

Measurements of CP -Violating Asymmetries in B Decays to ωK_S^0

The *BABAR* Collaboration

August 1, 2006

Abstract

We present preliminary measurements of CP -violating asymmetries for the decay $B^0 \rightarrow \omega K_S^0$. The data sample corresponds to 347 million $B\bar{B}$ pairs produced by e^+e^- annihilation at the $\Upsilon(4S)$ resonance. For the decay $B^0 \rightarrow \omega K_S^0$, we measure the time-dependent CP -violation parameters $S = 0.62_{-0.30}^{+0.25} \pm 0.02$, and $C = -0.43_{-0.23}^{+0.25} \pm 0.03$, where the first uncertainty is statistical and the second systematic.

Submitted to the 33rd International Conference on High-Energy Physics, ICHEP 06,
26 July—2 August 2006, Moscow, Russia.

Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

Work supported in part by Department of Energy contract DE-AC02-76SF00515.

The BABAR Collaboration,

B. Aubert, R. Barate, M. Bona, D. Boutigny, F. Couderc, Y. Karyotakis, J. P. Lees, V. Poireau,
V. Tisserand, A. Zghiche

*Laboratoire de Physique des Particules, IN2P3/CNRS et Université de Savoie, F-74941 Annecy-Le-Vieux,
France*

E. Grauges

Universitat de Barcelona, Facultat de Física, Departament ECM, E-08028 Barcelona, Spain

A. Palano

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

J. C. Chen, N. D. Qi, G. Rong, P. Wang, Y. S. Zhu

Institute of High Energy Physics, Beijing 100039, China

G. Eigen, I. Ofte, B. Stugu

University of Bergen, Institute of Physics, N-5007 Bergen, Norway

G. S. Abrams, M. Battaglia, D. N. Brown, J. Button-Shafer, R. N. Cahn, E. Charles, M. S. Gill,
Y. Groysman, R. G. Jacobsen, J. A. Kadyk, L. T. Kerth, Yu. G. Kolomensky, G. Kukartsev, G. Lynch,
L. M. Mir, T. J. Orimoto, M. Pripstein, N. A. Roe, M. T. Ronan, W. A. Wenzel

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

P. del Amo Sanchez, M. Barrett, K. E. Ford, A. J. Hart, T. J. Harrison, C. M. Hawkes, S. E. Morgan,
A. T. Watson

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

T. Held, H. Koch, B. Lewandowski, M. Pelizaeus, K. Peters, T. Schroeder, M. Steinke
Ruhr Universität Bochum, Institut für Experimentalphysik 1, D-44780 Bochum, Germany

J. T. Boyd, J. P. Burke, W. N. Cottingham, D. Walker

University of Bristol, Bristol BS8 1TL, United Kingdom

D. J. Asgeirsson, T. Cuhadar-Donszelmann, B. G. Fulsom, C. Hearty, N. S. Knecht, T. S. Mattison,
J. A. McKenna

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

A. Khan, P. Kyberd, M. Saleem, D. J. Sherwood, L. Teodorescu

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

V. E. Blinov, A. D. Bukin, V. P. Druzhinin, V. B. Golubev, A. P. Onuchin, S. I. Serednyakov,
Yu. I. Skovpen, E. P. Solodov, K. Yu Todyshev

Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia

D. S. Best, M. Bondioli, M. Bruinsma, M. Chao, S. Curry, I. Eschrich, D. Kirkby, A. J. Lankford, P. Lund,
M. Mandelkern, R. K. Mommsen, W. Roethel, D. P. Stoker

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

S. Abachi, C. Buchanan

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

S. D. Foulkes, J. W. Gary, O. Long, B. C. Shen, K. Wang, L. Zhang
University of California at Riverside, Riverside, California 92521, USA

H. K. Hadavand, E. J. Hill, H. P. Paar, S. Rahatlou, V. Sharma
University of California at San Diego, La Jolla, California 92093, USA

J. W. Berryhill, C. Campagnari, A. Cunha, B. Dahmes, T. M. Hong, D. Kovalskyi, J. D. Richman
University of California at Santa Barbara, Santa Barbara, California 93106, USA

T. W. Beck, A. M. Eisner, C. J. Flacco, C. A. Heusch, J. Kroseberg, W. S. Lockman, G. Nesom, T. Schalk,
B. A. Schumm, A. Seiden, P. Spradlin, D. C. Williams, M. G. Wilson
University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, California 95064, USA

J. Albert, E. Chen, A. Dvoretzkii, F. Fang, D. G. Hitlin, I. Narsky, T. Piatenko, F. C. Porter, A. Ryd,
A. Samuel
California Institute of Technology, Pasadena, California 91125, USA

G. Mancinelli, B. T. Meadows, K. Mishra, M. D. Sokoloff
University of Cincinnati, Cincinnati, Ohio 45221, USA

F. Blanc, P. C. Bloom, S. Chen, W. T. Ford, J. F. Hirschauer, A. Kreisel, M. Nagel, U. Nauenberg,
A. Olivas, W. O. Ruddick, J. G. Smith, K. A. Ulmer, S. R. Wagner, J. Zhang
University of Colorado, Boulder, Colorado 80309, USA

A. Chen, E. A. Eckhart, A. Soffer, W. H. Toki, R. J. Wilson, F. Winklmeier, Q. Zeng
Colorado State University, Fort Collins, Colorado 80523, USA

