Right-handed currents in two-body hadronic B decays

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Outline

1. Introduction
2. Effective Hamiltonian in the LRM
   - Left-Right models
   - Effective Hamiltonian for $\Delta B = 1$ and $\Delta S = 1$ transition
3. Two body hadronic B decays
   - Factorization approximation for the matrix elements of the operators
   - CP asymmetry in charged B meson decays
   - CP asymmetry in neutral B meson decays
   - Polarization fraction for $B \to V\,V$ modes
4. Summary

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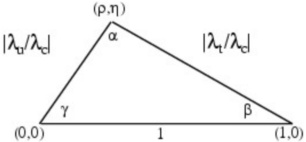
Introduction

Unitary triangle and CKM matrix

- In the SM , *CP* violation is expressed by *CP* angles γ and β which are the phases of the CKM matrix elements V_{ub} and V_{td} (relative to V_{cb}), respectively.



Unitary triangle ($\lambda_i = V_{id}^* V_{ib}$)

- CKM matrix expressed by the Wolfenstein parametrization:

$$V = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

Introduction

⊗ The standard $SU(2)_L \times U(1)$ model is being challenged because the consistency of the present experimental results with the general scheme of weak interactions and CP violation in the SM is nontrivial:

- Direct CP asymmetries in $B \to \pi K$:

$$\begin{aligned} A_{CP}(B^0 \to \pi^{\mp} K^{\pm}) &= -0.11 \pm 0.02 \quad \text{(FPCP 2006)} \\ A_{CP}(B^{\pm} \to \pi^0 K^{\pm}) &= 0.04 \pm 0.04 \quad \text{(FPCP 2006)} \end{aligned}$$

- Discrepancy between $\sin 2\beta_{J/\psi K_S}$ and $\sin 2\beta_{\phi K_S}$:

$$\begin{aligned} \sin 2\beta_{J/\psi K_S} &= 0.69 \pm 0.03 \quad \text{(ICFP 2005)} \\ \sin 2\beta_{\phi K_S} &= 0.47 \pm 0.19 \quad \text{(ICFP 2005)} \end{aligned}$$

- Polarization fractions in $B \to \phi K^*$:

$$\begin{aligned} \Gamma_L/\Gamma(B \to \phi K^*) &= 0.48 \pm 0.04 \quad \text{(FPCP 2006)} \\ \Gamma_{\perp}/\Gamma(B \to \phi K^*) &= 0.26 \pm 0.04 \quad \text{(FPCP 2006)} \end{aligned}$$

- And more ...

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Effective Hamiltonian in the LRM

Left-Right models

$*$ As one of the simplest extensions of the SM gauge group, we consider the left-right model (LRM) with group $SU(2)_L \times SU(2)_R \times U(1)$ which has the following features:

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

$$D^\mu f_{L,R} = \partial^\mu f_{L,R} + ig_{L,R} W^{\mu a}_{L,R} T^a_{L,R} f_{L,R} + ig_1 B^\mu S f_{L,R}$$

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

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

where

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

Effective Hamiltonian in the LRM

Left-Right models

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

$$\zeta_g < 0.033 \qquad \text{or} \qquad M_{W'} > (g_R/g_L) \times 440 \text{ GeV}$$

(B. Balke *et al.*, Phys. Rev. D **37** 587 (1988))

- W' mass limit can be lowered to approximately 400 GeV by taking the following forms of V^R:

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

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. Sanker, Phys. Rev. D **40** 1569 (1989))

- Following approximate bound can be obtained from the $b \to c$ semileptonic decays:

$$\xi_g \sin\theta_R \lesssim 0.013 \quad \text{for} \quad |V_{cb}^L| \approx 0.04$$

