Search for a Fermiophobic Higgs Boson Decaying into Diphotons in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV

T. Aaltonen,[24] J. Adelman,[14] T. Akimoto,[56] B. Álvarez González[r,12] S. Amerio[w,44] D. Amidei,[35] A. Anastassov,[39]
A. Annovi,[20] J. Antos,[15] G. Apollinari,[18] A. Apresyan,[49] T. Arisawa,[58] A. Artikov,[16] W. Ashmanskas,[18] A. Attal,[4]
A. Aurisano,[54] F. Azfar,[43] P. Azzurri[z,47] W. Badgett,[18] A. Barbaro-Galtieri,[29] V.E. Barnes,[49] B.A. Barnett,[26]
V. Bartsch,[31] G. Bauer,[33] P.-H. Beauchemin,[34] F. Bedeschi,[47] D. Beecher,[31] S. Behari,[26] G. Bellettini[x,47]
J. Bellinger,[60] D. Benjamin,[17] A. Beretvas,[18] J. Beringer,[29] A. Bhatti,[51] M. Binkley,[18] D. Bisello[w,44] I. Bizjak[cc,31]
R.E. Blair,[2] C. Blocker,[7] B. Blumenfeld,[26] A. Bocci,[17] A. Bodek,[50] V. Boisvert,[50] G. Bolla,[49] D. Bortoletto,[49]
J. Boudreau,[48] A. Boveia,[11] B. Brau[a,11] A. Bridgeman,[25] L. Brigliadori,[44] C. Bromberg,[36] E. Brubaker,[14]
J. Budagov,[16] H.S. Budd,[50] S. Budd,[25] S. Burke,[18] K. Burkett,[18] G. Busetto[w,44] P. Bussey[k,22] A. Buzatu,[34]
K. L. Byrum,[2] S. Cabrera[u,17] C. Calancha,[32] M. Campanelli,[36] M. Campbell,[35] F. Canelli[14,18] A. Canepa,[46]
B. Carls,[25] D. Carlsmith,[60] R. Carosi,[47] S. Carrillo[m,19] S. Carron,[34] B. Casal,[12] M. Casarsa,[18] A. Castro[v,6]
P. Catastini[y,47] D. Cauz[bb,55] V. Cavaliere[y,47] M. Cavalli-Sforza,[4] A. Cerri,[29] L. Cerrito[n,31] S.H. Chang,[28]
Y.C. Chen,[1] M. Chertok,[8] G. Chiarelli,[47] G. Chlachidze,[18] F. Chlebana,[18] K. Cho,[28] D. Chokheli,[16]
J.P. Chou,[23] G. Choudalakis,[33] S.H. Chuang,[53] K. Chung,[13] W.H. Chung,[60] Y.S. Chung,[50] T. Chwalek,[27]
C.I. Ciobanu,[45] M.A. Ciocci[y,47] A. Clark,[21] D. Clark,[7] G. Compostella,[44] M.E. Convery,[18] J. Conway,[8]
M. Cordelli,[20] G. Cortiana[w,44] C.A. Cox,[8] D.J. Cox,[8] F. Crescioli[x,47] C. Cuenca Almenar[u,8] J. Cuevas[r,12]
R. Culbertson,[18] J.C. Cully,[35] D. Dagenhart,[18] M. Datta,[18] T. Davies,[22] P. de Barbaro,[50] S. De Cecco,[52]
A. Deisher,[29] G. De Lorenzo,[4] M. Dell'Orso[x,47] C. Deluca,[4] C. Demay,[18] L. Demortier,[51] J. Deng,[17] M. Deninno,[6]
P.F. Derwent,[18] G.P. di Giovanni,[45] C. Dionisi[aa,52] B. Di Ruzza[bb,55] J.R. Dittmann,[5] M. D'Onofrio,[4] S. Donati[x,47]
P. Dong,[9] J. Donini,[44] T. Dorigo,[44] S. Dube,[53] J. Efron,[40] A. Elagin,[54] R. Erbacher,[8] D. Errede,[25] S. Errede,[25]
R. Eusebi,[18] H.C. Fang,[29] S. Farrington,[43] W.T. Fedorko,[14] R.G. Feild,[61] M. Feindt,[27] J.P. Fernandez,[32]
C. Ferrazza[z,47] R. Field,[19] G. Flanagan,[49] R. Forrest,[8] M.J. Frank,[5] M. Franklin,[23] J.C. Freeman,[18] I. Furic,[19]
M. Gallinaro,[52] J. Galyardt,[13] F. Garberson,[11] J.E. Garcia,[21] A.F. Garfinkel,[49] K. Genser,[18] H. Gerberich,[25]
D. Gerdes,[35] A. Gessler,[27] S. Giagu[aa,52] V. Giakoumopoulou,[3] P. Giannetti,[47] K. Gibson,[48] J.L. Gimmell,[50]
C.M. Ginsburg,[18] N. Giokaris,[3] M. Giordani[bb,55] P. Giromini,[20] M. Giunta[x,47] G. Giurgiu,[26] V. Glagolev,[16]
