CHARMED-PARTICLE LIFETIMES FROM NEUTRINO INTERACTIONS
EXPERIMENT #531

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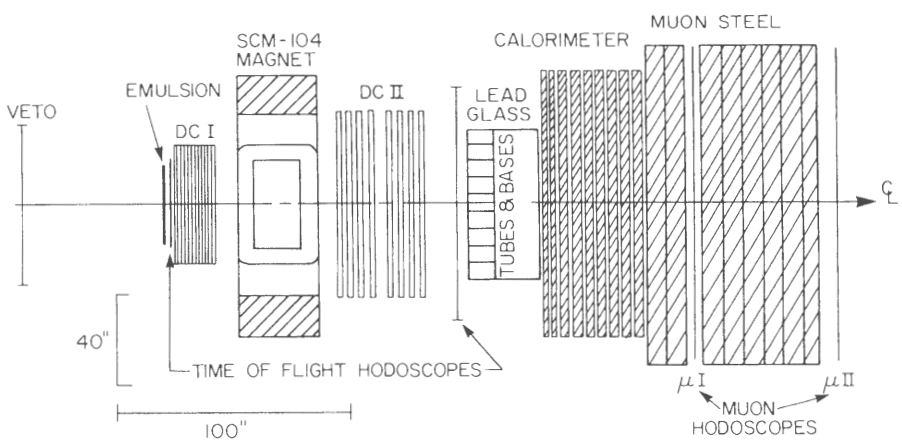
Ohio State University

Detection of charm in several Fermilab experiments, among them E-531, was discussed by L. Hand, L. Voyvodic, and the author in **Fermilab Report** in March 1979. Since that time, there have been significant new results from E-531 on charmed particles and their lifetimes and a discussion of these results is useful at this time.

The experiment is being carried out by a large collaboration of Canadian, Japanese, Korean, and U. S. physicists, including S. Bahk, D. Bailey, S. Conetti, P. Davis, S. Errede, J. Fischer, H. Fuchi, G. Fujioka, H. Fukushima, M. Gutzwiller, T. Hara, J. Harnois, C. Hebert, J. Hebert, Y. Homma, K. Hoshino, C. Kim, H. Kimura, T. Kondo, S. Kuramata, O. Kusumoto, S. Lokanathan, Y. Maeda, J. Martin, B. McLeod, M. Miyanishi, K. Moriyama, K. Niu, K. Niwa, Y. Noguchi, H. Okabe, J. Park, D. Pitman, J. Prentice, N. Reay, K. Reibel, T. Romanowski, H. Shibata, H. Shibuya, R. Sidwell, P. Sinervo, J. Song, N. Stanton, Y. Takahashi, S. Tasaka, S. Tatsumi, M. Teranaka, J. Trischuk, Y. Tsuzuki, N. Ushida, Y. Yanagisawa, J. Yokota, C. Yokoyama, and T. Yoon.

Equipment

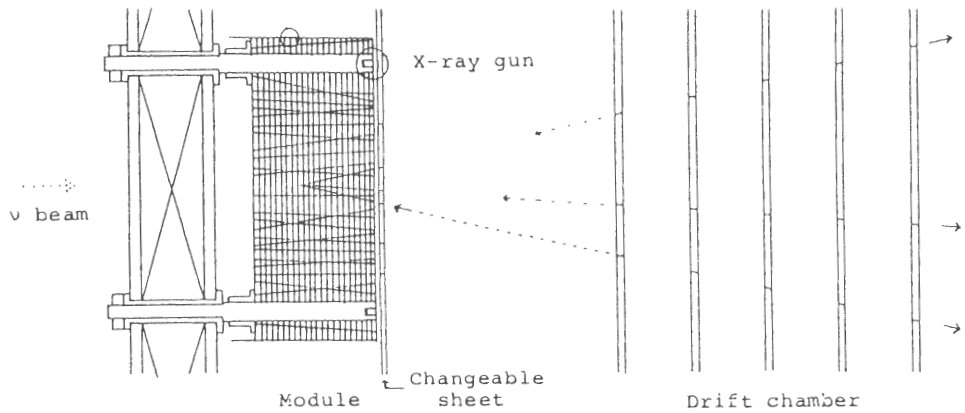
The hybrid emulsion spectrometer shown below has been exposed to the single-horn focused wide-band neutrino beam. A total of 7×10^{18} protons of 350 GeV/c momentum were incident on



Plan view of the experiment.

the production target. A simple neutrino trigger required only that no charged particle be incident and that two or more charged particles exit the emulsion and pass through the magnet. Charged and neutral-current events were accepted equally.

