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# ANALYZING POWER OF THE $pd \rightarrow t\pi^+$ REACTION AT 305, 330, 375 AND 400 MeV

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## Abstract

Analyzing power measurements of the $pd \rightarrow t\pi^+$ reaction are reported at incident proton energies of 305, 330, 375 and 400 MeV over the angular range from 68° to 145.5° in the center of mass. The results are compared with earlier measurements obtained at 400 and 500 MeV. The analyzing power at 375 MeV exhibits a distribution unlike that observed at lower energies. The analyzing power at 400 MeV, and for large pion emission angles, is in significant disagreement with other results, for the same energy, reported in the literature.

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The reaction $p+A \rightarrow (A+1)+\pi^+$ has been the subject of much experimental and theoretical study over the recent years. Although the initial interest in exclusive $(p,\pi)$ reactions originated from the large momentum transfer characterizing the reaction, it was soon realized that reactions of this type span a wide field of interest in pion-nucleus physics, such as pion-nucleus interaction in the form of pion distortion, proton-nucleus interaction manifested in proton distortion as well as the processes involving formation of the Δ-isobar and its interaction with the nuclear and pion fields. An extensive and updated compilation of experimental data relevant to $(p,\pi)$ reactions has been recently published[1]).

Polarization measurements in $(p,\pi)$ reactions have provided additional constraints to the theoretical treatment of such reactions. To date, all attempts to develop a general theoretical approach that would fit both the differential cross section and polarization analyzing powers $[A_y(\theta)]$ for complex nuclei have failed. On the other hand (for energies below 600 MeV) there is a theoretical model for the elementary channel $pp \rightarrow d\pi^+$ which in general is in good agreement with a wide range of spin-dependent measurements[2]). In light of the uncertainty surrounding the reaction mechanism for complex nuclei, in spite of the success in describing the elementary $pp \rightarrow d\pi^+$ process, it is important to examine in detail pion production in the very simplest few-nucleon systems. Clearly the $pd \rightarrow t\pi^+$ reaction is the simplest pion production reaction occurring on a complex nucleus, and as such should be extensively investigated experimentally. This reaction has indeed been studied in the 400 to 470 MeV region[3]), at 500 MeV[4]) and at 800 MeV[5]). A preliminary report of our results at 305 and 330 MeV has also been published[6]).

The analyzing power results at 305 and 330 MeV indicated very little dependence on incident proton energy[6]). The analyzing power distribution is very similar in shape (though not in magnitude) to that of the elementary $pp \rightarrow d\pi^+$ channel[6,7]). The results at 500 MeV[4]), on the other hand, indicate an analyzing power which is generally positive. To complicate matters even more, the analyzing power at 800 MeV[5]) has a shape similar to that of the $pp \rightarrow d\pi^+$ at 450 MeV[8])! Furthermore the results reported in the 400-470 MeV region[3]) are not consistent with those at either lower or higher energies, unless one assumes some violent changes in the analyzing power as a function of incident proton energy in the 330 to 500 MeV energy region.

In this paper we present analyzing power results for the $pd \rightarrow t\pi^+$ reaction at 305, 330 and 375 MeV; two large angle measurements were also taken at 400 MeV as a test of earlier data at this energy[3]). The purpose of the experiment was to provide results at energies that no polarization measurements were previously performed at as well as to clear up some of the uncertainty existing between different sets of data at 400 MeV.

The experiment was performed using 305, 330, 375 and 400 MeV polarized protons from the TRIUMF cyclotron. The beam intensity as well as the beam polarization were monitored using p-p elastic scattering in a 4-arm polarimeter that detected both the scattered and recoil protons from a $CH_2$ target. Typical beam polarizations were 78% and beam intensities were in the 5 to 8 nA range. For some of the measurements the beam intensity was also monitored by a secondary emission monitor downstream of the target.



The results at 305, 330 and 400 MeV (using a liquid deuterium, $LD_2$ target) were obtained using a single arm configuration involving a 50 cm Browne-Buechner spectrograph with a 24-counter hodoscope array along the focal plane providing the momentum information. The total experimental resolution of the spectrograph was ~2.2 MeV FWHM for central ray pions of ~65 MeV kinetic energy. The pion production target was a 3.16 cm diameter cell containing liquid deuterium ($LD_2$). Details of the experimental arrangement and the data analysis techniques will be published in length elsewhere[9]).

