Prediction for the decay width of a charged state near the $D_s\bar{D}^*/D_s^*\bar{D}$ threshold

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Very recently the existence of a charged state near the $D_s\bar{D}^*/D_s^*\bar{D}$ threshold was predicted. This state, that we call Z_{cs}^+, would be the strange partner of the recently observed $Z_c^\pm(3900)$. Using standard techniques of QCD sum rules, we evaluate the three-point function for the vertices $Z_{cs}^+ J/\psi K^+$, $Z_{cs}^+\eta_c K^{*+}$ and $Z_{cs}^+ D_s^+\bar{D}^{*0}$, and we make predictions for the corresponding decay widths in these channels.

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In a pioneering work, using the initial single pion emission mechanism (ISPE), the authors of Ref. [1] have predicted the existence of a charged state, close to the $D^*\bar{D}$ threshold, in the hidden-charm dipion decay of the charmoniumlike structure $Y(4260)$. This state, called $Z_c^+(3900)$, was soon after observed by the BESIII and BELLE collaborations in $e^+e^- \to J/\psi\pi^+\pi^-$ at $\sqrt{s} =$ 4260 MeV [2,3]. This observation was also confirmed by the authors of Ref. [4] using CLEO-c data. Stimulated by this discovery, the authors of Ref. [5] have extended the ISPE mechanism to include the kaon, the chiral partner of the pion. They call it the initial single chiral particle emission (ISChE) mechanism. Under the ISChE mechanism, it is possible to study the hidden-charm dikaon decay of a charmoniumlike states. In particular, studying the hidden-charm dikaon decay of the charmoniumlike structure $Y(4660)$, the authors of Ref. [5] find a sharp peak structure close to the $D_s\bar{D}^*/D_s^*\bar{D}$ threshold. Therefore, a charged charmoniumlike structure with hidden-charm and open-strange channels with mass close to the $D_s\bar{D}^*/D_s^*\bar{D}$ threshold, which we call $Z_{cs}^\pm$, should be seen in the $Y(4600) \to J/\psi K^+K^-$ decay.

The mass of a $J^P = 1^+$ $D_s\bar{D}^*$ molecular state was first predicted, using the QCD sum rules (QCDSR) method [6–8], in Ref. [9]. They found $m_{Z_{cs}} = (3.97 \pm 0.08)$ GeV, which is very close to the $D_s^+\bar{D}^{*0}$ threshold at 3.976 GeV. In this work we use the method of QCDSR to study some hadronic decays of $Z_{cs}^\pm$, considering the Z_{cs} as a tetraquark state, similar to what was done for the $Z_c^\pm(3900)$ state in Ref. [10]. Therefore, the interpolating field for Z_{cs}^+ is given by

$$j_\alpha = \frac{i\epsilon_{abc}\epsilon_{dec}}{\sqrt{2}}[(u_a^T C\gamma_5 c_b)(\bar{s}_d\gamma_\alpha C\bar{c}_e^T) - (u_a^T C\gamma_\alpha c_b)(\bar{s}_d\gamma_5 C\bar{c}_e^T)], \quad (1)$$

where $a, b, c, \ldots$ are color indices, and C is the charge conjugation matrix. The mass obtained in QCDSR for the Z_{cs} state described by the current in Eq. (1) is the same as the one obtained in Ref. [9], as expected from the results presented in Ref. [11]. Therefore, here we evaluate only the decay width. For a comprehensive review of the use of different currents to describe four-quark states, we refer the reader to Ref. [12].

We will consider four decay channels: $Z_{cs}^+ \to J/\psi K^+$, $Z_{cs}^+ \to \eta_c K^{*+}$, $Z_{cs}^+ \to \bar{D}^{*0}D_s^+$, and $Z_{cs}^+ \to \bar{D}^0 D_s^{*+}$. Besides these four discussed decay channels, $Z_{cs}^+ \to \chi_{c0}K^+$ via P wave is allowed, where the sum of the masses of χ_{c0} and Kaon is about 3912 MeV less than the central value of the mass of Z_{cs}^+ [9]. However, in this work we will not include this channel in our discussion since this P-wave decay and small phase space can suppress the decay width of $Z_{cs}^+ \to \chi_{c0}K^+$ compared with these two S-wave hidden-charm decay channels $Z_{cs}^+ \to J/\psi K^+$ and $Z_{cs}^+ \to \eta_c K^{*+}$.

