t_{20} in $\pi^+ d$ Elastic Scattering between 118 and 148 MeV

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(Received 2 August 1985)

The tensor polarization t_{20} in $\pi^+ d$ elastic scattering has been measured as a function of energy at 15° (laboratory) over the energy range $T_\pi = 118$ to 148 MeV. The angular distributions at 135 and 142 MeV between 15° and 35° were also measured. The t_{20} values are negative for all energies and angles investigated and are consistent with the data of Holt *et al.* and Ungricht *et al.*, resolving the previous discrepancy with the results of Ulbricht *et al.*, Grüebler *et al.*, and Konig *et al.* As there are no significant rapid variations in t_{20}, our data do not lend support to the existence of dibaryon resonance effects at these kinematic ranges.

PACS numbers: 25.80.Dj, 14.20.Pt, 24.70.+s, 25.10.+s

Polarization observables such as it_{11} and t_{20} in πd scattering have recently been measured[1,2] and compared with calculations based on a variety of models.[3–10] Since polarization is basically an interference phenomenon, the polarization observables furnish information on small effects that otherwise are difficult to observe.

The angular and energy dependences of the tensor polarization in $\pi^+ d$ elastic scattering have been measured by two groups, one at the Swiss Institute for Nuclear Research and the other at the Clinton P. Anderson Meson Physics Facility (LAMPF), but the results of these two groups differ drastically. The data[2] of Ulbricht *et al.*, Grüebler *et al.*, and Konig *et al.* show that t_{20} is generally positive and exhibits a pronounced peak in the $\theta_{\text{lab}}^{(d)} = 15°$ excitation curve at $T_\pi \simeq 134$ MeV. In addition, measured angular distributions at 134 and 142 MeV show a rapid angular dependence. The results have been interpreted as an indication of the existence of a dibaryon resonance, although no clear-cut evidence for such an effect is offered in the measurement of it_{11} and in the cross section.[11]

The results[1] of Holt *et al.* and Ungricht *et al.*, on the other hand, show that the angular distribution and excitation curve [at $\theta_{\text{lab}}^{(d)} = 18°$] of t_{20} are negative and smooth. This smooth behavior of the excitation curve and the angular distribution is, to a large extent, consistent with existing few-body theory. Indeed, the agreement between this experiment and a calculation by Garcilazo[10] is excellent.

In order to resolve the discrepancy in the measured tensor polarization between these two groups and to further our knowledge on the πNN interaction, we have measured t_{20} in $\pi^+ d$ elastic scattering as a function of energy at $\theta_{\text{lab}}^{(d)} = 15°$ between $T_\pi \simeq 118$ and 148 MeV and as a function of angle at $T_\pi \simeq 135$ and 142 MeV. The results are presented in this Letter.

The measurement was performed at TRIUMF in the M11 medium-energy π^+ channel. The experimental layout is shown schematically in Fig. 1. A liquid-deuterium (LD_2) target[12] (~ 100 mg/cm^2) was used with a pion flux of $3 \sim 5 \times 10^7$/s ($\Delta p/p \sim 2\%$). The spatial distribution of the pion beam was monitored by a retractable wire chamber W0 in front of the LD_2 target. The energy of the channel was calibrated by a combination of solid-state detectors and time-of-flight measurements.[13]

The recoil deuterons, focused on the ^{3}He polarimeter by a quadrupole triplet, were detected in coincidence with the scattered pions. The polarimeter consisted of four scintillation detectors and a cylindrical ^{3}He-gas cell, 10 cm in diameter and 10 cm long. The ^{3}He gas was maintained at ~ 1 atm (absolute) and at 4.2 K (~ 100 mg/cm^2). One of the four detectors (D) was used to detect deuterons incident on the polarimeter, while two of them (P1 and P) were placed behind the ^{3}He cell to detect protons from the ^{3}He(d,p) reactions in the ^{3}He cell. The fourth detector (V) was used as a veto counter to eliminate energetic particles (π^+, quasifree protons, etc.). Two wire

