Investigation of the $D^{*}_{s2}(2573)^{+}D^{+}K^{0}$ vertex via QCD sum rules

2014 J. Phys.: Conf. Ser. 562 012004

(http://iopscience.iop.org/1742-6596/562/1/012004)

Investigation of the $D^*_{s2}(2573)^+ D^+ K^0$ vertex via QCD sum rules

Y. Sarac[1], **K. Azizi**[2], **H. Sundu**[3]

[1]Electrical and Electronics Engineering Department, Atilim University, 06836 Ankara, Turkey
[2]Physics Department, Doğuş University, Acıbadem-Kadıköy, 34722 Istanbul, Turkey
[3]Department of Physics, Kocaeli University, 41380 Izmit, Turkey

E-mail: `yasemin.sarac@atilim.edu.tr`

Abstract. In this work the $D^*_{s2}(2573)^+ D^+ K^0$ vertex is studied and the coupling constant corresponding to the $D^*_{s2}(2573)^+ \to D^+ K^0$ transition is calculated. The calculation is performed using three point QCD sum rules method and the value of the coupling constant is obtained as $g_{D^*_{s2}DK} = (12.85 \pm 3.85)$ GeV^{-1}. The coupling constant is also used to calculate the decay width and the branching ratio of the considered transition.

1. Introduction

The orbitally excited charmed meson was firstly observed in 1986 [1] and the following past few decades have been an era of the observation of them [2, 3, 4, 5, 6, 7, 8, 9, 10, 11]. During these period there also have been several theoretical studies on the masses, strong and electromagnetic transitions of these mesons (See for instance the Refs. [12, 13, 14, 15] and the references there in). Although $D^*_{s2}(2573)$ meson's quantum numbers are not exactly known the width and decay modes of the $D^*_{s2}(2573)$ state favors $I(J^P) = 0(2^+)$ quantum numbers. Therefore in this work we consider it as a charmed strange tensor meson.

If one compares with the other types of mesons, in literature there are little theoretical studies on the properties of the tensor mesons. In order to gain useful information about the nature and internal structure of tensor mesons, the studies on the properties of these mesons may be helpful. This type of studies may provide a way to test the assumptions of some theoretical calculations and understand the experimental results. In the decays of B meson, the charmed tensor mesons appear as an intermediate state, therefore this type of work may also be helpful to gain information about the B meson. The possibility for a search on the decay properties of D^*_{s2} meson provides us with another motivation to study the properties of these mesons.

This work presents the analysis of the $D^*_{s2}(2573)^+ D^+ K^0$ vertex. The coupling form factor $g_{D^*_{s2}DK}$ for the considered vertex is calculated using QCD sum rules method [16]. In section 2, we present the details of the calculation made for coupling form factor. Section 3 presents numerical analysis of the coupling constant and the decay with of considered decay.

2. QCD sum rules for the strong coupling form factor

In order to obtain the coupling form factor $g_{D^*_{s2}DK}$ we use the following three-point correlation function:

$$\Pi_{\mu\nu}(p,p',q) = i^2 \int d^4x \int d^4y \; e^{-ip\cdot x} \; e^{ip'\cdot y} \; \langle 0|\mathcal{T}\left(J^D(y)\; J^K(0)\; J^{D^{*\dagger}_{s2}}_{\mu\nu}(x)\right)|0\rangle, \tag{1}$$

were $\mathcal{T}$ is the time ordering operator. The J^D, J^K and $J^{D^*_{s2}}_{\mu\nu}$ are the interpolating fields and can be written in terms of the quark field operators as: $J^D(y) = i\bar{d}(y)\gamma_5 c(y)$, $J^K(0) = i\bar{s}(0)\gamma_5 d(0)$ and $J^{D^*_{s2}}_{\mu\nu}(x) = \frac{i}{2}\left[\bar{s}(x)\gamma_\mu \overleftrightarrow{\mathcal{D}}_\nu(x)c(x) + \bar{s}(x)\gamma_\nu \overleftrightarrow{\mathcal{D}}_\mu(x)c(x)\right]$ where $\overleftrightarrow{\mathcal{D}}_\mu(x)$ is two-side covariant derivative.

The correlation function given in Eq. (1) can be calculated following two different ways. It is calculated in terms of hadronic parameters and this side is called as the physical side of the calculation. And also it is calculated in terms of quark and gluon degrees of freedom by the help of the operator product expansion (OPE) in deep Euclidean region which is the theoretical or QCD side. The match of coefficients of same structure obtained from both sides leads us to the QCD sum rules for the intended physical quantity. To supress the contribution of the higher states and continuum double Borel transformation with respect to the variables p^2 and p'^2 is applied.

