Strong Decay Widths and Coupling Constant of Recent Charm Meson States

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Abstract

Open charm hadrons with strange and non-strange mesons have been discovered in recent years. We study the spectra of several newly observed resonances by different collaborations like BaBar [2] and LHCb [3] etc. Using an effective Lagrangian approach based on heavy quark symmetry and chiral dynamics, we explore the strong decay widths and branching ratios of various resonances and suggest their $J^P$ values. We try to fit the experimental data to find the coupling constants involved in the strong decays through pseudoscalar mesons. The present work also discusses about the possible spin-parity assignments of recently observed states by LHCb collaboration. The tentative assignment of newly discovered state $D_s^*(3000)$ can be natural parity states ($0^-,1^+,2^-,3^+....$) while $D_J(3000)$ can be identified with unnatural parity states like ($0^+,1^-,2^+,3^-....$). Therefore, the missing doublets $2S,1D,1F,2P$ and $3S$ can be thought of filled up with these states. We study the two-body strong decay widths and branching ratios of missing doublets and plot branching ratios vs mass of decaying particle. These plots are used to analyze all assignments to $D_J(3000)$ deeply and various possibilities for $J^P$ values.

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1 Introduction

The hadrons containing a single heavy quark can be analyzed in a framework which is formulated for $N_f$ heavy quarks with mass $m_Q \gg \Lambda_{QCD}$ using heavy quark effective theory [1]. This theory assumes heavy quark to act as static color source and
its spin is $s_Q$ which can be thought of coupled to spin of light degrees of freedom $s_l$. Secondly, heavy quark flavor symmetry leads to interaction of heavy quark with light degrees of freedom through exchange of soft gluons only. The heavy quark spin-flavor symmetry can be exploited further to explore several hadronic properties. The motivation for present work arises due to recently observed charm and bottom meson states by experimental collaborations like BaBar, LHCb and CDF \[4\]. The heavy meson spectrum is one of the recent interest to place for the various particles at different resonances and energies. Recently, some excited charm meson states were observed which are $D(2550)$, $D(2600)$, $D(2750)$ and $D(2760)$ in the decay channels $D^0(2550) \rightarrow D^{*+}\pi^-$, $D^0(2600) \rightarrow D^{*+}\pi^-$, $D^0(2750) \rightarrow D^{+}\pi^-$, $D^+(2600) \rightarrow D^0\pi^+$ and $D^+(2760) \rightarrow D^0\pi^+$ in the inclusive $e^+e^- \rightarrow cc$ interactions by BaBar Collaboration \[2\]. The most suitable spin-parity assignments for $D(2750), D(2760)$ is $(2^-, 3^-)$ or 1D and for $D(2550), D(2600)$ is $(0^-, 1^-)$ i.e. 2S state respectively. LHCb collaboration \[3\] observed some new resonances in addition to above i.e. $D_J(3000)^+, D_J^0(2460)$ and $D_J^0(2760)$ and exists in the $D^{*+}\pi^-$ invariant mass spectrum. The states, $D_J^0(3000)^+, D_J^0(2460)$ and $D_J^0(2760)$ were observed in $D^0\pi^+$ spectrum whereas the states measured in $D^{*+}\pi^-$ spectrum were $D_1(2420)^0, D_2(2460)^0, D_J^0(2760)^0, D_J(2580)^0, D_J(2740)^0$ and $D_J(3000)^0$ respectively. A table for the properties of recently observed states has been shown below. Similar is the case in beauty sector. Very recently CDF Collaboration \[4\] has found evidence for a new resonance $B(5970)$ simultaneously in $B^0\pi^+$ and $B^{+}\pi^-$ mass distributions with a significance of 4.4 standard deviations and further reported the first study of resonances with orbitally excited $B^+$ mesons and updated measurement of orbitally excited $B^0$ and $B^0_s$ mesons. The branching ratio for $B^0_s \rightarrow B^{*+}K^-$ decays is also measured. The masses of new $B(5970)$ measured resonances are $5978 \pm 5(stat) \pm 12(syst) MeV/c^2$ for neutral state and $5961 \pm 5(stat) \pm 12(syst) MeV/c^2$ for charged asymmetry into $B\pi$ states. This state may be proposed as belonging to radially excited bottom meson family. Therefore, in past decades, we faced several ground as well as excited states of charm meson family such as discovery of $D_{sJ}(2460)$, $D_{sJ}(2632)$ and $D_{sJ}(3040)$ etc. In bottom meson family we witness some new states such as $B(5279)$, $B^*(5325)$ for $n=1$ family in $(0^-, 1^-)$ doublet. In the infinite heavy quark mass limit, a heavy light system $Q\bar{q}$ can be classified into doublets depending upon their quantum numbers. A heavy hadronic system containing heavy quark with spin quantum number $S_Q$ and light degrees of freedom $s_l$ that include light quark and gluons interacting through quark-antiquark pairs. It should have the quantum number of light quark that is $S_l$ in order to have total conserved quantum number $J$ where $J = S_Q + S_l$. Defining $J$ as
$J^2 = j(j+1)$ and $S_Q^2 = (s_Q)(s_Q+1)$ and $S_l^2 = (s_l)(s_l+1)$, the total spin $j \pm = s_l \pm \frac{1}{2}$ can be obtained by combining the spin of heavy quark spin $\frac{1}{2}$ with spin of light degrees of freedom. The heavy mesonic system form a degenerate doublet of ground state with $J = \pm 1$ and negative parity denoted as $D$ and $D^*$ for charm meson. The first excited states $0^+$ and $1^+$ heavy mesons are the quantum numbers of the $s_l^F = \frac{1}{2}^+$ doublet. There is also an excited doublet of heavy meson with $J^P = 1^+$ and $2^+$. Similarly, other excited mesonic states have their $J^P$ states. In this article, we identify the recent charmed meson states $D_J(2550)$, $D_J^*(2600)$, $D_J(2740)$, $D_J^*(2760)$, $D_J(3000)$ and $D_J^*(3000)$ with their $J^P$ assignment. These states were observed by LHCb collaboration and predicting their decay widths and masses. We study strong decays of these charmed mesons to ground states heavy mesons along with the emission of pseudo-scalar pions in heavy quark effective theory in the leading order approximations. Although the same work has been studied by [10] but we extend their predictions by fitting the experimental data to find the coupling constants in various strong decays. Also, we include two additional possibilities for assignment of $J^P$ states to $D_J^*(3000)$ and $D_J(3000)$. In the end, we also try to justify all the possible assignments to $D_J^*(3000)$ and $D_J(3000)$ by analyzing their branching ratios graphically.

