

Large time-dependent CP violation in the B_s^0 system and finite D^0 - \bar{D}^0 mass difference in a four generation standard model

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Combining the measured B_s mixing with $b \rightarrow s\ell^+\ell^-$ rate data, we find a sizable 4 generation t' quark effect is allowed, for example, with $m_{t'} \sim 300$ GeV and $V_{t's}^* V_{t'b} \sim 0.025e^{\pm i70^\circ}$, which could underlie the new physics indications in CP violation studies of $b \rightarrow s\bar{q}q$ transitions. With positive phase, large and negative mixing-dependent CP violation in B_s system is predicted, $\sin 2\Phi_{B_s} \sim -0.5$ to -0.7 . This also can be probed via width difference methods. As a corollary, the short distance generated D^0 - \bar{D}^0 mass difference is found to be consistent with, if not slightly higher than, recent B factory measurements, while CP violation is subdued with $\sin 2\Phi_D \sim -0.2$.

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Two decades after discovering large B_d^0 - \bar{B}_d^0 mixing [1], the long-standing bound of 14.4 ps^{-1} [2] on B_s^0 - \bar{B}_s^0 mixing finally turned into a precise measurement [3],

$$\Delta m_{B_s} = 17.77 \pm 0.10 \pm 0.07 \text{ ps}^{-1}, \quad (1)$$

and the focus is now on the associated CP violation (CPV). The measured [2] large CPV phase $\sin 2\Phi_{B_d} \sim 0.7$ in B_d mixing (also called $\sin 2\phi_1$ or $\sin 2\beta$) is consistent with the standard model (SM). However, $\sin 2\Phi_{B_s}^{\text{SM}} \simeq -0.04$ is small and offers a window on new physics (NP). The Tevatron can probe mixing-dependent CPV in B_s decay only if $\sin 2\Phi_{B_s}$ is large. Another method using the width difference has recently yielded [4]

$$\Delta \Gamma_{B_s} = 0.13 \pm 0.09 \text{ ps}^{-1}, \quad \phi_s = -0.70_{-0.39}^{+0.47}, \quad (2)$$

where $\phi_s \equiv 2\Phi_{B_s} \sim -40^\circ$ is sizable, but only 1.2σ [4] away from zero. But it is worth emphasizing that *any evidence for $\sin 2\Phi_{B_s} \neq 0$ before the turning on of LHC (Large Hadron Collider) would herald new physics.*

The situation in D^0 - \bar{D}^0 mixing is both similar and different. There is now an indication for $\Delta m_D \neq 0$ [5],

$$x_D \equiv \Delta m_D / \Gamma_D = 0.80 \pm 0.29 \pm 0.17\%, \quad (3)$$

which is 2.4σ from zero, while indications for effective width differences have been further strengthened,

$$y_{CP} = 1.31 \pm 0.32 \pm 0.25\%, \quad (4)$$

$$y'_D = 0.97 \pm 0.44 \pm 0.31\% \quad (5)$$

at 3.2σ [6] and 3.9σ [7] from zero, respectively. With no evidence for CPV, $y_{CP} \cong y_D \equiv \Delta \Gamma_D / 2\Gamma_D$ is expected, while $y'_D = y_D \cos \delta - x_D \sin \delta$ mixes y_D and x_D by a strong phase δ in $D \rightarrow K\pi$ decay. The SM predicts the *short-distance* Δm_D^{SD} and associated CPV $\sin 2\Phi_D$ to be negligible, but long-distance effects could generate $y_D \sim$

%, which in principle could generate the observed x_D . But a finite x_D^{SD} or $\sin 2\Phi_D$ would indicate NP.

