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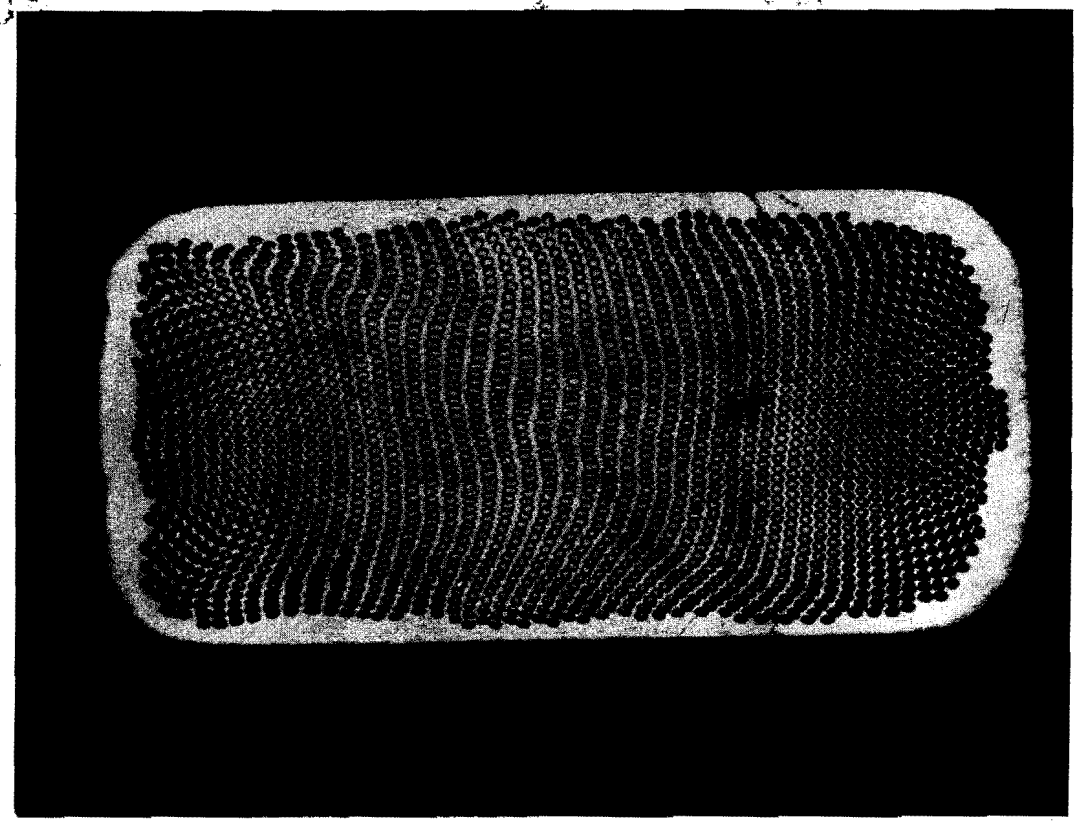
NATIONAL ACCELERATOR LABORATORY REPORT

September 1973



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THE COVER: A magnified cross section of the wire designed for use in superconducting magnets. Filaments of the superconducting material, niobium-titanium, are embedded in a copper matrix. Each of the 2,120 filaments is hand inserted into a copper tube; the tubes are then stacked in a copper shell, an ingot about 18 in. in diameter and 36 in. high. This ingot goes through two extrusion processes, reducing it to about 3/8 in. in diameter. It is then drawn through dies, twisted on itself, and squared up to its final dimension of 0.150 × 0.075 in. Each filament is then approximately 40 μm in diameter. Magnetic Corporation of America, in Waltham, Massachusetts, manufactures the wire using specifications supplied by NAL.

THE ENERGY DOUBLER DESIGN

A serious study of the possibility of raising the peak energy of protons available at NAL to the region of 1000 GeV by the construction of the so-called Energy Doubler is now in progress. This idea is not new--it has been discussed from time to time since the earliest days of the project. However, until the primary goal of getting the high-energy physics research program under way had been attained, no effort could be spared to take a closer look. By the end of 1972, sufficient progress had been made that some attention could be directed to a consideration of avenues for future developments at the Laboratory. In January of 1973, a small group was established under the direction of P. Reardon to initiate a design study on the Energy Doubler.

