ROLE OF MESON-MESON CORRELATION EFFECTS IN THE $\Xi N \rightarrow \rho \pi$ ANNIHILATION PROCESS

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Abstract

Meson-meson correlation effects are investigated in the $\Xi N \rightarrow \rho \pi$ annihilation process using a realistic meson-exchange model for the $\rho \pi$ interaction determined previously, together with a conventional baryon-exchange transition model and a consistent $\Xi N$ interaction. For $\Xi N$ $S$-states, they have a drastic effect and bring the relative $(^1S_0/^3S_1)$ branching ratio up to the experimental value, thus resolving the long-standing so-called “$\rho \pi$” puzzle. For $\Xi N$ $P$-states, their effect is of minor importance, and discrepancies remain for those ratios involving annihilation from the $\Xi N(^3P_J)$ state to $\rho \pi(l' = 2)$. 

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Reactions involving antinucleons (for a review see e.g. the papers by Amsler and Myhrer [1] and Dover et al. [2]) have always been considered to be the ideal place for finding quark effects since annihilation phenomena from the antinucleon-nucleon ($\bar{N}N$) system are supposed to be governed by short distance physics. However, if one tries to discriminate between different theoretical scenarios for the microscopic description of the annihilation process, it is not sufficient to look at global features like e.g. the total annihilation cross section. Rather, one should deal with specific annihilation channels and consider experimental information for annihilation from specific $\bar{N}N$ initial states. Indeed, corresponding experimental results from LEAR for two-meson annihilation (for references see [2]) are of particular interest since they provide clear evidence for the dynamical suppression of transitions which are in principle allowed by the conservation of fundamental quantum numbers. Such dynamical selection rules yield valuable information about the transition process and should impose in principle severe restrictions on the theoretical description of the annihilation mechanism, e.g. in terms of conventional baryon exchange or explicit quark-gluon exchange. Unfortunately, things are very much obscured by the presence of initial ($\bar{N}N$) and final (meson-meson) state interactions. Although it was often argued that the consideration of relative ratios should minimize these effects it turned out (see e.g. [3,4]) that there is a strong sensitivity to whether and even which kind of initial state interaction is included. The latter does not drop out even if ratios from the same partial wave are considered. The conclusion drawn in Refs. [3,4] was that a consistent description for the transition model and initial state $\bar{N}N$ interaction is required before we can seriously address the question about which transition mechanism is preferred. Here we will demonstrate that also, at least in some specific channels, meson-meson correlation effects have a considerable influence on the explanation of the experimental data.

The most prominent example for the realization of such a dynamical selection rule is the so-called “$\rho\pi$” puzzle in the $\bar{N}N \rightarrow \rho\pi$ annihilation process. Already in the sixties, $\rho\pi$ branching ratios in liquid hydrogen have been determined [5], the results being essentially the same for all charge combinations $\rho^+\pi^-, \rho^-\pi^+, \rho^0\pi^0$. The $\rho^0\pi^0$ combination, being a pure
isospin-zero state, can be produced only from the \((^3S_1, I = 0)\) protonium state whereas the charged combinations can also be generated from the \((^1S_0, I = 1)\) state. (Production from the \((^3S_1, I = 1)\) and \((^1S_0, I = 0)\) states is strictly forbidden due to \(G\)-parity conservation.) Since all \(S\)-states in protonium should be populated with about the same probability the annihilation from the \(^1S_0\) state in the \(\rho\pi\) channel is obviously strongly suppressed. In \(P\)-waves, however, such a suppression of annihilation from \(I = 1\) states cannot be seen in the recent results of the ASTERIX experiment \cite{3}.

In Table I, present empirical information about these ratios is compared with theoretical results, which we obtained recently \cite{3,4} using a model for the transition process based on baryon \((N, \Delta)\) exchange, see Fig. 1. An initial state interaction is either completely neglected (Born) or included (A(BOX) \cite{7}, D \cite{4}). Both \(\overline{NN}\) interactions use as elastic part the \(G\)-parity transformed (full) Bonn \(NN\) potential \cite{8}. In model A(BOX), annihilation has been accounted for by a simple phenomenological, energy and state independent optical potential with both real and imaginary part and three adjustable parameters. In model D \cite{4}, the annihilation part of the \(\overline{NN}\) interaction is split into two parts: Intermediate states with two mesons are described microscopically in terms of baryon-exchange processes, including all possible combinations of \(\pi, \eta, \rho, \omega, a_0, f_0, a_1, f_1, a_2, f_2, K, K^*\). Their strength has been adjusted in a consistent description of \(\overline{NN}\) scattering and annihilation to the empirical information about the annihilation into specific channels. The remaining part (three-meson channels etc.) is taken into account by a phenomenological optical potential of similar form as used in model A(BOX) \cite{7}.

