FERMILAB-PUB-96/449-E, D0PUB-96-15

Search for Top Squark Pair Production in the Dielectron Channel

S. Abachi,[14] B. Abbott,[28] M. Abolins,[25] B.S. Acharya,[43] I. Adam,[12] D.L. Adams,[37]
M. Adams,[17] S. Ahn,[14] H. Aihara,[22] G. Álvarez,[18] G.A. Alves,[10] E. Amidi,[29] N. Amos,[24]
E.W. Anderson,[19] S.H. Aronson,[4] R. Astur,[42] M.M. Baarmand,[42] A. Baden,[23]
V. Balamurali,[32] J. Balderston,[16] B. Baldin,[14] S. Banerjee,[43] J. Bantly,[5] J.F. Bartlett,[14]
K. Bazizi,[39] A. Belyaev,[26] J. Bendich,[22] S.B. Beri,[34] I. Bertram,[31] V.A. Bezzubov,[35]
P.C. Bhat,[14] V. Bhatnagar,[34] M. Bhattacharjee,[13] A. Bischoff,[9] N. Biswas,[32] G. Blazey,[30]
S. Blessing,[15] P. Bloom,[7] A. Boehnlein,[14] N.I. Bojko,[35] F. Borcherding,[14] J. Borders,[39]
C. Boswell,[9] A. Brandt,[14] R. Brock,[25] A. Bross,[14] D. Buchholz,[31] V.S. Burtovoi,[35]
J.M. Butler,[3] W. Carvalho,[10] D. Casey,[39] H. Castilla-Valdez,[11] D. Chakraborty,[42]
S.-M. Chang,[29] S.V. Chekulaev,[35] L.-P. Chen,[22] W. Chen,[42] S. Choi,[41] S. Chopra,[24]
B.C. Choudhary,[9] J.H. Christenson,[14] M. Chung,[17] D. Claes,[27] A.R. Clark,[22]
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M.A.C. Cummings,[16] D. Cutts,[5] O.I. Dahl,[22] K. De,[44] K. Del Signore,[24] M. Demarteau,[14]
D. Denisov,[14] S.P. Denisov,[35] H.T. Diehl,[14] M. Diesburg,[14] G. Di Loreto,[25] P. Draper,[44]
J. Drinkard,[8] Y. Ducros,[40] L.V. Dudko,[26] S.R. Dugad,[43] D. Edmunds,[25] J. Ellison,[9]
V.D. Elvira,[42] R. Engelmann,[42] S. Eno,[23] G. Eppley,[37] P. Ermolov,[26] O.V. Eroshin,[35]
V.N. Evdokimov,[35] S. Fahey,[25] T. Fahland,[5] M. Fatyga,[4] M.K. Fatyga,[39] J. Featherly,[4]
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B. Gómez,[1] G. Gómez,[23] P.I. Goncharov,[35] J.L. González Solís,[11] H. Gordon,[4] L.T. Goss,[45]
A. Goussiou,[42] N. Graf,[4] P.D. Grannis,[42] D.R. Green,[14] J. Green,[30] H. Greenlee,[14]
G. Griffin,[8] G. Grim,[7] N. Grossman,[14] P. Grudberg,[22] S. Grünendahl,[39] G. Guglielmo,[33]
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R. Hernández-Montoya,[11] T. Heuring,[15] R. Hirosky,[15] J.D. Hobbs,[14] B. Hoeneisen,[1,†]
J.S. Hoftun,[5] F. Hsieh,[24] Ting Hu,[42] Tong Hu,[18] T. Huehn,[9] A.S. Ito,[14] E. James,[2]
J. Jaques,[32] S.A. Jerger,[25] R. Jesik,[18] J.Z.-Y. Jiang,[42] T. Joffe-Minor,[31] K. Johns,[2]
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A.V. Kotwal,[12] J. Kourlas,[28] A.V. Kozelov,[35] E.A. Kozlovski,[35] J. Krane,[27]
M.R. Krishnaswamy,[43] S. Krzywdzinski,[14] S. Kunori,[23] S. Lami,[42] H. Lan,[14,*]
G. Landsberg,[14] B. Lauer,[19] J-F. Lebrat,[40] A. Leflat,[26] H. Li,[42] J. Li,[44] Y.K. Li,[31]
Q.Z. Li-Demarteau,[14] J.G.R. Lima,[38] D. Lincoln,[24] S.L. Linn,[15] J. Linnemann,[25]
R. Lipton,[14] Q. Liu,[14,*] Y.C. Liu,[31] F. Lobkowicz,[39] S.C. Loken,[22] S. Lökös,[42] L. Lueking,[14]
A.L. Lyon,[23] A.K.A. Maciel,[10] R.J. Madaras,[22] R. Madden,[15] L. Magaña-Mendoza,[11]

