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PHYSICS LETTERS B
Physics Letters B 605 (2005) 326–334
www.elsevier.com/locate/physletb

$J/\psi D^* D^*$ vertex from QCD sum rules

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Received 23 September 2004; received in revised form 29 October 2004; accepted 2 November 2004

Available online 19 November 2004

Editor: M. Cvetič

Abstract

We calculated the strong form factor and coupling constant for the $J/\psi D^* D^*$ vertex in a QCD sum rule calculation. We performed a double Borel sum rule for the three point correlation function of vertex considering both J/ψ and D^* mesons off-shell. The form factors obtained are very different, but they give the same coupling constant.

PACS: 14.40.Lb; 14.40.Nd; 12.38.Lg; 11.55.Hx

An important topic of RHIC physics is charmonium production [1]. The first results have already been reported [2], but they did not reach yet the quality of the previous lower energies measurements performed at CERN-SPS, where an anomalous suppression was found in the most central collisions [3].

Understanding charmonium production and destruction in these highly complicated collisions is a challenge for theorists, and in the last six years an intense effort was dedicated to understand charmonium interactions with light hadrons. This subject can be divided into high ($\sqrt{s} \geqslant 10$ GeV) and low ($\sqrt{s} \leqslant 10$ GeV) energy interactions. The latter have been treated mostly with the help of effective Lagrangians. In this approach one has a better control of the relevant symmetries, which dictate the dynamics [4–8]. However, very soon it was realized that working with effective Lagrangians requires a very good knowledge of the form factors associated with vertices involving charmed mesons as, for example, the $D^* D\pi$ vertex, to mention the most famous one. Choosing a softer or harder form factor may change the final cross section up to two orders of magnitude. This dramatic change outshines the detailed discussion concerning the role played by gauge invariance, anomalous parity couplings and other dynamical features of the interaction.

Until four years ago nothing was known about such form factors. At that time we launched a program of calculating these important quantities in the framework of QCD sum rules [9]. Since then we have been continuously

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0370-2693/$ – see front matter
doi:10.1016/j.physletb.2004.11.024

attacking this problem and computing different vertices [10–16]. In doing so, we have also improved the strategies to determine the coupling constants. One of them is experimentaly measured [17] but the others have to be estimated using a vector meson dominance analysis of some measured decays, or using SU(4) symmetry relations. In some cases our results gave support to these more empyrical estimates and in some other they did not.

As it frequently happens, during the execution of the project the original motivation was extended to a wider scope of questions concerning charmed mesons. A particularly interesting side product of our works, [12,14] and also the present one, is the conclusion regarding the "resolving power" of a compact (J/ψ) or an extended probe (ρ) hitting the D meson. It was reassuring to observe how the J/ψ behaves more like a point-like parton penetrating the D meson, whereas the ρ behaves more like a large hadron being able to measure the size of the D meson. All this information is encoded in the form factors. In what follows we will have a glimpse on how the J/ψ "sees" a D^* meson. From spin symmetry of the heavy quark effective theory (HQET) one would expect a similar behaviour as observed in the $J/\psi DD$ vertex [14].

The present calculation is part of this project. Although the method is the same as used before, because there are three vector particles involved, the number of Lorentz structures is much bigger and the calculation is considerably more involved. On the other hand, since the three particles are heavy, we feel more confident about neglecting some higher dimension contributions to the operator product expansion (OPE). We will compare our results with the ones from other models [18,19] and we will also check if the use of HQET symmetry is appropriate.

Following the QCDSR formalism described in our previous works [10–12], we write the three-point function associated with the $J/\psi D^* D^*$ vertex, which is given by

$$\Gamma^{(D^*)}_{\nu\alpha\mu}(p,p') = \int d^4x\, d^4y\, e^{ip'\cdot x}\, e^{-i(p'-p)\cdot y} \langle 0|T\bigl\{j^{D^*}_\nu(x) j^{\bar{D}^*}_\alpha(y) j^{\psi\dagger}_\mu(0)\bigr\}|0\rangle, \tag{1}$$

for an off-shell D^* meson, and

$$\Gamma^{(J/\psi)}_{\nu\alpha\mu}(p,p') = \int d^4x\, d^4y\, e^{ip'\cdot x}\, e^{-i(p'-p)\cdot y} \langle 0|T\bigl\{j^{D^*}_\nu(x) j^{\psi\dagger}_\mu(y) j^{D^*\dagger}_\alpha(0)\bigr\}|0\rangle, \tag{2}$$

for an off-shell J/ψ meson. The general expression for the vertices (1) and (2) has fourteen independent Lorentz structures. We can write $\Gamma_{\nu\alpha\mu}$ in terms of the invariant amplitudes associated with each one of these structures in the following form:

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

The correlator function, 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 is evaluated by using the Wilson operator product expansion (OPE). The OPE incorporates the effects of the QCD vacuum through an infinite serie 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 using the quark–hadron global duality.

In the QCD 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: $j^{D^*}_\nu(x) = \bar{c}(x)\gamma_\nu q(x)$ and $j^{\psi}_\mu(x) = \bar{c}(x)\gamma_\mu c(x)$, where q and c are the up/down and charm quark field respectively. Each one of these currents have the same quantum numbers as the associated meson.