Analysis of strong decays of the charmed mesons $D(2550)$, $D(2600)$, $D(2750)$ and $D(2760)$

Zhi-Gang Wang

Department of Physics, North China Electric Power University, Baoding 071003, P. R. China

Abstract

In this article, we study the strong decays of the newly observed charmed mesons $D(2550)$, $D(2600)$, $D(2750)$ and $D(2760)$ with the heavy quark effective theory in the leading order approximation, and tentatively identify the $(D(2550), D(2600))$ as the 2S doublet $(0^-, 1^-)$ and the $(D(2750), D(2760))$ as the 1D doublet $(2^-, 3^-)$, respectively. The identification of the $D(2750)$ and $D(2760)$ as the same particle with $J^P = 3^-$ is disfavored.

PACS numbers: 13.25.Ft; 14.40.Lb

Key Words: Charmed mesons, Strong decays

1 Introduction

Recently the Babar collaboration observed four excited charmed mesons $D(2550)$, $D(2600)$, $D(2750)$ and $D(2760)$ in the decay channels $D^0(2550) \to D^{*+}\pi^-, D^0(2600) \to D^{*+}\pi^-, D^{+}\pi^-$, $D^0(2750) \to D^{*+}\pi^-, D^0(2760) \to D^{+}\pi^-, D^+(2600) \to D^0\pi^+$ and $D^+(2760) \to D^0\pi^+$ respectively in the inclusive $e^+e^- \to c\bar{c}$ interactions at the SLAC PEP-II asymmetric-energy collider \cite{1}, see Table 1. The Babar collaboration also analyzed the helicity distributions to determine the spin-parity, and suggested that the $(D(2550), D(2600))$ (denoted as $(D', D'*)$ respectively in Table 2) may be the 2S radial excitation of the $(D, D^*)$, and the $(D(2750)$ and $D(2760)$ may be the $D$-wave states. Furthermore, the Babar collaboration measured the following ratios of the branching fractions:

\[
\begin{align*}
\text{Br} (D_1^{*}(2460)^0 \to D^{+}\pi^-) &= 1.47 \pm 0.03 \pm 0.16, \\
\text{Br} (D_2^{*}(2460)^0 \to D^{*+}\pi^-) &= 0.32 \pm 0.02 \pm 0.09, \\
\text{Br} (D(2600)^0 \to D^{+}\pi^-) &= 0.42 \pm 0.05 \pm 0.11. \\
\end{align*}
\]

In the heavy quark limit $m_Q \to \infty$, the heavy-light mesons $Q\bar{q}$ can be classified in doublets according to the total angular momentum of the light degrees of freedom $s_{\ell}$, $s_{\ell} = \bar{s}_q + \bar{L}$, where the $\bar{s}_q$ is the spin of the light antiquark $\bar{q}$ and the $\bar{L}$ is the orbital angular momentum of the light degrees of freedom \cite{2,3}. In the quark models, we usually use the $n$ to denote the radial quantum number. In the case $n = 1$, for $L = 0$, the doublet $(P, P^*)$ have the spin-parity $J^P_{s_L} = (0^+, 1^-)$; $L = 1$, the two doublets $(P'_0, P'_1)$ and $(P_1, P'_2)$ have the spin-parity $J^P_{s_L} = (0^+, 1^-)$ and $(1^+, 2^-)$, respectively; $L = 2$, the two doublets $(P'_1, P_2)$ and $(P'_2, P_3)$ have the spin-parity $J^P_{s_L} = (1^-, 2^-)$ and $(2^-, 3^-)$. 

\footnote{1E-mail:wangzgyiti@yahoo.com.cn}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
Meson & Branching Fraction \\
\hline
$D(2550)$ & $0.32 \pm 0.02 \pm 0.09$ \\
$D(2600)$ & $0.42 \pm 0.05 \pm 0.11$ \\
$D(2750)$ & $1.47 \pm 0.03 \pm 0.16$ \\
$D(2760)$ & \\
\hline
\end{tabular}
\caption{Branching fractions for the decays of the newly observed charmed mesons.}
\end{table}
respectively; where the superscript $P$ denotes the parity. The $n = 2, 3, 4, \cdots$ states are clarified by the analogous doublets, for example, $n = 2$, $L = 0$, the doublet $(P', P''')$ have the spin-parity $J^{P'}_{s_{I}} = (0^{−}, 1^{+})_{1/2}$; $n = 2$, $L = 1$, the two doublets $(P''', P')$ and $(P', P''')$ have the spin-parity $J^{P'}_{s_{I}} = (0^{+}, 1^{+})_{1/2}$ and $(1^{+}, 2^{+})_{3/2}$ respectively.

