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NUCLEAR STRUCTURE AT INTERMEDIATE ENERGIES

PROGRESS REPORT

for

January 1-December 31, 1989

CO-PRINCIPAL INVESTIGATORS

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NUCLEAR STRUCTURE AT INTERMEDIATE ENERGIES

2. Project Abstract and Overview

We report here on the large amount of progress made for the period since our latest report dated September 1, 1988, to July 31, 1989, for D.O.E. Three-Year Grant No. DE-FG05-87ER40309, third year. Results from previous experiments at Brookhaven using beams of polarized protons, heavy ions, and pions are detailed. A recently approved Brookhaven experiment using antiprotons is described. Current experiments at LAMPF, TRIUMF, Brookhaven and Fermilab using beams of polarized neutrons and protons, heavy ions and photons, are also discussed. Plans for future experiments at these laboratories, as well as the CERN Spin Muon Collaboration experiment are given in the Renewal Proposal (accompanying this report) for the Grant's three-year renewal.

The format we follow in both the Progress Report and the Proposal is to have a brief writeup on each individual experiment or project and to include in the appendices copies of published papers or manuscripts which give much greater detail. The aim is to concentrate on the physics goals, results, and their significance in the main body of the report.

In the section on Instrumentation Development, we detail the significant improvement in our computational capabilities as well as the developmental work on a charged coupled device which we will build for one of our experiments at Brookhaven.

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A.	"Spin Parameter Measurements in Inclusive Σ^0 Production," B. E. Bonner <i>et al.</i> , Phys. Rev. Lett. 62 , 1591 (1989).	
B.	"Search for a J^{PC} Exotic Hybrid Meson," S. U. Chung <i>et al.</i> , AIP Conf. Proc. No. 185	
C.	"Strangeness Production in Antiproton-Tantalum Interactions at 4 GeV/c," W. R. Gibbs and J. W. Kruk (submitted to Physics Letters)	
D.	"Analyzing Power of Inclusive Production of π^+ , π^- and K_S^0 By Polarized Protons at 13.3 and 18.5 GeV/c," B. E. Bonner, F. Nessi-Tedaldi <i>et al.</i> (submitted to Physical Review D.)	

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3. Personnel List

Personnel working on the project January 1, 1989-July 31, 1989:

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4. PROGRESS ON RESEARCH PROJECTS

A. Brookhaven AGS Experiments

(1) BNL E817 - Σ^0 Spin Transfer Experiment

After the discovery of sizeable polarization values in the inclusive production of hyperons at high x_F , a phenomenological description in terms of the recombination of fragments of the target with partons emerging from the sea reproduces rather well the regularities of the results. The production of Σ^0 hyperons in this model involves the transfer from the beam proton of a (ud) diquark in a triplet spin state. Thus, in the recombination process the fragments remember the spin of the incoming proton in contrast to the case for the production of Λ particles. As a consequence, spin dependent parameters, eg., analyzing power and polarization transfer, are expected to have non-vanishing values. For Σ^0 production, using the parametrization of DeGrand and Miettinen,¹ one obtains a prediction of $A = 20\%$ and $D = 67\%$.

We measured inclusive Σ^0 production through reconstruction of the decay $\Sigma^0 \rightarrow \Lambda \gamma$. The experiment was performed using the Brookhaven AGS polarized proton beam at 18.3 GeV/c momentum. The average beam polarization was 0.44. Charged particle tracks ($\Lambda \rightarrow p \pi^-$) were detected by the Brookhaven Multiparticle Spectrometer, whereas the γ 's from Σ^0 decay were detected with a lead glass wall. The calorimeter, consisting of 129 modules, was calibrated with 1 and 2 GeV/c electron beams.

We reconstructed $\sim 10K$ Σ^0 's, covering a kinematical range up to $\simeq 0.75$ in x_F and from 0.5 to 2. GeV/c in transverse momentum. We obtain values of analyzing power and polarization transfer in Σ^0 production which are smaller than expected from model predictions, namely $A = 0.002 \pm 0.03$ and $D = 0.26 \pm 0.16$. A check on our experiment is the fact that the Σ^0 polarization parameter, P , which we measure is consistent with a previous measurement performed with an unpolarized beam.² We have detailed in our publications³ an expansion of the model that includes a non-vanishing probability of diquark spin-flip during recombination and scattering. The additional terms in the production probability give a better agreement with the above data, while leaving the predictions for all other hyperon polarization measurements unchanged within their statistical accuracy. The conclusion is that we have considerably expanded the understanding of how particles are created by our spin tagging measurements. A copy of our publication is included with this report.

We have also submitted a paper to Physical Review D on earlier measurement of the analyzing power in meson production. A copy of that manuscript is also included with this report.

The Σ^0 experiment will consist of the Ph. D. thesis of Nety Krishna.

