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ANNUAL PROGRESS REPORT

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DISCLAIMER

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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 various high energy particle accelerators. In the past these experiments have almost exclusively used proton accelerators; however this year we are planning an experiment using photons, from the Cornell electron machine. The experiment and motivation for this experiment are directly related to our high energy photon program approved for running at the NAL accelerator. The experiments planned or in progress are concerned mainly with the strong and weak interactions; the experiments planned using the electromagnetic production of particles are a potential source of very interesting new information.

During FY72 the program included the following:

1) The successful operation of the streamer chamber with a hydrogen target in a π^- beam at the ZGS to study backward meson production.
2) The completion of the data taking phase of the on-line wire spark chamber experiment to compare CP violation in the $\overline{K}^o \to \pi^+\pi^-$ and $K^o \to \pi^+\pi^-$ decays.
3) The completion of the DOLLY system including the three measuring stations required for its application to the film from the streamer chamber.
4) The completion of the automatic scanning and measuring by DOLLY of film from the $\pi^- p \to n(A_2^o \text{ or } f^o)$.
5) The completion of the running of the first phase of the missing mass spectrometer at Serpukhov as part of the CERN-IHEP collaboration and the application of the five dimensional Euler-Dalitz partial wave analysis to the 3π data from the first runs in that experiment.
6) The completion of the analysis of the bubble chamber film collaboration studying the A_2 and A_3 mesons.
7) The running of the on-line wire spark chamber equipment to study the $\frac{d\sigma}{dt}$ dependence of π^- scattering using the excitation of the carbon 4.4 MeV level to specify the the final state.
8) The measurement of the interaction cross sections of Λ hyperons on complex nuclei.
9) The construction and delivery of multiwire proportional counters and the associated electronics for the external proton beam at NAL to be used in hybrid hydrogen bubble chamber experiments.

In the coming years we are planning experiments using the following techniques:

Streamer Chamber Experiments

Bubble Chamber and Mass Spectrometer Experiments

Experiments using Spark Chambers and Counter Hodoscopes

Experiments using Multiwire Proportional Counters.

The details of the individual experiments, in each of the above categories are given in Section III. In this summary section the discussion is subdivided into the physics involved in the strong and weak interaction experiments, and it is followed by a discussion of the common facilities.

Strong Interactions

The motivation for the various types of strong interaction experiments can be simplistically categorized into four aspects:

a. the properties and quantum numbers of "resonant" states,

b. a search for new and perhaps "exotic" resonant states,

c. the production dynamics of the "resonant" states and the continuous background,

d. higher energy phenomena.

The first application of the streamer chamber will be to the strong interaction studies of the first three aspects by a series of experiments on backward meson production. The advantage of the streamer chamber is that it has the large solid angle acceptance of the bubble chamber with a good momentum resolution combined with the capability of triggering to select infrequent types of events. Comparatively little is known about backward production because the bubble chamber studies have been dominated by the strong forward production mechanisms; the spectrometer studies that have been made have not had the large solid angle acceptance. Examples of how these studies fit into the above categories are the following: a) If the A_1^- were to be observed it would provide information about the state itself. b) It will be possible to look for production of doubly charged mesons which, if they exist at all, must have exceedingly small cross sections. c) The observation (or lack thereof) of the production of well known mesons in the backward direction will provide information about the importance of baryon exchange mechanisms.

Another major part of our program depends upon the algorithm developed by Ascoli for doing partial-wave analysis of three meson systems. It fits into categories a), c), and d) and includes analysis of data obtained in a collaboration at Serpukhov, our own experiments at ANL studying the production of A mesons, and the compendium of data from many bubble chamber groups. Earlier analysis made the assumption that the background and the main processes do not have a large interference term. Using the Ascoli analysis one can make plots of the interference terms that lead to Argand type diagrams which provide quantitative information on the resonant or non-resonant behavior of the various angular momentum-parity states as a function of the mass of the 3π system. The interesting thing is that one can see different types of behaviors in different decay modes.

Another example in category c): A new kind of experiment was successfully performed which makes use of the excitation of the 4.4 MeV state in carbon 12. Knowledge that the carbon was left in this state then specifies the final state of the system. The technique was first used in a pion scattering experiment. The group intends to apply the technique to the production of the A meson system.

Experiments planned for NAL and Cornell will use the photoproduction of pairs of mesons to look for 1^- mesons that are coupled to the photon and which have higher masses. (categories b and d)

The physicists at the University of Illinois are likely to be involved in using more than one technique, and in this sense we constitute one large group with a common pool of equipment and facilities.

Weak Interaction Experiments

The exciting theoretical development inthe weak interactions is the possibility of setting up renormalizable theories of the weak interactions. One group of these theories stem from the work of Weinberg, T'hoff, Higgs and B. Lee. These theories in general predict the existence of two charged intermediate vector bosons, a neutral vector boson, and the photon: These theories combine the weak and electromagnetic interactions. Another set of renormalizable theories comes from the work of Glashow and others and postulate the existence of heavy leptons. Therefore, our experiment using the high energy photons from NAL to produce pairs of intermediate vector bosons or heavy leptons (Bethe-Heitler mechanisms) has taken on an increasing interest.

The group at Illinois has had a major involvement with both CP violation and possible manifestations of higher order effects in the weak interactions. We anticipate further experiments in these areas.

Common Facilities

The details of the operation and development of common detecting equipment and of the measuring, scanning, and computing facilities are given in Section IV. The major development work in electronic systems will be concerned with equipment for NAL Experiment 87A. The systems engineering group are also providing a first model of a new low cost electronics logic system to be field tested in an experiment prior to enlarging it to replace our present obsolescent electronics module system.

During the past year considerable effort was devoted to procuring a PDP-10 system to meet both the batch processing computational needs and to provide on-line data analysis for data from the CSX/DOLLY System. It is planned to have the new system fully

operational early in the Fall of 1972. The Sigma II computer has been effectively in constant use on-line to either magnetostrictive chambers or counter hodoscopes in four different experiments during FY72. After completion of another experiment at ANL it will be moved down to Urbana and then to NAL for use with the multiwire proportional counter system.

II. Personnel

In the following subsections are listed the names of senior staff members and graduate students who are or who will be involved, in the elementary particle physics program.

