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ANNUAL PROGRESS REPORT

to

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ENERGY RESEARCH AND DEVELOPMENT
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Department of Physics
University of Illinois
at Urbana-Champaign
Urbana, Illinois

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I. SUMMARY OF SCOPE AND PURPOSE OF THE PROJECT

Our program in Elementary Particle Physics is carried out at the University of Illinois and at various high energy particle accelerators. During the present year, experiments included those using the neutrino beam at BNL, charged particle beams at FNAL, a neutral particle beam at FNAL, and the streamer chamber facility at ANL. In future years, our program will undoubtedly be influenced by our desire to perform measurements at increasingly higher energies. However, during the coming two years, the University of Illinois program will emphasize improved and new experiments in the areas where we have already made major contributions to the exciting developments in Elementary Particle Physics--specifically, the production of new particles at Fermilab and neutral current experiments using neutrino beams at BNL. The observation at Fermilab of narrow anti-baryon states which fit the charmed quark model has led us to make major modifications of our apparatus in order to obtain improved data. The observation of neutrino-proton elastic scattering, as well as other phenomena arising from neutral currents, has resulted in a series of new runs with the neutrino beam at BNL and the development of new detector techniques for neutrino experiments.

During FY77, major accomplishments included the following:

1. In the analysis of multi-hadron events obtained in the neutral beam experiment at Fermilab, we have observed two new narrow antibaryon states. The one at 2.26 GeV/c^2 decayed into $\bar{\Lambda}\pi^-\pi^-\pi^+$. The other state in the mass region $\sim$ 2.5 GeV/c^2 decayed with the emission of a pion into the state at 2.26 GeV/c^2. These decay modes and masses correspond to those predicted for the lowest mass states of charmed baryons.
2. The new photoproduction experiments at Fermilab are about to start running. Major modifications of the apparatus are planned which include an additional magnetic field, new multiwire proportional chambers with increased resolution and aperture, Čerenkov detectors to identify π/K/p, and larger aperture muon and electron detectors.
3. In the analysis of the data from the previous neutrino experiment at BNL, we have observed 7 dilepton events (μe) where we estimate that at most

2 events are background.

4. The new generation of neutrino experiments at BNL are scheduled to start taking data this spring. We hope to obtain improved determinations of the elastic scattering of neutrinos on protons as well as the dependence of the neutral currents on isotopic spin.
5. The muon inelastic scattering experiment at Fermilab has just completed a new series of runs. A more complete analysis of the previous runs confirmed that there is a significant deviation from simple Bjorken scaling in muon inelastic scattering by nucleons.
6. The analysis of data from the experiment studying dimuon production by high energy neutrons has been completed. The continuum of dimuon events with masses betewen the ρ and the J particles has a cross-section dependence on mass ($d\sigma/dm^2$) that has the shape that one expects for the Drell-Yan process but a magnitude that is 2 or 3 times that predicted by theories which include colored quarks.
7. The experiment at Fermilab using high energy pions to search for the production of charmed particles, to study ψ/J production, and to study multipion production is scheduled to start data taking this spring.
8. In the analysis of the data from the hybrid bubble chamber study of πp reactions at Fermilab, a positive correlation of oppositely charged particles emitted back-to-back has been observed; it is larger than expected from inclusive ρ^o and ω^o cross-sections.
9. In the analysis of the data from the streamer chamber at ANL, where we are studying the backward reaction $\pi^- p \rightarrow n + \pi\pi$, the ρ^o and f^o mesons are clearly present.

Details of the above and other parts of the program for the present year are given in part III. A. of this report.

<u>During the coming year, the major parts of our program will be:</u>

1. We should be completing the data taking phase of our new high energy photoproduction experiments in the neutral beam facility at Fermilab. The high multiplicity events will be studied for the production of both charmed baryons and charmed mesons. The two-body states in the mass region $m_{\mu\mu} \sim 4.7$ GeV/c^2 will be analyzed to see if there is a new narrow resonance. We will look at other two-body systems such as μe, $K\bar{K}$, and $p\bar{p}$.
2. We should be starting to run E-400 at Fermilab, which uses 400 GeV/c protons

and the particle detector in the neutral beam facility. One of the motivations is to study the particles that accompany the production of J/ψ by protons at the highest energies available at Fermilab.

3. We should be analyzing the neutral current neutrino data obtained in the runs at BNL. We will also be developing or constructing new equipment for an improved set of neutrino experiments.
4. We should be making improvements in the equipment involved in the study of pion production of charmed particles which uses the Chicago Cyclotron Magnet Spectrometer facility at Fermilab.
5. We should have completed the preliminary runs of pion dissociation into multipion states, and these experiments should be in the data analysis phase.
6. We should have completed the analysis of the streamer chamber data, including the study of the 4-pion states and 6-pion states.
7. We should be constructing and designing the proton recoil spectrometer and other equipment necessary to run the high energy K_L^o experiment to study how "naked quarks" get dressed.

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

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

Butler, J.
Cooper, J.
Downing, R.
Elliott, J.
Francis, W.
Messner, R.
Noggle, T.
Shupe, M.
Simaitis, J.
Wiss, J.
Wray, J.

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

Alverson, G.
Avery, P.
Barth, R.
Beece, D.
Bender, D.
Bronstein, J.
Bross, A.
Coleman, R.
Fuess, S.
Goodman, M.
Hicks, R.
Kleinfeld, D.
Lufkin, J.
MacKay, W.
Meyer, N.
Minor, E.
Nienaber, P.
Plumer, R.
Russell, J. J.
Sarracino, J.
Schreiber, B.
Smith, E.
Tortora, J.
Wagner, R.
Wroblicka, 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:

Chang, S. J.	Schult, R.
Grammer, G.	Stack, J.
Jones, L. M.	Sullivan, J.
Karliner, I.	Wright, J.
Ravenhall, D.	Wyld, H. W.

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 the Streamer Chamber at ANL

A. Technical Accomplishments During This Year

A1. Hadron Beam Development at Fermilab

(G. Ascoli, T. Kirk, with Fermilab physicists)

The equipment required to implement the plan to ramp a hadron beam to the Chicago Cyclotron Magnet (as described in last year's report) was installed in January 1977 and tested in February 1977. The performance was equal to the design expectations, giving a yield of 10^6 225 GeV $\pi^-/10^{12}$ 400 GeV protons, running parasitically to a neutrino horn run.

A2. Charm Search, ψ Production, and Pion Dissociation Using 225 GeV Pions

(G. Ascoli, J. Cooper, W. Francis, L. Holloway, T. Kirk, L. Koester, U. E. Kruse, R. Sard, M. Shupe, G. Alverson, D. Bender, D. Kleinfeld, W. MacKay, E. Smith, in collaboration with Harvard University, Oxford

University, Tufts University, and Max Planck Institute physicists)

As described in last year's report, Experiment 369 at Fermilab was approved to carry out the following goals:

a) Search for charmed particles produced in strong interactions, specifically, peripheral production of charmed particle pairs by 225 GeV π^-. Since our proposal was made, charmed mesons ($D \rightarrow K\pi$, $K\pi\pi\pi$) have been observed at SPEAR and charmed baryons have been photoproduced at Fermilab. Other experiments to detect charmed particles produced in hadronic interactions have so far been unsuccessful.

b) Study hadronic final states in which ψ/J particles are produced.

c) Explore pion dissociation at high energies.

