University of Nebraska - Lincoln
DigitalCommons@University of Nebraska - Lincoln

Kenneth Bloom Publications | Research Papers in Physics and Astronomy

1-23-2009

Measurement of the Angular and Lifetime Parameters of the Decays $B_d^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\varphi\psi$

V. M. Abazov
Joint Institute for Nuclear Research, Dubna, Russia

Kenneth A. Bloom
University of Nebraska - Lincoln, kbloom2@unl.edu

Gregory Snow
University of Nebraska - Lincoln, gsnow1@unl.edu

D0 Collaboration

Follow this and additional works at: http://digitalcommons.unl.edu/physicsbloom

Part of the Physics Commons

Abazov, V. M.; Bloom, Kenneth A.; Snow, Gregory; and Collaboration, D0, "Measurement of the Angular and Lifetime Parameters of the Decays $B_d^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\varphi\psi$" (2009). *Kenneth Bloom Publications.* Paper 278.
http://digitalcommons.unl.edu/physicsbloom/278

This Article is brought to you for free and open access by the Research Papers in Physics and Astronomy at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Kenneth Bloom Publications by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

Measurement of the Angular and Lifetime Parameters of the Decays $B_d^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\psi \phi$

V. M. Abazov,[36] B. Abbott,[75] M. Abolins,[65] B. S. Acharya,[29] M. Adams,[51] T. Adams,[49] E. Aguilo,[6] M. Ahsan,[59] G. D. Alexeev,[36] G. Alkhazov,[40] A. Alton,[64,*] G. Alverson,[63] G. A. Alves,[2] M. Anastasoaie,[35] L. S. Ancu,[35] T. Andeen,[53] B. Andrieu,[17] M. S. Anzelc,[53] M. Aoki,[50] Y. Arnoud,[14] M. Arov,[60] M. Arthaud,[18] A. Askew,[49] B. Åsman,[41] A. C. S. Assis Jesus,[3] O. Atramentov,[49] C. Avila,[8] F. Badaud,[13] L. Bagby,[50] B. Baldin,[50] D. V. Bandurin,[59] P. Banerjee,[29] S. Banerjee,[29] E. Barberis,[63] A.-F. Barfuss,[15] P. Bargassa,[80] P. Baringer,[58] J. Barreto,[2] J. F. Bartlett,[50] U. Bassler,[18] D. Bauer,[43] S. Beale,[6] A. Bean,[58] M. Begalli,[3] M. Begel,[73] C. Belanger-Champagne,[41] L. Bellantoni,[50] A. Bellavance,[50] J. A. Benitez,[65] S. B. Beri,[27] G. Bernardi,[17] R. Bernhard,[23] I. Bertram,[42] M. Besançon,[18] R. Beuselinck,[43] V. A. Bezzubov,[39] P. C. Bhat,[50] V. Bhatnagar,[27] C. Biscarat,[20] G. Blazey,[52] F. Blekman,[43] S. Blessing,[49] K. Bloom,[67] A. Boehnlein,[50] D. Boline,[62] T. A. Bolton,[59] E. E. Boos,[38] G. Borissov,[42] T. Bose,[77] A. Brandt,[78] R. Brock,[65] G. Brooijmans,[70] A. Bross,[50] D. Brown,[81] X. B. Bu,[7] N. J. Buchanan,[49] D. Buchholz,[53] M. Buehler,[81] V. Buescher,[22] V. Bunichev,[38] S. Burdin,[42,†] T. H. Burnett,[82] C. P. Buszello,[43] J. M. Butler,[62] P. Calfayan,[25] S. Calvet,[16] J. Cammin,[71] M. A. Carrasco-Lizarraga,[33] E. Carrera,[49] W. Carvalho,[3] B. C. K. Casey,[50] H. Castilla-Valdez,[33] S. Chakrabarti,[18] D. Chakraborty,[52] K. M. Chan,[55] A. Chandra,[48] E. Cheu,[45] F. Chevallier,[14] D. K. Cho,[62] S. Choi,[32] B. Choudhary,[28] L. Christofek,[77] T. Christoudias,[43] S. Cihangir,[50] D. Claes,[67] J. Clutter,[58] M. Cooke,[50] W. E. Cooper,[50] M. Corcoran,[80] F. Couderc,[18] M.-C. Cousinou,[15] S. Crépé-Renaudin,[14] V. Cuplov,[59] D. Cutts,[77] M. Ćwiok,[30] H. da Motta,[2] A. Das,[45] G. Davies,[43] K. De,[78] S. J. de Jong,[35] E. De La Cruz-Burelo,[33] C. De Oliveira