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# $\rho D^* D^*$ vertex from QCD sum rules

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**Abstract**

We calculate the form factors and the coupling constant in the $\rho D^* D^*$ vertex in the framework of QCD sum rules. We evaluate the three point correlation functions of the vertex considering both $\rho$ and $D^*$ mesons off-shell. The form factors obtained are very different but give the same coupling constant: $g_{\rho D^* D^*} = 6.60 \pm 0.31$. This number is 50% larger than what we would expect from SU(4) estimates.


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## 1. Introduction

Charmonium production is a very useful source of information in heavy ion collisions. The knowledge of the $J/\psi$ production rate can improve our understanding of these collisions and help us to know if there was a "color glass condensate" in the initial state. Charmonium production is very sensitive to the existence and to the properties of the intermediate "quark–gluon plasma" [1]. All the interesting effects happening in these initial and intermediate phases can be blurred by interactions in the final stage of these collisions, when charmonium states interact with other comovers such as pions, $\rho$ mesons and nucleons, which form a hot hadronic gas. Since these interactions occur at an energy of the order of magnitude of the temperature ($\simeq$100–150 MeV), their study has to be made with non-perturbative methods. These can be QCD sum rules [2], quark models and the effective Lagrangian approach [3,4]. This last approach has been developed for almost ten years now and a great progress in the understanding of the interactions of charmed mesons with light mesons and nucleons has been achieved. Part of this progress is due to a persistent study of the vertices involving charmed mesons, namely $D^* D\pi$ [5,6], $DD\rho$ [7], $DDJ/\psi$ [8], $D^* DJ/\psi$ [9,10], $D^* D^*\pi$ [11,12], $D^* D^* J/\psi$ [13], $D_s D^* K$, $D_s^* DK$ [14] and $DD\omega$ [15]. More specifically, it is very important to know the precise functional form of the form factors in these vertices and even to know how this form changes when one or the other (or both) mesons are off-shell. This careful determination of the charm form factors has been done bit by bit over the last seven years in the framework of QCD sum rules, which are the best tool to give a first principles answer to this problem.

Understanding charmonium production in heavy ion collisions would be already a good reason to study of hadronic charm form factors. However, since 2003, due the precise measurements of $B$ decays performed by Belle, BES and BaBar Collaborations, this subject gained a new relevance. In $B$ decays new particles have been observed, such as the $D_{sJ}(2317)$ and the $X(3872)$. These particles very often decay into an intermediate two body state, which then undergoes final state interactions, with the exchange of one or more virtual mesons. As an example of specific situation where a precise knowledge of the $\rho D^* D^*$ form factor is required, we may consider the decay $X(3872) \to J/\psi + \rho$. As suggested in [16], this decay proceeds in two steps. First the $X$ decays into a $D$–$D^*$ intermediate state and then these two particles exchange a $D^*$ producing the final $J/\psi$ and $\rho$. This is shown in Figs. 1b and 1f of [16]. In order to compute the effect of these interactions in the final decay rate we need the $\rho D^* D^*$ form factor.

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In the present Letter we calculate this form factor with QCDSR. The $\rho D^* D^*$ vertex is similar to the $J/\psi D^* D^*$ vertex treated in [13]. As before, because there are three vector particles involved, the number of Lorentz structures is very large and we have to choose a reliable one to perform the calculations. Here we introduce the pole-continuum analysis and impose the pole dominance as a criterion to reduce the freedom in the choice of the Borel parameter. In the next section, for completeness we describe the QCDSR technique and in Section 3 we present the results and compare them with results obtained in other works.

## 2. The sum rule for the $\rho D^* D^*$ vertex

Following our previous works and especially Ref. [13], we write the three-point function associated with the $\rho D^* D^*$ vertex, which is given by

$$\Gamma^{(\rho^+)}_{\nu\alpha\mu}(p,p',q) = \int d^4x\, d^4y\, e^{ip'\cdot x} e^{-iq\cdot y} \times \langle 0|T\{j^{D^{*0}}_\mu(x) j^{\rho^+\dagger}_\alpha(y) j^{D^{*-}\dagger}_\nu(0)\}|0\rangle \tag{1}$$

for an off-shell $\rho^+$ meson, where $q=(p'-p)$, and

$$\Gamma^{(D^{*-})}_{\nu\alpha\mu}(p,p',q) = \int d^4x\, d^4y\, e^{ip'\cdot x} e^{-iq\cdot y} \times \langle 0|T\{j^{D^{*0}}_\nu(x) j^{D^{*-}\dagger}_\alpha(y) j^{\rho^+\dagger}_\mu(0)\}|0\rangle, \tag{2}$$

for an off-shell $D^{*-}$ meson. Since there are two independent momenta and three Lorentz indices, the general expression for the vertices (1) and (2) has fourteen independent Lorentz structures. Therefore, we can write $\Gamma_{\nu\alpha\mu}$ in terms of fourteen invariant amplitudes associated with each one of these structures in the following form:

$$\begin{aligned}
\Gamma_{\nu\alpha\mu}(p,p',q) &= \Gamma_1(p^2,p'^2,q^2)g_{\mu\nu}p_\alpha + \Gamma_2(p^2,p'^2,q^2)g_{\mu\alpha}p_\nu \\
&+ \Gamma_3(p^2,p'^2,q^2)g_{\nu\alpha}p_\mu + \Gamma_4(p^2,p'^2,q^2)g_{\mu\nu}q_\alpha \\
&+ \Gamma_5(p^2,p'^2,q^2)g_{\mu\alpha}q_\nu + \Gamma_6(p^2,p'^2,q^2)g_{\nu\alpha}q_\mu \\
&+ \Gamma_7(p^2,p'^2,q^2)p_\mu p_\nu p_\alpha + \Gamma_8(p^2,p'^2,q^2)q_\mu p_\nu p_\alpha \\
&+ \Gamma_9(p^2,p'^2,q^2)p_\mu q_\nu p_\alpha + \Gamma_{10}(p^2,p'^2,q^2)p_\mu p_\nu q_\alpha \\
&+ \Gamma_{11}(p^2,p'^2,q^2)q_\mu q_\nu p_\alpha + \Gamma_{12}(p^2,p'^2,q^2)q_\mu p_\nu q_\alpha \\
&+ \Gamma_{13}(p^2,p'^2,q^2)p_\mu q_\nu q_\alpha + \Gamma_{14}(p^2,p'^2,q^2)q_\mu q_\nu q_\alpha.
\end{aligned} \tag{3}$$

However, not all of these fourteen invariant amplitudes, $\Gamma_i(p^2,p'^2,q^2)$, are independent. Due to current conservation $p^\mu \Gamma_{\nu\alpha\mu}(p,p',q)=0$ for an off-shell $D^{*-}$ meson, and $q^\alpha \Gamma_{\nu\alpha\mu}(p,p',q)=0$ for an off-shell $\rho^+$ meson. Current conservation introduces five constraints among these fourteen invariant amplitudes, such that only nine of them are independent. As an example, in the case of an off-shell $D^{*-}$ meson, the invariant amplitudes $\Gamma_5$ and $\Gamma_9$ are related through: $\Gamma_9 = -\Gamma_5/p^2$, in such a way that these two terms in Eq. (3) can be written in a form manifestly current conserving as: $\Gamma_5(p^2,p'^2,q^2)q_\nu(g_{\mu\alpha} - p_\alpha p_\mu/p^2)$. However, since the fourteen Lorentz structures appearing in Eq. (3) are indeed independent, we can write one sum rule for each one of these fourteen Lorentz structures. The kind of relation given above tell us that from these fourteen sum rules, only nine of them are independent, but these relations do not change the sum rules.

Eqs. (1) and (2) can be calculated in two different ways: using quark degrees of freedom (the theoretical or QCD side) or using hadronic degrees of freedom (the phenomenological side). In the QCD side the correlators are evaluated using the Wilson operator product expansion (OPE). The OPE incorporates the effects of the QCD vacuum through an infinite series of condensates of increasing dimension. On the other hand, the representation in terms of hadronic degrees of freedom is responsible for the introduction of the form factors, decay constants and masses. Both representations are matched invoking the quark–hadron global duality.

### 2.1. *The OPE side*

In the OPE or theoretical side each meson interpolating field appearing in Eqs. (1) and (2) can be written in terms of the quark field operators in the following form:

$$j^{\rho^+}_\nu(x) = \bar{d}(x)\gamma_\nu u(x) \tag{4}$$

and

$$j^{D^{*-}}_\mu(x) = \bar{c}(x)\gamma_\mu d(x), \tag{5}$$

where $u$, $d$ and $c$ are the up, down and charm quark field, respectively. Each one of these currents has the same quantum numbers of the associated meson.

For each one of the invariant amplitudes appearing in Eq. (3), we can write a double dispersion relation over the virtualities $p^2$ and $p'^2$, holding $Q^2=-q^2$ fixed:

$$\Gamma_i(p^2,p'^2,Q^2) = -\frac{1}{\pi^2}\int_{s_{\min}}^{\infty} ds \int_{u_{\min}}^{\infty} du\, \frac{\rho_i(s,u,Q^2)}{(s-p^2)(u-p'^2)}, \quad i=1,\ldots,14, \tag{6}$$

where $\rho_i(s,u,Q^2)$ equals the double discontinuity of the amplitude $\Gamma_i(p^2,p'^2,Q^2)$, calculated using the Cutkosky's rules. The invariant amplitudes receive contributions from all terms in the OPE. The first one of those contributions comes from the perturbative term and it is represented in Fig. 1.

We can work with any structure appearing in Eq. (3), but we must choose those which have less ambiguities in the QCD sum rules approach, which means, less influence from the higher dimension condensates and a better stability as a function of the Borel mass. We have chosen the $g_{\mu\alpha}q_\nu$ structure. In this structure the quark condensate (the condensate of lower dimension) contributes in the case of $D^*$ meson off-shell.