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Study of $B \to X(3872)K$, with $X(3872) \to J/\psi\pi^+\pi^-$

B. Aubert,[1] M. Bona,[1] Y. Karyotakis,[1] J. P. Lees,[1] V. Poireau,[1] E. Prencipe,[1] X. Prudent,[1] V. Tisserand,[1] J. Garra Tico,[2] E. Grauges,[2] L. Lopez,[3] A. Palano,[3] M. Pappagallo,[3] G. Eigen,[4] B. Stugu,[4] L. Sun,[4] G. S. Abrams,[5] M. Battaglia,[5] D. N. Brown,[5] J. Button-Shafer,[5] R. N. Cahn,[5] R. G. Jacobsen,[5] J. A. Kadyk,[5] L. T. Kerth,[5] Yu. G. Kolomensky,[5] G. Kukartsev,[5] G. Lynch,[5] I. L. Osipenkov,[5] M. T. Ronan,[5,*] K. Tackmann,[5] T. Tanabe,[5] W. A. Wenzel,[5] C. M. Hawkes,[6] N. Soni,[6] A. T. Watson,[6] H. Koch,[7] T. Schroeder,[7] D. Walker,[8] D. J. Asgeirsson,[9] T. Cuhadar-Donszelmann,[9] B. G. Fulsom,[9] C. Hearty,[9] T. S. Mattison,[9] J. A. McKenna,[9] M. Barrett,[10] A. Khan,[10] M. Saleem,[10] L. Teodorescu,[10] V. E. Blinov,[11] A. D. Bukin,[11] A. R. Buzykaev,[11] V. P. Druzhinin,[11] V. B. Golubev,[11] A. P. Onuchin,[11] S. I. Serednyakov,[11] Yu. I. Skovpen,[11] E. P. Solodov,[11] K. Yu. Todyshev,[11] M. Bondioli,[12] S. Curry,[12] I. Eschrich,[12] D. Kirkby,[12] A. J. Lankford,[12] P. Lund,[12] M. Mandelkern,[12] E. C. Martin,[12] D. P. Stoker,[12] S. Abachi,[13] C. Buchanan,[13] J. W. Gary,[14] F. Liu,[14] O. Long,[14] B. C. Shen,[14,*] G. M. Vitug,[14] Z. Yasin,[14] L. Zhang,[14] V. Sharma,[15] C. Campagnari,[16] T. M. Hong,[16] D. Kovalskyi,[16] M. A. Mazur,[16] J. D. Richman,[16] T. W. Beck,[17] A. M. Eisner,[17] C. J. Flacco,[17] C. A. Heusch,[17] J. Kroseberg,[17] W. S. Lockman,[17] T. Schalk,[17] B. A. Schumm,[17] A. Seiden,[17] L. Wang,[17] M. G. Wilson,[17] L. O. Winstrom,[17] C. H. Cheng,[18] D. A. Doll,[18] B. Echenard,[18] F. Fang,[18] D. G. Hitlin,[18] I. Narsky,[18] T. Piatenko,[18] F. C. Porter,[18] R. Andreassen,[19] G. Mancinelli,[19] B. T. Meadows,[19] K. Mishra,[19] M. D. Sokoloff,[19] F. Blanc,[20] P. C. Bloom,[20] W. T. Ford,[20] A. Gaz,[20] J. F. Hirschauer,[20] A. Kreisel,[20] M. Nagel,[20] U. Nauenberg,[20] A. Olivas,[20] J. G. Smith,[20] K. A. Ulmer,[20] S. R. Wagner,[20] R. Ayad,[21,+] A. M. Gabareen,[21] A. Soffer,[21,‡] W. H. Toki,[21] R. J. Wilson,[21] D. D. Altenburg,[22] E. Feltresi,[22] A. Hauke,[22] H. Jasper,[22] M. Karbach,[22] J. Merkel,[22] A. Petzold,[22] B. Spaan,[22] K. Wacker,[22] V. Klose,[23] M. J. Kobel,[23] H. M. Lacker,[23] W. F. Mader,[23] R. Nogowski,[23] K. R. Schubert,[23] R. Schwierz,[23] J. E. Sundermann,[23] A. Volk,[23] D. Bernard,[24] G. R. Bonneaud,[24] E. Latour,[24] Ch. Thiebaux,[24] M. Verderi,[24] P. J. Clark,[25] W. Gradl,[25] S. Playfer,[25] J. E. Watson,[25] M. Andreotti,[26] D. Bettoni,[26] C. Bozzi,[26] R. Calabrese,[26] A. Cecchi,[26] G. Cibinetto,[26] P. Franchini,[26] E. Luppi,[26] M. Negrini,[26] A. Petrella,[26] L. Piemontese,[26] V. Santoro,[26] F. Anulli,[27] R. Baldini-Ferroli,[27] A. Calcaterra,[27] R. de Sangro,[27] G. Finocchiaro,[27] S. Pacetti,[27] P. Patteri,[27] I. M. Peruzzi,[27,§] M. Piccolo,[27] M. Rama,[27] A. Zallo,[27] A. Buzzo,[28] R. Contri,[28] M. Lo Vetere,[28] M. M. Macri,[28] M. R. Monge,[28] S. Passaggio,[28] C. Patrignani,[28] E. Robutti,[28] A. Santroni,[28] S. Tosi,[28] K. S. Chaisanguanthum,[29] M. Morii,[29] R. S. Dubitzky,[30] J. Marks,[30] S. Schenk,[30] U. Uwer,[30] D. J. Bard,[31] P. D. Dauncey,[31] J. A. Nash,[31] W. Panduro