W_R contribution and CP angles measurements

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Abstract

Constraints on the parameters of the right-handed current quark mixing matrix V^R in $SU(2)_L \times SU(2)_R \times U(1)$ model are invetigated under $M_{W_R} = 1 \sim 10$ TeV with the recently observed CP violation in B decay and B-$\overline{B}$ mixing data. It is shown that there exist sets of parameters which can accommodate large CP violation as measured by Belle, $\sin 2\phi_1|_{exp} \simeq 1$.

The B factories at KEK and SLAC have established the existence of CP violation in B meson system by measuring the time-dependent CP asymmetry[1] of neutral B meson decays into $(c\bar{c})$ meson+neutral $K^{(*)}$ meson ;

$$A(t) = \frac{\Gamma[\overline{B^0}(t) \to f_{CP}] - \Gamma[B^0(t) \to f_{CP}]}{\Gamma[\overline{B^0}(t) \to f_{CP}] + \Gamma[B^0(t) \to f_{CP}]} = -\xi_f \sin 2\phi_1 \sin(\Delta M_B t), \tag{1}$$

where ξ_f is the CP eigenvalue of the final state. They obtained[2, 3]

$$\sin 2\phi_1 = \begin{cases} 0.59 \pm 0.14 \pm 0.05 & (BABAR) \\ 0.99 \pm 0.14 \pm 0.06 & (\text{Belle}) \end{cases} . \tag{2}$$

Let us check if the above value is consistent with the 3-generation standard model with Kobayashi-Maskawa mechanism of CP violation[4]. With the convention of KM matirx where ${V_{cb}}^* V_{cd}$ is real negative, geometrically defined $\sin 2\phi_1$ is given as

$$\sin 2\phi_1 = \sin\left(2\pi - 2\arg[\frac{-{V_{tb}}^* V_{td}}{-{V_{cb}}^* V_{cd}}]\right) = \sin\left(2\arg[-1 + \left|\frac{{V_{ub}}^* V_{ud}}{{V_{cb}}^* V_{cd}}\right| e^{-i\phi_3}]\right). \tag{3}$$

In the 3-generation standard model the observed $\sin 2\phi_1$ should agree with the above geometrically defined one. Assuming that new physics does not affect the determination of $|V_{ud}|$, $|V_{cd}|$ and $|V_{ub}/V_{cb}|$ which are obtained through tree level semi-leptonic processes, the prediction of $\sin 2\phi_1$ in terms of ϕ_3 by using eq.(3) and $|({V_{ub}}^* V_{ud})/({V_{cb}}^* V_{cd})|$ is given as Fig.1. The measured result $\sin 2\phi_1 > 0.4$ is consistent with $\phi_3 = 15^\circ \sim 145^\circ$. The neutral B meson mass difference ΔM_B in the standard model is also estimated as a function of ϕ_3. Once $|V_{ub}/V_{cb}|$ is given, $V_{tb}{V_{td}}^*$ can be expressed in terms of ϕ_3 and $|V_{ub}/V_{cb}|$ by using unitarity. Taking the ambiguity of hadron matrix elements to $\pm 30\%$ and errors of $|V_{ub}/V_{cb}|$, we find the standard model is consistent with the experimental value of ΔM_B for $\phi_3 = 20^\circ \sim 70^\circ$. The measured

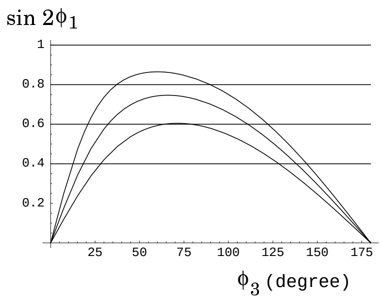

Figure 1: $\sin 2\phi_1$ in the 3-generation standard model. Upper, middle and lower curves correspond to $|V_{ub}/V_{cb}| = 0.11,\ 0.09$ and 0.07, respectively.

