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SQUARKS IN TEVATRON DILEPTON EVENTS ?

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We consider unusual events in the CDF and D0 dilepton+jets sample with very high E_T(lepton) and E_T(missing). It is possible, but very unlikely, that these events originate from top quark pair production; however, they have characteristics that are better accounted for by decays of supersymmetric quarks with mass in the region of 300 GeV.

For ten years, two primary signatures for squarks and gluinos have been discussed[1,2]. The first consists of events with jets plus large missing transverse energy. The second consists of multilepton events with jets and missing transverse energy ($\not\!\!E_T$). We have looked at the events reported by the CDF and D0 collaborations in their top quark to dileptons sample[3], and 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 pb^{-1}, the CDF Collaboration observed 10 such opposite-sign dilepton events, where 6 were expected from $\bar{t}t$ production with $m_t = 175$ GeV, and 2 events were expected from non-top Standard Model backgrounds [5,6,7]. The D0 collaboration has also observed dilepton events, one of which appears to have similar or even more dramatic characteristics [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 $E_S \equiv E_T^{\ell_1} + E_T^{\ell_2} + \not\!\!E_T$, 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 $\bar{t}t$ origin. A kinematic argument shows that the values of $E_T^{\ell_1}$, $E_T^{\ell_2}$ 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 $\bar{t}t$ production (neglecting neutrinos in the jets). This is also evident in Fig. 2 which shows $\not\!\!E_T$ with cuts satisfied by event B: $E_T^{\ell_1} \cos\theta(\ell_1 - \not\!\!E_T) > 100$ GeV

[a]presented by RMB at the DPF-96 Meeting, Minneapolis, Aug. 10-15

and $E_T^{\ell_2} \cos\theta(\ell_2 - \not{E}_T) > 40$ 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 ($\widetilde{\chi}^+$) and neutralinos ($\widetilde{\chi}^0$), yielding events with isolated charged leptons ℓ as well as jets and $\not{E}_T$ [1,2]. The isolated charged leptons can arise from both $\widetilde{\chi}^+, \widetilde{\chi}^0$ decays, such as $\widetilde{\chi}^+ \to \widetilde{\nu}\bar{e}$, $\widetilde{e}\bar{\nu}$ and $\widetilde{\chi}^0 \to \widetilde{e}\bar{e}$, $\widetilde{\nu}\bar{\nu}$, and also from slepton decays, for example $\widetilde{e} \to e\widetilde{\chi}_1^0$. There are plausible ranges of superpartner masses in which the cascade decays of squarks, $\widetilde{q} \to \widetilde{\chi} \to \widetilde{\ell} \to \ell$, could lead to a few $\ell\ell(\ell)jj \not{E}_T$ events, with extraordinarily high $\not{E}_T$ and E_T^ℓ, in the last Tevatron run.

We study the simplified case where the three $\widetilde{\chi}'$ states ($\widetilde{\chi}$ states relevant to $\widetilde{q}$ decays) are dominantly the $SU(2)_L$ gauginos: $\widetilde{\chi}_1^\pm \approx \widetilde{w}^\pm$ and $\widetilde{\chi}_2^0 \approx \widetilde{w}_3$, choosing $|\mu| > 300$ 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, $\widetilde{\chi}_1^\pm$ and $\widetilde{\chi}_2^0$, 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 $\widetilde{\chi}_1^0$, taken to be dominantly bino.. The $\widetilde{\chi}_1^0$ 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, arise from the decay of a $\widetilde{q}_L^{(\dagger)}\widetilde{q}_L$ pair. Since $\widetilde{g}$ decays to $q^\dagger\widetilde{q}$ or to $q\widetilde{q}^\dagger$, events from $\widetilde{g}\widetilde{q}$ and $\widetilde{g}\widetilde{q}^\dagger$ production look similar to $\widetilde{q}^\dagger\widetilde{q}$ events. Because $\widetilde{q}_L$ has a small hypercharge, the direct decay $\widetilde{q}_L \to q\widetilde{\chi}_1^0$ has a small branching ratio compared to the cascade mode $\widetilde{q}_L \to \widetilde{\chi}_2^0, \widetilde{\chi}_1^+ \to \widetilde{\ell} \to \ell\widetilde{\chi}_1^0$, These events have the number of isolated charged leptons, N_L, varying from 0 to 4. Neglecting phase space, $\frac{3}{4}$ of these $\widetilde{q}_L^{(\dagger)}\widetilde{q}_L$ events have $N_L \geq 2$.

