ORO-3509-14

PROGRESS REPORT ON CONTRACT NO. EY-76-S-05-3509, September 1977

TITLE: Elementary Particle Physics at The Florida State University

This report covers the ten-month period from 1 November 1976 to 31 August 1977. The experimental efforts during this period fall into two groups: continuing analysis of experimental data obtained in earlier years and equipment construction in preparation for new experiments that are approved for running at BNL and at SLAC. The theoretical effort has been directed both toward solution of new problems in areas opened up by discoveries of charm and allied phenomena, and toward problems of longer standing in strong and gravitational interactions.

A major highlight of experimental progress is a new experiment at SLAC, $\pi^{+}d$ at 18 GeV/c using the 40-inch bubble chamber with a γ-ray trigger from an array of lead glass. This experiment was conceived, proposed, defended and approved during this report period and so does not appear at all in the proposal for this ten-month period. Major construction of the lead-glass wall for this experiment was carried out by our group in the summer of 1977, enabling us to maintain a schedule that will produce data during 1978.

I. Logistics

A. Personnel

The number of Ph.D.'s in the group increased by one in the late Spring of 1977 when we hired Cherrill Spencer as a Research Associate. She was formerly a Research Associate for the Wisconsin group, stationed at SLAC working the on the "iron ball" experiment there. Now that she is part of our group, she is still at SLAC but working on the lead-glass wall for the experiment mentioned in the summary above and described in more detail in Section II.A. She brings to the experiment her expertise in counter and electronic techniques as well as knowledge of procedures as SLAC.

During a ten-week period is the Summer of 1977 Ewald Reya came here from Mainz, Germany to work with the theoretical part of our group. His presence now (as in his earlier stay as a research associate several years ago) has been a stimulus to productivity.

At the end of December of 1976 John Albright returned to F.S.U. from his stay at the Cavendish Laboratory of the University of Cambridge, England.

Four new graduate students have joined the group: Paul Michael Barlow, Merrill Jenkins, Graham McDearmon, and Farhang Amiri. At the present time we have 5 advanced graduate students (i.e. those that have completed all required work except the dissertation) and 5 other graduate students in their second or third year.

A significant step forward in relation to personnel occurred as a result of years of discussion with local administrators; we have achieved recognition of the principle that our commitments at national laboratories require us to be absent from Tallahassee for periods of time that are long by the standards of the rest of the department. This principle has led to the decision that during the fall quarter of 1977 each of the four experimental faculty members in the group will teach only one course, making it easier for us to find replacements to teach during our increasingly frequent visits to accelerators.

During the Summer of 1977 John Albright and Ronald Diamond had summer research collaboration appointments at Brookhaven National Laboratory.

B. Facilities

We have acquired an 8080 microprocessor and have embarked on the project of using it to control the data acquisition from our image-plane measuring devices. This piece of equipment gives us a flexibility in data gathering that will be much needed when we begin the analysis of pictures from the SLAC experiment.

Other gains in facilities are not so easy to see at F.S.U. because they exist at national laboratories. Much of the experimental effort has gone into building equipment at BNL and at SLAC. At BNL we acquired the plastic and brass for the K^+-detector to be used in the Ξ^* experiment (see II.B.). Much shop time both here and at BNL has gone into machining the brass as well as the plastic for scintillators and light guides. The latter are rather long and must be bent to odd shapes, so we had to build our own oven for heating the plastic; this part of the project is now completed. At SLAC we took over the lead-glass wall, formerly used at SPEAR, disassembled it, reconfigured blocks as double absorber blocks, and reassembled it into the new configuration required for detecting fast forward γ-rays behind the 40-inch rapid cycling bubble chamber.

II. Experimental Research Program

A. 250 and 360 GeV/c π^-p Experiments with the 15-Foot Bubble Chamber

This experiment is being analyzed in collaboration with Russ Huson's group at the Fermi National Accelerator Laboratory. It began as the initial engineering run of the Fermilab 15-foot bubble chamber (Experiment #234). The exposure was made during October 1974 and 46K useful pictures were obtained with an average of 4 tracks per picture - a sensitivity level of about 1.2 events/picture. A second exposure of 20K pictures was obtained last February at 360 GeV/c as the first part of a 200K approved exposure.

Throughout this report period measurements have been continued on various topologies in this experiment.

The physics interests in this experiment are manifold, and include: search for charmed particles, search for particle production mechanisms via inclusive studies of neutral strange particles, γ's and π^0's, study of the diffraction excitation of the beam π^-, etc.

Two scans of the 250 GeV/c film have been completed. These have been thorough scans, i.e., prong count, beam count, and Vee and gamma conversion pair search. A partial list of various topologies on the 250 GeV/c film is as follows:

	Number Available	Number Measured	Percentage Measured
Primary events	~20K	~5.0K	~25%
2-prg. inelastics	~2K	~2K	100%
4-prongs	~3.0K	~1.5K	~50%
6-prongs	~3.6K	~1K	~30%
Events with stopping protons	~6K	~0.3K	~5%
All GVA's*	~29K	~8K	~28%

Gammas(i.e. GA's)	~26K	~13K	~50%
Primary events with GVA's	~12K	~2.0K	~17%
V's & A's as strange part. candidates	~5.0K	~5.0K	100%
Primary events with identified K's or Λ's	~1.2K	~1.1K	~90%

*"G"-definite gamma, "V"-definitely not gamma, "A"-ambiguous

Status of Various Analyses in Progress Using the 250 GeV/c Data:

Search for Charm: Using approximately 660 primaries with identified K°'s, effective mass combinations of Kπ, K2π, and K3π, show no statistically significant evidence for charm. Also, under the assumption that the D lifetime may be larger that 10^{-13} seconds we are analyzing the distance by which 1-C fitted K°'s miss their associated primary vertices. Further, under the same lifetime assumption, we are examining track pairs of secondaries having masses near the D(1865) looking for gaps near the primary vertex, but so far have found no effect.

