

## Measurement of $CP$ -Asymmetries for the Decays $B^\pm \rightarrow D_{CP}^0 K^{*\pm}$ with the BABAR Detector

The BABAR Collaboration

August 28, 2004

### Abstract

Using a sample of 227 million  $\Upsilon(4S) \rightarrow B\bar{B}$  events collected with the BABAR detector at the PEP-II  $B$  Factory in 1999–2004, we study  $B^- \rightarrow D^0 K^* (892)^-$  decays where  $K^{*-} \rightarrow K_S^0 \pi^-$  and  $D^0 \rightarrow K^- \pi^+, K^- \pi^+ \pi^0, K^- \pi^+ \pi^+ \pi^-$  (non- $CP$  final states),  $K^+ K^-$ ,  $\pi^+ \pi^-$  ( $CP+$  eigenstates),  $K_S^0 \pi^0$ ,  $K_S^0 \phi$  and  $K_S^0 \omega$  ( $CP-$  eigenstates). The partial rate charge asymmetries  $\mathcal{A}_{CP}$  and the ratios  $\mathcal{R}_{CP}$  defined in the literature as the sum of the  $B^+$  and  $B^-$  partial rates to a charged  $K^*$  and a  $D^0$   $CP$ -eigenstate divided by the  $B \rightarrow D^0 K^*$  decay rate, are sensitive to the angle  $\gamma$  of the CKM unitarity triangle. We measure:

$$\begin{aligned} \mathcal{A}_{CP+} &= -0.09 \pm 0.20(stat.) \pm 0.06(syst.) \\ \mathcal{A}_{CP-} &= -0.33 \pm 0.34(stat.) \pm 0.10(syst.) (+0.15 \pm 0.10) \cdot (\mathcal{A}_{CP-} - \mathcal{A}_{CP+}) \\ \mathcal{R}_{CP+} &= +1.77 \pm 0.37(stat.) \pm 0.12(syst.) \\ \mathcal{R}_{CP-} &= +0.76 \pm 0.29(stat.) \pm 0.06(syst.) \begin{matrix} -0.04 \\ 0.14 \end{matrix} \end{aligned}$$

The third uncertainty quoted for the  $CP-$  measurements reflects possible interference effects in the final states with  $\phi$  and  $\omega$  resonances. All results are preliminary.

Submitted to the 32<sup>nd</sup> International Conference on High-Energy Physics, ICHEP 04,  
 16 August–22 August 2004, Beijing, China

---

*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, J.-M. Gaillard, A. Hicheur, Y. Karyotakis, J. P. Lees,  
V. Tisserand, A. Zghiche

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

A. Palano, 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, Inst. of Physics, N-5007 Bergen, Norway*

G. S. Abrams, A. W. Borgland, 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, V. G. Shelkov, W. A. Wenzel

*Lawrence Berkeley National Laboratory and University of California, Berkeley, CA 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, M. Steinke  
*Ruhr Universität Bochum, Institut für Experimentalphysik 1, D-44780 Bochum, Germany*

J. T. Boyd, N. Chevalier, W. N. Cottingham, M. P. Kelly, T. E. Latham, F. F. Wilson

*University of Bristol, Bristol BS8 1TL, United Kingdom*

T. Cuhadar-Donszelmann, C. Hearty, N. S. Knecht, T. S. Mattison, J. A. McKenna, D. Thiessen

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

A. Khan, P. Kyberd, L. Teodorescu

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

A. E. Blinov, V. E. Blinov, V. P. Druzhinin, V. B. Golubev, V. N. Ivanchenko, 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. Bruinsma, M. Chao, I. Eschrich, D. Kirkby, A. J. Lankford, M. Mandelkern, R. K. Mommsen,  
W. Roethel, D. P. Stoker

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

C. Buchanan, B. L. Hartfiel

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

S. D. Foulkes, J. W. Gary, B. C. Shen, K. Wang  
*University of California at Riverside, Riverside, CA 92521, USA*

D. del Re, H. K. Hadavand, E. J. Hill, D. B. MacFarlane, H. P. Paar, Sh. Rahatlou, V. Sharma  
*University of California at San Diego, La Jolla, CA 92093, USA*

J. W. Berryhill, C. Campagnari, B. Dahmes, O. Long, A. Lu, M. A. Mazur, J. D. Richman, W. Verkerke  
*University of California at Santa Barbara, Santa Barbara, CA 93106, USA*

T. W. Beck, A. M. Eisner, 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, CA 95064, USA*

J. Albert, E. Chen, G. P. Dubois-Felsmann, A. Dvoretzkii, D. G. Hitlin, I. Narsky, T. Piatenko,  
F. C. Porter, A. Ryd, A. Samuel, S. Yang  
*California Institute of Technology, Pasadena, CA 91125, USA*

S. Jayatilake, G. Mancinelli, B. T. Meadows, M. D. Sokoloff  
*University of Cincinnati, Cincinnati, OH 45221, USA*

T. Abe, F. Blanc, P. Bloom, S. Chen, W. T. Ford, U. Nauenberg, A. Olivas, P. Rankin, J. G. Smith,  
J. Zhang, L. Zhang  
*University of Colorado, Boulder, CO 80309, USA*

A. Chen, J. L. Harton, A. Soffer, W. H. Toki, R. J. Wilson, Q. Zeng  
*Colorado State University, Fort Collins, CO 80523, USA*

D. Altenburg, T. Brandt, J. Brose, M. Dickopp, E. Feltresi, A. Hauke, H. M. Lacker, R. Müller-Pfefferkorn,  
R. Nogowski, S. Otto, A. Petzold, J. Schubert, K. R. Schubert, R. Schwierz, B. Spaan, J. E. Sundermann  
*Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany*

