We present preliminary measurements of the CP asymmetry parameters and CP content in $B^0 \to K^+K^-K^0_L$ decays, with $B^0 \to \phi K^0_L$ events excluded. In a sample of 227 M $B\bar{B}$ pairs collected by the *BABAR* detector at the $PEP-II$ B Factory at SLAC, we find the CP parameters to be

$$S = 0.07 \pm 0.28(\text{stat})^{+0.11}_{-0.12}(\text{syst})$$

$$C = 0.54 \pm 0.22(\text{stat})^{+0.08}_{-0.09}(\text{syst})$$

where the first error is statistical and the second is systematic. Estimating the fraction of CP-odd final states from angular moments analysis in the $K^+K^-K^0_S$ CP-conjugate final state, $f_{odd}(K^+K^-K^0_L) = 0.92 \pm 0.07$ (stat) $\pm$ 0.06 (syst), we determine

$$\sin 2\beta_{\text{eff}} = 0.09 \pm 0.33\,(\text{stat})^{+0.13}_{-0.14}(\text{syst}) \pm 0.10(\text{syst CP-cont})$$

BABAR-CONF-05/002
SLAC-PUB-11309
hep-ex/0000
July 2005

Measurement of Time-dependent *CP*-Violating Asymmetries in $B^0 \to K^+K^-K^0_L$ Decays

The *BABAR* Collaboration

November 8, 2018

We present preliminary measurements of the CP asymmetry parameters and CP content in $B^0 \to K^+K^-K^0_L$ decays, with $B^0 \to \phi K^0_L$ events excluded. In a sample of 227 M $B\overline{B}$ pairs collected by the *BABAR* detector at the PEP-II B Factory at SLAC, we find the CP parameters to be

$$S = 0.07 \pm 0.28(\text{stat})^{+0.11}_{-0.12}(\text{syst})$$
$$C = 0.54 \pm 0.22(\text{stat})^{+0.08}_{-0.09}(\text{syst})$$

where the first error is statistical and the second is systematic. Estimating the fraction of CP-odd final states from angular moments analysis in the $K^+K^-K^0_S$ CP-conjugate final state, $f_{odd}(K^+K^-K^0_L) = 0.92 \pm 0.07$ (stat) ± 0.06 (syst), we determine

$$\sin 2\beta_{\text{eff}} = 0.09 \pm 0.33\,(\text{stat})^{+0.13}_{-0.14}(\text{syst}) \pm 0.10(\text{syst } CP\text{-cont})$$

where the last error is due to uncertainty on the CP content.

Contributed to the XXII$^{\text{st}}$ International Symposium on Lepton and Photon Interactions at High Energies, 6/30 — 7/5/2005, Uppsala, Sweden

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

Work supported in part by Department of Energy contract DE-AC03-76SF00515.

The *BABAR* Collaboration,

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

Laboratoire de Physique des Particules, F-74941 Annecy-le-Vieux, France

E. Grauges

IFAE, Universitat Autonoma de Barcelona, E-08193 Bellaterra, Barcelona, Spain

A. Palano, M. Pappagallo, A. Pompili

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, A. B. Breon, D. N. Brown, J. Button-Shafer, R. N. Cahn, E. Charles, C. T. Day, M. S. Gill, A. V. Gritsan, Y. Groysman, R. G. Jacobsen, R. W. Kadel, J. Kadyk, L. T. Kerth, Yu. G. Kolomensky, G. Kukartsev, G. Lynch, L. M. Mir, P. J. Oddone, 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

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

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

M. Fritsch, K. Goetzen, 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, N. Chevalier, W. N. Cottingham

University of Bristol, Bristol BS8 1TL, United Kingdom

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, L. Teodorescu

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

A. E. Blinov, V. E. Blinov, A. D. Bukin, V. P. Druzhinin, V. B. Golubev, E. A. Kravchenko, A. P. Onuchin, S. I. Serednyakov, Yu. I. Skovpen, E. P. Solodov, A. N. Yushkov

Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia

D. 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

C. Buchanan, B. L. Hartfiel, A. J. R. Weinstein

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

D. del Re, H. K. Hadavand, E. J. Hill, D. B. MacFarlane, 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, M. A. Mazur, J. D. Richman, W. Verkerke
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, G. P. Dubois-Felsmann, A. Dvoretskii, D. G. Hitlin, I. Narsky, T. Piatenko, F. C. Porter, A. Ryd, A. Samuel
California Institute of Technology, Pasadena, California 91125, USA

R. Andreassen, S. Jayatilleke, G. Mancinelli, B. T. Meadows, M. D. Sokoloff
University of Cincinnati, Cincinnati, Ohio 45221, USA

F. Blanc, P. Bloom, S. Chen, W. T. Ford, J. F. Hirschauer, A. Kreisel, U. Nauenberg, A. Olivas, P. Rankin, 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, J. L. Harton, A. Soffer, W. H. Toki, R. J. Wilson, Q. Zeng
Colorado State University, Fort Collins, Colorado 80523, USA

D. Altenburg, E. Feltresi, A. Hauke, B. Spaan
Universität Dortmund, Institut fur Physik, D-44221 Dortmund, Germany

T. Brandt, J. Brose, M. Dickopp, V. Klose, H. M. Lacker, R. Nogowski, S. Otto, A. Petzold, G. Schott, J. Schubert, K. R. Schubert, R. Schwierz, J. E. Sundermann
Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany

D. Bernard, G. R. Bonneaud, P. Grenier, S. Schrenk, Ch. Thiebaux, G. Vasileiadis, M. Verderi
Ecole Polytechnique, LLR, F-91128 Palaiseau, France

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

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

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

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

A. Buzzo, R. Capra, R. Contri, M. Lo Vetere, 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, E. Won, J. Wu

Harvard University, Cambridge, Massachusetts 02138, USA

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

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

W. Bhimji, D. A. Bowerman, P. D. Dauncey, U. Egede, R. L. Flack, J. R. Gaillard, G. W. Morton, J. A. Nash, M. B. Nikolich, G. P. Taylor, W. P. Vazquez