In his statement before the Joint Committee on Atomic Energy on March 9, 1971, NAL Director R. R. Wilson outlined the basic concept of the Energy Doubler. A system of superconducting magnets, able to be excited to 4.5 tesla--twice the maximum magnetic field of which the conventional main-ring magnets are capable--would be installed in the same tunnel as the Main Accelerator. The Main Ring would serve as the "booster" for the new machine. Protons would be accelerated from 8 GeV to an intermediate energy, for example 200 GeV, in the Main Ring, transferred to the Energy Doubler, and then raised to 1000 GeV (1 TeV). Thus the device would more than double the peak energy of protons now available for experiments at NAL.

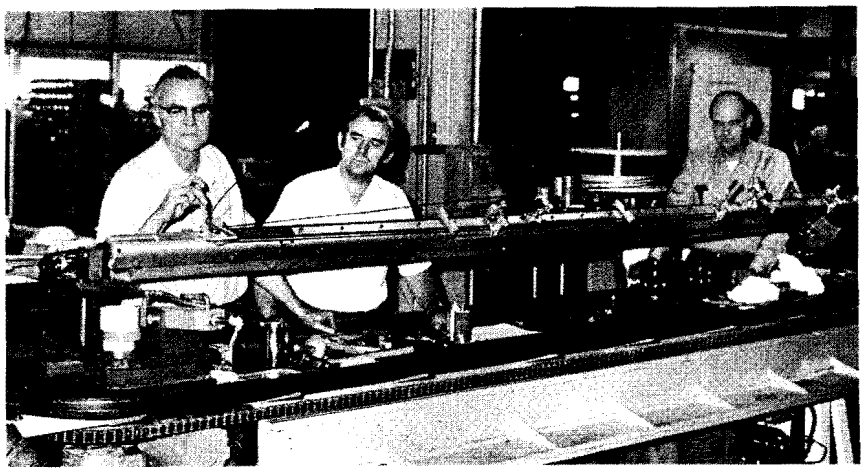
In the past, the construction of accelerator magnets has been based upon a familiar technology--that of steel and copper. In recent years, the conviction has grown among accelerator physicists that concerns for energy

conservation and for reduction of operating costs dictate that the next generation of machines realize the potential benefits offered by superconductivity. For some time, superconducting magnet development groups have been active at other laboratories in the United States. Before deciding to use a conventional magnet system, the designers of the Super Proton Synchrotron now being constructed at CERN carefully considered using superconducting components. Although they decided that a commitment to a new technology would be somewhat premature on their part, the consideration that they gave to it reflects the imminence of its application.

Since the main difference between the Energy Doubler and other accelerators would be the use of superconducting magnets, the focus of NAL's design study is on such magnets and their associated refrigeration equipment. An important milestone in the design of the present accelerator was the installation in a model enclosure (the Protomain Tunnel) in the NAL Village, of a "basic period" of the Main Ring. It consisted of a 200-ft segment of the ring made up of eight conventional dipole magnets and seven conventional quadrupole magnets. Following the same course, it is intended that by next spring, a basic period of the Energy Doubler will be functioning in the Protomain Tunnel. It will consist of eight superconducting dipole magnets and two superconducting quadrupole magnets.

Parallel efforts are in progress which are to converge on this goal. Seven small magnets, which for the most part represent studies in fabrication technique, have been built, and the first of the full-scale 20-ft long superconducting dipole magnets is now being assembled. In the present design,

