QUARK VERSUS HADRON DEGREES OF FREEDOM IN ANTIPROTON–PROTON ANNIHILATION*

E. Klempt

Institut für Strahlen- und Kernphysik der Universität Bonn
Nußallee 14–16 D-53115 Bonn, Germany
e-mail: klempt@iskp.uni-bonn.de

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Data on antiproton-proton annihilation at rest into two mesons are presented with special emphasis on the importance of dynamical selection rules. These selection rules reduce the frequency of some annihilation rates for otherwise allowed annihilation modes by one order of magnitude. It is shown that SU(3) breaking cannot be held responsible for such large effects. This fact motivates an analysis of $\bar{p}p$ branching ratios by SU(3) amplitudes. Different SU(3) coupling schemes and their interpretation are presented. A coupling scheme tracing the quark flux from the initial to the final state gives the best interpretation of the data and of the dynamical selection rules.

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1. Introduction

It is well known that at large distances or low momentum transfers nuclear interactions are well described by the exchange of baryons and mesons as fundamental particles. On the other hand, the most visible features of strong interaction processes at large momentum transfers are quark-quark interactions. Obviously, there should be a transition region in which the dynamics of baryons and mesons can be understood in terms of the underlying quark dynamics. This paper claims to demonstrate that $\bar{p}p$ annihilation at rest into two mesons provides direct evidence for quark dynamics at rather low momentum transfers.

There are a number of reasons why $\bar{p}p$ annihilation is an ideal field to investigate the dynamical role of constituent quarks:

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- Antiproton–proton annihilation is a rich source of mesons allowing systematic studies and comparisons of different branching ratios
- Dynamical selection rules are observed in p̄p annihilation which reduce otherwise allowed annihilation modes with no known reason
- Quarks were originally postulated using symmetry arguments in the energy regime of p̄p annihilation, hence it is natural to investigate the role of SU(3) in p̄p annihilation
- Models of p̄p annihilation based on meson- and baryon-dynamic exist and predict huge symmetry breaking effects. These models can therefore be faced with results derived from symmetry arguments

It is important to notice that p̄p annihilation can be dicussed in rather different languages. Quark models describe annihilation in terms of planar and non-planar diagrams (often called annihilation and rearrangement diagrams). On the other hand, p̄p annihilation may prefer to proceed via a few s-channel resonances (*e.g.*by mixing between p̄p system and $\bar{q}\bar{q}qq$ states having the same mass). In this case, a description in terms of s-channel amplitudes may be more appropiate. Or, finally, baryons and mesons might be the relevant degrees of freedom, and p̄p annihilation is most efficiently described by baryon exchange amplitudes. Fig. 1 visualises the different approaches.

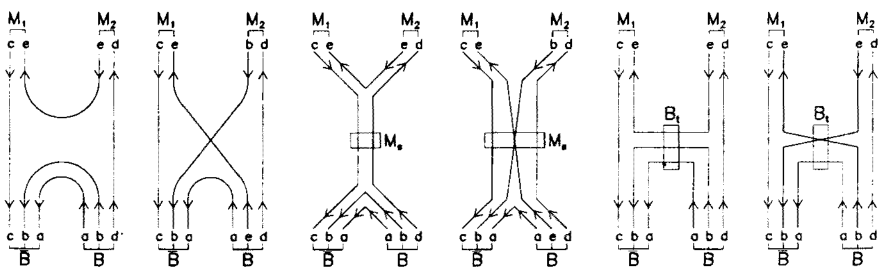

Fig. 1. Annihilation of protons and antiprotons in different coupling schemes. From left to right: the quark line coupling, s-channel coupling and baryon exchange coupling schemes.

2. Branching ratios for p̄p annihilation into two mesons

The empirical study of symmetries in p̄p annihilation into two mesons is made possible by the large number of two-body branching ratios now known with rather good precision (with errors of $\sim 10\%$). Most of the data points, in particular those with two neutral mesons [1–5] come from the

Crystal Barrel experiment [6]. All relevant branching ratios for annihilation into two pseudoscalar mesons and into one pseudoscalar and a vector meson are known; this is a decisive advantage allowing SU(3) fits to annihilation into two mesons from defined p̄p initial states to two mesons belonging to defined meson nonets. From these data the pseudoscalar mixing angle can be determined; this had been discussed at the Conference on Meson-Nucleus Interactions here in Cracow three years ago [7]. Annihilation at rest into two vector mesons is not considered here since there is no information on spin and isospin decomposition of p̄p annihilation into K*K*.