A proton recoil spectrometer was constructed at the University of Illinois. Installation of the target and associated counters and the photon recoil arms began in December 1976. Two targets are used in series -- a one-inch beryllium block followed by a 40cm liquid hydrogen appendix. The former will contribute to the (2μ) and other triggers not involving a slow proton. Scintillation counters upstream of the beryllium, between it and the hydrogen, and downstream of the hydrogen, serve to define the beam and identify interactions in one or the other target. The proton recoil arms, east and west, cover about 20% of the azimuth. Each consists of a multiwire proportional chamber alongside the hydrogen target, two 2m x 2m spark chambers, and two rows of scintillation counters for fast time-of-flight and pulse height discrimination. The MWPC and the counters are in the trigger; the spark chambers locate the recoiling proton track in space. The dynamical range covered is $M_x^2 \lesssim 45$ GeV^2, $0.04 < |t| < 0.4$ GeV^2. Installation and testing has been completed.

A brief test run was carried out at the end of February 1977. We have verified that a 225 GeV π^- beam of sufficient intensity and small enough to fit in our LH_2 target can be delivered to the experiment. We have further verified that the trigger rates are approximately as anticipated. Tuning of the detecting equipment is continuing, and we hope to obtain some data by May of this year.

A gamma-ray detector has been added downstream of the 2-meter Cerenkov counter. The equipment, which belongs to Tufts University, consists of a pile of lead-glass bricks plus scintillator fingers, for measuring the energy and locating the line of flight of fast forward photons. This detector comes with its own PDP-11 on-line computer and tape unit, so that it functions independently of the rest of the apparatus. It should add to our present charged particle detection capability an appreciable acceptance ($\lesssim$ 70%) for π^0's.

A3. Muon Inelastic Scattering at Fermilab

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

During FY77, the CHIO Group completed the data taking of their second major muon scattering experiment, E-398, (225 GeV muons on a 1.2 meter hydrogen target). These data, when combined with the existing data at 100 and 150 GeV, will constitute the primary world data resource for deeply inelastic virtual photon interactions with nucleons. Data in press from our preceding experiment, FNAL E98, indicate significant deviations from simple Bjorken scaling in the muon inclusive scattering. Analysis of the new 225 GeV data is confirming this observation and will establish the size of the effect and its kinematical behavior with good statistical precision. A first draft of a Physical Review Letter on the new scale violation data is in preparation.

In addition to the single arm inclusive muon data, we have spent a considerable effort analyzing elastic rho meson production. This system is particularly interesting at high energy since the conditions for vector dominance are well satisfied in this kinematical regime. We have now completed analysis on a sample of 136 elastic rho events. These events show excellent agreement with the predictions of vector dominance. A Physical Review Letter is in press on this subject. We expect to double the sample size with events from the new 225 GeV data run. These data will improve the quality of our conclusions in the areas of rho polarization measurement and the form of the four-momentum transfer (t) dependence. Finally, part of the group is at work on a large paper for the Physical Review in which the several results from the combined E98 and E398 data will be collected and summarized in a single place. In this paper, we will also report extended coverage of low momentum secondaries and strange particles made possible by installation in E398 of a set of 80 cm x 80 cm multiwire proportional chambers built at the University of Illinois. This paper should appear in FY78.

A4. Proportional Hybrid Bubble Chamber Experiments

(R. D. Sard, J. W. Cooper, R. Plumer, J. Tortora, in collaboration with Proportional Hybrid Spectrometer Consortium - Brown University, Johns Hopkins University, Illinois Institute of Technology, University of Illinois, University of Indiana, Massachusetts Institute of Technology, Rutgers/Stevens, Tennessee/Oak Ridge, and Yale/Fermilab)

The purpose of the present experiment is to survey inelastic hadron interactions at 150 GeV/c. In the 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 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 Cerenkov counter in the beam line permits tagging of the beam particles as π, K, or p. The consortium has in hand 108K π^- pictures and 158K π^+/p pictures, plus a new batch of 272,650 positive beam pictures (13% K^+, 54% π^+, 27% p) obtained in November 1976. The latter sample includes data from the prototype forward gamma detector. This device, essentially an array of lead-glass blocks and scintillator fingers, will add measurement of the momenta of fast forward π^0's to the present measuring capability for charged particles.

In FY77 we have participated in the testing of the prototype forward gamma detector and in the $\pi^+/K^+/p$ run. We expect to begin DOLLY measurements on the film obtained with positive beams in the near future.

The Illinois group has analyzed two-body rapidity correlations in the π^-p interactions at 147 GeV/c, as reported in Tortora's thesis.* For each charge combination (+ -, --, ++), the dependence of the longitudinal momentum correlations on azimuthal angle difference and transverse momentum has been studied. The observed positive correlation of oppositely charged particles emitted back-to-back azimuthally is larger than that expected from inclusive ρ^0 and ω^0 cross-sections. The positive correlations of like-sign particles imply clusters that either contain three or more charged particles or are multiply charged. The study of momentum correlations among the charged secondaries is continuing, current emphasis being on the search for jet and planarity features.

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* J. O. Tortora, "Two Body Rapidity Correlations in π^-p Interactions at 147 GeV/c," Thesis, Illinois, Sept. 1976 (Technical Report COO-1195-386).

In the $\pi^- p$ data we have found evidence in six, eight, and ten prong events for diffraction dissociation of the beam π^- into $(\pi^-\pi^+\pi^-)$. The mass and momentum transfer distributions of the (3π) system show a remarkable resemblance to those for pion dissociation in the exclusive channel $\pi^- p \rightarrow \pi^-\pi^+\pi^- p$.

A5. High Energy Photon Experiments at Fermilab

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

The analysis of the last data-taking run of Fermilab Experiment E-87A (ending December, 1975) will be completed by the end of FY77. The experiment was performed in the broad band photon beam at Fermilab, using a large aperture multi-particle spectrometer consisting of 15 multiwire proportional planes and a bending magnet for charged particle momentum analysis, and a particle identification system comprised of an electron shower detector, a hadron calorimeter, and a muon identifying bank of scintillation counters behind a large thickness of steel. The initial analysis of this data focused on the simplest final state $(\mu^+ + \mu^-)$ and provided further results on $\psi(3.1)$ and $\psi'(3.7)$ photoproduction as well as evidence for anomalous production of dimuons in the 4.7 GeV mass region. The analysis performed during FY77 has been concentrating on the more complex multi-hadronic final states.

The major result of the multi-hadronic analysis was the discovery of a new anti-baryon state of mass 2.26 GeV which decays into $\bar{\Lambda}\pi^-\pi^-\pi^+$. A study of the inclusive production of $\bar{\Lambda}\pi^-\pi^-\pi^+$ systems showed a narrow (full width = 40 ± 20 MeV) peak of approximately 50 events on top of a background of about 80 events. No such corresponding peak was found in the $\bar{\Lambda}\pi^+\pi^+\pi^-$ final states. We also observed evidence of a cascade $\bar{\Lambda}\pi^-\pi^-\pi^+\pi^+$ ($\sim$ 2.5 GeV) $\rightarrow \bar{\Lambda}\pi^+\pi^+\pi^-$ (2.26 GeV) and π^+. Our results are consistent with the predictions for a charmed anti-baryon $(\bar{C}_0^+/\bar{\Lambda}_c^-)$ of lowest mass near 2.26 GeV and of the two next higher states $(\bar{C}_1^-/\bar{\Lambda}_c^-, \bar{C}_1^*, \bar{Y}_c^*)$ near 2.42 and 2.48 GeV. The data were not sufficient, however, to allow a measurement of the longitudinal polarization of the $\bar{\Lambda}$ which would have determined whether or not parity had been violated in the decay. This, of course, is of importance in establishing the link between our data and the charm hypothesis; this measurement has high priority for our FY78 running.

