Search for supersymmetry in pp collisions at 7 TeV in events with jets and missing transverse energy

T; Hinzmann, A; Hoepfner, K; Hof, C; Klimkovich, T; Klingebiel, D; Kreuzer, P; Lanske, D; Magass, C; Masetti, G; Merschmeyer, M; Meyer, A; Papacz, P; Pieta, H; Reithler, H; Schmitz, Sa; Sonnenschein, L; Steggemann, J; Teyssier, D; Bontenackels, M; Davids, M; Duda, M; Fluegge, G; Geenen, H; Giffels, M; Ahmad, Wh; Heydhausen, D; Kress, T; Kuessel, Y; Linn, A; Nowack, A; Perchalla, L; Pooth, O; Rennefeld, J; Sauerland, P; Stahl, A; Thomas, M; Tornier, D; Zoeller, Mh; Martin, Ma; Behrenhoff, W; Behrens, U; Bergholz, M; Borras, K; Cakir, A; Campbell, A; Castro, E; Dammann, D; Eckerlin, G; Eckstein, D; Flossdorf, A; Flucke, G; Geiser, A; Glushkov, I; Hauk, J; Jung, H; Kasemann, M; Katkov, I; Katsas, P; Kleinwort, C; Kluge, H; Knutsson, A; Krucker, D; Kuznetsova, E; Lange, W; Lohmann, W; Mankel, R; Marienfeld, M; Melzer Pellmann, Ia; Meyer, Ab; Mnich, J; Mussgiller, A; Olzem, J; Parenti, A; Raspereza, A; Raval, A; Schmidt, R; Schoerner Sadenius, T; Sen, N; Stein, M; Tomaszewska, J; Volyanskyy, D; Walsh, R; Wissing, C; Autermann, C; Bobrovskyi, S; Draeger, J; Enderle, H; Gebbert, U; Kaschube, K; Kaussen, G; Klanner, R; Lange, J; Mura, B; Naumann Emme, S; Nowak, F; Pietsch, N; Sander, C; Schettler, H; Schleper, P; Schroder, M; Schum, T; Schwandt, J; Srivastava, Ak; Stadie, H; Steinbruck, G; Thomsen, J; Wolf, R; Barth, C; Bauer, J; Buege, V; Chwalek, T; De Boer, W; Dierlamm, A; Dirkes, G; Feindt, M; Gruschke, J; Hackstein, C; Hartmann, F; Heindl, Sm; Heinrich, M; Held, H; Hoffmann, Kh; Honc, S; Kuhr, T; Martschei, D; Mueller, S; Muller, T; Niegel, M; Oberst, O; Oehler, A; Ott, J; Peiffer, T; Piparo, D; Quast, G; Rabbertz, K; Ratnikov, F; Renz, M; Saout, C; Scheurer, A; Schieferdecker, P; Schilling, Fp; Schott, G; Simonis, Hj; Stober, Fm; Troendle, D; Wagner Kuhr, J; Zeise, M; Zhukov, V; Ziebarth, Eb; Daskalakis, G; Geralis, T; Kesisoglou, S; Kyriakis, A; Loukas, D; Manolakos, I; Markou, A; Markou, C; Mavrommatis, C; Ntomari, E; Petrakou, E; Gouskos, L; Mertzimekis, Tj; Panagiotou, A; Evangelou, I; Foudas, C; Kokkas, P; Manthos, N; Papadopoulos, I; Patras, V; Triantis, Fa; Aranyi, A; Bencze, G; Boldizsar, L; Debreczeni, G; Hajdu, C; Horvath, D; Kapusi, A; Krajczar, K; Laszlo, A; Sikler, F; Vesztergombi, G; Beni, N; Molnar, J; Palinkas, J; Szillasi, Z; Veszpremi, V; Raics, P; Trocsanyi, Zl; Ujvari, B; Bansal, S; Beri, Sb; Bhatnagar, V; Dhingra, N; Gupta, R; Jindal, M; Kaur, M; Kohli, Jm; Mehta, Mz; Nishu, N; Saini, Lk; Sharma, A; Singh, Ap; Singh, Jb; Singh, Sp; Ahuja, S; Bhattacharya, S; Choudhary, Bc; Gupta, P; Jain, S; Jain, S; Kumar, A; Shivpuri, Rk; Choudhury, Rk; Dutta, D; Kailas, S; Kataria, Sk; Mohanty, Ak; Pant, Lm; Shukla, P; Aziz, T; Guchait, M; Gurtu, A; Maity, M; Majumder, D; Majumder, G; Mazumdar, K; Mohanty, Gb; Saha, A; Sudhakar, K; Wickramage, N; Banerjee, S; Dugad, S; Mondal, Nk; Arfaei, H; Bakhshiansohi, H; Etesami, Sm; Fahim, A; Hashemi, M; Jafari, A; Khakzad, M; Mohammadi, A; Najafabadi, Mm; Mehdiabadi, Sp; Safarzadeh, B; Zeinali, M; Abbrescia, M; Barbone, L; Calabria, C; Colaleo, A; Creanza, Donato Maria; DE FILIPPIS, Nicola; De Palma, M; Dimitrov, A; Fiore, L; Iaselli, Giuseppe; Lusito, L; Maggi, Giorgio Pietro; Maggi, M; Manna, N; Marangelli, B; My, Salvatore; Nuzzo, S; Pacifico, N; Pierro, Ga; Pompili, A; Pugliese, Gabriella Maria Incoronata; Romano, E; Roselli, G; Selvaggi, G; Silvestris, L; Trentadue, R; Tupputi, S; 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; Giunta, M; Grandi, C; Marcellini, S; Meneghelli, M; Montanari, A; Navarria, Fl; Odorici, F; Perrotta, A; Primavera, F; Rossi, Am; Rovelli, T; Siroli, G; Travaglini, R; Albergo, S; Cappello, G; Chiorboli, M; Costa, S; Tricomi, A; Tuve, C; Barbagli, G; Ciulli, V; Civinini, C; D'Alessandro, R; Focardi, E; Frosali, S; Gallo, E; Gonzi, S; Lenzi, R; Meschini, M; Paoletti, S; Sguazzoni, G; Tropiano, A; Benussi, L; Bianco, S; Colafranceschi, S; Fabbri, F; Piccolo, D; Fabbricatore, P; Musenich, R; Benaglia, A; De Guio, F; Di Matteo, L; Ghezzi, A; Malberti, M; Malvezzi, S; Martelli, A; Massironi, A; Menasce, D; Moroni, L; Paganoni, M; Pedrini, D; Ragazzi, S; Redaelli, N; Sala, S; de Fatis, Tt; Tancini, V; Buontempo, S; Montoya, Cac; Cimmino, A; De Cosa, A; De Gruttola, M; Fabozzi, F; Iorio, Aom; Lista, L; Merola, M; Noli, P; Paolucci, P; Azzi, P; Bacchetta, N; Bellan, P; Bisello, D; Branca, A; Carlin, R; Checchia, P; Conti, E; De Mattia, M; Dorigo, T; Dosselli, U; Fanzago, F; Gasparini, F; Gasparini, U; Giubilato, P; Gresele, A; Lacaprara, S; Lazzizzera, I; Margoni, M; Mazzucato, M; Meneguzzo, At; Perrozzi, L; Pozzobon, N; Ronchese, P; Simonetto, F; Torassa, E; Tosi, M; Vanini, S; Zotto, P; Zumerle, G; Baesso, P; Berzano, U; Riccardi, C; Torre, P; Vitulo, P; Viviani, C; Biasini, M; Bilei, Gm; Caponeri, B; Fano, L; Lariccia, R; Lucaroni, A; Mantovani, G; Menichelli, M; Nappi, A; Santocchia, A; Servoli, L; Taroni, S; Valdata, M; Volpe, R; 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; Palmonari, F; Sarkar, S; Segneri, G; Serban, At; Spagnolo, P; Tenchini, R; Tonelli, G; Venturi, A; Verdini, Pg; Barone, L; Cavallari, F; Del Re, D; Di Marco, E; Diemoz, M; Franci, D; Grassi, M; Longo, E; Nourbakhsh, S; Organtini, G; Palma, A; Pandolfi, F; Paramatti, R; Rahatlou, S; Amapane, N; Arcidiacono, R; Argiro, S; Arneodo, M; Biino, C; Botta, C; Cartiglia, N; Castello, R; Costa, M; Demaria, N; Graziano, A; Mariotti, C; Marone, M; Maselli, S; Migliore, E; Mila, G; Monaco, V; Musich, M; Obertino, Mm; Pastrone, N; Pelliccioni, M; Romero, A; Ruspa, M; Sacchi, R; Sola, V; Solano, A; Staiano, A; Trocino, D; Pereira, Av; Belforte, S; Cossutti, F; Della Ricca, G; Gobbo, B; Montanino, D; Penzo, A; Heo, Sg; Chang, S; Chung, J; Kim, Dh; Kim, Gn; Kim, Je; Kong, Dj; Park, H; Son, D; Son, Dc; Kim, Z; Kim, Jy; Song, S; Choi, S; Hong, B; Jo, M; Kim, H; Kim, Jh; Kim, Tj; Lee, Ks; Moon, Dh; Park, Sk; Rhee, Hb; Seo, E; Shin, S; Sim, Ks; Choi, M; Kang, S; Kim, H; Park, C; Park, Ic; Park, S; Ryu, G; Choi, Y; Choi, Yk; Goh, J; Lee, J; Lee, S; Seo, H; Yu, I; Bilinskas, Mj; Grigelionis, I; Janulis, M; Martisiute, D; Petrov, P; Sabonis, T; Valdez, Hc; Burelo, Ed; Lopez Fernandez, R; Hernandez, As; Villasenor Cendejas, Lm; Moreno, S; Valencia, F; Ibarguen, Ha; Linares, Ec; Pineda, Am; Reyes Santos, Ma; Allfrey, P; Krofcheck, D; Butler, Ph; Doesburg, R; Silverwood, H; Ahmad, M; Ahmed, I; Asghar, Mi; Hoorani, Hr; Khan, Wa; Khurshid, T; Qazi, S; Cwiok, M; Dominik, W; Doroba, K; Kalinowski, A; Konecki, M; Krolikowski, J; Frueboes, T; Gokieli, R; Gorski, M; Kazana, M; Nawrocki, K; Romanowska Rybinska, K; Szleper, M; Wrochna, G; Zalewski, P; Almeida, N; David, A; Faccioli, P; Parracho, Pc; Gallinaro, M; Martins, R; Musella, P; Nayak, A; Ribeiro, Pq; Seixas, J; Silva, P; Varela, J; Wohri, Hk; Belotelov, I; Bunin, P; Golutvin, I; Kamenev, A; Karjavin, V; Kozlov, G; Lanev, A; Moisenz, P; Palichik, V; Perelygin, V; Shmatov, S; Smirnov, V; Volodko, A; Zarubin, A; Bondar, N; Golovtsov, V; Ivanov, Y; Kim, V; Levchenko, P; Murzin, V; Oreshkin, V; Smirnov, I; Sulimov, V; Uvarov, L; Vavilov, S; Vorobyev, A; Andreev, Y; Gninenko, S; Golubev, N; Kirsanov, M; Krasnikov, N; Matveev, V; Pashenkov, A; Toropin, A; Troitsky, S; Epshteyn, V; Gavrilov, V; Kaftanov, V; Kossov, M; Krokhotin, A; Lychkovskaya, N; Safronov, G; Semenov, S; Stolin, V; Vlasov, E; Zhokin, A; Boos, E; Dubinin, M; Dudko, L; Ershov, A; Gribushin, A; Kodolova, O; Lokhtin, I; Obraztsov, S; Petrushanko, S; Sarycheva, L; Savrin, V; Snigirev, A; Andreev, V; Azarkin, M; Dremin, I; Kirakosyan, M; Rusakov, Sv; Vinogradov, A; Azhgirey, I; Bitioukov, S; Grishin, V; Kachanov, V; Konstantinov, D; Korablev, A; Krychkine, V; Petrov, V; Ryutin, R; Slabospitsky, S; Sobol, A; Tourtchanovitch, L; Troshin, S; Tyurin, N; Uzunian, A; Volkov, A; Adzic, P; Djordjevic, M; Krpic, D; Milosevic, J; Aguilar Benitez, M; Maestre, Ja; Arce, P; Battilana, C; Calvo, E; Cepeda, M; Cerrada, M; Colino, N; De La Cruz, B; Pardos, C; Vazquez, Dd; Bedoya, C; Ramos, Jp; Ferrando, A; Flix, J; Fouz, Mc; Garcia Abia, R; Lopez, O; Lopez, S; Hernandez, Jm; Josa, Mi; Merino, G; Pelayo, J; Redondo, I; Romero, L; Santaolalla, J; Willmott, C; Albajar, C; Codispoti, G; de Troconiz, Jf; Cuevas, J; Menendez, Jf; Folgueras, S; Caballero, Ig; Iglesias, Ll; Garcia, Jmv; Cifuentes, Ja; Cabrillo, Ij; Calderon, A; Llatas, M; Chuang, Sh; Campderros, J; Felcini, M; Fernandez, M; Gomez, G; Sanchez, J; Jorda, C; Pardo, P; Virto, A; Marco, J; Marco, R; Rivero, C; Matorras, F; Sanchez, Fj; Gomez, J; Rodrigo, T; Jimeno, A; Scodellaro, L; Sanudo, M; Vila, I; Cortabitarte, R; Abbaneo, D; Auffray, E; Auzinger, G; Baillon, P; Ball, Ah; Barney, D; Bell, Aj; Benedetti, D; Bernet, C; Bialas, W; Bloch, P; Bocci, A; Bolognesi, S; Breuker, H; Brona, G; Bunkowski, K; Camporesi, T; Cano, E; Cerminara, G; Christiansen, T; Perez, Jac; Cure, B; D'Enterria, D; De Roeck, A; Di Guida, S; Ramos, Fd; Elliott Peisert, A; Frisch, B; Funk, W; Gaddi, A; Gennai, S; Georgiou, G; Gerwig, H; Gigi, D; Gill, K; Giordano, D; Glege, F; Garrido, Rgr; Gouzevitch, M; Govoni, P; Gowdy, S; Guiducci, L; Hansen, M; Harvey, J; Hegeman, J; Hegner, B; Henderson, C; Hesketh, G; Hoffmann, Hf; Honma, A; Innocente, V; Janot, R; Kaadze, K; Karavakis, E; Lecoq, P; Lourenco, C; Macpherson, A; Maki, T; Malgeri, L; Mannelli, M; Masetti, L; Meijers, F; Mersi, S; Meschi, E; Moser, R; Mozer, Mu; Mulders, M; Nesvoldl, E; Nguyen, M; Orimoto, T; Orsini, L; Perez, E; Petrilli, A; Pfeiffer, A; Pierini, M; Pimia, M; Polese, G; Racz, A; Antunes, Jr; Rolandi, G; Rommerskirchen, T; Rovelli, C; Rovere, M; Sakulin, H; Schafer, C; Schwick, C; Segoni, I; Sharma, A; Siegrist, P; Simon, M; Sphicas, P; Spiga, D; Spiropulu, M; Stockli, F; Stoye, M; Tropea, P; Tsirou, A; Tsyganov, A; Veresil, Gi; Vichoudis, P; Voutilainen, M; 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; Starodumov, A; Bortignon, P; Caminada, L; Chen, Z; Cittolin, S; Dissertori, G; Dittmar, M; Eugster, J; Freudenreich, K; Grab, C; Herve, A; Hintz, W; Lecomte, P; Lustermann, W; Marchica, C; del Arbol, Pmr; Meridiani, P; Milenovic, P; Moortgat, F; Nef, P; Nessi Tedaldi, F; Pape, L; Pauss, F; Punz, T; Rizzi, A; Ronga, Fj; Rossini, M; Sala, L; Sanchez, Ak; Sawley, Mc; Stieger, B; Tauscher, L; Thea, A; Theofilatos, K; Treille, D; Urscheler, C; Wallny, R; Weber, M; Wehrli, L; Weng, J; Aguilo, E; Amsler, C; Chiochia, V; De Visscher, S; Favaro, C; Rikova, Mi; Mejias, Bm; Regenfus, C; Robmann, P; Schmidt, A; Snoek, H; Chang, Yh; Chen, Kh; Chen, Wt; Dutta, S; Go, A; Kuo, Cm; Li, Sw; Lin, W; Liu, Mh; Liu, Zk; Lu, Yj; Mekterovic, D; Wu, Jh; Yu, Ss; Bartalini, P; Chang, P; Chang, Yh; Chang, Yw; Chao, Y; Chen, Kf; Hou, Ws; Hsiung, Y; Kao, Ky; Lei, Yj; Lu, Rs; Shiu, Jg; Tzeng, Ym; Wang, M; Adiguzel, A; Bakirci, Mn; Cerci, S; Demir, Z; Dozen, C; Dumanoglu, I; Eskut, E; Girgis, S; Gokbulut, G; Guler, Y; Gurpinar, E; Hos, I; Kangal, Ee; Karaman, T; Topaksu, Ak; Nart, A; Onengut, G; Ozdemir, K; Ozturk, S; Polatoz, A; Sogut, K; Tali, B; Topakli, H; Uzun, D; Vergili, Ln; Vergili, M; Zorbilmez, C; Akin, Iv; Aliev, T; Bilmis, S; Deniz, M; Gamsizkan, H; Guler, Am; Ocalan, K; Ozpineci, A; Serin, M; Sever, R; Surat, Ue; Yildirim, E; Zeyrek, M; Deliomeroglu, M; Demir, D; Gulmez, E; Halu, A; Isildak, B; Kaya, M; Kaya, O; Ozkorucuklu, S; Sonmez, N; Levchuk, L; Bell, P; Bostock, F; Brooke, Jj; Cheng, Tl; Clement, E; Cussans, D; Frazier, R; Goldstein, J; Grimes, M; Hansen, N; Hartley, D; Heath, Gp; Heath, Hf; Huckvale, B; Jackson, J; Kreczko, L; Metson, S; Newbold, Dm; Nirunpong, K; Poll, A; Senkin, S; Smith, Vj; Ward, S; Basso, L; Bell, Kw; Belyaev, A; Brew, C; Brown, Rm; Camanzi, B; Cockerill, Dja; Coughlan, Ja; Harder, K; Harper, S; Kennedy, Bw; Olaiya, E; Petyt, D; Radburn Smith, Bc; Shepherd Themistocleous, Ch; Tomalin, Ir; Womersley, Wj; Worm, Sd; Bainbridge, R; Ball, G; Ballin, J; Beuselinck, R; Buchmuller, O; Colling, D; Cripps, N; Cutajar, M; Davies, G; Della Negra, M; Fulcher, J; Futyan, D; Bryer, Ag; Hall, G; Hatherell, Z; Hays, J; Iles, G; Karapostoli, G; Lyons, L; Magnan, Am; Marrouche, J; Mathias, B; Nandi, R; Nash, J; Nikitenko, A; Papageorgiou, A; Pesaresi, M; Petridis, K; Pioppi, M; Raymond, Dm; Rompotis, N; Rose, A; Ryan, Mj; Seez, C; Sharp, P; Sparrow, A; Tapper, A; Tourneur, S; Acosta, Mv; Virdee, T; Wakefield, S; Wardrope, D; Whyntie, T; Barrett, M; Chadwick, M; Cole, Je; Hobson, Pr; Khan, A; Kyberd, P; Leslie, D; Martin, W; Reid, Id; Teodorescu, L; Hatakeyama, K; Bose, T; Jarrin, Ec; Fantasia, C; Heister, A; John, J; Lawson, P; Lazic, D; Rohlf, J; Sperka, D; Sulak, L; Avetisyan, A; Bhattacharya, S; Chou, Jp; Cutts, D; Ferapontov, A; Heintz, U; Jabeen, S; Kukartsev, G; Landsberg, G; Narain, M; Nguyen, D; Segala, M; Speer, T; Tsang, Kv; Borgia, Ma; Breedon, R; Sanchez, Mcdlb; Cebra, D; Chauhan, S; Chertok, M; Conway, J; Cox, Pt; Dolen, J; Erbacher, R; Friis, E; Ko, W; Kopecky, A; Lander, R; Liu, H; Maruyama, S; Miceli, T; Nikolic, M; Pellett, D; Robles, J; Salur, S; Schwarz, T; Searle, M; Smith, J; Squires, M; Tripathi, M; Sierra, Rv; Veelken, C; Andreev, V; Arisaka, K; Cline, D; Cousins, R; Deisher, A; Duris, J; Erhan, S; Farrell, C; Hauser, J; Ignatenko, M; Jarvis, C; Plager, C; Rakness, G; Schlein, P; Tucker, J; Valuev, V; Babb, J; Clare, R; Ellison, J; Gary, Jw; Giordano, F; Hanson, G; Jeng, Gy; Kao, Sc; Liu, F; Liu, H; Luthra, A; Nguyen, H; Shen, Bc; Stringer, R; Sturdy, J; Sumowidagdo, S; Wilken, R; Wimpenny, S; Andrews, W; Branson, Jg; Cerati, Gb; Dusinberre, E; Evans, D; Golf, F; Holzner, A; Kelley, R; Lebourgeois, M; Letts, J; Mangano, B; Muelmenstaedt, J; Padhi, S; Palmer, C; Petrucciani, G; Pi, H; Pieri, M; Ranieri, R; Sani, M; Sharma, V; Simon, S; Tu, Y; Vartak, A; Wurthwein, F; Yagil, A; 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; Vlimant, Jr; Bornheim, A; Bunn, J; Chen, Y; Gataullin, M; Kcira, D;

