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EXPERIMENTAL STUDIES OF PION-NUCLEUS INTERACTIONS AT INTERMEDIATE ENERGIES

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Las Cruces, NM 88003

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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 under a grant from the U. S. Department of Energy.

Most of these studies have involved investigations of various pion-nucleus interactions. The work has been carried out both with the LAMPF accelerator at the Los Alamos National Laboratory and with the cyclotron at the Paul Scherrer Institute (PSI) near Zurich, Switzerland. It represents a collaborative effort among several laboratories and universities. The NMSU personnel during this period include two faculty members, George R. Burleson and Gary S. Kyle; four postdoctoral research associates, Sanjoy Mukhopadhyay, Mohini Rawool-Sullivan, Minghong Wang, and Maozhi Wang; and five graduate students, Minghong Wang (who completed work for his Ph.D. degree during this period), Zhinan Lin, Qihua Zhao, Javier Urbina, and Maher El-Ghossain.

Part of the experimental work involves measurements of new data on double-charge-exchange scattering, using facilities at LAMPF which we helped modify, and on pion absorption, using a new detector system at PSI that covers nearly the full solid-angle region which we helped construct. Other work involved preparation for future experiments using polarized nuclear targets and a new high-resolution spectrometer system for detecting π^0 mesons. We also presented several proposals for work to be done in future years, involving studies related to pi-mesonic atoms, fundamental pion-nucleon interactions, studies of the difference between charged and neutral pion interactions with the nucleon, studies of the isospin structure of pion-nucleus interactions, and pion scattering from polarized ^3He targets. This work is aimed at improving our understanding of the pion-nucleon interaction, of the pion-nucleus interaction mechanism, and of nuclear structure.

2 Experimental Research

During this year we have been involved in data-taking in several experiments in pion-nucleus interactions at LAMPF and PSI, as well as in analysis and interpretation of data from past experiments and planning and preparation for future experiments. Our progress in this work is described below.

2.1 Experiments Run

In 1991 we were involved in data-taking runs on experiments at LAMPF on double-charge-exchange scattering and at PSI on pion absorption. These include the following:

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

This experiment, together with a companion experiment involving measurements of elastic scattering (described below), is a continuation of work begun by members of this collaboration in 1987, which obtained the first extensive set of measurements of pion-nucleus interactions at energies immediately above the $\Delta(1232)$ resonance. For this work, the P^3 Channel at LAMPF was modified in order to produce a dispersed beam spot, and the Large Aperture Spectrometer (LAS) was modified to improve its resolution. This resulted in a resolution of about 1.5–2.0 MeV at energies between 300 and 500 MeV.

The principal motivation for this work is based on the observation that the pion-nucleon interaction is considerably weaker at these energies than near the peak of the Δ resonance. This means that the resulting longer mean free paths for pions in nuclei and the weaker optical potentials should lead to more reliable theoretical calculations. 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 of particular interest because it must take place on at least two nucleons and therefore should have the possibility of giving new insight into nucleon-nucleon correlations. 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, measurements were carried out on both of these processes. Results of this work for transitions to double isobaric analog states (DIAS) have been published.[1, 2, 3] They have generally disagreed with most previous expectations. Recently-published results on the A-dependence of these cross sections at small angles are shown in Fig. 1.

During 1991, only a few days of beam were available to us, due to a decision of the LAMPF management to shorten the running schedule. (We expect the additional time orginally scheduled to be made available in 1992.) This is a survey experiment, so that within reasonable limits we are allowed to choose the data we take. In the time allowed, we decided that the most useful physics to study was that of small-angle excitation functions for nonanalog transitions, since no published data existed at these energies. The target chosen was ^{16}O, partly because new data had been taken with EPICS with this target in Experiment 1017U (discussed below), and because data rates should be high. The interest in nonanalog transitions at these energies lies in the observation that at resonance energies they are very well described by the Delta interaction (DINT) model,[4] while analog transitions seen to be consistent with a sequential mechanism. An attempt to describe DCX scattering with a combination of these two mechanisms has been unsuccessful, however.[5, 6] At energies above 300 MeV, the DINT mechanism predicts a very small cross section, while preliminary indications suggest a larger one. The preliminary results indicate that the cross sections at these energies are larger than those between 200 and 300 MeV, suggesting that another mechanism besides DINT is present at these higher energies.

LAMPF Experiment No. 1017U, *Interference Effects in Non-Analog 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.

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 non-analog transitions, however, the data in the resonance region, including angular distributions, are well described by the DINT mechanism,[4] as 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 such a mixture of amplitudes might be observed in certain characteristics of the angular distributions of non-analog 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 120 and 270 MeV, over an angular range between 5° and 40°. The results generally follow the simple diffractive behavior previously seen,