D. D. Altenburg, E. Feltresi, A. Hauke, H. Jasper, J. Merkel, A. Petzold, B. Spaan
Universität Dortmund, Institut für Physik, D-44221 Dortmund, Germany

T. Brandt, V. Klose, H. M. Lacker, W. F. Mader, R. Nogowski, J. Schubert, K. R. Schubert, R. Schwierz,
J. E. Sundermann, A. Volk
Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany

D. Bernard, G. R. Bonneaud, E. Latour, Ch. Thiebaux, M. Verderi
Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, F-91128 Palaiseau, France

P. J. Clark, W. Gradl, F. Muheim, S. Playfer, A. I. Robertson, Y. Xie
University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom

M. Andreotti, D. Bettoni, C. Bozzi, R. Calabrese, G. Cibinetto, E. Luppi, M. Negrini, A. Petrella,
L. Piemontese, E. Prencipe
Università di Ferrara, Dipartimento di Fisica and INFN, I-44100 Ferrara, Italy

F. Anulli, R. Baldini-Ferrolì, A. Calcaterra, R. de Sangro, G. Finocchiaro, S. Pacetti, P. Patteri,
I. M. Peruzzi,¹ M. Piccolo, M. Rama, A. Zallo
Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy

¹Also with Università di Perugia, Dipartimento di Fisica, Perugia, Italy

A. Buzzo, R. Capra, R. Contri, M. Lo Vetere, M. M. Macri, M. R. Monge, S. Passaggio, C. Patrignani,
E. Robutti, A. Santroni, S. Tosi

Università di Genova, Dipartimento di Fisica and INFN, I-16146 Genova, Italy

G. Brandenburg, K. S. Chaisanguanthum, M. Morii, J. Wu

Harvard University, Cambridge, Massachusetts 02138, USA

R. S. Dubitzky, J. Marks, S. Schenk, U. Uwer

Universität Heidelberg, Physikalisches Institut, Philosophenweg 12, D-69120 Heidelberg, Germany

D. J. Bard, W. Bhimji, D. A. Bowerman, P. D. Dauncey, U. Egede, R. L. Flack, J. A. Nash,
M. B. Nikolich, W. Panduro Vazquez

Imperial College London, London, SW7 2AZ, United Kingdom

P. K. Behera, X. Chai, M. J. Charles, U. Mallik, N. T. Meyer, V. Ziegler

University of Iowa, Iowa City, Iowa 52242, USA

J. Cochran, H. B. Crawley, L. Dong, V. Eyges, W. T. Meyer, S. Prell, E. I. Rosenberg, A. E. Rubin

Iowa State University, Ames, Iowa 50011-3160, USA

A. V. Gritsan

Johns Hopkins University, Baltimore, Maryland 21218, USA

A. G. Denig, M. Fritsch, G. Schott

Universität Karlsruhe, Institut für Experimentelle Kernphysik, D-76021 Karlsruhe, Germany

N. Arnaud, M. Davier, G. Grosdidier, A. Höcker, F. Le Diberder, V. Lepeltier, A. M. Lutz, A. Oyanguren,
S. Pruvot, S. Rodier, P. Roudeau, M. H. Schune, A. Stocchi, W. F. Wang, G. Wormser

*Laboratoire de l'Accélérateur Linéaire, IN2P3/CNRS et Université Paris-Sud 11, Centre Scientifique
d'Orsay, B.P. 34, F-91898 ORSAY Cedex, France*

C. H. Cheng, D. J. Lange, D. M. Wright

Lawrence Livermore National Laboratory, Livermore, California 94550, USA

C. A. Chavez, I. J. Forster, J. R. Fry, E. Gabathuler, R. Gamet, K. A. George, D. E. Hutchcroft,
D. J. Payne, K. C. Schofield, C. Touramanis

University of Liverpool, Liverpool L69 7ZE, United Kingdom

A. J. Bevan, F. Di Lodovico, W. Menges, R. Sacco

Queen Mary, University of London, E1 4NS, United Kingdom

G. Cowan, H. U. Flaecher, D. A. Hopkins, P. S. Jackson, T. R. McMahon, S. Ricciardi, F. Salvatore,
A. C. Wren

*University of London, Royal Holloway and Bedford New College, Egham, Surrey TW20 0EX, United
Kingdom*

D. N. Brown, C. L. Davis

University of Louisville, Louisville, Kentucky 40292, USA

J. Allison, N. R. Barlow, R. J. Barlow, Y. M. Chia, C. L. Edgar, G. D. Lafferty, M. T. Naisbit,
J. C. Williams, J. I. Yi

University of Manchester, Manchester M13 9PL, United Kingdom

C. Chen, W. D. Hulsbergen, A. Jawahery, C. K. Lae, D. A. Roberts, G. Simi

University of Maryland, College Park, Maryland 20742, USA

G. Blaylock, C. Dallapiccola, S. S. Hertzbach, X. Li, T. B. Moore, S. Saremi, H. Staengle

University of Massachusetts, Amherst, Massachusetts 01003, USA

R. Cowan, G. Sciolla, S. J. Sekula, M. Spitznagel, F. Taylor, R. K. Yamamoto

*Massachusetts Institute of Technology, Laboratory for Nuclear Science, Cambridge, Massachusetts 02139,
USA*