The remaining analysis in FY77 has been concentrated on final states containing at least 1 lepton. A search for the Bethe-Heitler pair production of proposed new heavy leptons as observed by their leptonic decays (i.e., a final state characterized by the presence of only 1 muon and 1 electron) has yielded only 1 event candidate. This preliminary result, coupled with the assumption of a 20% leptonic branching ratio, sets a limit on the existence of heavy leptons with mass $\lesssim$ 1.2 GeV. In order to be sensitive to the proposed 2 GeV heavy leptons, an increase in luminosity of about an order of magnitude is needed. Such an increase is planned for the FY78 running.

Searches have also been carried out for charmed pair production in which one particle decays semi-leptonically. No statistically significant peak has yet been seen in the $K_S^o + n\pi^{\pm}$ mass spectrum of those events containing an electron or a muon. Monte Carlo calculations are presently underway to determine the significance of this result.

A search has also been performed for events with 1 muon, 1 electron and some extra neutral energy in the observed final state. No mass peak should be expected in this data; however, a demonstration of the existence of genuine μe events from a non-trivial source would necessitate further study to try to determine the exact nature of such events. Preliminary analysis shows a total of 12 event candidates with 4 expected to be due to background sources. A further exposition of the nature of these events, should they be real, will probably have to await the higher luminosity running expected in FY78.

A6. <u>Neutron and Proton Experiments Using the Neutral Beam Facility at Fermilab</u>

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

The high energy neutron experiments at Fermilab - E-358 - were completed. They used the same basic detecting apparatus and the same beam line as the photon experiments but without the deuterium attenuator. In the detecting apparatus a large hadron attenuator was used upstream in order to observe only muons. Most of the results were reported in last year's Progress Report, and three articles have subsequently been published on this work. One concerns dimuon production as a function of the nuclear target. Another concerns the $p_\perp$ and $p_\parallel$ dependence of J production and of conventional mesons. The third result was a limit on the production of charmed particles in association with the J. For the continuum dimuons with effective masses between that of the ρ and J masses, we find the dependence of the production cross-section per nucleus to be of the form $A^{0.85\pm0.05}$. This is to be compared with our results for the ρ region which was $A^{0.63\pm0.03}$ and for the J, $A^{0.93\pm0.04}$. The A dependence of the dileptons in the ρ mass region seems to be a function of the $p_\perp$ of the pair. Specifically, for $p_\perp$'s greater than 1 GeV/c, the A dependence is rising and gets closer to unity. The shape of $d\sigma/dm^2$ per nucleon for the continuum region very much resembles the shape that one expects from a Drell-Yan type calculation. Depending on the model used, our experimental results seemed to lie a factor of 2 to 3 above the theoretically calculated values with color included.

As reported last year, we can set a limit on the production of charmed particles associated with J production by looking for an additional muon in coincidence with the J. We saw no muons above the level expected from π and K decays, and we set a limit of less than 6 events with an additional muon in three thousand J events.

Theoretical speculations concerned with J production in nucleon-nucleon collisions had led to the expectation that there would be charmed particles produced with the J particle. At the present time, there is no knowledge of what particles are produced accompanying the production of a J particle. A proposal was submitted and approved (E-400) to study the particles accompanying J production by protons using the equipment in the neutral beam facility but bringing a proton beam into the detecting area. This will allow us to study hadron production of J at the highest possible energy (the primary energy of the accelerator).

A7. A Study of Neutrino Induced Neutral Currents

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

The primary goal of the first phase of this experiment was the study of neutrino induced neutral currents in the elastic and single pion channels. The experiment was performed in a fast extracted, horn focused, wide-band neutrino beam at the Brookhaven National Laboratory alternating gradient synchrotron (AGS). The detector consisted of 21 modules of 6-ft x 6-ft narrow gap aluminum spark chambers interspersed with scintillation counters and five 8-ft x 8-ft range chambers. The spark chambers record all interactions during the 2.4-μsec spill, while the counters record the pulse height and time-of-flight of every hit during that period. The major effort for this fiscal year was the conclusion of the scanning and measuring effort and the reporting of our results. In addition, we have redesigned the apparatus and are currently beginning the second phase of the experiment.

While neutral currents have been known to exist for approximately four years, very little is known about their properties. The study of the simplest of the exclusive channels, i.e., elastic scattering and single pion production, will provide useful information on the space-time and isotopic spin composition of the neutral current interactions. During FY77 we have published the following results:

a) Observation of the Reaction $\nu_\mu + p \rightarrow \nu_\mu + p$

This is the simplest of the hadronic neutral current interactions. After imposing time-of-flight and pulse height cuts, 38 elastic candidates remain. Nineteen of these events are estimated to be background, leaving a signal of 19 events. Using our measurement of quasi-elastic events, we measure

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

The prediction of the Weinberg-Salam model is $R_{el} = 0.07$ for $\sin^2\theta\omega = 0.4$ and cuts similar to those imposed on our data. We have observed the reaction $\nu_\mu + p \rightarrow \nu_\mu + p$, but our measurement is not sufficiently accurate to test the model. In the experiment we are now constructing, we propose to reduce the error by a factor of three.

The limited anti-neutrino running and the "sky shine" background of our Phase I detector precluded any significant measurement of anti-neutrino elastic scattering during our previous run. With the improved shielding of Phase II, it is anticipated that we will measure this reaction in our future runs.

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

We have also studied the reactions

$\nu n \rightarrow \nu n \pi^o$	$\bar{\nu} n \rightarrow \bar{\nu} n \pi^o$
$\nu p \rightarrow \nu p \pi^o$	$\bar{\nu} p \rightarrow \bar{\nu} p \pi^o$
$\nu n \rightarrow \mu^- p \pi^o$	$\bar{\nu} p \rightarrow \mu^+ n \pi^o$

We can again express our results in terms of a ratio compared to the charged current interaction

$$R_o' = \frac{\sigma(\nu N \rightarrow \nu N'\pi^o)}{2\sigma(\nu N \rightarrow \mu^- N''\pi^o} = 0.17 \pm 0.04$$

$$\bar{R}_o' = \frac{\sigma(\bar{\nu}N \rightarrow \bar{\nu}N'\pi^o)}{2\sigma(\bar{\nu}N \rightarrow \mu^+ N''\pi^o)} = 0.39 \pm 0.18$$

Because the target is not composed of free nucleons, the theoretical calculations of these must be corrected for charge exchange effects. These effects have been calculated by Adler, Nussenov and Paschos. In the Weinberg-Salam model with $\sin^2\theta\omega = 0.35$, they predict that $R_o' = 0.20$ and $\bar{R}_o' = 0.25$, which is consistent with the observed ratios.

The $\pi^o p$ invariant mass, which is sensitive to the isospin $I = 3/2$ and $I = 1/2$ amplitudes in the final state can also be measured for these events. While there is a suggestion that the neutral current states may have a different isotopic spin composition compared to the charged current states, more data are needed before we can draw a firm conclusion.

We have also observed dilepton events in our detector. We define a dilepton event to be a neutrino interaction where one track has a path length greater than 2.7 collision lengths, accompanied by an electron shower with an energy greater than 1.5 GeV. We observe 7 events. At the 99% confidence level we estimate that, at most, 2 events are background. We can then state that

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

It must be noted that this has been measured in a wide band neutrino beam peaking at 1.8 GeV and has not been corrected for any detector efficiency or the cutoffs imposed to define the event. Further study of dilepton events in wide-band beams is anticipated at BNL.

