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

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FERMILAB-Pub-04/016-E February 2004

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. Borcherding,[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. Crépé-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,[24] 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. Pétroff,[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. Sorín,[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-Seguier,[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. Zylberstejn[13]
(DØ Collaboration)

[1] *Universidad de Buenos Aires, Buenos Aires, Argentina*

[2] *LAFEX, Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil*

[3] *Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*

[4] *Institute of High Energy Physics, Beijing, People's Republic of China*

[5] *Universidad de los Andes, Bogotá, Colombia*

[6] *Charles University, Center for Particle Physics, Prague, Czech Republic*

[7] *Institute of Physics, Academy of Sciences, Center for Particle Physics, Prague, Czech Republic*

[8] *Universidad San Francisco de Quito, Quito, Ecuador*

[9] *Laboratoire de Physique Subatomique et de Cosmologie, IN2P3-CNRS, Universite de Grenoble 1, Grenoble, France*

[10] *CPPM, IN2P3-CNRS, Université de la Méditerranée, Marseille, France*

[11] *Laboratoire de l'Accélérateur Linéaire, IN2P3-CNRS, Orsay, France*

[12] *LPNHE, Universités Paris VI and VII, IN2P3-CNRS, Paris, France*

[13] *DAPNIA/Service de Physique des Particules, CEA, Saclay, France*

[14] *Universität Mainz, Institut für Physik, Mainz, Germany*

[15] *Panjab University, Chandigarh, India*

[16] *Delhi University, Delhi, India*

[17] *Tata Institute of Fundamental Research, Mumbai, India*

[18] *CINVESTAV, Mexico City, Mexico*

[19] *FOM-Institute NIKHEF and University of Amsterdam/NIKHEF, Amsterdam, The Netherlands*

[20] *University of Nijmegen/NIKHEF, Nijmegen, The Netherlands*

[21] *Joint Institute for Nuclear Research, Dubna, Russia*

[22] *Institute for Theoretical and Experimental Physics, Moscow, Russia*

[23] *Moscow State University, Moscow, Russia*

[24] *Institute for High Energy Physics, Protvino, Russia*

[25] *Lancaster University, Lancaster, United Kingdom*

[26] *Imperial College, London, United Kingdom*

[27]*University of Arizona, Tucson, Arizona 85721*
[28]*Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720*
[29]*California State University, Fresno, California 93740*
[30]*University of California, Irvine, California 92697*
[31]*University of California, Riverside, California 92521*
[32]*Florida State University, Tallahassee, Florida 32306*
[33]*Fermi National Accelerator Laboratory, Batavia, Illinois 60510*
[34]*University of Illinois at Chicago, Chicago, Illinois 60607*
[35]*Northern Illinois University, DeKalb, Illinois 60115*
[36]*Northwestern University, Evanston, Illinois 60208*
[37]*Indiana University, Bloomington, Indiana 47405*
[38]*University of Notre Dame, Notre Dame, Indiana 46556*
[39]*Iowa State University, Ames, Iowa 50011*
[40]*University of Kansas, Lawrence, Kansas 66045*
[41]*Kansas State University, Manhattan, Kansas 66506*
[42]*Louisiana Tech University, Ruston, Louisiana 71272*
[43]*University of Maryland, College Park, Maryland 20742*
[44]*Boston University, Boston, Massachusetts 02215*
[45]*Northeastern University, Boston, Massachusetts 02115*
[46]*University of Michigan, Ann Arbor, Michigan 48109*
[47]*Michigan State University, East Lansing, Michigan 48824*
[48]*University of Nebraska, Lincoln, Nebraska 68588*
[49]*Columbia University, New York, New York 10027*
[50]*University of Rochester, Rochester, New York 14627*
[51]*State University of New York, Stony Brook, New York 11794*
[52]*Brookhaven National Laboratory, Upton, New York 11973*
[53]*Langston University, Langston, Oklahoma 73050*
[54]*University of Oklahoma, Norman, Oklahoma 73019*
[55]*Brown University, Providence, Rhode Island 02912*
[56]*University of Texas, Arlington, Texas 76019*

[57] *Rice University, Houston, Texas 77005*

[58] *University of Virginia, Charlottesville, Virginia 22901*

[59] *University of Washington, Seattle, Washington 98195*

Abstract

Using 85.2±3.6 pb^{-1} of $p\bar{p}$ collisions collected at $\sqrt{s}$=1.8 TeV with the DØ 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 $m_{\tilde{t}} < 122$ GeV/c^2 for a neutralino mass of 45 GeV/c^2.