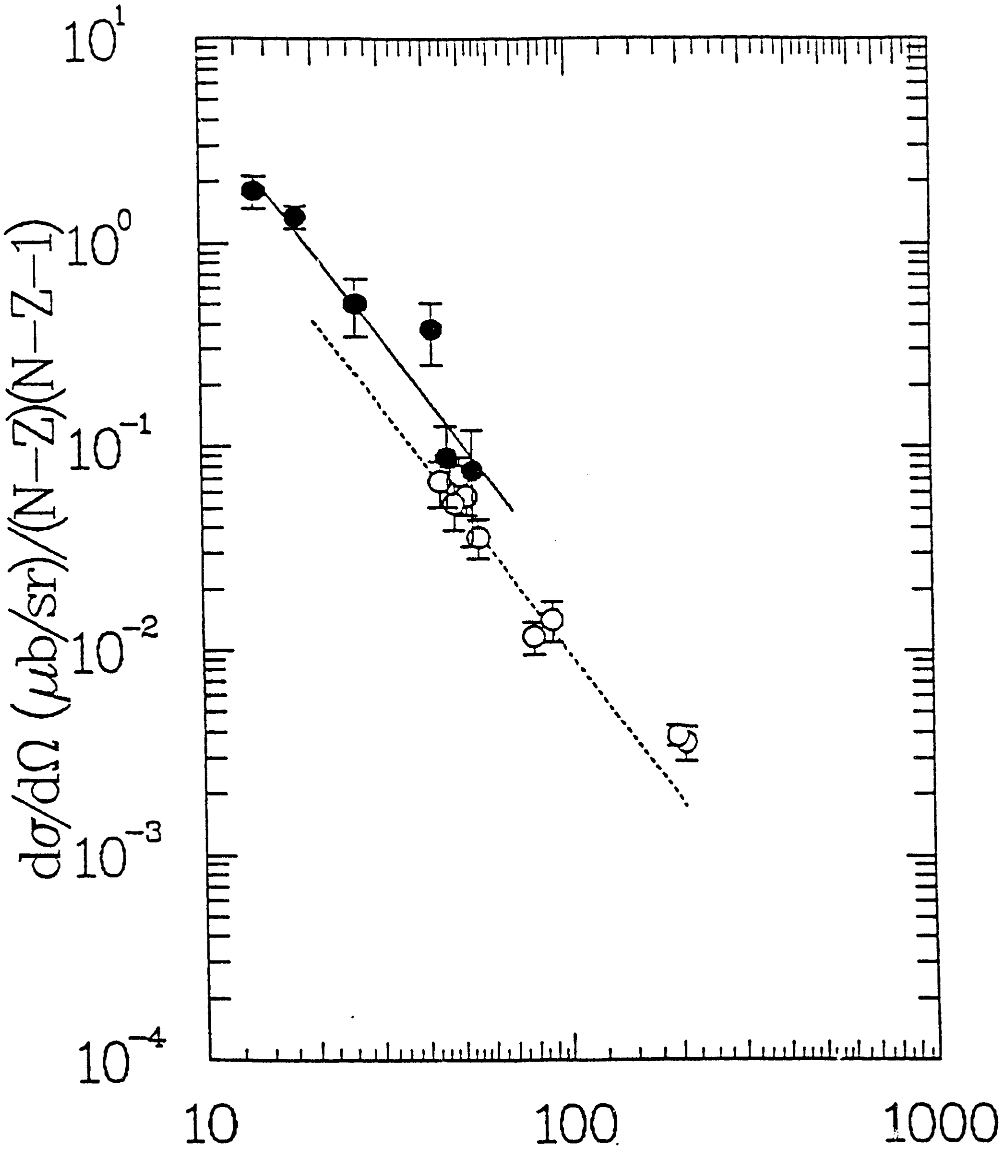

FIG. 1. Differential cross sections for (π^+, π^-) reactions to double isobaric analog states, divided by $(N-Z)(N-Z-1)$, as a function of nuclear mass number A at 500 MeV, from Ref. [3]. The solid line is $1105A^{-7.12/3}$ and the dashed line is $47.5A^{-5.40/3}$. The decrease in the exponential from the $A^{-10/3}$ value found at resonance energies is expected due to the deeper penetration of the pion into the nucleus at these energies.

but at the smaller angles some suggestions of anomalous behavior were noted in the preliminary data, which is being investigated further. These data, as well as those taken in Exp. 1107, are being analyzed by David Beatty, of Rutgers University, as part of a Ph.D. dissertation.

LAMPF Experiment No. 1140, *Search for η^o Component in Pion DCX Scattering*, University of Texas, Rutgers, LANL and NMSU (Rawool-Sullivan, El-Ghossain, and Burleson); C. L. Morris, LANL, and C. F. Moore, Texas Spokesmen.

It has recently been shown[7] that the η-N interaction is attractive, so that there exists the possibility of a bound state of an η in a nucleus. Haider and Liu[8] have shown that these bound η-nucleus states may be observed as intermediate states in pion DCX reactions. They would contribute a resonant amplitude with a width the order of 10 MeV which would interfere with the conventional sequential-scattering amplitude with a π^0 intermediate state, which is smoothly varying. This would result in a rapidly-varying cross section at a fixed momentum transfer, at a pion energy of about 420 MeV. At small angles the effect should be small, but at a momentum transfer of about 210 MeV/c it should be large and measurable. The purpose of this experiment was to search for an effect of this type.

In this experiment, excitation functions were measured for DCX scattering from ^{18}O to the analog state at momentum transfers of 0 and 210 MeV/c, with some data at 105 MeV/c, at energies between 390 and 440 MeV. The setup used was the same as for Exp. 1170 above, which was preceeded by this experiment. Some of the preliminary data are shown in Fig. 2, which gives no indication for such an effect, so that we expect to find an upper limit for this process. This work will serve as a Ph.D. thesis for John Johnson, of the University of Texas.

LAMPF Experiment No. 1210, *Excitation Mechanism for the Analog of the Anti-Analog State in Pion DCX in Heavy Nuclei*, Ben-Gurion University, University of Texas, Arizona State, LANL, and NMSU (Rawool-Sullivan); S. Mordechai, Ben-Gurion University, Spokesman.

Recent high-statistics data taken on the EPICS channel[9] revealed for the first time a feature of the reaction ^{93}Nb$(\pi^+,\pi^-)^{93}$Tc at 295 MeV. This feature is the excitation of a state below the DIAS ($IAS{\otimes}IAS$) state in ^{93}Tc, which has tentatively been identified as the analog of the antianalog state in ^{93}Mo ($IAS \otimes \bar{I}\bar{A}\bar{S}$), where the parent is the ground state of ^{93}Nb. Since this state is orthogonal to the DIAS, it should not be excited, but in Ref. [9], several possible mechanisms for ite excitation are discussed. A means of distinguishing among these possibilities is found at about 50 MeV, where pion scattering can be described approximately by plane waves. Here, different behaviors are predicted with angle for the ratio of the cross section for this state to that of the DIAS, for the different mechanisms. In this experiment,

