



UvA-DARE (Digital Academic Repository)

Search for pair production of light scalar top quarks in $p(p)$ -bar collisions at root $s=1.8$ TeV

Abbott (et al.), B.; Balm, P.W.; Blekman, F.; Bos, K.; Peters, O.

Published in:
Physical Review Letters

[Link to publication](#)

Citation for published version (APA):

Abbott (et al.), B., Balm, P. W., Blekman, F., Bos, K., & Peters, O. (2004). Search for pair production of light scalar top quarks in $p(p)$ -bar collisions at root $s=1.8$ TeV. *Physical Review Letters*, 93, 011801.

General rights

It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations

If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: <http://uba.uva.nl/en/contact>, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.

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

V. M. Abazov,²¹ B. Abbott,⁵⁴ A. Abdesselam,¹¹ M. Abolins,⁴⁷ V. Abramov,²⁴ B. S. Acharya,¹⁷ D. L. Adams,⁵² M. Adams,³⁴ S. N. Ahmed,²⁰ G. D. Alexeev,²¹ A. Alton,⁴⁶ G. A. Alves,² Y. Arnoud,⁹ C. Avila,⁵ V. V. Babintsev,²⁴ L. Babukhadia,⁵¹ T. C. Bacon,²⁶ A. Baden,⁴³ S. Baffioni,¹⁰ B. Baldin,³³ P. W. Balm,¹⁹ S. Banerjee,¹⁷ E. Barberis,⁴⁵ P. Baringer,⁴⁰ J. Barreto,² J. F. Bartlett,³³ U. Bassler,¹² D. Bauer,³⁷ A. Bean,⁴⁰ F. Beaudette,¹¹ M. Begel,⁵⁰ A. Belyaev,³² S. B. Beri,¹⁵ G. Bernardi,¹² I. Bertram,²⁵ A. Besson,⁹ R. Beuselinck,²⁶ V. A. Bezzubov,²⁴ P. C. Bhat,³³ V. Bhatnagar,¹⁵ M. Bhattacharjee,⁵¹ G. Blazey,³⁵ F. Blekman,¹⁹ S. Blessing,³² A. Boehnlein,³³ N. I. Bojko,²⁴ T. A. Bolton,⁴¹ F. Borchering,³³ K. Bos,¹⁹ T. Bose,⁴⁹ A. Brandt,⁵⁶ G. Briskin,⁵⁵ R. Brock,⁴⁷ G. Brooijmans,⁴⁹ A. Bross,³³ D. Buchholz,³⁶ M. Buehler,³⁴ V. Buescher,¹⁴ V. S. Burtovoi,²⁴ J. M. Butler,⁴⁴ F. Canelli,⁵⁰ W. Carvalho,³ D. Casey,⁴⁷ H. Castilla-Valdez,¹⁸ D. Chakraborty,³⁵ K. M. Chan,⁵⁰ S. V. Chekulaev,²⁴ D. K. Cho,⁵⁰ S. Choi,³¹ S. Chopra,⁵² D. Claes,⁴⁸ A. R. Clark,²⁸ B. Connolly,³² W. E. Cooper,³³ D. Coppage,⁴⁰ S. Crépe-Renaudin,⁹ M. A. C. Cummings,³⁵ D. Cutts,⁵⁵ H. da