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

Effective Hamiltonian in the LRM

Effective Hamiltonian for $\Delta B = 1$ and $\Delta S = 1$ transition

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

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

- Wilson Coefficients ($\mu = m_B$)

$$\begin{aligned}
C_1^q &= -0.308, & C_1^{q\prime} &= C_1^q \zeta_g \lambda_q^{RR} / \lambda_q^{LL} \\
C_2^q &= 1.144, & C_2^{q\prime} &= C_2^q \zeta_g \lambda_q^{RR} / \lambda_q^{LL} \\
C_3 = 0.014, \quad C_4 &= -0.030, & C_5 = 0.009, \quad C_6 &= -0.038 \\
C_7 = 0.045\alpha, \quad C_8 &= 0.048\alpha, & C_9 = -1.280\alpha, \quad C_{10} &= 0.328\alpha \\
C_7^\gamma &= -0.317 - 0.546 A^{tb}, & C_7^{\gamma\prime} &= -0.546 A^{ts*} \\
C_8^G &= -0.150 - 0.241 A^{tb}, & C_8^{G\prime} &= -0.241 A^{ts*}
\end{aligned}$$

where

$$A^{tD} = \xi_g \frac{m_t}{m_b} \frac{V_{tD}^R}{V_{tD}^L} e^{i\alpha_\circ} \quad (D = b, s)$$

Effective Hamiltonian in the LRM

Operators for $b \to s$ transition

- Current-Current

$$O_1^u = \left(\bar{s}_\alpha u_\beta\right)_{V-A} \left(\bar{u}_\beta b_\alpha\right)_{V-A}, \qquad O_2^u = (\bar{s}_\alpha u_\alpha)_{V-A} \left(\bar{u}_\beta b_\beta\right)_{V-A}$$

$$O_1^c = \left(\bar{s}_\alpha c_\beta\right)_{V-A} \left(\bar{c}_\beta b_\alpha\right)_{V-A}, \qquad O_2^c = (\bar{s}_\alpha c_\alpha)_{V-A} \left(\bar{c}_\beta b_\beta\right)_{V-A}$$

- QCD-Penguins

$$O_3 = (\bar{s}_\alpha b_\alpha)_{V-A} \sum_q \left(\bar{q}_\beta q_\beta\right)_{V-A}, \qquad O_4 = \left(\bar{s}_\alpha b_\beta\right)_{V-A} \sum_q \left(\bar{q}_\beta q_\alpha\right)_{V-A}$$

$$O_5 = (\bar{s}_\alpha b_\alpha)_{V-A} \sum_q \left(\bar{q}_\beta q_\beta\right)_{V+A}, \qquad O_6 = \left(\bar{s}_\alpha b_\beta\right)_{V-A} \sum_q \left(\bar{q}_\beta q_\alpha\right)_{V+A}$$

- Electroweak-Penguins

$$O_7 = \frac{3}{2} (\bar{s}_\alpha b_\alpha)_{V-A} \sum_q e_q \left(\bar{q}_\beta q_\beta\right)_{V+A}, \qquad O_8 = \frac{3}{2} \left(\bar{s}_\alpha b_\beta\right)_{V-A} \sum_q e_q \left(\bar{q}_\beta q_\alpha\right)_{V+A}$$

$$O_9 = \frac{3}{2} (\bar{s}_\alpha b_\alpha)_{V-A} \sum_q e_q \left(\bar{q}_\beta q_\beta\right)_{V-A}, \qquad O_{10} = \frac{3}{2} \left(\bar{s}_\alpha b_\beta\right)_{V-A} \sum_q e_q \left(\bar{q}_\beta q_\alpha\right)_{V-A}$$

- Magnetic-Penguins

$$O_7^\gamma = \frac{e}{8\pi^2} m_b \bar{s}_\alpha \sigma^{\mu\nu} (1 + \gamma_5) b_\alpha F_{\mu\nu}, \qquad O_8^G = \frac{g}{8\pi^2} m_b \bar{s}_\alpha \sigma^{\mu\nu} (1 + \gamma_5) T^a_{\alpha\beta} b_\beta G^a_{\mu\nu},$$

