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D→PV Decays with Final State Interactions*

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Abstract We employ one-particle-exchange method to study D→PV decays in D→Kρ, πK*, πρ processes. Taking a strong phase into account and considering nonfactorizable effect, we can get good results consistent with the experimental data. Nonfactorizable effect is not always large, but in some cases, this effect is necessary for accommodating the experimental data. Strong phases are approximately $SU(3)$ flavor symmetric.

Key words final interations, one particle exchange, strong phase, nonfactorization

1 Introduction

To understand the quark mixing sector of the standard model (SM) and search for new physics beyond the SM, one needs to study the decays of heavy mesons and calculate precisely the transition matrix elements of the heavy mesons decays. The short distance effects due to hard gluon exchange can be calculated reliably and the effective hamiltonian and factorization approach has been constructed[1,2], thus a lot of results which fit the experimental data well have been obtained by factorization approach. However, there are still many decay modes which can not be accommodated by factorization approach. In fact, the quarks inside heavy mesons are bound by strong interactions which are described by nonperturbative QCD. After weak decays of heavy mesons, the final particles can rescatter into other particle states through nonperturbative strong interactions[3,4], this is called the final state interaction (FSI). Many authors have studied FSI effects and found that the FSI effects may play a crucial role in some decay modes[5,6]. Therefore it is necessary to study heavy meson two-body weak decays beyond the factorization approach. The FSI process refers to the soft rescattering process which is controlled by nonperturbative QCD and can not be reliably evaluated with well-established theoretical frame. We have to rely on phenomenological models to analyze the FSI effects in certain processes. One can model this rescattering effect as one-particle-exchange process[7,8]. There are also other ways to treat the nonperturbative FSI effects in D decays, The readers can refer to Ref. [9]. In this paper, we study some channels of D→PV decays, i.e., D → Kρ, πK*, πρ (Here P stands for pseudoscalar meson, V vector meson). D_s→πφ has been studied in Ref. [10], we do not study it in this paper. We use the one-particle-exchange method to study the final state interactions in these decays. The magnitudes of hadronic couplings needed here are extracted from experimental data on the measured branching fractions of resonance decays. In addition, we consider a strong phase for the hadronic coupling[11] which is important for obtaining the correct branching ratios of D→PV decays. We also take into account some possible nonfactorizable effect[12,13], which is needed for some decay modes from the phenomenological point of view. The coupling constants extracted from experimental data are small for s-channel contribution and large for t-channel contribution. Therefore the s-channel contribution is numerically negligible in D→PV decays. We can safely drop the s-channel contribution in this paper.

The paper is organized as follows. Section 2 presents

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the calculation in naive factorization approach. Section 3 gives the main scheme of one-particle-exchange method. Section 4 is devoted to the numerical calculation and discussions. Finally a brief summary is given.

2 Calculations in the factorization approach

The low energy effective Hamiltonian for charm decays is given by [14]

$$\mathscr{H}_{\rm eff}=\frac{G_{\rm F}}{\sqrt{2}}\{V_{\rm us}V^*_{\rm cs}[C_1(\bar{s}c)_{V-A}(\bar{u}s)_{V-A}+C_2(\bar{s}s)_{V-A}(\bar{u}c)_{V-A}]+V_{\rm ud}V^*_{\rm cd}[C_1(\bar{d}c)_{V-A}(\bar{u}d)_{V-A}+C_2(\bar{d}d)_{V-A}(\bar{u}c)_{V-A}]+V_{\rm ud}V^*_{\rm cs}[C_1(\bar{s}c)_{V-A}(\bar{u}d)_{V-A}+C_2(\bar{s}d)_{V-A}(\bar{u}c)_{V-A}]\}+{\rm h.c.},\qquad(1)$$

where C_1 and C_2 are the Wilson coefficients at m_c scale. We need not consider the contributions of penguin operators in the decays of D→PV, since their effects are small in D decays. The values of C_1 and C_2 at m_c scale are taken to be $C_1=1.216$, $C_2=-0.415$[14].