Motta,² G. A. Davis,⁵⁰ K. De,⁵⁶ S. J. de Jong,²⁰ M. Demarteau,³³ R. Demina,⁵⁰ P. Demine,¹³ D. Denisov,³³ S. P. Denisov,²⁴ S. Desai,⁵¹ H. T. Diehl,³³ M. Diesburg,³³ S. Doulas,⁴⁵ L. V. Dudko,²³ L. Duflot,¹¹ S. R. Dugad,¹⁷ A. Duperrin,¹⁰ A. Dyshkant,³⁵ D. Edmunds,⁴⁷ J. Ellison,³¹ J. T. Eltzroth,⁵⁶ V. D. Elvira,³³ R. Engelmann,⁵¹ S. Eno,⁴³ P. Ermolov,²³ O. V. Eroshin,²⁴ J. Estrada,⁵⁰ H. Evans,⁴⁹ V. N. Evdokimov,²⁴ T. Ferbel,⁵⁰ F. Filthaut,²⁰ H. E. Fisk,³³ M. Fortner,³⁵ H. Fox,³⁶ S. Fu,⁴⁹ S. Fuess,³³ E. Gallas,³³ A. N. Galyaev,²⁴ M. Gao,⁴⁹ V. Gavrilov,²² R. J. Genik II,²⁵ K. Genser,³³ C. E. Gerber,³⁴ Y. Gershtein,⁵⁵ G. Ginther,⁵⁰ B. Gómez,⁵ P. I. Goncharov,²⁴ K. Gounder,³³ A. Goussiou,³⁸ P. D. Grannis,⁵¹ H. Greenlee,³³ Z. D. Greenwood,⁴² S. Grinstein,¹ L. Groer,⁴⁹ S. Grünendahl,³³ S. N. Gurzhiev,²⁴ G. Gutierrez,³³ P. Gutierrez,⁵⁴ N. J. Hadley,⁴³ H. Haggerty,³³ S. Hagopian,³² V. Hagopian,³² R. E. Hall,²⁹ C. Han,⁴⁶ S. Hansen,³³ J. M. Hauptman,³⁹ C. Hebert,⁴⁰ D. Hedin,³⁵ J. M. Heinmiller,³⁴ A. P. Heinson,³¹ U. Heintz,⁴⁴ M. D. Hildreth,³⁸ R. Hirosky,⁵⁸ J. D. Hobbs,⁵¹ B. Hoeneisen,⁸ J. Huang,³⁷ Y. Huang,⁴⁶ I. Iashvili,³¹ R. Illingworth,²⁶ A. S. Ito,³³ M. Jaffré,¹¹ S. Jain,⁵⁴ R. Jesik,²⁶ K. Johns,²⁷ M. Johnson,³³ A. Jonckheere,³³ H. Jöstlein,³³ A. Juste,³³ W. Kahl,⁴¹ S. Kahn,⁵² E. Kajfasz,¹⁰ A. M. Kalinin,²¹ D. Karmanov,²³ D. Karmgard,³⁸ R. Kehoe,⁴⁷ S. Kesisoglou,⁵⁵ A. Khanov,⁵⁰ A. Kharchilava,³⁸ B. Klima,³³ J. M. Kohli,¹⁵ A. V. Kostritskiy,²⁴ J. Kotcher,⁵² B. Kothari,⁴⁹ A. V. Kozelov,²² E. A. Kozlovsky,²⁴ J. Krane,³⁹ M. R. Krishnaswamy,¹⁷ P. Krivkova,⁶ S. Krzywdzinski,³³ M. Kubantsev,⁴¹ S. Kuleshov,²² Y. Kulik,³³ S. Kunori,⁴³ A. Kupco,⁷ V. E. Kuznetsov,³¹ G. Landsberg,⁵⁵ W. M. Lee,³² A. Leflat,²³ F. Lehner,^{33,*} C. Leonidopoulos,⁴⁹ J. Li,⁵⁶ Q. Z. Li,³³ J. G. R. Lima,³⁵ D. Lincoln,³³ S. L. Linn,³² J. Linnemann,⁴⁷ R. Lipton,³³ A. Lucotte,⁹ L. Lueking,³³ C. Lundstedt,⁴⁸ C. Luo,³⁷ A. K. A. Maciel,³⁵ R. J. Madaras,²⁸ V. L. Malyshev,²¹ V. Manankov,²³ H. S. Mao,⁴ T. Marshall,³⁷ M. I. Martin,³⁵ S. E. K. Mattingly,⁵⁵ A. A. Mayorov,²⁴ R. McCarthy,⁵¹ T. McMahon,⁵³ H. L. Melanson,³³ A. Melnitchouk,⁵⁵ M. Merkin,²³ K. W. Merritt,³³ C. Miao,⁵⁵ H. Miettinen,⁵⁷ D. Mihalcea,³⁵ N. Mokhov,³³ N. K. Mondal,¹⁷ H. E. Montgomery,³³ R. W. Moore,⁴⁷ Y. D. Mutaf,⁵¹ E. Nagy,¹⁰ M. Narain,⁴⁴ V. S. Narasimham,¹⁷ N. A. Naumann,²⁰ H. A. Neal,⁴⁶ J. P. Negret,⁵ S. Nelson,³² A. Nomerotski,³³ T. Nunnemann,³³ D. O'Neil,⁴⁷ V. Oguri,³ N. Oshima,³³ P. Padley,⁵⁷ K. Papageorgiou,³⁴ N. Parashar,⁴² R. Partridge,⁵⁵ N. Parua,⁵¹ A. Patwa,⁵¹ O. Peters,¹⁹ P. Pétrouff,¹¹ R. Piegaia,¹ B. G. Pope,⁴⁷ H. B. Prosper,³² S. Protopopescu,⁵² M. B. Przybycien,^{36,†} J. Qian,⁴⁶ S. Rajagopalan,⁵² P. A. Rapidis,³³ N. W. Reay,⁴¹ S. Reucroft,⁴⁵ M. Ridel,¹¹ M. Rijssenbeek,⁵¹ F. Rizatdinova,⁴¹ T. Rockwell,⁴⁷ C. Royon,¹³ P. Rubinov,³³ R. Ruchti,³⁸ B. M. Sabirov,²¹ G. Sajot,⁹ A. Santoro,³ L. Sawyer,⁴² R. D. Schamberger,⁵¹ H. Schellman,³⁶ A. Schwartzman,¹ E. Shabalina,³⁴ R. K. Shivpuri,¹⁶ D. Shpakov,⁴⁵ M. Shupe,²⁷ R. A. Sidwell,⁴¹ V. Simak,⁷ V. Sirotenko,³³ P. Slattery,⁵⁰ R. P. Smith,³³ G. R. Snow,⁴⁸ J. Snow,⁵³ S. Snyder,⁵² J. Solomon,³⁴ Y. Song,⁵⁶ V. Sorin,¹ M. Sosebee,⁵⁶ N. Sotnikova,²³ K. Soustruznik,⁶ M. Souza,² N. R. Stanton,⁴¹ G. Steinbrück,⁴⁹ D. Stoker,³⁰ V. Stolin,²² A. Stone,³⁴ D. A. Stoyanova,²⁴ M. A. Strang,⁵⁶ M. Strauss,⁵⁴ M. Strovink,²⁸ L. Stutte,³³ A. Sznajder,³ M. Talby,¹⁰ W. Taylor,⁵¹ S. Tentindo-Repond,³² T. G. Trippe,²⁸ A. S. Turcot,⁵² P. M. Tuts,⁴⁹ R. Van Kooten,³⁷ V. Vaniev,²⁴ N. Varelas,³⁴ F. Villeneuve-Seguié,¹⁰ A. A. Volkov,²⁴ A. P. Vorobiev,²⁴ H. D. Wahl,³² Z.-M. Wang,⁵¹ J. Warchol,³⁸ G. Watts,⁵⁹ M. Wayne,³⁸ H. Weerts,⁴⁷ A. White,⁵⁶ D. Whiteson,²⁸ D. A. Wijngaarden,²⁰ S. Willis,³⁵ S. J. Wimpenny,³¹ J. Womersley,³³ D. R. Wood,⁴⁵ Q. Xu,⁴⁶ R. Yamada,³³ T. Yasuda,³³ Y. A. Yatsunenko,²¹ K. Yip,⁵² J. Yu,⁵⁶ M. Zanabria,⁵ X. Zhang,⁵⁴ B. Zhou,⁴⁶ Z. Zhou,³⁹ M. Zielinski,⁵⁰ D. Zieminska,³⁷ A. Zieminski,³⁷ V. Zutshi,³⁵ E. G. Zverev,²³ and A. Zylberstein¹³

