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Light axigluon and single top production at the LHC

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Abstract: The light axigluon model can explain the Tevatron $t\bar{t}$ forward-backward asymmetry and at the same time satisfy the constraints from the electroweak precision measurement and the $ATLAS$ and CMS data, which induces the flavor changing (FC) couplings of axigluon with the SM and new quarks. We investigate the effects of these FC couplings on the s- and t-channel single top productions at the LHC and the FC decays $Z \to \bar{b}s + b\bar{s}$, $t \to c\gamma$ and cg. Our numerical results show that the light axigluon can give significantly contributions to single top production and the rare top decays $t \to c\gamma$ and cg.

Keywords: Phenomenological Models, Hadronic Colliders

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Contents

1 Introduction

The standard model (SM) of particle physics has been proven to be extremely successful describing collider experimented data so far. Even the discovery of a Higgs-like particle [1, 2] has confirmed the validity of the SM at the Fermi scale. However, the SM suffers from a key theoretical drawback, the so-called "hierarchy" problem, which means that it could be a low-energy effective theory valid only up to some cut-off energy scale Λ, about TeV scale. So new physics beyond the SM would be in an energy range accessible at the LHC and might be discovered in coming years, although, at the moment, there is not any collider hint of new physics at the LHC.

There are various new physics models extending the gauge group of the strong interaction sector give rise to massive color-octet vector boson, for example, the topcolor models [3–6] and chiral color models [7–12]. Other examples include the extra dimensional models [13] and technicolor [14, 15], which predict the existence of the Kaluza-Klein (KK) gluons and technirhos, respectively. Among these color-octet vector bosons, the new particles with axial-vector couplings to the SM quarks are called "axigluons", which might explain the anomalous forward-backward asymmetry (FBA) in the $t\bar{t}$ production observed at the Tevatron [16–18]. So far, there has been a significant amount of works to explain the $t\bar{t}$ FBA via axigluons, for example see [19–40]. Furthermore, the light axigluon A with a mass M_A in the range from $100GeV$ to $400GeV$ can explain the $t\bar{t}$ FBA and satisfy the constraints from the $ATLAS$ and CMS data [41–50], as long as its decay width is large and its couplings to the SM quarks are relatively small [33–39].

Top quark physics is expected to be a window to any new physics beyond the electroweak scale. At LHC energies, top quark is copiously produced both in pair and single productions, which allows for an unprecedented precision in the study of top observables, such as its couplings and rare decays [51–53]. At hadron colliders, single top quark production is an important process in probing the mechanism of electroweak symmetry breaking

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($EWSB$), providing informations complementary to those that can be obtained from top pair production [54–56]. Single top production is also very sensitive to new physics effects, whose strength can be assessed by precise measurement of the production cross section.

Single top production at hadron colliders has been observed in three channels: s-channel, t-channel [57–66] and tW associated production channel [67, 68], which accord with the SM predictions within experimental uncertainties. $ATLAS$ and CMS collaborations have started searching for the new physics effects on single top production.

Inspired by the solution of the light axigluon to the $t\bar{t}$ FBA, some axigluon-mediated phenomena are studied in this paper. We consider the contributions of the light axigluon with flavor changing (FC) couplings to the SM and new quarks to the FC decays $Z \to \bar{b}s(b\bar{s})$, the s- and t-channel single top productions, and rare top decays $t \to c\gamma$ and cg in the context of the light axigluon model proposed by Tavares and Schmaltz [36, 37]. The constraints on this new physics model from the electroweak precision observables and the relevant data given by hadron colliders are taken into account in our numerical calculations.

The rest of this paper is organized as follows: After reviewing the basic ingredients of the light axigluon model, in section 2, we calculate the contributions of the light axigluon to the FC decays $Z \to \bar{b}s$ and $b\bar{s}$. Corrections of the light axigluon to the cross sections of the s- and t-channel single top productions at the LHC are studied in section 3. The branching ratios of the rare top decays $t \to c\gamma$ and cg induced by light axigluon exchange are given in section 4. Section 5 is devoted to simple summary.

2 Light axigluon and the FC decays $Z \to \bar{b}s$ and $b\bar{s}$

The light axigluon model [36, 37] is based on the gauge group $G = \mathrm{SU}(3)_1 \times \mathrm{SU}(3)_2 \times \mathrm{SU}(2) \times \mathrm{U}(1)_Y$, where $\mathrm{SU}(2) \times \mathrm{U}(1)_Y$ is the conventional electroweak group and the extended gauge group $\mathrm{SU}(3)_1 \times \mathrm{SU}(3)_2$ is spontaneously broken to the QCD gauge group $\mathrm{SU}(3)_C$ by the vacuum expectation value (VEV) of a bifundamental scalar ϕ. This breaking pattern yields two mass eigenstates of color-octet gauge bosons. One is massless particle, which can be identified with the SM gluon, and the other is massive particle, which is called the light axigluon A. For its couplings to the SM quarks, there are the vector coupling $g_V \approx 0$ and the axial-vector coupling $g_A \neq 0$ in the case of assuming approximately parity symmetry. In order to cancel the gauge anomaly, the extra up- and down-type quarks are introduced into this model, and the lepton sector is exactly same as that of the SM. To explain the $t\bar{t}$ FBA, the axigluon A should have mass below $450GeV$, while should be broad with $\Gamma_A/M_A \sim 10 \sim 20\%$, where Γ_A and M_A represent its total decay width and mass, respectively.

