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Proposal for the Search of Four-Body Decays of the Stop

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Abstract

Following the recent studies of Boehm *et al.*, we propose a new strategy for stop $\tilde{t}_1$ search at DØ using Run 1 data, in the MSSM framework where the neutralino χ_1^0 is expected to be the lightest SUSY particle. In addition to the $\tilde{t}_1 \to c\chi_1^0$ channel, $\tilde{t}_1$ can be searched in four-body decays into an LSP, a bottom quark and two massless fermions, $\tilde{t}_1 \to b\chi_1^0 f\bar{f}'$. We discuss the search strategies through the different signatures due to $t\bar{t}$ and $\tilde{t}\bar{\tilde{t}}$ pair decays. Some similarity between top pair decay in the SM and those involving $\tilde{t}$ could be used to quickly set limits on this four-body channel.

1 Introduction

Up to now, searches for the lightest top squark "stop" $\tilde{t}_1$ at DØ - in the MSSM framework where the neutralino χ_1^0 is expected to be the lightest SUSY particle - have been made with the assumption that the main decay channel is the loop-induced decay into a charm quark and the LSP

$$\tilde{t}_1 \to c\chi_1^0$$

Recent studies [1] have analyzed higher order decay mode of the stop $\tilde{t}_1$. For small $\tilde{t}_1$ masses accessible at the Tevatron, they show that the four-body decay mode

$$\tilde{t}_1 \to b\chi_1^0 f\bar{f}'$$

can dominate over the loop-induced decay $\tilde{t}_1 \to c\chi_1^0$, if the chargino and slepton masses are not much larger than their present experimental bounds.

Some results of the studies presented in [1] are summarized in section 2, particulary the dominant diagrams and the branching ratio of the four-body decay channel. Section 3 describes the experimental signatures both for the four and the two-body decays of the stop $\tilde{t}_1$, the stop being produced directly from gluon fusion and quark annihilation or from $t\bar{t}$ pair decay. We also emphasize the similarities of some of these signatures with the SM top pair decays. Some conclusions and a first outlook at the upcoming studies are given in section 4.

2 The Four-Body Decay Mode

The four-body decay mode $\tilde{t}_1 \to b\chi_1^0 f\bar{f}'$ proceeds through several categories of diagrams as shown in fig. 1. The W-boson exchange diagrams with a virtual top quark, bottom squark or the two charginos states are shown in fig. 1a. A similar set of diagrams is obtained by replacing the W by the charged Higgs boson $H^{\pm}$ (fig. 1b). A third set of diagrams consists of the up and down sleptons or the first/second generation squark exchanges (fig. 1c).

Some of these diagrams can be neglected due to virtuality arguments: according to theoretical constraints and experimental bounds on the mass spectrum in the MSSM [1], the charged Higgs boson in fig. 1b has a much larger virtuality than the W boson in fig. 1a, so the diagrams in fig. 1b can be neglected; due to the experimental bounds on the first and second generation squarks $m_{\tilde{q}} \geq 250$ GeV, the squark exchange diagrams in fig. 1a

[1] At the tree level, the MSSM imposes the constraint $M_{H^\pm}^2 = M_A^2 + M_W^2$ on the charged and the pseudoscalar higgs bosons. Using this relation and the experimental bound on M_A leads to $M_{H^\pm} \geq 120$ GeV.

and fig. 1c can be equally neglected and for similar arguments the top quark exchange diagram in fig. 1a. The most significant contributions to the four-body decay mode will come in general from the chargino exchange diagram in fig. 1a and the sleptons exchange diagrams in fig. 1c.