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

M. J. Charles, W. F. Mader, U. Mallik, A. K. Mohapatra

University of Iowa, Iowa City, Iowa 52242, USA

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

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

N. Arnaud, M. Davier, X. Giroux, G. Grosdidier, A. Höcker, F. Le Diberder, V. Lepeltier, A. M. Lutz, A. Oyanguren, T. C. Petersen, M. Pierini, S. Plaszczynski, S. Rodier, P. Roudeau, M. H. Schune, A. Stocchi, G. Wormser

Laboratoire de l'Accélérateur Linéaire, F-91898 Orsay, France

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

Lawrence Livermore National Laboratory, Livermore, California 94550, USA

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

University of Liverpool, Liverpool L69 72E, United Kingdom

C. M. Cormack, F. Di Lodovico, W. Menges, R. Sacco

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

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

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

D. Brown, C. L. Davis

University of Louisville, Louisville, Kentucky 40292, USA

J. Allison, N. R. Barlow, R. J. Barlow, C. L. Edgar, M. C. Hodgkinson, M. P. Kelly, G. D. Lafferty, M. T. Naisbit, J. C. Williams

University of Manchester, Manchester M13 9PL, United Kingdom

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

University of Maryland, College Park, Maryland 20742, USA

G. Blaylock, C. Dallapiccola, S. S. Hertzbach, R. Kofler, V. B. Koptchev, X. Li, T. B. Moore, S. Saremi, H. Staengle, S. Willocq

University of Massachusetts, Amherst, Massachusetts 01003, USA

R. Cowan, K. Koeneke, 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, P. M. Patel, S. H. Robertson

McGill University, Montréal, Quebec, 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, J. Reidy, D. A. Sanders, D. J. Summers, H. W. Zhao

University of Mississippi, University, Mississippi 38677, USA

S. Brunet, D. Côté, P. Taras, B. Viaud

Université de Montréal, Laboratoire René J. A. Lévesque, Montréal, Quebec, Canada H3C 3J7

H. Nicholson

Mount Holyoke College, South Hadley, Massachusetts 01075, USA

N. Cavallo,[2] G. De Nardo, F. Fabozzi,[2] 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. Baak, H. Bulten, G. Raven, H. L. Snoek, L. Wilden

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, K. K. Gan, K. Honscheid, D. Hufnagel, P. D. Jackson, H. Kagan, R. Kass, T. Pulliam, A. M. Rahimi, R. Ter-Antonyan, Q. K. Wong

Ohio State University, Columbus, Ohio 43210, USA

J. Brau, R. Frey, O. Igonkina, M. Lu, C. T. Potter, N. B. Sinev, D. Strom, J. Strube, E. Torrence

University of Oregon, Eugene, Oregon 97403, USA

F. Galeazzi, M. Margoni, M. Morandin, 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, M. J. J. John, Ph. Leruste, J. Malclès, J. Ocariz, L. Roos, G. Therin

Universités Paris VI et VII, Laboratoire de Physique Nucléaire et de Hautes Energies, F-75252 Paris, France

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

P. K. Behera, L. Gladney, Q. H. Guo, J. Panetta
University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA

M. Biasini, R. Covarelli, S. Pacetti, M. Pioppi
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. Morganti, N. Neri, E. Paoloni, M. Rama, G. Rizzo, 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, 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

H. Schröder, G. Wagner, R. Waldi
Universität Rostock, D-18051 Rostock, Germany

T. Adye, N. De Groot, B. Franek, G. P. Gopal, 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, P.-F. Giraud, G. Graziani, G. Hamel de Monchenault, W. Kozanecki, M. Legendre, G. W. London, B. Mayer, G. Vasseur, Ch. Yèche, M. Zito
DSM/Dapnia, CEA/Saclay, F-91191 Gif-sur-Yvette, France

M. V. Purohit, A. W. Weidemann, J. R. Wilson, F. X. Yumiceva
University of South Carolina, Columbia, South Carolina 29208, USA

T. Abe, M. T. Allen, D. Aston, N. Bakel, R. Bartoldus, N. Berger, A. M. Boyarski, O. L. Buchmueller, R. Claus, M. R. Convery, M. Cristinziani, J. C. Dingfelder, D. Dong, J. Dorfan, D. Dujmic, W. Dunwoodie, S. Fan, R. C. Field, T. Glanzman, S. J. Gowdy, T. Hadig, V. Halyo, C. Hast, T. Hryn'ova, W. R. Innes, M. H. Kelsey, P. Kim, M. L. Kocian, D. W. G. S. Leith, J. Libby, S. Luitz, V. Luth, H. L. Lynch, H. Marsiske, R. Messner, D. R. Muller, C. P. O'Grady, V. E. Ozcan, A. Perazzo, M. Perl, 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. Swain, J. M. Thompson, J. Va'vra, M. Weaver, 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
Stanford University, Stanford, California 94305-4060, USA

M. Ahmed, S. Ahmed, M. S. Alam, J. A. Ernst, 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, R. F. Schwitters
University of Texas at Austin, Austin, Texas 78712, USA

J. M. Izen, I. Kitayama, X. C. Lou, S. Ye
University of Texas at Dallas, Richardson, Texas 75083, USA

F. Bianchi, M. Bona, 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, S. Grancagnolo, L. Lanceri, L. Vitale
Università di Trieste, Dipartimento di Fisica and INFN, I-34127 Trieste, Italy

F. Martinez-Vidal
IFIC, Universitat de Valencia-CSIC, E-46071 Valencia, Spain

R. S. Panvini[3]
Vanderbilt University, Nashville, Tennessee 37235, USA

Sw. Banerjee, B. Bhuyan, C. M. Brown, D. Fortin, K. Hamano, R. Kowalewski, 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
Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom

H. R. Band, X. Chen, B. Cheng, S. Dasu, M. Datta, A. M. Eichenbaum, K. T. Flood, M. Graham, J. J. Hollar, J. R. Johnson, P. E. Kutter, H. Li, R. Liu, B. Mellado, A. Mihalyi, Y. Pan, R. Prepost, P. Tan, J. H. von Wimmersperg-Toeller, S. L. Wu, Z. Yu
University of Wisconsin, Madison, Wisconsin 53706, USA