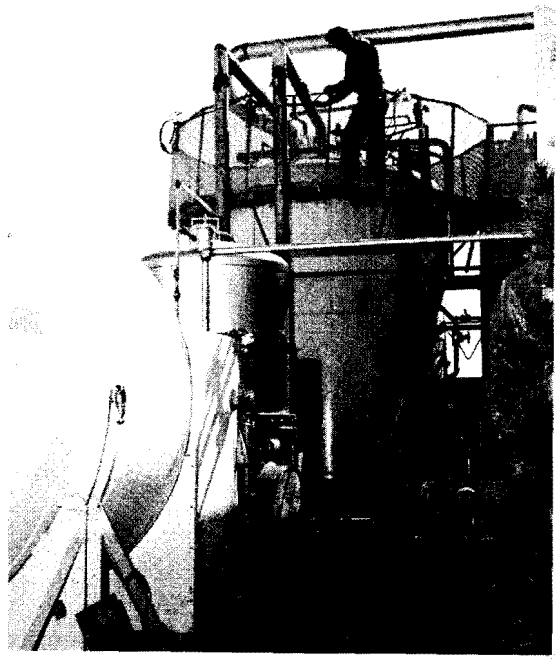
the beam pipe has a $2\frac{1}{4}$-in. $\times 1\frac{1}{2}$-in. aperture enclosed within a liquid-helium cryostat containing the superconducting coil. A room-temperature iron shield surrounds the cryostat; the shield contributes about 15 per cent to the central field. Filaments of niobium-titanium, the superconducting material, are embedded in a copper matrix to form a wire of a size and malleability that can be handled by relatively conventional coil-winding techniques. Nb-Ti was selected so that the design could be developed using materials that fall within present capabilities.



Coil winding for a 20-ft long Energy Doubler prototype magnet at the NAL Magnet Factory. J. Stull (L) and R. Brocker (C) examine the critical end region, while J. Hessinger (R) controls the motion of the wire supply reel.

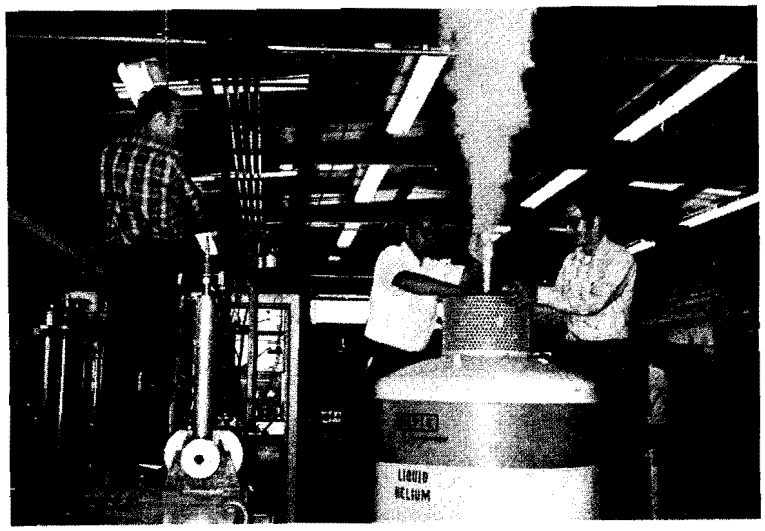
Keeping in mind the idea that magnets which can be produced in industry be developed, the prototypes are being designed and fabricated by NAL's Technical Service Section, under the general direction of H. Hinterberger. The Magnet Factory staff, led by W. Hanson and R. Brocker, has devised

winding and assembly techniques which lend themselves to mass production. Without doubt, many problems relating to field quality and reproducibility remain to be addressed, but the concentration on production methods will benefit these future studies.



The 200 liter-per-hour helium liquefier. V. Garzotto (above) and D. Richied work on the "cold box."

The other major emphasis of the design effort is on a study of the refrigeration system. A "used" 200-liter per hour helium liquefier has been procured and installed near the Protomain Tunnel. A closed-loop helium flow system has been assembled in the enclosure, and studies of refrigeration system design, including simulation of magnet heat loads, will be carried out in the near future. Since this liquefier has about one-half the capacity



E. Ioratti (L), D. Sutter (C), and B. Strauss (R) prepare to transfer liquid helium to magnet dewar. The cryostat at Ioratti's feet contains two identical 30-in. dipole magnets. The consistency of the fabrication techniques is tested by comparing their field qualities.

of that which would be needed in each of the 24 main-ring service buildings (one of two possibilities presently under consideration for the refrigeration system, the other being a 12-refrigerator arrangement), this aspect of the study is also being conducted on a significant scale. As full-size magnets become available, they will replace sections of the closed loop.

