The $\rho(\omega)/B^*(B)$ system and bound states in the unitary local Hidden Gauge approach

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Abstract. In this work, we study systems composed of a ρ/ω and B^* meson pair. We find three bound states in isospin, spin-parity channels $(1/2, 0^+)$, $(1/2, 1^+)$ and $(1/2, 2^+)$. The state with $J = 2$ can be a good candidate for the $B_2^*(5747)$. We also study the ρB system, and a bound state with mass 5728 MeV and width around 20 MeV is obtained, which can be identified with the $B_1(5721)$ resonance. In the case of $I = 3/2$, one obtains repulsion and thus, no exotic (molecular) mesons in this sector are generated in the approach.

1 Introduction

The present work is the extension to the b sector of the work of Ref. [1], for the $\rho(\omega)D^*$ system. Furhter details and references can be found in Ref. [2]. The interaction of the ρ, ω and D^* mesons was studied using the Local Hidden Gauge (LHG) Lagrangians of Refs. [3], where the vector mesons are considered as gauge bosons of a hidden symmetry transforming inhomogeneously. Choosing the appropriate gauge they can transform as in the non-linear realization of chiral symmetry. The extension to the charm sector, together with a non-perturbative treatment of the LHG amplitudes, provided the set of predictions that is compiled in Table 1. Fitting the $\frac{1}{2}(2^+)$ state to an already existing state, two more states were predicted and identified with other experimental states [4], the $D(2600)$ and $D^*(2640)$. It is remarkable that the $D(2600)$, the first row in Table 1, was measured after the theoretical prediction [5].

Table 1. Results of the unitary LHG approach in the charm sector. The $\rho(\omega)D^*$ interaction.

Model result			PDG state association [4]		
$I(J^{PC})$	Mass	Width	$I(J^{PC})$	Mass	Width
$\frac{1}{2}(0^+)$	2600 MeV	≈ 61 MeV	$D(2600)\ \frac{1}{2}(?^?)$	2612 ± 6 MeV	93 ± 14 MeV
$\frac{1}{2}(1^+)$	2620 MeV	0 MeV	$D^*(2640)\ \frac{1}{2}(?^?)$	2637 ± 6 MeV	< 15 MeV
$\frac{1}{2}(2^+)$	fitted	fitted	$D_2^*(2460)\ \frac{1}{2}(2^+)$	2462.6 ± 0.6	49.90 ± 1.3

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2 Formalism

The meson-meson bound states produced with this model will appear as poles in the scattering t-matrix, T, on the physical Riemann Sheet of the energy, in our case of $s = P^2$, being P the total four-momenta of the meson-meson system. Imposing unitarity on the right-hand cut is equivalent to solve the on-shell version of the factorized Bethe-Salpeter equation:

$$T^{I,J}(s) = V^{I,J}\left(1 - G(s)V^{I,J}(s)\right)^{-1}, \tag{1}$$

which depend on the total isospin I and spin J of the ρB^* and ωB^* two possible channels. Eq. (1) is a matrix equation in the channels space. The $V^{I,J}(s)$ are the tree level Feynman amplitudes associated to the possible $\rho(\omega)B^* \to \rho(\omega)B^*$ transitions, and the $G(s)$ is the two-meson loop function, regularized with a sharp cut-off Λ. Eq. (1) is equivalent to the following re-summation:

$$T^{I,J} = V^{I,J} + V^{I,J}GV^{I,J} + V^{I,J}GV^{I,J}GV^{I,J} + \dots. \tag{2}$$

2.1 The Local Hidden Gauge amplitudes

The Local Hidden Gauge Lagrangian for the vector meson interaction is the following,

$$\mathcal{L}_{III} = -\frac{1}{4}\left\langle V_{\mu\nu}V^{\mu\nu}\right\rangle, \tag{3}$$

where the symbol $\langle\rangle$ represents the trace in SU(4) flavor space (we consider u, d, s and b quarks), with

$$V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu - ig[V_\mu, V_\nu], \tag{4}$$

and V_μ is the following matrix,

$$V_\mu = \begin{pmatrix} \frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & \rho^+ & K^{*+} & B^{*+} \\ \rho^- & -\frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & K^{*0} & B^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi & B_s^{*0} \\ B^{*-} & \bar{B}^{*0} & \bar{B}_s^{*0} & \Upsilon \end{pmatrix}_\mu. \tag{5}$$

As can be seen in Eq. (5), the degrees of freedom are the vector meson fields. The local hidden gauge Lagrangian (3) contains a four vector contact term $\mathcal{L}_c \propto g^2$ and a meson exchange term $\mathcal{L}_{ex} \propto g$. At tree-level, the interaction involves contact diagrams and one meson exchange, as it is depicted in Fig. 1.