In these four channels, there is always a vector and pseudoscalar mesons as final states. For the last three cases, the pseudoscalar mesons are described by pseudoscalars currents:

$$j_5^{\eta_c} = i\bar{c}_a\gamma_5 c_a, \quad j_5^D = i\bar{c}_a\gamma_5 u_a, \quad \text{and} \quad j_5^{D_s} = i\bar{s}_a\gamma_5 c_a. \quad (2)$$

However, it is well known that the kaon cannot be well described, in QCDSR, by a pseudoscalar current [13]. Therefore, in the case of the $Z_{cs}^+ \to J/\psi K^+$ decay, we use an axial current to describe the kaon

$$j_{5\nu}^K = \bar{s}_a\gamma_5\gamma_\nu u_a. \quad (3)$$

For the vector mesons, we use the currents

$$j_\mu^\psi = \bar{c}_a\gamma_\mu c_a, \quad j_\mu^{D^*} = \bar{c}_a\gamma_\mu u_a, \quad j_\mu^{D_s^*} = \bar{s}_a\gamma_\mu c_a \quad \text{and} \quad j_\mu^{K^*} = \bar{s}_a\gamma_\mu u_a. \quad (4)$$

The QCDSR calculation of these four vertices are based on the three-point function given by

$$\Pi_{\mu i\alpha}(p, p', q) = \int d^4x\, d^4y\, e^{ip'.x}\, e^{iq.y}\, \Pi_{\mu i\alpha}(x, y), \quad (5)$$

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with

$$\begin{aligned}\Pi_{\mu\nu\alpha}(x,y) &= \langle 0|T[j_\mu^{\psi}(x)j_{5\nu}^{K}(y)j_\alpha^{\dagger}(0)]|0\rangle,\\ \Pi_{\mu\alpha}(x,y) &= \langle 0|T[j_5^{\eta_c}(x)j_\mu^{K^*}(y)j_\alpha^{\dagger}(0)]|0\rangle,\\ \Pi_{\mu\alpha}(x,y) &= \langle 0|T[j_\mu^{D^*}(x)j_5^{D_s}(y)j_\alpha^{\dagger}(0)]|0\rangle,\\ \Pi_{\mu\alpha}(x,y) &= \langle 0|T[j_\mu^{D_s^*}(x)j_5^{D}(y)j_\alpha^{\dagger}(0)]|0\rangle,\end{aligned} \tag{6}$$

for the four decays. In Eq. (6) $p = p' + q$.

The tetraquark current in Eq. (1) has a nontrivial color structure. However, due to Fierz transformation [12], the tetraquark current can be rewritten also in terms of molecular currents. Therefore, although one does not expect that the tetraquark state could decay, without color exchange, into mesons, fall apart decays are not supressed in the calculation. To assure that the nontrivial color structure of the current in Eq. (1) is maintained in the QCDSR calculation, in the operator product expansion (OPE) side, we will consider only the diagrams with nontrivial color structure, as in Ref. [10]. These diagrams are called color-connected (CC) diagrams. In the case of the $Z_{cs}^+ \to J/\psi K^+$ decay, one of the CC diagrams that contribute to the OPE side is shown in Fig. 1. Possible permutations (not shown) of the diagram in Fig. 1 also contribute.

The diagram in Fig. 1 contributes to many structures. However, as we can see below, only the structures $q_\nu g_{\mu\alpha}$ and $q_\nu p'_\mu p'_\alpha$ also appear in the phenomenological side. Following Ref. [10] we choose to work with the $q_\nu p'_\mu p'_\alpha$ structure. Therefore, in the OPE side and in the $q_\nu p'_\mu p'_\alpha$ structure, we obtain

$$\Pi^{(\mathrm{OPE})} = \frac{(\langle\bar{q}g\sigma.Gq\rangle + \langle\bar{s}g\sigma.Gs\rangle)}{24\sqrt{2}\pi^2}\frac{1}{q^2} \times \int_0^1 d\alpha \frac{\alpha(1-\alpha)}{m_c^2 - \alpha(1-\alpha)p'^2}. \tag{7}$$

The phenomenological side of the sum rule can be evaluated by inserting intermediate states for Z_{cs}, J/ψ, and K into Eq. (5). We get

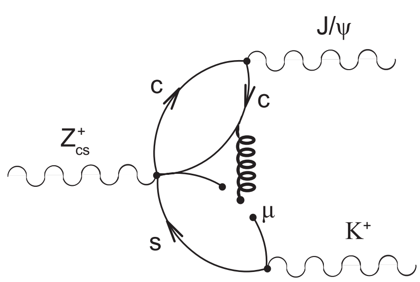

FIG. 1. CC diagram which contributes to the OPE side of the sum rule.

$$\Pi_{\mu\nu\alpha}^{(\mathrm{phen})}(p,p',q) = \frac{\lambda_{Z_{cs}} m_\psi f_\psi F_K g_{Z_{cs}\psi K}(q^2) q_\nu}{(p^2 - m_{Z_{cs}}^2)(p'^2 - m_\psi^2)(q^2 - m_K^2)} \times \left(-g_{\mu\lambda} + \frac{p'_\mu p'_\lambda}{m_\psi^2}\right)\left(-g_\alpha^\lambda + \frac{p_\alpha p^\lambda}{m_{Z_{cs}}^2}\right) + \cdots. \tag{8}$$

