Detecting a Light Stop from Top Decays at the Tevatron

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Abstract

We study the possibility of discovering or excluding a light top squark (stop) $\tilde{t}_1$ based on top quark decays in the $t\bar{t}$ events produced at the Fermilab Tevatron. In particular, we consider the Minimal Supersymmetric Standard Model with the sparticle spectrum $m_{\tilde{\chi}^+} + m_b, M_W + m_{\tilde{\chi}_1^0} + m_b > m_{\tilde{t}_1} > m_{\tilde{\chi}_1^0} + m_c$, where $\chi^0_1$ is the lightest neutralino, so that $t \rightarrow \tilde{t}_1 \chi^0_1$ and $\tilde{t}_1 \rightarrow c \chi^0_1$. All other sparticle masses are assumed to be heavier than $m_t$. Such a spectrum seeks to explain the experimental values of $\alpha_s(M^2_Z)$, $R_b$ and $A_{LR}$ obtained from LEP/SLC data. We find that the prospect to observe a light stop via this channel at the Tevatron is very promising.

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1 Introduction

A recent analysis of the strong and electroweak parameters extracted from LEP/SLC data has shown that there is better agreement between theory and experiment for the Minimal Supersymmetric Standard Model (MSSM) with light superpartners than for the Standard Model (SM) alone \[1\]. If the superpartners of the MSSM are light, then new top decay modes can exist. There are many compelling reasons to believe that the lightest superpartner is the lightest neutralino $\chi^0_1$ (see reference \(2\) for a review.) A reconciliation of the strong coupling measurement at the scale $M_Z$, $\alpha_s(M_Z^2)$, the observed branching ratio of $Z^0 \rightarrow b\overline{b}$, $R_b$, and the left-right asymmetry measured at the SLC, $A_{LR}$, is suggested by the MSSM where the lightest top squark ($\tilde{t}_1$), the lightest chargino $\chi^{\pm}_1$, and the lightest neutralino $\chi^0_1$ have masses below $m_t$, while all other superpartners are relatively heavy. As shown in Fig. 2 of Ref. \[1\], a large $m_{\chi^{\pm}_1}$ would preferentially require the branching ratio (BR) of $t \rightarrow \tilde{t}_1 \chi^0_1$ to be small. (The small branching ratio of any non–SM decay mode of the top quark is inferred from the current top quark data at the Tevatron. This will be shown in Sec. 3.) Over a large range of this parameter space, $m_{\chi^{\pm}_1} > m_{\tilde{t}_1}$ (see Fig. 1 of Ref. \[1\]). Therefore, the scenario arises where $t \rightarrow \tilde{t}_1 \chi^0_1$ provided that $m_t > m_{\tilde{t}_1} + m_{\chi^0_1}$. Furthermore, if $m_{\tilde{t}_1} < m_{\chi^{\pm}_1} + m_b$, and $M_W + m_{\chi^0_1} + m_b > m_{\tilde{t}_1} > m_{\chi^0_1} + m_c$, then the dominant decay of $\tilde{t}_1$ is $\tilde{t}_1 \rightarrow c \chi^0_1$ \[3\]. This is a flavor–changing–neutral–current decay.

Also recently, an analysis has been performed by the DØ collaboration to exclude light stop squarks from the jet and missing transverse energy signature expected from stop squark pair production \[4\]. The DØ analysis relies on the large cross section for pair production of light stop squarks via the partonic processes $q\overline{q}, gg \rightarrow \tilde{t}_1 \tilde{t}_1^*$ and the distinctive final state $\tilde{t}_1 \tilde{t}_1^* \rightarrow c \chi^0_1 \chi^0_1$ when $m_{\chi^{\pm}_1} + m_b > m_{\tilde{t}_1}$. The signature is two acollinear jets and large missing transverse energy ($E_T$). This signal is overshadowed by the background, however, when the $c$–jet and/or $E_T$ spectra becomes soft. As a result, the DØ analysis excludes the $(m_{\tilde{t}_1}, m_{\chi^0_1})$ values inside the region formed by joining the points (40,0), (60,30), (95,40), (110,20), (85,0) and (40,0) GeV. On the other hand, this region is excluded in a model independent fashion once $m_{\tilde{t}_1}$ and $m_{\chi^0_1}$ are specified. Here, we propose a method to improve the stop mass limit or discover the stop squark by studying the decays of the top quark to a stop squark and the lightest neutralino.