D. Glenzinski,[18] M. Gold,[38] N. Goldschmidt,[19] A. Golossanov,[18] G. Gomez,[12] G. Gomez-Ceballos,[33]
M. Goncharov,[33] O. González,[32] I. Gorelov,[38] A.T. Goshaw,[17] K. Goulianos,[51] A. Gresele[w,44] S. Grinstein,[23]
C. Grosso-Pilcher,[14] R.C. Group,[18] U. Grundler,[25] J. Guimaraes da Costa,[23] Z. Gunay-Unalan,[36] C. Haber,[29]
K. Hahn,[33] S.R. Hahn,[18] E. Halkiadakis,[53] B.-Y. Han,[50] J.Y. Han,[50] F. Happacher,[20] K. Hara,[56] D. Hare,[53]
M. Hare,[57] S. Harper,[43] R.F. Harr,[59] R.M. Harris,[18] M. Hartz,[48] K. Hatakeyama,[51] C. Hays,[43] M. Heck,[27]
A. Heijboer,[46] J. Heinrich,[46] C. Henderson,[33] M. Herndon,[60] J. Heuser,[27] S. Hewamanage,[5] D. Hidas,[17]
C.S. Hill[c,11] D. Hirschbuehl,[27] A. Hocker,[18] S. Hou,[1] M. Houlden,[30] S.-C. Hsu,[29] B.T. Huffman,[43] R.E. Hughes,[40]
U. Husemann,[36] M. Hussein,[36] U. Husemann,[61] J. Huston,[36] J. Incandela,[11] G. Introzzi,[47] M. Iori[aa,52] A. Ivanov,[8]
E. James,[18] B. Jayatilaka,[17] E.J. Jeon,[28] M.K. Jha,[6] S. Jindariani,[18] W. Johnson,[8] M. Jones,[49] K.K. Joo,[28]
S.Y. Jun,[13] J.E. Jung,[28] T.R. Junk,[18] T. Kamon,[54] D. Kar,[19] P.E. Karchin,[59] Y. Kato,[42] R. Kephart,[18] J. Keung,[46]
V. Khotilovich,[54] B. Kilminster,[18] D.H. Kim,[28] H.S. Kim,[28] H.W. Kim,[28] J.E. Kim,[28] M.J. Kim,[20] S.B. Kim,[28]
S.H. Kim,[56] Y.K. Kim,[14] N. Kimura,[56] L. Kirsch,[7] S. Klimenko,[19] B. Knuteson,[33] B.R. Ko,[17] K. Kondo,[58]
D.J. Kong,[28] J. Konigsberg,[19] A. Korytov,[19] A.V. Kotwal,[17] M. Kreps,[27] J. Kroll,[46] D. Krop,[14] N. Krumnack,[5]
M. Kruse,[17] V. Krutelyov,[11] T. Kubo,[56] T. Kuhr,[27] N.P. Kulkarni,[59] M. Kurata,[56] S. Kwang,[14] A.T. Laasanen,[49]
S. Lami,[47] S. Lammel,[18] M. Lancaster,[31] R.L. Lander,[8] K. Lannon[q,40] A. Lath,[53] G. Latino[y,47] I. Lazzizzera[w,44]
T. LeCompte,[2] E. Lee,[54] H.S. Lee,[14] S.W. Lee[t,54] S. Leone,[47] J.D. Lewis,[18] C.-S. Lin,[29] J. Linacre,[43] M. Lindgren,[18]
E. Lipeles,[46] A. Lister,[8] D.O. Litvintsev,[18] C. Liu,[48] T. Liu,[18] N.S. Lockyer,[46] A. Loginov,[61] M. Loreti[w,44]
L. Lovas,[15] D. Lucchesi[w,44] C. Luci[aa,52] J. Lueck,[27] P. Lujan,[29] P. Lukens,[18] G. Lungu,[51] L. Lyons,[43] J. Lys,[29]
R. Lysak,[15] D. MacQueen,[34] R. Madrak,[18] K. Maeshima,[18] K. Makhoul,[33] T. Maki,[24] P. Maksimovic,[26] S. Malde,[43]
S. Malik,[31] G. Manca[e,30] A. Manousakis-Katsikakis,[3] F. Margaroli,[49] C. Marino,[27] C.P. Marino,[25] A. Martin,[61]
V. Martin[l,22] M. Martínez,[4] R. Martínez-Ballarín,[32] T. Maruyama,[56] P. Mastrandrea,[52] T. Masubuchi,[56]
M. Mathis,[26] M.E. Mattson,[59] P. Mazzanti,[6] K.S. McFarland,[50] P. McIntyre,[54] R. McNulty[j,30] A. Mehta,[30]
P. Mehtala,[24] A. Menzione,[47] P. Merkel,[49] C. Mesropian,[51] T. Miao,[18] N. Miladinovic,[7] R. Miller,[36] C. Mills,[23]
M. Milnik,[27] A. Mitra,[1] G. Mitselmakher,[19] H. Miyake,[56] N. Moggi,[6] C.S. Moon,[28] R. Moore,[18] M.J. Morello[x,47]

