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$b \to s\ell^+\ell^-$ IN THE LEFT-RIGHT SYMMETRIC MODEL [a]

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We begin to analyze and contrast the predictions for the decay $b \to s\ell^+\ell^-$ in the Left-Right Symmetric Model(LRM) with those of the Standard Model(SM). In particular, we show that the forward-backward asymmetry of the lepton spectrum can be used to distinguish the SM from the simplest manifestation of the LRM.

1 Introduction

The study of rare B decays may provide us with a window into new physics beyond the SM. In particular, the decays $b \to s\gamma$ [1] and $b \to s\ell^+\ell^-$ [2] may arguably provide the cleanest environment for such searches since they are both reasonably well understood within the SM and most of the difficulties associated with hadrodynamics are avoided. In the LRM, the decay $b \to s\gamma$ has already been examined and many interesting features were uncovered [3]. In particular it was shown that left-right mixing terms can be enhanced by a helicity flip factor of $\sim m_t/m_b$. Here we turn to the decay $b \to s\ell^+\ell^-$ [4]. In order to analyse this mode we use the following procedure which is now relatively standard: (i) Determine the complete operator basis for the effective Hamiltonian, $\mathcal{H}_{eff}$, responsible for $b \to s$ transitions in the LRM; (ii) evaluate the coefficients of these operators at the weak scale; (iii) run these coefficients down to the relevant low energy scale $\mu \sim m_b$ via the RGE's and take the appropriate matrix elements; (iv) calculate observables. We outline these four steps in what follows with the details to be found elsewhere [5].

The decay rate for $b \to s\ell^+\ell^-$, including QCD corrections, is computed

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via the following effective Hamiltonian,

$$\mathcal{H}_{eff} = \frac{4G_F}{\sqrt{2}} \sum_{i=1}^{12} C_{iL}(\mu)\mathcal{O}_{iL}(\mu) + L \to R\,, \qquad (1)$$

which is evolved from the electroweak scale down to $\mu \sim m_b$ by the RGE's. The $\mathcal{O}_{iL,R}$ are the set of operators involving only the light fields which govern $b \to s$ transitions. The complete basis for each helicity structure consists of the usual six 4-quark operators $\mathcal{O}_{1-6L,R}$, the penguin-induced electro- and chromo-magnetic operators respectively denoted as $\mathcal{O}_{7,8L,R}$, as well as $\mathcal{O}_{9L,R} \sim e\bar{s}_{L,R\alpha}\gamma_\mu b_{L,R\alpha}\bar{\ell}\gamma^\mu\ell$, and $\mathcal{O}_{10L,R} \sim e\bar{s}_{L,R\alpha}\gamma_\mu b_{L,R\alpha}\bar{\ell}\gamma^\mu\gamma_5\ell$ which arise from box diagrams and electroweak(EW) penguins. In the LRM we not only have the augmentation of the operator basis via the obvious doubling of $L \to R$, but two new additional 4-quark operators of each helicity structure are also present at the tree-level due to a possible mixing between the $W_{L,R}$ gauge bosons: $\mathcal{O}_{11L,R} \sim (\bar{s}_\alpha\gamma_\mu c_\beta)_{R,L}(\bar{c}_\beta\gamma^\mu b_\alpha)_{L,R}$ and $\mathcal{O}_{12L,R} \sim (\bar{s}_\alpha\gamma_\mu c_\alpha)_{R,L}(\bar{c}_\beta\gamma^\mu b_\beta)_{L,R}$. Note that the extension of the operator basis implies that the conventional model-independent analysis of $b \to s\gamma$ and $b \to s\ell^+\ell^-$ by Hewett [2] will not apply in this case.

