## Measurement of the absolute branching fractions $B \rightarrow D \pi, D^{*} \pi, D^{* *} \boldsymbol{\pi}$ with a missing mass method

B. Aubert, ${ }^{1}$ M. Bona, ${ }^{1}$ D. Boutigny, ${ }^{1}$ F. Couderc, ${ }^{1}$ Y. Karyotakis, ${ }^{1}$ J. P. Lees, ${ }^{1}$ V. Poireau, ${ }^{1}$ V. Tisserand, ${ }^{1}$ A. Zghiche, ${ }^{1}$ E. Grauges, ${ }^{2}$ A. Palano, ${ }^{3}$ J. C. Chen, ${ }^{4}$ N. D. Qi, ${ }^{4}$ G. Rong, ${ }^{4}$ P. Wang, ${ }^{4}$ Y. S. Zhu, ${ }^{4}$ G. Eigen, ${ }^{5}$ I. Ofte, ${ }^{5}$ B. Stugu, ${ }^{5}$ G. S. Abrams, ${ }^{6}$ M. Battaglia, ${ }^{6}$ D. N. Brown, ${ }^{6}$ J. Button-Shafer, ${ }^{6}$ R. N. Cahn, ${ }^{6}$ E. Charles, ${ }^{6}$ M. S. Gill, ${ }^{6}$ Y. Groysman, ${ }^{6}$ R. G. Jacobsen, ${ }^{6}$ J. A. Kadyk, ${ }^{6}$ L. T. Kerth, ${ }^{6}$ Yu. G. Kolomensky, ${ }^{6}$ G. Kukartsev, ${ }^{6}$ G. Lynch, ${ }^{6}$ L. M. Mir, ${ }^{6}$ T. J. Orimoto, ${ }^{6}$ M. Pripstein, ${ }^{6}$ N. A. Roe,,${ }^{6}$ M. T. Ronan, ${ }^{6}$ W. A. Wenzel, ${ }^{6}$ P. del Amo Sanchez, ${ }^{7}$ M. Barrett, ${ }^{7}$ K. E. Ford, ${ }^{7}$ T. J. Harrison, ${ }^{7}$ A. J. Hart, ${ }^{7}$ C. M. Hawkes, ${ }^{7}$ A. T. Watson, ${ }^{7}$ T. Held, ${ }^{8}$ H. Koch, ${ }^{8}$ B. Lewandowski, ${ }^{8}$ M. Pelizaeus, ${ }^{8}$ K. Peters, ${ }^{8}$ T. Schroeder, ${ }^{8}$ M. Steinke, ${ }^{8}$ J. T. Boyd, ${ }^{9}$ J. P. Burke, ${ }^{9}$ W. N. Cottingham, ${ }^{9}$ D. Walker, ${ }^{9}$ D. J. Asgeirsson, ${ }^{10}$ T. Cuhadar-Donszelmann, ${ }^{10}$ B. G. Fulsom,,${ }^{10}$ C. Hearty, ${ }^{10}$ N.S. Knecht, ${ }^{10}$ T. S. Mattison, ${ }^{10}$ J. A. McKenna, ${ }^{10}$ A. Khan, ${ }^{11}$ P. Kyberd, ${ }^{11}$ M. Saleem, ${ }^{11}$ D. J. Sherwood, ${ }^{11}$ L. Teodorescu, ${ }^{11}$ V. E. Blinov, ${ }^{12}$ A. D. Bukin, ${ }^{12}$ V. P. Druzhinin, ${ }^{12}$ V. B. Golubev, ${ }^{12}$ A. P. Onuchin, ${ }^{12}$ S. I. Serednyakov, ${ }^{12}$ Yu. I. Skovpen, ${ }^{12}$ E. P. Solodov, ${ }^{12}$ K. Yu Todyshev, ${ }^{12}$ M. Bondioli, ${ }^{13}$ M. Bruinsma, ${ }^{13}$ M. Chao, ${ }^{13}$ S. Curry, ${ }^{13}$ I. Eschrich, ${ }^{13}$ D. Kirkby, ${ }^{13}$ A. J. Lankford, ${ }^{13}$ P. Lund, ${ }^{13}$ M. Mandelkern, ${ }^{13}$ R. K. Mommsen, ${ }^{13}$ W. Roethel, ${ }^{13}$ D. P. Stoker, ${ }^{13}$ S. Abachi, ${ }^{14}$ C. Buchanan, ${ }^{14}$ S. D. Foulkes, ${ }^{15}$ J. W. Gary, ${ }^{15}$ O. Long, ${ }^{15}$ B. C. Shen, ${ }^{15}$ K. Wang, ${ }^{15}$ L. Zhang, ${ }^{15}$ H. K. Hadavand, ${ }^{16}$ E. J. Hill, ${ }^{16}$ H. P. Paar, ${ }^{16}$ S. Rahatlou, ${ }^{16}$ V. Sharma, ${ }^{16}$ J. W. Berryhill, ${ }^{17}$ C. Campagnari, ${ }^{17}$ A. Cunha, ${ }^{17}$ B. Dahmes,,$^{17}$ T. M. Hong, ${ }^{17}$ D. Kovalskyi, ${ }^{17}$ J. D. Richman, ${ }^{17}$ T. W. Beck, ${ }^{18}$ A. M. Eisner, ${ }^{18}$ C. J. Flacco, ${ }^{18}$ C. A. Heusch, ${ }^{18}$ J. Kroseberg,,$^{18}$ W. S. Lockman, ${ }^{18}$ G. Nesom, ${ }^{18}$ T. Schalk, ${ }^{18}$ B. A. Schumm, ${ }^{18}$ A. Seiden, ${ }^{18}$ P. Spradlin, ${ }^{18}$ D. C. Williams, ${ }^{18}$ M. G. Wilson, ${ }^{18}$ J. Albert, ${ }^{19}$ E. Chen, ${ }^{19}$ A. Dvoretskii, ${ }^{19}$ F. Fang, ${ }^{19}$ D. G. Hitlin, ${ }^{19}$ I. Narsky, ${ }^{19}$ T. Piatenko, ${ }^{19}$ F. C. Porter, ${ }^{19}$
A. Ryd, ${ }^{19}$ G. Mancinelli, ${ }^{20}$ B. T. Meadows,,${ }^{20}$ K. Mishra, ${ }^{20}$ M.D. Sokoloff, ${ }^{20}$ F. Blanc, ${ }^{21}$ P. C. Bloom, ${ }^{21}$ S. Chen, ${ }^{21}$ W.T. Ford, ${ }^{21}$ J.F. Hirschauer, ${ }^{21}$ A. Kreisel, ${ }^{21}$ M. Nagel, ${ }^{21}$ U. Nauenberg, ${ }^{21}$ A. Olivas, ${ }^{21}$ W. O. Ruddick, ${ }^{21}$ J. G. Smith, ${ }^{21}$ K. A. Ulmer, ${ }^{21}$ S.R. Wagner, ${ }^{21}$ J. Zhang, ${ }^{21}$ A. Chen, ${ }^{22}$ E. A. Eckhart, ${ }^{22}$ A. Soffer, ${ }^{22}$ W. H. Toki, ${ }^{22}$ R. J. Wilson, ${ }^{22}$ F. Winklmeier, ${ }^{22}$ Q. Zeng, ${ }^{22}$ D. D. Altenburg, ${ }^{23}$ E. Feltresi, ${ }^{23}$ A. Hauke, ${ }^{23}$ H. Jasper, ${ }^{23}$ J. Merkel, ${ }^{23}$ A. Petzold, ${ }^{23}$ B. Spaan,,$^{23}$ T. Brandt, ${ }^{24}$ V. Klose, ${ }^{24}$ H. M. Lacker, ${ }^{24}$ W.F. Mader, ${ }^{24}$ R. Nogowski, ${ }^{24}$ J. Schubert,,${ }^{24}$ K. R. Schubert,,${ }^{24}$ R. Schwierz, ${ }^{24}$ J. E. Sundermann, ${ }^{24}$ A. Volk,,${ }^{24}$ D. Bernard, ${ }^{25}$ G. R. Bonneaud, ${ }^{25}$ E. Latour, ${ }^{25}$ Ch. Thiebaux,,${ }^{25}$ M. Verderi, ${ }^{25}$ P. J. Clark,,${ }^{26}$ W. Gradl, ${ }^{26}$ F. Muheim, ${ }^{26}$ S. Playfer,,${ }^{26}$ A. I. Robertson, ${ }^{26}$ Y. Xie, ${ }^{26}$ M. Andreotti, ${ }^{27}$ D. Bettoni, ${ }^{27}$ C. Bozzi, ${ }^{27}$ R. Calabrese, ${ }^{27}$ G. Cibinetto, ${ }^{27}$ E. Luppi, ${ }^{27}$ M. Negrini, ${ }^{27}$ A. Petrella, ${ }^{27}$ L. Piemontese, ${ }^{27}$ E. Prencipe, ${ }^{27}$ F. Anulli, ${ }^{28}$ R. Baldini-Ferroli, ${ }^{28}$ A. Calcaterra, ${ }^{28}$ R. de Sangro, ${ }^{28}$ G. Finocchiaro, ${ }^{28}$ S. Pacetti, ${ }^{28}$ P. Patteri, ${ }^{28}$ I. M. Peruzzi,,${ }^{28, *}$ M. Piccolo, ${ }^{28}$ M. Rama, ${ }^{28}$ A. Zallo, ${ }^{28}$ A. Buzzo, ${ }^{29}$ R. Contri, ${ }^{29}$ M. Lo Vetere, ${ }^{29}$ M. M. Macri, ${ }^{29}$ M. R. Monge, ${ }^{29}$ S. Passaggio, ${ }^{29}$ C. Patrignani, ${ }^{29}$ E. Robutti, ${ }^{29}$ A. Santroni, ${ }^{29}$ S. Tosi, ${ }^{29}$ G. Brandenburg ${ }^{30}$ K. S. Chaisanguanthum, ${ }^{30}$ M. Morii, ${ }^{30}$ J. Wu, ${ }^{30}$ R.S. Dubitzky, ${ }^{31}$ J. Marks, ${ }^{31}$ S. Schenk, ${ }^{31}$ U. Uwer, ${ }^{31}$ D. J. Bard, ${ }^{32}$ W. Bhimji, ${ }^{32}$ D. A. Bowerman, ${ }^{32}$ P.D. Dauncey, ${ }^{32}$ U. Egede, ${ }^{32}$ R.L. Flack, ${ }^{32}$ J. A. Nash, ${ }^{32}$ M. B. Nikolich, ${ }^{32}$ W. Panduro Vazquez, ${ }^{32}$ P. K. Behera, ${ }^{33}$ X. Chai, ${ }^{33}$ M. J. Charles, ${ }^{33}$ U. Mallik, ${ }^{33}$ N. T. Meyer, ${ }^{33}$ V. Ziegler, ${ }^{33}$ J. Cochran, ${ }^{34}$ H. B. Crawley, ${ }^{34}$ L. Dong, ${ }^{34}$ V. Eyges, ${ }^{34}$ W. T. Meyer, ${ }^{34}$ S. Prell,,${ }^{34}$ E. I. Rosenberg, ${ }^{34}$ A.E. Rubin, ${ }^{34}$ A. V. Gritsan, ${ }^{35}$ A. G. Denig, ${ }^{36}$ M. Fritsch, ${ }^{36}$ G. Schott, ${ }^{36}$ N. Arnaud, ${ }^{37}$ M. Davier, ${ }^{37}$ G. Grosdidier ${ }^{37}{ }^{37}$ A. Höcker, ${ }^{37}$ F. Le Diberder, ${ }^{37}$ V. Lepeltier, ${ }^{37}$ A. M. Lutz,${ }^{37}$ A. Oyanguren, ${ }^{37}$ S. Pruvot, ${ }^{37}$ S. Rodier, ${ }^{37}$ P. Roudeau, ${ }^{37}$ M. H. Schune, ${ }^{37}$ A. Stocchi, ${ }^{37}$ W. F. Wang, ${ }^{37}$ G. Wormser, ${ }^{37}$ C. H. Cheng, ${ }^{38}$ D. J. Lange, ${ }^{38}$ D. M. Wright, ${ }^{38}$ C. A. Chavez, ${ }^{39}$ I. J. Forster, ${ }^{39}$ J. R. Fry, ${ }^{39}$ E. Gabathuler, ${ }^{39}$ R. Gamet,,${ }^{39}$ K. A. George, ${ }^{39}$ D. E. Hutchcroft, ${ }^{39}$ D. J. Payne, ${ }^{39}$ K. C. Schofield, ${ }^{39}$ C. Touramanis, ${ }^{39}$ A. J. Bevan,,${ }^{40}$ F. Di Lodovico, ${ }^{40}$ W. Menges, ${ }^{40}$ R. Sacco, ${ }^{40}$ G. Cowan, ${ }^{41}$ H. U. Flaecher, ${ }^{41}$ D. A. Hopkins, ${ }^{41}$ P.S. Jackson, ${ }^{41}$ T. R. McMahon, ${ }^{41}$ S. Ricciardi, ${ }^{4}$ F. Salvatore, ${ }^{41}$ A. C. Wren, ${ }^{41}$ D. N. Brown, ${ }^{42}$ C.L. Davis, ${ }^{42}$ J. Allison, ${ }^{43}$ N. R. Barlow, ${ }^{43}$ R. J. Barlow, ${ }^{43}$ Y. M. Chia, ${ }^{43}$ C. L. Edgar, ${ }^{43}$ G.D. Lafferty, ${ }^{43}$ M. T. Naisbit, ${ }^{43}$ J. C. Williams, ${ }^{43}$ J. I. Yi, ${ }^{43}$ C. Chen, ${ }^{44}$ W. D. Hulsbergen, ${ }^{44}$ A. Jawahery, ${ }^{44}$ C. K. Lae, ${ }^{44}$ D. A. Roberts, ${ }^{44}$ G. Simi, ${ }^{44}$ G. Blaylock,,${ }^{45}$ C. Dallapiccola, ${ }^{45}$ S. S. Hertzbach,,${ }^{45}$ X. Li, ${ }^{45}$ T. B. Moore,,${ }^{45}$ S. Saremi, ${ }^{45}$ H. Staengle, ${ }^{45}$ R. Cowan, ${ }^{46}$ G. Sciolla, ${ }^{46}$ S. J. Sekula, ${ }^{46}$ M. Spitznagel, ${ }^{46}$ F. Taylor, ${ }^{46}$ R. K. Yamamoto, ${ }^{46}$ H. Kim, ${ }^{47}$ S. E. Mclachlin, ${ }^{47}$ P. M. Patel,,${ }^{47}$ S. H. Robertson, ${ }^{47}$ A. Lazzaro,,${ }^{48}$ V. Lombardo, ${ }^{48}$ F. Palombo, ${ }^{48}$ J. M. Bauer, ${ }^{49}$ L. Cremaldi, ${ }^{49}$ V. Eschenburg, ${ }^{49}$ R. Godang, ${ }^{49}$ R. Kroeger, ${ }^{49}$ D. A. Sanders, ${ }^{49}$ D. J. Summers, ${ }^{49}$ H. W. Zhao, ${ }^{49}$ S. Brunet, ${ }^{50}$ D. Côté, ${ }^{50}$ M. Simard, ${ }^{50}$ P. Taras, ${ }^{50}$ F. B. Viaud, ${ }^{50}$ H. Nicholson, ${ }^{51}$ N. Cavallo, ${ }^{52, \dagger}$ G. De Nardo, ${ }^{52}$ F. Fabozzi, ${ }^{52, \dagger}$ C. Gatto, ${ }^{52}$ L. Lista, ${ }^{52}$ D. Monorchio,,${ }^{52}$ P. Paolucci, ${ }^{52}$ D. Piccolo, ${ }^{52}$ C. Sciacca,,${ }^{52}$ M. A. Baak, ${ }^{53}$ G. Raven, ${ }^{53}$ H. L. Snoek, ${ }^{53}$ C. P. Jessop,,${ }^{54}$ J. M. LoSecco, ${ }^{54}$ T. Allmendinger, ${ }^{55}$ G. Benelli, ${ }^{55}$ L. A. Corwin, ${ }^{55}$ K. K. Gan, ${ }^{55}$ K. Honscheid, ${ }^{55}$ D. Hufnagel, ${ }^{55}$ P.D. Jackson, ${ }^{55}$ H. Kagan, ${ }^{55}$ R. Kass, ${ }^{55}$ A. M. Rahimi, ${ }^{55}$ J. J. Regensburger, ${ }^{55}$ R. Ter-Antonyan, ${ }^{55}$ Q. K. Wong, ${ }^{55}$ N. L. Blount, ${ }^{56}$ J. Brau, ${ }^{56}$ R. Frey, ${ }^{56}$ O. Igonkina, ${ }^{56}$ J. A. Kolb, ${ }^{56}$ M. Lu, ${ }^{56}$ R. Rahmat, ${ }^{56}$ N. B. Sinev, ${ }^{56}$ D. Strom, ${ }^{56}$ J. Strube, ${ }^{56}$ E. Torrence, ${ }^{56}$ A. Gaz,,${ }^{57}$ M. Margoni, ${ }^{57}$ M. Morandin, ${ }^{57}$ A. Pompili, ${ }^{57}$ M. Posocco, ${ }^{57}$
M. Rotondo, ${ }^{57}$ F. Simonetto, ${ }^{57}$ R. Stroili, ${ }^{57}$ C. Voci,,${ }^{57}$ M. Benayoun, ${ }^{58}$ H. Briand,,${ }^{58}$ J. Chauveau, ${ }^{58}$ P. David,,${ }^{58}$ L. Del Buono, ${ }^{58}$ Ch. de la Vaissière, ${ }^{58}$ O. Hamon, ${ }^{58}$ B. L. Hartfiel, ${ }^{58}$ Ph. Leruste, ${ }^{58}$ J. Malclès, ${ }^{58}$ J. Ocariz, ${ }^{58}$ L. Roos,,${ }^{58}$ G. Therin, ${ }^{58}$ L. Gladney, ${ }^{59}$ M. Biasini, ${ }^{60}$ R. Covarelli, ${ }^{60}$ C. Angelini, ${ }^{61}$ G. Batignani, ${ }^{61}$ S. Bettarini, ${ }^{61}$ F. Bucci, ${ }^{61}$ G. Calderini, ${ }^{61}$ M. Carpinelli, ${ }^{61}$ R. Cenci, ${ }^{61}$ F. Forti, ${ }^{61}$ M. A. Giorgi, ${ }^{61}$ A. Lusiani, ${ }^{61}$ G. Marchiori, ${ }^{61}$ M. A. Mazur, ${ }^{61}$ M. Morganti,,${ }^{61}$ N. Neri, ${ }^{61}$ E. Paoloni, ${ }^{61}$ G. Rizzo, ${ }^{61}$ J. J. Walsh, ${ }^{61}$ M. Haire, ${ }^{62}$ D. Judd, ${ }^{62}$ D. E. Wagoner, ${ }^{62}$ J. Biesiada, ${ }^{63}$ N. Danielson,,${ }^{63}$ P. Elmer, ${ }^{63}$ Y. P. Lau, ${ }^{63}$ C. Lu, ${ }^{63}$ J. Olsen, ${ }^{63}$ A. J.S. Smith, ${ }^{63}$ A. V. Telnov,,${ }^{63}$ F. Bellini, ${ }^{64}$ G. Cavoto, ${ }^{64}$ A. D’Orazio, ${ }^{64}$ D. del Re, ${ }^{64}$ E. Di Marco, ${ }^{64}$ R. Faccini, ${ }^{64}$ F. Ferrarotto, ${ }^{64}$ F. Ferroni, ${ }^{64}$ M. Gaspero, ${ }^{64}$ L. Li Gioi, ${ }^{64}$ M. A. Mazzoni, ${ }^{64}$ S. Morganti, ${ }^{64}$ G. Piredda, ${ }^{64}$ F. Polci, ${ }^{64}$ F. Safai Tehrani, ${ }^{64}$ C. Voena, ${ }^{64}$ M. Ebert, ${ }^{65}$ H. Schröder, ${ }^{65}$ R. Waldi, ${ }^{65}$ T. Adye, ${ }^{66}$ N. De Groot, ${ }^{66}$ B. Franek, ${ }^{66}$ E. O. Olaiya, ${ }^{66}$ F. F. Wilson, ${ }^{66}$ R. Aleksan, ${ }^{67}$ S. Emery, ${ }^{67}$ A. Gaidot, ${ }^{67}$ S. F. Ganzhur, ${ }^{67}$ G. Hamel de Monchenault, ${ }^{67}$ W. Kozanecki, ${ }^{67}$ M. Legendre, ${ }^{67}$ G. Vasseur,,${ }^{67}$ Ch. Yèche,,${ }^{67}$ M. Zito, ${ }^{67}$ X. R. Chen, ${ }^{68}$ H. Liu, ${ }^{68}$ W. Park, ${ }^{68}$ M. V. Purohit, ${ }^{68}$ J. R. Wilson, ${ }^{68}$ M. T. Allen, ${ }^{69}$ D. Aston, ${ }^{69}$ R. Bartoldus, ${ }^{69}$ P. Bechtle, ${ }^{69}$ N. Berger, ${ }^{69}$ R. Claus, ${ }^{69}$ J.P. Coleman, ${ }^{69}$ M. R. Convery, ${ }^{69}$ M. Cristinziani, ${ }^{69}$ J. C. Dingfelder, ${ }^{69}$ J. Dorfan, ${ }^{69}$ G.P. Dubois-Felsmann, ${ }^{69}$ D. Dujmic, ${ }^{69}$ W. Dunwoodie, ${ }^{69}$ R.C. Field, ${ }^{69}$ T. Glanzman, ${ }^{69}$ S. J. Gowdy, ${ }^{69}$ M. T. Graham, ${ }^{69}$ P. Grenier, ${ }^{69}$ V. Halyo, ${ }^{69}$ C. Hast, ${ }^{69}$ T. Hryn'ova, ${ }^{69}$ W. R. Innes, ${ }^{69}$ M. H. Kelsey, ${ }^{69}$ P. Kim, ${ }^{69}$ D. W. G. S. Leith, ${ }^{69}$ S. Li, ${ }^{69}$ S. Luitz, ${ }^{69}$ V. Luth,,${ }^{69}$ H.L. Lynch, ${ }^{69}$ D. B. MacFarlane, ${ }^{69}$ H. Marsiske, ${ }^{69}$ R. Messner, ${ }^{69}$ D. R. Muller, ${ }^{69}$ C.P. O'Grady, ${ }^{69}$ V.E. Ozcan, ${ }^{69}$ A. Perazzo, ${ }^{69}$ M. Perl, ${ }^{69}$ T. Pulliam, ${ }^{69}$ B. N. Ratcliff, ${ }^{69}$ A. Roodman, ${ }^{69}$ A. A. Salnikov, ${ }^{69}$ R. H. Schindler, ${ }^{69}$ J. Schwiening, ${ }^{69}$ A. Snyder, ${ }^{69}$ J. Stelzer, ${ }^{69}$ D. Su, ${ }^{69}$ M. K. Sullivan, ${ }^{69}$ K. Suzuki, ${ }^{69}$ S. K. Swain, ${ }^{69}$ J. M. Thompson, ${ }^{69}$ J. Va'vra, ${ }^{69}$ N. van Bakel, ${ }^{69}$ M. Weaver, ${ }^{69}$ A.J.R. Weinstein, ${ }^{69}$ W. J. Wisniewski, ${ }^{69}$ M. Wittgen, ${ }^{69}$ D. H. Wright, ${ }^{69}$ A. K. Yarritu, ${ }^{69}$ K. Yi, ${ }^{69}$ C. C. Young, ${ }^{69}$ P. R. Burchat, ${ }^{70}$ A. J. Edwards, ${ }^{70}$ S. A. Majewski, ${ }^{70}$ B. A. Petersen, ${ }^{70}$ C. Roat, ${ }^{70}$ L. Wilden, ${ }^{70}$ S. Ahmed, ${ }^{71}$ M. S. Alam, ${ }^{71}$ R. Bula, ${ }^{71}$ J. A. Ernst, ${ }^{71}$ V. Jain, ${ }^{71}$ B. Pan, ${ }^{71}$ M. A. Saeed, ${ }^{71}$ F. R. Wappler, ${ }^{71}$ S.B. Zain, ${ }^{71}$ W. Bugg, ${ }^{72}$ M. Krishnamurthy, ${ }^{72}$ S. M. Spanier, ${ }^{72}$ R. Eckmann, ${ }^{73}$ J. L. Ritchie, ${ }^{73}$ A. Satpathy, ${ }^{73}$ C. J. Schilling, ${ }^{73}$ R.F. Schwitters, ${ }^{73}$ J. M. Izen, ${ }^{74}$ X. C. Lou, ${ }^{74}$ S. Ye, ${ }^{74}$ F. Bianchi, ${ }^{75}$ F. Gallo, ${ }^{75}$ D. Gamba, ${ }^{75}$ M. Bomben, ${ }^{76}$ L. Bosisio, ${ }^{76}$ C. Cartaro, ${ }^{76}$ F. Cossutti, ${ }^{77}$ G. Della Ricca, ${ }^{76}$ S. Dittongo, ${ }^{76}$ L. Lanceri, ${ }^{76}$ L. Vitale, ${ }^{76}$ V. Azzolini, ${ }^{77}$ N. Lopez-March, ${ }^{77}$ F. Martinez-Vidal, ${ }^{77}$ Sw. Banerjee, ${ }^{78}$ B. Bhuyan, ${ }^{78}$ C. M. Brown, ${ }^{78}$ D. Fortin, ${ }^{78}$ K. Hamano, ${ }^{78}$ R. Kowalewski, ${ }^{78}$ I. M. Nugent, ${ }^{78}$ J. M. Roney ${ }^{78}$ R. J. Sobie,,${ }^{78}$ J. J. Back, ${ }^{79}$ P. F. Harrison, ${ }^{79}$ T.E. Latham, ${ }^{79}$ G. B. Mohanty, ${ }^{79}$ M. Pappagallo, ${ }^{79}$ H. R. Band, ${ }^{80}$ X. Chen, ${ }^{80}$ B. Cheng, ${ }^{80}$ S. Dasu, ${ }^{80}$ M. Datta, ${ }^{80}$ K. T. Flood, ${ }^{80}$ J. J. Hollar, ${ }^{80}$ P.E. Kutter, ${ }^{80}$ B. Mellado, ${ }^{80}$ A. Mihalyi, ${ }^{80}$ Y. Pan, ${ }^{80}$ M. Pierini, ${ }^{80}$ R. Prepost, ${ }^{80}$ S. L. Wu, ${ }^{80}$ Z. $\mathrm{Yu},{ }^{80}$ and H. Neal ${ }^{81}$
(BABAR Collaboration)
${ }^{1}$ Laboratoire de Physique des Particules, IN2P3/CNRS et Université de Savoie, F-74941 Annecy-Le-Vieux, France
${ }^{2}$ Universitat de Barcelona, Facultat de Fisica, Departament ECM, E-08028 Barcelona, Spain
${ }^{3}$ Università di Bari, Dipartimento di Fisica and INFN, I-70126 Bari, Italy ${ }^{4}$ Institute of High Energy Physics, Beijing 100039, China
${ }^{5}$ University of Bergen, Institute of Physics, N-5007 Bergen, Norway
${ }^{6}$ Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720, USA
${ }^{7}$ University of Birmingham, Birmingham, B15 2TT, United Kingdom
${ }^{8}$ Ruhr Universität Bochum, Institut für Experimentalphysik 1, D-44780 Bochum, Germany
${ }^{9}$ University of Bristol, Bristol BS8 1TL, United Kingdom
${ }^{10}$ University of British Columbia, Vancouver, British Columbia, Canada V6T $1 Z 1$
${ }^{11}$ Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom
${ }^{12}$ Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia
${ }^{13}$ University of California at Irvine, Irvine, California 92697, USA
${ }^{14}$ University of California at Los Angeles, Los Angeles, California 90024, USA
${ }^{15}$ University of California at Riverside, Riverside, California 92521, USA
${ }^{16}$ University of California at San Diego, La Jolla, California 92093, USA
${ }^{17}$ University of California at Santa Barbara, Santa Barbara, California 93106, USA
${ }^{18}$ University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, California 95064, USA
${ }^{19}$ California Institute of Technology, Pasadena, California 91125, USA
${ }^{20}$ University of Cincinnati, Cincinnati, Ohio 45221, USA
${ }^{21}$ University of Colorado, Boulder, Colorado 80309, USA
${ }^{22}$ Colorado State University, Fort Collins, Colorado 80523, USA
${ }^{23}$ Universität Dortmund, Institut für Physik, D-44221 Dortmund, Germany
${ }^{24}$ Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany

${ }^{25}$ Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, F-91128 Palaiseau, France<br>${ }^{26}$ University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom<br>${ }^{27}$ Università di Ferrara, Dipartimento di Fisica and INFN, I-44100 Ferrara, Italy<br>${ }^{28}$ Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy<br>${ }^{29}$ Università di Genova, Dipartimento di Fisica and INFN, I-16146 Genova, Italy<br>${ }^{30}$ Harvard University, Cambridge, Massachusetts 02138, USA<br>${ }^{31}$ Universität Heidelberg, Physikalisches Institut, Philosophenweg 12, D-69120 Heidelberg, Germany<br>${ }^{32}$ Imperial College London, London, SW7 2AZ, United Kingdom<br>${ }^{33}$ University of Iowa, Iowa City, Iowa 52242, USA<br>${ }^{34}$ Iowa State University, Ames, Iowa 50011-3160, USA<br>${ }^{35}$ Johns Hopkins University, Baltimore, Maryland 21218, USA<br>${ }^{36}$ Universität Karlsruhe, Institut für Experimentelle Kernphysik, D-76021 Karlsruhe, Germany<br>${ }^{37}$ Laboratoire de l'Accélérateur Linéaire, IN2P3/CNRS et Université Paris-Sud 11,<br>Centre Scientifique d'Orsay, B.P. 34, F-91898 ORSAY Cedex, France<br>${ }^{38}$ Lawrence Livermore National Laboratory, Livermore, California 94550, USA<br>${ }^{39}$ University of Liverpool, Liverpool L69 7ZE, United Kingdom<br>${ }^{40}$ Queen Mary, University of London, E1 4NS, United Kingdom<br>${ }^{41}$ University of London, Royal Holloway and Bedford New College, Egham, Surrey TW20 0EX, United Kingdom<br>${ }^{42}$ University of Louisville, Louisville, Kentucky 40292, USA<br>${ }^{43}$ University of Manchester, Manchester M13 9PL, United Kingdom<br>${ }^{44}$ University of Maryland, College Park, Maryland 20742, USA<br>${ }^{45}$ University of Massachusetts, Amherst, Massachusetts 01003, USA<br>${ }^{46}$ Massachusetts Institute of Technology, Laboratory for Nuclear Science, Cambridge, Massachusetts 02139, USA<br>${ }^{47}$ McGill University, Montréal, Québec, Canada H3A $2 T 8$<br>${ }^{48}$ Università di Milano, Dipartimento di Fisica and INFN, I-20133 Milano, Italy<br>${ }^{49}$ University of Mississippi, University, Mississippi 38677, USA<br>${ }^{50}$ Université de Montréal, Physique des Particules, Montréal, Québec, Canada H3C 3J7<br>${ }^{51}$ Mount Holyoke College, South Hadley, Massachusetts 01075, USA<br>${ }^{52}$ Università di Napoli Federico II, Dipartimento di Scienze Fisiche and INFN, I-80126, Napoli, Italy<br>${ }^{53}$ NIKHEF, National Institute for Nuclear Physics and High Energy Physics, NL-1009 DB Amsterdam, The Netherlands<br>${ }^{54}$ University of Notre Dame, Notre Dame, Indiana 46556, USA<br>${ }^{55}$ Ohio State University, Columbus, Ohio 43210, USA<br>${ }^{56}$ University of Oregon, Eugene, Oregon 97403, USA<br>${ }^{57}$ Università di Padova, Dipartimento di Fisica and INFN, I-35131 Padova, Italy<br>${ }^{58}$ Laboratoire de Physique Nucléaire et de Hautes Energies, IN2P3/CNRS, Université Pierre et Marie Curie-Paris6, Université Denis Diderot-Paris7, F-75252 Paris, France<br>${ }^{59}$ University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA<br>${ }^{60}$ Università di Perugia, Dipartimento di Fisica and INFN, I-06100 Perugia, Italy<br>${ }^{61}$ Università di Pisa, Dipartimento di Fisica, Scuola Normale Superiore and INFN, I-56127 Pisa, Italy<br>${ }^{62}$ Prairie View A\&M University, Prairie View, Texas 77446, USA<br>${ }^{63}$ Princeton University, Princeton, New Jersey 08544, USA<br>${ }^{64}$ Università di Roma La Sapienza, Dipartimento di Fisica and INFN, I-00185 Roma, Italy<br>${ }^{65}$ Universität Rostock, D-18051 Rostock, Germany<br>${ }^{66}$ Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingdom<br>${ }^{67}$ DSM/Dapnia, CEA/Saclay, F-91191 Gif-sur-Yvette, France<br>${ }^{68}$ University of South Carolina, Columbia, South Carolina 29208, USA<br>${ }^{69}$ Stanford Linear Accelerator Center, Stanford, California 94309, USA<br>${ }^{70}$ Stanford University, Stanford, California 94305-4060, USA<br>${ }^{71}$ State University of New York, Albany, New York 12222, USA<br>${ }^{72}$ University of Tennessee, Knoxville, Tennessee 37996, USA<br>${ }^{73}$ University of Texas at Austin, Austin, Texas 78712, USA<br>${ }^{74}$ University of Texas at Dallas, Richardson, Texas 75083, USA<br>${ }^{75}$ Università di Torino, Dipartimento di Fisica Sperimentale and INFN, I-10125 Torino, Italy<br>${ }^{76}$ Università di Trieste, Dipartimento di Fisica and INFN, I-34127 Trieste, Italy<br>${ }^{77}$ IFIC, Universitat de Valencia-CSIC, E-46071 Valencia, Spain<br>${ }^{78}$ University of Victoria, Victoria, British Columbia, Canada V8W 3P6<br>${ }^{79}$ Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom

[^0]${ }^{80}$ University of Wisconsin, Madison, Wisconsin 53706, USA<br>${ }^{81}$ Yale University, New Haven, Connecticut 06511, USA<br>(Received 20 September 2006; published 21 December 2006)


#### Abstract

We present branching fraction measurements of charged and neutral $B$ decays to $D \pi^{-}, D^{*} \pi^{-}$, and " $D^{* *}$ " $\pi^{-}$with a missing mass method, based on a sample of $231 \times 10^{6} \mathrm{Y}(4 S) \rightarrow B \bar{B}$ pairs collected by the BABAR detector at the PEP-II $e^{+} e^{-}$collider. One of the $B$ mesons is fully reconstructed and the other one decays to a reconstructed charged $\pi$ and a companion charmed meson identified by its recoil mass, inferred by kinematics. Here " $D^{* *}$ " refers to the sum of all the nonstrange charm meson states with masses in the range $2.2-2.8 \mathrm{GeV} / c^{2}$. We measure the branching fractions: $\mathcal{B}\left(B^{-} \rightarrow D^{0} \pi^{-}\right)=(4.49 \pm$ $0.21 \pm 0.23) \times 10^{-3}, \quad \mathcal{B}\left(B^{-} \rightarrow D^{* 0} \pi^{-}\right)=(5.13 \pm 0.22 \pm 0.28) \times 10^{-3}, \quad \mathcal{B}\left(B^{-} \rightarrow " D^{* * 0 "} \pi^{-}\right)=$ $(5.50 \pm 0.52 \pm 1.04) \times 10^{-3}, \quad \mathcal{B}\left(\bar{B}^{0} \rightarrow D^{+} \pi^{-}\right)=(3.03 \pm 0.23 \pm 0.23) \times 10^{-3}, \quad \mathcal{B}\left(\bar{B}^{0} \rightarrow D^{*+} \pi^{-}\right)=$ $(2.99 \pm 0.23 \pm 0.24) \times 10^{-3}, \mathcal{B}\left(\bar{B}^{0} \rightarrow " D^{* *+"} \pi^{-}\right)=(2.34 \pm 0.65 \pm 0.88) \times 10^{-3}$, and their ratios.

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Our understanding of hadronic $B$-meson decays has improved considerably during the past few years with the development of models based on the heavy quark effective theory (HQET), where collinear [1,2] or $k_{T}[3,4]$ factorization theorems are considered. Models such as the QCDimproved factorization (QCDF) [5,6] and the soft collinear effective theory (SCET) [1,7] use the collinear factorization, while the perturbative QCD (pQCD) approach [8,9] uses the $k_{T}$ factorization. In these models the amplitude of the $B \rightarrow D^{(*)} \pi$ two-body decay carries information about the difference $\delta$ between the strong-interaction phases of the two isospin amplitudes $A_{1 / 2}$ and $A_{3 / 2}$ that contribute [10,11]. A nonzero value of $\delta$ provides a measure of the departure from the heavy-quark limit and the importance of the final-state interactions in the $D^{(*)} \pi$ system. With the measurements by the $B A B A R$ [12] and BELLE [13] experiments of the color-suppressed $B$ decay $\bar{B}^{0} \rightarrow D^{(*) 0} \pi^{0}$ providing evidence for a sizeable value of $\delta$, an improved measurement of the color-favored decay amplitudes $\left(B^{-} \rightarrow D^{(*) 0} \pi^{-}\right.$and $\left.\bar{B}^{0} \rightarrow D^{(*)+} \pi^{-}\right)$is of renewed interest. In addition, the study of $B$ decays into $D, D^{*}$, and $D^{* *}$ mesons will allow tests of the spin symmetry [14-17] imbedded in HQET and of nonfactorizable corrections [18] that have been assumed to be negligible in the case of the excited states $D^{* *}$ [19].

