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HADRONIC COUPLINGS OF OPEN BEAUTY STATES *

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ABSTRACT

Strong interaction coupling parameters of particles with beauty quantum number are obtained using dispersion sum rules in various forms, e.g. current algebra sum rules, superconvergence sum rules and finite energy sum rules etc. These sum rules lead to a set of algebraic relations among masses and coupling constants. We compare the hadronic couplings of beautiful particles as obtained from various techniques and discuss their implications on the hadronic production of these states.

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I. INTRODUCTION

Recent years have witnessed a great deal of activities in the study of hadrons due to exciting discoveries of charm and beauty quantum numbers. Consequently, there has been an increase of the parameters required to describe the interaction properties of these states, e.g. coupling constants, form factors, etc. The main line of attack to the problem of finding a consistent scheme for understanding and predicting these quantities [1] is based on quantum chromodynamics (QCD) which is the candidate theory for strong interactions. However, these attempts suffer from the lack of proper understanding of non-perturbative effects. An alternative approach, which has so far played a central role in the strong interaction physics, is based on the S matrix phenomenology. This approach has given us many calculational tools in the form of current algebra sum rules, superconvergence relations, etc. Recently hadronic couplings of charmed particles have been calculated using these techniques by many authors [2)-8)]. In this paper we want to use these techniques to calculate hadronic couplings of open beauty particles. This theoretical study of hadronic parameters of beautiful particles will throw considerable light on the dynamics of flavour symmetry breaking as well as on the hadronic production of these particles.

Recently we have used PCAC Adler's consistency conditions [4], finite energy sum rules and superconvergence sum rules [5,6] to determine charmed particles coupling constants. We have further exploited these hadronic parameters to determine [7] the suppression factors for the charmed particle productions in exclusive πp and pp interactions. Recently, Chung et al. [9] have obtained experimental limits on D^* production in $\pi^- p$ interaction. We find that the experimental data support our findings. In this paper we shall make an extensive study of hadronic couplings of beautiful hadrons which have beauty ± 1, charm and strangeness quantum numbers zero. The masses and spin parities used for these particles have recently been calculated by various authors [10]. These parameters are tabulated in Table I. Recently Bologna-CERN-Frascati (BCF) collaboration [11,12] has reported the hadronic prodiction of beautiful baryons at $\sqrt{s}$ = 63 GeV. However, the experimental data are still incomplete and ambiguous [13]. We hope that in the near future we will have sufficient reliable experimental information on open beauty states to test our theoretical calculations.

The plan of the paper is as follows. In Sec.II we discuss the use of PCAC Adler's constraints on the invariant amplitudes for various elastic and inelastic processes involving beautiful baryons. Uses of superconvergence sum rules and finite energy sum rules involving various amplitudes as well as their combinations have been given in Sec.III. In Sec.IV we summarize the implications of our results and list the conclusions.

II. PCAC ADLER CONDITIONS

We consider the following elastic as well as inelastic processes involving pion and beautiful baryons:

$$\pi + \Lambda_b \longrightarrow \pi + \Lambda_b \tag{1}$$

$$\pi + \Sigma_b \longrightarrow \pi + \Sigma_b \tag{2}$$

$$\pi + \Lambda_b \longrightarrow \pi + \Sigma_b \tag{3}$$

$$\pi + \Lambda_b \longrightarrow \pi + \Sigma_b^* . \tag{4}$$

The derivations of Adler's consistency conditions on the invariant amplitudes of these processes are straightforward and have been discussed elsewhere [4]. We get the following conditions:

$$A^{\pi\Lambda_b}(\nu=0,\ \nu_B=0,\ K^2=0)=0 \tag{5}$$

$$A^{\pi\Sigma_b}(\nu=0,\nu_B=0,K^2=0) = \frac{4g^2_{\pi\Sigma_b\Sigma_b}\ K_{\pi\Sigma_b\Sigma_b}(0)}{m_{\Sigma_b}} \tag{6}$$

$$A^{\pi\Lambda_b\to\pi\Sigma_b}(\nu=0,\nu_B=0,K^2=0) = \frac{g_{\pi\Lambda_b\Sigma_b}\ K_{\pi\Lambda_b\Sigma_b}(0)}{m_{\Lambda_b}+m_{\Sigma_b}} \tag{7}$$

