Effects of Top-quark Compositeness on Higgs Boson Production at the LHC

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Abstract: Motivated by the possibility that the right-handed top-quark ($t_R$) is composite, we discuss the effects of dimension-six operators on the Higgs boson production at the LHC. When $t_R$ is the only composite particle among the Standard Model (SM) particles, the $(V + A) \otimes (V + A)$ type four-top-quark contact interaction is expected to have the largest coefficient among the dimension-six operators, according to the Naive Dimensional Analysis (NDA). We find that, to lowest order in QCD and other SM interactions, the cross section of the SM Higgs boson production via gluon fusion does not receive corrections from one insertion of the new contact interaction vertex. We also discuss the effects of other dimension-six operators whose coefficients are expected to be the second and the third largest from NDA. We find that the operator which consists of two $t_R$’s and two SM Higgs boson doublets can recognizably change the Higgs boson production cross section from the SM prediction if the cut-off scale is $\sim$ 1TeV.

Keywords: Higgs Physics, Hadronic Colliders, Technicolor and Composite Models.
1. Introduction

Even though we know that the Standard Model (SM) describes physics up to the weak scale very well, the mechanism of the electroweak symmetry breaking (EWSB) still remains unknown. To improve this situation, it is very important to search for the Higgs boson and study its properties in detail since in the SM it is the Higgs boson that is responsible for the EWSB. In view of this, the Large Hadron Collider (LHC) provides an excellent opportunity since it is expected to copiously produce the Higgs boson.

Another interesting particle of the SM is the top-quark. Since it is the only known quark whose mass is around the weak scale, it is natural to speculate that it plays a special role in the EWSB and/or that it has properties different from those of the other quarks. One of such interesting scenarios is the composite top-quark. For instance, in the scenario proposed in Refs. [1, 2], the right-handed top-quark $t_R$ is composite, which gives the same low energy predictions for the top-quark mass and the Higgs boson mass as the $tar{t}$ condensation models [3, 4, 5]. Also from different motivations, there are increasing interests in the possibility that the top-quark is composite [6, 7, 8, 9, 10]. It is therefore important to study phenomenological consequences from the compositeness of the top-quark.

If the top-quark is composite, the effects of the compositeness at low energies are described by higher dimensional operators, which are suppressed by the composite scale $\Lambda$ [6, 11]. For the left-handed top-quark, $\Lambda$ is constrained to be above the order of a few TeV from $Z \rightarrow b\bar{b}$ decays [6, 12], while for the right-handed top, the constraint is weaker: Ref. [8] quotes the bound $\Lambda/g_{\text{new}} \gtrsim 80$ GeV from the inclusive top pair production cross section at the Tevatron, where $g_{\text{new}}$ is the effective strong coupling constant which is associated with the four-top-quark contact interactions.

In this article, we study the effects of the right-handed top-quark compositeness on the Higgs boson production at the LHC. At the LHC, the dominant production process of the SM Higgs boson is gluon fusion, $gg \rightarrow H$, where the main contribution comes from the top-quark loop diagrams. This means that the properties of the top-quark, such as the anomalous couplings with gluon or the Higgs boson, directly affects the cross section of gluon fusion. In this article, we parametrize the effects of the $t_R$ compositeness by higher dimensional operators, and study those effects on $gg \rightarrow H$ without assuming a particular new physics model which makes $t_R$ composite.

This article is organized as following. In the next section, we set out our framework. We work with the low-energy effective Lagrangian, and use the Naive Dimensional Analysis (NDA) [13] to estimate the coefficients of the dimension-six operators relevant to our analysis. In Section 3, we discuss the effect of the $(V + A) \otimes (V + A)$ type four-top-quark contact interaction, which is expected to have the largest coefficient among the dimension-six operators according to NDA. In Section 4, we study the effects of other dimension-six operators whose coefficients are expected to be the second and the third largest from NDA. In Section 5, we conclude our study.
2. Effective Lagrangian

When the characteristic scale \( \Lambda \) of new physics is high enough, we can describe the effects of the new physics at low energies in terms of higher dimensional operators. In such a case, we may write the low-energy effective Lagrangian \( \mathcal{L}_{\text{eff}} \) as

\[
\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \sum_{n \geq 5} \sum_{i} \frac{C_i}{\Lambda^{n-4}} \mathcal{O}_i^{(n)},
\]

where \( i \) is the label for the dimension-\( n \) operators \( \mathcal{O}_i^{(n)} \) and \( C_i \) is the dimensionless coupling associated with \( \mathcal{O}_i^{(n)} \). \( \mathcal{L}_{\text{SM}} \) is the SM Lagrangian. In this article we consider CP-conserving higher-dimensional operators only.