J. Morlock,[27] P. Movilla Fernandez,[18] J. Mülmenstädt,[29] A. Mukherjee,[18] Th. Muller,[27] R. Mumford,[26] P. Murat,[18] M. Mussini[v],[6] J. Nachtman,[18] Y. Nagai,[56] A. Nagano,[56] J. Naganoma,[56] K. Nakamura,[56] I. Nakano,[41] A. Napier,[57] V. Necula,[17] J. Nett,[60] C. Neu[v],[46] M.S. Neubauer,[25] S. Neubauer,[27] J. Nielsen[g],[29] L. Nodulman,[2] M. Norman,[10] O. Norniella,[25] E. Nurse,[31] L. Oakes,[43] S.H. Oh,[17] Y.D. Oh,[28] I. Oksuzian,[19] T. Okusawa,[42] R. Orava,[62] K. Osterberg,[24] S. Pagan Griso[w],[44] E. Palencia,[18] V. Papadimitriou,[18] A. Papaikonomou,[27] A.A. Paramonov,[14] B. Parks,[40] S. Pashapour,[34] J. Patrick,[18] G. Pauletta[bb],[55] M. Paulini,[13] C. Paus,[33] T. Peiffer,[27] D.E. Pellett,[8] A. Penzo,[55] T.J. Phillips,[17] G. Piacentino,[47] E. Pianori,[46] L. Pinera,[19] K. Pitts,[25] C. Plager,[9] L. Pondrom,[60] O. Poukhov*,[16] N. Pounder,[43] F. Prakoshyn,[16] A. Pronko,[18] J. Proudfoot,[2] F. Ptohos[i],[18] E. Pueschel,[13] G. Punzi[x],[47] J. Pursley,[60] J. Rademacker[c],[43] A. Rahaman,[48] V. Ramakrishnan,[60] N. Ranjan,[49] J. Ray,[18] I. Redondo,[32] P. Renton,[43] M. Renz,[27] M. Rescigno,[52] S. Richter,[27] F. Rimondi[v],[6] L. Ristori,[47] A. Robson,[22] T. Rodrigo,[12] T. Rodriguez,[46] E. Rogers,[25] S. Rolli,[57] R. Roser,[18] M. Rossi,[55] R. Rossin,[11] P. Roy,[34] A. Ruiz,[12] J. Russ,[13] V. Rusu,[18] H. Saarikko,[24] A. Safonov,[54] W.K. Sakumoto,[50] O. Saltó,[4] L. Santi[bb],[55] S. Sarkar[aa],[52] L. Sartori,[47] K. Sato,[18] A. Savoy-Navarro,[45] P. Schlabach,[18] A. Schmidt,[27] E.E. Schmidt,[18] M.A. Schmidt,[14] M.P. Schmidt*,[61] M. Schmitt,[39] T. Schwarz,[8] L. Scodellaro,[12] A. Scribano[y],[47] F. Scuri,[47] A. Sedov,[49] S. Seidel,[38] Y. Seiya,[42] A. Semenov,[16] L. Sexton-Kennedy,[18] F. Sforza,[47] A. Sfyrla,[25] S.Z. Shalhout,[59] T. Shears,[30] P.F. Shepard,[48] M. Shimojima[p],[56] S. Shiraishi,[14] M. Shochet,[14] Y. Shon,[60] I. Shreyber,[37] A. Sidoti,[47] P. Sinervo,[34] A. Sisakyan,[16] A.J. Slaughter,[18] J. Slaunwhite,[40] K. Sliwa,[57] J.R. Smith,[8] F.D. Snider,[18] R. Snihur,[34] A. Soha,[8] S. Somalwar,[53] V. Sorin,[36] J. Spalding,[18] T. Spreitzer,[34] P. Squillacioti[y],[47] M. Stanitzki,[61] R. St. Denis,[22] B. Stelzer,[34] O. Stelzer-Chilton,[34] D. Stentz,[39] J. Strologas,[38] G.L. Strycker,[35] D. Stuart,[11] J.S. Suh,[28] A. Sukhanov,[19] I. Suslov,[16] T. Suzuki,[56] A. Taffard[f],[25] R. Takashima,[41] Y. Takeuchi,[56] R. Tanaka,[41] M. Tecchio,[35] P.K. Teng,[1] K. Terashi,[51] J. Thom[h],[18] A.S. Thompson,[22] G.A. Thompson,[25] E. Thomson,[46] P. Tipton,[61] P. Ttito-Guzmán,[32] S. Tkaczyk,[18] D. Toback,[54] S. Tokar,[15] K. Tollefson,[36] T. Tomura,[56] D. Tonelli,[18] S. Torre,[20] D. Torretta,[18] P. Totaro[bb],[55] S. Tourneur,[45] M. Trovato,[47] S.-Y. Tsai,[1] Y. Tu,[46] N. Turini[y],[47] F. Ukegawa,[56] S. Vallecorsa,[21] N. van Remortel[b],[24] A. Varganov,[35] E. Vataga[z],[47] F. Vázquez[m],[19] G. Velev,[18] C. Vellidis,[3] M. Vidal,[32] R. Vidal,[18] I. Vila,[12] R. Vilar,[12] T. Vine,[31] M. Vogel,[38] I. Volobouev[t],[29] G. Volpi[x],[47] P. Wagner,[46] R.G. Wagner,[2] R.L. Wagner,[18] W. Wagner,[27] J. Wagner-Kuhr,[27] T. Wakisaka,[42] R. Wallny,[9] S.M. Wang,[1] A. Warburton,[34] D. Waters,[31] M. Weinberger,[54] J. Weinelt,[27] W.C. Wester III,[18] B. Whitehouse,[57] D. Whiteson[f],[46] A.B. Wicklund,[2] E. Wicklund,[18] S. Wilbur,[14] G. Williams,[34] H.H. Williams,[46] P. Wilson,[18] B.L. Winer,[40] P. Wittich[h],[18] S. Wolbers,[18] C. Wolfe,[14] T. Wright,[35] X. Wu,[21] F. Würthwein,[10] S. Xie,[33] A. Yagil,[10] K. Yamamoto,[42] J. Yamaoka,[17] U.K. Yang[o],[14] Y.C. Yang,[28] W.M. Yao,[29] G.P. Yeh,[18] J. Yoh,[18] K. Yorita,[58] T. Yoshida,[42] G.B. Yu,[50] I. Yu,[28] S.S. Yu,[18] J.C. Yun,[18] L. Zanello[aa],[52] A. Zanetti,[55] X. Zhang,[25] Y. Zheng[d],[9] and S. Zucchelli[v],[6]