The helicity distributions favor identifying the $D^{0}(2550)$ as the $0^{−}$ state, the $D^{0}(2600)$ as the $1^{−}$, $2^{+}$, $3^{−}$ state, and the $D^{0}(2750)$ as the $1^{+}$, $2^{−}$ state [1]. From the Review of Particle Physics [4], we can see that only six low-lying states, $D$, $D^*$, $D_0(2400)$, $D_1(2430)$, $D_1(2420)$ and $D_2(2460)$ are established, while the $2S$ and $1D$ states are still absent. The newly observed charmed mesons $D(2550)$, $D(2600)$, $D(2750)$ and $D(2760)$ may be tentatively identified as the missing $2S$ and $1D$ states.

The mass is a fundamental parameter in describing a hadron, in Table 2, we present the predictions from some theoretical models, such as the relativized quark model based on a universal one-gluon-exchange-plus-linear-confinement potential [5], the semirelativistic quark potential model [6], the relativistic quark model includes the leading order $1/M_h$ corrections [7], the QCD-motivated relativistic quark model based on the quasipotential approach [8], for comparison. From the Table, we can see that the masses of the $D(2550)$, $D(2600)$ and $D(2750)$, $D(2760)$ lie in the regions of $2S$ and $1D$ states, respectively.

In Ref. [9], Sun et al study the strong decays of the $D(2550)$, $D(2600)$ and $D(2760)$ in the $3P_0$ model, and identify the $D(2600)$ as a mixture of the $2^3S_1 - 1^3D_1$ states and the $D(2760)$ as either the orthogonal partner of the $D(2600)$ or the $1^3D_3$ state. In Ref. [10], Zhong studies the strong decays of the $D(2550)$, $D(2600)$ and $D(2760)$ in a chiral quark model, and identifies the $D(2760)$ as the $1^3D_3$ state and the $D(2600)$ as the low-mass mixing state of the $1^3D_3 - 2^3S_1$ states.

In this work, we study the strong decays of the newly observed charmed mesons with the heavy quark effective theory in the leading order approximation to distinguish the different identifications. There have been several works using the heavy quark effective theory to identify the excited $D_s$ mesons, such as the $D_s(3040)$, $D_s(2700)$, $D_s(2860)$ [11] [12] [13] [14].

The article is arranged as follows: we study the strong decays of the newly observed charmed mesons with the heavy quark effective theory in Sect.2; in Sect.3, we present the numerical results and discussions; and Sect.4 is reserved for our conclusions.

| Mass [MeV] | Width [MeV] | Decay channel |
|------------|-------------|---------------|
| $D^0(2550)$ | 2539.4 ± 4.5 ± 6.8 | $D^{*+}\pi$ |
| $D^0(2600)$ | 2608.7 ± 2.4 ± 2.5 | $D^+\pi^-, D^{*+}\pi^-$ |
| $D^0(2750)$ | 2752.4 ± 1.7 ± 2.7 | $D^{*+}\pi^-$ |
| $D^0(2760)$ | 2763.3 ± 2.3 ± 2.3 | $D^+\pi^-$ |
| $D^+(2600)$ | 2621.3 ± 3.7 ± 4.2 | $D^0\pi^+$ |
| $D^+(2760)$ | 2769.7 ± 3.8 ± 1.5 | $D^0\pi^+$ |

Table 1: The experimental results from the Babar collaboration.
Table 2: The masses of the charmed mesons from different quark models compared with experimental data, and the possible identifications of the newly observed charmed mesons.

2 The strong decays with the heavy quark effective theory

In the heavy quark effective theory, the spin doublets can be described by the effective super-fields $H_a, S_a, T_a, X_a$ and $Y_a$, respectively \cite{15},

\begin{align}
H_a &= \frac{1 + \frac{\sqrt{}}{2}}{\frac{3}{2}} \left\{ P^{*}_{\mu \nu} \gamma_{\mu} - P_{\mu \nu} \gamma_{\nu} \right\}, \\
S_a &= \frac{1 + \frac{\sqrt{}}{2}}{\frac{3}{2}} \left\{ P^{\mu}_{\mu \nu} \gamma_{\mu} \gamma_{\nu} - P^{*}_{\mu \nu} \right\}, \\
T^{\mu}_{a} &= \frac{1 + \frac{\sqrt{}}{2}}{\frac{3}{2}} \left\{ P^{\mu}_{2 \nu} \gamma_{\nu} - P^{*}_{\nu} \sqrt{3} \gamma_{\mu} \left[ g^{\mu \nu} - \frac{\gamma'_{\mu}}{3} (\gamma_{\mu} - v_{\mu}) \right] \right\}, \\
X^{\mu}_{a} &= \frac{1 + \frac{\sqrt{}}{2}}{\frac{3}{2}} \left\{ P^{\mu}_{2 \nu} \gamma_{\nu} - P^{*}_{\nu} \sqrt{3} \gamma_{\mu} \left[ g^{\mu \nu} - \frac{\gamma'_{\mu}}{3} (\gamma_{\mu} - v_{\mu}) \right] \right\}, \\
Y^{\mu \nu}_{a} &= \frac{1 + \frac{\sqrt{}}{2}}{\frac{3}{2}} \left\{ P^{\mu \nu \sigma}_{3 \alpha \beta} \gamma_{\sigma} - P^{* \mu \nu \sigma}_{2 \alpha \beta} \sqrt{5} \gamma_{\mu} \left[ g^{\mu \nu} - \frac{\gamma_{\nu} g_{\beta} (\gamma_{\mu} - v_{\mu})}{5} - \frac{\gamma_{\beta} g_{\alpha} (\gamma'_{\nu} - v'_{\nu})}{5} \right] \right\} \right(2) \end{align}

