Distorted-wave impulse approximation calculations of proton polarization following π^+ absorption in nuclei

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We present distorted-wave impulse approximation calculations for the polarization of outgoing protons resulting from $(\pi^+, 2p)$ reactions using a quasideuteron absorption model with phenomenological amplitudes for the πNN vertex. As an example of the interesting interference and distorted-wave effects that can be observed from such reactions, we study the case of a ^{12}C target. Calculations are also compared to the recently published data for the nuclei ^{3,4}He.

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I. INTRODUCTION

In two recent Letters [1,2] data have been reported for emitted proton polarization following π^+ absorption on light nuclei. In addition, measurements of π^+ absorption on polarized ^{7}Li targets have been carried out at the PSI laboratory [3]. Since polarization observables involve interference effects, thereby increasing sensitivity to details of the reaction process, it is expected that such measurements will lead to an improved understanding of the dynamics of the reactions and of the underlying nuclear structure. These are important issues in view of the large contribution of pion absorption to the reaction cross section for pion-nucleus interactions.

It is well known that pion absorption on nuclei heavier than ^{2}H involves various multi-nucleon mechanisms [4]. However, in the region of the Δ resonance, absorption on $^3S_1$, $T = 0$ p-n pairs dominates, particularly for kinematics close to the free $\pi^+ + ^2\text{H} \rightarrow 2p$. This process is loosely (and perhaps simplistically) termed "quasideuteron" absorption. The two-nucleon absorption process leads to significant energy but little momentum deposited in the nuclear system, and the two nucleons are emitted with very large relative momentum. Thus, we might expect sensitivity to the smaller mean inter-nucleon distance, and hence higher density, in targets with $A > 2$.

Experimentally, almost all studies of quasideuteron absorption cross sections show an effective two-body cross section identical in angle and energy dependence to the free $\pi^+ + ^2\text{H} \rightarrow 2p$ cross section [5–8]. Furthermore, possible modifications to the overall magnitude of the cross section do not provide a useful signature of dynamical effects owing to sensitivity to both dynamics and details of nuclear structure. In Ref. [1] it is argued that this insensitivity arises from the dominance of the p-wave rescattering diagram involving the Δ resonance which is believed to mask short-range N-N effects. The effects of N-N correlations might be expected to show more clearly in the nonresonant s-wave rescattering, but its contribution to the cross section is small.

Polarization observables however, which involve interference between the dominant p-wave and the smaller s-wave rescattering, have potentially increased sensitivity to the short-ranged correlations. Such sensitivity is shown in the calculations of Niskanen and Thomas [9] for the polarization of the emitted proton in $^3\text{He}(\pi^+, 2p)$. These calculations, which show strong sensitivity in shape and magnitude to the short-ranged correlations, provided much of the motivation for the experiments of Refs. [1,2].

Comparisons of the theoretical predictions to the experimental data for the emitted proton polarization were presented in Refs. [1,2]. The results are disappointing in that the data more closely resemble the free $\pi^+ + ^2\text{H} \rightarrow 2p$ polarizations, and differ significantly from the predictions of the Niskanen and Thomas calculations.

In the present paper we use distorted-wave impulse approximation (DWIA) calculations to examine whether the emitted proton polarization can be considered a robust probe of short-range effects in two-nucleon pion absorption. In previous publications we presented DWIA calculations of two-nucleon pion absorption for cross sections [10] and for polarized target analyzing powers [11]. Here, we extend the calculations to emitted proton polarizations. Our calculations include only absorption on $^3S_1$ pairs and utilize the free $\pi^+ + ^2\text{H} \rightarrow 2p$ phenomenological amplitudes. Thus, we do not explicitly include short-range modifications to the π-NN vertex [9], although this would, in principle, be straightforward. Rather, we examine the effects of the initial and final state interactions on the proton polarization, as well as the role of the effective initial quasideuteron polarization resulting from a combination of nuclear structure and distortion effects.

Following a brief review of the DWIA formalism employed, calculations will be presented for $^{12}\text{C}(\pi^+, 2p)^{10}\text{B}$ to illustrate the types of effects obtained in a case for which a distorted-wave treatment is customary. These calculations show a rather strong sensitivity of the emitted proton polarization to various distortion effects. Despite reservations concerning the use of a distorted-wave approximation for such light targets, we also present calculations of ^{3,4}He for comparison with the experimental results. In this case our predicted proton analyzing powers are nearly identical to the two-body $\pi^+ + ^2\text{H} \rightarrow 2p$ values.