(CDF Collaboration[†])

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

[24]*Division of High Energy Physics, Department of Physics,*
University of Helsinki and Helsinki Institute of Physics, FIN-00014, Helsinki, Finland
[25]*University of Illinois, Urbana, Illinois 61801*
[26]*The Johns Hopkins University, Baltimore, Maryland 21218*
[27]*Institut für Experimentelle Kernphysik, Universität Karlsruhe, 76128 Karlsruhe, Germany*
[28]*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
[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, 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
[35]*University of Michigan, Ann Arbor, Michigan 48109*
[36]*Michigan State University, East Lansing, Michigan 48824*
[37]*Institution for Theoretical and Experimental Physics, ITEP, Moscow 117259, Russia*
[38]*University of New Mexico, Albuquerque, New Mexico 87131*
[39]*Northwestern University, Evanston, Illinois 60208*
[40]*The Ohio State University, Columbus, Ohio 43210*
[41]*Okayama University, Okayama 700-8530, Japan*
[42]*Osaka City University, Osaka 588, Japan*
[43]*University of Oxford, Oxford OX1 3RH, United Kingdom*
[44]*Istituto Nazionale di Fisica Nucleare, Sezione di Padova-Trento,* [w]*University of Padova, I-35131 Padova, Italy*
[45]*LPNHE, Universite Pierre et Marie Curie/IN2P3-CNRS, UMR7585, Paris, F-75252 France*
[46]*University of Pennsylvania, Philadelphia, Pennsylvania 19104*
[47]*Istituto Nazionale di Fisica Nucleare Pisa,* [x]*University of Pisa,*
[y]*University of Siena and* [z]*Scuola Normale Superiore, I-56127 Pisa, Italy*
[48]*University of Pittsburgh, Pittsburgh, Pennsylvania 15260*
[49]*Purdue University, West Lafayette, Indiana 47907*
[50]*University of Rochester, Rochester, New York 14627*
[51]*The Rockefeller University, New York, New York 10021*
[52]*Istituto Nazionale di Fisica Nucleare, Sezione di Roma 1,*
[aa]*Sapienza Università di Roma, I-00185 Roma, Italy*
[53]*Rutgers University, Piscataway, New Jersey 08855*
[54]*Texas A&M University, College Station, Texas 77843*
[55]*Istituto Nazionale di Fisica Nucleare Trieste/Udine,* [bb]*University of Trieste/Udine, Italy*
[56]*University of Tsukuba, Tsukuba, Ibaraki 305, Japan*
[57]*Tufts University, Medford, Massachusetts 02155*
[58]*Waseda University, Tokyo 169, Japan*
[59]*Wayne State University, Detroit, Michigan 48201*
[60]*University of Wisconsin, Madison, Wisconsin 53706*
[61]*Yale University, New Haven, Connecticut 06520*
[62]*Division of High Energy Physics, Department of Physics,*
University of Helsinki and HelsinkiInstitute of Physics, FIN-00014, Helsinki, Finland
(Dated: July 9, 2009)

A search for a narrow diphoton mass resonance is presented based on data from 3.0 fb^{-1} of integrated luminosity from $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV collected by the CDF experiment. No evidence of a resonance in the diphoton mass spectrum is observed, and upper limits are set on the cross section times branching fraction of the resonant state as a function of Higgs boson mass. The resulting limits exclude Higgs bosons with masses below 106 GeV/c^2 at a 95% Bayesian credibility level (C.L.) for one fermiophobic benchmark model.

PACS numbers: 12.38.Qk, 13.85.Rm, 14.80.Cp, 12.60.Jv, 12.60.Fr

[*]Deceased

[†]With visitors from [a]University of Massachusetts Amherst,

The standard model (SM) of particle physics has proven to be an extremely robust theory through its accurate predictions of many experimental results obtained over the last few decades. Although the Higgs mechanism [1] was proposed in the 1960's, the particle it predicts, the Higgs boson (h), has yet to be observed in nature.

The SM prediction for the $h \to \gamma\gamma$ branching fraction is extremely small (reaching a maximal value of only about 0.2% at a Higgs boson mass (m_h) ~ 120 GeV/c^2) [2]; however, in "fermiophobic" models, where the coupling of the Higgs boson to fermions is suppressed, the diphoton decay can be greatly enhanced. This phenomenon has been shown to arise in a variety of extensions to the SM [3, 4, 5, 6, 7], and the resulting collider phenomenology has been described [8, 9, 10]. For this fermiophobic case, the diphoton final state dominates at low Higgs boson masses and is therefore the preferred search channel.

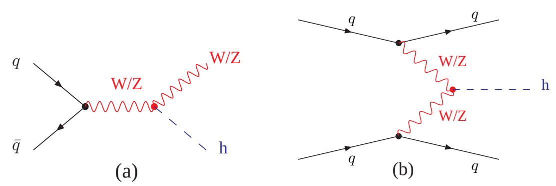

FIG. 1: The dominant production diagrams for the benchmark fermiophobic Higgs boson model: associated production with a vector boson (a), and vector boson fusion (b).

