Strong Decays of the Orbitally Excited Scalar D_0^* Mesons

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Introduction

In this work, We calculate the two-body strong decays of the orbitally excited scalar mesons $D_0^*(2400)$ and $D_J^*(3000)$.

The LHCb collaboration announced several new charmed structures in 2013, including the $D_J^*(3000)$ [1]

$$M_{D_J^*(3000)} = 3008.1 \pm 4.0 \text{ MeV}, \quad \Gamma_{D_J^*(3000)} = 110.5 \pm 11.5 \text{ MeV}. \tag{1}$$

Its parity is still uncertain in present experiments. From its decay mode of $D\pi$, many authors treat it as a natural parity particle. Considering that its mass is around 3000 MeV, the assignments of 2^3P_0, 1^3F_4, 3^3S_1, 1^3F_2 and 2^3P_2 are possible.

The $D^*\pi$ channel is forbidden for the $^3P_0$ states and other assignments have both $D\pi$ and $D^*\pi$ decay modes. However, $D_J(3000)$ was only found in $D^*\pi$ spectrum, while $D_J^*(3000)$ only in $D\pi$ spectrum in LHCb experiment. Thus, the assignment of 2^3P_0 for $D_J^*(3000)$ is more reasonable.

Method

We take the channel $D_0^*(2400)^0 \to D^+\pi^-$ as an example.

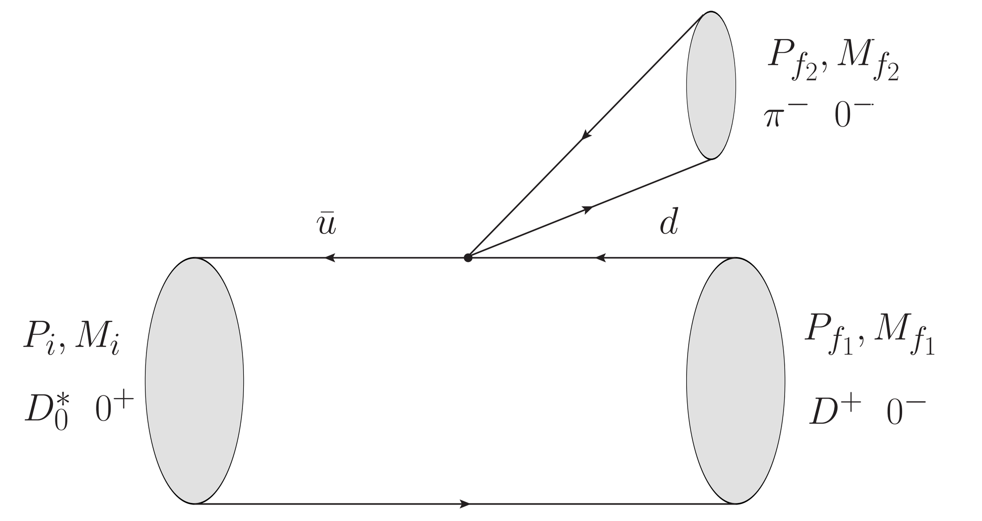

Figure 1: Feynman diagram for $D_0^*(2400)^0 \to D^+\pi^-$ (with the low-energy approximation).

By using the reduction formula, the transition matrix element can be written as

$$\begin{aligned} T =& \langle D^+(P_{f1})\pi^-(P_{f2}) \left| D_0^*(P_i) \right\rangle \\ =& \int \mathrm{d}^4x e^{\mathrm{i}P_{f2}\cdot x}(M_{f2}^2 - P_{f2}^2)\langle D^+(P_{f1}) \left| \phi_\pi(x) \right| D_0^*(P_i)\rangle, \end{aligned} \tag{2}$$

where, ϕ_π is the light pseudo-scalar meson field. By using PCAC rules, the field can be expressed as

$$\phi_\pi(x) = \frac{1}{M_{f2}^2 f_\pi}\partial^\mu(\bar{u}\gamma_\mu\gamma_5 d). \tag{3}$$

Inserting Eq. (3) into Eq. (2), the transition matrix can be written as

$$\begin{aligned} T =& \frac{-\mathrm{i}P_{f2}^\mu(M_{f2}^2 - P_{f2}^2)}{M_{f2}f_\pi}\int \mathrm{d}^4x e^{iP_{f2}\cdot x}\langle D^+(P_{f1}) \left| \bar{u}\gamma_\mu\gamma_5 d \right| D_0^*(P_i)\rangle \\ \approx& -\mathrm{i}\frac{P_{f2}^\mu}{f_\pi}(2\pi)^4\delta^4(P_i - P_{f1} - P_{f2})\langle D^+(P_{f1}) \left| \bar{u}\gamma_\mu\gamma_5 d \right| D_0^*(P_i)\rangle. \end{aligned} \tag{4}$$

