Probing top quark decay into a light top squark in the supersymmetric standard model at the upgraded Fermilab Tevatron

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We investigate the possibility of observing the exotic decay mode of the top quark into the lightest top squark ($\tilde{t}_1$) and neutralino ($\tilde{\chi}_1^0$) in the minimal supersymmetric standard model with R parity at the upgraded Fermilab Tevatron. First we examine the bounds for the branching fraction $B(t\to\tilde{t}_1\tilde{\chi}_1^0)$ from the available experimental data, and then consider all possible backgrounds and investigate the possibility of observing this final state at the Tevatron. We find that this final state is unobservable at run 1. However, run 2 can either discover it, or establish strong limits ($\sim$1%) on the branching fraction of this decay. [S0556-2821(98)06113-X]

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I. INTRODUCTION

Because of its large mass, the top quark has the potential to be a sensitive probe for new physics beyond the standard model (SM). In strongly interacting theories, such as top condensation and extended technicolor, the top quark plays an essential role in electroweak symmetry breaking and in the understanding of flavor physics. In weakly interacting theories, such as supersymmetry (SUSY) [1], the heavy top quark provides a solution to the electroweak symmetry breaking and makes it possible that the top quark may have some new decay modes. Among these new decay modes, the most interesting one is the decay into its lightest superpartner ($\tilde{t}_1$) plus the lightest neutralino ($\tilde{\chi}_1^0$) since both $\tilde{t}_1$ and $\tilde{\chi}_1^0$ can be quite light in the minimal SUSY model (MSSM).

In the MSSM, the lightest neutralino is likely to be the lightest supersymmetric particle (LSP), which is stable and is a candidate for the cold dark matter. The lightest top squark can also be quite light for the following reasons. First, the loop corrections to the top squark mass through Higgsino-quark loops and Higgs-squark loops are always negative, and such a correction is large due to heavy top quark mass [2]. Second, the off-diagonal terms in the squared-mass matrix of sfermion are proportional to the mass of its SM partner, which will lead to large mixing effects between left- and right-handed top squarks and large mass splitting between the two mass eigenstates of the top squark [3]. This will make the lighter top squark possibly the lightest charged SUSY particle. Also, electroweak baryogenesis in SUSY also requires a light top squark to have a strong first order phase transition [4].

If the lightest top squark is the lightest charged SUSY particle, then the top may decay $t\to\tilde{t}_1\tilde{\chi}_1^0$. The dominant decay of $\tilde{t}_1$ is $\tilde{t}_1\to c\tilde{\chi}_1^0$ via one loop processes [5], with a branching fraction of almost 100%.[1] This SUSY decay mode of the top quark will thus give rise to a new final state in $t\bar{t}$ production at the Fermilab Tevatron, namely, $t\bar{t}\to Wbc\tilde{\chi}_1^0\tilde{\chi}_1^0$.

The possibility for detecting the $Wbc\tilde{\chi}_1^0\tilde{\chi}_1^0$ final state in $t\bar{t}$ production was first discussed in Ref. [6] where the focus was mainly on the background $t\bar{t}\to W^-W^+b\bar{b}$. Since the number of top quark pairs will be significantly increased at run 2 of Fermilab, searching for this final state may be an important tool for probing SUSY at Fermilab. Therefore, a careful study of this final state is desirable. In this article, we will present a detailed analysis of this SUSY decay mode, including consideration of all the possible backgrounds, in the framework of the MSSM with the lightest neutralino being the LSP. In particular, we first determine the allowed range for $B(t\to\tilde{t}_1\tilde{\chi}_1^0)$ from the available experimental data, and then show what stronger bounds can be imposed on the branching fraction of this final state if it is not observed at the Tevatron. Given the present limits on SUSY couplings, we find that this final state cannot be seen at run 1, but run 2 can either discover it or provide very strong bounds on the branching fraction.

