ORO-3065-42

Subject: Progress Report for Contract E-(40-1)-3065 between the U. S. Energy Research and Development Administration and Duke University

Period: 1 September 1976 through 30 September 1977

## I. INTRODUCTION — OVERALL PROGRESS

We have been studying high energy $\pi^{\mp}$-proton, and $\pi^{\pm}$-Neon interactions in the SLAC 82-inch bubble chamber and in the Fermilab 30-inch bubble chamber. The present work is aimed at studying the production and interaction of pions in hydrogen and nuclei over the momentum range of 10 to 200 GeV/c. We have continued our study of the production of states involving $\pi^{o}$'s in hydrogen which have not been accessible to previous bubble chamber experiments. We have continued our studies of $\pi$-nuclear interactions over a wide range of bombarding energies (5-10, 15-200 GeV). The observation of the energy dependence of multiplicity and single particle spectra gives us very useful data and a better understanding of processes going on in a heavy nucleus. We still have an approved proposal to run the 30-inch chamber at Fermilab with a very heavy nucleus (Pb or U) at 200 GeV. This heavy nucleus would give approximately two times the nuclear path lengths as compared to neon. We cancelled our experiment at SLAC (40-inch bubble chamber using a large NaI crystal as a triggering device) in order to study direct electron production in $\pi^{\pm}$-p collisions at 18 GeV.

In January, 1977, we made a proposal to SLAC for the use of the "Lead-Glass Wall" in conjunction with the SLAC 40-inch bubble chamber. We were competing with a group from the University of California at Santa Barbara and Davis for the use of the Wall. Fortunately, our proposal was accepted. The experiment was proposed in collaboration with groups from the University of Tennessee at Knoxville and Florida State University. The

experiment replaces the previously approved experiment which was to be done with blocks of sodium iodide which would have been furnished by Professor R. Hofstadter's group at Stanford.

A number of papers have been submitted for publication or are in the process of preparation for publication at the present time. The results of our research are as follows.

## II. PROJECTS UNDERWAY

### A. Neutral Particle Production at Intermediate and High Energies

Over the past year we have continued and extended our studies of neutral particle production from $\pi^{\pm}$ - proton interactions at intermediate and high energies. In contrast to the detailed data which exists for charged particle production, experimental information on the production of neutral particles from hadronic collisions has accumulated rather slowly. Although $K^{o}$ and $\Lambda^{o}$ spectra are rather easily obtainable, the measurement of precise, fully inclusive $\gamma$ spectra is a difficult experimental task. We have approached this problem by using bubble chambers (for fully inclusive $\gamma$ detection) filled with light liquid mixtures (to insure relatively accurate energy measurements). We will first review the data we have available for analysis and then summarize the progress of various research topics.

Data currently available.

i) $\pi^{+}p$ at 10.5 GeV/c. $4.5 \times 10^{5}$ photos in the SLAC 82-inch bubble chamber filled with $H_2$-Neon (in collaboration with SUNY-Albany).

| | |
|---|---|
| $\gamma$'s measured | 26,000 |
| $V^{o}$'s measured | 1,000 |

ii) $\pi^{+}p$ at 15.0 GeV/c. $10^{6}$ photos in the SLAC 82-inch bubble chamber filled with $H_2$ (in cooperation with Columbia University).

| | |
|---|---|
| $\gamma$'s measured | 40,000 |
| $V^{o}$'s measured | 22,000 |

iii) $\pi^-$p and $\pi^-$ - Neon at 200 GeV/c. $5 \times 10^4$ photos in the FNAL 30-inch bubble chamber filled with $H_2$ - Neon (in collaboration with SUNY-Albany).

$\gamma$'s plus $V^o$'s scanned and edited, 4400.

The combined data at 10 and 15 GeV/c provide the best fully inclusive $\gamma$ measurements that are available as of this date. The data at 200 GeV/c is more exploratory but will provide useful comparisons to the lower energy data.