Inclusive Strange Particle Production: A paper on these results has been accepted for publication (see Enclosure C.1).

Multiplicity Study: The cross sections for various multiplicities were published previously and comparison with other experiments shows consistency and crude agreement with KNO scaling as has been found by others. However, we believe that further analysis in terms of the two-component models, the σ-model, and the ρρ-model, are necessary and fits to these will be made. So far the assumption of two components, each consisting of production of pion pairs according to Poisson distributions, seems to fit the data well. These fits have been made to other experiments at other energies for comparison. A paper on these results is in preparation.

Inclusive Photon Production: During this report period the FSU measuring facility has been devoted to a systematic measurement of γ-conversion electron pairs. Of the 12,000 available events with G's, V's or A's, >6000 have been measured so far, i.e., >15000 pairs. Measurements and their processing are still in progress and continuing. So far, using old reconstruction programs on a processed sample of 3000 events, there are 4200 3C gammas.

With an improved geometry program and remeasurement of failed events now completed, we anticipate at least 10,000 3C γ's.

Inclusive Strange Resonance Production: Inclusive production of resonances decaying into $V\pi$ or VV final states has been studied (where $V=K^o_s$, Λ, or $\bar{\Lambda}$). About 15-20% of inclusive K^o_s, Λ, or $\bar{\Lambda}$ production can be accounted for by $K^*(890)$, $Y^*(1385)$ and $\bar{Y}^*(1385)$ production. Ratios of charge states show $K^{*+} \approx K^{*-}$ and $Y^{*+} \approx Y^{*-}$, while $Y^{*+} >> Y^{*-}$. In $K^o_s K^o_s$ events, both S^* and A_2 peaks are seen. The S^* is found to be produced centrally in contrast to low energy exclusive experiments. Analyses of these results are close to completion and a paper is in preparation.

Search for Hadron Jets: A search for hadron jets has been made using the CM rapidity, y, and the azimuthal angle, ϕ, of each secondary in all events with at least one strange particle. In neither event-by-event y-ϕ plots nor in frequency distributions in y-ϕ plots was any evidence found for jet structures.

Correlation Studies in Strange Particle Events: Two-particle correlation functions $R(\Delta y)$ have been studied for $\pi\pi$, $K^o_s K^o_s$, $K^o_s\pi$, $\Lambda\pi$, and $\bar{\Lambda}\pi$ pairs. Dynamical correlations have been estimated by subtracting a Monte Carlo calculation containing only energy and momentum conservation correlations. $K^o_s K^o_s$ correlations are found to be considerably larger than $\pi\pi$ correlations, while $K^o_s\pi$, $\Lambda\pi$, and $\bar{\Lambda}\pi$ correlations are small. A paper on this has been submitted for publication (see Enclosure C.2).

Status of the 360 GeV/c Experiment:
The 360 GeV/c $\pi^- p$ experiment was originally intended to be an extension of Experiment #234 described above. It was proposed in October 1974 that we be given 500K pictures. The proposal was also presented to the PAC Subcommittee in December 1974. The FSU-Fermilab collaboration on the proposal was expanded in February and August 1975 to include the University of Maryland, University of California at Riverside and the University of Notre Dame. Then during the Fall of 1975, the proposal was approved for 200K pictures at the highest possible π^- beam momentum and became Experiment #384.

During January 1976 the experiment began as part of an attempt at double-pulsing the 15-foot chamber - one small fraction of the pulse for us and the rest for a neutrino experiment using the second set of cameras. However due to problems not related to the double-pulsing, the run was terminated early. We received only 20K pictures.

The major reason for wanting to do this 360 GeV/c experiment is that we believe it is important now to do a high-statistics high-energy hadron experiment. There are many interesting questions raised by the early data of Experiment #234 and others, but lack of statistical significance forces us to wait for more data. So far we have received only 4% or our original request.

In August 1977 we were informed that the priority decisions at Fermilab are such that it is unlikely that we will be able to get more film for the foreseeable future. Apparently lack of funds, insufficient manpower, and higher current interest in running neutrino experiments with the 15-foot chamber have made this necessary. We will probably have to wait for at least a year for continuation of this hadron experiment.

B. π^+d Using the 40-Inch Bubble Chamber With a Lead-Glass Wall at SLAC (Expt. # BC-67)

This is an experiment to be done in collaboration with Duke University, the University of Tennessee, Oak Ridge National Laboratory and the State University of New York at Albany. Last December we proposed to use the 40-inch bubble chamber at SLAC and to build a lead-glass wall be to placed behind the bubble chamber in order to trigger on gamma-rays; a copy of the proposal is attached (see Enclosure E.1).

We requested 40-million bubble chamber expansions and assuming we would get a 5% picture-taking trigger rate it would comprise a 2-million-picture exposure. We got approval, as a first stage, for ten million expansions to be operated in a triggered mode.

