Pure annihilation type $D \rightarrow PP(V)$ decays in the perturbative QCD approach *

ZOU Zhi-Tian  LI Cheng  LÜ Cai-Dian 1)

Institute of High Energy Physics and Theoretical Physics Center for Science Facilities, Chinese Academy of Sciences, Beijing 100049, People’s Republic of China

Abstract: The annihilation type diagrams are difficult to calculate in any kind of models or method. Encouraged by the the successful calculation of pure annihilation type $B$ decays in the perturbative QCD factorization approach, we calculate the pure annihilation type $D \rightarrow PP(V)$ decays in the perturbative QCD approach based on the $k_T$ factorization. Although the expansion parameter $1/m_D$ is not very small, our leading order numerical results agree with the existing experiment data for most channels. We expect the more accurate observation from experiments, which can help us learn about the dynamics of $D$ meson weak decays.

Key words: D meson, perturbative QCD, annihilation

PACS: 13.20.Ft, 12.38.Bx, 14.40.Lb

1 Introduction

After decades of study, the $D$ meson decays are still a hot topic in both theoretical side and experimental side, since they can provide useful information on flavor mixing, CP violation, strong interactions and even the new physics signal [1,8]. For example the recent observation of $D^0 - \bar{D}^0$ mixing provides us a new platform to explore new physics via flavor-changing neutral currents. By now, The CLEO-c and two B factories experiments have given many results about the $D$ decays. The BES-III experiment is expected to give more results. The accurate observation can help us understand the QCD dynamics and the $D$ meson weak decays. In recent years, many theoretical studies on the decays of $D$ meson have been done based on diagrammatic approach [4], the final-state interaction effects [5,6], combination of factorization and pole model [7], factorization assisted topological diagrammatic approach [8], and the perturbative QCD (PQCD) approach [9].

Most of the theoretical study show that the annihilation type diagrams in hadronic $D$ decays play a very important role [4,7,8]. For example in ref. [4], the authors take the model-independent diagrammatic approach to study the two-body nonleptonic $D$ decays, with all topological amplitudes extracted from the experimental data. Their analysis indicates that the SU(3) breaking effect and the annihilation type contributions are important to explain the experimental data. The importance of annihilation diagram contribution is also reflected from the large difference of $D^0$ and $D^*$ lifetime. However, these annihilation type diagrams are usually very difficult to calculate, since factorization may not work here. In ref. [7], the authors use the pole model to give large annihilation diagram contributions. It is worth of mentioning that the annihilation type diagrams can be perturbatively calculated without parametrization in the PQCD approach based on $k_T$ factorization [9,10]. For these pure annihilation type $B$ decays, the predications in the PQCD approach have been confirmed by experiments later [12,13].

The factorization that is proved in the $1/m_b$ expansion, can be applied to the corresponding $D$ meson decays straightforwardly. However, the expansion is much poorer in $D$ Decays than that in $B$ decays due to smaller $D$ meson mass. Anyway since there is no better method for the annihilation diagram calculation, the pure annihilation type decays $D^0 \rightarrow \bar{K}^0\phi$ were calculated in the PQCD approach [9], with a good agreement with the experimental result. In this work, we use the PQCD approach to analyze the 10 modes of pure annihilation type $D \rightarrow PP(V)$ decays. By keeping the intrinsic transverse momentum $k_T$ of valence quarks, the end point singularity, which will spoil the perturbative calculation, can be regulated by Sudakov form factor and threshold resummation. Therefore, the PQCD approach can give converging results with predictive power.

In standard model, two body hadronic $D$ meson weak decays are dominated by the contributions from tree operators, since the contributions from the penguin operators are suppressed both by the small elements of the Cabibbo-Kobayashi-Maskawa (CKM) matrix and by the relatively small $b$ quark mass in the $c - b - u$ penguin diagram. This is in contrast to the penguin amplitude

* Supported by National Science Foundation of China under the Grant No.11225812, 11235005 and 11075168
in $B$ decays, which can profit from a larger CKM element and a much larger $t$ quark mass. Although the suppressed penguin diagram contributions may be the main source of the direct asymmetry \cite{4,5,6,7}, we ignore the penguin contributions in this work due to the small effect on the branching fractions.

