Repository Istituzionale dei Prodotti della Ricerca del Politecnico di Bari

Search for exotic resonances decaying into WZ/ZZ in pp collisions at root s=7 TeV

This is a post print of the following article

Original Citation:
Search for exotic resonances decaying into WZ/ZZ in pp collisions at root s=7 TeV / Chatrchyan, S; Khachatryan, V; Sirunyan, Am; Tumasyan, A; Adam, W; Aguilo, E; Bergauer, T; Dragicevic, M; Ero, J; Fabjan, C; Friedl, M; Fruhwirth, R; Ghete, Vm; Hammer, J; Hormann, N; Hrubec, J; Jeitler, M; Kiesenhofer, W; Knunz, V; Krammer, M; Kratschmer, I; Liko, D; Mikulec, I; Pernicka, M; Rahbaran, B; Rohringer, C; Rohringer, H; Schofbeck, R; Strauss, J; Taurok, A; Waltenberger, W; Walzel, G; Widl, E; Wulz, Ce; Mossolov, V; Shumeiko, N; Gonzalez, Js; Bansal, M; Bansal, S; Cornelis, T; De Wolf, Ea; Janssen, X; Luyckx, S; Mucibello, L; Ochesanu, S; Roland, B; Rougny, R; Selvaggi, M; Staykova, Z; Van Haevermaet, H; Van Mechelen, P; Van Remortel, N; Van Spilbeeck, A; Blekman, F; Blyweert, S; D'Hondt, J; Suarez, Rg; Kalogeropoulos, A; Maes, M; Olbrechts, A; Van Doninck, W; Van Mulders, P; Van Onsem, Gp; Villella, I; Clerbaux, B; De Lentdecker, G; Dero, V; Gay, Apr; Hreus, T; Leonard, A; Marage, Pe; Mohammadi, A; Reis, T; Thomas, L; Vander Marcken, G; Vander Velde, C; Vanlaer, P; Wang, J; Adler, V; Beernaert, K; Cimmino, A; Costantini, S; Garcia, G; Grunewald, M; Klein, B; Lellouch, J; Marinov, A; Mccartin, J; Rios, Aao; 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; Forthomme, L; Giammanco, A; Hollar, J; Lemaitre, V; Liao, J; Militaru, O; Nuttens, C; Pagano, D; Pin, A; Piotrzkowski, K; Schul, N; Garcia, Jmv; Beliy, N; Caebergs, T; Daubie, E; Hammad, Gh; Alves, Ga; Martins, Mc; Damiao, Dd; Martins, T; Pol, Me; Souza, Mhg; Alda, Wl; Carvalho, W; Custodio, A; Da Costa, Em; Martins, Cd; De Souza, Sf; Figueiredo, Dm; Mundim, L; Nogima, H; Oguri, V; Da Silva, Wlp; Santoro, A; Jorge, Ls; Sznajder, A; Anjos, Ts; Bernardes, Ca; Dias, Fa; Tomei, Trfp; Gregores, Em; Lagana, C; Marinho, F; Mercadante, Pg; Novaes, Sf; Padula, Ss; Genchev, V; Iaydjiev, P; Piperov, S; Rodozov, M; Stoykova, S; Sultanov, G; Tcholakov, V; Trayanov, R; Vutova, M; Dimitrov, A; Hadjiiska, R; Kozhuharov, V; Litov, L; Pavlov, B; Petkov, P; Bian, Jg; Chen, Gm; Chen, Hs; Jiang, Ch; 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, Y; Li, W; Liu, S; Mao, Y; Qian, Sj; Teng, H; Wang, D; Zhang, L; Zou, W; Avila, C; Gomez, Jp; Moreno, Bg; Oliveros, Afo; Sanabria, Jc; 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, Pa; Finger, M; Finger, M; Assran, Y; Elgammal, S; Kamel, Ae; Mahmoud, Ma; Radi, A; Kadastik, M; Muntel, M; Raidal, M; Rebane, L; Tiko, A; Eerola, P; Fedi, G; Voutilainen, M; Harkonen, J; Heikkinen, A; Karimaki, V; Kinnunen, R; Kortelainen, Mj; 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; Korpela, A; Tuuva, T; Besancon, M; Choudhury, S; Dejardin, M; Denegri, D; Fabbro, B; Faure, Jl; Ferri, F; Ganjour, S; Givernaud, A; Gras, P; de Monchenault, Gh; 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; Broutin, C; Busson, P; Charlot, C; Daci, N; Dahms, T; Dobrzynski, L; de Cassagnac, Rg; Haguenauer, M; Mine, P; Mironov, C; Naranjo, In; Nguyen, M; Ochando, C; Paganini, P; Sabes, D; Salerno, R; Sirois, Y; Veelken, C; Zabi, A; Agram, Jl; Andrea, J; Bloch, D; Bodin, D; Brom, Jm; Cardaci, M; Chabert, Ec; Collard, C; Conte, E; Drouhin, F; Ferro, C; Fontaine, Jc; Gele, D; Goerlach, U; Juillot, P; Le Bihan, Ac; 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; Sgandurra, L; Sordini, V; Tschudi, Y; Verdier, P; Viret, S; Tsamalaidze, Z; Anagnostou, G; Autermann, C; Beranek, S; Edelhoff, M; Feld, L; Heracleous, N; Hindrichs, O; Jussen, R; Klein, K; Merz, J;

Availability:
This version is available at http://hdl.handle.net/11589/3265 since:

Published version
DOI:10.1007/JHEP02(2013)036

Publisher:

Terms of use:
(Article begins on next page)

10 October 2024

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; Guth, A; Hebbeker, T; Heidemann, C; Hoepfner, K; Klingebiel, D; Kreuzer, P; Merschmeyer, M; Meyer, A; Olschewski, M; Papacz, P; Pieta, H; Reithler, H; Schmitz, Sa; Sonnenschein, L; Steggemann, J; Teyssier, D; Weber, M; Bontenackels, M; Cherepanov, V; Erdogan, Y; Flugge, G; Geenen, H; Geisler, M; Ahmad, Wh; Hoehle, F; Kargoll, B; Kress, T; Kuessel, Y; Lingemann, J; Nowack, A; Perchalla, L; Pooth, O; Sauerland, P; Stahl, A; Martin, Ma; 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, Cd; 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; Kramer, M; Krucker, D; Kuznetsova, E; Lange, W; Lohmann, W; Lutz, B; Mankel, R; Marfin, I; Marienfeld, M; Melzer Pellmann, Ia; Meyer, Ab; Mnich, J; Mussgiller, A; Naumann Emme, S; Novgorodova, O; Olzem, J; Perrey, H; Petrukhin, A; Pitzl, D; Raspereza, A; Cipriano, Pmr; Riedl, C; Ron, E; Rosin, M; Salfeld Nebgen, J; Schmidt, R; Schoerner Sadenius, T; Sen, N; Spiridonov, A; Stein, M; Walsh, R; Wissing, C; Blobel, V; Draeger, J; Enderle, H; Erfle, J; Gebbert, U; Gorner, M; Hermanns, T; Hoing, Rs; 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; Schroder, M; Schum, T; Seidel, M; Sola, V; Stadie, H; Steinbruck, G; Thomsen, J; Vanelderen, L; Barth, C; Berger, J; Boser, 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, Kh; Honc, S; Katkov, I; Komaragiri, Jr; Pardo, Pl; Martschei, D; Mueller, S; Muller, T; Niegel, M; Nurnberg, A; Oberst, O; Oehler, A; Ott, J; Quast, G; Rabbertz, K; Ratnikov, F; Ratnikova, N; Rocker, S; Scheurer, A; Schilling, Fp; Schott, G; Simonis, Hj; Stober, Fm; 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, Tj; 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, Zl; Ujvari, B; Beri, Sb; Bhatnagar, V; Dhingra, N; Gupta, R; Kaur, M; Mehta, Mz; Nishu, N; Saini, Lk; Sharma, A; Singh, Jb; Kumar, A; Kumar, A; Ahuja, S; Bhardwaj, A; Choudhary, Bc; Malhotra, S; Naimuddin, M; Ranjan, K; Sharma, V; Shivpuri, Rk; Banerjee, S; Bhattacharya, S; Dutta, S; Gomber, B; Jain, S; Jain, S; Khurana, R; Sarkar, S; Sharan, M; Abdulsalam, A; Choudhury, Rk; Dutta, D; Kailas, S; Kumar, V; Mehta, P; Mohanty, Ak; Pant, Lm; Shukla, P; Aziz, T; Ganguly, S; Guchait, M; Maity, M; Majumder, G; Mazumdar, K; Mohanty, Gb; Parida, B; Sudhakar, K; Wickramage, N; Banerjee, S; Dugad, S; Arfaei, H; Bakhshiansohi, H; Etesami, Sm; Fahim, A; Hashemi, M; Hesari, H; Jafari, A; Khakzad, M; Najafabadi, Mm; Mehdiabadi, Sp; Safarzadeh, B; Zeinali, M; Abbrescia, M; Barbone, L; Calabria, C; Chhibra, Simranjit Singh; 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, Ac; Bonacorsi, D; Braibant Giacomelli, S; Brigliadori, L; Capiluppi, P; Castro, A; Cavallo, Fr; Cuffiani, M; Dallavalle, Gm; Fabbri, F; Fanfani, A; Fasanella, D; Giacomelli, P; Grandi, C; Guiducci, L; Marcellini, S; Masetti, G; Meneghelli, M; Montanari, A; Navarria, Fl; Odorici, F; Perrotta, A; Primavera, F; Rossi, Am; Rovelli, T; Siroli, Gp; 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, Ra; Martelli, A; Massironi, A; Menasce, D; Moroni, L; Paganoni, M; Pedrini, D; Ragazzi, S; Redaelli, N; Sala, S; de Fatis, Tt; Buontempo, S; Montoya, Cac; Cavallo, N; De Cosa, A; Dogangun, O; Fabozzi, F; Iorio, Aom; 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, At; Pazzini, J; Pozzobon, N; Ronchese, P; Simonetto, F; Torassa, E; Tosi, M; Vanini, S; Zotto, P; Zumerle, G; Gabusi, M; Ratti, Sp; Riccardi, C; Torre, P; Vitulo, P; Biasini, M; Bilei, Gm; 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; Bernardini, J; Boccali, T; Broccolo, G; Castaldi, R; D'Agnolo, Rt; Dell'Orso, R; Fiori, F; Foa, L; Giassi, A; Kraan, A; Ligabue, F; Lomtadze, T; Martini, L; Messineo, A; Palla, F; Rizzi, A; Serban, At; Spagnolo, P; Squillacioti, P; Tenchini, R; Tonelli, G; Venturi, A; Verdini, Pg; 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; Demaria, N; Mariotti, C; Maselli, S; Migliore, E; Monaco, V; Musich, M; Obertino, Mm; Pastrone, N; Pelliccioni, M; Potenza, A; Romero, A; Sacchi, R; Solano, A; Staiano, A; Trapani, Pp; Pereira, Av; Belforte, S; Candelise, V; Casarsa, M; Cossutti, F; Della Ricca, G; Gobbo, B; Marone, M; Montanino, D; Penzo, A; Schizzi, A; Heo, Sc; Kim, Ty; Nam, Sk; Chang, S; Kim, Dh; Kim, Gn; Kong, Dj; Park, H; Ro, Sr; Son, Dc; Son, T; Kim, Jy; Kim, Zj; Song, S; Choi, S; Gyun, D; Hong, B; Jo, M; Kim, H; Kim, Tj; Lee, Ks; Moon, Dh; Park, Sk; Choi, M; Kim, Jh; Park, C; Park, Ic; Park, S; Ryu, G; Cho, Y; Choi, Y; Choi, Yk; Goh, J; Kim, Ms; Kwon, E; Lee, B; Lee, J; Lee, S; Seo, H; Yu, I; Bilinskas, Mj; Grigelionis, I; Janulis, M; Juodagalvis, A; Castilla Valdez, H; De La Cruz Burelo, E; Heredia de la Cruz, I; Lopez Fernandez, R; Villalba, Rm; Martinez Ortega, J; Sanchez Hernandez, A; Villasenor Cendejas, Lm; Moreno, Sc; Valencia, Fv; Ibarguen, Has; Linares, Ec; Pineda, Am; Reyes Santos, Ma; Krofcheck, D; Bell, Aj; Butler, Ph; Doesburg, R; Reucroft, S; Silverwood, H; Ahmad, M; Ansari, Mh; Asghar, Mi; Hoorani, Hr; Khalid, S; Khan, Wa; Khurshid, T; Qazi, S; Shah, Ma; 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; Parracho, Pcf; Gallinaro, M; Seixas, J; Varela, J; Vischia, P; Belotelov, I; Golutvin, I; Gorbunov, I; Kamenev, A; Karjavin, V; Konoplyanikov, 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, A; Andreev, Y; 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; Ershov, A; Gribushin, A; Klyukhin, V; Kodolova, O; Lokhtin, I; Markina, A; Obraztsov, S; Perfilov, M; Petrushanko, S; Popov, A; Sarycheva, L; Savrin, V; Andreev, V; Azarkin, M; Dremin, I; Kirakosyan, M; Leonidov, A; Mesyats, G; Rusakov, Sv; Vinogradov, A; Azhgirey, I; Bayshev, I; Bitioukov, S; Grishin, V; Kachanov, V; Konstantinov, D; 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; Maestre, Ja; Arce, P; Battilana, C; Calvo, E; Cerrada, M; Llatas, Mc; Colino, N; De La Cruz, B; Peris, Ad; Vazquez, Dd; Bedoya, Cf; Ramos, Jpf; Ferrando, A; Flix, J; Fouz, Mc; Garcia Abia, P; Lopez, Og; Lopez, Sg; Hernandez, Jm; Josa, Mi; Merino, G; Pelayo, Jp; Olmeda, Aq; Redondo, I; Romero, L; Santaolalla, J; Soares, Ms; Willmott, C; Albajar, C; Codispoti, G; de Troconiz, Jf; Brun, H; Cuevas, J; Menendez, Jf; Folgueras, S; Caballero, Ig; Iglesias, Ll; Gomez, Jp; Cifuentes, Jab; Cabrillo, Ij; Calderon, A; Chuang, Sh; Campderros, Jd; Felcini, M; Fernandez, M; Gomez, G; Sanchez, Jg; Graziano, A; Jorda, C; Virto, Al; Marco, J; Marco, R; Rivero, Cm; Matorras, F; Sanchez, Fjm; Rodrigo, T; Rodriguez Marrero, Ay; Ruiz Jimeno, A; Scodellaro, L; Vila, I; Cortabitarte, Rv; Abbaneo, D; Auffray, E; Auzinger, G; Bachtis, M; Baillon, P; Ball, Ah; Barney, D; Benitez, Jf; Bernet, C; Bianchi, G; Bloch, P; Bocci, A; Bonato, A; Botta, C; Breuker, H; Camporesi, T; Cerminara, G; Christiansen, T; Perez, Jac; 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; Girone, M; Giunta, M; Glege, F; Garrido, Rgr; 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, Yj; 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, Mu; Mulders, M; Musella, P; Nesvold, E; Orimoto, T; Orsini, L; Cortezon, Ep; Perez, E; Perrozzi, L; Petrilli, A; Pfeiffer, A; Pierini, M; Pimia, M; Piparo, D; Polese, G; Quertenmont, L; Racz, A; Reece, W; Antunes, Jr; Rolandi, G; Rovelli, C; Rovere, M; Sakulin, H; Santanastasio, F; Schafer, C; Schwick, C; Segoni, I; Sekmen, S; Sharma, A; Siegrist, P; Silva, P; Simon, M; Sphicas, P; Spiga, D; Tsirou, A; Veres, Gi; Vlimant, Jr; Wohri, Hk; Worm, Sd; Zeuner, Wd; Bertl, W; Deiters, K; Erdmann, W; Gabathuler, K; Horisberger, R; Ingram, Q; Kaestli, Hc; Konig, S; Kotlinski, D; Langenegger, U; Meier, F; Renker, D; Rohe, T; Sibille, J; Bani, L; Bortignon, P; Buchmann, Ma; Casal, B; Chanon, N; Deisher, A; Dissertori, G; Dittmar, M; Donega, M; Dunser, M; Eugster, J; Freudenreich, K; Grab, C; Hits, D; Lecomte, P; Lustermann, W; Marini, Ac; del Arbol, Pmr; Mohr, N; Moortgat, F; Nageli, C; Nef, P; Nessi Tedaldi, F; Pandolfi, F; Pape, L; Pauss, F; Peruzzi, M; Ronga, Fj; Rossini, M; Sala, L; Sanchez, Ak; Starodumov, A; Stieger, B; Takahashi, M; Tauscher, L; Thea, A; Theofilatos, K; Treille, D; Urscheler, C; Wallny, R; Weber, Ha; Wehrli, L; Amsler, C; Chiochia, V; De Visscher, S; Favaro, C; Rikova, Mi; Mejias, Bm; Otiougova, P; Robmann, P; Snoek, H; Tupputi, S; Verzetti, M; Chang, Yh; Chen, Kh; Kuo, Cm; Li, Sw; Lin, W; Liu, Zk; Lu, Yj; Mekterovic, D; Singh, Ap; Volpe, R; Yu, Ss; Bartalini, P; Chang, P; Chang, Yh; Chang, Yw; Chao, Y; Chen, Kf; Dietz, C; Grundler, U; Hou, Ws; Hsiung, Y; Kao, Ky; Lei, Yj; Lu, Rs; Majumder, D; Petrakou, E; Shi, X; Shiu, Jg; Tzeng, Ym; Wan, X; Wang, M; Asavapibhop, B; Srimanobhas, N; Adiguzel, A; Bakirci, Mn; Cerci, S; Dozen, C; Dumanoglu, I; Eskut, E; Girgis, S; Gokbulut, G; Gurpinar, E; Hos, I; Kangal, Ee; Karaman, T; Karapinar, G; Topaksu, Ak; Onengut, G; Ozdemir, K; Ozturk, S; Polatoz, A; Sogut, K; Cerci, Ds; Tali, B; Topakli, H; Vergili, Ln; Vergili, M; Akin, Iv; Aliev, T; Bilin, B; Bilmis, S; Deniz, M; Gamsizkan, H; Guler, Am; Ocalan, K; Ozpineci, A; Serin, M; Sever, R; Surat, Ue; Yalvac, M; Yildirim, E; Zeyrek, M; Gulmez, E; Isildak, B; Kaya, M; Kaya, O; Ozkorucuklu, S; Sonmez, N; Cankocak, K; Levchuk, L; Bostock, F; Brooke, Jj; Clement, E; Cussans, D; Flacher, H; Frazier, R; Goldstein, J; Grimes, M; Heath, Gp; Heath, Hf; Kreczko, L; Metson, S; Newbold, Dm; Nirunpong, K; Poll, A; Senkin, S; Smith, Vj; Williams, T; Basso, L; Bell, Kw; Belyaev, A; Brew, C; Brown, Rm; Cockerill, Dja; Coughlan, Ja; Harder, K; Harper, S; Jackson, J; Kennedy, Bw; Olaiya, E; Petyt, D; Radburn Smith, Bc; Shepherd Themistocleous, Ch; Tomalin, Ir; Womersley, Wj; 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, Ag; Hall, G; Hatherell, Z; Hays, J; Iles, G; Jarvis, M; Karapostoli, G; Lyons, L; Magnan, Am; Marrouche, J; Mathias, B; Nandi, R; Nash, J; Nikitenko, A; Papageorgiou, A; Pela, J; Pesaresi, M; Petridis, K; Pioppi, M; Raymond, Dm; Rogerson, S; Rose, A; Ryan, Mj; Seez, C; Sharp, P; Sparrow, A; Stoye, M; Tapper, A; Acosta, Mv; Virdee, T; Wakefield, S; Wardle, N; Whyntie, T; Chadwick, M; Cole, Je; Hobson, Pr; Khan, A; Kyberd, P; Leggat, D; Leslie, D; Martin, W; Reid, Id; 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, Kv; Breedon, R; Breto, G; Sanchez, Mcd; Chauhan, S; Chertok, M; Conway, J; Conway, R; Cox, Pt; 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, Rv; 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, Me; Ellison, J; Gary, Jw; Giordano, F; Hanson, G; Jeng, Gy; Liu, H; Long, Or; Luthra, A; Nguyen, H; Paramesvaran, S; Sturdy, J; Sumowidagdo, S; Wilken, R; Wimpenny, S; Andrews, W; Branson, Jg; Cerati, Gb; 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; Wurthwein, 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, Sa; 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, Hb; Rogan, C; Spiropulu, M; Timciuc, V; Veverka, J; Wilkinson, R; Xie, S; Yang, Y; Zhu, Ry; Akgun, B; Azzolini, V; Calamba, A; Carroll, R; Ferguson, T; Iiyama, Y; Jang, Dw; Liu, Yf; Paulini, M; Vogel, H; Vorobiev, I; Cumalat, Jp; Drell, Br; Edelmaier, Cj; Ford, Wt; Gaz, A; Heyburn, B; Lopez, El; Smith, Jg; Stenson, K; Ulmer, Ka; Wagner, Sr; Alexander, J; Chatterjee, A; Eggert, N; Gibbons, Lk; Heltsley, B; Khukhunaishvili, A; Kreis, B; Mirman, N; Kaufman, Gn; Patterson, Jr; Ryd, A; Salvati, E; Sun, W; Teo, Wd; Thom, J; Thompson, J; Tucker, J; Vaughan, J; Weng, Y; Winstrom, L; Wittich, P; Winn, D; Abdullin, S; Albrow, M; Anderson, J; Bauerdick, Lat; Beretvas, A; Berryhill, J; Bhat, Pc; Bloch, I; Burkett, K; Butler, Jn; Chetluru, V; Cheung, Hwk; Chlebana, F; Elvira, Vd; Fisk, I; Freeman, J; Gao, Y; Green, D; Gutsche, O; Hanlon, J; Harris, Rm; 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, Jm; 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, Wj; Spiegel, L; Tan, P; Taylor, L; Tkaczyk, S; Tran, Nv; Uplegger, L; Vaandering, Ew; Vidal, R; Whitmore, J; W, Wu; Yang, F; Yumiceva, F; Yun, Jc; Acosta, D; Avery, P; Bourilkov, D; Chen, M; Cheng, T; Das, S; De Gruttola, M; Di Giovanni, Gp; Dobur, D; Drozdetskiy, A; Field, Rd; Fisher, M; Fu, Y; Furic, Ik; Gartner, J; Hugon, J; Kim, B; Konigsberg, J; Korytov, A; Kropivnitskaya, A; Kypreos, T; Low, Jf; Matchev, K; Milenovic, P; Mitselmakher, G; Muniz, L; Park, M; Remington, R; Rinkevicius, A; Sellers, P; Skhirtladze, N; Snowball, M; Yelton, J; Zakaria, M; Gaultney, V; Hewamanage, S; Lebolo, Lm; Linn, S; Markowitz, P; Martinez, G; Rodriguez, Jl; Adams, T; Askew, A; Bochenek, J; Chen, J; Diamond, B; Gleyzer, Sv; Haas, J; Hagopian, S; Hagopian, V; Jenkins, M; Johnson, Kf; Prosper, H; Veeraraghavan, V; Weinberg, M; Baarmand, Mm; Dorney, B; Hohlmann, M; Kalakhety, H; Vodopiyanov, I; Adams, Mr; Anghel, Im; Apanasevich, L; Bai, Y; Bazterra, Ve; Betts, Rr; Bucinskaite, I; Callner, J; Cavanaugh, R; Evdokimov, O; Gauthier, L; Gerber, Ce; Hofman, Dj; Khalatyan, S; Lacroix, F; Malek, M; O'Brien, C; Silkworth, C; Strom, D; Turner, P; Varelas, N; Akgun, U; Albayrak, Ea; Bilki, B; Clarida, W; Duru, F; Griffiths, S; Merlo, Jp; Mermerkaya, H; Mestvirishvili, A; Moeller, A; Nachtman, J; Newsom, Cr; Norbeck, E; Onel, Y; Ozok, F; Sen, S; Tiras, E; Wetzel, J; Yetkin, T; Yi, K; Barnett, Ba; Blumenfeld, B; Bolognesi, S; Fehling, D; Giurgiu, G; Gritsan, Av; Guo, Zj; Hu, G; Maksimovic, P; Rappoccio, S; Swartz, M; Whitbeck, A; Baringer, P; Bean, A; Benelli, G; Kenny, Rp; Murray, M; Noonan, D; Sanders, S; Stringer, R; Tinti, G; Wood, Js; Zhukova, V; Barfuss, Af; 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, Sc; Gomez, Ja; Hadley, Nj; Kellogg, Rg; Kirn, M; Kolberg, T; Lu, Y; Marionneau, M; Mignerey, Ac; Pedro, K; Peterman, A; Skuja, A; Temple, J; Tonjes, Mb; Tonwar, Sc; Twedt, E; Apyan, A; Bauer, G; Bendavid, J; Busza, W; Butz, E; Cali, Ia; Chan, M; Dutta, V; Ceballos, Gg; Goncharov, M; Hahn, Ka; Kim, Y; Klute, M; Krajczar, K; Li, W; Luckey, Pd; Ma, T; Nahn, S; Paus, C; Ralph, D; Roland, C; Roland, G; Rudolph, M; Stephans, Gsf; Stockli, F; Sumorok, K; Sung, K; Velicanu, D; Wenger, Ea; Wolf, R; Wyslouch, B; Yang, M; Yilmaz, Y; Yoon, As; Zanetti, M; Cooper, Si; Dahmes, B; De Benedetti, A; Franzoni, G; Gude, A; Kao, Sc; Klapoetke, K; Kubota, Y; Mans, J; Pastika, N; Rusack, R; Sasseville, M; Singovsky, A; Tambe, N; Turkewitz, J; Cremaldi, Lm; Kroeger, R; Perera, L; Rahmat, R; Sanders, Da; Avdeeva, E; Bloom, K; Bose, S; Butt, J; Claes, Dr; Dominguez, A; Eads, M; Keller, J; Kravchenko, I; Lazo Flores, J; Malbouisson, H; Malik, S; Snow, Gr; Baur, U; Godshalk, A; Iashvili, I; Jain, S; Kharchilava, A; Kumar, A; Shipkowski, Sp; 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, Ra; Pollack, B; Pozdnyakov, A; Schmitt, M; Stoynev, S; Velasco, M; Won, S; Antonelli, L; Berry, D; Brinkerhoff, A; Hildreth, M; Jessop, C; Karmgard, Dj; Kolb, J; Lannon, K; Luo, W; Lynch, S; Marinelli, N; Morse, Dm; Pearson, T; Planer, M; Ruchti, R; Slaunwhite, J; Valls, N; Wayne, M; Wolf, M; Bylsma, B; Durkin, Ls; Hill, C; Hughes, R; Kotov, K; Ling, Ty; Puigh, D; Rodenburg, M; Vuosalo, C; Williams, G; Winer, Bl; Adam, N; Berry, E; Elmer, P; Gerbaudo, D; Halyo, V; Hebda, P; Hegeman, J; Hunt, A; Jindal, P; Pegna, Dl; 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, Js; Zuranski, A; Acosta, Jg; Brownson, E; Huang, Xt; Lopez, A; Mendez, H; Oliveros, S; Vargas, Jer; Zatserklyaniy, A; Alagoz, E; Barnes, Ve; Benedetti, D; Bolla, G; Bortoletto, D; De Mattia, M; Everett, A; Hu, Z; Jones, M; Koybasi, O; Kress, M; Laasanen, At; Leonardo, N; Maroussov, V; Merkel, P; Miller, Dh; Neumeister, N; Shipsey, I; Silvers, D; Svyatkovskiy, A; Marono, Mv; Yoo, Hd; Zablocki, J; Zheng, Y; Guragain, S; Parashar, N; Adair, A; Boulahouache, C; Ecklund, Km; Geurts, Fjm; Padley, Bp; Redjimi, R; Roberts, J; Zabel, J; Betchart, B; Bodek, A; Chung, Ys; Covarelli, R; de Barbaro, P; Demina, R; Eshaq, Y; Ferbel, T; Garcia Bellido, A; Goldenzweig, P; Han, J; Harel, A; Miner, Dc; Vishnevskiy, D; Zielinski, M; Bhatti, A; Ciesielski, R; Demortier, L; Goulianos, K; Lungu, G; Malik, S; Mesropian, C; Arora, S; Barker, A; Chou, Jp; 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, Zc; 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, Pr; Jeong, C; Kovitanggoon, K; Lee, Sw; Libeiro, T; Roh, Y; Volobouev, I; Appelt, E; Delannoy, Ag; 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, Mw; 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, Pe; Don, Ckk; Lamichhane, P; Sakharov, A; Anderson, M; Belknap, Da; Borrello, L; Carlsmith, D; Cepeda, M; Dasu, S; Friis, E; Gray, L; Grogg, Ks; 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, Ga; Ross, I; Savin, A; Smith, Wh; Swanson, J.. - In: JOURNAL OF HIGH ENERGY PHYSICS. - ISSN 1029-8479. - 2(2013). [10.1007/JHEP02(2013)036]

