Constraints on flavor-changing $Z'$ models by $B_s$ mixing, $Z'$ production, and $B_s \rightarrow \mu^+\mu^-$

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(Dated: February 2, 2008)

Certain string-inspired $Z'$ models have non-universal interactions to three families of fermions and induced tree-level flavor-changing couplings. We use recent results on $B_s\overline{B}_s$ mixing to constrain the size of the flavor-changing couplings in the $b$-$s$ sector. In some highly predictive $Z'$ models, such a constraint on $b$-$s$ coupling can be translated into the flavor-diagonal couplings. Based on the $Z'$ production limits at the Tevatron, we obtain the limit on the leptonic couplings of $Z'$ and then make predictions for $B_s \rightarrow \mu^+\mu^-$ branching ratios. We conclude that with the present constraints from $B_s$ mixing and $Z'$ production, the muonic decay of $B_s$ may not be observed at the Tevatron if the projected integrated luminosity is less than $O(5-10)$ fb.

Searches for flavor-changing neutral currents (FCNC) have been pursued for many years. So far, the sizes of FCNC in the $u$-$c$, $b$-$s$, $s$-$d$, and $b$-$d$ sectors, in general, agree with the Standard Model (SM) predictions, namely, those derived from the Cabibbo-Kobayashi-Maskawa (CKM) mechanism in higher order. The FCNC effect in $b$-$s$ sector was recently confirmed in the $B_s$ meson mixing observed by both CDF and DØ:

CDF: $\Delta M_s = 17.33^{+0.42}_{-0.21}$ (stat.) $\pm 0.07$ (syst.) ps$^{-1}$,

DØ: $\Delta M_s = 19.0 \pm 1.215$ ps$^{-1}$,

where we have converted the 90\% C.L. bound $17 < \Delta M_s < 21$ ps$^{-1}$ of DØ into 1$\sigma$ range assuming the error is Gaussian. We combine both results, again assuming Gaussian errors, and get

$$\Delta M_s^{\text{exp}} = 17.46^{+0.47}_{-0.30} \text{ ps}^{-1} \quad (1\sigma \text{ range}). \quad (1)$$

We re-evaluate the SM prediction \cite{1}, using the best-fitted inputs (given later) before the announcement of the new $B_s$ mixing data,

$$\Delta M_s^{\text{SM}} = 19.52 \pm 5.28 \text{ ps}^{-1}. \quad (2)$$

It is important to use the best-fitted inputs without the new $B_s$ mixing data in order to determine if there is any discrepancy between the data and the SM prediction. Measurement of $B_s$ mixing is often used to determine the value of $|V_{ts}|$, but this is clearly inappropriate when the mixing has additional contribution from new physics. The SM prediction in Eq. (2) contains large uncertainty from the hadronic parameters, nevertheless, the data agrees fairly well with the SM value. Therefore, we can use the $B_s$ data to constrain new physics that may induce the $b$-$s$ transitions.

Another important channel to search for FCNC is the muonic $B_s$ decay, $B_s \rightarrow \mu^+\mu^-$, which has the largest chance to be detected at hadronic machines. In the SM, this process is loop-suppressed. However, many extensions of the SM predict a branching ratio large enough to be seen at hadron colliders. We consider an FCNC $Z'$ model inspired by string theory in this letter. The $B_s$ mixing and $B_s \rightarrow \mu^+\mu^-$ are highly correlated because from the $B_s$ data one can constrain the FCNC $b$-$s$-$Z'$ coupling, which is an essential element in the calculation of the muonic decay. One additional element is the $\mu$-$\mu'$-$Z'$ coupling. In order to make a reliable prediction for the muonic decay branching ratio, we take into account the $\sigma(Z') \cdot B(Z' \rightarrow e^+e^-)$ limits from the Tevatron. In the $Z'$ model considered here, the FCNC $b$-$s$-$Z'$ coupling is related to the flavor-diagonal couplings $qqZ'$ in a predictive way, which are then used to obtain the upper limits on the leptonic $\ell\ell Z'$ couplings. Therefore, we are able to predict the maximally allowed branching ratio for the muonic decay of $B_s$. The predicted branching ratio is always less than $9 \times 10^{-9}$ for $M_{Z'} = 200 - 900$ GeV. It implies that with the present constraints from $B_s$ mixing and $Z'$ production, the muonic decay of $B_s$ may not be observable at the Tevatron if the projected integrated luminosity is less than $O(5-10)$ fb.

In some string-inspired models, the three generations of SM fermions are constructed differently and may result in family non-universal couplings to an extra $U(1)$ gauge boson, $Z'$. Without loss of generality, we consider the case that the $Z'$ couples with a different strength to the third generation, as motivated by a particular class of string models \cite{2}. Once we do a unitary rotation from the interaction basis to mass eigenbasis, tree-level FCNCs are induced naturally. Several works have recently been done regarding the FCNCs in the down-quark sector \cite{1,3,4}. In order to increase the predictive power, we assume that the left-handed (LH) up-type sector is already in diagonal form, such that $V_{\text{CKM}} = V_{\text{dL}}$, where $V_{\text{dL}}$ is the LH down-type sector unitary rotation matrix. Since we do not have much information about either the right-handed (RH) up-type or the RH down-type sectors, we simply assume that their interactions with $Z'$ are family-universal and flavor-diagonal in the interaction basis. In this case, unitary rotations keep the RH couplings flavor-diagonal.