H. Kim, S. E. McLachlin, P. M. Patel, S. H. Robertson

McGill University, Montréal, Québec, Canada H3A 2T8

A. Lazzaro, V. Lombardo, F. Palombo

Università di Milano, Dipartimento di Fisica and INFN, I-20133 Milano, Italy

J. M. Bauer, L. Cremaldi, V. Eschenburg, R. Godang, R. Kroeger, D. A. Sanders, D. J. Summers,
H. W. Zhao

University of Mississippi, University, Mississippi 38677, USA

S. Brunet, D. Côté, M. Simard, P. Taras, F. B. Viaud

Université de Montréal, Physique des Particules, Montréal, Québec, Canada H3C 3J7

H. Nicholson

Mount Holyoke College, South Hadley, Massachusetts 01075, USA

N. Cavallo,² G. De Nardo, F. Fabozzi,³ C. Gatto, L. Lista, D. Monorchio, P. Paolucci, D. Piccolo,
C. Sciacca

Università di Napoli Federico II, Dipartimento di Scienze Fisiche and INFN, I-80126, Napoli, Italy

M. A. Baak, G. Raven, H. L. Snoek

*NIKHEF, National Institute for Nuclear Physics and High Energy Physics, NL-1009 DB Amsterdam, The
Netherlands*

C. P. Jessop, J. M. LoSecco

University of Notre Dame, Notre Dame, Indiana 46556, USA

T. Allmendinger, G. Benelli, L. A. Corwin, K. K. Gan, K. Honscheid, D. Hufnagel, P. D. Jackson,
H. Kagan, R. Kass, A. M. Rahimi, J. J. Regensburger, R. Ter-Antonyan, Q. K. Wong

Ohio State University, Columbus, Ohio 43210, USA

N. L. Blount, J. Brau, R. Frey, O. Igonkina, J. A. Kolb, M. Lu, R. Rahmat, N. B. Sinev, D. Strom,
J. Strube, E. Torrence

University of Oregon, Eugene, Oregon 97403, USA

²Also with Università della Basilicata, Potenza, Italy

³Also with Università della Basilicata, Potenza, Italy

A. Gaz, M. Margoni, M. Morandin, A. Pompili, M. Posocco, M. Rotondo, F. Simonetto, R. Stroili, C. Voci
Università di Padova, Dipartimento di Fisica and INFN, I-35131 Padova, Italy

M. Benayoun, H. Briand, J. Chauveau, P. David, L. Del Buono, Ch. de la Vaissière, O. Hamon,
B. L. Hartfiel, M. J. J. John, Ph. Leruste, J. Malcès, J. Ocariz, L. Roos, G. Therin
*Laboratoire de Physique Nucléaire et de Hautes Energies, IN2P3/CNRS, Université Pierre et Marie
Curie-Paris6, Université Denis Diderot-Paris7, F-75252 Paris, France*

L. Gladney, J. Panetta
University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA

M. Biasini, R. Covarelli
Università di Perugia, Dipartimento di Fisica and INFN, I-06100 Perugia, Italy

C. Angelini, G. Batignani, S. Bettarini, F. Bucci, G. Calderini, M. Carpinelli, R. Cenci, F. Forti,
M. A. Giorgi, A. Lusiani, G. Marchiori, M. A. Mazur, M. Morganti, N. Neri, E. Paoloni, G. Rizzo,
J. J. Walsh
Università di Pisa, Dipartimento di Fisica, Scuola Normale Superiore and INFN, I-56127 Pisa, Italy

M. Haire, D. Judd, D. E. Wagoner
Prairie View A&M University, Prairie View, Texas 77446, USA

J. Biesiada, N. Danielson, P. Elmer, Y. P. Lau, C. Lu, J. Olsen, A. J. S. Smith, A. V. Telnov
Princeton University, Princeton, New Jersey 08544, USA

F. Bellini, G. Cavoto, A. D'Orazio, D. del Re, E. Di Marco, R. Faccini, F. Ferrarotto, F. Ferroni,
M. Gaspero, L. Li Gioi, M. A. Mazzoni, S. Morganti, G. Piredda, F. Polci, F. Safai Tehrani, C. Voena
Università di Roma La Sapienza, Dipartimento di Fisica and INFN, I-00185 Roma, Italy

M. Ebert, H. Schröder, R. Waldi
Universität Rostock, D-18051 Rostock, Germany

T. Adye, N. De Groot, B. Franek, E. O. Olaiya, F. F. Wilson
Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingdom

R. Aleksan, S. Emery, A. Gaidot, S. F. Ganzhur, G. Hamel de Monchenault, W. Kozanecki, M. Legendre,
G. Vasseur, Ch. Yèche, M. Zito
DSM/Daphnia, CEA/Saclay, F-91191 Gif-sur-Yvette, France

X. R. Chen, H. Liu, W. Park, M. V. Purohit, J. R. Wilson
University of South Carolina, Columbia, South Carolina 29208, USA

M. T. Allen, D. Aston, R. Bartoldus, P. Bechtle, N. Berger, R. Claus, J. P. Coleman, M. R. Convery,
M. Cristinziani, J. C. Dingfelder, J. Dorfan, G. P. Dubois-Felsmann, D. Dujmic, W. Dunwoodie,
R. C. Field, T. Glanzman, S. J. Gowdy, M. T. Graham, P. Grenier,⁴ V. Halyo, C. Hast, T. Hryn'ova,
W. R. Innes, M. H. Kelsey, P. Kim, D. W. G. S. Leith, S. Li, S. Luitz, V. Luth, H. L. Lynch,
D. B. MacFarlane, H. Marsiske, R. Messner, D. R. Muller, C. P. O'Grady, V. E. Ozcan, A. Perazzo,
M. Perl, T. Pulliam, B. N. Ratcliff, A. Roodman, A. A. Salnikov, R. H. Schindler, J. Schwiening,
A. Snyder, J. Stelzer, D. Su, M. K. Sullivan, K. Suzuki, S. K. Swain, J. M. Thompson, J. Va'vra, N. van