References

1. T. A. DeGrand and H. I. Miettinen, Phys. Rev. D **24**, 2419 (1981).
2. E. C. Dukes *et al.*, Phys. Lett. **193B**, 135 (1987).
3. B. E. Bonner *et al.*, Phys. Rev. Lett. **62**, 1591 (1989); M. Nesi, 8th Intern. Symposium on "High Energy Spin Physics", Minneapolis, Minnesota (1988), AIP Conf. Proceedings **187** 66 (1989), ed. K. Heller.

(2) BNL E810 - Strangeness Production in Heavy Ion Collisions

The production of strangeness in heavy ion collisions is thought to be a useful diagnostic tool for the formation of a Quark Gluon Plasma (QGP). The production of a strange antibaryon is especially sensitive to the presence of a QGP. Furthermore we have learned through polarization measurements on hyperons in proton induced collisions (E817) that the strange quark can be used as a tracer for the spin dynamics of the process. Hence, we are studying the production of strangeness in heavy ion collisions using the 15 GeV/A heavy ion beams from the Brookhaven AGS.

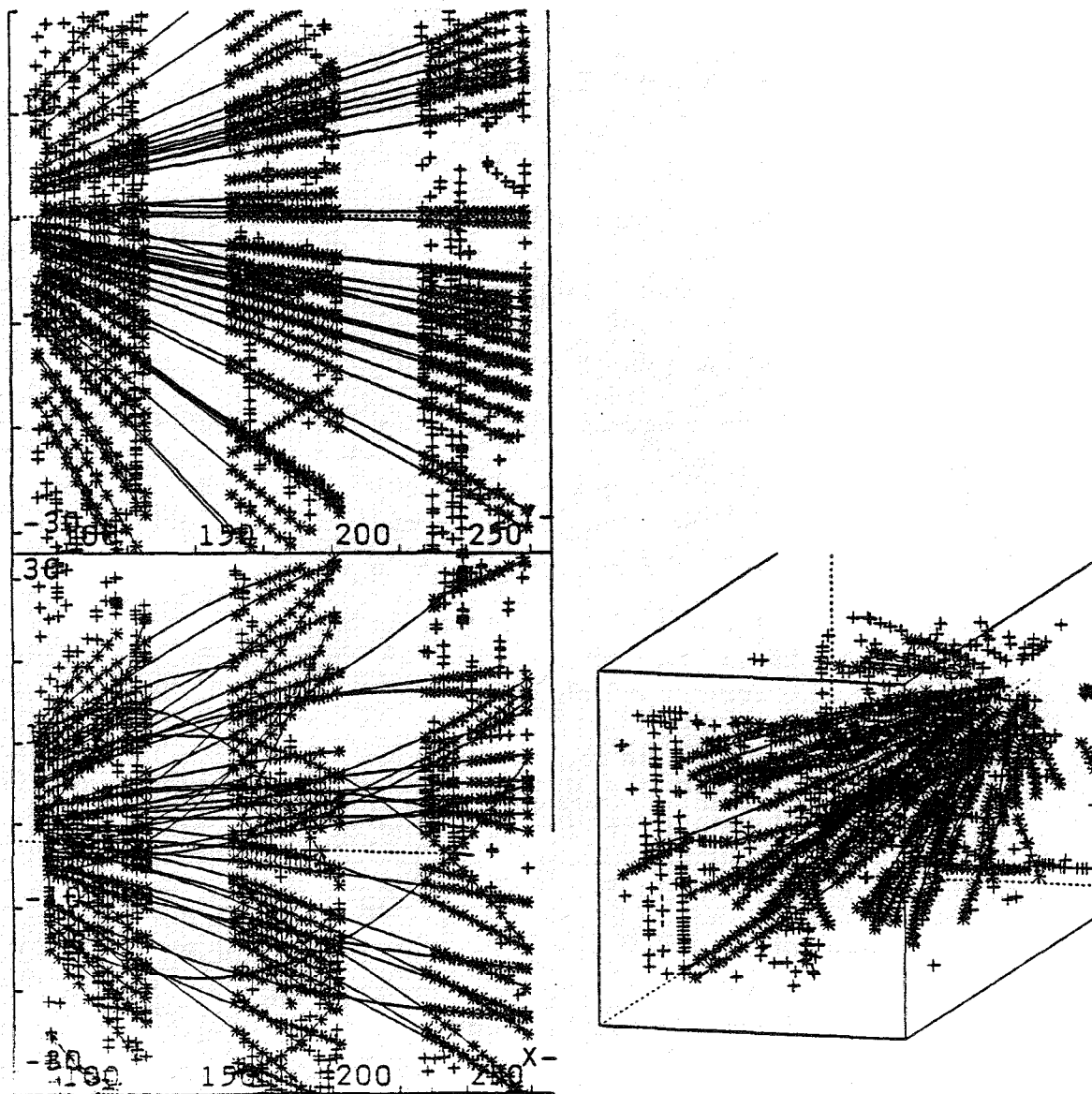
Analysis of the Dec 1987 14.5 GeV/A Si on aluminum data continues. This data was taken with a pair of matched, segmented hodoscopes which were used to require a neutral decay ($\Lambda \rightarrow p\pi^-$) in the region between the hodoscopes. The decay particles were detected with the BNL-Multiparticle Spectrometer (MPS) implemented with drift chambers. As reported last time, we reconstructed 250 Λ 's with a transverse momentum higher than 0.6 GeV/c and energies between 3 and 12 GeV. The transverse polarization is $P = -0.01 \pm 0.10$. The Λ to K , ratio was found to be 2.28 ± 0.3 . This is comparable with the Fritiof Monte Carlo prediction of 2.8. A manuscript is being prepared that will include the $\bar{\Lambda}/\Lambda$ ratio along with a comparison to the E817 ($p + Be \rightarrow \Lambda + X$) results and to the Fritiof Monte Carlo predictions.