(D0 Collaboration)

¹Universidad de Buenos Aires, Buenos Aires, Argentina²LAFEX, Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil

- ³Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
⁴Institute of High Energy Physics, Beijing, People's Republic of China
⁵Universidad de los Andes, Bogotá, Colombia
⁶Charles University, Center for Particle Physics, Prague, Czech Republic
⁷Institute of Physics, Academy of Sciences, Center for Particle Physics, Prague, Czech Republic
⁸Universidad San Francisco de Quito, Quito, Ecuador
⁹Laboratoire de Physique Subatomique et de Cosmologie, IN2P3-CNRS, Université de Grenoble 1, Grenoble, France
¹⁰CPPM, IN2P3-CNRS, Université de la Méditerranée, Marseille, France
¹¹Laboratoire de l'Accélérateur Linéaire, IN2P3-CNRS, Orsay, France
¹²LPNHE, Universités Paris VI and VII, IN2P3-CNRS, Paris, France
¹³DAPNIA/Service de Physique des Particules, CEA, Saclay, France
¹⁴Universität Mainz, Institut für Physik, Mainz, Germany
¹⁵Panjab University, Chandigarh, India
¹⁶Delhi University, Delhi, India
¹⁷Tata Institute of Fundamental Research, Mumbai, India
¹⁸CINVESTAV, Mexico City, Mexico
¹⁹FOM-Institute NIKHEF and University of Amsterdam/NIKHEF, Amsterdam, The Netherlands
²⁰University of Nijmegen/NIKHEF, Nijmegen, The Netherlands
²¹Joint Institute for Nuclear Research, Dubna, Russia
²²Institute for Theoretical and Experimental Physics, Moscow, Russia
²³Moscow State University, Moscow, Russia
²⁴Institute for High Energy Physics, Protvino, Russia
²⁵Lancaster University, Lancaster, United Kingdom
²⁶Imperial College, London, United Kingdom
²⁷University of Arizona, Tucson, Arizona 85721, USA
²⁸Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720, USA
²⁹California State University, Fresno, California 93740, USA
³⁰University of California, Irvine, California 92697, USA
³¹University of California, Riverside, California 92521, USA
³²Florida State University, Tallahassee, Florida 32306, USA
³³Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA
³⁴University of Illinois at Chicago, Chicago, Illinois 60607, USA
³⁵Northern Illinois University, DeKalb, Illinois 60115, USA
³⁶Northwestern University, Evanston, Illinois 60208, USA
³⁷Indiana University, Bloomington, Indiana 47405, USA
³⁸University of Notre Dame, Notre Dame, Indiana 46556, USA
³⁹Iowa State University, Ames, Iowa 50011, USA
⁴⁰University of Kansas, Lawrence, Kansas 66045, USA
⁴¹Kansas State University, Manhattan, Kansas 66506, USA
⁴²Louisiana Tech University, Ruston, Louisiana 71272, USA
⁴³University of Maryland, College Park, Maryland 20742, USA
⁴⁴Boston University, Boston, Massachusetts 02215, USA
⁴⁵Northeastern University, Boston, Massachusetts 02115, USA
⁴⁶University of Michigan, Ann Arbor, Michigan 48109, USA
⁴⁷Michigan State University, East Lansing, Michigan 48824, USA
⁴⁸University of Nebraska, Lincoln, Nebraska 68588, USA
⁴⁹Columbia University, New York, New York 10027, USA
⁵⁰University of Rochester, Rochester, New York 14627, USA
⁵¹State University of New York, Stony Brook, New York 11794, USA
⁵²Brookhaven National Laboratory, Upton, New York 11973, USA
⁵³Langston University, Langston, Oklahoma 73050, USA
⁵⁴University of Oklahoma, Norman, Oklahoma 73019, USA
⁵⁵Brown University, Providence, Rhode Island 02912, USA
⁵⁶University of Texas, Arlington, Texas 76019, USA
⁵⁷Rice University, Houston, Texas 77005, USA
⁵⁸University of Virginia, Charlottesville, Virginia 22901, USA
⁵⁹University of Washington, Seattle, Washington 98195, USA

(Received 9 February 2004; published 29 June 2004)

Using $85.2 \pm 3.6 \text{ pb}^{-1}$ of $p\bar{p}$ collisions collected at $\sqrt{s} = 1.8 \text{ TeV}$ with the D0 detector at Fermilab's Tevatron Collider, we present the results of a search for direct pair production of scalar top quarks (\tilde{t}),

the supersymmetric partners of the top quark. We examined events containing two or more jets and missing transverse energy, the signature of light scalar top quark decays to charm quarks and neutralinos. After selections, we observe 27 events while expecting 31.1 ± 6.4 events from known standard model processes. Comparing these results to next-to-leading-order production cross sections, we exclude a significant region of \tilde{t} and neutralino phase space. In particular, we exclude the \tilde{t} mass $m_{\tilde{t}} < 122 \text{ GeV}/c^2$ for a neutralino mass of $45 \text{ GeV}/c^2$.

DOI: 10.1103/PhysRevLett.93.011801

PACS numbers: 14.80.Ly, 12.60.Jv

Supersymmetry (SUSY) [1–3], one of the major extensions 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, superpartners of the gauge particles, include neutralinos (prime candidates for dark matter). Squarks include the left-handed and right-handed scalar top quarks or top squarks. These weak eigenstates mix to provide the mass eigenstates \tilde{t}_1 and \tilde{t}_2 .

Generic SUSY searches often make the simplifying assumption of mass degeneracy of first and second generation squarks. The scalar top quark masses, however, are expected to be substantially smaller than those of all other squarks [4–6]. If sufficiently light, scalar top quarks should be produced strongly at the Fermilab Tevatron through $q\bar{q}$ annihilation and gluon-gluon fusion with a cross section on the order of that of the top quark [7,8]. According to the next-to-leading order program PROSPINO [9], a $100 \text{ GeV}/c^2$ scalar top quark has a production cross section of about 12 pb and a $120 \text{ GeV}/c^2$ scalar top quark of approximately 4.2 pb.