Alternatively, a light stop discovery or exclusion can result from analyzing the decay
We propose a search for this decay in \( t \bar{t} \) production with the associated standard decay \( t \rightarrow \bar{b}W^- \) (and the charge conjugate final state). This final state provides the distinctive signature \( \ell^\pm b j \, \mathbb{E}_T \), where \( \ell = e \) or \( \mu \) and \( j \) is a non–b–jet. Demanding a high–\( p_T \), isolated lepton in the central rapidity region of the detector guarantees a high triggering efficiency and reduces backgrounds. Also, since we demand a leptonic decay of the \( W \) boson and because of the \( t \) cascade decay to a charm jet and neutralinos, the \( \mathbb{E}_T \) spectrum is harder than for direct stop pair production.

The outline of this paper is as follows: In Sec. 2, we show how the CDF and DØ top quark data set an upper bound on any non–SM decay mode (any mode other than \( t \rightarrow bW \)) of the top quark. Hence, \( \text{BR}(t \rightarrow \bar{t}_1 \chi_1^0) \) is bounded from above. In Sec. 3, we explain the details of defining the signal and reducing potential backgrounds for observing stop by studying \( t \bar{t} \) events. Discussion and conclusions are presented in Sec. 4.

### 2 Upper Bound on The Branching Ratio of Non–SM Decay Modes of The Top Quark

The existence of the top quark is now firmly established [5]. Kinematic reconstruction of the decay products of the top quark in the decay \( t \rightarrow bW^+ \rightarrow bjj \) (and the charge conjugate decay) suggests a top mass \( m_t = 176 \pm 8 \pm 10 \) GeV from the CDF data and \( m_t = 199^{+19}_{-21} \pm 22 \) GeV from the DØ data. Both experiments have reported production cross sections, which are a function of the assumed top mass used in the analysis. It is important to remember that these experiments have optimized their search for the process \( pp \rightarrow t\bar{t}X \rightarrow bW^+bW^-X \), so they actually report the product of the top production cross section \( \sigma_{\bar{t}t} \) and the branching ratio squared \( b^2 \), where \( b = \text{BR}(t \rightarrow bW) \). Based on single– and double–b–tagged events, CDF has also reported a measurement of \( b \) [6]. Finally, progress has been made in understanding the SM prediction for the production cross section [7], in which the effects of multiple soft-gluon emissions have been properly resummed.

Since the measurement of the cross section obtained from the “counting” experiments (counting the observed total \( t\bar{t} \) event numbers in various decay modes) and the measurement of the mass of the top quark (obtained from reconstructing the invariant mass of the top quark) are not strongly correlated, one can combine these results to find the best fitted values for \( m_t \) and \( \sigma_{\bar{t}t} \) [8]. Using these results, we construct a \( \chi^2 \) function for \( m_s = m_t - 176 \) GeV, \( \sigma_{\bar{t}t} \),
and $b^2$:

$$
\chi^2 = \left( \frac{m_\tau}{12.8} \right)^2 + \left( \frac{m_\tau - 23}{29.7} \right)^2 + \left( \frac{\ln(\sigma_{\pi} \times b^2/\sigma_{D0})}{\delta \ln \sigma_{D0}} \right)^2 + \\
\left( \frac{\ln(\sigma_{\pi} \times b^2/\sigma_{D0})}{\delta \ln \sigma_{D0}} \right)^2 + \left( \frac{b^2 - b_{CDF}^2}{\delta b_{CDF}^2} \right)^2 + \left( \frac{\ln(\sigma_{\pi}/\sigma_{th})}{\delta \ln \sigma_{th}} \right)^2.
$$