Martins,[3] K. DeVaughan,[67] F. Déliot,[18] M. Demarteau,[50] R. Demina,[71] D. Denisov,[50] S. P. Denisov,[39] S. Desai,[50] H. T. Diehl,[50] M. Diesburg,[50] A. Dominguez,[67] T. Dorland,[82] A. Dubey,[28] L. V. Dudko,[38] L. Duflot,[16] S. R. Dugad,[29] D. Duggan,[49] A. Duperrin,[15] J. Dyer,[65] A. Dyshkant,[52] M. Eads,[67] D. Edmunds,[65] J. Ellison,[48] V. D. Elvira,[50] Y. Enari,[77] S. Eno,[61] P. Ermolov,[38,§§] H. Evans,[54] A. Evdokimov,[73] V. N. Evdokimov,[39] A. V. Ferapontov,[59] T. Ferbel,[71] F. Fiedler,[24] F. Filthaut,[35] W. Fisher,[50] H. E. Fisk,[50] M. Fortner,[52] H. Fox,[42] S. Fu,[50] S. Fuess,[50] T. Gadfort,[70] C. F. Galea,[35] C. Garcia,[71] A. Garcia-Bellido,[71] G. A. Garcia-Guerra,[33] V. Gavrilov,[37] P. Gay,[13] W. Geist,[19] W. Geng,[15,65] C. E. Gerber,[51] Y. Gershtein,[49,‡] D. Gillberg,[6] G. Ginther,[71] B. Gómez,[8] A. Goussiou,[82] P. D. Grannis,[72] H. Greenlee,[50] Z. D. Greenwood,[60] E. M. Gregores,[4] G. Grenier,[20] Ph. Gris,[13] J.-F. Grivaz,[16] A. Grohsjean,[25] S. Grünendahl,[50] M. W. Grünewald,[30] F. Guo,[72] J. Guo,[72] G. Gutierrez,[50] P. Gutierrez,[75] A. Haas,[70] N. J. Hadley,[61] P. Haefner,[25] S. Hagopian,[49] J. Haley,[68] I. Hall,[65] R. E. Hall,[47] L. Han,[7] K. Harder,[44] A. Harel,[71] J. M. Hauptman,[57] J. Hays,[43] T. Hebbeker,[21] D. Hedin,[52] J. G. Hegeman,[34] A. P. Heinson,[48] U. Heintz,[62] C. Hensel,[22,§] K. Herner,[72] G. Hesketh,[63] M. D. Hildreth,[55] R. Hirosky,[81] J. D. Hobbs,[72] B. Hoeneisen,[12] M. Hohlfeld,[22] S. Hossain,[75] P. Houben,[34] Y. Hu,[72] Z. Hubacek,[10] V. Hynek,[9] I. Iashvili,[69] R. Illingworth,[50] A. S. Ito,[50] S. Jabeen,[62] M. Jaffré,[16] S. Jain,[75] K. Jakobs,[23] C. Jarvis,[61] R. Jesik,[43] K. Johns,[45] C. Johnson,[70] M. Johnson,[50] D. Johnston,[67] A. Jonckheere,[50] P. Jonsson,[43] A. Juste,[50] E. Kajfasz,[15] D. Karmanov,[38] P. A. Kasper,[50] I. Katsanos,[70] D. Kau,[49] V. Kaushik,[78] R. Kehoe,[79] S. Kermiche,[15] N. Khalatyan,[50] A. Khanov,[76] A. Kharchilava,[69] Y. M. Kharzheev,[36] D. Khatidze,[70] T. J. Kim,[31] M. H. Kirby,[53] M. Kirsch,[21] B. Klima,[50] J. M. Kohli,[27] E. V. Komissarov,[36,§§] J.-P. Konrath,[23] A. V. Kozelov,[39] J. Kraus,[65] T. Kuhl,[24] A. Kumar,[69] A. Kupco,[11] T. Kurča,[20] V. A. Kuzmin,[38] J. Kvita,[9] F. Lacroix,[13] D. Lam,[55] S. Lammers,[70] G. Landsberg,[77] P. Lebrun,[20] W. M. Lee,[50] A. Leflat,[38] J. Lellouch,[17] J. Li,[78,§§] L. Li,[48] Q. Z. Li,[50] S. M. Lietti,[5] J. K. Lim,[31] J. G. R. Lima,[52] D. Lincoln,[50] J. Linnemann,[65] V. V. Lipaev,[39] R. Lipton,[50] Y. Liu,[7] Z. Liu,[6] A. Lobodenko,[40] M. Lokajicek,[11] P. Love,[42] H. J. Lubatti,[82] R. Luna-Garcia,[33,‖] A. L. Lyon,[50] A. K. A. Maciel,[2] D. Mackin,[80] R. J. Madaras,[46] P. Mättig,[26] C. Magass,[21] A. Magerkurth,[64] P. K. Mal,[82] H. B. Malbouisson,[3] S. Malik,[67] V. L. Malyshev,[36] Y. Maravin,[59] B. Martin,[14] R. McCarthy,[72] M. M. Meijer,[35] A. Melnitchouk,[66] L. Mendoza,[8] P. G. Mercadante,[5] M. Merkin,[38] K. W. Merritt,[50] A. Meyer,[21] J. Meyer,[22,§] J. Mitrevski,[70] R. K. Mommsen,[44] N. K. Mondal,[29] R. W. Moore,[6] T. Moulik,[58] G. S. Muanza,[15] M. Mulhearn,[70] O. Mundal,[22] L. Mundim,[3] E. Nagy,[15] M. Naimuddin,[50] M. Narain,[77] N. A. Naumann,[35] H. A. Neal,[64] J. P. Negret,[8] P. Neustroev,[40] H. Nilsen,[23] H. Nogima,[3] S. F. Novaes,[5] T. Nunnemann,[25] V. O'Dell,[50] D. C. O'Neil,[6] G. Obrant,[40] C. Ochando,[16] D. Onoprienko,[59] N. Oshima,[50] N. Osman,[43] J. Osta,[55] R. Otec,[10] G. J. Otero y Garzón,[50] M. Owen,[44] P. Padley,[80] M. Pangilinan,[77] N. Parashar,[56] S.-J. Park,[22,§] S. K. Park,[31] J. Parsons,[70] R. Partridge,[77] N. Parua,[54] A. Patwa,[73] G. Pawloski,[80] B. Penning,[23] M. Perfilov,[38] K. Peters,[44] Y. Peters,[26] P. Pétroff,[16] M. Petteni,[43] R. Piegaia,[1] J. Piper,[65] M.-A. Pleier,[22] P. L. M. Podesta-Lerma,[33,¶] V. M. Podstavkov,[50] Y. Pogorelov,[55] M.-E. Pol,[2] P. Polozov,[37] B. G. Pope,[65] A. V. Popov,[39] C. Potter,[6] W. L. Prado da Silva,[3] H. B. Prosper,[49] S. Protopopescu,[73] J. Qian,[64] A. Quadt,[22,§]

