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(Task C)

Report
PROGRESS IN RESEARCH

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by the

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THE P-7 (LASL), TAMU, UTEXAS, COLLABORATION ON
MEDIUM ENERGY MEASUREMENTS OF n-p PARAMETERS

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MASTER

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I. INTRODUCTION

The purpose of this report is to summarize our progress in Medium Energy Research during 1978. The research has been supported by the U.S. Department of Energy Contract No. EY-76-C-05-2972, TASK C. The group, all from the University of Texas at Austin, consists of P.J. Riley, Professor of Physics, Charles Hollas, Research Scientist, and two Physics Graduate students, Charles Newsom and Ron Ransome. Our research program is one principally involving medium energy neutron experiments at LAMPF. It is a collaborative effort involving the University of Texas, Texas A & M University, and Los Alamos Scientific Laboratory. The aim of the experimental program is the determination of the nucleon-nucleon amplitudes at medium energy. The required data include both elastic and inelastic experiments, and in addition the measurement of polarization and spin correlation parameters. The progress reported here is progress involving the collaborative research program as a whole. We have tried to emphasize the research work that the University of Texas group was most concerned with.

During 1978 Charles Hollas completed the data analysis for experiment 262, "Test of Isospin Invariance in the Reaction $np \rightarrow d\pi^0$ ". A manuscript is now being written for publication. Much of his time was spent assisting in preparations for experiments 65, "Neutron-Proton Polarization Measurements Using a Polarized Target: Phase I. The n-p Polarization Observable $P(\theta)$," and 66, "Neutron-Proton Polarization Measurements Using a Polarized Target: Phase II. The n-p Spin Correlation Observable, $C_{NN}(\theta)$," particularly with the design and fabrication of the high efficiency neutron detector. During August he attended in 8th International Conference on Few Body Systems and Nuclear Forces, held in Graz, Austria, at which he presented the talk "A Test of Isospin Invariance in the $np \rightarrow d\pi^0$ Reaction at 795 MeV." After the conference he visited the SIN Laboratory, near Zurich, Switzerland. Much

of his time during the second half of 1978 has been spent in LAMPF experimental runs on experiments 65 (August) and 66 (December), and on preparations for experiment 360 "The Measurement of the Polarization Transfer Coefficients D_t and A_t at 800 MeV for the Reactions $d(\vec{p}, \vec{n})2p$, ${}^6\text{Li}(\vec{p}, \vec{n}){}^6\text{Be}$, and ${}^9\text{Be}(\vec{p}, \vec{n}){}^9\text{Be}$;" to be started during February of 1979. He is currently also serving as chairman of the Nucleon Physics Laboratory (NPL) working group and as a member of the LAMPF Technical Advisory Panel (TAP).

Charles Newsom has spent the past year in residence at Los Alamos, with the support of an Associated Western Universities (AWU) Fellowship. Much of his time during the early part of the year was spent on instrumentation work for experiment 65; during the spring he started to familiarize himself with the new data acquisition program to be used for experiment 65 by writing a program to control remotely 64 channels of a photomultiplier high voltage supply. Since then he has become an expert in programming and file manipulation on the PDP RSX 11 D operating system and with the LAMPF "Q" data acquisition programs. In addition, he has become expert in virtually all aspects of the existing experimental arrangement, including the polarized target, MWPC spectrometer, electronics, and programming of the PDP 11/60 computer. Most of his time during the fall has been involved in off-line data analysis of the data for experiment 65. His thesis work will be based on this measurement.

Ron Ransome spent the summer of 1978 at LAMPF with the support of an AWU summer thesis parts program, where he assisted during the experimental runs of experiment 65, and also in preparations for experiment 360. During the Spring and fall semesters at the University of Texas at Austin he completed his Ph.D. course requirements, passed his Ph.D. qualifying examinations, and wrote a Monte Carlo computer simulation code for experiment 387, "Energy Dependence of the Forward Angle np Differential Cross Section". As of January

1, 1979, he has moved to Los Alamos to begin his Ph.D. Dissertation research.

Peter Riley spent most of June and August in Los Alamos, where he assisted in data acquisition for experiment 65; he spent July at TRIUMF, Vancouver, where he worked with the BASQUE group in preliminary measurements of TRIUMF experiment 26, "The Differential Cross Section in Neutron-Proton Elastic Scattering between 210 and 495 MeV." During December he assisted in data acquisition for experiment 66 at LAMPF. He spent much additional time during the past year involved with preparations for LAMPF experiment 360; for which he is co-spokesman.

The largest effort during the year involved preparations and data acquisition for experiment 65 and 66. These experiments were the first to utilize a highly revised layout of our multi-wire proportional counter spectrometer (MWPC) system used in coincidence with a large high-efficiency neutron detector and a polarized proton target. Briefly, the MWPC was re-worked to as to obtain a two-fold increase in solid angle of the spectrometer; New MWPC's were designed and built to provide better reliability and greater flexibility in the placement of chambers. The neutron detector system was built and tested. A new PDP 11/60 computer with four times the memory (128 K versus 32 K) was procured and installed; software for the new system was developed. Since the new software is designed to include the recognition of elastic n-p events as observed (in coincidence) in the MWPC and in the neutron detector, a considerable amount of program work was involved. A larger trailer was modified into an instrumentation trailer to provide greater space for the data acquisition hardware. Finally, reliable operation and polarizations generally in excess of 80% were achieved with the large volume polarized proton target used in experiment 65 and 66.

Specific contributions by the University of Texas include the purchase of a VERSATEC Model 1100 A printer/plotter for use with the new PDP 11/60

system. This printer/plotter is now an indispensable part of the computer system, being used primarily to record on-line histograms and print-outs of the data and as a line printer for off-line analysis. During the early part of 1978 the University of Texas fabricated sixty new bleeder strings and tube bases for the 12-stage Amperex 2230 photo multiplier tubes used in the neutron and other scintillation counters for experiment 65. Later during 1978 the machine shop at the University of Texas fabricated the parts for the liquid hydrogen target chamber enclosure for the new large volume LH_2 scattering target to be used in experiment 360 (and succeeding experiments). Approximately 150 man hours of machine shop time were required for the LH_2 target fabrications.

II. EXPERIMENTAL RESEARCH

In the following we list and discuss briefly specific experiments and technical development work for experiments with which we have been involved during 1978. We do not include here descriptions of work either published or submitted for publication - the title pages of these manuscripts are given in Section V of this progress report.

1. A Test of Isospin Invariance in the $np \rightarrow d\pi^0$ Reaction at 795 MeV.

The concept of isotopic spin was introduced by Heisenberg in 1932 to describe the neutron and the proton as two states of the same particle, and since then many experiments have been devised to test the validity of this hypothesis. Recently Pedroni et al², as a result of $\pi^{\pm}p$ total cross section measurements, concluded that charge independence fails at the level of one percent at the Δ_{33} resonance. They reported a similar failure of charge symmetry in $\pi^{\pm}d$ total cross section measurements. Brandenburg, Coon, and Sauer³, after a critical examination of the binding-energy difference for the ${}^3\text{He}$, ${}^3\text{H}$ systems, concluded that 81 ± 29 KeV of the experimental binding energy difference must be attributed to nuclear charge asymmetry. Friar and Gibson⁴ have deduced very nearly the same result. In all of the above examples, however, large Coulomb effects must be calculated before the extraction of any isospin violating portions of the strong interaction. The measurements reported here provide a test of the validity of charge independence which is free of Coulomb corrections.

