

Measurement of the Branching Fraction for $B^\pm \rightarrow \chi_{c0} K^\pm$

B. Aubert,¹ R. Barate,¹ D. Boutigny,¹ J.-M. Gaillard,¹ A. Hicheur,¹ Y. Karyotakis,¹ J. P. Lees,¹ P. Robbe,¹ V. Tisserand,¹ A. Zghiche,¹ A. Palano,² A. Pompili,² J. C. Chen,³ N. D. Qi,³ G. Rong,³ P. Wang,³ Y. S. Zhu,³ G. Eigen,⁴ I. Ofte,⁴ B. Stugu,⁴ G. S. Abrams,⁵ A. W. Borgland,⁵ A. B. Breon,⁵ D. N. Brown,⁵ J. Button-Shafer,⁵ R. N. Cahn,⁵ E. Charles,⁵ C. T. Day,⁵ M. S. Gill,⁵ A. V. Gritsan,⁵ Y. Groysman,⁵ R. G. Jacobsen,⁵ R. W. Kadel,⁵ J. Kadyk,⁵ L. T. Kerth,⁵ Yu. G. Kolomensky,⁵ J. F. Kral,⁵ G. Kukartsev,⁵ C. LeClerc,⁵ M. E. Levi,⁵ G. Lynch,⁵ L. M. Mir,⁵ P. J. Oddone,⁵ T. J. Orimoto,⁵ M. Pripstein,⁵ N. A. Roe,⁵ A. Romosan,⁵ M. T. Ronan,⁵ V. G. Shelkov,⁵ A. V. Telnov,⁵ W. A. Wenzel,⁵ K. Ford,⁶ T. J. Harrison,⁶ C. M. Hawkes,⁶ D. J. Knowles,⁶ S. E. Morgan,⁶ R. C. Penny,⁶ A. T. Watson,⁶ N. K. Watson,⁶ K. Goetzen,⁷ T. Held,⁷ H. Koch,⁷ B. Lewandowski,⁷ M. Pelizaeus,⁷ K. Peters,⁷ H. Schmuecker,⁷ M. Steinke,⁷ N. R. Barlow,⁸ J. T. Boyd,⁸ N. Chevalier,⁸ W. N. Cottingham,⁸ M. P. Kelly,⁸ T. E. Latham,⁸ C. Mackay,⁸ F. F. Wilson,⁸ K. Abe,⁹ T. Cuhadar-Donszelmann,⁹ C. Hearty,⁹ T. S. Mattison,⁹ J. A. McKenna,⁹ D. Thiessen,⁹ P. Kyberd,¹⁰ A. K. McKemey,¹⁰ V. E. Blinov,¹¹ A. D. Bukin,¹¹ V. B. Golubev,¹¹ V. N. Ivanchenko,¹¹ E. A. Kravchenko,¹¹ A. P. Onuchin,¹¹ S. I. Serednyakov,¹¹ Yu. I. Skovpen,¹¹ E. P. Solodov,¹¹ A. N. Yushkov,¹¹ D. Best,¹² M. Bruinsma,¹² M. Chao,¹² D. Kirkby,¹² A. J. Lankford,¹² M. Mandelkern,¹² R. K. Mommsen,¹² W. Roethel,¹² D. P. Stoker,¹² C. Buchanan,¹³ B. L. Hartfiel,¹³ B. C. Shen,¹⁴ D. del Re,¹⁵ H. K. Hadavand,¹⁵ E. J. Hill,¹⁵ D. B. MacFarlane,¹⁵ H. P. Paar,¹⁵ Sh. Rahatlou,¹⁵ V. Sharma,¹⁵ J. W. Berryhill,¹⁶ C. Campagnari,¹⁶ B. Dahmes,¹⁶ N. Kuznetsova,¹⁶ S. L. Levy,¹⁶ O. Long,¹⁶ A. Lu,¹⁶ M. A. Mazur,¹⁶ J. D. Richman,¹⁶ W. Verkerke,¹⁶ T. W. Beck,¹⁷ J. Beringer,¹⁷ A. M. Eisner,¹⁷ C. A. Heusch,¹⁷ W. S. Lockman,¹⁷ T. Schalk,¹⁷ R. E. Schmitz,¹⁷ B. A. Schumm,¹⁷ A. Seiden,¹⁷ M. Turri,¹⁷ W. Walkowiak,¹⁷ D. C. Williams,¹⁷ M. G. Wilson,¹⁷ J. Albert,¹⁸ E. Chen,¹⁸ G. P. Dubois-Felsmann,¹⁸ A. Dvoretzki,¹⁸ D. G. Hitlin,¹⁸ I. Narsky,¹⁸ F. C. Porter,¹⁸ A. Ryd,¹⁸ A. Samuel,¹⁸ S. Yang,¹⁸ S. Jayatilleke,¹⁹ G. Mancinelli,¹⁹ B. T. Meadows,¹⁹ M. D. Sokoloff,¹⁹ T. Abe,²⁰ F. Blanc,²⁰ P. Bloom,²⁰ S. Chen,²⁰ P. J. Clark,²⁰ W. T. Ford,²⁰ U. Nauenberg,²⁰ A. Olivas,²⁰ P. Rankin,²⁰ J. Roy,²⁰ J. G. Smith,²⁰ W. C. van Hoek,²⁰ L. Zhang,²⁰ J. L. Harton,²¹ T. Hu,²¹ A. Soffer,²¹ W. H. Toki,²¹ R. J. Wilson,²¹ J. Zhang,²¹ D. Altenburg,²² T. Brandt,²² J. Brose,²² T. Colberg,²² M. Dickopp,²² R. S. Dubitzky,²² A. Hauke,²² H. M. Lacker,²² E. Maly,²² R. Müller-Pfefferkorn,²² R. Nogowski,²² S. Otto,²² J. Schubert,²² K. R. Schubert,²² R. Schwierz,²² B. Spaan,²² L. Wilden,²² D. Bernard,²³ G. R. Bonneaud,²³ F. Brochard,²³ J. Cohen-Tanugi,²³ P. Grenier,²³ Ch. Thiebaux,²³ G. Vasileiadis,²³ M. Verderi,²³ A. Khan,²⁴ D. Lavin,²⁴ F. Muheim,²⁴ S. Playfer,²⁴ J. E. Swain,²⁴ M. Andreotti,²⁵ V. Azzolini,²⁵ D. Bettoni,²⁵ C. Bozzi,²⁵ R. Calabrese,²⁵ G. Cibinetto,²⁵ E. Luppi,²⁵ M. Negrini,²⁵ L. Piemontese,²⁵ A. Sarti,²⁵ E. Treadwell,²⁶ F. Anulli,²⁷ * R. Baldini-Ferrolì,²⁷ M. Biasini,²⁷ * A. Calcaterra,²⁷ R. de Sangro,²⁷ D. Falciari,²⁷ G. Finocchiaro,²⁷ P. Patteri,²⁷ I. M. Peruzzi,²⁷ * M. Piccolo,²⁷ M. Pioppi,²⁷ * A. Zallo,²⁷ A. Buzzo,²⁸ R. Capra,²⁸ R. Contri,²⁸ G. Crosetti,²⁸ M. Lo Vetere,²⁸ M. Macri,²⁸ M. R. Monge,²⁸ S. Passaggio,²⁸ C. Patrignani,²⁸ E. Robutti,²⁸ A. Santroni,²⁸ S. Tosi,²⁸ S. Bailey,²⁹ M. Morii,²⁹ E. Won,²⁹ W. Bhimji,³⁰ D. A. Bowerman,³⁰ P. D. Dauncey,³⁰ U. Egede,³⁰ I. Eschrich,³⁰ J. R. Gaillard,³⁰ G. W. Morton,³⁰ J. A. Nash,³⁰ P. Sanders,³⁰ G. P. Taylor,³⁰ G. J. Grenier,³¹ S.-J. Lee,³¹ U. Mallik,³¹ J. Cochran,³² H. B. Crawley,³² J. Lamsa,³² W. T. Meyer,³² S. Prell,³² E. I. Rosenberg,³² J. Yi,³² M. Davier,³³ G. Grosdidier,³³ A. Höcker,³³ S. Laplace,³³ F. Le Diberder,³³ V. Lepeltier,³³ A. M. Lutz,³³ T. C. Petersen,³³ S. Plaszczynski,³³ M. H. Schune,³³ L. Tantot,³³ G. Wormser,³³ V. Brigljević,³⁴ C. H. Cheng,³⁴ D. J. Lange,³⁴ D. M. Wright,³⁴ A. J. Bevan,³⁵ J. P. Coleman,³⁵ J. R. Fry,³⁵ E. Gabathuler,³⁵ R. Gamet,³⁵ M. Kay,³⁵ R. J. Parry,³⁵ D. J. Payne,³⁵ R. J. Sloane,³⁵ C. Touramanis,³⁵ J. J. Back,³⁶ P. F. Harrison,³⁶ H. W. Shorthouse,³⁶ P. Strother,³⁶ P. B. Vidal,³⁶ C. L. Brown,³⁷ G. Cowan,³⁷ R. L. Flack,³⁷ H. U. Flaecher,³⁷ S. George,³⁷ M. G. Green,³⁷ A. Kurup,³⁷ C. E. Marker,³⁷ T. R. McMahon,³⁷ S. Ricciardi,³⁷ F. Salvatore,³⁷ G. Vaitsas,³⁷ M. A. Winter,³⁷ D. Brown,³⁸ C. L. Davis,³⁸ J. Allison,³⁹ R. J. Barlow,³⁹ A. C. Forti,³⁹ P. A. Hart,³⁹ M. C. Hodgkinson,³⁹ F. Jackson,³⁹ G. D. Lafferty,³⁹ A. J. Lyon,³⁹ J. H. Weatherall,³⁹ J. C. Williams,³⁹ A. Farbin,⁴⁰ A. Jawahery,⁴⁰ D. Kovalskyi,⁴⁰ C. K. Lae,⁴⁰ V. Lillard,⁴⁰ D. A. Roberts,⁴⁰ G. Blaylock,⁴¹ C. Dallapiccola,⁴¹ K. T. Flood,⁴¹ S. S. Hertzbach,⁴¹ R. Kofler,⁴¹ V. B. Koptchev,⁴¹ T. B. Moore,⁴¹ S. Saremi,⁴¹ H. Staengle,⁴¹

