TRI-PP-82-41
Nov 1982

PION PRODUCTION FROM DEUTERIUM BY THE BOMBARDMENT WITH POLARIZED PROTONS OF 277 AND 500 MeV

G.J. Lolos, E.G. Auld, G. Giles, G. Jones, B. McParland, D. Ottewell, P.L. Walden and W. Ziegler

Physics Department, University of British Columbia and TRIUMF, Vancouver, B.C., Canada V6T 2A6

Abstract

Analyzing power measurements of the $\vec{p}d \to t\pi^+$ reaction are reported at incident proton energies of 277 and 500 MeV. The 277 MeV results span the angular range from 70° to 130° in the centre of mass while the two 500 MeV measurements at large angles were taken as a check of published results. With the angular distribution of the analyzing power at 277 MeV being now available, an examination of the energy dependence of the analyzing power shows that it exhibits characteristics closely resembling the shape and magnitude of the distribution observed for nuclei in the 9-12 mass number range.

(to be submitted to Nuclear Physics A)

There has been accelerated interest in the past few years in the reactions of the type $pA \to (A+1)\pi^{\pm}$ for protons on light nuclei. This interest, both experimental and theoretical, was originally based on the expectation for such reactions of providing a probe of nuclear structure at large momentum transfer. Although the potential is there, the promise has not yet been fulfilled due mainly to problems with unravelling the reaction mechanism. As a result, the current emphasis has shifted to measurements designed to provide information primarily on the reaction mechanism rather than nuclear structure effects[1,2]).

Polarization measurements provide additional constraints on the various theoretical models proposed for these types of reactions. Thus far, with the exception of the $\vec{p}p \to d\pi^+$ reaction below 600 MeV[3]), theoretical understanding of pion production from complex nuclei has failed to even provide qualitative agreement with experiment. As a target nucleus the deuterium is particularly attractive, being the simplest such system with a well-defined ground state of the resulting daughter nucleus. The $pd \to t\pi^+$ with polarized protons has previously been studied in the 305 to 400 MeV region[4]), at 500 MeV[5]) and at 800 MeV[6]). Results reported earlier in the 400 to 470 MeV range[7]) are inconsistent with those of ref. [4]), basically as a result of severe background problems. The analyzing power angular distributions $A_N(\theta)$ in the 305 to 500 MeV region are characterized by a large but apparently gradual change in shape from a $\vec{p}p \to d\pi^+$-like negative peak at 305 MeV to large positive peaking at 500 MeV.

No experimental results were available for the $\vec{p}d \to t\pi^+$ analyzing power for energies lower than 305 MeV; in the case of heavier nuclei, i.e. ^9Be and ^{12}C, the $A_N(\theta)$ at T_p =.200 MeV (and lower energies for ^{12}C)

are very similar in shape (although larger in magnitude) when compared to that of the $pp \rightarrow d\pi^+$ reaction for similar kinematics[8]). For energies above 200 MeV the $^{12}C(\vec{p},\pi^+)^{13}C_{g.s.}$ analyzing power shows a large and sudden sign reversal[9]). The motivation of the present work was to investigate the shape of the $A_N(\theta)$ for the $\vec{p}d \rightarrow t\pi^+$ reaction at the kinematic region where the results for p-shell nuclei differed little from one nucleus to another[8]) being similar but not identical to that of the $pp \rightarrow d\pi^+$ reaction for the same kinematic region[10]).

In this paper we present the angular dependence of the analyzing power of the $\vec{p}d \rightarrow t\pi^+$ reaction at 277 MeV. Two large angle measurements, 137.5° and 148.9° (c.m.s.), were also taken at 500 MeV to provide a check with earlier results at this energy[5]); the experiment was performed using 277 and 500 MeV polarized protons from the TRIUMF cyclotron. The beam polarization was monitored using p-p elastic scattering in a 4-arm polarimeter with a CH_2 target as analyzer. The polarimeter detects both the scattered and recoil protons. Typical beam polarizations were ~75%. The beam intensity was monitored by a secondary emission monitor downstream of the target in addition to the beam intensity measurements provided by the polarimeter itself. Typical beam intensities were in the 10 to 15 nA range.

