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A QCDSR calculation of the $J/\psi D_s^* D_s$ strong coupling constant

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Abstract. In this work, we evaluate the coupling constant and the form factors of the vertex $J/\psi D_s^* D_s$ using the techniques of the QCD sum rules. We consider all the three mesons off shell, resulting in three different form factors. However, despite the different form factors, when extrapolated to the pole of each off-shell meson, we find coupling constants that are in completely agreement each other. The result for the vertex $J/\psi D_s^* D_s$ coupling constant is $g_{J/\psi D_s^* D_s} = 4.30^{+0.42}_{-0.37} GeV^-1$.

1. Introduction

The QCD sum rules has been used in the calculation of the coupling constants and form factors of various vertices and a great variety of mesons. Our group has calculated a graet number of vertices as the $D^*D\pi$ [1], $D^*D\rho$ [2], $J/\psi D^*D$ [3] and many others. In recent works using the QCDSR, vertices with the heavy beauty mesons(B, B^*, B_s, B_s^*,...) were object of study as the B_s^*BK [4], B_sB^*K [5], $B_s^*B_s\eta^{(\prime)}$ [6]. Vertices with strange-charmed mesons(D_s, D_s^*, D_{s1},...) has been studied as the $J/\psi D_sD_s$ [7, 8], $J/\psi D_s^*D_s^*$ [8] and others.

The strange-charmed vertices are a subject of a great interest actually in view of the new exotic states detected recently. Some of them with masses that lies just above the $D_s^{(*)}D_s^{(*)}$ mass threshold. Exotic states means that the usual quark-model description as $q\bar{q}$ does not hold for the case of new states. An example of exotic state is the $Y(4140)$, whose its first detection was made by the CDF collaboration [9], it has an observed decay in the pair $J/\psi\phi$. There are some interpretations for its internal structure as the $D_s\bar{D}_s^*$ molecular state [10], $D_s^*\bar{D}_s^*$ molecular state [11, 12, 13, 14], the tetraquark state [15] and a hybrid state [11]. Among these interpretations, we emphasize the molecular $D_s^*\bar{D}_s^*$ hypothesis, so that the decay $Y(4140) \to J/\psi\phi$ can be understood as an intermediate decay as $Y(4140) \to D_s^*\bar{D}_s^* \to J/\psi\phi$. The vertex $J/\psi D_s^*D_s$ is present in this decay, so that a precise knowledge of its form factor and coupling constant may contribute for the understanding of the constitution of the $Y(4140)$ meson.

In this present work, the vertex $J/\psi D_s^*D_s$ is studied by applying the QCDSR formalism. The development of this work consists in evaluating the form factors from the three point correlation

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function with quark and gluons degrees of freedom(OPE side) and with hadronic degrees of freedom(phenomenological side); so, the next step is to perform a double Borel transform in both sides and equating them. From the calculated form factor, we obtain the coupling constant by extrapolating its value to the pole of the off-shell meson.

2. Formalism

In this work, we calculate three different three point correlation functions [16], each corresponding to each off-shell meson. The correlation functions corresponds respectively to J/ψ off-shell, D_s^* off-shell and D_s off-shell.

$$\Gamma_{\mu\nu}^{(J/\psi)}(p,p') = \int \langle 0'|T\{j_5^{D_s}(x) j_\mu^{J/\psi\dagger}(y) j_\nu^{D_s^*\dagger}(0)\}|0'\rangle \, e^{ip'x} e^{-iqy} d^4x d^4y, \quad (1)$$

$$\Gamma_{\mu\nu}^{(D_s^*)}(p,p') = \int \langle 0'|T\{j_5^{D_s}(x) j_\nu^{D_s^*\dagger}(y) j_\mu^{J/\psi\dagger}(0)\}|0'\rangle \, e^{ip'x} e^{-iqy} d^4x d^4y, \quad (2)$$

$$\Gamma_{\mu\nu}^{(D_s)}(p,p') = \int \langle 0'|T\{j_\nu^{D_s^*}(x) j_5^{D_s\dagger}(y) j_\mu^{J/\psi\dagger}(0)\}|0'\rangle \, e^{ip'x} e^{-iqy} d^4x d^4y, \quad (3)$$

where $q = p' - p$ is the transferred momentum.