2 Formalism and Perturbative Calculation

For the pure annihilation type $D \rightarrow PP(V)$ decays, at the quark level, the dominant contributions are described by the effective Hamiltonian $H_{eff}$

$$H_{eff} = \frac{G_F}{\sqrt{2}} V_{qq} V_{e\ell}^* \left[ C_1(\mu) O_1(\mu) + C_2(\mu) O_2(\mu) \right] ,$$

where $V_{qq}$ and $V_{e\ell}$ are the corresponding CKM matrix elements, with $q^{(\ell)} = d,s$, and $C_{1,2}(\mu)$ are Wilson coefficients at the renormalization scale $\mu$. $O_{1,2}(\mu)$ are the four quark operators from tree diagrams

$$O_1 = (\bar{q}_a c_3)v_A(\bar{u}_b q_3)v_A, \quad O_2 = (\bar{q}_a c_3)v_A(\bar{u}_b q_3)v_A,$$

where $\alpha$ and $\beta$ are the color indices, $(\bar{q}_a c_3)v_A = \delta_{ab}\gamma^\nu(1-\gamma^5)c_3$. Conventionally, the combination of Wilson coefficients can be defined as

$$a_1 = C_2 + C_1/3, \quad a_2 = C_1 + C_2/3 .$$

In the hadronic matrix element calculation, the decay amplitude can be factorized into soft ($\Phi$), hard ($H$), and harder ($C$) dynamics characterized by different scales \cite{8,9,10}.

$$\mathcal{A} \sim \int dx_1 dx_2 dx_3 db_1 db_2 db_3 \left\{ 2\phi_M^\alpha(x_2) r_0 r_0 \phi_M^\beta(x_3) (x_2-1) - x_3 \phi_M^\beta(x_3) \right\} \times \left\{ 2\phi_M^\alpha(x_2) r_0 r_0 \phi_M^\beta(x_3) (x_2-1) + \phi_M^\beta(x_3) (x_2-1) + \phi_M^\beta(x_3) (x_2+1) \right\} ,$$

where $C_F = 4/3$ is the group factor of $SU(3)_c$, and $r_{0203} = m_{0203}/m_D$ with the chiral mass $m_{0203}$ of the pseudoscalar meson. The hard scale $t_{eff}$ and the functions $E_{eff}$ and $h_{eff}$ can be given by

$$t_e = \max\{ \sqrt{(r_2^3 + 1 - r_3^2)}(1 - r_2^2)(1 - r_3^2) \}$

$$E_{eff}(t) = \alpha_s(t) \exp[-S_{M_2}(t) - S_{M_3}(t)] ,$$

$$h_{eff}(\alpha_s, \beta, b_2, b_3) = \frac{i\pi}{2} 2H_0^{(1)}(\beta b_2) S_1(x_3) + \theta(b_2 - b_3) J_0(\alpha b_3) + \theta(b_3 - b_2) J_0(\alpha b_2) ,$$

with $r_{23} = m_{M_{23}}/m_D$, $\alpha^2 = (1 - x_3(1 - r_2^2))m_D^2$, $\beta^2 = (r_3^2 + x_2(1 - r_3^2))(1 - r_2^2) \rho_1(m_D^2)$, and $\alpha^2 = (r_3^2 + x_2(1 - r_3^2))(1 - r_2^2) \rho_2(m_D^2)$.