The Brookhaven MPS group has designed and built three large volume Time Projection Chambers (TPC) to track the large multiplicity of charge particles produced in nucleus-nucleus collisions. A test run in Dec 1988 using a 15 GeV/A Si beam was used to debug the TPC's, which performed well. Event multiplicities of up to 100 tracks per event could be reliably reconstructed, as is illustrated in Figure 1. Only about 2 1/2 TPC's were instrumented for this run. In addition to the TPC data a TOF hodoscope was implemented in an effort to detect $\bar{\Lambda}$'s by measuring the antiproton TOF. Preliminary analysis of this data showed that approximately 15% of the Λ 's produced could be reconstructed. No antilambdas could be seen above the combinatoric background. (However, the TOF information has not yet been included in the analysis.) The minimum bias trigger employed in this test run was inefficient; less than 10% of the events resulted in a vertex reconstructed at the target position. Furthermore, only about 10% of these events were central collisions.

Data was taken with three fully instrumented TPC's and the TOF hodoscope in June 1989, using a 14.2 GeV/A Si beam. After a careful study of possible triggers,

one was devised that gave up to 50% central collisions for a relatively thick target (0.1 interaction length). In addition to the usual beam defining counters, the trigger included veto counters around the beam pipe to suppress interactions in the beam counters, a veto counter after the MPS magnet to reject beam tracks that did not interact and a pair of counters downstream of the target which could be used to select high multiplicity events. Using this trigger at least 20,000 central collisions per target were collected for Al, Si, Cu, Sn, Au and Pb targets of various thicknesses (0.01 - 0.1 interaction lengths). Low bias data without the multiplicity counter requirement was also taken to check for systematic effects and acceptance corrections.

Figure 1
Reconstruction of an event in the MPS TPC's. The Y- and X-projections are shown on the left and a three dimensional view is on the right.



(3) BNL E818, Search for a J^{PC} Exotic Hybrid Meson

Gluonic degrees of freedom in QCD may give rise to two new spectroscopies in the same mass region as conventional $q\bar{q}$ mesons. Glueball⁴ and hybrid⁵ spectra with states in the mass range 700 to 3000 MeV are predicted by several models. Hybrids are color singlet states consisting of a $q\bar{q}$ color octet and a gluon. Unlike the glueballs, the model predictions for hybrids give low lying states that are J^{PC} exotic. The cross section for hybrid production is expected to be about the same as that of ordinary mesons, but the decay to a pair of $L = 0$ mesons is suppressed. This selection rule favors decay channels that have not been studied in high statistics experiments.⁶ Guided by these predictions, in E818 we will search for the $I = 1$, $J^{PC} = 1^{-+}$ hybrid $X(1900)$ which is predicted to decay to $\pi - b_1$ and $\pi - f_1$ final states.

The experiment utilizes the BNL MPS-II with a 12 GeV/c separated pion beam. The trigger is designed to look for a hybrid state produced in the b_1 exchange process

$$\pi^- p \rightarrow X^-(1900)p \quad (1)$$

and decaying thru the f_1 final state

$$X^-(1900) \rightarrow \pi^- f_1(1285). \quad (2)$$

The $f_1(1285)$ will be detected through the decay mode

$$f_1(1285) \rightarrow \pi^- a_0(980) \rightarrow \pi^- K^+ K^0 \rightarrow \pi^- K^+ \pi^- \pi^+ \quad (3)$$

This is illustrated in Figures 2 and 3.

One potential source of background is the diffractive dissociation of the beam pion into $KK\pi\pi$. In order to suppress this process relative to b_1 exchange, the experiment is designed to detect recoil protons with $-t > 0.3\text{GeV}^2$. For $-t > 0.3\text{GeV}^2$ the recoil proton has a laboratory momentum greater than 600 MeV/c, and a laboratory angle greater than 55 degrees with respect to the beam.

