Large and Fun CP Violation in B Meson Decays: Where to Search?

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The best place to search for direct CP violation is the already observed charmless $b \rightarrow s$ modes. In SM with FSI, $a_{CP}$ in $K\pi$ modes could be as large as 20–30% but differ in sign between $K^-\pi^+ / K^-\pi^0$ and $K^0\pi^-$. We illustrate possible New Physics effects that could lead to $a_{CP}$ of order 40–60% in $K\pi$ and $\phi K$ modes distinguishable from FSI.

$b \rightarrow s\gamma$ modes can also exhibit interesting asymmetries.

1 Motivation

1997 can be called the Year of the Strong Penguin: a handful of two-body charmless $b \rightarrow s$ decays were observed by CLEO for the first time, giving firm indication that strong penguins are dominant. Something completely unexpected also emerged in $\eta'$ modes: Not only exclusive modes are very sizable, semi-inclusive $B \rightarrow \eta' + X_s$ with fast $\eta'$ was found to be close to $10^{-3}$.

We concern ourselves here with direct CP violation in these modes. Given the statistics, the $a_{CP}$ reach is only $\sim 100\%$ at present. But, as B Factories are turning on soon, in 2–5 years this could go down to 30% to 10%. The modes that are already observed so far would certainly be the most sensitive probes. What physics do they and can they probe?

What has been observed so far are charmless $b \rightarrow s$ decays. The ordering $K\pi > \pi\pi$ clearly indicates that strong penguin $>$ tree. We recall that in SM, $a_{CP}$ for pure penguin $b \rightarrow s$ transitions are suppressed by the factor

$$Im\left(\frac{V_{us}V_{ub}^*}{|V_{cs}V_{cb}^*|}\right) \sim \eta \lambda^2 < 1.7\%,$$

(1)

so $a_{CP} > 10\%$ in pure penguin modes would imply New Physics! We therefore have a discovery window in the next few years for beyond SM (BSM) effects. The question then is: What BSM? Is large $a_{CP}$ possible in $b \rightarrow s$ modes? Rather than trying to be exhaustive, we wish to demonstrate that CP asymmetries in $b \rightarrow s$ transitions can indeed be large with simple extensions of SM, and sometimes even within SM.

New Physics will be illustrated with large color dipole $bsg$ coupling

$$-\frac{G_F}{\sqrt{2}} \frac{g}{16\pi^2} V_{tb} V_{ts}^* c_s s_\sigma^{\mu\nu}(1 + \gamma_5) b.$$

(2)

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In SM one finds $c_8^{\text{SM}}(m_b) \simeq -0.3$ which leads to $b \rightarrow sg$ (with $g$ on-shell) \( \sim 0.2\% \), a small rate that is usually neglected. But because $b \rightarrow sg$ just does not give tangible signatures, our experimental knowledge of the strength of $c_8$ is actually rather poor. In fact, the long-standing “deficit” in $B$ decay semileptonic branching ratio ($B_{s,L}$) and charm counting ($n_C$) point towards the possibility of sizable $b \rightarrow sg$ in Nature.\(^3\)\(^4\) If $b \rightarrow sg \approx 10\%$, which implies $c_8 \sim 2$, $B_{s,L}$ and $n_C$ can each be lowered by that amount and the problems would go away. A recent CLEO bound\(^5\) gives $b \rightarrow sg < 7\%$ at 90\% C.L., which comes indirectly from the study of $B \rightarrow D\bar{D}K + X$ decay. But even if one takes this seriously there is still much room, and $b \rightarrow sg$ at 1–5\% would be very hard to rule out. What we stress here is: if $c_8$ is large in Nature, it must be coming from New Physics and should carry naturally a KM-independent CP violating phase.

