

Semi-leptonic $b \rightarrow c$
transitions

Semi-leptonic $b \rightarrow u$
transitions

Leptonic $b \rightarrow u$
transitions

$b \rightarrow s\gamma$

$B\bar{B}$ mixing

$\sin 2\beta$ in LRM

Righ-handed currents in the B meson system

Soo-hyeon Nam

Korea Institute of Science and Technology Information

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<Workshop on Flavor Physics and CP violation >

Outline

Motivation

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Left-Right models

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Semi-leptonic Decays

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Summary

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⊗ Consistency of the present experimental results with the general scheme of weak interactions and CP violation in the SM is nontrivial:

- ▶ Discrepancy between $\sin 2\beta_{J/\psi K_S}$ and $\sin 2\beta_{\phi K_S}$?
- ▶ Large $\text{Br}(B \rightarrow \tau \nu)$?
- ▶ Polarization puzzle in $B \rightarrow VV$?
- ▶ And more ...

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Left-Right models

* General left-right model (LRM) with group $SU(2)_L \times SU(2)_R \times U(1)$ has the following features:

- ▶ Covariant derivative for the fermions $f_{L,R}$:

$$D^\mu f_{L,R} = \partial^\mu f_{L,R} + ig_{L,R} W_{L,R}^{\mu a} T_{L,R}^a f_{L,R} + ig_1 B^\mu S f_{L,R}$$

- ▶ Unbroken $U(1)$ (Electric Charge):

$$Q = T_L^3 + T_R^3 + S$$

- ▶ Quark & Lepton fields (T_L, T_R, S):

$$\begin{aligned} q'_L &= \begin{pmatrix} u' \\ d' \end{pmatrix}_L \sim \left(\frac{1}{2}, 0, \frac{1}{6}\right), & q'_R &= \begin{pmatrix} u' \\ d' \end{pmatrix}_R \sim \left(0, \frac{1}{2}, \frac{1}{6}\right), \\ l'_L &= \begin{pmatrix} \nu' \\ e' \end{pmatrix}_L \sim \left(\frac{1}{2}, 0, -\frac{1}{2}\right), & l'_R &= \begin{pmatrix} \nu' \\ e' \end{pmatrix}_R \sim \left(0, \frac{1}{2}, -\frac{1}{2}\right) \end{aligned}$$

- ▶ Higgs VEVs (simplest case):

$$\langle \Phi \rangle = \begin{pmatrix} k & 0 \\ 0 & k' \end{pmatrix}, \quad \langle \chi_L \rangle = \begin{pmatrix} 0 \\ v_L \end{pmatrix}, \quad \langle \chi_R \rangle = \begin{pmatrix} 0 \\ v_R \end{pmatrix}$$

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- ▶ Higgs couplings induce $W_L - W_R$ mixing leading to mass eigenstates:

$$\begin{pmatrix} W^+ \\ W'^+ \end{pmatrix} = \begin{pmatrix} \cos \xi & e^{-i\alpha_0} \sin \xi \\ -\sin \xi & e^{-i\alpha_0} \cos \xi \end{pmatrix} \begin{pmatrix} W_L^+ \\ W_R^+ \end{pmatrix}$$

where

$$\zeta_g \equiv \frac{g_R^2 M_W^2}{g_L^2 M_{W'}^2} \geq \xi_g \equiv \frac{g_R}{g_L} \xi$$

- ▶ Charged interaction Lagrangian:

$$\begin{aligned} L_{CC} = & -\frac{1}{\sqrt{2}} \bar{P} \gamma^\mu \left\{ [V^L g_L c_\xi L + V^R g_R s_\xi^+ R] W_\mu^+ + [-V^L g_L s_\xi L + V^R g_R c_\xi^+ R] W_\mu'^+ \right. \\ & + [(V^L M_P g_L c_\xi - V^R M_N g_R s_\xi^+) L + (-V^L M_N g_L c_\xi + V^R M_P g_R s_\xi^+) R] \frac{\varphi_\mu^+}{M_W} \\ & \left. + [-(V^L M_P g_L s_\xi + V^R M_N g_R c_\xi^+) L + (V^L M_N g_L s_\xi + V^R M_P g_R c_\xi^+) R] \frac{\varphi_\mu'^+}{M_{W'}} \right\} N \\ & + H.C. + \dots, \end{aligned}$$

