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Search for Light Top Squarks with the D0 Detector

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ABSTRACT

We present preliminary results of a search for pair produced top squarks, the supersymmetric partners to the top quark, under the assumption that the two-body decay $\tilde{t}_1 \to b\tilde{W}_1$ and three-body decay $\tilde{t}_1 \to bW\tilde{Z}_1$ are kinematically forbidden. This scenario is realized if $\tilde{t}_1$ is considerably lighter than all other squarks as well as $\tilde{W}_1$, all $\tilde{\nu}$s, and the top quark. Such light top squarks will dominantly decay via $\tilde{t}_1 \to c\tilde{Z}_1$ yielding a signal of two acollinear jets with $\not\!\!E_T$. The data reported here were taken during the 1992-1993 run of the DØ detector at the Fermilab Tevatron $p\overline{p}$ collider operating at $\sqrt{s} = 1.8$ TeV.

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INTRODUCTION

A spacetime symmetry, supersymmetry (SUSY) links bosons to fermions, introducing supersymmetric partners (sparticles) to all the SM particles. In combination with Grand Unification Theories, SUSY results in models which successfully unify the U(1), SU(2) and SU(3) couplings at 10^{16} GeV yet remain consistent with the experimental proton lifetime limits. Together with the natural solution offered to the fine-tuning problem, SUSY is an attractive extension to the Standard Model (SM).

Early limits on squark (the SUSY partner of the quark) masses have been set under the assumption that all squarks have the same mass. This was justified by a model that argued all scalar particles share a common mass at the energy scale where SUSY is broken. The degeneracy among squarks is broken only slightly by the small differences in electroweak interactions between left and right states and the different Yukawa interactions of the various families. However, a heavy top quark (1) means *its* Yukawa interactions become substantial and can drive top squark masses lower than all other squarks. Mass-splitting by left/right mixing may split the mass eigenstates even further, making one state, $\tilde{t}_1$, the lightest of all (2).

If kinematically accessible, the top squark is expected to decay through $\tilde{t}_1 \to b\tilde{W}_1$. If, however, $m_{\tilde{W}_1} > m_{\tilde{t}_1} + m_b$, the chargino becomes virtual and three-body decays $\tilde{t}_1 \to bl\tilde{\nu}$ or $\tilde{t}_1 \to b\nu\tilde{l}$ become accessible *unless* sleptons and sneutrinos are *also* heavier than $\tilde{t}_1$. Under this additional assumption, top squarks will dominantly decay via $\tilde{t}_1 \to c\tilde{Z}_1$ yielding an event signature of two acollinear jets with $\not{E}_T$ (3). The major backgrounds expected for this signal are vector boson production associated with jets and Standard Model multijet events with faked $\not{E}_T$ signals.

The top squark production occurs via gluon fusion and $q\bar{q}$ annihilation (4) and is thus fixed by QCD in terms of $m_{\tilde{t}_1}$. Its decay topology is determined by $m_{\tilde{Z}_1}$, the mass of the lightest neutralino. Thus the search is through a two-parameter phase space in $m_{\tilde{Z}_1}$ vs $m_{\tilde{t}_1}$. The region to be explored is the lower half-plane defined by the near-diagonal $m_{\tilde{t}_1} < m_{\tilde{Z}_1} + m_c$, hemmed in by $m_{\tilde{t}_1} > m_{\tilde{Z}_1} + m_b + m_W$ (to restrict competing 3-body decays).

A search was conducted for the SUSY partner of top quark, $\tilde{t}$, under the framework of a supergravity-GUT inspired Minimal Supersymmetric Standard Model (MSSM) (5). The model enforces conservation of R-parity which implies sparticles be produced in pairs, and that the Lightest Supersymmetric Particle (LSP) must be absolutely stable (6).

The results reported here on the $\tilde{t}_1$ search are preliminary.