S. Willocq,⁴¹ R. Cowan,⁴² G. Sciolla,⁴² F. Taylor,⁴² R. K. Yamamoto,⁴² D. J. J. Mangeol,⁴³ P. M. Patel,⁴³ A. Lazzaro,⁴⁴ F. Palombo,⁴⁴ J. M. Bauer,⁴⁵ L. Cremaldi,⁴⁵ V. Eschenburg,⁴⁵ R. Godang,⁴⁵ R. Kroeger,⁴⁵ J. Reidy,⁴⁵ D. A. Sanders,⁴⁵ D. J. Summers,⁴⁵ H. W. Zhao,⁴⁵ S. Brunet,⁴⁶ D. Cote-Ahern,⁴⁶ C. Hast,⁴⁶ P. Taras,⁴⁶ H. Nicholson,⁴⁷ C. Cartaro,⁴⁸ N. Cavallo,⁴⁸,[†] G. De Nardo,⁴⁸ F. Fabozzi,⁴⁸,[†] C. Gatto,⁴⁸ L. Lista,⁴⁸ P. Paolucci,⁴⁸ D. Piccolo,⁴⁸ C. Sciacca,⁴⁸ M. A. Baak,⁴⁹ G. Raven,⁴⁹ J. M. LoSecco,⁵⁰ T. A. Gabriel,⁵¹ B. Brau,⁵² K. K. Gan,⁵² K. Honscheid,⁵² D. Hufnagel,⁵² H. Kagan,⁵² R. Kass,⁵² T. Pulliam,⁵² Q. K. Wong,⁵² J. Brau,⁵³ R. Frey,⁵³ C. T. Potter,⁵³ N. B. Sinev,⁵³ D. Strom,⁵³ E. Torrence,⁵³ F. Colecchia,⁵⁴ A. Dorigo,⁵⁴ F. Galeazzi,⁵⁴ M. Margoni,⁵⁴ M. Morandin,⁵⁴ M. Posocco,⁵⁴ M. Rotondo,⁵⁴ F. Simonetto,⁵⁴ R. Stroili,⁵⁴ G. Tiozzo,⁵⁴ C. Voci,⁵⁴ M. Benayoun,⁵⁵ H. Briand,⁵⁵ J. Chauveau,⁵⁵ P. David,⁵⁵ Ch. de la Vaissière,⁵⁵ L. Del Buono,⁵⁵ O. Hamon,⁵⁵ M. J. J. John,⁵⁵ Ph. Leruste,⁵⁵ J. Ocariz,⁵⁵ M. Pivk,⁵⁵ L. Roos,⁵⁵ J. Stark,⁵⁵ S. T'Jampens,⁵⁵ G. Therin,⁵⁵ P. F. Manfredi,⁵⁶ V. Re,⁵⁶ P. K. Behera,⁵⁷ L. Gladney,⁵⁷ Q. H. Guo,⁵⁷ J. Panetta,⁵⁷ C. Angelini,⁵⁸ G. Batignani,⁵⁸ S. Bettarini,⁵⁸ M. Bondioli,⁵⁸ F. Bucci,⁵⁸ G. Calderini,⁵⁸ M. Carpinelli,⁵⁸ V. Del Gamba,⁵⁸ F. Forti,⁵⁸ M. A. Giorgi,⁵⁸ A. Lusiani,⁵⁸ G. Marchiori,⁵⁸ F. Martinez-Vidal,⁵⁸,[‡] M. Morganti,⁵⁸ N. Neri,⁵⁸ E. Paoloni,⁵⁸ M. Rama,⁵⁸ G. Rizzo,⁵⁸ F. Sandrelli,⁵⁸ J. Walsh,⁵⁸ M. Haire,⁵⁹ D. Judd,⁵⁹ K. Paick,⁵⁹ D. E. Wagoner,⁵⁹ N. Danielson,⁶⁰ P. Elmer,⁶⁰ C. Lu,⁶⁰ V. Miftakov,⁶⁰ J. Olsen,⁶⁰ A. J. S. Smith,⁶⁰ H. A. Tanaka,⁶⁰ E. W. Varnes,⁶⁰ F. Bellini,⁶¹ G. Cavoto,^{60,61} R. Faccini,^{15,61} F. Ferrarotto,⁶¹ F. Ferroni,⁶¹ M. Gaspero,⁶¹ M. A. Mazzoni,⁶¹ S. Morganti,⁶¹ M. Pierini,⁶¹ G. Piredda,⁶¹ F. Safai Tehrani,⁶¹ C. Voena,⁶¹ S. Christ,⁶² G. Wagner,⁶² R. Waldi,⁶² T. Adye,⁶³ N. De Groot,⁶³ B. Franek,⁶³ N. I. Geddes,⁶³ G. P. Gopal,⁶³ E. O. Olaiya,⁶³ S. M. Xella,⁶³ R. Aleksan,⁶⁴ S. Emery,⁶⁴ A. Gaidot,⁶⁴ S. F. Ganzhur,⁶⁴ P.