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PION- AND PROTON-NUCLEUS INTERACTIONS AT INTERMEDIATE ENERGY

Progress Report

June 1, 1991 - May 31, 1992

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SUMMARY

π -meson and proton beams from the Los Alamos Meson Physics Facility (LAMPF) and the Indiana University Cyclotron Facility (IUCF) were used in scattering and reaction experiments on atomic nuclei. The experimental data allow tests of models of the reaction mechanism and of nuclear structure. For example, the asymmetries observed in a pion scattering experiment on polarized ^{13}C nuclei were found to contain unique information on the isoscalar spin density. However, further experiments on polarized nuclei of simpler structure are needed to provide the data for a thorough analysis of the reaction mechanism. For this reason a pion scattering experiment on a polarized ^3He target is planned and a high-resolution study on $^6\text{Li}(\pi, \pi')$ will be done. An analysis of π -triton coincidence events from the $^4\text{He}(\pi, \pi' t)p$ reaction yielded evidence for direct triton knock-out from ^4He . This work will be continued at higher incident pion energies. Additional work on the $^4\text{He}(p, n)$ reaction at IUCF is planned to determine the isovector strength in mass-4 nuclei and the level parameters of ^4Li .

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1 Introduction

This progress report summarizes the research in Experimental Intermediate Energy Nuclear Physics done between June 1, 1991, and May 31, 1992, under contract No. DOE/DE-FG02-87ER40362 between the University of Minnesota and the United States Department of Energy.

The research activities were performed at the Los Alamos Meson Physics Facility (LAMPF) and the Indiana University Cyclotron Facility (IUCF).

The following personnel were actively involved in performing the experiments and in their analysis: Dr. James L. Langenbrunner and Dr. Michal Palarczyk as full-time Research Associates; Dr. Michael A. Franey as part-time Research Associate, and three graduate students: Carla M. Edwards, Yi-Fen Yen, and Michelle Espy. The collaboration with Dr. S. Chakravarti of California State Polytechnic University on DWIA calculations of asymmetries in pion-nucleus scattering was continued during his stay at LAMPF in the summer of 1992.

The preparations for the experiments, the data taking, and the analysis were done in collaboration with colleagues from the Los Alamos National Laboratory, New Mexico State University, Arizona State University, and the Universities of Indiana, Texas, Maryland, Pennsylvania, and Colorado.

The completed work is discussed in Section 2, the work in progress in section 3, and publications, etc. are listed in section 4.

2 Completed Work

2.1 Pion Scattering from Polarized ^{13}C

LAMPF Experiment 1025U

Spokesmen: G. R. Burleson (NMSU) and D. Dehnhard (U. Minn.)

The analysis of Exp. 1025U has been completed and has been described in detail in the Ph.D. Thesis of Dr. Yi-Fen Yen. Dr. Yen graduated at the end of 1991. We insert here an invited paper about this work which was presented at the International Symposium on Mesons and Light Nuclei V, September 1-6, 1992, Prague, C.S.F.R.

Measurements of asymmetries in pion scattering provide information on nuclear spin excitations and the pion-nucleus reaction dynamics. The first experiments have recently been carried out on several p-shell nuclei.[1] - [3] Theoretical analyses using different nu-

clear structure and pion-nucleus reaction models have not been successful in reproducing the data.[1] - [6] This may be due to a lack of understanding of either the pion-nucleus dynamics, or the structure of the nuclear transition, or both. In this paper we demonstrate the strong sensitivity of the asymmetry to the details of the nuclear transition density using ^{13}C as an example.

The differential cross section for pion-nucleus scattering is proportional to the sum of the squares of the spin-independent and spin-dependent scattering amplitudes, F and G , respectively, $d\sigma/d\Omega \propto |F|^2 + |G|^2$. Since for elastic scattering usually $|F|^2 \gg |G|^2$, $d\sigma/d\Omega$ is very insensitive to G . However, A_y is proportional to the interference term of the spin-independent and spin-dependent amplitudes ($A_y \propto \text{Im}(FG^*)$). Thus A_y depends sensitively on the spin-dependent amplitude G .

