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**Combined Tevatron upper limit on $gg \rightarrow H \rightarrow W^+W^-$
and constraints on the Higgs boson mass in fourth-generation fermion models**

T. Aaltonen^{†,15} V.M. Abazov^{‡,53} B. Abbott^{†,121} M. Abolins^{†,106} B.S. Acharya^{‡,35} M. Adams^{†,84} T. Adams^{†,80}
 J. Adelman^{†,83} E. Aguilo^{‡,7} G.D. Alexeev^{‡,53} G. Alkhozov^{‡,57} A. Alton^{ff†,104} B. Álvarez González^{x†,61}
 G. Alverson^{‡,99} G.A. Alves^{‡,2} S. Amerio^{fff†,39} D. Amidei^{†,104} A. Anastassov^{†,86} L.S. Ancu^{‡,52} A. Annovi^{†,38}
 J. Antos^{†,58} M. Aoki^{‡,82} G. Apollinari^{†,82} J. Appel^{†,82} A. Apresyan^{†,91} T. Arisawa^{†,46} Y. Arnaud^{‡,17} M. Arov^{‡,95}
 A. Artikov^{†,53} J. Asaadi^{†,128} W. Ashmanskas^{†,82} A. Askew^{‡,80} B. Āsman^{‡,62} O. Atramentov^{‡,109} A. Attal^{†,59}
 A. Aurisano^{†,128} C. Avila^{‡,10} F. Azfar^{†,70} J. BackusMayes^{‡,133} F. Badaud^{†,16} W. Badgett^{†,82} L. Bagby^{‡,82}
 B. Baldin^{‡,82} D.V. Bandurin^{‡,80} S. Banerjee^{‡,35} A. Barbaro-Galtieri^{†,72} E. Barberis^{‡,99} A.-F. Barfuss^{‡,18}
 P. Baringer^{‡,93} V.E. Barnes^{†,91} B.A. Barnett^{†,96} J. Barreto^{‡,2} P. Barria^{hh†,40} J.F. Bartlett^{‡,82} P. Bartos^{†,58}
 U. Bassler^{‡,21} G. Bauer^{†,101} S. Beale^{‡,7} A. Bean^{†,93} P.-H. Beauchemin^{†,6} F. Bedeschi^{†,40} D. Beecher^{†,68}
 M. Begalli^{‡,3} M. Begel^{†,117} S. Behari^{†,96} C. Belanger-Champagne^{‡,62} L. Bellantoni^{†,82} G. Bellettini^{gg†,40}
 J. Bellinger^{†,134} J.A. Benitez^{‡,106} D. Benjamin^{†,118} A. Beretvas^{†,82} S.B. Beri^{‡,33} G. Bernardi^{†,20} R. Bernhard^{‡,26}
 I. Bertram^{†,65} M. Besançon^{†,21} R. Beuselinck^{†,67} V.A. Bezzubov^{†,56} P.C. Bhat^{†,82} V. Bhatnagar^{†,33} A. Bhatti^{†,114}
 M. Binkley^{†,82} D. Bisello^{fff†,39} I. Bizjak^{ee†,68} R.E. Blair^{†,81} G. Blazey^{†,85} S. Blessing^{†,80} C. Blocker^{†,103}
 K. Bloom^{†,108} B. Blumenfeld^{†,96} A. Bocchi^{†,118} A. Bodek^{†,115} A. Boehnlein^{†,82} V. Boisvert^{†,115} D. Boline^{†,116}
 T.A. Bolton^{†,94} E.E. Boos^{†,55} G. Borissov^{†,65} D. Bortoletto^{†,91} T. Bose^{†,98} J. Boudreau^{†,125} A. Boveia^{†,77}
 A. Brandt^{†,127} B. Brau^{o†,77} A. Bridgeman^{†,87} L. Brigliadori^{ee†,37} R. Brock^{†,106} C. Bromberg^{†,106}
 G. Brooijmans^{†,113} A. Bross^{†,82} D. Brown^{†,22} E. Brubaker^{†,83} X.B. Bu^{†,8} D. Buchholz^{†,86} J. Budagov^{†,53}
 H.S. Budd^{†,115} S. Budd^{†,87} M. Buehler^{†,132} V. Buescher^{†,29} V. Bunichev^{†,55} S. Burdin^{gg†,65} K. Burkett^{†,82}
 T.H. Burnett^{†,133} G. Busetto^{fff†,39} P. Bussey^{†,64} C.P. Buszello^{†,67} A. Buzatu^{†,6} K.L. Byrum^{†,81} S. Cabrera^{z†,118}
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 M. Campanelli^{†,68} M. Campbell^{†,104} F. Canelli^{†,82,83} A. Canepa^{†,123} B. Carls^{†,87} D. Carlsmith^{†,134} R. Carosi^{†,40}
 M.A. Carrasco-Lizarraga^{†,50} E. Carrera^{†,80} S. Carrillo^{n†,79} S. Carron^{†,82} B. Casal^{†,61} M. Casarsa^{†,82}
 B.C.K. Casey^{†,82} H. Castilla-Valdez^{†,50} A. Castro^{ee†,37} P. Catastini^{hh†,40} D. Cauz^{†,42} V. Cavaliere^{hh†,40}
 M. Cavalli-Sforza^{†,59} A. Cerri^{†,72} L. Cerrito^{r†,68} S. Chakrabarti^{†,116} D. Chakraborty^{†,85} K.M. Chan^{†,90}
 A. Chandra^{†,130} S.H. Chang^{†,47} G. Chen^{†,93} Y.C. Chen^{†,9} M. Chertok^{†,73} S. Chevalier-Théry^{†,21} G. Chiarelli^{†,40}
 G. Chlachidze^{†,82} F. Chlebana^{†,82} D.K. Cho^{†,126} K. Cho^{†,47} S.W. Cho^{†,48} S. Choi^{†,49} D. Chokheli^{†,53}
 J.P. Chou^{†,100} B. Choudhary^{†,34} T. Christoudias^{†,67} K. Chung^{o†,82} W.H. Chung^{†,134} Y.S. Chung^{†,115}
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 A. Croc^{†,21} C. Cuenca Almenar^{†,78} J. Cuevas^{x†,61} R. Culbertson^{†,82} J.C. Cully^{†,104} D. Cutts^{†,126} M. Ćwiok^{†,36}
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 S. Errede^{†,87} N. Ershaidat^{dd†,20} R. Eusebi^{†,128} H. Evans^{†,88} A. Evdokimov^{†,117} V.N. Evdokimov^{†,56} G. Facini^{†,99}
 H.C. Fang^{†,72} S. Farrington^{†,70} W.T. Fedorko^{†,83} R.G. Feild^{†,78} M. Feindt^{†,28} A.V. Ferapontov^{†,126} T. Ferbel^{†,97,115}
 J.P. Fernandez^{†,60} C. Ferrazza^{ii†,40} F. Fiedler^{†,29} R. Field^{†,79} F. Filthaut^{†,52} W. Fisher^{†,106} H.E. Fisk^{†,82}
 G. Flanagan^{t†,91} R. Forrest^{†,73} M. Fortner^{†,85} H. Fox^{†,65} M.J. Frank^{†,131} M. Franklin^{†,100} J.C. Freeman^{†,82}
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 G. Ginther^{†,82,115} N. Giokaris^{†,32} M. Giordani^{kk†,42} P. Giromini^{†,38} M. Giunta^{†,40} G. Giurgiu^{†,96} V. Glagolev^{†,53}
 D. Glenzinski^{†,82} M. Gold^{†,111} N. Goldschmidt^{†,79} A. Golossanov^{†,82} G. Golovanov^{†,53} G. Gomez^{†,61}