Decay lengths as short as 5 microns are visible in the emulsion, and the downstream electronic spectrometer located events within the emulsion and provided information on decay products necessary for converting decay lengths into proper times. The spectrometer was characterized by large acceptance and used a variety of techniques including magnetic analysis, time of flight, lead-glass shower detection, and detection of penetrating particles for providing information about decay particles. Events were found by both volume scanning around drift-chamber predicted locations and by following drift-chamber tracks through an emulsion sheet back into the main emulsion stack, as shown in the drawing below. This sheet was changed many times during the experiment, providing a low-background, highly precise coupling between electronic detectors and the main body of emulsion.



Emulsion film chamber with changeable sheet.

Scanning Results.

	Track Follow-Back	Volume Scan
Events predicted by computer	1130	1002
After fiducial cuts	906	740
Searched for	700	736
Found	595	335
Multiprong charm decays found	25	8
Single-prong "kinks" found	18	19

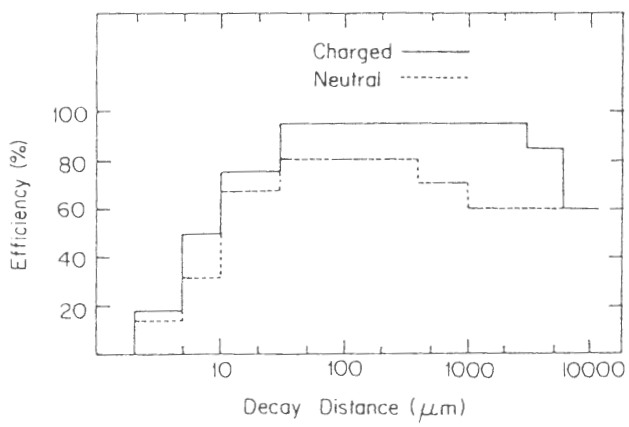
Scanning results as of the end of August are given on the previous page. The track follow-back method appears to be much more efficient than volume scanning and will be used exclusively in analysis of the forthcoming winter run. All scanning should be complete by the end of 1980.

Results

Currently, we have found 33 multiprong charm-decay candidates and over 30 single-prong "kinks." For the neutral decays, 10 of 12 are consistent with D^0 meson decays. One of the remaining candidates took place when the analyzing magnet was off, and the last one is a neutral decay (containing a proton) which appears consistent with a neutral-baryon hypothesis.

Of the charged decays, 2 are consistent only with F decays, 2 with charged D decays, and 7 with Λ_c^+ decays. An additional 4 decays are ambiguous between D and F and have been assigned as D mesons. If D and F mesons are produced equally, this would admit a possible background of 2 F mesons in the sample of charged D decays.

The lifetime for each charmed particle is obtained by maximizing a likelihood function that is weighted by the finding efficiency shown in the graph below. For decays that occur at distances less than 16 microns, tracks from the primary vertex obscure the decay point, thus reducing the efficiency.



Charm-finding efficiency.

The results of the lifetime fit are presented in the table on the next page. From the table we note that D^0, $F^{\pm}$, and Λ_c^+ particles are shorter-lived than the $D^{\pm}$ meson. This suggests that processes other than the simple radiative decay of the free charmed quark may be important in the calculation of these decay rates.

Lifetime Summary.