In the above equation, we have taken the quadratic sum of the statistical and systematic errors for measuring $m_t$. $\sigma_{CDF}$ and $\sigma_{D0}$ are functional fits to the observed CDF and DØ $\sigma_{\pi} \times b^2$, $\sigma_{th}$ is a functional fit to the theoretical production cross section, $b_{CDF}^2$ is the measured BR($t \rightarrow bW$), and all $\delta$’s are errors on these quantities, as listed below:

\[
\begin{align*}
\ln \sigma_{CDF} &= \ln(7.60) - 3.17 \times 10^{-3} m_* - 3.23 \times 10^{-5} m_*^2 - 2.94 \times 10^{-6} m_*^3 \\
\delta \ln \sigma_{CDF} &= \begin{cases} 
\frac{2.0}{7.6} & \sigma_{\pi} \leq 7.6 \text{pb} \\
\frac{2.4}{7.6} & \sigma_{\pi} > 7.6 \text{pb} 
\end{cases} \\
\ln \sigma_{D0} &= \ln(8.52) - 1.45 \times 10^{-2} m_* + 8.87 \times 10^{-5} m_*^2 \\
\delta \ln \sigma_{D0} &= \frac{2.4}{7.6} \\
\ln \sigma_{th} &= \ln(5.38) - 3.20 \times 10^{-2} m_* + 3.65 \times 10^{-5} m_*^2 \\
\delta \ln \sigma_{th} &= .1 \\
b_{CDF} &= .87 \\
\delta b_{CDF} &= \begin{cases} 
.32 & b \leq .87 \\
.18 & b > .87 
\end{cases}.
\end{align*}
\]

Finding the minimum value $\chi^2_{min}$ yields $m_t = 168.6^{+3.0}_{-3.0}$ GeV, $\sigma_{\pi} = 7.09^{+68}_{-62}$ pb and $b = 1.00^{+0.09}_{-0.13}$. At the 95% confidence level (C.L.) $b = .74$. This number, then, gives us an upper limit on BR($t \rightarrow X$), where $X \neq bW$. From the results of the fit described above, we conclude that BR($t \rightarrow X$) for $X \neq bW$ has to be less than $\sim 25\%$.

Some comments are in order. We have assumed that the experiments observe $t \rightarrow bW$, where a fraction of the $b$ quarks have been tagged. However, there might be non–SM decays involving $b$–quarks, such as $t \rightarrow bH^+$, where $H^+$ is a charged Higgs boson. Unfortunately, there is at present no way to exclude such a scenario for the data used in the fit described above when the mass of $H^+$ is about equal to $M_W$. The counting experiment measurement of $\sigma_{\pi}$ is sensitive to all events with a $b$–jet plus additional jets in the final state that satisfy a certain set of cuts. The top mass measurement only uses those events from the counting experiment satisfying a $M_W$ mass constraint. However, some of the events in this mass

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\(^3\) The theoretical prediction of $\sigma_{\pi}$ is 6.83 pb for $m_t = 168.6$ GeV.

\(^4\) We varied the parameter until the $\chi^2$ value increased from $\chi^2_{min}$ by $(1.96)^2$ units.
distribution are background events, which are subtracted statistically using the background estimated by the counting experiment. Therefore, we cannot define a subset of events that is background free and excludes non–SM decays of the top quark containing a $b$–quark. On the other hand, the mass distribution of the non–$b$–jets for the counting experiment is consistent with that expected from a $W$. We continue our current analysis using the assumption that the experiments do only measure the $bW$ final state. With a larger $t\bar{t}$ data sample in the near future, it would be better to use double-$b$-tagged events (from both $\ell +$ jets and dilepton samples) for the fit.

In the following section, we study how to directly observe the non–SM decay mode of the top quark $t \rightarrow \tilde{t}_1 \chi^0_1 \chi^0_1 \rightarrow c \chi^0_1 \chi^0_1$ and determine the minimum branching ratio of this mode to be detected at the Tevatron for a given set of the sparticle masses $m_{\tilde{t}_1}$ and $m_{\chi^0_1}$.