In the original light axigluon model [36, 37], the authors assume the existence of an exact global symmetry of the axigluon couplings, and thus the light axigluon only has flavor universal couplings to the SM quarks. In fact, this global symmetry is only approximate and there is mixing between new and ordinary quarks, which can induce flavor changing neutral currents ($FCNCs$) at tree level [69]. The new and ordinary quarks have same $\mathrm{SU}(2) \times \mathrm{U}(1)$ charge, their mixing does not give rise to the FC Z couplings at tree level.

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The new scalars can not induce $FCNCs$, thus the non-universal axigluon couplings are the main source of $FCNC$ for this model.

In this paper we will not assume the existence of an exact global symmetry of the axigluon couplings, which allows FC couplings of the axigluons to the SM quarks. If one assumes that these FC couplings are only axial-vector couplings, which are similar with their flavor conserving couplings to the SM quarks, then the axial-vector couplings of the light axigluon to the SM quarks can be general given by the Lagrangian

$$\mathcal{L} \supset g_s[\overline{u}_i\gamma_\mu\gamma_5(g_A^{u_i}\delta_{ij} + \varepsilon_u^{ij})u_j A^\mu + \overline{d}_i\gamma_\mu\gamma_5((g_A^{d_i}\delta_{ij} + \varepsilon_d^{ij})d_j A^\mu], \tag{2.1}$$

where A^μ is the light axigluon, g_s is the QCD coupling constant, u_i and d_i are the SM up- and down-type quarks, respectively. In above equation, we have neglected the color and spinor indices. $g_A^{u_i}$ and $g_A^{d_i}$ are the flavor independent coupling constants and there are $g_A^{u_i} = g_A^{d_i} = g_A^q$ [36, 37]. The FC coupling constants ε_u^{ij} and ε_d^{ij}, which arise from flavor symmetry breaking of new and light quarks, are given by the matrices

$$\varepsilon_u = \begin{pmatrix} 0 & g^{uc} & g^{ut} \\ (g^{uc})^* & 0 & g^{ct} \\ (g^{ut})^* & (g^{ct})^* & 0 \end{pmatrix}, \quad \varepsilon_d = \begin{pmatrix} 0 & g^{ds} & g^{db} \\ (g^{ds})^* & 0 & g^{bs} \\ (g^{db})^* & (g^{bs})^* & 0 \end{pmatrix}. \tag{2.2}$$

The couplings of the axigluon to a pair of ordinary quarks and to the corresponding partners have opposite sign. So, in order to get suppressed couplings of the ordinary quarks to the axigluon, the extra quarks and the SM quarks should have mixing [36, 37, 39, 70, 71]. The mixing can be obtained by adding a Yukawa coupling involving a scalar field ϕ in addition to the quark field of Q' with Q. After the spontaneous breakdown of $SU(3)_1 \times SU(3)_2 \to SU(3)_C$ induced by the VEV for ϕ, the new quarks from the line combinations of Q' and Q get masses, while their orthogonal combinations correspond to the SM quarks remain massless, which get masses from the SM Higgs VEV via Yukawa couplings. In the mass eigenstates, the mixing couplings of the axigluon to ordinary and new quarks, which are assumed to be axial-vector couplings, can be general written as

$$\mathcal{L}' \supset g_s g_A^{mix}[\overline{U}_{Hi}\gamma_\mu\gamma_5(\varepsilon_{Hu}^{ij})u_j A^\mu + \overline{D}_{Hi}\gamma_\mu\gamma_5(\varepsilon_{Hd}^{ij})d_j A^\mu]. \tag{2.3}$$

U_{Hi} and D_{Hi} represent the up-type and down-type new quarks, respectively. For the mixing coupling constant g_A^{mix}, there is the relation $(g_A^{mix})^2 + (g_A^q)^2 = 1$. For the two matrices ε_{Hu} and ε_{Hd}, they are related through the SM CKM matrix: $\varepsilon_{Hu}^+\varepsilon_{Hd} = V_{CKM}$, which is similar with the case for the mixing between the T-odd and T-even quarks in the LHT model [72]. In this paper, we assume that both ε_{Hu} and ε_{Hd} are nearly equal to the identity matrix, which provides us with a set of minimal flavor mixing scenarios. We take as examples two simple cases:

Case I $\varepsilon_{Hu} = I, \quad \varepsilon_{Hd} = V_{CKM}$,

Case II $\varepsilon_{Hd} = I, \quad \varepsilon_{Hu} = V_{CKM}$.

In case I, the mixing coupling g_A^{Qq} has no contributions to $D^0 - \overline{D^0}$ mixing, while contributes to $B_q^0 - \overline{B_q^0}$ and $K^0 - \overline{K^0}$ mixings. For case II, it is obvious that the mixing coupling g_A^{Qq} can only contribute to $D^0 - \overline{D^0}$ mixing. Reference [69] has obtained the

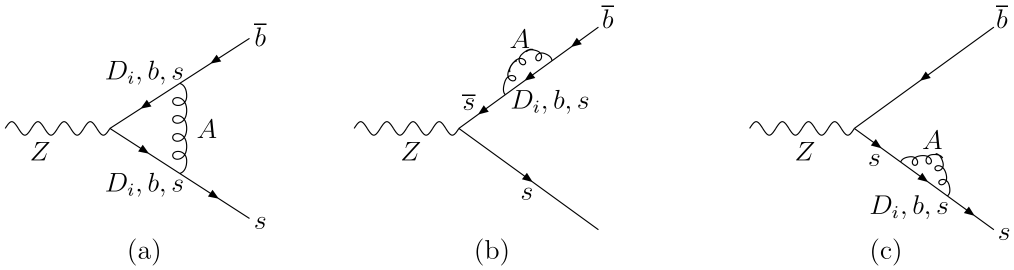

Figure 1. One-loop Feynman diagrams for the FC decay $Z \to \bar{b}s$ induced by light axigluon exchange.