The target consisted of a CD_2 (polyethylene) plastic enriched to 99% in deuterium with an areal density of 81.6 mg/cm^2. The pions were detected with a 65 cm Browne-Buechner magnetic spectrograph incorporating three helically wound multi-wire proportional chambers (MWPC) to provide track reconstruction and thus definition of particle position on the focal plane. A three scintillator telescope provided the fast trigger for event definition. Particle identification was based on energy loss,

time of flight and track reconstruction information. The overall system resolution was of the order of 800 keV FWHM.

A two-arm detection technique (pions in the spectrograph and the recoil tritons in a scintillator counter) was used in order to obtain pion spectra free of contamination from pions arising from the competing processes: $^{12}C(p,\pi^+)X$ and the triton break-up reactions. The recoil tritons were detected by a scintillation counter at the end of a horn connected to the target scattering chamber; this counter subtended an angle of ~1.6°, and could be positioned within an angular range of ~6° and ~11.5° in the lab. The event definition for the $pd \rightarrow t\pi^+$ reaction was:

$$\text{Event} \equiv (C1 \cdot C2 \cdot C3)_\pi \cdot C_t,$$

where C1, C2 and C3 are the counters in the pion spectrograph and C_t is the triton recoil counter. In the final data analysis the small background contribution from the ^{12}C content in the CD_2 target was subtracted on the basis of ^{12}C background runs with a carbon target. A typical $pd \rightarrow t\pi^+$ spectrum is shown in fig. 1.

The analyzing power A_N was calculated using the relation

$$A_N = \frac{Y_N(\uparrow) - Y_N(\downarrow)}{P(\uparrow)Y_N(\downarrow) + P(\downarrow)Y_N(\uparrow)}$$

where Y_N and P are the pion normalized yield and the magnitude of the beam polarization, respectively. The spin orientation (↑) or (↓) is assigned according to the Madison Convention[11]).

The results for $A_N(\theta)$ at 277 and 500 MeV are presented in table 1, and are also shown in fig. 2. In fig. 3 the energy dependence of the $A_N(\theta)$ for the $\vec{p}d \rightarrow t\pi^+$ and $^{12}C(\vec{p},\pi^+)^{13}C_{g.s.}$ are shown; this figure clearly shows the striking similarities between the two cases. Comparing the $A_N(\theta)$ for the $\vec{p}p \rightarrow d\pi^+$, $\vec{p}d \rightarrow t\pi^+$ and $^{12}C(\vec{p},\pi^+)^{13}C_{g.s.}$ reactions at similar centre-of-mass excitation energies as shown in fig. 3(a), the similarities between the deuteron and carbon reactions are highlighted further. The $A_N(\theta)$ for the deuteron reaction, when plotted against $q_{c.m.}$, is very much like the heavier nucleus. The striking similarities in shape and trend are, however, even more pronounced at higher energies as shown in fig. 3(b). The $\vec{p}d \rightarrow t\pi^+$ reaction follows the same pattern of change as the heavier nucleus; a similar behaviour has been observed in the $^9Be(\vec{p},\pi^+)^{10}Be_{g.s.}$ reaction[12]). At equivalent excitation energies in the centre of mass, the analyzing power angular distribution for the $\vec{p}p \rightarrow d\pi^+$ reaction is positive at all angles[13]).

If one assumes that the $NN \rightarrow NN\pi^+$ are the relevant amplitudes in reactions of the type $A(\vec{p},\pi^+)A+1$, then this drastic change in the energy dependence of the $A_N(\theta)$ with the addition of a single neutron is surprising indeed. In addition, there seem to be two quite different pictures emerging, one at low (below 200 MeV) incident proton energies and the other above this region. At centre-of-mass excitation energies equivalent to the first 50 MeV or so above threshold, for nuclei in the A = 10-16 mass number range, the $A_N(\theta)$ is very similar in shape for all nuclei tested. The magnitude of the analyzing power is larger for the nuclear targets, as compared to the single-nucleon case, but at forward angles the overall picture seems to emphasize the $NN \rightarrow NN\pi^+$-like channel. At the large angles where the momentum transfer gets larger and rescattering becomes more significant, the nuclear cases deviate from the single-nucleon pion production behaviour. This common behaviour for the $A_N(\theta)$ at small angles has been observed also in p-N and p-nucleus scattering with polarized protons[10,14]).

