PROBING NEW PHYSICS IN $B_S$ AND D MIXINGS, AND $A_{CP}(B^+ \to J/\psi K^+)$

GEORGE W.S. HOU

Department of Physics, National Taiwan University, Taipei, Taiwan 10617, R.O.C.

*E-mail: wshou@phys.ntu.edu.tw

A 4th generation could be consistent with the recently measured $\Delta m_{B_s}$, as well as $B(b \to s\ell^+\ell^-)$, which are SM-like, but generate large $\sin2\Phi_{B_s} \approx -0.5$ to $-0.7$. The sign is determined by the hint for New Physics in CPV measurements in charmless $B$ decays. The $4 \times 4$ unitarity allows one to connect to all processes involving flavor. Fixing $V_{tbs}, V_{tbs}$ and $V_{tbs}$ by $Z \to bb, b \to s$ and $s \to d$ processes, we predict $D$ mixing to be close to the current bound. As a further corollary, we suggest that $A_{CP}(B^+ \to J/\psi K^+)$ could be at 1% level or higher, where we give plausibility of an associated strong phase. Our predictions can be tested in the near future.

1. Introduction: SM Reigns?

The New York Times reported on July 4th the measurement of $B_s$ mixing at the Tevatron, stating that “it was right on the money as predicted by the Standard Model”, and quoting a CDF spokeswoman, “Our real hope was for something bizarre”.

The measured $\Delta m_{B_s} = 17.77 \pm 0.10 \pm 0.07$ ps$^{-1}$ is indeed consistent with SM, but there is still hope for something bizarre: Can CP violation in $B_s$ mixing be large? Given that $\sin2\Phi_{B_s} = -\sin2\beta_s \sim -0.04$ is very small, any definite measurement at the Tevatron would imply New Physics (NP). There is reason for hope. The $\Delta m_{B_s}$ value is somewhat lower than the CKM/UT fit projections made without using $\Delta m_{B_s}$ in the fit.

In the 4 generation model we predict $\sin2\Phi_{B_s}$ is large and negative, with two corollaries. One is finite $D$ mixing close to current bounds, the other is observable direct CPV (DCPV) in $B^+ \to J/\psi K^+$ decay. Mixing dependent CPV (TCPV) measured in $B^0 \to J/\psi K^0$, namely $S_{J/\psi K} = 0.685 \pm 0.032$, is also low against CKM/UT fit predictions, which could be due to NP phase.

Admittedly, SM4 has troubles with precision EW tests. But with the LHC approaching, we should keep an open mind. For $N_{\nu}$ counting, as discussed by Soddu, massive neutrinos call for NP. The reason we focus on the 4th generation is its ease in affecting heavy meson mixings and other electroweak penguins (EWP), and it naturally brings in a new CPV phase.

2. Large CPV in $B_s$ Mixing

The 4 generation unitarity for $b \to s$ transitions is $\lambda_u + \lambda_c + \lambda_t + \lambda_{t'} = 0$, where $\lambda_t \equiv V_{tb}^* V_{tb}$. Since $|\lambda_u| < 10^{-3}$ by direct measurement, one effectively has

$$\lambda_t \cong -\lambda_c - \lambda_{t'}, \quad (1)$$

where one has a NP CPV phase through $\lambda_{t'} \equiv V_{t's} V_{t'z} \equiv r_{s} e^{i\phi_{s}}$, and Eq. (1) becomes a triangle with potentially large area, i.e. large CPV effect.

The formula for $B_s$ mixing is

$$M_{12} \propto f_{B_s}^2 B_{B_s} \{ \lambda^2 S_0(t, t) - 2\lambda_c \lambda_{t'} \Delta S_0^{(1)} + \lambda_{t'}^2 \Delta S_0^{(2)} \}, \quad (2)$$

where $S_0(t, t)$ gives SM3 top effect, and the $t'$ effects are GIM subtracted and vanish with $\lambda_{t'}$, analogous to $\Delta C_i \equiv C_i - C_i^0$ terms that modify the Wilson coefficients $C_i$ for $b \to s$ decays. One also has analogous strong dependence on $m_{t'}$, i.e. nondecoupling of $t$ and $t'$ from box and $Z$ penguins.
Fig. 1. (a) $\Delta m_{B_s}$, (b) $\sin 2\Phi_{B_s}$ vs $\phi_{sb}$, for $m_t = 300$ GeV and $r_{sb} = 0.02, 0.025$ and 0.03. Larger $r_{sb}$ gives stronger variation.