H. Neal
Yale University, New Haven, Connecticut 06511, USA

[3]Deceased

1 INTRODUCTION

In the Standard Model (SM), *CP* violation arises from a single complex phase in the Cabibbo–Kobayashi–Maskawa (CKM) quark-mixing matrix [1]. Decays of B mesons into charmless hadronic final states with three kaons are dominated by $b \to s\bar{s}s$ gluonic penguin amplitudes, with smaller contributions from electroweak penguins, while other SM amplitudes are suppressed by CKM factors [2]. The time-dependent *CP*-asymmetry is obtained by measuring the proper time difference $\Delta t = t_{CP} - t_{\rm tag}$ between a fully reconstructed neutral B meson (B_{CP}) in the final state $K^+K^-K^0_L$, and the partially reconstructed recoil B meson ($B_{\rm tag}$). The decay products of $B_{\rm tag}$ provide evidence that it decayed either as B^0 or $\overline{B}^0$ (flavor tag). The decay rate $f_+(f_-)$ when the tagging meson is a $B^0(\overline{B}^0)$ is given by

$$f_\pm(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} [\, 1 \pm S \sin(\Delta m_d \Delta t) \mp C \cos(\Delta m_d \Delta t)], \tag{1}$$

where τ_{B^0} is the neutral B meson mean lifetime and Δm_d is the B^0–$\overline{B}^0$ oscillation frequency. The parameters C and S describe the magnitude of *CP* violation in the decay and in the interference between decay and mixing, respectively. The time-dependent *CP*-violating asymmetry is defined as $A_{CP} \equiv (f_+ - f_-)/(f_+ + f_-)$. In the SM, we expect $C = 0$ because there is only one decay mechanism and direct *CP* violation requires amplitudes with different phases. Neglecting CKM-suppressed contributions and assuming that $K^+K^-K^0_L$ decay proceeds through an S-wave, leading to a *CP*-odd final state, the time-dependent *CP*-violating parameter S in this decay and $B^0 \to J/\psi K^0$ are both equal to the same parameter $\sin 2\beta$ [3], where the latter decay is dominated by tree diagrams. Since many scenarios of physics beyond the SM introduce additional diagrams with heavy particles in the penguin loops and corresponding new phases, comparison of *CP*-violating observables with SM expectations is a sensitive probe for new physics [4]. Measurements of $\sin 2\beta$ in B decays to charmonium such as $B^0 \to J/\psi K^0_S$ have been reported by the *BABAR* [5] and Belle [6] collaborations, and the world average for $\sin 2\beta$ (0.736 ± 0.049 [7]) is in good agreement with SM expectations [8]. A deviation from this value in the case of loop-dominated channels might signal the presence of physics beyond the SM.

Measurements of the *CP* asymmetry in the decays $B^0 \to \phi K^0_S$ and $B^0 \to \phi K^0_L$ currently have large statistical uncertainties [9, 10]. More accurate *CP* asymmetry measurements have been performed in the final state $K^+K^-K^0_S$, (excluding $B^0 \to \phi K^0_S$) [11], which has a branching fraction several times larger than the resonant modes, The *CP* content of the final state, which is *a priori* unknown, is estimated using an angular-moment analysis.

In this document we report preliminary measurements of the time dependent *CP* asymmetry in the *CP* conjugate state $B^0 \to K^+K^-K^0_L$.

2 THE *BABAR* DETECTOR AND DATASET

This measurement is based on a sample of approximately 227 million $B\bar{B}$ pairs collected at the $\Upsilon(4S)$ resonance with the *BABAR* detector [12] at the PEP-II asymmetric-energy e^+e^- storage ring [13] located at the Stanford Linear Accelerator Center. The *BABAR* detector is fully described elsewhere [12]. The detector systems used in this analysis are a charged-particle tracking system consisting of a five-layer silicon vertex tracker (SVT) and a 40-layer drift chamber (DCH) surrounded by a 1.5-T solenoidal magnet with an instrumented flux return (IFR), an electromagnetic calorimeter (EMC) composed of 6580 CsI(Tl) crystals, and a detector of internally reflected

Cherenkov light (DIRC) providing excellent charged $K-\pi$ identification up to a momentum of 4.5 GeV/c, which is the relevant momentum range for this analysis.

3 EVENT RECONSTRUCTION

The $B^0 \to K^+K^-K^0_L$ candidate (B_{CP}) is reconstructed by combining a pair of oppositely charged tracks extrapolated from a common vertex and a K^0_L candidate. For the charged tracks we require at least 12 measured drift-chamber coordinates and a minimum transverse momentum of 0.1 GeV/c. The tracks must also originate within ± 10 cm along the beam axis and 1.5 cm in the transverse plane, with respect to the nominal beam spot. Charged kaons are distinguished from pion and proton tracks via a requirement on a likelihood ratio that combines dE/dx information from the SVT and the DCH for tracks with momentum $p < 0.7\,\mathrm{GeV}/c$. For tracks with higher p, dE/dx in the DCH and the Cherenkov angle and the number of photons as measured by the DIRC are used in the likelihood. These particle identification criteria limit the rate of pion misidentification as a kaon to less than 2%, with an efficiency of 70%.

