ANNUAL PROGRESS REPORT

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Department of Physics
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Key Personnel: A. Wattenberg
R. O. Simmons

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I. Summary of Scope and Purpose of the Project

Our program in elementary particle physics research will continue to be carried out at the University of Illinois and at various high energy particle accelerators. The experiments planned or in progress are concerned with the strong, the electromagnetic, and the weak interactions. The scope of the program in FY73 can best be briefly summarized by listing some of our major accomplishments during the present year.

During FY73 major accomplishments included the following:

- 1) The pictures from the first streamer chamber run were successfully carried through the DOLLY measuring system, reconstruction programs etc. to be put onto SUMX tapes.
- 2) The preliminary results from the backward production $\pi^- p \rightarrow$ fast forward p experiment in the streamer chamber shows that there is backward production of 3π in the mass region of the A_2 . It also shows pronounced ρ and f^0 production in the backward direction.
- 3) The three pion partial wave analysis (the Ascoli algorithm) was applied to the A_1 ($J^P = 1^+$, the enhancement is only in $\rho\pi$) and the A_3 ($J^P = 2^-$, the enhancement is only in $f\pi$) in order to obtain "Argand type" diagrams. In contrast to the A_2 where the phase goes through appreciable change, the phases of the A_1 and A_3 amplitudes do not change with the effective mass of the 3π , which rules out simple resonance interpretations for the A_1 and A_3 .
- 4) The multipion partial wave analysis has been applied to the production dynamics of the A_2 and the behavior is in disagreement with current models of strong interactions.
- 5) The present series of experiments using the University of Illinois 52 element neutron counter hodoscope were completed. It was found that:
 - a) the ω meson has a narrower width than previously measured;
 - b) the f^0 is not split;
 - c) ρ^0 production for $-t > 0.7$ is substantially larger than predicted.
- 6) The technique of observing the 4.4 MeV γ -ray from carbon in pion reactions, which isolates isoscalar exchange, has been used to study three pion production; the effective mass shows a strong enhancement in the A_1 region.
- 7) Most of the counters and electronic equipment for the lepton search and for the high energy photon experiments at NAL have been built and are being tested.
- 8) The analysis of the experiment to compare CP violation in K^0 and $\bar{K}^0$ decays was completed, and the CP violation parameters for $\bar{K}^0$, which had never been measured previously, were in agreement with the more precisely determined values for K^0 .

- 9) The final three measuring stations of the DOLLY film measuring system were put into full production on streamer chamber film and a total of 39,000 events have been measured.
- 10) The Digital Equipment Corp. PDP-10 system was installed and brought into routine service, and the University of Illinois IBM 7094 was removed from service in October 1972.

Details of the above and other parts of the FY73 program are given in Part III. A of this report.

During FY74 four major experiments have been approved for running; they are:

- 1) Streamer Chamber experiments at ANL which will measure the backward production of mesons with the aid of a neutron detector in the reactions $\pi^- p \rightarrow nX^0$ and $\pi^+ p \rightarrow nX^{++}$. The π^- experiment would observe the production of isoscalar mesons such as the f^0 as well as even G parity systems in a charged decay mode. The π^+ experiment should observe those exotic mesons which couple preferentially to baryon, antibaryon systems.
- 2) a high energy photon experiment, NAL 87A. After initial beam and equipment check outs we will study rho photoproduction at high energies. Any $J^P = 1^-$ objects which couple strongly to the photon will also be diffractively produced. Initial searches will be made for heavy leptons produced with a Bethe-Heitler cross section.
- 3) the high energy μp inelastic scattering experiment, the muon scattering facility at NAL, E-98, should be set up and the initial running should produce about 10^5 μp events. The principle areas of interest include studies of scaling behavior at values of ν and q^2 previously inaccessible and inclusive spectra of recoil hadrons.
- 4) a neutrino experiment at Brookhaven National Laboratory which should complete its first run. The purpose of the experiment is to study the existence or non-existence of neutral currents, and the feasibility of extending the sensitivity of such measurements.

In addition to the above, the program to understand the three pion system by the so-called multipion partial wave analysis should be completed. Attempts will be made to try to carry out a similar analysis on the $K\pi\pi$ system. The analysis of other experiments that have been run this year or in previous years should also be completed. One of the major ones is from the streamer chamber runs studying backward meson production in the reaction $\pi^- p \rightarrow pX^-$. Details on the above program for FY74 are given in Section III. B.

Some of the new, younger staff members are beginning to plan experiments of their own at colliding beam machines for future years. Their interest is in understanding the very large transverse momentum events that have been observed in an ISR experiment with which one of them was associated. If their experiments are approved, we would like to provide both the equipment and personnel necessary to carry out the experiments in which they are interested. Details of these experiments under consideration for future years are given in Section III.C. of this Progress Report.

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.

During the past year M. Gormley and T. Kirk were appointed to the Physics faculty. J. H. Smith has become Associate Head of the Physics Department, and D. Mortara is leaving to join a Medical-Physic Laboratory. This coming year, G. Gladding will become a member of the Physics faculty.

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

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

Barton, H.	Simaitis, J.
Downing, R.	Sokolsky, P.
Francis, W.	Taylor, R.
Klanner, R.	Wray, J.
Rhines, D.	(Two others)

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

Beamer, N.	Lufkin, J.	Roberts, T.
Bronstein, J.	Meyer, N.	Rothamel, J.
Chapin, T.	Mollet, Wm.	Sarracino, J.
Cormell, L.	Morris, G.	Snyder, A.
Cutler, R.	Nodulman, L.	Tortora, J.
Czechowski, M.	Noggle, T.	Weinstein, B.
Kantrowitz, M.	Pike, G.	Wheeler, D.
		Wojslaw, R.

B. The theoretical physicists at the University of Illinois have played an exceptionally active role in collaboration with the experimentalists during this past year. L. M. Jones and H. W. Wyld have collaborated with the experimentalists on calculations to understand the 3 pion system. In general, the interest of the theoretical staff in the experiments we are performing and are planning has been of great assistance to our program. Members of the theoretical staff are:

Chang, S.	Schult, R.
Hasslacher, B.	Stack, J.
Jones, L.M.	Sullivan, J.
Mason, A.L.	Wright, J.
Ravenhall, D.	Wyld, H.

In the present section and in Section IV, 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 the 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:

- Streamer Chamber Experiments
- Strong Interaction Experiments
- Electromagnetic Interaction Experiments
- Weak Interaction Experiments

A. Technical Accomplishments During the Past Year

A1. Streamer Chamber Development

(A. Abashian, B. Eisenstein, J.D. Hansen, T. O'Halloran, D. Rhines, P. Sokolsky, N. Beamer, W. Mollet, G.R. Morris in collaboration with M. Buttram, Iowa State Univ., and J. Watson, Argonne National Laboratory)

A 1.5m x 1.0m x 0.6m two gap streamer chamber and an associated 1 Megavolt pulsing system has been developed as an experimental facility in a high momentum beam at the ZGS at Argonne National Laboratory. Two experimental runs during FY72 provided 150,000 photographs of events for analysis. A number of improvements in the system in FY73 have led to increased stability and greater reliability of the system. Additionally, several studies necessary to the physics analysis have been completed in FY73.

A precise map has been made of the field of the 15 Kgauss magnet in which the chamber is located; the performance of the Marx Generator was improved by a new type of trigger gap, and the multipulsing of the streamer chamber has been made more stable by an improvement of the electrode geometry in the Blumline line spark gap. A system for automatically regulating the memory time of the streamer chamber was developed, and improved versions of the streamer chamber gas box and liquid hydrogen target were built.

So far in FY73 we have taken 125,000 pictures in runs and within a few weeks will take another 125,000. The running of the chamber and high voltage systems has been far more stable than in the first year of operation and has reached the point where it can truly be considered as an ANL facility. Most of the maintenance and improvement are now being done by the small but able staff of our ANL collaborators, and proposals are being received from other university groups to use the facility.

A2. $\pi^- p \rightarrow p X^-$ in the Backward Direction in the Streamer Chamber

(B. Eisenstein, J.D. Hansen, T. O'Halloran, D. Rhines, P. Sokolsky, N. Beamer, W. Mollet, G.R. Morris in collaboration with M. Buttram, Iowa State University and J. Watson, Argonne National Laboratory)

The data taking for this experiment will be completed in FY73. In the first run, at 8 GeV/c at the ZGS, 110,000 pictures were taken. The first pass through the measurement and analysis has been completed and an additional 25,000 pictures are being taken at this time.

The experiment was designed to study inelastic baryon-exchange reactions. The streamer chamber is triggered by the detection of a high momentum positive particle emerging forward from the LH_2 target in the streamer chamber and escaping

the magnet. A threshold Cherenkov counter used in anticoincidence verifies that the particle is not a pion and is therefore most likely a proton. The large geometric acceptance of the streamer chamber allows the study of multiprong events ($X^- \rightarrow \text{many charged}$).

Our motivation for studying backward inelastic reactions is manyfold. Previous experiments have shown that familiar mesons such as ρ and A_2 are produced in multipion final states and have suggested that other higher mass mesons are produced by baryon exchange as well. However these experiments have been either in bubble chambers with only a few hundred events in some multiplicity or in a missing mass spectrometer with no detail (in backward production) about the meson system other than mass. Our experiment will look in detail with good statistics (~ 3000 backward $\pi^- p \rightarrow p \pi^+ \pi^- \pi^-$, for example) at produced resonances. We will explore the production mechanism by determining spin density matrix elements and u-dependences. We hope to establish the existence and determine the quantum numbers for higher mass mesons. In particular, we hope to find evidence for exotic mesons whose coupling to $p\bar{p}$ has been suggested by several authors.

The initial 110,000 picture run was completed near the end of FY72. During FY73 the film was scanned for all interactions, and it was decided to measure all two and four prong events and a sample of six prong events. Since this was the first experiment at Illinois which used the full capabilities of DOLLY for automatic track following and digitizing, and since streamer chamber tracks are different from bubble chamber tracks (for which POLLY experience was available), considerable effort had to be made to achieve the efficiency required for production measuring. We are now able to measure the film routinely and have reached rates as high as 35 three view events/hour on prescanned film.

