

Repository Istituzionale dei Prodotti della Ricerca del Politecnico di Bari

Combined search for the quarks of a sequential fourth generation

This is a post print of the following article

Original Citation:

Combined search for the guarks of a sequential fourth generation / Chatrchyan, S.; Khachatryan, V.; Sirunyan, A. M.; Tumasyan, A.; Adam, W.; Aguilo, E.; Bergauer, T.; Dragicevic, M.; Eroe, J.; Fabjan, C.; Friedl, M.; Fruehwirth, R.; Ghete, V. M.; Hammer, J.; Hoermann, N.; Hrubec, J.; Jeitler, M.; Kiesenhofer, W.; Knuenz, V.; Krammer, M.; Kraetschmer, I.; Liko, D.; Mikulec, I.; Pernicka, M.; Rahbaran, B.; Rohringer, C.; Rohringer, H.; Schoefbeck, R.; Strauss, J.; Taurok, A.; Waltenberger, W.; Walzel, G.; Widl, E.; Wulz, C. E.; Mossolov, V.; Shumeiko, N.; Gonzalez J., Suarez; Bansal, M.; Bansal, S.; Cornelis, T.; De Wolf, E. A.; Janssen, X.; Luyckx, S.; Mucibello, L.; Ochesanu, S.; Roland, B.; Rougny, R.; Selvaggi, M.; Stavkova, Z.; Van Haevermaet, H.; Van Mechelen, P.; Van Remortel, N.; Van Spilbeeck, A.; Blekman, F.; Phis version : available ar high and the new formation of the self self self self. S.; D'Hondt, J.; Suarez R.; Gonzalez, Kalogeropoulos, A.; Maes, M.; Olbrechts, A.; Van Doninck, W.; Van Mulders, P.; Van Onsem, G. P.; Villella, I.; Clerbaux, B.; De Lentdecker, G.; Dero, V.; Gay, A. P. R.; Hreus, T.; Leonard, A.; Marage, P. E., Mohammadi, A.; Reis, T.; Thomas, L.; Vander Marcken, G.; Vander Velde, C.; Vanlaer, P.; Wang, J.; Roler, V.; Beernvert, K.; Cimmiro, A.; Costantini, S.; Garcia, G.; Grunewald, M.; Klein, B.; Lellouch, J.; Marinov, A.; Mccartin, J.; Rios A. A., Ocampo; Ryckbosch, D.; Strobbe, N.; Thyssen, F.; Tytgat, M.; Verwilligen, P.; Walsh, S.; Yazgan, E.; Zaganidis, N.; Basegmez, S.; Bruno, G.; Castello, R.; Ceard, L.; Delaere, C.; du Pree, T.; Favart, D.; Fertherofrugd:; Giammanco, A.; Hollar, J.; Lemaitre, V.; Liao, J.; Militaru, O.; Nuttens, C.; Pagano, D.; Pin, A.; Piotrzkowski, K.; Schul, N.; Garcia J. M., Vizan; Beliy, N.; Caebergs, T.; Daubie, E.; Hammad, G. H.; Alves, G. A.; Correa Martins Junior, M.; De Jesus Damiao, D.; Martins, T.; Pol, M. E.; Souza, M. H. G.; Alda Junior, W. L.; Carvalho, W.; Custodio, A.; Da Costa, E. M.; De Oliveira Martins, C.; Fonseca De Souza, S.; Matos Figueiredo, D.; Mundim, L.; Nogima, H.; Oguri, V.; Prado Da Silva, W. L.; Santoro, A.; Soares Jorge, L.; Sznajder, A.; Anjos, T. S.; Bernardes, C. A.; Dias, F. A.; Fernandez Perez Tomei, T. R.; Gregores, E. M.; Lagana, C.; Marinho, F.; Mercadante, P. G.; Novaes, S. F.; Padula Sandra, S.; Genchev, V.; Iaydjiev, P.; Piperov, S.; Rodozov, M.; Stoykova, S.; Sultanov, G.; Tcholakov, V.; Trayanov, R.; Vutova, M.; Dimitrov, A.; Hadijiska, R.; Kozhuharov, V.; Litov, L.; Pavlov, B.; Petkov, P.; Bian, J. G.; Chen. G. M.; Chen, H. S.; Jiang, C. H.; Liang, D.; Liang, S.; Meng, X.; Tao, J.; Wang, J.; Wang, X.; Wang, Z.; Xiao, H.; Xu, M.; Zang, J.; Zhang, Z.; Asawatangtrakuldee, C.; Ban, Y.; Guo, S.; Guo, Y.; Li, W.; Liu, S.; Mao, Y.; Qian, S. J.; Teng, H.; Wang, D.; Zhang, L.; Zhu, B.; Zou, W.; Avila, C.; Gomez, J. P.; Gomez Moreno, B.; Osorio Oliveros, A. F.; Sanabria, J. C.; Godinovic, N.; Lelas, D.; Plestina, R.; Polic, D.; Puljak, I.; Antunovic, Z.; Kovac, M.; Brigljevic, V.; Duric, S.; Kadija, K.; Luetic, J.; Morovic, S.; Attikis, A.; Galanti, M.; Mavromanolakis, G.; Mousa, J.; Nicolaou, C.; Ptochos, F.; Razis, P. A.; Finger, M.; Finger, M. J. r.; Assran, Y.; Elgam (Aulti Ge Kegines An Edith pathed) II, S.; Mahmoud, M. A.; Radi, A.; Kadastik, M.; Muentel, M.; Raidal, M.; Rebane, L.; Tiko, A.; Eerola, P.; Fedi, G.; Voutilainen, M.; Harkonen, J.; Heikkinen, A.; Karimaki, V.; Kinnunen, R.; Kortelainen, M. J.; Lampen, T.; Lassila Perini, K.; Lehti, S.; Linden, T.; Luukka, P.; Maenpaa, T.; Peltola, T.; Tuominen, E.; Tuominiemi, J.; Tuovinen, E.; Ungaro, D.; Wendland, L.; Banzuzi, K.; Karjalainen, A.; Korpela, A.; Tuuva, T.; Besancon, M.; Choudhury, S.; Dejardin, M.; Denegri, D.; Fabbro, B.; Faure, J. L.; Ferri, F.; Ganjour, S.; Givernaud, A.; Gras, P.; de Monchenault G., Hamel; Jarry, P.; Locci, E.; Malcles, J.; Millischer, L.; Nayak, A.; Rander, J.; Rosowsky, A.; Shreyber, I.; Titov, M.; Baffioni, S.; Beaudette, F.; Benhabib, L.; Bianchini, L.; Bluj, M.; B2011410, 2024 Busson, P.; Charlot, C.; Daci, N.; Dahms, T.; Dobrzynski, L.; de Cassagnac R., Granier; Haguenauer, M.; Mine, P.; Mironov, C.; Naranjo, I. N.; Nguyen, M.; Ochando, C.; Paganini, P.; Sabes, D.; Salerno, R.; Sirois, Y.; Veelken, C.; Zabi, A.; Agram, J. L.; Andrea, J.; Bloch, D.; Bodin, D.; Brom, J. M.; Cardaci, M.; Chabert, E. C.; Collard, C.; Conte, E.; Drouhin, F.; Ferro, C.; Fontaine, J. C.; Gele, D.; Goerlach, U.; Juillot, P.; Le Bihan, A. C.; Van Hove, P.; Fassi, F.; Mercier, D.;

Beauceron, S.; Beaupere, N.; Bondu, O.; Boudoul, G.; Chasserat, J.; Chierici, R.; Contardo, D.; Depasse, P.; El Mamouni, H.; Fay, J.; Gascon, S.; Gouzevitch, M.; Ille, B.; Kurca, T.; Lethuillier, M.; Mirabito, L.; Perries, S.; Sordini, V.; Tschudi, Y.; Verdier, P.; Viret, S.; Tsamalaidze, Z.; Anagnostou, G.; Beranek, S.; Edelhoff, M.; Feld, L.; Heracleous, N.; Hindrichs, O.; Jussen, R.; Klein, K.; Merz, J.; Ostapchuk, A.; Perieanu, A.; Raupach, F.; Sammet, J.; Schael, S.; Sprenger, D.; Weber, H.; Wittmer, B.; Zhukov, V.; Ata, M.; Caudron, J.; Dietz Laursonn, E.; Duchardt, D.; Erdmann, M.; Fischer, R.; Gueth, A.; Hebbeker, T.; Heidemann, C.; Hoepfner, K.; Klingebiel, D.; Kreuzer, P.; Magass, C.; Merschmeyer, M.; Meyer, A.; Olschewski, M.; Papacz, P.; Pieta, H.; Reithler, H.; Schmitz, S. A.; Sonnenschein, L.; Steggemann, J.; Teyssier, D.; Weber, M.; Bontenackels, M.; Cherepanov, V.; Erdogan, Y.; Fluegge, G.; Geenen, H.; Geisler, M.; Ahmad W., Haj; Hoehle, F.; Kargoll, B.; Kress, T.; Kuessel, Y.; Nowack, A.; Perchalla, L.; Pooth, O.; Sauerland, P.; Stahl, A.; Martin M., Aldaya; Behr, J.; Behrenhoff, W.; Behrens, U.; Bergholz, M.; Bethani, A.; Borras, K.; Burgmeier, A.; Cakir, A.; Calligaris, L.; Campbell, A.; Castro, E.; Costanza, F.; Dammann, D.; Pardos C., Diez; Eckerlin, G.; Eckstein, D.; Flucke, G.; Geiser, A.; Glushkov, I.; Gunnellini, P.; Habib, S.; Hauk, J.; Hellwig, G.; Jung, H.; Kasemann, M.; Katsas, P.; Kleinwort, C.; Kluge, H.; Knutsson, A.; Kraemer, M.; Kruecker, D.; Kuznetsova, E.; Lange, W.; Lohmann, W.; Lutz, B.; Mankel, R.; Marfin, I.; Marienfeld, M.; Melzer Pellmann, I. A.; Meyer, A. B.; Mnich, J.; Mussgiller, A.; Naumann Emme, S.; Olzem, J.; Perrey, H.; Petrukhin, A.; Pitzl, D.; Raspereza, A.; Cipriano P. M., Ribeiro; Riedl, C.; Ron, E.; Rosin, M.; Salfeld Nebgen, J.; Schmidt, R.; Schoerner Sadenius, T.; Sen, N.; Spiridonov, A.; Stein, M.; Walsh, R.; Wissing, C.; Autermann, C.; Blobel, V.; Draeger, J.; Enderle, H.; Erfle, J.; Gebbert, U.; Goerner, M.; Hermanns, T.; Hoeing, R. S.; Kaschube, K.; Kaussen, G.; Kirschenmann, H.; Klanner, R.; Lange, J.; Mura, B.; Nowak, F.; Peiffer, T.; Pietsch, N.; Rathjens, D.; Sander, C.; Schettler, H.; Schleper, P.; Schlieckau, E.; Schmidt, A.; Schroeder, M.; Schum, T.; Seidel, M.; Sola, V.; Stadie, H.; Steinbrueck, G.; Thomsen, J.; Vanelderen, L.; Barth, C.; Berger, J.; Boeser, C.; Chwalek, T.; De Boer, W.; Descroix, A.; Dierlamm, A.; Feindt, M.; Guthoff, M.; Hackstein, C.; Hartmann, F.; Hauth, T.; Heinrich, M.; Held, H.; Hoffmann, K. H.; Honc, S.; Katkov, I.; Komaragiri, J. R.; Pardo P., Lobelle; Martschei, D.; Mueller, S.; Mueller, Th; Niegel, M.; Nuernberg, A.; Oberst, O.; Oehler, A.; Ott, J.; Quast, G.; Rabbertz, K.; Ratnikov, F.; Ratnikova, N.; Roecker, S.; Scheurer, A.; Schilling, F. P.; Schott, G.; Simonis, H. J.; Stober, F. M.; Troendle, D.; Ulrich, R.; Wagner Kuhr, J.; Wayand, S.; Weiler, T.; Zeise, M.; Daskalakis, G.; Geralis, T.; Kesisoglou, S.; Kyriakis, A.; Loukas, D.; Manolakos, I.; Markou, A.; Markou, C.; Mavrommatis, C.; Ntomari, E.; Gouskos, L.; Mertzimekis, T. J.; Panagiotou, A.; Saoulidou, N.; Evangelou, I.; Foudas, C.; Kokkas, P.; Manthos, N.; Papadopoulos, I.; Patras, V.; Bencze, G.; Hajdu, C.; Hidas, P.; Horvath, D.; Sikler, F.; Veszpremi, V.; Vesztergombi, G.; Beni, N.; Czellar, S.; Molnar, J.; Palinkas, J.; Szillasi, Z.; Karancsi, J.; Raics, P.; Trocsanyi, Z. L.; Ujvari, B.; Beri, S. B.; Bhatnagar, V.; Dhingra, N.; Gupta, R.; Kaur, M.; Mehta, M. Z.; Nishu, N.; Saini, L. K.; Sharma, A.; Singh, J. B.; Kumar, Ashok; Kumar, Arun; Ahuja, S.; Bhardwaj, A.; Choudhary, B. C.; Malhotra, S.; Naimuddin, M.; Ranjan, K.; Sharma, V.; Shivpuri, R. K.; Banerjee, S.; Bhattacharya, S.; Dutta, S.; Gomber, B.; Jain, Sa; Jain, S. h.; Khurana, R.; Sarkar, S.; Sharan, M.; Abdulsalam, A.; Choudhury, R. K.; Dutta, D.; Kailas, S.; Kumar, V.; Mehta, P.; Mohanty, A. K.; Pant, L. M.; Shukla, P.; Aziz, T.; Ganguly, S.; Guchait, M.; Maity, M.; Majumder, G.; Mazumdar, K.; Mohanty, G. B.; Parida, B.; Sudhakar, K.; Wickramage, N.; Banerjee, S.; Dugad, S.; Arfaei, H.; Bakhshiansohi, H.; Etesami, S. M.; Fahim, A.; Hashemi, M.; Hesari, H.; Jafari, A.; Khakzad, M.; Najafabadi M., Mohammadi; Mehdiabadi S., Paktinat; Safarzadeh, B.; Zeinali, M.; Abbrescia, M.; Barbone, L.; Calabria, C.; Chhibra, S. S.; Colaleo, A.; Creanza, Donato Maria; DE FILIPPIS, Nicola; De Palma, M.; Fiore, L.; Iaselli, Giuseppe; Lusito, L.; Maggi, Giorgio Pietro; Maggi, M.; Marangelli, B.; My, Salvatore; Nuzzo, S.; Pacifico, N.; Pompili, A.; Pugliese, Gabriella Maria Incoronata; Selvaggi, G.; Silvestris, L.; Singh, G.; Venditti, R.; Zito, G.; Abbiendi, G.; Benvenuti, A. C.; Bonacorsi, D.; Braibant Giacomelli, S.; Brigliadori, L.; Capiluppi, P.; Castro, A.; Cavallo, F. R.; Cuffiani, M.; Dallavalle, G. M.; Fabbri, F.; Fanfani, A.; Fasanella, D.; Giacomelli, P.; Grandi, C.; Guiducci, L.; Marcellini, S.; Masetti, G.; Meneghelli, M.; Montanari, A.; Navarria, F. L.; Odorici, F.; Perrotta, A.; Primavera, F.; Rossi, A. M.; Rovelli, T.; Siroli, G. P.; Travaglini, R.; Albergo, S.; Cappello, G.; Chiorboli, M.; Costa, S.; Potenza, R.; Tricomi, A.; Tuve, C.; Barbagli, G.; Ciulli, V.; Civinini, C.; D'Alessandro, R.; Focardi, E.; Frosali, S.; Gallo, E.; Gonzi, S.; Meschini, M.; Paoletti, S.; Sguazzoni, G.; Tropiano, A.; Benussi, L.; Bianco, S.; Colafranceschi, S.; Fabbri, F.; Piccolo, D.; Fabbricatore, P.; Musenich, R.; Tosi, S.; Benaglia, A.; De Guio, F.; Di Matteo, L.; Fiorendi, S.; Gennai, S.; Ghezzi, A.; Malvezzi, S.; Manzoni, R. A.; Martelli, A.; Massironi, A.; Menasce, D.; Moroni, L.; Paganoni, M.; Pedrini, D.; Ragazzi, S.; Redaelli, N.; Sala, S.; de Fatis T., Tabarelli; Buontempo, S.; Carrillo Montoya, C. A.; Cavallo, N.; De Cosa, A.; Dogangun, O.; Fabozzi, F.; Iorio, A. O. M.; Lista, L.; Meola, S.; Merola, M.; Paolucci, P.; Azzi, P.; Bacchetta, N.; Bisello, D.; Branca, A.; Carlin, R.; Checchia, P.; Dorigo, T.; Dosselli, U.; Gasparini, F.; Gasparini, U.; Gozzelino, A.; Kanishchev, K.; Lacaprara, S.; Lazzizzera, I.; Margoni, M.; Meneguzzo, A. T.; Pazzini, J.; Pozzobon, N.; Ronchese, P.; Simonetto, F.; Torassa, E.; Tosi, M.; Vanini, S.; Zotto, P.; Zumerle, G.; Gabusi, M.; Ratti, S. P.; Riccardi, C.; Torre, P.; Vitulo, P.; Biasini, M.; Bilei, G. M.; Fano, L.; Lariccia, P.; Lucaroni, A.; Mantovani, G.; Menichelli, M.; Nappi, A.; Romeo, F.; Saha, A.; Santocchia, A.; Spiezia, A.; Taroni, S.; Azzurri, P.; Bagliesi, G.; Boccali, T.; Broccolo, G.; Castaldi, R.; D'Agnolo, R. T.; Dell'Orso, R.; Fiori, F.; Foa, L.; Giassi, A.; Kraan, A.; Ligabue, F.; Lomtadze, T.; Martini, L.; Messineo, A.; Palla, F.; Rizzi, A.; Serban, A. T.; Spagnolo, P.; Squillacioti, P.; Tenchini, R.; Tonelli, G.; Venturi, A.; Verdini, P. G.; Barone, L.; Cavallari, F.; Del Re, D.; Diemoz, M.; Fanelli, C.; Grassi, M.; Longo, E.; Meridiani, P.; Micheli, F.; Nourbakhsh, S.; Organtini, G.; Paramatti, R.; Rahatlou, S.; Sigamani, M.; Soffi, L.; Amapane, N.; Arcidiacono, R.; Argiro, S.; Arneodo, M.; Biino, C.; Cartiglia, N.; Costa, M.; De Remigis, P.; Demaria, N.; Mariotti, C.; Maselli, S.; Migliore, E.; Monaco, V.; Musich, M.; Obertino, M. M.; Pastrone, N.; Pelliccioni, M.; Potenza, A.; Romero, A.; Sacchi, R.; Solano, A.; Staiano, A.; Pereira A., Wile Way Batt 24te, S.; Candelise, V.; Cossutti, F.; Della Ricca, G.; Gobbo, B.; Marone, M.; Montanino, D.; Penzo, A.; Schizzi, A.; Heo, S. G.; Kim, T. Y.; Nam, S. K.; Chang, S.; Kim, D. H.; Kim, G. N.;

