

HNU-TH/95-09

May, 1995

Constraints on Masses of Charged PGBs in Technicolor Model from Decay $b \rightarrow s\gamma$

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Abstract

In this paper we calculate the contributions to the branching ratio of $B \rightarrow X_s\gamma$ from the charged Pseudo-Goldstone bosons appeared in one generation technicolor model. The current *CLEO* experimental results can eliminate large part of the parameter space in the $m(P^\pm) - m(P_8^\pm)$ plane, and specifically, one can put a strong lower bound on the masses of color octet charged PGBs P_8^\pm : $m(P_8^\pm) > 400 \text{ GeV}$ at 95%*C.L* for free $m(P^\pm)$.

PACS numbers: 13.40.Hq, 13.20.Jf

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1 Introduction

Recently the CLEO collaboration has observed[1] the exclusive radiative decay $B \rightarrow K^*\gamma$ with a branching fraction of $BR(B \rightarrow K^*\gamma) = (4.5 \pm 1.0 \pm 0.9) \times 10^{-4}$. The inclusive $b \rightarrow s\gamma$ branching ratio measured by CLEO[2] is:

$$BR(B \rightarrow X_s\gamma) = (2.32 \pm 0.57 \pm 0.35) \times 10^{-4}. \quad (1)$$

The newest upper and lower limits of this decay branching ratio are

$$1.0 \times 10^{-4} < BR(B \rightarrow X_s\gamma) < 4.2 \times 10^{-4}, \quad \text{at } 95\%C.L.. \quad (2)$$

As a loop-induced flavor changing neutral current(FCNC) process the inclusive decay(at quark level) $b \rightarrow s\gamma$ is in particular sensitive to contributions from those new physics beyond the Standard Model(SM)[3].

The decay $b \rightarrow s\gamma$ and its large leading log QCD corrections have been evaluated in the SM by several groups [4]. The reliability of the calculations of this decay is improving as partial calculations of the next-to-leading logarithmic QCD corrections to the effective Hamiltonian[5, 6].

On the other hand the discovery of the top quark and the measurement of its mass (in this paper we use the weighted average $m_t = 180 \pm 12 \text{ GeV}$ from the announced results of m_t by CDF and D0[7] wherever possible) at FERMILAB basically eliminated a source of uncertainties for the calculation of the decay $b \rightarrow s\gamma$ in the SM and in beyond theories. The great progress in theoretical studies and in experiments achieved recently encourage us to do more investigations about this decay in technicolor theories.

In this paper, we estimate the possible contributions to the decay $b \rightarrow s\gamma$ from the exchange of the charged Pseudo-Goldstone bosons which will appear in no-minimal technicolor models, such as the Farhi-Susskind one-generation technicolor model (OGTM) [8]. We know that the experimental data seems disfavor the OGTM which generally tend to predict S parameter large and positive [9]. Why we here still choose it to do the calculations? The reasons are the following:

(1) At first, presence of the Pseudo-Goldstone bosons in the particle spectrum is a common feature of those non-minimal TC models with ordinary or novel ETC sectors, no matter the specific differences of structures between those models. The gauge couplings of the PGBs are determined by their quantum numbers, while the Yukawa couplings of PGBs to ordinary fermions are generally proportional to fermion masses for many TC/ETC models. Among the non-minimal TC models, the OGTM [8] is the simplest and most frequently studied model. Many relevant works [10] have been done since the late 1970's. One can use those existed results directly in further investigations.

(2) On the other hand, the constraints on the S parameter could be relaxed considerably by introducing three additional parameters (V, W, X) [11]. A global fit to the data in which all six oblique parameters S through X are allowed to vary simultaneously gives the one standard deviation bound on S : $S \sim -0.93 \pm 1.7$ [12]. This fact means that the constraint on the OGTM from the parameter S could be considerably weakened if we consider the effects from light technifermions and light PGBs [13].