-F. Giraud,⁶⁴ G. Hamel de Monchenault,⁶⁴ W. Kozanecki,⁶⁴ M. Langer,⁶⁴ M. Legendre,⁶⁴ G. W. London,⁶⁴ B. Mayer,⁶⁴ G. Schott,⁶⁴ G. Vasseur,⁶⁴ Ch. Yeche,⁶⁴ M. Zito,⁶⁴ M. V. Purohit,⁶⁵ A. W. Weidemann,⁶⁵ F. X. Yumiceva,⁶⁵ D. Aston,⁶⁶ R. Bartoldus,⁶⁶ N. Berger,⁶⁶ A. M. Boyarski,⁶⁶ O. L. Buchmueller,⁶⁶ M. R. Convery,⁶⁶ D. P. Coupal,⁶⁶ D. Dong,⁶⁶ J. Dorfan,⁶⁶ D. Dujmic,⁶⁶ W. Dunwoodie,⁶⁶ R. C. Field,⁶⁶ T. Glanzman,⁶⁶ S. J. Gowdy,⁶⁶ E. Grauges-Pous,⁶⁶ T. Hadig,⁶⁶ V. Halyo,⁶⁶ T. Hryn'ova,⁶⁶ W. R. Innes,⁶⁶ C. P. Jessop,⁶⁶ M. H. Kelsey,⁶⁶ P. Kim,⁶⁶ M. L. Kocian,⁶⁶ U. Langenegger,⁶⁶ D. W. G. S. Leith,⁶⁶ S. Luitz,⁶⁶ V. Luth,⁶⁶ H. L. Lynch,⁶⁶ H. Marsiske,⁶⁶ R. Messner,⁶⁶ D. R. Muller,⁶⁶ C. P. O'Grady,⁶⁶ V. E. Ozcan,⁶⁶ A. Perazzo,⁶⁶ M. Perl,⁶⁶ S. Petrak,⁶⁶ B. N. Ratcliff,⁶⁶ S. H. Robertson,⁶⁶ A. Roodman,⁶⁶ A. A. Salmikov,⁶⁶ R. H. Schindler,⁶⁶ J. Schwiening,⁶⁶ G. Simi,⁶⁶ A. Snyder,⁶⁶ A. Soha,⁶⁶ J. Stelzer,⁶⁶ D. Su,⁶⁶ M. K. Sullivan,⁶⁶ J. Va'vra,⁶⁶ S. R. Wagner,⁶⁶ M. Weaver,⁶⁶ A. J. R. Weinstein,⁶⁶ W. J. Wisniewski,⁶⁶ D. H. Wright,⁶⁶ C. C. Young,⁶⁶ P. R. Burchat,⁶⁷ A. J. Edwards,⁶⁷ T. I. Meyer,⁶⁷ B. A. Petersen,⁶⁷ C. Roat,⁶⁷ S. Ahmed,⁶⁸ M. S. Alam,⁶⁸ J. A. Ernst,⁶⁸ M. Saleem,⁶⁸ F. R. Wappler,⁶⁸ W. Bugg,⁶⁹ M. Krishnamurthy,⁶⁹ S. M. Spanier,⁶⁹ R. Eckmann,⁷⁰ H. Kim,⁷⁰ J. L. Ritchie,⁷⁰ R. F. Schwitters,⁷⁰ J. M. Izen,⁷¹ I. Kitayama,⁷¹ X. C. Lou,⁷¹ S. Ye,⁷¹ F. Bianchi,⁷² M. Bona,⁷² F. Gallo,⁷² D. Gamba,⁷² C. Borean,⁷³ L. Bosisio,⁷³ G. Della Ricca,⁷³ S. Dittongo,⁷³ S. Grancagnolo,⁷³ L. Lancieri,⁷³ P. Poropat,⁷³,[§] L. Vitale,⁷³ G. Vuagnin,⁷³ R. S. Panvini,⁷⁴ Sw. Banerjee,⁷⁵ C. M. Brown,⁷⁵ D. Fortin,⁷⁵ P. D. Jackson,⁷⁵ R. Kowalewski,⁷⁵ J. M. Roney,⁷⁵ H. R. Band,⁷⁶ S. Dasu,⁷⁶ M. Datta,⁷⁶ A. M. Eichenbaum,⁷⁶ J. R. Johnson,⁷⁶ P. E. Kutter,⁷⁶ H. Li,⁷⁶ R. Liu,⁷⁶ F. Di Lodovico,⁷⁶ A. Mihalysi,⁷⁶ A. K. Mohapatra,⁷⁶ Y. Pan,⁷⁶ R. Prepost,⁷⁶ S. J. Sekula,⁷⁶ J. H. von Wimmersperg-Toeller,⁷⁶ J. Wu,⁷⁶ S. L. Wu,⁷⁶ Z. Yu,⁷⁶ and H. Neal⁷⁷