TABLE I

Branching ratios for p̄p annihilation at rest into two pseudoscalar and into one pseudoscalar and one vector meson

Initial state			Branching ratio
$\bar{p}p(^{13}P_{0,2})$	$\to$	$\pi^0\pi^0$	$(6.93 \pm 0.43)\cdot 10^{-4}$
$\bar{p}p(^{33}P_{0,2})$	$\to$	$\pi^0\eta$	$(2.12 \pm 0.12)\cdot 10^{-4}$
$\bar{p}p(^{33}P_{0,2})$	$\to$	$\pi^0\eta'$	$(1.23 \pm 0.13)\cdot 10^{-4}$
$\bar{p}p(^{13}P_{0,2})$	$\to$	$\eta\eta$	$(1.64 \pm 0.10)\cdot 10^{-4}$
$\bar{p}p(^{13}P_{0,2})$	$\to$	$\eta\eta'$	$(2.16 \pm 0.25)\cdot 10^{-4}$
$\bar{p}p(^{3}P_{0,2})$	$\to$	K^+K^-	$(0.83 \pm 0.05)\cdot 10^{-4}$
$\bar{p}p(^{3}P_{0,2})$	$\to$	$K^0\overline{K^0}$	$(0.26 \pm 0.10)\cdot 10^{-4}$
$\bar{p}p(^{33}S_1)$	$\to$	$\pi^+\pi^-$	$(3.07 \pm 0.13)\cdot 10^{-3}$
$\bar{p}p(^{3}S_1)$	$\to$	K^+K^-	$(0.99 \pm 0.05)\cdot 10^{-3}$
$\bar{p}p(^{3}S_1)$	$\to$	$K^0\overline{K^0}$	$(0.90 \pm 0.06)\cdot 10^{-3}$
$\bar{p}p(^{13}S_1)$	$\to$	$\pi^0\varrho^0$	$(1.65 \pm 0.08)\cdot 10^{-2}$
$\bar{p}p(^{13}S_1)$	$\to$	$\eta\omega$	$(1.51 \pm 0.12)\cdot 10^{-2}$
$\bar{p}p(^{33}S_1)$	$\to$	$\eta'\omega$	$(0.78 \pm 0.08)\cdot 10^{-2}$
$\bar{p}p(^{33}S_1)$	$\to$	$\pi^0\omega$	$(5.73 \pm 0.47)\cdot 10^{-3}$
$\bar{p}p(^{33}S_1)$	$\to$	$\eta\varrho^0$	$(4.60 \pm 0.50)\cdot 10^{-3}$
$\bar{p}p(^{33}S_1)$	$\to$	$\eta'\varrho^0$	$(1.81 \pm 0.44)\cdot 10^{-3}$
$\bar{p}p(^{33}S_1)$	$\to$	$\pi^0\Phi$	$(0.55 \pm 0.07)\cdot 10^{-3}$
$\bar{p}p(^{13}S_1)$	$\to$	$\eta\Phi$	$(0.66 \pm 0.16)\cdot 10^{-4}$
$\bar{p}p(^{33}S_1)$	$\to$	$K^*\overline{K}$+cc	$(2.46 \pm 0.24)\cdot 10^{-3}$
$\bar{p}p(^{13}S_1)$	$\to$	$K^*\overline{K}$+cc	$(0.08 \pm 0.04)\cdot 10^{-3}$
$\bar{p}p(^{31}S_0)$	$\to$	$\varrho^\pm\pi^\mp$	$(0.92 \pm 0.40)\cdot 10^{-3}$
$\bar{p}p(^{31}S_0)$	$\to$	$K^*\overline{K}$+cc	$(0.20 \pm 0.04)\cdot 10^{-3}$
$\bar{p}p(^{11}S_0)$	$\to$	$K^*\overline{K}$+cc	$(0.86 \pm 0.17)\cdot 10^{-3}$

Table I collects our present knowledge on $\bar{p}p$ annihilation at rest into two pseudoscalar mesons and into one pseudoscalar and a vector meson. There are several *dynamical selection rules* in the data [8, 9]; suppression of annihilation modes with *no reason*. The suppression of "weak" rates compared to "strong" rates is in the order of a factor 10 or larger (after dividing out the spin multiplicity of the initial state and accounting for the P/S ratio of annihilation in liquid H_2). The selection rules are summarised in Table II. Included is the selection rule for $\bar{p}p \rightarrow a_2(1320)\pi$. Data on this reaction are summarised in [10].