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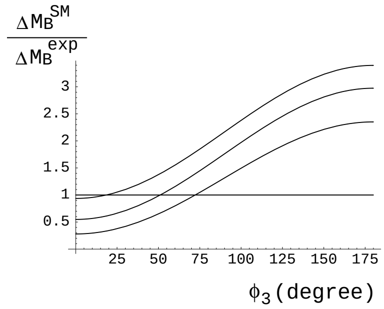

Figure 2: $\Delta M_B^{SM}/\Delta M_B^{exp}$ in the 3-generation standard model. Upper, middle and lower curves correspond to $|V_{ub}/V_{cb}| = 0.07,\ 0.09$ and 0.11, respectively.

values of $\sin 2\phi_1$ are consistent with the 3-generation standard model considering the errors at present, though the central value given by Belle is a bit high. If the high value by Belle is confirmed in the future, some new physics beyond the standard model is necessary.

In this work we investigate $SU(2)_L \times SU(2)_R \times U(1)$ model (L-R model)[5] as a possible candidate of new physics which can give larger CP asymmetry in the $\sin 2\phi_1$ determination than in the standard model. We investigate constraints on the model, and explore the possibility of obtaining a high value of CP asymmetry simultaneously satisfying constraints by ΔM_B and K-$\overline{K}$ system. So far several groups have investigated L-R model and showed that the gauge boson coupled to right-handed charged current (W_R) can affect significantly on the determination of the CP violation angles in B decays[6, 7, 8, 9]. Though W_R is much heavier than the ordinary W boson, some elements of the right-handed current quark mixing matrix V^R are not necessary suppressed in comparison with the CKM mixing matrix elements[4, 10]. Then W_R can contribute significantly to some processes where ordinary W boson contribution is much CKM suppressed.

There exists a sizable contribution to K-$\overline{K}$ mixing in L-R model from the box diagram with one W and one W_R exchange[6, 11, 12, 13], which allows only following forms of V^R to avoid constraint from CP violation in K-$\overline{K}$ mixing for not too heavy W_R with mass of $O(1)$ TeV or less [8];

$$V^R = \begin{pmatrix} 0 & 1 & 0 \\ \cos\theta_R & 0 & -e^{i\omega}\sin\theta_R \\ \sin\theta_R & 0 & e^{i\omega}\cos\theta_R \end{pmatrix}. \tag{4}$$

There are other kinds of allowd V^R. But they do not give significant contribution to B physics or need fine tunings among the parameters of CKM matrix and V^R, so we do not consider them here.

The contribution to B-$\overline{B}$ mixing is written as

$$M_{12}^B = M_{12}^{SM} + M_{LR} + M_{RR}, \tag{5}$$

where M_{12}^{SM} is the standard model contribution, M_{LR} from the box diagram with one W and one W_R exchange, and M_{RR} from two W_R exchange. The formulae of M_{RR} and M_{LR} are given in [8].

Now we evaluate M_{12}^B varying θ_R and ω in V^R with the following inputs; $M(W_R) = 1 \sim 10$ TeV, ϕ_3 in $V_{KM} = 45°, 90°, 135°$, $|V_{ub}/V_{cb}| = 0.09$, $f_B\sqrt{B_B} = 230$ MeV. Then we draw allowed regions by the experimental values of ΔM_B allowing $\pm 30\%$ ambiguity from errors in $f_B\sqrt{B_B}$ and $|V_{ub}/V_{cb}|$, and estimate CP asymmetry in $B \to (c\bar{c}) + K^{(*)}$ corresponding to $\sin 2\phi_1$, which we call as $Asy(\Psi K)$. First we take $M_{W_R} = 1$ TeV and $\phi_3 = 135°$. The allowed region and the predicted $Asy(\Psi K)$ are shown in Fig.3. It can be seen that only small portions of parameter space in θ_R and ω are allowed by ΔM_B. We fix $\theta_R = 100°$ and estimate ΔM_B and $Asy(\Psi K)$. With $\theta_R = 100°$ the CP phase ω in V^R is restricted to $30° \sim 90°$. If we further impose $Asy(\Psi K) > 0.4$ from the recent measurement, ω should be less than $60°$. It is interesting that large CP asymmetry given by Belle, $Asy(\Psi K) \sim 1$, is possible for $\omega = 30° \sim 45°$. Similar figures for $\theta_R = 90°$ and $45°$ are shown in Figs.5 and 6. The allowed region of θ_R and ω is severely restricted. This is because W_R gives significant contribution to B-$\overline{B}$ mixing even for $M_{W_R} \sim 1$ TeV as pointed out in ref.[8]. The standard model contribution M_{12}^{SM} is CKM suppressed by λ^6 ($\lambda \equiv |V_{us}| = 0.22$) while M_{LR} by λ^3. Though another suppression of $(M_W/M_{W_R})^2$ is incorporated in M_{LR}, the enhancement in loop function and λ^{-3} factor make M_{LR} similar order of magnitude with M_{12}^{SM}.

