MASTER

ANNUAL PROGRESS REPORT

to

UNITED STATES
DEPARTMENT OF ENERGY

Contract No. EY-76-C-02-1195

Department of Physics
University of Illinois
at Urbana-Champaign
Urbana, Illinois

Key Personnel: A. Wattenberg
R. O. Simmons

Submitted March 1978

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I. SUMMARY OF SCOPE AND PURPOSE OF THE PROJECT

The University of Illinois programs in Elementary Particle Physics are carried out at various high energy particle accelerators and at the Urbana Campus. During the past few years our six major experimental efforts have been following:

1. Neutral current experiments using neutrinos at Brookhaven National Laboratory.
2. Neutral beam experiments at Fermilab.
3. A charmed particle production and pion dissociation experiment using pions at the Chicago Cyclotron Magnet facility at Fermilab.
4. A streamer chamber program at Argonne National Laboratory.
5. A bubble chamber program at Fermilab.
6. A μ meson scattering program using the Chicago Cyclotron Magnet facility at Fermilab.

During the present year, we are completing our involvement in the last three activities, (4, 5, & 6).

In order for the University of Illinois program to maintain its success in making major contributions to the field of elementary particle physics, we feel that it is important to undertake the planning and construction of equipment for experiments at increasingly higher energies. Obviously, we also should continue those experiments which have been making outstanding contributions. Therefore our program for the coming years includes the initiation of experiments at colliding beam facilities, the planning of equipment for higher energy neutrino experiments, and a continuation of: the neutral current neutrino experiments at BNL, the neutral beam experiments at Fermilab, and the pion dissociation/charm production experiments at Fermilab using pions. The specifics of the present and future program are most concisely stated in the form of the two lists which follow.

During FY 1978, major activities include the following:

1. A new series of runs are in progress to study multi-hadron events, especially charmed particles, produced in the neutral beam at Fermilab. New apparatus has been installed and is operating which will allow us to better identify kaons and protons, as well as π^0 's, that are present in the events from these runs.
2. Data from earlier photoproduction experiments were analyzed, and using the vector dominance model, we find that the ratio of ρ' nucleon scattering to ρ nucleon scattering is very close to unity, which was not anticipated by the theorists.

We also have observed the $\rho' \rightarrow \pi^+ \pi^-$ decay mode; we obtained that

$$\frac{\Gamma(\rho' \rightarrow \pi^+ \pi^-)}{\Gamma(\rho' \rightarrow \pi^+ \pi^- \pi^+ \pi^-)} = .092 \pm .013.$$

The ρ photoproduction was studied as a function of energy; in the range from 30-160 GeV there is no observable change in $d\sigma/dt$ at $t = 0$.

3. The charm search, ψ production, and pion dissociation experiment using the Chicago Cyclotron facility at Fermilab obtained part of their data with 215 GeV pions. A preliminary analysis should be completed this year.
4. The BNL neutral current neutrino experiment is obtaining new data using a dichromatic beam and a wide band beam with improved apparatus.
5. The collaboration studying dimuon production by pions (with Chicago and Princeton, E-444) has obtained dimuons up to a mass of 11 GeV/c². The data in the mass region 9-10 GeV containing the T will be analyzed looking for the presence of resonances.
6. The muon inelastic scattering on hydrogen at Fermilab has been analyzed. The data confirms that the Bjorken scaling violation occurs independent of the scaling variables chosen. The importance is that the behavior of the quark "sea" can be successfully fitted with a global scale violation function.
7. The streamer chamber analysis is being completed. The exchange dynamics have been studied for the reactions producing ρ^0 and f^0 in the backward direction.
8. The analysis of the bubble chamber pion experiment at Fermilab showed that pionization is isotropic in the center of mass.
9. We are currently testing a prototype Iron/Argon Hadron Calorimeter at Fermilab, to be used in a new series of high energy neutrino experiments to study $d\sigma/dx dy$ for neutral current events.
10. Efforts have gone into the planning of a detector which will have good resolution for low energy γ rays to be used at the Cornell Electron Storage Ring. One of the main purposes is to study the spectra of the various "onium" states associated with the more massive new particles that should be produced at CESR.
11. The DEC PDP-10 processor has been replaced by a KI-10 processor with a theoretical speed-up factor of two.

During FY 1979, our anticipated activities will be the following:

1. We will be analyzing the data from the extension of the E-87A runs which are studying multi-hadron events produced in the neutral beam at Fermilab. The main emphasis will be on the properties of charmed particles.
2. E-401, the high intensity photoproduction experiment at Fermilab, should be in the data taking and analysis phase. Specifically, we will be studying two-

particle final states such as $K\bar{K}$, $p\bar{p}$, $\mu\mu$, and μe events for massive resonances.

3. The BNL neutral current neutrino experiment will have additional runs. The analysis of the data from the accumulated runs should give improved ratios of the neutrino proton scattering and dilepton production by neutrinos.
4. The charm search, ψ production, and pion dissociation experiment should complete their unfinished runs with some improvements in the apparatus and the data should be analyzed.
5. We should be contributing to the construction of apparatus for the high energy neutrino neutral current experiments at Fermilab.
6. The construction of apparatus for experiments at CESR should be underway and some of the equipment should be in a test phase.

II. PERSONNEL

In this section are listed the names of Senior Staff members and graduate students who are or will be involved in the Elementary Particle Physics Program at the University of Illinois in Urbana-Champaign.

Personnel who are or will be actively engaged in physics experiments in this program are:

1) Faculty members with the rank of Assistant Professor or higher:

Ascoli, G.	Kruse, U. E.
Brown, R. M.	O'Halloran, T. A.
Eisenstein, B.	Sard, R. D.
Gladding, G.	Thaler, J. J.
Holloway, L.	Wattenberg, A.
Koester, L. J.	

2) Senior Staff members holding research or professional appointments:
(Research Associates, Research Assistant Professors, Research Physicists, or Engineers)

Bross, A.	Shupe, M.
Butler, J.	Simaitis, J.
Cooper, J.	Wiss, J.
Downing, R.	Wray, J.
Elliott, J.	

3) Graduate Students (part time Research Assistants, Fellows, and Programmers):

Alverson, G.	Garren, L.	Negret, J.
Avery, P.	Goodman, M.	Nienaber, P.
Barth, R.	Hahn, S.	Noble, R.
Bender, D.	Hicks, R.	Richardson, D.
Budd, H.	Lufkin, J.	Russell, J. J.
Callahan, P.	MacKay, W.	Smith, E.
Fuess, S.	Minor, E.	Wroblecka, W.

- 4) There are theoretical physicists at the University of Illinois whose main area of interest is Elementary Particle Physics. The interaction of these physicists with the experimentalists is of great value to the High Energy Physics Experimental Program. Members of this group are:

Bitar, K. N.

Schult, R.

Chang, S. J.

Stack, J.

Grammer, G.

Sullivan, J.

Jones, L. M.

Wright, J.

Karliner, I.

Wyld, H. W.

Ravenhall, D.

III. EXPERIMENTAL PROGRAM

In this section, the discussion is divided into three categories:

- A. Technical Accomplishments During This Year
- B. Experiments Planned for the Coming Year
- C. Experiments that are Planned for Future Years

Below the title of each of the experiments are listed the names of Senior and Junior Staff members who are most directly involved in each experiment or development program. Within each of the above three time categories, the experiments are ordered in the following sequence:

Experiments Using Charged Particle Beams (mainly at Fermilab)

Experiments Using the Neutral Beam Facility at Fermilab

Experiments Using Neutrinos

Experiments Using Colliding Beams

A. Technical Accomplishments During This Year

A1. Charm Search, ψ Production, and Pion Dissociation Using 215 GeV Pions

(G. Ascoli, J. Cooper, L. Holloway, L. J. Koester, U. E. Kruse, R. D. Sard M. Shupe, G. Alverson, D. Bender, H. Budd, S. Hahn, W. MacKay, E. Smith, in collaboration with Harvard University, Oxford University, and Tufts University physicists)

As anticipated in last year's report, Experiment 369 at Fermilab completed a data acquisition run during July-August of 1977. FNAL 369 is a combined charm search, ψ/J production, diffraction excitation experiment run in the Chicago Cyclotron Spectrometer (CCM), with 215 GeV negative pions incident on beryllium and liquid hydrogen targets.

