work of Morris Binkley.

Construction began in early 1975 on the large, double-arm spectrometer experiment (E288) in P-Center to study dilepton production in proton-nucleus collisions. Data-taking started around mid-year.

Earth-moving equipment was much in evidence in the spring of 1975, with the construction of two pits to contain Portakamps housing equipment for Experiment #'s 48, 435, and 436 downstream of P-Center. The earth between P-Center and these pits gave a range requirement on the detected

muons. Data-taking commenced in mid-1975. A series of ten 20-ft deep, 4-ft diameter holes was bored in the earth near P-East for Experiment #325; these holes were for detectors of muons from the P-East target.

The electron-beam installation and the Tagged-Photon Laboratory were completed in late spring and early summer. In the Tagged-Photon building, the electron beam strikes a lead radiator where an electron can give off a high-energy photon in the same direction as the initial electron. The electron loses energy in the process and is deflected by a set of magnets into a scintillator and lead-glass hodoscope, determining its momentum. A comparison of this momentum with the initial momentum determines the photon energy. Thus the energy of each photon is known, or "tagged." The whole system, electron beam and tagging system, works very well.

Much effort was also directed in the spring and early summer of 1975 to making P-West an operational area. A first requirement was to be able to deliver beam to the three Proton Areas simultaneously. The Switchyard Group installed additional electrostatic septa and other equipment in Enclosure E to give three beams separated vertically by a few centimeters in Proton's Enclosure H. These were spread horizontally by a novel three-way split Lambertson magnet whose unique design and construction were largely in the hands of Ed Tilles. A complete rearrangement of the more than 30 magnets in Enclosure H, including replacement of some by ones of larger aperture, was necessary to accommodate the different positions of the beams compared with the previously existing two-way split. In April, 1975, all systems worked and beams were sent to the three areas simultaneously.

This was not, however, all that was needed to start experiments in P-West. The area had three approved experiments on proton-proton or proton-nucleus collisions, using few per cent transmission targets. Detectors in the experiments were required to be within inches of a 10^{11} or greater proton beam, and the requirements in beam cleanliness (absence of "halo" particles outside the small beam size) were therefore extremely stringent and had not been met in the early days of the area. In the P-West pretarget area, a large amount of shielding was placed and larger-aperture quadrupoles installed to reduce any interactions caused by halo (they were also installed in P-East for the same reason, and will later be installed in P-Center). The major improvement was the addition of three enclosures (the "Quadrupole Enclosures") in the 2,000 foot drift space between Enclosure H and the P-West pretarget area. These contained quadrupoles to focus the beam through a small collimator aperture that intercepted halo particles. Additional collimators and a magnet "dog leg" to remove off-momentum particles also cleaned up the beam. The results were dramatic: the halo was reduced by approximately a factor of 10,000. The rate, for example, was 150 particles/mm^2 at 5.6 cm from a 10^{12} proton beam. This beam cleanliness, which was the result of much work by Thornton Murphy and Brad Cox, enabled the three experiments in P-West, which had been under construction earlier, to get underway.

The rapid installation of facilities in the first half of 1975 was followed by a difficult period when the need was to get all the new equipment working reliably. This was complicated by the accelerator changing from 300- to

400-GeV operation in July; at the same time the newly installed experiments were understandably wanting steady beam after having waited for several years.

From September 1975 on, the emphasis of the area has changed from installation of new equipment to improving operational reliability (although equipment for individual experiments continued to be brought in). Beam control and diagnostic equipment was improved; a series of target-drawer improvements during the early part of the year paid off in considerably reduced down-time from water leaks; magnet cooling systems and vacuum systems were steadily instrumented more fully, and a change to more experienced permanent operating crews was made. The reliability of components also showed up in significantly reduced personnel-radiation exposures during late 1975 and early 1976. The work of Bob Sorber helped substantially in this reduction.