- Left-Right Mixed Current-Current

$$O_{11}^u = \frac{m_b}{m_u} \left(\bar{s}_\alpha u_\beta\right)_{V-A} \left(\bar{u}_\beta b_\alpha\right)_{V+A}, \qquad O_{12}^u = \frac{m_b}{m_u} (\bar{s}_\alpha u_\alpha)_{V-A} \left(\bar{u}_\beta b_\beta\right)_{V+A},$$

$$O_{11}^c = \frac{m_b}{m_c} \left(\bar{s}_\alpha c_\beta\right)_{V-A} \left(\bar{c}_\beta b_\alpha\right)_{V+A}, \qquad O_{12}^c = \frac{m_b}{m_c} (\bar{s}_\alpha c_\alpha)_{V-A} \left(\bar{c}_\beta b_\beta\right)_{V+A},$$

Effective Hamiltonian in the LRM

Effective Hamiltonian for $\Delta B = 1$ and $\Delta S = 1$ transition

- It is convenient to express the one-loop matrix elements of $\mathcal{H}_{eff}$ in terms of the tree-level matrix elements of the effective operators:

$$< sq\bar{q}|\mathcal{H}_{eff}|B >= -\frac{G_F}{\sqrt{2}}\lambda_t^{LL}\sum_{i=1}^{10} C_i^{eff} < sq\bar{q}|O_i|B >^{tree} +(C_iO_i \to C_i'O_i'),$$

with the effective WCs

$$C_1^{eff(\prime)} = C_1^{(\prime)}, \quad C_2^{eff(\prime)} = C_2^{(\prime)}, \quad C_3^{eff(\prime)} = C_3^{(\prime)} - \frac{1}{N_c}C_g^{(\prime)}, \quad C_4^{eff(\prime)} = C_4^{(\prime)} + C_g^{(\prime)}$$

$$C_5^{eff(\prime)} = C_3^{(\prime)} - \frac{1}{N_c}C_g^{(\prime)}, \quad C_6^{eff(\prime)} = C_4^{(\prime)} + C_g^{(\prime)}, \quad C_7^{eff(\prime)} = C_7^{(\prime)} + C_\gamma^{(\prime)}, \quad C_8^{eff(\prime)} = C_8^{(\prime)} + C_\gamma^{(\prime)}$$

where

$$\begin{aligned} C_g^{(\prime)} &= -\frac{\alpha_s}{8\pi}\left[\frac{1}{\lambda_t^{LL}}\sum_{q=u,c}\lambda_q^{LL}C_2^{q(\prime)}\mathcal{I}(m_q,k,m_b) + 2C_8^{G(\prime)}\frac{m_b^2}{k^2}\right] \\ C_\gamma^{(\prime)} &= -\frac{\alpha_s}{3\pi}\left[\frac{1}{\lambda_t^{LL}}\sum_{q=u,c}\lambda_q^{LL}(C_1^{q(\prime)} + \frac{1}{N_c}C_2^{q(\prime)})\mathcal{I}(m_q,k,m_b) + C_7^{\gamma(\prime)}\frac{m_b^2}{k^2}\right] \end{aligned}$$

$$\underbrace{\mathcal{I}(m,k,\mu) = 4\int_0^1 dx x(1-x)\ln\left[\frac{m^2 - k^2x(1-x)}{\mu^2}\right]}$$

$\Longrightarrow$ Two different CP even phases arise!

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Two body hadronic B decays

Factorization approximation for the matrix elements of the operators

- Consider the matrix element of the operator O_6 for the process $B^- \to \phi K^{*-}$:

$$
\begin{aligned}
< \phi K^{*-} | O_6 | B^- > &= \frac{1}{N_c} < \phi | \bar{s} \gamma^\mu s | 0 >< K^{*-} | \bar{s} \gamma_\mu (1 - \gamma_5) b | B^- > \\
&+ \underbrace{2 < \phi K^{*-} | \bar{s}(1 + \gamma_5) u | 0 >< 0 | \bar{u} \gamma_5 b | B^- >}_{\text{annihilation contribution, usually neglected in FA}}
\end{aligned}
$$

- "Annihilation contribution" to decay rates may be small (or may not, depending on specific decay modes), but could be important in *CP* asymmetry because it contains *strong* phases! $\Rightarrow$ We need to reduce "hadronic uncertainty" before considering any "new physics".
- *CP* violating asymmetry originates from the superposition of *CP*-odd(violating) phases in CKM matrix and *CP*-even(conserving) phases.