where the heavy field operators contain a factor $\sqrt{M_p}$ and have dimension of mass $\frac{3}{2}$. The ground state and radial excited state heavy mesons with the same heavy flavor have the same spin, parity, time-reversal and charge conjugation properties except for the masses, and can be denoted by the super-fields: $H_a, H'_a, H''_a, \ldots; S_a, S'_a, S''_a, \ldots; T_a, T'_a, T''_a, \ldots; \ldots$; etc, where the superscripts $t, n$ and $m$ denote the first, the second and the third radial excited states, respectively. With a simple replacement of the components $P_a, P^{*}_a, P^{*}_{0a}, \ldots$ to the corresponding radial excited states $P'_a, P''_a, P^{*}_0, \ldots$, we can obtain the corresponding super-fields $H'_a, S'_a, \ldots$. 

| $n, L, s, J^P$ | Experiment $[1, 4]$ | GI $[5]$ | MMS $[6]$ | PE $[7]$ | EFG $[8]$ |
|----------------|-----------------|------------|-------------|----------|----------|
| $D_1$          | $1S_{\frac{1}{2}}^0$ | 1867       | 1880       | 1869     | 1868     | 1871     |
| $D^*_1$        | $1S_{\frac{1}{2}}^1$ | 2008       | 2040       | 2011     | 2005     | 2010     |
| $D^{*}_0$      | $1P_{\frac{1}{2}}^{0+}$ | 2400       | 2400       | 2283     | 2377     | 2406     |
| $D^{*}_1$      | $1P_{\frac{1}{2}}^{1+}$ | 2427       | 2490       | 2421     | 2490     | 2469     |
| $D_1$          | $1P_{\frac{3}{2}}^{1+}$ | 2420       | 2440       | 2425     | 2417     | 2416     |
| $D^{*}_2$      | $1P_{\frac{3}{2}}^{2+}$ | 2460       | 2500       | 2468     | 2460     | 2460     |
| $D'_1$         | $1D_{\frac{3}{2}}^{1-}$ | ?2763      | 2820       | 2762     | 2795     | 2788     |
| $D'_2$         | $1D_{\frac{3}{2}}^{2-}$ | ?2752      | 2800       | 2833     | 2850     | 2806     |
| $D'_3$         | $1D_{\frac{3}{2}}^{3-}$ | ?2763      | 2830       | 2799     | 2863     | 2863     |
| $D''_1$        | $2S_{\frac{1}{2}}^0$  | ?2539      | 2580       | 2589     | 2581     | 2581     |
| $D''_1$        | $2S_{\frac{1}{2}}^1$  | ?2609      | 2640       | 2692     | 2632     | 2632     |
The light pseudoscalar mesons are described by the fields \( \xi = e^{i\frac{\pi S}{\Lambda^2}} \), where

\[
\mathcal{M} = \begin{pmatrix}
\sqrt{\frac{1}{2}} \pi^0 + \sqrt{\frac{1}{6}} \eta^0 & \pi^+ & K^+ \\
\pi^- & -\sqrt{\frac{1}{2}} \pi^0 + \sqrt{\frac{1}{6}} \eta^0 & K^0 \\
K^- & K^0 & -\sqrt{\frac{1}{2}} \eta^0
\end{pmatrix}.
\]

At the leading order, the heavy meson chiral Lagrangians \( \mathcal{L}_H, \mathcal{L}_S, \mathcal{L}_T, \mathcal{L}_X, \mathcal{L}_Y \) for the strong decays to \( D^{(*)}\pi, D^{(*)}\eta \) and \( D_s^{(*)}K \) are written as [16, 17, 18, 19, 20]:

\[
\begin{align*}
\mathcal{L}_H &= g_H \text{Tr} \left\{ \bar{H} a H b \gamma \mu \gamma_5 A^\mu_{ba} \right\}, \\
\mathcal{L}_S &= g_S \text{Tr} \left\{ \bar{H} a S_b \gamma \mu \gamma_5 A^\mu_{ba} \right\} + \text{h.c.}, \\
\mathcal{L}_T &= \frac{g_T}{\Lambda^2} \text{Tr} \left\{ \bar{H} a T^\mu_b (iD_\mu A + iD\mu A_{xb} \gamma_5) \right\} + \text{h.c.}, \\
\mathcal{L}_X &= \frac{g_X}{\Lambda^2} \text{Tr} \left\{ \bar{H} a X^\mu_b (iD_\mu A + iD\mu A_{xb} \gamma_5) \right\} + \text{h.c.}, \\
\mathcal{L}_Y &= \frac{1}{\Lambda^2} \text{Tr} \left\{ \bar{H} a Y^\mu_{ba} \left[ k_1 (D_{\mu A} + k_2 (D_{\mu A} A_\lambda + D_\nu D_\lambda A_{\mu})_{ba} \gamma_5 \gamma_5 \right] \right\} + \text{h.c.}.
\end{align*}
\]

where

\[
\begin{align*}
D_\mu &= \partial_\mu + \gamma_\mu, \\
V_\mu &= \frac{1}{2} \left( \xi^\dagger \partial_\mu \xi + \xi \partial_\mu \xi^\dagger \right), \\
A_\mu &= \frac{1}{2} \left( \xi^\dagger \partial_\mu \xi - \xi \partial_\mu \xi^\dagger \right),
\end{align*}
\]

\( \Lambda^2 \) is the chiral symmetry-breaking scale and taken as \( \Lambda^2 = 1 \text{ GeV} \) [11], the strong coupling constants \( g_H, g_S, g_T, g_X \) and \( g_Y = (k_1 + k_2) \) can be fitted phenomenologically if there are enough experimental data. The subscript indexes \( H, S, T, X \) and \( Y \) denote the interactions between the super-field \( H \) and the super-fields \( H, T, X \) and \( Y \), respectively. We have smeared the superscripts \( i, n, m, \cdots \) for simplicity, the notation \( g_H \) denotes the strong coupling constants in the vertexes \( H H A, H' H A, H' H' A, H'' H A, \cdots \), the notations \( g_S, g_T, g_X \) and \( g_Y \) should be understood in the same way. In this article, we intend to study the ratios among different decay channels, the strong coupling constants are canceled out with each other, and cannot lead to confusion.

From the heavy meson chiral Lagrangians \( \mathcal{L}_H, \mathcal{L}_S, \mathcal{L}_T, \mathcal{L}_X, \mathcal{L}_Y \), we can obtain the widths \( \Gamma \) for the strong decays to \( D^{(*)}\pi, D^{(*)}\eta \) and \( D_s^{(*)}K \) easily,

\[
\Gamma = \frac{p_{cm}}{8\pi M^2} |T|^2,
\]

where the \( T \) denotes the scattering amplitudes, the \( p_{cm} \) is the momentum of the final states in the center of mass coordinate.

In calculations, we take the approximation \( A_\mu \approx i\frac{\partial_\mu M}{c} \). In the case that the light pseudoscalar meson momenta are not very small, we should add other terms and introduce new unknown coupling constants. Furthermore, the flavor and spin violation corrections of order \( \mathcal{O}(1/m_Q) \) to the heavy quark limit may be sizable, again we should introduce
new unknown coupling constants, which will not necessarily canceled out in the ratios of the decay widths. We cannot estimate the role and the size of such corrections on general grounds, however, we expect that they would not be larger than (or as large as) the leading order contributions.

3 Numerical Results

The input parameters are taken from the particle data group $M_{π^+} = 139.57$ MeV, $M_{π^0} = 134.9766$ MeV, $M_{K^+} = 493.677$ MeV, $M_{K^0} = 547.853$ MeV, $M_{D^+} = 1869.60$ MeV, $M_{D^0} = 1864.83$ MeV, $M_{D^+} = 1968.47$ MeV, $M_{D_s^+} = 2010.25$ MeV, $M_{D_{s0}} = 2006.96$ MeV, $M_{D_s^{*+}} = 2112.3$ MeV, $M_{D(2460)} = 2460.1$ MeV [4].

The numerical values for the widths of the strong decays

$$D_2^* \rightarrow D^{*+}π^−, D^{+}π^−,$$

$$D' \rightarrow D^{*+}π^−, D^{*0}π^0,$$

$$D'(D_1^*, D_2^*, D_3^*) \rightarrow D^{*+}π^−, D^{+}π^−, D^{*0}π^0, D^{0}π^0, D^{*0}η, D^{0}η, D_s^{*+}K^−, D_s^{*−}K^−, \ (6)$$

are presented in Tables 3-4.

In Table 5, we present the experimental data for the ratio $\frac{Γ(D^+π^-)}{Γ(D^+π^0)}$ of the well established meson $D_2^*(2460)$ from the Babar [1], CLEO [21, 22], ARGUS [23], and ZEUS [24] collaborations, the prediction 2.30 from the heavy quark effective theory in the leading order approximation is in excellent agreement with the average experimental value 2.35. Compared with the experimental data from the Babar collaboration $\frac{Γ(D^+π^-)}{Γ(D^+π^0)} = 1.47 ± 0.03 ± 0.16$ [1], the heavy quark effective theory in the leading order approximation leads to a larger ratio.