12 October 2024

Published for SISSA by Springer

Received: *November 25, 2012*
Accepted: *January 9, 2013*
Published: *February 7, 2013*

Search for exotic resonances decaying into WZ/ZZ in pp collisions at $\sqrt{s} = 7$ TeV

The CMS collaboration

E-mail: cms-publication-committee-chair@cern.ch

Abstract: A search for new exotic particles decaying to the VZ final state is performed, where V is either a W or a Z boson decaying into two overlapping jets and the Z decays into a pair of electrons, muons or neutrinos. The analysis uses a data sample of pp collisions corresponding to an integrated luminosity of $5\,\mathrm{fb}^{-1}$ collected by the CMS experiment at the LHC at $\sqrt{s} = 7$ TeV in 2011. No significant excess is observed in the mass distribution of the VZ candidates compared with the background expectation from standard model processes. Model-dependent upper limits at the 95% confidence level are set on the product of the cross section times the branching fraction of hypothetical particles decaying to the VZ final state as a function of mass. Sequential standard model W' bosons with masses between 700 and 940 GeV are excluded. In the Randall-Sundrum model for graviton resonances with a coupling parameter of 0.05, masses between 750 and 880 GeV are also excluded.

Keywords: Hadron-Hadron Scattering

ArXiv ePrint: 1211.5779

Open Access, Copyright CERN,
for the benefit of the CMS collaboration

doi:10.1007/JHEP02(2013)036

JHEP02(2013)036

Contents

1 Introduction **1**

2 The CMS detector **2**

3 Collision data and Monte Carlo samples **3**

4 Reconstruction and event selection **5**
- 4.1 Dilepton channels 5
- 4.2 $E_{\mathrm{T}}^{\mathrm{miss}}$ channel 6

5 Background estimation **7**
- 5.1 Dilepton channels 7
- 5.2 $E_{\mathrm{T}}^{\mathrm{miss}}$ channel 8

6 Systematic uncertainties **10**
- 6.1 Background systematic effects 10
  - 6.1.1 Dilepton channels 10
  - 6.1.2 $E_{\mathrm{T}}^{\mathrm{miss}}$ channel 12
- 6.2 Signal systematics 13
  - 6.2.1 Dilepton channels 13
  - 6.2.2 $E_{\mathrm{T}}^{\mathrm{miss}}$ channel channel 14

7 Results **14**

8 Summary **17**

The CMS collaboration **24**

1 Introduction

In many extensions of the standard model (SM) of particle physics [1–3] the spontaneous breaking of the electroweak (EW) symmetry [4–9] is associated with new strong dynamics appearing at the TeV scale. For instance, the origin of the new dynamics may be due to new interactions [10–12], compact extra dimensions [13, 14], or a composite Higgs boson [15, 16]. In such scenarios the SM is an effective low-energy theory, valid for energies smaller than a new-physics scale Λ. In these theories, one expects the existence of new resonances coupling to pairs of vector bosons (ZZ, WZ, and WW). A minimal ultraviolet completion of this effective theory for composite models is described in ref. [17]. Other examples include Randall-Sundrum (RS) gravitons $\mathrm{G_{KK}}$ [13, 14] coupled to ZZ and WW, or technimesons [18,

JHEP02(2013)036

19] coupled to WZ. Limits from previous searches and from indirect bounds (e.g. in the EW sector and flavor physics) place the masses of these proposed RS resonances at or above the TeV scale [20–26]. These scenarios could be tested at the Large Hadron Collider (LHC), as long as $\Lambda \sim \mathcal{O}(\text{TeV})$, as suggested by the EW symmetry breaking scale. This analysis is sensitive to searches for resonances starting at 700 GeV and above. However, there are other theories that predict light resonances (e.g. low-scale technicolor) [18, 19].

In this Letter we present a search for heavy resonances decaying to WZ and ZZ final states, with one boson being a Z decaying to leptons, namely $\text{Z} \to \ell^+\ell^-$ ($\ell = \mu,\ \text{e}$) or $\nu\overline{\nu}$, and the second boson decays to hadrons, V (V=W, Z) $\to \text{q}\overline{\text{q}}$. For heavy resonances the decay of each V produces a highly boosted system in which the two fermions are emitted within a small opening angle in the laboratory frame. The hadronization of the $\text{V} \to \text{q}\overline{\text{q}}$ quarks would then produce two partially overlapping jets reconstructed as a single jet with mass close to the V mass, a topology very different from that of a typical quark or gluon jet. Monte Carlo (MC) simulations suggest that more than ∼70% of the decays would produce a merged-jet topology for resonances heavier than ∼800 GeV. This feature is exploited in a VZ final state, to discriminate a possible signal from the SM background (mainly coming from Z+jets events).

Thus, in this study we consider three final states: one heavy jet and either $\text{Z} \to \text{e}^+\text{e}^-$, $\text{Z} \to \mu^+\mu^-$, or $\text{Z} \to E_{\text{T}}^{\text{miss}}$, where $E_{\text{T}}^{\text{miss}}$ is the characteristic signature of neutrino production. We characterize the signal as a peak in the invariant mass of the VZ system (transverse mass in the case of $\text{Z} \to \nu\overline{\nu}$ decays). The search is performed with a data sample of pp collisions corresponding to an integrated luminosity of $5.0\,\text{fb}^{-1}$ collected by the Compact Muon Solenoid (CMS) detector at the LHC at $\sqrt{s} = 7\,\text{TeV}$ in 2011.

Results are presented in terms of two benchmark scenarios: i) the Sequential Standard Model (SSM) in which a new gauge boson W' with the same couplings as the SM W boson decays to a WZ pair; ii) a RS graviton, G_{KK}, decaying to ZZ. In both scenarios we search for resonances heavier than 700 GeV, where the considered boosted topology becomes relevant. The ratio of the 5-dimensional curvature to the reduced Planck mass ($k/\overline{M}_{\text{Pl}}$), which acts as the coupling constant in the RS model, is typically used as the phenomenological parameter in RS graviton searches. For the RS graviton scenario we consider values of the coupling parameter $k/\overline{M}_{\text{Pl}}$ up to 0.3.

Previous searches have been carried out in the context of both the SSM W' and RS graviton theoretical models. The most stringent limits have been produced at the LHC by the ATLAS and CMS collaborations in a large number of final states: $\text{W}' \to \ell\nu$ [27, 28], $\text{W}' \to \text{tb}$ [29, 30], $\text{W}' \to \text{WZ} \to 3\ell\nu$ [31, 32], and $\text{G}_{\text{KK}} \to \ell\ell$ [23, 33], $\text{G}_{\text{KK}} \to \gamma\gamma$ [24, 34] and $\text{G}_{\text{KK}} \to \text{ZZ} \to \ell\ell jj$ [35, 36].

2 The CMS detector

Here a brief description of the CMS detector is given with an emphasis on the elements most relevant for this analysis. A more detailed description can be found elsewhere [37]. A cylindrical coordinate system about the beam axis is used, in which the polar angle θ is measured with respect to the counterclockwise beam direction and the azimuthal angle,

JHEP02(2013)036

ϕ, is measured in the x-y plane in radians, where the x axis points towards the center of the LHC ring. The quantity η is the pseudorapidity, defined as $\eta = -\ln[\tan(\theta/2)]$. The layout comprises a superconducting solenoid providing a uniform magnetic field of 3.8 T. The bore of the solenoid is instrumented with various particle detection systems. The inner tracking system is composed of a pixel detector with three barrel layers at radii between 4.4 and 10.2 cm and a silicon strip tracker with 10 barrel detection layers extending outwards to a radius of 1.1 m. Each system is completed by two end-caps, extending the acceptance up to $|\eta| < 2.5$. A lead-tungstate crystal electromagnetic calorimeter with fine transverse $(\Delta\eta, \Delta\phi)$ granularity and a brass/scintillator hadronic calorimeter surround the tracking volume and cover the region $|\eta| < 3$. CMS also has extensive forward calorimetry. The steel return yoke outside the solenoid is instrumented with gas-ionization detectors which are used to identify muons in the range $|\eta| < 2.4$. The barrel region is covered by drift tube chambers and the end cap region by cathode strip chambers, each complemented by resistive plate chambers.

