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Search for top squark pair production in the dielectron channel

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This report describes the first search for top squark pair production in the channel $\tilde{t}_1\overline{\tilde{t}}_1 \rightarrow b\overline{b}\tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow ee+\text{jets}+\not{E}_T$ using $74.9 \pm 8.9\ \text{pb}^{-1}$ of data collected using the DØ detector. A 95% confidence level upper limit on $\sigma \cdot B$ is presented. The limit is above the theoretical expectation for $\sigma \cdot B$ for this process, but does show the sensitivity of the current DØ data set to a particular topology for new physics. [S0556-2821(98)00901-1]

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Supersymmetry (SUSY) is a fundamental space-time symmetry relating bosons and fermions [1]. Supersymmetric extensions to the standard model (SM) feature undiscovered superpartners for every SM particle—for example, there is a scalar quark (squark) for each of the two degrees of freedom for the spin-1/2 quarks. In most SUSY models, the masses of the squarks are approximately degenerate except for those of the top squarks. Because of large top family Yukawa interactions, the lighter top squark mass eigenstate ($\tilde{t}_1$) can have a much lower mass than the other squarks [2]. Top squarks will be pair produced at the Fermilab Tevatron; each will then decay into the lightest chargino $\tilde{\chi}_1^{\pm}$ and a b quark if that decay is kinematically allowed. If $m_{\tilde{\chi}_1^{\pm}}$ is greater than the mass of the top squark, the decays $\tilde{t}_1 \rightarrow bl\tilde{\nu}$ or $\tilde{t}_1 \rightarrow b\tilde{l}\nu$ can occur. If the sleptons are also heavier than the top squark, the loop decay $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$ should be dominant if $m_{\tilde{\chi}_1^{\pm}} \lesssim 100\ \text{GeV}/c^2$ [3].

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We assume here that the $\widetilde{\chi}_1^\pm$ decays to $l\nu_l\widetilde{\chi}_1^0$ or $q\overline{q'}\widetilde{\chi}_1^0$. Under R-parity conservation, the lightest neutralino will be stable and escape detection, resulting in missing transverse energy $\not{E}_T$. Thus, top squarks, pair produced at the Tevatron, result in final states similar to those of top quarks. However, as the decay of the chargino is to three particles, the decay products tend to be softer than those of the W boson. Since the $\widetilde{\chi}_1^\pm$ decay is almost always dominated by virtual W exchange, the branching fractions are expected to be be very close to W boson leptonic and hadronic decay branching fractions [2].

The results of a search for $\widetilde{t}_1 \rightarrow c\widetilde{\chi}_1^0$ have been published by the D0 Collaboration [4]. Nearly model independent lower limits on the masses of the top squark and lightest chargino have been set using the measured width of the Z boson and are approximately 45 GeV/c^2 [5] (these can be evaded by tuning the top squark mixing angle). Within the framework of the minimal supersymmetric standard model (MSSM) [6], the current limits on the pair production of charginos (which depend on the assumed value of the common scalar mass m_0) from the CERN e^+e^- collider LEP at $\sqrt{s}=$ 130, 136, and 161 GeV [7,8], lead to $m_{\widetilde{\chi}_1^\pm} > 62.0$ – 78.5 GeV/c^2 at the 95% C.L. [7]. The analysis described below is independent of the MSSM and supergravity [9] frameworks, instead depending only on the masses of the top squark, the lightest chargino, and the lightest neutralino, and on the branching fractions of the chargino decay.

Previous phenomological studies have considered final states with a single lepton + jets + $\not{E}_T$ and two leptons + jets + $\not{E}_T$ [2]. These studies, which used ISAJET [10] events smeared by typical detector resolutions, indicated that the single lepton channel cannot be studied at the Tevatron without excellent b-tagging capability due to the enormous background from W boson production. However, they did indicate that analysis of the dilepton channels (ee, $e\mu$ and $\mu\mu$) could lead to a limit on the mass of (or discovery of) the top squark at the Tevatron using the current data set.