A benchmark fermiophobic model is considered in which the Higgs boson does not couple to fermions, yet retains its SM couplings to bosons. In this model, the fermiophobic Higgs boson production is dominated by two processes: associated production (shown in Fig. 1(a)), and vector boson fusion (abbr. VBF, shown in Fig. 1(b)).

Each of the four experiments [11, 12, 13, 14] at the LEP electron-positron collider at CERN place 95% C.L. lower limits on the fermiophobic Higgs boson mass (the most stringent being 105.5 GeV/c^2), while a combination of these results obtains a 95% C.L. limit of 109.7 GeV/c^2 [15]. The CDF and D0 experiments at the Tevatron also searched for a fermiophobic Higgs boson [16, 17]. Most recently, the D0 experiment set limits on the production cross section of the fermiophobic Higgs boson with 1.1 fb^{-1} of data, resulting in a 95% C.L. lower limit on m_h of 100 GeV/c^2 [18]. In this Letter, we search the diphoton mass distribution from the Collider Detector at Fermilab (CDF) for a narrow resonance that could reveal the presence of a fermiophobic Higgs boson.

We use the CDF II detector [19, 20] to identify (ID) photon candidate events produced in $p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV. The innermost detector component is the silicon vertex tracker [21] which is surrounded by an open-cell drift chamber (COT, [22]). Both sample the trajectories of charged particles and determine their momentum as they curve in the presence of a 1.4 T axial magnetic field.

Particles that pass through the COT reach the electromagnetic and hadronic calorimeters [23, 24, 25], which are divided into two regions: central ($|\eta| < 1.1$) and forward or "plug" ($1.1 < |\eta| < 3.6$). At the approximate electromagnetic shower maximum, the calorimeters contain fine-grained detectors [26] that measure the shower shape and centroid position in the two dimensions transverse to the shower development. The calorimeters are surrounded by a system of muon chambers [27].

Three levels of real-time event selection (trigger) systems are used to filter events. The trigger paths used here require two clusters of deposited energy in the electromagnetic calorimeter. One path requires that both clusters have a transverse energy $E_T > 12$ GeV [20] and be isolated from other energy clusters in the calorimeter [28]. A second trigger has a cluster transverse energy requirement of $E_T > 18$ GeV without the requirement of cluster isolation. By combining these two trigger paths, virtually all of the identifiable diphoton events are recorded.

The analysis is divided into two independent subsamples according to the position of the photons: the first requires that both photons be located within the fiducial region of the central electromagnetic calorimeter ($|\eta| < 1.05$), and the second requires that one photon be located in this region and the other in the plug calorimeter ($1.2 < |\eta| < 2.8$). The former will be referred to as central-central (CC) events, and the latter as central-plug (CP) events [29]. The data were recorded between February of 2002 and April of 2008, corresponding to an integrated luminosity of 3.0 fb^{-1} for CC and 2.9 fb^{-1} for CP events.

Amherst, Massachusetts 01003, [b]Universiteit Antwerpen, B-2610 Antwerp, Belgium, [c]University of Bristol, Bristol BS8 1TL, United Kingdom, [d]Chinese Academy of Sciences, Beijing 100864, China, [e]Istituto Nazionale di Fisica Nucleare, Sezione di Cagliari, 09042 Monserrato (Cagliari), Italy, [f]University of California Irvine, Irvine, CA 92697, [g]University of California Santa Cruz, Santa Cruz, CA 95064, [h]Cornell University, Ithaca, NY 14853, [i]University of Cyprus, Nicosia CY-1678, Cyprus, [j]University College Dublin, Dublin 4, Ireland, [k]Royal Society of Edinburgh/Scottish Executive Support Research Fellow, [l]University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom, [m]Universidad Iberoamericana, Mexico D.F., Mexico, [n]Queen Mary, University of London, London, E1 4NS, England, [o]University of Manchester, Manchester M13 9PL, England, [p]Nagasaki Institute of Applied Science, Nagasaki, Japan, [q]University of Notre Dame, Notre Dame, IN 46556, [r]University de Oviedo, E-33007 Oviedo, Spain, [s]Texas Tech University, Lubbock, TX 79409, [t]IFIC(CSIC-Universitat de Valencia), 46071 Valencia, Spain, [u]University of Virginia, Charlottesville, VA 22904, [cc]On leave from J. Stefan Institute, Ljubljana, Slovenia,

A series of baseline selection criteria helps to remove background events and to ID high-energy photon candidates for the analysis. Individual photons are required to have $E_T > 15$ GeV, while the diphoton pair is required to have mass $m_{\gamma\gamma} > 30$ GeV/c^2. Photons are required to pass CDF standard photon ID requirements including the following [28, 30]: transverse shower profiles consistent with single photon expectation from test beam studies [31], additional transverse energy in the calorimeter in a cone of angular radius $R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.4$ [20] around the photon candidate be less than 2 GeV, and the scalar sum of the p_T of the tracks in the same cone be less than 2 GeV/c. Central photons must also be isolated in the shower maximum detector.