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Eartly, Dp; Elvira, Vd; Esen, S; Fisk, I; Freeman, J; Gao, Y; Gottschalk, E; Green, D; Gunthoti, K; Gutsche, O; Hahn, A; Hanlon, J; Harris, Rm; Hirschauer, J; Hooberman, B; James, E; Jensen, H; Johnson, M; Joshi, U; Khatiwada, R; Kilminster, B; Klima, B; Kousouris, K; Kunori, S; Kwan, S; Leonidopoulos, C; Limon, P; Lipton, R; Lykken, J; Maeshima, K; Marraffino, Jm; Mason, D; Mcbride, P; Mccauley, T; Miao, T; Mishra, K; Mrenna, S; Musienko, Y; Newman Holmes, C; O'Dell, V; Popescu, S; Pordes, R; Prokofyev, O; Saoulidou, N; Sexton Kennedy, E; Sharma, S; Soha, A; Spalding, Wj; Spiegel, L; Tan, R; Taylor, L; Tkaczyk, S; Uplegger, L; Vaandering, Ew; Vidal, R; Whitmore, J; W, Wu; Yang, F; Yumiceva, F; Yun, Jc; Acosta, D; Avery, P; Bourilkov, D; Chen, M; Di Giovanni, Gp; Dobur, D; Drozdetskiy, A; Field, Rd; Fisher, M; Fu, Y; Furic, Ik; Gartner, J; Goldberg, S; Kim, B; Klimenko, S; Konigsberg, J; Korytov, A; Kropivnitskaya, A; Kypreos, T; Matchev, K; Mitselmakher, G; Muniz, L; Pakhotin, Y; Prescott, C; 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Search for supersymmetry in pp collisions at 7 TeV in events with jets and missing transverse energy ☆

CMS Collaboration ⋆

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ABSTRACT

A search for supersymmetry with R-parity conservation in proton–proton collisions at a centre-of-mass energy of 7 TeV is presented. The data correspond to an integrated luminosity of 35 pb^{-1} collected by the CMS experiment at the LHC. The search is performed in events with jets and significant missing transverse energy, characteristic of the decays of heavy, pair-produced squarks and gluinos. The primary background, from standard model multijet production, is reduced by several orders of magnitude to a negligible level by the application of a set of robust kinematic requirements. With this selection, the data are consistent with the standard model backgrounds, namely $\text{t}\bar{\text{t}}$, W + jet and Z + jet production, which are estimated from data control samples. Limits are set on the parameters of the constrained minimal supersymmetric extension of the standard model. These limits extend those set previously by experiments at the Tevatron and LEP colliders.

1. Introduction

The standard model (SM) of particle physics has been extremely successful in describing phenomena at the highest energies attained thus far. Nevertheless, it is widely believed to be only an effective description of a more complete theory, which supersedes it at higher energy scales. Of particular theoretical interest is supersymmetry (SUSY) [1–6], which solves the “hierarchy problem” [7,8] of the SM at the expense of introducing a large number of supersymmetric particles with the same quantum numbers as the SM particles, but differing by half a unit of spin. If R-parity conservation [9] is assumed, supersymmetric particles are produced in pairs and decay to the lightest supersymmetric particle (LSP). If the LSP is neutral and weakly-interacting, it goes undetected giving rise to a signature with missing energy.

Experiments at the energy frontier, i.e. at the Fermilab Tevatron collider [10–13] and previously at the CERN Sp$\bar{\text{p}}$S [14,15], HERA [16,17] and LEP [18] colliders, have performed extensive searches for signs of SUSY. In the absence of a positive signal, lower limits on the masses of SUSY particles have been set. With its higher centre-of-mass energy of 7 TeV, the Large Hadron Collider (LHC) at CERN could produce SUSY particles (sparticles) with masses larger than the current limits. The dominant production channels of heavy coloured sparticles at the LHC are squark–squark, squark–gluino and gluino–gluino pair production. In the context of SUSY with R-parity conservation, heavy squarks and gluinos decay into quarks, gluons and other SM particles, as well as a neutralino (i.e. the LSP), which escapes undetected, leading to final states with several hadronic jets and large missing transverse energy. While squark–squark production usually leads to two jets, gluino production typically results in higher jet multiplicities. This Letter describes a search for the production and decay of SUSY particles by the CMS experiment, in events with two or more energetic jets and significant imbalance of transverse energy.

The search is not optimized in the context of any particular model of SUSY. To interpret the results, a simplified and practical model of SUSY-breaking, the constrained minimal supersymmetric extension of the standard model (CMSSM) [19,20], is used. The CMSSM is described by five parameters: the universal scalar and gaugino mass parameters (m_0 and $m_{1/2}$, respectively), the universal trilinear soft SUSY breaking parameter A_0, and two low-energy parameters, the ratio of the two vacuum expectation values of the two Higgs doublets, $\tan\beta$, and the sign of the Higgs mixing parameter, $\text{sign}(\mu)$. Throughout the Letter, two CMSSM parameter sets, referred to as LM0 and LM1 [21], are used to illustrate possible CMSSM yields. The parameter values defining LM0 are $m_0 = 200$ GeV, $m_{1/2} = 160$ GeV, $A_0 = -400$ GeV, $\tan\beta = 10$, and $\text{sign}(\mu) > 0$. Those for LM1 are $m_0 = 60$ GeV, $m_{1/2} = 250$ GeV, $A_0 = 0$, $\tan\beta = 10$, and $\text{sign}(\mu) > 0$.

2. The CMS detector

The central feature of the CMS apparatus is a superconducting solenoid, 13 m in length and 6 m in diameter, which provides an

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

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axial magnetic field of 3.8 T. The bore of the solenoid is instrumented with various particle detection systems. The steel return yoke outside the solenoid is in turn instrumented with gas detectors used to identify muons. Charged particle trajectories are measured by the silicon pixel and strip tracker, with full azimuthal coverage within $|\eta| < 2.5$, where the pseudorapidity η is defined as $\eta = -\ln\tan(\theta/2)$, with θ being the polar angle of the trajectory of the particle with respect to the counterclockwise beam direction. A lead-tungstate crystal electromagnetic calorimeter (ECAL) and a brass/scintillator hadron calorimeter (HCAL) surround the tracking volume and cover the region $|\eta| < 3$. In the region $|\eta| < 1.74$, the HCAL cells have widths of 0.087 in pseudorapidity and 0.087 in azimuth (ϕ). In the (η, ϕ) plane, and for $|\eta| < 1.48$, the HCAL cells map on to 5×5 ECAL crystal arrays to form calorimeter towers projecting radially outwards from close to the nominal interaction point. At larger values of $|\eta|$, the size of the towers increases and the matching ECAL arrays contain fewer crystals. Within each tower, the energy deposits in ECAL and HCAL cells are summed to define the calorimeter tower energies, subsequently used to provide the energies and directions of hadronic jets. The detector is nearly hermetic, which allows for energy-balance measurements in the plane transverse to the beam axis. A more detailed description of the CMS detector can be found elsewhere [22].

3. Event selection

3.1. Hadronic final state selection

The data sample used in this analysis is recorded with a trigger based on the scalar sum of the transverse energy E_T of jets, defined in general as $H_T = \sum_{i=1}^{N_{\text{jet}}} E_T^{j_i}$, where N_{jet} is the number of jets. Events are selected if they satisfy $H_T^{\text{trigger}} > 150$ GeV.

At the trigger level, the calorimeter response is not corrected to achieve a uniform and absolute scale of transverse jet energy; nevertheless the trigger requirement is fully efficient for events with an offline-reconstructed H_T in excess of 250 GeV, thus providing a high signal efficiency for the region of the CMSSM parameter space relevant for the present search, where squarks and gluinos have masses of several hundred GeV. Additionally, events are required to have at least one good reconstructed pp interaction vertex [23].