Firstly, these correlation functions are calculated using the quarks and gluons degrees of freedom(OPE side) and using the hadron degrees of freedom(phenomenological side). Then, the form factors and the coupling constants are obtained by equating both sides using the quark-hadron duality, after applying a double Borel transform in both sides.

2.1. The phenomenological side

The effective Lagrangian of $J/\psi D_s^* D_s$ vertex [17, 18] is given by

$$\mathcal{L}_{J/\psi D_s^* D_s} = -g_{J/\psi D_s^* D_s} \varepsilon^{\alpha\beta\gamma\delta} \partial_\alpha \psi_\beta \left(\partial_\gamma D_{s\delta}^{*-} D_s^+ + \partial_\gamma D_{s\delta}^{*+} D_s^- \right), \quad (4)$$

where $\varepsilon^{0123} = +1$ is the Levi-Civita totally antisymmetric tensor.

From this Lagrangian, we obtain the vertices of the hadronic processes that are used to the calculation of the phenomenological side . For the J/ψ, D_s^* and D_s off-shell cases, these vertices are, respectively:

$$\langle D_s^*(p) J/\psi(q)|D_s(p')\rangle = i g_{J/\psi D_s^* D_s}^{(J/\psi)}(q^2) \epsilon_\beta(q,\lambda) \epsilon_\delta(p,\lambda) q_\alpha p_\gamma \varepsilon^{\alpha\beta\gamma\delta}, \quad (5)$$

$$\langle J/\psi(p) D_s^*(q)|D_s(p')\rangle = i g_{J/\psi D_s^* D_s}^{(D_s^*)}(q^2) \epsilon_\beta(p,\lambda) \epsilon_\delta(q,\lambda) p_\alpha q_\gamma \varepsilon^{\alpha\beta\gamma\delta}, \quad (6)$$

$$\langle J/\psi(p) D_s(q)|D_s^*(p')\rangle = -i g_{J/\psi D_s^* D_s}^{(D_s)}(q^2) \epsilon_\beta(p,\lambda) \epsilon_\delta^*(p',\lambda) p_\alpha p'_\gamma \varepsilon^{\alpha\beta\gamma\delta}, \quad (7)$$

where $g_{J/\psi D_s^* D_s}^{(M)}(q^2)$ is the form factor of the $J/\psi D_s^* D_s$ vertex with meson M off-shell ($M = J/\psi, D_s, D_s^*$).

Using each of these vertices in the corresponding correlation function, we can obtain the phenomenological side. It is convenient to make the change of variables $p^2 \to -P^2$, $p'^2 \to -P'^2$ and $q^2 \to -Q^2$. Then, we have the correlation functions of the phenomenological side for each

off-shell case:

$$\Gamma_{\mu\nu}^{phen(J/\psi)} = \frac{Cg_{J/\psi D_s^* D_s}^{(J/\psi)}(q^2)p'^{\lambda}p^{\sigma}\varepsilon_{\mu\nu\lambda\sigma}}{(p^2+m_{D_s^*}^2)(q^2+m_{J/\psi}^2)(p'^2+m_{D_s}^2)} + h.r.\,, \tag{8}$$

$$\Gamma_{\mu\nu}^{phen(D_s^*)} = \frac{-Cg_{J/\psi D_s^* D_s}^{(D_s^*)}(q^2)p'^{\lambda}p^{\sigma}\varepsilon_{\mu\nu\lambda\sigma}}{(p^2+m_{J/\psi}^2)(q^2+m_{D_s^*}^2)(p'^2+m_{D_s}^2)} + h.r.\,, \tag{9}$$

$$\Gamma_{\mu\nu}^{phen(D_s)} = \frac{Cg_{J/\psi D_s^* D_s}^{(D_s)}(q^2)p'^{\lambda}p^{\sigma}\varepsilon_{\mu\nu\lambda\sigma}}{(p^2+m_{J/\psi}^2)(q^2+m_{D_s}^2)(p'^2+m_{D_s^*}^2)} + h.r.\,, \tag{10}$$

where $h.r.$ stands for the contributions of higher resonances and continuum states of each meson and C is defined as:

$$C = \frac{f_{D_s} f_{D_s^*} f_{J/\psi} m_{D_s}^2 m_{D_s^*} m_{J/\psi}}{(m_c + m_s)}\,. \tag{11}$$

