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NEW MEXICO STATE UNIVERSITY

EXPERIMENTAL STUDIES OF PION-NUCLEUS AND NUCLEON-NUCLEUS INTERACTIONS AT INTERMEDIATE ENERGIES

Progress Report
on DOE Grant No. DE-FG04-88ER40403

April 1, 1991 – March 31, 1994

New Mexico State University
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Contents

1 Introduction

This report summarizes the work on experimental research in intermediate energy nuclear physics carried out at New Mexico State University in 1991–94 under a grant from the U. S. Department of Energy.

Most of these studies involved investigations of various pion-nucleus interactions and nucleon-nucleus charge-exchange reactions. The work was carried out with the LAMPF accelerator at the Los Alamos National Laboratory and the cyclotrons at the Paul Scherrer Institute (PSI) near Zurich, Switzerland, at Indiana University (IUCF), and at TRIUMF in Vancouver, Canada, as collaborative efforts among several laboratories and universities. We have also worked on plans and preparations for new experiments involving studies of the quark structure of nucleons and nuclei, which would be carried out at Fermilab (FNAL), near Chicago, and at the HERA facility at the DESY laboratory in Hamburg, Germany. The NMSU personnel included two faculty members, five postdoctoral research associates, nine graduate students, and one undergraduate student.

The pion studies involved measurements of elastic scattering, single- and double-charge exchange scattering, quasielastic scattering, and absorption. The targets in these experiments included both polarized and unpolarized nuclei, as well as nucleons. The physics addressed by the pion work involved studies of nuclear structure, of the pion-nucleus and the pion-nucleon interaction mechanism, including its spin dependence, and investigation of the pion-nucleus absorption mechanism. The nucleon-nucleus charge-exchange work was aimed at increasing our understanding of the spin- and isospin-dependence of the nucleon-nucleus interaction. Some of the proposed and planned experimental work is aimed at investigating details of the quark structure of nucleons and nuclei, a fundamental problem of great interest.

2 Experimental Research

During this period we were involved in data taking on several experiments in pion-nucleus interactions at LAMPF, PSI, and TRIUMF, and on nucleon-nucleus charge-exchange reactions at LAMPF and IUCF, as well as in the analysis and interpretation of data from past experiments and the planning and preparation for future experiments. Our progress in this research is described below.

2.1 Experiments Run

Our principal research activities involved planning, preparing for, and taking data on several experiments, followed by studies and interpretations of the results. At LAMPF, the experiments run included the following: pion double-charge-exchange reactions; elastic pion scattering from polarized ^{3}He; quasifree scattering of pions from ^{2}H and ^{3,4}He; π-p charge exchange reactions; studies of the feasibility of observing the direct production of pionic atoms; pion-nucleus elastic scattering; and (p,n) and (n,p) reactions on various nuclei, including experiments with beams of polarized nucleons. At PSI, the experiments run included studies with the Large Acceptance Detector System (LADS) of pion absorption and quasifree scattering to multiparticle final states, and studies of quasifree scattering and absorption in polarized ^{7}Li. At TRIUMF, one student in our group was involved in the commisioning of the CHAOS detector and first measurements of $(\pi,2\pi)$ reactions with it. Summaries of this work are presented here.

LAMPF Experiment No. 1107, *Studies of Pion Double Charge Exchange Scattering at Energies above the Δ Resonance*, University of Texas, University of Pennsylvania, Rutgers, University of York (UK), LANL, and NMSU (Rawool-Sullivan, Park, Blanchard, Lail, El-Ghossain, and Burleson); G. Burleson, Spokesman.

This experiment, together with a companion experiment described below that involved measurements of elastic scattering, is a continuation of work begun by members of this collaboration that obtained the first extensive set of measurements of pion-nucleus interactions at energies immediately above the Δ(1232) resonance. The principal motivation for this work was based on the observation that the pion-nucleon interaction is considerably weaker at these energies than near the Δ resonance. This means that the resulting longer mean free paths for pions in nuclei and the weaker optical potential should lead to more reliable theoretical calculations. Studies at these energies also have advantages over those below the resonance, where the interaction is also weaker, but where second-order effects are larger.

Double-charge-exchange (DCX) scattering is or particular interest because it must take place on at least two nucleons and therefore should be able to give new insight into nucleon-nucleon correlations in the nucleus. In order to carry out detailed calculations of DCX at these energies, however, it is necessary to know how well models of the pion-nucleus interaction can reproduce simpler interactions, such as elastic scattering. Partly for this reason, we carried out measurements on both of these processes.

Results of our earlier DCX measurements of small-angle excitation functions and the A-dependence for transitions to double isobaric analog states (DIAS) have been published.[1, 2, 3] They have generally disagreed with most previous expectations. The agreement with new calculations of Oset and Strottman,[4] which include strong isovector medium polarization effects, appear to be very good, but, as discussed below, their calculations of elastic scattering fall below the data.

More recently, we measured angular distributions to DIAS states in ^{44,48}Ca at 400 MeV; preliminary results are shown in Fig. 1. Previous data on these, along with other nuclei in the $f_{7/2}$ shell, have been interpreted in terms of a two-amplitude model involving transitions through analog and nonanalog states.[6] This model has been very successful at low energies,[7] but it was found to be less successful at these higher energies.[2, 3] At low energies, the angular distributions of these nuclei were found to be very different,[7] with that for ^{48}Ca being flat and ^{44}Ca forward peaked. As seen in Fig. 1, the ^{44}Ca angular distribution is very similar to that predicted for ^{42}Ca.

We also measured a small-angle excitation function for DCX on ^{16}O, producing the first data on a nonanalog transition at these energies, with the results shown in Fig. 2. The interest in nonanalog transitions here lies in the observation that at resonance energies they appear to be dominated by the Delta interaction (DINT) model,[11] while analog transitions seem to be dominated by a sequential mechanism. An attempt to describe DCX scattering with a combination of these two mechanisms has been unsuccessful, however.[12, 13] At energies above 300 MeV, the DINT mechanism predicts a very small cross section, but the measurements in Fig. 2 show that the cross

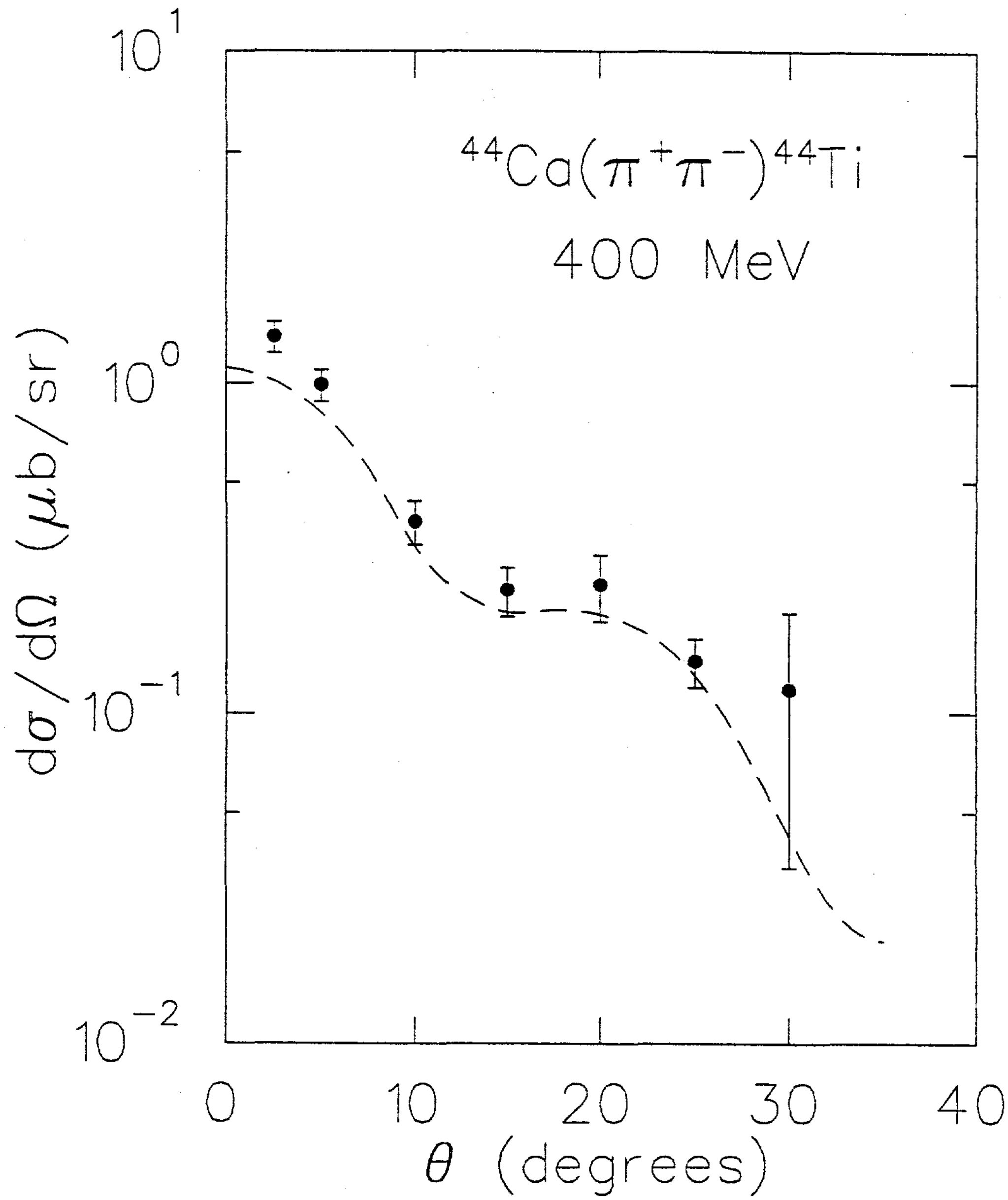

Figure 1: Angular distribution for the (π^+, π^-) DCX reaction on ^{44}Ca at 400 MeV, from Exp. 1107. The curve is a prediction of Oset and Strottman[5] for ^{42}Ca, scaled by the ratio of the ^{44}Ca and ^{42}Ca cross sections at 400 MeV, 5°.

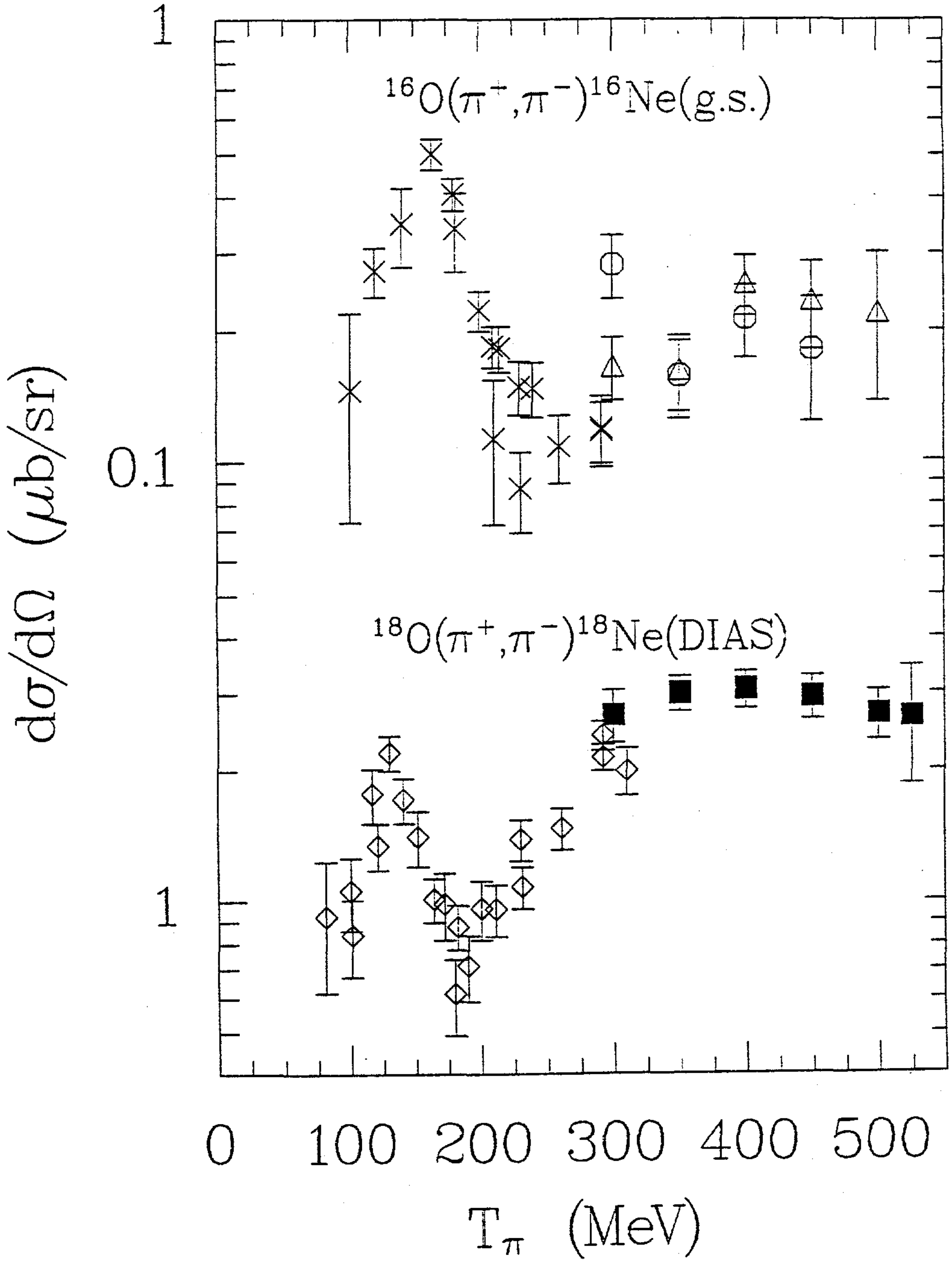

Figure 2: Forward-angle differential cross sections for $^{16}O(\pi^+,\pi^-)^{16}Ne$(g.s.) and $^{18}O(\pi^+,\pi^-)^{18}Ne$(DIAS). Shown are two data sets from this experiment, as open circles and triangles. Results from previous experiments[8, 9] are indicated by crosses. The ^{18}O results at lower energies (diamonds) are from ref.[10], and those at higher energies (filled squares) are from ref.[1].

sections at these energies are larger than between 200 and 300 MeV. They are similar in behavior to analog cross sections, but smaller by more than an order of magnitude (as compared, for example, to ^{18}O). This suggests sequential charge-exchange scattering as the dominant process, but suppressed by a mechanism not yet identified.

These results have been published,[14] and they will be included in the Ph.D. thesis of David Beatty, of Rutgers University.

LAMPF Experiment No. 1140, *Search for η Component in Pion DCX Scattering*, University of Texas, University of Minnesota, University of Pennsylvania, University of York (UK), King Fahd University (Saudi Arabia), LANL, and NMSU (Rawool-Sullivan, El-Ghossain, and Burleson); C. L. Morris, LANL, and C. F. Moore, Texas, Spokesmen.

Calculations by Haider and Liu[15] have shown that a bound state of an η in a nucleus may occur as an intermediate state in pion DCX. Such an effect would compete with π^0 channels in the continuum and would lead to a resonance-like structure in the DCX excitation function at fixed momentum transfer, due to interference between these channels. Their calculations for the reaction ^{14}C$(\pi^+,\pi^-)^{14}$O(DIAS) predict that this structure should occur with a fluctuation of $\sim$ 80% at a momentum transfer of 210 MeV/c. For the ^{18}O$(\pi^+,\pi^-)^{18}$Ne reaction, this effect should be seen at 420 MeV.

To search for this, data were taken on ^{18}O at fixed momentum transfers of 0, 105, and 210 MeV/c, for pion energies between 350 and 440 MeV. Systematic normalization errors in the data were reduced by taking a ratio of the $q = 0$ to $q = 210$ MeV/c cross sections, as shown in Fig. 3. For the unbound region of ^{18}Ne, no structure is seen, as expected, whereas for the region of the analog transition a fit with a straight line is very poor, indicating that there indeed may be structure in the η threshold region. The statistical precision of the data do not allow more than a qualitative characterization of this effect, however.

These results have been published[16], and they served as the basis of a Ph.D. thesis for John Johnson, of the University of Texas.

LAMPF Experiment No. 1017U, *Interference Effects in Nonanalog Pion Double Charge Exchange*, University of Pennsylvania, University of Texas, Rutgers, LANL, and NMSU (Rawool-Sullivan, Urbina); H. T. Fortune, Pennsylvania, and J. M. O'Donnell, LANL, Spokesmen.

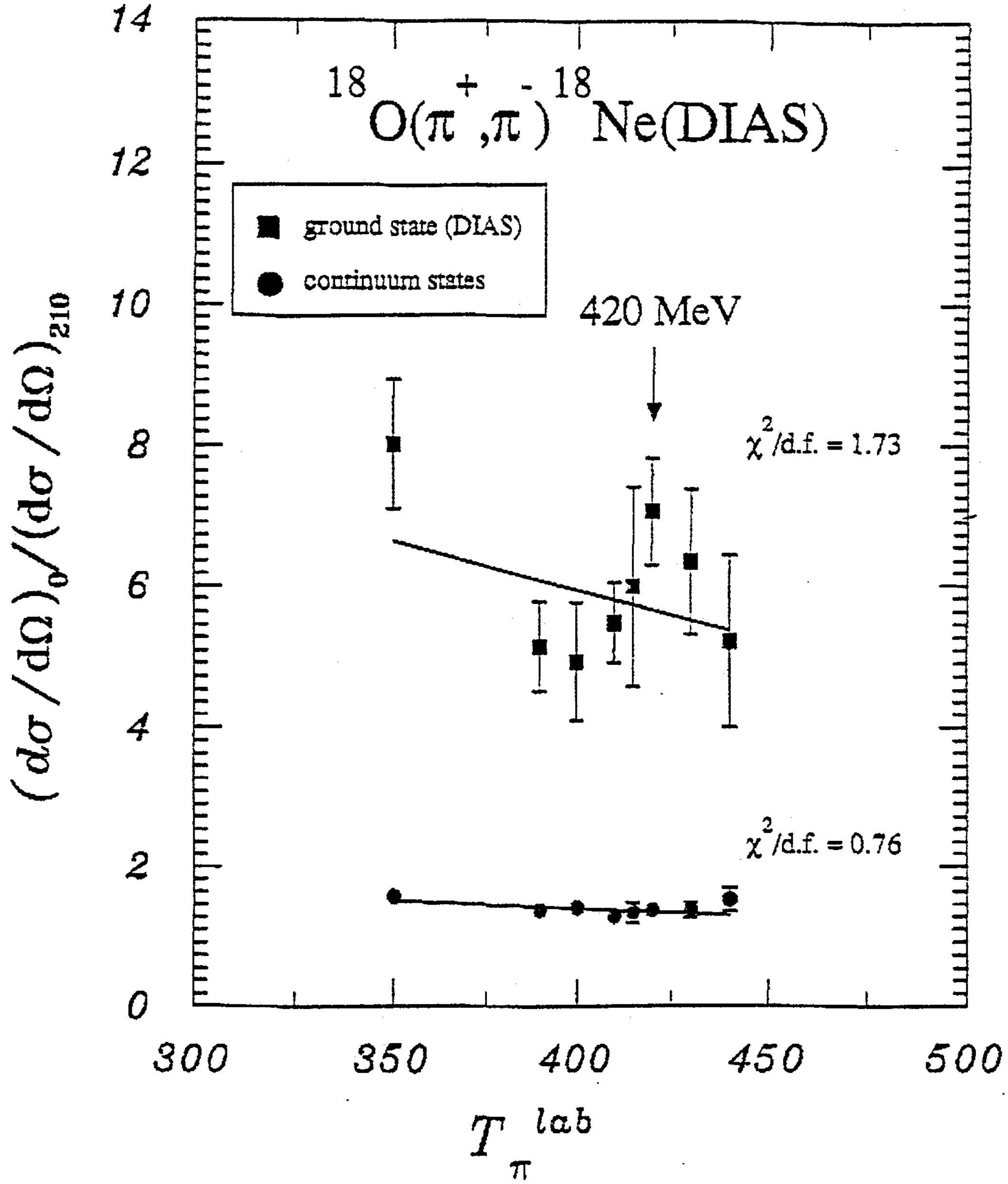

Figure 3: Ratios of the $q = 0$ and $q = 210$ MeV/c cross sections for the $^{18}O(\pi^+,\pi^-)^{18}Ne(DIAS)$ reaction as a function of pion energy, from Exp. 1140. The lower points represent data in the continuum region where no effect is expected, and the upper points represent the data in the region of the analog transition. The lines shown are the best straight-line fits to the data, with values of χ^2 per degree of freedom indicated.