The idea of an enhanced $bsg$ color dipole coupling and its associated new physics CP phase has been applied to $B \rightarrow \eta' + X_s$ decay. We have advocated that the $g^*g\eta'$ anomaly coupling mechanism\(^6\)\(^7\) is needed to account for the energetic $\eta'$ (or equivalently, the recoil $m_{X_s}$) spectrum. Then, with new CP phase $\sigma$ in $c_8 \cong 2e^{i\sigma}$ interfering with absorptive parts from usual $c_3-6$ penguin coefficients, $a_{CP}$ in inclusive $m_{X_s}$ spectrum could be at 10\% level.\(^7\)

We explore here the general impact of a large color dipole coupling on CP asymmetries in charmless $b \rightarrow s$ decays. If $b \rightarrow sg$ rate is really of order 1–10\% in Nature, even if this rate itself is hard to measure, other charmless $b \rightarrow s$ decays must be affected through interference effects.

2 Model of Unconstrained CP Phase

To have large $b \rightarrow sg$ and evade $b \rightarrow s\gamma$ constraint at the same time, one needs additional source for radiating gluons but not photons. Gluinos ($\tilde{g}$) fit the bill nicely. In SUSY one usually sets soft squark mass terms to be “universal” to suppress FCNC and to reduce the number of parameters. But it has been shown\(^8\)\(^9\) that nonuniversal soft $m_{\tilde{d}_i}$ masses could give large $c_8$ without violating the $b \rightarrow s\gamma$ constraint. In previous studies, however, the possibility of new CP phases were not considered.

As an existence proof, let us consider a minimal model of $\tilde{s} - \tilde{b}$ mixing, the simplest would be $LL$ mixing which mimics SM couplings, but one could also have $RR$ or $LR$ mixing models.\(^\ddagger\) The phase of $d_i$ quarks are fixed by gauge interaction, and there is just one mixing angle $\theta$ and one phase $\phi$. Since this mixing involves only the second and third generations, one evades low energy bounds that involve first generation quarks, such as neutron edm, the $K$ system, and even $B_{d^0}\bar{B}_{d^0}$ mixing. This is a natural model that is tailor made
for generating large effects in $b \to s$ transitions (as well as $B_s$ mixing)!

3 Direct CP Violation in Inclusive $b \to s\bar{q}q$ Decay

The theory of inclusive decays are cleaner since one can use the quark/parton language. The absorptive parts arising from short distance perturbative rescattering can be used and one is insensitive to long distance phases. However, experimental detection poses a challenge, unless partial reconstruction techniques can be made to work.

Since penguins dominate charmless $b \to s$ decays, one is interested in CP violation in pure penguin processes such as $b \to s\bar{d}d$ and $s\bar{s}s$. But since these rates and asymmetries occur at $\mathcal{O}(\alpha^2_S)$, care has to be taken in treating CP violation in the $b \to s\bar{u}u$ mode, which has the distinction of receiving also the tree contribution. Although the tree amplitude alone does not lead to CP violation, while tree–penguin interference occurs only at $\mathcal{O}(\alpha S)$, to be consistent with treating pure penguin CP asymmetries, one needs to take into account the absorptive part carried by the gluon propagator (bubble graph) associated with the penguin. This $\mathcal{O}(\alpha^2_S)$ tree–penguin interference term is needed to maintain CPT and unitarity in rates and hence $a_{CP}$.

The above discussion has been stated in terms of “full” theory (exact loop calculation) to lowest relevant order in $\alpha_S$. Since QCD corrections are important and relatively well developed by now, we adopt an operator language in computing inclusive rates. We start from the effective Hamiltonian

$$
H_{\text{eff}} = \frac{4G_F}{\sqrt{2}} \left[ V_{ub}V_{us}^*(c_1O_1 + c_2O_2) - V_{tb}V_{ts}^* c_1^3 O_3 \right],
$$

with $i$ summed over $u,c,t$ and $j$ over 3 to 8. The operators are defined as

$$
O_1 = \bar{u}_\alpha \gamma_\mu Lb \bar{d}_\beta \gamma^\mu L u_\alpha,
O_2 = \bar{u}_\gamma \mu Lb \bar{s}_\gamma \mu L u_\alpha,
$$