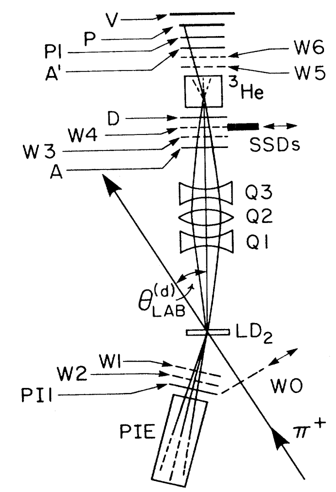

FIG. 1. Experimental configuration at TRIUMF. The scattered pions were detected in wire chambers (W1,W2) and scintillators (PI1,PIE). The recoil deuterons were focused by the quadrupole triplet onto the polarimeter consisting of a ^{3}He-gas cell surrounded by wire chambers (W3,W4,W5,W6), scintillators (D,P1,P,V), absorbers (A,A′), and retractable solid-state detectors (SSD's).

chambers, W3 and W4, provided information on position and angle of the incident deuterons. The angular and position information of the protons from the reaction ^{3}He(d,p) was also obtained by two wire chambers, W5 and W6, placed directly behind the ^{3}He cell.

The polarimeter was calibrated with use of a polarized deuteron beam from the Texas A & M University cyclotron. The polarimeter is, in principle, capable of analyzing it_{11}, t_{21}, and t_{22}, as well as t_{20}. Details of the polarimeter and its calibration may be found elsewhere.[14] The application of this calibration to the analysis of the experimental data requires deuteron energy as well as spatial distribution measurements. The energy distribution of each configuration was measured by retractable solid-state detectors (SSD's); the wire chambers (W3 and W4) gave the spatial and angular distributions. In addition the deuteron time of flight was measured.

The pion-arm detector system consisted of two wire chambers, W1 and W2, for position and angle information, and dE/dx (PI1) and E (PIE) detectors, whose spectra provided information on elastic and inelastic pions.

The identification of the protons from the reaction ^{3}He$(d,p)^4$He was performed primarily by displaying the time-of-flight spectrum of the counter D versus the pulse-height spectrum of the counter P for the $\mathrm{PI1}\cdot\mathrm{PIE}\cdot\mathrm{D}\cdot\mathrm{P1}\cdot\mathrm{P}\cdot\overline{\mathrm{V}}$ events, as shown in Fig. 2. The background from quasielastic proton groups is clearly separated from the (d,p) events. However, the locus

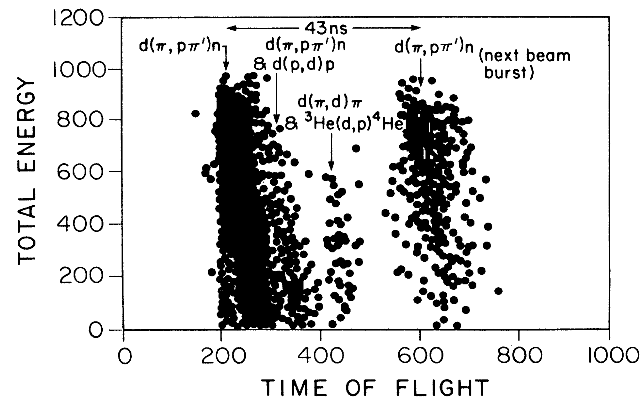

FIG. 2. Time of flight at D vs the total energy in P after the polarimeter showing the separation of (d,p) events from background. The scales drawn are in channel numbers. The separation of the beam bursts is 43 ns as indicated.

marked "$d(\pi,p\pi')n$ & $d(p,d)p$" resulting from this combination of reactions in the LD_2 target (pion-induced protons subsequently knocking out deuterons) is closer to the desired (d,p) events. These loci merge as the pion energy is increased and/or the deuteron angle is decreased and could be a major source of background in the determination of (d,p) events above 150 MeV and below 15°.

