EPJ Web of Conferences **202**, 04002 (2019)
CHARM 2018
https://doi.org/10.1051/epjconf/201920204002

Study of the D-mixing parameter y in the factorization-assisted topological-amplitude approach

Qin Qin[1,*]

[1]Theoretische Physik 1, Naturwissenschaftlich-Technische Fakultät, Universität Siegen,
Walter-Flex-Strasse 3, D-57068 Siegen, Germany

Abstract. The contributions to the $D^0 - \bar{D}^0$ mixing parameter y from the $D^0 \to PP, PV$ channels are calculated, based on the corresponding decay amplitudes extracted from data in the factorization-assisted topological-amplitude approach. It is found that the PP, PV contributions amount up to $y_{PP+PV} = (0.21 \pm 0.07)$, about one third of the experiment measurement $y_{\rm exp} = (0.63 \pm 0.08)\%$.

1 Introduction

Neutral meson mixings, as flavor-changing-neutral-current processes, have been regimes for searching new physics in different periods. For example, kaon and B_d mixings played crucial roles in the discoveries of the charm quark [1] and the top quark [2, 3]. Even today, it is still very important to study the mixing dynamics precisely to probe higher-scale physics. While the $B_{d(s)}$ meson mixings have been studied quite well in the heavy quark effective theory [4, 5], the tentative similar study of the D mixing [6] found a number for the y parameter smaller than the fit result of the data $y_{\rm exp} = (0.63 \pm 0.08)\%$ [7] assuming no CP violation in charm decays by three orders of magnitude. It indicates that $1/m_c$ with m_c being the charm quark mass might be too large to allow perturbative expansion. On the other hand, the so-called "exclusive approaches" to the D mixing dynamics have been attempted in the literature (see e.g. [8–11]). In such approaches, contributions to y from all D^0 decay channels are summed up, and the SU(3) flavor symmetry breaking effects, or more precisely the U-spin symmetry breaking effects, are crucial to evaluate the D mixing parameters. It was found by [8, 9] that the SU(3) breaking effects from only the phase spaces of different decay final states can naturally give a prediction for y at the percent level as the data. A quantitative study [11] summing up the measured branching ratios (and the unmeasured ones obtained from fit in the diagrammatic approach) gave the following predictions for the PP and PV contributions to y, $y_{PP} = (0.86 \pm 0.41) \times 10^{-3}$, $y_{PV} = (2.69 \pm 2.53) \times 10^{-3}$ $(A, A1)$ and $y_{PV} = (1.52 \pm 2.20) \times 10^{-3}$ $(S, S1)$ from two different solutions. The results have very large uncertainties, which are dominated by the worst measured channels. In the factorization-assisted topological-amplitude (FAT) approach [12, 13], the amplitude information is extracted from data through a global fit, and the uncertainties are well controlled by the most precisely measured channels. Therefore, we expect FAT to be a proper approach to the evaluation of the D mixing parameter y. Moreover, the FAT approach has been applied to studies of many D and B decays [12–18], and the SU(3) breaking effects are well captured.

---

[*] e-mail: qin@physik.uni-siegen.de

Precise data are available for $D^0 \to PP$ and PV decay channels [19], and make it possible to extract the corresponding hadronic amplitudes in the FAT approach and to thus make predictions for y_{PP} and y_{PV} [20]. The results turn out to be $y_{PP} = (0.10 \pm 0.02)\%$ and $y_{PV} = (0.11 \pm 0.07)\%$ [20], which constitute about one third of the data of the total y parameter. Therefore, it is also necessary to evaluate the contributions from other two-body and multi-particle hadronic D meson decays, probably in a different approach at the current stage because of lack of data.

The rest of the article is organized as follows. In Section 2 we present how the $D^0 \to PP$ and PV amplitudes are determined by data in the FAT approach, based on which the corresponding contributions to y are predicted. Section 3 is the conclusion.

