tive.

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Search for a Δ-Δ Component in the Deuteron Wave Function Using $\bar{p}d$ Interactions at 5.55 GeV/c

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From a bubble-chamber experiment, we studied the $\bar{p}d \to p_s\bar{p}p\pi^-$, $p_s\bar{p}p\pi^-\pi^0$, $p_s\bar{n}p\pi^-\pi^-$ reactions at 5.55 GeV/c in order to see whether a Δ-Δ component of the deuteron wave function can be observed in our data. This was achieved by searching for spectator $\Delta \to p_s\pi$ systems. We observed significant production of $\Delta \to p_s\pi$, a fraction of which is emitted in the backward laboratory hemisphere. The meaning of this high $\Delta \to p_s\pi$ production rate is discussed.

Recently the possibility that virtual Δ's may be present in the nucleus has been considered.[1,2] It has been suggested that a way to test such a picture is to study inelastic reactions on the deuteron.[3,4] Because of isospin conservation, the deuteron can transform into only two Δ's. Then following the impulse approximation, a fraction of the interactions induced by fast beam particles may occur on a virtual Δ, the other appearing as a Δ spectator (Δ_s). In this approach the observation of Δ_s in inelastic channels may give some information about the Δ-Δ component of the deuteron wave function. Furthermore the presence of Δ in the deuteron may also offer a way to study interactions on virtual Δ targets.

The percentage of the Δ-Δ component in the deuteron wave function has been estimated from theoretical calculations to be a few percent.[1,2] Although this percentage is small, we attempted to see if Δ_s appear among the outgoing particles in $\bar{p}d$ interactions at 5.55 GeV/c by collecting data from the following channels

$$\bar{p}d \to p_s\bar{p}p\pi^- \quad (1348 \text{ events}), \qquad (1)$$

$$\to p_s\bar{p}p\pi^-\pi^0 \quad (651 \text{ events}), \qquad (2)$$

$$\to p_s\bar{n}p\pi^-\pi^- \quad (221 \text{ events}). \qquad (3)$$

The present data which have already been partially studied[5] were obtained from a bubble chamber experiment. All the considered events contain an outgoing proton (p_s) stopping in the chamber. One has thus a sample in which the p_s presents roughly the behavior of a spectator proton. In order to search for Δ_s in the final state, we will consider the various outgoing $p_s\pi$ systems, and discuss later the biases introduced by taking only events having a proton stopping in the chamber. To decrease complications due to resonance reflection, we studied $p_s\pi$ systems in which the π does not contribute to resonance production with the remaining outgoing particles. In Reaction (1) we thus excluded the $\bar{p}d \to p_s\bar{\Delta}^{--}p$ subsample obtaining 1348 events. For channel (2) we consider all of the $p_s\pi^0$ systems since the π^0 contribute in a negligible amount to resonance production. Within the present statistics this is likewise true for the π^- in channel (3), allowing us to consider the two $p_s\pi^-$ combinations.

Using the $p_s\pi$ systems thus selected, we present in Fig. 1(a) the scatter plot of $\cos\theta$ versus the $p_s\pi$ effective mass ($M_{p_s\pi}$). Here θ is the laboratory emission angle of the $p_s\pi$ system defined with respect to the incoming beam direction. One sees from this plot that the events having their $M_{p_s\pi}$ in the Δ band ($1.15 < M_{p_s\pi} < 1.32$ GeV/c^2) are distributed over all the $\cos\theta$ range. A similar structure observed[3] in the reaction $\pi^+d \to p_sp\pi^+\pi^-\pi^0$ at 15 GeV/c[3] was accounted for by the existence of virtual Δ in the deuteron since the $p_s\pi^+$ systems in the Δ band seem to be emitted isotropically in the laboratory system as predicted by the impulse-approximation approach.[3] Even in this model such a picture is oversimplified because one neglects, among other things, the following effects: the cross-section variation of the studied process for the c.m. energy spread