Taking $m_t = 170$ GeV and the central value of $f_{B_s} \sqrt{B_{B_s}} = 295 \pm 32$ MeV from lattice, we find $\Delta m_{B_s}^{SM} \sim 24$ ps$^{-1}$, which is on the high side compared with Eq. (1). Of course $f_{B_s} \sqrt{B_{B_s}}$ could be lower, but it could also be higher. One may therefore need SM4 to bring $\Delta m_{B_s}$ down a bit.

Keeping $f_{B_s} \sqrt{B_{B_s}} = 295$ MeV, in Fig. 1(a) we plot $\Delta m_{B_s}$ vs $\phi_{sb}$ for $m_t = 300$ GeV and $r_{sb} = 0.02, 0.025$ and 0.03, where dashed line is the SM3 value, and solid band is the $2\sigma$ range of Eq. (1). We see that $\Delta m_{B_s}$ comes down to the CDF range in 1st and 4th quadrant. For $r_{sb} = 0.02, 0.025, 0.03$, we find $\phi_{sb} \simeq 52^\circ - 55^\circ, 62^\circ - 64^\circ, 67^\circ - 69^\circ$. This implies large CPV, i.e. large $\sin 2\Phi_{B_s}$, which is plotted in Fig. 1(b).

It is important to note that the parameter range above not only gives SM-like $\Delta m_{B_s}$, it also gives SM-like $B(b \to s \tau^+ \tau^-)$, as the latter is also dominated by EWP and box diagrams. In fact, combining $\Delta m_{B_s}$ with the $b \to s \tau^+ \tau^-$ rate, $|\phi_{sb}| \gtrsim 55^\circ$ is implied, which practically rules out the allowed range from $\Delta m_{B_s}$ for $r_{sb} \sim 0.02$. This leads to $|\sin 2\Phi_{B_s}| \sim 0.5$ to 0.7. Thus, things may still turn “bizarre”. Given that CDF has made precision measurement of $\Delta m_{B_s}$, can one pull off another coup in measuring $\sin 2\Phi_{B_s}$, before LHC start? Any definite measurement would be a discovery of NP!

Currently we have two hints for NP in CPV $b \to s$ transitions. Interestingly, they favor $\sin 2\Phi_{B_s} < 0$. One hint is TCPV in $b \to s\bar{q}q$: the $\Delta S \equiv S_{s\bar{q}q} - S_{sccs} < 0$ problem. The other hint is difference in DCPV between $B \to K^+ \pi^- \text{ vs } K^+ \pi^0$: the $-\Delta A_{K\pi} \equiv A_{K\pi} - A_{K\pi^0} < 0$ problem.

All measurements of TCPV in $b \to s\bar{q}q$ modes at present give values lower than charmonium modes, giving a combined significance of $2.5\sigma$. What aggravates this is the SM expectation of $\Delta S > 0$. In QCD, it was shown that $S_{K\pi}$ and $S_{K\bar{K}}$ are more robust than rates, which have large hadronic uncertainties. However, $S_{K'\pi}$ gets diluted away by effect of the large rate. In a model independent way, it has recently been shown that, if this discrepancy persists as data improves, it would definitely imply NP.

The difference $\Delta A_{K\pi} \simeq 0.15$ is now established. It is a puzzle because naively one expects it to be smaller. There are two possibilities. One is an enhancement of the color-suppressed tree $(C)$. The other is from $P_{K\pi}$ (the EWP), which would demand NP CPV effect. The latter case was demonstrated with the 4th generation, where the $\phi_{sb}$ phase of Eq. (2) affects $P_{K\pi}$. The C and $P_{K\pi}$ efforts were recently joined and carried to NLO in PQCD factorization. Both trends for $\Delta A_{K\pi}$ and $\Delta S$ can be accounted for by $A_{K\pi^0}$ and $R_c$. $R_c$ ratios are in good agreement with the new experimental results, while further prediction for $S_{\pi K}$ can be tested in the future.

As these are CPV measurables, the upshot from the $\Delta S$ and $\Delta A_{K\pi}$ discussion is that they select $\sin 2\Phi_{B_s} < 0$ in SM4.

