View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Digital.CSIC

Search for a new heavy gauge boson W' with event signature electron + missing transverse energy in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV

T. Aaltonen,[21] B. Álvarez González,[1,w] S. Amerio,[41a,41b] D. Amidei,[32] A. Anastassov,[36] A. Annovi,[17] J. Antos,[12] G. Apollinari,[15] J. A. Appel,[15] A. Apresyan,[46] T. Arisawa,[56] A. Artikov,[13] J. Asaadi,[51] W. Ashmanskas,[15] B. Auerbach,[59] A. Aurisano,[51] F. Azfar,[40] W. Badgett,[15] A. Barbaro-Galtieri,[26] V. E. Barnes,[46] B. A. Barnett,[23] P. Barria,[44c,44a] P. Bartos,[12] M. Bauce,[41b,41a] G. Bauer,[30] F. Bedeschi,[44a,44b,44c,44d] D. Beecher,[28] S. Behari,[23] G. Bellettini,[44b,44a] J. Bellinger,[58] D. Benjamin,[14] A. Beretvas,[15] A. Bhatti,[48] M. Binkley,[15,a] D. Bisello,[41b,41a] I. Bizjak,[28,aa] K. R. Bland,[5] B. Blumenfeld,[23] A. Bocci,[14] A. Bodek,[47] D. Bortoletto,[46] J. Boudreau,[45] A. Boveia,[11] B. Brau,[15,b] L. Brigliadori,[6b,6a] A. Brisuda,[12] C. Bromberg,[33] E. Brucken,[21] M. Bucciantonio,[44b,44a] J. Budagov,[13] H. S. Budd,[47] S. Budd,[22] K. Burkett,[15] G. Busetto,[41b,41a] P. Bussey,[19] A. Buzatu,[31] C. Calancha,[29] S. Camarda,[4] M. Campanelli,[33] M. Campbell,[32] F. Canelli,[12,15] A. Canepa,[43] B. Carls,[22] D. Carlsmith,[58] R. Carosi,[44a,44b,44c,44d] S. Carrillo,[16,l] S. Carron,[15] B. Casal,[1] M. Casarsa,[15] A. Castro,[6b,6a] P. Catastini,[15] D. Cauz,[52a,52b] V. Cavaliere,[44c,44a] M. Cavalli-Sforza,[4] A. Cerri,[26,g] L. Cerrito,[28,r] Y. C. Chen,[1] M. Chertok,[7] G. Chiarelli,[44a,44b,44c,44d] G. Chlachidze,[15] F. Chlebana,[15] K. Cho,[25] D. Chokheli,[13] J. P. Chou,[20] W. H. Chung,[58] Y. S. Chung,[47] C. I. Ciobanu,[42] M. A. Ciocci,[44c,44a] A. Clark,[18] G. Compostella,[41b,41a] M. E. Convery,[15] J. Conway,[7] M. Corbo,[42] M. Cordelli,[17] C. A. Cox,[7] D. J. Cox,[7] F. Crescioli,[44b,44a] C. Cuenca Almenar,[59] J. Cuevas,[1,w] R. Culbertson,[15] D. Dagenhart,[15] N. d'Ascenzo,[42,u] M. Datta,[15] P. de Barbaro,[47] S. De Cecco,[49a,49b] G. De Lorenzo,[4] M. Dell'Orso,[44b,44a] C. Deluca,[4] L. Demortier,[48] J. Deng,[14,d] M. Deninno,[6a,6b] F. Devoto,[21] M. d'Errico,[41b,41a] A. Di Canto,[44b,44a] B. Di Ruzza,[44a,44b,44c,44d] J. R. Dittmann,[5] M. D'Onofrio,[27] S. Donati,[44b,44a] P. Dong,[15] T. Dorigo,[41a,41b] K. Ebina,[56] A. Elagin,[51] A. Eppig,[32] R. Erbacher,[7] D. Errede,[22] S. Errede,[22] N. Ershaidat,[42,z] R. Eusebi,[51] H. C. Fang,[26] S. Farrington,[40] M. Feindt,[24] J. P. Fernandez,[29] C. Ferrazza,[44d,44a] R. Field,[16] G. Flanagan,[46,s] R. Forrest,[7] M. J. Frank,[5] M. Franklin,[20] J. C. Freeman,[15] I. Furic,[16] M. Gallinaro,[48] J. Galyardt,[10] J. E. Garcia,[18] A. F. Garfinkel,[46] P. Garosi,[44c,44a] H. Gerberich,[22] E. Gerchtein,[15] S. Giagu,[49b,49a] V. Giakoumopoulou,[3] P. Giannetti,[44a,44b,44c,44d] K. Gibson,[45] C. M. Ginsburg,[15] N. Giokaris,[3] P. Giromini,[17] M. Giunta,[44a,44b,44c,44d] G. Giurgiu,[23] V. Glagolev,[13] D. Glenzinski,[15] M. Gold,[35] D. Goldin,[51] N. Goldschmidt,[16] A. Golossanov,[15] G. Gomez,[1] G. Gomez-Ceballos,[30] M. Goncharov,[30] O. González,[29] I. Gorelov,[35] A. T. Goshaw,[14] K. Goulianos,[48] A. Gresele,[41a,41b] S. Grinstein,[4] C. Grosso-Pilcher,[11] R. C. Group,[55] J. Guimaraes da