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II. DWIA FORMALISM

As discussed in Refs. [10,11] we assume that the reaction is dominated by absorption on $^3S_1$ p-n pairs. This ansatz is supported by the results of Ohta, Lee, and Thies [12] who explicitly calculated contributions to the cross section from other p-n configurations, and found them to be small. We note here that it is possible that comparisons with polarization observables may reveal limitations in this approach. Following our usual choice of coordinates and notation [10,11], we write an amplitude factorized DWIA expression for the cross section for the reaction $A(\pi^+, cd)B$ leading to the emission of a nucleon c with spin projection ρ_c' as

$$\sigma_{BA}(\rho_c') = \frac{2\pi}{\hbar v}\omega_B c^2 \sum_{JM\rho_d''} \frac{1}{2J+1} \left| \sum_{\Lambda\Sigma\sigma_c'\sigma_d''}^{[n_1l_1j_1][n_2l_2j_2]LS} g S_{AB}^{1/2}([n_1l_1j_1][n_2l_2j_2];JT) \begin{bmatrix} l_1 & l_2 & L \\ \frac{1}{2} & \frac{1}{2} & S \\ j_1 & j_2 & J \end{bmatrix} \right.$$
$$\left. \times\, \hat{L}(L\Lambda S\Sigma|JM) T^{\alpha L\Lambda}_{\sigma_c'\sigma_d''\rho_c'\rho_d''} \langle \mathbf{k}'; \sigma_c'\sigma_d''; \tau_c\tau_d | t^\alpha | \mathbf{k}; S\Sigma; TN\rangle \right|^2, \qquad (1)$$

where

$$T^{\alpha L\Lambda}_{\sigma_c'\sigma_d''\rho_c'\rho_d''} = \frac{1}{(2L+1)^{1/2}} \int \chi^{(-)^*}_{\sigma_c'\rho_c'} \chi^{(-)^*}_{\sigma_d''\rho_d''} \chi^{(+)} G^{\alpha 0 L}_{\Lambda} d^3R, \qquad (2)$$

and $\langle \mathbf{k}'; \sigma_c'\sigma_d''; \tau_c\tau_d | t^\alpha | \mathbf{k}; S\Sigma; TN\rangle$ is properly the amplitude for pion absorption on a bound (and therefore off-shell) p-n pair in the state $|S\Sigma; TN\rangle$ with relative angular momentum, $\ell = 0$. For absorption on a $^3S_1$ pair we take the Bugg, Hasan, and Shypit (BHS) [13] *on-shell* amplitudes which reproduce quite well both observed ^{2}H(π^+, pp) analyzing powers as well as analyzing powers for the inverse $\vec{p} + p \to \pi^+ + {}^2$H reaction at energies close to the Δ resonance. Thus, we can hope that these amplitudes are appropriate for predicting emitted nucleon polarization in pion absorption. The "form factor" G is obtained by projecting two nucleon wave functions denoted by $[n_1l_1j_1][n_2l_2j_2]$ onto the $^3S_1$ relative motion. The distorted waves χ representing the emitted protons include spin-orbit terms in the corresponding optical potentials. Other details are to be found in Refs. [10,11]. In the calculations which follow, it is the expression outlined above which is evaluated for cases in which the incident and emitted particles are coplanar. If the axis of quantization is chosen parallel to the reaction normal, $\mathbf{k}_\pi \times \mathbf{k}_c$, then the polarization of proton c can be determined directly from Eq. (1).

Prior to reviewing the results of our calculations, it is instructive to consider simplifications of Eq. (1). For this purpose, we assume that only a single value of the transferred orbital and total angular momenta, L and J, contributes. While often the case, this depends on nuclear structure specifics. We also assume that spin-orbit effects for the emitted protons can be ignored. This is useful in order to elucidate some of the underlying physics; however, we shall show later that these terms can be significant. For the present, we use these approximations to write

$$\sigma_{BA}(\rho_c') = \frac{2\pi}{\hbar v}\omega_B \frac{1}{2J+1} \sum_{\rho_d''\Lambda\Sigma} (L\Lambda S\Sigma|JM)^2 |T^{\alpha L\Lambda}_{BA}|^2 \times |\langle \mathbf{k}'; \rho_c'\rho_d'' | t^\alpha | \mathbf{k}; S\Sigma\rangle|^2 \qquad (3)$$

where, for simplicity, structure amplitudes affecting only the overall normalization have been suppressed. For the almost trivial case of $L = 0$, $J = 1$ we obtain

$$\sigma^{L=0}_{BA}(\rho_c') = \frac{2\pi}{\hbar v}\omega_B \frac{1}{2J+1} |T^{00}_{BA}|^2 \sigma_{\pi d}(\rho_c'). \qquad (4)$$

Here it is clear that the predicted proton polarization (P_y) in the quasifree process is identical to the free two-body polarization. Modifications to the free polarization may then arise from the short-range effects sought (not included in the present calculations) or from more conventional sources, such as the emitted proton-residual nucleus potential.

