Title

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DISCLAIMER

FURTHER EVIDENCE FOR THE DOMINANCE OF NUCLEON-NUCLEON P-WAVE FORCES IN VECTOR POLARIZATIONS IN N-d SCATTERING BELOW 15 MeV*

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Abstract:

We have measured vector analyzing powers in deuteron-proton scattering with polarized deuterons incident at 20 and 30 MeV. Our results are in excellent agreement with very recent three-body calculations which clearly show that the nucleon-nucleon P-wave interaction is the dominant cause of the vector polarization in nucleon-deuteron scattering of these energies.

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During the past eight years the experimental determination of polarization effects in nucleon-deuteron scattering below 50 MeV has shown that measurable polarizations occur at energies as low as 2 MeV and that these rapidly reach substantial values with increasing energy.[1] Theoretical progress in fitting the experimental results has proved to be difficult, but recent three-body calculations[2-6] have now succeeded in providing polarizations of the magnitude required by experiment. The clear and important result of these calculations is that in any three-body calculation of N-d scattering the P-wave nucleon-nucleon interaction is the dominant cause of the nucleon and deuteron vector polarizations.

We report here on measurements of the vector analyzing power in $\vec{d}$-p scattering with polarized deuterons at energies of 20 and 30 MeV. These results provide further evidence for the importance of the P-wave interactions.

Pieper and Kowalski[2] used the unitary first-order approximation of Sloan[7] to calculate nucleon polarizations in N-d elastic scattering at energies up to 40 MeV. They found that even at 14 MeV the polarization was very sensitive to the contribution from P-wave components of the two-nucleon amplitudes used in the calculation, and these components were required to produce polarizations of sufficient magnitude. Although the angular dependence of the calculated polarizations showed little resemblance to the experimental data, they concluded that any further three-body calculation of the nucleon polarization must include P-wave two-nucleon amplitudes in a realistic way.

Aarons and Sloan,[3] on the other hand, obtained both nucleon and deuteron (vector and tensor) polarizations from an exact three-body calculation using a non-central, spin-dependent, two-body force. This two-body force had only two separable terms, corresponding to the $^1S_0$ and ($^3S_1$ - $^3D_1$) components of the two-nucleon interaction, and so did not include P-waves. The calculations over the range 3-23 MeV, gave deuteron tensor polarizations in qualitative agreement with experiment, but the nucleon and deuteron vector polarizations were much too small and exhibited an unrealistic angular dependence. They suggested that the inclusion of P-waves was necessary for calculating both the nucleon and deuteron vector polarizations. In a similar calculation of the nucleon polarization at 14 MeV, Doleschall[4] obtained the same result.[8] Further, in order to study the effect of the P-wave interaction specifically, he also made the calculation with separable terms corresponding to the $^1S_0$, $^3S_1$ (without the tensor force), and

$^3P_0$ two-body interactions. This gave polarizations of sufficient magnitude but of the wrong shape, indicating again that the P-wave interaction was the dominant cause of the observed nucleon polarization.

Finally, both Doleschall and Peiper have now included the complete P-wave set of $^1P_1$, $^3P_0$, $^3P_1$, and $^3P_2$ interactions in recent calculations,[5,6] and the improvement over the previous calculations is dramatic. The nucleon polarizations are in excellent agreement with the experimental data up to 14 MeV and qualitative agreement is achieved beyond that to 40 MeV.[6] The agreement with the deuteron vector polarizations is not as good, although the data are less accurate and less extensive, reaching only to 10.8 MeV.[9]

The purpose of the present work, therefore, was to obtain accurate angular distributions of the vector analyzing power, iT_{11}, in $\vec{d}$-p scattering with polarized deuterons at 20 and 30 MeV, corresponding to proton energies of 10 and 15 MeV. This would provide more accurate data at 10 MeV and extend the measurements to higher energies, thus providing further tests for the calculations. For time-reversal-invariant interactions, the vector analyzing power, iT_{11}, in $\vec{d}$-p scattering is equal to the deuteron vector polarization, it_{11}, produced in p-d scattering,[10] so the calculated polarizations and measured analyzing powers can be compared directly.

