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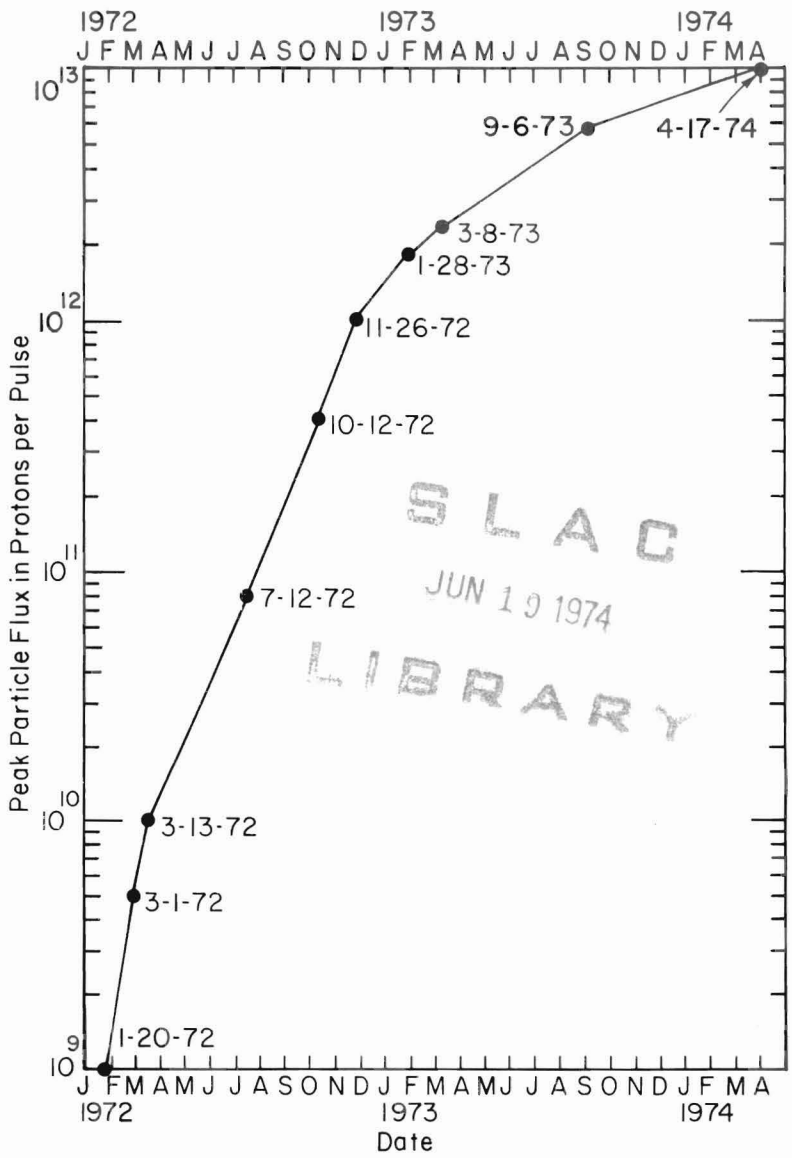

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Monthly Report of the Fermi National Accelerator Laboratory

May 1974

National Accelerator Laboratory

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NAL-74/6 0090.01

THE COVER: The progress made in raising the peak intensity capability of the accelerator is summarized in this graph. Some of the milestone dates are indicated in the steps toward the Laborator's goal of 10^{14} protons per pulse.

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ACCELERATOR OPERATION IMPROVING

Shortly after midnight on Wednesday April 17, 1974, an intensity of 1.01×10^{13} protons per pulse was recorded for the Fermilab accelerator. This is believed to be the highest intensity per pulse ever recorded for a proton synchrotron.

This record intensity occurred during a period of particularly good accelerator operation. In the week from April 15 to 21, the accelerator operated more than 94% of the time scheduled for both high energy physics research and accelerator studies. A greater number of protons--3.9×10^{17}--was accelerated than ever before, giving an average intensity of 5.2×10^{12} protons per pulse over all possible main ring magnet pulses during that week.

