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Searching for a stop-pair sample from top counting experiments at hadron colliders

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Abstract

The light stop if produced in hadron colliders in the form of $\tilde{t}_1\bar{\tilde{t}}_1$ pair and decaying through the likely decay chain $\tilde{t}_1 \to \tilde{\chi}^+ b$ followed by $\tilde{\chi}^+ \to \tilde{\chi}^0 f \bar{f}'$, can mimic closely a top quark event when the mass of the stop is close to that of the top quark. Because of the much lower production rate, the stop event can be buried under the top quark event sample. In order to uncover the stop event, specific selection cuts need to be applied. Through Monte Carlo simulation with suitable kinematic cuts, we found that such stop event can be extracted from the top quark sample and detected by the top counting experiments in the upcoming upgraded Tevatron and LHC. However, because of the small statistics of the Run 1 of the Tevatron, the stop signal remains hidden at Run 1.

1 Introduction

Search for SUSY particles is one of the primary tasks of the upgraded Fermilab Tevatron and the upcoming CERN Large Hadron Collider (LHC). Because of the unknown masses of the sparticles and other free parameters, various possibilities and strategies have to be considered in the search. Among the plethora of sparticles, superpartners of the top quark, i.e., the stops, especially the lighter of the two mass eigenstates, denoted as $\tilde{t}_1$, is of particular interest. This is because that this stop has color interactions and is likely to be the lightest sfermion. Therefore, it could be produced in the gluon-rich environment of high energy hadron colliders. The lightness of the stop is usually argued for the following reasons. Firstly, the large top quark Yukawa coupling can lead to a large negative one-loop contribution to the stop masses. Hence, the stops could be significantly lighter than other sfermions at the electroweak scale due to the renormalization group evolution, even if all sfermions have an universal mass at the unification scale. Secondly, since the mixing between the sfermions corresponding to the left- and right-handed states of a given fermion is proportional to the mass of the fermion, the large top quark mass can lead to a large mixing of the two stops. This in turn causes a sizable mass splitting between the two mass eigenstates to make the lighter one, i.e., $\tilde{t}_1$, even lighter so as to be accessible to the current and future hadron colliders. Thirdly, the existence of a light stop is preferred by electroweak baryogenesis [1]. Finally, on the theoretical ground, the scenario that the first two-generation sfermions are as heavy as 10 TeV while the third generation sfermions are significantly lighter conforms with the naturalness principle [2].

In the framework of minimal supersymmetric model (MSSM) with R-parity conservation, several possibilities of light stop searches from top quark decay have been considered in specific scenarios in the literature. We recapitulate them briefly below.

If the stop is the next-to-the-lightest super particle (NLSP), its only two-body decay mode is $\tilde{t}_1 \to c\tilde{\chi}_1^0$ via loops [3], where the lightest neutralino, $\tilde{\chi}_1^0$, is assumed to be the lightest sparticle (LSP). In the case that the stop is sufficiently light, one can consider the exotic top decay $t \to \tilde{t}_1\tilde{\chi}_1^0$ followed by $\tilde{t}_1 \to c\tilde{\chi}_1^0$. Studies showed that this decay chain in the $t\bar{t}$ pair events, if realized, can be observable in a large part of the SUSY parameter space at the future runs of the Tevatron collider [4].

Another possible decay mode of the stop in the case of R-parity conservation, if the stop is light but heavier than the NLSP, is $\tilde{t}_1 \to b\tilde{\chi}_1^+$ through the tree-level coupling, where $\tilde{\chi}_1^+$ denotes the lightest chargino. This decay mode will be the dominant decay channel of $\tilde{t}_1$ whenever it is allowed kinematically. The phenomenology of the $t\bar{t}$ production followed by the decay chain $t \to \tilde{t}_1\tilde{\chi}_1^0$ and $\tilde{t}_1 \to b\tilde{\chi}_1^+$ has been studied soon after the observation of the top quark [5]. But now the significant higher values of the lower bounds of the masses of $\tilde{t}_1$ and $\tilde{\chi}_1^0$, which are given by about 122 GeV [6] and 45 GeV [7] respectively, albeit under certain assumptions, make these top decay chains discussed above less likely.

