UTfit Collaboration: Average of D meson mixing data

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D MIXING

- Dispersive $D \to \bar{D}$ amplitude M_{12}
  - SM: long-distance dominated, at present not calculable-
  - NP: short-distance, calculable, local ops w. lattice
- Absorptive $D \to \bar{D}$ amplitude Γ_{12}
  - SM: long-distance dominated, at present not calculable
  - NP: negligible
- OBSERVABLES: $|M_{12}|$, $|\Gamma_{12}|$ and $\Phi_{12} = \arg(\Gamma_{12}/M_{12})$

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GIM & SU(3) [U-spin symmetry]

in the SM, CKM unitarity gives

$$V_{cd}V_{ud}^{*} + V_{cs}V_{us}^{*} + V_{cb}V_{ub}^{*} = \lambda_d + \lambda_s + \lambda_b = 0$$

$$\lambda_d \approx \lambda_s \approx O(\lambda_{Cabibbo}) \approx 0.22\,; \quad \lambda_b \approx O(\lambda^5_{Cabibbo}) \approx 1.5 \times 10^{-4}$$

we may write $\lambda_d = -\lambda_s - \lambda_b$, take, without loss of generality, λ_s real and define the (suppressed) complex parameter $r = \mathrm{Im}(\lambda_b)/\lambda_s \approx 6.4 \times 10^{-4}$. Then

$$M_{12}, \Gamma_{12} = \lambda_s^2(A_{dd}+A_{ss}-2A_{ds}) + 2\lambda_s\lambda_b(A_{dd}-A_{ds}-A_{db}+A_{sb}) + O(\lambda_b^2)$$

$$CPV \approx 2r\,(A_{dd}-A_{ds}-A_{db}+A_{sb})/(A_{dd}+A_{ss}-2A_{ds}) + O(\lambda_b^2)$$

GIM $(A_{dd}+A_{ss}-2A_{ds}) = (A_{dd}-A_{ds}-A_{db}+A_{sb}) = 0$ in the SU(3) symmetric limit

U-spin breaking effects $\sim \dfrac{(m_s - m_d)}{\Lambda_{QCD}} = \varepsilon$

$$M_{12}, \Gamma_{12} = \lambda_s^2 (A_{dd} + A_{ss} - 2A_{ds}) + 2\,\lambda_s \lambda_b\,(A_{dd} - A_{ds} - A_{db} + A_{sb})$$

$$\sim \lambda_s^2\,\varepsilon^2 + \lambda_s \lambda_b\,\varepsilon$$

CPV effects of the order of $(\mathrm{Im}(\lambda_b)/\lambda_s)\,/\varepsilon \approx 2 \times 10^{-3}$ if $\varepsilon = 30\%$

Real SM approximation: given the present uncertainties assume that in the SM

M_{12}, Γ_{12} are real

Basic Formulae

$$|D_{S,L}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle$$

All the relevant observables can be written in terms of δ , $x = \Delta m/\Gamma$, $y = \Delta\Gamma/(2\Gamma)$ *and* τ_D

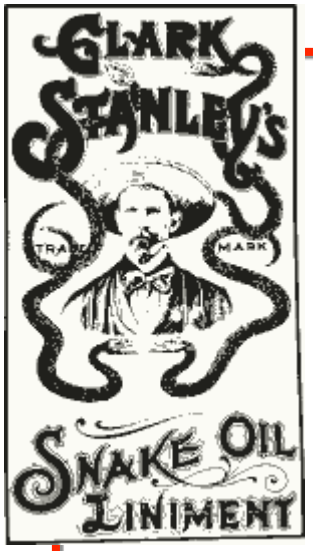
$$\delta = \frac{\left(1 - |q/p|^2\right)}{\left(1 + |q/p|^2\right)}$$

$$|M_{12}| = \frac{1}{\tau_D}\sqrt{\frac{x^2 + \delta^2 y^2}{4(1-\delta^2)}}\,, \quad |\Gamma_{12}| = \frac{1}{\tau_D}\sqrt{\frac{y^2 + \delta^2 x^2}{1-\delta^2}}$$

$$\sin\Phi_{12} = \frac{|\Gamma_{12}|^2 + 4|M_{12}|^2 - (x^2+y^2)|q/p|^2/\tau_D^2}{4|M_{12}\Gamma_{12}|}$$