Vazquez,[31] M. Tibbetts,[31] P. K. Behera,[32] X. Chai,[32] M. J. Charles,[32] U. Mallik,[32] J. Cochran,[33] H. B. Crawley,[33] L. Dong,[33] W. T. Meyer,[33] S. Prell,[33] E. I. Rosenberg,[33] A. E. Rubin,[33] Y. Y. Gao,[34] A. V. Gritsan,[34] Z. J. Guo,[34] C. K. Lae,[34] A. G. Denig,[35] M. Fritsch,[35] G. Schott,[35] N. Arnaud,[36] J. Béquilleux,[36] A. D'Orazio,[36] M. Davier,[36] J. Firmino da Costa,[36] G. Grosdidier,[36] A. Höcker,[36] V. Lepeltier,[36] F. Le Diberder,[36] A. M. Lutz,[36] S. Pruvot,[36] P. Roudeau,[36] M. H. Schune,[36] J. Serrano,[36] V. Sordini,[36] A. Stocchi,[36] W. F. Wang,[36] G. Wormser,[36] D. J. Lange,[37] D. M. Wright,[37] I. Bingham,[38] J. P. Burke,[38] C. A. Chavez,[38] J. R. Fry,[38] E. Gabathuler,[38] R. Gamet,[38] D. E. Hutchcroft,[38] D. J. Payne,[38] C. Touramanis,[38] A. J. Bevan,[39] K. A. George,[39] F. Di Lodovico,[39] R. Sacco,[39] M. Sigamani,[39] G. Cowan,[40] H. U. Flaecher,[40] D. A. Hopkins,[40] S. Paramesvaran,[40] F. Salvatore,[40] A. C. Wren,[40] D. N. Brown,[41] C. L. Davis,[41] K. E. Alwyn,[42] N. R. Barlow,[42] R. J. Barlow,[42] Y. M. Chia,[42] C. L. Edgar,[42] G. D. Lafferty,[42] T. J. West,[42] J. I. Yi,[42] J. Anderson,[43] C. Chen,[43] A. Jawahery,[43] D. A. Roberts,[43] G. Simi,[43] J. M. Tuggle,[43] C. Dallapiccola,[44] S. S. Hertzbach,[44] X. Li,[44] E. Salvati,[44] S. Saremi,[44] R. Cowan,[45] D. Dujmic,[45] P. H. Fisher,[45] K. Koeneke,[45] G. Sciolla,[45] M. Spitznagel,[45] F. Taylor,[45] R. K. Yamamoto,[45] M. Zhao,[45] S. E. Mclachlin,[46,*] P. M. Patel,[46] S. H. Robertson,[46] A. Lazzaro,[47] V. Lombardo,[47] F. Palombo,[47] J. M. Bauer,[48] L. Cremaldi,[48] V. Eschenburg,[48] R. Godang,[48] R. Kroeger,[48] D. A. Sanders,[48] D. J. Summers,[48] H. W. Zhao,[48] S. Brunet,[49] D. Côté,[49] M. Simard,[49] P. Taras,[49] F. B. Viaud,[49] H. Nicholson,[50] G. De Nardo,[51] L. Lista,[51] D. Monorchio,[51] C. Sciacca,[51] M. A. Baak,[52] G. Raven,[52] H. L. Snoek,[52] C. P. Jessop,[53] K. J. Knoepfel,[53] J. M. LoSecco,[53] G. Benelli,[54] L. A. Corwin,[54] K. Honscheid,[54] H. Kagan,[54] R. Kass,[54] J. P. Morris,[54] A. M. Rahimi,[54] J. J. Regensburger,[54] S. J. Sekula,[54] Q. K. Wong,[54] N. L. Blount,[55] J. Brau,[55] R. Frey,[55] O. Igonkina,[55] J. A. Kolb,[55] M. Lu,[55] R. Rahmat,[55] N. B. Sinev,[55] D. Strom,[55] J. Strube,[55] E. Torrence,[55] G. Castelli,[56] N. Gagliardi,[56] M. Margoni,[56] M. Morandin,[56] M. Posocco,[56] M. Rotondo,[56] F. Simonetto,[56] R. Stroili,[56] C. Voci,[56] P. del Amo Sanchez,[57] E. Ben-Haim,[57] H. Briand,[57] G. Calderini,[57] J. Chauveau,[57] P. David,[57] L. Del Buono,[57] O. Hamon,[57] Ph. Leruste,[57] J. Ocariz,[57] A. Perez,[57] J. Prendki,[57] L. Gladney,[58] M. Biasini,[59] R. Covarelli,[59] E. Manoni,[59] C. Angelini,[60] G. Batignani,[60] S. Bettarini,[60] M. Carpinelli,[60,‖] A. Cervelli,[60] F. Forti,[60] M. A. Giorgi,[60] A. Lusiani,[60] G. Marchiori,[60] M. Morganti,[60] N. Neri,[60] E. Paoloni,[60] G. Rizzo,[60] J. J. Walsh,[60] J. Biesiada,[61] D. Lopes Pegna,[61] C. Lu,[61] J. Olsen,[61] A. J. S. Smith,[61] A. V. Telnov,[61] E. Baracchini,[62] G. Cavoto,[62] D. del Re,[62] E. Di Marco,[62] R. Faccini,[62] F. Ferrarotto,[62]