For the so called non-factorizable diagrams (c) and (d) decays, which can profit from a larger CKM element and a much larger $t$ quark mass. Although the suppressed penguin diagram contributions may be the main source of the direct asymmetry \cite{4,5,6,7}, we ignore the penguin contributions in this work due to the small effect on the branching fractions.
(d) in Fig.1, the decay amplitude is

$$\mathcal{M}_{af} = 16\sqrt{3}\alpha\beta_1\beta_2 \int_0^1 dx_1 dx_2 dx_3 \int_0^1 b_1 db_1 b_2 db_2 \times \phi_D(x_1, b_1) \left\{ [\phi^A_{M_2}(x_2) \phi^A_{M_3}(x_3)(x_1 + x_2) + r_{aD}\phi^P_{M_2}(x_2) \phi^P_{M_3}(x_3)(x_1 + x_2 + x_3 + 3) + \phi^P_{M_2}(x_3)(1 - x_1 + x_2 - x_3) + \phi^P_{M_3}(x_2)(x_1 + x_2 + x_3 - 1) + \phi^P_{M_3}(x_3)(x_1 - x_2 + 1)] - h_{af}(\alpha, \beta_1, \beta_2) E_{af}(t_e) \right\},$$

with

$$t_g = \max\{\sqrt{(r_3^2 + x_2(1-r_3^2))(1-r_2^2)(1-x_3)m_D},$$

$$\sqrt{1 - [(1-r_2^2)(1-x_3)]} \left[ \phi^{P}_{M_3}(x_3)(x_1 + x_2 + x_3 + 1) + \phi^{P}_{M_2}(x_3)(x_1 - x_2 + x_3 - 1) - \phi^{P}_{M_2}(x_2)(x_1 + x_2 + x_3 - 1) - \phi^{P}_{M_3}(x_3)(x_1 + x_2 + x_3 - 1) \right] - h_{af}(\alpha, \beta_1, \beta_2) E_{af}(t_e),$$

$$t_h = \max\{\sqrt{(r_3^2 + x_2(1-r_3^2))(1-r_2^2)(1-x_3)m_D},$$

$$\sqrt{r_3^2 + x_2(1-r_3^2)(1-r_2^2)(1-x_3)m_D},$$

$$\int_0^1 dx_1 dx_2 dx_3 \int_0^1 b_1 db_1 b_2 db_2 \times \phi_D(x_1, b_1) \left\{ [\phi^A_{M_2}(x_2) \phi^A_{M_3}(x_3)(x_1 + x_2) + r_{aD}\phi^P_{M_2}(x_2) \phi^P_{M_3}(x_3)(x_1 + x_2 + x_3 + 3) + \phi^P_{M_2}(x_3)(1 - x_1 + x_2 - x_3) + \phi^P_{M_3}(x_2)(x_1 + x_2 + x_3 - 1) + \phi^P_{M_3}(x_3)(x_1 - x_2 + 1)] - h_{af}(\alpha, \beta_1, \beta_2) E_{af}(t_e) \right\}. \tag{8}$$

For those $D \to PV$ decays, the decay amplitudes are

$$\mathcal{M}_{af}^{PV} = 8C_F f_D \alpha \beta_1 \beta_2 \int_0^1 dx_1 dx_2 dx_3 \int_0^1 b_1 db_1 b_2 db_2 \times \left\{ [2\phi^P_{M_2}(x_2) r_{aD} r_\nu (\phi^P_{M_3}(x_3)x_3 - \phi^P_{M_2}(x_3)(x_3 - 2)) + \phi^P_{M_2}(x_3) \phi^P_{M_3}(x_2)(x_3 - 1)] - h_{af}(\alpha, \beta_1, \beta_2) E_{af}(t_e) \right\}, \tag{9}$$

$$t_g^{PV} = \max\{\sqrt{(r_3^2 + x_2(1-r_3^2))(1-r_2^2)(1-x_3)m_D},$$

$$\sqrt{1 - [(1-r_2^2)(1-x_3)]} \left[ \phi^{P}_{M_3}(x_3)(x_1 + x_2 + x_3 + 1) + \phi^{P}_{M_2}(x_3)(x_1 - x_2 + x_3 - 1) - \phi^{P}_{M_2}(x_2)(x_1 + x_2 + x_3 - 1) - \phi^{P}_{M_3}(x_3)(x_1 + x_2 + x_3 - 1) \right] - h_{af}(\alpha, \beta_1, \beta_2) E_{af}(t_e),$$