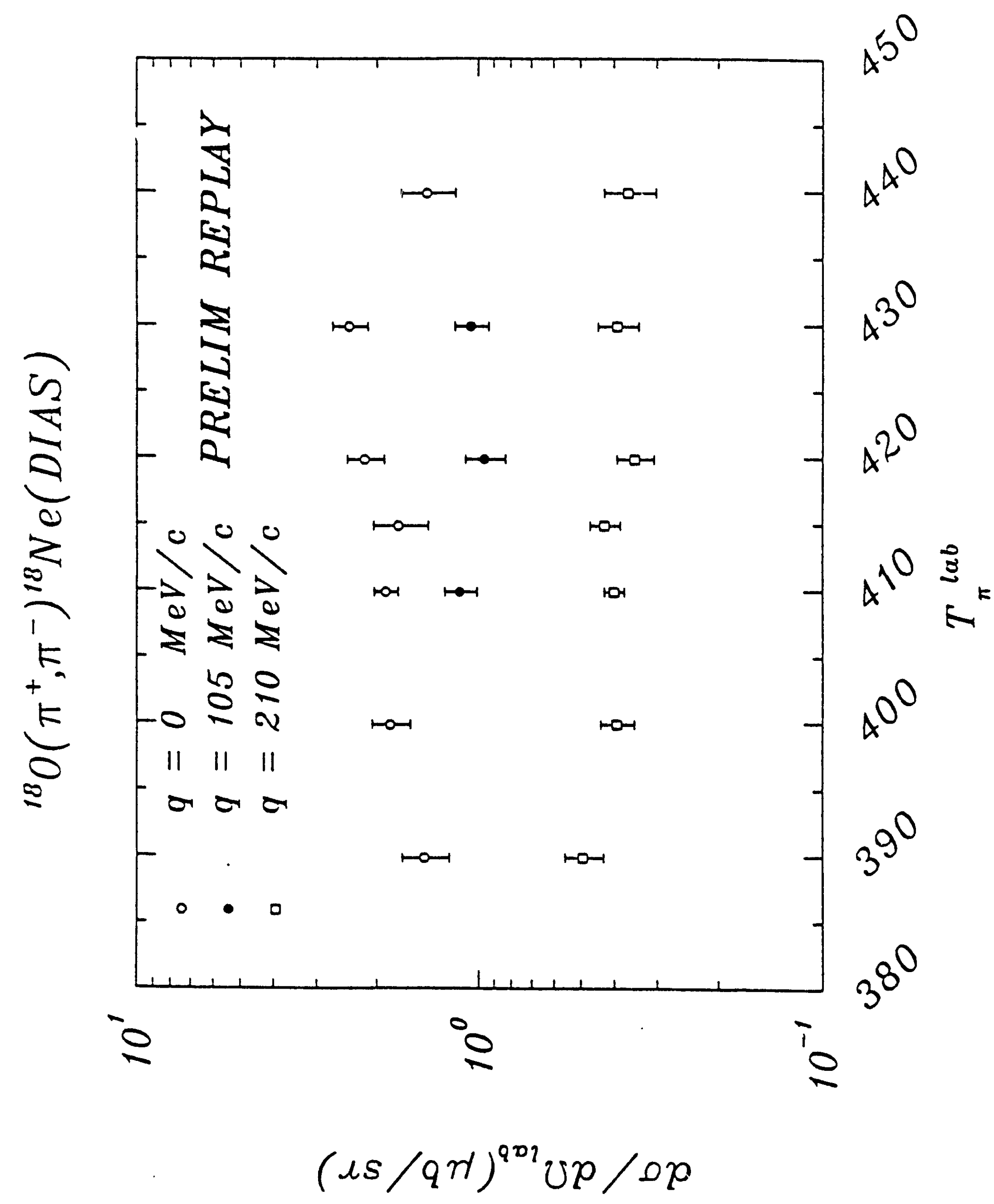

FIG. 2. Preliminary cross sections for the (π^+,π^-) reaction on ^{18}O at momentum transfers of 0, 105, and 210 MeV/c, from Exp. 1140. The signal of a bound η^0 meson in the intermediate state should be a rapid variation of the cross sections around 410 MeV.

cross sections were measured at 50 MeV for this reaction at different angles. The data suggest Coulomb mixing as the mechanism for the excitation of this state. These results are being prepared for publication.

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, Lin, Mukhopadhyay, Wang); Q. Ingram, PSI, Spokesman.

The Large Acceptance Detector System (LADS) at the Paul Scherrer Insitute (PSI) was proposed in order to investigate 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 pion absorption processes and the possibility of exotic mechanisms.[10, 11] More generally, the detector was 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 4π sr 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 main cylindrical array, which cover most of the solid angle, and two end-cap arrays, which close the ends. Two cylindrical multi-wire chambers with helical cathode strips provide tracking information. The detector covers 98.8% of the full solid angle. The LADS detector and electronics construction 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. A limited amount of data were obtained in the fall of 1989. The detector design and data taken in the 1989 run are described more fully in our previous DOE progress reports and in Ref.[12]

The PSI accelerator was shut down from January, 1990, until March, 1991, in order to upgrade the facility to run higher primary proton beam intensities. During this period much of the collaboration effort was concentrated on detector calibration and studies of its response, and on development of the replay software (LADYBIRD) and the Monte-Carlo code for the data analysis. Techniques were developed for calibration of the detectors, and routines in the analysis program LADYBIRD for track reconstruction, energy and momentum calculation, particle identification, and hit-to-particle association were written. Although much of the software was completed, improvements are still being made.

The NMSU group concentrated mainly on obtaining energy and time calibrations for the end-cap detectors, writing the subroutines to calculate particle energies, improving the track reconstruction code, and developing the Monte-Carlo code. Automated procedures are necessary for calibration of the 196 plastic scintillation counters in LADS. For the end-cap counters we developed procedures using the peaks arising from $\pi^+d \rightarrow pp$ and $\pi^+d \rightarrow \pi^+pn$ reactions in a deuterium gas target. The calculation of the particle energy uses ADC and position information and corrects for dE/dx losses in dead material, such as the gas target walls, and for the non-linear scintillator response to large energy deposition. Our contributions to the track reconstruction code were mainly improvements in the noise rejection. Fig. 3 shows a typical reconstruction of event verticies in the gas target.

The Monte-Carlo code is based upon the CERN GEANT package. The NMSU and Old Dominion groups wrote most of the user subroutines which specify the detector geometry, generate events in the target, and track the particles through the detector. Fairly sophisticated event generators, using upon the plane wave impulse approximation (PWIA), were written for the $\pi^+d \rightarrow pp$ and quasi-free $\pi^+d \rightarrow \pi^+pn$ reactions. A simple n-body phase space model of the $\pi^4He \rightarrow pppn$ reaction was also written. We intend to develop other event generators as they are needed. Presently we are developing software to determine detector efficiency corrections required because particles may suffer reactions in the scintillator material. We are also doing more general studies of the detector acceptance guided by the comparison of Monte-Carlo generated πd data with measured data. It is planned to eventually generate calibrated pseudo-data at the level of data summary tapes, which may be passed through the LADYBIRD program. Fig. 4 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.

The second run in the πM1 area of PSI began in May 1991 and continued until mid-October. Several improvements had been made to the detector during the shutdown. New trigger electronics were developed which gave us more flexibility for defining different trigger types (corresponding to various charged and neutral particle multiplicities), and permitted tagging of events according to the counters involved, which was particularly useful for setting up the end-cap detector, gains. A set of 'ring-counters' which surrounded the detector, together with an active scintillator target, served to define minimum ionizing particles passing through the center of the cylinder, which were used in setting up the cylinder counter gains. A multi-wire proportional chamber with visual and computer readouts gated by the trigger was added for beam tuning studies to minimize backgrounds from the gas target walls.