We identify a K^0_L candidate as in the *BABAR* analysis of the decay $B^0 \to J/\psi K^0_L$ analysis [14] either as a cluster of energy deposited in the EMC or as a cluster of hits in two or more layers of the IFR that cannot be associated with any charged track in the event. The K^0_L energy is not measured, therefore, we determine the K^0_L laboratory momentum from its flight direction as measured from the EMC or IFR cluster, and the constraint that the invariant $K^+K^-K^0_L$ mass agree with the known B^0 mass. In those cases where the K^0_L is detected in both the IFR and EMC we use the angular information from the EMC, because it has higher precision. In order to reduce background from π^0 decays, we reject an EMC K^0_L candidate cluster if it forms an invariant mass between 100 and 150 MeV/c^2 with any other neutral cluster in the event under the $\gamma\gamma$ hypothesis, or if it has energy greater than 1 GeV and contains two shower maxima consistent with two photons from a π^0 decay. The remaining background of K^0_L candidates due to photons and overlapping showers is further reduced with the use of a neural network $\mathcal{NN}_{EMC}$. The $\mathcal{NN}_{EMC}$ is constructed from cluster shape variables, trained using as signal measured $B^0 \to J/\psi K^0_L$ events and as background measured $K^+K^-K^0_L$ events which lie outside the signal region, and tested on $e^+e^- \to \phi(\to K^0_S K^0_L)\gamma$ events.

The results are extracted using an extended unbinned maximum likelihood fit. We parameterize the distributions of kinematic and topological variables for signal and background events in terms of probability density functions (PDFs) [17]. The selection requirements for these variables is loose to include background dominated regions which can then be extrapolated into the signal region. The main source of background, estimated from data, comes from random combinations of tracks produced in events of the type $e^+e^- \to q\bar{q}$, where $q = u, d, s, c$ (continuum). Background from decays of B mesons in other final states with and without charm is estimated using Monte Carlo simulation.

In the following we describe the event variables used in the maximum likelihood fit to characterize the signal and background: the energy difference $\Delta E = E^*_B - \frac{1}{2}\sqrt{s}$, where E^*_B is the energy of the B candidate and $\sqrt{s}$ is the total energy, both evaluated in the $\Upsilon(4S)$ rest frame, a neural network $\mathcal{NN}$ built with topological quantities, and Δt, described in Section 1. For signal events, ΔE is expected to peak at zero, with a broad tail for positive values of ΔE. We require $\Delta E < 0.08$ GeV, in order to be able to fix the shape of background under the signal peak. The ΔE resolution is 3.0 MeV, which includes the different resolutions for EMC and IFR events. This resolution has been validated on data using reconstructed $B^0 \to J/\psi K^0_L$ events.

Continuum events are characterized by a jet-like topology in the $\Upsilon(4S)$ rest frame, because of the large amount of phase space in the decay, while B mesons are produced almost at rest, so particles produced in B decays are distributed isotropically. One can then define a set of topological variables to quantify the sphericity of the event. One such quantity is the angle θ_{SPH} between the sphericity axis of the B_{CP} candidate and the sphericity axis formed from the other charged and neutral particles in the event. We also use the cosine of the angle θ_B between the B_{CP} momentum and the beam axis, and the sum of the momenta p_i of the other charged and neutral particles in the event weighted by the Legendre polynomials $L_0(\theta_i)$ and $L_2(\theta_i)$ where θ_i is the angle between the momentum of particle i and the thrust axis of the B_{CP} candidate. We use other variables characterizing a final state with a K^0_L. One is the reconstructed energy difference ΔE_{vis}, calculated in the laboratory frame as the difference between total reconstructed energy of the event, where the energy of the neutral particles is calibrated for an electromagnetic shower, and the two reconstructed kaon energies. The other is the cosine of the polar angle of the missing momentum, $\vec{p}_{miss}$, calculated as the difference between the sum of beam momenta and all tracks and EMC clusters, in the laboratory frame, excluding the K^0_L candidate. We combine these variables in a neural network $\mathcal{NN}$, which peaks at 0 for continuum events and at 1 for signal events. We apply a selection that retains 80% of signal events and rejects 84% of continuum background. The rest of the events are used for the maximum likelihood fit.

The remaining background originates from B decays where a neutral or charged pion is missed during the reconstruction (peaking B background). Since the branching fractions for these decay modes ($B^0 \to K^+K^-K^{*0}(K^0_L\pi^0)$, $B^0 \to K^{*+}(K^+\pi^0)K^-K^0_L$, $B^+ \to K^+K^-K^{*+}(K^0_L\pi^+)$, and $B^+ \to K^+K^0_LK^{*-}(K^-\pi^0)$) are not known, we build a cocktail of exclusive Monte Carlo samples, weighted with the relative efficiency, and the yield is floated in the final fit. The rest of the background originating from B decays comes from the combinations of particles originating from both B mesons that have continuum-like values of ΔE, so these events are included in the continuum component by the fit, without generating a bias in the fitted values of S and C parameters[4].

We suppress background from B decays that proceed through a $b \to c$ transition leading to the $K^+K^-K^0_L$ final state by applying invariant mass cuts to remove D^0, J/ψ, χ_{c0}, and $\psi(2S)$ decaying into K^+K^-, and D^+ and D^+_s decays into $K^+K^0_L$.

All the other tracks and clusters that are not associated with the reconstructed $B^0 \to K^+K^-K^0_L$ decay are used to form the $B_{\rm tag}$; its flavor is determined with a multivariate tagging algorithm [15]. The tagging efficiency ε and mistag probability w in five hierarchical and mutually exclusive categories are measured using fully reconstructed B^0 decays into the $D^{(*)-}X^+$ ($X^+ = \pi^+, \rho^+, a_1^+$) and $J/\psi K^{*0}$ ($K^{*0} \to K^+\pi^-$) flavor eigenstates ($B_{\rm flav}$ sample). The analyzing power $\varepsilon(1-2w)^2$ is (30.3 ± 0.4)%.

A detailed description of the Δt reconstruction algorithm is given in Ref. [14].