We are interested in the case where, among the SM fields, only the right-handed top-quark \( t_R \) is composite. We do not specify an underlying physics which makes \( t_R \) composite, and work with the effective Lagrangian Eq. (2.1).

To estimate the coefficients of the higher-dimensional operators, we use the Naive Dimensional Analysis (NDA) \[13\]. According to NDA, in the case where only \( t_R \) is composite among the SM particles, the following four-fermion operator is expected to have the largest coefficient among dimension-six operators:

\[
\mathcal{O}_{tt} = \frac{1}{2} (\bar{t}^\alpha \gamma_\mu P_R t_\alpha) (\bar{t}^\beta \gamma_\mu P_R t_\beta),
\]

where \( \alpha \) and \( \beta \) are color indices\(^1\). \( P_R \) is the right-handed projector, \( P_R \equiv (1 + \gamma_5)/2 \). We call this operator the leading order (LO) in NDA. According to NDA, the operator (2.2) is expected to have the coefficient

\[
C_{tt} = c_{tt} g_{\text{new}}^2,
\]

where \( g_{\text{new}} \) is the effective coupling constant which is associated with the new strong interactions which makes \( t_R \) composite, and \( c_{tt} \) is a constant of the order of one. The NDA argument requires that \( g_{\text{new}} \lesssim 4\pi \). For later discussions, we note here that since \( \mathcal{O}_{tt} \) is Hermitian, the Hermiticity of the Lagrangian implies that \( C_{tt} \) must be real. We also note that \( \mathcal{O}_{tt} \) is even under CP.

We also consider dimension-six operators whose coefficients are next-to-leading (NLO) and next-to-next-to-leading (NNLO) in the sense of NDA. The NLO operators are the dimension-six operators which have three \( t_R \) and a different up-type quark, namely,

\[
\mathcal{O}_{t_R^{\beta a}} \equiv (\bar{t}_R^\alpha \gamma_\mu t_R^\alpha) (\bar{t}_R^\beta \gamma_\mu u_R^\beta) + \text{h.c.},
\]

\[
\mathcal{O}_{t_R^{\beta b}} \equiv (\bar{t}_R^\alpha \gamma_\mu t_R^\alpha) (\bar{t}_R^\beta \gamma_\mu u_R^\alpha) + \text{h.c.},
\]

\[
\mathcal{O}_{t_R^{\beta c}} \equiv (\bar{t}_R^\alpha (T^a)_\alpha^\beta \gamma_\mu t_R^\delta) (\bar{t}_R^\gamma (T^a)_\gamma^\delta \gamma_\mu u_R^\beta) + \text{h.c.},
\]

\[
\mathcal{O}_{t_R^{\beta d}} \equiv (\bar{t}_R^\alpha (T^a)_\alpha^\beta \gamma_\mu t_R^\delta) (\bar{t}_R^\gamma (T^a)_\gamma^\delta \gamma_\mu u_R^\beta) + \text{h.c.},
\]

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\(^1\) We do not consider the operator \((\bar{T}^a \gamma_\mu P_R(T^a)_\alpha^\beta t_\alpha)(\bar{T}^a \gamma_\mu P_R(T^a)_\gamma^\delta t_\delta)\) since one can show that \((\bar{T}^a \gamma_\mu P_R(T^a)_\alpha^\beta t_\alpha)(\bar{T}^a \gamma_\mu P_R(T^a)_\gamma^\delta t_\delta) = (1/3) \bar{T}_R^a \gamma_\mu P_R(T_R^a)\gamma_\mu (\bar{T} T_R^a)\) with the help of the Fierz rearrangement and the identity \((T^a)_\alpha^\beta (T^a)_\gamma^\delta = \frac{1}{2} \delta_\alpha^\gamma \delta_\beta^\delta - \frac{1}{4} \delta_\alpha^\delta \delta_\beta^\gamma\), where \( T_a \) \((a = 1, \ldots, 8)\) are the generators of the color \( SU(3)_C \).
and also those operators which are obtained by replacing $u_R$ in the above operators with $c_R$. The NNLO dimension-six operators are those which have exactly two $t_R$ fields. Those operators which give corrections to $gg \to H$ at one-loop are the following:

$$O_{tG} \equiv g_s \left[ \bar{t}_R \gamma^\mu T^a t_R + \overline{D^\mu t_R} \gamma^\mu T^a t_R \right] G^a_{\mu\nu},$$  \hspace{1cm} (2.8)

$$O_{t4} \equiv i \left( \Phi^\dagger \Phi - \frac{v^2}{2} \right) \left( \bar{t}_R \gamma^\mu D^\mu t_R - \overline{D^\mu t_R} \gamma^\mu t_R \right),$$  \hspace{1cm} (2.9)

where $\Phi$ is the SM Higgs boson doublet, $v$ is the vacuum expectation value (VEV) of the Higgs boson, $v \sim 246\text{GeV}$, and $g_s$ is the gauge coupling constant of QCD. According to NDA, the NLO and NNLO operators are expected to have the coefficients $g_{\text{new}}/\Lambda^2$ and $1/\Lambda^2$, respectively, up to a coefficient of the order of one.

There are also four-fermion NNLO operators which consist of two $t_R$ fields and two other fermions. These operators could be constrained from low-energy flavor/precision physics, and for simplicity, we do not consider these four-fermion NNLO operators in this article.

The experimental constraints on $\Lambda$ are discussed in Refs. [3, 8]. In Ref. [8], from the top-quark pair production cross section at the Tevatron, they quote the bound $\Lambda/g_{\text{new}} \gtrsim 80\text{GeV}$. If the NDA estimate is saturated, namely when $g_{\text{new}} \sim 4\pi$, we have $\Lambda \gtrsim 1\text{TeV}$.

3. Corrections to $gg \to H$ from the four-$t_R$ contact interaction

We now discuss the effect of the four-$t_R$ contact interaction Eq. (2.2), which is expected to be the leading dimension-six operator from NDA, on the gluon fusion $gg \to H$ using the effective Lagrangian Eq. (2.1). The relevant diagrams are shown in Fig. 1. Interestingly, all the diagrams turn out to vanish separately. In the following few paragraphs, we discuss why this happens.

![Figure 1](image_url)

**Figure 1:** Feynman diagrams for the corrections to $gg \to H$ with one insertion of the four-$t_R$ contact interaction vertex, which is denoted by the black blobs. The solid lines stand for the top-quark. The curly and the dotted lines correspond to the gluon and the Higgs boson, respectively.

First let us discuss the diagram Fig. 1(a). By using the Fierz identity where necessary, we see that this diagram is proportional to the factor,

$$\int \frac{d^4k}{(2\pi)^d} \text{Tr} \left[ \frac{k + m_t}{k^2 - m_t^2} \frac{k + q + m_t}{(k + q)^2 - m_t^2} \gamma^\sigma P_R \right],$$  \hspace{1cm} (3.1)
where \( q \) is the momentum of the Higgs boson and \( d \) is the spacetime dimension. The integral (3.1) comes from the loop in the subdiagram Fig. 2 (a) of the diagram Fig. 1 (a). It is straightforward to see that this integral vanishes, by explicitly performing the integral.

![Figure 2](image_url)

**Figure 2:** Some subdiagrams of the diagrams in Fig. 1: (a) vertex corrections to the \( t-t \)-Higgs interaction. (a’) the “factorized form” of the diagram (a), which is obtained from (a) by using the Fierz rearrangement where necessary. (b) vertex corrections to the gluon-\( t-t \) interaction. (c) corrections to the top-quark self-energy.

