arXiv:0804.4412v1[hep-ex]
BABAR-PUB-08/001
SLAC-PUB-13133
May 2008

Angular Distributions in the Decays $B \to K^{*}\ell^{+}\ell^{-}$

B. Aubert,[1] M. Bona,[1] Y. Karyotakis,[1] J. P. Lees,[1] V. Poireau,[1] X. Prudent,[1] V. Tisserand,[1] A. Zghiche,[1] J. Garra Tico,[2] E. Grauges,[2] L. Lopez,[3] A. Palano,[3] M. Pappagallo,[3] G. Eigen,[4] B. Stugu,[4] L. Sun,[4] G. S. Abrams,[5] M. Battaglia,[5] D. N. Brown,[5] J. Button-Shafer,[5] R. N. Cahn,[5] R. G. Jacobsen,[5] J. A. Kadyk,[5] L. T. Kerth,[5] Yu. G. Kolomensky,[5] G. Kukartsev,[5] G. Lynch,[5] I. L. Osipenkov,[5] M. T. Ronan,[5,*] K. Tackmann,[5] T. Tanabe,[5] W. A. Wenzel,[5] C. M. Hawkes,[6] N. Soni,[6] A. T. Watson,[6] H. Koch,[7] T. Schroeder,[7] D. Walker,[8] D. J. Asgeirsson,[9] T. Cuhadar-Donszelmann,[9] B. G. Fulsom,[9] C. Hearty,[9] T. S. Mattison,[9] J. A. McKenna,[9] M. Barrett,[10] A. Khan,[10] M. Saleem,[10] L. Teodorescu,[10] V. E. Blinov,[11] A. D. Bukin,[11] A. R. Buzykaev,[11] V. P. Druzhinin,[11] V. B. Golubev,[11] A. P. Onuchin,[11] S. I. Serednyakov,[11] Yu. I. Skovpen,[11] E. P. Solodov,[11] K. Yu. Todyshev,[11] M. Bondioli,[12] S. Curry,[12] I. Eschrich,[12] D. Kirkby,[12] A. J. Lankford,[12] P. Lund,[12] M. Mandelkern,[12] E. C. Martin,[12] D. P. Stoker,[12] S. Abachi,[13] C. Buchanan,[13] J. W. Gary,[14] F. Liu,[14] O. Long,[14] B. C. Shen,[14,*] G. M. Vitug,[14] Z. Yasin,[14] L. Zhang,[14] V. Sharma,[15] C. Campagnari,[16] T. M. Hong,[16] D. Kovalskyi,[16] M. A. Mazur,[16] J. D. Richman,[16] T. W. Beck,[17] A. M. Eisner,[17] C. J. Flacco,[17] C. A. Heusch,[17] J. Kroseberg,[17] W. S. Lockman,[17] T. Schalk,[17] B. A. Schumm,[17] A. Seiden,[17] L. Wang,[17] M. G. Wilson,[17] L. O. Winstrom,[17] C. H. Cheng,[18] D. A. Doll,[18] B. Echenard,[18] F. Fang,[18] D. G. Hitlin,[18] I. Narsky,[18] T. Piatenko,[18] F. C. Porter,[18] R. Andreassen,[19] G. Mancinelli,[19] B. T. Meadows,[19] K. Mishra,[19] M. D. Sokoloff,[19] F. Blanc,[20] P. C. Bloom,[20] W. T. Ford,[20] J. F. Hirschauer,[20] A. Kreisel,[20] M. Nagel,[20] U. Nauenberg,[20] A. Olivas,[20] J. G. Smith,[20] K. A. Ulmer,[20] S. R. Wagner,[20] R. Ayad,[21,†] A. M. Gabareen,[21] A. Soffer,[21,‡] W. H. Toki,[21] R. J. Wilson,[21] D. D. Altenburg,[22] E. Feltresi,[22] A. Hauke,[22] H. Jasper,[22] M. Karbach,[22] J. Merkel,[22] A. Petzold,[22] B. Spaan,[22] K. Wacker,[22] V. Klose,[23] M. J. Kobel,[23] H. M. Lacker,[23] W. F. Mader,[23] R. Nogowski,[23] J. Schubert,[23] K. R. Schubert,[23] R. Schwierz,[23] J. E. Sundermann,[23] A. Volk,[23] D. Bernard,[24] G. R. Bonneaud,[24] E. Latour,[24] Ch. Thiebaux,[24] M. Verderi,[24] P. J. Clark,[25] W. Gradl,[25] S. Playfer,[25] A. I. Robertson,[25] J. E. Watson,[25] M. Andreotti,[26] D. Bettoni,[26] C. Bozzi,[26] R. Calabrese,[26] A. Cecchi,[26] G. Cibinetto,[26] P. Franchini,[26] E. Luppi,[26] M. Negrini,[26] A. Petrella,[26] L. Piemontese,[26] E. Prencipe,[26] V. Santoro,[26] F. Anulli,[27] R. Baldini-Ferroli,[27] A. Calcaterra,[27] R. de