The layout of the experiment is shown in Figure 4. The trigger will be set up to detect a recoil proton, a fast forward K^+ in coincidence with the two π^- 's from the $X^-(1900)$ and $f_1(1285)$ decays and a K^0 decay in the MPS. To do this we require a multiplicity of one in the cylindrical PWC (PC), to signal the proton: a coincidence between the appropriate wire clusters of proportional chambers P0 and P2, the hodoscope elements of H1, H2 and TOF and no signal from the corresponding cell of the segmented Cerenkov counter C1, to signal the fast forward K^+ ; a multiplicity of three in the PWC P1 to signal the K^+ , and two π^- 's; and a multiplicity of five in PWC P2 to signal the decay of the K^0 .

A test run in May 1989 demonstrated that the cylindrical chamber and long LH_2 target were operational. Trigger studies verified that the trigger described above would yield the expected background suppression. Data runs are scheduled for January 1990.

References

4. M. Chanowitz and S. Sharpe, Nucl. Phys. B222, 211 (1983); J. M. Cornwall and A. Soni, Phys. Lett. B120, 431 (1983); K. Ishikawa *et al.* Z. Phys. C21, 167 (1983).
5. F. E. Barnes, F. E. Close, and S. Monaghan, Nucl. Phys. B198, 380 (1982); M. Chanowitz and S. Sharp, *Ibid.*; E. Golowich, E. Haqq, and G. Karl, Phys. Rev. D28, 160 (1983).
6. N. Isgur and R. Kokoski, Phys. Rev. Lett. 54, 869 (1985).

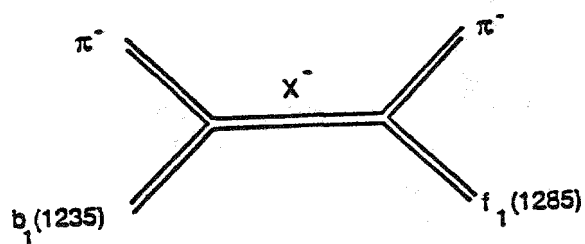


Figure 2

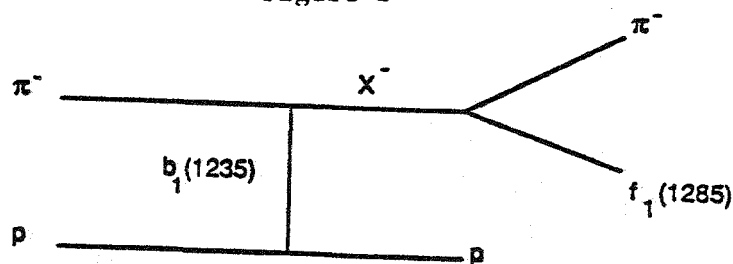


Figure 3

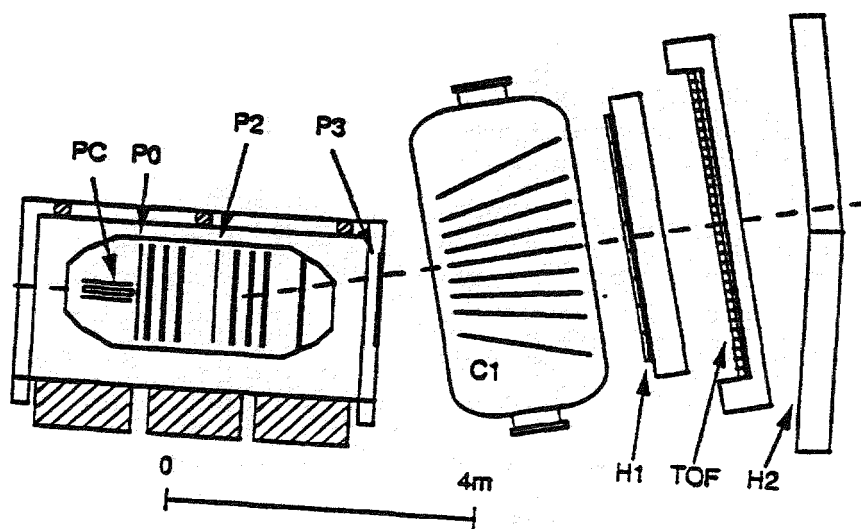


Figure 4

(4) BNL E854, Antiproton-Nucleus Interactions

In this new AGS experiment, we will study the potential formation of hot nuclear matter by antiproton-nucleus interactions at intermediate energies. This will probe the high temperature-low density region of the nuclear matter phase diagram, as opposed to the low temperature-high density region being studied in heavy ion collisions.