constraints on the mixing matrix ε_d by using the available data from neutral meson mixings, such as $B_q^0 - \overline{B_q^0}$, $K^0 - \overline{K^0}$ and $D^0 - \overline{D^0}$ mixings. Taking into account of these constants, in this section, we calculate the branching ratios of the FC decays $Z \to \bar{b}s$ and $b\bar{s}$ given by axigluon exchange as shown in figure 1. The self-energy diagrams figure 1(b) and (c) contribute a finite field renormalization and the individual diagrams are finite [73]. To fulfill the broad width of the axigluon, the first and second generation new quarks should be degenerate and lighter than the axigluon, while the third generation new quarks must be heavier [36, 37]. So we think that the contributions of the third generation new quarks to the FC decays $Z \to \bar{b}s(b\bar{s})$ decouple and only consider the contributions of the first and second generation new quarks. In our numerical estimation, we will take $M_{D_{H1}} = M_{D_{H2}} = M_H = 0.2M_A$. In this case, one can safely neglect the phase space suppression effect for the axigluon decaying to one new quark and one ordinary quark and there should be $\Gamma_A/M_A \sim 10 \sim 20\%$.

The light axigluon model predicts the existence of new scalar, which also has the mixing couplings to new and ordinary quarks. However, it can not induce FC couplings at tree level and thus in this paper we neglect the effects of the new scalar on the FC processes $Z \to \bar{b}s$ and $b\bar{s}$.

The corrections of color-octet gauge boson to the $Zb\bar{b}$ coupling are firstly studied by ref. [74] in the context of topcolor models, which contain only the leading-logarithmic contributions. The full one-loop results for the corrections of the axigluon to the $Zb\bar{b}$ coupling are given in refs. [38, 39] in the case of neglecting the bottom quark mass. Ref. [39] have further computed the contributions from new quarks and new scalar to the $Zb\bar{b}$ coupling and find that the two kinds of contributions have opposite sign and the effect of new scalar is much smaller than that of new quarks. Following refs. [38, 39], we can straightforwardly calculate the contributions of the light axigluon model to the FC couplings $Z\bar{b}s$ and $Zb\bar{s}$. Then, the effective $Z\bar{b}s$ coupling can be written as

$$g_P^{Zbs} = \frac{\alpha_s}{3\pi} g_P^{Zbb} [2 g_P^{Abb} g_P^{Abs} \kappa(x_z) + (g_A^{mix})^2 \kappa(x_z, x_h)(\varepsilon_{Hd}^{*13}\varepsilon_{Hd}^{12} + \varepsilon_{Hd}^{*23}\varepsilon_{Hd}^{22})], \tag{2.4}$$

where $P = L$ and R. g_P^{Zbb} and g_P^{Abb} represent the couplings of the gauge boson Z and axigluon A to the bottom quark pairs, respectively. The explicit expressions of the factors $\kappa(x_Z)$ and $\kappa(x_z, x_h)$ have been given in ref. [39]. Since the couplings of the axigluon to pair of ordinary quarks and pair of new quarks are flavor universal and the new and ordinary

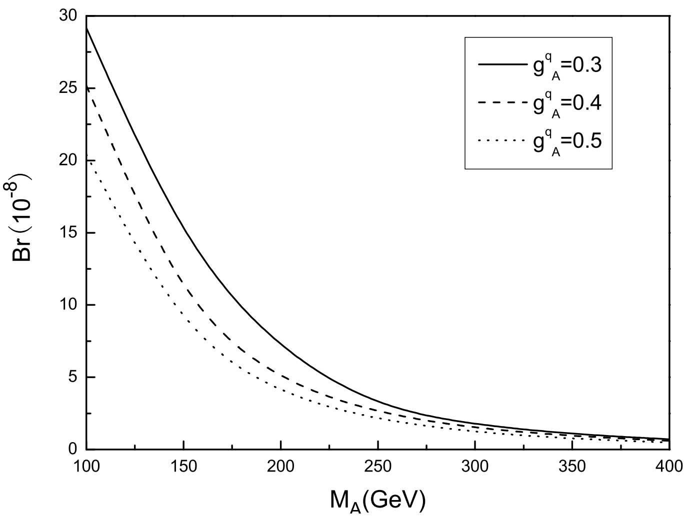

Figure 2. Variation of the branching ratio $Br(Z \to \bar{b}s + b\bar{s})$ with the axigluon mass M_A for $g_A^{bs} = 1.83 \times 10^{-3}$, $\varepsilon_{Hd} = V_{CKM}$ and three values of the coupling parameter g_A^q.