4 MAXIMUM LIKELIHOOD FIT

The CP asymmetry parameters are extracted from a $K^+K^-K^0_L$ sample which excludes $B^0 \to \phi K^0_L$ with an invariant mass veto: $|m(K^+K^-) - m(\phi)| > 15\,{\rm MeV}/c^2$. This excludes $B^0 \to \phi K^0_L$ events by three standard deviations. The average Δz resolution is $190\mu m$, dominated by the tagging vertex in the event. Thus, we can characterize the resolution using the much larger $B_{\rm flav}$ sample, which we use for signal parameterization. The amplitudes for the B_{CP} asymmetries and for the $B_{\rm flav}$ flavor

[4]This conclusion has been obtained simulating the fit on a sample of fully simulated Monte Carlo events.

oscillations are reduced by the same factor due to wrong tags. Both distributions are convolved with a common Δt resolution function. Backgrounds are accounted for by adding terms to the likelihood, incorporated with different assumptions about their Δt evolution and resolution function [14]. The Δt resolution function is parameterized as a sum of two Gaussian distributions with different mean values whose widths are given by a scale factor times the event-by-event uncertainty $\sigma_{\Delta t}$. A third Gaussian distribution, with a fixed large width, accounts for a small fraction of outlying events [5]. For the time-dependent fit we retain events that have $|\Delta t| < 20$ ps and whose estimated uncertainty $\sigma_{\Delta t}$ is less than 2.5 ps.

Since we measure the correlation among the observables to be small in the data sample used in the fit (the largest is 2.9 % between ΔE and $\mathcal{NN}$) we take the probability density function $\mathcal{P}^j_{i,c}$ for each event j to be a product of the PDFs for the separate observables. For each event hypothesis i (signal, backgrounds) and tagging category c, we define $\mathcal{P}^j_{i,c} = \mathcal{P}_i(\Delta E) \cdot \mathcal{P}_i(\mathcal{NN}) \cdot \mathcal{P}_i(\Delta t; \sigma_{\Delta t}, c)$, The likelihood function for each decay chain is then

$$\mathcal{L} = \prod_c \exp\left(-\sum_i N_{i,c}\right) \prod_j^{N_c} \left[\sum_i N_{i,c}\, \mathcal{P}^j_{i,c}\right], \tag{2}$$

where $N_{i,c}$ is the yield of events of hypothesis i obtained from the fit in category c, and N_c is the number of category c events in the sample. The total sample consists of 77577 $K^+K^-K^0_L$ candidates. The total reconstruction efficiency is $\langle\varepsilon\rangle = (23.1 \pm 0.6)\%$. We fixed in the fit $S_{B-bkg} = 0.42$ (as estimated from full Monte Carlo simulation of generic neutral and charged B-decays) and $C_{B-bkg} = 0$ (as the SM expectations). From the fit we find 777 ± 80 $K^+K^-K^0_L$ signal events ($B^0 \to \phi K^0_L$ excluded). The signal yield agrees with the branching fraction determined in the $K^+K^-K^0_S$ final state within one standard deviation, but the uncertainty in K^0_L efficiency is large. Figure 1 shows the ΔE distribution together with the result from the fit after a $\cos\theta_H$ cut to enhance signal, where θ_H is the angle between the K^+ candidate and the parent B_{CP} flight direction in the K^+K^- rest frame. The neural network output distribution together with the result from the fit after a requirement on the likelihood to enhance the sensitivity. The fit was tested with both a parameterized simulation of a large number of data-sized experiments and a full detector simulation. The likelihood of our data fit agrees with the likelihoods from fits to the simulated data. Figure 2 shows the comparison between data and Monte Carlo simulated events of the signal to background likelihood ratio $L_{\rm sig}/(L_{\rm sig} + L_{\rm bkg})$ distribution. It shows the goodness of the agreement between data and Monte Carlo parameterization event-by-event. The fit was also verified with our $J/\psi K^0_L$ data sample to check the fitted central value of sin2β and the sign of the *CP* eigenstate definition.

5 ESTIMATION OF *CP* CONTENT

The measurement of the *CP* content has been done in the $K^+K^-K^0_S$ final state from an angular moments analysis [11]. Since the $K^+K^-K^0_S$ final state has higher purity than can be obtained in the K^0_L final state, the angular analysis has not been repeated with our sample, but the results on the *CP*-conjugate state have been used. In order to take into account differences in the efficiency across the Dalitz plot between the $K^+K^-K^0_S$ and $K^+K^-K^0_L$ samples, which can change the relative amount of *CP*-even(odd) fraction in different $m(K^+K^-)$ regions, we use the f_{even} fraction measured in seven $m(K^+K^-)$ bins (excluding the ϕ region) in $B^0 \to K^+K^-K^0_S$ and compute a re-weighted average using $K^+K^-K^0_L$ yields in the same mass bins. Table 1 shows the $K^+K^-K^0_L$ efficiencies, yields and the measured $K^+K^-K^0_S$ f_{even}. Variations of the signal yield are shown also in the upper plot of Fig. 4.

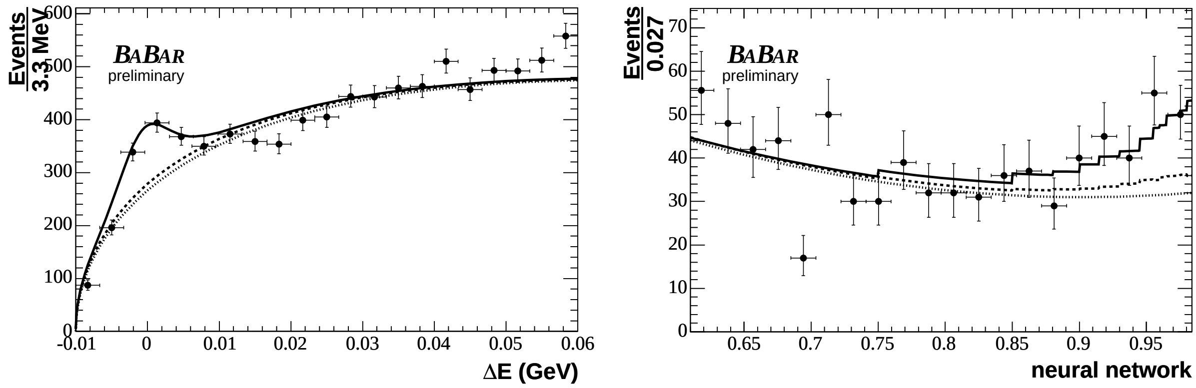

Figure 1: Distribution of the event variable ΔE after a $\cos\theta_H$ cut (left) and neural network output after a requirement on the likelihood, calculated without the plotted variable. The signal efficiency for the selection and likelihood requirements is 31% for ΔE and 8% for the neural network output. The solid line represents the fit result for the total event yield and the dashed line for the total background. The dotted line represents the continuum background, only.