Basically, the proposal is to use the 40-inch bubble chamber at SLAC in conjunction with the lead-glass blocks obtained by SLAC and LBL for use at SPEAR. These lead-glass blocks were used in Mark I and are now available for other experimental users until they are needed again for PEP. We will trigger the camera whenever there is a large deposition of photon energy in a portion of the lead-glass wall; several interesting reactions can be studied in this fashion. In particular we propose to study the following π^+d interactions.

$$\pi^+ d \rightarrow \pi^\circ_{forward}\ \pi^+ pn$$
$$\rightarrow \pi^\circ \pi^\circ pp$$
$$\rightarrow \eta^\circ \pi^+ pn$$
$$\rightarrow \omega^\circ \pi^+ pn$$
$$\rightarrow \pi^\circ \eta^\circ pp$$
$$\rightarrow \pi^\circ \omega^\circ pp$$
$$\rightarrow \pi^+ \pi^- \pi^\circ pp$$
$$\rightarrow \rho^+ d$$
$$\rightarrow \pi^+ \pi^\circ \pi^\circ d$$
$$\rightarrow \pi^+ \omega^\circ d$$

It will be necessary to place gamma-ray conversion plates in the 40-inch bubble chamber. By using the resolution of the wall we should be able to study reactions with two neutral particles; this opens an essentially unexplored domain. We propose to use 18 to 20 GeV/c incident π^+, which would produce mesonic masses up to 3 GeV/c^2. By concentrating on the reactions which are not dominated by Pomeron exchange, we hope to do a sensitive search for high-mass resonances. As mentioned before, an exposure of ten million expansions has already been approved.

Our group at F.S.U. took the prime responsibility for the construction of the lead-glass wall. This entailed taking apart the lead-glass wall which was used by the SLAC-LBL group in Mark I and putting it together in a new configuration. This involved the gluing of 88 pairs of lead-glass blocks.

Let us mention now more specific details Since SPEAR has a maximum energy of 3.7 GeV, the lead-glass blocks used there had only ten radiation lengths. Now for an 18 GeV $\pi^+ d$ experiment 10 radiation lengths are not enough, so for the central region around the beam it was deemed necessary to have 20 radiation lengths so that little of the energy will lead out the back of the lead glass. For this we had to put two lead-glass blocks together. Since each lead-glass block used in the LBL-SLAC experiment already had a phototube glued on one side and a prism on the other, we had to unwrap two blocks, remove a phototube from one block and a prism from the other block, and then glue the two lead-glass blocks together. As each lead-glass block weighed about 50 pounds - the combination over 100 pounds - it was a mammoth effort. One of us (J.L.) spent the whole summer at SLAC, and was joined temporarily by several other people who were there for various lengths of time up to a month. For this experiment we also hired a Research Associate (Cherrill Spencer) who is resident at SLAC and working full-time on this experiment. The progress we can report is that all lead-glass blocks, which are 6" by 6" by 15", have been taken apart, cleaned, put together, and 88 of them have been glued together for the central region. Three more pairs were made for a test system. Our lead-glass absorption wall, consisting of 240 blocks, is 4' by 8' (width and height, respectively). In addition to this we will build an active converted wall, 6' by 8', in which the gamma-rays coming from the bubble chamber can be converted. This will be built using 52 3" by 3" by 36" lead-glass blocks. Between this layer and the back lead-glass wall we will put our vertex detection system which will be composed of arrays of scintillator strips. The vertex detection system is being built by Tennessee and Oak Ridge. At this moment the lead-glass wall is being assembled in its new configuration. This fall we expect to be engaged in cabling (over 1000 cables), instrumenting the system, and preparing NOVA computer on-line programs to run the experiment.

The physics of this experiment should be quite unique in that it will be one of the first bubble chamber experiments to have a very high efficiency for detecting gamma-rays. Not only will we know the position of the gamma-rays, but we will also know their energy to within a few percent, allowing us to do fairly good π° physics. Since a large fraction of the events have π°'s in the final states it is necessary to select out a subsample. We have not quite settled all the details of the triggering, but we can say that using the on-line NOVA computer attached to the 40-inch bubble chamber some extraordinary triggers can be done, e.g. we can select for only gammas which come from η or ω, so we can study final states which have η° or ω°. We are not quite certain how well we can do with a lot of these triggers, but the first run of 10 million pulses ought to tell us in detail how far we can push this new technique of doing π° physics.

Since this experiment did not even get approved until late January of 1977, most of the work has been done at a very rapid rate. We plan to have everything ready for a possible test run in January 1978. In addition, if the SLAC accelerator comes on the air as scheduled in November, we plan to test some of our double blocks in an electron beam to measure the efficiencies of these lead-glass shower counters. So far this has entailed many trips to SLAC and we think in the future we will have to go even more, until the final run is completed, which will most likely be during the May-June cycle of the SLAC accelerator.

C. Ξ* Search (Experiment 673 at Brookhaven National Laboratory) Using the Multi-Particle Spectrometer (MPS)

This is an experiment which has been approved for 500 hours on the MPS and it is to be done in collaboration with several physicists from the Omega group at the Brookhaven National Lab, under the leadership of Suh-Urk Chung. There is a second experiment in the MPS looking for cascade resonances. The two experiments together were approved for 500 hours. We (Brookhaven and ourselves) are preparing the equipment for this experiment and Brandeis-Syracuse are preparing for the second experiment. Even if we run together we might analyze it separately, or it may turn out that all four groups will be participating in both experiments.