Microscopic calculations of analog DCX transitions in the $\Delta(1232)$ resonance region are unable to reproduce several aspects of the experimental data, in particular the small-angle excitation functions and the angular distributions at energies near the resonance, which have minima at too small an angle to be diffractive in character. For nonanalog transitions, however, the data in the resonance region, including angular distributions, seem to be well described by the DINT mechanism[11] mentioned above. While a combination of the DINT and sequential mechanisms has been unable to reproduce the anomalous behavior of analog transitions, it is possible that the effects of such a mixture of amplitudes might be observed in certain characteristics of the angular distributions of nonanalog transitions in the resonance energy region. It was the purpose of this experiment to search for this.

In this EPICS run, angular distributions for DCX on ^{16}O were measured at several energies between 180 and 292 MeV, over an angular range between 5° and 35°. The results indicate a shift in the position of the first minimum from that expected from diffractive scattering as a function of energy. This suggests that the simple DINT mechanism is not applicable for ^{16}O at energies near 230 MeV, and that at least two important amplitudes are present, but the sequential and DINT mechanisms do not have the needed properties. If the characteristics of DCX on both ^{16}O and ^{18}O are considered, however, it is unclear how any simple explanation can account for what is observed.

These results have been published,[9] and they served as part of the Ph.D. thesis of David Beatty, of Rutgers University.

LAMPF Experiment No. 1263, *Analog Contribution to Nonanalog Double Charge Exchange*, University of Pennsylvania, LANL, and NMSU (Blanchard, Lail, and Burleson); A. L. Williams and H. T. Fortune, University of Pennsylvania, Spokesmen.

In lowest order, DCX reactions are described in terms of two sequential single charge exchange (SCX) scatterings on two nucleons. For T=1/2 nuclei, the (π^+,π^-) reaction involves one scattering to analog states followed by a scattering to nonanalog states, or vice versa, since there is no transition route involving two sequential analog transitions. SCX data, which show strong cross sections for transitions to the isobaric analog state (IAS), suggest that the sequence of an initial analog transition followed by a nonanalog transition is the stronger. Measurements of DCX on a T=1/2 nucleus, when considered along with the single charge exchange to the IAS, should provide constraints on the nature of the nonanalog charge exchange mechanism.

In this experiment, small-angle excitation functions for $^{27}Al(\pi^+,\pi^-)^{27}P$ from $T_\pi = 100$ to 294 MeV were measured, for transitions both to the ground state and to an excited state at the position of a doublet in the final nucleus. The cross sections for these two transitions exhibit completely different behaviors. The ground-state transition has a minimum near 150 MeV, similar to what is seen in other nonanalog transitions for which $\Delta J^P = 0^+$ is permitted for only one of the sequential charge exchanges. The excited-state transition, however, has a maximum near 150 MeV, similar to what is seen in other transitions for which $\Delta J^P = 0^+$ is permitted for both of the sequential charge exchanges. This, together with the contrasting SCX excitation function for the analog transition in ^{27}Al, indicates the presence of an interfering amplitude in addition to the one describing the SCX analog reaction. This amplitude could depend strongly on the wave functions of the intermediate and final nuclear states.

These results have been submitted for publication.

LAMPF Experiment No. 1267, *Elastic Scattering of π^+ and π^- from Polarized ^{3}He at $T_\pi = 180$ MeV to 475 MeV*, U. of Minn., Simon Fraser University, Ohio University, LANL, and NMSU (Park, Blanchard, Lail, Nelson, and Burleson); D. Dehnhard, Minnesota, O. Häusser, Simon Fraser, and G. Burleson, Spokesmen.

Recent measurements of the asymmetry A_y of elastic scattering of pions from polarized p-shell spin-1/2 nuclei[17, 18] found asymmetries that are considerably smaller than were predicted.[19, 20, 21] For these nuclei, calculations generally show a strong dependence on the details of the nuclear structure, but they also suggest that the π-nucleus reaction mechanism is not sufficiently well known to explain these results. This indicates that a polarization experiment with pions on a nucleus with a well-known nuclear structure is needed, so as to allow a separation of the effects due to nuclear structure and to the π-nucleus reaction mechanism. Such a nucleus is ^{3}He.

The recent development at TRIUMF of an optically-pumped high-density polarized ^{3}He target[22] have made such experiments feasible, and the first pion results, at 100 MeV, have been reported.[23] This experiment found a large positive value of A_y near a cross-section minimum. The results have been reproduced fairly well with an optical-model calculation which uses realistic nuclear wave functions.[24] This work showed that at lower energies the prediction for A_y is roughly the same for both the full calculation and for a simple model which uses only the free pion-nucleon amplitudes with a Gaussian form factor for ^{3}He, both of which give a good representation of the experimental differential cross section. The predictions of these two models diverge at higher energies, however, resulting, for example, in a reversal of the sign of A_y above 200 MeV with the full calculation. The energy where the reversal occurs is dependent on the details of the interaction model used. This means that it is important to make asymmetry measurements at these higher energies as well.

This experiment used the TRIUMF target system with $\sim$ 6 atm of ^{3}He contained in a glass cell as a gas, along with N_2 and traces of Rb. The cell is placed in a vertical magnetic field of about 3 mT. The Rb atoms are polarized by optical pumping with a laser beam, and the ^{3}He nuclei are polarized by spin-exchange collisions with the Rb atoms. The N_2 is used as a quench gas. Polarizations of 35–45% were achieved.

As of this writing, data have been taken for π^+ at 100, 142, 180, and 256 MeV. Preliminary results indicate behavior different from most predictions.

LAMPF Experiment No. 1216, *The ^2H, ^3He,$^4He(\pi, \pi' x)$ Reaction,* U. of Minn, Rutgers, LANL, U. of Texas, Colorado University, Tohuko University, NMSU (Park); J. Langenbrunner, D. Dehnhard, U. of Minn., and M. K. Jones, Rutgers, Spokesmen.

Exclusive experiments of this type on the few-body nuclei ^{2}H, ^{3}He, and ^{4}He are motivated in part by the surprisingly large ratio of cross sections for $\sigma(\pi^+, \pi^{+\prime} p)$ to $\sigma(\pi^-, \pi^{-\prime} p)$ reported for ^{4}He.[25, 26]. Values for this ratio as high as 50 were found at an incident energy of 180 MeV for nuclear excitations between 30 and 50 MeV. In sharp contrast, in the same region of nuclear excitation the ratio of inclusive cross sections give the expected response $\sigma(\pi^+, \pi^{+\prime})/\sigma(\pi^-, \pi^{-\prime}) \cong 1$.

If the ^{4}He$(\pi, \pi' p)$ reaction were to proceed exclusively by quasielastic π-proton scattering, we would expect a ratio of 9 because the ratio of π^+-proton to π^--proton elastic scattering amplitudes equals 3 for the P_{33} resonance. However, for the decay of a state of good isospin, this ratio should be near unity.

The ^{16}O$(\pi^\pm, \pi^{\pm\prime} p)$ reaction showed a similar phenomenon in terms of the ratio [27]. Takaki and Thies[28] modeled the ^{16}O$(\pi^\pm, \pi^{\pm\prime} p)$ reaction by including a Δ–N interaction. In that model, a Δ–induced proton knockout amplitude interferes with the quasi-free proton knockout process ("medium effects"). Understanding such a phenomenon necessarily involves understanding the role of the nuclear medium, and perhaps the role of nuclear excitations. To explore this question further we undertook to measure these ratios for the simplest few-body nuclei, where much progress has been made in the quantitative understanding of the nuclear wavefunctions.[29]

Data were measured for the $(\pi^{\pm}, \pi^{\pm}p)$ reaction on ^{2}H, ^{3}He, and ^{4}He at incident pion energies of 180, 210, 240, and 300 MeV. Pions were detected with the Large Acceptance Spectrometer (LAS) and the recoil protrons were detected in coincidence with several CsI detectors centered around the free π-p scattering angle. As with ^{4}He, large cross-section ratios were also found for ^{3}He and ^{2}H, at momentum transfers of $q \sim 0.95$ fm^{-1}. At larger momentum transfers ($q \sim 1.5$ fm^{-1}), the ratios were found to be closer to the free pion-nucleon values at all incident energies. The conclusion is that at $q \sim 1$ fm^{-1}, one or more processes, such as multiple scattering or Δ-core interactions, interfere with quasielastic scattering, even in a system as simple as deuterium.

A preliminary version of these results has been reported at an international conference, and this work will serve as a Ph.D. thesis project for C. Whitley, of the University of Texas.

LAMPF Experiment No. 1268, $\pi^- p \rightarrow \pi^0 n$ *Cross Sections in the Region of the* Δ *Resonance*, the NMS Collaboration, including NMSU (Park, Zhao); M. E. Sadler, Abilene Christian University, Spokesman.

This experiment was run as part of the tuneup of the new Neutral Meson Spectrometer (NMS). This device is a new high-resolution, large-acceptance spectrometer for detecting neutral mesons which was built at at LAMPF, with contributions from several university groups. It is designed to detect the two-gamma decay of π^0 and η mesons, and it should have an intrinsic energy resolution for the decaying meson of $\sim$ 300 keV. It consists of two rectangular arrays of (pure) CsI scintillation counters for gamma-ray shower detection, preceeded by BGO gamma-ray converters with multiwire tracking chambers to determine the positions of the gamma rays. NMSU worked on tests of prototype photomultiplier tubes for the CsI counters, construction tests of the multiwire chambers, beam tests of parts of the system, and the initial development with pion beams.

The purpose of this experiment is to measure $\pi^- p \rightarrow \pi^0 n$ differential cross section in the region of the $\Delta(1232)$ resonance. The point is to check previous data, which do not agree well with partial-wave analyses at back angles. The existing data have quoted errors of 6–10% at these angles, and all involved the use of neutron counters, which are sometimes prone to efficiency variations. A set of systematic measurements by one group of a complete angular distribution does not exist at any energy. With the NMS to detect π^0 mesons, a systematic set of high-quality data should be possible for the first time. This should provide input for charge-independent partial-wave analyses which should be able to investigate charge-symmetry breaking, the charge splitting of the Δ, and to help clarify discrepancies at lower energies through analyticity constraints on the partial-wave analyses.

Data were taken for this experiment in fall, 1992, and in summer, 1993, as part of the NMS tuneup. Measurements were made of cross sections over the full angular range at six energies between 142 and 266 MeV. The data are currently being analyzed and will be used as a Ph.D. thesis for L. Nguyen, of Catholic University.

LAMPF Proposal No. 1239, *Feasibility of the Direct Production of Pionic Atoms*, Rutgers, Arizona State University, Joint Institute of Nuclear Research (Moscow), Academy of Sciences (Russia), LANL, and NMSU (Park, Burleson); M. Rawool-Sullivan, C. L. Morris, LANL, and P. Siegel, California Polytechnic Institute, Spokesmen.

One quantity of particular interest in pion physics is the threshold pion-nucleus amplitude, which has a bearing on chiral-symmetry breaking and on the anomalous behavior or the level shifts and widths of the energy levels of some π-mesonic atoms. When a negatively-charged pion is captured by an atom, it normally is initially found in a highly-excited orbit and then de-excites through electromagnetic transitions. For light nuclei, it generally reaches the 1s level, from which it annihilates on the nucleus. The measured x-ray spectrum gives information on the atomic energy levels, which in general are shifted from the pure Coulomb values by the strong interaction. In the lower angular-momentum states, these shifts are crucial in characterizing the thrsehold pion-nucleus optical potential.

For larger nuclei, the lower-level pionic wave functions overlap the nucleus more completely, so that their sensitivity to the pion-nucleus interaction is greater. Experimental observations of the energies and widths of these states in these nuclei would provide important constraints on theoretical models. For these nuclei, however, these low levels are seldom populated, since the pion is generally absorbed before it reaches them in a cascade process.

Several methods have been proposed for populating these states and determining their modification due to the strong interaction. One possibility is the (π^-,p) channel, corresponding to the incident pion being captured directly into a 1*s* or 2*p* atomic orbital after striking a proton and knocking it out of the nucleus. Calculations of cross sections for this process process, using the distorted-wave inpulse approximation, have been carried out by Kaufmann, *et al*,[30] which indicate that they are largest at small energies.

In 1992 we attempted to look for a signal of the formation of this system by using this reaction with a ^{58}Ni target with 30-MeV incident pions. Reaction products were detected with a set of of 30 plastic-BGO phoswich detectors which covered nearly the full solid angle (the 'BGO ball'). The trigger for the experiment required the pion to disappear from the beam and two hits to appear in the detector system.

Preliminary results were presented at an international conference this year, and analysis of the data is continuing.

LAMPF Experiment No. 1288, *Measurements of Differential Cross Sections for π^+ Scattering from ^{13}C at T_π = 130 and 223 MeV*, U. of Minn., LANL, Rutgers, and NMSU (Park); D. Dehnhard, Spokesman.

The first measurement of asymmetries of π^+ elastic scattering from polarized ^{13}C was carried out in 1989 with the Large Acceptance Spectrometer (LAS) at LAMPF.[18] In analyzing the data it became apparent that the acceptance of the LAS at large scattering angles was not sufficiently well known to extract reliable differential cross sections, a problem which did not affect the measurement of the asymmetry. However, for a thorough theoretical analysis of the asymmetry data it is important to have accurate differential cross section data as well. We therefore proposed to measure the relevant differential cross sections with the EPICS system.

The acceptance of EPICS is quite well known from many experiments and its superior energy resolution permitted higher-quality data to be taken. The measurements were carried out during the last run cycle of 1992 at $T_\pi = 130$ and 223 MeV, the previously-measured energies, but the allotted beam time was sufficient to take data only with π^+. Spectra were taken in 5° steps from 25° to 120°. The statistics accumulated were sufficient to use 1°–binning in replay.

Preliminary cross sections display well-defined first and second minima in the angular distributions. There appears to be good agreement with the previous cross section data at the forward angles, but in the region of the second minimum the new data show systematically smaller cross-sections at both energies. Since these measurements were performed with a slab target, which gives resolution allowing a good separation between the ground state and the first excited state, this indicates that there is a problem with the acceptance correction of the LAS at the larger angles. The new data from EPICS should now allow a better analysis of the asymmetry data in order to test a variety of pion-nucleus reaction models. Detailed analysis of the data is in progress.

LAMPF Experiment No. 1220, *Measurement of Cross-Section Angular Distribution for the* $^6Li(\pi^+,\pi^+)$ *at* $T_\pi = 100, 134, 164, 190$ *and* 219 *MeV,* University of Karlsruhe, U. of Minn, Rutgers, LANL, and NMSU (Park); E. Boschitz and B. Brinkmöller, University of Karlsruhe, Spokesmen.

The ^{6}Li nucleus shows properties typical of heavier nuclei, but it is light enough to allow calculations of nuclear processes with realistic interaction mechanisms. To study the spin dependence of the pion interaction with ^{6}Li, polarized data at the above energies (with the exception of 190 MeV) were taken at PSI,[31] with results that gave large asymmetries. However, very good knowledge of the differential cross sections is needed to put tighter constraints on models that are used to describe π-nucleus scattering. Therefore we made precise cross section measurements over an angular range between 30° and 120° in 1° bins, which allowed us to measured the depth and shape of the first minimum. These data are currently being analyzed. They will extend the data base and allow for a more rigorous test of theoreticals models for this reaction.

LAMPF Experiment No. 823U, *The (n,p) Reaction at 800 MeV as a Probe of Spin-Flip and Non-Spin-Flip Giant Resonances and the Quasi-Free Continuum,* LANL, Ohio University, Ohio State, and NMSU (Park); J. L. Ullmann, N. S. P. King, R. C. Haight, LANL, and J. Rapaport, Ohio University, Spokesmen.

This experiment was proposed several years ago and provided part of the impetus for building the Medium Resolution Spectrometer (MRS). The original proposal suggested a wide range of physics problems to be studied. One of the most interesting questions, that of the Gamow-Teller (GT) strength in medium-mass nuclei, has been studied at TRIUMF in recent years. These and similar experiments studying questions of nuclear structure are probably the most important application of the (n,p) reaction, since they address questions that cannot be answered in other ways. This experiment concentrated on two areas, the isovector giant monopole resonance (IVM) and the quasifree continuum. The isovector giant monopole resonance remains interesting, and its properties have only been observed in the (π,π^0) reaction.[32] Excitation of the quasifree continuum has been the subject of much experimental and theoretical interest. Although the physics questions may appear disjoint, they are in fact related. The extremely wide momentum acceptance of the MRS ($\Delta p/p = \pm$ 20%) makes it possible, even obligatory, to study both regions of excitation simultaneously, and information on the continuum is important to determine the "background" of the giant resonance region. The analysis of ^{90}Zr(n,p) data measured in this experiment is in progress. We also have measured quasifree cross sections in the ^{12}C(n,p) reaction at 800 MeV. Preliminary analysis indicates that the location of the position of the peak of the quasifree reaction disagrees with that of the free N-N reaction. This feature was observed at lower incident nucleon energy of 186 MeV.[33] We are in the process of studying why this is different.

LAMPF Experiment No. 881U, *Polarization Transfer in Quasifree (p,n) Reactions at 500 and 800 MeV*, LANL, Ohio State, IUCF, Ohio University, and NMSU (Park); T. N. Taddeucci, LANL, Spokesman.