This report describes the first search for the decay $\widetilde{t}_1 \rightarrow b\widetilde{\chi}_1^\pm$ in the channel $\widetilde{t}_1\overline{\widetilde{t}_1} \rightarrow ee$+jets+$\not{E}_T$ using 74.9±8.9 pb^{-1} of data. The data were collected at the Fermilab Tevatron at $\sqrt{s}=1.8$ TeV during 1994–1995. The D0 detector and data collection system are described in detail in Ref. [11]. The detector consisted of three major subsystems: a uranium-liquid argon calorimeter, central tracking detectors (with no central magnetic field), and a muon spectrometer. Electrons were identified by their longitudinal and transverse shower profiles in the calorimeter and were required to have a matching track in the central tracking chambers. In this analysis, they were restricted to have pseudorapidity $|\eta|<2.5$ and to be isolated from other energy depositions in the event. Jets were reconstructed using a cone algorithm of radius $\mathcal{R}=\sqrt{(\Delta\phi)^2+(\Delta\eta)^2}=0.7$ with $|\eta|<4.0$. The $\not{E}_T$ was determined from energy deposition in the calorimeter for $|\eta|<4.5$.

The acceptance for top squark events was calculated for a range of top squark and chargino masses using the ISAJET event generator and a detector simulation based on the GEANT program [12]. Samples were generated with top squark masses between 55 and 75 GeV/c^2 with $m_{\widetilde{\chi}_1^\pm}$ between 47 and 68 GeV/c^2, depending on $m_{\widetilde{t}_1}$. The mass of the lightest neutralino was set to the supergravity-motivated value $\frac{1}{2}m_{\widetilde{\chi}_1^\pm}$.

TABLE I. Background contributions from individual channels.

Background channel	Number of events
$t\overline{t}(170)\rightarrow ee$	0.03±0.01
$WW\rightarrow ee$	0.02±0.01
$Z\rightarrow ee$	0.09±0.01
$Z\rightarrow\tau\tau\rightarrow ee$	0.67±0.13
Misidentification	3.6±0.8
Total	4.4±0.8

The signature for $\widetilde{t}_1\overline{\widetilde{t}_1} \rightarrow b\overline{b}\widetilde{\chi}_1^+\widetilde{\chi}_1^-$ is two electrons, one or more jets, and $\not{E}_T$. Kinematic distributions for $(m_{\widetilde{t}_1}, m_{\widetilde{\chi}_1^\pm})$ = (65,47) GeV/c^2 are shown in Fig. 1. This analysis was restricted to events selected using a trigger which required one electromagetic cluster with transverse energy $E_T^e > 15$ GeV, one jet with $E_T^j > 10$ GeV, and $\not{E}_T >$ 14 GeV. Other kinematic quantities used to discriminate against background are the invariant mass of the two electrons m_{ee} and $E_T^{\text{sum}} = E_T^{e1} + E_T^{e2} + \not{E}_T$ (defined in Ref. [2] as bigness).

Cut optimization was done using the RGSEARCH [13] program. RGSEARCH uses a modified grid search based on Monte Carlo (MC) signal events and background samples to optimize event selection. In this study, the MC signal samples described above and the MC physics background samples listed in Table I were used. Several combinations of selection criteria were explored starting with the thresholds imposed by the trigger conditions. The final selection criteria are summarized in Table II. Other combinations included requirements on the E_T of a second jet and/or the azimuthal angle between the two electrons. These combinations increased the signal to background ratio, but reduced the signal efficiency significantly. Values for the upper limits on m_{ee} and E_T^{sum} were fixed while running RGSEARCH. The cut on m_{ee} was used to remove $Z\rightarrow ee$ events and that on E_T^{sum} to remove $t\overline{t}\rightarrow ee$+jets+$\not{E}_T$ events. Distributions of E_T^{sum} for top squark production with $(m_{\widetilde{t}_1}, m_{\widetilde{\chi}_1^\pm})$ = (65,47) GeV/c^2 and Monte Carlo top quark production are shown in Fig. 2.