quarks have same $\mathrm{SU}(2) \times \mathrm{U}(1)$ charge, in above equation we have added the contributions of the ordinary quarks b and s, and taken

$$g_L^{Zbb} = g_L^{ZD_iD_i} = \frac{e}{4S_W C_W}\left(1 - \frac{2}{3}S_W^2\right), \quad g_R^{Zbb} = g_R^{ZD_iD_i} = -\frac{e}{4S_W C_W} \cdot \frac{2}{3}S_W^2, \qquad (2.5)$$

where $i = 1$ and 2, $S_W = \sin\theta_W$ and $C_W = \cos\theta_W$, θ_W is the Weinberg angle. The FC coupling g_P^{Abs} can contribute to $B_s^0 - \overline{B_s^0}$ mixing at tree level and its upper bound has been obtained by ref. [69] as $|g_L^{bs}| = |g_R^{bs}| = |g_A^{bs}| \leq 1.83 \times 10^{-3}$. In fact, for the case I, the new quarks can also generate contributions to $B_s^0 - \overline{B_s^0}$ mixing via box diagrams that contain the light axigluon and new quark. However, the contributions from box diagrams are suppressed with respect to axigluon tree-level contributions by a loop factor $1/(16\pi^2)$ and two additional mixing matrix elements ε_{Hd}^{i3} and ε_{Hd}^{i2}. Therefore they cannot compete with the latter and are negligible. As numerical estimation, we will take $g_A^{bs} = 1.83 \times 10^{-3}$, $g_L^{Abb} = -g_R^{Abb} = g_A^q$.

In the SM, the FC decay $Z \to \bar{b}s + b\bar{s}$ originates from one loop diagrams with branching ratio $\sim 3 \times 10^{-8}$ [75–78]. For future linear collider (ILC), the expected sensitivity to the branching ratios of rare Z decays can be improved from 10^{-5} at the LEP to 10^{-8} at the Giga Z [79, 80]. The new physics effects might be detectable via $Z \to bs$ if it indeed affects this decay. A lot of theoretical studies involving the FC decay $Z \to bs$ have been given within some popular models beyond the SM, where its branching ratio can be significantly enhanced [81–92].

Using the effective couplings g_L^{Zbs} and g_R^{Zbs} given by eq. (2.4), we can easily calculate the partial width $\Gamma(Z \to \bar{b}s + b\bar{s})$. The numerical results for the branching ratio $Br(Z \to \bar{b}s + b\bar{s}) = \Gamma(Z \to \bar{b}s + b\bar{s})/\Gamma_{total}$ are shown in figure 2, in which we have taken the SM input parameters as: $\alpha_s(m_Z) = 0.118$, $S_W^2 = 0.231$, $\Gamma_{total} = 2.4945GeV$, and $M_Z = 91.1875GeV$ [93]. If the light axigluon can explain the $t\bar{t}$ FBA and at the same time satisfy

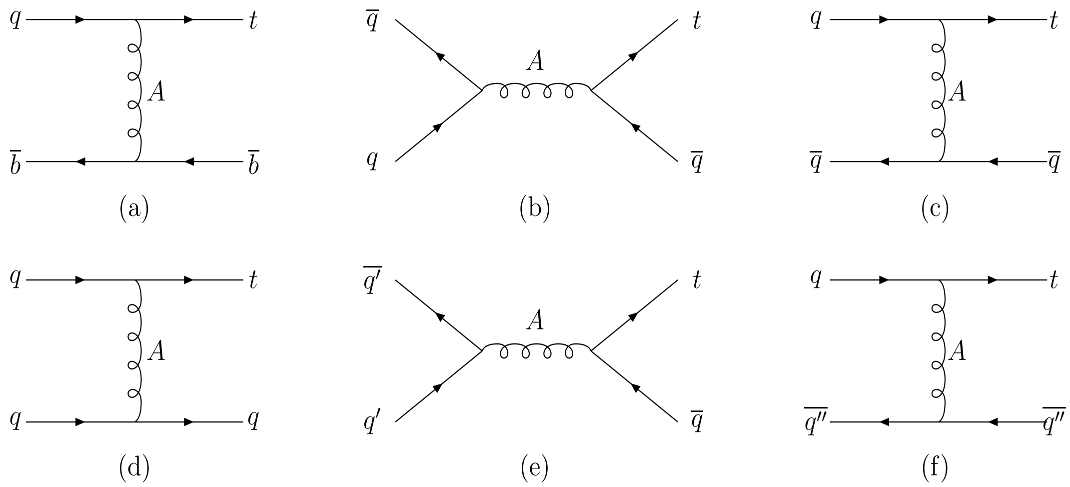

Figure 3. Leading order Feynman diagrams for $t\bar{b}$ and $t\bar{j}$ production contributed by the FC couplings g_A^{tq}, in which $q = u, c$, $q' = d, s, b$, and $q'' = d, s$.

the constraints from the electroweak precision observables and the relevant data given by hadron colliders, its mass should be in the range of $100GeV \sim 400GeV$, its total decay width $\Gamma_t^A = (0.1 \sim 0.2)M_A$ and the flavor conserving coupling g_A^q might be in the range of $0.3 \sim 0.5$ [33–39]. In our numerical estimation we have considered the effects of the axigluon width and taken $\Gamma_t^A = 0.1M_A$. For the mixing between the SM and new quarks, we have taken case I and assumed $M_H = 0.2M_A$. One can see from figure 2 that, in most of the parameter space, the value of the branching ratio $Br(Z \to \bar{b}s + b\bar{s})$ is smaller than 1×10^{-8}, which is still below the SM prediction. So considering the constraints of $B_s^0 - \overline{B_s^0}$ mixing on the FC coupling g_A^{bs}, the contribution of the light axigluon to the rare decays $Z \to \bar{b}s$ and $b\bar{s}$ is very difficult to be detected in near future. Certainly, if we assume $\varepsilon_{Hd} \neq V_{CKM}$, the numerical results should has some changes.