In the naive factorization approach, the decay amplitude can be generally factorized into a product of two current matrix elements and can be obtained from Eq.(1),

$$A(D^0\to\bar{K}^0\rho^0)=G_{\rm F}V_{\rm ud}V^*_{\rm cs}a_2m_{\rho^0}f_{\bar{K}^0}A_0^{D\rho}\epsilon_{\rho^0}\cdot P_{\bar{K}^0},$$

$$A(D^0\to K^-\rho^+)=\sqrt{2}G_{\rm F}V_{\rm ud}V^*_{\rm cs}a_1m_{\rho^+}f_{\rho^+}F^{DK}\epsilon_{\rho^+}\cdot P_{D^0},$$

$$A(D^+\to\bar{K}^0\rho^+)=\sqrt{2}G_{\rm F}V_{\rm ud}V^*_{\rm cs}m_{\rho^+}(a_1f_\rho F_1^{DK}\epsilon_{\rho^+}\cdot P_{D^+}+a_2f_KA_0^{D\rho^+}\epsilon_{\rho^+}\cdot P_{\bar{K}^0}),$$

$$A(D^0\to\pi^0\bar{K}^{*0})=G_{\rm F}V_{\rm ud}V^*_{\rm cs}m_{\bar{K}^{*0}}a_2f_{\bar{K}^{*0}}F_1^{D\pi}\epsilon_{\bar{K}^{*0}}\cdot P_{D^0},$$

$$A(D^0\to\pi^+K^{*-})=\sqrt{2}G_{\rm F}V_{\rm ud}V^*_{\rm cs}a_1m_{K^*}f_\pi A_0^{DK}\epsilon_{\bar{K}^{*-}}\cdot P_{\pi^+},$$

$$A(D^+\to\pi^+\bar{K}^{*0})=\sqrt{2}G_{\rm F}V_{\rm ud}V^*_{\rm cs}m_{\bar{K}^{*0}}(a_1f_\pi A_0^{DK^*}\epsilon_{\bar{K}^{*0}}\cdot P_{\pi^+}+a_2f_{\bar{K}^{*0}}F^{D\pi}\epsilon_{\bar{K}^{*0}}\cdot P_{D^+}),$$

$$A(D^+\to\pi^+\rho^0)=-G_{\rm F}V_{\rm ud}V^*_{\rm cd}a_1m_{\rho^0}f_\pi A_0^{D\rho}\epsilon_{\rho^0}\cdot P_\pi+G_{\rm F}V_{\rm ud}V^*_{\rm cd}a_2m_{\rho^0}f_\rho F_1^{D\pi}\epsilon_\rho\cdot P_D,$$

$$A(D^0\to\pi^+\rho^-)=\sqrt{2}G_{\rm F}V_{\rm ud}V^*_{\rm cd}m_{\rho^-}a_1f_\pi A_0^{D\rho}\epsilon_{\rho^-}\cdot P_\pi,$$

$$A(D^0\to\pi^0\rho^0)=-\frac{1}{\sqrt{2}}G_{\rm F}V_{\rm ud}V^*_{\rm cd}a_2m_{\rho^0}(f_\pi A_0^{D\rho}\epsilon_\rho\cdot P_\pi+f_\rho F_1^{D\pi}\epsilon_{\rho^0}\cdot P_{D^0}),$$

$$A(D^0\to\pi^-\rho^+)=\sqrt{2}G_{\rm F}V_{\rm ud}V^*_{\rm cd}a_1m_{\rho^+}f_\rho F_1^{D\pi}\epsilon_\rho\cdot P_{D^0},$$

$$A(D^+\to\pi^0\rho^+)=-G_{\rm F}V_{\rm ud}V^*_{\rm cd}m_\rho(a_1f_\rho F_1^{D\pi}\epsilon_{\rho^+}\cdot P_{D^0}+a_2f_\pi A^{D\rho}\epsilon_{\rho^0}\cdot P_{\pi^0}),\qquad(2)$$

where the parameters a_1 and a_2 are taken as[13]

$$a_1=c_1(\mu)+c_2(\mu)\left(\frac{1}{N_c}+\chi(\mu)\right),$$

$$a_2=c_2(\mu)+c_1(\mu)\left(\frac{1}{N_c}+\chi(\mu)\right),\qquad(3)$$

with the color number $N_c=3$, and $\chi(\mu)$ is the phenomenological parameter introduced for taking care of nonfactorizable effects. The relative signs in lines 7, 9, 11 of Eq.(2) arise from the iso-spin structure. For example, the component $u\bar{u}$ in one final meson π^0 or ρ^0 contributes an iso-spin factor $\frac{1}{\sqrt{2}}$, and the $d\bar{d}$ component contributes $-\frac{1}{\sqrt{2}}$. The parameters in calculation are 1) the form factors $F_1^{D\pi}(0)=0.69$, $F_1^{DK}(0)=0.76$, $A_0^{D\rho}(0)=0.67$, $A_0^{DK^*}(0)=0.73$[2]; 2) the decay constants $f_\pi=0.133\text{GeV}$, $f_K=0.158\text{GeV}$, $f_\rho=0.2\text{GeV}$, and $f_{K^*}=0.221\text{GeV}$.