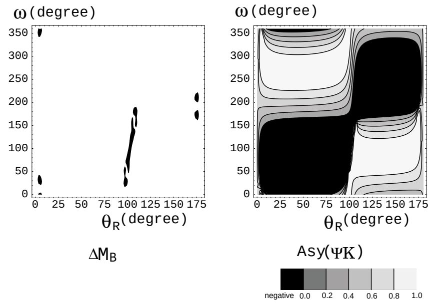

Figure 3: Allowed region by ΔM_B (left) and $Asy(\Psi K)$ (right) for $M_{W_R} = 1$ TeV and $\phi_3 = 135°$. Black painted regions are consistent with experimental value of ΔM_B in the left figure.

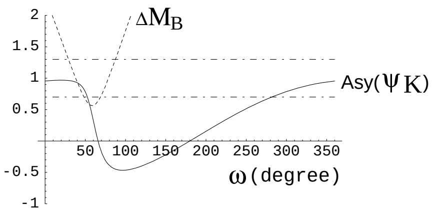

Figure 4: $\Delta M_B|_{theory}/\Delta M_B|_{exp}$ and $Asy(\Psi K)$ for $M_{W_R} = 1$ TeV, $\phi_3 = 135°$ and $\theta_R = 100°$.

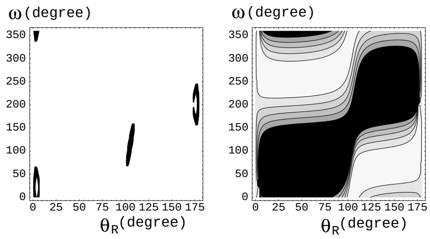

Figure 5: Same as Fig.3 for $\phi_3 = 90°$.

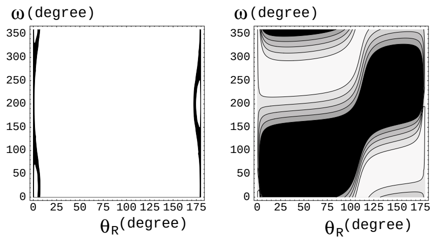

Figure 6: Same as Fig.3 for $\phi_3 = 45°$.

We have made same calculations for $M_{W_R} = 3, 5$ and 10 TeV. The results are shown in Figs.7-12 and 14. No allowed region remains at $M_{W_R} = 10$ TeV for $\phi_3 = 90°$ and $135°$. The allowed region spreads as M_{W_R} gets larger for $\phi_3 = 45°$ since the standard model contribution M_{12}^{SM} alone gives ΔM_B and $Asy(\Psi K)$ consistent with experimental data for $\phi_3 = 45°$. It is interesting that not a small are of allowed regions which give large CP asymmetry remains even for heavy W_R. For example, the figure for $M_{W_R} = 5$ TeV, $\phi_3 = 45°$ and $\theta_R = 30°$ is shown in Fig.13, and the figure for $M_{W_R} = 10$ TeV, $\phi_3 = 45°$ is shown in Fig.14.

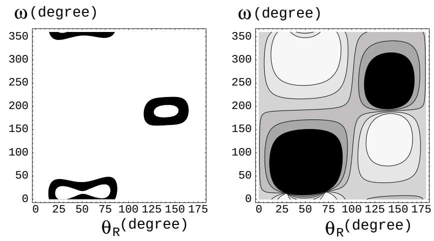

Figure 7: Same as Fig.3 for $M_{W_R} = 3$ TeV and $\phi_3 = 135°$.

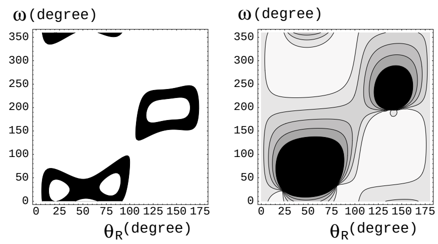

Figure 8: Same as Fig.3 for $M_{W_R} = 3$ TeV and $\phi_3 = 90°$.