This paper is organized as follows. In Sec. II we examine the bounds for $B(t\to\tilde{t}_1\tilde{\chi}_1^0)$ from the available experimental data. In Sec. III we examine all possible backgrounds and investigate the possibility of observing $t\bar{t}\to Wbc\tilde{\chi}_1^0\tilde{\chi}_1^0$ at the Fermilab Tevatron. And finally in Sec. IV we present a summary.

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[1]The four-body decay mode $\tilde{t}_1\to b\tilde{\chi}_1^0 f_1\bar{f}_2$ is kinematically suppressed by both $\tilde{\chi}_1^{\pm}-$ and $W^{\pm}-$ propagators and thus its partial width is negligibly small.

II. CURRENT BOUNDS FOR THE BRANCHING FRACTION $B(t\to\tilde{t}_1\tilde{\chi}_1^0)$

A. Bounds from the calculation of the decay width

The Collider Detector at Fermilab (CDF) Collaboration at the Fermilab Tevatron collider reported [7] an $ee\gamma\gamma+\not{E}_T$ event which does not have a standard model interpretation. This event can be explained by selectron pair production ($p\bar{p}\to\tilde{e}^+\tilde{e}^-$) in the MSSM. The region of the relevant parameters of the MSSM consistent with this event has been derived in Ref. [8]. Using this allowed region of the parameter space plus the lower bound of $m_{\tilde{t}_1}$ from the CERN e^+e^- collider LEP, we can derive an upper bound for the branching fraction of $t\to\tilde{t}_1\tilde{\chi}_1^0$.

In the MSSM, the decay $t\to\tilde{t}_1\tilde{\chi}_1^0$ has been calculated to one-loop level [9,10]. Here we neglect the loop corrections, which are only on the order of 10%; the partial width is given by

$$\Gamma(t\to\tilde{t}_1\tilde{\chi}_1^0)=\frac{1}{16\pi M_t^3}\lambda^{1/2}(M_t^2,M_{\tilde{\chi}_1^0}^2,M_{\tilde{t}_1}^2)[(|A|^2+|B|^2)\times(M_t^2+M_{\tilde{\chi}_1^0}^2-M_{\tilde{t}_1}^2)+4\,\mathrm{Re}(A^*B)M_tM_{\tilde{\chi}_1^0}], \tag{1}$$

where $\lambda(x,y,z)=(x-y-z)^2-4yz$, and A and B are given by

$$A=\frac{gm_tN_{14}^*}{2m_W\sin\beta}\cos\theta-\left[\frac{2}{3}eN'^*_{11}-\frac{2}{3}\frac{gS_W^2}{C_W}N'^*_{12}\right]\sin\theta, \tag{2}$$

$$B=\left[\frac{2}{3}eN'_{11}-\frac{2}{3}\frac{gS_W^2}{C_W}N'_{12}+\frac{gN'_{12}}{2C_W}\right]\cos\theta-\frac{gm_tN_{14}}{2m_W\sin\beta}\sin\theta. \tag{3}$$

Here $S_W\equiv\sin\theta_W$, $C_W\equiv\cos\theta_W$, $P_{L,R}\equiv\frac{1}{2}(1\mp\gamma_5)$, and $N'_{11}=N_{11}C_W+N_{12}S_W$ and $N'_{12}=-N_{11}S_W+N_{12}C_W$. N_{ij} are the elements of the 4×4 matrix N which diagonalizes the neutralino mass matrix [1]. θ is the mixing angle between left- and right-handed top squarks which are related to the mass eigenstates $\tilde{t}_i$ by

$$\begin{pmatrix}\tilde{t}_1\\ \tilde{t}_2\end{pmatrix}=\begin{pmatrix}\cos\theta & \sin\theta\\ -\sin\theta & \cos\theta\end{pmatrix}\begin{pmatrix}\tilde{t}_L\\ \tilde{t}_R\end{pmatrix}. \tag{4}$$

The parameters involved in $\Gamma(t\to\tilde{t}_1\tilde{\chi}_1^0)$ are

$$M_{\tilde{t}_1},M_2,M_1,\mu,\tan\beta,\theta, \tag{5}$$

where M_2 and M_1 are gaugino masses corresponding to SU(2) and U(1), μ is the coefficient of the H_1H_2 mixing term in the superpotential, and $\tan\beta=v_2/v_1$ is the ratio of the vacuum expectation values of the two Higgs doublets.