For q^2 dependence of the form factors, we take the BSW model[2], i.e., the monopole dominance assumption:

$$F_1(q^2)=\frac{F_1(0)}{1-q^2/m_{1^-}^2},\quad A_0(q^2)=\frac{A_0(0)}{1-q^2/m_{0^-}^2},\qquad(4)$$

where m_{1^-}, m_{0^-} are the relevant pole masses.

The decay width of a D meson at rest decaying into PV is

$$\Gamma(D\to PV)=\frac{1}{8\pi}|A(D\to PV)|^2\frac{|\boldsymbol{p}|}{m_D^2},\qquad(5)$$

where the momentum of the final state particle is given by

$$|\boldsymbol{p}|=\frac{[(m_D^2-(m_1+m_2)^2)(m_D^2-(m_1-m_2)^2)]^{1/2}}{2m_D},\qquad(6)$$

where m_1, m_2 are the masses of the final state particles. The corresponding branching ratio is

$$Br(D\to PV)=\frac{\Gamma(D\to PV)}{\Gamma_{\rm tot}}.\qquad(7)$$

The numerical results of the branch ratios of D decays are given in Table 1. The second column is for the case $\chi(\mu)=0$ which means there is no nonfactorizable contribution. When $\chi(\mu)=-\frac{1}{3}$, the parameters $a_1=1.216$ and $a_2=-0.415$. The parameters in the fourth column $a_1=1.26$, $a_2=-0.51$ are phenomenologically used in many references[15].

Comparing the results of the naive factorization in the second to fourth column of Table 1 with the experimental

Table 1. Branching ratios of D→PV obtained in the naive factorization approach and comparisions with the experimental results.

Decay mode	Br(Theory) $(\chi=0)$	Br(Theory) $\left(\chi=-\frac{1}{3}\right)$	Br(Theory) $(a_1=1.26, a_2=-0.51)$	Br(Experiment)
$D^0\to\bar{K}^0\rho^0$	1.02×10^{-4}	2.18×10^{-3}	3.29×10^{-3}	$(1.47\pm0.29)\times10^{-2}$
$D^0\to K^-\rho^+$	6.99×10^{-2}	8.70×10^{-2}	9.33×10^{-2}	$(10.2\pm0.9)\times10^{-2}$
$D^+\to K^0\rho^+$	16.08×10^{-2}	13.5×10^{-2}	12.99×10^{-2}	$(6.6\pm2.5)\times10^{-2}$
$D^0\to\pi^0K^{*0}$	2.64×10^{-4}	5.61×10^{-3}	8.5×10^{-3}	$(2.8\pm0.4)\times10^{-2}$
$D^0\to\pi^+K^*$	2.45×10^{-2}	3.05×10^{-2}	3.28×10^{-2}	$(6.0\pm0.5)\times10^{-2}$
$D^+\to\pi^+K^{*0}$	4.42×10^{-2}	7.86×10^{-3}	2.99×10^{-3}	$(1.92\pm0.19)\times10^{-2}$
$D^+\to\pi^+\rho^0$	2.25×10^{-3}	5.56×10^{-3}	6.85×10^{-3}	$(1.04\pm0.18)\times10^{-3}$
$D^0\to\pi^+\rho^-$	1.32×10^{-3}	1.64×10^{-3}	1.76×10^{-3}	—
$D^0\to\pi^0\rho^0$	1.24×10^{-3}	3.58×10^{-4}	5.54×10^{-4}	—
$D^0\to\pi^-\rho^+$	4.36×10^{-3}	5.42×10^{-3}	5.82×10^{-3}	—
$D^+\to\pi^0\rho^+$	6.15×10^{-3}	9.88×10^{-3}	1.12×10^{-2}	

data, one can notice that, even considering some nonfactorizable contribution, some of the results from the naive factorization approach deviate significantly from the experimental data.

3 The one-particle-exchange method for FSI

From Table 1, we can see that the calculation from naive factorization approach is in disagreement with the experimental results for the branching ratios of D→PV decays. The reason is that the physical picture of naive factorization is too simple, in which nonperturbative strong interaction is restricted in single hadrons, or between the initial and final hadrons which share the same spectator quark. If the mass of the initial particle is large, such as the case of B meson decays, the effect of nonperturbative strong interaction between the final hadrons most probably is small because the momentum transfer is large. However, in the case of the D meson, its mass is not so large. The energy scale of D decays is not very high. Nonperturbative effect may give large contribution. According to the one-particle-exchange method, there are s-channel and t-channel contributions to the final state interactions[7,8]. The diagrams of these nonperturbative rescattering effects can be depicted in Figs. 1 and 2. The first part D→P_1V_2 or D→V_1P_2 represents the direct decay where the decay amplitudes can be obtained by using naive factorization method. The second part represents rescattering process where the effective hadronic couplings are needed in numerical calculation, which can be extracted from experimental data on the relevant resonance decays.

