Branching Fraction and *CP* Asymmetries of $B^0 \to K_S^0 K_S^0 K_S^0$

B. Aubert,[1] R. Barate,[1] D. Boutigny,[1] F. Couderc,[1] Y. Karyotakis,[1] J. P. Lees,[1] V. Poireau,[1] V. Tissserand,[1] A. Zghiche,[1] E. Grauges-Pous,[2] A. Palano,[3] A. Pompili,[3] J. C. Chen,[4] N. D. Qi,[4] G. Rong,[4] P. Wang,[4] Y. S. Zhu,[4] G. Eigen,[5] I. Ofte,[5] B. Stugu,[5] G. S. Abrams,[6] A. W. Borgland,[6] A. B. Breon,[6] D. N. Brown,[6] J. Button-Shafer,[6] R. N. Cahn,[6] E. Charles,[6] C. T. Day,[6] M. S. Gill,[6] A. V. Gritsan,[6] Y. Groysman,[6] R. G. Jacobsen,[6] R. W. Kadel,[6] J. Kadyk,[6] L. T. Kerth,[6] Yu. G. Kolomensky,[6] G. Kukartsev,[6] G. Lynch,[6] L. M. Mir,[6] P. J. Oddone,[6] T. J. Orimoto,[6] M. Pripstein,[6] N. A. Roe,[6] M. T. Ronan,[6] W. A. Wenzel,[6] M. Barrett,[7] K. E. Ford,[7] T. J. Harrison,[7] A. J. Hart,[7] C. M. Hawkes,[7] S. E. Morgan,[7] A. T. Watson,[7] M. Fritsch,[8] K. Goetzen,[8] T. Held,[8] H. Koch,[8] B. Lewandowski,[8] M. Pelizaeus,[8] K. Peters,[8] T. Schroeder,[8] M. Steinke,[8] J. T. Boyd,[9] J. P. Burke,[9] N. Chevalier,[9] W. N. Cottingham,[9] M. P. Kelly,[9] T. E. Latham,[9] F. F. Wilson,[9] T. Cuhadar-Donszelmann,[10] C. Hearty,[10] N. S. Knecht,[10] T. S. Mattison,[10] J. A. McKenna,[10] D. Thiessen,[10] A. Khan,[11] P. Kyberd,[11] L. Teodorescu,[11] A. E. Blinov,[12] V. E. Blinov,[12] V. P. Druzhinin,[12] V. B. Golubev,[12] V. N. Ivanchenko,[12] E. A. Kravchenko,[12] A. P. Onuchin,[12] S. I. Serednyakov,[12] Yu. I. Skovpen,[12] E. P. Solodov,[12] A. N. Yushkov,[12] D. Best,[13] M. Bruinsma,[13] M. Chao,[13] I. Eschrich,[13] D. Kirkby,[13] A. J. Lankford,[13] M. Mandelkern,[13] R. K. Mommsen,[13] W. Roethel,[13] D. P. Stoker,[13] C. Buchanan,[14] B. L. Hartfiel,[14] A. J. R. Weinstein,[14] S. D. Foulkes,[15] J. W. Gary,[15] O. Long,[15] B. C. Shen,[15] K. Wang,[15] D. del Re,[16] H. K. Hadavand,[16] E. J. Hill,[16] D. B. MacFarlane,[16] H. P. Paar,[16] Sh. Rahatlou,[16] V. Sharma,[16] J. W. Berryhill,[17] C. Campagnari,[17] A. Cunha,[17] B. Dahmes,[17] T. M. Hong,[17] A. Lu,[17] M. A. Mazur,[17] J. D. Richman,[17] W. Verkerke,[17] T. W. Beck,[18] A. M. Eisner,[18] C. J. Flacco,[18] C. A. Heusch,[18] J. Kroseberg,[18] W. S. Lockman,[18] G. Nesom,[18] T. Schalk,[18] B. A. Schumm,[18] A. Seiden,[18] P. Spradlin,[18] D. C. Williams,[18] M. G. Wilson,[18] J. Albert,[19] E. Chen,[19] G. P. Dubois-Felsmann,[19] A. Dvoretskii,[19] D. G. Hitlin,[19] I. Narsky,[19] T. Piatenko,[19] F. C. Porter,[19] A. Ryd,[19] A. Samuel,[19] S. Yang,[19] S. Jayatilleke,[20] G. Mancinelli,[20] B. T. Meadows,[20] M. D. Sokoloff,[20] F. Blanc,[21] P. Bloom,[21] S. Chen,[21] W. T. Ford,[21] U. Nauenberg,[21] A. Olivas,[21] P. Rankin,[21] W. O. Ruddick,[21] J. G. Smith,[21] K. A. Ulmer,[21] J. Zhang,[21] L. Zhang,[21] A. Chen,[22] E. A. Eckhart,[22] J. L. Harton,[22] A. Soffer,[22] W. H. Toki,[22] R. J. Wilson,[22] Q. Zeng,[22] B. Spaan,[23] D. Altenburg,[24] T. Brandt,[24] J. Brose,[24] M. Dickopp,[24] E. Feltresi,[24] A. Hauke,[24] H. M. Lacker,[24] E. Maly,[24] R. Nogowski,[24] S. Otto,[24] A. Petzold,[24] G. Schott,[24] J. Schubert,[24] K. R. Schubert,[24] R. Schwierz,[24] J. E. Sundermann,[24] D. Bernard,[25] G. R. Bonneaud,[25] P. Grenier,[25] S. Schrenk,[25] Ch. Thiebaux,[25] G. Vasileiadis,[25] M. Verderi,[25] D. J. Bard,[26] P. J. Clark,[26] F. Muheim,[26] S. Playfer,[26] Y. Xie,[26] M. Andreotti,[27] V. Azzolini,[27] D. Bettoni,[27] C. Bozzi,[27] R. Calabrese,[27] G. Cibinetto,[27] E. Luppi,[27] M. Negrini,[27] L. Piemontese,[27] A. Sarti,[27] F. Anulli,[28] R. Baldini-Ferroli,[28] A. Calcaterra,[28] R. de