## 3 Detecting Stop Squarks in the Decay of Top Quarks in $t\bar{t}$ Pairs

In this section, we consider the MSSM models in which $m_t > m_{\tilde{t}_1} + m_{\chi^0_1}$ and $m_{\chi^0_1} + m_b$, $M_W + m_{\chi^0_1} + m_b > m_{\tilde{t}_1} > m_{\chi^0_1} + m_c$, and all other superpartners are heavier than $m_t$. Hence, the dominant decay of $\tilde{t}_1$ is $\tilde{t}_1 \rightarrow c \chi^0_1$. Since the branching ratios of the new decay modes are small ($< 25\%$) compared to the $bW$ final state, most top quarks decay in the standard fashion (see Sec. 2). As a result, we can use the $b$–quark and a high–$p_T$ lepton to tag $t\bar{t}$ production. The non–SM decay of the top quark $t \rightarrow \tilde{t}_1 \chi^0_1 \rightarrow c \chi^0_1 \chi^0_1$ provides an additional jet and missing transverse energy. The signature of the $t\bar{t}$ events of interest is thus $W(\rightarrow \ell\nu) + b + j + E_T$.

Throughout this study, we assume the top mass is 175 GeV. The top quark pair production cross section is given by the QCD calculation, $\sigma_{t\bar{t}}(m_t = 175$ GeV) = 5.52 pb. For each model studied, we determine the detection efficiencies for the signal $t(\rightarrow c \chi^0_1)\bar{t}(\rightarrow \bar{b}W^-(\rightarrow \ell^-\nu_\ell))$ (and the charge conjugate final state) and the backgrounds. The intrinsic backgrounds are $t(\rightarrow bW^+(\rightarrow X))\bar{t}(\rightarrow \bar{b}W^-(\rightarrow \ell^-\nu_\ell))$, $W^-\rightarrow (\ell^-\nu_\ell)X$, (and the charge conjugate final states) and $Z(\rightarrow \ell^+\ell^-)X$. For the signal rate, we include $\ell = e$ and $\mu$. For the background processes, we include $\ell = e, \mu$, and $\tau$ to account for the possible large $E_T$ background from $\tau$ decay. We note that $E_T$ can be faked if any additional jet or lepton escapes detection. The expected background event rate from $W+$jets,
Z+jets, etc. is calculated in the SM using PYTHIA 5.7 \[9\]. The W/Z + jets backgrounds are estimated from the W/Z + parton processes with a minimum $p_T = 20$ GeV. (The other backgrounds coming from a jet faking an isolated lepton with high $p_T$ can be ignored after demanding also a large $E_T$ in the event.) Signal events were generated for a set of $(m_{\tilde{t}_1}, m_{\chi_1^0})$ points (see Table 1) beyond the DØ search limit using an extended version of PYTHIA 5.7 \[10\].

Because of the presence of two neutralinos in the final state, we expect that the signal will have a harder $E_T$ spectrum than the backgrounds. Also, the correlation between the $E_T$ and the lepton momentum in pure W decays, as observed in the transverse mass $m_T$ distribution, should not be present in the signal. The transverse mass $m_T$ is defined by the expression $m_T^2 = 2p_T^{(\ell)} E_T (1 - \cos \Delta \phi_{\ell\nu})$, where $\Delta \phi_{\ell\nu}$ is the azimuthal angle between the lepton $\ell$ and the $E_T$ direction. Finally, the hadronic activity should be lower for the signal than for the $t\bar{t}$ background. We find that the following cuts enhances the signal with respect to the backgrounds:

- $p_T^{(\ell)} > 20$ GeV, $|\eta^{(\ell)}| < 1$. (I)
- $E_T > 60$ GeV. (II)
- $p_T^{(j)} > 15$ GeV, $|\eta^{(j)}| < 2$. (I)
- $n_{jets} = 2$. Jets are defined by summing the transverse energy $E_T$ in a toy calorimeter within a cone size $R = .7$ so that the jet transverse energy $E_T^j > 15$ GeV. (III)
- $m_T > 110$ GeV. (II)
- Fake $E_T$ discrimination: $\sqrt{(\pi - \Delta \phi_{j_1\nu})^2 + (\Delta \phi_{j_2\nu})^2} > .5$, where $j_1$ and $j_2$ are the highest and second highest $E_T$ jets and $\nu$ is the $E_T$ direction, and $\Delta \phi_{j\nu} > .1$ for all $j$. $\Delta \phi_{j\nu}$ is the azimuthal angle between the jet $j$ and the $E_T$ direction. (I)