$$t_h^{PV} = \max\{\sqrt{(r_3^2 + x_2(1-r_3^2))(1-r_2^2)(1-x_3)m_D},$$

$$\sqrt{r_3^2 + x_2(1-r_3^2)(1-r_2^2)(1-x_3)m_D},$$

$$\int_0^1 dx_1 dx_2 dx_3 \int_0^1 b_1 db_1 b_2 db_2 \times \phi_D(x_1, b_1) \left\{ [2\phi^P_{M_2}(x_2) r_{aD} r_\nu (\phi^P_{M_3}(x_3)x_3 - \phi^P_{M_2}(x_3)(x_3 - 2)) + \phi^P_{M_2}(x_3) \phi^P_{M_3}(x_2)(x_3 - 1)] - h_{af}(\alpha, \beta_1, \beta_2) E_{af}(t_e) \right\}. \tag{10}$$

with $r_\nu = r_3 = m_\nu/m_D$. For $D \to VP$ decays, the amplitudes are

$$\mathcal{A}_{af}^{VP} = 8C_F f_D \alpha \beta_1 \beta_2 \int_0^1 dx_1 dx_2 dx_3 \int_0^1 b_1 db_1 b_2 db_2 \times \left\{ [2\phi^P_{M_2}(x_2) r_{aD} r_\nu (\phi^P_{M_3}(x_3)x_3 - \phi^P_{M_2}(x_3)(x_3 - 2)) + \phi^P_{M_2}(x_3) \phi^P_{M_3}(x_2)(x_3 - 1)] - h_{af}(\alpha, \beta_1, \beta_2) E_{af}(t_e) \right\}, \tag{11}$$

$$t_g^{VP} = \max\{\sqrt{(r_3^2 + x_2(1-r_3^2))(1-r_2^2)(1-x_3)m_D},$$

$$\sqrt{1 - [(1-r_2^2)(1-x_3)]} \left[ \phi^{P}_{M_3}(x_3)(x_1 + x_2 + x_3 + 1) + \phi^{P}_{M_2}(x_3)(x_1 - x_2 + x_3 - 1) - \phi^{P}_{M_2}(x_2)(x_1 + x_2 + x_3 - 1) - \phi^{P}_{M_3}(x_3)(x_1 + x_2 + x_3 - 1) \right] - h_{af}(\alpha, \beta_1, \beta_2) E_{af}(t_e),$$

$$t_h^{VP} = \max\{\sqrt{(r_3^2 + x_2(1-r_3^2))(1-r_2^2)(1-x_3)m_D},$$

$$\sqrt{r_3^2 + x_2(1-r_3^2)(1-r_2^2)(1-x_3)m_D},$$

$$\int_0^1 dx_1 dx_2 dx_3 \int_0^1 b_1 db_1 b_2 db_2 \times \phi_D(x_1, b_1) \left\{ [2\phi^P_{M_2}(x_2) r_{aD} r_\nu (\phi^P_{M_3}(x_3)x_3 - \phi^P_{M_2}(x_3)(x_3 - 2)) + \phi^P_{M_2}(x_3) \phi^P_{M_3}(x_2)(x_3 - 1)] - h_{af}(\alpha, \beta_1, \beta_2) E_{af}(t_e) \right\}. \tag{12}$$

for $D \to PV$ decays, the decay amplitudes are
\[ M_{\alpha\beta}^\nu = 16 \sqrt{3} C_F \pi m_D \int_0^1 dx_1 dx_2 dx_3 \int_0^{1/\Lambda} b_1 db_1 b_2 db_2 \]

\[ \times \phi_D(x_1, b_1) \left\{ \phi_M^D(x_3) \phi_V(x_2) \right\} \]

\[ (x_1 + x_2 + (-2x_1 - 2x_2 + 1)r_0^D)) \]

\[ + r_{03} r_V \left( \phi_M^D(x_3) (\phi_V(x_2)(1-x_1 - x_2 - x_3) \right) \]

