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ANNUAL PROGRESS REPORT

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DISCLAIMER

NOTICE

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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. During the coming years these experiments will be continued or completed. Last year we envisioned that our longer range plans would have a general trend toward measurement at increasingly higher energies. However, the exciting new developments in Elementary Particle Physics, in which we have already played a role, are modifying our plans of last year. Specifically a new generation of neutrino experiments at BNL are being proposed, and an increased effort is being put into studies of newly discovered particles at FNAL; therefore there will be a reduced effort put into future ISR experiments during this coming year.

The scope of our program can best be summarized by listing some of our major accomplishments during the present year.

During FY76 major accomplishments include the following:

1. The observation in our BNL data of the elastic scattering of neutrinos by protons was announced at the Vanderbilt Meeting; this fundamental hadronic interaction is a consequence of neutral currents.

   The analysis of neutrino interactions in which a single π^o is produced indicates that the final states for neutral current interactions are not dominated by the $I = 3/2$ final states as is the case for the charge current neutrino actions.
2. In experiments at Fermilab which were studying the photoproduction of the ψ and ψ', in the $\mu^+\mu^-$ channel we observed 10 events in the mass region 4.7 ± 0.2 GeV/c^2; this number of events is a factor of 3 above the calculated Bethe-Heitler background. This leaves us with the tantalizing uncertainty of whether these events arose from a statistical fluctuation or from a new narrow resonance. We also have observed a new broad enhancement in the 2.2 GeV/c^2 mass range in the 6π channel. We have not seen any evidence for the photoproduction of the anomalous $\mu^\pm e^\mp$ type of events reported by workers at SPEAR.
3. Using the neutral beam at FNAL, we have studied the dynamics of J/ψ production by high energy neutrons on various targets. The fact that the J/ψ production varies almost directly as the number of nucleons in a nucleus indicates that the cross sections for J/ψ on nucleons is appreciably smaller than the cross section for normal strongly interacting particles such as ρ mesons. In the same neutron experiment, the

production of $\psi'(3.7)$ is down by at least a factor of 10 from J(3.1) production. In a search through 3,000 $J \to \mu\mu$ events, we see no evidence for the accompanying production of other "interesting" particles that have a (yield) x (branching ratio) greater than 4×10^{-3} for muon decay. These results are in disagreement with theoretical predictions for the ψ and ψ' in charmed particle models.

4. In the high energy inelastic muon scattering experiment at FNAL, measurements of νW_2 for neutrons and protons at large values of ν (20 $\to$ 130 GeV) and over a wide range of q^2 (0.5 $\to$ 15 (GeV/c^2) shows that Bjorken scaling behavior is maintained in this new kinematic region. The inclusive properties of hadrons produced in muon inelastic collisions have been compared to those for hadron collisions, and they are very similar except for the effects due to "leading particles".
5. The Illinois group using the FNAL hybrid bubble chamber analyzed the reaction $\pi^- p \to \pi^-\pi^+\pi^- p$ (at 140 GeV/c) for pion dissociation and proton dissociation. The pion dissociation data are consistent with the earlier results obtained in our experiments at Serpukhov.
6. The plans for the experiment to look for the production of charm particles by pions was completely revised; the redesigned experiment will include studies of the production by pions of J/ψ mesons, and the production of multipion states. A proton recoil detector has been designed and tested and an improved pion beam has been planned.
7. In the streamer chamber experiment at ANL studying the backward reaction $\pi^- p \to p\pi^+\pi^-\pi^-$, we have seen the suppression of Δ exchange and the dominance of quasi-two body production. In the backward reactions involving forward neutrons, we have seen $\pi^- p \to n\rho^o$ and nf^o, and $\pi^- p \to$ (quasi-two body) in states of higher multiplicity.

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. A new generation of neutrino experiments will be undertaken at BNL in order to obtain improved determinations of the elastic scattering of neutrinos on protons as well as the dependence of the neutral currents on isotopic spin.
2. We are scheduled to run a higher intensity photoproduction experiment at FNAL with Cherenkov detectors and liquid H_2 and D_2 targets. As well as giving us measurements of $d\sigma/dt$ for the ψ and ψ', we will obtain data on the photoproduction of $K\bar{K}$, $p\bar{p}$, μe, $\mu\mu$, etc. We will determine whether the anomalous number of events observed in the region of $M_{\mu\mu} \approx 4.7$ GeV/c^2 arose from a statistical fluctuation or from a new narrow resonance.

3. The particle identification equipment which is in the neutral beam facility at Fermilab will be used to study the particles that accompany the production of $J/\psi(3.1)$ by protons.
4. New runs of the muon nucleon inelastic scattering experiment at Fermilab are scheduled using 225 GeV/c muons. This data should permit the separation of scalar and transverse components of the photon-nucleon cross sections. A Cherenkov detector which is being added to the experiment will provide, for the first time, data on kaon production in muon nucleon inelastic scattering.
5. The proton recoil spectrometer should have been installed and data should have been obtained at Fermilab using high energy pions to search for production of charm particles, to study ψ/J production and to study multipion production.
6. We expect to participate in the remaining runs of Experiment 299, the proportional hybrid bubble chamber experiment at FNAL. These new runs will involve the use of a forward gamma detector.
7. The analysis of the data obtained in the streamer chamber experiments at ANL will be nearing completion. In the backward reactions $\pi^- p \rightarrow n$ + charged pions, we will analyze the ρ^o and f^o production and search for the production of heavy mesons. By comparison to the $\pi^- p \rightarrow p + X^-$ experiment, we hope to improve the general understanding of backward inelastic processes.

II. PERSONNEL

In the following subsections are listed the names of Senior Staff members and graduate students who are or will be involved in the Elementary Particle Physics Program.

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

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

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

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

Butler, J.	Nelson, B.
Cooper, J.	Noggle, T.
Downing, R.	Pang, C.
Elliott, J.	Simaitis, J.
Francis, W.	Wray, J.
Messner, R.	

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

Alverson, G.	Gronek, R.	Russell, J. J.
Avery, P.	Hicks, R.	Sarracino, J.
Bender, D.	Kumar, R.	Schreiber, B.
Bronstein, J.	Lufkin, J.	Smith, E.
Bross, A.	MacKay, W.	Tortora, J.
Coleman, R.	Meyer, N.	Wagner, R.
Emigh, D.	Nienaber, P.	Wroblicka, W.
Goodman, M.	Plumer, R.	

B. There is a group of theoretical physicists at the University of Illinois whose main area of interest is Elementary Particle Physics. The interaction of these theorists with the experimentalists is of great value to our experimental High Energy Physics program.

Members of the theoretical staff are:

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

III. EXPERIMENTAL PROGRAM

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

A. Technical Accomplishments during the Past Year

B. Experiments Planned for the Coming Year

C. Experiments that are Planned for Future Years

Below the title of each of the experiments there are listed the names of Senior Staff first and the Junior Staff second who are most directly concerned. Within each of the above three time categories the experiments are ordered in the following sequence:

Experiments using Charged Particle Beams (mainly at FNAL)

Experiments using the Neutral Beam Facility at FNAL

Neutrino Experiments at BNL

Streamer Chamber Experiment at ANL

A. Technical Accomplishments During the Past Year

A1. Muon Inelastic Scattering at FNAL

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

The muon nucleon inelastic scattering data logged by the Chicago-Harvard-Illinois Oxford Group in 1974-75 has now been analyzed and the results published or submitted for publication. Members of the group presented invited talks on the data at the 1975 Stanford International Symposium on Lepton and Photon Interactions and the Spring Washington APS Meeting, as well as giving a number of seminars and colloquia at various universities and national laboratories. The main results so far obtained include:

a) measurement of the proton and neutron structure function νW_2 at large values of ν(20-130 GeV) and over a wide range of q^2(0.1-15 $(\text{GeV}/c)^2$). We see the Bjorken scaling behavior maintained in this new kinematic regime with a ν dependent threshold in q^2. These results are of basic importance in the elucidation of nucleon structure.

b) the inclusive properties of hadrons produced in muon inelastic collisions have been fit to analytic functions of $p_\perp$ and Feynman x and compared to the equivalent spectra for hadron collisions. Leading particle effects excepted, there is a striking consistency between the two types of interactions. This means that the vector dominance picture of real photon hadron interactions is valid for virtual photons as well. Our data is uniquely suited for studying the virtual photon-hadron system.

c) the production of rho mesons by muons has been analyzed at high energy and over a moderate q^2 interval. The fitted elastic rho events are consistent with the vector dominance picture seen at lower energies. At the present energies the proton rho system is well separated from the recoil nucleon and the theoretical interpretation of the data is cleaner. Measurements of the rho polarization and four momentum transfer to the nucleon were extracted, and they support the vector dominance picture.

In addition to the data analysis discussed above, we have completed installation of a large multi-cell Cherenkov counter for charged kaon identification in the CCM Spectrometer. Twelve new MWPC planes were built by the Illinois group and will be installed in the magnet for low energy track measurement. We have also completed drift chambers which will surround the target to measure large angle recoil tracks. These improvements significantly upgrade the analysis power of the CCM Spectrometer for the next series of μn runs.

We will commence a new data run in May 1976 in which we expect to double the total amount of μN data. The new run will be at 225 GeV and will enable us to make our measurements of $R = \sigma_o/\sigma_t$, the separation parameter for longitudinal and transverse polarization components of the virtual photon-nucleon cross section. The data will be analyzed in FY77.

A2. Hadron Beam Developments at FNAL

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

We have worked closely together with physicists from FNAL in FY76 to improve the pion beam which can be delivered to the CCM Spectrometer during periods when the neutrino horn is operating. We have suggested a plan to FNAL which will increase the fluxes available during these periods by a factor 16; thereby making a new range of hadron experiments viable during times that the muon program is not running. They currently are in the process of implementing a version of this plan and expect to be able to deliver fluxes of 10^6 negative pions per burst to the CCM during neutrino horn running periods starting in the fall of 1976.

