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Proton-deuteron elastic scattering at 800 MeV

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Differential cross sections and polarization analyzing powers for proton-deuteron elastic scattering have been measured at 800 MeV incident proton kinetic energy over the range of center-of-mass angles from 14.1° to 153.6°. The differential cross sections are described by the Glauber theory of impulse approximation at forward angles ($-t<0.5$) and exhibit the exponential dependence on $\cos\theta_{\text{c.m.}}$ typical for these energies at backward angles ($\cos\theta_{\text{c.m.}}<-0.5$). The analyzing power shows considerable structure with strong positive peaks at forward and backward angles and a sharp dip at $t=-0.4$ typical at intermediate energies. There is no evidence for correspondence of the angular dependence of the analyzing power with that for the $pp\rightarrow d\pi^+$ reaction. At large momentum transfer the data favor calculations based on multiple scattering with a modified deuteron form factor rather than N^* exchange.

[NUCLEAR REACTIONS $^2\text{H}(p,p)^2\text{H}$, $E=800$ MeV, measured $\sigma(\theta)$ and $A_y(\theta)$.]

I. INTRODUCTION

There has been considerable interest in the proton-deuteron interaction as the simplest possible between protons and nuclei. Proton-deuteron elastic scattering, moreover, should show some correspondence with other proton-deuteron interactions such as pion production from the $pp\rightarrow d\pi^+$ reaction. We have measured both the differential cross section and the polarization analyzing power A_y, the asymmetry in the scattering of a polarized proton by an unpolarized target (which equals the polarization P if time reversal holds), for the elastic scattering of protons by deuterons for $T_p=800$ MeV and $14°<\theta_{\text{c.m.}}<154°$, with emphasis on precision measurements of the analyzing power.

The status of proton-deuteron elastic scattering at intermediate energies has been reviewed recently.[1] The differential cross section has been measured extensively[2-8] from 316 MeV to 5.73 GeV, with emphasis on backward angles. The analyzing power has been studied over as wide an energy range,[3-5,9,10] but with less precision. In addition, there have been efforts recently to determine the spin orientation of the scattered deuteron[11] and the tensor analyzing power.[12]

At forward angles, where the transferred momentum is small, the interaction should be dominated by the impulse approximation, and the differential cross section is expected to agree with that predicted by the theory of Glauber[13,14] and Watson.[15] The incident proton is considered to scatter successively from one or both of the individual nucleons in the deuteron with essentially a free nucleon-nucleon interaction. Interference between single and double scattering should produce a sharp dip when the four-momentum transfer squared $t=-0.4\,(\text{GeV}/c)^2$. The observed smoothing of the dip to the shape of a shoulder has been ascribed to either differences in the ratios of real to imaginary parts of the n-p and p-p forward scattering amplitudes[6] or to the admixture of d state in the deuteron.[14]

The analyzing power should also be large and positive in the forward direction as in free nucleon-nucleon scattering, though the angle at which the analyzing power peaks should be smaller than that of $\theta_{\text{c.m.}}=40°$ for p-p scattering[16] or $\theta_{\text{c.m.}}=30°$ for p-n scattering[17] as observed for other light nuclei.

It is at back angles that we might hope to learn more about the details of the deuteron wave function and its form factor, since they depend on the small radial components whose effects can only be observed for large momentum transfer.[7] Below 300 MeV, i.e., below the threshold for pion production, the reaction is well described by one nucleon exchange (ONE). There is a well-defined peaking at back angles, which is characteristic of nucleon-deuteron scattering from low energies to the GeV region.[1] Such a rise can be obtained with a calculation based on single scattering, since the cross section for free nucleon-nucleon scattering also rises at back angles.[18] At intermediate energies, however, the magnitude observed at back angles is larger than can be predicted with so simple a calculation.