Fig. 2 shows the branching ratio BR($\tilde{t}_1 \to b\chi_1^0 f\bar{f}'$) as a function of the lightest stop $\tilde{t}_1$ mass, for a fixed value of the common squark and slepton mass $m_{\tilde{q}} = m_{\tilde{l}} = 400$ GeV, $\tan\beta = 2.5$, a gaugino mass parameter $M_2 =$ 120 or 200 GeV, and three values of the parameter $\mu = 300$, 450 and 700 GeV. As can be seen, the branching ratio is very small in the lower stop mass range, and increases with increasing $m_{\tilde{t}}$, to reach values close to unity near the $m_{\tilde{t_1}} \sim m_b + m_{\chi^+}$ threshold. Note that even for the small values $m_{\tilde{t}_1} \sim$ 80 GeV the branching ratio for the four-body decay $\tilde{t}_1 \to b\chi_1^0 f\bar{f}'$ can reach the level of 90% (depending on μ). Since the top squarks with these mass values have already been experimentally ruled out with the assumption that they decay most of the time into $c\chi_1^0$, these searches have to be reconsidered in the light of the possible dominance of the four-body decay mode.

3 Experimental Signatures

The stop $\tilde{t}_1$ can be produced either in $t\bar{t}$ production by top quark decays into $\tilde{t}\chi_1^0$ or directly by stop pair $\tilde{t}\bar{\tilde{t}}$ production. Up to now, only the two-body stop decay $\tilde{t}_1 \to c\chi^0$ was considered producing a jet and some $\not{E}_T$. In the four-body decay mode $\tilde{t}_1 \to b\chi_1^0 f\bar{f}'$, besides a b-jet and some $\not{E}_T$ $f\bar{f}'$ are produced from the decay of a charged object (W, χ^+) and can be either $l\nu_l$ or $q\bar{q}'$.

Looking for the stop decay in top pair production where one of the top decays into $bq\bar{q}'$ (according to SM) while for the other we have $t \to \tilde{t}_1\chi_1^0$ leads to three different signatures summarized in table 1. Note that the second signature ($l + 4jets +$ $\not{E}_T$, and 2 of the jets are b) is similar to the standard $t\bar{t} \to lepton + jets$ channel, where one of the top decays into 3 jets and the other one to $bl\nu_l$. The third signature is similar to $t\bar{t} \to all\ jets$ apart from $\not{E}_T$.

Another set of signatures is obtained when one of the top decays into $bl\nu_l$, and the other into $t \to \tilde{t}_1\chi_1^0$, with $\tilde{t}_1 \to c\chi^0$ or $\tilde{t}_1 \to b\chi_1^0 f\bar{f}'$. This leads to three signatures summarized in table 2. Note that the second signature is similar to the standard dilepton $t\bar{t}$ channel where both top decay to $bl\nu_l$.

$bq\bar{q}' + c\chi^0$	$\rightarrow$	$b + 3\ jets + \not{E}_T$
$bq\bar{q}' + b\chi_1^0 l\nu_l$	$\rightarrow$	$2b + 2\ jets + l + \not{E}_T$
$bq\bar{q}' + b\chi^0 q\bar{q}'$	$\rightarrow$	$2b + 4\ jets + \not{E}_T$

Table 1: *$t\bar{t}$ decays with one of the t into $bq\bar{q}'$ and the other into $t \rightarrow \tilde{t}_1\chi_1^0$, with $\tilde{t}_1 \rightarrow c\chi^0$ (two-body decay) or $\tilde{t}_1 \rightarrow b\chi_1^0 f\bar{f}'$ (four-body decay). The first signature is due to the two-body decay of the stop $\tilde{t}_1$ and the others to the four-body mode. Note that the second signature is similar to the standard $t\bar{t} \rightarrow lepton + jets$ channel, and that the third one is similar to $t\bar{t} \rightarrow all\ jets$ apart from $\not{E}_T$.*

$bl\nu_l + c\chi^0$	$\rightarrow$	$b + jet + l + \not{E}_T$
$bl\nu_l + b\chi_1^0 l'\nu_{l'}$	$\rightarrow$	$2b + l + l' + \not{E}_T$
$bl\nu_l + b\chi^0 q\bar{q}'$	$\rightarrow$	$2b + 2\ jets + l + \not{E}_T$