Sangro,[27] G. Finocchiaro,[27] S. Pacetti,[27] P. Patteri,[27] I. M. Peruzzi,[27,§] M. Piccolo,[27] M. Rama,[27] A. Zallo,[27] A. Buzzo,[28] R. Contri,[28] M. Lo Vetere,[28] M. M. Macri,[28] M. R. Monge,[28] S. Passaggio,[28] C. Patrignani,[28] E. Robutti,[28] A. Santroni,[28] S. Tosi,[28] K. S. Chaisanguanthum,[29] M. Morii,[29] R. S. Dubitzky,[30] J. Marks,[30] S. Schenk,[30] U. Uwer,[30] D. J. Bard,[31] P. D. Dauncey,[31] J. A. Nash,[31] W. Panduro Vazquez,[31] M. Tibbetts,[31] P. K. Behera,[32] X. Chai,[32] M. J. Charles,[32] U. Mallik,[32] J. Cochran,[33] H. B. Crawley,[33] L. Dong,[33] W. T. Meyer,[33] S. Prell,[33] E. I. Rosenberg,[33] A. E. Rubin,[33] Y. Y. Gao,[34] A. V. Gritsan,[34] Z. J. Guo,[34] C. K. Lae,[34] A. G. Denig,[35] M. Fritsch,[35] G. Schott,[35] N. Arnaud,[36] J. Béquilleux,[36] A. D'Orazio,[36] M. Davier,[36] J. Firmino da Costa,[36] G. Grosdidier,[36] A. Höcker,[36] V. Lepeltier,[36] F. Le Diberder,[36] A. M. Lutz,[36] S. Pruvot,[36] P. Roudeau,[36] M. H. Schune,[36] J. Serrano,[36] V. Sordini,[36] A. Stocchi,[36] W. F. Wang,[36] G. Wormser,[36] D. J. Lange,[37] D. M. Wright,[37] I. Bingham,[38] J. P. Burke,[38] C. A. Chavez,[38] J. R. Fry,[38] E. Gabathuler,[38] R. Gamet,[38] D. E. Hutchcroft,[38] D. J. Payne,[38] C. Touramanis,[38] A. J. Bevan,[39] K. A. George,[39] F. Di Lodovico,[39] R. Sacco,[39] M. Sigamani,[39] G. Cowan,[40] H. U. Flaecher,[40] D. A. Hopkins,[40] S. Paramesvaran,[40] F. Salvatore,[40] A. C. Wren,[40] D. N. Brown,[41] C. L. Davis,[41] K. E. Alwyn,[42] N. R. Barlow,[42] R. J. Barlow,[42] Y. M. Chia,[42] C. L. Edgar,[42] G. D. Lafferty,[42] T. J. West,[42] J. I. Yi,[42] J. Anderson,[43] C. Chen,[43] A. Jawahery,[43] D. A. Roberts,[43] G. Simi,[43] J. M. Tuggle,[43] C. Dallapiccola,[44] S. S. Hertzbach,[44] X. Li,[44] E. Salvati,[44] S. Saremi,[44] R. Cowan,[45] D. Dujmic,[45] P. H. Fisher,[45] K. Koeneke,[45] G. Sciolla,[45] M. Spitznagel,[45] F. Taylor,[45] R. K. Yamamoto,[45] M. Zhao,[45] S. E. Mclachlin,[46,*] P. M. Patel,[46] S. H. Robertson,[46] A. Lazzaro,[47] V. Lombardo,[47] F. Palombo,[47] J. M. Bauer,[48] L. Cremaldi,[48] V. Eschenburg,[48] R. Godang,[48] R. Kroeger,[48] D. A. Sanders,[48] D. J. Summers,[48] H. W. Zhao,[48] S. Brunet,[49] D. Côté,[49] M. Simard,[49] P. Taras,[49] F. B. Viaud,[49] H. Nicholson,[50] G. De Nardo,[51] L. Lista,[51] D. Monorchio,[51] C. Sciacca,[51] M. A. Baak,[52] G. Raven,[52] H. L. Snoek,[52] C. P. Jessop,[53] K. J. Knoepfel,[53] J. M. LoSecco,[53] G. Benelli,[54] L. A. Corwin,[54] K. Honscheid,[54] H. Kagan,[54] R. Kass,[54] J. P. Morris,[54] A. M. Rahimi,[54] J. J. Regensburger,[54] S. J. Sekula,[54] Q. K. Wong,[54] N. L. Blount,[55] J. Brau,[55] R. Frey,[55] O. Igonkina,[55] J. A. Kolb,[55] M. Lu,[55] R. Rahmat,[55] N. B. Sinev,[55] D. Strom,[55] J. Strube,[55] E. Torrence,[55]