THE DATA SET

Data corresponding to a total integrated luminosity of 13.5 ± 0.7 pb^{-1} were collected by the D0 detector during its 1992-1993 run. D0 is a general purpose detector consisting of a central tracking system and nearly hermetic liquid argon calorimeter surrounded by a toroidal muon spectrometer. A detailed description can be found elsewhere (7). Events for this analysis were collected under a missing E_T ($\not{E}_T$) trigger requiring 30 GeV $\not{E}_T$ in hardware and 35 GeV in software.

The Single Interaction Cut

To ensure unambiguous $\not{E}_T$ assignments, we demanded events be identified as having only one primary vertex. An algorithm that combined timing information from a set of trigger counters together with reconstructed scalar E_T and the number of vertices found by tracking was used to select single interaction events (8). Its use effectively reduced our data set to a *single interaction equivalent luminosity* of 7.4 ± 0.4 pb^{-1}.

Angular Correlation Cuts

Badly mismeasured jets can produce false $\not{E}_T$, but such events usually show a correlation between the jet and $\not{E}_T$ directions. If a jet is identified as the leading object in an event by an overestimate of its energy, a false $\not{E}_T$ signal will be induced in a direction opposite to that of the jet. Jets with underestimated energy will tend to be aligned with the fake $\not{E}_T$. This is cited as the source of the clumping of events visible in the upper left-hand corner of Fig. 1, a feature not reproduced by either the SUSY signal or any of the expected physics backgrounds. This effect is observed not only in events from our $\not{E}_T$ triggers, but even those from a low E_T threshold single jet trigger (used to study detector induced background) when mild $\not{E}_T$ cuts are applied offline. A one-dimensional cut against high $\Delta\phi(\not{E}_T, jet1)$ values was applied to suppress these events. Additional cuts were made against jets aligned (within $\delta\phi = 0.1$) with the direction of the $\not{E}_T$.

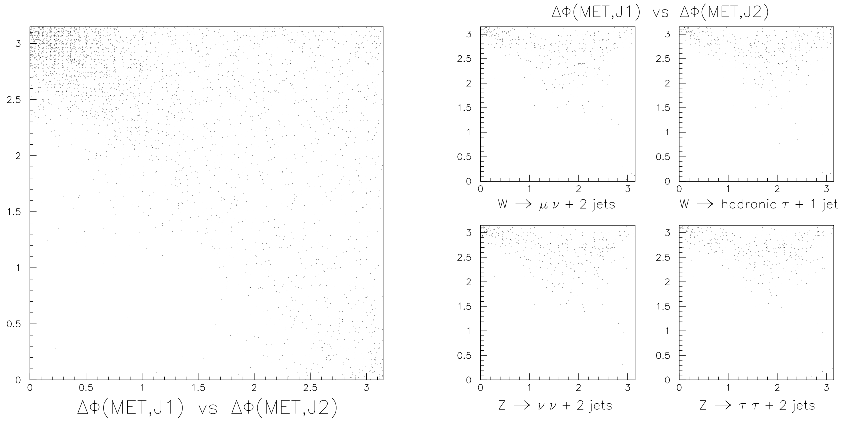

FIG. 1. The opening angle between $\not\!\!E_T$ and the leading jet runs up the ordinate, its angle with the next leading jet along the abcissa. At left are events from a low E_T threshold single jet trigger, after an offline $\not\!\!E_T > 15$ GeV cut has been applied. At right are some Monte Carlo of vector boson backgrounds.

SIGNAL

Signal events were generated using ISAJET 7.13 (9), which incorporates the latest implementation of ISASUSY (10). These files were processed through a GEANT simulation of the DØ detector (11) and reconstructed. Kinematic distributions sampled from the middle of the parameter space to be probed (Figure 2, left) show that the leading jets are fairly high in E_T, and the $\not\!\!E_T$ is large. The latter claim, however, does not hold over the full range of the region to be explored (Figure 2, right). Although it means sacrificing the rejection power of a high $\not\!\!E_T$ cut, a relatively low cut will allow coverage of more of the parameter space. Trigger thresholds fixed this cut at 40 GeV.

