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Polarized pion-deuteron breakup in the region of the 3,3 resonance

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The vector analyzing power iT_{11} for pion-deuteron breakup has been calculated at three different energies in the region of the 3,3 resonance and compared with recent data. The calculations have been performed using the relativistic Faddeev theory proposed by the author. The relationship of this theory to other formalisms is discussed, as well as the implications of our results to the question of the existence or nonexistence of dibaryon resonances.

The pion-deuteron system is one of the basic problems in medium-energy physics, which besides by being a three-body problem is amenable to an extract treatment through the use of standard relativistic Faddeev theories like the one formulated recently by the author[1] (which we will refer to hereafter as A), as well as by other existing formalisms.[2–5] These theories have been built upon the powerful concepts of Lorentz invariance and unitarity. Unitarity means that the integral equations satisfy the required discontinuity relations associated with the elastic, pion absorption, and breakup channels, so that the solutions of these equations satisfy the optical theorem. Lorentz invariance on the other hand, is achieved for example in A by using a relativistic isobar model for the πN and NN amplitudes, and by requiring that the spectator particles be always on the mass shell and the exchanged particles off the mass shell.[6] This feature of allowing some of the particles to be off the mass shell enables one to treat correctly processes in which a real or a virtual pion is created or absorbed by a nucleon. This also has the consequence in this theory that the one-pion-exchange potential of nucleon-nucleon scattering has the correct strength, which has been a problem in older theories.[7,8] In A we have shown that this theory can explain quite well the differential cross section and polarization observables of pion-deuteron elastic scattering. Thus, we like to see now if the theory can also describe the polarization observables of the breakup channel.

The inputs of the relativistic Faddeev theory are the transition potentials, which are standard Feynman diagrams representing a one-particle-exchange mechanism. In the case of the πNN system these transition potentials can be of two kinds, those corresponding to pion exchange between two πN isobars with nucleons as spectators, and those corresponding to nucleon exchange between a πN and a NN isobar with a nucleon as spectator in the first case and a pion as spectator in the second case. The πN isobars, corresponding to the six *S*- and *P*-wave pion-nucleon channels, are spin-$\frac{1}{2}$ spinors for the S_{11}, S_{31}, P_{11}, and P_{31} channels and spin-$\frac{3}{2}$ Rarita-Schwinger spinors for the P_{33} and P_{13} channels. The NN isobar representing the $^1S_0$ channel is just a constant (spin-0 spinor), while the isobar representing the $^3S_1$-$^3D_1$ channel is a spin-1 spinor. The couplings of the isobars to the pion and the nucleons are given by the standard relativistic vertices that couple particles of spin 0, $\frac{1}{2}$, 1, and $\frac{3}{2}$ with either positive or negative intrinsic parity.[1] The on-shell amplitudes for the six πN channels are constructed directly from the experimental pion-nucleon phase shifts, while for the nucleon-nucleon subsystem they are constructed by applying the unitary-pole approximation to the $^3S_1$-$^3D_1$ bound state and $^1S_0$ antibound state solutions of the Paris potential.[9,10]

A very popular theory of the πNN system in recent years has been the coupled NN-πNN theory proposed by Avishai and Mizutani[3] and by Blankleider and Afnan,[4] in which, however, no attempt has been made to describe particles off the mass shell. In that theory, moreover, the pion-nucleon P_{11} channel is decomposed into pole and nonpole parts in such a way that the effect of this channel on the observables is very large, while in the theory that we have just described the effect of the P_{11} channel is essentially negligible. As it has been pointed out by Ungricht *et al.*,[11,12] Shin *et al.*,[13] and Smith *et al.*,[14] the data for the tensor polarization t_{20} of pion-deuteron elastic scattering strongly suggest that the effect of the P_{11} channel is indeed very small.