Submitted to Physical Review Letters

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

G. Castelli,[56] N. Gagliardi,[56] A. Gaz,[56] M. Margoni,[56] M. Morandin,[56] M. Posocco,[56] M. Rotondo,[56] F. Simonetto,[56] R. Stroili,[56] C. Voci,[56] P. del Amo Sanchez,[57] E. Ben-Haim,[57] H. Briand,[57] G. Calderini,[57] J. Chauveau,[57] P. David,[57] L. Del Buono,[57] O. Hamon,[57] Ph. Leruste,[57] J. Ocariz,[57] A. Perez,[57] J. Prendki,[57] L. Gladney,[58] M. Biasini,[59] R. Covarelli,[59] E. Manoni,[59] C. Angelini,[60] G. Batignani,[60] S. Bettarini,[60] M. Carpinelli,[60, ¶] A. Cervelli,[60] F. Forti,[60] M. A. Giorgi,[60] A. Lusiani,[60] G. Marchiori,[60] M. Morganti,[60] N. Neri,[60] E. Paoloni,[60] G. Rizzo,[60] J. J. Walsh,[60] J. Biesiada,[61] Y. P. Lau,[61] D. Lopes Pegna,[61] C. Lu,[61] J. Olsen,[61] A. J. S. Smith,[61] A. V. Telnov,[61] E. Baracchini,[62] G. Cavoto,[62] D. del Re,[62] E. Di Marco,[62] R. Faccini,[62] F. Ferrarotto,[62] F. Ferroni,[62] M. Gaspero,[62] P. D. Jackson,[62] L. Li Gioi,[62] M. A. Mazzoni,[62] S. Morganti,[62] G. Piredda,[62] F. Polci,[62] F. Renga,[62] C. Voena,[62] M. Ebert,[63] T. Hartmann,[63] H. Schröder,[63] R. Waldi,[63] T. Adye,[64] B. Franek,[64] E. O. Olaiya,[64] W. Roethel,[64] F. F. Wilson,[64] S. Emery,[65] M. Escalier,[65] L. Esteve,[65] A. Gaidot,[65] S. F. Ganzhur,[65] G. Hamel de Monchenault,[65] W. Kozanecki,[65] G. Vasseur,[65] Ch. Yèche,[65] M. Zito,[65] X. R. Chen,[66] H. Liu,[66] W. Park,[66] M. V. Purohit,[66] R. M. White,[66] J. R. Wilson,[66] M. T. Allen,[67] D. Aston,[67] R. Bartoldus,[67] P. Bechtle,[67] J. F. Benitez,[67] R. Cenci,[67] J. P. Coleman,[67] M. R. Convery,[67] J. C. Dingfelder,[67] J. Dorfan,[67] G. P. Dubois-Felsmann,[67] W. Dunwoodie,[67] R. C. Field,[67] S. J. Gowdy,[67] M. T. Graham,[67] P. Grenier,[67] C. Hast,[67] W. R. Innes,[67] J. Kaminski,[67] M. H. Kelsey,[67] H. Kim,[67] P. Kim,[67] M. L. Kocian,[67] D. W. G. S. Leith,[67] S. Li,[67] B. Lindquist,[67] S. Luitz,[67] V. Luth,[67] H. L. Lynch,[67] D. B. MacFarlane,[67] H. Marsiske,[67] R. Messner,[67] D. R. Muller,[67] H. Neal,[67] S. Nelson,[67] C. P. O'Grady,[67] I. Ofte,[67] A. Perazzo,[67] M. Perl,[67] B. N. Ratcliff,[67] A. Roodman,[67] A. A. Salnikov,[67] R. H. Schindler,[67] J. Schwiening,[67] A. Snyder,[67] D. Su,[67] M. K. Sullivan,[67] K. Suzuki,[67] S. K. Swain,[67] J. M. Thompson,[67] J. Va'vra,[67] A. P. Wagner,[67] M. Weaver,[67] C. A. West,[67] W. J. Wisniewski,[67] M. Wittgen,[67] D. H. Wright,[67] H. W. Wulsin,[67] A. K. Yarritu,[67] K. Yi,[67] C. C. Young,[67] V. Ziegler,[67] P. R. Burchat,[68] A. J. Edwards,[68] S. A. Majewski,[68] T. S. Miyashita,[68] B. A. Petersen,[68] L. Wilden,[68] S. Ahmed,[69] M. S. Alam,[69] R. Bula,[69] J. A. Ernst,[69] B. Pan,[69] M. A. Saeed,[69] S. B. Zain,[69] S. M. Spanier,[70] B. J. Wogsland,[70] R. Eckmann,[71] J. L. Ritchie,[71] A. M. Ruland,[71] C. J. Schilling,[71] R. F. Schwitters,[71] B. W. Drummond,[72] J. M. Izen,[72] X. C. Lou,[72] S. Ye,[72] F. Bianchi,[73] D. Gamba,[73] M. Pelliccioni,[73] M. Bomben,[74] L. Bosisio,[74] C. Cartaro,[74] G. Della Ricca,[74] L. Lanceri,[74] L. Vitale,[74] V. Azzolini,[75] N. Lopez-March,[75] F. Martinez-Vidal,[75] D. A. Milanes,[75] A. Oyanguren,[75] J. Albert,[76] Sw. Banerjee,[76] B. Bhuyan,[76] H. H. F. Choi,[76] K. Hamano,[76] R. Kowalewski,[76] M. J. Lewczuk,[76] I. M. Nugent,[76] J. M. Roney,[76] R. J. Sobie,[76] T. J. Gershon,[77] P. F. Harrison,[77] J. Ilic,[77] T. E. Latham,[77] G. B. Mohanty,[77] H. R. Band,[78] X. Chen,[78] S. Dasu,[78] K. T. Flood,[78] Y. Pan,[78] M. Pierini,[78] R. Prepost,[78] C. O. Vuosalo,[78] and S. L. Wu[78]

(The BABAR Collaboration)