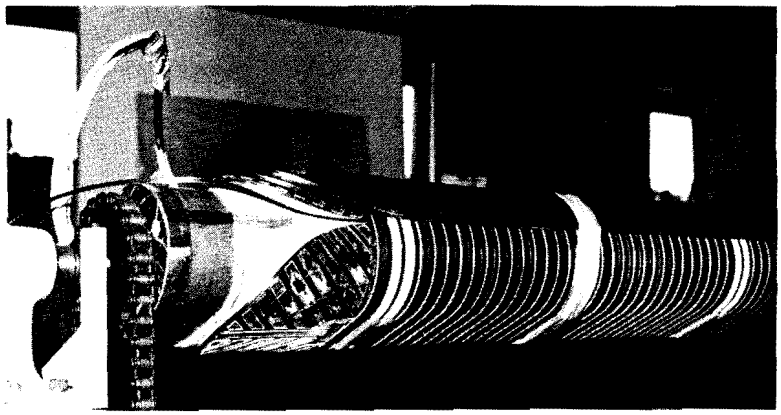
The Energy Doubler Group of the Accelerator Division plays a coordinating and testing role in these activities. Staff members include B. Strauss and D. Sutter, who are principally engaged in the prototype magnet phase of the study, and D. Richied, who has been responsible for the assembly of the liquefier pump-loop system. Following P. Reardon's appointment as Associate Director of the Laboratory in charge of the Accelerator Division, D. Edwards became group leader. Valuable

contributions to the study have been made by H. Hinterberger, head of the Technical Services Section, by L. Teng and the Accelerator Theory Group, and by other members of the Accelerator Division. W. Fowler, of the Neutrino Laboratory, and P. Vander Arend of Cryogenics Consultants, Inc., Allentown, Pennsylvania, have played a major role in the development of refrigeration system designs.

Although this work is characterized as an Energy Doubler Design Study, its results will be equally applicable to other superconducting magnet systems which might be developed at the Laboratory. The recommendations of the 1973 Summer Study, reported in the August issue of NALREP, included the development of both superconducting proton storage rings and superconducting beam lines. Thus, even if the Energy Doubler is not constructed, these efforts will not be wasted. In fact, at this stage, the Doubler Design Study may be described appropriately as a large-scale experimental investigation of the use of superconducting magnets in periodic focusing systems, whatever their application.

One very useful outgrowth of the work has been the development of superconducting components intended for use in the muon beam line. Designed with a larger aperture, it should increase both the energy and intensity of the beam in that experimental area. At present, the muon beam line is limited to operation at about 200 GeV.

In addition to applications of the superconducting technology such as this, it is interesting to consider the characteristics which the Energy Doubler might have as an accelerator and the uses to which it might be put.



A 4-in. × 6-in. cold bore dipole magnet is being developed for possible use in existing beam lines, as an outgrowth of the studies of superconductivity being carried out at NAL. The prototype, 10-ft long, is being assembled at the Magnet Factory. Mylar bands encircling the magnet strengthen the assembly to withstand magnetic forces; spaces between the double-banded coil will be filled with liquid helium.

To avoid excessive eddy-current losses in the magnets, and hence excessive thermal loads on the refrigeration system, the Doubler has been designed as a low repetition-rate machine, with a cycle time of the order of 100 seconds. Assuming that the Main Accelerator achieves its designed intensity of 5×10^{13} protons per pulse, a single turn injected from the Main Ring into the Doubler, accelerated to full energy and extracted, would result in an average external beam intensity of approximately 5×10^{11} protons per second. This is similar to the present intensity in the Main Ring when the accelerator is operated at 300 GeV. The lower repetition rate would not lead to a diminution of effective intensity for Internal Target Area experiments. At some point multiple turns of injected beam might be employed to increase the current in the Doubler, but this would be a later development.

The Doubler would take one pulse in about 16 from the Main Ring. Thus, some 15 pulses at 300 GeV could be delivered to the external experimental areas, followed by a Doubler pulse at 1000 GeV. Not only would superconducting components be required in some of the beam lines, but also additional switching capability would be needed in the switchyard to redirect the higher energy protons entering the external beam lines every 100 seconds. A very preliminary examination suggests that this will indeed be possible, with very little new construction, if the extraction is efficient enough that superconducting magnets can be used in the switchyard area. If the Doubler were located near the apex of the main-ring enclosure, its extracted beam could enter the existing external beam lines about 150 feet downstream of the Transfer Hall. Since the splitting station for the Proton Area is located in the Transfer Hall, corresponding splitting septa would have to be replicated in the Energy Doubler beam line.