Selection rules evidence the existence of an underlying symmetry, SU(3) is certainly the most obvious choice. The selection rules are very similar for annihilation into $\overline{K}K$ and into $K^*\overline{K}$, and for annihilation into $\pi\pi$, $\pi\rho$ or into $\pi a_2(1320)$. This fact constitues further evidence that the symmetry must be SU(3).

TABLE II

Summary of the most important *dynamical selection rules.* Strong and weak branching ratios differ by about one order of magnitude.

	Strong	Weak	Strong	Weak
$^{13}S_1$	$\rho\pi$			$K^*\overline{K}$, $\overline{K}K$
$^{33}S_1$		$a_2(1320)\pi$	$K^*\overline{K}$, $\overline{K}K$	
$^{11}S_0$	$a_2(1320)\pi$		$K^*\overline{K}$	
$^{31}S_0$		$\rho\pi$		$K^*\overline{K}$
$^{33}P_{0,2}$	$\pi\pi$			
$^{33}S_1$		$\pi\pi$		

3. SU(3) on besiege

The use of SU(3) symmetry has met with little enthusiasm; most theoreticians working in the field are convinced that SU(3) is heavily broken at these energies and that symmetry arguments are of little help in understanding annihilation dynamics. There are three main arguments raïsed against the use of SU(3) in the context of $\bar{p}p$ annihilation:

- Suppression of $s\bar{s}$ pair creation
- Initial state interactions
- Final state interactions

Furthermore, theoretical models often contradict the results obtained by SU(3) fits to data; this fact is considered as support of these critical points. Further arguments arise from practical considerations: SU(3) fits use real amplitudes; why shouldn't they be complex? There is a large number of amplitudes; how can they be disentangled?

In the following we show that SU(3) breaking effects cannot be the dynamical reason for the observed *dynamical selection rules.* This does not mean that these effects are unimportant; but they should change branching ratios by typically 20%, but not by a factor 10.

3.1. Suppression of $s\bar{s}$ pair creation

The branching ratios for annihilation into two strange mesons are smaller by typically one order of magnitude than the corresponding ratios for annihilation into non-strange mesons. We give an example:

$$\frac{3}{4} \cdot \frac{\bar{\mathrm{p}}\mathrm{p}(^3S_1)\to \mathrm{K}^*\mathrm{K}}{\bar{\mathrm{p}}\mathrm{p}(^3S_1)\to \rho\pi} = 0.10\,. \qquad (1)$$

There are two possible interpretations of this effect:

- Rearrangement diagrams could contribute significantly to $\bar{\mathrm{p}}\mathrm{p}$ annihilation.
- Production of $\mathrm{s}\bar{\mathrm{s}}$ pairs is suppressed by $\lambda\sim 0.15$.

The latter view is supported by fragmentation data finding $\lambda \sim 0.23$, and by the flux tube model [11]. It is important to note that the experimental value for λ is derived from inclusive data. SU(3) relates only amplitudes in which one $\bar{\mathrm{q}}\mathrm{q}$ pair is replaced by a $\mathrm{s}\bar{\mathrm{s}}$ pair with no further modifications of the process. In inclusive data this is, however, not under control. Hence it is more appropiate to determine λ from exclusive data, *e.g.*from meson decays. The MarkIII Collaboration studied J/ψ decays into a vector and a pseudoscalar meson in order to find "inert" or gluonic components in the η and η' wave functions. The result was negative. One of the (rather numerous) parameters was the suppression of $\mathrm{s}\bar{\mathrm{s}}$ pair creation compared to the creation of $\mathrm{u}\bar{\mathrm{u}}$ or $\mathrm{d}\bar{\mathrm{d}}$ pairs. From their fit a value $\lambda = 0.8$ was deduced [12]. Peters and Klempt fitted 16 decay modes of tensor mesons with SU(3) amplitudes allowing for $\mathrm{s}\bar{\mathrm{s}}$ suppression. They found $\lambda = 0.8 \pm 0.2$ [13].

