Decay constants of D_d, D_s, D_d^* and D_s^* mesons in the light-cone quark model

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Introduction

The decay constant of a meson is an useful parameter to study the weak decay processes such as quark mixing, CP violation, etc. The determination of this parameter is of prime interest in order to constrain the Cabibbo-Kobayashi-Maskawa (CKM) mixing matrix elements in the weak mesonic decays. The decay constants of pseudoscalar and vector mesons are useful for understanding the realization of chiral symmetry in QCD and for controlling the meson semileptonic decay widths, hadronic couplings and form factors.

The Standard Model (SM) of particle physics is subject to several high precision tests that try to verify the consistency of the theory. Several of those tests are directly related to the CKM matrix. The elements of the CKM matrix are fundamental parameters of the SM. A precise measurement of the individual CKM matrix elements will allow to test the unitarity of the quark mixing matrix and CP violation in the SM. Thus, it is crucial to know the values of CKM matrix elements accurately. However, the uncertainty in the knowledge of the decay constants of D mesons seriously hinders the precise extraction of the CKM matrix elements from experimental data, so it is essential to know the values of decay constants reliably in order to measure the CKM matrix elements. The understanding of decay constants is invaluable because they are single numbers expressing the amplitude for a meson to annihilate to a single particle (for e.g. a W boson or a photon), encapsulating information which reveals the inside structure of the hadron [1].

The purpose of this work is to examine the pseudoscalar and vector D mesons decay constants within the framework of the light-cone quark model (LCQM), which has been widely used in the phenomenological study of meson physics.

Light-cone framework

LCQM provides an advantage of the equal light-cone time ($x^+ = x^0 + x^3$) quantization and includes the important relativistic effects that are neglected in the traditional constituent quark model. Apart from this, the vacuum state in this approach is much simpler than that in other approaches. The light-cone wave functions are independent of the hadron momentum and thus are explicitly Lorentz invariant. A meson bound state consisting of a quark q_1 and an antiquark $\bar{q}_2$ with total momentum P and spin S can be written as [2]

$$\begin{aligned}|M(P,S,S_z)\rangle &= \int \frac{dp_1^+ d^2\mathbf{p}_{1\perp}}{16\pi^3}\frac{dp_2^+ d^2\mathbf{p}_{2\perp}}{16\pi^3}16\pi^3 \\ &\times\delta^3(\tilde{P}-\tilde{p}_1-\tilde{p}_2) \\ &\times\sum_{\lambda_1,\lambda_2}\Psi^{SS_z}(\tilde{p}_1,\tilde{p}_2,\lambda_1,\lambda_2) \\ &\times|q_1(p_1,\lambda_1)\bar{q}_2(p_2,\lambda_2)\rangle,\end{aligned}$$

where p_1 and p_2 are the on-mass-shell light-front momenta,

$$\tilde{p} = (p^+,\ \mathbf{p}_\perp),\ \mathbf{p}_\perp = (p^1,\ p^2),\ p^- = \frac{m^2+\mathbf{p}_\perp^2}{p^+}.$$

The light-front momenta p_1 and p_2 in terms of light-cone variables are

$$\begin{aligned}p_1^+ = xP^+, \quad p_2^+ = (1-x)P^+, \\ \mathbf{p}_{1\perp} = x\mathbf{P}_\perp + \mathbf{k}_\perp, \quad \mathbf{p}_{2\perp} = (1-x)\mathbf{P}_\perp - \mathbf{k}_\perp.\end{aligned}$$

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The momentum-space light-cone wave function Ψ^{SS_z} can be expressed as

$$\Psi^{SS_z}(\tilde{p}_1, \tilde{p}_2, \lambda_1, \lambda_2) = R^{SS_z}_{\lambda_1\lambda_2}(x, \mathbf{k}_\perp)\ \phi(x, \mathbf{k}_\perp),$$

where $R^{SS_z}_{\lambda_1\lambda_2}$ constructs a state of definite spin (S, S_z) out of the light-cone helicity (λ_1, λ_2) eigenstates. For convenience, we use the covariant form for $R^{SS_z}_{\lambda_1\lambda_2}$ which is given by

$$R^{SS_z}_{\lambda_1\lambda_2}(x, \mathbf{k}_\perp) = \frac{\sqrt{p_1^+ p_2^+}}{\sqrt{2}\ \widetilde{M}_0}\ \bar{u}(p_1, \lambda_1)\Gamma v(p_2, \lambda_2).$$