$$
O_{3,5} = \bar{s}_\alpha \gamma_\mu Lb \bar{q}_\gamma \mu L(R)q_\alpha,
O_{4,6} = \bar{s}_\alpha \gamma_\mu Lb \bar{q}_\gamma \mu L(R)q_\alpha,
$$

$$
\hat{O}_8 = \frac{\alpha_s}{4\pi} \hat{s}_\alpha \mu \nu T^a \frac{m_d q^\mu}{q^2} \bar{R}b \gamma^\mu T^a q,
$$

where $\hat{O}_8$ arises from the dimension 5 color dipole $O_8$ operator of Eq. (2), and $q = p_b - p_s$. We have neglected electroweak penguins for simplicity. The Wilson coefficients $c_j$ are evaluated to NLO order in regularization scheme independent way, for $m_t = 174$ GeV, $\alpha_s(m_Z^2) = 0.118$ and $\mu = m_b = 5$ GeV. Numerically, $c_{1,2} = -0.313$, $1.150$, $c_{3,4,5,6} = 0.017$, $-0.037$, $0.010$, $-0.045$, and $c_8 = -0.299$. We note that $c_{1,2}$ are resummations of series starting at $\mathcal{O}(\alpha^2_S)$, while $c_{3-6}$ start at $\mathcal{O}(\alpha^3_S)$ which is reflected in their relative...
smallness. However, one power of $\alpha_S$ is factored out by convention in defining $O_8$, hence $c_8$ starts at $O(\alpha_S^0)$ and its size is comparable to $c_1$ within SM. One has to keep track of the **relevant leading order** in $\alpha_S$ when comparing with “full theory” approach discussed earlier.

To get absorptive parts, we add $c_{4,6}^{u,c}(q^2) = -Nc_{3,5}^{u,c}(q^2) = -P^{u,c}(q^2)$ for $u$, $c$ quarks in the loop, where

$$P^{u,c}(q^2) = \frac{\alpha_s}{8\pi} c_2 \left( \frac{10}{9} + G(m_{u,c}^2, q^2) \right),$$

and

$$G(m^2, q^2) = 4 \int x(1-x)dx \ln \frac{m^2 - x(1-x)q^2}{\mu^2}.$$  

To respect CPT/unitarity at $O(\alpha_S^2)$, for $c_{3-8}$ at $\mu^2 = q^2 < m_b^2$, we substitute

$$\text{Im} c_8 = \frac{\alpha_s}{4\pi} c_8 \sum_{u,d,s,c} \text{Im} G(m_u^2, q^2),$$

$$\text{Im} c_{4,6} = -N\text{Im} c_{3,5} = \frac{\alpha_s}{8\pi} \left[ c_3^{u} \text{Im} G(m_u^2, q^2) + (c_4^{u} + c_6^{u}) \sum_{u,d,s,c} \text{Im} G(m_u^2, q^2) \right],$$

when interfering with the tree amplitude. We note that the use of operator language can be misleading at this stage since the absorptive parts are not resummed while the Wilson coefficients are. One could easily lose track of $\alpha_S$ counting that is needed for maintaining CPT/unitarity if one thinks too naively in effective theory language.

