Search for Light Scalar Top Quark Pair Production in $p\overline{p}$ Collisions at $\sqrt{s}$=1.8 TeV

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Abstract

We present the results of a search for direct pair production of scalar top quarks, supersymmetric partners of the top quark, using 85.2 ± 3.6 pb^{-1} of $p\bar{p}$ collisions collected at $\sqrt{s}$=1.8 TeV using the DØ detector at Fermilab's Tevatron Collider. We examined events with two or more jets plus missing transverse energy, the signature of light scalar top quark decays to a charm quark and a neutralino. After selection, we observe 27 events while expecting 31.1 ± 6.4 events from the known standard model processes. Comparing these results to next-to-leading-order production cross sections, we exclude a significant region of the scalar quark mass — neutralino mass parameter space. The highest scalar top quark mass value excluded is 122 GeV/c^2 for a neutralino mass of 45 GeV/c^2.

Supersymmetry (SUSY) [1–3], a theoretically appealing extension of the standard model (SM), introduces additional particle states. For every bosonic SM particle, it assigns a fermionic "superpartner" and for every SM fermion, a boson. The hypothesized SUSY particles include gauginos and scalar quarks or "squarks." The gauginos are the superpartners of the gauge particles and provide prime dark matter candidates, which include the neutralinos. Squarks include the left and right scalar top quarks or top squarks. These weak eigenstates mix to give the mass eigenstates $\tilde{t_1}$ and $\tilde{t_2}$.

Generic SUSY searches often make the simplifying assumption of mass-degenerate first and second generation squarks. The scalar top quark masses, however, are expected to be substantially lower than those of all other squarks [4–6]. If sufficiently light, scalar top quarks should be strongly produced at the Tevatron through $q\overline{q}$ annihilation and gluon-gluon fusion with a cross section on the order of that of the top quark [7, 8]. For a 100 GeV/c^2 scalar top quark, the next-to-leading-order (NLO) production cross section is about 12 pb. For a 120 GeV/c^2 scalar top quark, it is 4.2 pb. Calculations of scalar top quark cross sections were made using the program PROSPINO [9].

This analysis is sufficiently general that it applies to a broad class of SUSY models. We make no assumptions about gaugino unification, but assume that the lightest neutralino $\tilde{\chi}_1^0$ is the lightest supersymmetric particle (LSP) with conservation of R-parity guaranteeing its stability. We consider the special case where the scalar top quark is light enough that $m_{\tilde{t_1}} < m_b + m_W + m_{\tilde{\chi}_1^0}$ and $m_{\tilde{t_1}} < m_b + m_{\tilde{\chi}_1^+}$, precluding the decays $\tilde{t_1} \to b + W\tilde{\chi}_1^0$, $\tilde{t_1} \to b\tilde{\chi}_1^+$ and $\tilde{t_1} \to b\tilde{\chi}_1^{+*}$ ($\tilde{\chi}_1^{+*} \to l\tilde{\nu}$ or $\tilde{\chi}_1^{+*} \to \tilde{l}\nu$). The dominant decay is then $\tilde{t_1} \to c\tilde{\chi}_1^0$, yielding an event signature of two jets with missing transverse energy ($\not\!\!E_T$). We have made no attempt to identify jet flavor.

Scalar top quark signal characteristics were studied by generating Monte Carlo (MC) events for various combinations of $m_{\tilde{t_1}}$ and $m_{\tilde{\chi}_1^0}$ in the search region of parameter space using ISAJET [10] with its implementation of ISASUSY [11]. These events were processed by a GEANT [12] simulation of the DØ detector, a simulation of the trigger, and the standard DØ reconstruction program.

The major SM backgrounds expected for this signal are multijet events with apparent $\not\!\!E_T$ and vector boson (VB) production associated with jets. The VB backgrounds include those producing: neutrinos and jets (Z + 2 jets $\to$ $\nu\nu$+2 jets and W+jets where the W boson decays to a hadronically-decaying τ lepton), leptons from VB decays that escape detection, or electrons misidentified as jets. PYTHIA [13] was used to predict the acceptance for W/Z+jet production while the VECBOS [14, 15] Monte Carlo generator was used for $W/Z+2$ jets events. In each case, the cross sections reported by the generators were scaled to match measurements made at DØ for W/Z + jets events.

