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Analysis of the $D^*_{s3}(2860)$ as a D-wave $c\bar{s}$ meson with QCD sum rules

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Abstract

In this article, we assign the $D^*_{s3}(2860)$ to be a D-wave $c\bar{s}$ meson, and study the mass and decay constant of the $D^*_{s3}(2860)$ with the QCD sum rules by calculating the contributions of the vacuum condensates up to dimension-6 in the operator product expansion. The predicted mass $M_{D^*_{s3}} = (2.86 \pm 0.10)$ GeV is in excellent agreement with the experimental value $M_{D^*_{s3}} = (2860.5 \pm 2.6 \pm 2.5 \pm 6.0)$ MeV from the LHCb collaboration. The present prediction supports assigning the $D^*_{s3}(2860)$ to be the D-wave $c\bar{s}$ meson.

Keywords: $D^*_{s3}(2860)$; QCD sum rules

1. Introduction

In 2006, the BaBar collaboration observed the $D^*_{sJ}(2860)$ meson with the mass $(2856.6 \pm 1.5 \pm 5.0)$ MeV and the width $(48 \pm 7 \pm 10)$ MeV in decays to the final states D^0K^+ and $D^+K^0_S$ using 240 fb^{-1} of data recorded by the BaBar detector at the PEP-II asymmetric-energy e^+e^- storage rings at the Stanford Linear Accelerator Center [1]. In 2009, the BaBar collaboration confirmed the $D^*_{sJ}(2860)$ in the D^*K channel using 470 fb^{-1} of data recorded by the BaBar detector, and measured the ratio R among the branching fractions [2],

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$$R = \frac{\mathrm{Br}\left(D^*_{sJ}(2860) \to D^* K\right)}{\mathrm{Br}\left(D^*_{sJ}(2860) \to DK\right)} = 1.10 \pm 0.15 \pm 0.19\,. \tag{1}$$

The observation of the decays $D^*_{sJ}(2860) \to D^* K$ rules out the $J^P = 0^+$ assignment, the possible assignments are the $1^3\mathrm{D}_3$ $c\bar{s}$ meson [3–10], the $c\bar{s}$–$cn\bar{s}\bar{n}$ mixing state [11], the dynamically generated $D_1(2420)K$ bound state [12], etc.

In 2014, the LHCb collaboration observed a structure at 2.86 GeV with significance of more than 10σ in the $\overline{D}^0 K^-$ mass spectrum in the Dalitz plot analysis of the decays $B_s^0 \to \overline{D}^0 K^- \pi^+$ using a data sample corresponding to an integrated luminosity of 3.0 fb^{-1} of pp collision data recorded by the LHCb detector, the structure contains both spin-1 ($D^{*-}_{s1}(2860)$) and spin-3 ($D^{*-}_{s3}(2860)$) components, which can be assigned to be the $J^P = 1^-$ and 3^- members of the 1D family [13,14]. The measured masses and widths are $M_{D^*_{s3}} = (2860.5 \pm 2.6 \pm 2.5 \pm 6.0)$ MeV, $M_{D^*_{s1}} = (2859 \pm 12 \pm 6 \pm 23)$ MeV, $\Gamma_{D^*_{s3}} = (53 \pm 7 \pm 4 \pm 6)$ MeV, and $\Gamma_{D^*_{s1}} = (159 \pm 23 \pm 27 \pm 72)$ MeV, respectively. Furthermore, the LHCb collaboration obtained the conclusion that the $D^*_{sJ}(2860)$ observed by the BaBar collaboration in the inclusive $e^+e^- \to \overline{D}^0 K^- X$ production and by the LHCb collaboration in the $pp \to \overline{D}^0 K^- X$ processes consists of at least two particles [2,15].

If we assign the $D^*_{sJ}(2860)$ to be the $1^3\mathrm{D}_3$ state or the $D^*_{s3}(2860)$, the ratio R from the leading order heavy meson effective theory [3], the $^3\mathrm{P}_0$ model [4,9,16] and the relativized quark model [17] cannot reproduce the experimental value $R = 1.10 \pm 0.15 \pm 0.19$ [2]. In Ref. [18], we assign the $D^*_{s3}(2860)$ and $D^*_{s1}(2860)$ to be the $1^3\mathrm{D}_3$ and $1^3\mathrm{D}_1$ $c\bar{s}$ states, respectively, study their strong decays with the heavy meson effective theory by including the chiral symmetry breaking corrections. We can reproduce the experimental value $R = 1.10 \pm 0.15 \pm 0.19$ with suitable hadronic coupling constants if the chiral symmetry breaking corrections are large. The preferred assignment is $D^*_{sJ}(2860) = D^*_{s3}(2860)$, while the assignment $D^*_{sJ}(2860) = D^*_{s1}(2860)$ is not excluded.

According to the predictions of the potential models [19], the masses of the 1D $c\bar{s}$ states are about 2.9 GeV. It is reasonable to assign the $D^*_{s1}(2860)$ and $D^*_{s3}(2860)$ to be the $1^3\mathrm{D}_1$ and $1^3\mathrm{D}_3$ $c\bar{s}$ states, respectively. We can obtain further support by calculating the mass of the $D^*_{s3}(2860)$ based on the QCD sum rules. The QCD sum rules is a powerful theoretical tool in studying the ground state hadrons and has given many successful descriptions of the masses, decay constants, form-factors and hadronic coupling constants, etc. [20,21]. There have been many works on the spin-parity $J^P = 0^\pm, 1^\pm$ heavy-light mesons with the full QCD sum rules [22,23] (and references therein), while the works on the $J^P = 2^+$ are few [24,25], the $J^P = 3^-$ heavy-light mesons are only studied with the QCD sum rules combined with the heavy quark effective theory [26]. In this article, we assign the $D^*_{s3}(2860)$ to be a D-wave $c\bar{s}$ meson, study the mass and decay constant of the $D^*_{s3}(2860)$ with the full QCD sum rules in details by calculating the contributions of the vacuum condensates up to dimension-6 in the operator product expansion.

The article is arranged as follows: we derive the QCD sum rules for the mass and decay constant of the $D^*_{s3}(2860)$ in Sect. 2; in Sect. 3, we present the numerical results and discussions; and Sect. 4 is reserved for our conclusions.

2. QCD sum rules for the $D^*_{s3}(2860)$ as a D-wave meson

In the following, we write down the two-point correlation function $\Pi_{\mu\nu\rho\alpha\beta\sigma}(p)$ in the QCD sum rules,