Kerman and Kisslinger[19] proposed a 1%–2% admixture of excited nucleon state component in the ground state wave function, specifically the $N^*(\frac{5}{2}, \frac{1}{2})$ nucleon isobar with an invariant mass of 1688 MeV. The exchange of these components in proton-deuteron scattering would augment neutron exchange sufficiently to fit the observed yields. The mechanism almost entirely responsible for elastic scattering is thus fermion transfer (pick-up), because the momentum transfer required at the deuteron vertex is much smaller than that for single or double impulse collisions.[20]

Craigie and Wilkin[21] proposed that the reaction $pp \to d\pi^+$ should play a significant role, and they adapted a calculation of Yao[22] which related the $pp \to d\pi^+$ and $\pi p \to p\pi$ reactions. Since the latter correspondence held well above resonant energy, the correspondence between proton-deuteron scattering and the $pp \to d\pi^+$ reaction might hold above the pronounced resonance in that reaction corresponding to the mass of the $\Delta(\frac{3}{2}, \frac{3}{2})$ at 1236 MeV in the pion-nucleon system. They characterized the scattering as a two-step process in which the virtual reaction $pp \to d\pi^+$ is followed by absorption of the pion,[18] calculated from the so-called triangular graph which includes as input the $pp \to d\pi^+$ amplitude.[21]

Barry[23] obtained excellent fits to the available data with a corrected version of Craigie and Wilkin's calculations. He noted, however, that the excited nucleon theory of Kerman and Kisslinger[19] and the triangle graph of Craigie and Wilkin[21] were both different facets of the same one pion exchange (OPE) process. Kolybasov and Smordinskaya[18] extended the work of Craigie and Wilkin and added a smooth background to achieve excellent fits. Noble and Weber[24] found no convincing need for either exchange of excited N^* isobars in the deuteron wave function or pion-nucleon exchange contributions beyond the usual ONE. They claimed that Kerman and Kisslinger[19] incorrectly evaluated their wave functions in terms of $|\Delta| = |\vec{d}'/2 - \vec{p}|$ rather than $Q = [(p \cdot d')^2/M_d^2 - M_p^2]^{1/2}$. One really different alternative is that of Remler and Miller,[25] who took a multiple scattering approach, using knowledge of the deuteron structure and the nucleon-nucleon interaction, neglecting exchange terms. More recently Gurvitz and Rinat[26] have successfully fitted back angle pd scattering data above 1 GeV/c with a calculation based on single scattering plus neutron exchange, yielding a reasonable form factor for the deuteron, with no N^* content.

The observed cross section has passed many of the tests of comparison with the $pp \to d\pi^+$ reaction at back angles. The cross section at very back angles falls rapidly with energy except for a pronounced bump at about 600 MeV, which has been reproduced in calculations.[1,18] Furthermore, the shapes of the angular distributions have been fitted with the various recipes based on OPE, except for the lack of a dip at extreme back angles.[8]

Still, the ultimate test is to compare the analyzing powers for the two reactions. The reaction mechanism in proton-deuteron scattering is sensitive to the proton polarization.[18] We would thus expect the asymmetries resulting from incident polarized protons to be the same for both reactions at back angles and the same energies. Otherwise, if OPE is not dominant, the scattering of polarized protons by deuterons should be dominated by three-baryon exchange.[24]

One comparison at 425 MeV (Refs. 3 and 27) showed little agreement. Another measurement at 544 MeV (Refs. 4 and 28) was inconclusive because of poor statistics in the analyzing power for proton-deuteron scattering. Hence, we felt the need for precise measurements of the analyzing power for proton-deuteron elastic scattering at the same energy as recent measurements of the asymmetry in the $pp \to d\pi^+$ reaction,[29] i.e., 800 MeV.

II. EXPERIMENTAL PROCEDURE

The experimental method has been described elsewhere.[16,30] A floor plan of the experimental arrangement is given in Fig. 1. Measurements were made with the external proton beam (EPB) of the Los Alamos Meson Physics Facility (LAMPF). The position of the beam was monitored with a profile monitor, and its intensity (about 20 pA) was determined relatively with an Ar-CO_2 ion chamber and a Faraday cup,[31] with absolute normalization obtained by comparison of interspersed measurements of elastic proton-proton scattering with earlier highly accurate determinations.[16] The polarization of the incident beam was monitored with a polarimeter,[32] which was normalized absolutely by quenching the polarized beam at the source. The polarization was typically of the order of 0.75, reversed every three minutes, with an uncertainty of about 0.5%.