It has long been predicted that the longitudinal channel of quasielastic scattering should be shifted and enhanced with respect to the transverse channel at certain momentum transfers q. This effect is due to the q-dependence of the particle-hole interaction based on the $\pi + \rho + \mathrm{g}$ model.[34] In an earlier part of the experiment, polarization transfer measurements were made that isolated the nuclear responses in several nuclei at a q-value of about 1.8 fm^{-1}. The surprising result was that no enhancement of the longitudinal channel was seen.

It is important to examine this response at another q-value to help clarify the q-dependence of the underlying particle-hole interaction. Therefore, in this experiment we measured a complete set of polarization transfer observables at a laboratory angle of 12°, 500 MeV, corresponding to a q of 1.2 fm^{-1}. This was done on ^{2}H, ^{12}C, and ^{40}Ca. Analysis of the data is commencing at OSU, and it will be used as a part of Ph.D. requirement for B. Luther.

At 500 MeV, in addition to 12° measurements, we have taken data at 18° and 27° to study the q dependence. It is necessary to check if there is energy dependence in the results. To do this, we are taking data at 800 MeV at angles corresponding to the same q-values of the previously-published 500-MeV data. The on-line results seem to indicate that there is no energy dependence in the interpretation of the data.

LAMPF Experiment No. 1040, *Spin Transfer Measurements on Quasielastic and Quasifree Delta Production using the (p,n) Reaction at 500 and 800 MeV on Several Nuclei*, LANL, IUCF, Ohio University, Ohio State, the Niels Bohr Institute, and NMSU (Park); T. N. Taddeucci, LANL, and C. D. Goodman, IUCF, Spokesmen.

In this experiment we measured cross sections and spin depolarizations using the (p,n) reaction over the quasifree delta-production region on a number of nuclei. The data were taken on ^{2}H, ^{12}C, and ^{40}Ca at 800 MeV, 0°. Quasifree delta-production is the analogue of quasielastic scattering in which the struck nucleon is itself excited. These data compliment the existing data on the delta region using the (p,p'), $(^3He,t)$ and (e,e') reactions. In addition to this, these data should shed light on the large shift in the delta to lower excitations than was expected, which was noted in both the (e,e') data and previous (p,n) cross-section data. This effect is thought to be due to pionic correlations in the isovector channel.[35] D_{NN} measurements are predicted to be sensitive to these correlations and therefore should provide valuable information about the nuclear response in the delta excitation region. Data analysis is underway at OSU and will be used as a part of Ph.D. requirement for S. DeLucia.

LAMPF Experiment No. 1040U, *Spin Transfer Measurements on Quasielastic and Quasifree Delta Production using the (p,n) Reaction at 500 and 800 MeV on ^{208}Pb*, LANL, IUCF, Ohio University, Ohio State, the Niels Bohr Institute, and NMSU (Park); T. N. Taddeucci, LANL, and C. D. Goodman, IUCF, Spokesmen.

In this experiment, we are taking the $\hat{L}$-type data on ^{208}Pb in the delta region to complement the $\hat{N}$- and $\hat{S}$-type data taken with E1040. The $\hat{L}$-type data, along with $\hat{N}$- and $\hat{S}$-type measurements, makes it possible to fully extract the spin responses at 0°. This will give us both longitudinal and transverse spin responses on ^{208}Pb, a heavy nucleus. The motivation was to study mass dependence in the spin response. With the $\hat{N}$-type data, there was very little difference in spin responses between the ^{12}C and ^{208}Pb nuclei. We expect to complete the experiment by early October, 1993.

LAMPF Experiment No. 1294, *Spin Decomposition of the Giant Resonance Region for the Pb(p,n) Reaction at 800 MeV*, Ohio State, LANL, IUCF, Ohio University, and NMSU (Park); D. Prout and E. Sugarbaker, OSU, Spokesmen.

At the Neutron Time of Flight (NTOF) facility, we have measured cross sections and spin correlation parameters D_{NN} in the giant resonance region for the Pb(p,n) reaction at 800 MeV. At this energy a large concentration of strength above the Gamow-Teller resonance dominates the forward-angle cross section in both the (p,n) and $(^3He,t)$ reactions. This feature is absent at 200 MeV and 500 MeV, where most of the experimental and theoretical charge exchange work has been done. Measurements made in this experiment over laboratory angles of 0° to 5° in 1° steps will allow a multipole decomposition of this region to made and the spin character of this new feature to be determined.

IUCF Experiment No. 344, *The $^{10}B(p,n)^{10}C$ Reaction at 186 MeV*, Ohio University, Indiana University, University of Virginia, Ohio State, LANL, and NMSU (Park); J. Rapaport, Ohio, Spokesman.

The ^{10}B nucleus is probably the only stable one in nature for which, to a good approximation, the ground-state wave function can be described as a stretched configuration, *i.e.*, with two nucleons in the $1p_{3/2}$ subshells coupled to a total angular momentum $J^\pi = 3^+$. Thus, scattering and nuclear reactions on ^{10}B provide a unique opportunity to study transitions between an initial non-spherical target with a very well-described wave function and final states that are more spherical, such as the $J^\pi = 0^+$, $T = 1$ isobaric triplet of mass $A = 10$. For this reason, ^{10}B has been studied with many probes. In particular, the pure $M3$ electro-excitation of the $T = 0$ ground state of ^{10}B to the $T = 1$, $J^\pi = 0^+$ level at 1.74 MeV in ^{10}B has been studied by Hicks, *et al.*[36] Their results indicate excellent agreement with calculations that employ pure $1p_{3/2}$ single-particle wave functions for the $M3$ transition.

The ^{10}B(p,n)^{10}C reaction has been studied using the neutron time-of-flight facility at IUCF with an incident proton energy of 186 MeV between

$\theta_{\rm lab} = 0°$ and $50°$, in steps of $5°$. The IUCF neutron polarimeter was also used to measure polarization observables at $\theta_{\rm lab} = 0°$, $15°$, and $20°$ using an incident transverse-polarized proton beam. Measurements were made to study the $M3$ stretched ground-state transition, to study the GT and spin dipole energy distribution, and to obtain structure information to final-states in ^{10}C. Results for the $M3$ stretched ground-state transition agree well with cross-section calculations and polarization observables. The distribution of GT strength seems to be extended to a much higher energy than the predicted results of $1p$-$1h$ calculations. The same is observed for the spin dipole strength. Resonances at 16.5, 17.3 and 20.3 MeV excitation energy in ^{10}C seem to be the analog of 2^+, 2^-, and 1^- states previously observed in ^{10}B. This experiment served as a part of Ph.D. requirement of L. Wang from Ohio University, and a paper describing these results has been recently published.[37]

LAMPF-WNR Experiment No. 4N0039, *A Test of the Effective NN Isovector Tensor Interaction using the Stretched State in the $^{10}B(p,n)^{10}Be(gs)$ Reaction from Bombarding Energies of 70 to 240 MeV*, U.C. Davis, Ohio University, U. of Virginia, Loma Linda University, LANL, and NMSU (Park); D. S. Sorenson, LANL, Spokesman.

This experiment was done in part to complement the work done at IUCF mentioned above. Differential cross sections were measured for the "$0\hbar\omega$" $J^\pi = 0^+$ stretched state in the ^{10}B$(n,p)^{10}$Be(gs) reaction from 70 to 240 MeV. The uniqueness of the white neutron source at LAMPF-WNR provides neutrons with continuous energy distributions between 40 and 550 MeV. In this energy domain, LAMPF is the only facility in the world where the energy dependence of the effective nucleon-nucleon interaction can be studied simultaneously. At momentum transfers between 1 and 2 fm^{-1} the stretched states are mainly excited by the tensor interaction. Using structure information from electron scattering measurements, the Franey-Love interaction has been tested over the indicated energy range of 90 to 240 MeV and the M3Y interaction has been tested for the 70 MeV data. A paper describing the results has been recently submitted for publication.

LAMPF-WNR Experiment No. 4N0057, *The Gamow-Teller and Dipole Strength Distribution in $^{51}V(n,p)$ Reactions*, Ohio University, Ohio State, University of Minnesota, Indiana University, William and Mary, LANL, and NMSU (Park, Burleson); J. L. Ullmann, LANL, and B. K. Park, NMSU, Spokesmen.

At the Weapons Neutron Research (WNR) center, we measured angular distributions for the $^{51}V(n,p)^{51}Ti$ charge-exchange reaction for incident neutron energies between 60 and 260 MeV in the $0° \leq \theta_{lab} \leq 16°$ angular range. The ^{51}V nucleus has been studied with (e,e'), (p,p'), and (p,n) probes. No strong $M1$ strength in ^{51}V via inelastic electron scattering was observed by Bender, *et al*,[38] in contrast to a $^{51}V(p,p')^{51}V$ experiment by Djalali, *et al*,[39] in which a concentration of $M1$ strength was observed in the 10-MeV excitation energy region. The contradiction that exists in identifying Gamow-Teller and spin-dipole states in (e,e') and (p,p') data was examined with the (p,n) probe. The $^{51}V(p,n)^{51}Cr$ reaction at $E_p = 160$ MeV was studied by Rapaport, *et al*,[40] and the result agrees with that of Bender, *et al.* A quenching factor of 0.63 is reported in this work. The (n,p) reaction excites only $T_0 + 1$ final states, so the $^{51}V(n,p)^{51}Ti$ reaction will give us a better look at Gamow-Teller transitions. In addition, we will be able to test experimentally the Gamow-Teller sum rule $\sigma(GT) = \sigma(GT^-) - B(GT^+) = 3(N - Z)$. We have learned from the (p,n) experiments that a significant part of the sum-rule strength is carried by collective states formed by strong isospin-spin correlations in nuclei. In many cases, simple $1p - 1h$ models account for the energy systematics for both $L = 0$ and $L = 1$ resonances. An analysis of the total Gamow-Teller strength has shown that we consistently find less than the sum-rule strength. In addition to simple $1p - 1h$ shell model calculations using the code OXBASH, RPA calculations will be used to analyze the measured data.

PSI Experiment No. R-87-13, *Proposal to Study Multi-particle Final States in Pion-Nuclear Reactions with a Large Acceptance Detector (LADS)*, Universität Basel, Universität Karlsruhe, LANL, University of Maryland, MIT, Old Dominion University, PSI, University of Zagreb, and NMSU (Kyle, Haas, Lin, Mukhopadhyay, M. H. Wang, and M. Z. Wang); Q. Ingram, PSI, Spokesman.

The Large Acceptance Detector System (LADS) at the Paul Scherrer Insitute was built to study multiparticle final states resulting from pion interactions in nuclei. The initial experiment, a survey of pion absorption reactions in $^{3,4}He$ and heavier nuclei at several incident energies, was approved with high priority in the summer of 1987. The primary interest was to investigate the long-outstanding question of the role of multi-nucleon processes and the possibility of exotic mechanisms[41, 42] in pion absorption. The detector was also designed to be suitable for investigations of a variety of quasifree reactions, in order to obtain more detailed information about the interactions of the pion, the nucleon, and the delta in nuclei.

The primary detector design goals were a solid-angle acceptance as close to the maximum as possible and the capability to reconstruct the full kinematics of the outgoing particles. The design chosen consisted of 196 plastic scintillator counters arranged in a cylindrical array, which cover most of the solid angle, and two end-cap arrays, which close the ends. In the initial configuration, two cylindrical multi-wire chambers with helical cathode strips provided tracking information. In 1993 a third cylindrical multi-wire chamber was added to improve the tracking capability. The full system was completed within two years of the proposal at a relatively modest cost of about one million Swiss francs. The NMSU group had primary responsiblity for the design, construction, and operation of the end-cap counters. The detector in the 1991 configuration is shown in Fig. 4. It covers 98.8% of the full solid angle.

The electronics scheme used most recently was as follows. Specially designed Fast Discriminator Mean-Timer and Programmable Logic Modules, built by PSI on a Fastbus frame, processed and distributed the photomultiplier signals to the trigger, Fastbus ADC's, TDC's, and latches. The MWPC cathode ADC's were read out by Fastbus ADC's, and the MWPC anodes were read out by LeCroy PCOS-III electronics. Several different trigger types, corresponding to various charged and neutral particle multiplicities, were independently prescaled to emphasize the physics of interest. An LED system monitored phototube gain changes.

The πM1 beamline at PSI has an electrostatic separator which eliminates most proton and muon contamination. Time-of-flight and energy-loss information from counters in the beam further eliminated backgrounds. These counters also defined a pencil-beam geometry to minimize events from the target walls. The targets were in the form of pressurized gases contained in a cylindrical carbon-fiber vessel with hemispherical ends. The target cell dimensions were 25 cm length and 4 cm diameter, with 80 mg/cm^2 wall thickness. For a ^{4}He target at 100 bar, the ratio of gas-to-wall areal densities is about 2.5:1. An active lead-scintillator wall shielded the detector from particles which did not pass through the beam-defining counters. The

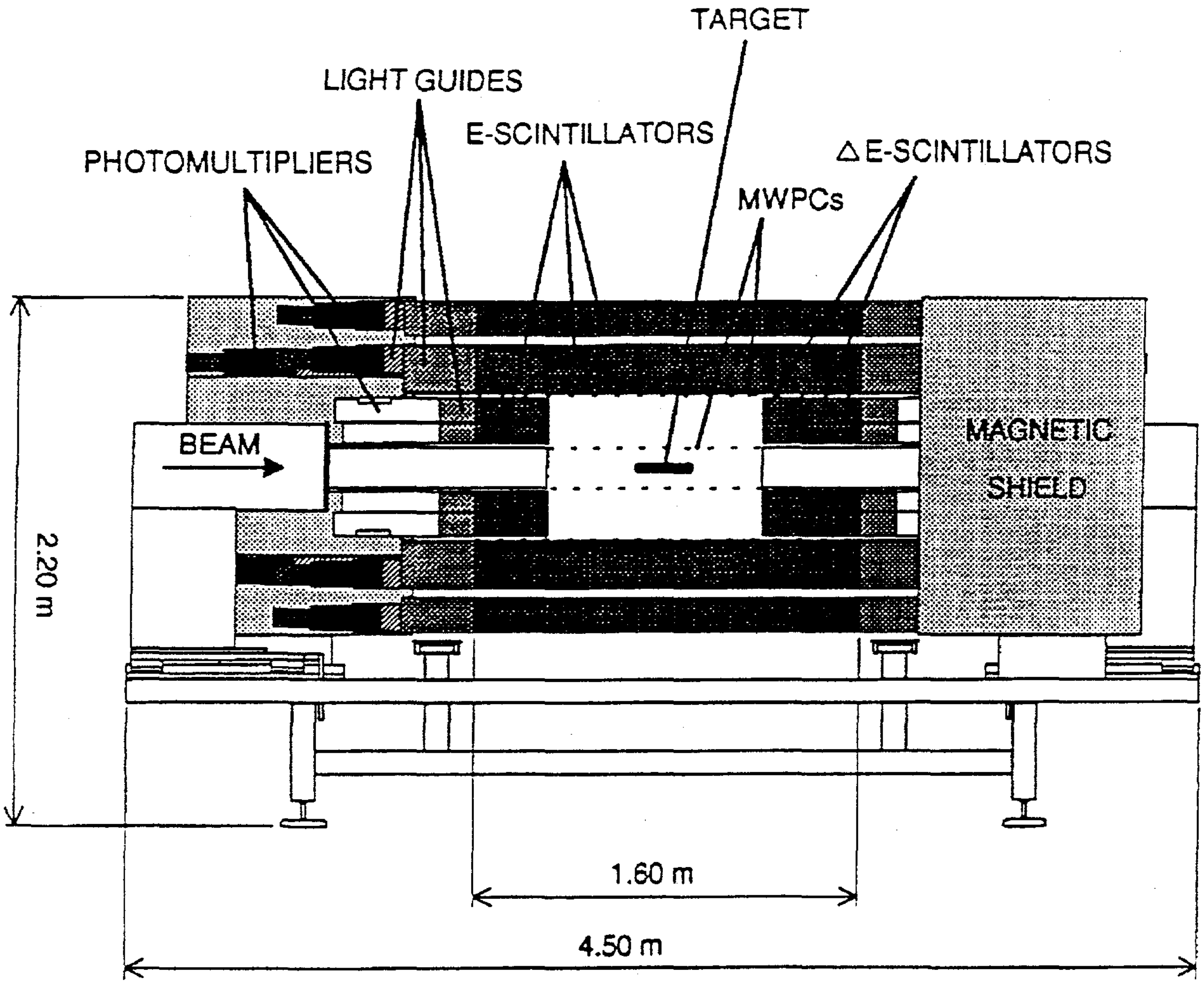

Figure 4: Diagram of the Large Acceptance Detector System (LADS) at PSI.

event trigger ensured that only one pion is present in the detector within the lifetime of an event. Fig. 5 shows that events from the target walls are easily resolved in the vertex reconstruction. The detector design is described more fully in our previous DOE progress reports and in Ref.[43].

The data acquisition system was controlled by an Aleph Event Builder (AEB), a front-end processor residing in Fastbus. The AEB read out the Fastbus and CAMAC electronics and built the event. A CERN Host Interface (CHI) buffered super-events and passed them over VME and Turbochannel buses to a Vaxstation 4000 which logged up to 800 events/second to 8-mm Exabyte tape. The events were also broadcast via Ethernet to other workstations which performed on-line monitoring and analysis tasks. One set of tasks analyzed LED events for changes in the phototube gains and monitored the photomultiplier supply voltages and the beamline magnet settings. Another task displayed ratios of event scalers in real time, to signal changes in the triggers. A dedicated VAX workstation provided by NMSU examined the raw data spectra for shape changes on a time scale of several minutes and alerted those on shift to potential problems.

LADS has had three runs. A limited amount of engineering data was obtained in the fall of 1989, after which the PSI accelerator was shut down until March, 1991. The first full run occured during March–September, 1991, when data were taken on ^{2}H, ^{3,4}He, ^{14}N, and ^{40}Ar at incident pion momenta of 220, 270, and 355 MeV/c. Typically, 20 million events were taken for each target/energy setting in about one day of running. For the ^{4}He data, 40 million events were taken per setting. About 400 gigabytes of data were taped.

The second full run was in March–June, 1993. For this run, several improvements were made in the detector, most notably the addition of a third MWPC to improve the tracking information, and changes were made in the computer front end to improve data-taking rates. Data were taken on ^{2}H, ^{3,4}He, ^{14}N, and ^{40}Ar at incident pion momenta of 170 and 450 MeV/c, and on Xe at the same five momenta as for the other targets. Typically 20–40 million events were taken for each combination of target and energy. We also made a very high statistics run on ^{4}He at 270 MeV/c with over 300 million events. In total, about 600 gigabytes of data were written to tape in 1993.

