BABAR-PUB-06/039
SLAC-PUB-12072

Measurement of the *CP* Asymmetry and Branching Fraction of $B^0 \to \rho^0 K^0$

B. Aubert,[1] R. Barate,[1] M. Bona,[1] D. Boutigny,[1] F. Couderc,[1] Y. Karyotakis,[1] J. P. Lees,[1] V. Poireau,[1]
V. Tisserand,[1] A. Zghiche,[1] E. Grauges,[2] A. Palano,[3] J. C. Chen,[4] N. D. Qi,[4] G. Rong,[4] P. Wang,[4] Y. S. Zhu,[4]
G. Eigen,[5] I. Ofte,[5] B. Stugu,[5] G. S. Abrams,[6] M. Battaglia,[6] D. N. Brown,[6] J. Button-Shafer,[6] R. N. Cahn,[6]
E. Charles,[6] M. S. Gill,[6] Y. Groysman,[6] R. G. Jacobsen,[6] J. A. Kadyk,[6] L. T. Kerth,[6] Yu. G. Kolomensky,[6]
G. Kukartsev,[6] G. Lynch,[6] L. M. Mir,[6] T. J. Orimoto,[6] M. Pripstein,[6] N. A. Roe,[6] M. T. Ronan,[6] W. A. Wenzel,[6]
P. del Amo Sanchez,[7] M. Barrett,[7] K. E. Ford,[7] T. J. Harrison,[7] A. J. Hart,[7] C. M. Hawkes,[7] S. E. Morgan,[7]
A. T. Watson,[7] T. Held,[8] H. Koch,[8] B. Lewandowski,[8] M. Pelizaeus,[8] K. Peters,[8] T. Schroeder,[8] M. Steinke,[8]
J. T. Boyd,[9] J. P. Burke,[9] W. N. Cottingham,[9] D. Walker,[9] T. Cuhadar-Donszelmann,[10] B. G. Fulsom,[10]
C. Hearty,[10] N. S. Knecht,[10] T. S. Mattison,[10] J. A. McKenna,[10] A. Khan,[11] P. Kyberd,[11] M. Saleem,[11]
D. J. Sherwood,[11] L. Teodorescu,[11] V. E. Blinov,[12] A. D. Bukin,[12] V. P. Druzhinin,[12] V. B. Golubev,[12]
A. P. Onuchin,[12] S. I. Serednyakov,[12] Yu. I. Skovpen,[12] E. P. Solodov,[12] K. Yu Todyshev,[12] D. S. Best,[13]
M. Bondioli,[13] M. Bruinsma,[13] M. Chao,[13] S. Curry,[13] I. Eschrich,[13] D. Kirkby,[13] A. J. Lankford,[13] P. Lund,[13]
M. Mandelkern,[13] R. K. Mommsen,[13] W. Roethel,[13] D. P. Stoker,[13] S. Abachi,[14] C. Buchanan,[14] S. D. Foulkes,[15]
J. W. Gary,[15] O. Long,[15] B. C. Shen,[15] K. Wang,[15] L. Zhang,[15] H. K. Hadavand,[16] E. J. Hill,[16] H. P. Paar,[16]
S. Rahatlou,[16] V. Sharma,[16] J. W. Berryhill,[17] C. Campagnari,[17] A. Cunha,[17] B. Dahmes,[17] T. M. Hong,[17]
D. Kovalskyi,[17] J. D. Richman,[17] T. W. Beck,[18] A. M. Eisner,[18] C. J. Flacco,[18] C. A. Heusch,[18] J. Kroseberg,[18]
W. S. Lockman,[18] G. Nesom,[18] T. Schalk,[18] B. A. Schumm,[18] A. Seiden,[18] P. Spradlin,[18] D. C. Williams,[18]
M. G. Wilson,[18] J. Albert,[19] E. Chen,[19] A. Dvoretskii,[19] F. Fang,[19] D. G. Hitlin,[19] I. Narsky,[19] T. Piatenko,[19]
F. C. Porter,[19] A. Ryd,[19] A. Samuel,[19] G. Mancinelli,[20] B. T. Meadows,[20] K. Mishra,[20] M. D. Sokoloff,[20] F. Blanc,[21]
P. C. Bloom,[21] S. Chen,[21] W. T. Ford,[21] J. F. Hirschauer,[21] A. Kreisel,[21] M. Nagel,[21] U. Nauenberg,[21] A. Olivas,[21]
W. O. Ruddick,[21] J. G. Smith,[21] K. A. Ulmer,[21] S. R. Wagner,[21] J. Zhang,[21] A. Chen,[22] E. A. Eckhart,[22]
A. Soffer,[22] W. H. Toki,[22] R. J. Wilson,[22] F. Winklmeier,[22] Q. Zeng,[22] D. D. Altenburg,[23] E. Feltresi,[23] A. Hauke,[23]
H. Jasper,[23] A. Petzold,[23] B. Spaan,[23] T. Brandt,[24] V. Klose,[24] H. M. Lacker,[24] W. F. Mader,[24] R. Nogowski,[24]