Table 1: Average efficiencies, yields for $B^0 \to K^+K^-K^0_L$, and f_{even}, calculated in the $K^+K^-K^0_S$ final state, for seven K^+K^- mass bins (excluding ϕ region).

$m(K^+K^-)$ GeV/c^2	$\langle\varepsilon\rangle$	*Signal yield*	f_{even} $(K^+K^-K^0_S)$
[1.1 ; 1.3]	0.153	67.6 ± 20.8	1.10 ± 0.18
[1.3 ; 1.5]	0.172	44.0 ± 21.3	0.99 ± 0.14
[1.5 ; 1.9]	0.188	93.9 ± 28.0	0.93 ± 0.21
[1.9 ; 2.3]	0.223	146.4 ± 28.1	0.95 ± 0.16
[2.3 ; 2.7]	0.258	117.4 ± 24.0	0.79 ± 0.24
[2.7 ; 3.1]	0.271	93.7 ± 21.8	0.74 ± 0.25
[3.1 ; 4.9]	0.242	141.9 ± 37.2	0.96 ± 0.43

Out of the ϕ region the sample consists mainly of S-wave decays, giving an f_{odd} fraction close to 1. We find the total fraction of *CP*-odd final states:

$$f_{odd} \;=\; 0.92 \pm 0.07 \text{ (stat)} \pm 0.06 \text{ (syst)},$$

where the systematic uncertainty is evaluated in the *BABAR* $B^0 \to K^+K^-K^0_S$ analysis [11].

6 SYSTEMATIC STUDIES

We consider systematic uncertainties in the *CP* coefficients S and C due to the parameterization of PDFs for the event yield in signal and background by varying the parameters within one standard deviation (evaluated from a fit to Monte Carlo simulated events). Since the real *CP* content of the B background is not known, we vary S_{B-bkg} and C_{B-bkg} in a conservative interval. About 50% of these

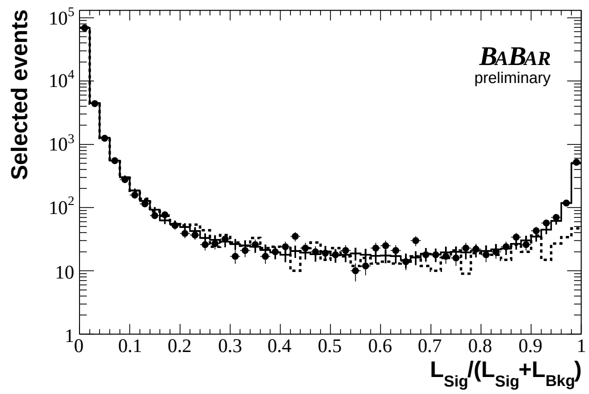

Figure 2: Distribution of signal to background likelihood ratio $L_{\rm sig}/(L_{\rm sig}+L_{\rm bkg})$. The solid line represents the Monte Carlo simulation of the entire sample, and the dashed line the simulation of background only.

events come from charged B decays, which show only direct *CP*-violation, while neutral B decays can violate *CP* both in mixing and decay. We therefore vary the B background *CP* parameters in the interval $-0.5 < S_{B-bkg}(C_{B-bkg}) < 0.5$, which corresponds to a uniform variation of the parameters for neutral B background in the whole physically allowed interval $-1 < S_{B-bkg}(C_{B-bkg}) < 1$. We evaluate the uncertainty associated with the assumed parameterization of the Δt resolution function for signal and B background, a possible difference in the efficiency between reconstructed B^0 and $\overline{B}^0$ decays, and the fixed values for Δm_d and τ_{B^0}, by varying the parameters within one standard deviation (extracted from a fit to the $B_{\rm flav}$ sample). We also estimate uncertainties coming from possible SVT layer misalignments. The bias in the coefficients due to the fit procedure is included in the uncertainty without making corrections to the final results. Finally, we estimate the errors due to the effect of doubly CKM-suppressed decays [16]. We add these contributions in quadrature to obtain the total systematic uncertainty. The summary is reported in Table 2.

7 RESULTS

The coefficients of the time-dependent *CP* asymmetry in $B^0 \to K^+K^-K^0_L$ decays (excluding the $B^0 \to \phi K^0_L$ final state) determined by the fit are:

$$S = 0.07 \pm 0.28\,(\text{stat})^{+0.11}_{-0.12}(\text{syst}),$$
$$C = 0.54 \pm 0.22\,(\text{stat})^{+0.08}_{-0.09},(\text{syst}).$$

Figure 3 shows the Δt distributions of the B^0- and the $\overline{B}^0$-tagged subsets together with the raw asymmetry, with the result of the combined time-dependent *CP*-asymmetry fit superimposed. We also fit the *CP* parameters in the same $m(K^+K^-)$ regions used to estimate the *CP*-odd fraction. The results are shown in Figure 4. The presence of both P- and S-wave decays in our *CP* sample dilutes the measurement of the sine coefficient. If we account for the measured *CP*-odd fraction, we can extract the SM parameter $\sin 2\beta$. Using the estimate of the *CP* content based on the angular moments, and setting $C = 0$ in the fit, we get

$$\sin2\beta_{\rm \ eff} = S/(2f_{odd}-1) = 0.09 \pm 0.33\,(\text{stat})^{+0.13}_{-0.14}(\text{syst}) \pm 0.10(\text{syst } CP\text{-cont})$$