⁴Also at Laboratoire de Physique Corpusculaire, Clermont-Ferrand, France

Bakel, M. Weaver, A. J. R. Weinstein, W. J. Wisniewski, M. Wittgen, D. H. Wright, A. K. Yarritu, K. Yi,
C. C. Young

Stanford Linear Accelerator Center, Stanford, California 94309, USA

P. R. Burchat, A. J. Edwards, S. A. Majewski, B. A. Petersen, C. Roat, L. Wilden

Stanford University, Stanford, California 94305-4060, USA

S. Ahmed, M. S. Alam, R. Bula, J. A. Ernst, V. Jain, B. Pan, M. A. Saeed, F. R. Wappler, S. B. Zain

State University of New York, Albany, New York 12222, USA

W. Bugg, M. Krishnamurthy, S. M. Spanier

University of Tennessee, Knoxville, Tennessee 37996, USA

R. Eckmann, J. L. Ritchie, A. Satpathy, C. J. Schilling, R. F. Schwitters

University of Texas at Austin, Austin, Texas 78712, USA

J. M. Izen, X. C. Lou, S. Ye

University of Texas at Dallas, Richardson, Texas 75083, USA

F. Bianchi, F. Gallo, D. Gamba

Università di Torino, Dipartimento di Fisica Sperimentale and INFN, I-10125 Torino, Italy

M. Bomben, L. Bosisio, C. Cartaro, F. Cossutti, G. Della Ricca, S. Dittongo, L. Lanceri, L. Vitale

Università di Trieste, Dipartimento di Fisica and INFN, I-34127 Trieste, Italy

V. Azzolini, N. Lopez-March, F. Martinez-Vidal

IFIC, Universitat de Valencia-CSIC, E-46071 Valencia, Spain

Sw. Banerjee, B. Bhuyan, C. M. Brown, D. Fortin, K. Hamano, R. Kowalewski, I. M. Nugent, J. M. Roney,
R. J. Sobie

University of Victoria, Victoria, British Columbia, Canada V8W 3P6

J. J. Back, P. F. Harrison, T. E. Latham, G. B. Mohanty, M. Pappagallo

Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom

H. R. Band, X. Chen, B. Cheng, S. Dasu, M. Datta, K. T. Flood, J. J. Hollar, P. E. Kutter, B. Mellado,
A. Mihalyi, Y. Pan, M. Pierini, R. Prepost, S. L. Wu, Z. Yu

University of Wisconsin, Madison, Wisconsin 53706, USA

H. Neal

Yale University, New Haven, Connecticut 06511, USA

1 INTRODUCTION

Measurements of time-dependent CP asymmetries in B^0 meson decays through a Cabibbo-Kobayashi-Maskawa (CKM) favored $b \rightarrow c\bar{c}s$ amplitude [1, 2] have firmly established that CP symmetry is not conserved in the neutral B meson system. The effect, arising from the interference between mixing and decay proportional to the CP -violating phase $\beta = \arg(-V_{cd}V_{cb}^*/V_{td}V_{tb}^*)$ of the CKM mixing matrix [3], manifests itself as an asymmetry in the time evolution of the $B^0\bar{B}^0$ pair.

In the Standard Model, decays of B^0 mesons to charmless hadronic final states such as ωK^0 proceed mostly via a single loop (penguin) amplitude with the same weak phase as the $b \rightarrow c\bar{c}s$ transition [4], but CKM-suppressed amplitudes and multiple particles in the loop introduce additional weak phases whose contribution may not be negligible; see Refs. [5, 6] for early quantitative work in addressing the size of these effects. We define ΔS as the difference between the magnitude of the time-dependent CP -violating parameter S (given in detail below) measured in these decays and $S = \sin 2\beta$ measured in decays to charmonium and a neutral kaon. For the decay $B^0 \rightarrow \omega K^0$, these additional contributions are expected to give $\Delta S \sim 0.1$ [7, 8], although this increase may be nullified when final-state interactions are included [8]. A value of ΔS inconsistent with this expectation could be an indication of new physics [9].

We present an improved preliminary measurement of the time-dependent CP -violating asymmetry in the decay $B^0 \rightarrow \omega K_S^0$, previously reported by the *BABAR* and Belle Collaborations [10, 11]. Charge-conjugate decay modes are implied throughout.

2 THE *BABAR* DETECTOR AND DATASET

The data were collected with the *BABAR* detector [12] at the PEP-II asymmetric-energy e^+e^- collider. An integrated luminosity of 316 fb^{-1} , corresponding to 347 million $B\bar{B}$ pairs, was recorded at the $\Upsilon(4S)$ resonance (center-of-mass energy $\sqrt{s} = 10.58 \text{ GeV}$). 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, both operating in a 1.5 T axial magnetic field. Charged-particle identification is provided by the energy loss in the tracking devices and by the measured Cherenkov angle from an internally reflecting ring-imaging Cherenkov detector covering the central region. Photons and electrons are detected by a CsI(Tl) electromagnetic calorimeter. The instrumented flux return of the magnet allows discrimination of muons from pions.

