A three body state with J=3 in the $\rho B^* \bar{B}^*$ interaction

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Abstract. We study the $\rho B^* \bar{B}^*$ system solving the Faddeev equations in the fixed center approximation. The $B^* \bar{B}^*$ system will be considered forming a cluster, and using the two-body ρB^* unitarized scattering amplitudes in the local Hidden Gauge approach we find a new $I(J^{PC}) = 1(3^{--})$ state. The mass of the new state corresponds to a two particle invariant mass of the ρB^* system close to the resonant energy of the $B_2^*(5747)$, indicating that the role of this $J = 2$ resonance is important in the dynamical generation of the new state.

1 Introduction

Here we study the interaction of the three body system composed of a ρ meson and a $B^* \bar{B}^*$ pair, further details and references can be found in Ref. [1]. We use the Fixed Center Approximation (FCA), that is, we consider the pair of b mesons forming a $J = 2$ cluster, and let the ρ meson interact with the cluster as can be seen in Fig. 1. The motivation for study such a system is that in previous works, the ρB^* interaction was found very attractive, specially in $J = 2$ where it was found the most bound state [2]. On the other hand, the $B^* \bar{B}^*$ interaction was studied in [3] and found degenerate states in all spins. We can think that the combination of these two attractive subsystems would generate a new $J = 3$ bound state with our formalism.

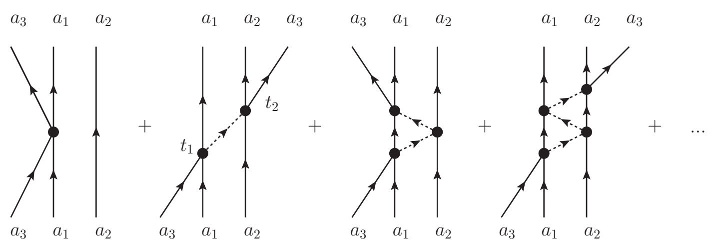

Figure 1. Interaction of three particles a_1, a_2 and a_3, in the FCA. The a_3 particle is the lighter one, in our case the ρ meson.

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2 Formalism

The main assumption is that the heavy B^* and $\bar{B}^*$ mesons will be forming a cluster of spin two. Then we can construct the diagrammatic series of Fig. 1 which account all the possible terms for the scattering of the ρ (particle a_3) and say, the B^* (particle a_1). Thus, denoting this sum as T_1:

$$T_1 = t_1 + t_1 G_0 t_2 + t_1 G_0 t_2 G_0 t_1 + \ldots, \tag{1}$$

$$T_2 = t_2 + t_2 G_0 t_1 + t_2 G_0 t_1 G_0 t_2 + \ldots, \tag{2}$$

where we have also written in Eq. (2) the series for the scattering with the $\bar{B}^*$ (particle a_2). From Eqs. (1) and (2) we deduce the coupled Faddeev equations,

$$T_1 = t_1 + t_1 G_0 T_2, \tag{3}$$

$$T_2 = t_2 + t_2 G_0 T_1, \tag{4}$$

and the full scattering T-matrix is $T = T_1 + T_2$. The G_0 (dashed line in Fig. 1) is the ρ propagator inside the cluster of mass $M_{\rm c}$,

$$G_0(q^0) = \frac{1}{2M_{\rm c}} \int_{\mathbb{R}^3} \frac{{\rm d}^3 q}{(2\pi)^3} F_R(\vec{q}^{\,2}) \frac{1}{(q^0)^2 - \vec{q}^{\,2} - m_{a_3}^2 + {\rm i}\epsilon}, \tag{5}$$

the F_R function in Eq. (5) is the form factor of the resonance or cluster, which is the Fourier transform of its wave function. There q^0 and m_{a_3} are the energy and the mass of the ρ meson. We will consider the following form factor description for s-wave functions

$$F_R(\vec{q}^{\,2}) = \frac{1}{N} \int_\Omega d^3 p \mathcal{A}(\vec{p}) \mathcal{A}(\vec{p} - \vec{q}), \quad \Omega := \left\{ \left|\vec{p}\right|, \left|\vec{p} - \vec{q}\right| < \Lambda \right\}, \tag{6}$$

where $\mathcal{A}$ and N are defined by,

$$\mathcal{A}(\vec{p}) = \frac{1}{M_{\rm c} - \omega_{a_1}(\vec{p}) - \omega_{a_2}(\vec{p})}, \tag{7}$$

$$N = F_R\left(\vec{q}^{\,2} = 0\right), \tag{8}$$

and Λ is a three-momentum cutoff used to regularize the meson-meson loop function in the $B^*\bar{B}^*$ system in order to obtain the $B^*\bar{B}^*$ as a bound state [4].

