New Physics in B–$\overline{B}$ mixing in the light of recent LHCb data

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We perform model-independent statistical analyses of three scenarios accommodating New Physics (NP) in $\Delta F = 2$ flavour-changing neutral current amplitudes. In a scenario in which NP in B_d–$\overline{B}_d$ mixing and B_s–$\overline{B}_s$ mixing is uncorrelated, we find the parameter point representing the Standard-Model disfavoured by 2.7 standard deviations. However, recent LHCb data on B_s neutral-meson mixing forbid a good accommodation of the DØ data on the semileptonic CP asymmetry $A_{\rm SL}$. We introduce a fourth scenario with NP in both $M_{12}^{d,s}$ and $\Gamma_{12}^{d,s}$, which can accommodate all data. We discuss the viability of this possibility and emphasise the importance of separate measurements of the CP asymmetries in semileptonic B_d and B_s decays. All results have been obtained with the CKMfitter analysis package, featuring the frequentist statistical approach and using Rfit to handle theoretical uncertainties.

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Flavour physics looks back to a quarter-century of precision studies at the B-factories with a parallel theoretical effort addressing the Standard Model (SM) predictions for the measured quantities [1]. With the parameters of the Cabibbo-Kobayashi-Maskawa (CKM) matrix [2] overconstrained by many measurements one can predict yet unmeasured quantities [3]. Still, the global fit to the CKM unitarity triangle reveals some discrepancies with the SM, driven by a conflict between $B(B \to \tau\nu)$ and $\sin(2\beta)$ measured from $B_d \to J/\Psi K$ [4, 5]. Furthermore, in May 2010 the DØ experiment reported a deviation of the semileptonic CP asymmetry (dimuon asymmetry) in $B_{d,s}$ decays from its SM prediction [6, 7] by $3.2\,\sigma$ [8]. In June 2011 this discrepancy has increased to $3.9\,\sigma$ [9]. In summer 2010 the data could be interpreted in well-motivated scenarios with New Physics (NP) in $B-\overline{B}$ mixing amplitudes [4]. In this letter we present novel analyses which include the new data of 2011, in particular from the LHCb experiment.

$B_q-\overline{B}_q\,(q = d, s)$ oscillations involve the off-diagonal elements M_{12}^q and Γ_{12}^q of the 2×2 mass and decay matrices, respectively. One can fix the three physical quantities $|M_{12}^q|$, $|\Gamma_{12}^q|$ and $\phi_q = \arg(-M_{12}^q/\Gamma_{12}^q)$ from the mass difference $\Delta M_q \simeq 2|M_{12}^q|$ among the eigenstates, their width difference $\Delta\Gamma_q \simeq 2\,|\Gamma_{12}^q|\cos\phi_q$ and the semileptonic CP asymmetry

$$a_{\rm SL}^q = {\rm Im}\,\frac{\Gamma_{12}^q}{M_{12}^q} = \frac{|\Gamma_{12}^q|}{|M_{12}^q|}\sin\phi_q \;=\; \frac{\Delta\Gamma_q}{\Delta M_q}\tan\phi_q. \quad (1)$$

M_{12}^q is especially sensitive to NP. Therefore the two complex parameters Δ_s and Δ_d, defined as

$$M_{12}^q \equiv M_{12}^{{\rm SM},q}\cdot\Delta_q\,, \qquad \Delta_q \equiv |\Delta_q|e^{i\phi_q^\Delta}, \qquad q = d, s, \quad (2)$$

can differ substantially from the SM value $\Delta_s = \Delta_d = 1$. Importantly, the NP phases $\phi_{d,s}^\Delta$ do not only affect $a_{\rm SL}^{d,s}$, but also shift the CP phases extracted from the mixing-induced CP asymmetries in $B_d \to J/\Psi K$ and $B_s \to J/\Psi\phi$ to $2\beta + \phi_d^\Delta$ and $2\beta_s - \phi_s^\Delta$, respectively. In summer 2010 the CDF and DØ analyses of $B_s \to J/\Psi\phi$ pointed towards a large negative value of ϕ_s^Δ, while simultaneously being consistent with the SM due to large errors. With a large $\phi_s^\Delta < 0$ we could accommodate DØ's large negative value for the semileptonic CP asymmetry reading $A_{\rm SL} = 0.6a_{\rm SL}^d + 0.4a_{\rm SL}^s$ in terms of the individual semileptonic CP asymmetries in the B_d and B_s systems. Moreover, the discrepancy between $B(B \to \tau\nu)$ and the mixing-induced CP asymmetry in $B_d \to J/\Psi K$ determining $2\phi_d^{\psi K} \equiv 2\beta + \phi_d^\Delta$ can be removed with $\phi_d^\Delta < 0$.