Initially we have concentrated on four prong events fitting $\pi^- p \rightarrow p \pi^+ \pi^- \pi^-$ and have an event sample (at the present) of ~ 350 events with $1 \lesssim m_{3\pi} \lesssim 2.8 \text{ GeV}/c^2$, for most of which the proton lies within 15° of 180° in the center-of-mass. The separation from 1-constraint events seems reliable, and the fitted error on $m_{3\pi}$ is typically $10\text{--}15 \text{ MeV}/c^2$. Although high statistics studies of the sort mentioned earlier must await the analysis of the current run, a number of conclusions are already possible. There is good evidence for production of A_2^- in $\pi^- p \rightarrow p A_2^-$, where the A_2 decays mainly via $\rho^0 \pi^-$. In fact, the final state shows a large amount of $\rho^0 \pi^-$ as well as some $f^0 \pi^-$, with evidence for $\pi^- p \rightarrow N^* \rho^0$. Structure is suggested at high $m_{3\pi}$ values ($\sim 2200 \text{ MeV}$) but must await higher statistics and more realistic acceptance corrections, than the simple ones which we are now employing.

A number of problems were found in this analysis which have been reduced in the current run. A small repositioning of the Cherenkov counter and the addition of a counter hodoscope behind the streamer chamber have reduced the number of triggers by slower protons. The combined effect will be that the current 250,000

picture run should yield five times as much good data as the original 110,000 picture run.

A3. $\pi^- p \rightarrow n X^0$ in the Backward Direction

(B. Eisenstein, T. O'Halloran, D. Rhines, P. Sokolsky, N. Beamer, W. Mollet, G.R. Morris in collaboration with M. Buttram, Iowa State University and J. Watson, Argonne National Laboratory)

As a complement to the study of $\pi^- p \rightarrow p X^-$, we are preparing a streamer chamber experiment to study $\pi^- p \rightarrow n X^0$. Not only does this reaction allow study of isoscalar mesons such as the f^0 , it also allows a study of even G-parity systems in their charged decay modes. When produced as X^- , such objects would have at least one π^0 in their decay and would not be accessible in 4-constraint fits.

Monte Carlo studies of this reaction in the streamer chamber have been performed, and the neutron detector has been designed and is being built. This experiment is scheduled for its first run in early FY74 in the 8 GeV/c π^- beam, but we hope to obtain some time before the end of FY73 for initial tests.

A4. Study of 3π System Produced in $\pi^- p \rightarrow \pi^- \pi^- \pi^+$

(G. Ascoli, L. Eisenstein, J.D. Hansen, L.M. Jones, U.E. Kruse, R.D. Sard, H.W. Wyld and R. Klanner, W. Kienzle (Cern))

An intensive effort was started three years ago at the University of Illinois to reach a detailed understanding of the enhancements observed in the charged 3π system. The method of analysis used is based on the same physical assumptions on which the familiar Dalitz plot analysis is based. The difference is that a fit to the experimental distribution in the 5-dimensional 'decay' space (2 Dalitz plot variables + 3 Euler angles) is made. The method has several advantages:

- The resolution for determining the contributions of different J^P (spin-parity) states to the 3π system is much greater.
- The polarization matrix (including the imaginary part) for each J^P state present can be measured.
- The interference terms between states of different J^P (including phases) can be measured.

The method of analysis (sometimes referred to as PWA - Partial Wave Analysis) has been applied to the following data:

- Our own bubble chamber data on $\pi^- p$ at 5 and 7.5 GeV.

- b) Bubble chamber data from other laboratories on $\pi^- p$ at 11 to 25 GeV and $\pi^+ p$ at 5 to 8 GeV.
- c) Spark chamber data for $\pi^- p$ at 25 and 40 GeV from CIBS (Cern-Ihep-Boson Spectrometer at Serpukhov). Two of us (R.D. Sard and G. Ascoli) have taken part in data-taking and analysis. R. Klanner (Cern-Munich) and W. Kienzle (Cern) have taken part in this analysis.

The initial program is essentially complete. The main results are:

- a) The A_1 enhancement is only in the state $J^P = 1^+$ ($S \rightarrow \rho\pi$). The phase of this amplitude does not change with 3π mass, thus ruling out a simple resonance interpretation of the A_1 effect.
- b) The A_3 enhancement is only in the state $J^P = 2^-$ ($S \rightarrow f\pi$). The phase of this amplitude is also independent of 3π mass, again ruling out a simple resonance interpretation of the A_3 effect.
- c) The polarization of the A_3 is found to agree closely with t-channel helicity conservation. The same result had been obtained earlier for the A_1 .
- d) The s- and t-dependence of the $A_2^\pm$ cross section and polarization indicate that (above ~ 10 GeV) the A_2 is produced mainly by isoscalar, "natural parity" exchanges (including presumably f^0 and Pomeron). The data correspond to an effective Regge trajectory with intercept $\alpha(0) = 0.84 \pm .08$ and slope $d\alpha/dt \sim \text{GeV}^{-2}$. The ratio of A_1 to A_2 to A_3 production is essentially constant from 11 to 40 GeV.
- e) The interference term between A_2 and A_1 has been measured as a function of s and t. The magnitude of the interference is maximal showing that the two amplitudes have the same dependence on nucleon spin variables (presumably both are non-flip). The relative phase ($A_2 - A_1$) is independent of t and moves slowly clockwise with increasing energy reaching $\sim -75^\circ$ at 40 GeV. It appears to us that our results on A_2 production pose a serious challenge to current models of strong interactions.

We list below for completeness and clarity some related topics of research - now in progress - even though some of these are presented in more detail in other sections of this report:

- a) We have started, in collaboration with our theoretical colleagues Lorella Jones and H. W. Wyld, a detailed comparison of the results of our analysis (with A_2 left out) with a Reggeized Deck model.
- b) H. W. Wyld has devised a method to take into account unitarity ($= \pi-\pi$ rescattering corrections) in our analysis. We want to see to what extent these corrections affect our results.
- c) Studies have been undertaken of the $\pi^- \pi^- \pi^+$ systems produced in the reactions:

$$\pi^- p \rightarrow \pi^- \pi^- \pi^+ C(\text{ground state}) \text{ at } 23 \text{ GeV.}$$

$$\pi^- p \rightarrow \pi^- \pi^- \pi^+ C^* \text{ at } 6 \text{ GeV}$$

$$\quad \quad \quad \downarrow$$

$$\quad \quad \quad C + 4.4 \text{ MeV } \gamma$$

- d) A preliminary study of the very large data sample ($\sim 70,000$ events) at 25 and 40 GeV confirms the results obtained in the bubble chamber data. If possible, it would be useful to carry out a more detailed study to look for possible smaller effects.
- e) A possible interpretation of the A_1 results as a "shielded" pole has been suggested by Jon Wright (Univ. of Illinois theorist). We will work with R. L. Miller and Jon Wright to compare the predictions of this model with the data.

For specific mesons, more details can be found in:

- 1) A_1 results: G. Ascoli, et al., Phys. Rev. Letters 26, 929 (1971).
Report by R. Klanner: Experimental Meson Spectroscopy (1972), p. 164.
G. Ascoli, et al., to be published.
- 2) A_2 results: Kruse, et al., Partial Wave Analysis of A_2 Production, Paper 602 for XVI Int. Conference on High Energy Physics (1972); to be published.
- 3) A_3 results: Experimental Meson Spectroscopy (1972) p. 185.
G. Ascoli, et al., Phys. Rev. D7, 669 (1973).
- A5. Comparison of $\pi^- p \rightarrow \pi^- \pi^- \pi^+$ Results with Deck Model
(G. Ascoli, L.M. Jones, U.E. Kruse, H.W. Wyld, R. Cutler, T. Roberts, B. Weinstein)

The lack of phase change with 3π mass of the A_1 and A_3 production amplitude, suggests a non-resonant interpretation like the Deck effect. We therefore have undertaken a detailed examination of the Deck effect to allow a better comparison with the data. This work has been started in collaboration with our theoretical physics colleagues, Lorella Jones and H.W. Wyld. The Deck model calculation uses the phase shift results for $\pi\pi$ and low energy πp scattering (continued to high-energy by the Barger-Phillips Regge fit), with a Reggeized π exchange. Since the model does not include A_2 production, a direct comparison of the model with the data is not possible. We have therefore proceeded along the following two lines:

- a. A partial wave analysis of the theoretical amplitude.
- b. We apply to a sample of Deck-model events (generated by Monte Carlo according to the model) the same partial wave analysis method used to fit the experimental data samples.

Preliminary results suggest that the model has a fair chance of fitting the data in the A_1 region, but a poor chance of fitting the data in the A_3 region.

A6. Unitarity Corrections to 3π Analysis

(G. Ascoli, H. W. Wyld)

An objection has been raised by G. Fox regarding the amplitudes used in our analysis of the 3π data. This objection may possibly be motivated by a desire to prevent the demise of the A_1 and A_3 as genuine resonances. The objection is that in our analysis we use decay amplitudes (from a given J^P state to the final 3π configuration) which ignore the possibility of $\pi\pi$ rescattering. To answer this objection, H. W. Wyld has found a method of constructing modified decay amplitudes which take such rescattering effects into account.

A calculation of these decay amplitudes has been carried out and the process of refitting the data using these modified amplitudes has begun. We have only preliminary results; they suggest that no major change in the previous conclusions will be obtained.

We expect that work outlined above will be finished, and final papers published, within the next 3 to 6 months.

A7. Upper Limit to Decay Mode $A_2 \rightarrow \eta'\pi$

(L. Eisenstein, P. Schultz)

The 6-prong events in our 5 GeV π^-p bubble chamber experiment were measured to look for $\pi^-p \rightarrow \pi^+\pi^-\pi^0\pi^+\pi^-\pi^-p$ events fitting the chain

$$\begin{aligned} \pi^-p &\rightarrow A_2^-p \\ &\quad | \rightarrow \eta'\pi^- \\ &\quad \quad | \rightarrow \eta\pi^+\pi^- \\ &\quad \quad \quad | \rightarrow \pi^+\pi^-\pi^0 \end{aligned}$$

No events with $M(6\pi) = 1.2 - 1.4$ GeV and $t' < 0.7$ GeV were found. This gives an upper limit (90% confidence) of 1.1% for the branching ratio

$$\frac{A_2^- \rightarrow \eta'\pi}{A_2^- \rightarrow \rho\pi} \quad . \quad \text{See L. Eisenstein, P.F. Schultz, G. Ascoli}$$

M.L. Ioffredo and J.D. Hansen, Phys. Rev. D7, 278 (1973).