[1] *Laboratoire de Physique des Particules, IN2P3/CNRS et Université de Savoie, F-74941 Annecy-Le-Vieux, France*
[2] *Universitat de Barcelona, Facultat de Fisica, Departament ECM, E-08028 Barcelona, Spain*
[3] *Università di Bari, Dipartimento di Fisica and INFN, I-70126 Bari, Italy*
[4] *University of Bergen, Institute of Physics, N-5007 Bergen, Norway*
[5] *Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720, USA*
[6] *University of Birmingham, Birmingham, B15 2TT, United Kingdom*
[7] *Ruhr Universität Bochum, Institut für Experimentalphysik 1, D-44780 Bochum, Germany*
[8] *University of Bristol, Bristol BS8 1TL, United Kingdom*
[9] *University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z1*
[10] *Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom*
[11] *Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia*
[12] *University of California at Irvine, Irvine, California 92697, USA*
[13] *University of California at Los Angeles, Los Angeles, California 90024, USA*
[14] *University of California at Riverside, Riverside, California 92521, USA*
[15] *University of California at San Diego, La Jolla, California 92093, USA*
[16] *University of California at Santa Barbara, Santa Barbara, California 93106, USA*
[17] *University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, California 95064, USA*
[18] *California Institute of Technology, Pasadena, California 91125, USA*
[19] *University of Cincinnati, Cincinnati, Ohio 45221, USA*
[20] *University of Colorado, Boulder, Colorado 80309, USA*
[21] *Colorado State University, Fort Collins, Colorado 80523, USA*
[22] *Universität Dortmund, Institut für Physik, D-44221 Dortmund, Germany*
[23] *Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany*
[24] *Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, F-91128 Palaiseau, France*
[25] *University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom*
[26] *Università di Ferrara, Dipartimento di Fisica and INFN, I-44100 Ferrara, Italy*

[27]Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy
[28]Università di Genova, Dipartimento di Fisica and INFN, I-16146 Genova, Italy
[29]Harvard University, Cambridge, Massachusetts 02138, USA
[30]Universität Heidelberg, Physikalisches Institut, Philosophenweg 12, D-69120 Heidelberg, Germany
[31]Imperial College London, London, SW7 2AZ, United Kingdom
[32]University of Iowa, Iowa City, Iowa 52242, USA
[33]Iowa State University, Ames, Iowa 50011-3160, USA
[34]Johns Hopkins University, Baltimore, Maryland 21218, USA
[35]Universität Karlsruhe, Institut für Experimentelle Kernphysik, D-76021 Karlsruhe, Germany
[36]Laboratoire de l'Accélérateur Linéaire, IN2P3/CNRS et Université Paris-Sud 11, Centre Scientifique d'Orsay, B. P. 34, F-91898 ORSAY Cedex, France
[37]Lawrence Livermore National Laboratory, Livermore, California 94550, USA
[38]University of Liverpool, Liverpool L69 7ZE, United Kingdom
[39]Queen Mary, University of London, E1 4NS, United Kingdom