We have spent several months culling through the large number of Columbia events and have written out the data cleanly on a relatively small number of tapes. We expect to do some useful physics with these data.

Research topic completed over the last year or in progress.

i) $\pi^o$ production in $\pi^+$p interactions at 10.5 GeV/c. A general survey of $\gamma$; $\pi^o$, and $\eta^o$ production characteristics has been completed (see section II. B. of last years progress report). The manuscript describing this work is attached and has been submitted to the Physical Review D for publication.

ii) We published a summary of our work on energy balance in the April 1, 1977 Physical Review D. This paper seems to be very elementary and fundamental in nature, yet it was, so far as we can tell, the first time such an experiment had been attempted. The experiment attempted to see whether all of the energy that is available in a $\pi$-p collision can be accounted for in terms of the production of particles that we know about, namely, $\pi$'s, K's, hyperons. The work was done by using the data from the exposure of the SLAC 82-inch bubble chamber with the hydrogen-neon mixture that we have utilized for the last several years. The results of the experiment showed that indeed to within about 5% one can account for the emerging energy from $\pi$-proton interactions. If, for example, light particles were

produced that decay into neutrinos and $\pi$ mesons or $\mu$'s and neutrinos, one would expect to find that a sizeable fraction of the energy might be unaccounted. The results are tantalizing enough that we are continuing this study with data obtained by the Columbia Group from an extensive $\pi^+$-p experiment carried on in hydrogen with an incident energy of 15 GeV (see vi below).

iii) Compton $e^-$ production. We have used the $\gamma$'s from $\pi$-nucleon interactions to make measurements of Compton $e^-$ production up to higher energies than have been done previously. At the time of last years progress report our preliminary data seemed to show an anomalous number of high energy $e^-$. We have now completed this work and find good agreement between our data and Q. E. D. predictions (for $e^-$ energies up to approximately 4.0 GeV) as shown in Figure 1. The report on this work is currently being written.

iv) Direct $\gamma$ production from $\pi^+$-p collisions at 10 and 15 GeV/c. By direct $\gamma$ production we mean those $\gamma$'s produced in hadronic collisions that do not come from the E. M. decays of hadrons ($\pi^o$'s, $\eta^o$'s, $\Sigma^o$, etc). These are possibly related to direct lepton production which seems to be E. M. in origin.

We are looking for direct $\gamma$'s in two ways. First by comparing the $\gamma$ spectra coming from fitted $\pi^o \rightarrow \gamma\gamma$ decays to the total inclusive $\gamma$ spectra. In addition, we look for anomalies in the $\gamma$ spectrum by making use of meson decay kinematics that require certain predictable properties of the decay $\gamma$ spectrum. We see a signal of low energy $\gamma$'s produced centrally (near Feynman x = 0) that cannot be explained by $\pi^o$ or $\eta^o$ decays. We are currently doing background studies of this effect in the 10.5 GeV/c $\pi^+$-p data. In addition, we are attempting to verify it using the 15 GeV/c $\pi^+$p data from the Columbia experiment.

v) $\pi^o$ and $\gamma$ production in 200 GeV/c $\pi^-$-p interactions. Using the 200 GeV data we can extend our analysis of $\gamma$ and $\pi^o$ spectra to a region where multiparticle production models make rather clear predictions. A