The targets were slabs of CD_2 ranging from 18 mg/cm^2 to 556 mg/cm^2, with corresponding slabs of pure C to investigate the contributions from quasielastic scattering, and CH_2 to determine if CH_2 contamination gave spurious information. All but the desired data were rejected kinematically. Both the scattered proton and the recoil deuteron were detected (for right and left

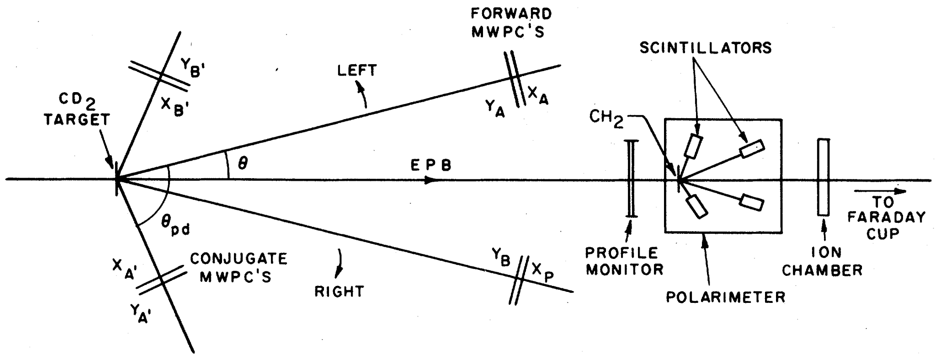

FIG. 1. Floor plan of experimental arrangement.

scattering) with x-y pairs of MWPC's.[33] The products of elastic scattering reactions were identified by kinematical constraints of the polar (θ_{pd}) and azimuthal angles with interpolation and subtraction of contributions from other sources such as quasielastic scattering from nucleons in the carbon nuclei. The backgrounds constituted from 25% to 90% with uncertainties from 2% to 4%. The data-acquisition system[34] was developed to minimize dead time, which was monitored for correction of the cross-section measurements; typical values of dead time were from 1% to 8%. The differential cross section was also corrected for the finite opening of the MWPC's with corrections from +2% to −11% and uncertainties of 1% to 4%. The only significant uncertainties in the analyzing power were those of counting statistics.

III. RESULTS

The observed differential cross section $d\sigma(\theta_{\text{c.m.}})/d\Omega$ for the elastic scattering of 800 MeV protons by deuterons is listed in Table I and plotted against $\cos\theta_{\text{c.m.}}$ in Fig. 2. The shape is typical of those observed at intermediate energies: The cross section decreases by several orders of magnitude at very forward angles, then with a sharp break it decreases more slowly until at very back angles it rises sharply again.

TABLE I. Differential cross sections and analyzing powers for proton-deuteron elastic scattering at $T_p = 800$ MeV. (Quantities with an asterisk are in the center-of-mass system.)

θ (°)	$d\sigma/d\Omega$ (μb/sr)	θ^* (°)	$\cos\theta^*$	t (GeV/c)^2	$d\sigma/dt$	$(d\sigma/d\Omega)^*$ (μb/sr)	$A_y(\theta^*)$
8.0		14.1	0.970	−0.042			0.340 ± 0.049
9.4		16.4	0.959	−0.055			0.450 ± 0.023
10.1	4920	17.8	0.952	−0.066	67 850	14 900 ± 4800	
10.9		19.2	0.945	−0.076			0.459 ± 0.026
12.4	2390	21.7	0.929	−0.098	32 600	7160 ± 1500	0.426 ± 0.006
14.9	745	26.2	0.898	−0.141	9970	2190 ± 260	0.418 ± 0.007
17.4	398	30.3	0.864	−0.188	5240	1150 ± 90	0.364 ± 0.015
19.9	114	34.6	0.823	−0.244	1470	322 ± 37	0.246 ± 0.013
22.4	57.7	38.7	0.780	−0.303	724	159 ± 18	0.096 ± 0.032
24.9	34.4	43.0	0.731	−0.371	420	92.2 ± 7.4	0.005 ± 0.006
27.4	34.2	47.0	0.682	−0.439	406	89.1 ± 4.9	0.056 ± 0.016
29.9	25.9	51.2	0.627	−0.515	297	65.3 ± 4.1	0.107 ± 0.023
35.0	25.4	59.2	0.512	−0.673	271	59.6 ± 3.9	0.225 ± 0.020
40.0	18.5	66.9	0.392	−0.839	182	40.0 ± 2.9	0.218 ± 0.035
45.0	17.3	74.4	0.269	−1.009	156	34.3 ± 2.4	0.149 ± 0.026
55.5	11.2	89.0	0.017	−1.357	82.4	18.1 ± 1.7	0.092 ± 0.031
60.0	11.8	94.9	−0.085	−1.497	78.8	17.3 ± 1.8	0.066 ± 0.029
68.9		105.7	−0.271	−1.754			−0.076 ± 0.029
69.8	10.4	106.8	−0.289	−1.778	56.0	12.3 ± 1.2	−0.137 ± 0.033
79.9	8.7	117.8	−0.467	−2.024	36.9	8.1 ± 1.0	−0.360 ± 0.028
89.9	11.7	127.6	−0.610	−2.222	38.7	8.5 ± 1.0	−0.220 ± 0.030
99.9	23.1	136.2	−0.722	−2.376	59.7	13.1 ± 1.3	0.071 ± 0.030
109.9	47.7	143.7	−0.806	−2.492	97.5	21.4 ± 1.8	0.217 ± 0.021
119.7	97.3	150.3	−0.869	−2.579	160	35.1 ± 2.9	0.230 ± 0.020
124.8	135.7	153.5	−0.895	−2.614	200	44.0 ± 4.7	0.190 ± 0.044