Particle	Lifetime ($\times 10^{-13}$ s)	Events
D^0	$1.01^{+0.43}_{-0.27}$	10
$D^{\pm}$	$10.3^{+10.5}_{-4.1}$	5
$F^{\pm}$	$2.2^{+2.8}_{-1.0}$	2
Λ_c^+	$1.36^{+0.84}_{-0.46}$	5

Based on these lifetimes, we can make several estimates:

1. Using the branching ratio for $D^+ \to X^0 e^+ \nu$ obtained at SLAC, the partial decay width for $D^+ \to X^0 e^+ \nu$ is calculated to be $1.9^{+1.4}_{-1.0} \times 10^{11} s^{-1}$, embarrassingly close to the value $2.6 \times 10^{11} s^{-1}$ predicted by Altarelli, Cabibbo, and Maiani before the discovery of charm.

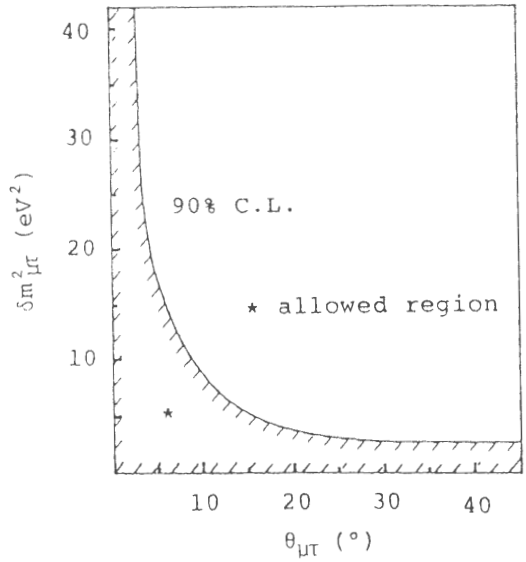
2. Assuming that the D^+ and D^0 meson have equal semi-leptonic widths, we calculate the branching ratio of $D^0 \to X^- e^+ \nu$ as about 2%.

3. If we relate the leptonic decay $F \to \tau\nu$ to $\pi \to \mu\nu$, we can estimate the branching ratio of $F \to \tau\nu$ as about 1.5% (for equal form factors).

Finally, we have seen 715 charged-current events, but no τ decays, allowing us to put a bound on the oscillation $\nu_\mu \leftrightarrow \nu_\tau$. Correcting for scanning efficiency (0.55) and the ratio $\sigma(\nu_\tau)/\sigma(\nu_\mu) = 0.6$ for our beam, we obtain the 90% confidence level for $\nu_\mu \leftrightarrow \nu_\tau$ oscillation given in the figure on the next page as a function of $\delta m^2 = (m^2_{\nu_\tau} - m^2_{\nu_\mu})$ and the strength of the mixing $\theta_{\mu\tau}$.

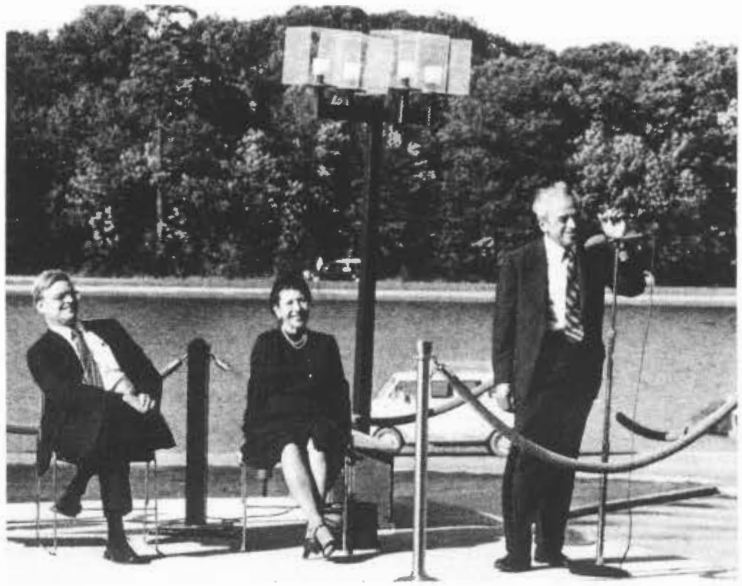
Future Work

The next E-531 exposure (with improved particle identification) will begin in December 1980 and should increase to over 140 the sample of found charm decays.