The contribution of the excited states is included by the dots. These include pole-continuum and continuum contributions. The form factor, $g_{Z_{cs}\psi K}(q^2)$, appearing in Eq. (8), is defined as the generalization for an off-shell kaon, of the on-mass-shell coupling constant $g_{Z_{cs}\psi K}$. The coupling constant can be extracted from the effective Lagrangian

$$\mathcal{L} = g_{Z_{cs}\psi K} Z_{cs}^\mu \psi_\mu \bar{K} + cc. \tag{9}$$

From the Lagrangian in Eq. (9), we get

$$\langle J/\psi(p')K(q)|Z_{cs}(p)\rangle = g_{Z_{cs}\psi K}(q^2)\varepsilon_\lambda^*(p')\varepsilon^\lambda(p), \tag{10}$$

where $\varepsilon_\alpha(p)$, $\varepsilon_\mu(p')$ are the polarization vectors of the Z_{cs} and J/ψ mesons, respectively.

The coupling $\lambda_{Z_{cs}}$ and the meson decay constants f_ψ and F_K appearing in Eq. (8) are defined through the current-state couplings:

$$\begin{aligned}\langle 0|j_\mu^\psi|J/\psi(p')\rangle &= m_\psi f_\psi \varepsilon_\mu(p'),\\ \langle 0|j_{5\nu}^K|K(q)\rangle &= iq_\nu F_K,\\ \langle Z_{cs}(p)|j_\alpha|0\rangle &= \lambda_{Z_{cs}}\varepsilon_\alpha^*(p).\end{aligned} \tag{11}$$

If one neglects the kaon mass in the right-hand side of Eq. (8), we can extract directly the coupling constant, $g_{Z_{cs}\psi\pi}$, instead of the form factor, like in Refs. [10,14]. Therefore, isolating the $q_\nu p'_\mu p'_\alpha$ structure in Eq. (8) and making a single Borel transformation to both $P^2 = P'^2 \to M^2$, we get the sum rule

$$A(e^{-m_\psi^2/M^2} - e^{-m_{Z_{cs}}^2/M^2}) + B\, e^{-s_0/M^2} = \frac{(\langle\bar{q}g\sigma.Gq\rangle + \langle\bar{s}g\sigma.Gs\rangle)}{24\sqrt{2}\pi^2}\int_0^1 d\alpha\, e^{\frac{-m_c^2}{\alpha(1-\alpha)M^2}}, \tag{12}$$

where s_0 is the continuum threshold parameter for Z_{cs}: $\sqrt{s_0} = (4.5 \pm 0.1)$ GeV [9], and

$$A = \frac{g_{Z_{cs}\psi K}\lambda_{Z_{cs}} f_\psi F_K (m_{Z_{cs}}^2 + m_\psi^2 + m_K^2)}{2m_{Z_{cs}}^2 m_\psi (m_{Z_{cs}}^2 - m_\psi^2)}. \tag{13}$$

As commented above, the dots in Eq. (8) include pole-continuum and continuum contributions. The parameter B in Eq. (12) is introduced to take into account the contributions associated with pole-continuum transitions, which are not suppressed when only a single Borel transformation is done in a three-point function sum rule, as shown in Refs. [15–18].

The numerical values for quark masses and QCD condensates used in this calculation are listed in Table I [8,19].

The numerical values of the meson masses and decay constants used in all calculations are given in Table II.

For the Z_{cs} mass and the meson-current coupling, $\lambda_{Z_{cs}}$, defined in Eq. (11), we use the values determined from the two-point sum rule [9]: $m_{Z_{cs}} = (3.97 \pm 0.08)$ GeV and $\lambda_{Z_{cs}} = (1.8 \pm 0.2) \times 10^{-2}$ GeV^5.

In Ref. [9] it was shown that the Borel window where the two-point function for Z_{cs} shows good OPE convergence and pole dominance is in the range $2.0 \leq M^2 \leq 3.0$ GeV^2. Therefore, we use here this same Borel window. In Fig. 2 we show, through the circles, the rhs of Eq. (12), i.e., the OPE side of the sum rule, as a function of the Borel mass. We can fit the OPE results with the analytical expression in the lhs of Eq. (12). We get $A = (1.28 \pm 0.02) \times 10^{-4}$ GeV^5 and $B = -(1.03^{+0.31}_{-0.23}) \times 10^{-3}$ GeV^5, using $\sqrt{s_0} = (4.5 \pm 0.1)$ GeV. With the value obtained for A, through the fit, and the expression in Eq. (13), we get for the coupling constant

$$g_{Z_{cs}\psi K} = (2.58(6)_{s_0}(15)_{m_c}(10)_{\langle\bar{q}q\rangle}(18)_{m_0^2}(12)_{\lambda})\ \text{GeV} \\ = (2.58 \pm 0.30)\ \text{GeV}, \quad (14)$$

TABLE I. QCD input parameters.