For $L > 0$, we note that the cross section carries different weights for the three spin projections of the $S = 1$ p-n pair. The weights depend upon values of the vector coupling coefficients $(L\Lambda S\Sigma|JM)$ and the distorted-wave amplitudes $T^{\alpha L\Lambda}_{BA}$. Thus, in general, absorption takes place on a polarized p-n pair and the emitted particle polarization will also depend upon polarization transfer observables in the two-body process.

As an aside, it is interesting to note that, for coplanar geometries, if the distorted-wave amplitude satisfies

$$|T^{\alpha L\Lambda}_{BA}|^2 = |T^{\alpha L-\Lambda}_{BA}|^2, \qquad (5)$$

there is only a tensor term in the p-n pair polarization. As noted by Gouweloos and Thies [14], this condition is satisfied in the plane wave limit since

$$T^{\alpha L\Lambda}_{BA} = (-)^\Lambda (T^{\alpha L-\Lambda}_{BA})^\star. \qquad (6)$$

However, if distortion effects are significant, distortion differences between the two emitted protons lead to an additional effective vector polarization of the struck pair due to the Maris effect [15]. This effect, which is due primarily to the different attenuations of the two outgoing nucleons, arises from the localization of the reaction to one side of the nucleus, as divided by a plane defined by the z axis and the recoil momentum of the residual nucleus $\mathbf{q}$. Since the orbital angular momentum transfer can be written as $\mathbf{l} = \mathbf{r} \times \mathbf{q}$, it follows that distortion effects leading to unequal contributions from the two hemispheres will lead to an effective polarization in $\mathbf{l}$.

III. DWIA CALCULATIONS

A. $^{12}C(\pi^+, \vec{p}p)^{10}B$

In order to illustrate some of the effects outlined above, we present results for the reaction $^{12}C(\pi^+, 2p)^{10}B$ at 120 and 250 MeV with an outgoing polarized proton detected at 50° in the laboratory system and a second proton at the quasifree angle such that, at appropriate detected energies, the residual ^{10}B can be left at rest. Spectroscopic amplitudes are taken from the 1p-shell structure calculations of Cohen and Kurath [16], the pion optical model potential from Cottingame and Holtkamp [17], and proton distorting potentials from Nadasen [18]. As stated above, the amplitudes for $^2H(\pi^+, pp)$ were taken from Ref. [13] at an energy corresponding to the initial relative momentum of the π^+-quasideuteron system (Initial Energy Prescription). In this prescription, the binding energy of the struck p-n pair is accounted for at the expense of lower energy outgoing nucleons. This choice of two-body on-shell prescription is consistent with trends observed in the energy dependence of the cross sections for two-nucleon absorption of pions [5,8,19]. Reference [11] describes, in more detail, the choice of potentials and parameters used in our calculations. We present calculations for transitions leading to the 3^+ ground state which is a pure $L = 2$ transition, and two 1^+ excited states at 0.72 and 2.2 MeV, which are mixtures of $L = 0$ and $L = 2$ terms.

We consider initially the transition to the (1^+; 0.72 MeV) first excited state of ^{10}B, since it is predominantly $L = 0$ with very little $L = 2$. In fact, to separate the various effects, we first present calculations for a pure $L = 0$ transition. Shown in Fig. 1 are plane wave impulse approximation, PWIA, and DWIA calculations of energy sharing cross sections, and emitted proton polarizations at incident pion energies of 120 and 250 MeV. The PWIA calculations are shown as dashed curves. DWIA calculations in which spin-orbit terms are also included in the distorting potentials are shown as continuous lines. The cross sections show a typical $L = 0$ behavior, peaking at the zero recoil momentum point at which the recoiling nucleus is left at rest, with nodes resulting from the $2S$ nature of the quasideuteron motion relative to the residual ^{10}B nucleus. In DWIA, we see that the primary effect on the cross sections is a reduction in the peak magnitude by about a factor of four to six, depending on pion energy, and a filling in of the minima. The polarizations show more interesting features. While the PWIA and no-spin-orbit DWIA calculations of P_y are both identical to the two-body analyzing power, as expected from Eq. (4), there are dramatic changes in P_y due to the outgoing proton spin-orbit potential. Near the quasifree point where the cross section peaks, the spin-orbit potential appears to "depolarize" the outgoing proton, only slightly for the higher pion energy but by nearly 30% at 120 MeV. Near the cross section minima, where there is destructive interference in the DWIA amplitude, dramatic oscillations occur at both pion energies.