3 ANALYSIS METHOD

From a $B^0\bar{B}^0$ pair produced in an $\Upsilon(4S)$ decay, we reconstruct one of the B mesons in the final state $f = \omega K_S^0$, a CP eigenstate with eigenvalue -1 . For the time evolution measurement, we also identify (tag) the flavor (B^0 or \bar{B}^0) and reconstruct the decay vertex of the other B . The asymmetric beam configuration in the laboratory frame provides a boost of $\beta\gamma = 0.56$ to the center-of-mass in the lab frame, which allows the determination of the proper decay time difference $\Delta t \equiv t_f - t_{\text{tag}}$ from the vertex separation of the two B meson candidates. Ignoring the Δt resolution (about 0.5 ps), the distribution of Δt is

$$F(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau} [1 \mp \Delta w \pm (1 - 2w)(S \sin(\Delta m_d \Delta t) - C \cos(\Delta m_d \Delta t))]. \quad (1)$$

The upper (lower) sign denotes a decay accompanied by a B^0 (\bar{B}^0) tag, τ is the mean B^0 lifetime, Δm_d is the mixing frequency, and the mistag parameters w and Δw are the average and difference, respectively, of the probabilities that a true B^0 (\bar{B}^0) meson is mistagged as a \bar{B}^0 (B^0). The parameter C measures direct CP violation.

The flavor-tagging algorithm [1] has seven mutually exclusive tagging categories of differing purities, including one for untagged events that we retain for yield determinations. The measured analyzing power, defined as efficiency times $(1 - 2w)^2$ summed over all categories, is $(30.4 \pm 0.3)\%$, as determined from a large sample of B decays to fully reconstructed flavor eigenstates (B_{flav}).

We reconstruct a B meson candidate by combining a K_S^0 with an $\omega \rightarrow \pi^+\pi^-\pi^0$ candidate. We select $K_S^0 \rightarrow \pi^+\pi^-$ decays by requiring the $\pi^+\pi^-$ invariant mass to be within 12 MeV ($\sim 4\sigma$) of the nominal K^0 mass and by requiring a flight length greater than three times its error. We require the $\pi^+\pi^-\pi^0$ invariant mass ($m_{3\pi}$) to be between 735 and 825 MeV. Distributions from the data and from Monte Carlo (MC) simulations [13] guide the choice of these selection criteria. We retain regions adequate to characterize the background as well as the signal for those quantities taken subsequently as observables for fitting. We also use the angle θ_H , defined in the ω rest frame as the angle of the direction of the boost from the B rest frame with respect to the normal to the ω decay plane. The quantity $\mathcal{H} \equiv |\cos \theta_H|$ is approximately flat for background decays and distributed as $\cos^2 \theta_H$ for signal decays.

A B meson candidate is characterized kinematically by the energy-substituted mass $m_{\text{ES}} \equiv \sqrt{(\frac{1}{2}s + \mathbf{p}_0 \cdot \mathbf{p}_B)^2 / E_0^2 - \mathbf{p}_B^2}$ and the energy difference $\Delta E \equiv E_B^* - \sqrt{s}/2$, where (E_0, \mathbf{p}_0) and (E_B, \mathbf{p}_B) are four-momenta of the $\Upsilon(4S)$ and the B candidate, respectively, and the asterisk denotes the center-of-mass rest frame. We require $|\Delta E| \leq 0.2$ GeV, $5.25 \leq m_{\text{ES}} \leq 5.29$ GeV, $|\Delta t| < 20$ ps and $\sigma_{\Delta t} < 2.5$ ps.

To help reject the dominant background from continuum $e^+e^- \rightarrow q\bar{q}$ events ($q = u, d, s, c$), we use the angle θ_T between the thrust axis of the B candidate and that of the rest of the tracks and neutral clusters in the event, calculated in the $\Upsilon(4S)$ rest frame. The distribution of $\cos \theta_T$ is sharply peaked near ± 1 for jet-like $q\bar{q}$ pairs and is nearly uniform for the isotropic B decays; we require $|\cos \theta_T| < 0.9$.

From MC simulations of $B^0\bar{B}^0$ and B^+B^- events, we find evidence for a small (0.3% of the total sample) $B\bar{B}$ background contribution. We have therefore added a $B\bar{B}$ component to the fit described below.

We use an unbinned, multivariate maximum-likelihood fit to extract signal yields and CP -violation parameters. We use the discriminating variables m_{ES} , ΔE , $m_{3\pi}$, \mathcal{H} , and a Fisher discriminant \mathcal{F} [14]. The Fisher discriminant combines five variables: the polar angles with respect to the beam axis in the $\Upsilon(4S)$ frame of the B candidate momentum and of the B thrust axis; the tagging category; and the zeroth and second angular moments of the energy flow, excluding the B candidate, about the B thrust axis [14]. We use Δt to extract the CP -violation parameters, S and C .

We define the probability density function (PDF) for each event i , hypothesis j (signal, $B\bar{B}$ background and $q\bar{q}$ background), and tagging category c :

$$\mathcal{P}_{j,c}^i \equiv \mathcal{P}_j(m_{\text{ES}}^i) \mathcal{P}_j(\Delta E^i) \mathcal{P}_j(\mathcal{F}^i, c) \mathcal{P}_j(m_{3\pi}^i) \mathcal{P}_j(\mathcal{H}^i) \mathcal{P}_j(\Delta t^i, \sigma_{\Delta t}^i, c), \quad (2)$$

where $\sigma_{\Delta t}^i$ is the error on Δt for event i . We write the extended likelihood function as

$$\mathcal{L} = \prod_c \exp\left(-\sum_j Y_j f_{j,c}\right) \prod_i^{N_c} \left[\sum_j Y_j f_{j,c} \mathcal{P}_{j,c}^i \right], \quad (3)$$

where Y_j is the fitted yield of events of species j , $f_{j,c}$ is the fraction of events of species j for each category c , and N_c is the number of events of category c in the sample. We fix $f_{\text{sig},c}$ and $f_{B\bar{B},c}$ to $f_{B_{\text{flav}},c}$, the values measured with the large B_{flav} sample [1].