3 The *FC* couplings of the light axigluon *A* and single top production at the *LHC*

In the SM, single top production dominantly occurs through electroweak processes, which are customary divided into three production channels: t-channel exchange of a space-like W boson, s-channel production and decay of a time-like W boson, and associated production of a top quark and an on-shell W boson. These partonic processes have their own distinct kinematics and do not interfcere with each other. Both at Tevatron and the LHC, the t-channel process is dominant one, which in five flavor $(5F)$ scheme proceeds via the partonic processes $qb \to q't$ and $\bar{q}b \to \overline{q'}t$ for single top production, and $q\bar{b} \to q'\bar{t}$ and $\bar{q}\bar{b} \to \overline{q'}\ \bar{t}$ for single antitop production. The s-channel partonic processes are $q\overline{q'} \to t\bar{b}$ and $\bar{q}q' \to \bar{t}b$ for single top and antitop productions, respectively. The contributions of charged and neutral color-octet vector bosons to top pairs and single top production has been studied in refs. [40, 94]. In this section we will consider the corrections of the light axigluon to the s- and t-channel single top productions via the FC couplings g_A^{tq} with $q = u$ or c. The relevant Feynman diagrams are shown in figure 3.

For the partonic process $q\bar{b} \to t\bar{b}$ as shown in figure 3 (a), the differential cross section with respect to emerging angle of the single top quark $\cos\theta_t$ can be written as

$$\frac{d\sigma(t\bar{b})}{d\cos\theta_t} = \frac{2\pi\alpha_s^2\beta(g_A^{tq})^2(g_A^b)^2}{9\hat{s}} P_t[\hat{s}(\hat{s}-m_t^2)+\hat{t}(\hat{t}-m_t^2)]. \tag{3.1}$$

The partonic process $q\bar{q} \to t\bar{q}$ is composed of the s- and t-channel diagrams corresponding to figure 3 (b) and 3 (c). Its differential cross section is given by

$$\begin{aligned}\frac{d\sigma(t\bar{q})}{d\cos\theta_t} = \frac{2\pi\alpha_s^2\beta(g_A^{tq})^2(g_A^q)^2}{9\hat{s}} &\{P_s[\hat{u}(\hat{u}-m_t^2)+\hat{t}(\hat{t}-m_t^2)] \\ &-\frac{P_sP_t}{3}(\hat{s}-M_A^2)(\hat{t}-M_A^2)\hat{u}(\hat{u}-m_t^2) \\ &+P_t[\hat{s}(\hat{s}-m_t^2)+\hat{u}(\hat{u}-m_t^2)]\}.\end{aligned} \tag{3.2}$$

The differential cross section of the t+u channel partonic process $qq \to t+q$ can be written as

$$\begin{aligned}\frac{d\sigma(tq)}{d\cos\theta_t} = \frac{2\pi\alpha_s^2\beta(g_A^{tq})^2(g_A^q)^2}{9\hat{s}} &\{P_t[\hat{u}(\hat{u}-m_t^2)+\hat{s}(\hat{s}-m_t^2)] \\ &+P_tP_u(\hat{t}-M_A^2)(\hat{u}-M_A^2)\hat{s}(\hat{s}-m_t^2) \\ &+P_u[\hat{t}(\hat{t}-m_t^2)+\hat{s}(\hat{s}-m_t^2)]\}.\end{aligned} \tag{3.3}$$

The differential cross section for the s-channel partonic $\overline{q'}q' \to t\bar{q}$ as shown in figure 3 (e) is given by

$$\frac{d\sigma_s(t\bar{q})}{d\cos\theta_t} = \frac{2\pi\alpha_s^2\beta(g_A^{tq})^2(g_A^{q'})^2}{9\hat{s}} P_s[\hat{u}(\hat{u}-m_t^2)+\hat{t}(\hat{t}-m_t^2)]. \tag{3.4}$$

The explicit expression of the differential cross section for the t-channel $q\overline{q''} \to t\overline{q''}$ is same as that for the process $q\bar{b} \to t\bar{b}$, as long as replace the initial state b quark by the quark q'' (d or s). In above equations, $\beta = 1 - \frac{m_t^2}{\hat{s}}$, $\hat{s}$, $\hat{t}$, and $\hat{u}$ are the usual Mandelstam variables,

$$P_i = \frac{1}{(i-M_A^2)^2 + M_A^2\Gamma_A^2} \qquad \textit{with} \quad i = \hat{s},\ \hat{t}, \textit{or}\ \hat{u}. \tag{3.5}$$

Using above equations we can calculate the cross sections of tb and tj production at the LHC induced by the light axigluon with the FC coupling g_A^{tq}. In our numerical calculations, we use the leading order parton distribution function of CTEQ6L1 [95] and choose the factorization and renormalization scales to be $\mu_f = \mu_r = m_t/2$ with $m_t = 173GeV$. Our numerical results are added $t\bar{b}$ and $\bar{t}b$ for the process $pp \to tb$, and similar for tj production with $j = u, c, d$, and s. It is obvious that the production cross sections depend on the mass parameter M_A, the coupling parameters g_A^{tq} and g_A^q, where we have taken $g_A^{tu} = g_A^{tc}$ and the flavor conserving coupling g_A^q being flavor universal.