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- ▶ Lower bound on $M_{W'}$ can be obtained from the limits on deviations of muon decay parameters:

$$\zeta_g < 0.034 \quad \text{or} \quad M_{W'} > (g_R/g_L) \times 440 \text{ GeV}$$

(C.A. Gagliardi, R.E. Tribble, and N.J. Williams, Phys. Rev. D **72** 073002 (2005))

- ▶ W' mass limit can be lowered to approximately 400 GeV by taking the following forms of V^R (ΔM_K yields no severe constraint on $M_{W'}$):

$$V_I^R = \begin{pmatrix} e^{i\omega} & 0 & 0 \\ 0 & c_R e^{i\alpha_1} & s_R e^{i\alpha_2} \\ 0 & -s_R e^{i\alpha_3} & c_R e^{i\alpha_4} \end{pmatrix}, \quad V_{II}^R = \begin{pmatrix} 0 & e^{i\omega} & 0 \\ c_R e^{i\alpha_1} & 0 & s_R e^{i\alpha_2} \\ -s_R e^{i\alpha_3} & 0 & c_R e^{i\alpha_4} \end{pmatrix}$$

where c_R (s_R) $\equiv \cos \theta_R$ ($\sin \theta_R$) ($0^\circ \leq \theta_R \leq 90^\circ$).

(P. Langacker and S.U. Sarker, Phys. Rev. D **40** 1569 (1989))

Semi-leptonic $b \rightarrow c$ transitions

- ▶ Four-Fermion interaction for $b \rightarrow c(u)$ semileptonic decays:

$$\mathcal{H}_{\text{eff}} = 2\sqrt{2}G_F V_{qb}^L [(\bar{q}_L \gamma_\mu b_L) + \xi_q (\bar{q}_R \gamma_\mu b_R)] (\bar{\ell}_L \gamma_\mu \nu_L),$$

where $\xi_q \equiv \xi(g_R V_{qb}^R)/(g_L V_{qb}^L)$ and $q = u, c$.

- ▶ Total decay rate of $B \rightarrow l\nu X_c$:

$$\Gamma(b \rightarrow cl\nu) \simeq \frac{G_F^2 m_b^5 |V_{cb}^L|^2}{192\pi^3} \left[(1 + r_c^2 \xi_c^2) f(x) - r_c \xi_c h(x) \right]$$

where $x \equiv m_c/m_b$, $f(x) \sim 1 + O(x^2)$, and $h(x) \sim 4x + O(x^3)$.

- ▶ Following approximate bound can be obtained by the comparison of $|V_{cb}|_{\text{incl}}$ and $|V_{cb}|_{\text{excl}}$:

$$\xi_c \approx 0.14 \pm 0.18$$

(M.B. Voloshin, Mod. Phys. Lett. A **12**, 1823 (1997))

Semi-leptonic $b \rightarrow u$ transitions

- ▶ $|V_{ub}^R|$ could be as large as λ for the following types of V^R :

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}, \quad \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}, \quad \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix}$$

(T.G. Rizzo, Phys. Rev. D **58** 114014 (1998))

- ▶ In the LRM,

$$|V_{ub}|_{incl} \simeq |V_{ub}| + O(\xi_g^2) \sim O(\lambda^4) \quad (\lambda \simeq 0.22)$$

- ▶ 2008 HFAG averages of the selected theoretical methods for $|V_{ub}|_{incl}$:

$$|V_{ub}|_{incl} \times 10^3 = \begin{cases} 4.48 \pm 0.16 \begin{smallmatrix} +0.25 \\ -0.26 \end{smallmatrix} & \text{(DGE)} \\ 3.78 \pm 0.13 \pm 0.24 & \text{(AC)} \\ 4.09 \pm 0.20 & \text{(Our average)} \end{cases},$$

(Compared to the recent average $(4.11 \pm 0.28) \times 10^{-3}$:

M. Antonelli, et al., Phys. Rept. **494** 197 (2010))

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Semi-leptonic $b \rightarrow u$ transitions