2.2. The OPE side

In order to obtain the OPE side; in the eqs. (1), (2) and (3), we use the interpolating currents in terms of quark fields: $j_\mu^{J/\psi} = \bar{c}\gamma_\mu c$, $j_\nu^{D_s^{*-}} = \bar{c}\gamma_\nu s$ and $j_5^{D_s^-} = i\bar{c}\gamma_5 s$. The OPE side is an expansion named as Wilson's Operator Product Expansion. This expansion is dominated by the perturbative term and followed by the non-perturbative contributions:

$$\Gamma_{\mu\nu}^{OPE(M)} = \Gamma_{\mu\nu}^{pert(M)} + \Gamma_{\mu\nu}^{non\text{-}pert(M)}\,, \tag{12}$$

where $\Gamma_{\mu\nu}^{pert(M)}$ is the perturbative term and $\Gamma_{\mu\nu}^{non\text{-}pert(M)}$ are the non-perturbative contributions to the correlation function. Considering the similarities between the $J/\psi D_s^* D_s$ and both $J/\psi D_s D_s$ and $J/\psi D^* D$ vertices, we expect a similar behavior regarding the OPE series as obtained in the two latter works [3, 7].Therefore, it should be adequate to consider non-perturbative contributions up to the mixed quark-gluon condensate:

$$\Gamma_{\mu\nu}^{non\text{-}pert} = \Gamma_{\mu\nu}^{\langle\bar{q}q\rangle} + \Gamma_{\mu\nu}^{m_q\langle\bar{q}q\rangle} + \Gamma_{\mu\nu}^{\langle g^2G^2\rangle} + \Gamma_{\mu\nu}^{\langle\bar{q}g\sigma Gq\rangle} + \Gamma_{\mu\nu}^{m_q\langle\bar{q}g\sigma Gq\rangle}\,. \tag{13}$$

The calculation of eq. (12) regarding the perturbative and the non-perturbative contributions of eq. (13) corresponds to the calculation of the diagrams of fig. 1. The J/ψ off-shell case is the only that has contributions from all the non-perturbative terms as a consequence of the application of the Borel transform. In the D_s and D_s^* off-shell cases the non-perturbative contributions are suppressed because these cases involves the condensates of charm quark that are very small or even zero.

Using the dispersions relations, the perturbative term (fig. 1a) for a given meson M off-shell can be written as:

$$\Gamma_{\mu\nu}^{pert(M)}(p,p') = -\frac{1}{4\pi^2}\int_0^\infty\int_0^\infty \frac{\rho_{\mu\nu}^{pert(M)}(s,u,t)}{(s-p^2)(u-p'^2)}dsdu\,, \tag{14}$$

where the spectral density $\rho_{\mu\nu}^{pert(M)}(s,u,t)$ is obtained by the application of Cutkosky's rules. The quantities $s=p^2$, $u=p'^2$ and $t=q^2$ are the Mandelstam variables.

The eq. (14) is the main contributing term of the OPE series in a QCDSR calculation. The spectral density can be parametrized as:

$$\rho_{\mu\nu}^{pert(M)}(s,u,t) = \frac{3}{\sqrt{\lambda}} F^{(M)}(s,u,t) p'^{\lambda} p^{\sigma} \varepsilon_{\mu\nu\lambda\sigma} \,, \tag{15}$$

where $\lambda = (u+s-t)^2 - 4us$ and $F^{(M)}$ is an invariant amplitude. For the J/ψ and D_s off shell, the invariant amplitude can be written as:

$$F^{(J/\psi)} = (m_s - m_c)(A+B) - m_s \,, \tag{16}$$

$$F^{(D_s)} = -F^{(D_s^*)} = (m_c - m_s)B - m_c \,, \tag{17}$$

where

$$A = \left[\frac{\bar{k}_0}{\sqrt{s}} - \frac{p'_0 \overline{|\vec{k}|} \overline{\cos\theta}}{|\vec{p'}|\sqrt{s}} \right] , \qquad B = \frac{\overline{|\vec{k}|}\overline{\cos\theta}}{|\vec{p'}|} \,. \tag{18}$$

The quark condensate in fig. 1b corresponds to the first non-perturbative contributions:

$$\Gamma_{\mu\nu}^{\langle\bar{s}s\rangle(J/\psi)} = \frac{-\langle\bar{s}s\rangle p'^{\lambda} p^{\sigma} \varepsilon_{\mu\nu\lambda\sigma}}{(p^2 - m_c^2)(p'^2 - m_c^2)} \,. \tag{19}$$

The expressions for the gluon condensates ($\langle g^2 G^2\rangle$) of fig. 1d-1i and mixed quark-gluon condensates ($\langle \bar{s} g\sigma \cdot Gs\rangle$) of fig. 1j-1o for the J/ψ off-shell case can be found in Ref. [23].