The experiment was performed in a 36-inch diameter scattering chamber, using the axially injected polarized deuteron beam from the Berkeley 88-inch cyclotron. The beam had a vector polarization of 82% of the maximum possible value $p_y = 2/\sqrt{3}\ it_{11} = 2/3$, and the tensor components were zero. A 7.5 cm diameter gas target with a 5 μm Havor foil window was used at H_2 gas pressures ranging from 0.25 to 0.75 atm. Left-right asymmetry data were taken simultaneously at two angles separated by 20°, using pairs of ΔE-E silicon detector telescopes. In order to eliminate instrumental asymmetries, alternate runs were taken with the spin vector of the beam oriented up and down with respect to the scattering plane. The angular resolution, defined by tantalum collimators, was 0.85° and 1.5° (FWHM) for the forward and backward telescopes, respectively. Two monitor counters were placed left and right of the beam axis at a scattering angle of $\theta \simeq 23°$ and azimuthal angles $\phi \simeq 70°$ and 110°. A polarimeter, consisting of a smaller scattering chamber containing a gas target and a pair of ΔE-E counter telescopes at equal left and right scattering angles, was placed downstream of the main scattering chamber and provided continuous monitoring of the beam polarization. The analyzer used was ^{4}He, whose analyzing power in $\vec{d}$-^{4}He elastic scattering had been measured in detail previously.[11] Particle identification was used with all detector systems except the monitors. This allowed simultaneous detection of forward scattered deuterons and recoil protons from backward scattered deuterons.

Our 20 MeV data are shown in Fig. 1, where the relative errors include the statistical error and a contribution of ±0.004 determined from measured asymmetries with the beam polarization set to zero. In addition, there is an overall normalization uncertainty of ±5%. The Saclay back angle data[9] at 21.7 MeV are also indicated in Fig. 1. The shapes of the angular distributions are similar, and the discrepancy of a factor of about 1.7 in overall normalization is most likely due to an uncertainty in the Saclay beam polarization.[12] Also shown in Fig. 1 is the result from Pieper's[6] recent calculation. The agreement is excellent, particularly in view of the fact that there has been no adjustment of the two-body input parameters in order to improve the fit to these data.

Figure 2 shows our 30 MeV data along with the predictions from the calculations of both Doleschall[5] and Pieper[6] at 28.2 MeV deuteron energy. They both fit the backward peak very well, but Pieper also succeeds in providing the negative maximum at θ = 95°. Clearly it would be of interest to identify the feature of the Pieper calculation that produces this result, which is not predicted by Doleschall. Of course, the calculations are not directly comparable. The Doleschall calculation is an exact one using the Faddeev-Lovelace-Amado[13] equations with a complete set of P-wave interactions, and it also provides good fits to the differential cross section and nucleon polarization data at the same energy.[5] The Pieper calculation is based on a perturbative treatment of three-particle scattering[14] in which the nucleon-nucleon T-matrix is taken as the sum of two parts: $t = t^{(s)} + t^{(w)}$. The strong part $t^{(s)}$ is derived from potentials of the Yamaguchi type[15] in the $^1S_0$ and $^3S_1$ partial waves, and it is treated exactly in the Faddeev equations. The weak part $t^{(w)}$ contains all the additional nucleon-nucleon input information and is treated in first order perturbation theory. Sets of both P and D partial waves are included, so it is possible that the D-wave contributions account for the major differences seen in the curves in Fig. 2.

Although the older work showed that the cross sections in N-d scattering could be quite well reproduced in three-body calculations using just the S-wave two-nucleon forces, it is now very clear that accurate and extensive polarization data have provided the tests that prove the necessity for the inclusion of higher partial waves in the calculations.

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FOOTNOTES AND REFERENCES

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FIGURE CAPTIONS

Fig. 1. The angular distribution of the vector analyzing power $iT_{11}(\theta)$ in $\vec{d}$-p scattering at 20 MeV. The solid curve is the theoretical result from Ref. 6. The dashed curve represents the back angle data from Ref. 9 at 21.7 MeV.

Fig. 2. Angular distribution of the vector analyzing power $iT_{11}(\theta)$ in $\vec{d}$-p scattering at 30 MeV. The dashed curve is from Ref. 5, the solid curve from Ref. 6, both calculated for E_d = 28.2 MeV.

