$b \to s\gamma$ in the littlest Higgs model

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The inclusive process $b \to s\gamma$ is studied in the littlest Higgs model. The contributions arising from new particles are normally suppressed by a factor of $O(v^2/f^2)$. Because of the large uncertainties of experimental measurements and theoretical predictions, the model parameters can escape from the constraints of present experiments provided $f \geqslant 1$ TeV.

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Little Higgs (LH) models [1–6], as an alternative approach to supersymmetric models, have been invented to stabilize the light Higgs boson mass by introducing new gauge bosons, scalars, and quarks. Unlike the case of supersymmetric models, the cancellation of quadratic divergences is realized through the same spin particles. The physical picture is that, below the TeV scale, the physics can be approximately described by the standard model (SM); for a higher energy scale of the order of $O(10)$ TeV, new particles might emerge. It is obvious that the LH model is not the end of the story; ultraviolet completion of the theory must be explored which is beyond the scope of this paper.

Based on the idea of the LH model, a model named the "littlest Higgs model" [5] has been constructed and its explicit interactions have been presented in Ref. [7]. A lot of phenomenological studies in this model have been performed [7–15]. In this Brief Report, we concentrate on the effects of new particles on the inclusive process $b \to s\gamma$, which is known as an ideal place to study new flavor physics [16].

In order to demonstrate the new physics effects, we use the leading-order results to estimate the branching ratio for the inclusive process $b \to s\gamma$, and

$$\mathrm{Br}^{LH}(b \to s\gamma) = \mathrm{Br}^{SM}(b \to s\gamma)\left(\frac{C_{7\gamma}^{LH}(m_b)}{C_{7\gamma}^{SM}(m_b)}\right)^2. \tag{1}$$

It is well known that the $C_{7\gamma}$ at scale of m_b can be easily obtained from $C_{7\gamma}$, C_{8G}, and C_2 at m_W scale through renormalization group equations [17].

The Wilson coefficients at the m_W scale can be generally written as

$$C_x^{LH}(m_W) = C_x^{SM}(m_W)[1 + \Delta_x^{LH}], \tag{2}$$

where x represents 7γ, $8G$, or 2, and Δ^{LH} arises, respectively, from unitarity violation (V) of the Cabibbo-Kobayashi-Maskawa matrix in the SM and the new charged gauge bosons as well as the new fermion T and new charged Higgs bosons $\Phi^{\pm}$,

$$\Delta_x^{LH} = \Delta_x^V + \Delta_x^T + \Delta_x^{W_H} + \Delta_x^{W_H T} + \Delta_x^{\Phi^{\pm}} + \Delta_x^{\Phi^{\pm} T}. \tag{3}$$

Here

$$C_{7\gamma}^{SM}(m_W) = -\frac{A(x_t)}{2},$$

$$C_{8G}^{SM}(m_W) = -\frac{D(x_t)}{2},$$

$$C_2^{SM} = 1 \tag{4}$$

with

$$A(x) = x\left[\frac{8x^2+5x-7}{12(x-1)^3} - \frac{(3x^2-2x)\ln x}{2(x-1)^4}\right],$$

$$D(x) = x\left[\frac{x^2-5x-2}{4(x-1)^3} + \frac{3x\ln x}{2(x-1)^4}\right]. \tag{5}$$

$\Delta_{7\gamma}$ can be written to $O(v^2/f^2)$ as [Δ_{8G} can be obtained by replacing A in Eq. (6) as D]

$$\Delta^V = -\frac{v^2}{f^2}[c^2(c^2-s^2) + x_L^2],$$

$$\Delta^T = \frac{v^2}{f^2}x_L^2\frac{A(x_T)}{A(x_t)},$$

$$\Delta^{W_H} = \left[\left(\frac{c}{s}\right)^2 + \frac{v^2}{f^2}\left\{c^2(c^2-s^2) - \left(\frac{c}{s}\right)^2 x_L^2\right\}\right]\frac{A(x_{w_H})}{A(x_t)}\frac{m_W^2}{m_{W_H}^2},$$

$$\Delta^{W_H T} = \frac{v^2}{f^2}\left(\frac{c}{s}\right)^2 x_L^2\frac{A(x_{w_H T})}{A(x_t)}\frac{m_W^2}{m_{W_H}^2},$$

$$\Delta^{\Phi^{\pm}} = \frac{\left|\frac{v}{f} - 2s_+\right|^2}{12}\frac{[A(x_{\Phi^{\pm}}) + 6B(x_{\Phi^{\pm}})]}{A(x_t)},$$

$$\Delta^{\Phi^{\pm} T} = \frac{\left|\frac{v}{f} - 2s_+\right|^2}{12}\frac{\frac{\lambda_1^2}{\lambda_2^2}A(x_{\Phi^{\pm} T})}{A(x_t)}\frac{m_t^2}{m_T^2}, \tag{6}$$

with $x_t = m_t^2/m_W^2$, $x_T = m_T^2/m_W^2$, $x_{w_H} = m_t^2/m_{W_H}^2$, $x_{w_H T} = m_T^2/m_{W_H}^2$, $x_{\Phi^\pm} = m_t^2/m_{\Phi^\pm}^2$, $x_{\Phi^\pm T} = m_T^2/m_{\Phi^\pm}^2$, $x_L^2 = \lambda_1^4/(\lambda_1^2 + \lambda_2^2)^2$, and $s_+ \approx 2v'/v < v/(2f)$. Here, B can be written as

$$B(y) = \begin{cases} \dfrac{y}{2}\left[\dfrac{\frac{5}{6}y - \frac{1}{2}}{(y-1)^2} - \dfrac{y - \frac{2}{3}}{(y-1)^3}\log y\right], & \text{for } \Delta_{7\gamma}^{\Phi^\pm} \\ \dfrac{y}{2}\left[\dfrac{\frac{1}{2}y - \frac{3}{2}}{(y-1)^2} + \dfrac{1}{(y-1)^3}\log y\right], & \text{for } \Delta_{8g}^{\Phi^\pm}. \end{cases} \tag{7}$$