Most experiments studying \bar{p} -nucleus interactions have been performed at rest. In this case the annihilation takes place on the surface of the nucleus and the outgoing pions propagate isotropically, with the result that little energy is deposited in the nuclear volume. However, if energetic antiprotons are used (6-10 GeV/c), annihilation occurs well inside the nucleus, and the Lorentz boost throws the outgoing pions forward into the nucleus. The pions happen to be at the right energy in the lab to be very effective at transferring energy to the nucleus; they will typically scatter 3-4 times before being absorbed. The total energy available in this case is also of course much greater than at rest.

Strottman and Gibbs⁷ have modelled antiproton annihilations in nuclei with hydrodynamic and intranuclear cascade models. In order to study such interactions in greater detail we started with the INC code of Gibbs and considerably extended its treatment of antiproton-nucleon interaction channels.⁸ The only experiment to date in which antiproton-nucleus interactions were studied at intermediate energies is that of Miyano *et al.*⁹ In this experiment 4 GeV/c antiprotons were incident on tantalum plates mounted in a bubble chamber. The production cross sections of K_s , Λ , and $\bar{\Lambda}$ and rapidity distributions of K_s and Λ were measured. The new INC code successfully reproduces all the features of these measurements.⁸ It is worth emphasizing that the code contains no exotic effects; however, it does contain all the known physics that we expect to occur.

The prediction of the code is that at antiproton momenta of 4-5 GeV/c a large fraction ($\sim 7\%$) of the antiproton-nucleus interactions will result in peak energy densities of $2.5 \text{ GeV}/\text{fm}^3$ or greater. As the beam momentum is raised to 9 GeV/c, this fraction rises to 80%; 30% of the interaction will give peak densities of $3.5 \text{ GeV}/\text{fm}^3$! Such large energy densities are usually considered sufficient to prompt a phase transition to a quark-gluon plasma. The essence of this experiment is to study antiproton-nucleus interactions in a variety of targets (Be, Al, Cu, Sn, Pb) for incident momenta in the range of 5-9 GeV/c and to compare the results with the predictions of the INC code. In particular we will measure cross sections and rapidity distributions for Λ and K -short production, as well as charged particle multiplicity and angular distributions. New physics effects will be signalled by the observation of a systematic breakdown of the code's predictions as the beam momentum is raised.

The proposal for this experiment was submitted to the Brookhaven PAC in January of 1989, and was approved for 400 hours of running. The experiment is presently scheduled for the next slow-extracted-beam period at Brookhaven. A copy of the proposal is attached to the Renewal Proposal.

References

7. D. Strottman and W. R. Gibbs, Phys. Lett. **149B**, 288 (1984).
8. W. R. Gibbs and J. W. Kruk, submitted to Phys. Lett. (copy attached).
9. K. Miyano *et al.*, Phys. Rev. Lett. **53**, 1725 (1984).

B. Nucleon-Nucleon Experiments

Rice has contributed to the progress of many medium-energy nucleon-nucleon physics experiments over the last year. Phase shift analyses based on existing elastic data provide a fairly complete and consistent description of the nucleon-nucleon interaction up to 500 MeV lab energy. The experiments in which we are involved will all play important roles in extending the description to 800 MeV. These include elastic experiments (LAMPF E1035 and E1072) which pin down the phase shifts at the higher energies and inelastic measurements (TRIUMF E372 and LAMPF 1097) for which limited amounts of data presently exist. The determination of the medium-energy interaction between nucleons is interesting on its own and is an essential ingredient in the description of nucleon-nucleus interactions.

(1) TRIUMF E-372, Single Pion Production in np Scattering

TRIUMF Experiment E372 has as its goal the measurement of the differential cross-section and analyzing power for the reaction $np \rightarrow pp\pi$ using a polarized neutron beam on a liquid hydrogen target. Very little data exists for this inelastic channel. We had fairly successful test run last summer and were scheduled to take data last February. However, the new optically-pumped ion source was not ready in time and the run was postponed. We are currently scheduled to run in December again contingent on the status of the source. Progress has been made over the last year in developing routines to do track and event reconstruction. The problem of track reconstruction has proved a difficult one and we have made contributions to the effort. We are in the process of developing routines which use the tracks and time-of-flight associated with each track to reconstruct the event. This event reconstruction enables us to discriminate against background events and determine the kinematics for good events.

(2) LAMPF E1035: Two- and Three-Spin Measurements in pp-pp

LAMPF Experiment E1035 is expected to provide a complete description of the spin structure of the elastic proton-proton interaction at 730 MeV beam energy. Data were taken during the summer of 1987 using a polarized beam and polarized target. The spin of the forward proton was measured using the JANUS recoil polarimeter. The data reduction and extraction of the two- and three-spin observables is nearly complete and the next step is to use the observables to calculate the scattering matrix up to the

overall phase and normalization. We contributed to the extraction of the observables and are responsible for calculating the scattering matrix from the observables. Results are expected to be published during the next year.