Costa,[20] Z. Gunay-Unalan,[33] C. Haber,[26] S. R. Hahn,[15] E. Halkiadakis,[50] A. Hamaguchi,[39] J. Y. Han,[47] F. Happacher,[17] K. Hara,[53] D. Hare,[50] M. Hare,[54] R. F. Harr,[57] K. Hatakeyama,[5] C. Hays,[40] M. Heck,[24] J. Heinrich,[43] M. Herndon,[58] S. Hewamanage,[5] D. Hidas,[50] A. Hocker,[15] W. Hopkins,[15,h] D. Horn,[24] S. Hou,[1] R. E. Hughes,[37] M. Hurwitz,[11] U. Husemann,[59] N. Hussain,[31] M. Hussein,[33] J. Huston,[33] G. Introzzi,[44a,44b,44c,44d] M. Iori,[49b,49a] A. Ivanov,[7,p] E. James,[15] D. Jang,[10] B. Jayatilaka,[14] E. J. Jeon,[25] M. K. Jha,[6a,6b] S. Jindariani,[15] W. Johnson,[7] M. Jones,[46] K. K. Joo,[25] S. Y. Jun,[10] T. R. Junk,[15] T. Kamon,[51] P. E. Karchin,[57] Y. Kato,[39,o] W. Ketchum,[11] J. Keung,[43] V. Khotilovich,[51] B. Kilminster,[15] D. H. Kim,[25] H. S. Kim,[25] H. W. Kim,[25] J. E. Kim,[25] M. J. Kim,[17] S. B. Kim,[25] S. H. Kim,[53] Y. K. Kim,[11] N. Kimura,[56] M. Kirby,[15] S. Klimenko,[16] K. Kondo,[56] D. J. Kong,[25] J. Konigsberg,[16] A. V. Kotwal,[14] M. Kreps,[24] J. Kroll,[43] D. Krop,[11] N. Krumnack,[5,m] M. Kruse,[14] V. Krutelyov,[51,e] T. Kuhr,[24] M. Kurata,[53] S. Kwang,[11] A. T. Laasanen,[46] S. Lami,[44a,44b,44c,44d] S. Lammel,[15] M. Lancaster,[28] R. L. Lander,[7] K. Lannon,[37,v] A. Lath,[50] G. Latino,[44c,44a] I. Lazzizzera,[41a,41b] T. LeCompte,[2] E. Lee,[51] H. S. Lee,[11] J. S. Lee,[25] S. W. Lee,[51,x] S. Leo,[44b,44a] S. Leone,[44a,44b,44c,44d] J. D. Lewis,[15] C.-J. Lin,[26] J. Linacre,[40] M. Lindgren,[15] E. Lipeles,[43] A. Lister,[18] D. O. Litvintsev,[15] C. Liu,[45] Q. Liu,[46] T. Liu,[15] S. Lockwitz,[59] N. S. Lockyer,[43] A. Loginov,[59] D. Lucchesi,[41b,41a] J. Lueck,[24] P. Lujan,[26] P. Lukens,[15] G. Lungu,[48] J. Lys,[26] R. Lysak,[12] R. Madrak,[15] K. Maeshima,[15] K. Makhoul,[30] P. Maksimovic,[23] S. Malik,[48] G. Manca,[27,c] A. Manousakis-Katsikakis,[3] F. Margaroli,[46] C. Marino,[24] M. Martínez,[4] R. Martínez-Ballarín,[29] P. Mastrandrea,[49a,49b] M. Mathis,[23] M. E. Mattson,[57] P. Mazzanti,[6a,6b] K. S. McFarland,[47] P. McIntyre,[51] R. McNulty,[27,j] A. Mehta,[27] P. Mehtala,[21] A. Menzione,[44a,44b,44c,44d] C. Mesropian,[48] T. Miao,[15] D. Mietlicki,[32] A. Mitra,[1] H. Miyake,[53] S. Moed,[20] N. Moggi,[6a,6b] M. N. Mondragon,[15,l] C. S. Moon,[25] R. Moore,[15] M. J. Morello,[15] J. Morlock,[24] P. Movilla Fernandez,[15] A. Mukherjee,[15] Th. Muller,[24] P. Murat,[15] M. Mussini,[6b,6a] J. Nachtman,[15,n] Y. Nagai,[53] J. Naganoma,[56] I. Nakano,[38] A. Napier,[54] J. Nett,[58] C. Neu,[55] M. S. Neubauer,[22] J. Nielsen,[26,f] L. Nodulman,[2] O. Norniella,[22] E. Nurse,[28] L. Oakes,[40] S. H. Oh,[14] Y. D. Oh,[25] I. Oksuzian,[55] T. Okusawa,[39] R. Orava,[21] L. Ortolan,[4] S. Pagan Griso,[41b,41a] C. Pagliarone,[52a,52b] E. Palencia,[1,g] V. Papadimitriou,[15] A. A. Paramonov,[2] J. Patrick,[15] G. Pauletta,[52b,52a] M. Paulini,[10] C. Paus,[30] D. E. Pellett,[7] A. Penzo,[52a,52b] T. J. Phillips,[14] G. Piacentino,[44a,44b,44c,44d] E. Pianori,[43] J. Pilot,[37] K. Pitts,[22] C. Plager,[8] L. Pondrom,[58] K. Potamianos,[46] O. Poukhov,[13,a] F. Prokoshin,[13,y] A. Pronko,[15] F. Ptohos,[17,i] E. Pueschel,[10] G. Punzi,[44b,44a] J. Pursley,[58] A. Rahaman,[45] V. Ramakrishnan,[58] N. Ranjan,[46] I. Redondo,[29] P. Renton,[40] M. Rescigno,[49a,49b] F. Rimondi,[6b,6a] L. Ristori,[45,15]