Additional information on spin transitions in nuclei is contained in the magnetic form factor $|F_{M1}|^2$. $^{13}\text{C}(e,e)$ data exist[7] over a large range of momentum transfers (Fig. 1). The solid line in (Fig. 1) is the predicted $|F_{M1}|^2$ using Cohen and Kurath (CK) wave functions[8,9] in the code ALLWORLD.[10] The squares of the isoscalar (isospin transfer $T=0$) and isovector ($T=1$) form factor amplitudes are shown as dotted and dashed lines, respectively. The $T=1$ part is dominant at large momentum transfers, $q \geq 1.5 \text{ fm}^{-1}$. At $q \approx 0.6 \text{ fm}^{-1}$, the $T=0$ and $T=1$ parts are of comparable magnitude. The square of the $T=1$ spin part (without the convection current terms) (chain-dotted) is a factor of $[(\mu_p - \mu_n)/(\mu_p + \mu_n)]^2 = 28.5$ larger than that of the $T=0$ spin part (chain-dashed). Here μ_p (μ_n) is the proton (neutron) magnetic moment. The coherent addition of the spin and current terms results in the above-mentioned different q -dependences of the $T=0$ and $T=1$ parts of $|F_{M1}|^2$ and gives a good fit to the experimental $|F_{M1}|^2$ up to $q \approx 1.3 \text{ fm}^{-1}$.

The asymmetry in pion scattering has an isospin sensitivity very different from that of $|F_{M1}|^2$. For P_{33} pion-nucleon resonance dominance, the ratio r of the $T=0$ and $T=1$ pion-nucleus scattering amplitudes is, independent of q , $r=+2$ for π^- and $r=-2$ for π^+ if protons and neutrons contribute equally to the transition and if first-order processes dominate. Terms analogous to the current terms in electron scattering are thought to be small in pion scattering.

Table I: Neutron $\langle n \rangle$ and proton $\langle p \rangle$ parts of transition density amplitudes.

	J(LS)	0(00)	1(01)	1(21)
CK $\langle n \rangle$		2.041	-0.235	+0.929
Ref.[8,9] $\langle p \rangle$		1.633	-0.003	+0.039
TW $\langle n \rangle$		2.041	-0.208	-0.096
Ref.[12] $\langle p \rangle$		1.633	-0.015	-0.516

Because of this very different isospin dependence of the spin transitions by electron and pion elastic scattering, the pion asymmetry provides information complementary to the magnetic form factor for comparison with nuclear model predictions, especially for the isoscalar spin part of the transition density. We note that pion-induced single-charge-exchange (SCX) reactions[3] proceed exclusively by the isovector parts of F and G .

The nuclear transition density amplitudes are usually classified[9] according to the total and the orbital angular momentum transfers J and L , and the spin transfer S . Specifically for elastic scattering on a spin $J_0 = \frac{1}{2}$ nucleus such as ^{13}C , there are three possible combinations (Table I) of $J(LS)$: 0(00), 1(01), and 1(21) since the $L=1$ terms can be neglected in a first-order calculation. In terms of the nuclear structure amplitudes, the pion-nucleus amplitude F is proportional to the 0(00) part and G is proportional to a combination of the 1(01) and 1(21) parts.

The elastic scattering cross sections and asymmetries were calculated by combining the $J=0$ scattering amplitude from a first-order optical potential using PIPIT[11] with the $J=1$ scattering amplitude from a distorted wave impulse approximation (DWIA) calculation using ARPIN[9]. Shell model transition densities (Table I) of CK[8,9] and of Tiator and Wright[12] (TW) and variations of these densities were employed.

The fits to the elastic differential cross sections of Ref.[2] are quite reasonable (top of Fig. 2). The choice of either the CK or TW densities has only a very small effect on $d\sigma/d\Omega$

which are dominated by the $0(00)$ amplitudes (identical for CK and TW). However the asymmetries calculated with the CK and TW densities are very different. The solid lines in Fig. 2 were calculated using the CK density. Except for angles near 60° , $q \approx 1.2 \text{ fm}^{-1}$ (up to which CK model reproduces the magnetic form factor), the DWIA calculation gives only a poor description of the π^- asymmetry data. Near 90° , $q \approx 1.6 \text{ fm}^{-1}$, the asymmetry data and predictions are out of phase. At the momentum transfers $q \geq 1.6 \text{ fm}^{-1}$ the CK model prediction also deviates significantly from the experimental $|F_{M1}|^2$. The π^+ asymmetry data are consistent with zero at all angles but the CK density predicts negative A_y near 90° .

The TW density had been designed to fit the anomalous $^{13}\text{C}(\gamma, \pi^-)$ cross sections[13]. Calculations with these densities fail to fit the π^- asymmetry data by predicting either negative (near 50°) or near zero A_y (at 90°) whereas the data are either positive at intermediate angles or consistent with zero at small and large angles. The "fit" with the TW densities to the π^+ data near 90° is probably fortuitous since the data at small angles do not show the predicted negative asymmetry.