To get the physical side one inserts complete sets of appropriate hadronic states into the correlation function with the same quantum numbers as the interpolating currents and obtains:

$$\Pi^{had}_{\mu\nu} = \frac{\langle 0 \mid J^K \mid K(q)\rangle\langle 0 \mid J^D \mid D(p')\rangle\langle D^*_{s2}(p,\epsilon) \mid J^{D^*_{s2}}_{\mu\nu} \mid 0\rangle}{(p^2 - m^2_{D^*_{s2}})(p'^2 - m^2_D)(q^2 - m^2_K)}\langle K(q)D(p') \mid D^*_{s2}(p,\epsilon)\rangle + \cdots\;, \tag{2}$$

By the usage of the explicit expressions of matrix elements appearing in Eq. (2) which can be parameterized in terms of the leptonic decay constants and strong coupling constant, and after a straight forward algebra one obtains the final form of the correlation function after double Borel transformation (for details see Ref. [17]):

In OPE side, we substitute the explicit forms of the interpolating currents into the correlation function Eq. (1) and after contracting out all quark pairs via Wick's theorem, we get

$$\Pi^{OPE}_{\mu\nu} = \frac{i^5}{2}\int d^4x \int d^4y e^{-ip\cdot x}e^{ip'\cdot y}\left\{Tr\left[\gamma_5\; S^{ji}_d(-y)\gamma_5 S^{i\ell}_c(y-x)\gamma_\mu \overleftrightarrow{\mathcal{D}}_\nu(x) S^{\ell j}_s(x)\right] + [\mu \leftrightarrow \nu]\right\}, \tag{3}$$

where $S^{i\ell}_c(x)$, $S^{\ell j}_s(x)$ and $S^{ji}_d(x)$ are the heavy and light quark propagators. After some straight forward calculations (for details see Ref. [17]) for this side we obtain the results in the form;

$$\Pi^{OPE}_{\mu\nu}(p,p',q) = \Pi_1(q^2)p_\mu p_\nu + \Pi_2(q^2)p_\nu p'_\mu + \Pi_3(q^2)p_\mu p'_\nu + \Pi_4(q^2)p'_\mu p'_\nu + \Pi_5(q^2)g_{\mu\nu}, \tag{4}$$

with same dirac structures as in physical side. Since the results are lengthy they will not be given here explicitely.

Equating the coefficients of the same Dirac structure obtained from both sides of the correlation function which is $p_\mu p'_\nu$ in our case, one gets the following sum rules for the coupling form factor

$$\begin{aligned} g_{D^*_{s2}DK} &= \frac{e^{\frac{m^2_{D^*_{s2}}}{M^2}} e^{\frac{m^2_D}{M'^2}} 6(m_c+m_d)(m_d+m_s)(m^2_K - q^2)m_{D^*_{s2}}}{f_{D^*_{s2}} f_D f_K m^2_D m^2_K\left[m^4_D + m^2_D(4m^2_{D^*_{s2}} - 2q^2) + (m^2_{D^*_{s2}} - q^2)^2\right]} \\ &\times \left\{\int_{(m_c+m_s)^2}^{s_0} ds \int_{(m_c+m_d)^2}^{s'_0} ds' e^{-\frac{s}{M^2}} e^{-\frac{s'}{M'^2}} \rho^{pert}_3(s,s',q^2) + \widehat{\mathbf{B}}\Pi^{nonpert}_3(q^2)\right\}\;, \end{aligned} \tag{5}$$

where s_0 and s'_0 are continuum thresholds, M^2 and M'^2 are the Borel mass parameters and $\rho_3(s,s',q^2) = \frac{1}{\pi}Im[\Pi_3]$.

3. Numerical Results

For the numerical analysis we used the following input parameters $m_c = (1.275\pm0.025)$ GeV [18], $m_d = (4.8^{+0.5}_{-0.3})$ MeV [18], $m_s = (95 \pm 5\ )$MeV [18], $m_{D^*_{s2}(2573)} = (2571.9 \pm 0.8)$ MeV [18], $m_D = (1869.62\pm0.15)$ MeV [18], $m_K = (493.677\pm0.016)$ MeV [18], $f_D = (206.7\pm8.9)$ MeV [18], $f_K = (156.1 \pm 0.2 \pm 0.8 \pm 0.2)$ MeV [18], $f_{D^*_{s2}(2573)} = (0.0230 \pm 0.0011)$ [14], $\langle \frac{\alpha_s G^2}{\pi} \rangle = (0.012 \pm 0.004)\ \mathrm{GeV}^4$.