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F. Ferroni,[62] M. Gaspero,[62] P. D. Jackson,[62] L. Li Gioi,[62] M. A. Mazzoni,[62] S. Morganti,[62] G. Piredda,[62] F. Polci,[62] F. Renga,[62] C. Voena,[62] M. Ebert,[63] T. Hartmann,[63] H. Schröder,[63] R. Waldi,[63] T. Adye,[64] B. Franek,[64] E. O. Olaiya,[64] W. Roethel,[64] F. F. Wilson,[64] S. Emery,[65] M. Escalier,[65] L. Esteve,[65] A. Gaidot,[65] S. F. Ganzhur,[65] G. Hamel de Monchenault,[65] W. Kozanecki,[65] G. Vasseur,[65] Ch. Yèche,[65] M. Zito,[65] X. R. Chen,[66] H. Liu,[66] W. Park,[66] M. V. Purohit,[66] R. M. White,[66] J. R. Wilson,[66] M. T. Allen,[67] D. Aston,[67] R. Bartoldus,[67] P. Bechtle,[67] J. F. Benitez,[67] R. Cenci,[67] J. P. Coleman,[67] M. R. Convery,[67] J. C. Dingfelder,[67] J. Dorfan,[67] G. P. Dubois-Felsmann,[67] W. Dunwoodie,[67] R. C. Field,[67] S. J. Gowdy,[67] M. T. Graham,[67] P. Grenier,[67] C. Hast,[67] W. R. Innes,[67] J. Kaminski,[67] M. H. Kelsey,[67] H. Kim,[67] P. Kim,[67] M. L. Kocian,[67] D. W. G. S. Leith,[67] S. Li,[67] B. Lindquist,[67] S. Luitz,[67] V. Luth,[67] H. L. Lynch,[67] D. B. MacFarlane,[67] H. Marsiske,[67] R. Messner,[67] D. R. Muller,[67] H. Neal,[67] S. Nelson,[67] C. P. O'Grady,[67] I. Ofte,[67] A. Perazzo,[67] M. Perl,[67] B. N. Ratcliff,[67] A. Roodman,[67] A. A. Salnikov,[67] R. H. Schindler,[67] J. Schwiening,[67] A. Snyder,[67] D. Su,[67] M. K. Sullivan,[67] K. Suzuki,[67] S. K. Swain,[67] J. M. Thompson,[67] J. Va'vra,[67] A. P. Wagner,[67] M. Weaver,[67] C. A. West,[67] W. J. Wisniewski,[67] M. Wittgen,[67] D. H. Wright,[67] H. W. Wulsin,[67] A. K. Yarritu,[67] K. Yi,[67] C. C. Young,[67] V. Ziegler,[67] P. R. Burchat,[68] A. J. Edwards,[68] S. A. Majewski,[68] T. S. Miyashita,[68] B. A. Petersen,[68] L. Wilden,[68] S. Ahmed,[69] M. S. Alam,[69] R. Bula,[69] J. A. Ernst,[69] B. Pan,[69] M. A. Saeed,[69] S. B. Zain,[69] S. M. Spanier,[70] B. J. Wogsland,[70] R. Eckmann,[71] J. L. Ritchie,[71] A. M. Ruland,[71] C. J. Schilling,[71] R. F. Schwitters,[71] B. W. Drummond,[72] J. M. Izen,[72] X. C. Lou,[72] S. Ye,[72] F. Bianchi,[73] D. Gamba,[73] M. Pelliccioni,[73] M. Bomben,[74] L. Bosisio,[74] C. Cartaro,[74] G. Della Ricca,[74] L. Lanceri,[74] L. Vitale,[74] V. Azzolini,[75] N. Lopez-March,[75] F. Martinez-Vidal,[75] D. A. Milanes,[75] A. Oyanguren,[75] J. Albert,[76] Sw. Banerjee,[76] B. Bhuyan,[76] H. H. F. Choi,[76] K. Hamano,[76] R. Kowalewski,[76] M. J. Lewczuk,[76] I. M. Nugent,[76] J. M. Roney,[76] R. J. Sobie,[76] T. J. Gershon,[77] P. F. Harrison,[77] J. Ilic,[77] T. E. Latham,[77] G. B. Mohanty,[77] H. R. Band,[78] X. Chen,[78] S. Dasu,[78] K. T. Flood,[78] Y. Pan,[78] M. Pierini,[78] R. Prepost,[78] C. O. Vuosalo,[78] and S. L. Wu[78]

(*BABAR* Collaboration)