In this paper, we estimate the possible contributions to the rare decay $b \rightarrow s\gamma$ from the charged PGBs in the framework of the OGTM. At least, one can regard our results as an estimation for the “correct” output of the future “realistic” TC models.

This paper is organized as follows: In Sec.2, we present the basic ingredients of the OGTM and then calculate the PGB contributions to $b \rightarrow s\gamma$ decay, together with the full leading log QCD corrections. In Sec.3, we obtain the branching ratios of this decay, and derive out the constraints on masses of charged PGBs by phenomenological analysis. The conclusions are also included in this section.

2 Charged PGBs and QCD Corrections to $b \rightarrow s\gamma$

In the OGTM [8], when the technifermion condensate $\langle \bar{T}T \rangle \neq 0$ was formed, the global flavor symmetry will break as follows: $SU(8)_L \times SU(8)_R \rightarrow SU(8)_{L+R}$. Consequently, 63 (Pseudo)-Goldstone bosons will be produced from this breaking. When all other interactions but the technicolor are turned off, these 63 Goldstone bosons are exactly massless. Three of them are eaten by the W^\pm and Z^0 gauge bosons. The others acquire masses when one turned on the gauge interactions, and therefore they are Pseudo-Goldstone Bosons(PGBs).

According to previous studies, the phenomenology of those color-singlet charged PGBs in the OGTM is very similar with that of the elementary charged Higgs bosons H^\pm of Type-I Two-Higgs-Doublet Model(2HDM) [14]. And consequently, the contributions to the decay $b \rightarrow s\gamma$ from the color-singlet charged PGBs in the OGTM will be very similar with that from charged Higgs bosons in the 2HDM. As for the color-octet charged PGBs, the situation is more complicated because of the involvement of the color interactions. Other neutral PGB’s don’t contribute to the rare decay $b \rightarrow s\gamma$.

The gauge couplings of the PGBs are determined by their quantum numbers. The Yukawa couplings of PGBs to ordinary fermions are induced by ETC interactions and hence are model dependent. However, these Yukawa couplings are generally proportional to fermion masses with small differences in the magnitude of the coefficients for different TC/ETC models. The relevant couplings needed in our calculation are directly quoted

from refs.[15, 16, 17] and summarized in Table 1, where the V_{ud} is the corresponding element of KM matrix. For the OGTM, the Goldstone boson decay constant F_π in Table 1 should be $F_\pi = v/2 = 123 \text{ GeV}$, in order to ensure the correct masses for the gauge bosons Z^0 and W^\pm [10].

Table 1: The gauge couplings and Effective Yukawa couplings for the OGTM.

$P^+ P^- \gamma_\mu$	$-ie(p_+ - p_-)_\mu$
$P_{8a}^+ P_{8b}^- \gamma_\mu$	$-ie(p_+ - p_-)_\mu \delta_{ab}$
$P^+ u d$	$i \frac{V_{ud}}{2F_\pi} \sqrt{\frac{2}{3}} [M_u(1 - \gamma_5) - M_d(1 + \gamma_5)]$
$P_{8a}^+ u d$	$i \frac{V_{ud}}{2F_\pi} 2\lambda_a [M_u(1 - \gamma_5) - M_d(1 + \gamma_5)]$
$P_{8a}^+ P_{8b}^- g_{c\mu}$	$-gf_{abc}(p_a - p_b)_\mu$

In ref.[18] the authors have estimated the contributions to $b \rightarrow s\gamma$ from the exchange of ETC gauge bosons in various ETC scenarios. In the case of “traditional” ETC (just the case which will be studied here), the dominant contribution to $b \rightarrow s\gamma$ occurs when the ETC gauge boson is exchanged between purely left-handed doublets and when the photon is emitted from the technifermion line. But the resulted ETC contribution is strongly suppressed with respect to the SM by a factor of $m_t/(4\pi v) < 0.09$ for $m_t < 200 \text{ GeV}$ [18]. In short, the ETC contribution to the decay $b \rightarrow s\gamma$ is small and will be masked by still large experimental and theoretical uncertainties. We therefore can neglect the ETC Contributions to $b \rightarrow s\gamma$ at present phenomenological analysis.