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S. Youssef,[15] J. Yu,[14] Y. Yu,[41] Q. Zhu,[28] Z.H. Zhu,[39] D. Zieminska,[18] A. Zieminski,[18]
E.G. Zverev,[26] and A. Zylberstejn[40]

(DØ Collaboration)

[1] *Universidad de los Andes, Bogotá, Colombia*
[2] *University of Arizona, Tucson, Arizona 85721*
[3] *Boston University, Boston, Massachusetts 02215*
[4] *Brookhaven National Laboratory, Upton, New York 11973*
[5] *Brown University, Providence, Rhode Island 02912*
[6] *Universidad de Buenos Aires, Buenos Aires, Argentina*
[7] *University of California, Davis, California 95616*
[8] *University of California, Irvine, California 92717*
[9] *University of California, Riverside, California 92521*
[10] *LAFEX, Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil*
[11] *CINVESTAV, Mexico City, Mexico*
[12] *Columbia University, New York, New York 10027*
[13] *Delhi University, Delhi, India 110007*
[14] *Fermi National Accelerator Laboratory, Batavia, Illinois 60510*
[15] *Florida State University, Tallahassee, Florida 32306*
[16] *University of Hawaii, Honolulu, Hawaii 96822*

[17] University of Illinois at Chicago, Chicago, Illinois 60607
[18] Indiana University, Bloomington, Indiana 47405
[19] Iowa State University, Ames, Iowa 50011
[20] Korea University, Seoul, Korea
[21] Kyungsung University, Pusan, Korea
[22] Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720
[23] University of Maryland, College Park, Maryland 20742
[24] University of Michigan, Ann Arbor, Michigan 48109
[25] Michigan State University, East Lansing, Michigan 48824
[26] Moscow State University, Moscow, Russia
[27] University of Nebraska, Lincoln, Nebraska 68588
[28] New York University, New York, New York 10003
[29] Northeastern University, Boston, Massachusetts 02115
[30] Northern Illinois University, DeKalb, Illinois 60115
[31] Northwestern University, Evanston, Illinois 60208
[32] University of Notre Dame, Notre Dame, Indiana 46556
[33] University of Oklahoma, Norman, Oklahoma 73019
[34] University of Panjab, Chandigarh 16-00-14, India
[35] Institute for High Energy Physics, 142-284 Protvino, Russia
[36] Purdue University, West Lafayette, Indiana 47907
[37] Rice University, Houston, Texas 77005
[38] Universidade Estadual do Rio de Janeiro, Brazil
[39] University of Rochester, Rochester, New York 14627
[40] CEA, DAPNIA/Service de Physique des Particules, CE-SACLAY, France
[41] Seoul National University, Seoul, Korea
[42] State University of New York, Stony Brook, New York 11794
[43] Tata Institute of Fundamental Research, Colaba, Bombay 400005, India
[44] University of Texas, Arlington, Texas 76019
[45] Texas A&M University, College Station, Texas 77843
(February 7, 2008)

Abstract

This report describes the first search for top squark pair production in the channel $\tilde{t}_1\bar{\tilde{t}}_1 \rightarrow b\bar{b}\tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow ee$+jets+$\not\!\!E_T$ using 74.9 ± 8.9 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.