J. Schubert,[24] K. R. Schubert,[24] R. Schwierz,[24] J. E. Sundermann,[24] A. Volk,[24] D. Bernard,[25] G. R. Bonneaud,[25]
P. Grenier,[25, *] E. Latour,[25] Ch. Thiebaux,[25] M. Verderi,[25] P. J. Clark,[26] W. Gradl,[26] F. Muheim,[26] S. Playfer,[26]
A. I. Robertson,[26] Y. Xie,[26] M. Andreotti,[27] D. Bettoni,[27] C. Bozzi,[27] R. Calabrese,[27] G. Cibinetto,[27] E. Luppi,[27]
M. Negrini,[27] A. Petrella,[27] L. Piemontese,[27] E. Prencipe,[27] F. Anulli,[28] R. Baldini-Ferroli,[28] A. Calcaterra,[28]
R. de Sangro,[28] G. Finocchiaro,[28] S. Pacetti,[28] P. Patteri,[28] I. M. Peruzzi,[28, †] M. Piccolo,[28] M. Rama,[28]
A. Zallo,[28] A. Buzzo,[29] R. Capra,[29] R. Contri,[29] M. Lo Vetere,[29] M. M. Macri,[29] M. R. Monge,[29] S. Passaggio,[29]
C. Patrignani,[29] E. Robutti,[29] A. Santroni,[29] S. Tosi,[29] G. Brandenburg,[30] K. S. Chaisanguanthum,[30] M. Morii,[30]
J. Wu,[30] R. S. Dubitzky,[31] J. Marks,[31] S. Schenk,[31] U. Uwer,[31] D. J. Bard,[32] W. Bhimji,[32] D. A. Bowerman,[32]
P. D. Dauncey,[32] U. Egede,[32] R. L. Flack,[32] J. A. Nash,[32] M. B. Nikolich,[32] W. Panduro Vazquez,[32] P. K. Behera,[33]
X. Chai,[33] M. J. Charles,[33] U. Mallik,[33] N. T. Meyer,[33] V. Ziegler,[33] J. Cochran,[34] H. B. Crawley,[34] L. Dong,[34]
V. Eyges,[34] W. T. Meyer,[34] S. Prell,[34] E. I. Rosenberg,[34] A. E. Rubin,[34] A. V. Gritsan,[35] A. G. Denig,[36]
M. Fritsch,[36] G. Schott,[36] N. Arnaud,[37] M. Davier,[37] G. Grosdidier,[37] A. Höcker,[37] F. Le Diberder,[37] V. Lepeltier,[37]
A. M. Lutz,[37] A. Oyanguren,[37] S. Pruvot,[37] S. Rodier,[37] P. Roudeau,[37] M. H. Schune,[37] A. Stocchi,[37]
W. F. Wang,[37] G. Wormser,[37] C. H. Cheng,[38] D. J. Lange,[38] D. M. Wright,[38] C. A. Chavez,[39] I. J. Forster,[39]
J. R. Fry,[39] E. Gabathuler,[39] R. Gamet,[39] K. A. George,[39] D. E. Hutchcroft,[39] D. J. Payne,[39] K. C. Schofield,[39]
C. Touramanis,[39] A. J. Bevan,[40] F. Di Lodovico,[40] W. Menges,[40] R. Sacco,[40] G. Cowan,[41] H. U. Flaecher,[41]
D. A. Hopkins,[41] P. S. Jackson,[41] T. R. McMahon,[41] S. Ricciardi,[41] F. Salvatore,[41] A. C. Wren,[41] D. N. Brown,[42]
C. L. Davis,[42] J. Allison,[43] N. R. Barlow,[43] R. J. Barlow,[43] Y. M. Chia,[43] C. L. Edgar,[43] G. D. Lafferty,[43]
M. T. Naisbit,[43] J. C. Williams,[43] J. I. Yi,[43] C. Chen,[44] W. D. Hulsbergen,[44] A. Jawahery,[44] C. K. Lae,[44]
D. A. Roberts,[44] G. Simi,[44] G. Blaylock,[45] C. Dallapiccola,[45] S. S. Hertzbach,[45] X. Li,[45] T. B. Moore,[45] S. Saremi,[45]
H. Staengle,[45] R. Cowan,[46] G. Sciolla,[46] S. J. Sekula,[46] M. Spitznagel,[46] F. Taylor,[46] R. K. Yamamoto,[46] H. Kim,[47]
S. E. Mclachlin,[47] P. M. Patel,[47] S. H. Robertson,[47] A. Lazzaro,[48] V. Lombardo,[48] F. Palombo,[48] J. M. Bauer,[49]
L. Cremaldi,[49] V. Eschenburg,[49] R. Godang,[49] R. Kroeger,[49] D. A. Sanders,[49] D. J. Summers,[49] H. W. Zhao,[49]

