Search for Chargino-Neutralino Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV

arXiv:0707.2362v1 [hep-ex] 16 Jul 2007

T. Aaltonen,[23] A. Abulencia,[24] J. Adelman,[13] T. Affolder,[10] T. Akimoto,[55] M.G. Albrow,[17] S. Amerio,[43] D. Amidei,[35] A. Anastassov,[52] K. Anikeev,[17] A. Annovi,[19] J. Antos,[14] M. Aoki,[55] G. Apollinari,[17] T. Arisawa,[57] A. Artikov,[15] W. Ashmanskas,[17] A. Attal,[3] A. Aurisano,[53] F. Azfar,[42] P. Azzi-Bacchetta,[43] P. Azzurri,[46] N. Bacchetta,[43] W. Badgett,[17] A. Barbaro-Galtieri,[29] V.E. Barnes,[48] B.A. Barnett,[25] S. Baroiant,[7] V. Bartsch,[31] G. Bauer,[33] P.-H. Beauchemin,[34] F. Bedeschi,[46] S. Behari,[25] G. Bellettini,[46] J. Bellinger,[59] A. Belloni,[33] D. Benjamin,[16] A. Beretvas,[17] J. Beringer,[29] T. Berry,[30] A. Bhatti,[50] M. Binkley,[17] D. Bisello,[43] I. Bizjak,[31] R.E. Blair,[2] C. Blocker,[6] B. Blumenfeld,[25] A. Bocci,[16] A. Bodek,[49] V. Boisvert,[49] G. Bolla,[48] A. Bolshov,[33] D. Bortoletto,[48] J. Boudreau,[47] A. Boveia,[10] B. Brau,[10] L. Brigliadori,[5] C. Bromberg,[36] E. Brubaker,[13] J. Budagov,[15] H.S. Budd,[49] S. Budd,[24] K. Burkett,[17] G. Busetto,[43] P. Bussey,[21] A. Buzatu,[34] K. L. Byrum,[2] S. Cabrera[q],[16] M. Campanelli,[20] M. Campbell,[35] F. Canelli,[17] A. Canepa,[45] S. Carillo[i],[18] D. Carlsmith,[59] R. Carosi,[46] S. Carron,[34] B. Casal,[11] M. Casarsa,[54] A. Castro,[5] P. Catastini,[46] D. Cauz,[54] M. Cavalli-Sforza,[3] A. Cerri,[29] L. Cerrito[m],[31] S.H. Chang,[28] Y.C. Chen,[1] M. Chertok,[7] G. Chiarelli,[46] G. Chlachidze,[17] F. Chlebana,[17] I. Cho,[28] K. Cho,[28] D. Chokheli,[15] J.P. Chou,[22] G. Choudalakis,[33] S.H. Chuang,[52] K. Chung,[12] W.H. Chung,[59] Y.S. Chung,[49] M. Cilijak,[46] C.I. Ciobanu,[24] M.A. Ciocci,[46] A. Clark,[20] D. Clark,[6] M. Coca,[16] G. Compostella,[43] M.E. Convery,[50] J. Conway,[7] B. Cooper,[31] K. Copic,[35] M. Cordelli,[19] G. Cortiana,[43] F. Crescioli,[46] C. Cuenca Almenar[q],[7] J. Cuevas[l],[11] R. Culbertson,[17] J.C. Cully,[35] S. DaRonco,[43] M. Datta,[17] S. D'Auria,[21] T. Davies,[21] D. Dagenhart,[17] P. de Barbaro,[49] S. De Cecco,[51] A. Deisher,[29] G. De Lentdecker[c],[49] G. De Lorenzo,[3] M. Dell'Orso,[46] F. Delli Paoli,[43] L. Demortier,[50] J. Deng,[16] M. Deninno,[5] D. De Pedis,[51] P.F. Derwent,[17] G.P. Di Giovanni,[44] C. Dionisi,[51] B. Di Ruzza,[54] J.R. Dittmann,[4] M. D'Onofrio,[3] C. Dörr,[26] S. Donati,[46] P. Dong,[8] J. Donini,[43] T. Dorigo,[43] S. Dube,[52] J. Efron,[39] R. Erbacher,[7] D. Errede,[24] S. Errede,[24] R. Eusebi,[17] H.C. Fang,[29] S. Farrington,[30] I. Fedorko,[46] W.T. Fedorko,[13] R.G. Feild,[60] M. Feindt,[26] J.P. Fernandez,[32] R. Field,[18] G. Flanagan,[48] R. Forrest,[7] S. Forrester,[7] M. Franklin,[22] J.C. Freeman,[29] I. Furic,[13] M. Gallinaro,[50] J. Galyardt,[12] J.E. Garcia,[46] F. Garberson,[10] A.F. Garfinkel,[48] C. Gay,[60] H. Gerberich,[24] D. Gerdes,[35] S. Giagu,[51] P. Giannetti,[46] K. Gibson,[47] J.L. Gimmell,[49] C. Ginsburg,[17] N. Giokaris[a],[15] M. Giordani,[54] P. Giromini,[19] M. Giunta,[46] G. Giurgiu,[25] V. Glagolev,[15] D. Glenzinski,[17] M. Gold,[37] N. Goldschmidt,[18] J. Goldstein[b],[42] A. Golossanov,[17] G. Gomez,[11] G. Gomez-Ceballos,[33] M. Goncharov,[53] O. González,[32] I. Gorelov,[37] A.T. Goshaw,[16] K. Goulianos,[50] A. Gresele,[43] S. Grinstein,[22] C. Grosso-Pilcher,[13] R.C. Group,[17] U. Grundler,[24] J. Guimaraes da Costa,[22] Z. Gunay-Unalan,[36] C. Haber,[29] K. Hahn,[33] S.R. Hahn,[17] E. Halkiadakis,[52] A. Hamilton,[20] B.-Y. Han,[49] J.Y. Han,[49] R. Handler,[59] F. Happacher,[19] K. Hara,[55] D. Hare,[52] M. Hare,[56] S. Harper,[42] R.F. Harr,[58] R.M. Harris,[17] M. Hartz,[47] K. Hatakeyama,[50] J. Hauser,[8] C. Hays,[42] M. Heck,[26] A. Heijboer,[45] B. Heinemann,[29] J. Heinrich,[45] C. Henderson,[33] M. Herndon,[59] J. Heuser,[26] D. Hidas,[16] C.S. Hill[b],[10] D. Hirschbuehl,[26] A. Hocker,[17] A. Holloway,[22] S. Hou,[1] M. Houlden,[30] S.-C. Hsu,[9] B.T. Huffman,[42] R.E. Hughes,[39] U. Husemann,[60] J. Huston,[36] J. Incandela,[10] G. Introzzi,[46] M. Iori,[51] A. Ivanov,[7] B. Iyutin,[33] E. James,[17] D. Jang,[52] B. Jayatilaka,[16] D. Jeans,[51] E.J. Jeon,[28] S. Jindariani,[18] W. Johnson,[7] M. Jones,[48] K.K. Joo,[28] S.Y. Jun,[12] J.E. Jung,[28] T.R. Junk,[24] T. Kamon,[53] P.E. Karchin,[58] Y. Kato,[41] Y. Kemp,[26] R. Kephart,[17] U. Kerzel,[26] V. Khotilovich,[53] B. Kilminster,[39] D.H. Kim,[28] H.S. Kim,[28] J.E. Kim,[28] M.J. Kim,[17] S.B. Kim,[28] S.H. Kim,[55] Y.K. Kim,[13] N. Kimura,[55] L. Kirsch,[6] S. Klimenko,[18] M. Klute,[33] B. Knuteson,[33] B.R. Ko,[16] K. Kondo,[57] D.J. Kong,[28] J. Konigsberg,[18] A. Korytov,[18] A.V. Kotwal,[16] A.C. Kraan,[45] J. Kraus,[24] M. Kreps,[26] J. Kroll,[45] N. Krumnack,[4] M. Kruse,[16] V. Krutelyov,[10] T. Kubo,[55] S. E. Kuhlmann,[2] T. Kuhr,[26] N.P. Kulkarni,[58] Y. Kusakabe,[57] S. Kwang,[13] A.T. Laasanen,[48] S. Lai,[34] S. Lami,[46] S. Lammel,[17] M. Lancaster,[31] R.L. Lander,[7] K. Lannon,[39] A. Lath,[52] G. Latino,[46] I. Lazzizzera,[43] T. LeCompte,[2] J. Lee,[49] J. Lee,[28] Y.J. Lee,[28] S.W. Lee[o],[53] R. Lefèvre,[20] N. Leonardo,[33] S. Leone,[46] S. Levy,[13] J.D. Lewis,[17] C. Lin,[60] C.S. Lin,[17] M. Lindgren,[17] E. Lipeles,[9] A. Lister,[7] D.O. Litvintsev,[17] T. Liu,[17] N.S. Lockyer,[45] A. Loginov,[60] M. Loreti,[43] R.-S. Lu,[1] D. Lucchesi,[43] P. Lujan,[29] P. Lukens,[17] G. Lungu,[18] L. Lyons,[42] J. Lys,[29] R. Lysak,[14] E. Lytken,[48] P. Mack,[26] D. MacQueen,[34] R. Madrak,[17] K. Maeshima,[17] K. Makhoul,[33] T. Maki,[23] P. Maksimovic,[25] S. Malde,[42] S. Malik,[31] G. Manca,[30] A. Manousakis[a],[15] F. Margaroli,[5] R. Marginean,[17] C. Marino,[26] C.P. Marino,[24] A. Martin,[60] M. Martin,[25] V. Martin[g],[21] M. Martínez,[3] R. Martínez-Ballarín,[32] T. Maruyama,[55] P. Mastrandrea,[51] T. Masubuchi,[55] H. Matsunaga,[55] M.E. Mattson,[58] R. Mazini,[34] P. Mazzanti,[5] K.S. McFarland,[49] P. McIntyre,[53] R. McNulty[f],[30] A. Mehta,[30] P. Mehtala,[23] S. Menzemer[h],[11] A. Menzione,[46] P. Merkel,[48] C. Mesropian,[50] A. Messina,[36] T. Miao,[17] N. Miladinovic,[6] J. Miles,[33] R. Miller,[36] C. Mills,[10] M. Milnik,[26] A. Mitra,[1] G. Mitselmakher,[18] A. Miyamoto,[27] S. Moed,[20] N. Moggi,[5] B. Mohr,[8] C.S. Moon,[28]

