Search for Scalar Top Quark Production in $pp$ Collisions at $\sqrt{s} = 1.96$ TeV

T. Aalto, B. Álvarez González, S. Amerio, D. Amidei, A. Anastassov, A. Annovi, J. Antos, G. Apollinari, J.A. Appel, T. Arisawa, A. Artikov, J. Asaadi, W. Ashmanskas, B. Auerbach, A. Aurisano, F. Azfar, W. Badgett, T. Bae, A. Barbaro-Galtieri, V.E. Barnes, B.A. Barnett, P. Barria, P. Bartos, M. Bauge, F. Bedeschi, S. Behari, G. Bellettini, J. Belling, D. Benjamin, A. Beretvas, A. Bhatti, D. Bisenio, I. Bizjak, K.R. Bland, B. Blumenfeld, A. Bocci, A. Bodek, D. Bortoletto, J. Boudreau, A. Boveia, L. Brigliardio, C. Bromberg, E. Brucken, J. Budagov, H.S. Budd, K. Burkett, G. Busetto, P. Bussey, A. Buzatu, A. Calamba, C. Calancha, S. Camarda, M. Campanelli, M. Campbell, C. Canelli, B. Carlso, R. Carosi, S. Carrillo, S. Carron, B. Casal, M. Casarsa, A. Castro, P. Castaniti, D. Cauz, V. Cavaliere, M. Cavalli-Sforza, C. Cerri, L. Cerrito, Y.C. Chen, M. Chertok, G. Chiarelli, G. Chlachidze, F. Chlebana, K. Cho, D. Chokheli, M. Chung, M.A. Ciocci, A. Clark, C. Clarke, G. Compostella, M.E. Convery, J. Conway, M. Corbo, M. Cordelli, C.A. Cox, D.J. Cox, F. Crescioli, J. Cuevas, R. Culbertson, D. Dagenhart, N. d’Askenazi, M. Datta, P. de Barbaro, M. Dell’Orso, L. Demortier, D. Denino, F. Devoto, M. d’Errico, A. Di Canto, B. Di Ruzza, J.R. Dittmann, M. D’Onofrio, S. Donati, P. Dong, M. Dorigo, T. Dorigo, K. Ebina, A. Elagin, A. Eppig, R. Erbacher, S. Errede, N. Ershaidat, F. Devoto, K. Ebina, M. Eusebi, M. Fallica, D. Farrington, M. Feindt, J.P. Fernandez, R. Field, G. Flanagan, M.J. Frank, M. Franklin, J.C. Freeman, Y. Funakoshi, I. Furic, M. Gallinaro, J.E. Garcia, A.F. Garfinkel, P. Garzelli, H. Gerberich, E. Gerchtein, S. Giagu, V. Giakoumopoulou, P. Giannetti, K. Gibson, C.M. Ginsburg, N. Giokaris, P. Gironimi, G. Giolou, V. Glagolev, D. Glezinski, M. Gold, N. Goldschmidt, G. Golossanov, G. Gomez, G. Gomez-Ceballos, M. Goncharov, O. Gonzalez, I. Gorelov, A.T. Goshaw, K. Goulianos, G. Grillstein, C. Grosso-Pilcher, R.C. Group, J. Guimaraes da Costa, S.R. Hahn, E. Halkiadakis, A. Hamaguchi, J.Y. Han, F. Happacher, K. Har, H. Hare, F.R. Harr, K. Hatakeyama, C. Hays, M. Heek, J. Heinrich, M. Herndon, S. Hewamanage, A. Hocker, W. Hopkins, D. Horn, S. Hou, R.E. Hughes, M. Hurwitz, U. Husemann, N. Hussain, M. Hussein, J. Huston, G. Iorio, A. Ivanov, E. James, D. Jang, B. Jayatilaka, E.J. Jeon, S. Jindariani, M. Jones, K.K. Joo, S.Y. Jun, T.R. Jung, T. Kamon, P.E. Karchin, A. Kasmi, Y. Kato, W. Ketchum, J. Keung, V. Khotilovich, B. Kilminster, D.H. Kim, H.S. Kim, J.E. Kim, M.J. Kim, S.B. Kim, S.H. Kim, Y.K. Kim, Y.J. Kim, N. Kinuma, M. Kirby, S. Klimento, K. Knoepfel, K. Kondo, D.J. Kong, J. Konigsberg, A.V. Kotwal, M. Kreps, J. Kroll, D. Krop, M. Kruse, V. Krutelyov, T. Kuhr, M. Kurata, S. Kwang, A.T. Laasanen, S. Lami, S. Lammel, M. Lancaster, R.L. Lander, K. Lannon, A. Lath, G. Latino, T. LeCompte, E. Lee, H.S. Lee, J.S. Lee, S.W. Lee, S. Leed, J.D. Lewis, A. Limasoni, C.-J. Lin, M. Lindgren, E. Lipeles, A. Lister, D.O. Litvintsev, C. Liu, H. Liu, Q. Liu, T. Liu, S. Lockwitz, A. Lognin, D. Luchessi, J.Lukec, P. Luej, P. Lujan, P. Lukens, G. Lungu, J. Lys, R. Lysak, R. Madrak, K. Maeshima, P. Maestro, S. Malik, G. Manca, A. Manousakis-Katsikakis, F. Margaroli, C. Marino, M. Martin, P. Mastrandrea, K. Matterna, M.E. Mattson, A. Mazzacane, P. Mazzanti, K.S. McFarland, P. McIntyre, R. McNulty, A. Mehta, P. Mehtala, C. Mesropian, T. Miao, D. Mietlicki, A. Mitra, H. Miyake, S. Moed, N. Moggi, M.N. Mondragon, C.S. Moon, R. Moore, M.J. Morello, J. Morlock, P. Movilla Fernandez, A. Mukherjee, T. Muller, P. Murat, M. Mussini, J. Nachtman, Y. Nagai, J. Nagana, I. Nakano, Z. Napier, J. Nett, C. Neu, M.S. Neubauer, J. Nielsen, L. Nodulman, S.Y. Noh, O. Ornella, L. Oakes, S.H. Oh, Y.D. Oh, I. Oksuzian, T. Okusawa, R. Orava, L. Ortolan, S. Pagan Griso, C. Pagliarone, M.E. Palencia, V. Papadimitriou, A.A. Paramonov, J. Patrick, G. Pauletta, M. Paulini, C. Paus, D.E. Pellett, A. Penzo, T.J. Phillips, G. Piacentino, E. Pianori, J. Pilot, K. Pitts, C. Plager, L. Pondrom, S. Poprocki, K. Potamianos, P. Prokoshin, A. Pranko, F. Ptoshkin, G. Punzi, A. Rahaman, V. Ramakrishnan, N. Ranjan, I. Redondo, P. Renton, M. Rescigno, T. Riddick, P. Rimondi, L. Ristori, A. Robson, T. Rodrigo, T. Rodriguez, E. Rogers, S. Rolli, R. Roser, F. Ruffini, A. Ruiz, J. Russ, V. Rusu, A. Safonov, W.K. Sakamoto, Y. Sakurai, S. Santi, K. Sato.  