 © 2011 American Physical Society

A. Robson,[19] T. Rodrigo,[1] T. Rodriguez,[43] E. Rogers,[22] S. Rolli,[54] R. Roser,[15] M. Rossi,[52a,52b] F. Rubbo,[15] F. Ruffini,[44c,44a] A. Ruiz,[1] J. Russ,[10] V. Rusu,[15] A. Safonov,[51] W. K. Sakumoto,[47] L. Santi,[52b,52a] L. Sartori,[44a,44b,44c,44d] K. Sato,[53] V. Saveliev,[42,u] A. Savoy-Navarro,[42] P. Schlabach,[15] A. Schmidt,[24] E. E. Schmidt,[15] M. P. Schmidt,[59,a] M. Schmitt,[36] T. Schwarz,[7] L. Scodellaro,[1] A. Scribano,[44c,44a] F. Scuri,[44a,44b,44c,44d] A. Sedov,[46] S. Seidel,[35] Y. Seiya,[39] A. Semenov,[13] F. Sforza,[44b,44a] A. Sfyrla,[22] S. Z. Shalhout,[7] T. Shears,[27] P. F. Shepard,[45] M. Shimojima,[53,t] S. Shiraishi,[11] M. Shochet,[11] I. Shreyber,[34] A. Simonenko,[13] P. Sinervo,[31] A. Sissakian,[13,a] K. Sliwa,[54] J. R. Smith,[7] F. D. Snider,[15] A. Soha,[15] S. Somalwar,[50] V. Sorin,[4] P. Squillacioti,[15] M. Stanitzki,[59] R. St. Denis,[19] B. Stelzer,[31] O. Stelzer-Chilton,[31] D. Stentz,[36] J. Strologas,[35] G. L. Strycker,[32] Y. Sudo,[53] A. Sukhanov,[16] I. Suslov,[13] K. Takemasa,[53] Y. Takeuchi,[53] J. Tang,[11] M. Tecchio,[32] P. K. Teng,[1] J. Thom,[15,h] J. Thome,[10] G. A. Thompson,[22] E. Thomson,[43] P. Ttito-Guzmán,[29] S. Tkaczyk,[15] D. Toback,[51] S. Tokar,[12] K. Tollefson,[33] T. Tomura,[53] D. Tonelli,[15] S. Torre,[17] D. Torretta,[15] P. Totaro,[52b,52a] M. Trovato,[44d,44a] Y. Tu,[43] N. Turini,[44c,44a] F. Ukegawa,[53] S. Uozumi,[25] A. Varganov,[32] E. Vataga,[44d,44a] F. Vázquez,[16,l] G. Velev,[15] C. Vellidis,[3] M. Vidal,[29] I. Vila,[1] R. Vilar,[1] M. Vogel,[35] G. Volpi,[44b,44a] P. Wagner,[43] R. L. Wagner,[15] T. Wakisaka,[39] R. Wallny,[8] S. M. Wang,[1] A. Warburton,[31] D. Waters,[28] M. Weinberger,[51] W. C. Wester III,[15] B. Whitehouse,[54] D. Whiteson,[43,d] A. B. Wicklund,[2] E. Wicklund,[15] S. Wilbur,[11] F. Wick,[24] H. H. Williams,[43] J. S. Wilson,[37] P. Wilson,[15] B. L. Winer,[37] P. Wittich,[15,h] S. Wolbers,[15] H. Wolfe,[37] T. Wright,[32] X. Wu,[18] Z. Wu,[5] K. Yamamoto,[39] J. Yamaoka,[14] T. Yang,[15] U. K. Yang,[11,q] Y. C. Yang,[25] W.-M. Yao,[26] G. P. Yeh,[15] K. Yi,[15,n] J. Yoh,[15] K. Yorita,[56] T. Yoshida,[39,k] G. B. Yu,[14] I. Yu,[25] S. S. Yu,[15] J. C. Yun,[15] A. Zanetti,[52a,52b] Y. Zeng,[14] and S. Zucchelli[6b,6a]

(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, Universitat Autonoma de Barcelona, E-08193, Bellaterra (Barcelona), Spain*
[5]*Baylor University, Waco, Texas 76798, USA*
[6a]*Istituto Nazionale di Fisica Nucleare Bologna, I-40127 Bologna, Italy;*
[6b]*University of Bologna, I-40127 Bologna, Italy*
[7]*University of California, Davis, Davis, California 95616, USA*
[8]*University of California, Los Angeles, Los Angeles, California 90024, USA*
[1]*Instituto de Fisica de Cantabria, CSIC-University of 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, FIN-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, Daejeon 305-806, Korea; Chonnam National University, Gwangju 500-757, Korea; Chonbuk National University, Jeonju 561-756, Korea*
[26]*Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
[27]*University of Liverpool, Liverpool L69 7ZE, United Kingdom*
[28]*University College London, London WC1E 6BT, United Kingdom*
[29]*Centro de Investigaciones Energeticas Medioambientales y Tecnologicas, E-28040 Madrid, Spain*
[30]*Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA*
[31]*Institute of Particle Physics: McGill University, Montréal, Québec, Canada H3A 2T8; Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6; University of Toronto, Toronto, Ontario, Canada M5S 1A7; and TRIUMF, Vancouver, British Columbia, Canada V6T 2A3*