Parameters	Values
m_c	(1.18–1.28) GeV
$\langle\bar{q}q\rangle$	$-(0.23 \pm 0.03)^3$ GeV^3
$m_0^2 \equiv \langle\bar{q}g\sigma.Gq\rangle/\langle\bar{q}q\rangle$	(0.8 ± 0.1) GeV^2
$\langle\bar{s}s\rangle/\langle\bar{q}q\rangle$	0.8

TABLE II. Meson masses and decay constants.

Quantity	Value	Reference
m_ψ	3.1 GeV	[20]
m_{η_c}	2.98 GeV	[20]
m_{D^*}	2.01 GeV	[20]
$m_{D_s^*}$	2.11 GeV	[20]
m_{D_s}	1.97 GeV	[20]
m_D	1.87 GeV	[20]
m_K^*	0.892 GeV	[20]
m_K	0.494 GeV	[20]
f_ψ	0.405 GeV	[20]
f_{η_c}	0.35 GeV	[21]
$f_{D_s^*}$	0.33 GeV	[22]
f_{D_s}	(0.24 ± 0.08) GeV	[23]
f_{D^*}	(0.24 ± 0.02) GeV	[14]
f_D	(0.18 ± 0.02) GeV	[14]
f_K	(0.16 ± 0.02) GeV	[20]
f_K^*	(0.22 ± 0.01) GeV	[20]

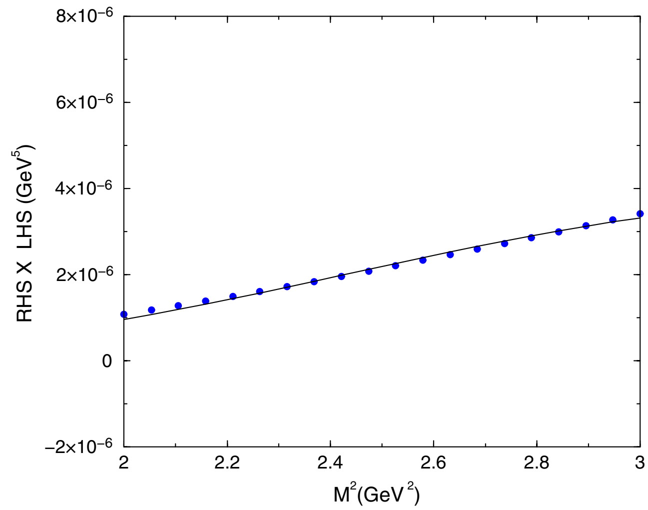

FIG. 2 (color online). Dots: the rhs of Eq. (12), as a function of the Borel mass for $\sqrt{s_0} = 4.5$ GeV. The solid line gives the fit of the QCDSR results through the lhs of Eq. (12).

where, in the first line of Eq. (14), we have indicated the uncertainties due to the variation of each parameter. With the value of $g_{Z_{cs}\psi K}$, we can estimate the decay width using the expression [10]

$$\Gamma(Z_{cs}^+ \to J/\psi K^+) = \frac{p^*(m_{Z_{cs}}, m_\psi, m_K)}{8\pi m_{Z_{cs}}^2} \frac{1}{3} g_{Z_{cs}\psi K}^2 \times \left(3 + \frac{(p^*(m_{Z_{cs}}, m_\psi, m_K))^2}{m_\psi^2}\right), \quad (15)$$

where

$$p^*(a, b, c) = \frac{\sqrt{a^4 + b^4 + c^4 - 2a^2b^2 - 2a^2c^2 - 2b^2c^2}}{2a}. \quad (16)$$

Here, the mass of Z_{cs}^+ is taken as (3.97 ± 0.08) GeV, which is from the QCDSR calculation [9]. We obtain

$$\Gamma(Z_{cs}^+ \to J/\psi K^+) = (11.2 \pm 3.5)\ \text{MeV}. \quad (17)$$

One can notice that the coupling in this case is smaller than $g_{Z_c\psi\pi}$, obtained in Ref. [10]. One of the possible reasons for that is the fact that the OPE side, in the Z_{cs} case, is smaller than the corresponding one for $Z_c^+(3900)$, due to the presence of the strange-quark condensate. Also, the current-coupling parameter $\lambda_{Z_{cs}}$ is bigger than λ_{Z_c}. In addition, the phase space of Z_{cs}^+ decay into $J/\psi K^+$ is smaller than that of $Z_c^+(3900) \to J/\psi\pi$), which is a reason why $\Gamma(Z_{cs}^+ \to J/\psi K^+)$ is less than half of the $\Gamma(Z_c^+(3900) \to J/\psi\pi)$.