Richard looked for strangeness suppression in J/ψ decays into baryons, into $\bar{\mathrm{p}}\mathrm{p}$, $\bar{\mathrm{n}}\mathrm{n}$, $\bar{\Lambda}\Lambda$, $\bar{\Sigma}\Sigma$, $\bar{\Xi}\Xi$, $\bar{\Delta}\Delta$ and $\bar{\Sigma}^*\Sigma^*$ [14]. After correcting for phase space (*i.e.*after division by the respective decay momenta) the squared invariant couplings are similar in size, but scale with 0.8^{n_s} where n_s is the number of $\mathrm{s}\bar{\mathrm{s}}$ pairs created. The creation of a second $\mathrm{s}\bar{\mathrm{s}}$ pair in $\bar{\Xi}\Xi$ is certainly a non-perturbative process but still governed by $\lambda\sim 0.8$! We conclude that there is no evidence for $\lambda\sim 0.15$ from exclusive data. But nearly all existing quark models impose or require dominance of planar diagrams and, therefore, $\lambda \sim 0.15$. Those models miss an important aspect of annihilation dynamics: *Nonplanar diagrams are important in $\bar{p}p$ annihilation.*

TABLE III

Selected J/ψ decays probing SU(3) symmetry. Data are taken from PDG. The frequencies are normalised to one charge state.

Channel	BR (10^{-3})	BR/$p^{2\ell+1}$
$\bar{p}p$	2.14±0.10	1.7
$\bar{n}n$	1.9 ±0.5	1.5
$\bar{\Lambda}\Lambda$	1.35±0.14	1.3
$\bar{\Sigma}\Sigma$	1.27±0.17	1.3
$\bar{\Xi}\Xi$	0.9 ±0.2	1.1
$\bar{\Delta}\Delta$	1.10±0.29	1.2
$\bar{\Sigma}^*\Sigma^*$	0.52±0.07	0.8

3.2. Initial state interactions

The pure antiproton-proton system is given by:

$$|\bar{p}p> = \{\frac{1}{\sqrt{2}}|I=0> + \frac{1}{\sqrt{2}}|I=1>\}\,. \quad (2)$$

In the presence of a charge exchange potential, $\bar{p}p$ and $\bar{n}n$ mix

$$\mathcal{H} = \begin{pmatrix} E_p + V_{\text{coulomb}} + V_{\text{strong}} & V_{\text{pn}} \\ V_{\text{np}} & E_{\text{n}} + V_{\text{strong}}\,. \end{pmatrix}$$

Strong interaction may thus lead to a change of the isospin decomposition:

$$|\bar{p}p> = \{a|I=0> + b|I=1>\}\;; \qquad a^2 + b^2 = 1\,. \quad (3)$$

The long-distance $\text{N}\bar{\text{N}}$ interactions interfere with the electromagetic interaction; one isospin component is thus attracted more strongly into the annihilation region, and an overall enhancement of one isospin component can result. Calculations find this effect [15] and the systematics of branching ratios supports the calculations [10] (at the 1σ level). For S-state annihilation it is of the order of 20%, certainly not sufficient to account for the dynamical selection rules.

There is one further argument against the possibility that initial state interactions are responsible for the dynamical selection rules: Annihilation of the $^3S_1$ state into $\rho\pi$ is very strong; hence the isoscalar part of the $^3S_1$ wave function must be large (in line with the observation that the rate for $\eta\omega$ is four times larger than that for $\eta\rho$). On the other hand, annihilation into K*K mostly proceeds via the isovector part of the $^3S_1$ p̄p wave function while there is practically no contribution from the isoscalar part. Hence the isoscalar part must be much smaller than the isovector part. But the isoscalar part cannot be both, large and small.

There is a possible escape: The coefficients a and b could be functions of the p̄p distances. Different annihilation modes could have different spatial distributions. In particular annihilation into $K^*\overline{K}$ could take place at distances with a large I=1 component, $\rho\pi$ at distances with large I=0 component of the p̄p atomic wave function. If this effect should be responsible for the dynamical selection rules, it would need to show a very strange behaviour since the momenta for these two processes differ only slightly.

It should be stressed that calculations of this effect require an extrapolation of meson-exchange picture to distances in which annihilation occurs.