(The BABAR Collaboration)

¹Laboratoire de Physique des Particules, F-74941 Annecy-le-Vieux, France

²Università di Bari, Dipartimento di Fisica and INFN, I-70126 Bari, Italy

³Institute of High Energy Physics, Beijing 100039, China

⁴University of Bergen, Inst. of Physics, N-5007 Bergen, Norway

⁵Lawrence Berkeley National Laboratory and University of California, Berkeley, CA 94720, USA

⁶University of Birmingham, Birmingham, B15 2TT, United Kingdom

⁷Ruhr Universität Bochum, Institut für Experimentalphysik 1, D-44780 Bochum, Germany

⁸University of Bristol, Bristol BS8 1TL, United Kingdom

⁹University of British Columbia, Vancouver, BC, Canada V6T 1Z1

¹⁰Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom

¹¹Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia

¹²University of California at Irvine, Irvine, CA 92697, USA

¹³University of California at Los Angeles, Los Angeles, CA 90024, USA

¹⁴University of California at Riverside, Riverside, CA 92521, USA

¹⁵University of California at San Diego, La Jolla, CA 92093, USA

¹⁶University of California at Santa Barbara, Santa Barbara, CA 93106, USA

¹⁷University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, CA 95064, USA

¹⁸California Institute of Technology, Pasadena, CA 91125, USA

- ¹⁹University of Cincinnati, Cincinnati, OH 45221, USA
²⁰University of Colorado, Boulder, CO 80309, USA
²¹Colorado State University, Fort Collins, CO 80523, USA
²²Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany
²³Ecole Polytechnique, LLR, F-91128 Palaiseau, France
²⁴University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom
²⁵Università di Ferrara, Dipartimento di Fisica and INFN, I-44100 Ferrara, Italy
²⁶Florida A&M University, Tallahassee, FL 32307, USA
²⁷Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy
²⁸Università di Genova, Dipartimento di Fisica and INFN, I-16146 Genova, Italy
²⁹Harvard University, Cambridge, MA 02138, USA
³⁰Imperial College London, London, SW7 2BW, United Kingdom
³¹University of Iowa, Iowa City, IA 52242, USA
³²Iowa State University, Ames, IA 50011-3160, USA
³³Laboratoire de l'Accélérateur Linéaire, F-91898 Orsay, France
³⁴Lawrence Livermore National Laboratory, Livermore, CA 94550, USA
³⁵University of Liverpool, Liverpool L69 3BX, United Kingdom
³⁶Queen Mary, University of London, E1 4NS, United Kingdom
³⁷University of London, Royal Holloway and Bedford New College, Egham, Surrey TW20 0EX, United Kingdom
³⁸University of Louisville, Louisville, KY 40292, USA
³⁹University of Manchester, Manchester M13 9PL, United Kingdom
⁴⁰University of Maryland, College Park, MD 20742, USA
⁴¹University of Massachusetts, Amherst, MA 01003, USA
⁴²Massachusetts Institute of Technology, Laboratory for Nuclear Science, Cambridge, MA 02139, USA
⁴³McGill University, Montréal, QC, Canada H3A 2T8
⁴⁴Università di Milano, Dipartimento di Fisica and INFN, I-20133 Milano, Italy
⁴⁵University of Mississippi, University, MS 38677, USA
⁴⁶Université de Montréal, Laboratoire René J. A. Lévesque, Montréal, QC, Canada H3C 3J7
⁴⁷Mount Holyoke College, South Hadley, MA 01075, USA
⁴⁸Università di Napoli Federico II, Dipartimento di Scienze Fisiche and INFN, I-80126, Napoli, Italy
⁴⁹NIKHEF, National Institute for Nuclear Physics and High Energy Physics, NL-1009 DB Amsterdam, The Netherlands
⁵⁰University of Notre Dame, Notre Dame, IN 46556, USA
⁵¹Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
⁵²Ohio State University, Columbus, OH 43210, USA
⁵³University of Oregon, Eugene, OR 97403, USA
⁵⁴Università di Padova, Dipartimento di Fisica and INFN, I-35131 Padova, Italy
⁵⁵Universités Paris VI et VII, Lab de Physique Nucléaire H. E., F-75252 Paris, France
⁵⁶Università di Pavia, Dipartimento di Elettronica and INFN, I-27100 Pavia, Italy
⁵⁷University of Pennsylvania, Philadelphia, PA 19104, USA
⁵⁸Università di Pisa, Dipartimento di Fisica, Scuola Normale Superiore and INFN, I-56127 Pisa, Italy
⁵⁹Prairie View A&M University, Prairie View, TX 77446, USA
⁶⁰Princeton University, Princeton, NJ 08544, USA
⁶¹Università di Roma La Sapienza, Dipartimento di Fisica and INFN, I-00185 Roma, Italy
⁶²Universität Rostock, D-18051 Rostock, Germany
⁶³Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingdom
⁶⁴DSM/Dapnia, CEA/Saclay, F-91191 Gif-sur-Yvette, France
⁶⁵University of South Carolina, Columbia, SC 29208, USA
⁶⁶Stanford Linear Accelerator Center, Stanford, CA 94309, USA
⁶⁷Stanford University, Stanford, CA 94305-4060, USA
⁶⁸State Univ. of New York, Albany, NY 12222, USA
⁶⁹University of Tennessee, Knoxville, TN 37996, USA
⁷⁰University of Texas at Austin, Austin, TX 78712, USA
⁷¹University of Texas at Dallas, Richardson, TX 75083, USA
⁷²Università di Torino, Dipartimento di Fisica Sperimentale and INFN, I-10125 Torino, Italy
⁷³Università di Trieste, Dipartimento di Fisica and INFN, I-34127 Trieste, Italy
⁷⁴Vanderbilt University, Nashville, TN 37235, USA
⁷⁵University of Victoria, Victoria, BC, Canada V8W 3P6
⁷⁶University of Wisconsin, Madison, WI 53706, USA
⁷⁷Yale University, New Haven, CT 06511, USA

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We present a measurement of the branching fraction of the decay $B^\pm \rightarrow \chi_{c0} K^\pm$ from a sample of 89 million $B\bar{B}$ pairs collected by the BABAR detector at the PEP-II asymmetric-energy B Factory at SLAC. The χ_{c0} meson is reconstructed through its two-body decays to $\pi^+\pi^-$ and

K^+K^- . We measure $\mathcal{B}(B^\pm \rightarrow \chi_{c0}K^\pm) \times \mathcal{B}(\chi_{c0} \rightarrow \pi^+\pi^-) = (1.32_{-0.27}^{+0.28}(\text{stat}) \pm 0.09(\text{syst})) \times 10^{-6}$ and $\mathcal{B}(B^\pm \rightarrow \chi_{c0}K^\pm) \times \mathcal{B}(\chi_{c0} \rightarrow K^+K^-) = (1.49_{-0.34}^{+0.36}(\text{stat}) \pm 0.11(\text{syst})) \times 10^{-6}$. Using the known values for the χ_{c0} decays branching fractions, we combine these results to obtain $\mathcal{B}(B^\pm \rightarrow \chi_{c0}K^\pm) = (2.7 \pm 0.7) \times 10^{-4}$.

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In the simplest approximation, weak decays like $B \rightarrow J/\psi K$ arise from the quark-level process $b \rightarrow c\bar{c}s$ through a current-current interaction that can be written $[\bar{c}\gamma^\mu(1-\gamma_5)c][\bar{s}\gamma_\mu(1-\gamma_5)b]$. The colorless current $\bar{c}\gamma_\mu(1-\gamma_5)c$, which can create the J/ψ , can create as well the P -wave state χ_{c1} . It cannot, however, create χ_{c0} , χ_{c2} or h_c , so their appearance would have to be ascribed to more complex mechanisms. The $b \rightarrow c\bar{c}s$ process also occurs through the interaction of two color-octet currents $J_8^{\mu(\bar{c}c)} J_8^{\mu(\bar{s}b)} = [\bar{c}(\lambda_a/2)\gamma_\mu(1-\gamma_5)c][\bar{s}(\lambda_a/2)\gamma^\mu(1-\gamma_5)b]$, where λ_a are color $SU(3)$ matrices. The current $J_8^{\mu(\bar{c}c)}$ can create a color-octet $c\bar{c}$ pair in an S state, which can then radiate a soft gluon to produce a P -wave bound state [1, 2]. Alternatively, the χ_{c0} , χ_{c2} , h_c states might arise from final state interactions that mix the $(c\bar{c})K$ channel with channels like $D^{(*)}D_s^{(*)}$ [3].

The first evidence for the $B^\pm \rightarrow \chi_{c0}K^\pm$ decay was reported by the Belle collaboration [4], who measured $\mathcal{B}(B^\pm \rightarrow \chi_{c0}K^\pm) = (6.0_{-1.8}^{+2.1} \pm 1.1) \times 10^{-4}$ on a sample of $31.3 \times 10^6 B\bar{B}$ events. Previously CLEO had reported an upper limit of $\mathcal{B}(B^\pm \rightarrow \chi_{c0}K^\pm) < 4.8 \times 10^{-4}$ at 90% C.L. [5].