Signal detection efficiency was restricted by the reconstruction and identification of low E_T electrons. Only approximately 15% of Monte Carlo events with $(m_{\widetilde{t}_1}, m_{\widetilde{\chi}_1^\pm})$ = (65,47) GeV/c^2 had two reconstructed electromagetic clusters (with an associated track) with $E_T^{e1} > 16$ GeV and

TABLE II. Kinematic cuts. E_T^{sum} is defined in the text.

$E_T^{e1} \geqslant 16$ GeV
$E_T^{e2} \geqslant 8$ GeV
$E_T^{j1} \geqslant 30$ GeV
$\not{E}_T \geqslant 22$ GeV
$m_{ee} \leqslant 60$ GeV/c^2
$E_T^{\text{sum}} \leqslant 90$ GeV

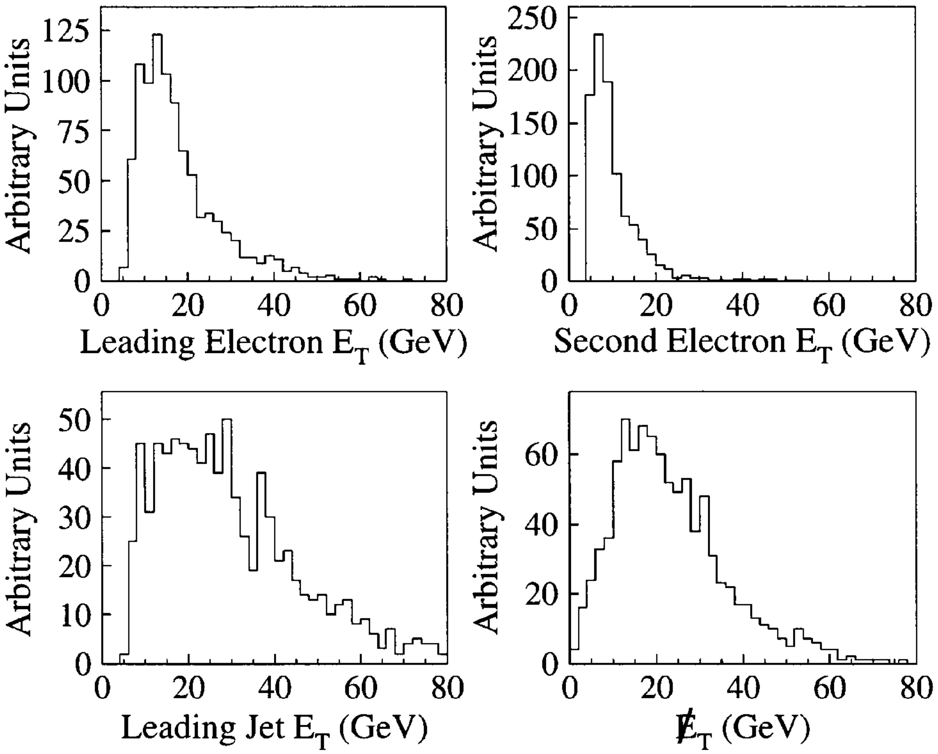

FIG. 1. Kinematic distributions for $(m_{\tilde{t}_1},m_{\tilde{\chi}_1^\pm})=(65,47)$ GeV/c^2.

$E_T^{e2}>8$ GeV. In addition, the identification efficiency for two electrons, one with $E_T=8$ GeV and one with $E_T=16$ GeV, was approximately 40%. It is, however, essential to include the second electron in the selection criteria to avoid being overwhelmed by W boson events.

Physics backgrounds were estimated by Monte Carlo simulation or from a combination of Monte Carlo and data. The instrumental background from jets misidentified as electrons was estimated entirely from data [14] using the jet misidentification probability for the electron identification and kinematic cuts used in this analysis $[(6.5\pm1.3)\times10^{-4}]$. Four physics backgrounds were considered in this study: $t\bar{t}$ production with a top quark mass of 170 GeV/c^2, WW production, and Z boson production with final states resulting in dielectrons. The contribution to the background from individual channels is given in Table I. The total predicted background is 4.4 ± 0.8 events.