The total decay widths of the $(D(2550), D(2600))$ with the spin-parity $(0^−, 1^−)_{3/2}$ are $Γ_{D'} ≈ 1.7g_H^2$ GeV and $Γ_{D''} ≈ 2.0g_H^2$ GeV, the ratio $\frac{Γ_{D'}}{Γ_{D''}} ≈ 0.85$, which is smaller than the experimental data $\frac{Γ_{D'}}{Γ_{D''}} = 1.40$, where we have used the central values of the widths $Γ_{D'} ≈ (130 ± 12 ± 13)$ MeV and $Γ_{D''} = (93 ± 6 ± 13)$ MeV from the Babar collaboration [1]. For the charmed mesons, the leading power flavor and spin violation corrections (of order $O(1/m_Q)$) to the heavy quark limit may be sizable, we have to introduce new unknown coupling constants, the discrepancy may be smeared with the optimal parameters, furthermore, more precise measurements are needed to make a reliable comparison. In the case of the ratio $\frac{Γ_{D_2^*}}{Γ_{D_2^*}}$, the prediction 0.30 from the heavy quark effective theory in the leading order approximation is also smaller than the experimental data 0.48 from the Review of Particle Physics [1], if the leading power spin corrections to the heavy quark limit are taken into account, the discrepancy can be smeared [25].

The ratio $\frac{Γ(D''→D^+π^-)}{Γ(D''→D^+π^0)} = 0.82$ from the heavy quark effective theory in the leading order approximation is larger than the experimental data 0.32±0.02±0.09 from the Babar collaboration [1], just like in the case of the ratio $\frac{Γ(D_2^*→D^+π^-)}{Γ(D_2^*→D^+π^0)}$, and again more precise measurements are needed to make a reliable comparison. The strong coupling constants $g_{D^∗Dπ}$ and $g_{D^∗D^∗π}$ receive sizable contributions from the flavor and spin violation corrections [20, 26]. In the present case, the strong coupling constants $g_{D^∗Dπ}$ and $g_{D^∗D^∗π}$ also receive the flavor and spin violation corrections besides the leading order strong coupling
constant $g_H$, which maybe account for the discrepancy. We can tentatively identify the $(D(2550), D(2600))$ as the doublet $(0^-, 1^-)_{\frac{1}{2}^+}$ with $n = 2$.

The existing theoretical estimations for the strong coupling constant $g_H$ among the ground state heavy mesons ($n = 1$) vary in a large range $g_H = 0.1 - 0.6$, it is difficult to select the ideal value (one can consult Ref. [27] for more literatures), we usually use the value determined from the precise experimental data on the decay $D^{*+} \rightarrow D^0 \pi^+$ from the CLEO collaboration [28, 29]. In the present case, the strong coupling constants involve the radial excited $S$-wave heavy mesons and ground state $D$-wave heavy mesons, therefore the situation is more involved, and it is impossible to determine the relevant parameters with the heavy quark effective theory itself without enough experimental data. The theoretical works focus on the strong coupling constants $g_H, g_S, g_T$ of the ground state $S$-wave and $P$-wave heavy mesons (one can consult Refs. [20, 27, 30] for more literatures), while the works on the strong coupling constants $g_H, g_S, g_T$ of the radial excited $S$-wave and $P$-wave heavy mesons and $g_X, g_Y$ of the ground state $D$-wave heavy mesons are rare due to lack experimental data [31]. In this article, we take the strong coupling constants $g_H, g_T, g_X$ and $g_Y$ as unknown parameters, and prefer the ratios of the decay widths in different channels to compare with the experimental data.

From Table 4, we can see that if we identify the $(D(2760), D(2750))$ as the doublet $(1^-, 2^-)_{\frac{1}{2}}$ with $n = 1$, the ratio $\frac{\Gamma(D^{*1} \rightarrow D^{*+} \pi^-)}{\Gamma(D_2 \rightarrow D^{*+} \pi^-)} = 4.07$ from the leading order heavy quark effective theory deviates from the experimental data $0.42 \pm 0.05 \pm 0.11$ greatly [1]2, which requires the flavor and spin violation corrections depressed by the inverse heavy quark mass $1/m_Q$ are as large as the leading order contributions and have opposite sign, it is impossible, as the heavy quark effective theory has given many successful descriptions of the hadron properties [2, 3, 20]. On the other hand, if we identify the $(D(2750), D(2760))$ as the doublet $(2^-, 3^-)_{\frac{1}{2}}$ with $n = 1$, the deviation of the ratio $\frac{\Gamma(D^{*1} \rightarrow D^{*+} \pi^-)}{\Gamma(D_2 \rightarrow D^{*+} \pi^-)} = 0.80$ from the upper bound of the experimental data $0.42 \pm 0.05 \pm 0.11$ is not large [1], the contributions from the flavor and spin violation corrections maybe smear the discrepancy.