For all of the data obtained using incident proton energies of 375 and for a portion of the 400 MeV results, a different system was employed. Pions produced from a $LD_2$ target were detected with a 65 cm Browne-Buechner magnetic spectrograph incorporating three helically wound multi-wire proportional chambers (MWPC) intercepting the focal plane, enabling track reconstruction and momentum definition. The event trigger was provided by a fast three-counter coincidence. Identification of the pion events was made on the basis of energy loss, time of flight and track reconstruction information. The resolution of this spectrograph was ~800 keV FWHM. The improved resolution of the newer spectrograph, coupled to the improved background rejection made possible by the use of MWPC's, made the use of a liquid $D_2$ target unnecessary. For the 375 and 400 MeV results with this system a $CD_2$ (polyethlene) target was used, enriched to 99% in deuterium, and with an areal density of 81.6 mg/cm$^2$. For most of the measurements, the exception being the $\theta_{\pi,LAB} = 52°$ and 69.6° measurements at 375 MeV, an additional constraint on the detected pions was imposed, namely the coincidence requirement with the associated triton events detected by a scintillator counter. The target scattering chamber was connected to a modified beam pipe incorporating a horn at the end of which the recoil detector was placed, a scintillator counter having an angular freedom of movement of ~6° to ~11.5° in the lab frame. The use of such a double arm arrangement resulted in high quality pion spectra as can be seen in fig. 1.

For $\theta_{\pi,LAB} = 52°$ and 69.6° (at an incident proton energy of 375 MeV), the triton recoil angle fell outside the effective horn window range of 6° to 11.5°; for these two cases the pions from the $CD_2$ were detected in a single arm arrangement. At these angles, however, the $pd \to t\pi^+$ cross section is sufficiently large so that the pion peak from this reaction stands out clearly above the pion spectrum generated from the $^{12}C(p,\pi^+)X$ inclusive reaction. As can be seen in fig. 2 the subtraction of the pion continuum arising from the $^{12}C(p,\pi^+)X$ reaction (measured using a carbon target) from the $CD_2$ pion spectrum resulted in a clean $pd \to t\pi^+$ spectrum. The continuum evident in the lower pion energy part of the spectrum in fig. 2 is a result of the break-up reactions $pd \to dn\pi^+$ and $pd \to pnn\pi^+$ having threshold excitations of 6.23 and 8.35 MeV respectively.

The analyzing power $A_y(\theta)$ was calculated using the equation

$$A_y(\theta) = \frac{Y_N(\uparrow) - Y_N(\downarrow)}{P(\uparrow)Y_N(\downarrow) + P(\downarrow)Y_N(\uparrow)} ,$$



where $Y_N$ and $P$ are the normalized yield and magnitude of the polarization respectively. The arrows indicate the spin orientation as spin up (↑) or spin down (↓) according to the Madison Convention[10]).

The spin averaged (unpolarized) differential cross section, for the 305, 330 and the earlier ($LD_2$) 400 MeV data, was calculated using the equation

$$\frac{d\sigma}{d\Omega}(\theta) = \frac{P(\uparrow)d\sigma(\downarrow)/d\Omega + P(\downarrow)d\sigma(\uparrow)/d\Omega}{P(\downarrow) + P(\uparrow)}$$

where the $d\sigma(\uparrow)/d\Omega$ and $d\sigma(\downarrow)/d\Omega$ are the differetial cross sections for the spin up and spin down configurations respectively[10]).

The calibration of the 65 cm Browne-Buechner spectrograph is currently being performed by normalizing relative to the $pp \to d\pi^+$ differential cross section. At present then, we can only extract the polarization analyzing power for the 375 and the later 400 MeV ($CD_2$) results.

The results of the $A_y(\theta)$ and $d\sigma(\theta)/d\Omega$ measurements for the 305, 330 and 400 MeV ($LD_2$) together with the 375 and recent 400 MeV ($LD_2$) $A_y(\theta)$ results are shown in figs. 3(a), (b) and are also presented in table 1. For comparison the results for 400 MeV from ref.[3]) and those for 500 MeV from ref.[4]) are also included in figs. 3(a) and (b). The error bars on all results reflect statistical uncertainties only. The uncertainty due to the carbon subtraction in the 375 and $CD_2$ 400 MeV results has also been folded in.