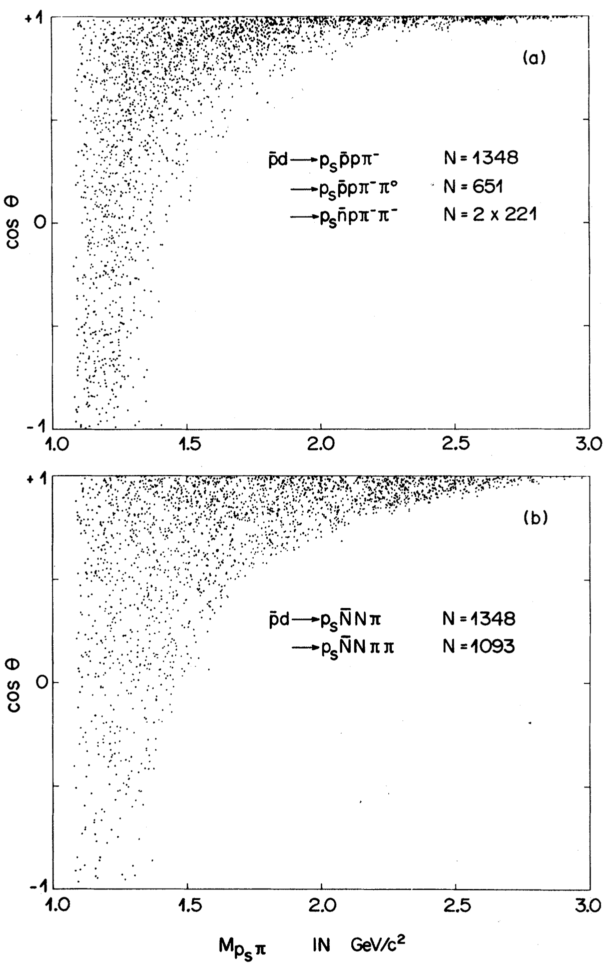

FIG. 1. (a) The $M_{p_s\pi}$, $\cos\theta$ scatter plot; the same plot for Monte Carlo events.

introduced by the Fermi motion of the Δ target, the variation of the invariant flux factor due to different beam-target momentum configurations, and the influence of the bias introduced by taking only events having an outgoing proton stopping in the bubble chamber. Nevertheless the observation of $\Delta \to p_s\pi$ emitted in the backward hemisphere ($\cos\theta < 0$) may support the idea that this Δ is a spectator system. This is because from kinematical considerations the Δ produced by the interaction of the beam particle with the deuteron or with their bound nucleons cannot be emitted in the $\cos\theta < 0$ region. Our data [Fig. 1(a)] show that we have a rather important number of $p_s\pi$ systems in the Δ mass band which are emitted in the $\cos\theta < 0$ range.

For comparison, we present in Fig. 1(b) a scatter plot obtained from phase-space events. These events were generated by a Monte Carlo

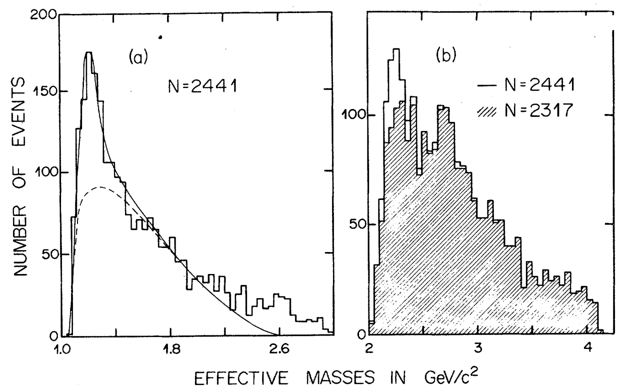

FIG. 2. (a) The $M_{p_s\pi}$ distribution. The solid curve represents the fitted data while the dashed line is the peripheral phase space. (b) The $M_{p_s p\pi^-}$ [channels (1) and (3)] and $M_{p_s p\pi^0}$ [channel (2)] effective mass distribution. The shaded area is obtained by excluding the events in the $\Delta \to p_s\pi$ band and emitted in the $\cos\theta > 0.75$ region.

method in the same amount as that given by our various channels. For the simulation of channel (1), we excluded the events having an $M_{\bar{p}\pi^-}$ mass value in the $\bar{\Delta}^{--}$ mass band. The calculation was made by assuming that p_s is a spectator proton described by the Hulthén wave function. The concentration of the events in the Δ band is more important for the experimental data than for the phase-space events, as can also be seen from the $M_{p_s\pi}$ distribution [Fig. 2(a)]. We fitted this distribution using an incoherent mixture of a Breit-Wigner function due to the $\Delta \to p_s\pi$ resonance and peripheral phase space obtained by a Monte Carlo calculation similar to that described above. This time each generated event was weighted by a factor $a\exp(b_1t_1)\exp(b_2t_2)$ for describing the peripheral nature of the studied reactions. Here t_1 (t_2) is the four-momentum transfer between the incident $\bar{p}$ (bound n) and the outgoing $\bar{N}$ (N) particle. The slopes b_1 and b_2 were adjusted simultaneously for each channel in such a way that the integrated t_1 and t_2 distributions agree with the experimental data (see Table I). As a result of

TABLE I. Slopes used for calculating the peripheral phase space.

