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Measurements of spin-correlation parameters A_{LL} and A_{SL} for $\vec{p}\vec{p} \rightarrow \pi d$ between 500 and 800 MeV

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Measurements of A_{LL} between 500 and 800 MeV and spin dependent cross sections derived from these measurements are presented for the reaction $pp \rightarrow \pi d$ at c.m. angles θ_π^* of 50°, 70°, and 90°. Angular distributions for A_{SL} are also presented for energies 500, 650, and 800 MeV. These are the first measurements of spin-correlation parameters in this channel above 590 MeV, and are in substantial disagreement with theoretical predictions of the triplet amplitudes above 600 MeV.

The importance of the study of inelasticity in nucleon-nucleon (NN) collisions has been enhanced recently by claims for the existence of highly inelastic resonant states in the NN system, the so-called dibaryon resonances.[1] From threshold ($\sim$290 MeV) to $\sim$500 MeV, the inelasticity is mostly in the two-body channel $NN \rightarrow \pi d$, but the cross section for the three-body channel $NN \rightarrow \pi NN$ grows rapidly with energy and becomes dominant above $\sim$500 MeV. The $NN \rightarrow \pi d$ channel has received extensive attention, partly because in this two-body final state, measurements can be made with accuracy, precision, and completeness which are much more difficult to attain in the three-body channel. In addition, for the two-body channels extensive theoretical calculations are available[2-4] which are based on Faddeev equations, and which provide a unified description of the three coupled channels $NN \rightarrow NN$, $NN \rightarrow \pi d$, and $\pi d \rightarrow \pi d$. Also, if the πd channel can be regarded as being fed from the general $NN \rightarrow \pi NN$ channel via final state interactions between the two nucleons, it may be expected to contain the effects of most of the phenomena (such as dibaryon resonances) which originate in the parent channel $NN \rightarrow \pi NN$.

Most of the precision measurements made to date in the $pp \rightarrow \pi d$ channel have been of those observables which can be measured with unpolarized targets. There is now a large body of data on unpolarized differential cross section (Ref. 5) $\sigma_{00}(\theta)$ and the analyzing power (Refs. 6 and 7) $A_{NO}(\theta)$ up to about 1.2 GeV. With the present state of development of theories of the $pp \rightarrow \pi d$ reaction, these experiments have not yet revealed any definitive signs of the proposed dibaryon resonances $^1D_2(\sim 2140$ MeV), $^3F_3(\sim 2220$ MeV), or $^1G_4(\sim 2430$ MeV). It was originally suggested by Hoshizaki[1] that in the elastic channel, spin-correlation measurements might provide better indications of such resonances. In view of the large ($\geq$80%) inelasticity subsequently attributed to these supposed resonances, it is reasonable to expect that spin-correlation measurements should be important also for the inelastic πd channel. Some of the first experiments of this type have indeed been done by Aprile *et al.* and Hoftiezer *et al.* at Schweizerisches Institut für Nuklearforschung (SIN).[8] However, these measurements are confined to energies below 590 MeV, which correspond to invariant masses below 2148 MeV, and therefore do not include the energy region of greatest interest. The first such measurements of the spin-correlation parameters $A_{LL}(\theta)$ and $A_{SL}(\theta)$ above 582 MeV are reported here and cover the proton energy range 500–800 MeV, which corresponds to the interesting invariant mass range 2112–2241 MeV.

The measurements were made at the Clinton P. Anderson Meson Physics Facility (LAMPF) with polarized proton beams in the 500-800-MeV energy range and with a longitudinally polarized target. At 600, 700, and 750 MeV pure longitudinally (L) polarized beams were used and only

$A_{LL}(\theta)$ was measured. At 500, 650, and 800 MeV, the beam contained both L and sideways (S) horizontal components of polarization. Beams containing two different mixtures of L and S polarization were used at each energy in order to extract both $A_{LL}(\theta)$ and $A_{SL}(\theta)$. A_{LL} is defined such that it is positive if cross sections with beam and target spins aligned in the laboratory are larger than cross sections with spins antialigned. For A_{SL} the positive sense for S type spin is towards the left if one faces the beam direction, while L is positive for spins pointing in the beam direction in the laboratory, and A_{SL} is positive if the sum of cross sections with both spins positive or both negative are greater than the sum with spins having opposite signs. The geometry of the polarized target magnet allowed pions with c.m. angles θ_π^* between 36° and 70° to be detected in a recoil detector assembly located completely outside the magnet. The detectors in this assembly consisted of multiwire proportional chambers (MWPC's) for position determination, and a large scintillation counter array for obtaining trigger, time of flight (TOF), and pulse height information. For θ_π^* between 70° and 131°, the pion detector was a small scintillator placed inside the magnet at $\sim 90°$ to the beam and ~ 13 cm from the target. In all cases the deuterons were detected in a magnetic spectrometer (22° bend angle) that was equipped with MWPC's and scintillators at both its entrance and exit. Time of flight, momentum analysis [$\Delta p/p = \pm 2\%$ full width at half maximum (FWHM)], and angle measurements ($\Delta\theta \sim 0.5°$ FWHM) were used to identify and select the deuterons and to make projections of their trajectories back to the target. These measurements, together with pion TOF, coplanarity, and pion target projections, which were available in the $\theta_\pi^* = 36°$–$70°$ region only, were used to define the true events. The background in the region $\theta_\pi^* < 70°$ (for the external pion detector) was typically 3–10%, while for the region $\theta_\pi^* > 70°$ (for the internal pion detector) it was 10–30%.