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

D. J. Bard, P. J. Clark, D. Lavin, 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, A. Sarti  
*Università di Ferrara, Dipartimento di Fisica and INFN, I-44100 Ferrara, Italy*

E. Treadwell  
*Florida A&M University, Tallahassee, FL 32307, USA*

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

A. Buzzo, R. Capra, R. Contri, G. Crosetti, 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*

S. Bailey, G. Brandenburg, K. S. Chaisanguanthum, M. Morii, E. Won

*Harvard University, Cambridge, MA 02138, USA*

R. S. Dubitzky, U. Langenegger

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

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

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

M. J. Charles, G. J. Grenier, U. Mallik

*University of Iowa, Iowa City, IA 52242, USA*

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

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

M. Biasini, R. Covarelli, M. Pioppi

*Università di Perugia, Dipartimento di Fisica and INFN, I-06100 Perugia, Italy*

M. Davier, X. Giroux, G. Grosdidier, A. Höcker, S. Laplace, F. Le Diberder, V. Lepeltier, A. M. Lutz,  
T. C. Petersen, S. Plaszczynski, M. H. Schune, L. Tantot, 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, CA 94550, USA*

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

*University of Liverpool, Liverpool L69 7ZE, United Kingdom*

J. J. Back,<sup>1</sup> C. M. Cormack, P. F. Harrison,<sup>1</sup> F. Di Lodovico, G. B. Mohanty<sup>1</sup>

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

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

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

D. Brown, C. L. Davis

*University of Louisville, Louisville, KY 40292, USA*

---

<sup>1</sup>Now at Department of Physics, University of Warwick, Coventry, United Kingdom

J. Allison, N. R. Barlow, R. J. Barlow, P. A. Hart, M. C. Hodgkinson, G. D. Lafferty, A. J. Lyon,  
J. C. Williams

*University of Manchester, Manchester M13 9PL, United Kingdom*

A. Farbin, W. D. Hulsbergen, A. Jawahery, D. Kovalskyi, C. K. Lae, V. Lillard, D. A. Roberts

*University of Maryland, College Park, MD 20742, USA*

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

*University of Massachusetts, Amherst, MA 01003, USA*

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

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

D. J. J. Mangeol, P. M. Patel, S. H. Robertson

*McGill University, Montréal, QC, 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, MS 38677, USA*

S. Brunet, D. Côté, P. Taras

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

H. Nicholson

*Mount Holyoke College, South Hadley, MA 01075, USA*

N. Cavallo,<sup>2</sup> F. Fabozzi,<sup>2</sup> 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, IN 46556, USA*

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

*Ohio State University, Columbus, OH 43210, USA*

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

*University of Oregon, Eugene, OR 97403, USA*

---

<sup>2</sup>Also with Università della Basilicata, Potenza, Italy

F. Colecchia, A. Dorigo, F. Galeazzi, M. Margoni, M. Morandin, M. Posocco, M. Rotondo, F. Simonetto,  
R. Stroili, G. Tiozzo, C. Voci

*Università di Padova, Dipartimento di Fisica and INFN, I-35131 Padova, Italy*

M. Benayoun, H. Briand, J. Chauveau, P. David, Ch. de la Vaissière, L. Del Buono, O. Hamon,  
M. J. J. John, Ph. Leruste, J. Malcles, J. Ocariz, M. Pivk, L. Roos, S. T'Jampens, G. Therin  
*Universités Paris VI et VII, Laboratoire de Physique Nucléaire et de Hautes Energies, F-75252 Paris,  
France*

P. F. Manfredi, V. Re

*Università di Pavia, Dipartimento di Elettronica and INFN, I-27100 Pavia, Italy*

P. K. Behera, L. Gladney, Q. H. Guo, J. Panetta

*University of Pennsylvania, Philadelphia, PA 19104, USA*

C. Angelini, G. Batignani, S. Bettarini, M. Bondioli, F. Bucci, G. Calderini, M. Carpinelli, F. Forti,  
M. A. Giorgi, A. Lusiani, G. Marchiori, F. Martinez-Vidal,<sup>3</sup> M. Morganti, N. Neri, E. Paoloni, M. Rama,  
G. Rizzo, F. Sandrelli, J. Walsh

*Università di Pisa, Dipartimento di Fisica, Scuola Normale Superiore and INFN, I-56127 Pisa, Italy*

M. Haire, D. Judd, K. Paick, D. E. Wagoner

*Prairie View A&M University, Prairie View, TX 77446, USA*

N. Danielson, P. Elmer, Y. P. Lau, C. Lu, V. Miftakov, J. Olsen, A. J. S. Smith, A. V. Telnov

*Princeton University, Princeton, NJ 08544, USA*

F. Bellini, G. Cavoto,<sup>4</sup> R. Faccini, F. Ferrarotto, F. Ferroni, M. Gaspero, L. Li Gioi, M. A. Mazzoni,  
S. Morganti, M. Pierini, G. Piredda, F. Safai Tehrani, C. Voena

*Università di Roma La Sapienza, Dipartimento di Fisica and INFN, I-00185 Roma, Italy*

S. Christ, G. Wagner, R. Waldi

*Universität Rostock, D-18051 Rostock, Germany*

T. Adye, N. De Groot, B. Franek, N. I. Geddes, G. P. Gopal, E. O. Olaiya

*Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingdom*

R. Aleksan, S. Emery, A. Gaidot, S. F. Ganzhur, P.-F. Giraud, G. Hamel de Monchenault, W. Kozanecki,  
M. Legendre, G. W. London, B. Mayer, G. Schott, 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, SC 29208, USA*