* Deceased.
With visitors from C. A. Savoy-Navarro, P. Schlabach, A. Schmidt, E. E. Schmidt, T. Schwarz, L. Scodellaro, A. Scribano, R. F. Scuri, S. Seidel, Y. Seiya, A. Semenov, S. F. Sforza, S. Z. Shalhout, T. Shears, P. Shepard, M. Shimojima, M. Shochet, I. Shreyber-Tecker, A. Simonenko, P. Sinervo, K. Sliwa, J. R. Smith, F. D. Snider, A. Soha, V. Sorin, H. Song, P. Squillacioti, M. Stancari, R. St. Denis, B. Stelzer, O. Stelzer-Chilton, D. Stentz, J. Strologas, G. L. Stricker, Y. Sudo, A. Sukhanov, I. Suslov, K. Takeuchi, J. Tang, M. Techco, P. K. Teng, J. Thom, G. A. Thompson, E. Thomson, D. Toback, S. Tokar, K. Tollefon, T. Tomura, D. Tonelli, S. Torre, D. Torretta, P. Totaro, M. Trovato, F. U. U. K. Yang, Y. C. Yang, Y. K. Yeh, Y. Yoh, K. Yorita, T. Yoshida, G. B. Yu, J. Yu, S. S. Yu, J. C. Yun, A. Zanetti, Y. Zeng, C. Zhou, S. Zucchelli