R. Moore,[17] M. Morello,[46] P. Movilla Fernandez,[29] J. Mülmenstädt,[29] A. Mukherjee,[17] Th. Muller,[26] R. Mumford,[25] P. Murat,[17] M. Mussini,[5] J. Nachtman,[17] A. Nagano,[55] J. Naganoma,[57] K. Nakamura,[55] I. Nakano,[40] A. Napier,[56] V. Necula,[16] C. Neu,[45] M.S. Neubauer,[9] J. Nielsen[n],[29] L. Nodulman,[2] O. Norniella,[3] E. Nurse,[31] S.H. Oh,[16] Y.D. Oh,[28] I. Oksuzian,[18] T. Okusawa,[41] R. Oldeman,[30] R. Orava,[23] K. Osterberg,[23] C. Pagliarone,[46] E. Palencia,[11] V. Papadimitriou,[17] A. Papaikonomou,[26] A.A. Paramonov,[13] B. Parks,[39] S. Pashapour,[34] J. Patrick,[17] G. Pauletta,[54] M. Paulini,[12] C. Paus,[33] D.E. Pellett,[7] A. Penzo,[54] T.J. Phillips,[16] G. Piacentino,[46] J. Piedra,[44] L. Pinera,[18] K. Pitts,[24] C. Plager,[8] L. Pondrom,[59] X. Portell,[3] O. Poukhov,[15] N. Pounder,[42] F. Prakoshyn,[15] A. Pronko,[17] J. Proudfoot,[2] F. Ptohos[e],[19] G. Punzi,[46] J. Pursley,[25] J. Rademacker[b],[42] A. Rahaman,[47] V. Ramakrishnan,[59] N. Ranjan,[48] I. Redondo,[32] B. Reisert,[17] V. Rekovic,[37] P. Renton,[42] M. Rescigno,[51] S. Richter,[26] F. Rimondi,[5] L. Ristori,[46] A. Robson,[21] T. Rodrigo,[11] E. Rogers,[24] S. Rolli,[56] R. Roser,[17] M. Rossi,[54] R. Rossin,[10] P. Roy,[34] A. Ruiz,[11] J. Russ,[12] V. Rusu,[13] H. Saarikko,[23] A. Safonov,[53] W.K. Sakumoto,[49] G. Salamanna,[51] O. Saltó,[3] L. Santi,[54] S. Sarkar,[51] L. Sartori,[46] K. Sato,[17] P. Savard,[34] A. Savoy-Navarro,[44] T. Scheidle,[26] P. Schlabach,[17] E.E. Schmidt,[17] M.P. Schmidt,[60] M. Schmitt,[38] T. Schwarz,[7] L. Scodellaro,[11] A.L. Scott,[10] A. Scribano,[46] F. Scuri,[46] A. Sedov,[48] S. Seidel,[37] Y. Seiya,[41] A. Semenov,[15] L. Sexton-Kennedy,[17] A. Sfyrla,[20] S.Z. Shalhout,[58] M.D. Shapiro,[29] T. Shears,[30] P.F. Shepard,[47] D. Sherman,[22] M. Shimojima[k],[55] M. Shochet,[13] Y. Shon,[59] I. Shreyber,[20] A. Sidoti,[46] P. Sinervo,[34] A. Sisakyan,[15] A.J. Slaughter,[17] J. Slaunwhite,[39] K. Sliwa,[56] J.R. Smith,[7] F.D. Snider,[17] R. Snihur,[34] M. Soderberg,[35] A. Soha,[7] S. Somalwar,[52] V. Sorin,[36] J. Spalding,[17] F. Spinella,[46] T. Spreitzer,[34] P. Squillacioti,[46] M. Stanitzki,[60] A. Staveris-Polykalas,[46] R. St. Denis,[21] B. Stelzer,[8] O. Stelzer-Chilton,[42] D. Stentz,[38] J. Strologas,[37] D. Stuart,[10] J.S. Suh,[28] A. Sukhanov,[18] H. Sun,[56] I. Suslov,[15] T. Suzuki,[55] A. Taffard[p],[24] R. Takashima,[40] Y. Takeuchi,[55] R. Tanaka,[40] M. Tecchio,[35] P.K. Teng,[1] K. Terashi,[50] J. Thom[d],[17] A.S. Thompson,[21] E. Thomson,[45] P. Tipton,[60] V. Tiwari,[12] S. Tkaczyk,[17] D. Toback,[53] S. Tokar,[14] K. Tollefson,[36] T. Tomura,[55] D. Tonelli,[46] S. Torre,[19] D. Torretta,[17] S. Tourneur,[44] W. Trischuk,[34] S. Tsuno,[40] Y. Tu,[45] N. Turini,[46] F. Ukegawa,[55] S. Uozumi,[55] S. Vallecorsa,[20] N. van Remortel,[23] A. Varganov,[35] E. Vataga,[37] F. Vazquez[i],[18] G. Velev,[17] C. Vellidis[a],[46] G. Veramendi,[24] V. Veszpremi,[48] M. Vidal,[32] R. Vidal,[17] I. Vila,[11] R. Vilar,[11] T. Vine,[31] M. Vogel,[37] I. Vollrath,[34] I. Volobouev[o],[29] G. Volpi,[46] F. Würthwein,[9] P. Wagner,[53] R.G. Wagner,[2] R.L. Wagner,[17] J. Wagner,[26] W. Wagner,[26] R. Wallny,[8] S.M. Wang,[1] A. Warburton,[34] D. Waters,[31] M. Weinberger,[53] W.C. Wester III,[17] B. Whitehouse,[56] D. Whiteson[p],[45] A.B. Wicklund,[2] E. Wicklund,[17] G. Williams,[34] H.H. Williams,[45] P. Wilson,[17] B.L. Winer,[39] P. Wittich[d],[17] S. Wolbers,[17] C. Wolfe,[13] T. Wright,[35] X. Wu,[20] S.M. Wynne,[30] A. Yagil,[9] K. Yamamoto,[41] J. Yamaoka,[52] T. Yamashita,[40] C. Yang,[60] U.K. Yang[j],[13] Y.C. Yang,[28] W.M. Yao,[29] G.P. Yeh,[17] J. Yoh,[17] K. Yorita,[13] T. Yoshida,[41] G.B. Yu,[49] I. Yu,[28] S.S. Yu,[17] J.C. Yun,[17] L. Zanello,[51] A. Zanetti,[54] I. Zaw,[22] X. Zhang,[24] J. Zhou,[52] and S. Zucchelli[5]