The cuts are separated into 3 sets (I–III) to show the behavior of the signal and background. Set (I) includes the minimal cuts $E_T > 20$ GeV and $n_{jets} \geq 2$. The effect of these cuts are illustrated in Table 1 for 11 signal $(m_{\tilde{t}_1}, m_{\chi_1^0})$ points and the 3 major backgrounds. For clarity, we have broken down the $t\bar{t}$ background into three explicit final states: $b\bar{b}(e^\pm, \mu^\pm)\nu jj$, $b\bar{b}\tau^\pm \nu jj$, and $b\bar{b}e^\pm \nu e^\mp \nu$, where $\ell = e, \mu$, and $\tau$. We find that the major background comes
Table 1: Efficiency of Cuts (I–III) for Signal and Background.

from the dilepton decays, $b\bar{b}e^\pm\nu jj$, where one lepton escapes detection. Note that the signal detection efficiencies $\epsilon_S$ are about the same, $\sim 0.06 - 0.08$ for various choices of $(m_{t_1}, m_{\chi_1^0})$ points. Also in Table 1, we present similar results using a wider pseudorapidity range: $|\eta^{(l)}|, |\eta^{(j)}| < 2.5$. We find that the detection efficiencies for the backgrounds do not change significantly, while the signal efficiencies increase by about 30%.

Given the efficiency for detecting the signal $\epsilon_S$ and the backgrounds $\epsilon_B$, their respective rates are a function of the branching ratio $\text{BR}(t \to c\chi_1^0\chi_1^0) \equiv b_X$. For the models considered, there are no other “new” decay modes of $t$, thus $\text{BR}(t \to bW) = 1 - b_X$. The signal rate is $\sigma_{t\bar{t}} \times 2 \times b_X \times (1 - b_X) \times 2/9 \times \epsilon_S$, where the factor of 2/9 accounts for the $e$ and $\mu$ decay modes of the $W$. The background rate from $t\bar{t}$ is $\sigma_{t\bar{t}} \times (1 - b_X)^2 \times \epsilon_{t\bar{t}}$. The other background
rates are simply a product of the production cross section and their efficiencies. Comparing the data with these predictions, one can then set an upper bound on $b_X$ for any given $(m_{\tilde{t}_1}, m_{\chi_1^0})$, and, therefore, can constrain the predicted allowed models from Ref. [1] if no signal is found.

From the discussion in Sec. 2, we conclude that $b_X < 25\%$ at the 95% C.L. inferred from a global fit to the CDF and DØ data (assuming the entire data sample to be $t \rightarrow bW$ events). Here, we would like to know the minimum $b_X$ that can be directly measured (in contrast to that inferred from fitting) by detecting the $t\bar{t}$ pair events at the Tevatron for a given integrated luminosity ($\mathcal{L}$) of the collider, if we demand a $3-\sigma$ effect. For simplicity (later, we perform a more thorough analysis), let us consider only the major background from the SM decays of $t\bar{t}$ pairs. Define the number of signal $N_S$ and background $N_B$ events:

$$N_S = \mathcal{L} \times \sigma_{t\bar{t}} \times 2 \times b_X \times (1 - b_X) \times 2/9 \times \epsilon_S,$$

$$N_B = \mathcal{L} \times \sigma_{t\bar{t}} \times (1 - b_X)^2 \times \epsilon_{t\bar{t}}. \quad (1)$$

Assuming that Gaussian statistics are applicable, a $3-\sigma$ effect of the signal over background requires

$$\frac{N_S}{\sqrt{N_B}} = \frac{4/9 \times b_X \times \sqrt{\mathcal{L} \cdot \sigma_{t\bar{t}} \cdot \epsilon_S}}{\sqrt{\epsilon_{t\bar{t}}}} \geq 3. \quad (2)$$