D. Aston, R. Bartoldus, N. Berger, A. M. Boyarski, O. L. Buchmueller, R. Claus, M. R. Convery,  
M. Cristinziani, G. De Nardo, D. Dong, J. Dorfman, D. Dujmic, W. Dunwoodie, E. E. Elsen, S. Fan,  
R. C. Field, T. Glanzman, S. J. Gowdy, T. Hadig, V. Halyo, C. Hast, T. Hryn'ova, W. R. Innes,

---

<sup>3</sup>Also with IFIC, Instituto de Física Corpuscular, CSIC-Universidad de Valencia, Valencia, Spain

<sup>4</sup>Also with Princeton University, Princeton, USA

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, S. Petrak,  
B. N. Ratcliff, A. Roodman, A. A. Salnikov, R. H. Schindler, J. Schwiening, G. Simi, A. Snyder, A. Soha,  
J. Stelzer, D. Su, M. K. Sullivan, J. Va'vra, S. R. Wagner, M. Weaver, A. J. R. Weinstein,  
W. J. Wisniewski, M. Wittgen, D. H. Wright, A. K. Yarritu, C. C. Young

*Stanford Linear Accelerator Center, Stanford, CA 94309, USA*

P. R. Burchat, A. J. Edwards, T. I. Meyer, B. A. Petersen, C. Roat

*Stanford University, Stanford, CA 94305-4060, USA*

S. Ahmed, M. S. Alam, J. A. Ernst, M. A. Saeed, M. Saleem, F. R. Wappler

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

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

*University of Tennessee, Knoxville, TN 37996, USA*

R. Eckmann, H. Kim, J. L. Ritchie, A. Satpathy, R. F. Schwitters

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

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

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

F. Bianchi, M. Bona, F. Gallo, D. Gamba

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

L. Bosisio, C. Cartaro, F. Cossutti, G. Della Ricca, S. Dittongo, S. Grancagnolo, L. Lanceri, P. Poropat,<sup>5</sup>  
L. Vitale, G. Vuagnin

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

R. S. Panvini

*Vanderbilt University, Nashville, TN 37235, USA*

Sw. Banerjee, C. M. Brown, D. Fortin, P. D. Jackson, R. Kowalewski, J. M. Roney, R. J. Sobie

*University of Victoria, Victoria, BC, Canada V8W 3P6*

H. R. Band, B. Cheng, S. Dasu, M. Datta, A. M. Eichenbaum, M. Graham, J. J. Hollar, J. R. Johnson,  
P. E. Kutter, H. Li, R. Liu, A. Mihalyi, A. K. Mohapatra, Y. Pan, R. Prepost, P. Tan, J. H. von  
Wimmersperg-Toeller, J. Wu, S. L. Wu, Z. Yu

*University of Wisconsin, Madison, WI 53706, USA*

M. G. Greene, H. Neal

*Yale University, New Haven, CT 06511, USA*

---

<sup>5</sup>Deceased

# 1 INTRODUCTION

The measurement of  $CP$  violation in  $B$  meson decays offers the means to over-constrain the unitarity triangle. A theoretically clean measurement of the angle  $\gamma = \arg(-V_{ud}V_{ub}^*/V_{cd}V_{cb}^*)$  is provided by the  $B^- \rightarrow D^{(*)0} K^{*-}$  [1] decay channels in which the favoured  $b \rightarrow c\bar{u}s$  and suppressed  $b \rightarrow u\bar{c}s$  penguin-less processes interfere [2]. In this paper we implement the method proposed by Gronau, Wyler and London by looking at the interference between  $B^- \rightarrow D^0 K^{*-}$  and  $B^- \rightarrow \bar{D}^0 K^{*-}$  when both  $D^0$  and  $\bar{D}^0$  decay to a  $CP$  eigenstate.

We define [3]:

$$\mathcal{A}_{CP\pm} = \frac{\Gamma(B^- \rightarrow D_{CP\pm}^0 K^{*-}) - \Gamma(B^+ \rightarrow D_{CP\pm}^0 K^{*+})}{\Gamma(B^- \rightarrow D_{CP\pm}^0 K^{*-}) + \Gamma(B^+ \rightarrow D_{CP\pm}^0 K^{*+})}, \quad (1)$$

$$\mathcal{R}_{CP\pm} = \frac{\Gamma(B^- \rightarrow D_{CP\pm}^0 K^{*-}) + \Gamma(B^+ \rightarrow D_{CP\pm}^0 K^{*+})}{\Gamma(B^- \rightarrow D^0 K^{*-})}. \quad (2)$$

$\mathcal{A}_{CP\pm}$  are the direct  $CP$ -violating asymmetries associated to each  $D^0$   $CP$  eigenstate.  $\mathcal{R}_{CP\pm}$  is twice the ratio of the charge-averaged branching fraction of the  $B \rightarrow D^0_{CP\pm} K^*$  decays to that of  $B^- \rightarrow D^0 K^{*-}$ . The latter branching fraction has been measured previously by BABAR [4], CLEO [5] and Belle [6]. These measurements average to  $(5.7 \pm 0.6) \cdot 10^{-4}$ . Both  $\mathcal{A}_{CP\pm}$  and  $\mathcal{R}_{CP\pm}$  carry  $CP$ -violating information. Neglecting  $D^0$ - $\bar{D}^0$  mixing:

$$\mathcal{R}_{CP\pm} = 1 \pm 2r_B \cos \delta \cos \gamma + r_B^2 \quad (3)$$

$$\mathcal{A}_{CP\pm} \times \mathcal{R}_{CP\pm} = \pm 2r_B \sin \delta \sin \gamma \quad (4)$$

where  $\delta$  is the  $CP$ -conserving strong phase phase difference between the  $B^- \rightarrow D^0 K^{*-}$  (favoured  $B$  decay) and  $B^- \rightarrow \bar{D}^0 K^{*-}$  (suppressed) amplitudes,  $\gamma$  is the  $CP$ -violating weak phase difference in the same processes and  $r_B \simeq 0.1$ - $0.3$  is the magnitude of the ratio of the amplitudes [3].