The $ee\gamma\gamma+\not{E}_T$ event can be explained as $\tilde{e}_L$ or $\tilde{e}_R$ pair production in the MSSM with $\tilde{\chi}_1^0$ being the LSP. If the $ee\gamma\gamma+\not{E}_T$ event is due to $\tilde{e}_L$ pair production, the allowed region of the parameter space is given as [8]

$$\begin{gathered}50\leqslant M_1\leqslant 92\text{ GeV},\quad 50\leqslant M_2\leqslant 105\text{ GeV},\\ 0.75\leqslant M_2/M_1\leqslant 1.6,\quad -65\leqslant\mu\leqslant -35\text{ GeV},\\ 0.5\leqslant|\mu|/M_1\leqslant 0.95,\quad 1\leqslant\tan\beta\leqslant 3,\\ 33\leqslant M_{\tilde{\chi}_1^0}\leqslant 55\text{ GeV}.\end{gathered} \tag{6}$$

If the $ee\gamma\gamma+\not{E}_T$ event is due to $\tilde{e}_R$ pair production, the allowed region is [8]

$$\begin{gathered}60\leqslant M_1\leqslant 85\text{ GeV},\quad 40\leqslant M_2\leqslant 85\text{ GeV},\\ 0.6\leqslant M_2/M_1\leqslant 1.15,\quad -60\leqslant\mu\leqslant -35\text{ GeV},\\ 0.5\leqslant|\mu|/M_1\leqslant 0.8,\quad 1\leqslant\tan\beta\leqslant 2.2,\\ 32\leqslant M_{\tilde{\chi}_1^0}\leqslant 50\text{ GeV}.\end{gathered} \tag{7}$$

Note that the decay of $b\to s\gamma$ is also sensitive to SUSY loops and the measurement of $B(b\to s\gamma)$ [11] could also constrain the SUSY parameter space. Detailed analyses have been performed in Ref. [12]. The dominant contributions arise from charged Higgs loops and chargino loops, which are proportional to top quark mass. The charged Higgs loops always adds constructively to the SM prediction. The contribution of chargino loops is proportional to $A_t\mu\tan\beta$ and thus, depending on sgn$(A_t\mu)$, it can have either sign relative to the SM and charged Higgs loop contributions. (Here A_t is the coefficient of the trilinear soft SUSY-breaking term $\tilde{t}_L\tilde{t}_RH_2$.) For small $\tan\beta$, as in Eqs. (6) and (7), the branching ratio of $b\to s\gamma$ is close to the SM result [12]. Therefore, the regions in Eqs. (6) and (7) are also allowed by the measurement of $B(b\to s\gamma)$. For large $\tan\beta$, which is not relevant for our analysis, some regions of SUSY parameter space which are sensitive to sgn$(A_t\mu)$ could be excluded [12].

Let us look at the experimental limits on masses of the lightest neutralino and top squark. In the framework of the MSSM with $\tilde{\chi}_1^0$ being the LSP, $\tilde{\chi}_1^0$ behaves similarly to the neutrino and escapes detection. But the tight relationships among the neutralino and chargino masses allow an indirect limit on $M_{\tilde{\chi}_1^0}$ to be derived. Assuming gaugino mass unification at the GUT scale, the ALEPH Collaboration derived the lower limit on $M_{\tilde{\chi}_1^0}$. For $\tan\beta>1$ and slepton mass heavier than 200 GeV, it is given by [13]

$$M_{\tilde{\chi}_1^0}>25\text{ GeV}. \tag{8}$$

This limit is weaker than the limits imposed by the $ee\gamma\gamma+\not{E}_T$ event.