The results of Table I indeed confirm that there is a considerable sensitivity to which kind of initial state interaction is used. Still, for the \(S\)-state ratio, all theoretical results quoted there are so far off the experimental values that one is tempted to conclude that the baryon exchange transition model cannot be appropriate to account for the empirical situation. There are numerous calculations based on alternative transition models in the literature \cite{9–12}; some of them do give at least a better description of the \(^1S_0/3S_1\) ratio. For example, the model of Maruyama et al. \cite{9} using the A2 mechanism (two \(\overline{q}q\) pair annihilations followed
by one $\eta q$ pair creation in a planar topology) and the $^3 P_0$ vertex, achieves a value of 1:10-18. Thus it appears that this quark model might be superior in comparison to conventional baryon-exchange, at least in this sector. However, this conclusion is definitely premature, for the following reason: So far, correlation effects in the outgoing meson-meson channel have been neglected completely; their inclusion in the description of the transition process might well lead to different theoretical values in Table II.

In this paper, we want to investigate the role of the final state interaction in the $NN \rightarrow \rho\pi$ transition process; especially we want to see whether its inclusion will bring the theoretical baryon-exchange model results in better agreement with the empirical situation.

Unfortunately, not much is known empirically about the interaction between a pion and a rho-meson since due to the short lifetime of the $\rho$-meson no $\rho\pi$ scattering data exists. Therefore, one has essentially to rely on a dynamical model. Recently we have constructed such a $\rho\pi \rightarrow \rho\pi$ amplitude [13] based on both s- and t-channel meson exchange diagrams, see Fig. 2, acting as driving terms in a scattering equation. Parameters (coupling constants and cutoff masses in formfactors) have been partly taken from other investigations, partly adjusted to empirical information about $a_1, \omega \rightarrow \rho\pi$ decay. The model has been successfully tested in the $NN$ system [14]: By using it as the basic ingredient in the correlated $\rho\pi$ exchange piece of the $NN$ interaction, it was possible to obtain sufficient $NN$ tensor force despite of having a soft $\pi NN$ formfactor demanded by numerous independent information.

The $\rho\pi$ interaction (with all parameters prefixed) is now considered in our calculation in two ways: First we include it in a DWBA-type approach in the final state only, cp. Fig. 2(a,b). In a second step, we perform a $NN, \rho\pi$ coupled channels calculation; in this way, it is also included in the initial state, see Fig. 2(c). The $NN$ interaction consists of course of an elastic and an annihilation part. In order to avoid double counting the effects of the $\rho\pi$ channel have to be removed from the $NN$ annihilation part in the coupled channels calculation. Since this can only be done in a well defined way for the consistent microscopic annihilation model D, only this model is used in the following.

We start by demonstrating the effect of the $\rho\pi$ interaction on the $\bar{p}p \rightarrow \rho\pi$ cross sections
in flight. The inclusion of the meson-meson interaction leads to a noticeable increase as demonstrated in Fig. 4. On the other hand the new results still lie in the experimental region, so a readjustment of formfactor parameters in the baryon exchange transition was not required. In the coupled channel approach, the inclusion of the $\rho\pi$ interaction modifies also the initial $\bar{NN}$ interaction, cp. Fig. 3(c). Fortunately, the resulting $\bar{NN} \rightarrow \bar{NN}$ observables are barely changed since the $\bar{NN} \rightarrow \rho\pi$ transition is anyhow a small contribution to the total annihilation. Thus a readjustment of parameters in this sector is likewise not necessary.

Table II contains the resulting branching ratios at rest, for the $\rho^+\pi^- + \rho^-\pi^+$ and $\rho^0\pi^0$ annihilation channels. As expected already from Fig. 4, the consideration of the $\rho\pi$ interaction increases both branching ratios. Its inclusion in both the initial and final state (CC) leads to a result in good agreement with experiment [15].