(CDF Collaboration*)

[1]*Institute of Physics, Academia Sinica, Taipei, Taiwan 11529, Republic of China*
[2]*Argonne National Laboratory, Argonne, Illinois 60439*
[3]*Institut de Fisica d'Altes Energies, Universitat Autonoma de Barcelona, E-08193, Bellaterra (Barcelona), Spain*
[4]*Baylor University, Waco, Texas 76798*
[5]*Istituto Nazionale di Fisica Nucleare, University of Bologna, I-40127 Bologna, Italy*
[6]*Brandeis University, Waltham, Massachusetts 02254*
[7]*University of California, Davis, Davis, California 95616*
[8]*University of California, Los Angeles, Los Angeles, California 90024*
[9]*University of California, San Diego, La Jolla, California 92093*
[10]*University of California, Santa Barbara, Santa Barbara, California 93106*
[11]*Instituto de Fisica de Cantabria, CSIC-University of Cantabria, 39005 Santander, Spain*
[12]*Carnegie Mellon University, Pittsburgh, PA 15213*
[13]*Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637*
[14]*Comenius University, 842 48 Bratislava, Slovakia; Institute of Experimental Physics, 040 01 Kosice, Slovakia*
[15]*Joint Institute for Nuclear Research, RU-141980 Dubna, Russia*
[16]*Duke University, Durham, North Carolina 27708*
[17]*Fermi National Accelerator Laboratory, Batavia, Illinois 60510*
[18]*University of Florida, Gainesville, Florida 32611*
[19]*Laboratori Nazionali di Frascati, Istituto Nazionale di Fisica Nucleare, I-00044 Frascati, Italy*
[20]*University of Geneva, CH-1211 Geneva 4, Switzerland*
[21]*Glasgow University, Glasgow G12 8QQ, United Kingdom*
[22]*Harvard University, Cambridge, Massachusetts 02138*
[23]*Division of High Energy Physics, Department of Physics, University of Helsinki and Helsinki Institute of Physics, FIN-00014, Helsinki, Finland*

