Gluino-mediated FCNCs in the MSSM with large $\tan \beta$

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We present results of our study of $\tan \beta$-enhanced loop corrections in the Minimal Supersymmetric Standard Model (MSSM) with Minimal Flavour Violation (MFV). We demonstrate that these corrections induce flavour changing neutral current (FCNC) gluino couplings which have a large impact on the Wilson coefficient $C_8$ of the chromomagnetic operator. To illustrate the phenomenological consequences of this gluino-squark contribution to $C_8$, we briefly discuss its effect on the mixing-induced CP asymmetry in the decay $B_d \to \phi K_S$. 

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1. Introduction

The Minimal Supersymmetric Standard Model (MSSM) contains two Higgs doublets $H_u$ and $H_d$ coupling to up-type and down-type quark fields, respectively. The neutral components of these Higgs doublets acquire vacuum expectation values (vevs) $v_u$ and $v_d$ with the sum $v_u^2 + v_d^2$ being fixed to $v^2 = (174 \text{ GeV})^2$ and the ratio $\tan \beta = \frac{v_u}{v_d}$ remaining as a free parameter. Large values of $\tan \beta$ are theoretically motivated by bottom-top Yukawa unification, which occurs in SO(10) GUT models with minimal Yukawa sector, and phenomenologically preferred by the anomalous magnetic moment of the muon [1]. Since a large value of $\tan \beta$ corresponds to $v_d / v_u$, it leads to enhanced corrections in amplitudes where the tree-level contribution is suppressed by the small vev $v_d$ but the loop-correction involves $v_u$ instead.

These $\tan \beta$-enhanced loop-corrections lead to a plethora of phenomenological consequences: They modify the relation between the down-type Yukawa couplings $y_d$ and the quark masses $m_d$ [2], give corrections to the elements of the CKM matrix [3] and induce FCNC couplings of the neutral Higgs bosons to down quarks [4]. Recently we found that also FCNC couplings of gluinos and neutralinos to down quarks are generated in this way [5]. In this article we explain how this FCNC gluino-couplings arise and discuss the phenomenological consequences.

2. Flavour-changing gluino coupling in naive MFV at large $\tan \beta$

At tree-level the bottom mass $m_b$ is generated by coupling the $b$-quark to the Higgs field $H_d$ and is thus proportional to the small vev $v_d$. For this reason self-energy amplitudes $\Sigma^{RL}_{i b i}$ ($i = d \bar{s}$) can be $\tan \beta$-enhanced compared to $m_b$ if they involve $v_u$ instead of $v_d$. In this article we discuss the impact of these enhanced self-energies in the framework of naive MFV as defined in Ref. [5]. For the analysis of the analogous effects in the general MSSM we refer to Ref. [6]. For definiteness we focus on $b \to s$ transitions and parameterise the corresponding self-energy, which is generated by chargino-squark-loops, as

$$\Sigma^{RL}_{bs} = V_{tb} V_{ts} m_b \varepsilon_{FC} \tan \beta : \tag{2.1}$$

In naive MFV the quark-squark-gluino coupling is flavour-diagonal at tree-level. It receives flavour-changing loop-corrections among which we want to consider those induced by an insertion of the self-energy $\Sigma^{RL}_{bs}$ in the down-quark line (see fig. 1 for the case of an external $s$-quark). If the $s$-quark is on-shell, this correction is local and can be promoted to a FCNC gluino coupling.
Since the $b$-quark propagator $i=m_b$ ($m_s$ is set to zero) cancels the factor $m_b$ in $\Sigma^{RL}_{bs}$, the resulting coupling is proportional to

$$\kappa_{bs} = g_s V_{tb} V_{ts} \varepsilon_{FC} \tan \beta :$$

(2.2)

If $\tan \beta$ is large enough to compensate for the loop-factor $\varepsilon_{FC}$, the coupling $\kappa_{bs}$ can be of order $\mathcal{O}(1)$ apart from the CKM factor $V_{tb} V_{ts}$, which preserves the MFV structure.