G. Gomez-Ceballos^{†,101} M. Goncharov^{†,101} O. González^{†,60} I. Gorelov^{†,111} A.T. Goshaw^{†,118} K. Goulios^{†,114}
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 G. Grenier^{†,23} A. Gresele^{ff†,39} S. Grinstein^{†,59} Ph. Gris^{†,16} J.-F. Grivaz^{†,19} A. Grohsjean^{†,21} C. Grosso-Pilcher^{†,83}
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 Z. Gunay-Unalan^{†,106} F. Guo^{†,116} J. Guo^{†,116} G. Gutierrez^{†,82} P. Gutierrez^{†,121} A. Haas^{hh†,113} C. Haber^{†,72}
 P. Haefner^{†,30} S. Hagopian^{†,80} S.R. Hahn^{†,82} J. Haley^{†,99} E. Halkiadakis^{†,109} I. Hall^{†,106} B.-Y. Han^{†,115}
 J.Y. Han^{†,115} L. Han^{†,8} F. Happacher^{†,38} K. Hara^{†,45} K. Harder^{†,69} D. Hare^{†,109} M. Hare^{†,102} A. Harel^{†,115}
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 M. Herndon^{†,134} K. Herner^{†,104} G. Hesketh^{†,99} J. Heuser^{†,28} S. Hewamanage^{†,131} D. Hidas^{†,109} M.D. Hildreth^{†,90}
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 M.J. Kim^{†,38} S.B. Kim^{†,47} S.H. Kim^{†,45} Y.K. Kim^{†,83} N. Kimura^{†,46} M.H. Kirby^{†,86} L. Kirsch^{†,103} M. Kirsch^{†,24}
 S. Klimenko^{†,79} J.M. Kohli^{†,33} K. Kondo^{†,46} D.J. Kong^{†,47} J. Konigsberg^{†,79} A. Korytov^{†,79} A.V. Kotwal^{†,118}
 A.V. Kozelov^{†,56} J. Kraus^{†,106} M. Kreps^{†,28} J. Kroll^{†,123} D. Krop^{†,83} N. Krumnack^{p†,131} M. Kruse^{†,118}
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 M. Lancaster^{†,68} R.L. Lander^{†,73} G. Landsberg^{†,126} K. Lannon^{v†,119} A. Lath^{†,109} G. Latino^{hh†,40}
 I. Lazzizzera^{ff†,39} P. Lebrun^{†,23} T. LeCompte^{†,81} E. Lee^{†,128} H.S. Lee^{†,83} H.S. Lee^{†,48} J.S. Lee^{†,47} S.W. Lee^{y†,128}
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 J. Linacre^{†,70} D. Lincoln^{†,82} C.-J. Lin^{†,72} M. Lindgren^{†,82} J. Linnemann^{†,106} V.V. Lipaev^{†,56} E. Lipeles^{†,123}
 R. Lipton^{†,82} A. Lister^{†,63} D.O. Litvintsev^{†,82} C. Liu^{†,125} T. Liu^{†,82} Y. Liu^{†,8} Z. Liu^{†,7} A. Lobodenko^{†,57}
 N.S. Lockyer^{†,123} A. Loginov^{†,78} M. Lokajicek^{†,13} L. Lovas^{†,58} P. Love^{†,65} H.J. Lubatti^{†,133} D. Lucchesi^{ff†,39}
 J. Lueck^{†,28} P. Lujan^{†,72} P. Lukens^{†,82} R. Luna-Garcia^{jj†,50} G. Lungu^{†,114} A.L. Lyon^{†,82} R. Lysak^{†,58}
 J. Lys^{†,72} A.K.A. Maciel^{†,2} D. Mackin^{†,130} D. MacQueen^{†,6} R. Madar^{†,21} R. Madrak^{†,82} K. Maeshima^{†,82}
 R. Magaña-Villalba^{†,50} K. Makhoul^{†,101} P. Maksimovic^{†,96} P.K. Mal^{†,71} S. Malde^{†,70} S. Malik^{†,68} S. Malik^{†,108}
 V.L. Malyshev^{†,53} G. Manca^{e†,66} A. Manousakis-Katsikakis^{†,32} Y. Maravin^{†,94} F. Margaroli^{†,91} C. Marino^{†,28}
 C.P. Marino^{†,87} A. Martin^{†,78} V. Martin^{k†,64} M. Martínez^{†,59} R. Martínez-Ballarín^{†,60} J. Martínez-Ortega^{†,50}
 P. Mastrandrea^{†,41} M. Mathis^{†,96} M.E. Mattson^{†,105} P. Mazzanti^{†,37} R. McCarthy^{†,116} K.S. McFarland^{†,115}
 C.L. McGivern^{†,93} P. McIntyre^{†,128} R. McNulty^{jj†,66} A. Mehta^{†,66} P. Mehtala^{†,15} M.M. Meijer^{†,52}
 A. Melnitchouk^{†,107} D. Menezes^{†,85} A. Menzione^{†,40} P.G. Mercadante^{†,4} M. Merkin^{†,55} C. Mesropian^{†,114}
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 A. Mitra^{†,9} G. Mitselmakher^{†,79} H. Miyake^{†,45} S. Moed^{†,100} N. Mogggi^{†,37} N.K. Mondal^{†,35} M.N. Mondragon^{n†,82}
 C.S. Moon^{†,47} R. Moore^{†,82} M.J. Morello^{†,40} J. Morlock^{†,28} T. Moulik^{†,93} P. Movilla Fernandez^{†,82} G.S. Muanza^{†,18}
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 O. Norriella^{†,87} S.F. Novaes^{†,5} T. Nunnemann^{†,30} E. Nurse^{†,68} L. Oakes^{†,70} G. Obrant^{†,57} S.H. Oh^{†,118} Y.D. Oh^{†,47}
 I. Oksuzian^{†,79} T. Okusawa^{†,44} D. Onoprienko^{†,94} R. Orava^{†,15} J. Orduna^{†,50} N. Osman^{†,67} J. Osta^{†,90}
 K. Osterberg^{†,15} G.J. Otero y Garzón^{†,1} M. Owen^{†,69} M. Padilla^{†,76} S. Pagan Griso^{ff†,39} C. Pagliarone^{†,42}
 E. Palencia^{†,82} M. Pangilinan^{†,126} V. Papadimitriou^{†,82} A. Papaikonomou^{†,28} A.A. Paramanov^{†,81} N. Parashar^{†,89}
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 S. Pashapour^{†,6} J. Patrick^{†,82} A. Patwa^{†,117} G. Pauletta^{kk†,42} M. Paulini^{†,124} C. Paus^{†,101} T. Peiffer^{†,28}