[24]*University of Illinois, Urbana, Illinois 61801*
[25]*The Johns Hopkins University, Baltimore, Maryland 21218*
[26]*Institut für Experimentelle Kernphysik, Universität Karlsruhe, 76128 Karlsruhe, Germany*
[27]*High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305, Japan*
[28]*Center for High Energy Physics: Kyungpook National University, Taegu 702-701, Korea; Seoul National University, Seoul 151-742, Korea; SungKyunKwan University, Suwon 440-746, Korea*
[29]*Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, California 94720*
[30]*University of Liverpool, Liverpool L69 7ZE, United Kingdom*
[31]*University College London, London WC1E 6BT, United Kingdom*
[32]*Centro de Investigaciones Energeticas Medioambientales y Tecnologicas, E-28040 Madrid, Spain*
[33]*Massachusetts Institute of Technology, Cambridge, Massachusetts 02139*
[34]*Institute of Particle Physics: McGill University, Montréal, Canada H3A 2T8; and University of Toronto, Toronto, Canada M5S 1A7*
[35]*University of Michigan, Ann Arbor, Michigan 48109*
[36]*Michigan State University, East Lansing, Michigan 48824*
[37]*University of New Mexico, Albuquerque, New Mexico 87131*
[38]*Northwestern University, Evanston, Illinois 60208*
[39]*The Ohio State University, Columbus, Ohio 43210*
[40]*Okayama University, Okayama 700-8530, Japan*
[41]*Osaka City University, Osaka 588, Japan*
[42]*University of Oxford, Oxford OX1 3RH, United Kingdom*
[43]*University of Padova, Istituto Nazionale di Fisica Nucleare, Sezione di Padova-Trento, I-35131 Padova, Italy*
[44]*LPNHE, Universite Pierre et Marie Curie/IN2P3-CNRS, UMR7585, Paris, F-75252 France*
[45]*University of Pennsylvania, Philadelphia, Pennsylvania 19104*
[46]*Istituto Nazionale di Fisica Nucleare Pisa, Universities of Pisa, Siena and Scuola Normale Superiore, I-56127 Pisa, Italy*
[47]*University of Pittsburgh, Pittsburgh, Pennsylvania 15260*
[48]*Purdue University, West Lafayette, Indiana 47907*
[49]*University of Rochester, Rochester, New York 14627*
[50]*The Rockefeller University, New York, New York 10021*
[51]*Istituto Nazionale di Fisica Nucleare, Sezione di Roma 1, University of Rome "La Sapienza," I-00185 Roma, Italy*
[52]*Rutgers University, Piscataway, New Jersey 08855*
[53]*Texas A&M University, College Station, Texas 77843*
[54]*Istituto Nazionale di Fisica Nucleare, University of Trieste/ Udine, Italy*
[55]*University of Tsukuba, Tsukuba, Ibaraki 305, Japan*
[56]*Tufts University, Medford, Massachusetts 02155*
[57]*Waseda University, Tokyo 169, Japan*
[58]*Wayne State University, Detroit, Michigan 48201*
[59]*University of Wisconsin, Madison, Wisconsin 53706*
[60]*Yale University, New Haven, Connecticut 06520*

We present the results of a search for associated production of the chargino and neutralino supersymmetric particles using up to 1.1 fb^{-1} of integrated luminosity collected by the CDF II experiment at the Tevatron $p\bar{p}$ collider at a center-of-mass energy of 1.96 TeV. The search is conducted by analyzing events with a large transverse momentum imbalance and either three charged leptons or two charged leptons of the same electric charge. The numbers of observed events are found to be consistent with standard model expectations. Upper limits on the production cross section are derived in different theoretical models. In one of these models a lower limit on the mass of the chargino is set at 129 GeV/c^2 at the 95% confidence level.

PACS numbers:

[*]With visitors from [a]University of Athens, 15784 Athens, Greece, [b]University of Bristol, Bristol BS8 1TL, United Kingdom, [c]University Libre de Bruxelles, B-1050 Brussels, Belgium, [d]Cornell University, Ithaca, NY 14853, [e]University of Cyprus, Nicosia CY-1678, Cyprus, [f]University College Dublin, Dublin 4, Ireland, [g]University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom, [h]University of Heidelberg, D-69120 Heidelberg, Germany, [i]Universidad Iberoamericana, Mexico D.F., Mexico, [j]University of Manchester, Manchester M13 9PL, England, [k]Nagasaki Institute of Applied Science, Nagasaki, Japan, [l]University de Oviedo,

Supersymmetry (SUSY) [1] is one of the most appealing and most studied theories for physics beyond the standard model (SM). SUSY predicts the existence of a super-partner particle (sparticle) for each SM particle, sharing the same quantum numbers but differing by half a unit of spin. SUSY addresses several problems of the SM: it can solve the "hierarchy problem" [2] (allowing the electroweak force and the gravitational force to coexist naturally), it can provide a good candidate for the cold dark matter in the universe [3] and it makes possible a unification of the fundamental forces at high energies [4]. Since no SUSY particles have been observed so far their masses must be much higher than those of their SM partners, and thus supersymmetry, if it exists, must be a broken symmetry.

A natural solution to the hierarchy problem and the prospect of gauge coupling unification suggest that sparticle masses are near the electroweak scale and thus may be observable at the Tevatron $p\bar{p}$ collider. We present a search for the associated production of the lightest chargino $\tilde{\chi}_1^\pm$ and the second-to-lightest neutralino $\tilde{\chi}_2^0$, which are mass eigenstates of the super-partners of the electroweak gauge and Higgs bosons.