3 Collision data and Monte Carlo samples

The preselection of the datasets for the analysis is different for the "dilepton" (VZ$\rightarrow$ $\mathrm{q\bar{q}}\,\ell^+\ell^-$, $\ell = \mathrm{e}, \mu$) and the "$E_{\mathrm{T}}^{\mathrm{miss}}$" (VZ$\rightarrow$ $\mathrm{q\bar{q}}\,\nu\bar{\nu}$) channels. For the dilepton channels, we consider events that were recorded with double-electron or single-muon triggers. The trigger thresholds changed with time, as a consequence of the increasing peak luminosity and the changes in running conditions. The tightest thresholds used in the trigger (i.e. 40 GeV for the single-muon trigger and 17 GeV for the dielectron trigger) are looser than the corresponding offline analysis requirements. Typical trigger efficiencies exceed 83% (95%) for the electron (muon) triggers. For the $E_{\mathrm{T}}^{\mathrm{miss}}$ channel, we use triggers requiring at least one calorimetric jet and missing transverse energy. These triggers have efficiencies of more than 99% for events with a leading jet of transverse momentum $p_{\mathrm{T}} > 160$ GeV and $E_{\mathrm{T}}^{\mathrm{miss}} > 300$ GeV after offline reconstruction and corrections, which allows resonances heavier than 1000 GeV to be probed with an efficiency above 20%. We use MC samples to study the signal and background. We consider the SM background processes that could contribute with two leptons and a (massive) jet in the final state. The summary of the signal samples is given in table 1, and the background samples, in table 2. The PYTHIA 6.424 [38] leading-order (LO) generator with tune Z2 [39] is used to generate the signal events and simulate the parton showering, with a full simulation of the detector based on GEANT4 9.4 package. Mass-dependent K factors are applied. For the $\mathrm{G_{KK}}$ analysis, next-to-leading order (NLO) corrections are calculated using the "two cutoff phase space slicing" method [40, 41] in the diphoton final state. For the W′ analysis, the next-to-next-to-leading order (NNLO) corrections are calculated with FEWZ [42] in the leptonic final state. These K factors are used for lack of better (N)NLO calculations for the final states considered. The background samples are generated using the MADGRAPH 5.1.1.0 matrix-element generator [43, 44], while PYTHIA is used for the parton showering and hadronization, with the same version and tuning as for signal samples. The parton distribution function (PDF) used is CTEQ6L1 [45]. Jets are matched to partons using the MLM scheme [46].

JHEP02(2013)036

Mass (GeV)	Cross section (pb)		K factor
	$G_{KK} \to q\bar{q}\,\ell^+\ell^-$ (e^+e^- or $\mu^+\mu^-$)	$G_{KK} \to q\bar{q}\,\nu\bar{\nu}$	
750	8.35×10^{-3}	5.03×10^{-2}	1.75
1000	1.52×10^{-3}	9.09×10^{-3}	1.78
1250	3.47×10^{-4}	2.16×10^{-3}	1.79
1500	8.83×10^{-5}	5.24×10^{-4}	1.78
1750	3.43×10^{-5}	2.04×10^{-4}	1.76
2000	7.05×10^{-6}	4.18×10^{-5}	1.76
	$W' \to q\bar{q}\,\ell^+\ell^-$ (e^+e^- or $\mu^+\mu^-$)	$W' \to q\bar{q}\,\nu\bar{\nu}$	
700	1.267×10^{-2}	7.45×10^{-2}	1.35
800	6.815×10^{-3}	4.06×10^{-2}	1.35
900	3.842×10^{-3}	2.31×10^{-2}	1.34
1000	2.286×10^{-3}	1.39×10^{-2}	1.33
1100	1.413×10^{-3}	8.45×10^{-3}	1.32
1200	8.955×10^{-4}	5.34×10^{-3}	1.31
1300	5.750×10^{-4}	3.42×10^{-3}	1.30
1400	3.784×10^{-4}	2.27×10^{-3}	1.28
1500	2.554×10^{-4}	1.50×10^{-3}	1.26

Table 1. Signal Monte Carlo samples. The listed cross sections are PYTHIA LO, per channel (e^+e^- or $\mu^+\mu^-$ or $\nu\bar{\nu}$). The notation $\nu\bar{\nu}$ includes all three neutrino flavors. The K factors comprise NLO (NNLO) corrections for the G_{KK} (W') samples. The G_{KK} samples are generated with $k/\overline{M}_{Pl} = 0.05$.

Channel	Cross section (pb)	Simulation Details
Dilepton Channels		
W+jets	212.5	LO ($p_T^W > 100\,\text{GeV}$)
$t\bar{t}$	157.5	NLO
γV+jets	56.5	LO
$Z/\gamma^*(\ell^+\ell^-)$+jets	25.1	LO ($p_T^Z > 100\,\text{GeV}$)
$W(\ell\nu)\,W(\ell\nu)$+jets	3.8	LO
$W(q\bar{q})\,Z(\ell^+\ell^-)$+jets	1.14	LO
$Z(q\bar{q})\,Z(\ell^+\ell^-)$+jets	0.57	LO
E_T^{miss} Channel		
QCD multijets	5856.0	LO ($500 < H_T < 1000\,\text{GeV}$)
QCD multijets	122.6	LO ($H_T > 1000\,\text{GeV}$)
$Z/\gamma(\nu\bar{\nu})$ + jets	32.92	LO ($H_T > 200\,\text{GeV}$)

Table 2. Background Monte Carlo samples. The notation ℓ stands for electrons, muons, or taus. The notation $\nu\bar{\nu}$ includes all three neutrino flavors.

JHEP02(2013)036

4 Reconstruction and event selection

Events are required to have at least one primary vertex of good quality, where the vertex is reconstructed within ± 24 cm of the nominal interaction point along the beam axis, with a transverse distance from the beam spot of less than 2 cm [47]. The events are reconstructed with the particle-flow (PF) technique [48]. The PF algorithm reconstructs a complete list of particle candidates in each event from the measurements in all the components of the CMS detector in an integrated fashion. The algorithm separately identifies muons, electrons, photons, charged and neutral hadrons. Charged hadrons that are consistent with primary vertices other than the leading one (defined as the vertex with the largest sum of track p_{T}^2) are removed from the collection of particle candidates used to reconstruct the jets, to mitigate the effects of multiple proton-proton interactions within the same bunch crossing (pileup). Electrons are reconstructed as isolated objects in the calorimeters which satisfy requirements on the shower shape and the ratio of the hadronic to the electromagnetic energy deposits. Due to the boosted topology of this analysis, some care is needed when reconstructing the $\mathrm{Z} \to \mathrm{e}^+\mathrm{e}^-$ decay: each reconstructed electron interferes with the isolation definition of the other electron and has to be excluded from the isolation calculation in order to avoid introducing inefficiencies. The isolation criterion for electrons is the combined relative isolation R_{iso} built upon information from the tracker, ECAL and HCAL. In calculating R_{iso}, the track momenta and energy deposits, excluding those associated with the electron itself, are summed in a cone of radius $\Delta R < 0.3$ around the electron direction, where $\Delta R \equiv \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$, and divided by the electron transverse momentum. Muon tracks are built by combining a track from the inner tracker and a track from the outer muon system. No explicit isolation requirement is imposed on the muon candidates. Lepton (electron and muon) candidates are required to have a transverse (longitudinal) distance to the leading vertex smaller than 2 (5) mm. Jets are clustered from the reconstructed PF particles using the infrared-safe anti-k_{T} [49] algorithm with a distance parameter of 0.7, as implemented in FASTJET [50, 51]. The jet momentum is determined as the vector sum of all particle momenta in the jet, and is found in the simulated data to be within 5% to 10% of the true momentum of the generator-level jet over the whole p_{T} spectrum and detector acceptance [52]. An area-based correction is applied to take into account the extra energy clustered in jets due to additional proton-proton interactions within the same bunch crossing, and for the average effect of out-of-time pileup interactions [53, 54]. Jet energy corrections are derived from the energy balance of dijet and photon+jet events. Additional selection criteria are applied to each event to remove spurious jet-like features originating from isolated noise patterns from the hadron or the electromagnetic calorimeters. The offline missing-transverse-momentum vector ($\vec{p_{\mathrm{T}}}^{\mathrm{miss}}$) is calculated as the negative vector sum of the transverse momenta of all PF particles reconstructed in the event, and its magnitude is denoted by $E_{\mathrm{T}}^{\mathrm{miss}}$.

4.1 Dilepton channels

Candidate events are required to have at least two good quality reconstructed leptons within the detector acceptance ($|\eta| < 2.5$ for electrons and $|\eta| < 2.4$ for muons, with at

JHEP02(2013)036

least one muon within $|\eta| < 2.1$ at the trigger level) with $p_{\mathrm{T}} > 45\,\mathrm{GeV}$. We also require at least one jet in the event reconstructed with $p_{\mathrm{T}} > 30\,\mathrm{GeV}$ within $|\eta| < 2.4$.

Whenever two same-flavor, opposite-sign leptons are found in the event, a Z candidate is formed summing the four-momenta of the leptons. We select the Z candidates by requiring their invariant mass to be in the range $70 < M_{\mathrm{Z}} < 110\,\mathrm{GeV}$ and with a transverse momentum $p_{\mathrm{T}}^{\mathrm{Z}} > 150\,\mathrm{GeV}$. If there are multiple Z candidates, the one with mass closest to the nominal Z mass is selected. The requirement that the dimuon mass is consistent with a $\mathrm{Z} \to \mu^+\mu^-$ decay strongly suppresses non-prompt muons from jets.

The V candidate is selected by requiring a reconstructed jet with $p_{\mathrm{T}} > 250\,\mathrm{GeV}$ and $|\eta| < 2.4$, having an invariant mass M_j (computed from the jet energy and momentum calculated as the vector sum of the four-momenta of the constituent PF particles) such that $65 < M_j < 120\,\mathrm{GeV}$. We require the jet to be well separated from the two leptons forming the Z candidate: $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} > 1.0$ for each lepton, where $\Delta\eta$ ($\Delta\phi$) is the pseudorapidity (azimuthal) distance between the jet and the lepton directions. The selection has been optimized by maximizing the quantity $N_{\mathrm{S}}/\sqrt{N_{\mathrm{S}} + N_{\mathrm{B}}}$ (where N_{S} and N_{B} are the number of expected signal and background events) for the lowest W' mass point (700 GeV) considered in this search.

Once the $\mathrm{Z} \to \ell\ell$ and (mono-jet) $\mathrm{V} \to \mathrm{q}\bar{\mathrm{q}}$ candidates have been reconstructed, we combine their four momenta to compute the mass of the parent particle, M_{VZ}. This variable is used to evaluate the hypothesis of the signal presence in the data sets analyzed.

4.2 $E_{\mathrm{T}}^{\mathrm{miss}}$ channel

For the $E_{\mathrm{T}}^{\mathrm{miss}}$ channel, background from W-boson decays is reduced through rejection of events with isolated electrons or muons with $p_{\mathrm{T}} > 20\,\mathrm{GeV}$. In order to further reduce leptonic backgrounds, we veto on the presence of isolated tracks. For all tracks with $p_{\mathrm{T}} > 10\,\mathrm{GeV}$ and $|\eta| < 2.4$, a hollow cone of $0.02 < \Delta R < 0.30$ is constructed. The isolation parameter of each track is defined as the scalar sum of all tracks with $p_{\mathrm{T}} > 1\,\mathrm{GeV}$ inside the cone, divided by the p_{T} of the track. Events containing a track with its isolation parameter smaller than 0.1 are discarded. Events are then selected if the jet with the highest transverse momentum has $p_{\mathrm{T}} > 300\,\mathrm{GeV}$ and $|\eta| < 2.4$, and $E_{\mathrm{T}}^{\mathrm{miss}}$ is larger than 300 GeV. In order to reduce the number of QCD multijet background events in the signal region, events with more than two jets with $p_{\mathrm{T}} > 30\,\mathrm{GeV}$ and $|\eta| < 2.4$ are discarded. Events with exactly two jets above 30 GeV are retained, if the azimuthal angle $\Delta\phi$ between the two jets is smaller than 2.8 radians. This condition improves the signal over background ratio by reducing the number of QCD dijet background events.

The signal sample is defined as the set of events that meet two extra requirements: the invariant mass of the leading jet, M_j, is larger than 70 GeV, and the jet-$E_{\mathrm{T}}^{\mathrm{miss}}$ transverse mass, defined as

$$M_{\mathrm{T}} = \sqrt{2\, p_{\mathrm{T}}^{\mathrm{jet}}\, E_{\mathrm{T}}^{\mathrm{miss}} \left[1 - \cos\Delta\phi(\mathrm{jet}, p_{\mathrm{T}}^{\mathrm{miss}})\right]}\ ,$$

is larger than 900 GeV. Figure 1 on the left (right) shows the two-dimensional M_{T} *vs* M_j distribution for the simulated SM backgrounds (for a simulated signal sample with $M_{\mathrm{G_{KK}}}$ = 1250 GeV).

JHEP02(2013)036

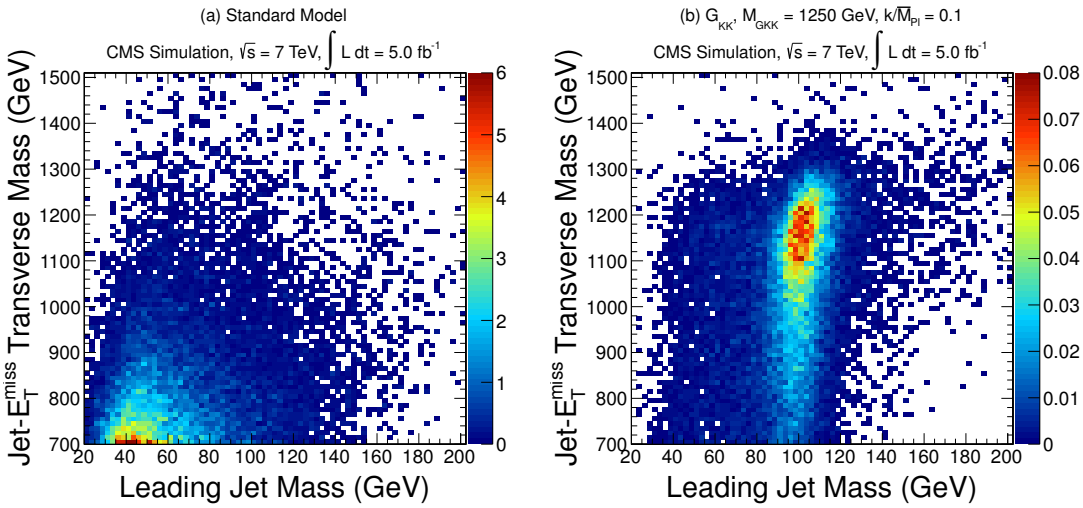

Figure 1. Distributions of leading jet plus $E_{\mathrm{T}}^{\mathrm{miss}}$ transverse mass *vs.* leading jet mass for simulated standard model background sample (left) and RS graviton signal with $M_{\mathrm{G_{KK}}} = 1250\,\mathrm{GeV}$ and $k/\overline{M}_{\mathrm{Pl}} = 0.05$ sample (right).

In contrast to the approach used for the dilepton channels, here we perform a single "event counting" experiment by comparing the number of expected background and observed events integrated over the region $M_j > 70\,\mathrm{GeV}$ and $M_{\mathrm{T}} > 900\,\mathrm{GeV}$.

5 Background estimation

We are discussing the background estimation separately for the dilepton and $E_{\mathrm{T}}^{\mathrm{miss}}$ channels.

5.1 Dilepton channels

The analysis of the simulated data shows that the dominant (∼90%) background after all selection requirements is the inclusive Z production ("Z+jets"), with additional contributions from $\mathrm{t\bar{t}}$+jets and the continuum SM diboson production (WZ and ZZ). The shape and the overall normalization of the expected background M_{VZ} distributions are derived from data, with additional cross-checks carried out with the inclusive simulated background samples. Effects caused by pileup are modeled by adding to the generated events multiple proton-proton interactions with a multiplicity distribution matched to the luminosity profile of the collision data.

The background is modeled using a control region consisting of a sideband in M_j ($30 < M_j < 65\,\mathrm{GeV}$). The remaining selections are applied unmodified to these events, providing a sample that is kinematically equivalent to the nominal selection. The robustness of this method against pileup effects, jet energy scale uncertainties, and variations in the sideband range has been confirmed with dedicated studies (section 6).

The procedure is as follows: we first produce the M_{VZ} distribution for the sideband selection. We define the ratio $\alpha(M_{\mathrm{VZ}})$ as the total number of Monte Carlo background entries in the M_{VZ} spectrum with the nominal ($65 < M_j < 120\,\mathrm{GeV}$) and sideband ($30 <$

JHEP02(2013)036

$M_j < 65\,\text{GeV}$) selections:

$$\alpha(M_{\text{VZ}}) = \frac{N_{\text{NS}}(M_{\text{VZ}})}{N_{\text{SB}}(M_{\text{VZ}})}$$

where $N_{\text{NS}}(M_{\text{VZ}})$ is the number of events in the signal region and $N_{\text{SB}}(M_{\text{VZ}})$ is the number of events in the sideband region, contained in a bin of the VZ mass distribution centered at a given value M_{VZ}. We then use the product of the M_{VZ} distribution made with the sideband selection in the data and the ratio $\alpha(M_{\text{VZ}})$ to derive an estimate of the background M_{VZ} distribution with the nominal selection. Following the example of other resonance searches [55], we fit the α-corrected sideband data M_{VZ} distribution to the following analytic function $f_A(M_{\text{VZ}})$, and the fit result is used to parametrize the expected SM background distribution:

$$f_A(M_{\text{VZ}}) = p_0 \frac{\left[1 - (\frac{M_{\text{VZ}}}{\sqrt{s}})\right]^{p_1}}{\left(\frac{M_{\text{VZ}}}{\sqrt{s}}\right)^{\left[p_2 + p_3 \log(\frac{M_{\text{VZ}}}{\sqrt{s}})\right]}} ,$$

where $\sqrt{s}$ is the collision energy, p_i, $i = 0, \ldots, 3$ are free parameters of the fit, and M_{VZ} is expressed in GeV. The fit determines both the shape and the overall normalization of the expected background as a function of M_{VZ}. The fitting functions are then used to describe the expected background in any subregion of the M_{VZ} spectrum in the electron and muon channels. There are several advantages in using the ratio $\alpha(M_{\text{VZ}})$ for the background modeling of the M_{VZ} distributions: the background estimation becomes insensitive to effects such pile-up corrections and integrated luminosity uncertainty which cancel out in the ratio; $\alpha(M_{\text{VZ}})$ is less sensitive to improper modeling of the matrix element calculation for the background and to theory systematics (e.g. normalization and factorization scale, PDFs, etc.) since the background composition is similar in the two regions.

The comparison of the estimated background with the prediction from the simulation and the data M_{VZ} distributions is shown in figure 2. No significant excess of events is observed, with the largest deviation appearing in the ∼900 GeV region in the muon channel. The tail of the M_{VZ} distribution, which is the region of interest for the new resonance search, is well described by the fit. A discrepancy is observed at low M_{VZ} values. Any modeling imperfections, quantified as the difference between the best-fit function and the MC simulation estimation, are taken into account in the limit calculation by assigning a systematic uncertainty.