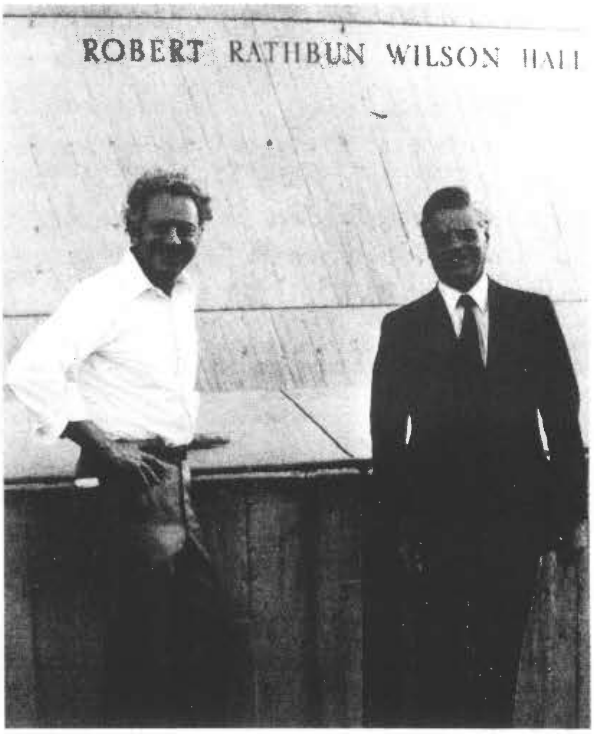
Upper limit of $\delta m^2_{\mu\tau}$.

This work has been supported in part by the National Science Foundation; the U. S. Department of Energy; the Natural Sciences and Engineering Research Council of Canada; the Department of Education of the Province of Quebec, Canada; the Ashigara Research Laboratories of the Fuji Photo Film Co., Ltd.; the Mitsubishi Monsanto Chemical Co., Ltd.; the Mitsubishi Foundation; the Nishina Memorial Foundation; the Nissan Science Foundation; the Ministry of Education of Japan; the Japan Society for Promotion of Science; and by the Japan-United States Cooperative Research Program.



Bob and Jane Wilson listening to Ned Goldwasser speaking at the dedication of the Central Laboratory as Robert Rathbun Wilson Hall on September 18.

(Photograph by Fermilab Photo Unit)



Leon Lederman (left) and Bob Wilson at the dedication of the Central Laboratory.

(Photograph by Fermilab Photo Unit)

FERMILAB SUMMER PROGRAM FOR MINORITY STUDENTS

F. T. Cole

The Fermi National Accelerator Laboratory has operated a summer program for minority students since 1971. The primary objective of the program is to stimulate young people to enter graduate school and pursue careers in physics or other technical fields.

In the program, approximately 20 students are brought to the Laboratory each summer for 11 weeks. They come mostly from small, predominantly minority institutions in the South and Southwest where it is difficult to have day-to-day contact with people actively engaged in frontier research. At Fermilab, each student works under close supervision by a scientist or engineer on a project that is part of the Fermilab program. The Laboratory pays the students' travel and offers a stipend. Housing is arranged at a local college.

The close contact with working scientists is at the heart of the success of the program. Members of a volunteer committee of scientists, working with the Fermilab Equal Opportunity office, visit institutions to interview and choose students. Committee members are active with students themselves and stimulate their colleagues to volunteer to supervise students. The daily discussion and collaboration with a supervisor teaches the student a great deal about physics and about how to be successful in a laboratory. A professor from one of the participating colleges is in residence to oversee the general progress of the students. On occasion, we have invited groups of professors for a final week to review the program.