In Fig.1 we draw the relevant Feynman diagrams which contribute to the decay $b \rightarrow s\gamma$, where the half-circle lines represent the W gauge boson as well as the charged PGBs P^\pm and P_8^\pm . In the evaluation we at first integrate out the top quark and the weak W bosons at $\mu = M_W$ scale, generating an effective five-quark theory. By using the renormalization group equation, we run the effective field theory down to b-quark scale to calculate the rate of radiative b decay.

After applying the full QCD equations of motion[19], a complete set of dimension-6 operators relevant for $b \rightarrow s\gamma$ decay can be chosen to be:

$$O_1 = (\bar{c}_{L\beta} \gamma^\mu b_{L\alpha}) (\bar{s}_{L\alpha} \gamma_\mu c_{L\beta}), \quad (3)$$

$$O_2 = (\bar{c}_{L\alpha} \gamma^\mu b_{L\alpha}) (\bar{s}_{L\beta} \gamma_\mu c_{L\beta}), \quad (4)$$

$$O_3 = (\bar{s}_{L\alpha} \gamma^\mu b_{L\alpha}) \sum_{q=u,d,s,c,b} (\bar{q}_{L\beta} \gamma_\mu q_{L\beta}), \quad (5)$$

$$O_4 = (\bar{s}_{L\alpha} \gamma^\mu b_{L\beta}) \sum_{q=u,d,s,c,b} (\bar{q}_{L\beta} \gamma_\mu q_{L\alpha}), \quad (6)$$

$$O_5 = (\bar{s}_{L\alpha}\gamma^{\mu}b_{L\alpha}) \sum_{q=u,d,s,c,b} (\bar{q}_{R\beta}\gamma_{\mu}q_{R\beta}), \quad (7)$$

$$O_6 = (\bar{s}_{L\alpha}\gamma^{\mu}b_{L\beta}) \sum_{q=u,d,s,c,b} (\bar{q}_{R\beta}\gamma_{\mu}q_{R\alpha}), \quad (8)$$

$$O_7 = (e/16\pi^2)m_b\bar{s}_L\sigma^{\mu\nu}b_RF_{\mu\nu}, \quad (9)$$

$$O_8 = (g/16\pi^2)m_b\bar{s}_L\sigma^{\mu\nu}T^ab_RG_{\mu\nu}^a. \quad (10)$$

The effective Hamiltonian appears just below the W-scale as

$$\mathcal{H}_{eff} = \frac{4G_F}{\sqrt{2}}V_{tb}V_{ts}^*\sum_{i=1}^8C_i(M_W^-)O_i(M_W^-). \quad (11)$$

with coefficients

$$C_i(M_W) = 0, \quad i = 1, 3, 4, 5, 6, \quad C_2(M_W) = -1, \quad (12)$$

$$C_7(M_W) = A(\delta) + \frac{B(x)}{3\sqrt{2}G_FF_{\pi}^2} + \frac{8B(y)}{3\sqrt{2}G_FF_{\pi}^2}, \quad (13)$$

$$C_8(M_W) = C(\delta) + \frac{D(x)}{3\sqrt{2}G_FF_{\pi}^2} + \frac{8D(y) + E(y)}{3\sqrt{2}G_FF_{\pi}^2}, \quad (14)$$

with $\delta = M_W/m_t$, $x = m(P^{\pm})/m_t$ and $y = m(P_8^{\pm})/m_t$. The functions A , B , C , D , and E are defined as,

$$A(\delta) = \frac{\frac{1}{3} + \frac{5}{24}\delta - \frac{7}{24}\delta^2}{(1-\delta)^3} + \frac{\frac{3}{4}\delta - \frac{1}{2}\delta^2}{(1-\delta)^4} \log[\delta] \quad (15)$$