By March, 1976, there were eight major experiment setups; three took beam simultaneously while many of the others ran parasitically. In late 1975, the Proton Area research program needs led to the use of a "front porch." Beams were sent to all three Proton Area, on a "front porch" of the main-ring magnet cycle at an energy below maximum (generally 200 GeV), and then approximately two seconds later, to all three areas again at maximum energy (generally 400 GeV). Thus six beams were sent to the Proton Area on each accelerator cycle--a large improvement over the one or two of a year earlier.

The intensities of the proton beams increased as more operational experience was gained and as the experimental needs demanded. Intensities

in excess of 5×10^{12} were used, and further increases look attainable.

A novel item brought into operation in early 1976 was a liquid-hydrogen target in the P-East target box for Experiment #300. The technical problems of operating such a target in beams approaching 10^{13} protons/pulse and in the relatively inaccessible target box with its severe radiation environment were successfully solved.

There were several other improvements in the area in late 1975 that made working conditions there somewhat more pleasant. A Field Office complex combining many previously scattered Portakamps was constructed, with the novel design by Bob Shovan, assisted by Bob Wilson. Concrete sidewalks replaced the old boardwalks and enabled staff and experimenters to get from one part of the area to another without almost disappearing into deep mud. The rest of the Laboratory was finally connected to the Proton Area by paved roads, immediately adding years of life to the cars of people working in the area. In February, 1976, the Control Room moved to its permanent location in the upper level of the Pagoda, giving the operating crews a better and more attractive location for controlling the area.

Experimental Program

While all the construction and improvements described above were being accomplished, physics experiments (the reason for all the effort) were also being carried out. We give a brief description of those experiments set up or completed in the past 18 months in the following pages. Their locations in the area are shown on page 8.

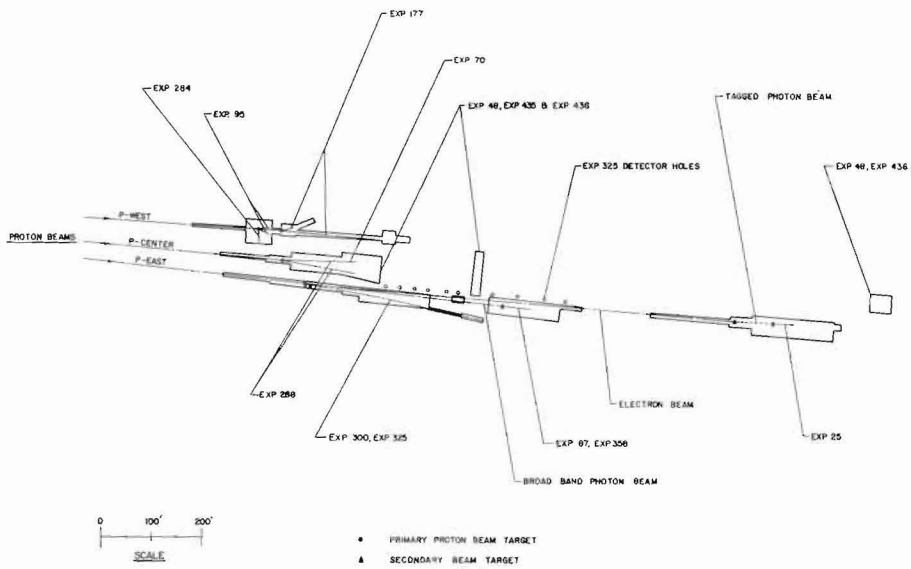


Diagram showing the locations of Proton-Area experiments set up or completed in the past 18 months.

P-East

E87/E358. These experiments in the broad-band photon beam used a spectrometer with a BM109 magnet and identification of electrons, muons, and hadrons. The goal was to study production of dileptons (together with other final states), by photons and neutrons on beryllium. A very important discovery in the experiment was that the ψ is a strongly interacting particle. In addition, the group has recently reported results consistent with photoproduction of a 4.7-GeV mass particle that decays into two muons.

E25. This experiment, to measure photon-proton total cross sections using the tagged photon beam will take data in mid-1976. In mid-1975, the experimenters tested their lead-glass detectors and proportional-chamber

system by measuring ψ photoproduction from deuterium with photons of 55 GeV.

