Difference in B^+ and B^0 Direct CP Asymmetry as an Effect of a Fourth Generation

Wei-Shu Hou, Makiko Nagashima, and Andrea Soddu

Department of Physics, National Taiwan University, Taipei, Taiwan 106, Republic of China

(Received 8 March 2005; revised manuscript received 20 June 2005; published 30 September 2005)

Direct CP violation in $B^0 \to K^+\pi^-$ decay has emerged at the -10% level, but the asymmetry in $B^+ \to K^+\pi^0$ mode is consistent with zero. This difference points towards possible new physics in the electroweak penguin operator. We point out that a sequential fourth generation, with sizable $V_{t's}^* V_{t'b}$ and near maximal phase, could be a natural cause. We use the perturbative QCD factorization approach for $B \to K\pi$ amplitudes. While the $B^0 \to K^+\pi^-$ mode is insensitive to t', we critically compare t' effects on direct CP violation in $B^+ \to K^+\pi^0$ with $b \to s\ell^+\ell^-$ and B_s mixing. If the $K^+\pi^0 - K^+\pi^-$ asymmetry difference persists, we predict $\sin 2\Phi_{B_s}$ to be negative.

DOI: 10.1103/PhysRevLett.95.141601 PACS numbers: 11.30.Er, 11.30.Hv, 12.60.−i, 13.25.Hw

Direct CP violation (DCPV) in $B^0 \to K^+\pi^-$ decay has recently been observed [1,2] at the B factories. The combined asymmetry is $\mathcal{A}_{K\pi} = -0.114 \pm 0.020$. However, the asymmetry in $B^+ \to K^+\pi^0$ decay is found to be [2,3] $\mathcal{A}_{K\pi^0} = +0.049 \pm 0.040$, which differs from $\mathcal{A}_{K\pi}$ by

$$\mathcal{A}_{K\pi^0} - \mathcal{A}_{K\pi} = +0.163 \pm 0.045, \qquad (1)$$

with 3.6σ significance. All existing models have predicted $\mathcal{A}_{K\pi^0} \sim \mathcal{A}_{K\pi}$, as this basically follows from isospin symmetry. The large difference of Eq. (1), if it persists, could indicate isospin breaking new physics (NP), likely [4] through the electroweak penguin (EWP) operator.

In this Letter we point out a natural source for such EWP effects: the existence of a fourth generation. The t' quark can modify the EWP coefficients, but leaves the strong and electromagnetic penguin coefficients largely intact. Equation (1) can be accounted for, provided that $m_{t'} \sim$ 300 GeV, and the quark mixing elements $V_{t's}^* V_{t'b}$ are not much smaller than V_{cb} and have near maximal CP phase. Independently, $b \to s\ell^+\ell^-$ and B_s mixing constraints can allow large t' effects only if [5] the associated CP phase is near maximal.

Precision electroweak data imply that $|m_{t'} - m_{b'}|$ cannot be too large [6]. Unitarity of quark mixing requires $|V_{ub'}| < 0.08$ [6], while constraining $V_{t's}^* V_{t'b}$ is the subject of this Letter. Since $b \to d$ transitions appear standard model (SM) like, we set $V_{t'd} \sim 0$. We thus decouple from $s \to d$ constraints such as ϵ_K and $K \to \pi\nu\nu$ as well [7].

Adding a fourth generation modifies short distance coefficients. Defining $\lambda_q = V_{qs}^* V_{qb}$, the effective Hamiltonian relevant for $B \to K\pi$ can be written as

$$H_{\rm eff} \propto \lambda_u (C_1 O_1 + C_2 O_2) + \sum_{i=3}^{10} (\lambda_c C_i^t - \lambda_{t'} \Delta C_i) O_i, \quad (2)$$

where $O_{1,2}$ are the tree operators, $\lambda_c C_i^t$ are the usual SM penguin terms, and $-\lambda_{t'}\Delta C_i$ with $\Delta C_i \equiv C_i^{t'} - C_i^t$ is the fourth generation effect. We have used $\lambda_u + \lambda_c + \lambda_t + \lambda_{t'} = 0$, simplified by ignoring $|\lambda_u| \lesssim 10^{-3}$, such that $\lambda_t \cong -\lambda_c - \lambda_{t'}$ [8]. The penguin coefficients $\lambda_t C_i^t + \lambda_{t'} C_i^{t'}$ at scale μ are then put [5] in the form of Eq. (2), which respect the SM limit for $\lambda_{t'} \to 0$ or $m_{t'} \to m_t$. Explicit forms for C_i and O_i can be found, for example, in Ref. [9].