**(3) LAMPF E818: Proton-Deuteron Elastic Scattering at 800 MeV
Two- and Three-Spin Observables**

The closely related LAMPF Experiment E818 took data at the same time as E1035 using a polarized deuterium target to measure elastic proton-deuteron spin observables. UCLA is now taking the lead role in the analysis of that data and we plan to contribute only as needed. The analysis should be completed in about a year.

(4) LAMPF E1072: pp Elastic Absolute Cross-Section Measurements

Data was taken for LAMPF Experiment E1072 last summer and fall. The goal of the experiment was to measure the absolute proton-proton elastic differential cross-section with an overall uncertainty of 2%. Data were taken over a wide angular range with beam energies from 500 to 800 MeV. Preliminary results indicate that the desired level of precision will be achieved or surpassed. Rice was involved in the data taking but will play a minor role in the analysis which should be completed in about a year.

(5) LAMPF E1097: Single Pion Production in np Scattering

LAMPF Experiment E1097 is an extension of TRIUMF Experiment E372 and will provide much more complete angular coverage and will utilize a polarized target enabling us to measure two-spin observables. The coverage is such that all protons will pass through the detector and all but the most backward portion of the pion phase space will be sampled. Phase I of the experiment which does not use a polarized target was approved by the LAMPF PAC last January and is expected to run in 1991. The approval and scheduling of phase II which requires the polarized target depends on the success of phase I. Phase II could run as early as 1992.

Rice has a strong commitment to Experiment E1097. Two of the four spokesmen are at Rice and one of these is acting as project manager. Two major Rice projects are the development of software to do simulations and data reduction and the design and construction of the wire chamber.

Considerable progress has been made in the development of the simulation program. Events are produced randomly in phase space and each particle is tracked through the detectors. This tracking includes energy loss and multiple scattering in the target and deflection in the field of the holding magnet. Background events are obtained by using a Fermi momentum distribution for the target proton. Future developments include more realistic descriptions of the detectors, decay of the pions and inclusion of other background channels. A separate analysis program is able to do good job of re-

constructing events taken from the simulation program although it "cheats" by using starting values calculated from the "true" momenta. Future development will involve removing the "cheats" and extending the analyzer to handle more sophisticated versions of the simulator. Both programs should also be optimized to run faster because each takes seconds to process an event.

Our current chamber design calls for four cylindrical drift chambers with wires running vertically parallel to the cylinder axis and covering horizontal angles back to 120 degrees. Horizontal position would be determined using the drift information and the vertical position using charge division. Thus each wire would provide three-dimensional information greatly simplifying the problem of track reconstruction. A test chamber is being built to measure the vertical position resolution.

C. FNAL Experiment E683: Photojets from Nuclei

This experiment will study the photoproduction of high p_t jets in the Wide Band Beam of the Tevatron. The QCD processes of interest are QCD Compton scattering $\gamma q \rightarrow gq$ (which dominates at high x_t), and quark-gluon fusion $\gamma g \rightarrow qq$. These processes are very distinctive, with the photon coupling as a point particle, giving all its energy to the two high- p_t jets, and producing no beam jet. These characteristics allow the separation of the direct-coupling processes from vector-meson-dominance-type processes. The dominance of the QCD Compton diagram at high p_t allows for the isolation of a fairly clean sample of gluon jets and will provide the first unbiased measurement of the gluon fragmentation function. The photon-gluon fusion process, which is important at intermediate p_t , should provide important constraints on the gluon structure function of the proton. Events in which the photon acts as a hadron are also of interest, since the photon structure function has been calculated from QCD but is poorly measured. We will have available to us a full second-order QCD calculation, provided by Jeff Owens, with which to compare our data.

Another aspect of the experiment that is of particular interest to our intermediate energy program is the A-dependence of jet production from nuclei. A-dependent effects are of interest in order to study the propagation of partons through nuclear matter and to understand the hadronization process. A photon beam is a clean probe of A-dependent effects, due to the absence of a beam jet.

Other processes which can be studied in this experiment include a higher-twist process, $\gamma q \rightarrow (\pi, \rho) + q$, and QED Compton scattering, $\gamma q \rightarrow \gamma q$. Confirmation of higher-twist processes is an important test of higher order effects in QCD. The A-dependence of these processes is also of interest.

Photons in the momentum range 200 to 500 GeV/c will be tagged with a momentum uncertainty of about 2%. The apparatus consists of a wide-angle magnetic spectrometer, the main calorimeter array, and a forward calorimeter. The main calorimeter is segmented in area and depth and consists of 528 modules.