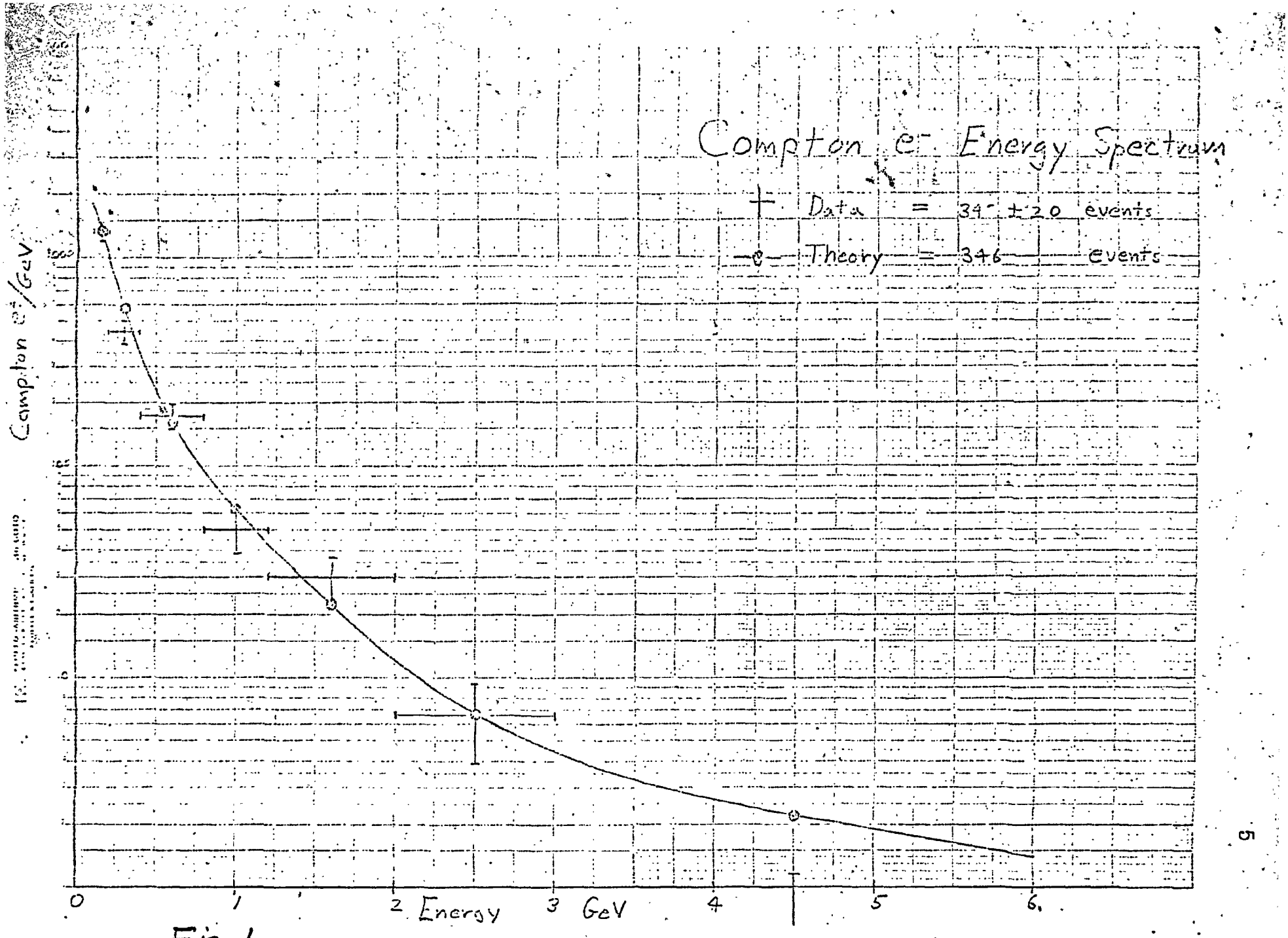
Compton e⁻ Energy Spectrum
Data = 34 ± 20 events
Theory = 346 events
Compton e⁻/GeV
0
1
2
3
4
5
6
Energy GeV

Fig. 1

measurement of $f_2^{oo}$ is a particularly nice way of choosing between various models. This high energy data together with the $\gamma$ and $\pi^o$ analysis done at 10 GeV will allow us to study the s dependence of $\gamma$ and $\pi^o$ production properties. The measurements of this data are in progress.

vi) Neutral energy balance studies using 15 GeV/c $\pi^+$-p interactions. This is the follow-up experiment to our energy balance work at 10.5 GeV/c. The advantage is that this data was taken from a hydrogen fill of the bubble chamber and eliminates the background of $\pi^+$-neon collisions that was present in our earlier experiment. The $\gamma$'s, $V^o$'s and charged tracks have been measured at Columbia but the data was not summarized in a form that could be used for this energy balance work. We are in the process of reanalyzing the data and making the careful separation of $\gamma$'s and $V^o$'s that is required for this experiment. The final data tapes have been written for doing this.