This experiment uses the MPS to look for all outgoing particles, but the specific trigger for cascade resonances is a K^--beam particle entering a hydrogen target and a slow K^+ coming out. Ξ's are formed by hyperon exchange and so the K^+ has low momentum, namely below 650 MeV/c. Such a detector was already built at Imperial College and they loaned that to us; it has an active area of 64cm x 100cm. We are in the process of building a second detector which has an active area of 140cm x 110cm; this active area is 2.5 times greater than the one we borrowed from Imperial College. Basically the detector is built of brass and scintillators, in which a slow K^+ is stopped and the time-delayed product of the K^+ is detected.

In February of 1977 we put the old K^+-detector in a separated K^+-beam at the low energy separated beam at Brookhaven National Laboratory. We attempted to reproduce all the results that the Imperial College group had obtained; we were successful in detecting K^+'s with an efficiency of better than 35%, which is what was expected. In order to be able to check our detection efficiency and, as well as later on, our observational efficiency, one of our members (Ronald Diamond) wrote a fairly complicated Monte Carlo program and this program not only can tell us which K^+'s are detected, but can give us the overall efficiencies of the system. This fairly complex Monte Carlo program was coded just for this MPS experiment. The actual test went fairly well; we were able to reproduce all the expected results, as a matter of fact we think the efficiency of K^+-detection quoted in our proposal was a bit conservative.

The second major item of progress is the building of the second K^+-detector, for whose construction we, at F.S.U., have taken prime responsibility. For this we purchased 8 brass sheets of 3/8-inch thickness and 110cm x 140cm. These are the degraders to slow down the K^+. In between these brass sheets there are ten planes of scintillator strips 1-1/2 inch wide. Our group bought the last plane scintillator, which does not have to be segmented, and Brookhaven bought the rest. In addition, 650 light guides, of about 6 feet long by 3/8" by 3/4", had to be built. We at Florida State University built all these light guides in our own machine shop and, with our own student technicians, polished every single one of them; it was a project which took about three months to complete. For the next step we designed and built an oven which could bend these light guides and bring them into bundles to be attached to 20 separate phototubes. We have completed the light guide production and light guide bending; right now we are in the process of gluing these light guides to the scintillators. We expect the second K^+-detector to be completed in the next few months. Soon thereafter we'll put it in the K^+-beam and test it to make sure that everything works.

For this purpose many of us had to go to Brookhaven, especially during the summer. We had two full-time graduate students there in addition to a full-time Research Associate who has been there since April 1976. J. Albright and R. Diamond each spent about 6 weeks at Brookhaven during the summer; V. Hagopian commuted to Brookhaven every other week during the construction of the K^+-detector.

<u>A Short Review of the Physics of Experiment</u>. This experiment will use a K^--beam of about 5 GeV/c and a slow K^+-trigger to fire all the spark chambers in the MPS. Every time a K^- goes in and a K^+ comes out a change of two units of strangeness occurs. This trigger detects most of the cascade resonances, as well as other final states which are not cascade resonances, e.g. Ω^-.

We estimate that this experiment will have a sensitivity of 1500 events per microbarn. This has been verified by our Monte Carlo calculation. The physics background of this experiment is that only two or possibly three cascade resonances are confirmed. Recently three bubble chamber experiments, with sensitivities of the order of 100 events per microbarn, have reported approximately 10 different cascade resonances. Upon looking at these data carefully, it is obvious that most of these claims are statistical fluctuations. In addition, another experiment using the streamer chamber at SLAC has also searched for the cascade resonances with a sensitivity of about 70 events per microbarn; they do have many peaks but these do not have the same masses as those of the bubble chamber experiments. So we say that the field of cascade resonances is very much confused at the present time, and not much is expected to happen in the future, until our MPS experiments run. The quark model predicts the existence of a Ξ^* for each octet and a Ξ^* for each decuplet, so this experiment will provide a good test of this model.

This MPS experiment has been one of the two major projects that our experimental group has undertaken in the past year. This is a complete departure from our previous type of experiment with bubble chambers, but, when you come right down to it, except for the building of the K^+-detector and the data taking, the analysis and the computations are very similar to those we have always done in bubble chambers, with the exception that we have eliminated the intermediate film. So we feel quite confident that we can carry this experiment to a successful conclusion.

The Spokesperson of this experiment is Dr. S.U. Chung of BNL. Since Dr. Chung is also the Spokesperson for another MPS experiment and is quite busy with that experiment, we have taken on the de facto leadership of this experiment and V. Hagopian has been functioning as Spokesperson.

D. π^+d at 15 GeV/c in the SLAC 82-Inch Bubble Chamber (Expt. BC-38)

This is a continuing experiment which has over 900,000 photographs and over 100,000 measured events. The first half was measured on the Univ. of Penn. HPD and the second half on the University of Tennessee Spiral Reader at Oak Ridge National Laboratory. Some strange particles were also measured on our image-plane digitizers. Already over 8 papers have been published on this experiment.

(1) Search for Charm: An extensive search for charmed mesons and baryons was performed during the past year with no candidates discovered. This search was the outgrowth of the one event we discovered, which was a V at a high mass corresponding to a lifetime of 2×10^{-10} seconds and if the particles of the V were assumed to be K^+ and π^- the mass was computed to be 1.86 GeV. In order to see if more such events were available all of the 900,000 photographs were scanned for more such events; no others were observed. In addition, in multi-prong events all possible combinations of two-body final states which gave a mass of the two outgoing particles close to 1.86 GeV were checked carefully on the scanning table to see if there were

any gap between the main vertex and the outgoing particles, denoting a very short-lived V. This entailed scanning approximately 5000 events. No good candidates were found, so we have effectively terminated our search for charmed particles. With the exception of that one single event reported earlier, we do not have any new candidates. The sensitivity of this experiment is still about 10 events per microbarn.