Two definite offers of new appointment to the Physics Faculty are in process at the present time, one of them as a replacement for personnel who are leaving. They should also provide an increased emphasis on research at NAL (the names of these people are not included in the list below). The Department of Physics at the University of Illinois is committed to a strong program in elementary particle physics.

A. Experimentalists who will be actively engaged in the program proposed herein are

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

Ascoli, G.	Mortara, D.
Brown, R.	O'Halloran, T.
Eisenstein, B.	Ravenhall, D.
Holloway, L.	Sard, R.
Koester, L.	Smith, J.
Kruse, U.	Wattenberg, A.

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

Barton, H.	Gladding, G.	Simaitis, J.
Buttram, M.	Gormley, M.	Taylor, R.
Downing, R.	Hansen, J.	Wray, J.
Eisenstein, L.	Kim, J.	Zander, D.
Fancher, D.	Schultz, P.	

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

Beamer, N.	Frank, J.	Nodulman, L.
Cormell, L.	Jordan, M.	Raither, S.
Czechowski, M.	Liu, W. K.	Sarracino, J.
Czechowski, N.	Marshall, D.	Sokolsky, P.
Cullum, R.	Mollet, W.	Wheeler, C.
Eitelbach, D.	Morris, G.	Wojslaw, R.

B. In the last few years, the staff of the theoretical physicists who are engaged in particle physics research has been augmented by the addition of several excellent young physicists. The experimentalists operate in close collaboration with these theorists. Members of the theoretical group are as follows:

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

III. Experimental Program

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 topics covered 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.

Bubble Chamber and "Mass Spectrometer" Experiments.

Experiments using spark chambers and counter hodoscopes.

Experiments using multiwire proportional counters.

A. Technical Accomplishments During the Past Year

A1. $\pi^- p \to p x^-$: Backward Meson Production in the Streamer Chamber

(A. Abashian, M. Buttram, B. Eisenstein, J. D. Hansen, T. O'Halloran, P. Schultz, P. Sokolsky, N. Beamer, W. Mollet, G. Morris in collaboration J. Dawson, J. Peerson, and J. Watson of Argonne National Laboratory)

The University of Illinois-ANL streamer chamber is now taking data in Experiment 297 at ANL. The Marx generator and Blumlein line have been in almost continuous use for over a year and are quite reliable, requiring only occasional maintenance. With the fast-charging system built by Argonne, we can recharge the Marx generator to 30 kv per stage in less than 200 milliseconds with voltage constant to 0.1%. We typically pulse the chamber twice during each ZGS spill.

The new lucite streamer chamber body has been in use for about five months and appears to work well, as does the new transmission line which carries the high voltage pulse to the chamber.

We are currently using a 1/10 liter liquid hydrogen target inside the streamer chamber. The target is basically a block of PVC foam with a hollow cavity containing the mylar hydrogen flask. As such the design is completely different from previous streamer chamber targets, and is, in fact the largest one (in terms of volume) that has been successfully used. Two 10 watt refrigerators are adequate to fill and maintain hydrogen in the target under running conditions. To date we have about 90,000 high voltage pulses on the chamber with the target full.

During the next few weeks the first major experimental run on this system will be undertaken. We anticipate a one to two hundred thousand picture exposure on the reaction $\pi^- p \to p x^-$ at 8 GeV/c, where the proton is fast forward in the laboratory. In a preliminary run we tested the system with a polyethylene target, and determined that all components were functioning properly. This especially includes a large aperture Cerenkov counter which distinguishes protons from the large background of fast pions.

Although it will probably require several months to learn how to measure the film efficiently on DOLLY, we expect to be well into the measuring and analysis of this exposure by the end of FY72.

If running time is available at Argonne after the $\pi^- p$ experiment (and before the planned ZGS shutdown) we hope to do another experiment, for which a proposal is now being submitted. We intend to look for the reaction $\pi^- n \to p\pi^-\pi^-$, where the $\pi^-\pi^-$ system is produced backwards in the center-of-mass. There are strong theoretical arguments that <u>if</u> exotic mesons exist they should be produced in backward reactions

such as this. The experiment is simple, since it is identical to the $\pi^- p \to p x^-$ experiment with hydrogen replaced by deuterium as a target.

A2. Analysis of the Reaction $\pi^- p \to p\pi^-\pi^-\pi^+$

(G. Ascoli, L. Eisenstein, J. D. Hansen, U. E. Kruse)

The analysis of the A_2 and A_3 systems in bubble chamber data from 5 to 25 GeV/c has been completed, and the results are being prepared for publication. Since last year we have extended our analysis of the A_2 to the data from 5 to 25 GeV/c, and we have confirmed the resonant behavior, that is the circular motion of the 2^+ production amplitude on the Argand diagram. The extended data has also allowed us to examine the dependence of the cross section on incident momentum and to determine an "effective" Regge trajectory. We find this "effective" Regge trajectory to be above the usual f trajectory. By comparison of π^- data with π^+ data we have shown that the interference between A_1 and A_2 is associated with isoscalar exchange for the A_2 since the magnitude and phase of the interference is the same for incident π^+ and incident π^-.

In the A_3 region our analysis has shown that the A_3 has spin-parity 2^- with the dominant decay mode being $f\pi$. We see 2^- to $\rho\pi$ decay as well, but it shows no peaking in the A_3 region.

In the bubble chamber data the interference of 2^- state with other states does not exhibit resonant behavior. The mass, width, production cross section, and polarization of the 2^- state have been determined.