From the above discussion we see that the discovery of the light stop through the top quark decay is not a promising possibility. However, the light stop offers a more direct route for its discovery at the Tevatron and LHC, i.e., the direct production of the stop pair, assuming the production cross section is sufficiently large and there exits a suitable decay channel for its identification. We note that since the stop pair production is a QCD process, the only uncertainty in the production cross section is the mass of the stop and how it decays.

If the stop is the NLSP and thus its only two-body decay mode is $\tilde{t}_1 \to c\tilde{\chi}_1^0$, then the signal of the stop pair production at hadron colliders can only be two jets plus missing energy [8]. The large QCD background renders the signal impossible to uncover. In this article, we examine, in the MSSM with R-parity conservation, the case of a stop with a mass close to that of the top quark and is heavier than the lightest chargino so that it decays dominantly through $\tilde{t}_1 \to b\tilde{\chi}_1^+$, followed by $\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 f\bar{f}'$ via a real or virtual W-boson intermediate state, where $\tilde{\chi}_1^+$ is the lightest chargino and $\tilde{\chi}_1^0$ the LSP. Then a stop pair event will look like a top quark pair event and can be easily masked by the latter [9]. Through a detailed Monte Carlo simulation, the possibility of uncovering the possible stop pair events from the top quark counting experiment at the Tevatron and LHC colliders is investigated in detail. As also being demonstrated below, for a stop as light as the top quark, the stop sample will generally be buried in the top sample at Run 1 because of the small statistics. But at the future runs of the upgraded Tevatron and at the LHC, such a stop sample can be revealed through a series of suitable selection cuts.

2 Stop pair production and signatures

Similar to the top quark pair production, in hadron collisions the stop pair can be produced in the $q\bar{q}$ annihilation and gluon-gluon fusion due to the $g\tilde{t}_1\bar{\tilde{t}}_1$ coupling. The lowest-order matrix elements will be used in our Monte Carlo simulation. The absolute values squared of the two processes are given by

$$|\mathcal{M}|^2(q\bar{q} \to \tilde{t}_1\bar{\tilde{t}}_1) = 16 g_s^4 \frac{\hat{t}_1\hat{u}_1 - m_{\tilde{t}_1}^2 \hat{s}}{\hat{s}^2}, \tag{1}$$

$$|\mathcal{M}|^2(gg \to \tilde{t}_1\bar{\tilde{t}}_1) = 2 g_s^4 \left[24\left(1 - 2\frac{\hat{t}_1\hat{u}_1}{\hat{s}^2}\right) - \frac{8}{3}\right]\left[1 - 2\frac{m_{\tilde{t}_1}^2 \hat{s}}{\hat{t}_1\hat{u}_1}\left(1 - \frac{m_{\tilde{t}_1}^2 \hat{s}}{\hat{t}_1\hat{u}_1}\right)\right], \tag{2}$$

where $\hat{s}$ is the center-of-mass energy squared of the parton process, $\hat{t}_1 = \hat{t} - m_{\tilde{t}_1}^2$ and $\hat{u}_1 = \hat{u} - m_{\tilde{t}_1}^2$ with $\hat{t}$ and $\hat{u}$ being Mandelstam variables. For parton distribution functions, we use CTEQ5L with $\mu = \sqrt{\hat{s}}$ [10]. For a stop with a mass close to the top quark, the QCD corrections enhance the total cross section of stop pair by a factor of ~ 1.2 at the Tevatron and ~ 1.4 at the LHC energies [11]. These enhancements are taken into account in our calculation.

Although the QCD coupling in stop production processes is as strong as the top quark production, the production rate of stop pair at a given energy is much smaller than the top pair for similar masses. The suppression of the stop pair production is caused largely by the fact that they are spin-0 particles: (1) There is no sum over the spin projects of the final states that can enhance the production rate by several fold. (2) The P-wave coupling in the $q\bar{q}$ annihilation process give rise to a β^3-dependence [11] that caused the cross section to be suppressed strongly near the threshold. While the suppression factors work at all collider energies, the stop production at the Tevatron is suppressed more severely because the dominant production of stop at the Tevatron is through the $q\bar{q}$ annihilation.

