Left-right mixing effects on leptonic and semileptonic b -> u decays

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- The dominant weak interaction in $b \to u$ decays in the SM is strongly suppressed by the quark mixing matrix element $|V_{ub}| \sim \lambda^4$ where $\lambda \simeq 0.22$.
- The relevant decays occur at the tree level, and are often sensitive to a non-standard physics beyond the SM if the new physics effects are not directly proportional to the small weak mixing.
- One of the simplest extensions of the SM corresponding to such a scenario is the general left-right model (LRM) with gauge group $SU(2)_L \times SU(2)_R \times U(1)$. (J. C. Pati and A. Salam, Phys. Rev. D10 275 (1974))
- Although the new physics effects in the LRM are followed by suppression factors such as the $W_L - W_R$ mixing angle ξ, such suppression could be compensated by the right-handed quark mixing matrix V^R if $V^R \neq V^L$ (nonmanifest LRM).

- From the global analysis of muon decay measurements, the lower bound on ξ can be obtained without imposing discrete left-right symmetry as follows:

$$\xi \leq \frac{g_R}{g_L}\frac{M^2_{W_L}}{M^2_{W_R}} < 0.034\frac{g_L}{g_R}$$

(S.-h. Nam, Phys. Rev. D66 055008 (2002))

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

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

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

- Although the mixing angle ξ is small, the combined parameter $\xi V^R_{ub}/V^L_{ub}$ could significantly contribute to the value of $|V_{ub}|$ extracted from the data in $b \to u$ decays.

- Four-Fermion interaction for $b \to c$ semileptonic decays:

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

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

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

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

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 $|V_{cb}|_{incl}$ and $|V_{cb}|_{excl}$:

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

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

- 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 $|V_{ub}|_{incl}$:

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

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

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

$$|V_{ub}|_{incl} \times 10^3 = \begin{cases} 4.46 \pm 0.16 \,{}^{+\,0.18}_{-\,0.17} & \text{(DGE)} \\ 4.16 \pm 0.14 \,{}^{+\,0.25}_{-\,0.22} & \text{(ADFR)} \\ 4.34 \pm 0.18 & \text{(Our average)} \end{cases}$$

- Recently obtained value of $|V_{ub}|_{excl}$ from $B \to \pi e \nu$ 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 $|V_{ub}|_{excl}$:

$$\begin{aligned} |V_{ub}|_{excl}^{\pi e \nu} &= |V_{ub}^L||1+\xi_u| \simeq |V_{ub}|_{incl}|1+\xi_u| \\ \Rightarrow \mathrm{Re}(\xi_u) &= -(0.14 \pm 0.12) \quad (2008) \\ &= -(0.19 \pm 0.11) \quad (\text{current update}) \end{aligned}$$

$\Longrightarrow$ Difference between the values of $|V_{ub}|$ obtained from inclusive and exclusive modes gets bigger $\to$ Hint for new physics?

- BELLE and BABAR collaborations had first found evidence for the purely leptonic $B^- \to \tau^- \bar{\nu}$ decays in 2007 and 2008:

$$Br(B^- \to \tau^- \bar{\nu}_\tau) = \begin{cases} (1.79 \, {}^{+\,0.56}_{-\,0.49} \, {}^{+\,0.46}_{-\,0.51}) \times 10^{-4} & \text{(BELLE)} \\ (1.2 \pm 0.4 \pm 0.3 \pm 0.2) \times 10^{-4} & \text{(BABAR)} \end{cases}$$
$$= (1.41 \, {}^{+\,0.43}_{+\,0.42}) \times 10^{-4} \quad \text{(2008 HFAG average)}$$

- The BABAR result is an average of two results, $(0.9 \pm 0.6 \pm 0.1) \times 10^{-4}$ and $(1.8^{+0.9}_{-0.8} \pm 0.4 \pm 0.2) \times 10^{-4}$, and the latter one is newer.

- Our earlier 2008 estimate of the branching fraction was:

$$Br(B^- \to \tau^- \bar{\nu}_\tau) = Br(B^- \to \tau^- \bar{\nu}_\tau)^{SM} |1 - \xi_u|^2$$
$$= (1.78 \pm 0.53) \times 10^{-4}$$

$\Longrightarrow$ agreed very well with the BELLE result and the newer BABAR result, but not with the older BABAR result.

- Current HFAG average of new BELLE and BABAR measurements for the purely leptonic $B^- \to \tau^- \bar{\nu}$ decays:

$$Br(B^- \to \tau^- \bar{\nu}_\tau) = \begin{cases} (1.54\,^{+0.38}_{-0.37}\,^{+0.29}_{-0.31}) \times 10^{-4} & \text{(BELLE)} \\ (1.76 \pm 0.49) \times 10^{-4} & \text{(BABAR)} \end{cases}$$
$$= (1.64 \pm 0.34) \times 10^{-4} \quad \text{(current HFAG average)}$$

- Our current estimate of the branching fraction is:

$$Br(B^- \to \tau^- \bar{\nu}_\tau) = Br(B^- \to \tau^- \bar{\nu}_\tau)^{SM} |1 - \xi_u|^2$$
$$= (1.72 \pm 0.37) \times 10^{-4}$$

$\Longrightarrow$ agrees very well with the current HFAG average.