The allowed range for ϕ_d^Δ implies a contribution to $A_{\rm SL}$ with the right (i.e. negative) sign. In our 2010 analysis in Ref. [4] we have determined the preferred ranges for Δ_s and Δ_d in a simultaneous fit to the CKM parameters in three generic scenarios in which NP is confined to $\Delta F = 2$ flavour-changing neutral currents. In our Scenario I we have treated Δ_s, Δ_d (and three more parameters related to K–$\overline{K}$ mixing) independently, corresponding to NP with arbitrary flavour structure. Scenario II implements minimal-flavour violation (MFV) with small bottom Yukawa coupling entailing real $\Delta_s = \Delta_d$. Scenario III covers MFV models in which $\Delta_s = \Delta_d$ is allowed to be complex. In Ref. [4] we have found an excellent fit in Sc. I (and a good fit in Sc. 3) with all discrepancies relieved through $\Delta_{d,s} \neq 1$, while the fit has returned K–$\overline{K}$ mixing essentially SM-like.

The recent LHCb measurement of the CP phase $\phi_s^{\psi\phi}$ from $A_{\rm CP}^{\rm mix}(B_s \to J/\Psi\phi)$ does not permit large deviations of ϕ_s^Δ from zero anymore. This trend was also confirmed by the latest CDF results [10]. The current situation with the phase $2\phi_s^{\psi\phi} \equiv 2\beta_s - \phi_s^\Delta$ and $A_{\rm SL}$ is as follows:

$$\begin{aligned} -2\phi_s^{\psi\phi} &= -43.5^\circ{}^{+21.8^\circ}_{-20.6^\circ} \pm 1.2^\circ \quad \text{DØ [11]} \\ -59.6^\circ \leq -2\phi_s^{\psi\phi} &\leq -2.3^\circ \quad \text{CDF [10]} \\ -2\phi_s^{\psi\phi} &= 8.6^\circ \pm 10.3^\circ \pm 3.4^\circ \quad \text{LHCb } J/\psi\phi \text{ [12]} \\ -2\phi_s^{\psi\phi} &= -25.2 \pm 25.2 \pm 1.2 \quad \text{LHCb } J/\psi f_0 \text{ [13]} \\ A_{\rm SL} &= (-7.87 \pm 1.72 \pm 0.93) \cdot 10^{-3} \quad \text{DØ [9]} \end{aligned} \tag{3}$$

Here $2\beta_s = 2\arg(-V_{ts}V_{tb}^*/(V_{cs}V_{cb}^*)) \simeq 2.2^\circ$.

From this discussion, there is a conflict between LHCb data on $B_s \to J/\psi\phi$ and the DØ measurement of $A_{\rm SL}$ which we cannot fully resolve in our Scenarios I, II and III. We therefore discuss a fourth scenario which also permits NP in the decay matrices Γ_{12}^s or Γ_{12}^d.

RESULTS FOR SCENARIOS I, II AND III

In Tab. I we summarise the changes in the inputs compared to Tabs. 1–7 of Ref. [4]. Following Ref. [3] we have included $K_{\ell 3}$, $K_{\ell 2}$, $\pi_{\ell 2}$ (and the related τ decays) for $|V_{ud}|$ and $|V_{us}|$. Concerning the measurements of (ϕ_s, Γ_s) from $B_s \to J/\psi\phi$, we have combined the CDF and LHCb results by taking the product of their 2D profile-likelihoods [10, 12]. Unfortunately, we could not obtain the corresponding likelihood from DØ. The impact of this omission is mild due to the smaller uncertainties of the CDF and LHCb results. We have neither used the LHCb result on $B_s \to J/\psi f_0$ as only ϕ_s (not the 2D likelihood) was provided in Ref. [13]. But we have included the flavour-specific B_s lifetime $\tau_{B_s}^{FS}$ [14] providing an independent constraint on $\Delta\Gamma_s$. We analyse the DØ measurement of $A_{\rm SL}$ with the production fractions at 1.8-2 TeV according to Ref. [14]: $f_s = 0.111 \pm 0.014$ and $f_d = 0.339 \pm 0.031$, corresponding to $A_{\rm SL} = (0.532 \pm 0.039) a_{\rm SL}^d + (0.468 \pm 0.039) a_{\rm SL}^s$.

