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Predictions for the quark-mixing doubly suppressed decays of charmed mesons

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Based on the results from analyzing the currently available data of quark-mixing nonsuppressed or singly suppressed decays of charmed mesons, the branching ratios of the quark-mixing doubly suppressed charm decays are predicted using the quark-diagram scheme.

Recently, considerable progress has been made in the experimental observation of quark-mixing nonsuppressed or singly suppressed charmed meson decays. Their implications, both experimental and theoretical, had been studied using the quark-diagram scheme.[1-3] Here we continue such studies and obtain further new results. It is now hopeful that the mixing-matrix doubly suppressed charm decays will be within reach by experiments in the near future.[4] The quark-mixing doubly suppressed decays are integrated parts with the quark-mixing nonsuppressed and singly suppressed decays in the analyses using the quark-diagram scheme.[5] Here we report the interesting results that most of the doubly suppressed decays can already be predicted based upon the current nonsuppressed and singly suppressed data. These results ought to be very useful for experimental planning, observation, and for furthering our understanding of nonleptonic weak decays.

All nonleptonic decays of charmed mesons can be described by amplitudes from the six distinct types of quark diagrams:[1,2] $\mathcal{A}$, the external-W-emission amplitude; $\mathcal{B}$, the internal-W-emission amplitude; $\mathcal{C}$, the W-exchange amplitude; $\mathcal{D}$, the W-annihilation amplitude; $\mathcal{E}$, the horizontal W-loop amplitude; and $\mathcal{F}$, the vertical W-loop amplitude. These are distinct diagrams with all QCD gluon effects included. The quark-diagram amplitudes for quark-mixing doubly suppressed D^+, D^0, and D_s^+ decays are given in Tables I–III for vector-pseudoscalar (VP), pseudoscalar-pseudoscalar (PP), and vector-vector (VV) decays, respectively. Note that we have included the effects of final-state interactions as well as some SU(3)-breaking effects. Our predicted branching ratios are also given in Tables I–III. [For decays involving SU(3) singlets in the final states, there exist in principle the hairpin diagrams, denoted in these tables by a subscript h. However, we ignore them here since there is no clear experimental evidence for their existence.[6]]

$D\rightarrow VP$ decays. Our analysis[3] of recent data of a charmed meson decaying into a vector meson and a pseudoscalar meson $D\rightarrow VP$ have established the following: From the measured decay rates of $D_s^+\rightarrow\phi\pi^+$, $D^+\rightarrow\phi\pi^+$, $\bar{K}^{*0}\pi^+$, and $D^0\rightarrow\phi\bar{K}^0$ we obtained the values for various quark-diagram amplitudes:

$$\begin{aligned}\mathcal{A}'&=(2.01\pm0.33)\times10^{-6}\,,\\ \mathcal{B}'&=-(3.12\pm0.44)\times10^{-6}\,,\\ |\underline{\mathcal{C}}'|&=(1.77\pm0.21)\times10^{-6}\,,\end{aligned}\tag{1}$$

where the primed amplitudes denote the case that the vector meson arises from the decay of the charm quark, and the underlined amplitude refers to the amplitudes of graphs involving the creation of $\bar{s}s$. From the measurements of $D_s^+\rightarrow\bar{K}^{*0}K^+$ and $D^0\rightarrow K^{*-}\pi^+,\bar{K}^{*0}\pi^0$ we get

$$\begin{aligned}&\mathcal{C}'=-0.43\times10^{-6},\quad \underline{\mathcal{D}}=(1.43\pm0.46)\times10^{-6}\,,\\ &\Delta_{\bar{K}^*\pi}\equiv(\delta_{1/2}-\delta_{3/2})_{\bar{K}^*\pi}=(97\pm13)^\circ\,.\end{aligned}\tag{2}$$

For unprimed amplitudes, three sets of solutions[3] can be derived from the observed rates of $D^+\rightarrow\rho^+\bar{K}^0$, $D^0\rightarrow\omega\bar{K}^0$, $\rho^0\bar{K}^0$, and ρ^+K^-. However, the recent ARGUS result[7] $B(D^0\rightarrow K^0\bar{K}^{*0})<3\times10^{-4}$ implies $\mathcal{C}\sim\mathcal{C}'$. This favors the solution

$$\begin{aligned}\mathcal{A}&=(3.50\pm0.05)\times10^{-6}\,,\\ \mathcal{B}&=-(1.97\pm0.12)\times10^{-6}\,,\\ \mathcal{C}&=-(0.39\pm0.05)\times10^{-6}\,,\\ \Delta_{\rho\bar{K}}&\equiv(\delta_{1/2}-\delta_{3/2})_{\rho\bar{K}}=(0\pm26)^\circ\,.\end{aligned}\tag{3}$$