As suggested by Yang⁵, if the strong interaction conserves isospin and is independent of the third component of isospin, the two cross sections

$$pp \rightarrow d\pi^+ \quad (1)$$

$$np \rightarrow d\pi^0 \quad (2)$$

must differ exactly by a factor of two. That is, angular distributions measured at the same c.m. energy for the two reactions must have the same shape and differ only in magnitude. An immediate consequence is that the $np \rightarrow d\pi^0$ angular distribution must be symmetric about 90° , since for reaction (1) identical particles are in the entrance channel. This test is independent and does not rely on any other measurement, or upon Coulomb corrections. A second consequence, that the shapes of reaction (1) and (2) are the same, requires accurate measurements for both reactions, Coulomb corrections, and in addition

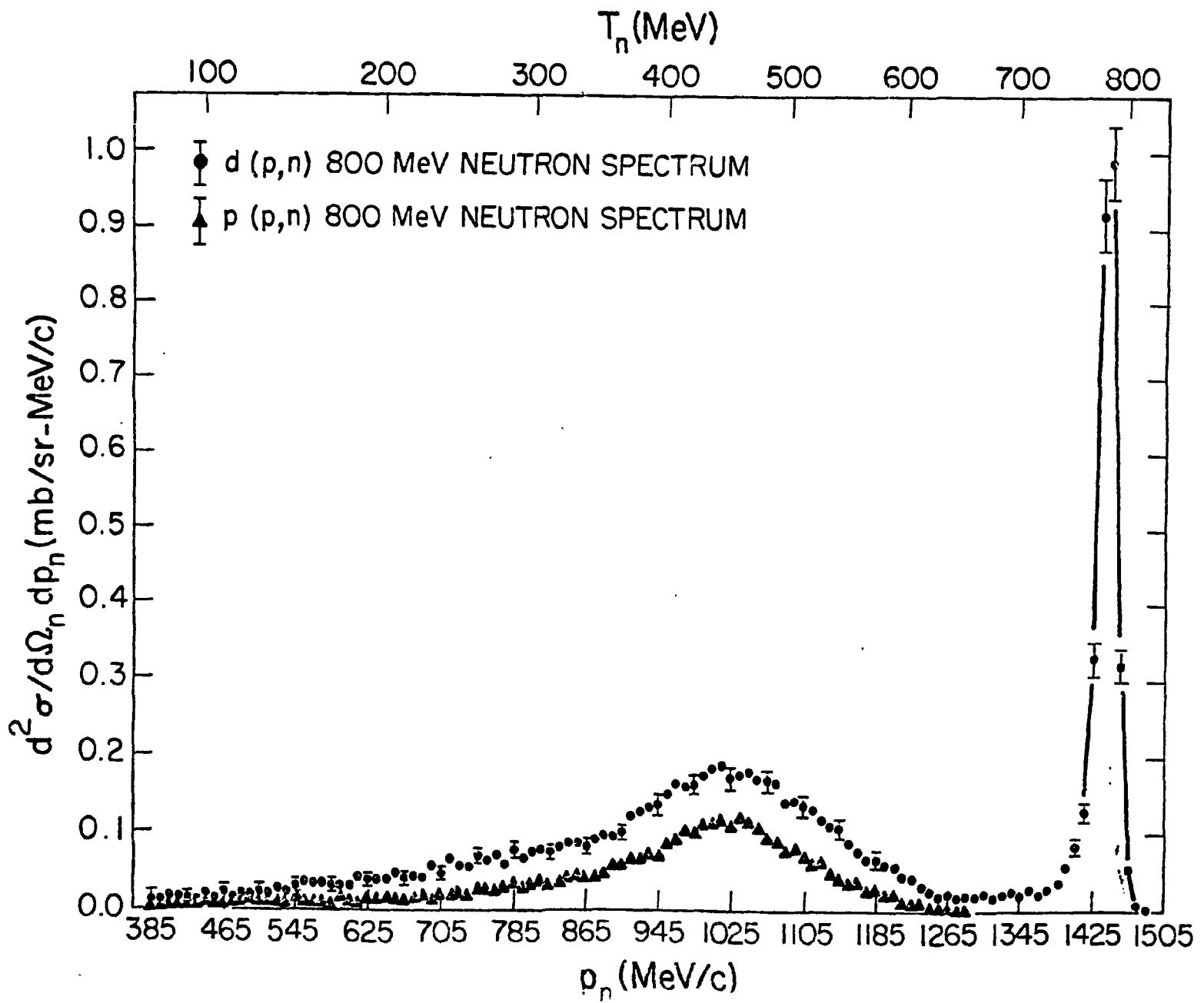
n-p and $\pi^+ - \pi^0$ mass differences must be considered. These same considerations hold for a comparison of the absolute magnitude of the cross section for the two reactions.

In 1952 Hildebrand obtained six data points in the $np \rightarrow d\pi^0$ angular distribution, and found no asymmetry about 90° . In addition, a fit to comparable $pp \rightarrow d\pi^+$ data passed through his data points. The most accurate recent $np \rightarrow d\pi^0$ measurements are those of Bartlet et al.⁷ and of Wilson et al.⁸ However, Bartlet et al. were not able to detect the need for a $\cos^4\theta$ term to fit their $np \rightarrow d\pi^0$ data; such a term is required to fit the most accurate $pp \rightarrow d\pi^+$ data. Wilson et al. were able to place an upper limit of about 1% on the real part of the ratio of isospin-violating to isospin-conserving amplitudes.

Both of the measurements of references (7) and (8) used a continuum neutron beam. Due to the reaction kinematics, deuterons corresponding to center-of-mass angles both greater and less than 90° are emitted into a forward cone in the laboratory system. In some regions ambiguities exist in determining the correct c.m. angle associated with an event. These ambiguities can be avoided if a monokinetic neutron beam is used. With the development at LAMPF of an intense, nearly monoenergetic neutron beam in area B, it was felt that a new measurement of $np \rightarrow d\pi^0$ could be made with greater precision than had been previously obtained.

The $np \rightarrow d\pi^0$ measurements were carried out using the LAMPF 800 MeV $p(d,n)2p$ 0° neutron beam and the MWPC spectrometer in area B of LAMPF. The neutron momentum spectrum is shown in figure 1. The accelerator was operated in a chopped beam mode, providing 40 nsec between micropulses. Using neutron time-of-flight measurements, we were able to select events which were initiated only by neutrons within the sharp high energy peak of the neutron momentum spectrum. Charged particle mass identification was provided by simultaneous measurement of momentum and flight time through the spectrometer, allowing a

Fig. 1. The Momentum spectrum of the LAMPF 0 degree neutron beam.



direct rest mass calculation for each event. The experiment consisted of the measurement of deuteron momentum only in the $np \rightarrow d\pi^0$ reaction.

Figure 2 shows a deuteron momentum spectrum at an average laboratory angle of 2 degrees. The peaks near 1600 MeV/c and 850 MeV/c result from deuterons from the $np \rightarrow d\pi^0$ reaction, emitted near 0° and 180° respectively in the center-of-mass. The momentum region between the peaks contains deuterons associated with double pion production. All the deuterons are emitted in the forward direction into a cone of half angle of approximately 15° . Since the spectrometer has an angular acceptance of approximately 4° , it was possible to measure the full deuteron angular range with four positions of the spectrometer. Target empty runs were made to provide data for background subtraction at all angles ($< 1\%$). Corrections were made to the data to account for loss of deuterons in the target and spectrometer (2.3 to 3.7%), and for deuteron contamination from the $np \rightarrow d\gamma$ reaction ($< 1\%$). Dead time effects in the data acquisition system were also accounted for ($< 10\%$). Absolute cross section measurements were not made.

For each event, the center-of-mass angle was calculated from a combination of the measured neutron flight time, and deuteron laboratory angle and momentum. The neutron momentum was determined to ~ 25 MeV/c, the deuteron momenta to $\sim 1\%$, and the deuteron angle to ~ 6 mrad. The events were then binned directly in the center of mass in angular bins of three degrees. The measured angular distribution is shown in Fig. 3. The symbol Δ indicates points less than 90° c.m., and the symbol ∇ indicates angles greater than 90° c.m. The solid curve is a fit to the data using the following functional form:

$$\frac{d\sigma}{d\Omega} = A_0 P_0 + A_1 P_1 + A_2 P_2 + A_4 P_4 + A_6 P_6 \quad (3)$$