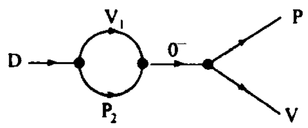

Fig. 1. s-channel contributions to final-state interaction in D→PV decays.

There are many resonances near the mass scale of the D meson. It is possible that nonperturbative interactions propagate through these resonance states, such as, K^* (892), K^* (1430), f_0 (1710), K^* (1680), K^*(1020), ϕ(1680), π(1300) etc. For s-channel the correct quantum number of the resonance should be $J^P=0^-$. Fig. 1 is the s-channel contribution to the final state interactions in D→PV, here V_1 and P_2 are the intermediate mesons. In Ref.[16] we can not find the relevant resonant state which has the correct quantum number 0^-, and at the same time can decay into the final PV states considered in this paper, with large possibility. So we can ignore the s-channel contribution in this paper.

Fig. 2 shows the t-channel contribution to the final state interactions. P_1, V_2 and V_1, P_2 are the intermediate states from direct weak decays. They rescatter into the final states by exchanging one pseudoscalar meson P. Because two-vector-meson decays of one pseudoscalar particle P→VV and V→PV have not been detected yet, one can assume that their couplings are too small. Therefore we do not consider the contributions through exchanging

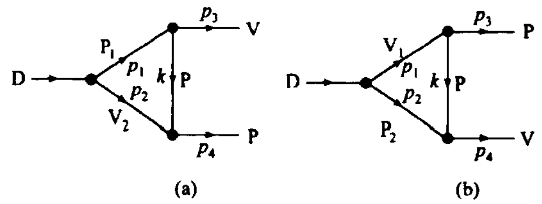

Fig.2. t-channel contributions to final-state interaction in D→PV due to one-particle-exchange. (a) D→P_1V_2→PV; (b) D→V_1P_2→PV.

vector particles[11,16]. In this paper the intermediate states are treated to be on their mass shell, because one assume the on-shell contribution dominates in the final state interactions. The exchanged resonances are treated as a virtual particle. Their propagators are taken as Breit-Wigner form,

$$\frac{i}{k^2 - m^2 + im\Gamma_{tot}}, \tag{8}$$

where $k = P_1 - P_3 = P_4 - P_2$ and Γ_{tot} is the total decay width of the exchanged resonance.

We consider the t-channel contribution. For the t-channel contribution, the concerned effective vertex in Fig.3 is VPP, which can be related to the V decay amplitude. Explicitly the amplitude of V→PP can be written as

$$T_{VPP} = g_{VPP}\epsilon\cdot(p_1 - p_2), \tag{9}$$

where p_1 and p_2 are the four-momentum of the two pseudoscalars, respectively. To extract g_{VPP} from experiment, one should square Eq.(9) to get the decay widths,

$$\Gamma(V\to PP) = \frac{1}{3}\frac{1}{8\pi}|g_{VPP}|^2\left[m_V^2 - 2m_1^2 - 2m_2^2 + \frac{(m_1^2 - m_2^2)^2}{m_V^2}\right]\frac{|\boldsymbol{p}|}{m_V^2}, \tag{10}$$

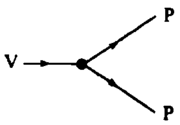

Fig.3. The effective coupling vertex on the hadronic level.

where m_1 and m_2 are the masses of the two final particles PP, respectively, and $|\boldsymbol{p}|$ is the momentum of one of the final particle P in the rest frame of V. From the above equations, one can see that only the magnitudes of the effective couplings $|g_{VPP}|$ can be extracted from experiment. On the quark level, the effective vertex should be controlled by nonperturbative QCD. It is reasonable that a strong phase can appear in the effective coupling, which is contributed by strong interaction. Therefore we can take a strong phase for each hadronic effective coupling[11]. In the following, the symbol g will only be used to represent the magnitude of the relevant effective coupling. The total one should be $ge^{i\theta}$, where θ is the strong phase. For example, the effective couplings will be written in the form of $g_{VPP}e^{i\theta_{VPP}}$.