2 Analysis

The determination the matching conditions for the 24 operators at the EW scale is somewhat cumbersome since the LRM contains a very large number of free parameters and, in addition to new tree graphs, 116, one-loop graphs must also be calculated.(Additional diagrams due to possible physical Higgs exchange are not yet included.) For simplicity, we will assume that the $Z - Z'$ mixing angle is zero, the $W - W'$ mixing angle(ϕ) is real, right-handed neutrinos are heavy($m_N \gg m_b$) and that the Z' and W' masses are correlated through the usual relationship that follows from $SU(2)_R$ breaking via Higgs triplets [6]. All remaining parameters, in particular the right-handed version of the CKM matrix, V_R, are left arbitrary. Using the results in Refs. [2,3], the RGE analysis is relatively straightforward with the 24×24 anomalous dimension matrices breaking into two 12×12 identical sets as the "L" and "R" operators are decoupled and do not mix under RGE evolution. This RGE running is performed at essentially full NLL.

For $b \to s\ell^+\ell^-$, the effective Hamiltonian above leads to the matrix element (neglecting the strange quark mass)

$$\mathcal{M} = \frac{\sqrt{2}G_F\alpha}{\pi}\Big[C_{9L}^{eff}\bar{s}_L\gamma_\mu b_L\bar{\ell}\gamma^\mu\ell + C_{10L}\bar{s}_L\gamma_\mu b_L\bar{\ell}\gamma^\mu\gamma_5\ell$$

$$-2C_{7L}^{eff}m_b\bar{s}_L i\sigma_{\mu\nu}\frac{q^\nu}{q^2}b_R\bar{\ell}\gamma^\mu\ell + L \to R\Bigg], \tag{2}$$

where q^2 is the momentum transferred to the lepton pair. Note that $C_{9L,R}^{eff}$ contains the usual phenomenological long distance terms and that all the CKM elements are now contained in the coefficients themselves. From here we can directly obtain the expression for the double differential decay distribution

$$\begin{aligned}\frac{d\Gamma}{dzds} \sim\; & \frac{3}{4}\beta(1-s)^2\Bigg\{ \left[(a_L^2+a_R^2)+(b_L^2+b_R^2)\right]\frac{1}{2}\left[(1+s)-(1-s)\beta^2z^2\right] \\ & \left[(a_L^2-a_R^2)-(b_L^2-b_R^2)\right]\beta zs + 4x(a_La_R+b_Lb_R) \\ & +\frac{4}{s^2}(C_{7L}^2+C_{7R}^2)(1-s)^2(1-\beta^2z^2) \\ & -\frac{2}{s}Re\left[C_{7L}(a_L+a_R)+C_{7R}(b_L+b_R)\right](1-s)(1-\beta^2z^2)\Bigg\},\end{aligned} \tag{3}$$

where $z=\cos\theta_{\ell\ell}$, $s=q^2/m_b^2$, $x=m_\ell^2/m_b^2$, $\beta=\sqrt{1-4x/s}$, $a_{R,L}=C_{9L}^{eff}\pm C_{10L}+2C_{7L}/s$ and $b_{L,R}=a_{L,R}(L\to R)$. We normalize this rate to the usual semileptonic branching fraction($B=0.1023$), including finite $m_c/m_b=0.29$ and QCD corrections with $\alpha_s(M_Z)=0.118$. LRM corrections to the semileptonic rate are, of course, also included; here the assumption that $m_N > m_b$ becomes relevant.

3 First Results

Since the LRM parameter space is so large, we have only begun to probe its intricacies. Let us look here at a rather simple example where $V_L=V_R$ and the $SU(2)_{L,R}$ gauge couplings are equal; this is the so-called "manifest" LRM. In this case the K_L-K_S mass difference and direct Tevatron collider searches require [7] that W_R be heavy; we take $M_{W_R}=1.6$ TeV so that $t_\phi=\tan\phi$ is now the only free parameter since W_R contributions are now almost completely decoupled. Fig.1 shows the prediction for the $b\to s\gamma$ branching fraction in this case and we see that the SM result is essentially obtained when $t_\phi=0$, apart from a very small correction of order $M_{W_L}^2/M_{W_R}^2$, but also that a conspiratorial solution occurs when $t_\phi\simeq-0.02$. The results of the CLEO experiment [8] are also shown. From the $b\to s\gamma$ perspective these two cases are indistinguishable, independent of what further improvements can be made in the branching fraction measurement.