D.E. Pellett[†],⁷³ B. Penning[†],⁸² A. Penzo[†],⁴² M. Perfilov[†],⁵⁵ K. Peters[†],⁶⁹ Y. Peters[†],⁶⁹ G. Petrillo[†],¹¹⁵ P. Pétroff[†],¹⁹ T.J. Phillips[†],¹¹⁸ G. Piacentino[†],⁴⁰ E. Pianori[†],¹²³ R. Piegai[†],¹ L. Pinera[†],⁷⁹ J. Piper[†],¹⁰⁶ K. Pitts[†],⁸⁷ C. Plager[†],⁷⁵ M.-A. Pleier[†],¹¹⁷ P.L.M. Podesta-Lerma[†],^{kk†},⁵⁰ V.M. Podstavkov[†],⁸² M.-E. Pol[†],² P. Polozov[†],⁵⁴ L. Pondrom[†],¹³⁴ A.V. Popov[†],⁵⁶ K. Potamianos[†],⁹¹ O. Poukhov[†],⁵³ M. Prewitt[†],¹³⁰ D. Price[†],⁸⁸ F. Prokoshin[†],^{aa†},⁵³ A. Pronko[†],⁸² S. Protopopescu[†],¹¹⁷ F. Ptohos[†],⁸² E. Pueschel[†],¹²⁴ G. Punzi[†],^{gg†},⁴⁰ J. Pursley[†],¹³⁴ J. Qian[†],¹⁰⁴ A. Quadt[†],²⁷ B. Quinn[†],¹⁰⁷ J. Rademacker[†],^{c†},⁷⁰ A. Rahaman[†],¹²⁵ V. Ramakrishnan[†],¹³⁴ M.S. Rangel[†],¹⁹ K. Ranjan[†],³⁴ N. Ranjan[†],⁹¹ P.N. Ratoff[†],⁶⁵ I. Razumov[†],⁵⁶ I. Redondo[†],⁶⁰ P. Renkel[†],¹²⁹ P. Renton[†],⁷⁰ M. Renz[†],²⁸ M. Rescigno[†],⁴¹ P. Rich[†],⁶⁹ S. Richter[†],²⁸ M. Rijssenbeek[†],¹¹⁶ F. Rimondi[†],^{ee†},³⁷ I. Ripp-Baudot[†],²² L. Ristori[†],⁴⁰ F. Rizatdinova[†],¹²² A. Robson[†],⁶⁴ T. Rodrigo[†],⁶¹ T. Rodriguez[†],¹²³ E. Rogers[†],⁸⁷ S. Rolli[†],¹⁰² M. Rominsky[†],⁸² R. Roser[†],⁸² M. Rossi[†],⁴² R. Rossin[†],⁷⁷ P. Roy[†],⁶ C. Royon[†],²¹ P. Rubinov[†],⁸² R. Ruchti[†],⁹⁰ A. Ruiz[†],⁶¹ J. Russ[†],¹²⁴ V. Rusu[†],⁸² B. Rutherford[†],⁸² H. Saarikko[†],¹⁵ A. Safonov[†],¹²⁸ G. Safronov[†],⁵⁴ G. Sajot[†],¹⁷ W.K. Sakumoto[†],¹¹⁵ A. Sánchez-Hernández[†],⁵⁰ M.P. Sanders[†],³⁰ B. Sanghi[†],⁸² L. Santi[†],^{kk†},⁴² L. Sartori[†],⁴⁰ K. Sato[†],⁴⁵ G. Savage[†],⁸² V. Saveliev[†],^{w†},²⁰ A. Savoy-Navarro[†],²⁰ L. Sawyer[†],⁹⁵ T. Scanlon[†],⁶⁷ D. Schaile[†],³⁰ R.D. Schamberger[†],¹¹⁶ Y. Scheglov[†],⁵⁷ H. Schellman[†],⁸⁶ P. Schlabach[†],⁸² T. Schliephake[†],³¹ S. Schlobohm[†],¹³³ A. Schmidt[†],²⁸ E.E. Schmidt[†],⁸² M.A. Schmidt[†],⁸³ M.P. Schmidt[†],^{*†},⁷⁸ M. Schmitt[†],⁸⁶ C. Schwanenberger[†],⁶⁹ T. Schwarz[†],⁷³ R. Schwienhorst[†],¹⁰⁶ L. Scodellaro[†],⁶¹ A. Scribano[†],^{hh†},⁴⁰ F. Scuri[†],⁴⁰ A. Sedov[†],⁹¹ S. Seidel[†],¹¹¹ Y. Seiya[†],⁴⁴ J. Sekaric[†],⁹³ A. Semenov[†],⁵³ H. Severini[†],¹²¹ L. Sexton-Kennedy[†],⁸² F. Sforza[†],^{gg†},⁴⁰ A. Sfyrla[†],⁸⁷ E. Shabalina[†],²⁷ S.Z. Shalhout[†],¹⁰⁵ V. Shary[†],²¹ A.A. Shchukin[†],⁵⁶ T. Shears[†],⁶⁶ P.F. Shepard[†],¹²⁵ M. Shimojima[†],^{u†},⁴⁵ S. Shiraishi[†],⁸³ R.K. Shivpuri[†],³⁴ M. Shochet[†],⁸³ Y. Shon[†],¹³⁴ I. Shreyber[†],⁵⁴ V. Simak[†],¹² A. Simonenko[†],⁵³ P. Sinervo[†],⁶ V. Sirotenko[†],⁸² A. Sisakyan[†],⁵³ P. Skubic[†],¹²¹ P. Slattery[†],¹¹⁵ A.J. Slaughter[†],⁸² J. Slaunwhite[†],¹¹⁹ K. Sliwa[†],¹⁰² D. Smirnov[†],⁹⁰ J.R. Smith[†],⁷³ F.D. Snider[†],⁸² R. Snihur[†],⁶ G.R. Snow[†],¹⁰⁸ J. Snow[†],¹²⁰ S. Snyder[†],¹¹⁷ A. Soha[†],⁸² S. Söldner-Rembold[†],⁶⁹ S. Somalwar[†],¹⁰⁹ L. Sonnenschein[†],²⁴ A. Sopczak[†],⁶⁵ V. Sorin[†],⁵⁹ M. Sosebee[†],¹²⁷ K. Soustruznik[†],¹¹ B. Spurlock[†],¹²⁷ P. Squillacioti[†],^{hh†},⁴⁰ M. Stanitzki[†],⁷⁸ J. Stark[†],¹⁷ R. St. Denis[†],⁶⁴ B. Stelzer[†],⁶ O. Stelzer-Chilton[†],⁶ D. Stentz[†],⁸⁶ V. Stolin[†],⁵⁴ D.A. Stoyanova[†],⁵⁶ M.A. Strang[†],¹¹² E. Strauss[†],¹¹⁶ M. Strauss[†],¹²¹ R. Ströhmer[†],³⁰ J. Strologas[†],¹¹¹ D. Strom[†],⁸⁴ G.L. Strycker[†],¹⁰⁴ L. Stutte[†],⁸² J.S. Suh[†],⁴⁷ A. Sukhanov[†],⁷⁹ I. Suslov[†],⁵³ P. Svoisky[†],⁵² A. Taffard[†],^{ff†},⁸⁷ M. Takahashi[†],⁶⁹ R. Takashima[†],⁴³ Y. Takeuchi[†],⁴⁵ R. Tanaka[†],⁴³ A. Tanasijczuk[†],¹ J. Tang[†],⁸³ W. Taylor[†],⁷ M. Tecchio[†],¹⁰⁴ P.K. Teng[†],⁹ J. Thom[†],^{h†},⁸² J. Thome[†],¹²⁴ G.A. Thompson[†],⁸⁷ E. Thomson[†],¹²³ B. Tiller[†],³⁰ P. Tipton[†],⁷⁸ M. Titov[†],²¹ S. Tkaczyk[†],⁸² D. Toback[†],¹²⁸ S. Tokar[†],⁵⁸ V.V. Tokmenin[†],⁵³ K. Tollefson[†],¹⁰⁶ T. Tomura[†],⁴⁵ D. Tonelli[†],⁸² S. Torre[†],³⁸ D. Torretta[†],⁸² P. Totaro[†],^{kk†},⁴² M. Trovato[†],^{ii†},⁴⁰ S.-Y. Tsai[†],⁹ D. Tsybychev[†],¹¹⁶ P. Ttito-Guzmán[†],⁶⁰ B. Tuchming[†],²¹ Y. Tu[†],¹²³ C. Tully[†],¹¹⁰ N. Turini[†],^{hh†},⁴⁰ P.M. Tuts[†],¹¹³ F. Ukegawa[†],⁴⁵ R. Unalan[†],¹⁰⁶ S. Uozumi[†],⁴⁷ L. Uvarov[†],⁵⁷ S. Uvarov[†],⁵⁷ S. Uzunyan[†],⁸⁵ R. Van Kooten[†],⁸⁸ W.M. van Leeuwen[†],⁵¹ N. van Remortel[†],^{b†},¹⁵ N. Varelas[†],⁸⁴ A. Varganov[†],¹⁰⁴ E.W. Varnes[†],⁷¹ I.A. Vasilyev[†],⁵⁶ E. Vataga[†],^{ii†},⁴⁰ F. Vázquez[†],^{n†},⁷⁹ G. Velev[†],⁸² C. Vellidis[†],³² P. Verdier[†],²³ L.S. Vertogradov[†],⁵³ M. Verzocchi[†],⁸² M. Vesterinen[†],⁶⁹ M. Vidal[†],⁶⁰ I. Vila[†],⁶¹ D. Vilanova[†],²¹ R. Vilar[†],⁶¹ P. Vint[†],⁶⁷ M. Vogel[†],¹¹¹ P. Vokac[†],¹² I. Volobouev[†],^{y†},⁷² G. Volpi[†],^{gg†},⁴⁰ P. Wagner[†],¹²³ R.G. Wagner[†],⁸¹ R.L. Wagner[†],⁸² W. Wagner[†],^{cc†},²⁸ J. Wagner-Kuhr[†],²⁸ H.D. Wahl[†],⁸⁰ T. Wakisaka[†],⁴⁴ R. Wallny[†],⁷⁵ M.H.L.S. Wang[†],¹¹⁵ S.M. Wang[†],⁹ A. Warburton[†],⁶ J. Warchol[†],⁹⁰ D. Waters[†],⁶⁸ G. Watts[†],¹³³ M. Wayne[†],⁹⁰ G. Weber[†],²⁹ M. Weber[†],^{ll†},⁸² M. Weinberger[†],¹²⁸ J. Weinelt[†],²⁸ W.C. Wester III[†],⁸² M. Wetstein[†],⁹⁷ A. White[†],¹²⁷ B. Whitehouse[†],¹⁰² D. Whiteson[†],^{ff†},¹²³ D. Wicke[†],²⁹ A.B. Wicklund[†],⁸¹ E. Wicklund[†],⁸² S. Wilbur[†],⁸³ G. Williams[†],⁶ H.H. Williams[†],¹²³ M.R.J. Williams[†],⁶⁵ G.W. Wilson[†],⁹³ P. Wilson[†],⁸² S.J. Wimpenny[†],⁷⁶ B.L. Winer[†],¹¹⁹ P. Wittich[†],^{h†},⁸² M. Wobisch[†],⁹⁵ S. Wolbers[†],⁸² C. Wolfe[†],⁸³ H. Wolfe[†],¹¹⁹ D.R. Wood[†],⁹⁹ T. Wright[†],¹⁰⁴ X. Wu[†],⁶³ F. Würthwein[†],⁷⁴ T.R. Wyatt[†],⁶⁹ Y. Xie[†],⁸² C. Xu[†],¹⁰⁴ S. Yacoub[†],⁸⁶ A. Yagil[†],⁷⁴ R. Yamada[†],⁸² K. Yamamoto[†],⁴⁴ J. Yamaoka[†],¹¹⁸ U.K. Yang[†],^{s†},⁸³ W.-C. Yang[†],⁶⁹ Y.C. Yang[†],⁴⁷ W.M. Yao[†],⁷² T. Yasuda[†],⁸² Y.A. Yatsunenko[†],⁵³ Z. Ye[†],⁸² G.P. Yeh[†],⁸² K. Yi[†],^{o†},⁸² H. Yin[†],⁸ K. Yip[†],¹¹⁷ J. Yoh[†],⁸² H.D. Yoo[†],¹²⁶ K. Yorita[†],⁴⁶ T. Yoshida[†],^{l†},⁴⁴ S.W. Youn[†],⁸² G.B. Yu[†],¹¹⁸ I. Yu[†],⁴⁷ J. Yu[†],¹²⁷ S.S. Yu[†],⁸² J.C. Yun[†],⁸² A. Zanetti[†],⁴² S. Zelitch[†],¹³² Y. Zeng[†],¹¹⁸ X. Zhang[†],⁸⁷ T. Zhao[†],¹³³ Y. Zheng[†],^{d†},⁷⁵ B. Zhou[†],¹⁰⁴ J. Zhu[†],¹¹⁶ M. Zielinski[†],¹¹⁵ D. Zieminska[†],⁸⁸ L. Zivkovic[†],¹¹³ and S. Zucchelli[†],^{ee†},³⁷

(The CDF[†] and D0[†] Collaborations)