E300/E325. The first of these experiments is a sequel to E100, which measured the large transverse momentum production of hadrons and leptons in 1973-74. A six-element focusing spectrometer detects particles produced at 77 mrad (approximately 90° in the c.m.) from a target in the primary proton beam. In Experiment #300, liquid-hydrogen and deuterium targets are used in addition to solid targets. Experiment #325 has large liquid scintillators in a series of holes in the earth near P-East. These detect muons from the target and the coincidences of these muons with hadrons or leptons in the main spectrometer will be studied. Running for these experiments started in January 1976.

P-Center

E70. This experiment completed data-taking in December 1974 on single large transverse-momentum lepton production in proton-nucleus interactions. An extensive rebuilding of shielding and experimental equipment in the area was carried out over the next several months to set up the two-arm spectrometer system for E288.

E288. Each arm, at a production angle of approximately 90° in the c.m. has electron, muon, and hadron identification. A study of dielectron production has revealed very interesting high-mass events with evidence for a 6-GeV mass particle. Studies of dimuon and dihadron production (with Cerenkov counters for particle identification) are scheduled for the next few months. Later this year, in another extensive rebuilding of the area,

the proton beam dump will be moved from its present location 10 feet downstream of the target to a new location at the downstream end of the enclosure. This should significantly reduce background in the detectors and enable considerably higher proton intensities to be used.

E48, E435, E436. These experiments used a variable-density copper target in the primary proton beam in P-Center, together with detectors in pits 200 and 700 feet downstream, to study prompt muon production close to the forward direction. Data on both single and pair production of prompt muons and their polarization have been obtained. The indication was that prompt muons appear to be produced mainly in low-mass muon pairs by electromagnetic interaction.

P-West

E95. The detection equipment consists of lead-glass arrays on two arms pivoting about a thin hydrogen or heavy-nucleus target in the proton beam. The goal is to study photon production, including the topical question of high-mass particles decaying into two or more photons. Preliminary results indicate that the equipment is performing satisfactorily and is capable of producing interesting results.

E284. A 2.4-GeV/c spectrometer pivoting about a hydrogen target is used to study proton-proton inclusive interactions; there is full particle identification on the spectrometer. The aim is to reduce uncertainties in the results to the 1% level for detailed comparison with inclusive-production models. Data taken in a preliminary run are very encouraging.

E177. This experiment studies large-angle proton-proton elastic scattering using two magnetic spectrometers. It was the most demanding of

the P-West experiments on beam cleanliness. After the addition of considerable shielding in the vicinity of the target and detection apparatus, the experiment is now taking data up to t of approximately 10 $(GeV/c)^2$.

Plans for the Future

When the Proton Area was designed, it was known that future expansion would be possible, and in the past year, the Proton Department has been actively designing new experimental facilities. They are indicated in the figure on page 2.

The first of these is the high-intensity pion beam conceived and designed by Brad Cox. The proton beam in P-West will be refocussed on a target 150 feet downstream of the existing enclosure. From the target, a secondary beam will be produced with as high an intensity as possible. To do this, the angular acceptance is large, as is the momentum acceptance (±5%). This beam is designed to give pion fluxes at some secondary momenta of over 10^{10} for 10^{13} protons, onto a spot approximately 0.5 cm square. The production angle can be varied to improve the $\bar{p}/\pi^-$ ratio.

The beam has been designed to achieve 1000 GeV, in order to enable hadron physics to start as soon as the Energy Doubler is available. To meet all the design criteria, the more than 50 magnets will be superconducting, making this the first major superconducting beam in the world. The technical problems are great, but appear solvable, and construction is scheduled to start in the next few months. There are already several approved experiments to use the beam, and it promises to become one of the Laboratory's major facilities.

The second important project under design is a Hyperon Area downstream of P-Center. This was described in the March 1976 NALREP and will not be enlarged upon here. A beam of hyperons up to 400 GeV will complement the Laboratory's beams and should produce some important physics. This project has been designed by Dave Eartly and Joe Lach.