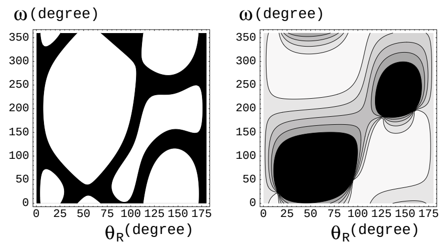

Figure 9: Same as Fig.3 for $M_{W_R} = 3$ TeV and $\phi_3 = 45°$.

Let us comment on other CP angles, ϕ_2 and ϕ_3. ϕ_2 is measured in the CP asymmetry in $B \to \pi\pi$ decay. CP violation occurs through the interference among B-$\overline{B}$ mixing, tree and penguin decays of $b \to u\bar{u}d$. W_R can contribute significantly to B-$\overline{B}$ mixing as in the case of ϕ_1. There also exists contribution to $b \to d$ penguin. The ratio to the standard model penguin up to log loop function is given as

$$\frac{g_L^2}{M_W^2} V_{tb}{}^* V_{td} : \frac{g_R^2}{M_{W_R}^2} V_{tb}^{R*} V_{td}^R = 1 : \beta_g \frac{e^{-i\omega} \sin 2\theta_R}{2 V_{tb}{}^* V_{td}}. \tag{6}$$

The magnitude of $|\beta_g/(2V_{tb}{}^* V_{td})|$ is about 0.3 for $M_{W_R} = 1$ TeV. W_R penguin is less than 10% of the standard model one taking the allowed region of θ_R into account. So we can neglect $b \to d$ W_R penguin. Then the effect on ϕ_2 is same as ϕ_1. For ϕ_3 we consider the measurement by using $B^\pm \to DK$. CP violation occurs through the interference between tree decays, $\bar{b} \to \bar{c}u\bar{s}$ and $\bar{b} \to \bar{u}c\bar{s}$ with common final state. W_R does not contribute to $\bar{b} \to \bar{u}c\bar{s}$ as $V_{ub}^R = 0$, but can affect $\bar{b} \to \bar{c}u\bar{s}$ decay.

$$\frac{g_L^2}{M_L^2} V_{cb}{}^* V_{us} : \frac{g_R^2}{M_R^2} V_{cb}^{R*} V_{us}^R = 1 : \beta_g \frac{(-e^{-i\omega} \sin\theta_R)}{V_{cb} V_{us}}. \tag{7}$$

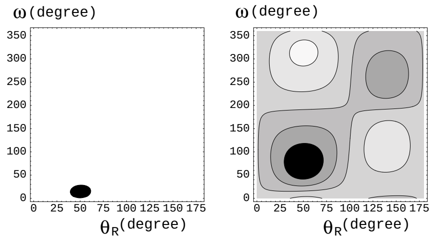

Figure 10: Same as Fig.3 for $M_{W_R} = 5$ TeV and $\phi_3 = 135°$.

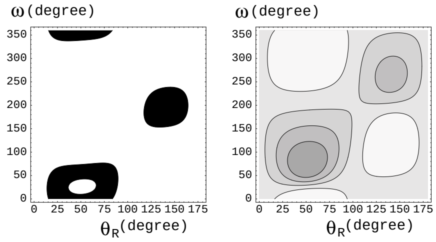

Figure 11: Same as Fig.3 for $M_{W_R} = 5$ TeV and $\phi_3 = 90°$.

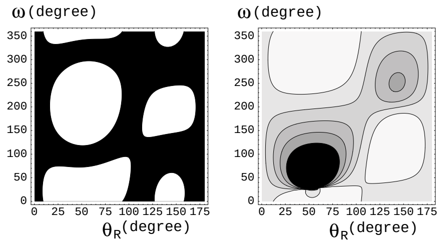

Figure 12: Same as Fig.3 for $M_{W_R} = 5$ TeV and $\phi_3 = 45°$.

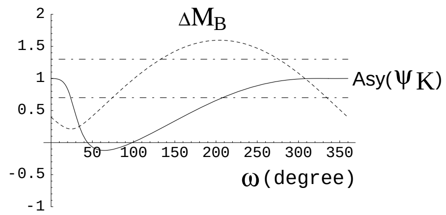

Figure 13: $\Delta M_B|_{theory}/\Delta M_B|_{exp}$ and $Asy(\Psi K)$ for $M_{W_R} = 5$ TeV, $\phi_3 = 45°$ and $\theta_R = 30°$.