2 Calculation of y_{PP} and y_{PV}

The D-mixing parameter y is defined by

$$y \equiv \frac{\Gamma_1 - \Gamma_2}{2\Gamma}, \tag{1}$$

where $\Gamma_{1,2}$ are the decay widths of the two mass eigenstates $D_{1,2}$, and Γ is their average. We neglect the tiny CP violation in D meson decays, and thus the CP eigenstates are identical to the mass eigenstates, i.e., $|D_{1,2}\rangle = |D_\pm\rangle = (|D^0\rangle \pm |\overline{D}^0\rangle)/\sqrt{2}$. Here we have adopted the convention $\mathcal{CP}|D^0\rangle = +|\overline{D}^0\rangle$. Then, the y parameter is further expressed as

$$\begin{aligned} y &= \frac{1}{2\Gamma}\sum_n \rho_n \left(|\mathcal{A}(D_+ \to n)|^2 - |\mathcal{A}(D_- \to n)|^2\right) \\ &= \frac{1}{\Gamma}\sum_n \eta_{\rm CP}(n)\rho_n \mathcal{R}e\left[\mathcal{A}(D^0 \to n)\mathcal{A}^*(D^0 \to \bar{n})\right], \end{aligned} \tag{2}$$

where ρ_n is the phase-space factor for the $D \to n$ decay, and $\eta_{\rm CP}$ is given by $\mathcal{CP}|n\rangle = \eta_{\rm CP}|\bar{n}\rangle$. We have $\eta_{\rm CP} = +1$ for both the PP and PV modes. Formula (2) is what we will take to compute the y parameter, and the unknown decay amplitudes will be extracted in the FAT approach.

In the FAT approach, each decay amplitude is factorized into short-distance Wilson coefficients and long-distance hadronic matrix elements. The matrix elements are formulated in different categories according to their corresponding different topological diagrams, including the color-favored tree-emission diagram T, the color-suppressed tree-emission diagram C, the W-exchange diagram E, and the W-annihilation diagram A. For each type of these diagrams, there are both factorizable contributions and nonfactorizable contributions. While factorizable contributions are either known in the literature or negligible, nonfactorizable contributions are parametrized by magnitudes with complex phases. We emphasize that the SU(3) breaking effects have been considered as many as we can in such a parametrizaion. The explicit formulations of the parametrizaions of the $D \to PP$ and PV amplitudes can be found in [12] and [13], respectively. Through the global fits to the data, the free parameters are determined with uncertainties as,

$$\begin{gathered} \chi^C = -0.81 \pm 0.01, \quad \phi^C = 0.22 \pm 0.14, \quad S_\pi = -0.92 \pm 0.07, \\ \chi^E_q = 0.056 \pm 0.002, \quad \phi^E_q = 5.03 \pm 0.06, \quad \chi^E_s = 0.130 \pm 0.008, \quad \phi^E_s = 4.37 \pm 0.10, \end{gathered} \tag{3}$$

Table 1. Branching ratios in units of 10^{-3} for the $D^0 \to PP$ decays. Predictions $\mathcal{B}$(FAT) in the FAT approach are compared with the experimental data $\mathcal{B}$(exp) [19].

Modes	$\mathcal{B}$(exp)	$\mathcal{B}$(FAT)
$\pi^0\overline{K}^0$	24.0 ± 0.8	24.2 ± 0.8
π^+K^-	39.3 ± 0.4	39.2 ± 0.4
$\eta\overline{K}^0$	9.70 ± 0.6	9.6 ± 0.6
$\eta'\overline{K}^0$	19.0 ± 1.0	19.5 ± 1.0
$\pi^+\pi^-$	1.421 ± 0.025	1.44 ± 0.02
K^+K^-	4.01 ± 0.07	4.05 ± 0.07
$K^0\overline{K}^0$	0.36 ± 0.08	0.29 ± 0.07
$\pi^0\eta$	0.69 ± 0.07	0.74 ± 0.03
$\pi^0\eta'$	0.91 ± 0.14	1.08 ± 0.05
$\eta\eta$	1.70 ± 0.20	1.86 ± 0.06
$\eta\eta'$	1.07 ± 0.26	1.05 ± 0.08
$\pi^0\pi^0$	0.826 ± 0.035	0.78 ± 0.03
π^0K^0		0.069 ± 0.002
π^-K^+	0.133 ± 0.009	0.133 ± 0.001
ηK^0		0.027 ± 0.002
$\eta' K^0$		0.056 ± 0.003

for the $D^0 \to PP$ decays, and

$$\begin{aligned} S_\pi &= -1.88 \pm 0.12, & \chi_P^C &= 0.63 \pm 0.03, & \phi_P^C &= 1.57 \pm 0.11, \\ \chi_V^C &= 0.71 \pm 0.03, & \phi_V^C &= 2.77 \pm 0.10, & \chi_q^E &= 0.49 \pm 0.03, \\ \phi_q^E &= 1.61 \pm 0.07, & \chi_s^E &= 0.54 \pm 0.03, & \phi_s^E &= 2.23 \pm 0.08, \end{aligned} \tag{4}$$

for the $D^0 \to PV$ decays. The theoretical inputs are the same as in [12, 13], except that the decay constants of the vector mesons are taken from [21]. The χ^2's per degree of freedom are 1.1 for the PP fit with 13 data, and 1.8 for the PV fit with 19 data. The PP and PV branching ratios calculated based on the parameters in (3) and (4) are listed in Table 1 and Table 2, respectively, compared to data. The consistence of the FAT and the experimental results suggests that the parametrizaions are reasonable.

