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ANNUAL PROGRESS REPORT

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University of Illinois
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Key Personnel: A. Wattenberg
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Submitted March 1975

MASTER

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I. SUMMARY OF SCOPE AND PURPOSE OF THE PROJECT

Our program in elementary particle physics research is 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 can best be briefly summarized by listing some of our major accomplishments during the present year.

During the present year the major accomplishments included:

- 1) Using the high energy photon beam at FNAL, we have photoproduced the newly discovered resonance at $3.1 \text{ GeV}/c^2$. From the t -dependence and the cross-section, we conclude that it is a $J^P = 1^-$ state and that it is not the intermediate vector boson of the weak interaction. From the photoproduction cross-section, assuming the vector dominance model and using the optical theorem, one obtains that the cross-section for the interaction of the $3.1 \text{ GeV}/c^2$ state with a nucleon is the order of 1 millibarn.
- 2) At FNAL, we have observed the direct neutron production of muon pairs. The $\mu^+\mu^-$ mass spectrum shows a continuum at low masses, a peak in the mass region of the ρ -meson, and a peak in the region of the so-called J or ψ particle. The cross-section for the production of the new particle with neutrons of $E_n \sim 250 \text{ GeV}$ is appreciably greater than that observed at BNL energies.
- 3) The study of baryon exchange processes has continued using the University of Illinois-ANL Streamer Chamber. In the reaction $\pi^- p \rightarrow p X^-$ the data indicates a suppression of Δ exchange.
- 4) The hybrid bubble collaboration at FNAL has completed the analysis of its first runs using π^- mesons. The data have provided the first evidence for a "leading particle" in the forward hemisphere in the center-of-mass.
- 5) The analysis of the pion production of three pions on complex nuclei is essentially completed. The dependence of the cross-section on the nuclear size (the A dependence) is being used to determine the cross-section for the various three pion states on nucleons. The cross-sections are not those that one would have naively anticipated for three independent pions.
- 6) Construction of equipment is underway to perform a search for the production of charmed particles by either pions or protons at FNAL. Tests have been run on special scintillation counters which would preferentially trigger on charmed particles, if they exist.

- 7) The muon inelastic scattering experiment at FNAL has obtained major runs, and preliminary analysis of the data shows that 50% of the good nuclear events are at $q^2 < 0.5 \text{ (GeV/c)}^2$. A small sample of the data shows the elastic production of ρ and ρ' mesons.
- 8) The neutrino experiment at BNL to study neutral currents has successfully carried out its runs and the analysis of about half the data. They find that the ratio for the neutrino production of events containing π^0 mesons in the neutral current mode to the charged current mode is:

$$R_0 = \frac{\sigma(\nu + \text{Al} \rightarrow \nu + \pi^0 + N')}{2 \sigma(\nu + \text{Al} \rightarrow \mu^- + \pi^0 + N'')} = 0.17 \pm 0.6$$

This ratio would correspond to a value of the Weinberg angle of

$$0.3 > \sin^2 \theta_w > 0.4.$$

- 9) The mass distribution has been measured in the neutrino reactions leading to π^0 's for both the charged and neutral currents. In the case of the charged currents one sees a large amount of $\Delta(1238)$ production; in the case of the neutral currents, one sees a distribution that is effectively flat.

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

During the coming year, the major parts of our program will be:

- 1) We will complete the initial data taking for the high energy photoproduction experiments at FNAL, and effort will be devoted to analyzing the data obtained. The data will contain information on the high energy photoproduction of $J^P = 1^-$ objects including the new resonances first observed at SPEAR. In that hadronic and leptonic channels were recorded, the data should provide additional information on the new family of particles.
- 2) The completion of the present experiments to study the neutron production of dimuons unless the results contain unanticipated phenomena.
- 3) The analysis of the data taken in the Streamer Chamber to study the backward meson production in the reaction $\pi^- p \rightarrow n X^0$ should be yielding results.
- 4) The hybrid bubble chamber consortium will be completing the analysis of the $\pi^- p$ runs. The University of Illinois-DOLLY system will be used as the Midwest data processing center for this consortium.

- 5) We hope to have pion and/or proton runs at FNAL to study the production of charmed particles, if they exist.
- 6) Further data taking should be obtained on the scattering of 225 GeV muons at FNAL. The increased data at high momentum will increase the sensitivity of the check on the validity of Bjorken scaling and will permit a better study of the mechanisms involved in the elastic production of vector mesons by muons.
- 7) The results from the neutral current neutrino experiment at BNL in which π^0 mesons are observed should be completed and provide data on the isotopic spin components present in neutral currents.
- 8) Data from the anti-neutrino runs at BNL to study neutral currents will be analyzed.
- 9) The equipment should have been constructed and installed for the ISR collaboration with CERN-Columbia, Oxford, and Rockefeller. The hadron calorimeter in conjunction with existing equipment will permit a study of the events that are accompanied by the production at large angles of energetic hadrons either neutral or charged.

II. PERSONNEL

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

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

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

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

2) Senior Staff members holding research or professional appointments:

(Research Associates, Research Assistant Professors, Research Physicists, or Engineers)

Cooper, J.	Nodulman, L.
Downing, R.	Noggle, T.
Francis, W.	Pang, C.
Klanner, R.	Rhines, D.
Messner, R.	Simaitis, J.
Nelson, B.	

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

Alverson, G.	Hagan, W.	Roberts, T.
Avery, P.	Hicks, R.	Russell, J. J.
Bronstein, J.	Lufkin, J.	Sarracino, J.
Bross, A.	Meyer, N.	Schreiber, B.
Chapin, T.	Mollet, W.	Tortora, J.
Coleman, R.	Oswald, K.	Wagner, R.
Cormell, L.	Pike, G.	Wheeler, D.
Gronek, R.	Plumer, R.	

3. The theoretical physicists at the University of Illinois continue to have active collaborations with the experimentalists. H. W. Wyld is collaborating with the experimentalists on calculations concerned with the 3 pion system. D. Ravenhall and R. Schult are involved with the groups using complex nuclei to study meson nucleon interactions. 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. J.	Sterman, G.
Grammer, G.	Suaya, R.
Jones, L. M.	Sullivan, J.
Ravenhall, D.	Wright, J.
Schult, R.	Wyld, H. W.
Stack, J.	

III. EXPERIMENTAL PROGRAM

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

- A. Technical Accomplishments during the Past Year
- B. Experiments planned for the Coming Year
- C. Experiments that are planned for Future Years

Below the title of each of the experiments there are listed the names of 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 at ANL

Experiments using Charged Particle Beams (mainly at FNAL)

Neutral Beam Experiments at FNAL

Colliding Beam Experiments

Neutrino Experiments at BNL

A. Technical Accomplishments During the Past Year

- Al. A Study of Reactions Producing a Fast Forward Nucleon in πN Interactions at 8 GeV/c
(B. Eisenstein, B. Nelson, T. O'Halloran, D. Rhines, B. Mollet, G. R. Morris, R. Wagner in collaboration with J. Watson, Argonne National Laboratory and N. Gelfand, University of Chicago)

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

We note in passing that the Streamer Chamber facility at Argonne is now enjoying a full program of experiments being performed by other university groups as well as our own.

During the past year we have accomplished the following:

- a) Study of Backward Meson Production in the Reaction $\pi^- p \rightarrow p X^-$. (E-297 at ANL).

This experiment attempts to isolate Δ exchange processes by triggering on a forward proton of high momentum. A counter hodoscope downstream of the streamer chamber magnet selects positive secondaries with momentum $\gtrsim \frac{1}{2} P_{\text{beam}}$, while a Cherenkov counter insures that the particle is not a pion. The data reduction is complete on a 270,000 picture exposure, and we are currently preparing some of the results for publication.