Kong, D. J.; Park, H.; Ro, S. R.; Son, D. C.; Son, T.; Kim, J. Y.; Kim Zero, J.; Song, S.; Choi, S.; Gyun, D.; Hong, B.; Jo, M.; Kim, H.; Kim, T. J.; Lee, K. S.; Moon, D. H.; Park, S. K.; Choi, M.; Kim, J. H.; Park, C.; Park, I. C.; Park, S.; Ryu, G.; Cho, Y.; Choi, Y.; Choi, Y. K.; Goh, J.; Kim, M. S.; Kwon, E.; Lee, B.; Lee, J.; Lee, S.; Seo, H.; Yu, I.; Bilinskas, M. J.; Grigelionis, I.; Janulis, M.; Juodagalvis, A.; Castilla Valdez, H.; De La Cruz Burelo, E.; Heredia de La Cruz, I.; Lopez Fernandez, R.; Magana Villalba, R.; Martinez Ortega, J.; Sanchez Hernandez, A.; Villasenor Cendejas, L. M.; Carrillo Moreno, S.; Vazquez Valencia, F.; Salazar Ibarguen, H. A.; Casimiro Linares, E.; Morelos Pineda, A.; Reyes Santos, M. A.; Krofcheck, D.; Bell, A. J.; Butler, P. H.; Doesburg, R.; Reucroft, S.; Silverwood, H.; Ahmad, M.; Ansari, M. H.; Asghar, M. I.; Hoorani, H. R.; Khalid, S.; Khan, W. A.; Khurshid, T.; Qazi, S.; Shah, M. A.; Shoaib, M.; Bialkowska, H.; Boimska, B.; Frueboes, T.; Gokieli, R.; Gorski, M.; Kazana, M.; Nawrocki, K.; Romanowska Rybinska, K.; Szleper, M.; Wrochna, G.; Zalewski, P.; Brona, G.; Bunkowski, K.; Cwiok, M.; Dominik, W.; Doroba, K.; Kalinowski, A.; Konecki, M.; Krolikowski, J.; Almeida, N.; Bargassa, P.; David, A.; Faccioli, P.; Ferreira Parracho, P. G.; Gallinaro, M.; Seixas, J.; Varela, J.; Vischia, P.; Belotelov, I.; Bunin, P.; Gavrilenko, M.; Golutvin, I.; Kamenev, A.; Karjavin, V.; Kozlov, G.; Lanev, A.; Malakhov, A.; Moisenz, P.; Palichik, V.; Perelygin, V.; Savina, M.; Shmatov, S.; Smirnov, V.; Volodko, A.; Zarubin, A.; Evstyukhin, S.; Golovtsov, V.; Ivanov, Y.; Kim, V.; Levchenko, P.; Murzin, V.; Oreshkin, V.; Smirnov, I.; Sulimov, V.; Uvarov, L.; Vavilov, S.; Vorobyev, A.; Vorobyev, An; Andreev, Y. u.; Dermenev, A.; Gninenko, S.; Golubev, N.; Kirsanov, M.; Krasnikov, N.; Matveev, V.; Pashenkov, A.; Tlisov, D.; Toropin, A.; Epshteyn, V.; Erofeeva, M.; Gavrilov, V.; Kossov, M.; Lychkovskaya, N.; Popov, V.; Safronov, G.; Semenov, S.; Stolin, V.; Vlasov, E.; Zhokin, A.; Belyaev, A.; Boos, E.; Bunichev, V.; Dubinin, M.; Dudko, L.; Gribushin, A.; Klyukhin, V.; Kodolova, O.; Lokhtin, I.; Markina, A.; Obraztsov, S.; Perfilov, M.; Petrushanko, S.; Popov, A.; Sarycheva, L.; Savrin, V.; Snigirev, A.; Andreev, V.; Azarkin, M.; Dremin, I.; Kirakosyan, M.; Leonidov, A.; Mesyats, G.; Rusakov, S. V.; Vinogradov, A.; Azhgirey, I.; Bayshev, I.; Bitioukov, S.; Grishin, V.; Kachanov, V.; Konstantinov, D.; Korablev, A.; Krychkine, V.; Petrov, V.; Ryutin, R.; Sobol, A.; Tourtchanovitch, L.; Troshin, S.; Tyurin, N.; Uzunian, A.; Volkov, A.; Adzic, P.; Djordjevic, M.; Ekmedzic, M.; Krpic, D.; Milosevic, J.; Aguilar Benitez, M.; Alcaraz Maestre, J.; Arce, P.; Battilana, C.; Calvo, E.; Cerrada, M.; Chamizo Llatas, M.; Colino, N.; De La Cruz, B.; Delgado Peris, A.; Dominguez Vazquez, D.; Fernandez Bedoya, C.; Fernandez Ramos, J. P.; Ferrando, A.; Flix, J.; Fouz, M. C.; Garcia Abia, P.; Gonzalez Lopez, O.; Goy Lopez, S.; Hernandez, J. M.; Josa, M. I.; Merino, G.; Puerta Pelayo, J.; Quintario Olmeda, A.; Redondo, I.; Romero, L.; Santaolalla, J.; Soares, M. S.; Willmott, C.; Albajar, C.; Codispoti, G.; de Troconiz, J. F.; Brun, H.; Cuevas, J.; Fernandez Menendez, J.; Folgueras, S.; Gonzalez Caballero, I.; Lloret Iglesias, L.; Piedra Gomez, J.; Brochero Cifuentes, J. A.; Cabrillo, I. J.; Calderon, A.; Chuang, S. H.; Duarte Campderros, J.; Felcini, M.; Fernandez, M.; Gomez, G.; Gonzalez Sanchez, J.; Graziano, A.; Jorda, C.; Lopez Virto, A.; Marco, J.; Marco, R.; Martinez Rivero, C.; Matorras, F.; Munoz Sanchez, F. J.; Rodrigo, T.; Rodriguez Marrero, A. Y.; Ruiz Jimeno, A.; Scodellaro, L.; Sobron Sanudo, M.; Vila, I.; Vilar Cortabitarte, R.; Abbaneo, D.; Auffray, E.; Auzinger, G.; Bachtis, M.; Baillon, P.; Ball, A. H.; Barney, D.; Benitez, J. F.; Bernet, C.; Bianchi, G.; Bloch, P.; Bocci, A.; Bonato, A.; Botta, C.; Breuker, H.; Camporesi, T.; Cerminara, G.; Christiansen, T.; Perez J. A., Coarasa; D'Enterria, D.; Dabrowski, A.; De Roeck, A.; Di Guida, S.; Dobson, M.; Dupont Sagorin, N.; Elliott Peisert, A.; Frisch, B.; Funk, W.; Georgiou, G.; Giffels, M.; Gigi, D.; Gill, K.; Giordano, D.; Giunta, M.; Glege, F.; Garrido R., Gomez Reino; Govoni, P.; Gowdy, S.; Guida, R.; Hansen, M.; Harris, P.; Hartl, C.; Harvey, J.; Hegner, B.; Hinzmann, A.; Innocente, V.; Janot, P.; Kaadze, K.; Karavakis, E.; Kousouris, K.; Lecoq, P.; Lee, Y. J.; Lenzi, P.; Lourenco, C.; Magini, N.; Maeki, T.; Malberti, M.; Malgeri, L.; Mannelli, M.; Masetti, L.; Meijers, F.; Mersi, S.; Meschi, E.; Moser, R.; Mozer, M. U.; Mulders, M.; Musella, P.; Nesvold, E.; Orimoto, T.; Orsini, L.; Cortezon E., Palencia; Perez, E.; Perrozzi, L.; Petrilli, A.; Pfeiffer, A.; Pierini, M.; Pimiae, M.; Piparo, D.; Polese, G.; Quertenmont, L.; Racz, A.; Reece, W.; Antunes J., Rodrigues; Rolandi, G.; Rovelli, C.; Rovere, M.; Sakulin, H.; Santanastasio, F.; Schaefer, C.; Schwick, C.; Segoni, I.; Sekmen, S.; Sharma, A.; Siegrist, P.; Silva, P.; Simon, M.; Sphicas, P.; Spiga, D.; Tsirou, A.; Veres, G. I.; Vlimant, J. R.; Woehri, H. K.; Worm, S. D.; Zeuner, W. D.; Bertl, W.; Deiters, K.; Erdmann, W.; Gabathuler, K.; Horisberger, R.; Ingram, Q.; Kaestli, H. C.; Koenig, S.; Kotlinski, D.; Langenegger, U.; Meier, F.; Renker, D.; Rohe, T.; Sibille, J.; Baeni, L.; Bortignon, P.; Buchmann, M. A.; Casal, B.; Chanon, N.; Deisher, A.; Dissertori, G.; Dittmar, M.; Donega, M.; Duenser, M.; Eugster, J.; Freudenreich, K.; Grab, C.; Hits, D.; Lecomte, P.; Lustermann, W.; Marini, A. C.; del Arbol P., Martinez Ruiz; Mohr, N.; Moortgat, F.; Naegeli, C.; Nef, P.; Nessi Tedaldi, F.; Pandolfi, F.; Pape, L.; Pauss, F.; Peruzzi, M.; Ronga, F. J.; Rossini, M.; Sala, L.; Sanchez, A. K.; Starodumov, A.; Stieger, B.; Takahashi, M.; Tauscher, L.; Thea, A.; Theofilatos, K.; Treille, D.; Urscheler, C.; Wallny, R.; Weber, H. A.; Wehrli, L.; Amsler, C.; Chiochia, V.; De Visscher, S.; Favaro, C.; Rikova M., Ivova; Mejias B., Millan; Otiougova, P.; Robmann, P.; Snoek, H.; Tupputi, S.; Verzetti, M.; Chang, Y. H.; Chen, K. H.; Kuo, C. M.; Li, S. W.; Lin, W.; Liu, Z. K.; Lu, Y. J.; Mekterovic, D.; Singh, A. P.; Volpe, R.; Yu, S. S.; Bartalini, P.; Chang, P.; Chang, Y. H.; Chang, Y. W.; Chao, Y.; Chen, K. F.; Dietz, C.; Grundler, U.; Hou, W. S.; Hsiung, Y.; Kao, K. Y.; Lei, Y. J.; Lu, R. S.; Majumder, D.; Petrakou, E.; Shi, X.; Shiu, J. G.; Tzeng, Y. M.; Wan, X.; Wang, M.; Adiguzel, A.; Bakirci, M. N.; Cerci, S.; Dozen, C.; Dumanoglu, I.; Eskut, E.; Girgis, S.; Gokbulut, G.; Gurpinar, E.; Hos, I.; Kangal, E. E.; Karaman, T.; Karapinar, G.; Topaksu A., Kayis; Onengut, G.; Ozdemir, K.; Ozturk, S.; Polatoz, A.; Sogut, K.; Cerci D., Sunar; Tali, B.; Topakli, H.; Vergili, L. N.; Vergili, M.; Akin, I. V.; Aliev, T.; Bilin, B.; Bilmis, S.; Deniz, M.; Gamsizkan, H.; Guler, A. M.; Ocalan, K.; Ozpineci, A.; Serin, M.; Sever, R.; Surat, U. E.; Yalvac, M.; Yildirim, E.; Zeyrek, M.; Guelmez, E.; Isildak, B.; Kaya, M.; Kaya, O.; Ozkorucuklu, S.; Sonmez, N.; Cankocak, K.; Levchuk, L.; Bostock, F.; Brooke, J. J.; Clement, E.; Cussans, D.; Flacher, H.; Frazier, R.; Goldstein, J.; Grimes, M.; Heath, G. P.; Heath, H. F.; Kreczko, L.; Metson, S.; Newbold, D. M.; Nirunpong, K.; Poll, A.; Senkin, S.; Smith, V. J.; Williams, T.; Basso, L.; Bell, K. W.; Belyaev, A.; Brew, 02; Regvon 24. M.; Cockerill, D. J. A.; Coughlan, J. A.; Harder, K.; Harper, S.; Jackson, J.; Kennedy, B. W.; Olaiya, E.; Petyt, D.; Radburn

Smith, B. C.; Shepherd Themistocleous, C. H.; Tomalin, I. R.; Womersley, W. J.; Bainbridge, R.; Ball, G.; Beuselinck, R.; Buchmuller, O.; Colling, D.; Cripps, N.; Cutajar, M.; Dauncey, P.; Davies, G.; Della Negra, M.; Ferguson, W.; Fulcher, J.; Futyan, D.; Gilbert, A.; Bryer A., Guneratne; Hall, G.; Hatherell, Z.; Hays, J.; Iles, G.; Jarvis, M.; Karapostoli, G.; Lyons, L.; Magnan, A. M.; Marrouche, J.; Mathias, B.; Nandi, R.; Nash, J.; Nikitenko, A.; Papageorgiou, A.; Pela, J.; Pesaresi, M.; Petridis, K.; Pioppi, M.; Raymond, D. M.; Rogerson, S.; Rose, A.; Ryan, M. J.; Seez, C.; Sharp, P.; Sparrow, A.; Stoye, M.; Tapper, A.; Acosta M., Vazquez; Virdee, T.; Wakefield, S.; Wardle, N.; Whyntie, T.; Chadwick, M.; Cole, J. E.; Hobson, P. R.; Khan, A.; Kyberd, P.; Leggat, D.; Leslie, D.; Martin, W.; Reid, I. D.; Symonds, P.; Teodorescu, L.; Turner, M.; Hatakeyama, K.; Liu, H.; Scarborough, T.; Charaf, O.; Henderson, C.; Rumerio, P.; Avetisyan, A.; Bose, T.; Fantasia, C.; Heister, A.; St John, J.; Lawson, P.; Lazic, D.; Rohlf, J.; Sperka, D.; Sulak, L.; Alimena, J.; Bhattacharya, S.; Cutts, D.; Ferapontov, A.; Heintz, U.; Jabeen, S.; Kukartsev, G.; Laird, E.; Landsberg, G.; Luk, M.; Narain, M.; Nguyen, D.; Segala, M.; Sinthuprasith, T.; Speer, T.; Tsang, K. V.; Breedon, R.; Breto, G.; Sanchez M., Calderon De La Barca; Chauhan, S.; Chertok, M.; Conway, J.; Conway, R.; Cox, P. T.; Dolen, J.; Erbacher, R.; Gardner, M.; Houtz, R.; Ko, W.; Kopecky, A.; Lander, R.; Miceli, T.; Pellett, D.; Ricci tam, F.; Rutherford, B.; Searle, M.; Smith, J.; Squires, M.; Tripathi, M.; Sierra R., Vasquez; Andreev, V.; Cline, D.; Cousins, R.; Duris, J.; Erhan, S.; Everaerts, P.; Farrell, C.; Hauser, J.; Ignatenko, M.; Jarvis, C.; Plager, C.; Rakness, G.; Schlein, P.; Traczyk, P.; Valuev, V.; Weber, M.; Babb, J.; Clare, R.; Dinardo, M. E.; Ellison, J.; Gary, J. W.; Giordano, F.; Hanson, G.; Jeng, G. Y.; Liu, H.; Long, O. R.; Luthra, A.; Nguyen, H.; Paramesvaran, S.; Sturdy, J.; Sumowidagdo, S.; Wilken, R.; Wimpenny, S.; Andrews, W.; Branson, J. G.; Cerati, G. B.; Cittolin, S.; Evans, D.; Golf, F.; Holzner, A.; Kelley, R.; Lebourgeois, M.; Letts, J.; Macneill, I.; Mangano, B.; Padhi, S.; Palmer, C.; Petrucciani, G.; Pieri, M.; Sani, M.; Sharma, V.; Simon, S.; Sudano, E.; Tadel, M.; Tu, Y.; Vartak, A.; Wasserbaech, S.; Wuerthwein, F.; Yagil, A.; Yoo, J.; Barge, D.; Bellan, R.; Campagnari, C.; D'Alfonso, M.; Danielson, T.; Flowers, K.; Geffert, P.; Incandela, J.; Justus, C.; Kalavase, P.; Koay, S. A.; Kovalskyi, D.; Krutelyov, V.; Lowette, S.; Mccoll, N.; Pavlunin, V.; Rebassoo, F.; Ribnik, J.; Richman, J.; Rossin, R.; Stuart, D.; To, W.; West, C.; Apresyan, A.; Bornheim, A.; Chen, Y.; Di Marco, E.; Duarte, J.; Gataullin, M.; Ma, Y.; Mott, A.; Newman, H. B.; Rogan, C.; Spiropulu, M.; Timciuc, V.; Veverka, J.; Wilkinson, R.; Xie, S.; Yang, Y.; Zhu, R. Y.; Akgun, B.; Azzolini, V.; Calamba, A.; Carroll, R.; Ferguson, T.; liyama, Y.; Jang, D. W.; Liu, Y. F.; Paulini, M.; Vogel, H.; Vorobiev, I.; Cumalat, J. P.; Drell, B. R.; Edelmaier, C. J.; Ford, W. T.; Gaz, A.; Heyburn, B.; Lopez E., Luiggi; Smith, J. G.; Stenson, K.; Ulmer, K. A.; Wagner, S. R.; Alexander, J.; Chatterjee, A.; Eggert, N.; Gibbons, L. K.; Heltsley, B.; Khukhunaishvili, A.; Kreis, B.; Mirman, N.; Kaufman G., Nicolas; Patterson, J. R.; Ryd, A.; Salvati, E.; Sun, W.; Teo, W. D.; Thom, J.; Thompson, J.; Tucker, J.; Vaughan, J.; Weng, Y.; Winstrom, L.; Wittich, P.; Winn, D.; Abdullin, S.; Albrow, M.; Anderson, J.; Bauerdick, L. A. T.; Beretvas, A.; Berryhill, J.; Bhat, P. C.; Bloch, I.; Burkett, K.; Butler, J. N.; Chetluru, V.; Cheung, H. W. K.; Chlebana, F.; Elvira, V. D.; Fisk, I.; Freeman, J.; Gao, Y.; Green, D.; Gutsche, O.; Hanlon, J.; Harris, R. M.; Hirschauer, J.; Hooberman, B.; Jindariani, S.; Johnson, M.; Joshi, U.; Kilminster, B.; Klima, B.; Kunori, S.; Kwan, S.; Leonidopoulos, C.; Linacre, J.; Lincoln, D.; Lipton, R.; Lykken, J.; Maeshima, K.; Marraffino, J. M.; Maruyama, S.; Mason, D.; Mcbride, P.; Mishra, K.; Mrenna, S.; Musienko, Y.; Newman Holmes, C.; O'Dell, V.; Prokofyev, O.; Sexton Kennedy, E.; Sharma, S.; Spalding, W. J.; Spiegel, L.; Tan, P.; Taylor, L.; Tkaczyk, S.; Tran, N. V.; Uplegger, L.; Vaandering, E. W.; Vidal, R.; Whitmore, J.; Wu, W.; Yang, F.; Yumiceva, F.; Yun, J. C.; Acosta, D.; Avery, P.; Bourilkov, D.; Chen, M.; Cheng, T.; Das, S.; De Gruttola, M.; Di Giovanni, G. P.; Dobur, D.; Drozdetskiy, A.; Field, R. D.; Fisher, M.; Fu, Y.; Furic, I. K.; Gartner, J.; Hugon, J.; Kim, B.; Konigsberg, J.; Korytov, A.; Kropivnitskaya, A.; Kypreos, T.; Low, J. F.; Matchev, K.; Milenovic, P.; Mitselmakher, G.; Muniz, L.; Remington, R.; Rinkevicius, A.; Sellers, P.; Skhirtladze, N.; Snowball, M.; Yelton, J.; Zakaria, M.; Gaultney, V.; Hewamanage, S.; Lebolo, L. M.; Linn, S.; Markowitz, P.; Martinez, G.; Rodriguez, J. L.; Adams, T.; Askew, A.; Bochenek, J.; Chen, J.; Diamond, B.; Gleyzer, S. V.; Haas, J.; Hagopian, S.; Hagopian, V.; Jenkins, M.; Johnson, K. F.; Prosper, H.; Veeraraghavan, V.; Weinberg, M.; Baarmand, M. M.; Dorney, B.; Hohlmann, M.; Kalakhety, H.; Vodopiyanov, I.; Adams, M. R.; Anghel, I. M.; Apanasevich, L.; Bai, Y.; Bazterra, V. E.; Betts, R. R.; Bucinskaite, I.; Callner, J.; Cavanaugh, R.; Evdokimov, O.; Gauthier, L.; Gerber, C. E.; Hofman, D. J.; Khalatyan, S.; Lacroix, F.; Malek, M.; O'Brien, C.; Silkworth, C.; Strom, D.; Varelas, N.; Akgun, U.; Albayrak, E. A.; Bilki, B.; Clarida, W.; Duru, F.; Griffiths, S.; Merlo, J. P.; Mermerkaya, H.; Mestvirishvili, A.; Moeller, A.; Nachtman, J.; Newsom, C. R.; Norbeck, E.; Onel, Y.; Ozok, F.; Sen, S.; Tiras, E.; Wetzel, J.; Yetkin, T.; Yi, K.; Barnett, B. A.; Blumenfeld, B.; Bolognesi, S.; Fehling, D.; Giurgiu, G.; Gritsan, A. V.; Guo, Z. J.; Hu, G.; Maksimovic, P.; Rappoccio, S.; Swartz, M.; Whitbeck, A.; Baringer, P.; Bean, A.; Benelli, G.; Grachov, O.; lii R. P., Kenny; Murray, M.; Noonan, D.; Sanders, S.; Stringer, R.; Tinti, G.; Wood, J. S.; Zhukova, V.; Barfuss, A. F.; Bolton, T.; Chakaberia, I.; Ivanov, A.; Khalil, S.; Makouski, M.; Maravin, Y.; Shrestha, S.; Svintradze, I.; Gronberg, J.; Lange, D.; Wright, D.; Baden, A.; Boutemeur, M.; Calvert, B.; Eno, S. C.; Gomez, J. A.; Hadley, N. J.; Kellogg, R. G.; Kirn, M.; Kolberg, T.; Lu, Y.; Marionneau, M.; Mignerey, A. C.; Pedro, K.; Peterman, A.; Skuja, A.; Temple, J.; Tonjes, M. B.; Tonwar, S. C.; Twedt, E.; Apyan, A.; Bauer, G.; Bendavid, J.; Busza, W.; Butz, E.; Cali, I. A.; Chan, M.; Dutta, V.; Ceballos G., Gomez; Goncharov, M.; Hahn, K. A.; Kim, Y.; Klute, M.; Krajczar, K.; Li, W.; Luckey, P. D.; Ma, T.; Nahn, S.; Paus, C.; Ralph, D.; Roland, C.; Roland, G.; Rudolph, M.; Stephans, G. S. F.; Stoeckli, F.; Sumorok, K.; Sung, K.; Velicanu, D.; Wenger, E. A.; Wolf, R.; Wyslouch, B.; Yang, M.; Yilmaz, Y.; Yoon, A. S.; Zanetti, M.; Cooper, S. I.; Dahmes, B.; De Benedetti, A.; Franzoni, G.; Gude, A.; Kao, S. C.; Klapoetke, K.; Kubota, Y.; Mans, J.; Pastika, N.; Rusack, R.; Sasseville, M.; Singovsky, A.; Tambe, N.; Turkewitz, J.; Cremaldi, L. M.; Kroeger, R.; Perera, L.; Rahmat, R.; Sanders, D. A.; Avdeeva, E.; Bloom, K.; Bose, S.; Butt, J.; Claes, D. R.; Dominguez, A.; Eads, M.; Keller, J.; Kravchenko, I.; Lazo Flores, J.; Malbouisson, H.; Malik, S.; Snow, G. R.; Baur, U.; Godshalk, A.; Iashvili, I.; Jain, S.; 成和個的這2024 A.; Kumar, A.; Shipkowski, S. P.; Smith, K.; Alverson, G.; Barberis, E.; Baumgartel, D.; Chasco, M.; Haley, J.;

Nash, D.; Trocino, D.; Wood, D.; Zhang, J.; Anastassov, A.; Kubik, A.; Mucia, N.; Odell, N.; Ofierzynski, R. A.; Pollack, B.; Pozdnyakov, A.; Schmitt, M.; Stoynev, S.; Velasco, M.; Won, S.; Antonelli, L.; Berry, D.; Brinkerhoff, A.; Hildreth, M.; Jessop, C.; Karmgard, D. J.; Kolb, J.; Lannon, K.; Luo, W.; Lynch, S.; Marinelli, N.; Morse, D. M.; Pearson, T.; Planer, M.; Ruchti, R.; Slaunwhite, J.; Valls, N.; Wayne, M.; Wolf, M.; Bylsma, B.; Durkin, L. S.; Hill, C.; Hughes, R.; Hughes, R.; Kotov, K.; Ling, T. Y.; Puigh, D.; Rodenburg, M.; Vuosalo, C.; Williams, G.; Winer, B. L.; Adam, N.; Berry, E.; Elmer, P.; Gerbaudo, D.; Halyo, V.; Hebda, P.; Hegeman, J.; Hunt, A.; Jindal, P.; Pegna D., Lopes; Lujan, P.; Marlow, D.; Medvedeva, T.; Mooney, M.; Olsen, J.; Piroue, P.; Quan, X.; Raval, A.; Safdi, B.; Saka, H.; Stickland, D.; Tully, C.; Werner, J. S.; Zuranski, A.; Acosta, J. G.; Brownson, E.; Huang, X. T.; Lopez, A.; Mendez, H.; Oliveros, S.; Vargas J. E., Ramirez; Zatserklyaniy, A.; Alagoz, E.; Barnes, V. E.; Benedetti, D.; Bolla, G.; Bortoletto, D.; De Mattia, M.; Everett, A.; Hu, Z.; Jones, M.; Koybasi, O.; Kress, M.; Laasanen, A. T.; Leonardo, N.; Maroussov, V.; Merkel, P.; Miller, D. H.; Neumeister, N.; Shipsey, I.; Silvers, D.; Svyatkovskiy, A.; Marono M., Vidal; Yoo, H. D.; Zablocki, J.; Zheng, Y.; Guragain, S.; Parashar, N.; Adair, A.; Boulahouache, C.; Ecklund, K. M.; Geurts, F. J. M.; Padley, B. P.; Redjimi, R.; Roberts, J.; Zabel, J.; Betchart, B.; Bodek, A.; Chung, Y. S.; Covarelli, R.; de Barbaro, P.; Demina, R.; Eshaq, Y.; Garcia Bellido, A.; Goldenzweig, P.; Han, J.; Harel, A.; Miner, D. C.; Vishnevskiy, D.; Zielinski, M.; Bhatti, A.; Ciesielski, R.; Demortier, L.; Goulianos, K.; Lungu, G.; Malik, S.; Mesropian, C.; Arora, S.; Barker, A.; Chou, J. P.; Contreras Campana, C.; Contreras Campana, E.; Duggan, D.; Ferencek, D.; Gershtein, Y.; Gray, R.; Halkiadakis, E.; Hidas, D.; Lath, A.; Panwalkar, S.; Park, M.; Patel, R.; Rekovic, V.; Robles, J.; Rose, K.; Salur, S.; Schnetzer, S.; Seitz, C.; Somalwar, S.; Stone, R.; Thomas, S.; Cerizza, G.; Hollingsworth, M.; Spanier, S.; Yang, Z. C.; York, A.; Eusebi, R.; Flanagan, W.; Gilmore, J.; Kamon, T.; Khotilovich, V.; Montalvo, R.; Osipenkov, I.; Pakhotin, Y.; Perloff, A.; Roe, J.; Safonov, A.; Sakuma, T.; Sengupta, S.; Suarez, I.; Tatarinov, A.; Toback, D.; Akchurin, N.; Damgov, J.; Dragoiu, C.; Dudero, P. R.; Jeong, C.; Kovitanggoon, K.; Lee, S. W.; Libeiro, T.; Roh, Y.; Volobouev, I.; Appelt, E.; Delannoy, A. G.; Florez, C.; Greene, S.; Gurrola, A.; Johns, W.; Johnston, C.; Kurt, P.; Maguire, C.; Melo, A.; Sharma, M.; Sheldon, P.; Snook, B.; Tuo, S.; Velkovska, J.; Arenton, M. W.; Balazs, M.; Boutle, S.; Cox, B.; Francis, B.; Goodell, J.; Hirosky, R.; Ledovskoy, A.; Lin, C.; Neu, C.; Wood, J.; Yohay, R.; Gollapinni, S.; Harr, R.; Karchin, P. E.; Don C., Kottachchi Kankanamge; Lamichhane, P.; Sakharov, A.; Anderson, M.; Belknap, D.; Borrello, L.; Carlsmith, D.; Cepeda, M.; Dasu, S.; Friis, E.; Gray, L.; Grogg, K. S.; Grothe, M.; Hall Wilton, R.; Herndon, M.; Herve, A.; Klabbers, P.; Klukas, J.; Lanaro, A.; Lazaridis, C.; Leonard, J.; Loveless, R.; Mohapatra, A.; Ojalvo, I.; Palmonari, F.; Pierro, G. A.; Ross, I.; Savin, A.; Smith, W. H.; Swanson, J.. - In: PHYSICAL REVIEW D, PARTICLES, FIELDS, GRAVITATION, AND COSMOLOGY. - ISSN 1550-7998. - 86:11(2012). [10.1103/PhysRevD.86.112003]

Combined search for the quarks of a sequential fourth generation

S. Chatrchyan *et al.** (CMS Collaboration)

(Received 5 September 2012; published 12 December 2012)

Results are presented from a search for a fourth generation of quarks produced singly or in pairs in a data set corresponding to an integrated luminosity of 5 fb⁻¹ recorded by the CMS experiment at the LHC in 2011. A novel strategy has been developed for a combined search for quarks of the up and down type in decay channels with at least one isolated muon or electron. Limits on the mass of the fourth-generation quarks and the relevant Cabibbo-Kobayashi-Maskawa matrix elements are derived in the context of a simple extension of the standard model with a sequential fourth generation of fermions. The existence of mass-degenerate fourth-generation quarks with masses below 685 GeV is excluded at 95% confidence level for minimal off-diagonal mixing between the third- and the fourth-generation quarks. With a mass difference of 25 GeV between the quark masses, the obtained limit on the masses of the fourth-generation quarks shifts by about ± 20 GeV. These results significantly reduce the allowed parameter space for a fourth generation of fermions.

