CP violating dimuon charge asymmetry with right-handed currents

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Outline

Motivation

$\otimes$ Like-sign dimuon charge asymmetry measured by D0 at Tevatron shows 3.2 σ deviation from the SM prediction:

- CP violating like-sign dimuon charge asymmetry for *b* hadrons is defined by

$$A^b_{sl} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

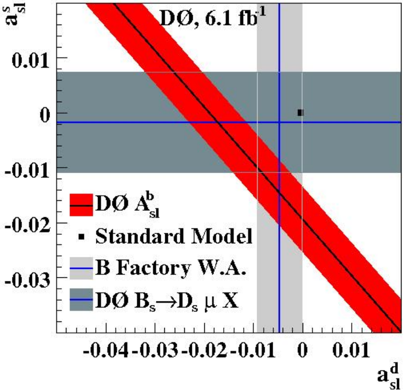
where $N_b^{++(--)}$ are the number of events where two *b* hadrons semileptonically decay into muons with charges of the same sign.

- D0 measurements:

$$A^b_{sl} = -0.00957 \pm 0.00251\ (\text{stat.}) \pm 0.00146\ (\text{syst.})$$

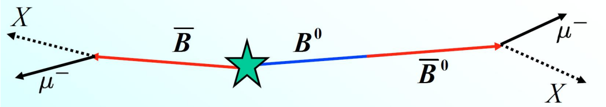
- SM prediction:

$$A^{b(SM)}_{sl} = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}$$



(should change figure later)

- $b\bar{b}$ production at Tevatron:



- One muon comes from direct semileptonic decay : $b \to \mu^- X$
- The other muon comes after neutral B meson mixing : $B^0 \to \bar{B}^0 \to \mu^- X$

- The asymmetry A^b_{sl} can be obtained from the charge asymmetry a^q_{sl} for "wrong-charge" semileptonic B^0_q-meson decays induced by $B^0_q\bar{B}^0_q$ oscillations:

$$a^q_{sl} \equiv \frac{\Gamma(\bar{B}^0_q \to \mu^+ X) - \Gamma(B^0_q \to \mu^- X)}{\Gamma(\bar{B}^0_q \to \mu^+ X) + \Gamma(B^0_q \to \mu^- X)} = \frac{|\Gamma^q_{12}|}{|M^q_{12}|} \sin\phi_q \quad (q = d, s)$$

  where $\phi_q \equiv \arg\left(-M^q_{12}/\Gamma^q_{12}\right)$.

- Since both B_d and B_s mesons are produced at the Tevatron, A^b_{sl} is given by a linear combination of a^d_{sl} and a^s_{sl}:

$$A^b_{sl} = (0.506 \pm 0.043)a^d_{sl} + (0.494 \pm 0.043)a^s_{sl}.$$

$*$ 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 $f_{L,R}$:

$$D^\mu f_{L,R} = \partial^\mu f_{L,R} + i g_{L,R} W^{\mu a}_{L,R} T^a_{L,R} f_{L,R} + i g_1 B^\mu S f_{L,R}$$

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

$$Q = T^3_L + T^3_R + S$$

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

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

- Higgs VEVs (simplest case):

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

Left-Right models

- 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

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

- Charged interaction Lagrangian:

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

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

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

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

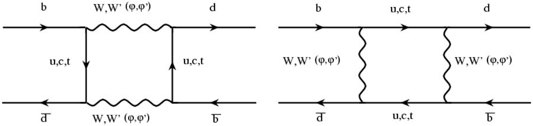
- W' mass limit can be lowered to approximately 400 GeV by taking the following forms of V^R (ΔM_K yields no severe constrant on $M_{W'}$):

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

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

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



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

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

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

where $\xi_g^{\pm} \equiv e^{\pm \alpha_\circ} \xi_g$, 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

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

$B\bar{B}$ mixing

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

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

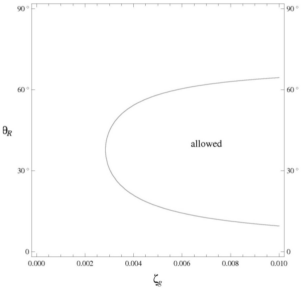
- In the case of V_{II}^R, $r_{LR}^s \sim 0$ and

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

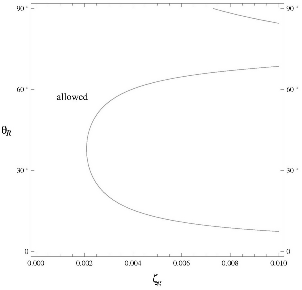
(S.-h. Nam, Phys. Rev. D **66** 055008 (2002))

Results

- Contour plot corresponding to $A^b_{sl} = -0.00957 \pm 0.00290$ for $\zeta_g = 2\xi_g$ and $\alpha_{2,3,4} = 90^\circ$:



$B_s\bar{B}_s\ (V^R_I)$



$B_d\bar{B}_d\ (V^R_{II})$

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 $b \to c(u)$ 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 $b \to s\gamma$ 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.