Within the Mandelstam formalism, we can write the transition amplitude as:

$$\begin{aligned} \mathcal{M} =& -\mathrm{i}\frac{P_{f2}^\mu}{f_\pi}\langle D^+(P_{f1}) \left| \bar{u}\gamma_\mu\gamma_5 d \right| D_0^*(P_i)\rangle \\ =& -\mathrm{i}\frac{P_{f2}^\mu}{f_\pi}\int \frac{\mathrm{d}^3q}{(2\pi)^3}\mathrm{Tr}\left[\bar{\varphi}_{P_{f1}}^{++}(q_{f1\perp})\frac{\not{P}_i}{M_i}\varphi_{P_i}^{++}(q_\perp)\gamma_\mu\gamma_5\right]. \end{aligned} \tag{5}$$

If ρ or ω meson appears in the final states, we choose the effective Lagrangian method to calculate the transition amplitude. The Lagrangian of quark-meson coupling can be expressed as

$$\mathcal{L}_{qqV} = \bar{q}_i(a\gamma_\mu + \frac{\mathrm{i}b}{2M_{P_{f2}}}\sigma_{\mu\nu}P_{f2}^\nu)V_{ij}^\mu q_j. \tag{6}$$

The transition amplitudes can be expressed as

$$\mathcal{M} = -\mathrm{i}\int \frac{\mathrm{d}^3q}{(2\pi)^3}\mathrm{Tr}\left[\bar{\varphi}_{P_{f1}}^{++}(q_{f1\perp})\frac{\not{P}_i}{M_i}\varphi_{P_i}^{++}(q_\perp)(a\gamma_\mu + \frac{\mathrm{i}b}{2M_{f2}}\sigma_{\mu\nu}P_{f2}^\nu)\varepsilon_2^\mu\right]. \tag{7}$$

The two-body decay width is

$$\Gamma = \frac{1}{8\pi}\frac{|\vec{P}_{f1}|}{M_i^2}|\mathcal{M}|^2. \tag{8}$$

Results and Discussion

The results of $D_0^*(2400)^{0,+}$ as $0^+(1P)$ state are shown in Table 1. Under the assumption of $0^+(2P)$ state, the results of $D_0^*(3000)^{0,+}$ are shown in Table 2-3. Considering many theoretical predictions of mass have divergence with present experimental data, we also calculate the total width changing with the mass, which is shown in Fig. 2.

Table 1: $D_0^*(2400)^{0,+}$ strong decay widths (MeV).

Chanel		Ours	Ref. [2]	Ref. [3]	Ref. [4]	Exp. [5]
$D_0^*(2400)^0 \to$	$D^+\pi^-$	151.5	266	283	277	267 ± 40
	$D^0\pi^0$	74.8				
$D_0^*(2400)^+ \to$	$D^+\pi^0$	81.6	□	□	□	230 ± 17
	$D^0\pi^+$	164.3				

Table 2: Two-body strong decay widths (MeV) of $D_J^*(3000)^0$ as the $2P(0^+)$ state. "-" means forbidden, "□" means not included.

Chanel	Final States	Ours	Ref. [6]	Ref. [7]	Ref. [8]	Ref. [9]
$D(^1S_0)\pi$	$D^+\pi^-$	11.6	23.94	49	25.4	66.2
	$D^0\pi^0$	6.1	11.97			33.3
$D(2^1S_0)\pi$	$D(2550)^+\pi^-$	6.9	□	□	18.6	□
	$D(2550)^0\pi^0$	3.3				
$D\eta$	$D^0\eta^0$	0.51	4.26	8.8	1.53	10.8
$D\eta'$	$D^0\eta'^0$	6.0	1.07	2.7	4.94	□
D_sK	$D_s^+K^-$	$\sim 10^{-3}$	2.85	6.6	0.76	54.2
$D_1(2420)\pi$	$D_1(2420)^0\pi^0$	18.7	26.20	38	$96.1(^1P_1)$	□
	$D_1(2420)^+\pi^-$	36.8	□			
$D_1(2420)\eta$	$D_1(2420)^0\eta^0$	0.85	1.37	1.1	□	□
$D_1(2430)\pi$	$D_1(2430)^0\pi^0$	2.1	6.69	30	□	□
	$D_1(2430)^+\pi^-$	4.1	□			
$D_1(2430)\eta$	$D_1(2430)^0\eta^0$	0.12	0.35	0.91	□	□
$D_s(2460)K$	$D_{s1}(2460)^+K^-$	1.2	12.81	1.5	□	□
$D^*\rho$	$D^*(2007)^0\rho^0$	7.0	31.60	41	32	□
	$D^*(2010)^+\rho^-$	13.3	62.01			
$D^*\omega$	$D^*(2007)^0\omega^0$	7.5	29.91	13	10.2	□
$D_s^*K^*$	$D_s^{*+}K^*(892)^-$	4.1	3.06	1.0	□	□
$D_s(2536)K^-$	$D_{s1}(2536)^+K^-$	-	6.40	-	-	-
Total		130.2	224.5	193.6	189.5	164.5
Experimental value			110.5 ± 11.5			

Table 3: Two-body strong decay widths (MeV) of $D_J^*(3000)^+$ as the $2P(0^+)$ state.