We also explore the possible identification of the $(D(2760))$ and $(D(2750))$ as the same $3^-$ state with $n = 1$, i.e. they are the $D_3$ state, the ratio $\frac{\Gamma(D^{*1} \rightarrow D^{*+} \pi^-)}{\Gamma(D_1 \rightarrow D^{*+} \pi^-)} = 1.94$ from the heavy quark effective theory in the leading order approximation is too large compared with the experimental data $\frac{\Gamma(D^{*0} \rightarrow D^{*+} \pi^-)}{\Gamma(D_1 \rightarrow D^{*+} \pi^-)} = 0.42 \pm 0.05 \pm 0.11$ [1], which again requires the flavor and spin violation corrections depressed by the inverse heavy quark mass $1/m_Q$ are as large as the leading order contributions and have opposite sign, such an identification is disfavored. On the other hand, the helicity distribution disfavors identifying the $(D(2750))$ as the $3^-$ state [1]. We can tentatively identify the $(D(2750), D(2760))$ as the doublet $(2^-, 3^-)_{\frac{1}{2}}$ with $n = 1$.

In this article, we also present the widths for the $D^{(*)}_s K$ and $D^{(*)}_s \eta$ decays, where the strong coupling constants are retained, the predictions can be confronted with the experienial data in the future at the BESIII, KEK-B, RHIC, PANDA and LHCb.

---

2We take the approximation $\Gamma_{D(2760)} = \Gamma_{D(2750)}$. 

---

We take the approximation $\Gamma_{D(2760)} = \Gamma_{D(2750)}$. 

---
| $nLs_J^P$ | Mass [MeV] | Decay channels | Width [GeV] |
|-----------|------------|----------------|-------------|
| $D_2^*$ | 1 $P \frac{1}{2} 2^+$ | $D^{*+} \pi^-; D^+ \pi^-$ | 0.0543879 $g_H^2; 0.124928 g_H^2$ |
| $D'$ | 2 $S \frac{1}{2} 0^-$ | $D^{*+} \pi^-; D^{*0} \pi^0$ | 1.13557 $g_H^2; 0.583137 g_H^2$ |
| $D^{*'}$ | 2 $S \frac{1}{2} 1^-$ | $D^{*+} \pi^-; D^+ \pi^-$; $D^0 K^-; D^+ K^-$; $D^{*0} \pi^0; D^0 \pi^0$; $D^{*0} \eta; D^0 \eta$ | 0.66068 $g_H^2; 0.54317 g_H^2$; 0.000518592 $g_H^2; 0.106459 g_H^2$; 0.336747 $g_H^2; 0.276487 g_H^2$; 0.00412868 $g_H^2; 0.0266957 g_H^2$ |
| $D_1^*$ | 1 $D \frac{1}{2} 1^-$ | $D^{*+} \pi^-; D^+ \pi^-$; $D^0 K^-; D^+ K^-$; $D^{*0} \pi^0; D^0 \pi^0$; $D^{*0} \eta; D^0 \eta$ | 0.339606 $g_X^2; 5.19392 g_X^2$; 0.0632191 $g_X^2; 1.86912 g_X^2$; 0.173223 $g_X^2; 2.65247 g_X^2$; 0.0266411 $g_X^2; 0.508904 g_X^2$ |
| $D_2$ | 1 $D \frac{1}{2} 2^-$ | $D^{*+} \pi^-; D^+ \pi^-$; $D^0 K^-; D^+ K^-$; $D^{*0} \pi^0; D^0 \pi^0$; $D^{*0} \eta; D^0 \eta$ | 1.27691 $g_X^2; 0$; 0.180643 $g_X^2; 0$; 0.653307 $g_X^2; 0$; 0.069308 $g_X^2; 0$ |
| $D_2^*$ | 1 $D \frac{1}{2} 2^-$ | $D^{*+} \pi^-; D^+ \pi^-$; $D^0 K^-; D^+ K^-; D^{*0} \pi^0; D^0 \pi^0$; $D^{*0} \eta; D^0 \eta$ | 0.2212263 $g_X^2; 0$; 0.00413833 $g_X^2; 0$; 0.114719 $g_X^2; 0$; 0.0027123 $g_X^2; 0$ |
| $D_3$ | 1 $D \frac{3}{2} 3^-$ | $D^{*+} \pi^-; D^+ \pi^-$; $D^0 K^-; D^+ K^-; D^{*0} \pi^0; D^0 \pi^0$; $D^{*0} \eta; D^0 \eta$ | 0.0907266 $g_X^2; 0.176388 g_X^2$; 0.00218128 $g_X^2; 0.018115 g_X^2$; 0.0468994 $g_X^2; 0.0912646 g_X^2$; 0.00124089 $g_X^2; 0.00618076 g_X^2$ |