As stated in the Introduction, we focus on the possibility of the $\tilde{t}_1$ decay chain $\tilde{t}_1 \to b\tilde{\chi}_1^+$ and $\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 f\bar{f}'$. We assume a SUSY spectrum in which all the sparticles involved in the decay chain are on-shell. We will specify the relevant mass values of the sparticles below. As pointed out early, the two-body decay channel $\tilde{t}_1 \to b\tilde{\chi}_1^+$ will be dominant if the final state particles are on shell. Thus in our calculation we approximate the branching ratio of this mode as 100%. For the subsequent 3-body decay of the chargino, we use its full matrix element in our Monte Carlo simulation and take the total width of chargino to be the sum of these 3-body decay channels of all allowed $f\bar{f}'$. We also assume that the charged Higgs boson, sleptons and squarks are much heavier than the W-boson so that these three-body decays proceed dominantly through the W-boson intermediate state [3].

So the stop pair $\tilde{t}_1\bar{\tilde{t}}_1$ production followed by the decay chain $\tilde{t}_1 \to b\tilde{\chi}_1^+ \to b\tilde{\chi}^0 f\bar{f}'$ gives rise to top-like signatures except for two extra neutralinos which escape detection. There are three possible observing channels for the stop-pair event: dilepton+2-jet, single lepton+4-jet and all(six)-jet. All three channels are associated with a significant amount of missing energies. The all-jet channel has the largest rate but will subject to a very large QCD background, and thus is not suitable for isolating the stop signal. The dilepton channel has the lowest rate and, furthermore, it is difficult to find a mechanism to enhance the stop/top rate to find the "smoking gun" of the stop pair production. So we will not use it, either. In the remaining single lepton+4-jet channel, the best signal is $\ell + 4j/b + \not{E}_T$ for the purpose of distinguishing the stop event from a top pair event. Here $4j/b$ represents a 4-jet event with at least one of the jets passing the b-tagging criterion. As is shown below, we can find very effective selection cuts to enhance the stop/top ratio for this signal.

3 Relevant SUSY parameters

There are several SUSY parameters involved in our calculation. First of all, the stop mass is the most important parameter. We will fix it in the range of 170 GeV in most of our numerical examples. But we will vary it to find out how heavy it can be for the stop signal to be observable. For the neutralino and chargino masses, as well as their couplings, there are four independent parameters: M, M', μ and $\tan\beta$. M is the $SU(2)$ gaugino mass and M' the hypercharge $U(1)$ gaugino mass, μ the coefficient of the Higgs mixing term in the superpotential, $\mu H_1 H_2$, and $\tan\beta = v_2/v_1$ the ratio of the vacuum expectation values of the two Higgs doublets. We work in the framework of the MSSM and assume the grand unification of the gaugino masses, which gives the relation $M' = \frac{5}{3} M \tan^2\theta_W \simeq 0.5M$. This reduces the independent parameters needed to three: M, μ and $\tan\beta$. For the three independent parameters, the chargino-neutralino sector can be divided into two regions, the gaugino-like region ($M < |\mu|$) and the higgsino-like region ($M > |\mu|$).

The gaugino-like region is favorable for the discovery of the stop signal. In this region the lightest neutralino $\tilde{\chi}_1^0$ is mainly composed of the hypercharge $U(1)$ gaugino (bino), and the lightest chargino $\tilde{\chi}_1^+$ is mainly composed of the charged $SU(2)$ gaugino (wino). So the $\tilde{\chi}_1^0$ mass is about half of that of the $\tilde{\chi}_1^+$. The large mass splitting between $\tilde{\chi}_1^0$ and $\tilde{\chi}_1^+$ is needed to produce the required energetic jets or lepton in the decay $\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 f \bar{f}'$, so that they can pass the necessary kinematic cuts.

On the contrary, the higgsino-like region is unfavorable for the stop signal. In this case, both the lightest neutralino $\tilde{\chi}_1^0$ and the lightest chargino $\tilde{\chi}_1^+$ are mainly composed of the higgsino fields. As a result, $\tilde{\chi}_1^0$ is almost degenerate with (but lighter than) $\tilde{\chi}_1^+$. Then the lepton or jets produced in the decay $\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 f \bar{f}'$ will be too soft to pass our selection cuts. So in this case the stop signal will be significantly reduced and likely hidden under the top events even stop pairs are produced.