## 2 THE BABAR DETECTOR AND DATASET

We look for  $B^- \rightarrow D_{CP}^0 K^{*-}$  decays with the data collected near the  $\Upsilon(4S)$  resonance with the BABAR detector at the PEP-II storage ring between October 1999 and May 2004. We accumulated an integrated luminosity of  $205 \text{ fb}^{-1}$  on the peak (227 million  $B\bar{B}$  pairs) and  $16 \text{ fb}^{-1}$  40 MeV below the resonance. The BABAR detector is described elsewhere [7]. We focus on the components which are relevant to this analysis. Charged-particle trajectories are measured by a five-layer double sided silicon vertex tracker (SVT) and a 40-layer drift chamber (DCH) immersed in a 1.5 T solenoidal magnetic field. Charged-particle identification is achieved by combining the light measured in a ring-imaging Cherenkov device (DIRC) with the ionization energy loss ( $dE/dx$ ) measured in the DCH and SVT. Photons are detected in a CsI(Tl) electromagnetic calorimeter (EMC) inside the coil. We use GEANT4 [8] based software to simulate the detector response and account for the varying beam and environmental conditions.

### 3 ANALYSIS METHOD

We reconstruct  $B^- \rightarrow D^0 K^* (892)^-$  decays. We select  $K^{*-}$  candidates in the  $K^{*-} \rightarrow K_S^0 \pi^-$  mode and  $D^0$  candidates in 8 decay channels. We optimize our event-selection criteria to minimize the statistical error on the signal yield, determined for each channel using simulated signal and background events. In order to maximize statistics and as we measure ratios (asymmetries and ratios of branching fractions), we use rather relaxed criteria to define a track or a photon candidate. In general a track must originate from the interaction point within 1.5 cm in the transverse plane and 10 cm along the beam. Very soft tracks, measured only by the SVT are also used. Loose criteria are employed to separate charged pions and kaons. Pions (kaons) are identified with more than 95% (90%) efficiency by an algorithm which rejects more than 85% (95%) of the kaons (pions) in the geometrical acceptance of the DIRC. Photon candidates are isolated energy deposits in the EMC with an energy above 30 MeV and a shape consistent with that of a photon-induced shower.

$K_S^0$  candidates are made from oppositely charged tracks assumed to be pions.  $K_S^0$  used to make  $D^0_{CP\pm}$  ( $K^*$ ) candidates are mass (mass and vertex) constrained. The pion pairs are selected according to their reconstructed invariant mass, required to be within 13 MeV/ $c^2$  from the known value [9]. For those used to search for a  $K^*$  we further require their flight direction and length to be as expected for a  $K_S^0$  coming from the interaction point. The  $K_S^0$  candidate flight path and momentum have to make an acute angle. The  $K_S^0$  candidate flight length in the transverse plane has to exceed its uncertainty by 3 standard deviations.  $\pi^0$  candidates combine pairs of photons with a total energy greater than 200 MeV and an invariant mass between 115 and 150 MeV/ $c^2$ . A mass constraint fit is applied to the selected  $\pi^0$  candidates.  $K^*$  candidates combine a  $K_S^0$  and a charged particle which are constrained to come from a single decay vertex. We select  $K^*$  candidates which have an invariant mass within 75 MeV/ $c^2$  of the known value [9]. Finally, since the  $K^*$  in  $B \rightarrow D^0 K^*$  is polarized, we require  $|\cos \theta_{K^*hel}| \geq 0.35$ , where  $\theta_{K^*hel}$  is the angle in the  $K^*$  rest frame between the daughter pion and the parent  $B$  momenta. Here and in other occurrences the helicity distribution discriminates well between a  $B$  meson decay and an event from the  $e^+e^- \rightarrow q\bar{q}$  continuum.

We select  $D^0$  in even  $CP$  ( $CP+$ ) eigenstates ( $K^+K^-$ ,  $\pi^+ \pi^-$ ), odd  $CP$  ( $CP-$ ) eigenstates ( $K_S^0 \pi^0$ ,  $K_S^0 \phi$  and  $K_S^0 \omega$ ), and non- $CP$  (flavour) eigenstates ( $K^- \pi^+$ ,  $K^- \pi^+ \pi^0$  and  $K^- \pi^+ \pi^+ \pi^-$ ). Composite particles included in the  $CP-$  modes are vertex constrained.  $\phi$  ( $\omega$ ) candidates are constructed from  $K^+ K^-$  ( $\pi^+ \pi^- \pi^0$ ) particle combinations with an invariant mass required to be within 12 (20) MeV/ $c^2$  of the known values [9]. We further select the  $\omega$  candidates with requirements on two helicity angles. The normal helicity angle, between the  $D^0$  momentum in the rest frame of the  $\omega$  and the normal to the plane containing all 3 decay pions, must have its cosine above 0.25 in magnitude. The Dalitz-helicity angle [10], defined as the angle between the momentum of one daughter pion in the  $\omega$  rest frame and the direction of one of the other two pions in the rest frame of those two pions, must have a cosine with a magnitude less than 0.9.

Except for the  $K_S^0 \pi^0$  final state, all  $D^0$  candidates are mass and vertex constrained. We select  $D^0$  candidates with an invariant mass differing from the known mass by less than 12 MeV/ $c^2$  for all channels except  $K_S^0 \pi^0$  (30 MeV/ $c^2$ ) and  $K_S^0 \omega$  (20 MeV/ $c^2$ ). These limits are about 2 standard deviations of the nearly-Gaussian resolutions.