DOI: 10.1103/PhysRevD.86.112003

I. INTRODUCTION

The existence of three generations of fermions has been firmly established experimentally [1]. The possibility of a fourth generation of fermions has not been excluded, although it is strongly constrained by precision measurements of electroweak observables. These observables are mainly influenced by the mass differences between the fourth-generation leptons or quarks. In particular, scenarios with a mass difference between the fourth-generation quarks smaller than the mass of the *W* boson are preferred, and even fourth-generation quarks with degenerate masses are allowed [2,3].

A new generation of fermions requires not only the existence of two additional quarks and two additional leptons, but also an extension of the Cabibbo-Kobayashi-Maskawa (CKM) [4,5] and Pontecorvo-Maki-Nakagawa-Sakata [6,7] matrices. New CKM (quark mixing) and Pontecorvo-Maki-Nakagawa-Sakata (lepton mixing) matrix elements are constrained by the requirement of consistency with electroweak precision measurements [8].

Previous searches at hadron colliders have considered either pair production *or* single production of *one* of the fourth-generation quarks [9–15]. The most stringent limits exclude the existence of a down-type (up-type) fourthgeneration quark with a mass below 611 (570) GeV [14,15]. These limits on the quark mass values enter a region where the coupling of fourth-generation quarks to the Higgs field becomes large and perturbative calculations for the weak interaction start to fail, assuming the absence

*Full author list given at the end of the article.

PACS numbers: 13.85.Rm, 12.60.-i, 14.65.Jk

of other phenomena beyond the standard model [16]. To increase the sensitivity and to use a consistent approach while searching for a new generation of quarks, we have developed a simultaneous search for the up-type and downtype fourth-generation quarks, based on both the electroweak and strong production mechanisms.

If a fourth generation of quarks exists, their production cross sections and decay branching fractions will be governed by an extended 4×4 CKM matrix, $V_{CKM}^{4\times4}$, in which we denote the up- and down-type fourth-generation quarks as t', and b', respectively. For simplicity, we assume a model with one free parameter, A, where $0 \le A \le 1$:

$$V_{\rm CKM}^{4\times4} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} & V_{ub'} \\ V_{cd} & V_{cs} & V_{cb} & V_{cb'} \\ V_{td} & V_{ts} & V_{tb} & V_{tb'} \\ V_{t'd} & V_{t's} & V_{t'b} & V_{t'b'} \end{pmatrix}$$
$$= \begin{pmatrix} \mathcal{O}(1) & \mathcal{O}(0) & \mathcal{O}(0) & 0 \\ \mathcal{O}(0) & \mathcal{O}(1) & \mathcal{O}(0) & 0 \\ \mathcal{O}(0) & \mathcal{O}(0) & \sqrt{A} & \sqrt{1-A} \\ 0 & 0 & -\sqrt{1-A} & \sqrt{A} \end{pmatrix}.$$

The complex phases are not shown for clarity. Within this model, mixing is allowed only between the third and the fourth generations. This is a reasonable assumption since the mixing between the third and the first two generations is observed to be small [17]. However, the limits presented in this paper would be too stringent if there is a fourth generation that mixes only with the first two generations, or the size of the mixing with the third generation is about the same as the mixing with the first two generations.

With this search, we set limits on the masses of the fourthgeneration quarks as a function of A. Since $\sqrt{A} = |V_{tb}|$, the lower limit of $|V_{tb}| > 0.81$ from the single-top production

Published by the American Physical Society under the terms of the Creative Commons Attribution 3.0 License. Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI.

cross section measurements [18] translates into a lower limit on the mixing between the third- and fourth-generation quarks in our model of A > 0.66.

Using the data collected from $\sqrt{s} = 7$ TeV protonproton collisions at the Large Hadron Collider (LHC), we search for fourth-generation quarks that are produced in pairs, namely $b'\bar{b}'$ and $t'\bar{t}'$, or through electroweak production, in particular tb', t'b, and t'b', where the charges are omitted in the notation. While the cross sections of the pair production processes do not depend on the value of A, the production cross sections of the tb' and t'b processes depend linearly on (1 - A), and the single-top and t'b'cross sections on A.

We assume the t' and b' masses to be degenerate within 25 GeV. In the case they are degenerate, they will decay in 100% of the cases to the third-generation quarks, since the decay of one fourth-generation quark to the other is kinematically not allowed. However, even for nonzero mass differences, the branching fractions of the $t' \rightarrow bW$ and the $b' \rightarrow tW \rightarrow (bW)W$ decays are close to 100%, provided that the mass difference is small [19]. For instance, for a mass splitting of 25 GeV, and for $V_{t'b'} = 0.005$ (which would correspond to A = 0.99975 in our model), less than 5% of the decays will be $b' \rightarrow t'W^*$ (in the case $m_{t'} < m_{b'}$) or $t' \rightarrow b' W^*$ (in the case $m_{t'} > m_{b'}$). For larger values of $V_{t'b}$, the branching fractions of $b' \rightarrow t'W^*$ (or $t' \rightarrow b'W^*$) decrease even further. Therefore, the decay chains remain unchanged as long as the mass splitting is relatively small. We expect the following final states:

(i) $t'b \rightarrow bWb$;

(ii) $t'\bar{t}' \rightarrow bWbW$;

(iii) $b't \rightarrow tWbW \rightarrow bWWbW$;

(iv) $b't' \rightarrow tWbW \rightarrow bWWbW;$

(v) $b'\bar{b}' \rightarrow tWtW \rightarrow bWWbWW$.

These decay chains imply that two jets from b quarks and one to four W bosons are expected in the final state for fourth-generation quarks produced both singly and in pairs. The W bosons decay to either hadronic or leptonic final states. Events with either one isolated lepton (muon or electron) or two same-sign dileptons or three leptons are selected. The different production processes are classified according to the number of observed W bosons.

II. THE COMPACT MUON SOLENOID DETECTOR

The central feature of the Compact Muon Solenoid (CMS) detector is a superconducting solenoid, 13 m in length and 6 m in internal diameter, providing an axial magnetic field of 3.8 T. The inside of the solenoid is equipped with various particle detection systems. Charged particle trajectories are measured by a silicon pixel and strip tracker, covering $0 < \phi < 2\pi$ in azimuth and $|\eta| < 2.5$, where the pseudorapidity η is defined as $-\ln[\tan(\theta/2)]$, and θ is the polar angle of the trajectory with respect to the anticlockwise-beam direction. A crystal

electromagnetic calorimeter and a brass/scintillator hadron calorimeter surround the tracking volume and provide high-resolution energy and direction measurements of electrons, photons, and hadronic jets. Muons are measured in gas-ionization detectors embedded in the steel return yoke outside the solenoid. The CMS detector also has extensive forward calorimetry covering up to $|\eta| < 5$. The detector is nearly hermetic, allowing for energy balance measurements in the plane transverse to the beam directions. A two-tier trigger system selects the most interesting proton collision events for use in physics analysis. A more detailed description of the CMS detector can be found elsewhere [20].

III. EVENT SELECTION AND SIMULATION

The search for the fourth-generation quarks is performed using the $\sqrt{s} = 7$ TeV proton-proton collisions recorded by the CMS experiment at the LHC. We have analyzed the full data set collected in 2011 corresponding to an integrated luminosity of (5.0 ± 0.1) fb⁻¹. Events are selected with a trigger requiring an isolated muon or electron, where the latter is accompanied by at least one jet identified as a b jet. The muon system, the calorimetry, and the tracker are used for the particle-flow event reconstruction [21]. Jets are reconstructed using the anti- $k_{\rm T}$ algorithm [22] with a size parameter of 0.5. Events are further selected with at least one high-quality isolated muon or electron with a transverse momentum $(p_{\rm T})$ exceeding 40 GeV in the acceptance range $|\eta| < 2.1$ for muons and $|\eta| < 2.5$ for electrons. The relative isolation, I_{rel} , is calculated from the other particle-flow particles within a cone of $\Delta R =$ $\sqrt{(\Delta \phi)^2 + (\Delta \eta)^2} < 0.4$ around the axis of the lepton. It is defined as $I_{\rm rel} = (E_{\rm T}^{\rm charged} + E_{\rm T}^{\rm photon} + E_{\rm T}^{\rm neutral})/p_{\rm T}$, where $E_{\rm T}^{\rm charged}$ and $E_{\rm T}^{\rm photon}$ are the transverse energies deposited by charged hadrons and photons, respectively, and $E_{\rm T}^{\rm neutral}$ is the transverse energy deposited by neutral particles other than photons. We identify muons and electrons as isolated when $I_{\rm rel} < 0.125$ and $I_{\rm rel} < 0.1$, respectively. The requirement on the relative isolation for electrons is tighter than for muons because the backgrounds for electrons are higher than for muons. Electron candidates in the transition region between electromagnetic calorimeter barrel and end cap $(1.44 < |\eta| < 1.57)$ are excluded because the reconstruction of an electron object in this region is not optimal. We require a missing transverse momentum $\not\!\!\!E_T$ of at least 40 GeV. The $\not\!\!\!E_T$ is calculated as the absolute value of the vector sum of the $p_{\rm T}$ of all reconstructed objects. Jets are required to have a $p_{\rm T} > 30$ GeV. The jet energies are corrected to establish a uniform response of the calorimeter in η and a calibrated absolute response in $p_{\rm T}$. Furthermore, a correction is applied to take into account the energy clustered in jets due to additional proton interactions in the same bunch crossing.

The observed data are compared to simulated data generated with POWHEG 301 [23,24] for the single-top process, PYTHIA 6.4.22 [25] for the diboson processes, and MADGRAPH 5.1.1 [26] for the signal and other standard model processes. The POWHEG and MADGRAPH generators are interfaced with PYTHIA for the decay of the particles as well as the hadronization and the implementation of a CMS custom underlying event tuning (tune Z2) [27]. The matching of the matrix-element partons to the parton showers is obtained using the MLM matching algorithm [28]. The CTEQ6L1 leading-order (LO) parton distributions are used in the event generation [29]. The generated events are passed through the CMS detector simulation based on GEANT4 [30], and then processed by the same reconstruction software as the collision data. The simulated events are reweighted to match the observed distribution of the number of simultaneous proton interactions. For the full data set collected in 2011, we observe on average about nine interactions in each event. We smear the jet energies in the simulation to match the resolutions measured with data [31]. At least one of the jets within the tracker acceptance $(|\eta| < 2.4)$ needs to be identified as a b jet. For the b-jet identification, we require the signed impact parameter significance of the third track in the jet (sorted by decreasing significance) to be larger than a value chosen such that the probability for a light quark jet to be misidentified as a b jet is about 1%. We apply scale factors measured from data to the simulated events to take into account the different *b*-jet efficiency and the different probability that a light quark or gluon is identified as a b jet in data and simulation [32].

The top-quark pair as well as the W and Z production cross section values used in the analysis correspond to the measured values from CMS [33,34]. We use the predicted cross section values for the single-top, $t\bar{t} + W$, $t\bar{t} + Z$, and same-sign WW processes [35–38]. The cross section values for the diboson production are obtained with the MCFM next-to-leading-order parton-level integrator [39,40].

For the pair-production of the fourth-generation quarks, we use the approximate next-to-next-to-leading-order cross section values from Ref. [41]. For the electroweak production processes mentioned above, we rescale the next-to-leading-order cross sections at 14 TeV [42] to 7 TeV using a scale factor defined as the ratio of the LO cross section at 7 TeV and the LO cross section at 14 TeV as obtained by the MADGRAPH event generator. The resulting production cross sections are maximal, hence assuming $|V_{tb'}| = |V_{t'b}| = |V_{t'b'}| = 1$, and are rescaled according to the value of *A*.

IV. EVENT CLASSIFICATION

Different channels are defined according to the number of W bosons in the final state. Given that the t' decay mode is the same as the top-quark decay mode, the t'b and $t'\bar{t}'$ processes will yield signatures that are very similar to, respectively, the single-top and $t\bar{t}$ processes in the standard model. We select these processes through the single-lepton decay channel. In the signal final states that contain a b'quark, we expect three or four W bosons. If two or more of these W bosons decay to leptons, we may have events with two leptons of the same charge or with three charged leptons. Although the branching fraction of these decays is small compared to that of other decay channels, these final states are very interesting because of the low background that is expected from standard model processes.

A. The single-electron and single-muon decay channels

On top of the aforementioned event selection criteria, we veto events with additional electrons or muons with $I_{\rm rel}$ < 0.2 and $p_{\rm T} > 10 {\rm ~GeV}$ for muons and $p_{\rm T} > 15 {\rm ~GeV}$ for electrons. We divide the selected single-lepton events into different subsamples according to the signal final states. Therefore, we define a procedure to count the number of W-boson candidates. Each event has at least one W boson that decays to leptons, consistent with the requirements of an isolated lepton and a large missing transverse momentum from the neutrino, which escapes detection. The decays of W bosons to $q\bar{q}$ final states are reconstructed with the following procedure. For each event, we have a collection of selected jets used as input for the reconstruction of the W-boson candidates. The one or two jets that are identified as b jets are removed from the collection. W-boson candidates are constructed from all possible pairs of the remaining jets in the collection. We use both the expected mass, $m_W^{\text{fit}} = 84.3 \text{ GeV}$, and the width, $\sigma_{mW}^{\text{fit}} =$ 9.6 GeV, from a Gaussian fit to the reconstructed mass distribution of jet pairs from the decay of a W boson in simulated $t\bar{t}$ events. The W-boson candidate with a mass that matches the value of m_W^{fit} best is chosen as a W boson if its mass is within a $\pm 1\sigma_{mW}^{fit}$ window around m_W^{fit} . The jet pair that provided the hadronically decaying W boson is removed from the collection, and the procedure is repeated until no more candidates are found for W bosons decaying to jets. Different exclusive subsamples are defined according to the number of b jets (exactly one or at least two) and the number of W-boson candidates (one, two, three, and at least four). There are seven subsamples, because we do not consider the subsample with only one b jet and one Wboson. The subsample with two b jets and one W boson is dominated by singly produced t' events. In this subsample, we apply a veto for additional jets with a transverse momentum exceeding 30 GeV. Furthermore, since $b\bar{b}$ background tends to have jets which are produced backto-back with balanced p_T , we remove this background by requiring $\Delta \phi(j_1, j_2) < \frac{\pi}{2} + \pi (p_{\rm T}^{j_1} - p_{\rm T}^{j_2})/(p_{\rm T}^{j_1} + p_{\rm T}^{j_2}).$

Table I summarizes the requirements that define the different single-lepton decay subsamples, after the criteria on the $\not\!\!\!E_T$, and the lepton and jet p_T and η are applied.

Table II shows the observed and predicted event yields. After the selection criteria, the dominant background

TABLE I. Overview of the event selection requirements defining the different subsamples in the single-lepton decay channel. The single-lepton decay channel is divided in seven different subsamples according to the number of b jets and the number of W-boson candidates.

Single-lepton decay channel				
1 W	2W	3 <i>W</i>	4W	
= 2 jets	\geq 4 jets	\geq 6 jets	\geq 8 jets	
= 2 b jets	eithe	$r = 1 \text{ or } \ge 2$	b jets	
$\Delta \phi(j_1, j_2)$ requirement	$1W \rightarrow q\bar{q}$	$2W \rightarrow q\bar{q}$	$3W \rightarrow q\bar{q}$	

contributions result from the production of top-quark pairs, W + jets, and single top. Other processes with very small contributions to the total background are Z + jets and diboson production, and also top-quark pairs produced in association with a W or Z boson. The combined event yield of these processes is about 1% of the total standard-model contribution. The multijet background is found to be negligible in each of the subsamples. The reason is the requirements of an isolated muon or electron with $p_T > 40$ GeV, a missing transverse momentum of 40 GeV, and at least one jet identified as a b jet. Data and simulation are found to agree within the combined statistic and systematic uncertainties.

B. The same-sign dilepton and trilepton decay channels

The transverse momentum of at least one of the leptons in the multilepton channel is required to be larger than 40 GeV, while the threshold is reduced to 20 GeV for additional leptons. Events with two muons or electrons with a mass within 10 GeV of the Z-boson mass are rejected to reduce the standard model background with Z bosons in the final state. We require at least four jets for the same-sign dilepton events. In the case of the trilepton events, the minimum number of required jets is reduced to two. Table III summarizes the event selection requirements defining the same-sign dilepton and trilepton decay

TABLE III. Overview of the event selection requirements specific to the same-sign dilepton and trilepton decay channels.

Same-sign dilepton	Trilepton	
= 2 isolated leptons with same sign	= 3 isolated leptons	
\geq 4 jets ($p_{\rm T}$ \geq 30 GeV, $ \eta $ $<$ 2.4)	$\geq 2 \text{ jets} (p_{\text{T}} > 30 \text{ GeV},$ n < 2.4)	
$\geq 1 b$ jet	$\geq 1 b$ jet	

channels that are applied on top of the other requirements on the $\not\!\!E_T$ and lepton and jet p_T and η .

There are several contributions to the total standardmodel background for the same-sign dilepton events. One of these contributions comes from events for which the charge of one of the leptons is misreconstructed, for instance in $t\bar{t}$ events with two W bosons decaying into leptons. Second, there are events with one prompt lepton and one nonprompt lepton passing the isolation and identification criteria. Finally, there is an irreducible contribution from standard-model processes with two prompt leptons of the same sign; e.g. $W^{\pm}W^{\pm}$, WZ, ZZ, $t\bar{t} + W$, and $t\bar{t} + Z$. Except for $W^{\pm}W^{\pm}$, these processes are also the main contributions to the total background for the trilepton subsample. The event yields for the irreducible component of the background for the same-sign dilepton channel and the total background in the case of the trilepton subsample are taken from the simulation. We obtain from the data the predicted number of background events for the first two contributions to the total background in the same-sign dilepton subsample.

For the same-sign dilepton events with at least one electron, the background is estimated from control samples. We determine the charge misidentification rate for electrons using a double-isolated-electron trigger. We require two isolated electrons with the dielectron invariant mass within 10 GeV of the Z-boson mass. We select

TABLE II. Event yields in the single lepton channel. Uncertainties reflect the combined statistical and systematic uncertainties. The prediction for the signal is shown for two different values of A and for a fourth-generation-quark mass $m_{q'} = 550$ GeV.

	1b 2W	1b 3W	1b 4W	2b 1W	2b 2W	2b 3W	2b 4W
$t\bar{t} + jets$	5630 ± 410	230^{+29}_{-26}	$3.0^{+1.9}_{-1.3}$	819^{+59}_{-62}	2810 ± 240	85^{+12}_{-10}	$0.6^{+0.8}_{-0.5}$
W + jets	490 ± 180	$8.0^{+3.1}_{-3.0}$	$0.3^{+0.9}_{-0.3}$	150^{+47}_{-46}	37 ± 12	$1.1^{+1.0}_{-0.4}$	$0.0\substack{+0.8\-0.0}$
Z + jets	36^{+5}_{-6}	$1.0\substack{+0.2\\-0.1}$	0	$7.1^{+1.0}_{-0.6}$	$2.8^{+1.0}_{-0.3}$	0	0
Single top	346 ± 64	$6.5^{+1.6}_{-1.5}$	$0.2\substack{+0.3\\-0.2}$	200 ± 34	110 ± 19	$2.5^{+0.7}_{-0.5}$	$0.0\substack{+0.1\-0.0}$
VV	15 ± 2	$0.4\substack{+0.3\\-0.1}$	$0.0\substack{+0.1\-0.0}$	15 ± 2	1.8 ± 0.3	$0.0\substack{+0.1\-0.0}$	$0.0\substack{+0.1\\-0.0}$
$t\bar{t}V$	28 ± 3	3.4 ± 0.5	0.1 ± 0.0	0.7 ± 0.2	15 ± 5	$1.5\substack{+0.3\\-0.2}$	0
Total background	6550 ± 450	249^{+29}_{-26}	$3.6^{+2.1}_{-1.3}$	1190^{+83}_{-85}	2970 ± 240	91^{+12}_{-10}	$0.6^{+1.2}_{-0.5}$
Observed	7003	242	8	1357	3043	91	4
Signal $(A = 1)$	55 ± 1	12 ± 1	0.9 ± 0.2	$1.0\substack{+0.2\\-0.3}$	49 ± 2	8.1 ± 0.4	0.5 ± 0.2
Signal $(A = 0.8)$	85 ± 2	14 ± 1	1.0 ± 0.2	69 ± 3	66 ± 2	9.2 ± 0.4	0.5 ± 0.2

TABLE IV. The prediction for the total number of background events compared with the number of observed events in the same-sign dilepton and the trilepton subsamples. The numbers of expected signal events are also shown for two possible scenarios.

Туре	2 muons	2 electrons	Electron + muon	Trilepton
Irreducible background Background from charge misid Background from fake leptons	0.77 ± 0.08 0.06 ± 0.06	0.59 ± 0.08 0.47 ± 0.08 0.30 ± 0.15	1.10 ± 0.11 0.71 ± 0.06 0.46 ± 0.17	0.96 ± 0.12
Total background Observed Signal ($A = 1$, $m_{q'} = 550$ GeV) Signal ($A = 0.8$, $m_{q'} = 550$ GeV)	$0.83 \pm 0.11 \\ 2 \\ 3.31 \pm 0.15 \\ 3.79 \pm 0.15$	$\begin{array}{c} 1.36 \pm 0.19 \\ 2 \\ 2.03 \pm 0.36 \\ 2.29 \pm 0.36 \end{array}$	$2.27 \pm 0.22 \\ 2 \\ 5.29 \pm 0.19 \\ 6.00 \pm 0.19 \\$	$\begin{array}{c} 0.96 \pm 0.12 \\ 1 \\ 3.37 \pm 0.16 \\ 3.65 \pm 0.16 \end{array}$

events with $\not\!\!\!E_T < 20 \text{ GeV}$ and a transverse mass $M_T =$

press background from top-quark and W + jets events. We define the charge misidentification ratio R as the number of events with two electrons of the same sign divided by twice the number of events with two electrons of opposite sign, i.e. $R = N_{SS}/2N_{OS}$. We obtain 0.14% and 1.4% for barrel and end-cap electron candidates, respectively. After the full event selection is applied, with the exception of the electron sign requirement, we obtain a number of selected data events with two electrons and with an electron and a muon in the final state. The background with two electrons or with an electron and a muon with the same sign is obtained by taking the number of oppositesign events and scaling it with R. The $p_{\rm T}$ spectrum of the electrons in the control sample and the signal region is similar. Therefore, no correction is applied for the $p_{\rm T}$ dependency of the charge misidentification ratio.