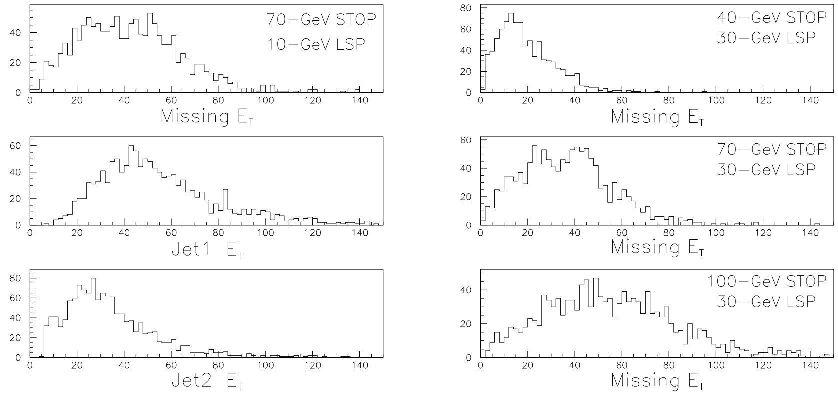

FIG. 2. The jet E_T's are seen to be healthy (left) in this sample of $m_{\tilde{t}_1} = 70$ GeV/c^2 $m_{Z_1} = 10$ GeV/c^2 ISAJET events. The $\not\!\!E_T$ is respectable, although scanning the region to be searched (right) shows $\not\!\!E_T$ to be rather feeble for low $m_{\tilde{t}_1}$.

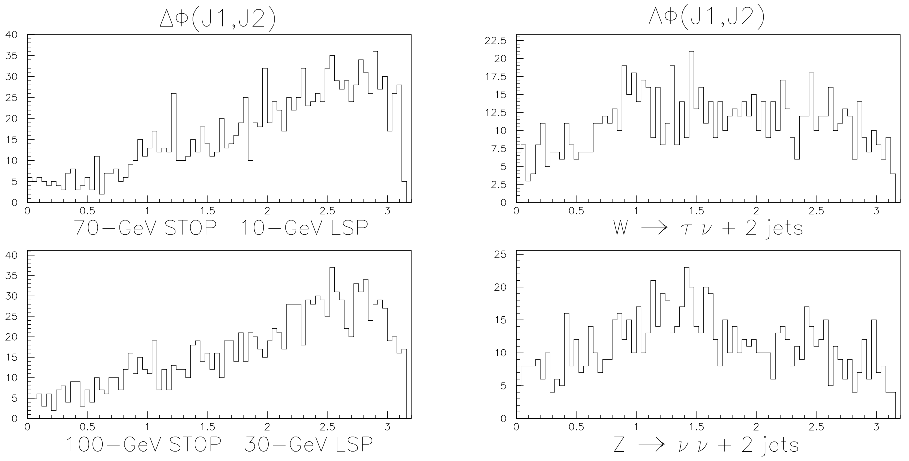

FIG. 3. The opening angle between the two leading jets tends toward higher values in the signal, though most of our background sources show relatively flat distributions.

FINAL SELECTION CUTS

Leptons are not primarily part of our signal, but appear only incidentally insofar as charm jets are in the final state. These tend to be low E_T objects. We gain some rejection against the vector boson background by discriminating against events with high-E_T electrons or muons.

The presence of two LSP's in the event suggests that the two leading jets in our signal be acollinear. But distributions of the opening angle between them (Fig.3) show that this angle tends to large values. A cut of $\Delta\phi(j1, j2) > 90^o$ preserves 70-75% of the signal. Background distributions tend to be flat.

Standard Model multijet events tend to be mostly back-to-back jet pairs. Thus we must also cut against two leading jets with an opening angle close to π. Monte Carlo distributions suggest an effective cut can be made at $\Delta\phi(j1, j2) < 165^o$.