A3. Charm Search, ψ Production and Multi-π Production using 150 GeV/c Pions

(G. Ascoli, J. Cooper, W. Francis, L. Holloway, T. Kirk, L. Koester, U. E. Kruse, R. Sard, G. Alverson, W. MacKay, E. Smith, in collaboration with Harvard University, Oxford University and Max Planck Institute physicists)

During the present fiscal year the data from the test run of FNAL Proposal 369 was evaluated to examine the feasibility of K^o detection in a charm search experiment. These results confirmed that the equipment functioned as designed; however the acceptance for K's produced centrally was small because of the many low energy large angle π's not detected. A complete redesign of the experiment for P-369 was carried out, culminating in a revised multipurpose experiment which was approved by the Program Committee.

The present proposal consists of three (3) parts: a search for charm particles, an exploration of the process of ψ particle production, and a study of $p3\pi$ and $p5\pi$ production in πp interactions.

During the current fiscal year, design, construction, and testing of some of the new components for this experiment have been started. In particular, a new beam design to give improved π beams has been carried out. A prototype proton recoil detector has been assembled and is being tested. Designs for a hydrogen target and proportional chambers to be used for the detection of the recoil protons are underway.

In the remainder of the present fiscal year and in the transition period there will be intensified effort to get the experiment ready. We need to optimize the trigger capabilities and consider best arrangement for shielding for the μ trigger, the possibility of a fast forward π trigger, and the feasibility of a K trigger. The design and construction of any new components will follow.

During the coming months we intend to review the status of Proposal 318 to study pion dissociation at Fermilab energies. The multipion production portion of E-369 is only a part of the original plan for Proposal 318. We are considering the best ways to implement the other parts of P-318; the search for π interactions at other energies, and a study of π^+ interactions. Together with parts of P-318, it may be possible to study interactions of K particles.

A4. Three Pion Production on Complex Nuclei at 23 GeV

(U. E. Kruse and T. Roberts in collaboration with Carnegie Mellon University, Northwestern University and University of Rochester Physicists)

The reaction $\pi^- + A \rightarrow \pi^+\pi^-\pi^- + A$ was studied on carbon, aluminum, copper, silver and lead. The spin-parity composition of the three-pion system has been analyzed using the Illinois method of partial wave analysis. The partial-wave results have been fitted with an optical model for three-pion production, with very good results. With this model the absorption of the three-pion system (in nuclear matter) turns out to be roughly equal to that of a single pion, 25 millibarns, except for the $J^P = 0^-$ component of the production, which is roughly 50 millibarns. In particular, the A_2($J^P = 2^+$, mass = 1310 MeV) is coherently produced, with an absorption of roughly 25 millibarns.

A5. Proportional Hybrid Bubble Chamber Experiments

(J. W. Cooper, R. D. Sard, R. Plumer, A. E. Snyder, J. Tortora, in collaboration with Proportional Hybrid Spectrometer Consortium (Brown, Johns Hopkins, Illinois Inst. Technology, Illinois, Indiana, Mass. Inst. Technology, Rutgers/Stevens, Tennessee/Oak Ridge, and Yale/Fermilab)

In this bubble chamber spectrometer the Fermilab 30-inch hydrogen bubble chamber is used to study the interaction vertex, while multi-wire 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 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 interactions at 150 GeV/c, using incident π^-, π^+, and p. The consortium has in hand 108K π^- pictures and 158K π^+/p pictures. 442K additional pictures have been approved (Exp. 299) and hopefully will have been taken by the end of FY77.

In FY76 we made progress toward the goal of a Midwestern production capability for processing raw hybrid bubble chamber data. While Illinois Tech. has been scanning and predigitizing the film and carrying out the bubble chamber geometry reconstruction (program GEOMAT), we have been measuring the predigitized film on DOLLY and have adapted the other programs of the data processing chain (PWGP for wire-chamber reconstruction and TRKORG for combination of wire-chamber and film data) to the Illinois computer. Most of our effort has been remeasurement of π^- film already measured on the MIT PEPR system. While the latter has worked with exemplary speed and accuracy, about 1/3 of the predigitized interactions require remeasurement because of lack of charge balance or failure to reconstruct every track. These events are currently being hand-measured at various consortium laboratories (MIT, Brown, Tennessee). With its built-in operator intervention feature, DOLLY measures all tracks, with only 2% rejected events on this high energy film.

The analysis power of the hybrid spectrometer will be greatly expanded by addition of the "Forward Gamma Detector" that is now under construction. 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 complete measuring capability for charged particles. The forward gamma detector should be operational during the latter phases of Experiment 299 (FY77).

The Illinois group has analyzed the reaction $\pi^- p \rightarrow \pi^-\pi^+\pi^- p$ at 147 GeV/c, as reported in Snyder's thesis.* The 105K π^- exposure yielded 156 accepted 4C-fits, divided between pion dissociation ($\sigma(\pi^- \rightarrow \pi^-\pi^+\pi^-) = 407\pm57\mu b$) and proton dissociation ($\sigma(p \rightarrow p\pi^+\pi^-) = 234\pm\mu b$). Only 4 of the events are possibly non-diffractive, corresponding to a cross section of 10-20μb. Subsequently, hand measurement of 4-prong events that had failed PEPR increased the sample size to 281, with no change in the final cross sections. A paper on this reaction (D. Fong et al.) has been submitted for publication.

The 25 and 40 GeV/c $\pi^- p \rightarrow \pi^-\pi^-\pi^+ p$ experiment at Serpukhov, in which Illinois participated (Ascoli, Klanner, Sard), provides a good-resolution high-statistics base for comparison with the pion dissociation data at 147 GeV/c. The energy and angle distributions are consistent with the Serpukhov observations, and the cross sections agree nicely with Klanner's (slowly falling) power-law fit to the 11-40 GeV/c data. The only other study of this reaction at Fermilab energies -- a bare bubble chamber experiment** with equally poor statistics -- had suggested instead a rising cross section.

We are also engaged in the inclusive analysis of the 147 GeV/c $\pi^- p$ inelastic data. We have histogrammed the multi-dimensional momentum and charge distributions and are developing techniques for computer drawn display of correlation contours. We confirm the finding of the wide-gap spectrometer group that there are short range positive correlations between oppositely charged particles with opposite transverse momenta and between like-charged particles with parallel transverse momenta. The maximum of the (+-) correlation is not at the center of the rapidity space ($y_1=y_2=0$) but at $y_1=y_2= -1$.

In order to disentangle systematic errors and conservation constraints from "real physics" effects, we are studying the data processing biases, and carrying out Monte Carlo simulations of various multi-particle production models.

A6. The $\bar{p}p \rightarrow \bar{p}\pi^-\pi^+ p$ Reaction at 25 and 40 GeV/c (CERN-Serpukhov data)

(G. Ascoli, R. Klanner, R. D. Sard, H. W. Wyld, Jr., R. T. Cutler, A. Snyder, and collaborators at CERN and Serpukhov)

The results reported last year have been published: Yu. M. Antipov et al., Nuclear Physics B99, 189 (1975) and R. T. Cutler and H. W. Wyld, Jr., Phys. Rev. D12, 1952 (1975). This completes our study of the diffractive dissociation of the anti-proton at 25 and 40 GeV/c, which are the highest energies at which this process has as yet been studied.

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* A. E. Snyder, "The Reaction $\pi^- p \rightarrow \pi^-\pi^+\pi^- p$ at 147 GeV/c", Thesis, Illinois, Sept. 1975 (Technical Report COO-1195-349).

** H. Bingham et al., Phys. Lett. 51B, 397 (1974).

A7. Studies of Large Transverse Momentum Phenomena at the ISR

(G. Gladding, M. Gormley, P. Avery, J. Russell in collaboration with groups from CERN, Columbia University, Oxford University and Rockefeller University)

During the past year, steady progress has been made on the construction of the fine-grained hadron calorimeter which we propose to add to the detector of the CERN-Columbia-Oxford-Rockefeller collaboration (CCOR) in order to further pursue large transverse momentum phenomena at the ISR. The original purpose of this calorimeter was to provide a total energy trigger (charged plus neutral, any number of particles) to study the possible production of "jets" without the previous constraint of requiring the presence of a single large transverse momentum particle. In addition, we have recently begun studies of the possibility of using the calorimeter simultaneously as a muon identifier in order to look for μ-e coincidences on both the same and opposite sides of the intersection region. One possible mechanism for producing these μ-e coincidences would be the production of a pair of interesting new particles having large semi-leptonic branching ratios.

The scintillator for the calorimeter has arrived and is being wrapped. Techniques have been established for the construction of the large lucite light pipes. Four such light pipes have been constructed and are currently being tested. The uniformity of the light transmission of these light pipes appears to be quite good ($\leq$ a few percent from finger to finger) as long as care is taken to cut all fingers for a given light pipe from the same sheet of lucite. We currently plan to make the first beam tests of 4 calorimeter modules some time toward the end of FY76.

A8. High Energy Photon Experiments at FNAL

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

Experiment E-87A at Fermilab is a broad band photon beam experiment which uses a multiwire proportional system, a magnet for determining the momentum of charged particles, an electron shower detector, a hadron calorimeter, and a muon identifying bank of scintillators behind a large thickness of steel. The initial runs reported last year used 300 GeV protons to produce the photons, and in these experiments we observed both $\psi(3.1)$ and $\psi(3.7)$ production. The runs were continued using 380 GeV/c protons during the spring of 1975 and the data were analyzed during the early months of FY76.

We increased our data on ψ + Be → Be + ψ (with $\psi \rightarrow \mu^+\mu^-$). A more precise analysis of the $\psi \rightarrow e^+e^-$ events was completed, and it confirmed that μe universality holds true in the decays of ψ particles.

We also undertook a search for new particles that may have been photoproduced. We did not see any narrow enhancements indicating new particles in the $\pi\pi$ distribution,

$K\pi$ distribution, and the $K\pi\pi$ distribution. In the $\pi^+\pi^-\pi^+\pi^-$ distribution we see a strong peaking in the region of the ρ'. A preliminary analysis of the $\pi\pi$ events in the same region indicates that the decay of the ρ' is less than 10% into two pions. Rather interestingly, when one looks at the $\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$, one sees a strong broad enhancement in the region slightly over 2 GeV. Further analysis is needed to determine whether this is a new state that corresponds to a continuation of the ρ and ρ' family.