3. $D$ Mixing Prediction

Four generation unitarity links all flavor changing and CPV processes together. With $V_{ts}^* V_{tb}$ large, one has to check for
One first saturates the $Z \times$ cc $\times$ $\times$ ical 4 $\times$ consistencies. Remarkably, when the above procedure is done, it was found that $B_d$ mixing and associated CPV (“$\sin \phi$”), as well as other $b \rightarrow d$ effects, all do not get much affected. The reason is because one cannot easily tell apart (at present level of errors) the $b \rightarrow d$ unitarity quadrangle in SM3.

One striking feature of the “fitted” $4 \times 4$ matrix is that $V_{ud} \simeq -0.0044 e^{-110^\circ}$, $V_{ts} \simeq -0.114 e^{-170^\circ}$, and $V_{ub} \simeq 0.068 e^{61^\circ}$, $V_{cb} \simeq 0.116 e^{66^\circ}$ are not smaller than 3rd generation elements. Though somewhat uncomfortable, this is data driven, and draws our interest to $D$ mixing, since

$$V_{ub}V_{cb}^* \equiv r_{uc} e^{-i\phi_{uc}} = +0.0033 e^{-i15^\circ},$$

(3) would affect $c \rightarrow u$ transitions via $b'$ loops. Since $|V_{ub}V_{cb}| \lesssim 10^{-4}$ by direct measurement, the unitarity condition is effectively

$$V_{ud}V_{cs}^* + V_{us}V_{cs} + V_{ub}V_{cb}^* \simeq 0,$$

(4) with $V_{ud}V_{cs}^* \simeq -0.218$ and $V_{us}V_{cs} \simeq 0.215$ real to better than 3 decimal places, much like in SM. These govern $c \rightarrow udd$ and $u\bar{s}s$ processes, where especially the latter could generate width difference $y_D = \Delta \Gamma_D/2\Gamma_D$ through long-distance effects.

Though small, $V_{ub}V_{cb}^*$ of Eq. (3) can affect $D^0$-$\bar{D}^0$ mixing, because $m_{b'} \sim m_t$ is expected, hence very heavy. The short distance effect corresponds to the $\Delta S_0^{(2)}$ term in Eq. (2), with $f_B^2 B B \lambda_t \rightarrow f_D^2 B_D |V_{ub}V_{cb}^*|$, and $m_{b'} \rightarrow m_{b'}$. This generates $\Delta \Gamma_D^b$ which would be vanishingly small in SM3 because of $|V_{ub}V_{cb}|^2$ suppression.

We used$^{13}$ $V_{ud}^* V_{tb} \equiv r_{db} e^{i\phi_{db}}$ to fit kaon data, and found $\phi_{db} \sim 10^\circ$ and $r_{db} \sim 10^{-3}$. For illustration, we take $f_D \sqrt{B_D} = 200$ MeV and plot $\Delta m_D$ vs $\phi_{db}$ in Fig. 2, for $m_{b'} = 230, 270$ and 310 GeV. Our scenario predicts $\Delta m_D^{SD} = \Delta m_D^B/\Gamma_D \sim 1\% - 3\%$, which lies just below the current bound$^{14}$ (horizontal line), and could be accessible soon. We find CPV in $D^0$ mixing to be no more than $-0.2$ level, which is consistent with null search for CPV.

There is in fact a hint for width difference. Averaging over $D^0$ decays to CP eigenstates $K^+K^-$ and $\pi^+\pi^-$ gives$^{14}$ $y_{CP} = 0.90 \pm 0.42 \%$. Another effort is to measure $x' = x_D \cos \delta + y_D \sin \delta$ and $y' = y_D \cos \delta - x_D \sin \delta$ in wrong-sign $D^0 \rightarrow K^+\pi^-$ decays, which could arise through mixing, or from doubly Cabibbo suppressed decays. The current best limit comes from Belle,$^{14}$ $|x'| < 2.7\%$ and $-1\% < y' < 0.7\%$. For small $\delta$ this implies $y' \sim y_D \sim 1\%$ and $x$ would be not much larger. However, for strong phase $\delta \sim 20^\circ - 50^\circ$, $x_D$ could be several times larger than $y_D \sim 1\%$. With an active program at the B factories and CLEO-c, and the expectation that BESIII and LHCb would start running in 2008, it looks promising that $x_D \sim 0.01$ to 0.03 can be discovered soon.