Jets are reconstructed offline from the energy deposits in the calorimeter towers, clustered by the anti-k_T algorithm [24] with a size parameter of 0.5. In this process, the contribution from each calorimeter tower is assigned a momentum, the magnitude and direction of which are given by the energy measured in the tower and the coordinates of the tower. The raw jet energy is obtained from the sum of the tower energies, and the raw jet momentum by the vectorial sum of the tower momenta, resulting in a nonzero jet mass. The raw jet energies are corrected to establish a relative uniform response of the calorimeter in η and a calibrated absolute response in transverse momentum p_T. The uncertainty on the energy scale of these corrected jets varies between 3% and 5%, depending on the jet p_T and $|\eta|$ [25]. The jets considered in this analysis are required to have $E_T > 50$ GeV, $|\eta| < 3$ and to pass jet identification criteria [26] designed to reject spurious signals in the calorimeters. The pseudorapidity of the jet with the highest E_T (leading jet) is required to be within $|\eta| < 2.5$ and the transverse energy of each of the two leading jets must exceed 100 GeV.

Events with jets passing the E_T threshold but not satisfying the jet identification criteria or the η acceptance requirement are vetoed, as this deposited energy is not accounted for in the event kinematics. Similarly, events in which an isolated lepton (electron [27] or muon [28]) with $p_T > 10$ GeV is identified are rejected to suppress events with genuine missing energy from neutrinos. Furthermore, to select a pure multijet topology, events are vetoed

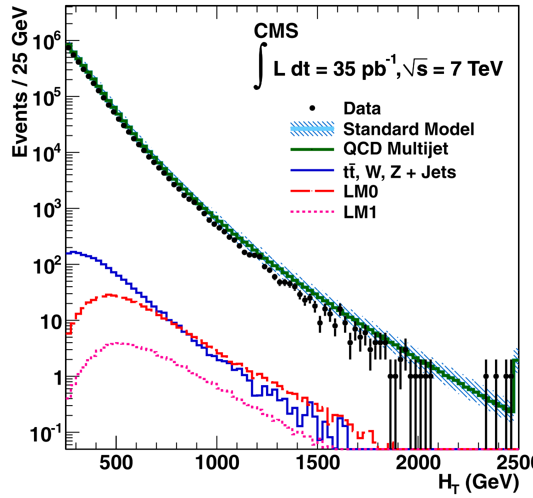

Fig. 1. H_T distribution after preselection, for data as well as for all standard model backgrounds and two SUSY signal samples with parameter sets LM0 and LM1, normalized to an integrated luminosity of 35 pb^{-1}. The hatched area corresponds to the uncertainty in the SM estimate as defined in Section 3.1. The SM distributions are only displayed for illustration purposes, as they are the result of Monte Carlo simulation, while the actual estimate of the background from SM processes in this search is based on data, as described in detail in Section 4.

in which an isolated photon [29] with $p_T > 25$ GeV is found. These vetoes reject 5% of the previously selected events in data and simulation.

At this preselection stage, the background from multijet production, as predicted by quantum chromodynamics (QCD), is still several orders of magnitude larger than the typical signal expected from SUSY. The H_T distribution for the selected events is shown in Fig. 1 and compared to simulation-based background estimates. The QCD multijet background is estimated using the PYTHIA6.4 [30] Monte Carlo generator with tune Z2 [31]. Electroweak backgrounds from W + jets, $Z \to \nu\bar{\nu}$ + jets and $t\bar{t}$ + jets events, which will be referred to collectively as the electroweak (EWK) backgrounds in what follows, are simulated using MADGRAPH [32]. The SM distribution, i.e. the sum of the QCD multijet and EWK distributions, is indicated in Fig. 1 as a hatched band representing the combined statistical and systematic uncertainties from the jet energy scale and resolution. The expected H_T distributions for two low-mass SUSY signal points, LM0 and LM1, are overlaid. With the exception of $t\bar{t}$, the SM processes fall off exponentially over the entire H_T range, whereas a broad peak at values of a few hundred of GeV is expected for the signal models. The selection is tightened by requiring the H_T of all jets to exceed 350 GeV, thus ensuring large hadronic activity in the event. This requirement substantially reduces the contributions from SM processes while maintaining a high efficiency for the SUSY topologies considered.

3.2. Final event selection for SUSY search

Jet mismeasurements, caused by possible detection inefficiencies or by nonuniformities in the calibration of the calorimeters, are the dominant source of large missing transverse energy $\not{E}_T$ in events from QCD multijet production. To control this background and to separate it from a genuine missing energy signal, a variable that is robust against energy mismeasurements, α_T, is used. For events with two jets, α_T, first introduced in Refs. [21,33] and inspired by Ref. [34], is defined as

$$\alpha_T = E_T^{j_2} / M_T,$$

where $E_T^{j_2}$ is the transverse energy of the less energetic of the two jets in the event and M_T is the transverse mass of the di-jet sys-

Table 1
The number of events observed and expected from Monte Carlo simulation after the selection requirements, for data and background samples (QCD multijet simulated with PYTHIA6.4(Z2), $Z \to \nu\bar{\nu}$, W + jets, $t\bar{t}$). The quoted errors represent the statistical uncertainties on the yields and all numbers are normalized to an integrated luminosity of 35 pb^{-1}.

Selection	Data	SM	QCD multijet	$Z \to \nu\bar{\nu}$	W + jets	$t\bar{t}$
$H_T > 250$ GeV	4.68M	5.81M	5.81M	290	2.0k	2.5k
$E_T^{j_2} > 100$ GeV	2.89M	3.40M	3.40M	160	610	830
$H_T > 350$ GeV	908k	1.11M	1.11M	80	280	650
$\alpha_T > 0.55$	37	30.5 ± 4.7	19.5 ± 4.6	4.2 ± 0.6	3.9 ± 0.7	2.8 ± 0.1
$\Delta R_{ECAL} > 0.3 \vee \Delta\phi^* > 0.5$	32	24.5 ± 4.2	14.3 ± 4.1	4.2 ± 0.6	3.6 ± 0.6	2.4 ± 0.1
$R_{miss} < 1.25$	13	9.3 ± 0.9	0.03 ± 0.02	4.1 ± 0.6	3.3 ± 0.6	1.8 ± 0.1

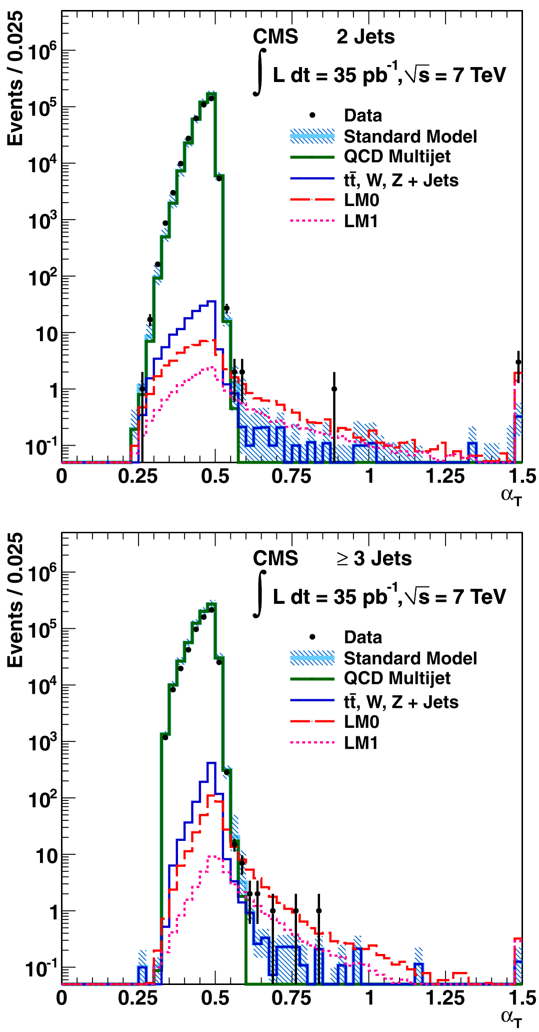

Fig. 2. Distribution of α_T for di-jet events (top) and $\geqslant$3-jet events (bottom), requiring $H_T > 350$ GeV. Events with $\alpha_T > 1.5$ are included in the rightmost bin. In both figures the hatched area corresponds to the uncertainty in the SM estimate as defined in Section 3.1.

tem, defined as

$$M_T = \sqrt{\left(\sum_{i=1}^{2} E_T^{j_i}\right)^2 - \left(\sum_{i=1}^{2} p_x^{j_i}\right)^2 - \left(\sum_{i=1}^{2} p_y^{j_i}\right)^2}.$$

For a perfectly measured di-jet event, with $E_T^{j_1} = E_T^{j_2}$ and jets back to back in ϕ, and in the limit where the jet momenta are large compared to their masses, the value of α_T is 0.5. In the case of an imbalance in the measured transverse energies of back to back jets, α_T takes on values smaller than 0.5, while for jets that are not back to back, α_T can be greater than 0.5.

For larger jet multiplicities, the n-jet system is reduced to a di-jet system by combining the jets in the event into two pseudo-jets. The E_T of each of the two pseudo-jets is calculated as the scalar sum of the contributing jet E_T's. The combination chosen is the one that minimizes the E_T difference between the two pseudo-jets. This simple clustering criterion has been found to result in the best separation between QCD multijet events and events with genuine $\not{E}_T$.

Values of α_T above 0.5 can occur for QCD multijet events, either with multiple jets failing the $E_T > 50$ GeV requirement, or with missing transverse energy arising from jet energy resolution or severe jet energy under-measurements due to detector inefficiencies. On the other hand, events with genuine $\not{E}_T$ often have much larger values of α_T, resulting in a good separation of signal events from the QCD multijet background.

The α_T distributions are shown separately for di-jet and $\geqslant$3-jet events in Fig. 2. As anticipated, these distributions peak at $\alpha_T = 0.5$ for QCD multijet events and then fall sharply in the range 0.5 to 0.55, reaching a level 4–5 orders of magnitude lower than the peak value. Multijet events from QCD background are therefore efficiently rejected by requiring α_T to exceed 0.55. Given the selection requirement $H_T > 350$ GeV, this threshold on α_T is equivalent to demanding $\not{H}_T/H_T > 0.4$, i.e. to $\not{H}_T > 140$ GeV.

To reject events with false missing energy arising from significant jet mismeasurements in masked regions of the ECAL, which amount to about 1% of the ECAL channel count, the following procedure is employed. The jet-based estimate of the missing transverse energy, $\not{H}_T = |\vec{\not{H}}_T| = |-\sum_{jets} \vec{p}_{T_{jet}}|$, which is obtained by summing the transverse momenta of all the jets in the event, is now recomputed while ignoring one of the reconstructed jets. The difference in azimuth between the recomputed $\vec{\not{H}}_T$ and the ignored jet is then calculated. The $\vec{\not{H}}_T$ is recomputed for each configuration that results from ignoring, in turn, each of the jets in the event, while leaving all other jets intact, and the minimum of all the azimuthal differences, $\Delta\phi^*$, is found. The jet whose subtraction from the calculation $\vec{\not{H}}_T$ yields this minimum value, is identified as the jet that is most likely to have given rise to the $\not{H}_T$ in the event. Events with $\Delta\phi^* < 0.5$ are rejected if the distance in the (η, ϕ) plane between the selected jet and the closest masked ECAL region, ΔR_{ECAL}, is smaller than 0.3.

Artificially large values of $\not{H}_T$ can also result in events with multiple jets below the selection requirement of $E_T > 50$ GeV, since these jets are not included in the computation of $\not{H}_T$. To protect against these events, $\not{H}_T$, i.e. the jet-based estimate of the missing energy, $\not{H}_T$, is compared to the calorimeter tower-based estimate, $\not{E}_T^{calo}$, which includes the energy from all jets, irrespective of threshold [35]. Events with $R_{miss} = \not{H}_T/\not{E}_T^{calo} > 1.25$ are rejected.

Table 1 lists the number of events passing each step of the event selection for data and simulation. The expectations from simulation are listed only for comparison; the actual expected yields from standard model processes are determined from control data samples, as described in the following section.

After the selection requirements on α_T, ΔR_{ECAL} and R_{miss}, the QCD multijet background predicted by PYTHIA6.4 is less than one event for an integrated luminosity of 35 pb^{-1}. This estimate is also obtained with PYTHIA8.1 [36] (tune 1) and with the MADGRAPH generator. After all selection requirements, the only significant remaining background stems from electroweak processes with genuine $\not\!E_T$ in the final state. In the di-jet case, the largest backgrounds with real missing energy are the associated production of W or Z bosons with jets, followed by the weak decays $Z \to \nu\bar{\nu}$ and $W \to \tau\nu$, or by leptonic W/Z decays in which one or more leptons are not reconstructed. At higher jet multiplicities, $t\bar{t}$ production followed by semileptonic weak decays of the t and $\bar{t}$ quarks becomes important. In this case, the three backgrounds, $Z \to \nu\bar{\nu}$ + jets, W + jets and $t\bar{t}$, are of roughly equal size. The largest fraction of the W + jets and $t\bar{t}$ backgrounds stem from $W \to \tau\nu$ decays where in two thirds of the cases the τ decays hadronically and is identified as a jet. The two remaining backgrounds from electrons or muons produced in W decays that fail either the isolation or acceptance requirements ($p_T > 10$ GeV and η coverage) are of similar size.

4. Background estimate from data

The SM background in the signal region is estimated directly from data using two independent methods. The first method makes use of control regions at lower H_T to estimate the total background from all SM processes (Section 4.1), while the second method estimates the contribution from electroweak processes using $W \to \mu\nu$ + jets (Section 4.2) and γ + jets (Section 4.3) events in the data.

4.1. Inclusive background estimate

The total background can be estimated from two control regions at low H_T: the HT250 region, which contains events with H_T between 250 and 300 GeV, and the HT300 region, which contains events with H_T between 300 and 350 GeV. Given the current experimental limits on the squark and gluino masses, these two regions are expected to be dominated by SM processes. The search region for the signal, which is referred to as the HT350 region in what follows, is defined as events with $H_T > 350$ GeV.

The method is based on the variable R_{α_T}, defined as the ratio of the number of events passing and failing a requirement on α_T, given all other selection requirements. To minimize the efficiency bias arising from the phase space reduction in the lower H_T regions, the p_T thresholds for the two bins are adjusted to keep the ratio of p_T/H_T constant in each region. In the HT300 region, the resulting thresholds are 86 GeV for the two leading jets and 43 GeV for additional jets. In the HT250 region the respective thresholds are 71 and 36 GeV. In the absence of a SUSY signal, the ratio R_{α_T} can then be extrapolated from the measured values in both control regions to predict the value in the signal region, HT350.

