Strangeness-changing hadronic B decays in left-right models

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Outline

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Introduction

$\otimes$ 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 $B \to \pi K$:

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

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

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

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

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

- And more ...

Outline

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

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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4. Summary

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 $B^- \to \phi K^{*-}$:

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

- "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. $\Rightarrow$ Detailed discussion on *CP* violation was given at the Collider Workshop 2006 at Argonne.

Two body hadronic B decays

Matrix Elements and Polarization Fraction

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

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

- 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 ,

$$\mathcal{A}(B \to V_1 V_2) = \frac{G_F}{\sqrt{2}}\sum_{q=u,c}\lambda_q^{LL}\left[c_\pm^I X_\pm^{(BV_1,V_2)} + c_\pm^A X_\pm^{(B,V_1V_2)}\right] \Rightarrow |\mathcal{A}(B\to V_1V_2)|^2 = |\mathcal{A}_L|^2 + |\mathcal{A}_\perp|^2 + |\mathcal{A}_\parallel|^2$$

- In the helicity basis,

$$\mathcal{A}_0 = \frac{G_F}{\sqrt{2}}\sum_{q=u,c}\lambda_q^{LL}\left[f_2 m_2(m_B+m_1)\left(c_-^I - c_+^I\right)A_1(m_2^2) - f_B m_B^2\left(c_-^A + c_+^A\right)V_1(m_B^2)\right]$$
$$\mathcal{A}_1 = \frac{G_F}{\sqrt{2}}\sum_{q=u,c}\lambda_q^{LL}\left[-\frac{2f_2 m_2}{m_B+m_1}\left(c_-^I - c_+^I\right)A_2(m_2^2) + f_B\left(c_-^A + c_+^A\right)V_2(m_B^2)\right]$$
$$\mathcal{A}_2 = \frac{G_F}{\sqrt{2}}\sum_{q=u,c}\lambda_q^{LL}\left[-\frac{2f_2 m_2}{m_B+m_1}\left(c_-^I + c_+^I\right)V(m_2^2) + f_B\left(c_-^A - c_+^A\right)A(m_B^2)\right]$$

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

Outline

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 $V^{L,R}$.
- 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 current experimental result of the polarization fraction for the ϕK^* channel can be explained in the LRM only if the annihilation contributions are included $\rightarrow$ must be explained simultaneously with other decay modes such as ρK^* (in progress).

Appendix

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

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

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