where P_i are Legendre polynomials. Table I lists the coefficients and their

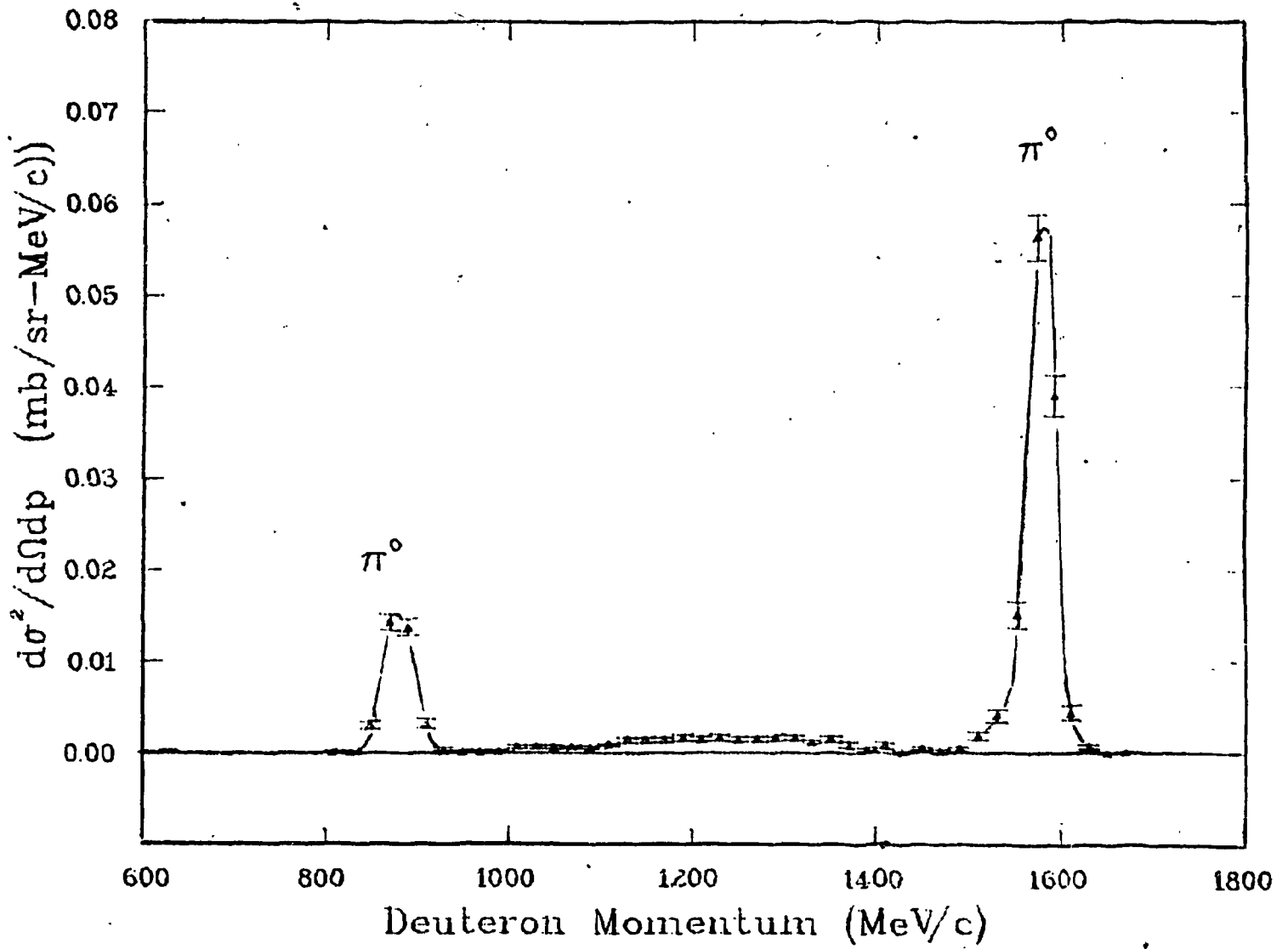


Fig. 2. $p(nd)X$ deuteron momentum spectrum.

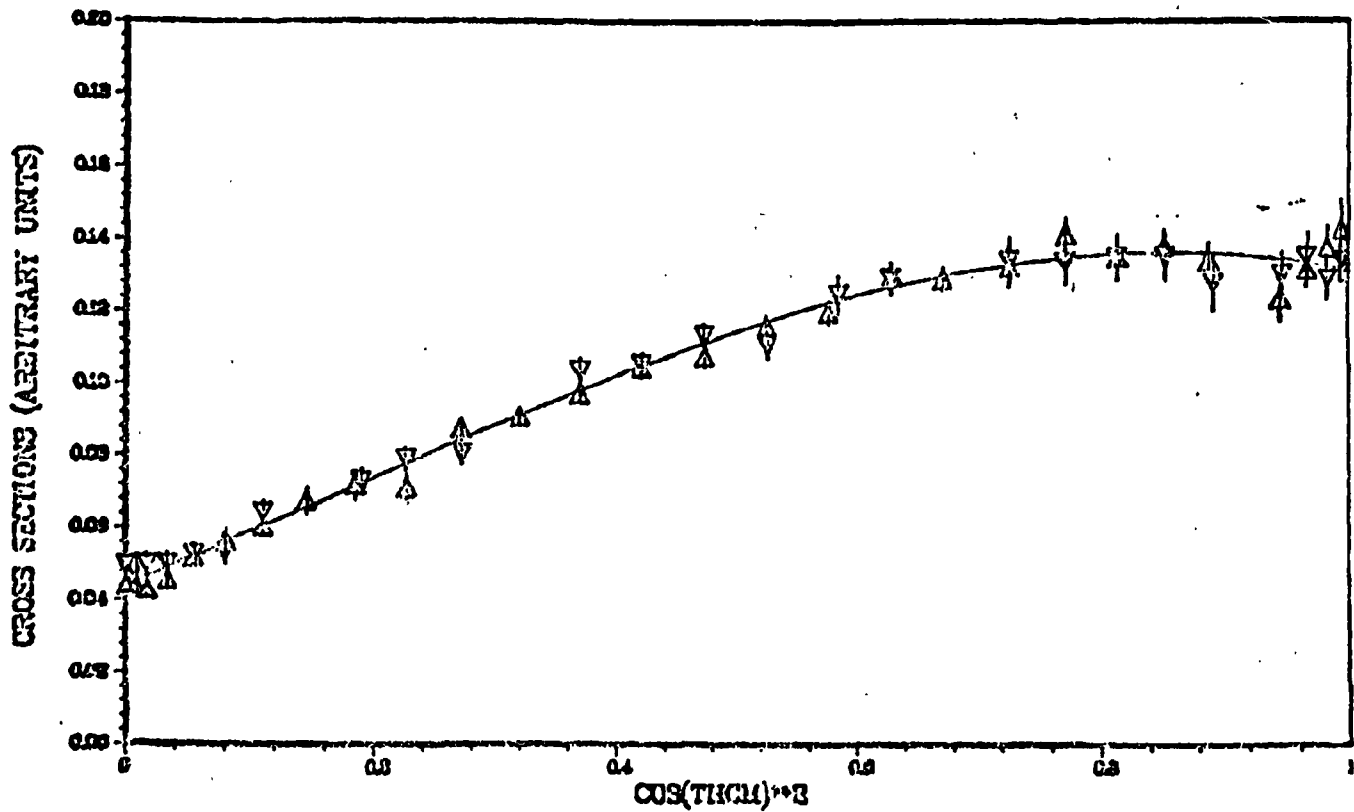
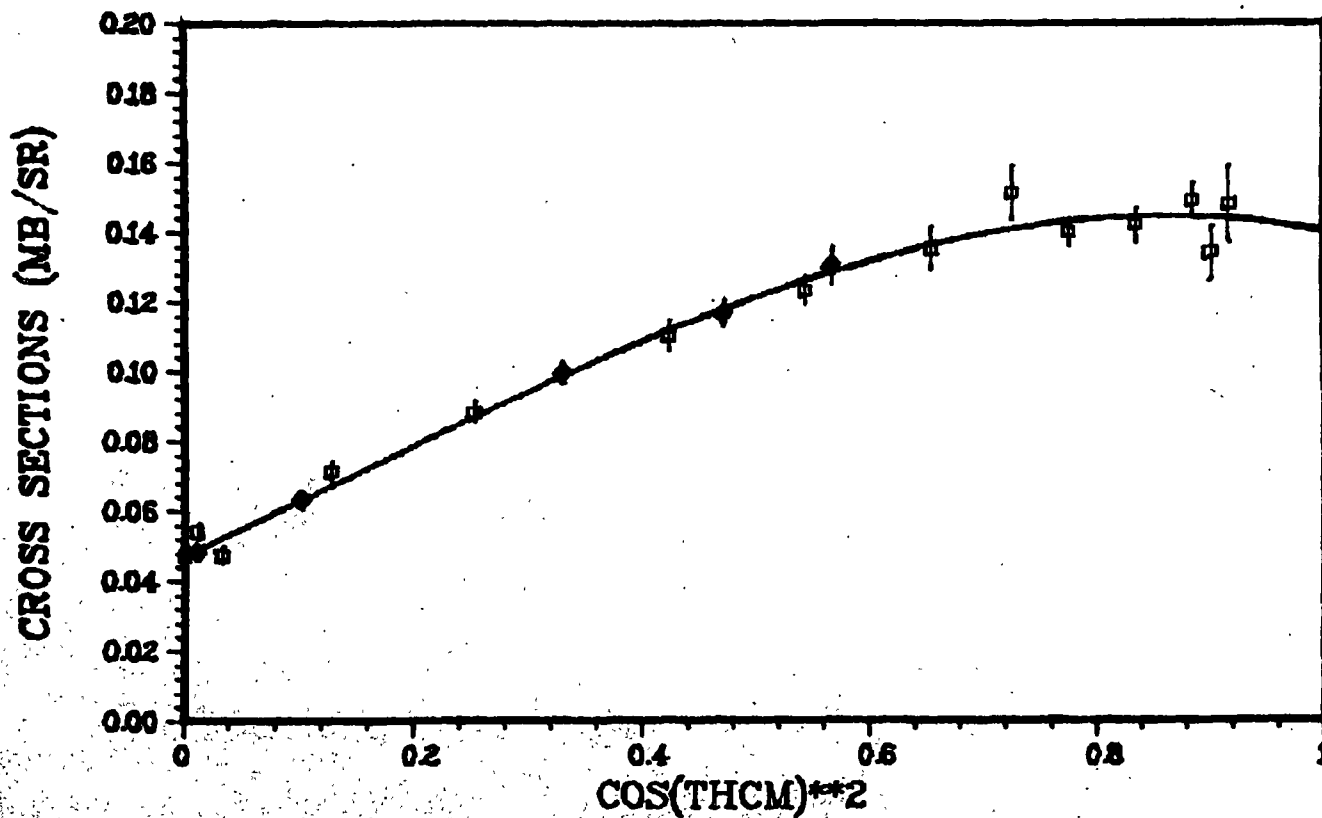