Further analysis of time-of-flight differences between counters and the energy deposited in each counter allowed a cleaner separation of (d,p) events. Backgrounds were measured without ^{3}He gas and/or LD_2 for selected configurations. The results indicated an effect that was $\lesssim 10\%$ of the true events.

The results presented in Fig. 3 were taken over a period of one year during three experimental running periods. The pion beam resolution was 2%, typically, but for the 142-MeV angular distribution 5% was used. We note that the consistently negative t_{20} values and the lack of any oscillatory nature in our data are in agreement with the measurements of Ref. 1.

Our data and the results of Ref. 1 suggest that the measured tensor polarization can be explained with conventional three-body theory without the introduction of exotic effects such as dibaryon resonances. The relativistic three-body model used by Garcilazo[10] reproduces our data rather well. In this model the pion-nucleon P_{11} partial wave is treated differently from that used by Blankleider and Afnan,[4] and by Avishai and Mizutani.[5] This model also gives fair agreement with measured iT_{11}. To obtain the fit, Garcilazo claims that the pion absorption effects were significantly reduced. The discrepancy with other models is thought to arise from the inadequate treatment of the P_{11} interactions. Indeed, turning off the P_{11} interactions brings the theory into better agreement with our results. Whether the origin of the discrepancies

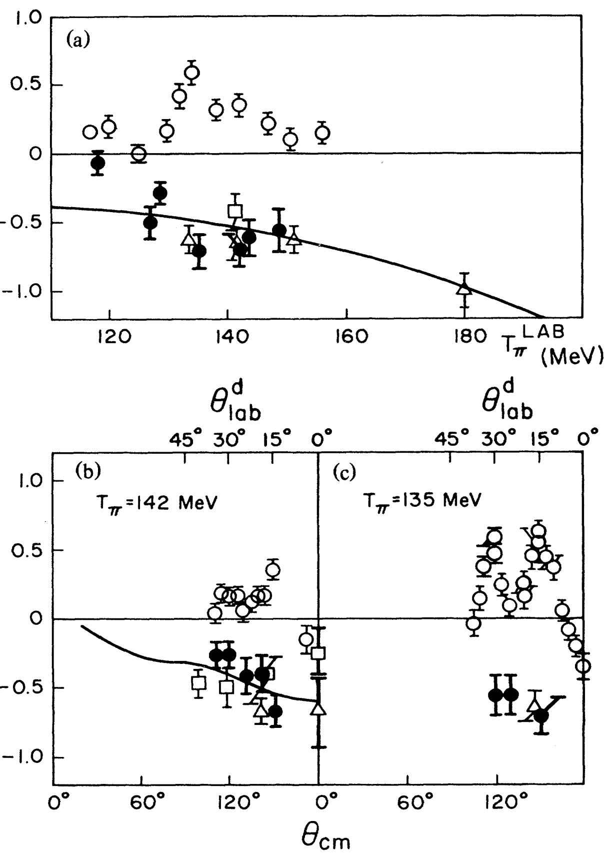

FIG. 3. t_{20} experimental values. The present results are shown with solid circles; open circles are from Ref. 2; open triangles and squares are from Ref. 1. The solid lines are the theoretical predictions from Ref. 10. (a) Excitation curve at $\theta_d^{(lab)} = 15°$ (18° for Ref. 1). (b) Angular distribution at 142 MeV. (c) Angular distribution at 135 MeV (134 MeV for Ref. 2).

between theory and experiment is due to a relativistic effect or inadequacies in the P_{11} interaction is not known and remains to be investigated through the measurement of other quantities, such as spin transfer coefficients for example.