[40]University of London, Royal Holloway and Bedford New College, Egham, Surrey TW20 0EX, United Kingdom
[41]University of Louisville, Louisville, Kentucky 40292, USA
[42]University of Manchester, Manchester M13 9PL, United Kingdom
[43]University of Maryland, College Park, Maryland 20742, USA
[44]University of Massachusetts, Amherst, Massachusetts 01003, USA
[45]Massachusetts Institute of Technology, Laboratory for Nuclear Science, Cambridge, Massachusetts 02139, USA
[46]McGill University, Montréal, Québec, Canada H3A 2T8
[47]Università di Milano, Dipartimento di Fisica and INFN, I-20133 Milano, Italy
[48]University of Mississippi, University, Mississippi 38677, USA
[49]Université de Montréal, Physique des Particules, Montréal, Québec, Canada H3C 3J7
[50]Mount Holyoke College, South Hadley, Massachusetts 01075, USA
[51]Università di Napoli Federico II, Dipartimento di Scienze Fisiche and INFN, I-80126, Napoli, Italy
[52]NIKHEF, National Institute for Nuclear Physics and High Energy Physics, NL-1009 DB Amsterdam, The Netherlands
[53]University of Notre Dame, Notre Dame, Indiana 46556, USA
[54]Ohio State University, Columbus, Ohio 43210, USA
[55]University of Oregon, Eugene, Oregon 97403, USA
[56]Università di Padova, Dipartimento di Fisica and INFN, I-35131 Padova, Italy
[57]Laboratoire de Physique Nucléaire et de Hautes Energies, IN2P3/CNRS, Université Pierre et Marie Curie-Paris6, Université Denis Diderot-Paris7, F-75252 Paris, France
[58]University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA
[59]Università di Perugia, Dipartimento di Fisica and INFN, I-06100 Perugia, Italy
[60]Università di Pisa, Dipartimento di Fisica, Scuola Normale Superiore and INFN, I-56127 Pisa, Italy
[61]Princeton University, Princeton, New Jersey 08544, USA
[62]Università di Roma La Sapienza, Dipartimento di Fisica and INFN, I-00185 Roma, Italy
[63]Universität Rostock, D-18051 Rostock, Germany
[64]Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingdom
[65]DSM/Dapnia, CEA/Saclay, F-91191 Gif-sur-Yvette, France
[66]University of South Carolina, Columbia, South Carolina 29208, USA
[67]Stanford Linear Accelerator Center, Stanford, California 94309, USA
[68]Stanford University, Stanford, California 94305-4060, USA
[69]State University of New York, Albany, New York 12222, USA
[70]University of Tennessee, Knoxville, Tennessee 37996, USA
[71]University of Texas at Austin, Austin, Texas 78712, USA
[72]University of Texas at Dallas, Richardson, Texas 75083, USA
[73]Università di Torino, Dipartimento di Fisica Sperimentale and INFN, I-10125 Torino, Italy
[74]Università di Trieste, Dipartimento di Fisica and INFN, I-34127 Trieste, Italy
[75]IFIC, Universitat de Valencia-CSIC, E-46071 Valencia, Spain
[76]University of Victoria, Victoria, British Columbia, Canada V8W 3P6
[77]Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom
[78]University of Wisconsin, Madison, Wisconsin 53706, USA