Let us consider now the $Z_{cs}^+ \to \eta_c K^{*+}$ decay. Considering only CC diagrams, like the one in Fig. 1, we get for the OPE side in the $p'_\mu q_\alpha$ structure

$$\Pi^{(\mathrm{OPE})} = \frac{-im_c(\langle\bar{q}g\sigma.Gq\rangle + \langle\bar{s}g\sigma.Gs\rangle)}{96\sqrt{2}\pi^2}\frac{1}{q^2} \times \int_0^1 d\alpha \frac{1}{m_c^2 - \alpha(1-\alpha)p'^2}. \quad (18)$$

The phenomenological side is obtained by saturating the correlation function in Eq. (5) with Z_{cs}^+, η_c, and K^{*+} states. The decay constants for vector (V) and pseudocalar (P) states are defined through the coupling of the current with the states,

$$\langle 0|j_\mu^V|V(q)\rangle = m_V f_V \varepsilon_\mu(q), \qquad \langle 0|j_5^P|P(q)\rangle = \frac{f_P m_P^2}{m_{q_1} + m_{q_2}}, \quad (19)$$

where m_{q_1} and m_{q_2} are the masses of the constituents quarks of the pseudoscalar meson P.

We get for the phenomenological side

$$\Pi_{\mu\alpha}^{(\mathrm{phen})}(p,p',q) = \frac{-i\lambda_{Z_{cs}} m_{K^*} f_{K^*} f_{\eta_c} m_{\eta_c}^2 g_{Z_{cs}\eta_c K^*}(q^2)}{2m_c(p^2 - m_{Z_{cs}}^2)(p'^2 - m_{\eta_c}^2)(q^2 - m_{K^*}^2)} \times \left(-g_{\mu\lambda} + \frac{q_\mu q_\lambda}{m_\rho^2}\right)\left(-g_\alpha^\lambda + \frac{p_\alpha p^\lambda}{m_{Z_c}^2}\right) + \cdots. \quad (20)$$

Isolating the $q_\alpha p'_\mu$ structure in Eq. (20) and making a single Borel transformation on both $P^2 = P'^2$, we get

$$C(e^{-m_{\eta_c}^2/M^2} - e^{-m_{Z_{cs}}^2/M^2}) + De^{-s_0/M^2} = \frac{Q^2 + m_{K^*}^2}{Q^2}\frac{m_c(\langle\bar{q}g\sigma.Gq\rangle + \langle\bar{s}g\sigma.Gs\rangle)}{96\sqrt{2}\pi^2} \times \int_0^1 d\alpha \frac{e^{\frac{-m_c^2}{\alpha(1-\alpha)M^2}}}{\alpha(1-\alpha)}, \quad (21)$$

where $Q^2 = -q^2$ and the parameter C is given in terms of the form factor

$$C = \frac{g_{Z_{cs}\eta_c K^*}(Q^2)\lambda_{Z_{cs}} m_{K^*} f_{K^*} f_{\eta_c} m_{\eta_c}^2}{2m_c m_{Z_{cs}}^2(m_{Z_{cs}}^2 - m_{\eta_c}^2)}. \quad (22)$$

To determine $g_{Z_{cs}\eta_c K^*}(Q^2)$ we use Eq. (21) and its derivative with respect to M^2 to eliminate D from Eq. (21). The form factor $g_{Z_{cs}\eta_c K^*}(Q^2)$ is shown in Fig. 3, as a function of both M^2 and Q^2. To extract $g_{Z_{cs}\eta_c K^*}(Q^2)$ we need first to establish the Borel window where the sum rule is as independent of the Borel mass as possible. From Fig. 3 we notice that this happens in the region $4.0 \le M^2 \le 10.0$ GeV^2.

In Fig. 4 we show, through the squares, the Q^2 dependence of the form factor $g_{Z_{cs}\eta_c K^*}(Q^2)$, obtained using $M^2 = 5.0$ GeV^2. As can be seen by Fig. 3, other values of the Borel mass, in the range $4.0 \le M^2 \le 10.0$ GeV^2, give equivalent results for the form factor. The coupling constant is defined as the value of the form factor at the meson pole [14]. Therefore, we need to extrapolate the form factor to a region of Q^2 where the QCDSR is not valid. To do that we parametrize the QCDSR results for $g_{Z_{cs}\eta_c K^*}(Q^2)$ using a monopole form:

$$g_{Z_{cs}\eta_c K^*}(Q^2) = \frac{g_1}{g_2 + Q^2}. \quad (23)$$

The fit gives $g_1 = 78.35$ GeV^{-2} and $g_2 = 24.3$ GeV. In Fig. 4 we also show, through the line, the fit of the QCDSR results, using Eq. (23). To determine the parameter D in Eq. (21), we have to substitute Eq. (23) into Eq. (22). Varying s_0 in the range given above, we get $D = (5.5 \pm 1.0) \times 10^{-3}$ GeV^5.