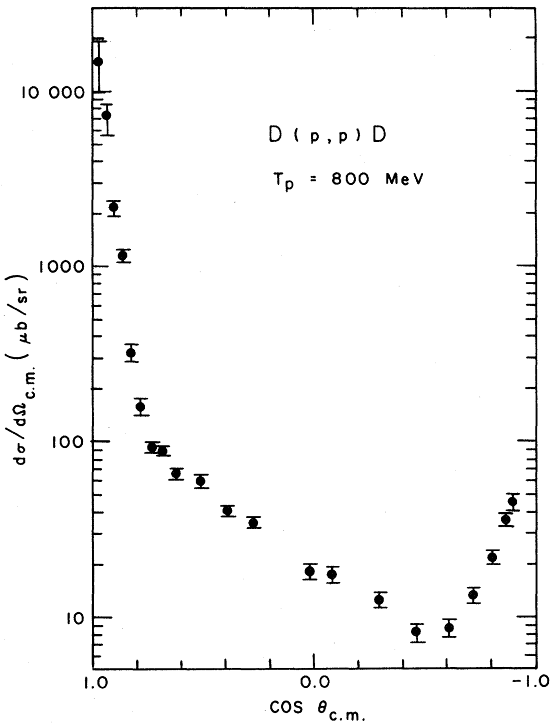

FIG. 2. Differential cross section $\sigma(\theta_{c.m.})$ vs $\cos\theta_{c.m.}$ for $T_p = 800$ MeV.

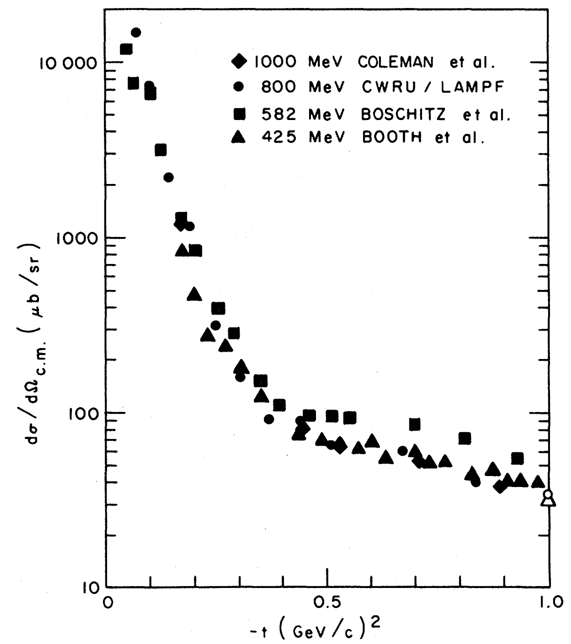

FIG. 3. Comparison of $\sigma(\theta_{c.m.})$ vs $-t$ at forward angles with data of Coleman *et al.* (Ref. 7), Boschitz *et al.* (Ref. 4), and Booth *et al.* (Ref. 3).

The behavior at forward angles is compared in Fig. 3 with other measurements between 400 and 1000 MeV, plotted against the four-momentum transfer squared t (in GeV$^2/c^2$). To the extent that the impulse approximation of Glauber theory[13,14] holds, the dependence on t should be independent of incident proton energy. This is true for $-t < 0.5$ GeV$^2/c^2$, beyond which the data at different energies begin to diverge. The predicted dip at $t = -0.4$ is barely perceptible as a shoulder.