Fig. 3 $np \rightarrow d\pi^0$ angular distribution data.

Fig. 4. $pp \rightarrow d\pi^+$ angular distribution data. The solid curve is that of fig. 3 from the fit to the $np \rightarrow d\pi^0$ data.



errors for both a sixth order and a fourth order Legendre polynomial fit.

The sixth order fit is clearly superior to the fourth order fit ($\kappa^2/N = 1.068$ versus 1.43).

TABLE I

Coefficients of the Legendre Polynomials.

	$\frac{A_2}{A_0}$	$\frac{A_1}{A_0}$	$\frac{A_4}{A_0}$	$\frac{A_6}{A_0}$	$\frac{\kappa^2}{N}$
Sixth order	0.8422 ± 0.0119	$.0074 \pm 0.0100$	$-.2418 \pm 0.0119$	$-.0793 \pm 0.0176$	1.068
Fourth order	0.825 ± 0.011		$-.242 \pm 0.011$	-0-	1.43

Another possible functional form for the data is

$$\frac{d\sigma}{d\Omega} = A + B \cos^2 \theta + C \cos^4 \theta + D \cos^6 \theta \quad (4)$$

The corresponding sixth order and fourth order coefficients are given below.

	\underline{A}	\underline{B}	\underline{C}	$\frac{\kappa^2}{N}$
Sixth order	0.34	0.305	-.694	1.068
Fourth order	0.232	-0.493	-0-	1.43

Although the Legendre coefficients for equation (3) are very similar for the fourth order and sixth order fits, the use of a sixth order term changes the value of B in equation (4) dramatically, and in fact reverses its sign from negative to positive. It would appear that the use of equation (3) involving Legendre polynomials is more realistic than equation (4).

It has been shown by Bartlett et al.⁷ that important isospin violating amplitudes (transitions from $I = 0$ to $I = 1$) can be

$$\begin{aligned} a_1 &= {}^1P_3 \rightarrow {}^3S_1 \\ a_2 &= {}^1P_1 \rightarrow {}^3P_1 \\ a_3 &= {}^1F_3 \rightarrow {}^3P_3 \end{aligned}$$

These amplitudes interfere with the strongest isospin conserving transition amplitude $a_0 = {}^1D_2 \rightarrow {}^3P_2$ which gives the dominant 2nd order Legendre polynomial slope to the data. The isospin violating amplitudes give rise to odd orders of Legendre Polynomials in the angular distribution. The ratios of the real parts of the isospin violating amplitude to the dominant nonviolating amplitude a_0 are given by

$$\operatorname{Re}\left(\frac{a_1}{a_0}\right) = \frac{1}{\sqrt{2}} A_{fb} \quad \operatorname{Re}\left(\frac{a_2}{a_0}\right) = 4 A_{fb} \quad \operatorname{Re}\left(\frac{a_3}{a_0}\right) = \frac{1}{\sqrt{2}} A_{fb}$$

where A_{fb} is the forward backward asymmetry, defined as

$$A_{fb} = \left[\int_0^{\pi/2} \sigma d\Omega - \int_{\pi/2}^{\pi} \sigma d\Omega \right] / \left[\int_0^{\pi} \sigma d\Omega + \int_{\pi/2}^{\pi} \sigma d\Omega \right]$$

From our fit to the data we obtain $A_{fb} = 0.0040 \pm 0.0054$. Thus we see no violation of isospin at the level of 0.5% in our measurement of the fore-aft asymmetry of the angular distribution.

A second test of isospin violation lies in the comparison of the shape of our $np \rightarrow d\pi^0$ angular distribution with that of the $pp \rightarrow d\pi^+$ reaction measured at the same energy. Figure 4 shows the 810 MeV $pp \rightarrow d\pi^+$ data of Richard-Serre et al.⁹ (ϕ) and the 800 MeV $pp \rightarrow d\pi^+$ data of the Rice-Houston group¹⁰ (\diamond). The solid curve is the sixth order Legendre polynomial fit to our $np \rightarrow d\pi^0$ data normalized to the Richard-Serre measurement. The fit to the data is excellent -- clearly the $np \rightarrow d\pi^0$ angular distribution agrees very well with existing $pp \rightarrow d\pi^+$ data, although more precise $pp \rightarrow d\pi^+$ data are needed for a more careful comparison of the two reactions. It is of interest that again, as for the $np \rightarrow d\pi^0$ reaction, the $pp \rightarrow d\pi^+$ data is better fit with a sixth order than with a fourth order expression.

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2. Measurement of the Deuteron Spectrum in $np \rightarrow d(\pi\pi)^0$ at 800 MeV

The "ABC" effect in double pion production reactions was first observed¹ as an enhancement in the missing spectrum from reaction $pd \rightarrow {}^3\text{He}(\pi\pi)^0$. Since then various models have evolved to explain this effect in pD reactions and also in the simpler reaction $np \rightarrow d(\pi\pi)^0$. The two most extensively developed theories are the two nucleon exchange model of Anjos, Levy, and Santoro² and the one-pion exchange model with double delta ($\Delta\Delta$) excitation of Bar-Nir, Risser, and Shuster³. An interesting extension⁴ of the latter model to allow for deep binding of the $\Delta\Delta$ system appears to account for the recent observation⁵ of a peak in the polarization of the proton from deuteron photodisintegration as well as the measurements so far reported in double pion production. These models yield predictions of the energy dependence and the detailed shape of the enhancements in the missing mass spectra. Data to test these models for $np \rightarrow d(\pi\pi)^0$ presently consist of the bubble chamber total cross section measurements⁶ at eight momenta from 1.75 to 3.5 GeV/c and one deuteron momentum spectrum⁷ at 4.5° and 1.88 GeV/c.