The other two solutions give too large values for the amplitude $\mathcal{C}$. The small rate for $D_s^+\rightarrow\rho^+\pi^0$ indicates[3] $\mathcal{D}\approx\mathcal{D}'$. The recent E691 result[8] for negligible $D_s^+\rightarrow\pi^+\omega$ implies $|\underline{\mathcal{D}}|>>|\mathcal{D}|\approx|\mathcal{D}'|$. Motivated by $\mathcal{C}\sim\frac{1}{4}\underline{\mathcal{C}}'$, though not very compelling, we will assume that $\mathcal{D}\sim\mathcal{D}'\sim\frac{1}{4}\underline{\mathcal{D}}$ for the purpose of giving specific $D\rightarrow VP$ rates.

With the quark-diagram amplitudes and the isospin phase-shift differences given by Eqs. (1)–(3), we are able to compute the branching fractions for all doubly suppressed $D\rightarrow VP$ decays except $D_s\rightarrow K^*K$.[9] The results are shown in Table I. Note that our predictions do take into account effects of final-state interactions obtained from data analyses in the quark-diagram scheme, as indicated by the phase shifts in Eqs. (2) and (3). Without final-state interactions the predicted branching ratio for $D \to K^{*0}\pi^0$ will be smaller by a factor of 3. Such final-state-interaction effects are still beyond the capability of most theoretical model calculations.

It is also worth emphasizing that our analysis gives non-negligible the so-called nonspectator diagrams, the W-annihilation diagram $\underline{D}$ and the W-exchange diagram, C and C', as evidenced by Eqs. (2) and (3), in contrast with most model calculations.[10–12] For example, in our scheme $D^+ \to \phi K^+$ arises solely from the W-annihilation diagram $\underline{\mathcal{D}}$.

$D \to PP$ decays. With the new data of $D^0 \to \bar{K}^0\eta'$, $D_s^+ \to \pi^+\eta$, and $D_s^+ \to \pi^+\eta'$, a unique set of solutions for the $D \to PP$ quark-diagram amplitudes $\mathcal{A}$, $\mathcal{B}$, $\mathcal{C}$, $\mathcal{D}$, $\underline{\mathcal{C}}$, and $\underline{\mathcal{D}}$ can now be obtained.[6] More precisely, the six amplitudes[13] can be determined from the measured decay rates of $D^+ \to \bar{K}^0\pi^+$, $\bar{K}^0K^+$, $D^0 \to \bar{K}^0\eta$, $\bar{K}^0\eta'$, $K^-\pi^+$, $\bar{K}^0\pi^0$, and $D_s^+ \to \bar{K}^0K^+, \pi^+\eta$ (in units of GeV):

$$\begin{aligned} &[\mathcal{A}]_{PP} \sim 3.4\times10^{-6}, \quad [\mathcal{B}]_{PP} \sim -2.1\times10^{-6}, \\ &[\mathcal{C}]_{PP} \sim -1.8\times10^{-6}, \quad [\mathcal{D}]_{PP} \sim -0.5\times10^{-6}, \\ &[\underline{\mathcal{C}}]_{PP} \sim -0.8\times10^{-6}, \quad [\underline{\mathcal{D}}]_{PP} \sim -0.4\times10^{-6}, \\ &\Delta_{\bar{K}\pi} \equiv (\delta_{1/2}-\delta_{3/2})_{\bar{K}\pi} = (79\pm11)^\circ . \end{aligned} \tag{4}$$

Evidently, the nonspectator contributions, especially the W-exchange diagrams, play an essential role in $D \to PP$ decays.

Using the quark-diagram amplitudes given by Eq. (4), it is straightforward to compute the branching fractions for quark-mixing doubly suppressed $D \to PP$ decays (see Table II). Again, it should be stressed that nonspectator diagrams and final-state interactions are included in our calculations. In addition to the prediction based upon detailed information of Eq. (4), we have also the following general relations between the doubly suppressed decays and nonsuppressed D^0 decays by comparing Table II with those of nonsuppressed decays given in the tables of Ref. 3:

TABLE I. Doubly suppressed charm-meson decays into a vector boson and a pseudoscalar meson.