The $K\pi$ amplitudes are dominated by $C_{4,6}^t$. To illustrate t' sensitivity, in Fig. 1 we plot $-\Delta C_i/|C_4^t|$ at m_b scale versus $m_{t'}$. The effect is clearly most prominent for the EWP C_9 coefficient, with linear $x_{t'} \equiv m_{t'}^2/M_W^2$ dependence arising from Z and box diagrams [8]. ΔC_7 has similar dependence but has weaker strength. For the strong penguin $\Delta C_{4,6}$, the t' effect in the QCD penguin loop is weaker than logarithmic [10] and is very mild. As we shall see, the $B^0 \to K^+\pi^-$ amplitude does not involve the EWP. In contrast, the $B^+ \to K^+\pi^0$ amplitude is sensitive to the EWP via $\Delta C_9 - \Delta C_7$ (virtual Z materializing as π^0).

We see that it is natural for the fourth generation to show itself through the EWP. The effect depends also on the quark mixing matrix product, parametrized as [5]

$$\lambda_{t'} = V_{t's}^* V_{t'b} = r_s e^{i\phi_s}. \qquad (3)$$

The phase ϕ_s is needed to affect the CPV observables, Eq. (1). Most works on the fourth generation have ignored the phase in $V_{t's}^* V_{t'b}$, making the fourth generation effect far less flexible hence uninteresting.

Let us first see how $\mathcal{A}_{K\pi} < 0$ can be generated. In the usual QCD factorization (QCDF) approach [11], strong phases are power suppressed, while strong penguin C_4 and C_6 coefficients pick up perturbative absorptive parts.

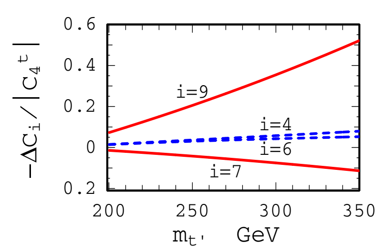

FIG. 1 (color online). The t' correction $-\Delta C_i$ normalized to the strong penguin coefficient $|C_4^t|$ (both at m_b scale) vs $m_{t'}$.

Thus, the predicted $\mathcal{A}_{K\pi}$ is small, and turns out to be positive. For the perturbative QCD factorization (PQCDF) [12] approach, one has an additional absorptive part coming from the annihilation diagram, which arises from a cut on the two quark lines in $B \to \bar{s}q \to K\pi$ decay. In this way, the PQCDF approach predicted [12] the sign and order of magnitude of $\mathcal{A}_{K\pi}$. By incorporating annihilation contributions as in PQCDF, however, QCDF can also [13] give negative $\mathcal{A}_{K\pi}$.

We adopt PQCDF as a definite calculational framework. The $\bar{B}^0 \to K^-\pi^+$ amplitude for the 3 generation SM is roughly given by

$$\mathcal{M}^{\rm SM}_{K^-\pi^+} \propto \lambda_u f_K F_e + \lambda_c (f_K F_e^P + f_B F_a^P), \tag{4}$$

where $F_e^{(P)}$ is the color-allowed tree (strong penguin) contribution and is real, and F_a^P is the strong penguin annihilation term that has a large imaginary part. We have dropped subdominant nonfactorizable effects for sake of presentation. Details cannot be given here, but these factorizable contributions can be computed by following Ref. [12], convoluting the hard part (related to short distance coefficients C_i) and the soft, nonperturbative meson wave functions. Basically, all the $F_j^{(P)}$s are integrals over Bessel functions, and, in particular, a Hankel function for F_a^P [12]. We give the SM numbers for F_e, F_e^P, and F_a^P in Table I, which leads to $\mathcal{A}_{K\pi} = -0.16$ for $\phi_3 \equiv \arg\lambda_u^* = 60°$ [value used throughout [14]], compared to the experimental value of -0.114 ± 0.020.