Sangro,[28] G. Finocchiaro,[28] P. Patteri,[28] I. M. Peruzzi,[28] M. Piccolo,[28] A. Zallo,[28] A. Buzzo,[29] R. Capra,[29] R. Contri,[29] G. Crosetti,[29] M. Lo Vetere,[29] M. Macri,[29] M. R. Monge,[29] S. Passaggio,[29] C. Patrignani,[29] E. Robutti,[29] A. Santroni,[29] S. Tosi,[29] S. Bailey,[30] G. Brandenburg,[30] K. S. Chaisanguanthum,[30] M. Morii,[30] E. Won,[30] R. S. Dubitzky,[31] U. Langenegger,[31] J. Marks,[31] U. Uwer,[31] W. Bhimji,[31] D. A. Bowerman,[32] P. D. Dauncey,[32] U. Egede,[32] J. R. Gaillard,[32] G. W. Morton,[32] J. A. Nash,[32] M. B. Nikolich,[32] G. P. Taylor,[32] M. J. Charles,[33] G. J. Grenier,[33] U. Mallik,[33] A. K. Mohapatra,[33] J. Cochran,[34] H. B. Crawley,[34] J. Lamsa,[34] W. T. Meyer,[34] S. Prell,[34] E. I. Rosenberg,[34] A. E. Rubin,[34] J. Yi,[34] N. Arnaud,[35] M. Davier,[35] X. Giroux,[35] G. Grosdidier,[35] A. Höcker,[35] F. Le Diberder,[35] V. Lepeltier,[35] A. M. Lutz,[35] T. C. Petersen,[35] M. Pierini,[35] S. Plaszczynski,[35] M. H. Schune,[35] G. Wormser,[35] C. H. Cheng,[36] D. J. Lange,[36] M. C. Simani,[36] D. M. Wright,[36] A. J. Bevan,[37] C. A. Chavez,[37] J. P. Coleman,[37] I. J. Forster,[37] J. R. Fry,[37] E. Gabathuler,[37] R. Gamet,[37] D. E. Hutchhcroft,[37] R. J. Parry,[37] D. J. Payne,[37] C. Touramanis,[37] C. M. Cormack,[38] F. Di Lodovico,[38] C. L. Brown,[39] G. Cowan,[39] R. L. Flack,[39] H. U. Flaecher,[39] M. G. Green,[39] P. S. Jackson,[39] T. R. McMahon,[39] S. Ricciardi,[39] F. Salvatore,[39] M. A. Winter,[39] D. Brown,[40] C. L. Davis,[40] J. Allison,[41] N. R. Barlow,[41] R. J. Barlow,[41] M. C. Hodgkinson,[41] G. D. Lafferty,[41] M. T. Naisbit,[41] J. C. Williams,[41] C. Chen,[42] A. Farbin,[42] W. D. Hulsbergen,[42] A. Jawahery,[42] D. Kovalskyi,[42] C. K. Lae,[42] V. Lillard,[42] D. A. Roberts,[42] G. Blaylock,[43] C. Dallapiccola,[43] S. S. Hertzbach,[43] R. Kofler,[43] V. B. Koptchev,[43] T. B. Moore,[43] S. Saremi,[43] H. Staengle,[43] S. Willocq,[43] R. Cowan,[44] K. Koeneke,[44] G. Sciolla,[44] S. J. Sekula,[44] F. Taylor,[44] R. K. Yamamoto,[44] P. M. Patel,[45] S. H. Robertson,[45] A. Lazzaro,[46] V. Lombardo,[46] F. Palombo,[46] J. M. Bauer,[47] L. Cremaldi,[47] V. Eschenburg,[47] R. Godang,[47] R. Kroeger,[47] J. Reidy,[47] D. A. Sanders,[47] D. J. Summers,[47] H. W. Zhao,[47] S. Brunet,[48] D. Côté,[48] P. Taras,[48] H. Nicholson,[49] N. Cavallo,[50,*] F. Fabozzi,[50,*] C. Gatto,[50] L. Lista,[50] D. Monorchio,[50] P. Paolucci,[50] D. Piccolo,[50] C. Sciacca,[50] M. Baak,[51] H. Bulten,[51] G. Raven,[51] H. L. Snoek,[51] L. Wilden,[51] C. P. Jessop,[52] J. M. LoSecco,[52] T. Allmendinger,[53] G. Bennelli,[53] K. K. Gan,[53] K. Honscheid,[53] D. Hufnagel,[53] H. Kagan,[53] R. Kass,[53] T. Pulliam,[53] A. M. Rahimi,[53] R. Ter-Antonyan,[53] Q. K. Wong,[53] J. Brau,[54] R. Frey,[54] O. Igonkina,[54] M. Lu,[54]