Channels	Predicted branching ratios	Amplitudes with SU(3) symmetry and no final-state interactions	Amplitudes with SU(3) breaking and final-state interactions
$D^+ \to \phi K^+$	$\mathbf{0.5\times10^{-4}}$	$-(s_1)^2 \times \{\underline{D} + D_h\}$	$\to \{\underline{D} + D_{\underline{h}}\}e^{i\delta^{\phi K}}$
$\to \omega K^+$	$\mathbf{2.5\times10^{-4}}$	$-(1/\sqrt{2})(s_1)^2 \times \{A' + D' + 2D_h\}$	$\to \{A' + D' + 2D_h\}e^{i\delta^{\omega K}}$
$\to K^{*+}\eta_8$		$-(1/\sqrt{6})(s_1)^2 \times \{A + D - 2D'\}$	$\to \{A + D - 2D' + 2D'_h - 2D'_{\underline{h}}\}e^{i\delta^{K^*\eta_8}}$
$\to K^{*+}\eta_0$		$-(1/\sqrt{3})(s_1)^2 \times \{A + D + D' + 3D'_h\}$	$\to \{A + D + D' + 2D'_h + D'_{\underline{h}}\}e^{i\delta^{K^*\eta_0}}$
$\to K^{*+}\eta$	$\mathbf{1.7\times10^{-4}}$	$\eta = \eta_8\cos\theta + \eta_0\sin\theta;\ \eta' = -\eta_8\sin\theta + \eta_0\cos\theta;\ \theta \approx 20^\circ$	
$\to \rho^+K^0$	$\mathbf{2.0\times10^{-4}}$	$-(s_1)^2 \times \{B + D'\}$	$\to \{(B + D') + (A' - B - 2D')(1/3)(1 - e^{-i\Delta_{\rho K}})\}e^{i\delta_{3/2}^{\rho K}}$
$\to \rho^0K^+$	$\mathbf{1.0\times10^{-4}}$	$(1/\sqrt{2})(s_1)^2 \times \{A' - D'\}$	$\to \{(A' - D') - (A' - B - 2D')(2/3)(1 - e^{-i\Delta_{\rho K}})\}e^{i\delta_{3/2}^{\rho K}}$
$\to K^{*0}\pi^+$	$\mathbf{1.1\times10^{-4}}$	$-(s_1)^2 \times \{B' + D\}$	$\to \{(B' + D) + \frac{1}{3}(A - B' - 2D)(1 - e^{-i\Delta_{K^*\pi}})\}e^{i\delta_{1/2}^{K^*\pi}}$
$\to K^{*+}\pi^0$	$\mathbf{2.2\times10^{-4}}$	$(1/\sqrt{2})(s_1)^2 \times \{A - D\}$	$\to \{(A - D) - \frac{2}{3}(A - B' - 2D)(1 - e^{-i\Delta_{K^*\pi}})\}e^{i\delta_{1/2}^{K^*\pi}}$
$D^0 \to \phi K^0$	$\mathbf{0.2\times10^{-4}}$	$-(s_1)^2 \times \{\underline{C} + C_h\}$	$\to \{\underline{C} + C_{\underline{h}}\}e^{i\delta^{\phi K}}$
$\to \omega K^0$	$\mathbf{0.9\times10^{-4}}$	$-(1/\sqrt{2})(s_1)^2 \times \{B + C' + 2C_h\}$	$\to \{B + C' + 2C_h\}e^{i\delta^{\omega K}}$
$\to K^{*+}\pi^-$	$\mathbf{1.9\times10^{-4}}$	$-(s_1)^2 \times \{A + C\}$	$\to \{(A + C) - \frac{1}{3}(A + B)(1 - e^{-i\Delta_{K^*\pi}})\}e^{i\delta_{1/2}^{K^*\pi}}$
$\to K^{*0}\pi^0$	$\mathbf{1.2\times10^{-4}}$	$-(1/\sqrt{2})(s_1)^2 \times \{B - C\}$	$\to \{(B - C) - \frac{2}{3}(A + B)(1 - e^{-i\Delta_{K^*\pi}})\}e^{i\delta_{1/2}^{K^*\pi}}$
$\to K^{*0}\eta_8$		$-(1/\sqrt{6})(s_1)^2 \times \{B' + C - 2\underline{C}'\}$	$\to \{B' + C - 2\underline{C}' + 2C'_h - 2C'_{\underline{h}}\}e^{i\delta_{1/2}^{K^*\eta_8}}$
$\to K^{*0}\eta_0$		$-(1/\sqrt{3})(s_1)^2 \times \{B' + C + \underline{C}' + 3C'_h\}$	$\to \{B' + C + \underline{C}' + 2C'_h + C'_{\underline{h}}\}e^{i\delta^{K^*\eta_0}}$
$\to K^*\eta$	$\mathbf{0.2\times10^{-4}}$	$\eta = \eta_8\cos\theta + \eta_0\sin\theta;\ \eta' = -\eta_8\sin\theta + \eta_0\cos\theta;\ \theta \approx 20^\circ$	
$\to \rho^-K^+$	$\mathbf{0.9\times10^{-4}}$	$-(s_1)^2 \times \{A' + C'\}$	$\to (A' + C') - 2/3(A' + B)(1 - e^{i\Delta_{\rho K}})\}e^{i\delta_{1/2}^{\rho K}}$
$\to \rho^0K^0$	$\mathbf{0.4\times10^{-4}}$	$-(1/\sqrt{2})(s_1)^2 \times \{B - C'\}$	$\to \{(B - C') - 1/3(A' + B)(1 - e^{i\Delta_{\rho K}})\}e^{i\delta_{1/2}^{\rho K}}$
$D_s^+ \to K^{*+}K^0$	$\mathbf{0.7\times10^{-4}}$	$-(s_1)^2 \times \{A + B\}$	$\to \{(A + B) + \frac{1}{2}(A' + B' - A - B)(1 - e^{-i\Delta_{K^*K}})\}e^{i\delta_1^{K^*K}}$
$\to K^{*0}K^+$	$\mathbf{0.6\times10^{-4}}$	$-(s_1)^2 \times \{A' + B'\}$	$\to \{(A' + B') - \frac{1}{2}(A' + B' - A - B)(1 - e^{-i\Delta_{K^*K}})\}e^{i\delta_1^{K^*K}}$