At energies higher than ~50 MeV above threshold, the angular distribution of the analyzing power for light nuclei deviates substantially

from that of the single-nucleon case; at these energies the large angle $A_N(\theta)$ are nearly identical, irrespective of nucleus or excitation of the final state[9]). It is observed in this paper that the $pd \rightarrow t\pi^+$ reaction $A_N(\theta)$ follows this pattern established by nuclei having a substantially larger number of nucleons. At these energies then, the neutron in the deuteron does not act merely as a spectator, as appears to be the case at lower energies, but it influences the reaction mechanism in a similar way as the presence of ten or more nucleons. In that respect, the $\vec{p}d \rightarrow t\pi^+$ reaction may be the more appropriate interaction in which microscopic theories of pion production in more complex nuclei should be based rather than the $pp \rightarrow d\pi^+$ reaction as is more usually supposed[1]). If that is indeed the case, studies of pion production from light nuclei (d, ^3He, ^4He, ^6Li and ^7Li) are particularly attractive because the few-nucleon nature of the problem would imply that there is some hope of developing an understanding at the microscopic level. In addition, investigations of nuclei differing only by one extra nucleon should be able to yield information on the importance of such effects as rescattering, momentum sharing and the nature of the "intrinsic" reaction process.

The assistance of Mrs. D. Sample in the data handling and analysis is gratefully acknowledged. This work was supported in part by the Natural Sciences and Engineering Research Council of Canada.

References

1) H.W. Fearing, in Progress in particle and nuclear physics, v.7, ed. D. Wilkinson (Pergamon, Oxford, 1981) p. 113

2) S.E. Vigdor, T.G. Throwe, M.C. Green, W.W. Jacobs, R.D. Bent, J.J. Kehayias, W.K. Pitts and T.E. Ward, contributed paper presented at the International Conference on Nuclear Structure, Amsterdam, Aug 30-Sep 3, 1982, and Phys. Rev. Lett. (to be published).

3) J.A. Niskanen, Nucl. Phys. **A298** (1978) 417

4) G.J. Lolos, E.L. Mathie, G. Jones, E.G. Auld, G. Giles, B. McParland, P.L. Walden, W. Ziegler and W.R. Falk, Nucl. Phys. **A386** (1982) 477

5) J.M. Cameron, L.G. Greeniaus, D.A. Hutcheon, C.A. Miller, G.A. Moss, R.P. Liljestrand, H. Wilson, R. Abegg, W.T.H. van Oers, A.W. Stetz, M.B. Epstein and D.J. Margaziotis, Phys. Lett. **103B** (1981) 317

6) K.K. Seth et al., Northwestern University Progress Report COO-2706-4 (1978)

7) E.G. Auld, R.R. Johnson, G. Jones, E.L. Mathie, P.L. Walden, D. Hutcheon, P. Kitching, W.C. Olsen, C.F. Perdrisat and B. Tatischeff, Phys. Lett. **93B** (1980) 258

8) E.G. Auld, A. Haynes, R.R. Johnson, G. Jones, T. Masterson, E.L. Mathie, D. Ottewell, P.L. Walden and B. Tatischeff, Phys. Rev. Lett. **41** (1978) 462

9) G.J. Lolos, P.L. Walden, E.L. Mathie, G. Jones, E.G. Auld, W.R. Falk and R.B. Taylor, Phys. Rev. **C25** (1982) 1086

10) G. Jones, in Meson-nuclear physics, ed. E.V. Hungerford, III, AIPCP No. 54 (AIP, New York, 1979) p. 116

11) Proceedings 3rd International symposium on polarization phenomena in nuclear reactions, eds. H.H. Barschall and W. Haeberli (University of Wisconsin, Madison, 1971)