(CDF Collaboration)

1. Institute of Physics, Academia Sinica, Taipei, Taiwan 11529, Republic of China
2. Argonne National Laboratory, Argonne, Illinois 60439, USA
3. University of Athens, 157 71 Athens, Greece
4. Institut de Fisica d’Altes Energies, ICREA, Universitat Autonoma de Barcelona, E-08193, Bellaterra (Barcelona), Spain
5. Baylor University, Waco, Texas 76798, USA
6. Istituto Nazionale di Fisica Nucleare Bologna, University of Bologna, I-40127 Bologna, Italy
7. University of California, Davis, California 95616, USA
8. University of California, Los Angeles, Los Angeles, California 90024, USA
9. Instituto de Fisica de Cantabria, CSIC-Universidad de Cantabria, 39005 Santander, Spain
10. Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA
11. Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637, USA
12. Comenius University, 842 48 Bratislava, Slovakia; Institute of Experimental Physics, 040 01 Kosice, Slovakia
13. Joint Institute for Nuclear Research, RU-141980 Dubna, Russia
14. Duke University, Durham, North Carolina 27708, USA
15. Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA
16. University of Florida, Gainesville, Florida 32611, USA
17. Laboratori Nazionali di Frascati, Istituto Nazionale di Fisica Nucleare, I-00044 Frascati, Italy
18. University of Geneva, CH-1211 Geneva 4, Switzerland
19. Glasgow University, Glasgow G12 8QQ, United Kingdom
20. Harvard University, Cambridge, Massachusetts 02138, USA
21. Division of High Energy Physics, Department of Physics, University of Helsinki and Helsinki Institute of Physics, FI-00014, Helsinki, Finland
22. University of Illinois, Urbana, Illinois 61801, USA
23. The Johns Hopkins University, Baltimore, Maryland 21218, USA
24. Institut für Experimentelle Kernphysik, Karlsruhe Institute of Technology, D-76131 Karlsruhe, Germany
25. Center for High Energy Physics, Kyungpook National University, Daegu 702-701, Korea; Seoul National University, Seoul 151-742, Korea; Sungkyunkwan University, Suwon 440-746, Korea; Korea Institute of Science and Technology Information,

With visitors from aIstituto Nazionale di Fisica Nucleare, Sezione di Cagliari, 09042 Monserrato (Cagliari), Italy, bUniversity of CA Irvine, Irvine, CA 92697, USA, cUniversity of CA Santa Barbara, Santa Barbara, CA 93106, USA, dUniversity of CA Santa Cruz, Santa Cruz, CA 95064, USA, eInstitute of Physics, Academy of Sciences of the Czech Republic, Czech Republic, fCERN, CH-1211 Geneva, Switzerland, gCornell University, Ithaca, NY 14853, USA, hUniversity of Cyprus, Nicosia CY-1678, Cyprus, iOffice of Science, U.S. Department of Energy, Washington, DC 20585, USA, jUniversity College Dublin, Dublin 4, Ireland, kETH, 8092 Zurich, Switzerland, lUniversity of Fukui, Fukui City, Fukui Prefecture, Japan 910-0017, mUniversidad Iberoamericana, Mexico D.F., Mexico, nUniversity of Iowa, Iowa City 52242, USA, oKinki University, Higashi-Osaka City, Japan 577-8502, pKansas State University, Manhattan, KS 66506, USA, qEwha Womans University, Seoul, 120-750, Korea, rUniversity of Manchester, Manchester M13 9PL, United Kingdom, sQueen Mary, University of London, London, E1 4NS, United Kingdom, tUniversity of Melbourne, Victoria 3010, Australia, uMonash Inc., Batavia, IL 60510, USA, vNagasaki Institute of Applied Science, Nagasaki, Japan, wNational Research Nuclear University, Moscow, Russia, xNorthwestern University, Evanston, IL 60208, USA, yUniversity of Notre Dame, Notre Dame, IN 46556, USA, zUniversidade de Oviedo, E-33007 Oviedo, Spain, aaCNRS-IN2P3, Paris, F-75205 France, bbTexas Tech University, Lubbock, TX 79009, USA, ccUniversidad Tecnica Federico Santa Maria, 110v Valparaíso, Chile, ddYarmouk University, Irbid 211-63, Jordan,
We report on a search for the supersymmetric partner of the top quark (scalar top) decaying into a charm quark and a neutralino in \( p\bar{p} \) collisions at \( \sqrt{s} = 1.96 \) TeV. The data sample, collected by the CDF II detector at the Fermilab Tevatron, corresponds to an integrated luminosity of 2.6 fb\(^{-1}\). Candidate events are selected by requiring two or more jets and a large imbalance in the transverse momentum. To enhance the analysis sensitivity, at least one of the jets is required to be identified as originating from a charm quark using an algorithm specifically designed for this analysis. The selected events are in good agreement with standard model predictions. In the case of large mass splitting between the scalar top quark and the neutralino we exclude a scalar top quark mass below 180 GeV/c\(^2\) at 95% confidence level.