S. Brunet,[50] D. Côté,[50] M. Simard,[50] P. Taras,[50] F. B. Viaud,[50] H. Nicholson,[51] N. Cavallo,[52,‡] G. De Nardo,[52] F. Fabozzi,[52,‡] C. Gatto,[52] L. Lista,[52] D. Monorchio,[52] P. Paolucci,[52] D. Piccolo,[52] C. Sciacca,[52] M. Baak,[53] G. Raven,[53] H. L. Snoek,[53] C. P. Jessop,[54] J. M. LoSecco,[54] T. Allmendinger,[55] G. Benelli,[55] K. K. Gan,[55] K. Honscheid,[55] D. Hufnagel,[55] P. D. Jackson,[55] H. Kagan,[55] R. Kass,[55] A. M. Rahimi,[55] R. Ter-Antonyan,[55] Q. K. Wong,[55] N. L. Blount,[56] J. Brau,[56] R. Frey,[56] O. Igonkina,[56] M. Lu,[56] R. Rahmat,[56] N. B. Sinev,[56] D. Strom,[56] J. Strube,[56] E. Torrence,[56] A. Gaz,[57] M. Margoni,[57] M. Morandin,[57] A. Pompili,[57] M. Posocco,[57] M. Rotondo,[57] F. Simonetto,[57] R. Stroili,[57] C. Voci,[57] M. Benayoun,[58] J. Chauveau,[58] H. Briand,[58] P. David,[58] L. Del Buono,[58] Ch. de la Vaissière,[58] O. Hamon,[58] B. L. Hartfiel,[58] M. J. J. John,[58] Ph. Leruste,[58] J. Malclès,[58] J. Ocariz,[58] L. Roos,[58] G. Therin,[58] L. Gladney,[59] J. Panetta,[59] M. Biasini,[60] R. Covarelli,[60] C. Angelini,[61] G. Batignani,[61] S. Bettarini,[61] F. Bucci,[61] G. Calderini,[61] M. Carpinelli,[61] R. Cenci,[61] F. Forti,[61] M. A. Giorgi,[61] A. Lusiani,[61] G. Marchiori,[61] M. A. Mazur,[61] M. Morganti,[61] N. Neri,[61] E. Paoloni,[61] G. Rizzo,[61] J. J. Walsh,[61] M. Haire,[62] D. Judd,[62] D. E. Wagoner,[62] J. Biesiada,[63] N. Danielson,[63] P. Elmer,[63] Y. P. Lau,[63] C. Lu,[63] J. Olsen,[63] A. J. S. Smith,[63] A. V. Telnov,[63] F. Bellini,[64] G. Cavoto,[64] A. D'Orazio,[64] D. del Re,[64] E. Di Marco,[64] R. Faccini,[64] F. Ferrarotto,[64] F. Ferroni,[64] M. Gaspero,[64] L. Li Gioi,[64] M. A. Mazzoni,[64] S. Morganti,[64] G. Piredda,[64] F. Polci,[64] F. Safai Tehrani,[64] C. Voena,[64] M. Ebert,[65] H. Schröder,[65] R. Waldi,[65] T. Adye,[66] N. De Groot,[66] B. Franek,[66] E. O. Olaiya,[66] F. F. Wilson,[66] R. Aleksan,[67] S. Emery,[67] A. Gaidot,[67] S. F. Ganzhur,[67] G. Hamel de Monchenault,[67] W. Kozanecki,[67] M. Legendre,[67] G. Vasseur,[67] Ch. Yèche,[67] M. Zito,[67] X. R. Chen,[68] H. Liu,[68] W. Park,[68] M. V. Purohit,[68] J. R. Wilson,[68] M. T. Allen,[69] D. Aston,[69] R. Bartoldus,[69] P. Bechtle,[69] N. Berger,[69] R. Claus,[69] J. P. Coleman,[69] M. R. Convery,[69] M. Cristinziani,[69] J. C. Dingfelder,[69] J. Dorfan,[69] G. P. Dubois-Felsmann,[69] D. Dujmic,[69] W. Dunwoodie,[69] R. C. Field,[69] T. Glanzman,[69] S. J. Gowdy,[69] M. T. Graham,[69] V. Halyo,[69] C. Hast,[69] T. Hryn'ova,[69] W. R. Innes,[69] M. H. Kelsey,[69] P. Kim,[69] D. W. G. S. Leith,[69] S. Li,[69] S. Luitz,[69] V. Luth,[69] H. L. Lynch,[69] D. B. MacFarlane,[69] H. Marsiske,[69] R. Messner,[69] D. R. Muller,[69] C. P. O'Grady,[69] V. E. Ozcan,[69] A. Perazzo,[69] M. Perl,[69] T. Pulliam,[69] B. N. Ratcliff,[69] A. Roodman,[69] A. A. Salnikov,[69] R. H. Schindler,[69] J. Schwiening,[69] A. Snyder,[69] J. Stelzer,[69] D. Su,[69] M. K. Sullivan,[69] K. Suzuki,[69] S. K. Swain,[69] J. M. Thompson,[69] J. Va'vra,[69] N. van Bakel,[69] M. Weaver,[69] A. J. R. Weinstein,[69] W. J. Wisniewski,[69] M. Wittgen,[69] D. H. Wright,[69] A. K. Yarritu,[69] K. Yi,[69] C. C. Young,[69] P. R. Burchat,[70] A. J. Edwards,[70] S. A. Majewski,[70] B. A. Petersen,[70] C. Roat,[70] L. Wilden,[70] S. Ahmed,[71] M. S. Alam,[71] R. Bula,[71] J. A. Ernst,[71] V. Jain,[71] B. Pan,[71] M. A. Saeed,[71] F. R. Wappler,[71] S. B. Zain,[71] W. Bugg,[72] M. Krishnamurthy,[72] S. M. Spanier,[72] R. Eckmann,[73] J. L. Ritchie,[73] A. Satpathy,[73] C. J. Schilling,[73] R. F. Schwitters,[73] J. M. Izen,[74] X. C. Lou,[74] S. Ye,[74] F. Bianchi,[75] F. Gallo,[75] D. Gamba,[75] M. Bomben,[76] L. Bosisio,[76] C. Cartaro,[76] F. Cossutti,[76] G. Della Ricca,[76] S. Dittongo,[76] L. Lanceri,[76] L. Vitale,[76] V. Azzolini,[77] F. Martinez-Vidal,[77] Sw. Banerjee,[78] B. Bhuyan,[78] C. M. Brown,[78] D. Fortin,[78] K. Hamano,[78] R. Kowalewski,[78] I. M. Nugent,[78] J. M. Roney,[78] R. J. Sobie,[78] J. J. Back,[79] P. F. Harrison,[79] T. E. Latham,[79] G. B. Mohanty,[79] M. Pappagallo,[79] H. R. Band,[80] X. Chen,[80] B. Cheng,[80] S. Dasu,[80] M. Datta,[80] K. T. Flood,[80] J. J. Hollar,[80] P. E. Kutter,[80] B. Mellado,[80] A. Mihalyi,[80] Y. Pan,[80] M. Pierini,[80] R. Prepost,[80] S. L. Wu,[80] Z. Yu,[80] and H. Neal[81]