- In the Local Hidden Gauge approach the interaction is mainly given by the vector meson exchange, being the exchange of heavy mesons penalized by their large mass.
- We make the approximation of neglecting the three-momenta of the external mesons, with respect to the masses: $\frac{\vec{k}_i^2}{M_i^2} \to 0$. This helps to simplify the formalism and the spin projections.
- We also have considered the large width of the ρ meson, and its two pion decay mechanism in order to give some width to the dynamically generated states.
- It can be shown that the meson exchange term of the Local Hidden Gauge Lagrangian Eq. (3), in the $\frac{\vec{k}_i^2}{M_i^2} \to 0$ limit, has the same structure as the vector-pseudoscalar term, thus the ρB interaction is easily obtained replacing $B^* \to B$ in the ρ exchange amplitudes. In our formalism there are no terms that link the ρB^* and ρB channels, the terms leading to these transitions are anomalous and small. There is another possibility using box diagrams, but this contribution was found also small.

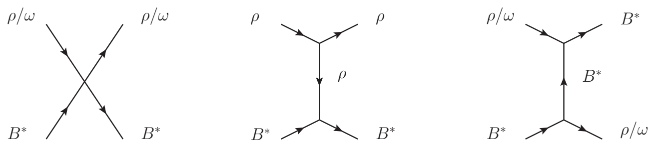

Figure 1. The possible tree-level diagrams for the $\rho(\omega)B^*(B)$ interaction.

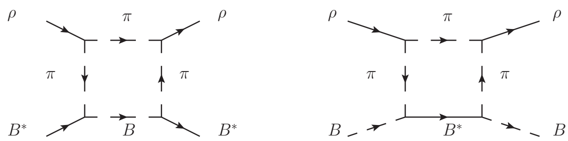

Figure 2. The $\rho \to \pi\pi$ decay is taken into account in the interaction $V^{I,J}$ in order to provide some width to the states.

- When we split the $\rho B^*(B)$ states in terms of the spin of the light quarks, we find that neglecting $\rho B^* \to \rho B$ transitions leads to a spin degeneracy in the mass of the states. Furthermore, it is found that the ρ exchange amplitudes are spin degenerated in the LHG, and not suppressed in the heavy quark mass power counting. The rest of amplitudes do not conserve the heavy quark spin symmetry, but they grow as $1/m_Q$ in the $m_Q \to \infty$ limit.

The $V^{I,J}$ potential employed to solve Eq. (1) is the sum of the meson exchange amplitudes and the contact terms of Fig 1, and the box diagrams contributions of Fig. 2.

3 Results

In Table 2 we find the set of predictions that it is obtained when fitting the $\frac{1}{2}(2^+)$ state, generated by the ρB^* interaction, to an already existing state, the $B_2^*(5747)$. We can appreciate that the mass difference of the states is small, revealing the near spin-degeneracy of the masses. As we have stated, this is due to the larger contribution of the ρ exchange in the interaction, and the fact that this contribution is spin degenerated in our formalism. We observe also that we predict states with spin 0 and 1 generated by the $\rho(\omega)B^*$ interaction. The ρB state, which is also a prediction, can be identified with an already $\frac{1}{2}(1^+)$ existing state, the $B_1(5721)^0$.

Table 2. Summary of the states found in the $\rho(\omega)B^*$ and ρB sectors using the unitary LHG approach.

Main channel	$I(J^P)$	M [Mev]	Γ [MeV]	Main decay channel	Exp (M, Γ) [MeV]
ρB^*	$\frac{1}{2}(0^+)$	5812	$25-45$	πB	
ρB^*	$\frac{1}{2}(1^+)$	5817	0		
ρB^*	$\frac{1}{2}(2^+)$	5745	$25-35$	πB	$(5743 \pm 5\,,\ 23^{+5}_{-11})$
ρB	$\frac{1}{2}(1^+)$	5728	$18-24$	πB^*	$(5726.8 \pm 2\,,\ 49^{+14}_{-23})$

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