Observable	Value and uncertainties	Ref.
$\mathcal{B}(K \to e\nu_e)$	$(1.584 \pm 0.020) \times 10^{-5}$	[15]
$\mathcal{B}(K \to \mu\nu_\mu)$	0.6347 ± 0.0018	[16]
$\mathcal{B}(\tau \to K\nu_\tau)$	0.00696 ± 0.00023	[16]
$\mathcal{B}(K \to \mu\nu_\mu)/\mathcal{B}(K \to \pi\nu_\mu)$	1.3344 ± 0.0041	[16]
$\mathcal{B}(\tau \to K\nu_\tau)/\mathcal{B}(\tau \to \pi\nu_\tau)$	$(6.53 \pm 0.11) \cdot 10^{-2}$	[17]
γ	$68\,^{+10}_{-11}{}^\circ$	[18]
Δm_d	$0.507 \pm 0.004 \text{ps}^{-1}$	[15]
Δm_s	$17.731 \pm 0.045 \text{ps}^{-1}$	[22, 23]
$A_{\rm SL}$	$(-74 \pm 19) \times 10^{-4}$	[9]
$\phi_s^{\psi\phi}$ vs. $\Delta\Gamma_s$	see text	[10, 12]

Theoretical Parameter	Value and uncertainties	Ref.
$\widehat{\mathcal{B}}_{B_s}$	$1.291 \pm 0.025 \pm 0.035$	[18]
f_{B_s}/f_{B_d}	$1.235 \pm 0.008 \pm 0.033$	[18]
$\mathcal{B}_{B_s}/\mathcal{B}_{B_d}$	$1.024 \pm 0.013 \pm 0.015$	[18]
$\hat{\mathcal{B}}_K$	$(0.732 \pm 0.004 \pm 0.036)$	[18]
f_K	$156.3 \pm 0.3 \pm 1.9 \text{MeV}$	[18]
f_K/f_π	$1.1985 \pm 0.0013 \pm 0.0095$	[18]
$\alpha_s(M_Z)$	$0.1184 \pm 0 \pm 0.0007$	[15]

TABLE I. Experimental and theoretical inputs inputs added or modified compared to Ref. [4] and used in our fits.

We summarise our results in Tabs. II and III and in Fig. 1 (Sc. I) as well as Fig. 2 (Sc. III). Even in Sc. I our fit to the data is significantly worse than in 2010 [4]: While $\phi_d^\Delta < 0$ alleviates the discrepancy of $A_{\rm SL}$ with the SM, the LHCb result on $\phi_s^{\psi\phi}$ prevents larger contributions from the B_s system to $A_{\rm SL}$. In Sc. I, we find pull values for $A_{\rm SL}$ and $\phi_s^\Delta - 2\beta_s$ of $2.9\,\sigma$ and $2.7\,\sigma$ respectively (compared to $1.2\,\sigma$ and $0.5\,\sigma$ in Ref. [4]). We do not quote pull values for $\Delta m_{d,s}$ in Sc. I, as these observables are not constrained once their experimental measurement is removed. As before, two distinct solutions exist for Δ_s with a slight preference for $\mathrm{Re}\,\Delta_s < 0$, owing to $\sin(\phi_s^\Delta) < 0$ preferred by $A_{\rm SL}$ and $\sin(\phi_s^\Delta - 2\beta_s) \geq 0$ favoured by $A_{\rm CP}^{\rm mix}(B_s \to J/\Psi\phi)$. (We have not included the recent LHCb determination of $\Delta\Gamma_s > 0$ [24] entailing $\mathrm{Re}\,\Delta_s > 0$). Tab. IV lists the p-values for various SM hypotheses within our NP Scenarios (more information can be found in Ref. [18]).

NEW PHYSICS IN Γ_{12}^s OR Γ_{12}^d

Several authors have discussed the possibility of a sizable new CP-violating contribution to Γ_{12}^s to explain the DØ measurement of A_{SL} [19] by postulating new B_s decay channels with large branching fraction. In such models also the width difference $\Delta\Gamma_s$ typically deviates from