Final state	b_1 [(GeV/c)$^{-2}$]	b_2 [(GeV/c)$^{-2}$]
$p_s\bar{p}p\pi^-$	4.4 ± 0.4	4.0 ± 0.4
$p_s\bar{p}p\pi^-\pi^0$	1.7 ± 0.1	2.2 ± 0.2
$p_s\bar{n}p\pi^-\pi^-$	1.7 ± 0.2	1.1 ± 0.1

this fit we obtain 401 ± 63 events that contribute to the $\Delta \to p_s\pi$ peak. One notices from Fig. 2(a) that the peripheral phase space does not describe the experimental distribution in the $M_{p_s\pi} \gtrsim 2.3$ GeV/c^2 region because of the influence of the resonance reflections. Indeed our data show that high-mass $\bar{p}\pi^-$ resonances (weakly present here) are populating the $M_{p_s\pi} > 2.3$ GeV/c^2 region. Let us also note that we attempted unsuccessfully to use a nonperipheral phase space to fit our data.

The percentage of Δ lost because of our event selection has been estimated by generating $\bar{p}d \to \Delta\bar{N}N$, $\Delta\bar{N}N\pi$ events with a Monte Carlo method and assuming that the Δ's decay isotropically in their rest frame. The generation was done according to our experimental Δ momentum distribution, the shape of which is not strongly affected by our bias as shown by our calculation. We obtain a loss of about 7%.

The important observed $\Delta \to p_s\pi$ production rate partly arises from the so-called d^* phenomenon studied in earlier papers.[6,7] We showed in particular that an important part (~20%) of the events fitting the reaction $\bar{p}d \to p_s\bar{p}n\pi^+\pi^-$ result from $\bar{p}d \to \bar{p}\pi^- d^*$, where the d^* enhancement at 2.18 GeV/c^2 transforms into a $p_sn\pi^+$ system. In this case most (~90%) of the $p_s\pi^+$ and $n\pi^+$ effective masses are in the Δ mass bands as can be seen from a $p_sn\pi^+$ Dalitz plot calculated for the d^* mass.[7] For the channels considered here, a similar d^* enhancement can appear, with $d^* \to pp\pi^-$ [channels (1) and (3)] or $d^* \to pp\pi^0$ [channel (2)]. The Clebsch-Gordan coefficients predict a branching ratio of $(d^* \to pp\pi^0, pp\pi^-)/(d^* \to pn\pi^+) = \frac{2}{3}$. Figure 2(b) displays the distribution of the $p_sp\pi$ effective mass ($M_{p_sp\pi}$) in which a prominent enhancement can be seen at 2.18 GeV/c^2. In order to remove the d^* events without eliminating the numerous events which are in the $M_{p_sp\pi} \sim 2.18$ GeV/c^2 region, we apply a cut on $\cos\theta$. Indeed the study of the d^* enhancement in the reaction $\bar{p}d \to p_s\bar{p}n\pi^+\pi^-$ has shown that practically all of the $p_s\pi^+$ systems coming from the $d^* \to pn\pi^+$ enhancement are emitted in the $\cos\theta > 0.75$ range. Excluding from our sample the events which have their $p_s\pi$ system in the Δ mass band and which are emitted in the $\cos\theta > 0.75$ range, we obtain the shaded histogram shown in Fig. 2(b). The d^* bump practically disappears.

Therefore to avoid a misinterpretation of our data we first consider the effective-mass distribution of the $p_s\pi$ system having its $\cos\theta < 0.75$. This $M_{p_s\pi}$ distribution [Fig. 3(a)] was fitted with a Breit-Wigner function and peripheral phase space deformed according to our selection criteria. The presence of a high number of $\Delta \to p_s\pi$ resonances (255 ± 40) clearly indicates that our data cannot be explained completely in terms of interactions having a real spectator proton in the final state. For estimating the number of $\Delta \to p_s\pi$ emitted in the backward hemisphere, it is difficult to fit the $M_{p_s\pi}$ distribution in the $-1 < \cos\theta < 0$ interval since the $\Delta(1236)$ Breit-Wigner function has a behavior very similar to the peripheral phase space in this region. Therefore we consider the $M_{p_s\pi}$ distribution in the $0 < \cos\theta < 0.75$ range from which 73 ± 35 events contribute to the $\Delta \to p_s\pi$ peak. This allows us to estimate by substraction that 182 ± 53 $\Delta \to p_s\pi$ are emitted in the $\cos\theta < 0$ region.