The data acquisition involved an Aleph Event Builder (AEB), a front-end pro-

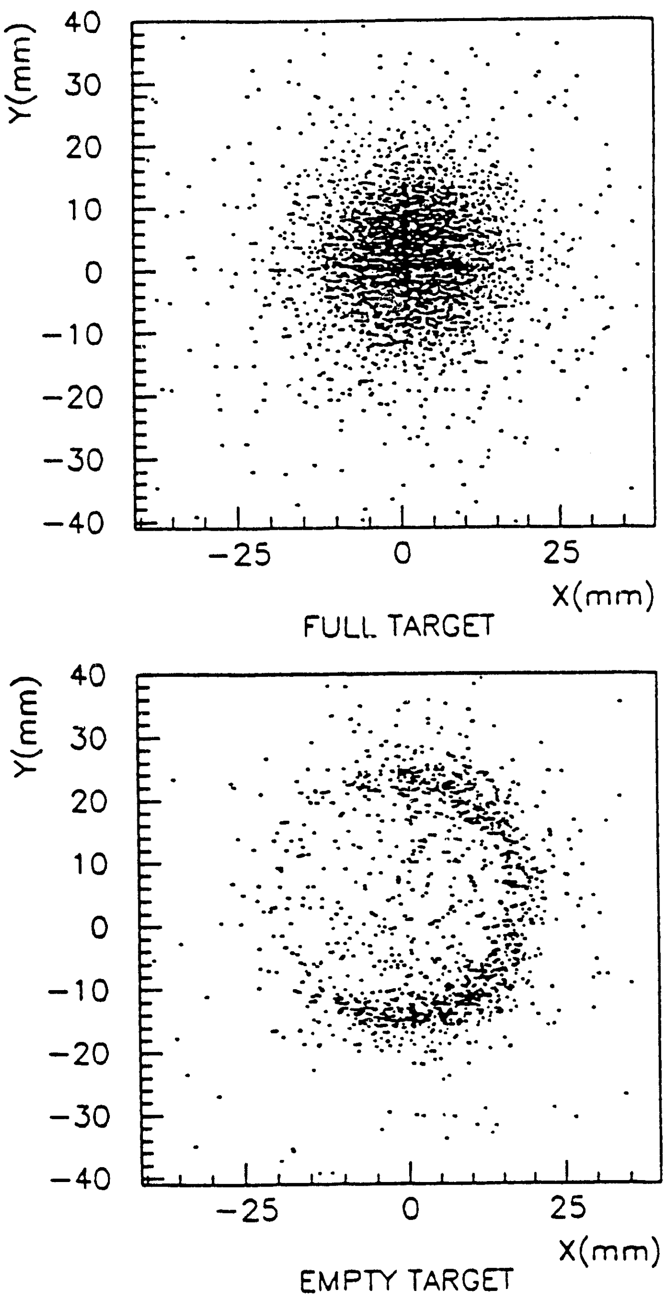

FIG. 3. Vertex distribution in X-Y for a gas target in LADS. Top: full target; bottom: empty target. The relative amount of target wall events are small and can be separated by applying a circular cut.

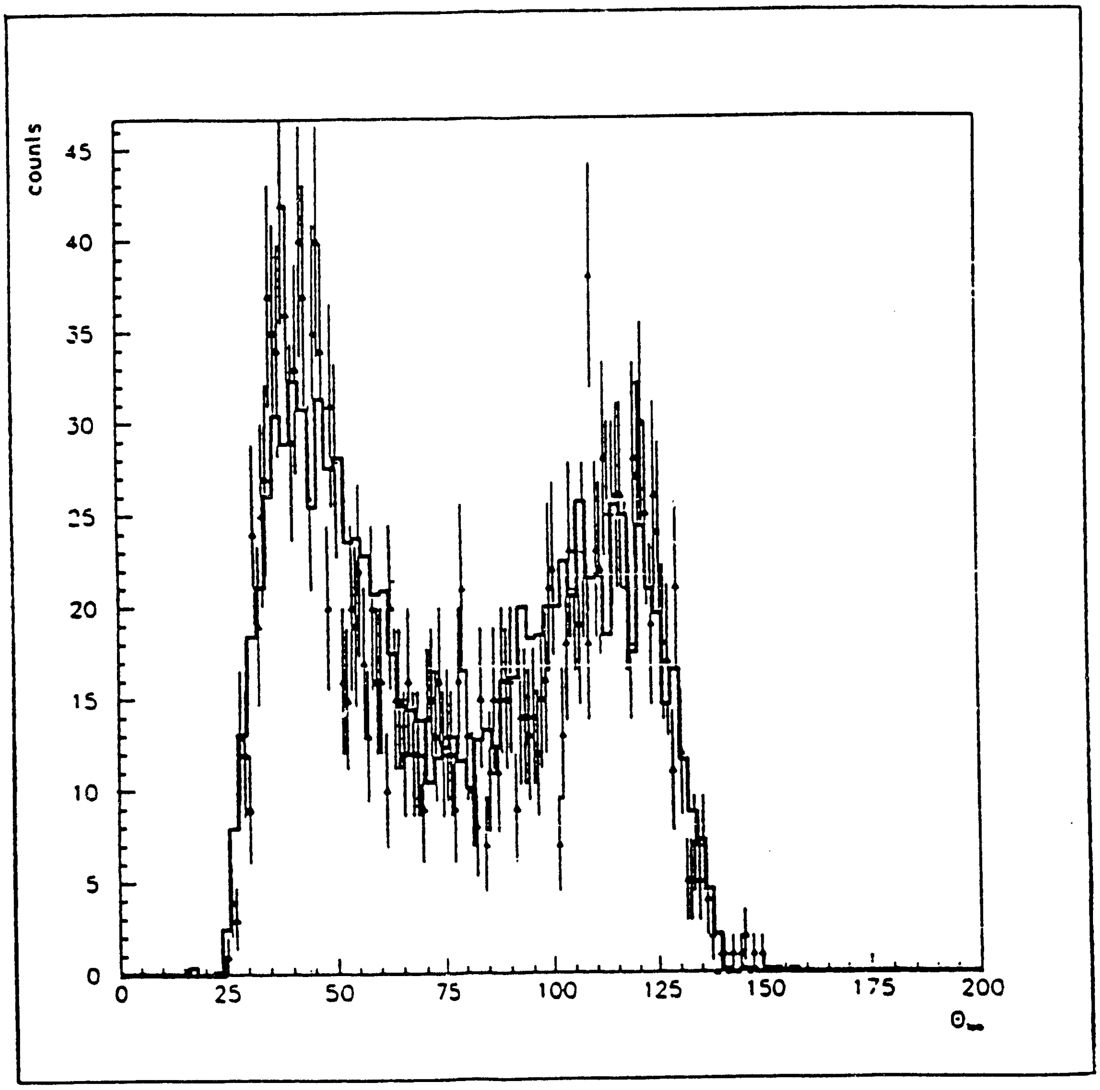

FIG. 4. Θ_{lab} distribution of d(π^+,pp) events at 165 MeV. Both protons are detected in the cylinder detectors. The bar plot is the Monte-Carlo simulated distribution.

cessor residing in Fastbus which read out the Fastbus and CAMAC electronics and built the event. In the 1989 run the event was sent to the MicroVAX 3500 computers via Ethernet with a net bandwidth of roughly 50K bps, corresponding to data rates of about 50Hz. For the 1991 running, data rates were improved to 400Hz by the addition of a Cern Host Interface (CHI), which buffered the events into super-events and passed them via a parallel bus to the MicroVAX responsible for data taping. This computer then broadcast the events onto the Ethernet for use by the other two VAXes which performed the on-line data analysis and monitored the data quality. The data were written directly to 8-mm Exabyte tapes.