PACS numbers: 14.80.Ly, 13.85.Rm

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. Due to large top family Yukawa interactions, the lighter top squark mass eigenstate ($\widetilde{t}_1$) can have a much lower mass than the other squarks [2]. Top squarks will be pair produced at the Tevatron; each will then decay into the lightest chargino $\widetilde{\chi}_1^{\pm}$ and a b quark if that decay is kinematically allowed. If $m_{\widetilde{\chi}_1^{\pm}}$ is greater than the mass of the top squark, the decay will proceed through slepton channels. If the sleptons are also heavier than the top squark, it will decay to a charm quark and the lightest supersymmetric particle (LSP or $\widetilde{\chi}_1^0$) with a 100% branching fraction.

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 is assumed to be stable and escapes 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 DØ Collaboration [3]. 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 [4]. Within the framework of the Minimal Supersymmetric Standard Model (MSSM) [5], the current limits on the pair production of charginos (which depend on the assumed value of the common scalar mass m_0) from LEP at $\sqrt{s}$ = 130, 136, and 161 GeV [6,7], lead to $m_{\widetilde{\chi}_1^{\pm}} > 62.0 - 78.5$ GeV/c^2 at the 95% CL [6]. The analysis described below is independent of the MSSM and supergravity [8] 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 [9] 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 DØ detector and data collection system are described in detail in Ref. [10]. 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 [11]. 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 $\frac{1}{2}m_{\widetilde{\chi}_1^\pm}$.

The signature for $\widetilde{t}_1\bar{\widetilde{t}}_1 \rightarrow b\bar{b}\widetilde{\chi}_1^+\widetilde{\chi}_1^-$ 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 $E_T^{\rm sum} = E_T^{e1} + E_T^{e2} + \not\!\!E_T$ (defined in Ref. [2] as bigness).

Cut optimization was done using the RGSEARCH [12] 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 $E_T^{\rm sum}$ were fixed while running RGSEARCH. The cut on m_{ee} was used to remove $Z \rightarrow ee$ events and that on $E_T^{\rm sum}$ to remove $t\bar{t} \rightarrow ee$+jets+$\not\!\!E_T$ events. Distributions of $E_T^{\rm sum}$ 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 $E_T^{e2} > 8$ 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 [13] using the jet misidentification probability for the electron identification and kinematic cuts used in this analysis ($(6.5 \pm 1.3) \times 10^{-4}$). 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% CL upper limit on $\sigma \cdot B$ using a Bayesian approach [14] 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 $m_{\widetilde{t}_1}$ with fixed $m_{\widetilde{\chi}_1^\pm} = 47$ GeV/c^2 is shown in Fig. 3 along with the predicted $\sigma \cdot B$. The choice of $m_{\widetilde{\chi}_1^\pm} = 47$ GeV/c^2 allows the widest range of $m_{\widetilde{t}_1}$. As can be seen, no limit on $m_{\widetilde{t}_1}$ can be set. The situation is similar for increased $m_{\widetilde{\chi}_1^\pm}$.

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 $\sigma \cdot B$ limit curve shown in Fig. 3 indicates the level of sensitivity in the current DØ data set to a particular topology for new physics: pair production of new particles which decay into leptons, jets, and non-interacting 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.

We thank H. Baer and X. Tata for useful discussions. We thank the staffs at Fermilab and the collaborating institutions for their contributions to the success of this work, and acknowledge support from the Department of Energy and National Science Foundation (U.S.A.), Commissariat à L'Energie Atomique (France), Ministries for Atomic Energy and Science and Technology Policy (Russia), CNPq (Brazil), Departments of Atomic Energy and Science and Education (India), Colciencias (Colombia), CONACyT (Mexico), Ministry of Education and KOSEF (Korea), CONICET and UBACyT (Argentina), and the A.P. Sloan Foundation.

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* Visitor from IHEP, Beijing, China.

† Visitor from Univ. San Francisco de Quito, Ecuador.

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TABLES

TABLE I. Background contributions from individual channels.

