EXCITED HEAVY MESONS FROM QCD SUM RULES (Postprint)

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Abstract

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Full Text

Preamble

Orbitally excited $L = 1$ charm mesons are studied using QCD sum rules within the framework of heavy quark effective theory. The meson masses and strong decay widths are obtained. This talk is based on our works in refs. 1 and 2, in collaboration with Y.B. Dai, C.S. Huang, M.Q. Huang, and H.Y. Jin.

The study of excited heavy mesons is interesting for the following reasons [**?**]. First, it may help us understand QCD more deeply in the nonperturbative regime. Second, it provides an alternative application of heavy quark effective theory (HQET), beyond that for ground-state heavy mesons. Finally, it is particularly useful for tagging in CP experiments [**?**].

In this talk, we focus on the $L = 1$ excited charm mesons. It is instructive to illustrate them in the constituent quark picture, although this is not strictly accurate (since L is not a conserved quantity). For the familiar ground-state ($L = 0$) mesons, there are two states with J^P quantum numbers: $D(0^-)$ and $D^*(1^-)$. Their difference lies only in the heavy quark spin direction. For the $L = 1$ case, there are four states: $D_0^*(0^+)$, $D_1'(1^+)$, $D_1(1^+)$, and $D_2^*(2^+)$. In the constituent picture, D_0^* contains one heavy quark and one light quark with spins aligned opposite to the orbital angular momentum. The D_1' state differs from D_0^* by a light quark spin flip, while D_1 is the same as D_1' except for the heavy quark spin direction. The D_2^* state is similar to D_1 but with different total angular momentum coupling. These heavy mesons can be systematically studied using

HQET [?]. In the heavy quark limit, the heavy quark spin symmetry $SU(2)$ implies that the four excited heavy mesons can be grouped into two doublets: (D_0^*, D_1') and (D_1, D_2^*). Although D_1' and D_1 have the same quantum numbers, they are clearly separated in the heavy quark limit. Their mixing occurs at order $1/m_c$, which can be studied within HQET. In the following, we present HQET sum rule calculations for the masses and strong decays of excited charm mesons at leading order.

The QCD sum rule [?] is a nonperturbative method rooted in QCD itself. The relevant interpolating currents must be specified. For the excited heavy mesons, we write the currents as follows [?]:

$$\bar{h}_v \Gamma D_\rho q,$$

with Γ denoting appropriate γ matrices. Here h_v is the heavy quark field with velocity v in HQET. We find that $\Gamma = \gamma_5 \gamma_\mu^\perp$ for D_0^*, $\Gamma = \gamma_5 (g_{\nu\rho} - v_\nu v_\rho)$ for D_1', $\Gamma = \gamma_\mu^\perp g_{\nu\rho}$ for D_1, and $\Gamma = \gamma_\mu^\perp v_\nu$ for D_2^* (in the meson rest frame, $\gamma_\mu^\perp = (0, \vec{\gamma})$). We have shown that the current for one of the two 1^+ states does not couple to the other in the limit $m_Q \to \infty$. The related decay constant f is defined as

$$\langle 0 | J^\dagger | D^{**}(v, \eta) \rangle = f \eta,$$

where D^{**} stands for any of the four excited mesons with polarization vector η, which is the ground state of J. (For more details, see ref. 1.)

1 Masses

In HQET, the meson masses are expanded as

$$M = m_Q + \bar{\Lambda} + \mathcal{O}(1/m_Q),$$

where $\bar{\Lambda}$ denotes the meson masses defined in HQET. They are independent of heavy quark flavor. For their calculation, the Green' s function is written as

$$\Gamma(\omega) = i \int d^4 x e^{ik\cdot x} \langle T J^\dagger(x) J(0) \rangle, \quad \omega = 2k \cdot v.$$

It can be expressed in hadronic language as

$$\Gamma(\omega) = \frac{f^2}{\bar{\Lambda} - \omega} + \text{resonance}.$$

The Feynman diagrams can be found in ref. 1. The condensates are included up to dimension five. Here the usual duality hypothesis is used for the resonance contribution. After Borel transformation, the sum rules for $\bar{\Lambda}$ are obtained:

$$\bar{\Lambda} = \frac{\int_0^{\omega_c} d\nu\, \nu^4 e^{-\nu/T}}{\int_0^{\omega_c} d\nu\, \nu^3 e^{-\nu/T}} \quad (0^+),$$

$$\bar{\Lambda} = \frac{\int_0^{\omega_c} d\nu\, \nu^5 e^{-\nu/T}}{\int_0^{\omega_c} d\nu\, \nu^4 e^{-\nu/T}} \quad (1^+),$$

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Imposing the usual criterion for the upper and lower bounds of the Borel parameter T, we obtain the numerical results:

$$\bar{\Lambda}(0^+) = 0.90 \pm 0.10 \text{ GeV},$$

$$\bar{\Lambda}(1^+) = 0.95 \pm 0.10 \text{ GeV},$$

where the error comes from the uncertainty of $\omega_c \sim 0.5$ GeV.