3.3. Final state interactions

The meaning of final state interactions is not uniquely defined. Two-meson final states with attractive meson-meson interactions could be favoured; and the branching ratio for annihilation into attractive meson-meson system would be larger than those for annihilation into repulsive meson-meson systems. However, there is no evidence for this effect in tensor meson decays at the 20% level. In particular, the $a_2(1320)$ and the $f_2(1270)$ decays into $\overline{K}K$ are compatible with SU(3), and no isospin selection rule is observed. It seems unlikely that this type of final-state interactions could be responsible for the dynamical selection rules in p̄p annihilation.

A second effect (mostly referred to as rescattering) leads to final states which are not produced primarily. The best known example is $\Phi\pi$ production:

$$\bar{p}p(^3S_1) \to K^*K = 2.4 \cdot 10^{-3}$$
$$\bar{p}p(^3S_1) \to \Phi\pi = 0.55 \cdot 10^{-3}\,.$$

In calculations only half of the observed $\Phi\pi$ rate is assigned to K*K rescattering [16, 17]; hence the rescattering contribution is estimated to $\sim$ 10% of the K*K rate. A second example is $\rho\rho$ production:

$$\bar{p}p(^1S_0) \to \rho\rho \sim 0.4 \cdot 10^{-2}$$
$$\bar{p}p(^1S_0) \to \pi a_2(1320) = 2.9 \cdot 10^{-2}\,.$$

Again, the rescattering contribution is of the order of $\sim$ 10% (or less since there should be also direct $\rho\rho$ production. Rescattering could be important for very small branching ratios (which could be zero without rescattering). In both processes isospin is conserved in rescattering. Rescattering is not an appropiate mechanism to enhance isoscalar and to suppress isosvector interactions and hence not an appropiate explanation of the isospin selection rules.

4. Annihilation dynamics and SU(3)

The existence of *dynamical selection rules* requires the presence of an underlying symmetry, of SU(3) [18]. But in a complex situation, SU(3) is not unique; SU(3) relations between different decay channels can be expressed in different coupling scheme; the relations between these schemes are fully described in [19]. Here we discuss:

- the Quark Coupling Scheme
- the S-Channel Coupling Scheme
- the T-U-Channel Coupling Scheme

The question arises if one of the schemes is best suited to describe annihilation dynamics, to incorporate the *dynamical selection rules* ? In the following we discuss the three coupling schemes. The fits are fully described in a thesis at Mainz using also some unpublished branching ratios on $\bar{p}d$ annihilation [20]. First we notice that all three coupling schemes allow to fit the data with identical χ^2:

$$\begin{array}{lll} \text{PS+PS:} & \chi^2 = 1.01, & N_F = 5 \\ \text{PS+V :} & \chi^2 = 0.42, & N_F = 3 \ . \end{array}$$

Even worse, they are several solutions in all three schemes giving the same χ^2. Hence little can be learned from these fits except that the various branching ratios are compatible with each other.

The question is if one of the coupling schemes provides a natural "explanation" of the dynamical selection rules. The concept is analogue to the situation of an atom in a magnetic field: you may use the strong-field or weak-field approximation to describe the atomic wave function. In both cases you find perfect agreement between data and calculated energies. But choosing wave function adopted to the particular situation leads to a more rapid convergence. We thus hope that the number of amplitudes can be reduced in one coupling scheme; we believe this coupling to be closer to an understanding of annihilation dynamics.

4.1. The quark coupling scheme

Fig. 2 shows the decomposition of the quark coupling scheme. There are 8 amplitudes which we denote as