(2) Longitudinal Phase Space Analysis of $\pi^+n \to \pi^+\pi^-p$ at 15 GeV/c. 3,114 events of the reaction $\pi^+d \to \pi^+\pi^-pp$ were studied. A longitudinal phase space analysis (LPS) was performed to separate the various t-channel exchange mechanisms, e.g. π or Pomeron exchange. The validity of the LPS method was tested for pion exchange by generating events using the one-pion exchange model modified by absorption (OPEA). The model and the data agreed extremely well. The principal features of the data include ρ°, f°, Δ° and N*'s. The LPS analysis also revealed g°, but a slight modification of the LPS selection criteria enhances the g° as verified also by the OPEA model calculations. A paper has now been published on this subject (see Enclosure B.1).

(3) Report on the Charm Search at the Tbilisi Conference. Even though the conference took place in 1976 the Proceedings, containing a review paper by V. Hagopian on the search for charmed mesons using bubble chambers, appeared in 1977. Here not only was our experiment reviewed and our single event reported, but also all the other bubble chamber and some emulsion experiments were reported. By now there seem to be quite a few examples of possible charmed meson or charmed baryon candidates in bubble chambers and nuclear emulsions; five cases have appeared so far. Even though each one of these events may have an alternate explanation, the statistical weight is leaning toward the explanation that these are really charmed mesons and charmed baryons. In each case there is a high-mass V separated from the main production vertex by a short distance. Eventually if enough of these events are gathered, a lifetime of the D, which decays into $K\pi$, may be determined (see Enclosuré B.2).

During the past year we have also continued our analysis of the 3-, 4-, 5- and 6-body final states at a much lower level. We have studied coherent production of 3π; we have studied noncoherent production of 3π final states and also 4-, 5-, and 6-pion states. Analyses of these are still continuing; the well-known resonances like ω and Δ are abundant, but we are now looking in more detail. In the future we plan to complete an analysis of the 3π phase shifts.

E. $K^0_sK^0_s$ and $\Lambda\bar{\Lambda}$ from π^-p Interactions at 200 GeV/c in the FNAL-MPS

A proposal has been submitted to Fermilab to search for narrow and broad resonances decaying into $\Lambda\bar{\Lambda}$, $\Lambda\bar{\Lambda}\pi^\pm$, $K^0_sK^0_s$, $K^0_sK^0_s\pi^\pm$ in π^-p interactions at 200 GeV/c using the Fermilab MPS. New resonances such as the ψ and upsilon (9.5 GeV) have been found by probing definite quantum states, decaying into e^+e^- or $\mu^+\mu^-$, which are restricted to $J^P=1^-$. We propose to expand this search to other quantum states such as 0^+, 0^-, and 2^+, decaying into two strange particles, with sensitivity better by an order of magnitude than in previous measurements. The experiment is a collaboration between F.S.U., BNL, Vanderbilt, Tufts and Arizona and has requested 600 hours on the Fermilab MPS. Estimates of acceptances and background for this experiment were made by F.S.U. based on our 250 GeV π^-p 15-foot bubble chamber data. Trigger rates and signal/background estimates were made by processing a small sample of data taken in a previous MPS experiment through MPS track recognition programs. This experiment was proposed to the Fermilab Program Advisory Committee on May 7th. The Committee recommended that the proposal be resubmitted in October with additional collaborators who have had previous experience using the Fermilab MPS.

F. Software Development

Further improvements were made to the Hydra geometry and kinematics programs which increased the passing rate for gammas from 60% to 80%. A scan efficiency program was written by P. Hays and it was determined that the scan efficiency for Gammas was 75%. The RESURX CRT plotting-editing program written by Doug Pewitt for the SLAC π^+d experiment was modified for the 250 GeV/c π^-p experiment, and a cutting back procedure was used to salvage gammas which failed geometry due to Bremsstrahlung.

Software development was continued for the EMR 6050 to allow simultaneous scanning and measuring. An EMR-Microprocessor-CRT-measuring table system was designed by Frank Rydeen and programming of the microprocessor for data acquisition, machine calibration and data quality control is in progress.

G. Neutrino Experiment at Fermilab

Last year we submitted a proposal to Fermilab (#521) to put metal plates in the 15-foot bubble chamber in order to help study neutrino interactions in deuterium. Since then six other proposals have been submitted calling for the insertion of plates in the bubble chamber. The physics merits of the idea are becoming more widely appreciated. Unfortunately, the plate designs of the various proposals differred significantly, and Fermilab rejected all the proposals last June, suggesting that they be resubmitted when the experimenters could agree on a common plate design. A meeting is to be held at Fermilab on September 16 and 17 for the purpose of deciding on the plate configuration. The proposals will then be resubmitted for consideration by the Fermilab PAC. The outlook for acceptance of the proposal is encouraging.

