\[ b \rightarrow s\gamma \text{ DECAY IN THE TWO HIGGS DOUBLET MODEL }^* \]

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ABSTRACT

QCD corrections to \( b \rightarrow s\gamma \) decay in the two Higgs doublet model are calculated from the energy scale of top quark to that of bottom. The constraints on the two Higgs doublet model from the new experimental bounds of \( b \rightarrow s\gamma \) by CLEO and the latest top quark mass by CDF and D0 are reanalyzed. It shows that the constraints become more stringent than that of the earlier analysis, i.e. a bigger region of the parameter space of the model is ruled out.

It is known that the experimental bounds of \( b \rightarrow s\gamma \) set very strong constraints on the two Higgs doublet model (2HDM), a minimal extension of the Standard Model (SM). In addition to searching for the neutral Higgs of minimal SM, phenomenologically to investigate possible extensions of SM is also another hot topic in particle physics, thus to apply the latest experimental results of the measurement on \( b \rightarrow s\gamma \) and the newly discovery of top quark to reexamine the constraints on the 2HDM so as to upgrade the allowed values of the model parameters is no doubt always to be interesting.

Reviewing the earlier analysis, one would find that the QCD correction effects owing to the change of the energy scale from top quark’s down to that of \( W \) boson were ignored. Indeed this piece of QCD correction itself is not great, but we treat them seriously, and finally find it being not negligible since this correction affects the constraints on the two Higgs doublet model sizable in the report.

There are two ways for 2HDM to avoid tree-level flavor changing neutral currents (FCNCs). The first (Model I) is to allow only one of the two Higgs doublets to couple to both types, u-type and d-type, of quarks but the other doublet is totally forbidden by certain discrete symmetry. The second (Model II) is to arrange as that one Higgs doublet couples to u-type quarks while the other couples to d-type quarks respectively due to a different discrete symmetry. It is of interest to note that the Model II, as a natural feature, occurs in such a theory as that with supersymmetry or with a Peccei-Quinn type of symmetry.

The effective Hamiltonian after integrating out the heavy top freedom is:

\[ \mathcal{H}_{\text{eff}} = 2\sqrt{2}G_F V_{tb}V_{ts}^* \sum_i C_i(\mu)O_i(\mu). \]  

(1)

The coefficients \( C_i(m_t) \) of effective operators \( O_i \) can be calculated from matching

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conditions at \( \mu = m_t \), and \( C_i(\mu) \) can be obtained from their renormalization group equation (RGE):

\[
\frac{d}{d\mu} C_i(\mu) = \sum_j (\gamma^\tau)_{ij} C_j(\mu),
\]

This is the very procedure which gives out the QCD corrections from \( m_t \) scale to \( M_W \) scale. In this stage, we calculate the anomalous dimensions \( \gamma_{ij} \) of operators, it shows that there are errors in the previous calculations. After corrections, we got the coefficients of operators at \( \mu = M_W \) by renormalization group running. The coefficients of operators at this stage changed due to this corrections, especially for operator \( O_8 \). When \( \mu = M_W \), one encounters with the W boson. If integrating out the W boson freedom further, once more six relevant four-quark operators will be added. Thus one obtains the effective Hamiltonian just below \( M_W \) scale.

The running of the coefficients of operators from \( \mu = M_W \) to \( \mu = m_b \) was well described in refs. With the running due to QCD, the coefficient of the operator at \( \mu = m_b \) scale is:

\[
C_{eff}^7(m_b) = \eta^{16/23} C_7(M_W) + \frac{8}{3} (\eta^{14/23} - \eta^{16/23}) C_8(M_W) + C_2(M_W) \sum_{i=1}^{8} h_i \eta^{a_i}.
\]

Here \( \eta = \alpha_s(M_W)/\alpha_s(m_b) \),

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

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

The explicit expressions of the coefficient of operators at \( \mu = M_W \) are given at previous paper.

Using the quite well established semileptonic decay rate \( Br(B \to X_c e \nu) \), one obtains

\[
\frac{BR(B \to X_s \gamma)}{BR(B \to X_c e \nu)} \approx \frac{|V_{ts}^* V_{tb}|^2}{|V_{cb}|^2} \frac{6 \alpha_{QED}}{\pi g(m_c/m_b)} |C_{eff}^7(m_b)|^2,
\]

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

\[
g(z) = 1 - 8z^2 + 8z^6 - z^8 - 24z^4 \log z,
\]

here we use \( m_c/m_b = 0.316 \). If we take experimental result \( Br(B \to X_c e \nu) = 10.8\% \), the branching ratios of \( B \to X_s \gamma \) is found.

The effects of QCD corrections from \( m_t \) to \( M_W \) can first be seen from values of \( C_i(M_W) \). The Figure 5 in previous paper shows that the effects of the QCD corrections are roughly within ten percent and not depend on \( \tan \beta \) very much. However,
one will see soon that the effects, though only in ten percent, will make substantial changes for the constraints on the parameter space of 2HDM.

Applying the CLEO newer experiment of $b \to s\gamma$ decay, $1.0 \times 10^{-4} < Br(B \to X_s\gamma) < 4.2 \times 10^{-4}$, at 95% C.L.\footnote{M.S.Alam et al., CLEO Collaboration, Phys. Rev. Lett. 74 (1995) 2885.} One can obtain the excluded region for model parameter $\tan\beta$ and $m_\phi$. Without QCD corrections from $m_t$ to $M_W$, the excluded region is more sensitive for changing of $\alpha_s$ than for $m_t$.\footnote{F. Abe et al., CDF Collaboration, Phys. Rev. Lett. 74, 2626 (1995); S. Abachi et al., D0 Collaboration, Phys. Rev. Lett. 74, 2632 (1995).} But after including this QCD corrections, it is interesting to note that the parameter space is more sensitive for changing of $m_t$ than for $\alpha_s$, especially in Model II.\footnote{A.J. Buras et al., Nucl. Phys. B424, 374 (1994); M. Ciuchini et al. Phys. Lett. B334 137 (1994); A.K. Grant, Phys. Rev. D51, 207 (1995); G.T. Park, preprint YUMS-95-9, SNUTP-95-030, hep-ph/9504369.}

for Model I, there are two bands in the $\tan\beta-M_\phi$ plane, excluded by our reanalysis with the latest measurements on $b \to s\gamma$ and $m_t$.\footnote{C.D. Lü, Nucl. Phys. B441 (1995) 33.} The excluded region is large, only two narrow windows in the parameter space are allowed. For model II, the analysis shows that there is a lower bound for mass of charged Higgs: 310 GeV, at 95% C.L..\footnote{H.E. Haber, G.L. Kane and T. Sterling, Nucl. Phys. B161 (1979) 493.} The previous analysis\footnote{S.L. Glashow and S. Weinberg, Phys. Rev. D15 (1977) 1958.} without QCD corrections from $m_t$ to $M_W$ gave a bound only 200 Gev. So the bound is more strict now.

In conclusion, due to the QCD corrections from $m_t$ to $M_W$, the new experimental value of $m_t$ and the bounds for $b \to s\gamma$, the constraints for 2HDM are strained substantially. For instance, the lower bound for the mass of the charged Higgs is put up at least 100 GeV for Model II.

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