PACS numbers: 14.80.Ly

I. INTRODUCTION

The standard model (SM) of elementary particles and fundamental interactions, however successful, is still incomplete since it does not explain the origin of electroweak symmetry breaking and does not give an answer to the gauge hierarchy problem \([1]\). A possible extension of the SM, supersymmetry (SUSY) \([2]\), solves these problems by introducing a symmetry that relates particles of different spin. R-parity \([2]\) conserving SUSY models also provide a prime candidate for the dark matter in the universe \([3]\), namely the stable lightest supersymmetric particle (LSP). In these models, the left-handed and right-handed quarks have scalar partners, respectively denoted as \( \tilde{q}_L \) and \( \tilde{q}_R \), which can
mix to form scalar quarks with mass eigenstates $\tilde{q}_{1,2}$. Several models predict that this mixing can be substantial for the scalar top (stop), yielding a stop mass eigenstate ($\tilde{t}_1$) significantly lighter than other scalar quarks. If the $\tilde{t}_1$ is sufficiently light, it can be pair-produced copiously in proton-antiproton collisions at center-of-mass energy of $\sqrt{s} = 1.96$ TeV at the Tevatron. A stop in the mass range accessible at the Tevatron is expected to decay, among other possibilities, into a charm quark and the lightest neutralino ($\tilde{\chi}^0_1$), which is often assumed to be the LSP. Assuming R-parity conservation, stops are produced in pairs. We consider a scenario where $m_{\tilde{t}_1} < m_b + m_{\tilde{\chi}^+}$ (where $\tilde{\chi}^+$ is a chargino), and $m_{\tilde{t}_1} < m_W + m_b + m_{\tilde{\chi}^0_1}$. Under these conditions the decay $\tilde{t}_1 \rightarrow c\tilde{\chi}^0_1$ is dominant. Results from searches using this final state at the Tevatron have been previously reported in $[5, 6]$. 

In this Letter, we report the search for $\tilde{t}_1 \rightarrow c\tilde{\chi}^0_1$ decays in $p\bar{p}$ collision data from 2.6 fb$^{-1}$ of integrated luminosity collected by the upgraded Collider Detector at Fermilab (CDF II) at the Tevatron. The final state contains two $c$ jets from the hadronization of the $c$ quarks and features an imbalance in transverse momentum (“missing transverse energy” or $E_T^\text{miss}$) from the two LSPs escaping detection.

II. ANALYSIS DESCRIPTION

CDF II is a multipurpose detector, described in detail elsewhere $[8]$. The charged-particle tracking system consists of silicon microstrip detectors and a cylindrical open-cell drift chamber, both of which are immersed in a 1.4 T solenoidal magnetic field coaxial with the beam line. The silicon detectors provide coverage in the pseudorapidity range $|\eta| \leq 2$ and are used to identify events with long-lived particle decays. The drift chamber surrounds the silicon detectors, has maximum tracking efficiency up to $|\eta| = 1$, and is used for charged particle momentum measurements. Segmented sampling calorimeters, which surround the tracking system, are arranged in a projective tower geometry and are used to measure the energy of interacting particles in the region $|\eta| < 3.6$. Muon candidates are identified by drift chambers, which extend up to $|\eta| = 1.5$, and are located outside the calorimeter volume. Jets are reconstructed from the energy depositions in the calorimeter cells using an iterative cone jet-clustering algorithm $[9]$, with a cone size of radius $R = \sqrt{(\Delta \phi)^2 + (\Delta \eta)^2} = 0.7$ $[7]$. Energy corrections $[10]$ are applied to account for effects such as nonlinear calorimeter response, underlying event, and the position of the interaction point, that influence the measured transverse jet energy.