To suppress the background due to  $e^+e^- \rightarrow q\bar{q}$  reactions,  $q \in \{u, d, s, c\}$ , we require  $|\cos \theta_B| \leq 0.9$  as, in the  $\Upsilon(4S)$  rest frame,  $B$  mesons are produced with a  $\sin^2 \theta_B$  distribution of the angle  $\theta_B$

of their momentum with the beam axis. We also use global event shape variables which translate quantitatively the fact that in the  $\Upsilon(4S)$  rest frame,  $q\bar{q}$  continuum events have a two-jet like topology whereas  $B\bar{B}$  events are more spherical. We require  $|\cos \theta_{thrust}| \leq 0.9$  where  $\theta_{thrust}$  is the angle between the thrust axes of the  $B$  candidate and the rest of the event (i.e. what is left after removing the tracks and clusters associated with the  $B$  candidate). We construct a Fisher discriminant [11] from  $\cos \theta_{thrust}$  and Legendre monomials [12] describing the energy flow in the rest of the event.

We identify final  $B$  candidates using two [nearly] independent kinematic variables: the beam-energy-substituted mass  $m_{ES} = \sqrt{(s/2 + \mathbf{p}_0 \cdot \mathbf{p}_B)^2/E_0^2 - p_B^2}$  and the energy difference  $\Delta E = E_B^* - \sqrt{s}/2$ , where the subscripts 0 and  $B$  refer to the  $e^+e^-$ -beam-system and the  $B$  candidate respectively;  $s$  is the square of the center-of-mass (CM) energy and the asterisk labels the CM frame. For all signal modes, the  $m_{ES}$  distributions are described by the same Gaussian function  $\mathcal{G}$  centered at the  $B$  mass with a 2.6 MeV/ $c^2$  resolution (except  $K_S^0 \pi^0$  which has a 2.8 MeV/ $c^2$  resolution). The  $\Delta E$  distribution depends more strongly on the signal mode.  $\Delta E$  is centered on zero for signal with a resolution of 11–13 MeV for all channels except  $K_S^0 \pi^0$  for which the resolution is asymmetric and about 30 MeV. We define a signal region  $|\Delta E| < 25$  MeV for all modes except  $K_S^0 \pi^0$  which uses  $< 50$  MeV.

For those events consistent with more than one  $B$  candidate — this occurs in  $< 25\%$  of selected events depending on the  $D^0$  mode — we choose that with the smallest  $\chi^2$  formed from the differences of the measured and true  $D^0$  and  $K^*$  masses scaled by the mass spread which includes the resolution and, for the  $K^*$ , the natural width. Simulations prove that no bias is introduced by this choice and the correct candidate is picked at least 82% of the time.

The total reconstruction efficiencies<sup>6</sup> after corrections, according to simulation of signal events, are: 12.5% and 12.9% for the  $CP+$  modes  $D^0 \rightarrow K^+K^-$  and  $\pi^+ \pi^-$ ; 5.0%, 10.2% and 2.3% for the  $CP-$  modes  $D^0 \rightarrow K_S^0 \pi^0$ ,  $K_S^0 \phi$  and  $K_S^0 \omega$ ; 13.5%, 5.2% and 8.0% for the  $D^0 \rightarrow K^- \pi^+$ ,  $K^- \pi^+ \pi^0$  and  $K^- \pi^+ \pi^+ \pi^-$  non- $CP$  modes.

## 4 PEAKING BACKGROUNDS

To study  $B\bar{B}$  backgrounds we look in *sideband* regions away from the signal region. We define a  $\Delta E$  sideband in the interval  $-100 \leq \Delta E \leq -60$  and  $60 \leq \Delta E \leq 200$  MeV for all modes except  $D^0 \rightarrow K_S^0 \pi^0$  for which the inside limit is  $\pm 95$  rather than 60 MeV. The lower limit ( $-100$  MeV/ $c^2$ ) is chosen to avoid selecting much of the background coming from  $D^{*0} \rightarrow D^0 \pi^0/\gamma$  decays. In this  $\Delta E$  sideband we see no significant evidence of a peaking background which could leak into the signal region. We define a second control region in the  $m_{D^0}$  sideband away from the  $D^0$  mass peak. This provides sensitivity to background sources which mimic signal both in  $\Delta E$  and  $m_{ES}$ : the (doubly) peaking background. This pollution comes from either charmed or charmless  $B$  meson decays which do not contain a true  $D^0$ . As many of the possible contributions to this background are not well known, we attempt to measure this contribution by including the  $m_{D^0}$  sideband in the fit. Relevant plots are shown on the third row of Figure 1.

A notable background for the  $B^- \rightarrow (D^0 \rightarrow \pi^+ \pi^-) (K^{*-} \rightarrow K_S^0 \pi^-)$  mode is the decay  $B^- \rightarrow (K_S^0 \pi^+ \pi^-)_{D^0} \pi^-$  which contains the same final state as the signal but has a 600 times higher

<sup>6</sup>The branching fractions of the unstable daughter particles are not included.

branching fraction. We therefore explicitly veto any selected  $B$ -candidate containing a  $(K_s^0 \pi^+ \pi^-)$  combination within 25 MeV/ $c^2$  of the  $D^0$  mass.