C. T. Potter,[54] N. B. Sinev,[54] D. Strom,[54] E. Torrence,[54] F. Colecchia,[55] A. Dorigo,[55] F. Galeazzi,[55] M. Margoni,[55] M. Morandin,[55] M. Posocco,[55] M. Rotondo,[55] F. Simonetto,[55] R. Stroili,[55] C. Voci,[55] M. Benayoun,[56] H. Briand,[56] J. Chauveau,[56] P. David,[56] L. Del Buono,[56] Ch. de la Vaissière,[56] O. Hamon,[56] M. J. J. John,[56] Ph. Leruste,[56] J. Malclès,[56] J. Ocariz,[56] L. Roos,[56] G. Therin,[56] P. K. Behera,[57] L. Gladney,[57] Q. H. Guo,[57] J. Panetta,[57] M. Biasini,[58] R. Covarelli,[58] M. Pioppi,[58] C. Angelini,[59] G. Batignani,[59] S. Bettarini,[59] M. Bondioli,[59] F. Bucci,[59] G. Calderini,[59] M. Carpinelli,[59] F. Forti,[59] M. A. Giorgi,[59] A. Lusiani,[59] G. Marchiori,[59] M. Morganti,[59] N. Neri,[59] E. Paoloni,[59] M. Rama,[59] G. Rizzo,[59] G. Simi,[59] J. Walsh,[59] M. Haire,[60] D. Judd,[60] K. Paick,[60] D. E. Wagoner,[60] N. Danielson,[61] P. Elmer,[61] Y. P. Lau,[61] C. Lu,[61] V. Miftakov,[61] J. Olsen,[61] A. J. S. Smith,[61] A. V. Telnov,[61] F. Bellini,[62] G. Cavoto,[61,62] A. D'Orazio,[62] E. Di Marco,[62] R. Faccini,[62] F. Ferrarotto,[62] F. Ferroni,[62] M. Gaspero,[62] L. Li Gioi,[62] M. A. Mazzoni,[62] S. Morganti,[62] G. Piredda,[62] F. Polci,[62] F. Safai Tehrani,[62] C. Voena,[62] S. Christ,[63] H. Schröder,[63] G. Wagner,[63] R. Waldi,[63] T. Adye,[64] N. De Groot,[64] B. Franek,[64] G. P. Gopal,[64] E. O. Olaiya,[64] R. Aleksan,[65] S. Emery,[65] A. Gaidot,[65] S. F. Ganzhur,[65] P.-F. Giraud,[65] G. Hamel de Monchenault,[65] W. Kozanecki,[65] M. Legendre,[65] G. W. London,[65] B. Mayer,[65] G. Vasseur,[65] Ch. Yèche,[65] M. Zito,[65] M. V. Purohit,[66] A. W. Weidemann,[66] J. R. Wilson,[66] F. X. Yumiceva,[66] T. Abe,[67] D. Aston,[67] R. Bartoldus,[67] N. Berger,[67] A. M. Boyarski,[67] O. L. Buchmueller,[67] R. Claus,[67] M. R. Convery,[67] M. Cristinziani,[67] G. De Nardo,[67] J. C. Dingfelder,[67] D. Dong,[67] J. Dorfan,[67] D. Dujmic,[67] W. Dunwoodie,[67] S. Fan,[67] R. C. Field,[67] T. Glanzman,[67] S. J. Gowdy,[67] T. Hadig,[67] V. Halyo,[67] C. Hast,[67] T. Hrny'ova,[67] W. R. Innes,[67] M. H. Kelsey,[67] P. Kim,[67] M. L. Kocian,[67] D. W. G. S. Leith,[67] J. Libby,[67] S. Luitz,[67] V. Luth,[67] H. L. Lynch,[67] H. Marsiske,[67] R. Messner,[67] D. R. Muller,[67] C. P. O'Grady,[67] V. E. Ozcan,[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] A. Soha,[67] J. Stelzer,[67] J. Strube,[54,67] D. Su,[67] M. K. Sullivan,[67] J. Va'vra,[67] S. R. Wagner,[67] M. Weaver,[67] W. J. Wisniewski,[67] M. Wittgen,[67] D. H. Wright,[67] A. K. Yarritu,[67] C. C. Young,[67] P. R. Burchat,[68] A. J. Edwards,[68] S. A. Majewski,[68] B. A. Petersen,[68] C. Roat,[68] M. Ahmed,[69] S. Ahmed,[69] M. S. Alam,[69] J. A. Ernst,[69] M. A. Saeed,[69] M. Saleem,[69] F. R. Wappler,[69] W. Bugg,[70] M. Krishnamurthy,[70] S. M. Spanier,[70] R. Eckmann,[71] H. Kim,[71] J. L. Ritchie,[71] A. Satpathy,[71] R. F. Schwitters,[71] J. M. Izen,[72] I. Kitayama,[72] X. C. Lou,[72] S. Ye,[72] F. Bianchi,[73] M. Bona,[73] F. Gallo,[73] D. Gamba,[73] L. Bosisio,[74] C. Cartaro,[74] F. Cossutti,[74] G. Della Ricca,[74] S. Dittongo,[74] S. Grancagnolo,[74] L. Lanceri,[74] P. Poropat,[74,†] L. Vitale,[74] G. Vuagnin,[74] F. Martinez-Vidal,[2,75] R. S. Panvini,[76,†] Sw. Banerjee,[77] B. Bhuyan,[77] C. M. Brown,[77] D. Fortin,[77] K. Hamano,[77] P. D. Jackson,[77] R. Kowalewski,[77] J. M. Roney,[77] R. J. Sobie,[77] J. J. Back,[78] P. F. Harrison,[78] G. B. Mohanty,[78] H. R. Band,[79] X. Chen,[79] B. Cheng,[79] S. Dasu,[79] M. Datta,[79] A. M. Eichenbaum,[79] K. T. Flood,[79] M. Graham,[79] J. J. Hollar,[79] J. R. Johnson,[79] P. E. Kutter,[79] H. Li,[79] R. Liu,[79] A. Mihalyi,[79] Y. Pan,[79] R. Prepost,[79] P. Tan,[79] J. H. von Wimmersperg-Toeller,[79] J. Wu,[79] S. L. Wu,[79] Z. Yu,[79] M. G. Greene,[80] and H. Neal[80]