For $B^- \to K^-\pi^0$, the difference with $K^-\pi^+$ is

$$\sqrt{2}\mathcal{M}^{\rm SM}_{K^-\pi^0} - \mathcal{M}^{\rm SM}_{K^-\pi^+} \propto \lambda_u f_\pi F_{ek} + \lambda_c f_\pi F_{ek}^P, \tag{5}$$

where F_{ek} is the color-suppressed tree term, while F_{ek}^P is the color-allowed EWP, and both are real. A negligible tree annihilation term $\lambda_u f_B F_a$ has been dropped. Since both the F_{ek} and F_{ek}^P terms are subdominant compared to F_e^P in the 3 generation SM, $\mathcal{A}_{K\pi^0}$ and $\mathcal{A}_{K\pi}$ cannot be far apart. From the values of F_{ek} and F_{ek}^P given in Table I, we get $\mathcal{A}_{K\pi^0} = -0.10$, which is less negative than $\mathcal{A}_{K\pi}$, but at some variance with Eq. (1).

Adding the t' quark, one finds $\mathcal{M}_{K^-\pi^+} \cong \mathcal{M}^{\rm SM}_{K^-\pi^+}$. The difference is proportional to $\lambda_{t'}(f_K \Delta F_e^P + f_B \Delta F_a^P)$, which is small unless $\lambda_{t'}$ is very large. This is because $F_{e,a}^P$ are strong penguins, hence $\Delta F_{e,a}^P$ depends very weakly on $m_{t'}$, as can be seen from Table I (for $m_{t'} = 300$ GeV) and Fig. 1. Thus, $\mathcal{A}_{K\pi}$ is insensitive to the fourth generation. For $K^-\pi^0$, one finds

$$\sqrt{2}\mathcal{M}_{K^-\pi^0} - \sqrt{2}\mathcal{M}^{\rm SM}_{K^-\pi^0} \propto -\lambda_{t'} f_\pi \Delta F_{ek}^P, \tag{6}$$

where again $\Delta F_{e,a}^P$ terms have been dropped, and ΔF_{ek}^P is the t' correction to the EWP, which is generated by $\Delta C_9 - \Delta C_7$ at short distance.

Let us put the $K^-\pi^+$ and $K^-\pi^0$ amplitudes in more heuristic form. Equation (4) can be put in the form

$$\mathcal{M}_{K^-\pi^+} \approx \mathcal{M}^{\rm SM}_{K^-\pi^+} \propto r e^{-i\phi_3} + e^{i\delta}, \tag{7}$$

and the fourth generation effect is minor. The ratio $r = |\lambda_u| f_K F_e / \lambda_c | f_K F_e^P + f_B F_a^P|$ parametrizes the relative strength of tree (T) versus strong penguins (P), and δ is the strong phase of $f_K F_e^P + f_B F_a^P$ arising from $F_a^P \equiv |F_a^P| e^{i\delta_a}$. Analogously, for $K^-\pi^0$ one roughly has

$$\mathcal{M}_{K^-\pi^0} \propto r\left(1 + \frac{f_\pi F_{ek}}{f_K F_e}\right) e^{-i\phi_3} + \frac{f_\pi F_{ek}^P}{|f_K F_e^P + f_B F_a^P|} + e^{i\delta} - \frac{f_\pi \Delta F_{ek}^P}{|f_K F_e^P + f_B F_a^P|} \left|\frac{V^*_{t's} V_{t'b}}{V^*_{cs} V_{cb}}\right| e^{i\phi_s}, \tag{8}$$

where F_{ek} and F_{ek}^P terms come from SM [see Eq. (5)], and the ΔF_{ek}^P term comes from the t' effect of Eq. (6). Since $r \sim 1/5$, we see from Table I that, for $m_{t'} \sim 300$ GeV and $|V_{t's} V_{t'b}| \equiv r_s$ not much smaller than $|V_{cb}| \sim 0.04$, the impact of t' on $\mathcal{A}_{K\pi^0}$ could be significant.