12) E.G. Auld, G. Jones, G.J. Lolos, E.L. Mathie, P.L. Walden and R.B. Taylor, Phys. Rev. **C25** (1982) 2222

13) G. Jones, in Pion production and absorption in nuclei, ed. R.D. Bent, AIPCP No. 79 (AIP, New York, 1981) p. 15

14) A.K. Kerman, H. McManus and R.M. Thaler, Ann. Phys. **8** (1959) 551

15) G.J. Lolos, E.G. Auld, G. Giles, G. Jones, B. McParland, P.L. Walden, W. Ziegler and W.R. Falk, Phys. Rev. C (to be published).

16) P. Walden, D. Ottewell, E.L. Mathie, T. Masterson, G. Jones, R.R. Johnson, A. Haynes and E.G. Auld, Phys. Lett. **81B** (1982) 156

Table 1. Analyzing power, $A_N(\theta)$, of the $pd \rightarrow t\pi^+$ reaction.

T_p (MeV)	$\theta_{\pi,c.m.}$ (deg)	$A_N(\theta)$
277	70.0	-0.42 (0.01)
	80.0	-0.49 (0.02)
	90.0	-0.62 (0.02)
	100.0	-0.66 (0.02)
	110.0	-0.64 (0.02)
	120.0	-0.45 (0.02)
	130.0	-0.38 (0.05)
500 (this work)	137.5	-0.24 (0.04)
	148.9	-0.22 (0.05)
500 [ref. [5])]	137.5	-0.19 (0.03)
	145.2	-0.21 (0.03)

Figure Captions

1. A characteristic (spin averaged) pion energy spectrum for T_p = 277 MeV and $\theta_{\pi,lab}$ = 51.0° for the $pd \rightarrow t\pi^+$ reaction. The small pion contamination due to the $^{12}C(p,\pi^+)X$ reaction has been subtracted.
2. The analyzing power results for T_p = 277 MeV (●) and T_p = 500 MeV (x) from this work in comparison with the results (□) at 500 MeV from ref. [5]). Statistical errors only are indicated.
3. Comparison of the analyzing power angular distributions $A_N(\theta)$ for the $\vec{p}d \rightarrow t\pi^+$ reaction (solid circles) and $^{12}C(\vec{p},\pi^+)^{13}C_{g.s.}$ reaction (crosses) for (a) T_p = 277 MeV for the deuteron and T_p = 200 MeV for the ^{12}C and (b) at T_p = 375 MeV and T_p = 216 MeV, respectively. The $^{12}C(\vec{p},\pi^+)^{13}C_{g.s.}$ results are taken from ref. [8]) for 200 MeV and from ref. [15]) for 216 MeV. The dash-dot lines in (a) are $\vec{p}p \rightarrow d\pi^+$ results at T_p = 375 MeV from ref. [16]). Lines are drawn to guide the eye. Statistical errors only are indicated.