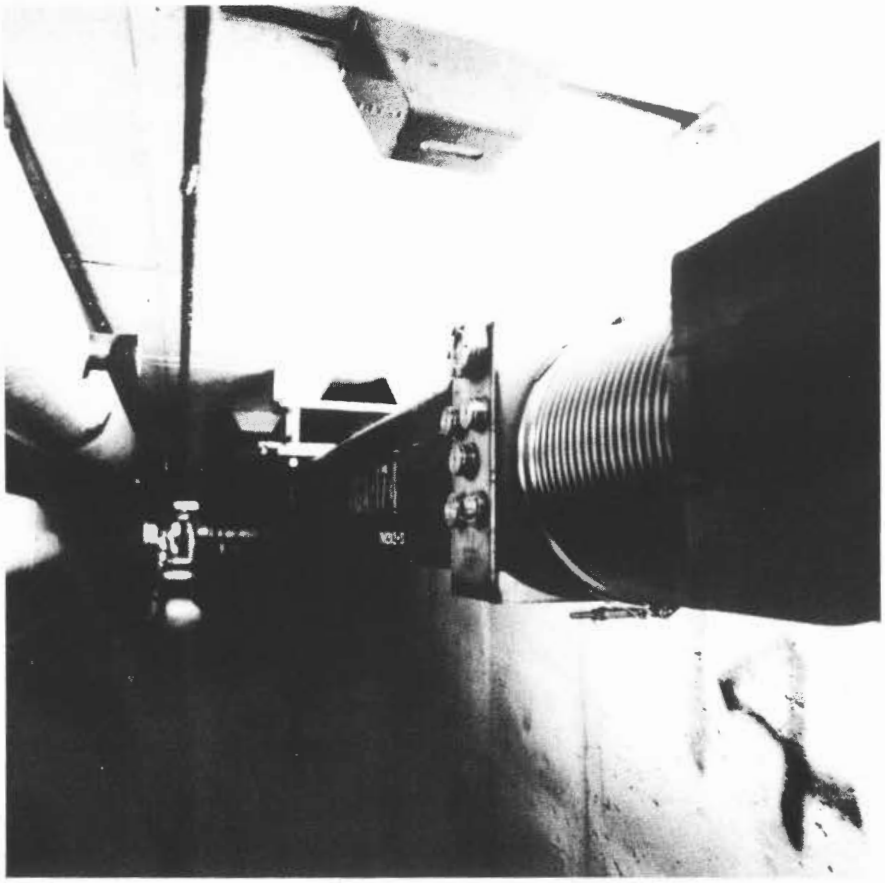
The Equal Opportunities Office attempts to keep in touch with former students, but of course there are some who are lost from sight. There is information at present on 94 students from the 1971 through 1979 programs. The following is known about their education:

1	Ph.D. in physics
1	M.D.
10	now working on Ph.D.'s in physics
1	in medical school
5	M.S. in physics
2	M.S. or other advanced degree in another field
3	now working on M.S.
4	recently received B.S. in physics
12	still undergraduates

The following is known about their present occupations:

3	university science teachers
3	secondary-school science teachers
48	other technical positions

Thus more than half of those about whom there is any information are in technical occupations. In view of the educational background of students participating in the program, this is generally considered to be a remarkable record. To try to increase the number of Ph.D.'s in physics, the Universities Research Association, the parent consortium of the Laboratory, has begun a new program of graduate fellowship in conjunction with the summer program for minorities. The first fellowship is expected to be awarded this year.



Superconducting magnets installed in the left bend to the Meson Area.

(Photograph by Fermilab Photo Unit)

Head and Deputy Head of the Research Division, Peter Koehler (sitting) and Charles Brown.

(Photograph by Fermilab Photo Unit)

EXCERPTS FROM THE AUTOBIOGRAPHY OF GURDON SALTONSTALL HUBBARD

One of **Fermilab Report's** readers was kind enough to share with the Assistant Editor the autobiography of one of the founding fathers of Chicago, Gurdon Saltonstall Hubbard, better known as Pa-pa-ma-ta-be, "The Swift Walker." One of the incidents related in the book is reprinted in its entirety for its local interest. The "Big Woods," referred to in Hubbard's first paragraph, is the woods at the northwest corner of Road A and Pine Street. After reading the incident, the Assistant Editor wonders how Hubbard would have fared in the recent Chicago Marathon.