Chanel	Final States	Width	Chanel	Final States	Width
$D(^1S_0)\pi$	$D^+\pi^0$	6.5	$D(2^1S_0)\pi$	$D^0\pi^+$	3.8
	$D^0\pi^+$	13.5		$D^0\pi^+$	7.7
$D\eta$	$D^0\eta^0$	0.56	$D\eta'$	$D^0\eta'^0$	5.7
$D(2420)\pi$	$D_1(2420)^+\pi^0$	18.3	$D(2430)\pi$	$D_1(2430)^+\pi^0$	2.1
	$D_1(2420)^0\pi^+$	37.4		$D_1(2430)^0\pi^+$	4.3
$D(2420)\eta$	$D_1(2420)^+\eta^0$	0.77	$D(2430)\eta$	$D_1(2430)^+\eta^0$	0.11
$D^*\rho$	$D^*(2010)^+\rho^0$	6.1	$D^*\omega$	$D^*(2010)^+\omega^0$	6.5
	$D^*(2007)^0\rho^-$	12.9	$D_s(2460)K$	$D_{s1}(2460)^+K^0$	1.2
D_sK	$D_s^+K^0$	0.05	$D_s^*K^*$	$D_s^{*+}K^*(892)^0$	3.8
Total			131.3		

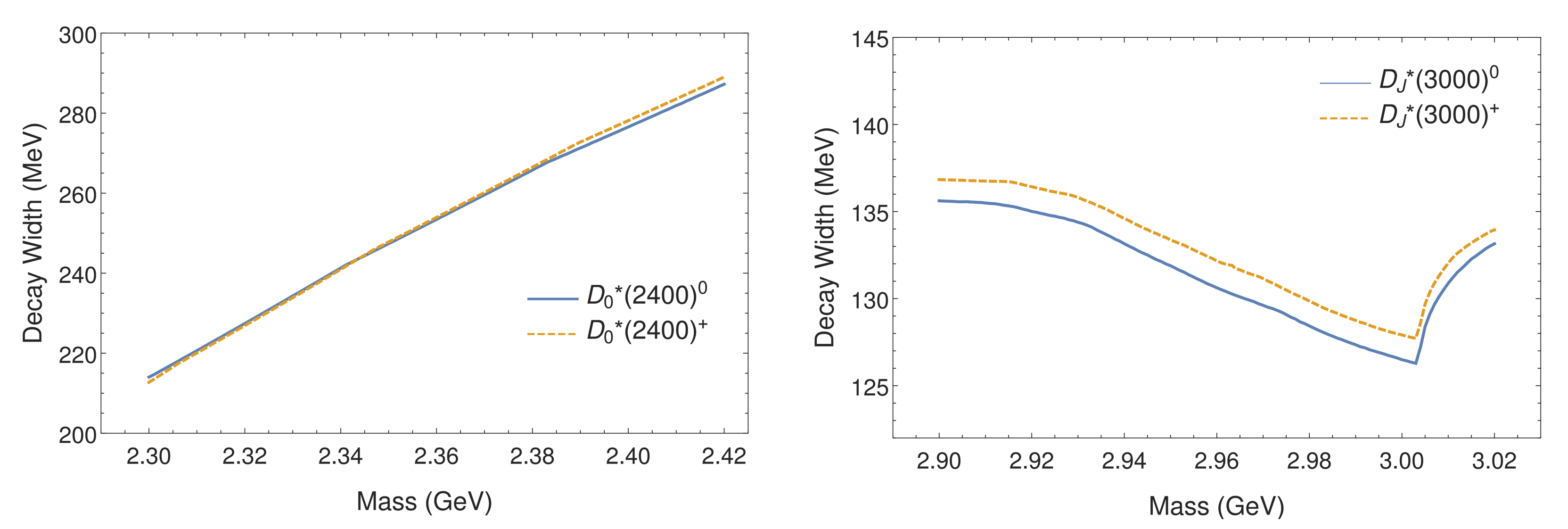

Figure 2: Total decay widths of $D_0^*(2400)$ and $D_J^*(3000)$ change with the masses.

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