This work presents the study of the $B^\pm \rightarrow \chi_{c0}K^\pm$ decay using data collected by the BABAR detector operating at the PEP-II asymmetric energy e^+e^- collider. The data sample consists of 81.9 fb^{-1} collected at the $\Upsilon(4S)$ resonance containing $88.9 \times 10^6 B\bar{B}$ pairs.

The BABAR detector is fully described elsewhere [6]. It consists of a tracking system for the detection of charged particles, a Cherenkov detector (DIRC) for particle identification, an electromagnetic calorimeter and a detector for muon and K_L^0 identification. The tracking system includes a 5-layer, double-sided silicon vertex tracker and a 40-layer drift chamber filled with a mixture of helium and isobutane, both in a 1.5-T magnetic field supplied by a superconducting solenoidal magnet. The DIRC is a novel imaging Cherenkov detector relying on total internal reflection in the radiator. The electromagnetic calorimeter consists of 6580 CsI(Tl) crystals. The iron flux return is segmented and instrumented with resistive plate chambers for muon and K_L^0 identification.

Events with $B\bar{B}$ pairs are selected by requiring the presence of at least three charged tracks, the ratio of the second to the zeroth order Fox-Wolfram moment [7] to be less than 0.5 and the total energy of all the charged and neutral particles to be greater than 4.5 GeV. We consider only events where at least one track identified as a kaon has a momentum greater than 900 MeV/c in

the e^+e^- center-of-mass frame.

We reconstruct the χ_{c0} meson in the decay modes $\chi_{c0} \rightarrow \pi^+\pi^-$ and $\chi_{c0} \rightarrow K^+K^-$ from an oppositely-charged pair of tracks identified as both pions or both kaons, respectively. Candidates for the decay $B^\pm \rightarrow \chi_{c0}K^\pm$ are formed by combining a track identified as a charged kaon (referred to as the ‘‘bachelor’’ kaon in the following) with a χ_{c0} candidate and performing a geometrical vertex fit. The efficiency for the kaon selection used is between 70% and 90%, depending on momentum, while the probability for a pion to be misidentified as a kaon is below 5%. All the tracks are required to have polar angles in the region $0.35 < \theta < 2.54$ rad, to have at least 12 hits in the drift chamber and a transverse momentum with respect to the beam direction larger than 100 MeV/c. In addition, tracks consistent with being from $K_S^0 \rightarrow \pi^+\pi^-$, $\eta \rightarrow \pi^+\pi^-\pi^0$, $\Lambda \rightarrow p\pi^-$ ($\bar{\Lambda} \rightarrow \bar{p}\pi^+$) decays and tracks from γ conversions are rejected. The χ_{c0} candidates are required to have invariant mass in the range $3.32 < m_{\chi_{c0}} < 3.50 \text{ GeV}/c^2$.

To reject the large combinatorial background coming from continuum $q\bar{q}$ events, a Fisher discriminant \mathcal{F} [8] is used, built from a linear combination of 11 quantities related to the event shape or the B kinematics. The coefficients are determined by maximizing the separation between signal and continuum background on simulated events.

The selection of B candidates relies on the kinematic constraints given by the $\Upsilon(4S)$ initial state. Two variables are defined: the beam-energy substituted mass, $m_{\text{ES}} = \sqrt{(s/2 + \mathbf{p}_0 \cdot \mathbf{p})^2/E_0^2 - |\mathbf{p}|^2}$, and $\Delta E = E^* - \sqrt{s}/2$, where \mathbf{p} is the momentum of the B candidate, (E_0, \mathbf{p}_0) is the four-momentum of the initial state, in the laboratory frame, and E^* is the B candidate energy, \sqrt{s} is the total energy, in the center-of-mass frame. For the $B^\pm \rightarrow \chi_{c0}K^\pm$, $\chi_{c0} \rightarrow K^+K^-$ mode, when an ambiguity arises in cases with the same three final state kaons, we select as the bachelor kaon the one with the highest center-of-mass momentum.

The values of the cuts for \mathcal{F} , m_{ES} and ΔE are determined by an optimization procedure aimed at maximizing the value of $S/\sqrt{S+B}$. The number S of signal candidates and B of background events surviving the selection are estimated on samples of simulated events and data from the ΔE ‘‘sidebands’’ of the $m_{\text{ES}}-\Delta E$ plane, respectively. The sidebands are defined by $5.2 < m_{\text{ES}} < 5.3 \text{ GeV}/c^2$, $0.1 < |\Delta E| < 0.2 \text{ GeV}$. The relative normalization of the signal and background samples is determined by assuming the value measured by

Belle for $\mathcal{B}(B^\pm \rightarrow \chi_{c0} K^\pm)$ and the world average for $\mathcal{B}(\chi_{c0} \rightarrow \pi^+ \pi^-)$ and $\mathcal{B}(\chi_{c0} \rightarrow K^+ K^-)$ [9]. The signal regions in ΔE and m_{ES} are defined by $-45 < \Delta E < 35$ MeV, $m_{\text{ES}} > 5.2750$ GeV/ c^2 for the $\chi_{c0} \rightarrow \pi^+ \pi^-$ mode and by $-70 < \Delta E < 60$ MeV, $m_{\text{ES}} > 5.2735$ GeV/ c^2 for the $\chi_{c0} \rightarrow K^+ K^-$ mode.

We apply a veto on fully reconstructed $B \rightarrow D^{(*)} h$ decays, where h denotes a π , K or ρ meson. We reject B candidates if at least one of their decay products also contributes to the reconstruction of a $B \rightarrow D^{(*)} h$ decay, with $|\Delta E| < 30$ MeV and $m_{\text{ES}} > 5.27$ GeV/ c^2 . To reduce the residual contamination from other B decays with charmed or charmless mesons in the final state, we require the invariant mass of the pair formed by the bachelor kaon with the oppositely charged track from the χ_{c0} decay to be greater than 2 GeV/ c^2 .