We thank The Citadel Press, New York, for granting permission to reprint the text that appears on the following pages.

Gurdon Saltonstall Hubbard

PA-PA-MA-TA-BE.—FROM ST. JOSEPH TO THE KANKAKEE.—"HUBBARD'S TRAIL."—UNDER THE ICE.—PEORIA AND ST. LOUIS.

In the month of March (1823), I had occasion to go alone to see some Indians who were camped at "Big Woods," on Fox River, in Du Page County, west of Chicago.

After I had transacted my business with them, and the evening before my return home, an Indian who belonged to another band, which was camped about ten miles distant, came into the wigwam where I was, and said he was going to my trading house. I gave him some supper, and told him I should start in the morning and that he could accompany me, to which he assented. We started in the morning as early as we could see to travel, and found the ground soft and muddy, and the walking hard and tedious, but I noticed that my companion walked very fast.

About noon he stopped to smoke, but having made up my mind that he wanted to race, I kept on as fast as possible and got a long distance ahead of him.

When I reached the Illinois River above Hennepin, and opposite my trading house, I discovered that the canoe which I had left there had been stolen. The bottom lands were overflowed from the river to the bluffs. I finally got upon a log, and by pulling on the bushes

and pushing with a stick, managed to propel it to the bank of the river.

I shouted to my men, and waited a long time for them to answer, but receiving no response, I jumped in and swam across, reaching my house about dark.

The following morning I sent my men back across the river to look for the Indian; they found him with a party of others on horseback, very much chagrined and disappointed at his defeat. I then learned that the band which I had visited had made a wager with the band to which my companion of the day before belonged that I could outwalk any one they could produce, and they had planned the race without intending that I should know of it.

The distance walked that day is seventy-five miles, in a direct line, according to the present survey. I suffered no inconvenience from it, though the Indian was very lame for a day or so.

Some have doubted that I could have walked so great a distance, but I was then young and in my prime, and had long had the reputation among the Indians of being a very rapid traveler, and had, in consequence, been named by them Pa-pa-ma-ta-be, "The Swift Walker."

It was a well-known fact, at that time, that Pierre Le Claire, who carried the news of the war of 1812, was sent by Major Robert Forsythe to his uncle, Mr. John Kinzie, at Chicago, and that he walked from the mouth

Gurdon Saltonstall Hubbard

of St. Joseph River around Lake Michigan to Chicago, a distance of ninety miles, in one continuous walk.

He arrived at Mr. Kinzie's, ate his supper, and crossed over the river to report to the officers of Fort Dearborn, before nine o'clock at night, having started before daylight from St. Joseph River.

SITUATION REPORT -- OCTOBER 1980

FERMI NATIONAL ACCELERATOR LABORATORY

PROGRAM PLANNING OFFICE
01 OCT 1980

EXPERIMENTAL PROGRAM SITUATION REPORT

THE EXPERIMENTAL PROGRAM SITUATION AT FERMILAB IS SUMMARIZED BELOW. THE EXPERIMENTS ARE LISTED SEPARATED BY EXPERIMENTAL AREA UNDER CATEGORIES THAT BEST DESCRIBE THEIR CIRCUMSTANCE AS OF OCTOBER 1, 1980. FOR EXPERIMENTS WHICH HAVE BEEN COMPLETED OR HAVE RECEIVED BEAM THERE IS INDICATION OF THE AMOUNT OF RUNNING TIME OF EXPOSURE. THE EXPERIMENTAL AREA NAMES ARE ABBREVIATED AS FOLLOWS: MESON AREA (MA), NEUTRINO AREA (NA), ZEVATRON AREA (TEV), PHOTON AREA (PA), INTERNAL TARGET AREA (ITA).