In the weeks just prior to April 17, a number of activities went on to make the higher intensity possible. First, the 8-GeV beam channel from the Booster Accelerator to the Main Ring was studied, realigned, and retuned, using repositioned beam detector devices. This enabled the beam to be matched more nearly to the main ring acceptance, thus improving transmission in the Main Ring. Secondly, the stability of the beam in the Linear Accelerator was improved, and the transport system into the Booster was tuned, providing better injection conditions in the Booster. Thirdly, the multiturn injection system in the Booster was improved. This series of magnets with time-varying fields enables the beam from the Linac to fill the radial aperture of the Booster during multiple turns, and provides a wider beam for the Main Ring. These efforts, coupled with the earlier work with correction elements and damper feedback systems in the Main Ring, provided the

capability for the increased intensity. The peak pulse was reached when some quadrupole magnets in the Booster were tuned, effectively increasing the aperture of the beam available to the Main Ring.

The next step in the quest for 10^{14} protons per pulse will be to consolidate regular accelerator operation at a higher level, and to reduce remaining beam losses in both the Booster and Main Ring Accelerators. Despite the record intensity, transmission efficiency in the Booster was quite poor, only 16%; that in the Main Ring was only 62%. Some of this is attributable to the multiturn injection scheme, which is a more complex system. Many accelerator studies remain to be done.

THE PROTON BEAM SWITCHYARD

Very early in the design of the Fermilab accelerator it was recognized that striking the circulating proton beam on a thick target placed directly inside the accelerator vacuum chamber to produce useful beams of secondary particles would be extremely undesirable. The radioactivity and radiation damage in accelerator components caused by beam scattered from such a target would be intolerable. Therefore, it was decided that there would be no internal targets (except extremely thin ones such as the gas jet from which beam scattering is negligible) and that all thick particle production targets would be placed in beam lines external to the Main Ring. Consequently, a system was needed through which the primary proton beam could be removed from the Main Accelerator and transported to external targeting stations. It was further decided that there would be only one extraction point. Thus, the induced radioactivity in the Main Accelerator could be kept at an absolute minimum, occurring principally in the vicinity of this extraction point, and caused only by the very small amount of beam lost during the high efficiency extraction process.

In order to provide protons onto a number of particle production targets, a beam splitting system which could separate the single extracted beam into branches going to several experimental areas simultaneously was necessary. With such a system, it would be possible to operate several experimental areas at one time, thus expanding the scope of the Laboratory's research program.

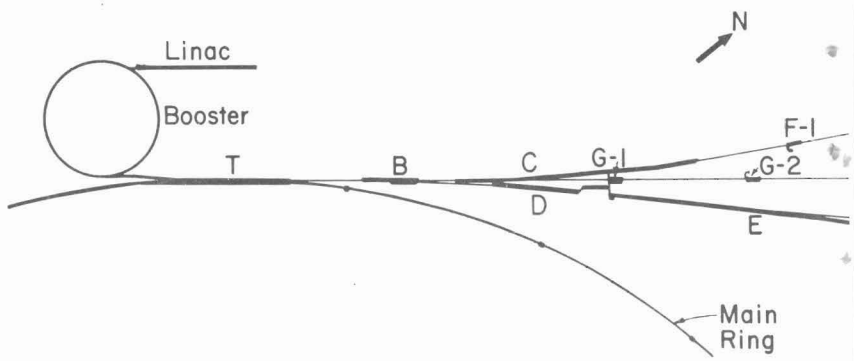
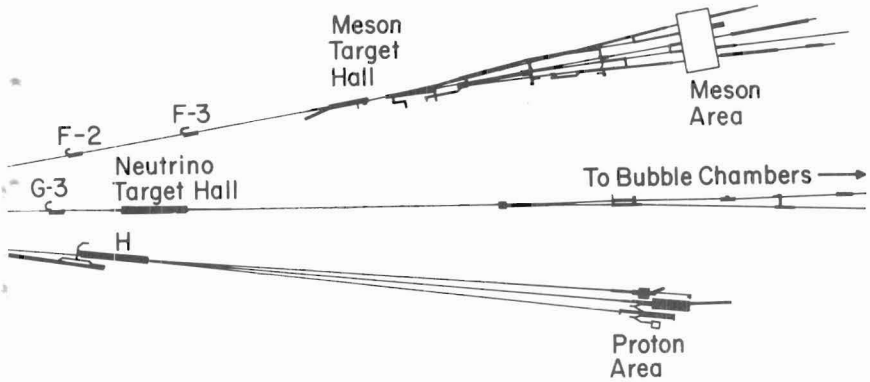


Fig. 1. Diagram of the accelerator system. The A-Zero straight section of the Main Ring in the Transfer Hall (T) is the point of injection and extraction of the primary proton beam. Extracted beam is transported to the three external experimental areas through a complex of tunnels (B, C, D, E,

The Accelerator staff began designing such a beam extraction, splitting, and transport system as an integral part of the project. Early in 1973 two splitting stations were installed, and on March 30 of that same year, simultaneous operation of all three external experimental areas--Meson, Neutrino, and Proton--was first achieved. Since then, two additional splitting stations have been installed in the Neutrino and Proton Area beam lines, bringing to five the number of external areas which can receive the primary proton beam at one time.