A3. Serpukhov Boson Spectrometer Experiment(CERN-IHEP Boson Spectrometer collaboration)

(G. Ascoli, L. Eisenstein, J. D. Hansen, U. E. Kruse and R. D. Sard)

Data taking in the 25 and 40 GeV/c negative beams at Serpukhov continued during this year, with participation by Sard and Ascoli. The last scheduled run is taking place during the writing of this report (April 1972). Reducing the data to the physics variables of interest is being done at CERN. The physics analysis, done mainly at CERN, has been focused on three aspects of the data:

a) $\pi^- p \to p$ + anything. At both energies the missing-mass spectrum shows the elastic peak, a peak in the 1.2 - 1.4 GeV region, and no other peak. The cross section for producing the higher mass meson resonances seen at lower energies (S, T, U, ...) is well below 3 $\mu b/(GeV/c)^2$. The shape of the smooth background ("swayback") is an important input for theories of inclusive reactions at asymptotically high energy.

b) π^-, K^-, $\bar{p}$ elastic scattering. Cerenkov counters in the beam line permit tagging of incident π^-, K^-, $\bar{p}$ at both momenta, and the elastic peak is included in the data selected by our trigger. In the four-momentum transfer range 0.1 - 0.4 $(GeV/c)^2$ the slope of the diffraction peak is constant at 8.5 ± 0.2 $(GeV/c)^{-2}$ for π^-, at 7.9 ± 0.2 $(GeV/c)^{-2}$ for K^-. For antiprotons it is 12.0 ± 0.2 $(GeV/c)^{-2}$ at 25 GeV/c and 11.2 ± 0.3 $(GeV/c)^{-2}$ at 40 GeV/c, leaving open a slight possibility of a small anti-shrinkage.

c) $\pi^- p \rightarrow p\pi^-\pi^+\pi^-$ partial wave analysis. The Illinois algorithm for determining the partial waves involved in the (3π) system has been applied to part of the 40 GeV/c data. There are large A_1, A_2, A_3 components with roughly the same polarizations as at lower energies. There are sizeable interference terms between $2^+(A_2)$ and $1^+(A_1)$ and between $2^-(A_3)$ and $1^+(A_1)$, showing the phase change with mass that is expected for real resonances. Some of the partial-wave fitting as well as experimental design has been carried out on the Illinois IBM 7094. (Part of the travel to CERN and Serpukhov during the present fiscal year is being financed by a grant from the University of Illinois Research Board.)

A4. Collaboration on Hybrid B.C. - Proportional Wire Spectrometer at NAL

(G. Ascoli, R. Downing, L. Eisenstein, J. D. Hansen, U. E. Kruse, R. Sard)

For the hybrid spectrometer collaboration, the University of Illinois took responsibility to construct and assemble the multi-wire proportional counters and associated electronics. These were tested at MIT and Rutgers, and they are now being installed in the external beam at NAL. A short run to yield about 20,000 pictures will be carried out as a feasibility study of the system.

A5. K^+d Reactions at 3.8 GeV/c

(B. Eisenstein, J. Kim, T. O'Halloran, P. Schultz, D. Marshall, W. Moninger, and M. Robinson)

The analysis of several reactions in bubble chamber data has been completed and the results are being prepared for publication. These include:

a) $K^+n \rightarrow K^0p$. We have reanalyzed previously published data of intermediate energies including our own and have compared the results to the predictions of a Regge model for meson-nucleon charge exchange. We find that a single model invoking degenerate ρ and A_2 exchange is inadequate to fit the data. Furthermore, a significant difference in the values and energy dependence of K^+n and K^-p charge exchange cross sections at intermediate

energy is not consistent with the expectations that these cross sections become the same at high energy. A paper will be submitted for publication in the immediate future. This analysis was the subject of Moninger's thesis.

b) $K^+n \rightarrow K^+\pi^-p$. Of particular interest is the behavior of S, P, and D partial waves in the $K^+\pi^-$ system above the region of the K*(890) structure. The behavior in the S-wave near the K*(1420) is similar to that seen at 12 GeV/c in the same reaction, and it suggests that many events counted as K*(1420) in some experiments are in actuality this "background". The analysis of this reaction is near completion and will form Marshall's thesis.

c) $K^+d \rightarrow K^+\pi^+\pi^-d$. We have studied the Q enhancement and in particular a narrow peak in the $K\pi\pi$ mass region of 1.3 GeV. A spin parity analysis shows that apart from having a larger ρ^oK component than the rest of the Q region, this peak shares all other properties with it - namely it is 1^+. This study was the subject of Robinson's thesis, and it is now being prepared for publication.

A6. A Study of the $\pi^-p \rightarrow \omega n$ at 3.65, 4.5 and 5.5 GeV/c.

(L. Holloway, B. Huld, D. Mortara, H. Frauenfelder, M. Jordan, A. Russell and E. Rosenberg in collaboration with group from the University of Illinois, Chicago Circle)

The analysis of the data from this experiment has been completed. Theses have been completed by E. Rosenberg and A. Russell. The results for the ω spin density matrix and differential cross section were consistent with previous experiments, but the higher statistics and spread over incident energies of this experiment conclusively demonstrated several new phenomena and confirmed others that had previously only been speculated to be true. Specifically, the production of ω's was shown to be consistent with a Regge exchange model including ρ exchange and lower, unnatural parity trajectories. A previously applied model using absorption was shown to be inadequate. The lack of a dip in the ρ-exchange contribution to the differential cross-section is not understood and may provide new impetus for ideas on high-energy phenomenology. A broad dip observed in the differential cross section from the unnatural parity contribution also provides exciting new information on exchange processes. The most important aspects of the above have been published (PRL 27, 1671, 1971). Other manuscripts, completing the report of useful information and summarizing the experimental detail, are presently in preparation.

A7. A Study of Possible Structure in the $f^o(1260)$ and $A_2^o(1300)$ Mesons Produced in $\pi^- p$ Interactions at 4.5 GeV/c.

(D. W. Mortara, G. Ascoli, L. E. Holloway, B. Huld, U. E. Koetz, U. E. Kruse, M. Jordan, L. Nodulman, R. Wojslaw in collaboration with group from the University of Illinois, Chicago Circle)

The measurement of some 600,000 pictures on DOLLY has been satisfactorily completed. This includes 500,000 pictures from the primary experiment, and 100,000 from a secondary calibration run. A large effort was put into automating the analysis of the automatic film measuring machine (DOLLY) output, which consisted basically of a crt scan of the pictures. We have achieved a satisfactory automatic track and shower recognition program through which 80% of the data has now been processed. This data has also been spatially and kinematically reconstructed. The analysis of the resulting data is in progress.

The secondary calibration run mentioned above consisted of setting up the neutron missing mass spectrometer to detect neutrons recoiling from ω^o mesons produced at 2.5 GeV/c incident beam momentum. The kinematics of the missing mass resolution here was quite similar for the f^o/A_2^o case. The narrow width of the ω^o was intended to be used in measuring and confirming our previous calculations of the missing mass resolution. Quite unexpectedly, the observed ω^o was actually narrower than the previously measured width, instead of being somewhat broader due to our experimental resolution. After a careful analysis, we concluded that the true width of the ω^o is 7.7 ± 1.0 MeV, approximately 40% smaller than previously thought. The uncertainty of 1 MeV is also comparable to the uncertainty obtained from the total sum of previous efforts to measure this width. We feel that the foregoing results excellently demonstrate the power of the neutron spectrometer. A paper on this result will be submitted soon to PRL for publication.