¹Universidad de Buenos Aires, Buenos Aires, Argentina

²LAFEX, Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil

³Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil

⁴Universidade Federal do ABC, Santo André, Brazil

⁵Instituto de Física Teórica, Universidade Estadual Paulista, São Paulo, Brazil

⁶Institute of Particle Physics: McGill University, Montréal,

- Québec, Canada; Simon Fraser University, Burnaby, British Columbia, Canada; University of Toronto, Toronto, Ontario, Canada; and TRIUMF, Vancouver, British Columbia, Canada
- ⁷Simon Fraser University, Burnaby, British Columbia, Canada; and York University, Toronto, Ontario, Canada
- ⁸University of Science and Technology of China, Hefei, People's Republic of China
- ⁹Institute of Physics, Academia Sinica, Taipei, Taiwan, Republic of China
- ¹⁰Universidad de los Andes, Bogotá, Colombia
- ¹¹Charles University, Faculty of Mathematics and Physics, Center for Particle Physics, Prague, Czech Republic
- ¹²Czech Technical University in Prague, Prague, Czech Republic
- ¹³Center for Particle Physics, Institute of Physics, Academy of Sciences of the Czech Republic, Prague, Czech Republic
- ¹⁴Universidad San Francisco de Quito, Quito, Ecuador
- ¹⁵Division of High Energy Physics, Department of Physics, University of Helsinki and Helsinki Institute of Physics, FIN-00014, Helsinki, Finland
- ¹⁶LPC, Université Blaise Pascal, CNRS/IN2P3, Clermont, France
- ¹⁷LPSC, Université Joseph Fourier Grenoble 1, CNRS/IN2P3, Institut National Polytechnique de Grenoble, Grenoble, France
- ¹⁸CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France
- ¹⁹LAL, Université Paris-Sud, CNRS/IN2P3, Orsay, France
- ²⁰LPNHE, Universités Paris VI and VII, CNRS/IN2P3, Paris, France
- ²¹CEA, Irfu, SPP, Saclay, France
- ²²IPHC, Université de Strasbourg, CNRS/IN2P3, Strasbourg, France
- ²³IPNL, Université Lyon 1, CNRS/IN2P3, Villeurbanne, France and Université de Lyon, Lyon, France
- ²⁴III. Physikalisches Institut A, RWTH Aachen University, Aachen, Germany
- ²⁵Physikalisches Institut, Universität Bonn, Bonn, Germany
- ²⁶Physikalisches Institut, Universität Freiburg, Freiburg, Germany
- ²⁷II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany
- ²⁸Institut für Experimentelle Kernphysik, Karlsruhe Institute of Technology, Karlsruhe, Germany
- ²⁹Institut für Physik, Universität Mainz, Mainz, Germany
- ³⁰Ludwig-Maximilians-Universität München, München, Germany
- ³¹Fachbereich Physik, Bergische Universität Wuppertal, Wuppertal, Germany
- ³²University of Athens, 157 71 Athens, Greece
- ³³Panjab University, Chandigarh, India
- ³⁴Delhi University, Delhi, India
- ³⁵Tata Institute of Fundamental Research, Mumbai, India
- ³⁶University College Dublin, Dublin, Ireland
- ³⁷Istituto Nazionale di Fisica Nucleare Bologna, ^{ee}University of Bologna, I-40127 Bologna, Italy
- ³⁸Laboratori Nazionali di Frascati, Istituto Nazionale di Fisica Nucleare, I-00044 Frascati, Italy
- ³⁹Istituto Nazionale di Fisica Nucleare, Sezione di Padova-Trento, ^{ff}University of Padova, I-35131 Padova, Italy
- ⁴⁰Istituto Nazionale di Fisica Nucleare Pisa, ^{gg}University of Pisa, ^{hh}University of Siena and ⁱⁱScuola Normale Superiore, I-56127 Pisa, Italy
- ⁴¹Istituto Nazionale di Fisica Nucleare, Sezione di Roma 1, ^{jj}Sapienza Università di Roma, I-00185 Roma, Italy
- ⁴²Istituto Nazionale di Fisica Nucleare Trieste/Udine, I-34100 Trieste, ^{kk}University of Trieste/Udine, I-33100 Udine, Italy
- ⁴³Okayama University, Okayama 700-8530, Japan
- ⁴⁴Osaka City University, Osaka 588, Japan
- ⁴⁵University of Tsukuba, Tsukuba, Ibaraki 305, Japan
- ⁴⁶Waseda University, Tokyo 169, Japan
- ⁴⁷Center for High Energy Physics: Kyungpook National University, Daegu, Korea; Seoul National University, Seoul, Korea; Sungkyunkwan University, Suwon, Korea; Korea Institute of Science and Technology Information, Daejeon, Korea; Chonnam National University, Gwangju, Korea; Chonbuk National University, Jeonju, Korea
- ⁴⁸Korea Detector Laboratory, Korea University, Seoul, Korea
- ⁴⁹SungKyunKwan University, Suwon, Korea
- ⁵⁰CINVESTAV, Mexico City, Mexico
- ⁵¹FOM-Institute NIKHEF and University of Amsterdam/NIKHEF, Amsterdam, The Netherlands
- ⁵²Radboud University Nijmegen/NIKHEF, Nijmegen, The Netherlands
- ⁵³Joint Institute for Nuclear Research, Dubna, Russia
- ⁵⁴Institute for Theoretical and Experimental Physics, Moscow, Russia
- ⁵⁵Moscow State University, Moscow, Russia

- ⁵⁶Institute for High Energy Physics, Protvino, Russia
- ⁵⁷Petersburg Nuclear Physics Institute, St. Petersburg, Russia
- ⁵⁸Comenius University, 842 48 Bratislava, Slovakia; Institute of Experimental Physics, 040 01 Kosice, Slovakia
- ⁵⁹Institut de Fisica d'Altes Energies, Universitat Autònoma de Barcelona, E-08193, Bellaterra (Barcelona), Spain
- ⁶⁰Centro de Investigaciones Energeticas Medioambientales y Tecnológicas, E-28040 Madrid, Spain
- ⁶¹Instituto de Fisica de Cantabria, CSIC-University of Cantabria, 39005 Santander, Spain
- ⁶²Stockholm University, Stockholm, Sweden, and Uppsala University, Uppsala, Sweden
- ⁶³University of Geneva, CH-1211 Geneva 4, Switzerland
- ⁶⁴Glasgow University, Glasgow G12 8QQ, United Kingdom
- ⁶⁵Lancaster University, Lancaster LA1 4YB, United Kingdom
- ⁶⁶University of Liverpool, Liverpool L69 7ZE, United Kingdom
- ⁶⁷Imperial College London, London SW7 2AZ, United Kingdom
- ⁶⁸University College London, London WC1E 6BT, United Kingdom
- ⁶⁹The University of Manchester, Manchester M13 9PL, United Kingdom
- ⁷⁰University of Oxford, Oxford OX1 3RH, United Kingdom
- ⁷¹University of Arizona, Tucson, Arizona 85721, USA
- ⁷²Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
- ⁷³University of California, Davis, Davis, California 95616, USA
- ⁷⁴University of California, San Diego, La Jolla, California 92093, USA
- ⁷⁵University of California, Los Angeles, Los Angeles, California 90024, USA
- ⁷⁶University of California Riverside, Riverside, California 92521, USA
- ⁷⁷University of California, Santa Barbara, Santa Barbara, California 93106, USA
- ⁷⁸Yale University, New Haven, Connecticut 06520, USA
- ⁷⁹University of Florida, Gainesville, Florida 32611, USA
- ⁸⁰Florida State University, Tallahassee, Florida 32306, USA
- ⁸¹Argonne National Laboratory, Argonne, Illinois 60439, USA
- ⁸²Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA
- ⁸³Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637, USA
- ⁸⁴University of Illinois at Chicago, Chicago, Illinois 60607, USA
- ⁸⁵Northern Illinois University, DeKalb, Illinois 60115, USA
- ⁸⁶Northwestern University, Evanston, Illinois 60208, USA
- ⁸⁷University of Illinois, Urbana, Illinois 61801, USA
- ⁸⁸Indiana University, Bloomington, Indiana 47405, USA
- ⁸⁹Purdue University Calumet, Hammond, Indiana 46323, USA
- ⁹⁰University of Notre Dame, Notre Dame, Indiana 46556, USA
- ⁹¹Purdue University, West Lafayette, Indiana 47907, USA
- ⁹²Iowa State University, Ames, Iowa 50011, USA
- ⁹³University of Kansas, Lawrence, Kansas 66045, USA
- ⁹⁴Kansas State University, Manhattan, Kansas 66506, USA
- ⁹⁵Louisiana Tech University, Ruston, Louisiana 71272, USA
- ⁹⁶The Johns Hopkins University, Baltimore, Maryland 21218, USA
- ⁹⁷University of Maryland, College Park, Maryland 20742, USA
- ⁹⁸Boston University, Boston, Massachusetts 02215, USA
- ⁹⁹Northeastern University, Boston, Massachusetts 02115, USA
- ¹⁰⁰Harvard University, Cambridge, Massachusetts 02138, USA
- ¹⁰¹Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA
- ¹⁰²Tufts University, Medford, Massachusetts 02155, USA
- ¹⁰³Brandeis University, Waltham, Massachusetts 02254, USA
- ¹⁰⁴University of Michigan, Ann Arbor, Michigan 48109, USA
- ¹⁰⁵Wayne State University, Detroit, Michigan 48201, USA
- ¹⁰⁶Michigan State University, East Lansing, Michigan 48824, USA
- ¹⁰⁷University of Mississippi, University, Mississippi 38677, USA
- ¹⁰⁸University of Nebraska, Lincoln, Nebraska 68588, USA
- ¹⁰⁹Rutgers University, Piscataway, New Jersey 08855, USA
- ¹¹⁰Princeton University, Princeton, New Jersey 08544, USA
- ¹¹¹University of New Mexico, Albuquerque, New Mexico 87131, USA
- ¹¹²State University of New York, Buffalo, New York 14260, USA
- ¹¹³Columbia University, New York, New York 10027, USA
- ¹¹⁴The Rockefeller University, New York, New York 10021, USA
- ¹¹⁵University of Rochester, Rochester, New York 14627, USA
- ¹¹⁶State University of New York, Stony Brook, New York 11794, USA
- ¹¹⁷Brookhaven National Laboratory, Upton, New York 11973, USA
- ¹¹⁸Duke University, Durham, North Carolina 27708, USA
- ¹¹⁹The Ohio State University, Columbus, Ohio 43210, USA