- ▶ Recently obtained value of $|V_{ub}|_{excl}$ from $B \rightarrow \pi e \nu$ is smaller than those of $|V_{ub}|_{incl}$:

$$|V_{ub}|_{excl}^{LCSR} = (3.5 \pm 0.4 \pm 0.2 \pm 0.1) \times 10^{-3}$$

- ▶ In the LRM, we can roughly estimate the mixing parameter ξ_u from the mismatch between the values of $|V_{ub}|_{incl}$ and $|V_{ub}|_{excl}$:

$$\begin{aligned} |V_{ub}|_{\pi e \nu} &= |V_{ub}^L| |1 + \xi_u| \simeq |V_{ub}|_{incl} |1 + \xi_u| \\ \Rightarrow \text{Re}(\xi_u) &= -(0.14 \pm 0.12) \end{aligned}$$

- ▶ For $\text{Re}(\xi_u) = -0.14$, the branching fraction for semileptonic $B \rightarrow \rho \ell \nu$ decays can be enhanced by 17% while the branching fraction for radiative leptonic $B \rightarrow \gamma \ell \nu$ decays can be reduced by 18%.

(C.-H. Chen and S.-h. Nam, Phys. Lett. **B666** 462 (2008))

Leptonic $b \rightarrow u$ transitions

- ▶ In 2006 (& 2007), the BELLE and BABAR collaborations have found first evidence for the purely leptonic $B^- \rightarrow \tau^- \bar{\nu}_\tau$ decays:

$$Br(B^- \rightarrow \tau^- \bar{\nu}_\tau) = \begin{cases} (1.79^{+0.56}_{-0.49} \pm 0.46) \times 10^{-4} & \text{(BELLE)} \\ (1.2 \pm 0.4 \pm 0.3 \pm 0.2) \times 10^{-4} & \text{(BABAR)} \end{cases}$$

- ▶ Our estimate (in 2008) of the branching fraction was:

$$\begin{aligned} Br(B^- \rightarrow \tau^- \bar{\nu}_\tau) &= Br(B^- \rightarrow \tau^- \bar{\nu}_\tau)^{SM} |1 - \xi_u|^2 \\ &= (1.38 \pm 0.31) \times 10^{-4} |1 - \xi_u|^2 \\ &= (1.78 \pm 0.53) \times 10^{-4} \end{aligned}$$

- ▶ Current experimental result (by UTfit Collaboration) is

$$Br(B^- \rightarrow \tau^- \bar{\nu}_\tau) = (1.73 \pm 0.34) \times 10^{-4}$$

⇒ agrees very well with our earlier prediction!

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**Leptonic $b \rightarrow u$
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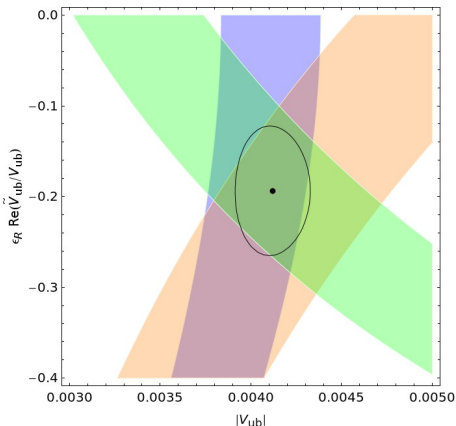
Non-leptonic Decays

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Summary



Constraints on $|V_{ub}|$ and $\epsilon_R \text{Re}\left(\frac{\tilde{V}_{ub}}{V_{ub}}\right)$ from $d B \rightarrow \pi l \nu$ (green), $B \rightarrow X_u l \nu$ (blue), and $B \rightarrow \tau \nu$ (orange). The bands denote the $\pm 1\sigma$ intervals of the various experimental constraints (Buras, Gemmler, Isidori, arXiv:1007.1993).