Analysis of data from the principle run shows large f^o and A_2^o signals in the data. We have at this point not observed any structure in the f^o, but the A_2^o spectrum is less simple. Suffice it to say now that while we have not observed a simple dipole structure, there appears to be interesting phenomena present which may potentially resolve differences between previous experiments with less statistics and poorer resolution. We expect to obtain final results in the next few months.

A8. Excitation of the 4.4 MeV State in C^{12} by Pion Scattering

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

An experiment has been performed at the Argonne ZGS (E-314) on the process

$$\pi^- C^{12} \rightarrow \pi^- C^{12} \ (4.4 \text{ MeV})$$
$$\hookrightarrow \gamma + C^{12} \ (\text{Ground})$$

A NaI detector was used to measure the energy of gamma rays emitted in coincidence with a scattered pion. The direction of the scattered pion was measured by magnetostrictive readout wire spark chambers on-line to the Sigma 2. The differential scattering cross section, $\frac{d\sigma}{dt}$, and polarization are to be extracted from the data. Preliminary results show qualitative agreement with the theoretical prediction of Ravenhall and Schult.

This experiment is the first of its kind to be performed successfully. The technique should prove to be quite useful in studying processes in which definite spin-parity final states restrict the quantum numbers in exchange mechanisms.

A9. The Reaction $\pi^- p \rightarrow \rho^o n$ at High Momentum Transfer

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

This experiment is currently in progress at the Argonne ZGS (E-321). Data will be taken on the reaction $\pi^- p \rightarrow \pi^+ \pi^- n$. The recoil neutrons are detected in a neutron counter hodoscope and the pion's directions are determined by wire spark chambers. The purpose of the experiment is to measure the differential cross section, $\frac{d\sigma}{dt}$, and polarization of ρ-mesons at high momentum transfer.

A10. Comparison of CP Violation in $\overline{K}^o$ and K^o Decays into $\pi^+\pi^-$

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

This experiment (Argonne E-256) was designed to compare directly the CP violating decays of K^o and $\overline{K}^o$ into $\pi^+\pi^-$. The $\overline{K}^o$ decay has not previously been directly observed.

Running on this wire spark chamber experiment was completed in the early autumn (1971) and the data analysis is proceeding. It has been possible to follow the decay spectra out to about 11 mean lives. At this point the errors in subtraction of the 3-body breakup background overwhelm the 2-body signal. There appear to be no major uncertainties, so that data analysis should be complete by summer (1972).

Preliminary results, which will be presented at the Washington APS meeting, show no significant deviation from currently accepted theories.

Studies of the production of K^o, $\bar{K}^o$ and Λ particles by 800 MeV/c K^+ and K^- incident on carbon, aluminum, tin, and lead targets were undertaken early in this experiment to determine the best target to use for charge exchange. These data have been analyzed and compared to a Monte Carlo production model with considerable success. This analysis has been used as a thesis by one student (D. Banner) and the material is being prepared for publication.

All. Measurement of Λ-Nucleus Cross Sections

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

This experiment (Argonne E-310) was performed in a K^- enriched beam and made use of the magnetostrictive chambers (from E-256) on-line to the Sigma 2. During our studies of the production of $\bar{K}^o$ from the K^- beam, we found there was a prolific production of Λ hyperons which, combined with our triggering and detection system, constituted an "effective beam" of Λ hyperons with energies in the range from about 150 MeV to 400 MeV. At these low energies, the short decay length precludes the use of a liquid hydrogen target of sufficient length to obtain statistically significant numbers of interactions to study the fundamental nucleon cross section. Also there already exists some data on this cross section from bubble chamber experiments by Trilling and collaborators. However no information exists on cross sections for Λ's on complex nuclei; therefore we undertook a measurement of the cross section of Λ's on carbon, aluminum, copper, tin, and lead. From what is known of the cross section in this energy region one expects that at the higher energy end an impulse approximation should be valid and at the lowest energy, one should probably use a potential well or optical model.

Sufficient data was taken to obtain the cross sections for the heavier nuclei to an accuracy of about 10% and the lighter nuclei to about 20%. The measurement was an attenuation experiment and therefore gives an interaction cross section.

A preliminary analysis was performed on-line and a more precise analysis will be performed later this spring. The results obtained were rather surprising, in that a naive impulse approximation led us to expect the cross sections would be approximately $\sigma \simeq 45\ A^{2/3}$ millibarns. The simple on-line analysis gave much higher cross sections, namely $\sigma \simeq 70\ A^{2/3}$ millibarns. The known corrections will lead to higher values. We hope that we will have some indication of the energy dependence of such cross sections and that we may gain some insight into why the average cross section over this energy region is so large.

B. Experiments Planned for the Coming Year

B1. $\pi^- p \to p x^-$: Backward Meson Production in the Streamer Chamber

(M. Buttram, B. Eisenstein, T. O'Halloran, P. Sokolsky, N. Beamer, W. Mollet, G. Morris in collaboration with J. Watson of ANL)

Measuring and analysis will continue on the data taken in the run completed in April 1972. For the experimental geometry and the beam momentum of 8 GeV/c the produced boson, x^-, will have a mass between ~0.8 and ~2.4 GeV. In addition to the well known mesons such as ρ^- and A_2^- we hope to determine whether a narrow A_1^- is produced backwards under these conditions where kinematic effects can produce at best an extremely broad enhancement. By analyzing all of the final state momenta we can determine spin density matrices for the processes we observe, and begin to elucidate the properties of inelastic baryon exchange reactions. Since our mass acceptance covers a region of many reported "new" resonances (R, S, T) we hope to shed some light on their properties. At present we anticipate another experimental run in the autumn of 1972 to enlarge our data sample.

As indicated in the next section, we also hope to find evidence for exotic mesons, E^-, in this reaction. These objects should be fairly narrow, since they are not coupled strongly to their pionic decay modes.

The appearance of mass bumps in the backward reaction which do not correspond to previously seen peripherally produced mesons would be very suggestive of such exotic states. The planned deuterium run (described in the next section), by searching for E^{--}, could then confirm their existence.