At LAMPF we have performed an experiment designed to measure the asymmetry in the reaction $np \rightarrow d\pi^0$ at 800 MeV. The unexpectedly large cross section we observe for the $np \rightarrow d(\pi\pi)^0$ process means that we also obtained the momentum spectrum of the deuterons from this reaction over the entire angular range. A deuteron momenta spectra over the angular range of .00 to .02 radians (laboratory) is shown in Fig. 5. The large peaks at 1600 MeV/c and 860 MeV/c deuteron momentum are associated with the $np \rightarrow d\pi^0$ process. The higher momentum peak corresponds to deuterons traveling forward in the center of mass system; the lower momentum peak corresponds to deuterons traveling backward in the center of mass system. The presence of these deuterons provides a convenient method of obtaining the absolute cross sections for the $np \rightarrow d(\pi\pi)^0$ process, and

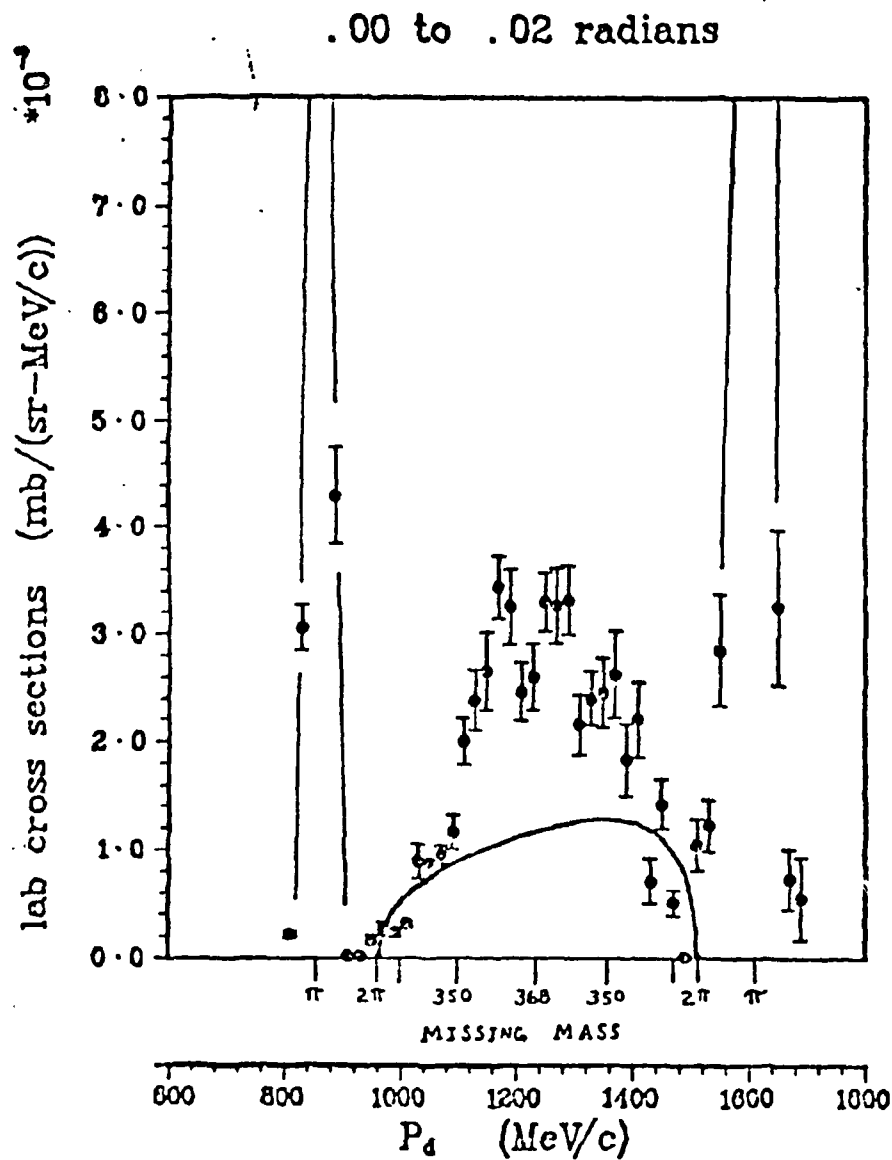


Fig. 5 Momentum spectrum of deuterons emitted near 0° lab from the reaction $np \rightarrow dx$. The upper and lower peaks arise from $np \rightarrow d\pi^0$ while the continuum between is from $np \rightarrow d(\pi\pi)^0$.

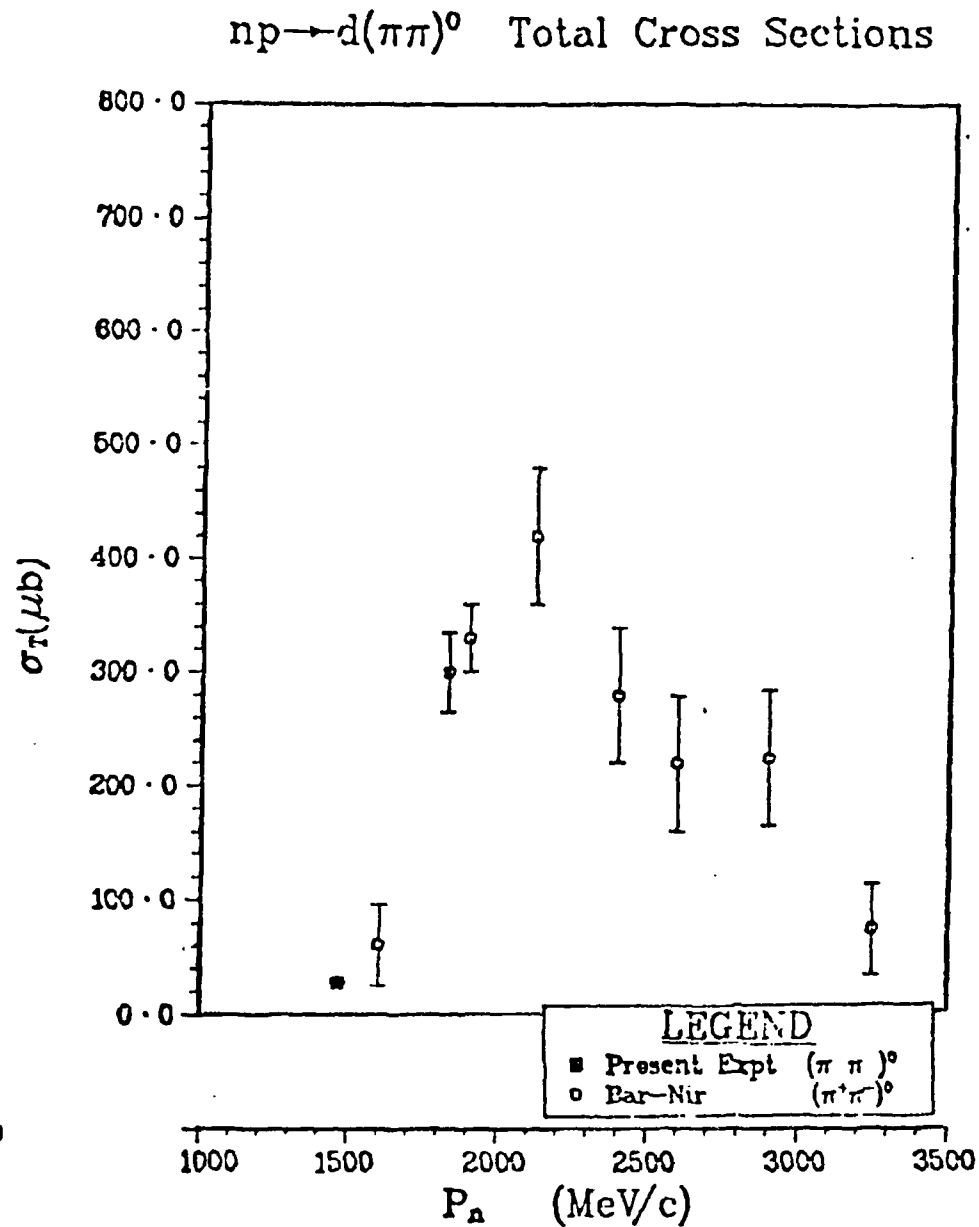


Fig. 6. Comparison of the present measurement of the total cross section for the reaction $np \rightarrow d(\pi\pi)^0$ to previous data at higher energy.

because of this, we have deferred publication of our $np \rightarrow d(\pi\pi)^{\circ}$ results until all corrections to the $np \rightarrow d\pi^{\circ}$ data have been completed. The region between the two $np \rightarrow d\pi^{\circ}$ peaks is the kinematically allowed region for double pion production. The ABC peak is usually observed at a $(\pi\pi)$ missing mass around $300 \text{ MeV}/c^2$. Although we cannot rule out a slight enhancement at approximately $300 \text{ MeV}/c^2$, the main enhancements appear in the central region near the maximum missing mass value; it is clear that the shape is very different from what has been observed at higher energy. The solid line is the result of a three-body phase space calculation, normalized at wider angles. The magnitude of the cross sections decrease almost monotonically as a function of angle from the maximum near zero degrees to zero at the phase space boundary near 0.15 radians.