In the following pages the layout, operation, and distinctive features of this system, known as the Switchyard, are briefly described.



and H) and manholes (F and G) connected by 12-in. diameter evacuated pipes. Splitting station for the Proton Area beam line is located in the Transfer Hall and tunnel B; Meson Area splitting station is in tunnels B and C.

The Switchyard Layout

The primary proton beam is extracted from the Main Ring in the Transfer Hall, at the A-Zero straight section of the ring, and transported straight ahead toward the Neutrino Area. Along the way, two splitting stations peel beam off--first to the right toward the Proton Area, and then to the left toward the Meson Area; the remaining beam being transported to the Neutrino Area. Provision has been made for an additional splitting station, so that beam can be sent to a future experimental area as well. A diagram of the accelerator, showing the Switchyard tunnels and manholes which enclose the bending and focusing magnets for the extraction and beam transport system, is shown in Fig. 1. In addition to being bent horizontally, the beam must be deflected vertically so that it arrives at targets located at different elevations in the experimental areas.

The Splitting Stations

The principal component of a beam splitting system is a septum which carries either an electric current or an electric charge to produce a difference in the fields on opposite sides of the septum--magnetic field for a current-carrying septum, and electric field for a charge-carrying septum. Segments of the extracted proton beam on opposite sides of the septum will travel in different directions because of the different fields. The thinner the septum, the less beam it intercepts, and the better the efficiency of the splitting. At

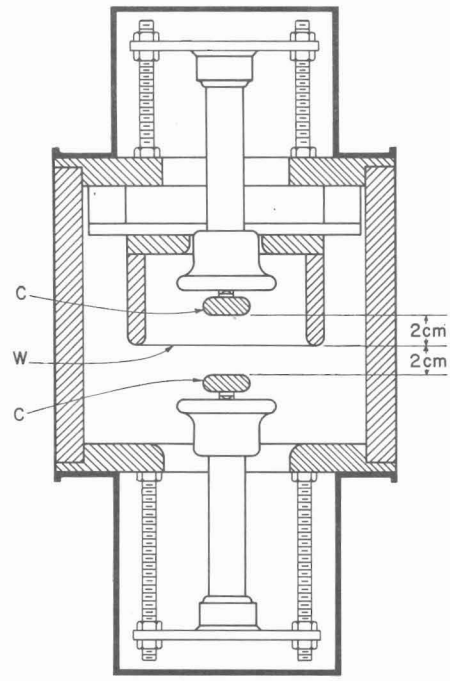


Fig. 2. Cross section of a 10-ft long electrostatic septum. Cathodes (C) are titanium. Wires (W) are 2/1000-in. diameter tungsten, spaced 20 to the inch. Normal operating voltage is 75 kV on each cathode, with the wires at ground.

Fermilab, electrostatic septa are employed (see Fig. 2). To form a perfectly flat septum by stretching a metallic foil 1/1000-in. thick is extremely difficult, since the septum foil wrinkles when struck and heated by the circulating proton beam. Instead, the electrostatic septa are formed of well aligned "walls" of thin wires with tension springs to take up any slack caused by heating. An effective thickness of 5/1000-in. has been attained for the septa in the beam splitting system. This corresponds to an expected beam loss on the septum on the order of 1%.

The basic concept of a splitting station is shown in Fig. 3. The beam is cut into two parts by the electrostatic septa. The two branches of the beam then drift for several hundred feet, diverging vertically by 0.2 mrad