2.3. The QCD sum rules

In order to obtain the expressions for the form factors, we make the change of variables $p^2 \to -P^2$, $p'^2 \to -P'^2$ and $q^2 \to -Q^2$ followed by a double Borel transform to both sides of the QCDSR in eqs. (8)-(10) and (12), which involves the transformation: $P^2 \to M^2$ and $P'^2 \to M'^2$, where M and M' are the Borel masses. After that, we equate the phenomenological and OPE sides, taking the quark-hadron duality. So, we obtain the QCDSR expressions for the form factor for each case off-shell:

$$g_{J/\psi D_s^* D_s}^{(J/\psi)}(Q^2) = \frac{-\frac{3}{4\pi^2}\int_{s_{inf}}^{s_0}\int_{u_{inf}}^{u_0} \frac{1}{\sqrt{\lambda}} F^{(J/\psi)} e^{-\frac{s}{M^2}} e^{-\frac{u}{M'^2}} ds du + \mathcal{BB}\left[\Gamma^{non\text{-}pert}\right]}{\frac{C}{(Q^2+m_{J/\psi}^2)} e^{-m_{D_s^*}^2/M^2} e^{-m_{D_s}^2/M'^2}} \,, \tag{20}$$

$$g_{J/\psi D_s^* D_s}^{(D_s^*)}(Q^2) = \frac{\frac{3}{4\pi^2}\int_{s_{inf}}^{s_0}\int_{u_{inf}}^{u_0} \frac{1}{\sqrt{\lambda}} F^{(D_s^*)} e^{-\frac{s}{M^2}} e^{-\frac{u}{M'^2}} ds du + \mathcal{BB}\left[\Gamma^{\langle g^2G^2\rangle}\right]}{\frac{C}{(Q^2+m_{D_s^*}^2)} e^{-m_{J/\psi}^2/M^2} e^{-m_{D_s}^2/M'^2}} \,, \tag{21}$$

$$g_{J/\psi D_s^* D_s}^{(D_s)}(Q^2) = \frac{-\frac{3}{4\pi^2}\int_{s_{inf}}^{s_0}\int_{u_{inf}}^{u_0} \frac{1}{\sqrt{\lambda}} F^{(D_s)} e^{-\frac{s}{M^2}} e^{-\frac{u}{M'^2}} ds du + \mathcal{BB}\left[\Gamma^{\langle g^2G^2\rangle}\right]}{\frac{C}{(Q^2+m_{D_s}^2)} e^{-m_{J/\psi}^2/M^2} e^{-m_{D_s^*}^2/M'^2}} \,, \tag{22}$$

As the QCDSR, the definition for the coupling constant $g_{J/\psi D_s^* D_s}$ is given by:

$$\lim_{Q^2 \to -m_M^2} g_{J/\psi D_s^* D_s}^{(M)}(Q^2) \,. \tag{23}$$

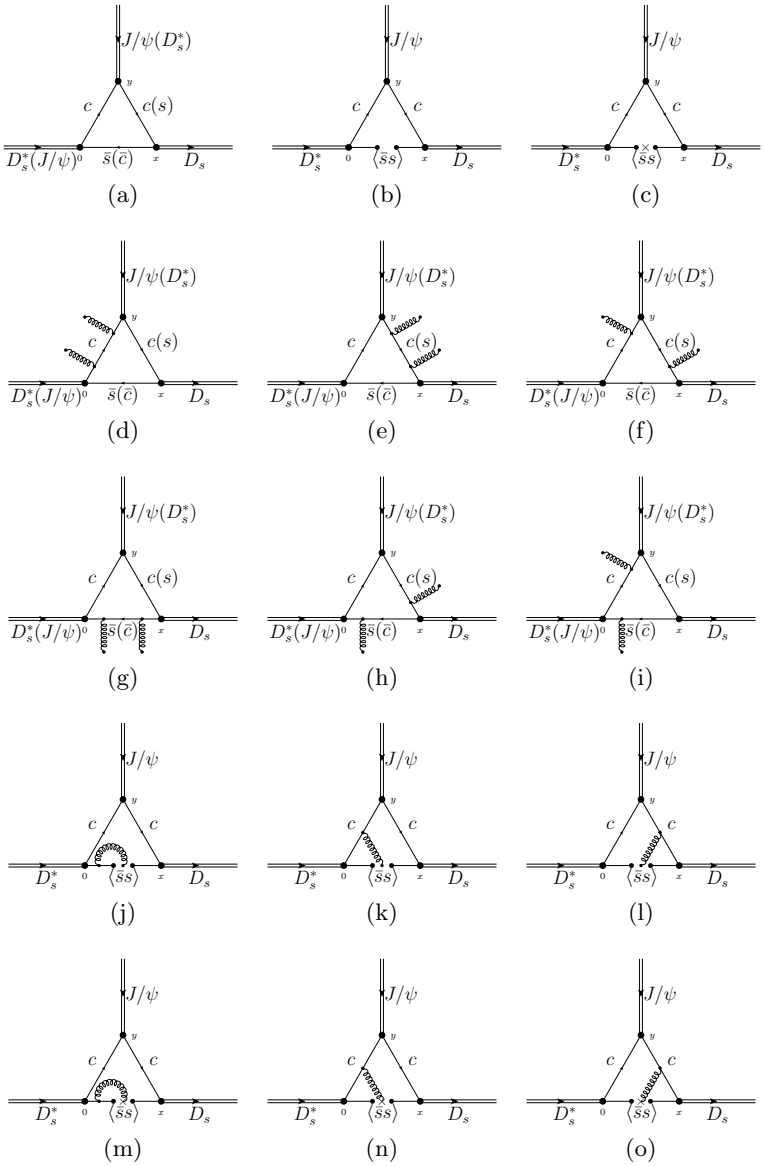


Figure 1: Contributing OPE diagrams for $J/\psi(D_s^*)$ off-shell. The D_s off-shell case corresponds to a permutation of the D_s and D_s^* mesons of the D_s^* off-shell case.

To calculate the coupling constants, it is necessary to extrapolate the results for the form factor to the region of $Q^2 < 0$. From eqs. (20)-(22) we can obtain the coupling constant from three different form factors, one for each meson off-shell. However, the coupling constant must be the same regardless the form factor used for the extrapolation. This condition is used to minimize the uncertainties in the determination of the coupling constant.

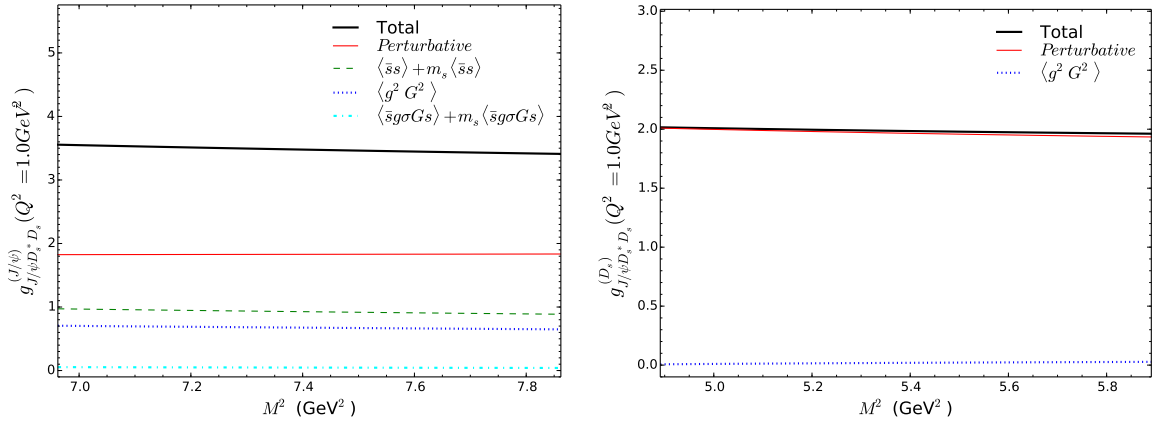
3. Results and discussion

The vertex $J/\psi D_s^* D_s$ has three different form factors shown in eqs. (20)-(22) . We perform numerical calculation of these form factors that gives results that must be fitted to an analytical function of Q^2. To minimize the uncertainties, it is required that these three form factors lead to the same coupling constant. This condition is useful to find the Borel masses and continuum thresholds and to reduce the errors.