(The *BABAR* Collaboration)

[1]*Laboratoire de Physique des Particules, F-74941 Annecy-le-Vieux, France*
[2]*Universitat de Barcelona, Facultat de Fisica Dept. ECM, E-08028 Barcelona, Spain*
[3]*Università di Bari, Dipartimento di Fisica and INFN, I-70126 Bari, Italy*
[4]*Institute of High Energy Physics, Beijing 100039, China*
[5]*University of Bergen, Institute of Physics, N-5007 Bergen, Norway*
[6]*Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720, USA*
[7]*University of Birmingham, Birmingham, B15 2TT, United Kingdom*
[8]*Ruhr Universität Bochum, Institut für Experimentalphysik 1, D-44780 Bochum, Germany*
[9]*University of Bristol, Bristol BS8 1TL, United Kingdom*
[10]*University of British Columbia, Vancouver, British Columbia, Canada V6T 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]*University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, California 95064, USA*
[19]*California Institute of Technology, Pasadena, California 91125, USA*

[20]University of Cincinnati, Cincinnati, Ohio 45221, USA
[21]University of Colorado, Boulder, Colorado 80309, USA
[22]Colorado State University, Fort Collins, Colorado 80523, USA
[23]Universität Dortmund, Institut für Physik, D-44221 Dortmund, Germany
[24]Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany
[25]Ecole Polytechnique, Laboratoire Leprince-Ringuet, F-91128 Palaiseau, France
[26]University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom
[27]Università di Ferrara, Dipartimento di Fisica and INFN, I-44100 Ferrara, Italy
[28]Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy
[29]Università di Genova, Dipartimento di Fisica and INFN, I-16146 Genova, Italy
[30]Harvard University, Cambridge, Massachusetts 02138, USA
[31]Universität Heidelberg, Physikalisches Institut, 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]Johns Hopkins University, Baltimore, Maryland 21218, USA
[36]Universität Karlsruhe, Institut für Experimentelle Kernphysik, D-76021 Karlsruhe, Germany
[37]Laboratoire de l'Accélérateur Linéaire, IN2P3-CNRS et Université Paris-Sud 11,
Centre Scientifique d'Orsay, B.P. 34, F-91898 ORSAY Cedex, France
[38]Lawrence Livermore National Laboratory, Livermore, California 94550, USA
[39]University of Liverpool, Liverpool L69 7ZE, United Kingdom
[40]Queen Mary, University of London, E1 4NS, United Kingdom
[41]University of London, Royal Holloway and Bedford New College, Egham, Surrey TW20 0EX, United Kingdom
[42]University of Louisville, Louisville, Kentucky 40292, USA
[43]University of Manchester, Manchester M13 9PL, United Kingdom
[44]University of Maryland, College Park, Maryland 20742, USA
[45]University of Massachusetts, Amherst, Massachusetts 01003, USA
[46]Massachusetts Institute of Technology, Laboratory for Nuclear Science, Cambridge, Massachusetts 02139, USA
[47]McGill University, Montréal, Québec, Canada H3A 2T8
[48]Università di Milano, Dipartimento di Fisica and INFN, I-20133 Milano, Italy
[49]University of Mississippi, University, Mississippi 38677, USA
[50]Université de Montréal, Physique des Particules, Montréal, Québec, Canada H3C 3J7
[51]Mount Holyoke College, South Hadley, Massachusetts 01075, USA
[52]Università di Napoli Federico II, Dipartimento di Scienze Fisiche and INFN, I-80126, Napoli, Italy
[53]NIKHEF, National Institute for Nuclear Physics and High Energy Physics, NL-1009 DB Amsterdam, The Netherlands
[54]University of Notre Dame, Notre Dame, Indiana 46556, USA
[55]Ohio State University, Columbus, Ohio 43210, USA
[56]University of Oregon, Eugene, Oregon 97403, USA
[57]Università di Padova, Dipartimento di Fisica and INFN, I-35131 Padova, Italy
[58]Universités Paris VI et VII, Laboratoire de Physique Nucléaire et de Hautes Energies, F-75252 Paris, France
[59]University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA
[60]Università di Perugia, Dipartimento di Fisica and INFN, I-06100 Perugia, Italy
[61]Università di Pisa, Dipartimento di Fisica, Scuola Normale Superiore and INFN, I-56127 Pisa, Italy
[62]Prairie View A&M University, Prairie View, Texas 77446, USA
[63]Princeton University, Princeton, New Jersey 08544, USA
[64]Università di Roma La Sapienza, Dipartimento di Fisica and INFN, I-00185 Roma, Italy
[65]Universität Rostock, D-18051 Rostock, Germany
[66]Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingdom
[67]DSM/Dapnia, CEA/Saclay, F-91191 Gif-sur-Yvette, France
[68]University of South Carolina, Columbia, South Carolina 29208, USA
[69]Stanford Linear Accelerator Center, Stanford, California 94309, USA
[70]Stanford University, Stanford, California 94305-4060, USA
[71]State University of New York, Albany, New York 12222, USA
[72]University of Tennessee, Knoxville, Tennessee 37996, USA
[73]University of Texas at Austin, Austin, Texas 78712, USA
[74]University of Texas at Dallas, Richardson, Texas 75083, USA
[75]Università di Torino, Dipartimento di Fisica Sperimentale and INFN, I-10125 Torino, Italy
[76]Università di Trieste, Dipartimento di Fisica and INFN, I-34127 Trieste, Italy
[77]IFIC, Universitat de Valencia-CSIC, E-46071 Valencia, Spain
[78]University of Victoria, Victoria, British Columbia, Canada V8W 3P6
[79]Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom
[80]University of Wisconsin, Madison, Wisconsin 53706, USA
[81]Yale University, New Haven, Connecticut 06511, USA

We present a measurement of the branching fraction and time-dependent CP asymmetry of $B^0 \to \rho^0 K^0$. The results are obtained from a data sample of 227×10^6 $\Upsilon(4S) \to B\overline{B}$ decays collected with the *BABAR* detector at the PEP-II asymmetric-energy B Factory at SLAC. From a time-dependent maximum likelihood fit yielding 111 ± 19 signal events we find $\mathcal{B}(B^0 \to \rho^0 K^0) = (4.9 \pm 0.8 \pm 0.9) \times 10^{-6}$, where the first error is statistical and the second systematic. We report the measurement of the CP parameters $S_{\rho^0 K^0_S} = 0.20 \pm 0.52 \pm 0.24$ and $C_{\rho^0 K^0_S} = 0.64 \pm 0.41 \pm 0.20$.