We have presented in the above the major contributions in PQCDF framework. Performing a detailed calculation following Ref. [12], we plot $\mathcal{A}_{K\pi}$ and $\mathcal{A}_{K\pi^0}$ in Fig. 2(a) for $m_{t'} = 300$, 350 GeV and $r_s = 0.01$ and 0.03. We see that, indeed, $\mathcal{A}_{K\pi}$ is almost independent of t', while it is clear that the largest impact on $\mathcal{A}_{K\pi^0}$ is for $\phi_s \sim \pm\pi/2$ and large $m_{t'}$ and r_s. To maximize $\mathcal{A}_{K\pi^0} - \mathcal{A}_{K\pi} > 0$, $\phi_s \sim +\pi/2$ is selected, and Eq. (1) can in principle be accounted for.

The $\mathcal{A}_{K\pi} \sim -0.16$ value is at some variance with the experimental value of -0.114 ± 0.020. This number depends crucially on the strong penguin phase. Rather than varying detailed model parameters, we vary $\delta \equiv \arg(f_K F_e^P + f_B F_a^P)$. The sign difference between tree and strong penguin constitutes a phase of π, and $\pi - \delta \sim 24°$ is perturbative. We plot $\mathcal{A}_{K\pi}$ and $\mathcal{A}_{K\pi^0}$ versus ϕ_s in Fig. 2(b) for $m_{t'} = 300$ GeV and $r_s = 0.03$, for $\delta = 155°$, 156° (nominal), and 160°. We see that a slightly smaller $\pi - \delta$ lowers $|\mathcal{A}_{K\pi}|$ and is preferred. Note that $\mathcal{A}_{K\pi^0} \sim 0$ around $\phi_s \sim 90°$ is due to a near cancellation between the ϕ_3 (tree) and ϕ_s (EWP) contributions. Thus, we think PQCDF can account for $\mathcal{A}_{K\pi} = -0.114 \pm 0.020$ without

TABLE I. Factorizable contributions for $B^{0[+]} \to K^+\pi^{-[0]}$ in standard model, and for $m_{t'} = 300$ GeV. The difference between the t' and t penguin contributions gives ΔF_j^P. "N/A" stands for "not applicable."

	Tree	t penguin	t' penguin
$F_e^{(P)}$	0.841 [0.843]	-0.074 [-0.075]	-0.076 [-0.078]
$F_a^{(P)}$	N/A [$0.001 + 0.002i$]	$0.003 + 0.026i$ [$0.003 + 0.026i$]	$0.003 + 0.026i$ [$0.003 + 0.026i$]
$F_{ek}^{(P)}$	N/A [-0.105]	N/A [-0.014]	N/A [-0.029]

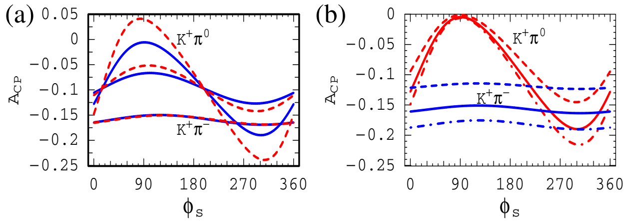

FIG. 2 (color online). Direct CPV asymmetries $\mathcal{A}_{K\pi}$ and $\mathcal{A}_{K\pi^0}$ vs $\phi_s \equiv \arg V^*_{t's}V_{t'b}$. In (a) the solid and dashed curves are for $m_{t'} = 300$ and 350 GeV, respectively, and for $r_s \equiv |V^*_{t's}V_{t'b}| = 0.01$ and 0.03. All curves for $\mathcal{A}_{K\pi}$ coalesce, but for $\mathcal{A}_{K\pi^0}$, the $r_s = 0, 03$ curves are steeper. For (b) the strong penguin absorptive phase δ is varied from 155° (dot-dashed line), 156° (solid line) to 160° (dashed line) for $m_{t'} = 300$ GeV and $r_s = 0.03$.

affecting $\mathcal{A}_{K\pi^0}$, but the NP phase ϕ_s should be rather close to 90°.