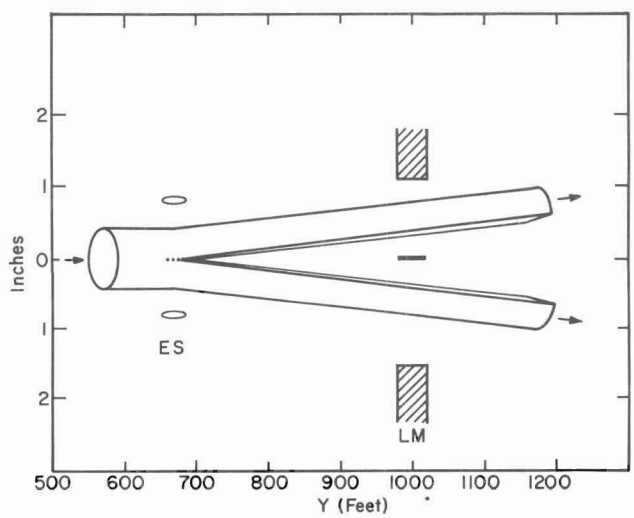


Fig. 3. The basic design of a splitting station. Beam is incident on an electrostatic septum (ES), which splits it vertically by 0.2 mrad into two portions which drift to a septum magnet (LM) further downstream. At the LM, lower beam, in a field-free region, is undeflected; upper beam is bent 7 mrad horizontally (perpendicular to the plane of the paper).

until they are separated sufficiently to clear the iron septum in a magnetic septum (see Fig. 4). The lower beam passes through the field-free region of the magnet and is undeflected. The upper portion is bent 7 mrad horizontally. After drifting several hundred more feet the beams are separated enough to be treated as distinct entities, using standard dipole and quadrupole magnets. An image profile of the two beams constructed by wire chambers as they emerge from the magnet after both vertical and horizontal separation is shown in Fig. 5.

Four small bending magnets are used to displace the beam at the electrostatic septa in a parallel manner, to vary the splitting ratio. Through the computer these magnets are controlled by one setting, so in principle the splitting ratio can be easily set by adjusting one knob. In practice, some details of beam line tuning still must be worked out. At present, changing the split ratio displaces the beam position downstream. These displacements are small, but they are important at subsequent splitting stations.

Experience with the splitting system has shown that the accelerator, the transport magnets, and hence, the beam position, are normally quite stable. Therefore, the splitting ratio is usually constant. It has been possible to split off portions of the beam as small as 0.1%. Thus, with the accelerator operating at 10^{12} protons per pulse, it is possible to give an experimenter a stable beam as small as 10^{9} protons per pulse on his primary target.

One crucial problem with the splitting stations is that in separating the primary beam into two parts it is necessary to place something into the beam vacuum pipe, in this case the wires of the electrostatic septa. Thus, beam

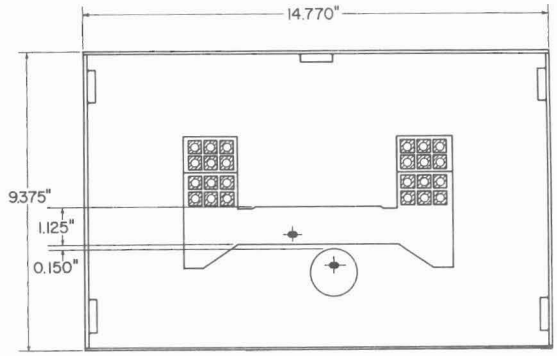


Fig. 4. Cross section of a septum magnet. The field-free region is within the circular hole in the bottom.

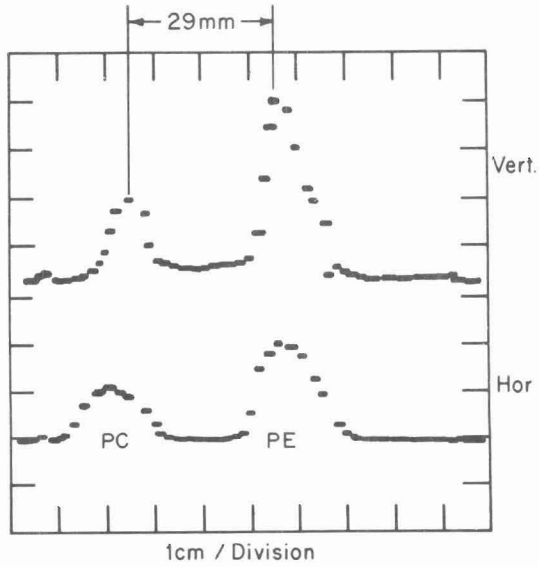


Fig. 5. Profile from a SWIC located immediately downstream of a septum magnet. Top trace is a vertical profile showing the two beams separated by 29 mm resulting from a 0.1-mrad opening angle produced by an electrostatic septum and a 1000-ft drift space. Lower trace is a horizontal profile, showing a 30-mm separation resulting from a 4-mrad bend by the septum magnets and a 20-ft drift space. Left beam was directed to Proton Central (PC); the right, to Proton East (PE).

losses will be proportional to the septum thickness divided by the beam width. Beam optics and device apertures force us to limit the beam width to 1 or 2 cm. The septa presently used employ 2/1000-in. diameter wires, and have an apparent width over a 10-ft long septum of 5/1000-in. By carefully monitoring and controlling beam handling operations it is possible to avoid high loss conditions; for the past nine months the residual radioactivity of the splitting station components has been lower than it was last June, despite increasing beam currents. With improved septa, increased shielding of critical devices, more sophisticated mechanical handling methods, and more experienced beam operators, the splitting stations should be able to accommodate the projected tenfold increase in beam intensity.