Fig. 3(top) shows the evolution of R_{α_T} as a function of H_T for two thresholds on α_T, namely $\alpha_T > 0.51$ and $\alpha_T > 0.55$. For $\alpha_T > 0.51$, the numerator of R_{α_T} is dominated by the QCD multijet background, for which the missing transverse energy mostly originates from energy mismeasurements. As the relative resolution of calorimetric energy measurements improves with energy, and therefore with H_T, the relative importance of this background is expected to decrease with increasing H_T. This effect is clearly visible in Fig. 3(top), which shows the falling behaviour for seven equidistant bins in H_T. In contrast, for $\alpha_T > 0.55$, the numerator

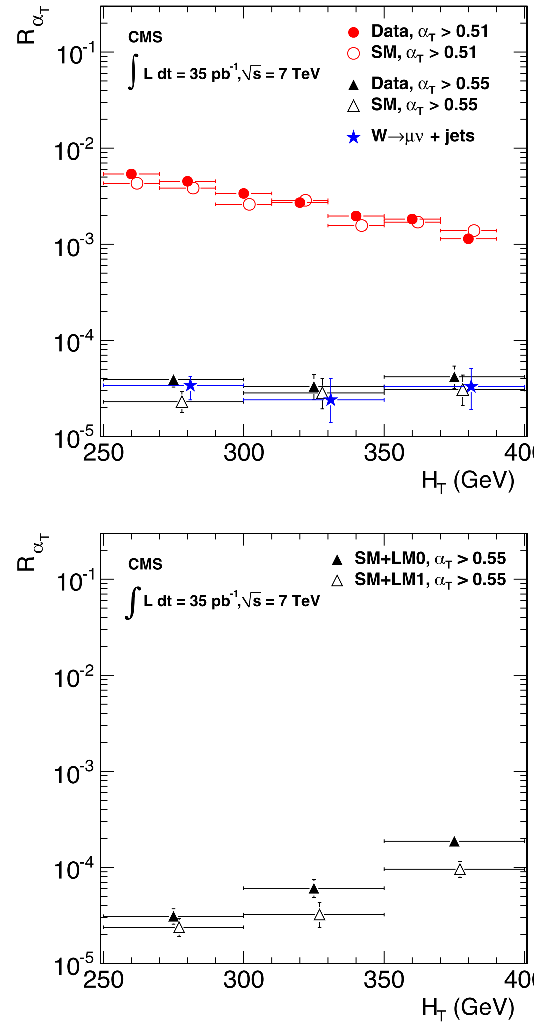

Fig. 3. Evolution of the ratio R_{α_T} as a function of H_T for events with $N_{jet} \geqslant 2$; (top) for data and SM backgrounds, and two different values of α_T, as well as for an independent $W \to \mu\nu$ + jets control sample (Section 4.2); (bottom) for the SM backgrounds added to the SUSY signal expected from each of the two benchmark points, LM0 and LM1. Markers are offset horizontally for improved visibility.

of R_{α_T} is dominated by the electroweak background, with genuine $\not\!E_T$, the relative importance of which is expected to be constant with increasing H_T.

The latter behaviour is confirmed in an independent sample of events with a W decaying to $\mu\nu$, accompanied by jets. (The selection of these events is given in Section 4.2.) The ratio of the number of selected $W \to \mu\nu$ + jets events to the number of events failing the W selection (hence dominated by the QCD multijet background) is shown in Fig. 3(top) for the same H_T bins, and confirms the independence of R_{α_T} on H_T when the numerator is dominated by events with genuine $\not\!E_T$.

The ratio R_{α_T} in the HT350 region can be estimated from the R_{α_T} values measured in regions HT250 and HT300, for $\alpha_T > 0.55$, using the double ratio R_R:

$$R_R = \frac{R_{\alpha_T}(\mathrm{HT300})}{R_{\alpha_T}(\mathrm{HT250})} = \frac{R_{\alpha_T}(\mathrm{HT350})}{R_{\alpha_T}(\mathrm{HT300})}. \quad (1)$$

The total number of events with $\alpha_T > 0.55$ expected from SM processes in the signal region is the product of the extrapolated R_{α_T}(HT350) and the number of events with $\alpha_T < 0.55$ in the $H_T > 350$ GeV region. The total number of background events in HT350 thus estimated is $9.4^{+4.8}_{-4.0}$(stat) $\pm$ 1.0(syst). The dominant systematic uncertainty for this method is estimated by varying the relative magnitude of the three EWK processes, while maintaining the H_T dependence of each process to the one predicted by the Monte Carlo. The background estimate is insensitive to this variation: since $R_R \approx 1$, the change in the estimate is always much smaller than the statistical uncertainty. Even under extreme variations of the individual EWK processes by up to five times higher values than those predicted by simulation, the systematic uncertainty is at least a factor two smaller than the statistical uncertainty. The same comments hold for the background estimate variants described below.

For comparison, Fig. 3(bottom) shows the expectation of R_{α_T} if a SUSY signal from each of the two benchmark points LM0 and LM1 were present in addition to the SM backgrounds. The signal is predominantly visible in the HT350 region, especially for LM1, which has larger squark and gluino masses. There is, nevertheless, a sizeable signal in the HT300 control region as well. This contamination of the control region by a potential signal is taken into account in the limit calculation (Section 5.1) and both benchmark points are ruled out with a confidence level of 99% or higher (Section 5.2).

A variant of this background estimation method relies on the R_{α_T} measurement in the HT300 bin only and uses a small correction from MC simulation to predict R_{α_T} in the signal region. This variant results in an estimate of $12.0^{+8.1}_{-6.3}(\text{stat}) \pm 0.4(\text{syst})$ events. Another variant, also based on the independence of R_{α_T} on H_T when the data sample is dominated by EWK processes, i.e. for $\alpha_T > 0.55$, uses the weighted average of the R_{α_T} values measured in the two control regions. This value is then also used in the signal region to obtain a background estimate of $12.5 \pm 1.9(\text{stat}) \pm 0.7(\text{syst})$. Within uncertainties, the three estimates are in agreement. Furthermore, in the simulation all methods are shown to provide an unbiased estimator of the number of total background events. For the remainder of this Letter the result of the first method, which relies entirely on measured data and makes the most conservative assumption on the evolution of the double ratio with H_T, is used to estimate the total background.

4.2. W + jets and $\mathrm{t\bar{t}}$ background

A second background estimation method uses an independent selection of $\mathrm{W} \to \mu\nu$ + jets events in the data in order to assess the contribution from SM processes with genuine $\not\!\!E_T$. The $\mathrm{W} \to \mu\nu$ + jets are selected as described in [37], with an energetic and isolated muon in the final state, and by requiring the transverse mass of the W to be larger than 30 GeV (to ensure a very pure sample originating from W + jets and $\mathrm{t\bar{t}}$). The muons are required to be separated from the jets in the event by a distance larger than 0.5 in the (η, ϕ) plane. Since $\alpha_T > 0.55$ implies $\not\!\!H_T/H_T > 0.4$, only events with $\not\!\!H_T > 140$ GeV are considered in the signal region (HT350). In the lower H_T regions, this requirement is scaled accordingly to $\not\!\!H_T > 120$ (100) GeV for HT300 (HT250).

In the HT350 region this selection yields 25 events, in agreement with the 29.4 ± 1.4 events predicted by the simulation. In the HT250 (HT300) region, 134 (52) W candidates are reconstructed, in agreement with the prediction of 135.5 ± 3.2 (56.7 ± 2.2) events. The fraction of $\mathrm{W} \to \mu\nu$ + jets events with $\alpha_T > 0.55$ in the data is also in good agreement with the simulation: seven data events are found in the signal region, compared with 5.9 ± 0.6 events predicted, whereas 32 (12) events in the data pass the $\alpha_T > 0.55$ requirement in the HT250 (HT300) region, compared to 29.2 ± 1.4 (11.1 ± 1.1) events expected.

The number of W + jets and $\mathrm{t\bar{t}}$ events satisfying the hadronic final state selection of Section 3, $N^{\mathrm{W;had}}_{\mathrm{data}}$, can be estimated from the number of events in the muon sample, $N^{\mathrm{W};\mu}_{\mathrm{data}}$, and the expected relative ratio of these two types of events. The value of this ratio is taken from Monte Carlo simulation, which yields $N^{\mathrm{W;had}}_{\mathrm{data}} = N^{\mathrm{W;had}}_{\mathrm{MC}}/N^{\mathrm{W};\mu}_{\mathrm{MC}} \times N^{\mathrm{W};\mu}_{\mathrm{data}} \approx 0.86 \times N^{\mathrm{W};\mu}_{\mathrm{data}}$. The total background from W + jets and $\mathrm{t\bar{t}}$ processes is thus estimated to be $6.1^{+2.8}_{-1.9}(\text{stat}) \pm 1.8(\text{syst})$. Given the reliance on simulation for the factor $N^{\mathrm{W;had}}_{\mathrm{MC}}/N^{\mathrm{W};\mu}_{\mathrm{MC}}$, conservative uncertainties on all the parameters entering this ratio have been assigned. The systematic uncertainty is estimated to be 30% and is dominated by the uncertainty on the efficiency for vetoing leptons.

4.3. $\mathrm{Z} \to \nu\bar{\nu}$ + jets background

The remaining irreducible background stems from $\mathrm{Z} \to \nu\bar{\nu}$+jets events. An estimate of this background can be obtained from γ + jets events, which have a larger production cross section but kinematic properties similar to those of $\mathrm{Z} \to \nu\bar{\nu}$+jets events when the photon is ignored [38]. These γ + jets events provide a measurement of the acceptance of the $\alpha_T > 0.55$ requirement directly from data. The γ + jets sample is selected by requiring photons, i.e. localized electromagnetic depositions satisfying very tight isolation criteria, with $p_T > 100$ GeV, $|\eta| < 1.45$, and with a distance in the (η, ϕ) plane to any jet larger than 1.0. Subsequently, the photon is ignored and the same hadronic final state selection as described in Section 3 is applied. As in Section 4.2, $\not\!\!H_T$ is required to exceed 140 GeV. This selection yields seven events in the data compared with 6.5 ± 0.4 expected from simulation. The relative acceptances, together with the appropriate ratio of cross sections for γ + jets and $\mathrm{Z} \to \nu\bar{\nu}$ + jets, taken from simulation, are then used to estimate the number of $\mathrm{Z} \to \nu\bar{\nu}$ + jets events in the signal region, found to be $N(\mathrm{Z} \to \nu\bar{\nu}+\text{jets}) = 4.4^{+2.3}_{-1.6}(\text{stat}) \pm 1.8(\text{syst})$. The main systematic uncertainties arise from the ratio of cross sections between γ + jets and $\mathrm{Z} \to \nu\bar{\nu}$ + jets in the simulation (30%), the efficiency for photon identification (20%), and the purity of the photon selection (20%), which add up to $\approx 40\%$.

To check the validity of this uncertainty estimate, the number of γ + jets events can also be used to predict the number of W + jets events. Ten W + jets events are observed with $250 < H_T < 350$ GeV, $N_{\text{jets}} = 2$ and $\alpha_T > 0.55$, in agreement with the prediction of $8.5 \pm 1.5(\text{stat}) \pm 2.6(\text{syst})$ from the γ + jets process. This agreement gives confidence that the magnitude of the assigned systematic uncertainties is adequate.

As a further cross-check, the $\mathrm{W} \to \mu\nu$ + jets sample discussed above is used to estimate the background from $\mathrm{Z} \to \nu\bar{\nu}$ + jets events. With the observed number of reconstructed $\mathrm{W} \to \mu\nu$+jets events, the ratio of cross sections and branching ratios for W and Z bosons, and the ratio of reconstruction efficiencies estimated from simulation, $4.9^{+2.6}_{-1.8}(\text{stat}) \pm 1.5(\text{syst})$ $\mathrm{Z} \to \nu\bar{\nu}$ + jets events are predicted, in agreement with the value obtained from the γ + jets sample.

4.4. Background estimate summary

The SM backgrounds to this analysis have been evaluated with independent data control samples. First, from the lower H_T regions in the data, a prediction for the total SM background of $9.4^{+4.8}_{-4.0}(\text{stat}) \pm 1.0(\text{syst})$ events in the signal region is obtained. Then, with a $\mathrm{W} \to \mu\nu$ + jet control sample, a contribution of $6.1^{+2.8}_{-1.9}(\text{stat}) \pm 1.8(\text{syst})$ events from the combination of W + jets and $\mathrm{t\bar{t}}$ processes is estimated. Finally, with the γ + jets sample, the background from $\mathrm{Z} \to \nu\bar{\nu}$ + jets events is estimated to be $4.4^{+2.3}_{-1.6}(\text{stat}) \pm 1.8(\text{syst})$. Therefore, the estimate of the SM background arising from EWK processes with genuine $\not\!\!E_T$ is $10.5^{+3.6}_{-2.5}$ events, which is in agreement with the inclusive estimate obtained

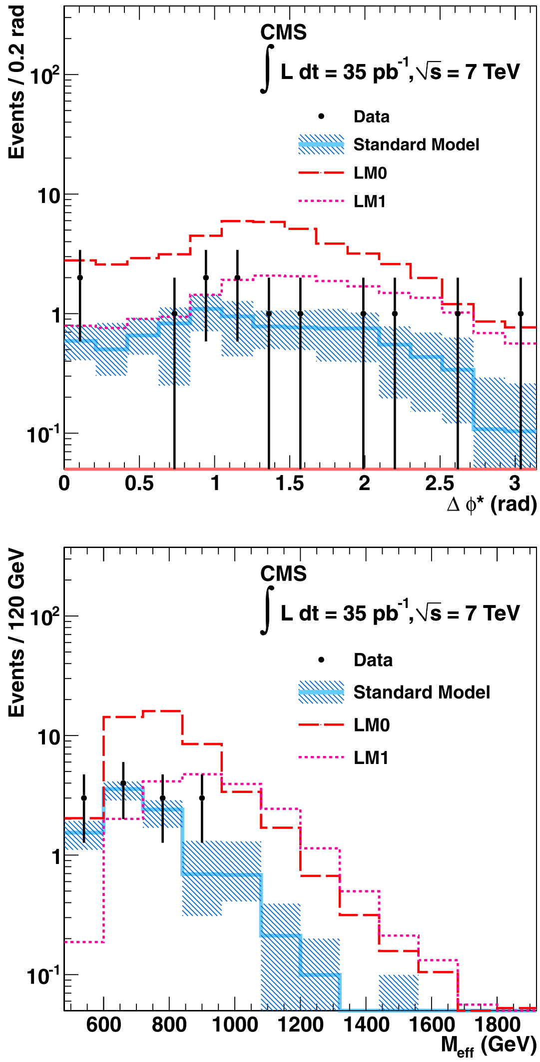

Fig. 4. Top: the $\Delta\phi^*$ distribution after all selection requirements. Bottom: the effective mass M_{eff} distribution after all selection requirements for SM processes and two low mass SUSY benchmark points. In both figures the hatched area corresponds to the uncertainty in the SM estimate as defined in Section 3.1.

from the lower H_{T} control regions. All these background estimates are used in the limit calculation.