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, 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 $\tilde{t}_1 \rightarrow bW\tilde{\chi}_1^0$, $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{+*}$, and $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{+*}$ ($\tilde{\chi}_1^{+*} \rightarrow l^+\tilde{\nu}$ or $\tilde{\chi}_1^{+*} \rightarrow \tilde{l}^+\nu$). The dominant decay is then $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$, yielding an event signature of two jets with missing transverse energy (\cancel{E}_T). We make no attempt to tag the b or c hadrons in jets.

Characteristics of the scalar top quark signal were studied by generating Monte Carlo (MC) events for various combinations of $m_{\tilde{t}_1}$ and $m_{\tilde{\chi}_1^0}$, using ISAJET [10] with its implementation of ISASUSY [11]. These events were processed through a GEANT [12] simulation of the D0 detector, a simulation of the trigger, and the standard D0 reconstruction program.

The major SM backgrounds expected for this signal are multijet events with artificial \cancel{E}_T and vector boson (VB) production with associated jets. The VB backgrounds include those producing neutrinos and jets ($Z + 2 \text{ jets} \rightarrow \nu\nu + 2 \text{ jets}$ and $W + \text{ jets}$, 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 $W/Z + \text{ jet}$ production, while the VECBOS [14,15] Monte Carlo generator was used for $W/Z + 2 \text{ jets}$ events. In each case, the calculated cross sections were scaled to match internal D0 reconstruction and acceptance studies for $W/Z + n \text{ jets}$. We also used the cross section for $\tilde{t}\tilde{t}$ production measured at D0 [16] and the HERWIG generator to calculate the acceptance for the $\tilde{t}\tilde{t}$ background arising from top quark decays to an undetected charged lepton, a neutrino, and a jet.

The data correspond to an integrated luminosity of $85.2 \pm 3.6 \text{ pb}^{-1}$ collected during the 1994–1995 Tevatron run. The D0 detector consisted of a central tracking system and a uranium/liquid-argon calorimeter surrounded by a toroidal muon spectrometer. A detailed description of the D0 detector and data collection system can be found in Ref. [17]. Events were collected using a trigger requiring two jets, one with $E_T > 25 \text{ GeV}$ and the second with $E_T > 10 \text{ GeV}$, and $\cancel{E}_T > 25 \text{ GeV}$, but rejecting events in which the direction of the leading jet and the \cancel{E}_T are aligned within a polar angle of 14° . Jets are reconstructed off-line using an iterative cone algorithm [18] of radius 0.5 in $\eta - \phi$ space. A requirement of at least two jets with $E_T > 50 \text{ GeV}$, $\cancel{E}_T > 40 \text{ GeV}$, and *all jets* satisfying a difference in azimuth $\Delta\phi(\text{jet}, \cancel{E}_T) > 30^\circ$ guaranteed full trigger efficiency. To suppress VB backgrounds we removed events with electrons or muons with $E_T > 10 \text{ GeV}$.

Multijet backgrounds dominate this sample and arise when mismeasured jets or a misidentified interaction vertex induce an apparent \cancel{E}_T . Requiring $\Delta\phi(\text{jet}, \cancel{E}_T) < 165^\circ$ eliminates events with jets back to back to the \cancel{E}_T . We reduce the number of events with poorly measured jet energies by requiring that the $\Delta\phi$ between the \cancel{E}_T and the jet with the second highest E_T exceed 60° . We also removed those events in which jets deposited most of their energy within the narrow intercryostat region ($0.8 < |\eta| < 1.2$), where the central and end cap calorimeters meet. We refer to the 354 events surviving these criteria as our *base* sample (see Table I).

To reduce the background from mismeasured vertices, the central drift chamber (CDC) was used to associate charged tracks with jets within the fiducial volume of the CDC, $|\eta_d| < 1$ [19]. Event by event these tracks establish the origin of each jet, which was required to be no farther

TABLE I. Number of events surviving in the jets + \cancel{E}_T sample after the application of selection criteria. These 88 events form the clean sample.

