HOW TO SEARCH FOR A LIGHT STOP AT THE TEVATRON

GREGORY MAHLON
Department of Physics, University of Michigan, 500 E. University Ave., Ann Arbor, MI 48109, USA

We describe a method for searching for a light stop squark ($\tilde{t}_1 + \tilde{\chi}_1^0 < M_t$) at the Fermilab Tevatron. Traditional searches rely upon stringent background-reducing cuts which, unfortunately, leave very few signal events given the present data set. To avoid this difficulty, we suggest using a milder set of cuts, combined with a “superweight,” whose purpose is to discriminate between signal and background. The superweight consists of a sum of terms (each of which are either zero or one) assigned event-by-event depending upon the values of various observables. By construction, the superweight “large” for the signal and “small” for the background. We apply this method to the detection of stops coming from top decay. It is straightforward to adapt our method to other processes.

Motivated by recent suggestive experimental results, we consider the detection potential of a light stop squark at the Fermilab Tevatron, using the current data set. We focus on SUSY models where the decay $t \rightarrow \tilde{t}_1 \tilde{\chi}_1^0$ is kinematically allowed. Furthermore, we assume that the lightest chargino state, $\tilde{\chi}_1^\pm$ is heavy enough to forbid the decay $\tilde{t} \rightarrow \tilde{\chi}_1^0 b$. In this case, the stop decays via $\tilde{t} \rightarrow \tilde{\chi}_1^0 c$ with 100% branching fraction. Thus, the free parameters entering into our discussion are $\tilde{M}_t$, $\tilde{M}_{\chi_1}$, and $B(t \rightarrow \tilde{\chi}_1^0)$.

For the purposes of this discussion, we ignore the additional complications which arise within the framework of a complete SUSY model ($e.g.$ top decays to $\chi_2^0$ or $\chi_3^0$, and additional top production in the cascade decays of squarks and gluinos). Instead, we focus upon the basic signal for the presence of stops in top quark decay

$$p\bar{p} \rightarrow t\bar{t}; \quad t \rightarrow \tilde{t}_1 \tilde{\chi}_1^0 \rightarrow c\tilde{\chi}_1^0 c\tilde{\chi}_1^0$$

$$\tilde{t} \rightarrow bW^- \rightarrow b\ell^- \bar{\nu}_\ell,$$

(1)

(plus the charge-conjugated state), which appears in the detector as a charged lepton, two jets, and missing transverse energy. The net effect of including the complications mentioned above is the appearance of additional soft jets in the final state, and, (with the right cuts) a somewhat larger signal.

An important feature of this process is that for the stop and LSP masses under investigation, the $b$ becomes the jet with the largest transverse energy over 70% of the time. This is a consequence of the larger phase space for the decay of top to $Wb$ versus its decay to $\tilde{t}_1 \tilde{\chi}_1^0$. Thus, the properties of the leading jet are very similar to the properties of the $b$ jet.
Assuming tree-level SM production with a $K$-factor of unity and a branching ratio of 50% for top to stop, we estimate that the cross section times all branching ratios for \ref{Eq.1} is about 0.6 pb. This is to be compared to the largest SM background, the production of a $W$ plus two jets, which for some set of loose cuts contributes about 770 pb. Our goal in introducing the superweight method is to effectively deal with this large background without cutting away all of the signal.

We begin by requiring each event to pass the series of cuts designed to reduce the SM backgrounds to a manageable level (see Table 1). We then define the superweight $\mathcal{X}$ on an event-by-event basis as the number of criteria in Table 2 which are true, that is, $\mathcal{X} \equiv \sum_{i=1}^{N} C_i$, where each of the $C_i$’s evaluate to 0 or 1. The $C_i$ have been chosen such that events coming from the signal (Eq. 1) tend to have a large value of $\mathcal{X}$, while background events tend to have a small value of $\mathcal{X}$.

There are two issues in the selection of the criteria in Table 2: choice of the observable, and choice of the cut point. The physics of the signal and backgrounds should be used as a guide in deciding which quantities should be investigated as potential superweight elements. For example, $C_9$ was inspired by the observation that since the leading jet is usually the $\bar{b}$ jet, it should combine with the observed lepton to form a $\bar{t}$ quark. Hence, there should be an upper limit on the transverse mass of the leading jet and the lepton. We determine the placement of the cut point as follows. First, observe that the mean contribution of a given $C_i$ to the superweight for some class of events is precisely the fraction of events for which that criterion is true. Put differently, $\langle C_i \rangle$ is the area under a plot of $(1/\sigma) d\sigma/dQ$ lying above $Q_0$ for an observable $Q$ and cut point $Q_0$. Thus, to select the cut point, we compare the values of this area for the signal and background distributions as a function of $Q_0$, choosing the point where the difference is the greatest. For a superweight criterion to

Table 1: Cuts applied before evaluating the superweight.

| Condition                       |
|--------------------------------|
| $p_T(\ell) > 20$ GeV           |
| $E_T > 20$ GeV                 |
| $p_T(j_1) > 15$ GeV (jets 1 & 2)|
| $p_T(j_3) < 10$ GeV (jet 3)    |
| $|\eta(\ell)| < 1$             |
| $|\eta(j_h)| < 2$              |
| $\Delta R(j, j) > 0.4$         |
| $\Delta R(j, \ell) > 0.4$     |
| $m_T(\ell, E_T) > 100$ GeV    |

Table 2: Superweight components

| Condition                       |
|--------------------------------|
| $C_1$ $E_T > 65$ GeV           |
| $C_2$ $p_T(j_2) + E_T > 95$ GeV|
| $C_3$ $E_T - p_T(\ell) > 0$ GeV|
| $C_4$ $m_T(\ell, E_T) > 125$ GeV|
| $C_5$ $\phi_{j_1, \ell} < 2.4$ radians |
| $C_6$ $p_T(\ell) + E_T > 95$ GeV |
| $C_7$ $p_T(j_1) + E_T > 95$ GeV |
| $C_8$ $\cos \theta_{j_1, \ell} > -0.15$ |
| $C_9$ $m_T(j_1, \ell) < 125$ GeV |
| $C_{10}$ $m(j_1, j_2, \ell) < 200$ GeV |
be useful, the optimal value of $Q_0$ should be reasonably stable over the range of parameters being investigated. Using the definition in Table 2, we find that the mean superweight for the signal is 7.4 or greater, depending on the SUSY masses. For the background, the mean superweight is 2.6.

We present our estimate of the number of signal events in 100 pb$^{-1}$ passing all of the cuts which have a superweight of 6 or greater in Fig. 1. For comparison, we obtain 4.9 events for the sum of all backgrounds. Hence, we expect to have sensitivity in a significant area of the $\tilde{M}_t$-$\tilde{M}_{\text{LSP}}$ plane, and urge the Fermilab experiments to try this type of approach.

References

1. S. Park, “Search for New Phenomena in CDF,” 10th Topical Workshop on Proton-Antiproton Collider Physics, edited by Rajendran Raja and John Yoh, AIP Press, 1996; See also the talk by G.L. Kane at the XXVIII International Conference on High Energy Physics, Warsaw, July 1996.
2. G.L. Kane and S. Mrenna, hep-ph/9605351 (1996).
3. G. Mahlon and G.L. Kane, hep-ph/9609210 (1996).
4. S. Abachi, et. al., Phys. Rev. Lett. 76, 2222 (1996); P. Mättig, talk at the XXVIII International Conference on High Energy Physics, Warsaw, July 1996.