Non-leptonic $b \rightarrow s$ transition

- Effective Hamiltonian for $\Delta B = 1$ and $\Delta S = 1$ transition in the LRM:

$$\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}} \left[\sum_{\substack{i=1,2,11,12 \\ q=u,c}} \lambda_q^{LL} C_i^q O_i^q - \lambda_t^{LL} \left(\sum_{i=3}^{10} C_i O_i + C_7^\gamma O_7^\gamma + C_8^G O_8^G \right) \right] \\ + (C_i O_i \rightarrow C_i' O_i')$$

- Wilson Coefficients ($\mu = 1.5 \text{ GeV}$):

$$\begin{aligned} C_1^q &= -0.443, & C_1^{q'} &= C_1^q \zeta_g \lambda_q^{RR} / \lambda_q^{LL} \\ C_2^q &= 1.224, & C_2^{q'} &= C_2^q \zeta_g \lambda_q^{RR} / \lambda_q^{LL} \\ C_3 &= 0.023, & C_4 &= -0.045, & C_5 &= 0.012, & C_6 &= -0.064 \\ C_7 &= 0.008\alpha, & C_8 &= 0.064\alpha, & C_9 &= -1.403\alpha, & C_{10} &= 0.482\alpha \\ C_7^\gamma &= -0.385 - 17.07A^{tb}, & C_7^{\gamma'} &= -17.07A^{ts*} \\ C_8^G &= -0.175 - 7.506A^{tb}, & C_8^{G'} &= -7.506A^{ts*} \\ C_{11}^{u'} &= 0.623A^{us*}, & C_{12}^{u'} &= 0.881A^{us*}. \end{aligned}$$

where

$$\lambda_q^{AB} \equiv V_{qs}^{A*} V_{qb}^B, \quad A^{tD} = \xi_g \frac{V_{tD}^R}{V_{tD}^L} e^{i\alpha_\circ} \quad (D = b, s)$$

Non-leptonic $b \rightarrow s$ transition

Operators

Current-Current

$$O_1^U = (\bar{s}_\alpha u_\beta)_{V-A} (\bar{u}_\beta b_\alpha)_{V-A},$$

$$O_1^C = (\bar{s}_\alpha c_\beta)_{V-A} (\bar{c}_\beta b_\alpha)_{V-A},$$

$$O_2^U = (\bar{s}_\alpha u_\alpha)_{V-A} (\bar{u}_\beta b_\beta)_{V-A}$$

$$O_2^C = (\bar{s}_\alpha c_\alpha)_{V-A} (\bar{c}_\beta b_\beta)_{V-A}$$

QCD-Penguins

$$O_3 = (\bar{s}_\alpha b_\alpha)_{V-A} \sum_q (\bar{q}_\beta q_\beta)_{V-A},$$

$$O_5 = (\bar{s}_\alpha b_\alpha)_{V-A} \sum_q (\bar{q}_\beta q_\beta)_{V+A},$$

$$O_4 = (\bar{s}_\alpha b_\beta)_{V-A} \sum_q (\bar{q}_\beta q_\alpha)_{V-A}$$

$$O_6 = (\bar{s}_\alpha b_\beta)_{V-A} \sum_q (\bar{q}_\beta q_\alpha)_{V+A}$$

Electroweak-Penguins

$$O_7 = \frac{3}{2} (\bar{s}_\alpha b_\alpha)_{V-A} \sum_q e_q (\bar{q}_\beta q_\beta)_{V+A},$$

$$O_9 = \frac{3}{2} (\bar{s}_\alpha b_\alpha)_{V-A} \sum_q e_q (\bar{q}_\beta q_\beta)_{V-A},$$

$$O_8 = \frac{3}{2} (\bar{s}_\alpha b_\beta)_{V-A} \sum_q e_q (\bar{q}_\beta q_\alpha)_{V+A}$$

$$O_{10} = \frac{3}{2} (\bar{s}_\alpha b_\beta)_{V-A} \sum_q e_q (\bar{q}_\beta q_\alpha)_{V-A}$$

Magnetic-Penguins

$$O_7^\gamma = \frac{e}{8\pi^2} m_b \bar{s}_\alpha \sigma^{\mu\nu} (1 + \gamma_5) b_\alpha F_{\mu\nu},$$

$$O_8^G = \frac{g}{8\pi^2} m_b \bar{s}_\alpha \sigma^{\mu\nu} (1 + \gamma_5) T_{\alpha\beta}^a b_\beta G_{\mu\nu}^a,$$

Left-Right Mixed Current-Current

$$O_{11}^U = (\bar{s}_\alpha u_\beta)_{V-A} (\bar{u}_\beta b_\alpha)_{V+A},$$

$$O_{11}^C = (\bar{s}_\alpha c_\beta)_{V-A} (\bar{c}_\beta b_\alpha)_{V+A},$$

$$O_{12}^U = (\bar{s}_\alpha u_\alpha)_{V-A} (\bar{u}_\beta b_\beta)_{V+A},$$

$$O_{12}^C = (\bar{s}_\alpha c_\alpha)_{V-A} (\bar{c}_\beta b_\beta)_{V+A},$$

► The operator basis is doubled by O_i' which are the chiral conjugates of O_i .