Having made all these precautions, we can square amplitudes in a straightforward manner to obtain rates and arrive at the asymmetries. Since at lower order one has $b \rightarrow s g$ decay, the $|c_8|^2$ term has a log $q^2$ pole behavior. We regulate it by simply cutting it off at 1 GeV. Fig. 1(a) gives the rates for $b \rightarrow s dd$ (solid) and $b \rightarrow s dd$ (dashed) vs. $y = q^2/m_b^2$. The SM result does not show a prominent low $q^2$ tail since $b \rightarrow s g$ is small, and the asymmetry comes mostly from below $c \bar{c}$ threshold. For larger $q^2$ the $\alpha_{CP}$ is GIM suppressed. The SM asymmetry is indeed tiny. For new physics enhanced $c_8 = 2e^{i\sigma}$, we consider the cases for $\sigma = \pi/4$, $\pi/2$ and $3\pi/4$. Besides a very prominent low $q^2$ tail since $b \rightarrow s g$ is now $\sim 10\%$, the salient feature is the rather large rate asymmetries above $c \bar{c}$ threshold. The reason is because the new physics $\sigma$ phase now evades the SM constraint of Eq. (1), and the $c_8$ amplitude interferes with standard $c_{3-6}$ penguins which carry the absorptive parts due to (perturbative) $c\bar{c}$ rescattering, but the $u\bar{u}$ rescattering absorptive part is suppressed by $V_{ub}$. Note that for $\sigma = \pi/4$, $3\pi/4$ one has constructive, destructive interference, respectively.
For the latter case, the overall rate is close to SM but the asymmetries are much larger, reaching 30% for large $q^2$.

For $b \rightarrow s\bar{u}u$ the tree diagram also contributes, and one has to include the absorptive part in gluon propagator as discussed earlier. Because of this, the rate asymmetries in SM occur both below and above $c\bar{c}$ threshold, as can be seen in Fig. 1(b). Each are larger than the $b \rightarrow s\bar{d}d$ case but are of opposite sign hence they tend to cancel each other. If $c_8$ is enhanced, however, the dominant mechanism is again interference between $c_8$ and the usual penguins, hence the results are similar to the $b \rightarrow s\bar{d}d$ case. For $b \rightarrow s\bar{s}s$ mode, one has to take into account identical particle effects. As seen in Fig. 1(c), this leads to the peculiar shapes at large and small $q^2$, and the asymmetry is now smeared over all $q^2$. But otherwise it is similar to the $b \rightarrow s\bar{d}d$ case.

The integrated inclusive results are summarized in Table 1.

| $b \rightarrow s\bar{d}d$ | $b \rightarrow s\bar{u}u$ | $b \rightarrow s\bar{s}s$ |
|---------------------------|---------------------------|---------------------------|
| $\sigma = 0$              | $\sigma = 0$              | $\sigma = 0$              |
| $\sigma = \pi/4$          | $\sigma = \pi/2$          | $\sigma = 3\pi/4$         |
| $\sigma = \pi$            | $\sigma = \pi$            | $\sigma = \pi$            |
| SM                        | SM                        | SM                        |
| 2.6/0.8                   | 2.4/1.4                   | 2.0/0.9                   |
| 8.5/0.4                   | 8.1/0.2                   | 6.9/0.4                   |
| 7.6/3.4                   | 7.5/2.6                   | 6.2/3.2                   |
| 1.5/6.5                   | 5.5/5.6                   | 4.4/6.0                   |
| 2.9/8.1                   | 3.2/8.1                   | 2.6/7.1                   |
| 1.9/0.5                   | 2.0/3.5                   | 1.8/0.4                   |
4 Direct CP Violation in Exclusive Charmless Hadronic Modes

The exclusive modes are more accessible experimentally, as evidenced by the handful of observed modes. Unfortunately, the theory is not clean. One has to evaluate all possible hadronic matrix elements of operators in Eq. (3). Faced with CLEO data, it has become popular to use $N_{\text{eff}}$ rather than the value of 3 as dictated by QCD. Although it is a measure of deviation from factorization, it becomes in reality a new process dependent fit parameter. One is still subject to usual approximations and imprecise knowledge of form factors and the $q^2$ value to take. CP asymmetries are especially sensitive to the latter. At the rate level, the $K\pi$ modes are approximately manageable, but the $\eta'K$ and $\omega K$ modes seem high while the $\phi K$ mode seems low. Thus, even introducing $N_{\text{eff}}$ as a new parameter, there are problems everywhere already in rate. A new development in 1998 is that the $B^- \to K^-\pi^0$ mode has been observed, while the $B^- \to K^0\pi^-$ rate came down considerably. One has now three measured $K\pi$ modes and their rates are all around $1.4 \times 10^{-5}$.