In our calculation we choose the following representative set of values for the parameters in the gaugino-like region

$$M = 100 \text{ GeV}, \mu = -200 \text{ GeV}, \tan\beta = 1. \tag{3}$$

The chargino and neutralino masses in units of GeV are then given by

$$\begin{aligned} &m_{\tilde{\chi}_1^+} = 120,\ m_{\tilde{\chi}_2^+} = 220, \\ &m_{\tilde{\chi}_1^0} = 55,\ m_{\tilde{\chi}_2^0} = 122,\ m_{\tilde{\chi}_3^0} = 200,\ m_{\tilde{\chi}_4^0} = 227. \end{aligned} \tag{4}$$

As expected, $m_{\tilde{\chi}_1^0}$ is about half of $m_{\tilde{\chi}_1^+}$.

It should be remarked that SUSY parameters are generally not well-constrained experimentally at the present time. The only robust constraints are the LEP and Tevatron lower bounds on some of the sparticle masses [12]. In addition, the intermediate value of $\tan\beta$ is favored by low energy experiments [13]. Therefore, the above SUSY parameter values used in our calculation are not the only choice. They are a set of representative values which are allowed by the current experimental bounds and often applied for simulation.

4 Selection of $\ell + 4j/b + \not{E}_T$ events

In making the analyses, we simulate the energy resolution of the detector by assuming a Gaussian smearing of the energy of the final state particles,

$$\begin{aligned}\Delta E/E &= 30\%/\sqrt{E} \oplus 1\%, \text{ for leptons }, &(5)\\ &= 80\%/\sqrt{E} \oplus 5\%, \text{ for hadrons }, &(6)\end{aligned}$$

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

The basic selection cuts are chosen as follows. For the Tevatron, the cuts are

$$\begin{aligned} p_T^\ell &\geq 20 \text{ GeV },\\ p_T^{\rm miss} &\geq 20 \text{ GeV },\\ p_T^{jet} &\geq 15 \text{ GeV },\\ \eta_{jet},\ \eta_\ell &\leq 2.0 ,\\ \Delta R_{jj},\ \Delta R_{j\ell} &\geq 0.5 . \end{aligned} \tag{7}$$

For the LHC, the cuts are chosen to be

$$\begin{aligned} p_T^\ell &\geq 20 \text{ GeV },\\ p_T^{\rm miss} &\geq 30 \text{ GeV },\\ p_T^{jet} &\geq 20 \text{ GeV },\\ \eta_{jet},\ \eta_\ell &\leq 3.0 ,\\ \Delta R_{jj},\ \Delta R_{j\ell} &\geq 0.4 . \end{aligned} \tag{8}$$

Here p_T denotes the transverse momentum, η is the pseudo-rapidity, and ΔR is the separation in the azimuthal angle-pseudo rapidity plane ($\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$) between a jet and a lepton or between two jets.

For the signal, we require to tag at least one b in $\ell + 4j/b + \not{E}_T$. The tagging efficiency is 53% at Run 1 and expected to reach 85% at Run 2 and Run 3 [14]. For the LHC we assume the tagging efficiency to be the same as the Tevatron Run 2. Under the above basic selection cuts and b-tagging, the ratio of the top events $\ell + 4j/b + \not{E}_T$ to the QCD backgrounds is about 12:1 [14], which we will use to evaluate the QCD backgrounds.

We noticed that for the top events and W+jets background events the missing energy comes only from the neutrino of the W decay, while for the stop events the missing energy contains two extra neutralinos. From the transverse momentum of the lepton, $\vec{P}_T^\ell$, and the missing transverse momentum, $\vec{P}_T^{\rm miss}$, we construct the transverse mass

$$m_T(\ell, p_T^{\rm miss}) = \sqrt{(|\vec{P}_T^\ell| + |\vec{P}_T^{\rm miss}|)^2 - (\vec{P}_T^\ell + \vec{P}_T^{\rm miss})^2}. \tag{9}$$