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 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]. According to the next-to-leading order (NLO) program PROSPINO [9], a 100 GeV/c^2 scalar top quark has a production cross section of about 12 pb, and a 120 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 (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 $\tilde{t}_1 \to bW\tilde{\chi}_1^0$, $\tilde{t}_1 \to b\tilde{\chi}_1^+$, 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 made no attempt to identify jet flavor.

Characteristics of scalar top quark signal were studied by generating Monte Carlo (MC) events for various combinations of $m_{\tilde{t}_1}$ and $m_{\tilde{\chi}_1^0}$, ISAJET [10] with its implementation of ISASUSY [11]. These events were processed through 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 calculated cross sections were scaled to match measurements made at DØ for W/Z + jets events. We also used the cross section for $t\bar{t}$ production measured at DØ [16] and the HERWIG generator to calculate the acceptance for $t\bar{t}$ background arising from top quark decays to an unobserved charged lepton, a neutrino, and a jet.

The data correspond to an integrated luminosity of 85.2 ± 3.6 pb^{-1} collected during the 1994 – 1995 Tevatron run. The DØ detector consisted of a central tracking system and a 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 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, but 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 required at least two jets, each with E_T>50 GeV, $\not\!\!E_T > 40$ GeV, and all jets satisfying a difference in azimuth $\Delta\phi(\text{jet}, \not\!\!E_T) > 30°$. This guaranteed full trigger efficiency. To suppress VB backgrounds, we removed events containing electrons or muons with E_T>10 GeV.

Multijet backgrounds dominate this sample and arise when mismeasured jets or a misidentified interaction vertex induce an apparent $\not\!\!E_T$. To reduce effects from poorly measured jets we removed those events in which jets deposit most of their energy within the region of the calorimeter that has coarse energy sampling. Requiring $\Delta\phi(\text{jet}, \not\!\!E_T) < 165°$ eliminates events with jets back-to-back with $\not\!\!E_T$. We refer to the collection of events surviving these criteria 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 the region of $|\eta_d| < 1$ [18], 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 criterion, applied to all tracks in each event, optimized effciency versus error on track-matched $W \to e\nu$ data samples. Table I lists the observed number of events from the jets plus $\not\!\!E_T$ sample that survive each selection cut down to this *clean* sample.

To predict the multijet background in the *clean* sample, we used a collection of 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 $\Delta\phi(\text{jet 2}, \not\!\!E_T) < 60°$ (where jet 2 refers to the jet with the second largest E_T). We chose the 50 cm value because

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
$30^\circ < \Delta\phi(\text{jet}, \not\!\!E_T) < 165^\circ)$	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.

Source	Events in *clean* sample	Events in optimized sample
W/Z	$63.04 \pm 6.92\ ^{+18.08}_{-12.42}$	$24.15 \pm 3.64\ ^{+8.95}_{-6.34}$
$t\bar{t}$	$3.93 \pm 0.02\ ^{+0.23}_{-0.50}$	$3.40 \pm 0.02\ ^{+0.23}_{-0.04}$
QCD Multijet	22.5 ± 7.5	3.55 ± 1.4
Total Background	89.5 ± 14.7	31.1 ± 6.4
Data	88	27

TABLE II: A comparison of Standard Model and QCD multijet backgrounds to the number of candidates in the *clean* and final RGS optimized samples. For W/Z/$t\bar{t}$ the first uncertainty is statistical, the second systematic. For QCD and the total observed, the single uncertainty combines statistical plus systematic.

it provides the best agreement 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 (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. Vector Boson background, which include, in order of contribution $W \rightarrow \tau + \nu +$ 2jets, $Z \rightarrow \nu + \nu +$ 2jets and $W \rightarrow \mu +$ 2jets, are now comparable to the predicted multijet background (see table II).