An analysis also was made of μe events where the mass of the pair must be greater than 1.1 GeV. We reported that

$\sigma(\gamma + Be \rightarrow e^{\pm} + \mu^{\mp} + 0) \times \epsilon$ is less than 6×10^{-34} cm^2/Be where 0 is nothing else observed and ϵ includes the geometric accpetance of the μe spectrometer.

The final data taking run of Experiment 87A used 400 GeV/c protons on Be and Cu targets, and it was completed in December 1975. The goals were:

a) to make an improved measurement of the production parameters of the ψ and $\psi'(3.7)$.
b) to search for diffractively produced high mass vector mesons by looking for their decays into $\mu\mu$, ee, and multi-hadron final states.
c) to search for the production of pairs of other interesting particles (e.g. $D + \bar{D}$, or heavy lepton pairs) by looking for their leptonic decays (μ,e), semi-leptonic decays, (μ, hadrons), (e, hadrons) and hadronic decays (multi-hadron final state).

The bulk of the data on all of the above final states were taken simultaneously at moderate intensity. Over 15 million events were written on tape and have been reconstructed. The early analysis of this data has been focused on the simplest final state, $\mu^+\mu^-$. The analysis of the more complicated final states involving electrons and multi-hadrons is proceeding.

The dimuon mass spectrum from this data shows a clean ψ peak containing 200 events and a clustering of 12 events around the $\psi'(3.7)$ mass. The t-distribution of the ψ events s-ows a clear coherent (e^{60t}) peak from the Be nucleus, an e^{3t} dependence at moderate $t(-.2 < t < -1.0\ (GeV/c)^2)$ which we identify with production involving a single nucleon, and a less steep dependence ($\approx e^{1t}$) at large $t(> 1.0\ (GeV/c)^2)$. The extraction of the coherent and incoherent cross-section and an investigation of the large t events is currently in progress.

A high intensity run was limited to observing only dimuons and was motivated to try to pursue the possible existence of a new meson at 4.7 GeV suggested by our moderate intensity data with a mass of 4.7 $\pm$ 0.2 GeV. Dimuons from Bethe-Heitler production in this region were predicted to be at the level of 0.25 events. High intensity data taking was made possible by the addition of 10 inches of Pb following the Be and Cu targets but preceding the first proportional chamber. Combining the moderate and high intensity data we find 10 events in the 4.7 $\pm$ 0.2 GeV mass region. From a careful study of the nature of these events, we have concluded that they are indeed real, that they are not experimental artifacts. The Bethe-Heitler contribution to this mass region is calculated to be 3.5

events. Final calculations are near completion on the comparison of the dependence of the observed events on photon energy, t, and energy asymmetry with those expected for the Bethe-Heitler process. If we were to interpret these events as a narrow resonance then to be consistent with the SPEAR energy scan data, the total width of such a resonance would have to be less than 20 to 45 KeV, depending on the assumptions used to estimate its total cross-section on nucleons.

A9. High Energy Neutron Experiments at FNAL

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

During the spring of 1975, the neutron experiment, E-358, had an additional run using 380 GeV/c protons to produce neutrons with an average energy of about 320 GeV/c. To obtain a beam that is predominantly neutrons 3.8 centimeters of lead are placed in the neutral beam line to selectively attenuate the photons. 61 centimeters of beryllium followed by a 183 centimeters of iron were installed downstream of the neutron target so that in this phase of the experiment we were only observing muons. The data were analyzed in the early months of FY76 and preliminary results were reported at the 1975 International Symposium on Lepton and Photon Interactions at SLAC. The cross-section for the production of J/ψ ($3.1\ GeV/c^2$) $\rightarrow \mu\mu$ with 320 GeV neutrons is very similar to that we had previously obtained with 250 GeV neutrons; this indicates a fairly flat energy dependence of the cross section at these higher energies.

The mass spectra of the dimuons shows clear peaks at the ρ mass and at the J/ψ mass with a continuum between them. The events in the dimuon continuum have been compared with the predictions of the Drell-Yan model, and they are found to be consistent in shape and in magnitude with the theoretically predicted distributions.

The final data taking run of Experiment 358 was completed in September 1975. The goals of this experiment were:

a) to measure the A-dependence of ρ, J/ψ, and the dimuon continuum.
b) to make a high statistics measurement of J/ψ production so as to be sensitive to the possible production of ψ'(3.7 GeV) and to study whether extra muons accompany J/ψ production.
c) to make an improved measurement of the production parameters of the ρ, J/ψ, and the dimuon continuum.

Data were taken on Be, Al, Cu, and Pb targets using a neutron beam derived from a 400 GeV proton beam at a variety of intensities in order to accomplish the above goals.

A preliminary analysis of the A-dependence of the ρ and ψ production has recently been completed and a publication is being prepared. The main result of this analysis is that the ρ and the J/ψ have a different A-dependence in complex nuclei. Namely,

$$\sigma(n + A \to \rho + \ldots) \propto A^{0.6 \pm .05}$$

and

$$\sigma(n + A \to J + \ldots) \propto A^{0.93 \pm .05}$$

The difference could be explained as arising from the J/ψ having a lower probability than the ρ meson for interacting in a complex nucleus.

A total of 700 $J \to \mu\mu$ events have been reconstructed as coming from the four targets; an additional 2300 $J \to \mu\mu$ events have been reconstructed as originating in the hadronic absorber which follows the targets. We see no evidence of an enhancement in the dimuon mass spectrum in the region of the $\psi'(3.7)$. Using the target event sample, we can set a limit at the 90% confidence level on the ratio of the production cross-sections of the $\psi'(3.7)$ to the J/ψ (3.1) as

$$\frac{\sigma_{\psi'}}{\sigma_J} < 0.10.$$

The absence of $\psi'(3.7)$ production to this level is quite surprising in light of the current models for J/ψ particles. A more detailed study of the final state accompanying the J/ψ (as is planned in Experiment 400) would seem to be called for as an aid to understanding the real production mechanism.

A search through the 3000 $J \to \mu\mu$ events seen in this experiment has revealed only four (4) candidates for the reaction

$$n + A \quad J|_{\to\mu\mu} + \mu + \ldots$$

The extra muon in the above reaction could constitute a signature for the production of another interesting particle (e.g. J, $D+\bar{D}$, etc.) accompanying the J. The extra muons in the four (4) events we have seen, however, have low momentum, low $p_\perp$ and are consistent with estimates of muons to be expected from pion decay. We thus set a limit on the fraction of J events we see which could have an interesting extra muon to be

$$\left.\frac{\sigma(J + \mu)}{\sigma(J)}\right|_{\text{observed}} < \frac{6}{3000} = 0.2\%.$$

The strength of this limit can be seen from the fact that since our acceptance for the extra muon is good (40-50%), we should expect the above ratio to be an order of magnitude higher than our observed limit if an interesting particle with a semi-leptonic branching ratio $\geq$ 5% is produced in the forward hemisphere every time a J is produced.

Improvements in the monitoring system for this last experiment have allowed us to reduce our systematic uncertainties in the measurement of the ρ and J cross-sections to the order of $\pm$ 30%. Our present results for the ρ are:

$$\frac{d\sigma}{dx_F} \propto (1-x_F)^{5.5}$$

$$\frac{d\sigma}{dp_\perp^2} \propto e^{-3.3p_\perp}$$

Our present results for the J/ψ are:

$$\frac{d\sigma}{dx_F} \propto (1-x_F)^{6.5}$$

$$\frac{d\sigma}{dp_\perp^2} \propto e^{-1.6p_\perp} \qquad \text{fox } x_F > 0.25$$

TThe analysis of the errors to be associated with these parametrizations is almost completed. The new results represent a more accurate version of the values we have previously reported, and they strengthen the possibility that over half of the direct single lepton production observed at large $p_\perp$ in hadron interactions can be accounted for by the dimuon sources measured in our experiment.

A10. A Study of $\bar{\nu}$ and ν Induced Neutral Currents

(L. Holloway, L. Nodulman, T. O'Halloran, C. Pang, A. Bross, T. Chapin in collaboration with Columbia University and Rockefeller University)

Our attention has been focused on three basic final states in neutrino neutral current interactions during this fiscal year:

a) The elastic scattering of neutrinos $\nu_\mu + p \rightarrow \nu_\mu + p$.
b) Single pion production by neutrinos $\nu_\mu + N \rightarrow \nu_\mu + N + \pi^0$.
c) Dilepton production by neutrinos $\nu_\mu + N \rightarrow \mu + e + \ldots$.

The simplest of the neutrino hadronic interactions is the elastic scattering of ν_μ's by protons. It has never been observed previously. The best upper limit prior to our result was by Cundy et al. (Phys. Lett. 31B, 478 (1970).

$$R_{el} = \frac{\sigma(\nu_\mu + p \rightarrow \nu_\mu + p)}{\sigma(\nu_\mu + n \rightarrow \mu^- p)} < 0.12 \pm 0.06 \quad .$$

We have observed this fundamental interaction and find R_{el} to be 0.25 ± 0.12. In our present data sample the error on R_{el} is dominated by systematic effects. The removal of these systematic effects will be the focal point of a new proposal to be submitted to Brookhaven National Laboratory.

The central motivation for the measurement of R_{el} besides its inherent fundamental significance is to compare it with current theoretical models. These models have been reviewed by Sakurai and Urrutia (Phys. Rev. D11, 159 (1975)). There are basically three models:

a) The Salam-Weinberg model.

b) The baryon-current model proposed by Sakurai.

c) A model proposed by Bég and Zee in which the neutrino is postulated to possess an anomalously large charge radius.