 © 2009 The American Physical Society

B. Quinn,[66] A. Rakitine,[42] M. S. Rangel,[2] K. Ranjan,[28] P. N. Ratoff,[42] P. Renkel,[79] P. Rich,[44] M. Rijssenbeek,[72] I. Ripp-Baudot,[19] F. Rizatdinova,[76] S. Robinson,[43] R. F. Rodrigues,[3] M. Rominsky,[75] C. Royon,[18] P. Rubinov,[50] R. Ruchti,[55] G. Safronov,[37] G. Sajot,[14] A. Sánchez-Hernández,[33] M. P. Sanders,[17] B. Sanghi,[50] G. Savage,[50] L. Sawyer,[60] T. Scanlon,[43] D. Schaile,[25] R. D. Schamberger,[72] Y. Scheglov,[40] H. Schellman,[53] T. Schliephake,[26] S. Schlobohm,[82] C. Schwanenberger,[44] A. Schwartzman,[68] R. Schwienhorst,[65] J. Sekaric,[49] H. Severini,[75] E. Shabalina,[51] M. Shamim,[59] V. Shary,[18] A. A. Shchukin,[39] R. K. Shivpuri,[28] V. Siccardi,[19] V. Simak,[10] V. Sirotenko,[50] P. Skubic,[75] P. Slattery,[71] D. Smirnov,[55] G. R. Snow,[67] J. Snow,[74] S. Snyder,[73] S. Söldner-Rembold,[44] L. Sonnenschein,[17] A. Sopczak,[42] M. Sosebee,[78] K. Soustruznik,[9] B. Spurlock,[78] J. Stark,[14] V. Stolin,[37] D. A. Stoyanova,[39] J. Strandberg,[64] S. Strandberg,[41] M. A. Strang,[69] E. Strauss,[72] M. Strauss,[75] R. Ströhmer,[25] D. Strom,[53] L. Stutte,[50] S. Sumowidagdo,[49] P. Svoisky,[35] A. Sznajder,[3] A. Tanasijczuk,[1] W. Taylor,[6] B. Tiller,[25] F. Tissandier,[13] M. Titov,[18] V. V. Tokmenin,[36] I. Torchiani,[23] D. Tsybychev,[72] B. Tuchming,[18] C. Tully,[68] P. M. Tuts,[70] R. Unalan,[65] L. Uvarov,[40] S. Uvarov,[40] S. Uzunyan,[52] B. Vachon,[6] P. J. van den Berg,[34] R. Van Kooten,[54] W. M. van Leeuwen,[34] N. Varelas,[51] E. W. Varnes,[45] I. A. Vasilyev,[39] P. Verdier,[20] L. S. Vertogradov,[36] M. Verzocchi,[50] D. Vilanova,[18] F. Villeneuve-Seguier,[43] P. Vint,[43] P. Vokac,[10] M. Voutilainen,[67,**] R. Wagner,[68] H. D. Wahl,[49] M. H. L. S. Wang,[50] J. Warchol,[55] G. Watts,[82] M. Wayne,[55] G. Weber,[24] M. Weber,[50,††] L. Welty-Rieger,[54] A. Wenger,[23,‡‡] N. Wermes,[22] M. Wetstein,[61] A. White,[78] D. Wicke,[26] M. Williams,[42] G. W. Wilson,[58] S. J. Wimpenny,[48] M. Wobisch,[60] D. R. Wood,[63] T. R. Wyatt,[44] Y. Xie,[77] C. Xu,[64] S. Yacoob,[53] R. Yamada,[50] W.-C. Yang,[44] T. Yasuda,[50] Y. A. Yatsunenko,[36] H. Yin,[7] K. Yip,[73] H. D. Yoo,[77] S. W. Youn,[53] J. Yu,[78] C. Zeitnitz,[26] S. Zelitch,[81] T. Zhao,[82] B. Zhou,[64] J. Zhu,[72] M. Zielinski,[71] D. Zieminska,[54] A. Zieminski,[54,§§] L. Zivkovic,[70] V. Zutshi,[52] and E. G. Zverev[38]

(D0 Collaboration)

[1]*Universidad de Buenos Aires, Buenos Aires, Argentina*
[2]*LAFEX, Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil*
[3]*Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*
[4]*Universidade Federal do ABC, Santo André, Brazil*
[5]*Instituto de Física Teórica, Universidade Estadual Paulista, São Paulo, Brazil*
[6]*University of Alberta, Edmonton, Alberta, Canada, Simon Fraser University, Burnaby, British Columbia, Canada, York University, Toronto, Ontario, Canada, and McGill University, Montreal, Quebec, Canada*
[7]*University of Science and Technology of China, Hefei, People's Republic of China*
[8]*Universidad de los Andes, Bogotá, Colombia*
[9]*Center for Particle Physics, Charles University, Prague, Czech Republic*
[10]*Czech Technical University, Prague, Czech Republic*
[11]*Center for Particle Physics, Institute of Physics, Academy of Sciences of the Czech Republic, Prague, Czech Republic*
[12]*Universidad San Francisco de Quito, Quito, Ecuador*
[13]*LPC, Université Blaise Pascal, CNRS/IN2P3, Clermont, France*
[14]*LPSC, Université Joseph Fourier Grenoble 1, CNRS/IN2P3, Institut National Polytechnique de Grenoble, Grenoble, France*
[15]*CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France*
[16]*LAL, Université Paris-Sud, IN2P3/CNRS, Orsay, France*
[17]*LPNHE, IN2P3/CNRS, Universités Paris VI and VII, Paris, France*
[18]*CEA, Irfu, SPP, Saclay, France*
[19]*IPHC, Université Louis Pasteur, CNRS/IN2P3, Strasbourg, France*
[20]*IPNL, Université Lyon 1, CNRS/IN2P3, Villeurbanne, France and Université de Lyon, Lyon, France*
[21]*III. Physikalisches Institut A, RWTH Aachen University, Aachen, Germany*
[22]*Physikalisches Institut, Universität Bonn, Bonn, Germany*
[23]*Physikalisches Institut, Universität Freiburg, Freiburg, Germany*
[24]*Institut für Physik, Universität Mainz, Mainz, Germany*
[25]*Ludwig-Maximilians-Universität München, München, Germany*
[26]*Fachbereich Physik, University of Wuppertal, Wuppertal, Germany*
[27]*Panjab University, Chandigarh, India*
[28]*Delhi University, Delhi, India*
[29]*Tata Institute of Fundamental Research, Mumbai, India*
[30]*University College Dublin, Dublin, Ireland*
[31]*Korea Detector Laboratory, Korea University, Seoul, Korea*
[32]*SungKyunKwan University, Suwon, Korea*