[32]*University of Michigan, Ann Arbor, Michigan 48109, USA*
[33]*Michigan State University, East Lansing, Michigan 48824, USA*
[34]*Institution for Theoretical and Experimental Physics, ITEP, Moscow 117259, Russia*
[35]*University of New Mexico, Albuquerque, New Mexico 87131, USA*
[36]*Northwestern University, Evanston, Illinois 60208, USA*
[37]*The Ohio State University, Columbus, Ohio 43210, USA*
[38]*Okayama University, Okayama 700-8530, Japan*
[39]*Osaka City University, Osaka 588, Japan*
[40]*University of Oxford, Oxford OX1 3RH, United Kingdom*
[41a]*Istituto Nazionale di Fisica Nucleare, Sezione di Padova-Trento, I-35131 Padova, Italy*
[41b]*University of Padova, I-35131 Padova, Italy*
[42]*LPNHE, Universite Pierre et Marie Curie/IN2P3-CNRS, UMR7585, Paris, F-75252 France*
[43]*University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA*
[44a]*Istituto Nazionale di Fisica Nucleare Pisa, I-56127 Pisa, Italy*
[44b]*University of Pisa, I-56127 Pisa, Italy*
[44c]*University of Siena, I-56127 Pisa, Italy*
[44d]*Scuola Normale Superiore, I-56127 Pisa, Italy*
[45]*University of Pittsburgh, Pittsburgh, Pennsylvania 15260, USA*
[46]*Purdue University, West Lafayette, Indiana 47907, USA*
[47]*University of Rochester, Rochester, New York 14627, USA*
[48]*The Rockefeller University, New York, New York 10065, USA*
[49a]*Istituto Nazionale di Fisica Nucleare, Sezione di Roma 1, I-00185 Roma, Italy*
[49b]*Sapienza Università di Roma, I-00185 Roma, Italy*
[50]*Rutgers University, Piscataway, New Jersey 08855, USA*
[51]*Texas A&M University, College Station, Texas 77843, USA*
[52a]*Istituto Nazionale di Fisica Nucleare Trieste/Udine, I-34100 Trieste, I-33100 Udine, Italy*
[52b]*University of Trieste/Udine, I-33100 Udine, Italy*
[53]*University of Tsukuba, Tsukuba, Ibaraki 305, Japan*
[54]*Tufts University, Medford, Massachusetts 02155, USA*
[55]*University of Virginia, Charlottesville, Virginia 22906, USA*
[56]*Waseda University, Tokyo 169, Japan*
[57]*Wayne State University, Detroit, Michigan 48201, USA*
[58]*University of Wisconsin, Madison, Wisconsin 53706, USA*
[59]*Yale University, New Haven, Connecticut 06520, USA*

(Received 23 December 2010; published 3 February 2011)

[a]Deceased.
[b]Visitor from University of Massachusetts Amherst, Amherst, MA 01003, USA.
[c]Visitor from Istituto Nazionale di Fisica Nucleare, Sezione di Cagliari, 09042 Monserrato (Cagliari), Italy.
[d]Visitor from University of California Irvine, Irvine, CA 92697, USA.
[e]Visitor from University of California Santa Barbara, Santa Barbara, CA 93106, USA.
[f]Visitor from University of California Santa Cruz, Santa Cruz, CA 95064, USA.
[g]Visitor from CERN, CH-1211 Geneva, Switzerland.
[h]Visitor from Cornell University, Ithaca, NY 14853, USA.
[i]Visitor from University of Cyprus, Nicosia CY-1678, Cyprus.
[j]Visitor from University College Dublin, Dublin 4, Ireland.
[k]Visitor from University of Fukui, Fukui City, Fukui Prefecture, Japan 910-0017.
[l]Visitor from Universidad Iberoamericana, Mexico D.F., Mexico.
[m]Visitor from Iowa State University, Ames, IA 50011, USA.
[n]Visitor from University of Iowa, Iowa City, IA 52242, USA.
[o]Visitor from Kinki University, Higashi-Osaka City, Japan 577-8502.
[p]Visitor from Kansas State University, Manhattan, KS 66506, USA.
[q]Visitor from University of Manchester, Manchester M13 9PL, United Kingdom.
[r]Visitor from Queen Mary, University of London, London, E1 4NS, United Kingdom.
[s]Visitor from Muons, Inc., Batavia, IL 60510, USA.
[t]Visitor from Nagasaki Institute of Applied Science, Nagasaki, Japan.
[u]Visitor from National Research Nuclear University, Moscow, Russia.
[v]Visitor from University of Notre Dame, Notre Dame, IN 46556, USA.
[x]Visitor from Texas Tech University, Lubbock, TX 79609, USA.
[y]Visitor from Universidad Tecnica Federico Santa Maria, 110v Valparaiso, Chile.
[z]Visitor from Yarmouk University, Irbid 211-63, Jordan.
[aa]On leave from J. Stefan Institute, Ljubljana, Slovenia.

We present a search for a new heavy charged vector boson W' decaying to an electron-neutrino pair in $p\bar{p}$ collisions at a center-of-mass energy of 1.96 TeV. The data were collected with the CDF II detector and correspond to an integrated luminosity of 5.3 fb^{-1}. No significant excess above the standard model expectation is observed and we set upper limits on $\sigma \cdot \mathcal{B}(W' \rightarrow e\nu)$. Assuming standard model couplings to fermions and the neutrino from the W' boson decay to be light, we exclude a W' boson with mass less than 1.12 TeV/c^2 at the 95% confidence level.