In this paper we present new measurements of the branching fractions for the decays $B^{-} \rightarrow D^{0} \pi^{-}, D^{* 0} \pi^{-}$, $" D^{* * 0} " \pi^{-}$, and $\bar{B}^{0} \rightarrow D^{+} \pi^{-}, D^{*+} \pi^{-}, " D^{* *+} " \pi^{-}$[20], based on a missing mass method previously used by $B A B A R$ [21]. Here " $D^{* *}$ " refers to the sum of all the nonstrange charm meson states with masses in the range $2.2-2.8 \mathrm{GeV} / c^{2}$. This analysis uses $\mathrm{Y}(4 S) \rightarrow B \bar{B}$ events in which a $B^{+}$or a $B^{0}$ meson, denoted $B_{\mathrm{reco}}$, decays into a hadronic final state and is fully reconstructed. The decays of the recoiling $\bar{B}$ into a charged pion and a charmed meson, i.e. $\bar{B} \rightarrow \pi^{-} X$, are studied. The charged pion is reconstructed and the mass of the $X=D, D^{*}$, " $D^{* *}$ " is inferred from the kinematics of the two-body $B$ decay. This method, unlike the previous exclusive measurements
[22,23], does not assume that the $\Upsilon(4 S)$ decays into $B^{+}$ and $B^{0}$ with equal rates, nor does it rely on the $D, D^{*}$, or $D^{* *}$ decay branching fractions.

The measurements presented here are based on a sample of $231 \times 10^{6} B \bar{B}$ pairs $\left(210 \mathrm{fb}^{-1}\right)$ recorded at the $\Upsilon(4 S)$ resonance with the $B A B A R$ detector at the PEP-II asymmetric-energy $B$ factory at SLAC. The BABAR detector is described in detail elsewhere [24]. Charged-particle trajectories are measured by a 5-layer double-sided silicon vertex tracker (SVT) and a 40-layer drift chamber (DCH), both operating in a $1.5-\mathrm{T}$ solenoidal magnetic field. Charged-particle identification is provided by the average energy loss ( $\mathrm{d} E / \mathrm{d} x$ ) in the tracking devices and by an internally reflecting ring-imaging Cherenkov detector. Photons are detected by a $\mathrm{CsI}(\mathrm{Tl})$ electromagnetic calorimeter. Muons are identified by the instrumented magnetic-flux return (IFR). We use Monte Carlo (MC) simulations of the BABAR detector based on GEANT4 [25] to optimize selection criteria and determine selection efficiencies.

We reconstruct $B^{+}$and $B^{0}$ decays ( $B_{\text {reco }}$ ) in the modes $B^{+} \rightarrow \bar{D}^{(*) 0} \pi^{+}, \bar{D}^{(*) 0} \rho^{+}, \bar{D}^{(*) 0} a_{1}^{+}$, and $B^{0} \rightarrow D^{(*)-} \pi^{+}$, $D^{(*)-} \rho^{+}, D^{(*)-} a_{1}^{+} . \bar{D}^{0}$ candidates are reconstructed in the $K^{+} \pi^{-}, K^{+} \pi^{-} \pi^{0}, K^{+} \pi^{-} \pi^{+} \pi^{-}$, and $K_{S}^{0} \pi^{+} \pi^{-}$decay channels, while $D^{-}$candidates are reconstructed in the $K^{+} \pi^{-} \pi^{-}$and $K_{S}^{0} \pi^{-}$modes, and $K_{S}^{0}$ mesons are reconstructed to $\pi^{+} \pi^{-} . D^{*}$ candidates are reconstructed in the $D^{*-} \rightarrow \bar{D}^{0} \pi^{-}$and $\bar{D}^{* 0} \rightarrow \bar{D}^{0} \pi^{0}$ decay modes. A $3 \sigma$ cut is applied to the $D$ meson mass $m_{D}$ (and to the $D^{*}-D$ mass difference $\left.\Delta m_{D^{*}}\right)$ where $\sigma=\sigma_{m_{D}}\left(\sigma_{\Delta m_{D^{*}}}\right)$ is the resolution on $m_{D}\left(\Delta m_{D^{*}}\right)$ and is determined from data. A vertex fit is performed on $D\left(D^{*}\right)$ with the mass constrained to the nominal value [26]. Two nearly independent variables are defined to identify the fully reconstructed $B$ candidates kinematically. The first one is the beam-energy substituted mass, $\mathrm{m}_{\mathrm{ES}}=\sqrt{\left(s / 2+\mathbf{p}_{i} \cdot \mathbf{p}_{B}\right)^{2} / E_{i}^{2}-\mathbf{p}_{B}^{2}}$, where $\mathbf{p}_{B}$ is the $B_{\text {reco }}$ momentum and $\left(E_{i}, \mathbf{p}_{i}\right)$ is the four-momentum of the initial $e^{+} e^{-}$system, both measured in the laboratory frame. The invariant mass of the initial $e^{+} e^{-}$system is
$\sqrt{s}$. The second variable is $\Delta \mathrm{E}=E_{B}^{*}-\sqrt{s} / 2$, where $E_{B}^{*}$ is the $B_{\text {reco }}$ candidate energy in the center-of-mass frame. To define the $B_{\text {reco }}$ sample (Fig. 1), we require $|\Delta \mathrm{E}|<n \sigma_{\Delta E}$, where the measured resolutions $\sigma_{\Delta E}$ range from 12 to 35 MeV and $n=2$ or 3 , both depending on the $B_{\text {reco }}$ mode. The $B_{\text {reco }}$ candidate multiplicity is 1.4 for data as well as for the MC simulation sample. For events with more than one candidate, we select the $B_{\text {reco }}$ with the best $\chi^{2}$ defined with the variables $m_{D}, \Delta m_{D^{*}}$, and $\Delta \mathrm{E}$. The MC simulation shows that the recoil variables are reconstructed well within their experimental resolution when using this selection.

The number of $B_{\text {reco }}$ is extracted from the $m_{\mathrm{ES}}$ spectra (Fig. 1) in the $5.27-5.29 \mathrm{GeV} / c^{2}$ signal region. The $m_{\mathrm{ES}}$ distribution is fitted to the sum of a broad combinatorial background and a narrow signal in the mass interval $5.21-5.29 \mathrm{GeV} / c^{2}$. The combinatorial background is described by an empirical phase-space threshold function [27] and the signal with a Crystal Ball function [28] which is a Gaussian function centered at the $B$ meson mass


FIG. 1 (color online). $\quad m_{\text {ES }}$ spectra of reconstructed (a) $B^{+}$and (b) $B^{0}$ candidates. The solid curve is the sum of the fitted signal and background whereas the dashed curve is the background component only.
modified to account for photon radiation energy loss. All of the parameters specifying the functions describing the $B_{\text {reco }}$ signal and background distributions are determined from data. The measured yields of reconstructed $B^{+}$and $B^{0} \quad$ candidates, $\quad N_{B^{+}}=189474 \pm 7487$ and $N_{B^{0}}=$ $103169 \pm 3303$, are obtained by subtracting the fitted and the peaking (described below) backgrounds from the total number of events found in the signal region. These $B_{\text {reco }}$ numbers serve as the normalization of all branching fraction measurements reported in this paper. The error is dominated by the systematic uncertainties due to the fit of the combinatorial background and to the determination of the peaking background. We assign $2.3 \%$ uncertainty to $N_{B^{+}}$and $1.8 \%$ to $N_{B^{0}}$ as a fit uncertainty, obtained by varying the lower boundary of the fit interval from 5.20 to $5.23 \mathrm{GeV} / c^{2}$. The contamination of misreconstructed $B^{0}$ events in the $B^{+}$signal (and vice versa) induces a peaking background near the $B$ mass. From the MC simulation, the fraction of $B^{0}$ events in the reconstructed $B^{+}$ signal sample is found to be $\left(3.2 \pm 3.2_{\text {syst. }}\right) \%$ and the fraction of $B^{+}$events in the reconstructed $B^{0}$ signal sample $\left(2.8 \pm 2.8_{\text {syst. }}\right) \%$. A $100 \%$ systematic uncertainty is conservatively assigned to these numbers taking into account the possible differences in the reconstruction efficiency in data and MC, as well as the branching fraction uncertainties for those $B$ decay modes contributing to the peaking background. The total systematic uncertainties on $N_{B^{+}}$and $N_{B^{0}}$ are $3.9 \%$ and $3.2 \%$, respectively.