\[ + \phi_V(x_2)(1-x_1 - x_2 - x_3) \right) \]

\[ + \phi_V(x_2)(x_1 + x_2 + x_3 - 1) \]

\[ + \phi_V(x_2)(x_1 + x_2 + x_3 + 1) \right) \]

\[ - h_{\alpha\beta}(\alpha, \sqrt{|\beta|^2}, b_1, b_2) E_{\alpha\beta}(t_c) \]

\[ (1-x_3 + r_0^D(x_1 - x_2 - 2)) \]

\[ + r_{03} r_V \phi_M^D(x_3) (\phi_V(x_2)(1-x_1 - x_2 - x_3) \right) \]

\[ + \phi_V(x_2)(1-x_1 - x_2 - x_3) \right) \]

\[ + \phi_V(x_2)(x_1 + x_2 + x_3 - 1) \]

\[ + \phi_V(x_2)(x_1 + x_2 + x_3 + 1) \right) \]

\[ - h_{\alpha\beta}(\alpha, \sqrt{|\beta|^2}, b_1, b_2) E_{\alpha\beta}(t_d) \right) \].

(15)

with \( r_V = r_2 = m_V / m_D \). The form of the wave functions of final state pseudoscalar mesons and vector mesons can be found in ref.\[13\], with the different Gegenbauer moments used in this work as

\[ a_0^A = 0.70, a_2^A = 0.45, a_4^A = 0.70, a_6^A = 0.36, \]

\[ a_0^\pi = 0.80, a_2^\pi = 0.60, a_4^\pi = 0.10, a_6^\pi = 0.5, \]

\[ a_0^K = -0.2, a_2^K = 0.65, a_4^K = 0.2, a_6^K = 0.6, \]

\[ a_0^{\alpha\beta} = 0.70, a_2^{\alpha\beta} = 0.6, a_4^{\alpha\beta} = 0.11. \]

(16)

Since the energy release in \( D \) decays is smaller than that in \( B \) decays, our light meson wave functions have larger SU(3) (3) breaking in \( D \) decays. For the distribution amplitudes of \( D / D_s \) meson, we take the same model as the \( B \) meson \[13\] with different hadronic parameters \( \omega = 0.35 / 0.5 \) for \( D / D_s \) meson.

With the functions obtained in the above, the amplitudes of these pure annihilation decay channels can be given by

\[ A(D^0 \rightarrow K^+ \phi) = \frac{G_F}{\sqrt{2}} V_{cd} V_{ud} [a_1 A_{\alpha\beta}^{K^+ \phi} + C_2 M_{\alpha\beta}^{K^+ \phi}]. \]

(17)

\[ A(D_s \rightarrow \pi^+ \pi^0) = \frac{G_F}{2} V_{cs} V_{ud} [a_2 (A_{\alpha\beta}^{\pi^+ \pi^0} - A_{\alpha\beta}^{\pi^+ \pi^0}) \]

\[ + C_2 (M_{\alpha\beta}^{\pi^+ \pi^0} - M_{\alpha\beta}^{\pi^+ \pi^0})] \]

\[ \sim 0, \]

(18)

\[ A(D_s \rightarrow \pi^0 \rho^+) = \frac{G_F}{\sqrt{2}} V_{cs} V_{ud} [a_2 (A_{\alpha\beta}^{\pi^0 \rho^+} - A_{\alpha\beta}^{\pi^0 \rho^+}) \]

\[ + C_2 (M_{\alpha\beta}^{\pi^0 \rho^+} - M_{\alpha\beta}^{\pi^0 \rho^+})], \]

(19)