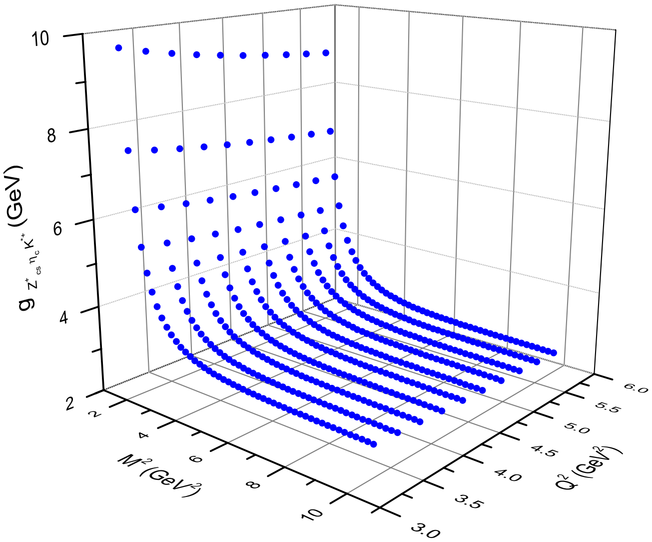

FIG. 3 (color online). QCDSR results for the form factor $g_{Z_{cs}\eta_c K^*}(Q^2)$ as a function of Q^2 and M^2 for $\sqrt{s_0} = 4.5$ GeV.

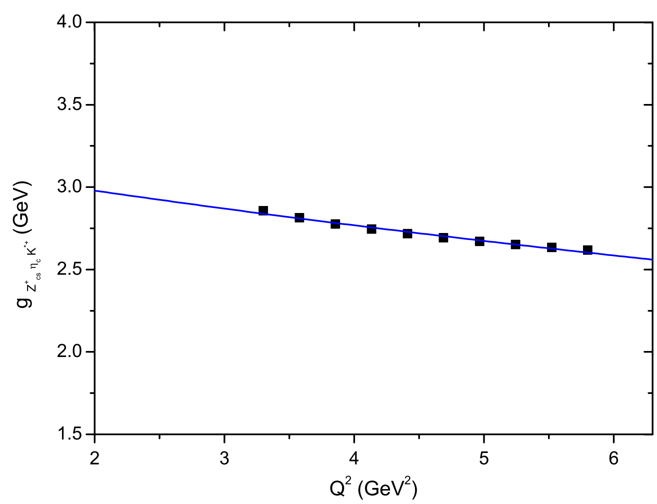

FIG. 4 (color online). QCDSR results for $g_{Z_{cs}\eta_c K^*}(Q^2)$, as a function of Q^2, for $\sqrt{s_0} = 4.5$ GeV (squares). The solid line gives the parametrization of the QCDSR results through Eq. (30).

The coupling constant is obtained by using Eq. (23) and $Q^2 = -m_{K^*}^2$:

$$g_{Z_{cs}\eta_c K^*} = g_{Z_{cs}\eta_c K^*}(-m_{K^*}^2) = (3.40(7)_{s_0}(13)_{m_c}(11)_{\langle\bar{q}q\rangle}(17)_{m_0^2}(13)_\lambda)\ \text{GeV} = (3.4 \pm 0.3)\ \text{GeV}. \quad (24)$$

The uncertainty due to the variations of each parameter is again indicated in the first line of Eq. (24). Using this in Eq. (15), and varying $m_{Z_{cs}}$ in the range $m_{Z_{cs}} = (3.97 \pm 0.08)$ GeV, we get

$$\Gamma(Z_{cs}^+ \to \eta_c K^{*+}) = (10.8 \pm 6.2)\ \text{MeV}. \quad (25)$$

Next we consider the decays $Z_{cs}^+ \to D_s^+ \bar{D}^{*0}$ and $Z_{cs}^+ \to D_s^{*+}\bar{D}^0$. Here we give only the expressions for $Z_{cs}^+ \to D_s^+ \bar{D}^{*0}$. The expression for $Z_{cs}^+ \to D_s^{*+}\bar{D}^0$, can be easily obtained from the prior by exchanging the corresponding meson masses and condensates. As always the phenomenological side is obtained by considering the contribution of the Z_{cs}, D_s, and D^* mesons to the correlation function in Eq. (5):

$$\Pi_{\mu\alpha}^{(\text{phen})}(p, p', q) = \frac{-i\lambda_{Z_{cs}} m_{D^*} f_{D^*} f_{D_s} m_{D_s}^2 g_{Z_{cs}D^*D_s}(q^2)}{(m_c + m_s)(p^2 - m_{Z_{cs}}^2)(p'^2 - m_{D^*}^2)(q^2 - m_{D_s}^2)} \times \left(-g_{\mu\lambda} + \frac{p'_\mu p'_\lambda}{m_{D^*}^2}\right)\left(-g_\alpha^\lambda + \frac{p_\alpha p^\lambda}{m_{Z_{cs}}^2}\right) + \cdots. \quad (26)$$