Background Channel	Number of Events
$t\bar{t}(170) \rightarrow ee$	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

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

$E_T^{e1} \geq 16$ GeV
$E_T^{e2} \geq 8$ GeV
$E_T^{j1} \geq 30$ GeV
$\not\!\!E_T \geq 22$ GeV
$m_{ee} \leq 60$ GeV/c^2
$E_T^{\rm sum} \leq 90$ GeV

FIGURES

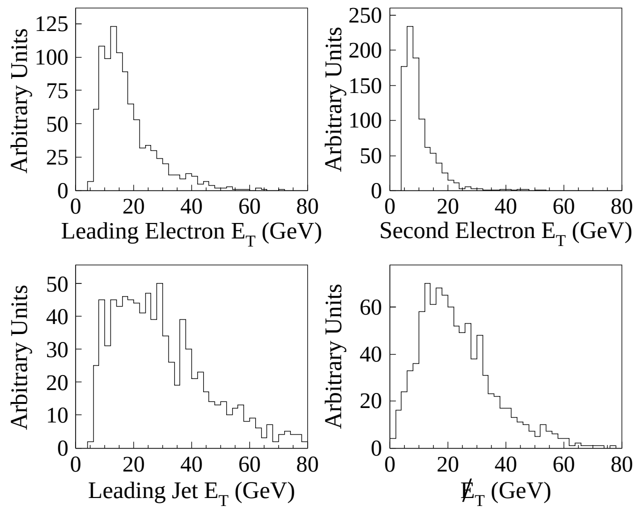

FIG. 1. Kinematic distributions for ($m_{\tilde{t}_1}$,$m_{\tilde{\chi}_1^\pm}$) = (65,47) GeV/c^2.

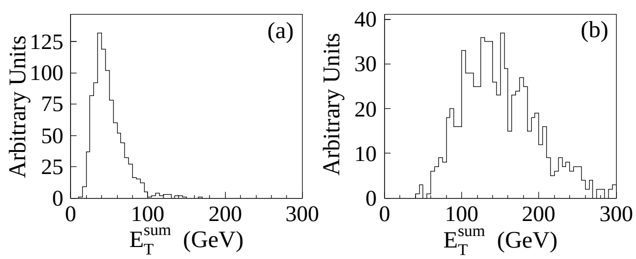

FIG. 2. Distributions of $E_T^{\rm sum}$ for (a) ($m_{\tilde{t}_1}$,$m_{\tilde{\chi}_1^\pm}$) = (65,47) GeV/c^2 and (b) top quark production with $m_t = 170$ GeV/c^2.

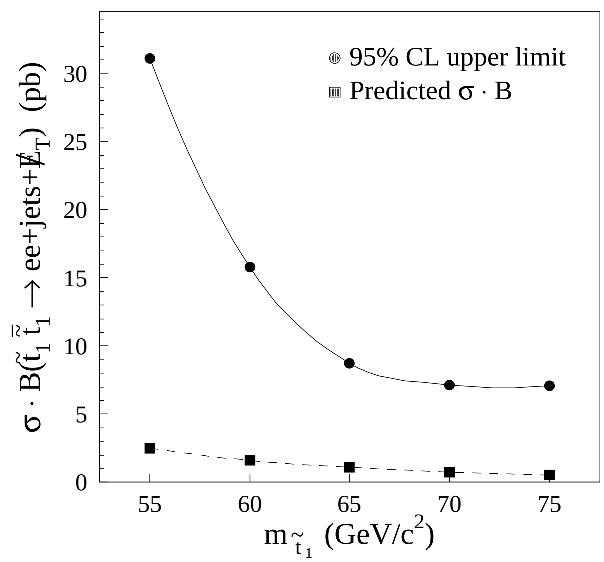

FIG. 3. Our 95% confidence level upper limit on $\sigma \cdot B$ as a function of $m_{\tilde{t}_1}$ for $m_{\tilde{\chi}_1^{\pm}} = 47$ GeV/c^2. Also shown are the predicted values from ISAJET.