To entertain a large EWP effect in CPV in $b \to s$ decay, one needs to be mindful of the closely related $b \to s\ell^+\ell^-$ and B_s mixing constraints, as well as the usually stringent $b \to s\gamma$ constraint. We have checked that the $b \to s\gamma$ rate constraint is well satisfied for the range of parameters under discussion. This is because on-shell photon radiation is generated by the $b \to s$ transition operator $O_{7\gamma}$, and the associated coefficient $\Delta C_{7\gamma}$ has weaker $m_{t'}$ dependence than ΔC_7 shown in Fig. 1. However, $b \to s\ell^+\ell^-$ is generated by EWP [8] operators very similar to O_{7-10} in Eq. (2) for $b \to s\bar{q}q$. The difference is basically just in the Z charge of q versus ℓ, hence with same $m_{t'}$ dependence. The box diagram for B_s mixing also has similar $m_{t'}$ dependence. Taking the formulas from Ref. [5], we plot $b \to s\ell^+\ell^-$ rate ($m_{\ell\ell} > 0.2$ GeV) and Δm_{B_s} versus ϕ_s in Figs. 3(a) and 3(b), for $m_{t'} = 300$, 350 GeV and $r_s = 0.01$ and 0.03.

We can understand the finding of Ref. [5] that $\phi_s \sim 90°$ is best tolerated by the $b \to s\ell^+\ell^-$ and Δm_{B_s} constraints. For $\cos\phi_s < 0$, the $b \to s\ell^+\ell^-$ rate gets greatly enhanced [5], and would run against recent measurements. One is therefore forced to the $\cos\phi_s > 0$ region, where t' effect is destructive against SM t effect. For Δm_{B_s}, the effect gets destructive for $\cos\phi_s > 0$ when r_s is sizable. Since one just has a lower bound [6] of 14.4 ps^{-1}, Δm_{B_s} tends to push one away from the $\cos\phi_s > 0$ region. The combined effect is to settle around $\phi_s \sim \pm\pi/2$, i.e., imaginary [5]. This result is independent of the discrepancy of Eq. (1).

For sake of discussion we have plotted, as horizontal solid straight lines in Fig. 3(a), the 1σ range of $\mathcal{B}(B \to X_s\ell^+\ell^-) = (6.1^{+2.0}_{-1.8}) \times 10^{-6}$ [6] for $m_{\ell\ell} > 0.2$ GeV. This is the Particle Data Group (PDG) 2004 average over Belle and BaBar results [15,16], with a combined total of 154 M $B\bar{B}$ pairs. Belle has recently measured [17] with 152 M $B\bar{B}$ pairs the value $\mathcal{B}(B \to X_s\ell^+\ell^-) = (4.11 \pm 0.83^{+0.74}_{-0.70}) \times 10^{-6}$ for $m_{\ell\ell} > 0.2$ GeV, which would be more stringent. However, this lower result should be confirmed by *BABAR*, hence we use the more conservative [18] PDG 2004 range.