In our scheme, events A and B arise from cascade decays of $\widetilde{q}_L^{(\dagger)}\widetilde{q}_L$. 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 ϵ is the detection efficiency ≈ 0.25 and σ_T is the total $\widetilde{q}_L^\dagger\widetilde{q}_L + \widetilde{q}_L\widetilde{q}_L + \widetilde{q}_L^\dagger\widetilde{q}_L^\dagger$ production cross section. There are two contributions to σ_T which may be important: direct $\widetilde{q}_L^\dagger\widetilde{q}_L$ production, and $\widetilde{q}_L\widetilde{g}$, $\widetilde{q}_L^\dagger\widetilde{g}$ production

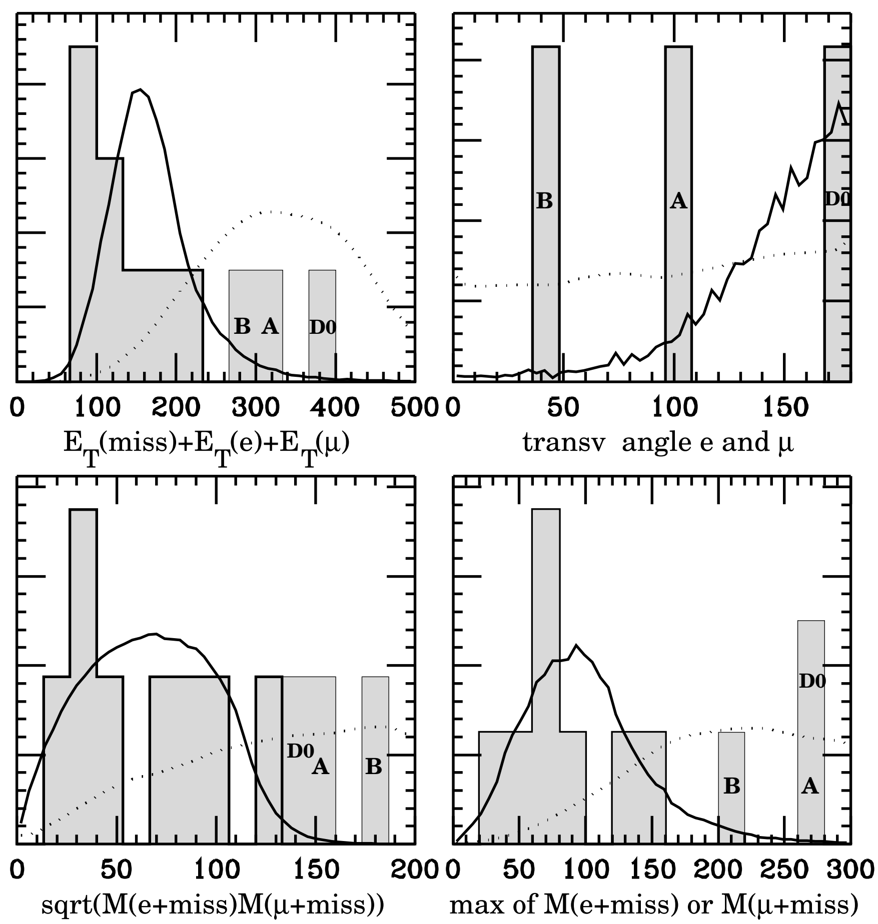

Figure 1: Expected distributions for (a) $E_S = E_T^{\ell_1} + E_T^{\ell_2} + \not\!\!E_T$, (b) θ_T between the two leptons for $E_S > 250$ GeV, (c) the product of the transverse masses of $\ell_1 + \not\!\!E_T$ and $\ell_2 + \not\!\!E_T$, and (d) the maximum of the two transverse masses in c). The solid curves are for $t\bar{t}$ production. The dotted curve has both leptons from $\widetilde{\ell} \rightarrow \ell \widetilde{\chi}_1^0$ decays. The histograms show the CDF data. The three events mentioned in the text are labelled A, B, and D0.

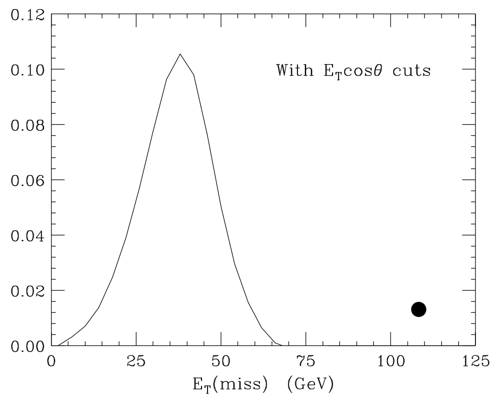

Figure 2: Missing E_T for top quark events with cuts allowed by event B (which is shown as the solid dot): $E_T^{\ell_1} \cos\theta(\ell_1 - \not\!\!E_T) > 100$ GeV and $E_T^{\ell_2} \cos\theta(\ell_2 - \not\!\!E_T) > 40$ GeV.

followed by $\widetilde{g} \to \widetilde{q}_L^\dagger q, \widetilde{q}_L q^\dagger$. The relative importance of these two contributions depends on $m_{\widetilde{g}}$ and $m_{\widetilde{q}_R}$, which we have not determined. For example, with $m_{\widetilde{g}} = 330$ GeV and $m_{\widetilde{q}_R} = m_{\widetilde{q}_L} = 