[1]*Laboratoire de Physique des Particules, IN$_2$P$_3$/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]*University of Bergen, Institute of Physics, N-5007 Bergen, Norway*
[5]*Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720, USA*
[6]*University of Birmingham, Birmingham, B15 2TT, United Kingdom*
[7]*Ruhr Universität Bochum, Institut für Experimentalphysik 1, D-44780 Bochum, Germany*
[8]*University of Bristol, Bristol BS8 1TL, United Kingdom*
[9]*University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z1*
[10]*Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom*
[11]*Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia*
[12]*University of California at Irvine, Irvine, California 92697, USA*
[13]*University of California at Los Angeles, Los Angeles, California 90024, USA*
[14]*University of California at Riverside, Riverside, California 92521, USA*
[15]*University of California at San Diego, La Jolla, California 92093, USA*
[16]*University of California at Santa Barbara, Santa Barbara, California 93106, USA*
[17]*University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, California 95064, USA*
[18]*California Institute of Technology, Pasadena, California 91125, USA*
[19]*University of Cincinnati, Cincinnati, Ohio 45221, USA*
[20]*University of Colorado, Boulder, Colorado 80309, USA*
[21]*Colorado State University, Fort Collins, Colorado 80523, USA*
[22]*Technische Universität Dortmund, Fakultät Physik, D-44221 Dortmund, Germany*
[23]*Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany*
[24]*Laboratoire Leprince-Ringuet, CNRS/IN$_2$P$_3$, Ecole Polytechnique, F-91128 Palaiseau, France*
[25]*University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom*
[26]*Università di Ferrara, Dipartimento di Fisica and INFN, I-44100 Ferrara, Italy*
[27]*Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy*
[28]*Università di Genova, Dipartimento di Fisica and INFN, I-16146 Genova, Italy*
[29]*Harvard University, Cambridge, Massachusetts 02138, USA*
[30]*Universität Heidelberg, Physikalisches Institut, Philosophenweg 12, D-69120 Heidelberg, Germany*
[31]*Imperial College London, London, SW7 2AZ, United Kingdom*
[32]*University of Iowa, Iowa City, Iowa 52242, USA*
[33]*Iowa State University, Ames, Iowa 50011-3160, USA*

[34]*Johns Hopkins University, Baltimore, Maryland 21218, USA*
[35]*Universität Karlsruhe, Institut für Experimentelle Kernphysik, D-76021 Karlsruhe, Germany*
[36]*Laboratoire de l'Accélérateur Linéaire, IN$_2$P$_3$/CNRS et Université Paris-Sud 11, Centre Scientifique d'Orsay, B. P. 34, F-91898 ORSAY Cedex, France*
[37]*Lawrence Livermore National Laboratory, Livermore, California 94550, USA*
[38]*University of Liverpool, Liverpool L69 7ZE, United Kingdom*
[39]*Queen Mary, University of London, E1 4NS, United Kingdom*
[40]*University of London, Royal Holloway and Bedford New College, Egham, Surrey TW20 0EX, United Kingdom*
[41]*University of Louisville, Louisville, Kentucky 40292, USA*
[42]*University of Manchester, Manchester M13 9PL, United Kingdom*
[43]*University of Maryland, College Park, Maryland 20742, USA*
[44]*University of Massachusetts, Amherst, Massachusetts 01003, USA*
[45]*Massachusetts Institute of Technology, Laboratory for Nuclear Science, Cambridge, Massachusetts 02139, USA*
[46]*McGill University, Montréal, Québec, Canada H3A 2T8*
[47]*Università di Milano, Dipartimento di Fisica and INFN, I-20133 Milano, Italy*
[48]*University of Mississippi, University, Mississippi 38677, USA*
[49]*Université de Montréal, Physique des Particules, Montréal, Québec, Canada H3C 3J7*
[50]*Mount Holyoke College, South Hadley, Massachusetts 01075, USA*
[51]*Università di Napoli Federico II, Dipartimento di Scienze Fisiche and INFN, I-80126, Napoli, Italy*
[52]*NIKHEF, National Institute for Nuclear Physics and High Energy Physics, NL-1009 DB Amsterdam, The Netherlands*
[53]*University of Notre Dame, Notre Dame, Indiana 46556, USA*
[54]*Ohio State University, Columbus, Ohio 43210, USA*
[55]*University of Oregon, Eugene, Oregon 97403, USA*
[56]*Università di Padova, Dipartimento di Fisica and INFN, I-35131 Padova, Italy*
[57]*Laboratoire de Physique Nucléaire et de Hautes Energies, IN$_2$P$_3$/CNRS, Université Pierre et Marie Curie-Paris6, Université Denis Diderot-Paris7, F-75252 Paris, France*
[58]*University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA*
[59]*Università di Perugia, Dipartimento di Fisica and INFN, I-06100 Perugia, Italy*
[60]*Università di Pisa, Dipartimento di Fisica, Scuola Normale Superiore and INFN, I-56127 Pisa, Italy*
[61]*Princeton University, Princeton, New Jersey 08544, USA*
[62]*Università di Roma La Sapienza, Dipartimento di Fisica and INFN, I-00185 Roma, Italy*
[63]*Universität Rostock, D-18051 Rostock, Germany*
[64]*Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingdom*
[65]*DSM/Dapnia, CEA/Saclay, F-91191 Gif-sur-Yvette, France*
[66]*University of South Carolina, Columbia, South Carolina 29208, USA*
[67]*Stanford Linear Accelerator Center, Stanford, California 94309, USA*
[68]*Stanford University, Stanford, California 94305-4060, USA*
[69]*State University of New York, Albany, New York 12222, USA*
[70]*University of Tennessee, Knoxville, Tennessee 37996, USA*
[71]*University of Texas at Austin, Austin, Texas 78712, USA*
[72]*University of Texas at Dallas, Richardson, Texas 75083, USA*
[73]*Università di Torino, Dipartimento di Fisica Sperimentale and INFN, I-10125 Torino, Italy*
[74]*Università di Trieste, Dipartimento di Fisica and INFN, I-34127 Trieste, Italy*
[75]*IFIC, Universitat de Valencia-CSIC, E-46071 Valencia, Spain*
[76]*University of Victoria, Victoria, British Columbia, Canada V8W 3P6*
[77]*Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom*
[78]*University of Wisconsin, Madison, Wisconsin 53706, USA*