$$a_2^{\pi\Lambda_b\to\pi\Sigma_b^*}(\nu=0,\nu_B=0,K^2=0) = 0 , \tag{8}$$

where g is the coupling constant, $K_{\pi\Lambda_b\Sigma_b}(0)$ is the pionic form factor of the vertex evaluated at $K^2=0$ and

$$\nu = -\frac{K.(p_i+p_f)}{m_i+m_f}$$

$$\nu_B = \frac{K.q}{m_i+m_f} .$$

We have decomposed the matrix element for meson baryon scattering $M(K,m_\pi) + B(p_i,m_i) \to M(q,m_\pi) + B'(p_f,m_f)$ into the invariant amplitudes as follows:

$$T = -A + i\gamma.K\ B \tag{9}$$

for the processes (1)-(3) and

$$T_\alpha = a_1 K_\alpha + a_2 q_\alpha + i\gamma.K(b_1K_\alpha + b_2 q_\alpha) \tag{10}$$

for the process (4).

In the numerical evaluation of the consistency conditions, we use unsubtracted dispersion relations for the invariant amplitude

$$A(\nu,t) = \frac{1}{\pi}\int_{-\infty}^{\infty}\frac{\mathrm{Im}\ A(\nu',t)}{\nu'-\nu}\,d\nu' \tag{11}$$

and evaluate them by pole term contributions in s as well as u channels at fixed $t=m_\pi^2$ (i.e. $\nu_B=0$). The usual procedure is to make a subtraction at threshold in writing the dispersion relation for the amplitude A. However, in the absence of experimental information for the processes (1)-(4), we are unable to determine this subtraction constant. We have also shown that in the low-energy limits which we consider in evaluating the integral, our results do not change much even if we take the modified form for the dispersion relation based on the finite energy sum rule for the amplitude [14].

Saturating the condition (5) with the help of known $I = 1$ beautiful baryon states Σ_b and Σ_b^* in the narrow width approximation we get

$$1.4\, \Gamma_{\Sigma_b} - \Gamma_{\Sigma_b^*} = 0 \, , \tag{12}$$

where Γ_{Σ_b} and $\Gamma_{\Sigma_{b^*}}$ are the widths of Σ_b and Σ_b^* for the decay into $\Lambda_b \pi$ channel, respectively. We can relate the widths of Σ_b^* and Y_1^* (1385) on the basis of single quark transition scheme [14] motivated by Melosh transformation and we get

$$\Gamma_{\Sigma_b^* \to \Lambda_b \pi} = 0.89\, \Gamma_{Y_1^* \to \Lambda\pi} \, . \tag{13}$$

Using the width for $Y_1^* \to \Lambda\pi$ decay mode, we get the width for Σ_b^* as follows:

$$\Gamma_{\Sigma_b^* \to \Lambda_b \pi} = 27.6 \text{ MeV} \, . \tag{14}$$

Now from (12) we can predict

$$\Gamma_{\Sigma_b \to \Lambda_b \pi} = 19.8 \text{ MeV} \, . \tag{15}$$

The values of the corresponding coupling constants can be calculated and are given as

$$\frac{g^2_{\pi \Lambda_b \Sigma_b}}{4\pi} = 275.7 \tag{16}$$

$$\frac{g^2_{\pi \Lambda_b \Sigma_b^*}}{4\pi m_\pi^2} = 5.8 \, . \tag{17}$$

Similarly from the consistency conditions (6)-(8), after the saturation of dispersion integral with the known low-lying beautiful baryon states, we get

$$790.4\, g^2_{\pi \Sigma_b \Sigma_b^*} + 0.17\, g^2_{\pi \Lambda_b \Sigma_b} = 0.68\, g^2_{\pi \Sigma_b \Sigma_b} \tag{18}$$

$$754.05\, g_{\pi \Lambda_b \Sigma_b^*}\, g_{\pi \Sigma_b \Sigma_b^*} + -0.087\, g_{\pi \Lambda_b \Sigma_b}\, g_{\pi \Sigma_b \Sigma_b} = 0.087\, g^2_{\pi \Lambda_b \Sigma_b} \tag{19}$$

$$0.623\, g_{\pi \Sigma_b \Sigma_b^*}\, g_{\pi \Lambda_b \Sigma_b} - 1.99\, g_{\pi \Sigma_b^* \Sigma_b^*}\, g_{\pi \Lambda_b \Sigma_b^*} = 0 \, . \tag{20}$$