Table 3: The strong decay widths of the newly observed charmed mesons with possible identifications.
| $nLs\ell J^P$ | Mass [MeV] | Ratio |
|----------------|--------------|-------|
| $D_2^*$ | $1P^\frac{3}{2}2^+$ | 2460.1 | $\frac{\Gamma(D^+\pi^-)}{\Gamma(D^{*+}\pi^-)} = 2.30$ |
| $D^{*'}$ | $2S^\frac{1}{2}1^-$ | ?2608.7 | $\frac{\Gamma(D^\pi^-)}{\Gamma(D^{*\pi^-})} = 0.82$; $\frac{\Gamma(D^{\pi^0}\eta)}{\Gamma(D^{*+}\pi^-)} = 0.51$; $\frac{\Gamma(D^0\eta)}{\Gamma(D^{*+}\pi^-)} = 0.42$; $\frac{\Gamma(D^{*+}K^-)}{\Gamma(D^{*+}\pi^-)} = 0.16$; $\frac{\Gamma(D^{*0}\eta)}{\Gamma(D^{*+}\pi^-)} = 0.044$; $\frac{\Gamma(D^{*+}\eta)}{\Gamma(D^{*+}\pi^-)} = 0.013$; $\frac{\Gamma(D^{*+}K^-)}{\Gamma(D^{*+}\pi^-)} = 0.001$ |
| $D_1$ | $1D^\frac{3}{2}1^-$ | ?2763.3 | $\frac{\Gamma(D^\pi^-)}{\Gamma(D^{+}\pi^-)} = 15.29$; $\frac{\Gamma(D^{\pi^0}\eta)}{\Gamma(D^{+}\pi^-)} = 7.81$; $\frac{\Gamma(D^{*+}K^-)}{\Gamma(D^{*+}\pi^-)} = 5.50$; $\frac{\Gamma(D^{*0}\eta)}{\Gamma(D^{+}\pi^-)} = 1.50$; $\frac{\Gamma(D^{*+}K^-)}{\Gamma(D^{*+}\pi^-)} = 0.51$; $\frac{\Gamma(D^{*+}K^-)}{\Gamma(D^{*+}\pi^-)} = 0.19$; $\frac{\Gamma(D^{*+}K^-)}{\Gamma(D^{*+}\pi^-)} = 0.067$ |
| $D_2$ | $1D^\frac{3}{2}2^-$ | ?2752.4 | $\frac{\Gamma(D^{\pi^0}\eta)}{\Gamma(D^{+}\pi^-)} = 0.51$; $\frac{\Gamma(D^{*+}K^-)}{\Gamma(D^{*+}\pi^-)} = 0.14$; $\frac{\Gamma(D^{*+}\eta)}{\Gamma(D^{*+}\pi^-)} = 0.054$ |
| $D_3$ | $1D^\frac{5}{2}2^-$ | ?2752.4 | $\frac{\Gamma(D^{\pi^0}\eta)}{\Gamma(D^{+}\pi^-)} = 0.52$; $\frac{\Gamma(D^{*+}K^-)}{\Gamma(D^{*+}\pi^-)} = 0.019$; $\frac{\Gamma(D^{*+}\eta)}{\Gamma(D^{*+}\pi^-)} = 0.012$ |
| $D_4$ | $1D^\frac{5}{2}3^-$ | ?2763.3 | $\frac{\Gamma(D^\pi^-)}{\Gamma(D^{+}\pi^-)} = 1.94$; $\frac{\Gamma(D^{\pi^0}\eta)}{\Gamma(D^{+}\pi^-)} = 1.01$; $\frac{\Gamma(D^{*+}K^-)}{\Gamma(D^{*+}\pi^-)} = 0.52$; $\frac{\Gamma(D^{*+}K^-)}{\Gamma(D^{*+}\pi^-)} = 0.20$; $\frac{\Gamma(D^{*+}K^-)}{\Gamma(D^{*+}\pi^-)} = 0.068$; $\frac{\Gamma(D^{*+}K^-)}{\Gamma(D^{*+}\pi^-)} = 0.024$; $\frac{\Gamma(D^{*+}K^-)}{\Gamma(D^{*+}\pi^-)} = 0.014$ |
| $D_1^*$ | $1D^\frac{3}{2}1^-$ | ?2763.3 | $\frac{\Gamma(D_1^*\rightarrow D^\pi^-)}{\Gamma(D_2\rightarrow D^{*+}\pi^-)} = 4.07$ |
| $D_2^*$ | $1D^\frac{3}{2}2^-$ | ?2752.4 | $\frac{\Gamma(D_2^*\rightarrow D^\pi^-)}{\Gamma(D_2\rightarrow D^{*+}\pi^-)} = 0.80$ |