The beam intensity was monitored with an Ar-CO_2 ion chamber upstream of the target, and by a polarimeter consisting of four pairs of scintillation counters viewing a thin CH_2 target just upstream of the ion chamber. This polarimeter was designed to measure the transverse components S and N (vertical) of the beam polarization. The direction of the polarization vector at the target could be accurately determined (to within $\pm 2°$) by knowledge of its direction at the source and its precessions in the beam transport system. The magnitude of the overall polarization was measured by the quench ratio method,[9] which was also used to calibrate the beam polarimeter. The target polarization was monitored with an NMR system[10] which was read every two minutes. This system was calibrated with thermal equilibrium measurements (TEM) and found to have a precision and accuracy of ±4%. The TEM was a measure of the NMR signal with no microwave enhancement and the target temperature raised to 1 K from an operating value of 0.5 K.

The angular distributions measured for A_{SL} for three energies are shown in Fig. 1 along with the predictions of a partial wave analysis (PWA)[11,12] and theoretical calculations by the Lyon group (L)[2] and by Blankleider and Afnan (B).[3] The B calculations are essentially a transmission of the amplitudes from their theory as published,[3] but the L calculations include some improvements to their theory as published.[2] Before the present data[13,14] were included in the PWA data base,[11] the PWA "predictions" for A_{SL} above 600 MeV were in marked disagreement with our data. A recent analysis up to 800 MeV by Hiroshige,[12] including the present data, gives the good agreement shown in Fig. 1. Another PWA by Bugg[15] gives similar results although he uses Ref. 3 for fixing some of the amplitudes, whereas Hiroshige used Ref. 2 for this purpose. The disagreement between the measured A_{SL} values and the two theoretical predictions (L and B) clearly increases with energy. Better insight as to the possible cause of this discrepancy can be gained by considering the singlet-triplet separation that is obtained in the notation of Foroughi,[16] with the pure triplet cross section σ^T and the mixed singlet and triplet cross section σ^{SM} defined as follows:

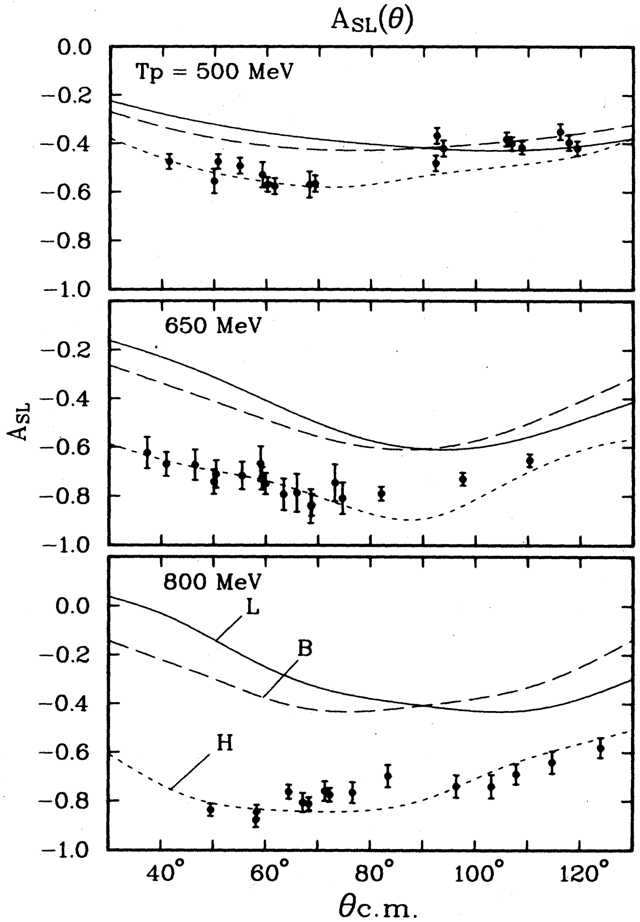

FIG. 1. The angular distribution of A_{SL} at three energies with theoretical calculations from Ref. 3 (large dashes, B) and Ref. 2 (solid line, L). The short dashes (H) are Hiroshige's PWA from Ref. 12.