Our final selection cuts of

$$\begin{gathered} \not{E}_T > 40 \text{ GeV} \\ E_T^{jet2} > 30 \text{ GeV} \\ 90^o < \Delta\phi(j_1, j_2) < 165^o \\ 10^o < \Delta\phi(j_1, \not{E}_T) < 125^o \\ 10^o < \Delta\phi(j_{3,4}, \not{E}_T) \end{gathered}$$

with a *VETO* against events with:

$$\begin{gathered} E_T^{\mu} > 10 \text{ GeV} \\ E_T^{el} > 10 \text{ GeV} \end{gathered}$$

leave a total of two candidates in the single interaction Missing E_T triggers.

TABLE 1. Expected Vector Boson backgrounds to the $\tilde{t}$ signal.

Background Process	Expected # of events
$W \to e\bar{\nu}$	0.52 ± 0.30
$W \to \mu\bar{\nu}$	0.84 ± 0.42
$W \to \tau\bar{\nu}$	0.99 ± 0.64
$Z \to \nu\bar{\nu}$	0.37 ± 0.32
$Z \to \mu\bar{\mu}$	0.06 ± 0.05
$Z \to \tau\bar{\nu}$	0.08 ± 0.05
TOTAL	2.86 ± 0.93

BACKGROUND

To estimate the vector boson associated background, we generated W/Z plus n jet samples using the Monte Carlo (MC) generator VECBOS (12), interfaced with ISAJET (9) to dress up the final parton states. VECBOS allowed us to specify n, the number of primary jets associated with the vector boson production. Since ISAJET also allows control over the decay of the tau, we were careful to count its hadronic decays as contributing to the jet total. Events were then passed through a GEANT simulation of the DØ detector (11), reconstructed and subjected to our selection criteria. Table 1 lists the expected background from this source.

To estimate the contribution from Standard Model multijet production, we fit the $\not\!\!E_T$ spectrum of a set of single low jet E_T triggers, and then determined the fraction of such events that passed our selection cuts, as a function of $\not\!\!E_T$. For our final selection cuts that contribution was predicted to be negligible.

The combined background is consistent with the number of observed candidates.

CONCLUSIONS

No excess of events, unexplained by the Standard Model, were observed. With two candidates, our preliminary background subtracted 95% Confidence Level exclusion contour is shown in Fig. 4. This contour intersects the $m_{\tilde{t}_1} = m_{\tilde{Z}_1} + m_b + m_W$ line at 106 GeV/c^2 . The gap between the LEP limit and our own exclusion region is due to the limitation of the $\not\!\!E_T$ trigger threshold. The 1994-95 data run now carries a customized filter which employs some of the offline cuts against low-E_T jets aligned with $\phi(\not\!\!E_T)$ permitting the $\not\!\!E_T$ cut to be lowered to 25 GeV, which may allow us to cover this area more completely. The region between $m_{\tilde{t}_1} = m_{\tilde{Z}_1} + m_c$ and our excluded area requires additional statistics.

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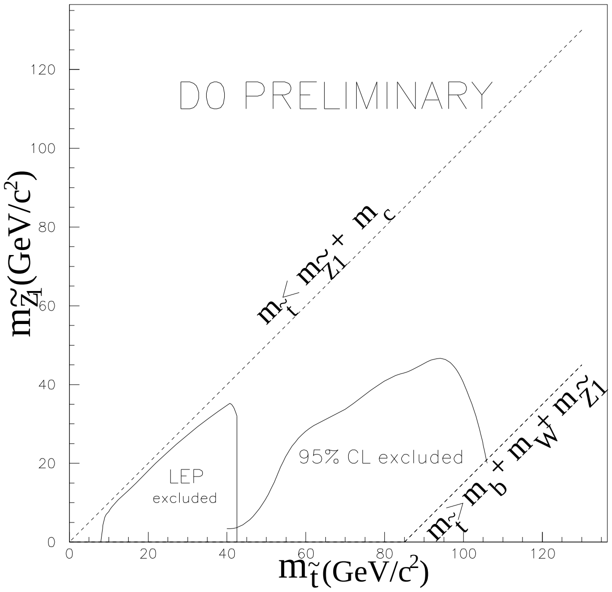

FIG. 4. The 95% Confidence Level contour. For comparison, the latest exclusion contour from OPAL(13) is shown.

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