Tests were also made of a neutron time-of-flight detector wall in coincidence with LADS. Previous studies suggested that multi-nucleon absorption

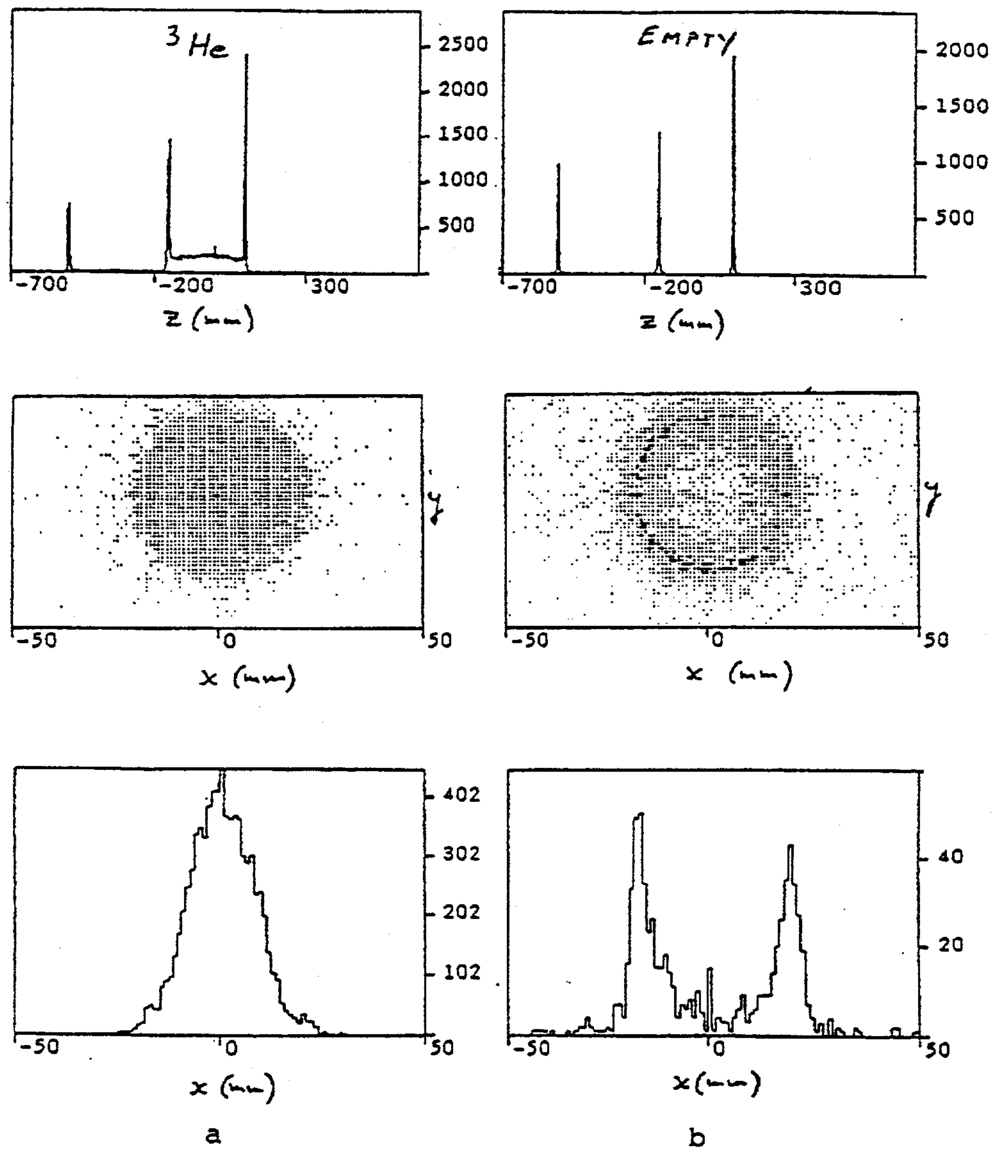

Figure 5: Vertex distribution in X-Y for a gas target in LADS. Top: full target; bottom: empty target. The relative amount of target wall events are small and can be separated by applying a circular cut.

processes often involve emission of one or more energetic neutrons.[44, 45] The LADS detector has good neutron detection efficiency but poor neutron energy resolution, and therefore it was designed to run at high beam intensities in coincidence with external detectors. The test results indicate that such running is feasable. However, the necessity for such running is not yet clear, as many channels involving neutrons can be adequately reconstructed without the n-wall.

The data-analysis software LADYBIRD has been developed by the collaboration. It performs the functions of checking the completeness of the data, calibration of the plastic and wire chamber information, track finding, clusterizing plastic hits, and particle identification. A test package and histogramming capabilities based upon the CERN HBOOK utility are included. LADYBIRD may either be used to produce the final spectra or to produce data summary files in (DSF's) of calibrated information in the form of PAW n-tuples for further analysis.

Since the detector construction was completed, our group, together with colleagues at Old Dominion University, has been involved in developing a Monte-Carlo code based upon the CERN GEANT package. We wrote most of the detector geometry modeling, event generators, and tracking subroutines. The code can make cuts on pseudo data similar to those in LADYBIRD and generate PAW n-tuple files for comparison with the data. It is an integral part of the analysis. It will be used to generate distributions for different reactions and make acceptance corrections. Fig. 6 shows a comparison of the measured and Monte-Carlo generated angular distributions for the $\pi^+ d \rightarrow pp$ reaction detected in the main cylinder counters.

Presently five persons from our group (Kyle, Chang, Haas, Lin, Wang) are spending most of their time on the analysis of LADS data. William Gibbs, a theoretician at NMSU, is providing theoretical guidance and support for this work. One goal of the analysis is to determine the energy and target mass dependencies of integrated cross sections for total absorption and for the different absorption channels as distinguished by the number of spectator particles. The separation of channels is done by reconstructing the spectator momentum distributions and comparing them with $(e, e'p)$ measurements. Another project studies kinematic distributions for the $^4\text{He}(\pi^+, 3p)$ reaction compared with simple models to search for signatures of different processes. The Intranuclear Cascade (INC) Model of Gibbs is used to generate distributions arising from on-shell processes of two-nucleon absorption with initial-

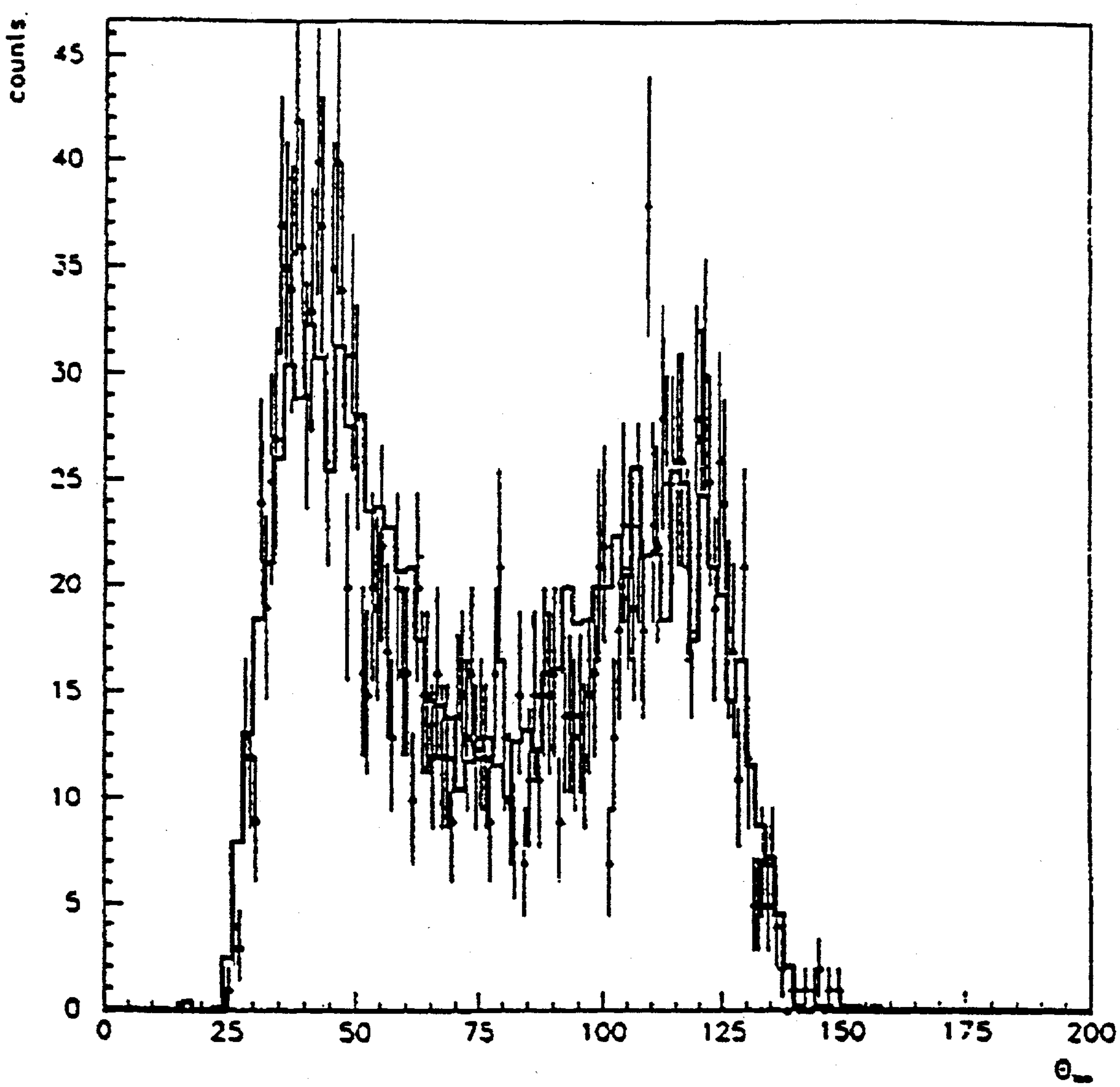

Figure 6: Laboratory-angle distribution of d(π^+,pp) events at 16.5 MeV. Both protons are detected in the cylinder detectors. The bar plot is the Monte-Carlo simulated distribution.

state or final-state interactions. Some comparisons are shown in Figs. 7 and 8. This work will be the basis of the Ph.D. thesis of an NMSU student (Lin). His work will be extended to a comparison of cross sections and kinematic distributions for the $(\pi^+, 3p)$ and $(\pi^+, 2pn)$ reactions, which are expected to have different contributions from initial-state and final-state interactions.

Another student is studying pion multiple-scattering distributions. We have data for the reactions $d(\pi^+, \pi^+ pn)$ and $d(\pi^+, \pi^0 pp)$ over the full solid angle, including previously unmeasured out-of-plane kinematics. These reactions are of considerable interest because significant deviations from Fadeeyev calculations, possibly arising from residual $\Delta - N$ interactions,[46] have been observed. We will also, for the first time, study the systematics of pion-nucleus multiple scattering for A>2, which are related to the questions of multinucleon pion absorption.

PSI Experiment No. R91-11, *The* $^7\vec{Li}(\pi^+, \pi^+ p)^6He$ *Reaction*, Old Dominion University, University of Maryland, Universität Karlsruhe, American University, PSI, and NMSU (Kyle, Wang, Lin, Chang); N. Chant, Maryland, A. Klein, ODU, and G. Kyle, Spokespersons.

This experiment was proposed in January 1992 and ran for eleven weeks starting in July, 1992. Cross sections and analyzing powers for the reaction ^{7}Li$(\pi^+, \pi^+ p)^6$He were measured. The scattered pions were analyzed with the SUSI spectrometer and the proton energies were measured with an array of plastic scintillation stopping counters which we designed and helped construct. Measurements were made at 240 MeV at pion angles of 60^0, 80^0, and 110^0, with coincident proton angles roughly centered about the free π-p kinematical region. The ^{7}Li target polarization was typically 35-45%.

The aim of this experiment was to study the two different types of asymmetries that arise from pion-proton quasielastic scattering. One of these is the intrinsic pion-nucleon asymmetry, as modified by the nuclear medium. The other arises from the relatively strong optical absorption of the incoming pion relative to the outgoing pion, which localizes the the reaction on one side of the polarized nucleus. This is known at Newn's polarization, and it has been discussed in the context of pion-nucleus scattering by Gibbs and Siegel.[47] According to calculations of Roos and Chant,[48] it should be possible to separate these effects in an experiment of this kind, because they have very different kinematic dependencies. The intrinsic π-p asymmetry is large at forward pion angles and small at backward angles, and it is little affected

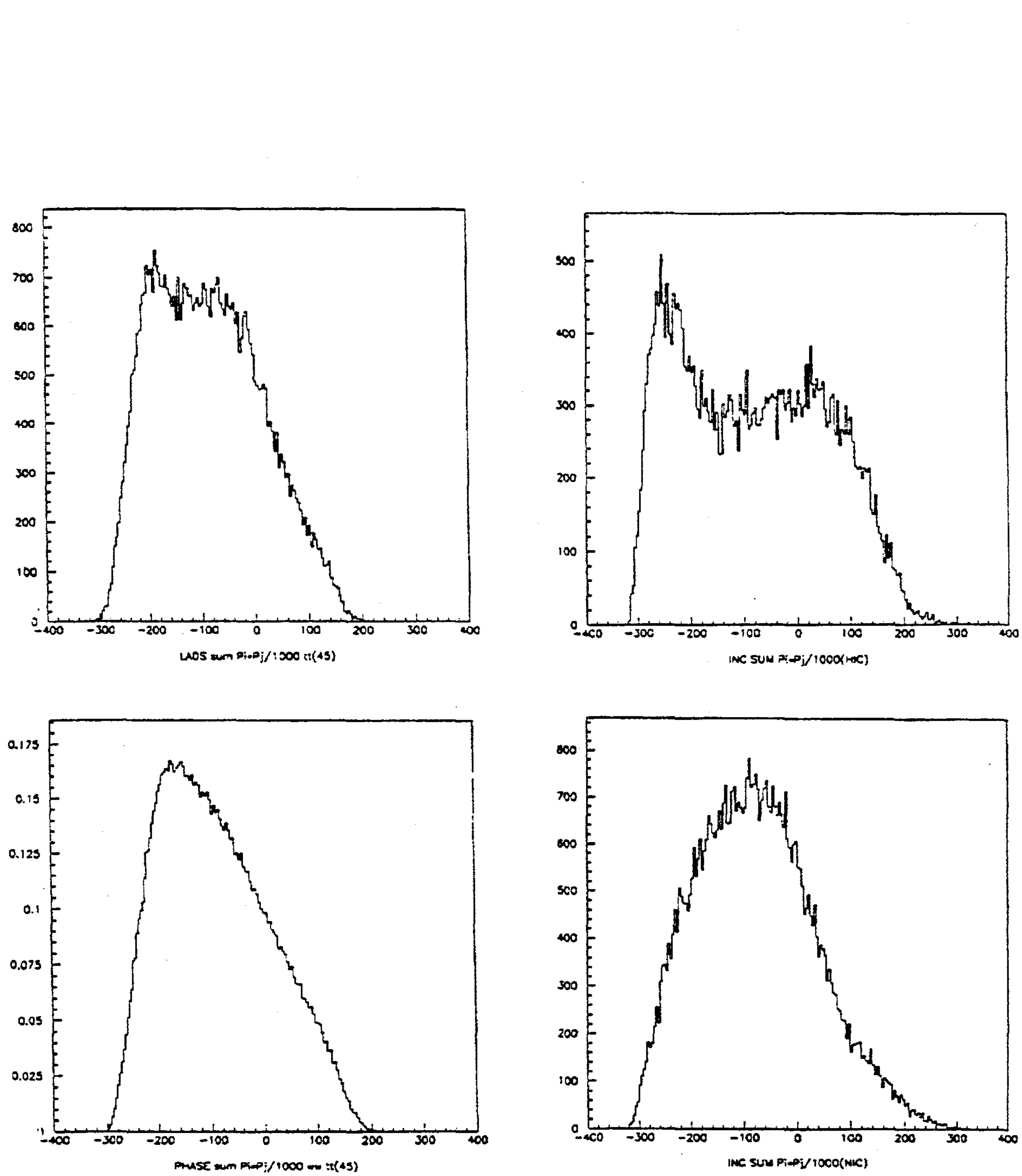

Figure 7: A comparison of distributions for ^{4}He$(\pi^+, 3p)$ at 355 MeV/c. The dot product $\vec{p_i} \cdot \vec{p_j}$ for the momenta of any two protons is shown for the data, INC models of initial- and final-state intercations, and Fermi-broadened 3-proton phase space.

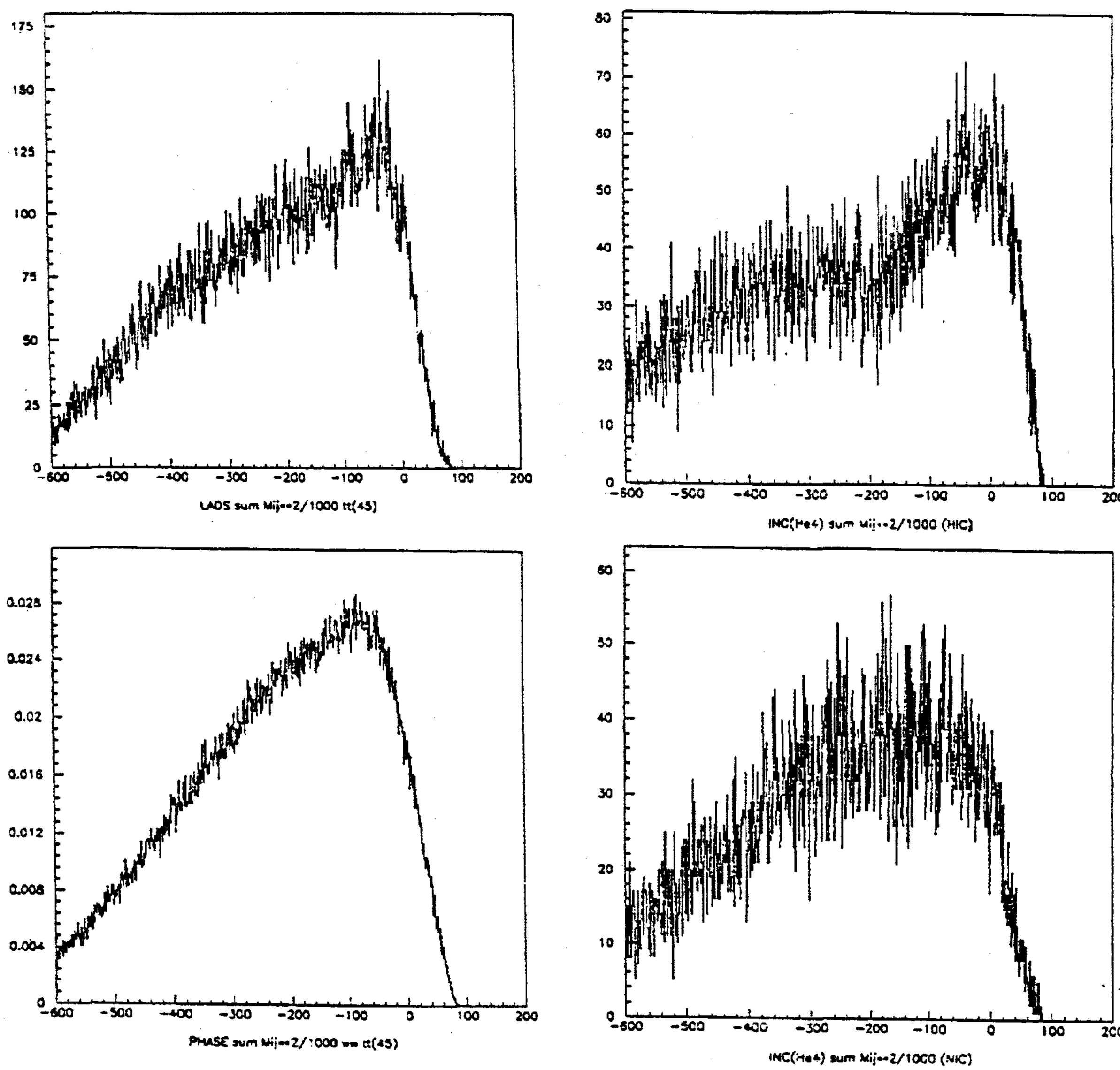

Figure 8: The pseudoinvariant mass distribution $M_{ij}^2 = (T_i + T_j)^2 - (\vec{p_i} + \vec{p_j})^2$ for the same cases as the previous figure. The peak at $M_{ij}^2 = M_\pi^2 = 20 \times 10^3$ may be a signature of on-shell pion rescattering followed by a two-nucleon absorption process.

by Fermi motion, which means that for a fixed pion angle it is essentially independent of proton angle. The Newn's polarization effect occurs for all pion angles, but for fixed pion angle it has a very characteristic sign change as the proton angle passes through the free π-p kinematical point. These results may help shed light on the unexpectedly small asymmetries observed in elastic scattering on ^{15}N[17] and ^{13}C,[18] and they may also be sensitive to the strength of the delta-nucleus spin-orbit interaction. The data analysis is underway at Maryland as part of the Ph.D. thesis of Mohammed Khayat.