Under the restriction $M_{\tilde{t}_1}-M_{\tilde{\chi}_1^0}>10$ GeV, the direct search for a top squark from all four experiments at LEP give a lower bound on $M_{\tilde{t}_1}$ [14]:

$$M_{\tilde{t}_1}>75\text{ GeV}(95\%\text{ C.L.}). \tag{9}$$

Under a stronger restriction $M_{\tilde{t}_1}-M_{\tilde{\chi}_1^0}>30$ GeV, the D0 Collaboration at Fermilab searched for the jets$+\not{E}_T$ signal of a top squark and obtained the limit $M_{\tilde{t}_1}>90$ GeV [15].

Taking the lower limit of 75 GeV (or 90 GeV) for the top squark mass, varying the other relevant parameters in the allowed regions in Eqs. (6) or (7), and varying θ from 0 to 2π, we obtain an upper bound on the branching fraction [the bounds yielded from Eqs. (6) and (7) are approximately the same]:

$$B(t\to\tilde{t}_1\tilde{\chi}_1^0)\leqslant\begin{cases}0.54 & \text{for } M_{\tilde{t}_1}>75 \text{ GeV},\\ 0.48 & \text{for } M_{\tilde{t}_1}>90 \text{ GeV}.\end{cases} \qquad (10)$$

Note that in Ref. [16] an upper bound of 80 GeV of the top squark mass was derived from R_b data.[2] However, as pointed out in Ref. [17], this upper bound for the top squark mass is not necessary because only the chargino–top-squark loops are considered in the analyses of Ref. [16]. If the Higgs-loop contribution are taken into account, no explicit bound can be derived for the top squark mass [17]. Further, the value of R_b has been moving closer to the SM prediction [18]. If one takes the more recent values of R_b [19] the R_b problem essentially disappears. Therefore, for both theoretical and experimental reasons we do not regard R_b as being useful in setting an upper bound on the top squark mass.

B. Bounds from the available data at Fermilab

An upper bound for the decay $t\to\tilde{t}_1\tilde{\chi}_1^0\to c\tilde{\chi}_1^0\tilde{\chi}_1^0$ can also be derived from the available data at Fermilab. Currently, the Fermilab top quark pair production counting rate is interpreted as a measurement of $\sigma(t\bar{t})\times B^2(t\to bW)$. Since the final states $t\bar{t}\to Wb\bar{c}\tilde{\chi}_1^0\tilde{\chi}_1^0$ and $t\bar{t}\to c\tilde{\chi}_1^0\tilde{\chi}_1^0\bar{c}\tilde{\chi}_1^0\tilde{\chi}_1^0$ do not have enough leptons or jets to be included in the dileptonic, leptonic, or hadronic event samples, they are not included in the current Fermilab counting experiments. So the quantity $[1-B(t\to\tilde{t}_1\tilde{\chi}_1^0)]^2$, which gives the fraction of events in which both the t and $\bar{t}$ decay normally,[3] should lie within the measured range of $\sigma[t\bar{t}]_{\rm exp}/\sigma[t\bar{t}]_{\rm QCD}$. Note that in our analyses we, for simplicity, neglected the SUSY effects [22,23] in $t\bar{t}$ production and thus the theoretical value of $\sigma[t\bar{t}]$ is given by the SM value $\sigma[t\bar{t}]_{\rm QCD}$. The production cross section measured by CDF with an integrated luminosity of 110 pb^{-1} is $\sigma[t\bar{t}]_{\rm exp}=8.5^{+4.4}_{-3.4}, 6.8^{+2.3}_{-1.8}, 10.7^{+7.6}_{-4.4}$ pb in the dilepton, lepton+jets, and all-hadronic channels, respectively [24]. The SM expectation for top mass of 175 GeV is $\sigma[t\bar{t}]_{\rm QCD}=5.5^{+0.1}_{-0.4}$ pb [25]. By comparing $\sigma[t\bar{t}]_{\rm exp}$ from each channel with $\sigma[t\bar{t}]_{\rm QCD}[1-B(t\to\tilde{t}_1\tilde{\chi}_1^0)]^2$, we find that the 2σ upper bounds on $B(t\to\tilde{t}_1\tilde{\chi}_1^0)$ for the various channels are given by

$$B(t\to\tilde{t}_1\tilde{\chi}_1^0)\leqslant\begin{cases}0.44 & \text{dilepton channel},\\ 0.23 & \text{lepton+jets channel},\\ 0.41 & \text{all-hadronic channel}.\end{cases} \qquad (11)$$

Here the upper bound from lepton+jets channel is comparable to the upper bound of 0.25 [6] obtained by a global fit to the available data.