Candidate events used for this search are selected by an online event selection system (trigger) that requires $E_T \geq 35$ GeV and two jets. Further selections are applied off-line to remove accelerator-produced and detector-related backgrounds as well as cosmic-ray events. After off-line event reconstruction, the events are required to have $E_T \geq 50$ GeV, and at least two jets with $|\eta| \leq 2.4$ and $E_T \geq 25$ GeV. The highest-$E_T$ jet is required to have $E_T \geq 35$ GeV and at least one of the selected jets is required to be in the region $|\eta| \leq 0.9$.

The hadrons in jets coming from $b$ or $c$ quark fragmentation, heavy-flavor (HF) jets, have a measurable flight path, yielding secondary vertices relative to the $p\bar{p}$ interaction point (primary vertex). We require the events to have exactly one jet identified as a HF jet by the secondary-vertex tagging algorithm $[11]$, since requiring two HF-identified jets enhances the sample with events containing two $b$ quarks and reduces the signal acceptance. This criteria defines a preselection which is used as the basis of background studies and further optimization for the signal sample, as described below.

Dominant SM backgrounds are pair and single top-quark production, electroweak single and di-boson production, HF multijet production, and light-flavor multijet events where one of the jets is falsely tagged as a HF jet (mistag). The latter two background contributions are estimated from data. The ALPGEN $[12]$ event generator interfaced with the parton-shower model from the PYTHIA $[13]$ event generator is used to estimate the electroweak boson production, the MADGRAPH $[14]$ generator is used to model the single top events, while the PYTHIA event generator is used to model the top-quark pair and diboson backgrounds. For the event generation the CTEQ5L $[15]$ parton distribution functions (PDFs) are used. Simulated events are passed through the GEANT3-based $[16]$ CDF II detector simulation $[17]$ and are weighted by the probability that they would pass the trigger selection. The single top-quark and diboson contributions are normalized to the theoretical cross sections $[18, 20]$. The contributions for the electroweak boson samples are normalized to the next-to-leading order cross sections calculated with MCFM $[21]$. We use the measured top-quark pair production cross section of $\sigma_{t\bar{t}} = 7.02 \pm 0.63$ pb $[22]$. Mistags are estimated based on the mistag rate $[11]$ observed in inclusive jet data. The mistag rate is parametrized as a function of jet $E_T$, $|\eta|$, secondary-vertex track-multiplicity, the number of primary vertices in the event, primary vertex $z$-position, and the scalar sum of $E_T$ of all jets in the event. To estimate the HF multijet background from data, we use a multijet tag rate estimator (MUTARE) described elsewhere $[23, 24]$. The HF multijet prediction from MUTARE is scaled by a multiplicative factor that is obtained in a signal-free region.

To avoid potential biases when searching for new physics, we test the various background contributions in distinct control regions that are defined $a\ priori$. The three control regions used to validate the SM prediction are denoted as multijet, lepton, and pre-optimization regions. The multijet control region is defined to have the second leading $E_T$ jet
TABLE I: Comparison of the total number of expected and observed events in the control regions. The total uncertainty is computed by taking into account the (anti)correlations between the partial uncertainties. In the lepton region the HF multijet prediction is scaled to match the observed events in order to perform shape comparisons only.

| Regions:                  | Multijet | Lepton | Pre-optimization |
|----------------------------|----------|--------|------------------|
| W/Z + jets                 | 457 ± 190| 375 ± 156| 1551 ± 644       |
| Diboson                    | 17 ± 2   | 45 ± 5 | 118 ± 13         |
| Top pair                   | 188 ± 21 | 547 ± 60| 870 ± 96         |
| Single top                 | 11 ± 2   | 71 ± 10| 130 ± 19         |
| HF multijets               | 75407 ± 23376| 268 ± 83| 12935 ± 4010     |
| Light-flavor jets          | 65839 ± 8427| 720 ± 92| 7741 ± 991       |
| Total expected             | 141919 ± 24849| 2026 ± 208| 23345 ± 4182     |
| Observed                   | 143441   | 2026   | 22792            |