B2. $\pi^- n \to p E^{--}$: A Search for Exotic Mesons

(M. Buttram, B. Eisenstein, T. O'Halloran, P. Sokolsky, N. Beamer, W. Mollet, G. Morris in collaboration with J. Watson of ANL)

At present there is little experimental evidence for either peripheral production of exotic mesons or their exchange in peripheral processes. On the other hand, the principle of duality applied to baryon-anti baryon scattering requires that exotic mesons be exchanged in the u-channel. Backward production is then the most likely place to search for these exotics, since they are strongly coupled to $B\bar{B}$ systems but only weakly coupled to mesons. For exotics with masses less than twice the nucleon mass, we thus anticipate a narrow width for pion decay.

The streamer chamber is an ideal tool for a search for these states in the reaction $\pi^- n \rightarrow p(\pi^-\pi^-)$ at 8 GeV/c. The experiment is identical to the study $\pi^- p \rightarrow px^-$, except that the target is deuterium.

Although we are proposing this experiment for FY72, the imminent ZGS shutdown will likely defer running until FY73. We hope to begin with ~ 100,000 pictures and increase the sample size should preliminary data analysis warrant it. With the experience in measurement and analysis obtained from the $\pi^- p \rightarrow px^-$ analysis, we anticipate completion of a major part of the processing of the data from the exotic search during FY73.

B3. $\pi^- p \rightarrow nx^o$: Backward Meson Production in the Streamer Chamber

(M. Buttram, B. Eisenstein, T. O'Halloran, P. Sokolsky, N. Beamer, W. Mollet, G. Morris in collaboration with J. Watson of ANL)

A proposal is being prepared for ANL to study the reaction $\pi^- p \rightarrow nx^o$ at 8 GeV/c, where the neutron is fast and forward in the laboratory. Experimentally, we will accomplish this by replacing the Cerenkov counter downstream of the streamer chamber with a scintillator-spark chamber array designed to detect neutrons. Time gating the neutron detector will discriminate against slow neutrons, and the spark chambers will locate the neutron interaction point sufficiently well that its direction is known to ~ ±1.0 mrad.

This experiment will permit the study of backward produced ρ^o, f^o, and perhaps g^o mesons as well as ω^o. Although ω^o production will yield a 0-constraint fit, it is sufficiently narrow that we are optimistic about seeing it above background if it is produced. Since both proton and Δ^+ exchange are allowed for ρ^o production, while only proton exchange can contribute to f^o production, we expect to be able to learn about the relative importance of these various processes in inelastic baryon exchange reactions. (This must be contrasted to the reaction $\pi^- p \rightarrow px^-$, where only Δ^{++} exchange is allowed.)

Furthermore, since our mass acceptance will extend to ~ 2.4 GeV, we can search for other neutral mesons which couple strongly to $B\bar{B}$ systems.

As a byproduct, we will also gather data on the reaction $\pi^- p \rightarrow K^o_{(fast)}+\ldots$. Since long lived K^o mesons will also trigger the neutral particle detector with high efficiency, much of our data will be on this reaction. Estimates are now being made on the relative amounts of fast neutron and K^o triggers, and our preliminary conclusions are that we will, in fact, have more K^o triggers.

The neutral particle detector, which will be designed in FY72, will be constructed and installed in the streamer chamber in FY73. We hope to have a first run of ~ 200,000 pictures during the late fall of 1972.

B4. Analysis of the Reaction $\pi^- p \rightarrow p\pi^-\pi^-\pi^+$

(G. Ascoli, L. Eisenstein, U. E. Kruse)

The analysis of bubble chamber data for this reaction should be completed in the coming year with the completion of the work on the A_1.

B5. Serpukhov Boson Spectrometer Experiment (CERN-IHEP) Boson Spectrometer collaboration

(G. Ascoli, L. Eisenstein, U. E. Kruse and R. D. Sard)

The partial-wave analysis will be applied to the $K^- p \rightarrow pK^-\pi^+\pi^-$ data as well as $\pi^- p \rightarrow p\pi^-\pi^+\pi^-$ at both energies (25 and 40 GeV/c) and over the entire range of four momentum transfers accepted by the apparatus (0.05 - 0.37 $(GeV/c)^2$). The main physics problem that we plan to study is the nature of the A_1, A_3, Q, and L systems: are they resonances or threshold enhancements? The collaboration with CERN in this analysis will require several trips of extended duration.

B6. NAL Hybrid Spectrometer

(G. Ascoli, R. Downing, L. Eisenstein, U. E. Kruse, and R. Sard)

The proportional wire chambers, associated electronics and PDP-9 computer should be installed at NAL in the late spring of 1972. A short run to yield about 20,000 pictures will be carried out as a feasibility study of the system. It appears likely that a proposal to NAL for an experiment to study reactions of the form $\pi^- p \rightarrow \pi^- (p^*)$ (where p* represents baryonic states formed by exciting the target proton) will be made.

B7. A Measurement of the Three Pion Mass Spectrum in the Reaction $\pi^- C^{12} \rightarrow \pi^+\pi^-\pi^- C^{12}$* (4.4 MeV)

(G. Ascoli, H. Barton, Jr., L. Holloway, L. Koester, Jr., U. E. Kruse, D. Ravenhall, J. Smith, L. Nodulman, W. K. Liu)

As a continuation of the experiment $\pi^- C \rightarrow \pi^- C^*$ we hope to investigate reactions in which a three pion system is formed (such as the A_1, A_2, A_3 system) together with C*. We have proposed to ANL (P-323) to measure the 3 pion mass spectrum in the reaction $\pi^- C^{12} \rightarrow \pi^+\pi^-\pi^- C^{12}$* where the carbon nucleus is left in the 4.45 MeV excited state. A NaI counter will detect the 4.45 MeV γ-ray in coincidence with a 3-pion final state. The Argonne "effective mass spectrometer" will be used to determine the 3-pion momenta.

This experiment may clarify some of the current questions in diffraction production from complex nuclei. In existing experiments there is a strong difference between the 3π mass spectrum for complex nuclei and the 3π spectrum from hydrogen. The proposed experiment may lead to a better understanding of this difference by introducing a new, well defined final state.