As in the previous cases, in the OPE side, we consider only the CC diagrams, and we work with the $p'_\alpha p'_\mu$ structure. We get

$$\Pi^{(\text{OPE})} = \frac{-im_c}{48\sqrt{2}\pi^2}\left[\frac{\langle\bar{s}g\sigma.Gs\rangle}{m_c^2 - q^2}\int_0^1 d\alpha \frac{\alpha(2+\alpha)}{m_c^2 - (1-\alpha)p'^2} - \frac{\langle\bar{q}g\sigma.Gq\rangle}{m_c^2 - p'^2}\int_0^1 d\alpha \frac{\alpha(2+\alpha)}{m_c^2 - (1-\alpha)q^2}\right]. \quad (27)$$

For these decays we could also have the contribution of the dimension-eight condensate, of the kind shown in Fig. 5. However, this diagram does not contribute to the $p'_\alpha p'_\mu$ structure. Therefore, the sum rule in the $p'_\mu p'_\alpha$ structure is

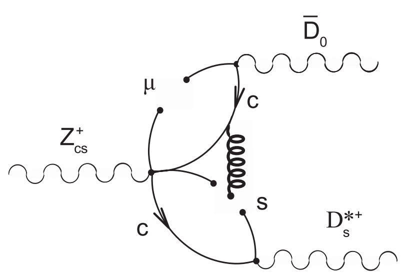

FIG. 5. Dimension-8 CC diagram, which contributes to the OPE side of the sum rule.

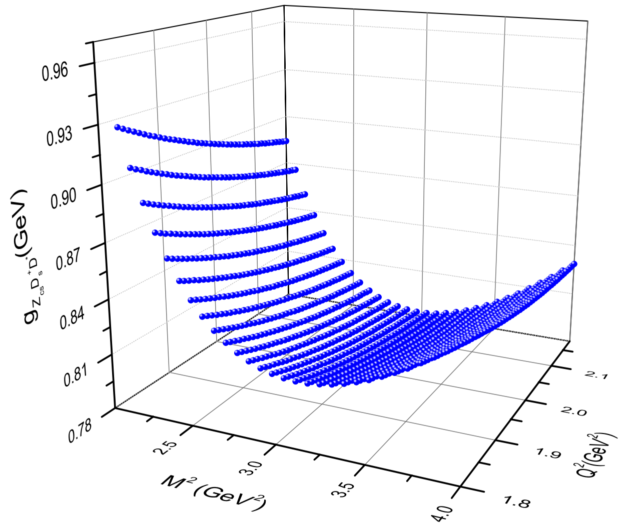

FIG. 6 (color online). QCDSR results for the form factor $g_{Z_{cs}D^*D_s}(Q^2)$ as a function of Q^2 and M^2 for $\sqrt{s_0} = 4.5$ GeV.

$$\frac{1}{Q^2 + m_{D_s}^2}\left[E(e^{-m_{D^*}^2/M^2} - e^{-m_{Z_{cs}}^2/M^2}) + F e^{-s_0/M^2}\right] = \frac{m_c}{48\sqrt{2}\pi^2}\left[\frac{\langle\bar{s}g\sigma.Gs\rangle}{m_c^2 + Q^2}\int_0^1 d\alpha \frac{\alpha(2+\alpha)}{1-\alpha} e^{\frac{-m_c^2}{\alpha(1-\alpha)M^2}} - \langle\bar{q}g\sigma.Gq\rangle e^{-m_c^2/M^2}\int_0^1 d\alpha \frac{\alpha(2+\alpha)}{m_c^2 + (1-\alpha)Q^2}\right], \quad (28)$$

where the parameter E is defined in terms of the form factor $g_{Z_{cs}D_sD^*}(Q^2)$:

$$E = \frac{g_{Z_{cs}D_sD^*}(Q^2)\lambda_{Z_{cs}} f_{D^*} f_{D_s} m_{D_s}^2}{(m_c + m_s)m_{D^*}(m_{Z_{cs}}^2 - m_{D^*}^2)}. \quad (29)$$

The form factor $g_{Z_{cs}D_sD^*}(Q^2)$ extracted from Eq. (28) is shown in Fig. 6, as a function of both M^2 and Q^2. From this figure we see that there is a good Borel stability in the region $2.75 \le M^2 \le 3.25$ GeV^2. Therefore, we fix $M^2 = 3.0$ GeV to extract the Q^2 dependence of the form factor.

