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The UTfit collaboration average of D meson mixing data: Winter 2014

The UTfit collaboration

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Abstract: We update the analysis of D meson mixing including the latest experimental results as of January 2014. 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.

Keywords: Beyond Standard Model, Heavy Quark Physics, CP violation

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Almost two years ago, we presented our combination of the D mixing experimental data, yielding a quite precise determination of the mixing parameters showing no sign of CP violation [1]. Recently, the LHCb Collaboration has improved several important measurements [2, 3], and updates have also come from the other experiments [4–7]. These improvements result in a remarkable accuracy in the determination of the CP violating phase in charm mixing, implying strong contraints on possible extensions of the Standard Model (SM). An update of our fit is timely and can be of use for phenomenological analyses of physics beyond the SM.

In this letter, we perform a fit to the experimental data in table 1 following the statistical method described in ref. [24] improved with a Markov-chain Monte Carlo as implemented in the BAT library [25]. The following parameters are varied with flat priors in a sufficiently large range:

$$x = \frac{\Delta m}{\Gamma}\,, \qquad y = \frac{\Delta\Gamma}{2\Gamma}\,, \qquad \left|\frac{q}{p}\right|\,, \qquad \delta_{K\pi}\,, \qquad \delta_{K\pi\pi}\,, \qquad R_D\,, \tag{1}$$

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

$$R_D = \frac{\Gamma(D^0 \to K^+\pi^-) + \Gamma(\bar{D}^0 \to K^-\pi^+)}{\Gamma(D^0 \to K^-\pi^+) + \Gamma(\bar{D}^0 \to K^+\pi^-)}\,. \tag{2}$$

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 $\mathcal{O}(10^{-3})$. One can then write the following equations [1, 26–30]:

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

valid for Cabibbo allowed and doubly Cabibbo suppressed final states.

Observable	Value	Correlation Coeff.					Reference
y_{CP}	$(0.866 \pm 0.155)\%$						[4, 5, 8–11]
A_Γ	$(-0.014 \pm 0.052)\%$						[2, 4, 5, 12]
x	$(0.79 \pm 0.29 \pm 0.08 \pm 0.12)\%$	1	-0.007	-0.255α	0.216		[13]
y	$(0.30 \pm 0.24 \pm 0.1 \pm 0.07)\%$	-0.007	1	-0.019α	-0.280		[13]
$\lvert q/p \rvert$	(0.96 ± 0.21)	-0.255α	-0.019α	1	-0.128α		[13]
ϕ	$(-2.5 \pm 10.5)^\circ$	0.216	-0.280	-0.128α	1		[13]
x	$(0.16 \pm 0.23 \pm 0.12 \pm 0.08)\%$	1	0.0615				[14]
y	$(0.57 \pm 0.20 \pm 0.13 \pm 0.07)\%$	0.0615	1				[14]
R_M	$(0.0130 \pm 0.0269)\%$						[15–19]
$(x'_+)_{K\pi\pi}$	$(2.48 \pm 0.59 \pm 0.39)\%$	1	-0.69				[20]
$(y'_+)_{K\pi\pi}$	$(-0.07 \pm 0.65 \pm 0.50)\%$	-0.69	1				[20]
$(x'_-)_{K\pi\pi}$	$(3.50 \pm 0.78 \pm 0.65)\%$	1	-0.66				[20]
$(y'_-)_{K\pi\pi}$	$(-0.82 \pm 0.68 \pm 0.41)\%$	-0.66	1				[20]
R_D	$(0.533 \pm 0.107 \pm 0.045)\%$	1	0	0	-0.42	0.01	[6]
x^2	$(0.06 \pm 0.23 \pm 0.11)\%$	0	1	-0.73	0.39	0.02	[6]
y	$(4.2 \pm 2 \pm 1)\%$	0.	-0.73	1	-0.53	-0.03	[6]
$\cos \delta_{K\pi}$	$(0.84 \pm 0.2 \pm 0.06)$	-0.42	0.39	-0.53	1	0.04	[6]
$\sin \delta_{K\pi}$	$(-0.01 \pm 0.41 \pm 0.04)$	0.01	0.02	-0.03	0.04	1	[6]
R_D	$(0.3030 \pm 0.0189)\%$	1	0.77	-0.87			[21]
$(x'_+)^2_{K\pi}$	$(-0.024 \pm 0.052)\%$	0.77	1	-0.94			[21]
$(y'_+)_{K\pi}$	$(0.98 \pm 0.78)\%$	-0.87	-0.94	1			[21]
A_D	$(-2.1 \pm 5.4)\%$	1	0.77	-0.87			[21]
$(x'_-)^2_{K\pi}$	$(-0.020 \pm 0.050)\%$	0.77	1	-0.94			[21]
$(y'_-)_{K\pi}$	$(0.96 \pm 0.75)\%$	-0.87	-0.94	1			[21]
R_D	$(0.364 \pm 0.018)\%$	1	0.655	-0.834			[22]
$(x'_+)^2_{K\pi}$	$(0.032 \pm 0.037)\%$	0.655	1	-0.909			[22]
$(y'_+)_{K\pi}$	$(-0.12 \pm 0.58)\%$	-0.834	-0.909	1			[22]
A_D	$(2.3 \pm 4.7)\%$	1	0.655	-0.834			[22]
$(x'_-)^2_{K\pi}$	$(0.006 \pm 0.034)\%$	0.655	1	-0.909			[22]
$(y'_-)_{K\pi}$	$(0.20 \pm 0.54)\%$	-0.834	-0.909	1			[22]
R_D	$(0.351 \pm 0.035)\%$	1	-0.967	0.900			[7]
$(y'_{\rm CPA})_{K\pi}$	$(0.43 \pm 0.43)\%$	-0.967	1	-0.975			[7]
$(x'_{\rm CPA})^2_{K\pi}$	$(0.008 \pm 0.018)\%$	0.900	-0.975	1			[7]
R_D	$(0.3568 \pm 0.0058 \pm 0.0033)\%$	1	-0.894	0.77	-0.895	0.772	[3]
$(y'_+)_{K\pi}$	$(0.48 \pm 0.09 \pm 0.06)\%$	-0.894	1	-0.949	0.765	-0.662	[3]
$(x'_+)^2_{K\pi}$	$(6.4 \pm 4.7 \pm 3)10^{-5}$	0.77	-0.949	1	-0.662	0.574	[3]
$(y'_-)_{K\pi}$	$(0.48 \pm 0.09 \pm 0.06)\%$	-0.895	0.765	-0.662	1	-0.95	[3]
$(x'_-)^2_{K\pi}$	$(4.6 \pm 4.6 \pm 3)10^{-5}$	0.772	-0.662	0.574	-0.95	1	[3]