We note that the CK and TW values are very similar for $1(01)$ but totally different for $1(21)$ (Table I). What is primarily a $1(21)$ neutron particle-hole (p-h) amplitude in CK, is almost a pure proton (p-h) amplitude in TW. We have therefore studied how A_y is affected by renormalizing the $1(21)$, that is, the "quadrupole spin-flip" amplitude, by a factor α . The solid line in Fig. 3 shows again the calculated A_y with the $1(21)$ value of CK. Arbitrarily changing the sign of the $1(21)$ amplitude essentially flips the sign of the asymmetry (dashed line). Using two times the CK value nearly doubles A_y (chain-dashed line) and making the $1(21)$ piece zero gives a very small A_y (dotted line) which arises only from the interference of the $0(00)$ and $1(01)$ amplitudes. Thus A_y is exceedingly sensitive to the quadrupole spin-flip term. However, it appears that no value of the $1(21)$ amplitude would fit the data with the $0(00)$ and $1(01)$ parts left unchanged.

In order to explore the effects on A_y of possible higher-shell components in the nuclear wave functions, we have also done calculations with the phenomenological wave functions of Ref. [14] which are a mixture of $1p$ and $2p$ shell components. We find (Fig. 4) that for both

π^- and π^+ the 2p admixtures reduce the asymmetry near the first diffraction minimum but increase it near the second one with no improvement in the fit to the data. Relatively larger effects from the 2p admixtures were found in DWIA calculations for SCX.[15]

Before conclusions can be drawn from the asymmetries about the validity of nuclear wave functions, the pion-nucleus reaction model needs to be understood better. Preliminary calculations in the Δ -hole model[4] show significant differences in the asymmetries when compared to first-order optical potential predictions. Pion scattering on polarized ^3He might provide[16,17,18] the needed information for a thorough test of reaction models because the nuclear structure of ^3He is very well known and excellent wave functions exist from 3-body Faddeev calculations.[19] A first experiment on polarized ^3He has recently been performed at TRIUMF at $T_\pi = 100$ MeV [20]. These measurements should be extended to higher energies in order to exploit the strong energy dependence of the π -nucleon interaction and the larger range of q that becomes accessible.[18]

In conclusion, recently measured asymmetry data for pion scattering from ^{13}C are only poorly understood theoretically. If the pion-nucleus reaction dynamics were reliably known, these data would provide information on the spin transition density, specifically its isoscalar component, which is needed for tests of nuclear structure models. The best test of the reaction models may be provided by measurements of pion scattering on polarized ^3He since its structure is well known.

References

- [1] R. Tacik *et al.*, Phys. Rev. Lett. **63**, 1784 (1989).
- [2] Yi-Fen Yen *et al.*, Phys. Rev. Lett. **66**, 1959 (1991).
- [3] J. J. G3rgen *et al.*, Phys. Rev. Lett. **66**, 2193 (1991).
- [4] M. Thies, private communication.
- [5] R. Mach and S. S. Kamalov, Nucl. Phys. **A511**, 601 (1990) and R. Mach, Invited talk Proceedings International Symposium on Mesons and Light Nuclei V, Sept 1-6, 1992,

Prague, C.S.F.R., Springer Verlag, Wien, in press.

- [6] E. Boschitz, Invited talk, Proceedings International Symposium on Mesons and Light Nuclei V, Sept 1-6, 1992, Prague, C.S.F.R., Springer Verlag, Wien, in press.
- [7] R. S. Hicks *et al.*, Phys. Rev. C **26**, 339 (1982).
- [8] S. Cohen and D. Kurath, Nucl. Phys. **73**, 1 (1965).
- [9] T.-S. Lee and D. Kurath, Phys. Rev. C **21**, 293 (1980).
- [10] J. Carr, F. Petrovich, and J. Kelly, computer code ALLWORLD, unpublished.
- [11] R. A. Eisenstein and F. Tabakin, Comput. Phys. Commun. **12**, 237 (1976).
- [12] L. Tiator and L. E. Wright, Phys. Rev. C **30**, 989 (1984).
- [13] P. C. Dunn *et al.*, Phys. Lett. **B196**, 434 (1987).
- [14] C. Bennhold and L. Tiator, Phys. Lett. **B 238**, 31 (1990).
- [15] S. S. Kamalov, C. Bennhold, and R. Mach, preprint 1991.
- [16] C. Bennhold *et al.*, Universität Mainz, preprint MKPH-T-91-8.
- [17] S. S. Kamalov, Invited talk, Proceedings International Symposium on Mesons and Light Nuclei V, Sept 1-6, 1992, Prague, C.S.F.R., Springer Verlag, Wien, in press.
- [18] S. Chakravarti *et al.*, Invited talk, Proceedings International Symposium on Mesons and Light Nuclei V, Sept 1-6, 1992, Prague, C.S.F.R., Springer Verlag, Wien, in press.
- [19] J. L. Friar *et al.*, Phys. Rev. C **34**, 1463 (1986).
- [20] B. Larson *et al.*, Contribution to the 5th Conference on the Intersections between Particle and Nuclear Physics, May 24-29, 1991, Tucson, Arizona.