Note that in our analyses and in Ref. [6], the possible enhancement of $t\bar{t}$ production cross section in the MSSM relative to the SM prediction was neglected. If the possible enhancement of $t\bar{t}$ production cross section from gluino and squark pair productions is taken into account [23], the upper bound for $B(t\to\tilde{t}_1\tilde{\chi}_1^0)$ can be relaxed to 0.5, which is comparable to the bound in Eq. (10).

So the current bounds on the decay $t\to\tilde{t}_1\tilde{\chi}_1^0$ from various analyses are quite weak. We also note that for reasonable values of A and B in Eqs. (2) and (3), the limit on $B(t\to\tilde{t}_1\tilde{\chi}_1^0)$ is easily saturated, even for values of $M_{\tilde{t}_1}$ and $M_{\tilde{\chi}_1^0}$ somewhat close to threshold. Therefore, it is necessary to search for this decay in the future runs of the Tevatron collider.

III. OBSERVING $t\bar{t}\to Wbc\tilde{\chi}_1^0\tilde{\chi}_1^0$ AT THE TEVATRON

Under the assumption that the top quark (or top antiquark) decays via the normal weak interactions to Wb, the top antiquark (top quark) decays to $\tilde{t}_1\tilde{\chi}_1^0$, and the light top squark decays to $c\tilde{\chi}_1^0$, then the final state of interest is $Wbc\tilde{\chi}_1^0\tilde{\chi}_1^0$. Because of the large QCD backgrounds, it is very difficult to search for the signal from the hadronic decays of W at the Tevatron. We therefore look for events with the leptonic decay of the W. Thus, the signature of this process is an energetic charged lepton, one b-quark jet, one light c-quark jet, plus missing E_T from the neutrino and the unobservable $\tilde{\chi}_1^0$'s. We assumed silicon vertex tagging of the b-quark jet with 50% efficiency and the probability of 0.4% for a light quark jet to be misidentified as a b jet. The potential SM backgrounds are (1) $bq(\bar{q})\to tq'(\bar{q}')$, (2) $q\bar{q}'\to W^*\to t\bar{b}$, (3) $Wb\bar{b}$, (4) Wjj, (5) $t\bar{t}\to W^-W^+b\bar{b}$, (6) $gb\to tW$, and (7) $qg\to q't\bar{b}$. The quark-gluon process (7) can occur with a W-boson intermediate state in either the t channel or the s channel. We found backgrounds (6) and (7) to be negligible since they have an extra jet, and can mimic our signal (before b tagging) only if a jet is missed in the detector. The background process (5) can mimic our signal if both W's decay leptonically and one charged lepton is not detected, which we assumed to occur if the lepton pseudorapidity and transverse momentum satisfy $|\eta(l)|>3$ and $p_T(l)<10$ GeV, respectively.

To simulate the detector acceptance, we made a series of

[2] If we use this upper bound on the top squark mass, we obtain a lower bound $B(t\to\tilde{t}_1\tilde{\chi}_1^0)>0.07$.

[3] Here we assume that the only exotic decay mode of top quark in R-parity conserving MSSM is $t\to\tilde{t}_1\tilde{\chi}_1^0$. If charged a Higgs boson is light enough, $t\to H^+b$ is also possible; its phenomenological implications at Tevatron have been studied [20]. The flavor changing neutral current (FCNC) decays $t\to cZ, c\gamma, cg, ch$ are negligibly small in R-parity conserving MSSM [21].