TABLE II. Doubly suppressed charm-meson decays to two pseudoscalars.

Channels	Predicted branching ratios	Amplitudes with SU(3) symmetry and no final-state interactions	Amplitudes with SU(3) breaking and final-state interactions
$D^+ \to K^0\pi^+$	2.1×10^{-4}	$-(s_1)^2\times\{\mathcal{B}+\mathcal{D}\}$	$\to \{(\mathcal{B}+\mathcal{D})+(\mathcal{A}-\mathcal{B}-2\mathcal{D})(1/3)(1-e^{-i\Delta_{K\pi}})\}e^{i\delta^{K\pi}_{3/2}}$
$\to K^+\pi^0$	3.7×10^{-4}	$(1/\sqrt{2})(s_1)^2\times\{\mathcal{A}-\mathcal{D}\}$	$\to \{(\mathcal{A}-\mathcal{D})-(\mathcal{A}-\mathcal{B}-2\mathcal{D})(2/3)(1-e^{-i\Delta_{K\pi}})\}e^{i\delta^{K\pi}_{3/2}}$
$\to K^+\eta_8$		$-(1/\sqrt{6})(s_1)^2\times\{\mathcal{A}-\mathcal{D}\}$	$\to \{\mathcal{A}-\mathcal{D}+2\mathcal{D}_h-2\mathcal{D}_{\underline{h}}\}e^{i\delta^{K\eta_8}}$
$\to K^+\eta_0$		$-(1/\sqrt{3})(s_1)^2\times\{\mathcal{A}+2\mathcal{D}+3\mathcal{D}_h\}$	$\to \{\mathcal{A}+2\mathcal{D}+2\mathcal{D}_h+\mathcal{D}_{\underline{h}}\}e^{i\delta^{K\eta_0}}$
$\to K^+\eta$	1.5×10^{-4}	$\eta=\eta_8\cos\theta+\eta_0\sin\theta$	
$\to K^+\eta'$	0.1×10^{-4}	$\eta'=-\eta_8\sin\theta+\eta_0\cos\theta;\ \theta\approx20^\circ$	
$D^0 \to K^+\pi^-$	1.2×10^{-4}	$-(s_1)^2\times\{\mathcal{A}+\mathcal{C}\}$	$\to$ same as for $K^-\pi^+$
$\to K^0\pi^0$	0.6×10^{-4}	$-(1/\sqrt{2})(s_1)^2\times\{\mathcal{B}-\mathcal{C}\}$	$\to$ same as for $\bar{K}^0\pi^0$
$\to K^0\eta_8$		$-(1/\sqrt{6})(s_1)^2\times\{\mathcal{B}-\mathcal{C}\}$	$\to$ same as for $\bar{K}^0\eta_8$
$\to K^0\eta_0$		$-(1/\sqrt{3})(s_1)^2\times\{\mathcal{B}+2\mathcal{C}+3\mathcal{C}_h\}$	$\to$ same as for $\bar{K}^0\eta_0$
$\to K^0\eta$	0.4×10^{-4}	$\eta=\eta_8\cos\theta+\eta_0\sin\theta$	
$\to K^0\eta'$	0.6×10^{-4}	$\eta'=-\eta_8\sin\theta+\eta_0\cos\theta;\ \theta\approx20^\circ$	
$D_s^+ \to K^+K^0$	0.3×10^{-4}	$-(s_1)^2\times\{\mathcal{A}+\mathcal{B}\}$	$\to \{(\mathcal{A}+\mathcal{B})\}e^{i\delta^{KK}_1}$