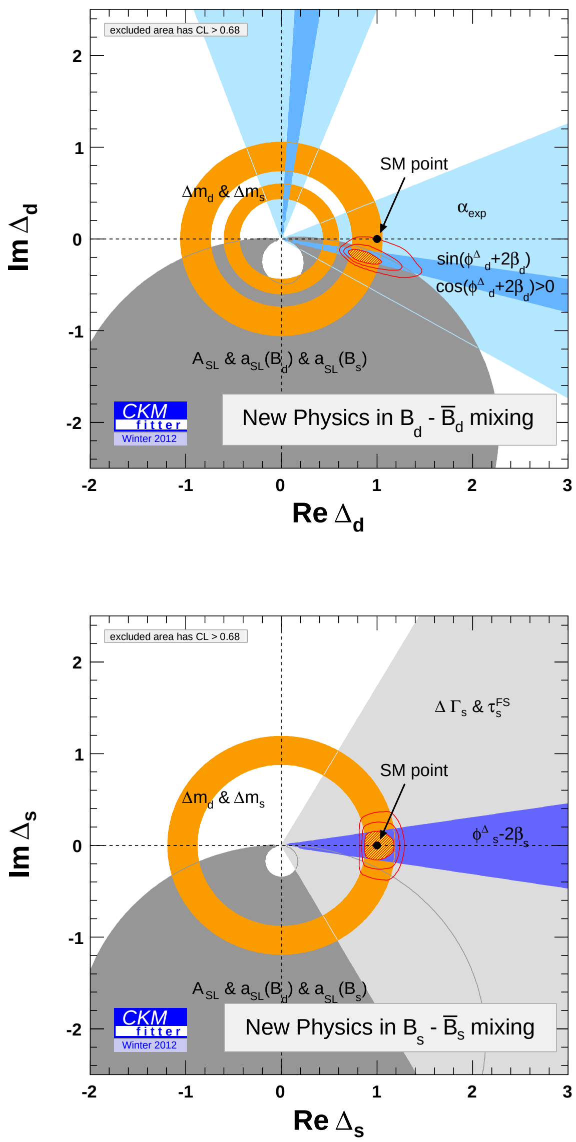

FIG. 1. Complex parameters Δ_d (up) and Δ_s (down) in Scenario I. Here $\alpha_{\rm exp} \equiv \alpha - \phi_d^\Delta/2$. The coloured areas represent regions with CL < 68.3 % for the individual constraints. The red area shows the region with CL < 68.3 % for the combined fit, with the two additional contours delimiting the regions with CL < 95.45 % and CL < 99.73 %. The p-value for the 2D SM hypothesis $\Delta_d = 1$ ($\Delta_s = 1$) is 3.2 σ (0.8 σ).

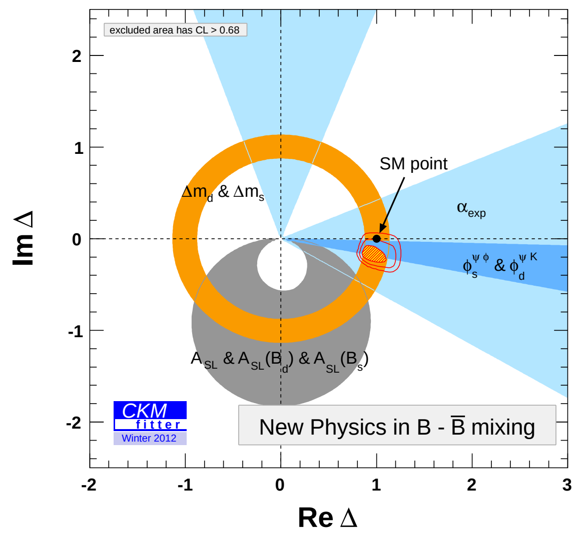

FIG. 2. Constraint on the complex parameter $\Delta \equiv \Delta_d = \Delta_s$ from the fit in Scenario III with same conventions as in fig. 1. The p-value for the 2D SM hypothesis $\Delta = 1$ is 2.7 σ.