The potential effect of multiple interactions per bunch crossing (pileup) in the event selection and in the background estimates is evaluated by comparing the fraction $R_{\alpha_{\text{T}}}$, for several thresholds on α_{T}, between events with only one primary vertex and events with more than one primary vertex. No discernible difference has been found.

The remaining events are found to exhibit the topological and kinematic properties expected from the SM backgrounds. Two distributions, which are expected to show good separation between the SM background and the SUSY signal, are shown in Fig. 4. The $\Delta\phi^*$ variable (Section 3.2) is useful in identifying mismeasured jets, since jet mismeasurements in QCD multijet events result in small values of $\Delta\phi^*$, whereas events with genuine $\not{E}_{\text{T}}$, e.g. from EWK processes, populate $\Delta\phi^*$ evenly. In Fig. 4(top) the $\Delta\phi^*$ distribution for the 13 data events which pass all selection requirements is displayed. The data are consistent with EWK processes and there is no indication of an enhanced contribution from QCD multijet processes which would manifest itself at small values of $\Delta\phi^*$.

The "effective mass", $M_{\text{eff}} = H_{\text{T}} + \not{H}_{\text{T}}$, which characterizes the overall energy scale of the event, is shown in Fig. 4(bottom) after all selection requirements. The data are compared with the SM background expectation along with two SUSY benchmark points. The shape and magnitude of the M_{eff} distribution observed in the data are consistent with the expectation from the SM backgrounds. The yields expected from the LM0 and LM1 benchmark SUSY models are in excess of the data over most of the M_{eff} range.

Both these variables exhibit differences between SUSY signal events and events from SM backgrounds and could, therefore, be used to improve the limits extracted in the following section. We have chosen not to do so because the current search has been optimized for the demonstration of a potential new signal, rather than for the extraction of the most stringent limits in the SUSY parameter space.

In summary, 13 events are observed in the data, a yield consistent, within the uncertainties, with the expectation from the SM processes. In addition, the kinematic properties of these events are consistent with the EWK backgrounds, with a negligible contribution from QCD multijet processes.

5. Interpretation of the result

5.1. Method and limit on signal yield

The background estimation methods described in the previous section are combined to provide an estimate of the total number of background events. This estimate is found to be compatible with the number of events selected. An upper limit on the number of non-SM events consistent with the measurements is derived using the Feldman–Cousins method [39], which is generalized to take into account nuisance parameters by using the Profile Likelihood ratio [40]. The input to the profiling method is the total likelihood function L_{total} for the measurements in the control and signal regions. To construct this likelihood function, the numbers of events observed in the signal region and in each of the control samples are treated as independent event-counting experiments. The total likelihood function can be written as

$$L_{\text{total}} = L_{\text{signal}} \cdot L_{\text{inclusive}} \cdot L_{\text{W/t}\bar{\text{t}}} \cdot L_{\text{Z}\to\nu\bar{\nu}}, \tag{2}$$

where the different factors correspond to the likelihood of the measurement in the signal region, L_{signal}, of the inclusive background extraction method using all three H_{T} bins defined in Section 4.1, $L_{\text{inclusive}}$, of the exclusive measurement of $\text{t}\bar{\text{t}}$ and W + jet event background described in Section 4.2, $L_{\text{W/t}\bar{\text{t}}}$, and of the $\text{Z}\to\nu\bar{\nu}$ background component described in Section 4.3, $L_{\text{Z}\to\nu\bar{\nu}}$.

The likelihood functions are taken as Poisson-distributed probabilities to measure the number of events observed while expecting to see the estimated number of background events plus a certain fraction of CMSSM SUSY signal events. The expected backgrounds in the auxiliary measurements and in the signal-like region are related as described in Section 4. The ratio of the expected signal events in the control region and in the signal region is model-dependent and varies from point to point in the CMSSM parameter space.

The expected number of background events and the systematic uncertainties on the background prediction and on the signal selection efficiency are treated as nuisance parameters. The probability density functions which describe the systematic uncertainties are assumed to be Gaussian with variance given by the systematic uncertainties derived in the previous section.

The systematic uncertainties on the signal event yield can be split into two parts: theoretical uncertainties on the predicted cross section of the different production processes (squark–squark, squark–gluino, gluino–gluino) and experimental uncertainties on the integrated luminosity [41] and on the selection efficiency.

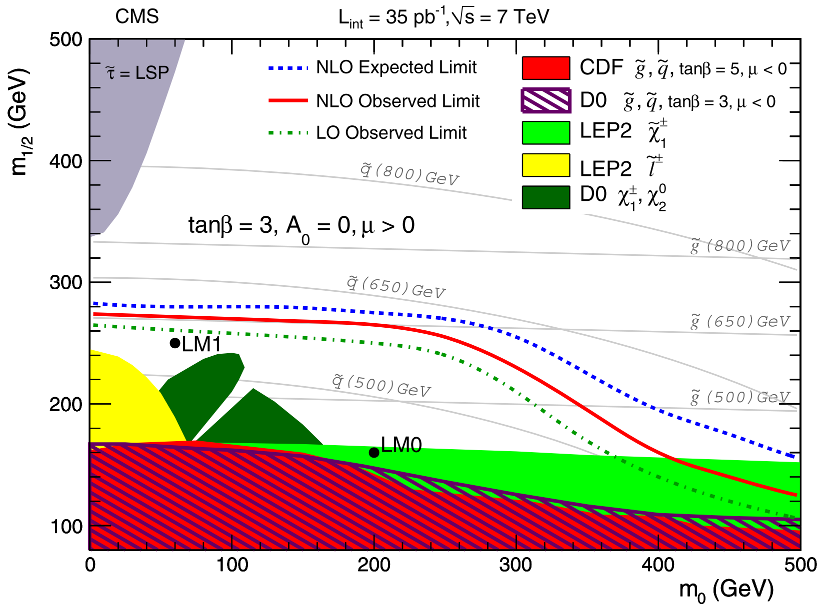

Fig. 5. Measured (red line) and expected (dashed blue line) 95% CL exclusion contour at NLO in the CMSSM $(m_0, m_{1/2})$ plane for $\tan\beta = 3$, $A_0 = 0$ and $\text{sign}(\mu) > 0$. The measured LO exclusion contour is shown as well (dot-dashed green line). The area below the curves is excluded by this measurement. Exclusion limits obtained from previous experiments are presented as filled areas in the plot. Grey lines correspond to constant squark and gluino masses. The plot also shows the two benchmark points LM0 and LM1 for comparison. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this Letter.)

Whereas the theoretical uncertainties are strongly model dependent, the experimental uncertainties are found to be essentially independent of the signal model. The experimental systematic uncertainties on the estimated event yield are the uncertainty on the luminosity measurement (11%), the effect of rejecting events with jets pointing to masked ECAL regions (3%), the modelling of the lepton and photon vetoes in the simulation (2.5%), and the effect of the uncertainty in the jet energy scale and resolution on the selection efficiency (2.5%). These uncertainties are included in the limit calculation. The effect of multiple interactions per bunch crossing on the signal is evaluated by comparing the efficiency for signal events passing all selection requirements with and without the inclusion of multiple interactions in the simulation. The effect on the efficiency is negligible.

If a potential signal contamination in the background control samples is ignored, an upper limit on the number of signal events compatible with the observations at 95% confidence level (CL) can be obtained. For an integrated luminosity of 35 pb^{-1} this number is 13.4 events. The p value for the hypothesis of standard model background only, calculated from the ratio of likelihoods, is 0.3.

5.2. Interpretation within the CMSSM

To interpret the consistency of the observed number of events with the background expectation in the context of a model, and also to facilitate the comparison with previous experimental results, an exclusion limit in the CMSSM is set. This limit is obtained by testing, for each point in the parameter space, whether the number of signal events predicted after all selection requirements is compatible with observations at 95% CL.

Signal contamination in the data control samples used to estimate the background is also taken into account by explicitly including the number of signal expected in the control regions. As the search is designed for robustness and background control, the same selection is applied at each point in the parameter space, and no dedicated optimization for the CMSSM parameter space is performed.

Table 2
Breakdown of expected event yields and selection efficiencies for the most important production channels of the LM1 benchmark point after all selection requirements. No distinction has been made between $\tilde{q}$ and $\bar{\tilde{q}}$. The quoted errors represent the statistical uncertainties on the yields and efficiencies. The efficiencies ϵ_{total} and $\epsilon_{\text{signature}}$ are defined in the text in Section 5.2.

Production mechanism	Yields for 35 pb^{-1}	ϵ_{total} (%)	$\epsilon_{\text{signature}}$ (%)
$\tilde{q}\tilde{q}$	9.7 ± 0.1	16.0 ± 0.1	22.2 ± 0.4
$\tilde{q}\tilde{g}$	8.8 ± 0.1	14.4 ± 0.1	23.0 ± 0.5
$\tilde{g}\tilde{g}$	0.71 ± 0.02	12.0 ± 0.4	22.5 ± 2.0

An example of the analysis efficiency and corresponding event yields after all selection requirements, broken down by the most relevant production processes (squark–squark ($\tilde{q}\tilde{q}$), squark–gluino ($\tilde{q}\tilde{g}$), and gluino–gluino ($\tilde{g}\tilde{g}$)), is presented in Table 2 for the benchmark point LM1. Two different experimental efficiencies ϵ_{total} and $\epsilon_{\text{signature}}$ are given. The first number, ϵ_{total}, is normalized to the total number of signal events in LM1, while $\epsilon_{\text{signature}}$ is defined with respect to the total number of all-hadronic events in LM1 where, as in the analysis, leptons and photons are vetoed. For the different production mechanisms, ϵ_{total} varies from 12% to 16%. The signature-based efficiency is almost constant, varying between 22% and 23%, which indicates that the analysis has a uniform sensitivity to the different production channels in LM1. With the current data, the LM1 and LM0 benchmark points are excluded at 99.2% CL and 99.99% CL, respectively.

The 95% CL limit in the $(m_0, m_{1/2})$ plane, for $\tan\beta = 3$, $A_0 = 0$ and $\text{sign}(\mu) > 0$, is shown in Fig. 5. The SUSY particle spectrum is calculated using SoftSUSY [42], and the signal events are generated at leading order (LO) with PYTHIA6.4. Next-to-leading order (NLO) cross sections, obtained with the program Prospino [43], are used to calculate the observed and expected exclusion contours. Systematic uncertainties on the NLO predictions due to the choice of the renormalization and factorization scales have been taken into account. The uncertainties on the used parton distribution functions (PDF) for CTEQ6.6 [44] are estimated from the envelope provided by the CTEQ6.6 error function. For reference, the observed limit using LO cross sections is also shown.

The expected limit covers a larger part of the $(m_0, m_{1/2})$ plane than the measured limit, as the number of events observed in the signal region is slightly larger than the number of background events predicted from the control regions. The excluded regions for the CDF search for jets + missing energy final states [10] were obtained for $\tan\beta = 5$, while those from D0 [12] were obtained for $\tan\beta = 3$, each with approximately 2 fb^{-1} of data. The LEP-excluded regions are based on searches for sleptons and charginos [18]. A comparison of the exclusion limit for $\tan\beta = 3$ to that for $\tan\beta = 10$ for fixed values of $A_0 = 0$ and $\text{sign}(\mu) > 0$ indicates that the exclusion reach is only weakly dependent on the value of $\tan\beta$; the limit shifts by less than 20 GeV in m_0 and by less than 10 GeV in $m_{1/2}$. The D0 exclusion limit, valid for $\tan\beta = 3$ and obtained from a search for associated production of charginos $\chi_1^{\pm}$ and neutralinos χ_2^0 in trilepton final states [13], is also included in Fig. 5. In contrast to the other limits presented in Fig. 5, the result of the trilepton search is strongly dependent on the choice of $\tan\beta$ and it reaches its highest sensitivity in the CMSSM for $\tan\beta$ values below ten.

6. Summary

The first search for supersymmetry in events collected by the CMS experiment from proton–proton collisions at a centre-of-mass energy of 7 TeV has been presented. The final states with two or more hadronic jets and significant missing transverse energy, as expected from high-mass squark and gluino production and decays, have been analysed in data corresponding to an integrated luminosity of 35 pb^{-1}. A search for a SUSY signal has been performed at high values of the scalar sum of the transverse energy of jets, H_T. The primary background, from QCD multijet events, has been reduced by several orders of magnitude down to a negligible level using a robust set of requirements designed specifically for the exploratory, early data-taking phase of the experiment. The sum of standard model backgrounds has been estimated from an extrapolation of the data observed at lower H_T values. The only remaining backgrounds have been found to stem from electroweak processes, namely W + jet, Z + jet, and $t\bar{t}$ production, where the weak decays of the vector bosons involve high-momentum neutrinos. An independent estimate of the electroweak backgrounds, from $W \to \mu\nu$ + jets decays as well as γ + jets events in the data together with input from simulation, has been found to be well compatible with the estimate from control samples in data. Here, conservatively large systematic uncertainties have been assigned to the background estimates. The measurements are in agreement with the expected contributions from standard model processes. Limits on the CMSSM parameters have been derived, and have been shown to improve significantly those set by previous experiments.