Figure 1: Magnetic form factor squared, $|F_M|^2$, from $^{13}\text{C}(e,e)$. Data of Ref.[7]. Solid line: prediction with program ALLWORLD[10] using CK densities. Dashed (dotted) line: T=1 (T=0) parts; chain-dashed: T=0 spin part only; chain-dotted: T=1 spin part only.

Figure 2: Elastic differential cross sections and asymmetries for $^{13}\text{C}(\pi, \pi)$ at 130 MeV. Data of Ref.[2]. Solid (dashed) line: DWIA calculation with CK (TW) densities.

Figure 3: Elastic differential cross sections and asymmetries for $^{13}\text{C}(\pi, \pi)$ at 130 MeV. Data of Ref.[2]. Solid line: DWIA calculation with CK densities ($\alpha=1$). Other curves, see text.

Figure 4: Data as for Fig. 3. Solid line: DWIA calculation with TW densities. Dashed (chain-dashed) line: with 16% (6%) 2p-shell admixture.

2.2 The $^4\text{He}(\pi, \pi t)p$ Reaction

LAMPF Experiment 998

We have continued the analysis of the work on the $^4\text{He}(\pi, \pi t)p$ reaction (LAMPF Exp. 998). The triton coincidence yields from this reaction were included in the angular correlation function from the $^4\text{He}(\pi, \pi p)$ reaction.[1] This gave us angular correlation data over a wide range of proton angles. In collaboration with W. R. Gibbs (LANL and NMSU) we have established that the angular correlation function at large proton emission angles (with the tritons emitted into the forward direction), can only be explained by a significant contribution of direct pion-induced triton knockout. A paper on this result is currently being prepared for publication.

References

- [1] M. K. Jones, D. Dehnhard, S. K. Nanda, S. Sterbenz, C. L. Morris, M. Plum, J. D. Zumbro, Ahmed Hussein, D. S. Oakley, M. J. Smithson, A. L. Williams, J. McDonald, M. A. Bryan, A. H. Fuentes, M. Lynker, D. Crockett, M. A. Machuca, S. Mordechai, and C. Fred Moore, Phys. Rev. C **42**, R807 (1990); M. K. Jones, Ph. D. thesis, University of Minnesota; and preprint submitted to Phys. Rev. C.

3 Work in Progress

3.1 The $^4\text{He}(\bar{p}, n)^4\text{Li}$ Reaction at 100, 147, and 200 MeV.

IUCF Experiments 342 and 342U.

Spokespersons : M. Palarczyk, B. Brinkmüller, D. Dehnhard, and L. C. Bland (IUCF).

In April of last year we performed the first (p, n) experiment ever done on ^4He . The Neutron-Time-Of-Flight Facility (NTOF) at the Indiana University Cyclotron Facility (IUCF) was used. This experiment is planned to be the Ph. D. Thesis experiment of Carla M. Edwards.

The primary goal of the experiment is the investigation of the ${}^4\text{He}(\bar{p},n){}^4\text{Li}$ reaction over a range of incident proton energies where the relative strengths of the spin-dependent and spin-independent nucleon-nucleus force change significantly. This strong energy dependence should aid in determining the contributions from excitations of states in ${}^4\text{Li}$ (having different multipolarities) to the continuum spectra. Thus, this reaction will provide new information on the isovector excitations of mass-4 nuclei and about the parameters of levels in ${}^4\text{Li}$ which have been quite controversial recently.

Previous work on mass-4 nuclei has reported significant differences between the level parameters deduced from the relative energy spectra of the breakup products $p + {}^3\text{He}$ from different reactions involving ${}^4\text{Li}$. The present experiment should allow a direct determination of the level energies and widths of ${}^4\text{Li}$.