For completeness, in Fig. 2 we show calculations for the (1^+; 0.72 MeV) state, including the small $L = 2$ contribution. The effect of the $L = 2$ term on the cross section is very small, and only significant in the regions of the minima and secondary maxima. Similarly, near the peak of the cross section where the $L = 0$ yield dominates, P_y is basically the same as in Fig. 1. However, away from the quasifree point significant differences due to the $L = 2$ contributions are apparent, even in PWIA, particularly in the regions of the minima. This qualitative behavior is the same at both energies. DWIA calculations with only central terms for the emitted proton optical potentials are shown as dotted lines. Also included for reference are the corresponding two-body $^2H(\pi^+, 2p)$ polarizations which are shown as a dash-dot curve.

We next consider the transition to the 3^+ ground state. Since this is an $L = 2$ transition, the emitted proton polarization in a no-spin-orbit DWIA calculation does not simply take the two-body $^2H(\pi^+, 2p)$ value, but is modified due to both vector and tensor polarization of the struck deuteron. As we have noted, the tensor terms arise predominantly from angular momentum geometry; whereas the vector term arises, via the Maris effect, largely from the central parts of the distorting potentials. Shown in Fig. 3 are the DWIA calculations, again

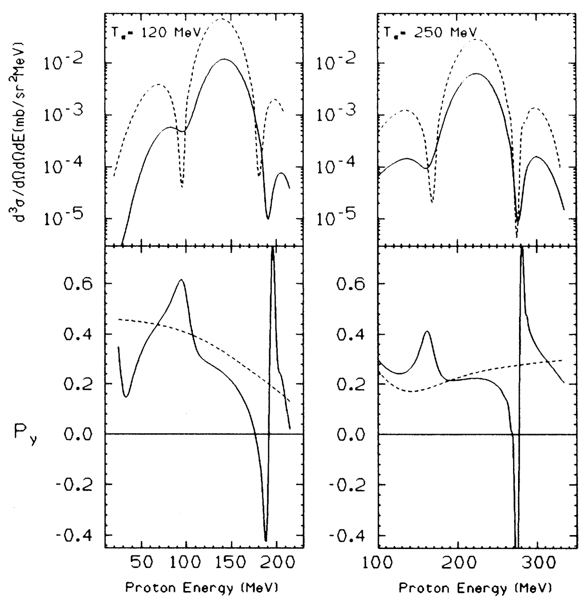

FIG. 1. Calculations of $^{12}C(\pi^+, 2p)^{10}B(1^+; 0.72$ MeV) for $L = 0$ only at incident energies of 120 MeV (left side) and 250 MeV (right side). The emitted proton (quasifree) angles are $50°/-108°$ ($50°/-99°$) for 120 MeV (250 MeV). PWIA calculations are shown as dashed lines. DWIA calculations including spin-orbit terms are shown as solid lines. The top panels display the energy sharing cross sections, the bottom panels compare the emitted proton polarization P_y. For $L = 0$, DWIA calculations with spin-orbit terms omitted, and PWIA calculations of P_y are identical to the free $\pi^+ + {}^2H \rightarrow 2p$ polarizations; therefore, only PWIA (dash) results are shown. Thus the two curves in the bottom panels also demonstrate the role in DWIA of spin-orbit terms in the optical potential for the emitted protons.

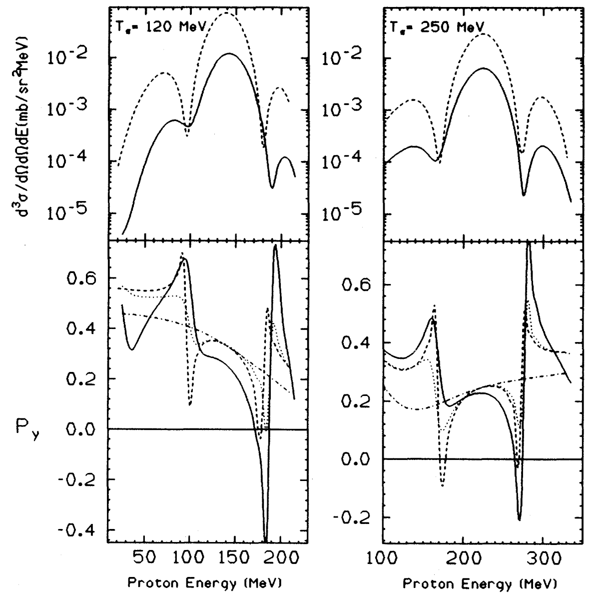

FIG. 2. Calculations of $^{12}C(\pi^+, 2p)^{10}B(1^+; 0.72$ MeV), including both $L = 0$ and $L = 2$ contributions. Outgoing proton angles are the same as in Fig. 1. PWIA results are shown as dash lines, free $\pi^+ + {}^2H \to 2p$ polarizations are shown as dash-dot lines, dotted lines are no-spin-orbit DWIA polarizations, and finally continuous lines represent DWIA results including spin-orbit terms.