PSI Experiment No. R91-11.2, *The* $^7\vec{Li}(\pi,pp)^5He$ *Reaction*, Old Dominion University, University of Maryland, Universität Karlsruhe, American University, PSI, and NMSU (Kyle, Wang, Haas); N. Chant, Maryland, and A. Klein, ODU, Spokespersons.

This experiment ran for nine weeks in summer, 1993, with the same apparatus as R-91-11. Asymmetries were measured for the ^{7}Li$(\pi,pp)^5$He reaction at 165 MeV. One proton was detected by SUSI at 50^0, and the second proton was detected with stopping counters placed at several angles near that corresponding to free πd absorption. Cross-section data were also obtained at several angles.

The motivation is to study medium modifications of the quasideuteron absorption process and the effects of distortions. Of particular interest are calculations of analyzing powers for the $^3\vec{H}e(\pi^+,pp)$ reaction[49] which predict considerable sensitivity to the short-range part of the wavefunction. These effects may be enhanced by the higher nuclear density of lithium. DWIA calculations[50] show that for non-zero angular momentum transfers, distortion effects are also very important and lead to large analyzing powers. However, tensor analyzing powers are found to be relatively insensitive to distortion effects.

Analysis of these data will be the basis for the Ph.D. theses of T. Greco at ODU and T. Payerle at Maryland.

2.2 Analysis of Past Experiments

We have also worked on the analysis of data and the interpretation of the results of past experiments at LAMPF and PSI, in preparation for publication. Summaries of this are given here.

LAMPF Experiment No. 316, *Measurements of Low-Energy π^--Nucleus Elastic Scattering*, Northwestern University, MIT, Saclay, LANL, and NMSU; K. K. Seth, Northwestern, and G. Burleson, Spokesmen.

In this experiment we measured cross sections for π^- scattering on a number of nuclei, from ^{12}C to ^{208}Pb, at 20, 30, 40, and 50 MeV, as well as some π^+ scattering at 50 MeV, using a range telescope of scintillation counters. The 30- and 50-MeV results were published,[51] but the remainder of the data were not, partly beacuse they lacked reliable normalizations. During summer, 1992, measurements were carried out on the Clamshell spectrometer in the LEP channel at LAMPF where we obtained data to give a normalization at 40 MeV. With that, together with normalizations to data similar to ours at 20 MeV which also came from Clamshell measurements, we submitted a final paper on these results. The 20-MeV data are shown in Fig. 9, together with predictions of the MSU optical model.[52] As was found previously with a similar model,[51] the agreement is good for the smaller nuclei but poor for the heavier nuclei.

LAMPF Experiment No. 1106, *Studies of Pion-Nucleus Elastic Scattering at Energies above the Δ Resonance*, University of Texas, University of Pennsylvania, George Washington University, LANL and NMSU (Faucett, Rawool-Sullivan, and Burleson); K. S. Dhuga, GWU, Spokesman.

This experiment is a companion to Exp. 1107 above. As discussed there, the purpose of this work is to produce elastic pion-nucleus data at energies between 300 and 500 MeV, in order to determine how well it can be described by simple theories based on multiple scattering. Before the high-energy DCX data can be reliably understood, it is necessary to be able to explain the simpler elastic-scattering data. Several theoretical papers have been written describing calculations of pion-nucleus elastic scattering at energies above the Δ resonance.[54, 55, 56, 57]

In this work, differential elastic cross sections were measured at 400 and 500 MeV for $\pi^{\pm}$ scattering on ^{12}C, ^{40}Ca, ^{90}Zr, and ^{208}Pb. In the initial analysis of the data, questions arose concerning its absolute normalization and

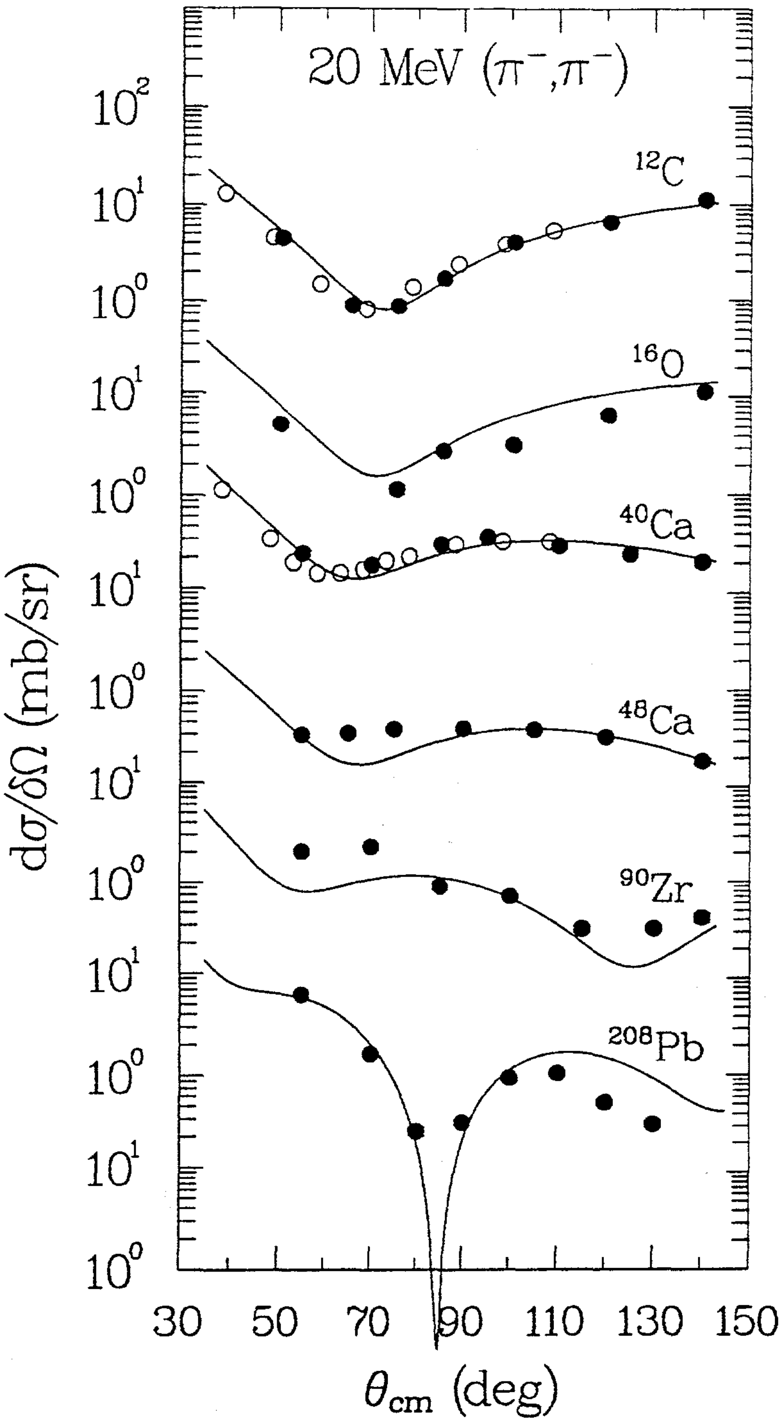

Figure 9: Differential cross section for π^- elastic scattering from the nuclei indicated, from Exp. 316, compared with previous measurements.[53] The curves are predictions of the MSU model.[52]

the absolute values of the scattering angles. To answer these, additional data were taken both in 1990 and 1991, and measurements of elastic scattering from ^{28}Si were made in 1992. Analysis of the data is now complete; the ^{28}Si results have been submitted for publication and the rest of the data is being prepared for publication. Part of this work will form the basis of a Ph.D. thesis of George Kharimanis of the University of Texas.

The ^{28}Si results at 400 MeV are shown in Fig. 10, compared with predictions of the ROMPIN code.[58] This code has fully-covariant kinematics, exact Fermi-averaging integration, covariant normalizations and phase-space factors, invariant amplitudes, and finite-range and physically-motivated two-body off-shell amplitudes. In the resonance region, predictions of this code are in quantitative agreement with elastic-scattering data. Here, however, the predictions fall below the data, as do those of all other calculations. This same behavior has been seen in studies of K^+-nucleus scattering,[59, 60, 61] as well as with pion-nucleus data at higher energies. The suggestion is that there may be a common origin for these observed discrepancies that is not yet understood. Possibilities include an increased in-medium kaon-nucleon interaction,[61] scattering from an enhanced heavy-meson cloud,[62] or a large effective shift in the mass of N^* resonances in the nuclear medium.[63]

LAMPF Experiment No. 1025, *Pion Elastic and Inelastic Scattering from Polarized ^{13}C*, University of Minnesota, Arizona State University, University of Texas, University of Pennsylvania, and NMSU (Burleson, Klein, Cranston, Burman, and Kyle); D. Dehnhard, Minnesota and G. Burleson, Spokesmen.

These data, involving the use of a polarized ^{13}C target, were taken with the EPICS system. The target material was ^{13}C-enriched toluene, and it was used with a standard LAMPF polarized nuclear target setup, which involved a 2.5-T magnet, a ^{3}He refrigerator system, a system for delivering microwaves, and an NMR device for measuring the polarization. Measurements were made of $\pi^\pm$ elastic and inelastic scattering at 162 MeV over an angular range from 30° to 90°. The elastic data will supplement data taken previously at higher and lower energies, where a surprisingly small asymmetry was found.[18] This energy was chosen principally because differential cross sections for $\pi^\pm$ elastic and inelastic scattering have been measured there.[64] Since the inelastic peaks in the data overlap each other, the cross-section data will be used as constraints in extracting the asymmetries. They will also be

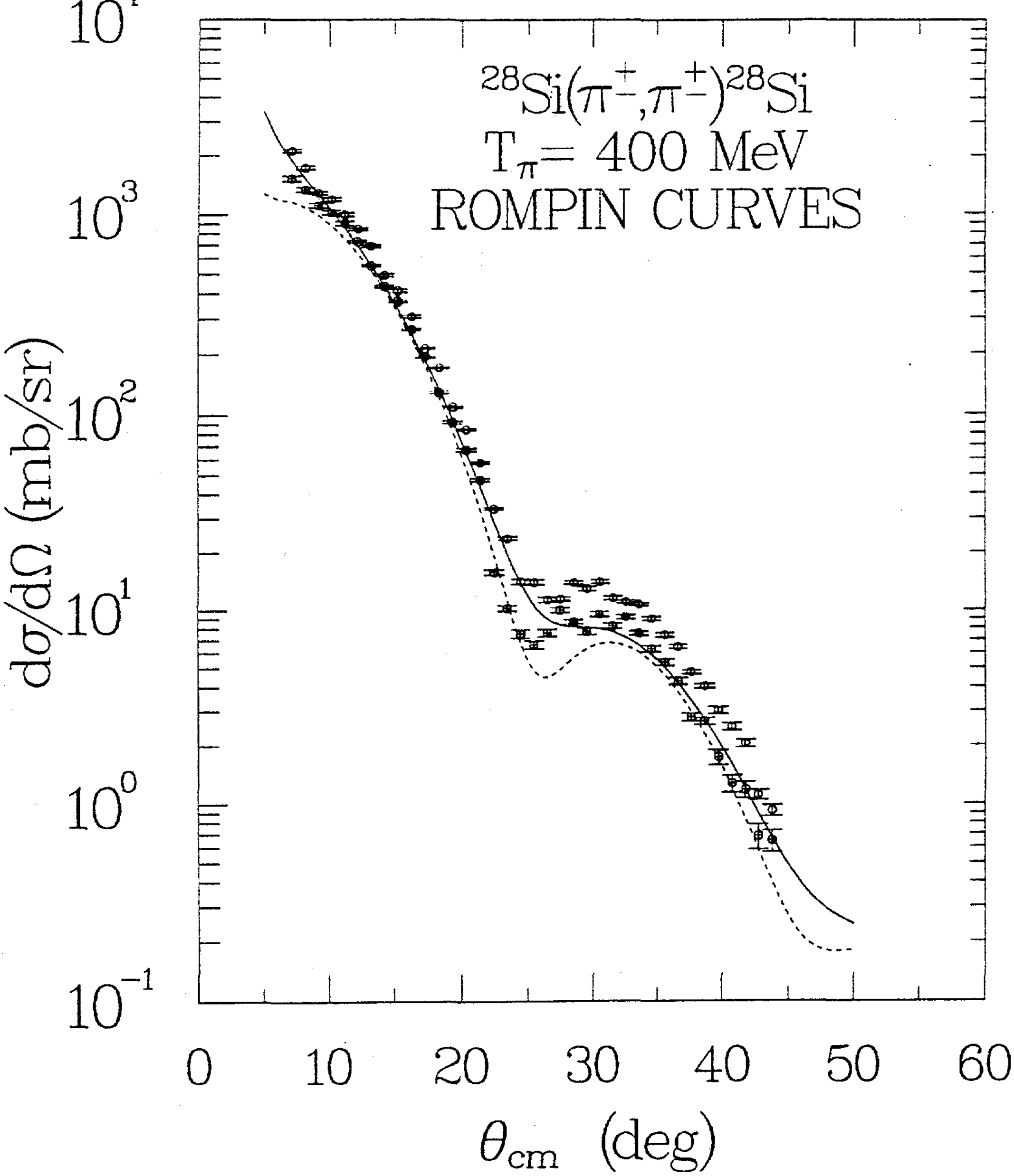

Figure 10: Differential cross sections for the elastic scattering of $\pi^{\pm}$ from ^{28}Si at 400 MeV. The curves are predictions of the ROMPIN code.[58]

needed for comparison with theoretical predictions, some of which indicate that the asymmetry should be large.[65] The resolution achieved was about 1 MeV, which is adequate to allow the extraction of data for several excited states.

The analysis of these data is being carried out by Kevin Johnson of the University of Texas, to be used for a Ph.D. thesis.

PSI Experiment No. R-83-28, *A Measurement of the Reaction $^{16}O(\pi^+,pp)^{14}N$ over a Broad Kinematic Range for Pion Energies of 115 and 163 MeV,* University of Maryland, MIT, PSI, and NMSU (Kyle); G. Kyle, Spokesman.

This experiment, which was run in 1986-87, studied the role of the simplest quasifree absorption process in which a pion is absorbed on a nucleon pair in ^{16}O. Previous inclusive measurements of $^{12}C(\pi^+,pp)$ by Altmann suggested that the unperturbed two-nucleon process constituted only about 10% of the total absorption at $\Delta(1232)$ resonance energies.[66] Such a small contribution is difficult to reconcile with DWIA models, which successfully explain inclusive (π^+,p) data, and with more recent exclusive measurements of $^{58}Ni(\pi^+,pp)$.[67, 68, 69] In order to resolve these discrepancies, we measured the exclusive (π^+,pp) reaction which made possible a better separation of the two-nucleon absorption from the multinucleon "background" and also gave information about the contributions from nucleons in different shells. The data were analyzed by two Ph.D. students at Maryland.[70, 71]

After correction for final state interactions, the data show that a two-nucleon process can explain about 75% of the total absorption cross section at 115 MeV, as seen in Fig. 11. A substantial contribution from cross-shell absorption on s- and p-shell nucleon pairs was seen. At 165 MeV, the fraction dropped to about 40%. The uncorrected two-nucleon cross section was about twice that reported by Altmann. A similar discrepancy was seen by Burger in the case of ^{58}Ni.[69] The disagreement apparently arises from their cross section normalization rather than from energy thresholds. If we apply similar acceptance cuts to our data the angular correlations have similar shape but about twice the magnitude of Altmann's. Therefore it appears that the Altmann experiment seriously underestimated the strength of two-nucleon absorption.