The prediction for R_{el} by models b) and c) within our experimental range is $R_{el} \approx 0.10 \rightarrow 0.18$. The prediction by model a) is $R_{el} \approx 0.07$. It now appears to be feasible to make an experimental test to distinguish between models b) and c) and model a). It cannot be done with our present experimental apparatus but based on our past experience we are confident that we can do the experiment after a substantial modification to our present experimental setup.

The cross section for single pions by neutrinos is also a sensitive test of the various models for neutrino interactions. We have measured

$$R_{\pi^o} = \frac{\sigma(\nu_\mu + Al \rightarrow \nu_\mu + N' + \pi^o)}{2\sigma(\nu_\mu + Al \rightarrow \mu^- + N'' + \pi^o)}$$

and find $R_{\pi^o} = 0.16 \pm 0.04$. This measurement agrees with Cundy et al. We are also measuring the $p\pi^o$ mass spectrum in the neutral current and the charged current interactions in order to look at the isospin structure in the neutral current induced interactions. Our present data indicates that the neutral current final state is not dominated by the $I = 3/2$ final state as the charged current final state is. The final analysis is now being done and we will present our results in the immediate future.

The observation of dilepton final states by neutrinos at Brookhaven energies is an important but exceedingly difficult measurement. If the dilepton states are observed (or even a significant measurement of the upper limit is determined) it will enable us to see if a threshold exists between Brookhaven and Fermilab energies. We have had candidates for such events in the final state

$$\nu_\mu + N \rightarrow \mu e + \ldots \quad .$$

We are in the process of determining whether the events are significant or if they are simply the tail of a background distribution. It is anticipated that our analysis will be done by late this spring.

There are other aspects of our experiment where we have had to bite the bullet and admit that we will not have a significant result. In order to eliminate any theoretical uncertainty in our determination of R_{π^o} off a nuclear target such as Al, it would be desirable to also measure R_{π^+} and R_{π^-} . We are now convinced that we need at least a partial magnetic field in our apparatus in order to determine the sign of the charge of the particle. This will allow us to determine these numbers independent of any model and with a substantial reduction of the systematic background. We are planning, therefore, to measure these numbers in our next experiment.

We also do not have a significant number of $\bar{\nu}$ events in the π^o final state induced by neutral currents. (We define a significant number to be 10^2 in the neutral current final state.) We would anticipate making a definitive measurement of this reaction in our next experiment.

The results of FY76 have been gratifying and tantalizing. Therefore, we have changed our future priorities and desire to begin installation of our second experiment early this summer with preliminary data taking during the fall neutrino run and final data taking during the spring of 1977.

A11. A Study of Reactions Producing a Fast Forward Nucleon in πN Interactions at 8 GeV/c

(B. Eisenstein, B. Nelson, 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.

During the current (FY76) fiscal year and the transition period we have accomplished, or intend to accomplish the following:

a) Study of Backward Inelastic Reactions in $\pi^- p \rightarrow pX^-$. (E-297 at ANL)

This experiment attempts to isolate u-channel baryon exchange processes by triggering on a proton of high momentum produced forward in the laboratory system by the 8 GeV/c π^- beam. A counter hodoscope downstream of the streamer chamber magnet selects positive secondaries with momentum $\gtrsim 1/2\ p_{beam}$, and a Cherenkov counter insures that the particle is not a pion. About 270,000 pictures were analyzed,with the emphasis on reactions with four charge particles in the final state.

A paper has appeared in the Physical Review (Phys. Rev. D1, 5 (1976)) summarizing the results of the analysis of the reaction $\pi^- p \rightarrow p\pi^+\pi^-\pi^-$. Briefly we find that the reaction is dominated by the production of ρ^o, f^o, and various $p\pi^-$ resonances, with mesons backward and baryons forward in the overall center-of-mass system. Quasi-two body production, e.g. $\rho^o N^*(1520)$, is very important and has been studied to find evidence for backward peaks in the differential cross sections (in u). Such peaking appears to be established for the specific reaction quoted above, but the evidence is less conclusive for several others. All of these final states (meson + baryon) can be produced with the u-channel exchange of a baryon with the quantum numbers of a nucleon, and the decay angular distribution of the ρ^o and f^o are consistent with nucleon exchange.

We have found no clear evidence for Δ^{++} exchange processes, which would be required for reactions such as $\pi^- p \rightarrow p + (A_1^-, A_2^-)$ and conclude that at 8 GeV/c, Δ exchange is suppressed relative to nucleon exchange.

In an attempt to seek evidence for Δ exchange and also to understand the general nature of reactions that produce fast forward protons, we are currently studying the center-of-mass longitudinal and transverse momentum distributions of events with four charged particles in the final state. If the results prove of interest, we may extend the study to six charged particle events, which would necessitate the measuring and analyzing of more six prongs than currently exist on our final data tapes. This work will, in any event, be completed during FY76, and represents the last effort that we expect to put into exploiting the fast-proton data.

b) Study of Backward Meson Production in the Reaction $\pi^- p \rightarrow nX^o$. (E-345 at ANL)

This experiment is similar to the previous one in that the streamer chamber is triggered by the detection of a fast forward baryon, in this case a 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 the pX^- experiment, $X^- \rightarrow$ (all charged) are mesons with odd G-parity. Thus the nX^o experiment is complementary to the previously described one. Since a forward neutron can result from nucleon exchange, the suppression of Δ exchange seen in E-297 is irrelevant. However, some N^* production can occur which complicates acceptance corrections. During the current year we have been analyzing events coming from a $\sim$ 250,000 picture exposure made in early 1975, with special emphasis on events with two charged particles in the final state. All such events have been measured, and reconstruction and fitting procedures are underway. Preliminary indications of the quasi-two body reactions $\pi^- p \rightarrow n + (\rho^o, f^o)$ have been seen in this data. It is our hope to complete the analysis of these channels and submit results for publication before the end of FY76.

We have also begun to measure events with four and six charged particles in the final state. The analysis of a previous "test run" of the experiment yielded among the four-prongs the reactions $\pi^- p \rightarrow N^* + (\rho^o, f^o)$, where the "$N^*$" decays to $n\pi^+\pi^-$. This is the analogue of the quasi-two body reaction seen in the fast-proton experiment, and the new data ought to give a good statistical sample for study. We will also search for reactions like $\pi^- p \rightarrow nm^o$, where $m^o \rightarrow \pi^+\pi^+\pi^-\pi^-$. The test run data is not of sufficent statistical significance to be certain, but shows no evidence for prominent 4π resonance production. We expect to measure more than half of the four- and six-prong events during the current fiscal year.

c) Search for Exotic Mesons in the Reaction $\pi^+p \rightarrow nX^{++}$.

A study of the data, trigger rates, etc., from the production run of the fast-neutron experiment has convinced us that the current experimental setup cannot do a good job of studying this reaction. At present we have no plans to continue this experiment.

B. Experiments Planned for the Coming Year

B1. Muon Inelastic Scattering at FNAL

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

The CHIO Group will continue taking muon scattering data at 225 GeV on both hydrogen and deuterium with the intention of finishing the muon nucleon experiment in FY77. The data will be reduced and analyzed during FY77. We shall have measured νW_2 in hydrogen and deuterium as well as it has been measured in iron by the Cornell-MSU collaboration. We will also be able to report values for $R = \sigma_o/\sigma_t$, the separation parameter in virtual photon-nucleon scattering. The scaling behavior of the νW_2 will then be known separately for protons and neutrons as well as for scalar and transverse virtual photons.

The inclusive hadron properties already measured will be supplemented by measurement of charged and neutral kaons. This new capability is a result of recent installation of a multi-cell Cherenkov counter and new MWPC planes in the CCM magnet gap. The kaon data will be the first information of this type to be obtained in muon nucleon inelastic scattering.

We will increase our data sample size for rho meson production by muons and hope to see production of the phi meson as well. The increase in statistics from the new runs will be particularly useful here.

B2. Muon Heavy Nucleus Scattering

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

The CHIO Group has resubmitted a proposal to study the behavior of shadowing in virtual photon-nucleus interactions in FY76. The proposal was deferred at that time but is likely to become active in late FY77. This interesting topic has continued to grow in importance with publication of contradictory results at lower energies in recent months. The high energy muon beam is an ideal place to decide the issue cleanly, and we hope to get started taking data soon. The amount of running necessary to do this experiment is not excessive, and one run of several months should be adequate.

B3. Charm Search, ψ Production, and Multi-π Production using 150 GeV/c Pions

(G. Ascoli, J. Cooper, W. Francis, L. Holloway, T. Kirk, L. Koester, U. E. Kruse, R. Sard, G. Alverson, W. MacKay, E. Smith in collaboration with Harvard University, Oxford University and Max Planck Institute physicists)

As mentioned in Section A, the present proposal, E-369 consists of three parts: the search for charm particles, an exploration of the production process of ψ particles, and the study of $p3\pi$ and $p5\pi$ production in πp interactions. Several triggers are proposed for these searches combining a proton recoil trigger, a single μ trigger, and a μ pair trigger. We are considering also a charged K trigger. For the charm search we propose to use three combinations of triggers: First is a proton and muon trigger for looking for the final state $pD\bar{D}$ with one of the D (charm) mesons decaying to a μ; the second trigger is a proton and pair of muons for looking for the same final state but with both of the D mesons decaying to muons; the third trigger is a muon pair to look for $D\bar{D}$ without the requirement that there be a proton recoil (without the requirement of peripheral production). This latter muon pair trigger will simultaneously give us J/ψ events. For the part of the experiment to study $p3\pi$ and $p5\pi$ production the proton recoil trigger by itself will be used after a suitable reduction by scaling.

During the first half of FY77 the remaining components that are needed for FNAL E-369 will be constructed and tested as well as a revised beam. The components include the hydrogen target, the proton recoil detector, and the μ shield.

Also during this time, we will develop programs to handle the data to be expected from the experiment. We hope that the running of the experiment and the data analysis will begin in FY77.