- ¹²⁰Langston University, Langston, Oklahoma 73050, USA
¹²¹University of Oklahoma, Norman, Oklahoma 73019, USA
¹²²Oklahoma State University, Stillwater, Oklahoma 74078, USA
¹²³University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA
¹²⁴Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA
¹²⁵University of Pittsburgh, Pittsburgh, Pennsylvania 15260, USA
¹²⁶Brown University, Providence, Rhode Island 02912, USA
¹²⁷University of Texas, Arlington, Texas 76019, USA
¹²⁸Texas A&M University, College Station, Texas 77843, USA
¹²⁹Southern Methodist University, Dallas, Texas 75275, USA
¹³⁰Rice University, Houston, Texas 77005, USA
¹³¹Baylor University, Waco, Texas 76798, USA
¹³²University of Virginia, Charlottesville, Virginia 22901, USA
¹³³University of Washington, Seattle, Washington 98195, USA
¹³⁴University of Wisconsin, Madison, Wisconsin 53706, USA

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We combine results from searches by the CDF and D0 collaborations for a standard model Higgs boson (H) in the process $gg \rightarrow H \rightarrow W^+W^-$ in $p\bar{p}$ collisions at the Fermilab Tevatron Collider at $\sqrt{s} = 1.96$ TeV. With 4.8 fb^{-1} of integrated luminosity analyzed at CDF and 5.4 fb^{-1} at D0, the 95% Confidence Level upper limit on $\sigma(gg \rightarrow H) \times \mathcal{B}(H \rightarrow W^+W^-)$ is 1.75 pb at $m_H = 120 \text{ GeV}$, 0.38 pb at $m_H = 165 \text{ GeV}$, and 0.83 pb at $m_H = 200 \text{ GeV}$. Assuming the presence of a fourth sequential generation of fermions with large masses, we exclude at the 95% Confidence Level a standard-model-like Higgs boson with a mass between 131 and 204 GeV.

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Exploring the mechanism for breaking the $SU(2) \times U(1)$ electroweak gauge symmetry is a priority in high energy physics. Not only are this symmetry and its breaking [1] necessary components for the consistency of the successful standard model (SM) [2], but measurable properties of the breaking mechanism are also very sensitive to possible phenomena that have not yet been observed at collider experiments. Measuring these properties, or setting limits on them, can constrain broad classes of extensions to the SM.

A natural extension to the SM that can be tested with Higgs boson search results at the Fermilab Tevatron Collider is the presence of a fourth generation of fermions with masses much larger than those of the three known generations [3]. While fits to precision electroweak data favor a low-mass Higgs boson in the SM, the addition of a fourth generation of fermions to the SM modifies the fit parameters such that a heavy Higgs boson is consistent for up to $m_H \approx 300 \text{ GeV}$ at the 68% Confidence Level (C.L.) [4]. Measurements of the Z boson decay width [5] exclude models in which the fourth neutrino mass eigenstate has a mass less than 45 GeV. If the neutrino masses are very large, however, a fourth generation of fermions is not yet excluded.

One consequence of the extra fermions is that the ggH coupling is enhanced by a factor of roughly three rela-

tive to the SM coupling [4, 6, 7]. Since the lowest-order ggH coupling arises from a quark loop. The top quark contribution is the largest due to its large coupling with the Higgs boson. In the limit $m_{q4} \gg m_H$, where m_{q4} is the fourth-generation quark mass, the Higgs boson coupling cancels the mass dependence for each of the three propagators in the loop, and the contribution to the ggH coupling becomes asymptotically independent of the masses of the two fourth-generation quarks. Each additional fourth-generation quark then contributes as much as the top quark, and the ggH coupling is thus enhanced by a factor K_e of approximately three.

The production cross section will be enhanced by a factor of K_e^2 . For m_H near the low end of our search range, $m_H \approx 110 \text{ GeV}$, the $gg \rightarrow H$ production cross section is enhanced by roughly a factor of nine relative to the SM prediction. This factor drops to approximately 7.5 near the upper end of the search range, $m_H \approx 300 \text{ GeV}$, assuming asymptotically large masses for the fourth-generation quarks. The reason for this drop is that the denominator of the enhancement factor, the SM cross section, has a larger contribution from the SM top quark as m_H nears $2m_t$. The partial decay width for $H \rightarrow gg$ is enhanced by the same factor as the production cross section. However, because the decay $H \rightarrow gg$ is loop-mediated, the $H \rightarrow W^+W^-$ decay continues to dominate for Higgs boson masses $m_H > 135 \text{ GeV}$.

We consider two scenarios for the masses of the fourth-generation fermions. In the first scenario, the ‘‘low-mass’’ scenario, we set the mass of the fourth-generation neu-

*Deceased

trino to $m_{\nu 4} = 80$ GeV, and the mass of the fourth-generation charged lepton to $m_{\ell 4} = 100$ GeV in order to evade experimental constraints [8] and to have the maximum impact on the Higgs boson decay branching ratios. In the second scenario, the “high-mass” scenario, we set $m_{\nu 4} = m_{\ell 4} = 1$ TeV, so that the fourth-generation leptons do not affect the decay branching ratios of the Higgs boson. In both scenarios, we choose the masses of the quarks to be those of the second scenario in Ref. [7], that is, we set the mass of the fourth-generation down-type quark to be $m_{d4} = 400$ GeV and the mass of the fourth-generation up-type quark to be $m_{u4} = m_{d4} + 50$ GeV + $10 \log(m_H/115 \text{ GeV})$ GeV. The other mass spectrum of Ref. [7] chooses $m_{d4} = 300$ GeV, resulting in slightly larger predictions for $\sigma(gg \rightarrow H)$. We use the next-to-next-to-leading order (NNLO) production cross section calculation of Ref. [7], which builds on the NNLO SM calculations of Refs. [9–16], the results of which are also listed in Ref. [17].

The CDF and D0 Collaborations have searched for the SM Higgs boson in the decay $H \rightarrow W^+W^-$ using all SM production processes: $gg \rightarrow H$, $qq \rightarrow WH$, $qq \rightarrow ZH$, and vector-boson fusion (VBF) [18–20]. The results of these searches for the SM Higgs boson cannot be used directly to constrain fourth-generation models, as the ggH coupling is enhanced but the WWH and ZZH couplings are not, and the signal acceptances and the backgrounds in the multiple analysis channels differ for the various production modes. Therefore, these searches rely on the SM to predict the ratios of the production rates of the $gg \rightarrow H$, WH , ZH , and VBF signals. Previous external analyses have used the Tevatron’s SM Higgs boson search results to constrain fourth-generation models, incorrectly arguing that the WH , ZH , and VBF production rates are not significant, thus obtaining only approximate results. Furthermore, the SM results [18–20] extend only up to m_H of 200 GeV. This paper addresses both of these issues by placing limits on $\sigma(gg \rightarrow H) \times \mathcal{B}(H \rightarrow W^+W^-)$ up to $m_H = 300$ GeV.

Previously, the CDF and D0 collaborations have published searches for the process $gg \rightarrow H \rightarrow W^+W^-$, also neglecting the WH , ZH , and VBF signal contributions [21, 22]. The D0 search includes a fourth-generation interpretation. Here we update these searches with those using 4.8 fb^{-1} from CDF [18] and 5.4 fb^{-1} from D0 [19]. We present new limits on $\sigma(gg \rightarrow H) \times \mathcal{B}(H \rightarrow W^+W^-)$ in which the $gg \rightarrow H$ production mechanism is considered as the unique signal source. These limits are compared to models for Higgs boson production in which the ggH coupling is enhanced by the presence of a single additional generation of fermions. In this comparison, the decay branching ratios of the Higgs boson are also modified to reflect changes due to the fourth generation relative to the SM prediction. While the decays of the heavy quarks and leptons may include W bosons in the final state, we do not include these as additional sources of signal. The branching ratios for $H \rightarrow W^+W^-$ are calculated using HDECAY [23] modified to include fourth-generation

fermions [4]. The modified Higgs branching ratio to W^+W^- is multiplied by the cross section [7] to predict the fourth-generation enhanced $gg \rightarrow H \rightarrow W^+W^-$ production rate.

The event selections are similar for the corresponding CDF and D0 analyses. Both collaborations select events with large \cancel{E}_T and two oppositely charged, isolated leptons, targeting the $H \rightarrow W^+W^-$ signal in which both W bosons decay leptonically. The D0 analysis classifies events in three channels defined by the number of charged leptons (e or μ), e^+e^- , $e^\pm\mu^\mp$, and $\mu^+\mu^-$ and no classification based upon jet multiplicity. The CDF analysis separates opposite-sign candidate events into five non-overlapping channels. Events are classified by their jet multiplicity (0, 1, or ≥ 2), and the 0 and 1 jet channels are further divided according to whether both leptons are in the central part of the detector or if either lepton is in the forward part of the detector. Two changes have been made in the D0 event selection from the analysis presented in Ref. [19]. For higher Higgs boson masses ($m_H > 200$ GeV), the dilepton azimuthal-opening angle distribution is no longer peaked at low values ($\Delta\phi(\ell, \ell) < 1$). Therefore, to enhance the signal acceptance for large m_H , the requirement on the dilepton azimuthal-opening angle [$\Delta\phi(\ell, \ell)$] has been removed for $e^\pm\mu^\mp$ candidate events and relaxed to $\Delta\phi(\ell, \ell) < 2.5$ in the e^+e^- and $\mu^+\mu^-$ candidate events. In addition, a requirement on the ϕ -opening angle between the leading muon and the missing transverse energy, $\Delta\phi(\mu, \cancel{E}_T) > 0.5$, has been included to remove additional background in a signal-free region. The predicted contributions from the different background processes are compared with the numbers of events observed in data for the CDF and D0 analyses in Tables I and II, respectively.