DOI: 10.1103/PhysRevD.83.031102 PACS numbers: 14.70.Pw, 12.60.Cn, 13.85.Rm

The W' [1] is a postulated charged heavy vector boson which is predicted in models that extend the gauge structure of the standard model. In the left-right (LR) symmetric model [2] considered here, the right-handed W' boson mass is obtained by the symmetry breaking of the right-handed electroweak gauge group of $SU(2)_R \times SU(2)_L \times U(1)_{B,L}$. This provides a natural explanation for the observed suppression of $V + A$ currents in low-energy weak processes. The LR symmetric model can also be motivated by the manifestation of a higher symmetry predicted at intermediate energies in grand unified theories [3].

The manifest LR symmetric model assumes that the right-handed Cabibbo-Kobayashi-Maskawa matrix and the gauge coupling constants are identical to those of the standard model [4]. The W' can decay in the same way as the standard model W, with the exception that the tb [5] decay channel is accessible if the W' is heavy enough and that the diboson decay channel ($W' \rightarrow WZ$) is suppressed in the extended gauge model [1].

The W' boson has been previously searched for in high-energy physics experiments using final state signatures such as leptons, jets, and/or missing energy. The most recent direct searches for a charged heavy vector boson have been performed at the Tevatron collider at Fermilab. The CDF experiment previously set limits on the cross section times branching fraction in the decay mode $W' \rightarrow tb$ and excluded a W' boson mass below 800 GeV/c^2 at the 95% confidence level (C.L.) using 1.9 fb^{-1} data of $p\bar{p}$ collisions [6]. The D0 experiment set limits on the product of the cross section and branching fraction in the decay mode $W' \rightarrow e\nu$ and excluded a W' boson mass below 1.00 TeV/c^2 at the 95% C.L. using 1.0 fb^{-1} of data [7]. Both of these recent mass limits assume that the couplings between the new vector boson and the fermionic final states are the same as in the standard model.

In this paper, we present the results of a search for a W' boson in the $e\nu$ decay mode, assuming the manifest LR symmetric model and the right-handed neutrino from the boson decay to be light ($m_\nu \ll m_{W'}$) and stable. Under these assumptions, the results in this paper can be useful in the generic model [1] since the kinematics of the left- and right-handed W' bosons is not different. We use a data sample corresponding to 5.3 fb^{-1} integrated luminosity of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV recorded by the upgraded Collider Detector at Fermilab (CDF II). We select events that are consistent with the production of the standard model W and the heavier W' boson that decay to an electron and neutrino in the final state. The analysis technique applied is the same as in a previous search [8].

The CDF II detector is described in detail elsewhere [9]. CDF II is a general purpose solenoidal detector which combines precision charged-particle tracking with fast projective calorimetry and fine-grained muon detection. Tracking systems are contained inside a superconducting solenoid, 1.5 m in radius and 4.8 m in length, which generates a 1.4 T magnetic field parallel to the beam axis. Calorimeters and muon systems surround the solenoid and the tracking system. Electron candidates are identified by an energy deposit in the electromagnetic calorimeter with a track pointing to it. A set of charged-particle detectors surrounding the calorimeters identify muon candidates. The energy of the electron candidate is measured by the calorimeter and its direction is determined from the tracking system. The component of the neutrino momentum transverse to the beam line is inferred to be equal to the missing transverse energy $\not{E}_T$ [10], which is derived from the transverse energy imbalance of all the deposited energy in the calorimeters.

The on-line selection requires either one electron candidate in the electromagnetic calorimeter with transverse energy $E_T > 18$ GeV that has a matching track with transverse momentum $p_T > 9$ GeV/c or an electron candidate in the electromagnetic calorimeter with transverse energy $E_T > 70$ GeV. No restrictions on the amount of energy leakage into the hadronic calorimeter were imposed, in order to ensure high efficiency for high-E_T electrons. We select the candidate event sample off-line by requiring an isolated electron candidate with $E_T > 25$ GeV and the existence of an associated track with $p_T > 15$ GeV/c that is contained in the fiducial region of the tracking system of $|\eta| < 1.0$ [11]. Electron candidates are selected based on an E_T-dependent isolation cut [12] in order to maximize the efficiency in the high-E_T region. The electron shower profile is required to be consistent with that of test-beam electrons in order to match with the expected electromagnetic shower [13]. In events with high-energy muons, the $\not{E}_T$ is adjusted by adding the muon momentum and removing the expected ionization energy deposition in the calorimeter. The $\not{E}_T$ is corrected further for η- and energy-dependent nonuniformities of the calorimeter response. In the final selection, the corrected $\not{E}_T$ is required to be greater than 25 GeV. Dilepton events coming from

Drell-Yan, $t\bar{t}$, and diboson backgrounds are vetoed by rejecting events with a second isolated lepton, either an electron or a muon, with $p_T > 15$ GeV$/c$. QCD multijet events are a background to $W/W' \rightarrow e\nu$ when a jet is misidentified as an electron and mismeasured jets lead to significant $\not\!\!E_T$. The electron candidate E_T and the event $\not\!\!E_T$ are likely to significantly differ in magnitude in this case. In contrast, a $W/W' \rightarrow e\nu$ event will have an electron and neutrino emitted in opposite directions which results in the electron E_T and $\not\!\!E_T$ being of comparable magnitude, respectively, assuming the p_T of the boson is much smaller than its mass. Thus, in order to reduce the QCD multijet background, we require the candidate events to satisfy $0.4 < E_T/\not\!\!E_T < 2.5$. The efficiency of this requirement is larger than 99% for W/W' events whereas the rejection fraction is ~40% for QCD multijet events with $E_T > 100$ GeV. After all selection requirements, the transverse mass of a candidate event is calculated as

$$m_T \equiv \sqrt{2E_T\not\!\!E_T(1 - \cos\phi_{e\nu})}, \quad (1)$$

where $\phi_{e\nu}$ is the azimuthal opening angle between the electron candidate and the $\not\!\!E_T$ direction.