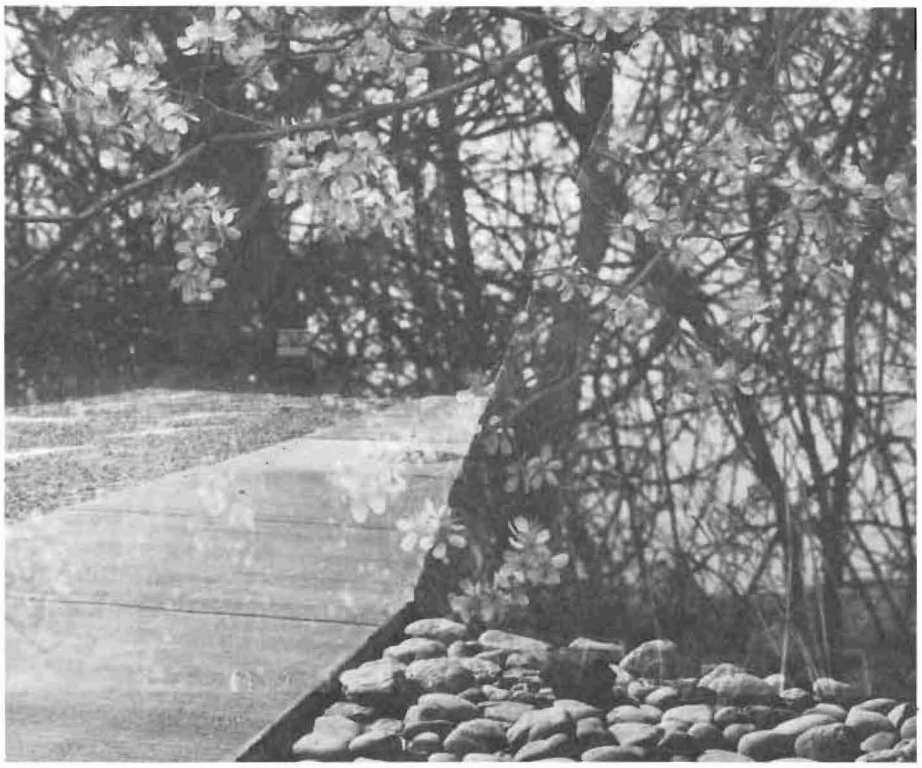
Acknowledgment

The achievements in the Proton Area in the past one-and-a-half years, and the hectic pace at which they have been carried out, were only possible because of the dedication, enthusiasm, and extremely hard work of the approximately 50 people in the Proton Department. The people associated with individual projects have been noted earlier; all projects have included Ron Currier (Mechanical), Al Guthke (Experimental Area), Carmen Rotolo (Instrumentation), and Age Visser (Electrical). The exciting physics now coming out of Proton is a tribute to their work.

NOTES AND ANNOUNCEMENTS

APPOINTMENTS. . .

Art Greene has been appointed Assistant Director and head of the Program Planning Office, effective last month. In that capacity he will be working under Ned Goldwasser's general direction. The Program Planning Office will have respondibility for setting schedules, for supervision of the Operations Group, and for conducting the biweekly, Monday All Experimenters' Meetings and the weekly, Tuesday, Scheduling Meetings.



Multiple exposure depicting spring around the Meson Area.
(Photograph by Dawn Hall)

RESEARCH ACTIVITIES DURING APRIL 1976

Reported by Halsey Allen

Activities during the first two weeks of April were primarily involved with the startup and tuneup of the accelerator and final preparations in the Proton and Neutrino Areas for the re-establishment of the high-energy physics research program. At the same time, repair work on the Meson-Area target train continued. Accelerator startup was greatly slowed by the failure of two splices and one cable in the main-ring power-feeder system; these all occurred consecutively within a period of five days. Additional less serious difficulties were also encountered in the startup of several accelerator systems. The "turn-on" effort was further hampered by several failures in the capacitor bank system as attempts were made to commission it as an operational part of the main-ring power supply. As a consequence, there was essentially no stable operation for the physics research program until after mid-month. The accelerator-related problems were further compounded by a failure of the neutrino focusing horn during the startup of the Neutrino Area, thus frustrating a plan to establish a solidly running neutrino research program, using the 15-ft bubble chamber, prior to bringing the Proton and Meson Areas back into operation.