(*BABAR* Collaboration)

[1]*Laboratoire de Physique des Particules, F-74941 Annecy-le-Vieux, France*
[2]*IFAE, Universitat Autonoma de Barcelona, E-08193 Bellaterra, Barcelona, Spain*
[3]*Dipartimento di Fisica and INFN, Universit'a di Bari, I-70126 Bari, Italy*
[4]*Institute of High Energy Physics, Beijing 100039, China*
[5]*Institute of Physics, University of Bergen, N-5007 Bergen, Norway*
[6]*Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720, USA*
[7]*University of Birmingham, Birmingham, B15 2TT, United Kingdom*
[8]*Institut für Experimentalphysik 1, Ruhr Universität Bochum, D-44780 Bochum, Germany*
[9]*University of Bristol, Bristol BS8 1TL, United Kingdom*
[10]*University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z1*
[11]*Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom*
[12]*Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia*
[13]*University of California at Irvine, Irvine, California 92697, USA*
[14]*University of California at Los Angeles, Los Angeles, California 90024, USA*
[15]*University of California at Riverside, Riverside, California 92521, USA*
[16]*University of California at San Diego, La Jolla, California 92093, USA*
[17]*University of California at Santa Barbara, Santa Barbara, California 93106, USA*
[18]*Institute for Particle Physics, University of California at Santa Cruz, Santa Cruz, California 95064, USA*
[19]*California Institute of Technology, Pasadena, California 91125, USA*
[20]*University of Cincinnati, Cincinnati, Ohio 45221, USA*
[21]*University of Colorado, Boulder, Colorado 80309, USA*
[22]*Colorado State University, Fort Collins, Colorado 80523, USA*

[23]Institut für Physik, Universität Dortmund, D-44221 Dortmund, Germany
[24]Institut für Kernund Teilchenphysik, Technische Universität Dresden, D-01062 Dresden, Germany
[25]Ecole Polytechnique, LLR, F-91128 Palaiseau, France
[26]University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom
[27]Dipartimento di Fisica and INFN, Università di Ferrara, I-44100 Ferrara, Italy
[28]Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy
[29]Dipartimento di Fisica and INFN, Università di Genova, I-16146 Genova, Italy
[30]Harvard University, Cambridge, Massachusetts 02138, USA
[31]Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, D-69120 Heidelberg, Germany
[32]Imperial College London, London, SW7 2AZ, United Kingdom
[33]University of Iowa, Iowa City, Iowa 52242, USA
[34]Iowa State University, Ames, Iowa 50011-3160, USA
[35]Laboratoire de l'Accélérateur Linéaire, F-91898 Orsay, France
[36]Lawrence Livermore National Laboratory, Livermore, California 94550, USA
[37]University of Liverpool, Liverpool L69 72E, United Kingdom
[38]Queen Mary, University of London, E1 4NS, United Kingdom
[39]Royal Holloway and Bedford New College, University of London, Egham, Surrey TW20 0EX, United Kingdom
[40]University of Louisville, Louisville, Kentucky 40292, USA
[41]University of Manchester, Manchester M13 9PL, United Kingdom
[42]University of Maryland, College Park, Maryland 20742, USA
[43]University of Massachusetts, Amherst, Massachusetts 01003, USA
[44]Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA
[45]McGill University, Montréal, Quebec, Canada H3A 2T8
[46]Dipartimento di Fisica and INFN, Università di Milano, I-20133 Milano, Italy
[47]University of Mississippi, University, Mississippi 38677, USA
[48]Laboratoire René J. A. Lévesque, Université de Montréal, Montréal, Quebec, Canada H3C 3J7
[49]Mount Holyoke College, South Hadley, Massachusetts 01075, USA
[50]Dipartimento di Scienze Fisiche and INFN, Università di Napoli Federico II, I-80126, Napoli, Italy
[51]NIKHEF, National Institute for Nuclear Physics and High Energy Physics, NL-1009 DB Amsterdam, The Netherlands
[52]University of Notre Dame, Notre Dame, Indiana 46556, USA
[53]Ohio State University, Columbus, Ohio 43210, USA
[54]University of Oregon, Eugene, Oregon 97403, USA
[55]Dipartimento di Fisica and INFN, Università di Padova, I-35131 Padova, Italy
[56]Laboratoire de Physique Nucléaire et de Hautes Energies, Universités Paris VI et VII, F-75252 Paris, France
[57]University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA
[58]Dipartimento di Fisica and INFN, Università di Perugia, I-06100 Perugia, Italy
[59]Dipartimento di Fisica, Scuola Normale Superiore and INFN, Università di Pisa, I-56127 Pisa, Italy
[60]Prairie View A&M University, Prairie View, Texas 77446, USA
[61]Princeton University, Princeton, New Jersey 08544, USA
[62]Dipartimento di Fisica and INFN, Università di Roma La Sapienza, I-00185 Roma, Ital
[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]Dipartimento di Fisica Sperimentale and INFN, Università di Torino, I-10125 Torino, Italy
[74]Dipartimento di Fisica and INFN, Università di Trieste, I-34127 Trieste, Italy
[75]IFIC, Universitat de Valencia-CSIC, E-46071 Valencia, Spain
[76]Vanderbilt University, Nashville, Tennessee 37235, USA
[77]University of Victoria, Victoria, British Columbia, Canada V8W 3P6
[78]Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom
[79]University of Wisconsin, Madison, Wisconsin 53706, USA
[80]Yale University, New Haven, Connecticut 06511, USA
(Received 4 February 2005; published 1 July 2005)

We present measurements of the branching fraction and time-dependent CP-violating asymmetries in $B^0 \to K^0_S K^0_S K^0_S$ decays based on 227×10^6 $\Upsilon(4S) \to B\bar{B}$ decays collected with the *BABAR* detector at the PEP-II asymmetric-energy B factory at SLAC. We obtain a branching fraction of $(6.9^{+0.9}_{-0.8} \pm 0.6) \times 10^{-6}$, and CP asymmetries $C = -0.34^{+0.28}_{-0.25} \pm 0.05$ and $S = -0.71^{+0.38}_{-0.32} \pm 0.04$, where the first uncertainties are statistical and the second systematic.