Let us now look again at the relative branching ratios from specific $\bar{NN}$ partial wave states (cp. Table III). The inclusion of the meson-meson interaction changes the $^1S_0/^3S_1$ ratio (corresponding to $\pi/\omega$ quantum numbers respectively) drastically: The change is so large that, in a DWBA calculation, the result nearly coincides with the empirical value; the full coupled channel calculation (which includes the $\rho\pi$ interaction also in the $\bar{NN}$ annihilation potential, cp. Fig. 3(c)) leads to a somewhat smaller ratio well within the experimental error bars. On the other hand, the modification of the $P$-state ratios is quite small. While the $^1P_1/^3P_1(l' = 0)$ ratio is in agreement with experiment, annihilation from the $\bar{NN}(^3P)$ state into the $\rho\pi$ system with relative orbital angular momentum $l' = 2$ provides the largest contribution of all $P$-states, in sharp contrast to experiment where annihilation from this state appears to be negligible.

In this context the question arises whether the introduction of the $\rho\pi$ interaction in the $\bar{NN}$ $P$-states keeps not only the ratios essentially the same but also the absolute values. This is indeed the case: The change of the absolute $P$-state values is likewise of the order of $10 - 20\%$ only, as for the ratios.

As shown in Table IV the $\rho\pi$ interaction reduces the $^1S_0$ contribution strongly while it increases the $^3S_1$ contribution leading to the extremely small ratio of Table III, in agreement
with experiment. Note that this drastically different role of the $\rho\pi$ interaction in the $^1S_0$ versus $^3S_1$ state does not imply a comparably strong state dependence of this interaction. (In fact, the difference between the $\rho\pi$ interactions in these partial waves is quite small). If, for example, we artificially use exactly the same $\rho\pi$ interaction, which enters the $\bar{p}p$ $^1S_0$ state, in both $^1S_0$ and $^3S_1$, we obtain qualitatively the same results as before. This fact demonstrates once more that correlation effects do not drop out even when relative ratios from the same partial wave are considered.

In summary, the inclusion of the interaction between a pion and a rho in the $\overline{NN} \rightarrow \rho\pi$ annihilation process provides drastic changes in the relative branching ratios. For $S$-states, it brings the result in agreement with experiment and is thus a promising candidate to resolve the long-standing “$\rho\pi$ puzzle”. Our model agrees with the experimental information also in case of the $^1P_1/^3P_1(l' = 0)$ ratio, but it is in contrast to the present empirical values for ratios involving annihilations from the $^3P$ states into $\rho\pi$ with $l' = 2$. Whether an extension of our $\rho\pi$ interaction model (e.g. by adding a suitable pole term in the relevant partial wave or considering the coupling to additional channels, for example $\overline{K}K^* \pm \overline{K}^*K$), or improved data can solve this problem remains to be seen. In any case and in more general terms, meson-meson correlation effects have to be included and treated in a consistent way before one can seriously address the question about the relevant transition mechanism in $\overline{NN}$ annihilation.

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TABLES

TABLE I. Ratios of branching ratios “at rest” for the annihilation $\bar{p}p \to \rho^\pm \pi^\mp$. The experimental values are calculated from data given in Ref. [6]. The theoretical results are obtained as relative cross sections at $p_{lab} = 100 MeV/c$. The theoretical values are based on a transition model pictorially described in Fig. 1, i.e. without final state interaction. The initial state interaction is either neglected, too (Born) or taken from model A(BOX) [7] and D [4].

| $\bar{p}p$ | Born | A(BOX) | D | Exp. |
|------------|------|--------|---|------|
| $(^{1}S_{0}, I = 1)$ | : | 1 | 1 | 1 |
| $(^{3}S_{1}, I = 0)$ | | 3.45 | 2.29 | 4.67 | 35±16 |
| $(^{1}P_{1}, I = 0)$ | : | 1 | 1 | 1 |
| $(^{3}P_{1,2}, I = 1)$ | | 5.28 | 9.10 | 2.95 | 0.84±0.22 |

TABLE II. Branching ratios “at rest” for annihilation into $\rho\pi$. The data are taken from Ref. [15]. The theoretical results are obtained as relative cross sections at $p_{lab} = 100 MeV/c$. The first column denotes the results based on the transition model without final state interaction (Fig. 1) using model D [4] as initial state interaction. In the second (third) column, the meson-meson interaction is included in a DWBA calculation (as final state interaction) or in a full $NN, \rho\pi$ coupled-channel (CC) calculation.