2 The Lagrangian for Strong Decays to Heavy Mesons

A single field $H_a$ where it annihilates the $s_l = \frac{1}{2}^-$ meson doublet, pseudoscalar and vector mesons can be mentioned as[5]

$$H_a = \frac{1 + \gamma}{2} (P_a^\mu \gamma_\mu - P_a^* \gamma_5)$$ (1)

Here $a$ is the SU(3) index. In charm mesons sector, $H_a$ consists of the $D^0, D^+, D_s^+$ pseudo-scalar mesons and $D_s^{*0}, D_s^{*+}, D_s^{*+}$ vector mesons. The lowest lying excited states are the $J^P = 0^+$ and $1^+$ i.e. $s_l^F = \frac{1}{2}^+$ doublet and represented by the fields $S_a$ [6]. The fields for excited spin doublets are mentioned below:

$$S_a = \frac{1 + \gamma}{2} (P_{1a}^\mu \gamma_\mu - P_{0a}^* \gamma_5)$$ (2)

$$T_a^\mu = \frac{1 + \gamma}{2} (P_{2a}^{\mu\nu} \gamma_{\mu\nu} - P_{1a}^{\mu\nu} \sqrt{\frac{3}{2}} \gamma_5 [g^\mu\nu - \frac{1}{3} \gamma^\mu (\gamma^\nu - v^\nu)])$$ (3)

$$X_a^\mu = \frac{1 + \gamma}{2} (P_{2a}^{*\mu\nu} \gamma_{\mu\nu} - P_{1a}^{*\mu\nu} \sqrt{\frac{3}{2}} [g^{\mu\nu} - \frac{1}{3} \gamma^\mu (\gamma^\nu + v^\nu)])$$ (4)

$$Y_a^{\mu\nu} = \frac{1 + \gamma}{2} (P_{3a}^{*\mu\nu\sigma} \gamma_{\mu\nu\sigma} - P_{2a}^{*\mu\nu} \gamma_5 \frac{5}{3} [g^{\mu\nu}_a \gamma_5 g^{\rho}_a \gamma_5 - g^{\mu}_a \gamma_5 \gamma_5 (\gamma^\nu - v^\nu)] - g^{\mu}_a \gamma_5 (\gamma^\nu - v^\nu))$$ (5)
\[
Z_\mu^\nu = 1 + \frac{\gamma}{2} (P_{3a}^\mu \gamma_5 \gamma_\sigma - P_{3a}^\mu \gamma_5 \gamma_\sigma \sqrt{\frac{3}{2} g_{\mu\nu}^\sigma g_{\beta}^\gamma - \frac{g_{\mu\gamma}^\alpha (\gamma^\mu + v^\mu)}{5} - \frac{g_{\mu\beta}^\alpha (\gamma^\nu + v^\nu)}{5}) \right)
\]