$$A_1^+ , A_2^+ , R_1^+ , R_2^+ , R_3^+ , A_1^- , A_2^- , R_1^-$$

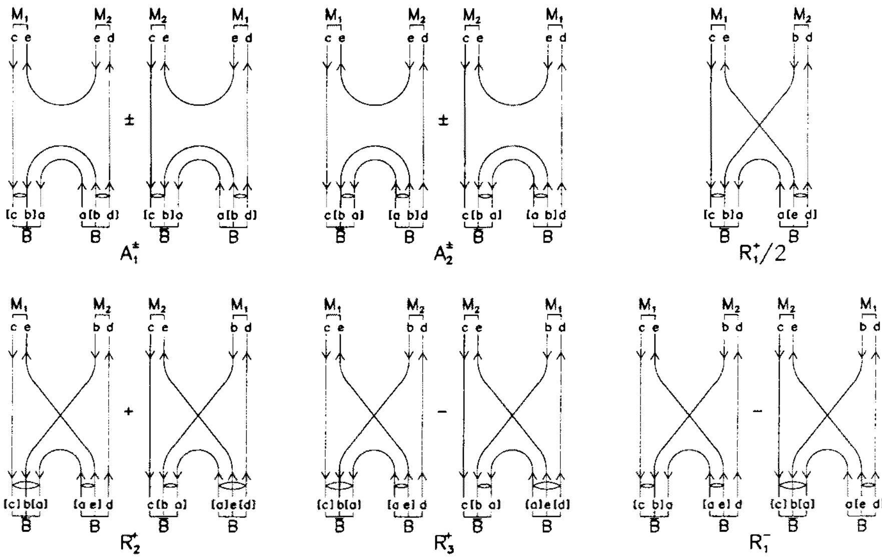

Fig. 2. Explicite representation of quark-line amplitudes of all independent couplings in the quark-line scheme.

The scheme permits a reduction of the number of free parameters to 3 parameters only. These are $A_1^\pm, A_2^\pm, R_1^+$ (5.parameters with the constraint $A_1^\pm + A_2^\pm = 0$). The χ^2 is still acceptable.

$$\begin{array}{ll} \text{PS+PS:} & \chi^2 = 5.6, \quad \text{N}_F = 9 \\ \text{PS+V :} & \chi^2 = 3.8, \quad \text{N}_F = 5 \end{array}$$

The dynamical selection rules are directly related to the properties of these amplitudes: $A_1^\pm + A_2^\pm = 0$ is associated with the selection rules in strange meson production, and $R_1^- \ll R_1^+$ is related to the $\rho\pi$ puzzle, the $a_2(1320)$ production anomaly and to the small $\pi\pi$ rate in $\bar{\text{p}}\text{p}$ annihilation from the $^3S_1$ initial state.

4.2. The S-channel coupling scheme

Fig. 3 shows the decomposition of the s-channel coupling scheme. Again, there are 8 amplitudes which we denote as

$$s_1, s_{8_{ss}}, s_{8_{sa}}, s_{8_{as}}, s_{8_{aa}}, s_{10}, s_{\bar{1}0}, s_{27}.$$

The coupling scheme classifies the SU(3) structure of the intermediate state in the s-channel. The couplings to an octet intermediate ($\bar{q}q$ or $\bar{q}\bar{q}qq$) state can be symmetric or antisymmetric; this flexibility leads to four amplitudes. The intermediate state could also be flavour singlet, decuplet, $\{\bar{1}0\}$ or q $\{27\}$-plet. It might be natural to assume that decuplet, $\{\bar{1}0\}$ and $\{27\}$-plet do not contribute to the annihilation process. Indeed, the data are compatible with this assumption. The number of free parameters is thus reduced to 5 without excessive increase of χ^2.

$$\begin{array}{lll} \text{PS+PS:} & \chi^2 = 2.4, & \text{N}_F = 7 \\ \text{PS+V :} & \chi^2 = 17, & \text{N}_F = 6 \end{array}$$

There is, however, no obvious relation between the dynamical selection rules and the s-channel amplitudes.

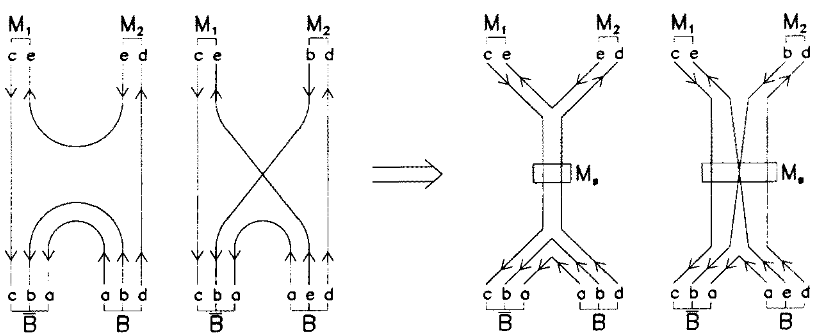

Fig. 3. Schematic connection between couplings in the quark and the s-channel scheme.