$\phi = \arg(q/p) = \arg(y+ix) - \arg(\Gamma_{12})$

$|q/p| \neq 1 \longleftrightarrow \phi \neq 0$ is a signal of NP



UTfit

M.Bona *et al.*, UTfit
JHEP0507:028, 2005

www.utfit.org

A. Bevan, M. Bona, M. Ciuchini,
D. Derkach, E. Franco, V. Lubicz,
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9. The UTfit collaboration average of D meson mixing data: Winter 2014

UTfit Collaboration (A.J. Bevan (Queen Mary, U. of London) *et al.*). Feb 7, 2014. 8 pp.
Published in **JHEP 1403 (2014) 123**
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e-Print: **arXiv:1402.1664** **[hep-ph]** | **PDF**

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]

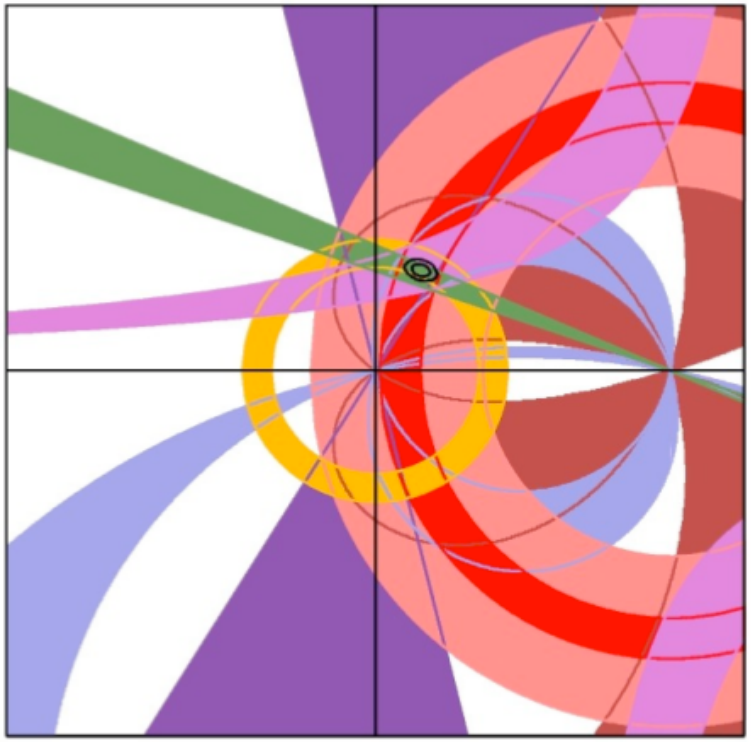
Latest UTfit results

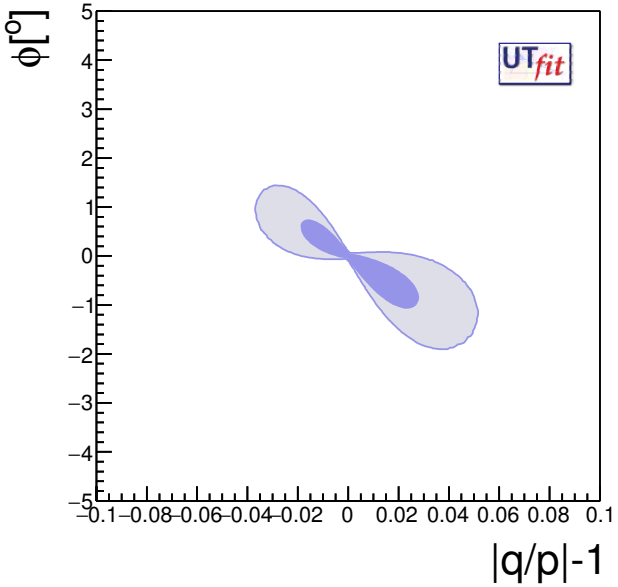
$$x = (3.6 \pm 1.5) \times 10^{-3}$$

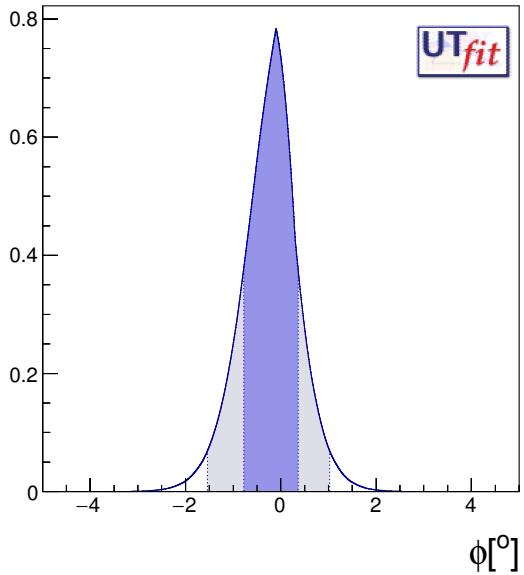
$$y = (5.8 \pm 0.6) \times 10^{-3}$$

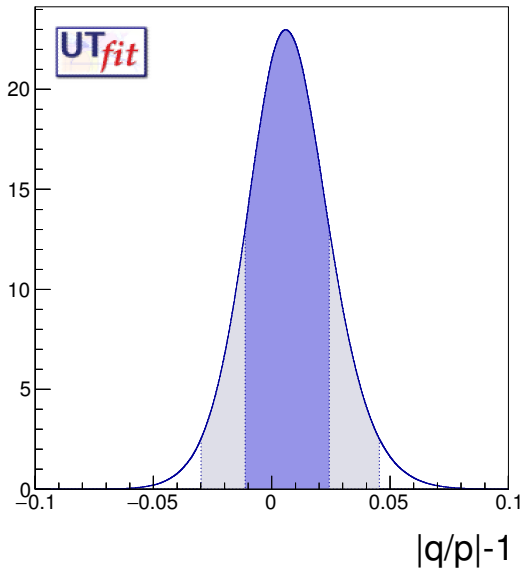
$$|q/p| = (0.6 \pm 1.8) \times 10^{-2}$$