The main source of non-combinatorial background remaining after the selection described comes from non-resonant B decays with the same final state as the signal, $B^\pm \rightarrow K^\pm \pi^+ \pi^-$ and $B^\pm \rightarrow K^\pm K^+ K^-$. A reliable evaluation of the expected contamination from these processes cannot be obtained based on the available measurements. These modes are expected to behave as ‘‘peaking background’’, that is to peak in m_{ES} and ΔE , while the distribution of $m_{\chi_{c0}}$ is expected to be flat: this is used to separate their contribution from the signal by means of a fit to the data, as described below.

The background from misreconstructed χ_{c0} decays to other modes is studied on simulated events and found to be negligible with respect to the other background sources for both the $\pi^+ \pi^-$ and the $K^+ K^-$ modes.

The number of signal events is extracted by a simultaneous unbinned maximum likelihood fit to the m_{ES} and $m_{\chi_{c0}}$ distributions for the events in the ΔE signal band. Three components are assumed to contribute to the selected sample: a signal component, modeled with a non-relativistic Breit-Wigner function convolved with a Gaussian distribution in $m_{\chi_{c0}}$, and a Gaussian distribution in m_{ES} ; a combinatorial background component, modeled with a flat distribution in $m_{\chi_{c0}}$, and an Argus threshold function [10] in m_{ES} ; a peaking background component, modeled with a flat distribution in $m_{\chi_{c0}}$, and a Gaussian distribution in m_{ES} , assuming the same resolution as for the signal.

In the fit the B^\pm and χ_{c0} masses are fixed to their PDG values [9]; the χ_{c0} width is fixed to the value recently measured by E835 [11], $\Gamma(\chi_{c0}) = (9.8 \pm 1.0 \pm 0.1)$ MeV/ c^2 . The width of the Gaussian peak in m_{ES} and the $m_{\chi_{c0}}$ resolution are determined from Monte Carlo samples. The Argus shape parameter and the relative weight of the three components are left as free parameters in the fit.

We verify the goodness of the fit with the three-component model using a Monte Carlo technique. For each of the two χ_{c0} decay modes, we simulate a number of experiments by randomly generating samples of events distributed in m_{ES} and $m_{\chi_{c0}}$ according to the dis-

tributions used in the fit. The number of events generated for each sample is equal to the number of events in the corresponding real data sample; the parameters of the distributions are set to their fixed or fitted values. For each sample, the fit is repeated in the same conditions as on real data. The pulls for the number of signal and background events are distributed as expected. The probability of having a worse fit than the one on data is found to be about 65% and 27% for $\chi_{c0} \rightarrow \pi^+ \pi^-$ and $\chi_{c0} \rightarrow K^+ K^-$, respectively.

We check the reliability of the yield extraction on a sample containing known amounts of combinatorial background, peaking background and signal events. We also verify the stability of the fit results against variations of the parameters fixed in the fit by floating them one at a time.

The signal and background yields resulting from the fit to the data are reported in Table I. The maximum correlation we observe is about -40% , between the number of signal and peaking background events, for both the $\pi^+ \pi^-$ and the $K^+ K^-$ modes. Figure 1 shows the m_{ES} and the $m_{\chi_{c0}}$ distributions for events in the ΔE signal region for the two modes considered. The results of the fit are superimposed.

We evaluate the systematic uncertainty to be attributed to the yield extraction by varying each fixed parameter, one at a time, by its error and repeating the fit. This results in a 2.4% (3.3%) fractional uncertainty for the $\chi_{c0} \rightarrow \pi^+ \pi^-$ ($\chi_{c0} \rightarrow K^+ K^-$) mode.

The statistical significance of the signal, defined as $\sqrt{2 \log \mathcal{L}_{\text{max}} / \mathcal{L}_0}$, where $\mathcal{L}_{\text{max}} / \mathcal{L}_0$ is the likelihood ratio for the fit with respect to the null signal hypothesis, is 8.1 (6.8) standard deviations (σ) for the $\chi_{c0} \rightarrow \pi^+ \pi^-$ ($\chi_{c0} \rightarrow K^+ K^-$) mode. When the systematic uncertainties are taken into account, the significances of the signals become 7.7σ and 6.4σ , respectively.

An alternative fitting method is employed to cross-check the results. An unbinned maximum likelihood fit to the $m_{\chi_{c0}}$ distribution only is used to extract the yield for the events selected in the $m_{\text{ES}} - \Delta E$ signal region. The signal component is modeled with a Breit-Wigner shape convolved with a Gaussian resolution function, while the background component is modeled with a linear function. This fit yields $N_{\text{sig}}(\chi_{c0} \rightarrow \pi^+ \pi^-) = 32.9_{-6.1}^{+5.7}$ and $N_{\text{sig}}(\chi_{c0} \rightarrow K^+ K^-) = 29.7_{-6.6}^{+6.5}$. Both values are com-

TABLE I: Number of signal (N_{sig}), combinatorial background (N_{comb}) and peaking background (N_{pkg}) events obtained by the fit described in the text (with statistical errors only).

Mode	N_{sig}	N_{comb}	N_{pkg}
$\chi_{c0} \rightarrow \pi^+ \pi^-$	$33.0_{-6.7}^{+7.0}$	111_{-11}^{+12}	$12.3_{-6.3}^{+7.3}$
$\chi_{c0} \rightarrow K^+ K^-$	$30.4_{-6.9}^{+7.3}$	102_{-11}^{+12}	$22.2_{-7.6}^{+8.5}$

patible with the results obtained with the primary fitting method.

The overall selection efficiency, estimated by using simulated data, is $(27.4 \pm 1.5)\%$ for the $\chi_{c0} \rightarrow \pi^+\pi^-$ mode and $(22.3 \pm 1.3)\%$ for the $\chi_{c0} \rightarrow K^+K^-$ mode. The quoted uncertainty is mainly due to differences between real and simulated data in the track reconstruction efficiency and in the efficiency of the ΔE cut for the $\chi_{c0} \rightarrow \pi^+\pi^-$ mode and to differences between real and simulated data in the track reconstruction and particle identification efficiencies for the $\chi_{c0} \rightarrow K^+K^-$ mode.