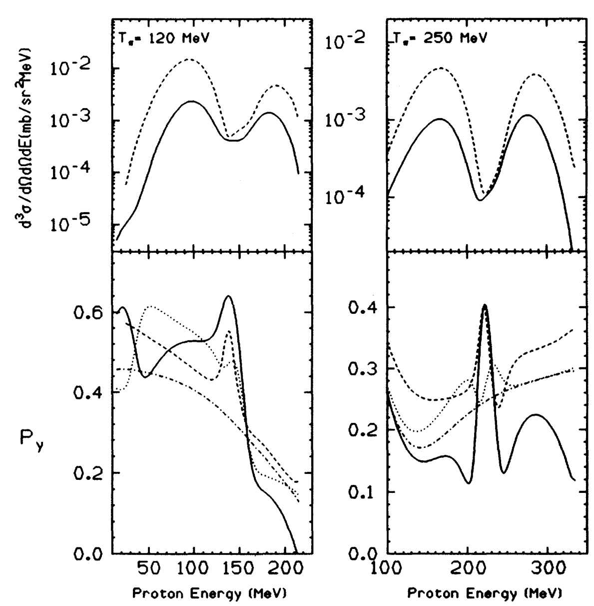

FIG. 3. Calculations of $^{12}C(\pi^+, 2p)^{10}B(3^+; 0.0$ MeV). Outgoing proton angles are the same as in Fig. 1. PWIA results are shown as dash lines, free $\pi^+ + {}^2H \to 2p$ polarizations are shown as dash-dot lines, dotted lines are no-spin-orbit DWIA polarizations, and finally continuous lines represent DWIA results including spin-orbit terms.

for 120 and 250 MeV. As for the $L = 0$ case the distortion effects reduce the cross section significantly, but with little change in shape. However, the predictions for emitted proton polarization, shown in the bottom panels of Fig. 3, differ significantly both in shape and magnitude. The differences between the PWIA and the two-body proton polarization in $\pi^+ + {}^2H \to 2p$ (dashed versus dash-dot curve in the bottom panels) reflect the role of the tensor polarization of the quasideuteron which is to increase the average outgoing proton polarization by roughly 0.05, as well as showing larger effects in the cross section minima. The differences between the no-spin-orbit DWIA and the PWIA calculations (dotted versus dashed curve in the bottom panels) show the additional contribution from the quasideuteron vector polarization associated with the Maris effect. Clearly, even the central terms in the distorting potentials play an important role in determining the outgoing proton polarization; e.g., at 120 MeV increasing P_y on the low energy side of the quasifree peak and decreasing it on the high energy side. The bottom panels of Fig. 3 also show the effect of the emitted proton spin-orbit potential (solid curves). As in the case of $L = 0$, the effects are very important, changing P_y by more than 0.1. Particularly striking effects are obtained in the region near the minimum in cross section where interference effects are most important.

Finally, for the transition to the $(1^+; 2.2$ MeV) excited state of ^{10}B the $L = 2$ spectroscopic amplitude is quite comparable to the $L = 0$ amplitude [16], being approximately 1.7 times as large. Therefore, we might expect to see additional effects due to the interference of the two L values. Calculations are shown in Fig. 4. As expected, in addition to the effects discussed for the pure L transitions discussed above, significant interference effects between the two amplitudes are observed in the calculated polarizations.

In Fig. 5 we present additional calculations for the predominantly $L = 0$ transition to the $(1^+; 0.72$ MeV) first excited state of ^{10}B. As noted above, the DWIA calculations shown so far use an initial energy prescription in which the effective energy for the two-body $^2H(\pi^+, 2p)$ amplitudes is chosen to match the initial π^+-^2H relative momentum. An alternative *on-shell* prescription is to account for the binding energy of the struck p-n pair at the expense of the incident pion. For comparison, we show the results obtained using a final energy prescription in which the two-body amplitudes are evaluated at an energy chosen to reproduce the energy in the rest frame of the emitted proton pair. Frequently, these two choices tend to bracket the off-shell amplitude behavior. We see that the emitted proton polarization is rather sensitive to this choice of on-shell energy prescription, particularly at the lower pion energy. Thus we can speculate that there may well be significant sensitivity to off-shell effects in the region of the Δ resonance. We note that this choice of prescription for the two-body amplitudes also has a significant effect on the overall magnitude of the cross sections; however, due to other influences this does not have a diagnostic value.