Borel mass parameters M^2 and M'^2 and continuum thresholds s_0 and s'_0 appearing in our results are auxiliary parameters, which are not physical parameters. Therefore we need to determine the working regions of them from our analysis seeking weak dependency of our results on them. From our analysis we obtained their working regions as $8.5\ \mathrm{GeV}^2 \leq s_0 \leq 9.4\ \mathrm{GeV}^2$, $4.7\ \mathrm{GeV}^2 \leq s'_0 \leq 5.6\ \mathrm{GeV}^2$, $3\ \mathrm{GeV}^2 \leq M^2 \leq 8\ \mathrm{GeV}^2$ and $2\ \mathrm{GeV}^2 \leq M'^2 \leq 5\ \mathrm{GeV}^2$.

The coupling constant is defined as the value of the form factor at $Q^2 = -q^2 = -m_K^2$ which is outside of the reliable region of our sum rules calculations. Therefore to extend our result we use the fit function $g_{D^*_{s2}DK}(Q^2) = c_1 \exp\left[-\frac{Q^2}{c_2}\right] + c_3$ where $Q^2 = -q^2$ and obtain the fit parameters, $c_1 = (12.03 \pm 3.61)\ \mathrm{GeV}^{-1}$, $c_2 = (12.73 \pm 3.18)\ \mathrm{GeV}^2$ and $c_3 = (0.81 \pm 0.24)\ \mathrm{GeV}^{-1}$ from our analysis. And from the fit function we obtain the coupling constant as $g_{D^*_{s2}DK}(Q^2 = -m_K^2) = (12.85 \pm 3.85)\ \mathrm{GeV}^{-1}$.

After determination of the coupling constant the final task of our work is to obtain the decay width and the branching ratio of the considered transition using the value of the coupling constant and the decay with formula given in Ref. [17]. The decay width is achieved as $\Gamma = (1.84 \pm 0.48) \times 10^{-3}$ GeV and using the total width of the initial particle, $\Gamma_{D^*_{s2}(2573)^0} = (17 \pm 4)$ MeV [18], the branching ratio is obtained as $BR = (1.08 \pm 0.27) \times 10^{-1}$.

Acknowledgement

This work has been supported in part by the Scientific and Technological Research Council of Turkey (TUBITAK) under the research project 114F018.

References

[1] Albrecht H et al. (ARGUS Collaboration) 1986 *Phys. Rev. Lett.* **56** 549.
[2] H. Albrecht et al. (ARGUS Collaboration) 1989 *Phys. Lett. B* **232** 398; Albrecht H et al. (ARGUS Collaboration) 1989 *Phys. Lett. B* **231** 208; Albrecht H et al. (ARGUS Collaboration) 1989 *Phys. Lett. B* **221** 422; Albrecht H et al. (ARGUS Collaboration) 1989 *Phys. Lett. B* **230** 162; Albrecht H et al. (ARGUS Collaboration) 1992 *Phys. Lett. B* **297** 425.
[3] Frabetti P L et al. (E687 Collaboration) 1994 *Phys. Rev. Lett.* **72** 324.
[4] Anjos J C et al. (E691 Collaboration) 1989 *Phys. Rev. Lett.* **62** 1717.
[5] Alexander J P et al (CLEO Collaboration) 1993 *Phys. Lett. B* **303** 377.
[6] Avery P et al. (CLEO Collaboration) 1990 *Phys. Rev. D* **41** 774; Avery P et al. (CLEO Collaboration) 1994 *Phys. Lett. B* **331** 236.
[7] Kubota Y et al. (CLEO Collaboration) 1994 *Phys. Rev. Lett.* **72** 1972.
[8] Bergfeld T et al. (CLEO Collaboration) 1994 *Phys.Lett. B* **340** 194.
[9] Link J et al. (FOCUS Collaboration) 2004 *Phys. Lett. B* **586** 11.
[10] Abe K et al. (BELLE Collaboration) 2004 *Phys. Rev. D* **69** 112002.
[11] Abazov V M et al. (D0 Collaboration) 2005 *Phys. Rev. Lett.* **95** 161602.
[12] Godfrey S 2005 *Phys. Rev. D* **72** 054029.
[13] Sundu H and Azizi K 2012 *Eur. Phys. J. A* **48** 81.
[14] Azizi K, Sundu H, Süngü J Y and Yinelek N 2013 *Phys. Rev. D* **88** 036005 ; 2013 *Phys. Rev. D* **88**, 099901(E).
[15] Azizi K, Sundu H, Türkan A Y and Veli Veliev E 2014 *J.Phys. G* **41** 035003.
[16] Shifman M A, Vainshtein A I and Zakharov V I 1979 *Nucl. Phys. B* **147** 385 ; 1979 *Nucl. Phys. B* **147** 448.
[17] Azizi K, Sarac Y and Sundu H 2014 arXiv:1402.6887.
[18] Beringer et al. (Particle Data Group) 2012 *Phys. Rev. D* **86** 010001 and 2013 partial update for the 2014 edition.