Taking $\sigma_{t\bar{t}} = 5.5 \text{ pb}$, $\mathcal{L} = 2 \text{ fb}^{-1}$, $\epsilon_S = 0.1$ and $\epsilon_{t\bar{t}} = 0.01$, the above equation gives $b_X \geq 6\%$. Substituting $b_X$ into Eq. 1, one would expect to observe approximately $N_S = 30$ and $N_B = 100$ events in the $2 \text{ fb}^{-1}$ data sample if $\text{BR}(t \rightarrow c\chi_1^0 \chi_1^0) = .06$. Although the ratio of signal to background is about 1 to 3, the distributions in $m_T$ for the signal and the background events are very different. A few examples of $m_T$ distributions for the signal and background are given in Fig. 1. The distributions shown have passed all cuts I–III except for the $m_T$ cut, and have been normalized to have the same unit area. The $t\bar{t}$ background is denoted by large hatches, $W+\text{jets}$ with small hatches, and three representative signal points $(m_{\tilde{t}_1}, m_{\chi_1^0})$ have clear regions outlined by solid ($(50,30)$ GeV), dot–dashed ($(90,50)$ GeV) and dashed ($(100,60)$ GeV) lines. $m_T$ is larger for a heavier $\chi_1^0$ and, in that case, the background event can be easily distinguished from the signal event.

Since the detection efficiency of the signal is not sensitive to the masses of $\tilde{t}_1$ and $\chi_1^0$, the limit on $b_X$ can either confirm the MSSM predictions by finding a stop squark or exclude

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As shown in Table 1, after the cuts I–III, the backgrounds $Z(\rightarrow \ell^+\ell^-)X$ and $W^\pm(\rightarrow \ell\nu)X$, where $\ell = e, \mu,$ and $\tau$, are 2.1 fb and 7.8 fb, respectively.
Figure 1: Transverse Mass $m_T$ Distribution for Signals and Backgrounds

the corresponding parameters of the model. The branching ratio that can be probed for 200 pb$^{-1}$, 2 fb$^{-1}$, and 10 fb$^{-1}$ is listed in Table 2 including all backgrounds and using Poisson statistics where applicable. To summarize Table 2, the worst $b_X$ reach for the models considered is .45, .10, and .04 for 200 pb$^{-1}$, 2 fb$^{-1}$ and 10 fb$^{-1}$. With the increased pseudorapidity coverage, the reach is extended to .33, .08, and .04 for 200 pb$^{-1}$, 2 fb$^{-1}$ and 10 fb$^{-1}$. The value of $b_X$ reachable in the present data sample is comparable to the indirect limit from the cross section and mass measurements (see Sec. 2)\textsuperscript{6} and clearly consistent with the measurement of the branching ratio from CDF.

4 Discussion and Conclusions

From a global fit to the available data for the top quark mass, production cross section, and SM branching ratio and the predicted top production cross section, we have determined the allowed non–SM branching ratio for top quark decay. This branching ratio is bounded

\textsuperscript{6} The 3–σ bound on $b$ from the global fit discussed in Sec. 2 is .61. Consequently, the bound on $b_X$ is .39.
With Larger $\eta$ Acceptance

| $m_{\tilde{t}_1}$ (GeV) | $m_{\chi_1^0}$ (GeV) | $b_X$ vs. Luminosity | $b_X$ vs. Luminosity With Larger $\eta$ Acceptance |
|------------------------|----------------------|----------------------|---------------------------------------------------|
| 200 pb$^{-1}$ | 2 fb$^{-1}$ | 10 fb$^{-1}$ | 200 pb$^{-1}$ | 2 fb$^{-1}$ | 10 fb$^{-1}$ |
| 50 | 20 | .33 | .08 | .04 | .22 | .06 | .03 | .22 | .06 | .03 |
| 50 | 30 | .35 | .09 | .04 | .22 | .06 | .03 | .22 | .06 | .03 |
| 50 | 40 | .45 | .10 | .04 | .32 | .07 | .03 | .32 | .07 | .03 |
| 60 | 30 | .33 | .08 | .04 | .23 | .06 | .03 | .23 | .06 | .03 |
| 60 | 40 | .33 | .08 | .04 | .26 | .06 | .03 | .26 | .06 | .03 |
| 80 | 40 | .32 | .07 | .03 | .30 | .07 | .03 | .30 | .07 | .03 |
| 80 | 60 | .39 | .09 | .04 | .33 | .08 | .04 | .33 | .08 | .04 |
| 90 | 50 | .31 | .07 | .03 | .22 | .06 | .03 | .22 | .06 | .03 |
| 90 | 70 | .36 | .09 | .04 | .30 | .07 | .03 | .30 | .07 | .03 |
| 100 | 40 | .31 | .07 | .03 | .22 | .06 | .03 | .22 | .06 | .03 |
| 100 | 60 | .31 | .07 | .03 | .22 | .06 | .03 | .22 | .06 | .03 |