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CMS Collaboration

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

Yerevan Physics Institute, Yerevan, Armenia

W. Adam, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan, M. Friedl, R. Frühwirth, V.M. Ghete, J. Hammer [1], S. Hänsel, C. Hartl, M. Hoch, N. Hörmann, J. Hrubec, M. Jeitler, G. Kasieczka, W. Kiesenhofer, M. Krammer, D. Liko, I. Mikulec, M. Pernicka, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, F. Teischinger, P. Wagner, W. Waltenberger, G. Walzel, E. Widl, C.-E. Wulz

Institut für Hochenergiephysik der OeAW, Wien, Austria

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

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

L. Benucci, K. Cerny, E.A. De Wolf, X. Janssen, T. Maes, L. Mucibello, S. Ochesanu, B. Roland, R. Rougny, M. Selvaggi, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel

Universiteit Antwerpen, Antwerpen, Belgium

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

Vrije Universiteit Brussel, Brussel, Belgium

O. Charaf, B. Clerbaux, G. De Lentdecker, V. Dero, A.P.R. Gay, G.H. Hammad, T. Hreus, P.E. Marage, L. Thomas, C. Vander Velde, P. Vanlaer, J. Wickens

Université Libre de Bruxelles, Bruxelles, Belgium

V. Adler, S. Costantini, M. Grunewald, B. Klein, A. Marinov, J. Mccartin, D. Ryckbosch, F. Thyssen, M. Tytgat, L. Vanelderen, P. Verwilligen, S. Walsh, N. Zaganidis

Ghent University, Ghent, Belgium

S. Basegmez, G. Bruno, J. Caudron, L. Ceard, J. De Favereau De Jeneret, C. Delaere, P. Demin, D. Favart, A. Giammanco, G. Grégoire, J. Hollar, V. Lemaitre, J. Liao, O. Militaru, S. Ovyn, D. Pagano, A. Pin, K. Piotrzkowski, N. Schul

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

N. Beliy, T. Caebergs, E. Daubie

Université de Mons, Mons, Belgium

G.A. Alves, D. De Jesus Damiao, M.E. Pol, M.H.G. Souza

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

W. Carvalho, E.M. Da Costa, C. De Oliveira Martins, S. Fonseca De Souza, L. Mundim, H. Nogima, V. Oguri, W.L. Prado Da Silva, A. Santoro, S.M. Silva Do Amaral, A. Sznajder, F. Torres Da Silva De Araujo

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

F.A. Dias, M.A.F. Dias, T.R. Fernandez Perez Tomei, E.M. Gregores[2], F. Marinho, S.F. Novaes, Sandra S. Padula

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

N. Darmenov[1], L. Dimitrov, V. Genchev[1], P. Iaydjiev[1], S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, V. Tcholakov, R. Trayanov, I. Vankov

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

M. Dyulendarova, R. Hadjiiska, V. Kozhuharov, L. Litov, E. Marinova, M. Mateev, B. Pavlov, P. Petkov

University of Sofia, Sofia, Bulgaria

J.G. Bian, G.M. Chen, H.S. Chen, C.H. Jiang, D. Liang, S. Liang, J. Wang, J. Wang, X. Wang, Z. Wang, M. Xu, M. Yang, J. Zang, Z. Zhang

Institute of High Energy Physics, Beijing, China

Y. Ban, S. Guo, Y. Guo, W. Li, Y. Mao, S.J. Qian, H. Teng, L. Zhang, B. Zhu, W. Zou

State Key Lab. of Nucl. Phys. and Tech., Peking University, Beijing, China

A. Cabrera, B. Gomez Moreno, A.A. Ocampo Rios, A.F. Osorio Oliveros, J.C. Sanabria

Universidad de Los Andes, Bogota, Colombia

N. Godinovic, D. Lelas, K. Lelas, R. Plestina[3], D. Polic, I. Puljak

Technical University of Split, Split, Croatia

Z. Antunovic, M. Dzelalija

University of Split, Split, Croatia

V. Brigljevic, S. Duric, K. Kadija, S. Morovic

Institute Rudjer Boskovic, Zagreb, Croatia

A. Attikis, M. Galanti, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis, H. Rykaczewski

University of Cyprus, Nicosia, Cyprus

M. Finger, M. Finger Jr.

Charles University, Prague, Czech Republic

A. Awad, S. Khalil[4]

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt

A. Hektor, M. Kadastik, K. Kannike, M. Müntel, M. Raidal, L. Rebane

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

V. Azzolini, P. Eerola

Department of Physics, University of Helsinki, Helsinki, Finland

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

Helsinki Institute of Physics, Helsinki, Finland

K. Banzuzi, A. Korpela, T. Tuuva

Lappeenranta University of Technology, Lappeenranta, Finland

D. Sillou

Laboratoire d'Annecy-le-Vieux de Physique des Particules, IN2P3–CNRS, Annecy-le-Vieux, France

M. Besancon, S. Choudhury, M. Dejardin, D. Denegri, B. Fabbro, J.L. Faure, F. Ferri, S. Ganjour, F.X. Gentit, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, J. Malcles, M. Marionneau, L. Millischer, J. Rander, A. Rosowsky, I. Shreyber, M. Titov, P. Verrecchia

DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France

S. Baffioni, F. Beaudette, L. Bianchini, M. Bluj [5], C. Broutin, P. Busson, C. Charlot, T. Dahms, L. Dobrzynski, R. Granier de Cassagnac, M. Haguenauer, P. Miné, C. Mironov, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Thiebaux, B. Wyslouch [6], A. Zabi

Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3–CNRS, Palaiseau, France

J.-L. Agram [7], J. Andrea, A. Besson, D. Bloch, D. Bodin, J.-M. Brom, M. Cardaci, E.C. Chabert, C. Collard, E. Conte [7], F. Drouhin [7], C. Ferro, J.-C. Fontaine [7], D. Gelé, U. Goerlach, S. Greder, P. Juillot, M. Karim [7], A.-C. Le Bihan, Y. Mikami, P. Van Hove

Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France

F. Fassi, D. Mercier

Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules (IN2P3), Villeurbanne, France

C. Baty, N. Beaupere, M. Bedjidian, O. Bondu, G. Boudoul, D. Boumediene, H. Brun, N. Chanon, R. Chierici, D. Contardo, P. Depasse, H. El Mamouni, A. Falkiewicz, J. Fay, S. Gascon, B. Ille, T. Kurca, T. Le Grand, M. Lethuillier, L. Mirabito, S. Perries, V. Sordini, S. Tosi, Y. Tschudi, P. Verdier, H. Xiao

Université de Lyon, Université Claude Bernard Lyon 1, CNRS–IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France

L. Megrelidze, V. Roinishvili

E. Andronikashvili Institute of Physics, Academy of Science, Tbilisi, Georgia

D. Lomidze

Institute of High Energy Physics and Informatization, Tbilisi State University, Tbilisi, Georgia

G. Anagnostou, M. Edelhoff, L. Feld, N. Heracleous, O. Hindrichs, R. Jussen, K. Klein, J. Merz, N. Mohr, A. Ostapchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Sprenger, H. Weber, M. Weber, B. Wittmer

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany

M. Ata, W. Bender, M. Erdmann, J. Frangenheim, T. Hebbeker, A. Hinzmann, K. Hoepfner, C. Hof, T. Klimkovich, D. Klingebiel, P. Kreuzer, D. Lanske [†], C. Magass, G. Masetti, M. Merschmeyer, A. Meyer, P. Papacz, H. Pieta, H. Reithler, S.A. Schmitz, L. Sonnenschein, J. Steggemann, D. Teyssier

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

M. Bontenackels, M. Davids, M. Duda, G. Flügge, H. Geenen, M. Giffels, W. Haj Ahmad, D. Heydhausen, T. Kress, Y. Kuessel, A. Linn, A. Nowack, L. Perchalla, O. Pooth, J. Rennefeld, P. Sauerland, A. Stahl, M. Thomas, D. Tornier, M.H. Zoeller

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

M. Aldaya Martin, W. Behrenhoff, U. Behrens, M. Bergholz [8], K. Borras, A. Cakir, A. Campbell, E. Castro, D. Dammann, G. Eckerlin, D. Eckstein, A. Flossdorf, G. Flucke, A. Geiser, I. Glushkov, J. Hauk, H. Jung, M. Kasemann, I. Katkov, P. Katsas, C. Kleinwort, H. Kluge, A. Knutsson, D. Krücker, E. Kuznetsova, W. Lange, W. Lohmann [8], R. Mankel, M. Marienfeld, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, J. Olzem, A. Parenti, A. Raspereza, A. Raval, R. Schmidt [8], T. Schoerner-Sadenius, N. Sen, M. Stein, J. Tomaszewska, D. Volyanskyy, R. Walsh, C. Wissing

Deutsches Elektronen-Synchrotron, Hamburg, Germany

C. Autermann, S. Bobrovskyi, J. Draeger, H. Enderle, U. Gebbert, K. Kaschube, G. Kaussen, R. Klanner, J. Lange, B. Mura, S. Naumann-Emme, F. Nowak, N. Pietsch, C. Sander, H. Schettler, P. Schleper, M. Schröder, T. Schum, J. Schwandt, A.K. Srivastava, H. Stadie, G. Steinbrück, J. Thomsen, R. Wolf

University of Hamburg, Hamburg, Germany

C. Barth, J. Bauer, V. Buege, T. Chwalek, W. De Boer, A. Dierlamm, G. Dirkes, M. Feindt, J. Gruschke, C. Hackstein, F. Hartmann, S.M. Heindl, M. Heinrich, H. Held, K.H. Hoffmann, S. Honc, T. Kuhr, D. Martschei, S. Mueller, Th. Müller, M. Niegel, O. Oberst, A. Oehler, J. Ott, T. Peiffer, D. Piparo, G. Quast, K. Rabbertz, F. Ratnikov, M. Renz, C. Saout, A. Scheurer, P. Schieferdecker, F.-P. Schilling, G. Schott, H.J. Simonis, F.M. Stober, D. Troendle, J. Wagner-Kuhr, M. Zeise, V. Zhukov [9], E.B. Ziebarth

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

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

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

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

University of Athens, Athens, Greece

I. Evangelou, C. Foudas, P. Kokkas, N. Manthos, I. Papadopoulos, V. Patras, F.A. Triantis

University of Ioánnina, Ioánnina, Greece

A. Aranyi, G. Bencze, L. Boldizsar, G. Debreczeni, C. Hajdu [1], D. Horvath [10], A. Kapusi, K. Krajczar [11], A. Laszlo, F. Sikler, G. Vesztergombi [11]

KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary

N. Beni, J. Molnar, J. Palinkas, Z. Szillasi, V. Veszpremi

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

P. Raics, Z.L. Trocsanyi, B. Ujvari

University of Debrecen, Debrecen, Hungary

S. Bansal, S.B. Beri, V. Bhatnagar, N. Dhingra, R. Gupta, M. Jindal, M. Kaur, J.M. Kohli, M.Z. Mehta, N. Nishu, L.K. Saini, A. Sharma, A.P. Singh, J.B. Singh, S.P. Singh

Panjab University, Chandigarh, India

S. Ahuja, S. Bhattacharya, B.C. Choudhary, P. Gupta, S. Jain, S. Jain, A. Kumar, R.K. Shivpuri

University of Delhi, Delhi, India

R.K. Choudhury, D. Dutta, S. Kailas, S.K. Kataria, A.K. Mohanty [1], L.M. Pant, P. Shukla

Bhabha Atomic Research Centre, Mumbai, India

T. Aziz, M. Guchait [12], A. Gurtu, M. Maity [13], D. Majumder, G. Majumder, K. Mazumdar, G.B. Mohanty, A. Saha, K. Sudhakar, N. Wickramage

Tata Institute of Fundamental Research – EHEP, Mumbai, India

S. Banerjee, S. Dugad, N.K. Mondal

Tata Institute of Fundamental Research – HECR, Mumbai, India

H. Arfaei, H. Bakhshiansohi, S.M. Etesami, A. Fahim, M. Hashemi, A. Jafari, M. Khakzad, A. Mohammadi, M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh, M. Zeinali

Institute for Studies in Theoretical Physics & Mathematics (IPM), Tehran, Iran

M. Abbrescia [a,b], L. Barbone [a,b], C. Calabria [a,b], A. Colaleo [a], D. Creanza [a,c], N. De Filippis [a,c], M. De Palma [a,b], A. Dimitrov [a], L. Fiore [a], G. Iaselli [a,c], L. Lusito [a,b,1], G. Maggi [a,c], M. Maggi [a], N. Manna [a,b], B. Marangelli [a,b], S. My [a,c], S. Nuzzo [a,b], N. Pacifico [a,b], G.A. Pierro [a], A. Pompili [a,b], G. Pugliese [a,c], F. Romano [a,c], G. Roselli [a,b], G. Selvaggi [a,b], L. Silvestris [a], R. Trentadue [a], S. Tupputi [a,b], G. Zito [a]

[a] *INFN Sezione di Bari, Bari, Italy*
[b] *Università di Bari, Bari, Italy*
[c] *Politecnico di Bari, Bari, Italy*

G. Abbiendi [a], A.C. Benvenuti [a], D. Bonacorsi [a], S. Braibant-Giacomelli [a,b], L. Brigliadori [a], P. Capiluppi [a,b], A. Castro [a,b], F.R. Cavallo [a], M. Cuffiani [a,b], G.M. Dallavalle [a], F. Fabbri [a], A. Fanfani [a,b], D. Fasanella [a], P. Giacomelli [a], M. Giunta [a], C. Grandi [a], S. Marcellini [a], M. Meneghelli [a,b], A. Montanari [a], F.L. Navarria [a,b], F. Odorici [a], A. Perrotta [a], F. Primavera [a], A.M. Rossi [a,b], T. Rovelli [a,b], G. Siroli [a,b], R. Travaglini [a,b]

[a] *INFN Sezione di Bologna, Bologna, Italy*
[b] *Università di Bologna, Bologna, Italy*

S. Albergo [a,b], G. Cappello [a,b], M. Chiorboli [a,b,1], S. Costa [a,b], A. Tricomi [a,b], C. Tuve [a]

[a] *INFN Sezione di Catania, Catania, Italy*
[b] *Università di Catania, Catania, 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], P. Lenzi [a,b], M. Meschini [a], S. Paoletti [a], G. Sguazzoni [a], A. Tropiano [a,1]

[a] *INFN Sezione di Firenze, Firenze, Italy*
[b] *Università di Firenze, Firenze, Italy*

L. Benussi, S. Bianco, S. Colafranceschi [14], F. Fabbri, D. Piccolo

INFN Laboratori Nazionali di Frascati, Frascati, Italy

P. Fabbricatore, R. Musenich

INFN Sezione di Genova, Genova, Italy

A. Benaglia [a,b], F. De Guio [a,b,1], L. Di Matteo [a,b], A. Ghezzi [a,b,1], M. Malberti [a,b], S. Malvezzi [a], A. Martelli [a,b], A. Massironi [a,b], 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], V. Tancini [a,b]

[a] *INFN Sezione di Milano-Biccoca, Milano, Italy*
[b] *Università di Milano-Bicocca, Milano, Italy*

S. Buontempo [a], C.A. Carrillo Montoya [a], A. Cimmino [a,b], A. De Cosa [a,b], M. De Gruttola [a,b], F. Fabozzi [a,15], A.O.M. Iorio [a], L. Lista [a], M. Merola [a,b], P. Noli [a,b], P. Paolucci [a]

[a] INFN Sezione di Napoli, Napoli, Italy
[b] Università di Napoli "Federico II", Napoli, Italy

P. Azzi [a], N. Bacchetta [a], P. Bellan [a,b], D. Bisello [a,b], A. Branca [a], R. Carlin [a,b], P. Checchia [a], E. Conti [a], M. De Mattia [a,b], T. Dorigo [a], U. Dosselli [a], F. Fanzago [a], F. Gasparini [a,b], U. Gasparini [a,b], P. Giubilato [a,b], A. Gresele [a,c], S. Lacaprara [a,16], I. Lazzizzera [a,c], M. Margoni [a,b], M. Mazzucato [a], A.T. Meneguzzo [a,b], L. Perrozzi [a,1], N. Pozzobon [a,b], P. Ronchese [a,b], F. Simonetto [a,b], E. Torassa [a], M. Tosi [a,b], S. Vanini [a,b], P. Zotto [a,b], G. Zumerle [a,b]