Selection	Events
2 jets and \cancel{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
$\cancel{E}_T > 40$ GeV	13 752
$30 < \Delta\phi(\text{jet}, \cancel{E}_T) < 165^\circ$	4 650
$60 < \Delta\phi(\text{jet } 2, \cancel{E}_T)$	2 327
Lepton rejection	2 009
All jets reside outside D0 intercryostat region	354
Vertex confirmation	88

than 8 cm from the reconstructed event vertex. This *vertex confirmation* was 80% efficient for $W \rightarrow e\nu$ data samples in which electron tracks matched to electromagnetic calorimeter showers provided well-defined interaction vertices, while keeping the mismatched rate below 2%. Table I lists the observed number of events from the jets plus \cancel{E}_T sample that survive each selection cut down to this *clean* sample.

To predict the multijet background remaining in the clean sample, we used events from the base sample where the jet vertex position deviated by 15–50 cm from the event vertex. We normalized this *background* sample to the clean sample using events with $\Delta\phi(\text{jet } 2, \cancel{E}_T) < 60^\circ$ (where jet 2 refers to the jet with the second largest E_T). We chose the 50 cm value because it provides the best agreement between the background prediction and the data for the \cancel{E}_T region between 30 and 40 GeV, which is dominated by multijet events. Changing this value to 100 cm (the full width of the instrumented interaction region) increases the multijet prediction by 22%, which we take as an estimate of the systematic uncertainty of the method. Reversing the order of the vertex confirmation and $\Delta\phi(\text{jet } 2, \cancel{E}_T)$ selection with no change in the relative pass rate of events from our base sample showed they provide a legitimate criteria for separating subsets for this study. VB background, which includes, in decreasing order of importance $W \rightarrow \tau + \nu + 2$ jets, $Z \rightarrow \nu + \nu + 2$ jets, and $W \rightarrow \mu + 2$ jets, is comparable to the predicted background from multijet production (see Table II).

A random grid search (RGS) [20] based on the energy of the two leading jets and the \cancel{E}_T was used to optimize the final selection criteria to apply to the clean sample. RGS uses Monte Carlo-generated scalar top quark events to investigate the region of phase space most heavily populated by signal. The RGS was run for the mass points, $m_{\tilde{t}} = 115$ GeV/ c^2 and $m_{\tilde{\chi}_0} = 20$ GeV/ c^2 , and $m_{\tilde{t}} = 130$ GeV/ c^2 and $m_{\tilde{\chi}_0} = 30$ GeV/ c^2 optimizing rejection of background relative to signal by maximizing the quantity $N_{\text{signal}}/\sqrt{N_{\text{signal}} + N_{\text{background}}}$. This was sub-

TABLE II. A comparison of standard model and QCD multi-jet backgrounds to the number of candidates in the clean and final RGS optimized samples. For $W/Z/\tilde{t}\tilde{t}$ the first uncertainty is statistical, the second systematic. For QCD and the total observed, the statistical and systematic uncertainties have been added in quadrature.

Source	Events in <i>clean</i> sample	Events in optimized sample
W/Z	$63.0 \pm 6.9^{+18.1}_{-12.4}$	$24.2 \pm 3.6^{+9.0}_{-6.3}$
$\tilde{t}\tilde{t}$	$3.9 \pm 0.02^{+0.2}_{-0.5}$	$3.4 \pm 0.02^{+0.2}_{-0.04}$
QCD multijet	22.5 ± 7.5	3.6 ± 1.4
Total background	89.5 ± 14.7	31.1 ± 6.4
Data	88	27

ject to the requirements of $> 2\%$ efficiency for signal, while restricting multijet backgrounds to account for no more than 50% of the total background. The selection criteria as determined by RGS for each mass point was within 1–2 GeV of our final cuts, chosen to be leading jet $E_T > 60$ GeV, second jet $E_T > 50$ GeV, and $\cancel{E}_T > 60$ GeV. Our final sample and estimated background are reported in Table II. Figure 1 compares data and background for several physics distributions. The additional contribution for a 130 GeV/ c^2 scalar top quark, 30 GeV/ c^2 neutralino signal is indicated by the cross-hatched regions on the figure.