| $\bar{p}p \to$ | no FSI | DWBA | CC | EXP. |
|----------------|--------|------|----|------|
| $\rho^+ \pi^- + \rho^- \pi^+$ | 2.32 | 2.50 | 2.73 | 3.4 ± 0.2 |
| $\rho^0 \pi^0$ | 0.85 | 1.08 | 1.19 | 1.4 ± 0.1 |
TABLE III. Ratios of branching ratios “at rest” for the annihilation $p\bar{p} \rightarrow \rho^{\mp}\pi^\mp$. The experimental values are calculated from data given in Ref. [6]. The theoretical results are obtained as relative cross sections at $p_{lab} = 100 MeV/c$. The first column denotes the results based on the transition model without final state interaction (Fig.[1]) using model D [4] as initial state interaction. In the second (third) column, the meson-meson interaction is included in a DWBA calculation as final state interaction or in a full $NN,\rho\pi$ coupled-channels (CC) calculation. $l'$ denotes the orbital angular momentum of the $\rho\pi$ system.

|       | no FSI | DWBA | CC   | Exp. |
|-------|--------|------|------|------|
| $p\bar{p}(^1S_0, I = 1)$ | 1      | 1    | 1    | 1    |
| $p\bar{p}(^3S_1, I = 0)$ | 4.67   | 32.4 | 23.9 | 35±16 |
| $p\bar{p}(^1P_1, I = 0)$ | 1      | 1    | 1    | 1    |
| $p\bar{p}(^3P_{1.2}, I = 1)$ | 2.95   | 3.02 | 2.95 | 0.84±0.22 |
| $p\bar{p}(^1P_1, I = 0)$ | 1      | 1    | 1    | 1    |
| $p\bar{p}(^3P_1) \rightarrow l' = 0$ | 0.54   | 0.68 | 0.64 | 0.8±0.2 |
| $p\bar{p}(^1P_1, I = 0)$ | 1      | 1    | 1    | 1    |
| $p\bar{p}(^3P_{1.2}) \rightarrow l' = 2$ | 2.41   | 2.34 | 2.31 | 0.04±0.015 |
| $(^3P_1 + ^3P_2)$ | (0.36+2.05) | (0.20+2.14) | (0.20+2.11) |

TABLE IV. Partial cross sections in $[\mu b]$ at $p_{lab} = 100 MeV/c$ for the annihilation $p\bar{p} \rightarrow \rho^{\pm}\pi^\mp$ from $NN$ S-states. The first column denotes the results based on the transition model without final state interaction (Fig.[1]) using model D [4] as initial state interaction. In the second (third) column, the meson-meson interaction is included in a DWBA calculation as final state interaction or in a full $NN,\rho\pi$ coupled-channels (CC) calculation.

|       | no FSI | DWBA | CC   |
|-------|--------|------|------|
| $p\bar{p}(^1S_0, I = 1)$ | 0.727  | 0.137| 0.203|
| $p\bar{p}(^3S_1, I = 0)$ | 3.396  | 4.423| 4.854|
FIGURES

FIG. 1. $\bar{N}N \rightarrow \rho\pi$ transition model without final state interaction as used in [3,4].

FIG. 2. Driving terms used to construct our $\rho\pi \rightarrow \rho\pi$ amplitude.

FIG. 3. $\bar{N}N \rightarrow \rho\pi$ transition model of the present paper including the $\rho\pi$ interaction (a). In the DWBA-type approach based on the $\bar{N}N$ interaction model D [4], processes (b) are included whereas (c) is not. In an alternative full coupled channels (CC) calculation, the latter is also taken into account.

FIG. 4. $\bar{N}N \rightarrow \rho\pi$ cross sections in flight. The data are taken from [16]. For the dash-dotted (dashed) curve, the $\rho\pi$ interaction is neglected (included) and the initial state $\bar{N}N$ interaction model is taken to be model D [4]. The $\bar{N}N, \rho\pi$ coupled channels approach including the $\rho\pi$ interaction yields the solid line.
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http://arxiv.org/ps/nucl-th/9412007v1
This figure "fig1-2.png" is available in "png" format from:

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Figure 1

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Figure 2
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Figure 4