(6)

\[
R_a^{\mu\nu} = 1 + \frac{\gamma}{2} (P_{4a}^\mu \gamma_5 \gamma_\sigma - P_{3a}^\mu \gamma_5 \gamma_\sigma \sqrt{\frac{7}{4} g_{\alpha\mu}^\nu g_{\rho}^\beta \gamma_\alpha (\gamma^\mu - v^\mu) - \frac{g_{\alpha\rho}^\nu g_{\beta}^\gamma (\gamma^\mu - v^\mu)}{7} - \frac{g_{\alpha\gamma}^\rho g_{\beta}^\nu (\gamma^\nu - v^\nu)}{7}) \right)
\]

(7)

The super fields \(H_a\) contain s-wave mesons whereas \(S_a, T_a\) contain the p-wave mesons. The light pseudoscalar mesons are described by the fields \(\xi = \exp i \frac{M}{\tau} \). The pion octet is introduced by the vector and axial combinations \(V^\mu = \frac{1}{2} \xi \partial^\mu \xi^\dagger + \xi^\dagger \partial^\mu \xi\) and \(A^\mu = \frac{1}{2} \xi^\dagger \partial^\mu \xi - \xi^\dagger \partial^\mu \xi\). We choose \(f_\pi = 130 \text{MeV}\). Here, all traces are taken over Dirac spinor indices, light quark \(SU(3)_L\) flavor indices \(a = u, d, s\) and heavy quark flavor indices \(Q = c, b\). The Dirac structure of chiral Lagrangian has been replaced by velocity vector \(v\). At the leading order, the heavy meson chiral chiral Lagrangian terms \(L_H, L_S, L_T, L_X, L_Y, L_Z, L_R\) for the strong decays to the \(D^{(*)}\pi, D^{(*)}\eta\) and \(D^{(*)}_b K\) states can be written as:

\[
L_H = g_H Tr \{ \bar{H}_a H_b \gamma_5 A^\mu_{ba} \}
\]

(8)

\[
L_S = g_S Tr \{ \bar{H}_a S_b \gamma_5 A^\mu_{ba} \} + h.c.,
\]

(9)

\[
L_T = \frac{g_T}{\Lambda} Tr (\bar{H}_a T^\mu_{ba} (D^\mu A + i \bar{D} A)_{ba} \gamma_5) + h.c.,
\]

(10)

\[
L_X = \frac{g_X}{\Lambda} Tr (\bar{H}_a X^\mu_{ba} (i D^\mu A + i \bar{D} A)_{ba} \gamma_5) + h.c.,
\]

(11)

where \(D^\mu = \partial^\mu + \nu^\mu, \{D^\mu, D^\nu\} = D^\mu D^\nu + D^\nu D^\mu, \{D^\mu, D^\nu, D^\rho\} = D^\mu D^\rho D^\nu + D^\rho D^\nu D^\mu, D^\nu D^\rho D^\mu + D^\rho D^\mu D^\nu, D^\mu D^\rho D^\nu + D^\nu D^\rho D^\mu\). These terms describe the transitions of positive and negative parity mesons with the emission of light pseudo-scalar mesons. The mixing angle between two states are determined by including spin symmetry violating corrections in the Lagrangian. The term should respect parity and time reversal and may be of generic form as written below.

\[
L_{d1} = \frac{h_1}{2 \kappa_1 \Lambda} Tr [\bar{H} \sigma^\mu^\nu T^\alpha \sigma^\mu^\nu \gamma_5 (i D_\alpha A^\kappa + i D^\kappa A)_{\alpha}] + h.c.
\]

(14)

The corresponding operator for the mixing of \(1^+\) in \(2S\) and \(1D\) respectively is due to spin symmetry violating effect and can be written as: \(L_{mix} = g_1 Tr [\bar{H} \phi_{\mu^\nu} X^\mu \sigma^\nu \nu^\rho] + h.c..\)
3 Strong Decay Width Formula and Coupling Constants

From the chiral Lagrangian terms, we can obtain the decay widths $\Gamma$ for strong
decays to final states $D^{(*)}\pi$, $D^{(*)}\eta$, $D_s^{(*)}K$ where the symmetry breaking scale
$\Lambda_X = 1$GeV. The expression for decay widths if we consider various doublets
which the decaying meson belongs to are as follows where $M$ denotes the emission
of pseudoscalar mesons i.e. $\pi$, $K$ and $\eta$ fields.