[33]CINVESTAV, Mexico City, Mexico
[34]FOM-Institute NIKHEF and University of Amsterdam/NIKHEF, Amsterdam, The Netherlands
[35]Radboud University Nijmegen/NIKHEF, Nijmegen, The Netherlands
[36]Joint Institute for Nuclear Research, Dubna, Russia
[37]Institute for Theoretical and Experimental Physics, Moscow, Russia
[38]Moscow State University, Moscow, Russia
[39]Institute for High Energy Physics, Protvino, Russia
[40]Petersburg Nuclear Physics Institute, St. Petersburg, Russia
[41]Lund University, Lund, Sweden, Royal Institute of Technology and Stockholm University, Stockholm, Sweden, and Uppsala University, Uppsala, Sweden
[42]Lancaster University, Lancaster, United Kingdom
[43]Imperial College, London, United Kingdom
[44]University of Manchester, Manchester, United Kingdom
[45]University of Arizona, Tucson, Arizona 85721, USA
[46]Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720, USA
[47]California State University, Fresno, California 93740, USA
[48]University of California, Riverside, California 92521, USA
[49]Florida State University, Tallahassee, Florida 32306, USA
[50]Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA
[51]University of Illinois at Chicago, Chicago, Illinois 60607, USA
[52]Northern Illinois University, DeKalb, Illinois 60115, USA
[53]Northwestern University, Evanston, Illinois 60208, USA
[54]Indiana University, Bloomington, Indiana 47405, USA
[55]University of Notre Dame, Notre Dame, Indiana 46556, USA
[56]Purdue University Calumet, Hammond, Indiana 46323, USA
[57]Iowa State University, Ames, Iowa 50011, USA
[58]University of Kansas, Lawrence, Kansas 66045, USA
[59]Kansas State University, Manhattan, Kansas 66506, USA
[60]Louisiana Tech University, Ruston, Louisiana 71272, USA
[61]University of Maryland, College Park, Maryland 20742, USA
[62]Boston University, Boston, Massachusetts 02215, USA
[63]Northeastern University, Boston, Massachusetts 02115, USA
[64]University of Michigan, Ann Arbor, Michigan 48109, USA
[65]Michigan State University, East Lansing, Michigan 48824, USA
[66]University of Mississippi, University, Mississippi 38677, USA
[67]University of Nebraska, Lincoln, Nebraska 68588, USA
[68]Princeton University, Princeton, New Jersey 08544, USA
[69]State University of New York, Buffalo, New York 14260, USA
[70]Columbia University, New York, New York 10027, USA
[71]University of Rochester, Rochester, New York 14627, USA
[72]State University of New York, Stony Brook, New York 11794, USA
[73]Brookhaven National Laboratory, Upton, New York 11973, USA
[74]Langston University, Langston, Oklahoma 73050, USA
[75]University of Oklahoma, Norman, Oklahoma 73019, USA
[76]Oklahoma State University, Stillwater, Oklahoma 74078, USA
[77]Brown University, Providence, Rhode Island 02912, USA
[78]University of Texas, Arlington, Texas 76019, USA
[79]Southern Methodist University, Dallas, Texas 75275, USA
[80]Rice University, Houston, Texas 77005, USA
[81]University of Virginia, Charlottesville, Virginia 22901, USA
[82]University of Washington, Seattle, Washington 98195, USA
(Received 1 October 2008; published 20 January 2009)

We present measurements of the linear polarization amplitudes and the strong relative phases that describe the flavor-untagged decays $B_d^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\psi \phi$ in the transversity basis. We also measure the mean lifetime $\bar{\tau}_s$ of the B_s^0 mass eigenstates and the lifetime ratio $\bar{\tau}_s/\tau_d$. The analyses are based on approximately 2.8 fb^{-1} of data recorded with the D0 detector. From our measurements of the angular parameters we conclude that there is no evidence for a deviation from flavor SU(3) symmetry for these decays and that the factorization assumption is not valid for the $B_d^0 \to J/\psi K^{*0}$ decay.

DOI: 10.1103/PhysRevLett.102.032001 PACS numbers: 14.20.Mr, 13.25.Hw, 13.30.Eg, 14.40.Nd

B mesons are fertile ground to study CP violation and search for evidence of new physics. There are elements, in addition to CP violation, involved in the theoretical description of B meson decays, such as flavor SU(3) symmetry, factorization, and final-state strong interactions. To understand the role CP violation plays in these decays, it is essential to understand and isolate the effect of each of these elements in the B meson decays.