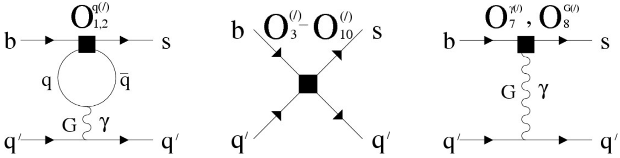
Two body hadronic B decays

CP asymmetry in charged *B* meson decays

- For charged B meson decays, *CP* violating asymmetry originates from the superposition of *CP*-odd(violating) phases and *CP*-even(conserving) phases.

$$A_{CP} = \frac{\Gamma(B^+ \to f^+) - \Gamma(B^- \to f^-)}{\Gamma(B^+ \to f^+) + \Gamma(B^- \to f^-)}$$

- *CP*-even phases arise from the absorptive part of the amplitudes.



Diagrams for penguin-induced $b \to s\bar{q}'q'$

Two body hadronic B decays

CP asymmetry in charged *B* meson decays

- Matrix elements of $O_{1,2}^{(\prime)}$:

$$
\begin{aligned}
< O_1^{q(\prime)} >^{\rm peng} &= \frac{\alpha}{3\pi}\mathcal{I}(m_q, k, m_b) < P_\gamma^{(\prime)} > \\
< O_2^{q(\prime)} >^{\rm peng} &= \frac{\alpha_s(m_b)}{8\pi}\mathcal{I}(m_q, k, m_b)\Big(< P_G^{(\prime)} > + \frac{8}{9}\frac{\alpha}{\alpha_s(m_b)} < P_\gamma^{(\prime)} > \Big)
\end{aligned}
$$

where

$$P_G^{(\prime)} = O_4^{(\prime)} + O_6^{(\prime)} - \frac{1}{N_c}(O_3^{(\prime)} + O_5^{(\prime)}), \qquad P_\gamma^{(\prime)} = O_7^{(\prime)} + O_9^{(\prime)} \quad (N_c = 3)$$

$$\mathcal{I}(m, k, \mu) = 4\int_0^1 dx x(1-x)\ln\left[\frac{m^2 - k^2 x(1-x)}{\mu^2}\right]$$

- Matrix elements of $O_7^{\gamma(\prime)}$ and $O_8^{G(\prime)}$:

$$< O_7^{\gamma(\prime)} >^{\rm peng} = -\frac{\alpha}{3\pi}\frac{m_b^2}{k^2} < P_\gamma^{(\prime)} >, \qquad < O_8^{G(\prime)} >^{\rm peng} = -\frac{\alpha_s}{4\pi}\frac{m_b^2}{k^2} < P_G^{(\prime)} >$$

where k^2 is expected to be typically in the range $m_b^2/4 \leq k^2 \leq m_b^2/2$.

(A. Ali and C. Greub, Phys. Rev. D **57** 2996 (1998))

Two body hadronic B decays

CP asymmetry in charged *B* meson decays

- We evaluate *CP* asymmetries in $B^{\pm} \to \phi K^{(*)\pm}$ decays.
- Transition amplitude for $B^{-} \to \phi K^{(*)-}$ in the LRM using the naive factorization approximation (NFA):

$$\mathcal{A}(B^{-} \to \phi K^{(*)-})_{I} \simeq \frac{G_F}{\sqrt{2}}\Bigg[\Big\{-0.67 + 1.1e^{i\varphi_c} + 0.02e^{i(\varphi_u-\gamma)} + 10\xi_g c_R e^{i\alpha_4}\Big\}X_{-}^{(B^{-}K^{(*)-},\phi)} + \Big\{27\zeta_g c_R s_R e^{i(\varphi_c+\alpha_4-\alpha_3)} + 250\xi_g s_R e^{-i\alpha_3}\Big\}X_{+}^{(B^{-}K^{(*)-},\phi)}\Bigg] \times 10^{-3}$$