(Dated: April 28, 2008)

We use a sample of 384 million $B\overline{B}$ events collected with the *BABAR* detector at the PEP-II e^+e^- collider to study angular distributions in the rare decays $B \to K^* \ell^+ \ell^-$, where $\ell^+\ell^-$ is either e^+e^- or $\mu^+\mu^-$. For low dilepton invariant masses, $m_{\ell\ell} < 2.5\,\mathrm{GeV}/c^2$, we measure a lepton forward-backward asymmetry $\mathcal{A}_{FB} = 0.24^{+0.18}_{-0.23} \pm 0.05$ and K^* longitudinal polarization $F_L = 0.35 \pm 0.16 \pm 0.04$. For $m_{\ell\ell} > 3.2\,\mathrm{GeV}/c^2$, we measure $\mathcal{A}_{FB} = 0.76^{+0.52}_{-0.32} \pm 0.07$ and $F_L = 0.71^{+0.20}_{-0.22} \pm 0.04$.

PACS numbers: 13.20.He

The decays $B \to K^*\ell^+\ell^-$, where $K^* \to K\pi$ and $\ell^+\ell^-$ is either an e^+e^- or $\mu^+\mu^-$ pair, arise from flavor-changing neutral currents (FCNC), which are forbidden at tree level in the Standard Model (SM). The lowest-order SM processes contributing to these decays are the photon or Z penguin and the W^+W^- box diagrams shown in Fig. 1. The amplitudes can be expressed in terms of effective Wilson coefficients for the electromagnetic penguin, C_7, and the vector and axial-vector electroweak contributions, C_9 and C_{10} respectively, arising from the interference of the Z penguin and W^+W^- box diagrams [1]. The angular distributions in these decays as a function of dilepton mass squared $q^2 = m^2_{\ell^+\ell^-}$ are sensitive to many possible new physics contributions [2].

We describe measurements of the distribution of the angle θ_K between the K and the B directions in the K^* rest frame. A fit to $\cos\theta_K$ of the form [3]

$$\frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K) \tag{1}$$

determines F_L, the K^* longitudinal polarization fraction. We also describe measurements of the distribution of the angle θ_ℓ between the $\ell^+(\ell^-)$ and the $B(\overline{B})$ direction in the $\ell^+\ell^-$ rest frame. A fit to $\cos\theta_\ell$ of the form [3]

$$\frac{3}{4}F_L(1-\cos^2\theta_\ell)+\frac{3}{8}(1-F_L)(1+\cos^2\theta_\ell)+\mathcal{A}_{FB}\cos\theta_\ell \tag{2}$$

determines $\mathcal{A}_{FB}$, the lepton forward-backward asymmetry. These measurements are done in a low q^2 region between $4m^2_\mu$ and $6.25\,\mathrm{GeV}^2/c^4$, and in a high q^2 region above $10.24\,\mathrm{GeV}^2/c^4$. We remove the J/ψ and $\psi(2S)$ resonances by vetoing events in the regions $q^2 = 6.25$-$10.24\,\mathrm{GeV}^2/c^4$ and $q^2 = 12.96$-$14.06\,\mathrm{GeV}^2/c^4$ respectively.