Since now the PP and PV decay amplitudes can be calculated taking the fit results of the parameters (3) and (4), the corresponding contributions to y, y_{PP} and y_{PV} are computed using the formula (2) to be

$$y_{PP} = (1.00 \pm 0.19) \times 10^{-3}, \tag{5}$$

$$y_{PV} = (1.12 \pm 0.72) \times 10^{-3}, \tag{6}$$

respectively. Combing them together, we have

$$y_{PP+PV} = (0.21 \pm 0.07)\%, \tag{7}$$

which indicates that the PP and PV contributions make up about one third of the measured total value, $y_{\rm exp} = (0.63 \pm 0.08)\%$. We emphasize that our result (7) is the most precise one up to now.

Table 2. Same as Table I but for the $D^0 \to PV$ decays.

Modes	$\mathcal{B}$(exp)	$\mathcal{B}$(FAT)
$\pi^0\overline{K}^{*0}$	37.5 ± 2.9	35.9 ± 2.2
$\overline{K}^0\rho^0$	$12.8^{+1.4}_{-1.6}$	13.5 ± 1.4
π^+K^{*-}	54.3 ± 4.4	62.5 ± 2.7
$K^-\rho^+$	111.0 ± 9.0	105.0 ± 5.2
$\eta\overline{K}^{*0}$	9.6 ± 3.0	6.1 ± 1.0
$\eta'\overline{K}^{*0}$	< 1.10	0.19 ± 0.01
$\overline{K}^0\omega$	22.2 ± 1.2	22.3 ± 1.1
$\overline{K}^0\phi$	$8.47^{+0.66}_{-0.34}$	8.2 ± 0.6
$\pi^+\rho^-$	5.09 ± 0.34	4.5 ± 0.2
$\pi^-\rho^+$	10.0 ± 0.6	9.2 ± 0.3
K^+K^{*-}	1.62 ± 0.15	1.8 ± 0.1
K^-K^{*+}	4.50 ± 0.30	4.3 ± 0.2
$K^0\overline{K}^{*0}$	0.18 ± 0.04	0.19 ± 0.03
$\overline{K}^0K^{*0}$	0.21 ± 0.04	0.19 ± 0.03
$\eta\rho^0$		1.4 ± 0.2
$\eta'\rho^0$		0.25 ± 0.01
$\pi^0\rho^0$	3.82 ± 0.29	4.1 ± 0.2
$\pi^0\omega$	0.117 ± 0.035	0.10 ± 0.03
$\pi^0\phi$	1.35 ± 0.10	1.4 ± 0.1
$\eta\omega$	2.21 ± 0.23	2.0 ± 0.1
$\eta'\omega$		0.044 ± 0.004
$\eta\phi$	0.14 ± 0.05	0.18 ± 0.04
π^0K^{*0}		0.103 ± 0.006
$K^0\rho^0$		0.039 ± 0.004
π^-K^{*+}	$0.345^{+0.180}_{-0.102}$	0.40 ± 0.02
$K^+\rho^-$		0.144 ± 0.009
ηK^{*0}		0.017 ± 0.003
$\eta'K^{*0}$		0.00055 ± 0.00004
$K^0\omega$		0.064 ± 0.003
$K^0\phi$		0.024 ± 0.002

3 Conclusion

In conclusion, while the heavy quark effective theory fails in the study of the $D^0 - \bar{D}^0$ mixing dynamics, an exclusive approach might be feasible to evaluate the mixing parameter y. In the FAT approach, the $D^0 \to PP$ and PV decay amplitudes can be extracted from the abundant precise data of the corresponding decay channels, and the SU(3) symmetry breaking effects are under control. With the extracted amplitudes, we were able to make the prediction for the PP and PV contributions to y, as $y_{PP+PV} = (0.21 \pm 0.07)\%$. We emphasize that this result is the most precise one up to now. Comparing it to the data $y_{\rm exp} = (0.63 \pm 0.08)\%$, we find that the order of the measured y can be naturally explained and that the contributions to y from other decay channels are also important. However, the estimation of the other contributions in the FAT approach is very difficult, if not impossible, owing to lack of data at the current stage. More data or a new strategy is expected to solve this problem.