With the conclusion of Phase I of the neutral current events, we have begun construction of Phase II and anticipate our first run this fiscal year. Substantial modifications have been made to the detector and the experimental area.

We are also planning to measure all of the film automatically at the University of Illinois with the digitized events being analyzed at Columbia University and the University of Illinois. Every effort is being made to reduce the two years it took us to analyze $\sim 10^6$ neutrino and anti-neutrino pictures.

Our former detector was housed in an air tent. Brookhaven National Laboratory has now constructed a concrete block house which will surround the detector. We made preliminary measurements of the background during the neutrino run last fall, and we find it is substantially reduced. We have also installed a magnet with a 6-ft x 6-ft aperture which will allow us to make crude measurements of the sign and momentum of the charged particles. This will enable us to measure the charged pion ratio in addition to the neutral pion ratios we have already measured. The detectors have also been surrounded by an array of counters which will detect wide angle muons not observed in the spark chambers. This will reduce the corrections to the $\pi^o p$ invariant mass distributions and allow us to have a statistically significant measurement of this mass distribution.

In order to pursue our examination of the dilepton events, six of the blocks of the 2000 ton magnet used for the Cosmotron were modified for use as toroid magnets. In our final configuration, we will have 100 tons interspersed with modified 8-ft chambers. We will then be capable of operating in either wide-band or narrow band running and will be able to measure dilepton production as a function of energy. Indeed we will be able to go above and below the charm production threshold which in many models is the source of these dilepton events.

We have also begun to test a charge-coupled photo-device, an array of photodiodes, to be used for spark chamber data capture instead of film. If the tests prove successful, we anticipate reducing our film demands and greatly increasing our data reduction capabilities.

A8. A Study of Reactions Producing a Fast Forward Neutron in $\pi^- p \rightarrow nX^o$ at 8 GeV/c

(B. Eisenstein, J. Elliott, W. Mollet, R. Wagner, W. Wroblicka, in collaboration with J. Watson, Argonne National Laboratory and N. Gelfand, G. R. Morris, University of Chicago)

We are continuing 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 isolates u-channel baryon exchange processes by triggering on a fast forward neutron. The neutrons interact in thick-plate optical spark chambers located 11m downstream of the streamer chamber and the secondaries from these interactions are detected by scintillation counters. Time-of-flight is used to discriminate against slow neutrons. A lead/scintillator array upstream of the neutron chambers removes most of the γ-rays which would also trigger the system. On the other hand, K^o mesons are indistinguishable from neutrons at the level of the trigger.

The channels $X^o \rightarrow \pi^+\pi^-$, $\pi^+\pi^+\pi^-\pi^-$, etc., represent even G-parity mesons, while in a pX^- experiment, $X^- \rightarrow$ (all charged) are mesons with odd G-parity. Thus the nX^o experiment is complementary to our earlier fast proton experiment. Since a forward neutron can result from nucleon exchange, the suppression of Δ exchange seen in that earlier experiment is irrelevant. However, some N^* production can occur which complicates acceptance corrections.

During the current year we will complete the analysis of events from the full $\sim$ 400,000 picture exposures made in 1974 and 1975, with emphasis on events with two and four charged particles in the final state. The "data reduction" (i.e., scanning, measuring, reconstruction, and fitting) is complete except for a sample of events with four charged particles which are currently being remeasured and which will shortly be added to the data. We are now engaged in an effort to improve our knowledge of the efficiency of the neutron detector so that we can determine the overall cross-sections and understand better the geometric acceptances of both the streamer chamber and the neutron detector. The latter is required to correct for geometric losses both in total cross-sections and in differential cross-sections and is expected to be essentially complete in the spring of 1977.

a) <u>Backward Meson Production in the Reaction $\pi^-p \rightarrow n\pi^+\pi^-$</u>

The reaction $\pi^-p \rightarrow n\pi^+\pi^-$ is dominated by 3 quasi-2-body channels $\Delta^-\pi^+$, $n\rho^o$, and nf^o. In each case the baryon is produced near 180^o in the center-of-mass. The f^o, being as isoscalar, can be produced only via I = 1/2 exchange in the u-channel, for example a nucleon. Indeed, $d\sigma/du$ for this channel appears to have a dip similar to that seen in the backward elastic reaction $\pi^-p \rightarrow p\pi^-$, where the dip is usually attributed to the vanishing of the nucleon Regge trajectory at a "wrong signature nonsense zero." The f^o decay angular distribution is consistent with the exchange of a J = 1/2 particle, further supporting the hypothesis of nucleon exchange.

The ρ^o channel shows signs of interference from the production of another particle as well, and we are now studying the possibility that it is caused by either ε^o or ω^o production.

b) Study of the Reaction $\pi^- p \rightarrow n + 4\pi$, 6π

The reaction $\pi^- p \rightarrow n\pi^+\pi^+\pi^-\pi^-$ contains many reaction channels. There is clear evidence for ρ^o, f^o, and Δ^- production, but not of Δ^+ production. Two quasi-2-body channels have been tentatively identified: $\pi^- p \rightarrow N^{*o}(1670) + (\rho^o/f^o)$, where the N^{*o} decays to $\Delta^-\pi^+$. The absence of observed $\Delta^+\pi^-$ decays indicates that the N^* should be identified with the $5/2^-$ resonance at 1670 MeV rather than the $5/2^+$ N^* (1688). Further analysis of these channels continues.

Final states with six charged particles, $\pi^- p \rightarrow n\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-$, are beginning to be studied. The problem of large backgrounds in the fitted data and combinatorial effects in exclusive channels is severe, but there is preliminary evidence of Δ^- and ρ^o production.

We expect that the current fiscal year (FY77) will see the completion of the analysis of the reaction $\pi^- p \rightarrow n\pi^+\pi^-$, and much progress on the analysis of $\pi^- p \rightarrow n\pi^+\pi^+\pi^-\pi^-$, in particular in the study of events which do not belong to the $N^*\rho^o$ or N^*f^o channels.

B. Experiments Planned for the Coming Year

B1. Charm Search, ψ Production

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

Assuming our first data runs of Experiment 369 to have been carried out successfully in the spring of 1977, we expect to carry out the analysis of the data and to plan further runs using improvements of a technical nature and refinements of the trigger suggested by the first run. Specifically, new proportional chambers will be constructed in order to improve the acceptance and the stereo view for multi-track reconstruction. These should improve our ability to detect secondary tracks, particularly of low energy. We are considering replacing spark chambers with drift chambers to allow a higher rate of data taking. There are many problems in using a combination of spark chambers and multi-wire proportional chambers, and changing to drift chambers would, for example, eliminate such problems as the spark noise pick-up on the multi-wire proportional chamber electronics. Other improvements may include a Cerenkov detector which distinguishes $\pi/K/p$ at higher momenta.

B2. <u>π-dissociation Experiment</u>

(G. Ascoli, L. Holloway, R. Klanner, L. Koester, U. E. Kruse, R. Sard, J. Cooper, M. Shupe, G. Alverson, D. Bender, W. MacKay, E. Smith)

As part of E369, we expect to obtain a limited amount of data on π-dissociation ($\pi^- p \to 3\pi + p$, $5\pi + p$, ...). We probably will want to make a more careful study of these phenomena, using both π^- and π^+ at more than one energy. We expect to submit a proposal (in effect, reactivating Fermilab P-318). The 3π data obtained at lower energies at Serpukov raised questions that made some theorists unhappy. Data obtained at Fermilab would be of appreciably higher energy and would also extend the mass range.