The $W' \rightarrow e\nu$ signal events are generated with PYTHIA [14] using the CTEQ5L [15] parton distribution functions (PDFs) and a simulation of the CDF II detector [16]. Since the cross sections calculated by PYTHIA are at leading order, next-to-next-to-leading-order K factors are applied to the leading order cross sections. Mass-dependent next-to-next-to-leading-order K factors from Ref. [17] are obtained with an approximate magnitude around 1.3. The total acceptance times efficiency of the event selection cuts ranges from 45% to 35% and decreases above a W' boson mass of 800 GeV$/c^2$. Figure 1 shows the expected W' boson transverse mass distributions for various input masses with the background predictions. The on-shell production of heavy bosons near the kinematic limit is suppressed due to the smallness of the PDFs at large momentum fraction, which results in the low acceptance rate of W' events at high mass above 800 GeV$/c^2$ after applying the kinematic selection requirements.

The background sources to $W' \rightarrow e\nu$ are primarily processes with an electron and missing energy in the final state. These sources of background are $W \rightarrow e\nu$, $W \rightarrow \tau\nu \rightarrow e\nu\nu\nu$, $Z/\gamma^* \rightarrow \tau\tau \rightarrow eX$, tt, and diboson (WW, WZ) production. The $Z/\gamma^* \rightarrow ee$ process can also produce missing energy when one of the electrons escapes detection. The m_T distributions and acceptance times efficiency of the nonmultijet backgrounds are obtained using PYTHIA and a simulation of the CDF II detector. Theoretical cross section predictions are used to estimate the expected background yields [17–19]. For the QCD multijet background estimation, a data-driven method is applied that uses the distribution of the azimuthal angle between the primary electron candidate and the vector sum of the jet energy. For

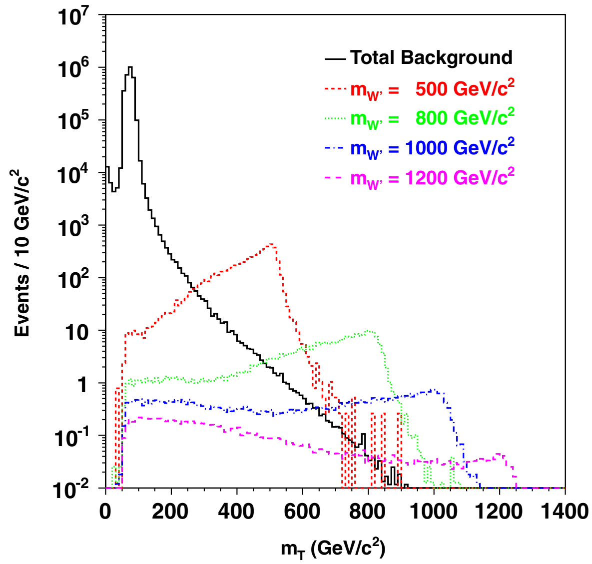

FIG. 1 (color online). The transverse mass distributions for $W' \rightarrow e\nu$ signal events generated using PYTHIA with total background expectation.

the multijet case, a jet misidentified as an electron candidate will appear to recoil against the rest of the jet in the event. Therefore, a back-to-back distribution is expected in the azimuthal opening angle. The $W/W' \rightarrow e\nu$ process, however, does not have a strong correlation in this angle. The QCD multijet contribution is estimated by a likelihood fit to the data using the different angular shapes. The multijet m_T distribution is obtained using a QCD enriched sideband sample with the isolation cut inverted. The data and the total background m_T distributions are compared in Fig. 2. The contributions from $W \rightarrow e\nu$, QCD multijet, and

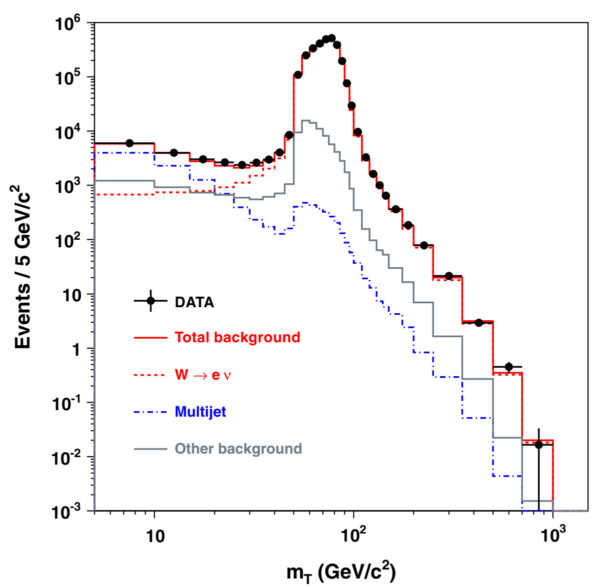

FIG. 2 (color online). The transverse mass distributions of $e\nu$ candidate events compared to the total backgrounds.

TABLE I. The event yields for the background sources in m_T above 200 GeV/c^2 compared to the observed data.