The Doubler might also be used as a "beam stretcher." In this mode it need not accelerate at all. Each main-ring pulse would be transferred to the Doubler and then slow-extracted until the next pulse became available. No matter what state of refinement the slow-extraction system in the present Main Ring reaches, the duty factor will be limited ultimately by the electrical power needed to sustain the flat-top. The attractive possibility of a 100 per cent duty factor external proton beam presents itself, even at present energies.

If the 1000-GeV proton storage rings proposed by participants at the 1973 Summer Study become a reality, the Energy Doubler would permit

injection at the energy of storage, thereby avoiding the problems and cost involved in building high-current storage rings which also accelerate.

Finally, the Energy Doubler may be needed to sustain operation at 400 or 500 GeV. Because of the high cost of electrical power, and the prospect of higher costs and continuing shortages in the future, it may become necessary and desirable to use superconducting magnets for operation at energies below 500 GeV. In this manner, although the higher field capabilities of the magnets would not be utilized, there would be substantial reductions in the amount of electrical power consumed, and correspondingly substantial financial savings.

However, none of these ideas can become more than interesting prospects until we learn how to build economical and reliable superconducting magnet systems. It is on these limited problems that the emphasis has been placed to date.

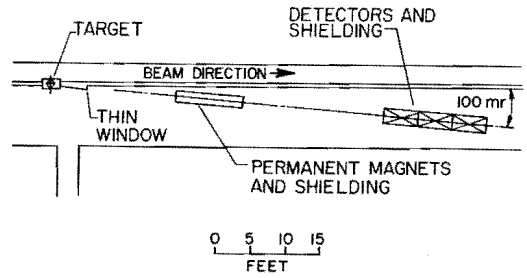
LARGE TRANSVERSE MOMENTUM PHEONMENA IN HADRON COLLISIONS

Reported by J. K. Walker

In the last year interest in particle production phenomena at large angles and energies (large transverse momentum $p_\perp$) has greatly increased, primarily because of the striking experimental results of three groups working at the CERN Intersecting Storage Ring Facility. At the XVI International Conference on High Energy Physics held in Illinois last fall, these groups reported that the measured rate of pions produced greatly exceeded the theoretical prediction of $\exp(-6\, p_\perp)$ at large transverse momenta. Since the Conference, the experimenters at CERN have reported new results. There is now additional data from a group working at NAL. The members of that research team are D. Carey, M. Goldberg, J. Johnson, D. Ritchie, A. Roberts, R. Shafer, D. Theriot, E. von Goeler, J. K. Walker, and M. Wong from NAL, and F. Taylor from Northern Illinois University at Dekalb.

The NAL experiment, Particle Production #63A, examined gamma rays produced from protons in the energy range of 50 to 400 GeV. The group studied the reaction $p + p \rightarrow \gamma$ + "anything" for gamma production at a laboratory angle of 100 mrad. A schematic drawing of their apparatus, set up in the Internal Target Area, is shown in Fig. 1. The circulating proton beam in the NAL accelerator performs multiple transversals through a gas or carbon filament target during the acceleration cycle.

Fig. 1. Diagram of the apparatus set up in NAL's Internal Target Area to study gamma production in proton-proton collisions.



The gamma rays were detected in a lead-glass counter. An example of the pulse-height distribution of the lead-glass counter is shown in Fig. 2 for proton energies of 50, 100, and 375 GeV. Data were obtained to a $p_\perp$ between 3 and 4 GeV/c at 14 incident proton energies. The observed gamma spectra were fitted with a function of the form

$$\frac{d\sigma_\lambda}{dp_\perp d\Omega} = A \exp(-Bp_\perp - Cp_\perp^{\,2}).$$

The results for B and C as functions of incident proton energy are shown in Fig. 3. They show the well-known energy independence of the B parameter; the average value of B is given by $\langle B \rangle = 5.59 \pm 0.01\,(\mathrm{GeV}/c)^{-1}$.