Detailed published calculations for $n + p \rightarrow d + (\pi\pi)^{\circ}$ at our incident neutron momentum do not exist. However, our data can be compared to Fig. 4 of Bar-Nir, Risser, and Shuster³ and with Fig. 11 of Anjos, Levy, and Santora² to obtain a rough idea of how their calculations predict the data. At $P_n = 1.5 \text{ GeV}/c$, Ref. 3 predicts a maximum cross section for the central region of $\sim 0.6 \text{ } \mu\text{b}/(\text{sr-MeV}/c)$. From the graph in Fig. 11 on Ref. 2, the maximum value of the cross section in this region is $\sim 1.5 \text{ } \mu\text{b}/(\text{sr-MeV}/c)$. No calculations are published on the angular dependence of the cross sections.

From our data we extract a value for the total cross section of $28.23 \text{ } \mu\text{b}$ for the process $n + p \rightarrow d + (\pi\pi)^{\circ}$. This value is plotted in Fig. 6 with the $n + p \rightarrow d \pm (\pi^+ \pi^-)^{\circ}$ data of Bar-Nir et al.⁶

¹A. Abrashian et al., Phys. Rev. Letters 5 (1960) 258.

²J. C. Anjos, D. Levy, and A. Santoro, Nuovo Cimento 33A (1977) 471.

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⁴T. Kamae and T. Fujita, Phys. Rev. Letters 38 (1977) 471.

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⁶I. Bar-Nir et al., Nucl. Phys. B54 (1973) 468.

⁷G. Bizard et al., Proc. 5th Int. Conf. on High-Energy Physics and Nuclear Structure, Uppsala, Sweden, 1973.

3. The Inclusive Reaction $np \rightarrow pX$ at 800 MeV

As a byproduct of experiment 262, high statistics momentum spectra of protons associated with pion production ($np \rightarrow p n \pi^0$ and $np \rightarrow p p \pi^-$) were accumulated at proton angles from 0° to 35° lab. Reduction of this data from the very large amount of data accumulated for experiment 262 has been completed during the past year. In each case, the effect of the Δ resonance between the unobserved pion and nucleon is the dominant feature. Comparison to the Stephenson, Gibbs, and Gibson calculation will be made as we did for the 0° $pp \rightarrow n p \pi^+$ data. In order to search for some systematic behavior in the large amount of data, the cross sections were transformed to $d\sigma/dtdM$, where t is the square of the 4-momentum transfer between incident neutron and outgoing proton and M is the invariant mass of the unobserved particles. Plots of this quantity versus t for cuts in M show an exponential decrease with increasing t and the slope of the decrease is about the same for all values of M . Whether this behavior, which has been predicted from a statistical model of R. Weiner, does provide confirmation of the model is being investigated.

4. n-p Scattering Experiments with a Polarized Target (Experiment 65 and 66)

Two of our early proposals were No. 65 and 66. The object of proposal 65 is to measure the n-p asymmetry (polarization) function, $A_y(\theta)$, in the backward hemisphere by scattering an unpolarized neutron beam from a polarized target. The existing data at LAMPF energies is now at least 10 years old and was obtained by quasifree scattering on deuterium. A representation of these data is shown in Fig. 7. The results of Expt 65 will increase the weight of the data set by a substantial amount and confirm the shape of the asymmetry parameter. The experimental design has also allowed data to be accumulated for several intervals of neutron energy between 400 and 800 MeV.

The object of Expt 66 is more ambitious, namely to measure the spin correlation parameter $A_{yy}(\theta)$, in the backward hemisphere, at 650 MeV and other LAMPF energies. This measurement is made by scattering polarized neutrons from the polarized target. Various causes drive the signal rate down, nevertheless it should be possible to obtain data at $\theta_{c.m.}$ 120 deg and larger. Figure 8 shows two phase shift predictions for this observable at 630 MeV; no data exist at these energies. It is seen that back angle data, even if of low weight, could have a significant impact on a phase shift analysis, and thereby improve understanding of the spin-spin part of the interaction and of the tensor force.

Experiment 65 employed an unpolarized zero-degree neutron beam from a thick beryllium neutron production target. The unpolarized neutron beam was scattered from a polarized proton target and the resulting asymmetry measured. The momentum of the recoil proton was measured in a magnetic spectrometer and the scattered neutron was detected in a massive scintillator array. The experiment had a preliminary run in March, a three week run in June, and a month's run during August. Some of the preparations and instrumentation work that were carried out for the experiment are described in what

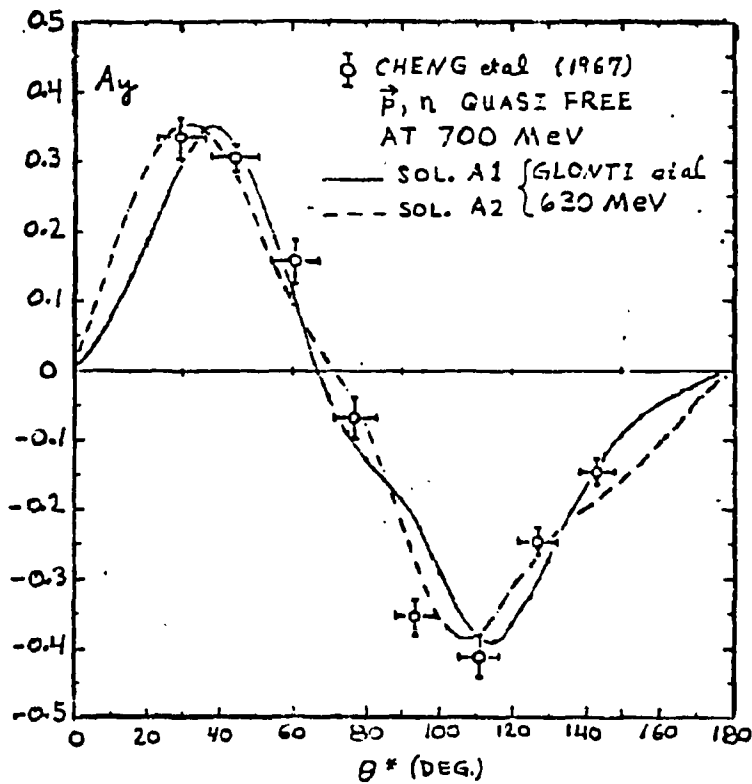


Fig. 7.

n-p asymmetry parameter, $A_y(\theta)$ vs c.m. angle showing prior data of Cheng et al. and phase shift predictions.

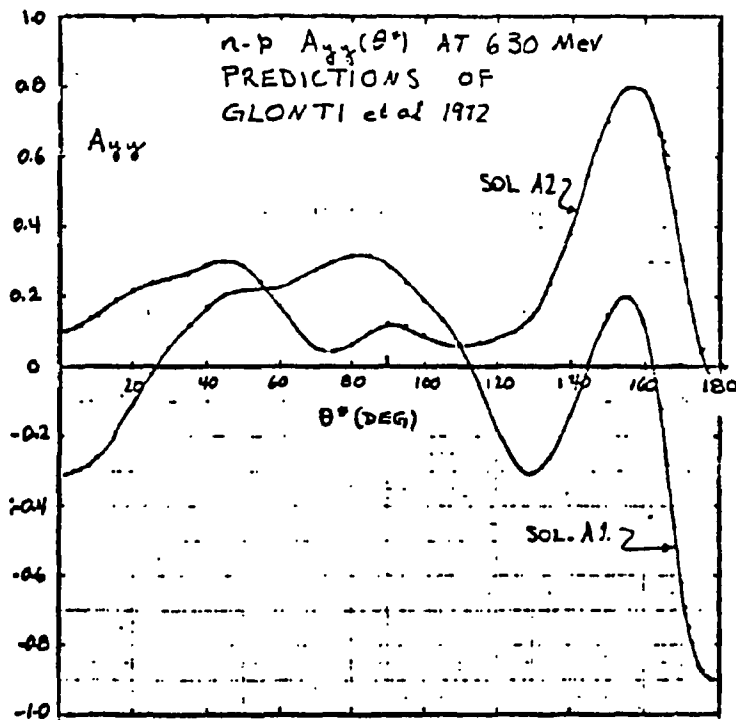


Fig. 8.