The fact that the diagram Fig. 1 (a) vanishes can be understood from a more general argument. First, we should note that, with the help of the Fierz rearrangement, the subdiagram Fig. 2 (a) of the diagram Fig. 1 (a) can be written in a “factorized form” in Fig. 2 (a’). Here, by “factorized form” we mean that the two top-quark fields in one of the \( t\gamma^\mu t_R \) factors in \( \mathcal{O}_H \) are both associated with the external top-quark lines in Fig. 2 (a’), and the two top-quark fields in the other \( t\gamma^\mu t_R \) in \( \mathcal{O}_H \) are contracted with the top quarks from the top-Yukawa coupling to form the loop. Next, we should note that if we integrate out high-momentum modes in the loop of Fig. 2 (a’), we expect that at low energies, the effect of this diagram is equivalent to a dimension-six operator which consists of one factor of \( t\gamma^\mu t_R \) and two SM Higgs boson doublets. (Once we require that two \( t_R \)’s and a SM Higgs boson doublet should be contained in a dimension-six operator, we need one more SM Higgs doublet for the operator to be invariant under the SM gauge group.) In addition, to contract over the Lorentz index \( \mu \), we need to include a (covariant) derivative in such a dimension-six operator. Summing up the above, the possible candidates for the dimension-six operator which effectively describes the diagram Fig. 2 (a’) at low energies are:

\[
\begin{align*}
(\overline{D}_\mu t\gamma^\mu t_R) \Phi^\dagger \Phi, \\
(\overline{t}\gamma^\mu D_\mu t_R) \Phi^\dagger \Phi, \\
(\overline{t}\gamma^\mu t_R)(D_\mu \Phi)\Phi, \\
(\overline{t}\gamma^\mu t_R)\Phi^\dagger D_\mu \Phi, \\
\end{align*}
\]

and their linear combinations. Now, if we carefully look into the structure of the diagram Fig. 2 (a’), we see that it is sufficient to consider only the operators Eqs. (3.2, 3.3) and their linear combinations. This is because the only momentum which can appear in the effective vertex obtained after integrating over the loop momentum in Fig. 2 (a’) is that of the Higgs boson. At this stage, we are left with only two candidates:

\[
\begin{align*}
\mathcal{O}_{t_2} & \equiv i (\overline{t}\gamma^\mu t_R) \left[ \Phi^\dagger D_\mu \Phi - (D_\mu \Phi)^\dagger \Phi \right], \\
\overline{\mathcal{O}}_{t_2} & \equiv (\overline{t}\gamma^\mu t_R) \left[ \Phi^\dagger D_\mu \Phi + (D_\mu \Phi)^\dagger \Phi \right],
\end{align*}
\]

and their linear combinations.
where we have taken linear combinations of Eqs. (3.4, 3.5). The advantage of the basis Eqs. (3.6, 3.7) is that the operators \( O_{12} \) and \( \overline{O}_{12} \) are Hermitian, and at the same time, eigenstates of CP: The operator \( O_{12} \) is even under CP, while \( \overline{O}_{12} \) is CP-odd. We should also note here that since both \( O_{12} \) and \( \overline{O}_{12} \) are Hermitian, their coefficients in the effective Lagrangian must be real. Now, as discussed in Section 2, since the operator \( O_{tt} \) as well as its coefficient \( C_{tt} \) and the top-Yukawa coupling cannot be a source of CP-violation, the effective vertex for Fig. 2 (a′) must be described by a CP-conserving operator. In our case, the only candidate is \( O_{12} \), but actually this is impossible since after the EWSB, \( O_{12} \) reduces to \((g_Z/2)(H + v)^2 Z^\mu (i\gamma_\mu t_R)\) in the unitarity gauge, where \( g_Z \) is the SM gauge coupling associated with the \( Z \)-boson, and it does not provide an effective \( t_R t_R H \) vertex. We are now left with no candidate, which means that the subdiagram Fig. 2 (b) vanishes after integrating over the loop momentum. In fact, by explicitly performing the integral Eq. (3.1), we see that it really does.