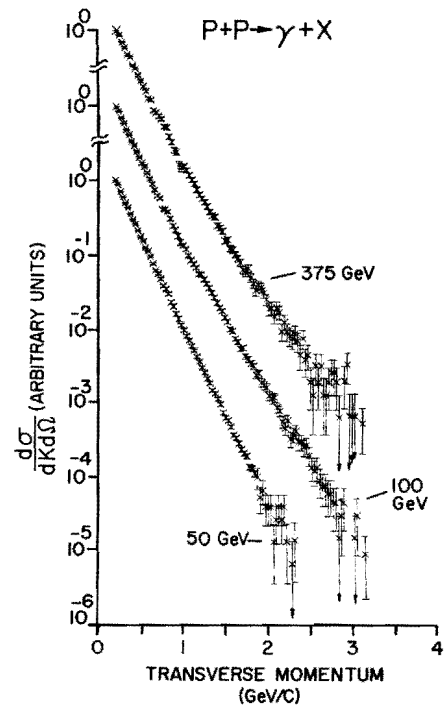


Fig. 2. Single photon-inclusive cross section $d\sigma/dKd\Omega$ versus transverse momentum for 50, 100, and 375 GeV incident protons.

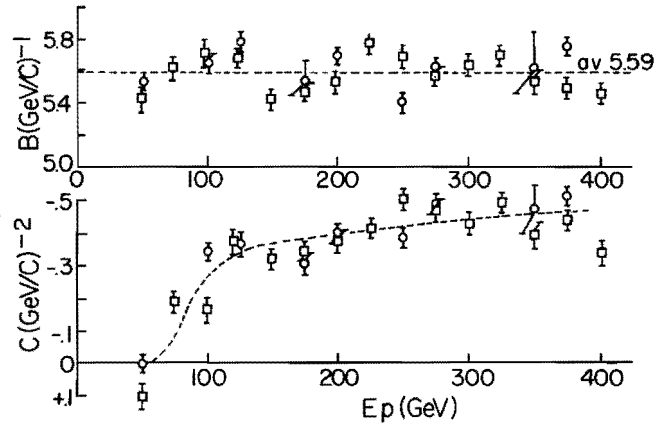


Fig. 3. Values of the parameters B and C for the photon cross sections. Circles and squares represent hydrogen and carbon data, respectively.

The C parameter, on the other hand, starts at zero, increases sharply between 50 and 125 GeV, and then varies rather slowly with additional increase in energy.

The C parameter is important because it represents the deviation from a pure exponential $p_\perp$ distribution for the cross section. If this result is confirmed by measurements at angles of 80 and 120 mrad, which are being analyzed, and by data currently being recorded at 200 mrad, this is an extremely interesting conclusion. It is conceivable that the observed transition energy, about 100 GeV, has something to do with the energy scale associated with the rising proton-proton total cross section. For example, the rising cross section can be represented by the expression

$$\sigma_T = 38 + 0.68 \log^2 \left(\frac{E}{100}\right),$$

in which the laboratory energy (E) is in units of GeV and σ is in units of millibarns. This reproduces the observed cross section from energies available

at Serpukhov to the peak energy possible at the CERN ISR. A possible connection between these two phenomena, which have an apparent energy scale of about 100 GeV, would be of great significance.

THE USER'S EXECUTIVE COMMITTEE

Reported by W. Walker

The User's Executive Committee is an elected group representing the physicists using the National Accelerator Laboratory. An effort is made to have representation by discipline as well as by geographic region.

The Committee serves as a channel for communication between Users and the Laboratory administration. We also communicate regularly with the Board of Trustees of Universities Research Association, Inc. The function of the Committee has changed somewhat as the Laboratory has developed. In a sense we serve as a "safety valve," giving advice and input about matters not of direct concern to other established groups.

During the last year we have discussed a wide range of topics at our meetings, including the housing situation at NAL, scheduling of accelerator time, computers, and the impact of the Energy Doubler on the accelerator program, among other things. NALREP is an outgrowth of discussions of the User's Executive Committee. The setup of PREP has had input from our committee, as has the moving of a CDC 6600 computer to NAL.

On occasion, the Committee has established short term ad hoc committees to consider specific problems. Last winter one such group looked into the problem of constructing hadron beams to the 30-in. and 15-ft bubble chambers. Their report has been forwarded to the Director.

