Selected Studies of B oscillation

Soo-hyeon Nam

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work in progress

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< France-Korea particles physics mini-workshop >

Outline

⊗ Do we really see NP effects in $B\bar{B}$ mixing now?

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Anatomy of new physics in B-$\bar{B}$ mixing

A. Lenz[1,2,*] and U. Nierste[3,†]

[1]*Institut für Physik, Technische Universität Dortmund, D-44221 Dortmund, Germany*
[2]*Institut für Theoretische Physik, Universität Regensburg, D-93949 Regensburg, Germany*
[3]*Institut für Theoretische Teilchenphysik, Universität Karlsruhe, Karlsruhe Institute of Technology, D-76128 Karlsruhe, Germany*

J. Charles,[4,‡] S. Descotes-Genon,[5,§] A. Jantsch,[6,∥] C. Kaufhold,[7,¶] H. Lacker,[8,**] S. Monteil,[9,††]
V. Niess,[9,‡‡] and S. T'Jampens[7,§§]

(CKMfitter Group)

[4]*Centre de Physique Théorique, Campus de Luminy, Case 907, F-13288 Marseille Cedex 9, France (UMR 6207 du CNRS associée aux Universités d'Aix-Marseille I et II et Université du Sud Toulon-Var; laboratoire affilié à la FRUMAM-FR2291)*
[5]*Laboratoire de Physique Théorique d'Orsay, UMR8627, CNRS/Université Paris-Sud 11, 91405 Orsay Cedex, France*
[6]*Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), Föhringer Ring 6, 80805 München, Germany*
[7]*Laboratoire d'Annecy-Le-Vieux de Physique des Particules, 9 Chemin de Bellevue, BP 110, F-74941 Annecy-le-Vieux Cedex, France (UMR 5814 du CNRS-IN2P3 associée à l'Université de Savoie)*
[8]*Humboldt-Universität zu Berlin, Institut für Physik, Newtonstr. 15, D-12489 Berlin, Germany*
[9]*Laboratoire de Physique Corpusculaire de Clermont-Ferrand, Université Blaise Pascal, 24 Avenue des Landais F-63177 Aubière Cedex, (UMR 6533 du CNRS-IN2P3 associée à l'Université Blaise Pascal)*

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We analyze three different new physics scenarios for $\Delta F = 2$ flavor-changing neutral currents in the quark sector in the light of recent data on neutral-meson mixing. We parametrize generic new physics contributions to B_q-$\bar{B}_q$ mixing, $q = d, s$, in terms of one complex quantity Δ_q, while three parameters Δ_K^{tt}, Δ_K^{ct}, and Δ_K^{cc} are needed to describe K-$\bar{K}$ mixing. In scenario I, we consider uncorrelated new physics contributions in the B_d, B_s, and K sectors. In this scenario, it is only possible to constrain the parameters Δ_d and Δ_s whereas there are no nontrivial constraints on the kaon parameters. In scenario II, we study the case of minimal flavor violation (MFV) and small bottom Yukawa coupling, where $\Delta \equiv \Delta_d = \Delta_s = \Delta_K^{tt}$. We show that Δ must then be real, so that no new CP phases can be accommodated, and express the remaining parameters Δ_K^{cc} and Δ_K^{ct} in terms of Δ in this scenario. Scenario III is the generic MFV case with large bottom Yukawa couplings. In this case, the kaon sector is uncorrelated to the B_d and B_s sectors. As in the second scenario one has $\Delta_d = \Delta_s \equiv \Delta$, however, now with a complex parameter Δ. Our quantitative analyses consist of global Cabibbo-Kobayashi-Maskawa (CKM) fits within the Rfit frequentist statistical approach, determining the standard model parameters and the new physics parameters of the studied scenarios simultaneously. We find that the recent measurements indicating discrepancies with the standard model are well accommodated in Scenarios I and III with new mixing phases, with a slight preference for Scenario I that permits different new CP phases in the B_d and B_s systems. Within our statistical framework, we find evidence of new physics in both B_d and B_s systems. The standard model hypothesis $\Delta_d = \Delta_s = 1$ is disfavored with p-values of 3.6σ and 3.3σ in Scenarios I and III, respectively. We also present an exhaustive list of numerical predictions in each scenario. In particular, we predict the CP phase in $B_s \to J/\psi\phi$ and the difference between the B_s and B_d semileptonic asymmetries, which will be both measured by the LHCb experiment.

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- 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

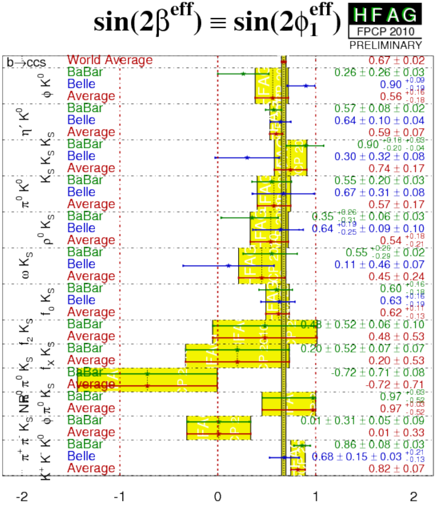
$$M_{12} = M_{12}^{SM} + M_{12}^{NP} = M_{12}^{SM}\left(1 + r_{NP}\right), \quad r_{NP} = \frac{< \bar{B}^0|H_{eff}^{NP}|B^0 >}{< \bar{B}^0|H_{eff}^{SM}|B^0 >}$$