	Events in m_T bins (GeV/c^2)				
	200–250	250–350	350–500	500–700	700–1000
$W \to e\nu$	711^{+50}_{-50}	359^{+25}_{-25}	85^{+6}_{-6}	13^{+1}_{-1}	$1.1^{+0.1}_{-0.1}$
Multijet	9^{+2}_{-2}	6^{+1}_{-1}	2^{+2}_{-2}	$0.2^{+1.6}_{-0.2}$	$0.01^{+1.10}_{-0.01}$
Other background	70^{+9}_{-6}	33^{+4}_{-3}	8^{+1}_{-1}	$1^{+0.1}_{-0.1}$	$0.09^{+0.01}_{-0.01}$
Total background	790^{+61}_{-58}	398^{+31}_{-30}	94^{+9}_{-8}	14^{+3}_{-1}	$1.2^{+1.2}_{-0.1}$
Data	784	426	88	18	1

the other backgrounds in the mass region above $m_T = 200$ GeV/c^2 are listed in Table I. This comparison shows good agreement between the data and the total backgrounds.

In order to quantify the size of the potential signal contributions in the data sample, a binned maximum likelihood fit was performed on the observed m_T distribution between 0 and 1500 GeV/c^2, using the background predictions and the expected W' boson contribution for different mass values ranging from 500 to 1300 GeV/c^2. The fit results are shown in Table II, normalized to

$$\beta \equiv \frac{\sigma \cdot \mathcal{B}(W' \to e\nu)}{\sigma \cdot \mathcal{B}(W' \to e\nu)_{\rm LR}}, \quad (2)$$

where the numerator is the observed cross section times the branching fraction and the denominator is that expected from the manifest LR symmetric model. The expected signal yield was normalized to the observed W boson yield obtained from the fit. This removes several sources of systematic uncertainty such as the integrated luminosity,

TABLE II. The expected numbers of events from the $W' \to e\nu$ process, $N_{\rm exp}$, assuming the manifest LR symmetric model and normalized by the observed W boson yield. We also show the observed relative rate of the W' boson production from the fit described in the text and the 95% C.L. upper limit on this relative rate. The uncertainties are statistical only and do not include systematic uncertainties. The 95% upper limits include both statistical and systematic uncertainties.

$m_{W'}$	$N_{\rm exp}$	$\beta(= \frac{\sigma\cdot\mathcal{B}(W'\to e\nu)}{\sigma\cdot\mathcal{B}(W'\to e\nu)_{\rm LR}})$	
(GeV/c^2)	(events)	Fit ($\times 10^{-2}$)	Upper limit
500	5828	$0.08^{+0.21}_{-0.08}$	5.38×10^{-3}
550	3407	$0.18^{+0.26}_{-0.18}$	7.16×10^{-3}
600	2037	$0.28^{+0.36}_{-0.28}$	1.01×10^{-2}
650	1218	$0.43^{+0.54}_{-0.43}$	1.52×10^{-2}
700	731	$0.36^{+0.83}_{-0.36}$	2.22×10^{-2}
750	433	$0.15^{+1.07}_{-0.15}$	2.80×10^{-2}
800	263	$0.03^{+1.36}_{-0.03}$	3.82×10^{-2}
850	160	$0.00^{+1.89}_{-0.00}$	5.68×10^{-2}
900	100	$0.00^{+2.80}_{-0.00}$	8.79×10^{-2}
950	62	$0.00^{+4.53}_{-0.00}$	1.49×10^{-1}
1000	41	$0.00^{+6.64}_{-0.00}$	2.48×10^{-1}
1050	27	$0.00^{+10.8}_{-0.00}$	4.36×10^{-1}
1100	19	$0.00^{+17.7}_{-0.00}$	7.62×10^{-1}
1150	14	$0.00^{+32.5}_{-0.00}$	1.39
1200	10	$0.00^{+62.7}_{-0.00}$	2.47
1250	8.1	$0.00^{+114}_{-0.00}$	3.96
1300	6.7	$0.00^{+224}_{-0.00}$	6.24

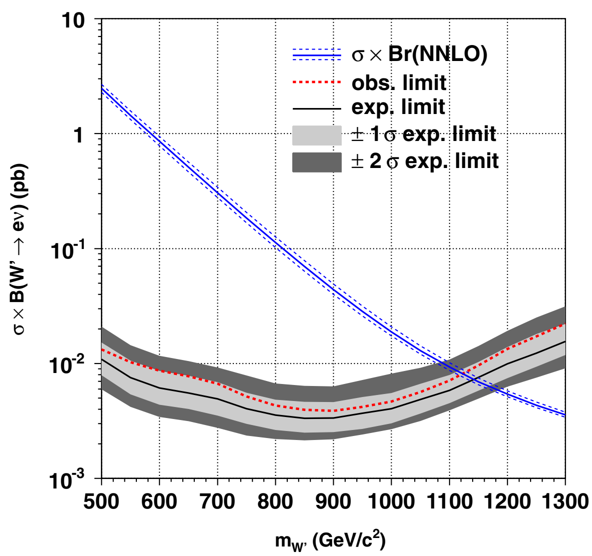

FIG. 3 (color online). The 95% C.L. limits on the cross section times the branching fraction as a function of W' boson mass and the expected limits from the simulated experiments with background only. The black solid lines represent the median expected; the shaded bands indicate the $\pm 1\sigma$ and $\pm 2\sigma$ invervals on the expected limits. The region above the red dashed line (observed limit) is excluded at the 95% C.L. The cross section times the branching fraction assuming the manifest LR symmetric model, $\sigma \cdot \mathcal{B}(W' \to e\nu)_{\rm LR}$, is shown along with its uncertainty. The intercept of the cross section limit curve and the lower bound of the theoretical cross section yields $m_{W'} > 1.12$ TeV/c^2 at the 95% C.L.

the trigger, and the identification efficiencies, all of which cancel in the ratio.