The approved amount of beam for the experiment was 2×10^{11} negative pions during 600 hours of running. However, in the 600 hours of running, only 0.4×10^{11} negative pions, or about 20% of the approved number, were delivered to the Muon Lab.

The primary reasons for the reduction were (1) a 50% duty factor for beam actually delivered to the Muon Lab, (2) a one-week loss due to July 5-12 heat wave, and (3) a one-week loss due to collapse of the Sigma 3 data logging computer.

As the run neared its end, we redistributed the trigger priorities to complete the largest possible fraction of our high rate (diffraction) trigger. The final fractions of all triggers are tabulated below:

<u>EXPERIMENT</u>	<u>TRIGGER</u>	<u>TOTAL EVENTS</u>	<u>EXPECTED EVENTS</u>	<u>%</u>
Charm search	$\mu \cdot P$	309K	600K	51%
ψ/J production	2μ	129K	650K	20%
Diffraction excitation	Low mass P	389K	400K	97%

We expected that this number of diffractive triggers would produce an adequate data base for the $\pi \rightarrow 3\pi$, 5π partial wave analysis. The charm search data sample will allow a meaningful analysis, though clearly not to the intended level of statistical significance. The 2μ data sample is too small to allow more than a preliminary look at particle production in association with the ψ .

Preliminary analysis of 2μ and 3π final states is underway at the University of Illinois. Roughly 10% of the former sample and 20% of the latter have been looked at at this time. Using the HEPG PDP-10 and the University Cyber system, invariant mass plots of these two full data samples will be completed early in the spring of 1978.

In anticipation of further data acquisition with an improved and more reliable CCM facility, we have begun the construction of five large multiwire proportional chambers. The purpose of these chambers is to provide an accurate determination of charged particle trajectories in the middle of the cyclotron magnet. In each chamber module, there are three sets of anode wires with 2mm spacing, so that in each chamber the actual space location of the track should be determined. This will improve the tracking information for low and medium momentum tracks, where previous information has come only from the Chicago 1m x 1m proportional chambers, which give only x and y coordinates. The new chambers are designed to have a sensitive area roughly 0.93m x 1.08m.

At this time the first chamber planes have been wound on the winding facility at Fermilab, and our intention is to assemble and test the first module in early 1978. The tests will include a set of amplifiers which were designed for the new chambers and which have had preliminary tests while connected to the proton chambers.

A2. Muon Inelastic Scattering at Fermilab

(T. Kirk, W. Francis, R. Hicks, in collaboration with groups from the University of Chicago, Harvard University and Oxford University)

The data taking phase of the CHI collaboration has been completed. The last runs were with 225 GeV muons on a 1.2 meter hydrogen target. Both the scattered muons and the produced hadrons were measured in a large spectrometer. Properties of the hadron spectra for proton and deuteron targets have been analyzed for the 147 GeV muon runs. A comprehensive article (W. A. Loomis, et al.) has been prepared and submitted to Physical Review. Some aspects of the jet behavior of the hadrons in the photon fragmentation region have been studied.

A preliminary analysis of the 225 GeV/muon scattering data has been performed; the data from this analysis was presented at the Hamburg Electron-Photon International Conference. The data confirms that Bjorken violation scaling occurs independent of the scaling variables chosen. The importance is that an unambiguous behavior of the quark sea can be successfully fitted with a global scale violation function. By a phenomenological fitting, one can relate this to a simple parton picture. A more sophisticated calculation of scale violation using asymptotic freedom has been successfully performed by Buras and Gaimers. A report on this is being prepared for publication in Physical Review Letters.

The production of inclusive strange hadrons has been measured in the forward hemisphere, including both charged and neutrals. The analysis of this data is in progress and attention is being paid to the possibility of observing charmed particle production from muons. The analysis of all of the above experiments should be completed in FY78.

A3. Hadron Induced Dimuon Production at Fermilab

(J. Thaler, in collaboration with groups from the University of Chicago and Princeton University)

Data taking for E-444 was completed on January 3, 1978. This experiment was performed in a tagged hadron beam and used the large acceptance Chicago Cyclotron Magnet spectrometer facility to analyze the final state muons. Particle identification was achieved by placing four threshold Cherenkov counters in the beam, and the outgoing muons were identified by requiring that they pass through 6 m of steel. The beam contains, at 225 GeV, useful numbers of π^+ , p, $\bar{p}$, and K^+ . To enhance the acceptance for high mass dimuons, we doubled the spectrometer aperture by borrowing two large MWPC's from CERN.

Our previous experiment, E-331, had provided us with a hint of isospin

violation in the nonresonant production of muon pairs. The evidence consists of a difference between the dimuon production cross sections, on an isoscalar (carbon) target, using π^+ and π^- incident beams. This property of dimuon production is an inherent feature of the most popular theoretical models, such as that of Drell and Yan, so E-444 was designed to measure it more accurately than E-331 and at higher dimuon masses where the effect is expected to be larger. Preliminary analysis of the data was performed during the run and showed that we have dimuons of masses up to 11 GeV, allowing a test of isospin conservation below 9 GeV. Above 9 GeV, the low statistics and possible presence of the T in the data prevent a meaningful test.

In the mass region, 9-10 GeV, containing the T, we have 50-100 events. Confirmation of the presence of a resonance in our data awaits completion of the final analysis.

We have enough events to measure the production of the ψ and the lower mass dimuon continuum with precision. We have nearly 10^5 π^- induced ψ 's, so that investigation of the more subtle aspects of the production is possible (e.g., a search for ψ polarization).

By the end of FY78, we will be well into the final analysis, and our most topical results, the test of the Drell-Yan model and the measurement of T production rates, will be in hand.

A4. Proportional Hybrid Bubble Chamber Experiments

(R. D. Sard, J. W. Cooper, R. L. Plumer, in collaboration with the International Hybrid Spectrometer Consortium - Brown University, Johns Hopkins University, Illinois Institute of Technology, University of Illinois, Massachusetts Institute of Technology, Indiana University, Rutgers/Stevens, Tennessee/Oak Ridge, Yale/Fermilab, plus the Universities of Nijmegen/Cambridge/Mons/Padua/Pavia/Trieste/Rome/CERN, and Tel-Aviv/Technion/Weizmann)

In this bubble chamber spectrometer, the Fermilab 30-inch hydrogen bubble chamber is used to study the interaction vertex and measure low-momentum tracks, while multiwire proportional chambers downstream of the bubble chamber's magnet determine the momenta of fast forward tracks. Upstream wire chambers serve to associate the observed secondaries with particular beam tracks, and a 2-channel Cherenkov counter in the beam line permits tagging of the beam particles as π , K, or p. The purpose of the present experiment is to survey inelastic hadron-proton interactions at 150 GeV/c. The consortium has in hand 108K " π^- " pictures and 430K " π^+/p " pictures. The former are 94% π^- , 1.9% K^- , and 1.3% $\bar{p}$. The latter are 43% π^+ , 46% p, and 7% K^+ . A large (63%) fraction of the positive pictures have data from the prototype forward gamma

detector, an array of lead-glass blocks and scintillator fingers that should make possible momentum measurements on fast forward π^0 's.

Since the previous report, DOLLY, the automated film measuring machine, has been used for some 600 hours of bubble-chamber film measurement. On 15,000 frames of the π^+/p exposures, 2200 events of all multiplicities were measured. The use of DOLLY for this type of measurement is currently being terminated with "certification" measurements on standard consortium inter-calibration rolls.

We have studied jet structure and planarity in the π^-p interactions, as reported in Plumer's thesis.* The study used the final data summary tape of E-154 (π^-), which includes remeasurements of events which had failed PEPR; there should be no bias in the high-multiplicity data. After beam and target diffraction effects are allowed for, there remains no evidence for jet structure. There is no evidence for planarity. In sum, pionization is essentially isotropic in the center of mass.

The evidence for pion diffraction in high-multiplicity events was presented by Cooper at the Washington APS meeting (April 1977) and will be included in a paper on diffractive effects of pions of both signs. Using rapidity-gap cuts, we found that for each multiplicity - 6, 8, 10, and possibly 12 prong - roughly 1-2% of the events involve three-body pion dissociation $\pi^-p \rightarrow (\pi^- \pi^+ \pi^-)$, with the same dependence on mass and four-momentum transfer as in $\pi^-p \rightarrow (\pi^- \pi^+ \pi^-)p$.