Table 1: Parametrization of the form factors and numerical results for the coupling constant of this work.

Quantity	J/ψ off-shell	D_s^* off-shell	D_s off-shell
Q^2 (GeV^2)	[0.5, 2.0]	[1.0, 3.0]	[1.0, 4.0]
M^2 (GeV^2)	[7.0, 7.9]	[5.3, 7.3]	[4.9, 5.9]
$g^{(M)}_{J/\psi D_s^* D_s}(Q^2)$	$\frac{A}{B+Q^2}$	$Ae^{-Q^2/B}$	$Ae^{-Q^2/B}$
A	193.4 GeV	2.003 GeV^{-1}	2.330 GeV^{-1}
B (GeV^2)	54.46	6.027	6.122
$g^{(M)}_{J/\psi D_s^* D_s} \pm \sigma$ (GeV^{-1})	$4.31^{+1.21}_{-1.20}$	$4.20^{+1.32}_{-1.12}$	$4.39^{+1.44}_{-1.30}$

Table (1) shows the parameters used in this calculation. The continuum threshold parameters, s_0 and u_0, are defined as $s_0 = (m_i + \Delta_i)^2$ and $u_0 = (m_o + \Delta_o)^2$, where the quantities Δ_i and Δ_o have been determined imposing the most stable Borel window. In order to include the pole and to exclude the contributions from higher resonances and continuum states, the values for $\Delta_{J/\psi}$, $\Delta_{D_s^*}$ and Δ_{D_s} cannot be far from the experimental value (when available) of the distance between the pole and the first excited state [19, 24]. In our analysis, we have found that the best values are $\Delta_{D_s} = 0.6$ GeV and $\Delta_{D_s^*} = \Delta_{J/\psi} = 0.5$ GeV, which leads to a stable Borel windows for the three off-shell cases, as shown in fig. 2 for J/ψ and D_s off-shell. Figures for D_s^* off-shell are omitted as they are very similar to the D_s off-shell case.

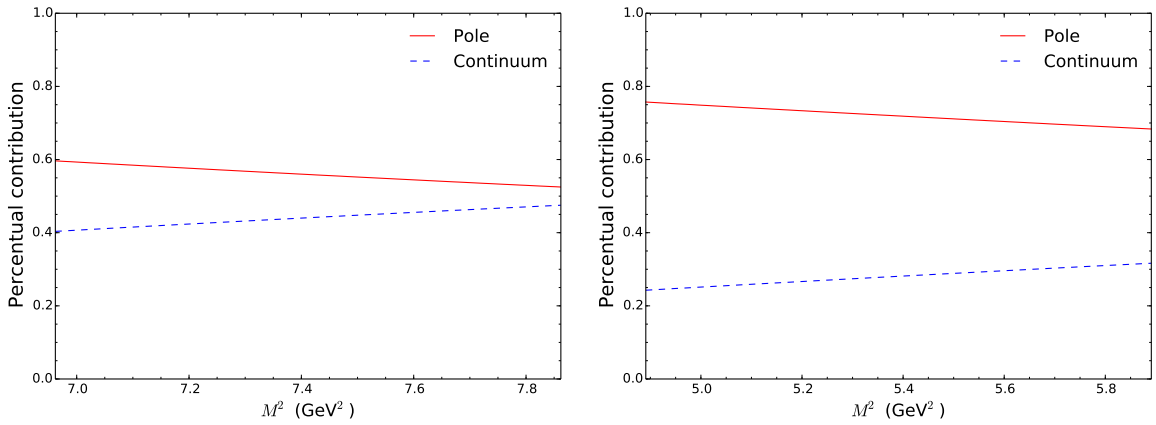


(a) (b)

Figure 2: OPE contributions for J/ψ off-shell (panel **(a)**) and D_s off-shell (panel **(b)**).