TABLE I. Typical signal and background cross sections in units of fb after various cuts at the Tevatron. The basic cuts are $p_T^{\rm all} \geqslant 20$ GeV, $|\eta_{\rm all}| \leqslant 2.5$, and $\Delta R \geqslant 0.5$, and the transverse mass cut is $m_T \geqslant 90$ GeV. The signal $t\bar{t} \to Wb\bar{c}\tilde{\chi}_1^0\tilde{\chi}_1^0$ results were calculated by assuming $M_{\tilde{t}_1}=100$ GeV and $M_{\tilde{\chi}_1^0}=40$ GeV. We have also everywhere assumed the use of silicon vertex tagging of the b-quark jet with 50% efficiency and the probability of 0.4% for a light quark jet to be misidentified as a b jet. The charge conjugate channels have been included. The numerical results do not include the branching fractions for the top quark and top antiquark decays; the actual cross sections are found by multiplying the given cross sections by the branching fraction factor in the last column, where x stands for $B(t \to \tilde{t}_1\tilde{\chi}_1^0)$.

	Run 1		Run 2		
	basic cuts	basic+m_T cut	basic cuts	basic+m_T cut	BF factor
$t\bar{t} \to Wb\bar{c}\tilde{\chi}_1^0\tilde{\chi}_1^0$	331	172	457	242	$2x(1-x)$
$qb \to q't$	79.5	2.31	116	4.96	$1-x$
$q\bar{q}' \to t\bar{b}$	32.0	1.77	39.0	2.25	$1-x$
$Wb\bar{b}$	113	2.04	132	2.50	1
Wjj	392	2.30	505	2.88	1
$t\bar{t}$	5.69	2.72	7.9	3.82	$(1-x)^2$

basic cuts on the transverse momentum (p_T), the pseudorapidity (η), and the separation in the azimuthal angle-pseudorapidity plane [$\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$] between a jet and a lepton or between two jets. These cuts are chosen to be

$$p_T^l, p_T^{\rm jet}, p_T^{\rm miss} \geqslant 20 \text{ GeV}, \tag{12}$$

$$|\eta_{\rm jet}|, |\eta_l| \leqslant 2.5, \tag{13}$$

$$\Delta R_{jj}, \Delta R_{jl} \geqslant 0.5. \tag{14}$$

Note that in our numerical calculation, the difference between neutralino and top squark masses is larger than 10 GeV. If this mass difference is too small, stronger kinematic cuts should be imposed to simulate the detector acceptance.

Further simulation of detector effects is made by assuming a Gaussian smearing of the energy of the final state particles, given by

$$\Delta E/E = 30\%/\sqrt{E} \oplus 1\%, \text{ for leptons}, \tag{15}$$

$$= 80\%/\sqrt{E} \oplus 5\%, \text{ for hadrons}, \tag{16}$$

where $\oplus$ indicates that the energy dependent and independent terms are added in quadrature and E is in GeV.

In order to substantially reduce the background, we apply a cut on the transverse mass defined by

$$m_T = \sqrt{(P_T^l + P_T^{\rm miss})^2 - (\vec{P}_T^l + \vec{P}_T^{\rm miss})^2}. \tag{17}$$

Without smearing, m_T is always less than M_W (and peaks just below M_W) if the only missing energy comes from a neutrino from W decay, which is the case for most of the background events (single top, Wbb, Wjj). Smearing pushes some of this above M_W. For the signal m_T is spread about equally above and below M_W, due to the extra missing energy of the neutralinos. Therefore we also require

$$m_T > 90 \text{ GeV}. \tag{18}$$

In our numerical evaluation, we assumed $M_t = 175$ GeV, $\sqrt{s} = 1.8$ TeV, and an integrated luminosity of 0.1 fb^{-1} for run 1, and $\sqrt{s} = 2$ TeV and an integrated luminosity of 10 fb^{-1} for run 2.

The comparison of signal and background cross sections after various cuts at run 1 and run 2 are shown in Table I. For convenience the numerical results shown are obtained without including the appropriate branching ratios; the actual cross sections are found by multiplying the given values by the branching fraction factors $x = B(t \to c\tilde{\chi}_1^0\tilde{\chi}_1^0)$ and $1-x = B(t \to bW)$. The products of the appropriate branching fractions in each case are given in the last column of Table I.