H. Beam Design at CERN

From the middle of August until the middle of December of 1976 Albright was at the Cavendish Laboratory of the University of Cambridge, England on a faculty development leave from F.S.U. Along with W.W. Neale from Cambridge he performed calculations to determine the magnet currents needed to transport particles at 150 GeV/c from the SPS at CERN to BEBC, using the S3 beam. This beam has rf separators that can be used to reject some of the π^- from a negative beam and thus provide a beam that is enriched with K^- and $\bar{p}$. In order for an enriched beam of this type to be useful a tagging system is needed. Discrimination between K^- and $\bar{p}$ is easy to do with a Cerenkov counter; the $K^-\pi^-$ discrimination can be done with a transition radiation counter. Albright and Neale went to Aachen, Germany and got the group there to agree to build a transition detector for CERN. Plans to test the system have been delayed indefinitely as a result of decisions at CERN to use BEBC for neutrino experiments rather than hadrons. So our hopes at CERN have gone the same way as our plans to study high-energy kaon interactions at Fermilab.

I. K^-d at Low Energy

A paper on the reaction $K^-n \to \Lambda\pi^-$ for $\sqrt{s}$ between 1550 and 1650 MeV has been accepted for publication in Physical Review D (see Enclosure C.3). This work is based on data from K^- momenta of 570 and 620 MeV/c. The analysis of the data from 470 and 520 MeV/c was completed during this report period and is being written up as a Ph.D. dissertation. Some of the results were presented at the Washington meeting of the APS (see Enclosure A.2).

J. Integrals of Products of Airy Functions

Airy functions are solutions of the Airy equation $y''-xy=0$. This equation occurs in quantum mechanics in the problem of a linearly rising potential. For this reason airy functions have been much used in recent years in quark confinement theories. Several years ago at F.S.U. it was discovered that integrals of the form $\int x^n y^2 dx$, $\int x^n y' y dx$ and $\int x^n y'^2 dx$ can be expressed in terms of tabulated functions. While on leave at Cambridge, Albright obtained a much more compact derivation of the results, generalized some of the formulae and published a paper on it (see Enclosure A.2).

K. ISIS

A large multi-wire proportional drift chamber is being built to be placed downstream from the 30-inch bubble chamber at Fermilab. The name ISIS is an acronym for Identification of Secondary Particles by Ionization Sampling. The actual construction of the device is being done by MIT (Kistiakowsky, Pless), Yale (Ludlam), Tennessee (Bugg), IIT (Barnstein) and Indiana (Alyea). The FSU contribution so far has been to study problems associated with analyzing the data that come from ISIS. A maximum likelihood approach is indicated, but to use it one needs to know the distribution of energy losses. Monte Carlo calculations have been started to investigate the Landau distribution and the distribution of Blunck and Leisegang. Our interest in this device is related to future experiments we intend to propose using the 30-inch chamber at FNAL.

III. Particle Theory Program:

A. Diffraction Dissociation and Strong Absorption (P.K. Williams)

A paper "Inelastic Diffraction and Factorization Properties in the Direct and Crossed Channels" (Enclosure C.6) has been submitted for publication. Here we introduce a simple phenomenological framework based on approximate factorization properties in the direct and crossed channels. Observed gross features of diffraction become related to gross features of diffractive states. From the observed slope-mass correlation it emerges through this framework that crossed-channel factorization is broken; increasingly massive diffractive states become increasingly transparent and strong absorption for these states weakens to vanishing.

Another paper "Model Bounds on Slopes for Inelastic Diffractive Processes" (Enclosure C.) is based on a subset of the assumptions in the first paper which leads to upper and lower bounds on slope parameters ($d\sigma/dt$ logrithmic slopes). For example, for $pp \to pp^*$ diffraction dissociation the upper (lower) slope is 1.5 (0.5) times the pp elastic slope, and the data tend to support this. This paper will be submitted as a "comment" on the first paper.

Some further work will proceed in the context of eikonal models or generalized vector dominance models, to which this model bears some resemblance; to incorporate strong absorption in a self-consistent way and to calculate same explicitly; to work out further consequences and to further compare with data, especially on ψ, ψ'...T... photoproduction, nuclear absorption phenomena and strong absorption weakening.

B. W → Hadron Jets (P.K. Williams and BNL Collaborators)

During the period July 18-29, 1977, I participated in the Isabelle workshop at BNL. A paper "Considerations on W → Hadron Jets" was submitted to the workshop proceedings (Enclosure C.8). Further work along these lines may include a careful calculation of W-Hadron signal and expected background rates in pp collisions, in the context of asymptotically free theories of quarks and gluons.

C. Phenemenology of Quarks and Partons (P.K. Williams, F. Amiri)

We are reviewing the phenemenology of hadronic constituents with the idea of applying it to hadronic production processes. This work will continue as a thesis project.

D. The Role of A_1 Exchange in the Reaction $\pi^- p \to (\pi^+\pi^-)n$ (J.D. Kimel, J. Owens)

Data have become available, at 17.2 GeV/c, which show strong target polarization effects for the reaction $\pi^- p \to (\pi^+\pi^-)n$. These data require the presence of an exchange with the quantum numbers of the A_1. A simple model based on π, A_2, and A_1 Regge pole exchange together with parametrized n=0 cuts is found to provide an excellent description of both the polarized and unpolarized data. This paper has now been published (see Enclosure B.5).

E. Longitudinal Phase Space Analysis of $\pi^+ n \to \pi^+\pi^- p$ at 15 GeV/c (J.D. Kimel)

This collaborative effort between the experimental and theoretical groups, which was published this year, is discussed in detail under the experimental section (see Enclosure B.1).

