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Investigating the $D^*\rho$ system using QCD sum rules

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In this talk I show the results we have found by studying the $D^*\rho$ system with the method of QCD sum rules. We have investigated the different isospin and spin configurations and obtain three D^* mesons with isospin $I = 1/2$, spin $S = 0$, 1, 2 and with masses 2500 ± 67 MeV, 2523 ± 60 MeV, and 2439 ± 119 MeV, respectively. Comparing our results with the states listed by the Particle Data Group, the last state can be related to $D_2^*(2460)$ (spin 2), while one of the first two might be associated with $D^*(2640)$, whose spin-parity is unknown. In the case of $I = 3/2$ we also find evidences of three states with spin 0, 1 and 2, respectively, with masses 2467 ± 82 MeV, 2420 ± 128 MeV, and 2550 ± 56 MeV.

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1. Introduction

The interest in the charmed meson spectroscopy has grown exponentially since the discovery of the D and D^* mesons [1], and experimental facilities like Cleo, Belle, BaBar, etc., are bringing every time more relevant information about the charmed meson spectra [2].

However, in spite of all the efforts, a rather scarce information is available on basic properties of the charmed meson resonances like spin, isospin, parity, etc [3]. It is also interesting to notice that the energy region studied experimentally, 2400-2750 MeV, covers a range of only 350 MeV from the first to the last excited state, while the interaction of a D or a D^* meson, due to their heavy mass (around 2000 MeV), with a vector or few pseudoscalar mesons could give rise to a resonance with a mass close to 3000 MeV. Recently, a theoretical work along this line was made in Ref. [4], where a system formed of a D meson and the $f_0(980)$ resonance was investigated and a new D meson state with mass around 2900 MeV was predicted. Similarly, with another recent study of the $D^*\rho$ system in s-wave using effective field theories [5] an effort has been made to shed some more light on the nature of two of the D^* resonances listed by the PDG: $D_2^*(2460)$ and $D^*(2640)$. In Ref. [5] the spin-parity of the former state was confirmed to be $J^P = 2^+$, and the spin and parity of the latter one was predicted to be $J^P = 1^+$. In addition, a new state with mass close to 2600 MeV and spin 0, thus $J^P = 0^+$, was predicted.

In this talk I present the results obtained from our investigation of the $D^*\rho$ system using QCD sum rules.

2. Framework

The starting point to determine the mass of the possible $D^*\rho$ states with the QCD sum rule method is the evaluation of the two-point correlation function

$$\Pi(q^2) = i\int d^4x\, e^{iqx}\langle 0|T\left[j(x)j^\dagger(0)\right]|0\rangle, \tag{2.1}$$

where q is the momentum flowing from 0 to ∞, $T[\cdots]$ represents the T-ordered product and j is the current associated to the $D^*\rho$ system.

The simplest current we can use for the $D^*\rho$ system is of the form

$$j_{\mu\nu}(x) = \left[\bar{q}_a^1(x)\gamma_\mu c_a(x)\right]\left[\bar{q}_b^2(x)\gamma_\nu q_b^3(x)\right], \tag{2.2}$$

with $q^1(x)$, $q^2(x)$ and $q^3(x)$ representing the fields of the light quarks u or d, $c(x)$ is the field for the quark c, a and b are color indices and γ represents the Dirac matrix.

The correlation function in Eq. (2.1) has to be projected on isospin and spin. For the projection on spin, as shown in Refs. [6, 7], we use the following projectors

$$\begin{aligned} &\mathscr{P}^{(0)} = \frac{1}{3}\Delta^{\mu\nu}\Delta^{\alpha\beta}, \quad \mathscr{P}^{(1)} = \frac{1}{2}\left(\Delta^{\mu\alpha}\Delta^{\nu\beta} - \Delta^{\mu\beta}\Delta^{\nu\alpha}\right), \\ &\mathscr{P}^{(2)} = \frac{1}{2}\left(\Delta^{\mu\alpha}\Delta^{\nu\beta} + \Delta^{\mu\beta}\Delta^{\nu\alpha}\right) - \frac{1}{3}\Delta^{\mu\nu}\Delta^{\alpha\beta}, \end{aligned} \tag{2.3}$$

with

$$\Delta_{\mu\nu} \equiv -g_{\mu\nu} + \frac{q_\mu q_\nu}{q^2}, \quad g_{\mu\nu} \equiv \text{metric tensor}. \tag{2.4}$$

Equations (2.3) correspond to the covariant extrapolation of the nonrelativistic projectors found in Ref. [5] (for more details see Refs. [6, 7]), which implicitly assume that we have relative angular momentum $L = 0$ for the two vector states. Thus we project the currents only on $J^P = 0^+$, 1^+ and 2^+.