- It is interesting to note that this is the only information needed from the $B^*\bar{B}^*$ system. One is not taking the $B^*\bar{B}^*$ interaction explicitly, but it is considered implicitly since it leads to the binding of the $B^*\bar{B}^*$ system, and we can determine the wave function and the form factor from this information.
- The t_1 and t_2 are the ρB^* and $\rho\bar{B}^*$ interaction in $J = 2$, studied in [2] with the unitarization of amplitudes given by the local Hidden Gauge approach, that generated the $B_2^*(5747)$. In this formalism we have $t_1 = t_2$.
- The quantum numbers of the cluster are $I(J^{PC}) = 0(2^{++})$, and the ρ meson is an isotriplet, thus it is necessary to write the 3 body $T(I = 1)$ matrix in terms of proper isospin states of the ρB^* and $B^*\bar{B}^*$ subsystems. This provides the result

$$T = \frac{2\tilde{t}}{1 - \tilde{t} G_0}, \tag{9}$$

where $\tilde{t} = \frac{t_1(I_{\rho B^*}=1/2) + 2t_1(I_{\rho B^*}=3/2)}{3} \times \frac{M_{\rm c}}{m_{B^*}}$, being the last factor included to ensure the correct normalization convention of the amplitudes in the sums of Eqs. (1) and (2), as in Ref. [4], with respect to the convention used in [2].

- The sources of uncertainties of the model are the propagator cut off, Λ, which is translated into uncertainties in the cluster mass, and the way of sharing the total energy between the two subsystems. We have estimated the variation of the results tied to these sources of about 60 MeV in the mass, and 10 MeV in the width of the $J = 3$ bound state found.

3 Results

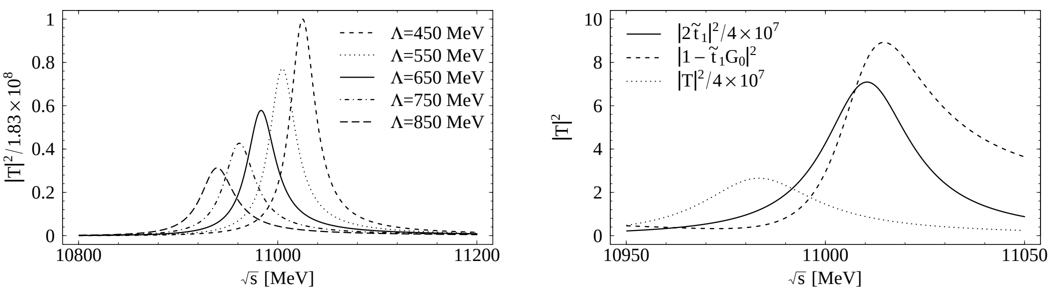

Figure 2. (Left) modulus squared of the total T matrix of Eq. (9). (Right) plot of the numerator and denominator of Eq. (9) together with the total T.

As we can see in the left panel of Fig. 2, we find a $I(J^P) = 1(3^-)$ bound state of the three body system with a mass $M = 10968 \pm 57$ MeV and a width of 36 ± 7 MeV. In the right panel of Fig. 2 we have plotted the modulus squared of the t_1, which is the contribution of the $J = 2$ ρB^* interaction, the solid line. We can see a clear peak, which is directly related with the $B_2^*(5747)$ resonant state found in the unitary Hidden Gauge formalism. Furthermore, we have plotted the denominator of T, $1 - G_0\tilde{t}_1$, dashed line, which is the effect of the ρ orbiting around the heavy mesons in the FCA. This term is the responsible of displacing the peak to lower energies, see the dotted line, and we appreciate that the strong binding energy of the two subsystems plays a fundamental role on the generation of the three-body state.

References

[1] M. Bayar, P. Fernandez-Soler, Z. F. Sun and E. Oset, Eur. Phys. J. A **52** no.4, 106 (2016)
[2] P. Fernandez-Soler, Z. F. Sun, J. Nieves and E. Oset, Eur. Phys. J. C **76** no.2, 82 (2016)
[3] A. Ozpineci, C. W. Xiao and E. Oset, Phys. Rev. D **88** 034018 (2013)
[4] L. Roca and E. Oset, Phys. Rev. D **82** 054013 (2010)