The PDF $\mathcal{P}_{\text{sig}}(\Delta t, \sigma_{\Delta t}, c)$ is given by $F(\Delta t)$ (Eq. 1) with tag category (c) dependent mistag parameters convolved with the signal resolution function (a sum of three Gaussians) determined from the B_{flav} sample. The other PDF forms are: the sum of two Gaussians for all signal shapes except \mathcal{H} , and for the peaking component of the $m_{3\pi}$ background; the sum of three Gaussians for $\mathcal{P}_{q\bar{q}}(\Delta t, c)$ and $\mathcal{P}_{B\bar{B}}(\Delta t, c)$; an asymmetric Gaussian with different widths below and above the peak for $\mathcal{P}_j(\mathcal{F})$ (a small “tail” Gaussian is added for $\mathcal{P}_{q\bar{q}}(\mathcal{F})$); Chebyshev functions of second to fourth order for the \mathcal{H} distribution for signal and the slowly-varying shapes of the ΔE , $m_{3\pi}$, and \mathcal{H} distributions for backgrounds; and, for $\mathcal{P}_{q\bar{q}}(m_{\text{ES}})$, a phase-space-motivated empirical function [15], with a small Gaussian added for $\mathcal{P}_{B\bar{B}}(m_{\text{ES}})$.

We determine the PDF parameters from simulation for the signal and $B\bar{B}$ background components. We study large control samples of $B \rightarrow D\pi$ decays of similar topology to verify the simulated resolutions in ΔE and m_{ES} , adjusting the PDFs to account for any differences found. For the $q\bar{q}$ background we use $(m_{\text{ES}}, \Delta E)$ sideband data to obtain initial PDF-parameter values, but ultimately leave many of them free to vary in the final fit.

4 RESULTS

The free parameters in the fit are the following: the signal, $B\bar{B}$ background, and $q\bar{q}$ background yields; the three shape parameters of $\mathcal{P}_{q\bar{q}}(\mathcal{F})$; the slopes of $\mathcal{P}_{q\bar{q}}(\Delta E)$ and $\mathcal{P}_{q\bar{q}}(m_{3\pi})$; the fraction of the peaking component of $\mathcal{P}_{q\bar{q}}(m_{3\pi})$; the m_{ES} background shape parameter ξ [15]; S ; C ; the fraction of background events in each tagging category; and the six primary parameters describing the Δt background shape. The parameters τ and Δm_d are fixed to world-average values [16]. Table 1 shows the results of the fit. The errors have been scaled by ~ 1.10 to account for a slight underestimate of the fit errors predicted by our simulations when the number of signal events is small.

Table 1: Total sample size, detection efficiency, signal yield, $B\bar{B}$ background yield and CP -asymmetry parameters S and C from the fit.

Quantity	ωK_S^0
Total fit sample	12636
Eff. (%)	23.0
Fit signal yield	142^{+17}_{-16}
$B\bar{B}$ yield	38^{+25}_{-22}
S	$0.62^{+0.25}_{-0.30}$
C	$-0.43^{+0.25}_{-0.23}$

Fig. 1 shows projections onto the fit variables for a subset of the data (including 45–65% of signal events) for which the signal likelihood (computed without the variable plotted) exceeds a threshold that optimizes the sensitivity. Fig. 2 shows the Δt projections and asymmetry of the time-dependent fit applying the same event selection criteria as for Fig. 1. Based on explicit variation