Can $\sin 2\Phi_{B_s}$ be large? If so, can it be linked to finite Δm_D^{SD} ? Can $\sin 2\Phi_D$ be finite? Although Eqs. (1)–(5) are not inconsistent with the SM, the window for NP is tantalizing. In this paper we show that, by combining Δm_{B_s} with $b \rightarrow s\ell^+\ell^-$ rate and enlarging to 4 sequential generations (SM4), a sizable CPV phase in $V_{t's}^* V_{t'b}$ is typically inferred, leading to sizable $\sin 2\Phi_{B_s} < 0$. This new CPV phase is preferred by NP hints in CPV in charmless $b \rightarrow s\bar{q}q$ transitions. SM-like CPV in $b \rightarrow d$ transitions follow from imposing $Z \rightarrow b\bar{b}$ and kaon constraints. Besides $\sin 2\Phi_{B_s} < 0$ and rather enhanced $K_L \rightarrow \pi^0 \nu \bar{\nu}$, we find Δm_D^{SD} at the level of Eq. (3) or higher, but $\sin 2\Phi_D$ is subdued. The unifying thread behind all these phenomena is the nondecoupling of t and t' (and b') quarks, where t' brings in two new CPV phases.

The 4th generation is in fact disfavored by electroweak precision tests, although loopholes do exist [2]. However, direct search for b' and t' quarks has never ceased to be pursued at the energy frontier [2], which would open up greatly in the era of the LHC. One should therefore keep an open mind when searching for NP in the flavor and CPV frontier. After all, with the richness of phenomena already from the 3×3 quark mixing matrix V , enlarging it to 4×4 implies considerable enrichment. What we stress is that the 4th generation very naturally impacts on box and electroweak penguin (EWP) diagrams that enter Δm_{B_s} and $\mathcal{B}(b \rightarrow s\ell^+\ell^-)$, by the nondecoupling of t and t' quark effects [8]. Destructive interference can allow a sizable t' contribution in association with a large CPV phase in $V_{t's}^* V_{t'b}$ [9].

B_s mixing and $b \rightarrow s\ell^+\ell^-$ all involve $b \leftrightarrow s$ transitions, where currently there are two hints for NP involving CPV. Mixing-dependent CPV measured in many $b \rightarrow s\bar{q}q$ modes gives [10] the trend $\mathcal{S}_{s\bar{q}q} < \mathcal{S}_{c\bar{c}s}$ (the $\Delta \mathcal{S}$ problem). A second hint is the observed [10] difference in direct CPV

in $B^0 \rightarrow K^+ \pi^-$ vs $B^+ \rightarrow K^+ \pi^0$ (the $\Delta \mathcal{A}_{K\pi}$ problem). So the hope for large $\sin 2\Phi_{B_s}$ is not unfounded. Fourth generation effects through EWP may also be behind these NP hints, as has been shown in several papers [11–13]. In fact, in Ref. [11] we showed that the parameter space implied by $\Delta \mathcal{A}_{K\pi}$ is independently supported by combining the Δm_{B_s} bound at that time with $\mathcal{B}(b \rightarrow s \ell^+ \ell^-)$. However, since Δm_{B_s} and $\mathcal{B}(b \rightarrow s \ell^+ \ell^-)$ suffer far less hadronic uncertainties, with Δm_{B_s} now precisely known, the strategy should be switched around.

Throughout this paper, we will take $m_{t'} \simeq 300$ GeV for the sake of illustration. We stress that *changing $m_{t'}$ does not affect the effects that we discuss, but leads to a shift in the parameter range*. Extending the quark mixing matrix V from 3×3 to 4×4 , all processes involving flavor are affected. With $V_{t's}^* V_{t'b}$ determined from $b \rightarrow s$ transitions, we were able to [14] more or less fix V from considering $Z \rightarrow b\bar{b}$ and rare kaon constraints. Remarkably, the stringent kaon constraints imply [14] $b \rightarrow d$ measurements such as Δm_{B_d} and $\sin 2\Phi_{B_d}$ would be SM-like, a necessary condition to survive NP tests [15], while $K_L \rightarrow \pi^0 \nu \bar{\nu}$ could be greatly enhanced. It is critical to include (two) new CPV phases, not only because they are naturally present, but also because it enriches and enlarges [9] the parameter space and phenomena. A recent study [16] of the 4th generation, aimed towards checking whether $V_{tb} = 1$, ignored CPV and assumed $V_{t's}$ to be real.