We derive the branching fractions as $\mathcal{B} = N_{\text{sig}}/(\epsilon N_{B^\pm})$, where ϵ denotes the overall signal efficiency and N_{B^\pm} is the total number of B^\pm mesons produced in the data sample considered. The value of N_{B^\pm} is determined from the measured number of $B\bar{B}$ pairs, $N_{B\bar{B}} = (88.9 \pm 1.0) \times 10^6$, and using $\mathcal{B}(\Upsilon(4S) \rightarrow B^+B^-) = (0.513 \pm 0.013)$ [9]. We obtain:

$$\mathcal{B}(B^\pm \rightarrow \chi_{c0}(\pi^+\pi^-)K^\pm) = 1.32^{+0.28}_{-0.27}(\text{stat}) \pm 0.09(\text{syst}),$$

$$\mathcal{B}(B^\pm \rightarrow \chi_{c0}(K^+K^-)K^\pm) = 1.49^{+0.36}_{-0.34}(\text{stat}) \pm 0.11(\text{syst}),$$

expressed in units of 10^{-6} . The systematic error combines the uncertainties from the determination of the number of $B\bar{B}$ pairs, from the branching fraction for

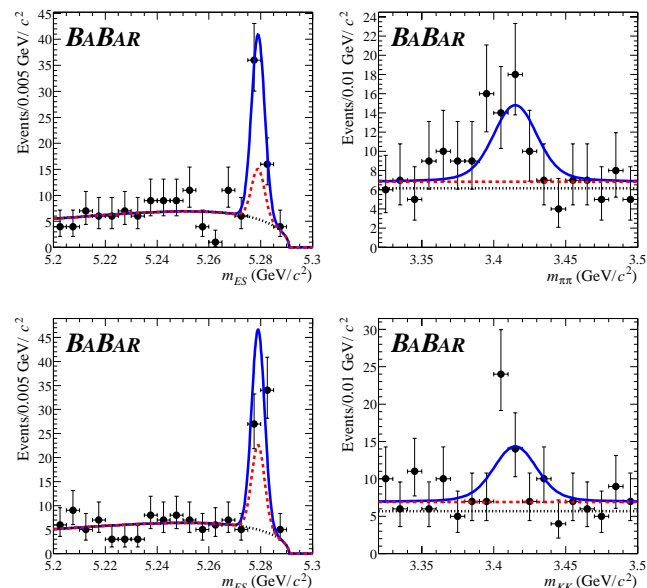


FIG. 1: Extraction of the signal yield for $\chi_{c0} \rightarrow \pi^+\pi^-$ (top) and $\chi_{c0} \rightarrow K^+K^-$ (bottom). Left: m_{ES} distribution; right: $m_{\chi_{c0}}$ distribution. Dots with error bars represent the data; lines represent projection of the fitted functions for the three contributions: combinatorial background (dotted), peaking + combinatorial background (dashed), signal + backgrounds (solid).

TABLE II: Branching fraction for $B^\pm \rightarrow \chi_{c0}K^\pm$ with the two χ_{c0} decay modes. The meaning of the quoted errors and of the combined measurement is explained in the text.

Mode	$\mathcal{B}(B^\pm \rightarrow \chi_{c0}K^\pm) (\times 10^{-4})$
$\chi_{c0} \rightarrow \pi^+\pi^-$	$2.83^{+0.60}_{-0.58} \pm 0.19 \pm 0.52$
$\chi_{c0} \rightarrow K^+K^-$	$2.63^{+0.63}_{-0.60} \pm 0.19 \pm 0.43$
combined	2.7 ± 0.7

$\Upsilon(4S) \rightarrow B^+B^-$, from the yield extraction and from the signal efficiency.

The ratio of the branching fractions for the χ_{c0} into the two modes is:

$$\frac{\mathcal{B}(\chi_{c0} \rightarrow \pi^+\pi^-)}{\mathcal{B}(\chi_{c0} \rightarrow K^+K^-)} = 0.88^{+0.28}_{-0.27}(\text{stat}) \pm 0.07(\text{syst})$$

which is compatible within the quoted errors with the world average [9].

Using $\mathcal{B}(\chi_{c0} \rightarrow \pi^+\pi^-) = (4.68 \pm 0.26 \pm 0.65) \times 10^{-3}$ and $\mathcal{B}(\chi_{c0} \rightarrow K^+K^-) = (5.68 \pm 0.35 \pm 0.85) \times 10^{-3}$, as reported by the BES collaboration [12], we measure the values of $\mathcal{B}(B^\pm \rightarrow \chi_{c0}K^\pm)$ reported in Table II. There the first quoted error is statistical, the second is systematic and the third accounts for the uncertainty on the χ_{c0} decay branching fractions. The measurements of $\mathcal{B}(B^\pm \rightarrow \chi_{c0}K^\pm)$ obtained with the two χ_{c0} decay modes are compatible. Taking into account the correlated errors, we have combined them and derived the value reported in Table II.

In summary, we have studied the process $B^\pm \rightarrow \chi_{c0}K^\pm$, reconstructing the χ_{c0} meson through its decay modes $\chi_{c0} \rightarrow K^+K^-$ and $\chi_{c0} \rightarrow \pi^+\pi^-$; the measured branching fraction is $\mathcal{B}(B^\pm \rightarrow \chi_{c0}K^\pm) = (2.7 \pm 0.7) \times 10^{-4}$. The result is significantly different from the zero value expected from the color-singlet current-current contribution alone.

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* Also with Università di Perugia, Perugia, Italy

[†] Also with Università della Basilicata, Potenza, Italy

[‡] Also with IFIC, Instituto de Física Corpuscular, CSIC-Universidad de Valencia, Valencia, Spain

[§] Deceased

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