In Fig. 7 we show, through the squares, the Q^2 dependence of the form factor. Again, to extract the coupling constant, we have to extrapolate the QCDSR results to $Q^2 = -m_{D_s}^2$. To do that we use an exponential form

$$g_{Z_{cs}D_sD^*}(Q^2) = g_1 e^{-g_2 Q^2} \quad (30)$$

to fit the QCDSR results. We have used an exponential form in this case since it was not possible to fit the QCDSR results with the monopole form in Eq. (23). However, as shown in Ref. [14], both forms are acceptable to describe hadronic form factors. We get $g_1 = 0.94$ GeV and $g_2 = 0.09$ GeV^{-2}. The line in Fig. 7 shows the fit of the QCDSR results for $\sqrt{s_0} = 4.5$ GeV, using Eq. (30). We get for the coupling constant

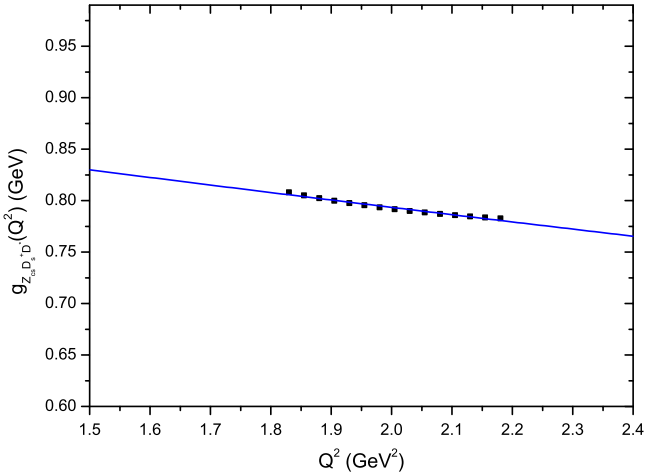

FIG. 7 (color online). QCDSR results for $g_{Z_{cs}D^*D_s}(Q^2)$, as a function of Q^2, for $\sqrt{s_0} = 4.5$ GeV (squares). The solid line gives the parametrization of the QCDSR results through Eq. (30).

$$\begin{aligned} g_{Z_{cs}D_sD^*} &= g_{Z_{cs}D_sD^*}(-m^2_{D_s}) \\ &= (1.40(7)_{s_0}(9)_{m_c}(11)\langle\bar{q}q\rangle(17)_{m_0^2}(17)_\lambda)\ \text{GeV} \\ &= (1.4 \pm 0.3)\ \text{GeV}. \end{aligned} \quad (31)$$

With this coupling and using the bigger value predicted for the $m_{Z_{cs}}$ mass in Ref. [9] (since for values of the mass bellow the threshold the decay is not possible), we get for the decay width in this channel:

$$\Gamma(Z^+_{cs} \to D^+_s\bar{D}^{*0}) = (1.5 \pm 1.5)\ \text{MeV}. \quad (32)$$

For the $Z^+_{cs} \to D^{*+}_s\bar{D}^0$, doing a similar analysis, we arrive at

$$g_{Z_{cs}D^*_sD} = g_{Z_{cs}D^*_sD}(-m^2_D) = (1.4 \pm 0.4)\ \text{GeV}, \quad (33)$$

that leads to a similar result

$$\Gamma(Z^+_{cs} \to D^{*+}_s\bar{D}^0) = (1.4 \pm 1.4)\ \text{MeV}. \quad (34)$$

TABLE III. Coupling constants and decay widths in different channels.

Vertex	Coupling constant (GeV)	Decay width (MeV)
$Z^+_{cs}J/\psi K^+$	2.58 ± 0.30	11.2 ± 3.5
$Z^+_{cs}\eta_c K^{*+}$	3.4 ± 0.3	10.8 ± 6.2
$Z^+_{cs}D^+_s\bar{D}^{*0}$	1.4 ± 0.3	1.5 ± 1.5
$Z^+_{cs}\bar{D}^0D^{*+}_s$	1.4 ± 0.4	1.4 ± 1.4

I. CONCLUSIONS

In this work we have estimated, using the QCDSR approach, the decay widths of the charmoniumlike structure with hidden charm and open strange, that we call Z^+_{cs}. This state was predicted in Ref. [5] under the ISChE mechanism and should be seen in the hidden-charm dikaon decay of a charmoniumlike state $Y(4660)$. We have studied four decay channels and have considered only color connected diagrams. This is justified by the fact that we expect the Z_{cs} state to be a genuine tetraquark state, with a nontrivial color configuration. The obtained couplings, with the respective decay widths, are given in Table III.

Considering these four decay channels, we get a total width $\Gamma = (24.9 \pm 12.6)$ GeV for Z_{cs} which is smaller than the total decay width of its nonstrange partner the $Z^+_c(3900)$: $\Gamma = (46 \pm 22)$ MeV from BESIII [2] and $\Gamma = (63 \pm 35)$ MeV from BELLE [3].

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