PROCEEDINGS OF SCIENCE

Neutral charm mixing results from the **UT***fit* Collaboration

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We update here the analysis of D meson mixing including the latest experimental results. We derive constraints on the parameters M_{12}, Γ_{12} and Φ_{12} that describe D meson mixing using all available data, allowing for CP violation. We also provide posterior distributions for observable parameters appearing in D physics.

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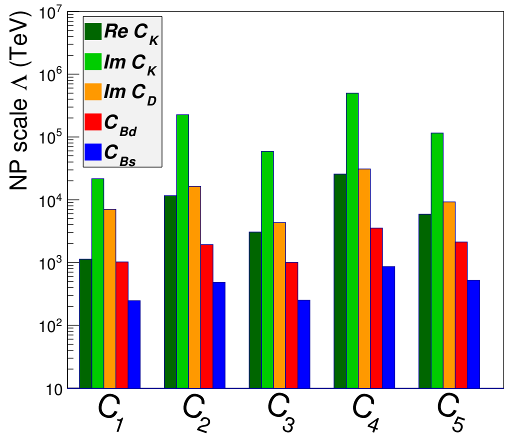

Figure 1: Bounds on the NP scale Λ from $\Delta F = 2$ decays. See Ref. [3] for details and the **UT***fit* updates given at this conference.

1. Introduction

Since 2012, the **UT***fit* Collaboration has performed its own combination of the D mixing experimental data, yielding a quite precise determination of the mixing parameters showing no sign of CP violation [1, 2]. The spectacular experimental progress that we have witnessed in the past few years is leading us in the precision charm physics era, calling for substantial theoretical advances to fully exploit the wealth of available data.

Fig. 1 shows the lower bounds on the new-physics (NP) scale Λ coming from all the neutral meson systems: the case shown corresponds to a general NP scenario, with arbitrary NP flavour structures ($|F_i| \sim 1$ where F_i is a function of the NP flavour couplings) with arbitrary phase and a loop factor $L_i = 1$ corresponding to strongly-interacting and/or tree-level NP. If we consider the most general effective Hamiltonian for $\Delta F = 2$ processes, we can translate the current constraints from a model-independent NP global UT fit into allowed ranges for the Wilson coefficients of $H_{\rm eff}^{\Delta F=2}$. The full procedure and analysis details are given in [3]. These coefficients have the general form

$$C_i(\Lambda) = \frac{F_i\, L_i}{\Lambda^2} \tag{1.1}$$

For a generic strongly-interacting theory with arbitrary flavour structure, one expects $F_i \sim L_i \sim 1$ so that the allowed range from the fit for each of the $C_i(\Lambda)$ can be immediately translated into a lower bound on Λ. Specific assumptions on the flavour structure of NP corresponds to particular choices of the F_i functions. As Fig. 1 shows, the overall constraint on the NP scale comes from the kaon system (Im C_K^4), but charm physics also provides quite stringent constraints, allowing us to probe energies as high as 10^4 TeV, with ample room for sizable improvements, both from the theoretical and experimental point of view.

We present here the updated fit to the experimental data that are reported in Table 1 of the 2014 Ref. [2]: Table 1 here shows only the results updated after the 2014 analysis, following the statistical method described in Ref. [4] improved with a Markov-chain Monte Carlo as implemented

Table 1: Subset of the experimental data updated since the 2014 analysis [2]. The averages are taken from the HFAG [6]. $\alpha = (1+|q/p|)^2/2$. Asymmetric errors have been symmetrised.