In order not to spoil the perturbative expansion a special treatment is required for these $\tan \beta$-enhanced corrections to resum them to all orders. This is usually done using an effective theory with the SUSY particles integrated out keeping only Higgs fields and SM fields [8–11]. However, since we want to study $\tan \beta$-enhanced effects in the quark-squark-gluino-coupling, we cannot integrate out the gluino and squarks and this technique is not appropriate here. In Ref. [5] instead the diagrammatic method developed in Ref. [11] is extended to the case of flavour-changing interactions. The result is that contributions of the form $(\text{loop}\tan \beta)^n$ can be included to all orders $n = 1, 2, \ldots$ into the FCNC gluino coupling by replacing

$$\varepsilon_{FC} \tan \beta \rightarrow \frac{\varepsilon_{FC} \tan \beta}{1 + \langle \varepsilon_b \varepsilon_{FC} \rangle \tan \beta}$$

(2.3)

in Eq. (2.2). Here $\varepsilon_b$ denotes the counterpart of $\varepsilon_{FC}$ in the parameterisation of the flavour-conserving self-energy $\Sigma^{RL}_{bs}$ analogous to Eq. (2.1). Explicit formulae for $\varepsilon_b$ and $\varepsilon_{FC}$ can be found in Ref. [5].

3. Sizable effect in $C_8$

The FCNC gluino coupling discussed in the last section gives rise to new contributions to the Wilson coefficients of the effective $\Delta B = 1$ and $\Delta B = 2$ Hamiltonians. Most of these contributions turn out to be numerically small for two reasons: Firstly, the FCNC gluino coupling is numerically small; for positive $\mu$ typical values are around $\kappa_{bs}$ $\mathcal{O}(1) V_{tb} V_{ts}$. Secondly, unlike the higgsino-part of chargino diagrams, the gluino contributions suffer from a GIM suppression because the gluino coupling is universal for all quark flavours.

![Figure 2](image-url)

**Figure 2:** Left: Magnitudes of chargino and gluino contributions to $C_8$ scanned over the MSSM parameter space. Right: $S_{\phi_{K_S}}$ as a function of $A_t$. j
There is one exception: Chirally enhanced contributions to the magnetic and chromomagnetic operators $\hat{Q}_7$ and $\hat{Q}_8$ involve a left-right-flip in the squark-line which is proportional to the corresponding quark mass and thus distinguishes between different squark flavours. Whereas the corresponding contribution from gluino-squark-loops to $C_7$ is accidentally small, the one to $C_8$ can indeed contribute as much as the well known chargino-squark diagram. This can be seen from the left diagram in fig. 2 where the magnitudes of both contributions $C_8^{\text{c}}$ and $C_8^{\text{g}}$ are shown for a scan over the MSSM parameter space with positive $\mu$. The colour code (yellow: $200 \text{GeV} < \mu < 400 \text{GeV}$, red: $400 \text{GeV} < \mu < 600 \text{GeV}$, blue: $600 \text{GeV} < \mu < 800 \text{GeV}$, black: $800 \text{GeV} < \mu < 1000 \text{GeV}$) reflects the fact that the importance of $C_8^{\text{g}}$ grows with $\mu$. All points in the plot are in agreement with the constraints from $B(\bar{B} \to X_s \gamma)$ and the experimental lower bounds for the sparticle and lightest Higgs Boson masses. Note that we allow for an arbitrary phase for the parameter $A_t$. However, to avoid the possibility of fulfilling the $B(\bar{B} \to X_s \gamma)$ constraint by an unnatural fine-tuning of this phase, the additional condition $|C_7^{\text{Susy}}| < |C_7^{\text{SM}}|$ is imposed.

As a consequence the $\tan\beta$-enhanced FCNC gluino coupling should affect those low energy observables with a strong dependence on $C_8$. To illustrate this fact we have plotted the mixing-induced CP asymmetry $S_{\phi K_S}$ of the decay $\bar{B}^0 \to \phi K_S$ as a function of $A_t$ in the right diagram of fig. 2. The parameter point chosen for the plot fulfills all constraints mentioned above. The shaded area represents the experimental $1\sigma$ range, the dotted line the SM contribution in leading-order QCD factorisation. For the results corresponding to the dashed and the solid lines we have in addition taken into account the effects of $C_8^{\text{c}}$ and $C_8^{\text{g}}$, respectively. The plot demonstrates that for complex $A_t$ the gluino-squark contribution can indeed have a large impact on $S_{\phi K_S}$, especially if $|\beta - \alpha|$ is large.

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