Targeting

In the Meson Area, the split, extracted proton beam hits a single target which is the source for five secondary beams. The beam position can be monitored by a loss monitor mounted near the target. A plot of the target loss monitor (TLM) signal normalized to the Meson beam line intensity reading as a target is moved across the beam line is shown in Fig. 6. Since the beam spot is much smaller than the width of the target, it can be used to "measure" the width of the target.

The beams transported to the Neutrino Area are more complex than those to other areas, because of the variety of conditions desired for operating both bubble chamber and counter experiments. There are two primary targets in the Neutrino Area. One target, located upstream of the 1000-ft long decay pipe, is the source of mesons. It is placed on a train of beam elements, and

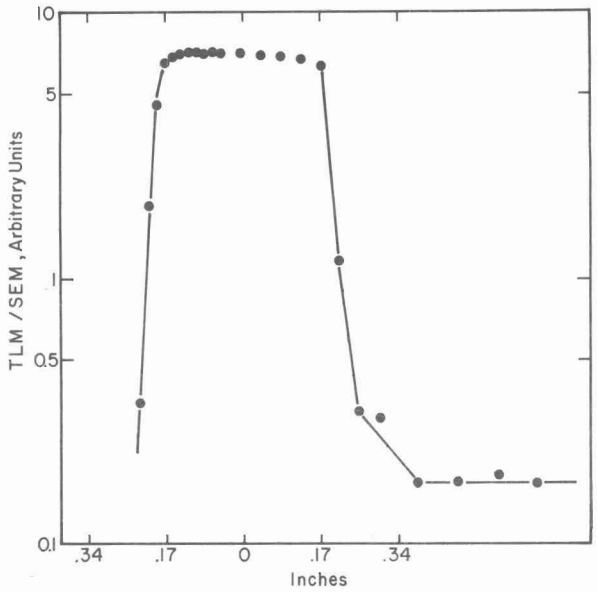


Fig. 6. The Meson Area target loss normalized to the Meson Area SEM (which measures beam intensity) as a target is scanned across the beam line. The tantalum target has a width of 0.375 in. and is 12-in. long. The beam spot is typically 0.040-in. (1 mm) wide, as is suggested by the sharp edges of this plot. The value of TLM/SEM, which is unique for each target, is a monitor of targeting efficiency. When the TLM signal is strong, the beam is hitting the target; when weak, it is missing the target and going on to the beam dump. This ratio is available to experimenters as a train of pulses and on a TV screen.

is known as the "train" target. The decay of mesons provides the neutrino and muon beams. The other target, located downstream of the meson decay pipe, is the source of hadron beams for the bubble chambers. It is struck by a proton beam which bypasses the train target, and consequently is known as the "bypass" target. This beam line originates from the neutrino splitting station, which consists of fast and slow switching magnets in manhole G-2, electrostatic septa in manhole G-3, and septum magnets in the Neutrino Target Hall.

Table I. Neutrino Area Beams.

Combination	Train Target	Bypass Target
1	Slow[a]	Slow
2	Slow	Fast[b]
3	Slow	Multiple[c]
4	Fast	Slow
5	Fast	Fast
6	Fast and slow	Multiple

[a]The normal 1-sec spill.
[b]A 100-μsec pulse containing a large fraction of the beam, which occurs 50 msec after the slow spill and goes only to the Neutrino Area.
[c]As many as five 300-μsec pulses occurring during the slow spill and sent to the 15-ft multiple-pulsed bubble chamber.