A8. Serpukhov Spectrometer Experiment (Cern-Ihep-Boson Spectrometer Collaboration).

(G. Ascoli, R. Klanner, R. Sard)

The taking of data in the 25 and 40 GeV/c negative beam at Serpukhov was completed in April 1972. Since then the processing and fitting of the data have been completed at Cern (with participation by G. Ascoli and R.D. Sard, made possible,

in part, by a renewed travel grant from the Univ. of Illinois Research Board). Our main effort has been in the partial wave analysis of the $\pi^- p \rightarrow p \pi^- \pi^- \pi^+$ events, now numbering about 70,000, discussed above. We have also assembled smaller samples of $K^- p \rightarrow p K^- \pi^- \pi^+$ and $\bar{p} p \rightarrow \bar{p} p \pi^- \pi^+$ events. Highlights of some interesting by-product results obtained in FY73 are:

- a) differential cross section and scaling in the inclusive reactions $\pi^- p \rightarrow p + \text{anything}$ and $K^- p \rightarrow p + \text{anything}$. Our data cover the $-t$ range $0.18-0.32(\text{GeV}/c)^2$ for $\pi^- p$, $0.08-0.48$ for $K^- p$. All the missing mass spectra[†] show broad enhancements in the differential cross sections at 25 and 40 GeV ($s = 48$ and $76(\text{GeV}/c)^2$), there is, to within the 10% absolute normalization uncertainty, scaling with respect to the center-of-mass longitudinal momentum ($x = -0.90$ to -0.75).
- b) $\pi^- p$, $K^- p$, $\bar{p} p$ elastic scattering.* The differential cross sections have been measured in the $-t$ range -0.80 to -0.07 . For $\pi^- p$ and $K^- p$ the curve of $\log d\sigma/dt$ versus t is concave upward; between 25 and 40 GeV/c the extrapolated total elastic cross section falls as $p_{\text{inc}}^{-0.25}$. For $\bar{p} p$ it is not clear that a curved fit is better than a linear one; the total elastic cross section falls as $p_{\text{inc}}^{-0.4}$. The results join smoothly to lower energy results. For $\pi^- p$ and $K^- p$ there appears to be shrinkage of the diffraction cone; for $\bar{p} p$ the dependence on s and t is more complex.

A9. A Model That Could Account for the ρ' Data

(D. Mortara)

Over the past year evidence has mounted for a ρ' resonance with the quantum number of the ρ meson and a mass of ~ 1.5 GeV. The ρ' may suffer from the same ambiguity which has plagued another predicted particle, namely the A_1 . A model based on the decay $\rho^0 \rightarrow \rho^0 + \epsilon^0$ is shown to produce a peak near the ρ - ϵ threshold, i.e. at the observed ρ' peak, and the data of the SLAC-Berkeley collaboration is shown to be qualitatively fitted by the model. The model also explains the apparent absence of a $\pi^+ \pi^-$ decay mode for the ρ' .

[†] $\pi^- p$ Missing Mass paper. Y.M. Antipov, R. Baud, R. Busnello, G. Damgaard, M.N. Kienzle-Focacci, W. Kienzle, R. Klanner, L.G. Landsberg, A.A. Lebedev, C. Lechanoine, P. Lecomte, M. Martin, V. Roinishvili, R.D. Sard, F.A. Yotch and A. Weitsch, Phys. Letters 40B, 147 (1972).

* CIBS Elastic Scattering paper. Y.M. Antipov, G. Ascoli, R. Busnello, G. Damgaard, M.N. Kienzle-Focacci, W. Kienzle, R. Klanner, L.G. Landsberg, A.A. Lebedev, C. Lechanoine, P. Lecomte, M. Martin, V. Roinishvili, R.D. Sard, A. Weitsch and F.A. Yotch. Submitted to XVI Int. Conference on High Energy Physics, Batavia, Illinois 6-13 September 1972.

A10. A Study of the $f^0(1270)$ and $A_2^0(1300)$ Mesons Produced in π^-p Interactions

(L. Holloway, B. Huld, M. Jordan, U. Koetz, U. E. Kruse, D. Mortara,
L. Nodulman in collaboration with a group from the Univ. of Illinois
Chicago Circle)

In this experiment the recoil neutron's direction and time-of-flight were measured with a 52 element neutron counter hodoscope. Optical spark chambers provided information on the pions' trajectories. Around 600,000 photographs were taken and automatically measured with DOLLY. Analysis of data from the principle run at Argonne (E-237) on the reaction $\pi^-p \rightarrow \pi^+\pi^-n$ is now complete. We find no evidence for dipole structure in the f^0 mass region; the mass spectrum is better described by a simple Breit-Wigner shape than a dipole, with confidence levels of 92% and 5% respectively. The two pi differential cross section in the f^0 region is consistent with Wolf's one pion exchange model for momentum transfer $-t \lesssim 0.7(\text{GeV}/c)^2$. The larger than predicted cross section for greater momentum transfer may be attributed to natural parity exchange contributions, as evidenced in the f^0 decay angular distribution. A report on these results is currently being prepared for publication.

Analysis of the reaction $\pi^-p \rightarrow \pi^+\pi^-\pi^0n$ from the principle run is continuing. A reasonably pure sample of events can be obtained, showing a large A_2^0 signal. A more complete description of these data, including information on production at high momentum transfer, will be forthcoming as final analysis is completed in the next few months.

A report on the new measurement of the ω^0 width obtained in the 2.5 GeV/c calibration run, which establishes the missing mass resolution of the neutron detection system has been published. (Phys. Letters 42B, 117 (1972)).

A11. The Reaction $\pi^-p \rightarrow \rho^0n$ at High Momentum Transfer

(H.R. Barton, Jr., L.E. Holloway, D.W. Mortara, L.J. Koester, Jr., U.E. Kruse,
J. H. Smith, L. Nodulman and R. Wojslaw)

Data taking has been completed on this experiment at Argonne (E-321). The purpose of the experiment is to measure the differential cross section $d\sigma/dt$, and the polarization of ρ -mesons at high momentum transfer. A large array of neutron counters were used with time-of-flight to obtain the neutron energy and angle. The 2π mesons trajectories were observed in the Univ. of Illinois magnetostrictive readout wire spark chambers.

Spark chamber track reconstruction programs and kinematic fitting programs have been prepared and the raw data have been passed through them. This was our first experiment exclusively using wire spark chambers to detect the decay products of the ρ^0 and f^0 mesons. During the year, we have dramatically improved our

capability to reconstruct higher multiplicity events detected in large assemblies of spark chambers. Our approach is a road making technique used successfully in reconstructing bubble chamber events measured under minimum guidance. We believe that the expertise acquired will be useful to us as large bubble chambers are phased out and counter-spark chamber detectors replace them.

Preliminary results show a sharp forward peak in the differential cross section with a break at about $-t = 0.5(\text{GeV}/c)^2$. The subsequent behavior of $d\sigma/dt$ can be characterized by an exponential decrease of the form $\exp[1.5t]$. This behavior lasts out to $-t = 2.5(\text{GeV}/c)^2$, the largest value obtained in our experiment. Our results agree with currently available data for $-t < 1.0(\text{GeV}/c)^2$. Our data for $-t > 1.0$ add significantly to that available. The shape of $d\sigma/dt$ agrees with that predicted by the Wolf one-pion-exchange model for $-t < \sim 0.7$ whereas for $-t > \sim 0.7$ our measured values are substantially larger than those predicted.

These preliminary results will be presented at the Washington APS meeting.

A12. Excitation of the 4.4 MeV State in C^{12} by Pion Scattering

(L. Holloway, L.J. Koester, Jr., D. Ravenhall, J.H. Smith, J. Groves, L. Nodulman, and W.K. Liu)

A program of experiments directed toward the use of nuclear targets to simplify the study of high energy interactions was begun in FY72 with Experiment E-314 at Argonne National Laboratory. In this experiment 4.5 GeV/c pions scattered from carbon were observed in coincidence with a 4.4 MeV gamma ray. The gamma ray was detected with a NaI(Tl) crystal.

Good measurements of the momentum transfer dependence of the reaction $\pi^- C^{12} \rightarrow \pi^- C^{12*}$ (4.44 MeV) were obtained for four different γ angles. The differential cross section has a maximum at about $-t = 0.045(\text{GeV}/c)^2$ and a pronounced dip in the forward direction because the C^{12} is left in a 2^+ final state. The results are consistent with CERN measurements at lower energies, but the interactions radius is smaller in our case because 4.5 GeV/c is well above the pion-nucleon resonance region. The azimuthal distribution of the γ rays is characteristic of electric quadrupole radiation and shows that the final state is composed primarily of $M = 0$ with about 15% $M = \pm 2$ and very little $M = 1$ contributions.

Thus we have demonstrated the feasibility of observing characteristic gamma rays in coincidence with high energy phenomena. Other experiments are now in progress which will exploit this technique (E-323). A paper is being prepared for the Physical Review.

A13. A Study of Reaction $\pi^- C \rightarrow C^* \pi^- \pi^- \pi^+$ at 6 GeV/c

(G. Ascoli, H.R. Barton, Jr., L. Holloway, L.J. Koester, Jr., U.E. Kruse, L. Nodulman, T. Roberts, B. Weinstein and R. Wojslaw)

The experiment $\pi^- C^{12} \rightarrow C^* \pi^- \pi^- \pi^+$ (C^*^{12} corresponding to the 4.4 MeV excited state) was run at the ZGS at Argonne (E-323) during December 1972, January and part of February 1973. The charged pions were detected in the ANL effective mass spectrometer; the γ rays from the decay of the 4.4 MeV excited state in carbon were detected in a NaI crystal mounted near the carbon target. Details of the NaI system are given elsewhere in this report. The analysis of these events has started on the PDP-10 computer in Urbana and a preliminary analysis shows we have roughly 2000 events. The effective mass spectrum shows a strong enhancement in the A_1 region with a differential cross section of the form $d\sigma/dt \sim t e^{45t}$.

This experiment is unique in that it is the first of its kind in which high energy particle production processes have been observed in conjunction with a nuclear level transition. The advantage of this technique is that the isotopic spin zero exchange amplitude is isolated thus simplifying the total reaction amplitude.