From these equations, we can find the values of remaining coupling constants

$$\frac{g^2_{\pi \Lambda_b \Sigma_b}}{4\pi} = 275.6 \, , \quad \frac{g^2_{\pi \Sigma_b \Sigma_b}}{4\pi} = 96.4 \, ,$$

$$\frac{g^2_{\pi \Sigma_b \Sigma_b^*}}{4\pi m_\pi^2} = 1.15 \, , \quad \frac{g^2_{\pi \Sigma_b^* \Sigma_b^*}}{4\pi} = 5.4 \, . \tag{21}$$

III. SUPERCONVERGENCE SUM RULES

Let us consider the following processes involving pion and beautiful baryons:

$$\pi^+ + \Sigma_b^- \to \pi^- + \Sigma_b^+ \tag{22}$$

$$\pi^+ + \Sigma_b^- \to \pi^- + \Sigma_b^{*+} \tag{23}$$

$$\pi + \Lambda_b \to \pi + \Lambda_b \tag{24}$$

$$\pi + \Lambda_b \to \pi + \Sigma_b^* \, . \tag{25}$$

These processes are similar to the processes considered in the charmed baryon case [5]. Therefore, corresponding superconvergence sum rules can be written as follows:

$$\int_{-\infty}^{\infty} \mathrm{Im}\; B^{I_t=2}(\nu,0)\,d\nu = 0 \tag{26}$$

for the process (22). And

$$\int_{-\infty}^{\infty} \mathrm{Im}\; a_2^{I_t=2}(\nu,0)\,d\nu = 0 \tag{27}$$

$$\int_{-\infty}^{\infty} \mathrm{Im}\; b_1^{I_t=2}(\nu,c)\,d\nu = 0 \tag{28}$$

for the process (23). Similarly we deduce

$$\int_{-\infty}^{\infty} \mathrm{Im}\; B^{I_t=0}_{(\nu,0)}\,d\nu = 0 \tag{29}$$

for (24), and finally for the process (25)

$$\int_{-\infty}^{\infty} \mathrm{Im}\; b_2^{I_t=1}(\nu,0)\,d\nu = 0 \;. \tag{30}$$

After saturating these sum rules with the beautiful baryons listed in Table I and using the value of $g^2_{\pi\Lambda_b\Sigma_b^*}/4\pi m_\pi^2 = 5.8$ from (17), we get the following values of the coupling constants:

$$\frac{g^2_{\pi\Lambda_b\Sigma_b}}{4\pi} = 242.7\;, \qquad \frac{g^2_{\pi\Sigma_b\Sigma_b}}{4\pi} = 124.5\;,$$

$$\frac{g^2_{\pi\Sigma_b\Sigma_b^*}}{4\pi m_\pi^2} = 0.82\;, \quad \frac{g^2_{\pi\Sigma_b^*\Sigma_b^*}}{4\pi} = 93.2\;, \quad \frac{g'^2_{\pi\Sigma_b^*\Sigma_b^*}}{4\pi} = 0.46\;. \tag{31}$$

These values can be compared with the values given in Eq.(21) obtained from PCAC conditions. We find that all the values of the coupling constants agree within 20% except for the value of $g^2_{\pi\Sigma_b^*\Sigma_b^*}$. This difference we obtained [5] in the charmed baryon case as well.