$(0^-,1^-)$ to $(0^-,1^-) + M$

$$\Gamma(1^- \rightarrow 0^-) = C_M \frac{g_Y^2}{6\pi f_\pi^2} \frac{M_f}{M_i} |p_\pi M|^3$$  \hspace{1cm} (15)

$$\Gamma(1^- \rightarrow 1^-) = C_M \frac{g_Y^2}{3\pi f_\pi^2} \frac{M_f}{M_i} |p_M^- M|^3$$ \hspace{1cm} (16)

$(0^+,1^+)$ to $(0^-,1^-) + M$

$$\Gamma(1^+ \rightarrow 1^-) = C_M \frac{g_Y^2}{2\pi f_\pi^2} \frac{M_f}{M_i} |p_M^- [m^2_{\pi M} + |p_M|^2]|$$ \hspace{1cm} (17)

$$\Gamma(1^+ \rightarrow 0^-) = C_M \frac{g_Y^2}{2\pi f_\pi^2} \frac{M_f}{M_i} |p_M^- [m^2_{\pi M} + |p_M|^2]|$$ \hspace{1cm} (18)

$(1^+,2^+)$ to $(0^-,1^-) + M$

$$\Gamma(1^+ \rightarrow 1^-) = C_M \frac{2g_T^2}{3\pi f_\pi^2 \Lambda^2} \frac{M_f}{M_i} |p_M^5 |$$ \hspace{1cm} (19)

$$\Gamma(2^+ \rightarrow 0^-) = C_M \frac{4g_T^2}{15\pi f_\pi^2 \Lambda^2} \frac{M_f}{M_i} |p_M^5 |$$ \hspace{1cm} (20)

$$\Gamma(2^+ \rightarrow 1^-) = C_M \frac{2g_T^2}{5\pi f_\pi^2 \Lambda^2} \frac{M_f}{M_i} |p_M^5 |$$ \hspace{1cm} (21)

$(1^-,2^-)$ to $(0^-,1^-) + M$

$$\Gamma(1^- \rightarrow 0^-) = C_M \frac{4g_X^2}{9\pi f_\pi^2 \Lambda^2} \frac{M_f}{M_i} |p_M^3 | [m^2_{\pi M} + |p_M|^2]$$ \hspace{1cm} (22)

$$\Gamma(1^- \rightarrow 1^-) = C_M \frac{2g_X^2}{9\pi f_\pi^2 \Lambda^2} \frac{M_f}{M_i} |p_M^3 | [m^2_{\pi M} + |p_M|^2]$$ \hspace{1cm} (23)

$$\Gamma(2^- \rightarrow 1^-) = C_M \frac{2g_X^2}{3\pi f_\pi^2 \Lambda^2} \frac{M_f}{M_i} |p_M^5 | [m^2_{\pi M} + |p_M|^2]$$ \hspace{1cm} (24)

$(2^-,3^-)$ to $(0^-,1^-) + M$

$$\Gamma(2^- \rightarrow 1^-) = C_M \frac{4g_X^2}{15\pi f_\pi^2 \Lambda^4} \frac{M_f}{M_i} |p_M^7 |$$ \hspace{1cm} (25)
\[
\Gamma(3^- \to 0^-) = C_M \frac{4g_Y^2}{35\pi f_\pi^2 \Lambda^1} \frac{M_f}{M_i} |\vec{p}_M|^7 
\]
(26)

\[
\Gamma(3^- \to 1^-) = C_M \frac{16g_Y^2}{105\pi f_\pi^2 \Lambda^1} \frac{M_f}{M_i} |\vec{p}_M|^7 
\]
(27)