PACS numbers: 13.25.Hw, 12.15.Hh, 11.30.Er

Decays of B^0 mesons to the $\rho^0 K^0$ final state are expected to be dominated by $b \to s$ penguin amplitudes. Neglecting Cabibbo-Kobayashi-Maskawa (CKM) suppressed amplitudes, the mixing-induced *CP* violation parameter $S_{\rho^0 K^0_S}$ should equal $\sin 2\beta$, which is well measured in $B^0 \to J/\psi K^0$ decays [1]. Within the Standard Model (SM), only small deviations from this prediction are expected [2]. In the Standard Model , a single phase in the CKM matrix governs *CP* violation [3], but if heavy non-SM particles appear in additional penguin diagrams, new *CP*-violating phases could enter and $S_{\rho^0 K^0_S}$ would not equal $\sin 2\beta$ [4]. Observation of a significant discrepancy would be a clear signal of new physics.

In this Letter we present the first observation of the decay $B^0 \to \rho^0 K^0$ and a measurement of the *CP*-violating asymmetries $S_{\rho^0 K^0_S}$ and $C_{\rho^0 K^0_S}$ from a time-dependent maximum likelihood analysis. A non-zero value of $S_{\rho^0 K^0_S}$ indicates CP violation due to the interference between decays with and without mixing. Direct CP violation leads to a non-zero value of $C_{\rho^0 K^0_S}$. We take a quasi-two-body (Q2B) approach, restricting ourselves to the region of the $B^0 \to \pi^+\pi^- K^0_S$ Dalitz plot dominated by the ρ^0 and treating other $B^0 \to \pi^+\pi^- K^0_S$ contributions as non-interfering background. The effects of interference with other resonances are estimated and taken as systematic uncertainties.

The data were collected with the *BABAR* detector at the PEP-II asymmetric-energy e^+e^- storage ring at SLAC. An integrated luminosity of $205\,\mathrm{fb}^{-1}$, corresponding to 227×10^6 $B\overline{B}$ pairs, was collected at the $\Upsilon(4S)$ resonance (center-of-mass (CM) energy $\sqrt{s} = 10.56\,\mathrm{GeV}$), and $16\,\mathrm{fb}^{-1}$ was collected about 40 MeV below the resonance (off-resonance data). The *BABAR* detector is described in detail elsewhere [5]. Charged particles are detected and their momenta measured by the combination of a silicon vertex tracker (SVT), consisting of five layers of double sided detectors, and a 40-layer central drift chamber (DCH), both operating in the 1.5 T magnetic field of a solenoid. Charged-particle identification is provided by the average energy loss in the tracking devices and by an internally reflecting ring-imaging Cherenkov detector (DIRC) covering the central region.

We reconstruct $B^0 \to \rho^0 K^0_S$ candidates (B^0_{rec} in the following) from combinations of ρ^0 and K^0_S candidates, both reconstructed in their $\pi^+\pi^-$ decay mode. For the $\pi^+\pi^-$ pair from the ρ^0 candidate, we remove tracks identified as very likely to be electrons, kaons, or protons. The mass of the ρ^0 candidate is restricted to the interval $0.4 < m(\pi^+\pi^-) < 0.9\,\mathrm{GeV}/c^2$. The K^0_S candidate is required to have a mass within $13\,\mathrm{MeV}/c^2$ of the nominal K^0_S mass [6] and a decay vertex separated from the ρ^0 decay vertex by at least three times the estimated seperation measurement uncertainty. In addition, the cosine of the angle in the lab frame between the K^0_S flight direction and the vector between the ρ^0 decay vertex and the K^0_S decay vertex must be greater than 0.995. Vetoes against $B^0 \to D^+\pi^-$ and $B^0 \to K^*\pi^-(K^* \to K^0_S\pi^+)$ are imposed by requiring that the invariant masses of both $K^0_S\pi$ combinations are more than $0.055\,\mathrm{GeV}/c^2$ and $0.040\,\mathrm{GeV}/c^2$ from the K^{*+} and D^+ masses [6] respectively. To exclude events with poorly reconstructed vertices we require the estimated error on Δt to be less than 2.5 ps and that $|\Delta t|$ must be less than 20 ps, where Δt is the proper time difference between the decay of the reconstructed B meson (B^0_{rec}) and its unreconstructed partner (B^0_{tag}), $t_{\mathrm{rec}} - t_{\mathrm{tag}}$. It is determined from the measured relative displacement of the two B-decay vertices and the known boost of the e^+e^- system.

Two kinematic variables are used to discriminate between signal and combinatorial background. The first is ΔE, the difference between the measured CM energy of the B candidate and $\sqrt{s}/2$, where $\sqrt{s}$ is the CM beam energy. The second is the beam-energy substituted mass $m_{\mathrm{ES}} \equiv \sqrt{(s/2 + \mathbf{p}_i \cdot \mathbf{p}_B)^2/E_i^2 - \mathbf{p}_B^2}$, where the B^0_{rec} momentum $\mathbf{p}_B$ and the four-momentum of the initial $\Upsilon(4S)$ state (E_i, $\mathbf{p}_i$) are defined in the laboratory frame. We require $|\Delta E| < 0.15\,\mathrm{GeV}$ and $5.23 < m_{\mathrm{ES}} < 5.29\,\mathrm{GeV}/c^2$.