DOI: 10.1103/PhysRevLett.95.011801 PACS numbers: 13.25.Hw, 11.30.Er, 14.40.Nd

The amplitude of time-dependent CP violation (CPV) predicted for $b \to c\bar{c}s$ decays of neutral B mesons in the standard model (SM) is $\sin 2\beta$ where $\beta = \arg(-V_{cd}V^*_{cb}/V_{td}V^*_{tb})$ is the CP violating phase difference between mixing and decay amplitudes, with V_{ij} the elements of the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix [1]. This prediction has been well tested at the B factories in recent years [2]. The SM also predicts the amplitude of CPV in $b \to s\bar{q}q$ $(q = d, s)$ decays, defined as $\sin 2\beta_{\rm eff}$, to be approximately $\sin 2\beta$. However, since $b \to s\bar{q}q$ decays are dominated by one-loop transitions that can potentially accommodate large virtual particle masses, contributions from physics beyond the SM could invalidate this prediction, making these decays especially sensitive to new physics [3]. An active program has arisen to measure $\beta_{\rm eff}$ in as many $b \to s\bar{q}q$ "penguin" modes as possible [4]. However, many of these final states are affected by additional SM physics contributions that obscure the measurement of $\beta_{\rm eff}$ [5], or are not CP eigenstates. Two decays to CP eigenstates that have been noted as having small theoretical uncertainties in the measurement of $\beta_{\rm eff}$ are $B^0 \to \phi K^0_s$ [6–8] (CP odd) and $B^0 \to K^0_S K^0_S K^0_S$ (CP even) [9].

In this Letter we present a measurement of time-dependent CP-violating asymmetries in the decay $B^0 \to K^0_S K^0_S K^0_S$, along with a measurement of the branching fraction (BF). Until recently the small branching fraction [10] and the absence of charged decay tracks originating at the B^0 decay vertex have limited the ability to extract CP parameters from $B^0 \to K^0_S K^0_S K^0_S$. However, techniques recently developed to deal with the reconstruction of the B^0 decay vertex in $B^0 \to K^0_S \pi^0$ have made this measurement possible [11].

The time-dependent CP asymmetry is obtained by measuring the proper-time difference $\Delta t \equiv t_{CP} - t_{\rm tag}$ between a fully reconstructed decay $B^0 \to K^0_S K^0_S K^0_S$ and the partially reconstructed tagging B meson ($B_{\rm tag}$). The asymmetry in the decay rate f_+ (f_-) when the tagging meson is a B^0 ($\bar{B}^0$) is given as

$$f_\pm(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau} \times [1 \pm S\sin(\Delta m_d \Delta t) \mp C\cos(\Delta m_d \Delta t)], \qquad (1)$$

where the parameters C and S describe the amount of CP violation in decay and in the interference between decay with and without mixing, respectively. Neglecting CKM-suppressed amplitudes, we expect $S = -\sin 2\beta$ and $C = 0$ in the SM.

The results presented here are based on 226.6 ± 2.5 million $\Upsilon(4S) \to B\bar{B}$ decays collected with the *BABAR* detector at the PEP-II asymmetric-energy e^+e^- collider, located at the Stanford Linear Accelerator Center. The *BABAR* detector [12] provides charged-particle tracking through a combination of a five-layer double-sided silicon microstrip detector (SVT) and a 40-layer central drift chamber, both operating in a 1.5 T magnetic field. Charged kaon and pion identification is achieved through measurements of particle energy loss in the tracking system and Cherenkov cone angle in a detector of internally reflected Cherenkov light. A segmented CsI(Tl) electromagnetic calorimeter provides photon detection and electron identification. Finally, the instrumented flux return of the magnet allows discrimination of muons from pions.

Candidates for $B^0 \to K^0_S K^0_S K^0_S$ are formed by combining three K^0_S candidates in an event. We reconstruct $K^0_S \to \pi^+\pi^-$ candidates from pairs of oppositely charged tracks. The two-track combinations must form a vertex with a $\pi^+\pi^-$ invariant mass within 12 MeV$/c^2$ (about 4σ) of the nominal K^0_S mass [13], a reconstructed flight distance between 0.2 and 40.0 cm from the beam spot in the plane transverse to the beam, and an angle between the transverse flight direction and the transverse momentum vector of less than 200 mrad. For each B candidate two nearly independent kinematic variables are computed, namely, the beam-energy-substituted mass $m_{\rm ES} = \sqrt{(s/2 + \mathbf{p}_i \cdot \mathbf{p}_B)^2/E_i^2 + p_B^2}$, and the energy difference $\Delta E = E^*_B - \sqrt{s}/2$. Here, $(E_i, \mathbf{p}_i)$ is the four vector of the initial e^+e^- system, $\sqrt{s}$ is the center-of-mass energy, $\mathbf{p}_B$ is the reconstructed momentum of the B^0 candidate, and E^*_B is its energy calculated in the e^+e^- rest frame. For signal decays, the $m_{\rm ES}$ distribution peaks near the B^0 mass with an rms deviation of about 2.5 MeV$/c^2$ and the ΔE distribution peaks near zero with an rms deviation of about 14 MeV. We select candidates within the window $5.22 < m_{\rm ES} < 5.30$ GeV$/c^2$ and $-120 < \Delta E < 120$ MeV, which includes the signal peak and a "sideband" region for background characterization.