Major progress in the past year includes:

- All calorimeter phototubes and bases have been checked and bad channels repaired.
- The beam calorimeter is under construction and should be complete this summer.
- The muon hodoscope/veto has been constructed and is in place. It will be cabled up and operational within a month.
- The main calorimeter transporter has been installed and is operational. The transporter moves the calorimeter both horizontally and vertically for calibration purposes.
- The beam calorimeter transporter has been installed, but the motor drive (for horizontal motion) is not yet installed.
- The SCM105 magnet has been installed, the power supply connected, and the magnetic field mapped.
- The chambers downstream of the magnet have been tested and are fully operational. They will be installed in late July.
- The main calorimeter is completely cabled up, and tests of the LED and pulser calibration systems are underway.
- Tests of trigger hardware are underway.

We expect to take data during the next fixed target run at Fermilab.

D. Theoretical Progress

A publication by Professor P.M.Stevenson, of the Rice High Energy Group, I. M. Duck and Professor E.C.G.Sudarshan of the University of Texas, entitled "Can a Measurement of a Spin-1/2 Particle's Spin Component Yield a Value 100?" has been accepted for publication by Physical Review D.

Ian Duck and his graduate student, Alan Mattingly, have been working on construction of a quark-soliton model of the nucleon which interpolates between the MIT bag model of arbitrarily confined relativistic quarks and the Skyrme model in which the nucleon is a topological knot in the pion field. Confinement is achieved using the color dielectric model. The field equations are solved numerically for the so-called hedgehog state for which the field equations reduce to radial ones. Nucleon observables are calculated by projecting the quark-soliton hedgehog ground state onto spin-isospin eigenstates, which are taken to be variationally best nucleon and nucleon isobar states.

E. Instrumentation Developments

(1) CCD Development

We are developing a charge coupled device (CCD) detector system for use in conjunction with the BNL TPC's in our heavy ion experiment E810, described above. The CCD's will be used in a box surrounding the target to provide high resolution tracking very near the interaction point.

Readout of the GEC P8600 CCD detector requires three distinct functions; the Clock Generator, the Pulse Driver, and Amplification and Signal Conditioning. The Clock Generator Module is a CAMAC module which has been completed and tested. Design and development of the Pulse Driver Module is past the initial stages and a working model exists. A faster version of Driver Module is still desired. Current work is on the Amplifier and Signal Conditioning Module. This is the most difficult part of the process because very small signals must be recovered in the presence of orders of magnitude larger reset pulse feedthrough. As now operating, low light levels can be detected but not signal levels corresponding to minimum ionizing particles. Work is nearing completion on a better version of the gated amplifier which is expected to enable detection of the low levels required.

It is expected that the Multi-event Recorder system, CAMAC interface and software to be supplied by Brookhaven will be integrated with our system soon. Tests at normal operating temperature (180 deg K) under actual experiment conditions will then be possible.

(2) Computer Acquisition

We are currently in the process of doubling our computer power by the acquisition of two Vaxstation 3200's. This is intended to give us much better interactive usage of existing analysis programs. Complete analysis of most of our experiments requires at least an order of magnitude greater CPU power.

Since the computations for track reconstruction and Monte-Carlo event simulation are far too lengthy for our local machines, we have gotten a seed grant to experiment with running code on the the NEC-SX supercomputer at the Houston Area Research Council (HARC). This machine would give us both the cpu power we need and reasonable access to tape drives. Both of these requirements are necessary for analysis of the large numbers of tapes generated by our typical experiments. The initial phase of the project involves conversion and testing of necessary libraries to run on the SX. To date portions of the CERN libraries have been successfully converted to run without optimization. The KERNELIB, and HBOOK3 have been converted. These are used by all of our analysis code. The ZEBRA package and HBOOK4 are in the process of being converted. These along with GEANT are necessary for our Monte-Carlo event simulations.

(3) Computer Software

The installation of the connection to the High Energy Physics network (HEPNET) has been completed, and it works fairly well. The cost of the link from Texas A&M to Fermilab is supported by a consortium of several universities including Texas A&M, U.T., and Rice. The main difficulty has been with interactive access during peak hours. This could be solved by increasing the link speed from 9600 to 56kb.

5. Changes in Personnel

There were no changes in personnel during the reporting period within the Faculty or the Staff. The Bonner Lab welcomed an old friend, Professor Balram Bhakar from the University of Manitoba, for the summer. Professor Bhakar was a Research Associate in the Bonner Lab in the early 1960's.

Graduate Students: A. H. Mohammadzadeh received his M.A. degree at the May Commencement. Two graduate students joined the Medium Energy Group, C-N Chiou and T. L. Gaussiran. Two new graduate students, Hung Cao from Texas A&M and Greg Morrow from Notre Dame, who will enter Rice in the fall worked with the group during the summer. The undergraduate summer assistants, David Branning and Georgios Georghakis, will be senior physics majors in the fall.

