Constraints on Extended Technicolor Models from $B \rightarrow \mu^+\mu^-X$

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Abstract

A recent study by Randall and Sundrum shows that models of Extended Technicolor (ETC) have interesting implications on rare $B$ decays. We extend their study to the decay $B \rightarrow \mu^+\mu^-X$. ETC models with a GIM mechanism predict a decay rate that is a factor of order 30 above the Standard Model, violating the experimental upper bound by a factor of 2–4. “Traditional” ETC models predict a decay rate that is a factor of order 4 above the Standard Model, and will be probed when an improvement in the sensitivity of experiments by a factor of order 2–4 is achieved.
In a recent paper, Randall and Sundrum studied the contributions to the decays $b \rightarrow s\gamma$ and $B_s \rightarrow \mu^+\mu^-$ from various classes of Extended Technicolor (ETC) models. Models with and without a GIM mechanism were considered. In both cases, the radiative decay has roughly the same rate as in the Standard Model (SM). However, ETC contributions enhance the rate for $B_s \rightarrow \mu^+\mu^-$ by one to two orders of magnitude. In this paper, we point out that a similar enhancement occurs for the decay $b \rightarrow s\mu^+\mu^-$. This is particularly interesting because there exists an upper bound on this rate which is only an order of magnitude above the SM rate and, furthermore, near term experiments are expected to further improve this bound. In this brief note, we estimate $BR(b \rightarrow s\mu^+\mu^-)$ in the two classes of ETC models discussed in ref. and compare it to the present experimental upper bound.

The first class of models considered in ref., or “traditional” ETC models, contains the minimal set of interactions necessary for quark mass generation. (The study is restricted to models where neither composite nor fundamental scalars are involved in the quark mass generation.) It is this very minimal set of interactions that are considered in the generation of flavor changing neutral currents (FCNC). As such, it is safe to assume that predictions based on these can be considered as lower bounds. The caveat, of course, is the possibility of cancellations once additional interactions are incorporated. The rates that we find strongly deviate from the SM ones and, therefore, unless these additional cancellations are rather precise, one may conceivably rule out this class of models in the near future.

The second class of models, those with a “techni-GIM” mechanism, incorporate interactions beyond the minimal set of traditional models. They are theoretically appealing since, unlike traditional ETC, the massive vector bosons of the ETC interactions are nearly degenerate, with masses of a few TeV. Although these are rather light by traditional ETC standards, this class of models avoids many dangerous low energy FCNC interactions by incorporating an automatic techni-GIM cancellation mechanism. In the absence of masses, the quark sector has a large $SU(3)^3$ flavor symmetry. If the only parameters that break this symmetry are the quark mass matrices (in the weak eigenstate basis), all of the flavor changing interactions must be proportional to them. Techni-GIM cancellations occur when one rotates to
the mass eigenstate basis. However, as we show below, this class of models seems to violate the existing bound on the rate for $b \rightarrow s\mu^+\mu^-$. The flavor changing interactions that are induced at low energies by these classes of ETC models, and that are relevant for $b \rightarrow s\mu^+\mu^-$, are \([i]\) the neutral current $Z$-boson coupling

$$
\xi^{(i)} \frac{m_t}{16\pi v \cos \theta_W \sin \theta_W} \frac{e}{\sin^2 \theta_W} Y_u^{33} Y_u^{32} s L \gamma_\mu b_L Z^\mu,
$$

which is present and of similar strength in traditional models and in models with a techni-GIM mechanism, and \((ii)\) the 4-fermion interaction

$$
\xi^{(ii)} \frac{m_t}{4\pi v^3} Y_u^{33} Y_u^{32} s L \gamma_\mu b_L \bar{\mu}_L \gamma^\mu \mu_L,
$$

which is highly suppressed in traditional models, but not in models with a techni-GIM mechanism. Here, $v = 246$ GeV is the electroweak symmetry breaking scale. The coefficients $\xi^{(i)}$ and $\xi^{(ii)}$ are model-specific. The normalization of the matrix $Y_u$ is such that $Y_u^{33} = 1$. Following ref. \[1\], we take for our computations, as a rough estimate of the couplings, $Y_u^{32} \sim V_{ts}$, $\xi^{(i)} \sim 1$, and $\xi^{(ii)} \sim 1$ in models with a techni-GIM, while $\xi^{(ii)} \ll 1$ in traditional models. The dominant ETC contributions to the decay Hamiltonian

$$
\mathcal{H}_{\text{eff}} = 2\sqrt{2} G_F \sum_{j=8,9} C_j \mathcal{O}_j,
$$

where

$$
\mathcal{O}_8 = V_{ts} (e^2/16\pi^2) s L \gamma_\mu b_L \bar{\mu}_L \gamma^\mu \mu,
$$

$$
\mathcal{O}_9 = V_{ts} (e^2/16\pi^2) s L \gamma_\mu b_L \bar{\mu}_L \gamma^\mu \gamma_5 \mu,
$$