Observable	Value	Correlation Coeff.				Reference
y_{CP}	$(0.835 \pm 0.155)\%$					[7, 8, 9, 10] [11, 12, 13, 14]
A_Γ	$(-0.059 \pm 0.040)\%$					[15, 11, 12] [13, 16, 17]
x	$(0.53 \pm 0.19 \pm 0.06 \pm 0.07)\%$	1	0.054	-0.074	-0.031	[18]
y	$(0.28 \pm 0.15 \pm 0.05 \pm 0.05)\%$	0.054	1	0.034	-0.019	[18]
$\|q/p\|$	$(0.91 \pm 0.16 \pm 0.50 \pm 0.60)$	-0.074	0.034	1	0.044	[18]
ϕ	$(-6 \pm 11 \pm 3 \pm 4)^\circ$	-0.031	-0.019	0.044	1	[18]

in the BAT library [5]. The input averages are taken from the Heavy Flavour Averaging Group (HFAG) [6]. The following parameters are varied with flat priors in a sufficiently large range:

$$x = \frac{\Delta m}{\Gamma}, \qquad y = \frac{\Delta\Gamma}{2\Gamma}, \qquad \left|\frac{q}{p}\right|, \qquad \delta_{K\pi}, \qquad \delta_{K\pi\pi}, \qquad R_D, \tag{1.2}$$

where q and p are defined as $|D_{L,S}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle$ with $|p|^2+|q|^2=1$, $\delta_{K\pi(\pi)}$ is the strong phase difference between the amplitudes $A(\bar{D} \to K^+\pi^-(\pi^0))$ and $A(D \to K^+\pi^-(\pi^0))$ and

$$R_D = \frac{\Gamma(D^0 \to K^+\pi^-) + \Gamma(\bar{D}^0 \to K^-\pi^+)}{\Gamma(D^0 \to K^-\pi^+) + \Gamma(\bar{D}^0 \to K^+\pi^-)}. \tag{1.3}$$

We make the following assumptions in order to combine the measurements in Table 1: i) we assume that Cabibbo allowed (CA) and doubly Cabibbo suppressed (DCS) decays are purely tree-level SM processes, neglecting direct CP violation; ii) we neglect the weak phase difference between these channels, which is of $\mathscr{O}(10^{-3})$. One can then write the following equations [19, 20, 21, 22, 23, 1]:

$$\begin{aligned}
&\delta = \frac{1-|q/p|^2}{1+|q/p|^2}, \quad \arg(\Gamma_{12}\, q/p) = \arg(y + i\delta x),\\
&A_M = \frac{|q/p|^4-1}{|q/p|^4+1}, \quad R_M = \frac{x^2+y^2}{2},\\
&\begin{pmatrix} x'_f \\ y'_f \end{pmatrix} = \begin{pmatrix} \cos\delta_f & \sin\delta_f \\ -\sin\delta_f & \cos\delta_f \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix},\\
&(x'_\pm)_f = \left|\frac{q}{p}\right|^{\pm 1} (x'_f \cos\phi \pm y'_f \sin\phi), \quad (y'_\pm)_f = \left|\frac{q}{p}\right|^{\pm 1} (y'_f \cos\phi \mp x'_f \sin\phi),\\
&y_{\mathrm{CP}} = \left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right) \frac{y}{2}\cos\phi - \left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right) \frac{x}{2}\sin\phi,\\
&A_\Gamma = \left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right) \frac{y}{2}\cos\phi - \left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right) \frac{x}{2}\sin\phi,\\
&(y'_{\mathrm{CPA}})_f = \frac{(y'_+)_f + (y'_-)_f}{2}, \quad (x'_{\mathrm{CPA}})^2_f + (y'_{\mathrm{CPA}})^2_f = \frac{(x'_+)^2_f + (x'_-)^2_f + (y'_+)^2_f + (y'_-)^2_f}{2},
\end{aligned}$$

Table 2: Results of the fit to D mixing data.