[a] INFN Sezione di Padova, Padova, Italy
[b] Università di Padova, Padova, Italy
[c] Università di Trento (Trento), Padova, Italy

P. Baesso [a,b], U. Berzano [a], C. Riccardi [a,b], P. Torre [a,b], P. Vitulo [a,b], C. Viviani [a,b]

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

M. Biasini [a,b], G.M. Bilei [a], B. Caponeri [a,b], L. Fanò [a,b], P. Lariccia [a,b], A. Lucaroni [a,b,1], G. Mantovani [a,b], M. Menichelli [a], A. Nappi [a,b], A. Santocchia [a,b], L. Servoli [a], S. Taroni [a,b], M. Valdata [a,b], R. Volpe [a,b,1]

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

P. Azzurri [a,c], G. Bagliesi [a], J. Bernardini [a,b], T. Boccali [a,1], G. Broccolo [a,c], R. Castaldi [a], R.T. D'Agnolo [a,c], R. Dell'Orso [a], F. Fiori [a,b], L. Foà [a,c], A. Giassi [a], A. Kraan [a], F. Ligabue [a,c], T. Lomtadze [a], L. Martini [a,17], A. Messineo [a,b], F. Palla [a], F. Palmonari [a], S. Sarkar [a,c], G. Segneri [a], A.T. Serban [a], P. Spagnolo [a], R. Tenchini [a,*], G. Tonelli [a,b,1], A. Venturi [a,1], P.G. Verdini [a]

[a] INFN Sezione di Pisa, Pisa, Italy
[b] Università di Pisa, Pisa, Italy
[c] Scuola Normale Superiore di Pisa, Pisa, Italy

L. Barone [a,b], F. Cavallari [a], D. Del Re [a,b], E. Di Marco [a,b], M. Diemoz [a], D. Franci [a,b], M. Grassi [a], E. Longo [a,b], S. Nourbakhsh [a], G. Organtini [a,b], A. Palma [a,b], F. Pandolfi [a,b,1], R. Paramatti [a], S. Rahatlou [a,b]

[a] INFN Sezione di Roma, Roma, Italy
[b] Università di Roma "La Sapienza", Roma, Italy

N. Amapane [a,b], R. Arcidiacono [a,c], S. Argiro [a,b], M. Arneodo [a,c], C. Biino [a], C. Botta [a,b,1], N. Cartiglia [a], R. Castello [a,b], M. Costa [a,b], N. Demaria [a], A. Graziano [a,b,1], C. Mariotti [a], M. Marone [a,b], S. Maselli [a], E. Migliore [a,b], G. Mila [a,b], V. Monaco [a,b], M. Musich [a,b], M.M. Obertino [a,c], N. Pastrone [a], M. Pelliccioni [a,b,1], A. Romero [a,b], M. Ruspa [a,c], R. Sacchi [a,b], V. Sola [a,b], A. Solano [a,b], A. Staiano [a], D. Trocino [a,b], A. Vilela Pereira [a,b,1]

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

S. Belforte [a], F. Cossutti [a], G. Della Ricca [a,b], B. Gobbo [a], D. Montanino [a,b], A. Penzo [a]

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

S.G. Heo

Kangwon National University, Chunchon, Republic of Korea

S. Chang, J. Chung, D.H. Kim, G.N. Kim, J.E. Kim, D.J. Kong, H. Park, D. Son, D.C. Son

Kyungpook National University, Daegu, Republic of Korea

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

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

S. Choi, B. Hong, M. Jo, H. Kim, J.H. Kim, T.J. Kim, K.S. Lee, D.H. Moon, S.K. Park, H.B. Rhee, E. Seo, S. Shin, K.S. Sim

Korea University, Seoul, Republic of Korea

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

University of Seoul, Seoul, Republic of Korea

Y. Choi, Y.K. Choi, J. Goh, J. Lee, S. Lee, H. Seo, I. Yu

Sungkyunkwan University, Suwon, Republic of Korea

M.J. Bilinskas, I. Grigelionis, M. Janulis, D. Martisiute, P. Petrov, T. Sabonis

Vilnius University, Vilnius, Lithuania

H. Castilla Valdez, E. De La Cruz Burelo, R. Lopez-Fernandez, A. Sánchez Hernández, L.M. Villasenor-Cendejas

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

S. Carrillo Moreno, F. Vazquez Valencia

Universidad Iberoamericana, Mexico City, Mexico

H.A. Salazar Ibarguen

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

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

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

P. Allfrey, D. Krofcheck

University of Auckland, Auckland, New Zealand

P.H. Butler, R. Doesburg, H. Silverwood

University of Canterbury, Christchurch, New Zealand

M. Ahmad, I. Ahmed, M.I. Asghar, H.R. Hoorani, W.A. Khan, T. Khurshid, S. Qazi

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

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

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

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

Soltan Institute for Nuclear Studies, Warsaw, Poland

N. Almeida, A. David, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, P. Martins, P. Musella, A. Nayak, P.Q. Ribeiro, J. Seixas, P. Silva, J. Varela, H.K. Wöhri

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

I. Belotelov, P. Bunin, I. Golutvin, A. Kamenev, V. Karjavin, G. Kozlov, A. Lanev, P. Moisenz, V. Palichik, V. Perelygin, S. Shmatov, V. Smirnov, A. Volodko, A. Zarubin

Joint Institute for Nuclear Research, Dubna, Russia

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

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

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

Institute for Nuclear Research, Moscow, Russia

V. Epshteyn, V. Gavrilov, V. Kaftanov[†], M. Kossov[1], A. Krokhotin, N. Lychkovskaya, G. Safronov, S. Semenov, V. Stolin, E. Vlasov, A. Zhokin

Institute for Theoretical and Experimental Physics, Moscow, Russia

E. Boos, M. Dubinin[18], L. Dudko, A. Ershov, A. Gribushin, O. Kodolova, I. Lokhtin, S. Obraztsov, S. Petrushanko, L. Sarycheva, V. Savrin, A. Snigirev

Moscow State University, Moscow, Russia

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

P.N. Lebedev Physical Institute, Moscow, Russia

I. Azhgirey, S. Bitioukov, V. Grishin[1], V. Kachanov, D. Konstantinov, A. Korablev, V. Krychkine, V. Petrov, R. Ryutin, S. Slabospitsky, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

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

P. Adzic[19], M. Djordjevic, D. Krpic[19], J. Milosevic

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

M. Aguilar-Benitez, J. Alcaraz Maestre, P. Arce, C. Battilana, E. Calvo, M. Cepeda, M. Cerrada, N. Colino, B. De La Cruz, C. Diez Pardos, 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, I. Redondo, L. Romero, J. Santaolalla, C. Willmott

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

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

Universidad Autónoma de Madrid, Madrid, Spain

J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias, J.M. Vizan Garcia

Universidad de Oviedo, Oviedo, Spain

J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, M. Chamizo Llatas, S.H. Chuang, J. Duarte Campderros, M. Felcini[20], M. Fernandez, G. Gomez, J. Gonzalez Sanchez, C. Jorda, P. Lobelle Pardo, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, J. Piedra Gomez[21], T. Rodrigo, A. Ruiz Jimeno, L. Scodellaro, M. Sobron Sanudo, I. Vila, R. Vilar Cortabitarte

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

D. Abbaneo, E. Auffray, G. Auzinger, P. Baillon, A.H. Ball, D. Barney, A.J. Bell [22], D. Benedetti, C. Bernet [3], W. Bialas, P. Bloch, A. Bocci, S. Bolognesi, H. Breuker, G. Brona, K. Bunkowski, T. Camporesi, E. Cano, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, B. Curé, D. D'Enterria, A. De Roeck, S. Di Guida, F. Duarte Ramos, A. Elliott-Peisert, B. Frisch, W. Funk, A. Gaddi, S. Gennai, G. Georgiou, H. Gerwig, D. Gigi, K. Gill, D. Giordano, F. Glege, R. Gomez-Reino Garrido, M. Gouzevitch, P. Govoni, S. Gowdy, L. Guiducci, M. Hansen, J. Harvey, J. Hegeman, B. Hegner, C. Henderson, G. Hesketh, H.F. Hoffmann, A. Honma, V. Innocente, P. Janot, K. Kaadze, E. Karavakis, P. Lecoq, C. Lourenço, A. Macpherson, T. Mäki, L. Malgeri, M. Mannelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, R. Moser, M.U. Mozer, M. Mulders, E. Nesvold [1], M. Nguyen, T. Orimoto, L. Orsini, E. Perez, A. Petrilli, A. Pfeiffer, M. Pierini, M. Pimiä, G. Polese, A. Racz, J. Rodrigues Antunes, G. Rolandi [23], T. Rommerskirchen, C. Rovelli [24], M. Rovere, H. Sakulin, C. Schäfer, C. Schwick, I. Segoni, A. Sharma, P. Siegrist, M. Simon, P. Sphicas [25], D. Spiga, M. Spiropulu [18], F. Stöckli, M. Stoye, P. Tropea, A. Tsirou, A. Tsyganov, G.I. Veres [11], P. Vichoudis, M. Voutilainen, W.D. Zeuner

CERN, European Organization for Nuclear Research, Geneva, 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 [26], A. Starodumov [27]

Paul Scherrer Institut, Villigen, Switzerland

P. Bortignon, L. Caminada [28], Z. Chen, S. Cittolin, G. Dissertori, M. Dittmar, J. Eugster, K. Freudenreich, C. Grab, A. Hervé, W. Hintz, P. Lecomte, W. Lustermann, C. Marchica [28], P. Martinez Ruiz del Arbol, P. Meridiani, P. Milenovic [29], F. Moortgat, P. Nef, F. Nessi-Tedaldi, L. Pape, F. Pauss, T. Punz, A. Rizzi, F.J. Ronga, M. Rossini, L. Sala, A.K. Sanchez, M.-C. Sawley, B. Stieger, L. Tauscher [†], A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, M. Weber, L. Wehrli, J. Weng

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

E. Aguiló, C. Amsler, V. Chiochia, S. De Visscher, C. Favaro, M. Ivova Rikova, B. Millan Mejias, C. Regenfus, P. Robmann, A. Schmidt, H. Snoek

Universität Zürich, Zurich, Switzerland

Y.H. Chang, K.H. Chen, W.T. Chen, S. Dutta, A. Go, C.M. Kuo, S.W. Li, W. Lin, M.H. Liu, Z.K. Liu, Y.J. Lu, D. Mekterovic, J.H. Wu, S.S. Yu

National Central University, Chung-Li, Taiwan

P. Bartalini, P. Chang, Y.H. Chang, Y.W. Chang, Y. Chao, K.F. Chen, W.-S. Hou, Y. Hsiung, K.Y. Kao, Y.J. Lei, R.-S. Lu, J.G. Shiu, Y.M. Tzeng, M. Wang

National Taiwan University (NTU), Taipei, Taiwan

A. Adiguzel, M.N. Bakirci [30], S. Cerci [31], Z. Demir, C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, Y. Guler, E. Gurpinar, I. Hos, E.E. Kangal, T. Karaman, A. Kayis Topaksu, A. Nart, G. Onengut, K. Ozdemir, S. Ozturk, A. Polatoz, K. Sogut [32], B. Tali, H. Topakli [30], D. Uzun, L.N. Vergili, M. Vergili, C. Zorbilmez

Cukurova University, Adana, Turkey

I.V. Akin, T. Aliev, S. Bilmis, M. Deniz, H. Gamsizkan, A.M. Guler, K. Ocalan, A. Ozpineci, M. Serin, R. Sever, U.E. Surat, E. Yildirim, M. Zeyrek

Middle East Technical University, Physics Department, Ankara, Turkey

M. Deliomeroglu, D. Demir [33], E. Gülmez, A. Halu, B. Isildak, M. Kaya [34], O. Kaya [34], S. Ozkorucuklu [35], N. Sonmez [36]

Bogazici University, Istanbul, Turkey

L. Levchuk

National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine

P. Bell, F. Bostock, J.J. Brooke, T.L. Cheng, E. Clement, D. Cussans, R. Frazier, J. Goldstein, M. Grimes, M. Hansen, D. Hartley, G.P. Heath, H.F. Heath, B. Huckvale, J. Jackson, L. Kreczko, S. Metson, D.M. Newbold [37], K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, S. Ward

University of Bristol, Bristol, United Kingdom

L. Basso, K.W. Bell, A. Belyaev, C. Brew, R.M. Brown, B. Camanzi, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, B.W. Kennedy, E. Olaiya, D. Petyt, B.C. Radburn-Smith, C.H. Shepherd-Themistocleous, I.R. Tomalin, W.J. Womersley, S.D. Worm

Rutherford Appleton Laboratory, Didcot, United Kingdom

R. Bainbridge, G. Ball, J. Ballin, R. Beuselinck, O. Buchmuller, D. Colling, N. Cripps, M. Cutajar, G. Davies, M. Della Negra, J. Fulcher, D. Futyan, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, G. Karapostoli, L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko [27], A. Papageorgiou, M. Pesaresi, K. Petridis, M. Pioppi [38], D.M. Raymond, N. Rompotis, A. Rose, M.J. Ryan, C. Seez, P. Sharp, A. Sparrow, A. Tapper, S. Tourneur, M. Vazquez Acosta, T. Virdee, S. Wakefield, D. Wardrope, T. Whyntie

Imperial College, London, United Kingdom

M. Barrett, M. Chadwick, J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, D. Leslie, W. Martin, I.D. Reid, L. Teodorescu

Brunel University, Uxbridge, United Kingdom

K. Hatakeyama

Baylor University, Waco, USA

T. Bose, E. Carrera Jarrin, C. Fantasia, A. Heister, J.St. John, P. Lawson, D. Lazic, J. Rohlf, D. Sperka, L. Sulak

Boston University, Boston, USA

A. Avetisyan, S. Bhattacharya, J.P. Chou, D. Cutts, A. Ferapontov, U. Heintz, S. Jabeen, G. Kukartsev, G. Landsberg, M. Narain, D. Nguyen, M. Segala, T. Speer, K.V. Tsang

Brown University, Providence, USA

M.A. Borgia, R. Breedon, M. Calderon De La Barca Sanchez, D. Cebra, S. Chauhan, M. Chertok, J. Conway, P.T. Cox, J. Dolen, R. Erbacher, E. Friis, W. Ko, A. Kopecky, R. Lander, H. Liu, S. Maruyama, T. Miceli, M. Nikolic, D. Pellett, J. Robles, S. Salur, T. Schwarz, M. Searle, J. Smith, M. Squires, M. Tripathi, R. Vasquez Sierra, C. Veelken