The presence of neutrinos in the final state prevents event-by-event reconstruction of the Higgs boson mass and thus other variables are used for separating the signal from the background. For example, the angle $\Delta\phi(\ell, \ell)$ in signal events is smaller on average than that in background events, the missing transverse momentum is larger, and the total transverse energy of the jets is lower. In these analyses, the final discriminants are neural-network (NN) [24, 25] outputs based on several kinematic variables. For CDF, the list of network inputs includes likelihood ratio discriminant variables constructed from matrix-element probabilities [18].

Both CDF and D0 have extended their searches to the range $110 < m_H < 300$ GeV. Separate neural networks are trained to distinguish the $gg \rightarrow H$ signal from the backgrounds for each of the test masses, which are separated by increments of 5 or 10 GeV. Distributions of the network outputs for CDF and D0 are shown in Figs. 1 and 2, comparing the data with predictions for a Higgs boson of mass $m_H = 200$ GeV. Because the background composition and the signal kinematics are functions of the number of jets in the event, the CDF NN output distributions are shown separately for 0, 1, and 2 or more jets, summed over lepton categories. For D0, as the de-

TABLE I: Expected and observed event yields in the 0-jet exclusive, 1-jet exclusive, and 2-jet inclusive samples at final selection for the CDF analysis summed across all lepton categories. The systematic uncertainty is shown for all samples. The signal expectation is given for the low-mass fourth-generation scenario with a SM Higgs mass of 200 GeV with a predicted $\sigma(gg \rightarrow H) \times BR(H \rightarrow W^+W^-)$ of 1.02 pb.

CDF Run II $\int \mathcal{L} = 4.8 \text{ fb}^{-1}$	0-jet	1-jet	≥ 2 -jets
$Z/\gamma^* \rightarrow \ell^+\ell^-$	128 ± 30	133 ± 42	51 ± 17
$t\bar{t}$	1.99 ± 0.31	48.4 ± 7.6	145 ± 24
WW	447 ± 48	121 ± 13	25.6 ± 5.8
WZ	19.7 ± 2.7	20.0 ± 2.7	5.30 ± 0.73
ZZ	29.9 ± 4.1	8.0 ± 1.1	2.36 ± 0.32
W + jets	154 ± 37	59 ± 15	21.9 ± 5.9
$W\gamma$	112 ± 19	16.2 ± 3.6	2.72 ± 0.67
Total Background	893 ± 79	406 ± 52	254 ± 33
$gg \rightarrow H$ ($M_H = 200 \text{ GeV}$)	35.2 ± 5.0	20.2 ± 5.1	8.5 ± 5.1
Data	950	393	224

TABLE II: Expected and observed event yields in each channel at the final selection for the D0 analysis summed across all jet multiplicities. The systematic uncertainty after fitting is shown for all samples at final selection. The signal expectation is given for the low-mass fourth-generation scenario with a SM Higgs mass of 200 GeV with a predicted $\sigma(gg \rightarrow H) \times BR(H \rightarrow W^+W^-)$ of 1.02 pb.

D0 Run II $\int \mathcal{L} = 5.4 \text{ fb}^{-1}$	$e^+\mu^\mp$	e^+e^-	$\mu^+\mu^-$
$Z/\gamma^* \rightarrow e^+e^-$	< 0.1	370 ± 24	–
$Z/\gamma^* \rightarrow \mu^+\mu^-$	7.0 ± 0.1	–	2056 ± 58
$Z/\gamma^* \rightarrow \tau^+\tau^-$	28.0 ± 0.2	0.8 ± 0.1	6.9 ± 0.6
$t\bar{t}$	176 ± 15	58.9 ± 5.5	74.9 ± 6.8
WW	304 ± 18	102 ± 7.3	145 ± 11
WZ	13.4 ± 0.2	18.1 ± 1.0	31.4 ± 2.0
ZZ	1.1 ± 0.1	15.2 ± 0.9	26.9 ± 1.7
W + jets/ γ	156 ± 12	154 ± 14	118 ± 13.7
Multijet	10.4 ± 2.5	1.4 ± 0.1	72.7 ± 13.7
Total Background	696 ± 26	720 ± 32	2532 ± 58
$gg \rightarrow H$ ($M_H = 200 \text{ GeV}$)	36.5 ± 5.4	15.8 ± 2.2	19.0 ± 2.9
Data	684	719	2516

tector response is different for electrons and muons, the NN distributions are shown separately for e^+e^- , $e^\pm\mu^\mp$, and $\mu^+\mu^-$ selections.

The details of the signal and background estimations and the systematic uncertainties are provided in Refs. [18–20]. We set limits on $\sigma(gg \rightarrow H) \times \mathcal{B}(H \rightarrow W^+W^-)$ as a function of m_H . We use the same two statistical methods employed in Ref. [20], namely the modified frequentist (CL_s) and Bayesian techniques in order to study the consistency of the results. Each method is applied at each test mass to calculate an observed upper limit on $\sigma(gg \rightarrow H) \times \mathcal{B}(H \rightarrow W^+W^-)$. Pseudo-experiments drawn from systematically varied background-only predictions are used to compute the limits we expect to obtain in the absence of a signal. We present both the Bayesian and CL_s observed and expected limits in Ref. [17]. The limits calculated with the two methods agree within 6% for all Higgs boson mass hypotheses. Correlated systematic uncertainties

are treated in the same way as they are in Ref. [20]. The sources of correlated uncertainty between CDF and D0 are the total inelastic $p\bar{p}$ cross section used in the luminosity measurement, the SM diboson background production cross sections (WW , WZ , and ZZ), and the $t\bar{t}$ and single top quark production cross sections. Instrumental effects such as trigger efficiencies, lepton identification efficiencies and misidentification rates, and the jet energy scales used by CDF and D0 remain uncorrelated. To minimize the degrading effects of systematics on the search sensitivity, the signal and background contributions are fit to the data observations by maximizing a likelihood function over the systematic uncertainties for both the background-only and signal+background hypotheses [26]. When setting limits on $\sigma(gg \rightarrow H) \times \mathcal{B}(H \rightarrow W^+W^-)$, we do not include the theoretical uncertainty on the prediction of $\sigma(gg \rightarrow H) \times \mathcal{B}(H \rightarrow W^+W^-)$ in the fourth-generation models since these limits are independent of the pre-

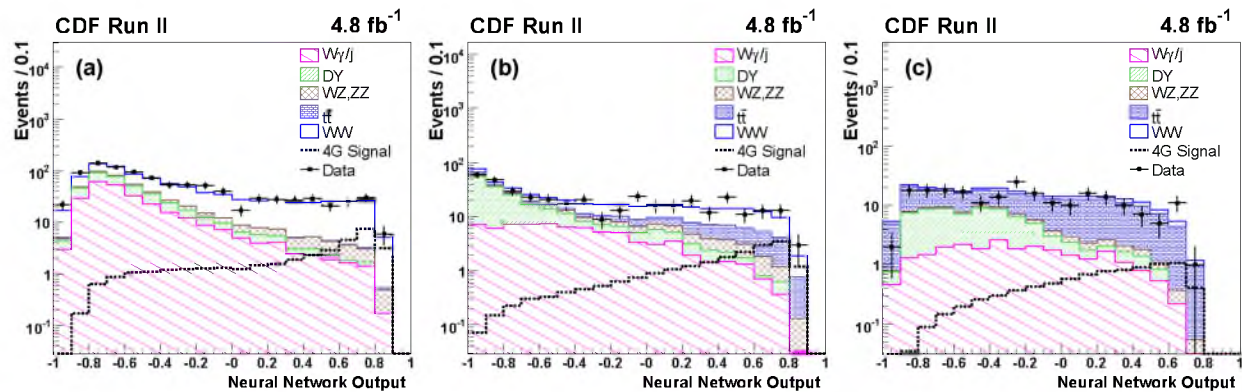


FIG. 1: Distributions of the neural network outputs for the search for a Higgs boson of mass $m_H = 200$ GeV, from CDF. The data are shown as points with uncertainty bars, and the background predictions are shown stacked. The figures show the distributions for events with (a) zero, (b) one, and (c) two or more identified jets, respectively. The distributions are summed over lepton categories. The fourth-generation signal, normalized to the prediction of the low-mass scenario, is shown not stacked.