parameter	result @ 68% prob.	95% prob. range
$\lvert M_{12}\rvert$ [ps^{-1}]	$(4.3 \pm 1.8) \cdot 10^{-3}$	$[0.6, 7.5] \cdot 10^{-3}$
$\lvert\Gamma_{12}\rvert$ [ps^{-1}]	$(14.1 \pm 1.4) \cdot 10^{-3}$	$[11.1, 17.3] \cdot 10^{-3}$
$\Phi_{M_{12}}$ [°]	(0.8 ± 2.6)	$[-5.8, 8.8]$
x	$(3.5 \pm 1.5) \cdot 10^{-3}$	$[0.5, 6.3] \cdot 10^{-3}$
y	$(5.8 \pm 0.6) \cdot 10^{-3}$	$[4.5, 7.1] \cdot 10^{-3}$
$\lvert q/p\rvert - 1$	0.007 ± 0.018	$[-0.030, 0.045]$
ϕ[°]	-0.21 ± 0.57	$[-1.53, 1.02]$

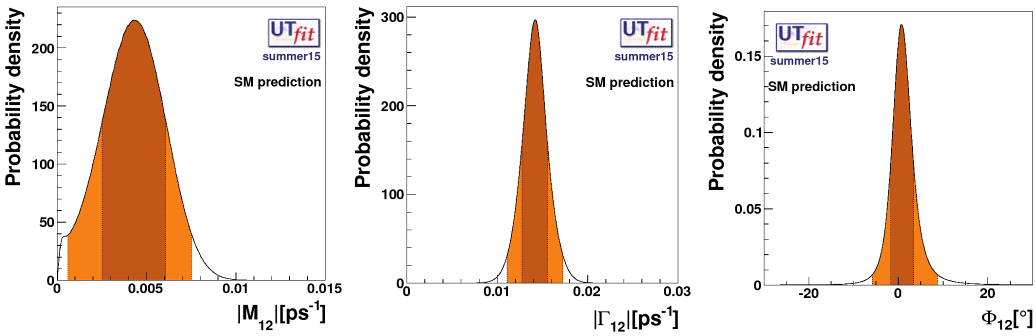

Figure 2: One-dimensional p.d.f. for the parameters $|M_{12}|$, $|\Gamma_{12}|$ and $\Phi_{M_{12}}$.

valid for CA and DCS final states f.

In the standard CKM phase convention (taking CP$|D\rangle = |\bar{D}\rangle$), within the approximation we are using, CA and DCS decay amplitudes have vanishing weak phase and $\phi = \arg(q/p)$. Given the present experimental accuracy, one can assume Γ_{12} to be real, leading to the relation

$$\phi = \arg(y + i\delta x)\,. \tag{1.4}$$

For the purpose of constraining NP, it is useful to express the fit results in terms of the $\Delta C = 2$ effective Hamiltonian matrix elements M_{12} and Γ_{12}:

$$|M_{12}| = \frac{1}{\tau_D}\sqrt{\frac{x^2+\delta^2 y^2}{4(1-\delta^2)}} \sim \frac{x}{2\tau_D} + \mathscr{O}(\delta^2)\,, \quad |\Gamma_{12}| = \frac{1}{\tau_D}\sqrt{\frac{y^2+\delta^2 x^2}{1-\delta^2}} \sim \frac{y}{\tau_D} + \mathscr{O}(\delta^2)\,,$$
$$\sin\Phi_{12} = \frac{|\Gamma_{12}|^2 + 4|M_{12}|^2 - (x^2+y^2)|q/p|^2/\tau_D^2}{4|M_{12}\Gamma_{12}|} \sim \frac{x^2+y^2}{xy}\delta + \mathscr{O}(\delta^2)\,, \tag{1.5}$$

with $\Phi_{12} = \arg(\Gamma_{12}/M_{12})$ and $\tau_D = 0.41$ ps. Consistently with the assumptions above, Γ_{12} can be taken real with negligible NP contributions, and a non-vanishing $\Phi_{12} = -\Phi_{M_{12}}$ can be interpreted as a signal of new sources of CP violation in M_{12}.