B4. Multi-Pion and Kaon Experiments at FNAL Energies

(G. Ascoli, R. Klanner, L. Koester, U. E. Kruse, R. Sard in collaboration with Northeastern University physicists)

We hope that the studies during FY76 for investigating multi-hadron final states (3π, 5π for πp interactions, $Km\pi$ for Kp interactions) will permit us to submit a revision or supplement for P-318 early in FY77.

Proposal P-318 was submitted to Fermilab in June 1974 to measure the diffractive dissociation of the pion into 3π, 5π, ... states at momenta of 50 → 200 GeV and small momentum transfers ($t = 0.05 - 0.4\ \mathrm{GeV}^2$). The proposal suggested that the Muon Scattering Facility (built by a Chicago-Harvard-Oxford team around the Chicago Cyclotron Magnet) be used, with modest additions and modifications.

The physics goals of the proposed study are:

a) To extend to higher energies measurements on the energy dependence of the production of low mass 3π states.

b) To extend the study of diffractive dissociation of the pion to higher masses ($M_{3\pi}$ to 5 or 6 GeV) and to higher multiplicities.

c) To clear up - by studies of $A_3^{\pm}$ production at higher energies - the apparent discrepancy between A_3^- and A_3^+ studies.

The π^-p interactions will be measured in E-369 at one energy. We feel that such data will give us a significant improvement in our knowledge of these processes at high energies since only very small statistic samples from bubble chambers are currently available. It will be important to continue this search at other energies and with positive incident particles as well. We hope that these other parts of P-318 will be approved for running.

B5. Proportional Hybrid Bubble Chamber Experiments

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

We expect to participate in the remaining runs of Experiment 299 (π^-/π^+p at 150 GeV/c), involving initial use of the forward gamma detector, and to measure a sizeable fraction of the new film.

We plan to concentrate on the inclusive analysis of the data, using theoretical model calculations to guide us in the search for significant features. The new data on π^+p and pp at the same energy as π^-p will aid us in sorting out beam-dependent effects.

We are not planning further research with the 30-inch hybrid bubble chamber system beyond Experiment 299.

B6. Studies of Large Transverse Momentum Phenomena at the ISR

(G. Gladding, M. Gormley, P. Avery in collaboration with groups from CERN, Columbia University, Oxford University and Rockefeller University)

Difficulties in the fabrication of the aluminum coils for the superconducting solenoidal magnet at CERN has caused a considerable delay to the CCOR experiment. In addition, the Illinois personnel involved in this effort have been and will continue to be in FY77 dominantly involved in the FNAL experiments concerning the production of interesting new particles by photons and nucleons. Consequently, we estimate that the Illinois contribution will be delayed approximately 1 year from our projections of last year.

In the interim, however, we plan to use a portion ($\sim$ 10 modules or 25% of the total) of the fine-grained hadron calorimeter in Experiments E-400 and E-401 at Fermilab. In particular, we will use these modules to increase dramatically our acceptance at large angles which will enable us to pursue at a 5-10 times lower cross-section level the photoproduction of high mass $\mu^+\mu^-$ or e^+e^- pairs, and $\mu^\pm e^\mp$ pairs which might come from the decay of heavy lepton or charm-anticharm pairs. Current plans show Experiments E-400 and E-401 to run in FY77. We hope to have the complete calorimeter available at CERN for data taking runs there in FY78.

B7. High p_T Correlation Experiment at the ISR

(B. Eisenstein, L. Holloway, D. Bender, in collaboration with groups from LBL, Harvard, CERN and the Scandanavian Universities)

The study of the dynamics of events containing large p_T secondaries is of considerable interest. While much work has been done, mainly through requiring one high p_T particle in the trigger, in most cases the particles have not been identified (often not even the sign), and many questions remain unanswered. It is apparent that a clear distinction between models requires a reliable identification of the particle to find out which quantum numbers are locally conserved.

We intend to concentrate on the study of particles with transverse momentum above 1 GeV/c and make the following requirements on our apparatus:

a) The solid angle should be large, ≃ 1 sr to ensure reasonable counting rates even for large p_T particles.

b) The range in rapidity should be wide enough, ≃ ± 2 units, to investigate the rapidity dependence.

c) The gross features of the azimuthal correlation should be measurable.

d) Charge particles should be identifiable by absorption (muons) or by Cherenkov and time-of-flight measurements (hadrons).

e) The apparatus should allow interesting physical quantities, such as invariant mass of a two-particle system to be included in the trigger condition. Several such trigger conditions should be used in parallel.

The apparatus, as presently considered, uses a large aperture magnetic spectrometer symmetric with respect to both horizontal and vertical symmetry planes of the intersection. This spectrometer will identify and measure the momentum of charged hadrons produced within the approximately 2/3 steradian solid angle within a 20° opening in azimuth on either side of the beams and covers the angular range 20° to 160°.

The proposal as submitted by the collaboration to the CERN ISRC is currently in a deferred state. An adhoc committee has been appointed by the CERN NPRC to study the need for major new large aperture detectors at the ISR and until the report is submitted (April 1976) no large scale commitment will be made. Meanwhile, development of the drift chambers and associated readout electronics is proceeding at a reduced rate.

B8. Study of Photoproduced Two-Body Final States at High Energy

(G. Gladding, M. Gormley, R. Messner, A. Wattenberg, A. Avery, R. Coleman, J. Russell, in collaboration with Fermi National Accelerator Laboratory physicists)

In FY77 we are scheduled to take additional data on the properties of high mass photoproduced final states with an improved detector arrangement. This work (E-401) is a natural continuation of the program of high energy photoproduction and pair production in which we have been active for the last three years (E-87). The major additions to the experimental detector arrangement are an additional magnet and a pair of large aperture Cherenkov counters for identifying outgoing hadrons. The additional magnet performs two functions: it sweeps out zero-degree electron-positron pairs with a momentum less than 20 GeV/c, and it will focus some of the pairs arising from the decays of massive parents. In Experiment E-87 one limitation on the maximum flux of beam particles was dictated by the rate of zero-degree electron-positron pairs which the first few proportional chambers of the spectrometer could tolerate without being desensitized in the region around the beam. The new magnet would sweep the low energy pairs outside the aperture of the spectrometer and remove this rate limitation, thereby allowing us to make use of an order of magnitude higher flux.

The runs planned in FY77 will employ a liquid target for a major fraction of the running time and will extend our recent studies of photon interactions in the following ways:

a) With a liquid target (H_2 or D_2) we will measure the s and t dependence of the cross-section of $\psi(3.1)$ and $\psi'(3.7)$ photoproduction on a single nucleon, viz. the energy dependence of $(d\sigma/dt)_{t_{min}}$ for photoproduction and the momentum transfer distribution. We will also be able to extract the total scattering cross section of the $\psi(3.1)$ and $\psi'(3.7)$ on a single nucleon without having to unfold nuclear physics from the process. We expect to detect an order to magnitude larger sample than in our earlier work, namely (3000 $\psi(3.1) \rightarrow \mu^+\mu^-$ events and 100 $\psi'(3.7) \rightarrow \mu^+\mu^-$ events).

b) With identification of final state hadrons, via the addition of Cherenkov counters, we will measure the mass spectrum of photoproduced $K\bar{K}$, $p\bar{p}$, μe, etc. pairs. Resonant structure in the mass spectra of these final states could arise from a variety of mechanisms: the diffractive photoproduction of heavy 1^- states (vector mesons), the production of 0^- states via the Primakoff mechanism, etc. The experiment's sensitivity for observing resonant production in these two body final states corresponds to a product of (cross section) x (branching ratio) of less than a nanobarn. Our detector has good acceptance for two body final states with masses in the range from 3.0 to 8.0 GeV/c^2, and our measurement of the two body mass spectrum will be made simultaneously with the collection of $\psi(3.1)$ and $\psi'(3.7)$ events.

There may be non-resonant photoproduction mechanisms which were not observed at lower energies due to t_{min} effects which will become observable at higher energies with the increase in intensity. An example would be higher invariant mass events.

c) We will measure the dynamics of high energy photoproduction of some of the known vector mesons, particularly the rho meson, on hydrogen. The energy dependence of the total cross section and the shape of the momentum transfer distribution at high energies are of particular interest to theorists - specifically the results will permit an evaluation of vector dominance type models at large S.

d) With increased statistics we should clarify whether the μ pair events we previously observed at $M_{\mu\mu} \approx 4.7$ GeV/c^2 were due to a statistical fluctuation in a background or are due to a narrow resonance in that mass region.

The construction of the Cherenkov counters should be completed and the experiment should be in the data taking phase by the middle of FY77. We hope that all the data can be collected during FY77.

B9. Study of Final States Produced with the J(3.1) in Hadronic Collisions

(G. Gladding, M. Gormley, R. Messner, A. Wattenberg, P. Avery, R. Coleman, M. Goodman, J. Russell, in collaboration with M. Binkley, I. Gaines, J. Peoples, and L. Read at Fermi National Accelerator Laboratory)

The cross section obtained from extrapolating the data of E-358 at Fermilab for the reaction: (neutron + nucleon) → (J(3.1) + anything) is surprisingly large: namely the order of 10^{-31} cm^2. A comparison with the cross-section obtained in the MIT-BNL experiment shows that the hadron production cross section rises by several orders of magnitude in going from AGS to Fermilab energies. This suggests that J(3.1) production in hadronic collisions may be dominated by different mechanisms at high and low energies. Consequently, it is important to measure the properties of other particles which may be present when the J(3.1) is produced in high energy hadron collisions. There have been a number of theoretical speculations that hadronic collisions which produce a J(3.1) simultaneously produce other unusual states, such as charmed mesons or baryons; in contrast ordinary hadronic collisions rarely produce these unusual states. In fact, if the Zweig-Izuki rule were strictly true for charmed quarks, then the J(3.1) must either be produced in pairs or in conjunction with charmed mesons and/or baryons.