For comparison with other measurements between 400 MeV and 2.6 GeV at back angles, the cross section is plotted in Fig. 4 vs $\cos\theta_{c.m.}$. Alder[2] noted that over a wide energy range, for $\cos\theta_{c.m.} < -0.5$, there was an exponential dependence on $\cos\theta_{c.m.}$, which might result from exponential dependence on $t = (\vec{p} - \vec{p}\,')^2 = 2p_{c.m.}^2(\cos\theta_{c.m.} - 1)$. He also noted that the exponential coefficient was s dependent (i.e., varied with incident proton kinetic energy), which could be avoided by plotting vs the Fermi momentum of the nucleon exchanged $|\Delta| = |\vec{d}\,'/2 - \vec{p}|$, although the fit is not as good. Dubal[8] also observed a decrease in s dependence when the backward cross section $\sigma(180°)$ is plotted vs Δ.

Also plotted in Fig. 4 are the neutron-deuteron scattering data of Bonner *et al.*[35] at 794 MeV; the straight line is their fit to an exponential dependence on momentum transfer, indicative of particle exchange. The excellent agreement verifies the absolute normalization of the *nd* scattering data, which in turn support the normalization of the *pd* data of Dubal *et al.*,[8] undermining the justification for introducing N^* con-

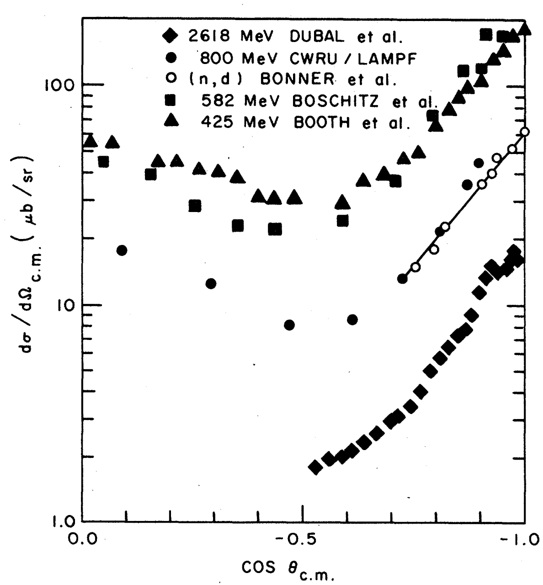

FIG. 4. Comparison of $\sigma(\theta_{c.m.})$ vs $\cos\theta_{c.m.}$ at backward angles with data of Dubal *et al.* (Ref. 8), Boschitz *et al.* (Ref. 4), and Booth *et al.* (Ref. 3) and with *nd* data of Bonner *et al.* (Ref. 35). Line is fitted to *nd* data.

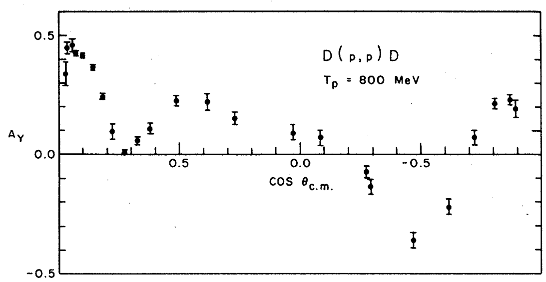

FIG. 5. Analyzing power $A_y(\theta_{c.m.})$ vs $\cos\theta_{c.m.}$ for T_p = 800 MeV.

tent in the deuteron. The measurements of Bonner *et al.*[36] of *nd* scattering at 180° raised serious doubts about the validity of the triangular diagram technique of Craigie and Wilkin.[21] The shoulder they observed in the excitation function has been shown[37] to overlap that found at 180° in $\pi^- d$ scattering when plotted at the same momentum transfer, which implies that neither the triangle diagram nor N^* exchange contributes significantly to Nd scattering at large momentum transfer.