The results of the fit are reported in Table 2. The corresponding probability density functions (p.d.f.'s) are shown in Figs. 2 and 3. As can be seen from Table 2, the fitted value of δ is at the percent level and indeed the central values of $|M_{12}|$, $|\Gamma_{12}|$ and Φ_{12} are compatible with the expanded formulae in eq. (1.5). However in our fit we used the exact formulae since the region of $x \lesssim 10^{-4}$,

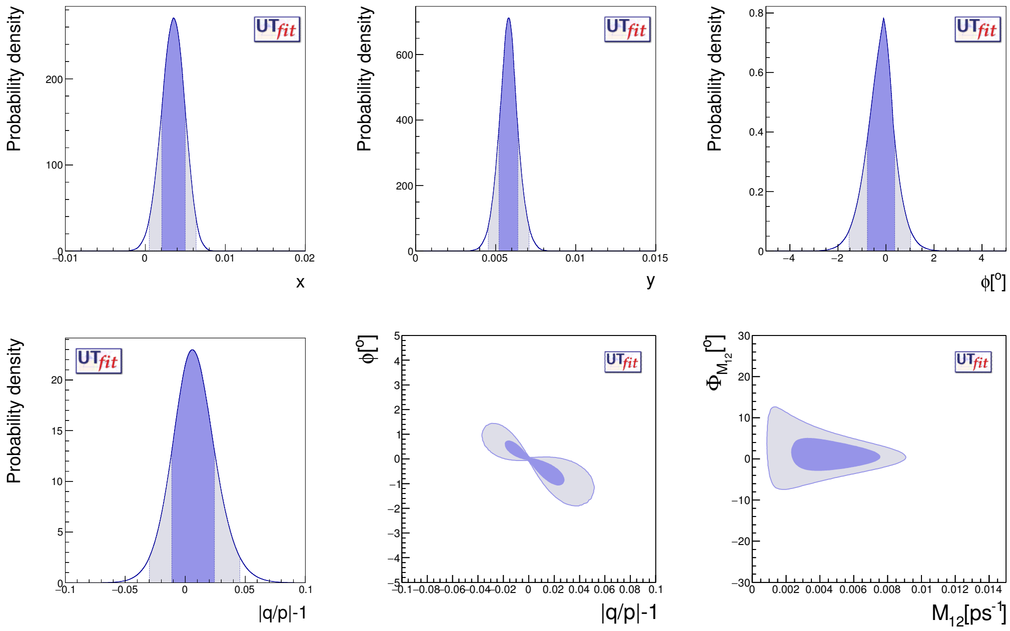

Figure 3: Results of the updated fit to D mixing data. One- and two-dimensional p.d.f.'s are shown for the parameters x, y, ϕ, and $|q/p|$. See Ref. [2] for details.

still allowed by experimental data (although with probability less than 5%), breaks the validity of the small δ expansion.

The results in Table 2 can be used to constrain NP contributions to $D-\bar{D}$ mixing and decays. Our results are in very good agreement with the fit labelled "No direct CPV in DCS decays" by HFAG [6], now that HFAG uses the theoretical relation in eq. (1.4) as we suggested in our first paper [1].

References

[1] A. J. Bevan *et al.*, "The UTfit Collaboration Average of D Meson Mixing Data: Spring 2012," *JHEP*, vol. 10, p. 068, 2012.

[2] A. J. Bevan *et al.*, "The UTfit collaboration average of D meson mixing data: Winter 2014," *JHEP*, vol. 03, p. 123, 2014.

[3] M. Bona *et al.*, "Model-independent constraints on $\Delta F = 2$ operators and the scale of new physics," *JHEP*, vol. 0803, p. 049, 2008.

[4] M. Ciuchini *et al.*, "2000 CKM triangle analysis: A Critical review with updated experimental inputs and theoretical parameters," *JHEP*, vol. 0107, p. 013, 2001.

[5] A. Caldwella, D. Kollar, and K. Kroninger, "BAT – The Bayesian analysis toolkit," *Computer Physics Communications*, vol. 180, pp. 11, 2197–2209, 2009.