A14. Collaboration on Hybrid Bubble Chamber Proportional Wire Spectrometer at NAL (NAL Experiment 154)

(G. Ascoli, R. Downing, U.E. Kruse, R.D. Sard, V.J. Simaitis, A. Snyder, J. Tortora)

This spectrometer uses the MURA-ANL-NAL 30-inch hydrogen bubble chamber target, with proportional wire chambers upstream and downstream for beam tagging and measurement of secondary momenta. The upstream chambers and all the amplifiers were designed and built at Illinois. The upstream part of the system has been in operation at NAL since the fall of 1972 as the "Upstream Tagging Facility", an essential part of 30-inch bubble chamber operations there. We have maintained the chambers for bubble chamber users and have been involved in survey and error analysis of the system. The downstream chambers are now being made ready at NAL for a short, 20,000 picture, run to test the entire system. It is anticipated that the test will take place before the end of FY73.

A15. High Energy Photon Experiments at NAL

(G. Gladding, M. Gormley, T. O'Halloran, A. Wattenberg, J. Bronstein, L. Cornell, J. Sarracino, D. Wheeler in collaboration with W. Lee and B. Knapp Columbia Univ., J. Peoples NAL, and F. Harris and D. Yount Univ. of Hawaii)

This is an experiment which makes use of the high energy photons from π^0 decay that are produced at 0° at NAL. There are two major parts to experiment NAL 87A. One part is related to the electromagnetic interaction as described in this subdivision. The second part (described in A16 below) is related to theoretical conjectures concerning the weak interactions. The initial runs will check the instrumentation and will study the spectrum of the beam.

Among the earliest experiments, we will measure the cross section for rho meson photoproduction with 20-200 GeV photons and we will explore the mass range from 1-10 GeV for $J^P = 1^-$ states. In that the photon is coupled to the $J^P = 1^-$ family of particles, the use of a very high energy photon beam provides a very natural mechanism for the diffraction production of such states.

Liquid hydrogen and a series of nuclear targets will be used in order to study the rho meson diffractive photoproduction at very high energy and the variation of the cross-section of vector mesons on nucleons as a function of energy. The simple vector dominance model predicts that the rho photoproduction cross-section will be constant.

Experiments will be performed in the recently constructed Proton East (EE4) Laboratory. The equipment for these experiments consists of fifteen multi-wire proportional counter planes and a magnet in order to provide good momentum resolution. The photon beam will be monitored by a quantameter and shower detectors will be used to determine the spectrum. During FY73 the quantameter was constructed, and it was calibrated to an accuracy of the order of 0.5% at SLAC. The multiwire proportional counters were constructed at Columbia, and one of them has been at Illinois since early in the fall attached to the Univ. of Illinois electronics systems. All the amplifiers and associated electronics, including the interface to the computer, have been constructed and the assembly is almost complete including various checking systems. Installation of this equipment at NAL should begin during May or June, and it may take several months.

A16. Search for Heavy Leptons and Intermediate Bosons by High Energy Photon-Pair Production (NAL 87A Experiment)

(G. Gladding, M. Gormley, T. O'Halloran, A. Wattenberg, J. Bronstein, L. Cornell, J. Sarracino, D. Wheeler in collaboration with W. Lee and B. Knapp Columbia Univ., J. Peoples NAL, and F. Harris and D. Yount, Univ. of Hawaii)

These measurements also make use of the beam of high energy photons one can obtain at small production angles at NAL. If there are heavy leptons or intermediate vector bosons with masses below 9 GeV, then they should be produced by high energy photons with at least the Bethe-Heitler cross-section for pair production. The equipment is being set up to look for such particles by detecting the leptonic

decay modes with the aid of electromagnetic shower detectors and twelve feet of steel followed by scintillation counters for detecting muons. The multiwire proportional counters and magnet system (described in Section A15) will measure the transverse momentum which allows us to determine the mass of the decaying particle. As the cross-sections are low for these processes, one needs an intense beam of photons, and this is why the experiments are performed in a broad band photon beam. The neutrons which are present in such a beam are attenuated by the use of 100 ft. of deuterium.

During FY73 NAL has completed the structure in which this experiment will be performed, and they have also built and tested the first 35' section of the neutron attenuator. The Univ. of Illinois group has contributed to the instrumentation for beam monitoring and to the design of the neutral beam. The shower detectors are being assembled at Illinois (the development of these shower detectors is described in Section IV). We have also built the electronics and interfacing for the multiwire proportional counters. The interface to the Sigma 2 has been checked and a good deal of effort has gone into the software for the initial running period. We plan to start the installation of this equipment in the EE-4 area at NAL during FY73.

A17. Comparison of CP Violation in $\bar{K}^0$ and K^0 Decays into $\pi^+\pi^-$

(M. Gormley, L.J. Koester, Jr., J.H. Smith, A. Wattenberg, D. Banner, J. Frank, S. Raither)

This experiment (Argonne E-256) was designed to compare directly the CP violation of $\bar{K}^0$ and K^0 decays into $\pi^+\pi^-$. CP violation in the $\bar{K}^0$ decay had not previously been directly observed. The pi mesons from K decays were observed in a three sided array of twelve magnetostrictive wire spark chambers which were triggered by counter hodoscopes. The analysis was completed last summer, and an article was submitted last fall (Phys. Rev. April 1973). K^0 ($\bar{K}^0$) mesons were produced by charge exchange of K^+ (K^-) in a carbon target subdivided into nine wafers by scintillation counters which allowed us to determine the production point. The time distributions of the decays $K^0 \rightarrow \pi^+\pi^-$ and $\bar{K}^0 \rightarrow \pi^+\pi^-$ were directly compared. The experiment shows a difference in the decay distributions of the K^0 and $\bar{K}^0$ mesons and therefore constitutes a direct experimental proof that CP is violated independent of any theoretical conventions.

A phenomenological χ^2 analysis of the $\bar{K}^0$ decays was performed in terms of the CP violating parameters $\bar{\eta}$ and $\bar{\phi}$ and resulting values are: $|\bar{\eta}| = (3.5 \pm 1.4) \times 10^{-3}$ and $|\bar{\phi}| = 66^\circ \pm 21^\circ$. These values are in reasonable agreement with the much more precisely determined values of $|\eta|$ and ϕ .

A18. The Energy Dependence of the $K_{\mu 3}$ Form Factors

(A. Wattenberg and M. Kantrowitz in collaboration with R. Abrams, Univ. of Illinois Chicago Circle and Kycia Group at BNL)

This is an experiment performed at BNL using optical spark chambers and it should yield the order of 20,000 events on the polarization of the muon from $K_{\mu 3}$ decays. The direction of the decay electron from the muon gives us statistical information on the polarization of the muon. From the μ polarization as a function of position in the Dalitz plot, one determines the ratio of the $K_{\mu 3}$ form factors, and thus whether there is a different energy dependence for the form factors. All the film will have been measured once by May 1973 and any remeasurements should be finished during this summer.

B. Experiments Planned for the Coming Year

B1. $\pi^- p \rightarrow p X^-$ in the Backward Direction

(B. Eisenstein, T. O'Halloran, D. Rhines, P. Sokolsky, N. Beamer, W. Mollet, G.R. Morris in collaboration with M. Buttram, Iowa State University, J. Watson, Argonne National Laboratory and N. Gelfand, on leave from the Univ. of Chicago)

Analysis will continue on the film currently being taken. From this new 250,000 picture sample we expect at least 2500 events of $\pi^- p \rightarrow p \pi^+ \pi^- \pi^-$. In addition we will study events with one and five charged pions in the final state, events with one π^0 , and events such as $\pi^- p \rightarrow \bar{p} \bar{p} p \pi^-$ and $K^+ p K^- \pi^-$. Some events in the latter category have already been found, but have not been examined in detail. The film scanning and measuring process will be completed by mid FY74, and physics analysis should occupy at least the rest of the year.

B2. $\pi^- p \rightarrow n X^0$ in the Backward Direction

(B. Eisenstein, T. O'Halloran, D. Rhines, P. Sokolsky, N. Beamer, W. Mollet, G.R. Morris in collaboration with M. Buttram, Iowa State University, J. Watson, Argonne National Laboratory and N. Gelfand, on leave from the Univ. of Chicago)

In order to define a fast forward neutron for triggering the streamer chamber, a set of heavy plate spark chambers and scintillation counters will be placed about 10 meters downstream of the streamer chamber. A lead-scintillator "gamma ray filter" precedes these chambers to reduce photon initiated triggers and to veto charged particles incident on the chambers. The detection of the neutron initiated hadron shower in the chambers will trigger the system, and the measurement of the interaction point in the chambers will allow reconstruction of the neutron line of flight. A short (< 10 nsec) gate on the counters will separate fast neutron events from the background of slower neutrons. In addition, magnetostrictive wire spark chambers will be installed in the beam to give a more accurate determination of the beam momentum for the 3-constraint fit to $\pi^- p \rightarrow n +$ (all charged).

ANL is now beginning construction of an addition to our present experimental area to house the neutron detectors. The γ -ray filter is being constructed, as are the stands and mirror mounts for the spark chambers. The chambers themselves will be old Illinois devices with new plates for this experiment. The first one (of three) is now completed and being tested. The magnetostrictive chambers again have been previously used in an experiment here.

We have been initially approved for 150,000 pictures. Our intent is to achieve statistics comparable to those for the $\pi^- p \rightarrow p X^-$ experiment.

Assuming an initial run in early FY74 (as currently on the ZGS schedule) we anticipate the 150,000 picture exposure completed by mid-year. Scanning and measuring can then proceed since the facilities will be freed by completion of this phase of the $\pi^- p \rightarrow pX^-$ experiment. Some preliminary work will be required to utilize the digital beam track information and the neutron direction as measured in the spark chambers. We anticipate that by late FY74 enough events will be analyzed to allow some preliminary physics conclusions and to guide us in the subsequent run.

B3. $\pi^+ p \rightarrow nX^{++}$ in the Backward Direction

(B. Eisenstein, T. O'Halloran, D. Rhines, P. Sokolsky, N. Beamer, W. Mollet, G.R. Morris in collaboration with M. Buttram, Iowa State University, J. Watson Argonne National Laboratory and N. Gelfand, on leave from the Univ. of Chicago)

A proposal is now being written to study the backward production of double charged meson systems at 8 GeV in the reaction $\pi^+ p \rightarrow nX^{++}$. Particular emphasis will be initially placed on the states $X^{++} \rightarrow \pi^+ \pi^+$, $\pi^+ \pi^+ \pi^+ \pi^-$. The experiment is motivated by the remarks by several authors that exotic mesons should exist and couple preferentially to baryon-antibaryon systems. Thus their production is more likely to be experimentally observed in baryon, rather than meson, exchange reactions.