The above selection criteria define an inclusive diphoton sample. However, the fermiophobic Higgs boson is only produced at a non-negligible rate in association with a W or Z boson or via the VBF process. In order to improve sensitivity, the event selection was further extended to take advantage of the final state features present in these production modes. Associated production dominates the production process (for $m_h = 100$ GeV/c^2 its rate is about four times larger than VBF), so the optimization was carried out on the basis of the associated production process alone. A selection based on the following observables was optimized: diphoton transverse momentum ($p_T^{\gamma\gamma}$), transverse momentum of the second highest p_T jet (p_T^{j2}) for hadronic decays of W/Z, and missing transverse energy ($\not\!\!E_T$) or transverse momentum of an isolated track (p_T^{iso}) for leptonic decays of W/Z.

For the optimization study, a Bayesian method with a flat prior probability was used to estimate the expected limits based on signal and background event expectations in a 10 GeV/c^2 mass window centered at 100 GeV/c^2. The diphoton background is composed of SM diphoton events ($\sim$ 25 %) and events in which either one or both photon candidates are actually quark or gluon jets which were misidentified as photons ($\sim$ 75 %). Higgs boson events with only the diphoton decay mode and SM diphoton events were generated using the PYTHIA 6.2 [32] Monte Carlo event generator and a parametrized response of the CDF II detector [33, 34]. All PYTHIA samples were made with CTEQ5L [35] parton distribution functions, where the PYTHIA underlying event model is tuned to CDF jet data [36]. The background component arising from jets misidentified as photons was estimated using photon identification control regions from data. The control regions do not overlap with the signal region, as the events in the control region are required to fail at least one of the standard electromagnetic energy fraction or isolation requirements, yet pass a looser set of these requirements.

The optimization shows that a requirement of $p_T^{\gamma\gamma} > 75$ GeV/c is approximately as sensitive as any combination of the other selection criteria. With this requirement on $p_T^{\gamma\gamma}$, roughly 30% of the signal remains (slightly varying with m_h) while more than 99.5% of the background is removed. Although the cut was optimized based on associated production, VBF also has a higher average $p_T^{\gamma\gamma}$ than the background processes and is included in the analysis with the same selection.

The detector acceptance for signal events is calculated using the PYTHIA event generator samples described above. Since a pure sample of reconstructed photons is not available in the data, corrections to the photon identification efficiencies due to imperfections in the detector simulation are derived using electrons from Z boson decays. This is justified since the energy deposition in the EM calorimeter by electrons and photons is almost indistinguishable. The electrons are selected with a slightly modified version of the photon ID requirements to allow the presence of a high p_T track. A correction factor to the ID efficiency of the simulation of 0.97 (0.94) is derived for central (plug) photons by comparing ID efficiencies from the detector simulation with the ID efficiencies measured in data.

The largest systematic uncertainties on the expected number of Higgs boson events arise from the luminosity measurement (6%), varying the parameters controlling the amount of initial and final state radiation from the parton shower model of PYTHIA (4%) [37], and the PYTHIA modeling of the shape of the $p_T^{\gamma\gamma}$ distribution for the signal (4%). The latter uncertainty was obtained by studying the effect on the acceptance from the differences in the shape of the $p_T^{\gamma\gamma}$ distribution from leading-order, next-to-leading-order, and PYTHIA predictions [38]. Other systematic uncertainties were also considered due to uncertainties in photon ID efficiency, the electromagnetic energy scale, and parton distribution functions [39, 40]. The signal acceptances are included in Table I and they have a relative uncertainty of 8% (9%) for CC (CP).

The decay of a Higgs boson into a diphoton pair appears as a very narrow peak in the invariant mass distribution of these two photons. The diphoton mass resolution as determined from simulation is better than 3% for the Higgs boson mass region studied here and is limited by the energy resolution of the electromagnetic calorimeters. The simulated resolution was compared with data using electrons from Z boson decays and is found to model the detector well. The diphoton invariant mass distribution shown in Fig. 2 could be sensitive to a resonance in the context of the fermiophobic benchmark model (see the inserts in Fig. 2 for the signal shape expected from simulation). No evidence of such a resonance is apparent in the data. As a background prediction to be used for setting limits on a diphoton resonance, the data is fit to a sum of two exponentials multiplied by a fractional degree polynomial, where the degree of one term is a parameter of the fit. The fit, excluding a 10 GeV/c^2 mass window centered at each test m_h, is performed for each m_h hypothesis (10-GeV/c^2 steps from

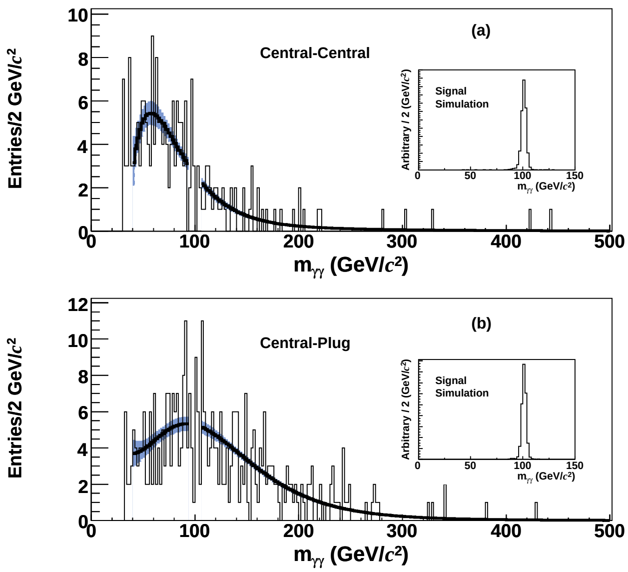

FIG. 2: The invariant mass distribution of central-central (a) and central-plug (b) photon pairs after the requirement of $p_T^{\gamma\gamma} > 75$ GeV/c, shown with the fit to the data for the hypothesis of a m_h of 100 GeV/c^2. The gap in the fit centered at 100 GeV/c^2 represents the signal region for this mass point that was excluded from the fit. The error bands show the statistical uncertainty in the fit. The expected shape of the signal from simulation is shown in the inserts.