Table 2: *$t\bar{t}$ decays with one of the t into $bl\nu_l$ and the other into $t \rightarrow \tilde{t}_1\chi_1^0$; $\tilde{t}_1 \rightarrow c\chi^0$ (two-body decay) or $\tilde{t}_1 \rightarrow b\chi_1^0 f\bar{f}'$ (four-body decay). Note that the second signature is similar to the standard dilepton $t\bar{t}$ channel.*

Finally, stop pair $\tilde{t}\tilde{t}$ production leads to the signatures summarized in table 3, where both stop decay to $c\chi^0$ or $b\chi_1^0 f\bar{f}'$, or one stop into $c\chi^0$ and the other one to $b\chi_1^0 f\bar{f}'$.

$c\chi^0 + c\chi^0$	$\rightarrow$	$2\ jets + \not{E}_T$
$c\chi^0 + b\chi_1^0 l\nu_l$	$\rightarrow$	$b + jet + l + \not{E}_T$
$c\chi^0 + b\chi^0 q\bar{q}'$	$\rightarrow$	$b + 3\ jets + \not{E}_T$
$2 \times (b\chi_1^0 l\nu_l)$	$\rightarrow$	$2b + l + l' + \not{E}_T$
$b\chi_1^0 l\nu_l + b\chi^0 q\bar{q}'$	$\rightarrow$	$2b + 2\ jets + l + \not{E}_T$
$2 \times (b\chi^0 q\bar{q}')$	$\rightarrow$	$2b + 4\ jets + \not{E}_T$

Table 3: *$\tilde{t}\tilde{t}$ pair decays.*

Merging these different stop production modes, we get six different signatures summarized in table 4. They contain 2, 4 or 6 jets and up to two possible different charged leptons; all are signed by the presence of $\not{E}_T$. Note that five of these six signatures (except $2\ jets+\ \not{E}_T$, due to $\tilde{t}\tilde{t} \rightarrow 2 \times (c\chi^0)$) can be produced when at least one stop decays to $b\chi_1^0 f\bar{f}'$.

$6\ jets$		$+\ \not{E}_T$
$4\ jets$		$+\ \not{E}_T$
$4\ jets$	$+l$	$+\ \not{E}_T$
$2\ jets$		$+\ \not{E}_T$
$2\ jets$	$+l$	$+\ \not{E}_T$
$2\ jets$	$+l+l'$	$+\ \not{E}_T$

Table 4: *Two-body $\tilde{t}_1 \rightarrow c\chi^0$ and four-body $\tilde{t}_1 \rightarrow b\chi_1^0 f\bar{f}'$ stop $\tilde{t}_1$ signatures due to the tt and $\tilde{t}\tilde{t}$ pair decays. All of these signatures except $2\ jets+\ \not{E}_T$ can be produced when at least one stop decays to $b\chi_1^0 f\bar{f}'$.*

4 Search Strategies

We have studied experimental signatures of the four-body decays of the lightest top squark into the lightest neutralino, a bottom quark and two massless fermions, $\tilde{t}_1 \to b\chi_1^0 f\bar{f}'$ in the MSSM framework, where the neutralino χ_1^0 is expected to be the lightest SUSY particle. Including the four-body decay, we are considering a much larger set of signatures than the $\tilde{t}_1 \to c\chi_1^0$ decay search.

Due to the similarity between some of these signatures and the SM $t\bar{t}$ signatures - especially the lepton + 4 jets one - we can use the selection criteria for the standard $t\bar{t}$ cross section analysis [2] for a preliminary study of sensitivity, as all SM backgrounds are well known and the data were carefully analyzed. The first step in this stop-search analysis consists in implementing the four-body decay $\tilde{t}_1 \to b\chi_1^0 f\bar{f}'$ in the Monte Carlo simulation, for which we will use the PYTHIA [3] program, and in calculating the corresponding efficiencies. A more complete analysis with selection criteria optimized for the signal and an improved $\not{E}_T$ reconstruction [4, 5] will then follow.