The sample of $B^0 \to K^0_S K^0_S K^0_S$ candidates is dominated by random $K^0_S K^0_S K^0_S$ combinations from $e^+e^- \to q\bar{q}$ $(q = u, d, s, c)$ fragmentation. Monte Carlo (MC) studies show that contributions from other B meson decays can be neglected. We exploit topological observables to discriminate the jetlike $e^+e^- \to q\bar{q}$ events from the more uniformly distributed $B\bar{B}$ events. In the $\Upsilon(4S)$ rest frame we compute the angle θ^*_T between the thrust axis of the B^0

candidate and that of the remaining particles in the event. While $|\cos\theta_T^*|$ is highly peaked near 1 for $e^+e^- \rightarrow q\bar{q}$ events, it is nearly uniformly distributed for $B\bar{B}$ events. We require $|\cos\theta_T^*| < 0.9$, eliminating ~68% of the background. In addition, we use a Fisher discriminant variable ($\mathcal{F}$), based on the momenta and angles of tracks in the event [11], in the maximum-likelihood fit described below.

For the 1.4% of events with more than one candidate we select the combination with the smallest $\chi^2 = \Sigma_i(m_i - m_{K_S^0})^2/\sigma_{m_i}^2$, where m_i ($m_{K_S^0}$) is the measured (nominal K_S^0) mass and σ_{m_i} is the estimated uncertainty on the mass of the ith K_S^0 candidate. We also remove all B^0 candidates that have a $K_S^0K_S^0$ mass combination within 3σ (45 MeV/c^2) of the χ_{c0} or χ_{c2} mass. While we expect few χ_{c0} and $\chi_{c2} \rightarrow K_S^0K_S^0$ decays in our final sample, these are $b \rightarrow c\bar{c}s$ decays that would bias the CP-asymmetry measurement.

We extract the results from unbinned maximum-likelihood fits to the kinematic, event-shape ($\mathcal{F}$) and Δt variables. We maximize the logarithm of an extended likelihood function

$$\mathcal{L} = e^{-(N_S+N_B)} \times \prod_i^{N_T}[N_S\mathcal{P}_S^i + N_B\mathcal{P}_B^i],$$

where $\mathcal{P}_S$ and $\mathcal{P}_B$ are the probability density functions (PDFs) for signal (S) and continuum background (B), N_T is the total number of events, and N_S and N_B are the event yields to be determined from the fit. The product is over the selected events. The observables are sufficiently uncorrelated that we can construct the likelihoods as the products of one-dimensional PDFs. The PDFs for signal are parameterized from signal MC events. For background PDFs we determine the functional form from data in the sideband regions of the other observables where backgrounds dominate. We include these regions in the fitted sample and simultaneously extract the parameters of the background PDFs along with the fit results.

For the branching fraction fit we use only the kinematic and event-shape variables ($\mathcal{P}_{BF} = \mathcal{P}(m_{\rm ES})\mathcal{P}(\Delta E)\mathcal{P}(\mathcal{F})$). There are two yields and six continuum PDF parameters floated in the fit. There are 721 $K_S^0K_S^0K_S^0$ candidates that pass all the above criteria, and the fit to this data yields $N_S = 88 \pm 10$ events and $N_B = 633 \pm 26$ events. Figure 1 shows the $m_{\rm ES}$ and ΔE distributions for these events with the results of the fit plotted as curves. As a check we also add a fit component for random combinatorial B background, with PDF parameters determined from large MC samples. This fit finds 14 ± 11 candidates assigned to the B background. These candidates come from the continuum background; the signal yield changes by less than one candidate. A signal reconstruction efficiency of 5.6% is derived from a large MC sample in which the K_S^0 reconstruction efficiency is carefully matched with that observed in large hadronic data samples. Assuming equal

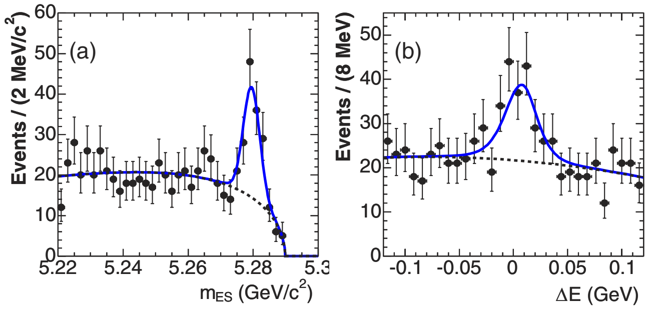

FIG. 1 (color online). Distribution of (a) $m_{\rm ES}$ and (b) ΔE for all events that pass the selections used for determining the branching fraction. The solid (dashed) curves are the PDF projections for the signal plus background (background only) from the fit.

production rates of $B^0\bar{B}^0$ and B^+B^-, we determine $\mathcal{B}(B^0 \rightarrow K_S^0K_S^0K_S^0) = (6.9^{+0.9}_{-0.8} \pm 0.6) \times 10^{-6}$.

The largest systematic error (5%) for the branching fraction measurement comes from our uncertainty on the efficiency of reconstructing $K_S^0 \rightarrow \pi^+\pi^-$ decays [14]. We determine uncertainties of 4% for the effect of the candidate selection cuts and 5% for the parametrization of the PDFs used in the fit. The remaining uncertainties, including possible errors in modeling the $K_S^0K_S^0K_S^0$ Dalitz plot distribution in determining the signal efficiency, combine to 2%.