We used the DØ measured cross section for $t\bar{t}$ production [16] and the HERWIG generator to calculate the acceptance for the $t\bar{t}$ backgrounds in which a top quark decays to an unobserved charged lepton, a neutrino, and a jet.

Data corresponding to an integrated luminosity of 85.2 ± 3.6 pb^{-1} were collected during the 1994 – 1995 Tevatron run. The DØ detector consists of a central tracking system and a nearly hermetic uranium/liquid-argon calorimeter surrounded by a toroidal muon spectrometer. A detailed description of the DØ detector and data collection system can be found in Ref. [17]. Events for this analysis were collected using a trigger requiring two jets, one with $E_T > 25$ GeV and the second with $E_T > 10$ GeV, and $\not{\!\!E}_T > 25$ GeV, and rejecting events in which the direction of the leading jet and the $\not{\!\!E}_T$ are aligned within a polar angle of 14°. An offline selection was made requiring events with at least two jets each with E_T>50 GeV, $\not{\!\!E}_T$> 40 GeV, and all jets satisfying $\Delta\phi(\text{jet}, \not{\!\!E}_T) > 30°$, guaranteeing high trigger efficiency. To suppress VB backgrounds, we removed events containing electrons or muons with E_T>10 GeV.

Mulitjet backgrounds arise when mismeasured jets or a misidentified interaction vertex induce an apparent $\not{\!\!E}_T$. To reduce the effects of poorly measured jet energies, those events in which jets land within the narrow portion of the DØ dectector with only coarse energy sampling were removed. We refer to the collection of events surviving these cuts as our *base sample*.

To reduce the instances of mismeasured vertices, the central drift chamber (CDC) was used to associate charged tracks with central jets for $|\eta| < 1$, which is within the fiducial volume of the CDC. These tracks establish the origin of each jet, which was required to be no further than 8 cm from the reconstructed event vertex. This cut was determined through studies done on all tracks in each event. The remaining events form a *clean sample*.

To predict the multijet background remaining in the *clean sample*, we used a collection of events from the *base sample* where the jet vertex position deviates by 15–50 cm from the event vertex position. We normalized this *deviant sample* to the *clean sample* using events with $\Delta\phi(\text{jet 2}, \not{\!\!E}_T) < 60°$. We chose the 50 cm value since it provides the best agreement

Selection cuts	Events
2 jets and $\not\!\!E_T$ trigger	536,678
No detector malfunction or accelerator noise	487,715
Leading jet E_T>50 GeV	205,461
Second jet E_T>50 GeV	106,505
$\not\!\!E_T$>40 GeV	13,752
Vertex confirmation	3417
Lepton rejection	2950
All jets reside outside DØ coarse sampling region	520
$\Delta\phi$(jet, $\not\!\!E_T$) ($>30^0$, $<165^0$)	88

TABLE I: Number of events surviving in the jets + $\not\!\!E_T$ sample after the application of selection criteria. These 88 events form the *clean sample*.

between the background prediction and the data for the $\not\!\!E_T$ region between 30 and 40 GeV, which is dominated by multijet events. Changing this value to 100 cm increases the multijet prediction by 22% in this region, which we take as an estimate of the systematic error of the method. Table I gives the observed number of events for the jets plus $\not\!\!E_T$ sample after each of the cuts.

A random grid search (RGS) [18] was used to optimize the final physics cuts applied to the *clean sample*. An RGS uses Monte-Carlo-generated scalar top quark events to investigate the space of observables most heavily populated by signal. We ran the RGS over two different scalar top quark mass points, $m_{\tilde{t}} = 115$ GeV/c^2, $m_{\tilde{\chi}} = 20$ GeV/c^2 and $m_{\tilde{t}} = 130$ GeV/c^2, $m_{\tilde{\chi}} = 30$ GeV/c^2. To optimize our rejection of background relative to signal, we maximized the quantity

$$\frac{N_{\rm signal}}{\sqrt{(N_{\rm signal} + N_{\rm background})}},$$

with the criteria of $> 2\%$ signal efficiency and mulitjet backgrounds accounting for $< 50\%$ of the total background. Our final selection cuts and estimated background are reported in Table II. Figure 1 shows data versus background for several physics distributions. A 130 GeV/c^2 scalar top quark signal is superimposed on the figures.

We find the number of selected events to be consistent with the expected backgrounds. This result can be represented as an excluded region in the $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0}$ plane, which is shown

Selection cuts	Candidate events	Predicted background events
Leading jet E_T>60 GeV Second jet E_T>50 GeV $\not\!\!E_T$>60 GeV	27	31.1 $\pm$ 6.4

TABLE II: Physics cuts established from the random grid search.