Neutron time-of-flight spectra were taken with two fixed neutron detector stations, one located at a distance of 76 m from the target at a nominal scattering angle of 0° , the other at a distance of 50.6 m, nominally at 24° . the "beam swinger" magnet at IUCF can vary the direction of the incident proton beam between 0° and 20° , allowing scattering angles between 0° and 20° to be observed at the first detector station, while angles between 24° and 44° may be observed at the second. Data were taken at 0° , 5° , 10° , 16° , 24° , 29° , 34° , and 40° , at three proton energies: 100, 147, and 200 MeV. At 200 MeV, data at four additional angles were taken: 7° , 20° , 31° , and 44° .

The target cell was a welded stainless steel box with Havar windows. When filled with helium, the cell was cooled with liquid nitrogen to a temperature of 109 K and the pressure in the cell was typically 5 kT. Operation at low temperature and high pressure increases the number of scattering centers by a factor of 18 compared to standard temperature and pressure. The ratio of scattering centers in the helium gas to those in the windows was about 10 to 1 which assured a good peak-to-background ratio.

At all angles and energies, spectra were taken with an empty target for background subtraction, and from ${}^{12}\text{C}$ and ${}^{13}\text{C}$ foils for normalization of the yields to previously measured cross sections. A few spectra were also measured with methane (enriched in ${}^{13}\text{C}$) in the target cell to look for possible systematic differences between spectra from solid and

gaseous targets.

The neutron TOF spectra are currently being analyzed. At 100 MeV the data look mostly reasonable and the carbon yields compare well to previously published values. The majority of the 147 MeV data, however, show an oscillatory pattern in the position-corrected TOF spectra which is clearly due to some instrumental artifact. We are presently trying to develop a method to extract useful data from these spectra.

At 200 MeV, the spectra at 10° and 16° , with ^4He in the target cell, contain a distinct peak of about 2 to 2.5 MeV width with large positive asymmetry. The energy of this peak is near the threshold of the $^4\text{He}(p,n)$ reaction and it is superimposed to a broad continuum. A width of about 2 to 2.5 MeV appeared reasonable for a state in ^4Li since values as small as 1 to 1.5 MeV and as large as 5 MeV had been reported previously. However, the position of this peak as a function of angle did not follow the expected kinematic behavior of a state in ^4Li , but the possibility existed that perhaps different states in ^4Li were seen at the two angles.

In order to find out whether the observed peak was due to an experimental artifact, we decided to fill the target cell with ^3He . This was done near the end of the scheduled beam time. If similar structures would be observed in the $^3\text{He}(p,n)^3\text{p}$ reaction, they would be a strong indication of an experimental problem. Quite surprisingly, peaks of a width similar to that for ^4He , were observed with ^3He at 10° and 16° . Also, the kinematic shift between the two angles did not agree with expectations based on the kinematics of a $^3\text{He}(p,n)^3\text{p}$ reaction to a (very unlikely) state in the 3-proton system. This behavior is similar to that of the peak in the spectra from ^4He which did not follow the kinematics of a single state in ^4Li . In addition, the difference between the peak positions in the spectra from ^3He and ^4He did not agree with expectations. Finally, these peaks also did not match simultaneously the expected kinematic behavior, the strengths, and the asymmetries of (p,n) reactions on any likely contaminants.

After conclusion of the run and after much deliberation, a process was identified which most likely produces these peaks. It successfully explains their positions, their widths and kinematic behavior, the shift of the peaks between ^3He and ^4He , the observed asymmetries,

the fact that these peaks were seen only for a small range of angles, and several other observed features. This process involves protons, elastically scattered from the target, passing the beam dump magnet and the sweep magnet downstream from the target. The protons get deflected by about 10° by the sweep magnet and thus travel in a direction slightly to the left of the 0° detector station. They slow down due to the energy loss in the air and then scatter from some material, most likely air, reaching the detectors primarily from the side. (The detectors consist of 1-m long scintillators, aligned with the direction of the reaction neutrons and a position-sensitive signal is derived from the photomultiplier timing signals from the two ends of the scintillators).