A5. A Study of Reactions Producing a Fast Forward Neutron in $\pi^-p \rightarrow nx^0$ at 8 GeV/c
(B. Eisenstein, J. Elliott, R. Wagner, W. T. Wroblecka, in collaboration with the University of Chicago)

We are completing the program of surveying baryon exchange processes in the University of Illinois-Argonne National Laboratory Streamer Chamber. The Streamer Chamber facility, originally developed by our group, is ideally suited to study rare processes where a selective trigger is necessary to distinguish the process from background reactions whose cross-sections exceed the one of interest by several orders of magnitude. In particular, the study of many-body final states requires $\sim 4\pi$ acceptance in solid angle, which is very difficult to achieve with conventional narrow-gap chambers, while in a triggered bubble chamber the data acquisition rate is lower than in the streamer chamber by an order of magnitude or more.

This experiment isolated u-channel baryon exchange processes by triggering on a fast forward neutron. The neutrons interacted in thick-plate optical spark

* R. L. Plumer, "Jet Structure and Planarity in π^-p Interactions at 147 GeV/c," Thesis, Illinois, September 1977 (Technical Report C00-1195-414).

chambers located 11 m downstream of the streamer chamber and the secondaries from these interactions were detected by scintillation counters. Time-of-flight was used to discriminate against slow neutrons. A lead/scintillator array upstream of the neutron chambers removed most of the γ -rays which would also trigger the system.

a) Resonance Production in the Reaction $\pi^- p \rightarrow n \pi^+ \pi^-$

A paper was submitted to the Physical Review describing the apparatus and the features of this reaction. It was found to be dominated by the quasi-two-body final states $\Delta^- \pi^+$, $\rho^0 n$, and $f^0 n$. The absence of Δ^+ production suggests the $I = 3/2$ exchange is not large, but a more careful study indicates that $I = 3/2$ exchange is by no means ruled out compared to $I = 1/2$ exchange. In ρ^0 production, a significant interference with a s-wave background is required to interpret the decay angular distribution. The production of f^0 is consistent with simple nucleon ($I = 1/2$) exchange, and $d\sigma/du$ exhibits a dip where the nucleon Regge trajectory is expected to vanish.

b) Study of the Reaction $\pi^- p \rightarrow n \pi^+ \pi^- \pi^0$

Since neither the neutron's momentum nor the π^0 are observed, this is a 0-C "fit". Nevertheless, for events with physical solutions for the 0-C calculation, an excess of events in the ω^0 region is seen. The number of ω^0 events above background is consistent with the number of ρ^0 events produced in $\pi^- p \rightarrow n \rho^0$. We are continuing this investigation, hoping to get a cleaner sample of ω^0 for study.

c) Study of the Reactions $\pi^- p \rightarrow n + 4\pi$, $n + 6\pi$

The reaction $\pi^- p \rightarrow n \pi^+ \pi^+ \pi^- \pi^-$ is complicated by the production of many resonances in the final state. We have identified Δ^- , ρ^0 , f^0 , and one or more baryon resonances decaying into $\Delta^- \pi^+$. These channels overlap and are made more obscure by the two pairs of identical particles in the final state. An effort is being made to find a reliable procedure to isolate the various reactions.

In the reaction $\pi^- p \rightarrow n \pi^+ \pi^+ \pi^+ \pi^- \pi^- \pi^-$, although ρ^0 and Δ^- appear to be produced, the combinatorial problem is severe. It is not likely that the various final state channels will be isolated with any degree of reliability.

For both reactions we are studying the distributions of longitudinal and transverse center-of-mass momentum, to see if they are similar to those found in reactions mediated by meson exchange.

Most of our study of this data will be completed in FY78, and we expect to submit an article describing reactions b) and/or c) during the current fiscal year.

A6. Multi-Hadron Events Produced by High Energy Photons at Fermilab

(J. Butler, G. Gladding, T. O'Halloran, A. Wattenberg, J. Wiss, P. Avery, P. Callahan, M. Goodman, R. Noble, J. Russell, in collaboration with groups from Columbia University and Fermilab)

Experiment 87A was reactivated because of the great interest in obtaining more data on the newly discovered anti-baryon state at 2.26 GeV, which has been interpreted as the charmed anti-baryon, $\bar{\Lambda}_c$. This changed the running schedule for all our high energy photon experiments at Fermilab, and it led to the postponement of Experiment 401 and 458. These experiments use the broad-band photon beam at Fermilab with a large aperture multi-particle spectrometer and a particle identification system. For the new runs, the apparatus has been modified in a variety of ways. An additional bending magnet was put upstream of the target in order to increase our acceptance. The downstream bending magnet was enlarged and additional coils were added. The target now consists of twenty-one 1 mm thick scintillators attached to an ADC system so that we can measure the pulse height as a function of distance from the production point in the target. The purpose of the segmented target is to see if charmed mesons and baryons have a lifetime which is observable due to time dilation. We will be looking for an increase in the number of particles downstream from the production point due to the decay of charmed particles in the target itself.

A set of lead glass blocks had been borrowed and substituted for the previous lead and scintillator electromagnetic shower detector. The lead glass system provides better granularity so that the data can be analyzed for γ -rays and π^0 mesons. Many of the decays of the charmed particles include either γ 's or π^0 's, either from the decay of excited states or in the weak decays of the charmed ground states. Therefore, in order to be able to observe a large number of decay modes and also possibly to measure their branching ratios, we needed a detecting system which could identify γ 's and π^0 's and measure their energy more accurately than the previous system. Two multicell Cherenkov detectors have been installed to identify π 's, K's, and protons. The Cherenkov detectors will allow us to remove the ambiguities between K_S^0 and Λ 's which existed previously when we could not distinguish between π 's and protons. Also, this detector will allow us to look for the charmed mesons that decay via charged K's, whereas previously we were limited to those that decayed via the K_S^0 mode.

The multi-hadron events obtained in previous runs were analyzed to see if they were accompanied by electrons or muons. The idea being that the photons produce charmed particles in pairs, and if one of them decays semi-leptonically, it is a clear indication that one is dealing with particles which are decaying via the weak

interaction. $\bar{\Lambda}\pi\pi$ events in the mass region of $2.26 \text{ GeV}/c^2$ were analyzed for additional tracks that were identified as muons or electrons. The number of such events found were above background but not at a statistically significant level. The background arises from pions that decay in flight to muons and from pions that interact in the electromagnetic shower detectors and simulate electrons. The new data obtained in the runs during FY78 will be analyzed for such events.

A7. Photoproduction of Two Particle States at Fermilab

(J. Butler, G. Gladding, A. Wattenberg, J. Wiss, P. Avery, M. Goodman, J. Russell, in collaboration with a group from Fermilab)

In FY78, we have been constructing additional equipment to be used in Fermilab Experiment 401. This experiment will be a high-intensity study of the two particle mass spectrum of $K\bar{K}$, $p\bar{p}$, $K\pi$, μe , $\mu\mu$, and ee pairs.

We have constructed a set of large scintillation counters which are to be placed behind the steel of the main analyzing magnet in order to identify muons produced at angles larger than those subtended by the "inner" detector. These counters will be most useful in the μe phase of the experiment.

We have also constructed an "outer" electromagnetic shower detector consisting of lead-scintillator sandwiches, the first 3 radiation lengths being viewed by 6 separate photomultipliers giving vertical segmentation while the last 16 radiation lengths are viewed by 1 photomultiplier. Two such detectors will be installed immediately upstream of the main analyzing magnet in order to identify and measure the energy of electrons produced at angles larger than those subtended by the "inner" detector. These detectors will be most useful during the high intensity ee and μe running.

We are constructing a 50 scintillation counter hodoscope capable of measuring vertical positions to 1 mm. This detector will be placed immediately downstream of the target and will allow a measurement of the vertical (i.e., the bending plane coordinate) production position upstream of the first analyzing magnet. This direct measurement before any bending takes place makes possible a good measurement of the production angle and momentum of tracks in the outer detector. The resulting improvement in the mass resolution obtained by the addition of this detector will be essential for the high mass dilepton running.

We expect to construct, later in the year, a simple recoil detector, consisting of scintillation counters which surround the liquid hydrogen or deuterium target. This detector will be used to study the recoil nature of the interesting events we accept. In particular, we expect to use this detector to separate the coherent and incoherent contributions to the photoproduction of ψ and higher mass dileptons.