F. Spin Dependence in Inclusive Reactions (J.F. Owens)

During the past year I continued my study of the spin dependence of inclusive reaction amplitudes. Particular attention was paid to the effects of absorptive corrections and to devising experimental tests which could detect such effects. One phase of this analysis concerning the reaction $pp \to \Delta^{++} + X$, was carried out in conjunction with G.R. Goldstein of Tufts University. These results have been completed and published (see Enclosure B.4).

A second area of investigation centered on the process $Ap \to \Lambda + X$, $A = \pi^\pm$, $K^\pm$, p, or $\bar{p}$. This type of reaction is of interest since the Λ polarization may be measured using the angular distribution of its weak decay. Thus, double correlation experiments using a polarized target become practical, thereby opening up the possibility of performing an amplitude analysis for this reaction. Two models were devised, both of which adequately describe the existing data, but which give markedly different predictions for such double correlation observables. Data for these observables should yield much information concerning the underlying exchange structure in this type of reaction. The results of this analysis have been submitted for publication in Nuclear Physics B. (See Enclosure C.9.)

G. Gluon Contribution to Hadronic J/ψ Production (J.F. Owens, E. Reya)

In conjunction with M. Glück of the University of Mainz, Mainz, West Germany, we have studied J/ψ production in hadronic reactions. The ratios of cross sections obtained using different beams provides crucial information concerning the nature of the underlying production mechanism. In particular, it is crucial to take into account the contribution from gluon-gluon fusion as well as that of the more conventional quark-quark annihilation term. This two-component, quantum chromodynamic, model provides an excellent description of the existing data. The results of this study have been submitted for publication in the Physical Review (see Enclosure C.5).

H. Gluon Effects and the Quantum Chromodynamic Description of High-p_T Reactions (J.F. Owens, E. Reya)

In the context of quantum chromodynamics, the production of large transverse momentum (p_T) particles in hadron collisions stems from internal parton-parton scattering. Early attempts to pursue this hard scattering model were unable to describe the data without the use of adjustable parameters. In conjunction with M. Glück of the University of Mainz, Mainz, West Germany, we have been investigating this problem. The results of our studies show that it is of crucial importance to include the effects of gluon-gluon and gluon-quark scattering in addition to the contribution from quark-quark scattering. Using parton distribution and fragmentation functions determined from analyses of deep inelastic lepton data we have been able to predict both the normalization and the p_T dependence of the available pion production data at $p_T \gtrsim 5$ GeV/c and $\sqrt{s} \gtrsim 50$ GeV. This has been done without the aid of any free parameters. The results of this research will soon be submitted for publication.

IV. Gravitational Theory Program:

A. Gravitation (P.A.M. Dirac, L. Halpern, R. Parosns)

We have been working on the question of the variation of G, collecting the results of various people and trying to fit them together.

Van Flandern's observations of the motion of the moon provide evidence for the variation of G with multiplicative creation of matter. Muller has completed his analysis of ancient eclipses and his results agree with Van Flandern's. But the problem cannot be considered as settled because the effect to be observed is not much greater than the probable errors.

There was a workshop held in Tallahassee in February 1977, attended by Canuto and Hsieh, from the Goddard Space Research Center, Maeder, from the Department of Astrophysics of the University of Geneva in Switzerland, V. Mansfield of Cornell University and S. Malin of Colgate University. The workship dealt with theoretical implications of varying G. One gets an acceptable theory of solar evolution with multiplicative creation, not with additive creation.

Prof. Runcom visited Tallahassee to give talks about the moon. He asserts that the evolution of the moon is not consistent with multiplicative creation. So the question is still wide open.

It is likely that the question will be settled by observations from the Viking lander on Mars. The distance of Mars from the Earth is now being monitored with great accuracy and if these observations can be continued for one Martian year (two Earth years) it would suffice to distinguish the various theories.

Dirac has developed his theory of extended particles and spoke about his recent work at the Coral Gables Conference on High-Energy Physics in January 1977. It was published in the report of the conference called "Deeper Pathways in High-Energy Physics (1977)," (see Enclosure B.8).

Dirac attended the meeting of the European Conference on Particle Physics in Budapest, in July 1977, and gave a talk on the development of the relativistic wave equation of the electron.

Halpern completed his work on De Sitter symmetric field equations in Riemannian spaces. This work was published in the Journal of General Relativity and

Gravitation (see Enclosure B.7). A generalization of this work to conformal and more general symmetries has been performed and was expected to be presented at the 8th International Conference on General Relativity and Gravitation. The lecture could not be held because of Halpern's accident (broken leg) but this work will be published.

The work on the Gravitational Analogue of the Magnetic Monopole (Enclosure C.10), submitted in a preliminary form to Foundations of Physics and distributed as a preprint, was considerably extended and generalized.

R. Parsons has been working on the problem of energy localization in gravitational waves. The goal of this work is to generalize P. Dirac's solution of the problem for plane waves to the case of waves from localized sources.

ENCLOSURES TO PROGRESS REPORT

Reprints or Preprints Removed

for the period 1 November 1976 to 31 August 1977

A. Papers Presented at Meetings

1. APS Chicago Meeting, February 1977; Bull. Am. Phys. Soc. Vol. 22, No. 1 (1977).

   a. "Correlations Involving Pions and Neutral Strange Particles," by R. Harris, D. Bogert, *et al.*; p. 23.

   b. "Inclusive γ Production and Correlations in $\pi^- p$ at 250 GeV/c," by P. Hays, J.R. Albright, *et al.*; p. 48.