3 Numerical Results and Discussions

For numerical analysis, we use the following input parameters:

\[ f_{D/D_s} = 0.23 / 0.257 GeV; f_K = 0.16 GeV; f_\pi = 0.13 GeV, \]

\[ f_{\rho}^{(T)} = 0.209 / 0.165 GeV; f_{K^*}^{(T)} = 0.217 / 0.185 GeV, \]

\[ f_{\omega}^{(T)} = 0.195 / 0.145 GeV; f_{\phi}^{(T)} = 0.220 / 0.185 GeV, \]

\[ |V_{cd}| = 0.252 \pm 0.00065, |V_{ud}| = 0.9742 \pm 0.0002, \]

\[ |V_{cs}| = 0.97344 \pm 0.00016, |V_{us}| = 0.2253 \pm 0.00065, \]

\[ m_{\Lambda} = 1.4 GeV, m_{\Lambda K} = 1.66 GeV, A_{QCD}^{f_{3/2}} = 0.375 GeV. \]

(20)

After numerical calculation, the branching ratios of these decays together with experimental measurements \[22\] are listed in Table \[1\]. We also list the results from diagrammatic approach \[1\] and pole model \[2\] for comparison.

The branching ratio obtained from the analytic formulas may be sensitive to many parameters especially those in the meson wave function. The theoretical uncertainties in our calculations, shown in Table \[1\] are caused by the variation of (i) the hadronic parameters, such as the shape parameters and the Gegenbauer moments in wave functions of initial and final state mesons; (ii) the unknown next-to-leading order QCD corrections and nonperturbative power corrections, characterized by the choice of the \( A_{QCD} = 0.375 \pm 0.05 \) GeV and the variations of the factorization scales defined in eq.\[1\] and eq.\[9\], respectively.

In hadronic \( D \) decays, the SU(3) breaking effect is remarkable, which can be demonstrated by the decay channel \( D^0 \rightarrow K^0 \bar{K}^0 \), with large branching ratio from experimental measurement. There are two kinds contributions from the quark pair \( d \bar{d} \) and \( s \bar{s} \) produced through
weak vertex. In SU(3) limit, the two contributions exactly cancel with each other due to the cancelation of the CKM matrix elements. Thus the diagrammatic approach results in zero branching ratio for this channel. Taking the SU(3) breaking effect into account, we give the result in agreement with the experimental data. For the decay \( D^0 \to K^0 \phi \), we reproduce the result of ref.\cite{4}, which agrees well with the experimental data. For \( D_s^+ \to \pi^+ \rho^0 \) decay, the branching ratio vanishes due to the exact cancelation of the contributions from \( u\bar{u} \) and \( d\bar{d} \) components. In fact, this decay is forbidden because the two pions cannot form an s wave isospin 1 state due to the Bose-Einstein statistics. Any non-zero data for this decay may indicate the signal of new physics beyond the standard model.

| decay modes | this work | Br(diagrammatic) | Br(pole model) | Br(Exp) |
|-------------|-----------|------------------|----------------|---------|
| \( D^0 \to K^0 \bar{K}^0 \) | 0.29^{+0.05}_{-0.08} | 0 | 0.3^{+0.1}_{-0.1} | 0.34^{+0.08}_{-0.08} |
| \( D_s^0 \to \pi^+ \pi^0 \) | 0 | 0 | 0 | <0.34 |
| \( D_s^0 \to K^0 \bar{K}^0 \phi \) | 8.55^{+1.60}_{-0.41} | 8.68^{+0.139}_{-0.022} | 0.8^{+0.2}_{-0.022} | 8.34^{+0.65}_{-0.05} |
| \( D^0 \to K^0 K^{*0} \) | 0.44^{+0.20}_{-0.14} | 0.29^{+0.022}_{-0.022} | 0.16^{+0.05}_{-0.05} | <0.56 |
| \( D^0 \to K^0 K^{*0} \) | 0.54^{+0.20}_{-0.15} | 0.29^{+0.022}_{-0.022} | 0.16^{+0.05}_{-0.05} | <1.0 |
| \( D^0 \to K^0 K^{*0} \phi \) | 0.012^{+0.004}_{-0.004} | 0.006^{+0.005}_{-0.005} | 0.020^{+0.006}_{-0.006} | 0.020^{+0.006}_{-0.006} |
| \( D^+ \to K^+ \phi \) | 0.025^{+0.012}_{-0.008} | 0.020^{+0.006}_{-0.006} | 0.020^{+0.006}_{-0.006} | 0.020^{+0.006}_{-0.006} |
| \( D_s^+ \to \pi^+ \rho^0 \) | 2.11^{+0.87}_{-0.25} | 4.0^{+0.40}_{-0.40} | 4.0^{+0.40}_{-0.40} | 0.2^{+0.12}_{-0.12} |
| \( D_s^+ \to \pi^+ \omega \) | 0.050^{+0.22}_{-0.025} | 0 | 0 | 2.5^{+0.7}_{-0.7} |
| \( D_s^+ \to \pi^0 \rho^0 \) | 2.11^{+0.87}_{-0.24} | 4.0^{+0.40}_{-0.40} | 4.0^{+0.40}_{-0.40} | 0.2^{+0.12}_{-0.12} |