The coefficients \(C_M\) are different for the various light pseudoscalar mesons: \(C_{\pi^+} = C_{K^+} = 1, C_{\pi^0} = C_{K^s} = \frac{1}{2}, C_\eta = \frac{1}{6}\). \(\vec{p}_M\) is the three momentum of M. The higher order corrections to heavy quark limit can also be considered by adding terms of the order \(\frac{1}{m_Q}\) with some unknown constants. The decay rates depend upon effective coupling constants. The parameters used in the above expressions for decay widths are taken from the particle data group[7]. Thus the numerical values of decay widths come out in terms of coupling constants \(g_H, g_Y, g_X\) etc. Here the first radial excitation of \(D^\ast\) is represented as \(\tilde{D}^\ast\). The first radially excited state of H is governed by the decay constant \(\tilde{g}_H\) which can be fitted to experimental data within mass range of 2600-2700 MeV. Coupling constants can either be determined theoretically or by fitting the experimental data. However, various quark models [20, 21] and sum rule (eg. QCD sum rules)[15, 17, 19] techniques predict the coupling constants. Another possible method is to use lattice QCD [18] which incorporate QCD in their first principle. Using experimental data of decay widths and branching ratios as input, one can fit the experimental data to find the effective coupling constants. The coupling constants play an important role in heavy quark phenomenology. They are directly related to charm meson strong decays and are further useful to explore other decays of charm mesons involving pionic emissions.

4 Spin-parity Analysis for Non-strange Charm Meson States

The recent experimental data of charm meson states from LHCb and BaBar collaboration motivates us to find the best fit values of coupling constants in strong decays. The table 1 mentions the recent experimental data of non-strange charm mesons.

Table 1: Experimental Status of Latest Charm Mesons
| Sr. No | Charm Meson state | Mass(\text{MeV}) | Width(\text{MeV}) | Decay Channel |
|-------|-------------------|------------------|------------------|---------------|
| 1     | $D_s^0(2650)^0$   | 2649.2 ± 3.5     | 140.2 ± 17.1     | $D^+\pi^-$    |
| 2     | $D_s^0(2760)^0$   | 2761.1 ± 5.1     | 74.4 ± 3.4       | $D^+\pi^-$    |
| 3     | $D_s(2580)^0$     | 2579.5 ± 3.4     | 23.9 ± 4.5       | $D^+\pi^-$    |
| 4     | $D_s(2740)^0$     | 2757.0 ± 3.5     | 73.2 ± 13.4      | $D^+\pi^-$    |
| 5     | $D_s(3000)^0$     | 2971.8 ± 8.7     | 188.1 ± 44.8     | $D^+\psi^-$   |
| 6     | $D_s^+(2760)$     | 2760.1 ± 1.1     | 74.4 ± 3.4       | $D^+\pi^+$    |
| 7     | $D_s^0(3000)^0$   | 3008.1 ± 4.0     | 110.5 ± 11.5     | $D^+\pi^-$    |
| 8     | $D_s^+(2760)$     | 2771.7 ± 1.7     | 66.7 ± 6.6       | $D^+\pi^+$    |
| 9     | $D_s^0(3000)^0$   | 3008.1 ± 4.0     | 110.5 ± 11.5     | $D^+\pi^-$    |

The states with $J^P = (0^-, 1^-, 0^+, 1^+, 1^+, 2^+)$ are well known. The doublets having spin-parity assignments $s_l^P = \frac{3}{2}^-$, consists of $D_1(2420)$ and $D_2^*(2460)$ in non-strange sector. The states $(D_0^0(2400), D_1(2430))$ belong to $s_l^P = \frac{1}{2}^+$ charm doublet\([2]\). The experimental data on decay widths suggest that states $(0^+, 1^+)$ are quite broad, expecting to decay via s-wave whereas the states belonging to $(1^+, 2^+)$ doublets are quite narrow and decay via d-wave. The measured branching ratio by BaBar Collaboration is given as:

$$\frac{BR(D_2^0(2460) \rightarrow D^+\pi^-)}{BR(D_2^0(2460) \rightarrow D^{*+}\pi^-)} = 1.47 \pm 0.03 \pm 0.16 \quad (28)$$

There are few more recent states whose branching ratios as measured by BaBar is mentioned below.

$$\frac{BR(D^0(2600) \rightarrow D^+\pi^-)}{BR(D^0(2600) \rightarrow D^{*+}\pi^-)} = 0.32 \pm 0.02 \pm 0.09 \quad (29)$$

$$\frac{BR(D^0(2760) \rightarrow D^+\pi^-)}{BR(D^0(2750) \rightarrow D^{*+}\pi^-)} = 0.42 \pm 0.05 \pm 0.11 \quad (30)$$