The positions of the peaks in the TOF spectra were found to be those expected from the TOF of protons which slow down as they travel the approximately 76 m to the 0° detector station. The TOF depends, of course, on the energy of the protons as they leave the target. This energy is angle- and target-dependent and the scattering angle is affected by the dump and sweep magnets. This explains the unusual angle- and target-mass dependence of the peaks, e. g., the shifts in peak positions between ^3He and ^4He . The yields and the observed large positive asymmetries of the peaks are consistent with the yields and the asymmetries of elastic proton scattering.

The observance of the peaks only in our 10° and 16° spectra suggests that, whereas the downstream magnets are intended to prevent protons from reaching the neutron detectors, there exists a narrow "window" of angles (and momenta) through which protons escape and reach the 0° detector station. In this context it is useful to know that the field of the dump magnet is set to zero for the 13° swinger setting. Thus the field of the dump magnet is relatively small (and of opposite sign) for the 10° and 16° settings (where the peaks from proton scattering were observed). Apparently, the sweep magnet in the " 0° neutron channel" does not prevent all scattered charged particles (which escaped the dump magnet) from reaching the 0° -neutron detector station. At 100 MeV the protons are stopped in the air before they reach the 0° -station. Thus no peaks are expected and none were seen.

In the 24° -neutron channel, we had installed a copper plate because this channel was not equipped with a sweep magnet. Different thicknesses were chosen, depending on the

beam energy, so that the energy losses in the plate and in the air were sufficient to stop charged particles and no narrow structures were observed in the neutron spectra with this detector.

Because the spectra at 200 MeV contained these peaks, a proposal update was presented to the PAC at IUCF and 15 additional shifts of beam time were approved. This time will be used to take a set of spectra with the proton events removed by an absorber plate installed in the 0° beam line. We hope that we will be able to perform this experiment soon. Clean spectra are necessary to confidently draw conclusions about the existence or nonexistence of narrow structures in ^4Li , which was one of the original goals of this experiment.

3.2 $(\pi, \pi' X)$ Coincidence Measurements on ^4He , ^3He , and D

LAMPF Experiment 1216

Spokespersons: J. L. Langenbrunner, D. Dehnhard and M. K. Jones (Rutger's U.)

LAMPF Experiment 1216 has been scheduled for the summer of this year. This experiment will measure angular correlation functions for the $(\pi^\pm, \pi^\pm' X)$ reactions on D, ^3He , and ^4He where X is a proton, deuteron, or triton. The experiment is to be done with the large acceptance spectrometer (LAS) in the P3 channel at three incident energies, 180, 240, and 300 MeV. Data will be taken over a range of momentum transfers and target excitation energies so as to cover the kinematic conditions of simple quasifree $(\pi, \pi' X)$ scattering, and the energy region near particle breakup threshold. These data will allow tests of pion-nucleus reaction models, including a model which predicts significant contributions from quasi-free triton knock-out from ^4He , or deuteron knockout from ^3He or ^4He .

One of us (J. L.) collaborated with C. L. Morris and R. M. Whitton of Los Alamos National Laboratory to develop new detectors with improved charged-particle identification and energy resolution, which will be essential to Experiment 1216. These detectors consist of a thin-plastic scintillator optically coupled to a CsI crystal which is optically coupled to a photomultiplier, forming a "CsI-phoswich" detector. Use is made of the *fast* component

of the CsI signal and the *slow* component of the plastic scintillator, that is, the operation of the detectors is the reverse of that of previous phoswich detectors. A "Letter" about this detector development is in press (Nucl. Instr. and Methods A).

3.3 Elastic Scattering of π^+ and π^- from Polarized ^3He at $T_\pi = 180$ to 475 MeV.

LAMPF Experiment 1267.

Spokespersons: D. Dehnhard (U. Minnesota), G. R. Burleson (New Mexico State U.), and O. Häusser (TRIUMF).

At the recent Program Advisory Committee meeting at LAMPF in January one of us (D.D.) presented a proposal to measure elastic scattering of π^+ and π^- from polarized ^3He at $T_\pi = 180$ and to 475 MeV. The proposal was well received by the committee and was allotted 840 hours of beam at A⁻ priority. Below we quote the "summary" of the proposal. This experiment is likely to run in 1993. However, during the summer of 1992 we will do a test run to determine the level of background events and to develop methods of background reduction should that be necessary.