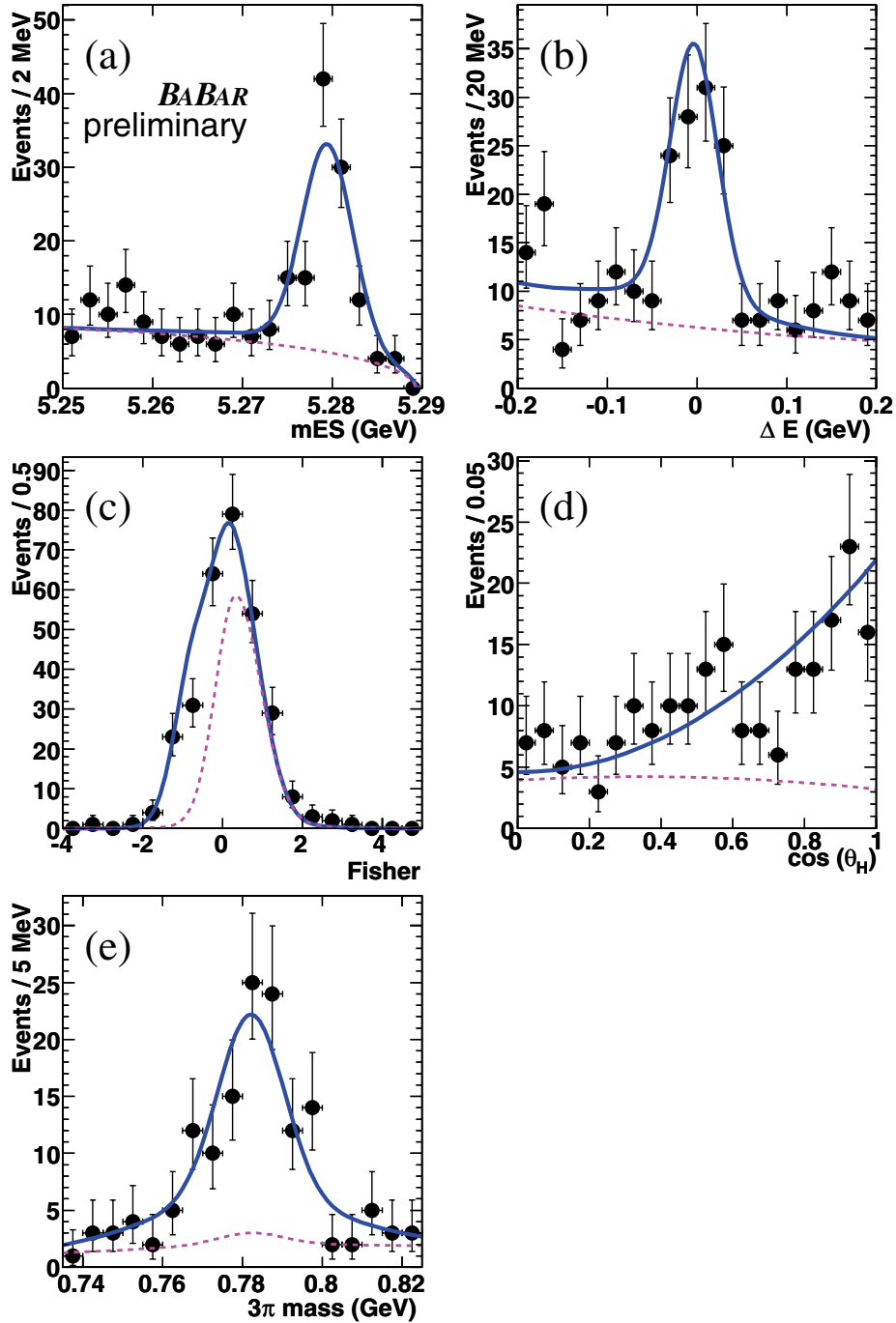


Figure 1: B candidate projections for $B^0 \rightarrow \omega K_S^0$ of (a) m_{ES} , (b) ΔE , (c) \mathcal{F} , (d) \mathcal{H} , and (e) $m_{3\pi}$, shown for a signal-enhanced subset of the data (points with error bars), with the fit function (solid line), and the background components (dashed line) overlaid.

of C with S allowed to float, we find the correlation between S and C to be negligible.

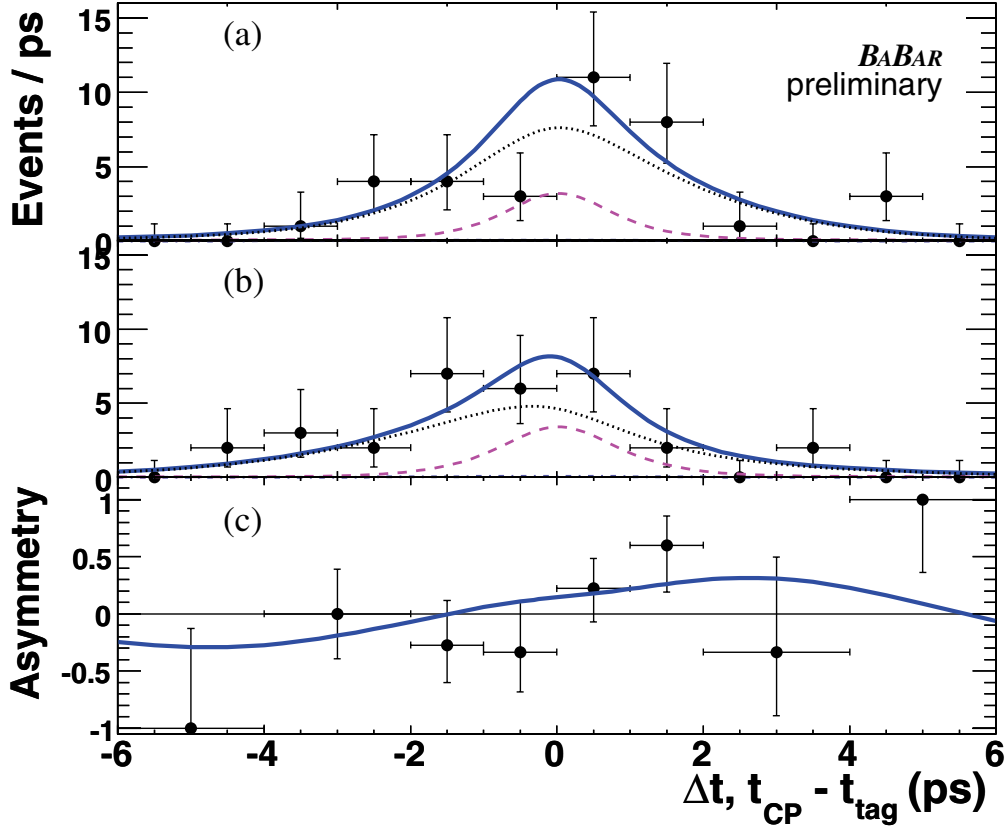


Figure 2: Projections onto Δt for $B^0 \rightarrow \omega K_s^0$, where t_{CP} is the decay time for the signal B meson. Data (points with errors), the fit function (solid line), background component (dashed line), and signal component (dotted line) are shown for events in which the tag meson is (a) B^0 and (b) \bar{B}^0 , and the asymmetry $(N_{B^0} - N_{\bar{B}^0}) / (N_{B^0} + N_{\bar{B}^0})$ is shown in (c), where N indicates the total number of events passing the same cuts as for Fig. 1.