Phase-shift predictions for n-p spin correlation parameter $A_{yy}(\theta)$ vs c.m. angle at 630 MeV.

follows. A new on-line computer program was developed for use with the new PDP 11/60 computer. Programming for the data acquisition was done in the context of the "Q" program developed at LAMPF. In order to increase the solid angle of the multiwire proportional chamber (MWPC) spectrometer a new MWPC system was developed. This included new chambers based on a LAMPF design, which were cheaper and simpler to fabricate than the old ones. Extensive modifications were made in the MWPC electronics incorporating preamplifier drivers at the chambers with remote files containing the comparator logic boards. The neutron detectors consist of 18 NE 110 plastic scintillator bar counters. To each end of these are coupled an XP 2030 photomultiplier (PMT) which employ bleeder-string circuits and magnetic shields of our own design. The 36 high voltages are supplied by remote computer controlled high-voltage supplies. Each PMT has been coupled to a constant fraction discriminator. Time and pulse amplitudes are digitized for each PMT. The polarized target was installed during the spring and became operational in June. The NMR electronics were put under computer control, allowing regular updates on the target polarization, which was maintained at approximately 80% during the experimental runs. The major target control functions were made remote, allowing the experimenter to adjust cryogenic valves and to change microwave frequencies and attenuation from the experimental trailer.

During the fall a substantial effort was invested in the analysis of results of the August runs. This consisted chiefly in improvements in the so-called replay program for the PDP-11/60 computer. An important part of this was concerned with neutron energy resolution of the experimental equipment, which is now believed to be less than 50 MeV (FWHM). The replay programs have also been made operational at the LAMPF Mother computer. The analysis has so far only been concerned with scattering angles of the neutron

near 110 deg. c.m. The current results confirm what appeared at an early stage in comparison to prior work. The behavior as function of incident neutron energy is displayed in Fig. 9, where our measured asymmetries, $e = P_t A_y (\theta_n^* = 105.7)$, are plotted as function of incident neutron energy. These results are preliminary. The symbol P_t represents the polarized target polarization while A_y represents the n-p analyzing power. Also shown on the figure is a curve representing the data of Cheng et al.¹ and normalized to our data near 600 MeV. The feature of greatest interest and concern to us is the strong indication of reduction in magnitude of our data compared to Cheng above 600 MeV. At the moment we do not have an explanation for the discrepancy, however, our analysis effort is just getting under way.

During the fall the equipment was set up in area B for the neutron-proton spin correlation experiment (experiment 66) at the 20 degree neutron beam line. The major pieces of equipment are the polarized target and magnetic spectrometer and two neutron precession magnets. These last two magnets were furnished, mapped and aligned by LAMPF personnel. A collimator of rectangular cross section was fabricated and installed for the experiment. The liquid deuterium neutron production target system was brought back into service by MP-7. Unfortunately the target loop sprang a leak but it was able to be used during much of the experimental run. The experimental runs lasted for the month of December.

The experiment necessarily consists of two stages. The first stage is the measurement of neutron beam characteristics of spectral shape, intensity and polarization. Two production targets were employed for this purpose, namely deuterium and beryllium. The neutrons so produced are scattered from the hydrogen content of a polyethylene target at neutron c.m. angles near 110 deg. At this stage it has been confirmed that the neutron polarizations are small

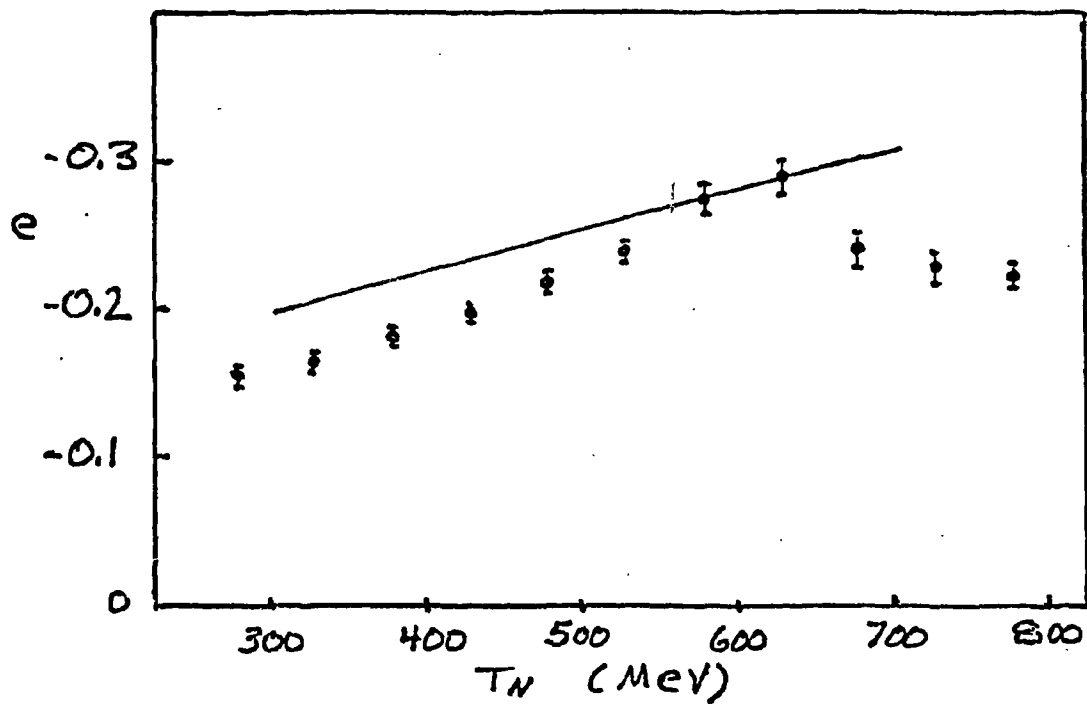


Fig. 9. The asymmetry, $e = P_{\text{target}} A_y (\theta_{\text{c.m.}} = 105.7^\circ)$, versus incident neutron energy. The points represent preliminary data of experiment 65. The curve represents the trend of the data of Cheng et al. at $\theta_{\text{c.m.}} = 105^\circ$.

in the high energy part of the spectrum near 650 MeV. For deuterium the polarization is near 23% while for beryllium the polarization is about 15%. The neutron flux is about a factor of 15 lower than that of Exp. 65 at 0° . At $3\mu\text{A}$ average proton beam the neutron flux from deuterium incident on the polarized target is about $8 \times 10^3 / (\text{sec} - \text{cm}^2)$. In the second stage the polarized neutrons are scattered from the polarized target. Signal rates vary from a few hundred to a few thousand per hour depending on angle. In spite of these difficulties, useful data were produced by the end of the run.

5. Preparations for Experiment 360

The object of this experiment is chiefly to measure neutron polarization generated by the quasifree charge exchange polarization transfer processes $\vec{p} + d \rightarrow \vec{n}$, $\vec{p} + {}^6\text{Li} \rightarrow \vec{n}$, and $\vec{p} + {}^9\text{Be} \rightarrow \vec{n}$ at zero degrees. The spectrometer and MWPC system will be employed as set-up for Exp. 65 and 66, including the bulk of the software. A large liquid hydrogen target chamber enclosure has been fabricated by the University of Texas for the experiment. This is being integrated into a working target system by the cryogenics section of MP-7. One of the same precession magnets installed for Exp. 66 will be moved to the zero degree neutron line for Exp. 360. In addition a larger sized circular collimator will be provided. The first run on the experiment is expected to be performed in February of 1979. Unfortunately the liquid deuterium target loop, which sprang a leak during the running of experiment 66 in December, cannot be repaired by February, so that we expect to carry out the initial runs for experiment 360 using the solid targets ${}^6\text{Li}$ and ${}^9\text{Be}$ only.

6. Preliminary Measurements of TRIUMF experiment 26 with the BASQUE GROUP.

The BASQUE at TRIUMF is measuring forward-angle free n-p differential cross sections at 210, 325, 415, and 500 MeV. Following the successful measurements of free n-p Wolfenstein parameters over a large angular range, this observable will form the last in a "complete set" of n-p experiments at the above energies. Phase shift predictions indicated that an accuracy of 1-2% is required over the full angular range.