University of California, Davis, Davis, USA

V. Andreev, K. Arisaka, D. Cline, R. Cousins, A. Deisher, J. Duris, S. Erhan, C. Farrell, J. Hauser, M. Ignatenko, C. Jarvis, C. Plager, G. Rakness, P. Schlein [†], J. Tucker, V. Valuev

University of California, Los Angeles, Los Angeles, USA

J. Babb, R. Clare, J. Ellison, J.W. Gary, F. Giordano, G. Hanson, G.Y. Jeng, S.C. Kao, F. Liu, H. Liu, A. Luthra, H. Nguyen, B.C. Shen [†], R. Stringer, J. Sturdy, S. Sumowidagdo, R. Wilken, S. Wimpenny

University of California, Riverside, Riverside, USA

W. Andrews, J.G. Branson, G.B. Cerati, E. Dusinberre, D. Evans, F. Golf, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, B. Mangano, J. Muelmenstaedt, S. Padhi, C. Palmer, G. Petrucciani, H. Pi, M. Pieri, R. Ranieri, M. Sani, V. Sharma [1], S. Simon, Y. Tu, A. Vartak, F. Würthwein, A. Yagil

University of California, San Diego, La Jolla, 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, J.R. Vlimant

University of California, Santa Barbara, Santa Barbara, USA

A. Bornheim, J. Bunn, Y. Chen, M. Gataullin, D. Kcira, V. Litvine, Y. Ma, A. Mott, H.B. Newman, C. Rogan, V. Timciuc, P. Traczyk, J. Veverka, R. Wilkinson, Y. Yang, R.Y. Zhu

California Institute of Technology, Pasadena, USA

B. Akgun, R. Carroll, T. Ferguson, Y. Iiyama, D.W. Jang, S.Y. Jun, Y.F. Liu, M. Paulini, J. Russ, N. Terentyev, H. Vogel, I. Vorobiev

Carnegie Mellon University, Pittsburgh, USA

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

University of Colorado at Boulder, Boulder, USA

L. Agostino, J. Alexander, A. Chatterjee, S. Das, N. Eggert, L.J. Fields, L.K. Gibbons, B. Heltsley, W. Hopkins, A. Khukhunaishvili, B. Kreis, V. Kuznetsov, G. Nicolas Kaufman, J.R. Patterson, D. Puigh, D. Riley, A. Ryd, X. Shi, W. Sun, W.D. Teo, J. Thom, J. Thompson, J. Vaughan, Y. Weng, L. Winstrom, P. Wittich

Cornell University, Ithaca, USA

A. Biselli, G. Cirino, D. Winn

Fairfield University, Fairfield, USA

S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, M. Atac, J.A. Bakken, S. Banerjee, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, I. Bloch, F. Borcherding, K. Burkett, J.N. Butler, V. Chetluru, H.W.K. Cheung, F. Chlebana, S. Cihangir, M. Demarteau, D.P. Eartly, V.D. Elvira, S. Esen, I. Fisk, J. Freeman, Y. Gao, E. Gottschalk, D. Green, K. Gunthoti, O. Gutsche, A. Hahn, J. Hanlon, R.M. Harris, J. Hirschauer, B. Hooberman, E. James, H. Jensen, M. Johnson, U. Joshi, R. Khatiwada, B. Kilminster, B. Klima, K. Kousouris, S. Kunori, S. Kwan, C. Leonidopoulos, P. Limon, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, D. Mason, P. McBride, T. McCauley, T. Miao, K. Mishra, S. Mrenna, Y. Musienko [39], C. Newman-Holmes, V. O'Dell, S. Popescu [40], R. Pordes, O. Prokofyev, N. Saoulidou, E. Sexton-Kennedy, S. Sharma, A. Soha, W.J. Spalding, L. Spiegel, P. Tan, L. Taylor, S. Tkaczyk, L. Uplegger, E.W. Vaandering, R. Vidal, J. Whitmore, W. Wu, F. Yang, F. Yumiceva, J.C. Yun

Fermi National Accelerator Laboratory, Batavia, USA

D. Acosta, P. Avery, D. Bourilkov, M. Chen, G.P. Di Giovanni, D. Dobur, A. Drozdetskiy, R.D. Field, M. Fisher, Y. Fu, I.K. Furic, J. Gartner, S. Goldberg, B. Kim, S. Klimenko, J. Konigsberg, A. Korytov, A. Kropivnitskaya, T. Kypreos, K. Matchev, G. Mitselmakher, L. Muniz, Y. Pakhotin, C. Prescott, R. Remington, M. Schmitt, B. Scurlock, P. Sellers, N. Skhirtladze, D. Wang, J. Yelton, M. Zakaria

University of Florida, Gainesville, USA

C. Ceron, V. Gaultney, L. Kramer, L.M. Lebolo, S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

Florida International University, Miami, USA

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

Florida State University, Tallahassee, USA

M.M. Baarmand, B. Dorney, S. Guragain, M. Hohlmann, H. Kalakhety, R. Ralich, I. Vodopiyanov

Florida Institute of Technology, Melbourne, USA

M.R. Adams, I.M. Anghel, L. Apanasevich, Y. Bai, V.E. Bazterra, R.R. Betts, J. Callner, R. Cavanaugh, C. Dragoiu, E.J. Garcia-Solis, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, F. Lacroix, M. Malek, C. O'Brien, C. Silvestre, A. Smoron, D. Strom, N. Varelas

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

U. Akgun, E.A. Albayrak, B. Bilki, K. Cankocak[41], W. Clarida, F. Duru, C.K. Lae, E. McCliment, J.-P. Merlo, H. Mermerkaya, A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, E. Norbeck, J. Olson, Y. Onel, F. Ozok, S. Sen, J. Wetzel, T. Yetkin, K. Yi

The University of Iowa, Iowa City, USA

B.A. Barnett, B. Blumenfeld, A. Bonato, C. Eskew, D. Fehling, G. Giurgiu, A.V. Gritsan, Z.J. Guo, G. Hu, P. Maksimovic, S. Rappoccio, M. Swartz, N.V. Tran, A. Whitbeck

Johns Hopkins University, Baltimore, USA

P. Baringer, A. Bean, G. Benelli, O. Grachov, M. Murray, D. Noonan, V. Radicci, S. Sanders, J.S. Wood, V. Zhukova

The University of Kansas, Lawrence, USA

T. Bolton, I. Chakaberia, A. Ivanov, M. Makouski, Y. Maravin, S. Shrestha, I. Svintradze, Z. Wan

Kansas State University, Manhattan, USA

J. Gronberg, D. Lange, D. Wright

Lawrence Livermore National Laboratory, Livermore, USA

A. Baden, M. Boutemeur, S.C. Eno, D. Ferencek, J.A. Gomez, N.J. Hadley, R.G. Kellogg, M. Kirn, Y. Lu, A.C. Mignerey, K. Rossato, P. Rumerio, F. Santanastasio, A. Skuja, J. Temple, M.B. Tonjes, S.C. Tonwar, E. Twedt

University of Maryland, College Park, USA

B. Alver, G. Bauer, J. Bendavid, W. Busza, E. Butz, I.A. Cali, M. Chan, V. Dutta, P. Everaerts, G. Gomez Ceballos, M. Goncharov, K.A. Hahn, P. Harris, Y. Kim, M. Klute, Y.-J. Lee, W. Li, C. Loizides, P.D. Luckey, T. Ma, S. Nahn, C. Paus, D. Ralph, C. Roland, G. Roland, M. Rudolph, G.S.F. Stephans, K. Sumorok, K. Sung, E.A. Wenger, S. Xie, M. Yang, Y. Yilmaz, A.S. Yoon, M. Zanetti

Massachusetts Institute of Technology, Cambridge, USA

P. Cole, S.I. Cooper, P. Cushman, B. Dahmes, A. De Benedetti, P.R. Dudero, G. Franzoni, J. Haupt, K. Klapoetke, Y. Kubota, J. Mans, V. Rekovic, R. Rusack, M. Sasseville, A. Singovsky

University of Minnesota, Minneapolis, USA

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

University of Mississippi, University, USA

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

University of Nebraska-Lincoln, Lincoln, USA

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

State University of New York at Buffalo, Buffalo, USA

G. Alverson, E. Barberis, D. Baumgartel, O. Boeriu, M. Chasco, S. Reucroft, J. Swain, D. Wood, J. Zhang

Northeastern University, Boston, USA

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

Northwestern University, Evanston, USA

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

University of Notre Dame, Notre Dame, USA

B. Bylsma, L.S. Durkin, J. Gu, C. Hill, P. Killewald, K. Kotov, T.Y. Ling, M. Rodenburg, G. Williams

The Ohio State University, Columbus, USA

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

Princeton University, Princeton, USA

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

University of Puerto Rico, Mayaguez, USA

E. Alagoz, V.E. Barnes, G. Bolla, L. Borrello, D. Bortoletto, A. Everett, A.F. Garfinkel, Z. Gecse, L. Gutay, Z. Hu, M. Jones, O. Koybasi, M. Kress, A.T. Laasanen, N. Leonardo, C. Liu, V. Maroussov, P. Merkel, D.H. Miller, N. Neumeister, I. Shipsey, D. Silvers, A. Svyatkovskiy, H.D. Yoo, J. Zablocki, Y. Zheng

Purdue University, West Lafayette, USA

P. Jindal, N. Parashar

Purdue University Calumet, Hammond, USA

C. Boulahouache, V. Cuplov, K.M. Ecklund, F.J.M. Geurts, J.H. Liu, B.P. Padley, R. Redjimi, J. Roberts, J. Zabel

Rice University, Houston, USA

B. Betchart, A. Bodek, Y.S. Chung, R. Covarelli, P. de Barbaro, R. Demina, Y. Eshaq, H. Flacher, A. Garcia-Bellido, P. Goldenzweig, Y. Gotra, J. Han, A. Harel, D.C. Miner, D. Orbaker, G. Petrillo, D. Vishnevskiy, M. Zielinski

University of Rochester, Rochester, USA

A. Bhatti, R. Ciesielski, L. Demortier, K. Goulianos, G. Lungu, C. Mesropian, M. Yan

The Rockefeller University, New York, USA

O. Atramentov, A. Barker, D. Duggan, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, D. Hits, A. Lath, S. Panwalkar, R. Patel, A. Richards, K. Rose, S. Schnetzer, S. Somalwar, R. Stone, S. Thomas

Rutgers, The State University of New Jersey, Piscataway, USA

G. Cerizza, M. Hollingsworth, S. Spanier, Z.C. Yang, A. York

University of Tennessee, Knoxville, USA

J. Asaadi, R. Eusebi, J. Gilmore, A. Gurrola, T. Kamon, V. Khotilovich, R. Montalvo, C.N. Nguyen, I. Osipenkov, J. Pivarski, A. Safonov, S. Sengupta, A. Tatarinov, D. Toback, M. Weinberger

Texas A&M University, College Station, USA

N. Akchurin, J. Damgov, C. Jeong, K. Kovitanggoon, S.W. Lee, Y. Roh, A. Sill, I. Volobouev, R. Wigmans, E. Yazgan

Texas Tech University, Lubbock, USA

E. Appelt, E. Brownson, D. Engh, C. Florez, W. Gabella, W. Johns, P. Kurt, C. Maguire, A. Melo, P. Sheldon, S. Tuo, J. Velkovska

Vanderbilt University, Nashville, USA

M.W. Arenton, M. Balazs, S. Boutle, M. Buehler, S. Conetti, B. Cox, B. Francis, R. Hirosky, A. Ledovskoy, C. Lin, C. Neu, R. Yohay

University of Virginia, Charlottesville, USA

S. Gollapinni, R. Harr, P.E. Karchin, P. Lamichhane, M. Mattson, C. Milstène, A. Sakharov

Wayne State University, Detroit, USA

M. Anderson, M. Bachtis, J.N. Bellinger, D. Carlsmith, S. Dasu, J. Efron, L. Gray, K.S. Grogg, M. Grothe, R. Hall-Wilton [1], M. Herndon, P. Klabbers, J. Klukas, A. Lanaro, C. Lazaridis, J. Leonard, R. Loveless, A. Mohapatra, D. Reeder, I. Ross, A. Savin, W.H. Smith, J. Swanson, M. Weinberg

University of Wisconsin, Madison, USA

* Corresponding author.
E-mail address: Roberto.Tenchini@cern.ch (R. Tenchini).

† Deceased.

1 Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.
2 Also at Universidade Federal do ABC, Santo Andre, Brazil.
3 Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3–CNRS, Palaiseau, France.
4 Also at British University, Cairo, Egypt.
5 Also at Soltan Institute for Nuclear Studies, Warsaw, Poland.
6 Also at Massachusetts Institute of Technology, Cambridge, USA.
7 Also at Université de Haute-Alsace, Mulhouse, France.
8 Also at Brandenburg University of Technology, Cottbus, Germany.
9 Also at Moscow State University, Moscow, Russia.
10 Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.
11 Also at Eötvös Loránd University, Budapest, Hungary.
12 Also at Tata Institute of Fundamental Research – HECR, Mumbai, India.
13 Also at University of Visva-Bharati, Santiniketan, India.
14 Also at Facoltà Ingegneria Università di Roma “La Sapienza”, Roma, Italy.
15 Also at Università della Basilicata, Potenza, Italy.
16 Also at Laboratori Nazionali di Legnaro dell’INFN, Legnaro, Italy.
17 Also at Università degli studi di Siena, Siena, Italy.
18 Also at California Institute of Technology, Pasadena, USA.
19 Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia.
20 Also at University of California, Los Angeles, Los Angeles, USA.
21 Also at University of Florida, Gainesville, USA.
22 Also at Université de Genève, Geneva, Switzerland.
23 Also at Scuola Normale e Sezione dell’INFN, Pisa, Italy.
24 Also at INFN Sezione di Roma; Università di Roma “La Sapienza”, Roma, Italy.

[25] Also at University of Athens, Athens, Greece.
[26] Also at The University of Kansas, Lawrence, USA.
[27] Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.
[28] Also at Paul Scherrer Institut, Villigen, Switzerland.
[29] Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.
[30] Also at Gaziosmanpasa University, Tokat, Turkey.
[31] Also at Adiyaman University, Adiyaman, Turkey.
[32] Also at Mersin University, Mersin, Turkey.
[33] Also at Izmir Institute of Technology, Izmir, Turkey.
[34] Also at Kafkas University, Kars, Turkey.
[35] Also at Suleyman Demirel University, Isparta, Turkey.
[36] Also at Ege University, Izmir, Turkey.
[37] Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.
[38] Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy.
[39] Also at Institute for Nuclear Research, Moscow, Russia.
[40] Also at Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania.
[41] Also at Istanbul Technical University, Istanbul, Turkey.