As is well-known, if P_T^ℓ and $p_T^{\rm miss}$ are from the decay products of a parent particle, the transverse mass is bound by the mass of the parent particle. For the top quark and W+jets background events, where the only missing energy is from the neutrino of the W decay, $m_T(\ell, p_T^{\rm miss})$ is always less than M_W and peaks just below M_W, although kinematic smearings can push the bound and the peak above M_W. For the stop events, there is no such peak due to the extra missing energies of the neutralinos. The transverse mass distributions of the stop and top quark events are shown in Fig.1. The transverse mass distribution of the top quark events indeed conforms with the expectation, i.e., it peaks just below 80 GeV and significant distribution appears above 80 GeV due to the smearing. In order to substantially enhance the ratio stop/top, Fig. 1 suggests that we apply the following cut,

$$m_T(\ell, p_T^{\rm miss}) \notin 50 \sim 100 {\rm GeV}. \tag{10}$$

To further enhance the stop/top ratio, we construct four different invariant masses, denoted as $M(3j)$ by using three jets out of the four jets in the event. We define the one which is closest to 175 GeV as the reconstructed top quark and denote its value as $M_{\rm top}(3j)$. The $M_{\rm top}(3j)$ distribution at the upgraded Tevatron energy is shown in Fig.2. As expected, for the top quark events, there is a peak at the top quark mass, M_t = 175 GeV. To enhance the stop/top ratio further, we suppress the top quark events by selecting $M_{\rm top}(3j)$ to be 20 GeV away from the top quark mass (175 GeV), i.e.,

$$|M_{\rm top}(3j) - M_t| \ \ \geq \ \ 20 \ {\rm GeV}. \tag{11}$$

5 Numerical results

For the parameter values specified in Sec. 3, the $\ell + 4j/b + \not{E}_T$ cross section from the stop and top quark events at the Tevatron and LHC, under various cuts, are presented in Table 1. The basic selection cuts Eqs. (7) and (8), which are necessary to reduce the QCD background, affect the stop cross section more than that of the top quark and therefore lower the stop/top ratios. This is because the lepton and jets from the stop events are relatively softer and thus harder to pass the selection cuts, resulting in the stop/top ratios below 5%. This makes the discovery of a stop impossible if the systematic uncertainty is considered. However, the cut of the reconstructed top quark mass suppresses the top quark and stop cross sections respectively by factors of about 12 and 1.6, drastically enhancing the stop/top ratio. The transverse mass cut can further increase the stop/top ratio by suppressing the top cross section by a factor of about 3.3 and that of the stop by 1.9.

In extracting the new physics signal from the top quark events, various uncertainties have to be taken into account besides the experimental statistical and systematic errors. The present uncertainty of the standard model $t\bar{t}$ cross section is at the 5%

level [15]. Additional uncertainties that come from the error in m_t will be much reduced with the expected more precise determination of m_t (within 2.8 and 0.8 GeV as quoted for Run 2 and 3 [14]). For illustration we use the total systematic error of 5%. Combined with the statistical error for each run, we obtain the total errors for the top quark events as listed in Table 2. In estimating the statistical errors, the QCD backgrounds which are mainly W+jets have also been taken into account. Under the basic selection cuts they are reduced to about 1/12 of the top events in the channel of $\ell+4j/b+\not{E}_T$ [14]. The cut on the reconstructed top mass $M_{\rm top}(3j)$ cannot suppress the QCD backgrounds significantly and, therefore, to be conservative, we neglect such suppressions. However, the transverse mass cut is expected to suppress the QCD W+jets backgrounds significantly because the missing energy is only from the neutrino of the W decay just like in a top event. So we assumed the transverse mass cut suppress the QCD backgrounds by a factor of about 3 as in the top quark case.

As indicated in Tables 1 and 2, although the stop/top ratio is enhanced significantly by the suitable cuts, Run 1 of the Tevatron is unable to observe the stop events because of the small statistics. So even for the favorable case (gaugino-like region) under consideration, the stop pair events will still be hidden in the top pair samples.

For Run 2A with a luminosity of 2 fb^{-1}, the statistical error is still large. As showed in Table 2, after combined with the 5% systematic error, the total error is 6%, 14% and 24% under three different selection cuts. Comparing with the stop/top ratio in Table 1, which is 4%, 30% and 49% under the corresponding cuts, we see that the $M_{\rm top}(3j)$ and $m_T(\ell, p_T^{\rm miss})$ cuts drive the sensitivity to the 2σ level. This is still below the discovery limit which is usually required to be a 5σ deviation or more.