The SM predicts a distinctive variation of $\mathcal{A}_{FB}$ arising from the interference between the different amplitudes. The expected SM dependence of A_{FB} and F_L on q^2 along with variations due to opposite-sign Wilson coefficients are shown in Fig. 3. At low q^2, where C_7 dominates, $\mathcal{A}_{FB}$ is expected to be small with a zero-crossing point at $q^2 \sim 4\,\mathrm{GeV}^2/c^4$ [4, 5]. There is an experimental constraint on the magnitude of C_7 coming from the branching fraction for $b \to s\gamma$ [6], which corresponds to the limit $q^2 \to 0$. However, a reversal of the sign of C_7 is allowed. At high q^2, the product of C_9 and C_{10} is expected to give a large positive asymmetry. Right-handed weak currents have an opposite-sign C_9C_{10} which would give a negative $\mathcal{A}_{FB}$ at high q^2. Contributions from non-SM processes can change the magnitudes and relative signs of C_7, C_9 and C_{10}, and may introduce complex phases between them [3, 7].

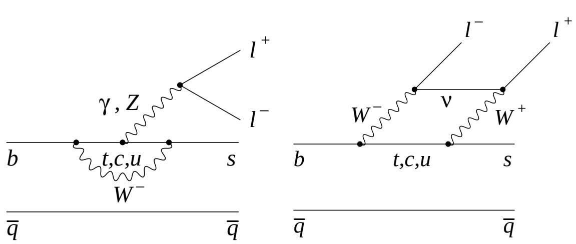

FIG. 1: Lowest-order Feynman diagrams for $b \to s\ell^+\ell^-$.

We reconstruct signal events in six separate flavor-specific final states containing an e^+e^- or $\mu^+\mu^-$ pair, and a $K^*(892)$ candidate reconstructed as $K^+\pi^-$, $K^+\pi^0$ or $K^0_S\pi^+$ (or their charge conjugates). To understand combinatorial backgrounds we also reconstruct samples containing the same hadronic final states and $e^\pm\mu^\mp$ pairs, where no signal is expected because of lepton flavor conservation. To understand backgrounds from hadrons (h) misidentified as muons, we similarly reconstruct samples containing $h^\pm\mu^\mp$ pairs with no particle identification requirement for the $h^\pm$.

We use a dataset of 384 million $B\overline{B}$ pairs collected at the $\Upsilon(4S)$ resonance with the BABAR detector [8] at the PEP-II asymmetric-energy e^+e^- collider. Tracking is provided by a five-layer silicon vertex tracker and a 40-layer drift chamber in a 1.5 T magnetic field. We identify electrons with a CsI(Tl) electromagnetic calorimeter, and muons using an instrumented magnetic flux return. Electrons (muons) are required to have momenta $p > 0.3(0.7)\,\mathrm{GeV}/c$ in the laboratory frame. We add photons to electrons when they are consistent with bremsstrahlung, and do not use electrons that arise from photon conversions to low-mass e^+e^- pairs. We identify K^+ using a detector of internally reflected Cherenkov light, as well as ionization energy loss information as measured in the tracking system. Charged tracks other than identified e, μ and K candidates are treated as pions. Neutral $K^0_S \to \pi^+\pi^-$ candidates are required to have an invariant mass consistent with the nominal K^0 mass [9], and a flight distance from the e^+e^- interaction point which is more than three times its uncertainty. Neutral pion candidates are formed from two photons with $E_\gamma > 50\,\mathrm{MeV}$, and an invariant mass between 115 and $155\,\mathrm{MeV}/c^2$. We require $K^*(892)$ candidates to have an invariant mass $0.82 < M(K\pi) < 0.97\,\mathrm{GeV}/c^2$.