As can be seen from fig. 3(a), the results at 375 MeV exhibit a qualitatively different analyzing power angular distribution $A_y(\theta)$ than do those at 305 and 330 MeV. The $A_y(\theta)$ appears nearly identical at 305 and 330 MeV; at 375 MeV, however, the minimum for $A_y(\theta)$

appears to have shifted to a smaller angle than the $\theta_{\pi,c.m.} \simeq 85°$ characterizing the 305 and 330 MeV results. One can also discern a tendency for the $A_y(\theta)$ shape to change gradually from that of a basically negative $pp \rightarrow d\pi^+$-like shape at 330 MeV to that of the $pd \rightarrow t\pi^+$ at 500 MeV. The two sets of analyzing power data at 400 MeV ($LD_2$ and $CD_2$) are also in reasonable agreement, although they were taken with quite different experimental systems. The slightly larger values indicated by the most recent data can be accounted for by the improved resolution of the new spectrograph as well as the $\pi^+$-t coincidence required in the 2-arm experiment. These two factors reduce the contribution of the break-up reactions to a minimum. Our two sets of results at 400 MeV are in sharp disagreement with the 400 MeV results reported in ref.[3]). A possible source of this disagreement could be the difficulty encountered in ref.[3]) in separating the exclusive $pd \rightarrow t\pi^+$ reaction pions from the pions arising from a) the inclusive channels and b) from the two step process of forward pion production via $pd \rightarrow t\pi^+$ followed by a backward $\pi$-d elastic scattering.

In conclusion, although some energy dependence is observed in the analyzing power between 300 and 375 MeV, the 500 MeV results of ref.[5]) imply a still more significant change in $A_y(\theta)$ between 375 and 500 MeV for the forward angles. In light of the rapid sign reversals of the $A_y(\theta)$ observed in $^{12}C$ [ref.[11])] the sign reversal observed here between 375 and 500 MeV is perhaps not surprising any more. The $pd \rightarrow t\pi^+$ reaction must be explored in more detail, especially to determine the incident proton energy at which the $A_y(\theta)$ sign reversal takes place. These rapid changes of the sign of $A_y(\theta)$ at different proton energies for different nuclei may simply signify the onset of the



$\Delta$-isobar contribution and they may depend more on nuclear mass rather than intrinsic nuclear structure, although evidence of intrinsic nuclear structure sensitivity has also been observed[12]). As yet, there is still too little data on the spin dependence of the $pd \rightarrow t\pi$ reaction to be able to form a coherent picture.

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## References


1) H.W. Fearing, Progress in Particle and Nuclear Physics, v.7, ed. D. Wilkinson (Pergamon, 1981) p. 113

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

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

4) R. Abegg et al., Polarization Phenomena in Nuclear Physics, Santa Fe, 1980, ed. G.G. Ohlsen et al., AIPCP No. 69 (AIP, New York, 1980)

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

6) G. Jones, Meson-Nuclear Physics Conference, Houston, 1979, ed. E.V. Hungerford III, AIPCP No. 54 (AIP, New York, 1979)

7) P.L. Walden, D. Ottewell, E.L. Mathie, T. Masterson, G. Jones, R.R. Johnson, A. Haynes and E.G. Auld, Phys. Lett. 81B, (1979) 156

8) W.R. Falk, E.G. Auld, G. Giles, G. Jones, G.J. Lolos, P. Walden and W. Ziegler, Phys. Rev. C (in press)

9) E.L. Mathie, G. Jones, T. Masterson, D. Ottewell, P.L. Walden, E.G. Auld, A. Haynes and R.R. Johnson, Nucl. Phys. A (to be published)

10) Proceedings 3rd International Symposium on Polarization Phenomena in Nuclear Reactions, eds. H.H. Barschall and W. Haeberli (Univ. of Wisconsin, Madison, 1971)

11) 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)

12) G.J. Lolos, Pion Production and Absorption in Nuclei, Bloomington, 1981, ed. R.D. Bent, AIPCP No. 79 (AIP, New York, 1982)




Table 1

Analyzing power, $A_y(\theta)$, and differential cross section, $d\sigma/d\Omega(\theta)$, of the $pd \to t\pi^+$ reaction.

| $T_p$(MeV) | $\theta_{c.m.}$(deg) | $A_y(\theta)$ | $d\sigma/d\Omega(\theta)$(μb/sr) |
|---|---|---|---|
| 305 | 68.0 | -0.36(0.01) | 2.04(0.12) |
| | 89.0 | -0.60(0.01) | 0.93(0.06) |
| | 113.0 | -0.40(0.02) | 0.57(0.03) |
| | 144.0 | -0.14(0.03) | 0.57(0.03) |
| 330 | 75.3 | -0.47(0.02) | 1.50(0.09) |
| | 81.0 | -0.53(0.02) | 1.05(0.06) |
| | 90.0 | -0.53(0.02) | 0.92(0.06) |
| | 107.0 | -0.43(0.02) | 0.76(0.05) |
| | 116.5 | -0.26(0.03) | 0.85(0.05) |
| | 126.0 | -0.21(0.02) | 0.70(0.04) |
| | 145.0 | -0.09(0.06) | 0.65(0.04) |
| 375 | 69.8 | -0.50(0.02) | |
| | 90.0 | -0.45(0.03) | |
| | 110.8 | -0.13(0.03) | |
| | 120.1 | -0.21(0.03) | |
| | 130.0 | -0.31(0.06) | |
| 400($CD_2$) | 120.1 | -0.19(0.01) | |
| | 130.0 | -0.18(0.03) | |
| 400($LD_2$) | 125.5 | -0.27(0.02) | 0.71(0.04) |
| | 138.0 | -0.25(0.04) | 0.68(0.04) |
| | 145.5 | -0.13(0.03) | 0.87(0.05) |