We now discuss the diagram Fig. 1 (b). This diagram contains the correction to the gluon-\( t_R t_R \) vertex as a subdiagram, which we show in Fig. 2 (b). By judiciously using the Fierz identity when calculating the diagram Fig. 1 (b), the subdiagram Fig. 2 (b) can be shown to be proportional to

\[
\int \frac{d^d k}{(2\pi)^d} \text{Tr} \left[ \frac{k + m_t}{k^2 - m_t^2} \gamma^\mu \frac{k + p_1 + m_t}{(k + p_1)^2 - m_t^2} \gamma^\nu P_R \right],
\]  

where \( p_1^\mu \) is the gluon momentum. This integral is familiar from the one-loop corrections in QED: It can be written in the form,

\[
(p_1^\mu p_1^\nu - g^{\mu\nu} p_1^2) \Pi(p_1^2),
\]

where \( \Pi(p_1^2) \) is a function which does not have a pole at \( p_1^2 = 0 \). In this expression, the first term vanishes when multiplied by the gluon polarization vector \( \epsilon_\mu(p_1) \), and the second term also vanishes for on-shell gluons. It follows that the diagram Fig. 1 (b) vanishes for transversely polarized on-shell gluons.

The diagrams Fig. 1 (c) and Fig. 1 (d) also vanish. To see this, we look into the subdiagram shown in Fig. 2 (c). By using the Fierz identity where necessary, the self-energy diagram Fig. 2 (c) contains the factor,

\[
\int \frac{d^d k}{(2\pi)^d} \text{Tr} \left[ \frac{k + m_t}{k^2 - m_t^2} \gamma^\sigma P_R \right],
\]

which vanishes from the \( \gamma \) matrix algebra in \( d \)-dimensions and from the angular average over \( k^\mu \). Therefore, the diagrams Fig. 1 (c) and Fig. 1 (d) vanish.

Summing up, to lowest order in QCD and other SM interactions, the parton-level cross section of \( gg \rightarrow H \) does not receive corrections from one insertion of the contact interaction Eq. (2.2).

An obvious corollary of this conclusion is that, to lowest order in QCD and other SM interactions, the decay rate of \( H \rightarrow \gamma \gamma \) does not receive corrections from one insertion of the contact interaction Eq. (2.2).

\(^2\)The effects of these operators at colliders are discussed e.g. in Refs. [14, 15].
4. Effects from subleading dimension-six operators

In this section we discuss the effects from subleading dimension-six operators on the Higgs boson production at the LHC.

At NLO in NDA, we have the operators Eqs. (2.4)-(2.7) and also those operators which are obtained by replacing $u_R$ in Eqs. (2.4)-(2.7) with $c_R$. Interestingly, only one of the operators (2.4)-(2.7) is independent. In fact, by using the Fierz transformation and the identity for the $SU(3)_C$ generators $T^a$ which we mentioned in Footnote 1, we can show that

\begin{align}
O_{t_R^3}^{kb} &= O_{t_R^3}^{ka}, \\
O_{t_R^3}^{ce} &= \frac{1}{3} O_{t_R^3}^{ca}, \\
O_{t_R^3}^{cd} &= O_{t_R^3}^{ce}.
\end{align}

Hence it is sufficient to consider the effects from $O_{t_R^3}^{ka}$.

The effects from the operator $O_{t_R^3}^{ka}$ on $gg \rightarrow H$ is not very interesting: It gives contribution only at two-loop order or higher, and hence its effect on $gg \rightarrow H$ is too small to be interesting.

Now we discuss the effects from the NNLO dimension-six operators. Those NNLO operators which are relevant to $gg \rightarrow H$ at one-loop are $O_{tG}$ and $O_{t_4}$, as discussed in Section 2.

The operator $O_{tG}$ does not give contribution to $gg \rightarrow H$ at one-loop order. This can be seen in the following way. The operator $O_{tG}$ can be written as

\begin{equation}
O_{tG} = (\text{total derivative}) - g_s \left[ \bar{t}_R \gamma^\mu T^a t_R \right] D^\mu G^{ag},
\end{equation}

where the first term is a total derivative, which does not give contribution to $gg \rightarrow H$ as long as we work in perturbation theory. The second term can potentially give contribution to $gg \rightarrow H$ through the two diagrams in Fig. 3. Interestingly, the contributions from the two diagrams separately vanish: The diagram Fig. 3 (a) vanishes for the on-shell gluons since this diagram is proportional to $\epsilon_\nu(p)p^2 - p^\mu p_\nu \epsilon_\mu(p)$, where $p^\mu$ is the momentum of the gluon and $\epsilon_\mu(p)$ is the polarization vector of the gluon\textsuperscript{3}. The diagram Fig. 3 (b) also vanishes since the color factor associated with the top-quark loop is $\text{Tr}(T^a) = 0$.