A paper has already been accepted for publication in Physical Review Letters on the absence of A_1^- and A_2^- production. We have sought evidence for a narrow A_1 in our data on $\pi^- p \rightarrow p(\pi^+ \pi^- \pi^-)$ because over the years such an effect has been reported in $\bar{p}$ experiments in bubble chambers and in a missing-mass spectrometer study of baryon exchange. In the former experiments the statistics are limited, while in the latter experiment there is a great deal of "background" under the A_1 since the spectrometer does not isolate the $\pi^+ \pi^- \pi^-$ final state. We have found no evidence for narrow A_1 production and have placed an upper limit on the process which, while not inconsistent with the spectrometer results, suggests that their signal was of questionable significance.

We have no evidence for A_2 production as well. This is interpreted as due to the suppression of Δ exchange relative to nucleon exchange at 8 GeV/c incident momentum.

A paper is now being written for submission to Physical Review on the other features of the final state $p\pi^+\pi^-\pi^-$. This state is dominated by the production of (in the center-of-mass system) forward baryon resonances and backward meson resonances. We see ρ^0 , f^0 , $\Delta^{++}(1236)$, $\Delta^0(1236)$, $N^{*0}(1520)$, and $N^{*0}(1688)$.

Since the experimental trigger was optimized for protons produced alone, rather than from N^* decays, these channels are more difficult to analyze because they require some detailed models of acceptance. This work has been performed and we have evidence for backward peaking in at least one quasi-two body channel: $\rho^0 N^*(1520)$. The other channels are more difficult to interpret due to more sensitivity to the model of the acceptance. We hope to submit this paper in the near future.

A study is also being made of other channels in the reaction $\pi^- p \rightarrow pX^-$ involving strange particles, for example $\pi^- p \rightarrow pK^- K^+ \pi^-$, where the trigger was a fast forward K^+ . These events are dominated by $K^{*0}(890)$ and hyperon resonance production but also contain a clear signal for f^0 and/or A_2^0 in $K^+ K^-$. These events have "uncommon" kinematics, since the K^+ trigger must be $\gtrsim 4$ GeV/c but also $\lesssim 5$ GeV/c since that is the K threshold of the Cherenkov counter. In addition, other final states such as $pp\pi^-$ and $p\pi^+\pi^-\pi^0$ are being investigated.

b) Study of Backward Meson Production in the Reaction $\pi^- p \rightarrow nX^0$. (E-345 at ANL).

This experiment is similar to the previous one in that the streamer chamber is triggered by the detection of a fast forward baryon, in this case a neutron. The neutrons interact in thick-plate optical spark chambers located 11 m downstream of the streamer chamber and the secondaries from these interactions are detected by scintillation counters. Time-of-flight is used to discriminate against slow neutrons. A lead-scintillator array upstream of the neutron chambers removes most of the γ -rays which would also trigger the system. On the other hand, K^0 mesons are indistinguishable from neutrons at the level of the trigger.

The channels $X^0 \rightarrow \pi^+\pi^-$, $\pi^+\pi^+\pi^-\pi^-$, etc., represent even G-parity mesons, while in the pX^- experiment, $X^- \rightarrow$ (all charged) are mesons with odd G-parity. Thus the nX^0 experiment is complementary to the previously described one. Since a forward neutron can result from nucleon exchange, the suppression of Δ exchange seen in E-298 is irrelevant. However, some N^* production can occur which again complicates acceptance corrections.

The original exposure of 180,000 pictures was measured and studies are in progress on the final states where $X^0 \rightarrow \pi^+\pi^-$, $\pi^+\pi^+\pi^-\pi^-$, and $\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-$. In the first channel, a clear signal is seen for $\pi^-p \rightarrow np^0$. It was discovered, however, that the number of "good events" (i.e. those fitting $\pi^-p \rightarrow n + (m\pi^+) + (m\pi^-)$) was much lower than anticipated due to various sources of background. For this reason the apparatus was improved to diminish the rate of false triggers and a new run was made which yielded $\sim 250,000$ pictures much richer in the events of interest. The scanning and measuring of this new data is just beginning.

By the end of FY75 we hope to have final results on the physics of the original exposure, but definite conclusions about the 4 and 6 pion final states will probably require the higher statistics which will result when we analyze the new run.

c) Search for Exotic Mesons in the Reaction $\pi^+p \rightarrow nX^{++}$. (E-360 at ANL).

The 30,000 pictures taken during FY74 have been measured and analyzed. As with the reaction $\pi^-p \rightarrow nX^0$, the yield of good events was low due to background problems. It also seems that competition from the reaction $\pi^+p \rightarrow (n\pi^+) + X^+$ is very significant and implies that a search for exotic X^{++} systems demands high statistics. For this reason it appeared wise to defer further running on this experiment until the background and neutron trigger were better understood. Hopefully this will be clarified by the results of the new run on $\pi^-p \rightarrow nX^0$, but this information is not likely to be available before the end of FY75.

A2. Muon Inelastic Scattering at FNAL

(T. Kirk, W. Francis, and R. Hicks)

The program of inelastic muon scattering by the Chicago-Harvard-Illinois-Oxford (CHIO) Group is now beginning to yield physics results. During the past year we had our first two major data runs (Spring 1974, Winter 1975), and we now have about 800K triggers distributed between hydrogen and deuterium at two beam energies. The yield of good nuclear events seems to be about 10% of all triggers, and half of these are at $q^2 \gtrsim 0.5 \text{ (GeV/c)}^2$. This is a solid data sample, and we are pushing the data through the analysis programs. The results obtained from a small sample ($\sim 10\%$) of the data already show some interesting results for hadrons recoiling from the muon collisions. We see elastic production of both the ρ meson and the ρ' meson and should be able to distinguish their form factor regulators when a larger data sample is processed. This comparison will give basic new

information about the role of the vector mesons in the interaction of photons with matter. In particular, we will find out whether the form factor is regulated by the mass of the particle produced (say the ρ') or by the lightest available vector meson (the ρ). This question cannot be answered by presently known data.

We are also getting our first results on the inclusive longitudinal and transverse momentum distributions for hadrons from inelastic muon collisions. At low q^2 , the transverse momenta look like the corresponding spectra from hadron collisions. At higher values of q^2 , we seem to see no change, but until our full data sample is processed, we will not have a definitive result. If there is no q^2 dependence of the transverse momentum spectra, we are confronted with a very difficult situation in theoretical terms. We are keen to press ahead on this topic with a large data sample. Once we have processed all our data, we should also have sufficient statistical power to study the correlations of longitudinal momenta as well as the inclusive spectra and to compare them to the corresponding hadron processes. By vector dominance, these spectra should be equivalent to those produced by a beam of ρ mesons. It will be interesting to compare the longitudinal spectra (and rapidity correlations) for real pseudoscalar mesons (say pions) with those from our (virtual) vector mesons. This work is well underway.

Finally, we are working hard on the inclusive muon scattering spectra since this data is directly comparable with the results of single arm scattering experiments done at SLAC, BNL, and FNAL in recent years. All of these efforts have reported results consistent with Bjorken scaling, but the high energy results so far are confined to heavy element targets and seem to leave some uncertainty associated with them. We will present results for hydrogen and deuterium and hope to clarify the scaling picture at high energies and moderate q^2 values. This work has gone more slowly than the hadron properties because of the necessity to bring more sources of systematic error under control and to apply radiative corrections. Nevertheless, we hope to produce νW_2 curves for protons and neutrons in the coming year and to measure the R parameter over at least a limited range of q^2 . The ultimate power of our experiment to test scaling will come with an improved muon beam as discussed in the section on future plans.