## B. $\pi^+$, $\pi^-$-Neon Interactions at 10.5 GeV

We have recently submitted a paper to the Physical Review which describes our work on $\pi^+$ or $\pi^-$-Neon interactions at 10.5 GeV. This paper contains many of the results of the thesis work of W. Yeager. The interesting results of this experiment are that the rapidity distribution of the pions that are produced can be accounted for fairly accurately in terms of either 1, 2, or 3 collisions in the struck nucleus. What is seen is a systematic shift in the center of the rapidity distribution as one goes from low to high multiplicity events. The high multiplicity events are consistent with the result of three collisions in the struck nucleus. The characteristics of these events are really quite different from high multiplicity events from $\pi$-proton collisions. The result is that the mean value, or most probable value, of rapidity is shifted to a lower value. This most probable value corresponds to a center of mass frame which is consistent with that of a pion colliding with three

nucleons. Another interesting fact is that in high multiplicity events the nucleons carry a large fraction of the momentum. In the 20 - 30% events in which two or more nucleons are stuck in the neon nucleus, about 30 - 40% of the total outgoing momentum is carried by the nucleons. This means that there are large numbers of neutrons and protons emerging from the collisions with momentum between 1 and 2 GeV. These results are interesting enough that it is probably worthwhile to pursue further measurements at 10 GeV.

C. Study of Direct $e^{\pm}$ Production in $\pi^{\pm}$-p Interactions at 18 GeV/c

(Duke-SLAC-Imperial College Collaboration)

In September and October of last year, we began an experiment at SLAC whose purpose was to determine the number of directly produced electrons in relatively high energy $\pi$-p collisions. This work is being carried out in collaboration with the bubble chamber group at SLAC and at Imperial College in London. Electrons are identified by using three 1-radiation length tantalum plates which are mounted in the bubble chamber. Electrons of energy greater than 200-300 MeV produce a readily identifiable electromagnetic shower in these plates. We include a picture of a characteristic shower produced by an electron beam into the chamber.

The experiment was successfully run at SLAC in October and November of 1976. Approximately 275 K pictures of $\pi^-$p and 275 K pictures of $\pi^+$p interactions were taken at 18 GeV/c in the SLAC 1-meter hydrogen-filled bubble chamber. A system of hodoscopes and proportional wire chambers located both upstream and downstream of the chamber permitted us to trigger the camera flash only when there appeared to be an interaction within the fiducial volume. The pictures have turned out to be extremely clear and easy to analyze. Approximately 40% of the pictures contain a useful interaction..

The object of the experiment is to search for anomolous "direct" or "prompt" $e^+$ and $e^-$ tracks produced in hadron-hadron collisions. Anomolous production of $e^\pm$ has been reported recently by a variety of experiments in widely different kinematic regions. However, because these previously reported experiments are electronic, they are forced to rely on complicated background subtractions and do not provide information on the characteristics of the events from which the anomolous $e^\pm$ tracks emerge. Our aim in the present experiment is to observe a small number of complete events which have either single or pair-produced $e^\pm$ tracks. The bulk of our data is in the kinematic region of small $p_T$ and small Feynman x.