A8. High Energy Photoproduction of Vector Mesons at Fermilab

(G. Gladding, M. Gormley, R. Messner, T. O'Halloran, A. Wattenberg, J. Bronstein, R. Coleman, J. Sarracino, in collaboration with groups from Columbia University, Fermilab, and the University of Hawaii)

Two independent analyses have been performed using the earlier photon data from runs with 300 GeV and 400 GeV protons. The data has been analyzed for the ρ (770), the ρ' (1500), and the ϕ (1020) vector mesons. The energy dependence of ρ photoproduction from beryllium shows no evidence for an energy variation of the forward cross-section in the range from 30 to 160 GeV photons.

In the 300 GeV proton running, we also used targets of aluminum, copper, and lead, as well as beryllium. This permitted us to do a standard optical model analysis of the A-dependence of the ρ and ρ' photoproduction yields, and to obtain the ratio of the cross-section for the scattering of ρ' and ρ on nucleons. When one performs this analysis using the 300 GeV data, one finds that the ratio of the cross-sections is 1.05 ± 0.18 . Using the beryllium data alone, from the 400 GeV proton runs, we obtained the ratio of these two cross-sections to be $0.98 \pm .14$, and $\sigma(\rho N) = 27.4 \pm 2.2$ mb. The results of these analyses indicate that the ratio of the ρ and ρ' nucleon cross-sections is close to 1.0. The importance of this result is that under the generalized vector dominance model where one uses a purely diagonal form of the vector matrix, one expects that the cross-section should have varied as $1/m^2$ for the vector meson. The experimental results seem to imply that the vector dominance model in its diagonal form may not be applicable.

The decay $\rho' \rightarrow \pi\pi$ was measured for the first time and the result is

$$\frac{\Gamma(\rho' \rightarrow \pi^+ \pi^-)}{\Gamma(\rho' \rightarrow \pi^+ \pi^- \pi^+ \pi^-)} = .092 \pm .013.$$

A9. A Study of Neutrino Induced Neutral Currents

(A. Bross, R. M. Brown, T. O'Halloran, S. Fuess, J. Negret, P. Nienaber, in collaboration with Columbia University and Brookhaven National Laboratory)

The primary goal of this experiment is the study of neutrino induced neutral currents in the elastic and single pion channels. In an earlier phase of this experiment we measured the following properties of neutral current interactions.

a) The Reaction $\nu_\mu + p \rightarrow \nu_\mu + p$

This was the first observation of the simplest of the hadronic neutral current interactions. We observed

$$R_{el} = \frac{\sigma(\nu_\mu + p \rightarrow \nu_\mu + p)}{\sigma(\nu_\mu + m \rightarrow \mu^- + p)} = 0.23 \pm 0.09$$

b) Single Pion Production in Neutrino and Anti-Neutrino Reactions

We observed:

$$R_o' = \frac{\sigma(\nu N \rightarrow \nu N' \pi^0)}{\sigma(\nu N \rightarrow \mu^- N'' \pi^0)} = 0.17 \pm 0.04$$

$$\bar{R}_o' = \frac{\sigma(\bar{\nu} N \rightarrow \bar{\nu} N' \pi^0)}{\sigma(\bar{\nu} N \rightarrow \mu^+ N'' \pi^0)} = 0.39 \pm 0.18$$

We were not, on the basis of our previous run, able to establish the isotopic spin of the hadronic final state.

In addition to our study of the neutral current interaction, we observed 7 dilepton events and we established

$$R = \frac{\sigma(\nu N \rightarrow \mu^- e + \text{---})}{\sigma(\nu N \rightarrow \mu^- + \text{---})} > 3 \times 10^{-4}$$

During FY78 our major effort consisted of rebuilding the detector with the design based on our previous results and implementing automatic measuring and pattern recognition in our data reduction.

The detector now consists of 14 modules of 6 ft. x 6 ft. narrow gap aluminum spark chambers with a plane of scintillation counters behind each chamber. Each plane consists of three 2 ft. x 6 ft. counters viewed by a photomultiplier at each end. The 14 modules are followed by a wide aperture magnet and an additional 8 modules of the narrow gap chambers. These chambers are surrounded on three sides by banks of scintillation counters which will detect wide angle muons leaving the chamber.

The detector has several features which were not in the earlier phases of this experiment.

(1) By mounting photomultipliers on each end of the counters between each module, we are now able to increase our discrimination between protons and pions on the basis of a pulse height analysis. The most significant background in our previous analysis of the reaction $\nu_\mu + p \rightarrow \nu_\mu + p$ was the reaction $\nu_\mu + p \rightarrow \nu_\mu \pi^+ n$. This should now be reduced.

(2) By surrounding the chambers on three sides by scintillation counters, we are now able to detect wide angle muons. In our previous analysis of π^0 production, we had to make a cut in the data to eliminate this problem and this significantly reduced our statistics.

(3) With the installation of the wide aperture magnet, we will now attempt to measure charged single pion production which will give us another handle on the

isotopic spin of the neutral current interaction.

The above changes to the detector were made to enhance our studies of the neutral current interaction. We have also rearranged the detector to improve our ability to detect dilepton events. Following the 8 downstream narrow gap chambers, we have installed six 8 ft. diameter toroids interspersed with 8 ft. x 8 ft. thick plate aluminum spark chambers. This 50 ton detector will allow us to study the reaction $\nu_{\mu} + N \rightarrow \mu^{-} \mu^{+} + \dots$.

During FY78 we are scheduled for the following runs:

- (1) A test exposure in the narrow band dichromatic beam. We expect to measure rates and also have a preliminary look at the dilepton final states.
- (2) A wide band run of $\bar{\nu}$ and ν interactions which will complete our ν exposure and allow us to begin our $\bar{\nu}$ analysis. We have already substantially completed our ν running and in February 1978 will begin our $\bar{\nu}$ run.
- (3) A beam dump experiment which will allow us to look for new particles such as the recently proposed axion which will interact in our detector.

In order to handle the data from these runs, we have made several substantial improvements in our data analyses:

- (1) We are able to automatically digitize the film we exposed during the summer of 1977 on the University of Illinois DOLLY system. The procedure has been compared with manually scanned film and is completely reliable.
- (2) We are now in the process of developing pattern recognition programs to automatically scan the film. Initially we are starting with the elastic and quasi-elastic interactions, and we will later move on to higher topologies. This program, while it is not complete at the current time, will be finished during FY78.

With the implementation of pattern recognition, a major consideration in the future will be film cost and the time for film digitization. In order to solve these problems, we have developed a camera utilizing charge coupled devices (CCD). We are planning to test our first camera in March 1978.

If the CCD camera is successful, we will have developed a system which, coupled to the pattern recognition programs currently being developed, will enable us to analyze the data at a pace substantially higher than we currently enjoy.

A10. Inclusive Hadron Production by Neutrinos at Fermilab

(B. Eisenstein, L. Holloway, and others, in collaboration with Harvard University and the University of Chicago)

a) Neutral Currents

The demonstration of the existence of neutral weak currents occurred

several years ago. With the design of the new N-30 narrow band dichromatic neutrino beam at Fermilab, it will be possible to study neutral currents at high energies, where the cross-section is large, and to measure $d^2\sigma/dx dy$ or $d^2\sigma/dQ^2 dv$ over a reasonable range of these variables.

The N-30 beam selects mesons (π and K) of a definite momentum (~ 250 GeV/c) for subsequent decays yielding neutrinos. Since these are two-body decays, the direction of the neutrino in the lab (measured by its interaction point in the target) determines its energy. It is only necessary to select reactions of the form $\nu + p \rightarrow \nu' + x$ where E_x , the hadronic energy, is sufficiently large that the possibility of pion parentage of the beam neutrino is excluded. The resulting events have a broad distribution of neutrino energy, known to within an error of the order $\sigma \sim 10\%$.

We are proposing to build an instrumented calorimeter which will

- (1) serve as the target and determine the primary vertex,
- (2) measure E_x with high precision,
- (3) measure the hadronic system angle, θ_x , with high precision.

In this way we will calculate (x,y) or, equivalently, (Q^2, ν) for each event.