Table II shows the signal cross sections versus $M_{\tilde{t}_1}$ and $M_{\tilde{\chi}_1^0}$. The actual cross sections are obtained by multiplying the given cross sections by the branching fraction factor $2x(1-x)$.

At run 1, with the basic+m_T cuts the number of background events is always less than 1, and the number of signal events is always less than 9 even for the maximum value of $x(=0.5)$. Thus the signal is unobservable at run 1 under the minimal discovery criteria $S \geqslant 3\sqrt{B+S}$. The m_T cut hurts the signal, but, as we pointed out above, it reduces the background much more than the signal. Even when the m_T cut is relaxed, this final state is unobservable at run 1.

At run 2 this signal is observable even for quite small values of $B(t \to \tilde{t}_1\tilde{\chi}_1^0)$. In Fig. 1 we show $B(t \to \tilde{t}_1\tilde{\chi}_1^0)$ versus $M_{\tilde{\chi}_1^0}$ for the signal to be observable under the more conservative discovery criteria $S \geqslant 5\sqrt{B}$. The region above each curve is the corresponding observable region. From this figure we can see that run 2 can probe $B(t \to \tilde{t}_1\tilde{\chi}_1^0)$ to a couple of percent, depending on the lightest neutralino and top squark masses. For example, $B(t \to \tilde{t}_1\tilde{\chi}_1^0)$ can be probed down to 1.4% for $M_{\tilde{t}_1} = 100$ GeV and $M_{\tilde{\chi}_1^0} = 50$ GeV. These limits on $B(t \to \tilde{t}_1\tilde{\chi}_1^0)$ are much stronger than the current ones.

TABLE II. Signal $t\bar{t}\rightarrow Wb\bar{c}\tilde{\chi}_1^0\tilde{\chi}_1^0$ cross section in units of fb versus $M_{\tilde{t}_1}$ and $M_{\tilde{\chi}_1^0}$. The actual cross sections are found by multiplying the given cross sections by the branching fraction factor $2x(1-x)$ where x stands for $B(t\rightarrow\tilde{t}_1\tilde{\chi}_1^0)$. The basic cuts and m_T cut are the same as in Table I. The use of silicon vertex tagging of the b-quark jet with 50% efficiency is assumed.

		Run 1		Run 2	
$M_{\tilde{t}_1}$ (GeV)	$M_{\tilde{\chi}_1^0}$ (GeV)	basic cuts	basic+m_T cut	basic cuts	basic+m_T cut
	30	287	152	397	214
	35	273	146	378	206
70	40	253	137	351	194
	45	226	125	314	176
	50	188	106	262	151
	55	133	79	187	113
	30	309	162	427	228
	35	300	158	414	222
80	40	287	153	397	215
	45	270	145	375	206
	50	247	135	343	191
	55	215	120	299	170
	30	327	170	451	239
	35	321	167	442	235
90	40	313	164	432	231
	45	302	160	418	225
	50	288	154	399	217
	55	269	146	372	206
	30	341	176	470	246
	35	336	174	464	244
100	40	331	172	457	242
	45	324	170	448	238
	50	316	166	436	234
	55	305	161	421	227

Note that in Sec. II we discussed the available experimental limit on the masses of the lightest neutralino and top squark as well as the limits on the branching ratio $B(t\rightarrow\tilde{t}_1\tilde{\chi}_1^0)$. Both from the current limits on the lightest neutralino and top squark masses and from the current bounds on the branching ratio $B(t\rightarrow\tilde{t}_1\tilde{\chi}_1^0)$, this decay can still possibly occur and may be detected at run 2. If not observed at run 2, a much stronger limit can be obtained on the branching ratio. Of course, direct searches for SUSY particles through direct production, such as top squark pair production, have been and will be made at LEP and the Tevatron. Future searches will either discover SUSY particles or improve the current lower limits on SUSY particle masses. However, the search for the exotic decay $t\rightarrow\tilde{t}_1\tilde{\chi}_1^0$ at run 2 will also provide useful information on SUSY, and would be complementary to the direct searches.