Let us illustrate how the 4th generation enters box and EWP diagrams. For $b \rightarrow s$ transitions, 4th generation unitarity gives $\lambda_u + \lambda_c + \lambda_t + \lambda_{t'} = 0$, where $\lambda_i \equiv V_{is}^* V_{ib}$. Since $|\lambda_u| < 10^{-3}$ by direct measurement, one has $\lambda_t \equiv -\lambda_c - \lambda_{t'}$. M_{12} for B_s mixing is then proportional to

$$f_{B_s}^2 B_{B_s} \{ \lambda_c^2 S_0(t, t) - 2\lambda_c \lambda_{t'} \Delta S_0^{(1)} + \lambda_{t'}^2 \Delta S_0^{(2)} \}, \quad (6)$$

where the first SM3 term is practically real (Γ_{12} , which gives $\Delta \Gamma_{B_s}$, is generated by interference of $b \rightarrow c\bar{c}s$ decay final states between B_s and \bar{B}_s). With

$$\Delta S_0^{(1)} \equiv S_0(t, t') - S_0(t, t),$$

$$\Delta S_0^{(2)} \equiv S_0(t', t') - 2S_0(t, t') + S_0(t, t),$$

the t' terms in Eq. (6) respect Glashow-Iliopoulos-Maiani cancellation and vanish with $\lambda_{t'}$, analogous to $\Delta C_i \equiv C_i^{t'} - C_i^t$ [9,11] that modifies the Wilson coefficients C_i for $b \rightarrow s \bar{q} q$ (and $s \ell^+ \ell^-$) decays. The normalized $\Delta S_0^{(i)}$ [to $S_0' = S_0(t, t)$] are plotted in Figure 1(a) vs $m_{t'}$, which can be compared to $\Delta C_{7,9}$ (normalized to C_4^t [11]) plotted in Fig. 1(b). The strong $m_{t'}$ dependence illustrates the non-decoupling of SM-like heavy quarks from box and EWP diagrams [8]. In contrast, the strong penguin corrections $\Delta C_{4,6}$ shown in Fig. 1(b) have very mild $m_{t'}$ dependence [17]. The electromagnetic (i.e. photonic) penguin is likewise, which we will return to in our discussion later. Thus,

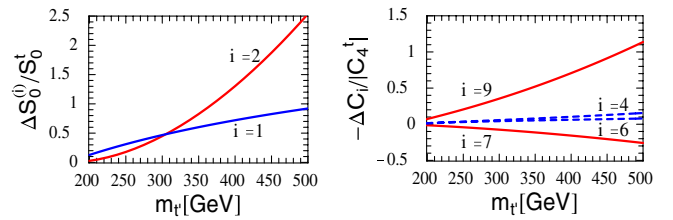


FIG. 1 (color online). Normalized t' corrections (a) $\Delta S_0^{(i)}/S_0'$ (for box diagrams) and (b) $-\Delta C_i/|C_4^t|$ (for penguins) vs $m_{t'}$.

the 4th generation is of particular interest for processes involving boxes and Z penguins, the focus of our study.

Besides the strong $m_{t'}$ dependence of B_s mixing, $\lambda_{t'}$ brings in a weak phase, which we parameterize as

$$\lambda_{t'} \equiv V_{t's}^* V_{t'b} \equiv r_{sb} e^{i\phi_{sb}}. \quad (7)$$

This phase was not emphasized 20 years ago in the original work of Ref. [8], leading some authors to claim very narrow allowed parameter range from data. But as was emphasized [9] later, the phase enriches the parameter space considerably, allowing *large* effects from t' even when *both* Δm_{B_s} and $\mathcal{B}(b \rightarrow s \ell^+ \ell^-)$ appear SM-like. For example, when $\lambda_{t'}$ is close to imaginary, the t and t' contributions are largely real and imaginary, respectively, hence add only in quadrature and do not interfere in $\mathcal{B}(b \rightarrow s \ell^+ \ell^-)$. But this is just ripe for CPV.