Overall we have demonstrated that, for a typical p-shell nucleus, the polarization of the emitted nucleon in

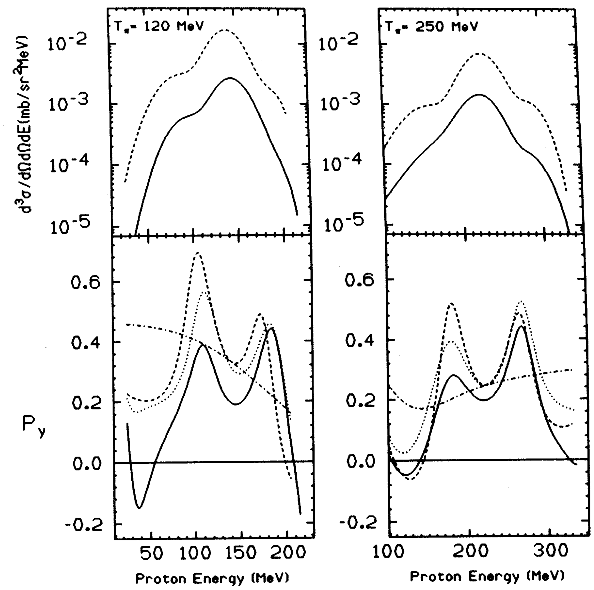

FIG. 4. Calculations of $^{12}C(\pi^+,2p)^{10}B(1^+;2.2$ MeV), including both $L=0$ and $L=2$ contributions. Outgoing proton angles are the same as in Fig. 1. PWIA results are shown as dash lines, free $\pi^+ + {}^2H \rightarrow 2p$ polarizations are shown as dash-dot lines, dotted lines are no-spin-orbit DWIA polarizations, and finally continuous lines represent DWIA results including spin-orbit terms.

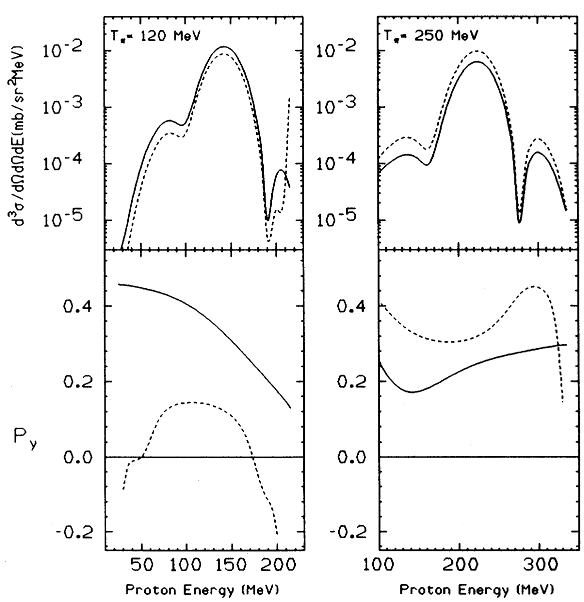

FIG. 5. Calculations of $^{12}C(\pi^+,2p)^{10}B(1^+;0.72$ MeV) showing differences between initial energy (solid line) and final energy (dashed line) DWIA predictions. The emitted proton (quasifree) angles are $50°/-108°$ ($50°/-99°$) for 120 MeV (250 MeV).

pion absorption is rather strongly effected by a variety of dynamical effects other than short-range correlations. First, the nuclear structure considerations leading to tensor polarization of the struck quasideuteron and the central parts of the final state interactions which give rise to additional quasideuteron vector polarization can both have major impact. Second, the spin-orbit part of the proton-nucleus interaction leads to substantial additional modification of the emitted nucleon polarization. Third, we have suggested, though not unequivocally established, that the fundamental off-shell πNN amplitudes may well differ significantly from typical on-shell approximations used in our DWIA.

B. $^{3,4}He(\pi^+,\vec{p}p)^{1,2}H$

To date the only published polarization observables for pion absorption are those of outgoing proton polarizations for $^3He(\pi^+,2p)$ [1] and $^4He(\pi^+,2p)$ [2] at two incident pion energies of 120 and 250 MeV for each isotope. As mentioned earlier these studies attempt to identify the predicted effects [9] of short-range N-N correlations arising from the decrease in the average internucleon spacing in ^3He and ^4He [20]. The calculations accompanying the data, especially for 120 MeV incident pions, differ markedly from the measurements; for example, the ^4He calculations in Ref. [2] produce an emitted proton polarization of the opposite sign compared to the measurement. Rather surprisingly, for both isotopes the data at 120 MeV lie closer to the polarizations obtained for $\pi^+ + {}^2H \rightarrow 2p$. This result seems to suggest that for energies near the Δ resonance, short-range correlation effects do not alter significantly the outgoing nucleon polarizations, in spite of the smaller p-n separations. This outcome is consistent with cross section measurements of $^{3,4}He(\pi^+,2p)$ in the Δ resonance region, in which the observed differential cross sections have the same angle and energy dependence as those from $^2H(\pi^+,2p)$, and a magnitude consistent with a simple estimate of the number of $^3S_1$ pairs contained (see, for example, Ref. [19] and references therein). Thus, the two-nucleon absorption mechanism at energies near the Δ resonance does not seem to exhibit any modifications that could be ascribed to short-range N-N effects from the bound quasideuteron. These observations perhaps result from the relatively long propagation distance of the Δ isobar, diluting any observable short-range correlation effects.