FIG. 1: Distribution of $\not{E}_T$ in the pre-optimization region. SM prediction (stacked histograms) and observed distribution (dots) are shown, where HF multijets and light-flavor jets are predicted from data.
TABLE II: Number of expected and observed events in the signal region before and after CHAOS application. Prediction for the signal point \((m(\tilde{t}_1) = 125 \text{ GeV}/c^2, m(\tilde{\chi}_1^0) = 70 \text{ GeV}/c^2)\) is also shown. Correlated and uncorrelated uncertainties in the total background and expected signal were treated separately in the analysis although they are combined here.

| Signal region               | Before CHAOS | Final (after CHAOS) |
|----------------------------|--------------|---------------------|
| W/Z + jets                 | 423.6 ± 185.0| 60.9 ± 26.6         |
| Diboson                     | 36.9 ± 6.5   | 10.7 ± 1.9          |
| Top pair                    | 61.9 ± 15.5  | 4.6 ± 1.3           |
| Single top                  | 39.0 ± 9.7   | 3.2 ± 0.8           |
| HF Multijets                | 279.6 ± 208.3| 20.4 ± 15.2         |
| Light-flavor jets           | 658.3 ± 259.6| 32.2 ± 12.7         |
| Total expected              | 1499.3 ± 277.1| 132.0 ± 24.4        |
| Observed                    | 1496         | 115                 |
| \(t_1\) signal             | 250.0 ± 66.2 | 90.2 ± 23.9         |

choose a reference signal point with \(m(\tilde{t}_1) = 125 \text{ GeV}/c^2\) and \(m(\tilde{\chi}_1^0) = 70 \text{ GeV}/c^2\) to perform the optimization. The signal acceptance is obtained using the PYTHIA event generator and CTEQ5L PDFs. Total signal yields are normalized to the NLO production cross section determined with the PROSPINO event generator \([26]\) and the CTEQ6M \([27, 28]\) PDFs. The uncertainty of the NLO production cross section is estimated to be 20%, arising from the scale dependence and the uncertainties on the PDFs. The NN output lies within \(-1\) and 1, where the background peaks at \(-1\) and the signal peaks at 1. We define our signal region as events with NN output scores > 0.

The final stage in the optimization is the application of a charm hadron analysis oriented separator (CHAOS) technique \([24]\), explicitly designed for this analysis to obtain a sample enriched in \(c\) jets. CHAOS is a NN producing a two-dimensional output and trained with the SNNS v4.3 package \([29]\) to determine whether a jet identified as HF has been produced from the hadronization process of a light quark falsely tagged as a HF jet, a \(b\) quark, or a \(c\) quark. The two-dimensional output structure allows the separation of the three different targets during the same training process. Depending on the flavor of the original parton, the jet identified as HF and its secondary vertex have different characteristics, mainly related to the tracking. Using properties of the tracks forming the secondary vertex and the tracks of the jets within a neural network, CHAOS allows enhancement of the jet selection with a desired flavor, in particular \(c\) jets. We apply CHAOS to the jet identified as HF and we find that the optimal cut has a selection efficiency \([24]\) of 34% for \(c\) jets, 7.3% for \(b\) jets, and 4.9% for light jets.

The systematic uncertainties on the signal and the background predictions, taking into account correlated and uncorrelated uncertainties, are studied. Correlated uncertainties, affecting both the background prediction and signal acceptance, are dominated by the uncertainties on the performance of the \(b\)-tagging algorithm and CHAOS, which are 4.4% \([11]\) and 9.2% respectively, and the luminosity (6%) \([8]\). Uncorrelated systematic uncertainties on the background predictions are dominated by uncertainties on the MUTARE parameterization (30%), the mistag rate (16% \([11]\) for light-flavor multijets), the top-quark pair-production cross section (11%), the single top-quark production cross section (13%), and the diboson production cross section (10% for \(WW/WZ\) and 20% for \(ZZ\)). The uncertainty on the normalization of the boson plus HF jets to the total inclusive boson production cross section translates into a 10% uncertainty in the SM predictions. Correlated and uncorrelated uncertainties are evaluated separately and combined in quadrature.