## 5 YIELD AND $CP$ FIT

An unbinned extended maximum likelihood fit to  $m_{ES}$  distributions in the range  $5.2 \leq m_{ES} \leq 5.3$  GeV/ $c^2$  is used to determine yields and  $CP$ -violating quantities  $\mathcal{A}_{CP}$  and  $\mathcal{R}_{CP}$ . We use a *universal* Gaussian function  $\mathcal{G}$  to describe the signal shape for all modes considered. The combinatorial background in the  $m_{ES}$  distribution is modeled using a threshold function  $\mathcal{A}rg$  first considered by the Argus collaboration [13]. Its shape is governed by one parameter  $\xi$  that is left to float in the fit and a second,  $E_{MAX} = \sqrt{s}/2$ , which is fixed at 5.2910 GeV/ $c^2$ . We fit simultaneously  $m_{ES}$  distributions of nine samples (1) the non- $CP$ , (2)  $CP+$  and (3)  $CP-$   $D^0$  modes in the (i) signal region, (ii) the  $m_{D^0}$  sideband and (iii) the  $\Delta E$  sideband. We fit three types of probability density functions ( $PDF$ ) combining  $\mathcal{G}(m_{ES}; x_j)$  and  $\mathcal{A}rg(m_{ES}; \xi)$  weighted by the unknown event yields. We call  $x_j$ , the mean and standard deviation of  $\mathcal{G}$  and  $\xi$  the shape parameters of the  $PDF$ . In the  $\Delta E$  sideband, we fit:  $\mathcal{A}rg$ . In the  $m_{D^0}$  sideband we fit:  $a_{sb} \cdot \mathcal{A}rg + b_{sb} \cdot \mathcal{G}$ . where  $\mathcal{G}$  accounts for the doubly peaking  $B$ -decays. Finally, we fit:  $a \cdot \mathcal{A}rg + b \cdot \mathcal{G} + c \cdot \mathcal{G}$  in the signal region. Here  $b$  is scaled from  $b_{sb}$  according to the  $m_{D^0}$  sideband and signal window widths and is fixed;  $c$  is the  $B^\pm \rightarrow D^0 K^{*\pm}$  signal. The motivation to perform the fit just described is as follows: the non- $CP$  mode sample with relatively high statistics helps constrain the  $PDF$  shape for the low statistics  $CP$  mode distributions. The  $\Delta E$  sideband sample helps define the Argus background shape.

The values of  $\xi$  obtained for each data sample were found to be consistent with each other, but subject to large uncertainties. We have therefore constrained  $\xi$  to take the same value for all data samples in the fit. We assume that the  $B$  decays found in the  $m_{D^0}$  sideband have the same final states as the signal and that we can therefore fit the same Gaussian to the signal and doubly peaking  $B$  background.

Furthermore, the  $CP$  samples (in the signal region) are split into the  $B^-$  and  $B^+$  sub-samples. The likelihood function is written so as to directly extract the four physical quantities,  $\mathcal{A}_+$ ,  $\mathcal{A}_-$ ,  $\mathcal{R}_+$  and  $\mathcal{R}_-$ . The doubly peaking  $B$ -background is assumed to *not* violate  $CP$  and so is split equally between the  $B^-$  and  $B^+$  sub-samples. This assumption is considered further when we discuss the systematic uncertainties. Fig. 1 shows graphically the results of the fit. The nominal fit results are shown in table 1.

	non- $CP$	$CP+$	$CP-$
Yield	$498 \pm 29$	$34.4 \pm 6.9$	$15.1 \pm 5.8$
$N_{peak}$	$10.9 \pm 6.6$	$2.5 \pm 1.3$	$2.4 \pm 2.2$
$\mathcal{A}_{CP}$		$-0.09 \pm 0.20$	$-0.33 \pm 0.34$
$\mathcal{R}_{CP}$		$1.77 \pm 0.37$	$0.76 \pm 0.29$

Table 1: Results from the fits. For each  $D^0$  mode class, we give the event yield, the peaking background contribution,  $\mathcal{A}_{CP}$  and  $\mathcal{R}_{CP}$ . The uncertainties are statistical only.

The fit stability and accuracy have been studied by performing 1000 simulated experiments at