4.3. *The T-U-channel coupling scheme*

Fig. 4. shows the decomposition of the t–u–channel coupling scheme. The 8 amplitudes are now given by

$$B_1, B_{8_{ss}}, B_{8_{sa}}, B_{8_{as}}, B_{8_{aa}}, B_{10}, B_{\bar{1}0}, B_{27}.$$

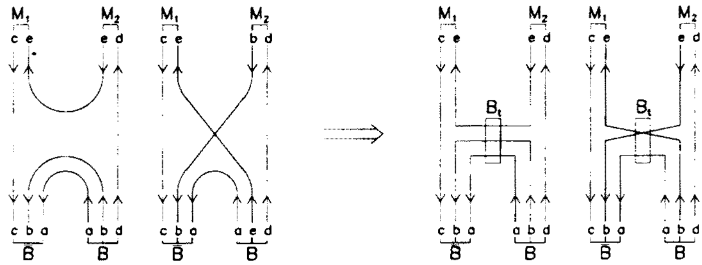

Fig. 4. Schematic connection between couplings in the quark and the baryon-exchange scheme.

In the baryon-exchange picture exchange contributions due to $\{\overline{10}\}$ and $\{27\}$-plet exchanges should be small; further the four N-N-PS and N-N-V couplings (with different symmetry ss, as, sa, ss) should be related by one F/D ratio. Hence we expect that the number of parameters can be reduced to four: B_1, B_8, B_{10} and F/D. This fit gives no reasonable solution:

$$\begin{array}{lll} \text{PS+PS:} & \chi^2 = 123, & N_F = 9 \\ \text{PS+V :} & \chi^2 = 68, & N_F = 6\,. \end{array}$$

The F/D ratios found in the fit are also incompatible with information from other sources.

5. Conclusions

The Crystal Barrel Collaboration has provided new and precise data on p̄p annihilation into two mesons. The data show clear evidence for the existence of *dynamical selection rules* in p̄p annihilation. The selection rules make the influence of SU(3) in p̄p annihilation appearant. Contrary to the wideheld belief we have seen that there is no evidence for strong SU(3) violation at momentum transfers relevant in p̄p annihilation.

SU(3) symmetry can be exploited in three different coupling schemes, the quark coupling scheme, the s-channel coupling scheme and the t-u-channel coupling scheme. All coupling schemes can be used to describe p̄p annihilation data into two pseudoscalar or one pseudoscalar and one vector meson. However, the quark coupling scheme gives a most natural interpretation of the observed *dynamical selection rules.* These correspond to symmetry relations between quark-line amplitudes which warrant an interpretation.

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REFERENCES

[1] C. Amsler *et al.*, *Phys. Lett.* **B294**, 451 (1992).
[2] C. Amsler *et al.*, *Phys. Lett.* **B297**, 214 (1992).
[3] C. Amsler *et al.*, *Z. Phys.* **C58**, 175 (1993).
[4] C. Amsler *et al.*, *Phys. Lett.* **B311**, 371 (1993).
[5] C. Amsler *et al.*, *Phys. Lett.* **B319**, 373 (1993).
[6] E. Aker *et al.*, *Nucl. Instr. Meth.* **A321**, 69 (1992).
[7] E. Klempt, *Acta Phys. Pol.* **B24**, 1813 (1993).
[8] C. B. Dover, T. Gutsche, M. Maruyama, A. Faessler, *Prog. Part. Nucl. Phys.* **29**, 87 (1992).
[9] E. Klempt, *Phys. Lett.* **B308**, 174 (1993).
[10] E. Klempt, *Phys. Lett.* **B244**, 122 (1990).
[11] H.G. Dosch, D. Gromes, *Phys. Rev.* **D33**, 1378 (1986).
[12] D. Coffmann *et al.*(MarkIII Collaboration), *Phys. Rev.* **D38**, 2695 (1988).
[13] K. Peters, E. Klempt, *Phys. Lett.* **B352**, 467 (1995).
[14] J.M. Richard, private communication.
[15] J. Carbonell, G. Ihle, J. M. Richard, *Z. Phys.* **A334**, 329 (1989); J.M. Richard, C. Dover, J. Carbonell, *Phys. Rev.* **C44**, 1281 (1991).
[16] M.P. Locher *et al.*, *Z. Phys.* **A351**, 83 (1995).
[17] A.V. Anisovitch, E. Klempt, *Z. Phys.* **A354**, 197 (1996).
[18] E. Klempt, *Phys. Lett.* **B308**, 179 (1993).
[19] E. Klempt, J.G. Körner, F. Walter, *Z. Phys.* **A354**, 67 (1996).
[20] F. Walter, Dissertation, Mainz.