Besides the values of the Borel masses and the continuum thresholds, we also need to know the values of decay constants, quark masses, condensates and hadrons and quark masses. These values are: $f_{D_s} = 257.15 \pm 6.1(MeV)$ [19], $f_{D_s^*} = 301 \pm 13(MeV)$ [19], $f_{J/\psi} = 416 \pm 6(MeV)$ [19], $m_c = 1.27^{+0.07}_{-0.09}$ (GeV) [19], $m_s = 101^{+29}_{-21}$ (MeV)[19], $\langle\bar{s}s\rangle = -(290 \pm 15)^3$ (MeV^3)[25], $\langle g^2 G^2\rangle = 0.88 \pm 0.16$(GeV^4)[26], $\langle\bar{s}g\sigma \cdot Gs\rangle = (0.8 \pm 0.2)\langle\bar{s}s\rangle$(GeV^5)[27]. The masses of hadrons of this vertex are $m_{D_s} = 1.968$ GeV, $m_{D_s^*} = 2.112$ GeV and $m_{J/\psi} = 3.097$ GeV [19].

The form factor obtained for the J/ψ off-shell case was well adjusted by a monopolar curve, while for the D_s^* and D_s off-shell cases, the form factors were well adjusted by exponential curves in fig. 4. The coupling constant of the J/ψ off-shell is $g^{(J/\psi)}_{J/\psi D_s^* D_s} \pm \sigma(GeV^{-1}) = 4.31^{+1.21}_{-1.20} GeV^{-1}$.



(a) (b)

Figure 3: Pole and continuum contributions for the J/ψ off-shell (panel **(a)**) and for D_s off-shell (panel **(b)**), both at $Q^2 = 1$ GeV^2.

The value found for the D_s^* off-shell case is $g^{(D_s^*)}_{J/\psi D_s^* D_s} \pm \sigma(GeV^{-1}) = 4.20^{+1.32}_{-1.12} GeV^{-1}$ and the coupling constant of the D_s off-shell case is $g^{(D_s)}_{J/\psi D_s^* D_s} \pm \sigma(GeV^{-1}) = 4.39^{+1.44}_{-1.30} GeV^{-1}$.

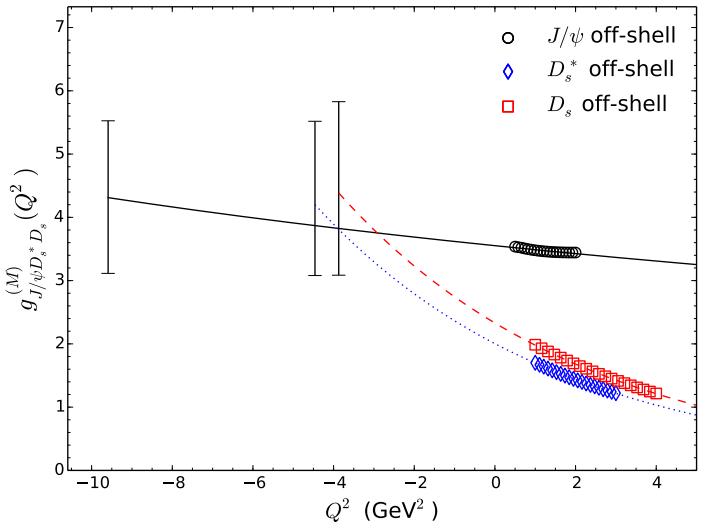


Figure 4: Form factors of the $J/\psi D_s^* D_s$ vertex.

4. Conclusion

In this work we have calculated the $g_{J/\psi D_s^* D_s}$ coupling constant by three different QCD sum rules: one with the D_s meson off-shell, another with the D_s^* meson off-shell and a third one with the J/ψ meson off-shell. This procedure allowed us to reduce the uncertainties related to the method, leading to compatible coupling constants, as seen in fig. 4.

Taking the mean value between the numbers presented in table 1, we obtain the following

final result for $g_{J/\psi D_s^* D_s}$:

$$g_{J/\psi D_s^* D_s} = 4.30^{+1.53}_{-1.22}\ \text{GeV}^{-1}\ . \tag{24}$$

This coupling constant was obtained from sum rules that respect the pole dominance over the continuum, the perturbative contribution of the OPE being the dominant one and the form factor stability regarding the Borel mass in the whole Borel window, as shown in fig. 3.