Several computer tasks automatically monitored the data taking. One task analyzed LED events for changes in the phototube gains. Others monitored the stability of the photomultiplier supply voltages and the beamline magnet settings. Yet another 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 detector problems.

In 1991 data were taken on pressurized gas targets of ^{2}H, ^{3,4}He, ^{14}N, and ^{40}Ar at incident pion momenta of 220, 270, and 355 MeV/c. The logic permitted several different trigger types according to charged and neutral particle multiplicities, which were prescaled to emphasize the events with two or more charged particles. 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. The data filled about 200 8-mm video cassettes, equivalent to about 2500 9-track data tapes. We expect to have more running on additional targets and energies in late 1992 or early 1993.

Test were also made of a neutron time-of-flight detector wall in coincidence with the LADS. Previous studies suggested that multi-nucleon absorption processes often involve emission of one or more energetic neutrons.[13, 14] 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. Preliminary test results indicate that such running is probably feasable, but details are not yet available.

After four years of intense effort, the LADS detector has been constructed and most of the software necessary for production data replay is finished. One of the NMSU students (Wang) has completed the requirements for the Ph.D. degree, based in part on development of LADS hardware and software. Six other dtudents, including one from NMSU (Lin), are expected to base thesis projects on analysis of the LADS data from the 1989 and 1991 runs.

2.2 Analysis of Past Experiments

Work has been in progress on the analysis of data and the interpretation of the results of past experiments, in preparation for publication. This work includes the following:

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 with that experiment, 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 for any theory 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.[15, 16, 17, 18] 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 original analysis of the data, questions arose concerning its absolute normalization and the absolute values of the scattering angles. To answer these, additional data were taken both in 1990 and 1991. The analysis of the original data was carried out by George Kharimanis, a student at the University of Texas, and that of the new data was carried out principally by one of us (MR), with Charles Whatley, a student at Texas, under her supervision. An example of this work in shown in Fig. 5. Comparison of the results with the predictions of Ernst, et al,[15] is in progress. These results is being prepared for publication.

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.

This experiment was run in 1990, using the EPICS system. The target material used was ^{13}C-enriched toluene, 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.[19] This energy was chosen principally because differential cross sections for $\pi^{\pm}$ elastic and inelastic

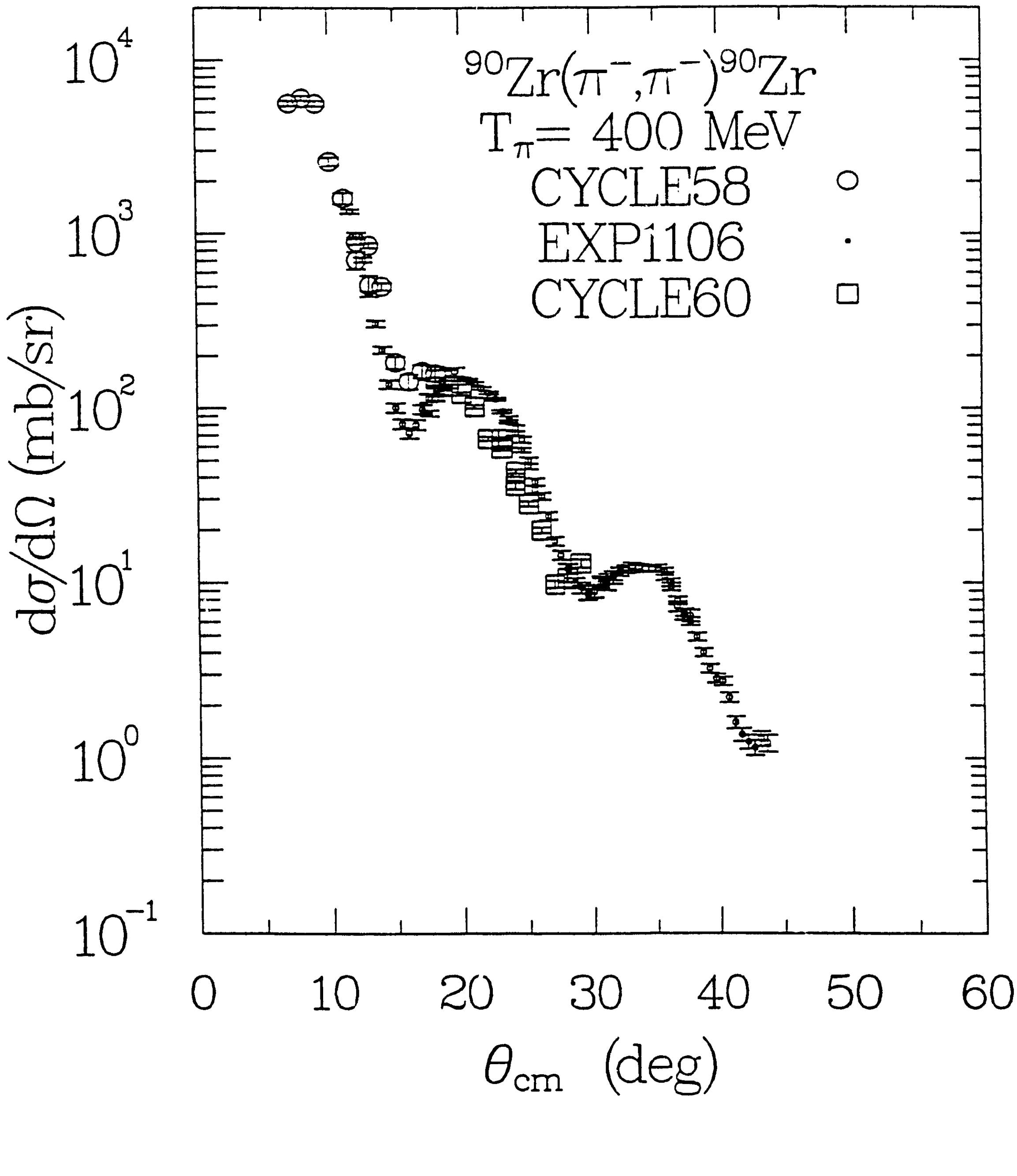

FIG. 5. Differential cross sections for the elastic scattering of π^- on ^{90}Zr at 400 MeV, from Exp. 1106. The data from Cycle 58 was taken in 1990, and that from Cycle 60 was taken in 1991.

scattering have been measured there.[20] 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 needed for comparison with theoretical predictions, some of which have previously been made.[21] 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(π^+,pp) by Altmann suggested that the unperturbed two-nucleon process constituted only about 10% of the total absorption at Δ(1232) resonance energies.[22] 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(π^+,pp).[23, 24, 25] 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.[26, 27]

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. 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.[25] 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 under-reports the strength of two-nucleon absorption.