The polarization analyzing power $A_y(\theta_{c.m.})$ is listed in Table I and plotted vs $\cos\theta_{c.m.}$ in Fig. 5. The value fluctuates rapidly between +0.5 and −0.5. The measurements are compared with those at lower energies in Fig. 6, plotted against t to

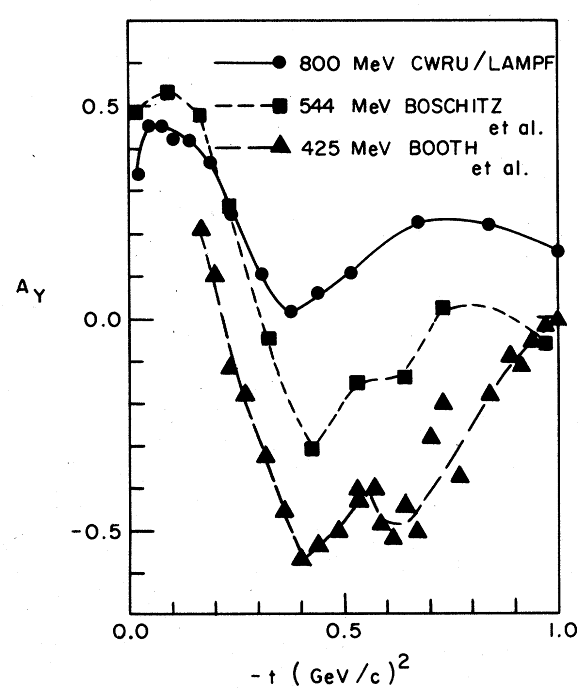

FIG. 6. Comparison of $A_y(\theta_{c.m.})$ vs $-t$ at forward angles with data of Boschitz *et al.* (Ref. 4) and Booth *et al.* (Ref. 3). Lines are to guide the eye.

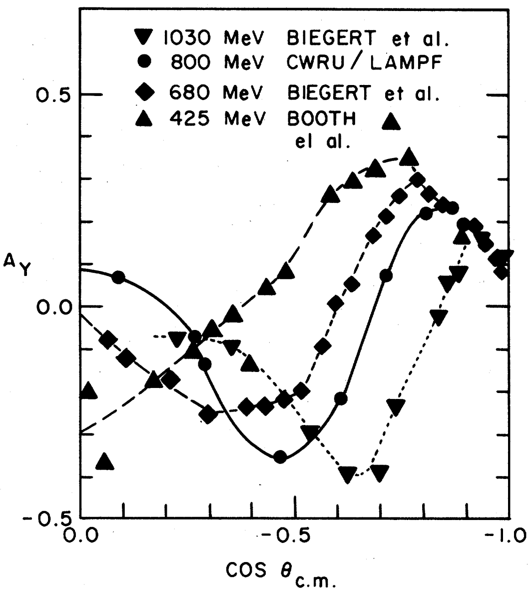

FIG. 7. Comparison of $A_y(\theta_{c.m.})$ vs $\cos\theta_{c.m.}$ at back angles with data of Biegert *et al.* (Ref. 9) and Booth *et al.* (Ref. 3). Lines are to guide the eye.

emphasize agreement with the impulse approximation. As expected, there is a strongly positive peak at forward angles, with a maximum value of 0.46 at 18° for the 800 MeV data. A sharp dip occurs at $t = -0.4$ at all energies, much sharper than in the cross section at the same value of t, but not so deep at higher energies. For $-t > 0.5$, the data at different energies diverge considerably, with those at 800 MeV generally more positive.

The back-angle behavior is compared in Fig. 7, plotted vs $\cos\theta_{c.m.}$. At intermediate angles the behavior is strikingly different, but the analyzing power always manages to reach a positive peak with $A_y \simeq 0.3$ before dropping to zero at 180°. There is an apparent tendency for that peak to be crowded more towards backward angles at higher energies, which is exactly opposite what Anderson[10] found below 600 MeV. Curiously enough, A_y seems to have a minimum just at $\cos\theta_{c.m.} = 0.5$, where the cross section also shows a definite break in shape.

The wild fluctuations with angle of the analyzing power for proton-deuteron elastic scattering are in stark contradiction with the always positive, smooth, nearly $\cos^2\theta_{c.m.}$ angular variations of the analyzing power recently measured for the $pp \to d\pi^+$ reaction.[28,29] The latter can be described best with a Legendre polynomial series containing only s-, p-, and d-wave contributions. However, the energy dependence of the polynomial coefficients exhibits the same peaking at 600 MeV as the cross section.[28] The only correspondence between the angular distributions of the analyzing powers for the two reactions is that they are both positive at very backward angles, but that comparison is better below[3] the resonance energy of 600 MeV than at[9] or equally far above (800 MeV).