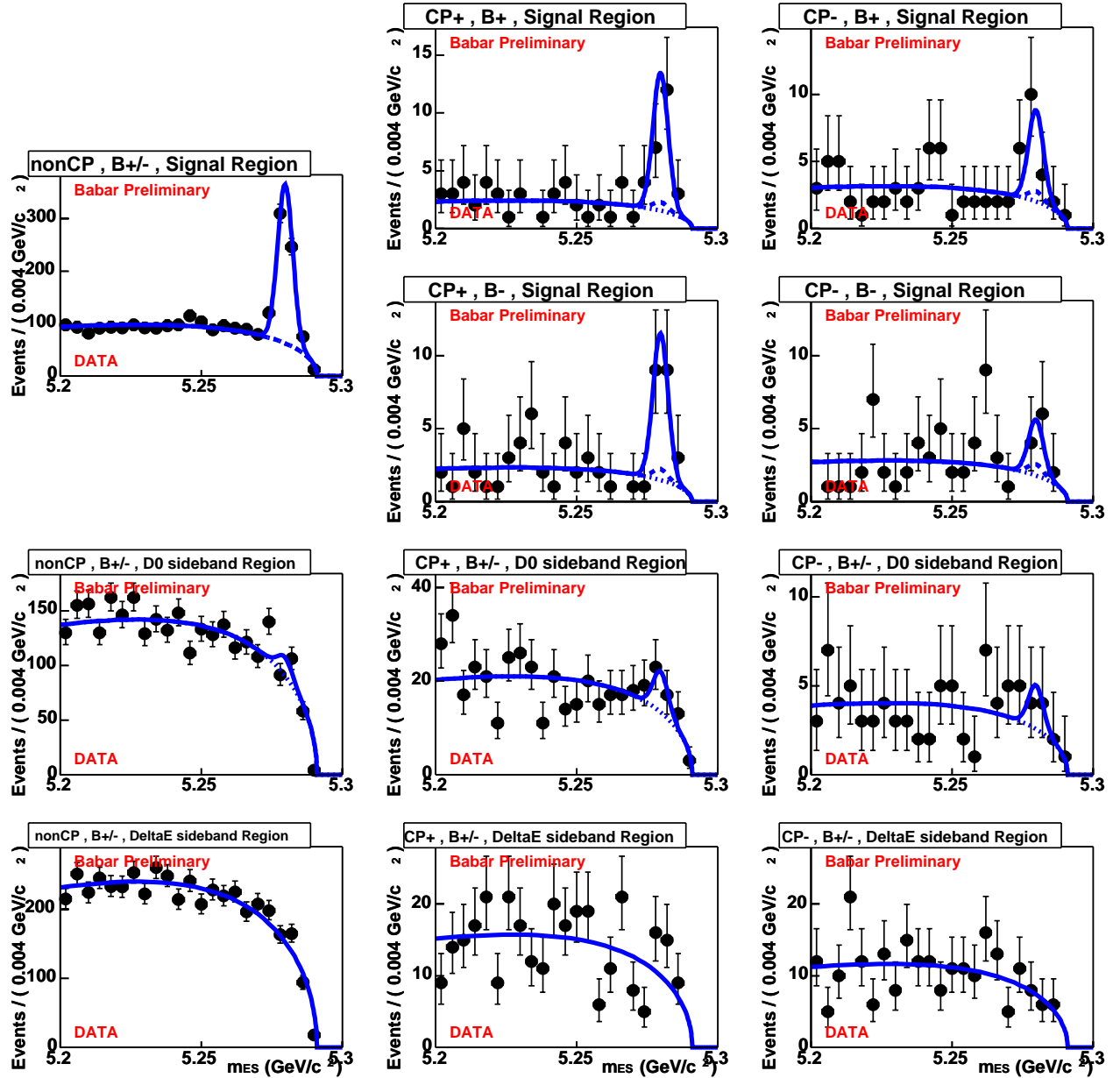


Figure 1: The simultaneous fit. The  $m_{ES}$  distributions are shown for the non-CP modes in the first column, CP<sup>+</sup> modes in the second column and CP<sup>-</sup> in the third. The fits in the signal region are shown in the top two rows, fits of the peaking background in the  $m_{D^0}$  sideband are in the third row and the fits of the background in the  $\Delta E$  sideband are in the fourth. For the CP modes in the signal region, B<sup>+</sup> and B<sup>-</sup> distributions are shown separately in the first and second rows.

the optimum found by the fit in the parameter space. The value of the likelihood function in the fit falls well within the range observed with the simulated experiments.

The yields we observe for the non- $CP$  modes are compatible with our previous measurements of the  $B^- \rightarrow D^0 K^{*-}$  branching ratio [4]. The statistical significance of the  $CP+$  ( $CP-$ ) yields are 6.8 (2.9) standard deviations. It should be noted that the measured  $\mathcal{A}_{CP-}$  could differ from the physical quantity, as background under the  $\phi$  and  $\omega$  resonances with odd and even  $CP$  could be present. These possible interference effects are accounted for in the systematics.

## 6 SYSTEMATIC STUDIES

### 6.1 $CP$ -asymmetries

Although most systematic errors cancel in the asymmetries, three effects must be considered. An asymmetry inherent to the detector or analysis may exist. After running the analysis code on a high statistics  $B^- \rightarrow D^0 \pi^-$  sample (with  $K^*$  cuts removed), the final selection shows an asymmetry of  $(-1.9 \pm 0.8)\%$ . We quote a systematic uncertainty of  $\pm 2.7\%$ .

The second substantial systematic effect is that due to a possible  $CP$ -asymmetry in the peaking background. Although there is no physics ansatz that requires the peaking background to be asymmetric, it cannot be excluded. To get an estimate, we remark that if there is an asymmetry  $\mathcal{A}_{peak}$ , a systematic error on  $\mathcal{A}_{CP}$  is given by  $\mathcal{A}_{peak} \times \frac{b}{c}$ , where  $b$  is the contribution of the peaking background and  $c$  the signal yield. Assuming conservatively  $\mathcal{A}_{peak} \leq 50\%$ , we obtain systematic errors of  $\pm 3.5\%$  and  $\pm 8.0\%$  on  $\mathcal{A}_{CP+}$  and  $\mathcal{A}_{CP-}$  respectively.

Finally a systematic correction must be applied to  $\mathcal{A}_{CP-}$  which stems from the background under the  $\phi$  and  $\omega$  resonances. Looking at the  $D^0 \rightarrow K^- K^+ K_S^0$  Dalitz plot [14] we see a contribution of the  $a_0(980)$  under the  $\phi$ . The  $a_0(980)$  is a  $0^{++}$  state which induces a  $CP+$  pollution. We crudely estimate a bias on  $\mathcal{A}_{CP-}$  with a linear dependance on the difference of the measured asymmetries,  $\delta\mathcal{A}_{\mathcal{A}_{CP-}} = 0.15 \pm 0.10 \cdot (\mathcal{A}_{CP-} - \mathcal{A}_{CP+})$  which we quote as a separate systematic uncertainty.