Another important background contribution to the samesign dilepton channel originates from jets being misidentified as an electron or a muon ("fake" leptons). Two collections of leptons, "loose" and "tight", are defined based on the isolation and identification criteria. Loose leptons are required to fulfill $I_{\rm rel} < 0.2$, in contrast with $I_{\rm rel} < 0.125(0.1)$ for tight muons (electrons). Moreover, we require $|\eta| < 2.5$ and $p_T < 10(15)$ for loose muons (electrons). Additionally, several identification criteria, intended to ensure the consistency of the lepton track with the primary vertex, are relaxed. We require at least one loose electron or muon. Additionally, we require $\not\!\!\!E_T <$ 20 GeV and $M_T < 25$ GeV to suppress background from top-quark and W + jets events. Moreover, we veto events with leptons of the same flavor which have a dilepton mass within 20 GeV of the Z-boson mass. We count the number of loose and tight leptons with a $p_{\rm T}$ below 35 GeV. The threshold on the $p_{\rm T}$ is required to suppress contamination from W + jets events, which would bias the estimation, because leptons produced in jets have typically a soft $p_{\rm T}$ spectrum. The probability that a loose (L) lepton passes the tight (T) selection criteria is then given by the ratio $\epsilon_{\rm TL} = N_{\rm T}/N_{\rm L}$. To estimate the number of events from the background source with a nonprompt lepton, we count the number of events in data that pass the event selection criteria with one lepton passing the tight selection criteria and a second lepton passing the loose, but not the tight, criteria. This yield is multiplied by $\epsilon_{TL}(1 - \epsilon_{TL})$ to determine the number of events with a nonprompt lepton in the analysis. The statistical uncertainty on the estimated number of events is large because only a few events are selected with one tight and one loose, but not tight, lepton.

The total number of expected background events for the same-sign dilepton and trilepton channels is given in Table IV.

V. SETTING LOWER LIMITS ON THE FOURTH-GENERATION QUARK MASSES

We have defined different subsamples according to the reconstructed final state. In each of the different subsamples, we reconstruct observables that are sensitive to the presence of the fourth-generation quarks. These observables are used as input to a fit of the combined distributions for the standard-model (background-only) hypothesis and the signal-plus-background hypothesis. With the profile likelihood ratio as a test statistic, we calculate the 95% confidence level (CL) upper limits on the combined input cross section of the signal as a function of the $V_{\rm CKM}^{4\times4}$ parameter A and the mass of the fourth-generation quarks.

A. Observables sensitive to the fourth-generation quark production

The expected number of events is small in the subsamples with two leptons of the same sign, the trilepton subsample, and the two single-lepton subsamples with four *W*-boson candidates. As a consequence, the event counts in each of these subsamples are used as the observable. Table IV summarizes the event counts for the subsamples with two leptons of the same sign and the trilepton subsample.

In the single-lepton subsamples with one or three W bosons, we use S_T as the observable to discriminate between the standard model background and the fourth-generation signal, where S_T is defined as the scalar sum of the transverse momenta of the reconstructed objects in the final state, namely:



FIG. 1 (color online). The S_T distribution for the subsamples with two *b* jets and one *W* boson (a), one *b* jet and three *W* bosons (b), two *b* jets and two *W* bosons (c), and the m_{bW} distribution for the subsample with two *b* jets and two *W* bosons (d). The data distributions of these observables are compared to their expectation from the simulation assuming the fitted nuisance parameters. The fitted values of the nuisance parameters represent the systematic shifts that are applied on the simulation to fit the data in the background-only hypothesis. As an illustration, the total uncertainty band is shown around the simulated expected distribution before taking into account the fitted values of the nuisance parameters. The expected distribution for a signal is shown for two different values of the $V_{CKM}^{4\times4}$ parameter *A* and for *b'* and *t'* masses of 550 GeV. The cross section of the signal in the plots is scaled by a factor of eight for visibility. The last bin in all the histograms includes the overflow. We do not expect much signal for A = 1 in (a), because the subsample with two *b* jets and one *W* boson is mainly sensitive to single *t'*-quark production.

where the sum runs over the number of reconstructed hadronically decaying W bosons; p_T^l is the p_T of the lepton, p_T^b the p_T of the b jet, p_T^j the p_T of the second b jet or, if there is no additional jet identified as a b jet, the p_T of the jet with the highest transverse momentum in the event that is not used in the W-boson reconstruction, and $p_T^{W_{q\bar{q}}}$ the p_T of the *i*th reconstructed W boson decaying to jets. In general, the decay products of the fourth-generation quarks are expected to have higher transverse momenta compared to the standard-model background. This is shown in Fig. 1 for three of the subsamples. The dominant contribution to the selected signal events in the subsample with two *b* jets and one *W* boson would come from the t'bprocess. Almost no signal events are selected for A = 1, because in that case, the production cross section of t'b is equal to zero. The subsamples with two *W* bosons are dominated by $t\bar{t}$ events. In this case, we use two sensitive observables: S_T and the mass of the hadronic *bW* system,

COMBINED SEARCH FOR THE QUARKS OF A ...

TABLE V. Overview of the observables used in the limit calculation.

Subsample	Observable
Single-lepton 1W	ST
Single-lepton 2W	$S_{\rm T}$ and m_{bW}
Single-lepton 3W	ST
Single-lepton 4W	Event yield
Same-sign dilepton	Event yield
Trilepton	Event yield

 m_{bW} . The latter observable is sensitive to the fourthgeneration physics, because of the higher mass of a hypothetical fourth-generation t' quark compared to the top-quark mass. To obtain a higher sensitivity with the m_{bW} observable, four jets need to be assigned to the quarks to reconstruct the final state $t'\bar{t}' \rightarrow WbWb \rightarrow q\bar{q}b\ell\nu_{\ell}b$. Therefore, six observables with discriminating power between correct and wrong jet/quark assignments are combined with a likelihood ratio method. These observables are angles between the decay products, the W-boson mass, the transverse momentum of the top quark decaying to hadrons, and an observable related to the values of the *b*-jet identification variable for the jets. The jet/quark assignment with the largest value of the likelihood ratio is chosen. The mass of the bW system is then reconstructed from this chosen jet/quark assignment. The lower plots in Fig. 1 show the projections of the two-dimensional $S_{\rm T}$ versus m_{bW} distribution.

An overview of the observables used in the fit for the presence of the fourth-generation quarks is presented in Table V.

B. Fitting for the presence of fourth-generation quarks

We construct a single histogram "template" that contains the information of the sensitive observables from all the subsamples. Different template distributions are made for the signal corresponding to the different values of A and the fourth-generation quark masses $m_{q'}$. The binning of the two-dimensional observable distribution in the singlelepton subsamples with two W bosons is defined using the following procedure. We use a binning in the dimension of m_{bW} such that the top-quark pair background events are uniformly distributed over the bins. Second, the binning in the dimension of $S_{\rm T}$ in each of the m_{bW} bins is chosen to obtain uniformly distributed top-quark pair events also in this dimension.

The templates of the sensitive observables are used as input to obtain the likelihoods for the background-only and the signal-plus-background hypotheses. Systematic uncertainties are taken into account by introducing nuisance parameters, which may affect the shape and the normalization of the templates. In a case where the systematic uncertainty alters the shape of the templates, template morphing [43,44] is used to interpolate linearly on a bin-by-bin basis between the nominal templates and systematically shifted ones.

The normalization of the templates is affected by the uncertainty in the integrated luminosity, the lepton efficiency, and the normalization of the background processes. The integrated luminosity is measured with a precision of 2.2% [45] and has the same normalization effect on all the templates. The uncertainty in the lepton efficiency is a combination of the uncertainties in the trigger, selection, and identification efficiencies, which amounts to 3% and 5% for muon and electron, respectively. For the uncertainty in the normalization of the background processes, we use the uncertainties in the production cross section of the various standard-model processes. The most important contributions that affect the normalization of the templates are the 12% [33] (30%) uncertainty for the top-quark pair (single-top) production cross section and a 50% uncertainty for the W production cross section because of the large fraction of selected events with jets from heavy-flavor quarks. For the multilepton channel, we take into account the uncertainties in the background estimation obtained from the data. We also include the uncertainties in the production cross sections of Z (5% [34]), WW (35%), WZ (42%), ZZ (27%), $t\bar{t} + W$ (19%), $t\bar{t} + Z$ (28%), and $W^{\pm}W^{\pm}$ (49%). The uncertainties in the normalization of diboson and top-quark pair production in association with a boson are taken from a comparison of the next-to-leadingorder and the LO predictions.

The largest systematic effects on the shape of the templates originate from the jet energy corrections [31] and the scale factors between data and simulation for the *b*-jet efficiency and the probability that a light quark or gluon is identified as a *b* jet [32]. These effects are estimated by varying the nominal value by ± 1 standard deviation. The uncertainty in the jet energy resolution of about 10% has a relatively small effect on the expected limits. The same is true for the uncertainty in the modeling of multiple interactions in the same beam crossing. The latter effect is evaluated by varying the average number of interactions in the simulation by 8%.

The probability density functions of the backgroundonly and the signal-plus-background hypotheses are fitted to the data to fix the nuisance parameters in both models. In the signal-plus-background model, an additional variable, defined as the cross section for the fourth-generation signal obtained by combining the separate search channels, is included. In the combined cross section variable, the relative fraction of each fourth-generation signal process is fixed according to the probed model parameters (A, $m_{q'}$). Using a Gaussian approximation for the probability density function of the test statistic, we determine the 95% CL expected and observed limits on the combined cross section variable using the CL_s criterion [46–48]. We exclude the point (A, $m_{q'}$) at the 95% CL if the upper limit on the combined cross section variable is smaller than its predicted value within the fourth-generation model. The procedure is repeated for each value of A and $m_{q'}$.

C. Results and discussion

We use the CL_s procedure to calculate the combined limit for the single-muon, single-electron, same-sign dilepton, and trilepton channels. When the value of the $V_{CKM}^{4\times4}$ parameter A approaches unity, the standard model single-top and the t'b' processes reach their maximal values for the production cross section. When the value of A decreases, the cross section of these processes decreases linearly with A. At the same time, the expected cross section of the t'b and tb' processes increases with (1 - A) and is equal to zero for A = 1. Therefore, the t'band tb' processes are expected to enhance the sensitivity for fourth-generation quarks when the parameter A decreases. This is visible in the upper part of Fig. 2 where both the expected and observed limits on $m_{q'}$ are more stringent for smaller values of A. For instance, the limit on the fourth-generation quark masses increases by 70 GeV for A = 0.9 compared to the value of the limit for $A \sim 1$. While the t'b and tb' processes do not contribute for $A \sim 1$, the inclusion of the t'b' process results in a more stringent limit (a difference of about 30 GeV) compared to when this process is not taken into account.

The existence of fourth-generation quarks with degenerate masses is excluded for all parameter values below the line using the assumed model of the $V_{\text{CKM}}^{4\times4}$ matrix. In particular, fourth-generation quarks with a degenerate mass below 685 GeV are excluded at the 95% CL for a parameter value of $A \sim 1$. It is worth noting that no limits can be set for A exactly equal to unity (A = 1), because in this special case, the fourth-generation quarks would be stable in the assumed model. The analysis is, however, valid for values of A extremely close to unity. The distance between the primary vertex and the decay vertex of the fourth-generation quarks is less than 1 mm for $1 - A > 2 \times 10^{-14}$, a number obtained using the LO formula for the decay width of the top quark in which the top-quark mass is replaced with a fourth-generation-quark mass of 600 GeV.

Up to now, the masses of the fourth-generation quarks were assumed to be degenerate. However, if a fourth generation of chiral quarks exists, this is not necessarily the case. Therefore, it is interesting to study how the limit would change for nondegenerate quark masses. If we assume nondegenerate masses, another decay channel for the fourth-generation quarks is possible. Namely, the branching fraction for the decay of t'(b') into b'(t'), and an off-shell W boson becomes nonzero. For values of the mass splitting up to about 25 GeV, this branching fraction is small as noted in the introduction. We assume a mass splitting of 25 GeV and unchanged branching fractions for the t' and b' decays. The sensitivity of the analysis increases or decreases depending on the specific values of the masses and hence the production cross sections of



FIG. 2 (color online). Top: Exclusion limit on $m_{t'} = m_{b'}$ as a function of the $V_{\text{CKM}}^{4\times4}$ parameter *A*. The parameter values below the solid line are excluded at 95% CL. The inner (outer) band indicates the 68% (95%) confidence interval around the expected limit. The slope indicates the sensitivity of the analysis to the t'b and tb' processes. Bottom: For a $V_{\text{CKM}}^{4\times4}$ parameter value $A \sim 1$, the exclusion limit on $m_{t'}$ versus $m_{t'} - m_{b'}$ is shown. The exclusion limit is calculated for mass differences up to 25 GeV. The existence of up-type fourth-generation quarks with mass values below the observed limit are excluded at the 95% CL.

the fourth-generation quarks. The effect of the mass difference between the fourth-generation quarks on the exclusion limit is shown in the bottom plot of Fig. 2 for a $V_{\rm CKM}^{4\times4}$ parameter $A \sim 1$. For instance, in case $m_{t'} = m_{b'} +$ 25 GeV ($m_{t'} = m_{b'} - 25$ GeV), the limit on $m_{t'}$ increases about +20(-20) GeV with respect to the degenerate-mass

COMBINED SEARCH FOR THE QUARKS OF A ...

case. To obtain this limit, we do not take into account the electroweak t'b' process, which results in more conservative exclusion limits. In particular, one observes that quarks with degenerate masses below about 655 GeV are excluded at the 95% CL compared to 685 GeV when the t'b' process is included.

VI. SUMMARY

Results from a search for a fourth generation of quarks have been presented. A simple model for a unitary CKM matrix has been defined based on a single parameter $A = |V_{tb}|^2 = |V_{t'b'}|^2$. Degenerate masses have been assumed for the fourth-generation quarks, hence $m_{t'} =$ $m_{b'}$. The information is combined from different subsamples corresponding to different final states with at least one electron or muon. Observables have been constructed in each of the subsamples and used to differentiate between the standard-model background and the processes with fourth-generation quarks. With this strategy, the search for singly and pair-produced t' and b' quarks has been combined in a coherent way into a single analysis. Model-dependent limits are derived on the mass of the quarks and the $V_{\text{CKM}}^{4\times4}$ matrix element A. The existence of fourth-generation quarks with masses below 685 GeV is excluded at 95% confidence level for minimal off-diagonal mixing between the third- and the fourth-generation quarks. A nonzero cross section for the single fourthgeneration quark production processes, corresponding to a value of the $V_{\text{CKM}}^{4\times4}$ parameter A < 1, gives rise to a more stringent limit. When a mass difference of 25 GeV is assumed between t' and b' quarks, the limit on $m_{t'}$ shifts by about +20(-20) GeV for $m_{t'} = m_{b'} + 25$ GeV ($m_{t'} =$ $m_{b'} - 25$ GeV). These results significantly reduce the allowed parameter space for a fourth generation of fermions and raise the lower limits on the masses of the fourth generation quarks to the region where nonperturbative effects of the weak interactions are important.

ACKNOWLEDGMENTS

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC machine. We thank the technical and administrative staff at CERN and other CMS institutes, and acknowledge support from BMWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES (Croatia); RPF (Cyprus); MoER, SF0690030s09 and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NKTH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); NRF and WCU (Korea); LAS (Lithuania); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); MSI (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Armenia, Belarus, Georgia, Ukraine, Uzbekistan); MON, RosAtom, RAS and RFBR (Russia); MSTD (Serbia); SEIDI and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); ThEP, IPST and NECTEC (Thailand); TUBITAK and TAEK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA). Individuals have received support from the Marie-Curie program and the European Research Council (European Union); the Leventis Foundation; the A.P. Sloan Foundation; the Alexander von Humboldt Foundation; the Austrian Science Fund (FWF); the Belgian Federal Science Policy Office: the Fonds pour la Formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA-Belgium); the Agentschap voor Innovatie door Wetenschap en Technologie (IWT-Belgium); the Ministry of Education, Youth and Sports (MEYS) of Czech Republic; the Council of Science and Industrial Research, India; the Compagnia di San Paolo (Torino); and the HOMING PLUS program of Foundation for Polish Science, cofinanced from European Union, Regional Development Fund.

- D. E. Groom *et al.* (Particle Data Group), Eur. Phys. J. C 15, 357 (2000).
- [2] H. Flaecher, M. Goebel, J. Haller, A. Hoecker, K. Moenig, and J. Stelzer, Eur. Phys. J. C 60, 543 (2009).
- [3] M. Buchkremer, J.-M. Gerard, and F. Maltoni, J. High Energy Phys. 06 (2012) 135.
- [4] N. Cabibbo, Phys. Rev. Lett. 10, 531 (1963).
- [5] M. Kobayashi and T. Maskawa, Prog. Theor. Phys. 49, 652 (1973).
- [6] B. Pontecorvo, Sov. Phys. JETP 6, 429 (1957).
- [7] Z. Maki, M. Nakagawa, and S. Sakata, Prog. Theor. Phys. 28, 870 (1962).

- [8] E. Asilar, E. Cavlan, O. Dogangun, S. Kefeli, E. Ozcan, M. Sahin, and G. Unel, Eur. Phys. J. C 72, 1966 (2012).
- [9] G. Aad *et al.* (ATLAS), Phys. Rev. Lett. **109**, 032001 (2012).
- [10] G. Aad et al. (ATLAS), Phys. Rev. D 86, 012007 (2012).
- [11] G. Aad *et al.* (ATLAS), J. High Energy Phys. 04 (2012) 069.
- [12] G. Aad et al. (ATLAS), Phys. Rev. Lett. 108, 261802 (2012).
- [13] S. Chatrchyan et al. (CMS), Phys. Lett. B 716, 103 (2012).
- [14] S. Chatrchyan *et al.* (CMS), J. High Energy Phys. 05 (2012) 123.
- [15] S. Chatrchyan et al. (CMS), Phys. Lett. B 718, 307 (2012).

S. CHATRCHYAN et al.

- [16] M. S. Chanowitz, M. A. Furman, and I. Hinchliffe, Nucl. Phys. B153, 402 (1979).
- [17] K. Nakamura *et al.* (Particle Data Group), Phys. Rev. D 86, 010001 (2012).
- [18] V. M. Abazov et al. (D0), Phys. Rev. D 85, 091104 (2012).
- [19] Y. Chao, K.-F. Chen, S.-K. Chen, W.-S. Hou, B.-Y. Huang, and Y.-J. Lei, Phys. Rev. D 84, 014029 (2011).
- [20] S. Chatrchyan et al. (CMS), JINST 3, S08004 (2008).
- [21] CMS Collaboration (CMS), Commissioning of the Particle-Flow Reconstruction in Minimum-Bias and Jet Events from Collisions at 7 TeV, CMS Physics Analysis Summary CMS-PAS-PFT-10-002 (2010), http://cdsweb .cern.ch/record/1279341.
- [22] M. Cacciari, G. P. Salam, and G. Soyez, J. High Energy Phys. 04 (2008) 063.
- [23] S. Alioli, P. Nason, C. Oleari, and E. Re, J. High Energy Phys. 09 (2009) 111.
- [24] E. Re, Eur. Phys. J. C 71, 1547 (2011).
- [25] T. Sjöstrand, S. Mrenna, and P.Z. Skands, J. High Energy Phys. 05 (2006) 026.
- [26] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer, and T. Stelzer, J. High Energy Phys. 06 (2011) 128.
- [27] R. Field, arXiv:1010.3558.
- [28] M. L. Mangano, M. Moretti, F. Piccinini, and M. Treccani, J. High Energy Phys. 01 (2007) 013.
- [29] J. Pumplin, D. R. Stump, J. Huston, H. L. Lai, P. Nadolsky, and W. K. Tung, J. High Energy Phys. 07 (2002) 012.
- [30] J. Allison *et al.*, IEEE Trans. Nucl. Sci. 53, 270 (2006).
- [31] S. Chatrchyan et al. (CMS), JINST 6, P11002 (2011).
- [32] CMS Collaboration (CMS), b-Jet Identification in the CMS Experiment, CMS Physics Analysis Summary CMS-PAS-BTV-11-004 (2011), http://cdsweb.cern.ch/ record/1427247.

- [33] S. Chatrchyan *et al.* (CMS), Phys. Rev. D **84**, 092004 (2011).
- [34] S. Chatrchyan *et al.* (CMS), J. High Energy Phys. 10 (2011) 132.
- [35] N. Kidonakis, Phys. Rev. D 83, 091503 (2011).
- [36] N. Kidonakis, Phys. Rev. D 81, 054028 (2010).
- [37] N. Kidonakis, Phys. Rev. D 82, 054018 (2010).
- [38] V. Hirschi, R. Frederix, S. Frixione, M. V. Garzelli, F. Maltoni, and R. Pittau, J. High Energy Phys. 05 (2011) 044.
- [39] J. M. Campbell and R. K. Ellis, Nucl. Phys. B, Proc. Suppl. 205-206, 10 (2010).
- [40] J. M. Campbell and R. K. Ellis, Phys. Rev. D 60, 113006 (1999).
- [41] M. Aliev, H. Lacker, U. Langenfeld, S. Moch, P. Uwer, and M. Wiedermann, Comput. Phys. Commun. 182, 1034 (2011).
- [42] J. M. Campbell, R. Frederix, F. Maltoni, and F. Tramontano, J. High Energy Phys. 10 (2009) 042.
- [43] A. L. Read, Nucl. Instrum. Methods Phys. Res., Sect. A 425, 357 (1999).
- [44] J. S. Conway, in Proceedings of PHYSTAT 2011 Workshop on Statistical Issues Related to Discovery Claims in Search Experiments and Unfolding, edited by H. B. Propser and L. Lyons (CERN, 2001), p. 115 [http:// cdsweb.cern.ch/record/1306523].
- [45] CMS Collaboration, CMS Physics Analysis Summary Report No. CMS-PAS-SMP-12-008, 2012 [http://cdsweb .cern.ch/record/1434360].
- [46] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, Eur. Phys. J. C 71, 1554 (2011).
- [47] T. Junk, Nucl. Instrum. Methods Phys. Res., Sect. A 434, 435 (1999).
- [48] A. L. Read, J. Phys. G 28, 2693 (2002).