In the decay $\Upsilon(4 S) \rightarrow B_{\text {reco }} \bar{B}_{X \pi}$ where $\bar{B}_{X \pi}$ is the recoiling $\bar{B}$ which decays into $\pi^{-} X$, the invariant mass of the $X$ system is derived from the missing 4-momentum $p_{X}$ applying energy-momentum conservation:

$$
p_{X}=p_{\mathrm{Y}(4 S)}-p_{B \mathrm{reco}}-p_{\pi^{-}}
$$

The 4-momentum of the $\Upsilon(4 S), p_{\Upsilon(4 S)}$ is computed from the beam energies and $p_{\pi^{-}}$and $p_{B r e c o}$ are the measured 4momenta of the pion and of the reconstructed $B_{\text {reco }}$, respectively. The $B_{\text {reco }}$ energy is constrained by the beam energies. The $\bar{B} \rightarrow D \pi^{-}, \bar{B} \rightarrow D^{*} \pi^{-}$, or $\bar{B} \rightarrow$ " $D^{* * *} \pi^{-}$ signal yields peak at the $D, D^{*}$, and " $D^{* *}$ " masses in the missing mass spectrum, respectively.

The charged pion candidates, chosen among the tracks that do not belong to the $B_{\text {reco }}$, are required to have produced at least 12 DCH hits and to have transverse momentum larger than $0.1 \mathrm{GeV} / c^{2}$. For the charged $B_{\text {reco }}$, the pion candidate has the opposite sign to the $B_{\text {reco }}$. For neutral $B_{\text {reco }}$, because of the $B^{0}-\bar{B}^{0}$ mixing, the corresponding requirement is not applied. Muon tracks are rejected using the IFR information, electrons tracks using the energy loss in the SVT and the DCH, or the ratio of the candidate's EMC energy deposition to its momentum $(E / p)$. Protons and kaons are rejected based on information from the DIRC and energy loss in the SVT and the DCH. The rejection efficiency is $97 \%$ and there is no peaking trend

TABLE I. Signal yields, efficiencies, and branching fractions for $\bar{B} \rightarrow D \pi^{-}, \bar{B} \rightarrow D^{*} \pi^{-}$, and $\bar{B} \rightarrow{ }^{\prime \prime} D^{* *} " \pi^{-}$. The first error is statistical except for the efficiencies for which it is mainly systematic. The second error on the branching fractions is systematic. The $\bar{B} \rightarrow{ }^{"} D^{* * "} \pi^{-}$branching fractions are given for the $2.2-2.8 \mathrm{GeV} / c^{2}$ mass range which in addition to the $P$-wave states may include some yet unknown charm meson states.

| Decay mode | Yield | Efficiency | $\mathcal{B}\left(10^{-3}\right)$ |
| :--- | :---: | :---: | :---: |
| $B^{-} \rightarrow D^{0} \pi^{-}$ | $677 \pm 32$ |  | $4.49 \pm 0.21 \pm 0.23$ |
| $B^{-} \rightarrow D^{* 0} \pi^{-}$ | $774 \pm 33$ | $0.796 \pm 0.007$ | $5.13 \pm 0.22 \pm 0.28$ |
| $B^{-} \rightarrow " D^{* * 0} " \pi^{-}$ | $829 \pm 78$ | $5.50 \pm 0.52 \pm 1.04$ |  |
| $\bar{B}^{0} \rightarrow D^{+} \pi^{-}$ | $248 \pm 19$ | $3.03 \pm 0.23 \pm 0.23$ |  |
| $\bar{B}^{0} \rightarrow D^{*+} \pi^{-}$ | $245 \pm 19$ | $0.793 \pm 0.007$ | $2.99 \pm 0.23 \pm 0.24$ |
| $\bar{B}^{0} \rightarrow " D^{* *+} " \pi^{-}$ | $192 \pm 54$ | $2.34 \pm 0.65 \pm 0.88$ |  |

in the missing mass distribution from remaining kaons, protons, muons, or electrons. The multiplicity of the pion candidates which give a missing mass smaller than $4.15 \mathrm{GeV} / c^{2}$ is 1.05 in both data and MC simulation. For events with more than one candidate the simulation shows that the contribution of the wrong candidates to the signal yields is less than $0.2 \%$, thus negligible compared to the statistical uncertainties. The pion reconstruction efficiency is determined from the MC simulation and reported in Table I.

The signal yields for the different decay modes are extracted from the missing mass spectra. The data distributions and the $b \bar{b}$ and the $q \bar{q}(q=c, u, d, s)$ background expectations are shown in Figs. 2(a) and 2(b). The shape of the background is taken from MC and the normalization is scaled to match the data in the sideband region $2.8-3.2 \mathrm{GeV} / c^{2}$. The error on the background normalization is $2 \%$. This is determined using the statistical errors of MC and data samples. The $b \bar{b}$ background contribution is obtained from $B \bar{B}$ MC simulation excluding the $D \pi, D^{*} \pi$, and $D^{* *} \pi$ signals using the MC truth information. The background-subtracted missing mass distributions are shown in Figs. 2(c) and 2(d).

The $D \pi$ and $D^{*} \pi$ signal yields are extracted by a $\chi^{2}$ fit to the background-subtracted missing mass distribution in the range $1.65-2.20 \mathrm{GeV} / c^{2}$. The $D \pi$ and $D^{*} \pi$ components are each modeled by a sum of two Gaussian functions $G_{i=1,2}$ to account for tails in the mass distributions. The resulting ten parameters (two yield fractions $f\left(D^{(*)}\right)=\left\|G_{2}\left(D^{(*)}\right)\right\| /\left\|G_{1}\left(D^{(*)}\right)\right\|$, four central values $m_{i}\left(D^{(*)}\right)$, and four widths $\sigma_{i}\left(D^{(*)}\right)$ ) are constrained in order to improve the convergence of the fit, using assumptions that have been tested with MC simulation: we fix the fractions $f(D)=f\left(D^{*}\right)$ and the mass differences $m_{i}\left(D^{*}\right)-m_{i}(D)=\Delta m$, where $\quad \Delta m=0.1421 \mathrm{GeV} / c^{2}$ $\left(0.1406 \mathrm{GeV} / c^{2}\right)$ is the world average $D^{* 0}-D^{0}\left(D^{*+}-\right.$ $D^{+}$) mass difference [26]. Simultaneously, we apply


FIG. 2 (color online). Top: missing mass distributions obtained in the recoil of $B^{+}$(a) and $B^{0}(b)$. The points with error bars show the data and the histograms show the background contributions ( $b \bar{b}$ and $q \bar{q}(q=c, u, d, s)$ ) predicted by the MC simulation. Bottom: background-subtracted missing mass spectra for $B^{+}$(c) and $B^{0}$ (d). The curves show the result of the fits to the $D \pi$ and $D^{*} \pi$ components.

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Gaussian constraints to the width ratios $\sigma_{i}\left(D^{*}\right) / \sigma_{i}(D)=$ $0.900 \pm 0.015$.