5.2 $E_{\text{T}}^{\text{miss}}$ channel

By analyzing simulated data we determine that the dominant backgrounds in this channel after all selections are inclusive $\text{Z} \to \nu\overline{\nu}$ (∼70%) and $\text{W} \to \ell\nu$ (∼30%) production, with the charged lepton remaining undetected in the latter. To estimate the SM background, we use a sideband-based technique similar to that described above, which utilizes events that meet all other requirements but the M_j and M_{T} thresholds. In particular, the events which meet all the selection requirements are classified into four regions according to two thresholds in jet mass and two thresholds in M_{T}:

JHEP02(2013)036

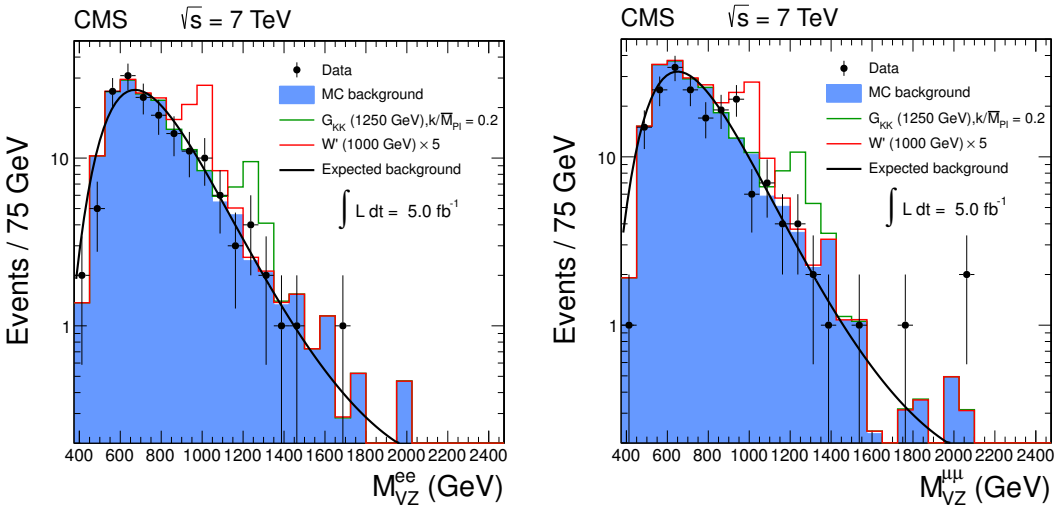

Figure 2. The comparison of the estimated background (black curve) with the total MC background (blue histogram) and the data (black points) for $M_{\rm VZ}$ distributions for the electron (left) and the muon (right) channels.

- Signal region A: $M_j > 70\,\text{GeV}$, $M_{\rm T} > 900\,\text{GeV}$;
- Sideband region B: $20 < M_j < 70\,\text{GeV}$, $M_{\rm T} > 900\,\text{GeV}$;
- Sideband region C: $20 < M_j < 70\,\text{GeV}$, $700 < M_{\rm T} < 900\,\text{GeV}$;
- Sideband region D: $M_j > 70\,\text{GeV}$, $700 < M_{\rm T} < 900\,\text{GeV}$;

The numbers of events observed in the above regions are denoted as $N_{\rm A}, \ldots, N_{\rm D}$. The estimated total background $B_{\rm est}$ in Region A is given by the expression

$$B_{\rm est} = N_{\rm D} \cdot \frac{N_{\rm B}}{N_{\rm C}} \cdot \frac{1}{\rho} \tag{5.1}$$

where ρ is a correction factor to account for the correlation between the jet mass and the jet-$E_{\rm T}^{\rm miss}$ transverse mass. The ρ parameter is estimated from the simulated SM samples by rearranging eq. (5.1) in the following way:

$$\rho = \frac{N_{\rm D} \cdot N_{\rm B}}{N_{\rm A} \cdot N_{\rm C}} \tag{5.2}$$

and setting the values of $N_{\rm A}, \ldots, N_{\rm D}$ to the ones from the SM prediction. Using the values reported in table 3 gives $\rho = 0.42 \pm 0.02$. The value of ρ thus derived in then reinserted in eq. (5.1). Setting $N_{\rm B}, N_{\rm C}, N_{\rm D}$ to the yields observed in the data, we obtain an estimate of the remaining background $B_{\rm est} = 153 \pm 20$ events. Figures 3 (left) and 3 (right) show the comparison between the simulated SM background in Region A (scaled to the estimated value $B_{\rm est}$—a scale factor of 11%) and data, together with an example signal for the M_j and $M_{\rm T}$ distributions. There is agreement between the expected background and data distributions.

JHEP02(2013)036

Region	Yield	Data	SM Simulation	Data/Sim Ratio
A: signal	N_{A}	138	131 ± 3	1.05 ± 0.02
B: sideband	N_{B}	125	125 ± 3	1.00 ± 0.03
C: sideband	N_{C}	542	579 ± 7	0.94 ± 0.01
D: sideband	N_{D}	283	259 ± 5	1.09 ± 0.02

Table 3. Event yields for simulated SM samples, data, and the data/simulation ratio in the four regions described in the text. The quoted uncertainties include those due to the finite statistics of the simulated samples.

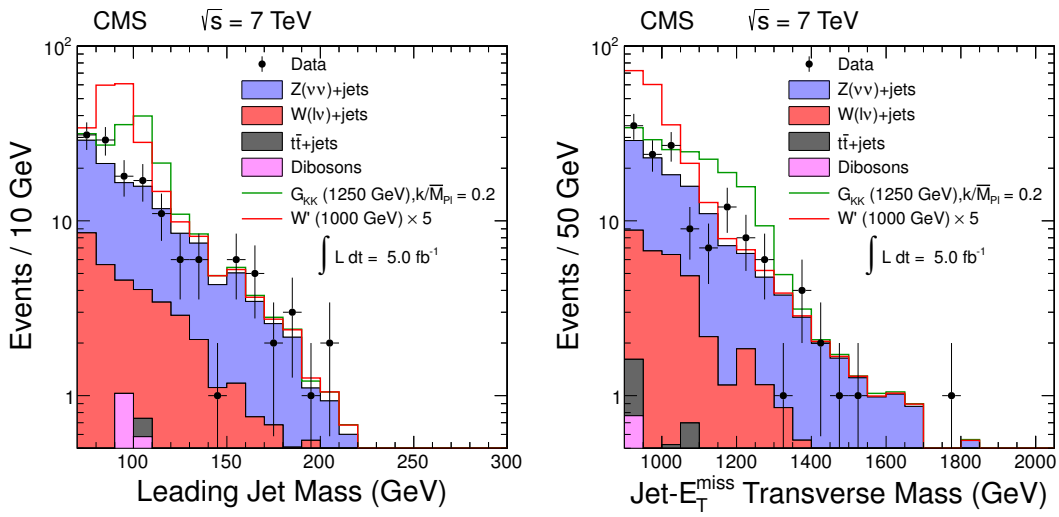

Figure 3. Comparison between ρ-corrected simulated backgrounds and data in Region A for the leading jet mass (left) and jet-$E_{\mathrm{T}}^{\mathrm{miss}}$ transverse mass (right) distributions.

6 Systematic uncertainties

The systematic uncertainties that are considered in this analysis can be divided into two main categories: the uncertainty in the determination of the SM background and the uncertainty in the expected yields of signal events. All the systematic uncertainties are summarized in tables 4 and 5 for the dilepton and $E_{\mathrm{T}}^{\mathrm{miss}}$ channels, respectively. The total systematic uncertainty is the combination of the signal and background systematic effects, assuming they are completely uncorrelated.

6.1 Background systematic effects

As we employ a method based on control samples in data for the background determination, several systematic effects are eliminated. In the following, we consider the remaining relevant uncertainties in detail for the dilepton and $E_{\mathrm{T}}^{\mathrm{miss}}$ channels.

6.1.1 Dilepton channels

The expected number of background events in each mass window is determined by the integral of the function $f_A(M_{\mathrm{VZ}})$ in the corresponding region. The statistical uncertainty

JHEP02(2013)036

		Background				Signal	
Mass Point (GeV)	Mass Window (GeV)	Stat. (%)	Fit variations (%)	Diff. w/ MC (%)	JES (%)	JES (%)	PDF (%)
W′ model, electron channel							
700	640–760	8	3	1	4	1	4
800	755–845	8	21	1	5	1	5
900	855–945	9	21	2	7	1	5
1000	930–1070	11	17	5	2	1	6
1100	1020–1180	12	22	4	3	1	6
1200	1130–1270	15	26	6	7	1	6
1300	1220–1380	17	46	6	41	1	7
1400	1320–1480	20	64	28	14	1	8
1500	1390–1610	23	72	31	26	1	9
RS model, electron channel							
750	690–810	8	14	3	2	1	4
1000	940–1060	11	17	5	7	1	6
1250	1180–1320	16	36	3	8	1	7
1500	1390–1610	23	72	3	26	1	9
1750	1540–1960	31	64	10	48	1	10
2000	1760–2240	42	42	26	110	1	11
W′ model, muon channel							
700	640–760	7	10	4	6	1	4
800	755–845	8	19	6	8	1	5
900	855–945	9	16	2	8	1	5
1000	930–1070	10	15	8	1	1	6
1100	1020–1180	12	20	8	1	1	6
1200	1130–1270	14	29	21	2	1	7
1300	1220–1380	16	43	30	6	1	7
1400	1320–1480	19	50	68	10	1	8
1500	1390–1610	22	46	54	24	1	9
RS model, muon channel							
750	690–810	7	14	2	7	1	4
1000	940–1060	10	15	6	7	1	6
1250	1180–1320	15	37	4	1	1	7
1500	1390–1610	22	46	54	24	1	9
1750	1540–1960	30	33	31	52	1	11
2000	1760–2240	40	64	23	130	1	11

Table 4. Systematic uncertainties in the dilepton channels for given mass point and optimized mass window for the background (columns 3–6) and signal (columns 7–8) expected yields, following the procedures described in the text. In addition to the estimated signal uncertainties listed in the table, constant uncertainties are considered on the integrated luminosity (2.2%), the lepton reconstruction and trigger efficiencies as determined by the "tag and probe" method (2%) [56] and the V mass selection as determined from a sample of boosted $t\bar{t}$ events (9%).

JHEP02(2013)036

Mass Point (GeV)	PDF (%)	JES (%)	$E_{\mathrm{T}}^{\mathrm{miss}}$ (%)	Total (%)
W′ model				
700	4	9	9	13
800	5	8	8	12
900	5	8	8	12
1000	5	7	7	11
1100	6	5	6	10
1200	6	2	4	7
1300	7	1	3	8
1400	8	1	3	9
1500	8	1	3	9
RS model				
750	4	7	7	10
1000	4	1	3	5
1250	4	1	3	5
1500	4	1	3	5
1750	4	1	3	5
2000	4	1	3	5

Table 5. Systematic uncertainties in the $E_{\mathrm{T}}^{\mathrm{miss}}$ channel for the expected signal yields for the W′ mass range $M_{\mathrm{W}'} \in [700, 1500]$ GeV and graviton mass range $M_{\mathrm{G_{KK}}} \in [750, 2000]$ GeV.

is calculated by employing the full covariance error matrix of the fit parameter uncertainties in the integral of the fitting function in the mass window. The pileup and jet energy scale (JES) systematics can potentially affect the background determination through the $\alpha(M_{\mathrm{VZ}})$ ratio and are considered separately. The former is found to have a negligible effect. For the latter, the uncertainty is evaluated by varying the jet p_{T} to $p_{\mathrm{T}} \pm \sigma_{\mathrm{JES}}(p_{\mathrm{T}}, \eta)$, where $\sigma_{\mathrm{JES}}(p_{\mathrm{T}}, \eta)$ is the total jet uncertainty, and applying the full fitting procedure. The yield differences, in each mass window, between the expected background with the positive ($N_{+\mathrm{Bgd}}$) and negative ($N_{-\mathrm{Bgd}}$) jet energy scale variation with respect to the nominal selection and fit are taken as the $\pm 1\,\sigma$ estimates for the JES systematic uncertainty. We also consider several variations in the fitting procedure (fitting range, functional form, and sideband definition). These variations are compared to the difference in the number of expected background events in the mass window as estimated from data and with MC simulation. The largest of the two is used as the systematic uncertainty in the background determination.

6.1.2 $E_{\mathrm{T}}^{\mathrm{miss}}$ channel

To evaluate the robustness of the evaluation of the expected background two tests are conducted.

The first test studies the dependence of the correction factor ρ on the definition of the sideband regions. We vary the definition of the sideband regions by changing the thresholds in the M_j and M_{T} variables in the intervals 20–70 GeV and 650–750 GeV, respectively. We

JHEP02(2013)036

find that the resultant variation in the mean estimated background is typically 5% or less, confirming the robustness of the sideband method.

A second test is used to check the propagation of all the uncertainties involved in the $B_{\rm est}$ calculations. We generate a series of pseudo-experiments with the number of events constrained to be equal to that of the actual experiment. We obtain a value of ρ and calculate the mean estimated background in each case. The distribution of the values of $B_{\rm est}$ thus obtained has a variance of 20 events. This result is in agreement with the estimated uncertainty on $B_{\rm est}$ obtained in section 5.2, using the yields of $N_{\rm B}$, $N_{\rm C}$ and $N_{\rm D}$ observed in the data.

The mean expected SM background in Region A, within the uncertainties calculated above, is compatible with the observed event yield in the signal region, $N_{\rm A} = 138$ events.

6.2 Signal systematics

There are several systematic uncertainties in the expected signal yields that are common across channels. These uncertainties are on the luminosity measurement, the JES effects on jets, the PDF, and the trigger and reconstruction efficiencies. A value of 2.2% was taken for the uncertainty in the measurement of the integrated luminosity [57].

To determine the effect of JES uncertainty, we vary the jet $p_{\rm T}$ to $p_{\rm T} \pm \sigma_{\rm JES}(p_{\rm T}, \eta)$, where $\sigma_{\rm JES}(p_{\rm T}, \eta)$ is the total jet uncertainty, and apply the full analysis selection. The differences in the signal yields $N_{+\rm sig}$ and $N_{-\rm sig}$ with respect to the nominal selection $N_{\rm sig}$ are taken as the $\pm 1\,\sigma$ estimates for the JES systematic uncertainty. For W′ and RS signals with the mass in the range [700, 2000] GeV in the dilepton channels and in the range [1250, 2000] GeV in the $E_{\rm T}^{\rm miss}$ channel, this systematic uncertainty is less than 1%. However, for resonance masses in the range [700, 1200] GeV in the $E_{\rm T}^{\rm miss}$ channel this systematic uncertainty is found to be between 2 and 9%, owing to threshold effects. To estimate the systematic uncertainty associated with the choice of the PDF used for the simulated samples, three scenarios are considered: CTEQ6.6, MSTW2008 and NNPDF2.0 [58]. The systematic uncertainty is set to half of the difference between the maximum and the minimum PDF values predicted for each mass point [59].

6.2.1 Dilepton channels

To account for differences in trigger and reconstruction efficiencies between the Monte Carlo simulation and data, we determine scaling factors by using data control samples of $\mathrm{Z} \to \mu\mu$ and $\mathrm{Z} \to \mathrm{ee}$ candidate events [60, 61]. We derive corrections for the muon (0.974 ± 0.001) and the electron (0.960 ± 0.004) channels and we apply them to the expected signal yields. These numbers assume that the efficiency does not vary with $p_{\rm T}$ ($E_{\rm T}$). However, we observe a small decrease (increase) in the efficiency in the asymptotic high-$p_{\rm T}$ (high-$E_{\rm T}$) region for muons (electrons) of about 2%. This small difference is used as the systematic uncertainty in the expected number of signal events for each mass point considered in this study. Finally, we assign a 9% systematic uncertainty on the V mass selection efficiency. This is determined by studying an independent sample of boosted $\mathrm{t\bar{t}} \to \mathrm{Wb\,Wb}$ events in which one of the W bosons decays leptonically and the other hadronically.

JHEP02(2013)036

Mass Point (GeV)	Window (GeV)	$N_{\rm bgd}$	$N_{\rm obs}$	$\epsilon_{\rm sig}$ (%)	Obs. Limit (pb)	Exp. Limit (pb)
W′ model						
700	640-760	39.7 ± 3.9	43	37±4	0.44	0.37
800	755-845	24.6 ± 5.7	23	36±4	0.33	0.35
900	855-945	17.1 ± 4.2	12	40±4	0.18	0.24
1000	930-1070	17.1 ± 3.5	17	49±5	0.20	0.20
1100	1020-1180	12.0 ± 3.0	13	48±5	0.20	0.18
1200	1130-1270	6.3 ± 1.9	5	41±5	0.13	0.15
1300	1220-1380	4.4 ± 2.8	6	32±4	0.25	0.20
1400	1320-1480	2.7 ± 1.8	2	23±3	0.18	0.19
1500	1390-1610	2.5 ± 2.0	2	19±2	0.22	0.22
RS model						
750	690-810	37.1 ± 6.0	32	27±3	0.21	0.25
1000	940-1060	14.6 ± 3.1	16	35±4	0.14	0.13
1250	1180-1320	4.9 ± 1.9	7	35±4	0.11	0.08
1500	1390-1610	2.5 ± 2.0	2	27±3	0.08	0.08
1750	1540-1960	2.0 ± 1.7	1	16±2	0.10	0.12
2000	1760-2240	1.3 ± 1.6	0	17±2	0.06	0.05

Table 6. Electron channel: search window for each mass point with the corresponding signal efficiency ("$\epsilon_{\rm sig}$") and the numbers of mean expected background ("$N_{\rm bgd}$") and observed ("$N_{\rm obs}$") events. The uncertainties include both statistical and systematic effects. These numbers are used as input for the calculation of the expected and observed exclusion limits on $\sigma(\mathrm{pp} \to \mathrm{W}') \times \mathcal{B}(\mathrm{W}' \to \mathrm{WZ})$ and $\sigma(\mathrm{pp} \to \mathrm{G_{KK}}) \times \mathcal{B}(\mathrm{G_{KK}} \to \mathrm{ZZ})$ at 95% CL which are reported in the last two columns.

6.2.2 $E_{\rm T}^{\rm miss}$ channel channel

Propagating the jet energy scale effects to the calculation of $E_{\rm T}^{\rm miss}$, and accounting for the anticorrelation between jets and $E_{\rm T}^{\rm miss}$ itself, we estimate a systematic effect of around 3% for all values of $M_{\rm G}$ studied, except for the lowest $M_{\rm G} = 750\,\mathrm{GeV}$. In this case, because of threshold effects, the systematic effect is found to be around 7%.

Summing in quadrature the uncertainties above, we arrive at a final 5% systematic uncertainty on the signal acceptance and efficiency except for $M_{\rm G} = 750\,\mathrm{GeV}$, where a value of 10% is obtained for the final systematic uncertainty on the signal acceptance and efficiency.