We should also note a more precise $t\bar{t}$ cross section measured at run 2 will further strengthen the upper bound for $B(t\rightarrow\tilde{t}_1\tilde{\chi}_1^0)$ given in Eq. (11). However, as our results show,

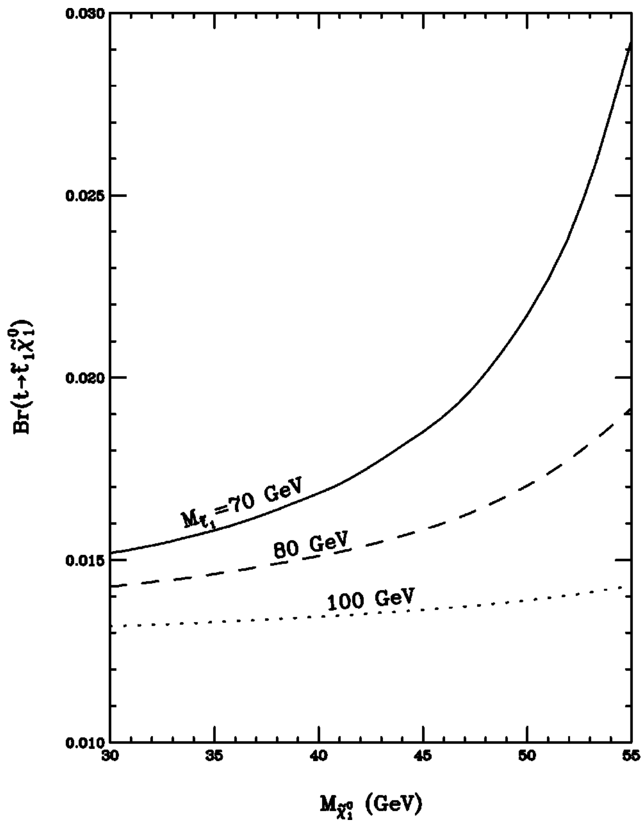

FIG. 1. The value of $B(t\rightarrow\tilde{t}_1\tilde{\chi}_1^0)$ versus $M_{\tilde{\chi}_1^0}$ for the signal to be observable at run 2 under the discovery criterion $S\geqslant 5\sqrt{B}$. The solid, dashed, and dotted curves are for $M_{\tilde{t}_1}=70$, 80, and 100 GeV, respectively. The region above the curve is the observable region.

it is meaningful to search for the decay $t\rightarrow\tilde{t}_1\tilde{\chi}_1^0$ in run 2 since it is observable for quite small values of $B(t\rightarrow\tilde{t}_1\tilde{\chi}_1^0)$.

IV. SUMMARY

In the framework of the MSSM with the lightest neutralino being the LSP, we first determined the upper bounds for the branching fraction $B(t\rightarrow\tilde{t}_1\tilde{\chi}_1^0)$ from the available experimental data. Then we investigated the possibility of observing $t\rightarrow\tilde{t}_1\tilde{\chi}_1^0$ at the Tevatron by searching for the final state $t\bar{t}\rightarrow Wbc\tilde{\chi}_1^0\tilde{\chi}_1^0$. We found that (a) this final state is unobservable at run 1, and (b) run 2 can either discover this new decay mode or place much stronger upper limits (at the level of 1%) on the branching fraction $B(t\rightarrow\tilde{t}_1\tilde{\chi}_1^0)$. In our analysis, we neglected the possibility of the enhancement of the top pair production cross section in the MSSM. In particular, the gluino pair production might be significant [23], and would give rise to a new final state $t\bar{t}\tilde{t}\tilde{t}^*$. This will not affect our conclusion significantly since it will give a final state with more jets than the signal we are considering. With such a mechanism of exotic top pair production, the upper bound on $B(t\rightarrow\tilde{t}_1\tilde{\chi}_1^0)$ can be relaxed up to 50% [23], which will enhance the observability of this new mode at the Tevatron and strengthen our conclusion.

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