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We present measurements of the decays $B^+ \to X(3872)K^+$ and $B^0 \to X(3872)K^0$ with $X(3872) \to J/\psi\pi^+\pi^-$. The data sample used, collected with the *BABAR* detector at the PEP-II e^+e^- asymmetric-energy storage ring, corresponds to $455 \times 10^6 B\bar{B}$ pairs. Branching fraction measurements of $\mathcal{B}(B^+ \to X(3872)K^+) \times \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) = (8.4 \pm 1.5 \pm 0.7) \times 10^{-6}$ and $\mathcal{B}(B^0 \to X(3872)K^0) \times \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) = (3.5 \pm 1.9 \pm 0.4) \times 10^{-6}$ are obtained. We set an upper limit on the natural width of the $X(3872)$ of $\Gamma < 3.3$ MeV/c^2 at the 90% confidence level.

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[*] Deceased.
[†] Now at Temple University, Philadelphia, PA 19122, USA.
[‡] Now at Tel Aviv University, Tel Aviv, 69978, Israel.
[§] Also with Università di Perugia, Dipartimento di Fisica, Perugia, Italy.
[‖] Also with Università di Sassari, Sassari, Italy.

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The $X(3872)$ was discovered in 2003 by the Belle Collaboration [1] which reported the observation of a narrow resonance in exclusive $B^{\pm}$ decays to $K^{\pm}(J/\psi\pi^+\pi^-)$. The new state was then confirmed by CDF [2], D0 [3], and *BABAR* [4,5].

There has been great interest in this narrow state, with numerous theoretical interpretations having been proposed, including a $\bar{D}^0D^{*0}$ molecule, a diquark-antidiquark, a tetraquark state, a hybrid charmonium, or a classical charmonium state. The diquark-antidiquark model [6] predicts the $X(3872)$ states to be produced at equal rates in B^0 and B^+ decays with a mass difference of (8 ± 3) MeV$/c^2$. The S-wave molecule model [7] predicts the neutral B branching fraction to be much smaller than the charged B one.

Studies of angular distributions by CDF [8] favor the quantum number assignment $J^{PC} = 1^{++}$ or 2^{-+}.

The X(3872) has also been observed in the $X(3872) \rightarrow J/\psi\gamma$ decay mode by *BABAR* [9], indicating that it must have positive C-parity. Therefore, the $\pi^+\pi^-$ pair in the $X(3872) \rightarrow J/\psi\pi^+\pi^-$ must have a negative C-parity and an odd orbital angular momentum L, to satisfy $C(\pi^+\pi^-) = -1 = (-1)^{L+S}$, with $S = 0$. The $\pi^+\pi^-$ invariant mass distribution has been studied by CDF [10], and found to be consistent with a ρ^0 meson, where the J/ψ and the ρ^0 are in a relative S-wave.

Both *BABAR* [11] and Belle [12] have observed the $X(3872) \rightarrow \bar{D}^0D^{*0}$ decay. These searches were motivated by the fact that the $X(3872)$ was barely above the $\bar{D}^0D^{*0}$ mass threshold. The mass measurement results are very consistent between the two experiments but are about 3 MeV$/c^2$ (representing $\simeq 4$ standard deviations) above the mass measured in the $J/\psi\pi^+\pi^-$ decay mode.

We report herein an analysis of $B^+ \rightarrow X(3872)K^+$ and $B^0 \rightarrow X(3872)K^0$, with $X(3872) \rightarrow J/\psi\pi^+\pi^-$, where charge conjugation is implied throughout. We present updated branching fractions for the two channels and extract the mass and width of the $X(3872)$ state. The data sample used for this analysis, collected by the *BABAR* detector at the PEP-II asymmetric-energy e^+e^- storage ring operated at the Stanford Linear Accelerator Center, corresponds to a total integrated luminosity of 413 fb^{-1}, recorded at the $\Upsilon(4S)$ resonance.

The *BABAR* detector is described in detail in Ref. [13]. Charged particle momenta are measured with a 5-layer double-sided silicon vertex tracker (SVT) and a 40-layer drift chamber (DCH) inside a 1.5-T superconducting solenoidal magnetic field. A calorimeter consisting of 6580 CsI (Tl) crystals (EMC) is used to measure electromagnetic energy. A ring-imaging Cherenkov detector (DIRC) is used to identify charged hadrons, aided by the dE/dx measurement in SVT and DCH. Muons are identified by the instrumented magnetic flux return (IFR). Particle attributes are reconstructed in the laboratory frame and then boosted to the e^+e^- center-of-mass (CM) frame using the asymmetric beam energy information. We use a GEANT 4 [14] Monte Carlo simulation (MC) to estimate the signal efficiencies, employing a sample in which one of the generated B mesons decays to the signal mode and the other to a representative sample of B decays.

Charged particles are required to have transverse momenta greater than 100 MeV$/c$ in the laboratory frame. The distance of closest approach of charged tracks must be within ± 10 cm of the z coordinate (along the beam axis) of the primary vertex and within a circle of radius 1.5 cm in the x-y plane. Kaons, electrons, and muons are separated from pions based on information from the IFR and DIRC, energy loss in the SVT and DCH (dE/dx), and the ratio of the associated EMC energy deposition (E_{cal}) to its momentum (E_{cal}/p).