Table 4: The ratios of the strong decay widths of the newly observed charmed mesons with possible identifications.

| Babar | CLEO | CLEO | ARGUS | ZEUS | This work |
|-------|------|------|-------|------|-----------|
| $1.47 \pm 0.03 \pm 0.16$ | $2.2 \pm 0.7 \pm 0.6$ | $2.3 \pm 0.8$ | $3.0 \pm 1.1 \pm 1.5$ | $2.8 \pm 0.8^{+0.5}_{-0.6}$ | $2.30$ |

Table 5: The ratio of $\frac{\Gamma(D_2^*(2460)^0\rightarrow D^+\pi^-)}{\Gamma(D_2^*(2460)^0\rightarrow D^{*+}\pi^-)}$ from the experimental data compared with the prediction from the leading order heavy quark effective theory.
4 Conclusion

In this article, we study the strong decays of the newly observed charmed mesons $D(2550)$, $D(2600)$, $D(2750)$ and $D(2760)$ with the heavy quark effective theory in the leading order approximation, and tentatively identify the $(D(2550), D(2600))$ as the doublet $(0^-, 1^-)$ with $n = 2$ and $(D(2750), D(2760))$ as the doublet $(2^-, 3^-)$ with $n = 1$, respectively. The identification of the $D(2750)$ and $D(2760)$ as the same particle with $J^P = 3^-$ is disfavored. The other predictions can be confronted with the experimental data in the future at the BESIII, KEK-B, RHIC, PANDA and LHCb.

Acknowledgment

This work is supported by National Natural Science Foundation of China, Grant Numbers 10775051, 11075053, and Program for New Century Excellent Talents in University, Grant Number NCET-07-0282, and the Fundamental Research Funds for the Central Universities.

References

[1] P. del Amo Sanchez et al, arXiv:1009.2076.
[2] A. V. Manohar and M. B. Wise, Camb. Monogr. Part. Phys. Nucl. Phys. Cosmol. 10 (2000) 1.
[3] M. Neubert, Phys. Rept. 245 (1994) 259.
[4] K. Nakanura et al, J. Phys. G37 (2010) 075021.
[5] S. Godfrey and N. Isgur, Phys. Rev. D32 (1985) 189.
[6] T. Matsuki, T. Morii and K. Sudoh, Prog. Theor. Phys. 117 (2007) 1077.
[7] M. Di Pierro and E. Eichten, Phys. Rev. D64 (2001) 114004.
[8] D. Ebert, R. N. Faustov and V. O. Galkin, Eur. Phys. J. C66 (2010) 197.
[9] Z. F. Sun, J. S. Yu, X. Liu and T. Matsuki, arXiv:1008.3120.
[10] X. H. Zhong, arXiv:1009.0359.
[11] P. Colangelo and F. De Fazio, Phys. Rev. D81 (2010) 094001.
[12] P. Colangelo, F. De Fazio, S. Nicotri and M. Rizzi, Phys. Rev. D77 (2008) 014012.
[13] P. Colangelo, F. De Fazio and S. Nicotri, Phys. Lett. B642 (2006) 48.
[14] P. Colangelo, F. De Fazio and R. Ferrandes, Phys. Lett. B634 (2006) 235.
[15] A. F. Falk, Nucl. Phys. B378 (1992) 79.
[16] M. B. Wise, Phys. Rev. D45 (1992) 2188.
[17] G. Burdman and J. F. Donoghue, Phys. Lett. B280 (1992) 287.

[18] P. Cho, Phys. Lett. B285 (1992) 145.

[19] T. M. Yan, H. Y. Cheng, C. Y. Cheung, G. L. Lin, Y. C. Lin and H. L. Yu, Phys. Rev. D46 (1992) 1148.

[20] R. Casalbuoni, A. Deandrea, N. Di Bartolomeo, F. Feruglio, R. Gatto and G. Nardulli, Phys. Rept. 281 (1997) 145.

[21] P. Avery et al, Phys. Lett. B331 (1994) 236.

[22] P. Avery et al, Phys. Rev. D41 (1990) 774.

[23] H. Albrecht et al, Phys. Lett. B232 (1989) 398.

[24] S. Chekanov et al, Eur. Phys. J. C60 (2009) 25.

[25] A. F. Falk and T. Mehen, Phys. Rev. D53 (1996) 231.

[26] C. G. Boyd and B. Grinstein, Nucl. Phys. B442 (1995) 205.

[27] Z. G. Wang, Nucl. Phys. A796 (2007) 61.

[28] S. Ahmed et al, Phys. Rev. Lett. 87 (2001) 251801.

[29] A. Anastassov et al, Phys. Rev. D65 (2002) 032003.

[30] Z. G. Wang and S. L. Wan, Phys. Rev. D74 (2006) 014017.

[31] P. Z. Huang, L. Zhang and S. L. Zhu, Phys. Rev. D81 (2010) 094025.