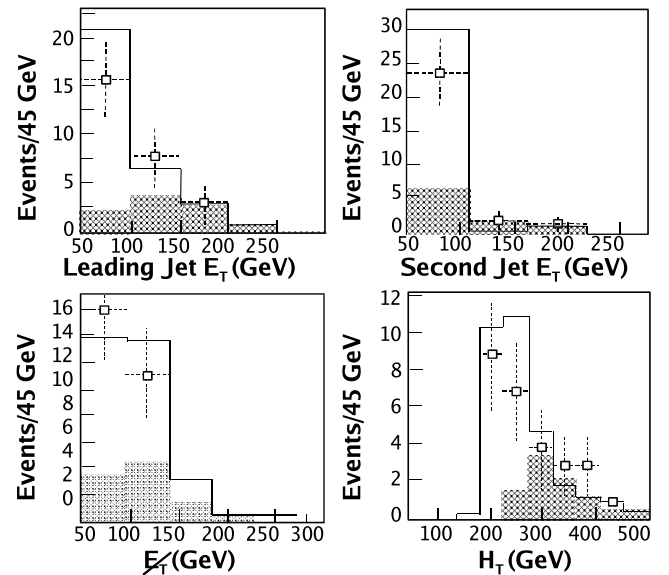


FIG. 1. Data (points) and predicted background (histograms) after final selections. The additional contributions expected from a $M_{\tilde{t}} = 130$ GeV/ c^2 , $M_{\tilde{\chi}_0} = 30$ GeV/ c^2 scalar top quark are shown by shaded histograms. The plots correspond to the E_T of the leading jet, second jet, \cancel{E}_T (the three parameters optimized using the RGS), and H_T , where $H_T = \cancel{E}_T + \sum_i E_T(\text{jet}_i)$, to demonstrate agreement with variables not directly optimized via RGS.

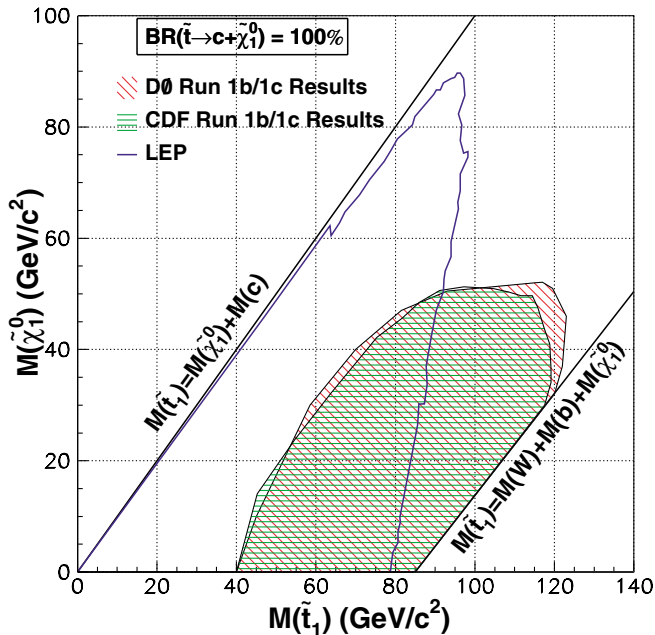


FIG. 2 (color online). Regions in the $(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0})$ plane excluded at the 95% confidence level assuming 100% branching of $\tilde{t} \rightarrow c\tilde{\chi}_1^0$. Limits from the CERN e^+e^- collider LEP [21] and Collider Detector and Fermilab (CDF) [22] are also shown in the figure. The dashed lines correspond to kinematic cutoffs from the masses of the $\tilde{\chi}_1^0$, m_c , m_b , and m_W .

We find the number of observed events is consistent with expected background. Errors on signal efficiencies and the fraction of background events passing final selection include the statistical uncertainties from finite MC samples and systematics from the jet energy scale (about 7%), luminosity (4.3%), and W/Z cross sections (about 6%). The systematic uncertainty in simulating the trigger is dominated by a hardware trigger response (introducing a 5% uncertainty in acceptance). The systematic uncertainty in identifying leptons in data ranged from 2%–12% (with dependence on the detector $\eta - \phi$ position of the lepton and jet multiplicity), and the vertex confirmation procedure includes a systematic 1% in its efficiency. The signal acceptance of the final selection for a scalar top quark mass of $M_{\tilde{t}} = 115 \text{ GeV}/c^2$, $M_{\tilde{\chi}_1^0} = 40 \text{ GeV}/c^2$ was $2.7\% \pm 0.1\%$. This null result can be represented by a region of exclusion in the $(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0})$ plane, which is shown in Fig. 2 (along with results from previous experiments). A Bayesian method, using a flat prior for the signal cross section and Gaussian priors for background and acceptance, sets the 95% confidence level (C.L.) upper limits. The highest excluded scalar top quark mass value excluded is $122 \text{ GeV}/c^2$ for a neutralino mass of $45 \text{ GeV}/c^2$. The highest excluded neutralino mass excluded is $52 \text{ GeV}/c^2$ for a $117 \text{ GeV}/c^2$ scalar top quark mass.