Strong Decays

The pionic decays of heavy hadrons can be studied by combining heavy quark symmetry and chiral symmetry [**?**]. The excited heavy meson decays have been studied in this framework [**?**, **?**]. However, we will not use the soft pion approximation because the pion energy is about 500 MeV in this case. The decay widths are given by, for example:

$$\Gamma(D_0^* \to D\pi) = \frac{g'^2}{2\pi f_\pi^2} \frac{M_D}{M_{D_0^*}} p_\pi^3,$$

$$\Gamma(D_2^* \to D\pi) = \frac{g^2}{2\pi f_\pi^2} \frac{M_D}{M_{D_2^*}} p_\pi^5,$$

where summation over charged and neutral pion final states is implied, and g' and g are universal quantities describing the decay amplitudes that we will calculate using QCD sum rules.

For this purpose, the Green’ s function is constructed as

$$\tilde{\Gamma} = i\int d^4x e^{-ik\cdot x}\langle T J_{D^{(*)}}(x) J^\dagger(0)\rangle,$$

with $J_{D^{(*)}}$ being the currents for $D^{(*)}$ mesons. The hadronic expression is

$$\tilde{\Gamma} = \frac{(2\bar{\Lambda}_{D^{(*)}}) f_{D^{(*)}} f_{D^{**}}}{(2\bar{\Lambda}_{D^{(*)}} - k\cdot v)(2\bar{\Lambda}_{D^{**}} - k'\cdot v)} + \text{res.},$$

where $k' = k - 2\bar{\Lambda}_{D^{(*)}}q$. Instead of taking the soft pion limit, we put $k\cdot v = 2\bar{\Lambda}_{D^{(*)}}$. In the operator product expansion of HQET,

$$\tilde{\Gamma} = i\langle T\bar{q}(v\cdot t)\Gamma_{D^{(*)}}\Gamma D_\rho q(0)\rangle + \text{res.},$$

where the required matrix element $\alpha(x)D_\rho q$ can be found in ref. 2. With the parameters

$$h_1 = 0, \quad h_2 = \frac{24 f_\pi}{h}, \quad b_1 = \dots, \quad e_2 = \frac{12 f_\pi}{h}, \quad a_1 = \dots,$$

$$d_1 = 0, \quad d_2 = \frac{8 f_\pi}{h}, \quad c_1 = \frac{12 f_\pi}{h}, \quad \langle\bar{q}q\rangle = 0.2 \text{ GeV}^3,$$

and e_2 is fixed from QCD sum rules [?]: $e_2 \simeq -0.002$ GeV, the final sum rules for g' and g are:

$$g' f_{D^*} f_D = \frac{2}{3}\left(h_1 + 3h_2\Delta + g_2\Delta^2\right) + \left[3b_1 + 3\Delta(c_1 + d_1) + \Delta^2(4c_2 + 2d_2 - \bar{\Lambda}_D^2 g_2 + (c_2 - \dots)e_2)\right](1 + 2\bar{\Lambda}_{D^*}/T),$$

$$g f_D^2 f_D = \frac{2}{3}\bar{\Lambda}_D\left[\dots\right](1 + 2\bar{\Lambda}_D/T),$$

where $\Delta = \bar{\Lambda}_{D^{**}} - \bar{\Lambda}_D$. The range of the Borel parameter is fixed by requiring that the $1/T$ term be small in the OPE for the original sum rules, and that T not be too large compared to $2(\bar{\Lambda}_1 - \bar{\Lambda})$, where $\bar{\Lambda}_1$ is the mass of the first radial excitation in HQET. We obtain the numerical results:

$$g' = 0.5 \pm 0.1 \text{ GeV}^{-1/2}, \quad g = 1.0 \pm 0.2 \text{ GeV}^{-3/2}.$$

For discussion, our methods improve upon previous calculations using sum rules in full QCD [?], which had problems including contamination from the other 1^+ state and using the soft pion approximation. The $1/m$ corrections [?] and radiative corrections can be included systematically. The experimental data on the D_2^* width [?] can be explained by assuming the pionic decay mode is dominant. However, that of D_1 cannot be understood in this way, perhaps due to mixing of the two 1^+ states at order $1/m$ as well as the relatively large branching ratios for $D_1 \to D^{(*)}\rho$.

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