7 Results

We do not observe any significant excess over the expected background. We employ the modified frequentist $\mathrm{CL_S}$ statistical method [62, 63] to search for exotic VZ resonances. For the dilepton channels we use a series of search windows corresponding to different mass hypotheses. Each mass window is optimized to give the best exclusion limit, a procedure which is also appropriate for establishing a new resonance discovery. The mass windows

JHEP02(2013)036

Mass Point (GeV)	Window (GeV)	$N_{\rm bgd}$	$N_{\rm obs}$	$\epsilon_{\rm sig}$ (%)	Obs. Limit (pb)	Exp. Limit (pb)
W′ model						
700	640–760	48.7 ± 8.9	45	40±4	0.40	0.45
800	755–845	28.6 ± 6.9	21	40±4	0.25	0.34
900	855–945	19.2 ± 4.3	23	41±4	0.37	0.29
1000	930–1070	18.7 ± 3.7	26	51±6	0.34	0.22
1100	1020–1180	12.9 ± 3.1	12	52±6	0.17	0.18
1200	1130–1270	6.7 ± 2.2	8	44±5	0.18	0.15
1300	1220–1380	4.6 ± 2.1	4	42±5	0.13	0.13
1400	1320–1480	2.9 ± 2.0	1	39±5	0.08	0.11
1500	1390–1610	2.6 ± 1.7	2	40±5	0.11	0.11
RS model						
750	690–810	44.1 ± 9.2	34	30±3	0.19	0.26
1000	940–1060	15.9 ± 3.4	20	39±4	0.17	0.13
1250	1180–1320	5.2 ± 2.1	6	41±5	0.08	0.07
1500	1390–1610	2.6 ± 1.7	2	44±6	0.05	0.05
1750	1540–1960	2.1 ± 1.4	2	32±5	0.06	0.06
2000	1760–2240	1.3 ± 1.9	2	42±6	0.06	0.05

Table 7. Muon channel: search window for each mass point with the corresponding signal efficiency ("$\epsilon_{\rm sig}$") and the numbers of mean expected background ("$N_{\rm bgd}$") and observed ("$N_{\rm obs}$") events. The uncertainties include both statistical and systematic effects. These numbers are used as input for the calculation of the expected and observed exclusion limits on $\sigma(pp \to \mathrm{W}') \times \mathcal{B}(\mathrm{W}' \to \mathrm{WZ})$ and $\sigma(pp \to \mathrm{G_{KK}}) \times \mathcal{B}(\mathrm{G_{KK}} \to \mathrm{ZZ})$ at 95% CL, which are reported in the last two columns.

optimization has been carried out separately for the W′ and RS graviton hypotheses to account for differences in the width and efficiencies. For the $E_{\rm T}^{\rm miss}$ channel we perform a single counting experiment in the $M_{\rm T} > 900\,\mathrm{GeV}$ and $M_j > 70\,\mathrm{GeV}$ region. We calculate 95% confidence level (CL) exclusion limits on the combined products of the cross section times the branching ratio $\sigma(\mathrm{pp} \to \mathrm{W}') \times \mathcal{B}(\mathrm{W}' \to \mathrm{WZ})$ and $\sigma(\mathrm{pp} \to \mathrm{G_{KK}}) \times \mathcal{B}(\mathrm{G_{KK}} \to \mathrm{ZZ})$ for the three final states under study (separately and combined) as a function of the mass of the hypothetical resonance. We interpret these exclusion limits in two benchmark signal models: SSM W′ and RS graviton.

The limit setting is performed by looking for an excess over the expected background in the VZ mass distributions for the three channels separately. Tables 6 and 7 show the search windows for each mass point with the corresponding signal efficiency and the numbers of expected background and observed events in the electron and muon channels, respectively. These numbers are used as input for the calculation of the expected and observed exclusion limits on cross section times branching ratios at 95% CL that are also reported in the same tables. Table 8 shows the signal efficiency and the observed and expected exclusion limits

JHEP02(2013)036

Mass Point (GeV)	ϵ_{sig} (%)	Obs. Limit (pb)	Exp. Limit (pb)
W′ model			
700	0.2±0.1	29	33
800	0.9±0.1	7.0	8.2
900	8.0±0.5	0.77	0.90
1000	31±2	0.19	0.23
1100	49±2	0.13	0.15
1200	58±3	0.11	0.13
1300	64±3	0.10	0.11
1400	66±3	0.09	0.11
1500	69±3	0.09	0.11
RS model			
750	0.7±0.1	4.1	4.8
1000	25±2	0.12	0.14
1250	43±3	0.07	0.08
1500	54±3	0.06	0.07
1750	60±3	0.05	0.06
2000	63±3	0.05	0.06

Table 8. $E_{\text{T}}^{\text{miss}}$ channel: expected and observed exclusion limits on $\sigma(\text{pp} \to \text{W}') \times \mathcal{B}(\text{W}' \to \text{WZ})$ and $\sigma(\text{pp} \to \text{G}_{\text{KK}}) \times \mathcal{B}(\text{G}_{\text{KK}} \to \text{ZZ})$ at 95% CL for each mass point with the corresponding signal efficiency ("ϵ_{sig}"). In the $M_{\text{T}} > 900\,\text{GeV}$ region the expected background is $B_{\text{est}} = 153 \pm 29$, including both statistical and systematic uncertainties, and the number of observed events is 138. These parameters are common for all mass points considered in this channel.

as a function of the signal mass in the $E_{\text{T}}^{\text{miss}}$ channel. The combined results are reported in table 9. The exclusion limits as a function of the VZ resonance mass can be seen in figure 4, where a linear interpolation is used between the benchmark mass values. These limits can be interpreted in the theoretical framework of the W′ and RS graviton models. We exclude SSM W′ bosons with masses in the range 700–940 (890) GeV in the SSM at NNLO (LO) at 95% CL These results are complementary to the ones obtained in the tri-lepton analysis (with $M_{\text{W}'} > 1143\,\text{GeV}$ in the SSM [64]). The exclusion limit calculated in the RS graviton model rules out masses ($M_{\text{G}_{\text{KK}}}$) in the range 750–880 (800) GeV for $k/\overline{M}_{\text{Pl}} = 0.05$ at NLO (LO). Assuming the resonance width is much smaller than the experimental resolution for the range of $k/\overline{M}_{\text{Pl}}$ considered here, the limit can be translated into the $M_{\text{G}_{\text{KK}}}$-$k/\overline{M}_{\text{Pl}}$ plane. We do this by using the quadratic dependence of the cross section on $k/\overline{M}_{\text{Pl}}$, and by assuming that the signal efficiency remains the same. The result is shown in figure 5.

These results are particularly relevant in the context of RS models proposed in recent studies [65], with SM fields propagating in the extra dimension where the graviton coupling to light fermions is strongly suppressed. This opens the possibility to an enhancement of the branching fractions for final states with V pairs, and motivates the investigation

JHEP02(2013)036

Mass Point (GeV)	Window	Obs. Limit (pb)	Exp. Limit (pb)
W′ model			
700	640–760	0.30	0.25
800	755–845	0.14	0.21
900	855–945	0.19	0.18
1000	930–1070	0.19	0.15
1100	1020–1180	0.11	0.12
1200	1130–1270	0.09	0.09
1300	1220–1380	0.09	0.09
1400	1320–1480	0.05	0.08
1500	1390–1610	0.07	0.08
RS model			
750	690–810	0.12	0.16
1000	940–1060	0.13	0.09
1250	1180–1320	0.07	0.05
1500	1390–1610	0.04	0.04
1750	1540–1960	0.05	0.05
2000	1760–2240	0.04	0.03

Table 9. Combined channels: expected and observed exclusion limits on $\sigma(\mathrm{pp} \to \mathrm{W}') \times \mathcal{B}(\mathrm{W}' \to \mathrm{WZ})$ and $\sigma(\mathrm{pp} \to \mathrm{G_{KK}}) \times \mathcal{B}(\mathrm{G_{KK}} \to \mathrm{ZZ})$ at 95% CL for the electron, muon, and $E_{\mathrm{T}}^{\mathrm{miss}}$ channels combined for each mass point and search window.

of large values of $k/\overline{M}_{\mathrm{Pl}}$ [65]. In this scenario the previously-published searches for RS gravitons decaying to $\gamma\gamma$ and $\ell^+\ell^-$ final states [24] do not impose stringent bounds, since the branching fraction for these final states is suppressed. The results derived in this analysis are currently the most stringent in the V pair channel, and provide important constraints that are complementary to the ones from the search for resonances decaying to boosted top pairs [66].

8 Summary

A search for new exotic particles decaying to the VZ final state was performed, where V is either a W or a Z decaying to hadrons, and the Z decays to electrons, muons, or a neutrino pair. The analysis is based on a data sample of pp collisions corresponding to an integrated luminosity of $5.0\,\mathrm{fb}^{-1}$ collected by the CMS experiment at the LHC at $\sqrt{s} = 7\,\mathrm{TeV}$ in 2011. No significant excess is observed in the mass distribution of the VZ candidates compared with the background expectation from standard model processes. Lower bounds at the 95% confidence level are set in two theoretical models on the mass of hypothetical particles decaying to the VZ final state. Assuming heavy charged vector bosons in the sequential standard model, W′ bosons are excluded with masses in the range 700–940 (890) GeV at NNLO (LO). In the Randall–Sundrum model, graviton resonances with masses in the range

JHEP02(2013)036

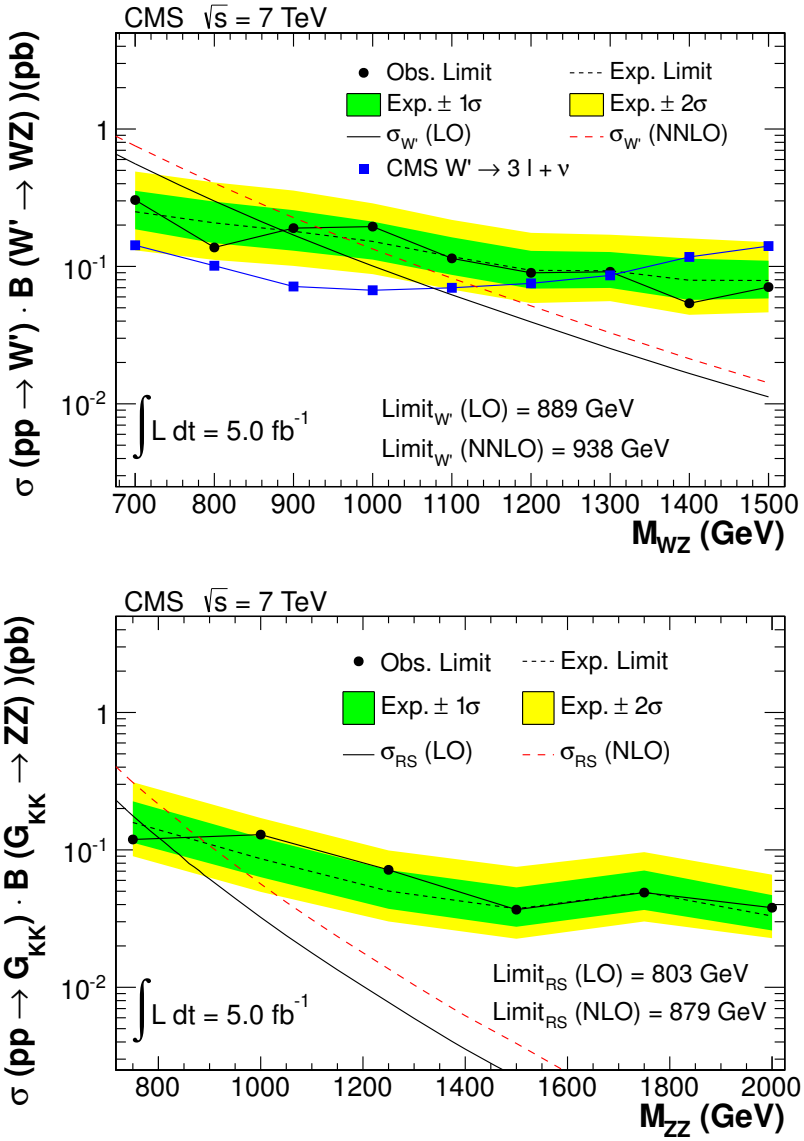

Figure 4. Observed and expected 95% CL upper cross section limits and comparison with the theoretical predictions in W′ (top) and RS graviton with $k/\overline{M}_{\rm Pl} = 0.05$ (bottom) models for the combination of electron, muon, and $E_{\rm T}^{\rm miss}$ channels. The limits are calculated with the modified frequentist $\rm CL_S$ statistical method.

750–880 (800) GeV at NLO (LO) are excluded for $k/\overline{M}_{\rm Pl}$ =0.05. These are the first results from the LHC on VZ searches using final states with a boosted massive jet and a lepton pair or missing transverse energy.

Acknowledgments

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition,

JHEP02(2013)036

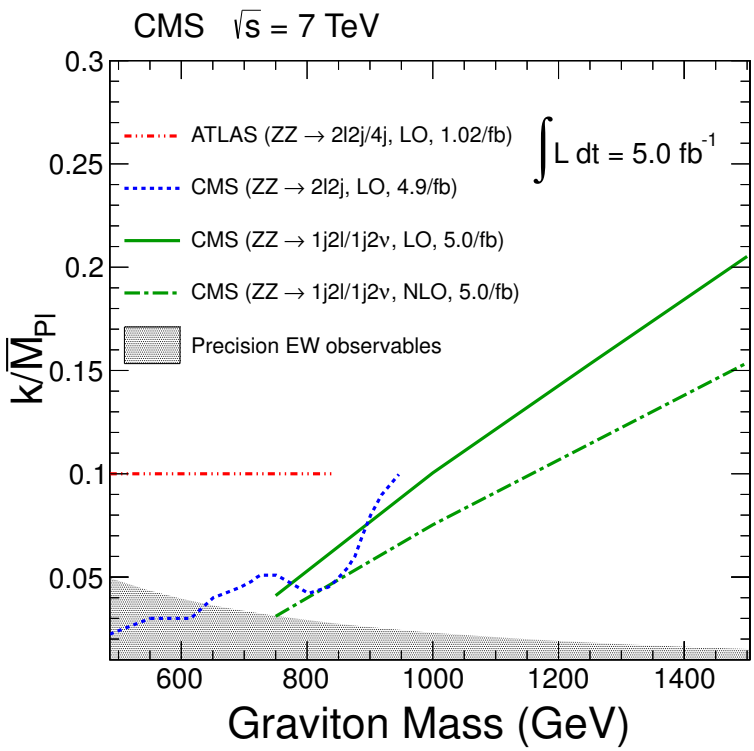

Figure 5. Observed exclusion limits from this analysis (ZZ $\to 1j\,2\ell/1j\,2\nu$) interpreted in the context of the RS graviton model, assuming a LO prediction (solid green line) and NLO prediction (dot-dashed green line). Also shown are results from ATLAS (ZZ $\to 2\ell\,2j/4j$) [35] (dot-dot-dashed red line) and another CMS publication (ZZ $\to 2\ell\,2j$) [36] (dotted blue line). The shaded region corresponds to the indirect limits derived from precision electroweak observables in [22].

we gratefully acknowledge the computing centres and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: BMWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MEYS (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 programme and the European Research Council (European Union); the

JHEP02(2013)036

Leventis Foundation; the A. P. Sloan Foundation; the Alexander von Humboldt Foundation; 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 programme of Foundation for Polish Science, cofinanced from European Union, Regional Development Fund.

Open Access. This article is distributed under the terms of the Creative Commons Attribution License which permits any use, distribution and reproduction in any medium, provided the original author(s) and source are credited.

References

[1] S.L. Glashow, *Partial symmetries of weak interactions*, *Nucl. Phys.* **22** (1961) 579 [INSPIRE].

[2] S. Weinberg, *A model of leptons*, *Phys. Rev. Lett.* **19** (1967) 1264 [INSPIRE].

[3] A. Salam, *Weak and electromagnetic interactions*, in *Elementary particle physics: relativistic groups and analyticity*, N. Svartholm ed., Almqvist & Wiksell, Stockholm, Sweden (1968).

[4] F. Englert and R. Brout, *Broken symmetry and the mass of gauge vector mesons*, *Phys. Rev. Lett.* **13** (1964) 321 [INSPIRE].

[5] P.W. Higgs, *Broken symmetries, massless particles and gauge fields*, *Phys. Lett.* **12** (1964) 132 [INSPIRE].

[6] P.W. Higgs, *Broken symmetries and the masses of gauge bosons*, *Phys. Rev. Lett.* **13** (1964) 508 [INSPIRE].

[7] G. Guralnik, C. Hagen and T. Kibble, *Global conservation laws and massless particles*, *Phys. Rev. Lett.* **13** (1964) 585 [INSPIRE].

[8] P.W. Higgs, *Spontaneous symmetry breakdown without massless bosons*, *Phys. Rev.* **145** (1966) 1156 [INSPIRE].

[9] T. Kibble, *Symmetry breaking in nonAbelian gauge theories*, *Phys. Rev.* **155** (1967) 1554 [INSPIRE].

[10] S. Weinberg, *Implications of dynamical symmetry breaking*, *Phys. Rev.* **D 13** (1976) 974.

[11] S. Weinberg, *Implications of dynamical symmetry breaking: an addendum*, *Phys. Rev.* **D 19** (1979) 1277 [INSPIRE].

[12] L. Susskind, *Dynamics of spontaneous symmetry breaking in the Weinberg-Salam theory*, *Phys. Rev.* **D 20** (1979) 2619 [INSPIRE].

[13] L. Randall and R. Sundrum, *A large mass hierarchy from a small extra dimension*, *Phys. Rev. Lett.* **83** (1999) 3370 [hep-ph/9905221] [INSPIRE].

[14] L. Randall and R. Sundrum, *An alternative to compactification*, *Phys. Rev. Lett.* **83** (1999) 4690 [hep-th/9906064] [INSPIRE].

[15] D.B. Kaplan and H. Georgi, SU(2) $\times$ U(1) *breaking by vacuum misalignment*, *Phys. Lett.* **B 136** (1984) 183 [INSPIRE].

JHEP02(2013)036

[16] K. Agashe, R. Contino and A. Pomarol, *The minimal composite Higgs model*, *Nucl. Phys.* **B 719** (2005) 165 [hep-ph/0412089] [INSPIRE].

[17] R. Contino, D. Marzocca, D. Pappadopulo and R. Rattazzi, *On the effect of resonances in composite Higgs phenomenology*, *JHEP* **10** (2011) 081 [arXiv:1109.1570] [INSPIRE].

[18] E. Eichten and K. Lane, *Low-scale technicolor at the Tevatron and LHC*, *Phys. Lett.* **B 669** (2008) 235 [arXiv:0706.2339] [INSPIRE].

[19] E. Eichten, K. Lane, A. Martin and E. Pilon, *Testing the Technicolor Interpretation of CDF's dijet excess at the LHC*, arXiv:1201.4396 [INSPIRE].

[20] T. Gherghetta and A. Pomarol, *Bulk fields and supersymmetry in a slice of AdS*, *Nucl. Phys.* **B 586** (2000) 141 [hep-ph/0003129] [INSPIRE].

[21] S.J. Huber and Q. Shafi, *Fermion masses, mixings and proton decay in a Randall-Sundrum model*, *Phys. Lett.* **B 498** (2001) 256 [hep-ph/0010195] [INSPIRE].

[22] H. Davoudiasl, J. Hewett and T. Rizzo, *Experimental probes of localized gravity: on and off the wall*, *Phys. Rev.* **D 63** (2001) 075004 [hep-ph/0006041] [INSPIRE].

[23] ATLAS collaboration, *Search for dilepton resonances in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector*, *Phys. Rev. Lett.* **107** (2011) 272002 [arXiv:1108.1582] [INSPIRE].

[24] CMS collaboration, *Search for signatures of extra dimensions in the diphoton mass spectrum at the Large Hadron Collider*, *Phys. Rev. Lett.* **108** (2012) 111801 [arXiv:1112.0688] [INSPIRE].

[25] D0 collaboration, V.M. Abazov et al., *Search for resonant WW and WZ production in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV*, *Phys. Rev. Lett.* **107** (2011) 011801 [arXiv:1011.6278] [INSPIRE].

[26] CDF collaboration, T. Aaltonen et al., *Search for Randall-Sundrum gravitons in the diphoton channel at CDF*, *Phys. Rev.* **D 83** (2011) 011102 [arXiv:1012.2795] [INSPIRE].