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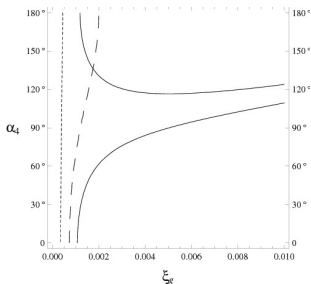
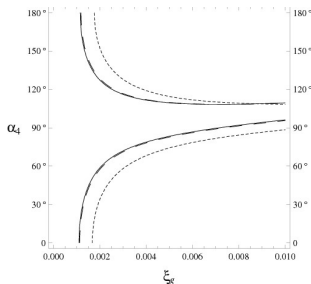
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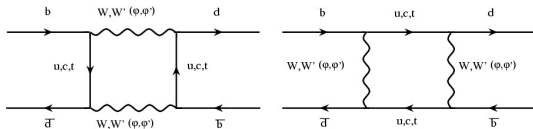
 $\sin 2\beta$ in LRM

 $b \rightarrow s\gamma$

- Recent measurements of the $b \rightarrow s\gamma$ decay rate have indirectly limited new physics contributions to a few percent.
- Contour plot corresponding to $|\delta_{LRM}^{s\gamma}| \leq 0.1$ for $\sin \theta_R = 0.04$ (solid line), 0.24 (dashed line), and 0.75 (dotted line) respectively, where $\delta_{LRM}^{s\gamma} = (|C_7^\gamma|_{LRM}^2 - |C_7^\gamma|_{SM}^2) / |C_7^\gamma|_{SM}^2$. The left region of the contour is allowed:


 Type I (V_L^R)

 Type II (V_{II}^R)

- Effective Hamiltonian in the $B\bar{B}$ system is obtained from the box diagrams:



$$H_{eff}^{B\bar{B}} = H_{eff}^{SM} + H_{eff}^{RR} + H_{eff}^{LR} :$$

$$H_{eff}^{SM} = \frac{G_F^2 M_W^2}{4\pi^2} (\lambda_i^{LL})^2 S(x_i^2) (\bar{d}_L \gamma_\mu b_L)^2$$

$$H_{eff}^{LR} = \frac{G_F^2 M_W^2}{2\pi^2} \{ [\lambda_c^{LR} \lambda_t^{RL} x_c x_t \zeta_g A_1(x_t^2, \zeta) + \lambda_t^{LR} \lambda_t^{RL} x_t^2 \zeta_g A_2(x_t^2, \zeta)] (\bar{d}_L b_R) (\bar{d}_R b_L) \\ + \lambda_t^{LL} \lambda_t^{RL} x_b \xi_g^- [x_t^3 A_3(x_t^2) (\bar{d}_L \gamma_\mu b_L) (\bar{d}_R \gamma_\mu b_R) + x_t A_4(x_t^2) (\bar{d}_L b_R) (\bar{d}_R b_L)] \}$$

where $\xi_g^\pm \equiv e^{\pm\alpha} \xi_g$, and $x_i \equiv m_i/M_W$ ($i = u, c, t$)

- The $B^0\bar{B}^0$ mixing matrix element in the LRM can be written as

$$M_{12} = M_{12}^{SM} + M_{12}^{LR} = M_{12}^{SM} (1 + r_{LR}^q), \quad r_{LR}^q = \frac{\langle \bar{B}_q^0 | H_{eff}^{LR} | B_q^0 \rangle}{\langle \bar{B}_q^0 | H_{eff}^{SM} | B_q^0 \rangle}$$