TOTAL NUMBER OF APPROVED EXPERIMENTS - 305

AREA-BEAM		SPOKESPERSON	EXTENT OF RUN TO DATE	DATE COMPLETED
A. EXPERIMENTS THAT HAVE COMPLETED DATA TAKING (265):				
(ONLY EXPERIMENTS COMPLETED SINCE 1 JAN 1980 ARE LISTED BELOW)				
MA-M1	PARTICLE SEARCH #490	SANDWEISS	850 HOURS	9 JAN 1980
-M2	CHARGED HYPERON MAG MOMENT #620	PONDROM	900 HOURS	22 JAN 1980
-M3	PARTICLE SEARCH #584	WINSTEIN	400 HOURS	22 JAN 1980
NA-NO-DICHROM	NEUTRINO #616	SCIULLI	2,500 HOURS	22 JAN 1980
-NO-WB HORN	NEUTRINO #553	SHEPARD	1,500 HOURS	1 APR 1980
-MUON/HADRON	PARTICLE SEARCH #610	KIRK	1,250 HOURS	23 JUN 1980
-15-FT	PARTICLE SEARCH #595	BODEK	1,450 HOURS	16 JUN 1980
-OTHER	MONOPOLE #562	BARTLETT	COSMIC RAY RUNNING	23 JUN 1980
B. EXPERIMENTS THAT ARE IN PROGRESS (14):			EXTENT OF RUN TO DATE	DATE OF RECENT RUN
MA-M1	PARTICLE SEARCH #515	ROSEN	1,500 HOURS	1 JUL 1980
-M4	KAON CHARGE EXCHANGE #585	FRANCIS	2,450 HOURS	1 JUL 1980
-M6	ELASTIC SCATTERING #577	RUBINSTEIN	550 HOURS	1 JUL 1980
	PARTICLE SEARCH #582	GREEN	800 HOURS	1 JUL 1980
NA-NO-HORN	15-FOOT NEUTRINO/H2O/NE #53A	BALTAY	160K PIX	1 JUL 1977
	15-FOOT ANTI-NEUTRINO/H2O/NE#180	ERMOLOV	273K PIX	1 JUL 1977
	15-FOOT ANTI-NEUTRINO/D2 #390	GARFINKEL	10K PIX	1 APR 1979
	NEUTRINO #531	REAT	1,150 HOURS	1 JUL 1979
	15-FOOT & EMULSION/NEUTRINO#564	VOYVODIC	EMULSION EXPOSURE	1 JUL 1979
-OTHER	NUCLEAR FRAGMENTS #466	SUGARMAN	40 TARGETS EXPOSED	1 JUL 1980
PA-PE	PHOTOPRODUCTION #516	NASH	2,050 HOURS	1 JUL 1980
-PW	DI-MUON #426	SHOCHET	700 HOURS	1 JUL 1980
	DI-MUON #537	COX	1,000 HOURS	1 JUL 1980
ITA-L-O	PARTICLE SEARCH #591	GUTAY	150 HOURS	1 APR 1980
C. EXPERIMENTS THAT ARE IN TEST STAGE (5):			EXTENT OF RUN TO DATE	DATE OF RECENT RUN
MA-M2	BEAM DUMP #613	ROE	350 HOURS	1 JUL 1980
-M6	HADRON JETS #557	MALAMUD	250 HOURS	1 APR 1980
NA-NO-DICHROM	NEUTRINO #594	WALKER	550 HOURS	1 JUL 1980
-OTHER	QUARK #549	LONGO	1 TARGETS EXPOSED	1 OCT 1978
PA-PC	CHARGED HYPERON #497	LACH	900 HOURS	1 JUL 1980
D. EXPERIMENTS BEING INSTALLED (1):			EXTENT OF APPROVAL	
PA-PW	PARTICLE SEARCH #650	WEBB	500 HOURS	
E. EXPERIMENTS TO BE SET UP WITHIN A YEAR (8):			EXTENT OF APPROVAL	
MA-M1	DIRECT PHOTON PRODUCTION #625	NELSON	UNSPECIFIED	NOTE: THE ABILITY TO SET UP THESE EXPERIMENTS DURING THE NEXT YEAR IS CONTINGENT ON THE AVAILABILITY OF FUNDS.
-M3	CP VIOLATION #617	WINSTEIN	1,000 HOURS	