## FIGURE CAPTIONS

Fig. 1. Pion spectrum from the pd → tπ⁺ reaction in a two arm arrangement when both the pion and the triton are detected. The carbon contribution in the $CD_2$ target has been subtracted from the pion spectrum.

Fig. 2. Pion spectrum from the reaction pd → tπ⁺ in a single arm experiment when only the pions are detected. The spectra shown are from the $CD_2$ as well as from a carbon target, both normalized to the total charge on target as well as to the carbon content in the $CD_2$ target. The spectrum resulting from the $CD_2$–C subtraction is also shown. The peak in the $CD_2$–C spectrum is from the pd → tπ⁺ reaction while the continuum is due to pions from the pd → dnπ⁺ and pd → pnnπ⁺ break-up reactions.

Fig. 3. Analyzing power angular distributions $A_y(\theta)$ for: a) ⧫-375 MeV, ▲-305 and ⦶ -330 MeV this work; ◆-500 MeV from ref.[4]) b) ▲-400 MeV this work ($CD_2$ target), ⦶-400 MeV this work ($LD_2$ target); ✕-400 MeV from ref.[3]). Statistical errors only are indicated. The lines through the data points serve only as guides to the eye.

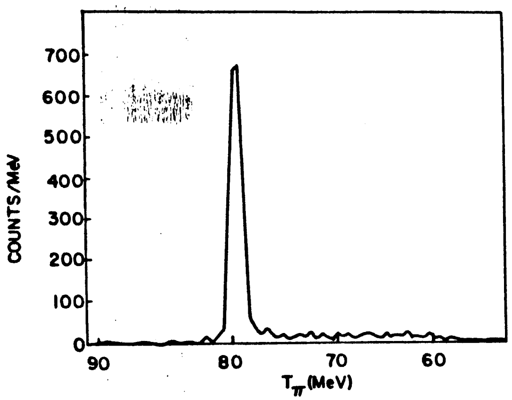

Fig. 1

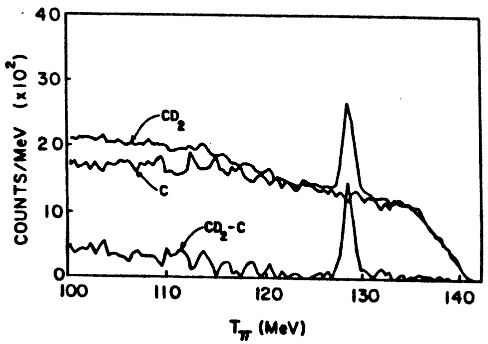

Fig. 2

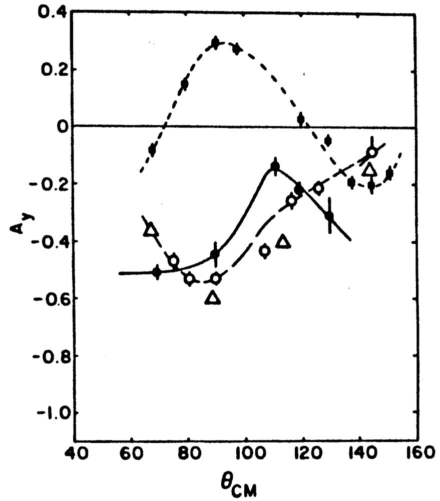

Fig. 3(a)

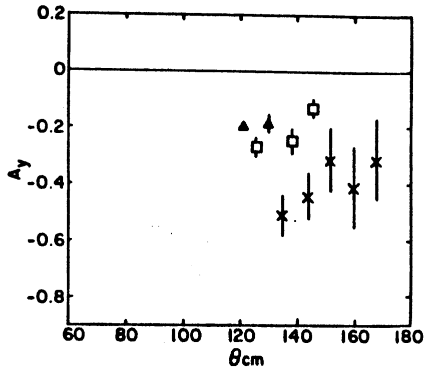

Fig. 3(b)