E-400 at Fermilab will test some of these ideas in a model independent way be using a high energy proton beam to study the reaction:

$$p + \text{nucleon} \rightarrow J(3.1) + Y + \text{anything}$$
$$\quad \hookrightarrow \mu^+\mu^-$$

the basic idea is to trigger on high mass dimuons and to measure the properties of the final state particles which appear in the forward hemisphere (Y). If unusual particles such as charmed mesons or baryons are contained in the final state Y, this type of trigger is exceptionally powerful because it is sensitive to all possible decay modes of the unusual state Y.

For example, one can measure whether or not there is an excess of strange particles which accompany dileptons. Since we will use the E-87/E-358 particle identification detector which measures the energy of forward-going charged and neutral particles, we will be able to look for resonance structure in the final state Y which accompanies J(3.1) production in hadronic collisions.

In order to do this experiment we have chosen to use a proton beam rather than the neutron beam used in E-358. The proton beam will allow us to study hadron collisions at the highest possible energy (the primary energy of the accelerator), will provide a much smaller beam-spot size, and will be monoenergetic. The use of a monoenergetic beam provides us with another degree of flexibility in that it will allow us to measure and/or trigger on missing energy in hadronic collisions.

We plan to bring a low-intensity proton beam into the experimental area (EE-4) at Fermilab and to study the intensity, backgrounds, and optics of the beam in the summer of 1976. The data taking phase of the experiment is currently scheduled for the late fall of 1976.

B10. A Study of $\bar{\nu}$ and ν Induced Neutral Currents

(T. O'Halloran, C. Pang, A. Bross and P. Nienaber in collaboration with Columbia University and Rockefeller University)

We will begin our second ν, $\bar{\nu}$ experiment during FY77. The goals of this experiment are based on what we have learned during the past few years. It has become apparent to us that there are definite advantages in our decision to do a second generation experiment at Brookhaven. The final states we are examining are simple and allow us to make substantial and definitive tests of the models that presently exist for the neutral current interactions. It is well known that the cross-section for any simple channel saturates about 500 MeV above threshold due to the form factors that are present for the hadronic vertex. It is also well known that the total cross-section rises linearly with laboratory energy. If a primary motivation for the experiment is the measurement of some particularly simple final state, then Brookhaven offers an advantage over other accelerators. The experiment we are proposing takes advantage of these facts.

We will measure the following rates in our next experiment:

a) A measurement of $$R_{el} = \frac{\sigma(\nu_\mu + p \rightarrow \nu_\mu + p)}{\sigma(\nu_\mu + n \rightarrow \mu^- + p)} .$$

During the present fiscal year we measured $R_{el} = 0.25 \pm 0.12$. The error is not limited by statistics, but by systematics. The dominant final state we must discriminate against is $\nu_\mu + p \rightarrow \nu_\mu n\pi^+$. With the addition of 1 or 2 magnets we will be able to make a crude measurement of the momentum of the positive track and distinguish the two possible mass states by range.

b) A measurement of $$R_{\pm,0} = \frac{\sigma(\nu_\mu + Al \rightarrow \nu_\mu + N' + \pi^{\pm 0})}{\sigma(\nu_\mu + Al \rightarrow \mu^{\mp} N'' + \pi^{+,0})}$$

Again the inclusion of a magnetic field will enable us to separate the various charged single pion states. This will free us from the theoretical uncertainty inherent in the nuclear physics corrections to our data.

c) A search for the dilepton states $\nu_\mu + Al \rightarrow \ell^+\ell^- + \ldots$.

At the present time we are limited to μe final states due to their unique structure. By rearranging the apparatus to put more mass at the downstream end, we will attempt to measure

$$\nu_\mu + Al \rightarrow \mu^+\mu^- + \ldots$$

in addition to enhancing our ability to observe the μe final state.

At the present time we hope to make our major modifications next summer, and to have a preliminary run during the next fall. The major part of our data taking would occur during the spring and fall of 1977.

B11. A Study of Reactions Producing a Fast Forward Nucleon in πN Interactions at 8 GeV/c
(B. Eisenstein, J. Elliot, R. Wagner, W. Wroblicka, in collaboration with J. Watson, Argonne National Laboratory and N. Gelfand, G. R. Morris, University of Chicago)

a) Study of Backward Meson Production in the Reaction $\pi^- p \rightarrow nX^o$

Most of our effort will be placed on the final states with four and six charged particles. All of the measuring and data reduction for these events will be completed during FY77, and we anticipate that early in this time period we will be studying physics distributions from about one-half of the final sample.

Our first intention will be to search for high mass $(2\pi^+2\pi^-)$ and $(3\pi^+3\pi^-)$ systems ($m \lesssim 2.7$ GeV/c^2) as well as to compare final states such as $(n\pi^+)_{fast}$ $(\pi^+\pi^-\pi^-)_{slow}$ which can be produced only via Δ^{++} exchange to states like $(n\pi^-)_{fast}$ $(\pi^+\pi^+\pi^-)_{slow}$ which can also occur via nucleon exchange.

In addition, we will complete the study of final states with two charged particles. Excluding the reaction $\pi^- p \rightarrow n + (\rho^o, f^o)$ we see evidence for $\pi^- p \rightarrow \Sigma^- K^+$ ($\Sigma^- \rightarrow n\pi^-$, n triggering) and $\pi^- p \rightarrow \Lambda^o K^o$ ($\Lambda^o \rightarrow p\pi^-$, K^o triggering). We must await higher statistics on these channels before it will be clear how interesting they are.

C. Experiments that are Planned for Future Years

C1. Muon Scattering at FNAL

(W. Francis, T. Kirk, in collaboration with other groups)

After completion of E-98/E-398, the CHIO muon nucleon experiments, we hope to see an upgrading of the FNAL muon beam by an order of magnitude in intensity with an equivalent improvement in the muon halo contamination. This would enable a new generation of muon scattering experiments designed to carry to higher values of q^2 the work being presently completed. Preliminary discussions with FNAL management gives us reason to hope that such an improvement could be contemplated in the next two years. If all goes well, the tests of Bjorken scaling could be extended out to $q^2 \sim 100\ (\text{GeV/c})^2$ at ν values up to 200 GeV. This would represent a significant advance over the present situation.

C2. Charm Search, ψ Production and Multi-π Production

(G. Ascoli, J. Cooper, W. Francis, L. Holloway, T. Kirk, L. Koester, U. E. Kruse, R. Sard, G. Alverson, W. MacKay, E. Smith, in collaboration with others)

The results of the present intense effort by other groups and by us to look for charmed particle production will have a great influence on our program for FY78 and beyond. If charmed particles are produced with reasonable cross sections, the versatility of the large CCM spectrometer at FNAL should allow us to study the various decay modes of charmed particles. If the cross sections are small or if hadronic production has not been observed, we may want to revise our geometry and our triggers so we can work with higher beam rates and lower backgrounds to continue our searches.

We hope to produce results in multi-π production during FY77 that will allow us to plan further multi-hadron final state experiments with the CCM Spectrometer. We see the extension of the planned experiments to higher energies and to other incident beams as very interesting programs for FY78.

C3. Photoproduction Experiments at Fermilab

(G. Gladding, R. Messner, T. O'Halloran, A. Wattenberg, P. Avery, R. Coleman, M. Goodman, J. Russell, in collaboration with groups from Columbia University and Fermi National Accelerator Laboratory)

We probably will still be analyzing data from Experiment E-401 which is basically a study of two-body reactions produced with a high intensity photon beam. If exciting new phenomena are encountered in the course of running E-401, we will submit proposals to continue such studies.

From the runs that have already taken place, we have acquired a good deal of knowledge of both the capabilities and limitations of our present beam and equipment. With continuing experience with the new setup of E-401, specifically the inclusion of Cherenkov detectors for distinguishing between baryons, kaons and pions, we should be able to undertake experiments that will allow us to study the photoproduction of multi-body hadronic final states. The data which exists from the runs we have already taken indicate some very interesting phenomena in the hadronic final states. As well as exploring these, we would also like to study the mass spectra of hadronic final states which are produced in association with a single charged lepton (electron or muon). Proposals for such experiments are currently being considered and should be submitted during the coming year. We anticipate a continuation of high energy photoproduction experiments at Fermilab during FY78.

C4. A Study of $\bar{\nu}$ and ν Induced Neutral Currents

(T. O'Halloran, C. Pang, A. Bross and P. Nienaber, in collaboration with Columbia University and Rockefeller University)

Data taking for these experiments will end in early FY78. The remaining part of the year will be spent in data analysis. The future aspects of this program will depend on the results we have obtained.

C5. A Study of Reactions Producing a Fast Forward Nucleon in N Interactions at 8 GeV/c

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

The program should be essentially complete. The publication of some results may necessitate the analysis of the full data sample, and could occur during this time period.

IV. OPERATIONS AND DEVELOPMENT OF COMMON FACILITIES

A. Technical Accomplishments during the Past Year

A1. Data Acquisition Systems

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

The DOLLY/CSX-1 precision CRT film measuring system continues in heavy use on three experiments. 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. A total of 207,000 events are scheduled for measurement in FY76.

Significant improvements have been made in the program for streamer chamber measurements. Rates of 70 events/hr. on pre-scanned 2-prong events are now achieved. A total of 182,000 events were measured in FY76.

Measurement of spark chamber film from the neutrino experiments BNL 605/652 continues. This program involves automatic film advance and fiducial measurement with manual-aided spark measurements. A total of 18,000 frames has been measured at rates varying from 20 event/hr. for complex topologies to 60 events/hr. for single track events.

Bubble chamber film from FNAL E-154 ($\pi^{\pm}$p,pp) and successor experiments has also been measured. This film is pre-scanned and clear points pre-digitized on image plane machines. The DOLLY system has been tested and run in the following modes:

(1) The DOLLY operator measures events of all topologies with instructions to intervene only minimally with the DOLLY measuring program. Thus events with several overlapping tracks, with extra beam tracks overlapping the event, or with extra tracks from nearby events must be rejected. The measuring rate in this mode is ∿ 10 events/hour with about 25% of all events rejected by the operator.

(2) The operator measures only 2,4,6 prongs with the same instructions as in (1) above. The measuring rate is ∿13/hour with only about 5% of the events rejected.