2. APS Washington, D.C., Meeting, April 1977; Bull. Am. Phys. Soc. Vol. 22, No. 4 (1977).

   a. "$K^- d$ Interactions in the Region from 1500 to 1650 MeV/c^2 C-M Energy," by N.F. Ezquerra, W.A. Morris, and J.R. Albright; p. 623.

B. Papers Published

1. "Longitudinal-Phase-Space Analysis of $\pi^+ n \rightarrow \pi^+ \pi^- p$ at 15 GeV/c," by J.E. Richey, V. Hagopian, J.D. Kimel, S. Hagopian, J.E. Lannutti, B. Wind, C.P. Horne, N.D. Pewitt, J.R. Bensinger and H.O. Cohn, Phys. Rev. D15, 3155 (1977).

2. "Search for New Particles Using Bubble Chambers," by V. Hagopian, Proceedings of the 18th International Conference on High-Energy Physics, p. N15 (1977).

3. "Integrals of Products of Airy Functions," by J.R. Albright, J. Phys. A10, 485 (1977).

4. "The Role of Absorptive Corrections in a Triple-Regge Analysis of $pp \rightarrow \Delta^{++} + X$," by G.R. Goldstein and J.F. Owens, Nucl. Phys. B118, 29 (1977).

5. "The Role of A_1 Exchange in the Reaction $\pi^- p \rightarrow (\pi^+ \pi^-) n$," by J.D. Kimel and J.F. Owens, Nucl. Phys. B122, 464 (1977).

6. "An Approach to a Unified Treatment of Electromagnetic and Gravitational Theory Emerging from the Covariant Dirac Equation," by Leopold Halpern, Proceedings of the Marcel Grossman Conference, p. 113 (1977).

7. "Gravitational Law and Spinning Electron Equation in a De Sitter Symmetric Space," by L. Halpern, General Relativity and Gravitation 8, 623 (1977).

8. "The Dynamics of Streams of Matter," by P.A.M. Dirac, in *Deeper Pathways in High-Energy Physics* (Plenum, New York, 1977), p. 1.

Preprints + Reprints Removed

C. Papers Submitted for Publication

1. "Inclusive Production of Neutral Strange Particles in 250 GeV/c $\pi^- p$ Interactions," by D. Bogert, R. Hanft, R. Harris, F.R. Huson, S. Kahn, J.R. Albright, S. Hagopian, P. Hays and J.E. Lannutti, accepted by Phys. Rev. D.

2. "Two-Particle Correlations Involving Neutral Strange Particles," by R. Harris, D. Bogert, R. Hanft, F.R. Huson, S. Kahn, W. Smart, N.N Biswas, J.M. Bishop, N.M. Cason, V.P. Kenney, W.D. Shephard, J.R. Albright, S. Hagopian, P. Hays and J.E. Lannutti, submitted to Phys. Rev. D.

3. "Reaction $K^-+n\rightarrow\Lambda^\circ+\pi^-$ from 1550 to 1650 MeV," by W. A. Morris, J.R. Albright, A.P. Colleraine, J.D. Kimel, and J.E. Lannutti, accepted by Phys. Rev. D.

4. "Charm Effects in Deep Inelastic Muon-Proton Scattering," by M. Glück and E. Reya. submitted to Nucl. Phys. B.

5. "Gluon Contribution to Hadronic J/ψ Production," by M. Glück, J.F. Owens and E. Reya, submitted to Phys. Rev. D.

6. "Inelastic Diffraction and Factorization Properties in the Direct and Crossed Channels," by P.K. Williams, submitted to Phys. Rev. D.

7. "Model Bounds on Slopes for Inelastic Diffractive Processes," by P.K. Williams, submitted to Phys. Rev. D. Copies attached to last year's progress report.

8. "Considerations on $W \rightarrow$ Hadron Jets," by S.U. Chung, V. Flaminio, E.A. Paschos, F.E. Paige, T.L. Trueman and P.K. Williams, submitted to Summer 1977 Isabelle Workshop.

9. "Regge Cuts and the Spin Dependence of Inclusive Λ Production," by J.F. Owens, submitted to Nucl. Phys. B.

10. "On the Gravitational Analogue of the Magnetic Monopole," by L. Halpern, accepted for publication by Foundations of Physics. Copies attached to last year's progress report.

11. "Conclusions from the Extended Gauge Principle of Dirac's Equation," by L. Halpern, accepted for publication in the Proceedings of the Bonn Conference on Differential Geometry and Physics. Copies attached to last year's progress report.

12. "Gravitational and Inertial Effects on Superconducting Shielding," by L. Halpern and J. Perk, accepted for publication by Physica. Copies attached to the progress report of the year before last.

D. Book Submitted for Publication

1. "Proceedings of the Workshop Meeting on the Measurement of Cosmological Variations of the Gravitational Constant." Copies not available.

In this book there are two articles by our members which are listed below.

2. "Introduction to the Basic Ideas of the Large Number Hypothesis," by P.A.M. Dirac.

3. "Two Methods for Measuring the Variation of the Gravitational Parameter, G, Using Superconducting Technology," by L. Halpern and C. Long.

E. Proposals

1. Proposal for Use of the 40-Inch Bubble Chamber With the Pb-Glass Wall, L. Fortney, et al.