$$= \frac{G_F}{\sqrt{2}}\Big[C_{tot}\cdot X_{-}^{(B^{-}K^{(*)-},\phi)} + C'_{tot}\cdot X_{+}^{(B^{-}K^{(*)-},\phi)}\Big] \times 10^{-3}$$

$$\mathcal{A}(B^{-} \to \phi K^{(*)-})_{II} \simeq \frac{G_F}{\sqrt{2}} C_{tot}\cdot X_{-}^{(B^{-}K^{(*)-},\phi)} \times 10^{-3}$$

where $\gamma = 60^{\circ}$, (φ_u, φ_c)=$(127^{\circ}, 149^{\circ})$ and

$$X_{-}^{(B^{-}K^{-},\phi)} = X_{+}^{(B^{-}K^{-},\phi)} \equiv < \phi|\bar{s}\gamma_{\mu}s|0 >< K^{-}|\bar{s}\gamma^{\mu}b|B^{-} >,$$

$$X_{\pm}^{(B^{-}K^{*-},\phi)} \equiv < \phi|\bar{s}\gamma_{\mu}s|0 >< K^{*-}|\bar{s}\gamma^{\mu}(1\pm\gamma_5)b|B^{-} >$$

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

Two body hadronic B decays

CP asymmetry in charged *B* meson decays

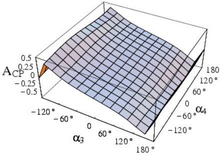
- SM value of *CP* asymmetry:

$$A_{CP}^{SM}(B^{\pm} \to \phi K^{(*)\pm}) \simeq 0.01$$

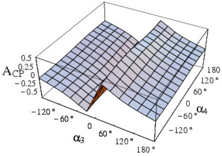
- Current data on the *CP* asymmetries in $B^{\pm} \to \phi K^{(*)\pm}$ (FPCP 2006):

$$A_{CP}^{\rm expt}(B^{\pm} \to \phi K^{\pm}) = 0.037 \pm 0.05, \quad A_{CP}^{\rm expt}(B^{\pm} \to \phi K^{*\pm}) = 0.05 \pm 0.11$$

- Behavior of A_{CP} as $\alpha_{3,4}$ are varied:

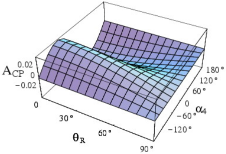


$(B^{\pm} \to \phi K^{\pm})_I$



$(B^{\pm} \to \phi K^{*\pm})_I$

or

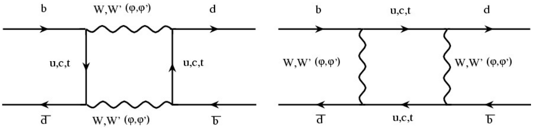


$(B^{\pm} \to \phi K^{(*)\pm})_{II}$

Two body hadronic B decays

Effective Hamiltonian for $B\bar{B}$ mixing

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



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

$$
\begin{aligned}
H_{eff}^{SM} &= \frac{G_F^2 M_W^2}{4\pi^2} (\lambda_t^{LL})^2 S(x_t^2) (\bar{d}_L \gamma_\mu b_L)^2 \\
H_{eff}^{LR} &= \frac{G_F^2 M_W^2}{2\pi^2} \{ [\lambda_c^{LR} \lambda_t^{RL} x_c x_t \zeta_g A_1(x_t^2, \zeta) + \lambda_t^{LR} \lambda_t^{RL} x_t^2 \zeta_g A_2(x_t^2, \zeta)] (\bar{d}_L b_R)(\bar{d}_R b_L) \\
&+ \lambda_t^{LL} \lambda_t^{RL} x_b \xi_g^- [x_t^3 A_3(x_t^2)(\bar{d}_L \gamma_\mu b_L)(\bar{d}_R \gamma_\mu b_R) + x_t A_4(x_t^2)(\bar{d}_L b_R)(\bar{d}_R b_L)] \}
\end{aligned}
$$

where $\xi_g^\pm \equiv e^{\pm \alpha_\circ} \xi_g, \quad \lambda_i^{AB} \equiv V_{id}^{A*} V_{ib}^{B}, \quad x_i \equiv m_i / M_W \; (i = u, c, t)$