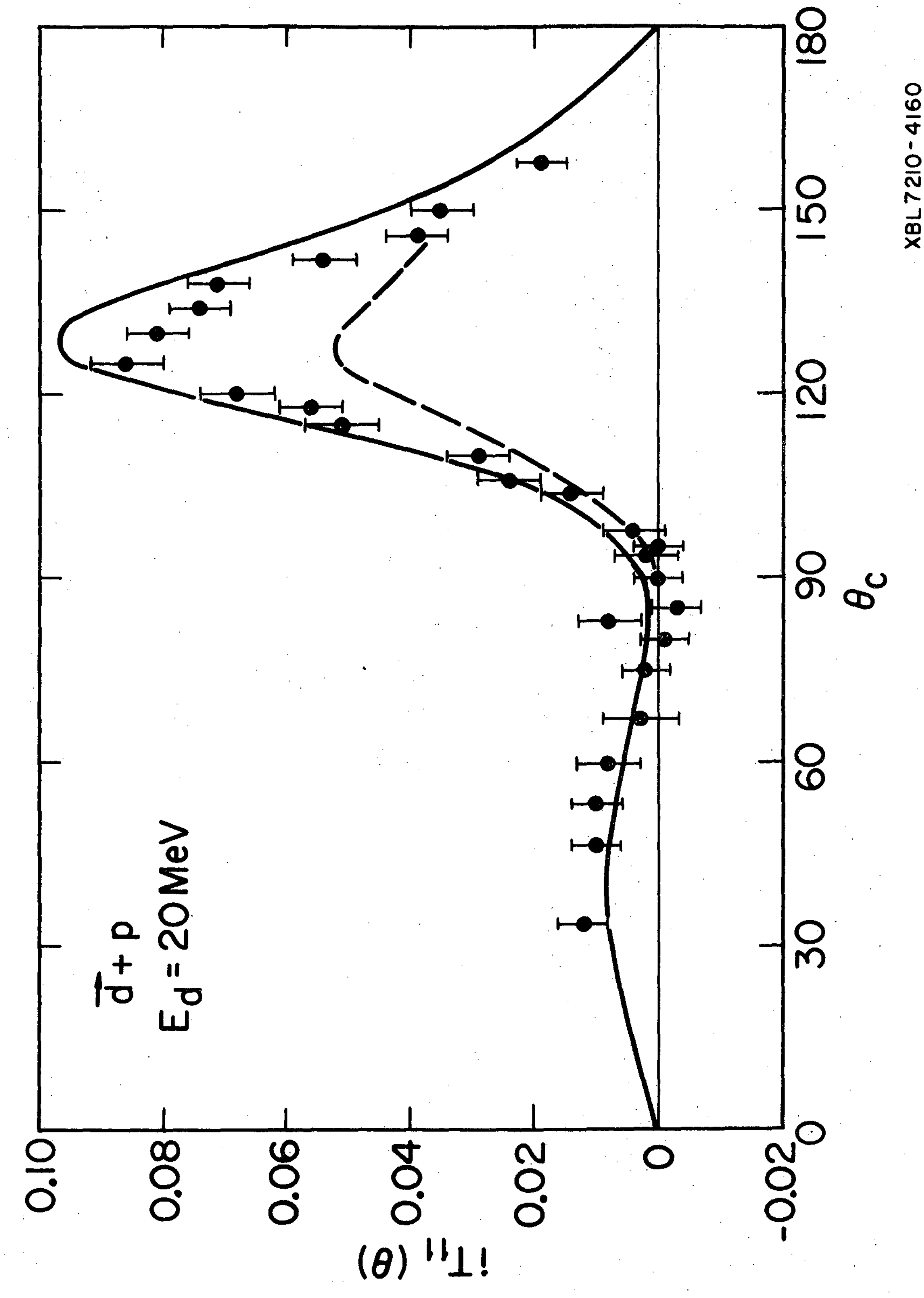
d + p
E_d = 20 MeV
iT_11 (θ)
θ_c
0.10
0.08
0.06
0.04
0.02
0
-0.02
0
30
60
90
120
150
180
XBL 7210-4160