$$\sigma^T \equiv \sigma_{00}(1 + A_{LL}) = |T_2|^2 + |T_3|^2 + |T_6|^2 \ ,$$

where T_i are pure triplet amplitudes, and

$$\sigma^{SM} \equiv \sigma_{00}(1 - A_{LL}) = |M_1|^2 + |M_4|^2 + |S|^2 \ ,$$

where the M_i are a mixture of singlet and triplet amplitudes. These tend to be small in comparison with the pure singlet amplitude S, and in fact are zero at 90°. Values of these spin-dependent cross sections obtained by combining the A_{LL} data of the present experiment with fits to the spin independent cross sections σ_{00} given in Ref. 6 are shown for three angles in Fig. 2. The values obtained from the A_{LL} data of Aprile *et al.*[8] are also shown and are in agreement except for the 500 MeV point at 90°. The characteristic feature exhibited by the data at all three angles is a broad peak centered slightly below 600 MeV in the case of σ^{SM} and at somewhat higher energy, near 670 MeV, in the case of σ^T. These shapes can be understood qualitatively, without invoking dibaryons, as arising from threshold effects in the intermediate state which consists of the NΔ, in an S state for singlet transitions and in a P state for triplet transitions.[17] The S state NΔ is predominantly fed from the $^1D_2$ pp partial wave initial state, and the P state from the five partial waves $(^3P_{1,2}, {}^3F_{2,3,4})$. Similar behavior has been observed in Ref. 6 in the analysis of A_{NO}. The overall peaking is already manifested in σ_{00}, but the separation into triplet and singlet dominated parts shows the details that relate more to the orbital states of the intermediate NΔ system.

Also shown in Fig. 2 are the results of the most recent PWA[12] and the predictions of the two unified theories (L,B).[2,3] Since the PWA was based in part on the present data it is not surprising that the fit is good. Both of the theoretical predictions show energy dependence qualitatively similar to the broad peaks exhibited by the data, with the peaks of the B prediction[3] being somewhat stronger, broader, and higher in energy than those of the Lyon group.[2] Both calculations, without including dibaryons, do reasonably well (especially those of the Lyon group) in predicting the magnitudes of the peaks in σ^{SM} and the energy dependence of this singlet-dominated cross section, but fail qualitatively to fit the shapes and maxima for the triplet cross sections σ^T. This failure of the theories to predict triplet amplitudes correctly was noted earlier by Saha *et al.*[6] The fact that the theories do reasonably well in predicting the $^1D_2$ dominated cross sections lends some credence to them, but their conspicuous failure to predict the triplet cross sections indicates serious problems.

The Lyon group used relativistic kinematics for all of the particles, whereas Blankleider and Afnan treated only the pion kinematics relativistically. Neither group treated spin relativistically.[18] Both used information from the πN P_{11} amplitude to establish the πNN vertex, but neither incorporated the heavier vector meson exchanges. Furthermore, the handling of the intermediate pion was not truly relativistic in either treatment, since virtual pions going backward (in time) were not included. It is important to determine whether the predictions of these theories will be altered significantly by corrections for these known deficiencies. The better agreement of the predictions with the data in the case of σ^{SM} may stem from the fact that only the $^1D_2$ partial wave is involved. It is expected that inclusion of vector meson exchanges will primarily affect the triplet amplitudes, and the fact that there are five partial waves in this case may be a complexity which is difficult to treat with these theories. It may be that improvements to these calculations can eliminate their failure to predict the experimental results for σ^T. The need for hypothesizing dibaryon resonances or some other new phenomenon to explain the data is not yet clear. In fact, a phenomenological treatment by Kamo and Watari[19] which did include dibaryon resonances gave predictions for A_{LL} at 600 MeV which differed from both the present 600 MeV and the SIN 582 MeV results[8] by more than 0.3 (ten standard deviations) over much of the angular range. The only conclusion that can safely be drawn from these data is that more complete and reliable theoretical calculations are needed.

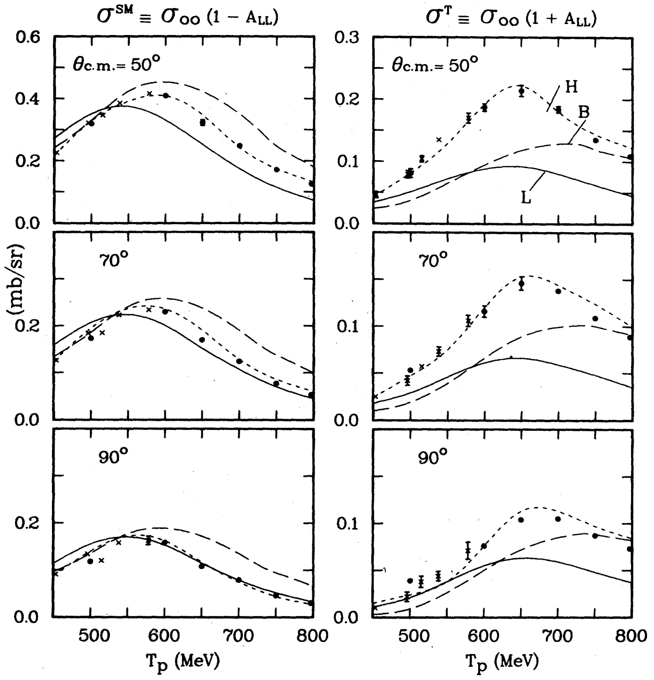

FIG. 2. The singlet-dominated and triplet forms of the spin dependent cross sections. ●, present results; ×, from Ref. 8. Errors are statistical only. The curves are from references as in Fig. 1.

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