Figure 3(b) presents the $\cos\theta$ distribution for events in the Δ mass band. In this band the Δ

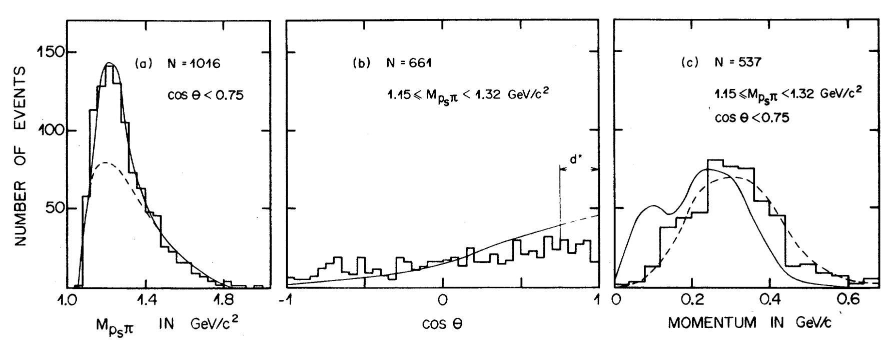

FIG. 3. (a) The $p_s\pi$ mass distribution with the full curve representing the fitted distribution and the dashed line the peripheral phase space. (b) The $\cos\theta$ for the $p_s\pi$ system with the curve representing the peripheral phase space normalized in $-1 < \cos\theta < 0.75$. (c) The laboratory momentum distribution of the $p_s\pi$ systems. The full curve is the calculation from Ref. 4 deformed by our selection criteria. The dashed curve is peripheral phase space.

over background ratio is about 40%. The curve in Fig. 3(b) represents the peripheral phase space prediction normalized to the data in the $\cos\theta < 0.75$ range where the d^* production is negligible. The experimental distribution presents an isotropic component which cannot be accounted for by only the phase space prediction. For the events in the $\Delta \to p_s\pi$ mass band and with $\cos\theta < 0.75$ we compare the experimental momentum distribution of the $p_s\pi$ system [Fig. 3(c)] with the peripheral phase space (dashed curve) and the distribution (full curve) deduced from the Δ-Δ component of the deuteron wave function calculated in Ref. 4. To this end we calculated the modifications introduced in the theoretical distribution because of our event selection. This was achieved by a Monte Carlo calculation assuming still an isotropic decay of the Δ_s. In contrast to the peripheral phase-space prediction [see Fig. 3(c)], the distribution obtained is not able to describe our data. The same calculation also showed that the expected isotropic distribution of the Δ_s in the laboratory system is not affected by selecting events with a stopping proton.

To summarize, we showed that an important fraction of the studied events have $\Delta \to p_s\pi$ resonances in the final state. Even if we remove the $d^* \to p_s p\pi$ events present in our sample we still have about 255 ± 40 $\Delta \to p_s\pi$ events, 182 ± 53 of which are emitted in the backward hemisphere. The $\Delta \to p_s\pi$ production rate is even higher if one takes into account the losses (~7%) due to our event selection.

In contrast to the laboratory momentum distribution of the $\Delta \to p_s\pi$ events, the laboratory angular distribution of these resonances is not well described by peripheral phase space since there is an excess of $\Delta \to p_s\pi$ events in the $\cos\theta < 0$ region. This last fact as well as the strong $\Delta \to p_s\pi$ production rate may support the idea of events produced with spectator Δ in the final state. If one assumes that all the $\Delta \to p_s\pi$ are spectator systems and that the $\bar{p}n$ and $\bar{p}\Delta$ interactions leading to the observed final states have equal cross sections, one obtains that the Δ-Δ component of the deuteron wave function is about ~16%. This high percentage when compared with theoretical calculations may suggest that other mechanisms contribute to the $\Delta \to p_s\pi$ production. In particular one can also worry about the validity of the impulse approximation for systems having a large binding energy as for the Δ-Δ case. In any case the high $\Delta \to p_s\pi$ production rate clearly establishes that an important part of our events cannot be considered as being produced with real spectator nucleons. Further theoretical and experimental investigations will certainly be necessary in order to relate more closely the Δ observed in the final state with the possible existence of the Δ-Δ component of the deuteron wave function.

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