Chargino-neutralino production, $p\bar{p} \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2^0 + X$, is one of the most interesting SUSY processes at the Tevatron in models in which the gauginos are light. This process can be detected through the observation of isolated charged leptons [5] and a large imbalance in the transverse energy ($\not\!\!E_T$) from the decays $\tilde{\chi}_1^\pm \rightarrow \ell^\pm \nu \tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \rightarrow \ell^+\ell^- \tilde{\chi}_1^0$, where $\ell = e, \mu, \tau$ and $\tilde{\chi}_1^0$ is the lightest SUSY particle, which is assumed to be stable and to escape detection. This signature has the experimental advantage that at hadron colliders leptons are relatively rare compared to the copiously produced jets, they are well identifiable, and the SM backgrounds are rather small as they arise primarily from electroweak processes. We use three benchmark models based on the minimal supersymmetric standard model (MSSM) to interpret the data. The models differ mostly in the leptonic branching ratios of the $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ and in the kinematic properties of the leptons.

Previous searches at LEP excluded chargino masses below 103.5 GeV/c^2 [6] and masses of the lightest neutralino $\tilde{\chi}_1^0$ below 50.3 GeV/c^2 [7] at the 95% confidence level (CL). These constraints are very robust and do not change much within minimal supergravity-inspired SUSY models. The D0 collaboration recently constrained the lightest chargino mass to be larger than 117 GeV/c^2 at 95% CL in a specific scenario [8].

This letter summarizes and interprets the results from seven individual search channels with different lepton flavors and kinematic properties in the final state. The analyses use $p\bar{p}$ collision data taken by the CDF II detector at the Tevatron accelerator with a center-of-mass energy of $\sqrt{s} = 1.96$ TeV. The data, collected between March 2002 and February 2006, correspond to an integrated luminosity between 0.7 and 1.1 fb^{-1}, depending on the decay signature.

The CDF II detector [9] is cylindrically symmetric around the beam-pipe in which the protons and antiprotons collide [5]. The transverse momentum of charged particles, p_T, is measured by a tracking system composed of an eight-layer silicon strip detector [10] and a 96-layer drift chamber [11]; both are located inside a solenoid providing a magnetic field of 1.4 T aligned along the beam axis. The tracking efficiency is nearly 100% in the "central" region ($|\eta| < 1$) and decreases towards higher η. Electromagnetic and hadronic calorimeters [12, 13] surrounding the solenoid measure the energies of particles up to $|\eta| < 3.6$. Wire chambers and scintillators are installed around the hadronic calorimeter to detect muons with $|\eta| < 1.4$. Gas Cherenkov counters [14] measure the average number of $p\bar{p}$ inelastic collisions per bunch crossing and thereby determine the beam luminosity.

We now outline the seven individual analyses that are then combined to achieve maximum sensitivity. The like-sign (LS) analyses ($e^\pm e^\pm$, $e^\pm \mu^\pm$, $\mu^\pm \mu^\pm$) [15] require two leptons of the same electric charge and do not require the detection of a third lepton. In the trilepton analyses, the third lepton candidate can either be a fully reconstructed electron or muon ($e\ell\ell$ [16], $\mu\ell\ell$ [16], $\mu\mu\ell$ [17], $\ell = e, \mu$) or a "track" from a charged particle (eet). The eet analysis gains acceptance in detector areas where the electron/muon detection is less efficient, and adds sensitivity to hadronic decays of τ-leptons. The LS, $e\ell\ell$ and $\mu\ell\ell$ analyses trigger on a single high p_T lepton while the $\mu\mu\ell$ and eet analyses use dilepton triggers with lower lepton p_T thresholds. There is some overlap between the individual analyses which is taken into account for the combination: it is up to 30% between some of the analyses as explained later in this letter.

The dominant SM background sources are diboson production with three or more prompt leptons (WZ/γ^*, ZZ/γ^*) and Drell-Yan (DY) events in which the third lepton results either from the conversion of a bremsstrahlung photon ($Z/\gamma^* + \gamma$, with $\gamma \rightarrow e^+e^-$) or from a misidentified hadron. With Z/γ^* we denote the production of a Z or a virtual photon. For the LS analyses $W\gamma$ production with a photon conversion is also a significant background. Smaller background contributions arise from heavy flavor production ($t\bar{t}$ and $b\bar{b}$) with semileptonic b- and c-hadron decays. All these background sources are modeled using several Monte Carlo (MC) event generators. Backgrounds from $t\bar{t}$, ZZ and

E-33007 Oviedo, Spain, [m]University of London, Queen Mary College, London, E1 4NS, England, [n]University of California Santa Cruz, Santa Cruz, CA 95064, [o]Texas Tech University, Lubbock, TX 79409, [p]University of California, Irvine, Irvine, CA 92697, [q]IFIC(CSIC-Universitat de Valencia), 46071 Valencia, Spain,

DY production are generated using PYTHIA [18]. The $W\gamma$ and WZ/γ^* backgrounds are generated using for the hard-scattering process a program by U. Baur and E. L. Berger [19] and MADEVENT [20], respectively. In all cases PYTHIA is used for the parton showering and hadronization and the parton distribution functions are parameterized using CTEQ5 [21]. All MC events are subsequently passed through the CDF II detector simulation based on the GEANT3 [22] framework. The simulated events are then reconstructed and analyzed in the same way as the data. The $b\bar{b}$ background was determined using a combination of MC and data estimates [17] and is negligible in most of the analyses.

An additional background source is hadrons that are misidentified as a lepton ("mis-id"). We determine the misidentification probability in jet data samples as a function of the lepton p_T or E_T using jets and tracks and applied to the two leptons (one lepton) data sample for the trileptons (LS) analyses [15, 16].

In the LS, $e\ell\ell$ and $\mu\ell\ell$ analyses, events are triggered on one well-identified central electron with $E_T > 18$ GeV or muon with $p_T > 18$ GeV/c. In the eet ($\mu\mu\ell$) analysis events are triggered on two central electrons (muons) with $E_T > 4$ GeV ($p_T > 4$ GeV/c). We select additional electrons in the central and the forward calorimeters. Electrons are required to have a shower shape consistent with that expected for an electron and to have a track matched to the calorimeter cluster. Muons are required to deposit an amount of energy in the calorimeter consistent with the expectation for a minimum ionizing particle; additionally, trigger muons must have associated hits in the muon detectors. Dedicated algorithms reject photon conversions and cosmic rays [16]. We require all leptons to be isolated from other particles in the event. For the electrons and muons in the $e\ell\ell$, $\mu\ell\ell$, eet and $\mu\mu\ell$ analyses the isolation requirement is based only on the calorimeter energy deposits. For the track of the eet analysis it is based only on charged tracks, and for electrons and muons in the LS analyses it is based on both.