In these results, there is the form factor given by a monopolar parametrization when the heaviest meson (J/ψ) is off-shell, while an exponential one is the case when one of the lightest mesons (D_s or D_s^*) is off-shell. Furthermore, the OPE series presents, in both vertices, the same hierarchy for the contribution of each term, as well as comparable contributions among terms of the same dimension.

We can also compare our result for the $g_{J/\psi D_s^* D_s}$ coupling constant eq. (24) with the results of previous QCDSR works, presented in table 2.

Table 2: Values of coupling constants obtained using different methods.

QCDSR [20] $(GeV)^{-1}$	QCDSR [3] $(GeV)^{-1}$	QCDSR [7]	VMD [21, 22]
$g_{J/\psi D_s^* D_s} = 3.03 \pm 0.62$	$g_{J/\psi D^* D} = 4.0 \pm 0.6$	$g_{J/\psi D_s D_s} = 5.98^{+0.67}_{-0.58}$	$g_{J/\psi DD} = 7.44$

Finally, we can compare our result with the coupling constant $g_{J/\psi DD}$ from the vector meson dominance (VMD) [21, 22] using the SU(3) and HQET relations, which leads to $g_{J/\psi D_s^* D_s} = 3.84$ GeV^{-1}. This coupling is also compatible with the one of eq. (24) within 1σ.

References

[1] Navarra F S, Nielsen M and Bracco M E 2002 *Phys. Rev. D* **65** 037502
[2] Rodrigues B O et al 2011 *Nucl. Phys. A* **852** 127
[3] Matheus R D et al 2005 *Int. J Mod. Phys. E* **14** 555
[4] Cerqueira Jr A, Rodrigues B O and Bracco M E 2012 *Nucl. Phys. A* **874** 130
[5] Cerqueira Jr A, Rodrigues B O, Bracco M and Nielsen M 2015 *Nucl. Phys. A* **936** 45-58
[6] Yazici E et al 2013 *Eur. Phys. J Plus* **128** 113
[7] Rodrigues B O, Bracco M and Chiapparini M 2014 *Nucl. Phys. A* **929** 143
[8] Khosravi R, Janbazi M 2013 *Phys. Rev. D* **87** 016003
[9] Aaltonen T et al (CDF Collaboration) 2009 *Phys. Rev. Lett.* **102** 242002
[10] Qiao, Cong-Feng, Tang and Liang 2014 *EPL* **107** 31001
[11] Mahajan N 2009 *Phys. Lett. B* **679** 228
[12] Albuquerque R M, Bracco M E and Nielsen M 2009 *Phys. Lett. B* **678** 186
[13] Liu X, Zhu S L and Nielsen M 2009 *Phys. Rev. D* **80** 017502
[14] Wang Z G 2009 *Eur. Phys. J* **63** 115
[15] Stancu F 2010 *J Phys. G Nucl. Part. Phys.* **37** 075017
[16] Bracco M E et al 2012 *Prog. Part. Nucl. Phys.* **67** 1019
[17] Liu X, Zhang B and Zhu S L 2007 *Phys. Lett. B* **645** 185
[18] Azevedo R S and Nielsen M 2004 *Phys. Rev. C* **69** 035201
[19] Nakamura K et al 2010 *J Phys. G Nucl. Par. Phys* **37** 1422
[20] Khosravi R, Janbazi M 2013 *Phys. Rev. D* **89** 016001
[21] Oh Y, Song T and Lee S H 2001 *Phys. Rev. C* **63** 034901
[22] Oh Y, Song T and Lee S H 2007 *Phys. Rev. C* **75** 064903
[23] Rodrigues B O, Bracco M E, Chiapparini M and Cerqueira Jr A 2015 *Eur. Phys. J***51** 1-8
[24] Badalian A M and Bakker B L G 2011 *Phys. Rev. D***84** 034006
[25] McNeile C et al 2013 *Phys. Rev. D***87** 034503
[26] Narison S 2012 *Phys. Lett. B***706** 412
[27] Ioffe B 2006 *Prog Part. Nucl. Phys.***56** 232