(3) The operator measures events of all topologies with the instructions to point measure all tracks which DOLLY is unable to measure automatically. This point-measuring is done using the electronic display of hits and misses and has the full accuracy of the machine. The optical display is used for guidance only. The measuring rate is cut to ∿ 5/hour, but only 2% of the events are rejected.

Data are not yet available on the geometry reconstruction rates for the above measuring modes.

All events in the $\pi^- p$ film have been previously measured at the Massachusetts Institute of Technology by the PEPR system. We are using the operator intervention feature of DOLLY (mode (3) above) to remeasure those events in which the PEPR measurements failed to result in the reconstruction of all tracks with overall event charge balance. A sample of 254 such events was remeasured at a rate of 3.3 events/hour. This rate can be compared to the rate of 2-3 events/hour for the same experiment on hand measuring machines at Brown University.

A2. Computer Operations

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

In FY76 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, 15 time-sharing terminals (teletypes and CRT) were connected to the system with an average total connect time of 2700 hours per terminal.

Actual CPU execution time amounted to ∿ 3500 hours which is approaching 50% of all available CPU time. As a result during the prime working hours (9 A.M. to 10 P.M.) the users experienced significant delays in program execution, at times to an extent that made interactive programming awkward, if not impossible. This was particularly true when two or more sizeable programs (> 20K words) were under concurrent execution. A major effort of the systems programming personnel has been to improve time-sharing scheduling and memory overlay procedures to reduce conflicts as much as possible. Nevertheless, it is clear that the increased complexity and data base of current experiments has created a computing requirement for experimental design and data analysis which is significantly greater than the computing power this group now operates. A rough survey of the group's total computing operations in FY76 indicates that the total computations executed on systems outside the PDP-10 system (e.g. the CDC 6600 at FNAL, IBM 195 at Rutherford, etc.) was 4 to 6 times that executed in-house. Therefore, a study of the group's computing needs - current and projected - was begun in FY76.

To improve time-sharing performance for large jobs and to provide needed backup for the ten year-old CSX-1 memory, an additional 32K of MOS memory was constructed and added to the PDP-10 system. Designs for additional memory blocks are underway.

Other systems programming accomplishments include a PDP-10 cross-assembler and loader for CSX-1 programs. This significantly speeds up preparation of DOLLY programs. Software has been developed and installed for the Tektronix 4014 graphics display terminal. This large size display has been useful in design of experimental arrays and analysis of particle track data. In addition it has served as a line printer output station for rapid scanning of pages of histogram and scatter plots.

To meet the needs for faster and more efficient magnetic tape writing, the initial elements of a 9-track 800/1600 bpi tape system have been added. Eventually, it will be possible to eliminate the current IBM 7-track tape system which now no longer matches to the tapes generated at other computer installations.

A3. Engineering Systems

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

The major effort for FY76 has been the continued development and testing of elements of the University of Illinois modular electronics system and the production, design, and fabrication of electronics for the proportional chambers of Experiment FNAL E-398.

A general purpose interface has been added to the PDP-10 computer to facilitate electronic test equipment checkout. Experimental apparatus may now be tested with PDP-10 software before being installed at the experimental site. This interface is built using the University of Illinois high energy modular electronic system with a total of 16 module ports.

For remote data acquisition systems, a 1-5 megabit serial data link has been developed and installed in HEPG modular electronic systems. This simplifies the connections between the computer and remote arrays or other data sources.

In preparation for coming experiments the electronics shop of this group has constructed 800 8-channel proportional chamber amplifier cards, 35 general purpose modules, 15 module boxes or crates, 1000 coaxial cables, etc. At the same time, approximately 25 new plug-in modules have been designed and tested. Development and construction of the modular electronic system has been undertaken in cooperation with other groups in the university on a cost-sharing basis.

B. Plans for Facilities for the Coming Year

B1. Data Acquisition Systems

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

During FY77 hardware development for the DOLLY/CSX-1 system will be somewhat limited, with principal attention on signal detection circuitry. Software development on existing experiments will consist primarily of operational adjustments and improvements including implementing a scheduler which will permit concurrent measurements on three bays. Contingent upon neutrino experiment plans, a major effort will be devoted towards programs for automatic scanning of spark chamber film.

Film measurement with DOLLY is projected also for streamer and bubble chamber film through FY77. Subsequent applications of the system depend on future experiment plans.

B2. Computer Operations

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

During FY77 the full impact of the ability to schedule foreground/background operations of the CPU will be realized. Total CPU utilization is expected to be about 4500 hours. The programming staff is expected to work in the following support areas:

- Developing routines to perform computer aided testing and diagnostics for electronic modules built by the group's technical staff for use in the various experiments.
- Assisting the normal program development for data analysis of new experiments.
- Facilitating use of the on-line graphics display in data analysis.
- Investigating the use of job size in calculating priority scheduling in the timesharing environment. This would allow the use of larger programs, which many of the researchers would find very beneficial. Degradation of services to other users would be minimized by setting aside certain hours for such use or by granting the large job CPU time only after all other needs were serviced.
- Investigating technical questions for computer aided circuit board design and layout. The major effort will lie in adapting existing routines and techniques to the HEPG computer and display equipment.

B3. Engineering Systems

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

There will be continued development for the University of Illinois modular electronics system. This will involve design and construction of special purpose logic modules as required by individual experiments.

A time digitizer system with a resolution of 2 nanoseconds is under design. For this a new technique has been developed which reduces the cost and power requirements. In the course of this development an inexpensive method to generate prototypes of three or four layer boards was devised. Work will continue on this system and a hardware track reconstruction computer system will be developed in conjunction with it.

Work will begin on the use of charged coupled devices (CCD's) for use with optical spark chambers. Use of such devices appears to offer a considerable savings in film cost and data analysis time by virtue of the generation of online digitized data.

Development of large scale, high speed data memories will proceed, based upon the experience with FNAL experiment E-87A, as well as the memory developments for the inhouse computers. These semiconductor memories will be developed using 4K and, as eventually available, 16K MOS RAM chips. These memories will be compatible with the University of Illinois modular electronic systems.

Exploratory studies will be started on the use of microprocessors as the control systems in the modular data systems. The speed and low cost of these elements make them very attractive for enhanced control capabilities within the modular systems.

B4. Liquid Argon Shower Counter

(T. Kirk, in collaboration with physicists from Harvard University and Fermilab)

We have already begun planning for construction of a large many-celled electron/photon shower detector to replace the photon spark chambers in the CCM spectrometer. The detector would consist of a large tank of liquid argon containing some 11 tons of lead plates electrically divided into shower counter sections about 10 cm on a side by 20 radiation lengths deep. We anticipate that this device will enable us to measure photon energies from 500 MeV to 200 GeV with an accuracy of better than 10% $\sqrt{1/E}$, where E is the energy of the photon in GeV.

A design for the electronics is already being tested and a small model is being constructed to test the resolution is a small dewar containing a single shower counter element. Design of the cryogenic system will proceed in FY77.

PUBLICATIONS SUBMITTED OR PUBLISHED AND PAPERS PRESENTED DURING THE CALENDAR YEAR 1975

W. A. Loomis, W. R. Francis, R. G. Hicks, T. B. W. Kirk, et al. "Inclusive Hadron Production in Inelastic Muon-Proton Scattering at 150 GeV/c." Phys. Rev. Lett. 35, 22, 1483 (1975).

L. W. Mo, W. R. Francis, R. G. Hicks, T. B. W. Kirk, et al. "High Energy Muon Scattering at Fermilab." Proceedings of 1975 Int. Symposium on Lepton and Photon Interactions at High Energies, Stanford Univ., Ca. (Editor: W. T. Kirk) (1975).

Yu. M. Antipov, G. Ascoli, R. Klanner, R. Sard, et al. "Analysis of the Reaction $K^- p \rightarrow K^- \pi^- \pi^+ p$ at 40 GeV/c." Nuclear Physics B86, 381 (1975).

Yu. M. Antipov, G. Ascoli, R. Klanner, R. Sard, et al. "The Reaction $\bar{p}p \rightarrow \bar{p}\pi^- \pi^+ p$ at 25 and 40 GeV/c." Nuclear Physics B99, 189 (1975).

D. Fong, R. D. Sard, A. Snyder, J. Tortora, et al. "Topological and Leading Particle Cross Sections for 147 GeV/c π^--p Interactions." AIP Conf. Proceedings #23, Particles & Fields, College of William and Mary (Edited by C. E. Carlson) (1975) 332.

L. Koester, T. Roberts, R. Sard, et al. "Hadron Production at 0.8 mrad by 300 GeV Protons Incident on a Thick Aluminum Target." Proceedings of Int. Colloquium, La Physique du Neutrino a Haute Energie, No. 245, Ecole Polytechnique, Paris (1975) 385.

L. J. Koester, Jr. "Scattering and Multipion Production Reaction Leaving C^{12} in the 2^+ State." Proceedings of Topical Meeting on High Energy Collisions, Trieste (1975) 113.

G. Ascoli and H. W. Wyld. "Unitary States for Three Pions." Phys. Rev. D12, 43 (1975).

J. Bronstein, R. Coleman, L. Cormell, G. Gladding, M. Gormley, R. Messner, T. O'Halloran, J. Sarracino, A. Wattenberg, D. Wheeler, et al. "Photoproduction of Narrow Resonances." Phys. Rev. Lett. 34, 16, 1040 (1975).

J. Bronstein, R. Coleman, L. Cormell, G. Gladding, M. Gormley, R. Messner, T. O'Halloran, J. Sarracino, A. Wattenberg, D. Wheeler, et al. "Dimuon Production by Neutrons." Phys. Rev. Lett. 34, 16, 1044 (1975).

A. Wattenberg. "Photoproduction at FNAL." Proceedings IV Int. Nucleon Antinucleon Symposium, Syracuse University (1975) I-92.