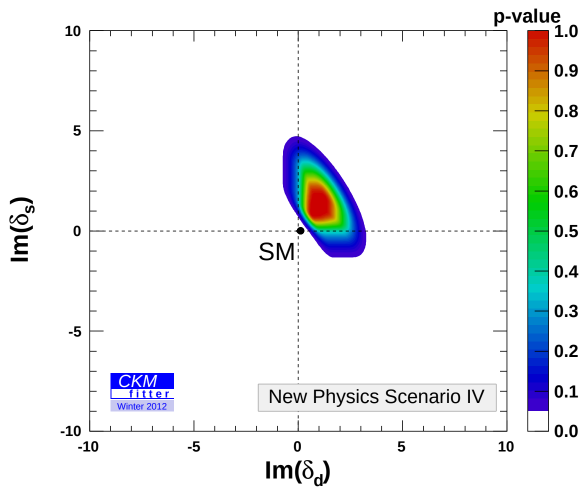

FIG. 3. Constraints on $\mathrm{Im}\,\delta_d, \mathrm{Im}\,\delta_s$ in Scenario IV. The 1D 68%CL intervals are $\mathrm{Im}\,\delta_d = 0.92^{+1.11}_{-0.69}$, $\mathrm{Im}\,\delta_s = 1.2^{+1.6}_{-1.0}$. The p-value for the 2D SM hypothesis $\mathrm{Im}\,\delta_d = 0.097, \mathrm{Im}\,\delta_s = -0.0059$ is 3.2 σ.

the SM prediction in Ref. [7, 20, 21]. Γ_{12}^s is dominated by the CKM-favoured tree-level decay $b \to c\bar{c}s$. Any competitive new decay mode will lower the total B_s width, which LHCb finds as $\Gamma_s = 0.657 \pm 0.009 \pm 0.008$ [12], implying $\Gamma_s/\Gamma_d = 0.998 \pm 0.014 \pm 0.012$ in excellent agreement with the SM expectation $0 \leq \Gamma_s/\Gamma_d - 1 \leq 4 \cdot 10^{-4}$ [21]. The new interaction will open new $b \to s$ decay modes affecting precisely measured inclusive B_d and B^+ quantities [4]. Furthermore, decays mediated by a new particle with mass $M > M_W$ will add a term of order M_W^4/M^4 to $\Gamma_{12}^s/\Gamma_{12}^{\mathrm{SM},s}$, while Δ_s normally receives a larger contribution of order M_W^2/M^2. In models involving a fermion pair $(f, \overline{f})$ in the final state, e.g. those with an enhanced $B_s \to \tau\overline{\tau}$ decay [19], one can solve this problem through chirality suppression. The extra contribution to M_{12}^s is down by another factor of m_f^2/M^2, while that to Γ_{12}^s is affected by the milder factor of m_f^2/m_b^2. Quantities like $\Gamma_{d,s}$ will not be chirality suppressed.

Quantity		1σ	3σ
$\mathrm{Re}(\Delta_d)$		$0.757^{+0.132}_{-0.083}$	$0.76^{+0.61}_{-0.18}$
$\mathrm{Im}(\Delta_d)$		$-0.181^{+0.053}_{-0.045}$	$-0.18^{+0.17}_{-0.20}$
$\lvert\Delta_d\rvert$		$0.778^{+0.136}_{-0.090}$	$0.78^{+0.63}_{-0.19}$
$\mathrm{Re}(\Delta_s)$		$-0.895^{+0.082}_{-0.120}$	$-0.89^{+0.21}_{-0.45}$
	or	$0.895^{+0.020}_{-0.018}$	$0.89^{+0.43}_{-0.19}$
$\mathrm{Im}(\Delta_s)$		$-0.04^{+0.17}_{-0.17}$	$-0.04^{+0.57}_{-0.54}$
$\lvert\Delta_s\rvert$		$0.895^{+0.120}_{-0.079}$	$0.89^{+0.45}_{-0.14}$
$\phi_d^\Delta + 2\beta$ [deg] (!)		$17.^{+13.}_{-11.}$	$17.^{+40.}_{-51.}$
$\phi_s^\Delta - 2\beta_s$ [deg] (!)		$-123.9^{+9.0}_{-13.6}$	$-124.^{+26.}_{-70.8}$
	or	$-61.8^{+13.4}_{-8.9}$	$-62.^{+70.}_{-26.}$
A_{SL} $[10^{-4}]$ (!)		$-15.5^{+14.3}_{-5.9}$	$-15.^{+33.}_{-20.}$
A_{SL} $[10^{-4}]$		$-20.6^{+5.7}_{-6.5}$	$-21.^{+22.}_{-24.}$
$a^s_{\mathrm{SL}} - a^d_{\mathrm{SL}}$ $[10^{-4}]$		$33.^{+12.}_{-13.}$	$33.^{+44.}_{-55.}$
a^d_{SL} $[10^{-4}]$ (!)		$-35.8^{+6.9}_{-4.6}$	$-36.^{+27.}_{-14.}$
a^s_{SL} $[10^{-4}]$ (!)		$-3.^{+11.}_{-13.}$	$-3.^{+41.}_{-50.}$
$\Delta\Gamma_d[\mathrm{ps}^{-1}]$		$0.00505^{+0.00084}_{-0.00129}$	$0.0051^{+0.0023}_{-0.0033}$
$\Delta\Gamma_s[\mathrm{ps}^{-1}]$ (!)		$-0.169^{+0.080}_{-0.023}$	$-0.169^{+0.113}_{-0.041}$
			or $0.168^{+0.041}_{-0.112}$
$\Delta\Gamma_s[\mathrm{ps}^{-1}]$		$-0.104^{+0.020}_{-0.025}$	$-0.104^{+0.046}_{-0.075}$
	or	$0.1030^{+0.0058}_{-0.0043}$	$0.103^{+0.071}_{-0.044}$
$B \to \tau\nu$ $[10^{-4}]$ (!)		$1.471^{+0.075}_{-0.261}$	$1.47^{+0.23}_{-0.90}$
$B \to \tau\nu$ $[10^{-4}]$		$1.482^{+0.073}_{-0.120}$	$1.48^{+0.23}_{-0.59}$