Factorization states that the decay amplitude of B meson decays can be expressed as the product of two single current matrix elements [1] and this implies that the relative strong phases are 0 (mod π) [2]. A different measured value for the strong phases would indicate the presence of final-state strong interactions. The B_d^0 meson can be formed by replacing the s quark with the d quark in the B_s^0 meson. From flavor SU(3) symmetry applied to the $B_d^0 - B_s^0$ system one expects that the theoretical description is similar; in particular, the $B_d^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\psi\phi$ [3] decays, can be described in the transversity basis [2] by the relative strong phases δ_1 and δ_2, and by the three independent components A_0, $A_\parallel$, and $A_\perp$. The components A_0 and $A_\parallel$ represent the CP-even and $A_\perp$ the CP-odd contributions to the decay amplitude.

Other observables of these decays are the lifetimes of both mesons, which allow us to compare with theoretical predictions of the lifetime ratio. Phenomenological models predict differences of about 1% [4,5] between the B_d^0 and B_s^0 lifetimes. Previous B meson lifetime measurements [6] are consistent with these predictions.

In this Letter we report the measurements of the parameters that describe the time-dependent angular distributions of the decays $B_d^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\psi\phi$ in the transversity basis, where the initial B meson flavor is not determined ("untagged"). We study the B_d^0 and B_s^0 mesons to verify the validity of the factorization assumption [2] and to check if flavor SU(3) symmetry [2] holds for these decays. We also report the lifetime ratio $\bar{\tau}_s/\tau_d$ for these mesons and the width difference $\Delta\Gamma_s$ between the light and heavy B_s^0 mass eigenstates. The analyses were performed using data collected with the D0 detector [7] in Run II of the Fermilab Tevatron Collider during 2003–2007 with an integrated luminosity of approximately 2.8 fb^{-1} of $p\bar{p}$ collisions at a center-of-mass energy of 1.96 TeV. In contrast with the flavor-tagged analysis reported in Ref. [8], in this Letter we report a simultaneous analysis of both the B_d^0 and B_s^0 meson decays, carried out in such a way that a straightforward comparison between their angular and lifetime parameters can be performed.

We use the $B_s^0 \to J/\psi\phi$, $J/\psi \to \mu^+\mu^-$, $\phi \to K^+K^-$ selection described in Ref. [9]. The decay $B_d^0 \to J/\psi K^{*0}$, $J/\psi \to \mu^+\mu^-$, $K^{*0} \to K^\pm\pi^\mp$ is reconstructed using similar selection criteria and algorithms as the B_s^0 channel because they have the same four-track topology in the final state. The differences are the requirement that the transverse momentum of the pion be greater than 0.7 GeV/c, the invariant mass for the $(J/\psi, K^{*0}(892))$ pair be in the range 4.93–5.61 GeV/c^2, and the selection of the $K^{*0}(892)$ candidates by demanding the two-particle invariant mass between 850 and 930 MeV/c^2. Because of the lack of charged particle identification, we assign the mass of the pion and kaon to the latter two tracks and use the combination with invariant mass closest to the K^{*0} mass.

The proper decay length (PDL), defined as in Refs. [10,11], for a given B_d^0 or B_s^0 candidate is determined by measuring the distance traveled by each b-hadron candidate in a plane transverse to the beam direction, and then applying a Lorentz boost correction. In the B_d^0 and B_s^0 final selection, we require a PDL uncertainty of less than 60 μm. We find 334199 and 41691 candidates that pass the B_d^0 and B_s^0 selection criteria, respectively (see Fig. 1).

We denote the set of the angular variables defined in the transversity basis, where the decays $B_d^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\psi\phi$ are studied, as $\boldsymbol{\omega} = \{\varphi, \cos\theta, \cos\psi\}$. The description of these decays in this basis gives us access to the three linear polarization amplitudes at production time, $t = 0$, $|A_0(0)|$, $|A_\parallel(0)|$, and $|A_\perp(0)|$, satisfying

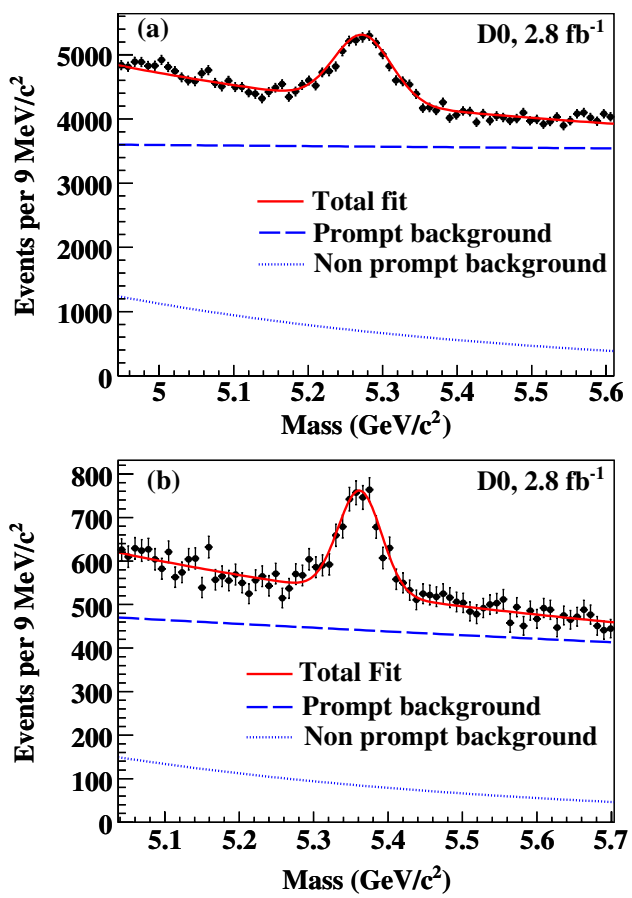

FIG. 1 (color online). Invariant mass distribution for selected (a) B_d^0 and (b) B_s^0 candidate events. The points with error bars represent the data, and the curves represent the fit projections for the total and the background components.