The information from the BaBar Collaboration and the quark model suggests that $D^0(2550)$ state lies in $0^-$ state. The $D^0(2600)$ corresponds to $1^-$ state either in the 2S or 1D spectrum respectively because this state was observed in both $D\pi$ and $D^*\pi$ channels. If we find the mass of these particular states using heavy quark symmetry and other theoretical models \([13], [14]\), it can be suggested that the state $D(2600)$ can be identified as either radial excitation of heavy quark doublet $H$ or 1D. The branching ratios for $D\pi$ and $D^*\pi$ for both the decay states are calculated as $\frac{BR(D^0(2600) \rightarrow D^{*+}\pi^-)}{BR(D^0(2600) \rightarrow D^+\pi^-)} = 0.82$ for 2S and $\frac{BR(D^0(2600) \rightarrow D^{*+}\pi^-)}{BR(D^0(2600) \rightarrow D^+\pi^-)} = 0.38$ The comparison with the experimental data results in favor of 1D assignment. Therefore, the possible assignment for this particular state can be 1D respectively. The theoretical estimation of coupling constant for the strong decay width of mesons in this particular state is $0.53 \pm 0.01$. The theoretical estimation of branching ratios from
the heavy quark effective theory \[11\] leads to the conclusion that there may be possibility of violations in flavor and spin symmetry. In ref.\[8\], Sun et al. used the \(3P_0\) model to examine the strong decays of these states and they concluded that \(D^0(2600)\) state can be identified as the mixture of \(2^4S_1\) and \(1^3D_3\) state. Therefore, the other possibility is that \(D(2600)\) may be considered as a mixing state of \(2S\) and \(1D\) respectively. The other two states \(D(2750)\) and \(D(2760)\) can be identified with \(J^P = (2^-, 3^-)\) assignment. It is very interesting to point out that non-strange partner of \(D_{sJ}(2860)\) can be associated with \(D(2760)\) due to mass gap which is about 150 MeV. There are also several references like \[10, 11\] which suggest possible assignment for \(D(2750)\) and \(D_s(2760)\) state with the \(l=2, n=1\) state. Moreover, the branching ratio measurement \(\frac{BR(D^0(2760) \rightarrow D^+ \pi^-)}{BR(D^0(2760) \rightarrow D^+ \pi^-)}\) gives value 0.80 from the leading order effective theory which is found to be matching with the experimental data. Saturating the total decay width with the ground state to two body decays, we can fit the experimental data of LHCb and BaBar to estimate the coupling constant. We take the experimental data of decay widths of recent states as mentioned in table 1 to find the hadronic coupling constants. The decay widths are calculated using the decay formulae given above. We can fit the experimental data of BaBar and LHCb collaborations to estimate the coupling constants. The observed radially excited non-strange charm meson states in the heavy meson spectrum are the two resonances (\(D(2550), D^*(2600)\)). The values of coupling constant is obtained from the measured width of (\(D(2550)\)) and the computed value is 0.35 ± 0.03 \[11\]. The calculated value of coupling constants in our fitting program for \(D(2550)\) comes out to be 0.40 ± 0.05. The best fit value of these coupling constants is estimated with in experimental error using chi-square minimization technique. The errors are clearly dominated by the statistical and systematic uncertainties. To check the consistency of our fitting algorithm, the coupling constant estimation is being carried out for the decays of \(J^P = (0^+, 1^+)\) and the fitted value comes out to be 0.53 ± 0.04. This value has been found to be matching well with predictions from other theoretical approaches\[11\]. The value of coupling constants for \(D(2750)\) and \(D^*(2760)\) states are also estimated in our fitting program which are 0.61 ± 0.01 and 0.79 ± 0.03. Let us consider new states predicted by LHCb in the \(D\pi\) and \(D^*\pi\) spectrum and from the strong decays, the states are labeled as \(D_{sJ}^+(3000) \rightarrow D^+ \pi^-\) and \(D_{sJ}^+(3000) \rightarrow D^0 \pi^+\). On the basis of LHCb data\[2\], the angular distribution of \(D_{sJ}(3000) \rightarrow D^* \pi\) is found to be consistent with unnatural parity. The possible spin-parity assignment for \(D_{sJ}(3000)\) can be \(J^P = 0^-, 1^+, 2^-, 3^+\) and \(D_{sJ}^+(3000)\) have possible spin-parity assignments \(J^P = 0^+, 1^-, 2^+, 3^-, 4^+\)...... Thus, it can be stated that the two states can be higher radial excitations or can belong to 1F states in the meson spectrum. Some possible
indications about the possible assignment of $J^P$ quantum numbers can be realized from the masses of these states. One of the well known potential models [13] calculated the masses of all possible excited mesonic states and we can suggest the following possible spin and parities assignments of these newly discovered states. To extract the detailed information about the newly observed states, we present the summary of all $D$ meson states and various possibilities of $D^*_J(3000)$ and $D^*_J(3000)^0$ in the table 2 below.