In our original design we considered Uranium/Liquid Argon for the calorimeter since it is capable of the best resolution on E_x . Monte Carlo studies showed that the resolution on θ_x was, in fact, the limit on the accuracy of reconstructing each event, and we decided to use Iron/Liquid Argon. The latter configuration can give a far better angular resolution and the loss of energy resolution is not important.

The calorimeter design calls for iron "plates", 3.6 m x 3.6 m x 0.3 cm, separated by 0.4 cm liquid argon gaps. Every other "plate" is in reality made from 180 strips of iron, electrically isolated, which give alternately x or y distributions of the energy collected in that plane. The total of ~ 1600 planes represents ~ 4700 gm/cm² of absorber. We anticipate resolutions on hadron energy measurements

$$\sigma(E_x)/E_x = 0.5/\sqrt{E_x} \text{ (GeV)}$$

and direction determination

$$\sigma(\theta_x) = 4 + 60/\sqrt{E_x} \text{ (GeV)} \text{ in mrad.}$$

This corresponds, for example, to $\sigma(E_x) = 5$ GeV and $\sigma(\theta_x) = 10$ mrad for a 100 GeV hadronic system.

In order to verify that the calorimeter will achieve these resolutions, a small prototype has been built and is being tested, as described in Section A.11.

Extensive Monte Carlo studies have been done assuming the above resolutions and assuming a downstream spectrometer (one already existing at Fermilab) to detect muons and to distinguish neutral-from charged-current events. Excellent resolution on x and y are predicted for $0 \lesssim x \lesssim 1$, $0.2 \lesssim y \lesssim 0.95$ for $100 \text{ GeV} \lesssim E_\nu \lesssim 250 \text{ GeV}$. The event rate for all interactions, with incident neutrinos, is $\sim 1500/\text{day}$, of which 20% will be neutral-current.

We hope that the proposal will be approved in the spring of the current fiscal year and that construction of the calorimeter, electronics, etc., can begin shortly afterwards.

b) Charged Currents

Since neutral current events will represent only $\sim 20\%$ of the total neutrino cross-section, we expect the data to contain $\sim 1200/\text{day}$ charged current interactions.

Since we will measure the momentum of the muon, as well as the hadron system and neutrino energy, as in the case of neutral current events, we will actually be overconstrained and can do a 3-c fit to the event. We then expect excellent precision on (x, y) or (Q^2, ν) for these charged current events over a very wide range. This will also yield high resolution measurements of spectrum of the produced hadron mass and $B(x) = \frac{\bar{q}(x) - q(x)}{\bar{q}(x) + q(x)}$, where $\bar{q}(q)$ are the probabilities of anti-quark(quark) momentum fraction x .

All. Iron/Liquid Argon Calorimeter Development

(B. Eisenstein, L. Holloway, W. T. Wroblecka, and others, in collaboration with Fermilab, Harvard University, and the University of Chicago)

We have built and are currently testing, a small prototype of the calorimeter described in Section A.10. The plates are $0.6 \text{ m} \times 0.6 \text{ m}$, rather than $3.6 \text{ m} \times 3.6 \text{ m}$. The overall depth is 1.64 m , rather than 11.2 m . In all other respects, the prototype is identical to the large calorimeter, both physically and in terms of the readout of the 2.0 cm strips. It has an effective thickness of $\sim 680 \text{ gm/cm}^2$, and should contain hadron showers of energy up to 150 GeV .

The prototype calorimeter is being tested in a beam of hadrons, muons, and electrons at energies up to several hundred GeV. These tests have several goals;

- (1) the energy and angle resolution of both hadron showers and electromagnetic showers
- (2) the ability to discriminate between hadronic and electromagnetic showers
- (3) the ability to "see" a muon emerging from a hadronic shower
- (4) the stability of the device, noise problems, etc.

In parallel with hardware development we have already tested both on-line (data acquisition and diagnostic) programs and off-line (analysis) programs, and

we expect rapid conclusions from the data acquired in the test runs.

In order to gain experience using the detector to obtain physics results, we are currently exploring the possibility of either adding a modest external detector or taking advantage of existing facilities at Fermilab. We believe that the device will have potential value for a number of hadronic or leptonic reactions.

A12. Lepton-Photon Studies at CESR

(G. Gladding, J. Thaler, and L. Garren, in collaboration with the University of Chicago, Princeton University, Carlton University, and the NRC of Canada)

We have submitted a proposal to perform an experiment in the North area at CESR, the Cornell Electron Storage Ring. This experiment, CESR N-1, will examine the properties of the photons, electrons, and muons produced in e^+e^- collisions at center of mass energies between 8 and 16 GeV. The principal thrust of this experiment will be twofold: First, based on the experience with the J/ψ particle and its relatives, we expect the $T(9.5)$ and $T'(9.9)$ to be 1^- members of a family of particles containing a new, heavy quark. We plan to measure with precision the monochromatic photons expected to be emitted by some of the transitions between members of this family and thus probe the nature of the forces binding the quarks together. Second, the possible existence of a heavy lepton of mass ~ 1.9 GeV prompts us to consider the possible existence of heavier, hitherto unobserved leptons. We propose to search for the existence of such particles by looking for the characteristic $\mu e +$ nothing decays of a pair of leptons produced in the reaction:

$$e^+e^- \rightarrow L^+L^- \rightarrow (\mu\nu\bar{\nu})(e\nu\bar{\nu})$$

In addition to these two primary objectives of the experiment we expect that almost any apparatus will be sensitive to the grosser features of e^+e^- annihilation into hadrons. This includes sensitivity to new resonances and to steps in R , the ratio of hadron to muon production.

One important aspect of the CESR environment is the low event rate in the presence of potentially serious cosmic ray and machine related backgrounds. For this reason, we feel that it is important to build the best possible detector with which to perform the experiment. We have designed an apparatus which has several desirable features:

- (1) unsurpassed energy resolution for photons of energies from ~ 10 MeV up to full beam energy (~ 8 GeV)
- (2) excellent $e-\mu-\pi$ identification
- (3) nearly complete solid angle coverage

We plan to obtain this performance by surrounding the interaction region with a segmented array of sodium iodide (NaI) crystals. Sodium iodide can measure the energy of a 100 MeV photon to 3%, more than a factor of ten better than any other detector. This will allow us to measure the hyperfine splitting between the P-states having masses between the T and T'.

Separation of muons from pions is facilitated by the presence of an iron absorber surrounding the sodium iodide. Including the NaI, particles must traverse 7 absorption lengths of material to reach the outside. We will detect interactions with five layers of scintillator and drift chambers within the absorber. The π - μ separation is then limited by the probability that a pion will decay before it interacts, $1.5\%/p(\text{GeV})$. The probability is small because of the compact apparatus - the mean absorption length for pions is 80 cm.

Separation of electrons from pions is accomplished by measuring the longitudinal development of the shower. We will require: 1) that the cascade process begin promptly, in the first four radiation lengths of the NaI, and 2) that low energy cascades ($E < 2.5 \text{ GeV}$) have died out before 16 radiation lengths, and high energy cascades before 24 r.l. The first requirement is made possible by the fact that the NaI is segmented into rectangular blocks 4 radiation lengths on a side. The second is imposed using a layer plastic scintillator and drift chamber at both the 16 and 24 r.l. depths. The effectiveness of these requirements for e - π separation is strongly energy dependent. The fraction of π 's that are called e 's falls from about 10% at low energy to below 1% above 2.5 GeV.

The apparatus covers about 97% of the total solid angle; we have left holes only for the beam pipe. This large coverage is desirable to maximize the event rate, but more importantly it is crucial to the unambiguous identification of the heavy lepton decays:

$$L^+L^- \rightarrow (\mu^+ \nu_\mu \bar{\nu}_L) (e^- \bar{\nu}_e \nu_L) .$$

The composite coverage, in conjunction with good particle identification, should allow us to collect a clean sample of heavy lepton events.

We expect a decision by the CESR advisory committee in the spring of 1978. Upon approval, we will begin construction of the apparatus.