In the following, we take $m_{t'} = 170$ GeV. The central value of $f_{B_s} \sqrt{B_{B_s}} = 295 \pm 32$ MeV [18] would give the SM3 expectation of ~ 24 ps $^{-1}$ [19], which seems a little high compared with Eq. (1). Of course, $f_{B_s} \sqrt{B_{B_s}}$ could be in the lower range, but *it could also turn out higher*. Some new physics that interferes destructively with SM3 is clearly welcome. Keeping $f_{B_s} \sqrt{B_{B_s}} = 295$ MeV, we plot Δm_{B_s} vs ϕ_{sb} in Fig. 2(a) for $m_{t'} = 300$ GeV and several r_{sb} values. The SM3 value is shown as a dashed line, and the 2σ range of Eq. (1) is the solid band. We see that destructive interference occurs for ϕ_{sb} in the 1st and 4th quadrants, bringing Δm_{B_s} down from SM3 value to the CDF (Collider Detector at Fermilab) range, while the 2nd and 3rd quadrants are ruled out. For given r_{sb} , one projects a rather narrow ϕ_{sb} range. For $r_{sb} = 0.02, 0.025, 0.03$ (cf. $\lambda_c = V_{cs}^* V_{cb} \simeq 0.04$ for top contribution), we find $\phi_{sb} \simeq 52^\circ - 55^\circ, 62^\circ - 64^\circ, 67^\circ - 69^\circ$, respectively. These are quite imaginary and imply large $\sin 2\Phi_{B_s}$, which is plotted in Fig. 2(b).

What is remarkable is the consistency of the observed $b \rightarrow s \ell^+ \ell^-$ rate with the above projection. This is because the $b \rightarrow s \ell^+ \ell^-$ process is also dominated by EWP and box diagrams [8]. The current world average is $\mathcal{B}(b \rightarrow s \ell^+ \ell^-) = (4.5 \pm 1.0) \times 10^{-6}$ [2] (a cut on $m_{\ell\ell} > 0.2$ GeV is applied), which is lower than two years ago. We follow the next-to-next-to-leading order (NNLO) calculation of Ref. [20] and incorporate [11] the 4th genera-

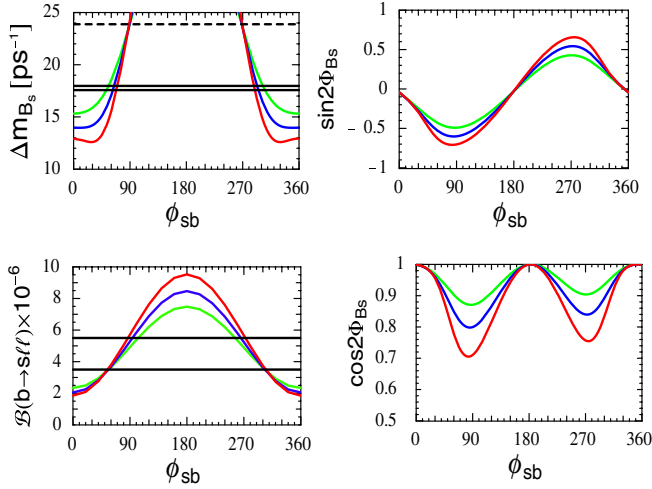


FIG. 2 (color online). (a) Δm_{B_s} , (b) $\sin 2\Phi_{B_s}$, (c) $\mathcal{B}(b \rightarrow s\ell^+\ell^-)$, and (d) $\cos 2\Phi_{B_s}$ vs ϕ_{sb} , for $m_{t'} = 300$ GeV and $r_{sb} = 0.02, 0.025,$ and 0.03 , where $V_{t's}^* V_{t'b} \equiv r_{sb} e^{i\phi_{sb}}$. Larger r_{sb} gives stronger variation. The dashed line in (a) is the nominal SM3 result, and the solid bands for (a) and (c) are 2σ and 1σ experimental ranges, respectively.

tion effect by modifying short distance Wilson coefficients. Although formulas in Ref. [21] are simpler, it is less clear how to incorporate the 4th generation. We have checked that the Λ_{QCD}/m_b corrections in Ref. [21] do not affect the NNLO result by much. We find $\mathcal{B}(b \rightarrow s\ell^+\ell^-)|_{\text{SM}} \approx 4.26 \times 10^{-6}$, in good agreement with data.