We use the Gaussian wave function to describe the radial part $\phi(x, \mathbf{k}_\perp)$:

$$\phi(x, \mathbf{k}_\perp) = \frac{4\pi^{3/4}}{\beta^{3/2}}\sqrt{\frac{dk_z}{dx}}\exp(-\frac{\mathbf{k}_\perp^2 + k_z^2}{2\beta^2}).$$

Decay constants

The decay constants of pseudoscalar and vector mesons are defined by

$$\begin{aligned}\langle 0|A^\mu|P\rangle &= i f_P P^\mu, \\ \langle 0|V^\mu|V\rangle &= i f_V M_V \epsilon^\mu.\end{aligned}$$

Using light-cone wave function, it is straightforward to show that the decay constant of a pseudoscalar meson and a vector meson is given by [2]

$$\begin{aligned} f_P &= 2\sqrt{6}\int \frac{dx d^2\mathbf{k}_\perp}{2(2\pi)^3}\phi(x, \mathbf{k}_\perp)\frac{\mathcal{A}}{\sqrt{\mathcal{A}^2 + \mathbf{k}_\perp^2}}, \\ f_V &= 2\sqrt{6}\int \frac{dx d^2\mathbf{k}_\perp}{2(2\pi)^3}\frac{\phi(x, \mathbf{k}_\perp)}{\sqrt{\mathcal{A}^2 + \mathbf{k}_\perp^2}}\frac{1}{M_0} \\ &\Big\{m_1 m_2 + x(1-x)M_0^2 + \mathbf{k}_\perp^2 + \frac{\mathcal{B}}{2W} \\ &\left[\frac{m_1^2 + \mathbf{k}_\perp^2}{1-x} - \frac{m_2^2 + \mathbf{k}_\perp^2}{x} - (1-2x)M_0^2\right]\Big\}. \end{aligned} \quad (1)$$

Calculations and Results

In the numerical calculations, we have used the constituent quark masses given by $m_c = 1.5$ GeV, $m_d = 0.22$ GeV and $m_s = 0.40$ GeV. The decay constants f_P and f_V can be calculated using Eqs. 1 for a given value β. In Figs. 1 & 2 we present the decay constants f_P and f_V as functions of β for the D mesons having s and d quarks as their light quark.

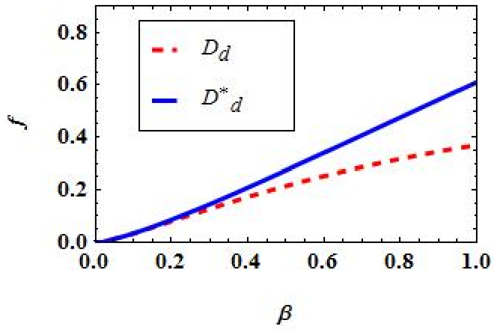

FIG. 1: f_{D_d} and $f_{D_d^*}$ (GeV) as functions of β

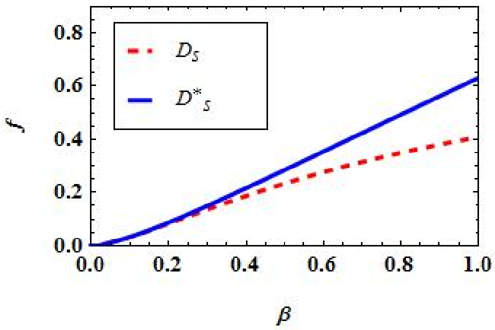

FIG. 2: f_{D_s} and $f_{D_s^*}$ (GeV) as functions of β

We have calculated the values of decay constants by using the values of β [1]. The results we obtained are as follows in GeV units:

$$\begin{aligned} f_{D_d} = 0.219, \quad f_{D_d^*} = 0.282, \\ f_{D_s} = 0.253, \quad f_{D_s^*} = 0.315. \end{aligned}$$

These results can be compared with other theoretical and experimental results [1].

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