B. Experiments Planned for the Coming Year

B1. Charm Search, ψ Production, and Pion Dissociation Using 215 GeV Pions

(G. Ascoli, J. Cooper, L. Holloway, L. J. Koester, U. E. Kruse, R. D. Sard, M. Shupe, G. Alverson, D. Bender, H. Budd, S. Hahn, W. MacKay, E. Smith in collaboration with Harvard University, Oxford University, and Tufts University physicists)

Data analysis will proceed at the University of Illinois, Oxford University, Fermilab, and Tufts University. Oxford is producing secondary tapes of the entire data sample. These secondary tapes contain data with geometrical distortions removed from the spark coordinates. Some reconstructed track information is also included. The University of Illinois and Fermilab participants will be developing higher level analysis routines. Tufts is computing calibration constants for the Tufts lead glass array.

As routines are written at Illinois or Fermilab, they are tested on PDP-10's and on the Illinois Cyber. Preliminary studies and error and cut analysis of a sample of the data are also done on these computers. Fermilab has mounted secondary data tapes on the Berkeley 7600 and shown that analysis production can be carried out using that computer. We expect to have all Oxford secondary tapes installed at Berkeley and to do the final full analysis of the data there.

As soon as the first of the new proportional chamber modules is found to be satisfactory, we will proceed with the construction of the remaining four chambers. The G-10 frames for these chambers are already finished. The winding and assembly of these chambers will then proceed with the benefit of experience from the first chamber.

Our analysis of the three triggers should indicate the areas where the experiment is hurt most by the lack of statistics (see Section A). Assuming that chamber construction proceeds without incident, we expect to propose a second data run to take place during FY79.

B2. Hadron Induced Dimuon Production at Fermilab

(J. Thaler, in collaboration with the University of Chicago and Princeton University)

In FY79 we expect to complete the analysis of E-444 and publish the results. Because the experiment is similar to E-331, we anticipate no great problems in finishing. We expect our experiment to be the definitive work on the production of dimuons of masses from 2 GeV to 9 GeV because of the large acceptance of the

apparatus and good resolution of the spectrometer. We have no plans for the further data collection.

B3. Proportional Hybrid Bubble Chamber Experiments

(R. D. Sard, J. W. Cooper, R. L. Plumer, in collaboration with the International Hybrid Spectrometer Consortium - Brown University, Johns Hopkins University, Illinois Institute of Technology, University of Illinois, Massachusetts Institute of Technology, Indiana University, Rutgers/Stevens, Tennessee/Oak Ridge, Yale/Fermilab, plus the Universities of Nijmegen/Cambridge/Mons/Padua/Pavia/Trieste/Rome/CERN, and Tel-Aviv/Technion/Weizmann)

Our future participation in these experiments is limited to data analysis. We expect to contribute to the study of correlations and clustering, as well as beam diffraction.

We are not planning further research with the 30-inch hybrid bubble chamber system.

B4. A Study of Reactions Producing a Fast Forward Neutron in $\pi^- p \rightarrow nx^0$ at 8 GeV/c

(B. Eisenstein, W. T. Wroblecka, in collaboration with the University of Chicago)

The Thesis of Wroblecka, and any remaining work on the analysis of this reaction, should be completed early in FY79.

B5. Photoproduction of Two Particle States at Fermilab

(J. Butler, G. Gladding, A. Wattenberg, J. Wiss, P. Avery, M. Goodman, J. Russell, in collaboration with a group from Fermilab)

In FY79 we are scheduled to take data on Experiment 401. We expect to break the running up into two parts, one at moderate intensity (1×10^{12} protons/pulse) and one at high intensity ($\geq 3 \times 10^{12}$ protons/pulse).

During the moderate intensity running we will use liquid hydrogen and liquid deuterium targets. The emphasis of this running will be on precise measurements of $\psi(3.1)$ and $\psi'(3.7)$ production cross-sections as well as exploratory investigations of the two-body hadronic spectrum ($p\bar{p}$, $K\bar{K}$, $K\pi$, etc.). We expect to measure the energy dependence of $\psi(3.1)$ production from 40-150 GeV, and to obtain an initial measurement of the $\psi'(3.7)$ - nucleon cross-section in this energy region. The $\psi(3.1)$ and $\psi'(3.7)$ will be identified by their decay into e^+e^- or $\mu^+\mu^-$ pairs. In addition to these dilepton triggers, we will also accept two-body hadronic final states. In order to reduce the trigger rate from copious ρ and multi-pion production, we may use the Cherenkov detector in the final trigger logic to enhance the $K\bar{K}$, $p\bar{p}$ and $K\pi$ signals.

During the high intensity running, we will use a 3-inch beryllium target and concentrate on a measurement of the high mass $\mu\mu$ and ee mass spectrum and a search for anomalous μe production. In order to reach the maximum intensity possible, we are planning to deaden the region of the chambers which contain the 0-degree e^+e^- pairs produced in the target. We hope to be able to run at a high enough data rate for more than 600 hours in order to obtain more than 20 μe events coming from a 1.8 GeV heavy lepton and $\gtrsim 100 \mu\mu$ and ee events coming from a 5.0 GeV/c² heavy meson with a production cross-section of 1% of that of the $\psi(3.1)$.

B6. Multi-Hadron Events Produced by High Energy Photons at Fermilab

(J. Butler, G. Gladding, T. O'Halloran, A. Wattenberg, J. Wiss, P. Avery, P. Callahan, M. Goodman, J. Russell, in collaboration with groups from Columbia University and Fermilab)

The analysis of the E-87A data will probably be completed during FY79.

E-458 is scheduled to run after the experiment E-401. E-458, which is a multi-hadron experiment, will be very much influenced by two factors. One will be the results of E-87A; the other is that with the present level of funding projected in the President's budget, we may have to curtail our plans for several experiments, including 458.

In E-458, we had planned to study the properties of the charmed baryons and the charmed mesons. In the case of the charmed baryons, we hope that we will be in a position to look for parity violation, possibly to try to measure the lifetime, and to search for higher energy states that decay into the charmed ground state baryons. All studies of the photoproduction of charmed mesons will be very dependent upon the observation of charmed mesons in the data from E-87A.

To perform the above, we anticipate that we may need the following additions to the detecting apparatus: an improved lifetime detector, a photon-electron shower detecting system with good spatial and energy resolution, and drift chambers to improve the resolution of the multiparticle spectrometer system. With the present level of funding, we cannot afford more than one modest new addition to the apparatus.

B7. A Study of Neutrino Induced Interactions at BNL Energies

(A. Bross, R. M. Brown, T. O'Halloran, S. Fuess, J. Negret, P. Nienaber, in collaboration with Columbia University and Brookhaven National Laboratory)

At the present time, we are tentatively scheduled for a run at BNL in October 1978. This will be the first exposure following the FY 1978 run which is going on as this is written. It is our present intention to request that the run

be devoted to wide band $\bar{\nu}$. This will complete our wide band $\bar{\nu}$ analysis. It should be recognized, however, that this is contingent upon the results we obtain from the runs in FY 1978. There are several question which will be answered by these runs:

(1) What is the flux and spectrum in the narrow band run? The film taken during the test run is currently being analyzed at Columbia and Illinois. During this spring, we will have determined both of the above quantities and we will also have searched for dilepton candidates at the higher incident neutrino energy.

(2) We are currently beginning our first substantial $\bar{\nu}$ running in the new detector. By the end of FY 1978 we will understand the background problems and be able to set a limit on the level to which we can measure these interactions. The amount of future running is obviously contingent on these measurements.

(3) We are also about to begin a beam dump experiment which will allow us to look for interactions initiated by particles other than ν_{μ} or ν_e . The results observed during this run could also affect our future plans.

B8. Inclusive Hadron Production by Neutrinos at Fermilab

(B. Eisenstein, L. Holloway, and others, in collaboration with Harvard University and the University of Chicago)

Fiscal year 1979 should be one primarily of construction of apparatus for the high energy neutral current neutrino experiments and by late FY 1979, the installation of the apparatus. We hope to be able to accept beam by the beginning of fiscal year 1980 and to have preliminary physics results before the end of that year. It is anticipated that subsequent runnings and data analysis will extend through fiscal year 1981.

B9. Lepton-Photon Studies at CESR

(G. Gladding, J. Thaler, and L. Garren, in collaboration with the University of Chicago, Princeton University, Carlton University, and the NRC of Canada)

We expect the large part of this year to be spent on construction and testing of the apparatus. We hope to place the NaI detector in a test beam at Fermilab or Brookhaven to measure its response to electrons and pions before installation at CESR.