The t-channel contribution in Fig.2(a) is

$$A^{FSI}_{P_1,V_2} = \frac{1}{2}\int\frac{d^3\boldsymbol{p}_1}{(2\pi)^3 2E_1}\int\frac{d^3\boldsymbol{p}_2}{(2\pi)^3 2E_2}(2\pi)^4\delta^4(p_D - p_1 - p_2)$$
$$A(D\to P_1V_2)\times g_1\epsilon_3\cdot(p_1 + k)\frac{ie^{i(\theta_1+\theta_2)}}{k^2 - m^2 + im\Gamma_{tot}}\times$$
$$F(k^2)^2 g_2\epsilon_2\cdot(p_4 + k), \tag{11}$$

where $F(k^2) = (\Lambda^2 - m^2)/(\Lambda^2 - k^2)$ is the form factor which is introduced to compensate the off-shell effect of the exchanged particle at the vertices[17]. We choose the lightest resonance state as the exchanged particle that gives the largest contribution to the decay amplitude. After a few steps of integration to the above equation, we get

$$A^{FSI}_{P_1,V_2} = \int_{-1}^{1}\frac{d(\cos\theta)}{2\pi\, m_D}|\boldsymbol{p}_1|X_1 g_1\frac{ie^{i(\theta_1+\theta_2)}}{k^2 - m^2 + im\Gamma_{tot}}\times$$
$$F(k^2)^2\, g_2 H_1, \tag{12}$$

where

$$H_1 = m_2 f_1 A_0\Big[-(E_1E_4 + |\boldsymbol{p}_2||\boldsymbol{p}_4|\cos\theta) + \frac{1}{2m_2^2}(M_D^2 - m_1^2 - m_2^2)(E_2E_4 - |\boldsymbol{p}_2||\boldsymbol{p}_4|\cos\theta)\Big]\times$$
$$\Big[\frac{1}{m_3}(|\boldsymbol{p}_3|E_1 - E_3|\boldsymbol{p}_1|)\Big], \tag{13}$$

and X_1 represents the relevant direct decay amplitude of D decaying to the intermediate pair P_1 and V_2 divided by $\langle P_1|(V-A)_\mu|0\rangle\langle V_2|(V-A)^\mu|D\rangle$,

$$X_1 \equiv \frac{A(D\to P_1V_2)}{\langle P_1|(V-A)_\mu|0\rangle\langle V_2|(V-A)^\mu|D\rangle}.$$

The t-channel contribution in Fig.2(b) is

$$A^{FSI}_{V_1,P_2} = \frac{1}{2}\int\frac{d^3\boldsymbol{p}_1}{(2\pi)^3 2E_1}\int\frac{d^3\boldsymbol{p}_2}{(2\pi)^3 2E_2}(2\pi)^4\delta^4(p_D - p_1 - p_2)\times$$
$$A(D\to V_1P_2)\times g_1\epsilon_1\cdot(p_3 - k)\frac{ie^{i(\theta_1+\theta_2)}}{k^2 - m^2 + im\Gamma_{tot}}\times$$
$$F(k^2)^2 g_2\epsilon_4\cdot(p_2 - k), \tag{14}$$

and we obtain

$$A^{FSI}_{V_1,P_2} = \int_{-1}^{1}\frac{d(\cos\theta)}{2\pi\, m_D}|\boldsymbol{p}_1|\frac{ie^{i(\theta_1+\theta_2)}}{k^2 - m^2 + im\Gamma_{tot}}\times$$
$$X_2 g_1 g_2 F(k^2)^2\, H_2, \tag{15}$$

where

$$H_2 = m_1 f_1 F_1\Big[- M_D E_3 + \frac{1}{m_1^2} E_1 M_D (E_1 E_3 - |\boldsymbol{p}_1| |\boldsymbol{p}_3| \cos\theta)\Big] \times \frac{1}{m_4}(|\boldsymbol{p}_4| E_2 - E_4 |\boldsymbol{p}_2| \cos\theta), \tag{16}$$

and X_2 represents the relevant direct decay amplitude of D decaying to the intermediate pair V_1 and P_2 divided by $\langle V_1 | (V-A)_\mu | 0 \rangle \langle P_2 | (V-A)^\mu | D \rangle$,

$$X_2 \equiv \frac{A(D \to V_1 P_2)}{\langle V_1 | (V-A)_\mu | 0 \rangle \langle P_2 | (V-A)^\mu | D \rangle}.$$

4　Numerical calculation and discussions

To calculate the FSI contribution of D decays with the Eqs. (12) and (15), we need to know which channels can rescatter into the final states. For D→Kρ, πK*, πρ, from Figs. 4—6, one can see that D→πK*→Kρ, D→Kρ→Kρ, D→πK*→πK*, D→ρK→πK*, D→πρ→πρ and D→KK*→πρ can give the largest contributions, because these intermediate states have the largest couplings with the final states and the masses of the exchanged mesons are small which give the largest t-channel contributions.