T. O'Halloran with J. Bronstein, R. Coleman, L. Cormell, G. Gladding, M. Gormley, R. Messner, J. Sarracino, A. Wattenberg, D. Wheeler, et al. "New Particle Production by Neutrons." Proceedings of 1975 Int. Symposium on Lepton and Photon Interactions at High Energies, Stanford, Ca. (Editor: W. T. Kirk) (1975) 189.

W. Lee with J. Bronstein, R. Coleman, L. Cormell, G. Gladding, M. Gormley, R. Messner, J. Sarracino, A. Wattenberg, D. Wheeler et al. "Photoproduction of New Particles at Fermilab." Proceedings of 1975 Int. Symposium on Lepton and Photon Interactions at High Energies, Stanford, Ca. (Editor: W. T. Kirk) (1975) 213.

J. Bronstein, R. Coleman, L. Cormell, G. Gladding, M. Gormley, R. Messner, T. O'Halloran, J. Sarracino, A. Wattenberg, D. Wheeler, et al. "Dimuon Production by Photons and Neutrons." Proceedings of Int. Colloquium, La Physique du Neutrino a Haute Energie, No. 245, Ecole Polytechnique, Paris (1975) 61.

A. Abashian, N. Beamer, A. Bross, B. Eisenstein, N. Gelfand, J. D. Hansen, W. Mollet, G. R. Morris, B. Nelson, T. O'Halloran, J. R. Orr, D. Rhines, P. Schultz, P. Sokolsky, and R. G. Wagner. "Search for Backward A_1 and A_2 Production in $\pi^- p \rightarrow p \pi^- \pi^+ \pi^-$ at 8 GeV/c." Phys. Rev. Lett. 34, 11, 691 (1975).

A. Abashian, B. Eisenstein, J. D. Hansen, W. Mollet, G. R. Morris, B. Nelson, T. O'Halloran, J. R. Orr, D. Rhines, P. Schultz, P. Sokolsky and R. G. Wagner, with J. Watson, N. M. Gelfand and M. Buttram. "Backward Production in $\pi^- p \rightarrow p\pi^+ \pi^- \pi^-$ at 8 GeV/c." (accepted for publication in Phys. Rev.)

D. S. Rhines. "A Possible Broad 3π Resonance near 1900 GeV/c Coupling to $N\bar{\Delta}$." Proceedings IV Int. Nucleon Antinucleon Symposium, Syracuse University (1975) IV-23.

W. Lee, T. Chapin, L. Holloway, L. Nodulman, T. O'Halloran, C. Pang, et al. "Single π Production in Neutrino Interactions." Proceedings of Int. Colloquium, La Physique du Neutrino a Haute Energie, No. 245, Ecole Polytechnique, Paris (1975) 205.

Theses

A. E. Snyder. "The Reaction $\pi^- p \rightarrow \pi^- \pi^- \pi^+ \pi^- p$ at 147 GeV/c."

T. J. Roberts. "Three Pion Production on Complex Nuclei at 23 GeV/c."

L. R. Cormell. "Photoproduction of Electron Pairs at High Energy."

Technical Report

J. Tortora. "MATCH: Improving the Efficiency of the Decision Lattice Scanner." Technical Report #5502 (1975).

Other Talks Presented at Conferences

C. Pang. "Single π^0 Production by the Weak Neutral Current," Weak Interaction Conf. at Argonne National Laboratory, 3/6/75.

C. Pang. "Single π^0 Production by the Weak Neutral Current." Weak Interaction Conf. at Brookhaven National Laboratory, 10/29/75.

A. Wattenberg. "High Energy Photoproduction of New Massive Particles." Int. Conf. on High Energy Physics, Palermo, Italy, June 26, 1975.

A. Wattenberg. "Dimuon Production by High Energy Neutrons." Int. Conf. on High Energy Physics, Palermo, Italy, June 26, 1975.

Talks given at APS Meetings

W. Mollet, N. Beamer, B. Eisenstein, N. Gelfand, G. R. Morris, B. Nelson, D. Rhines, R. Wagner and J. Watson. "Backward Production in the Reaction $\pi^- p \rightarrow nX^o$ at 8.0 GeV/c." Bull. Am Phys. Soc., Series 11, 20, 612 (1975).

T. Chapin, G. Alverson, A. Bross, L. Holloway, L. Nodulman, T. O'Halloran, C. Pang, et al. "Study of the Single Charged Pion Production in Neutrino Reactions." Bull. Am. Phys. Soc., Series 11, 20, 614 (1975).

L. Cormell, J. Bronstein, R. Coleman, G. Gladding, M. Gormley, R. Messner, T. O'Halloran, J. Sarracino, A. Wattenberg, D. Wheeler, et al. "Production of Large Invariant Mass e^+e^- Pairs by High Energy Photons." Bull. Am. Phys. Soc, Series 11, 20, 712 (1975)

D. Wheeler, J. Bronstein, R. Coleman, L. Cormell, G. Gladding, M. Gormley, R. Messner, T. O'Halloran, J. Sarracino, A. Wattenberg, et al. "$\mu^+\mu^-$ Pair Production by High Energy Neutrons at FNAL." Bull. Am. Phys. Soc., Series 11, 20, 712 (1975).

T. J. Roberts, U. E. Kruse, et al. "Three Pion Production on Complex Nuclei." Bull. Am. Phys. Soc., Series 11, 20, 651 (1975)

E. Hafen, J. Tortora and MIT Consortium. "Inclusive Δ^{++} and ρ^o Production in 147 GeV/c $\pi^- p$ Interactions." Bull. Am. Phys. Soc., Series 11, 20, 546 (1975)

A. E. Snyder, R. D. Sard and MIT Consortium. "The Exclusive Reaction $\pi^- p \rightarrow \pi^- p \pi^+ \pi^-$ at 147 GeV/c Using the Proportional Wire Hybrid System." Bull. Am. Phys. Soc. Series 11, 20, 546 (1975)

T. Ludlam, A. E. Snyder, J. Tortora and MIT Consortium. "Charged Pion Production in 147 GeV/c $\pi^- p$ Collisions." Bull. Am. Phys. Soc., Series 11, 20, 546 (1975)

U. Karshon, R. D. Sard, J. tortora and MIT Consortium. "Study of Double Leading Effects in $\pi^- p$ Interactions at 147 GeV/c." Bull. Am. Phys. Soc., Series 11, 20, 546 (1975).

C. Fu, A. E. Snyder and MIT Consortium. "Diffractive Excitation in 147 GeV/c $\pi^- p$ Collisions." Bull. Am. Phys. Soc., Series 11, 20, 546 (1975).

T. C. Ou, R. D. Sard and MIT Consortium. "Strange Particles Produced by $\pi^- p$ Collisions at 147 GeV/c." Bull. Am. Phys. Soc., Series 11, 20, 546 (1975).

E. B. Brucker, R. D. Sard, A. E. Snyder, and MIT Consortium. "Gamma Ray Production in $\pi^- p$ Reactions at 147 GeV/c." Bull. Am. Phys. Soc., Series 11, 20, 546 (1975).

R. Whitman, A. Wattenberg, et al. "Measurement of the Decay Spectrum in $K_{\mu 3}^+$ Decay." Bull. Am. Phys. Soc., Series 11, 20, 614 (1975).

L. Teig, A. Bross, T. Chapin, L. Holloway, L. Nodulman, T. O'Halloran, C. Pang, et al. "Single Production by Antineutrinos." Bull. Am. Phys. Soc., Series 11, 20, 614 (1975).

E. Maddry, A. Bross, T. Chapin, L. Holloway, L. Nodulman, T. O'Halloran, C. Pang, et al.

"Single π^o Production by Neutrinos." Bull. Am. Phys. Soc., Series 11, 20, 613 (1975).

D. Nease, J. Bronstein, R. Coleman, L. Cormell, G. Gladding, M. Gormley, R. Messner, T. O'Halloran, J. Sarracino, A. Wattenberg, D. Wheeler, et al. "Observation of the 3.1 GeV/c^2 Narrow Resonance in the Reaction $\gamma + Be \rightarrow \mu^+ + \mu^- + X$." Bull. Am. Phys. Soc., Series 11, 20, 712 (1975).

S. D. Smith, J. Bronstein, R. Coleman, L. Cormell, G. Gladding, M. Gormley, R. Messner, T. O'Halloran, J. Sarracino, A. Wattenberg, D. Wheeler, et al. "Photoproduction of Hadrons at Fermilab." Bull. Am. Phys. Soc., Series 11, 20, 712 (1975).

A. Wijangco, J. Bronstein, R. Coleman, L. Cormell, G. Gladding, M. Gormley, R. Messner, T. O'Halloran, J. Sarracino, A. Wattenberg, D. Wheeler, et al. "Photoproduction of Massive Dileptons Accompanied by Other Particles." Bull. Am. Phys. Soc., Series 11, 20, 712 (1975).

P. Leung, J. Bronstein, R. Coleman, L. Cormell, G. Gladding, M. Gormley, R. Messner, T. O'Halloran, J. Sarracino, A. Wattenberg, D. Wheeler, et al. "Strange Particle Photoproduction at FNAL Energies." Bull. Am. Phys. Soc., Series 11, 20, 712 (1975).

W. R. Francis, T. Kirk, R. Hicks and Chicago-Harvard-Illinois groups. "Hadron Spectra from Muon Scattering at 150 GeV." Bull. Am. Phys. Soc., Series 11, 20, 713 (1975).

T. Quirk, W. Francis, R. Hicks, T. Kirk and Chicago-Harvard-Illinois group. "Rho Meson Production by Muon Scattering at 150 GeV." Bull. Am. Phys. Soc., Series 11, 20, 713 (1975).

W. A. Loomis, W. Francis, R. Hicks, T. Kirk and Chicago-Harvard-Illinois group. "Search for Muonproduction of High Mass Vector Mesons." Bull. Am. Phys. Soc., Series 11, 20, 713 (1975).

E. D. Alyea, J. Tortora and MIT Consortium. "Topological Cross Sections for $\pi^- p$ Interactions at 147 GeV/c." Bull. Am. Phys. Soc., Series 11, 20, 546 (1975).