[27] ATLAS collaboration, *Search for a heavy gauge boson decaying to a charged lepton and a neutrino in $1\,fb^{-1}$ of pp collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector*, *Phys. Lett.* **B 705** (2011) 28 [arXiv:1108.1316] [INSPIRE].

[28] CMS collaboration, *Search for leptonic decays of W' bosons in pp collisions at $\sqrt{s} = 7$ TeV*, *JHEP* **08** (2012) 023 [arXiv:1204.4764] [INSPIRE].

[29] ATLAS collaboration, *Search for tb resonances in proton-proton collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector*, *Phys. Rev. Lett.* **109** (2012) 081801 [arXiv:1205.1016] [INSPIRE].

[30] CMS collaboration, *Search for a W' boson decaying to a bottom quark and a top quark in pp collisions at $\sqrt{s} = 7$ TeV*, *Phys. Lett.* **B 718** (2013) 1229 [arXiv:1208.0956] [INSPIRE].

[31] ATLAS collaboration, *Search for resonant WZ production in the $WZ \to \ell\nu\ell'\ell'$ channel in $\sqrt{s} = 7$ TeV pp collisions with the ATLAS detector*, *Phys. Rev.* **D 85** (2012) 112012 [arXiv:1204.1648] [INSPIRE].

[32] CMS collaboration, *Search for a W' or techni-ρ decaying into WZ in pp collisions at $\sqrt{s} = 7$ TeV*, *Phys. Rev. Lett.* **109** (2012) 141801 [arXiv:1206.0433] [INSPIRE].

[33] CMS collaboration, *Search for narrow resonances in dilepton mass spectra in pp collisions at $\sqrt{s} = 7$ TeV*, *Phys. Lett.* **B 714** (2012) 158 [arXiv:1206.1849] [INSPIRE].

JHEP02(2013)036

[34] ATLAS collaboration, *Search for extra dimensions using diphoton events in 7 TeV proton-proton collisions with the ATLAS detector*, *Phys. Lett.* **B 710** (2012) 538 [arXiv:1112.2194] [INSPIRE].

[35] ATLAS collaboration, *Search for new particles decaying to ZZ using final states with leptons and jets with the ATLAS detector in $\sqrt{s} = 7$ TeV proton-proton collisions*, *Phys. Lett.* **B 712** (2012) 331 [arXiv:1203.0718] [INSPIRE].

[36] CMS collaboration, *Search for a narrow spin-2 resonance decaying to a pair of Z vector bosons in the semileptonic final state*, *Phys. Lett.* **B 718** (2013) 1208 [arXiv:1209.3807] [INSPIRE].

[37] CMS collaboration, *The CMS experiment at the CERN LHC*, 2008 *JINST* **3** S08004 [INSPIRE].

[38] T. Sjöstrand, S. Mrenna and P.Z. Skands, *PYTHIA 6.4 physics and manual*, *JHEP* **05** (2006) 026 [hep-ph/0603175] [INSPIRE].

[39] CMS collaboration, *Measurement of the underlying event activity at the LHC with $\sqrt{s} = 7$ TeV and comparison with $\sqrt{s} = 0.9$ TeV*, *JHEP* **09** (2011) 109 [arXiv:1107.0330] [INSPIRE].

[40] M.C. Kumar et al., *Diphoton signals in theories with large extra dimensions to NLO QCD at hadron colliders*, *Phys. Lett.* **B 672** (2009) 45.

[41] M. Kumar, P. Mathews, V. Ravindran and A. Tripathi, *Direct photon pair production at the LHC to order α_s in TeV scale gravity models*, *Nucl. Phys.* **B 818** (2009) 28 [arXiv:0902.4894] [INSPIRE].

[42] R. Gavin, Y. Li, F. Petriello and S. Quackenbush, *FEWZ 2.0: a code for hadronic Z production at next-to-next-to-leading order*, *Comput. Phys. Commun.* **182** (2011) 2388 [arXiv:1011.3540] [INSPIRE].

[43] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer and T. Stelzer, *MadGraph 5: going beyond*, *JHEP* **06** (2011) 128 [arXiv:1106.0522] [INSPIRE].

[44] M. Herquet and F. Maltoni, *MadGraph/MadEvent: a multipurpose event generator*, *Nucl. Phys. Proc. Suppl.* **179-180** (2008) 211 [INSPIRE].

[45] J. Pumplin et al., *New generation of parton distributions with uncertainties from global QCD analysis*, *JHEP* **07** (2002) 012 [hep-ph/0201195] [INSPIRE].

[46] M.L. Mangano, M. Moretti, F. Piccinini and M. Treccani, *Matching matrix elements and shower evolution for top-quark production in hadronic collisions*, *JHEP* **01** (2007) 013 [hep-ph/0611129] [INSPIRE].

[47] CMS collaboration, *Tracking and primary vertex results in first 7 TeV collisions*, CMS-PAS-TRK-10-005 (2010).

[48] CMS collaboration, *Particle-flow event reconstruction in CMS and performance for jets, taus and MET*, CMS-PAS-PFT-09-001 (2009).

[49] M. Cacciari, G.P. Salam and G. Soyez, *The anti-k_t jet clustering algorithm*, *JHEP* **04** (2008) 063 [arXiv:0802.1189] [INSPIRE].

[50] M. Cacciari and G.P. Salam, *Dispelling the N^3 myth for the k_t jet-finder*, *Phys. Lett.* **B 641** (2006) 57 [hep-ph/0512210] [INSPIRE].

JHEP02(2013)036

[51] M. Cacciari, G.P. Salam and G. Soyez, *FastJet user manual*, *Eur. Phys. J.* **C 72** (2012) 1896 [arXiv:1111.6097] [INSPIRE].

[52] CMS collaboration, *Determination of jet energy calibration and transverse momentum resolution in CMS*, 2011 *JINST* **6** P11002 [arXiv:1107.4277] [INSPIRE].

[53] M. Cacciari and G.P. Salam, *Pileup subtraction using jet areas*, *Phys. Lett.* **B 659** (2008) 119 [arXiv:0707.1378] [INSPIRE].

[54] M. Cacciari, G.P. Salam and G. Soyez, *The catchment area of jets*, *JHEP* **04** (2008) 005 [arXiv:0802.1188] [INSPIRE].

[55] CMS collaboration, *Search for resonances in the dijet mass spectrum from 7 TeV pp collisions at CMS*, *Phys. Lett.* **B 704** (2011) 123 [arXiv:1107.4771] [INSPIRE].

[56] CMS collaboration, *Measurement of the W and Z inclusive production cross sections at $\sqrt{s} = 7$ TeV with the CMS experiment at the LHC*, CMS-PAS-EWK-10-002 (2010).

[57] CMS collaboration, *Absolute calibration of the luminosity measurement at CMS: winter 2012 update*, CMS-PAS-SMP-12-008 (2012).

[58] M. Whalley, D. Bourilkov and R. Group, *The Les Houches accord PDFs (LHAPDF) and LHAGLUE*, hep-ph/0508110 [INSPIRE].

[59] M. Botje, J. Butterworth, A. Cooper-Sarkar, A. de Roeck, J. Feltesse, et al., *The PDF4LHC Working Group Interim Recommendations*, arXiv:1101.0538 [INSPIRE].

[60] CMS collaboration, *Performance of CMS muon reconstruction in pp collision events at $\sqrt{s} = 7$ TeV*, 2012 *JINST* **7** P10002.

[61] CMS collaboration, *Measurements of inclusive W and Z cross sections in pp collisions at $\sqrt{s} = 7$ TeV*, *JHEP* **01** (2011) 080 [arXiv:1012.2466] [INSPIRE].

[62] A.L. Read, *Presentation of search results: the CL(s) technique*, *J. Phys.* **G 28** (2002) 2693 [INSPIRE].

[63] T. Junk, *Confidence level computation for combining searches with small statistics*, *Nucl. Instrum. Meth.* **A 434** (1999) 435 [hep-ex/9902006] [INSPIRE].

[64] CMS collaboration, *Search for a W' or techni-ρ decaying into wz in pp collisions at $\sqrt{s} = 7$ TeV*, *Phys. Rev. Lett.* **109** (2012) 141801 [arXiv:1206.0433] [INSPIRE].

[65] K. Agashe, H. Davoudiasl, G. Perez and A. Soni, *Warped gravitons at the LHC and beyond*, *Phys. Rev.* **D 76** (2007) 036006 [hep-ph/0701186] [INSPIRE].

[66] CMS collaboration, *Search for anomalous $t\bar{t}$ production in the highly-boosted all-hadronic final state*, *JHEP* **09** (2012) 029 [arXiv:1204.2488] [INSPIRE].

JHEP02(2013)036

The CMS collaboration

Yerevan Physics Institute, Yerevan, Armenia

S. Chatrchyan, V. Khachatryan, A.M. Sirunyan, A. Tumasyan

Institut für Hochenergiephysik der OeAW, Wien, Austria

W. Adam, E. Aguilo, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan[1], M. Friedl, R. Frühwirth[1], V.M. Ghete, J. Hammer, N. Hörmann, J. Hrubec, M. Jeitler[1], W. Kiesenhofer, V. Knünz, M. Krammer[1], I. Krätschmer, D. Liko, I. Mikulec, M. Pernicka[†], B. Rahbaran, C. Rohringer, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, W. Waltenberger, G. Walzel, E. Widl, C.-E. Wulz[1]

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

V. Mossolov, N. Shumeiko, J. Suarez Gonzalez

Universiteit Antwerpen, Antwerpen, Belgium

M. Bansal, S. Bansal, T. Cornelis, E.A. De Wolf, X. Janssen, S. Luyckx, L. Mucibello, S. Ochesanu, B. Roland, R. Rougny, M. Selvaggi, Z. Staykova, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

Vrije Universiteit Brussel, Brussel, Belgium

F. Blekman, S. Blyweert, J. D'Hondt, R. Gonzalez Suarez, A. Kalogeropoulos, M. Maes, A. Olbrechts, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Villella

Université Libre de Bruxelles, Bruxelles, Belgium

B. Clerbaux, G. De Lentdecker, V. Dero, A.P.R. Gay, T. Hreus, A. Léonard, P.E. Marage, A. Mohammadi, T. Reis, L. Thomas, G. Vander Marcken, C. Vander Velde, P. Vanlaer, J. Wang

Ghent University, Ghent, Belgium

V. Adler, K. Beernaert, A. Cimmino, S. Costantini, G. Garcia, M. Grunewald, B. Klein, J. Lellouch, A. Marinov, J. Mccartin, A.A. Ocampo Rios, D. Ryckbosch, N. Strobbe, F. Thyssen, M. Tytgat, P. Verwilligen, S. Walsh, E. Yazgan, N. Zaganidis

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

S. Basegmez, G. Bruno, R. Castello, L. Ceard, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco[2], J. Hollar, V. Lemaitre, J. Liao, O. Militaru, C. Nuttens, D. Pagano, A. Pin, K. Piotrzkowski, N. Schul, J.M. Vizan Garcia

Université de Mons, Mons, Belgium

N. Beliy, T. Caebergs, E. Daubie, G.H. Hammad

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

G.A. Alves, M. Correa Martins Junior, D. De Jesus Damiao, T. Martins, M.E. Pol, M.H.G. Souza

JHEP02(2013)036

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
W.L. Aldá Júnior, W. Carvalho, A. Custódio, E.M. Da Costa, C. De Oliveira Martins, S. Fonseca De Souza, D. Matos Figueiredo, L. Mundim, H. Nogima, V. Oguri, W.L. Prado Da Silva, A. Santoro, L. Soares Jorge, A. Sznajder

Instituto de Fisica Teorica [a], Universidade Estadual Paulista [b], Sao Paulo, Brazil
T.S. Anjos[b,3], C.A. Bernardes[b,3], F.A. Dias[a,4], T.R. Fernandez Perez Tomei[a], E.M. Gregores[b,3], C. Lagana[a], F. Marinho[a], P.G. Mercadante[b,3], S.F. Novaes[a], Sandra S. Padula[a]

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria
V. Genchev[5], P. Iaydjiev[5], S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, V. Tcholakov, R. Trayanov, M. Vutova

University of Sofia, Sofia, Bulgaria
A. Dimitrov, R. Hadjiiska, V. Kozhuharov, L. Litov, B. Pavlov, P. Petkov

Institute of High Energy Physics, Beijing, China
J.G. Bian, G.M. Chen, H.S. Chen, C.H. Jiang, D. Liang, S. Liang, X. Meng, J. Tao, J. Wang, X. Wang, Z. Wang, H. Xiao, M. Xu, J. Zang, Z. Zhang

State Key Lab. of Nucl. Phys. and Tech., Peking University, Beijing, China
C. Asawatangtrakuldee, Y. Ban, Y. Guo, W. Li, S. Liu, Y. Mao, S.J. Qian, H. Teng, D. Wang, L. Zhang, W. Zou

Universidad de Los Andes, Bogota, Colombia
C. Avila, J.P. Gomez, B. Gomez Moreno, A.F. Osorio Oliveros, J.C. Sanabria

Technical University of Split, Split, Croatia
N. Godinovic, D. Lelas, R. Plestina[6], D. Polic, I. Puljak[5]

University of Split, Split, Croatia
Z. Antunovic, M. Kovac

Institute Rudjer Boskovic, Zagreb, Croatia
V. Brigljevic, S. Duric, K. Kadija, J. Luetic, S. Morovic

University of Cyprus, Nicosia, Cyprus
A. Attikis, M. Galanti, G. Mavromanolakis, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis

Charles University, Prague, Czech Republic
M. Finger, M. Finger Jr.

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt
Y. Assran[7], S. Elgammal[8], A. Ellithi Kamel[9], M.A. Mahmoud[10], A. Radi[11,12]

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
M. Kadastik, M. Müntel, M. Raidal, L. Rebane, A. Tiko

JHEP02(2013)036

Department of Physics, University of Helsinki, Helsinki, Finland
P. Eerola, G. Fedi, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland
J. Härkönen, A. Heikkinen, V. Karimäki, R. Kinnunen, M.J. Kortelainen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, P. Luukka, T. Mäenpää, T. Peltola, E. Tuominen, J. Tuominiemi, E. Tuovinen, D. Ungaro, L. Wendland

Lappeenranta University of Technology, Lappeenranta, Finland
K. Banzuzi, A. Karjalainen, A. Korpela, T. Tuuva

DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France
M. Besancon, S. Choudhury, M. Dejardin, D. Denegri, B. Fabbro, J.L. Faure, F. Ferri, S. Ganjour, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, J. Malcles, L. Millischer, A. Nayak, J. Rander, A. Rosowsky, I. Shreyber, M. Titov

Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
S. Baffioni, F. Beaudette, L. Benhabib, L. Bianchini, M. Bluj[13], C. Broutin, P. Busson, C. Charlot, N. Daci, T. Dahms, L. Dobrzynski, R. Granier de Cassagnac, M. Haguenauer, P. Miné, C. Mironov, I.N. Naranjo, M. Nguyen, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Veelken, A. Zabi

Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France
J.-L. Agram[14], J. Andrea, D. Bloch, D. Bodin, J.-M. Brom, M. Cardaci, E.C. Chabert, C. Collard, E. Conte[14], F. Drouhin[14], C. Ferro, J.-C. Fontaine[14], D. Gelé, U. Goerlach, P. Juillot, A.-C. Le Bihan, P. Van Hove

Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France, Villeurbanne, France
F. Fassi, D. Mercier

Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France
S. Beauceron, N. Beaupere, O. Bondu, G. Boudoul, J. Chasserat, R. Chierici[5], D. Contardo, P. Depasse, H. El Mamouni, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, M. Lethuillier, L. Mirabito, S. Perries, L. Sgandurra, V. Sordini, Y. Tschudi, P. Verdier, S. Viret

Institute of High Energy Physics and Informatization, Tbilisi State University, Tbilisi, Georgia
Z. Tsamalaidze[15]

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
G. Anagnostou, C. Autermann, S. Beranek, M. Edelhoff, L. Feld, N. Heracleous, O. Hindrichs, R. Jussen, K. Klein, J. Merz, A. Ostapchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Sprenger, H. Weber, B. Wittmer, V. Zhukov[16]

JHEP02(2013)036

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany

M. Ata, J. Caudron, E. Dietz-Laursonn, D. Duchardt, M. Erdmann, R. Fischer, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, D. Klingebiel, P. Kreuzer, M. Merschmeyer, A. Meyer, M. Olschewski, P. Papacz, H. Pieta, H. Reithler, S.A. Schmitz, L. Sonnenschein, J. Steggemann, D. Teyssier, M. Weber

RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany

M. Bontenackels, V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, W. Haj Ahmad, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, J. Lingemann[5], A. Nowack, L. Perchalla, O. Pooth, P. Sauerland, A. Stahl

Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, J. Behr, W. Behrenhoff, U. Behrens, M. Bergholz[17], A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, E. Castro, F. Costanza, D. Dammann, C. Diez Pardos, G. Eckerlin, D. Eckstein, G. Flucke, A. Geiser, I. Glushkov, P. Gunnellini, S. Habib, J. Hauk, G. Hellwig, H. Jung, M. Kasemann, P. Katsas, C. Kleinwort, H. Kluge, A. Knutsson, M. Krämer, D. Krücker, E. Kuznetsova, W. Lange, W. Lohmann[17], B. Lutz, R. Mankel, I. Marfin, M. Marienfeld, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, S. Naumann-Emme, O. Novgorodova, J. Olzem, H. Perrey, A. Petrukhin, D. Pitzl, A. Raspereza, P.M. Ribeiro Cipriano, C. Riedl, E. Ron, M. Rosin, J. Salfeld-Nebgen, R. Schmidt[17], T. Schoerner-Sadenius, N. Sen, A. Spiridonov, M. Stein, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany

V. Blobel, J. Draeger, H. Enderle, J. Erfle, U. Gebbert, M. Görner, T. Hermanns, R.S. Höing, K. Kaschube, G. Kaussen, H. Kirschenmann, R. Klanner, J. Lange, B. Mura, F. Nowak, T. Peiffer, N. Pietsch, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, M. Schröder, T. Schum, M. Seidel, V. Sola, H. Stadie, G. Steinbrück, J. Thomsen, L. Vanelderen

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

C. Barth, J. Berger, C. Böser, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, M. Guthoff[5], C. Hackstein, F. Hartmann, T. Hauth[5], M. Heinrich, H. Held, K.H. Hoffmann, S. Honc, I. Katkov[16], J.R. Komaragiri, P. Lobelle Pardo, D. Martschei, S. Mueller, Th. Müller, M. Niegel, A. Nürnberg, O. Oberst, A. Oehler, J. Ott, G. Quast, K. Rabbertz, F. Ratnikov, N. Ratnikova, S. Röcker, A. Scheurer, F.-P. Schilling, G. Schott, H.J. Simonis, F.M. Stober, D. Troendle, R. Ulrich, J. Wagner-Kuhr, S. Wayand, T. Weiler, M. Zeise

Institute of Nuclear Physics "Demokritos", Aghia Paraskevi, Greece

G. Daskalakis, T. Geralis, S. Kesisoglou, A. Kyriakis, D. Loukas, I. Manolakos, A. Markou, C. Markou, C. Mavrommatis, E. Ntomari