70 to 150 GeV/c^2). The fit for a m_h of 100 GeV/c^2 is shown in Fig. 2.

After the background fit for each mass hypothesis has been determined, the presence or absence of a Higgs boson signal is ascertained on the basis of a binned likelihood method incorporating the simulated signal shape and the systematic uncertainties. We calculate a Bayesian C.L. limit for each mass hypothesis based on the combined binned likelihood of the mass distributions for the CC and CP samples. A posterior density in $\sigma\times\mathcal{B}(h \to \gamma\gamma)$ is obtained by multiplying this likelihood by Gaussian prior densities for the background normalizations and systematic uncertainties leaving the production cross section ($\sigma\times\mathcal{B}(h \to \gamma\gamma)$) with a uniform prior density. A 95% C.L. limit is then determined such that 95% of the posterior density for $\sigma\times\mathcal{B}(h \to \gamma\gamma)$ falls below the limit [41].

The results of the limit calculation are included in Table I and displayed graphically in Fig. 3. The SM cross sections assumed in the benchmark fermiophobic model are used to convert the limits on $\sigma\times\mathcal{B}(h \to \gamma\gamma)$ into limits on $\mathcal{B}(h \to \gamma\gamma)$. The result excludes the benchmark model predictions (at 95% C.L.) for m_h of less than 106 GeV/c^2.

This Letter presents the results of a search for a narrow resonance in the diphoton mass spectrum using data comprising 3.0 fb^{-1} of integrated luminosity from the CDF II detector at the Tevatron. Selected events include two photons in the central detector or one photon in the central and one in the plug detector. There is no evidence of a narrow resonance. Limits are placed on the production cross section and the branching fraction for the Higgs boson decay into a photon pair and compared to the predictions of a benchmark fermiophobic model resulting in a limit on the Higgs boson mass of $m_h > 106$ GeV/c^2 at the 95% C.L. This mass limit is approximately as strong as any previous single experiment, and the result significantly extends the excluded region of $\mathcal{B}(h \to \gamma\gamma)$ for m_h above 110 GeV/c^2.

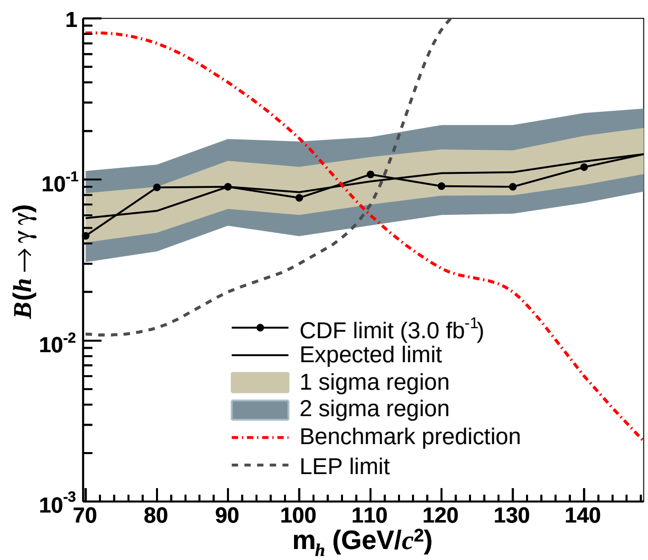

FIG. 3: The 95% C.L. upper limit on the branching fraction for the fermiophobic Higgs boson decay to diphotons, as a function of m_h. The shaded regions represent the one and two sigma probability of fluctuations of the observed limit away from the expected limit based on the distribution of possible experimental outcomes. For reference, the 95% C.L. limits from LEP are also included.

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 Science and Engineering Foundation and the Korean Research Foundation; the Science and Technology Facilities Council and the Royal Society, UK; the Institut National de Physique Nucleaire et Physique des Particules/CNRS; the Russian Foundation for Basic Research; the Ministe-

TABLE I: Observed and expected 95% C.L. limits on the production cross section and branching fraction and theory predictions for the fermiophobic benchmark Higgs boson model. Total signal acceptance is also included. Note that the CP channel is not included for the 90 GeV/c^2 point [29].

		$\sigma\times\mathcal{B}(h \to \gamma\gamma)$ (fb)			$\mathcal{B}(h \to \gamma\gamma)$ (%)		
	Acceptance (%)	Limits			Limits		
m_h (GeV/c^2)	(CC +CP)	Expected	Observed	Theory [2]	Expected	Observed	Theory
70	4.8	88.1	68.2	1240	5.8	4.5	81
80	6.2	68.3	95.4	749	6.4	8.9	70
90	4.4	70.7	70.8	312	9.1	9.1	40
100	8.8	48.3	44.5	104	8.3	7.7	18
110	10	41.8	46.2	25.8	9.7	10.7	6.0
120	11	36.3	30.2	9.3	10.9	9.1	2.8
130	12	27.8	22.6	5.0	11.0	9.0	2.0
140	13	26.6	24.4	1.2	12.0	11.9	0.6
150	15	23.5	23.9	0.3	14.6	14.9	0.2

rio de Ciencia e Innovación, and Programa Consolider-Ingenio 2010, Spain; the Slovak R&D Agency; and the Academy of Finland.