S. Chatrchyan,¹ V. Khachatryan,¹ A. M. Sirunyan,¹ A. Tumasyan,¹ W. Adam,² E. Aguilo,² T. Bergauer,² M. Dragicevic,² J. Erö,² C. Fabjan,^{2,b} M. Friedl,² R. Frühwirth,^{2,b} V. M. Ghete,² J. Hammer,² N. Hörmann,² J. Hrubec,² M. Jeitler,^{2,b} W. Kiesenhofer,² V. Knünz,² M. Krammer,^{2,b} I. Krätschmer,² D. Liko,² I. Mikulec,² M. Pernicka,^{2,a} B. Rahbaran,² C. Rohringer,² H. Rohringer,² R. Schöfbeck,² J. Strauss,² A. Taurok,² W. Waltenberger,² G. Walzel,² E. Widl,² C.-E. Wulz,^{2,b} V. Mossolov,³ N. Shumeiko,³ J. Suarez Gonzalez,³ M. Bansal,⁴ S. Bansal,⁴ T. Cornelis,⁴ E. A. De Wolf,⁴ X. Janssen,⁴ S. Luyckx,⁴ L. Mucibello,⁴ S. Ochesanu,⁴ B. Roland,⁴ R. Rougny,⁴ M. Selvaggi,⁴ Z. Staykova,⁴ H. Van Haevermaet,⁴ P. Van Mechelen,⁴ N. Van Remortel,⁴ A. Van Spilbeeck,⁴ F. Blekman,⁵ S. Blyweert,⁵ J. D'Hondt,⁵ R. Gonzalez Suarez,⁵ A. Kalogeropoulos,⁵ M. Maes,⁵ A. Olbrechts,⁵ W. Van Doninck,⁵ P. Van Mulders,⁵ G. P. Van Onsem,⁵ I. Villella,⁵ B. Clerbaux,⁶ G. De Lentdecker,⁶ V. Dero,⁶ A. P. R. Gay,⁶ T. Hreus,⁶ A. Léonard,⁶ P. E. Marage,⁶ A. Mohammadi,⁶ T. Reis,⁶ L. Thomas,⁶ G. Vander Marcken,⁶ C. Vander Velde,⁶ P. Vanlaer,⁶ J. Wang,⁶ V. Adler,⁷ K. Beernaert,⁷ A. Cimmino,⁷ S. Costantini,⁷ G. Garcia,⁷ M. Grunewald,⁷ B. Klein,⁷ J. Lellouch,⁷ A. Marinov,⁷ J. Mccartin,⁷ A. A. Ocampo Rios,⁷ D. Ryckbosch,⁷ N. Strobbe,⁷ F. Thyssen,⁷ M. Tytgat,⁷ P. Verwilligen,⁷ S. Walsh,⁷ E. Yazgan,⁷ N. Zaganidis,⁷ S. Basegmez,⁸ G. Bruno,⁸ R. Castello,⁸ L. Ceard,⁸ C. Delaere,⁸ T. du Pree,⁸ D. Favart,⁸ L. Forthomme,⁸ A. Giammanco,^{8,c} J. Hollar,⁸ V. Lemaitre,⁸ J. Liao,⁸ O. Militaru,⁸ C. Nuttens,⁸ D. Pagano,⁸ A. Pin,⁸ K. Piotrzkowski,⁸ N. Schul,⁸ J. M. Vizan Garcia,⁸ N. Beliy,⁹ T. Caebergs,⁹ E. Daubie,⁹ G. H. Hammad,⁹ G. A. Alves,¹⁰ M. Correa Martins Junior,¹⁰ D. De Jesus Damiao,¹⁰ T. Martins,¹⁰ M. E. Pol,¹⁰ M. H. G. Souza,¹⁰ W. L. Aldá Júnior,¹¹ W. Carvalho,¹¹ A. Custódio,¹¹ E. M. Da Costa,¹¹ C. De Oliveira Martins,¹¹ S. Fonseca De Souza,¹¹ D. Matos Figueiredo,¹¹ L. Mundim,¹¹ H. Nogima,¹¹ V. Oguri,¹¹ W. L. Prado Da Silva,¹¹ A. Santoro,¹¹ L. Soares Jorge,¹¹ A. Sznajder,¹¹ T. S. Anjos,^{12,d} C. A. Bernardes,^{12,d} F. A. Dias,^{12,e} T.R. Fernandez Perez Tomei,¹² E. M. Gregores,^{12,d} C. Lagana,¹²

F. Marinho,¹² P.G. Mercadante,^{12,d} S.F. Novaes,¹² Sandra S. Padula,¹² V. Genchev,^{13,f} P. Iaydjiev,^{13,f} S. Piperov,¹³ M. Rodozov,¹³ S. Stoykova,¹³ G. Sultanov,¹³ V. Tcholakov,¹³ R. Trayanov,¹³ M. Vutova,¹³ A. Dimitrov,¹⁴ R. Hadjiiska,¹⁴ V. Kozhuharov,¹⁴ L. Litov,¹⁴ B. Pavlov,¹⁴ P. Petkov,¹⁴ J. G. Bian,¹⁵ G. M. Chen,¹⁵ H. S. Chen,¹⁵ C. H. Jiang,¹⁵ D. Liang,¹⁵ S. Liang,¹⁵ X. Meng,¹⁵ J. Tao,¹⁵ J. Wang,¹⁵ X. Wang,¹⁵ Z. Wang,¹⁵ H. Xiao,¹⁵ M. Xu,¹⁵ J. Zang,¹⁵ Z. Zhang,¹⁵ C. Asawatangtrakuldee,¹⁶ Y. Ban,¹⁶ S. Guo,¹⁶ Y. Guo,¹⁶ W. Li,¹⁶ S. Liu,¹⁶ Y. Mao,¹⁶ S. J. Qian,¹⁶ H. Teng,¹⁶ D. Wang,¹⁶ L. Zhang,¹⁶ B. Zhu,¹⁶ W. Zou,¹⁶ C. Avila,¹⁷ J. P. Gomez,¹⁷ B. Gomez Moreno,¹⁷ A. F. Osorio Oliveros,¹⁷ J. C. Sanabria,¹⁷ N. Godinovic,¹⁸ D. Lelas,¹⁸ R. Plestina,^{18,g} D. Polic,¹⁸ I. Puljak,^{18,f} Z. Antunovic,¹⁹ M. Kovac,¹⁹ V. Brigljevic,²⁰ S. Duric,²⁰ K. Kadija,²⁰ J. Luetic,²⁰ S. Morovic,²⁰ A. Attikis,²¹ M. Galanti,²¹ G. Mavromanolakis,²¹ J. Mousa,²¹ C. Nicolaou,²¹ F. Ptochos,²¹ P. A. Razis,²¹ M. Finger,²² M. Finger, Jr.,²² Y. Assran,^{23,h} S. Elgammal,^{23,i} A. Ellithi Kamel,^{23,j} S. Khalil,^{23,i} M. A. Mahmoud,^{23,k} A. Radi,^{23,l,m} M. Kadastik,²⁴ M. Müntel,²⁴ M. Raidal,²⁴ L. Rebane,²⁴ A. Tiko,²⁴ P. Eerola,²⁵ G. Fedi,²⁵ M. Voutilainen,²⁵ J. Härkönen,²⁶ A. Heikkinen,²⁶ V. Karimäki,²⁶ R. Kinnunen,²⁶ M. J. Kortelainen,²⁶ T. Lampén,²⁶ K. Lassila-Perini,²⁶ S. Lehti,²⁶ T. Lindén,²⁶ P. Luukka,²⁶ T. Mäenpää,²⁶ T. Peltola,²⁶ E. Tuominen,²⁶ J. Tuominiemi,²⁶ E. Tuovinen,²⁶ D. Ungaro,²⁶ L. Wendland,²⁶ K. Banzuzi,²⁷ A. Karjalainen,²⁷ A. Korpela,²⁷ T. Tuuva,²⁷ M. Besancon,²⁸ S. Choudhury,²⁸ M. Dejardin,²⁸ D. Denegri,²⁸ B. Fabbro,²⁸ J. L. Faure,²⁸ F. Ferri,²⁸ S. Ganjour,²⁸ A. Givernaud,²⁸ P. Gras,²⁸ G. Hamel de Monchenault,²⁸ P. Jarry,²⁸ E. Locci,²⁸ J. Malcles,²⁸ L. Millischer,²⁸ A. Nayak,²⁸ J. Rander,²⁸ A. Rosowsky,²⁸ I. Shreyber,²⁸ M. Titov,²⁸ S. Baffioni,²⁹ F. Beaudette,²⁹ L. Benhabib,²⁹ L. Bianchini,²⁹ M. Bluj,^{29,n} C. Broutin,²⁹ P. Busson,²⁹ C. Charlot,²⁹ N. Daci,²⁹ T. Dahms,²⁹ L. Dobrzynski,²⁹ R. Granier de Cassagnac,²⁹ M. Haguenauer,²⁹ P. Miné,²⁹ C. Mironov,²⁹ I. N. Naranjo,²⁹ M. Nguyen,²⁹ C. Ochando,²⁹ P. Paganini,²⁹ D. Sabes,²⁹ R. Salerno,²⁹ Y. Sirois,²⁹ C. Veelken,²⁹ A. Zabi,²⁹ J.-L. Agram,^{30,o} J. Andrea,³⁰ D. Bloch,³⁰ D. Bodin,³⁰ J.-M. Brom,³⁰ M. Cardaci,³⁰ E. C. Chabert,³⁰ C. Collard,³⁰ E. Conte,^{30,o} F. Drouhin,^{30,o} C. Ferro,³⁰ J.-C. Fontaine,^{30,o} D. Gelé,³⁰ U. Goerlach,³⁰ P. Juillot,³⁰ A.-C. Le Bihan,³⁰ P. Van Hove,³⁰ F. Fassi,³¹ D. Mercier,³¹ S. Beauceron,³² N. Beaupere,³² O. Bondu,³² G. Boudoul,³² J. Chasserat,³² R. Chierici,^{32,f} D. Contardo,³² P. Depasse,³² H. El Mamouni,³² J. Fay,³² S. Gascon,³² M. Gouzevitch,³² B. Ille,³² T. Kurca,³² M. Lethuillier,³² L. Mirabito,³² S. Perries, ³² V. Sordini, ³² Y. Tschudi, ³² P. Verdier, ³² S. Viret, ³² Z. Tsamalaidze, ^{33,p} G. Anagnostou, ³⁴ S. Beranek, ³⁴ M. Edelhoff,³⁴ L. Feld,³⁴ N. Heracleous,³⁴ O. Hindrichs,³⁴ R. Jussen,³⁴ K. Klein,³⁴ J. Merz,³⁴ A. Ostapchuk,³⁴ A. Perieanu,³⁴ F. Raupach,³⁴ J. Sammet,³⁴ S. Schael,³⁴ D. Sprenger,³⁴ H. Weber,³⁴ B. Wittmer,³⁴ V. Zhukov,^{34,q} M. Ata,³⁵ J. Caudron,³⁵ E. Dietz-Laursonn,³⁵ D. Duchardt,³⁵ M. Erdmann,³⁵ R. Fischer,³⁵ A. Güth,³⁵ T. Hebbeker,³⁵ C. Heidemann,³⁵ K. Hoepfner,³⁵ D. Klingebiel,³⁵ P. Kreuzer,³⁵ C. Magass,³⁵ M. Merschmeyer,³⁵ A. Meyer,³⁵ M. Olschewski,³⁵ P. Papacz,³⁵ H. Pieta,³⁵ H. Reithler,³⁵ S. A. Schmitz,³⁵ L. Sonnenschein,³⁵ J. Steggemann,³⁵ D. Teyssier,³⁵ M. Weber,³⁵ M. Bontenackels,³⁶ V. Cherepanov,³⁶ Y. Erdogan,³⁶ G. Flügge,³⁶ H. Geenen,³⁶ M. Geisler,³⁶ W. Haj Ahmad,³⁶ F. Hoehle,³⁶ B. Kargoll,³⁶ T. Kress,³⁶ Y. Kuessel,³⁶ A. Nowack,³⁶ L. Perchalla,³⁶ O. Pooth,³⁶ P. Sauerland,³⁶ A. Stahl,³⁶ M. Aldaya Martin,³⁷ J. Behr,³⁷ W. Behrenhoff,³⁷ U. Behrens,³⁷ M. Bergholz,^{37,r} A. Bethani,³⁷ K. Borras,³⁷ A. Burgmeier,³⁷ A. Cakir,³⁷ L. Calligaris,³⁷ A. Campbell,³⁷ E. Castro,³⁷ F. Costanza,³⁷ D. Dammann,³⁷ C. Diez Pardos,³⁷ G. Eckerlin,³⁷ D. Eckstein,³⁷ G. Flucke,³⁷ A. Geiser,³⁷ I. Glushkov,³⁷ P. Gunnellini,³⁷ S. Habib,³⁷ J. Hauk,³⁷ G. Hellwig,³⁷ H. Jung,³⁷ M. Kasemann,³⁷ P. Katsas,³⁷ C. Kleinwort,³⁷ H. Kluge,³⁷ A. Knutsson,³⁷ M. Krämer,³⁷ D. Krücker,³⁷ E. Kuznetsova,³⁷ W. Lange,³⁷ W. Lohmann,^{37,r} B. Lutz,³⁷ R. Mankel,³⁷ I. Marfin,³⁷ M. Marienfeld,³⁷ I.-A. Melzer-Pellmann,³⁷ A. B. Meyer,³⁷ J. Mnich,³⁷ A. Mussgiller,³⁷ S. Naumann-Emme,³⁷ J. Olzem,³⁷ H. Perrey,³⁷ A. Petrukhin,³⁷ D. Pitzl,³⁷ A. Raspereza,³⁷ P. M. Ribeiro Cipriano,³⁷ C. Riedl,³⁷ E. Ron,³⁷ M. Rosin,³⁷ J. Salfeld-Nebgen,³⁷ R. Schmidt,^{37,r} T. Schoerner-Sadenius,³⁷ N. Sen,³⁷ A. Spiridonov,³⁷ M. Stein,³⁷ R. Walsh,³⁷ C. Wissing,³⁷ C. Autermann,³⁸ V. Blobel,³⁸ J. Draeger,³⁸ H. Enderle,³⁸ J. Erfle,³⁸ U. Gebbert,³⁸ M. Görner,³⁸ T. Hermanns,³⁸ R. S. Höing,³⁸ K. Kaschube,³⁸ G. Kaussen,³⁸ H. Kirschenmann,³⁸ R. Klanner,³⁸ J. Lange,³⁸ B. Mura,³⁸ F. Nowak,³⁸ T. Peiffer,³⁸ N. Pietsch,³⁸ D. Rathjens,³⁸ C. Sander,³⁸ H. Schettler,³⁸ P. Schleper,³⁸ E. Schlieckau,³⁸ A. Schmidt,³⁸ M. Schröder,³⁸ T. Schum,³⁸ M. Seidel,³⁸ V. Sola,³⁸ H. Stadie,³⁸ G. Steinbrück,³⁸ J. Thomsen,³⁸ L. Vanelderen,³⁸ C. Barth,³⁹ J. Berger,³⁹ C. Böser,³⁹ T. Chwalek,³⁹ W. De Boer,³⁹ A. Descroix,³⁹ A. Dierlamm,³⁹ M. Feindt,³⁹ M. Guthoff,^{39,f} C. Hackstein,³⁹ F. Hartmann,³⁹ T. Hauth,^{39,f} M. Heinrich,³⁹ H. Held,³⁹ K. H. Hoffmann,³⁹ S. Honc,³⁹ I. Katkov,^{39,q} J. R. Komaragiri,³⁹ P. Lobelle Pardo,³⁹ D. Martschei,³⁹ S. Mueller,³⁹ Th. Müller,³⁹ M. Niegel,³⁹ A. Nürnberg,³⁹ O. Oberst,³⁹ A. Oehler,³⁹ J. Ott,³⁹ G. Quast,³⁹ K. Rabbertz,³⁹ F. Ratnikov,³⁹ N. Ratnikova,³⁹ S. Röcker,³⁹ A. Scheurer,³⁹ F.-P. Schilling,³⁹ G. Schott,³⁹ H. J. Simonis,³⁹ F. M. Stober,³⁹ D. Troendle,³⁹ R. Ulrich,³⁹ J. Wagner-Kuhr,³⁹ S. Wayand,³⁹ T. Weiler,³⁹ M. Zeise,³⁹ G. Daskalakis,⁴⁰ T. Geralis,⁴⁰ S. Kesisoglou,⁴⁰

A. Kyriakis,⁴⁰ D. Loukas,⁴⁰ I. Manolakos,⁴⁰ A. Markou,⁴⁰ C. Markou,⁴⁰ C. Mavrommatis,⁴⁰ E. Ntomari,⁴⁰ L. Gouskos,⁴¹ T. J. Mertzimekis,⁴¹ A. Panagiotou,⁴¹ N. Saoulidou,⁴¹ I. Evangelou,⁴² C. Foudas,⁴² P. Kokkas,⁴² N. Manthos,⁴² I. Papadopoulos,⁴² V. Patras,⁴² G. Bencze,⁴³ C. Hajdu,⁴³ P. Hidas,⁴³ D. Horvath,^{43,s} F. Sikler,⁴³ V. Veszpremi,⁴³ G. Vesztergombi,^{43,t} N. Beni,⁴⁴ S. Czellar,⁴⁴ J. Molnar,⁴⁴ J. Palinkas,⁴⁴ Z. Szillasi,⁴⁴ J. Karancsi,⁴⁵ P. Raics,⁴⁵ Z. L. Trocsanyi,⁴⁵ B. Ujvari,⁴⁵ S. B. Beri,⁴⁶ V. Bhatnagar,⁴⁶ N. Dhingra,⁴⁶ R. Gupta,⁴⁶ M. Kaur,⁴⁶ M. Z. Mehta,⁴⁶ N. Nishu,⁴⁶ L. K. Saini,⁴⁶ A. Sharma,⁴⁶ J. B. Singh,⁴⁶ Ashok Kumar,⁴⁷ Arun Kumar,⁴⁷ S. Ahuja,⁴⁷ A. Bhardwaj,⁴⁷ B. C. Choudhary,⁴⁷ S. Malhotra,⁴⁷ M. Naimuddin,⁴⁷ K. Ranjan,⁴⁷ V. Sharma,⁴⁷ R. K. Shivpuri,⁴⁷ S. Banerjee,⁴⁸ S. Bhattacharya,⁴⁸ S. Dutta,⁴⁸ B. Gomber,⁴⁸ Sa. Jain,⁴⁸ Sh. Jain,⁴⁸ R. Khurana,⁴⁸ S. Sarkar,⁴⁸ M. Sharan,⁴⁸ A. Abdulsalam,⁴⁹ R. K. Choudhury,⁴⁹ D. Dutta,⁴⁹ S. Kailas,⁴⁹ V. Kumar,⁴⁹ P. Mehta,⁴⁹ A. K. Mohanty,^{49,f} L. M. Pant,⁴⁹ P. Shukla,⁴⁹ T. Aziz,⁵⁰ S. Ganguly,⁵⁰ M. Guchait,^{50,u} M. Maity,^{50,v} G. Majumder,⁵⁰ K. Mazumdar,⁵⁰ G. B. Mohanty,⁵⁰ B. Parida,⁵⁰ K. Sudhakar,⁵⁰ N. Wickramage,⁵⁰ S. Banerjee,⁵¹ S. Dugad,⁵¹ H. Arfaei,⁵² H. Bakhshiansohi,^{52,w} S. M. Etesami,^{52,x} A. Fahim,^{52,w} M. Hashemi,⁵² H. Hesari,⁵² A. Jafari,^{52,w} M. Khakzad,⁵² M. Mohammadi Najafabadi,⁵² S. Paktinat Mehdiabadi,⁵² B. Safarzadeh,^{52,y} M. Zeinali,^{52,x} M. Abbrescia,^{53a,53b} L. Barbone,^{53a,53b} C. Calabria,^{53a,53b,f} S. S. Chhibra,^{53a,53b} A. Colaleo,^{53a} D. Creanza,^{53a,53c} N. De Filippis, 53a,53c,f M. De Palma, 53a,53b L. Fiore, 53a G. Iaselli, 53a,53c L. Lusito, 53a,53b G. Maggi, 53a,53c M. Maggi, 53a B. Marangelli,^{53a,53b} S. My,^{53a,53c} S. Nuzzo,^{53a,53b} N. Pacifico,^{53a,53b} A. Pompili,^{53a,53b} G. Pugliese,^{53a,53c} G. Selvaggi,^{53a,53b} L. Silvestris,^{53a} G. Singh,^{53a,53b} R. Venditti,^{53a} G. Zito,^{53a} G. Abbiendi,^{54a} A. C. Benvenuti,^{54a} D. Bonacorsi,^{54a,54b} S. Braibant-Giacomelli,^{54a,54b} L. Brigliadori,^{54a,54b} P. Capiluppi,^{54a,54b} A. Castro,^{54a,54b} F. R. Cavallo,^{54a} M. Cuffiani,^{54a,54b} G. M. Dallavalle,^{54a} F. Fabbri,^{54a} A. Fanfani,^{54a,54b} D. Fasanella,^{54a,54b,f} P. Giacomelli,^{54a} C. Grandi,^{54a} L. Guiducci,^{54a,54b} S. Marcellini,^{54a} G. Masetti,^{54a} M. Meneghelli,^{54a,54b,f} A. Montanari,^{54a} F. L. Navarria,^{54a,54b} F. Odorici,^{54a} A. Perrotta,^{54a} F. Primavera,^{54a,54b} A. M. Rossi,^{54a,54b} T. Rovelli, ^{54a,54b} G. P. Siroli, ^{54a,54b} R. Travaglini, ^{54a,54b} S. Albergo, ^{55a,55b} G. Cappello, ^{55a,55b} M. Chiorboli, ^{55a,55b} S. Costa,^{55a,55b} R. Potenza,^{55a,55b} A. Tricomi,^{55a,55b} C. Tuve,^{55a,55b} G. Barbagli,^{56a} V. Ciulli,^{56a,56b} C. Civinini,^{56a} R. D'Alessandro, ^{56a,56b} E. Focardi, ^{56a,56b} S. Frosali, ^{56a,56b} E. Gallo, ^{56a} S. Gonzi, ^{56a,56b} M. Meschini, ^{56a} S. Paoletti, ^{56a} G. Sguazzoni,^{56a} A. Tropiano,^{56a} L. Benussi,⁵⁷ S. Bianco,⁵⁷ S. Colafranceschi,^{57,z} F. Fabbri,⁵⁷ D. Piccolo,⁵⁷ P. Fabbricatore,^{58a} R. Musenich,^{58a} S. Tosi,^{58a,58b} A. Benaglia,^{59a,59b} F. De Guio,^{59a,59b} L. Di Matteo,^{59a,59b,f} S. Fiorendi, ^{59a,59b} S. Gennai, ^{59a,f} A. Ghezzi, ^{59a,59b} S. Malvezzi, ^{59a} R. A. Manzoni, ^{59a,59b} A. Martelli, ^{59a,59b} A. Massironi,^{59a,59b,f} D. Menasce,^{59a} L. Moroni,^{59a} M. Paganoni,^{59a,59b} D. Pedrini,^{59a} S. Ragazzi,^{59a,59b} N. Redaelli,^{59a} S. Sala,^{59a} T. Tabarelli de Fatis,^{59a,59b} S. Buontempo,^{60a} C. A. Carrillo Montoya,^{60a} N. Cavallo,^{60a,aa} A. De Cosa,^{60a,60b,f} O. Dogangun,^{60a,60b} F. Fabozzi,^{60a,aa} A. O. M. Iorio,^{60a} L. Lista,^{60a} S. Meola,^{60a,bb}
 M. Merola,^{60a,60b} P. Paolucci,^{60a,f} P. Azzi,^{61a} N. Bacchetta,^{61a,f} D. Bisello,^{61a,61b} A. Branca,^{61a,61b,f} R. Carlin,^{61a,61b} P. Checchia,^{61a} T. Dorigo,^{61a} U. Dosselli,^{61a} F. Gasparini,^{61a,61b} U. Gasparini,^{61a,61b} A. Gozzelino,^{61a} K. Kanishchev,^{61a,61c} S. Lacaprara,^{61a} I. Lazzizzera,^{61a,61c} M. Margoni,^{61a,61b} A. T. Meneguzzo,^{61a,61b} J. Pazzini,^{61a,61b} N. Pozzobon,^{61a,61b} P. Ronchese,^{61a,61b} F. Simonetto,^{61a,61b} E. Torassa,^{61a} M. Tosi,^{61a,61b} G. Zumerle,^{61a,61b} M. Gabusi,^{62a,62b} S. P. Ratti,^{62a,62b} C. Riccardi,^{62a,62b} P. Torre, 62a,62b P. Vitulo, 62a,62b M. Biasini, 63a,63b G. M. Bilei, 63a L. Fanò, 63a,63b P. Lariccia, 63a,63b A. Lucaroni, 63a,63b,f G. Mantovani, ^{63a,63b} M. Menichelli, ^{63a} A. Nappi, ^{63a,63b,a} F. Romeo, ^{63a,63b} A. Saha, ^{63a} A. Santocchia, ^{63a,63b}
A. Spiezia, ^{63a,63b} S. Taroni, ^{63a,63b} P. Azzurri, ^{64a,64c} G. Bagliesi, ^{64a} T. Boccali, ^{64a} G. Broccolo, ^{64a,64c} R. Castaldi, ^{64a}
R. T. D'Agnolo, ^{64a,64c} R. Dell'Orso, ^{64a} F. Fiori, ^{64a,64b,f} L. Foà, ^{64a,64c} A. Giassi, ^{64a} A. Kraan, ^{64a} F. Ligabue, ^{64a,64c} T. Lomtadze,^{64a} L. Martini,^{64a,cc} A. Messineo,^{64a,64b} F. Palla,^{64a} A. Rizzi,^{64a,64b} A. T. Serban,^{64a,dd} P. Spagnolo,^{64a} P. Squillacioti,^{64a,f} R. Tenchini,^{64a} G. Tonelli,^{64a,64b,f} A. Venturi,^{64a} P. G. Verdini,^{64a} L. Barone,^{65a,65b} F. Cavallari,^{65a} D. Del Re, ^{65a,65b} M. Diemoz, ^{65a} C. Fanelli, ^{65a} M. Grassi, ^{65a,65b,f} E. Longo, ^{65a,65b} P. Meridiani, ^{65a,65b} F. Micheli, ^{65a,65b} S. Nourbakhsh, ^{65a,65b} G. Organtini, ^{65a,65b} R. Paramatti, ^{65a} S. Rahatlou, ^{65a,65b} M. Sigamani, ^{65a} L. Soffi, ^{65a,65b} N. Amapane, ^{66a,66b} R. Arcidiacono, ^{66a,66c} S. Argiro, ^{66a,66b} M. Arneodo, ^{66a,66c} C. Biino, ^{66a} N. Cartiglia, ^{66a} M. Costa,^{66a,66b} P. De Remigis,^{66a} N. Demaria,^{66a} C. Mariotti,^{66a,f} S. Maselli,^{66a} E. Migliore,^{66a,66b} V. Monaco,^{66a,66b} M. Musich,^{66a,f} M. M. Obertino,^{66a,66c} N. Pastrone,^{66a} M. Pelliccioni,^{66a} A. Potenza,^{66a,66b} A. Romero,^{66a,66b} R. Muslen, M. M. Obertnio, M. Fastione, M. Felletolin, A. Foteliza, A. Kolleto, A. Kolleto, R. Sacchi, ^{66a,66b} A. Solano, ^{66a,66b} A. Staiano, ^{66a} A. Vilela Pereira, ^{66a} S. Belforte, ^{67a} V. Candelise, ^{67a,67b} F. Cossutti, ^{67a} G. Della Ricca, ^{67a,67b} B. Gobbo, ^{67a} M. Marone, ^{67a,67b,f} D. Montanino, ^{67a,67b,f} A. Penzo, ^{67a} A. Schizzi, ^{67a,67b} S. G. Heo, ⁵³ T. Y. Kim, ⁵³ S. K. Nam, ⁵³ S. Chang, ⁵⁴ D. H. Kim, ⁵⁴ G. N. Kim, ⁵⁴ D. J. Kong, ⁵⁴ H. Park, ⁵⁴ S. R. Ro, ⁵⁴ D. C. Son, ⁵⁴ T. Son, ⁵⁴ J. Y. Kim, ⁵⁵ Zero J. Kim, ⁵⁵ S. Song, ⁵⁵ S. Choi, ⁵⁶ D. Gyun, ⁵⁶ B. Hong, ⁵⁶ M. Jo, ⁵⁶ H. Kim, ⁵⁶ T. J. Kim, ⁵⁶ K. S. Lee, ⁵⁶ D. H. Moon, ⁵⁶ S. K. Park, ⁵⁶ M. Choi, ⁵⁷ J. H. Kim, ⁵⁷ C. Park, ⁵⁷