310$ GeV, the direct production contributes 0.03 pb to σ_T, while squark-gluino production contributes 0.05 pb to σ_T. For these parameters, a further production rate, σB, for dilepton events of 0.04 pb arises from $\widetilde{q}_L^{(\dagger)} \widetilde{q}_R^{(\dagger)}$ production, giving a total expectation of about 2.5 events with $N_L \geq 2$. If $\widetilde{\tau}_L$ is degenerate with $\widetilde{e}_L$ and $\widetilde{\mu}_L$, 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 $\widetilde{\chi}'$ 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 $m_{\widetilde{q}_R}$ and $m_{\widetilde{g}}$. The production of $\widetilde{g}\widetilde{q}$ contributes equally to same-sign[2] and opposite-sign dileptons ($\widetilde{q}^{(\dagger)}\widetilde{q}$ production can also lead to same-sign events). When right-handed squarks are produced, they decay directly to the LSP: $\widetilde{q}_R \to q_R \widetilde{\chi}_1^0$, so that several new signals are possible. For example, with $m_{\widetilde{g}} = 330$ GeV and $m_{\widetilde{q}_R} = m_{\widetilde{q}_L} = 310$ GeV, we find a production rate, σB, for $(jj \not\!\!E_T, jj\ell \not\!\!E_T)$

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 $jj\ \not\!\!E_T$ events have $E_T^j \sim 50 - 230$ GeV and $\not\!\!E_T \sim 50 - 280$ GeV.

The reach in squark mass in this scenario exceeds that of several previous analyses, because the signal can be kinematically distinguished from the $\bar{t}t$ 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. It may also be possible to identify a few events with large $\not\!\!E_T$ and 0, 1, 2 same-sign, or three isolated leptons in the present data.

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