In the SM, single top production at hadron colliders was first considered in ref. [96]. Now the production cross sections for the s- and t-channels have been calculated up to

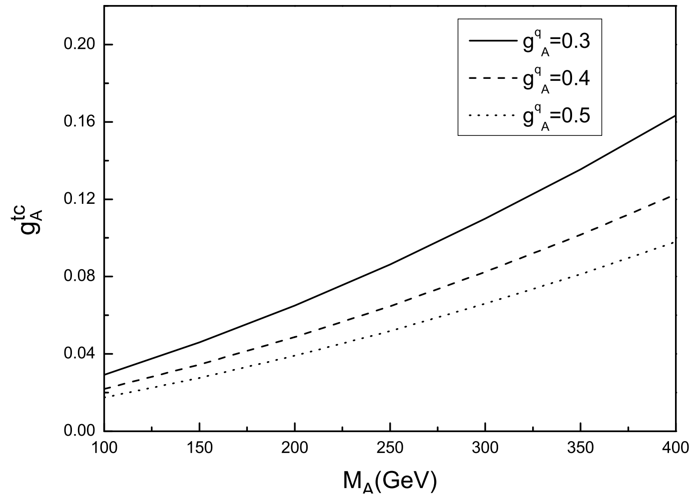

Figure 4. In the case of $\delta\sigma^s/\sigma^s_{SM} = 10\%$, the FC coupling g_A^{tq} as function of the axigluon mass M_A for $g_A^q = 0.3$(solid line), 0.4(dashed line) and 0.5(dotted line).

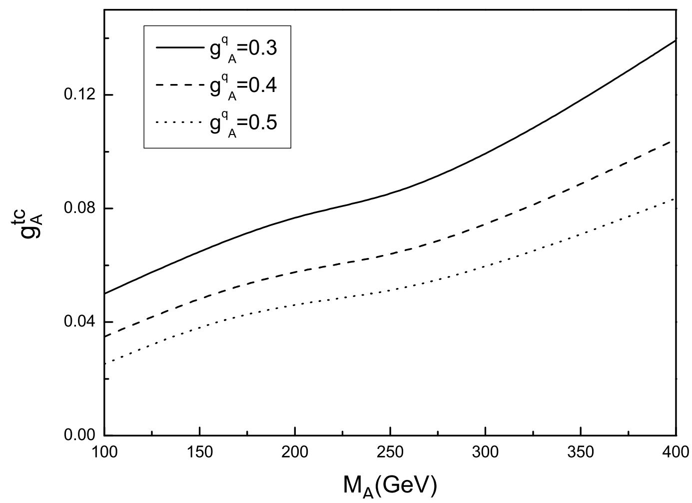

Figure 5. In the case of $\delta\sigma^t/\sigma^t_{SM} = 10\%$, the FC coupling g_A^{tq} as function of the axigluon mass M_A for $g_A^q = 0.3$(solid line), 0.4(dashed line) and 0.5(dotted line).

next-to-next-to leading logarithm ($NNLL$) accuracy [97–102]: $\sigma_s = 1.04 \pm 4\%\ pb$ and $\sigma_t = 2.26 \pm 5\%\ pb$ at Tevatron with the centre-of-mass ($c.m.$) energy $\sqrt{s} = 1.96TeV$ and $\sigma_s = 12 \pm 6\%\ pb$ and $\sigma_t = 243 \pm 4\%\ pb$ at the LHC with $\sqrt{s} = 14TeV$. The s- and t-channel cross sections have been measured at Tevatron by CDF and DO collaborations and the measurement precision can reach 18% [57–61]. The measurement precision for the t-channel cross section at the $8TeV$ LHC reported by $ATLAS$ and CMS is about 15% [62–66]. It will be enhanced in coming years. For example, ref. [103] has shown that the cross section of the t-channel single top production at the $14TeV$ LHC can be measured with a precision of 5%.

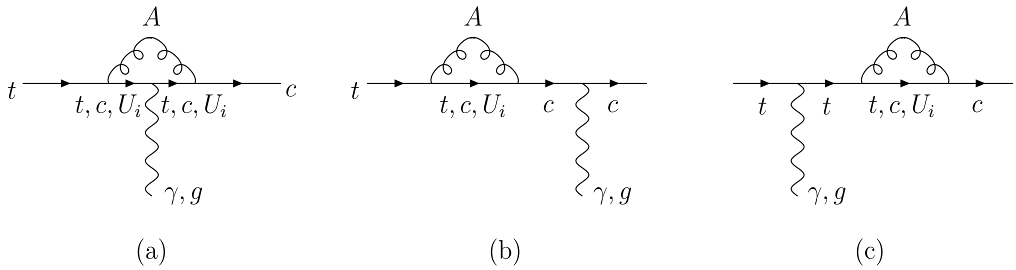

Figure 6. Feynman diagrams for the rare top decays $t \to c\gamma$ and cg coming from the FC coupling g_A^{tc}, in which $i = 1$ and 2.

From above discussions we can see that the theoretical error of the SM $NNLO$ cross section at the $14TeV$ LHC for the s- and t-channel productions could be as large as 5%, the same amount of the expected precision at the $14TeV$ LHC. So if the relative correction of the light axigluon to the single top production cross section is larger than 10%, the $14TeV$ LHC should detect this correction effect. In figure 4 and figure 5 we demand that $\delta\sigma^s/\sigma^s_{SM} = 10\%$ and $\delta\sigma^t/\sigma^t_{SM} = 10\%$, where σ^s_{SM} and σ^t_{SM} are the SM $NNLO$ predictions for the s- and t-channel single top production cross sections at the LHC with $\sqrt{s} = 14TeV$, $\delta\sigma^s$ and $\delta\sigma^t$ are induced by the light axigluon A, and plot the FC coupling g_A^{tq} as a function of the mass parameter M_A for different values of the flavor conserving g_A^q. In our numerical calculation, we have taken the central values for σ^s_{SM} and σ^t_{SM}. From these figures one can see that the contributions of the light axigluon to the production cross sections of the processes $pp \to tb + X$ and $pp \to tj + X$ increase as the coupling parameters g_A^{tq} and g_A^q increasing, while decrease as M_A increasing. For $100GeV \leq M_A \leq 400GeV$ and $0.3 \leq g_A^q \leq 0.5$, the values of FC coupling g_A^{tq} are in the ranges of $0.017 \sim 0.163$ and $0.024 \sim 0.139$ for $\delta\sigma^s/\sigma^s_{SM} = 10\%$ and $\delta\sigma^t/\sigma^t_{SM} = 10\%$, respectively. We expect that, in near future, the LHC can authenticate this correction effect on single top production or at least give constraint on the FC coupling g_A^{tq}.