References

[1] C. Boehm, A. Djouadi and Y. Mambrini, "Decays of the Lightest Top Squark", hep-ph/9907428.

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[3] T. Sjostrand, Computer Physics Commun. **82**, 74 (1994).
S. Mrenna, Computer Physics Commun. **101**, 232 (1997).

[4] B. Knuteson *et al.*, "p($\not{E}_T$): The missing transverse energy resolution of an event", DØ note 3629.

[5] G. Bernardi, B. Olivier, B. Knuteson and M. Strovink, "NADA: A New Event by Event Hot Cell Killer", DØ note 3687.

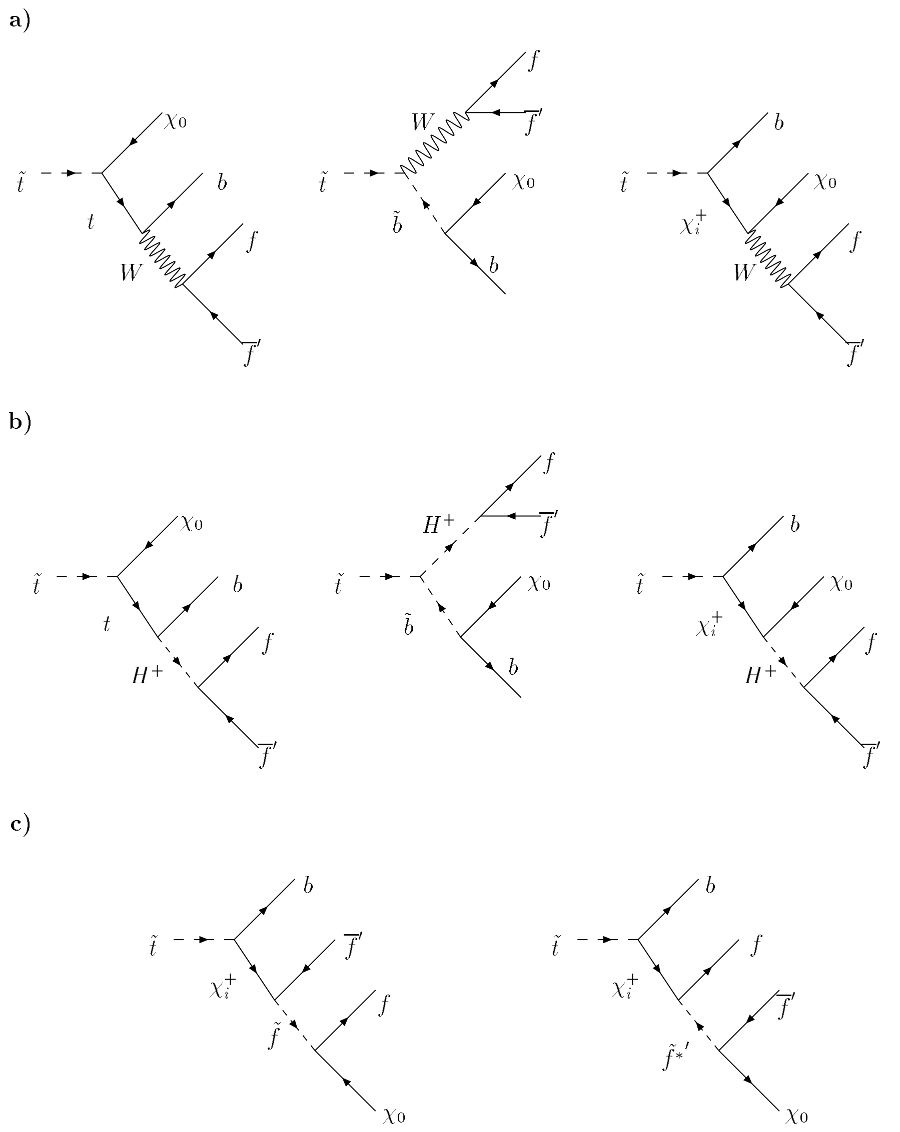

Figure 1: *Feynman diagrams contributiong to the stop $\tilde{t_1}$ four-body decay mode $\tilde{t}_1 \to b\chi_1^0 f\bar{f}'$ [1] .*