In addition to the physics results first discussed, we have made some modest improvements to the spectrometer in the past year and have done the bulk of analysis program development. New discriminators were provided by the Illinois collaborators for improvement of the trigger, and the Illinois Group has been centrally involved in writing the analysis software and in processing the data.

A3. Proportional Hybrid Bubble Chamber Experiments

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

In this visual target spectrometer the Fermilab 30-inch hydrogen bubble chamber is used with proportional wire chambers upstream and downstream. The upstream system includes a two-channel Cherenkov counter, by means of which incident beam particles are tagged as pions, kaons, or protons. The wire planes improve the momentum resolution over that of the bare bubble chamber, permitting measurement of the fast forward secondaries (at 100 GeV/c the resolution is $\pm 5\%$). At the same time the advantages of the bare bubble chamber--unbiased data sampling and full geometric acceptance--are retained.

The film and tapes from the 100,000 picture 150 GeV/c π^-p run of March 1974 have been processed. Except for remeasurements, data processing is complete. The first results have been published in Physics Letters 53B, 290 (1974).

The data have provided the first evidence for a leading-particle peak in the forward center-of-mass hemisphere. The fraction of inelastic events with a leading π^- falls from 70% of those with two charged prongs to 45% for the four-prong events to less than 13% for the six-prong events. The elastic cross-section has also been determined, with an inelastic contamination of less than 5%. It appears that only about half of the (2, 4, 6) charged-prong events can be accounted for by a factorizable exchange mediating elastic scattering and diffractive excitation of target and projectile. The same conclusion follows from a comparison with elastic and leading particle cross-section in pp reactions at 205 GeV/c.

Fermilab has approved two competing hybrid systems for the 30-inch bubble chamber, ours and a counter-controlled wide-gap optical spark chamber system (FNAL Expt. 2-B). At the October 1974 meeting of the bubble chamber subcommittee of the Program Advisory Committee both groups presented their results. The outcome of this "shoot-out" was a decision by Fermilab in favor of the proportional wire system as the future laboratory hybrid facility. The request of our consortium for a large additional exposure (1.2×10^6 pictures) at 150 GeV/c was approved (Expt. 299) for an initial 600,000 pictures, with an invitation to ask for the remainder at a later date. A 150,000 picture π^+p run has just taken place (February 1975), and we expect to get the remaining 450,000 pictures in the fall of 1975.

The experiment is designed to compare roughly equal numbers of π^-p , π^+p , and pp interactions at the same energy. The complete coverage by the hybrid system of the entire range of secondary momenta will make possible clear separation between peripheral and central collisions.

A4. Unitarized 3- π Amplitudes and the Status of A_1 as a Resonance
(G. Ascoli and H. W. Wyld)

Previously reported studies^{1/} of the low mass $\pi^+\pi^-\pi^-$ system failed to find the dependence of the phase of the A_1 ($1^+S \rightarrow \rho\pi$) on the 3- π mass expected for a resonance. G. Fox^{2/} attempted to save the interpretation of the A_1 as a resonance by suggesting that incorrect phases may have been obtained by using "decay" amplitudes (for $A_1 \rightarrow 3\pi$) which did not satisfy unitarity ($\pi^+\pi_1^-$ rescattering following $A_1 \rightarrow \rho^0\pi_1^- \rightarrow \pi^+\pi_2^-\pi_1^-$ was not taken into account).

To test the validity of this criticism we undertook some time ago to construct decay amplitudes in which $\pi^+\pi^-$ rescattering is included (and which explicitly satisfy the unitarity conditions) and to re-analyze the 3- π data using these "unitarized amplitudes". The rather lengthy computations are now complete and the results have been submitted for publication.^{3/}

We found that the results of the analysis using the new unitarized amplitudes differ in no significant way from the results obtained previously. In particular, we still find no appreciable phase change of the A_1 amplitude into 3- π mass. We conclude that rescattering corrections are not likely to improve the standing of the A_1 as a resonance.

A5. Analysis of the $K\pi\pi$ System in the $K^-p \rightarrow K^-\pi^+\pi^-p$ 40 GeV data from CIBS (Cern-Ihep-Boson-Spectrometer) at Serpukhov
(G. Ascoli, R. Klanner)

The analysis of the data obtained in 1972 by the Cern-Ihep-Illinois group at Serpukhov has been completed and a final publication has been written.^{4/}

^{1/} Yu. M. Antipov et al., Nuclear Physics B63, 153 (1973).

^{2/} G. Fox, Experimental Meson Spectroscopy-1972, p. 271, AIP Conf. Proc. #8.

^{3/} G. Ascoli and H. W. Wyld, Unitary States for Three Pions, Illinois Preprint ILL-(TH)-75-4, submitted to Phys. Rev. A preliminary account is given in: G. Ascoli and H. W. Wyld, Exp. Meson Spectroscopy-1974, p. 59.

Yu. M. Antipov et al., Nuclear Physics B86, 381 (1974).

Briefly the main results are:

a) The energy dependence for production of the $K^*(1420)$ ($2^+D \rightarrow K_{890}^* \pi$) and of the $Q(1^+S \rightarrow K_{890}^* \pi)$ states is similar to that for A_2 and $A_1 \rightarrow 3\pi$ states.

b) The production amplitude for the Q shows no significant dependence of the phase on $K\pi\pi$ mass. This excludes any (single) interpretation for the Q as a resonance.

A6. Carnegie Mellon-Northwestern-Rochester-University of Illinois Collaboration

(U. E. Kruse and T. Roberts)

The analysis of the reaction $\pi^- + \text{nucleus} \rightarrow \pi^- \pi^+ \pi^- + \text{nucleus}$ in several elements ($C \rightarrow Pb$) has continued. The preliminary analysis completed early in 1974^{1/} showed strong similarity to the results for the same reaction in hydrogen. In particular, the ratio of the differential cross-sections for production of A_2 (the $2^+D \rightarrow \rho\pi$ state) and of A_1 (the $1^+S \rightarrow \rho\pi$ state) was found to be the same on nuclear targets as on hydrogen, in contrast to previous experiments.

The next step in the analysis is to obtain information about the effective interaction of each $3-\pi$ state with nuclear matter from the A -dependence of the differential cross-section for producing each spin-parity $3-\pi$ state. This step in the analysis requires a careful study of the acceptance of the spectrometer and trigger used in the experiment. This technical phase has now been completed, and the final analysis--using the Glauber optical model--has been started.

We expect the analysis to be completely finished and written up within six months.

A7. The $\bar{p}p \rightarrow \bar{p}\pi^-\pi^+p$ Reaction at 25 and 40 GeV/c (CERN-Serpukhov data)

(R. Klanner, R. D. Sard, H. W. Wyld, Jr., R. T. Cutler, A. Snyder)

Analysis of the 2500-event sample of this reaction has continued. Moments of the angular distributions in the $(\bar{p}\pi^-\pi^+)$ and $(\bar{p}\pi^-)$ rest frames have been calculated. The peak in the $\bar{p}\pi\pi$ mass distribution near 1.7 GeV is associated with the presence of a partial wave of $J \gtrsim 5/2$. Comparison with the recently published SLAC-LBL isobar analysis of $N\pi\pi$ systems^{2/} suggests that the peak is due to the anti-baryon counterpart of the $J^P = 5/2^- N^*(1670)$.