From Eqs. (12), (15) and considering Figs. 4—6, we can calculate the amplitudes of D→PV decays. In this paper we consider D→Kρ, πK* and πρ decays. There should be some input parameters in our calculation, such as, the transition form factors for D decays, decay constants of the final mesons, the phenomenological nonfactorizable parameter $\chi(\mu)$, the off-shell compensating parameter Λ in function $F(k^2)$ introduced in Eq. (11), the effective couplings of relevant hadronic states and the relevant strong phases for these effective couplings. For the

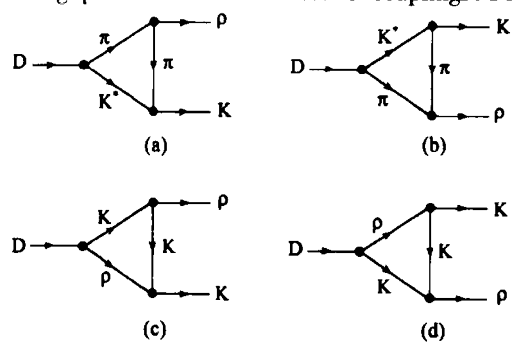

Fig. 4.　Intermediate states in rescattering process for D→Kρ decays.

transition form factors and decay constants, we take 1) the form factors $F_1^{D\pi}(0) = 0.69$, $F_1^{DK}(0) = 0.76$, $A_0^{D\rho}(0) = 0.67$, $A_0^{DK^*}(0) = 0.73$[2]; 2) the decay constants $f_\pi = 0.133$GeV, $f_K = 0.158$GeV, $f_\rho = 0.2$GeV and $f_{K^*} = 0.221$GeV. We should be careful for these parameters, because except for the decay constants f_π and f_K etc., the values of the transition form factors have not been known exactly yet. We have to take them from model-dependent calculations. For the phenomenological nonfactorizable parameter $\chi(\mu)$, at first, we tried to proceed by taking $\chi(\mu) = 0$, which means that nonfactorizable contribution is neglected. We find that if nonfactorizable contribution is neglected, no matter how the other parameters (the strong phases and Λ) are tuned, we can not reproduce the experimental data for all the D→PV decays simultaneously. So we have to keep it as an phenomenological parameter which will be determined later. The hadronic effective couplings involved in this study are $g_{\rho\pi\pi}$ and $g_{K^*K\pi}$, which can be determined from the centeral values of the measured decay widths of ρ→ππ and K*→Kπ[16]. We obtain $g_{\rho\pi\pi} = 6.0$, $g_{K^*K\pi} = 4.6$, $g_{\rho KK} = \frac{1}{\sqrt{2}} g_{\rho\pi\pi}$[8]. The parameter Λ in the off-shellness compensating function $F(k^2)$ in-

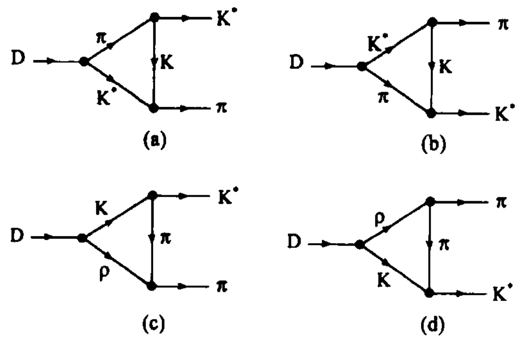

Fig. 5.　Intermediate states in rescattering process for D→πK* decays.

troduced in Eq. (11) is not an universal parameter. It is process-dependent in general. However, in this paper we use one value for Λ in all the possible channels of D→PV decays. We assume Λ is in the range from 0.5GeV to 1.0GeV, which is the range of the masses of the final state particles ρ and K* etc.. We scanned all the possible value for $\chi(\mu)$ and Λ, and find that if we take $\chi(\mu) = -0.26$ and $\Lambda = 0.7$GeV, we can reproduce the experimental data of all the detected D→PV decay modes well. $\chi(\mu) = -0.26$ means the nonfactorizable contribution is not very large. $\Lambda = 0.7\mathrm{GeV}$ is in the mass range of the final state particles. In the following we give the decay amplitudes of some D→PV decay modes as function of the strong phases $\theta_{K^* K\pi}$, $\theta_{\rho\pi\pi}$ and $\theta_{\rho KK}$ by taking $\chi(\mu) = -0.26$ and $\Lambda = 0.7\mathrm{GeV}$,

$$A(D^0 \to \overline{K}^0 \rho^0) = -5.26 \times 10^{-7} + 3.42 \times 10^{-7} i e^{i2\theta_{\rho KK}} + 9.49 \times 10^{-7} i e^{i(\theta_{\rho KK} + \theta_{\rho\pi\pi})},$$