- In the case of $V_l^R, r_{LR}^d \sim 0$ and

$$r_{LR}^s \approx \left\{ -2.77 \left(\frac{1 - \zeta_g - (4.92 - 19.7\zeta_g) \ln(1/\zeta_g)}{1 - 5.47\zeta_g} \right) \zeta_g s_R^2 e^{i(\alpha_2 - \alpha_3)} \right. \\ \left. + 153 \left(\frac{1 - 5.02\zeta_g - (0.498 - 1.99\zeta_g) \ln(1/\zeta_g)}{1 - 9.94\zeta_g + 28.9\zeta_g^2} \right) \zeta_g s_R c_R e^{i(-\alpha_3 + \alpha_4)} \right. \\ \left. + 1.72\zeta_g s_R e^{-i\alpha_3} \right\}$$

- In the case of $V_{ll}^R, r_{LR}^s \sim 0$ and

$$r_{LR}^d \approx \left\{ 16.9 \left(\frac{1 - \zeta_g - (4.92 - 19.7\zeta_g) \ln(1/\zeta_g)}{1 - 5.47\zeta_g} \right) \zeta_g s_R^2 e^{i(-2\beta + \alpha_2 - \alpha_3)} \right. \\ \left. - 783 \left(\frac{1 - 5.02\zeta_g - (0.498 - 1.99\zeta_g) \ln(1/\zeta_g)}{1 - 9.94\zeta_g + 28.9\zeta_g^2} \right) \zeta_g s_R c_R e^{i(-\beta - \alpha_3 + \alpha_4)} \right. \\ \left. - 8.78\zeta_g s_R e^{i(-\beta - \alpha_3)} \right\}$$

(S.-h. Nam, Phys. Rev. D **66** 055008 (2002))

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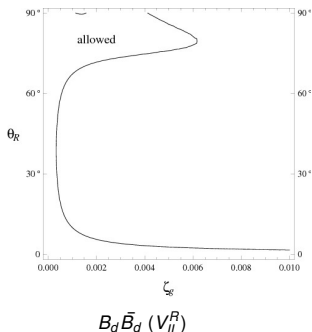
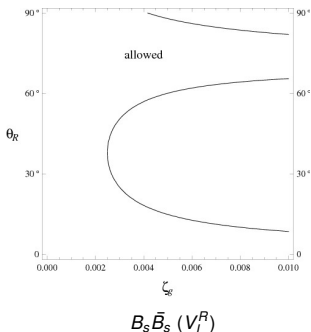
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- Contour plot corresponding to $0.7 < |1 + r_{LR}| < 1.3$
for $\zeta_g = 2\xi_g$ and $\alpha_{2,3,4} = 120^\circ$:



- ▶ For neutral B mesons decays, CP asymmetry can be expressed by the parametrization invariant quantity λ :

$$\lambda \equiv - \left(\frac{q}{p} \right)_B \frac{\mathcal{A}(\bar{B}^0 \rightarrow \bar{f})}{\mathcal{A}(B^0 \rightarrow f)}, \quad \left(\frac{q}{p} \right)_B \simeq \frac{M_{12}^*}{|M_{12}|},$$

- ▶ In the SM, the CP angle β is simply the imaginary part of λ :

$$\sin 2\beta = \text{Im}\lambda(B \rightarrow J/\psi K_S) \simeq \text{Im}\lambda(B \rightarrow \phi K_S)$$

- ▶ $B \rightarrow J/\psi K_S$ decay is governed by the tree-level contribution. In the LRM:

$$\mathcal{A}(B \rightarrow J/\psi K_S)_I \simeq \frac{G_F}{\sqrt{2}} \lambda_c^{LL} \left\{ 1 + 25(c_{RR} s_R \xi_g e^{-i(\alpha_2 - \alpha_1)} - 2s_R \xi_g e^{-i\alpha_2}) \right\} \chi^{(BK_S, J/\psi)}$$

$$\mathcal{A}(B \rightarrow J/\psi K_S)_{II} \simeq \frac{G_F}{\sqrt{2}} \lambda_c^{LL} \left\{ 1 - 50s_R \xi_g e^{-i\alpha_2} \right\} \chi^{(BK_S, J/\psi)}$$

where $\chi^{(BK_S, J/\psi)} \equiv \langle J/\psi | \bar{c} \gamma_\mu c | 0 \rangle \langle K_S | \bar{s} \gamma^\mu b | B^0 \rangle$