The CP-fit PDF for a given tagging category is $\mathcal{P}_{CP}^c = \mathcal{P}_{BF}\mathcal{P}^c(\Delta t, \sigma_{\Delta t})\epsilon^c$ where ϵ^c is the tagging efficiency for tag category c. The total likelihood $\mathcal{L}$ is the product of likelihoods for each tagging category, and the free parameters are determined by maximizing the quantity $\ln\mathcal{L}$. Along with the CPV asymmetries S and C, the fit extracts ϵ^c for the background and other background parameters. The background PDFs include parameters for the Δt-resolution function $\mathcal{R}$ and for asymmetries in the rate of B^0 versus $\bar{B}^0$ tags. We extract 25 parameters from the CP fit.

We use a neural network to determine the flavor of the $B_{\rm tag}$ meson from kinematic and particle-identification information [15]. Each event is assigned to one of six mutually exclusive tagging categories, designed to combine flavor tags with similar performance and Δt resolution. We parameterize the performance of this algorithm with a data sample ($B_{\rm flav}$) of fully reconstructed $B^0 \rightarrow D^{(*)-}\pi^+/\rho^+/a_1^+$ decays. The effective tagging efficiency obtained from this sample is $Q \equiv \Sigma_c\epsilon^c(1-2w^c)^2 = 0.305 \pm 0.004$, where ϵ^c and w^c are the efficiencies and mistag probabilities, respectively, for events tagged in category c.

We compute the proper-time difference $\Delta t = (z_{CP} - z_{\rm tag})/\gamma\beta c$ using the known boost of the e^+e^- system and the measured $\Delta z = z_{CP} - z_{\rm tag}$, the difference of the reconstructed decay vertex positions of the $B^0 \rightarrow K_S^0K_S^0K_S^0$ and $B_{\rm tag}$ candidate along the boost direction (z). A description of the inclusive reconstruction of the B_{tag} vertex is given in Ref. [16]. For the $B^0 \to K^0_S K^0_S K^0_S$ decay, where no charged particles are present at the decay vertex, we constrain the B meson production vertex to the interaction point (IP) in the transverse plane using a geometric fit. The position and size of the interaction region are determined on a run-by-run basis from the spatial distribution of vertices from two-track events. The uncertainty on the IP position, which follows from the size of the interaction region, is about 150 μm horizontally and 4 μm vertically. The uncertainty on z_{CP}, a convolution of the interaction region and the vertex of the $B^0 \to K^0_S K^0_S K^0_S$ decay, is about 75 μm. The uncertainty on z_{tag} is about 200 μm and thus the uncertainty in Δz is dominated by the uncertainty in the vertex of the tagging decay. The resulting resolution is comparable to that in $B^0 \to J/\psi K^0_S$ [11].

Simulation studies show that the procedure we use to determine the vertex for a $B^0 \to K^0_S K^0_S K^0_S$ decay provides an unbiased estimate of z_{CP}. The estimate of the Δt error in an event reflects the strong dependence of the z_{CP} resolution on the number of SVT layers traversed by the K^0_S decay daughters. However, essentially all events have at least one K^0_S candidate for which both tracks have at least one hit in the inner three SVT layers (at radii from 3.2 to 5.4 cm). In this case the mean Δt resolution is comparable to that in decays in which the vertex is directly reconstructed from charged particles originating at the B decay point [16]. For a small fraction (0.1%) of the signal events, at least one K^0_S has tracks with hits in the outer two SVT layers (at radii 9.1 to 1.4.4 cm) but none of the three K^0_S's have hits in the inner three layers. In this case the resolution is nearly 2 times worse but the event can still be used in the CP fit. Events with $\sigma_{\Delta t} > 2.5$ ps or $|\Delta t| > 20$ ps are excluded from the CP fit.

The resolution function $\mathcal{R}$ is parameterized as the sum of a "core" and a "tail" Gaussian distribution, each with a width and mean proportional to $\sigma_{\Delta t}$, and a third Gaussian with a mean of zero and a width fixed at 8 ps [16]. We have verified with MC simulation that the parameters of $\mathcal{R}$ for $B^0 \to K^0_S K^0_S K^0_S$ decays are similar to those obtained from the B_{flav} sample. Therefore, we extract these parameters from a fit to the B_{flav} sample. We find that the Δt distribution of background candidates is well described by a delta function convolved with a resolution function having the same functional form as that for the signal. The parameters of the background function are determined in the fit.

The fit including Δt and tagging information yields $S = -0.71^{+0.38}_{-0.32} \pm 0.04$ and $C = -0.34^{+0.28}_{-0.25} \pm 0.05$. Fixing $C = 0$ we obtain $\sin 2\beta = -S = 0.79^{+0.29}_{-0.36} \pm 0.04$. Figure 2 shows distributions of Δt for B^0-tagged and $\bar{B}^0$-tagged events, and the asymmetry $\mathcal{A}(\Delta t) = (N_{B^0} - N_{\bar{B}^0})/(N_{B^0} + N_{\bar{B}^0})$, obtained by making a likelihood ratio cut to remove the background component.