A brief report on the 165 MeV results has been published,[28] and a paper describing the 115 MeV results has been submitted for publication.[29] A more complete paper on the comparison of the two energies in preparation.

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, 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, Rawool); B. G. Ritchie, ASU, Spokesman.

These proposals 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.[30, 31, 32]

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, 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.[33, 34] 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.[10, 11]

The reactions ^{4}He(π^+,2p)pn and ^{4}He(π^+,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.[35] The data analysis was based upon a Monte-Carlo simulation of the experiment using quasi-free phase space events generators. First results, which have been submitted for publication, show that, after correction by a factor of 1.4 for effects of final state interactions, the cross section ^{4}He(π^+,2p)pn reaction can explain only about 50% of the total absorption cross section.[36, 37] Analysis of the 3p channel is underway.

2.3 Preparation for Future Experiments

Work has also been in progress on plans and preparations for future experiments, including submissions of proposals to laboratory advisory committees. This includes the following:

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 physics of this proposed measurement is related to 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.[38] 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. Naive estimates of the former give a value of about 25 MeV, while analyses of pion-nucleon data have given values of 64 ± 8 MeV. Part of the discrepancy is believed to be related to 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.

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 this proposal to attempt to resolve some of these discrepancies by carrying out measurements of a new quantity, the asymmetry of $\pi^{\pm}$ scattering from a polarized proton target. In particular, we would like to take such data at 45 and 67 MeV, where differential cross-section measurements exist. The experimental setup used would be the same as used previously by this group.[19] This proposal was presented to the LAMPF Program Advisory Committee (PAC) in August, 1991, and it was given approval but no allocation of running time until specific questions raised by the proposal are addressed. We plan to present a response to these questions at the the January, 1992, meeting of the PAC.

LAMPF Proposal No. 1239, *Feasibility of the Direct Production of Pionic Atoms at LAMPF*, University of Texas, Rutgers, University of York, California Polytechnic Institute, Arizona State University, LANL, and NMSU; M. Rawool-Sullivan, C. L. Morris, LANL, and P. Siegel, California Polytechnic Institute, Spokesmen.

One quantity of particular interest in the pion-nucleus interaction 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 pi-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. In this proposal, we wish to investigate the possibility of observing these states through the direct-capture process,

$$\pi^- + (N, Z+1) \rightarrow p + (N, Z)_{\pi^-},$$

where the subscript π^- refers to the pion in an atomic state. This process represents the incident pion being captured directly into a $1s$ or $2p$ atomic orbital after striking a proton and knocking it out of the nucleus. Calculations of cross sections for this process, using the distorted-wave impulse approximation, have been carried out by Kaufmann, *et al.*[39] As might be expected, these cross sections are largest at small energies.

We would like to begin investigating this process, to determine whether information on these levels in such nuclei can be obtained in this manner. Since the cross sections are small, the signal-to-background rate is crucial, however. The background consists primarily of particles resulting from pion absorption in flight, since quasi-free knock-out of protons cannot be produced at the proton energy expected from atomic formation. Unfortunately, we have been unable to find experimental cross sections for these processes which would allow us to investigate the expected signal-to-background ratio, and internuclear cascade codes do not appear to be adequate for realistic estimates. The purpose of this preliminary proposal is to investigate these backgrounds, using the so-called BGO ball as a detector, as well as to determine the feasibility of using it to detect the expected signal as well. This proposal was presesnted to the PAC in August, 1991, and was approved for 96 hours of running, with an A^- priority. We hope to be able to run this test in 1992.

LAMPF Proposal No. 1267, *Elastic Scattering of π^+ and π^- from Polar-*

ized ^3He at T_π = 180 MeV to 475 MeV, University of Minnesota, TRIUMF, Ohio University, Tel Aviv University, LANL, and NMSU; D. Dehnhard, Minnesota, O. Häusser, TRIUMF, and G. Burleson, Spokesmen.

For this work, we propose to bring a polarized ^{3}He target from TRIUMF to LAMPF. This target has been used for several experiments at TRIUMF[40, 41, 42], and has been described in the literature.[43] AT LAMPF, we propose to measure the analyzing power A_y for both $\pi^\pm$ elastic scattering from polarized ^{3}He at incident energies between 180 and 475 MeV. Such measurements are not easily feasible at TRIUMF because of the lower beam rates there and the absense of suitable spectrometers. At LAMPF, such measurements are easily feasible.

Recent measurements of A_y for pion scattering from ^{3}He at 100 MeV found large values,[42] but similar measurements with ^{13}C and ^{15}N found values of A_y small or consistent with zero,[19, 44] in contrast to the large values predicted by theory.[21, 45] For the p-shell nuclei, the predicted asymmetries showed a strong dependence on the details of the nuclear structure, which suggests that information on nuclear spin excitations is contained in the data. The failure of the calculations to reproduce the measured values of A_y implies that the π-nucleus reaction mechanism, as related in particular to spin-flip scattering, is not sufficiently well understood. This suggests the importance of measuring asymmetries on a nucleus of well-known structure, for which the effects of the reaction mechanism and the nuclear structure can be separated.

Such a nucleus is ^{3}He, since reliable wave functions have been found for it by Faddeev calculations.[46, 47, 48] The 100-MeV pion asymmetry data were reproduced fairly well by optical model calculations,[42] as well as by a simple model using only free pi-nucleon amplitudes with a simple ^{3}He form factor.[49] At higher energies, however, predictions of this model and of a full multiple-scattering theory diverge,[49] leading to a prediction of a sign change of A_y at an energy of about 215 MeV. The predictions are also different for π^+ and π^-. In this experiment, we propose to measure this asymmetry at five energies from 180 to 475 MeV, at angles where the maximum effects are expected. From this we hope to find information which can be used to help understand the nature of pion spin-dependent interactions in nuclei, and of spin-dependent nuclear structure as well.