We plot $\mathcal{B}(b \rightarrow s\ell^+\ell^-)$ vs ϕ_{sb} in Fig. 2(c), together with the 1σ range of data. The dependence on r_{sb} and ϕ_{sb} resembles the Δm_{B_s} case. We see that for $r_{sb} \sim 0.02, 0.025,$ and 0.03 , $|\phi_{sb}| \gtrsim 55^\circ$ is implied, which practically rules out the allowed range from Δm_{B_s} for $r_{sb} \sim 0.02$. Of course, there are uncertainties in both the measurements and the theory, but our discussion makes clear that combining $\mathcal{B}(b \rightarrow s\ell^+\ell^-)$ with Δm_{B_s} , one can constrain further the allowed parameter space.

Returning to Fig. 2(b), we see that $\sin 2\Phi_{B_s} \sim -0.5$ to -0.7 for $r_{sb} \sim 0.025$ to 0.03 for ϕ_{sb} in the 1st quadrant, which can give $\Delta \mathcal{A}_{K\pi} \sim 0.15$ and $\Delta S < 0$ [12,13]. The latter excludes the opposite sign case of ϕ_{sb} in the 4th quadrant. Note that one recovers the SM3 expectation of ~ -0.04 for $\phi_{sb} = 0$. Measuring mixing-dependent CPV should be no problem at LHC experiments such as LHCb, but it is exciting that, with the Tevatron sensitivity of 0.2 per experiment [22], our prediction could be tested at the 3σ level before the LHC is turned on.

We plot the somewhat redundant $\cos 2\Phi_{B_s}$ in Fig. 2(d), which can be probed by comparing $\Delta\Gamma_{B_s}/\Gamma_{B_s}$ measurements in non- CP and CP eigenstates [23] and other width difference approaches. The recent result by the D0 Collaboration [4] is given in Eq. (2). The Belle experiment has collected data in 2006 on the $Y(5S)$ [24] for the purpose of B_s physics, but it remains to be seen how

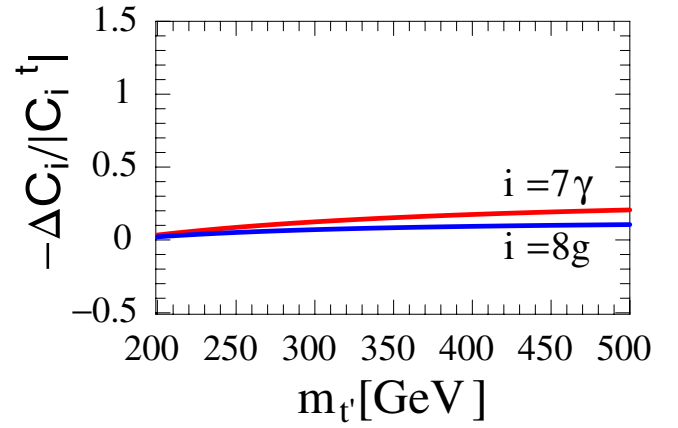


FIG. 3 (color online). $-\Delta C_{7\gamma}/|C_{7\gamma}^t|$ and $-\Delta C_{8g}/|C_{8g}^t|$ vs $m_{t'}$, which governs on shell photon and gluon emission.

much data would be needed for $\cos 2\Phi_{B_s}$ to be profitably probed. With central parameter values we find $\sin 2\Phi_{B_s} \sim -0.55$ hence $\cos 2\Phi_{B_s} \sim 0.84$. It is possible that the $\Delta\Gamma_{B_s}$ approach could reach the precision to probe $\cos 2\Phi_{B_s} \lesssim 0.85$.