Summary of Proposal

We propose to measure analyzing powers A_y for both π^+ and π^- elastic scattering from polarized ^3He at incident energies between $T_\pi = 180$ MeV and 475 MeV. Large analyzing powers were recently observed at $T_\pi = 100$ MeV. The proposed measurements are in an energy region where the π -nucleon force is strongly energy- and isospin-dependent. Theoretical calculations predict that these dependences result in strongly energy-dependent A_y which differ for π^+ and π^- . Excellent Faddeev wave functions are available for ^3He which imply that the spin of ^3He is nearly 90% due to that of the unpaired neutron. Thus nuclear structure uncertainties are minimized and information on the spin- and energy-dependence of the π -neutron interaction in nuclei and the π -nucleus reaction mechanism will be obtained.

3.4 Measurement of Angular Distributions $d\sigma/d\Omega$ for ${}^6\text{Li}(\pi^+, \pi^+)$

Spokespersons: E. Boschitz and B. Brinkmüller (U. of Karlsruhe and PSI)

Participants: S. J. Greene, D. Dehnhard, J. L. Langenbrunner, M. A. Palarczyk, C. M. Edwards, E. Boschitz, B. Brinkmüller, R. Meier, and S. Ritt.

This experiment has been tentatively scheduled for September of this year. It requires the high resolution capability of EPICS to resolve the low-lying states of ${}^6\text{Li}$. It was proposed by the Karlsruhe/PSI group and will be done with major participation of the U. of Minnesota group. We quote here the summary from the proposal.

Summary of Proposal:

${}^6\text{Li}$ shows typical properties of heavier nuclei, but is sufficiently light to allow the calculation of nuclear processes with realistic interactions. At $T_\pi = 100$ MeV, 134 MeV, 164 MeV, and 219 MeV, iT_{11} has been measured in a previous ${}^6\text{Li}(\pi, \pi)$ experiment at PSI on a polarized ${}^6\text{Li}$ target. Measurements of T_{20} and additional measurements of iT_{11} will be made at these energies and at $T_\pi = 190$ MeV in future PSI experiments. To supplement the polarization data, very good knowledge of the elastic differential cross sections is needed to put constraints on the models that are used to describe π -nucleus scattering. We therefore propose to measure the angular distributions for ${}^6\text{Li}(\pi^+, \pi^+)$ scattering from $\Theta_{lab} = 25^\circ$ to $\Theta_{lab} = 120^\circ$ at the above-mentioned energies using the EPICS spectrometer.

4 Publications etc.

4.1 Published papers

1. "Asymmetry measurements of pion elastic scattering from polarized ^{13}C in the energy region of the P_{33} resonance,"
Yi-Fen Yen, B. Brinkmüller, D. Dehnhard, S. M. Sterbenz, Yi-Ju Yu, Brian Berman, G. R. Burleson, K. Cranston, A. Klein, G. S. Kyle, R. Alarcon, T. Averett, J. R. Comfort, J. J. Görgen, B. G. Ritchie, J. R. Tinsley, M. Barlett, G. W. Hoffmann, K. Johnson, C. F. Moore, M. Purcell, H. Ward, A. Williams, J. A. Faucett, S. J. Greene, J. 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, M. A. Khandaker and S. Chakravarti, *Phys. Rev. Lett.* **66**, 1959 (1991).
2. "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. Brinkmüller, D. Dehnhard, Yi-Fen 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).
3. "Elastic scattering of π^+ and π^- from ^4He between 90 and 240 MeV,"
B. Brinkmüller, C. L. Blilie, D. Dehnhard, M. K. Jones, G. M. Martinez, S. K. Nanda, S. M. Sterbenz, Yi-Fen Yen, L. G. Atencio, J. A. Faucett, S. J. Greene, C. L. Morris, S. J. Seestrom, G. R. Burleson, K. S. Dhuga, R. W. Garnett, K. Maeda, C. Fred Moore, S. Mordechai, A. Williams, S. H. Yoo, and L. C. Bland, *Phys. Rev. C* **44**, 2031 (1991).
4. "Inelastic scattering of polarized protons from ^4He at 500 and 800 MeV,"
S. M. Sterbenz, D. Dehnhard, M. K. Jones, S. K. Nanda, C. E. Parman and Yi-Fen

- Yen, K. W. Jones, C. L. Morris, Phys. Rev. C , (1992) in press.
5. "CsI-phoswich detector for charged-particle identification,"
J. L. Langenbrunner, C. L. Morris, R. M. Whitton, Nucl. Instr. and Meth. A (Letter to the Editor), in press, (1992).
  6. "Test of superconducting radio-frequency cavity bombarded by protons,"
J. M. O'Donnell, B. J. Mc Cloud, C. L. Morris, J. B. McClelland, B. Rusnak, H. A. Thiessen, J. L. Langenbrunner, Nucl. Instr. and Meth. A, in press, (1992).