University of Athens, Athens, Greece

L. Gouskos, T.J. Mertzimekis, A. Panagiotou, N. Saoulidou

JHEP02(2013)036

University of Ioánnina, Ioánnina, Greece
I. Evangelou, C. Foudas, P. Kokkas, N. Manthos, I. Papadopoulos, V. Patras

KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
G. Bencze, C. Hajdu, P. Hidas, D. Horvath[18], F. Sikler, V. Veszpremi, G. Vesztergombi[19]

Institute of Nuclear Research ATOMKI, Debrecen, Hungary
N. Beni, S. Czellar, J. Molnar, J. Palinkas, Z. Szillasi

University of Debrecen, Debrecen, Hungary
J. Karancsi, P. Raics, Z.L. Trocsanyi, B. Ujvari

Panjab University, Chandigarh, India
S.B. Beri, V. Bhatnagar, N. Dhingra, R. Gupta, M. Kaur, M.Z. Mehta, N. Nishu, L.K. Saini, A. Sharma, J.B. Singh

University of Delhi, Delhi, India
Ashok Kumar, Arun Kumar, S. Ahuja, A. Bhardwaj, B.C. Choudhary, S. Malhotra, M. Naimuddin, K. Ranjan, V. Sharma, R.K. Shivpuri

Saha Institute of Nuclear Physics, Kolkata, India
S. Banerjee, S. Bhattacharya, S. Dutta, B. Gomber, Sa. Jain, Sh. Jain, R. Khurana, S. Sarkar, M. Sharan

Bhabha Atomic Research Centre, Mumbai, India
A. Abdulsalam, R.K. Choudhury, D. Dutta, S. Kailas, V. Kumar, P. Mehta, A.K. Mohanty[5], L.M. Pant, P. Shukla

Tata Institute of Fundamental Research - EHEP, Mumbai, India
T. Aziz, S. Ganguly, M. Guchait[20], M. Maity[21], G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage

Tata Institute of Fundamental Research - HECR, Mumbai, India
S. Banerjee, S. Dugad

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
H. Arfaei[22], H. Bakhshiansohi, S.M. Etesami[23], A. Fahim[22], M. Hashemi, H. Hesari, A. Jafari, M. Khakzad, M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh[24], M. Zeinali

INFN Sezione di Bari [a], Università di Bari [b], Politecnico di Bari [c], Bari, Italy
M. Abbrescia[a,b], L. Barbone[a,b], C. Calabria[a,b,5], S.S. Chhibra[a,b], A. Colaleo[a], D. Creanza[a,c], N. De Filippis[a,c,5], M. De Palma[a,b], L. Fiore[a], G. Iaselli[a,c], L. Lusito[a,b], G. Maggi[a,c], M. Maggi[a], B. Marangelli[a,b], S. My[a,c], S. Nuzzo[a,b], N. Pacifico[a,b], A. Pompili[a,b], G. Pugliese[a,c], G. Selvaggi[a,b], L. Silvestris[a], G. Singh[a,b], R. Venditti[a,b], G. Zito[a]

INFN Sezione di Bologna [a], Università di Bologna [b], Bologna, Italy
G. Abbiendi[a], A.C. Benvenuti[a], D. Bonacorsi[a,b], S. Braibant-Giacomelli[a,b], L. Brigliadori[a,b], P. Capiluppi[a,b], A. Castro[a,b], F.R. Cavallo[a], M. Cuffiani[a,b],

JHEP02(2013)036

G.M. Dallavalle[a], F. Fabbri[a], A. Fanfani[a,b], D. Fasanella[a,b,5], P. Giacomelli[a], C. Grandi[a], L. Guiducci[a,b], S. Marcellini[a], G. Masetti[a], M. Meneghelli[a,b,5], A. Montanari[a], F.L. Navarria[a,b], F. Odorici[a], A. Perrotta[a], F. Primavera[a,b], A.M. Rossi[a,b], T. Rovelli[a,b], G.P. Siroli[a,b], R. Travaglini[a,b]

INFN Sezione di Catania [a], Università di Catania [b], Catania, Italy
S. Albergo[a,b], G. Cappello[a,b], M. Chiorboli[a,b], S. Costa[a,b], R. Potenza[a,b], A. Tricomi[a,b], C. Tuve[a,b]

INFN Sezione di Firenze [a], Università di Firenze [b], Firenze, Italy
G. Barbagli[a], V. Ciulli[a,b], C. Civinini[a], R. D'Alessandro[a,b], E. Focardi[a,b], S. Frosali[a,b], E. Gallo[a], S. Gonzi[a,b], M. Meschini[a], S. Paoletti[a], G. Sguazzoni[a], A. Tropiano[a]

INFN Laboratori Nazionali di Frascati, Frascati, Italy
L. Benussi, S. Bianco, S. Colafranceschi[25], F. Fabbri, D. Piccolo

INFN Sezione di Genova [a], Università di Genova [b], Genova, Italy
P. Fabbricatore[a], R. Musenich[a], S. Tosi[a,b]

INFN Sezione di Milano-Bicocca [a], Università di Milano-Bicocca [b], Milano, Italy
A. Benaglia[a,b], F. De Guio[a,b], L. Di Matteo[a,b,5], S. Fiorendi[a,b], S. Gennai[a,5], A. Ghezzi[a,b], S. Malvezzi[a], R.A. Manzoni[a,b], A. Martelli[a,b], A. Massironi[a,b,5], D. Menasce[a], L. Moroni[a], M. Paganoni[a,b], D. Pedrini[a], S. Ragazzi[a,b], N. Redaelli[a], S. Sala[a], T. Tabarelli de Fatis[a,b]

INFN Sezione di Napoli [a], Università di Napoli "Federico II" [b], Napoli, Italy
S. Buontempo[a], C.A. Carrillo Montoya[a], N. Cavallo[a,26], A. De Cosa[a,b,5], O. Dogangun[a,b], F. Fabozzi[a,26], A.O.M. Iorio[a], L. Lista[a], S. Meola[a,27], M. Merola[a,b], P. Paolucci[a,5]

INFN Sezione di Padova [a], Università di Padova [b], Università di Trento (Trento) [c], Padova, Italy
P. Azzi[a], N. Bacchetta[a,5], D. Bisello[a,b], A. Branca[a,b,5], R. Carlin[a,b], P. Checchia[a], T. Dorigo[a], U. Dosselli[a], F. Gasparini[a,b], U. Gasparini[a,b], A. Gozzelino[a], K. Kanishchev[a,c], S. Lacaprara[a], I. Lazzizzera[a,c], M. Margoni[a,b], A.T. Meneguzzo[a,b], J. Pazzini[a,b], N. Pozzobon[a,b], P. Ronchese[a,b], F. Simonetto[a,b], E. Torassa[a], M. Tosi[a,b,5], S. Vanini[a,b], P. Zotto[a,b], G. Zumerle[a,b]

INFN Sezione di Pavia [a], Università di Pavia [b], Pavia, Italy
M. Gabusi[a,b], S.P. Ratti[a,b], C. Riccardi[a,b], P. Torre[a,b], P. Vitulo[a,b]

INFN Sezione di Perugia [a], Università di Perugia [b], Perugia, Italy
M. Biasini[a,b], G.M. Bilei[a], L. Fanò[a,b], P. Lariccia[a,b], A. Lucaroni[a,b,5], G. Mantovani[a,b], M. Menichelli[a], A. Nappi[a,b†], F. Romeo[a,b], A. Saha[a], A. Santocchia[a,b], A. Spiezia[a,b], S. Taroni[a,b]

INFN Sezione di Pisa [a], Università di Pisa [b], Scuola Normale Superiore di Pisa [c], Pisa, Italy
P. Azzurri[a,c], G. Bagliesi[a], J. Bernardini[a], T. Boccali[a], G. Broccolo[a,c], R. Castaldi[a], R.T. D'Agnolo[a,c,5], R. Dell'Orso[a], F. Fiori[a,b,5], L. Foà[a,c], A. Giassi[a], A. Kraan[a],

JHEP02(2013)036

F. Ligabue[a,c], T. Lomtadze[a], L. Martini[a,28], A. Messineo[a,b], F. Palla[a], A. Rizzi[a,b], A.T. Serban[a,29], P. Spagnolo[a], P. Squillacioti[a,5], R. Tenchini[a], G. Tonelli[a,b], A. Venturi[a], P.G. Verdini[a]

INFN Sezione di Roma [a], Università di Roma [b], Roma, Italy

L. Barone[a,b], F. Cavallari[a], D. Del Re[a,b], M. Diemoz[a], C. Fanelli[a,b], M. Grassi[a,b,5], E. Longo[a,b], P. Meridiani[a,5], F. Micheli[a,b], S. Nourbakhsh[a,b], G. Organtini[a,b], R. Paramatti[a], S. Rahatlou[a,b], M. Sigamani[a], L. Soffi[a,b]

INFN Sezione di Torino [a], Università di Torino [b], Università del Piemonte Orientale (Novara) [c], Torino, Italy

N. Amapane[a,b], R. Arcidiacono[a,c], S. Argiro[a,b], M. Arneodo[a,c], C. Biino[a], N. Cartiglia[a], M. Costa[a,b], N. Demaria[a], C. Mariotti[a,5], S. Maselli[a], E. Migliore[a,b], V. Monaco[a,b], M. Musich[a,5], M.M. Obertino[a,c], N. Pastrone[a], M. Pelliccioni[a], A. Potenza[a,b], A. Romero[a,b], R. Sacchi[a,b], A. Solano[a,b], A. Staiano[a], P.P. Trapani[a,b], A. Vilela Pereira[a]

INFN Sezione di Trieste [a], Università di Trieste [b], Trieste, Italy

S. Belforte[a], V. Candelise[a,b], M. Casarsa[a], F. Cossutti[a], G. Della Ricca[a,b], B. Gobbo[a], M. Marone[a,b,5], D. Montanino[a,b,5], A. Penzo[a], A. Schizzi[a,b]

Kangwon National University, Chunchon, Korea

S.G. Heo, T.Y. Kim, S.K. Nam

Kyungpook National University, Daegu, Korea

S. Chang, D.H. Kim, G.N. Kim, D.J. Kong, H. Park, S.R. Ro, D.C. Son, T. Son

Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea

J.Y. Kim, Zero J. Kim, S. Song

Korea University, Seoul, Korea

S. Choi, D. Gyun, B. Hong, M. Jo, H. Kim, T.J. Kim, K.S. Lee, D.H. Moon, S.K. Park

University of Seoul, Seoul, Korea

M. Choi, J.H. Kim, C. Park, I.C. Park, S. Park, G. Ryu

Sungkyunkwan University, Suwon, Korea

Y. Cho, Y. Choi, Y.K. Choi, J. Goh, M.S. Kim, E. Kwon, B. Lee, J. Lee, S. Lee, H. Seo, I. Yu

Vilnius University, Vilnius, Lithuania

M.J. Bilinskas, I. Grigelionis, M. Janulis, A. Juodagalvis

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico

H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz, R. Lopez-Fernandez, R. Magaña Villalba, J. Martínez-Ortega, A. Sanchez-Hernandez, L.M. Villasenor-Cendejas

Universidad Iberoamericana, Mexico City, Mexico

S. Carrillo Moreno, F. Vazquez Valencia

JHEP02(2013)036

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

H.A. Salazar Ibarguen

Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico

E. Casimiro Linares, A. Morelos Pineda, M.A. Reyes-Santos

University of Auckland, Auckland, New Zealand

D. Krofcheck

University of Canterbury, Christchurch, New Zealand

A.J. Bell, P.H. Butler, R. Doesburg, S. Reucroft, H. Silverwood

National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan

M. Ahmad, M.H. Ansari, M.I. Asghar, H.R. Hoorani, S. Khalid, W.A. Khan, T. Khurshid, S. Qazi, M.A. Shah, M. Shoaib

National Centre for Nuclear Research, Swierk, Poland

H. Bialkowska, B. Boimska, T. Frueboes, R. Gokieli, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, G. Wrochna, P. Zalewski

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland

G. Brona, K. Bunkowski, M. Cwiok, W. Dominik, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal

N. Almeida, P. Bargassa, A. David, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, J. Seixas, J. Varela, P. Vischia

Joint Institute for Nuclear Research, Dubna, Russia

I. Belotelov, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin, V. Konoplyanikov, G. Kozlov, A. Lanev, A. Malakhov, P. Moisenz, V. Palichik, V. Perelygin, M. Savina, S. Shmatov, V. Smirnov, A. Volodko, A. Zarubin

Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia

S. Evstyukhin, V. Golovtsov, Y. Ivanov, V. Kim, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev, An. Vorobyev

Institute for Nuclear Research, Moscow, Russia

Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, M. Kirsanov, N. Krasnikov, V. Matveev, A. Pashenkov, D. Tlisov, A. Toropin

Institute for Theoretical and Experimental Physics, Moscow, Russia

V. Epshteyn, M. Erofeeva, V. Gavrilov, M. Kossov, N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, V. Stolin, E. Vlasov, A. Zhokin

JHEP02(2013)036

Moscow State University, Moscow, Russia

A. Belyaev, E. Boos, V. Bunichev, M. Dubinin[4], L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, A. Markina, S. Obraztsov, M. Perfilov, S. Petrushanko, A. Popov, L. Sarycheva[†], V. Savrin

P.N. Lebedev Physical Institute, Moscow, Russia

V. Andreev, M. Azarkin, I. Dremin, M. Kirakosyan, A. Leonidov, G. Mesyats, S.V. Rusakov, A. Vinogradov

State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia

I. Azhgirey, I. Bayshev, S. Bitioukov, V. Grishin[5], V. Kachanov, D. Konstantinov, V. Krychkine, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia

P. Adzic[30], M. Djordjevic, M. Ekmedzic, D. Krpic[30], J. Milosevic

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain

M. Aguilar-Benitez, J. Alcaraz Maestre, P. Arce, C. Battilana, E. Calvo, M. Cerrada, M. Chamizo Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, D. Domínguez Vázquez, C. Fernandez Bedoya, J.P. Fernández Ramos, A. Ferrando, J. Flix, M.C. Fouz, P. Garcia-Abia, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, G. Merino, J. Puerta Pelayo, A. Quintario Olmeda, I. Redondo, L. Romero, J. Santaolalla, M.S. Soares, C. Willmott

Universidad Autónoma de Madrid, Madrid, Spain

C. Albajar, G. Codispoti, J.F. de Trocóniz

Universidad de Oviedo, Oviedo, Spain

H. Brun, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias, J. Piedra Gomez

Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain

J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, S.H. Chuang, J. Duarte Campderros, M. Felcini[31], M. Fernandez, G. Gomez, J. Gonzalez Sanchez, A. Graziano, C. Jorda, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, I. Vila, R. Vilar Cortabitarte

CERN, European Organization for Nuclear Research, Geneva, Switzerland

D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, J.F. Benitez, C. Bernet[6], G. Bianchi, P. Bloch, A. Bocci, A. Bonato, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, D. D'Enterria,

JHEP02(2013)036

A. Dabrowski, A. De Roeck, S. Di Guida, M. Dobson, N. Dupont-Sagorin, A. Elliott-Peisert, B. Frisch, W. Funk, G. Georgiou, M. Giffels, D. Gigi, K. Gill, D. Giordano, M. Girone, M. Giunta, F. Glege, R. Gomez-Reino Garrido, P. Govoni, S. Gowdy, R. Guida, M. Hansen, P. Harris, C. Hartl, J. Harvey, B. Hegner, A. Hinzmann, V. Innocente, P. Janot, K. Kaadze, E. Karavakis, K. Kousouris, P. Lecoq, Y.-J. Lee, P. Lenzi, C. Lourenço, N. Magini, T. Mäki, M. Malberti, L. Malgeri, M. Mannelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, R. Moser, M.U. Mozer, M. Mulders, P. Musella, E. Nesvold, T. Orimoto, L. Orsini, E. Palencia Cortezon, E. Perez, L. Perrozzi, A. Petrilli, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, G. Polese, L. Quertenmont, A. Racz, W. Reece, J. Rodrigues Antunes, G. Rolandi[32], C. Rovelli[33], M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas[34], D. Spiga, A. Tsirou, G.I. Veres[19], J.R. Vlimant, H.K. Wöhri, S.D. Worm[35], W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland

W. Bertl, K. Deiters, W. Erdmann, K. Gabathuler, R. Horisberger, Q. Ingram, H.C. Kaestli, S. König, D. Kotlinski, U. Langenegger, F. Meier, D. Renker, T. Rohe, J. Sibille[36]

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

L. Bäni, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, A. Deisher, G. Dissertori, M. Dittmar, M. Donegà, M. Dünser, J. Eugster, K. Freudenreich, C. Grab, D. Hits, P. Lecomte, W. Lustermann, A.C. Marini, P. Martinez Ruiz del Arbol, N. Mohr, F. Moortgat, C. Nägeli[37], P. Nef, F. Nessi-Tedaldi, F. Pandolfi, L. Pape, F. Pauss, M. Peruzzi, F.J. Ronga, M. Rossini, L. Sala, A.K. Sanchez, A. Starodumov[38], B. Stieger, M. Takahashi, L. Tauscher[†], A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, H.A. Weber, L. Wehrli

Universität Zürich, Zurich, Switzerland

C. Amsler, V. Chiochia, S. De Visscher, C. Favaro, M. Ivova Rikova, B. Millan Mejias, P. Otiougova, P. Robmann, H. Snoek, S. Tupputi, M. Verzetti

National Central University, Chung-Li, Taiwan

Y.H. Chang, K.H. Chen, C.M. Kuo, S.W. Li, W. Lin, Z.K. Liu, Y.J. Lu, D. Mekterovic, A.P. Singh, R. Volpe, S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan

P. Bartalini, P. Chang, Y.H. Chang, Y.W. Chang, Y. Chao, K.F. Chen, C. Dietz, U. Grundler, W.-S. Hou, Y. Hsiung, K.Y. Kao, Y.J. Lei, R.-S. Lu, D. Majumder, E. Petrakou, X. Shi, J.G. Shiu, Y.M. Tzeng, X. Wan, M. Wang

Chulalongkorn University, Bangkok, Thailand

B. Asavapibhop, N. Srimanobhas

Cukurova University, Adana, Turkey

A. Adiguzel, M.N. Bakirci[39], S. Cerci[40], C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, E. Gurpinar, I. Hos, E.E. Kangal, T. Karaman, G. Karapinar[41], A. Kayis

JHEP02(2013)036

Topaksu, G. Onengut, K. Ozdemir, S. Ozturk[42], A. Polatoz, K. Sogut[43], D. Sunar Cerci[40], B. Tali[40], H. Topakli[39], L.N. Vergili, M. Vergili

Middle East Technical University, Physics Department, Ankara, Turkey
I.V. Akin, T. Aliev, B. Bilin, S. Bilmis, M. Deniz, H. Gamsizkan, A.M. Guler, K. Ocalan, A. Ozpineci, M. Serin, R. Sever, U.E. Surat, M. Yalvac, E. Yildirim, M. Zeyrek

