Analyzing power of the $\vec{p}p \rightarrow \pi^+ d$ reaction at 400 and 450 MeV

W. R. Falk,* E. G. Auld, G. Giles, G. Jones, G. J. Lolos, P. Walden, and W. Ziegler
Physics Department, University of British Columbia and TRIUMF,
Vancouver, British Columbia, Canada V6T 2A6
(Received 30 November 1981)

Analyzing power measurements of the $\vec{p}p \rightarrow \pi^+ d$ reaction have been made at proton bombarding energies of 400 and 450 MeV, over the angular range from 76–119° center of mass. The data at 400 MeV confirm older measurements; no previous data at 450 MeV have been reported. A comparison of these data with theoretical predictions of Niskanen reveals generally good agreement, although the data tend to exhibit slightly greater asymmetry about 90° than predicted by theory.

[NUCLEAR REACTIONS $\vec{p}p \rightarrow d\pi^+$, polarized protons, $T_p = 400$ and 450 MeV; measured $A_y(\theta)$.]

The reaction $\vec{p}p \rightarrow \pi^+ d$ is of fundamental importance in intermediate energy physics since it is the most elementary π production reaction that can be studied. An understanding of this reaction is necessary, not only from the point of view of providing information on the inelastic nucleon-nucleon amplitudes, but also as a basic ingredient in theories of the pion-nucleus interaction where pion absorption on nucleon pairs is still very poorly understood.[1]

Spin-dependent measurements of the $pp \rightarrow d\pi$ reaction have for many years provided theorists with the most demanding quantities to interpret. In fact, only the theoretical treatment of Niskanen[2] has been able to provide a reasonable fit to such data. A considerable body of information on the analyzing power of the $\vec{p}p \rightarrow \pi^+ d$ reaction now exists in the energy range from threshold to 425 MeV,[3] from 500–600 MeV,[4] and in the neighborhood of 800 MeV.[5]

The new data of Ref. 4 have shown that the parameters in a partial wave expansion[6] of the spin dependent differential cross section are nonzero out to fifth order. For the whole of the 500–600 MeV range, the analyzing power $A_y(\theta)$ is positive over the entire angular range. This is in contrast to the situation below 425 MeV (Ref. 3), where $A_y(\theta)$ is mostly negative and the spin-dependent nonzero parameters have only been established out to the third term. The higher-order terms of Ref. 4 arise from the contribution of the higher partial waves (d, f, etc.), which appear at higher incident proton energy. The experimental data reported here on the analyzing power of the $\vec{p}p \rightarrow \pi^+ d$ reaction at 450 MeV provide additional new information that help constrain the theoretical predictions in the previously unexplored 425–500 MeV region.

The experiment was performed using 400 and 450 MeV polarized protons from the TRIUMF cyclotron. The pions were detected with a 65 cm Browne-Buechner magnetic spectrograph incorporating three helically wound multiwire proportional chambers for track reconstruction and momentum definition. A fast three-counter coincidence was used for definition of the event trigger. Identification of the pion events was made on the basis of energy loss, time of flight, and track reconstruction. A CH_2 target of areal density 149.5 mg/cm^2 was employed in the measurements, and each run with this target was immediately followed by a run on an appropriate carbon target for purposes of background subtraction. Figure 1 displays such a background-subtracted spectrum. The overall energy resolution (FWHM) of the deuteron peak is 1.77 MeV, most of this width arising from the kinematic spread $dT/d\theta$. Events on the low-energy side of the deuteron peak arise from the $pp \rightarrow pn\pi^+$ reaction. Simultaneous measurements of the polarization and intensity of the proton beam were accomplished using elastic p-p scattering in a 4-arm 8-counter polarimeter that detected both the scattered and recoil protons. The analyzing power of the polarimeter was 0.339 and 0.353 at 400 and

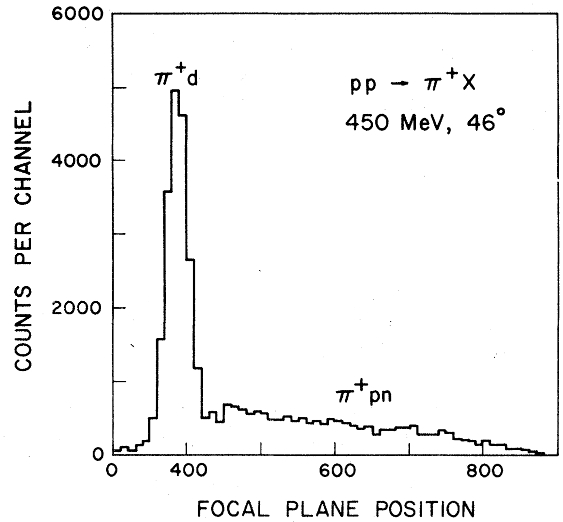

FIG. 1. Pion energy spectrum from the $\vec{p}p \to \pi^+ d$ reaction. Events from the $pp \to pn\pi^+$ reaction are present on the low-energy side of the peak. The background from the carbon in the target has been subtracted.