There are striking analogies between this Fermion reaction and the Boson reactions $\pi^-/K^- + p \rightarrow \pi^-/K^- + \pi^- + \pi^+ + p$. The distributions in production variables of the 3-body states are similar. The preferred decay into $\bar{\Delta}\pi$ is analogous to that into $\rho/K^* \pi$, and the unnatural $5/2^- \bar{N}^*(1670)$ peak (d-wave $\bar{\Delta}\pi$) would correspond to the $2^+A_2/K^*(1420)$ in the Boson reaction.

- U. E. Kruse et al., Coherent Pion Dissociation into Three Pions on Nuclear Targets, Phys. Rev. Lett. 32, 23, 1328 (1974).

^{2/} R. S. Longacre et al., SLAC-PUB-1390 (rev.), LBL 2637 (rev.) July/Oct. 1974.

A paper on this portion of the Serpukhov data is in preparation. A comparison of this data with the Deck-type model found to be appropriate for the $\pi^- p \rightarrow \pi^- \pi^- \pi^+ p$ reaction has been made by Wyld and Cutler. There is reasonable agreement with the m and t distributions, but not with the angular distributions. The discrepancies may be due to resonances not present in the model.

A8. Pion Diffraction Dissociation at FNAL Energies

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

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

The physics goals of the proposed study are:

- a) To extend to higher energies the study of the energy dependence of the production of low mass 3π states.
- b) To extend the study of diffractive dissociation of the pion to higher masses ($M_{3\pi}$ to 5 or 6 GeV) and to higher multiplicities.
- c) To clear up - by studies of $A_3^\pm$ production at higher energies - the apparent discrepancy between A_3^- and A_3^+ results.

During the summer of 1974 we demonstrated the feasibility of obtaining suitable $\pi^\pm$ beams at the Chicago Cyclotron by transporting hadrons to the Chicago Cyclotron without appreciable losses. We concluded that with very minor modifications, beams of positive and negative π 's of the desired intensity ($\sim 10^5$ particles/sec) and quality ($\sim 1 \text{ cm} \times 1 \text{ cm}$ beam size) at energies up to 170-200 GeV could be obtained to allow the proposed study to be carried out compatibly with other experiments in the neutrino area (e.g. operation of the 15 foot bubble chamber).

Together with R. Stefanski and others, we made a new measurement of the fluxes of $\pi^\pm$, $K^\pm$, and $p^\pm$ produced by 300 GeV/c protons on an aluminum target at momenta between 25 and 225 GeV/c. These results are important to experimenters measuring neutrino cross-sections, and we are preparing a paper for publication.

In the November 1974 meeting of the Program Advisory Committee, (which followed by a few days the discovery of the ψ/J meson at SLAC/BNL), final consideration of the proposal was deferred.

19. Charmed Particle Search

(G. Ascoli, L. Holloway, T. Kirk, R. Klanner, and L. J. Koester)

Following discovery of the $\psi(J)$ at SLAC(BNL) interest in a search for charmed particles was revived, since a possible interpretation of the ψ states is that they are bound states of charm and anticharm particles. The considerations which motivated physicists to postulate the existence of charm (anticharm) particles lead to a strong presumption that such particles should often decay into hadronic final states of strangeness $+1(-1)$. Based on this conjecture we proposed (Fermilab proposal P-369) to look for associated production of charmed mesons (or baryons) and anticharm mesons by triggering the Muon Spectrometer (built by a Chicago-Harvard-Oxford team around the Chicago Cyclotron Magnet) on events with two visible V^0 decays ($2(K_S^0 \rightarrow \pi^+ \pi^-)$ or $K_S^0 \rightarrow \pi^+ \pi^-$ and $\Lambda^0 \rightarrow p \pi^-$). The large acceptance of the spectrometer is ideally suited to study high mass states (the mass of the lightest charmed meson is expected to be $\gtrsim 2$ GeV). A test of the proposed trigger was approved by Fermilab and is tentatively expected to occur in the March-April 1975 running period. The counters required for the trigger (topologically we require n charged particles just downstream of the target, $n + 4$ particles some 2 meters farther downstream) must have unusually small thickness and good pulse height resolution. We have constructed the counters and tested them (successfully) in a muon beam.

A10. High Energy Photon Experiments at FNAL

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

FNAL Expt. 87A has proceeded fairly well on the program outlined in last year's Schedule 189. It is currently one of the prime experiments at FNAL due to our having encountered new phenomena.

Our detection equipment consists of the following: multiwire proportional chambers and a magnet which allows us to determine the momentum of charged particles, an electromagnetic shower detector, a hadron calorimeter, a large block of steel followed by horizontal and vertical counter hodoscopes to identify muons, electrons, photons, charged hadrons, and neutral hadrons. The installation by FNAL of the remaining 70' of liquid deuterium for attenuating the neutrons was somewhat delayed and was completed in the early fall. In a series of runs the following things have been accomplished:

- a) Measurements of the photon spectrum produced by 200, 300, and 380 GeV protons on beryllium.
- b) Data has been obtained on diffractive ρ -production from nuclear targets.
- c) A measurement of the photoproduction of massive $J^P = 1^-$ states. The most significant thing is that by observing $\mu^+\mu^-$ and e^+e^- pairs, we have measured the photoproduction of the narrow resonance at a mass of $3.10 \text{ GeV}/c^2$. The t -dependence of this cross-section is very similar to that of ρ -production in the small t region indicating that it is a $J^P = 1^-$ object. The cross-section obtained is

$$\sigma(\gamma + \text{Be} \rightarrow 3.1 + x) = 16 \pm 5 \text{ nanobarns/nucleus.}$$

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

$$\quad \quad \quad \mu^+\mu^-$$

The error includes both a statistical error and the uncertainties in the absolute flux and acceptance calculations. By assuming vector dominance and the optical theorem and using the branching ratio data from the SPEAR collaboration, one can obtain the total cross-section for the interaction of the $3.1 \text{ GeV}/c^2$ particle with a nucleon. The value obtained is the order of one millibarn; this value is much too large for the particle to be the intermediate vector boson of the weak interaction. From the photoproduction cross-section theorists conclude that the $3.1 \text{ GeV}/c^2$ resonance is a hadron. A report of the preliminary results on the production of the $3.1 \text{ GeV}/c^2$ particle has been accepted for publication in Phys. Rev. Letters.

We have also observed the photoproduction of the $3.7 \text{ GeV}/c^2$ narrow resonance. During the months of February and March data is being taken using 380 GeV protons to produce higher energy photons on the possibility that if more massive $J^P = 1^-$ states exist, we could observe them. The present data taking is recording events in both hadronic channels and leptonic channels.

All. High Energy Neutron Experiments at FNAL

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

A great deal of interest developed last year in the observation of energetic muons and electrons in single arm experiments at FNAL. By using the neutral beam without the liquid D_2 attenuator, we were in an excellent position to study whether muon pairs were being produced by high energy neutrons. Experiment 358 was proposed, and data has been taken in a series of runs during this year. The normal detecting arrangement was modified by the installation of a supplementary hadron calorimeter (followed by steel to attenuate the hadrons) about 1 meter downstream of the target.

This permitted us to work with a high intensity beam and to look for muon pairs. We have observed the following:

a) There is an appreciable production of muon pairs by high energy neutrons. In the lower mass region there is a continuum with a large enhancement at the mass of the ρ -meson.

b) In the higher mass region, we have observed the new mass peak reported at $3.1 \text{ GeV}/c^2$. The width of the peak is consistent with our experimental resolution. In the runs using 300 GeV protons, we have obtained 43 events in the $3.1 \text{ GeV}/c^2$ region. These events are produced with a considerably larger value of $p_{\perp}^2$ than the ρ -meson. Due to acceptance limitations, the energy of these events was in the region above 70 GeV. From this data we obtain

$$(n + B \rightarrow 3.1 + x) = 3.6 \times 10^{-33} \text{ cm}^2/\text{nucleons for } |x| > 0.24, \\ \downarrow \mu^+ \mu^- \quad \text{where } x \sim E_{3.1}/E_n$$

This cross-section is appreciably larger than that observed by J. K. Aubert et al. (Phys. Rev. Lett. 33, 1404 (1974)).