$$A(D^0 \to K^- \rho^+) = 4.127 \times 10^{-6} - 1.167 \times 10^{-7} i e^{i2\theta_{\rho KK}} - 1.72 \times 10^{-7} i e^{i(\theta_{K^* K\pi} + \theta_{\rho\pi\pi})},$$

$$A(D^+ \to \overline{K}^0 \rho^+) = 3.40 \times 10^{-6} + 1.886 \times 10^{-6} i e^{i2\theta_{\rho KK}} + 1.15 \times 10^{-6} i e^{i(\theta_{K^* K\pi} + \theta_{\rho\pi\pi})},$$

$$A(D^0 \to \pi^0 \overline{K}^{*0}) = -8.244 \times 10^{-7} + 1.135 \times 10^{-6} i e^{i2\theta_{K^* K\pi}} + 5.42 \times 10^{-7} i e^{i(\theta_{K^* K\pi} + \theta_{\rho\pi\pi})},$$

$$A(D^0 \to \pi^+ K^{*-}) = 2.389 \times 10^{-6} - 6.16 \times 10^{-7} i e^{i2\theta_{K^* K\pi}},$$

$$A(D^+ \to \pi^+ \overline{K}^{*0}) = 1.2056 \times 10^{-6} + 3.7368 \times 10^{-7} i e^{i2\theta_{K^* K\pi}} + 1.81603 \times 10^{-6} i e^{i(\theta_{K^* K\pi} + \theta_{\rho\pi\pi})},$$

$$A(D^+ \to \pi^+ \rho^0) = -5.69 \times 10^{-7} - 6.94 \times 10^{-7} i e^{i2\theta_{KK\pi}} + 2.48 \times 10^{-7} i e^{i(\theta_{K^* K\pi} + \theta_{\rho KK})},$$

$$A(D^0 \to \pi^+ \rho^-) = -4.8216 \times 10^{-7} + 1.137 \times 10^{-7} i e^{i(\theta_{K^* K\pi} + \theta_{\rho KK})} + 2.1 \times 10^{-7} i e^{i2\theta_{\rho\pi\pi}},$$

$$A(D^0 \to \pi^0 \rho^0) = -2.066 \times 10^{-7} + 1.3177 \times 10^{-7} i e^{i2\theta_{K^* K\pi}} + 1.1726 \times 10^{-7} i e^{i(\theta_{\rho kk} + \theta_{K^* K\pi})},$$

$$A(D^0 \to \pi^- \rho^+) = -8.736 \times 10^{-7} + 6.879 \times 10^{-8} i e^{i(\theta_{K^* K\pi} + \theta_{\rho KK})} + 2.08 \times 10^{-7} i e^{i2\theta_{\rho\pi\pi}},$$

$$A(D^+ \to \pi^0 \rho^+) = 7.95 \times 10^{-7} + 1.133 \times 10^{-7} i e^{i2\theta_{\rho\pi\pi}} + 1.198 \times 10^{-7} i e^{i(\theta_{K^* K\pi} + \theta_{\rho\pi\pi})} \quad (17)$$

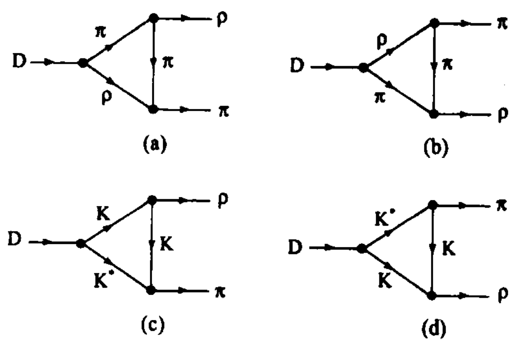

Fig.6. Intermediate states in rescattering process for D→πρ decays.

The phases of the effective hadronic couplings $\theta_{K^* K\pi}$, $\theta_{\rho\pi\pi}$ and $\theta_{\rho KK}$ can not be known from direct experimental measurement or from any nonperturbative calculations because there are no any such kind of calculations yet. We only know that the values of $\theta_{K^* K\pi}$, $\theta_{\rho\pi\pi}$ and $\theta_{\rho KK}$ should not differ too much according to $SU(3)$ flavor symmetry. We tried some values for these phase parameters, and find that the ranges which can reproduce the experimental data of the measured D→PV decays are not very narrow. To show that the experimental data can be accommodated, we give the numerical results for $\theta_{K^* K\pi} = 51.0°$, $\theta_{\rho KK} = 51.0°$ and $\theta_{\rho\pi\pi} = 57.3°$ in Table 2.