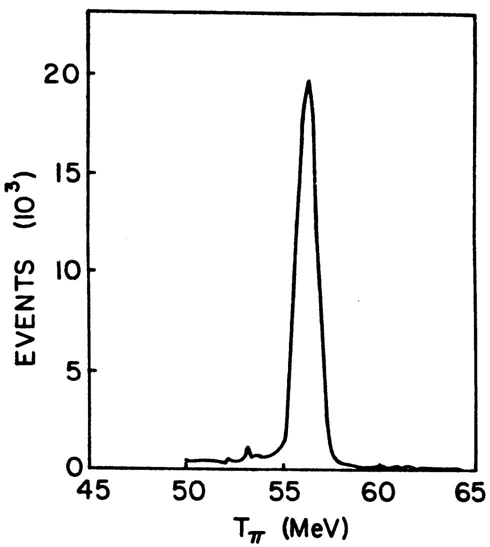
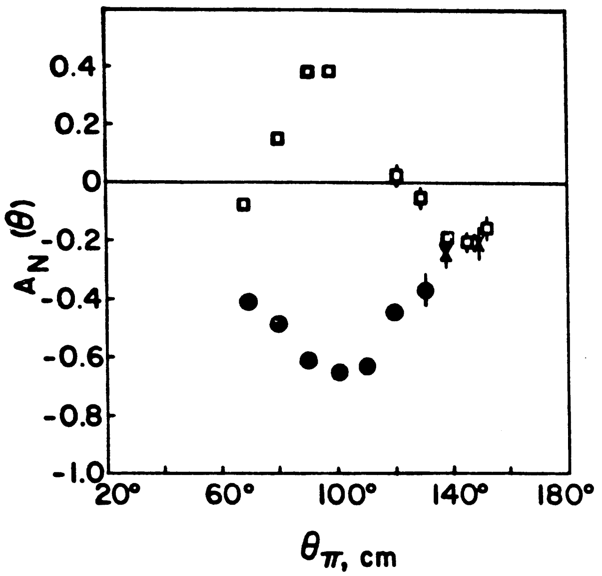
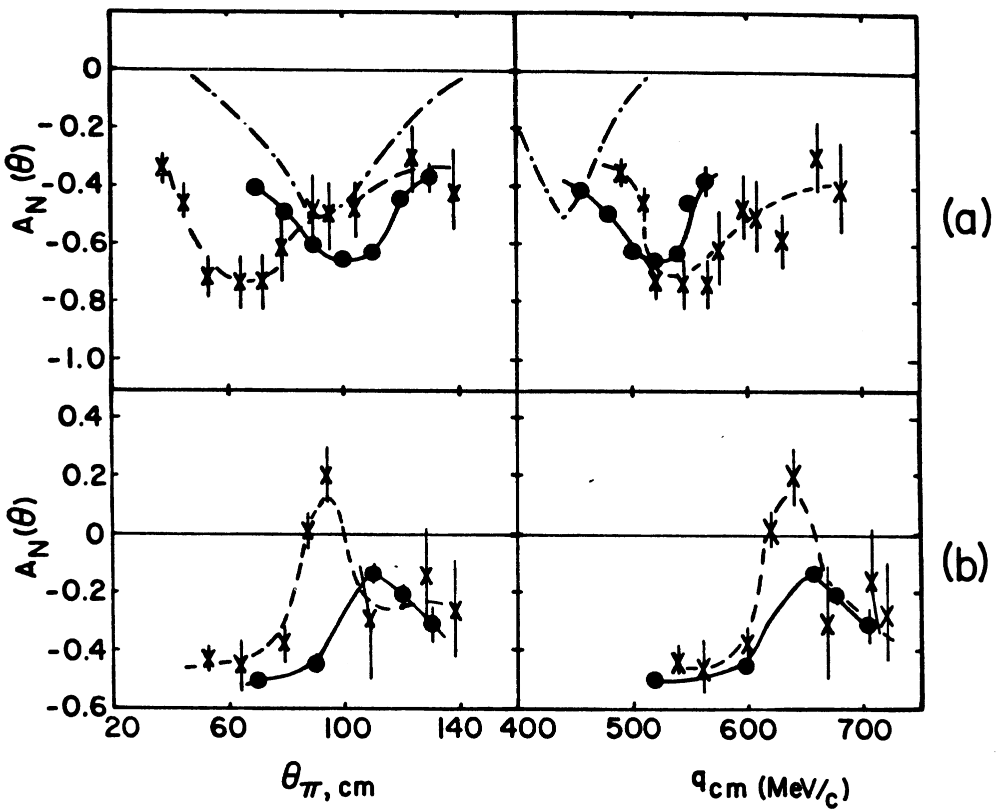


Fig. 1



0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
$A_N(\theta)$
20°
60°
100°
140°
180°
θ_π, cm

Fig. 2



0
-0.2
-0.4
-0.6
-0.8
-1.0
$A_N(\theta)$
(a)
0.4
0.2
0
-0.2
-0.4
-0.6
$A_N(\theta)$
(b)
20
60
100
140
400
500
600
700
θ_π, cm
q_{cm} (MeV/c)

Fig. 3