The data at 250 MeV incident pion energy, however, do show some deviation from the two-body process, with emitted proton polarizations that are generally reduced from those measured in $\pi^+ + {}^2H \rightarrow 2p$. This may perhaps be due to a reduction in the role of the Δ in masking effects from short-range correlations, but without more extensive data, it is impossible to make a definitive statement. As with the lower energy, the calculations fail to reproduce the data satisfactorily.

To examine whether any of the effects discussed in the previous section on $^{12}C(\pi^+,2p)$ provide an explanation for some of the differences observed between the experimental data and the calculations, we have performed

DWIA calculations for $^{3,4}\text{He}(\pi^+, 2p)$. We point out that in our treatment, aside from spin-orbit terms in the final state optical potentials, it is only that component of the target wave function in which the quasideuteron is in a relative d-state ($L = 2$) with respect to the residual nucleus which can give rise to differences of the emitted proton polarization from that observed for $\pi^+ + {}^2\text{H} \rightarrow 2p$. While the helium isotopes are light nuclei and distortion effects are not expected to play a major role, it is possible that such d-state effects may be significant and that spin-orbit distortions may also play some role.

For ^{3}He, we obtained $G_\Lambda^{\alpha 0 L}$, the projection of the target wave function on the deuteron, from a variational calculation using the Reid soft core interaction [21]. For the ^{4}He case, $G_\Lambda^{\alpha 0 L}$ was obtained from the variational Monte Carlo treatment of Schiavilla *et al.* [22], which has been used in our previous studies of ^{4}He and is in good agreement with data [7,23]. In both cases, the d-wave component is small. The pion optical model potential was chosen to satisfactorily reproduce pion elastic scattering. In most calculations the outgoing protons were described as plane waves. However, in a few sample cases, we included a purely real spin-orbit potential to gauge the size of the effects.

Calculations of the energy sharing distribution for $^3\text{He}(\pi^+, 2p)$ are presented in Fig. 6. The presentation is similar to the previous figures, although PWIA calculations are not included. We find that whereas the $L = 2$ component has little effect on the cross section, it does indeed create major changes in the emitted proton polarization, at least in the regions where its contributions to the cross section are non-negligible. However, the overall integrated $L = 2$ contribution to the cross section is small which implies that contributions to the emitted proton polarization from the $L = 2$ amplitude will probably be small in experiments which integrate over large regions of phase space where $L = 0$ dominates. Such is the case for the reported experiments [1,2]. As a result, we find the contributions from the $L = 2$ component to be negligible when we integrate over the experimental geometry. In the bottom panel of Fig. 6 we show the effects of a real spin-orbit potential. Again, although the changes in polarization are significant, the overall contribution to the polarization measured in the experimental geometry is negligible. Indeed, the polarizations which we obtain from our calculations are essentially the same as those calculated using the two-body BHS amplitudes which we use as input to our calculations. In Fig. 7 we show DWIA calculations (no spin-orbit terms) for the angular distribution of the outgoing proton polarization for both helium isotopes and at the two energies where data are available. We note that the 120 MeV data points are well reproduced in a DWIA calculation employing the BHS amplitudes, while the 250 MeV data are consistantly overestimated in both helium isotopes. This disagreement may well be a reflection of the limited amount of experimental data available at these higher energies which can be used to place sufficient constraints on the extracted amplitudes for the free pion absorption pro-