In Eq. (6), f is the scale where new physics enters, $\lambda_{1,2}$ are parameters in Yukawa interactions which give ''raw'' masses to SM fermions and vectorlike top quark and are supposed to be of the order of unity [7], and c and s are sin and cos of the charged sector mixing angle θ when the Higgs field breaks $[\mathrm{SU}(2)\otimes \mathrm{U}(1)]^2$ into its diagonal subgroup $[\mathrm{SU}(2)\otimes \mathrm{U}(1)]_{SM}$. It should be noted that the main contributions come from the first two terms in Eq. (6), which are only suppressed by $O(v^2/f^2)$. And Δ_2^{LH} can be expressed as

$$\Delta_2^{LH} = -\frac{v^2}{f^2}c^2(s^2 - s^2) + \frac{x_{w_H}}{x_t}\frac{c^2}{s^2}. \tag{8}$$

In the following we present some numerical analysis and adopt the mass relation of new particles at leading order as

$$\frac{m_{w_H}}{m_w} = \sqrt{\frac{1}{s^2c^2}\frac{f^2}{v^2} - 1} \approx \frac{1}{sc}\frac{f}{v},$$

$$\frac{m_T}{m_t} = \frac{\lambda_1^2 + \lambda_2^2}{\lambda_1\lambda_2}\frac{f}{v},$$

$$\frac{m_{\Phi^\pm}}{m_H} = \sqrt{2}\,\frac{f}{v} \tag{9}$$

with $m_H = 115$ GeV. Motivations of the little Higgs model imply that the masses of additional Higgs bosons and gauge bosons are of the order of TeV. Therefore from Eq. (9) we must require that $1/sc$ cannot be too large. In our numerical calculations we choose $\frac{1}{2} < \tan\theta < 10$, which corresponds to $1/sc < 10$. At the same time, we omit the s_+ contribution.

The SM theoretical estimation is, at next-to-leading order [16],

$$\mathrm{Br}^{SM}(b \to s\gamma) = (3.32 \pm 0.30) \times 10^{-4}. \tag{10}$$

However, because the new physics contributions are only calculated to leading order, we adopt here the leading-order results in the SM as [18]

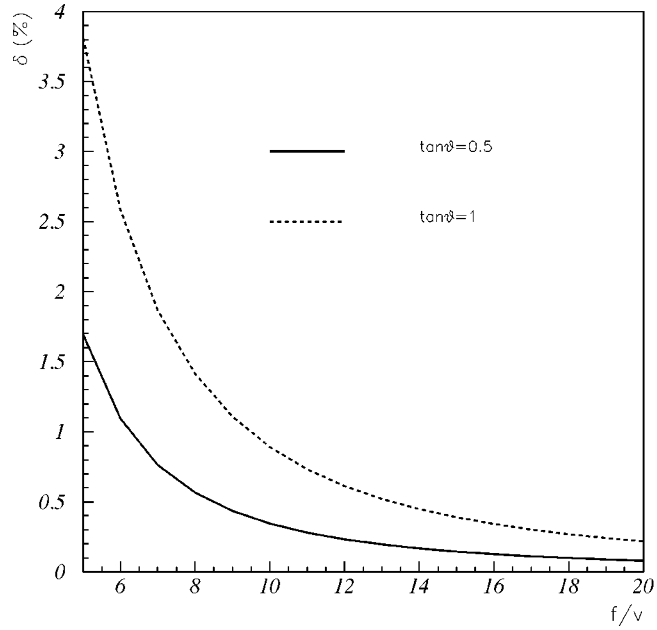

FIG. 1. The relative correction $\delta = \mathrm{Br}^{LH} - \mathrm{Br}^{SM}/\mathrm{Br}^{SM}$ as a function of f/v with $\lambda_1/\lambda_2 = 5$.

$$\mathrm{Br}^{SM}(b \to s\gamma) = (2.8 \pm 0.8) \times 10^{-4}, \tag{11}$$

and the experimental measurement is quoted as [19]

$$\mathrm{Br}(b \to s\gamma) = (3.3 \pm 0.4) \times 10^{-4}. \tag{12}$$

We have scanned the parameter space and found that the parameters can escape the constraints from the experimental measurements provided $f \geqslant 1$ TeV. In order to demonstrate the new physics effects, in Fig. 1, we show the relative correction

$$\delta = \frac{\mathrm{Br}^{LH} - \mathrm{Br}^{SM}}{\mathrm{Br}^{SM}}$$

as a function of f/v with $\lambda_1/\lambda_2 = 5$. From the figure, it is obvious that effects arising from new particles in the littlest Higgs model can change the SM value at a level of a few percents with $f/v = 5$–20.

To summarize, the contributions to inclusive process $b \to s\gamma$ from new particles in the littlest Higgs model have been studied. The new physics effects are suppressed at least by a factor of $O(v^2/f^2)$ and can escape the constraints from $b \to s\gamma$ for $f \geqslant 1$ TeV. We note that the constraints from $b \to s\gamma$ are relatively loose due to the large theoretical and experimental uncertainties.

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