By the third weekend in April, a modified neutrino program, using a bare target, as well as a research effort in each of the three Proton Area beamlines was underway. The momentum of this effort was disrupted shortly thereafter, however, when a two-day down period resulted from the failure of two main-ring magnets, an extraction septum and other assorted

minor accelerator problems. During this period, work began on the installation of the repaired horn trainload, and final installation and survey of the Meson target train was completed. After accelerator operation was restored, the Proton Area research program was resumed and startup and tuneup of the Meson Area began, followed five shifts later by full operation of the Neutrino Area with the horn focusing system. The last eight days in the month saw a somewhat erratic but gradually stabilizing accelerator operation providing 400-GeV slow- and fast-spilled beam to a relatively full program in all experimental areas. Over 250 hours of useful beam time were available for the April high-energy physics-research effort, but these were delivered in a large number of shorter-than-normal running intervals between programmed and unscheduled interruptions in the operation.

The Neutrino Area program received the highest priority this month, using high-intensity fast spill and the 15-ft bubble chamber filled with a 70%-30% neon-hydrogen mixture for the Neutrino #53A experiment. The chamber operated nearly flawlessly throughout this period, recording some 16,000 pictures during the four-day bare-target run and an additional 41,000 during the eight days of running with the horn. At the same time, downstream from the chamber, the emulsion stack for Particle Search #247 was also exposed in the neutrino beam and a total of 6.5×10^{17} protons tuned as a hadron beam for tests and detector calibrations was delivered in fast spill on the two targets used during the course of the run. After the horn had been reinstalled, slow spill was also set up and the N1 "muon beamline" was tuned as a hadron beam for tests and detector calibrations by the Muon #319 group.

During the two weeks of Proton-Area operation in April, all three target stations were being used. The Di-Lepton #288 experiment, running in Proton-Central, collected data on high-mass di-muon production. In Proton-East, Particle Search #300/#325 used their hydrogen target to complete the data-taking phase of the #300 cross-section experiment and then switched to the use of the multihole spectrometer to collect data on di-muon events in the high-mass region for the #325 phase of the run. Photon Search #95A in Proton-West used available beam time to check out their equipment and calibrate detectors in preparation for their second data-taking run.

Startup of the Meson Area proceeded very smoothly once the target-train installation was completed. After one to two shifts of beam tuning and targeting studies, the experiments in the secondary beamlines began to receive stable beam for tuneup and equipment-checkout purposes. In the remaining week of running during April, Particle Search #357 in the M2 beamline, Particle Search #366 in the M3 line, K^0 Regeneration #425 in the M4 neutral beam and Inclusive Scattering #118A, using the single-arm spectrometer in the east branch of M6, all completed work on tuneup of their beams and apparatus and had begun the data-taking phase of their work. In M1E, Polarized Scattering #61 worked on startup of their polarized target and superconducting analysis magnet and also used some available beam for apparatus tuneup and trigger studies in preparation for their first data-taking run.

Three experiments in the Internal-Target Area used the beam to tune up their apparatus in preparation for subsequent data-taking work. The new

warm gas jet being used by Proton-Nucleon Scattering #198A and Polarized Scattering #313 was debugged and brought into operation, together with the main elements on the spectrometer arm, including the superconducting magnets. Beam was used to perform tests on the jet and the detectors on the spectrometer were tested and calibrated with secondaries produced both in the gas jet and from a rotating target. By the end of the month, both experiments had reached the stage of preliminary data taking. Proton-Proton Inelastic #321 spent about one week rechecking and debugging their detectors and gas jet. They then proceeded into a data-taking mode, double-pulsing their 3-mil jet at 200 and 400 GeV each accelerator cycle. The Proton-Nucleon Scattering #381 group also did some preliminary checking of their equipment.