$$B(y) = \frac{-\frac{11}{36} + \frac{53}{72}y - \frac{25}{72}y^2}{(1-y)^3} + \frac{-\frac{1}{4}y + \frac{2}{3}y^2 - \frac{1}{3}y^3}{(1-y)^4} \log[y], \quad (16)$$

$$C(\delta) = \frac{\frac{1}{8} - \frac{5}{8}\delta - \frac{1}{4}\delta^2}{(1-\delta)^3} - \frac{\frac{3}{4}\delta^2}{(1-\delta)^4} \log[\delta] \quad (17)$$

$$D(y) = \frac{-\frac{5}{24} + \frac{19}{24}y - \frac{5}{6}y^2}{(1-y)^3} + \frac{\frac{1}{4}y^2 - \frac{1}{2}y^3}{(1-y)^4} \log[y], \quad (18)$$

$$E(y) = \frac{\frac{3}{2} - \frac{15}{8}y - \frac{5}{8}y^2}{(1-y)^3} + \frac{\frac{9}{4}y - \frac{9}{2}y^2}{(1-y)^4} \log[y], \quad (19)$$

The second terms (third terms) in eqs.(13,14) represent the contributions to the coefficients $C_7(M_W)$ and $C_8(M_W)$ from the color-singlet charged PGBs P^{\pm} (color octets P_8^{\pm}) in the OGTM.

The running of the coefficients of operators from $\mu = M_W$ to $\mu = m_b$ was well described in refs.[4]. After renormalization group running we have the QCD corrected coefficients of operators at $\mu = m_b$ scale.

$$C_7^{eff}(m_b) = \eta^{16/23}C_7(M_W) + \frac{8}{3}(\eta^{14/23} - \eta^{16/23})C_8(M_W) + C_2(M_W)\sum_{i=1}^8h_i\eta^{a_i}. \quad (20)$$

With $\eta = \alpha_s(M_W)/\alpha_s(m_b)$,

$$h_i = \left(\frac{626126}{272277}, -\frac{56281}{51730}, -\frac{3}{7}, -\frac{1}{14}, -0.6494, -0.0380, -0.0186, -0.0057 \right),$$

$$a_i = \left(\frac{14}{23}, \frac{16}{23}, \frac{6}{23}, -\frac{12}{23}, 0.4086, -0.4230, -0.8994, 0.1456 \right).$$

3 The $B \rightarrow X_s \gamma$ decay rate and phenomenology

Following refs.[4],

$$BR(B \rightarrow X_s \gamma)/BR(B \rightarrow X_c e \bar{\nu}) \simeq \Gamma(b \rightarrow s \gamma)/\Gamma(b \rightarrow c e \bar{\nu}). \quad (21)$$

Then

$$\frac{BR(B \rightarrow X_s \gamma)}{BR(B \rightarrow X_c e \bar{\nu})} \simeq \frac{|V_{tb} V_{ts}^*|^2}{|V_{cb}|^2} \frac{6\alpha_{QED}}{\pi g(m_c/m_b)} |C_7^{eff}(m_b)|^2 \left(1 - \frac{2\alpha_s(m_b)}{3\pi} f(m_c/m_b) \right)^{-1}, \quad (22)$$

where the phase space factor $g(z)$ is given by:

$$g(z) = 1 - 8z^2 + 8z^6 - z^8 - 24z^4 \log z, \quad (23)$$

and the factor $f(m_c/m_b)$ of one-loop QCD correction to the semileptonic decay is,

$$f(m_c/m_b) = (\pi^2 - 31/4)(1 - m_c^2/m_b^2) + 3/2. \quad (24)$$

Afterwards one obtains the $B \rightarrow X_s \gamma$ decay rate normalized to the quite well established semileptonic decay rate $Br(B \rightarrow X_c e \bar{\nu})$. If we take experimental result $BR(B \rightarrow X_c e \bar{\nu}) = 10.8\%$ [20], the branching ratios of $B \rightarrow X_s \gamma$ is found to be:

$$BR(B \rightarrow X_s \gamma) \simeq 10.8\% \times \frac{|V_{tb} V_{ts}^*|^2}{|V_{cb}|^2} \frac{6\alpha_{QED}}{\pi g(m_c/m_b)} |C_7^{eff}(m_b)|^2 \left(1 - \frac{2\alpha_s(m_b)}{3\pi} f(m_c/m_b) \right)^{-1}. \quad (25)$$