Although our data resolve the controversy in the measurements of t_{20}, there remains the discrepancy in values between the data of the present work and Ref. 1 and the data of Ref. 2. In order to reconcile the sources of the discrepancy we have investigated a number of experimental parameters. The measured tensor polarization is given by $t_{20} = (\epsilon - \langle\epsilon_0\rangle)/\langle\epsilon_0 T_{20}\rangle$, where ϵ is the measured efficiency from (d,p) events and $\langle\epsilon_0\rangle$ ($\langle\epsilon_0 T_{20}\rangle$) is the calibrated efficiency (multiplied by analyzing power) for deuterons weighted according to the measured spatial, angular, and energy distributions. Our conclusions are as follows: (1) The deuteron energy spectra needed to obtain the unpolarized efficiency, $\langle\epsilon_0\rangle$, must be measured accurately, otherwise it leads to erroneous results in obtaining the vital quantity $\epsilon - \langle\epsilon_0\rangle$. Sharper energy spectra result in higher $\langle\epsilon_0\rangle$ values and consequently more positive t_{20} values (as T_{20} is negative). (2) All the deuterons detected by the counter D must enter the ^{3}He-gas cell. Should any miss the cell the result would be small ϵ values and more positive t_{20} values. (3) The measured deuteron energy depends on the deuteron position at the polarimeter. If the cell is too small to encompass the complete distribution the result is an $\langle\epsilon_0\rangle$ value which is too large and subsequently a t_{20} value that is too positive. (4) Some of the measured deuteron spectra confirm significant "unwanted" deuterons which are detected in the counter D but which never reach the ^{3}He cell energetically. These deuterons decrease ϵ. Unless these effects are checked very carefully the data would result in erroneous values of t_{20}, possibly including rapid changes over energy and angle. For details see the discussion in Ref. 14.

The financial support of the Natural Sciences and Engineering Research Council (Canada) and the National Research Council (Canada) through TRIUMF is gratefully acknowledged. We are indebted to Dr. K. Wolf for arranging and assisting in the polarimeter calibration at the Texas A&M Cyclotron Institute. Thanks are also due to Dr. B. Blankleider and Dr. A. W. Thomas for stimulating discussions, and Dr. R. J. Holt and Dr. W. Grüebler for helpful communication and discussions. The assistance of the TRIUMF support staff has been invaluable during the experiment.

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[1]R. J. Holt *et al.*, Phys. Rev. Lett. **43**, 1229 (1979); R. J. Holt *et al.*, Phys. Rev. Lett. **47**, 472 (1981); E. Ungricht *et al.*, Phys. Rev. Lett. **52**, 333 (1984); E. Ungricht *et al.*, Phys. Rev. C **31**, 934 (1985).

[2]J. Ulbricht *et al.*, Phys. Rev. Lett. **48**, 311 (1982); W. Grüebler *et al.*, Phys. Rev. Lett. **49**, 444 (1982); V. Konig *et al.*, J. Phys. G **9**, L211 (1983); V. Konig *et al.*, J. Phys. G **9**, L211 (1983); Swiss Institute for Nuclear Research Annual Reports 1983 (NL38) and 1984 (NL18) (unpublished).

[3]A. W. Thomas and A. S. Rinat, Phys. Rev. C **20**, 216 (1979).

[4]B. Blankleider and I. R. Afnan, Phys. Rev. C **24**, 1572 (1981).

[5]Y. Avishai and T. Mizutani, Phys. Rev. C **27**, 312 (1983).

[6]M. Betz and T. S. H. Lee, Phys. Rev. C **23**, 375 (1981).

[7]R. Händel, M. Dillig, and M. G. Huber, Phys. Lett. **73B**,

4 (1978).
[8]M. P. Locher and M. E. Sainio, Phys. Lett. **121B**, 227 (1983).
[9]B. Blankleider and I. R. Afnan, Phys. Rev. C **31**, 1380 (1985).
[10]H. Garcilazo, Phys. Rev. Lett. **53**, 652 (1984).
[11]G. R. Smith *et al.*, Phys. Rev. C **29**, 2206 (1984), and references cited therein.
[12]T. E. Drake *et al.*, to be published.
[13]G. M. Stinson, TRIUMF Report No. TRI-DNA-80-5 (unpublished); D. Ottewell *et al.*, to be published.
[14]Y. M. Shin *et al.*, to be published.