TABLE II. CL intervals for the results of the fits in Scenario I. The notation (!) means that the fit output represents the indirect constraint with the corresponding direct input removed.

Phenomenologically it is much easier to postulate NP in Γ^d_{12} rather than Γ^s_{12}, because Γ^d_{12} is constituted by Cabibbo-suppressed decay modes like $b \to c\bar{c}d$. Also here chirality suppression is welcome to avoid problems with M^d_{12}, but inclusive decay observables like the semileptonic branching fraction or the unmeasured $\Delta\Gamma_d$ pose no danger. Clearly, testing this hypothesis calls for a better measurement of a^d_{SL}. We have studied a Scenario IV including the possibility of NP in $\Gamma^{d,s}_{12}$. We stress that Sc. IV permits NP in the $|\Delta F| = 1$ transitions contributing to Γ^q_{12}, but not in other $|\Delta F| = 1$ quantities entering our fits, such as $\mathcal{B}(B \to \tau\nu)$. Further no new CP phase in $b \to c\bar{c}s$, which would change $\phi^\Delta_{d,s}$, is considered. Such a phase might further increase the hadronic uncertainty from penguin pollution, which is not an issue in the SM at the current levels of experimental precision.

Handy new parameters are

$$\delta_q = \frac{\Gamma^q_{12}/M^q_{12}}{\mathrm{Re}\,(\Gamma^{\mathrm{SM},q}_{12}/M^{\mathrm{SM},q}_{12})}, \qquad q = d, s, \tag{4}$$

$\mathrm{Re}\,\delta_q$, $\mathrm{Im}\,\delta_q$ amount to $(\Delta\Gamma_q/\Delta M_q)/(\Delta\Gamma^{\mathrm{SM}}_q/\Delta M^{\mathrm{SM}}_q)$ and $-a^q_{\mathrm{SL}}/(\Delta\Gamma^{\mathrm{SM}}_q/\Delta M^{\mathrm{SM}}_q)$, respectively. The best fit values of the SM predictions are $\delta^{\mathrm{SM}}_s = 1 - 0.0059\,i$ and $\delta^{\mathrm{SM}}_d = 1. + 0.097\,i$. $\mathrm{Re}\,\delta_d$ is experimentally only weakly constrained. We illustrate the correlation between $\mathrm{Im}\,\delta_d$ and $\mathrm{Im}\,\delta_s$ in Fig. 3, relegating correlations of $\mathrm{Re}\,\delta_s$ with $\mathrm{Im}\,\delta_{d,s}$ to Ref. [18]). The p-value of the SM hypothesis $\Delta_d = \Delta_s = 1$, $\delta_{d,s} = \delta^{\mathrm{SM}}_{d,s}$ is 2.8 σ.

We stress that too large values for $|\delta_s - \delta^{\mathrm{SM}}_s|$ are in conflict with other observables as explained in the previous paragraph. We have also studied Scenario IV without NP in the B_s sector ($\Delta_s = 1$ and $\delta_s = \delta_{s,\mathrm{SM}}$). It could accommodate the main anomalies by improving the fit by 3.5σ, but with large contributions to Γ^d_{12}: $\mathrm{Im}\,\delta_d = 1.48^{+0.92}_{-0.65}$.