During the month of March, FNAL has scheduled additional running for E-358 using 380 GeV protons to produce higher energy neutrons.

A paper on the production of the dimuons by neutrons has been accepted for publication in Phys. Rev. Letters.

A12. A Study of $\bar{\nu}$ and ν Induced Neutral Currents

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

The apparatus for this experiment consists of a set of 6' x 6' spark chamber modules interspersed with scintillation counters. The entire apparatus weighs 26 tons, of which approximately 5 tons is in a fiducial volume measuring 4' x 4'. We have at this time had exposures of both ν (400K pictures) and $\bar{\nu}$ (50K pictures) at Brookhaven National Laboratory.

The major goal of the experiment is the analysis of single pion production and the study of the isotopic composition of the pion-nucleon system in the final states. Recognizing the complexity of the Aluminum target, we are attempting to extract the following final states:

At the present time we have analyzed 200K of the ν exposure and 25K of the $\bar{\nu}$ exposure.

We have presented the following results:

$$a) \quad R' = \frac{\sigma(\nu_{\mu} + Al \rightarrow \nu_{\mu} + N' + \pi^0)}{2 \sigma(\nu_{\mu} + Al \rightarrow \mu^- + N'' + \pi^0)} = 0.17 \pm 0.06$$

Upon correcting for the charge exchange interaction in the Aluminum nucleus, we find a value for the Weinberg angle of $\sin^2 \theta_w = 0.3 \rightarrow 0.4$. A value which is consistent with the results of CERN.

b) We have studied the invariant mass of the $\pi^0 p$ system in the reactions:

1. $\nu_{\mu} + p \rightarrow \nu_{\mu} + p + \pi^0$.
2. $\nu_{\mu} + n \rightarrow \mu^- + p + \pi^0$.

We find that reaction 2) is dominated by the production of the $\Delta(1238)$ indicating that the charged current neutrino interaction is dominated by an $I = 3/2$ in the final state corresponding to a $\Delta I = 1$ transition. We do not see such a dominance in the neutral current induced interactions indicating that the neutral current probably has a substantial $\Delta I = 0$ transition.

c) We have observed 5 neutral current events induced by $\bar{\nu}$ which indicates that we will, at the end of our spring run, have enough statistics to make a meaningful determination of the ratio of single pion neutral current production induced by ν and $\bar{\nu}$.

31. A Study of Reactions Producing a Fast Forward Nucleon in πN Interactions at 8.0 GeV/c

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

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

Although most of the analysis of this experiment should be completed in FY75, there may be features of some of the previously unstudied channels which will remain of interest, in particular those containing neutral pions.

b) Study of Backward Meson Production in the Reaction $\pi^- p \rightarrow n X^0$.

We intend to give highest priority to the completion of the measuring, data reduction, and physics analysis of the 250,000 picture exposure of January 1975. In addition to the systematic study of final states such as np^0 and nf^0 , we hope to search for high mass $(2\pi^+ 2\pi^-)$ and $(3\pi^+ 3\pi^-)$ systems ($m \lesssim 2.7 \text{ GeV}/c^2$) as well as to compare final states such as $(n\pi^+)_{\text{fast}} (\pi^+ \pi^- \pi^-)_{\text{slow}}$ which can be produced only via Δ^{++} exchange to states like $(n\pi^-)_{\text{fast}} (\pi^+ \pi^+ \pi^-)_{\text{slow}}$ which can also occur via nucleon exchange.

There is preliminary indication that some events fitting $\pi^- p \rightarrow n\pi^-\pi^+$ are really $\pi^- p \rightarrow \Sigma^- K^+$ or $K^- p \rightarrow \Sigma^- \pi^+$ with the Σ^- fast and forward, its decay neutron being the triggering particle. For these events the Σ decay was within the target and unseen. In addition, a few percent of the events have visibly "kinked" tracks. Should the yield of such events be sufficient, we will be able to study the backward associated production (mediated by Λ^0 exchange) of $\Sigma^- K^+$ and compare it to the neutron exchange production of $\Sigma^- \pi^+$.

Finally, we will have a large sample of events triggered by fast neutral kaons. To date no systematic study has been made of these events in our data, and we expect to do so in FY76.

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

A decision will be made on the future of this experiment. A high statistics study will almost certainly require some modification of the existing neutron trigger. In the light of current expectations for available running time at the ZGS, it is unlikely that an experimental run could occur before the end of FY76 or early FY77. Some funds will be requested in the FY76 budget for such hardware modifications.

B2. Muon Inelastic Scattering at FNAL

(T. Kirk, W. Francis, R. Hicks)

We anticipate substantial additional data taking for the CHIO muon scattering collaboration in FY76 plus continuing intensive analysis effort on data already taken and data to come. The emphasis in the near future will be on running at higher muon beam energy and continued improvement of the spectrometer, trigger system, and the muon beam. We will continue to alternate liquid hydrogen and liquid deuterium in the target in order to extract both proton and neutron scattering behavior. We discuss the items mentioned in order.

The muon beam energy can now be raised to 225 GeV as a result of efforts by the University of Illinois and Fermilab to improve the operating characteristics of the muon line magnets. The higher energy data helps us separate the scaling functions and gives us better acceptance at the higher values of q^2 . In consequence, we expect to run almost exclusively at 225 GeV from now on. In this way, we hope to extend the sensitivity of our test of the validity of Bjorken scaling and the quality of our measurement of the propagator behavior in elastic vector meson production (ρ , ρ' , and maybe ϕ and ω). We hope to reduce the halo around the beam at the same time as we raise its energy.

The spectrometer will be improved by installation of a multi-cell gas Cherenkov counter built by the Oxford Group, cylindrical drift chambers around the target supplied by the Harvard Group, and proportional chambers near the beam (where our spark chambers are deadened) by the Illinois Group. These improvements are moderate in effort, but will significantly improve the ability of the spectrometer to analyze final state hadrons. At the present time, we cannot tell pions, kaons, and protons apart or reconstruct hadron tracks which stay in the beam. The first condition is improved by the Cherenkov counter and the second by the Illinois proportional chambers.

The fast electronics will be reworked to permit a more efficient trigger at higher beam rates. This is a technical improvement which helps us take data with less dead time and fewer bad triggers. The muon beam will be improved by installing larger aperture bending magnets, quadrupole shims and perhaps some halo spoiler magnets.

As a result of the improvements noted above, we will increase our data sample by about a factor two (mostly at 225 GeV), and our analyzed sample by a factor more like 20. This will enable us to test Bjorken scaling on protons and neutrons with a sensitivity comparable to the E-26 test in Fe targets, to separate νW_2 and W_1 over an appreciable kinematic region and to follow the vector meson and hadron properties to fairly large values of q^2 and $p_{\perp}$.

B3. Muon Nucleus Scattering

(T. Kirk, W. Francis, R. Hicks)

In view of steadily increasing theoretical interest, the CHIO muon scattering group is planning to resubmit to FNAL our proposal for muon scattering from heavy element nuclei. The generalized vector dominance theory (GVD) indicates that we should observe the phenomenon of nuclear shadowing in a clear manner at small to moderate q^2 values and high beam energies. The shadowing should gradually vanish as the value of q^2 is increased. The effect was looked for at BNL and SLAC, but these accelerators were incapable of achieving high enough values of the relevant scaling variable ω' . This is certainly true if we require q^2 to be in the Bjorken scaling regime.