Table 2: Limit on Branching Ratio $b_X$ as a Function of Luminosity for the Models Studied.

to be less than about 25% at the 95% C.L. Since this branching ratio is small, we studied the possibility of observing the rare decay of $t \rightarrow \tilde{t}_1 \chi_1^0$ in association with the SM decay $\tilde{t} \rightarrow bW^- \rightarrow b\ell^-\nu$ (and the charge conjugate decays). Additionally, we required $m_{\chi_1^\pm} + m_b, M_W + m_{\chi_1^\pm} + m_b > m_{\tilde{t}_1} > m_{\chi_1^0} + m_c$, so that the dominant stop squark decay mode is $\tilde{t}_1 \rightarrow c\chi_1^0$. For the models studied, we found that the signal detection efficiency is approximately constant and almost independent of the stop or neutralino mass for the mass region considered. If no signal is found, we could exclude models with BR($t \rightarrow \tilde{t}_1 \chi_1^0$) larger than .33, .08 and .04 at the 3–$\sigma$ level for the Tevatron with a luminosity of 200 pb$^{-1}$, 2 fb$^{-1}$ and 10 fb$^{-1}$, respectively. If a signal is found, the signal (background) event yields for the smallest $b_X$ are 8(5), 26(80), and 68(430) for a 200 pb$^{-1}$, 2 fb$^{-1}$ and 10 fb$^{-1}$ data sample.

If, contrary to our assumptions about the lightest chargino, $m_{\chi_1^\pm} + m_b < m_{\tilde{t}_1}$, then the two body decay $\tilde{t}_1 \rightarrow b\chi_1^+$ dominates. For models discussed in Ref. [1], a light chargino would preferentially decay via $\chi_1^\pm \rightarrow f\bar{f} \chi_1^0$. The final state is similar to that from the SM decay, but the $\chi_1^\pm$ decay products are softer and have a lower acceptance. It is therefore better to detect the light chargino directly from chargino pair production than from the top.
quark decay.

In conclusion, we find that the prospect to observe a light stop at the Tevatron is very promising. Unless a stop signal can be found in the current or upcoming data at the Tevatron, it will be difficult to reconcile experiment with low energy Supersymmetry in the case that $t \rightarrow \tilde{t}_1 \chi^0_1 \rightarrow c \chi^0_1 \chi^0_1$ is the dominant non-SM decay mode.

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References

[1] G.L. Kane, R.G. Stuart, and J.D. Wells, Phys. Lett. B354 (1995) 350.

[2] H.E. Haber and G.L. Kane, Phys. Rep. 117 (1985) 75.

[3] H. Baer et al., Phys. Rev. D44 (1991) 725.

[4] D.R. Claes, “The Search for Squarks, Gluinos, and Stop Squarks in DO”, FERMILAB-CONF-95-186-E, August 1995.

[5] F. Abe et al., Phys. Rev. Lett. 73, 225 (1994); S. Abachi et al., Phys. Rev. Lett. 72, 2138 (1994).

[6] The CDF Collaboration and J. Incandela, “CDF Top Quark Production and Mass”, FERMILAB–CONF–95/237–E, July 1995.

[7] E.L. Berger and H. Contopanagos, “Perturbative Gluon Resummation of the Top–Quark Production Cross Section,” ANL–HEP–PR–95–31, July 1995.

[8] D.E. Soper, Notes from the summary talk of the QCD Session of the XXX Rencontre de Moriond Les Arcs, France, March 1995.

[9] H.U. Bengtsson and T. Sjöstrand, Comp. Phys. Comm. 46 (1987) 43.

[10] S. Mrenna, “Simulating Supersymmetry With PYTHIA 5.7 and JETSET 7.4,” CITHE–68–1987, July 1995.