The $B^+ \rightarrow J/\psi\pi^+\pi^-K^+$ and $B^0 \rightarrow J/\psi\pi^+\pi^-K^0_S$ decays are reconstructed as follows. Electrons and bremsstrahlung photons satisfying $2.95 < m(e^+e^-(\gamma)) < 3.14$ GeV$/c^2$ are used to form $J/\psi \rightarrow e^+e^-$ candidates. Photons are reconstructed from EMC clusters. The lateral energy profile (LAT) [15] is used to discriminate electromagnetic from hadronic clusters. Photons are required to have a minimum energy of 30 MeV, to satisfy LAT < 0.8, and to be in the fiducial volume $0.41 < \theta < 2.41$ rad. A pair of muons within the mass interval $3.06 < m(\mu^+\mu^-) < 3.14$ GeV$/c^2$ is required for a $J/\psi \rightarrow \mu^+\mu^-$ candidate. A mass constraint to the nominal J/ψ mass [16] is imposed in the fit of the lepton pairs. We reconstruct $K^0_S \rightarrow \pi^+\pi^-$ candidates from pairs of oppositely charged tracks forming a vertex with a χ^2 probability greater than 0.1%, a flight-length (l) significance $l/\sigma(l) > 16$ (where $\sigma(l)$ is the measurement error), and an invariant mass within 15 MeV$/c^2$ of the nominal K^0_S mass [16]. We form $X(3872)$ candidates by combining J/ψ candidates with two oppositely charged pion candidates, all fitted to a common vertex. Finally, we form $B^+(B^0)$ candidates by combining $X(3872)$ candidates with $K^+(K^0_S)$ candidates. To suppress continuum background, we select only events with a ratio of the second to the zeroth Fox-Wolfram moment [17] less than 0.5.

We use two kinematic variables to identify signal events coming from B decays: the difference between the energy of the B candidate and the beam energy, $\Delta \mathrm{E} = E^*_B - \sqrt{s}/2$, and the energy-substituted mass $\mathrm{m_{ES}} = \sqrt{(s/2 + \mathbf{p}_i \cdot \mathbf{p}_B)^2/E_i^2 - \mathbf{p}_B^2}$. Here $(E_i, \mathbf{p}_i)$ is the four-vector (in the laboratory frame) and $\sqrt{s}$ is the center-of-mass energy of the e^+e^- system, E^*_B is the energy of the B candidate in the CM system, and $\mathbf{p}_B$ the momentum in the laboratory frame. The signature of signal events is $\Delta E \approx 0$, and $\mathrm{m_{ES}} \approx m_B$, where m_B is the nominal mass of the B meson [16].

If there are multiple candidates in a single event (about 9% of the events), we select the candidate with the smallest value of $|\Delta E|$. We optimize the signal selection criteria by maximizing the ratio $n_s^{\rm mc}/(a/2 + \sqrt{n_b^{\rm mc}})$ [18], where $a = 3$ represents the desired significance of signal-to-background ratio in the number of sigmas and $n_s^{\rm mc}$ ($n_b^{\rm mc}$) are the number of reconstructed MC signal (background) events. The optimization is performed by varying the selected ranges of ΔE, $|m_{\rm ES} - m_B|$, $X(3872)$, and K_S^0 candidate masses, the K_S^0 flight significance, and the particle identification (PID) selection requirements for the leptons, pions, and charged kaons. The criteria $|\Delta E| < 20$ MeV and $|m_{\rm ES} - m_B| < 6\ {\rm MeV}/c^2$, which represent about 3 standard deviations of the resolution of the quantities, were found to be optimal for selecting signal events.

We extract the number of signal events with an extended, unbinned maximum-likelihood fit to the m_X distribution, where m_X is the $J/\psi\pi^+\pi^-$ invariant mass.

The probability density function (PDF), normalized to the total number of events, is $\mathcal{P}(m_X) = \sum_t n_t \mathcal{P}_t(m_X)$ where n_t is the number of events of category t and $\mathcal{P}_t$ is the associated PDF. We consider only two different event categories: signal and combinatorial background (which arises mainly from B decays). The signal PDF is modeled by a Lorentzian function that describes both the natural width and the experimental resolution. We model combinatorial background events by a linear function in m_X. For the neutral mode fit, the width of the Lorentzian has been fixed to the value obtained from the charged mode fit.

The fit is performed in the region $3.8 < m_X < 4.0\ {\rm GeV}/c^2$, after applying the optimized selection criteria on all other variables. The signal region projections of the one-dimensional fit to the data are shown in Fig. 1 for the B^+ (top) and B^0 (bottom) modes. We obtain 93.4 ± 17.2 signal events for the B^+ mode (n_s^+) and 9.4 ± 5.2 signal events for the B^0 mode (n_s^0). We interpret the observed events in either mode as the $X(3872)$. Results are summarized in Table I. We fit the $J/\psi\pi^+\pi^-$ system invariant mass in the $m_{\rm ES}$ sideband region ($m_{\rm ES} < 5.27\ {\rm GeV}/c^2$) and observe no signal.

TABLE I. Fit results for both $B^+ \to X(3872)K^+$ and $B^0 \to X(3872)K_S^0$ modes. In the fit to the B^0 mode, the width is fixed to the value obtained from the B^+ mode. Errors are statistical only. The mass measurements are subsequently corrected.