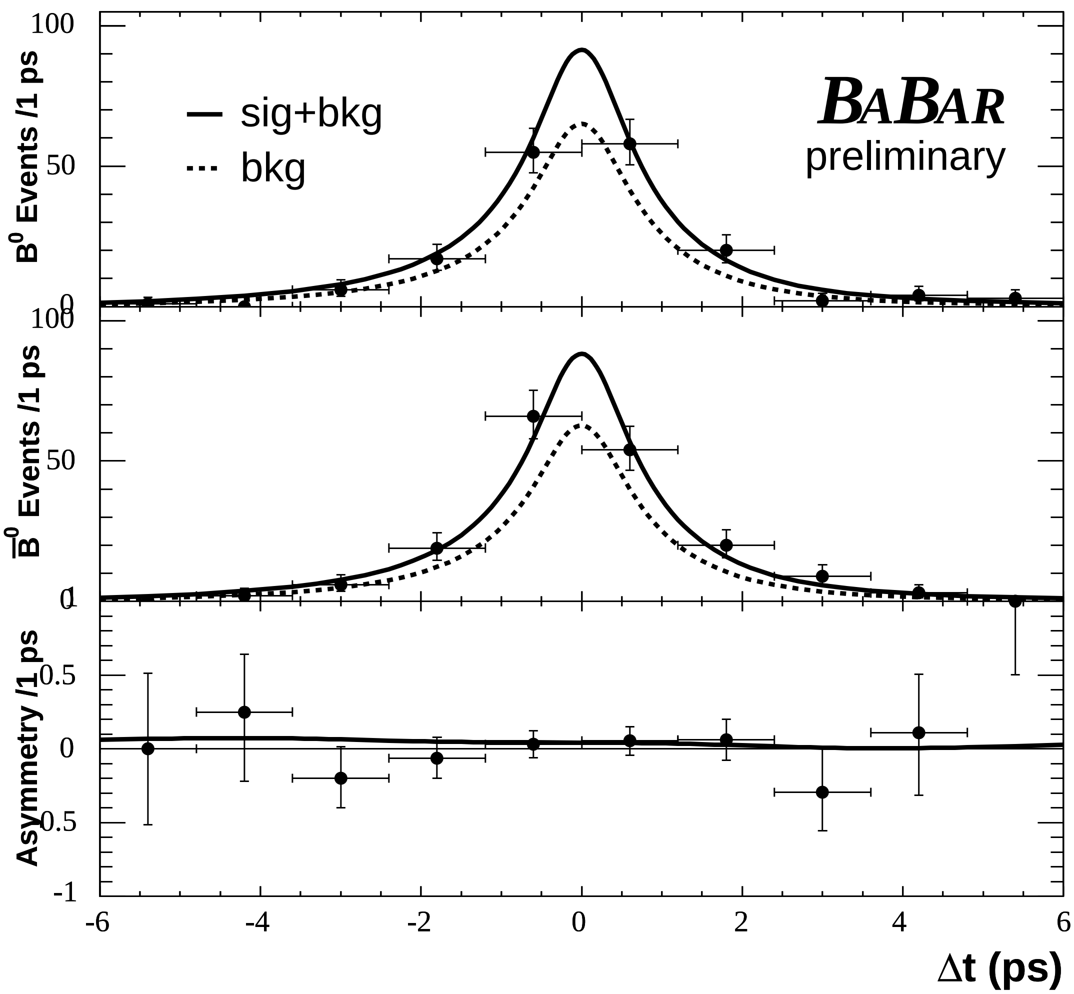

Figure 3: Distributions of Δt for $B^0 \to K^+K^-K^0_L$ candidates with (top) B^0- and (middle) $\overline{B}^0$-tags. The solid lines refer to the fit for all events; the dashed lines correspond to the background. The bottom plot shows the asymmetry. A requirement on signal-to-background ratio to enhance the signal is applied.