$|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2 = 1$ [12]; and the CP conserving strong phases $\delta_1 \equiv \arg[A_\parallel^* A_\perp]$, and $\delta_2 \equiv \arg[A_0^* A_\perp]$. Since only the relative phases of the amplitudes can enter physics observables, we are free to fix the phase of one of them, and we choose to fix $\delta_0 \equiv \arg(A_0) = 0$.

According to the standard model, CP-violation effects in the B_s^0 system are very small [13]. In this analysis, we assume CP conservation and express the differential decay rate for the untagged decay $B_s^0 \to J/\psi\phi$ as [2]:

$$d^4\mathcal{P}/(d\boldsymbol{\omega}dt) \propto e^{-\Gamma_L t}[|A_0|^2 f_1(\boldsymbol{\omega}) + \mathrm{Re}(A_0^* A_\parallel) f_5(\boldsymbol{\omega}) + |A_\parallel|^2 f_2(\boldsymbol{\omega})] + e^{-\Gamma_H t}|A_\perp|^2 f_3(\boldsymbol{\omega}), \quad (1)$$

where $\Gamma_{L(H)} \equiv 1/\tau_{L(H)}$ is the inverse of the lifetime corresponding to the light (heavy) mass eigenstate. The measured parameters, the width difference $\Delta\Gamma_s \equiv \Gamma_L - \Gamma_H$ and the mean lifetime $\bar{\tau}_s \equiv 1/\bar{\Gamma} = 2/(\Gamma_L + \Gamma_H)$, are given in terms of these inverse lifetimes. The angular functions $f_i(\boldsymbol{\omega})$ are defined in Ref. [2]. In this decay, we have access to the phase $\delta_\parallel = \arg(A_0^* A_\parallel)$, which is related to δ_1 and δ_2 by $\delta_\parallel = \delta_2 - \delta_1$.

In the B_d^0 system, there is evidence of interference between the P- and S-wave $K\pi$ amplitudes [14], which is taken into account in this analysis. The differential decay rate for the untagged decay $B_d^0 \to J/\psi K^{*0}$ is given by [2,14]:

$$\begin{aligned} d^4\mathcal{P}/(d\boldsymbol{\omega}dt) \propto e^{-\Gamma_d t}\{&\cos^2\lambda[|A_0|^2 f_1(\boldsymbol{\omega}) \\ &+ |A_\parallel|^2 f_2(\boldsymbol{\omega}) + |A_\perp|^2 f_3(\boldsymbol{\omega}) \\ &- \zeta \mathrm{Im}(A_\parallel^* A_\perp) f_4(\boldsymbol{\omega}) + \mathrm{Re}(A_0^* A_\parallel) f_5(\boldsymbol{\omega}) \\ &+ \zeta \mathrm{Im}(A_0^* A_\perp) f_6(\boldsymbol{\omega})] + \sin^2\lambda \cdot f_7(\boldsymbol{\omega}) \\ &+ \tfrac{1}{2}\sin 2\lambda[f_8(\boldsymbol{\omega})\cos(\delta_\parallel - \delta_s)|A_\parallel| \\ &+ f_9(\boldsymbol{\omega})\sin(\delta_\perp - \delta_s)|A_\perp| \\ &+ f_{10}(\boldsymbol{\omega})\cos(\delta_s)|A_0|]\}, \end{aligned} \quad (2)$$

where $\Gamma_d \equiv 1/\tau_d$ is the inverse of the B_d^0 lifetime, $\zeta = +1(\zeta = -1)$ for $K^+(K^-)$; λ, δ_s, and $f_i(\boldsymbol{\omega})$ are defined in Refs. [2,14]. For the B_d^0, $\Delta\Gamma_d$ is expected to be zero [13].

An unbinned likelihood fit is performed to extract all the B_d^0 and B_s^0 parameters. For the jth B meson candidate, the inputs for the fit are the mass m_j, PDL ct_j, PDL uncertainty σ_{ct_j}, and the angular variables $\boldsymbol{\omega}_j$. The likelihood function $\mathcal{L}$ for the untagged decays $B_d^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\psi\phi$, is defined by

$$\mathcal{L} = \prod_{j=1}^{N}[f_s \mathcal{F}_s^j + (1 - f_s)\mathcal{F}_b^j], \quad (3)$$

where N is the total number of selected events and f_s is the fraction of signal events in the sample, a free parameter in the fit.

$\mathcal{F}_s$ is the product of the signal probability distribution functions (PDF) of mass, PDL, and transversity angles, and the angular acceptances, which are determined via Monte Carlo simulations. The mass and PDL signal distributions are modeled for both decays in the same way. The mass distribution is modeled by a Gaussian function with free mean and width. The PDL distribution is described [10] by the convolution of an exponential, whose decay constant is one of the fit parameters with a resolution function represented by two weighted Gaussian functions centered at zero. The widths $s_i\sigma_{ct_j}$ of each Gaussian with scale factors s_i ($i = 1, 2$) are free parameters in the fit to allow for a possible misestimate of the PDL uncertainty. The transversity angular distributions are modeled by the corresponding normalized equations (1) and (2). The contribution where the mass of the K and π are misassigned in our data is estimated by using Monte Carlo studies to be about 13% and is taken into account.

$\mathcal{F}_b$ is the product of the background PDF of the same variables and the angular acceptance as in the signal. We separate the background contributions into two types. The prompt background accounts for directly produced J/ψ mesons combined with random tracks. Nonprompt background is due to J/ψ mesons produced by a b hadron decay combined with tracks that come from either a multibody decay of the same b hadron or from hadronization. The mass distribution for the background is modeled by two independent normalized negative-slope exponentials, one for the prompt and one for the nonprompt contributions. The PDL distribution for the prompt background is parametrized by the resolution function described above. The PDL distribution for the nonprompt background is modeled by a sum of two exponential components for positive ct and one for negative ct that account for a mix of heavy flavor meson decays and their possible misreconstruction. The angular distributions for the background components are modeled by a shape similar to that of the signal, but with an independent set of amplitudes and phases.

