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Gluino-mediated FCNCs in the MSSM with large tanβ

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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 $v^2 \approx (174\text{ GeV})^2$ and the ratio $\tan\beta \equiv v_u/v_d$ remaining as a free parameter. Large values of $\tan\beta$ (~ 50) 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 $v_d \ll v_u$, 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_i} and the quark masses m_{d_i} [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 tanβ

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 Σ_{bi}^{RL} $(i = d,s)$ 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

$$\Sigma_{bs}^{RL} = V_{tb}^* V_{ts}\, m_b\, \varepsilon_{FC} \tan\beta. \tag{2.1}$$

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 Σ_{bs}^{RL} 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.

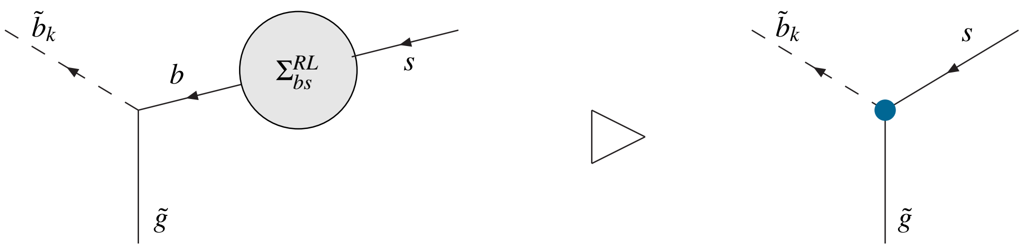

Figure 1: FCNC gluino coupling for an on-shell s-quark induced by the $\tan\beta$-enhanced self-energy Σ_{bs}^{RL}

Since the b-quark propagator $-i/m_b$ (m_s is set to zero) cancels the factor m_b in Σ^{RL}_{bs}, the resulting coupling is proportional to

$$\kappa_{bs} \;=\; g_s\, V^*_{tb} V_{ts}\, \varepsilon_{FC}\, \tan\beta\,. \tag{2.2}$$

If $\tan\beta$ is large enough to compensate for the loop-factor ε_{FC}, the coupling κ_{bs} can be of order $\mathscr{O}(1)$ 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 intgrated out keeping only Higgs fields and SM fields [2–4]. 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. [7] is extended to the case of flavour-changing interactions. The result is that contributions of the form $(\mathrm{loop}\times\tan\beta)^n$ can be included to all orders $n = 1, 2, \ldots$ into the FCNC gluino coupling by replacing

$$\varepsilon_{FC}\,\tan\beta \;\longrightarrow\; \frac{\varepsilon_{FC}\,\tan\beta}{1+(\varepsilon_b-\varepsilon_{FC})\,\tan\beta} \tag{2.3}$$

in Eq. (2.2). Here ε_b denotes the counterpart of ε_{FC} in the parameterisation of the flavour-conserving self-energy Σ^{RL}_b analogous to Eq. (2.1). Explicit formulae for ε_b and ε_{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 μ typical values are around $\kappa_{bs} \sim 0.1 \cdot V^*_{tb}V_{ts}$. 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.

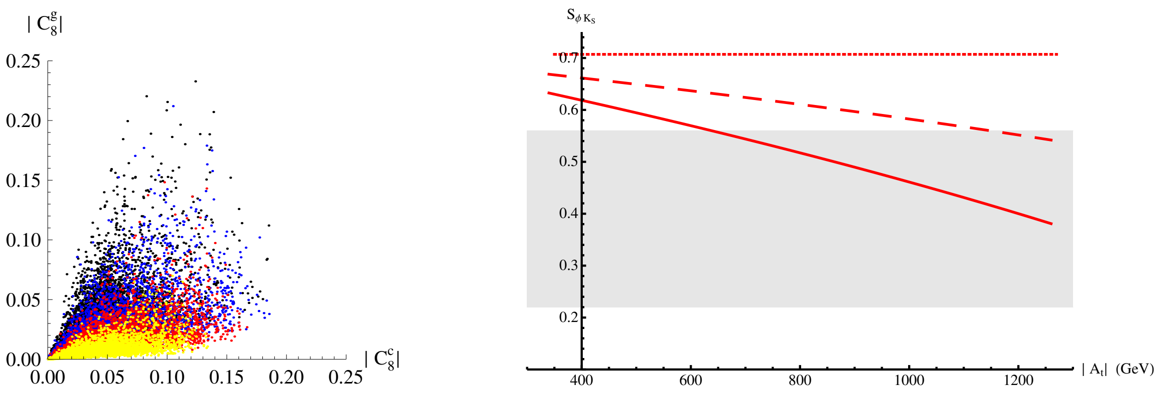

Figure 2: Left: Magnitudes of chargino and gluino contributions to C_8 scanned over the MSSM parameter space. Right: $S_{\phi K_S}$ as a funtion of $|A_t|$.

There is one exception: Chirally enhanced contributions to the magnetic and chromomagnetic operators $\mathscr{O}_7$ and $\mathscr{O}_8$ involve a left-right-flip in the squark-line which is proportional to the corresponding quark mass und 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 $|C_8^c|$ and $|C_8^g|$ are shown for a scan over the MSSM parameter space with positive μ. The colour code (yellow: $200\,\mathrm{GeV} < \mu < 400\,\mathrm{GeV}$, red: $400\,\mathrm{GeV} < \mu < 600\,\mathrm{GeV}$, blue: $600\,\mathrm{GeV} < \mu < 800\,\mathrm{GeV}$, black: $800\,\mathrm{GeV} < \mu < 1000\,\mathrm{GeV}$) reflects the fact that the importance of C_8^g grows with μ. All points in the plot are in agreement with the constraints from $\mathscr{B}(\bar{B} \to X_s\gamma)$ 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 $\mathscr{B}(\bar{B} \to X_s\gamma)$ constraint by an unnatural fine-tuning of this phase, the additional condition $|C_7^{Susy}| < |C_7^{SM}|$ 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 1σ 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^c and $C_8^c + C_8^g$, 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 $|A_t|$ is large.

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