Table 2: Table showing all non-strange charm meson states

| $s_p$  | $J^P$ | $J^P$ | $J^P$ | $J^P$ | $J^P$ | $J^P$ | $J^P$ | $J^P$ |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|       |       |       |       |       |       |       |       |       |
| $n=1$ |       |       |       |       |       |       |       |       |
| $D(1869)(J^P = 0^-)$ | $D^*(2400)(J^P = 0^-)$ | $D_J(2460)(J^P = 1^-)$ | $D^*(2750)(J^P = 1^-)$ | $D^*_J(3000)(J^P = 2^-)$ | $D_J(3000)(J^P = 3^-)$ | $D_J(3000)(J^P = 2^-)^*$ | $D_J(3000)(J^P = 3^-)^*$ |
| $n=2$ |       |       |       |       |       |       |       |       |
| $D(2550)(J^P = 0^-)$ | $D^*_J(3000)(J^P = 0^-)^*$ | $D_J(3000)(J^P = 1^-)^*$ | $D^*_J(3000)(J^P = 1^-)^*$ | $D^*_J(3000)(J^P = 2^-)^*$ | $D_J(3000)(J^P = 3^-)^*$ | $D_J(3000)(J^P = 2^-)^*$ | $D_J(3000)(J^P = 3^-)^*$ |
| $n=3$ |       |       |       |       |       |       |       |       |
| $D_J(3000)(J^P = 0^-)^*$ | $D^*_J(3000)(J^P = 1^-)^*$ |       |       |       |       |       |       |

Wang et al. [10] also suggested the various possibilities of $D_J(3000)$ states and calculated the decay widths of these states in terms of relevant coupling constants. We also suggest the same but we add the two more possibilities i.e. $(1^-, 2^-)$ and $(2^-, 3^-)$ lying in 1D spectrum. To analyze the spectrum of above $J^P$ states, we study the two body decay behavior and calculate the branching ratios for the states for which decay to $PM$ and $P^*M$ both are allowed.

Table 3: Ratios of decay width for $D^*_J(3000)$ state

| $D^*_J(3000)$ | $D^*_J(3000) \rightarrow D^*\pi$ | $BR(D^*_J \rightarrow D^+\pi^-)$ | $BR(D^*_J \rightarrow D^+\pi^-)$ |
|---------------|-------------------------------|--------------------------------|--------------------------------|
| $s^+_p = \frac{5}{2}^+ , J^P = 2^+$ | f-wave | 0.343 | 0.343 |
| $s^+_p = \frac{5}{2}^+ , J^P = 4^+$ | f-wave | 0.52 | 0.52 |
| $s^+_p = \frac{1}{2}^+ , J^P = 0^+$ | s-wave | 0 | 0 |
| $s^+_p = \frac{3}{2}^+ , J^P = 2^+$ | d-wave | 0.955 | 0.955 |
| $s^+_p = \frac{1}{2}^- , J^P = 1^-$ | p-wave | 1.57 | 1.57 |
| $s^+_p = \frac{5}{2}^- , J^P = 3^-$ | f-wave | 0.68 | 0.68 |
| $s^+_p = \frac{3}{2}^- , J^P = 1^-$ | p-wave | 0.32 | 0.32 |