Fig. 1

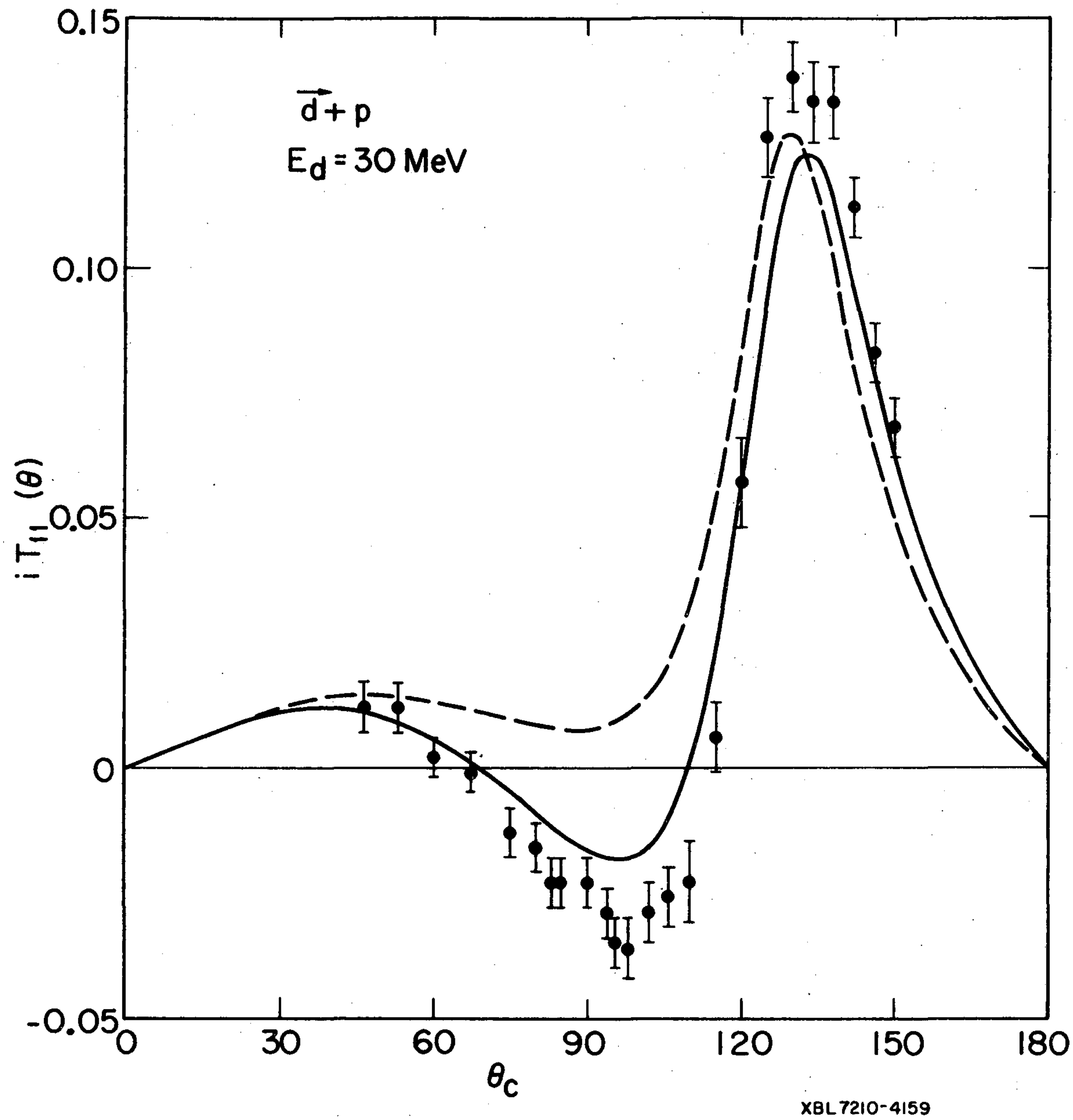
0.15
0.10
0.05
0
-0.05
$\vec{d}$ + p
E_d = 30 MeV
i T_{11} (θ)
0
30
60
90
120
150
180
θ_C
XBL 7210-4159

Fig. 2

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