The results of our measurements are summarized in Table I. Figures 1 and 2 show the mass and the PDL distributions for the B_d^0 and B_s^0 candidates, respectively, with the projected results of the fits. The parameters with

TABLE I. Summary of measurements for the decays $B_d^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\psi\phi$. The uncertainties are only statistical.

Parameter	B_d^0	B_s^0	Units
$\lvert A_0\rvert^2$	0.587 ± 0.011	0.555 ± 0.027	$\cdots$
$\lvert A_\parallel\rvert^2$	0.230 ± 0.013	0.244 ± 0.032	$\cdots$
δ_1	-0.38 ± 0.06	$\cdots$	rad
δ_2	3.21 ± 0.06	$\cdots$	rad
$\delta_\parallel$	$\cdots$	$2.72^{+1.12}_{-0.27}$	rad
τ	1.414 ± 0.018	1.487 ± 0.060	ps
$\Delta\Gamma_s$	$\cdots$	$0.085^{+0.072}_{-0.078}$	ps^{-1}
N_{sig}	11195 ± 167	1926 ± 62	$\cdots$

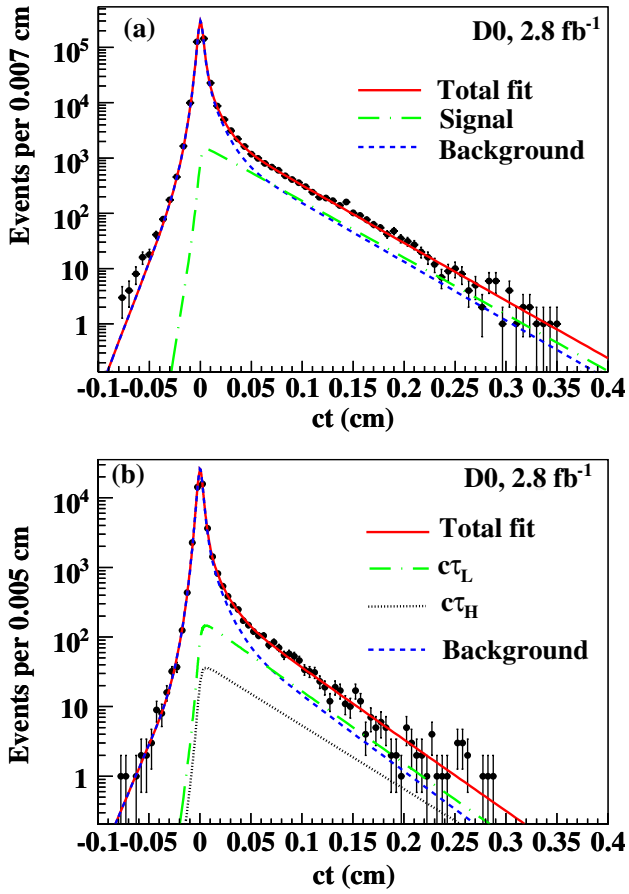

FIG. 2 (color online). PDL distribution for selected (a) B_d^0 and (b) B_s^0 candidate events. The points with error bars represent the data, and the curves represent the fit projections for the total, signal, and background components.

the strongest correlations are the linear amplitudes for the B_d^0, and the width difference and the mean lifetime for the B_s^0.

Table II summarizes the systematic uncertainties in our measurements for B_d^0 and B_s^0 decays. To study the systematic uncertainty due to the model for the mass distributions, we vary the shapes of the mass distributions for background by using two normalized first-order polynomials instead of the nominal two negative exponentials. We estimate the systematic uncertainty due to the resolution on the PDL by using one Gaussian function for the resolution model. The fitting code is tested for the presence of biases by generating 1300 pseudoexperiments for B_d^0 and 1000 for B_s^0, each with the same statistics as our data samples. We generated the events following the PDL, mass, and transversity angular distributions described above. The differences between the input and output values are quoted as the systematic uncertainty due to the fitting. The systematic uncertainty for $\delta_\parallel$ reported for this source is due to an intrinsic ambiguity for this parameter in Eq. (1). The pseudoexperiments produced also cover the other solution for $\delta_\parallel$. The contribution from the detector alignment uncertainty is taken from Ref. [11]. Other potential sources of systematic uncertainties have been investigated and found to give negligible variations in the measured parameters. The systematic uncertainties for the ratio $\bar{\tau}_s/\tau_d$ are obtained by finding the ratio of the lifetimes for each systematic variation on Table II and taking the difference between this value and the nominal ratio.

In conclusion, we have measured the angular and lifetime parameters for the time-dependent angular untagged decays $B_d^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\psi\phi$, the lifetime ratio of both B mesons, and the width difference $\Delta\Gamma_s$ for the B_s^0 meson. From the measured lifetime parameters $\bar{\tau}_s$ and τ_d we obtain the ratio $\bar{\tau}_s/\tau_d = 1.052 \pm 0.061(\text{stat}) \pm 0.015(\text{syst})$ which is consistent with the theoretical prediction [5] and previous measurements [6]. The measurement of the width difference $\Delta\Gamma_s = 0.085^{+0.072}_{-0.078}(\text{stat}) \pm 0.006(\text{syst})\ \text{ps}^{-1}$ is consistent with the theoretical prediction [5,13] and with the value reported in Refs. [6,15]. D0 also has a measurement of $\Delta\Gamma_s$ in a flavor-tagged analysis of $B_s^0 \to J/\psi\phi$ in Ref. [8].