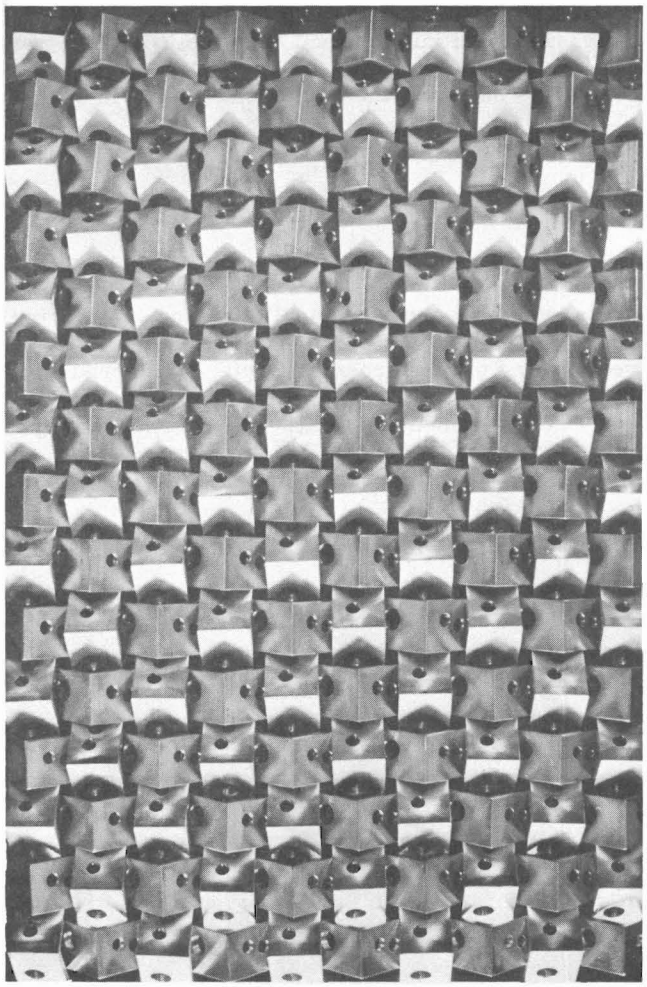
The neutrino splitting station makes it possible to deliver six combinations of beam spills to the Neutrino Area, as listed in Table I. The most interesting one is the sixth, when slow and fast beams are sent to the train target and the kicking magnet in the G-2 manhole is used to send four 300-μsec-long pulses down the bypass line to the bubble chamber for multiple exposures of the 30-in. chamber every accelerator cycle.

The Proton Area consists of three separate, independently operable areas--Proton East (PE), Proton Central (PC), and Proton West (PW). Until recently, beam could be directed to only one of these branch areas at a time, by switching magnets in enclosure H. A splitting station has just been installed to make it possible to send beam to Proton Central and one of the other branches simultaneously. Future plans include the installation of a triple-type splitting station so that beam can be delivered to all three areas at the same time.

Conclusions

The installation of the triple-split planned for the Proton Area will mark the completion of the initially defined beam splitting and transport system. The basic concepts have proved quite sound--beam is successfully transported over long distances through widely spaced, small-aperture magnets, and with rather simple splitting stations working well at acceptable levels of induced radioactivity. For the future, our goals are to consolidate what exists through improvements such as increasing local shielding, improving the vacuum system, redesigning the electrostatic septa, and increasing use of computers in processing the instrumentation data. For the longer term the Switchyard must be prepared to work with the accelerator producing 10^{14} protons per pulse, and operating at energies of 400 GeV and higher.

Based on material supplied by E. Bleser



An array of door latches which had just been produced by the Fermilab Machine Shop. They were later installed in the interlock safety system throughout the accelerator and external experimental areas, by which access to the beam lines is controlled from the Main Control Room.

(Photo by A. R. Donaldson)

NOTES AND ANNOUNCEMENTS

NEUTRINO WORKSHOP TO BE CONTINUED THIS SUMMER . . .

A workshop was held at Fermilab on Saturday, May 18, to discuss second generation neutrino experiments. B. W. Lee presented an overview of what has been learned thus far from neutrino experiments at the Laboratory, and discussed some possible physics objectives of second-generation experiments. F. Nezrick described the CERN neutrino program, and B. Roe and P. Limon presented ideas for new or improved neutrino beams. J. K. Walker summarized the existing and possible future sites for neutrino detectors.

Ideas for new detectors were then discussed. F. R. Huson presented a plan for a 60-meter modular hydrogen bubble chamber. L. Osborne and D. Nygren each presented their ideas about the building of some massive electronic detectors. In the ensuing open discussion, the following broad concepts were suggested as being most useful for further study this summer:

1. Design of an optimum broad- and narrow-band low energy neutrino beam for the 15-ft bubble chamber. The objective would be to provide low energy neutrino fluxes ten times more intense than the present beam.