I. C. Park,⁵⁷ S. Park,⁵⁷ G. Ryu,⁵⁷ Y. Cho,⁵⁸ Y. Choi,⁵⁸ Y. K. Choi,⁵⁸ J. Goh,⁵⁸ M. S. Kim,⁵⁸ E. Kwon,⁵⁸ B. Lee,⁵⁸ J. Lee,⁵⁸ S. Lee,⁵⁸ H. Seo,⁵⁸ I. Yu,⁵⁸ M. J. Bilinskas,⁵⁹ I. Grigelionis,⁵⁹ M. Janulis,⁵⁹ A. Juodagalvis,⁵⁹ H. Castilla-Valdez,⁶⁰ E. De La Cruz-Burelo,⁶⁰ I. Heredia-de La Cruz,⁶⁰ R. Lopez-Fernandez,⁶⁰ R. Magaña Villalba,⁶⁰ J. Martínez-Ortega,⁶⁰ A. Sánchez-Hernández,⁶⁰ L. M. Villasenor-Cendejas,⁶⁰ S. Carrillo Moreno,⁶¹ F. Vazquez Valencia,⁶¹ H. A. Salazar Ibarguen,⁶² E. Casimiro Linares,⁶³ A. Morelos Pineda,⁶³ M. A. Reyes-Santos,⁶³ D. Krofcheck,⁶⁴ A. J. Bell,⁶⁵ P. H. Butler,⁶⁵ R. Doesburg,⁶⁵ S. Reucroft,⁶⁵ H. Silverwood,⁶⁵ M. Ahmad,⁶⁶ M. H. Ansari,⁶⁶ M. I. Asghar,⁶⁶ H. R. Hoorani,⁶⁶ S. Khalid,⁶⁶ W. A. Khan,⁶⁶ T. Khurshid,⁶⁶ S. Qazi,⁶⁶ M. A. Shah,⁶⁶ M. Shoaib,⁶⁶ H. Bialkowska,⁶⁷ B. Boimska,⁶⁷ T. Frueboes,⁶⁷ R. Gokieli,⁶⁷ M. Górski,⁶⁷ M. Kazana,⁶⁷ K. Nawrocki,⁶⁷ K. Romanowska-Rybinska,⁶⁷ M. Szleper,⁶⁷ G. Wrochna,⁶⁷ P. Zalewski,⁶⁷ G. Brona,⁶⁸ K. Bunkowski,⁶⁸ M. Cwiok,⁶⁸ W. Dominik,⁶⁸ K. Doroba,⁶⁸ A. Kalinowski,⁶⁸ M. Konecki,⁶⁸ J. Krolikowski,⁶⁸ N. Almeida,⁶⁹ P. Bargassa,⁶⁹ A. David,⁶⁹ P. Faccioli,⁶⁹ P. G. Ferreira Parracho,⁶⁹ M. Gallinaro,⁶⁹ J. Seixas,⁶⁹ J. Varela,⁶⁹ P. Vischia,⁶⁹ I. Belotelov,⁷⁰ P. Bunin,⁷⁰ M. Gavrilenko,⁷⁰ I. Golutvin,⁷⁰ A. Kamenev,⁷⁰ V. Karjavin,⁷⁰ G. Kozlov,⁷⁰ A. Lanev,⁷⁰ A. Malakhov,⁷⁰ P. Moisenz,⁷⁰ V. Palichik,⁷⁰ V. Perelygin,⁷⁰ M. Savina,⁷⁰ S. Shmatov,⁷⁰ V. Smirnov,⁷⁰ A. Volodko,⁷⁰ A. Zarubin,⁷⁰ S. Evstyukhin,⁷¹ V. Golovtsov,⁷¹ Y. Ivanov,⁷¹ V. Kim,⁷¹ P. Levchenko,⁷¹ V. Murzin,⁷¹ V. Oreshkin,⁷¹ I. Smirnov,⁷¹ V. Sulimov,⁷¹ L. Uvarov,⁷¹ S. Vavilov,⁷¹ A. Vorobyev,⁷¹ An. Vorobyev,⁷¹ Yu. Andreev,⁷² A. Dermenev,⁷² S. Gninenko,⁷² N. Golubev,⁷² M. Kirsanov,⁷² N. Krasnikov,⁷² V. Matveev,⁷² A. Pashenkov,⁷² D. Tlisov,⁷² A. Toropin,⁷² V. Epshteyn,⁷³ M. Erofeeva,⁷³ V. Gavrilov,⁷³ M. Kossov,⁷³ N. Lychkovskaya,⁷³ V. Popov,⁷³ G. Safronov,⁷³ S. Semenov,⁷³ V. Stolin,⁷³ E. Vlasov,⁷³ A. Zhokin,⁷³ A. Belyaev,⁷⁴ E. Boos,⁷⁴ V. Bunichev,⁷⁴ M. Dubinin,^{74,e} L. Dudko,⁷⁴ A. Gribushin,⁷⁴ V. Klyukhin,⁷⁴ O. Kodolova,⁷⁴ I. Lokhtin,⁷⁴ A. Markina,⁷⁴ S. Obraztsov,⁷⁴ M. Perfilov,⁷⁴ S. Petrushanko,⁷⁴ A. Popov,⁷⁴ L. Sarycheva,^{74,a} V. Savrin,⁷⁴ A. Snigirev,⁷⁴ V. Andreev,⁷⁵ M. Azarkin,⁷⁵ I. Dremin,⁷⁵ M. Kirakosyan,⁷⁵ A. Leonidov,⁷⁵ G. Mesyats,⁷⁵ S. V. Rusakov,⁷⁵ A. Vinogradov,⁷⁵ I. Azhgirey,⁷⁶ I. Bayshev,⁷⁶ S. Bitioukov,⁷⁶ V. Grishin,^{76,f} V. Kachanov,⁷⁶ D. Konstantinov,⁷⁶ A. Korablev,⁷⁶ V. Krychkine,⁷⁶ V. Petrov,⁷⁶ R. Ryutin,⁷⁶ A. Sobol,⁷⁶ L. Tourtchanovitch,⁷⁶ S. Troshin,⁷⁶ N. Tyurin,⁷⁶ A. Uzunian,⁷⁶ A. Volkov,⁷⁶ P. Adzic,^{77,ee} M. Djordjevic,⁷⁷ M. Ekmedzic,⁷⁷ D. Krpic,^{77,ee} J. Milosevic,⁷⁷ M. Aguilar-Benitez,⁷⁸ J. Alcaraz Maestre,⁷⁸ P. Arce,⁷⁸ C. Battilana,⁷⁸ E. Calvo,⁷⁸ M. Cerrada,⁷⁸ M. Chamizo Llatas,⁷⁸ N. Colino,⁷⁸ B. De La Cruz,⁷⁸ A. Delgado Peris,⁷⁸ D. Domínguez Vázquez,⁷⁸ C. Fernandez Bedoya,⁷⁸ J. P. Fernández Ramos,⁷⁸ A. Ferrando,⁷⁸ J. Flix,⁷⁸ M. C. Fouz,⁷⁸ P. Garcia-Abia,⁷⁸ O. Gonzalez Lopez,⁷⁸ S. Goy Lopez,⁷⁸ J. M. Hernandez,⁷⁸ M. I. Josa,⁷⁸ G. Merino,⁷⁸ J. Puerta Pelayo,⁷⁸ A. Quintario Olmeda,⁷⁸ I. Redondo,⁷⁸ L. Romero,⁷⁸ J. Santaolalla,⁷⁸ M. S. Soares,⁷⁸ C. Willmott,⁷⁸ C. Albajar,⁷⁹ G. Codispoti,⁷⁹ J. F. de Trocóniz,⁷⁹ H. Brun,⁸⁰ J. Cuevas,⁸⁰ J. Fernandez Menendez,⁸⁰ S. Folgueras,⁸⁰ I. Gonzalez Caballero,⁸⁰ L. Lloret Iglesias,⁸⁰ J. Piedra Gomez,⁸⁰ J. A. Brochero Cifuentes,⁸¹ I. J. Cabrillo,⁸¹ A. Calderon,⁸¹ S. H. Chuang,⁸¹ J. Duarte Campderros,⁸¹ M. Felcini,^{81,ff} M. Fernandez,⁸¹ G. Gomez,⁸¹ J. Gonzalez Sanchez,⁸¹ A. Graziano,⁸¹ C. Jorda,⁸¹ A. Lopez Virto,⁸¹ J. Marco,⁸¹ R. Marco,⁸¹ C. Martinez Rivero,⁸¹ F. Matorras,⁸¹ F. J. Munoz Sanchez,⁸¹ T. Rodrigo,⁸¹ A. Y. Rodríguez-Marrero,⁸¹ A. Ruiz-Jimeno,⁸¹ L. Scodellaro,⁸¹ M. Sobron Sanudo,⁸¹ I. Vila,⁸¹ R. Vilar Cortabitarte,⁸¹ D. Abbaneo,⁸² E. Auffray,⁸² G. Auzinger,⁸² M. Bachtis,⁸² P. Baillon,⁸² A. H. Ball,⁸² D. Barney,⁸² J. F. Benitez,⁸² C. Bernet,^{82,g} G. Bianchi,⁸² P. Bloch,⁸² A. Bocci,⁸² A. Bonato,⁸² C. Botta,⁸² H. Breuker,⁸² T. Camporesi,⁸² G. Cerminara,⁸² T. Christiansen,⁸² J. A. Coarasa Perez,⁸² D. D'Enterria,⁸² A. Dabrowski,⁸² A. De Roeck,⁸² S. Di Guida,⁸² M. Dobson,⁸² N. Dupont-Sagorin,⁸² A. Elliott-Peisert,⁸² B. Frisch,⁸² W. Funk,⁸² G. Georgiou,⁸² M. Giffels,⁸² D. Gigi,⁸² K. Gill,⁸² D. Giordano,⁸² M. Giunta,⁸² F. Glege,⁸² R. Gomez-Reino Garrido,⁸² P. Govoni,⁸² S. Gowdy,⁸² R. Guida,⁸² M. Hansen,⁸² P. Harris,⁸² C. Hartl,⁸² J. Harvey,⁸² B. Hegner,⁸² A. Hinzmann,⁸² V. Innocente,⁸² P. Janot,⁸² K. Kaadze,⁸² E. Karavakis,⁸² K. Kousouris,⁸² P. Lecoq,⁸² Y.-J. Lee,⁸² P. Lenzi,⁸² C. Lourenço,⁸² N. Magini,⁸² T. Mäki,⁸² M. Malberti,⁸² L. Malgeri,⁸² M. Mannelli,⁸² L. Masetti,⁸² F. Meijers,⁸² S. Mersi,⁸² E. Meschi,⁸² R. Moser,⁸² M. U. Mozer,⁸² M. Mulders,⁸² P. Musella,⁸² E. Nesvold,⁸² T. Orimoto,⁸² L. Orsini,⁸² E. Palencia Cortezon,⁸² E. Perez,⁸² L. Perrozzi,⁸² A. Petrilli,⁸² A. Pfeiffer,⁸² M. Pierini,⁸² M. Pimiä,⁸² D. Piparo,⁸² G. Polese,⁸² L. Quertenmont,⁸² A. Racz,⁸² W. Reece,⁸² J. Rodrigues Antunes,⁸² G. Rolandi,^{82,gg} C. Rovelli,^{82,hh} M. Rovere,⁸² H. Sakulin,⁸² F. Santanastasio,⁸² C. Schäfer,⁸² C. Schwick,⁸² I. Segoni,⁸² S. Sekmen,⁸² A. Sharma,⁸² P. Siegrist,⁸² P. Silva,⁸² M. Simon,⁸² P. Sphicas,^{82,ii} D. Spiga,⁸² A. Tsirou,⁸² G. I. Veres,^{82,t} J. R. Vlimant,⁸² H. K. Wöhri,⁸² S. D. Worm,^{82,jj} W. D. Zeuner,⁸² W. Bertl,⁸³ K. Deiters,⁸³ W. Erdmann,⁸³ K. Gabathuler,⁸³ R. Horisberger,⁸³ Q. Ingram,⁸³ H. C. Kaestli,⁸³ S. König,⁸³ D. Kotlinski,⁸³ U. Langenegger,⁸³ F. Meier,⁸³ D. Renker,⁸³ T. Rohe,⁸³ J. Sibille,^{83,kk} L. Bäni,⁸⁴ P. Bortignon,⁸⁴ M. A. Buchmann,⁸⁴ B. Casal,⁸⁴ N. Chanon,⁸⁴ A. Deisher,⁸⁴ G. Dissertori,⁸⁴ M. Dittmar,⁸⁴

M. Donegà,⁸⁴ M. Dünser,⁸⁴ J. Eugster,⁸⁴ K. Freudenreich,⁸⁴ C. Grab,⁸⁴ D. Hits,⁸⁴ P. Lecomte,⁸⁴ W. Lustermann,⁸⁴ A. C. Marini,⁸⁴ P. Martinez Ruiz del Arbol,⁸⁴ N. Mohr,⁸⁴ F. Moortgat,⁸⁴ C. Nägeli,^{84,11} P. Nef,⁸⁴ F. Nessi-Tedaldi,⁸⁴ F. Pandolfi,⁸⁴ L. Pape,⁸⁴ F. Pauss,⁸⁴ M. Peruzzi,⁸⁴ F. J. Ronga,⁸⁴ M. Rossini,⁸⁴ L. Sala,⁸⁴ A. K. Sanchez,⁸⁴ A. Starodumov,^{84,mm} B. Stieger,⁸⁴ M. Takahashi,⁸⁴ L. Tauscher,^{84,a} A. Thea,⁸⁴ K. Theofilatos,⁸⁴ D. Treille,⁸⁴ C. Urscheler,⁸⁴ R. Wallny,⁸⁴ H. A. Weber,⁸⁴ L. Wehrli,⁸⁴ C. Amsler,⁸⁵ V. Chiochia,⁸⁵ S. De Visscher,⁸⁵ C. Favaro,⁸⁵ M. Ivova Rikova,⁸⁵ B. Millan Mejias,⁸⁵ P. Otiougova,⁸⁵ P. Robmann,⁸⁵ H. Snoek,⁸⁵ S. Tupputi,⁸⁵ M. Verzetti,⁸⁵ Y. H. Chang,⁸⁶ K. H. Chen,⁸⁶ C. M. Kuo,⁸⁶ S. W. Li,⁸⁶ W. Lin,⁸⁶ Z. K. Liu,⁸⁶ Y. J. Lu,⁸⁶ D. Mekterovic,⁸⁶ A. P. Singh,⁸⁶ R. Volpe,⁸⁶ S. S. Yu,⁸⁶ P. Bartalini,⁸⁷ P. Chang,⁸⁷ Y. H. Chang,⁸⁷ Y. W. Chang,⁸⁷ Y. Chao,⁸⁷ K. F. Chen,⁸⁷ C. Dietz,⁸⁷ U. Grundler,⁸⁷ W.-S. Hou,⁸⁷ Y. Hsiung,⁸⁷ K. Y. Kao,⁸⁷ Y. J. Lei,⁸⁷ R.-S. Lu,⁸⁷ D. Majumder,⁸⁷ E. Petrakou,⁸⁷ X. Shi,⁸⁷ J. G. Shiu,⁸⁷ Y. M. Tzeng,⁸⁷ X. Wan,⁸⁷ M. Wang,⁸⁷ A. Adiguzel,⁸⁸ M. N. Bakirci,^{88,nn} S. Cerci,^{88,00} C. Dozen,⁸⁸ I. Dumanoglu,⁸⁸ E. Eskut,⁸⁸ S. Girgis,⁸⁸ G. Gokbulut,⁸⁸ E. Gurpinar,⁸⁸ I. Hos,⁸⁸ E. E. Kangal,⁸⁸ T. Karaman,⁸⁸ G. Karapinar,^{88,pp} A. Kayis Topaksu,⁸⁸ G. Onengut,⁸⁸ K. Ozdemir,⁸⁸ S. Ozturk,^{88,qq} A. Polatoz,⁸⁸ K. Sogut,^{88,rr} D. Sunar Cerci,^{88,oo} B. Tali,^{88,oo} H. Topakli,^{88,nn} L. N. Vergili,⁸⁸ M. Vergili,⁸⁸ I. V. Akin,⁸⁹ T. Aliev,⁸⁹ B. Bilin,⁸⁹ S. Bilmis,⁸⁹ M. Deniz,⁸⁹ H. Gamsizkan,⁸⁹ A. M. Guler,⁸⁹ K. Ocalan,⁸⁹ A. Ozpineci,⁸⁹ M. Serin,⁸⁹ R. Sever,⁸⁹ U. E. Surat,⁸⁹ M. Yalvac,⁸⁹ E. Yildirim,⁸⁹ M. Zeyrek,⁸⁹ E. Gülmez,⁹⁰ B. Isildak,^{90,ss} M. Kaya,^{90,tt} O. Kaya,^{90,tt} S. Ozkorucuklu,^{90,uu} N. Sonmez,^{90,vv} K. Cankocak,⁹¹ L. Levchuk,⁹² F. Bostock,⁹³ J. J. Brooke,⁹³ E. Clement,⁹³ D. Cussans,⁹³ H. Flacher,⁹³ R. Frazier,⁹³ J. Goldstein,⁹³ M. Grimes, ⁹³ G. P. Heath, ⁹³ H. F. Heath, ⁹³ L. Kreczko, ⁹³ S. Metson, ⁹³ D. M. Newbold, ⁹³, ^{jj} K. Nirunpong, ⁹³ A. Poll, ⁹³ S. Senkin, ⁹³ V. J. Smith, ⁹³ T. Williams, ⁹³ L. Basso, ⁹⁴, ^{ww} K. W. Bell, ⁹⁴ A. Belyaev, ⁹⁴, ^{ww} C. Brew, ⁹⁴ R. M. Brown, ⁹⁴ D. J. A. Cockerill,⁹⁴ J. A. Coughlan,⁹⁴ K. Harder,⁹⁴ S. Harper,⁹⁴ J. Jackson,⁹⁴ B. W. Kennedy,⁹⁴ E. Olaiya,⁹⁴ D. Petyt,⁹⁴ B. C. Radburn-Smith,⁹⁴ C. H. Shepherd-Themistocleous,⁹⁴ I. R. Tomalin,⁹⁴ W. J. Womersley,⁹⁴ B. Fetyt, B. C. Radount-Sinut, C. H. Shepherd-Themistocieous, T. R. Tomain, W. J. womersley, "
R. Bainbridge, ⁹⁵ G. Ball, ⁹⁵ R. Beuselinck, ⁹⁵ O. Buchmuller, ⁹⁵ D. Colling, ⁹⁵ N. Cripps, ⁹⁵ M. Cutajar, ⁹⁵ P. Dauncey, ⁹⁵ G. Davies, ⁹⁵ M. Della Negra, ⁹⁵ W. Ferguson, ⁹⁵ J. Fulcher, ⁹⁵ D. Futyan, ⁹⁵ A. Gilbert, ⁹⁵ A. Guneratne Bryer, ⁹⁵ G. Hall, ⁹⁵ Z. Hatherell, ⁹⁵ J. Hays, ⁹⁵ G. Iles, ⁹⁵ M. Jarvis, ⁹⁵ G. Karapostoli, ⁹⁵ L. Lyons, ⁹⁵ A.-M. Magnan, ⁹⁵ J. Marrouche, ⁹⁵ B. Mathias, ⁹⁵ R. Nandi, ⁹⁵ J. Nash, ⁹⁵ A. Nikitenko, ^{95,mm} A. Papageorgiou, ⁹⁵ J. Pela, ⁹⁵ M. Pesaresi, ⁹⁵ K. Petridis,⁹⁵ M. Pioppi,^{95,xx} D. M. Raymond,⁹⁵ S. Rogerson,⁹⁵ A. Rose,⁹⁵ M. J. Ryan,⁹⁵ C. Seez,⁹⁵ P. Sharp,^{95,a} A. Sparrow,⁹⁵ M. Stoye,⁹⁵ A. Tapper,⁹⁵ M. Vazquez Acosta,⁹⁵ T. Virdee,⁹⁵ S. Wakefield,⁹⁵ N. Wardle,⁹⁵ T. Whyntie,⁹⁵ A. Sparlow, M. Stoye, A. Tappel, M. Vazquez Acosa, T. Vildee, S. Wakeheld, N. Waldle, T. Wilynde, M. Chadwick, ⁹⁶ J. E. Cole, ⁹⁶ P. R. Hobson, ⁹⁶ A. Khan, ⁹⁶ P. Kyberd, ⁹⁶ D. Leggat, ⁹⁶ D. Leslie, ⁹⁶ W. Martin, ⁹⁶ I. D. Reid, ⁹⁶ P. Symonds, ⁹⁶ L. Teodorescu, ⁹⁶ M. Turner, ⁹⁶ K. Hatakeyama, ⁹⁷ H. Liu, ⁹⁷ T. Scarborough, ⁹⁷ O. Charaf, ⁹⁸ C. Henderson, ⁹⁸ P. Rumerio, ⁹⁸ A. Avetisyan, ⁹⁹ T. Bose, ⁹⁹ C. Fantasia, ⁹⁹ A. Heister, ⁹⁹ J. St. John, ⁹⁹ P. Lawson, ⁹⁹ D. Lazic, ⁹⁹ J. Rohlf, ⁹⁹ D. Sperka, ⁹⁹ L. Sulak, ⁹⁹ J. Alimena, ¹⁰⁰ S. Bhattacharya, ¹⁰⁰ D. Cutts, ¹⁰⁰ A. Ferapontov, ¹⁰⁰ D. Lazic, ⁹⁹ J. Rohlf, ⁹⁹ D. Sperka, ⁹⁹ L. Sulak, ⁹⁹ J. Alimena, ¹⁰⁰ S. Bhattacharya, ¹⁰⁰ D. Cutts, ¹⁰⁰ A. Ferapontov, ¹⁰⁰ U. Heintz, ¹⁰⁰ S. Jabeen, ¹⁰⁰ G. Kukartsev, ¹⁰⁰ E. Laird, ¹⁰⁰ G. Landsberg, ¹⁰⁰ M. Luk, ¹⁰⁰ M. Narain, ¹⁰⁰ D. Nguyen, ¹⁰⁰ M. Segala, ¹⁰⁰ T. Sinthuprasith, ¹⁰⁰ T. Speer, ¹⁰⁰ K. V. Tsang, ¹⁰⁰ R. Breedon, ¹⁰¹ G. Breto, ¹⁰¹ M. Calderon De La Barca Sanchez, ¹⁰¹ S. Chauhan, ¹⁰¹ M. Chertok, ¹⁰¹ J. Conway, ¹⁰¹ R. Conway, ¹⁰¹ P. T. Cox, ¹⁰¹ J. Dolen, ¹⁰¹ R. Erbacher, ¹⁰¹ M. Gardner, ¹⁰¹ R. Houtz, ¹⁰¹ W. Ko, ¹⁰¹ A. Kopecky, ¹⁰¹ R. Lander, ¹⁰¹ T. Miceli, ¹⁰¹ D. Pellett, ¹⁰¹ F. Ricci-tam, ¹⁰¹ B. Rutherford, ¹⁰¹ M. Searle, ¹⁰¹ J. Smith, ¹⁰¹ M. Squires, ¹⁰¹ M. Tripathi, ¹⁰¹ R. Vasquez Sierra, ¹⁰¹ V. Andreev, ¹⁰² D. Cline, ¹⁰² R. Cousins, ¹⁰² J. Duris, ¹⁰² S. Erhan, ¹⁰² P. Everaerts, ¹⁰² C. Farrell, ¹⁰² J. Hauser, ¹⁰² M. Ignatenko, ¹⁰³ C. Jarvis, ¹⁰² C. Plager, ¹⁰² G. Rakness, ¹⁰² P. Schlein, ¹⁰³ F. Giordano, ¹⁰³ G. V. Jane, ¹⁰³ G. V. Jane, ¹⁰³ A. Luther, ¹⁰³ H. Nguyan, ¹⁰³ S. Paramagugann, ¹⁰³ V. Valdev, M. Weber, J. Babb, K. Clafe, M. E. Dinardo, J. Ellison, J. W. Gary, F. Glordano, G. Hanson, ¹⁰³ G. Y. Jeng, ^{103,yy} H. Liu, ¹⁰³ O. R. Long, ¹⁰³ A. Luthra, ¹⁰³ H. Nguyen, ¹⁰³ S. Paramesvaran, ¹⁰³ J. Sturdy, ¹⁰³ S. Sumowidagdo, ¹⁰³ R. Wilken, ¹⁰³ S. Wimpenny, ¹⁰³ W. Andrews, ¹⁰⁴ J. G. Branson, ¹⁰⁴ G. B. Cerati, ¹⁰⁴ S. Cittolin, ¹⁰⁴ D. Evans, ¹⁰⁴ F. Golf, ¹⁰⁴ A. Holzner, ¹⁰⁴ R. Kelley, ¹⁰⁴ M. Lebourgeois, ¹⁰⁴ J. Letts, ¹⁰⁴ I. Macneill, ¹⁰⁴ B. Mangano, ¹⁰⁴ S. Padhi, ¹⁰⁴ C. Palmer, ¹⁰⁴ G. Petrucciani, ¹⁰⁴ M. Pieri, ¹⁰⁴ M. Sani, ¹⁰⁴ V. Sharma, ¹⁰⁴ S. Simon, ¹⁰⁴ E. Sudano, ¹⁰⁴ M. Tadel, ¹⁰⁴ Y. Tu, ¹⁰⁴ A. Vartak, ¹⁰⁴ S. Wasserbaech, ^{104,zz} F. Würthwein, ¹⁰⁴ A. Yagil, ¹⁰⁴ J. Yoo, ¹⁰⁴ E. Sudano, ¹⁰⁷ M. Tadel, ¹⁰⁷ Y. Tu, ¹⁰⁷ A. Vartak, ¹⁰⁷ S. Wasserbaech, ¹⁰⁷ F. Würthwein, ¹⁰⁴ A. Yagil, ¹⁰⁴ J. Yoo, ¹⁰⁴ D. Barge, ¹⁰⁵ R. Bellan, ¹⁰⁵ C. Campagnari, ¹⁰⁵ M. D'Alfonso, ¹⁰⁵ T. Danielson, ¹⁰⁵ K. Flowers, ¹⁰⁵ P. Geffert, ¹⁰⁵ J. Incandela, ¹⁰⁵ C. Justus, ¹⁰⁵ P. Kalavase, ¹⁰⁵ S. A. Koay, ¹⁰⁵ D. Kovalskyi, ¹⁰⁵ V. Krutelyov, ¹⁰⁵ S. Lowette, ¹⁰⁵ N. Mccoll, ¹⁰⁵ V. Pavlunin, ¹⁰⁵ F. Rebassoo, ¹⁰⁵ J. Ribnik, ¹⁰⁵ J. Richman, ¹⁰⁵ R. Rossin, ¹⁰⁵ D. Stuart, ¹⁰⁵ W. To, ¹⁰⁵ C. West, ¹⁰⁵ A. Apresyan, ¹⁰⁶ A. Bornheim, ¹⁰⁶ Y. Chen, ¹⁰⁶ E. Di Marco, ¹⁰⁶ J. Duarte, ¹⁰⁶ M. Gataullin, ¹⁰⁶ Y. Ma, ¹⁰⁶ A. Mott, ¹⁰⁶ H. B. Newman, ¹⁰⁶ C. Rogan, ¹⁰⁶ M. Spiropulu, ¹⁰⁶ V. Timciuc, ¹⁰⁶ J. Veverka, ¹⁰⁶ R. Wilkinson, ¹⁰⁶ S. Xie, ¹⁰⁶ Y. Yang, ¹⁰⁶ R. Y. Zhu, ¹⁰⁶ B. Akgun, ¹⁰⁷ V. Azzolini, ¹⁰⁷ A. Calamba, ¹⁰⁷ R. Carroll, ¹⁰⁷ T. Ferguson, ¹⁰⁷ Y. Iiyama, ¹⁰⁷ D. W. Jang, ¹⁰⁷ Y. F. Liu, ¹⁰⁷ M. Paulini, ¹⁰⁷ H. Vogel, ¹⁰⁷ I. Vorobiev, ¹⁰⁷ J. P. Cumalat, ¹⁰⁸ B. R. Drell, ¹⁰⁸