(S.-h. Nam, Phys. Rev. D **68** 115006 (2003))

- Transition amplitude for $B \rightarrow \phi K$ in the LRM:

$$\begin{aligned} \mathcal{A}(B \rightarrow \phi K)_I &\simeq -\frac{G_F}{\sqrt{2}} \left[\left\{ 1.77 - 0.027e^{-i(\gamma+\varphi)} + 16.2\xi_g C_{RS} R e^{i(\alpha_4-\alpha_3)} \right. \right. \\ &\quad \left. \left. - 13.1\xi_g (C_{RE} e^{i\alpha_4} + 24.0s_{RE} e^{-i\alpha_3}) \right\} 10^{-3} \chi^{(BK,\phi)} \right. \\ &\quad \left. + \left\{ 3.32 - 0.031e^{-i(\gamma+\varphi)} + 18.9\xi_g C_{RS} R e^{i(\alpha_4-\alpha_3)} \right. \right. \\ &\quad \left. \left. - 16.4\xi_g (C_{RE} e^{i\alpha_4} + 24.7s_{RE} e^{-i\alpha_3}) \right\} 10^{-1} \chi^{(B,K\phi)} \right] \\ \mathcal{A}(B \rightarrow \phi K)_{II} &\simeq -\frac{G_F}{\sqrt{2}} \left[\left\{ 1.77 - 0.027e^{-i(\gamma+\varphi)} - 13.1\xi_g C_{RE} e^{i\alpha_4} \right\} 10^{-3} \chi^{(BK,\phi)} \right. \\ &\quad \left. + \left\{ 3.32 - 0.031e^{-i(\gamma+\varphi)} - 16.4\xi_g C_{RE} e^{i\alpha_4} \right\} 10^{-1} \chi^{(B,K\phi)} \right] \end{aligned}$$

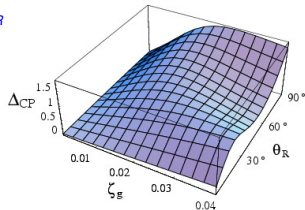
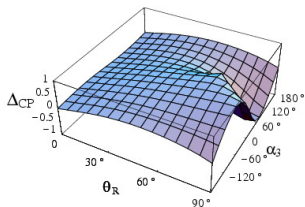
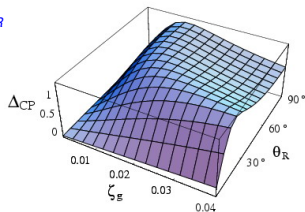
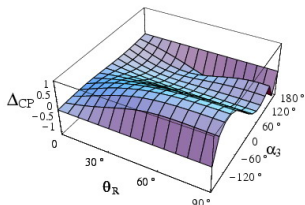
where $\gamma = 60^\circ$, $\varphi = 87^\circ$ (CP-even phase), and

$$\begin{aligned} \chi^{(BK,\phi)} &\equiv \langle \phi | \bar{s} \gamma_\mu s | 0 \rangle \langle K | \bar{s} \gamma^\mu b | B \rangle, \\ \chi^{(B,K\phi)} &\equiv \pm \langle K \phi | \bar{s} \gamma_\mu (1(\pm\gamma_5)) d | 0 \rangle \langle 0 | \bar{d} \gamma^\mu \gamma_5 b | B \rangle \end{aligned}$$

$\sin 2\beta$ in LRM

* Plots of the CP asymmetry difference

$$\Delta_{CP} \equiv \text{Im}\lambda(B \rightarrow J/\psi K_S) - \text{Im}\lambda(B \rightarrow \phi K_S) :$$