---

[1] P. W. Higgs, Phys. Rev. Lett. **13**, 508 (1964).
[2] A. Djouadi, J. Kalinowski, and M. Spira, Comput. Phys. Commun. **108**, 56 (1998).
[3] H. E. Haber, G. L. Kane, and T. Sterling, Nucl. Phys. B **161**, 493 (1979).
[4] J. F. Gunion, R. Vega, and J. Wudka, Phys. Rev. D **42**, 1673 (1990).
[5] J. L. Basdevant et al., Phys. Lett. B **313**, 402 (1993).
[6] V. Barger et al. (1992), arXiv:hep-ph/9211234.
[7] A. G. Akeroyd, Phys. Lett. B **368**, 89 (1996).
[8] B. A. Dobrescu, Phys. Rev. **D63**, 015004 (2001).
[9] G. L. Landsberg and K. T. Matchev, Phys. Rev. D **62**, 035004 (2000).
[10] S. Mrenna and J. D. Wells, Phys. Rev. D **63**, 015006 (2001).
[11] A. Heister et al. (ALEPH Collaboration), Phys. Lett. B **544**, 16 (2002).
[12] J. Abdallah et al. (DELPHI Collaboration), Eur. Phys. J. C **35**, 313 (2004).
[13] P. Achard et al. (L3 Collaboration), Phys. Lett. B **568**, 191 (2003).
[14] G. Abbiendi et al. (OPAL Collaboration), Phys. Lett. B **544**, 44 (2002).
[15] A. Rosca (LEP) (2002), arXiv:hep-ex/0212038.
[16] A. A. Affolder et al. (CDF Collaboration), Phys. Rev. D **64**, 092002 (2001).
[17] B. Abbott et al. (D0 Collaboration), Phys. Rev. Lett. **82**, 2244 (1999).
[18] V. Abazov et al. (D0 Collaboration), Phys. Rev. Lett. **101**, 051801 (2008).
[19] D. E. Acosta et al. (CDF Collaboration), Phys. Rev. D **71**, 032001 (2005).
[20] We use a cylindrical coordinate system with its origin in the center of the detector, where θ and ϕ are the polar and azimuthal angles, respectively, and pseudorapidity is $\eta = -\ln\,\tan(\theta/2)$. The missing E_T ($\vec{\not\!E}_T$) is defined by $\vec{\not\!E}_T = -\sum_i E_T^i \hat{n}_i, i =$ calorimeter tower number, where $\hat{n}_i$ is a unit vector perpendicular to the beam axis and pointing at the i^{th} calorimeter tower. $\vec{\not\!E}_T$ is corrected for high-energy muons and also jet energy corrections. We define $\not\!E_T = |\vec{\not\!E}_T|$. The transverse momentum p_T is defined to be $p\sin\theta$.
[21] A. Sill (CDF Collaboration), Nucl. Instrum. Methods **447**, 1 (2000).
[22] A. A. Affolder et al. (CDF Collaboration), Nucl. Instrum. Methods **526**, 249 (2004).
[23] L. Balka et al. (CDF Collaboration), Nucl. Instrum. Methods **267**, 272 (1988).
[24] S. Bertolucci et al. (CDF Collaboration), Nucl. Instrum. Methods **267**, 301 (1988).
[25] M. G. Albrow et al. (CDF Collaboration), Nucl. Instrum. Methods **480**, 524 (2002).
[26] G. Apollinari et al., Nucl. Instrum. Methods **412**, 515 (1998).
[27] G. Ascoli et al., Nucl. Instrum. Methods **268**, 33 (1988).
[28] S. Wynne, Ph.D. thesis, Liverpool University, FERMILAB-THESIS-2007-17.
[29] The CP channel is not used for the 90 GeV/c^2 Higgs mass hypothesis due to reduced sensitivity caused by contamination from the Z boson mass peak.
[30] T. Aaltonen et al. (CDF Collaboration), Phys. Rev. Lett. **99**, 171801 (2007).
[31] F. Abe et al. (CDF Collaboration), Phys. Rev. D **48**, 2998 (1993).
[32] T. Sjostrand et al., Comput. Phys. Commun. **135**, 238 (2001).
[33] R. Brun et al. (1987), unpublished, CERN-DD/EE/84-1.
[34] G. Grindhammer, M. Rudowicz, and S. Peters, Nucl. Instrum. Methods **290**, 469 (1990).
[35] H. L. Lai et al. (CTEQ Collaboration), Eur. Phys. J. **C12**, 375 (2000).
[36] R. Field and R. C. Group (CDF Collaboration) (2005), ArXiv:hep-ph/0510198.
[37] We constrain the rate of initial state radiation using Drell-Yan events in data.
[38] S. Mrenna and C. P. Yuan, Phys. Lett. B **416**, 200 (1998).
[39] D. Stump et al., J. High Energy Phys. **0410**, 046 (2003).
[40] D. Bourilkov, R. C. Group, and M. R. Whalley (2006), arXiv:hep-ph/0605240.

[41] C. Amsler et al. (Particle Data Group), Phys. Lett. B **667**, 1 (2008).