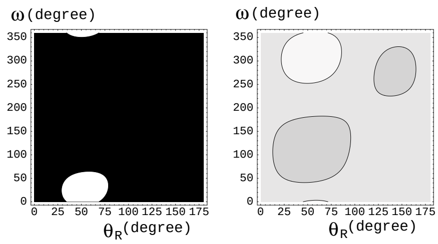

Figure 14: Same as Fig.3 for $M_{W_R} = 10$ TeV and $\phi_3 = 45°$.

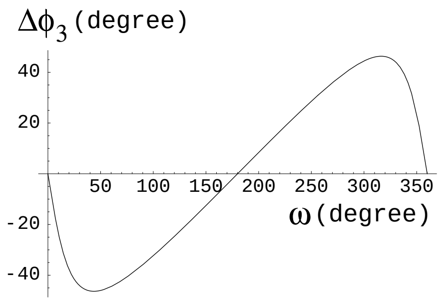

Figure 15: $\Delta\phi_3$ for $M_{W_R} = 1$ TeV, $\phi_3 = 135^\circ$ and $\theta_R = 100^\circ$.

The deviation of measured ϕ_3, $\Delta\phi_3$ from the standard model value for $M_{W_R} = 1$ TeV, $\phi_3 = 135^\circ$ in CKM matrix and $\theta_R = 100^\circ$ is given in Fig.15. The deviation can reach -45° for $\omega = 40^\circ$ As W_R gets heavier the deviation becomes small in proportional to $1/M_{W_R}^2$. This deviation cannot be observed in the measurements of ϕ_3 in $B \to K\pi$ since $V_{us}^R V_{ub}^{R*} = 0$. So we can expect disagreement between two kinds of measurements of ϕ_3.

In conclusion, we have investigated W_R effects on B-$\overline{B}$ mixing and CP asymmetry in B decays, and found that W_R effect is sizable even for $M_{W_R} = 1 \sim 10$ TeV. The experimental values of ΔM_B and CP asymmetry in $B \to (c\bar{c}) + K^{(*)}$, $Asy(\Psi K)$, severely constrain the parameters of right-handed quark mixing matrix V^R. With allowed parameters the CP asymmetry $Asy(\Psi K)$ can be as large as 1 which is the central value of Belle. If future experiments confirms the high value of $Asy(\Psi K)$, fine measurements of ϕ_2 and ϕ_3 in various modes are necessary to distinguish this kind of model and other new physics.

Acknowledgments

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References

[1] A.B. Carter and A.I. Sanda, Phys. Rev. Lett. **45** 952 (1980), Phys. Rev. **D23** 1567 (1981); I.I. Bigi and A.I. Sanda, Nucl. Phys. **B193** 85 (1981), Nucl. Phys. **B281** 41 (1987).

[2] *BABAR* Collaboration, Phys. Rev. Lett. **87**, 091802 (2001).

[3] Belle Collaboration, Phys. Rev. Lett. 87, 091801 (2001).

[4] M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973).

[5] R.N. Mohapatra and J.C. Pati, Phys. Rev. **D11** 566 (1975), **D11** 2558 (1975); G. Senjanovic and R.N. Mohapatra, Phys. Rev. **D12** 1502 (1975); G. Senjanovic, Nucl. Phys. **B153** 334 (1979).

[6] D. London and D. Wyler, Phys. Lett. **B232** 503 (1989).

[7] H. Nishiura, E. Takasugi and M. Tanaka, Prog.Theor.Phys. **84**, 116 (1990); **84**, 502 (1990); **85**, 343 (1991).

[8] T. Kurimoto, A. Tomita and S. Wakaizumi, Phys. Lett. **B381**, 470 (1996).

[9] D. Silverman and H. Yao, hep-ph/9706359 .

[10] N. Cabibbo, Phys. Rev. Lett, **10**, 531 (1963).

[11] F.I. Olness and M.E. Ebel, Phys. Rev. **D30** 1034 (1984).

[12] P. Langacker and S.U. Sankar, Phys. Rev. **D40** 1569 (1989).

[13] G. Barenboim, J. Bernabeu, J. Prades, M. Raidal, Phys.Rev. **D55**, 4213 (1997).