We exclude events in which two leptons form an invariant mass $m_{\ell\ell} < 15$ GeV/c^2 or $76 < m_{\ell\ell} < 106$ GeV/c^2 in order to remove DY and diboson events. The lower mass threshold additionally removes $b\bar{b}$ background. For the $e\ell\ell$ (LS) analysis the lower mass value is raised to 20 (25) GeV/c^2 to improve the sensitivity. For the LS analysis the mass interval near the Z resonance is changed to $66 < m_{\ell\ell} < 116$ GeV/c^2. Backgrounds from DY production are further reduced by requiring $\not{E}_T > 15$ GeV (for the eet analysis the requirement is $\not{E}_T > 20$ GeV). The $t\bar{t}$ background is reduced by vetoing events with large hadronic jet activity. Requirements on the angles between the leptons and $\not{E}_T$ are placed in order to reduce the cosmic-ray background. A detailed description of the selection requirements is given elsewhere [15, 16, 17].

To illustrate the model sensitivity of the search we use three example SUSY models. The first model is the scenario of minimal supergravity (mSUGRA) [23], a grand unified theory including gravity which has five independent parameters, fully determining all the masses and couplings of the SUSY particles. Since the present analysis is most sensitive to the common gaugino mass $m_{1/2}$, we fix the other four parameters: the common scalar mass is set to $m_0 = 60$ GeV/c^2, the higgsino mixing parameter (μ) is taken to be positive, the trilinear coupling (A_0) is set to 0, and the ratio of the vacuum expectation values of the two Higgs fields ($\tan\beta$) is set to 3. In mSUGRA the lightest slepton is a SUSY partner of the τ leading to a larger branching ratio to τ-leptons: about 90% of the events contain at least one τ-lepton. The second model we call "MSSM (W/Z model)": all the parameters are taken to be the same as in the above model, but the branching ratio of $\tilde{\chi}_1^\pm(\tilde{\chi}_2^0)$ into leptons is fixed to be the same as the branching ratio of the $W(Z)$ gauge boson into leptons. In the third model, the "MSSM (no $\tilde{\ell}$-mixing)", the slepton chirality eigenstates are the mass eigenstates, resulting in nearly equal branching ratios of $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ to all three lepton flavors. In this model about 30% of the events contain no τ-leptons. For all three scenarios the relationship between the masses of the gauginos is $m_{\tilde{\chi}_1^\pm} \approx m_{\tilde{\chi}_2^0} \approx 2m_{\tilde{\chi}_1^0}$. The slepton mass value is approximately $0.31 \cdot m_{\tilde{\chi}_1^\pm} + 67$ GeV/c^2.

For the first and second models, the most stringent constraint on the chargino mass to date is the LEP limit of 103.5 GeV/c^2 while for the third model the most stringent limit is 117 GeV/c^2 as obtained by the D0 collaboration [8].

For the signal simulation we use SOFTSUSY [24] and ISAJET [25] to compute the sparticle mass spectrum; PYTHIA is used to generate the hard-scattering events, the parton radiation, and the hadronization. CTEQ5 is used for the parton distribution functions. The CDF II detector's response to these events is then simulated.

The signal acceptance for the process $p\bar{p} \to \tilde{\chi}_1^\pm\tilde{\chi}_2^0 + X \to \ell\ell\ell\nu\tilde{\chi}_1^0\tilde{\chi}_1^0 + X$, ($\ell = e, \mu, \tau$), in the MSSM (no $\tilde{\ell}$-mixing) scenario varies from 2.7% at $m_{\tilde{\chi}_1^\pm} \approx 105$ GeV/c^2, where only the LS analysis is sensitive, to 6.2% at $m_{\tilde{\chi}_1^\pm} \approx 160$ GeV/c^2, where the acceptance of the trilepton analyses is maximal. The acceptance in the MSSM (W/Z model) rises from 3.0% at low $m_{\tilde{\chi}_1^\pm}$ to 4.0% at $m_{\tilde{\chi}_1^\pm} \approx 150$ GeV/c^2. The acceptance for mSUGRA is only 1.0%, independent of $m_{\tilde{\chi}_1^\pm}$, due to the enhanced decay of $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ into τ-leptons. For all models, the acceptance of the LS analyses is nearly independent of the chargino mass while the acceptance of the trilepton analyses improves with increasing chargino mass.

There are systematic uncertainties on both the signal acceptance and the background prediction that have been evaluated by many comparisons of data and simulation [15, 16, 17]. The signal acceptance has an uncertainty due to the lepton selection ($1.5\% - 13\%$) and trigger ($< 0.5\%$) efficiencies, the modeling of QCD radiation ($2\% - 12\%$), the parton distribution functions (1%), the integrated luminosity (6%), and the jet energy measurement ($1\% - 5\%$). The background is also affected by the lepton- and jet-related uncertainties and the luminosity uncertainty. Additionally, we consider uncertainties on the lepton misidentification rate (50% for the trilepton and $10\% - 20\%$ for the LS analysis), the conversion background ($3\% - 16\%$) and the theoretical cross sections (7% for diboson, 10% for $t\bar{t}$ and 5% for DY production). Finally, the statistical uncertainties on the Monte Carlo samples are taken into account.

In Table I, the number of observed events is compared to the background contributions for each analysis. The number of data events is consistent with the background expectation in all analyses and no evidence of non-SM physics is observed. There is a slight excess of the data in the $e^{\pm}\mu^{\pm}$ and eet analyses. Figure 1 shows the $\not{E}_T$ distribution for the eet analysis. The observed data agree well with SM predictions at low values of $\not{E}_T$ where the background is dominant.

Table I: The numbers of expected and observed events for each analysis before events which are shared by more than one analysis are assigned to a single analysis. For the eet analysis the background from misidentified jets is included in the $Z/\gamma^* + \gamma$ background estimate of this analysis..