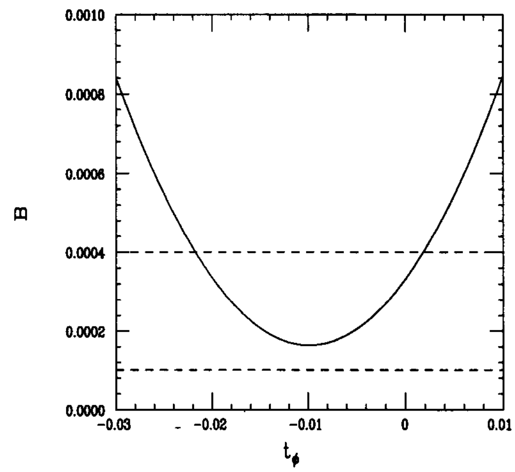

Figure 1: Prediction for the $b \to s\gamma$ branching fraction for $m_t(m_t) = 170$ GeV as a function of the tangent of the $W - W'$ mixing angle in the LRM at NLL for the case discussed in the text. The 95% CL CLEO results lie inside the dashed lines.

Can $b \to s\ell^+\ell^-$ be used to distinguish these two cases? Fig.2 shows both the differential invariant mass distribution of the lepton pair as well as the forward-backward asymmetry for these two scenarios. ($m_N = 300$ GeV was assumed here but the results are found to be insensitive to this choice.) While it is clear that the two decay distributions are very similar and cannot separate the two scenarios, it is obvious that the predictions for the asymmetry are quite different particularly in the highly sensitive region below the J/ψ peak. It is in this region that one has the most sensitivity to interference between the terms involving one of the $C_{7L,R}$ operators and terms proportional to $C_{9,10L,R}$. In fact a χ^2 fit to Monte Carlo data generated with the LRM as input is very poor if we allow for the existence of only the SM operators. Other observables, such as the polarization of final state τ's lack this sensitivity. This simple demonstration shows the added power of the observables associated with the $b \to s\ell^+\ell^-$ decay and their ability to distinguish models with new physics from the SM. The analysis presented here only scratches the surface of the LRM giving us a flavor for what is possible; a more detailed study of the possible structure of V_R will be given elsewhere[5].

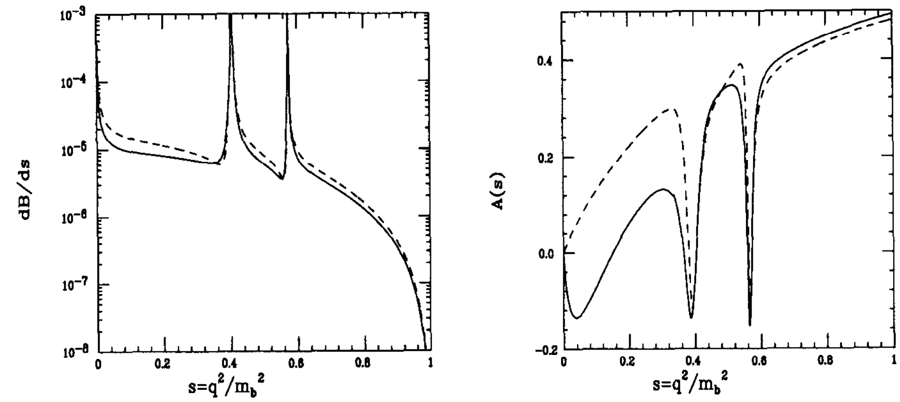

Figure 2: Differential decay distribution and lepton forward-backward asymmetry for the decay $b \to s\ell^+\ell^-$ in the SM(solid) and LRM(dashed) for the case discussed in the text. The lepton mass is ignored.

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