We thank the staffs at Fermilab and collaborating institutions, and acknowledge support from the Department

of Energy and National Science Foundation (USA), Commissariat à l'Énergie Atomique and CNRS/Institut National de Physique Nucléaire et de Physique des Particules (France), Ministry for Science and Technology and Ministry for Atomic Energy (Russia), CAPES, CNPq, and FAPERJ (Brazil), Departments of Atomic Energy and Science and Education (India), Colciencias (Colombia), CONACyT (Mexico), Ministry of Education and KOSEF (Korea), CONICET and UBACyT (Argentina), The Foundation for Fundamental Research on Matter (The Netherlands), PPARC (United Kingdom), Ministry of Education (Czech Republic), A. P. Sloan Foundation, and the Research Corporation.

*Visitor from University of Zurich, Zurich, Switzerland.

†Visitor from Institute of Nuclear Physics, Krakow, Poland.

- [1] H. Haber and G. Kane, *Phys. Rep.* **117**, 75 (1985).
- [2] H. Nilles, *Phys. Rep.* **110**, 1 (1984).
- [3] X. Tata, in *The Standard Model and Beyond*, edited by J. Kim (World Scientific, Singapore, 1991), p. 304.
- [4] H. Baer, M. Drees, R. Godbole, J. F. Gunion, and X. Tata, *Phys. Rev. D* **44**, 725 (1991).
- [5] H. Baer, J. Sender, and X. Tata, *Phys. Rev. D* **50**, 4517 (1994).
- [6] R. Demina, J. D. Lykken, K. T. Matchev, and A. Nomeroski, *Phys. Rev. D* **62**, 035011 (2000).
- [7] J. Ellis and S. Rudaz, *Phys. Lett.* **128B**, 248 (1983); A. Bouquet, J. Kaplan, and C. Savoy, *Nucl. Phys.* **B262**, 299 (1985).
- [8] D0 Collaboration, S. Abachi *et al.*, *Phys. Rev. Lett.* **74**, 2632 (1995); CDF Collaboration, F. Abe *et al.*, *Phys. Rev. Lett.* **74**, 2626 (1995).
- [9] W. Beenakker, R. Hopker, and M. Spira, hep-ph/9611232 (unpublished).
- [10] Computer code ISAJET, version 7.13, in F. Paige and S. Protopopescu, Brookhaven National Laboratory Report No. 38304, 1986 (unpublished).
- [11] H. Baer *et al.*, in *Proceedings of the Workshop on Physics at the Current Accelerators and Supercolliders*, edited by J. Hewett (Argonne National Laboratory, Argonne, IL, 1993), p. 703.
- [12] Computer code GEANT, version 3.15, in R. Brun and C. Carminati, CERN Program Library W5013, 1993 (unpublished).
- [13] M. Bengtsson and T. Sjöstrand, *Comput. Phys. Commun.* **43**, 367 (1987); S. Mrenna, *Comput. Phys. Commun.* **101**, 232 (1997); T. Sjöstrand, L. Lonnblad, and S. Mrenna, hep-ph/0108264 (unpublished).
- [14] F. A. Berends, H. Kuijff, B. Tausk, and W. T. Giele, *Nucl. Phys.* **B357**, 32 (1990).
- [15] W. Beenakker, F. A. Berends, and T. Sack, *Nucl. Phys.* **B367**, 287 (1991).
- [16] D0 Collaboration, B. Abbott *et al.*, *Phys. Rev. D* **60**, 012001 (1999).

- [17] D0 Collaboration, S. Abachi *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **338**, 185 (1994), and references therein.
- [18] D0 Collaboration, B. Abbott *et al.*, Phys. Rev. D **64**, 032003 (2001).
- [19] η_d refers to the pseudorapidity measured relative to the center of the detector.
- [20] H. B. Prosper *et al.*, in *Proceedings of the International Conference on Computing in High Energy Physics '95* (World Scientific, River Edge, New Jersey, 1996).
- [21] LEP SUSY Working Group, J. Abdallah *et al.*, http://lepsusy.web.cern.ch/lepsusy/www/squarks_summer02/squarks_pub.html; http://lepsusy.web.cern.ch/lepsusy/www/squarks_summer02/st_c_mass_lim_192208_lr.eps.gz (unpublished); ALEPH, Phys. Lett. B **537**, 5 (2002); OPAL, Phys. Lett. B **545**, 272 (2002); **548**, 258(E) (2002).
- [22] CDF Collaboration, T. Affolder *et al.*, Phys. Rev. Lett. **84**, 5704 (2000).