B3. <u>Proportional Hybrid Bubble Chamber Experiments</u>

(R. D. Sard, J. W. Cooper, R. Plumer, in collaboration with Proportional Hybrid Spectrometer Consortium - Brown University, Johns Hopkins University, Illinois Institute of Technology, University of Illinois, University of Indiana, Massachusetts Institute of Technology, Rutgers/Stevens, Tennessee/Oak Ridge, and Yale/Fermilab)

We expect to complete our share of the film measuring of Fermilab Experiment 299 early in FY78. Future participation in this experiment will be limited to data analysis, with concentration on correlations and clustering, and beam diffraction. The new data on $\pi^+ p$ and pp at the same energy as $\pi^- p$ will aid us in sorting out beam-dependent effects.

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

B4. <u>Experiments with Polarized Beams and Targets</u>

(L. Koester and others, in collaboration with a group from Rice University)

Experiments with the polarized proton beams and the polarized proton targets at the Argonne ZGS have been very fruitful. Recent measurements show exciting things happening in the polarized neutron-proton scattering. These measurements will be extended at Argonne, using a polarized deuteron beam which is under development, and an existing polarized proton target. We would participate in all phases of the experiment and make some rather modest contributions to the apparatus, most of which already exists at Argonne.

B5. High Energy Photon Experiments at Fermilab

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

In FY78 we are scheduled to take data on two Fermilab experiments, E-401 and E-458. E-401 is a study of photoproduced massive two-body final states. Careful measurements of $\psi(3.1)$ and $\psi'(3.7)$ photoproduction will be done with a liquid hydrogen target. In addition, a high-intensity run will be made in which the mass spectrum of $K\bar{K}$, $\bar{p}p$, $K\pi$, μe, $\mu\mu$ and ee pairs will be studied. E-458 is a study of photoproduced massive multi-hadronic final states. The primary purpose of this experiment is to further elucidate the characteristics of charmed baryon production and to search for evidence of the proposed charmed strange meson $F^{\pm}$, as indicated in decays involving two K mesons.

Many improvements are now being made to the E-87A detector which will benefit both E-401 and E-458. An additional set of coils has been added to our initial analyzing magnet. This increases the magnetic field which improves the mass resolution -- specifically, the resolution for massive dimuon states (3.7 and 4.7 GeV/c^2) will be improved by about a factor of 1.6 from this effect alone.

An additional vertical bending magnet is being installed immediately downstream from the target. This magnet will sweep out low energy e^+e^- pairs produced in the target to allow for the high intensity running needed for E-401. Furthermore, the acceptance of massive pairs produced by the more copious lower energy photons should be increased by this additional magnet. E-458 will benefit from the possible momentum measurement of large angle tracks which would have previously been lost.

Two large-area Cerenkov counters are presently being constructed for use in E-401 and E-458. Both experiments will benefit from the π/K/p identification afforded by these counters. Positive K and p identification will allow a much more sensitive charmed particle search.

Charged particles produced at 35-100 mrad from the beam which would have eluded the E-87A apparatus will be accepted by a new outer detector of E-401 and E-458. The trajectories will be measured with the use of enlarged multi-wire proportional chambers upstream of the main analyzing magnet. Partial particle identification will be provided by an electron shower counter hodoscope located upstream of the main analyzing magnet and a set of scintillation counters to detect the muons which penetrate the steel of that magnet. This additional acceptance will be most effective for the μe phase of E-401.

Some E-458 running will be done with a target consisting of 20 1/16" scintillation counters. It is hoped that a peak in the mass spectrum of certain multi-hadronic states will be accompanied by an indication in this target counter of the production of a state with an observable lifetime.

Additional electronics will improve the resolution and triggering efficiency of the detector. In particular, a measurement of the drift time for every 8 wires should improve the spatial resolution by a factor of 2-3 for most events. Further refinements in wire chamber multiplicity and energy deposition measurements should provide a more efficient and bias-free triggering system for events of interest in E-458.

B6. Proton Experiments Using the Neutral Beam Facility at Fermilab

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

The broad band neutral beam will be modified to transmit 400 GeV protons to a target in our detector pit at an intensity of 10^6 to 10^8 protons per pulse (it will be possible to restore the broad band photon beam for additional photoproduction experiments). A small spot proton beam will impinge on an H_2 target which can also be filled with D_2. The detecting apparatus will be the same as that described above which is being used in experiments E-401 and E-458. Depending on when the run is scheduled, we may add a proton recoil spectrometer which would be most useful with the mono-energetic charged particle beam.

The basic motivation for this experiment is to try to obtain some understanding of the hadronic production of J particles using the most energetic beam available at Fermilab. With the aid of the existing particle identification detectors and the Cerenkov detectors now being added, we should be able to study whatever states are produced at the same time that the J particle is being produced. We will study the multi-particle final states produced in coincidence with dileptons. We will also measure the yield and production dynamics of the $\rho^o(770)$, $\phi^o(1020)$, and the continuum of dimuon masses between 0.5 and 6.0 GeV/c^2. With the Cerenkov detector, we can look for an increase of K production when the mass of the dilepton pairs is close to that of the ϕ^o. In the course of performing the photoproduction experiments, we hope to study the feasibility of using the

Cerenkov detector to selectively trigger on a pair of either baryons or kaons. If this trigger results in a sufficient reduction (10^{-2}) in the number of normal multipion triggers, we would have the sensitivity to look for charm production at a level of [σ x branching ratio] $\gtrsim$ 1 nanobarn. New developments may occur before this run starts which will affect the goals for this experiment.

B7. A Study of Neutrino Induced Neutral Currents

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

We will be continuing the neutral current experiments in order to obtain improved data and to study additional channels. At the present time we can anticipate one more rearrangement of the apparatus. A second magnet will be added to the vertex detector and four drift chambers will be installed in order to increase the resolution of the momentum measurements of the charged tracks.

If enough neutrino pulses are received in FY77 (10^{6}), we will turn our attention to the study of anti-neutrino interactions and dilepton production.

Anti-neutrino interactions have lower incident flux and a lower cross-section. It is imperative, therefore, that we have a substantial neutrino run in order to understand the background problems and the detector efficiencies before beginning. We anticipate a request for 2 x 10^{6} pulses of anti-neutrino running. We will then measure the exclusive channels previously measured for the neutrino run. This will give us a complete set of the simplest hadronic channels and allow us to make stringent tests of the various models for the neutral current interactions.

We would also anticipate that the toroidal detector for the neutrino-induced dilepton events will have evolved to its final configuration. We would then anticipate a request for 2 x 10^{6} pulses in a narrow band beam which will allow us to study this interesting final state as a function of neutrino energy. The relative priority between the anti-neutrino running and the study of dilepton production will depend on the physics we observe in our present run and the accelerator schedule.