[6] Y. Amhis *et al.*, "Averages of b-hadron, c-hadron, and τ-lepton properties as of Summer 2016," hep-ex/1612.07233, 2016.

[7] J. M. Link *et al.*, "A Measurement of lifetime differences in the neutral D meson system," *Phys. Lett.*, vol. B485, pp. 62–70, 2000.

[8] S. E. Csorna *et al.*, "Lifetime differences, direct CP violation and partial widths in D^0 meson decays to K^+K^- and $\pi^+\pi^-$," *Phys. Rev.*, vol. D65, p. 092001, 2002.

[9] A. Zupanc *et al.*, "Measurement of y_{CP} in D^0 meson decays to the $K_S^0 K^+K^-$ final state," *Phys. Rev.*, vol. D80, p. 052006, 2009.

[10] R. Aaij *et al.*, "Measurement of mixing and CP violation parameters in two-body charm decays," *JHEP*, vol. 04, p. 129, 2012.

[11] J. P. Lees *et al.*, "Measurement of $D^0-\overline{D}^0$ Mixing and CP Violation in Two-Body D^0 Decays," *Phys. Rev.*, vol. D87, no. 1, p. 012004, 2013.

[12] M. Staric, "New Belle results on $D^0-\overline{D}^0$ mixing," in *Proceedings, 5th International Workshop on Charm Physics (Charm 2012): Honolulu, Hawaii, USA, May 14-17, 2012*, 2012.

[13] R. Aaij *et al.*, "Measurements of indirect CP asymmetries in $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decays," *Phys. Rev. Lett.*, vol. 112, no. 4, p. 041801, 2014.

[14] M. Ablikim *et al.*, "Measurement of y_{CP} in $D^0-\overline{D}^0$ oscillation using quantum correlations in $e^+e^- \to D^0\,\overline{D}^0$ at $\sqrt{s} = 3.773\,\mathrm{GeV}$," *Phys. Lett.*, vol. B744, pp. 339–346, 2015.

[15] E. M. Aitala *et al.*, "Measurements of lifetimes and a limit on the lifetime difference in the neutral D meson system," *Phys. Rev. Lett.*, vol. 83, pp. 32–36, 1999.

[16] T. A. Aaltonen *et al.*, "Measurement of indirect CP-violating asymmetries in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays at CDF," *Phys. Rev.*, vol. D90, no. 11, p. 111103, 2014.

[17] R. Aaij *et al.*, "Measurement of indirect CP asymmetries in $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decays using semileptonic B decays," *JHEP*, vol. 04, p. 043, 2015.

[18] T. Peng *et al.*, "Measurement of $D^0-\overline{D}^0$ mixing and search for indirect CP violation using $D^0 \to K_S^0\,\pi^+\pi^-$ decays," *Phys. Rev.*, vol. D89, no. 9, p. 091103, 2014.

[19] G. Branco *et al.*, "CP Violation," *Int.Ser.Monogr.Phys.*, vol. 103, 1999.

[20] G. Raz, "Interpreting experimental bounds on $D^0-\overline{D}^0$ mixing in the presence of CP violation," *Phys. Rev.*, vol. D66, p. 057502, 2002.

[21] M. Ciuchini, E. Franco, D. Guadagnoli, V. Lubicz, M. Pierini, V. Porretti, and L. Silvestrini, "$D-\overline{D}$ mixing and new physics: General considerations and constraints on the MSSM," *Phys. Lett.*, vol. B655, pp. 162–166, 2007.

[22] A. L. Kagan and M. D. Sokoloff, "On Indirect CP Violation and Implications for $D^0-\overline{D}^0$ and $B_s-\overline{B}_s$ mixing," *Phys. Rev.*, vol. D80, p. 076008, 2009.

[23] Y. Grossman, Y. Nir, and G. Perez, "Testing New Indirect CP Violation," *Phys. Rev. Lett.*, vol. 103, p. 071602, 2009.