2. Design of a massive (≈3000 tons) electronic detector which would be a hundred times the mass of the neon-filled 15-ft chamber and ten times more massive than existing electronic neutrino detectors. The objective could be to provide a look at the highest possible neutrino energies.

3. Methods for improving the neutrino intensity by making changes in the existing area. This might involve some tests of muon attenuation by means of magnetic shielding.

4. Design of a massive electronic detector utilizing liquid hydrogen cells. The mass of hydrogen would be a factor of ten more than that presently in the 15-ft bubble chamber.

A "mini" study of these ideas will take place at the Laboratory from July 15 to August 9. Anyone wishing to participate for a week or longer of this period should contact J. K. Walker, Ext. 3603, as soon as possible.

Reported by J. K. Walker

USERS OFFICE ESTABLISHED . . .

A Fermilab Users Office has been established in response to many requests from visiting experimenters. The office is located on the Atrium floor of the Central Laboratory, adjacent to the elevators in the east wing. It is headed by Cynthia Sazama, who can be reached on Ext. 3136.

Among the services available through this office are assistance in contacting Laboratory staff members regarding nontechnical, work-related problems, and in arranging meetings for the Users Executive Committee and the Users Organization. A message board has been set up. Bicycles may be rented through this office also. Some secretarial assistance may be offered later. Housing, travel arrangements, and the like will continue to be handled by their respective offices.

FOOD SERVICE EXPANDED . . .

Grill service is now available in the cafeteria throughout the day, from 7:30 a.m. to 8:00 p.m. Bacon, eggs, and other breakfast items will be cooked to order upon request any time except during the peak lunch rush.

FACILITY UTILIZATION SUMMARY - APRIL 1974

Performance during April was the best the accelerator has had to date. This can be measured through the productivity of the high energy physics research program, the reliability of the accelerator systems, and the number of accelerated protons delivered. Overall efficiency during the time scheduled for high energy physics research was 77%, with 456 of the 596 hours of scheduled beam time actually available for experimental use. Extracted beam intensities averaged between 0.7×10^{13} and 0.8×10^{13} protons per pulse throughout the month, and a peak intensity of 1.0×10^{13} protons per pulse was attained as well. This high operating level facilitated the completion of running time for six experiments.

In the Meson Area, the Total Cross Section #104 group completed preliminary data taking at incident momenta of 50, 100, 150, and 200 GeV/c. Neutron Dissociation #27A and Multigamma #230 completed data taking, and four other groups, including Elastic Scattering #7, Pion Charge Exchange #111, K^0 Regeneration #82, and Elastic Scattering #96 took data. Missing Mass #51A, Photon Inclusive #268, Neutron Backward Scattering #12, and Elastic Scattering #69A were engaged in beam tuning and equipment checking during the last several days of the month.

Activity in the Neutrino Area was centered in the Muon Laboratory and the 30-in. bubble chamber. The triplet trainload was tuned during the first few days of the month, and priority then went to data taking by the Muon #26 group. This experiment was completed, with 2×10^{17} protons on target with the muon beam tuned for 56 GeV/c, and an additional 1.3×10^{17} protons with

the beam tuned for 150 GeV/c. In mid-April, the Muon #98 group resumed data taking, receiving 4.2×10^{17} protons on the muon target during the remainder of the month. Simultaneously, "pinged beam" was transported to the 30-in. bubble chamber target, and 187,000 pictures were taken. Commitments to three groups were completed, with 51,000 pictures of π^--p interactions at 200 GeV for Experiment #243; 37,000 pictures of p-p interactions at 60 GeV for Experiment #228; and 20,000 pictures to investigate p-p interactions at 300 GeV and another 54,000 pictures at 200 GeV for Hybrid #2B. Following a series of retargeting tests in the hadron beam line, 25,000 pictures of π^+-p interactions at 200 GeV were accumulated for Experiment #217.

Five experimental groups used the beam in the Proton Area during April: Lepton #70 searched for directly produced muons at 83 mrad in Proton Center, Particle Search #100A completed their data taking and Photoproduction #87 was set up and began checking out equipment after changes had been made in Proton East, and Photon Search #95A conducted beam tests of the transport system to Proton West.

The four groups using the Internal Target Area continued their work. Rotating targets were used to produce secondary particles at various incident beam energies for Particle Search #184, Proton-Proton Inelastic #221, and Photon Search #63A. Proton-Deuteron Scattering #186 and Photon Search #63A collected data using the deuterium gas-jet target.

A summary of the facility utilization for the month of April follows.