Systematic uncertainties on the CP parameters are given in Table I. The systematic errors are evaluated with large

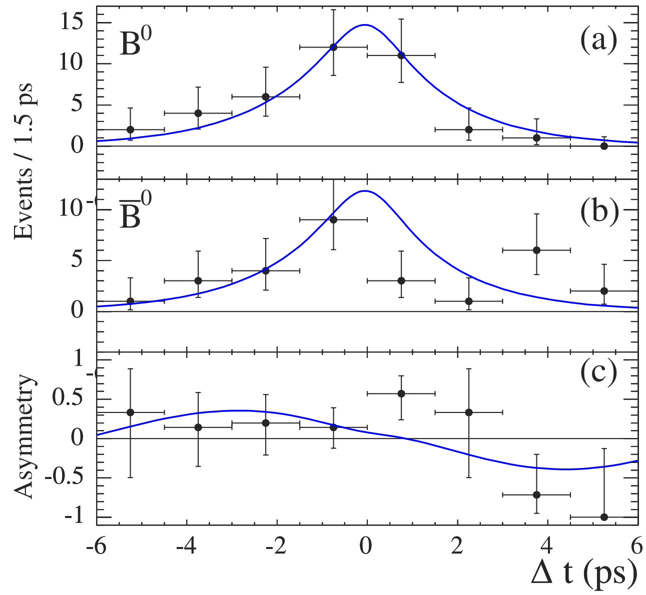

FIG. 2 (color online). Distributions of Δt for background subtracted events for B_{tag} tagged as (a) B^0 or (b) $\bar{B}^0$, and (c) the asymmetry $\mathcal{A}(\Delta t)$. We use a likelihood ratio cut that removes 96% of the background while retaining 95% of the signal.

samples of simulated B_{flav} and $B^0 \to K^0_S K^0_S K^0_S$ decays. We employ the difference in resolution function parameters extracted from these samples to vary the resolution function parameters extracted from the B_{flav} sample in data. We also perform fits to the simulated $B^0 \to K^0_S K^0_S K^0_S$ signal with parameters obtained either from signal or B_{flav} events to account for any potential bias due to the vertexing technique. Several SVT misalignment scenarios are applied to the simulated $B^0 \to K^0_S K^0_S K^0_S$ events to estimate detector effects. We consider large variations, several times the IP size, of the IP position and resolution and find they have negligible impact. Asymmetries in the rate of B^0 versus $\bar{B}^0$ tags in the background events, which are free parameters in the fit, are fixed to zero as a systematic uncertainty. The systematic error due to correlations in the fit variables is extracted from a fit to a sample of randomly selected signal MC events added to background events from a parametrized MC calculation. We allow for

TABLE I. Systematic uncertainties on S and C.

	$\sigma(S)$	$\sigma(C)$
Resolution function	0.017	0.017
Vertex reconstruction	0.020	0.022
SVT alignment	0.015	0.008
Background asymmetry	0.007	0.022
Fit correlation	0.016	0.004
Tag-side interference	0.008	0.015
PDFs	0.025	0.026
Total	0.044	0.047

the possible interference between the suppressed $\bar{b} \to \bar{u}c\bar{d}$ and the favored $b \to c\bar{u}d$ amplitude for some tagside B decays [17]. Finally, we include a systematic uncertainty to account for imperfect knowledge of the PDFs used in the fit. Most of the uncertainties on the PDFs are statistical and some are associated with data and MC differences. As an additional check, a B background component is added to the CP fit and we find the variation of the asymmetries to be negligible.

In summary, we have measured the $B^0 \to K_S^0 K_S^0 K_S^0$ branching fraction and the time-dependent CPV asymmetries. The BF measurement is in good agreement with previous measurements [10]. The measurements of S and C are in good agreement with the SM expectation.

We are grateful for the excellent luminosity and machine conditions provided by our PEP-II colleagues, and for the substantial dedicated effort from the computing organizations that support *BABAR*. The collaborating institutions wish to thank SLAC for its support and kind hospitality. This work is supported by DOE and NSF (USA), NSERC (Canada), IHEP (China), CEA and CNRS-IN2P3 (France), BMBF and DFG (Germany), INFN (Italy), FOM (The Netherlands), NFR (Norway), MIST (Russia), and PPARC (United Kingdom). Individuals have received support from CONACyT (Mexico), A. P. Sloan Foundation, Research Corporation, and Alexander von Humboldt Foundation.

Note added.—We became aware of a submission by the Belle Collaboration [18] on the same subject, while this paper was under review.

*Also with Università della Basilicata, Potenza, Italy
†Deceased

[1] N. Cabibbo, Phys. Rev. Lett. **10**, 531 (1963); M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973).
[2] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **94**, 161803 (2005); K. Abe *et al.* (Belle Collaboration), Phys. Rev. D **71**, 072003 (2005).
[3] Y. Grossman and M. P. Worah, Phys. Lett. B **395**, 241 (1997); M. Ciuchini, E. Franco, G. Martinelli, A. Masiero, and L. Silvestrini, Phys. Rev. Lett. **79**, 978 (1997).
[4] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **94**, 041802 (2005); Phys. Rev. D **71**, 111102 (2005); K.-F. Chen *et al.* (Belle Collaboration), hep-ex/0504023 [Phys. Rev. D (to be published)].
[5] Y. Grossman, Z. Ligeti, Y. Nir, and H. Quinn, Phys. Rev. D **68**, 015004 (2003).
[6] K. Abe *et al.* (Belle Collaboration), Phys. Rev. Lett. **91**, 261602 (2003).
[7] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **93**, 071801 (2004).
[8] Unless explicitly stated otherwise, conjugate decay modes are assumed throughout this paper.
[9] T. Gershon and M. Hazumi, Phys. Lett. B **596**, 163 (2004).
[10] A. Garmash *et al.* (Belle Collaboration), Phys. Rev. D **69**, 012001 (2004).
[11] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **93**, 131805 (2004).
[12] B. Aubert *et al.* (*BABAR* Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **479**, 1 (2002).
[13] Particle Data Group, S. Eidelman *et al.*, Phys. Lett. B **592**, 1 (2004).
[14] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **69**, 071101 (2004).
[15] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **89**, 201802 (2002).
[16] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **66**, 032003 (2002).
[17] O. Long, M. Baak, R. N. Cahn, and D. Kirkby, Phys. Rev. D **68**, 034010 (2003).
[18] K. Sumisawa *et al.* (Belle Collaboration), hep-ex/0503023 [Phys. Rev. Lett. (to be published)].