4 The light axigluon and the rare top decays $t \to c\gamma$ and cg

It is well known that in the SM the rare top decays $t \to qV$ ($q = u, c$ and $V = \gamma, g, Z$) mediated by $FCNCs$ are highly GIM suppressed with branching ratios of $Br(t \to cV) \sim 10^{-14} \sim 10^{-12}$ [104, 105], which are far below the detectable level of current or near future experiments. However, some new physics models can enhance these branching ratios significantly [106–108]. So rare top decays offer an opportunity to test the SM and search for new physics effects. Any positive signal of rare top decay processes would clearly indicate new physics beyond the SM.

On the experimental side, rare top decays are being searched for at Tevatron [109, 110] and LHC [111–113]. $ATLAS$ collaboration has set upper limit on the branching ratio $Br(t \to cg) < 2.7 \times 10^{-4}$ at 95% C.L. [113]. The sensitivity of $ATLAS$ to the branching ratio $Br(t \to c\gamma)$ is expected to be of the order of 10^{-4} [114].

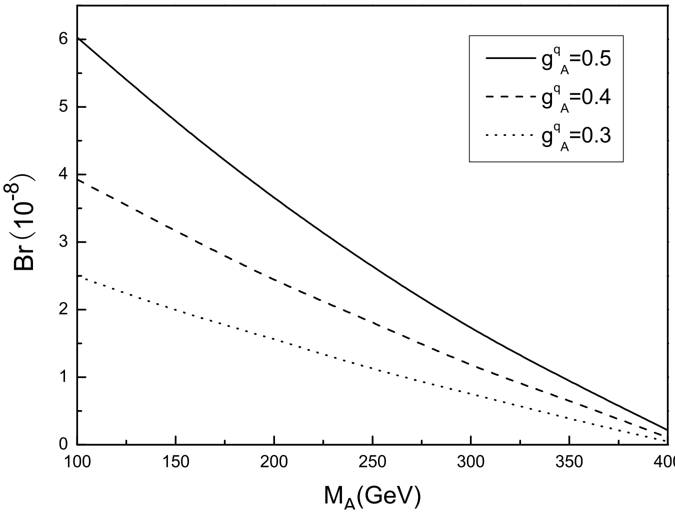

Figure 7. The branching ratio $Br(t \to c\gamma)$ as a function of the axigluon mass M_A for three values of the flavor conserving coupling g_A^q.

From discussions given in above sections we can see that the light axigluon with FC couplings can contribute rare top decays. In this section we will calculate the branching ratios $Br(t \to c\gamma)$ and $Br(t \to cg)$ induced by the light axigluon. The relevant Feynman diagrams are shown in figure 6. In this section, we also assume that the contributions of the third generation new quarks to the rare top decays $t \to c\gamma$ and $t \to cg$ decouple. Compared to the FC couplings of the light axigluon A to the new quarks and the SM quarks, the FC couplings of the scalar ϕ to the new quarks and the SM quarks arise at higher order, their FC effects are much smaller than those induced by the axigluon A. Thus, in this section, we neglect the contributions of the scalar ϕ to the rare top decays $t \to c\gamma$ and $t \to cg$ as done for $Z \to bs$ in section 2.

Considering electromagnetic gauge invariance, the amplitude of the rare decay $t \to c\gamma$ can be general written as

$$M(t \to c\gamma) = i\overline{u}(P_c)\sigma^{\mu\nu}q_\nu(A_\gamma + B_\gamma\gamma_5)u(P_t)\varepsilon^*_\mu(q), \tag{4.1}$$

where $q = P_t - P_c$ is the photon momentum and ε is its polarization vector, in which P_t and P_c represent the momenta of top and charm quarks, respectively. A similar structure is valid for $t \to cg$ with form factors A_g and B_g. For the light axigluon A with zero vector couplings to the SM and new quarks i.e. $g_V^{tq} \approx 0$, $g_V^{Q_Hq} \approx 0$ and $g_V^q \approx 0$ [36, 37, 39], there are $A_\gamma \neq 0$, $A_g \neq 0$ and $B_\gamma = 0$, $B_g = 0$. Recently, ref. [115] has calculated the contributions of color-singlet gauge bosons predicted by the 331 models to the rare top decay $t \to c\gamma$ and give the explicit expressions for the relevant form factors. In this paper we will use LoopTools [116, 117] to obtain our numerical results.