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

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

Mixing Induced *CP* asymmetry

- Discrepancy between $\sin 2\beta_{tree}$ and $\sin 2\beta_{penguin}$



⊗ 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

$$A_{sl}^{b} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

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

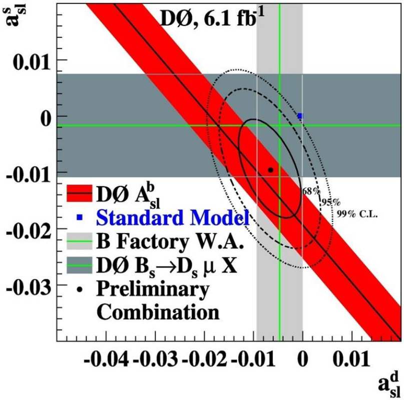
- D0 measurements (V.M. Abazov *et al.*, Phys. Rev. D **82**, 032001 (2010)):

$$A_{sl}^{b} = -0.00957 \pm 0.00251 \,(\text{stat.}) \pm 0.00146 \,(\text{syst.})$$

- SM prediction (A. Lenz, U. nierste, JHEP 0706, 072 (2007)):

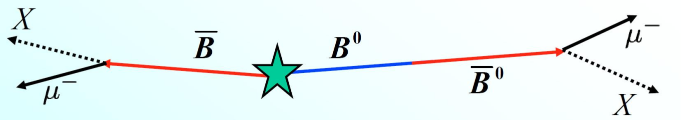
$$A_{sl}^{b(SM)} = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}$$

Dimuon Charge Asymmetry



(V.M. Abazov *et al.*, Phys. Rev. D **82**, 032001 (2010))

- $b\bar{b}$ 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:

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

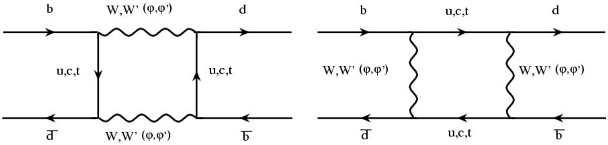
  where $\phi_q \equiv \arg\left(-M^q_{12}/\Gamma^q_{12}\right)$.

- 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}:

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

(Y. Grossman, Y.Nir, G. Raz, PRL **97**, 151801 (2006))

- $B\bar{B}$ mixing matrix element is obtained from the box diagrams:



- If NP = LRM, there could be possibly large right-handed current contributions to $B\bar{B}$ mixing matrix element with 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))

$B\bar{B}$ mixing

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

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

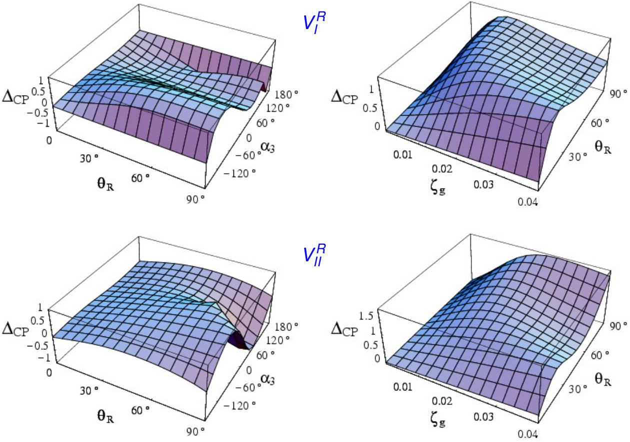
- In the case of V_{II}^R, $r_{LR}^s \sim 0$ and

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

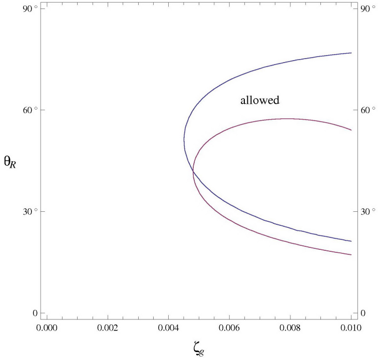
(S.-h. Nam, Phys. Rev. D **66** 055008 (2002))

Results

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



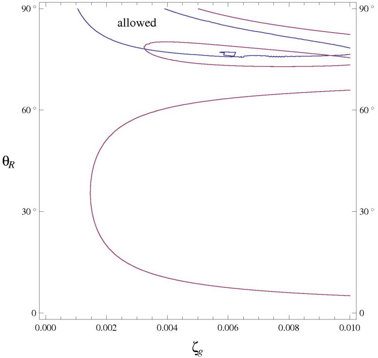
$*$ Contour plot corresponding to $A_{sl}^{b} = -0.00957 \pm 0.00290$:



$B_s \bar{B}_s$ (V_l^R)

preliminary

∗ Contour plot corresponding to $A_{sl}^{b} = -0.00957 \pm 0.00290$:



$B_d \bar{B}_d \ (V_{ll}^{R})$

preliminary

Summary

- The deviation of the dimuon charge asymmetry from the SM prediction may imply the CP violation beyond the SM.
- 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 $V^{L,R}$.
- Right-handed currents cannot significantly contribute to ΔM_{B_d} and ΔM_{B_s} simultaneously.
- The new angle and phases in the right-handed quark mixing matrice V^R can explain the D0 dimuon charge asymmetry at Tevatron.

$*$ 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):

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

Appendix

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:

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