	$e^{\pm}e^{\pm}$	$e^{\pm}\mu^{\pm}$	$\mu^{\pm}\mu^{\pm}$	$e\ell\ell$	$\mu\ell\ell$	eet	$\mu\mu\ell$
$Z/\gamma^* + \gamma$	0.49	0.62	–	0.18	0.30	0.54	0.06
$W\gamma$	1.54	1.63	–	–	–	–	–
$t\bar{t} + b\bar{b}$	0.01	0.03	0.01	0.04	0.03	0.22	0.06
WW, WZ, ZZ	0.32	0.82	0.53	0.39	0.66	0.21	0.09
mis-id.	0.60	0.90	0.38	0.14	0.27	–	0.20
total	2.96	4.00	0.92	0.75	1.26	0.97	0.41
uncertainty	± 0.48	± 0.57	± 0.12	± 0.36	± 0.27	± 0.28	± 0.11
observed	4	8	1	0	1	3	1

The data can be used to constrain the cross section times branching ratio, $\sigma \times \mathcal{B}$, and the allowed mass range of charginos for the SUSY scenarios discussed earlier.

The first step in combining the results of the seven analyses is to remove overlaps: events which are selected by more than one analysis are assigned to the channel with the highest *a priori* signal-to-background ratio to obtain the best sensitivity. The frequentist-based "CL$_s$" method [26, 27] is then used on the resulting non-overlapping analyses. The correlations between the systematic uncertainties of the individual analyses have been evaluated for both the signal and the background and are taken into account in the limit calculation.

A mass limit for the chargino is derived from the cross section limit by comparing the observed limit to the next-to-leading order calculation for the cross section [28]. An uncertainty of 10% on the signal theoretical cross section is included in the limit calculation [29].

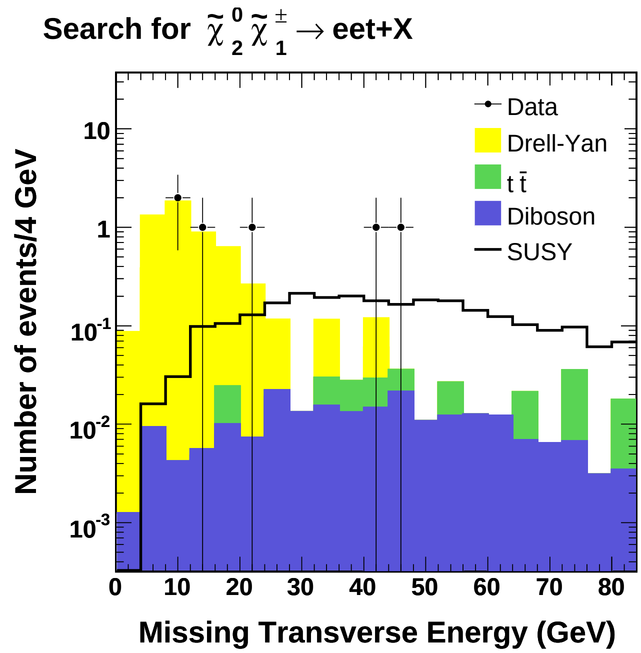

Figure 1: Missing transverse energy distribution for the eet analysis after all the selection criteria are applied except for the cut $\not{E}_T > 20$ GeV. The observed data (points) are compared to the sum of the SM contributions (stacked, filled histograms). The open histogram shows the expected SUSY contribution for the mSUGRA scenario described in the text with $m_{\tilde{\chi}_1^{\pm}} = 113$ GeV/c^2 and $\sigma \times \mathcal{B} = 0.6$ pb.

Figure 2 shows the 95% CL upper limit on the $\sigma \times \mathcal{B}$ as a function of the chargino mass in the three theoretical scenarios mSUGRA, MSSM (W/Z model), and MSSM (no $\tilde{\ell}$-mixing). In each scenario the observed and the expected limits are compared with the theoretical $\sigma \times \mathcal{B}$ predictions. The expected limit is defined to be the median limit one would obtain in a sample of independent experiments in which no signal is present. It is used to estimate the *a priori* sensitivity of the search since it does not depend on the observed data. The observed limit is typically a factor of two larger than the expected, due to the fact that the number of events observed is higher than the predicted background in the eet and $e^{\pm}\mu^{\pm}$ analyses.

In the mSUGRA scenario (Fig. 2a) $\sigma \times \mathcal{B} > 1$ pb is excluded for all $m_{\tilde{\chi}_1^{\pm}}$. The limit improves with increasing mass down to 0.8 pb at $m_{\tilde{\chi}_1^{\pm}} = 150$ GeV/c^2. In the MSSM W/Z model and no $\tilde{\ell}$-mixing scenarios (Fig. 2b and c) the limits on $\sigma \times \mathcal{B}$ range between 0.2 and 0.4 pb. In the MSSM (no $\tilde{\ell}$-mixing) scenario (Fig. 2c) we set a 95% CL lower limit on the chargino mass of 129 GeV/c^2, which is the most stringent limit to date. In the mSUGRA and MSSM (no $\tilde{\ell}$-mixing) scenarios the expected chargino mass limits are 122 GeV/c^2 and 157 GeV/c^2, respectively.

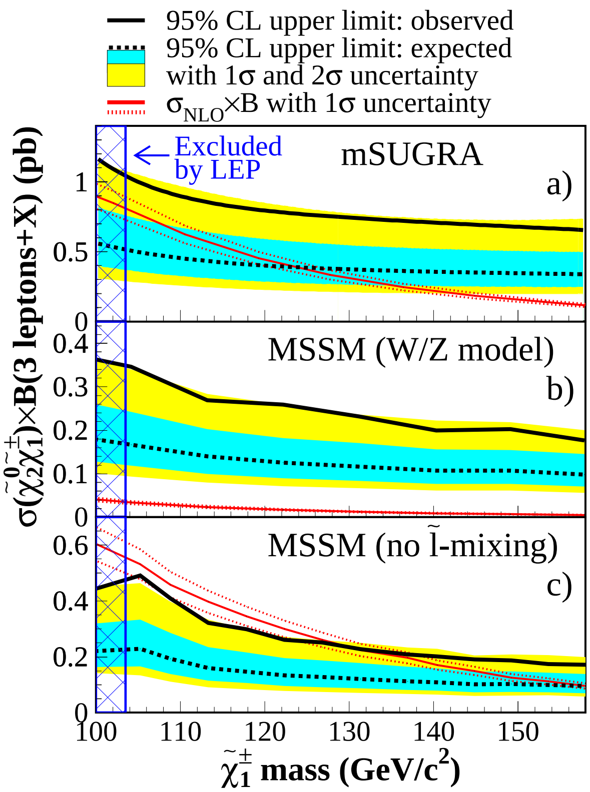

Figure 2: Cross section times branching ratio for $p\bar{p} \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 + X \rightarrow \ell\ell\ell + X$ production as function of the chargino mass. Shown are the observed and expected experimental upper limits together with the theoretical cross section for the mSUGRA (a), the MSSM (W/Z model) (b), and the MSSM (no $\tilde{\ell}$-mixing) (c) scenario as described in the text. Also shown are the 1σ and 2σ ranges for the expected limit.