In order to handle the data generated in this series of runs, it is obvious that we cannot continue to scan and measure as we have done to date. We are attacking this problem in two ways:

a) In FY76 we developed the use of DOLLY, our automatic measuring machine, to scan and digitize the film automatically. At the present time, we anticipate an event rate of $\sim$ 500 frames/hour or $\sim 5 \times 10^4$ frames/week. This will clearly be sufficient for FY77. The item that now becomes dominant, however, is film cost.

b) In order to increase our output at a reduced cost, we have begun to study the use of charge-coupled devices. A charge-coupled device is an array of photo-diodes. The array we are planning to use is 512 x 310. At the present time, we are using a very simple array to study cosmic rays in a small spark chamber. In late FY77 or early FY78 we will install an array in parallel with the film and make a systematic study of its properties in an actual experimental exposure. If it proves successful, we would expect it to become the dominant mode of data collection.

B8. 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, but to date little is known about their properties other than that they occur $\sim$ 20% of the time in neutrino interactions at low energies. 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 measure $d^2\sigma/dxdy$ or $d^2\sigma/Q^2d\nu$ over a reasonable range of these variables.

According to the design, the N-30 beam is double-peaked in E_ν with the higher energy peak centered at $\sim$ 250 GeV with $\sigma \sim$ 10% for 500 GeV incident protons. This represents a good measurement of the energy of the incident neutrino, whose direction is already well known. To study the reaction $\nu + p \rightarrow \nu' + x$ then requires a determination of the energy and direction of x, the recoiling hadronic system.

We are proposing to build an instrumented calorimeter to

1) serve as the target,
2) measure E_x with high precision, and
3) measure θ_x with sufficient precision to calculate (Q^2, ν) or (x,y) for each event.

In a preliminary design, the calorimeter will be made of thin plates of depleted uranium in a bath of liquid argon. Work by Willis and co-workers at CERN on U/A calorimeters shows that we may expect a resolution in the energy of x of $\delta E_x/E_x \sim .25/\sqrt{E_x(\text{GeV})}$, which is at least three times smaller than has been achieved with Fe-plate devices. The calorimeter is sufficiently large ($2\text{m}^2 \times 5000\ \text{gm/cm}^2$) that the hadron shower is effectively contained, even at high E_x.

Periodically along the length of the device ($\sim$ every 35 gm/cm^2 in the current design), three plates will be made of thin strips which will provide a position sampling of the energy deposition of the cascade in the liquid argon. By measuring the centroid of the shower at various depths, we expect to find θ_x to a precision of better than 13 mrad for $E_x > 150$ GeV.

The major restriction on the acceptance of the experiment will be the requirement that $E_x > 150$ GeV, which is imposed in the analysis. This is necessary to ensure that the initiating neutrino indeed came from the upper peak of the two-humped spectrum. Thus $y \approx E_x/E_\nu \gtrsim 0.6$, and the analyzable events will have

$$0 \lesssim x \lesssim 1 \quad , \quad 0.6 \lesssim y \lesssim 1$$

or

$$\nu \gtrsim 150\ \text{GeV} \quad , \quad 0 \lesssim Q^2 \lesssim 2m_p\nu .$$

The estimated event rate, with $E_x > 150$ GeV, with 10^{13} protons/pulse at 500 GeV, is $\sim$ 30 per day for incident neutrinos. In order to distinguish between charged and neutral current events, a downstream muon spectrometer is required. We hope to use one of the existing facilities at Fermilab for this purpose, making any modifications necessary to insure compatibility with the calorimeter. Discussions to this end will be initiated with members of the staff at Fermilab and the several users groups concerned.

b) Charged Currents

Since neutral current events will represent only $\sim$ 20% of the total neutrino cross-section, we expect the data to contain $\sim$ 700/day charged current interactions.

Since we will measure the angle and energy of the hadron system, as well as the momentum and direction of the muon, we will be able to utilize the entire neutrino energy spectrum and calculate E_ν in each event. For the high energy events, where E must be in the upper peak of the spectrum, we will actually be overconstrained and can do a 1-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 the 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.

B9. Uranium/Liquid Argon Calorimeter Development

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

We propose to build and test a small prototype of the calorimeter described in Section B8 to study, in particular, the angular resolution. The device should be tested in a high energy (> 50 GeV) charged beam at Fermilab. The project includes design and construction of the low-noise amplifiers for the U-238 plates and thin strips, as well as the plate construction and cyrogenics. It is anticipated that, in FY78, this effort can be completed, the design of the actual calorimeter finalized, and construction begun.

B10. A Study of Reactions Producing a Fast Forward Neutron in $\pi^- p \rightarrow nX^o$ at 8 GeV/c

(B. Eisenstein, J. Elliott, R. Wagner, W. Wroblicka, in collaboration with J. Watson, Argonne National Laboratory, and N. Gelfand, University of Chicago)

The final phase of the streamer chamber program of surveying baryon exchange processes should occur in FY78. We will complete the analysis of reactions involving four and six charged particles in the final state. All of the effort can go into "physics," since the problems of determining neutron chamber and streamer chamber efficiencies (i.e., the "acceptance") will have been solved for the analysis of the two charged particle final state. In addition to the understanding of the data seen in this experiment, we will attempt to integrate the new results with our data from the previous baryon exchange experiment where the trigger was a fast proton, and we studied, in particular, the final state $\pi^- p \rightarrow p\pi^+\pi^-\pi^-$ at 8 GeV/c. Our ultimate goal is a consistent picture of the phenomenology of inelastic baryon exchange.

reactions at 8 GeV/c π^- beam momentum which, together with forthcoming results at other energies from other laboratories, can lead to an understanding of baryon exchange reactions in general.

C. Experiments that are Planned for Future Years

C1. Searches for Charm, Beauty, and Truth

(G. Ascoli, L. Holloway, L. J. Koester, U. E. Kruse, R. D. Sard, and others)

If our efforts to find Charm using the multi-particle spectrometer (CCM) at Fermilab prove successful, it seems reasonable to expect to plan further experiments to study additional physics aspects of charmed particles and perhaps of other new particles. It is premature to try to spell out these experiments in detail until results from the current experiment have been obtained. It seems clear in any case that an effort to upgrade the existing spectrometer, already unique at Fermilab as far as acceptance is concerned, should be continued in collaboration with Fermilab and other universities.

C2. High Energy Photon Experiments at Fermilab

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

Much of FY79 will probably be spent analyzing the data from E-401 and E-458 and preparing new equipment for further extensions of these two experiments. The determination of the exact nature of these extensions must await the initial analysis of the data which should be forthcoming in FY78. We can, however, make educated guesses concerning these extensions and indicate the attendant requirements for further detectors.

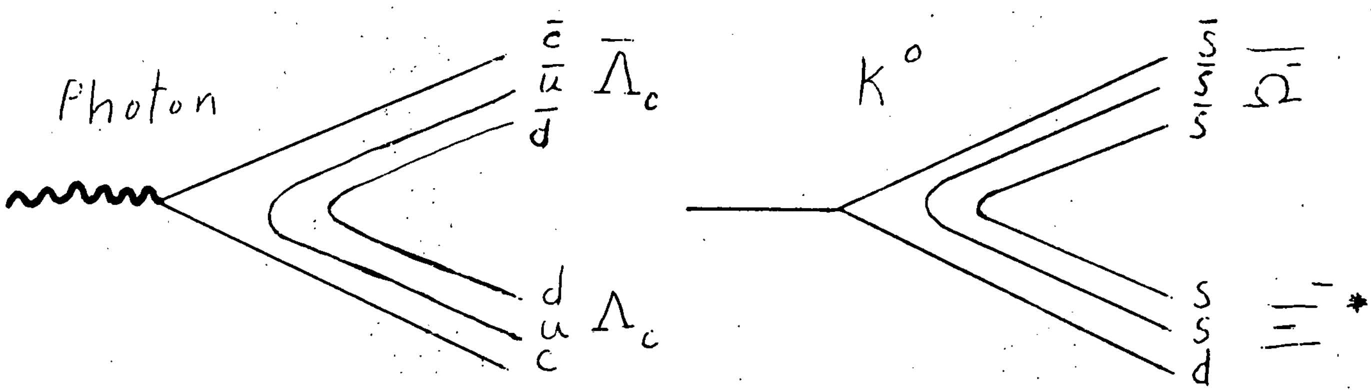
One possible extension would be the study of the copious ψ photoproduction at large t. This program would require a recoil detector carefully integrated with the liquid hydrogen target.