Continuum $e^+e^- \to q\bar{q}$ ($q = u, d, s, c$) events are the dominant background. To enhance discrimination between signal and continuum, we use a neural network (NN) to combine five variables: the cosine of the angle between the B^0_{rec} direction and the beam axis in the CM, the cosine of the angle between the thrust axis of the B^0_{rec} candidate and the beam axis, the sum of momenta transverse to the direction of flight of the B^0_{rec}, and the zeroth and second angular moments $L_{0,2}$ of the energy flow about the B^0_{rec} thrust axis. The moments are defined by $L_j = \sum_i \mathbf{p}_i \times |\cos\theta_i|^j$, where $\mathbf{p}_i$ is its momentum and θ_i is the angle with respect to the B^0_{rec} thrust axis of the track or neutral cluster i excluding the tracks that make up the B^0_{rec} candidate. The NN is trained with off-resonance data and Monte Carlo (MC)[7] simulated signal events.

selected signal events are reconstructed incorrectly with low momentum tracks from the other B meson being used to form the ρ^0 candidate. In total, 20,073 events pass all selection criteria in the on-resonance sample.

An unbinned extended maximum likelihood fit is used to extract the $\rho^0 K^0_S$ CP asymmetry and branching fraction. There are ten components in the fit: signal, continuum background and eight separate backgrounds from B decays. Large samples of MC-simulated events are used to identify these specific B backgrounds. Where an individual decay mode makes a significant contribution to the dataset (one or more events expected in the data) we include it as a separate contribution to the fit. Probability density functions (PDFs) are taken from simulation with the expected number of B background events fixed to values estimated from known branching fractions [6] and MC efficiencies (Table I). Where only upper limits are available, decay modes are not included in the default fit but are used in alternate fits to evaluate systematics.

Events from B decays that do not come from individually significant channels are collected together into two "bulk" B contributions to the fit (B^0 and B^+). The assumption is made that $B^0 \rightarrow f_0(600) K^0_S$ can be neglected, with support from [8, 9] which do not require this mode to describe $B^+ \rightarrow K^+\pi^+\pi^-$.

The events in the data sample have their unreconstructed Bs flavor-tagged as B^0 or $\overline{B}^0$ with the method described in [10]. Events are separated into four flavor-tagging categories and an "untagged" category, depending upon the method used to determine the flavor. Each category has a different expected purity and accuracy of tagging. The likelihood function for the N_k candidates in flavor tagging category k is

$$\mathcal{L}_k = e^{-N'_k} \prod_{\rm i=1}^{N_k} \left\{ N_S \epsilon_k \left[(1 - f^k_{\rm MR}) \mathcal{P}^{S^{\rm CR}}_{\rm i,k} + f^k_{\rm MR} \mathcal{P}^{S^{\rm MR}}_{\rm i,k} \right] \right. \\ \left. + N_{\rm C,k} \mathcal{P}^{C}_{\rm i,k} + \sum_{\rm j=1}^{n_B} N_{\rm B,j} \epsilon_{\rm j,k} \mathcal{P}^{B}_{\rm ij,k} \right\}, \qquad (1)$$

where N'_k is the sum of the signal and background yields for events tagged in category k, N_S is the number of $\rho^0 K^0_S$ signal events in the sample, ϵ_k is the fraction of signal events tagged in category k, $f^k_{\rm MR}$ is the fraction of mis-reconstructed (MR) signal events in tagging category k and the superscript CR implies correctly reconstructed signal. $N_{\rm C,k}$ is the number of continuum background events that are tagged in category k, and $N_{\rm B,j} \epsilon_{\rm j,k}$ is the number of B-background events of class j that are tagged in category k. The B-background event yields are fixed in the default fit to values shown in Table I. The values ϵ_k and f^k are determined from MC for B-backgrounds and from a sample of B decays of known flavor for signal. The total likelihood $\mathcal{L}$ is the product of the likelihoods for each tagging category.

Each signal and background PDF is defined as: $\mathcal{P}_k = \mathcal{P}(m_{\rm ES}) \cdot \mathcal{P}(\Delta E) \cdot \mathcal{P}_k({\rm NN}) \cdot \mathcal{P}(\cos\theta_{\pi^+}) \cdot \mathcal{P}(\Delta t) \cdot \mathcal{P}(m_{\pi^+\pi^-})$ where $m_{\rm ES}$, ΔE, NN, $m(\pi^+\pi^-)$ are the variables described previously, and $\cos\theta_{\pi^+}$ is the angle between the K^0_S and the π^+ from the ρ^0 in the ρ^0 meson's center-of-mass frame.

Background Mode	$N_{\rm expected}$
Bulk B^+	197±98
Bulk B^0	197±98
$B^0 \rightarrow D^+\pi^-$	40±6
$B^0 \rightarrow \eta' K^0_S$	34±5
$B^0 \rightarrow f_0(980) K^0_S$	22±4
$B^0 \rightarrow K^*_0(1430)^+\pi^-$	7±1
$B^0 \rightarrow \rho^0 K^{*0}$	3±3
$B^0 \rightarrow (K^0_S\pi^+\pi^-)_{\rm NR}$	2±1

TABLE I: Expected number of events from each B background source.

The Δt PDF for signal events is defined as

$$\mathcal{P}(\Delta t) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B} \times \\ \left[1 + \frac{\Delta D}{2} + q \langle D \rangle \left(S_{\rho^0 K^0_S} \sin(\Delta m_d \Delta t) - \right.\right. \\ \left.\left. C_{\rho^0 K^0_S} \cos(\Delta m_d \Delta t) \right) \right] \otimes R_{\rm sig}(\Delta t, \sigma_{\Delta t}), \quad (2)$$

where τ_B and Δm_d are the average lifetime and eigenstate mass difference of the neutral B meson, $q = +1$ (-1) when $B^0_{\rm rec} = B^0$ ($\overline{B}^0$), $\langle D \rangle$ describes the dilution effect from imperfect flavor tagging, and ΔD is the difference in this dilution between B^0 and $\overline{B}^0$ tags. This formalism is found to effectively describe both correctly and incorrectly reconstructed signal. $\langle D \rangle$, ΔD and the Δt resolution function, $R_{\rm sig}(\Delta t, \sigma_{\Delta t})$, have parameters fixed to values taken from a sample where Bs of known flavor can be reconstructed [10]. "Untagged" events have a $\langle D \rangle$ of 0, reflecting the lack of tag information.