The prompt electrons in our experiment are observed in two ways: (1) by curl-up in the 26 kilogauss field together with minimum track ionization; (2) by producing an electromagnetic shower in a system of three tantalum plates (each one radiation length thick) mounted in the bubble chamber. "Conventional" sources of $e^+$ and $e^-$, such as $\pi^0 \rightarrow \gamma e^+ e^-$ or $\rho^0 \rightarrow e^+ e^-$, are also observed in this experiment. Such conventional sources are all easily identified and can be subtracted from the over-all signal. Our experiment is sensitive to single $e^+$ or $e^-$ tracks and is especially sensitive to $e^+e^-$ pairs having a mass $\gtrsim m_\pi/2$.

Further details on the experimental setup and on the objectives of the experiment may be found in the attached copy of the proposal (SLAC Proposal No. BC-65, August, 1976).

In addition to the 18 GeV $\pi^\pm$ film, special samples of "calibration" film were taken:

(1) $e^+$ beam at 1.57 GeV (3000 pictures),
(2) $\pi^\pm$ beam at 1.57 GeV (110K tracks into chamber),
(3) $\pi^\pm$ beam at 3.14 GeV (130K tracks into chamber).

The beam tracks in these samples were deliberately steered into the plates.

Sample (1) was used to verify that we properly understood the shower characteristics of energetic $e^+$ and $e^-$ tracks hitting the plates. A short paper has been prepared on this subject (see attached paper, entitled "High Energy Electromagnetic Showers," submitted to American Journal of Physics). Samples (2) and (3) have been studied to determine the $\pi$-rejection characteristics of the tantalum plate system. The Duke group has been particularly concerned with this aspect. Preliminary results from about 45% of the calibration sample indicate that no more than about 1 in 20,000 to 40,000 $\pi^\pm$ tracks can "fake" an $e^\pm$ shower. Thus the method is sensitive enough to detect single $e^\pm$ tracks down to a level of $e/\pi \simeq 0.5 \times 10^{-4}$. Preliminary results on this subject were given at the Washington APS meeting (April 1977). For a more detailed discussion of this topic, see the BC-65 Memos 9, 10, 13, 20, 23, and 24 attached to our Progress Report No. ORO-3065-40, dated 11 May 1977.

The analysis of the main body of the 18 GeV data is well under way. Duke has just completed a double scan of its share of about 150 K pictures. A physicist edit of the candidates has also been carried out. Our RIPPLE measuring facility was set up to measure these events and is nearly finished except for remeasurements. Our colleagues at SLAC have already made a first measuring pass through about 50% of the 18 GeV film sample, and some preliminary results based on these measurements were presented at the Washington APS meeting in April. The $e/\pi$ rate for events with a single $e^\pm$ is small (less than $3 \times 10^{-5}$ at the 90% confidence level), and perhaps consistent with zero. The $e/\pi$ rate for $e^+e^-$ pairs is $(0.9 \pm 0.5) \times 10^{-4}$ in the region $p_T > 250$ MeV/c and $m(e^+e^-) > m_\pi$. We find more events for $m(e^+e^-) > m_{\pi/2}$ than can be accounted for Dalitz decays of $\pi^o$, $\eta^o$'s, $\omega^o$'s, etc. It seems likely that these events can be accounted for in terms of some sort of hadronic bremsstrahlung process.

## D. $\pi^- p$ - Interactions at 200 GeV

Our work on determining the probability for charge exchange across rapidity gaps as a test of the multiperipheral model was completed and published in Physical Review Letters.

A study of multiparticle rapidity clustering has now been completed and a paper has been prepared for publication. The analysis determines the amount of dynamical clustering by comparing the data to what is expected from a model which contains all the kinematical effects of particle production. The results of the study show that the cluster size consists of two particles with no indication of clusters of three or more particles. Cluster production accounts for 20% of all charged particles.