	$B^+ \to X(3872)K^+$	$B^0 \to X(3872)K_S^0$
Parameters		
$m_{X,\rm fit}$	3870.86 ± 0.60	3868.13 ± 1.53
m_X Lorentz $\Gamma_{\rm fit}$	5.43 ± 1.52	Fixed to 5.43
Linear background slope	-0.30 ± 0.04	-0.28 ± 0.03
Yields		
Signal n_S	93.4 ± 17.2	9.4 ± 5.2

The efficiency is determined from MC samples with a $X(3872)$ signal of zero natural width at $3.872\ {\rm GeV}/c^2$. The decay model consists of the sequential isotropic decays $B \to X(3872)K$, $X(3872) \to J/\psi\rho^0$, and $\rho^0 \to \pi^+\pi^-$. This yields a more accurate description of the observed $\pi^+\pi^-$ invariant mass distribution [4], compared to a three-body decay. Efficiencies are corrected for the small differences (0.3%) in K_S^0 reconstruction efficiencies that are found by comparing data and MC control samples. The final reconstruction efficiencies are $(20.60 \pm 0.10)\%$ for the $B^+ \to X(3872)K^+$ mode and $(14.50 \pm 0.09)\%$ for the $B^0 \to X(3872)K_S^0$ mode, where the errors are dominated by the size of the signal MC samples.

The fit is validated with MC experiments, where we embed samples of the number of expected signal events into MC background samples. On average, the number of signal events found is in good agreement with the signal sample size. The fit is further validated with a set of parametrized MC experiments, based on the signal PDF parameters, which return the number of input signal events with no significant bias.

The systematic errors on the branching fraction are summarized in Table II. They include uncertainties in the number of $B\bar{B}$ events, secondary branching fractions [16], efficiency calculations due to limited MC statistics, the MC decay model of the $X(3872)$, PID, charged particle track-

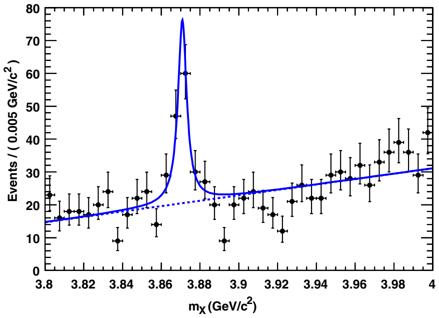

FIG. 1 (color online). Fits to the $m(J/\psi\pi^+\pi^-)$ distributions of (top) $B^+ \to X(3872)K^+$ and (bottom) $B^0 \to X(3872)K_S^0$ candidates drawn from the 413 fb^{-1} sample. The dashed line represents the combinatorial background PDF and the solid line the sum of background plus the signal PDF.

ing, K_S^0 reconstruction, background modelling (BM), and those arising from fixing the width in the $B^0 \to X(3872)K_S^0$ mode. The production ratio of B^0 and B^+ mesons in $\Upsilon(4S)$ decays is taken to be 1.031 ± 0.033 [16].

The total fractional errors, 8.8% and 11.7% for the B^+ and B^0 modes, respectively, are obtained by adding the uncertainties in Table II in quadrature.

The significance is estimated as $\sqrt{-2\ln(\mathcal{L}_0/\mathcal{L}_{\max})}$ where $\mathcal{L}_{\max}$ and $\mathcal{L}_0$ are likelihoods returned by the nominal fit and by the fit with the signal yield fixed at zero. The estimated statistical significance of each signal is 8.6σ and 2.3σ, for the B^+ and B^0 modes, respectively.

Using n_s^0 and n_s^-, the efficiencies, the secondary branching fractions, and the number of $B\bar{B}$ events, we obtain the branching fractions $\mathcal{B}(B^0 \to X(3872)K^0) \times \mathcal{B}(X \to J/\psi\pi^+\pi^-) = (3.5 \pm 1.9 \pm 0.4) \times 10^{-6}$ and $\mathcal{B}(B^+ \to X(3872)K^+) \times \mathcal{B}(X \to J/\psi\pi^+\pi^-) = (8.4 \pm 1.5 \pm 0.7) \times 10^{-6}$. We also calculate a 90% confidence level (C.L.) upper limit on the neutral branching fraction as $\mathcal{B}(B^0 \to X(3872)K^0) \times \mathcal{B}(X \to J/\psi\pi^+\pi^-) < 6.0 \times 10^{-6}$ (90%, C.L.). For the ratio of branching fractions, in which most of the systematic errors cancel, we obtain

$$R(X) = \frac{\mathcal{B}(B^0 \to X(3872)K^0}{\mathcal{B}(B^+ \to X(3872)K^+)} = 0.41 \pm 0.24 \pm 0.05,$$

where the first (second) uncertainty is statistical (systematic). Assuming Gaussian errors, we calculate the upper limit $R(X) < 0.73$ at 90% C.L.