After application of the cuts to the data sample, two events remained. Given no observed excess of events above the expected background, we set a 95% C.L. upper limit on $\sigma\cdot B$ using a Bayesian approach with a flat prior distribution for the signal cross section. The statistical and systematic uncertainties on the efficiency, the integrated luminosity, and the background estimation were included in the limit calculation with Gaussian prior distributions. The resulting upper limit on $\sigma\cdot B$ as a function of $m_{\tilde{t}_1}$ with fixed $m_{\tilde{\chi}_1^\pm}=47$ GeV/c^2 is shown in Fig. 3 along with the predicted $\sigma\cdot B$. The choice of $m_{\tilde{\chi}_1^\pm}=47$ GeV/c^2 allows the widest range of $m_{\tilde{t}_1}$ to be displayed. As can be seen, no limit on $m_{\tilde{t}_1}$ can be set. The 95% C.L. upper limits on $\sigma\cdot B$ for all $(m_{\tilde{t}_1},m_{\tilde{\chi}_1^\pm})$ mass combinations considered in this analysis are given in Table III.

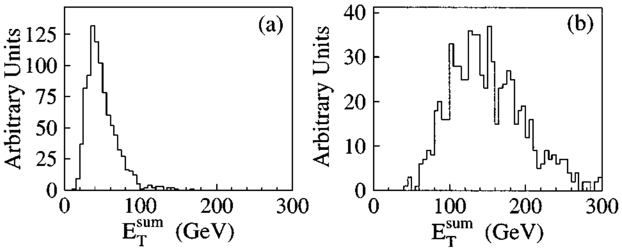

FIG. 2. Distributions of E_T^{sum} for (a) $(m_{\tilde{t}_1},m_{\tilde{\chi}_1^\pm})=(65,47)$ GeV/c^2 and (b) top quark production with $m_t=170$ GeV/c^2.

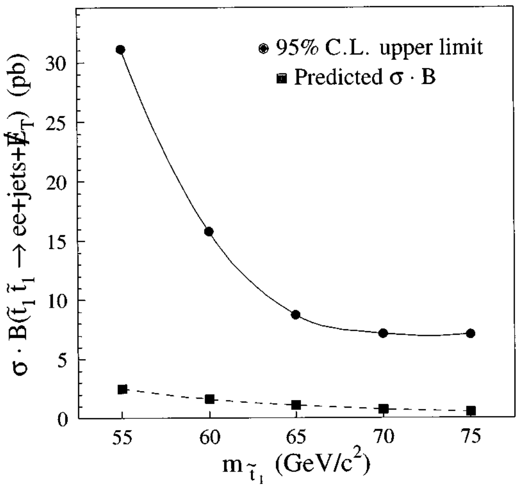

FIG. 3. Our 95% confidence level upper limit on $\sigma\cdot B$ as a function of $m_{\tilde{t}_1}$ for $m_{\tilde{\chi}_1^\pm}=47$ GeV/c^2. Also shown are the predicted values from ISAJET.

TABLE III. The 95% C.L. upper limits on $\sigma \cdot B$ for all $(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^\pm})$ mass combinations considered.

$m_{\tilde{t}_1}$ (GeV/c^2)	$m_{\tilde{\chi}_1^\pm}$ (GeV/c^2)	95% C.L. Limit on $\sigma \cdot B$ (pb)
55	47	31
60	47	16
60	52	14
65	47	8.8
65	52	7.9
65	58	7.6
70	47	7.2
70	50	5.2
70	62	6.6
75	47	7.1
75	54	4.9
75	61	6.2
75	68	6.5

Although the recent results on chargino pair production from LEP limit the likelihood for a light top squark to decay to a *b* quark and a chargino within the MSSM, the limits on $\sigma \cdot B$ given in Table III indicate the level of sensitivity in the current D0 data set to a particular topology for new physics: pair production of new particles which decay into leptons, jets, and noninteracting particles. Such a new particle, with a top-like signature, could be detectable in the current data set down to a production cross section times branching ratio of order 10 pb.

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