For Run 2B (15 fb^{-1}) and Run 3 (30 fb^{-1}), the statistical errors are significantly reduced, as shown in Table 2. For example, comparing the total errors (5%, 6%, 8% under the three selection cuts) at Run 3 with the stop contributions (4%, 30%, 49% under the three corresponding cuts), we conclude that the stop event under the $M_{\rm top}(3j)$ and $m_T(\ell, p_T^{\rm miss})$ cuts is observable ($\geq 5\sigma$).

For LHC, because of the large production rates, even for the low luminosity run (say 10 fb^{-1}), the statistical error is reduced to be negligible. So the total error under each selection cut is dominated by the systematical error which is assumed to be 5%. Comparing with the stop contributions (5%, 40%, 62% under the three selection cuts), one sees that the stop sample after the $M_{\rm top}(3j)$ and $m_T(\ell, p_T^{\rm miss})$ cuts will undoubtedly be observable.

In the above results of stop events we fixed stop mass to be 170 GeV. In Figs.3 and 4 we present the stop/top ratio versus stop mass under the basic plus $m_T(\ell, p_T^{\rm miss})$ plus $M_{\rm top}(3j)$ cuts. The horizontal dotted lines are the limits required by the discovery (5σ), evidence (3σ) and (if not observed) exclusion (2σ) of the production of stop pairs. We see that the LHC (10 fb^{-1}) is able to discover a $135 \sim 215$ GeV stop, while Run 2B (15 fb^{-1}) of the Tevatron can discover a $135 \sim 175$ GeV stop. If not discovered, a stop lighter than 245 (200) GeV will be excluded by LHC (Run 2B of the Tevatron) at 95% C.L.. Of course, such results are valid only for the gaugino-like scenario with the specific parameter values we considered as given in Sec. 3

The peaks in Figs. 3 and 4 are the artifact of the cuts applied and can be understood as follows. As the stop mass decreases, the stop pair production rate increases. However, the b-jet from $\tilde{t}_1 \to \tilde{\chi}_1^+ b$ becomes softer and thus harder to pass the selection cuts so as to decrease the ratio stop/top. At low values of stop mass, this latter effect is stronger and thus the net effect is to decrease the ratio stop/top for decreasing stop mass. At the high end of the stop mass, the phase space suppression of the production rate leads to decreasing stop/top for increasing stop mass. The balance of these opposite effects give rise to the peaks. The peak will shift to higher value for higher parton center of mass energy as shown in Figs. 3 and 4.

6 Summary and discussion

We have investigated the potential of the detection of the top-like events of light stop pair at hadron colliders for the case that the mass of the lighter stop is close to that of the top quark, and the SUSY parameters lie in a range which allows the extraction of the stop signal. Because of the much lower production rate relative to the top quark pair production, the extraction of the stop event from the top sample requires special consideration to enhance the ratio stop/top. Through Monte Carlo simulation with suitable cuts, we found that a stop signal in the channel $\ell + 4j/b + \not{E}_T$ may be detectable in the top counting experiment in the upgraded Tevatron and LHC. However, because of the small statistics, Run 1 of the Tevatron is unable to detect such a stop presence, leaving the stop event hidden in the top pair sample even if it is produced.

We note that our calculation represents the results of a limited set of numerical examples rather than the scanning of the whole SUSY parameter space allowed. Our results are dependent on the mass values of the sparticles involved: the stop $\tilde{t}_1$, chargino $\tilde{\chi}_1^+$ and the neutralino $\tilde{\chi}_1^0$. To validate our analysis, the stop mass must be larger than those of the lightest chargino and neutralino, and their mass spectrum has to be gaugino like. Finally, as already stated in Sec. 3, we also note that if the lightest neutralino and chargino are higgsino-like and thus their masses are close, the leptons and jets in the final states would be too soft to pass our proposed isolation cuts. Then, the stop signal would not be observable. They will remain hidden in the top pair sample even if the stops are produced at the upgraded Tevatron and LHC.

It should be pointed out that throughout our analysis we worked in the MSSM with R-parity conservation. If R-parity is violated, there are also some interesting phenomenologies in the top-stop sector at the Tevatron and LHC energies, some of which have been explored elsewhere [16].