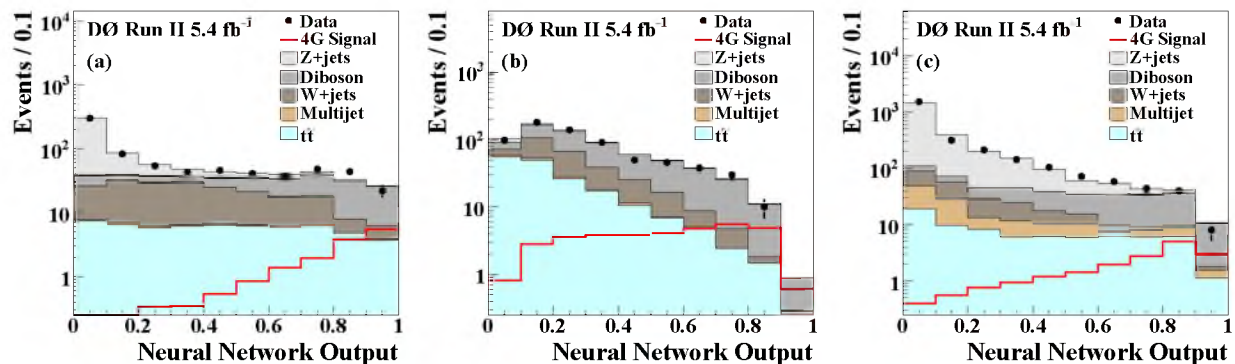


FIG. 2: Distributions of the neural network outputs for the search for a Higgs boson of mass $m_H = 200$ GeV, from D0 summed over all jet multiplicities. (a) shows the distribution for the di-electron selection, (b) shows the distribution for the electron-muon selection, and (c) shows the distribution for the di-muon selection. The data are shown as points with uncertainty bars, and the background predictions are shown stacked. The background uncertainty is the post-fit systematic uncertainty. The fourth-generation signal, normalized to the prediction of the low-mass scenario, is shown not stacked.

dictions. When setting limits on m_H in the context of fourth-generation models, however, we include the uncertainties on the theoretical predictions as described below.

Before computing the cross-section limits, we investigate the properties of the signal and background predictions in each bin of the analyses, as well as those of the observed data. Because there are many channels to combine, we represent the data in a compact form by sorting the bins of each analysis by their signal-to-background ratio s/b , where s and b are the number of signal and background events, repetitively. The predictions and observations in bins of similar s/b are then collected. For the $m_H = 200$ GeV search, the background subtracted data distribution compared with the signal prediction can be seen in Fig. 3. The background used and its uncertainties are shown after fitting to the data. No significant excess is observed in the data, and the theory predicts a

measurable excess over the background.

The separate limits on $\sigma(gg \rightarrow H) \times \mathcal{B}(H \rightarrow W^+W^-)$ from CDF and D0 are shown in Figs. 4(a) and 4(b), respectively. Since CDF separates the different jet categories into separate channels, theoretical uncertainties on the relative contributions of the $gg \rightarrow H$ signal in the separate jet channels [27] are included in the same way as signal acceptance uncertainties. The combined limits on $\sigma(gg \rightarrow H) \times \mathcal{B}(H \rightarrow W^+W^-)$ are shown in Fig. 4(c) along with the fourth-generation theory predictions for the high-mass and low-mass scenarios. The uncertainty bands shown on the low-mass theoretical prediction are the sum in quadrature of the MSTW 2008 [28] 90% C.L. parton distribution function (PDF) uncertainties and the factorization and renormalization scale uncertainties from Table 1 of Ref. [7], which are also reported Ref. [17], giving a total uncertainty of 15% for

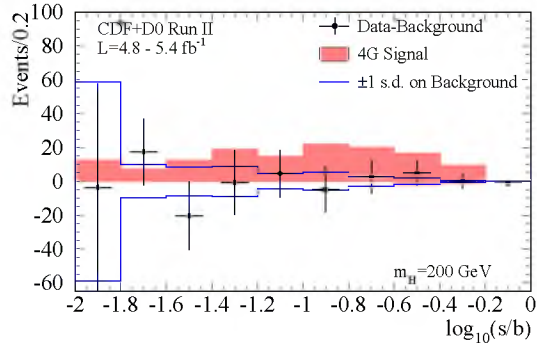


FIG. 3: Background-subtracted data distribution for the discriminant histograms, summed for bins of s/b , for the $m_H = 200$ GeV combined search. The background is fitted to the data under the background-only hypothesis, and the uncertainty on the background is the post-fit systematic uncertainty. The signal, which is normalized to the low-mass fourth-generation SM expectation, is shown with a filled histogram. The uncertainties shown on the background-subtracted data points are the square roots of the post-fit background predictions in each bin, representing the expected statistical uncertainty on the data.

$m_H = 160$ GeV. The scale uncertainties are determined by recalculating the cross sections with the scale multiplied by factors of $1/2$ and 2 . The scale uncertainties are independent of m_H and are similar to the uncertainties for SM $\sigma(gg \rightarrow H)$ predictions [12, 29]. The PDF uncertainties, however, grow with increasing m_H , as higher- x gluons are required to produce more massive Higgs bosons.

In order to set limits on m_H in these two scenarios, we perform a second combination, including the uncertainties on the theoretical predictions of $\sigma(gg \rightarrow H) \times \mathcal{B}(H \rightarrow W^+W^-)$ due to scale and PDF uncertainties at each value of m_H tested. The resulting limits are computed relative to the model prediction, and are shown in Fig. 4(d) for the low-mass scenario, which gives the smaller excluded range of m_H . In this scenario, we exclude at the 95% C.L. a SM-like Higgs boson with a mass in the range $131 - 204$ GeV. Using the median limits on $\sigma(gg \rightarrow H) \times \mathcal{B}(H \rightarrow W^+W^-)$, expected in the absence of a signal, to quantify the sensitivity, we expect to exclude the mass range $125 - 218$ GeV. In the high-mass scenario, which predicts a larger $\mathcal{B}(H \rightarrow W^+W^-)$ at high m_H than that predicted in the low-mass scenario, we exclude at the 95% C.L. the mass range $131 - 208$ GeV and expect to exclude the mass range $125 - 227$ GeV.

In summary, we presented a combination of CDF and D0 searches for the $gg \rightarrow H \rightarrow W^+W^-$ process and set an upper limit on $\sigma(gg \rightarrow H) \times \mathcal{B}(H \rightarrow W^+W^-)$ as a function of m_H . We compared these limits with the prediction of the minimal SM with a sequential fourth

generation of heavy fermions added on, and excluded at the 95% C.L. the Higgs boson mass range $131 < m_H < 204$ GeV, with an expected excluded range of $125 - 218$ GeV.

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With visitors to CDF from ^{a†}University of Massachusetts Amherst, 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†}University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom; ^{l†}University of Fukui, Fukui City, Fukui Prefecture, Japan 910-0017; ^{m†}Kinki University, Higashi-Osaka City, Japan 577-8502; ^{n†}Universidad Iberoamericana, Mexico D.F., Mexico; ^{o†}University of Iowa, Iowa City, IA 52242; ^{p†}Iowa State University, Ames, IA 50011; ^{q†}Kansas State University, Manhattan, KS 66506; ^{r†}Queen Mary, University of London, London, E1 4NS, England; ^{s†}University of Manchester, Manchester M13 9PL, England; ^{t†}Muons, Inc., Batavia, IL 60510; ^{u†}Nagasaki Institute of Applied Science, Nagasaki, Japan; ^{v†}University of Notre Dame, Notre Dame, IN 46556; ^{w†}Obninsk State University, Obninsk, Russia; ^{x†}University de Oviedo, E-33007 Oviedo, Spain; ^{y†}Texas Tech University, Lubbock, TX 79609; ^{z†}IFIC(CSIC-Universitat de Valencia), 56071 Valencia, Spain; ^{aa†}Universidad Tecnica Federico Santa Maria, 110v Valparaiso, Chile; ^{bb†}University of Virginia, Charlottesville, VA 22906; ^{cc†}Bergische Universität Wupper-