The apparatus will be identical to that for the experiment $\pi^- p \rightarrow nX^0$, with the addition of two beam Cherenkov counters to tag π^+ mesons in an incident positive beam. We hope to run this experiment immediately on conclusion of the $\pi^- p \rightarrow nX^0$ run. The analysis of the data would be carried out in parallel for the two experiments.

B4. Future Studies of the 3π System Produced in $\pi^- p \rightarrow 3\pi p$.

(G. Ascoli, L.M. Jones, R. Klanner, U.E. Kruse, R.D. Sard, H.W. Wyld and W. Kienzle (Cern))

- a) The study of the Deck effect and its comparison with the experimental 3π observations should be completed in FY74 and submitted for publication.
- b) The study of the effect of unitarity corrections on our results will probably be completed in FY74, unless unexpected differences arise requiring a very detailed resurvey of the A_1 - A_2 - A_3 data.
- c) The proposed study of the Jon Wright model for the A_1 is in a very preliminary state. It is therefore not possible to predict the rate of progress at this time.

- d) The plans for future analysis of the CIBS data sample are not settled at this time. Future plans hinge on two points:
- 1) The results obtained for a) and b) above, which will determine to a considerable extent whether an analysis based on higher statistics is worthwhile.
 - 2) The future plans of our Cern collaborators (principally W. Kienzle).

B5. Study of the Reaction $\pi^- C^{12} \rightarrow C^{12} \pi^- \pi^- \pi^+$ at 23 GeV

(G. Ascoli, R. Klanner, U.E. Kruse, T. Roberts, B. Weinstein)

The Carnegie-Mellon-Northwestern collaboration (Edelstein, Rosen) has obtained large samples of $\pi^- C^{12} \rightarrow C^{12} \pi^- \pi^- \pi^+$ at 23 GeV at Brookhaven National Laboratory and we hope to analyze these events in the near future. Previous studies of this reaction have not made a detailed analysis of the 3π state. By applying the Partial Wave Analysis to this data we should be able to obtain good information on the 3π system formed coherently and presumably leaving the carbon nucleus in the ground state. It should complement our own data from E-323 with carbon nucleus in the 4.4 MeV excited state.

B6. Proposed Studies of $K^\pm \pi^+ \pi^-$ System

(G. Ascoli, R. Klanner, U.E. Kruse, R.D. Sard)

In the $K\pi\pi$ system produced in $K^\pm p$ reactions, one sees enhancements (Q , K_{1420}^* , L) which bear at least a superficial similarity to the A_1 , A_2 and A_3 enhancements in the 3π system. No detailed analysis of the type used by us in studying the 3π system has been carried out up to now.

Several differences between the $K-\pi-\pi$ and the 3π system may exist:

- a) In the Q -region, both the $K_{890}^*-\pi$ and the $K-\rho$ decay modes have been reported. In at least one study a change in the relative phase with $K\pi\pi$ mass has been suggested.
- b) In the Q -region, the polarization appears to be inconsistent with either s - or t -channel helicity conservation.
- c) The K_{1420}^* cross-section appears to fall off with increasing energy faster than the A_2 .
- d) Results in the L -region are contradictory. In one experiment ($K^+ p$ at 12 GeV, LRL) the data are interpreted as being consistent with an enhancement (Deck?) only in the $K_{1420}^*-\pi$ decay mode, while in other experiments (e.g. $K^- p$ at 10 GeV, ABC) enhancements in other decay channels have also been seen.

It appears to us to be desirable to try to clarify the experimental situation, possibly by carrying out a partial wave analysis similar to that used on the (3π) system. The current situation is:

- a) In April 1972 we participated in a run at Serpukhov, designed to obtain data on $K^- p \rightarrow K^- \pi^+ \pi^- p$ at 40 GeV. The reduction of the data (event selection, kinematic fitting, study of acceptance and $K^- \rightarrow \pi^-$ ambiguity) is not yet complete. After this work is completed (in 4-6 months) we will decide whether the data sample is adequate for a detailed physics study.
- b) We have access to the World summary of $K^+ p$ interactions and we have discussed (in particular with Arthur Rosenfeld) the possibility of analyzing other existing data as well.
- c) If (a) and (b) fail, we will look into the feasibility of obtaining new data, possibly at BNL.

We anticipate that a thorough study of the $K\pi\pi$ system will require about two years.

B7. Proposed Studies of the $\bar{p} \pi^- \pi^-$ System

(R. D. Sard, R. Klanner, J. Tortora)

The same Serpukhov runs that produced the $K^- p$ data at 25 and 40 GeV/c referred to above also yielded a sample of $\bar{p} p$ data at these momenta, as the four Cherenkov counters in the beam line permitted unambiguous identification of individual beam particles. The reaction $\bar{p} p \rightarrow \bar{p} p \pi^- \pi^+$ has been singled out for analysis, and we have obtained in FY73 about 1700 fitted events at 25 GeV/c and about 1500 at 40 GeV/c. These samples are too small for partial wave analysis, but they should permit a qualitative study of the dissociation of the anti-proton into anti-delta plus π^+ at large s and small t. We intend to look into this possibility as soon as the tapes of fitted events are received from Cern.

B8. NAL Proportional Hybrid Spectrometer (NAL Experiment 154)

(G. Ascoli, U.E. Kruse, R.D. Sard, A. Snyder, J. Tortora)

The data of the 20,000 picture test will be processed on the MIT PEPR. Assuming that the test is successful, we shall be proposing, in collaboration with the other members of the consortium (MIT, Yale, Johns Hopkins, Rutgers, Tennessee, Indiana, Illinois Inst. of Technology, NAL) a series of full-scale experiments. Our main interests at Illinois are:

- a) Two-particle inclusive experiments: One needs to measure the correlations between secondary particle momenta, in order to test Feynman's idea that in the high-energy limit the interactions depend in a simple way on proximity in

longitudinal momentum space. The inclusive reaction $\pi^- p \rightarrow \pi^- \pi^- + \text{anything}$, at 200 GeV/c or higher, would be used. An exposure yielding about 30,000 pictures is needed, of these about 5000 would contain events with four or more prongs. We would use DOLLY to locate the vertex and to measure low-momentum secondaries. The downstream wire chambers, with the bubble chamber vertex measurement, determine the large momenta.

- b) $\pi^- p \rightarrow p \pi^- \pi^+ \pi^-$: The hybrid system will have a lead converter before the last downstream chamber to tag photons from π^0 -decay. It thus should be possible to collect a sample of events of this channel without excessive π^0 contamination. A 60,000 picture exposure would yield about 1000 cases. It will be of interest to compare the differential cross sections with respect to four-momentum transfer and effective mass with those found in the Serpukhov 25 and 40 GeV/c exposures, in order to make a more decisive test of scaling.
- c) Elastic scattering: With the vector momenta of both prongs measured by the hybrid system, it is possible to do kinematic fitting of elastic events, for discrimination against inelastic events with neutral pions. This discrimination should be good down to $|t| = 0.05 \text{ GeV}^2/c^2$. A batch of 50,000 $\pi^- p$ pictures at 200 GeV/c would, conservatively, yield about 2000 scatters with $|t| > 0.05 (\text{GeV}/c)^2$ enough for a preliminary determination of the shape and absolute magnitude of the elastic cross section.

We are in consultation with our partners in the consortium with regard to the physics plans and are preparing concrete proposals for the next phase of the PHS experiment.

B9. The Reaction $\pi^- p \rightarrow \rho^0 n$ at High Momentum Transfer

(H.R. Barton, Jr., L.E. Holloway, D.W. Mortara, L.J. Koester, Jr., U.E. Kruse, J.H. Smith, L. Nodulman and R. Wojslaw)

Final analysis of the data from E-321 should be completed. The extraction of the accessible ρ spin density matrix elements will be made in addition to those combinations which isolate the natural- and unnatural-parity exchange components.

B10. A Study of Reaction $\pi^- C^{12} \rightarrow C^{*12} \pi^- \pi^- \pi^+$ at 6 GeV/c

(G. Ascoli, H.R. Barton, Jr., L.E. Holloway, L.J. Koester, Jr., U.E. Kruse, L. Nodulman, T. Roberts, B. Weinstein, R. Wojslaw)

The analysis of this experiment (E-323) is continuing and we hope that it will be essentially complete during FY74.

We are currently comparing the estimated magnet acceptance with the actual 3-pion events found. When the magnetic acceptance is understood we should be able to

apply our partial wave analysis program to examine the spin-parity content of the 3-pion system.

During the run we also collected information on the reactions $\pi^- C^{12} \rightarrow C^{12} \pi^- \pi^- \pi^+$, $\pi^+ C^{12} \rightarrow \pi^+ C^{12} \pi^+ \pi^-$ (4.4 MeV), and $p C^{12} \rightarrow p C^{12} \pi^0$. We hope to analyze these results during FY74.

B11. Experiments Using Characteristic Nuclear Gamma Rays to Identify High Energy Interactions

(L.E. Holloway, L.J. Koester, Jr., U.E. Kruse, D. Ravenhall, R. Cutler, T. Roberts, B. Weinstein)

In experiments E-314 and E-323 we used the 4.4 MeV γ ray from C^{12} to identify the final state. This final state has isospin $T = 0$, as does the initial state, so the interaction can go by Pomeron exchange. We would like to observe a final state with $T \neq 0$ in order to require the exchange of some kind of meson. So far, we have been unable to detect the 15.1 MeV gamma ray from C^{12} representing a $T = 1$ state, down to the 1% level. Among other possible targets, Li^6 has a 3.56 MeV state of $T = 1$ which cannot decay by particle emission. We are working on a proposal to use the Argonne Effective Mass Spectrometer with a Li^6 target and our NaI (Tl) detector to observe this kind of transition. If we are successful, we may have a good tool for studying isotopic spin one exchange amplitudes.

The Argonne group has plans for increasing the acceptance of the Effective Mass Spectrometer. This improvement would make possible much more sensitive experiments of the type we want to do, and we support their proposal.