The proper understanding of virtual photon shadowing in heavy nuclei has been clouded by uncertainties in applying radiative corrections in heavy nuclei since the radiative corrections are largest in the same kinematic regions as the expected shadowing effect. We are lucky to have Dr. Garland Grammer, a theorist who has done a lot of work in this area joining us at Illinois in fall 1975. He has expressed interest in the shadowing experiment and has offered to help us with the radiative corrections. This represents a large technical advantage.

The technical modifications to the muon scattering spectrometer at FNAL that are necessary in order to carry out this experiment are minimal. Basically, we have to remove the hydrogen target cup and replace it with solid targets. The trigger and apparatus otherwise remain the same. The analysis programs to process the data (with the exception of the radiative corrections) already exist, and we expect to proceed as soon as we obtain approval for the experiment.

B4. Proportional Hybrid Bubble Chamber Experiments

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

The Illinois contingent is currently preparing to measure the new π^+/p bubble chamber film on the DOLLY/CSX-1/PDP-10 system. Together with the Illinois Institute of Technology group (for scanning, predigitizing, and computing) we shall constitute data Center C of the consortium (Center A is MIT/Yale/Brown; Center B is Johns Hopkins/Rutgers/Tennessee).

Remeasurement of Expt. 154 events is under way. The results of the first

measurements are being checked here and at IIT. A rate of at least 10 events/hr seems attainable (the average prong number is 7.3 with 27% having at least 10 prongs). We expect to measure some 25,000 events (200,000 exposed frames) between now and the end of FY76. The main problem in reconstructing film taken at Fermilab energies is that of matching tracks in the different views of high-multiplicity events. A scheme to use the hit-miss pattern of the DOLLY scans for this purpose (as a human does in matching gaps and blobs) is being tested. If it is successful it will reduce significantly the number of incompletely reconstructed events.

The physics analysis of Expt. 154 (π^-p at 150 GeV/c) is being done by a number of subcommittees of the consortium. We are active in three - "leading particle" studies, exclusive reactions, and correlations in inclusive reactions.

The "leading particle" group is concerned with factorization and diffractive effects in inclusive channels. Some preliminary results have been summarized above. Studies of azimuthal correlations and missing-mass distributions relative to the "leading particle" are under way.

The second group has obtained a sample of some 200 fitted events of the exclusive channel $\pi^-p \rightarrow \pi^- \pi^- \pi^+ p$. We intend to compare the energy and angle distributions with those found in our Serpukhov 40 GeV sample.

As soon as data from the π^+p runs become available, it will be analyzed in parallel with the π^-p data, for comparison of π^-p , π^+p , and pp reactions. We expect this analysis to get under way in FY76.

The consortium has decided to make a significant improvement to the present hybrid system - incorporation of a Forward Gamma Detector (FGD), downstream of the wire chambers. The FGD will consist essentially of a pile of lead-glass Cherenkov counters for energy determination combined with a lead-scintillation sandwich for vertex location.

We propose to use the FGD in the remaining exposures of Expt. 299. A good deal of work lies ahead in the way of assembling, testing, and calibrating the device.

B5. Charmed Particle Search

(G. Ascoli, L. Holloway, T. Kirk, R. Klanner, L. J. Koester)

Assuming that the test of the trigger will be successful during FY76, we expect to study the production of charmed particles, provided they exist and that their production cross-section is within an order of magnitude of the theoretical estimates.

B6. Pion Diffraction Dissociation at FNAL Energies

(G. Ascoli, R. Klanner, U. E. Kruse, L. J. Koester, R. D. Sard, in collaboration with Northeastern University physicists) (P-318)

Although program committee action on this proposal has been deferred until early FY76, we are continuing to prepare the apparatus. We are confident of approval because the experiment concerns solid physical measurements that must be carried out to answer outstanding questions about strong interactions. We have already procured scintillators for a large (6 ft. x 6 ft.) recoil proton hodoscope which can identify particles by a combination of range, time-of-flight, and pulse height. Preliminary tests show that the signal uniformity is good, and the time-of-flight can be measured to a sufficiently small fraction of a nano-second regardless of position.

We have also designed a large multiwire proportional counter array for use with this experiment and P-369.

We hope the initial running of this experiment will occur in FY76.

B7. High Energy Photon Experiments at FNAL

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

During the first months of FY76 there will be additional running of Expt. 87A. By the time this running takes place, we should have preliminary analyses of the data from the present runs which include both lepton and hadron channels. The next set of runs will be influenced by which channels have provided interesting events. Some of the possibilities that come to mind at this time are the following:

a) If we have encountered evidence for new particles but have a statistical uncertainty, we may push for increasing the statistics to clarify the situation.

b) Studies of photoproduction dynamics of $J^P = 1^-$ objects. Up to the present, the runs have been of an exploratory nature, and we have not followed up on some of the questions concerning production dynamics that have been raised by the analysis of this data. For example, at small t one sees a t -dependence of the $3.1 \text{ GeV}/c^2$ resonance which indicates that it is diffractively produced. However at larger values of t there are uncertainties as to whether the number of events fit the diffractive mechanism or whether other production processes are also present, i.e. large angle scattering or the decay of higher mass objects.

At the present time we have only a few events at the $3.7 \text{ GeV}/c^2$ resonance. We hope that our analysis of the hadron channels will either give us adequate photoproduction data or will indicate the best way to study both the $3.7 \text{ GeV}/c^2$ resonance and the $4.1 \text{ GeV}/c^2$ enhancement that is observed at SPEAR. If the present runs do not yield adequate data to determine whether these resonances are diffractively photoproduced and if by special running conditions we can enhance the data taking rate of higher mass objects we may do so.

c) Most of our data has been taken with a beryllium target. By running with higher Z^2 targets, one may obtain information on both the production dynamics and on the nucleon interactions of $J^P = 1^-$ objects. It would be of interest to do this for the ρ -meson as well as for the new resonances if the event rates are adequate.

d) Studies of branching ratios of new resonances. Our apparatus identifies leptons, hadrons, and photons, and at high energies the decay of the particles are folded forward; therefore we may be in a better position to study certain branching ratios than the groups at SLAC or BNL.

In the runs that are scheduled for this summer, it may not be feasible to follow up all of the above possibilities, and we will probably have to make choices. If we are forced to forego measuring interesting phenomenon because of the amount of time that is scheduled for Expt. 87A, we may submit a request or a new proposal for additional runs in FY76.

A great deal of effort will go into analyzing the large quantity of data which is being obtained in the scheduled runs. From our experiences with our equipment, we are also anticipating that some modifications and new equipment would be desirable to permit us to take higher intensities and possibly to identify K-mesons by use of a Cherenkov detector. The design and construction of such equipment should be started fairly early if it is to be available for new runs during the latter half of FY76.

B8. High Energy Neutron Experiments at FNAL

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

The scheduled running of Expt. 358 should be completed during the present fiscal year, therefore the main effort in FY76 will be analyzing data obtained during the previous runs. Obviously if some events of an unexpected nature are encountered which warrant further running, requests for such runs would be submitted to FNAL.

One of the interesting questions on which we may not have obtained statistically

significant data has to do with the dynamics of the production of the $3.1 \text{ GeV}/c^2$ particle by neutrons - specifically, the number of events as a function of the transverse and longitudinal momenta. The few events we have observed at large transverse momenta may be statistical fluctuations or they may be indicative of interesting production mechanisms. We have the possibility of obtaining data at larger transverse momenta by using a more compact geometry than we have used in our present runs. The decision on whether to devote effort to this will depend on the results of the analysis of our present data and information from other groups that are involved in the hadron production of such particles.