$$\Gamma(D^0\to K^+\pi^-)=\left[\frac{s_1}{c_1}\right]^4\Gamma(D^0\to K^-\pi^+),\quad \Gamma(D^0\to K^0\pi^0)=\left[\frac{s_1}{c_1}\right]^4\Gamma(D^0\to\bar{K}^0\pi^0)\,,$$
$$\Gamma(D^0\to K^0\eta)=\left[\frac{s_1}{c_1}\right]^4\Gamma(D^0\to\bar{K}^0\eta),\quad \Gamma(D^0\to K^0\eta')=\left[\frac{s_1}{c_1}\right]^4\Gamma(D^0\to\bar{K}^0\eta')\,, \tag{5}$$

where

$$s_1\approx|V_{cd}^*|\simeq|V_{us}|,\quad c_1\approx|V_{cs}^*|\approx|V_{ud}|,\quad \eta=\eta_8\cos\theta+\eta_0\sin\theta,\quad \eta'=-\eta_8\sin\theta+\eta_0\cos\theta,\quad \theta\approx20^\circ\,. \tag{6}$$

TABLE III. Doubly suppressed charm-meson decays into two vector bosons.

Channels	Predicted branching ratios	Amplitudes with SU(3) symmetry and no final-state interactions	Amplitudes with SU(3) breaking and final-state interactions
$D^+ \to \phi K^{*+}$		$-(s_1)^2\times\{\underline{\mathcal{D}}+\mathcal{D}_h\}$	$\to \{\underline{\mathcal{D}}+\mathcal{D}_{\underline{h}}\}e^{i\delta^{\phi K^*}}$
$\to \omega K^{*+}$		$-(1/\sqrt{2})(s_1)^2\times\{\mathcal{A}+\mathcal{D}+2\mathcal{D}_h\}$	$\to \{\mathcal{A}+\mathcal{D}+2\mathcal{D}_h\}e^{i\delta^{\omega K^*}}$
$\to \rho^+K^{*0}$		$-(s_1)^2\times\{\mathcal{B}+\mathcal{D}\}$	$\to \{(\mathcal{B}+\mathcal{D})+(\mathcal{A}-\mathcal{B}-2\mathcal{D})(1/3)(1-e^{-i\Delta_{\rho K^*}})\}e^{i\delta^{\rho K^*}_{3/2}}$
$\to \rho^0K^{*+}$		$(1/\sqrt{2})(s_1)^2\times\{\mathcal{A}-\mathcal{D}\}$	$\to \{(\mathcal{A}-\mathcal{D})-(\mathcal{A}-\mathcal{B}-2\mathcal{D})(2/3)(1-e^{-i\Delta_{\rho K^*}})\}e^{i\delta^{\rho K^*}_{3/2}}$
$D^0 \to \phi\ K^{*0}$		$-(s_1)^2\times\{\underline{\mathcal{C}}+\mathcal{C}_h\}$	$\to \{\underline{\mathcal{C}}+\mathcal{C}_h\}e^{i\delta^{\phi K^*}}$
$\to \omega\ \bar{K}^{*0}$	6×10^{-5}	$-(1/\sqrt{2})(s_1)^2\times\{\mathcal{B}+\mathcal{C}+2\mathcal{C}_h\}$	$\to \{\mathcal{B}+\mathcal{C}'+2\mathcal{C}_h\}e^{i\delta^{\omega K^*}}$
$\to \rho^-K^{*+}$		$-(s_1)^2\times\{\mathcal{A}+\mathcal{C}\}$	$\to \{(\mathcal{A}+\mathcal{C})-2/3(\mathcal{A}+\mathcal{B})(1-e^{i\Delta_{\rho K^*}})\}e^{i\delta^{\rho K^*}_{1/2}}$
$\to \rho^0K^{*0}$		$-(1/\sqrt{2})(s_1)^2\times\{\mathcal{B}-\mathcal{C}\}$	$\to \{(\mathcal{B}-\mathcal{C})-1/3(\mathcal{A}+\mathcal{B})(1-e^{i\Delta_{\rho K^*}})\}e^{i\delta^{\rho K^*}_{1/2}}$
$D_s^+ \to K^{*+}K^{*0}$		$-(s_1)^2\times\{\mathcal{A}+\mathcal{B}\}$	$\to \{(\mathcal{A}+\mathcal{B})\}e^{i\delta^{K^*K^*}_1}$