Table 1. Experimental data used in the analysis, from ref. [23] and online updates at http://www.slac.stanford.edu/xorg/hfag/. $\alpha = (1 + |q/p|)^2/2$. Asymmetric errors have been symmetrized.

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parameter	result @ 68% prob.	95% prob. range
$\lvert M_{12}\rvert$ [ps^{-1}]	$(4.4 \pm 2.0) \cdot 10^{-3}$	$[0.3, 7.7] \cdot 10^{-3}$
$\lvert\Gamma_{12}\rvert$ [ps^{-1}]	$(14.9 \pm 1.6) \cdot 10^{-3}$	$[11.7, 18.5] \cdot 10^{-3}$
$\Phi_{M_{12}}$ [°]	(2.0 ± 2.7)	$[-4, 12]$
$\delta_{K\pi}$ [°]	(8 ± 13)	$[-22, 30]$
$\delta_{K\pi\pi}$ [°]	(-6 ± 23)	$[-50, 43]$
x	$(3.6 \pm 1.6) \cdot 10^{-3}$	$[0.3, 6.7] \cdot 10^{-3}$
y	$(6.1 \pm 0.7) \cdot 10^{-3}$	$[4.8, 7.6] \cdot 10^{-3}$
$\lvert q/p\rvert$	1.016 ± 0.018	$[0.981, 1.058]$
δ	$(-1.6 \pm 1.8) \cdot 10^{-2}$	$[-5.7, 1.9] \cdot 10^{-2}$
ϕ[°]	-0.5 ± 0.6	$[-1.8, 0.6]$
R_D	$(3.50 \pm 0.04) \cdot 10^{-3}$	$[3.43, 3.57] \cdot 10^{-3}$
A_Γ	$(1.4 \pm 1.5) \cdot 10^{-4}$	$[-1.5, 4.4] \cdot 10^{-4}$
R_M	$(2.4 \pm 0.6) \cdot 10^{-5}$	$[1.6, 4.1] \cdot 10^{-5}$
A_M	$(3.2 \pm 3.6) \cdot 10^{-2}$	$[-3.8, 11.3] \cdot 10^{-2}$
$y_{\rm CP}$	$(6.1 \pm 0.7) \cdot 10^{-3}$	$[4.8, 7.6] \cdot 10^{-3}$

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

In the standard CKM phase convention (taking $\mathrm{CP}|D\rangle = |\bar{D}\rangle$), 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,[1] leading to the relation

$$\phi = \arg(y + i\delta x)\,. \tag{3}$$

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}:

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

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 nonvanishing $\Phi_{12} = -\Phi_{M_{12}}$ 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 figures 1 and 2. Some two-dimensional p.d.f.'s are displayed in figure 3.