Analysis of these data is now complete and the results have been published.[72, 73, 74]

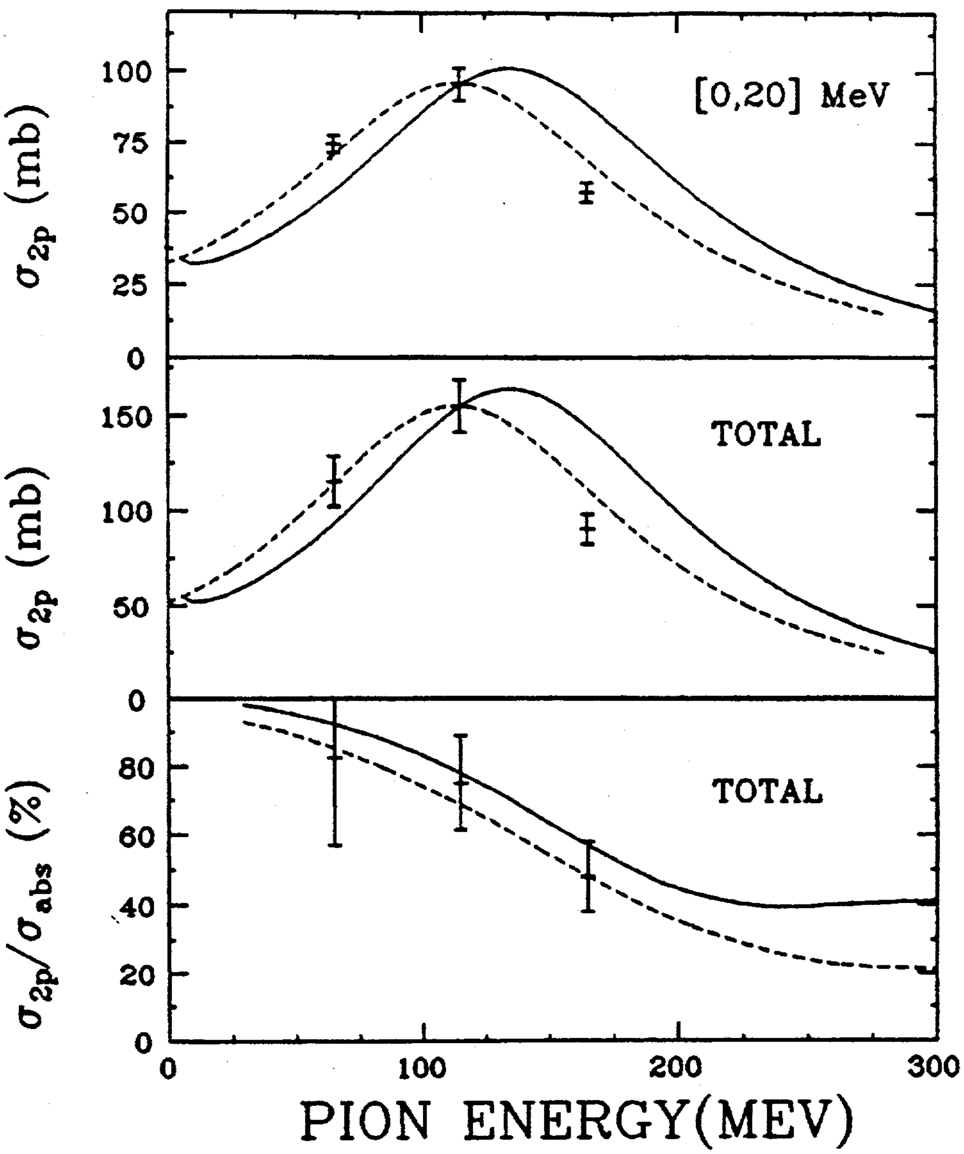

Figure 11: Cross section for $^{16}O(\pi^+,pp)^{14}N$ after correction for final state attenuation. Top: for excitation energy less than 20 MeV. Middle: for full excitation energy range. Bottom: fraction of 2p cross section to the total absorption cross section.

PSI Experiment No. R-87-05.1, *A Study of the Reaction $^6Li(\pi^+,pp)$ over the Δ(1232) Resonance Region,* Arizona State University, University of Maryland, PSI, and NMSU (Kyle, Dhuga, and Wang); P. G. Roos, Maryland, and G. Kyle, Spokesmen; and **LAMPF Experiment No. 948**, *Quasideuteron Absorption on ^6Li and ^{10}B*, Arizona State University, University of Maryland, University of South Carolina, and NMSU (Kyle and Rawool-Sullivan); B. G. Ritchie, ASU, Spokesman.

These experiments studied the two-nucleon absorption process in ^{6}Li for eight energies between 30 and 220 MeV. The purposes were to measure the A-dependence of the two-nucleon process and compare the absorption on the loosely-bound valence nucleons with that on the tightly-bound core nucleons. The LAMPF experiment was run in December, 1986, and the PSI experiment followed in summer, 1987. Details are described in our previous progress reports. Students at Maryland (PSI) and Arizona State (LAMPF) analyzed these data as a part of their Ph.D. dissertations and have reported preliminary results.[75, 76, 77]

PSI Experiment No. R-87-09, *Pion Absorption in Flight and Nucleon Multiplicities,* NIKHEF, University of Maryland, NIKHEF-K (Amsterdam), KFK Karlsruhe, PSI, and NMSU (Kyle, Mukhopadhyay, and Wang); H. Breuer, Maryland, and Th. S. Bauer, NIKHEF, Spokesmen.

This experiment, which was run at PSI in 1988, studied the absorption of pions in ^{4}He and ^{16}O at energies around the $\Delta(1232)$ resonance, using a detector array which covered about 55% of the full solid angle. It was motivated by the interesting behavior seen in existing ^{3,4}He data, where the total absorption cross section increased strongly from ^{3}He to ^{4}He, out of proportion to the increase in nucleon pairs, while the inelastic cross section showed a corresponding drop.[78, 79] This behavior might indicate the onset of a strong four-nucleon absorption mode, which could possibly arise from the very interesting $\Delta N \rightarrow \Delta\Delta$ process.[41, 42]

The reactions ^{4}He$(\pi^+, 2p)$pn and ^{4}He$(\pi^+, 3p)$n were measured at several energies from 65 to 330 MeV, and the previous NIKHEF measurements on ^{16}O were extended to 115 and 165 MeV.[80] The data analysis was based upon a Monte-Carlo simulation of the experiment using quasi-free phase space events generators. Our first published results show that, after correction by a factor of 1.4 for effects of final state interactions, the cross section ^{4}He$(\pi^+, 2p)$pn reaction can explain only about 50% of the total absorption cross section.[81] Analysis of the $3p$ channel is nearly complete and a paper should be submitted later this year.

2.3 Preparation for Future Experiments

We have also worked on plans and preparations for future experiments at various laboratories. This has been unusually difficult during this period, due to the uncertainty of the continuation of operation of laboratories such as LAMPF and of the funding of a proposed experiment such as Hermes. We continue to explore the range of possibilities of carrying out what we feel are quality experiments in nuclear physics, however, recognizing that some experiments we would like to carry out are not limited to a particular laboratory. Some of those proposed at LAMPF, for example, are possible at PSI as well. We have also worked on plans for experiments at PSI, IUCF, and TRIUMF. The work we have done in this is summarized here.

LAMPF Proposal No. 1178, *Analyzing Powers for the* $\pi^- p \to \pi^0 n$ *Reaction*, and **LAMPF Proposal No. 1256,** $\pi^\pm \vec{p}$ *Analyzing Powers at 45 and 67 MeV*, Arizona State University, University of Minnesota, Abilene Christian University, Rudjer Boskvic Instutite, Old Dominion University, University of Texas, University of Wyoming, LAMPF, and NMSU; J. R. Comfort, Arizona, and G. Burleson, Spokesmen.

The principal motivation of these proposed measurements involves studies of the mechanism of the breaking of chiral symmetry, which is generally believed to be related to the interaction responsible for producing non-zero quark masses. A test of this is the evaluation of the so-called 'sigma' term.[82] Values for this quantity can be found both from the formalism related to the model of hadron mass splitting and from analysis of low-energy pion-nucleon scattering data. The current estimate of the former is 35 ± 5 MeV, while analyses of pion-nucleon data have given a value of 64 ± 8 MeV. Part of the discrepancy is believed to stem from the strange-quark content of the nucleon, to which the sigma term is related. A precise evaluation of this quantity would give information on the strange quarks in the nucleon, a subject of much interest.

The problem in evaluating the sigma term from experimental pion-nucleon data is that there are major unresolved discrepancies among the various existing low-energy data sets, all of which consist of differential cross-section measurements. It is the purpose of these experiments to try to resolve some of these discrepancies by making measurements of new quantities, the asymmetries of pions scattered from a polarized proton target, in both the $\pi^\pm$

elastic and the π^- charge-exchange channels. We propose to take data at 45 and 67 MeV, where differential cross-section measurements exist. We note that experiments similar to E1256 are planned or are in progress at PSI and TRIUMF.

For the charge-exchange experiment, we have proposed to use the new Neutral Meson Spectrometer (NMS) system, and for the elastic scattering experiment we have proposed to use the Large Aperture Spectrometer (LAS) system. Both of these would run in the Low Energy Pion (LEP) Channel. The polarized target setup would be essentially the same as we used previously at pion energies above 100 MeV.[18, 83, 84] Some modifications would be necessary, however, which result from the lower energy of the pions. These include the use of a dilution refrigerator with a thin window rather than a ^{3}He cryostat, to allow running in frozen-spin mode with a low magnetic field around the polarized target, and providing for the rotation of the refrigerator so as to minimize the contribution of the target thickness to the experimental resolution. For the charge-exchange experiment, the NMS would have to be used without its mounting stand, because of interference between it and the polarized target magnet.

Both of these experiments were given the highest rating of A by the LAMPF Program Advisory Committee (PAC), and in its July, 1993, meeting, the Pion Subcommittee of the PAC recommeded that Exp. 1178 receive the top priority among all approved LEP experiments. We note that Exp. 1178 can be carried out at PSI if the NMS were taken there. Further discussion of this possibility is given below.

LAMPF Proposal No. 1300, *Measurement of Asymmetries A_y and Differential Cross Sections of Pion-Induced Single Charge Exchange on Polarized ^{3}He*, University of Minnesota, Simon Fraser University, TRIUMF, Ohio University, William and Mary, LANL, and NMSU; D. Dehnhard, Minnesota, O. Häusser, Simon Fraser, and B. K. Park, Spokesmen.

In this exeriment, we propose to measure the analyzing powers A_y and differential cross sections for the $^3\vec{\mathrm{He}}(\pi^-,\pi^0)^3\mathrm{H}$ reaction at T_π = 200, 285, and 360 MeV between 40° and 120°, an energy region where the π-nucleus force is strongly energy- and isospin-dependent. The pion-induced single-charge-exchange (SCX) reaction on ^{3}He principally involves only one proton in the nucleus, namely the one with its spin direction opposed to that of the neutron, which carries most of the nuclear spin. There are two particular aspects of the tri-nucleon system that would be addressed with this experiment, the spin structure of these nuclei and a quantity that is related to the nucleon positions, which should allow separation of the nucleonic and non-nucleonic degrees of freedom. The measurements would be carried out with the NMS and the TRIUMF polarized ^{3}He target system described above. Interactions in the ^{3}He gas will be distinguished from those in the glass walls of the target by detecting the recoil triton in coincidence with the π^0. At the July, 1993, PAC meeting, this experiment was approved for 450 hours of beam and given an A$^-$ rating. We note that it can also be carried out with the NMS at PSI.

LAMPF Letter of Intent, *A Program of Pion Physics with the NMS at PSI*, submitted by G. Burleson, for members of the NMS Collaboration and others (Abilene Christian University, Arizona State, Ben-Gurion University, University of Colorado, INS (Moscow), University of Minnesota, University of Pennsylvania, Rudjer Boskovic Institute, University of Texas, University of Tübingen, LANL, and NMSU).

We note that a major program of research in pion physics at LAMPF with the NMS has been proposed, but it appears possible that it may be terminated just as it is beginning. If this occurs, we have proposed in this Letter of Intent, which was submitted to the LAMPF PAC and the LAMPF management, that the system be taken to PSI to continue this work.

This appears to be very feasible, both from a technical and a practical point of view. At PSI there are pion beams with intensities and resolutions comparable to those at LAMPF, and there appears to be adequate running time available. This group has both the strength and the experience necessary for such an effort, and the costs needed appear to be manageable. Consideration of the details involved for such a program have identified no major obstacle so far. Both the LAMPF and PSI managements seem receptive to the idea. If the appropriate circumstances arise which make it appropriate to pursue this further, we plan to do so.

IUCF Proposal No. 92-105/Experiment No. E371,*Cross Section and $D_{NN}(\theta)$ Measurements in $^{16,17,18}O(p,n)$ Reactions at 100 and 186 MeV*, University of Minnesota, IUCF, Ohio University, Ohio State LANL, and NMSU; M. Palarczyk, Minnesota, C. D. Goodman IUCF, and B. K. Park, Spokesmen.

In this work we will measure differential cross sections for the $^{16,17,18}O(p,n)$ reactions at 100 and 186 MeV incident proton energies in order to decompose the L = 1 resonances observed in this process into non-spin transfer (GDR) and spin transfer (GSDR) transitions. The Gamow-Teller (GT) strength and L = 1 resonances in $^{16,17,18}F$ will be determined up to about 30 MeV excitation energy, using a multipole decomposition analysis. It is essential to understand the behavior of the L = 1 resonances to correctly identify the GT strength at higher excitation energies and to have a good model for the continuum background. We will also measure the spin-transfer coefficient $D_{NN}(0°)$ for the $^{17}O(\vec{p},\vec{n})^{17}F$(g.s.) and $^{18}O(\vec{p},\vec{n})^{18}F$(1.04 MeV) reactions. This experiment will study anomalies in the behavior of spin transfer and cross sections for mirror target transitions, *i.e.*, mixed GT and F transitions, for targets with J>0. The proposal was approved by the IUCF PAC in December, 1992. The experiment is expected to be carried out in two stages: 1) two days of beam time in October, 1993, for testing the gas-cell system, and 2) completion in spring, 1994.

TRIUMF Proposal No. 623, *Kinematically Complete Meaurements of Quasifree Pion-Nucleus Single and Double Scattering Reactions,* University of Maryland, Old Dominion University, TRIUMF, University of British Colombia, and NMSU(Kyle and Chang); G. Smith, TRIUMF, and G. Kyle, Spokesmen.

This proposal was approved by the TRIUMF EEC in December, 1990, to use the CHAOS detector, a magnetic spectrometer with 360° angular coverage which is under development at TRIUMF. We will initially measure the exclusive $(\pi^{\pm},\pi^{\pm}p)$, $(\pi^{\pm},\pi^{\pm}2p)$, and $(\pi^{+},\pi^{-}2p)$ reactions in ^{4}He and ^{16}O at 165 and 240 MeV. Later, measurements may be extended to other targets and energies.

One goal is to study the competition of different reaction mechanisms in these processes and ultimately gain new information about the delta-nucleon interaction. In the delta-hole model two types of amplitudes are expected to contribute to nucleon removal: the direct (sequential) removal involving formation and decay of the $\Delta(1232)$ resonance, and nucleon removal involving hard ΔN scattering.[85] Previous experiments have observed large variations in the cross section ratios for $(\pi^{+},\pi^{+}p)/(\pi^{-},\pi^{-}p)$, which cannot be explained with the direct amplitude alone but were explained by the delta-hole predictions.[27, 86, 87] From these models the strength of the

$\Delta - N$ interaction in isospin channels I = 1 and 2 was obtained.[28, 88] A similar interaction was required to explain measurements of the polarization asymmetry, iT_{11}, for π^+d elastic scattering.[46]

Measurement of the double-scattering and double-charge-exchange reactions will further test this model. The double-scattering reaction $(\pi^+, \pi^+ 2p)$ should be dominated by the sequential formation and decay of the delta, whereas the $(\pi^+, \pi^- 2p)$ and $(\pi^-, \pi^- 2p)$ reactions should be strongly modified by $\Delta - N$ scattering amplitude, which gives rise to the DINT diagram mentioned above for coherent DCX.

This experiment will also measure the multiplicities of emitted nucleons, which are related to the mean-free paths for pion and nucleon propagation in nuclei. These measurements would test theoretical models of the reactive content of the pion-nucleus optical potential.[89]

The CHAOS detector was commisioned in 1992-93. A student from NMSU (Chang) participated in the commisioning runs and first data measurements of $(\pi, 2\pi)$ reactions with it. This experiment may run in the latter part of 1994.

HERMES: *A Proposal to Measure the Deep Inelastic Spin-Dependent Structure Functions of the Nucleon at HERA,* University of Alberta, Argonne National Laboratory, California Institute of Technology, University of Colorado, DESY/Zuethen, University of Erlangen-Nürnberg, LNF Frascatti, MPI Heidelberg, University of Illinois–Urbana, University of Liverpool, University of Wisconsin–Madison, Universität Marburg, Massachusetts Institute of Technology, Universität München, NIKHEF, INFN Sezione Sanita (Rome), St. Peterburg Nuclear Physics Institute, Simon Fraser University/TRIUMF, Yerevan Physics Institute, and NMSU; R. Milner, MIT, and K. Rith, Erlangen, Spokesmen.

Deep inelastic electron scattering has played a crucial role in the development of quantum chromodynaics (QCD). Within the parton picture, the deep inelastic structure functions provide information about the momentum distributions of quarks and gluons in the nucleons. The spin-dependent structure functions, measured using polarized beam and target, provide information on the spin distribution of partons in the nucleon.[90] Perturbative QCD makes definite predictions about the evolution of the structure functions with momentum transfer and their shape at large x (the parton momentum fraction).[91, 92, 93] The dependence of the structure functions on x provides a constraint on hadron models, which contain ideas about the nonperturbative aspects of QCD and yield vastly different predictions for the spin-dependent structure functions of the nucleons. Of particular interest are the Bjorken[94] and Ellis-Jaffe[95] sum rules involving integrals of the spin structure functions. The Bjorken sum rule depends upon only very general ideas such as current algebra. The Ellis-Jaffe sum rule, which seems to be violated by the experimental results, requires additional assumptions such as the absence of sea quark polarization.

Only two measurements, with rather large uncertainties, have been made of the spin-dependent structure function $g_1^p(\mathrm{x})$ for the proton,[96, 97] which indicate the surprising result that the spin of the proton is not related very strongly to the spin of its quarks. More recently, experiments by the Spin Muon Collaboration (SMC) at CERN and E142 at SLAC have presented first results for $g_1^n(x)$ for the neutron, extracted from measurements on deuterium.[98, 99] SMC concludes that the first moment of $g_1^d(x)$ is smaller than the prediction of the Ellis-Jaffe sum rule and indicates that the contribution of quark spins to the nucleon spin is compatible with zero. The E142 data, on the other hand, are consistent with the Ellis-Jaffe sum rule, but if taken with the EMC results for the proton they lead to a violation of the fundamental Bjorken sum rule. Clearly this situation should be investigated further.

The HERMES collaboration has proposed to measure the spin-dependent structure functions of the proton and neutron with a precision unmatched by other techniques, using the 30-GeV electron beam of the HERA accelerator at the DESY laboratory in Hamburg, Germany. The experiment involves scattering polarized electrons from polarized gas targets of hydrogen, deuterium and ^{3}He. The scattering asymmetries can be measured with much higher precision than previously because of the high current (60 mA) and polarization (60%) expected for the beam and the high polarization ($\geq$60%) and low dilution of polarized nucleons in the gas targets.

The unique capabilities of the HERMES detector system will make possible many other measurements, including

- Determining the structure function g_2, associated with transverse target polarization, for both the neutron and proton. This very interesting structure function allows the first direct study of quark-gluon correlation functions without contamination by leading twist-2 structure functions.[100]

- Studying, for the first time, the structure functions $B_1(x)$ and $\Delta(x)$, associated with rank-2 (tensor) spin variables. These are necessarily associated with *nuclear effects*.[101, 102]

- Making the first definitive measurements of coincident hadrons produced in spin-dependent deep inelastic scattering. These measurements will provide information on the flavor dependence of the polarized structure functions as well as the contributions of orbital angular momentum.[103, 104]

- Exploring the failure of the Gottfried sum rule through measurements of unpolarized production of π^+ and π^- on both the proton and neutron in deep inelastic scattering.[105, 106]

The detector system would consist of a magnetic volume with tracking multi-wire proportional chambers for primary energy measurement, a Cerenkov detector for tagging coincidence pions, a transition-radiation detector for hadron rejection as part of the second-level trigger, a hodoscope, and a calorimeter with preshower hodoscope for hadron rejection and first-level trigger. We have proposed to work together with Caltech, Illinois, NIKHEF and Frascatti on the calorimeter. We have worked on specification of the phototubes and bases for the lead-glass calorimeter, and we will provide the readout electronics. We have also taken primary responsibility for the first-level trigger electronics and overall responsibility for the first- and second-level trigger systems. One of our students would also analyze a portion of the data.