Initial experimental work with the Neutral Meson Spectrometer (NMS) System at LAMPF, the NMS Collaboration (including University of Colorado, MIT, Arizona State University, Abilene Christian University, LANL, and NMSU).

This device is a new high-resolution, large-acceptance spectrometer for detecting neutral mesons which is now under construction at LAMPF, with contributions from several university groups. It is designed to detect the two-gamma decay of π^0 and η^0

mesons and is expected to have an energy resolution for the meson of better than 300 keV. It will consist of two rectangular arrays of (pure) CsI scintillation counters for gamma-ray shower detection, preceeded by BGO converters with multiwire tracking chambers to determine the positions of the gamma rays. NMSU has worked on tests of prototype photomultiplier tubes for the CsI counters, construction and tests of the multiwire chambers, and beam tests of parts of the system.

At meetings of the NMS collaboration in August and November, 1991, discussions of plans for the device and for the first experiments to be run with it were held. The system will probably be only partly complete in summer, 1992, so it was decided to set it up at is exists at that time in a beam, make it operational, and carry out some experiments, both as a test of the system and to study some new physics. Suitable experiments must not require good resolution, however. Two experiments that were felt to be suitable, and which have been proposed by members of the collaboration, are *Measurements of* $\pi^- p \rightarrow \pi^0 n$ *Cross Sections in the Region of the* Δ *Resonance*, M. E. Sadler, Abilene Christian University, Spokesman; and *Measurements of Pion Single Charge Exchange of the Deuteron* ($\pi^- d \rightarrow \pi^0 nn$), J. L. Matthews, MIT, and R. M. Whitton, LANL, Spokesmen. It is expected that the full collaboration will participate in this work.

At the August meeting, it was also decided that, since the existing proposals for experiments with the NMS were not really suitable for a tune-up experiment or especially appropriate for a first physics measurement, an experiment suitable for a tune-up of the system, which also contains new and interesting physics, should be submitted. It is expected that this experiment would be run in 1993.

The experiment suggested at that time was **LAMPF Proposal No. 1269**, *Precise Measurements of Isovector Transitions in* ^{13}C *and* ^{7}Li *induced by Pion Single Charge Exchange*, E. R. Kinney, University of Colorado, and G. Burleson, Spokesmen. Here we propose to make precise measurements of the angular distributions of the reactions $^{13}\mathrm{C}(\pi^+,\pi^0)^{13}\mathrm{N}$ and $^{7}\mathrm{Li}(\pi^+,\pi^0)^{7}\mathrm{Be}$ at incident energies of 162 and 292 MeV, for both ground states and T=1/2 excited states. Previous studies[50, 51] have been unable to cleanly resolve the ground states from the first excited states of the recoiling nuclei. These data, together with previous measurements[52] of elastic and inelastic scattering of $\pi^\pm$ from ^{13}C, will allow, for the first time, an isospin decomposition of the transition amplitudes for pion scattering to these states. This includes extraction of T=1/2 and T=3/2 amplitudes, as well as isoscalar and isovector amplitudes, with their relative phase angles. Examples of such extractions, using existing data, are given in the proposal. In addition, the reaction $^{13}\mathrm{C}(\pi^-,\pi^0)^{13}\mathrm{B}$ will be investigated to cleanly study transitions to T=3/2 states. The results of theoretical analyses of these data are expected to be sensitive to microscopic details of the pion-nucleus interaction, expectially the effects of direct Δ-nucleon interactions.

We also propose to investigate a predicted energy variation of the position of the minimum of the ground-state isobaric analog transition which is similar to that seen in analaog transitions in DCX scattering (described above in the discussion of Exp. 1017U). After many years of investigation, an anomalous shift in the minimum of DCX analog transitions near the peak of the Δ resonance has not been satisfactorily explained. It is speculated that the proposed measurement may indicate that the anomaly can be attrributed to larger radii of the valence neutrons than is cuttently believed.

Also being presented to the PAC is **LAMPF Proposal No. 1258**, *The Direct Measurement of the π-Nucleon Interaction Strength Difference between π^+ and π^0*, University of Minnesota, Argonne National Laboratory, University of Texas, University of Illinois at Chicago, Leningrad Nuclear Physics Institute, California Polytechnic Institute, LANL, and NMSU; M. Rawool-Sullivan, W. R. Gibbs, and G. Burleson, NMSU, Spokesmen.

This proposed experiment involves the use of the NMS, together with a polarized ^{10}B target, for measurements of the asymmetry in the $^{10}B(\pi^+,\pi^0)^{10}C$ reaction. The theoretical motivation for this work has been discussed by Siegel and Gibbs.[53] Since the ground state of ^{10}B has spin-parity 3^+ and that of ^{10}C has 0^+, the pion must transfer 3 units of angular momentum to the nucleus. If we restrict ourselves to the p-shell, such a large ΔJ can only be achieved by a ΔL=2, ΔS=1 reaction, so that it can proceed only through the spin-flip amplitude of the πN interaction. In the plane-wave limit there is only a single πN amplitude contributing, and the asymmetry vanishes. If, however, there are distortions present, due to the difference of the incoming and outgoing waves, the asymmetry is not zero. The measurement of this asymmetry therefore is a direct test of the difference between the interaction of the charged and neutral pions with the nucleon. Because of the short lifetime of the neutral pion, and because the interaction of the charged pion with the nucleon is known only to about 5%, measurements of this kind are the only method of directly investigating such differences, and this experiment is the first one proposed that would provide information of this type. Measurements of charge-symmetry breaking in the πN system should have a large impact on our understanding of the strong interaction.

Besides an operational NMS, this experiment requires a polarized ^{10}B target. While the feasibility of polarizing ^{10}B has been indirectly demonstrated,[54] a useful target has not been developed. If the physics of this experiment is approved by the PAC, an effort will be mounted to produce such a target.

LAMPF Proposal No. 1172, *Cross Sections and Analyzing Power Measurements for $^7Li(\pi,\pi p)^6He$ with Good Kinematic Resolution*, Old Dominion University,

University of Maryland, University of Minnesota, Arizona State University, University of Texas, University of Pennsylvania, University of Colorado, Universität Karlsruhe, TRIUMF, LAMPF, and NMSU; N. Chant, Maryland, and A. Klein, Old Dominion, Spokesmen.

This experiment, which was originally scheduled to run at LAMPF in summer, 1990, and rescheduled for summer, 1991, will not be run at LAMPF due to the low ^{7}Li polarization obtained with a ^{3}He cryostat. Because a suitable $^{3-4}$He dilution cryostat is not available at LAMPF, the proposal will be submitted in January, 1992, to PSI, where a ^{7}Li polarization of up to 45% was demonstrated in Fall, 1991.