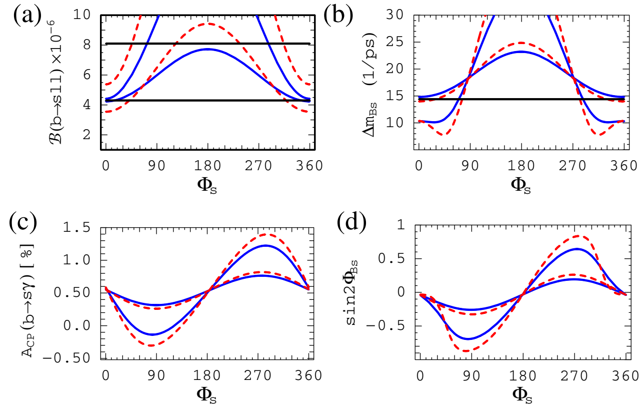

FIG. 3 (color online). (a) $\mathcal{B}(b \to s\ell^+\ell^-)$, (b) Δm_{B_s}, (c) $A_{CP}(b \to s\gamma)$, and (d) $\sin 2\Phi_{B_s}$ vs $\phi_s = \arg V^*_{t's}V_{t'b}$. Notation is the same as Fig. 2(a), with effect strongest for larger r_s and $m_{t'}$. Horizontal solid band in (a) corresponds to 1σ experimental range, and solid line in (b) is the lower limit, both from Ref. [6]. The experimental range for (c) is outside the plot.

For Δm_{B_s}, we plot the PDG bound of 14.4 ps^{-1} [6] as horizontal solid straight line in Fig. 3(b).

Comparing Figs. 2(a), 3(a), and 3(b), we set $\mathcal{A}_{K\pi^0} > -0.05$ as a requirement for a solution, for otherwise it is hard to satisfy Eq. (1), and in any case the fourth generation would seem no longer needed. This requirement demands $r_s > 0.01$. For $m_{t'} = 350$ GeV and $r_s = 0.03$, which can best bring $\mathcal{A}_{K\pi^0} \gtrsim 0$, Figs. 3(a) and 3(b) mutually exclude each other. For $m_{t'} = 300$ GeV and $r_s = 0.03$ (the case for $m_{t'} = 350$ GeV and $r_s = 0.02$ is very similar), one finds $\phi_s \simeq 75°$ gives $\mathcal{A}_{K\pi^0} \sim 0$. However, $\mathcal{B}(b \to s\ell\ell)$ must be close to the maximal value of $\sim 8 \times 10^{-6}$, and Δm_{B_s} would be just above the bound. For lower r_s values, the solution space is broader. For example, for $m_{t'} = 300$ GeV and $r_s = 0.02$, one has $\mathcal{A}_{K\pi^0} \gtrsim -0.05$ for $\phi_s \sim 63°$–$100°$. $\mathcal{B}(b \to s\ell\ell)$ can reach below 6×10^{-6}, but then Δm_{B_s} would again approach the current bound.

We see that for a range of parameter space roughly around $m_{t'} \sim 300$ GeV and $0.01 < r_s \lesssim 0.03$, solutions to Eq. (1) can be found that do not upset $b \to s\ell\ell$ and Δm_{B_s}. Both large t' mass and sizable $V_{t's}$ mixing are needed; no solutions are found for $m_{t'} = 250$ GeV.

As the CPV effect through the EWP is large, one may worry if similar effects may show up already in $b \to s\gamma$. We follow Ref. [19], extend to 4 generations, and plot $A_{CP}(b \to s\gamma)$ versus ϕ_s in Fig. 3(c). Like the $A_{K\pi^0}$ case, the t' effect cancels against the SM phase. $|A_{CP}(b \to s\gamma)|$ is in general *smaller* than the SM value of $\sim 0.5\%$, and consistent with the current measurement of 0.004 ± 0.036 [20]. In fact, it is below the sensitivity for the proposed high luminosity "Super B factory."

As prediction, we find $\sin 2\Phi_{B_s} < 0$ for CPV in B_s mixing, which is plotted versus ϕ_s in Fig. 3(d). We find $\sin 2\Phi_{B_s}$ in the range of -0.2 to -0.7 and correlating with $\mathcal{A}_{K\pi^0} - \mathcal{A}_{K\pi}$. Three generation SM predicts zero.

Note that refined measurements of $\mathcal{B}(b \to s\ell\ell)$ and future measurements of Δm_{B_s} and $\sin 2\Phi_{B_s}$, together with theory improvements, can pinpoint $m_{t'}$, r_s, and ϕ_s. We note further that [6] $14.4\ \text{ps}^{-1} < \Delta m_{B_s} < 21.8\ \text{ps}^{-1}$ cannot yet be excluded because data are compatible with a signal in this region. We eagerly await B_s mixing and associated CPV measurement in the near future.