We shall not discuss the $\eta'$ modes here since it must have a large contribution from anomaly mechanism and is rather difficult to treat. But we do wish to explore whether an enhanced $c_8$ could improve agreement with experiment. Before we do so, however, we point out that the $K\pi$ modes offer a rather interesting subtlety: they in general have two isospin components and exhibit larger $a_{CP}$ within SM, and they are very sensitive to final state interaction (FSI) phases. As shown in Ref. [12] but now put in terms of the angle $\gamma$, in the absence of FSI phases one finds for $B^- \to K^-\pi^0$ mode

$$a_{uu} \propto \frac{\#_1 \sin \gamma}{\left| \#_2 - \#_3 \cos \gamma \right|^2},$$

where $\#_1$ comes from interference, while $\#_2$ and $\#_3$ come from penguin and tree $b \to s\bar{u}u$ amplitudes, respectively. $\#_3$ and the dispersive part of $\#_2$ have the same sign. At the time of Ref. [12], $\cos \gamma < 0$ was favored, while $\sin \gamma$ was smaller than today, hence $a_{uu}$ was not very large. The present preferred value is $\gamma \sim 64^\circ$, however, and one now has destructive rather than constructive interference. Hence, one not only gains from $\sin \gamma \sim 0.9$ in the numerator, there is also extra enhancement from the denominator of Eq. (5), and $a_{uu}$ as large as 10% is possible. Furthermore, since one can write $(\bar{s}u)(\bar{u}b) = [(\bar{s}u)(\bar{u}b) + (\bar{s}d)(\bar{d}b)]/2 + [(\bar{s}u)(\bar{u}b) - (\bar{s}d)(\bar{d}b)]/2$, there is in general two isospin components from the tree level $O_1$ and $O_2$ operators. These two isospin amplitudes may develop FSI phases that are different from each other. If such is the case, it could overrun the perturbatively generated (hence $\alpha_S$ suppressed) absorptive phases, and much larger CP asymmetries can be achieved. While this is good news for CP violation search in general, it is bad news for search of new
physics. Can one distinguish between new physics effects and SM with large FSI phases? The answer is yes, if one compares several modes.

Let us give a little more detail for sake of illustration. We separate the $\bar{B} \to K^-\pi^+$ amplitude into two isospin components, $A = A_{1/2} + A_{3/2}$. Since color allowed amplitudes dominate, $N_{ii} \simeq N = 3$. Defining $v_i = V^\ast_{ib}V_{ib}$ and assuming factorization, we find,

$$A_{1/2} = \frac{G_F}{\sqrt{2}} f_K F_0 (m_B^2 - m_\pi^2) \left\{ v_u \left[ \frac{2}{3} \left( \frac{c_1}{N} + c_2 \right) - \frac{r}{3} \left( c_1 + c_2 \right) \right] \right.$$  

$$- v_j \left[ \frac{c_3^j}{N} + c_4^j + \frac{2m_K^2}{(m_b - m_u)(m_s + m_u)} \left( \frac{c_3^j}{N} + c_4^j \right) \right] - v_t \frac{\alpha_s m_b^2}{4\pi q^2} c_8 \tilde{S}_{\pi K} \right\} , \tag{6}$$