B12. Interactions of K_L^0 Mesons in Hydrogen and Deuterium

(A. Wattenberg in collaboration with groups from SLAC, Univ. of Colorado and Univ. California at Irvine)

In the course of considering experiments to study the strong interactions of K_L^0 mesons at NAL, it became obvious that it would be desirable to perform some of the experiments at lower energies as well as at NAL. Arrangements have been made to collaborate with Hitlin, Liu, Morse, Nauenberg and Condon in an experiment at SLAC which will include the t dependence of regeneration in hydrogen and deuterium, the production of K^* mesons, and the production ratios of various charged states.

B13. High Energy Photon Experiments at NAL

(G. Gladding, M. Gormley, T. O'Halloran, A. Wattenberg, J. Bronstein, L. Cornell, J. Sarracino, D. Wheeler in collaboration with W. Lee and B. Knapp Columbia Univ., J. Peoples NAL, and F. Harris and D. Yount, Univ. of Hawaii)

During the summer and fall of FY74 initial studies of the beam composition,

the photon spectrum, and the functioning of the equipment, should take place. An excellent check on the reliability of the equipment will be the measurement of rho meson photoproduction.

The search for $J^P = 1^-$ objects could be made more sensitive if the polarized photon technique that was developed at SLAC last year were available, if not initially, at least long range. Therefore we hope to make a preliminary study of the degree of linear polarization and/or the angular distribution of coherent pair production by single crystals.

B14. μp Inelastic Scattering at NAL

(T. Kirk, W. Francis, and M. Kantrowitz in collaboration with groups from Univ. of Chicago, Harvard University and Oxford University)

The Univ. of Illinois began to participate in the construction and operation of the Muon Scattering Facility at NAL with the arrival of Professor T. B. Kirk in FY73. The first experiment (NAL-E98) scheduled for this facility will be muon proton inelastic scattering with detection and momentum determination of final state hadrons. Physicists from the Univ. of Chicago, Harvard Univ., Oxford Univ. and the Univ. of Illinois are collaborating in the experiment. The purposes of the investigation are manifold, but principal areas of interest include:

- 1) scaling behavior (or lack of it) in ν and q^2 regimes previously inaccessible;
- 2) expansion of the scaling function νW_2 to large values of ω ;
- 3) inclusive spectra of recoil hadrons from γ^*p (virtual photon proton) collisions (an indication of parton relaxation mechanisms);
- 4) detailed study of interesting exclusive final states such as rho and omega production;
- 5) virtual photoproduction total cross section with almost real photons;
- 6) a new and tighter bound on μe universality (by comparing $e p$ and μp scaling behavior);
- 7) exotic or hitherto unseen processes such as excited leptons or muon charge exchange.

The equipment is essentially complete and is being erected at NAL. Data taking will begin this spring. In FY74 the initial running should be completed (with about 100,000 events collected), and a large fraction of the analysis should be done. Software for this job is about one half completed at present. The contribution of the Univ. of Illinois to E-98 will increase sharply in FY74 with the addition of a Post Doctoral Fellow, a thesis student, and substantial use of the Univ. of Illinois computational facilities.

B15. Search for Heavy Leptons and Intermediate Bosons by High Energy Photon-Pair Production (NAL 87A)

(G. Gladding, M. Gormley, T. O'Halloran, A. Wattenberg, J. Bronstein, L. Cornell, J. Sarracino, D. Wheeler in collaboration with W. Lee and B. Knapp, Columbia Univ., J. Peoples NAL, and F. Harris and D. Yount, Univ. of Hawaii)

The installation of the equipment for this experiment should be completed and the calibration of the electron detectors should take place early in FY74. After obtaining experience with the photon beam and with our apparatus from measuring rho meson photoproduction, we will make measurements to establish the existence or non-existence of heavy leptons. Any charged particle that exists will be produced with at least a Bethe-Heitler cross-section, and if they are in the mass range $2-9 \text{ GeV}/c^2$ and have a reasonable branching ratio into two or three body decay modes that include electrons or muons, they will be detected by our apparatus.

Even if the running phases were completed in FY74, there still will be involvement with analyzing the data from this experiment in FY75. However, we trust that the results from the first phase of the heavy lepton measurements will be of sufficient interest that more detailed studies with the high energy photon beam will be undertaken.

B16. Study of Neutral Currents in Leptonic and Semi-Leptonic Processes Induced by High Energy Neutrinos

(L. Holloway, T. A. O'Halloran and others)

The purpose of this experiment is to search for neutral currents in leptonic processes, i.e., $\nu_\mu + e^- \rightarrow \nu_\mu + e^-$ and semi-leptonic processes, e.g., $\nu_\mu + p \rightarrow \nu_\mu + p + \pi^0$.

The interest in this experiment has been generated by Weinberg's theory which attempts to unify the weak and electromagnetic interactions. At the present time the experimental bounds for the test of this theory are:

$$R_1 = \frac{\sigma(\nu + p \rightarrow \nu + p + \pi^0) + \sigma(\nu + n \rightarrow \nu + n + \pi^0)}{2\sigma(\nu + n \rightarrow \mu^- + p + \pi^0)} \leq 0.14$$

and $\sigma(\nu_\mu + e^- \rightarrow \nu_\mu + e^-) \leq 0.7 \times 10^{-41} \text{ Ev cm}^2$. This would place a limit of $\sin^2 \theta \leq 0.6$ on the Weinberg Mixing angle.

The experiment will use optical spark chambers interspersed with 1/4" aluminum plates and scintillation counters. The ultimate sensitivity of the proposed experiment can be indicated by comparing the flux rates used to determine the present limit on R_1 with those available previously. The total integrated flux on the Columbia experiment which gave the limit $R_1 \leq 0.14$ was about 10^{17} protons. We are proposing in the present experiment a run of 10^6 pulses with 10^{13} proton/pulse. In addition we

get an additional factor of 5 from the improved ν beam and a factor of 2 for the increased mass of the chambers and scintillation counter systems. It is possible therefore to lower R_1 to 10^{-4} if the background can be understood and reduced. In addition, one would expect ~ 20 events for the reaction $\nu_\mu + e^- \rightarrow \nu_\mu + e^-$ at $\sin^2 \theta \sim 0.4$ which is the minimum point in the cross section.

At the present time the initial tuning of the ν beam will take place this summer. A run which will enable us to study the background rate to the level of $R_1 = 10^{-3}$ is scheduled this winter. The experiment is done in collaboration with Brookhaven National Laboratory, Columbia University and Rockefeller University.

C. Experiments that are Planned for Future Years

C1. Backward Reactions in the Streamer Chamber

(B. Eisenstein, W. Mollet, T. O'Halloran, D. Rhines and others)

Analysis should be completed by early FY75 on the study of $\pi^- p \rightarrow p X^-$. The complementary experiment, $\pi^- p \rightarrow n X^0$, will have completed the measuring of the initial 150,000 picture exposure. Since we intend to enlarge the data sample if the preliminary results warrant it, another run may occur in late FY74 or early FY75. Similar remarks hold for the reaction $\pi^+ p \rightarrow n X^{++}$. Physics analysis of these latter experiments should be nearing completion by late FY75.

C2. Particle Correlations at Large Transverse Momentum

(G. Gladding, M. Gormley in collaboration with CERN)

One of the most important and intriguing results of recent data from the ISR is the shape of the transverse momentum ($p_{\perp}$) spectrum of secondaries produced in pp collisions at large center-of-mass energies (s).

The existing data can be summarized as follows: At small values of $p_{\perp}$ (0-2 GeV/c) the invariant cross section for the production of secondary particles shows an exponential behavior. The observed counting rates at large $p_{\perp}$ (3-6 GeV/c) are several orders of magnitude greater than what would be expected from an extrapolation of the small $p_{\perp}$ data. Any theory which has attempted to cope with these results associates the small $p_{\perp}$ data with interactions at the surface of the proton and either assumes the existence of point-like hadronic constituents (partons) or invokes the use of elementary point-like couplings to "understand" the unexpected counting rates at large $p_{\perp}$. Since the appropriate variable for describing such processes appears to be $\sqrt{s}/p_{\perp}$, the ISR is by far the most favorable accelerator at which to pursue such studies.

The existing experimental data at large $p_{\perp}$ is both exciting and meager; by and large it consists of inclusive measurements, i.e. experiments in which only a single secondary is detected on one side of the interaction region. To obtain additional information on the mechanism involved in the production of such events, it is highly desirable to study particle correlations at large transverse momentum by placing detectors on both sides of the interaction region. We are preparing a proposal to the ISR for an experiment which would look at many particles using large solid angle detectors on both sides of the interaction region. By making simultaneous measurements on each side of the interaction region, we will be able to study the correlations which exist in the production of large $p_{\perp}$ secondaries and to ask questions such as whether or not they are manifestations of hadronic jets. In addition, the apparatus we plan to use represents a very natural detector for studying both

inclusive and exclusive reactions involving neutrons and other neutral hadrons.

The equipment we plan to use would subtend approximately 1 steradian on each side of the interaction region and would consist of a set of scintillation counters, wire chambers, and shower detectors, followed by a hadron calorimeter. The shower detector and calorimeter will be used to select events with energies ≥ 2 GeV, while the scintillation counters and wire chambers will provide a measure of charged particle multiplicities of such events. The shower detectors will be similar in design to those already constructed for NAL experiment E-87. The energy resolution of these counters was measured to be $\pm 5\%$ at 6 GeV, which is more than adequate for the ISR experiment.

We view this new experiment as a natural extension of the experiment recently completed at the ISR on the production of large transverse momentum π^0 's. One of us (G. Gladding) participated in the π^0 production experiment and has experience in running at the ISR. To our knowledge, there are no other current proposals to explore this new region of large $p_{\perp}$ hadron production in the manner we are proposing.

C3. High Energy Diffraction Production of Multi-Pion States

(G. Ascoli, U.E. Kruse, R. Klanner)

The result of the CIBS experiment which showed that the A_2 was diffractively produced at 40 GeV is very provocative. It raises the question as to whether other natural parity multi-pion states are produced at 40 GeV or higher energies. We are considering exploring the possibility of extracting and analyzing five pion data from either existing runs or those that could be performed with existing spectrometers.