Other extensions we anticipate now all involve the construction of an elaborate large area photon position and energy detector. Such a detector would allow reconstruction of produced resonances (charmed and otherwise) which involve π^0's, and γ's in their decays. In particular, production of even spin objects via the Primakoff effect and observation of their subsequent decay into 2 photons would be a prime prospect for such analysis. Further, the improved e/π rejection afforded by such a detector should allow a single lepton trigger to be used to study charm spectroscopy.

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

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

The interpretation of the new narrow meson resonances observed at SPEAR and the narrow anti-baryon resonance observed at Fermilab as charmed particle states implies that there should be additional states, specifically, states which are both charmed and strange and states 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 be observed within the next year. The question then arises as to whether one can get insight into what one should expect for production cross-sections of charmed strange particles and what is the best possibility of successfully searching for them. A simplistic production model visualizes 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 or charmed quarks rather than up and down quarks?" Specifically, in this model, for a photoproduction experiment, the photon couples to a charmed and anti-charmed quark pair as shown in the figure below and additional quark-anti-quark pairs are added to form baryons and anti-baryons.



In models where the additional quark pairs are added via a massless vector meson coupling (e.g., gluons) or in bag models (e.g., four-dimensional square wells), one would expect that the production of strange relative to non-strange charmed baryons might vary as a power law with the mass of the quarks, i.e., M^{-4}. In statistical models, and more complex production reactions, one might expect an exponential dependence on the mass of quarks. It may be that in simple diffractive dissociation production, a power law is a good parametrization, whereas in inelastic production processes, one will get an exponential law.

We are preparing a proposal to study these questions using a K_L^o beam with the ultimate goal of observing the production of strange charmed baryon/anti-baryon pairs. A K_L^o meson consists of a strange and down quark-anti-quark pair. In a diffractive dissociation process, one can visualize these as getting dressed with additional strange-anti-strange quarks or up and down quarks or charmed quarks. The exploratory experiment consists of looking at the ratio of singly strange, to doubly strange, to triply strange baryon-anti-baryon states produced in a K_L^o beam. It would be desirable to know whether it was diffractive production or multi-particle production as the mechanisms may be different; a proton recoil spectrometer could help in distinguishing between the two processes. Such a detector will be added to the existing detecting apparatus that is in the neutral beam facility at Fermilab. The Cerenkov detectors permit the identification of particles with baryonic masses. An improved photon detector would allow us to determine the energy of π^o mesons.

The K_L^o intensity in the present beam is the order of 1% of the number of photons, namely about 10^3 K_L^o mesons per 10^{12} protons on target. The Princeton-Chicago group has run with the same beam at a level of about 10^{13} protons per pulse. We could gain another factor of 10 by using only half the deuterium attenuator; the photons will be removed by six radiation lengths of lead upstream in the beam line. The major problem is not the intensity, but that the interaction cross-sections for K mesons is about 200 times that for photons. One therefore needs to study how to enhance the triggers of the particles of interest by a factor of the order of 10^2, in order to make it feasible to observe the production of particles which may have a cross-section times branching ratio at the level of 1 to 10 nanobarns. During the background runs in the forthcoming photon experiments, the feasibility of such a trigger will be investigated. The choice of studying anti-baryons instead of mesons is that baryons are more easily identified and probably have fewer decay channels. Therefore the branching ratios will be higher than for mesonic states. Independent of any models for production processes, it will be of value to compare the ratio of the production of esoteric particles by both photons and K_L^o mesons.

C4. <u>A Study of Neutrino Induced Neutral Currents</u>

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

The neutrino program at BNL in FY79 will depend on the physics we have studied during the previous two years and the detector and analysis development that occurs during this time. In all probability we will not have completed the program outlined in FY77 and FY78 unless there is an increased amount of time available for neutrino running. It seems clear that we will have constructed a powerful detector and by FY79 we will understand its systematic biases very well. If our development of the charge - coupled device is successful, perhaps at last we can begin to study the most fundamental of neutrino interactions

$$\nu_\mu + e \rightarrow \nu_\mu + e$$

C5. <u>Inclusive Hadron Production by Neutrinos at Fermilab</u>

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

Fiscal Year FY79 should be one primarily of construction of the calorimeter and its electronics, and, by late FY79, the installation of the apparatus. We hope to be able to accept beam by the beginning of fiscal year FY80, and have preliminary physics results before the end of that year. It is anticipated that subsequent runnings and data analysis will extend through fiscal year FY81.

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 heavy use during this period on film derived from spark chambers, bubble chambers, and streamer chambers. The system is scheduled for 137 hours of operation per week, with the remaining 31 hours required for equipment maintenance and calibration as well as program development.

Work has continued on improving the stability of the DOLLY detection system. The photomultiplier high voltage distribution was reworked and a calibration technique using LED's was developed. This work has been done to allow the addition of automatic monitoring and control hardware via the Illinois modular electronics system.

Completion of film measurement from streamer chamber film is planned by the end of FY77. A total of 50,000 events are scheduled to be measured or remeasured during FY77. Rates of up to 70 events per hour have been achieved.

Bubble chamber film from FNAL E-154 ($\pi^{\pm}p$, pp) and successor experiments has also been measured; completion of measurements of this film is planned by the end of FY78.

Measurement of spark chamber film from the neutrino experiment work at BNL 605/652 has been completed. This film was measured in a semi-automatic mode where the operator manually designated points in the film corresponding to the event characteristics - e.g., vertices, end points, etc. A total of 1500 frames were measured in FY77.

Measurement of similar spark chamber film from the follow-on neutrino experiment BNL 693 is scheduled using quite different measuring and pattern recognition strategies. Because $\sim 10^6$ frames of film are expected by the end of FY77, the manual methods of scanning and measuring previously used will be inadequate. A new DOLLY control program has been written which automatically advances film, measures frame marks and fiducials, and then predicts the location of the spark chamber gaps. The gaps are then automatically scanned and all sparks therein digitized and written out through disk files on the attached PDP-10. No pattern recognition processing will be attempted on the spark data within the CSX-1; it will be left for subsequent off-line processing on the PDP-10 system. Operator intervention is expected to be minimal, providing that the quality of film, fiducials, etc., is maintained. Consequently, it is expected that measuring rates up to 500-700 frames per hour can be achieved, using multi-bay operation on the DOLLY system. Initial single bay measuring rates of 350 frames per hour have been obtained. Most of the 10^6 frames are scheduled for DOLLY measurement by the end of FY77.

Spark chamber data reduction and analysis programs in the PDP-10 will initially focus on simple filtering techniques to achieve a 10^{-2}-10^{-3} reduction in event candidates followed by computer-aided manual scanning for the final pattern recognition process. As understanding of the difficult process of pattern recognition of the spark chamber data develops, further automatic procedures will be incorproated in the program. Initial studies in "cluster-filtering" indicate that a simple test for spark continuities can generate a raw data reduction up to 10^{-2}.