In conclusion, we present a search for the associated production of charginos and neutralinos using events with isolated leptons and large $\not\!\!E_T$. The observed data are consistent with standard model predictions. Limits are derived on the cross section times the leptonic branching ratio for this process and on the mass of the lightest chargino under different theoretical assumptions. In the MSSM (no $\tilde{\ell}$-mixing) scenario, chargino masses below 129 GeV/c^2 are excluded at the 95% confidence level, extending the previous limits by 12 GeV/c^2.

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. We thank Tilman Plehn and Benjamin Allanach for their help on the theoretical interpretation. 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 Science and Engineering Foundation and the Korean Research Foundation; the Particle Physics and Astronomy Research Council and the Royal Society, UK; the Institut National de Physique Nucleaire et Physique des Particules/CNRS; the Russian Foundation for Basic Research; the Comisión Interministerial de Ciencia y Tecnología, Spain; the European Community's Human Potential Programme under contract HPRN-CT-2002-00292; and the Academy of Finland.

[1] J. Wess and B. Zumino, Nucl. Phys. **B 70**, 39 (1974).

[2] E. Witten, Nucl. Phys. **B 188**, 513 (1981); N. Sakai, Z. Phys. C **11**, 153 (1981); S. Dimopoulos, Nucl. Phys. **B 193**, 150 (1981).

[3] J. Ellis, J. S. Hagelin, D. V. Nanopoulos, K. Olive, and M. Srednicki, Nucl. Phys. **B 238**, 453-476 (1984); H. Goldberg, Phys. Rev. Lett **50**, 1419 (1983)

[4] S. Dimopoulos, S. Raby, and F. Wilczek, Phys. Rev. D **24**, 1681 (1981).

[5] We use a cylindrical coordinate system where the z axis is along the proton beam direction and θ is the polar angle. Pseudorapidity is $\eta = -\ln\tan(\theta/2)$, while transverse momentum is $p_T = |p|\sin\theta$ and transverse energy is $E_T = E\sin\theta$. Missing transverse energy, $\not\!\!E_T$, is defined as the magnitude of $-\Sigma_i E_{\mathrm{T}}^i \hat{n}_i$, where $\hat{n}_i$ is the unit vector in the azimuthal plane that points from the beam line to the i^{th} calorimeter tower. The quantity E_T^{iso} (p_T^{iso}) is defined as the scalar sum of the transverse energies (momenta) within a cone of $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.4$ around the selected electron (muon or track). For electrons (muons, tracks) we require the E_T^{iso} to be less than 2 GeV or 10% of the electron E_T (muon or track p_T).

[6] LEP SUSY Working Group (ALEPH, DELPHI, L3 and OPAL experiments), note LEPSUSYWG/01-03.1.

[7] LEP SUSY Working Group (ALEPH, DELPHI, L3 and OPAL experiments), note LEPSUSYWG/02-06.2.

[8] V. Abazov *et al.* (D0 Collaboration), Phys. Rev. Lett. **95**, 151805 (2005).

[9] D. Acosta, *et al.* (CDF Collaboration), Phys. Rev. D **71**, 032001 (2005).

[10] C. S. Hill *et al.*, Nucl. Instrum. Methods A **530**, 1 (2004); A. Sill *et al.*, Nucl. Instrum. Methods in Phys. Res. A **447**, 1 (2000); A. Affolder *et al.*, Nucl. Instrum. Methods A **453**, 84 (2000).

[11] A. Affolder *et al.*, Nucl. Instrum. Methods A **526**, 249 (2004).

[12] L. Balka *et al.*, Nucl. Instrum. Methods A **267**, 272 (1988); S. Bertolucci *et al.*, Nucl. Instrum. Methods A **267**, 301 (1988).

[13] M. Albrow *et al.*, Nucl. Instrum. Methods A **480**, 524 (2002).

[14] D. Acosta *et al.*, Nucl. Instrum. Methods A **461**, 540 (2001).

[15] A. Abulencia *et al.* (CDF Collaboration), Phys. Rev. Lett. **98**, 221803 (2007).

[16] A. Abulencia *et al.* (CDF Collaboration), *to be submitted to Phys. Rev. D.*

[17] A. Abulencia *et al.* (CDF Collaboration), *to be submitted to Phys. Rev. D.*

[18] T. Sjöstrand, and S. Mrenna, LU-TP 01, hep-ph/0108264 (we use version 6.3).

[19] U. Baur, and E. L. Berger, Phys. Rev. D **41**, 1476 (1990).

[20] F. Maltoni, and T. Stelzer, J.High Energy Phys. **0302**, 027 (2003).

[21] H. L. Lai *et al.*, Eur. Phys. J. C **12**, 375 (2000).

[22] R. Brun, and F. Carminati, CERN Program Library Long Writeup W5013 (1993).

[23] H. P. Nilles, Phys. Rep. **110**, 1 (1984).

[24] B. C. Allanach, Comput. Phys. Commun. 143 (2002) 305-331, hep-ph/0104145 (we use version 2.0.7).

[25] F. Paige, et al., hep-ph/0312045 (we use version 7.71).

[26] T. Junk, Nucl. Instrum. Methods A **434**, 435 (1999).

[27] A. L. Read, J. Phys. G **28**, 2693-2704 (2002).

[28] W. Beenakker, R. Hopker and M. Spira, hep-ph/9611232.

[29] T. Plehn and M. Spira, *private communication*.