In this way, the correlation function used to described the properties of the $D^*\rho$ system is given by

$$\Pi^{I,S}(q^2) = \mathscr{P}_{\Delta}^{(S)}\Pi^{I}_{\mu\nu,\alpha\beta}\cdot, \tag{2.5}$$

with

$$\Pi^{I}_{\mu\nu,\alpha\beta} = i\int d^4x\, e^{iqx}\langle 0|T\left[j^{I}_{\mu\nu}(x)\, {j^{I}_{\alpha\beta}}^{\dagger}(0)\right]|0\rangle. \tag{2.6}$$

The superscript I in Eqs. (2.5) and (2.6) means isospin projection, which can be done considering the corresponding Clebsch-Gordan coefficients.

To evaluate Eq. (2.6) we need to rely on its dual nature: for large momentum the correlation function represents a quark-antiquark fluctuation and can be calculated using perturbative QCD. At small momentum, the currents $j^\dagger$ and j of Eq. (2.1) can be interpreted as operators of creation and annihilation of hadrons with the same quantum numbers as the ones of the current j. The first way of evaluating the correlation function is called "OPE description" (Operator Product Expansion), while the second receive the name of "Phenomenological description." (for more details see Ref. [6]). Ideally, the results from the evaluation of the correlation function within the two approaches mentioned should be the same at some range of q^2 at which we could just directly equate both expressions. However, this is not exactly true due to the approximations involved in the two methods. A way of solving this is by applying the Borel transformation to both correlation functions and then equating them. In this way it is possible to determine the mass and coupling to the current used of a state formed in the system under study. The disadvantage of the Borel transformation is that it introduces a new parameter, the Borel mass. Ideally, the results should not depend on the value of the Borel mass used to determine them. But, in a realistic case, this is not completely true and one relies on the existence of a range of Borel masses (or Borel "window") in which the results obtained for the mass and the coupling can be relied upon.

3. Results

For the case of isospin $I = 1/2$ and spin $S = 2$, the mass sum rule is stable in the Borel window found and gives as a result

$$m_{1/2,2} = (2.428 \pm 0.151)\,\text{GeV}. \tag{3.1}$$

The value shown in Eq. (3.1) is obtained by averaging the mass over the Borel window and by calculating the standard deviation to determine the error. To estimate the uncertainty of the result in Eq. (3.1), we consider the change found in the mass of the state while varying the quark masses and condensates within the error related to them. Taking into account all these sources of errors, averaging over the results found in the different Borel windows and calculating the standard deviation, we obtain

$$m_{1/2,2} = (2.439 \pm 0.119)\,\mathrm{GeV},$$
$$\lambda_{1/2,2} = (8.14 \pm 1.61) \times 10^{-3}\,\mathrm{GeV}^5. \tag{3.2}$$

Analogously, we repeat this process for the cases spin 0 and 1, respectively and obtain: $m_{1/2,0} = (2.500 \pm 0.067)\,\mathrm{GeV}$, $m_{1/2,1} = (2.523 \pm 0.060)\,\mathrm{GeV}$.

The state found in this manuscript with spin 2 can be associated with the $D_2^*(2450)$ listed by the PDG. For the states with spin 0 and 1, there is only one candidate listed by the PDG and that is $D^*(2640)$. However, nothing is known about the spin and parity of this state. In Ref. [5], the widths related to the resonances found were calculated, obtaining a width of around 40 MeV for the state with spin 2, 60 MeV for the state with spin 0 and practically zero width for the state with spin 1. Since the width listed by the PDG for $D^*(2640)$ is $\Gamma < 15$ MeV, the authors of Ref. [5] associated the state with spin 1 to $D^*(2640)$ and predicted the existence of a state with spin 0 and a similar mass, but with a much larger width. In this manuscript, we have calculated the masses and couplings for the different states. To make a proper identification of $D^*(2640)$ with one of the states with spin 0 and 1, a QCD sum rule calculation to determine the width of each of the states might be helpful. However, this is beyond the scope of the present manuscript. Thus, with the information at hand, we can only confirm the existence of two nearly degenerate states with mass around 2500 ± 60 MeV and spin 0 and 1, respectively, one of which can probably be related to $D^*(2640)$.

For the case $I = 3/2$, we find also three states with masses 2.467 ± 0.082 GeV, 2.420 ± 0.128 GeV, 2.550 ± 0.056 GeV and spins 0, 1, and 2, respectively.

4. Summary

Using an approach based on QCD sum rules, we have studied the interaction of a D^* and a ρ mesons and investigated the existence of resonances for the different isospins and spins. For the isospin $1/2$ case, we have found three states with masses 2.500 ± 0.067 GeV, 2.523 ± 0.060 GeV and 2.439 ± 0.119 GeV and spin 0, 1 and 2, respectively. For the case of isospin $3/2$, we have obtained three states with masses 2.467 ± 0.082 GeV, 2.420 ± 0.128 GeV, 2.550 ± 0.056 GeV and spins 0, 1, and 2, respectively.

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