C4. Further Studies of $\pi^- C \rightarrow \pi^- \pi^- \pi^+ C^*$

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

One objective in studying the reactions ($\pi^- C \rightarrow \pi^- \pi^- \pi^+ C^*$) was to look for the possibility that the A_2 meson is produced in this reaction. We considered this to be a distinct possibility because:

- a) The cross-section for $\pi^- p \rightarrow A_2^- p$ falls with energy at a slow enough rate to suggest that Pomeron exchange is a major contributor.
- b) A_2 production has not been seen yet in $\pi^- C \rightarrow 3\pi C$ (ground state). This could result simply from the fact that A_2 production vanishes at small momentum transfer and that the probability of the nucleus remaining in the ground state are larger momentum transfers is small. In $\pi^- C \rightarrow \pi^- C^*$ the cross section peaks at finite momentum transfers ($\sim 0.05 \text{ GeV}^2$).

If the current experiment (E-323) should indeed show a reasonable amount of A_2 production many interesting possibilities for study suggest themselves which

would require further data. They include:

- a) Study of the A_2 production amplitude in a pure isoscalar exchange reaction.
- b) A test, using a well-established $3-\pi$ resonance, of current ideas about the propagation of such an object in nuclear matter.

C5. K_L^0 Experiments at NAL

(T. Kirk, M. Gormley, A. Wattenberg and others)

There are a number of very interesting experiments which the Univ. of Illinois group would like to perform using high energy K^0 beams. With the ISR indicating an extraordinary increase in the total pp-cross section at highest energies, it becomes of increasing interest to push the regeneration experiments to the highest possible energies. These experiments measure the particle-antiparticle cross section difference in a way that is virtually free of systematic error. Of equal importance is the fact that real and imaginary scattering amplitudes are separated and explicitly measured. There are a variety of production reactions with K^0 mesons which provide unique information for the study of strong interactions. It is our intention to select some of the more interesting of these (e.g. fast forward production of Λ^0 and $\bar{\Lambda}$ and K^*) and to try to plan experiments using mainly existing equipment.

C6. High Intensity Muon Beam

(T. Kirk and W. Francis)

In order to realize the full potential of the NAL machine to contribute to electromagnetic physics, a new high intensity ($10^8 \mu's/10^{13} p's$) muon beam must be planned and constructed. A sub-committee of the E-98 group has been formed to study this problem and make recommendations and/or proposals to NAL. It is expected that the Univ. of Illinois will be centrally involved in this endeavor and that a specific beam proposal will result. Planning meetings will take place during the summer and early fall of 1973.

C7. High Energy Photon Experiments at NAL

(G. Gladding, M. Gormley, T. O'Halloran, A. Wattenberg, J. Bronstein, L. Cornell, J. Sarracino in collaboration with W. Lee and B. Knapp Columbia Univ., J. Peoples NAL, and F. Harris and D. Yount, Univ. of Hawaii)

We should be analyzing the data obtained in FY74. The first study will be of the photoproduction of rho mesons and a search for other $J^P = 1^-$ mesons. By studying the production and decay of the ρ^0 meson we should be able to investigate

diffractive production. If the present promise of polarized photons matures, we will have a rather sensitive technique to study this important mechanism over a significant energy range. We should be able to extend our search for heavier vector mesons.

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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, J. Wray, R. Stamerjohn)

The final three measuring stations of the DOLLY precision CRT film measuring system remaining were completed and put into full production on streamer chamber film. A total of 39,000 events of streamer chamber film were measured at rates of the order of 10-20 events/hour. These film measuring stations have 2:1 optics for better matching to 35mm film. Signal detectors and CRT control circuitry have been improved significantly over that for the initial station.

Software development for the streamer chamber film continues towards greater automation of the measuring process. The initial streamer chamber film required a considerable amount of operator intervention because of faint tracks, flares, etc. Film advance, frame location, and fiducial measurements are now completely automated. Film taken after the streamer chamber engineering improvement program has improved track quality and should permit more automatic measurements.

A2. Computer Operations

(R. Brown, M. Czechowski, N. Meyer, R. Uphoff, J. Wray)

During FY73 the Digital Equipment Corp. PDP-10 system was installed and shaken down for full production use by the group. The University-owned IBM 7094 operated by this group was removed from service in October 1972. A total of 2800 PDP-10 CPU hours is projected for FY73 as compared to 2763 CPU hours for the IBM 7094 computer in FY72.

The time-sharing system of the PDP-10 computer has generally proved most effective in matching to the varied computing requirements of the group. Some problems have arisen with fast memory conflicts between large programs or heavy I/O users (tape or disks) and the time-sharing users as a result of the minimal memory size of 65K (system software plus the permanently resident software for the DOLLY/CSX-1 link preempt 35K of this). In addition, users with large data sets arising from Monte Carlo work or the fitting of data from large experiments have been handicapped by the limited disk space available. The single 60 million character disk serves for all system and user programs and data set storage.

A3. Engineering Systems

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

The major effort for FY73 has been the continued development and testing of the instrumentation for the NAL Experiment 87. 10,000-wire amplifier register cards

were built and tested. An interface and buffer for the Sigma 2 Computer was developed for high speed data acquisition during beam spill and slow speed readout during beam off periods. A stable, low cost PMX divider system has been constructed.

Concurrent with this about 30 general purpose modules have been designed and tested to replace the twelve year old NIM equipment at the University of Illinois. This data handling system resembles the CAMAC hardware, but achieves the same objectives at greater speed and considerably lower cost. Full use is being made of ECL and TTL integrated circuits for the eventual construction of a sizable set of logic modules.

A useful and somewhat unique data link system has been developed to couple the TI-960 data acquisition computer to the PDP-10 central facility for storage of program and data files in the larger machine; it also provides for the TI-960 easy access to the more powerful compilers and assemblers available on the PDP-10 as a host machine. This technique takes advantage of the teletype communications available on both machines to enable trivial interconnection problems since both computers appear as teletypes to each other. Data phone connections between the two computers have also been tested for providing remote coupling.

A4. Development of a Large Area Electromagnetic Shower Detecting System with Good Resolution

(G. Gladding, M. Gormley, A. Wattenberg, L. Cornell, W. Minescalco and D. Wheeler)

NAL 87A and other experiments require shower detectors with a large area (24 sq. ft. for NAL 87A) and the order of more than 20 radiation lengths. The best resolution can be obtained with large NaI crystals and the next best probably with lead glass (R.S. Jones, Ph.D. Thesis, Univ. of Illinois 1961); however the cost would have been greater than \$200,000. Tests with lead plates sandwiched between inexpensive plastic sheets (using Cherenkov radiation) indicated the resolution was not adequate for the experiment. We therefore undertook to build a system of sandwiches of lead and plastic scintillators (plastic scintillators were originally developed for this use - see Pugh, Gomez, and Frisch Pg. 169-174, Lab. for Nuclear Science, MIT Annual Progress Report 1953). Two of the difficulties that arise in the use of plastic scintillators are:

- 1) the attenuation of light in the plastic scintillators leads to a variation in response across the length of the scintillator and
- 2) the faces of photomultiplier tubes do not have uniform response.

These problems have been reduced to a level where the effect across the scintillators should be less than $\pm 3\%$. The lack of uniformity due to attenuation was reduced by a scheme suggested by A. Tollestrup and R. Walker of Cal. Tech.,

namely to use Wratten filters to absorb out most of the UV light which has the large attenuation coefficient. Extensive tests were made on several plastic scintillators and various Wratten filters. Tests were also run at Argonne National Laboratory and the resolution in a 6 GeV/c electron beam was found to be $\pm 5\%$. The large shower detecting system is now being assembled, as well as the detectors. It includes a built-in standardization to each tube connected by optical fibers.

A5. Development of NaI Detector for γ -ray Detection in Such Reactions as

(L. Holloway, L.J. Koester, Jr., J.H. Smith, R. Taylor, R. Wojslaw)

In experiments where pion interactions leave a nucleus in an excited state, the small cross sections and high neutron backgrounds place stringent requirements on the gamma ray detector including: (1) large solid angle, (2) high efficiency, (3) good energy resolution, and (4) fast time resolution.

These specifications were fulfilled after some development work in FY73. We used an 8-in. diameter by 4-in. long NaI (Tl) scintillator joined by a conical light pipe to a 5-in. diameter RCA 4522 phototube. We tried larger phototubes, but there was appreciable difficulty in obtaining good magnetic shielding.

Timing signals from the anode standardized by a constant fraction discriminator gave time-of-flight measurement to ± 1.5 nsec and effectively discriminated against neutrons from the target. Pulse height measurement of signals from an early dynode through a simple amplifier with very good base line recovery designed by Roger Taylor was good enough to observe 100 keV Doppler shifts on the 4.4 MeV gamma ray.

A problem in making pulse height measurements with pulsed accelerators is that the gain of the phototube increases by about 2% for each doubling of the counting rate. This effect has been seen with Amperex, DuMont, and RCA phototubes. It is aggravated by slumping of dynode potentials at high average currents but still occurs with these fixed solidly. We succeeded in calibrating the gain for each event by immediately pulsing a standardized light emitting diode (Monsanto MV2) which was imbedded in the light pipe. The amplitude of the LED signal was recorded by the on-line computer, and the appropriate correction was applied to the event signal. The resulting gamma ray line spectrum was much narrower after this correction.

Since the end of the experimental run, we have tried to measure the relaxation time of the gain change in the phototube in conditions of rapidly fluctuating intensity. Our results thus far seem to indicate at least two time constants, one of the order of 100 μ sec and the other at several milliseconds.

B. Plans for Facilities for the Coming Year

B1. Data Acquisition Systems

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

Hardware developments of the DOLLY system will taper off. Principle activities will involve the connection of a real time clock and a teletype into the CSX-1 system to simplify maintenance and operations procedures. Software developments will continue towards more automatic measurement procedures which should be realizable as streamer chamber film quality improves.

There are 125,000 new pictures on hand from the most recent run. 300,000 additional pictures should result from the approved experiments; these should be measured during FY74. Further requirements for film measuring are expected to derive from the neutrino experiment at Brookhaven and the 30" chamber at NAL.

During FY74 programming studies will be made towards the incorporation of on-line track matching and fitting in the PDP-10 computer concurrent with the measuring process on the DOLLY/CSX-1 system. The time-sharing system of the PDP-10 permits easy control of such intermittent processes. Development of this technique will become important as measuring rates improve and as the failures in the matching or fitting of tracks become an important component in the processing speed.