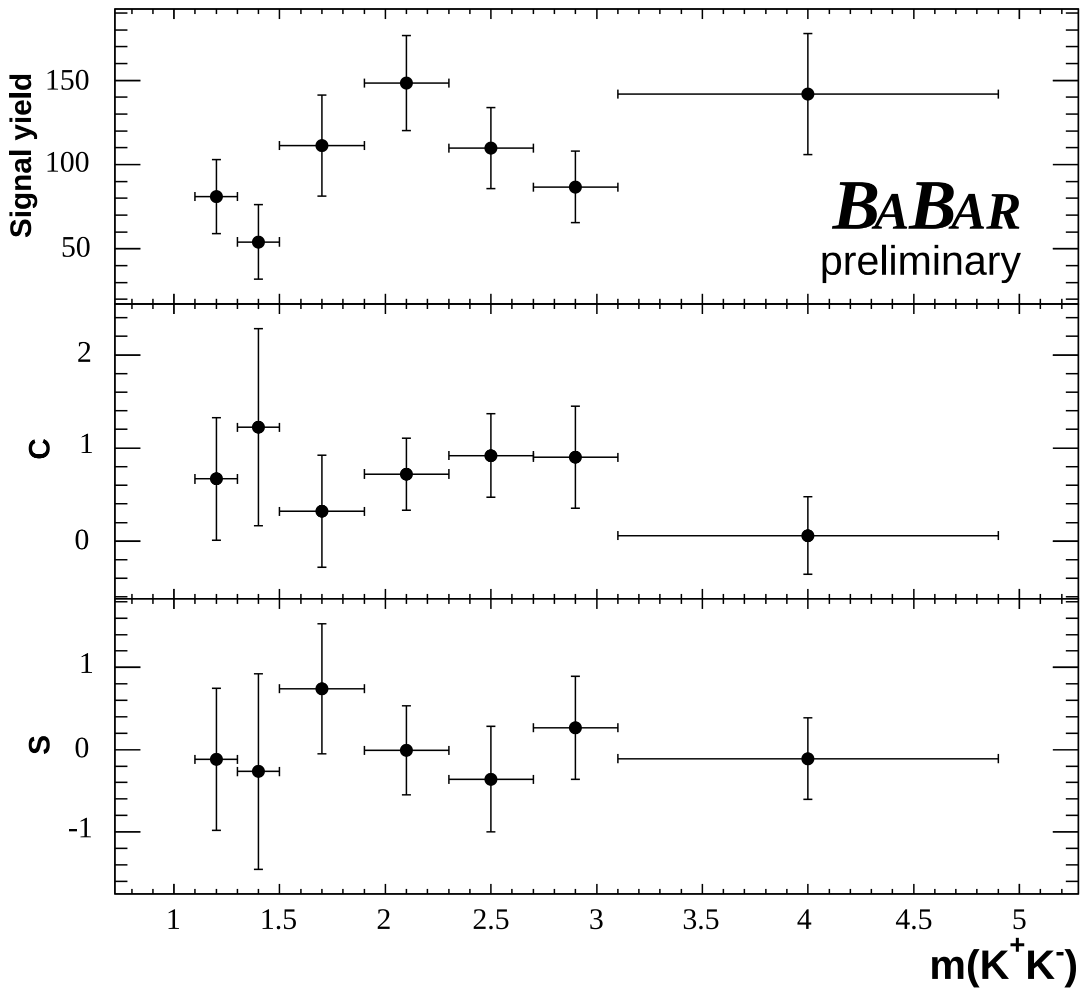

Figure 4: Distribution of signal yield (top), C (middle) and S (bottom) parameters in 7 different $m(K^+K^-)$ intervals.

Table 2: Summary of systematic uncertainties on the parameters S and C. The total systematic errors are obtained by adding in quadrature all individual sources.

Source	$\Delta\ S(+)$	$\Delta\ S(-)$	$\Delta\ C(+)$	$\Delta\ C(-)$
Δm_d	0.004	-0.001	0.000	-0.001
τ_{B^0}	0.01	0.01	0.00	-0.00
Δt model	0.02	0.02	0.02	0.01
Tagging	0.04	0.04	0.03	0.03
B background CP	0.10	0.10	0.06	0.07
Signal and background PDFs	0.03	0.03	0.02	0.02
fit biases	0.00	0.00	0.02	0.02
SVT local alignment	0.01	0.01	0.00	0.00
doubly-CKM-suppressed decays	0.00	0.00	0.01	0.01
Total	0.11	0.12	0.08	0.09

where the last error is due to uncertainty on the *CP* content. Since this uncertainty is multiplicative and the fitted value of S is close to 0, we conservatively computed this uncertainty shifting the measured value of S within 1 standard deviation.

8 SUMMARY

In a sample of 227 million $B\overline{B}$ mesons, we have obtained preliminary measurements of the *CP* content and *CP* parameters in the $K^+K^-K^0_L$ final state that excludes $B^0 \to \phi K^0_L$ decays. We estimated the fraction of S-wave events (*CP*-odd fraction) from measured value in the $K^+K^-K^0_S$ final state, which has higher purity than $K^+K^-K^0_L$. The result shows the dominance of *CP*-odd final states. We compute the average of $\sin 2\beta_{\text{eff}}$ and C parameter in $K^+K^-K^0_S$ and $K^+K^-K^0_L$ final states treating the systematic errors and the uncertainty on the *CP* content as completely correlated. This gives the most conservative estimation of the combined uncertainty. We obtain:

$$[\sin 2\beta_{\text{ eff}}]_{\text{av}} = 0.41 \pm 0.18\ (\text{stat}) \pm 0.07\ (\text{syst}) \pm 0.11\ (CP\text{content})$$
$$[C]_{\text{av}} = 0.23 \pm 0.12\ (\text{stat}) \pm 0.07\ (\text{syst})$$

The result agrees within one standard deviation with the value of $\sin 2\beta$ in the $B^0 \to (\bar{c}c)K^0$ decays [15].

9 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, and the Particle Physics and Astronomy Research Council (United Kingdom). Individuals have received support from CONACyT (Mexico), the A. P. Sloan Foundation, the Research Corporation, and the Alexander von Humboldt Foundation.

References

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

[2] N. G. Deshpande and J. Trampetic, Phys. Rev. D **41**, 895 (1990); N. G. Deshpande and G. He, Phys. Lett. B **336**, 471 (1994); R. Fleischer, Z. Phys. C **62**, 81 (1994); Y. Grossman *et al.*, Phys. Rev. D **68**, 015004 (2003).

[3] A. B. Carter and A. I. Sanda, Phys. Rev. D **23**, 1567 (1981); I. I. Bigi and A. I. Sanda, Nucl. Phys. B **193**, 85 (1981); Y. Grossman and M. P. Worah, Phys. Lett. B **395**, 241 (1997); R. Fleischer, Int. J. Mod. Phys. A **12**, 2459 (1997); D. London and A. Soni, Phys. Lett. B **407**, 61 (1997).

[4] M. Ciuchini, E. Franco, A. Masiero and L. Silvestrini, Phys. Rev. D **67**, 075016 (2003) [Erratum-ibid. D **68**, 079901 (2003)] [arXiv:hep-ph/0212397].

[5] B. Aubert *et al.*, [*BABAR* Collaboration], Phys. Rev. Lett. **89**, 201802 (2002).

[6] K. Abe *et al.*, [Belle Collaboration], Phys. Rev. D **66**, 071102 (2002).

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

[8] J. Charles *et al.* [CKMfitter Group], arXiv:hep-ph/0406184; M. Bona *et al.* [UTfit Collaboration], arXiv:hep-ph/0501199.

[9] K. Abe *et al.* [Belle Collaboration], Phys. Rev. Lett. **91**, 261602 (2003).

[10] B. Aubert [*BABAR* Collaboration], BABAR-CONF-04/033

[11] B. Aubert [*BABAR* Collaboration], BABAR-CONF-04/025

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

[13] PEP-II Conceptual Design Report, SLAC-R-418 (1993).

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

[15] B. Aubert *et al.*, [*BABAR* Collaboration], 'Improved Measurement of Time-Dependent *CP* Violation in $B^0 \to (\bar{c}c)K^0$ Decays', Contribution to ICHEP 2004.

[16] O. Long, M. Baak, R. N. Cahn and D. Kirkby, Phys. Rev. D **68**, 034010 (2003).

[17] B. Aubert *et al.*, [*BABAR* Collaboration], Phys. Rev. Lett. **87**, 151801 (2001).