6. 1989 Publications, Presentations, & Theses

Publications

"Measurement of $\pi^+d \rightarrow \Delta^{++}n$ at Intermediate Energy," P. V. Pancella, G. S. Mutchler *et al.*, Physical Review **C38**, 2716 (December 1988).

"Measurement of the Imaginary Part of the $I = 1\bar{N}N$ S-Wave Scattering Length," G. S. Mutchler *et al.*, *Intersections Between Particle and Nuclear Physics-Rockport*, AIP Conf. Proc. No. **176**, ed. Gerry M. Bunce (1988), p. 435.

"Spin Parameter Measurements in Inclusive Hyperon Production," Francesca Nessi-Tedaldi *et al.*, *Ibid*, p. 1180.

"Neutron-Proton Analyzing Power Measurements from 375 to 775 MeV," C. R. Newsom, B. E. Bonner, *et al.*, Physical Review **C39**, 965 (March 1989).

"Spin-Parameter Measurements in Inclusive Σ^0 Production," B. E. Bonner *et al.*, Physical Review Letters **62**, 1591 (3 April 1989).

"Spin Parameter Measurements in Inclusive Hyperon Production," Marzio Nesi, *Proceedings of the Symposium on Future Polarization at Fermilab*, ed. Berger, Morfin, Read, and Yokosawa (1988), p. 197.

"Spin Parameter Measurements in Inclusive Λ , Σ^0 , K_S and $\bar{\Lambda}$ Production," Marzio Nesi, *High-Energy Spin Physics*, AIP Conf. Proc. No. 187, ed. Kenneth J. Heller (1988), p. 66.

"Search for a J^{PC} Exotic Hybrid Meson," S. U. Chung, B. E. Bonner, G. S. Mutchler *et al.*, *Glueballs, Hybrids, and Exotic Hadrons*, AIP Conf. Proc. No. 185, ed. Suh-Urk Chung, (1989), p. 631.

"Preliminary Results of $\bar{p}p$ at 8 GeV/c," A. Boehnlein, B. Bonner, G. Mutchler, *et al.*, *Ibid.*, p. 446.

"Can a Measurement of a Spin-1/2 Particle's Spin Component Yield a Value 100?" I. M. Duck, P. M. Stevenson, and E.C.G. Sudarshan, accepted for publication by Physical Review D.

"Strangeness Production in Antiproton-Tantalum Interactions at 4 GeV/c," W. R. Gibbs and J. W. Kruk (submitted to Physics Letters, July, 1989), Rice Preprint DOE/ER/040309-9.

"Analyzing Power of Inclusive Production of π^+ , π^- and K_S^0 by Polarized Protons at 13.3 and 18.5 GeV/c," B. E. Bonner, F. Nesi-Tedaldi *et al.* (submitted to Physical Review D.), Rice Preprint DOE/ER/040309-12.

Presentations

"Strangeness Production with Antiprotons at Lear," IX European Symposium on Antiproton-Proton Interactions and Fundamental Symmetries-Mainz (September 1988), P. D. Barnes, B. E. Bonner *et al.*,

"A TPC for Large Solid Angle Relativistic Ion Experiments," IEEE Nuclear Science Symposium-Orlando (November 1988), K. J. Foley, B. E. Bonner, G. S. Mutchler *et al.*

"Antiproton-Nucleus Interactions at 5-10 GeV/c," Joint Spring Meeting of the Texas Section of the APS and AAPTS, University of Houston, March 3-4, 1989, J. W. Kruk *et al.*

"P, A, and D for Inclusive Σ^0 ," *Ibid.*, N. M. Krishna *et al.*

Thesis

"The Quark-Skyrme Nucleon" Alan Mattingly, M.A., Rice University, July 28, 1989.

Co-Principal Investigators

B. E. Bonner, Chairman, Physics Department
& Director, T.W. Bonner Nuclear Laboratories
G. S. Mutchler, Professor of Physics

**7. COPIES OF SELECTED PUBLICATIONS and
MANUSCRIPTS ***

- A. "Spin Parameter Measurements in Inclusive Σ^0 Production,"
B. E. Bonner *et al.*, Phys. Rev. Lett. 62, 1591 (1989).
- B. "Search for a J^{PC} Exotic Hybrid Meson," S. U. Chung *et al.*,
AIP Conf. Proc. No. 185
- C. "Strangeness Production in Antiproton-Tantalum Interactions
at 4 GeV/c," W. R. Gibbs and J. W. Kruk (submitted to
Physics Letters)
- D. "Analyzing Power of Inclusive Production of π^+ , π^- and K_S^0 By
Polarized Protons at 13.3 and 18.5 GeV/c," B. E. Bonner, F.
Nessi-Tedaldi *et al.* (submitted to Physical Review D.)

* removed and cycled separately -