B9. Studies of Large Transverse Momentum Phenomena at the ISR

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

Within the past year we have investigated the possibilities of using a large solid angle hadron calorimeter to study the physics of high transverse momentum phenomena at the ISR. We are interested in adding this calorimeter to the detector arrangement of the CERN-Columbia-Oxford-Rockefeller Collaboration (CCOR). Detailed calculations on the design and the expected performance of the calorimeter were completed this past year (with the generous assistance of A. Gabriel - Oak Ridge National Laboratory) and a proposal summarizing our ideas has been transmitted to the CCOR Group.

The addition of a calorimeter to the CCOR detectors would improve one's ability to identify and separate electrons from pions and would enable one to trigger on total energy deposition (charged plus neutral) at large angles, thereby allowing us to pursue the following physics:

a) to study the reaction $pp \rightarrow e^+e^-$ + anything for dilepton masses in the range $2-10 \text{ GeV}/c^2$. This mass range is of great interest at the current time because of the observation of new states at $3.1 \text{ GeV}/c^2$ and $3.7 \text{ GeV}/c^2$ that have been observed at SPEAR, BNL, and FNAL.

b) to measure the transverse momentum spectrum of neutrons and antineutrons in the inclusive reaction $pp \rightarrow n$ (or $\bar{n}$) + anything at large transverse momentum.

c) to explore the high transverse momentum region for the presence of unusual states with hadronic decay modes, e.g. $\psi(3.7) \rightarrow \pi^+\pi^-\gamma$.

The CCOR detectors will be installed in the latter part of FY76. The calorimeter should be available for installation at the same time. We hope to be in the data taking phase during FY77.

B10. High p_T Correlation Experiment at the ISR

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

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

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

- a) The solid angle should be large, ≈ 1 sr to ensure reasonable counting rates even for large p_T particles.
- b) The range in rapidity should be wide enough, $\approx \pm 2$ units, to investigate the rapidity dependence.
- c) The gross features of the azimuthal correlation should be measurable.
- d) Charge particles should be identifiable by absorption (muons) or by Cherenkov and time-of-flight measurements (hadrons).
- e) The apparatus should allow interesting physical quantities, such as invariant mass of a two-particle system to be included in the trigger condition. Several such trigger conditions should be used in parallel.

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

Design and construction of the experimental apparatus will take place during FY76 and FY77. Installation and data collection will start in FY77.

The University of Illinois will contribute mainly to the design and construction of the drift chambers and read-out electronics.

B11. A Study of $\bar{\nu}$ and ν Induced Neutral Currents

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

We will have reached the proposed objectives of these two experiments by the end of FY76. FY76 will be dedicated to the analysis of our current data. We will make a decision during this period on future plans based on the data we have acquired.

C. Experiments that are Planned for Future Years

C1. A Study of Reactions Producing a Fast Forward Nucleon in πN Interactions at 8.0 GeV/c

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

With the exception of the possibility of a new run on the reaction $\pi^+ p \rightarrow nX^{++}$, this program should be completing the analysis of the results obtained from previous runs.

C2. Pion Diffraction Dissociation at FNAL Energies

(G. Ascoli, R. Klanner, U. E. Kruse, L. J. Koester, R. D. Sard, in collaboration with Northeastern University physicists) (P-318)

Either this experiment will be in a data taking phase or analysis of the data should be taking place during FY77.

C3. Muon Inelastic Scattering at High Intensity and High Energy

(T. Kirk, W. Francis, G. Gladding)

We hope to see an increase in the muon beam intensity at FNAL of a factor twenty or so in the next two years, together with a similar improvement in the beam to halo ratio. We have started preliminary talks with Fermilab people on how to bring this about and feel that such a goal is within reason. If we achieve this purpose, the Muon Scattering Spectrometer will reach its full potential and the program as initially conceived brought to fruition.

The program includes a test of Bjorken scaling out to very large q^2 values ($q^2 \sim 100 \text{ (GeV/c)}^2$), and a measurement of the recoil hadron properties under extreme conditions. We use both hydrogen and deuterium targets so that results will be obtained for both neutrons and protons. The separation of νW_2 and W_1 will be possible over a substantial range of kinematical variables.

C4. High Energy Neutral Beam Experiments at FNAL

(G. Gladding, M. Gormley, R. Messner, T. O'Halloran, A. Wattenberg, J. Bronstein, R. Coleman and others. We anticipate that this will be a collaborative effort.)

In that we are in a very exciting period in a rapidly developing field, our plans for FY77 may not become definite until some time during FY76. New proposals will have to be written and submitted for these experiments. We are in the unique

situation of having higher energy photons than are available at any other accelerator in the world; also our basic detecting system has the capability of identifying and measuring the energy of leptons, photons, and hadrons. However our future running may benefit from different geometrical arrangements of our present detecting system and/or the installation of some additional equipment as discussed below. There are a variety of possible continuations of our present neutral beam experiments; a few of these possibilities are discussed below:

a) Modification of the apparatus to increase the acceptance for larger angle events: increasing the angular acceptance of our apparatus has several advantages and one disadvantage. They are the following:

- 1) It increases the probability of our seeing higher mass events. At the present time running at 400 GeV our acceptance for masses up to $5 \text{ GeV}/c^2$ is of the order of 20%. By increasing the angular aperture, we will raise this acceptance to a higher value and thereby could increase the data taking rate.
- 2) With the present geometry for the $3.1 \text{ GeV}/c^2$ resonance, we are limited to photons whose energies are above about 80 GeV. By increasing the angular acceptance, we would be able to study the production of this resonance by lower energy photons. At the present time, it appears that the cross-section is very energy dependent, and it is obviously interesting to see how this cross-section is actually varying as a function of photon energy.
- 3) There is the possibility that there are particles, which due to some attribute, are produced only in pairs and have observable branching ratio to leptonic decays. (Charm particles or heavy leptons are two such types of particles.) Such particles, when pair produced have an initial opening angle and then when they decay into leptons there is an additional transverse momentum which must be added to this opening angle. By going to larger angles, we would enhance the probability of observing such particles - specifically by detecting μe coincidences where one of the pair produced particles decays into a muon and the other particle into an electron.
- 4) A disadvantage to larger angles is that if we do not plan to enlarge the size of our detectors, we can obtain the larger angles either by a more compressed geometry or by a magnet with an appreciably larger aperture. In a compressed geometry using the present apparatus, we would be giving up some angular resolution and thereby mass resolution. The

angular resolution probably could be improved by the addition of some drift chambers. In regard to larger magnets, they are likely to have less uniform magnetic fields and need appreciably larger corrections, possibly also affecting our resolution. Consequently there could be a loss in resolution associated with increasing the angular acceptance.

b) Liquid hydrogen and deuterium targets: Our plans to study photoproduction with a liquid hydrogen target have not yet materialized. If we have not obtained photoproduction data using a liquid hydrogen target during FY76, we would hope to do so during FY77. The motivation is to obtain a better understanding of both the diffractive and non-diffractive mechanisms involved in photoproduction of $J^P = 1^-$ objects.

c) Production by the Primakoff effect of $J = 0$ and $J = 2$ objects: If there are $J = 0$ objects which have an inhibited coupling to hadrons, they can be observed via the Primakoff effect if $\Gamma_{\gamma\gamma} > 100$ KeV. A very speculative example of such is if there are particles which have "color", in this case the $J = 0$ states would have the $\gamma\gamma$ decay mode as one of their main branching ratios. Production by a photon beam is one of the few ways to look for such particles as they would rarely be produced by direct hadron reactions. A minor modification of our apparatus would be necessary to allow us to directly look for the $\gamma\gamma$ decay mode of such objects.