where $F_0 = F_0^{B\pi}(m_K^2)$ is a BSW form factor, $\tilde{S}_{\pi K} \sim -0.76$ is a complicated form factor normalized to $F_0$, and $r$ is some ratio of $B \to K$ and $B \to \pi$ form factors and a measure of SU(3) breaking. For $A_{3/2}$ one sets $c_{3-8}^j$ to zero and substitutes $2/3$, $-r/3 \to 1/3$, $r/3$. The $K^-\pi^0$ mode is analogous, with modifications in $A_{3/2}$ and an overall factor of $1/\sqrt{2}$. The penguins contribute only to $A_{1/2}$, hence the naively pure penguin $B^- \to \bar{K}^0\pi^-$ amplitude has just Eq. (6) with $c_{1,2}$ set to zero. Note that the $c_{5,6}$ effects are sensitive to current quark masses because of effective density-density interaction. The absorptive part for $c_{3-8}$ are evaluated at $q^2 \approx m_b^2/2$ which favors large $a_{CP}$, but $q^2$ could be as low as $m_b^2/4$. We plot in Fig. 2(a) and (b) the branching ratio ($Br$) and $a_{CP}$ vs. angle $\gamma$. For $K^-\pi^+, a_{CP}$ peaks at the sizable $\sim 10\%$ just at the currently favored value of $\gamma \approx 64^\circ$. But for $K^0\pi^-, a_{CP} \approx \eta\lambda^2$ is very small. We have used $m_s(\mu = m_b) \approx 120$ MeV since it enhances the rates. With $m_s(\mu = 1$ GeV) $\simeq 200$ MeV, the rates would be a factor of 2 smaller. We find $K^-\pi^+, \bar{K}^0\pi^-, K^-\pi^0 \sim 1.4$, $1.6$, $0.7 \times 10^{-5}$, respectively.

To illustrate the effect of FSI, we now write $A = A_{1/2} + A_{3/2}e^{i\delta}$ and plot in Fig. 2(c) and (d) the $Br$ and $a_{CP}$ vs. $\delta$ for $\gamma = 64^\circ$. The rate is not very sensitive to $\delta$ which reflects penguin dominance, but $a_{CP}$ can now reach 20%, even 30% for $K^-\pi^0$. We stress that the naively pure penguin $K^0\pi^-$ mode is in fact also quite susceptible to FSI phases as it is the isospin partner of $K^-\pi^0$, which definitely receives tree contributions. The $B^- \to \bar{K}^0\pi^-$ mode can receive tree contributions through FSI rescattering. Comparing Fig. 2(b) and (d), $a_{CP}$ in this mode can be much larger than the naive factorization result. However, the $a_{CP}$ for $K^0\pi^-$ and $K^-\pi^+$ are out of phase, hence, comparing the two cases can give information on the FSI phase $\delta$.

For physics beyond SM such as $c_8 = 2e^{i\sigma}$, there are too many parameters and one needs a strategy. We set $N = 3$ and try to fit observed $Br$’s with the phase $\sigma$, then find the preferred $a_{CP}$. Since the $c_8$ term now dominates, one
is less sensitive to the FSI phase $\delta$. In fitting $Br$'s, we find that destructive interference is necessary which can be understood from the inclusive results of Fig. 1. This means that large $a_{CP}$s are preferred! We plot in Fig. 2(e) and (f) the $Br$ and $a_{CP}$ vs. the new physics phase $\sigma$, for $\gamma = 64^\circ$ and $\delta = 0$. The $K^-\pi^+$ and $\bar{K}^0\pi^-$ modes are very close in rate for $\sigma \sim 45^\circ - 180^\circ$, but the $K^-\pi^0$ mode remains a factor of 2 smaller. However, the $a_{CP}$ can now reach 50% for $K^-\pi^+/\bar{K}^0\pi^-$ and 40% for $K^-\pi^0$. These are truly large asymmetries and would be easily observed, perhaps even before B Factories turn on (i.e. with CLEO II.V data!). They are in strong contrast to the SM case with FSI phase $\delta$, Fig. 2(d), and can be distinguished.

Genuine pure penguin processes arising from $b \to s \bar{s}s$ give cleaner probes of new physics $CP$ violation effects since they are insensitive to FSI phase. The amplitude for $B^- \to \phi K^-$ decay is

$$A(B \to \phi K) \simeq -i \frac{G_F}{\sqrt{2}} f_{\phi} m_\phi 2 p_B \cdot \epsilon \phi F_1(m_\phi^2) \left\{ v_j \left( c_j^3 + \frac{c_j^4}{N} + c_j^5 \right) \right\} + \nu \frac{\alpha_s m_\phi^2}{4 \pi q_1^2} c_8 \tilde{S}_{\phi K} \right\}.$$  