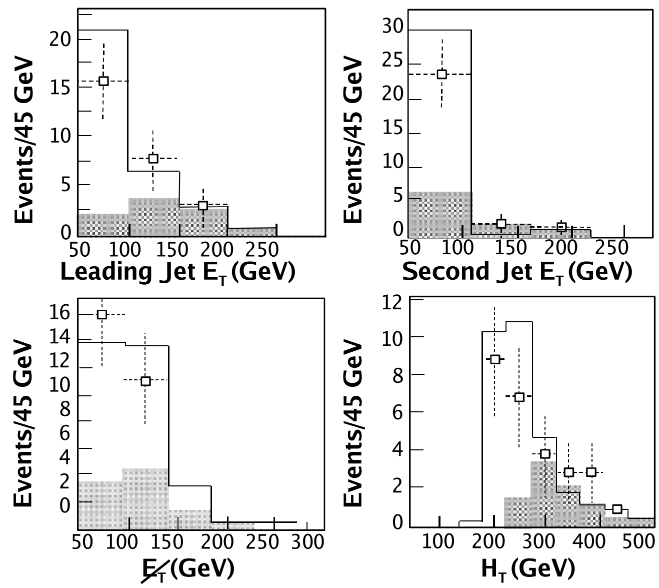

FIG. 1: Data (points) and predicted background (histograms) after final selections. The additional contributions expected from a 130 GeV/c^2 scalar top quark are shown by shaded histograms. The plots correspond to the E_T of the leading jet, second jet, $\not{E}_T$ (the three parameters optimized using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

A random grid search (RGS) [19] was used to optimize the final criteria to be applied 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. We ran the RGS for the mass points, $m_{\tilde{t}} = 115$ GeV/c^2 and $m_{\tilde{\chi}} = 20$ GeV/c^2, and $m_{\tilde{t}} = 130$ GeV/c^2 and $m_{\tilde{\chi}} = 30$ GeV/c^2 and optimized our rejection of background relative to signal by maximizing the quantity $N_{\text{signal}}/\sqrt{N_{\text{signal}} + N_{\text{background}}}$, subject to the requirements of $> 2\%$ efficiency for signal, and multijet backgrounds accounting for $< 50\%$ of the total background. Our final selection and estimated background are reported in Table II. Figure 1 compares data and background for several physics distributions. An additional contribution for a 130 GeV/c^2 scalar top quark signal is indicated by the cross-hatched regions on the figure.

We find the number of selected events to be consistent with expected background. This 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 previous results from other experiments). A Bayesian method using a flat prior for the signal cross section and Gaussian priors for background and acceptance

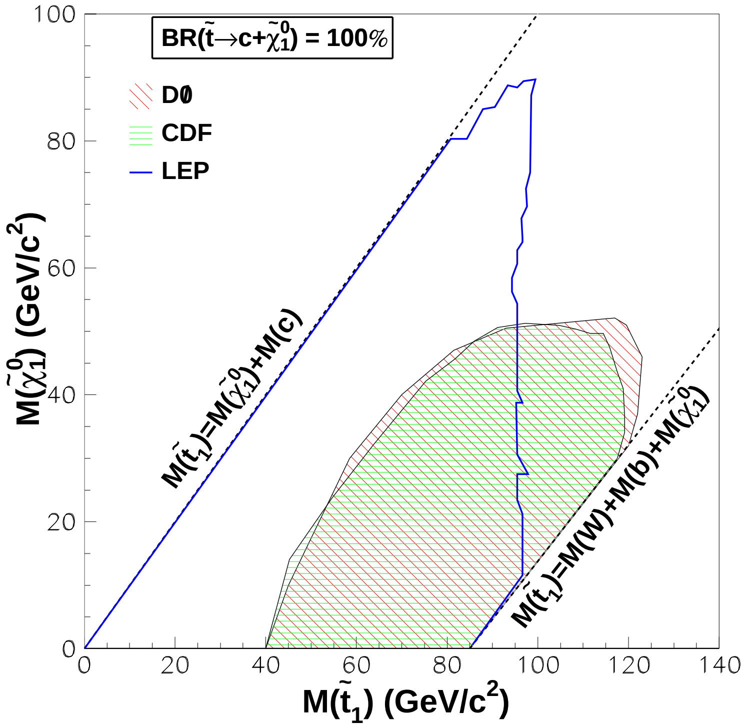

FIG. 2: Limits on the scalar top quark pair production cross section at 95% confidence, as a function of $m_{\tilde{t}}$ and $m_{\tilde{\chi}_1^0}$ assuming 100% branching of $\tilde{t} \rightarrow c\chi_1^0$. Limits from LEP [20] and CDF [21] are also shown in the figure. The dashed lines correspond to kinematic cutoffs from the masses of the χ_1^0, m_c, m_b and m_W.

uncertainties, is used to determine our 95% confidence level (CL) upper limits. 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.

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'Energie 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.

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[*] Visitor from University of Zurich, Zurich, Switzerland.

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

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