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Table 1: Cross sections for $\ell + 4j/b + \not{E}_T$, from stop and top quark pairs at the Tevatron and LHC. The basic cuts are given in Eqs.(7) and (8). The $M_{\rm top}(3j)$ and $m_T(\ell, p_T^{\rm miss})$ cuts are given by $|M_{\rm top}(3j) - M_t| > 20$ GeV and $m_T(\ell, p_T^{\rm miss}) \notin 50 - 100$ GeV. The stop events were calculated by assuming $M_{\tilde{t}_1} = 170$ GeV, $M = 100$ GeV, $\mu = -200$ GeV and $\tan\beta = 1$. Tagging at least one b-jet is assumed for 53% efficiency for the Tevatron (1.8 TeV), 85% efficiency for the upgraded Tevatron (2 TeV) and LHC. The 'No cut' column gives the result under the condition of b-tagging in the absence of any kinematic cuts. The charge conjugate channels are included.

		no cut	basic cuts	basic cuts + $M_{\rm top}(3j)$ cut	basic cuts + $M_{\rm top}(3j)$ cut + $m_T(\ell, p_T^{\rm miss})$ cut
Tevatron (1.8 TeV)	stop (fb)	59	12	7.4	3.9
	top (fb)	750	317	26.0	8.0
	stop/top (%)	7.9	3.8	28.5	48.8
Tevatron (2 TeV)	stop (fb)	136	27	17	8.8
	top (fb)	1652	690	57	18
	stop/top (%)	8.2	3.9	30.0	48.9
LHC (14 TeV)	stop (pb)	26	2.92	1.94	0.90
	top (pb)	170	60.8	4.86	1.46
	stop/top (%)	15.3	4.8	40.0	62.0

Table 2: Numbers of expected top quark events in the channel $\ell + 4j/b + \not{E}_T$, together with the associated errors. The estimated total error is obtained by combing the statistical errors and a 5% systematic uncertainty.

		basic cuts	basic cuts + $M_{\rm top}(3j)$ cut	basic cuts + $M_{\rm top}(3j)$ cut + $m_T(\ell, p_T^{\rm miss})$ cut
Run 1 (0.1 fb^{-1})	top events	32	3	1
	Stat. error (%)	18.5	81.6	141.4
	Total error (%)	19.2	81.8	141.5
Run 2A (2 fb^{-1})	top events	1380	114	36
	Stat. error (%)	2.8	13.3	23.6
	Total error (%)	5.7	14.2	24.1
Run 2B (15 fb^{-1})	top events	10350	855	270
	Stat. error (%)	1.0	4.8	8.6
	Total error (%)	5.1	7.0	10.0
Run 3 (30 fb^{-1})	top events	20700	1710	540
	Stat. error (%)	0.7	3.4	6.1
	Total error (%)	5.1	6.1	7.9
LHC (10 fb^{-1})	top events	6.1×10^5	4.9×10^4	1.5×10^4
	Stat. error (%)	0.1	0.6	1.2
	Total error (%)	5.0	5.0	5.1

Figure 1: The transverse mass, $m_T(\ell, p_T^{\rm miss})$, distribution of $\ell + 4j/b + \not{E}_T$ at the Tevatron collider. The solid curve is for the stop event with stop mass of 170 GeV. The dotted curve is for the top quark event scaled down by a factor of 0.1.

Figure 2: The reconstructed top quark mass, $M_{\mathrm{top}}(3j)$, distribution of $\ell + 4j/b + \not{E}_T$ at the Tevatron collider. The solid curve is for the stop events with stop mass of 170 GeV. The dotted curve is for the top quark event scaled down by a factor of 0.1.

Figure 3: The solid curve is the ratio of the stop to top quark event numbers versus the stop mass under the basic+$m_T(\ell, p_T^{\rm miss})$+$M_{\rm top}(3j)$ cuts for the upgraded Tevatron (2 TeV). The three horizontal dotted lines are the discovery, evidence and exclusion limits at Run 2B (15 fb^{-1}).

Figure 4: The same as Fig. 3, but for the LHC with a luminosity of 10 fb^{-1}.