\textbf{Figure 3:} The contributions from $O_{tG}$ to $gg \rightarrow H$ at one-loop, which turn out to be zero.

\textsuperscript{3}If we consider the effect of initial state radiation, the gluons are not necessarily on-shell, and this
Finally, the operator $O_{t4}$ can give finite correction to $gg \rightarrow H$ via the diagram Fig. 4 (a). After a straightforward calculation, the amplitude $M_{t4}$ for Fig. 4 (a) turns out to be

$$M_{t4} = -\frac{C_{t4} v^2}{\Lambda^2} M_{\text{SM(top, 1-loop)}},$$

where $M_{\text{SM(top, 1-loop)}}$ is the LO SM contribution from the top-quark loop. The amplitude $M_{t4}$ interferes with the contribution from the SM contribution, and in total we obtain

$$M_{\text{total}} = \left(1 - \frac{C_{t4} v^2}{\Lambda^2}\right) M_{\text{SM(top, 1-loop)}},$$

where we neglect the contribution from the $b$-quark loop and the higher order corrections. The cross section is then given by

$$\sigma(gg \rightarrow H; \text{total}) = \left(1 - \frac{C_{t4} v^2}{\Lambda^2}\right)^2 \sigma(gg \rightarrow H; \text{SM(top, 1-loop)}).$$

In Fig. 5 we show a contour plot of the cross section of $gg \rightarrow H$ normalized by the LO SM prediction as a function of $\Lambda$ and $C_{t4}$. In this normalization we expect that the bulk of the QCD corrections cancel between the numerator and the denominator. From the figure we see that there are some regions where the correction can be sizable, for example, for $(\Lambda, C_{t4}) = (1 \text{TeV}, \pm 2)$, the correction to the cross section of $gg \rightarrow H$ is $\sim \pm 24\%$ compared to the LO prediction in the SM.

Argument does not necessarily hold. Such a process is part of the NLO QCD corrections to the Higgs boson production, and we can give a crude estimate for the size of the QCD corrections as

$$\frac{\sigma(\text{NLO}; pp \rightarrow H + X)_{\text{SM+O}_{tG}}}{\sigma(\text{LO}; pp \rightarrow H + X)_{\text{SM}}} \sim \frac{\sigma(\text{NLO}; pp \rightarrow H + X)_{\text{SM}} m_H^2}{\sigma(\text{LO}; pp \rightarrow H + X)_{\text{SM}} \Lambda^2} \sim O(1) \times \frac{m_H^2}{\Lambda^2},$$

where $\sigma(\text{LO}; pp \rightarrow H + X)_{\text{SM}}$ and $\sigma(\text{NLO}; pp \rightarrow H + X)_{\text{SM}}$ are the LO and NLO (in QCD) SM predictions for the Higgs boson production cross section in $pp$ collisions, respectively, and $\sigma(\text{NLO}; pp \rightarrow H + X)_{\text{SM+O}_{tG}}$ is the NLO (in QCD) cross section for the same process with one insertion of $O_{tG}$. In the equation above, we have included a factor of $1/\Lambda^2$ since the process involves an insertion of the dimension-six operator, and, to match the dimension, included a factor of $m_H^2$ since $m_H$ is the typical energy scale of the process. We see that for $(m_H, \Lambda) \approx (100\text{GeV}, 1000\text{GeV})$ the correction to the cross section is of the order of 1% compared to the LO SM prediction. Of course, a more elaborate calculation is necessary to obtain a more accurate prediction, which is, however, beyond the scope of this paper.

Figure 4: (a) The one-loop contribution from $O_{t4}$ to $gg \rightarrow H$. (b) The one-loop contribution from $O_{t4}$ to $H \rightarrow \gamma\gamma$ decay.
The operator $O_{t4}$ also gives the correction to the decay rate of $H \to \gamma\gamma$ by the diagram Fig. 4 (b). For the Higgs mass range $100\,\text{GeV} \lesssim m_H \lesssim 200\,\text{GeV}$, this decay mode is important for the SM Higgs boson searches at the LHC. The $H \to \gamma\gamma$ decay width in this case is given by