Using eq. (4.1), the partial widths of $t \to c\gamma$ and $t \to cg$ contributed by the light

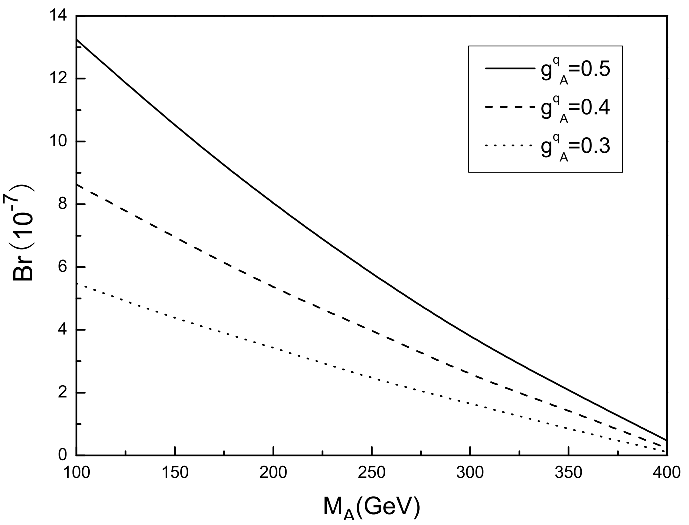

Figure 8. The branching ratio $Br(t \to cg)$ as a function of the axigluon mass M_A for three values of the flavor conserving coupling g_A^q.

axigluon can be written as

$$\Gamma(t \to c\gamma) = \frac{m_t^3}{8\pi}\left(1 - \frac{m_c^2}{m_t^2}\right)^3 |A_\gamma|^2, \tag{4.2}$$

$$\Gamma(t \to cg) = \frac{C_F m_t^3}{8\pi}\left(1 - \frac{m_c^2}{m_t^2}\right)^3 |A_g|^2, \tag{4.3}$$

where $C_F = 4/3$ is a color factor.

To obtain numerical results, we have assumed that the top total decay width is dominated by the decay $t \to Wb$. The FC coupling g_A^{tc} is determined by the parameters g_A^q and M_A via the relation $\delta\sigma^t/\sigma_{SM}^t = 10\%$. For calculation the contributions of the first and second generation new quarks, we take the case II: $\varepsilon_{Hd} = I$, $\varepsilon_{Hu} = V_{CKM}$ and assume $M_H = 0.2M_A$. In figure 7 and figure 8 we plot the branching ratios $Br(t \to c\gamma)$ and $Br(t \to cg)$ as functions of the axigluon mass M_A for three values of the flavor conserving coupling g_A^q. One can see from these figures that the light axigluon A can indeed enhance the branching ratios $Br(t \to c\gamma)$ and $Br(t \to cg)$. For $0.3 \leq g_A^q \leq 0.5$ and $100GeV \leq M_A \leq 400GeV$, the values of $Br(t \to c\gamma)$ and $Br(t \to cg)$ are in the ranges of $4.8 \times 10^{-9} \sim 5.9 \times 10^{-8}$ and $1.1 \times 10^{-8} \sim 1.3 \times 10^{-6}$, respectively. Replacing the FC couplings g_A^{tc} and $g_A^{U_i c}$ by g_A^{tu} and $g_A^{U_i u}$, we can easily calculate the contributions of the light axigluon A to the rare top decays $t \to u\gamma$ and ug.

5 Conclusions

The light axigluon A with a mass M_A in the range from $100GeV$ to $400GeV$ predicted by the light axigluon model [36, 37] can explain the $t\bar{t}$ FBA and satisfy the constraints from the $ATLAS$ and CMS data, as long as its decay width is large and its couplings to the SM quarks are relatively small. In order to get suppressed couplings of the light axigluon A to

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the SM quarks, the new quarks and the SM quarks should have mixing, which can induce the FC couplings to the new quarks and the SM quarks. Furthermore, to fulfill the broad width of the axigluon, the new quarks, at least the first and second generation new quarks, are lighter than the light axigluon. In this paper, we assume the flavor conserving axigluon couplings are universal and pure axial vector-like, and investigate some FC phenomena mediated by the light axigluon.

The contributions of the light axigluon model to the FC decays $Z \to \bar{b}s, b\bar{s}$ and $t \to c\gamma, cg$ mainly come from the FC quark- quark- axigluon coupling $g_A^{qq'}$ and the FC quark-new quark- axigluon coupling $g_A^{qQ_H}$. Considering the constraints of meson mixing on the FC coupling $g_A^{qq'}$ and assuming that both ε_{Hu} and ε_{Hd} are nearly equal to the identity matrices and satisfy the relation $\varepsilon_{Hu}^{+}\varepsilon_{Hd} = V_{CKM}$ to give the value of $g_A^{qQ_H}$, we calculate the branching ratios $Br(Z \to \bar{b}s + b\bar{s})$, $Br(t \to c\gamma)$ and $Br(t \to cg)$ in the context of the light axigluon model. Our numerical results show that, in most of parameter space, the value of the branching ratio $Br(Z \to \bar{b}s + b\bar{s})$ is smaller than 1×10^{-8}, which is still below the SM prediction. Compared to the SM predictions, the branching ratios $Br(t \to c\gamma)$ and $Br(t \to cg)$ can be significantly enhanced in the light axigluon model, while are still lower than the corresponding current experimental upper limits.

It is well known that single top production is very sensitive to new physics beyond the SM, whose effects can be assessed by precise measurement of the production cross section. In this paper, we study the correction effects of the light axigluon A to the s- and t-channel single top productions at the LHC. We find that, in near future, the LHC should observe this correction effect with reasonable values for the FC coupling g_A^{tq} or at least give constraint on the FC coupling g_A^{tq}. If one demands $\delta\sigma^s/\sigma^s_{SM} = 10\%$ and $\delta\sigma^t/\sigma^t_{SM} = 10\%$, the values of the FC coupling g_A^{tq} should be in the ranges of $0.017 \sim 0.163$ and $0.024 \sim 0.139$, respectively.

Acknowledgments

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