Since the new theory has been very successful in explaining the polarization observables of the πd elastic reaction, the obvious next step is to see if this theory can also explain the polarization observables of the breakup reaction. The only available polarization observable of the breakup reaction is the vector analyzing power iT_{11}, which has been measured recently by Gyles *et al.*[15,16] in a kinematically complete experiment and compared with predictions obtained using the old Aaron-Amado-Young (AAY) theory.[2] In this experiment, they have detected the pion and the proton in coincidence at opposite sides of the beam, measuring the angles of both particles with respect to the incident direction of the beam, as well as the momentum of the proton. They have chosen six values of the pion and proton angles which contain the π^+p quasi-free point; that is, a value of the proton momentum for which the neutron is left almost at rest in the laboratory system, so that the differential cross sections are large and, consequently, the vector analyzing power can be measured with sufficiently good accuracy. They have measured iT_{11} not only for these six angle pairs, but for all 36 combinations of the pion and proton angles.[16] As they move away from the quasifree point, however, the differential cross section drops off rapidly and the accuracy for iT_{11} becomes progressively worst. Therefore, we have selected their data for the six quasifree angle pairs to compare with the theory, and show this comparison in Fig. 1. As we see from this figure, there is quite good agreement between theory and experiment within the accuracy of the data. We should point out that the pion and proton angles in Fig. 1 are the angles at which the particles were detected, which do not correspond exactly to the angles resulting from the breakup reaction, since the magnetic field used to polarize the target deflects the two outgoing charged particles, so that the true breakup angles which were used in the calculation are slightly different and vary with the proton momentum. We have found, however,[16] that using the fixed detection angles in the calculation would not change the results very much.

We would now like to comment on some issues that have attracted a considerable amount of attention in recent years. The first is that of the appropriate theory of the πNN system. It is significant that precisely the polarization observables of πd elastic scattering (which are more sensitive than the differential cross section) have shown promise to distinguish between different types of relativistic Faddeev theories; therefore, it would be quite useful if predictions of the NN-πNN theory[3–5] were also available, for the polarization observables of the breakup channel. Since the present theory is able to describe quite well the polarization observables of the elastic channel and, as we have shown here, also those of the breakup channel, it seems that this type of theory is quite appropriate to describe the πd system. The second issue deals with the suggestion that pion-deuteron scattering is sensitive to the excitation of dibaryon resonances,[17,18] since according to the calculations of Refs. 19 and 20 these dibaryons, once created, will decay with overwhelming branching ratios into the πd breakup channel. Thus, since polarization observables are the most sensitive quantities, it is clear that the polarization observables of the breakup reaction would be the best place for a dibaryon resonance signal to show up. As we see in Fig. 1, however, the data for the vector analyzing power are in good agreement with the theory within the accuracy of the data, and there is no indication of any exotic resonance being present. Finally, we would like to comment on the recent trend to add new degrees of freedom into an already quite complicated theory, by including the excitation of intermediate dibaryon resonances and the generalization to the chiral bag model.[21,22] We believe that if something important can be learned from the results of our calculations, it is the fact that in order to understand the πd system, what one needs is not a more complicated theory, but precisely the opposite; that is, a simpler theory.

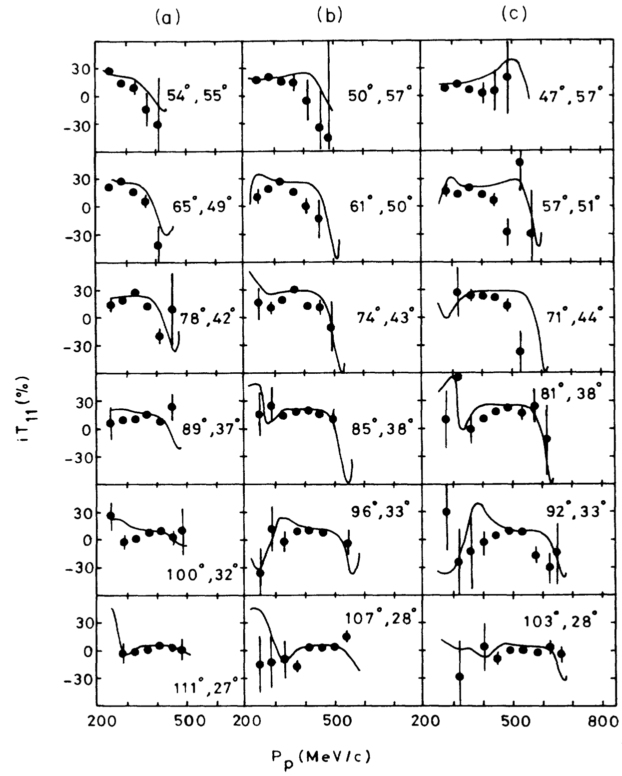

FIG. 1. Vector analyzing power iT_{11} for the reaction $\pi^+ d \rightarrow \pi^+ pn$ at incident pion energies of (a) $T_\pi = 180$ MeV, (b) $T_\pi = 228$ MeV, and (c) $T_\pi = 294$ MeV, as a function of the proton momentum. The first angle is that of the pion and the second one that of the proton.

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