FACILITY UTILIZATION SUMMARY -- APRIL 1976

I. Summary of Accelerator Operations

		Hours	
A. Accelerator use for physics research			
Accelerator physics research		4.4	
High energy physics research		254.5	
Research during other use		(51.5)	
	Subtotal		258.9
B. Other activities			
Accelerator setup and tuning to experimental areas		15.5	
Scheduled interruption		213.1	
Unscheduled interruption		231.5	
	Subtotal		460.1
C. Unmanned time			
	Total		719.0*

II. Summaries of High Energy Physics Research Use

	# of Expts.	Hours	Results
A. Counter experiments	14	2110.7	
B. Bubble-chamber experiments	1	179.9	57,343 pictures
C. Emulsion experiments			
D. Special target experiments			
E. Test experiments			
F. Engineering studies and tests			
G. Other beam use	-	12.4	Beamline tuning
	15	2303.0	1 expt. completed

III. Number of Protons Accelerated and Delivered ($\times 10^{18}$) at 400 GeV

A. Beam accelerated in Main Ring	Total		1.05
B. Beam delivered to experimental areas			
Meson Area		0.08	
Neutrino Area			
Fast Spill		0.65	
Slow Spill		0.04	
Proton Area		0.14	
	Total		0.91

*Change to Central Daylight Time, 0200, April 25.

IV. Beam Utilization By Experiment

	Hours	Results
A. Meson Area		
Polarized Scattering #61	114.3	Tuneup and tests
Inclusive Scattering #118A	122.5	Data
Particle Search #357	133.3	Data
Particle Search #366	156.4	Data
K^0 Regeneration #425	146.3	Data
B. Neutrino Area		
15' ν/H_2&Ne #53A	179.9	57,343 pictures
Particle Search #247	215.0	Tagged emulsion data
Muon #319	90.0	Tests
C. Proton Area		
Photon Search #95A	156.7	Calibration
Di-Lepton #288	140.8	Data
Particle Search #300	94.8	Data, completed
Particle Search #325	101.5	Data
D. Internal Target Area		
p-N Scattering #198A	237.3	Spectrometer tests
p-p Polarization #313	237.3	Spectrometer tests
p-p Inelastic #321	164.5	Data
Total	2290.6	

PROPOSALS RECEIVED DURING APRIL AND MAY 1976

No.	Title	Submitted By
479	Neutron-Deuteron Elastic Scattering	T. Roberts
480	Proposal to Search for Heavy Bosons, Heavy Leptons and Charmed Particles at SSR	L. Mo
481	Investigation of Multiple Production by π^- Mesons with Emulsion Chamber	Y. Takahashi
482	Study of Dimuon Events Produced in Neutrino Interactions	B. Barish
483	Proton-Proton Elastic Scattering at $\|t\| = 374$ $(GeV/c)^2$	M. Longo
484	Proposal to Study ψ Production Using the E416 Apparatus	H. Lubatti
485	A Proposal to Investigate Exotic Reggeon Exchange in the Inclusive Production of Charged Hyperons	P. Shepard
486	Proposal to Study the Atomic Number Dependence of the Difference Between Particle and Anti-Particle Total Cross Sections	B. Winstein
487	A Proposal to Study the Origins of "Extra" Prompt Muons Produced in Deep Inelastic Muon-Nucleon Scattering	A. Sessoms
488	Proposal for a Study of Heavy Particle Production and Dynamics Near X = 0 and the Dependence on Incident Quantum Numbers	I. Pless
489	Production to Study Neutrino Interactions in Hydrogen and Nuclei with an Internal Target and Converter System in the 15-Ft Bubble Chamber	F. Nezrick
490	Search for Short Lived Particles Using a High Resolution Streamer Chamber	J. Sandweiss

DATES TO REMEMBER

June 19-25, 1976	Extended Summer Meeting of the Fermilab Program Advisory Committee (Aspen, Colorado).
June 28-July 9, 1976	Summer Study on the Use of the Energy Saver/ Doubler.

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