The " $D^{* *}$ " yields are defined as the excess of candidates in the missing mass range $2.2-2.8 \mathrm{GeV} / c^{2}$, and the $\bar{B} \rightarrow$ " $D^{* *} " \pi^{-}$branching fractions refer to the contributions of all nonstrange charm meson states in the same region. The range is chosen in order to maximize the acceptance to the four $P$-wave $D^{* *}$ states predicted by the theory given the $34 \mathrm{MeV} / c^{2}$ mass resolution, determined from MC simulation, in the same region. The well-known narrow $D_{1}$ and $D_{2}^{*}$ states [26] are fully contained in this range, and more than $90 \%$ of the broad $D_{0}$ and $D_{1}^{\prime}$, are covered if measured masses and widths $[29,30]$ are used. The event yields, the efficiencies, and the resulting branching fractions are reported in Table I.

The uncertainty related to $\pi$ reconstruction efficiency is due to the MC sample statistics and the systematic uncertainty on track reconstruction and particle identification algorithms. The uncertainty due to the yield extraction is estimated by fitting the MC sample. The difference between the generated and the fitted yield is found to be consistent with zero for each signal component and the MC sample statistical uncertainty is taken as a systematic uncertainty. We evaluate the uncertainty on the missing mass resolution in the $D \pi$ and $D^{*} \pi$ yield extraction by varying by 1 standard deviation the ratio $\sigma_{i}^{D^{*}} / \sigma_{i}^{D}$ while $\sigma_{2}^{D^{*}}$ and $m_{2}^{D^{*}}$ are allowed to vary in the fit. The difference in the yield is taken as systematic uncertainty. The uncertainty related to the background subtraction is dominated by the contribution of the $D^{(*)} \rho$ decay channels. We varied the branching fractions of these background components within the uncertainties of the most recent measurements [26] and the changes in the fitted yields are taken as systematic uncertainties. The effect of the $2 \%$ error in the background normalization is also included in the systematic uncertainties. Because of the threshold shape of $D^{(*)} \rho$ contribution and to the fast varying combinatorial background, $B \rightarrow$ " $D^{* *} " \pi$ branching fractions have larger systematic errors than $B \rightarrow D \pi$ and $B \rightarrow D^{*} \pi$ branching fractions. The summary of these systematic uncertainties is reported in Table II.

Using the measured branching fractions we compute the following ratios:

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$$
\begin{aligned}
\mathcal{B}\left(B^{-}\right. & \left.\rightarrow D^{* 0} \pi^{-}\right) / \mathcal{B}\left(B^{-} \rightarrow D^{0} \pi^{-}\right) \\
& =1.14 \pm 0.07 \pm 0.04 \\
\mathcal{B}\left(B^{-}\right. & \left.\rightarrow{ }^{"} D^{* * 0 "} \pi^{-}\right) / \mathcal{B}\left(B^{-} \rightarrow D^{0} \pi^{-}\right) \\
& =1.22 \pm 0.13 \pm 0.23 \\
\mathcal{B}\left(\bar{B}^{0}\right. & \left.\rightarrow D^{*+} \pi^{-}\right) / \mathcal{B}\left(\bar{B}^{0} \rightarrow D^{+} \pi^{-}\right) \\
& =0.99 \pm 0.11 \pm 0.08 \\
\mathcal{B}\left(\bar{B}^{0}\right. & \left.\rightarrow " D^{* *+} " \pi^{-}\right) / \mathcal{B}\left(\bar{B}^{0} \rightarrow D^{+} \pi^{-}\right) \\
& =0.77 \pm 0.22 \pm 0.29 .
\end{aligned}
$$

The first uncertainty is statistical and the second is systematic. In addition to the cancellation of many of the systematic errors, the ratios are insensitive to the absolute normalization scale.

In summary, we have measured the branching fractions for the decays $B^{-} \rightarrow D^{0} \pi^{-}, \quad B^{-} \rightarrow D^{* 0} \pi^{-}, \quad B^{-} \rightarrow$ $" D^{* * 0}{ }^{"} \pi^{-}, \quad \bar{B}^{0} \rightarrow D^{+} \pi^{-}, \quad \bar{B}^{0} \rightarrow D^{*+} \pi^{-}, \quad$ and $\quad \bar{B}^{0} \rightarrow$ " $D^{* *+} " \pi^{-}$, using a missing mass method. This measurement does not assume that the $Y(4 S)$ decays into $B^{+}$and $B^{0}$ with equal rates, nor does it rely on the $D, D^{*}$, or " $D^{* *}$, intermediate branching fractions. The results for $\mathcal{B}(B \rightarrow$ $\left.D \pi^{-}\right)$and $\mathcal{B}\left(B \rightarrow D^{*} \pi^{-}\right)$are compatible with previous world averages [26]. We have extracted a new result for $\mathcal{B}\left(B \rightarrow " D^{* *} " \pi^{-}\right)$branching fractions where " $D^{* *}$ " excited states correspond to the yield measured in the mass range $2.2-2.8 \mathrm{GeV} / c^{2}$. The isospin study $[10,11]$ will become competitive with the exclusive measurements [23] if the statistical error is reduced by a factor of 2. With regard to spin symmetry, the values measured for the ratios $\mathcal{B}\left(B^{-} \rightarrow D^{* 0} \pi^{-}\right) / \mathcal{B}\left(B^{-} \rightarrow D^{0} \pi^{-}\right)$and $\mathcal{B}\left(\bar{B}^{0} \rightarrow D^{*+} \pi^{-}\right) / \mathcal{B}\left(\bar{B}^{0} \rightarrow D^{+} \pi^{-}\right)$are close to 1 , as predicted by different theoretical models [14-18], and their precision is comparable or better than the current world averages [26].

We are grateful for the extraordinary contributions of our PEP-II colleagues in achieving the excellent luminosity and machine conditions that have made this work possible. The success of this project also relies critically on the expertise and dedication of the computing organizations that support $B A B A R$. The collaborating institutions

TABLE II. Total relative systematic uncertainties for the branching fractions $\mathcal{B}\left(B^{-} \rightarrow\left(D^{0}, D^{* 0},{ }^{\prime \prime} D^{* * 0}{ }^{0}\right) \pi^{-}\right)$and $\mathcal{B}\left(\bar{B}^{0} \rightarrow\right.$ $\left(D^{+}, D^{*+}, " D^{* *+")} \pi^{-}\right)$.

| Syst. Source | $B^{-} \rightarrow D^{0} \pi^{-}$ | $B^{-} \rightarrow D^{* 0} \pi^{-}$ | $B^{-} \rightarrow " D^{* * 0 "} \pi^{-}$ | $\bar{B}^{0} \rightarrow D^{+} \pi^{-}$ | $\bar{B}^{0} \rightarrow D^{*+} \pi^{-}$ | $\bar{B}^{0} \rightarrow " D^{* *+"} \pi^{-}$ |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: |
| $N_{B}$ | $3.9 \%$ | $3.9 \%$ | $3.9 \%$ | $3.2 \%$ | $3.2 \%$ | $3.2 \%$ |
| Efficiency | $0.9 \%$ | $0.9 \%$ | $0.9 \%$ | $0.9 \%$ | $0.9 \%$ | $0.9 \%$ |
| Yield extraction | $2.7 \%$ | $2.7 \%$ | $5.1 \%$ | $5.4 \%$ | $5.1 \%$ | $5.9 \%$ |
| Missing mass resolution | $0.9 \%$ | $0.8 \%$ | $\cdots$ | $1.9 \%$ | $1.1 \%$ | $\cdots$ |
| Background subtraction | $1.6 \%$ | $2.3 \%$ | $17.7 \%$ | $3.7 \%$ | $5.4 \%$ | $37.1 \%$ |
| Total | $5.2 \%$ | $5.4 \%$ | $18.9 \%$ | $7.6 \%$ | $8.2 \%$ | $37.7 \%$ |

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[^0]:    *Also with Università di Perugia, Dipartimento di Fisica, Perugia, Italy.
    ${ }^{\dagger}$ Also with Università della Basilicata, Potenza, Italy.