We have delayed the discussion of $b \rightarrow s\gamma$ until now, to make clear the contrast: the well-measured $\mathcal{B}(b \rightarrow s\gamma)$, which is in agreement with the SM expectation, does not provide a better constraint. The relevant operator is $\sigma_{\mu\nu} m_b R$, which is of dipole form, with coefficient $C_{7\gamma}$, which should not be confused with C_7 . The point is that, unlike C_9 and C_7 , the 4th generation correction $\Delta C_{7\gamma}$ has a rather mild dependence on $m_{t'}$. We plot $-\Delta C_{7\gamma}$ normalized to $|C_{7\gamma}^t|$ (as well as $-\Delta C_{8g}$ normalized to $|C_{8g}^t|$, the gluonic dipole counterpart), in Fig. 3. Comparing with Fig. 1(b), the $m_{t'}$ dependence is stronger than $-\Delta C_{4,6}/|C_4^t|$, but much weaker than $-\Delta C_{7,9}/C_4^t$.

In addition to the milder dependence on $m_{t'}$, as we have mentioned, t and t' effects add mostly in quadrature for the range of ϕ_{sb} under discussion. The combined effect is that $\mathcal{B}(b \rightarrow s\gamma)$ does not pose a problem [11]. To make this point clear, we plot $\mathcal{B}(b \rightarrow s\gamma)$ vs ϕ_{sb} in Figs. 4(a) and 4(b) for $m_{t'} = 300, 350,$ and $500, 700$ GeV, respectively,

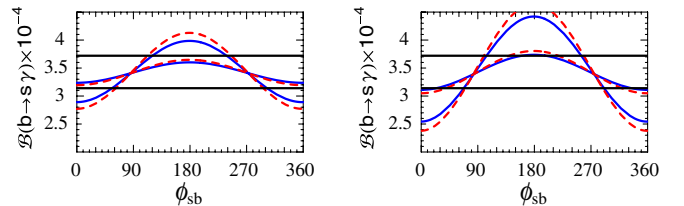


FIG. 4 (color online). $\mathcal{B}(b \rightarrow s\gamma)$ vs ϕ_{sb} for $m_{t'} =$ (a) 300 (solid line), 350 (dashed line), (b) 500 (solid line), 700 (dashed line) GeV. For each $m_{t'}$, two curves are shown, one each for $r_{sb} = 0.01$ and 0.03 , to illustrate the range, where larger value gives stronger variation.

for $r_{sb} = 0.01$ and 0.03 , for sake of illustration. We have taken the next-to-leading order results of Ref. [25], which give an SM value of 3.4×10^{-4} . Indeed the variation of the curves are much milder compared with that of $b \rightarrow s\ell^+\ell^-$ plotted in Fig. 2(c), even for extreme $m_{l'}^+$ masses such as 500–700 GeV. The values stay closer to the experimental range, especially for ϕ_{sb} near 90° . We also point out that the 4th generation in our scenario gives rise to a smaller $\mathcal{A}_{CP}(b \rightarrow s\gamma)$ than SM (see Fig. 3(c) of Ref. [11]) and again does not pose any problem.

We note that our ϕ_{sb} range tends to reduce $\mathcal{B}(b \rightarrow s\gamma)$ by a small amount. Recent next-to-next-to-leading order calculations lead to a smaller [26] SM expectation. This could pose a problem, but the NNLO calculation is yet incomplete [27]. The situation should be watched, but in any case this would be a generic problem, not just for the 4th generation model.

A 4th generation affects all flavor changing phenomena, including D^0 mixing. For this purpose, it is useful to take the 4×4 parametrization [28] that puts phases in V_{ub} (as in SM3), $V_{t's}$, and $V_{t'd}$. With $V_{t's}^* V_{t'b}$ determined, in a previous study [14] we used $Z \rightarrow b\bar{b}$ to fix $V_{t'b} \sim -0.22$, hence $V_{t's} \sim -0.114e^{-i70^\circ}$. The kaon constraints then imply $V_{t'd} \sim -0.0044e^{-i10^\circ}$, leading to enhanced $K_L \rightarrow \pi^0\nu\nu$ [14]. It is nontrivial that $b \rightarrow d$ observables become SM-like, while $b \rightarrow s$ has large CPV, which can be seen by comparing Fig. 1(b) to 1(a) of Ref. [14]: one can barely tell apart the SM4 $b \rightarrow d$ quadrangle from the SM3 triangle, while the SM4 $b \rightarrow s$ quadrangle is *large* and distinct from the squashed SM3 “triangle.”