C. Experiments that are Planned for Future Years

C1. Charm Search, ψ Production, and Pion Dissociation Using 215 GeV Pions

(G. Ascoli, J. Cooper, L. Holloway, L. J. Koester, U. E. Kruse, R. D. Sard M. Shupe, G. Alverson, D. Bender, H. Budd, S. Hahn, W. MacKay, E. Smith, in collaboration with Harvard University, Oxford University, and Tufts

University physicists)

In the long run, the collaboration hopes to improve the rate capability of the Chicago Cyclotron Magnet spectrometer by replacing all spark chambers in the system with drift chambers. This should make possible a factor of at least ten in the rate of data acquisition. At this time we are considering the possibilities of the construction of such chambers.

C2. Photoproduction of Two Particle States at Fermilab

(J. Butler, G. Gladding, T. O'Halloran, A. Wattenberg, J. Wiss, P. Avery, M. Goodman, J. Russell, in collaboration with a group from Fermilab)

Part of FY80 will probably be spent analyzing the data from Experiment 401. Should interesting features be found in this data, we will propose extensions to pursue the interesting physics suggested by these results. There are possible areas which a proposal for an extension could emphasize. For example, we might choose to pursue $\psi(3.1)$ photoproduction at large t by constructing a more elaborate recoil detector. Should we find indications of additional structure in the two-body mass spectrum, we may wish to further improve the mass resolution by the addition of drift chambers to the outer detector.

Finally, if we detect a μe signal, we will look into ways of improving our π/e rejection and our trigger in order to run at higher intensity with thicker targets.

C3. K_L^0 Experiments Using the Neutral Beam Facility at Fermilab

(J. Butler, G. Gladding, T. O'Halloran, A. Wattenberg, J. Wiss, P. Avery, M. Goodman, J. Russell, in collaboration with groups from Fermilab and Columbia University)

The charmed particle scheme includes states, some of which are charmed and strange, and some of which are doubly charmed. The cross-section for the production of such states may very well be inhibited by several orders of magnitude and they may not have been observed even within the next two years. Therefore, it becomes of interest to study the production of particles with higher numbers of strange quarks and/or charmed quarks. A simplistic production model might visualize the bare quarks being produced and then dressing themselves with other quarks. The question arises, "How do naked quarks get dressed and how much more does it cost to dress them with strange quarks and charmed quarks rather than up and down quarks?" It would be desirable to study this question using K_L^0 mesons and to see to what extent particles which are doubly strange or triply strange are reduced in their production relative to those that are singly strange. The ultimate goal of such studies would be that of observing strange charmed baryons or anti-baryon pairs.

Before submitting a proposal for such an experiment, we would like to have data from the present E-87A run to analyze. Some of the runs which we will take include having lead absorbers in so that only the K_L^0 and the neutrons are present in the beam. We would hope to perform the experiment with only very minor modifications of the apparatus, but perhaps modifying the beam attenuators to optimize the K_L^0 signal relative to the neutron backgrounds.

C4. A Study of Neutrino Induced Interactions

(A. Bross, R. M. Brown, T. O'Halloran, S. Fuess, J. Negret, P. Nienaber, in collaboration with Columbia University and Brookhaven National Laboratory)

The neutrino program at BNL in FY 1980 and beyond will depend on the results we obtain in the next 18 months. When this program began, it was regarded as a search for neutral currents, i.e., a short experiment. In the past few years it has developed into a program which measured the exclusive channels of the neutral current supplementing the data obtained at the higher FNAL energies. The detector and the accompanying analysis have evolved as the measurements became more sophisticated. We have built a powerful detector and are in the process of developing a sophisticated data reduction system. In the final analysis, however, the program will depend on the results we obtain, as it has in the past.

C5. Inclusive Hadron Production by Neutrinos at Fermilab

(B. Eisenstein, L. Holloway, and others, in collaboration with Harvard University and the University of Chicago)

It is our intention to be able to run with incident neutrinos early in FY 1980 and to complete the taking of data and analysis of the first run during that year. We anticipate running with anti-neutrinos and/or acquiring more neutrino data in FY 1981. It is clear that we must remain flexible since this is reasonably far in the future; the design of the calorimeter as a "general" detector helps assure this flexibility.

C6. Lepton-Photon Studies at CESR

(G. Gladding, J. Thaler, and L. Garren, in collaboration with the University of Chicago, Princeton University, Carlton University, and the NRC of Canada)

CESR is scheduled to begin operation in late FY 1979 or early FY 1980. We expect to be ready to take data at that time. From previous storage ring experience, we anticipate that data taking will continue for about one to two years.

After the initial run, it will be possible to reconfigure the apparatus, should that be desirable. We have designed the apparatus to facilitate changes.

IV. OPERATIONS AND DEVELOPMENT OF COMMON FACILITIES

A. Technical Accomplishments During This Year

A1. Data Acquisition Systems

(R. Brown, R. Downing, T. Noggle, V. Simaitis, R. Barth, J. Lufkin, J. Wray)

The DOLLY/CSX-1 precision CRT film measuring system continues in very heavy use during this period on film derived from spark chambers and bubble chambers. The system is now scheduled for 160 hours of operation per week with the remaining 8 hours scheduled for equipment maintenance and calibrations. Work has continued on improving the sensitivity, stability of the DOLLY detection system. A software calibration procedure has been developed which permits stabilizing the sensitivity to the quality of the film; this is invoked periodically during the film measuring runs. In addition, monitoring meters have been installed at the operator's console to further improve control over the sensitivity.

During this period, bubble chamber film from FNAL E-154 (π^+p , pp) and successor experiments has been measured at a small but regular rate. Measurement of this film will be completed by the end of FY 1978.

Heaviest use of the DOLLY system has been in the measurement of the spark chamber film from the neutrino experiment work at BNL 693. Over 400,000 frames will be measured in FY 1978 at speeds ranging from 100-400 frames per hour. These measurements are made in a completely automatic mode wherein the control program advances film, measures frame marks and fiducials, and predicts the location of the spark chamber gaps. Gaps are scanned automatically and all sparks therein are digitized and written out to disk files on the attached PDP-10. Because operator intervention has turned out to be minimal when the quality of the film and fiducials is maintained, it has been possible for the DOLLY operators to combine DOLLY monitoring with manual film scanning for special events.

A2. Computer Operations

(R. Brown, J. Wray, R. Barth, J. Lufkin, D. Richardson, E. Minor)

In FY 1978 the PDP-10 computing system was operational and available for time-sharing in batch use approximately 8000 hours. For most of this time, the system was actively connected to the CSX-1 computer for on-line processing of DOLLY-measuring events and CSX-1 program development. In addition, up to 24 time-sharing terminals (teletypes and CRT terminals) were connected to the system. Total CPU time is projected to exceed 3000 hours. A number of additions and improvements were made to the system:

- The DEC PDP-10 processor has been replaced by a KI-10 processor with a theoretical speed-up factor of 2. Most important has been the incorporation of virtual memory to permit the development of large programs without the necessity of overlay or other restrictive procedures; production programs, however, require different memory management for efficient execution. The rise in magnetic tape processing has revealed some problems with the scheduler which need further work. However, the net effect has been a substantial increase in the rate at which data can be analyzed.

- A second pair of 9-track, 800/1600 BPI tape units has been installed, making a set of four to service the magnetic tapes generated on-site by the various experiments. The acquisition of these more modern units has, as expected, generated a substantial increase in the analysis of experimental tapes. The power of the system is still not adequate to permit initial track finding and other raw data reduction processes. However, second level and subsequent analysis is now available for the researchers within the system capability.

- Additional MOS memory has been added to the system to increase the total available to 192K words. This has been important to accommodate the increased use of the machine by multiple time-sharing users; the system still remains memory limited during heaviest use.

- Two additional RPO-3 disk drives have been added to the system, dedicated to experiments BNL-693 and FNAL-401,458. These provide data base storage during data analysis in these experiments.

- A second Tektronix graphic station has been installed for use in track finding program development and on-line scanning/measuring of previously processed data from the DOLLY/CSX film scanning system. These two Tektronix units are logically connected to adjacent CRT terminals so that control dialogs can be conducted at the CRT terminal while graphic plotting, etc., occurs on the Tektronix terminals. These terminals have proved to be a significant help in the debugging of pattern recognition programs, as well as speeding up the flow of data towards the analysis phase.