In numerical calculations we always use $M_W = 80.22 \text{ GeV}$, $\alpha_s(m_Z) = 0.125$, $m_c = 1.5 \text{ GeV}$, $m_b = 4.8 \text{ GeV}$ and $|V_{tb} V_{ts}^*|^2/|V_{cb}|^2 = 0.95$ [20] as input parameters.

Fig.2 is the plot of the branching ratio $Br(B \rightarrow X_s \gamma)$ as a function of the top quark mass. The upper dashed curve in Fig.2 represents the branching ratio in the standard model, while the solid curve shows the same ratio with the inclusion of the contributions from P^\pm and P_8^\pm assuming $m(P^\pm) = 300 \text{ GeV}$ and $m(P_8^\pm) = 600 \text{ GeV}$. The band between two dash-dotted lines corresponds to the newest CLEO limits: $1.0 \times 10^{-4} < BR(B \rightarrow X_s \gamma) < 4.2 \times 10^{-4}$ at 95% C.L. [2].

Generally speaking, the contribution to the decay $b \rightarrow s \gamma$ from color singlet P^\pm is small when compared with the dominate contribution from the color octet P_8^\pm , since

there is a color enhancement factor 8 appeared in the third terms in eqs.(13, 14) for the functions $B(y)$ and $D(y)$. As illustrated by Fig.3, large part of the parameter space in the $m(P^\pm) - m(P_8^\pm)$ plan can be excluded according to the current *CLEO* 95% C.L. limits on the ratio $BR(B \rightarrow X_s \gamma)$ [2]. It is easy to see that no direct limits on $m(P^\pm)$ can be obtained at present, but at the same time, one can simply read out the lower bound on the mass of color octet PGBs: $m(P_8^\pm) > 440 \text{ GeV}$ for free $m(P^\pm)$ (assuming $m_t = 180 \text{ GeV}$), if we simply interpret the *CLEO* 95% C.L. limits on the ratio $BR(B \rightarrow X_s \gamma)$ as the bounds on the masses of charged PGBs.

Of course, we have not considered the effects of other possible uncertainties, such as that of $\alpha_s(m_Z)$. The inclusion of those additional uncertainties will surely weaken the lower limit on $m(P_8^\pm)$, i.e., the lower limit will become $m(P_8^\pm) > 400 \text{ GeV}$ at 95% C.L. if we include an additional 20% theoretical uncertainties.

As a conclusion, the size of contribution to the rare decay of $b \rightarrow s \gamma$ from the PGBs strongly depends on the values of the masses of the top quark and the charged PGBs. This is quite different from the SM case. By the comparison of the theoretical prediction with the current data one can derive out the constraints on the masses of the color octet charged PGBs: $m(P_8^\pm) > 400 \text{ GeV}$ at 95% C.L. for free $m(P^\pm)$, assuming $m_t = 180 \text{ GeV}$.

ACKNOWLEDGMENT

This work was supported in part by the National Natural Science Foundation of China, the funds from Henan Science and Technology Committee and China Postdoctoral Science Foundation.

References

- [1] R. Ammar, et al., CLEO Collaboration, Phys. Rev. Lett. **71**, 674 (1993).
- [2] M.S.Alam et al., CLEO Collaboration, Phys.Rev.Lett. **74**, 2885 (1995).
- [3] J.L. Hewett, SLAC Preprint, SLAC-PUB-6521, 1994; and references therein.
- [4] M. Misiak, Phys. Lett. **B269**, 161 (1991); K. Adel, Y.P. Yao, Mod. Phys. Lett. **A8**, 1679 (1993); Phys. Rev. **D49**, 4945 (1994); M. Ciuchini et al., Phys. Lett. **B316**, 127(1993); C.S. Gao, J.L. Hu, C.D. Lü and Z.M. Qiu, hep-ph/9408351, to appear in Phys. Rev. D.