C. J. Edelmaier,¹⁰⁸ W. T. Ford,¹⁰⁸ A. Gaz,¹⁰⁸ B. Heyburn,¹⁰⁸ E. Luiggi Lopez,¹⁰⁸ J. G. Smith,¹⁰⁸ K. Stenson,¹⁰⁸ K. A. Ulmer,¹⁰⁸ S. R. Wagner,¹⁰⁸ J. Alexander,¹⁰⁹ A. Chatterjee,¹⁰⁹ N. Eggert,¹⁰⁹ L. K. Gibbons,¹⁰⁹ B. Heltsley,¹⁰⁹ A. Khukhunaishvili,¹⁰⁹ B. Kreis,¹⁰⁹ N. Mirman,¹⁰⁹ G. Nicolas Kaufman,¹⁰⁹ J. R. Patterson,¹⁰⁹ A. Ryd,¹⁰⁹
E. Salvati,¹⁰⁹ W. Sun,¹⁰⁹ W. D. Teo,¹⁰⁹ J. Thom,¹⁰⁹ J. Thompson,¹⁰⁹ J. Tucker,¹⁰⁹ J. Vaughan,¹⁰⁹ Y. Weng,¹⁰⁹
L. Winstrom,¹⁰⁹ P. Wittich,¹⁰⁹ D. Winn,¹¹⁰ S. Abdullin,¹¹¹ M. Albrow,¹¹¹ J. Anderson,¹¹¹ L. A. T. Bauerdick,¹¹¹ L. Winström, P. Witten, D. Winn, S. Abdulini, M. Alorow, J. Anderson, L. A. I. Bauerdick, A. Beretvas,¹¹¹ J. Berryhill,¹¹¹ P.C. Bhat,¹¹¹ I. Bloch,¹¹¹ K. Burkett,¹¹¹ J. N. Butler,¹¹¹ V. Chetluru,¹¹¹
H. W. K. Cheung,¹¹¹ F. Chlebana,¹¹¹ V. D. Elvira,¹¹¹ I. Fisk,¹¹¹ J. Freeman,¹¹¹ Y. Gao,¹¹¹ D. Green,¹¹¹ O. Gutsche,¹¹¹
J. Hanlon,¹¹¹ R. M. Harris,¹¹¹ J. Hirschauer,¹¹¹ B. Hooberman,¹¹¹ S. Jindariani,¹¹¹ M. Johnson,¹¹¹ U. Joshi,¹¹¹
B. Kilminster,¹¹¹ B. Klima,¹¹¹ S. Kunori,¹¹¹ S. Kwan,¹¹¹ C. Leonidopoulos,¹¹¹ J. Linacre,¹¹¹ D. Lincoln,¹¹¹
R. Lipton,¹¹¹ J. Lykken,¹¹¹ K. Maeshima,¹¹¹ J. M. Marraffino,¹¹¹ S. Maruyama,¹¹¹ D. Mason,¹¹¹ P. McBride,¹¹¹ K. Mishra,¹¹¹ S. Mrenna,¹¹¹ Y. Musienko,^{111,aaa} C. Newman-Holmes,¹¹¹ V. O'Dell,¹¹¹ O. Prokofyev,¹¹¹ K. Mishra, ¹¹⁷ S. Mirenna, ¹¹⁷ Y. Musienko, ¹¹¹ M. J. Spalding, ¹¹¹ L. Spiegel, ¹¹¹ P. Tan, ¹¹¹ L. Taylor, ¹¹¹ S. Tkaczyk, ¹¹¹ N. V. Tran, ¹¹¹ L. Uplegger, ¹¹¹ E. W. Vaandering, ¹¹¹ R. Vidal, ¹¹¹ J. Whitmore, ¹¹¹ W. Wu, ¹¹¹ F. Yang, ¹¹¹ F. Yumiceva, ¹¹¹ J. C. Yun, ¹¹¹ D. Acosta, ¹¹² P. Avery, ¹¹² D. Bourilkov, ¹¹² M. Chen, ¹¹² T. Cheng, ¹¹² S. Das, ¹¹² M. De Gruttola, ¹¹² G. P. Di Giovanni, ¹¹² D. Dobur, ¹¹² A. Drozdetskiy, ¹¹² R. D. Field, ¹¹² M. Fisher, ¹¹² Y. Fu, ¹¹² I. K. Furic, ¹¹² J. Gartner, ¹¹² J. Hugon, ¹¹² B. Kim, ¹¹² J. Konigsberg, ¹¹² A. Korytov, ¹¹² A. Kropivnitskaya, ¹¹² T. Kypreos, ¹¹² J. F. Low, ¹¹² K. Matchev, ¹¹² P. Milenovic, ^{112,bbb} G. Mitselmakher, ¹¹² L. Muniz, ¹¹² R. Remington, ¹¹² S. Spiele, ¹¹³ A. Spiele, ¹¹³ A. Spiele, ¹¹⁴ A. Remington, ¹¹⁴ S. Kim, ¹¹² J. Spiele, ¹¹² J. Spiele, ¹¹² L. Muniz, ¹¹² R. Remington, ¹¹² Spiele, ¹¹³ A. Spiele, ¹¹⁴ A. Spiele, ¹¹⁴ A. Spiele, ¹¹⁴ A. Remington, ¹¹⁴ Spiele, ¹¹⁴ A. Spiele, ¹¹⁴ A. Spiele, ¹¹⁵ A. Korytov, ¹¹⁵ A. Kropivnitskaya, ¹¹⁶ T. Kypreos, ¹¹² J. F. Low, ¹¹² K. Matchev, ¹¹² P. Milenovic, ^{112,bbb} G. Mitselmakher, ¹¹² L. Muniz, ¹¹² R. Remington, ¹¹³ Spiele, ¹¹³ A. Spiele, ¹¹⁴ A. Spiele, ¹¹⁵ A. Spiele, ¹¹⁴ A. Spiele, ¹¹⁴ A. Spiele, ¹¹⁴ A. Spiele, ¹¹⁵ A. Spiele, ¹¹⁴ A. Spiele, ¹¹⁵ A. Spiele, ¹¹⁵ A. Spiele, ¹¹⁴ A. Spiele, ¹¹⁴ A. Spiele, ¹¹⁵ A. Spiele, ¹¹⁴ A. Spiele, ¹¹⁵ A. Spiele, ¹¹⁵ A. Spiele, ¹¹⁶ A. Spiele, ¹¹⁶ A. Spiele, ¹¹⁷ A. Spiele, ¹¹⁶ A. Spiele, ¹¹⁷ A. Spiele, ¹¹⁸ A. Spiele, ¹¹⁸ A. Spiele, ¹¹⁹ A. Spiele, ¹¹¹ A. Spi A. Rinkevicius,¹¹² P. Sellers,¹¹² N. Skhirtladze,¹¹² M. Snowball,¹¹² J. Yelton,¹¹² M. Zakaria,¹¹² V. Gaultney,¹¹³ S. Hewamanage,¹¹³ L. M. Lebolo,¹¹³ S. Linn,¹¹³ P. Markowitz,¹¹³ G. Martinez,¹¹³ J. L. Rodriguez,¹¹³ T. Adams,¹¹⁴ S. Hewamanage, ¹¹⁵ L. M. Lebolo, ¹¹⁵ S. Linn, ¹¹⁵ P. Markowitz, ¹¹⁵ G. Martinez, ¹¹⁵ J. L. Rodriguez, ¹¹⁵ T. Adams, ¹¹⁴ A. Askew, ¹¹⁴ J. Bochenek, ¹¹⁴ J. Chen, ¹¹⁴ B. Diamond, ¹¹⁴ S. V. Gleyzer, ¹¹⁴ J. Haas, ¹¹⁴ S. Hagopian, ¹¹⁴ W. Jenkins, ¹¹⁴ K. F. Johnson, ¹¹⁴ H. Prosper, ¹¹⁴ V. Veeraraghavan, ¹¹⁴ M. Weinberg, ¹¹⁴ M. Meinberg, ¹¹⁴ M. Jenkins, ¹¹⁵ M. Hohlmann, ¹¹⁵ H. Kalakhety, ¹¹⁵ I. Vodopiyanov, ¹¹⁵ M. R. Adams, ¹¹⁶ I. M. Anghel, ¹¹⁶ L. Apanasevich, ¹¹⁶ Y. Bai, ¹¹⁶ V. E. Bazterra, ¹¹⁶ R. R. Betts, ¹¹⁶ I. Bucinskaite, ¹¹⁶ J. Callner, ¹¹⁶ R. Cavanaugh, ¹¹⁶ O. Evdokimov, ¹¹⁶ L. Gauthier, ¹¹⁶ C. E. Gerber, ¹¹⁶ D. J. Hofman, ¹¹⁶ S. Khalatyan, ¹¹⁶ F. Lacroix, ¹¹⁶ M. Malek, ¹¹⁶ C. O'Brien, ¹¹⁶ C. Silkworth, ¹¹⁶ D. Strom, ¹¹⁶ N. Varelas, ¹¹⁶ U. Akgun, ¹¹⁷ E. A. Albayrak, ¹¹⁷ B. Bilki,^{117,ccc} W. Clarida,¹¹⁷ F. Duru,¹¹⁷ S. Griffiths,¹¹⁷ J.-P. Merlo,¹¹⁷ H. Mermerkaya,^{117,ddd} A. Mestvirishvili,¹¹⁷ A. Moeller,¹¹⁷ J. Nachtman,¹¹⁷ C. R. Newsom,¹¹⁷ E. Norbeck,¹¹⁷ Y. Onel,¹¹⁷ F. Ozok,¹¹⁷ S. Sen,¹¹⁷ E. Tiras,¹¹⁷ J. Wetzel,¹¹⁷ T. Yetkin,¹¹⁷ K. Yi,¹¹⁷ B. A. Barnett,¹¹⁸ B. Blumenfeld,¹¹⁸ S. Bolognesi,¹¹⁸ D. Fehling,¹¹⁸ G. Giurgiu,¹¹⁸ A. V. Gritsan,¹¹⁸ Z. J. Guo,¹¹⁸ G. Hu,¹¹⁸ P. Maksimovic,¹¹⁸ S. Rappoccio,¹¹⁸ M. Swartz,¹¹⁸ A. Whitbeck,¹¹⁸ P. Baringer,¹¹⁹ A. Bean,¹¹⁹ G. Benelli,¹¹⁹ O. Grachov,¹¹⁹ R. P. Kenny Iii,¹¹⁹ M. Murray,¹¹⁹ D. Noonan,¹¹⁹ S. Sanders,¹¹⁹ R. Stringer,¹¹⁹ G. Tinti,¹¹⁹ J. S. Wood,¹¹⁹ V. Zhukova,¹¹⁹ A. F. Barfuss,¹²⁰ T. Bolton,¹²⁰ I. Chakaberia, ¹²⁰ A. Ivanov, ¹²⁰ S. Khalil, ¹²⁰ M. Makouski, ¹²⁰ Y. Maravin, ¹²⁰ S. Shrestha, ¹²⁰ I. Svintradze, ¹²⁰ J. Gronberg, ¹²¹ D. Lange, ¹²¹ D. Wright, ¹²¹ A. Baden, ¹²² M. Boutemeur, ¹²² B. Calvert, ¹²² S. C. Eno, ¹²² J. Gronberg, ¹²¹ D. Lange, ¹²¹ D. Wright, ¹²¹ A. Baden, ¹²² M. Boutemeur, ¹²² B. Calvert, ¹²² S. C. Eno, ¹²² J. A. Gomez, ¹²² N. J. Hadley, ¹²² R. G. Kellogg, ¹²² M. Kirn, ¹²² T. Kolberg, ¹²² Y. Lu, ¹²² M. Marionneau, ¹²² A. C. Mignerey, ¹²² K. Pedro, ¹²² A. Peterman, ¹²² A. Skuja, ¹²² J. Temple, ¹²² M. B. Tonjes, ¹²² S. C. Tonwar, ¹²² E. Twedt, ¹²³ A. Apyan, ¹²³ G. Bauer, ¹²³ J. Bendavid, ¹²³ W. Busza, ¹²³ E. Butz, ¹²³ I. A. Cali, ¹²³ M. Chan, ¹²³ V. Dutta, ¹²³ G. Gomez Ceballos, ¹²³ M. Goncharov, ¹²³ K. A. Hahn, ¹²³ Y. Kim, ¹²³ M. Klute, ¹²³ K. Krajczar, ¹²³, eee W. Li, ¹²³ P. D. Luckey, ¹²³ T. Ma, ¹²³ S. Nahn, ¹²³ C. Paus, ¹²³ D. Ralph, ¹²³ C. Roland, ¹²³ G. Roland, ¹²³ M. Rudolph, ¹²³ G. S. F. Stephans, ¹²³ F. Stöckli, ¹²³ K. Sumorok, ¹²³ K. Sung, ¹²³ D. Velicanu, ¹²³ E. A. Wenger, ¹²³ R. Wolf, ¹²³ B. Wyslouch, ¹²³ M. Yang, ¹²³ Y. Yilmaz, ¹²³ A. S. Yoon, ¹²³ M. Zanetti, ¹²³ S. I. Cooper, ¹²⁴ B. Dahmes, ¹²⁴ A. De Benedetti, ¹²⁴ G. Franzoni, ¹²⁴ A. Gude, ¹²⁴ S. C. Kao, ¹²⁴ K. Klapoetke, ¹²⁴ J. Mans, ¹²⁴ J. Mans, ¹²⁵ N. Pastika,¹²⁴ R. Rusack,¹²⁴ M. Sasseville,¹²⁴ A. Singovsky,¹²⁴ N. Tambe,¹²⁴ J. Turkewitz,¹²⁴ L. M. Cremaldi,¹²⁵ R. Kroeger,¹²⁵ L. Perera,¹²⁵ R. Rahmat,¹²⁵ D. A. Sanders,¹²⁵ E. Avdeeva,¹²⁶ K. Bloom,¹²⁶ S. Bose,¹²⁶ J. Butt,¹²⁶ D. R. Claes,¹²⁶ A. Dominguez,¹²⁶ M. Eads,¹²⁶ J. Keller,¹²⁶ I. Kravchenko,¹²⁶ J. Lazo-Flores,¹²⁶ H. Malbouisson,¹²⁶ D. R. Claes, ¹²⁶ A. Dominguez, ¹²⁶ M. Eads, ¹²⁶ J. Keller, ¹²⁶ I. Kravchenko, ¹²⁶ J. Lazo-Flores, ¹²⁶ H. Malbouisson, ¹²⁶ S. Malik, ¹²⁶ G. R. Snow, ¹²⁶ U. Baur, ¹²⁷ A. Godshalk, ¹²⁷ I. Iashvili, ¹²⁷ S. Jain, ¹²⁷ A. Kharchilava, ¹²⁷ A. Kumar, ¹²⁷ S. P. Shipkowski, ¹²⁷ K. Smith, ¹²⁷ G. Alverson, ¹²⁸ E. Barberis, ¹²⁸ D. Baumgartel, ¹²⁸ M. Chasco, ¹²⁸ J. Haley, ¹²⁸ D. Nash, ¹²⁸ D. Trocino, ¹²⁸ D. Wood, ¹²⁸ J. Zhang, ¹²⁸ A. Anastassov, ¹²⁹ A. Kubik, ¹²⁹ N. Mucia, ¹²⁹ N. Odell, ¹²⁹ R. A. Ofierzynski, ¹²⁹ B. Pollack, ¹²⁹ A. Pozdnyakov, ¹²⁹ M. Schmitt, ¹²⁹ S. Stoynev, ¹²⁹ M. Velasco, ¹²⁹ S. Won, ¹²⁹ L. Antonelli, ¹³⁰ D. Berry, ¹³⁰ A. Brinkerhoff, ¹³⁰ M. Hildreth, ¹³⁰ C. Jessop, ¹³⁰ D. J. Karmgard, ¹³⁰ J. Kolb, ¹³⁰ K. Lannon, ¹³⁰ W. Luo, ¹³⁰ S. Lynch, ¹³⁰ N. Marinelli, ¹³⁰ D. M. Morse, ¹³⁰ T. Pearson, ¹³⁰ M. Planer, ¹³⁰ R. Ruchti, ¹³⁰ J. Slaunwhite, ¹³⁰ N. Valls, ¹³⁰ M. Wayne, ¹³⁰ M. Wolf, ¹³⁰ B. Bylsma, ¹³¹ L. S. Durkin, ¹³¹ C. Hill, ¹³¹ R. Hughes, ¹³¹