A3. Engineering Systems

(A. Bross, R. Downing, T. Noggle, V. Simaitis)

A system consisting of eight (expandable to twelve) 320 x 512 CCD's has been installed for experiment 693 at BNL. The "cameras" are read-out in parallel at 5 mhz into their local 2K word semiconductor memory. A LSI-11 controls the read-out of this data to a magnetic tape and also on a sampling basis to the BNL PDP-10 for on-line checking. A maximum of 16K-32 bit words can be recorded for each

event.

New multiwire chamber electronics for 7500 wires has been completed with ECL 10K technology. The system is completely ECL from the amplifier through to the computer interface. This system will also serve as a general high speed wire chamber system for future experiments.

Work has continued on new ultra-high speed ECL modules for use in front-end trigger logic. Twenty general purpose modules now exist. These modules are currently being used in two running experiments. A micro-processor monitoring and control is now being designed into this system.

A 48K word block of memory was added to the PDP-10 system using 4K memory chips. The system is designed so that 16K memory chips can be used when economical without addition design being needed. The PDP-10 now has 128K words of University of Illinois-built memory.

A4. Micro-channel Plate Photomultiplier Study

(J. Thaler)

Due to the fact that many high energy physics experiments are now conducted almost entirely within large magnetic fields, the search for a photomultiplier which is capable of operating in environments of 20-50 kilogauss has become more pressing. Conventional dynode structure vacuum tube photomultipliers can only tolerate a few gauss, and shielding against ambient fields of greater than several hundred gauss is difficult. There is a new device, still largely in the prototype phase, which shows promise. It is the microchannel plate (MCP) photomultiplier, which consists of a ceramic plate about 1 mm thick with a high density of very small ($\sim 20\mu$) pores through it. If a 2kV potential is placed across this plate, then the injection of an electron at one end of a pore results in a cascade due to the secondary emission properties of the pore walls. Gains of 10^6 - 10^7 are obtainable. The compact geometry of the MCP makes it relatively immune to the presence of magnetic fields; they have been operated, with no shielding, in 3 kilogauss fields.

A \$10,000 University of Illinois Research Board grant has been obtained to purchase two of these devices for study. We intend to learn the general behavior characteristics of the MCP's and to study their behavior in large magnetic fields. For this latter purpose, there are two high field (75 kg) superconducting magnets owned by the solid state group here which are suitable, as well as our own research group's apparatus.

B. Plans for Facilities for the Next Two Years

B1. Data Acquisition Systems

(R. Brown, R. Downing, V. Simaitis, R. Barth, J. Lufkin, J. Wray)

Subsequent to FY 1978, the continued use of the DOLLY/CSX-1 system is projected for continued automatic measuring of neutrino spark chamber film for experiment BNL 693 and follow-on, subject to the rate of development of the charge coupled device on-line semi-conductor camera. Since the latter device offers a significant reduction in film purchase and processing costs, further film use will be heavily restricted as soon as this CCD system is demonstrated operational. No further experiments utilizing film are contemplated by this group. Consequently, it is expected that within this time period, the DOLLY system will be put on stand-by basis.

Studies will continue with pattern recognition programs for spark chamber and other chamber data, using the PDP-10 system. It is expected that data derived from the CCD camera devices can also be directly fed into these data analysis programs.

B2. Computer Operations

(R. Brown, J. Wray, R. Barth, J. Lufkin, D. Richardson, E. Minor)

In FY 1979 and following, use of the PDP-10 system is expected to grow towards saturation, with total utilization dependent upon the amount of experimental data reduction done on this machine vis-a-vis other potentially available more powerful units. Total CPU utilization can only be predicted within the range of 3500-6000 hours. The programming staff is expected to work in the following support areas:

- Normal programming development for data analysis and new experiment design.
- Continued development of on-line graphics techniques and displays for data analysis and computer aided scanning.
- Improved software and hardware techniques, coupling the PDP-10 to experimental assembly sites in the Physics Building for assistance in the preparation and check-out of apparatus.

B3. New High Speed Standard Systems

(R. Downing, V. Simaitis)

R. Downing is a member of the "Fast System Design Group" sponsored by the U.S. NIM Committee. This group has the task of designing a new high speed standard data-acquisition system. Mr. Downing is a member of the "System Topology" committee and chairman of the "Transmission Schemes and Device Studies" committee. This system will give future experiments at least an order of magnitude improvement over CAMAC

in speed and a multi-processor (multi-controller) capability which is not now available. Some of the basic problems associated with high-speed ECL buses have already been studied by this engineering group. The University of Illinois will be involved in developing future prototype portions of this system.

Work on high-speed logic systems for fast triggers will continue. Basic high speed modules have been built and tested. We will begin to design micro-processor monitoring and control of these systems.

Studies will begin on 100 mhz fiber optic data links. At this bandwidth, we can replace many multiconductor data cables resulting in lower cost and fewer electrical problems.

V. PUBLICATIONS SUBMITTED OR PUBLISHED AND PAPERS
PRESENTED DURING CALENDAR YEAR 1977

- W. R. Francis, T. B. W. Kirk, R. G. Hicks, et al. "Diffractive Production of ρ Mesons by 147-GeV Muons." Phys. Rev. Lett. 38, 12, 633 (1977).
- H. L. Anderson, W. R. Francis, T. B. W. Kirk, R. G. Hicks, et al. "Measurement of the Proton Structure Function from Muon Scattering." Phys. Rev. Lett. 38, 25, 1450 (1977).
- W. A. Loomis, W. R. Francis, T. B. W. Kirk, R. G. Hicks, et al. "Hadron Production in Muon-Proton and Muon-Deuteron Collisions." (Submitted to Phys. Rev. in November 1977).
- R. Coleman, J. Bronstein, G. Gladding, M. Goodman, M. Gormley, R. Messner, T. O'Halloran, J. Sarracino, A. Wattenberg, et al. "Search for Semi-Leptonic Weak Decays of Charmed Particles in γ -Be Collisions." Bull. Am. Phys. Soc., Vol. 22, 4, 553, April 1977.
- J. W. Cooper, R. D. Sard, A. Snyder, J. Tortora, et al. "Evidence for Inclusive Pion Diffraction Dissociation in $\pi^- p \rightarrow (\pi^- \pi^- \pi^+) + X$ at 147 GeV/c." Bull. Am. Phys. Soc., Vol. 22, 4, 584, April 1977.
- J. Bronstein, R. Coleman, G. Gladding, M. Goodman, M. Gormley, R. Messner, T. O'Halloran, J. Sarracino, A. Wattenberg, et al. "High Energy Photo-production of Vector Mesons." Bull. Am. Phys. Soc., Vol. 22, 4, 553, April 1977.
- B. Eisenstein, J. Elliott, W. Mollet, B. Nelson, D. S. Rhines, R. G. Wagner, and W. T. Wroblecka, et al. "Backward Resonance Production in $\pi^- p \rightarrow n \pi^+ \pi^-$." (Submitted to Phys. Rev. D in November 1977).
- B. Knapp, J. Bronstein, R. Coleman, G. Gladding, M. Goodman, M. Gormley, R. Messner, T. O'Halloran, J. Sarracino, A. Wattenberg, et al. "Search for the Leptonic Decays of Charmed Baryons and Mesons." (To appear in the Proceedings of the V International Conference on Experimental Meson Spectroscopy, Boston, Massachusetts, April 29-30, 1977).
- D. Brick, R. Sard, A. Snyder, J. Tortora, et al. "Inclusive Δ^{++} Production in $\pi^- p$ Interactions at 147 GeV/c." (Submitted to Phys. Rev. D in 1977).
- M. Heller, R. L. Plumer, et al. "Test Results of 31 cm x 31 cm Lead Glass Electromagnetic Shower Detector." (Submitted to Nuclear Instruments and Methods, October 1977).

THESES

Coleman, Richard Neal. "Search for Semileptonic Decays of Photoproduced Charmed Mesons."

Bronstein, John Michael. "High Energy Photoproduction of the ρ and ρ' Vector Mesons."

Plumer, Richard Lee. "Jet Structure and Planarity in $\pi^- p$ Interactions at 147 GeV/c."

Bross, Alan David. "Muon-Electron Final State in Neutrino Interactions."

Wagner, Robert G. "Backward Resonance Production in $\pi^- + p \rightarrow n\pi^+\pi^-$ at 8 GeV/c."