Similarly, constructing the superconvergent combination from the invariant amplitudes for the processes $\pi N \to \pi N$, $KN \to KN$, $BN \to BN$, $\pi\pi \to \pi\pi$, $\pi D \to \pi D$ and $\pi B \to \pi B$, we find [6] the following superconvergence sum rules:

$$\int_{-\infty}^{\infty} \mathrm{Im}\,\left(B^{\rho}_{\pi N} A^{\rho}_{BN} - A^{\rho}_{\pi N} B^{\rho}_{BN} \right) d\nu = 0\,, \tag{32}$$

$$\int_{-\infty}^{\infty} \mathrm{Im}\,\left(B^{\rho}_{KN} A^{\rho}_{BN} - A^{\rho}_{KN} B^{\rho}_{BN} \right) d\nu = 0\,, \tag{33}$$

$$\int_{-\infty}^{\infty} \mathrm{Im}\left[\left(M^{\rho}_{\pi\pi} B^{\rho}_{BN} \right) - \left(M^{\rho}_{\pi B} B^{\rho}_{\pi N} \right) \right] d\nu = 0, \tag{34}$$

$$\int_{-\infty}^{\infty} \mathrm{Im}\,\left(M^{\rho}_{\pi B} - M^{\rho}_{\pi D} \right) d\nu = 0\,. \tag{35}$$

In order to saturate sum rules obtained above, we retain the contributions from the low-lying states only in s as well as u channels. For example, we use N and Δ states $\pi N \to \pi N$; Λ_b, Σ_b, Σ_b^* for BN BN; Λ, Σ, Y_1^* for $KN \to KN$, ρ for $\pi\pi \to \pi\pi$, D^* for $\pi D \to \pi D$ and B^*, B^{**} for $\pi B \to \pi B$. We further use $\Gamma_{B^{**}\to B\pi} = 93$ KeV [Ref.16], $g^2_{\pi DD^*}/4\pi = 0.4$ [Ref.6], $g^2_{\rho\pi\pi}/4\pi = 2.9$, $g^2_{KN\Lambda}/4\pi = 10$, $g^2_{KN\Sigma}/4\pi = 3$, $g^2_{KNY_1^*}/4\pi m_K^2 = 6.03$, $g^2_{\pi NN}/4\pi = 14.6$ and $g^2_{\pi N\Delta}/4\pi m_\pi^2 = 18$. We finally get the following values of the coupling constants:

$$\frac{g^2_{B^*B\pi}}{4\pi} = 2.43\;, \qquad \frac{g^2_{BN\Lambda_b}}{4\pi} = 1317.8\;,$$

$$\frac{g^2_{BN\Sigma_b}}{4\pi} = 1172.7\;, \qquad \frac{g^2_{BN\Sigma_b^*}}{4\pi m_B^2} = 32.4\,. \tag{36}$$

IV. CONCLUSIONS

We find that the values of the coupling constants for the beautiful particles are much larger than the corresponding values for the charmed and strange particles. It emphasizes the role of SU(5) flavour symmetry breaking. As the masses of the particles become larger, their coupling strengths also increase. It should be mentioned that we have nowhere considered SU(5) flavour symmetry in our calculations. But in our calculations, we are relating the symmetry breaking of particle couplings to the known symmetry breaking in particle masses because we are getting algebraic relations in masses and coupling constants after saturating the sum rules. We hope that this increased value of the coupling for the beautiful baryons will play a dominant role in increasing the production cross-sections for these particles. We hope that in the near future, sufficient experimental data will become available to test these predictions.

In conclusion, superconvergence and current algebra sum rules give a significant tool to calculate hadronic coupling strengths involving particles and resonances. Although these sum rules are of great theoretical interest, it is difficult to give any convincing saturation scheme [14] for them. However, the saturation scheme employed here, has been found to be successful in the past in predicting many coupling constants. Moreover, lack of experimental information on beautiful baryon spectroscopy prompts us to stick to the saturation by low-lying states only. We hope that the values of these coupling constants obtained here will help us in drawing a dynamical scheme for the breaking mechanism of flavour symmetry.

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Table I

Particles	J^P	I	Charm	Strangeness	Beauty	Mass (GeV)	Strong decay mode
B	0^-	$\frac{1}{2}$	0	0	1	5.28	-
B*	1^-	$\frac{1}{2}$	0	0	1	5.36	-
B**	2	$\frac{1}{2}$	0	0	1	5.55	$B\pi$
Λ_b	$\frac{1}{2}^+$	0	0	0	-1	5.625	-
Σ_b	$\frac{1}{2}^+$	0	0	0	-1	5.846	$\Lambda_b\pi$
Σ_b^*	$\frac{3}{2}^+$	0	0	0	-1	5.869	$\Lambda_b\pi$

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