$$\phi = \arg(q/p) = (-0.05^{+0.41}_{-0.72})^{o}$$







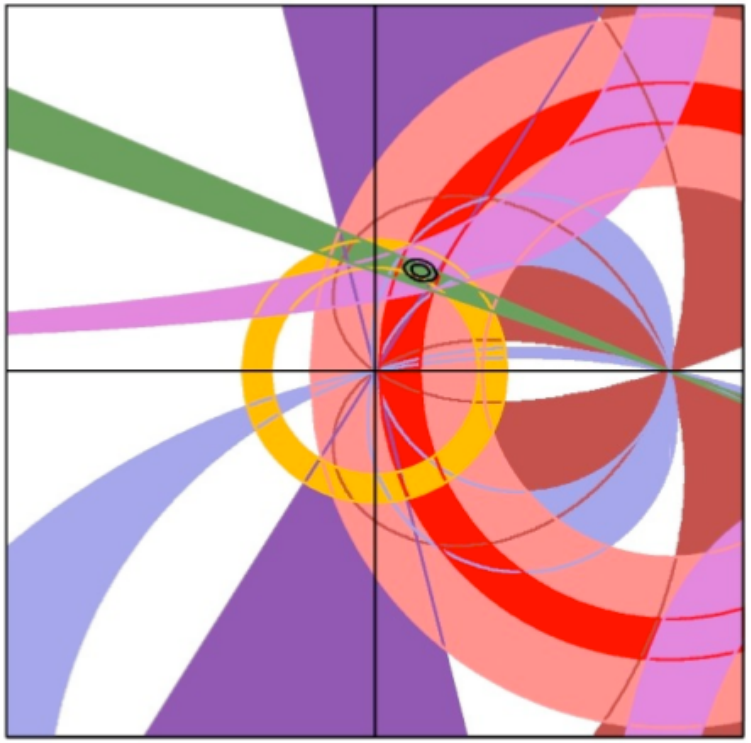


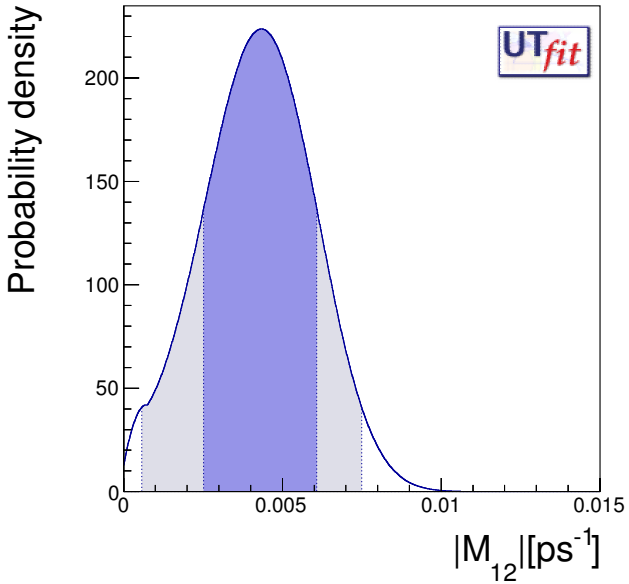
Latest UTfit results

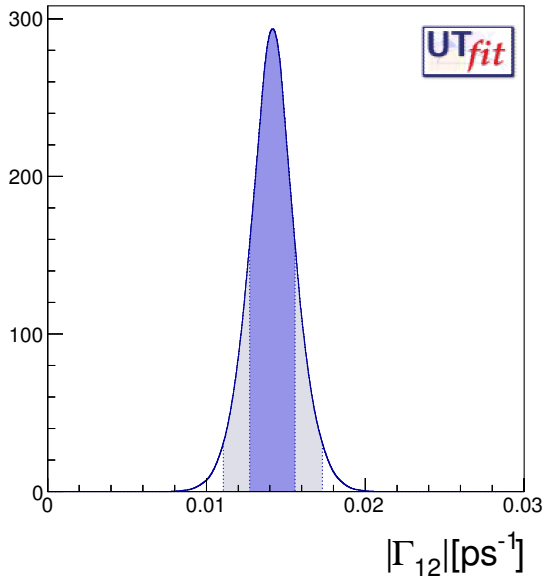
$$|M_{12}| = (4 \pm 2)\,\mathrm{fs}^{-1}$$

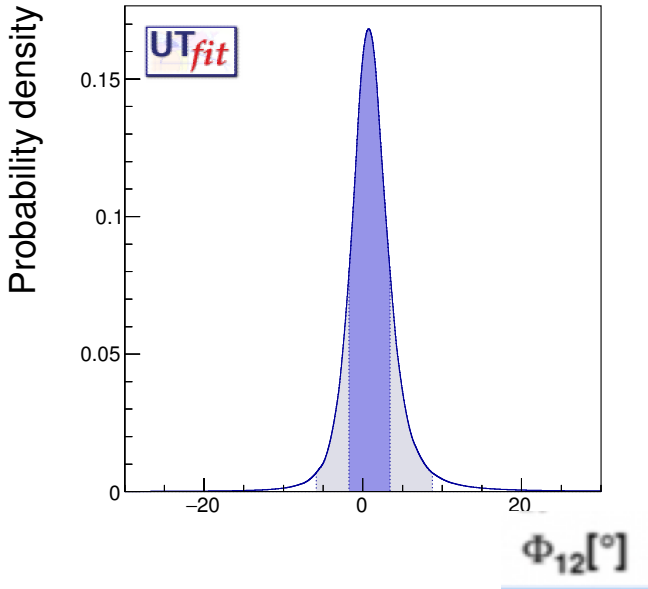
$$|\Gamma_{12}| = (14.2 \pm 1.4)\,\mathrm{fs}^{-1}$$

$$\Phi_{12} = (0.7 \pm 2.5)^{o}$$









TESTING THE NEW PHYSICS SCALE

Effective Theory Analysis ΔF=2

$$C_j(\Lambda) = \frac{LF_j}{\Lambda^2} \Rightarrow \Lambda = \sqrt{\frac{LF_j}{C_j(\Lambda)}}$$