By unitarity one then finds $V_{cb'} \sim 0.116e^{i66^\circ}$ and $V_{ub'} \sim 0.028e^{i61^\circ}$, giving

$$V_{ub'}V_{cb'}^* \equiv r_{uc}e^{-i\phi_{uc}} \sim +0.0033e^{-i5^\circ}, \quad (8)$$

which affects $c \rightarrow u$ transitions via b' loops. With $|V_{ub}V_{cb}| \lesssim 10^{-4}$ by direct measurement hence $V_{ud}V_{cd}^* + V_{us}V_{cs}^* + V_{ub'}V_{cb'}^* \equiv 0$, Eq. (8) implies $V_{ud}V_{cd}^* \simeq -0.218$ and $V_{us}V_{cs}^* \simeq 0.215$ are real to better than 3 decimal places, very much like in SM3. These govern $c \rightarrow u\bar{d}\bar{d}$ and $u\bar{s}\bar{s}$ decays that generate y_D [29], which in turn could generate $|x_D^{\text{LD}}| \sim |y_D|$ by dispersion relations.

Long-distance effects are beyond our scope. Our interest is in the $V_{ub'}V_{cb'}^*$ term. Though small, it cannot be ignored, since $m_{b'} \sim m_{l'}$ by electroweak precision constraints hence is very heavy. This can generate x_D^{SD} , analogous to Eq. (6) for Δm_{B_s} , which would be vanishingly small in SM3 because of $|V_{ub}V_{cb}|^2$ suppression.

To illustrate the short-distance effect generated by b' , we take $f_D\sqrt{B_D} = 200$ MeV and plot Δm_D vs $\phi_{db} \equiv \arg V_{t'd}^* V_{t'b}$ in Fig. 5(a), for $m_{b'} = 230, 270,$ and 310 GeV, respectively, and $r_{db} \equiv |V_{t'd}^* V_{t'b}| = 10^{-3}$. The reason we plot against ϕ_{db} is because ϕ_{db} and r_{db} are fitted [14] to kaon data, after fixing $r_{sb} \sim 0.025$ and $\phi_{sb} \sim 65^\circ$. We found $\phi_{db} \sim 10^\circ$ and $r_{db} \sim 10^{-3}$. We see that Δm_D^{SD} lies just below the Particle Data Group (PDG) bound (solid

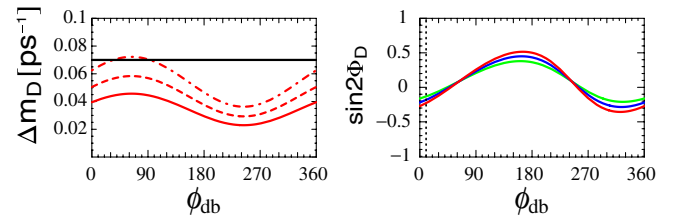


FIG. 5 (color online). (a) Δm_D vs ϕ_{db} for $m_{b'} = 230$ (solid line), 270 (dashed line) and 310 (dotted-dashed line) GeV and $r_{db} = 10^{-3}$, where $V_{t'd}^* V_{t'b} \equiv r_{db} e^{-i\phi_{db}}$; (b) $\sin 2\Phi_D$ vs ϕ_{db} for $m_{b'} = 270$ GeV and $r_{db} \sim (0.8, 1, 1.2) \times 10^{-3}$. The solid horizontal line in (a) is the PDG bound, while the dashed band is the 2σ range of Eq. (3).

line) but is slightly higher than the upper range of Eq. (3) (dashed band), which is interesting. With $y_D \sim 1\%$, $|x_D^{\text{LD}}|$ could be comparable [29]. Thus, our rough prediction of x_D^{SD} could be plainly consistent with Eq. (3), or imply destructive interference between short- and long-distance x_D^{SD} and x_D^{LD} . This is reminiscent of the situation in Δm_K .