[1] See ref. [31] for a discussion of the size of $\arg(\Gamma_{12})$.

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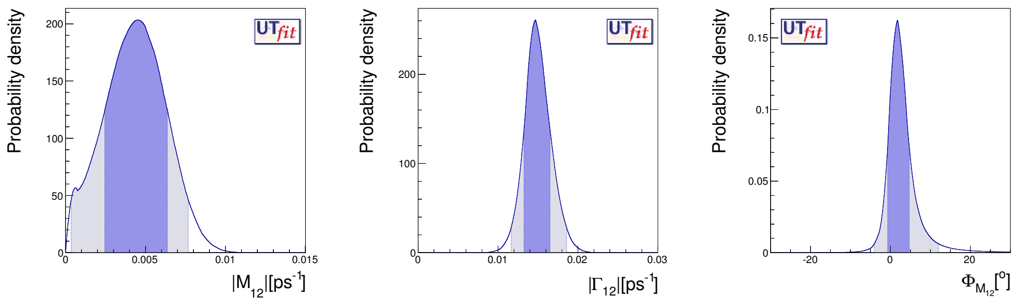

Figure 1. One-dimensional p.d.f. for the parameters $|M_{12}|$, $|\Gamma_{12}|$ and $\Phi_{M_{12}}$.

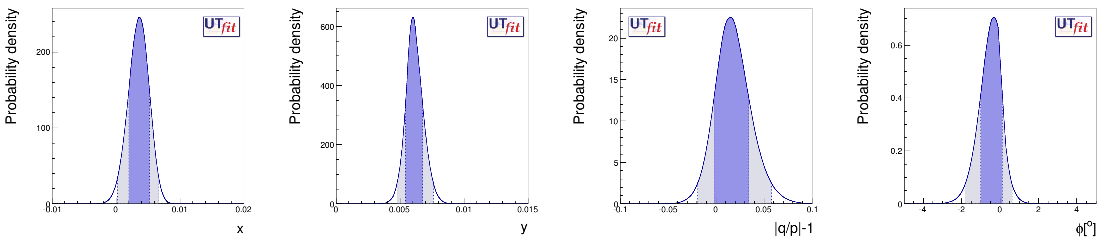

Figure 2. One-dimensional p.d.f. for the parameters x, y, $|q/p| - 1$ and ϕ.

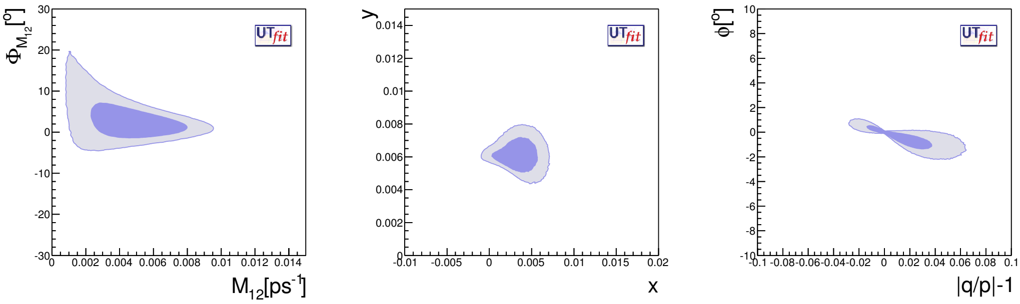

Figure 3. Two-dimensional p.d.f. for Φ_{12} vs $|M_{12}|$ (left), y vs x (middle) and ϕ vs $|q/p| - 1$ (right).

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. (4). However in our fit we used the exact formulae since the region of $x \lesssim 10^{-4}$, 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 labeled "No direct CPV in DCS decays" by HFAG [23] and online updates at http://www.slac.stanford.edu/xorg/hfag/, now that HFAG uses the theoretical relation in eq. (3) as we suggested in our previous paper.

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