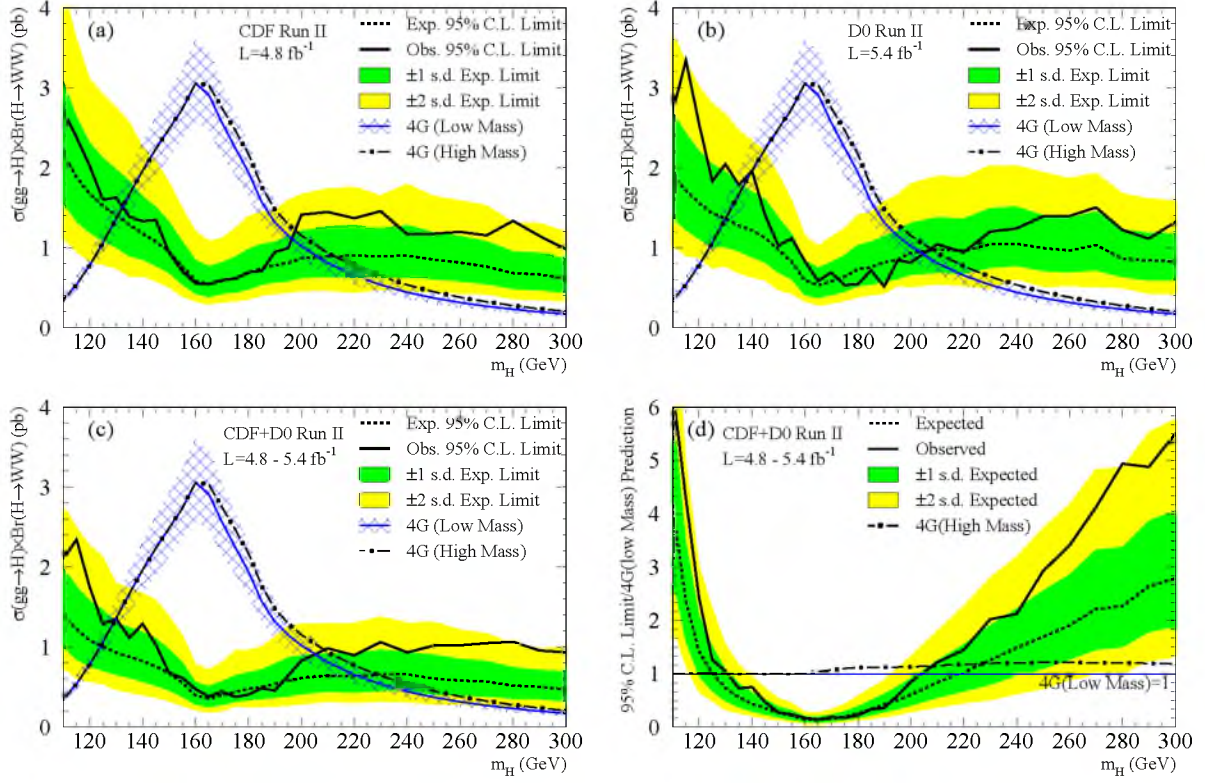


FIG. 4: The CDF, D0, and combined observed (solid black lines) and median expected (dashed black lines) 95% C.L. upper limits on $\sigma(gg \rightarrow H) \times \mathcal{B}(H \rightarrow W^+W^-)$ are shown in figures (a) through (c). The shaded bands indicate the ± 1 standard deviation (s.d.) and ± 2 s.d. intervals on the distribution of the limits that are expected if a Higgs boson signal is not present. Also shown on each graph is the prediction for a fourth-generation model in the low-mass and high-mass scenarios, 4G (Low mass) and 4G (High mass) respectively. The hatched areas indicate the theoretical uncertainty from PDF and scale uncertainties. The lighter curves show the high-mass theoretical prediction. Figure (d) shows the 95% C.L. combined limit relative to the low-mass theoretical prediction, where the uncertainties in the signal prediction are included in the limit. Also shown in Figure (d) is the prediction of the signal rate in the high-mass scenario, divided by that of the low-mass scenario.

tal, 42097 Wuppertal, Germany; ^{dd†}Yarmouk University, Irbid 211-63, Jordan; and ^{ee†}On leave from J. Stefan Institute, Ljubljana, Slovenia, and with visitors to D0 from ^{ff†}Augustana College, Sioux Falls, SD, 61201; ^{gg†}The University of Liverpool, Liverpool, UK; ^{hh†}SLAC, Menlo

Park, CA, 94025; ^{ii†}ICREA/IFAE, Barcelona, Spain; ^{jj†}Centro de Investigacion en Computacion - IPN, Mexico City, Mexico; ^{kk†}ECFM, Universidad Autonoma de Sinaloa, Culiacán, Mexico; and ^{ll†}Universität Bern, Bern, Switzerland.

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Auxiliary material

TABLE I: The fourth-generation enhanced $\sigma(gg \rightarrow H)$ listed in fb for the low-mass scenario described in the text with $m_{d4} = 300$ GeV and $m_{d4} = 400$ GeV along with the $\mathcal{B}(H \rightarrow W^+W^-)$ for Higgs masses between 110 - 300 GeV. The uncertainty on the predicted cross section from variations in the PDF and factorization and renormalization scale are also listed in percentage where these have been determined from the MSTW 2008 90% C.L. uncertainty and by modification of the scale by factors of 1/2 and 2, respectively.

m_H (GeV)	$\sigma(gg \rightarrow H)$	$\sigma(gg \rightarrow H)$	uncert.		uncert.		$BR(H \rightarrow W^+W^-)$	
	$m_{d4} = 300$ GeV	$m_{d4} = 400$ GeV	PDF up(%)	PDF down(%)	μ up(%)	μ down(%)	$m_{d4} = 300$ GeV	$m_{d4} = 400$ GeV
110	12384	12308	12	-11	12	-8	0.028	0.028
115	10798	10725	12	-11	12	-8	0.050	0.051
120	9449.9	9384.3	12	-11	12	-8	0.083	0.083
125	8298.8	8240.0	12	-12	12	-8	0.13	0.13
130	7314.0	7258.7	12	-12	12	-8	0.19	0.19
135	6465.1	6414.2	12	-12	12	-8	0.26	0.26
140	5731.4	5684.1	13	-12	12	-8	0.35	0.35
145	5094.6	5050.4	13	-12	12	-8	0.44	0.44
150	4540.5	4498.5	13	-12	12	-8	0.55	0.55
155	4055.6	4017.6	13	-12	12	-8	0.68	0.68
160	3630.2	3595.1	13	-13	12	-8	0.85	0.85
165	3253.7	3220.7	14	-13	12	-8	0.91	0.91
170	2924.1	2893.2	14	-13	12	-8	0.89	0.88
175	2633.9	2604.4	14	-13	12	-8	0.86	0.86
180	2376.7	2348.9	14	-13	12	-8	0.83	0.83
185	2147.2	2121.5	15	-13	12	-8	0.74	0.74
190	1943.9	1919.7	15	-14	12	-8	0.69	0.69
195	1763.2	1740.2	15	-14	12	-8	0.66	0.66
200	1601.8	1580.0	15	-14	12	-8	0.65	0.65
210	1328.1	1308.4	16	-14	12	-8	0.62	0.62
220	1107.7	1089.6	16	-15	12	-8	0.60	0.60
230	928.61	912.21	17	-15	12	-8	0.59	0.59
240	782.52	767.44	17	-15	12	-8	0.58	0.58
250	662.60	648.81	18	-16	12	-8	0.58	0.58
260	563.53	550.90	19	-16	12	-8	0.57	0.58
270	481.49	469.93	19	-16	12	-8	0.57	0.57
280	413.24	402.68	20	-17	12	-8	0.58	0.58
290	356.39	346.53	21	-17	12	-8	0.58	0.58
300	308.70	299.71	21	-17	12	-8	0.58	0.58

TABLE II: The observed and median expected 95% C.L. upper limits on $\sigma(gg \rightarrow H) \times \mathcal{B}(H \rightarrow W^+W^-)$ for m_H between 110 GeV and 300 GeV, obtained with the Bayesian and CL_s methods. The ratio of the observed and expected Bayesian 95% C.L. upper limits to the $\sigma(gg \rightarrow H) \times \mathcal{B}(H \rightarrow W^+W^-)$ predictions of the low-mass fourth generation scenario are listed. Also listed are the $\sigma(gg \rightarrow H) \times \mathcal{B}(H \rightarrow W^+W^-)$ predictions of the low-mass and the high-mass fourth-generation scenarios discussed in the text for a fourth-generation down-type quark mass of 400 GeV. All limits and predictions are presented in pb.

m_H [GeV]	Obs.	Bayes		CL_s		4 th Gen	4 th Gen	
		Ratio Low Mass (Obs./4Gen)	Exp.	Ratio Low Mass (Exp./4Gen)	Obs.	Exp.	Low Mass	High Mass
110	2.10	6.2	1.41	4.2	2.07	1.40	0.34	0.35
115	2.35	4.4	1.22	2.3	2.34	1.25	0.54	0.54
120	1.75	2.2	1.08	1.4	1.77	1.15	0.78	0.78
125	1.29	1.2	1.00	0.94	1.25	1.05	1.06	1.06
130	1.36	1.0	0.93	0.68	1.41	0.98	1.36	1.36
135	1.12	0.67	0.88	0.53	1.14	0.90	1.67	1.67
140	1.29	0.66	0.82	0.42	1.25	0.83	1.96	1.96
145	1.03	0.46	0.76	0.34	0.99	0.80	2.25	2.24
150	0.68	0.27	0.67	0.27	0.65	0.68	2.49	2.49
155	0.62	0.23	0.56	0.20	0.59	0.55	2.74	2.74
160	0.47	0.15	0.40	0.13	0.47	0.40	3.06	3.06
165	0.38	0.13	0.36	0.12	0.37	0.36	2.92	3.03
170	0.45	0.18	0.40	0.16	0.43	0.40	2.57	2.76
175	0.38	0.17	0.44	0.20	0.36	0.44	2.25	2.47
180	0.41	0.21	0.48	0.24	0.40	0.48	1.96	2.17
185	0.48	0.31	0.50	0.32	0.48	0.53	1.57	1.76
190	0.46	0.35	0.54	0.41	0.46	0.55	1.32	1.48
195	0.65	0.57	0.58	0.50	0.64	0.60	1.15	1.30
200	0.83	0.81	0.61	0.60	0.84	0.64	1.02	1.15
210	0.98	1.2	0.64	0.79	0.99	0.68	0.81	0.94
220	0.90	1.4	0.63	0.97	0.93	0.66	0.65	0.77
230	1.06	2.0	0.67	1.2	1.09	0.69	0.54	0.64
240	0.93	2.1	0.66	1.5	0.90	0.67	0.45	0.54
250	1.02	2.8	0.60	1.6	1.02	0.63	0.37	0.45
260	1.02	3.2	0.58	1.8	1.07	0.62	0.32	0.38
270	1.05	3.9	0.57	2.1	1.07	0.60	0.27	0.33
280	1.07	4.7	0.52	2.3	1.08	0.53	0.23	0.28
290	0.96	4.8	0.50	2.5	0.92	0.50	0.20	0.24
300	0.93	5.5	0.47	2.8	0.91	0.48	0.17	0.21