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Top anomalous decays in R-parity violating SUSY

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Abstract: The flavor-changing top-quark decay $t \to ch$, where h is the lightest CP-even Higgs boson in the minimal supersymmetric standard model, is examined in the R-parity-violating supersymmetric model. Within the existing bounds on the relevant R-parity-violating couplings, the branching ratio for $t \to ch$ can be as large as about 10^{-5} in some part of the parameter space, reaching a level accessible at the LHC and at e^+e^- Linear Colliders with high luminosities.

The study of heavy-particle decays via flavor-changing neutral-currents (FCNC) has been playing an important role in testing the standard model (SM) and probing new physics beyond the SM. As the heaviest elementary particle in the SM with a mass at the electroweak scale, the top quark is more likely to be sensitive to new physics. Kinematically it is accessible to many FCNC decay modes, such as $t \to cV$ ($V = \gamma, Z, g$) and $t \to ch$, where h is a Higgs boson. In the SM these FCNC decay modes are highly suppressed by the GIM mechanism, with typical branching ratios of $10^{-14} - 10^{-10}$ [1, 2], which are too small to be detectable at collider experiments. On the other hand, observation of any of such FCNC top-quark decays would be robust evidence for new physics [3, 4, 5, 6].

Top quarks will be copiously produced at the next generation of colliders. At Tevatron II with an integrated luminosity of 10 fb^{-1}, there will be about 8×10^4 top quarks produced,

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while there will be about 100 times more at the LHC with the same luminosity. At the LHC with a luminosity of 100 fb^{-1} there will be more than 10^8 tops per year, including both $t\bar{t}$ and single top production, for $m_h = 120$ GeV [7]. At a proposed e^+e^- Linear Collider with $\sqrt{s} = 500$ GeV and luminosity of 300 fb^{-1}, such as TESLA, one expect 1.6×10^5 tops [7, 8]. With such large data samples, good sensitivities may be reached for the rare decay channels $t \to cV$ [3], and for studying other related processes at hadron colliders [4]. A more recent study showed that the channel $t \to ch$ could also be detectable [5], reaching a sensitivity of $Br(t \to ch) \sim 10^{-5}$ at the LHC and a few percent at the Tevatron. While these high detection sensitivities are still far above the SM expectation for the rare decay channels [1, 2], in many scenarios beyond the SM the branching ratios of these FCNC top-quark decays could be significantly enhanced [1, 6, 9, 10, 11, 12, 13].

In the minimal supersymmetric (SUSY) standard model (MSSM) with R-parity conservation, it was shown [10] that the possibility for observing the decay channel $t \to ch$ could be greatly enhanced (here h is the lightest CP-even Higgs boson). Kinematically this decay mode is always allowed because of the strict theoretical upper bound on the Higgs boson mass [14], and the decay receives dominant contributions from the SUSY QCD (SQCD) loops of flavor-changing interactions [10]. If the gluino and squarks involved in the contributing SQCD loops are both light of order 100 GeV, the branching ratio could be enhanced to a level of 10^{-5}. The branching ratio falls off quickly for heavier sparticles in the loops.

In this talk which is basically a short version of [15], we examine the R-parity-violating contributions to $t \to ch$. It is well-known that R-parity conservation in SUSY theory, which implies the separate conservation of baryon number and lepton number, is put in by hand. R-parity violation ($\not{R}$) can be made perfectly consistent with other fundamental principles such as gauge invariance, supersymmetry and renormalizability [16]. If $\not{R}$ is included in the MSSM, $t \to ch$ will receive new contributions from the loops of $\not{R}$ interactions. These can be significant, since the relevant $\not{R}$ couplings inducing $t \to ch$ involve the third-generation fermions and are subject to rather weak bounds from existing experiments. We find that the branching ratio for $t \to ch$ from $\not{R}$ contributions can be indeed as high as about 10^{-5} in some part of parameter space, reaching a level accessible at future high luminosity colliders.