The table 3 collects the ratios of decay width for $D^*_J(3000)$ state. Predicted ratios along with graphs can be analyzed to exclude some of the assignments.
Figure 1: Graph showing branching ratios Vs mass of decaying particle
The graphs show the variation of branching ratios Vs mass of decaying particle. From the graphs, it can be stated that the states lying in 3S doublet around the mass values of 3000 MeV does not produce ratios less than or around 1. The spin partner of $D_J^*(3000)$ is $D_J(3000)$ which is observed to decay via $D^+\pi^-$ channel. The other possible decay modes are $DK$ and $D\eta$. If $D_J(3000)$ and $D_J^*(3000)$ belongs to $2P(0^+,1^+)$ doublet then the allowed decay modes for $D_J^*(3000)$ does not include $D^*\pi^-$ decay channels which agrees well with the experiments. In all other cases, decays to both the channels $D\pi$ and $D^*\pi$ are observed. Moreover, the calculation of branching ratios ($\frac{\Gamma(D_J^*(3000)\rightarrow D^+\pi^-)}{\Gamma(D_J(3000)\rightarrow D^+\pi^-)}$) for all possible doublets suggests that the possible assignment of these two states can also be either ($J^P = (1^-,2^-)$) or ($J^P = (2^+,3^+)$) for $D_J^*(3000)$ and $D_J(3000)$ mesons. The state $3^3S_1$ state decays to $D^*\pi,DK,D_sK$ and $D\eta$ and the coupling constant for this particular state lies near the value of $\simeq 0.1$. Also, the similar state appears to be a narrow D meson state. But its partial decay width to $D^*\pi$ appears to be almost double than that of $D\pi$ mode which is completely inconsistent with predictions by LHCb collaboration. If we assign $2P(J^P = (1^+,2^+))$ doublet to these mesons than the coupling constant for strong decays to $\pi,K,\eta$ should lie between 0.12-0.15. For $2^3D_3$ state, ($D\pi,DK,D\eta$) are the allowed decay modes. Additional decay channels may include $D(2460)\pi$ and $D(2420)\pi$. The additional information about these decay channels may help to estimate coupling constant precisely. In addition to this, $2^3D_1$ state has most prominent decay mode is $D\pi$ therefore the ideal decay mode to search for this state is $D\pi$. The ratio of total decay widths for $D_J^*(3000)$ and $D_J(3000)$ can be calculated from the experimental data of LHCb collaboration.

$$\frac{\Gamma(D_J^*(3000))}{\Gamma(D_J(3000))} = 0.587 \pm 0.083$$

The strong decay width ratios when calculated in HQET with leading order for all the possible assignments produce values very far from the experimental values. Thus, only $\frac{1}{m_Q}$ corrections when included, more authentic results can be produced. Similar analysis can be carried out for the $D_J(3000)$ mesons. The various possibilities include $3^1S_0$, $2P(1^+)$ and $1D(2^-)$ and $1F$ etc. A closer look at the decay width of all the above states in the $D^*\pi$ spectrum suggests that the most possible assignment can belong to $2P$ state. The most prominent decay mode for $2P(1^+)$ in $(1^+,2^+)$ doublet is found to be $D^*\pi$ which matches well with the experimental data on decay width for $D_J(3000)$. However, if we consider the $D_J(3000)$ as the spin partner of $D_J^*(3000)$ then the only possibility can be that $2P(1^+)$ in $(0^+,1^+)$ overlaps with that with $1^+$ in $(1^+,2^+)$ doublet.
5 Conclusion

We study the heavy meson decay width in the framework of heavy quark effective theory that represents heavy quark and chiral symmetry at $\Lambda_{QCD} \simeq 1 GeV$. We studied the recent charm meson states with their $J^P$ assignment. The upcoming results at collaborations like LHCb produces the data for branching ratios that is used to calculate the decay width, coupling constants and suitable $J^P$ states. The coupling constants and their studies are important to study heavy meson phenomenology. The accurate prediction of coupling constants help to study the detailed interaction of heavy mesons. The present work calculates the coupling constant for strong decays of non-strange charm meson states ($D(2550), D(2600), D(2750)$ and $D(2760)$) by using Chi-square minimization techniques. The numerical values of decay widths from the collaborations like LHCb, BaBaR and CDF are used to extract the values of coupling constants. The various assignments of $J^P$ values to the above mentioned states are also analyzed. The $J^P$ assignment for $D^0(2550)$ state is $0^-$ while $D^0(2600)$ is identified as mixture of $2^3S_1$ and $1^3D_3$ state with $J^P = 1^-$. The states $D(2750)$ and $D(2760)$ are identified with $J^P = (2^-, 3^-)$ assignment. All assignments to $D_J(3000)$ are analyzed deeply and various possibilities for $J^P$ states has been checked. Two more possibilities i.e. $(1^-, 2^-)$ and $(2^-, 3^-)$ lying in 1D spectrum have also been included for analysis. Most possible assignment in the present work is favored in $2P(1^+)$ for $D_J(3000)$ state. While investigating for decays, it is concluded that the results on decay widths are further helpful to search for un-known resonances so that the excited meson spectrum for D meson family is clear to theorists as well as experimentalists.

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