Systematic uncertainties on the signal and the background rates were considered for the PDFs, the jet energy scale, the theoretical cross sections, the multijet background, the initial and final state radiation of the signal, and the energy scale of the electromagnetic calorimeter. The dominant contribution to the systematic uncertainty comes from the PDFs. The total systematic uncertainty varies from $\pm 5\%$ to $\pm 10\%$ for W' boson masses ranging from $m_{W'} = 500$ to $1300\ \mathrm{GeV}/c^2$.

To determine the limit on β, we use a Bayesian approach [20] by constructing a marginalized posterior probability distribution $[p(\beta)]$ from the likelihood function. Sources of systematic uncertainty are included as nuisance parameters in the definition of the likelihood function. The 95% C.L. upper limits on the ratio of the observed to the expected cross section are obtained from the fit. We use the resulting likelihood function, and the obtained upper limits are summarized in Table II and plotted in Fig. 3 as a function $m_{W'}$ together with the expected limits obtained from simulated experiments with background only. Using theoretical predictions that assume the manifest LR symmetric model [4], the limits on the cross section times the branching fraction are converted into limits on the mass of the W' boson. The lower mass limit can be set at the mass value for which $\beta_{95} = 1$, where $\int_0^{\beta_{95}} p(\beta) d\beta = 0.95$. We take the lower bound of the theoretical cross section to obtain the mass limit. Hence, the 95% C.L. is found to be $m_{W'} > 1.12\ \mathrm{TeV}/c^2$.

In summary, we have performed a search for a new heavy charged vector boson decaying to an electron-neutrino pair with a light and stable neutrino in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. We do not observe any statistically significant excess over the background expectations. We use a fit to the m_T distribution to set upper limits on the production and decay rate of a W' boson as a function of $m_{W'}$ and exclude a W' boson with $m_{W'} < 1.12\ \mathrm{TeV}/c^2$ at the 95% C.L., assuming the manifest LR symmetric model.

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 Balduin Una Forschung, Germany; the World Class University Program, the National Research Foundation of Korea; the Science and Technology Facilities Council and the Royal Society, United Kingdom; the Institut National de Physique Nucleaire et Physique des Particules/CNRS and Universite Pierre et Marie Curie; the Russian Foundation for Basic Research; the Ministerio de Ciencia e Innovación, and Programa Consolider-Ingenio 2010, Spain; the Slovak R&D Agency; and the Academy of Finland.

[1] G. Altarelli *et al.*, Z. Phys. C **45**, 109 (1989); **47**, 676(E) (1990).

[2] J. C. Pati and A. Salam, Phys. Rev. D **10**, 275 (1974); R. N. Mohapatra and J. C. Pati, Phys. Rev. D **11**, 566 (1975); **11**, 2558 (1975); G. Senjanovic and R. N. Mohapatra, Phys. Rev. D **12**, 1502 (1975).

[3] R. N. Mohapatra, *Unification and Supersymmetry* (Springer, New York, 2003).

[4] M. A. Bég *et al.*, Phys. Rev. Lett. **38**, 1252 (1977); G. Senjanovic, Nucl. Phys. **B153**, 334 (1979).

[5] We omit charge, antiparticle, and flavor-tagging neutrino symbols when representing the decay modes but assume proper charge conjugation throughout this report. For example, $W'^+ \to e^+ \nu_e$ and its charge conjugate are denoted as $W' \to e\nu$.

[6] T. Aaltonen *et al.* (CDF Collaboration), Phys. Rev. Lett. **103**, 041801 (2009).

[7] V. M. Abazov *et al.*, Phys. Rev. Lett. **100**, 031804 (2008).

[8] A. Abulencia *et al.* (CDF Collaboration), Phys. Rev. D **75**, 091101 (2007).

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

[10] Missing transverse energy $\not{E}_T$ is defined as the magnitude of $-\sum_i E_T^i \hat{n}_i$, where $\hat{n}_i$ is a unit vector in the azimuthal plane that points from the beam line to the center of the ith calorimeter tower.

[11] We use a coordinate system where θ is the polar angle to the proton beam, ϕ is the azimuthal angle about the beam axis, and η is the pseudorapidity defined as $-\ln(\tan(\theta/2))$. Energy (track momentum) measured transverse to the beam line is denoted as E_T (p_T).

[12] The additional energy ($\equiv E_T^{0.4} - E_T^{\mathrm{ele}}$) must be less than $3 + 0.02 \times E_T^{\mathrm{ele}}$, where $E_T^{0.4}$ is the transverse energy in the cone of $\Delta R(\equiv \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}) < 0.4$ centered on the electron track and E_T^{ele} is the transverse energy of the electron candidate. Both energies are in units of GeV.

[13] D. Acosta *et al.* (CDF Collaboration), Phys. Rev. Lett. **94**, 091803 (2005).

[14] T. Sjöstrand *et al.*, Comput. Phys. Commun. **135**, 238 (2001).

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

[16] T. Affolder *et al.* (CDF Collaboration), Nucl. Instrum. Methods **447**, 1 (2000).

[17] R. Hamberg, W. L. van Neerven, and T. Matsuura, Nucl. Phys. **B359**, 343 (1991); **B644**, 403(E) (2002).

[18] J. M. Campbell and R. K. Ellis, Phys. Rev. D **60**, 113006 (1999).

[19] M. Cacciari *et al.*, J. High Energy Phys. 04 (2004) 068; N. Kidonakis and R. Vogt, Phys. Rev. D **68**, 114014 (2003).

[20] T. Junk, Nucl. Instrum. Methods Phys. Res., Sect. A **434**, 435 (1999).