### III. RESULTS

The signal region is analyzed after the background predictions are determined. We observe 115 events, where 132.0 ± 24.4 are expected from background, as summarized in Table I where yields before selecting events based on CHAOS output are also shown. Since no significant deviation from the SM prediction is observed, the results are used to calculate a 95% C.L. exclusion limit for the \(t_1\) pair production cross section.

We have used the differences in shape of the NN output to set the limits. These limits are computed using a Bayesian likelihood method \([31]\) with a flat prior probability for the signal cross section and Gaussian priors for the uncertainties on acceptance and backgrounds. Figure 2 shows the expected and observed limits as a function of \(m(\tilde{t}_1)\) for a neutralino mass of 80 GeV/c^2.

We exclude, assuming \(\text{BR}(\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0) = 100\%\), \(\tilde{t}_1\) masses up to 180 GeV/c^2 at 95% C.L. In addition, a 95% C.L. limit is obtained in the mass parameter plane of the model. Figure 3 shows the excluded region in the stop-neutralino mass plane of the analysis, compared with results from previous analyses \([5, 6, 20]\). The limit obtained with the
FIG. 2: Observed (solid line) and expected (solid line with dashed band) 95% C.L. upper limit on the stop cross section (solid line with shaded band) as a function of the stop mass for an assumed value of the neutralino mass. The shaded band denotes the uncertainty on the NLO stop pair-production cross section.

FIG. 3: Excluded region at 95% C.L. in the $m(\tilde{t}_1)-m(\tilde{\chi}_1^0)$ plane. The result is compared to the previous results from CDF [3], from D0 [5], and from LEP [30] experiments at CERN.

The present analysis improves the results of previous searches using a similar topology, and represents the world’s best limit in the region of large mass splitting.

IV. SUMMARY

To summarize, we have searched for the pair production of stop decaying into a charm quark and a neutralino, in 2.6 fb$^{-1}$ of CDF Run II data. We observe 115 candidate events, which are in agreement with SM background expectations of $132.0 \pm 24.4$ events. No evidence for stop is observed, and we exclude a region in the stop and neutralino mass plane at 95% C.L. as shown in Fig. 3. Assuming BR($\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$) = 100%, we exclude stop masses up to 180 GeV/c$^2$ at 95% C.L. for a neutralino mass of 90 GeV/c$^2$. 
Acknowledgements

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Culture, Sports, Science and Technology of Japan; the Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; the Swiss National Science Foundation; the A.P. Sloan Foundation; the Bundesministerium für Bildung und Forschung, Germany; the Korean World Class University Program, the National Research Foundation of Korea; the Science and Technology Facilities Council and the Royal Society, UK; the Russian Foundation for Basic Research; the Ministerio de Ciencia e Innovación, and Programa Consolider-Ingenio 2010, Spain; the Slovak R&D Agency; the Academy of Finland; and the Australian Research Council (ARC).

[1] E. Gildener, Phys. Rev. D 14, 1667 (1976).
[2] For a review of SUSY, see S. P. Martin, hep-ph/9709356, and references therein.
[3] H. Goldberg, Phys. Rev. Lett. 50, 1419 (1983); J. Ellis et al., Nucl. Phys. B238 (1984) 453.
[4] V. M. Abazov et al. (D0 Collaboration), Phys. Rev. D 71, 032001 (2005).
[5] M. Cacciari et al., J. High Energy Phys. 04 (2004) 068.
[6] T. Sjöstrand et al., Comput. Phys. Commun. 135, 238 (2001). We use PYTHIA v. 6.216.
[7] T. Aaltonen et al. (CDF Collaboration), Phys. Rev. D 75, 072010 (2007).
[8] J. Campbell and R. K. Ellis, MCFM-Monte Carlo for FeMeTobarn processes, http://mcfm.fnal.gov/. We use MCFM v. 5.8.1.
[9] W. Beenakker et al., Nucl. Phys. B492, 51 (1997); W. Beenakker, R. Hopker, and M. Spira, hep-ph/9611232. We use PROSPINO v. 1.0.