$$
\Gamma(H \to \gamma\gamma) = \frac{\alpha^2 g^2}{1024\pi^3} \frac{m_H^3}{m_W^2} N_c Q_t^2 \left(1 - \frac{C_{t4} v^2}{\Lambda^2}\right) F_{1/2} \left(\frac{4m_t^2}{m_H^2}\right) + F_1 \left(\frac{4m_W^2}{m_H^2}\right),
$$

where $N_c = 3$ and $Q_t = 2/3$. In the above expressions we use the approximation that we include only the $W$-boson and the $t$-quark contributions. The functions $F_{1/2}(\tau)$ and $F_1(\tau)$ are given by

$$
F_{1/2}(\tau) = -2\tau[1 + (1 - \tau)f(\tau)],
$$

$$
F_1(\tau) = 2 + 3\tau + 3\tau(2 - \tau)f(\tau),
$$

$$
f(\tau) = \begin{cases} 
\sin^{-1}(\sqrt{1/\tau})^2, & \text{for } \tau \geq 1, \\
-\frac{1}{4}[\ln((1 + \sqrt{1-\tau})/(1 - \sqrt{1-\tau})) - i\pi]^2, & \text{for } \tau < 1,
\end{cases}
$$

which are the functions which appear in the SM contribution to the $H \to \gamma\gamma$ decay (for review, see e.g. Ref. [16]). In Fig. 5 we show a contour plot of $\Gamma(H \to \gamma\gamma)$ normalized by the LO SM prediction as a function of $\Lambda$ and $C_{t4}$. In the figure we take $m_H = 120\,\text{GeV}$, but this figure does not change very much for $100\,\text{GeV} \lesssim m_H \lesssim 200\,\text{GeV}$. We find that the correction to $\Gamma(H \to \gamma\gamma)$ is opposite in sign to the correction to $\sigma(gg \to H)$. We also see that the correction is smaller than that to $\sigma(gg \to H)$, and is about $\pm 8\%$ for $\Lambda = 1\,\text{TeV}$ and $C_{t4} = 1$. 

**Figure 5:** Contour plot of the cross section of $gg \to H$ normalized by the leading order SM prediction as a function of $\Lambda$ and $C_{t4}$.
5. Conclusions

We have studied the effects of the right-handed top-quark compositeness on the Higgs boson production at the LHC. We find that, to lowest order in QCD and other SM interactions, there is no correction from one insertion of the four-$t_R$ contact interaction, whose coefficient in $L_{\text{eff}}$ is expected to be the largest among dimension-six operators, according to NDA. We also find that the NLO dimension-six operators (in the sense of NDA) are four-fermion contact interactions which involve three $t_R$’s and a different right-handed up-type quark. This operator does not give corrections to $gg \to H$ up to and including one-loop. Finally, we find that the NNLO operator $O_{t4}$ can give correction of $\sim \pm 24\%$ to the Higgs boson production cross section $\sigma(gg \to H)$ for $\Lambda = 1$TeV and $C_{t4} = \mp 2$. For the same parameters, we see that the correction to the decay rate of the Higgs boson to two photons is about $\mp 8\%$, where the sign is opposite to that of the correction to $\sigma(gg \to H)$. In total, for $\Lambda = 1$TeV and $C_{t4} = \mp 2$, we expect $\pm 16\%$ correction in the product of the production cross section $\sigma(gg \to H)$ and the partial decay rate $\Gamma(H \to \gamma\gamma)$, compared to the SM prediction, if the Higgs boson mass is in the range between 100GeV and 200GeV. This
Figure 7: Contour plot of the cross section of $gg \rightarrow H$ times $\Gamma(H \rightarrow \gamma\gamma)$, normalized by the leading order SM prediction as a function of $\Lambda$ and $C_{t4}$.

effect would be recognizable in the Higgs boson searches at the LHC. If the Higgs boson is heavier, and the $WW$ decay channel is open, then we do not have to rely on the $H \rightarrow \gamma\gamma$ channel. In this case, the correction to $\sigma(gg \rightarrow H)\Gamma(H \rightarrow WW)$ is $\sim \pm 24\%$ for $\Lambda = 1\text{TeV}$ and $C_{t4} = \pm 2$, which means that the effect from the top-quark compositeness will be a little bit more clearly seen in this channel.

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