Another analysis which has been completed and has been prepared for publication is our determination of the inelastic diffractive cross-section, solely from the forward/backward multiplicity distribution. The technique (suggested by H. I. Miettinen, SLAC), which is completely new, depends only on the use of hemisphere multiplicity scaling for the non-diffractive component (which we demonstrate to be true). The diffractive cross-sections obtained for 2, 4, 6, and 8 prongs are 1.28, 1.56, 0.38, and 0.15 mb, respectively. The ratio of pion to proton diffraction obtained from our analysis is somewhat different from that of previous analyses but agrees much better with what is expected from a triple-Regge model prediction. This technique is novel and seems to be a simpler means of making estimates of the diffraction dissociation cross sections.

## III. STATUS OF RIPPLE AND COMPUTING SYSTEM

The RIPPLE system continues to operate without major change. The film transport has been partially modified to accept the new 40" BC film. An electronic change to adapt the hit detection system to bright field film has been constructed, installed, and debugged. Measurements have been made on nearly all of the film we have scanned in the direct electron production.

A new large display CRT has been purchased as a replacement because of repeated failures of the power supplies and deflection system in the present display.

Considerable effort has been spent interfacing the surplus CDC line printer and card reader to the SIGMA-5 computer. The unavailability of a standard controller at a reasonable price made it necessary to design and construct both controllers here. Both units are now functioning under the RBM monitor although a persistent interference problem between the printer and the disk makes operation unreliable. The FORTRAN part of the RIPPLE software has been compiled once under the new monitor while using the printer to obtain a listing. This software must be extensively modified to conform to the new monitor and FORTRAN.

## IV. PROGRESS ON THE Pb-GLASS WALL

In early July the Pb-Glass Wall was removed from SPEAR at SLAC. We had a sizeable number of physicists at SLAC at this time. There were three or four physicists and students from Duke and a similar number from Florida State at SLAC essentially all summer. We will have one person there this fall (Dr. Peter Lucas), and the other two groups will also have one representative present at SLAC.

We unstacked the Pb-glass in July and reconfigured the blocks as necessary. We converted approximately 180 blocks into $\sim 90$ double blocks

which were then rewrapped with phototubes attached. In the last month we have completed our work of restacking the back part of the wall in its new rack. We expect to have the active converter part of the wall re-stacked in the next month.

A considerable amount of work has gone into studies of the on-line data acquisition and monitoring for this experiment which will ultimately have about 400 photomultipliers read into ADC's. We have simulated the data flow from the ADC's into a Nova computer via a CAMAC interface and are studying the integration of this data with that acquired in standard 40" bubble chamber operation. The details of the fast hardware trigger and subsequent slow computer software filter still have to be fixed. Some actual beam will probably be required in order to optimize our electromagnetic trigger from the Pb-glass wall.

Duke has taken the primary responsibility for the electronic hardware and software aspects of this experiment and our group is gaining considerable technical experience in the process.

Duke University

# HIGH ENERGY PHYSICS

# PUBLICATIONS LIST

## 1976-1977

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2. "Direct Evidence for the Bose-Einstein Effect in Inclusive Two-particle Reaction Correlations," N. N. Biswas, J. M. Bishop, N. M. Cason, V. P. Kenney, W. D. Shephard, J. W. Lamsa, W. D. Walker, J. S. Loos, L. R. Fortney, A. T. Goshaw, W. J. Robertson, G. Levman, V. A. Sreedhar, T. S. Yoon, G. Hartner, and P. M. Patel, Phys. Rev. Letters 37, 175-178 (1976).

3. "$\pi^-p$ Charge-transfer Cross Sections at 205 GeV/c, and an Apparent Universality of the Charge-transfer Spectrum," G. Levman, B. M. Schwarzschild, T. S. Yoon, G. Hartner, P. M. Patel, L. R. Fortney, A. T. Goshaw, J. W. Lamsa, J. S. Loos, W. J. Robertson, W. D. Walker, J. M. Bishop, N. N. Biswas, N. M. Cason, E. D. Fokitis, V. P. Kenney, and W. D. Shephard, Phys. Rev. D 14, 711-715 (1976).

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