4.2 Papers in preparation

1. " $^4\text{He}(\pi, \pi' p)^3\text{H}$ reaction near the P_{33} π -nucleon resonance,"
M. K. Jones, D. Dehnhard, S. K. Nanda, S. M. Sterbenz, C. L. Morris and M. Plum,
J. D. Zumbro, Ahmed H. Hussein, D. S. Oakley, M. J. Smithson, A. L. Williams,
J. McDonald, M. A. Bryan, A. H. Fuentes, M. Lynker, D. Crockett, M. A. Machuca,
S. Mordechai, and C. Fred Moore, to be submitted to Phys. Rev. C (1992).
2. "Evidence for direct triton knockout in the $^4\text{He}(\pi, \pi t)$ reaction,"
J. L. Langenbrunner, M. K. Jones, D. Dehnhard, C. L. Morris, W. R. Gibbs, to be
submitted to Phys. Rev. C, (1992)
3. "Pion production at small angles for PILAC,"
J. L. Langenbrunner, C. P. Pillai, Los Alamos Report No. LA-UR-91-1268, to be
submitted to Nucl. Instr. and Meth. A (1992).

4.3 Invited talks

1. "Pion-nucleus interactions at P3 energies," D. Dehnhard, Informal Meeting on Physics with Polarized Targets, August 18, 1991, LAMPF, Los Alamos, N.M.
2. "Pion elastic scattering on a polarized ^{13}C target", D. Dehnhard, Yi-Fen Yen, M. A. Franey, and S. Chakravarti, International Symposium on Mesons and Light Nuclei

V, September 1-6, 1991, Prague, C.S.F.R.

3. "Spin excitations of nuclei by pions", S. Chakravarti, C. M. Edwards, D. Dehnhard, and M. A. Franey, International Symposium on Mesons and Light Nuclei V, September 1-6, 1991, Prague, C.S.F.R.
4. "Pion scattering and reactions on polarized nuclei," D. Dehnhard, Indian Summer School on Nuclear Physics, September 8-13, 1991, Sazava, C.S.F.R.
5. "Results of BGO resolution studies," J. L. Langenbrunner, Informal Meeting of Neutral Meson Spectrometer (NMS) Collaboration, November 15, 1991, LAMPF, Los Alamos.
6. "Effect of proton beam on scruncher performance", J. L. Langenbrunner, Workshop on PILAC Superconducting Cavity, October 5, 1991, LAMPF, Los Alamos.

4.4 Contributed papers and abstracts

1. "Pion-proton integral cross section from 60 to 260 MeV,"
R. A. Ristenen, B. J. Kriss, S. Hoibraten, M. Halcomb, M. D. Kohler, J. J. Kraushaar, S. P. Parry, A. Saunders, W. R. Smythe, C. L. Morris R. M. Whitton, J. T. Brack, J. L. Langenbrunner, E. F. Gibson, Contribution to the IV. International Symposium on Pion-Nucleon Physics and Structure of the Nucleon, Bad Honnef, Germany, September 9-13, 1991.
2. "Coincidence measurement of ${}^4\text{He}(\pi, \pi' p)\text{T}$ and ${}^4\text{He}(\pi, \pi' t)p$," J. L. Langenbrunner, M. K. Jones, D. Dehnhard, C. L. Morris, and W. R. Gibbs, Bull. Am. Phys. Soc. (Spring Meeting of the APS, Washington 1992).
3. "Pion production at small angles for PILAC", J. L. Langenbrunner, M. Barakat, E. Hungerford, C. Pillai, N. Tanaka, K. W. Jones, L. Rybarczyk, D. B. Barlow, J. Donahue, C. L. Morris, J. McClelland, H. A. Thiessen, and R. D. Werbeck, Bull Am. Phys. Soc. (Spring Meeting of the APS, Washington 1992).

4.5 Contribution to general report

1. "Pion-nucleus interactions with high-energy pions", D. J. Ernst and D. Dehnhard, in PILAC Users Group Report on the Physics with PILAC, Los Alamos National Laboratory Report, LA-UR-92-150, 161 (1991).

4.6 Degree granted

Ms. Yi-Fen Yen, Ph.D., University of Minnesota, December 1991.

Title of Ph.D. Thesis:

"Pion Elastic Scattering from Polarized ^{13}C in the Energy Region of the P_{33} Resonance,"

**DATE
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8/27/92