- Differential decay rate for $B \to \rho\ell\nu$ mode:

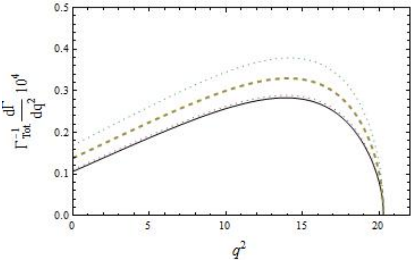
$$\frac{d^2\Gamma(B^0 \to \rho^- \ell^+ \nu_\ell)}{dy\, d\cos\theta_\ell} = \frac{G_F^2 m_B^2 |\mathbf{p}_\rho| y}{256\pi^3} |V_{ub}^L|^2 \left[(1-\cos\theta_\ell)^2 |H_+|^2 \right.$$
$$\left. + (1+\cos\theta_\ell)^2 |H_-|^2 + 2\sin\theta_\ell{}^2 |H_0|^2\right],$$

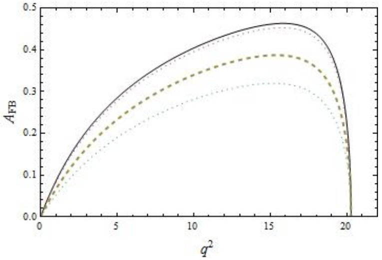
where the three helicity amplitudes $H_{\pm,0}$ depend effectively on only three form factors V and $A_{1,2}$:

$$H_\pm = \frac{1}{m_B + m_\rho}\left[(m_B + m_\rho)^2 (1-\xi_u) A_1(q^2) \mp 2 m_B |\mathbf{p}_\rho| (1+\xi_u) V(q^2)\right],$$

$$H_0 = \frac{m_B(1-\xi_u)}{2 m_\rho (m_B + m_\rho)\sqrt{y}}\left[\left(1 - \frac{m_\rho^2}{m_B^2} - y\right)(m_B + m_\rho)^2 A_1(q^2) - 4 |\mathbf{p}_\rho|^2 A_2(q^2)\right]$$

- $d\Gamma(B^0 \to \rho^- \ell^+ \nu_\ell)/dq^2$ distribution and $A_{\rm FB}(B^0 \to \rho^- \ell^+ \nu_\ell)$ as a function of q^2 for the SM (solid line), ξ_u^r = -0.14 (dashed line), and its error (dotted line).





- Differential decay rate for $B \to \gamma \ell \nu_\ell$ mode:

$$\frac{d^2\Gamma(B^- \to \gamma \ell^- \bar{\nu}_\ell)}{dy d\cos\theta} = \frac{\alpha_{em} G_F^2 m_B^5}{512\pi^2} y\,(1-y)^3\,|V_{ub}^L|^2 \left(1-\hat{m}_\ell^2\right)^2 I(q^2, \cos\theta),$$

with

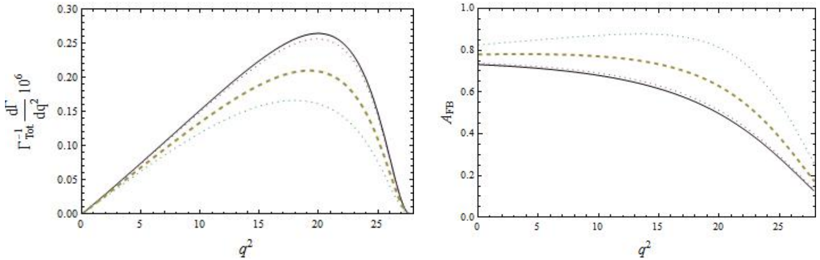
$$\begin{aligned} I(q^2,\cos\theta) &= |F_V' + F_A'|^2 \left[1+\hat{m}_\ell^2 + \left(1-\hat{m}_\ell^2\right)\cos\theta\right](1+\cos\theta) \\ &\quad + |F_A' - F_V'|^2 \left[1+\hat{m}_\ell^2 - \left(1-\hat{m}_\ell^2\right)\cos\theta\right](1-\cos\theta)\,, \end{aligned}$$

where

$$F_V' = F_V(1+\xi_u) \quad F_A' = F_A(1-\xi_u).$$

Other semi-leptonic $b \to u$ transitions

- $d\Gamma(B^- \to \gamma \ell^- \bar{\nu}_\ell)/dq^2$ distribution and $A_{\rm FB}(B^- \to \gamma \ell^- \bar{\nu}_\ell)$ as a function of q^2 for the SM (solid line), ξ_u^r = -0.14 (dashed line), and its error (dotted line).



Summary

- Admixture of a right-handed $b \to u$ current could give a significantly different contributions to the inclusive and exclusive rates of the semileptonic decays of the B mesons.
- From the current mismatch between $|V_{ub}|_{incl}$ and $|V_{ub}|_{excl}$ obtained from the independent experiments, we estimate the size of the left-right mixing parameter ξ_u to be
  $\mathrm{Re}(\xi_u) = -(0.14 \pm 0.12)$ (2008 prediction, published)
  $\mathrm{Re}(\xi_u) = -(0.19 \pm 0.11)$ (current update).
- For $\mathrm{Re}(\xi_u) = -0.14$, we show that the branching fraction for leptonic $B \to \tau\nu$ and semileptonic $B \to \rho\ell\nu$ decays can be enhanced by 30% and 17%, respectively, while the branching fraction for radiative leptonic $B \to \gamma\ell\nu$ decays can be reduced by 18%.
- Since the left-right mixing contributions obtained in this letter in leptonic and semileptonic $b \to u$ decays are not simply negligible, our estimate could be a reasonable guide to search for the existence of the right-handed current.