4. DCPV in $B^+ \rightarrow J/\psi K^+$

One intriguing “prediction” we can make is $A_{J/\psi K^+} \neq 0.\,^{15}$ The $B^+ \rightarrow J/\psi K^+$ is dominated by the color-suppressed $b \rightarrow c\bar{c} s$ tree, while inclusion of the penguin in SM3 does not alter the weak phase, which is $\simeq 0$. But the full amplitude is likely carrying a strong phase $\delta$, since all color-suppressed modes observed
so far seem enhanced, with effective underlying strong phase. Examples are $B^0 \rightarrow D^0 \pi^0$, $\pi^0 \pi^0$. Although the strong phase in the latter is still not settled, the former has a strong phase $\sim 30^\circ$ that is measured. The most relevant is $B \rightarrow J/\psi K^*$, where angular analysis gives strong phase difference between helicity amplitudes at order $30^\circ$.

The $t'$ effect in the $Z$ penguin brings the weak $\phi_{sb}$ phase to $F_{EW}$ amplitude. Unlike the above “hadronic” effects that enhance $C$, the virtual $Z$ produces a small color-singlet $c \bar{c}$ pair that exits without much interaction, thereby not accumulating much strong phase. While a little hand waving, we see that both weak and strong phases are present, the prerequisites for DCPV.

We plot $S_{J/\psi K}$ vs $\phi_{sb}$ in Fig. 3(a), for $\delta = 0$. Similar to $\Delta S$, which has $S_{J/\psi K}$ as reference point, $S_{J/\psi K}$ itself does dip downwards for $\phi_{sb} \sim 65^\circ$, reaching roughly 0.69. This does not change significantly when $\delta$ remains small. In Fig. 3(b) we plot $A_{J/\psi K^+}$ vs $\delta$ for $\phi_{sb} = 65^\circ$. We find that $A_{J/\psi K^+}$ can reach above 1% for $|\delta| \sim 30^\circ$.

The experimental situation is interesting. From $A_{J/\psi K^+} \sim +0.03$ based on 89M $B\bar{B}$s, BaBar flipped sign by adding 35M, becoming $-0.030 \pm 0.014 \pm 0.010$, with larger systematic error, and is now consistent with Belle value of $-0.026 \pm 0.022 \pm 0.017$ based on 32M. The current world average is $-0.024 \pm 0.014$, based on 166M $B\bar{B}$s. But the world has now over 1000M $B\bar{B}$s and growing, thus, our 1% projection can be seriously probed. Note that the number could be higher, e.g. in the less constrained $Z'$ model. To realize a 1% measurement, it seems that one needs to work hard on systematic error. But this should be worthwhile if one wants to enter the “Super B factory” era, with 100 times more data, where any measurement of interest is likely to be systems limited.

With luck, our prediction can be confirmed by 2008.

Acknowledgments

I thank Makiko Nagashima and Andrea Soddu for collaboration.

References

1. S. Giagu [CDF Collab.], hep-ex/0610044.
2. Plenary talk by M. Hazumi, this proceedings.
3. J. Erler, hep-ph/0604035.
4. A. Soddu in neutrino parallel session.
5. W.S. Hou, R.S. Willey and A. Soni, Phys. Rev. Lett. 58, 1608 (1987).
6. A. Arhrib and W.S. Hou, Eur. Phys. J. C27, 555 (2003).
7. W.S. Hou, M. Nagashima and A. Soddu, hep-ph/0610385.
8. W.S. Hou, M. Nagashima and A. Soddu, Phys. Rev. Lett. 95, 141601 (2005).
9. Plenary talk by R. Barlow, this proceedings.
10. W.S. Hou, M. Nagashima, G. Raz and A. Soddu, JHEP 0609, 012 (2006).
11. R. Sinha, B. Misra and W.S. Hou, Phys. Rev. Lett. 97, 131802 (2006).
12. W.S. Hou, H.n. Li, S. Mishima and M. Nagashima, hep-ph/0611107.
13. W.S. Hou, M. Nagashima and A. Soddu, Phys. Rev. D72, 115007 (2005).
14. Plenary talk by P. Pakhlov, this proceedings.
15. W.S. Hou, M. Nagashima and A. Soddu, hep-ph/0605080.
16. W.M. Yao et al. [Particle Data Group], J. Phys. G33, 1 (2006).