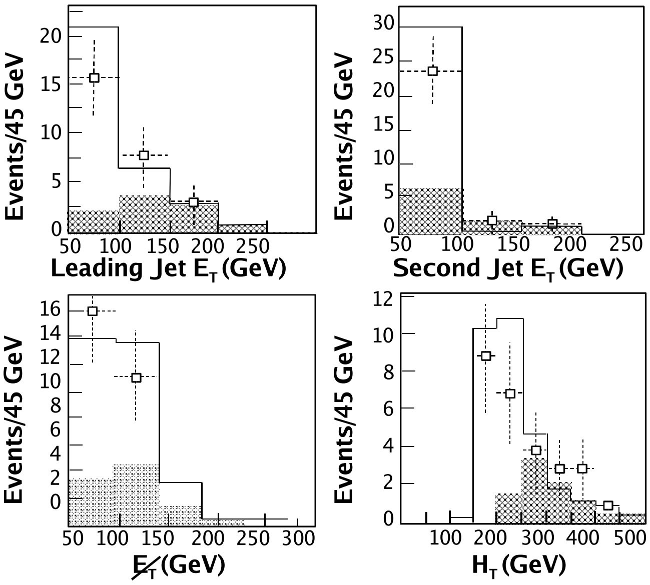

FIG. 1: Data (histograms) vs. predicted background (points) after final physics cuts. The additional contributions expected to be made by a 130 GeV/c^2 scalar top quark are superimposed over the figures (shaded histograms). The plot shown are leading jet E_T, second jet E_T, $\not\!\!E_T$ (parmeters optimized in RGS) and H_T (where H_T $=\not\!\!E_T+\Sigma_i E_T(\text{jet}_i)$) to demonstrate agreement with distributions not optimized in RGS.

in Fig. 2. A Bayesian method is used, applying a flat prior distribution for the signal cross section and Gaussian priors for background and acceptance uncertainties, to determine our 95% confidence level (CL) upper limit. The highest scalar top quark mass value excluded is 122 GeV/c^2 for a neutralino mass of 45 GeV/c^2. The highest neutralino mass excluded is 52 GeV/c^2 for a 117 GeV/c^2 scalar top quark mass.

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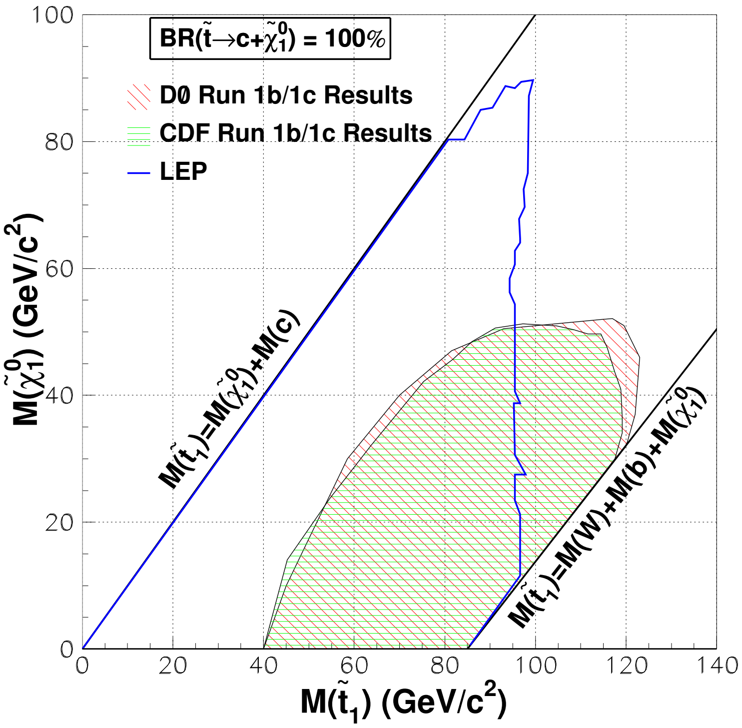

FIG. 2: Limits on the scalar top quark pair production cross section at 95% confidence level as a function of $m_{\tilde{t}}$ and $m_{\tilde{\chi}_1^0}$. Overlaid on the figure are limit results from LEP [19] and CDF [20] .

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