Acknowledgements

The author is grateful to Hua-Yu Jiang, Hsiang-nan Li, Cai-Dian Lü and Fu-Sheng Yu for collaborations on the papers related to this talk. This author also thanks the organizers for the invitation to the 9th International Workshop on Charm Physics. The travel to the workshop was supported by DFG Forschergruppe FOR 1873 "Quark Flavour Physics and Effective Field Theories".

References

[1] M. K. Gaillard and B. W. Lee, Phys. Rev. D **10**, 897 (1974).

[2] H. Albrecht *et al.* [ARGUS Collaboration], Phys. Lett. B **192**, 245 (1987).

[3] C. Albajar *et al.* [UA1 Collaboration], Phys. Lett. B **186**, 247 (1987) Erratum: [Phys. Lett. B **197**, 565 (1987)].

[4] A. Lenz and U. Nierste, JHEP **0706**, 072 (2007) [hep-ph/0612167].

[5] A. Lenz and U. Nierste, arXiv:1102.4274 [hep-ph].

[6] M. Bobrowski, A. Lenz, J. Riedl and J. Rohrwild, JHEP **1003**, 009 (2010) [arXiv:1002.4794 [hep-ph]].

[7] Y. Amhis *et al.* [HFLAV Collaboration], Eur. Phys. J. C **77**, no. 12, 895 (2017) [arXiv:1612.07233 [hep-ex]], "updated results and plots available at `https://hflav.web.cern.ch`".

[8] A. F. Falk, Y. Grossman, Z. Ligeti and A. A. Petrov, Phys. Rev. D **65**, 054034 (2002) [hep-ph/0110317].

[9] A. F. Falk, Y. Grossman, Z. Ligeti, Y. Nir and A. A. Petrov, Phys. Rev. D **69**, 114021 (2004) [hep-ph/0402204].

[10] M. Gronau and J. L. Rosner, Phys. Rev. D **86**, 114029 (2012), [arXiv:1209.1348 [hep-ph]].

[11] H. Y. Cheng and C. W. Chiang, Phys. Rev. D **81**, 114020 (2010) [arXiv:1005.1106 [hep-ph]].

[12] H. n. Li, C. D. Lü and F. S. Yu, Phys. Rev. D **86**, 036012 (2012) [arXiv:1203.3120 [hep-ph]].

[13] H. n. Li, C. D. Lü, Q. Qin and F. S. Yu, Phys. Rev. D **89**, 054006 (2014) [arXiv:1305.7021 [hep-ph]].

[14] Q. Qin, H. N. Li, C. D. Lü and F. S. Yu, Int. J. Mod. Phys. Conf. Ser. **29**, 1460209 (2014).

[15] S. H. Zhou, Y. B. Wei, Q. Qin, Y. Li, F. S. Yu and C. D. Lü, Phys. Rev. D **92**, 094016 (2015) [arXiv:1509.04060 [hep-ph]].

[16] S. H. Zhou, Q. A. Zhang, W. R. Lyu and C. D. Lü, Eur. Phys. J. C **77**, 125 (2017) [arXiv:1608.02819 [hep-ph]].

[17] C. Wang, Q. A. Zhang, Y. Li and C. D. Lu, Eur. Phys. J. C **77**, 333 (2017) [arXiv:1701.01300 [hep-ph]].

[18] F. S. Yu, D. Wang and H. n. Li, Phys. Rev. Lett. **119**, no. 18, 181802 (2017) doi:10.1103/PhysRevLett.119.181802 [arXiv:1707.09297 [hep-ph]].

[19] M. Tanabashi *et al.* [Particle Data Group], Phys. Rev. D **98**, no. 3, 030001 (2018). doi:10.1103/PhysRevD.98.030001

[20] H. Y. Jiang, F. S. Yu, Q. Qin, H. n. Li and C. D. Lü, Chin. Phys. C **42**, no. 6, 063101 (2018) doi:10.1088/1674-1137/42/6/063101 [arXiv:1705.07335 [hep-ph]].

[21] A. Bharucha, D. M. Straub and R. Zwicky, JHEP **1608**, 098 (2016) [arXiv:1503.05534 [hep-ph]].