Assuming that there are only trilinear couplings, one obtains the $\not{R}$ Lagrangian

$$\mathcal{L}_{\lambda''} = -\frac{1}{2}\lambda''_{ijk}\left[\tilde{d}^k_R(\bar{u}^i_R)^c d^j_R + \tilde{d}^j_R(\bar{d}^k_R)^c u^i_R + \tilde{u}^i_R(\bar{d}^j_R)^c d^k_R\right] + h.c. \tag{1}$$

Constraints on the couplings have been obtained from various processes [17, 18, 19, 20, 21, 22, 23, 24] and their phenomenology at hadron and lepton colliders has been intensively investigated [24, 25]. For brevity, only the terms with Baryon-number violation ($\not{B}$) are displayed, and the similar Lepton-number violating ($\not{L}$) terms, *i.e.* those with λ''s, are left out. Also, the limits on the $\not{L}$ couplings are stricter than for those with $\not{B}$. With $\not{B}$ couplings, the decay $t \to ch$ can proceed through four simple 1-loop diagrams (see Fig. 1 in [15]).

The induced effective tch vertex is given by $V = ie\frac{\lambda''_{2jk}\lambda''_{3jk}}{16\pi^2}2FP_L$, where $P_L = \frac{1}{2}(1-\gamma_5)$. For simplicity and space limitation, we have assumed that all fermion masses can be neglected with respect to m_t [15]. Then, only a single diagram survives, *i.e.* the one with h emitted from $\tilde{d}^k$ line, corresponding to the upper right one in Fig. (1) in [15], and $F = Y m_t (C_{11} - C_{12})(-p_t, k, m_{d^j}, m_{\tilde{d}^k}, m_{\tilde{d}^k})$, where k is the Higgs momentum. The functions C_{ij} are the conventional 3-point Feynman integrals [26], with arguments as indicated in the bracket following them. The only surviving constant for $m_q << m_t$ is $Y = -\frac{1}{3} m_Z \tan\theta_W \sin(\alpha+\beta)$, where α is the neutral Higgs boson mixing angle, and $\tan\beta = v_2/v_1$ [27].

We now discuss the numerical results for $Br(t \to ch)$, as presented in Figs. 3–5 in [15]. For the SM parameters involved, we take $m_t = 175$ GeV, $m_Z = 91.187$ GeV, $m_W = 80.3$ GeV, $\alpha = 1/128$, $\sin^2\theta_W = 0.232$. The SUSY parameters involved are the following:

(1) For the $\not{B}$ couplings λ''_{2jk} and λ''_{3jk}, we take their upper limits [22, 28], which are of $\mathcal{O}(1)$. We note that the current bounds for the $\not{B}$ couplings are generally quite weak (see however [19]).

(2) We assume a common mass for all squarks.

(3) At tree level the Higgs sector of the MSSM is determined by two free parameters, *e.g.*, m_A and $\tan\beta$. When radiative corrections are included, several other parameters enter through the loops [14]. Then a single parameter ϵ [29], determines α and $m_{h,H}$. We constrain the parameter space of the Higgs sector as given in [30].

We presented the maximum values of the branching ratio in Fig. (5) in [15], for $\tan\beta = 10$ as a function of m_A, for two squark masses. One sees that there is only little dependence on m_A. $Br(t \to ch)$ can reach 10^{-5} for $m_{\tilde{q}} = 100$ GeV, dropping by more than an order of magnitude when $m_{\tilde{q}} = 200$ GeV.

In addition, the dependence on $\tan\beta$, away from its excluded values, is mild [15]. We have also demonstrated the decoupling property of the MSSM, *i.e.*, for $m_{\tilde{q}} \gtrsim 500$ GeV, the branching ratio goes down like $1/m_{\tilde{q}}^4$.

In summary, we found that the FCNC decay $t \to ch$ can be significantly enhanced relative to that of the SM, in SUSY theories with R-parity violation. The branching ratio depends quadratically on the products of $\not{R}$ couplings, and scales with the heavy mass of the squarks in the loops as $m_{\tilde{q}}^{-4}$, and it can be at least as large as that in the MSSM. In the optimistic scenario that the involved couplings take their current upper bounds and $m_{\tilde{q}} \approx 100$ GeV, the branching ratio can be as large as 10^{-5}, which is potentially accessible at the future LHC and Linear Colliders.

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