We plan to measure cross sections and analyzing powers for the reaction $^7Li(\pi^+,\pi^+p)^6He$. The scattered pions will be analyzed with the SUSI spectrometer, and the proton energies will be measured with an array of plastic scintillation counters we are constructing. Measurements will be made at 240 MeV at pion angles of 60^0, 85^0, and 110^0, with coincident proton angles roughly centered about the quasifree kinematics.

The aim of this experiment is 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 pion, compared to the proton, 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.[53] According to calculations of Roos and Chant,[55] it should be possible to separate these effects in an experiment of this kind, since forward scattering should contain strong contributions from the spin dependence of πp scattering and backward scattering relatively little. These results may help shed light on the unexpectedly small asymmetries observed in elastic scattering on ^{13}C and ^{15}N, and they may also be sensitive to the strength of the delta-nucleus spin-orbit interaction.

We expect this experiment to run in summer, 1992.

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; G. Kyle and G. Smith, 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 construction 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 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 $\Delta - N$ scattering.[56] 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.[57, 58, 59] From these models the strength of the $\Delta - N$ interaction in isospin, I=1,2, channels was obtained.[60, 61] A similar interaction was required to explain measurements of the polarization asymmetry, iT_{11}, for $\pi^+ d$ elastic scattering.[62]

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.[63].

We expect this experiment to run in 1993.

HERMES: *A Proposal to Measure the Deep Inelastic Spin-Dependent Structure Functions of the Nucleon at HERA,* Argonne National Laboratory, Caltech, MPI Heidelberg, University of Illinois–Urbana, LANL, University of Wisconsin, University of Marburg, MIT, Universität München, Stanford University, Universita di Torino, TRIUMF/Alberta/Simon Fraser, College of William and Mary, and NMSU; R. Milner, MIT, and K. Rith, Heidelberg, 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.[64] Perturbative QCD makes definite predictions about the evolution of the structure functions with momentum transfer Q^2 and their shape at large x (the parton momentum fraction).[65, 66, 67] 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[68] and Ellis-Jaffe[69] sum rules involving integrals of the spin structure functions. The Bjorken sum rule, which has not been experimentally tested, depends upon only very general properties such as current algebra. The Ellis-Jaffe sum rule, which seems to be violated by the experimental results on the proton, 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 $g_1(\mathrm{x})$ for the proton,[70, 71] and none have been made for the neutron. The results of these measurents have indicated the surprising result that the spin of the proton is not related very strongly to the spin of its quarks. This clearly 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 $A_1(x)$ and $A_2(x)$ 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 low dilution of polarized nucleons in the gas targets. The experiment will also set upper limits for two deuteron structure functions, $b_1(x)$ and $\Delta(x)$, which are expected to be small but which in principal can contribute to the deep inelastic cross section for a polarized deuteron target.

The detector system would consist of a magnetic volume with tracking multiwire proportional chambers for primary energy measurement, a transition radiation detector for hadron rejection, a trigger hodoscope, and a calorimeter for background rejection which also serves as the first-level trigger. We have proposed to work together with Caltech, Illinois, and Los Alamos on the calorimeter, and 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 and September, 1990, and approval was recommended under two conditions: demonstration of target density and polarization and demonstration of 60% transverse electron beam polarization. An electron polarization of 8% was observed in November 1991. The DESY machine physicists are confident that with a focussed effort on alignment of the magnetic elements and polarization calculations, they can improve the polarization to a high value. Further tests will take place in 1992. DESY accepts that target performance has been demonstrated, and, therefore, it is possible that the proposal will be given full approval next year.

A proposal has been submitted to the DOE and NSF for funding US participation.

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3 Publications

The following is a list of publications of the NMSU group between October 1, 1990 and January 1, 1992, not previously reported. The names of the authors previously or currently supported by DOE under this grant 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.-

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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).

3.2 Papers Submitted for Publication

1. *A Simple Three-Dimensional Magnetic Field Interpolation Techniques*; **R. W. Garnett** and G. R. Burleson; submitted to Nuclear Instruments and Methods.
2. *Accelerator Measurement of NaI Response to Medium Energy Neutrons and Applications to a Satellite-Borne Spectrometer*, P. P. Dunphy, E. L. Chupp, M. Popecki, D. J. Forrest, H. Spinka, T. Shima, D. Lopiano, G. Glass, **G. Burleson**, and **M. Beddo**; submitted to Journal of Experimental Astronomy.
3. *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; submitted to Nuclear Instruments and Methods.

4. *Neutron-Proton Elastic Scattering and Spin-Spin Correlation Parameter Measurement between 500 and 800 MeV*, W. R. Ditzler, D. Hill, J. Hoftiezer, K. F. Johnson, D. Lopiano, T. Shima, H. Shimizu, H. Spinka, R. Stanek, D. Underwood, R. Wagner, A. Yokosawa, **G. R. Burleson, J. A. Faucett, C. Fontenla, R. W. Garnett**, C. Lucini, **M. W. Rawool**, T. S. Bhatia, G. Glass, J. C. Hiebert, R. A. Kenefick, S. Nath, L. C. Northcliffe, R. Damjanovich, J. J. Jarmer, J. Vaninetti, R. H. Jeppesen, and G. E. Trippard; submitted to Physical Review C.

5. *Dominance of the Two-Nucleon Mechanism in* $^{16}O(\pi^+,pp)$ *at 115 MeV*, D. J. Mack, H. Breuer, N. S. Chant, S. D. Hyman, F. Khazaie, B. G. Ritchie, P. G. Roos, 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; submitted to Physical Review C.

6. *Two Nucleon Absorption of* π^+ *in* ^4He *at* $T_{\pi^+}=115$ *and 165 MeV*, F. Adimi, H. Breuer, B.S. Flanders, M.A. Khandaker, M.G. Khayat, 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 Physical Review C.

4 Advanced Degree Awarded

During 1991, the following student was awarded a Ph.D. degree:

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, through March 31, 1992 (projected) is given below. We note that Mohini Rawool-Sullivan is expected to leave the grant early in 1992, and that we expect to have a replacement for her soon after that.

Faculty Members:

George R. Burleson, 6 man-months

Gary S. Kyle, 6 man-months

Postdoctoral Research Associates:

Sanjoy Mukhopadhyay, 3 man-months

Mohini Rawool-Sullivan, 10 man-months

Minghong Wang, 4 man-months

Maozhi Wang, 3 man-months

Graduate Students:

Minghong Wang, [illegible] man-months

Zhinan Lin, 12 man-months

Qihua Zhao, 7 man-months

Maher El-Ghossain, 5 man-months

Javier Urbina, 3 man-months

END

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