Using Kinematical Characteristics to Identify Squarks and Gluinos*

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ABSTRACT

Many studies of discovery techniques for squarks and gluinos have concentrated on statistical means of separating the supersymmetric signal from backgrounds such as top quark pair production. In the 1988 Snowmass workshop, we pointed out that like-sign dilepton (plus jets) events are a distinctive signature for gluinos and squarks with virtually no background. Here we emphasize that in some cases kinematic features can also distinguish the signal from backgrounds even with very few events.

We examine some interesting events from current Tevatron data and show that their kinematic features are quite different from those expected for top quarks.

The two primary signatures for squarks and gluinos use different analysis techniques to separate a supersymmetric signal from backgrounds such as top quark pair production\cite{1, 2}. The signal consisting of events with jets plus large missing transverse energy requires “statistical” arguments, i.e.: that more events are seen than expected under given cuts. The second signal, which consists of multilepton events with jets and missing transverse energy ($E_T$), could in some cases be observed with very few events, because these events have characteristics not expected in any background; that is, there are two leptons with the same sign both with quite large $E_T$. This was discussed in Snowmass 1988. Here we show that kinematic features can play the same role and allow the identification of squarks and/or gluinos with very few events.

To show that this is possible, we examine some events reported by the CDF and D0 collaborations in their top quark to dileptons sample\cite{3}. We find that two CDF events and one D0 event have characteristics significantly different from other events in the top quark sample and similar to the second class of signature events for squarks and gluinos. While we cannot rule out a statistical fluctuation of the top signal or detector effects, we feel it worthwhile to examine the consequences for supersymmetry if these events are the precursors of a real supersymmetry signal. This work was first reported in Ref. 4; more details can be found there.

In 110 $\text{pb}^{-1}$, the CDF Collaboration observed 10 such opposite-sign dilepton events, where 6 were expected from $\tilde{t}$ production with $m_t = 175$ GeV, and 2 events were expected from non-standard Model backgrounds \cite{5, 6, 7}. The D0 collaboration has also observed dilepton events, one of which appears to have similar or even more dramatic characteristics \cite{8}. However, there is a large uncertainty in the measurement of the muon $E_T$ and of $\not E_T$.

These events which we label A, B, and C (C being the D0 event) have large values of $E_S \equiv E_T^q + E_T^\tau + \not E_T$, see Fig. 1a. Event A contains a third isolated charged track, which is likely to be an electron. A third isolated, hard charged lepton would make this event inconsistent with a $\tilde{t}$ origin. A kinematic argument shows that the values of $E_T^q$, $E_T^\tau$ and $\not E_T$ of event B cannot arise from the decay of any pair of $W$'s whether or not the $W$'s originated in $\tilde{t}$ production (neglecting neutrinos in the jets). This is also evident in Fig. 2 which shows $\not E_T$ with cuts satisfied by event B: $E_T^q \cos \theta (\ell_1 - \not E_T) > 100$ GeV and $E_T^{\tau} \cos \theta (\ell_2 - \not E_T) > 40$ GeV.

In Figs. 1b-d we show three additional plots that demonstrate that a top quark explanation for these events is quite unlikely. In Fig. 1b we require large $E_S$ and see that top quark events are unlikely to yield a small transverse angle between the leptons. Figs. 1c and 1d make no cuts and show very good fits to most of the reported CDF top quark events, but events A-C are on the tails of the distributions.

Heavier squarks and gluinos often decay via a sequence of cascades through charginos ($\tilde{\chi}^\pm$) and neutralinos ($\tilde{\chi}^0$), yielding events with isolated charged leptons $\ell$ as well as jets and $\not E_T$ \cite{1, 2}. The isolated charged leptons can arise from both $\tilde{\chi}^\pm$, $\tilde{\chi}^0$ decays, such as $\tilde{\chi}^\pm \rightarrow \tilde{\nu} \ell$, $\tilde{\nu} \ell$, and $\tilde{\chi}^0 \rightarrow \tilde{\nu} \ell$, $\tilde{\nu} \ell$, and also from slepton decays, for example $\tilde{e} \rightarrow e\tilde{\chi}_i^0$. There are plausible ranges of superpartner masses in which the cascade decays of squarks, $\tilde{q} \rightarrow \tilde{\chi}^- \ell - \ell$, could lead to a few $\ell\ell(jj)\not E_T$ events, with extraordinarily high $\not E_T$ and $E_T$, in the last Tevatron run.

We study the simplified case where the three $\tilde{\chi}_i^0$ states (of $\tilde{\chi}^0$ states relevant to $\tilde{\nu}$ decays) are dominantly the $SU(2)_L$ gauginos: $\tilde{\chi}_1^0 \approx \tilde{\nu}$ and $\tilde{\chi}_2^0 \approx \tilde{\mu}$, choosing $M_{1L} > 300$ GeV (for $M_2 = 260$ GeV).