Each member of the User's Executive Committee is assigned one specific area on which to focus his attention. The current members of the Committee, and their areas of responsibility, are:

Name	Institution	Responsibility
B. Barish	California Institute of Technology	Facilities
D. Drickey	University of Calif., Los Angeles	Services
V. Kistiakowsky	Massachusetts Inst. of Technology	Bubble Chambers
T. Kycia	Brookhaven National Laboratory	Services
M. Law	Harvard University	Computing
W. Lee	Columbia University	Facilities
U. Nauenberg	University of Colorado	Computing
J. Rosen	Northwestern University	Magnets
G. Smith	Michigan State University	Housing
L. Teng	National Accelerator Laboratory	Accelerator
W. Walker, Chr.	Duke University	Bubble Chambers

S. Burton, secretary to the User's Executive Committee, has her office in the Program Planning Office on the fourth floor of the Central Laboratory Building. Any comments, criticism, and suggestions any User has may be directed either to her or to one of the Committee members. Her mailing address is

Users Organization
National Accelerator Laboratory
P. O. Box 700
Batavia, Illinois 60510.

Either way, you may be sure that your ideas will be given careful consideration. The Committee's raison d'etre is to serve the User community. We urge you to communicate with us.

NOTES AND ANNOUNCEMENTS

WORKSHOP ON HADRON JETS SCHEDULED. . .

A one-day workshop will be held on October 12, 1973, to explore the possibility of studying "hadron jets." Representatives of groups having proposals on this topic and any other interested persons are invited to participate in the workshop, which will be held in the Curia, NAL Village, at 9:00 a.m. The proposals or letters submitted to NAL are

Proposal/Letter	Institutions	Spokesman
Hadron Jet #200	Harvard University University of Pennsylvania University of Wisconsin	C. Rubbia
Hadron Jet #222	University of Chicago	J. Pilcher
Hadron Jet #223	University of Calif., Los Angeles	P. Schlein
Hadron Jet #236	University of Washington	P. Mockett
Letter of Intent	University of Pennsylvania	W. Selove
Letter of Intent	California Institute of Technology	J. Pine

The meeting will begin with a discussion of the theoretical background leading to interest in studying hadron jets. Panel members are B. Barish (Chairman), J. Bjorken, S. Brodsky, M. Gell-Mann, and T. O'Halloran. Representatives of each group which has submitted a proposal will then be invited to present their ideas (approximately one-half hour each).

The purposes of the workshop are to define as clearly as possible the physics objectives of the jet experiments, to delineate what can be done at NAL, and to explore how well the experiments proposed meet these objectives.

The panel members will formulate recommendations for presentation to the Program Advisory Committee in November.

NAL'S CENTER OF ACTIVITY SHIFTS. . .

A bike-in of area residents and NAL staff members, and a formal ribbon cutting ceremony conducted by Batavia Mayor Robert Brown officially opened the new main entrance to NAL on Sunday, September 9. On the west side of the Laboratory, the winding, divided two-lane road connects with Kirk Road about one mile south of the Wilson Road entrance to the site. It is the most direct route to the Central Laboratory Building from the west side of the site (North Aurora, Batavia, Geneva, St. Charles). Kirk Road connects with State Route 5, the East-West Tollway at the Farnsworth Avenue interchange, facilitating access to NAL from all points.

The opening of this entrance heralds a new phase in the development of the Laboratory site. As the Central Laboratory Building, already a landmark to the surrounding communities, nears completion, NAL offices are gradually being relocated in it. Over 200 employees are now working in the building. Although their offices are still temporary, and in most cases will be changed, they are presently located as follows:

Ground Floor: Machine shops, Instrument Repair Facility, Communications Center (telephone operators), temporary cafeteria, and Proton Section Laboratory.

Second Floor: Plant Modifications Section and DUSAF offices, east wing. Neutrino Section, west wing.

Third Floor: Accelerator Division Mechanical Engineering Section, east wing. Proton Section, west wing.

Fourth Floor: Accelerator Division Theory Group, east wing. Director's Office, Program Planning Office, Physics Department, and Director of Personnel Services, west wing.