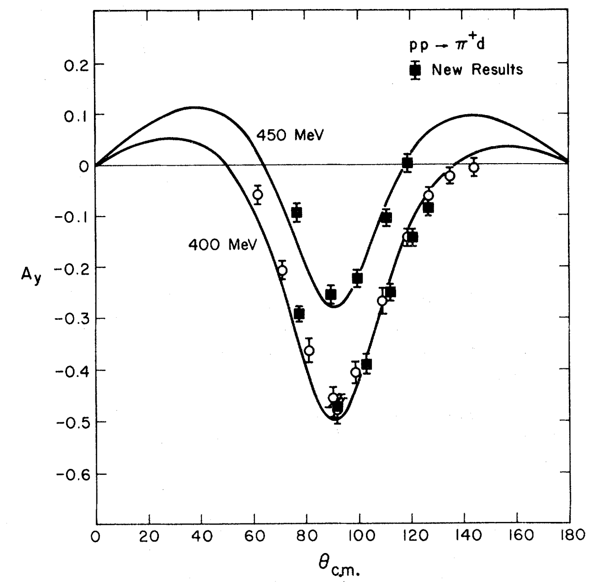

FIG. 2. Analyzing power of the $\vec{p}p \to \pi^+ d$ reaction. The solid squares represent the current results whereas the open circles are data from Ref. 3. The solid curves are theoretical predictions from Niskanen (Ref. 2).

450 MeV, respectively. Typical beam polarizations were 66% and intensities 1–2 nA.

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 $Y_N(\uparrow)$ and $Y_N(\downarrow)$ are the normalized yields for spin up and down, respectively, and $P(\uparrow)$ and $P(\downarrow)$ are the beam polarizations for spin up and down, respectively.

TABLE I. Analyzing power A_y of the $\vec{p}p \to \pi^+ d$ reaction.

T_p (MeV)	$\theta_{c.m.}$ (deg)	A_y
400	77.0	−0.292 (0.014)
	91.1	−0.473 (0.018)
	102.5	−0.392 (0.016)
	111.7	−0.253 (0.013)
	120.2	−0.141 (0.012)
	126.4	−0.087 (0.011)
450	76.3	−0.095 (0.016)
	89.5	−0.259 (0.015)
	99.3	−0.220 (0.014)
	110.7	−0.108 (0.014)
	118.8	−0.003 (0.013)

Results of the current measurements of A_y are summarized in Table I and are also shown in Fig. 2, along with previous results[3] obtained at 400 MeV. The errors are due to statistics only. The systematic uncertainties due to the beam current monitor as well as due to the subtraction of the pions from the $\vec{p}p \to pn\pi^+$ reaction have not been folded in. Their combined contribution, however, is estimated to be less than the statistical uncertainty. The current measurements at 400 MeV were undertaken as a check and comparison with the earlier data, and indeed, the agreement of the two sets of data is excellent. The new data were obtained with a completely different apparatus and on a different proton beam line at TRIUMF from that used for the previous data. Theoretical calculations of the analyzing powers are shown as the solid curves in Fig. 2, which were obtained using Niskanen's amplitudes.[2] Although the general agreement between the experimental data and the theoretical calculation is good, there is some indication that the experimental results have a slightly greater asymmetry about 90° than predicted by theory, suggesting that the theory underestimates the higher partial wave contributions. Current lack of knowledge of the unpolarized differential cross section precludes further analysis of these data to extract the partial wave amplitudes.

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

---

*Permanent address: Physics Department, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2.

[1]A. W. Thomas and R. H. Landau, Phys. Rep. 58, 121 (1980).

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

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

[4]J. Hoftiezer, C. Weddingen, B. Favier, S. Jaccard, P. Walden, P. Chatelain, F. Foroughi, C. Nüssbaum, and J. Piffaretti, contribution to 9th ICOHEPANS, Versailles, 1981 (unpublished).

[5]H. Nann, S. Iversen, M. Kaletka, J. Hird, K. Seth, B. Hoistad, R. L. Burman, and G. Kyle, Phys. Lett. 88B, 257 (1979).

[6]J. A. Niskanen, in *Polarization Phenomena in Nuclear Physics—1980,* Proceedings of the 5th International Symposium on Polarization Phenomena in Nuclear Physics, Sante Fe, edited by G. G. Ohlsen, R. E. Brown, N. Jarmie, M. W. McNaughton, and G. M. Hale (AIP, New York, 1981), p. 62.