It is of interest to predict the asymmetries for the other two $B \to K\pi$ modes. $K^0\pi^-$ is analogous to $\mathcal{M}_{K^-\pi^+}$ except tree contribution is absent. We find $\mathcal{M}_{\bar{K}^0\pi^-} \cong \mathcal{M}^{\rm SM}_{\bar{K}^0\pi^-} \propto \lambda_c(f_K F_e^P + f_B F_a^P)$, so $\mathcal{A}_{K^0\pi} \simeq 0$ and insensitive to t'. For $\bar{B}^0 \to \bar{K}^0\pi^0$, we have $\mathcal{M}_{\bar{K}^0\pi^0} \propto \lambda_u f_\pi F_{ek} + \lambda_c(-f_K F_e^P - f_B F_a^P + f_\pi F_{ek}^P) - \lambda_{t'} f_\pi \Delta F_{ek}^P$. Numerics can still be obtained from Table I, giving $\mathcal{A}_{K^0\pi} - \mathcal{A}_{K^0\pi^0} \sim 0.1$ if $\mathcal{A}_{K\pi^0} - \mathcal{A}_{K\pi}$ is of order suggested by Eq. (1). The impact on mixing-dependent CPV in ϕK_S and $\eta' K_S$ modes is insignificant [5].

The measurement of $\mathcal{A}_{K\pi^0}$ itself should not yet be viewed as settled, since the recent *BABAR* value of $+0.06 \pm 0.06 \pm 0.01$ changed sign from the previous [21] value of $-0.09 \pm 0.09 \pm 0.01$. But if $\mathcal{A}_{K\pi^0} \sim 0$, hence Eq. (1), stays, we would need a large effect in the EWP with a new CPV phase. Note that, unlike most treatments of the EWP, our strong phase is not a fitted parameter, but calculated from PQCDF [22].

We have also studied separately the final state rescattering (FSI) model [23] as a different proposed source of strong phase. In this model, one allows $K^+\pi^{-,0} \leftrightarrow K^0\pi^{0,+} \leftrightarrow K^{0,+}\eta$ rescattering in the final state (power suppressed in QCDF and PQCDF), and, to avoid double counting, one uses naïve factorization amplitudes as source before rescattering. In this way, one can account [23] for $\mathcal{A}_{K\pi} < 0$, and also generate a sizable $\pi^0\pi^0$ via rescattering from $\pi^+\pi^-$. Neither QCDF nor PQCDF can account for $\mathcal{B}(B^0 \to \pi^0\pi^0) > 10^{-6}$. However, in contrast to Eq. (1), $\mathcal{A}_{K\pi^0}$ is found [23] to be more negative than $\mathcal{A}_{K\pi}$ for $\mathcal{A}_{K\pi} < 0$. We find no solution to Eq. (1), even when t' is considered. Besides the problem that already exists in 3 generation SM, rescattering brings the electroweak penguin into the $K^-\pi^+$ amplitude from the $\bar{K}^0\pi^0$ mode, so adding the t' does not help.

We have shown that a fourth generation t' quark can account for $\mathcal{A}_{K\pi^0} \sim 0$. Using PQCD factorization calculations, one can account for $\mathcal{A}_{K\pi} < 0$ (untouched by t') and generate the needed $\mathcal{A}_{K\pi^0} - \mathcal{A}_{K\pi}$ splitting, which repeats in $\mathcal{A}_{K^0\pi} - \mathcal{A}_{K^0\pi^0}$. The closely related $b \to s\ell^+\ell^-$ mode should have a rate not less than 6×10^{-6}, and B_s mixing should not be far above the current bound of $14.4\ \text{ps}^{-1}$. In fact, between the $b \to s\ell^+\ell^-$ rate and the bound on B_s mixing, $V^*_{t's}V_{t'b}$ should be near imaginary if one wants a large t' effect. We predict a quite measurable *CP* violating phase $\sin 2\Phi_{B_s}$ in the -0.2 to -0.7 range. Refined measurements of the last three measurables can determine $m_{t'}$ and the strength and phase of $V^*_{t's}V_{t'b}$.