Bogazici University, Istanbul, Turkey
E. Gülmez, B. Isildak[44], M. Kaya[45], O. Kaya[45], S. Ozkorucuklu[46], N. Sonmez[47]

Istanbul Technical University, Istanbul, Turkey
K. Cankocak

National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine
L. Levchuk

University of Bristol, Bristol, United Kingdom
F. Bostock, J.J. Brooke, E. Clement, D. Cussans, H. Flacher, R. Frazier, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, L. Kreczko, S. Metson, D.M. Newbold[35], K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, T. Williams

Rutherford Appleton Laboratory, Didcot, United Kingdom
L. Basso[48], K.W. Bell, A. Belyaev[48], C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, J. Jackson, B.W. Kennedy, E. Olaiya, D. Petyt, B.C. Radburn-Smith, C.H. Shepherd-Themistocleous, I.R. Tomalin, W.J. Womersley

Imperial College, London, United Kingdom
R. Bainbridge, G. Ball, R. Beuselinck, O. Buchmuller, D. Colling, N. Cripps, M. Cutajar, P. Dauncey, G. Davies, M. Della Negra, W. Ferguson, J. Fulcher, D. Futyan, A. Gilbert, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, M. Jarvis, G. Karapostoli, L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko[38], A. Papageorgiou, J. Pela, M. Pesaresi, K. Petridis, M. Pioppi[49], D.M. Raymond, S. Rogerson, A. Rose, M.J. Ryan, C. Seez, P. Sharp[†], A. Sparrow, M. Stoye, A. Tapper, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle, T. Whyntie

Brunel University, Uxbridge, United Kingdom
M. Chadwick, J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, D. Leggat, D. Leslie, W. Martin, I.D. Reid, P. Symonds, L. Teodorescu, M. Turner

Baylor University, Waco, USA
K. Hatakeyama, H. Liu, T. Scarborough

The University of Alabama, Tuscaloosa, USA
O. Charaf, C. Henderson, P. Rumerio

Boston University, Boston, USA
A. Avetisyan, T. Bose, C. Fantasia, A. Heister, J. St. John, P. Lawson, D. Lazic, J. Rohlf, D. Sperka, L. Sulak

JHEP02(2013)036

Brown University, Providence, USA

J. Alimena, S. Bhattacharya, D. Cutts, A. Ferapontov, U. Heintz, S. Jabeen, G. Kukartsev, E. Laird, G. Landsberg, M. Luk, M. Narain, D. Nguyen, M. Segala, T. Sinthuprasith, T. Speer, K.V. Tsang

University of California, Davis, Davis, USA

R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, J. Dolen, R. Erbacher, M. Gardner, R. Houtz, W. Ko, A. Kopecky, R. Lander, T. Miceli, D. Pellett, F. Ricci-Tam, B. Rutherford, M. Searle, J. Smith, M. Squires, M. Tripathi, R. Vasquez Sierra

University of California, Los Angeles, Los Angeles, USA

V. Andreev, D. Cline, R. Cousins, J. Duris, S. Erhan, P. Everaerts, C. Farrell, J. Hauser, M. Ignatenko, C. Jarvis, C. Plager, G. Rakness, P. Schlein[†], P. Traczyk, V. Valuev, M. Weber

University of California, Riverside, Riverside, USA

J. Babb, R. Clare, M.E. Dinardo, J. Ellison, J.W. Gary, F. Giordano, G. Hanson, G.Y. Jeng[50], H. Liu, O.R. Long, A. Luthra, H. Nguyen, S. Paramesvaran, J. Sturdy, S. Sumowidagdo, R. Wilken, S. Wimpenny

University of California, San Diego, La Jolla, USA

W. Andrews, J.G. Branson, G.B. Cerati, S. Cittolin, D. Evans, F. Golf, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, I. Macneill, B. Mangano, S. Padhi, C. Palmer, G. Petrucciani, M. Pieri, M. Sani, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech[51], F. Würthwein, A. Yagil, J. Yoo

University of California, Santa Barbara, Santa Barbara, USA

D. Barge, R. Bellan, C. Campagnari, M. D'Alfonso, T. Danielson, K. Flowers, P. Geffert, J. Incandela, C. Justus, P. Kalavase, S.A. Koay, D. Kovalskyi, V. Krutelyov, S. Lowette, N. Mccoll, V. Pavlunin, F. Rebassoo, J. Ribnik, J. Richman, R. Rossin, D. Stuart, W. To, C. West

California Institute of Technology, Pasadena, USA

A. Apresyan, A. Bornheim, Y. Chen, E. Di Marco, J. Duarte, M. Gataullin, Y. Ma, A. Mott, H.B. Newman, C. Rogan, M. Spiropulu, V. Timciuc, J. Veverka, R. Wilkinson, S. Xie, Y. Yang, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA

B. Akgun, V. Azzolini, A. Calamba, R. Carroll, T. Ferguson, Y. Iiyama, D.W. Jang, Y.F. Liu, M. Paulini, H. Vogel, I. Vorobiev

University of Colorado at Boulder, Boulder, USA

J.P. Cumalat, B.R. Drell, C.J. Edelmaier, W.T. Ford, A. Gaz, B. Heyburn, E. Luiggi Lopez, J.G. Smith, K. Stenson, K.A. Ulmer, S.R. Wagner

JHEP02(2013)036

Cornell University, Ithaca, USA

J. Alexander, A. Chatterjee, N. Eggert, L.K. Gibbons, B. Heltsley, A. Khukhunaishvili, B. Kreis, N. Mirman, G. Nicolas Kaufman, J.R. Patterson, A. Ryd, E. Salvati, W. Sun, W.D. Teo, J. Thom, J. Thompson, J. Tucker, J. Vaughan, Y. Weng, L. Winstrom, P. Wittich

Fairfield University, Fairfield, USA

D. Winn

Fermi National Accelerator Laboratory, Batavia, USA

S. Abdullin, M. Albrow, J. Anderson, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, I. Bloch, K. Burkett, J.N. Butler, V. Chetluru, H.W.K. Cheung, F. Chlebana, V.D. Elvira, I. Fisk, J. Freeman, Y. Gao, D. Green, O. Gutsche, J. Hanlon, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, B. Kilminster, B. Klima, S. Kunori, S. Kwan, C. Leonidopoulos, J. Linacre, D. Lincoln, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, S. Maruyama, D. Mason, P. McBride, K. Mishra, S. Mrenna, Y. Musienko[52], C. Newman-Holmes, V. O'Dell, O. Prokofyev, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, P. Tan, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, R. Vidal, J. Whitmore, W. Wu, F. Yang, F. Yumiceva, J.C. Yun

University of Florida, Gainesville, USA

D. Acosta, P. Avery, D. Bourilkov, M. Chen, T. Cheng, S. Das, M. De Gruttola, G.P. Di Giovanni, D. Dobur, A. Drozdetskiy, R.D. Field, M. Fisher, Y. Fu, I.K. Furic, J. Gartner, J. Hugon, B. Kim, J. Konigsberg, A. Korytov, A. Kropivnitskaya, T. Kypreos, J.F. Low, K. Matchev, P. Milenovic[53], G. Mitselmakher, L. Muniz, M. Park, R. Remington, A. Rinkevicius, P. Sellers, N. Skhirtladze, M. Snowball, J. Yelton, M. Zakaria

Florida International University, Miami, USA

V. Gaultney, S. Hewamanage, L.M. Lebolo, S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

Florida State University, Tallahassee, USA

T. Adams, A. Askew, J. Bochenek, J. Chen, B. Diamond, S.V. Gleyzer, J. Haas, S. Hagopian, V. Hagopian, M. Jenkins, K.F. Johnson, H. Prosper, V. Veeraraghavan, M. Weinberg

Florida Institute of Technology, Melbourne, USA

M.M. Baarmand, B. Dorney, M. Hohlmann, H. Kalakhety, I. Vodopiyanov

University of Illinois at Chicago (UIC), Chicago, USA

M.R. Adams, I.M. Anghel, L. Apanasevich, Y. Bai, V.E. Bazterra, R.R. Betts, I. Bucinskaite, J. Callner, R. Cavanaugh, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, F. Lacroix, M. Malek, C. O'Brien, C. Silkworth, D. Strom, P. Turner, N. Varelas

JHEP02(2013)036

The University of Iowa, Iowa City, USA

U. Akgun, E.A. Albayrak, B. Bilki[54], W. Clarida, F. Duru, S. Griffiths, J.-P. Merlo, H. Mermerkaya[55], A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, E. Norbeck, Y. Onel, F. Ozok[56], S. Sen, E. Tiras, J. Wetzel, T. Yetkin, K. Yi

Johns Hopkins University, Baltimore, USA

B.A. Barnett, B. Blumenfeld, S. Bolognesi, D. Fehling, G. Giurgiu, A.V. Gritsan, Z.J. Guo, G. Hu, P. Maksimovic, S. Rappoccio, M. Swartz, A. Whitbeck

The University of Kansas, Lawrence, USA

P. Baringer, A. Bean, G. Benelli, R.P. Kenny Iii, M. Murray, D. Noonan, S. Sanders, R. Stringer, G. Tinti, J.S. Wood, V. Zhukova

Kansas State University, Manhattan, USA

A.F. Barfuss, T. Bolton, I. Chakaberia, A. Ivanov, S. Khalil, M. Makouski, Y. Maravin, S. Shrestha, I. Svintradze

Lawrence Livermore National Laboratory, Livermore, USA

J. Gronberg, D. Lange, D. Wright

University of Maryland, College Park, USA

A. Baden, M. Boutemeur, B. Calvert, S.C. Eno, J.A. Gomez, N.J. Hadley, R.G. Kellogg, M. Kirn, T. Kolberg, Y. Lu, M. Marionneau, A.C. Mignerey, K. Pedro, A. Peterman, A. Skuja, J. Temple, M.B. Tonjes, S.C. Tonwar, E. Twedt

Massachusetts Institute of Technology, Cambridge, USA

A. Apyan, G. Bauer, J. Bendavid, W. Busza, E. Butz, I.A. Cali, M. Chan, V. Dutta, G. Gomez Ceballos, M. Goncharov, K.A. Hahn, Y. Kim, M. Klute, K. Krajczar[57], W. Li, P.D. Luckey, T. Ma, S. Nahn, C. Paus, D. Ralph, C. Roland, G. Roland, M. Rudolph, G.S.F. Stephans, F. Stöckli, K. Sumorok, K. Sung, D. Velicanu, E.A. Wenger, R. Wolf, B. Wyslouch, M. Yang, Y. Yilmaz, A.S. Yoon, M. Zanetti

University of Minnesota, Minneapolis, USA

S.I. Cooper, B. Dahmes, A. De Benedetti, G. Franzoni, A. Gude, S.C. Kao, K. Klapoetke, Y. Kubota, J. Mans, N. Pastika, R. Rusack, M. Sasseville, A. Singovsky, N. Tambe, J. Turkewitz

University of Mississippi, Oxford, USA

L.M. Cremaldi, R. Kroeger, L. Perera, R. Rahmat, D.A. Sanders

University of Nebraska-Lincoln, Lincoln, USA

E. Avdeeva, K. Bloom, S. Bose, J. Butt, D.R. Claes, A. Dominguez, M. Eads, J. Keller, I. Kravchenko, J. Lazo-Flores, H. Malbouisson, S. Malik, G.R. Snow

State University of New York at Buffalo, Buffalo, USA

U. Baur, A. Godshalk, I. Iashvili, S. Jain, A. Kharchilava, A. Kumar, S.P. Shipkowski, K. Smith

JHEP02(2013)036

Northeastern University, Boston, USA

G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, J. Haley, D. Nash, D. Trocino, D. Wood, J. Zhang

Northwestern University, Evanston, USA

A. Anastassov, A. Kubik, N. Mucia, N. Odell, R.A. Ofierzynski, B. Pollack, A. Pozdnyakov, M. Schmitt, S. Stoynev, M. Velasco, S. Won

University of Notre Dame, Notre Dame, USA

L. Antonelli, D. Berry, A. Brinkerhoff, M. Hildreth, C. Jessop, D.J. Karmgard, J. Kolb, K. Lannon, W. Luo, S. Lynch, N. Marinelli, D.M. Morse, T. Pearson, M. Planer, R. Ruchti, J. Slaunwhite, N. Valls, M. Wayne, M. Wolf

The Ohio State University, Columbus, USA

B. Bylsma, L.S. Durkin, C. Hill, R. Hughes, K. Kotov, T.Y. Ling, D. Puigh, M. Rodenburg, C. Vuosalo, G. Williams, B.L. Winer

Princeton University, Princeton, USA

N. Adam, E. Berry, P. Elmer, D. Gerbaudo, V. Halyo, P. Hebda, J. Hegeman, A. Hunt, P. Jindal, D. Lopes Pegna, P. Lujan, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, P. Piroué, X. Quan, A. Raval, B. Safdi, H. Saka, D. Stickland, C. Tully, J.S. Werner, A. Zuranski

University of Puerto Rico, Mayaguez, USA

J.G. Acosta, E. Brownson, X.T. Huang, A. Lopez, H. Mendez, S. Oliveros, J.E. Ramirez Vargas, A. Zatserklyaniy

Purdue University, West Lafayette, USA

E. Alagoz, V.E. Barnes, D. Benedetti, G. Bolla, D. Bortoletto, M. De Mattia, A. Everett, Z. Hu, M. Jones, O. Koybasi, M. Kress, A.T. Laasanen, N. Leonardo, V. Maroussov, P. Merkel, D.H. Miller, N. Neumeister, I. Shipsey, D. Silvers, A. Svyatkovskiy, M. Vidal Marono, H.D. Yoo, J. Zablocki, Y. Zheng

Purdue University Calumet, Hammond, USA

S. Guragain, N. Parashar

Rice University, Houston, USA

A. Adair, C. Boulahouache, K.M. Ecklund, F.J.M. Geurts, B.P. Padley, R. Redjimi, J. Roberts, J. Zabel

University of Rochester, Rochester, USA

B. Betchart, A. Bodek, Y.S. Chung, R. Covarelli, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, A. Garcia-Bellido, P. Goldenzweig, J. Han, A. Harel, D.C. Miner, D. Vishnevskiy, M. Zielinski

The Rockefeller University, New York, USA

A. Bhatti, R. Ciesielski, L. Demortier, K. Goulianos, G. Lungu, S. Malik, C. Mesropian

JHEP02(2013)036

Rutgers, the State University of New Jersey, Piscataway, USA
S. Arora, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Duggan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, A. Lath, S. Panwalkar, M. Park, R. Patel, V. Rekovic, J. Robles, K. Rose, S. Salur, S. Schnetzer, C. Seitz, S. Somalwar, R. Stone, S. Thomas

University of Tennessee, Knoxville, USA
G. Cerizza, M. Hollingsworth, S. Spanier, Z.C. Yang, A. York

Texas A&M University, College Station, USA
R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon[58], V. Khotilovich, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Safonov, T. Sakuma, S. Sengupta, I. Suarez, A. Tatarinov, D. Toback

Texas Tech University, Lubbock, USA
N. Akchurin, J. Damgov, C. Dragoiu, P.R. Dudero, C. Jeong, K. Kovitanggoon, S.W. Lee, T. Libeiro, Y. Roh, I. Volobouev

Vanderbilt University, Nashville, USA
E. Appelt, A.G. Delannoy, C. Florez, S. Greene, A. Gurrola, W. Johns, C. Johnston, P. Kurt, C. Maguire, A. Melo, M. Sharma, P. Sheldon, B. Snook, S. Tuo, J. Velkovska

University of Virginia, Charlottesville, USA
M.W. Arenton, M. Balazs, S. Boutle, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, C. Lin, C. Neu, J. Wood, R. Yohay

Wayne State University, Detroit, USA
S. Gollapinni, R. Harr, P.E. Karchin, C. Kottachchi Kankanamge Don, P. Lamichhane, A. Sakharov

University of Wisconsin, Madison, USA
M. Anderson, D.A. Belknap, L. Borrello, D. Carlsmith, M. Cepeda, S. Dasu, E. Friis, L. Gray, K.S. Grogg, M. Grothe, R. Hall-Wilton, M. Herndon, A. Hervé, P. Klabbers, J. Klukas, A. Lanaro, C. Lazaridis, J. Leonard, R. Loveless, A. Mohapatra, I. Ojalvo, F. Palmonari, G.A. Pierro, I. Ross, A. Savin, W.H. Smith, J. Swanson

†: Deceased
1: Also at Vienna University of Technology, Vienna, Austria
2: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
3: Also at Universidade Federal do ABC, Santo Andre, Brazil
4: Also at California Institute of Technology, Pasadena, USA
5: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
6: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
7: Also at Suez Canal University, Suez, Egypt
8: Also at Zewail City of Science and Technology, Zewail, Egypt
9: Also at Cairo University, Cairo, Egypt
10: Also at Fayoum University, El-Fayoum, Egypt
11: Also at British University in Egypt, Cairo, Egypt
12: Now at Ain Shams University, Cairo, Egypt

JHEP02(2013)036

13: Also at National Centre for Nuclear Research, Swierk, Poland
14: Also at Université de Haute-Alsace, Mulhouse, France
15: Now at Joint Institute for Nuclear Research, Dubna, Russia
16: Also at Moscow State University, Moscow, Russia
17: Also at Brandenburg University of Technology, Cottbus, Germany
18: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
19: Also at Eötvös Loránd University, Budapest, Hungary
20: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India
21: Also at University of Visva-Bharati, Santiniketan, India
22: Also at Sharif University of Technology, Tehran, Iran
23: Also at Isfahan University of Technology, Isfahan, Iran
24: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
25: Also at Facoltà Ingegneria, Università di Roma, Roma, Italy
26: Also at Università della Basilicata, Potenza, Italy
27: Also at Università degli Studi Guglielmo Marconi, Roma, Italy
28: Also at Università degli Studi di Siena, Siena, Italy
29: Also at University of Bucharest, Faculty of Physics, Bucuresti-Magurele, Romania
30: Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia
31: Also at University of California, Los Angeles, Los Angeles, USA
32: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
33: Also at INFN Sezione di Roma; Università di Roma, Roma, Italy
34: Also at University of Athens, Athens, Greece
35: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
36: Also at The University of Kansas, Lawrence, USA
37: Also at Paul Scherrer Institut, Villigen, Switzerland
38: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
39: Also at Gaziosmanpasa University, Tokat, Turkey
40: Also at Adiyaman University, Adiyaman, Turkey
41: Also at Izmir Institute of Technology, Izmir, Turkey
42: Also at The University of Iowa, Iowa City, USA
43: Also at Mersin University, Mersin, Turkey
44: Also at Ozyegin University, Istanbul, Turkey
45: Also at Kafkas University, Kars, Turkey
46: Also at Suleyman Demirel University, Isparta, Turkey
47: Also at Ege University, Izmir, Turkey
48: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
49: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
50: Also at University of Sydney, Sydney, Australia
51: Also at Utah Valley University, Orem, USA
52: Also at Institute for Nuclear Research, Moscow, Russia
53: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
54: Also at Argonne National Laboratory, Argonne, USA
55: Also at Erzincan University, Erzincan, Turkey
56: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
57: Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
58: Also at Kyungpook National University, Daegu, Korea

JHEP02(2013)036