Effective Hamiltonian in the mixing amplitudes

$$H_{eff}^{\Delta B=2} = \sum_{i=1}^{5} C_i(\mu) Q_i(\mu) + \sum_{i=1}^{3} \tilde{C}_i(\mu) \tilde{Q}_i(\mu)$$

$$Q_1 = \bar{q}_L^{\alpha} \gamma_\mu b_L^{\alpha} \; \bar{q}_L^{\beta} \gamma^\mu b_L^{\beta} \quad \text{(SM/MFV)}$$

$$Q_2 = \bar{q}_R^{\alpha} b_L^{\alpha} \; \bar{q}_R^{\beta} b_L^{\beta} \qquad Q_3 = \bar{q}_R^{\alpha} b_L^{\beta} \; \bar{q}_R^{\beta} b_L^{\alpha}$$

$$Q_4 = \bar{q}_R^{\alpha} b_L^{\alpha} \; \bar{q}_L^{\beta} b_R^{\beta} \qquad Q_5 = \bar{q}_R^{\alpha} b_L^{\beta} \; \bar{q}_L^{\beta} b_R^{\alpha}$$

$$\tilde{Q}_1 = \bar{q}_R^{\alpha} \gamma_\mu b_R^{\alpha} \; \bar{q}_R^{\beta} \gamma^\mu b_R^{\beta}$$

$$\tilde{Q}_2 = \bar{q}_L^{\alpha} b_R^{\alpha} \; \bar{q}_L^{\beta} b_R^{\beta} \qquad \tilde{Q}_3 = \bar{q}_L^{\alpha} b_R^{\beta} \; \bar{q}_L^{\beta} b_R^{\alpha}$$

C(Λ) coefficients are extracted from data

L is loop factor and should be :
L=1 tree/strong int. NP
L=α^2_s or α^2_W for strong/weak perturb. NP

$F_1 = F_{SM} = (V_{tq} V_{tb}^*)^2$
$F_{j=1} = 0$ — **MFV**

$|F_j| = F_{SM}$
arbitrary phases — **NMFV**

$|F_j| = 1$
arbitrary phases — **Flavour generic**

LOWER LIMITS ON NP SCALE

Parameter	95% allowed range (GeV^{-2})	Lower limit on Λ (TeV) for arbitrary NP
$\mathrm{Im}C_D^1$	$[-1.3, 2.0] \cdot 10^{-14}$	$7.0 \cdot 10^3$
$\mathrm{Im}C_D^2$	$[-2.5, 1.7] \cdot 10^{-15}$	$19.9 \cdot 10^3$
$\mathrm{Im}C_D^3$	$[-2.4, 3.6] \cdot 10^{-14}$	$5.3 \cdot 10^3$
$\mathrm{Im}C_D^4$	$[-5.1, 7.8] \cdot 10^{-16}$	$35.9 \cdot 10^3$
$\mathrm{Im}C_D^5$	$[-5.3, 8.0] \cdot 10^{-15}$	$11.2 \cdot 10^3$

Is really CPV negligible in the SM ?

- CPV could be dynamically enhanced
- SU(3)-U-spin could be badly broken

Grossman, Kagan, Ligeti, Perez, Petrov and Silvestrini, stay tuned

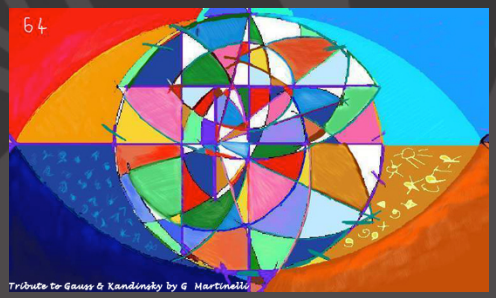
CHARM CPV @ HI LUMINOSITY

- "Extreme" flavour experiment (LHCb upgrade L x 100)

  see e.g. talk by G. Punzi @ 1st Future Hadron Collider Workshop

- Naïve extrapolation, scaling LHCb upgrade estimates:
  - $\delta x=1.5\ 10^{-5}$, $\delta y=10^{-5}$, $\delta|q/p|=10^{-3}$, $\delta\phi=.3°$ (from $K_s\pi\pi$); $\delta y_{CP}=\delta A_\Gamma=4\ 10^{-6}$ (from K^+K^-)
  - $\delta\phi_{M12} = \pm 0.1°$ (1.7 mrad) and $\delta\phi_{\Gamma 12} = \pm 0.2°$ (3.4 mrad) @ 95% prob.
  - $\Lambda>3\ 10^5$ TeV, close to the bound from ε_K

THANKS FOR YOUR ATTENTION



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