I. Summary of Accelerator Operations

	Hours	
A. Accelerator use for physics research		
Accelerator physics research	42	
High energy physics research	456	
Research during other use	(45)	
Subtotal		498
B. Other activities		
Accelerator setup and tuning to experimental areas	16	
Scheduled interruption	47	
Unscheduled interruption	159	
Subtotal		222
C. Unmanned time		0
Total		720

II. Summaries of High Energy Physics Research Use

	# of Expts.	Hours	Results
A. Counter experiments	21	3547	3547 hours
B. Bubble chamber experiments	4	237	187,035 pictures
C. Emulsion experiments	-	-	-
D. Special target experiments	1	35	1 target
E. Test experiments	-	-	-
F. Engineering studies and tests	-	135	135 hours
G. Other beam use	-	217	217 hours
	26	4171	

III. Number of Protons Accelerated and Delivered

		Protons
A. Beam accelerated in Main Ring	Total	13.44×10^{17}
B. Beam delivered to experimental areas		
Meson Area		2.35×10^{17}
Neutrino Area		
Main beam		8.21×10^{17}
Bubble chamber beam		0.15×10^{17}
Proton Area		0.71×10^{17}
	Total	11.42×10^{17}

MANUSCRIPTS SUBMITTED FOR PUBLICATION DURING MARCH AND APRIL 1974

Experimental Physics

F. T. Dao et al. NAL-Pub-73/80-EXP	Charged Particle Multiplicity Distributions From 14.75 GeV/c $\bar{p}p$ Interactions (Submitted to Physics Letters)
F. T. Dao et al. NAL-Pub-73/81-EXP	Inclusive Neutral Particle Production in 14.75 GeV/c Antiproton Interactions (Submitted to Physics Letters)
M. Atac et al. NAL-Pub-74/18-EXP	$\lvert g_A/g_V \rvert$ in the Decay $\Sigma^- \rightarrow ne^-\bar{\nu}$ (Submitted to Phys. Rev. Letters)
M. Atac et al. NAL-Pub-74/20-EXP	Search for Ξ^{*-}, Σ^{*-}, and Ω^- Production by Negative Hyperons on Nuclei (Submitted to Physics Letters)
J. K. Walker et al. NAL-Pub-74/28-THY/EXP	Impact Picture and the Ratio of Elastic to Total Cross Section at ISR Energies (Submitted to Physics Letters)
J. Whitmore and M. Derrick NAL-Pub-74/30-EXP (Experiment 141)	Multiplicity Distributions in the Reaction $p + p \rightarrow p +$ Anything (Submitted to Physics Letters B)
R. Stefanski et al. (Experiment 1A)	Further Observation of Muonless Neutrino-Induced Inelastic Interactions (Submitted to Phys. Rev. Letters)
Y. W. Yu and N. T. Porile (Experiment 81)	Interaction of ^{238}U with 300 and 11.5 GeV Protons: Cross Sections and Recoil Properties in the A ~ 130 Mass Region (Submitted to Phys. Rev. C)
P. L. Jain et al. (Experiment 114)	Coherent Production of Particles by 200 GeV/c Protons in Nuclear Emulsion (Submitted to Nuovo Cimento Letters)
P. L. Jain et al. (Experiment 114)	Direct Electron Pair Production by 200-GeV Protons (Submitted to Phys. Rev. Letters)
S. Konishi et al. (Experiment 117A)	Inelastic Cross Sections for Proton-Nucleus Collisions at 205 GeV/c in Nuclear Emulsion (Submitted to Phys. Rev. Letters)

Theoretical Physics

J. Bartels NAL-Pub-73/87-THY	A Field-Theoretic Study of the Regge-Eikonal Model I (Submitted to Nuovo Cimento)
J. Bartels NAL-Pub-73/88-THY	A Field-Theoretic Study of the Regge-Eikonal Model II (Submitted to Nuovo Cimento)
J. B. Bronzan et al. NAL-Pub-74/23-THY	Obtaining Real Parts of Scattering Amplitudes Directly from Cross Section Data Using Derivative Analyticity Relations (Submitted to Phys. Rev. Letters)
A. R. White and K. Kang NAL-Pub-74/27-THY	CDD Zeroes in the Pomeranchukon Scattering Amplitude (Submitted to Phys. Rev. D)
H. D. I. Abarbanel and J. B. Bronzan NAL-Pub-74/31-THY	The Pomeranchuk Singularity in a Reggeon Field Theory with Quartic Couplings (Submitted to Phys. Rev.)