Quantity	Deviation wrt SM	Sc. I	Sc. II	Sc. III
$\phi_d^\Delta + 2\beta$	2.7 σ	2.0 σ	2.6 σ	0.1 σ
$\phi_s^\Delta - 2\beta_s$	1.0 σ	2.7 σ	1.0 σ	2.2 σ
$\lvert\epsilon_K\rvert$	0.0 σ	-	0.5 σ	-
Δm_d	1.0 σ	-	1.0 σ	0.8 σ
Δm_s	0.0 σ	-	0.4 σ	1.2 σ
A_{SL}	3.7 σ	2.9 σ	3.7 σ	2.8 σ
a^d_{SL}	0.9 σ	0.2 σ	0.8 σ	0.4 σ
a^s_{SL}	0.2 σ	0.2 σ	0.2 σ	0.1 σ
$\Delta\Gamma_s$	0.0 σ	0.7 σ	0.1 σ	1.1 σ
$\mathcal{B}(B \to \tau\nu)$	2.8 σ	0.7 σ	2.6 σ	1.1 σ
$\mathcal{B}(B \to \tau\nu)$, A_{SL}	4.6 σ	2.6 σ	4.1 σ	3.0 σ
$\phi_s^\Delta - 2\beta_s$, A_{SL}	3.4 σ	2.5 σ	3.4 σ	3.1 σ
$\mathcal{B}(B \to \tau\nu)$, $\phi_s^\Delta - 2\beta_s$, A_{SL}	4.1 σ	2.2 σ	4.1 σ	2.9 σ

TABLE III. Pull values for selected parameters and observables in SM and Scenarios I, II, III, in terms of the number of equivalent standard deviations between the direct measurement and the full indirect fit predictions.

Hypothesis	Sc. I	Sc. II	Sc. III
$\mathrm{Im}\Delta_d = 0$	3.2σ		2.9σ
$\mathrm{Im}\Delta_s = 0$	0.2σ		
$\Delta_d = 1$	3.2σ	1.3σ	2.7σ
$\Delta_s = 1$	0.8σ		
$\mathrm{Im}\Delta_d = \mathrm{Im}\Delta_s = 0$	2.8σ		
$\Delta_d = \Delta_s = 1$	2.7σ		

TABLE IV. p-values for various Standard Model hypotheses in the framework of three NP Scenarios considered. These numbers are computed from the χ^2 difference with and without the hypothesis constraint, interpreted with the appropriate number of degrees of freedom.

CONCLUSIONS

We have performed new global fits to flavour physics data in scenarios with generic NP in the $B_d - \overline{B}_d$ and $B_s - \overline{B}_s$ mixing amplitudes, as defined in Ref. [4]. Our results represent the status of the end of the year 2011. Unlike in summer 2010 the two complex NP parameters Δ_d and Δ_s (parametrising NP in $M_{12}^{d,s}$) are not sufficient to absorb all discrepancies with the SM, namely the DØ measurement of $A_{\rm SL}$ and the inconsistency between $B(B \to \tau\nu)$ and $A_{\rm CP}^{\rm mix}(B_d \to J/\Psi K)$. Still in Scenario I, which fits Δ_d and Δ_s independently, we find the SM point $\Delta_d = \Delta_s = 1$ disfavoured by $2.7\,\sigma$; this value was $3.6\,\sigma$ in our 2010 analysis [4] We notice that data still allow sizeable NP contributions in both B_d and B_s sectors up to 30-40% at the 3 σ level. The preference of Sc. I over the SM mainly stems from the fact that $B(B \to \tau\nu)$ favours $\phi_d^\Delta < 0$ which alleviates the problem with $A_{\rm SL}$.

In order to fully reconcile A_{SL} with $\phi_s^{\psi\phi}$ we have extended our study to a Scenario IV, which permits NP in both $M_{12}^{d,s}$ and $\Gamma_{12}^{d,s}$. While this scenario can accommodate all data, it is difficult to find realistic models in which the preferred NP contributions to Γ_{12}^s (composed of Cabibbo-favoured tree-level decays) comply with other measurements. There are fewer phenomenological constraints on the Cabibbo-suppressed quantity Γ_{12}^d; a possible conflict with M_{12}^d can be circumvented with chirality suppression. NP in M_{12}^d and Γ_{12}^d with the B_s system essentially SM-like appears thus as an interesting possibility, requiring only a mild statistical upward fluctuation in the DØ data on $A_{\rm SL}$. Clearly, independent measurements of $a_{\rm SL}^d$, $a_{\rm SL}^s$ and/or $a_{\rm SL}^s - a_{\rm SL}^d$ are necessary to determine whether scenarios with NP in Γ_{12}^d and/or Γ_{12}^s are a viable explanation of discrepancies in $\Delta F = 2$ observables with respect to the Standard Model.