- [5] A.J. Buras et al., Nucl. Phys. **B370**, 69(1992), Addendum, ibid. **B375**, 501 (1992); **B400**, 37 (1993) and **B400**, 75 (1993).
- [6] M. Ciuchini et al., Phys. Lett. **B301**, 263(1993); Nucl. Phys. **B415**, 403 (1994).
- [7] CDF Collaboration, F.Abe et al., Phys.Rev.Lett. **74**, 2626 (1995); D0 Collaboration, S.Abachi et al., Phys.Rev.Lett. **74**, 2632 (1995).
- [8] E.Farhi and L.Susskind, Phys.Rev. **D20**, 3464(1979); S.Dimopoulos, Nucl.Phys. **B168**, 69(1980); For a review see E.Farhi and L.Susskind, Phys.Rep. **74**, 277(1981), and reference there in.
- [9] M.E.Peskin and T. Takeuchi, *Phys.Rev.Lett.* **65**, 964 (1990); *Phys.Rev.* **D43**, 381 (1992).
- [10] E.Eichten, I.Hinchliffe, K.Lane and C.Quigg, *Phys.Rev.* **D34**, 1547 (1986); E.Eichten, I.Hinchliffe, K.Lane and C.Quigg, *Rev. Mod. Phys.* **56**, 579 (1984); For a recent review of dynamical electroweak symmetry breaking see: S.F.King, *Rep.Prog.Phys.* **58**, 263 (1995).
- [11] I.Maksymyk, C.P.Burgess and D.London, *Phys.Rev.* **D50**, 529 (1994).
- [12] C.P.Burgess, S.Goldfry, M.Konig, D.London and I Maksymyk, *Phys.Lett.* **326B**, 276 (1994).
- [13] N.Evans, *Phys. Rev.* **D49**, 4785 (1994).
- [14] J.F.Gunion and H.E. Haber, *Nucl. Phys.* **B278**, 449 (1986).
- [15] J.Ellis, M.K.Jaillard, D.V.Nanopoulos and P.Sikivie, *Nucl. Phys.* **B182**, 529 (1981); S.Dimopoulos and J.Ellis, *Nucl. Phys.* **B182**, 505 (1981).
- [16] R.S.Chivukula, R.Rosenfeld and E.H.Simmons, *Strongly Coupled Electroweak Symmetry Breaking: Implications of Models*, hep-ph/9503202.
- [17] Z.J.Xiao, L.D.Wan, J.M.Yang and G.R.Lu, *Phys.Rev.* **D49**, 5949 (1994).
- [18] L.Randall and R.S.Sundrum, Phys.Lett.**B312**, 148 (1993).
- [19] H.D. Politzer, Nucl. Phys. **B172**, 349 (1980); H. Simma, preprint, DESY 93-083.
- [20] Particle Data Group, Phys. Rev. **D50**, 1173 (1994).

Figure Captions

Fig.1: The Feynman diagrams which contribute to the rare radiative decay $b \rightarrow s\gamma$. The half-circle-lines in the loop represent the W gauge boson and charged PGBs propergators.

Fig.2: The plot of the branching ratio of $b \rightarrow s\gamma$ versus the top quark mass m_t assuming $m(P^\pm) = 300 \text{ GeV}$ and $m(P_8^\pm) = 600 \text{ GeV}$. For more details see the text.

Fig.3: Allowed range in the $m(P^\pm) - m(P_8^\pm)$ plan for $m_t = 180 \text{ GeV}$, the band is corresponding to the current *CLEO* 95% C.L. limits on the ratio $BR(B \rightarrow X_s\gamma)$ as given in eq.(2).