B8. Neutron Counter Hodoscope

(L. Holloway, D. Mortara, U. E. Kruse, L. Koester, Jr., L. Nodulman, R. Wojslaw)

We will no doubt continue to have interest in the study of the neutral boson spectrum by means of the reaction $\pi^- p \rightarrow x^o n$ and $K^- p \rightarrow x^o n$. Preliminary analysis of some previous data have shown interesting structure in the mass region of 960 MeV. Further experiments confirming these results are being considered.

B9. The Energy Dependence of $K_{\mu 3}$ Form Factors

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

This is an experiment which used optical spark chambers at Brookhaven National Laboratory and which should yield the order of 20,000 events on the polarization of the muon from $K^+_{\mu 3}$ decays. In that we know the energy of the incoming K^+, and we have information on the π^o decay, this data should be free of ambiguity. We have been measuring the film at the University of Illinois in parallel with measurements at the Chicago Circle branch of the University of Illinois. Due to financial limitations the measuring on this film was spread out over a longer period of time and it will not be completed until FY73. The yield of good $K_{\mu 3}$ events is coming out to be about 40% which is slightly above what was expected.

B10. Search for Heavy Leptons and Intermediate Bosons by High Energy Photon Pair Production (NAL Proposal 87A)

(M. Gormley, G. Gladding, T. O'Halloran, A. Wattenberg in collaboration with W. Lee and B. Knapp, Columbia University; J. Peoples, Cornell University; and D. Yount, University of Hawaii)

This experiment makes use of the beam of high energy photons one can obtain at small production angles at NAL. The experiment was approved and the plans are to

set it up in the Proton East Laboratory. The most recent NAL plans envision installation of equipment this coming fall. The amplifiers and registers for the multiwire proportional counters have been built and are currently being tested. Studies of the energy resolution and of the π rejection ratio of the electron shower detectors were performed at ANL and at the Cornell Wilson Laboratory. We have used the slippage in the (optimistic) time schedule of the NAL machine from last fall to try to produce more economical detectors and to make plans to use the same multiwire proportional counter system in a related experiment at Cornell studying $K\bar{K}$ and $p\bar{p}$ production as described below.

B11. A Measurement of the K^+K^- and $p\bar{p}$ Photo Produced Mass Spectrum

(M. Gormley, A. Wattenberg, J. Sarracino, D. Wheeler in collaboration with Cornell group)

A proposal to measure the mass spectrum of K^+K^- and $p\bar{p}$ pairs, photo produced from a 10 GeV bremsstrahlung beam, is being submitted to the Cornell Wilson Synchrotron. This experiment is complementary to NAL Experiment 87A and is stimulated by the possibility that there exist heavy vector mesons in addition to the ρ, ω, and Φ.

The K^+K^- and $p\bar{p}$ channels should be studied because these channels could be prominent decay modes for some heavy vector mesons and because the recent data of Cline contains the suggestion of a heavy vector meson which is coupled to the $K\bar{K}$ and $p\bar{p}$ systems. It is important to establish whether or not this object is coupled to the photon.

We expect to complete construction of all the equipment required for NAL Experiment 87A by September 1972. We will use the multiwire proportional counters constructed for NAL Experiment 87A to measure the K^+K^- and $p\bar{p}$ mass spectra at Cornell. The only additional piece of equipment which will be needed is a large aperture Cerenkov counter in order to veto π mesons.

C. Experiments that are Planned for Future Years

C1. Development of a New Streamer Chamber

(M. Buttram, B. Eisenstein, T. O'Halloran, P. Sokolsky, N. Beamer, W. Mollet, G. Morris and others)

Since the streamer chamber system developed by our group in collaboration with ANL will remain at the ZGS as a user facility, we should begin to collaborate on building a "third-generation" streamer chamber in order to permit experiments using this technique at higher energies. We anticipate, for energies at NAL (or BNL), the need for a chamber of a smaller gap spacing of perhaps 8 inches compared to the present 12 inches. The chamber and its required auxiliary devices would be built and tested while experimental objectives were being firmed. The very long lead time on procurement, design, construction, and testing, requires that the design phase of this program begin during FY73 if we are to have a streamer chamber capability by FY74 or FY75.

During FY74 the following should be built or bought: high voltage supplies, a Marx generator and Blumlein line, a gas purifier, a streamer chamber and a transmission line. Our goal would be to have a working system which produced high quality, automatically measurable pictures of cosmic ray events here at Illinois before moving the system to an accelerator for an experiment. Although much of the new equipment will be quite similar to our present system, we already see some modifications which should be made to both simplify construction, thereby reducing costs, and to increase reliability.

C2. Streamer Chamber Experiments at NAL

(M. Buttram, B. Eisenstein, T. O'Halloran, P. Sokolsky, N. Beamer, W. Mollet, G. Morris and others)

The new streamer chamber is intended for use at a high energy machine. One possibility which we are considering is to employ it at NAL as a vertex detector in conjunction with one of the spectrometer facilities being planned at this time by other groups. With the beginning of a regular physics program at NAL still some time in the future, and since already approved experiments will occupy running time for its first few years, our target date of FY74 or FY75 for the apparatus seems well matched to the machine schedule. We plan to explore the experimental applications of a streamer chamber at NAL during FY73.

C3. Streamer Chamber Experiments at ANL

(M. Buttram, B. Eisenstein, T. O'Halloran, P. Sokolsky, N. Beamer, W. Mollet, G. Morris in collaboration with J. Watson of ANL (and others))

It is clear that analysis will likely still be in progress on some aspects of the experiments $\pi^- p \to px^-$ and $\pi^- p \to (nx^o$ or $K^o Y^o)$. Although the use of the streamer chamber facility by other groups may modify our objectives, we are pursuing the possibility of extending our ANL studies of baryon exchange reactions to those induced by π^+ mesons. Only a beam Cerenkov counter need be added to the existing system to achieve the required beam. We are also studying the feasibility of doing the backward reaction $pp \to dx^+$, since this process can only proceed via nucleon exchange.

C4. Hybrid Spectrometer Experiments at NAL

(G. Ascoli, R. Downing, L. Eisenstein, U. E. Kruse and R. D. Sard)

We have a long range interest in strong interaction physics in the NAL energy range. This involves studies of resonances as well as studies of the background ("inclusive" experiments). Whether such experiments are best carried out with a hybrid bubble chamber spectrometer may be clarified by the feasibility studies. We shall push this approach if it seems promising.