The experimental was initially set up at the 9° port of the Fast Neutron facility at TRIUMF to measure forward n-p scattering. The neutron production target consists of a 20 cm long LD₂ target. Monitors at the 0° and 9° ports indicated that the primary sweep magnet left an unacceptably large charged particle flux in the 9° port, whereas the 0° port was extremely clean of charged particles. Higher neutron flux at 0° and a more mono-energetic neutron beam were additional factors favoring the 0° beam. The equipment was moved to the 0° port, and is presently set up there.

The experimental techniques follow closely those of R. Carlini et al.¹ at LAMPF. The 0° neutron beam is monitored at the collimator exit by detecting protons scattered left, right, and forward from a CH₂ converter. These monitors track together to better than 0.5% without correction for random counting rates. Further collimation downstream, immediately before a liquid hydrogen target (LH₂) is used to reduce the "wings" of the neutron beam. A second sweep magnet is also used upstream of the LH₂ to remove charged particles produced by the monitor and by (n,p) reactions in the neutron collimator. A thin scintillator is used to veto any charged particles passing into the 20 cm long by 14 cm diameter LH₂ target. To reduce air scattering a helium bag is interposed between the LH₂ target and the shielded beam dump. The LH₂ target is monitored by a wide angle monitor (20°).

Neutrons are detected by conversion in a 53 x 53 x 10 cm thick block of carbon. Knockout charged particles traverse a $1/2 \text{ m}^2$ timing scintillator (P_1), 7 m^2 multiwire proportional counters (MWPC) that give the conversion coordinates, 1 m^2 aluminum degrader to give the detector an energy threshold of about 80 MeV, and a final 1 m^2 trigger scintillator (P_2). Charged particles are vetoed by a 1 m^2 MWPC and scintillator placed before the converter. Neutron time-of-flight (TOF) to P_1 are recorded with respect to the cyclotron RF. An internal $P_1 - P_2$ TOF is used to eliminate gamma ray background and charged particles traversing the detector backward, but stopping in the converter.

Preliminary data have been recorded to test the on-line software, off-line event reconstruction, equipment status, and the effectiveness of secondary beam-line collimation. On the basis of these measurements, improved collimation has been installed. By using the TRIUMF 5:1 RF selector, a chopped beam structure having a period of 215 nanoseconds can be produced. This facility proved to be an invaluable test tool for unfolding the inelastic background from the elastic n-n peak in the $P_1 - \text{RF}$ TOF spectra. Neutrons arriving at the converter modulo 215 nanoseconds were ranged out in the detector. Cosmic rays, arriving randomly, gave a flat TOF spectra.

1. R. Carlini, et al., Phys. Rev. Lett. 41, 1341, (1978).

III. CURRENT LAMPF PROPOSALS

- No. 262 "Test of Isospin Invariance in the Reaction $np \rightarrow d\pi^0$ " B.E. Bonner, Spokesman. Data acquisition and analysis have been completed.
- No. 263 "Measurement of the Energy and Angular Variation of the np Charge Exchange Cross Section" B.E. Bonner, Spokesman. Data acquisition and analysis have been completed.
- No. 264 "Measurement of the Energy Variation of the nD Elastic Differential Cross Section near 180° " B.E. Bonner, Spokesman. Data acquisition and analysis have been completed. Papers describing the experimental measurements of proposals 262, 263, and 264 have already been published. Final manuscripts based on these experiments are in preparation.
- No. 65 "Neutron-proton Polarization Measurements Using a Polarized Target: Phase I. The n-p Polarization Observable" J.E. Simmons, Spokesman. Data acquisition on this experiment was completed during September, 1978. Analysis of the data is now in progress.
- No. 66 "Neutron-Proton Polarization Measurements Using a Polarized Target: Phase II. The n-p Spin Correlation Observable" J.E. Simmons, Spokesman. Preliminary data acquisition has been carried out during December, 1978. We expect to take additional data on this experiment during 1979.
- No. 360 "The Measurement of the Polarization Transfer Coefficients D_t and A_t at 800 MeV for the Reactions $d(\vec{p}, \vec{n})2p$, ${}^6\text{Li}(\vec{p}, \vec{n}){}^6\text{Be}$, and ${}^9\text{Be}(\vec{p}, \vec{n}){}^9\text{B}$ " P.J. Riley and J.E. Simmons, Spokesmen. A preliminary experimental run is scheduled for February, 1979. We expect to complete the measurements during cycle 24, after the spring shutdown of LAMPF.
- No. 403 "A Measurement of the Triple Scattering Parameter D_t for the Charge Exchange Region in np Scattering." We expect to carry out this measurement immediately after the completion of Experiment 360 during cycle 24, in June of 1979, B.E. Bonner, spokesman.
- No. 402 "A Measurement of the Polarization Transfer Coefficients $D_t(0^\circ)$ and $A_t^+(0^\circ)$ in the Reaction $\vec{p} p \rightarrow \vec{n} X$ at 800 MeV", G. Glass and J.E. Simmons, Spokesmen. This proposal was deferred at the last PAC meeting, and will be reconsidered by the PAC during January, 1979. If approved, we expect to carry out this measurement as soon as possible after experiment 403, during the summer of 1979.
- No. 366 "Non-Resonant Pion Production in the Reaction $np \rightarrow \pi^- pp$ " B.W. Mayes and G.S. Mutchler, Spokesmen. A realistic date for the experimental runs is September, 1979.
- No. 387 "Energy Dependence of the Forward Angle np Differential Cross Section", B.E. Bonner, Spokesman. This proposal will be considered by the PAC during January, 1979. If approved, we expect to carry out these measurements during late 1979 or early 1980.

IV. PUBLICATIONS DURING 1978

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2. B.E. Bonner, J.E. Simmons, G. Glass, C.L. Hollas, C.R. Newsom and P.J. Riley, "np Charge Exchange Scattering for Neutron Energies 300-800 MeV", AIP Conference Proceedings No. 41, Nucleon-Nucleon Interactions - 1977, Editors H. Fearing, D. Measday, A. Strathdee, Published by the American Institute of Physics, (1978), pg. 538.
3. G. Glass, M. Jain, B.E. Bonner, C.L. Hollas, C.R. Newsom and P.J. Riley, "The Inclusive Reaction, $np \rightarrow pX$ at 800 MeV", AIP Conference Proceedings No. 41, Nucleon-Nucleon Interactions - 1977, Editors H. Fearing, D. Measday, A. Strathdee, Published by the American Institute of Physics, (1978), pg. 544.
4. C.L. Hollas, C.R. Newsom, P.J. Riley, B.E. Bonner, and G. Glass, "A Measurement of the Deuteron Spectrum in $np \rightarrow d(\pi\pi)^0$ at 800 MeV", AIP Conference Proceedings No. 41, Nucleon-Nucleon Interactions - 1977, Editors H. Fearing, D. Measday, A. Strathdee, Published by the American Institute of Physics, (1978), pg. 550.
5. P.J. Riley, C.W. Bjork, B.E. Bonner, J.E. Simmons, J. Wallace, M.L. Evans, G. Glass, J.C. Hiebert, M. Jain, L.C. Northcliffe, and C.G. Cassapakis, "Quasi-Elastic Charge Exchange in $nd \rightarrow pnn$ at 800 MeV", AIP Conference Proceedings No. 41, Nucleon-Nucleon Interactions - 1977, Editors H. Fearing, D. Measday, A. Strathdee, Published by the American Institute of Physics, (1978), pg. 560.

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9. B.E. Bonner, J.E. Simmons, C.R. Newsom, P.J. Riley, G. Glass, J.C. Hiebert, Mahavir Jain, and L.C. Northcliffe, "Systematics of 0° Neutron Production by 800 MeV Protons on Targets with $27 \leq A \leq 238$ ", Phys. Rev. C18, 1418 (1978).
10. B.E. Bonner, J.E. Simmons, C.L. Hollas, C.R. Newsom, P.J. Riley, G. Glass and Mahavir Jain, "Measurement of np Charge Exchange for Neutron Energies 150-800 MeV", Phys. Rev. Letters 41, 1200 (1978).
11. B.E. Bonner, J.E. Simmons, Mahavir Jain, G. Glass, C.L. Hollas, C.R. Newsom, and P.J. Riley, "n-p Charge Exchange Scattering from 150 to 800 MeV". Few Body Systems and Nuclear Forces I, Proceedings, Graz 1978, Edited by H. Zingl, M. Haftel and H. Zankel, Springer-Verlag, (1978), pg. 3.
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