R. Hughes, ¹³¹ K. Kotov, ¹³¹ T. Y. Ling, ¹³¹ D. Puigh, ¹³¹ M. Rodenburg, ¹³¹ C. Vuosalo, ¹³¹ G. Williams, ¹³¹
B. L. Winer, ¹³¹ N. Adam, ¹³² E. Berry, ¹³² P. Elmer, ¹³² D. Gerbaudo, ¹³² V. Halyo, ¹³² P. Hebda, ¹³² J. Hegeman, ¹³²
A. Hunt, ¹³² P. Jindal, ¹³² D. Lopes Pegna, ¹³² P. Lujan, ¹³² D. Marlow, ¹³² T. Medvedeva, ¹³² M. Mooney, ¹³² J. Olsen, ¹³²
P. Piroué, ¹³² X. Quan, ¹³² A. Raval, ¹³² B. Safdi, ¹³² H. Saka, ¹³² D. Stickland, ¹³² C. Tully, ¹³² J. S. Werner, ¹³²
A. Zuranski, ¹³² J. G. Acosta, ¹³³ E. Brownson, ¹³³ X. T. Huang, ¹³³ A. Lopez, ¹³³ H. Mendez, ¹³³ S. Oliveros, ¹³³
J. E. Ramirez Vargas, ¹³³ A. Zatserklyaniy, ¹³³ E. Alagoz, ¹³⁴ V. E. Barnes, ¹³⁴ D. Benedetti, ¹³⁴ G. Bolla, ¹³⁴
D. Bortoletto, ¹³⁴ M. De Mattia, ¹³⁴ A. Everett, ¹³⁴ Z. Hu, ¹³⁴ M. Jones, ¹³⁴ O. Koybasi, ¹³⁴ M. Kress, ¹³⁴
D. Bortoletto, ¹³⁴ M. Leonardo, ¹³⁴ V. Maroussov, ¹³⁴ P. Merkel, ¹³⁴ D. H. Miller, ¹³⁴ N. Neumeister, ¹³⁴ I. Shipsey, ¹³⁴
D. Silvers, ¹³⁴ A. Svyatkovskiy, ¹³⁴ M. Vidal Marono, ¹³⁴ H. D. Yoo, ¹³⁴ J. Zablocki, ¹³⁴ Y. Zheng, ¹³⁶ S. Guragain, ¹³⁵
N. Parashar, ¹³⁵ A. Adair, ¹³⁶ C. Boulahouache, ¹³⁶ K. M. Ecklund, ¹³⁶ F. J. M. Geurts, ¹³⁶ B. P. Padley, ¹³⁶ R. Redjimi, ¹³⁶
J. Roberts, ¹³⁶ J. Zabel, ¹³⁶ B. Betchart, ¹³⁷ A. Bodek, ¹³⁷ Y. S. Chung, ¹³⁷ R. Covarelli, ¹³⁷ D. C. Miner, ¹³⁷
D. Vishnevskiy, ¹³⁷ M. Zielinski, ¹³⁷ A. Bhatti, ¹³⁸ R. Ciesielski, ¹³⁸ L. Demortier, ¹³⁸ K. Goulianos, ¹³⁸ G. Lungu, ¹³⁸
S. Malik, ¹³⁸ C. Mesropian, ¹³⁹ M. Park, ¹³⁹ P. Patel, ¹³⁹ Y. Gershtein, ¹³⁹ R. Gray, ¹³⁹ E. Halkiadakis, ¹³⁹
D. Hidas, ¹³⁹ A. Lath, ¹³⁹ S. Panwalkar, ¹³⁹ M. Park, ¹³⁹ R. Stone, ¹³⁹ Y. Gershtein, ¹³⁹ R. Gray, ¹³⁹ K. Rose, ¹³⁹ S. Salur, ¹³⁹ S. Schnetzer, ¹³⁹ C. Seitz, ¹³⁹ S. Somalwar, ¹³⁹ R. Stone, R. Hughes,¹³¹ K. Kotov,¹³¹ T. Y. Ling,¹³¹ D. Puigh,¹³¹ M. Rodenburg,¹³¹ C. Vuosalo,¹³¹ G. Williams,¹³¹ S. Spanier, ¹⁴⁰ Z. C. Yang, ¹⁴⁰ A. York, ¹⁴⁰ R. Eusebi, ¹⁴¹ W. Flanagan, ¹⁴¹ J. Gilmore, ¹⁴¹ T. Kamon, ¹⁴¹ M. V. Khotilovich, ¹⁴¹ R. Montalvo, ¹⁴¹ I. Osipenkov, ¹⁴¹ Y. Pakhotin, ¹⁴¹ A. Perloff, ¹⁴¹ J. Roe, ¹⁴¹ A. Safonov, ¹⁴¹ T. Sakuma, ¹⁴¹ S. Sengupta, ¹⁴¹ I. Suarez, ¹⁴¹ A. Tatarinov, ¹⁴¹ D. Toback, ¹⁴¹ N. Akchurin, ¹⁴² J. Damgov, ¹⁴² C. Dragoiu, ¹⁴² P. R. Dudero, ¹⁴² C. Jeong, ¹⁴² K. Kovitanggoon, ¹⁴² S. W. Lee, ¹⁴² T. Libeiro, ¹⁴² Y. Roh, ¹⁴² I. Volobouev, ¹⁴² E. Appelt, ¹⁴³ A. G. Delannoy, ¹⁴³ C. Florez, ¹⁴³ S. Greene, ¹⁴³ A. Gurrola, ¹⁴³ W. Johns, ¹⁴³ C. Johnston, ¹⁴³ P. Kurt, ¹⁴³ C. Maguire, ¹⁴³ A. Melo, ¹⁴³ M. Sharma, ¹⁴³ P. Sheldon, ¹⁴³ B. Snook, ¹⁴³ S. Tuo, ¹⁴³ J. Velkovska, ¹⁴³ M. W. Arenton, ¹⁴⁴ M. Balazs, ¹⁴⁴ S. Boutle, ¹⁴⁴ B. Cox, ¹⁴⁴ B. Francis, ¹⁴⁴ J. Goodell, ¹⁴⁴ R. Hirosky, ¹⁴⁴ A. A. Lee, ¹⁴⁴ C. K. ¹⁴⁴ C. K. ¹⁴⁴ C. K. ¹⁴⁴ P. V. Lee, ¹⁴⁴ C. C. ¹⁴⁴ P. V. Lee, ¹⁴⁴ C. K. ¹⁴⁴ P. V. Lee, ¹⁴⁴ P. V. Lee, ¹⁴⁵ P. K. ¹⁴⁵ P. K. ¹⁴⁴ P. ¹⁴⁴ P. ¹⁴⁴ P. V. Lee, ¹⁴⁴ P. V. Lee, ¹⁴⁵ P. K. ¹⁴⁵ P. K. ¹⁴⁴ P. ¹⁴⁴ P. ¹⁴⁴ P. V. Lee, ¹⁴⁴ P. V. Lee, ¹⁴⁵ P. ¹⁴⁵ P. ¹⁴⁴ P. ¹⁴⁴ P. ¹⁴⁴ P. ¹⁴⁴ P. ¹⁴⁵ P. ¹⁴⁵ P. ¹⁴⁵ P. ¹⁴⁴ P. ¹⁴⁴ P. ¹⁴⁴ P. ¹⁴⁴ P. ¹⁴⁵ P. ¹⁴⁵ P. ¹⁴⁵ P. ¹⁴⁴ P. ¹⁴⁴ P. ¹⁴⁴ P. ¹⁴⁵ P. ¹⁴⁵ P. ¹⁴⁵ P. ¹⁴⁴ P. ¹⁴⁵ P. ¹⁴⁴ P. ¹⁴⁵ P. ¹⁴⁴ P. ¹⁴⁵ P. ¹⁴⁵ P. ¹⁴⁵ P. ¹⁴⁴ P. ¹⁴⁵ P. ¹⁴⁴ P. ¹⁴⁴ P. ¹⁴⁴ P. ¹⁴⁴ P. ¹⁴⁵ P. ¹⁴⁴ P. ¹⁴⁵ P. ¹⁴⁵ P. ¹⁴⁵ P. ¹⁴⁴ P. ¹⁴⁵ P. ¹⁴⁴ P. ¹⁴⁵ P. J. Velkovska, ¹⁶⁵ M. W. Arenton, ¹¹⁴ M. Balazs, ¹¹⁴ S. Boutle, ¹¹⁴ B. Cox, ¹¹⁴ B. Francis, ¹¹⁴ J. Goodell, ¹¹⁴ R. Hirosky, ¹¹⁴ A. Ledovskoy, ¹⁴⁴ C. Lin, ¹⁴⁴ C. Neu, ¹⁴⁴ J. Wood, ¹⁴⁴ R. Yohay, ¹⁴⁴ S. Gollapinni, ¹⁴⁵ R. Harr, ¹⁴⁵ P. E. Karchin, ¹⁴⁵ C. Kottachchi Kankanamge Don, ¹⁴⁵ P. Lamichhane, ¹⁴⁵ A. Sakharov, ¹⁴⁵ M. Anderson, ¹⁴⁶ D. Belknap, ¹⁴⁶ L. Borrello, ¹⁴⁶ D. Carlsmith, ¹⁴⁶ M. Cepeda, ¹⁴⁶ S. Dasu, ¹⁴⁶ E. Friis, ¹⁴⁶ L. Gray, ¹⁴⁶ K. S. Grogg, ¹⁴⁶ M. Grothe, ¹⁴⁶ R. Hall-Wilton, ¹⁴⁶ M. Herndon, ¹⁴⁶ A. Hervé, ¹⁴⁶ P. Klabbers, ¹⁴⁶ J. Klukas, ¹⁴⁶ A. Lanaro, ¹⁴⁶ C. Lazaridis, ¹⁴⁶ J. Leonard, ¹⁴⁶ R. Loveless, ¹⁴⁶ A. Mohapatra, ¹⁴⁶ I. Ojalvo, ¹⁴⁶ F. Palmonari, ¹⁴⁶ G. A. Pierro, ¹⁴⁶ I. Ross, ¹⁴⁶ A. Savin, ¹⁴⁶ W. H. Smith, ¹⁴⁶ and J. Swanson¹⁴⁶

(CMS Collaboration)

¹Yerevan Physics Institute, Yerevan, Armenia

²Institut für Hochenergiephysik der OeAW, Wien, Austria

³National Centre for Particle and High Energy Physics, Minsk, Belarus

⁴Universiteit Antwerpen, Antwerpen, Belgium

⁵Vrije Universiteit Brussel, Brussel, Belgium

⁶Université Libre de Bruxelles, Bruxelles, Belgium

⁷Ghent University, Ghent, Belgium

⁸Université Catholique de Louvain, Louvain-la-Neuve, Belgium

⁹Université de Mons, Mons, Belgium

¹⁰Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

¹¹Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil

¹²Instituto de Fisica Teorica, Universidade Estadual Paulista, Sao Paulo, Brazil

¹³Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

¹⁴University of Sofia, Sofia, Bulgaria

¹⁵Institute of High Energy Physics, Beijing, China

¹⁶State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China

¹⁷Universidad de Los Andes, Bogota, Colombia

¹⁸Technical University of Split, Split, Croatia

¹⁹University of Split, Split, Croatia

²⁰Institute Rudjer Boskovic, Zagreb, Croatia

²¹University of Cyprus, Nicosia, Cyprus

²²Charles University, Prague, Czech Republic

²³Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt ²⁴National Institute of Chemical Physics and Biophysics, Tallinn, Estonia ²⁵Department of Physics, University of Helsinki, Helsinki, Finland ²⁶Helsinki Institute of Physics, Helsinki, Finland ²⁷Lappeenranta University of Technology, Lappeenranta, Finland ²⁸DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France ²⁹Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France ³⁰Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France ³¹Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France, Villeurbanne, France ³²Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France ³Institute of High Energy Physics and Informatization, Tbilisi State University, Tbilisi, Georgia ³⁴RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany ³⁵RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany ³⁶RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany ³⁷Deutsches Elektronen-Synchrotron, Hamburg, Germany ³⁸University of Hamburg, Hamburg, Germany ³⁹Institut für Experimentelle Kernphysik, Karlsruhe, Germany ⁴⁰Institute of Nuclear Physics "Demokritos", Aghia Paraskevi, Greece ⁴¹University of Athens, Athens, Greece ⁴²University of Ioánnina, Ioánnina, Greece ⁴³KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary ⁴⁴Institute of Nuclear Research ATOMKI, Debrecen, Hungary ⁴⁵University of Debrecen, Debrecen, Hungary ⁴⁶Panjab University, Chandigarh, India ⁴⁷University of Delhi, Delhi, India ⁴⁸Saha Institute of Nuclear Physics, Kolkata, India ⁴⁹Bhabha Atomic Research Centre, Mumbai, India ⁵⁰Tata Institute of Fundamental Research - EHEP, Mumbai, India ⁵¹Tata Institute of Fundamental Research - HECR, Mumbai, India ⁵²Institute for Research in Fundamental Sciences (IPM), Tehran, Iran ^{53a}INFN Sezione di Bari, Bari, Italy ^{53b}Università di Bari, Bari, Italy ⁵³ Politecnico di Bari, Bari, Italy ^{54a}INFN Sezione di Bologna, Bologna, Italy ^{54b}Università di Bologna, Bologna, Italy ^{55a}INFN Sezione di Catania, Catania, Italy ^{55b}Università di Catania, Catania, Italy ^{56a}INFN Sezione di Firenze, Firenze, Italy ^{56b}Università di Firenze, Firenze, Italy ⁵⁷INFN Laboratori Nazionali di Frascati, Frascati, Italy ^{58a}INFN Sezione di Genova, Genova, Italv ^{58b}Università di Genova, Genova, Italy ^{59a}INFN Sezione di Milano-Bicocca, Milano, Italy ^{59b}Università di Milano-Bicocca, Milano, Italy ^{60a}INFN Sezione di Napoli, Napoli, Italy ^{60b}Università di Napoli "Federico II," Napoli, Italy ^{61a}INFN Sezione di Padova, Padova, Italv ^{61b}Università di Padova, Padova, Italy ⁶¹cUniversità di Trento (Trento), Padova, Italy ^{62a}INFN Sezione di Pavia, Pavia, Italy ^{62b}Università di Pavia, Pavia, Italy ^{63a}INFN Sezione di Perugia, Perugia, Italy ^{63b}Università di Perugia, Perugia, Italy ^{64a}INFN Sezione di Pisa, Pisa, Italy ^{64b}Università di Pisa, Pisa, Italy ⁶⁴cScuola Normale Superiore di Pisa, Pisa, Italy ^{65a}INFN Sezione di Roma, Roma, Italy ^{65b}Università di Roma "La Sapienza," Roma, Italy

^{66a}INFN Sezione di Torino, Torino, Italy ^{66b}Università di Torino, Torino, Italy ^{66c}Università del Piemonte Orientale (Novara), Torino, Italy ^{67a}INFN Sezione di Trieste, Trieste, Italy ^{67b}Università di Trieste, Trieste, Italy ⁵³Kangwon National University, Chunchon, Korea ⁵⁴Kyungpook National University, Daegu, Korea ⁵⁵Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea ⁵⁶Korea University, Seoul, Korea ⁵⁷University of Seoul, Seoul, Korea ⁵⁸Sungkyunkwan University, Suwon, Korea ⁵⁹Vilnius University, Vilnius, Lithuania ⁶⁰Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico ⁶¹Universidad Iberoamericana, Mexico City, Mexico ⁶²Benemerita Universidad Autonoma de Puebla, Puebla, Mexico ⁶³Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico ⁶⁴University of Auckland, Auckland, New Zealand ⁶⁵University of Canterbury, Christchurch, New Zealand ⁶⁶National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan ⁶⁷National Centre for Nuclear Research, Swierk, Poland ⁶⁸Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland ⁶⁹Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal ⁷⁰Joint Institute for Nuclear Research, Dubna, Russia ⁷¹Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia ⁷²Institute for Nuclear Research, Moscow, Russia ⁷³Institute for Theoretical and Experimental Physics, Moscow, Russia ⁷⁴Moscow State University, Moscow, Russia ⁷⁵P.N. Lebedev Physical Institute, Moscow, Russia ⁷⁶State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia ⁷⁷University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia ⁷⁸Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain ⁷⁹Universidad Autónoma de Madrid, Madrid, Spain ⁸⁰Universidad de Oviedo, Oviedo, Spain ⁸¹Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain ⁸²CERN, European Organization for Nuclear Research, Geneva, Switzerland ⁸³Paul Scherrer Institut, Villigen, Switzerland ⁸⁴Institute for Particle Physics, ETH Zurich, Zurich, Switzerland ⁸⁵Universität Zürich, Zurich, Switzerland ⁸⁶National Central University, Chung-Li, Taiwan ⁸⁷National Taiwan University (NTU), Taipei, Taiwan ⁸⁸Cukurova University, Adana, Turkey ⁸⁹Middle East Technical University, Physics Department, Ankara, Turkey ⁹⁰Bogazici University, Istanbul, Turkey ⁹¹Istanbul Technical University, Istanbul, Turkey ⁹²National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine ⁹³University of Bristol, Bristol, United Kingdom ⁹⁴Rutherford Appleton Laboratory, Didcot, United Kingdom ⁹⁵Imperial College, London, United Kingdom ⁹⁶Brunel University, Uxbridge, United Kingdom ⁹⁷Bavlor University. Waco. Texas. USA ⁹⁸The University of Alabama, Tuscaloosa, Alabama, USA ⁹⁹Boston University, Boston, Massachusetts, USA ¹⁰⁰Brown University, Providence, Rhode Island, USA ¹⁰¹University of California, Davis, Davis, California, USA ¹⁰²University of California, Los Angeles, Los Angeles, USA ¹⁰³University of California, Riverside, Riverside, California, USA ¹⁰⁴University of California, San Diego, La Jolla, California, USA ¹⁰⁵University of California, Santa Barbara, Santa Barbara, California, USA ¹⁰⁶California Institute of Technology, Pasadena, California, USA ¹⁰⁷Carnegie Mellon University, Pittsburgh, Pennsylvania, USA ¹⁰⁸University of Colorado at Boulder, Boulder, Colorado, USA

¹⁰⁹Cornell University, Ithaca, New York, USA ¹¹⁰Fairfield University, Fairfield, Connecticut, USA ¹¹¹Fermi National Accelerator Laboratory, Batavia, Illinois, USA ¹¹²University of Florida, Gainesville, Florida, USA ¹¹³Florida International University, Miami, Florida, USA ¹¹⁴Florida State University, Tallahassee, Florida, USA ¹¹⁵Florida Institute of Technology, Melbourne, Florida, USA ¹¹⁶University of Illinois at Chicago (UIC), Chicago, Illinois, USA ¹¹⁷The University of Iowa, Iowa City, Iowa, USA ¹¹⁸Johns Hopkins University, Baltimore, Maryland, USA ¹¹⁹The University of Kansas, Lawrence, Kansas, USA ¹²⁰Kansas State University, Manhattan, Kansas, USA ¹²¹Lawrence Livermore National Laboratory, Livermore, California, USA ¹²²University of Maryland, College Park, Maryland, USA ¹²³Massachusetts Institute of Technology, Cambridge, Massachusetts, USA ¹²⁴University of Minnesota, Minneapolis, Minnesota, USA ¹²⁵University of Mississippi, Oxford, Mississippi, USA ¹²⁶University of Nebraska-Lincoln, Lincoln, Nebraska, USA ¹²⁷State University of New York at Buffalo, Buffalo, New York, USA ¹²⁸Northeastern University, Boston, Massachusetts, USA ¹²⁹Northwestern University, Evanston, Illinois, USA ¹³⁰University of Notre Dame, Notre Dame, Indiana, USA ¹³¹The Ohio State University, Columbus, Ohio, USA ¹³²Princeton University, Princeton, New Jersey, USA ¹³³University of Puerto Rico, Mayaguez, Puerto Rico ¹³⁴Purdue University, West Lafayette, Indiana, USA ¹³⁵Purdue University Calumet, Hammond, Indiana, USA ¹³⁶Rice University, Houston, Texas, USA ¹³⁷University of Rochester, Rochester, New York, USA ¹³⁸The Rockefeller University, New York, New York, USA ¹³⁹Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA ¹⁴⁰University of Tennessee, Knoxville, Tennessee, USA ¹⁴¹Texas A&M University, College Station, Texas, USA ¹⁴²Texas Tech University, Lubbock, Texas, USA ¹⁴³Vanderbilt University, Nashville, Tennessee, USA ¹⁴⁴University of Virginia, Charlottesville, Virginia, USA

¹⁴⁵Wayne State University, Detroit, Michigan, USA

¹⁴⁶University of Wisconsin, Madison, Wisconsin, USA

^aDeceased.

^bAlso at Vienna University of Technology, Vienna, Austria.

^cAlso at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia.

^dAlso at Universidade Federal do ABC, Santo Andre, Brazil.

^eAlso at California Institute of Technology, Pasadena, CA, USA.

^fAlso at CERN, European Organization for Nuclear Research, Geneva, Switzerland.

^gAlso at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France.

^hAlso at Suez Canal University, Suez, Egypt.

ⁱAlso at Zewail City of Science and Technology, Zewail, Egypt.

^jAlso at Cairo University, Cairo, Egypt.

^kAlso at Fayoum University, El-Fayoum, Egypt.

¹Also at British University, Cairo, Egypt.

^mNow at Ain Shams University, Cairo, Egypt.

ⁿAlso at National Centre for Nuclear Research, Swierk, Poland.

^oAlso at Université de Haute-Alsace, Mulhouse, France.

^pNow at Joint Institute for Nuclear Research, Dubna, Russia.

^qAlso at Moscow State University, Moscow, Russia.

^rAlso at Brandenburg University of Technology, Cottbus, Germany.

^sAlso at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.

^tAlso at Eötvös Loránd University, Budapest, Hungary.

S. CHATRCHYAN et al.

- ^uAlso at Tata Institute of Fundamental Research HECR, Mumbai, India.
- ^vAlso at University of Visva-Bharati, Santiniketan, India.
- ^wAlso at Sharif University of Technology, Tehran, Iran.
- ^xAlso at Isfahan University of Technology, Isfahan, Iran.
- ^yAlso at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Teheran, Iran.
- ^zAlso at Facoltà Ingegneria Università di Roma, Roma, Italy.
- ^{aa}Also at Università della Basilicata, Potenza, Italy.
- ^{bb}Also at Università degli Studi Guglielmo Marconi, Roma, Italy.
- ^{cc}Also at Università degli Studi di Siena, Siena, Italy.
- ^{dd}Also at University of Bucharest, Faculty of Physics, Bucuresti-Magurele, Romania.
- ^{ee}Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia.
- ^{ff}Also at University of California, Los Angeles, Los Angeles, CA, USA.
- ^{gg}Also at Scuola Normale e Sezione dell' INFN, Pisa, Italy.
- ^{hh}Also at INFN Sezione di Roma, Università di Roma "La Sapienza," Roma, Italy.
- ⁱⁱAlso at University of Athens, Athens, Greece.
- ^{jj}Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.
- ^{kk}Also at The University of Kansas, Lawrence, KS, USA.
- ¹¹Also at Paul Scherrer Institut, Villigen, Switzerland.
- ^{mm}Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.
- ⁿⁿAlso at Gaziosmanpasa University, Tokat, Turkey.
- ^{oo}Also at Adiyaman University, Adiyaman, Turkey.
- ^{pp}Also at Izmir Institute of Technology, Izmir, Turkey.
- ^{qq}Also at The University of Iowa, Iowa City, IA, USA.
- ^{rr}Also at Mersin University, Mersin, Turkey.
- ^{ss}Also at Ozyegin University, Istanbul, Turkey.
- ^{tt}Also at Kafkas University, Kars, Turkey.
- ^{uu}Also at Suleyman Demirel University, Isparta, Turkey.
- ^{vv}Also at Ege University, Izmir, Turkey.
- ^{ww}Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
- ^{xx}Also at INFN Sezione di Perugia, Università di Perugia, Perugia, Italy.
- ^{yy}Also at University of Sydney, Sydney, Australia.
- ^{zz}Also at Utah Valley University, Orem, UT, USA.
- ^{aaa}Also at Institute for Nuclear Research, Moscow, Russia.
- ^{bbb}Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.
- ^{ccc}Also at Argonne National Laboratory, Argonne, IL, USA.
- ^{ddd}Also at Erzincan University, Erzincan, Turkey.
- eee Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary.
- ^{fff}Also at Kyungpook National University, Daegu, Korea.