Our measurements for the linear polarization amplitudes for the B_d^0, taking into account the interference between the $K\pi$ S wave and P wave, are $|A_0|^2 = 0.587 \pm 0.011(\text{stat}) \pm 0.013(\text{syst})$ and $|A_\parallel|^2 = 0.230 \pm 0.013(\text{stat}) \pm 0.025(\text{syst})$; and for B_s^0: $|A_0|^2 = 0.555 \pm 0.027(\text{stat}) \pm 0.006(\text{syst})$, and $|A_\parallel|^2 = 0.244 \pm 0.032(\text{stat}) \pm 0.014(\text{syst})$ are consistent and competitive with those reported in the literature [6,14,16]. Our measurement of the strong phases δ_1 and δ_2 indicates the presence of final-state interactions for the decay

TABLE II. Summary of systematic uncertainties in the measurement of angular and lifetime parameters. The total uncertainties are given combining individual uncertainties in quadrature.

	B_d^0					B_s^0					
Source	$\lvert A_0\rvert^2$	$\lvert A_\parallel\rvert^2$	δ_1 (rad)	δ_2 (rad)	τ_d (ps)	$\lvert A_0\rvert^2$	$\lvert A_\parallel\rvert^2$	$\delta_\parallel$ (rad)	$\Delta\Gamma_s$ (ps^{-1})	$\bar{\tau}_s$ (ps)	$\bar{\tau}_s/\tau_d$
Mass background	···	0.024	0.09	0.05	0.030	0.004	0.002	0.02	···	0.021	0.009
PDL resolution	0.013	0.008	0.02	0.03	0.013	0.005	0.003	···	···	0.016	0.012
Fitting code	0.001	···	···	···	0.004	0.004	0.014	0.26	0.001	0.008	0.003
Alignment	···	···	···	···	0.007	···	···	···	···	0.007	···
Total	0.013	0.025	0.09	0.06	0.034	0.006	0.014	0.26	0.001	0.028	0.015

$B_d^0 \to J/\psi K^{*0}$ [2] since $\delta_1 = -0.38 \pm 0.06(\text{stat}) \pm 0.09(\text{syst})$ rad is 3.5σ away from zero, where σ is the total uncertainty. From the comparison of the measured amplitudes and strong phases [17] for both decays we conclude that they are consistent with being equal for B_d^0 and B_s^0 and hence there is no evidence for a deviation from flavor SU(3) symmetry. In our sample we find that the $K\pi$ S-wave intensity, as described in Ref. [14], is $(4.0 \pm 1.0)\%$.

We thank the staffs at Fermilab and collaborating institutions, and acknowledge support from the DOE and NSF (U.S.); CEA and CNRS/IN2P3 (France); FASI, Rosatom and RFBR (Russia); CNPq, FAPERJ, FAPESP, and FUNDUNESP (Brazil); DAE and DST (India); Colciencias (Colombia); CONACyT (Mexico); KRF and KOSEF (Korea); CONICET and UBACyT (Argentina); FOM (The Netherlands); STFC (United Kingdom); MSMT and GACR (Czech Republic); CRC Program, CFI, NSERC, and WestGrid Project (Canada); BMBF and DFG (Germany); SFI (Ireland); The Swedish Research Council (Sweden); CAS and CNSF (China); and the Alexander von Humboldt Foundation (Germany).

*Visitor from Augustana College, Sioux Falls, SD, USA.
†Visitor from The University of Liverpool, Liverpool, U.K.
‡Visitor from Rutgers University, Piscataway, NJ, USA.
§Visitor from II. Physikalisches Institut, Georg-August-University, Göttingen, Germany.
‖Visitor from Centro de Investigacion en Computacion-IPN, Mexico City, Mexico.
¶Visitor from ECFM, Universidad Autonoma de Sinaloa, Culiacán, Mexico.
**Visitor from Helsinki Institute of Physics, Helsinki, Finland.
††Visitor from Universität Bern, Bern, Switzerland.
‡‡Visitor from Universität Zürich, Zürich, Switzerland.
§§Deceased.

[1] T. E. Browder, K. Honscheid, and D. Pedrini, Annu. Rev. Nucl. Part. Sci. **46**, 395 (1996).
[2] A. S. Dighe, I. Dunietz, and R. Fleischer, Eur. Phys. J. C **6**, 647 (1999), and references therein.
[3] Unless explicitly stated, the appearance of a specific charge state will also imply its charge conjugate throughout the Letter.
[4] E. Franco *et al.*, Nucl. Phys. **B633**, 212 (2002).
[5] A. Lenz, arXiv:0802.0977.
[6] W.-M. Yao *et al.* (Particle Data Group), J. Phys. G **33**, 1 (2006) and 2007 partial update for the 2008 edition.
[7] V. Abazov *et al.* (D0 Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **565**, 463 (2006).
[8] V. Abazov *et al.* (D0 Collaboration), Phys. Rev. Lett. **101**, 241801 (2008).
[9] V. Abazov *et al.* (D0 Collaboration), Phys. Rev. Lett. **98**, 121801 (2007).
[10] V. Abazov *et al.* (D0 Collaboration), Phys. Rev. Lett. **94**, 102001 (2005).
[11] V. Abazov *et al.* (D0 Collaboration), Phys. Rev. Lett. **94**, 042001 (2005).
[12] Throughout the paper, if not explicit dependence on time is stated, we denote $A_i(0) \equiv A_i$ for $i = \{0, \|, \perp\}$.
[13] A. Lenz and U. Nierste, J. High Energy Phys. 06 (2007) 072.
[14] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **71**, 032005 (2005).
[15] T. Aaltonen *et al.* (CDF Collaboration), Phys. Rev. Lett. **100**, 121803 (2008).
[16] K. Abe *et al.* (Belle Collaboration), Phys. Rev. Lett. **95**, 091601 (2005).
[17] Using the relation between these phases we obtain $\delta_{\|,B_d^0} = 3.59 \pm 0.06 \pm 0.09$ rad.