4 Summary

In this work, we calculate the branching ratio of the 10 pure annihilation type \( D_s^{(*)} \to PP(V) \) decays in the perturbative QCD factorization approach without considering soft final states interactions. For most channels, our results agree well with the experimental data. The SU(3) breaking effect is found to be remarkable, which can be indicated by the large branching ratio of \( D^0 \to K^0 \bar{K}^0 \) decay. We hope that the super B factories and BES-III can provide more accurate measurements for these decays, which will help us learn about the QCD dynamics in \( D \) meson decays and the annihilation mechanism.

We are very grateful to Yu Xin and Yu Fu-Sheng for helpful discussions.

References

1. Arfuso M, Neadows B, Petrov A. A, Ann. Rev. Nucl. Part. Sci, 2008, 58, 249-291
2. Piirtskhalava D, Uttayarat P, Phys. Lett B, 2012, 712, 81C86
3. Bhattacharya B, Gronau M, Rosner J. L, Phys. Rev. D, 2012, 85., 054014
4. Cheng H. Y, Chiang C. W, Phys. Rev. D, 2010, 81, 074021
5. Ablikim M, Du D. S, Yang M. Z, High Energy Phys. Nucl. Phys, 2003, 27, 759-766
6. Li J. W, Yang M. Z, Du D. S, High Energy Phys. Nucl. Phys, 2003, 27, 665-672
7. Yu F. S, Wang X. X, Lü C. D, Phys. Rev. D, 2011, 84, 074019
8. Li H. N, Lü C. D, Yu F. S, Phys. Rev. D, 2012, 86, 036012
9. Du D. S, Li Y, Lü C. D, Chin. Phys. Lett, 2006, 23, 2038-2041
10. Lü C. D, Ukai K, Eur. Phys. J. C, 2003, 28, 305
11. Li Y, Lü C. D, J. Phys. G, 2003, 29, 2115; High Energy Phys. & Nucl. Phys, 2003, 27, 1062
12. Li Y, Lü C. D, Xiao Z. J, Yu X. Q, Phys. Rev. D, 2004, 70, 034009
13. Ali A et al., Phys. Rev. D, 2007, 76, 074018
14. Lü C. D, Ukai K, Eur. Phys. J. C, 2003, 28, 305
15. Li R. H, Lü C. D, Zou H, Phys. Rev. D, 2008, 78, 014018
16. Brod J, Kagan A. L, Zupan J, Phys.Rev. D, 2012, 86, 014023
17. Liu X, Xiao Z. J, Lü C. D, Phys. Rev. D, 2010, 81, 014002
18. Li H. N, Phys. Rev. D, 2002, 66, 094010
19. Li H. N, Tseng B, Phys. Rev. D, 1998, 57, 443
20. Lü C. D, Yang M. Z, Eur. Phys. J. C, 2002, 23, 275-287
21. Lü C. D, Yang M. Z, Eur. Phys. J. C, 2003, 28, 515
22. Beringer J et al. (Particle Data Group), Phys. Rev. D, 2012, 86, 010001