(7)
The relevant $q^2$ is determined by kinematics: $q^2_1 = m^2_0/2$ as before, but for amplitudes without Fierzing $q^2_2 = m^2_0$. We have dropped color octet contributions and have checked that they are indeed small. Since the amplitude is pure penguin, $c_8$ should have no absorptive part. As shown in Fig. 2(a) and (b), the SM rate of $\sim 1 \times 10^{-5}$ is above the CLEO bound of $0.5 \times 10^{-5}$ while $a_{CP}$ is uninterestingly small. If we allow for new physics enhanced $c_8 = 2 e^{i\sigma}$, one again needs destructive interference to match observed rate. The results are plotted in Fig. 2(e) and (f) vs. $\sigma$. The rate is lower than the $\bar{K}_0 \pi^-/K^-\pi^+$ modes because it is not sensitive to $1/m_s$ and we have used a low $m_s$ value to boost up $B \to K\pi$. The $a_{CP}$ could now reach almost 60%, thanks to the destructive interference preferred by fitting the CLEO limit on rate. We note that the SM asymmetry for $B \to \phi K$ should be of order 1%.

One can now construct an attractive picture. We have noted that recent studies cannot explain the low $B \to \phi K$ upper limit within SM. If $c_8$ is enhanced by new physics and interferes destructively with SM, $B \to \phi K$ can be brought down to below $5 \times 10^{-6}$. The experimentally observed $\bar{K}^0\pi^- \simeq K^-\pi^+$ follows from $c_8$ dominance, and their rate $\sim 1.4 \times 10^{-5}$ which is 2–3 times larger than the $\phi K$ mode suggests a low $m_s$ value and slight tunings of BSW form factors. Around $\sigma \sim 145^\circ$, the rates are largely accounted for, but $a_{CP}$ for $\phi K$, $K^-\pi^+/K^0\pi^0$ and $\bar{K}^0\pi^-$ could be enhanced to the dramatic values of 55%, 45% and 35%, respectively, and all of the same sign. This is certainly distinct from the sign correlations of SM with FSI.

On the down side, within the scenario of strong penguin dominance, which includes the case of enhanced $c_8$, the $B^- \to K^-\pi^0$ rate is always about a factor of two smaller than the $K^-\pi^+$ mode, and we are unable to accommodate recent CLEO findings. We are also barely able to accommodate $B \to \omega K$. Within SM one needs $1/N_{eff} \sim 1$ to be able to account for the large $B \to \omega K \simeq 1.5 \times 10^{-5}$ value, while for $1/N_{eff} \simeq 0$ one can account for only half. Adding new physics induced $c_8 = 2 e^{i\sigma}$ effect, we are able to account for $Br$ for both large and small $N_{eff}$, but not for $N = 3$. However, $a_{CP}$ is never more than a few % and hence not very interesting. Since the $\omega K$ mode has a single isospin amplitude, it is insensitive to FSI rescattering phases.

5 CP Violation in $b \to s\gamma$ Decays

We have emphasized that the $b \to s$ modes that are already observed are the best places for CP search. Clearly, the $B \to K^*\gamma$ and $b \to s\gamma$ modes were the first ever observed penguins in $B$ decay, and they should provide a good window. We note that the observed recoil $m_X$, spectrum for $B \to \gamma + X_s$ is basically orthogonal to that for $B \to \eta' + X_s$, and is clearly dominated by
K resonances. However, besides the $B \rightarrow K^*\gamma$ mode, the higher resonance contributions to the inclusive spectrum has not yet been disentangled.