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[1] A. J. Buras, *Climbing NLO and NNLO Summits of Weak Decays*, arXiv:1102.5650 [hep-ph] and references therein.
[2] N. Cabibbo, Phys. Rev. Lett. **10** (1963) 531-533. M. Kobayashi, T. Maskawa, Prog. Theor. Phys. **49** (1973) 652-657.
[3] J. Charles *et al.*, Phys. Rev. D **84** (2011) 033005 [arXiv:1106.4041 [hep-ph]].
[4] A. Lenz *et al.*, Phys. Rev. D **83** (2011) 036004 [arXiv:1008.1593 [hep-ph]].
[5] E. Lunghi and A. Soni, Phys. Lett. B **697** (2011) 323 [arXiv:1010.6069 [hep-ph]].
M. Bona *et al.* [UTfit Collaboration], Phys. Lett. B **687** (2010) 61 [arXiv:0908.3470 [hep-ph]].
[6] M. Beneke, G. Buchalla, A. Lenz and U. Nierste, Phys. Lett. B 576 (2003) 173, arXiv:hep-ph/0307344.
[7] A. Lenz and U. Nierste, JHEP 0706 (2007) 072, arXiv:hep-ph/0612167.
[8] V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. D **82** (2010) 032001 [arXiv:1005.2757 [hep-ex]] and Phys. Rev. Lett. **105** (2010) 081801 [arXiv:1007.0395 [hep-ex]].
[9] V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. D **84** (2011) 052007 [arXiv:1106.6308 [hep-ex]].
[10] T. Aaltonen *et al.* [CDF Collaboration], arXiv:1112.1726 [hep-ex].
[11] V. M. Abazov *et al.* ([DØ collaboration]), DØ Conference note 6098.
[12] R. Aaij *et al.* [LHCb Collaboration], arXiv:1112.3183 [hep-ex].
[13] R. Aaij *et al.* [The LHCb Collaboration], arXiv:1112.3056 [hep-ex].
[14] E. Barberio *et al.* [Heavy Flavour Averaging Group], arXiv:1010.1589 [hep-ex] and update on the HFAG web site: `http://www.slac.stanford.edu/xorg/hfag/`.
[15] K. Nakamura *et al.* [Particle Data Group], J. Phys. G **37** (2010) 075021, and 2011 partial update for the 2012 edition.
[16] M. Antonelli, V. Cirigliano, G. Isidori, F. Mescia, M. Moulson, H. Neufeld, E. Passemar and M. Palutan *et al.*, Eur. Phys. J. C **69** (2010) 399 [arXiv:1005.2323 [hep-ph]].
[17] S. Banerjee [BaBar Collaboration], arXiv:0811.1429 [hep-ex].
[18] Updates and numerical results of: The CKMfitter Group (J. Charles *et al.*), Eur. Phys. J. C **41**, 1 (2005), arxiv:hep-ph/0406184, available on the CKMfitter group web site: `http://ckmfitter.in2p3.fr/`
[19] A. Dighe, A. Kundu and S. Nandi, Phys. Rev. D **82** (2010) 031502 [arXiv:1005.4051 [hep-ph]]. C. W. Bauer and N. D. Dunn, Phys. Lett. B **696** (2011) 362 [arXiv:1006.1629 [hep-ph]]. S. Oh and J. Tandean, Phys. Lett. B **697** (2011) 41 [arXiv:1008.2153 [hep-ph]]. C. Bobeth and U. Haisch, arXiv:1109.1826 [hep-ph].
[20] M. Beneke, G. Buchalla and I. Dunietz, Phys. Rev. D54 (1996) 4419, arXiv:hep-ph/9605259; M. Beneke, G. Buchalla, C. Greub, A. Lenz and U. Nierste, Phys. Lett.B 459 (1999) 631, arXiv:hep-ph/9808385; M. Ciuchini, E. Franco, V. Lubicz, F. Mescia and C. Tarantino, JHEP 0308 (2003) 031, arXiv:hep-ph/0308029.
[21] A. Lenz and U. Nierste, arXiv:1102.4274 [hep-ph].
[22] R. Aaij *et al.* [LHCb Collaboration], arXiv:1112.4311 [hep-ex].
[23] A. Abulencia *et al.* [CDF Collaboration], Phys. Rev. Lett. **97** (2006) 242003 [hep-ex/0609040].
[24] R. Aaij, *et al.* [LHCb Collaboration], arXiv:1202.4717 [hep-ex].