We use the $B^+ \to \psi(2S)\ K^+$ and $B^0 \to \psi(2S)\ K^0$ decays, with $\psi(2S) \to J/\psi\pi^+\pi^-$, in the $\psi(2S)$ mass region [16] as control modes. We measure the branching fractions and obtain the ratio of neutral to charged branching fractions $R(\psi(2S)) = 0.81 \pm 0.05 \pm 0.01$, in agreement with the world average of 0.96 ± 0.11 [16]. We also use these control modes to correct the $X(3872)$ mass. We fit the $J/\psi\pi^+\pi^-$ invariant mass in the $\psi(2S)$ and $X(3872)$ region. We correct the $X(3872)$ mass measurement, $m_{X,\mathrm{fit}}$, by the difference between the $\psi(2S)$ world average mass [16], $m_{\psi(2S)}$, and its measured mass, $m_{\psi(2S),\mathrm{fit}}$, which yields $m_X = m_{X,\mathrm{fit}} - m_{\psi(2S),\mathrm{fit}} + m_{\psi(2S)}$. The result for the B^+ mode is $(3871.4 \pm 0.6 \pm 0.1)\ \mathrm{MeV}/c^2$ and $(3868.7 \pm 1.5 \pm 0.4)\ \mathrm{MeV}/c^2$ for the B^0 mode, where the first error is the statistical uncertainty on $m_{X,\mathrm{fit}}$ and the second is the uncertainty on $m_{\psi(2S),\mathrm{fit}}$ and $m_{\psi(2S)}$. In the neutral mode we have also included an uncertainty that arises from fixing the width to the value obtained from the charged mode. The mass difference of the $X(3872)$ states produced in B^0 and B^+ decays is $\Delta m = (2.7 \pm 1.6 \pm 0.4)\ \mathrm{MeV}/c^2$.

TABLE II. Summary of (fractional) systematic uncertainties on the branching fraction measurements for both modes.

	$B^+ \to X(3872)K^+$	$B^0 \to X(3872)K_S^0$
Tracking	1.8	1.4
K_S^0 correction	n/a	0.7
PID	1.9	1.4
MC model	1.3	0.9
B counting	1.1	1.1
MC statistics	0.5	0.6
Secondary BF	3.3	3.3
BM	7.5	4.2
Fixed width	n/a	10.1
Total fractional error	8.8	11.7

The natural width Γ_X of the $X(3872)$ is obtained using the B^+ mode by subtracting the full width at half maximum of the resolution function measured from MC Γ_{Res} from the data Γ_{fit}, $\Gamma_X = \Gamma_{\mathrm{fit}} - \Gamma_{\mathrm{Res}}$, with both the resolution and the natural width of the $X(3872)$ parametrized by a Lorenztian function. We estimate a systematic error on the width by comparing the nominal value to the value determined when using a two-Gaussian resolution function. We determine the natural width of the $X(3872)$ to be $(1.1 \pm 1.5 \pm 0.2)\ \mathrm{MeV}/c^2$, where the first uncertainty is statistical and the second systematic. From this result we calculate the 90% C.L. upper limit on the natural width $\Gamma_X < 3.3\ \mathrm{MeV}/c^2$.

In summary, we have performed an updated study of the decays $B^+ \to X(3872)K^+$ and $B^0 \to X(3872)K^0$ with $X(3872) \to J/\psi\pi^+\pi^-$. The branching fraction measurements in the B^+ and B^0 modes are in good agreement with previous results, with comparable or better errors. The ratio of the branching fractions is $R = 0.41 \pm 0.24 \pm 0.05$ and the observed mass difference is $\Delta m = (2.7 \pm 1.6 \pm 0.4)\ \mathrm{MeV}/c^2$, consistent with either the molecular or diquark-antidiquark model within 2 standard deviations. Finally, we provide an updated upper limit of the natural width of the $X(3872)$, $\Gamma_X < 3.3\ \mathrm{MeV}/c^2$ (90%, C.L.).

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[1] S. K. Choi *et al.* (Belle Collaboration), Phys. Rev. Lett. **91**, 262001 (2003).

[2] D. Acosta *et al.* (CDF Collaboration), Phys. Rev. Lett. **93**, 072001 (2004).

[3] V. M. Abazov *et al.* (D0 Collaboration), Phys. Rev. Lett. **93**, 162001 (2004).

[4] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **71**, 071103 (2005).

[5] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **73**, 011101(R) (2006).

[6] L. Maiani, F. Piccinini, A. D. Polosa, and V. Riquer, Phys. Rev. D **71**, 014028 (2005).

[7] E. Braaten and M. Kusunoki, Phys. Rev. D **71**, 074005 (2005).

[8] D. Acosta *et al.* (CDF Collaboration), Phys. Rev. Lett. **98**, 132002 (2007).

[9] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **74**, 071101 (2006).

[10] D. Acosta *et al.* (CDF Collaboration), Phys. Rev. Lett. **96**, 102002 (2006).

[11] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **77**, 011102 (2008).

[12] S. K. Choi *et al.* (Belle Collaboration), Phys. Rev. Lett. **97**, 162002 (2006).

[13] B. Aubert *et al.* (*BABAR* Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **479**, 1 (2002).

[14] S. Agostinelli *et al.* (GEANT4 Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **462**, 152 (2001).

[15] A. Drescher *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **237**, 464 (1985).

[16] W.-M. Yao *et al.* (Particle Data Group), J. Phys. G **33**, 1 (2006).

[17] S. Wolfram and G. C. Fox, Nucl. Phys. **B149**, 413 (1979).

[18] G. Punzi, in Proceedings of the Conference on Statistical Problems in Particle Physics, Astrophysics and Cosmology, PHYSTAT2003, 2003, edited by L. Lyons, R. Mount, and R. Reitmeyer, eConf C030908, p. 79 (2003).