It is important to realize that, although in our previous discussions of enhanced $b \rightarrow s\gamma$, one must reckon with the $b \rightarrow s\gamma$ constraint, the converse is not true. One can have interesting impact on $b \rightarrow s\gamma$ without affecting $b \rightarrow s\gamma$ by much. Our example of $\bar{s}_{L,R} \rightarrow \bar{b}_{L,R}$ mixings can generate a lot of effects. The $c_7O_7$ operator structure of SM can become $c_7O_7 + c'_7O'_7$, where $O'_7$ has opposite chirality to $O_7$ (and likewise for the gluonic $O_8$). This leads to much enrichment of the physics compared to SM:

- **Direct CP violation in $b \rightarrow s\gamma$ and $B \rightarrow K^*\gamma$**
  Since SM accounts for the observed $b \rightarrow s\gamma$ rate already, one has the constraint $|c_7^{SM}|^2 \sim |c_7^{SM} + c_7^{New}|^2$, hence one prefers $c_7^{New}$ to be small. We find that a $c_{CP}$ larger than 10% is possible in certain parameter space, especially when the new physics effect has opposite sign w.r.t. SM.

- **Mixing dependent CP violation**
  This requires interference between $O_7$ and $O'_7$, the two different chiralities. For $B^0 \rightarrow M^0\gamma$, where $M^0$ is a CP eigenstate with eigenvalue $\xi$, one obtains a mixing dependent asymmetry:

  $$A_{mix} = 2\xi \frac{|c_7c'_7|}{|c_7|^2 + |c'_7|^2} \sin[\phi_B - \phi - \phi'],$$

  where $\phi^{(t)}$ are the weak phases of $c_7^{(t)}$. Note that $\phi^{(t)}$ could vanish and one could still have CP violation through $\phi_B$ from $B$-mixing within SM. We find that the coefficient to the phase factor can reach 80% in special regions of parameter space of our model. Unfortunately, $B^0 \rightarrow K^{*0}\gamma \rightarrow K_S\pi^0\gamma$ does not give a vertex, and one would need to turn to either $B_s \rightarrow \phi\gamma$, or $B_d \rightarrow K_1^{0}\gamma, K_2^{*0}\gamma$, none of which are yet observed.

- **Chirality probe: $\Lambda_b \rightarrow \Lambda\gamma$**
  How does one know that both SM-like $b \rightarrow s_L\gamma_{L'}$ and new physics induced $b \rightarrow s_R\gamma_{R'}$ transitions occur? The best way, independent of CP violation (but direct $a_{CP}$ in rates is of course possible), is to search for $\Lambda_b \rightarrow \Lambda\gamma$ decay, since $\Lambda \rightarrow p\pi$ decay is self-analyzing. One has:

  $$\frac{d\Gamma}{d\cos\theta} \propto 1 + \frac{|c_7|^2 - |c'_7|^2}{|c_7|^2 + |c'_7|^2} \cos\theta,$$

  where $\theta$ is the angle between the direction of $\vec{p}_\Lambda$ in $\Lambda_b$ frame and the direction of the $\Lambda$ polarization in its rest frame. The coefficient of $\cos\theta$
is clearly equal to 1 in SM, but could be different in Nature. We find that even $-1$ is possible! When and where will $\Lambda_b \rightarrow \Lambda \gamma$ decay be measured?

6 Discussion and Conclusion

We must recall that $B$ physics has had its share of surprises. The long $b$ lifetime was discovered without much theory encouragement. $B_d$ mixing was in fact discovered with theory “discouragement”. More recently, the $\eta'K$ and $\omega K$ modes turn out to be much larger than theory expectations, while the huge inclusive fast $\eta' + X_s$ simply came out of the blue without theory warnings. We therefore must be on guard for CP violation.

In the narrow sense, we have discussed a large $\tilde{s} - \tilde{b}$ squark mixing model that could generate large color dipole $bsg$ coupling which carries an unconstrained new CP phase, and lead to large impact on CP violating asymmetries: in $\eta' + X_s$, charmless 2-body modes such as $K\pi$ and $\phi K$, $b \rightarrow s\gamma$, even in $J/\psi K_S \pi^0$ modes. In the broad sense, we have illustrated that large CP asymmetries may just pop up everywhere as B Factories turn on!

Let’s search for CP violation in already observed modes, assuming they are large!

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