The critical test would be CPV. Although $\phi_{db} \sim 10^\circ$, in Fig. 5(b) we plot $\sin 2\Phi_D$ vs ϕ_{db} for $m_{b'} = 270$ GeV and $r_{db} = (0.8, 1, 1.2) \times 10^{-3}$. Because of the tiny $\phi_{uc} \sim 5^\circ$, our scenario *predicts rather small, but still finite CPV in D^0 mixing*, at not more than -0.2 level. It is remarkable that this is consistent with no hints so far for CPV in D mixing from experiment [2,5–7]. But a nonzero $\sin 2\Phi_D$ should be of great interest in the longer term.

We note that experimental hints for $\Delta\Gamma_D$ have been around for some time [2], which stimulated the theoretical suggestion [29] that $y_D \sim \%$ level is possible in SM. The recent measurement of $y_D' = y_D \cos \delta - x_D \sin \delta$ by BABAR [7] in wrong-sign $D^0 \rightarrow K^+ \pi^-$ decays, Eq. (5), is consistent with the previous Belle [30] measurement, though higher in value. Unfortunately, the strong phase difference δ between the mixing and doubly Cabibbo suppressed amplitudes is unknown. With an active program at the B factories and CLEO-c, and the start of BESIII and LHCb in 2008, one expects the y_D and x_D measurements to improve. Measurement of δ , such as with methods developed in Ref. [31], could shed further light on consistency of different measurements. y_{CP}, y_D, x_D, δ could all become measured in a few years. But with $y_D \sim 1\% \sim x_D$ the likely outcome, to elucidate whether one has a SM or NP effect, ultimately one has to measure $\sin 2\Phi_D$, which perhaps could be done by LHCb, but may have to await a super B factory.

Comparatively, measuring $\sin 2\Phi_{B_s} \sim -0.55$ before 2008 should be more promising. Note that the $\Delta\Gamma_{B_s}$ approach already yields some nonvanishing negative value, Eq. (2), but the errors are still too accommodating. With Δm_{B_s} already measured, the standard approach would be a time-dependent CPV study with more data, performing an angular resolved simultaneously fit to both mass and width mixings. Clearly the SM expectation of -0.04 is out of

reach at the Tevatron, but with 8 fb^{-1} or more data and an expected sensitivity of -0.2 per experiment [22], it is of great interest to see whether evidence for $\sin 2\Phi_{B_s} \neq 0$ could emerge before the LHC data arrives.

We have only illustrated the possible outcome for CPV in the B_s system, as well as mixing and CPV in the D^0 system. The numbers are not very precise and should not be taken literally, since uncertainties in hadronic parameters such as $f_{B_s}^2 B_{B_s}$ are large. But if a 4th generation is present in nature, it is quite likely that it contributes to B_s - \bar{B}_s and D^0 - \bar{D}^0 mixings as well as $b \rightarrow s\ell^+\ell^-$ the way we suggested. This is especially true, in light of the mixing-dependent and direct CPV “anomalies” in $b \rightarrow s\bar{q}q$ decays. Put in other words, the discovery of $\sin 2\Phi_{B_s} < 0$ would provide more confirmation, as well as information on, the scenario that we have proposed. We stress once

again that, changing $m_{t'}$ from our nominal value of 300 GeV does not affect the effects that we discuss, but leads to just a shift in the parameter range.

In summary, we show that the current measurements of B_s mixing and $b \rightarrow s\ell^+\ell^-$ rate, though consistent with the standard model, can accommodate a 4th generation. The predicted large and negative CP violation phase in B_s mixing can be tested already at the Tevatron. As a corollary, we predict short-distance D^0 mixing to be close to present sensitivities, with a subdued but finite CP violation phase that can be probed in the future.

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