C5. Search for Heavy Leptons and Intermediate Bosons by High Energy Photon Pair Production (NAL Proposal 87A)

(M. Gormley, G. Gladding, T. O'Halloran, A. Wattenberg in collaboration with W. Lee and B. Knapp, Columbia University; J. Peoples, Cornell University; and D. Yount, University of Hawaii)

If there are delays in the construction, procurement, or operating schedule at NAL, then the running phase of this experiment will extend into FY74. Even if the running phase were completed in FY73, we will be involved with analyzing the data from this experiment in FY74. We trust that the results from the first phase will be of sufficient interest that further studies with the high energy photon beam will be very desirable.

C6. Very High Energy K_L^o Experiments at NAL

(R. Brown, M. Gormley and A. Wattenberg)

Our interest in very high energy K_L^o experiments continues. We will try to measure the very high energy K_L^o spectrum which will be present in the Proton East Laboratory. The equipment being used in NAL Experiment 87A is excellent for measuring the K_L^o spectrum by looking at the CP violating decays. By using lead to remove the gamma rays and a lithium hydride filter to preferentially reduce the number of neutrons, we hope to obtain a reasonable yield of high energy K_L^o mesons with a useful ratio of K_L^o's to neutrons.

IV. Operation and Development of Common Facilities

A. Technical Accomplishments During the Past Year

A1. Film Measuring System

(R. Brown, R. Downing, J. Simaitis, J. Wray and D. Zander)

The first of the four projected measuring stations of the DOLLY precision CRT film measuring system was used in full production on the f^{o} A_2 spark chamber experiment. A total of 535,000 frames were measured at rates ranging from 500 to 600 frames/hr.

Installation of the remaining three measuring stations was completed in FY72. These stations have 2:1 optics for better matching to the 35 mm film of the Illinois Argonne National Laboratory streamer chamber. Software development for the streamer chamber film is well under way. Initial mode will use "clear point" guidance specified by operator until film and experiment parameters are better known. Measuring rates in this mode will be completely dominated by operator instructions.

All SMP measurements were completed in FY72. The Illinois SMP's have been withdrawn from service.

A2. Computer Operations

(R. Brown, M. Czechowski, N. Czechowski, D. Eitelbach, J. Wray)

In FY71 the computational requirements of the High Energy Group were met with the university owned IBM 7094 computer operated by the staff of this group. A total of 2800 7094 CPU hours is projected for FY72 as compared to 2508 CPU hours in FY71. Effective cost for CPU hour remains approximately $60-70 per 7094 CPU hours.

Considerable effort was spent during FY72 in procurement of a Digital Equipment Corp. PDP-10 system to meet both the batch processing computational needs and to provide on-line data analysis for data from the CSX-DOLLY system. In addition, a limited amount of time sharing will be accommodated initially. The new system, expected to be installed in June 1972 and fully operational by September 1972 will provide increased speed and capability at lower operational cost.

A3. Engineering Systems

(R. Downing, J. Simaitis, D. Zander)

A new low cost logic system is being built to replace the older NIM equipment. This system provides not only replacement for the NIM fast logic modules, but also

provides a data handling system that can be easily connected to a computer for on-line experiments. Full use is being made of ECL and TTL integrated circuits in the design. The first equipment is being used by Holloway, et al at Argonne National Laboratory. This equipment will also be used in instrumenting NAL Experiment 87A.

The wire proportional chambers and amplifiers for use on NAL Experiment 154 were completed and sent to MIT to mate with the readout equipment and computer. This will become part of the 30" bubble chamber upstream beam monitor. The Illinois portion of the hardware for this experiment is complete.

A major effort has been put into the system and instrumentation for the NAL Experiment 87A. This includes the amplifiers and registers for a 6000 multiwire proportional counter system, the multiwire counter logic, and the interfacing of this to the Sigma 2 computer.

B. Plans for Facilities for the Coming Year

B1. DOLLY Film Measuring Operations

(R. Brown, R. Downing, J. Simaitis, J. Wray and D. Zander)

The original measuring station (Bay 3) will have its CRT coils and circuits upgraded to correspond to the improvements incorporated in the other three stations. Programs for measurement of streamer chamber film will be under continued development towards nearly automatic scanning and measuring.

Projections for the amount of streamer chamber film measured rest on projected streamer chamber experiments at ANL. A peak capacity of approximately 500,000 frames per year should be possible by the end of FY73.

B2. Computer Operations

(R. Brown, M. Czechowski, N. Czechowski, D. Eitelbach, J. Wray)

Principal effort in FY73 will be transfer of operations onto the PDP-10 computer. Although most of the group's programs are written in FORTRAN IV, there yet remains identification and correction of dialect incompatibilities.

Another task involves the transfer of I/O operations for CSX-1 computer onto the PDP-10. This implies modification of CSX-1 system programs plus development of a special PDP-10 system task for I/O processing. Also to be installed and tested is the special communication interface which enables the CSX-1 65K memory to be shared between the two computers.

Projected computer use for FY73 is 4000 CPU hours. This significant rise from FY72 will ensue from the advent of time-sharing plus the addition of I/O operations previously accomplished separately from the main frame on the IBM 7094/1401 system.

B3. Engineering Systems and Development

(R. Downing, J. Simaitis, R. Taylor, and D. Zander)

The shower detecting system that will be used in NAL Experiment 87A requires borrowing from Columbia University pulse height analyzers and the electronic logic systems interfaced to the computer. In order to allow us to conduct experiments independently of the Columbia group in the future, we should construct the borrowed parts of the system.

We anticipate the use of multiwire proportional counters in future experiments; construction of additional and borrowed parts of the system should be started during FY73 so that they will be available in FY74.

V. Publications Submitted or Published and Papers Presented During the Calendar Year 1971

M. L. Ioffredo, G. Ascoli, D. V. Brockway, L. Eisenstein, U. E. Kruse and P. F. Schultz, and others. "Failure of S-channel Helicity Conservation in A_1 Production." Paper presented at Fall Meeting of Division of Particles & Fields, American Physical Society, Austin, Texas, November 5-7, 1970.