The $m_{\rm ES}$, ΔE, NN, $\cos\theta_{\pi^+}$ and $m(\pi^+\pi^-)$ PDFs for signal and B background are taken from MC simulation. In general they are non-parametric, with the exception of $m_{\rm ES}$ and ΔE for signal signal PDFs appear as solid curves in Figure 1 The CP parameters for $\eta' K^0_S$ and $f_0 K^0_S$ backgrounds are fixed to $C = 0$ and $S = \sin 2\beta$ (for $\eta' K^0_S$) and $S = -\sin 2\beta$ (for $f_0 K^0_S$), in accordance with SM expectations. For the remaining B backgrounds the parameters C and S are fixed to 0. The PDF parameters describing the continuum background are either allowed to vary freely in the fit or else determined separately from off-resonance data.

There are 16 free parameters in the fit: the yield of signal events, $S_{\rho K^0_S}$ and $C_{\rho K^0_S}$ and 13 that parameterize the continuum background. The continuum parameters are: the yields (5), and those asociated with the second order polynomial describing the ΔE distribution (2), the ARGUS [11] function describing the $m_{\rm ES}$ distribution (1) and the double Gaussian used to model the Δt distribution (5).

The fit yields 111 ± 19 signal events. We calculate the branching fraction from the measured signal yield, efficiency (including the $\rho^0 \to \pi^+\pi^-$, $K^0 \to K^0_S$ and $K^0_S \to \pi^+\pi^-$ branching fractions), and the number of $B\overline{B}$ events. The result is $\mathcal{B}(B^0 \to \rho^0 K^0) = (4.9 \pm 0.8 \pm 0.9) \times 10^{-6}$, where the first error is statistical and the second systematic. The likelihood ratio between the fit result of 111 signal events and the null hypothesis of zero signal shows that this is excluded at the 8.7σ level. When additive systematic effects are included we exclude the null hypothesis at the 5.0σ level. The fit for CP parameters gives $S_{\rho^0 K^0_S} = 0.20 \pm 0.52 \pm 0.24$ and $C_{\rho^0 K^0_S} = 0.64 \pm 0.41 \pm 0.20$.

Figure 1 shows ${}_s\mathcal{P}lots$ [12] of the discriminating variables in the fit. Knowledge of the level of background and our ability to distinguish it from signal can be gained from the errors in these plots. In addition, Fig. 1(f) shows the ratio $\mathcal{L}_S/(\mathcal{L}_S + \mathcal{L}_B)$ for all events, where $\mathcal{L}_S$ and $\mathcal{L}_B$ are the likelihoods for each event to be signal or background, respectively.

Figure 2 shows ${}_s\mathcal{P}lots$ of Δt. Untagged events are removed, and events are split into B^0_{tag} tags and $\overline{B}^0_{\text{tag}}$ tags. An ${}_s\mathcal{P}lot$ of asymmetry $(N_{B^0_{\text{tag}}} - N_{\overline{B}^0_{\text{tag}}})/(N_{B^0_{\text{tag}}} + N_{\overline{B}^0_{\text{tag}}})$ as a function of Δt is also shown.

Systematic errors are listed in Table II. We estimate biases due to the fit procedure from fits to a large number of simulated experiments. We vary parameters fixed in the nominal fit by their uncertainty and include the change in result as the corresponding systematic error. The systematic uncertainties arise from sources including the parameterization of the signal Δt resolution function, the mistag fractions, and discrepancies between data and the simulation including the effect of alternative models for resonances.

We estimate the systematic uncertainly due to neglecting the intereference between $B^0 \to K^0_S\pi^+\pi^-$ from both parameterized and full simulations that take interference into account. We include contibutions from $\rho^0(770)K^0_S$, $f_0(980)K^0_S$, $K^*_0(1430)^+\pi^-$, $K^*_0(892)^+\pi^-$ and $f_2(1270)K^0_S$, as well as two $K^0_S\pi\pi$ non-resonant contributions. We simulate many samples with different relative phases between modes. We also vary the amplitude of each mode within limits based on the best available information [8, 9]. Each simulation is then subjected to the standard selection and fitting procedure. The systematic uncertainty is taken from the width of a Gaussian fitted to the distribution of the results.

In summary, we have established the existance of the decay $B^0 \to \rho^0 K^0$ and measured its branching fraction with the significance of 5 standard deviations. Our measurement agrees within errors with $\mathcal{B}(B^0 \to \omega K^0)$ as measured in [13], as expected if a single penguin amplitude dominates these decays. We have extracted the CP violating parameters S and C for $B^0 \to \rho^0 K^0_S$ which are consistent with those measured in charmonium channels [1].