This work is supported in part by NSC-93-2112-M-002-020, NSC93-2811-M-002-053, and NSC93-2811-M-002-047. We thank H. n. Li for providing the program for computing amplitudes in PQCDF.

[1] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **93**, 131801 (2004).
[2] Y. Chao *et al.* (Belle Collaboration), Phys. Rev. Lett. **93**, 191802 (2004).
[3] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **94**, 181802 (2005).
[4] A. J. Buras *et al.*, Nucl. Phys. **B697**, 133 (2004); V. Barger *et al.*, Phys. Lett. B **598**, 218 (2004); S. Nandi and A. Kundu, hep-ph/0407061; S. Mishima and T. Yoshikawa, Phys. Rev. D **70**, 094024 (2004); Y. L. Wu and Y. F. Zhou, *ibid.* **71**, 021701 (2005); S. Baek *et al.*, *ibid.* **71**, 057502 (2005).
[5] A. Arhrib and W. S. Hou, Eur. Phys. J. C **27**, 555 (2003).
[6] S. Eidelman *et al.* (Particle Data Group), Phys. Lett. B **592**, 1 (2004).
[7] For other issues regarding the fourth generation (such as unification of couplings), see, e.g., P. H. Frampton, P. Q. Hung, and M. Sher, Phys. Rep. **330**, 263 (2000).
[8] W. S. Hou, R. S. Willey, and A. Soni, Phys. Rev. Lett. **58**, 1608 (1987).
[9] G. Buchalla, A. J. Buras, and M. E. Lautenbacher, Rev. Mod. Phys. **68**, 1125 (1996).
[10] W. S. Hou, Nucl. Phys. **B308**, 561 (1988).
[11] M. Beneke *et al.*, Nucl. Phys. **B606**, 245 (2001).
[12] Y. Y. Keum, H. n. Li, and A. I. Sanda, Phys. Rev. D **63**, 054008 (2001).
[13] M. Beneke and M. Neubert, Nucl. Phys. **B675**, 333 (2003).
[14] A $\pm 10°$ change in ϕ_3 hardly affects our results.
[15] J. Kaneko *et al.* (Belle Collaboration), Phys. Rev. Lett. **90**, 021801 (2003).
[16] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **93**, 081802 (2004).
[17] M. Iwasaki *et al.* (Belle Collaboration), hep-ex/0503044.
[18] Inspecting Ref. [22], we find the M_{X_s} mass bins covering K and K^* are at some variance with the $B \to K^*\ell\ell$ result reported in K. Abe *et al.*, hep-ex/0410006, based on 275 M $B\bar{B}$ pairs, and A. Ishikawa *et al.*, Phys. Rev. Lett. **91**, 261601 (2003), based on 152 M $B\bar{B}$ pairs. This gives further reason for caution.
[19] A. L. Kagan and M. Neubert, Eur. Phys. J. C **7**, 5 (1999).
[20] See webpage of Heavy Flavor Averaging Group, http://www.slac.stanford.edu/xorg/hfag/.
[21] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **91**, 021801 (2003).
[22] Recently, H. n. Li, S. Mishima, and A. I. Sanda, hep-ph/0508041, find at next-to-leading order in PQCDF, a larger color-suppressed tree (F_{ek}) term. This suppresses the effect of the SM weak phase $e^{-i\phi_3}$ [see Eq. (8)] and makes $\mathcal{A}_{K\pi^0}$ less negative. While we do not necessarily advocate it, we welcome this development as it would allow more parameter space for the fourth generation.
[23] W. S. Hou and K. C. Yang, Phys. Rev. Lett. **84**, 4806 (2000); C. K. Chua, W. S. Hou, and K. C. Yang, Mod. Phys. Lett. A **18**, 1763 (2003).