$D \to VV$ Decays. Based on the quark-diagram scheme (see Table III), the following predictions can be made:

$$\Gamma(D^0 \to \phi K^{*0}) = \left[\frac{s_1}{c_1}\right]^4 \Gamma(D^0 \to \phi \bar{K}^{*0}) \ ,$$

$$\Gamma(D^0 \to \omega K^{*0}) = \left[\frac{s_1}{c_1}\right]^4 \Gamma(D^0 \to \omega \bar{K}^{*0}) \ ,$$

$$\Gamma(D^0 \to \rho^- K^{*+}) = \left[\frac{s_1}{c_1}\right]^4 \Gamma(D^0 \to \rho^+ K^{*-}) \ , \qquad (7)$$

$$\Gamma(D^0 \to \rho^0 K^{*0}) = \left[\frac{s_1}{c_1}\right]^4 \Gamma(D^0 \to \rho^0 \bar{K}^{*0}) \ ,$$

$$|\mathcal{A}(D_s^+ \to K^{*+} K^{*0})| = \left[\frac{s_1}{c_1}\right]^2 |\mathcal{A}(D^+ \to \rho^+ \bar{K}^{*0})| \ .$$

Using the recent ARGUS measurement[7] $B(D^0 \to \bar{K}^{*0}\omega) = (2.0 \pm 0.5 \pm 0.3)\%$, we predict $B(D^0 \to K^{*0}\omega) \sim 6 \times 10^{-5}$.

To summarize, branching fractions of the doubly quark-mixing-matrix suppressed decays of charmed mesons are predicted using the quark-diagram scheme together with the existing data. Measurements of these doubly suppressed charm decays are important in our effort to understand the nonleptonic-decay mechanism.

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[6] See L. L. Chau, H. Y. Cheng, and T. Huang [Report No. UCD-89-18 (unpublished)] for an updated analysis. In our previous paper (Ref. 3) an assumption on the nonspectator amplitudes $\underline{\mathcal{C}}$ and $\underline{\mathcal{D}}$ has to be made in order to determine six quark-diagram amplitudes from five measured decay rates as the data for $D^0 \to \bar{K}^0\eta'$ were not available at that time.

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[9] The present data for $D^0 \to K^{*-}K^+$ and $K^{*+}K^-$ are not accurate enough to determine the phase-shift difference of $(\delta_0 - \delta_1)_{K^*K}$. Our predictions for $D_s \to K^*K$ rates are obtained in the absence of final-state interactions.

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[13] The other set of solutions is (in units of GeV)

$$[\mathcal{A}]_{PP} \sim 1.9 \times 10^{-6}, \quad [\mathcal{B}]_{PP} \sim -0.6 \times 10^{-6} \ ,$$

$$[\mathcal{C}]_{PP} \sim -3.0 \times 10^{-6}, \quad [\mathcal{D}]_{PP} \sim -1.3 \times 10^{-6} \ ,$$

$$[\underline{\mathcal{C}}]_{PP} \sim -0.8 \times 10^{-6}, \quad [\underline{\mathcal{D}}]_{PP} \sim -1.9 \times 10^{-6} \ ,$$

$$(\delta_{1/2} - \delta_{3/2})_{\bar{K}\pi} = (101 \pm 11)^\circ \ .$$

However, this solution leads to the prediction $B(D_s^+ \to \pi^+\eta') \sim 0.1\%$ and hence is ruled out by current experiments.