For particles with spin 2 (like the f^0), although they are not photo-produced by the vector dominance mechanism, they can be coherently produced at very small angles by the Primakoff effect. By observing the 2π or other hadronic decay modes, one could determine the $\gamma\gamma$ branching ratio of $J = 2$ objects. $\Gamma_{\gamma\gamma}$ is not known for anything except the lower mass pseudoscalar mesons.

d) Polarizing the photon beam: by a series of single crystals, SLAC has successfully polarized a photon beam. Calculations have been done for our situation. The advantage is that the production of $J^P = 1^-$ states with polarized photons would give us additional information on the production dynamics at high energies of vector mesons, and also it would possibly improve our ability to identify higher mass states that may be masked in our present backgrounds.

e) Our neutral beam includes photons, neutrons, and K_L^0 mesons. If new developments indicate that some members of the family of new particles would have an enhanced production by strange particles, we would give consideration to using the K_L^0 mesons that are present in our beam in order to perform production experiments.

The following is a direct quote from Section C4 of last year: "... there is a reasonable probability that we will have encountered some unanticipated phenomena. The further investigation of such phenomena could take precedence over our present plans...."

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, J. Lufkin, R. Gronek, R. Stamerjohn, and K. Oswald)

Measuring continues on streamer chamber film using the CSX-1/DOLLY precision CRT measuring system. The program for this system has been frozen as development efforts of the personnel are directed elsewhere. During FY75 a total of 55,000 streamer chamber events were measured at rates of 20 to 30 events/hr.

The program for the measurement of neutrino experiment (BNL-605) spark chamber film has been developed. This is a simple program mainly involving manual measurements of sparks with automatic fiducial measurement and film frame advance. Measuring rates of 40 to 50 events/hr. are standard with a total of 16,000 pictures measured in FY75.

A considerable amount of effort has been devoted to the development and refinement of the program for the measurement of bubble chamber film (FNAL 154 and successors). The program which must work with image plane digitizer clear point measurements on each track requires special procedures because of the number of tracks in the forward cone. Measuring rates of the order of 20 to 40 events/hr. are expected. At the same time studies are under way on the development of bubble "signatures" - the detailed pattern of bubbles developed in each track. Initial efforts to use these patterns for the matching of tracks from different views are very encouraging. These studies are important because of the difficulties in reliable matching of tracks of such high energy tracks.

Work continues towards improved understanding of signal detection techniques. System stabilities are now approximately 2μ over a 24 hour period. Specific studies are aimed at matching detector parameters more closely to the requirements of individual film from various experiments.

A2. Computer Operations

(R. Brown, L. Holloway, G. Dobratz, N. Meyer, B. Schreiber, and J. Wray)

During FY75 the DEC PDP-10 system was used in time-sharing and batch operations for approximately 3000 CPU hours. The CSX-1 was linked to the PDP-10 for approximately 8000 hours. A majority of this time was used for on-line processing

of DOLLY measurements, with the remainder used for program development. A total of 16 time-sharing terminals including CRT terminals have been installed within the group facilities. Competition for memory space by large programs as well as the requirements for additional memory set by the more recent monitor releases has been eased by the addition of 32K of MOS memory installed by the group's technical staff. This has included the development of error detection circuitry which provides useful recording of all detection and correction actions for the early detection of failing memory elements.

EVPROC, a procedure for scheduling the direct processing of DOLLY measured events to arbitrarily deep levels of analysis has been installed. This speeds the flow of events through the total analysis schedule.

A3. Engineering Systems

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

The major effort for FY75 has been continued development and testing of the University of Illinois modular electronics system. This system is similar to CAMAC hardware but of greater speed and considerably lower cost. Two experiments currently in progress, FNAL 87A and BNL 605, are using this system. In addition, the system is now being used at the University of Illinois Superconducting Linac for monitoring, control, and data gathering purposes.

An interface between the University of Illinois modular system and the standard CAMAC system has been developed.

A4. Large Area Electromagnetic Shower Detecting System

(G. Gladding, M. Gormley, A. Wattenberg, J. Bronstein, R. Coleman, L. Cormell, and D. Wheeler)

The large area shower detector referred to in previous Progress Reports has been in use for over a year. The pulse height monitoring system has worked very well and the entire system has remained more stable than anticipated. The light pulser and photo-diode system for monitoring the pulse height has had a stability of about 2% over periods of several months, and the shower detectors themselves have also remained stable to within a few percent over the same periods.

A5. High Energy Hadron Calorimeter

(T. O'Halloran, R. Coleman, J. Sarracino, D. Smith of Columbia University and J. Knauer and D. Yount of the University of Hawaii)

A hadron calorimeter with an area of approximately 42 sq. ft. has partially been installed for use in the high energy neutral beam experiments at FNAL. The

completed installation has been delayed because the vendor has been late in delivering and has sent sheets of scintillation material which were useless and had to be returned. The system is therefore operating with a poorer resolution than it will have when it is completed. The system consists of 48 layers of steel 2 inches thick with slabs of scintillator between the steel layers. Modules 16" high and 33" wide have been tested and calibrated at FNAL, and the calorimeter is in use during the present data taking runs.

B. Plans for Facilities for the Coming Year

B1. Data Acquisition Systems

(R. Brown, R. Downing, T. Noggle, J. Simaitis, J. Wray, J. Lufkin, R. Gronek, R. Stamerjohn, and K. Oswald)

During FY76 work will continue at a modest level on DOLLY hardware studies aimed primarily at further understanding of detection schemes to provide better matching to the experimental film. Software development will concentrate on continued adaptations of the tight coupling between the PDP-10 and the CSX-1 computers to speed up measuring rates and on-line processing. Program development for production measuring of very high energy events in the 30" bubble chamber (FNAL 154 and successors) will be given high priority. Specific attention will be devoted to the development of bubble signature matching techniques with correlation schemes realized either in hardware or software.

B2. Computer Operations

(R. M. Brown, N. Meyer, B. Schreiber)

Continued growth of the PDP-10 time-sharing use is expected with a total of up to 3500 hours CPU time anticipated. Programming effort will be devoted to the development of interactive graphic facilities for:

- a) Data tracking program development,
- b) Manual data filtering, and
- c) Presentation of line-printer output for review and selection prior to printing.

It is expected that these facilities will be of considerable value in the research program of the group as well as reduce significantly the amount of paper used in printing.

B3. Engineering Systems

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

There will be continued development for the University of Illinois logic module system. Design studies will start for a multiplexed wire drift chamber readout system. A digitally controlled photomultiplier high voltage supply will be developed. This will allow computer monitoring and control of photomultiplier voltages and gains.

24. Hadron Calorimeter for Colliding Beam Experiments

(G. Gladding, M. Gormley, P. Avery, and J. J. Russell)

A great deal of effort has gone into the design of a hadron calorimeter to measure the energy of hadrons of somewhat lower energy. The first use planned is in a collaboration with the CCOR group at ISR. The design has been greatly assisted by T. A. Gabriel (Oak Ridge National Laboratory) who has performed detailed calculations of the expected resolution for the calorimeter. Specifically, the design chosen will have a Gaussian width of 37% for hadrons with an energy of 2 GeV. The calorimeter consists of modules with successfully increasing area as one proceeds away from the interaction region. Each module consists of 16 sheets of steel (1.0 cm thick) sandwiched between 16 sheets of solid scintillator (0.48 cm thick). Thus the detector is a conventional, total absorption counter except that it has rather fine sampling properties and has a large area for detection. Present plans call for completion of the detector during the fall and installation early in the winter.

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