B2. Computer Operations

(R. Brown, M. Czechowski, N. Meyer, R. Uphoff, J. Wray)

Principal effort in FY74 will be the development of on-line data fitting programs for the DOLLY/CSX-1 film measuring system. There will also be continued program development of data fitting and matching programs as well as general systems development.

Projected computer use for FY74 is 4000 CPU hours. This growth from the use in previous years will arise from the inevitable expansion of time-sharing as well as the advent of data processing on several high data rate experiments.

B3. Engineering Systems

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

Final set up and testing of all instrumentation for Experiment 87A will be made at NAL. A computer monitor system will be completed for sampling high voltage dividers in numbers up to 256.

Development of modules for the Univ. of Illinois logic system will continue. Specifically planned is an interface with the CAMAC system for connecting with existing systems at National Laboratories. Primarily this will involve the ability to connect the Univ. of Illinois crates to a branch-highway system of the CAMAC variety.

C. Plans for Facilities in Future Years

C1. Data Acquisition Systems

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

The DOLLY system will be in full production on streamer chamber film as well as other optical readout experiments.

C2. Computer Operations

(R. Brown, M. Czechowski, N. Meyer, R. Uphoff, J. Wray)

PDP-10 computing operations will grow under time-sharing development. Saturation in use of the PDP-10 system at 6000 hours of use is expected in the vicinity of the FY75-76 period.

C3. Engineering Systems

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

Aside from continued development in support of high energy physics experiments, the long range plans involve extensive development of the fast logic modules for the Univ. of Illinois logic system. Also, envisaged is the continued incorporation of mini-computer systems and microprogrammed logic modules into the experimental hardware.

C4. Development of the Capability for Building Large Area Multiwire Proportional Counters

(R. Downing, J. Simaitis, R. Taylor and others)

The University of Illinois has been in the business of constructing complete systems of multiwire proportional counters including all the amplifiers and other associated electronics. These have been in use at NAL associated with the Hybrid Bubble Chamber effort. We have also constructed and put into operation a complete system of amplifiers and associated electronics for large detecting systems; however, we have been dependent on other groups with whom we have collaborated to provide us with large area multiwire proportional chambers. Our plans for future experiments require our having the capability of building such chambers here at Illinois in the sizes and shapes appropriate for the experiments. Therefore, we need devote some engineering effort to building large chambers; budgetary limitations will curtail this effort in FY74.

V. Publications Submitted or Published and Papers
Presented during the Calendar Year 1972

- W. Moninger, II, B. Eisenstein, J. Kim, D. Marshall, T. A. O'Halloran, M. Robinson, P. F. Schultz. " K^+ n Charge Exchange at 3.8 GeV/c." To be published in Phys. Rev., June 1973.
- J. S. Frank, S. Raither, D. Banner, M. Gormley, L. J. Koester, Jr., J. H. Smith, and A. Wattenberg. "A Comparison of CP Violation in the Decays $\bar{K}^0 \rightarrow \pi^+ \pi^-$ and $K^0 \rightarrow \pi^+ \pi^-$. Bull. Am. Phys. Soc. Series 11, Vol. 17, 4, 493 (1972).
- D. A. Marshall, B. I. Eisenstein, J. Kim, W. R. Moninger, T. A. O'Halloran, M. R. Robinson, and P. F. Schultz. "The Reaction $K^+ d \rightarrow K^+ \pi^- p p$ at 3.8 GeV/c." Bull. Am. Phys. Soc., Series 11, Vol. 17, 1, 145 (1972).
- Richard M. Brown and Jerald J. Wray. "Some Software Techniques for the DOLLY System." ANL-7934 Proceedings of the Informal Colloquium on POLLY and POLLY-like Devices, pg. 48 (1972).
- M. Jordan, G. Ascoli, H. R. Barton, Jr., L. E. Holloway, Bent Huld, U. E. Kruse, D. W. Mortara, L. Nodulman and S. Bernstein, D. W. McLeod, S. Margulies, Univ. of Ill., Chicago Circle. "A New Determination of the Width of the $\omega(782)$." Bull. Am. Phys. Soc. Series 11, Vol. 17, 1, 64 (1972).
- R. T. Edwards, E. W. Beier, W. K. Bertram, D. P. Herzo, L. J. Koester, and A. Wattenberg. "Search for Direct Processes in $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ Decays." Phys. Rev. D5, 2720 (1972).
- R. W. Downing, J. Simaitis, and D. Zander. "University of Illinois DOLLY Hardware." ANL-7934 Proceedings of the Informal Colloquium on POLLY and POLLY-like Devices, pg. 41 (1972).
- G. Ascoli, D. V. Brockway, L. Eisenstein, J. D. Hansen, M. L. Ioffredo, and U. E. Kruse with others. "Spin Parity Analysis of the A_3 ." Phys. Rev. D7, 669 (1973).
- R. M. Brown, R. W. Downing, L. E. Holloway, B. Huld, M. Jordan, U. Koetz, U. E. Kruse, D. W. Mortara, L. J. Nodulman, V. J. Simaitis, J. J. Wray, D. R. Zander with S. Bernstein, S. Margulies, D. W. McLeod, Univ. of Ill., Chicago Circle. "A New Measurement of the $\omega(784)$ Width." Phys. Letters, 42B, 117 (1972).
- G. Ascoli and Illinois-GHMS-H-ABBCCH-ND-W Collaboration. "Study of A_3 in $\pi^- p \rightarrow \pi^+ \pi^- \pi^- p$." AIP Conference Proceedings #8, 3rd Int. Conf. on Experimental Meson Spectroscopy, pg. 185 (1972).
- D. Banner, J. Frank, M. Gormley, L. J. Koester, S. Raither, J. H. Smith, and A. Wattenberg. "Experimental Comparison of CP Violation in $\bar{K}^0 \rightarrow \pi^+ \pi^-$ and $K^0 \rightarrow \pi^+ \pi^-$ Decays." XVI Int. Conference on High Energy Physics, NAL (1972).
- D. Banner, J. Frank, M. Gormley, L. J. Koester, S. Raither, J. H. Smith, and A. Wattenberg. "Experimental Comparison of CP Violation in $\bar{K}^0 \rightarrow \pi^+ \pi^-$ and $K^0 \rightarrow \pi^+ \pi^-$ Decays. To be published in Phys. Rev. D., April 1973.

- L. Holloway, B. Huld, U. Koetz, U. Kruse, M. Jordan, D. Mortara, L. Nodulman, R. Wojtawski, and S. Bernstein, S. Margulies, D. McLeod, Univ. of Ill., Chicago Circle. "Missing-Mass Spectrum Near 960 MeV from $\pi^- p \rightarrow n + (\text{mm})$." AIP Conference Proceedings #8, 3rd Int. Conf. on Experimental Meson Spectroscopy, pg. 133 (1972).
- P. F. Schultz, "Some 5.0 GeV/c $\pi^- p$ Cross Sections." Internal Report.
- L. E. Holloway, B. Huld, M. Jordan, U. Koetz, U. E. Kruse, D. W. Mortara, L. J. Nodulman, and S. Bernstein, S. Margulies, D. W. McLeod, Univ. of Ill., Chicago Circle. "A Search for Structure in the $f^0(1260)$ and $A_2^0(1315)$ Mesons." XVI Int. Conference on High Energy Physics, NAL (1972).
- L. Eisenstein, P. F. Schultz, G. Ascoli, M. L. Ioffredo, and J. D. Hansen. "Upper Limit to the $A_2 \rightarrow \eta \pi$ Decay Mode." Phys. Rev. D7, 278 (1973).
- D. W. Mortara. "Is There a ρ' ." Submitted to Phys. Rev.
- P. Sokolsky. "The University of Illinois - A.N.L. Streamer Chamber System." 1st Int. Conference on Streamer Chamber Technology ANL (1972).
- H. H. Bingham, L. Eisenstein, Y. Goldschmidt-Clermont, V. P. Henri, and J. Quinquard with others. "An Analysis of the Reaction $K^+ p \rightarrow Q^+ p$ from 2.5 to 12.7 GeV/c." Nucl. Phys. B48, 589 (1972).
- Y. M. Antipov, R. D. Sard and others, CERN-IHEP Boson Spectrometer Collaboration. "Missing Mass Spectra Observed in $\pi^- p + p \rightarrow p + X^-$ at 25 and 40 GeV/c." Phys. Letters, 40B, 147 (1972).
- G. Ascoli. "Partial Wave Analysis of the A_1 , A_2 , and A_3 ." Proceedings of the XVI Int. Conference on High Energy Physics, Vol. 1, 3 (1972).
- Y. M. Antipov, G. Ascoli, R. D. Sard and others, CERN-IHEP Boson Spectrometer Collaboration. " A_1 and A_2 Production at 40 GeV/c." AIP Conference Proceedings #3, 3rd Int. Conf. on Experimental Meson Spectroscopy, pg. 164 (1972).
- G. Ascoli and others. "Summary of the Experimental Situation Regarding A_1 , A_2 , A_3 Production." XVI Int. Conference on High Energy Physics, NAL (1972).
- Y. M. Antipov, G. Ascoli, R. D. Sard and others, CERN-IHEP Boson Spectrometer Collaboration. "Elastic Scattering of $\pi^- p$, $K^- p$, and $\bar{p} p$ at 25 and 40 GeV/c." XVI Int. Conference on High Energy Physics, NAL (1972).

Theses

- D. Banner. "Production of Neutral Kaons and Lambdas from Charged Kaon Interactions with Complex Nuclei."
- D. Marshall. "Reaction $K^+ n \rightarrow K^+ \pi^- p$ at 3.8 GeV/c."
- S. Raither. "Comparison of CP Violation in the Decays $K^0 \rightarrow \pi^+ \pi^-$ and $\bar{K}^0 \rightarrow \pi^+ \pi^-$."
- J. Frank, "Time Decay Distributions of $\bar{K}^0$ and K^0 to $\pi^+ \pi^-$ - A CP Test."
- M. Jordan. "Mass Spectra of f^0 and A_2^0 Mesons in Reactions $\pi^- p \rightarrow n \pi^+ \pi^-$ and $\pi^- p \rightarrow n \pi^- \pi^0$ at 4.5 GeV/c."
- P. Sokolsky. "Observation of Backward Meson Production in $\pi^- p$ Interactions at 8.0 GeV/c in a Streamer Chamber."