5 SYSTEMATIC UNCERTAINTIES

We estimate systematic uncertainties in S and C from the following sources: potential dilution due to $B\bar{B}$ background (0.01); variation of the PDF shapes used in the fit (0.01); knowledge of the parameters used to model the signal Δt distribution (0.02); and interference between the CKM-suppressed $\bar{b} \rightarrow \bar{u}c\bar{d}$ amplitude and the favored $b \rightarrow c\bar{u}d$ amplitude for some tag-side B decays [17] (0.02 for C , negligible for S), where the value in parentheses is the size of the estimated systematic uncertainty. By applying distortions to MC samples and refitting all tracks, we find that the uncertainty due to possible SVT misalignment and position and size of the beam spot are negligible. The uncertainties in the parameters of fits to the B_{flav} sample are used for the uncertainties in the signal PDF parameters: Δt resolutions, tagging efficiencies, and mistag rates. Published measurements [16] are used for τ_B and Δm_d . Summing all systematic uncertainties in quadrature, we obtain 0.02 for S and 0.03 for C .

6 SUMMARY

In conclusion, we have presented preliminary results for the time-dependent asymmetry parameters for the decay $B^0 \rightarrow \omega K_s^0$, $S = 0.62_{-0.30}^{+0.25} \pm 0.02$ and $C = -0.43_{-0.23}^{+0.25} \pm 0.03$, where the first uncertainty is statistical and the second systematic. If we fix $C = 0$, we find $S = 0.63_{-0.33}^{+0.28}$, where the uncertainty is statistical only. This value of S and the world-average value of $\sin 2\beta$ [1, 2] yield a value of $\Delta S = -0.09 \pm 0.31$, in good agreement with the Standard Model expectation near zero.

7 ACKNOWLEDGMENTS

We are grateful for the extraordinary contributions of our PEP-II colleagues in achieving the excellent luminosity and machine conditions that have made this work possible. The success of this project also relies critically on the expertise and dedication of the computing organizations that support *BABAR*. The collaborating institutions wish to thank SLAC for its support and the kind hospitality extended to them. This work is supported by the US Department of Energy and National Science Foundation, the Natural Sciences and Engineering Research Council (Canada), Institute of High Energy Physics (China), the Commissariat à l’Energie Atomique and Institut National de Physique Nucléaire et de Physique des Particules (France), the Bundesministerium für Bildung und Forschung and Deutsche Forschungsgemeinschaft (Germany), the Istituto Nazionale di Fisica Nucleare (Italy), the Foundation for Fundamental Research on Matter (The Netherlands), the Research Council of Norway, the Ministry of Science and Technology of the Russian Federation, Ministerio de Educación y Ciencia (Spain), and the Particle Physics and Astronomy Research Council (United Kingdom). Individuals have received support from the Marie-Curie IEF program (European Union) and the A. P. Sloan Foundation.

References

- [1] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. Lett. **94**, 161803 (2005).
- [2] Belle Collaboration, K. Abe *et al.*, Phys. Rev. D **66**, 071102(R) (2002).
- [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); D. Atwood and A. Soni, Phys. Lett. B **405**, 150 (1997).
- [5] Y. Grossman *et al.*, Phys. Rev. D **68**, 015004 (2003).
- [6] M. Beneke and M. Neubert, Nucl. Phys. B **675**, 333 (2003).
- [7] M. Beneke, Phys. Lett. B **620**, 143 (2005).
- [8] H-Y. Cheng, C-K. Chua, and A. Soni, Phys. Rev. D **72**, 014006 (2005).
- [9] D. London and A. Soni, Phys. Lett. B **407**, 61 (1997).
- [10] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. D **74**, 011106 (2006).
- [11] Belle Collaboration, K. F. Chen *et al.*, Phys. Rev. D **72**, 012004 (2005).
- [12] *BABAR* Collaboration, B. Aubert *et al.*, Nucl. Instr. Methods Phys. Res., Sect. A **479**, 1 (2002).
- [13] The *BABAR* detector Monte Carlo simulation is based on GEANT4: S. Agostinelli *et al.*, Nucl. Instr. Methods Phys. Res., Sect. A **506**, 250 (2003).
- [14] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. D **70**, 032006 (2004).
- [15] $f(x) \propto x\sqrt{1-x^2} \exp[-\xi(1-x^2)]$, with $x \equiv m_{ES}/E_B^*$ and ξ a parameter to be fit. See ARGUS Collaboration, H. Albrecht *et al.*, Phys. Lett. B **241**, 278 (1990).
- [16] Particle Data Group, Y.-M. Yao *et al.*, J. Phys. **G33**, 1 (2006).
- [17] O. Long, M. Baak, R. N. Cahn, and D. Kirkby, Phys. Rev. D **68**, 034010 (2003).
- [18] Belle Collaboration, C.H. Wang *et al.*, Phys. Rev. D **70**, 012001 (2004); CLEO Collaboration, C.P. Jessop *et al.*, Phys. Rev. Lett. **85**, 2881 (2000).
- [19] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. Lett. **92**, 061801 (2004).