Semi-leptonic $b \rightarrow c$
transitions

Semi-leptonic $b \rightarrow u$
transitions

Leptonic $b \rightarrow u$
transitions

$b \rightarrow s\gamma$

$B\bar{B}$ mixing

$\sin 2\beta$ in LRM

Summary

- ▶ In the LRM, the W' contributions to $B^0\bar{B}^0$ mixing and CP asymmetry in B^0 decays are highly dependent upon the phases in the mass mixing matrices $V^{L,R}$.
- ▶ Admixture of a right-handed $b \rightarrow c(u)$ current could give a significantly different contributions to the inclusive and exclusive rates of the semileptonic decays of the B mesons.
- ▶ In hadronic B decays, different CP even phases arise from the annihilation contributions as well as the loop corrections of the current-current operators.
- ▶ The mixing angle ξ_g receives strong constraint from $b \rightarrow s\gamma$ especially in the manifest LRM.
- ▶ Right-handed currents cannot significantly contribute to ΔM_{B_d} and ΔM_{B_s} simultaneously.
- ▶ If there is a large discrepancy between $\sin 2\beta_{J/\psi K_S}$ and $\sin 2\beta_{\phi K_S}$, the manifest LRM is disfavored.

Motivation

Left-Right models

Semi-leptonic Decays

Semi-leptonic $b \rightarrow c$
transitions

Semi-leptonic $b \rightarrow u$
transitions

Leptonic $b \rightarrow u$
transitions

Non-leptonic Decays

$b \rightarrow s\gamma$

$B\bar{B}$ mixing

$\sin 2\beta$ in LRM

Summary

Back up

Polarization fraction for $B \rightarrow V V$ modes

- ▶ The decay $B \rightarrow V_1 V_2$ is described by the amplitude

$$\mathcal{A}(B \rightarrow V_1 V_2) = \mathcal{A}_0 \varepsilon_1^* \cdot \varepsilon_2^* + \mathcal{A}_1 (\varepsilon_1^* \cdot p_2)(\varepsilon_2^* \cdot p_1) + i\mathcal{A}_2 \varepsilon^{\alpha\beta\gamma\delta} \varepsilon_{1\alpha}^* \varepsilon_{2\beta}^* p_{1\gamma} p_{2\delta}$$

- ▶ The three helicity amplitudes can be rewritten in the transversity basis as:

$$\begin{aligned} \mathcal{A}_L &= -x\mathcal{A}_0 - m_1 m_2 (x^2 - 1)\mathcal{A}_1, & \mathcal{A}_{||} &= -\sqrt{2}\mathcal{A}_0 \\ \mathcal{A}_{\perp} &= -\sqrt{2}m_1 m_2 \sqrt{x^2 - 1}\mathcal{A}_2, & x &\equiv \frac{p_1 \cdot p_2}{m_1 m_2} \end{aligned}$$

- ▶ In the LRM ,

$$\begin{aligned} \mathcal{A}(B \rightarrow V_1 V_2) &= \frac{G_F}{\sqrt{2}} \sum_{q=u,c} \lambda_q^{LL} \left[C_{\pm}^L X_{\pm}^{(BV_1, V_2)} + C_{\pm}^A X_{\pm}^{(B, V_1 V_2)} \right] \\ \Rightarrow |\mathcal{A}(B \rightarrow V_1 V_2)|^2 &= |\mathcal{A}_L|^2 + |\mathcal{A}_{\perp}|^2 + |\mathcal{A}_{||}|^2 \end{aligned}$$

Polarization Fraction for the ϕK^* channel

- In the helicity basis,

$$\mathcal{A}_0 = \frac{G_F}{\sqrt{2}} \sum_{q=u,c} \lambda_q^{LL} \left[f_2 m_2 (m_B + m_1) (c_-^l - c_+^l) A_1(m_2^2) - f_B m_B^2 (c_-^A + c_+^A) V_1(m_B^2) \right]$$

$$\mathcal{A}_1 = \frac{G_F}{\sqrt{2}} \sum_{q=u,c} \lambda_q^{LL} \left[-\frac{2f_2 m_2}{m_B + m_1} (c_-^l - c_+^l) A_2(m_2^2) + f_B (c_-^A + c_+^A) V_2(m_B^2) \right]$$

$$\mathcal{A}_2 = \frac{G_F}{\sqrt{2}} \sum_{q=u,c} \lambda_q^{LL} \left[-\frac{2f_2 m_2}{m_B + m_1} (c_-^l + c_+^l) V(m_2^2) + f_B (c_-^A - c_+^A) A(m_B^2) \right]$$

⇒ Right-handed contribution can enhance \mathcal{A}_\perp and \mathcal{A}_\parallel .

- Illustration of the behavior of Γ_L/Γ for the ϕK^* channel by varying θ_R :