Most of the offices remaining in the NAL Village will be moved to the Central Laboratory Building as soon as space can be prepared for them. There are still some inconveniences of course; a high point for the present occupants was the first functioning of an elevator in the northwest corner of the building. This ended the mandatory stair-climbing exercise which had challenged employees and visitors alike.

APPOINTMENTS. . .

D. Pinyan joined the Laboratory as Senior Safety Officer in August. He replaces H. Allen, who now heads the Operations Section. Pinyan, who holds the M.S. degree from the University of Washington in microbiology, has had nearly 14 years of experience in campus and laboratory safety. He came here from the University of California, where he worked first at Lawrence Berkeley Laboratory, and more recently, at Lawrence Livermore Laboratory.

M. Awschalom has accepted a one-year appointment as Section Head of Research Services, effective September 15. Awschalom, who joined the Laboratory staff in 1967, will continue to serve as Laboratory Radiation Safety Officer, and for the time being, as Acting Head of the Radiation Physics Group. Prior to coming to NAL, he was on the staff on the Princeton-Penn Accelerator in Princeton, New Jersey.

W. Baker, who has served as Section Head of Research Services since 1971, plans to devote himself to Total Cross Section Experiment #104, now being set up in the Meson Area.

ACCELERATOR UTILIZATION SUMMARY - AUGUST 1973

The accelerator was operated at 300 GeV during the first three weeks of August, and then at 200 GeV. During the 300-GeV operation, Particle Search Experiment #100 in the Proton Area took data on the flux of particles at very high transverse momentum, while Neutron Experiment #4-I measured neutron total cross sections on hydrogen in the Meson Area. In the Neutrino Area, the beam was shared between Neutrino Experiment #21 and Muon Experiment #26; the latter group collected data at 53 and 150 GeV/c. In the 30-in. bubble chamber, phase 1 of π^+p Experiment #121A was completed; 57,750 pictures were taken. The beam was then returned for 100 GeV π^- and 53,400 pictures were taken to complete π^-p Experiment #125. During 200-GeV operation, particular emphasis was placed upon operating the M2 secondary beam in a series of runs for Quark Search Experiment #75.

The accelerator performed well during August. The overall number of protons accelerated was 6.5×10^{17}, with an average intensity of 1.7×10^{12} protons per pulse. During a 300-GeV study period, a new intensity record of 5.2×10^{12} protons per pulse was reached, primarily as a result of improved Booster performance. Recently, 12×10^{12} protons have been injected into the Main Ring, and nearly half of them then accelerated to full energy. The summary of the accelerator utilization for the month of August is:

I. Summary of Accelerator Operations

A. Accelerator hours for physics research

Accelerator physics research	75
High energy physics research	379
Subtotal:	454

B. Nonphysics hours

Accelerator setup and tuning to experimental areas	54
Scheduled interruption	13
Unscheduled interruption	223
Subtotal:	290

C. Unmanned hours	0
Total:	744

II. Summaries of Experimental Use

A. Integrated number of hours in external beams:

For approved experiments	1887
Other (for beam tuning and studies)	716
Total:	2603

B. Total hours charged to approved experiments	1878
C. Total bubble-chamber pictures for approved experiments	84,000
D. Total number of experiments to which time or pictures were charged	16

Note: These tabulations do not include 1241 hours of parasitic time run for the above approved experiments, nor do they include an additional experiment which ran parasitically for a total of 303 hours.

PROPOSALS RECEIVED DURING JULY AND AUGUST 1973

Experiment Number	Title	Submitted By
232	400-GeV Protons on Complex Nuclei	D. T. King
233	300 GeV (and 400 GeV) Proton Interactions in Nuclear Emulsion	J. Hebert
234	An Engineering Run for the NAL 15-Ft Cryogenic Bubble Chamber	W. Fowler R. Huson
235	Neutron Small-Angle Elastic Scattering	L. W. Jones
236	A Proposal to Explore the Large-P_t Domain: Inclusive Cross Sections and Possible Jet Structure	P. M. Mockett
237	Emulsion Exposure to 300 GeV Protons	J. J. Lord
238	Emulsion Exposure to 400 GeV Protons	J. J. Lord
239	Proposal for a Further Search for Long Lived Particles at NAL	W. Frati
240	A Measurement of Proton-Proton Total Cross Sections	M. J. Longo