are then

$$
C_8^{(i)} = C_9^{(i)} (1 - 4 \sin^2 \theta_W) \quad C_8^{(i)} = \xi^{(i)} m_t/8v\alpha_{\text{QED}},
$$

$$
C_8^{(ii)} = -C_9^{(ii)} \quad C_9^{(ii)} = \xi^{(ii)} m_t/4v\alpha_{\text{QED}},
$$

for the interactions \((i)\) and \((ii)\), respectively. There are no short distance QCD corrections to this effective Hamiltonian. More precisely, there is no multiplicative correction to $C_8$ since the FCNC is partially conserved. There are additive corrections \[1\] to $C_8$ that arise from mixing of the SM four-quark interaction into the operator $\mathcal{O}_8$. Since the ETC contributions are
much larger than the SM ones, there are effectively no short distance QCD corrections.

The differential rate $d\Gamma(b \to s\mu^+\mu^-)/dx$, where $x = (p_{\mu^+} + p_{\mu^-})^2/m_B^2$, is usually expressed in units $\Gamma(b \to ce\bar{\nu}_e)$, in which case the dependence on CKM parameters drops out. The rate is given by

$$\frac{1}{\Gamma(b \to ce\bar{\nu}_e)} \frac{d\Gamma(b \to s\mu^+\mu^-)/dx = \frac{\alpha^2_{QED}}{4\pi^2 f(m_c/m_b)} (1 - x)^2(1 + 2x)(|C_8|^2 + |C_9|^2)}{4\pi^2 f(m_c/m_b)} (1 - x)^2(1 + 2x)(|C_8|^2 + |C_9|^2)$$

($f(0.3) = 0.52$ is a phase space factor) and is plotted in fig. 1, for $m_t = 160$ GeV, for both type $(i)$ and $(ii)$ contributions. The SM result [4] is also given in the figure for comparison.

Similar to the results of ref. [1] for the decay $B_s \to \mu^+\mu^-$, we find that the rate for $b \to s\mu^+\mu^-$ is enhanced, compared to the SM, by a factor of approximately 4 for type $(i)$ interactions, and by a factor of approximately 30 for type $(ii)$ interactions. The corresponding integrated rates are given in table 1 for various values of $m_t$. They should be compared to the experimental upper bound [2]: $BR(B \to \mu^+\mu^-X) \leq 5 \times 10^{-5}$. We stress that these estimates are very rough since the precise values of the coefficients $\xi\,(i)$ and $\xi\,(ii)$ are not known. Moreover, the various contributions may interfere destructively. Fig. 1 shows that destructive interference could significantly reduce the rate. Nevertheless, it is unlikely that the resulting cancellations would be so fine-tuned as to reduce the rate down to a level close to that of the SM. Note that even the SM contribution could significantly reduce the total rate through destructive interference with ETC amplitudes.

In ETC models that have a GIM mechanism, the 4-fermion interaction $(ii)$ gives the dominant effect in $b \to s\mu^+\mu^-$. Our results, given in table 1, imply that this type of ETC models are ruled out by experiment, unless the $Z$-exchange contribution from $(i)$ adds destructively or if the various couplings of order one are somewhat suppressed compared to our naive estimates. An improvement of the experimental bound by a factor of a few would be sufficient to rule out that case too – barring delicate cancellations or fine-tuning. For traditional models, the type $(ii)$ interaction is highly suppressed and the rate is dominated by the type $(i)$ interaction. The rate is lower than in the previous case by an order of magnitude, and is marginally
allowed by the current experimental upper limit. Again, it should be probed in the near future when on-going experiments at CLEO and the Tevatron derive a bound stronger than the present one by a factor of a few.

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References

[1] L. Randall and R. Sundrum, preprint MIT-CTP-2211 (1993).

[2] C. Albajar et al. (UA1 Collaboration), Phys. Lett. B262 (1991) 163.

[3] See, for example, report of the δ-working group in the proceedings of the Workshop on B-Physics in Hadron Accelerators (Snowmass 1993), to be published.

[4] B. Grinstein, M. Savage and M. Wise, Nucl. Phys. B319 (1989) 271.
Figure Captions

Figure 1: The differential decay rate $d\Gamma(b \to s\mu^+\mu^-)/dx$ ($x = (p_{\mu^+} + p_{\mu^-})^2/m_B^2$) due to the ETC interactions (i) and (ii) and in the SM, for $m_t = 160$ GeV.

Table Captions

Table 1: The branching ratio for $B \to \mu^+\mu^-X$ in the SM, and that due to the ETC interactions (i) and (ii).
| $m_t$/GeV | SM     | (i)    | (ii)   |
|-----------|--------|--------|--------|
| 130       | $3.5 \times 10^{-6}$ | $1.5 \times 10^{-5}$ | $1 \times 10^{-4}$ |
| 160       | $5.1 \times 10^{-6}$ | $2 \times 10^{-5}$  | $1.5 \times 10^{-4}$ |
| 190       | $7.4 \times 10^{-6}$ | $3 \times 10^{-5}$  | $2 \times 10^{-4}$  |