### 6.2 $\mathcal{R}_{CP}$

$\mathcal{R}_{CP}$  are ratios of rates of processes differing by the final state of the  $D^0$ . We have to consider the uncertainties affecting the selection algorithms for the differing  $D$  channels. They bring small correction factors which account for the difference between the actual detector response and the simulation model. The main effects stem from the approximate modeling of the tracking efficiency (1.2 % per track), the  $K_S^0$  reconstruction efficiency for  $CP-$  modes of the  $D^0$  (2.0 % per  $K_S^0$ ), the  $\pi^0$  reconstruction efficiency for the  $K_S^0 \pi^0$  channel (3 %) and the efficiency and misidentification probabilities from the particle identification (2 % per track). A substantial effect is the uncertainty on the measured branching ratios [9]. We find 4.8 % and 7.5 % for the systematic uncertainties on the selection of the  $D^0$  to  $CP+$  and  $CP-$  channels and 4.0 % for  $D^0$  to non- $CP$  channels. Altogether, we find systematic uncertainties on the relative efficiencies to be 6.2 % and 8.5 % on  $\mathcal{R}_{CP+}$  and  $\mathcal{R}_{CP-}$  respectively. Here also we quote as a separate systematic uncertainty, a possible bias due to structure under the  $\phi$  and  $\omega$  resonances. We conservatively estimate this bias to lie between  $-18$  and  $-5\%$  using the  $D^0 \rightarrow K^- K^+ K_S^0$  Dalitz plot [14].

## 7 PHYSICS RESULTS

We quote the final results:

$$\begin{aligned}
 \mathcal{A}_{CP+} &= -0.09 \pm 0.20(stat.) \pm 0.06(syst.) \\
 \mathcal{A}_{CP-} &= -0.33 \pm 0.34(stat.) \pm 0.10(syst.) (+0.15 \pm 0.10) \cdot (\mathcal{A}_{CP-} - \mathcal{A}_{CP+}) (bias) \\
 \mathcal{R}_{CP+} &= +1.77 \pm 0.37(stat.) \pm 0.12(syst.) \\
 \mathcal{R}_{CP-} &= +0.76 \pm 0.29(stat.) \pm 0.06(syst.) \pm_{0.14}^{0.04} (bias)
 \end{aligned}$$

For the  $CP-$  measurements, the third uncertainty reflects a possible bias due to interference effects in the final states with  $\phi$  and  $\omega$  resonances.

These can be compared with the preliminary results by the Belle collaboration [6] using 95.8  $B\bar{B}$  pairs:  $\mathcal{A}_{CP+} = -0.02 \pm 0.33 \pm 0.07$ ;  $\mathcal{A}_{CP-} = +0.19 \pm 0.50 \pm 0.04$ . The results are in agreement at the one standard deviation level. As expected our statistical errors are reduced. We quote much larger systematic uncertainties because we account for a possibly high  $CP$ -asymmetry in the background and for structures under the  $\phi$  and  $\omega$  resonances whereas reference [6] does not.

We use equation (3) to derive  $r_B^2 = 0.23 \pm 0.24$ . Although the central value is large (it translates to  $r_B=0.47$ ), a null value is within one-standard deviation.

## 8 SUMMARY

In summary, we present preliminary observations of the decays of charged B mesons to a  $K^*$  and a  $D^0$  where the latter particle is seen in final states of even and odd  $CP$ . We express the results in terms of  $\mathcal{R}_{CP}$  and  $\mathcal{A}_{CP}$ . With more statistics, these quantities will constrain  $r_B$ , the ratio of amplitudes defined in equations (3 and 4) and the angle  $\gamma$  of the unitary triangle by application of the Gronau-London-Wyler method.

## 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] Charge conjugate channels are implied throughout the paper.
- [2] M. Gronau and D. Wyler, Phys. Lett. B **265**, 172 (1991).  
M. Gronau and D. London., Phys. Lett. B **253**, 483 (1991).  
I. Dunietz, Phys. Lett. B **270**, 75 (1991).  
I. Dunietz, Z. Phys. C **56**, 129 (1992).  
D. Atwood, I. Dunietz and A. Soni, Phys. Rev. D **63**, 036005 (2001) [arXiv:hep-ph/0008090].  
D. Atwood and A. Soni, Phys. Rev. D **68**, 033003 (2003) [arXiv:hep-ph/0304085].  
A. Giri, Y. Grossman, A. Soffer and J. Zupan, Phys. Rev. D **68**, 054018 (2003) [arXiv:hep-ph/0303187].
- [3] M. Gronau, Phys. Rev. D **58**, 037301 (1998).
- [4] The BABAR Collaboration, B. Aubert *et al.*, Phys. Rev. D **69**, 051101 (2004).
- [5] The CLEO Collaboration, R. Mahapatra *et al.*, Phys. Rev. Lett. **88**, 101803 (2002).
- [6] The Belle Collaboration, K. Abe *et al.*, [arXiv:hep-ex/0307074], submitted to the EPS and Lepton Photon conferences in 2003.
- [7] The BABAR Collaboration, B. Aubert *et al.*, Nucl. Instr. Meth. A **479**, 1 (2002).
- [8] GEANT4 Collaboratiom, S. Agostinelli *et al.*, Nucl. Instr. Meth. A **506**, 250 (2003).
- [9] Particle Data Group, S. Eidelman *et al.*, Phys. Lett. B **592**, 1 (2004).
- [10] The BABAR Collaboration, B. Aubert *et al.*, Phys. Rev. D **69**, 032004 (2004).
- [11] R. A. Fisher “The use of multiple measurements in taxonomic problems”, Annals Eugen. **7**, 179 (1936)
- [12] The BABAR Collaboration, B. Aubert *et al.*, Phys. Rev. Lett. **89**, 281802 (2002).
- [13] The ARGUS collaboration H. Albrecht *et al.*, Phys. Lett. B **185**, 218, (1987); *ibid.* **241**, 278, (1990).
- [14] The BABAR Collaboration, paper submitted to this Conference. **I hope ....** BAD 954 “Dalitz plot analysis of  $D^0 \rightarrow K_S^0 K^+ K^-$ ”.