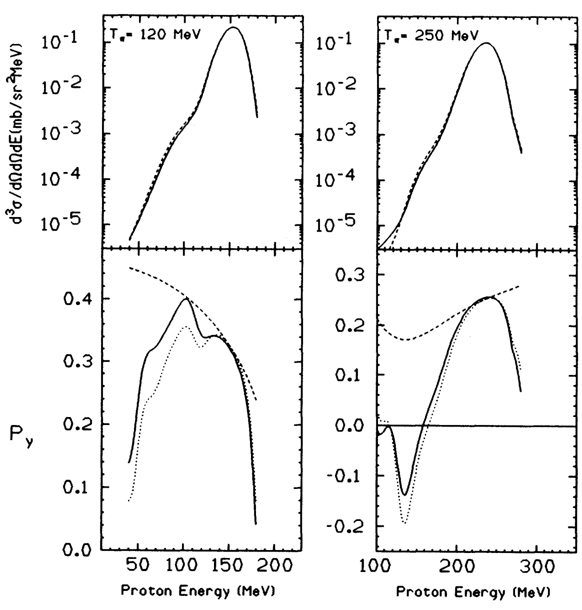

FIG. 6. Calculations of $^3\text{He}(\pi^+, 2p)$ for incident energies of 120 MeV (left side) and 250 MeV (right side). The emitted proton (quasifree) angles are $50° / -108°$ ($50° / -99°$) for 120 MeV (250 MeV). The top panels display the DWIA energy sharing cross sections for $L = 0$ only (dashed curve) and for a sum of $L = 0$ and $L = 2$ (solid curve). The bottom panels show the corresponding emitted proton polarizations, P_y. The bottom panels also show the effect of including a real spin-orbit potential for the emitted protons (dotted curve).

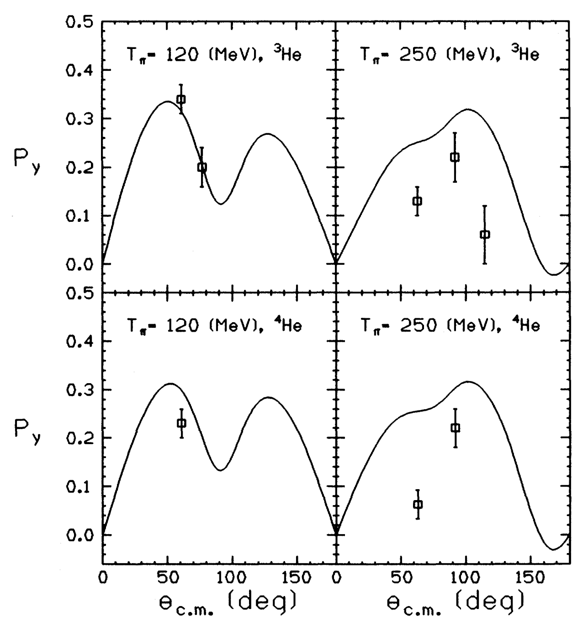

FIG. 7. DWIA calculations (no spin-orbit terms) of the emitted proton polarizations for $^3\text{He}(\pi^+, 2p)$ (top panels) and $^4\text{He}(\pi^+, 2p)$ (bottom panels) at incident energies of 120 MeV (left side) and 250 MeV (right side). The data are from Refs. [1,2]. The calculations include $L = 2$ contributions and use distorted waves for the incident pion and outgoing plane waves for the nucleons.

cess. The trends in the angular distribution of P_y in the calculation, however, follow those observed in the data.

Thus, we conclude that for polarizations of outgoing nucleons from absorption on ^{3,4}He, the contributions from distortions, including spin-orbit terms, and from $L = 2$ components in the target nuclei wave functions are negligible for the experimental configuration reported and therefore do not explain the observed discrepancies. We emphasize again that any differences in the free $\pi^+ + {}^2\text{H} \rightarrow 2p$ polarizations between our calculations and those contained in Refs. [1,2] simply reflect the differences in the fit to the two-body data.

IV. CONCLUSIONS

Overall we have demonstrated that, for a typical light nucleus, the polarization of the emitted nucleon in pion absorption is rather strongly modified by a variety of dynamical effects other than short-range correlations. These include angular momentum couplings implicit in the nuclear structure considerations which lead to tensor polarization of the struck quasideuteron, as well as distortion effects which give rise to additional vector polarization. In addition, the spin-orbit part of the proton-nucleus interaction leads to a substantial modification of the emitted nucleon polarization. Finally, we have suggested, though not unequivocally established, that the fundamental off-shell πNN amplitudes, may well differ significantly from typical on-shell approximations used in our DWIA. Thus, for a typical nucleus, while we expect measurements of the polarization of the emitted protons to lead to interesting tests of the absorption reaction mechanism, we would not consider the polarization to be a robust indicator of short-range effects.

For $^{3,4}\text{He}(\pi^+, 2p)$ the effects discussed above are much less pronounced, and experiments in which the leading $L = 0$ component dominates may have sensitivity to the short-range correlations. However, one must be careful to include spin-dependent effects in the final state interactions and properly treat the rather rapidly varying off-shell amplitudes. The fact that the emitted proton polarization data so closely resemble $\pi^+ + {}^2\text{H} \rightarrow 2p$ suggests that any short-range correlation effects are being masked, possibly as a result of the large experimental acceptance. Indeed, as we show in the energy sharing distribution of Fig. 6, a more restricted energy acceptance is necessary in order to isolate the different dynamical contributions to the observed outgoing nucleon polarizations.

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