Table 2. The branching ratios of D→PV.

Decay mode	Factorization	Factorization + FSI	Experiment
$D^0 \to \overline{K}^0 \rho^0$	2.18×10^{-3}	1.57×10^{-2}	$(1.47 \pm 0.29) \times 10^{-2}$
$D^0 \to K^- \rho^+$	8.70×10^{-2}	9.61×10^{-2}	$(10.2 \pm 0.9) \times 10^{-2}$
$D^+ \to \overline{K}^0 \rho^+$	13.5×10^{-2}	5.79×10^{-2}	$(6.6 \pm 2.5) \times 10^{-2}$
$D^0 \to \pi^0 \overline{K}^{*0}$	5.61×10^{-3}	3.13×10^{-2}	$(2.8 \pm 0.4) \times 10^{-2}$
$D^0 \to \pi^+ K^{*-}$	3.05×10^{-2}	4.56×10^{-2}	$(6.0 \pm 0.5) \times 10^{-2}$
$D^+ \to \pi^+ K^{*0}$	7.86×10^{-3}	1.86×10^{-2}	$(1.92 \pm 0.19) \times 10^{-2}$
$D^+ \to \pi^+ \rho^0$	5.56×10^{-3}	1.36×10^{-3}	$(1.04 \pm 0.18) \times 10^{-3}$
$D^0 \to \pi^+ \rho^-$	1.64×10^{-3}	3.6×10^{-3}	—
$D^0 \to \pi^0 \rho^0$	3.58×10^{-4}	1.12×10^{-3}	—
$D^0 \to \pi^- \rho^+$	5.42×10^{-3}	6.9×10^{-3}	—
$D^+ \to \pi^0 \rho^+$	9.88×10^{-3}	4.22×10^{-3}	—

Table 2 shows that the contribution of FSI is strongly channel dependent. For example, for $D^0 \to \overline{K}^0 \rho^0$, the braching ratio in naive factorization is 2.18×10^{-3}, while the braching ratio including FSI is 1.57×10^{-2}. We can see that FSI contribution in $D^0 \to \overline{K}^0 \rho^0$ is large, but FSI contribution in $D^0 \to K^- \rho^+$ is small. The reason for the difference is that the external rescattering diagrams for $D^0 \to \overline{K}^0 \rho^0$ and $D^0 \to K^- \rho^+$ are different. Without the contribution of FSI, predictions of naive factorization for most detected D→PV decays are seriously in disagreement with the experimental results. After including FSI, the results can accommodate the experimental data well. For the other decay modes $D^0 \to \pi^+ \rho^-$, $\pi^0 \rho^0$, $\pi^- \rho^+$ and $D^+ \to \pi^0 \rho^+$, their branching ratios have not been detected in experiment yet. In our model, they are all predicted to be at the order of $\mathcal{O}(10^{-3})$. For $D^0 \to \pi^+ \rho^-$ and $\pi^- \rho^+$, the effect of FSI is constructive. While for $D^0 \to \pi^0 \rho^0$ and $D^+ \to \pi^0 \rho^+$, FSI effects are destructive to the prediction of naive factorization.

Before the end of this section, some comments should be given: there are many uncertainties in the input parameters which may change the above result numerically, such as, the D decay transition form factors and some decay constants which have not been known exactly. They need to be measured from leptonic and semileptonic decays of D mesons which are quite possible in CLEO-C program in the near future. The other sources which may cause uncertainties are the shape of the off-shell compensating function $F(k^2)$, or in more general the effective hadronic couplings in the off-shell region, the strong phases of the effective couplings, and the nonfactorization parameter $\chi(\mu)$, both of which are needed to be studied in some nonperturbative methods based on non-peturbative QCD in the future.

5 Summary

We have studied some channnels of D→PV decays. The total decay amplitude includes direct weak decays and final state rescattering effects. The direct weak decays are calculated in the factorization approach, and the final state interaction effects are studied in the one-particle-exchange method. The predictions of naive factorization are far from the experimental data for most decay modes. After including the contribution of final state interactions, the theoretical predictions can accommodate the experimental data well. The strong phases of the effective hadronic couplings are neccessary to reproduce experimental data.

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D→PV 衰变及末态相互作用*

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摘要 运用单粒子交换方法研究 D→PV 衰变中的 D→κρ,πκ*,πρ 过程. 考虑了强相位及非因子化贡献,能得到与实验数据很吻合的结果. 结果表明:非因子化贡献一般不是很大,但是在一些衰变道非因子化贡献是不可忽略的;强相位具有近似的 $SU(3)$ 对称性.

关键词 末态相互作用 单粒子交换方法 强相位 非因子化

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