Gurvitz[38] has recently calculated the analyzing power for *pd* scattering for comparison with the data of Biegert *et al.*[9] at $T_p \geq 1.03$ GeV. They find excellent agreement with their model of noneikonal multiple scattering; at very back angles the positive peaking requires the inclusion of neutron pickup. Their calculation yields a form factor for the deuteron which is quite different from that obtained from conventional deuteron wave functions. The results appear consistent with our measurements at 800 MeV, but may not hold at lower energies.

It appears that the analyzing power for *pd* scattering at 800 MeV is best described at large momentum transfer by multiple scattering plus *n* exchange, and the differential cross section no longer justifies considering N^* exchange and the triangle diagram. But it should be noted that the measurements of tensor analyzing power by Igo *et al.*[12] are in disagreement with both models, and it may well be that the calculations suffer from insufficient knowledge of the *NN* amplitudes, which therefore requires measurements of more elastic scattering observables.

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[1] J. E. Simmons, in *Proceedings of the Sixth International Conference on High Energy Physics and Nuclear Structure*, edited by D. E. Nagle *et al.* (AIP, New York, 1975), p. 103.

[2] J. C. Alder, W. Dollhoff, C. Lunke, C. F. Perdrisat, W. K. Roberts, P. Kitching, G. Moss, W. C. Olsen, and J. R. Priest, Phys. Rev. C 6, 2010 (1972).

[3] N. E. Booth, C. Dolnick, R. J. Esterling, J. Parry, J. Scheid, and D. Sherden, Phys. Rev. D 4, 1261 (1971).

[4] E. T. Boschitz, W. K. Roberts, J. S. Vincent, M. Blecher, K. Gotow, P. C. Gugelot, C. F. Perdrisat, L. W. Swenson, and J. R. Priest, Phys. Rev. C 6, 457 (1972).

[5] M. G. Albrow, M. Borghini, B. Bosnjakovic, F. C. Erné, Y. Kimura, J. P. Lagnaux, J. C. Sens, and F. Udo, Phys. Lett. 35B, 247 (1971).

[6] G. W. Bennett, J. L. Friedes, H. Palevsky, R. J. Sutter, G. J. Igo, W. D. Simpson, G. C. Phillips, R. L. Stearns, and D. M. Corley, Phys. Rev. Lett. 19, 387 (1967).

[7] E. Coleman, R. M. Heinz, O. E. Overseth, and D. E. Pellett, Phys. Rev. Lett. 16, 761 (1966); E. Coleman, R. M. Heinz, O. E. Overseth, and D. E. Pellett, Phys. Rev. 164, 1655 (1967).

[8] L. Dubal, C. K. Hargrove, E. P. Hincks, R. J. McKee, H. Mes, A. C. Thompson, L. Bird, C. H. Halliwell, R. W. Morrison, J. Walters, J. B. McCaslin, and A. R. Smith, Phys. Rev. D 9, 597 (1974).

[9] E. Biegert, J. Carroll, W. Dragoset, Jr., R. Klem, J. Lesikar, M. L. Marshak, J. McClelland, T. Mulera, E. A. Peterson, J. B. Roberts, K. Ruddick, R. Talaga, and A. Wriekat, Phys. Rev. Lett. 41, 1098 (1978).

[10] A. N. Anderson, J. M. Cameron, D. A. Hutcheon, J. Källne, B. K. S. Koene, B. T. Murdoch, W. T. H. van Oers, and A. W. Stetz, Phys. Rev. Lett. 40, 1553 (1978).

[11] G. Bunce, O. E. Overseth, J. Walker, H. Halpern, R. Handler, L. Pondrom, and S. Olsen, Phys. Rev. Lett. 28, 120 (1972).

[12] G. J. Igo, M. Bleszynski, J. B. Carroll, A. Sagle, C. L. Morris, R. Klem, T. Joyce, Y. Makdisi, M. Marshak, B. Mossberg, E. A. Peterson, K. Ruddick, and J. Whittaker, Phys. Rev. Lett. 43, 425 (1979).