In this scenario there are five flavors of left-handed squarks with masses in the region of 310 GeV. These decay to $SU(2)_L$ gauginos, $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$, of mass near 260 GeV, which in turn decay to left-handed sleptons with mass near 220 GeV. The hardest charged leptons are produced in the final cascade of the sleptons to the LSP $\tilde{\chi}_1^0$, taken to be dominantly bino. The $\tilde{\chi}_1^0$ mass is given by the hypercharge gaugino mass parameter, $M_1$, which is therefore several times less than $M_2$. The region of parameters of interest to us does not allow the relation $M_2 \approx 2M_1$, which occurs in simple schemes of grand unification with large messenger scales for supersymmetry breaking.

In our scheme, dilepton events, such as events A and B, are from the decay of a $q_L \tilde{q}_L$ pair. Since $\tilde{g}$ decays to $q_L^q$ or to $q_L^q$, events from $\tilde{g}\tilde{g}$ or $\tilde{g}\tilde{q}$ production look similar to $q_L^q\not E_T$ events. Because $\tilde{q}_L$ has a small hypercharge, the direct decay $\tilde{q}_L \rightarrow q_L^0$ has a small branching ratio compared to the cascade mode $\tilde{q}_L \rightarrow \tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm \rightarrow \ell - \ell \tilde{\chi}_1^\pm$. These events have the number of

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isolated charged leptons, $N_L$, varying from 0 to 4. Neglecting phase space, $\frac{3}{4}$ of these $\tilde{q}_L\tilde{q}_L$ events have $N_L \geq 2$.

In our scheme, events $A$ and $B$ arise from cascade decays of $\tilde{q}_L^{\pm}\tilde{q}_L^\mp$. In a run of 110 pb$^{-1}$ the expected number of events with $N_L \geq 2$ is $(\sigma_T/0.05$ pb) ($\epsilon/0.25$), where $\epsilon$ is the detection efficiency $\approx 0.25$ and $\sigma_T$ is the total $\tilde{q}_L^\pm\tilde{q}_L^\mp + \tilde{q}_Lg\tilde{q}_L + \tilde{q}_L^\mp\tilde{g}$ production cross section. There are two contributions to $\sigma_T$ which may be important: direct $\tilde{q}_L^\pm\tilde{q}_L$ production, and $\tilde{q}_Lg, \tilde{q}_L\tilde{g}$ production followed by $\tilde{g} \to \tilde{q}_L\tilde{g}, \tilde{q}_L\tilde{g}$. The relative importance of these two contributions depends on $m_{\tilde{g}}$ and $m_{\tilde{q}}$, which we have not determined. For example, with $m_{\tilde{g}} = 330$ GeV and $m_{\tilde{q}} = m_{\tilde{q}} = 310$ GeV, the direct production contributes 0.03 pb to $\sigma_T$, while squark-gluino production contributes 0.05 pb to $\sigma_T$. For these parameters, a further production rate, $\sigma_B$, for dilepton events of 0.04 pb arises from $\tilde{q}_L^\pm\tilde{q}_L^\mp$ production, giving a total expectation of about 2.5 events with $N_L \geq 2$. If $\tilde{g}_L$ is degenerate with $\tilde{e}_L$ and $\tilde{\mu}_L$, this would be depleted by a factor of about 2.

Perhaps the most notable result of our analysis is that with only three candidate events from a hadron collider, we are able to roughly estimate the masses of six supersymmetric particles (and the gaugino/Higgsino content of the $\chi'$ states at 260 GeV). Clearly more data are needed to refine these estimates and to establish the particular scenario we have described.

If our scenario is correct, we also anticipate the observation of events with large missing $E_T$ and 0, 1, 2, 3, and (very rarely) 4 leptons (though some may have significant backgrounds). These 1-lepton events may have only two jets and hence would not be in the top quark sample.

Additional signatures may also be present, depending on the values of $m_{\tilde{g}}$ and $m_{\tilde{q}}$. The production of $g\tilde{q}$ contributes equally to same-sign [2] and opposite-sign dileptons ($\tilde{q}\tilde{q}$ production can also lead to same-sign events). When right-handed squarks are produced, they decay directly to the LSP: $\tilde{q}_R \to q_R\chi^0_1$, so that several new signals are possible. For example, with $m_{\tilde{g}} = 330$ GeV and $m_{\tilde{q}} = 310$ GeV, we find a production rate, $\sigma_B$, for $(jj E_T, jj E_T)$ events of (0.13, 0.17) pb. The standard model backgrounds for these $N_L = 0, 1$ events are larger than for the case of $N_L = 2$. However, the signal events are prominent: the $jj E_T$ events have $E_T \sim 50-250$ GeV and $E_T \sim 50-280$ GeV.

The reach in squark mass in this scenario exceeds that of several previous analyses, because the signal can be kinematically distinguished from the $t\bar{t}$ background. The superpartner masses of our scheme are so high that no supersymmetric particle would be found at LEP2, and a 500 GeV NLC would not find all of these particles. If this turns out to be the first evidence for supersymmetry, the confirmation will come in the next Tevatron run which may obtain 10-20 times as many events.

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II. REFERENCES


[5] These events are included in the reported top quark dilepton sample, and have been discussed at recent conferences, for example SUSY96, and Seongwan Park, Proceedings, 10th Topical Workshop on Proton-Antiproton Collider Physics, Batavia, IL, 9-13 May 1995, ed. R. Raja and J. Yoh (American Inst. Physics, 1996), FERMILAB-CONF-95-155-E.