Two body hadronic B decays

CP asymmetry in neutral *B* meson decays

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

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

where the $B^0\bar{B}^0$ mixing matrix element can be written as

$$M_{12} = M_{12}^{SM} + M_{12}^{LR} = M_{12}^{SM}\left(1 + r_{LR}\right), \quad r_{LR} = \frac{<\bar{B}^0|H_{eff}^{LR}|B^0>}{<\bar{B}^0|H_{eff}^{SM}|B^0>}$$

- In the case of V_I^R, there is no significant contribution of H_{eff}^{LR}.
- In the case of V_{II}^R,

$$r_{LR} \approx I\Bigg\{17.3I\left(\frac{1-\zeta_g-(4.92-19.7\zeta_g)\ln(1/\zeta_g)}{1-5.47\zeta_g}\right)\zeta_g s_R^2 e^{i\delta_1} - 796\left(\frac{1-5.02\zeta_g-(0.498-1.99\zeta_g)\ln(1/\zeta_g)}{1-9.94\zeta_g+28.9\zeta_g^2}\right)\zeta_g s_R c_R e^{i\delta_2} - 8.93\xi_g s_R e^{i\delta_3}\Bigg\}$$

where $I = 0.008/|V_{td}^L|$, $\delta_1 = -2\beta + \alpha_2 - \alpha_3$, $\delta_2 = -\beta - \alpha_3 + \alpha_4$, and $\delta_3 = -\beta - \alpha_3$.

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

Two body hadronic B decays

CP asymmetry in neutral *B* meson decays

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

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

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

$$\mathcal{A}(B \to J/\psi K_s)_I \simeq \frac{G_F}{\sqrt{2}} \lambda_c^{LL} \left\{ 1 + 25(c_R s_R \zeta_g e^{-i(\alpha_2 - \alpha_1)} - 2 s_R \xi_g e^{-i\alpha_2}) \right\} X^{(BK_S, J/\psi)}$$

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

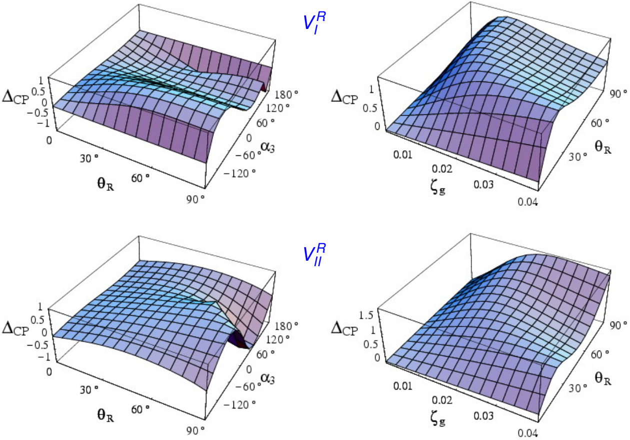
where $X^{(BK_S, J/\psi)} \equiv < J/\psi | \bar{c}\gamma_\mu c | 0 >< K_s | \bar{s}\gamma^\mu b | B^\circ >$

- The transition amplitude in $B \to \phi K_S$ decays can be simply obtained from the charged mode by replacing the hadronic matrix element $X^{(B^- K^-, \phi)} \to X^{(BK_s, \phi)}$

Two body hadronic B decays

CP asymmetry in neutral *B* meson decays

∗ Plots of the *CP* asymmetry difference $\Delta_{CP} \equiv \mathrm{Im}\lambda(B \to J/\psi K_S) - \mathrm{Im}\lambda(B \to \phi K_S)$:



Two body hadronic B decays

Polarization fraction for $B \to V\,V$ modes

- Polarization fraction for the ϕK^* channel in the SM (NFA):

$$\frac{\Gamma_L}{\Gamma} = \frac{|\mathcal{A}_L|^2}{|\mathcal{A}_L|^2 + |\mathcal{A}_\perp|^2 + |\mathcal{A}_\parallel|^2} = 1 - \mathcal{O}\left(\frac{1}{m_b^2}\right), \qquad \frac{\Gamma_\perp}{\Gamma_\parallel} = 1 + \mathcal{O}\left(\frac{1}{m_b}\right)$$

- Longitudinal polarization fraction for the ϕK^* channel in the LRM (NFA):

$$\left(\frac{\Gamma_L}{\Gamma}\right)_{\rm LRM} \simeq \frac{|\mathcal{A}_L^{\rm SM}|^2(1-r')^2}{|\mathcal{A}_L^{\rm SM}|^2(1-r')^2 + |\mathcal{A}_\perp^{\rm SM}|^2(1-r')^2 + |\mathcal{A}_\parallel^{\rm SM}|^2(1+r')^2}, \qquad r' \equiv \frac{C'_{tot}}{C_{tot}}$$

$\Rightarrow$ cannot satisfy $\Gamma_L^{\rm LRM}/\Gamma \approx 0.5$ and $\Gamma_\perp^{\rm LRM} \approx \Gamma_\parallel^{\rm LRM}$ simultaneously.

- In fact, the NFA fails in some hadronic decay modes. For example,

$$< \phi K^{*-}|O_6|B^- >= \frac{1}{N_c} < \phi|\bar{s}\gamma^\mu s|0 >< K^{*-}|\bar{s}\gamma_\mu(1-\gamma_5)b|B^- > + \underbrace{2 < \phi K^{*-}|\bar{s}(1+\gamma_5)u|0 >< 0|\bar{u}\gamma_5 b|B^- >}$$

annihilation contribution is not negligible!

Two body hadronic B decays

Polarization fraction for $B \to V\,V$ modes

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

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

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

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

- In the LRM ,

$$\mathcal{A}(B \to V_1 V_2) = \frac{G_F}{\sqrt{2}} \sum_{q=u,c} \lambda_q^{LL} \left[C_\pm^I X_\pm^{(BV_1, V_2)} + C_\pm^A X_\pm^{(B, V_1 V_2)} \right]$$

$$\Rightarrow |\mathcal{A}(B \to V_1 V_2)|^2 = |\mathcal{A}_L|^2 + |\mathcal{A}_\perp|^2 + |\mathcal{A}_\parallel|^2$$

Two body hadronic B decays

Polarization fraction for $B \to V V$ modes

- In the helicity basis,

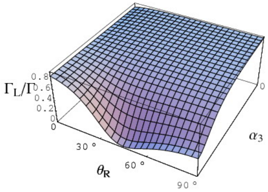
$$\mathcal{A}_0 = \frac{G_F}{\sqrt{2}} \sum_{q=u,c} \lambda_q^{LL} \left[f_2 m_2 (m_B + m_1) \left(c_-^I - c_+^I \right) A_1(m_2^2) - f_B m_B^2 \left(c_-^A + c_+^A \right) V_1(m_B^2) \right]$$

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

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

$\Rightarrow$ 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:



Outline

1 Introduction

2 Effective Hamiltonian in the LRM
- Left-Right models
- Effective Hamiltonian for $\Delta B = 1$ and $\Delta S = 1$ transition

3 Two body hadronic B decays
- Factorization approximation for the matrix elements of the operators
- CP asymmetry in charged B meson decays
- CP asymmetry in neutral B meson decays
- Polarization fraction for $B \to V\,V$ modes

4 Summary

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 matrix $V^{L,R}$.
- If CP asymmetries in $B^{\pm} \to \phi K^{(*)\pm}$ decays are large or different from each other, V_I^R is more probable than V_{II}^R.
- 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.
- The current experimental result of the polarization fraction for the ϕK^* channel can be explained in the LRM only if the annihilation contributions are included $\to$ must be explained simultaneously with other decay modes such as ρK^* (in progress).