[13] R. J. Glauber, in *Lectures in Theoretical Physics*, edited by W. E. Britten *et al.* (Interscience, New York, 1959), Vol. 1, p. 315.

[14] V. Franco and R. J. Glauber, Phys. Rev. 142, 1195 (1966); V. Franco, Phys. Rev. Lett. 16, 944 (1966); V. Franco and E. Coleman, *ibid.* 17, 827 (1966); V. Franco and R. J. Glauber, *ibid.* 22, 370 (1969).

[15] M. L. Goldberger and K. M. Watson, *Collision Theory* (Wiley, New York, 1964).

[16] H. B. Willard, B. D. Anderson, H. W. Baer, R. J. Barrett, P. R. Bevington, A. N. Anderson, H. Willmes, and N. Jarmie, Phys. Rev. C 14, 1545 (1976).

[17] J. E. Simmons, private communication.

[18] V. M. Kolybasov and N. Ya. Smordisnkaya, Yad. Fiz. 17, 1211 (1973) [Sov. J. Nucl. Phys. 17, 630 (1973)].

[19] A. K. Kerman and L. S. Kisslinger, Phys. Rev. 180, 1483 (1969).

[20] J. S. Vincent, W. K. Roberts, E. T. Boschitz, L. S.

Kisslinger, K. Gotow, P. C. Gugelot, C. F. Perdrisat, L. W. Swenson, and J. R. Priest, Phys. Rev. Lett. 24, 236 (1970).

[21]N. S. Craigie and C. Wilkin, Nucl. Phys. B14, 477 (1969).

[22]T. Yao, Phys. Rev. 134, B454 (1964).

[23]G. W. Barry, Ann. Phys. 73, 482 (1972).

[24]J. V. Noble and H. J. Weber, Phys. Lett. 50B, 233 (1974).

[25]E. A. Remler and R. A. Miller, Ann. Phys. (N.Y.) 82, 189 (1974).

[26]S. A. Gurvitz and S. A. Rinat, Phys. Lett. 60B, 405 (1976).

[27]C. L. Dolnick, Nucl. Phys. B22, 461 (1970).

[28]M. G. Albrow, S. Andersson-Almehed, B. Bošnjaković, F. C. Erné, Y. Kimura, J. P. Lagnaux, J. C. Sens, and F. Udo, Phys. Lett. 34B, 337 (1971).

[29]R. Joseph, F. Cverna, H. Willard, M. McNaughton, E. Winkelmann, C. Hwang, B. Bonner, and N. King, Bull. Am. Phys. Soc. 24, 688 (1979); F. Cverna, M. McNaughton, C. Hwang, B. Bonner, N. King, H. Willard, E. Winkelmann, and R. Joseph, in the Proceedings of the Second Conference on Meson-Nuclear Physics, 1979, Houston, Texas (to be published), p. 64.

[30]P. R. Bevington, M. W. McNaughton, H. B. Willard, H. W. Baer, E. Winkelmann, F. Cverna, E. P. Chamberlin, N. S. P. King, R. R. Stevens, H. Willmes, and M. A. Schardt, Phys. Rev. Lett. 41, 384 (1978).

[31]R. J. Barrett, B. D. Anderson, H. B. Willard, A. N. Anderson, and N. Jarmie, Nucl. Instrum. Methods 129, 441 (1975).

[32]M. W. McNaughton *et al.*, unpublished; E. P. Chamberlin *et al.*, Bull. Am. Phys. Soc. 23, 540 (1978).

[33]P. R. Bevington, R. J. Barrett, B. D. Anderson, F. H. Cverna, and A. N. Anderson, Nucl. Instrum. Methods 129, 373 (1975).

[34]P. R. Bevington and R. A. Leskovec, Nucl. Instrum. Methods 147, 431 (1977).

[35]B. E. Bonner, J. E. Simmons, M. L. Evans, G. Glass, J. C. Hiebert, Mahavir Jain, L. C. Northcliffe, C. W. Bjork, P. J. Riley, and C. G. Cassapakis, Phys. Rev. C 17, 671 (1978).

[36]B. E. Bonner, C. L. Hollas, C. R. Newson, P. J. Riley, and G. Glass, Phys. Rev. Lett. 39, 1253 (1977).

[37]E. Myrher and B. E. Bonner, private communication.

[38]S. A. Gurvitz, Phys. Lett. 85B, 5 (1979).