The proposal for this experiment was presented to the Physics Research Committee (PRC) at DESY in March, 1990, and the experiment received full approval after demonstrating full technical feasibility in June, 1993. Preparations are presently underway for a test run with a dummy target cell in early 1994. It is planned that the full detector be mounted in the west Hall of HERA in early 1995.

A proposal was submitted to the DOE and NSF in January, 1993, for funding of the US participation. This proposal is currently under review. In it NMSU requested additional funds for equipment, travel and operating expenses.

Fermilab Experiment No. E866: *Measurement of $\overline{d}(x)/\overline{u}(x)$ in the Proton,* Abilene Christian University, Academia Sinica (Taiwan), California Institute of Technology, Fermi National Accelerator Laboratory, Los Alamos National Laboratory, Northern Illinois University, Texas A&M University, and NMSU; G. Garvey, LANL, Spokesman.

This experiment proposes to study the question of isospin breaking in the sea-quark distributions of the nucleon. While it is usually assumed that the light quark (u, d) sea of the nucleon is flavor symmetric, this symmetry is not intrinsic to QCD. There is circumstantial evidence that $\overline{d}(x) \neq \overline{u}(x)$ in the proton. The evidence is the recently-observed violation of the so-called Gottfried sum rule (GSR),[105] which states that with the assumption of flavor symmetry,

$$\int_0^1 \frac{F_2^p(x) - F_2^n(x)}{x} dx = \frac{1}{3},$$

where F_2^p and F_2^n are spin-independent structure functions of the proton and neutron. Recently the New Muon Collaboration (NMC)[106] found that

$$\int_{0.004}^{0.8} \frac{F_2^p(x) - F_2^n(x)}{x} dx = 0.227 \pm 0.007 \pm 0.014,$$

and after extrapolation they find that

$$\int_0^1 \frac{F_2^p(x) - F_2^n(x)}{x} dx = 0.240 \pm 0.016,$$

which is 5.56 standard deviations away from the GSR value.

The large violation of the GSR has attracted a great deal of attention on the nucleon sea. The Drell-Yan process with incident nucleons is very sensitive to the antiquark distribution of the target. A previous Fermilab experiment, E772, measured ratios of Drell-Yan yield from nuclear targets ranging from deuterium to tungsten,[107] with results that are inconsistent with most attempts to reconcile the GSR violation as due to $\overline{d}(x) \neq \overline{u}(x)$, but the sensitivity of this experiment is low.

This experiment has proposed to compare Drell-Yan yields from hydrogen and deuterium targets with systematic errors of $\leq \pm 1.5\%$ over the range $0.04 \leq x \leq 0.3$. This ratio is related to the sea quarks by

$$\frac{Y_{DY}^{p+p}}{Y_{DY}^{p+D}} \cong 1 - \left[\frac{\overline{d}^p(x) - \overline{u}^p(x)}{\overline{d}^p(x) + \overline{u}^p(x)}\right] \quad .$$

The experiment would be carried out with essentially the same equipment as E772. The targets would be 50-cm-long liquid hydrogen and liquid deuterium. The experiment was approved for 9 weeks of running time, which is expected in mid-1995 at FNAL.

Our group recently joined this collaboration. We have begun working with physicists from Los Alamos on various aspects of the relative normalization of data for the two targets. In particular we will provide computers and software for monitoring the experiment, similar to that which was used for the LADS experiment.

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3 Publications and Presentations

The following is a list of publications and presentations of the NMSU group between October 1, 1990, and October 30, 1993. The names of authors supported by DOE under this grant while the work reported was done are in bold type.

3.1 Published Papers

1. *Polarized Proton Elastic Scattering from Polarized* ^{13}C, G. W. Hoffmann, M. L. Barlett, W. Kielhorn, G. Pauletta, M. Purcell, L. Ray, J. F. Amann, J. J. Jarmer, K. W. Jones, S. Penttilä, N. Tanaka, **G. Burleson, J. Faucett**, M. Gilani, **G. Kyle, L. Stevens**, T. Mack, D. Mihailidis, D. Dehnhard, T. Averett, J. Comfort, J. Görgen, J. Tinsley, B. C. Clark, S. Hama, and R. L. Mercer; Phys. Rev. Lett. **65**, 3096 (1990).

2. *Analyzing Powers for the Reaction* $\pi^- \vec{p} \rightarrow \pi^0 n$ *at* $T_{\pi^-} = 161$ *MeV*, J. J. Görgen, J. R. Comfort, T. Averett, J. DeKorse, B. Franklin, B. G. Ritchie, J. Tinsley, **G. Kyle, B. Berman, G. Burleson, K. Cranston, A. Klein**, J. A. Faucett, J. J. Jarmer, J. N. Knudson, S. Penttilä, N. Tanaka, B. Brinkmöller, D. Dehnhard, Y. F. Yen, S. Høibråten, H. Breuer, B. S. Flanders, M. A. Khandaker, D. L. Naples, D. Zhang, M. L. Barlett, G. W. Hoffmann, and M. Purcell; Phys. Rev. D **42**, 2374 (1990).

3. *Pion Double Charge Exchange on* $T = 2$ *Nuclei in the* $\Delta_{3/2,3/2}$ *Resonance Region*, P. A. Seidl, M. A. Bryan, M. Burlein, **G. R. Burleson, K. S. Dhuga**, H. T. Fortune, R. Gilman, S. J. Greene, M. A. Machuca, C. F. Moore, S. Mordechai, C. L. Morris, D. S. Oakley, M. A. Plum, G. Rai, M. J. Smithson, Z. F. Wang, D. L. Watson, and J. D. Zumbro; Phys. Rev. C **42**, 1929 (1990).

4. *Pion Double Charge Exchange on* $^{42,44,48}Ca$ *for* $300 \leq T_\pi \leq 550$ *MeV*, A. L. Williams, J. A. McGill, C. L. Morris, **G. R. Burleson, J. A. Faucett**, D. S. Oakley, M. Burlein, H. T. Fortune, J. M. O'Donnell, G. P. Kahrimanis, and C. F. Moore; Phys. Rev. C **43**, 766 (1991).

5. *Analyzing Powers for Pion Charge Exchange on Polarized ^{13}C*, J. J. Görgen, J. R. Comfort, T. Averett, J. DeKorse, B. Franklin, B. G. Ritchie, J. Tinsley, **G. Kyle, B. Berman, G. Burleson, K. Cranston, A. Klein**, J. A. Faucett, J. J. Jarmer, J. N. Knudson, S. Penttilä, N. Tanaka, B. Brinkmöller. D. Dehnhard, Y. F. Yen, S. Høibråten, H. Breuer, B. S. Flanders, M. A. Khandaker, D. L. Naples, D. Zhang, M. L. Barlett, G. W. Hoffmann, and M. Purcell; Phys. Rev. Lett. **66**, 2193 (1991).

6. *Asymmetry Measurements of Pion Elastic Scattering from Polarized ^{13}C in the Energy Region of the P_{33} Resonance*, Y.-F. Yen, B. Brinkmöller, D. Dehnhard, Y.-J. Yu, **B. Berman, G. R. Burleson, K. Cranston, A. Klein, G. S. Kyle**, R. Alarcon, T. Averett, J. R. Comfort, J. Görgen, R. Ritchie, A. Williams, J. A. Faucett, S. J. Greene, J. Jarmer, J. A. McGill, C. L. Morris, S. Penttilä, N. Tanaka, H. T. Fortune, E. Insko, R. Ivie, J. M. O'Donnell, D. Smith, S. Høibråten, M. A. Khandaker, and S. Chakravarti; Phys. Rev. Lett. **66**, 1959 (1991).

7. *Measurements of $\Delta\sigma_L(np)$ between 500 and 800 MeV*, **M. Beddo, G. Burleson, J. A. Faucett, S. Gardiner, G. Kyle, R. Garnett**, D. P. Grosnick, D. Hill, K. F. Johnson, D. Lopiano, Y. Ohashi, T. Shima, H. Spinka, R. Stanck, D. Underwood, A. Yokosawa, G. Glass, R. Kenefick, S. Nath, L. Northcliffe, J. J. Jarmer, S. Penttilä, R. H. Jeppesen, G. Trippard, M. Devereux, and P. Kroll; Phys. Lett. **B258**, 24 (1991).

8. *Mass Dependence of High-Energy Pion Double Charge Exchange*, A. L. Williams, K. W. Johnson G. P. Kharimanis, H. Ward, C. F. Moore, J. A. McGill, C. L. Morris, **G. R. Burleson, J. A. Faucett, M. Rawool-Sullivan**, D. S. Oakley, M. Burlein, H. T. Fortune, E. Insko, R. Ivie, J. M. O'Donnell, and D. Smith; Phys. Rev. C **44**, 2025 (1991).

9. *Elastic Scattering of π^+ and π^- from ^4He between 90 and 240 MeV*, B. Brinkmöller, C. L. Blilie, M. K. Jones, G. M. Martinez, S. K. Nanda, S. M. Sterbenz, Y. F. Yen, L. G. Atencio, S. J. Greene, C. L. Morris, S. J. Seestrom, **G. R. Burleson, K. S. Dhuga, J. A. Faucett, R. W. Garnett**, K. Maeda, C. F. Moore, S. Mordechai, A. Williams, S. H. Yoo, and L. C. Bland; Phys. Rev. C 44, 2031 (1991).

10. *A Neutron Hodoscope for Medium Energy np Scattering Experiments*, **R. Garnett**, D. Grosnick, K. Johnson, D. Lopiano, Y. Ohashi, A. Rask, T. Shima, H. Spinka, R. Stanek, D. Underwod, A. Yokosawa, M. Beddo, **G. Burleson, J. Faucett, G. Kyle**, M. Devereux, G. Glass, S. Nath, J. J. Jarmer, S. Penttilä, R. Jeppesen, and G. Tripard; Nucl. Instrm. and Methods **A309**, 508 (1991).

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12. *A New Multiplexing Scheme for Cathode-Strip Readout Chambers*, **M. W. Rawool-Sullivan**, J. F. Amann, L. G. Atencio, R. L. Boudrie R. Lomax, C. L. Morris, M. Murray, and R. M. Whitton; Nucl. Instr. and Methods **A311**, 168 (1992).

13. *A Simple Three-Dimensional Magnetic Field Interpolation Technique*, **R. W. Garnett**, and **G. R. Burleson**; Nucl. Instr. and Methods **A313**, 501 (1992).

14. *Accelerator Measurements of NaI Response to Medium Energy Neutrons and Application to a Satellite-Borne Spectrometer*, P. P. Dunphy, E. L. Chupp, M. Popecki, D. J. Forrest, D. Lopiano, T. Shima, H. Spinka, G. Glass, **G. Burleson**, and **M. Beddo**; Exp. Astronomy **2**, 233 (1992).

15. *Neutron-Proton Elastic Scattering Spin-Spin Parameter Measurements between 500 and 800 MeV: I. C_{SL} and C_{LL} Measurements at Backward c.m. Angles*, W. R. Ditzler, D. Hill, J. Hoftiezer, K. F. Johnson, D. Lopiano, T. Shima, H. Shimizu, H. Spinka, R. Stanek, D. Underwood, R. G. Wagner, A. Yokosawa, **G. R. Burleson, J. A. Faucett, C. A. Fontanla, R. W. Garnett, C. Luchini, M. W. Rawool-Sullivan**, T. S. Bhatia, G. Glass, J. C. Hiebert, R. Kenefick, S. Nath, L. C. Northcliffe, R. Damjanovich, J. J. Jarmer, J. Vaninetti, R. H. Jeppesen, and G. E. Tripard; Phys. Rev. D **46**, 2792 (1992).

16. *Dominance of the Two-Nucleon Mechanism in $^{16}O(\pi^+,pp)$ at 115 MeV*, D. J. Mack, P. G. Roos, H. Breuer, N. S. Chant, S. D. Hyman, F. Khazie, B. G. Ritchie, J. D. Silk, **G. S. Kyle**, P. A. Amaudruz, Th. S. bauer, C. H. Q. Ingram, D. Renker, R. A. Schumacher, U. Sennhauser, and W. J. Burger; Phys. Rev. C **45**, 1767 (1992).

17. *Two-Nucleon Absorption of π^+ in ^4He at T_{π^+} = 114 and 162 MeV*, F. Adimi, H. Breuer, B. S. Flanders, M. A. Khandaker, M. G. Khayat, P. G. Roos, D. Zhang, Th. Bauer, J. Konijn, C. T. A. M. de Laat, **G. S. Kyle, S. Mukhopadhyay, M. Wang**, and R. Tacik; Phys. Rev. C **45**, 2598 (1992).

18. *Neutron-Proton Elastic Scattering Spin-Spin Correlation Parameter Measurements between 500 and 800 MeV. II. C_{SS} and C_{LS} at Forward c.m. Angles*, T. Shima, D. Hill, K. F. Johnson, H. Shimizu, H. Spinka, R. Stanek, G. Glass, J. C. Hiebert, R. A. Kenefick, S. Nath, L. C. Northcliffe, **G. R. Burleson, R. W. Garnett, J. A. Faucett, M. W. Rawool-Sullivan**, R. Damjanovich, J. Jarmer, R. H. Jeppesen, and J. E. Tripard; Phys. Rev. D **47**, 29 (1993).

19. *Systematics of the Double Isobaric Analog State Cross Section at 50 MeV*, H. Ward, J. M. Applegate, N. Auerbach, J. Beck, J. Johnson, K. Koch, C. Fred Moore, S. Mordechai, C. L. Morris, J. M. O'Donnell, **M. Rawool-Sullivan**, B. G. Ritchie, D. L. Watson, and C. Whitley; Phys. Rev. C **47**, 687 (1993).

20. *Pion Double Charge Exchange on ^{16}O above the $\Delta(1232)$ Resonance*, D. P. Beatty, H. T. Fortune, A. L. Williams, D. A. Smith, P. Hui, S. Loe, M. A. Landau, J. M. O'Donnell, **M. Rawool-Sullivan, J. Urbina**, and D. L. Watson; Phys. Lett. **B305**, 13 (1993).

21. *$^{10}B(p,n)^{10}C$ Reaction at 186 MeV*, L. Wang, J. Rapaport, C. D. Goodman, C. C. Foster, Y. Wang, R. A. Lindgren, E. Sugarbaker, D. Marchlenski, S. deLucia, B. Luther, L. Rybarcyk, T. N. Taddeucci, and **B. K. Park**; Phys. Rev. C. **47**, 2123 (1993).

22. *Search for an η Bound State in Pion Double Charge Exchange on ^{18}O*, J. D. Johnson, **G. R. Burleson**, C. Edwards, **M. El-Ghossain**, M. A. Espy, R. Garnett, A. Hussein, K. Johnson, C. F. Moore, C. L. Morris,

J. M. O'Donnell, M. Palarczyk, **M. Rawool-Sullivan**, H. Ward, D. Watson, C. Whitley, and A. L. Williams; Phys. Rev. C **47**, 2571 (1993).

23. *Energy Dependence of Two-Nucleon Pion Absorption on ^{16}O*, S. D. Hyman, D. J. Mack, P. G. Roos, H. Breuer, N. Chant, F. Khazaie, B. G. Ritchie, J. D. Silk, **G. Kyle**, P. A. Amaudruz, Th. S. Bauer, C. H. Q. Ingram, D. Renker, R. A. Schumacher, U. Sennhauser, and W. J. Burger; Phys. Rev. C **47** 1184 (1993).

24. *Energy Dependence of Multipole Strength Distributions in the $^{32}S(n,p)^{32}P$ Reaction*, **B. K. Park**, J. Rapaport, G. Fink, J. L. Ullmann, A. G. Ling, D. S. Sorenson, F. P. Brady, J. L. Romero, C. R. Howell, W. Tornow, and W. Unkelbach; Phys. Rev. C **48**, 711 (1993).

25. *Dipole and Spin-Dipole Resonances in Charge-Exchange Reactions on ^{12}C*, X. Yang, J. Rapaport, L. Wang, **B. K. Park**, S. DeLucia, B. Luther, D. Marchlenski, E. Sugarbaker, C. Foster, C. D. Goodman, Y. Wang, A. Ling, L. Rybarcyk, D. S. Sorenson, T. N. Taddeucci, J. L. Ullmann, C. R. Howell, and W. Tornow; Phys. Rev. C **48**, 1158 (1993).

26. *Pion Double Charge Exchange on ^{16}O at T_π = 300–500 MeV*, D. P. Beatty, **G. R. Burleson, M. Rawool-Sullivan, M. El-Ghossain**, H. T. Fortune, A. L. Williams, D. A. Smith, C. L. Morris, R. Garnett, D. L. Watson, J. Johnson, H. Ward, C. Whitley, S. K. Matthews, M. Palarczyk, C. Edwards, M. Espy, O. Hashimoto, and H. Tomoyuki, Phys. Rev. C. **48**, 1428 (1993).

3.2 Papers Submitted for Publication

1. *Spin Correlation Measurements for $\vec{p} + \vec{p}$ Elastic Scattering at 497.5 MeV*, G. W. Hoffmann, M. L. Barlett, W. Kielhorn, G. Pauletta, J. F. Amann, J. J. Jarmer, K. W. Jones, S. Penttilä, N. Tanaka, **G. Burleson, J. Faucett, M. Gilani, G. Kyle, L. Stevens**, A. M. Mack, D. Mihalidis, D. Dehnhard, T. Averett, J. Comfort, J. Görgen, J. Tinsley, and B. Clark; submitted to Phys. Rev. D.

2. *Interference Effects in Non-Analog Pion Double Charge Exchange*, M. G. McKinzie, H. T. Fortune, P. Hui, R. Ivie, C. Laymon, X. Li, S. Loe,

D. A. Smith, A. L. Williams, J. M. O'Donnell, **S. Blanchard, G. R. Burleson**, and **B. Lail**; submitted to Phys. Rev. C.

3. *Negative Pion-Nucleus Elastic Scattering at 20 and 40 MeV*, **G. Burleson, G. Blanpied, W. Cottingame, G. Daw, B. Park**, K. K. Seth, D. Barlow, S. Iversen, M. Kaletka, H. Nann, A. Saha, D. Smith, R. P. Redwine, W. Burger, M. Farkhondeh, B. Saghai, and R. Anderson; submitted to Phys. Rev. C.

4. *Pion Elastic Scattering on ^{28}Si at $T_\pi = 400$ MeV*, M. W. Rawool-Sullivan, C. L. Morris, J. M. O'Donnell, R. M. Whitton, **B. K. Park, G. R. Burleson**, D. L. Watson, J. Johnson, A. L. Williams, D. A. Smith, D. J. Ernst, and C. M. Chen; submitted to Phys. Rev. C.