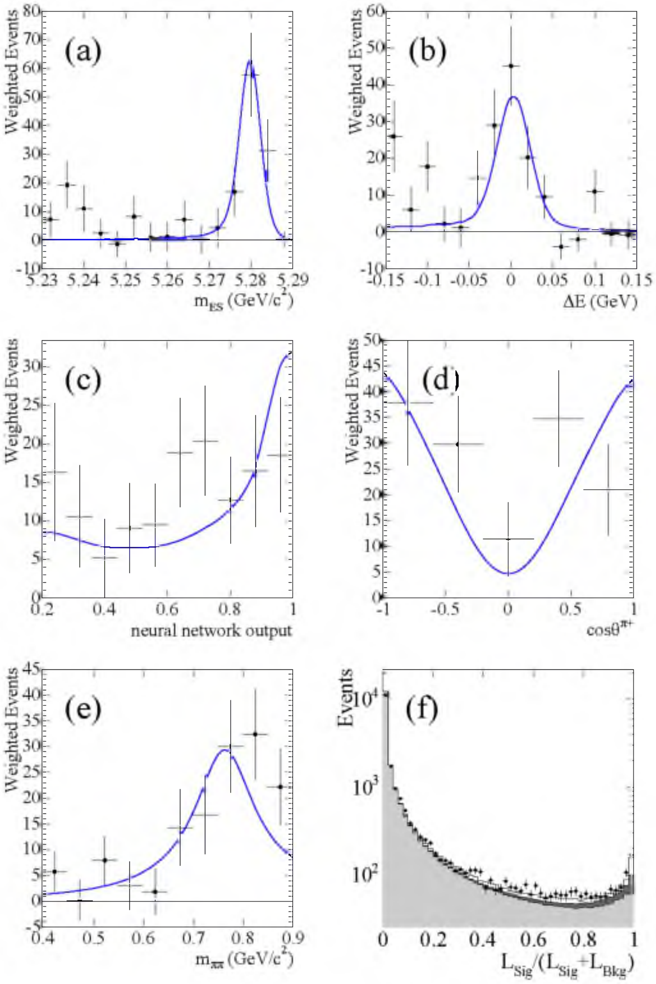

FIG. 1: ${}_s\mathcal{P}lots$ of Maximum Likelihood fit discriminating variables: (a) m_{ES}, (b) ΔE, (c) Neural Network output, (d) $\cos\theta_{\pi^+}$, (e) invariant mass of the $\pi^+\pi^-$ combination. Lines are projections of signal PDFs for each variable. (f) is a plot of the likelihood of an event being signal calculated for all events in our dataset and compared to the predictions of our PDF (predicted continuum in light grey, B Background in dark grey and signal in white).

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), MEC (Spain), and PPARC (United Kingdom). Individuals have received support from the Marie Curie EIF (European Union) and the A. P. Sloan Foundation.

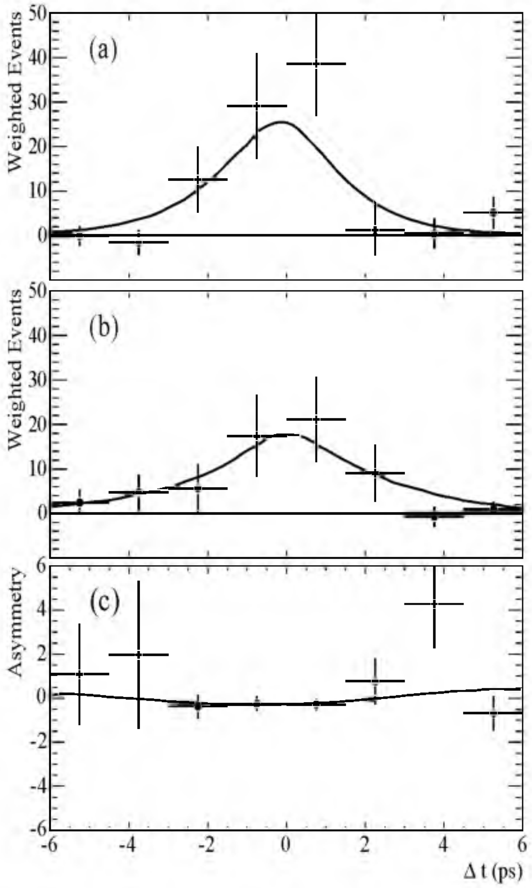

FIG. 2: $_s\mathcal{P}lots$ of Δt, overlaid with projected signal PDFs, split into (a) $B^0_{\rm tag}$ tags, (b) $\overline{B}^0_{\rm tag}$ tags and (c) the asymmetry $(N_{B^0_{\rm tag}} - N_{\overline{B}^0_{\rm tag}})/(N_{B^0_{\rm tag}} + N_{\overline{B}^0_{\rm tag}})$ as a function of Δt .

Mis-reco'd events and fit bias	0.12	0.09	10
PDF uncertainties	0.13	0.18	2
Tagging parameters	0.02	0.01	-
Neglect of intereference	0.14	0.09	7
ρ^0 mass shape	0.07	0.05	3
B Background BF	0.02	0.10	13
CP of background	0.04	0.00	-
Tracking efficiency & B counting	-	-	6
Total	0.24	0.20	19

TABLE II: Summary of contributions to the systematic error.

---

[*] Also at Laboratoire de Physique Corpusculaire, Clermont-Ferrand, France

[†] Also with Università di Perugia, Dipartimento di Fisica, Perugia, Italy

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

[1] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. Lett. **94**, 161803 (2005), BELLE Collaboration, K. Abe *et al.*, Phys. Rev. D **71**, 072003 (2005).

[2] G. Buchalla *et al.*, JHEP **0509**, 074 (2005); M. Beneke, Phys. Lett. B **620**, 143 (2005); H. Y. Cheng, C. K. Chua and A. Soni, Phys. Rev. D **72**, 014006 (2005).

[3] N. Cabibbo, Phys. Rev. Lett. **10**, 531 (1963); M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973).

[4] Y. Grossman and M. P. Worah, Phys. Lett. B **395**, 241 (1997); M. Ciuchini *et al.*, Phys. Rev. Lett. **79**, 978 (1997); D. London and A. Soni, Phys. Lett. B **407**, 61 (1997).

[5] *BABAR* Collaboration, B. Aubert *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **A479**, 1 (2002).

[6] Particle Data Group, S. Eidelman *et al.*, Phys. Lett. B **592**, 1 (2004).

[7] S. Agostinelli *et al.* [GEANT4 Collaboration], Nucl. Instrum. Meth. A **506**, 250 (2003).

[8] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. D **72** 072003 (2005).

[9] BELLE Collaboration, A. Garmash *et al.*, Phys. Rev. D **71**, 092003 (2005).

[10] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. D **66**, 032003 (2002).

[11] ARGUS Collaboration, H. Albrecht *et al.*, Phys. Lett. **B241**, 278 (1990).

[12] M. Pivk and F. R. Le Diberder, Nucl. Instrum. Methods Phys. Res. Sect. A **A555**, 356 (2005).

[13] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. D **74**, 011106 (2006).