-M6	HADRON JETS #609	SELOVE	1,500 HOURS	
NA-NO-IN	30-INCH HYBRID #565	PLESS	PARASITIC RUNNING	
	30-INCH HYBRID #570	PLESS	1,500 HOURS	
	30-INCH HYBRID #597	WHITMORE	1,000 HOURS	
PA-PE	PHOTON DISSOCIATION #612	GOULIANOS	1,150 HOURS	
-PC	B & CHARM PARTICLE PROD. #630	SANDWEISS	600 HOURS	
F. OTHER APPROVED EXPERIMENTS (12):			EXTENT OF APPROVAL	
MA-M1	HIGH MASS PAIRS #605	BROWN	1,000 HOURS	
-M2	NEUTRAL HYPERON #555	DEVLIN	450 HOURS	
	POLARIZED SCATTERING #561	YOKOSAWA	UNSPECIFIED	
	TRANSITION MAGNETIC MOMENT #619	DEVLIN	250 HOURS	
NA-OTHER	EMULSION/PROTONS @ 500 #526	WOLITER	EMULSION EXPOSURE	
	EMULSION/PROTONS @ 500 #524	WILKES	EMULSION EXPOSURE	
	EMULSION/PROTONS @ 500 #576	NEBERT	3 STACKS	
TEV-NEUTRINO	NEUTRINO #634	STEINBERGER	UNSPECIFIED	
	NEUTRINO #652	SCIULLI	UNSPECIFIED	
PA-PE	PARTICLE SEARCH #400	PEOPLES	500 HOURS	
	PHOTOPRODUCTION #458	LEE	UNSPECIFIED	
-PW	FORWARD SEARCH #635	ANDERSON	1,000 HOURS	
PENDING PROPOSALS (29):			EXTENT OF REQUEST	
MA-M1	PHOTON SEARCH #614	ROSEN	300 HOURS	
-M2	CP VIOLATION #621	THOMSON	1,200 HOURS	
	BEAM DUMP #644	LONGO	2,000 HOURS	
-M4	INCLUSIVE POLAR. OF LAMBDA #663	KOBRAK	1,000 HOURS	
-M6	PARTICLE SEARCH #623	LAI	1,000 HOURS	
NA-NO-SSBT	NEUTRINO OSCILLATIONS #664	FRY	330K PIX	
-MUON/HADRON	OPEN GEOMETRY MUON SPEC. #665	KIRK	3,000 HOURS	
-30-IN	30-INCH PARTICLE SEARCH #657	VOYVODIC	100 HOURS	
TEV-NEUTRINO	15-FT NEUTRINO/H2 & NE #632	MORRISON	250K PIX	
	NEUTRINO #635	MO		
	15-FT NEUTRINO/D2 #637	ARMOSOV		
	15-FT NEUTRINO #641	KITAGAKI	200K PIX	
	HYBRID NEUTRINO #647	PETERSON	UNSPECIFIED	
	NEUTRINO #649	TAYLOR		
	15-FT NEUTRINO/D2 #651	MILLER	100K PIX	
-BEAM DUMP	15-FT BEAM DUMP #646	BALTAY		
	BEAM DUMP #654	LEE	UNSPECIFIED	
	BEAM DUMP #656	WHITAKER		
-MUON	MUON #640	LOKEN	6,500 HOURS	
	MUON #643	BRANDENBURG	2,500 HOURS	
	MUON #648	BENVENUTI	600 HOURS	
	MUON #658	ECKARDT		
PA-PC	CHANNELING #660	GIBSON	300 HOURS	

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AREA-PROM		SPOKESPERSON	EXTENT OF REQUEST
	PARTICLE SEARCH #653	BEAT	1,500 HOURS
ITA-C-2	PROTON-PROTON SCATTERING #5000	FRANZINI	1,000 HOURS
ITA-E-0	ELECTRON TARGET FACILITY #659	WILSON	1,000 HOURS
MISC1	NUC CALIBRATION CROSS SECT #631	BAKER	25 EXPOSURES
	HIGH ENERGY HAD.-NUC. INT. #661	GUTBROD	700 HOURS
	CORRELATION IN NUC BREAKUP #662	STEINBERG	400 HOURS