5. *Energy Dependence of $^{10}B(n,p)$ Reaction*, D. S. Sorenson, J. L. Ullmann, A. G. Ling, **B. K. Park**, J. Rapaport, F. P. Brady, and J. L. Romero; submitted to Phys. Rev. C.

6. *A Large Solid Angle Study of Pion Absorption in ^3He*, T. Alteholz, G. Backenstoss, D. Bosnar, H. Breuer, A. Brkovič, H. Döbbeling, T. Dooling, W. Fong, M. Furic, P. Gram, N. K. Gregory, A. Hoffart, Q. Ingram, A. Klein, K. Koch, J. Köhler, B. Kotlinski, M. Kroedel, **G. Kyle**, A. Lehmann, Z. Lin, G. Mahl, K. Michaelian, A. O. Mateos, S. Mukhopadhyay, T. Petkovič, R. P. Redwine, D. Rowntree, A. A. Schumacher, U. Sennhauser, N. Simicevic, F. D. Smit, G. van der Steenhoven, D. R. Tieger, R. Trezeciak, H. Ullrich, M. Wang, M. H. Wang, H. J. Weyer, M. Wildi, and K. E. Wilson; submitted to Phys. Rev. Lett.

7. *Excitation Function for $^4He(\pi^+,pp)^2H$ Two-Nucleon Absorption across the Δ-Resonance*, H. Breuer, M. G. Khayat, F. Adimi, B. S. Flanders, M. A. Khandaker, P. G. Roos, D. Zhang, Th. S. Bauer, J. Konijn, C. T. A. M. de Laat, **G. S. Kyle, S. Mukhopadhyay, M. Wang**, and R. Tacik; submitted to Phys. Rev. Lett.

3.3 Papers Presented at Meetings and Conferences

At the Spring Meeting of the American Physical Society, Washington, DC, April 20–24, 1992:

1. *A_{nn} for 500 MeV $\vec{p} + \vec{p}$ Elastic Scattering*, G. Hoffmann, M. Barlett, W. Kielhorn, G. Pauletta, M. Purcell, L. Ray, J. Amann, J. Jarmer, K. Jones, S. Penttilä, N. Tanaka, **G. Burleson, J. Faucett, M. Gilani, L. Stevens**, A. Mack, D. Milaildis, T. Averett, J. Comfort, J. Görgen, and J. Tinsley; Bull. Am. Phys. Soc. **37**, 903 (1992).

2. *Pion Absorption in ^4He*, F. Adami, M. G. Khayat, H. Breuer, B. S. Flanders, M. Khandaker, P. G. Roos, D. Zhang, Th. S. Bauer, J. Konijn, C. T. A. M. de Laat, **G. Kyle, S. Mukhopadhyay, M. Wang**, and R. Tacik; Bull. Am. Phys. Soc. **37**, 915 (1992).

3. *Pion Double Charge Exchange on ^{16}O above the Resonance*, D. P. Beatty, R. Gilman, Q. Sun, H. T. Fortune, A. L. Williams, D. Smith, P. Hui, S. Loe, M. A. Landau, **M. Rawool-Sullivan, J. Urbina**, J. M. O'Donnell, and D. L. Watson; Bull. Am. Phys. Soc. **37**, 916 (1992).

4. *The Search for the Eta Component of Pion Double Charge Exchange*, J. D. Johnson, C. F. Moore, K. W. Johnson, H. Ward, C. Whitley, A. Hussein, R. W. Garnett, L. C. Liu, C. L. Morris, J. M. O'Donnell, **G. R. Burleson, M. W. Rawool-Sullivan, M. El-Ghossain**, D. Dehnhard, C. Edwards, M. A. Espy, M. Palarczyk, A. L. Williams, and D. L. Watson; Bull. Am. Phys. Soc. **37**, 916 (1992).

5. *Pion-Nucleus Elastic Scattering at Energies above the Δ(1232) Resonance*, **M. W. Rawool-Sullivan**, J. A. Faucett, **G. R. Burleson**, K. W. Johnson, G. P. Kharimanis, A. L. Williams, C. Whitley, C. F. Moore, J. A. McGill, C. L. Morris, D. J. Ernst, K. S. Dhuga, E. Insko, J. M. O'Donnell, and H. T. Fortune; Bull. Am. Phys. Soc. **37**, 916 (1992).

6. *High-Energy Pion Double Charge Exchange on ^{16}O*, D. P. Beatty, **M. Rawool-Sullivan, G. R. Burleson, M. El-Ghossain**, H. T. Fortune, A. L. Williams, D. Smith, D. L. Morris, R. Garnett, J. Johnson, H. Ward, C. Whitley, S. K. Matthews, M. Palarczyk, C. Edwards, M. Espy, and D. Watson; Bull. Am. Phys. Soc. **37**, 916 (1992).

At the Workshop on Electronuclear Physics with Internal Targets and the BLAST Detector, Arizona State University, March, 1992:

1. *Pion-Nucleus Multiple Scattering Processes and the Delta-Nucleon Interaction*, **G. S. Kyle**, invited talk (proceedings published by World Scientific, 1993).

At the Second US–Japan Symposium on Pion Physics above the Delta, Los Alamos, NM, August, 1992:

1. Measurements of DCX at LAMPF, 300–500 MeV, **G. R. Burleson**, invited talk.

At the Fall Meeting of the Division of Nuclear Physics of the Americal Physical Society, Santa Fe, NM, October 14–17, 1992:

1. *The Search for the Eta Component of Pion Double Charge Exchange*, J. D. Johnson, C. F. Moore, K. W. Johnson, H. Ward, C. Whitley, A. Hussein, R. W. Garnett, L. C. Liu, C. L. Morris, J. M. O'Donnell, **G. R. Burleson, M. W. Rawool-Sullivan, M. El-Ghossain**, D. Dehnhard, C. Edwards, M. A. Espy, M. Palarazyk, A. L. Williams, and D. L. Watson; Bull. Am. Phys. Soc. **37**, 1292 (1992).

2. *$^4He(\pi^+,ppd)$ at 114 MeV*, F. Adimi, M. G. Khayat, H. Breuer, B. S. Flanders, M. Khandaker, P. G. Roos, D. Zhang, Th. S. Bauer, J. Konijn, C. T. A. M. de Laat, **G. Kyle, S. Mukhopadhyay, M. Wang**, and R. Tacik; Bull. Am. Phys. Soc. **37**, 1303 (1992).

3. *Large Solid Angle Measurements of the Pion-Nucleus Absorption Cross Section in the Region of the Δ Resonance*, N. Simicevic, W. Fong, N. K. Gregory, R. P. Redwine, D. Rowntree, K. E. Wilsin, G. Backenstoss, J. Köhler, M. Krödel, A. Lehmann, H. J. Weyer, M. Wildi, R. Schumacher, T. Alterholz, A. Hoffart, H. Ullrich, P. A. M. Gram, H. Breuer, F. D. Smit, **G. Kyle, Z. Lin, S. Mukhopadhyay, M. H. Wang**, G. van der Steenhoven, T. Dooling, A. Klein, H. Döbbeling, Q. Ingram, K. Koch, B. Kotlinski, G. Mahl, M. Michaelian, U. Sennhauser, D. Bosnar, R. Brkovic, M. Furic, and T. Petkovic; Bull. Am. Phys. Soc. **37**, 1303 (1992).

4. *Left-Right Asymmetry Measurements for Pion Scattering off Polarized ^{13}C*, C.K. Johnson, M. Purcell, H. Ward, A. Williams, S. Worm, B. Brinkmöller, D. Dehnhard, J. Langenbrunner, M. Palarczyk, C. Reidel, Y. Yen, G. Burleson, M. Ghossain, A. Klein, **G. Kyle, S. Mukhopadhyay, M. Wang**, R. Ivie, M. Kagarlis, S. Loe, M. Mackenzie, J. O'Donnel, D. Smith, M. Khandaker, M. Khayat, C. Allgower, J. Comfort, J. Jarmer, S. Penttila, and N. Tanaka, Bull. Am. Phys. Soc. **37**, 1304 (1992)

At the Spring Meeting of the American Physical Society, Washington, DC, April 12–15, 1993:

1. *Forward Angle Cross Sections for Pion-Nucleon Single Charge Exchange in the Region of the $\Delta(1232)$ Resonance*, L. Nguyen-Tansill, H. Cranell, D. Isenhower, J. Redmon, M. Sadler, C. Mertz, J. Wise, J. Connelly, J. Amann, C. Morris, M. Rawool-Sullivan, R. M. Whitton, **B. Park, Q. Zhao**, P. P. Hui, A. Marusic, and I. Supek; Bull. Am. Phys. Soc. **38**, 942 (1993).

2. *$(\pi^{\pm},\pi^{\pm})$ Reactions on ^2H, ^3He, and ^4He*, C. R. Whitley, K. Johnson, C. F. Moore, J. L. Langenbrunner, D. Dehnhard, C. M. Edwards, M. Espy, M. Palarczyk, P. Yurek, J. D. Zumbro, C. L. Morris, J. N. O'Donnell, M. Rawool-Sullivan, R. M. Whitton, M. K. Jones, **B. K. Park**, B. J. Kriss, and K. Maeda; Bull. Am. Phys. Soc. **38**, 943 (1993).

3. *Study of the Charge Exchange Quasifree Scattering at $E_\pi = 186$ MeV for Light Nuclei*, L. Wang, X. Yang, J. Rapaport, S. deLucia, B. Luther, D. Marchlenski, E. Sugarbaker, C. Foster, C. D. Goodman, A. Smith, Y. Wang, L. Rybarcyk, T. N. Taudeucci, and **B. K. Park**; Bull. Am. Phys. Soc. **38**, 982 (1993).

4. *Spin-Dipole Strength Observed in Charge Exchange Reactions on P-Shell Nuclei*, X. Yang, L. Wang, J. Rapaport, S. deLucia, B. Luther, D. Marchlenski, E. Sugarbaker, C. Foster, C. D. Goodman, A. Smith, Y. Wang, L. Rybarcyk, T. N. Tauddeucci, and **B. K. Park**; Bull. Am. Phys. Soc. **38**, 1051 (1993).

5. *Backward Angle n-p Differential Cross Sections for $65 \leq E_n \leq 250$ MeV*, A. E. Feldman, J. Rapaport, Ch. Elster, B. Barmore, F. P. Brady,

G. Fink, C. R. Howel, A. Ling, **B. K. Park**, J. L. Romero, D. Sorenson, W. Tornow, J. L. Ullmann, and X. Yang; Bull. Am. Phys. Soc. **38**, 1062 (1993).

At the RIKEN International Workshop on Delta Excitation in Nuclei, Japan, May, 1993:

1. Charge Exchange Spin Observable Measurements at NTOF: *Quasielastic and*
   Quasifree Delta Production, D. Prout, J. McClelland, E. Sugarbaker, T. N. Taddeucci, B. Luther, L. J. Rybarczyk, D. Marchlenski, S. Delucia, D. Cooper, **B. K. Park**, D. J. Mercer, X. Y. Chen, C. Gaarde, T. Sams, W. C. Sailor, T. A. Carey, R. C. Byrd, J. Rapaport, C. D. Goodman, W. Huang, Y. Yang, E. Gülmez, C. A. Whitten, and W. P. Alford.

At the XIII International Conference on Particles and Nuclei, Perugia, Italy, June 28–July 2, 1993:

1. *Large π^+/π^- Cross Section Ration in the $(\pi,\pi'p)$ Reaction on ^2H, ^3He, and ^4He*, C. R. Whitley, K. Johnson, J. Johnson, C. F. Moore, J. L. Langenbrunner, D. Dehnhard, C. M. Edwards, M. A. Espy, M. Palarczyk, P. D. Yruek, M. K. Jones, J. D. Zumbro, C. L. Morris, J. M. O'Donnell, M. Rawool-Sullivan, R. M. Whitton, **B. K. Park**, B. J. Kriss, and K. Maeda.

2. *Multi-Nucleon Pion Absorption Studies with LADS*, G. Backenstoss, A. Lehmann, J. Köhler, M. Kroedel, H. J, Weyer, M. Wildi, R. Schumacher, T. Alteholz, A. Hoffart, R. Trezeciak, H. Ullrich, P. Gram, H. Breuer, W. Fong, N. Gregory, R. P. Redwine, D. Rowntree, N. Simicevic, D. Tieger, K. E. Wilson, **G. Kyle, Z. Lin, S. Mukhopadhyay, M. H. Wang**, G. van der Steenhoven, T. Dooling, A. Klein, H. Döbbeling, Q. Ingram K. Koch, B. Kotlinski, G. Mahl, K. Michaelian, U. Sennhauser, F. D. Smit, D. Androic, D. Bosnar, A. Brkivic, M. Furid, and T. Petkovic.

3. *Pion Elastic Scattering above the Δ Resonance*, M. W. Rawool-Sullivan, C. L. Morris, J. M. O'Donnell, R. M. Whitton, **B. Park, G. R.**

Burleson, D. L. Watson, J. Johnson, A. L. Williams, and D. A. Smith.

At the Fall Meeting of the Division of Nuclear Physics of the Americal Physical Society, Asilomar, CA, October 22–24, 1993:

1. *Interference Effects in Non-Analog Pion Double Charge Exchange*, H. T. Fortune, M. G. McKinzie, P. Hui, C. Laymon, X. Lie, S. Roe, R. Ivie, D. A. Smith, A. L. Williams, J. M. O'Donnell, **S. Blanchard, G. R. Burleson**, and **B. Lail**; Bull. Am. Phys. Soc. **38**, 1816 (1993).

2. *Measurements of Quasi-Free Pion Single Charge Exchange (SCX) in* ^{3}He *at* $T_{\pi} = 245$ *MeV*, M. L. Dowell, E. J. Beise, G. W. Dodson, S. Gilad, S. Høibråten, L. D. Pham, R. P. Redwine, D. R. Tieger, E. Piazetsky, S. A. Wood, F. Irom, M. J. Leitch, **G. S. Kyle**, S. H. Rokni, and L. C. Smith; Bull. Am. Phys. Soc. **38**, 1816 (1993).

3. *High Energy Pion Double Charge Exchange on* $^{44,48}Ca$, P. Hui, A. L. Williams, H. T. Fortune, M. McKinzie, D. A. Smith, **S. Blanchard, G. R. Burleson, B. K. Park, B. Lail**, C. L. Morris, J. M. O'Donnell, M. Rawool-Sullivan, K. Johnson, J. Johnson, C. Whitley, D. P. Beatty, M. Jones, C. Edwards, M. Espy, M. Palarczyk, P. Yurek, and D. L. Watson; Bull. Am. Phys. Soc. **38**, 1817 (1993).

4. *Pion Absorption Channels in* ^{4}He *at 114 MeV*, F. Adimi, M. G. Khayat, H. Breuer, B. S. Flanders, M. Khandaker, P. G. Roos, D. Zhang, Th. S. Bauer, J. Konijn, C. T. A. M deLaat, **G. Kyle, S. Mukhopadhyay, M. Wang**, and R. Tacik; Bull. Am. Phys. Soc. **38**, 1817 (1993).

5. $\pi^{-}p \rightarrow \pi^{0}n$ *Cross Sections in the Region of the* Δ *Resonance*, L. Nguyen-Tansill, H. Cranell, D. Isenhower, J. Redmon, M. Sadler, C. Mertz, J. Wise, J. Connelly, J. Amann, C. Morris, M. Rawool-Sullivan, R. M. Whitton, **B. Park, Q. Zhao**, P. P. Hui, A. Marusic, and I. Supek; Bull. Am. Phys. Soc. **38**, 1818, (1993).

6. *Three Nucleon Pion Absorption on* ^{3}He *with LADS*, D. Rowntree, W. Fong, N. K. Gregory, A. O. Mateos, R. P. Redwine, N. Simicevic, D. R. Tieger, K. E. Wilson, G. Backenstoss, J. Koehler, M. Kroedel, A. Lehmann, H. J. Weyer, M. Wildi, R. Schumacher, T. Alteholz, A. Hoffart, R. Trezeciak, H. Ullrich, P. Gram, H. Breuer F. D. Smit, **J.**

Haas, G. Kyle, Z. Lin, S. Mukhopadhyay, M. Wang, M. H. Wang, G. van der Steenhover, T. Dooling, A. Klein, H. Doebbeling, Q. Ingram, K. Koch, B. Kotlinski, G. Mahl, K. Michaelian, U. Sennhauser, D. Andric, D. Bosnar, A. Brokovic, M. Furic, and T. Petrovic; Bull. Am. Phys. Soc. **38**, 1818 (1993).

7. *The Energy Dependence of the Effective N-N Isovector Tensor Interaction Using the Stretched Transition from* 3^+ *Ground State of* ^{10}B *to the* 0^+ *Ground State of* ^{10}Be *over the Energy Range of 50 to 250 MeV*, D. S. Sorenson, F. P. Brady, B. Clausen, R. C. Haight, R. A. Lindgren, A. Ling, **B. K. Park**, J. Rapaport, J. L. Romero, J. L. Ullmann, and C. Wuest; Bull. Am. Phys. Soc. **38**, 1826 (1993).

8. *Quasifree Polarization-Transfer Measurements in the* $(\vec{p},\vec{n})$ *Reaction at* 12.5°, B. Luther, D. Prout, E. Sugarbaker, S. Delucia, T. N. Taddeucci, J. McClelland, R. C. Byrd, L. Rybarcyk, and **B. Park**; Bull. Am. Phys. Soc. **38**, 1830 (1993).

9. *Measurements of* D_{NN} *and* D_{LL} *for* $(\vec{p},\vec{n})$ *Reactions at 800 MeV on the Delta Region*, S. Delucia, B. Luther, D. Prout, E. Sugarbaker, D. Cooper, T. N. Taddeucci, **B. Park**, J. Rapaport, T. Sams, C. D. Goodman, C. Glasshauser, and G. Edwards; Bull. Am. Phys. Soc. **38**, 1830 (1993).

4 Advanced Degree Awarded

In 1991, the following student was awarded a Ph.D. degree, based on work carried out under this grant:

Minghong Wang, *A Large Acceptance Detector System for Pion Absorption Studies*

5 Personnel

The effort that has been devoted to this grant by those supported by it, from April 1, 1991, projected through March 31, 1994 is given below.

Faculty Members:

George R. Burleson, 18 man-months

Gary S. Kyle, 18 man-months

Postdoctoral Research Associates:

Sanjoy Mukhopadhyay, 3 man-months

Mohini Rawool-Sullivan, 10 man-months

Minghong Wang, 3 man-months

Maozhi Wang, 27 man-months

Brent K. Park, 24 man-months

Graduate Students:

Minghong Wang, 8 man-months

Zhinan Lin, 36 man-months

Qihua Zhao, 31 man-months

Tinghua Chang, 22 man-months

Sean P. Blanchard, 6 man-months

Brian A. Lail, 6 man-months

Jon P. Haas, 3 man-months

Maher El-Ghossain, 5 man-months

Javier Urbina, 3 man-months

Undergraduate Student:

Brett Nelson, 2 man-months