This pattern recognition work is also strongly coupled to the developmental program for a charged coupled device optical input system (CCD), which is planned to replace the film data acquisition techniques. Common data formats and information content are planned in both systems so as to simplify the changeover as the new CCD system evolves.

A2. <u>Computer Operations</u>

(R. Brown, J. Wray, R. Barth, J. Lufkin, N. Meyer, E. Minor, B. Schreiber)

In FY77, the PDP-10 computing system was operational and available for time sharing and batch use approximately 8000 hours. For most of this time, the system was connected to the CSX-1 computer for on-line processing of DOLLY measured events and CSX-1 program development. In addition, up to 24 time-sharing terminals (Teletypes and CRT terminals) were connected to the system with a projected average total connect time of 2700 hours per terminal. Total CPU time is projected to exceed 4000 hours. A number of additions and improvements were made to the system:

- Eight additional time-sharing terminals were added to the system using the University of Illinois-developed modular electronic system (BBX). Time-sharing terminals are now available in some of the offices as well as in equipment assembly areas in the Physics Building.

- Additional modular electronic systems (BBX) have been added to the system so that a total of five exist to couple various experimental systems into the DEC-10 computer. Included in such systems are a module check-out stand to provide quick and facile check-out capabilities on BBX modules, multi-wire chamber read-out connection for checking equipment for FNAL experiment 369, and connection for the experiment BNL 693 charge-coupled camera system.

- Additional MOS memory is scheduled to be added to the system to increase the total to 192K words. This should significantly reduce interference between large programs in the time-sharing mode.

- A second pair of 9-track 800/1600 BPI tape units has been installed, permitting removal of the original IBM 7-track units from service after systematic conversion of all current data tapes to the new format. Communication with the group's data acquisition systems at experimental sites has been thereby improved significantly.

- The addition of two disk drives dedicated to experiments BNL 693 and FNAL 401, 458 is projected for the latter part of FY77. This will significantly help with data base management for the large experimental data reductions.

A3. <u>Engineering Systems</u>

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

Development work on an inexpensive trigger circuit for PMX's has been completed. These circuits have temperature stability, slew, etc., parameters that are as good as or better than the best ones commercially available. Approximately 100 channels have been implemented at a cost of $75 per channel. New sub-nanosecond ECL I.C.'s are being designed into high-speed logic modules for use with a next generation modular electronic system.

A 65K word MOS buffer memory was built for experiment FNAL 87A and was test run for three months as an extra system memory on the PDP-10. The installation has proved very reliable and led to the possibility of adding this type of memory to the PDP-10 permanently.

A prototype time-digitizer for drift chambers has been tested, and a 200 wire system is under construction. A 384 ns time period is recorded with a resolution of 2 ns per wire. Multiple hits within a group of 20 wires can be resolved down to 2 ns.

Work has begun on a 320 x 512 CCD "camera" for on-line data acquisition of optical spark chambers for BNL 693. A prototype will be tested at BNL within the near future.

The engineering group has had a considerable amount of interaction with other University of Illinois research groups - e.g., the Linear Accelerator, Materials Research Laboratory, and the Physics Department. The modular electronics developed by High Energy has been adopted by these groups as a standard set of data collection hardware, and the cost of development for many modules has been shared with them.

B. Plans for Facilities for the Next Two Years

B1. Data Acquisition Systems

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

Subsequent to FY77, the continued use of the DOLLY/CSX-1 system is projected for the continued automatic measuring of neutrino spark chamber film for experiment BNL 693. A total of 2×10^6 frames are proposed for FY78, but it is expected that the charge coupled device camera system now under development will assume a major role in data acquisition of spark chamber information. During this time, there will be some joint operation of both film and CCD camera systems to provide a cross-calibration of the two. Following successful operation of the CCD camera system, future DOLLY operations depend on other optical data experiments.

Studies will continue with pattern recognition techniques for spark chamber data of the experiment 693 on the PDP-10 system. Accompanying that will be work with techniques for aids for scanning of film and/or CCD derived information using graphic techniques and devices connected to the PDP-10.

B2. Computer Operations

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

In FY78 and following, use of the PDP-10 system is expected to grow toward saturation, with total utilization actually dependent upon the amount of experimental data reduction done on this machine vis-á-vis other potentially available, more powerful units. Therefore, 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:

- Assisting normal programming development for data analysis of new experiments.

- 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.

- Exploration of special purpose processors for fast integer arithmetic applicable for the simple searches for and reconstruction of tracks detected in multi-wire arrays.

B3. Engineering Systems

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

New multi-wire proportional chamber electronics for Experiment 369 will be constructed. This involves instrumenting about 7500 wires. The system will be designed around the newer 10K ECL circuitry instead of the old ECL II which is used in present experiments.

Upon completion of the testing of the CCD camera prototype, an array of 11 cameras will be implemented for BNL experiment 605. This system will contain buffer memory for 4000 data points and a mini-computer controlled data acquisition system.

Work will continue on a next generation of modular data acquisition hardware. Emphasis will be on the data read-out and control system. This will be developed with micro- (or mini-) processors as an integral part.

As demands on the PDP-10 system expand, large units of memory (probably 256K words) may be designed using the 16K MOS memory chips. This will be an extension of the current 4K MOS systems now in operation. From our past experience we believe that this can be done for approximately 1/4 the cost of commercially available memories with no reliability penalty.

V. PUBLICATIONS SUBMITTED OR PUBLISHED AND PAPERS PRESENTED DURINC CALENDAR YEAR 1976

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Theses

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Mollet, W. L. "Backward Production in Pi Minus Plus Proton Goes to Neutron Pi Plus Pi Minus at 8 GeV/c."

Wheeler, C. D. "Dimuon Production by High Energy Neutrons."

Tortora, J. O. "Two Body Rapidity Correlations in π^-p Interactions at 147 GeV/c."

Sarracino, J. "Photoproduction of the $\psi(3095)$ and $\psi'(3684)$ at FNAL Energies."

Invited Talks

A. Wattenberg. Rapporteur. "Photoproduction of New Particles." XVIII International Confernece on High Energy Physics, Tbilisi, USSR, July 15-21, (1976).

A. Wattenberg. "Production of New Particles by High Energy Photons & Neutrons." Northern Illinois University. April 7, 1976.

M. Gormley. "Photoproduction of Massive Dimuon Pairs." Illinois State University. April 13, 1976.

T. Kirk. "Inelastic Muon Proton Interactions at Fermilab." American Physical Society Meeting, Washington, D. C. April 29, 1976.

T. O'Halloran. "Photoproduction of Charmed Baryons." University of Michigan. September 13, 1976.

G. Gladding. "Experimental Evidence for Charm." University of Illinois at Urbana-Champaign. September 7, 1976.

T. O'Halloran. "Under the Spell of Charm." University of Illinois at Urbana-Champaign. September 9, 1976.

A. Wattenberg. "Evidence for Chamed Particles." Purdue University. September 30, 1976.

G. Gladding. "Photoproduction of Charmed Anti-Baryons." Massachusetts Institute of Technology. September 29, 1976.

G. Gladding. "Photoproduction of Charmed Particles." Argonne National Laboratory. October 21, 1976.

W. Francis. "Rho-Muon Production at 150 GeV." University of Chicago. October 4, 1976.

T. Kirk. "Nucleon Structure for Virtual Photon Probes." University of Illinois at Urbana-Champaign. September 27, 1976.

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