G. Ascoli, D. V. Brockway, L. Eisenstein, M. L. Ioffredo, U. E. Kruse and P. F. Schultz. "Failure of S-channel Helicity in the A_1^- Production." Phys. Rev. Letters 26, 929-932 (1971)

M. F. Graham, A. Abashian, L. H. Jones, P. M. Mantsch, J. R. Orr, J. H. Smith and R. D. Stutzke; M. J. Glaubman, Northeastern University. "A Test of the $\Delta S=\Delta Q$ Selection Rule in $K^o_{\mu 3}$ Decay." Accepted for publication in Il Nuovo Cimento.

L. H. Jones, A. Abashian, M. F. Graham, P. M. Mantsch, J. R. Orr, J. H. Smith and R. D. Stutzke; M. J. Glaubman, Northeastern University. "Search for the Decay $K^o_S \rightarrow \pi^+\pi^-\pi^o$." Accepted for publication in Il Nuovo Cimento.

P. M. Mantsch, A. Abashian, M. F. Graham, L. H. Jones, J. R. Orr, J. H. Smith and R. D. Stutzke; M. J. Glaubman, Northeastern University. "A Test of the $\Delta S = \Delta Q$ Selection Rule in K^o_{e3} Decay." Accepted for publication in Il Nuovo Cimento.

M. R. Robinson, B. Eisenstein, J. Kim, D. A. Marshall, W. R. Moninger, T. A. O'Halloran, Jr. and P. F. Schultz. "Coherent Q Meson Production in K^+d Interactions at 3.8 GeV/c." Paper presented at the Washington Meeting of the American Physical Society, February 1971.

W. R. Moninger, B. Eisenstein, J. Kim, D. A. Marshall, T. A. O'Halloran, Jr., M. R. Robinson and P. F. Schultz. "K^+n Charge-Exchange Scattering at 3.8 GeV/c." Paper presented at the Washington Meeting of the American Physical Society, February 1971.

L. Eisenstein, "Partial Wave Analysis of the 3π System in the Mass Region 1.0 to 2.0 GeV." Proceedings of the 4th Hawaii Topical Conference, August 1971.

L. Holloway, B. Huld, M. Jordan, D. Mortara, E. Rosenberg and A. Russell with others. "Determination of the ω^o Spin-Density Matrix Elements in the Reaction $\pi^- p \rightarrow \omega^o n$." Physical Review Letters 27, 1671-1674 (1971).

G. Ascoli, D. Brockway, H. Crawley, L. Eisenstein, R. Hanft, M. Ioffredo, U. E. Kruse. "Partial Wave Analysis and Polarization Study in the A_1 and Q Regions." Paper presented at the International Conference on Meson Resonances and Related Electromagnetic Phenomena, Bologna, Italy, April 1971.

G. Ascoli, D. Brockway, L. Eisenstein, M. Ioffredo and U. E. Kruse. "Isoscalar and Isovector Exchange Amplitudes in A_2 Production." Paper presented at the International Conference on Meson Resonances and Related Electromagnetic Phenomena, Bologna, Italy, April 1971.

G. Ascoli, D. Brockway, L. Eisenstein, M. Ioffredo and U. E. Kruse. "Partial Wave Analysis and Polarization Study in the A_3 and L Regions." Paper presented at the International Conference on Meson Resonances and Related Electromagnetic Phenomena, Bologna, Italy, April 1971.

Y. M. Antipov, R. D. Sard and others. "The Charged Non-Strange Boson-Mass Spectrum from 2.2 to 3.4 GeV Observed in 25 GeV $\pi^- p$ Interactions." Paper presented at the International Conference on Elementary Particles, Amsterdam, Holland, 30 June - 6 July, 1971.

H. H. Bingham, L. Eisenstein and others. "An Analysis of the Reaction $K^+ p \rightarrow Q^+ p$ from 2.5 to 12.7 GeV/c." Paper presented at the International Conference on Meson Resonances and Related Electromagnetic Phenomena, Bologna, Italy, April 1971.

F. Grard, L. Eisenstein and others. "Test of Helicity Conservation in the Reaction $K^+ p \rightarrow Q^+ p$." Il Nuovo Cimento 2, 305-311 (1971).

L. J. Koester, D. G. Ravenhall. "Experiments with Nuclei at the ZGS." Proceedings of Summer Workshop No. 3 at Argonne National Laboratory, July 1971.

Theses

M. F. Graham. "A Test of the $\Delta S = \Delta Q$ Selection Rule in $K^o_{\mu 3}$ Decay."

L. H. Jones. "Search for the Decay $K^o_S \rightarrow \pi^+ \pi^- \pi^o$."

E. Rosenberg. "Study of the Omega-Zero Spin-Density Matrix Elements in the Reaction Pi-Minus Proton Goes to Omega-Zero Neutron at 3.65, 4.5, and 5.5 GeV/c."

W. Moninger. "A Study of K-Plus Neutron Charge Exchange Scattering Using the Reaction K-Plus Deuteron Goes to Proton Proton K-Zero at 3.8 GeV/c."

M. Robinson. "Coherent Production of the Kaon, Pion, Pion System by Positive 3.8 GeV/c Kaons on Deuterium."

A. Russell. "A Study of the Differential Cross Section of the Reaction $\pi^- p \rightarrow \omega^o n$ at 3.65, 4.5, 5.5 GeV/c."

Other Talks Presented

U. E. Kruse. "Some Recent Experimental Results for the A_1, A_3, Q and L Mesons." Conference on the Phenomenology of Particle Physics given at Cal Tech, March 1971.

G. Ascoli, D. Brockway, L. Eisenstein, M. Ioffredo, J. D. Hansen and U. E. Kruse. "Partial Wave Analysis of the 3π Decay of the A_3." Amsterdam International Conference on Elementary Particles, 30 June - 6 July, 1971.

M. Buttram. "Backward Meson Production in the Illinois-ZGS Streamer Chamber." Argonne National Laboratory Workshop, July 1971.

L. Holloway. "The Use of Neutron and Gamma Ray Detectors in Meson Spectroscopy." Argonne National Laboratory Workshop, July 1971.

U. E. Kruse. "Partial Wave Analysis in Meson Spectroscopy." Argonne National Laboratory Workshop, July 1971.

Additional Comments

During FY72 ten graduate students will have written theses based on work of the High Energy Physics Group and will have been awarded their Ph.D. Degrees. What is not shown above is that since December 31st, 1971 five additional articles have been written and submitted for publication or are being circulated to collaborating groups.