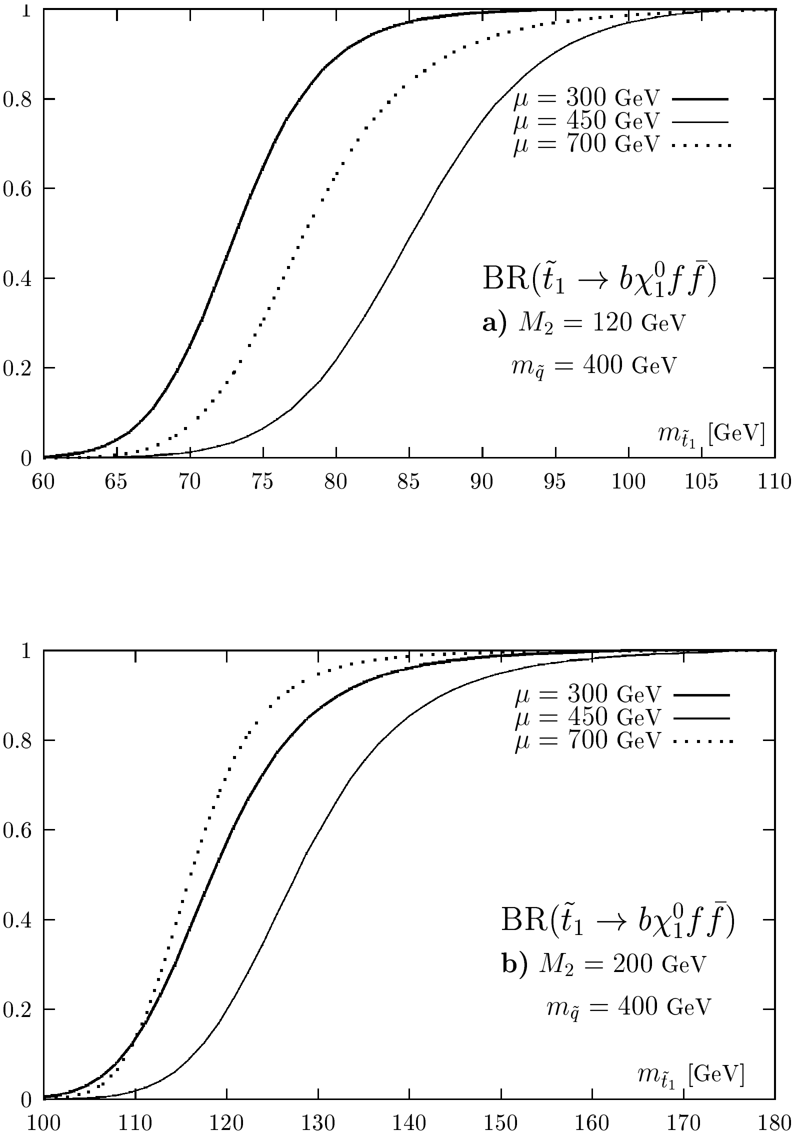

Figure 2: *The branching ratio $BR(\tilde{t}_1 \to b\chi_1^0 f\bar{f}')$ as a function of the squark mass $m_{\tilde{t}_1}$ for a scalar mass $m_{\tilde{q}} = 400$ GeV,* $\tan\beta = 2.5$ *and a gaugino mass M_2 of 120 (a) and 200 GeV (b) [1].*