$B \to K^*\ell^+\ell^-$ decays are characterized by the kinematic variables $m_{\mathrm{ES}} = \sqrt{s/4 - p^{*2}_B}$ and $\Delta E = E^*_B - \sqrt{s}/2$, where p^*_B and E^*_B are the B momentum and energy in the center-of-mass (CM) frame, and $\sqrt{s}$ is the total CM energy. We define a fit region $m_{\mathrm{ES}} > 5.2\,\mathrm{GeV}/c^2$, with $-0.07 < \Delta E < 0.04$ ($-0.04 < \Delta E < 0.04$) GeV for e^+e^- ($\mu^+\mu^-$) final states in the low q^2 region, and $-0.08 < \Delta E < 0.05$ ($-0.05 < \Delta E < 0.05$) GeV for high q^2. We use the wider (narrower) ΔE windows to select the $e^\pm\mu^\mp$ ($h^\pm\mu^\mp$) background samples.

The most significant background arises from combinations of leptons from semileptonic B and D decays.

In $B\overline{B}$ events the leptons are kinematically correlated if they come from $B \to D^{(*)}\ell\nu$, $D \to K^{(*)}\ell\nu$. Uncorrelated backgrounds combine leptons from separate B decays or from continuum $e^+e^- \to c\bar{c}$ events. We suppress both these types of combinatorial background through the use of neural networks (NN). For each final state we use four separate NN optimized to suppress either continuum or $B\overline{B}$ backgrounds in either the low or high q^2 regions. Inputs to these NN include event shape variables, vertexing information and missing energy. We simultaneously optimize the NN and ΔE selections across all six final states in each q^2 bin to give the best statistical signal significance in the $m_{\rm ES}$ signal region, $m_{\rm ES} > 5.27\,{\rm GeV}/c^2$.

There is a contribution in the signal region from $B \to D(K^*\pi)\pi$ decays, where both pions are misidentified. The misidentification rates for muons and electrons are 2% and 0.1%, respectively, so this background is only significant in the $\mu^+\mu^-$ final states. These events are vetoed if the invariant mass of the $K^*\pi$ system is in the range 1.84-1.90 $\rm GeV/c^2$.

After all these selections have been applied, the final reconstruction efficiency for signal events varies from 1.5% for $K^+\pi^0\mu^+\mu^-$ in the low q^2 region to 12.6% for $K^+\pi^-e^+e^-$ in the high q^2 region.

For each q^2 region, we combine events from all six final states and perform three successive unbinned maximum likelihood fits. Because of the relatively small number of signal candidates in each q^2 region, a simultaneous fit over three dimensions is not possible and an iterated fitting procedure is required. We initially fit the $m_{\rm ES}$ distribution using events with $m_{\rm ES} > 5.2\,{\rm GeV}/c^2$ to obtain the signal and background yields, N_S and N_B respectively. We use an ARGUS shape [10] with a free shape parameter to describe the combinatorial background in this fit. For the signal, we use a Gaussian shape with a mean $m_{\rm ES} = 5.2791 \pm 0.0001\,{\rm GeV}/c^2$ and $\sigma = 2.60 \pm 0.03\,{\rm MeV}/c^2$, which are determined from a fit to the vetoed charmonium samples. In this and subsequent fits we account for a small contribution from misidentified hadrons by subtracting the $K^*h^\pm\mu^\mp$ events, weighted by the probability for the $h^\pm$ to be misidentified as a muon. We also account in all fits for charmonium events that escape the veto, and for mis-reconstructed signal events.

The second fit is to the cosine of the helicity angle of the K^* decay, $\cos\theta_K$, for events with $m_{\rm ES} > 5.27\,{\rm GeV}/c^2$. In this fit, the only free parameter is F_L, with the normalizations for signal and combinatorial background events taken from the initial $m_{\rm ES}$ fit. We model the $\cos\theta_K$ shape of the combinatorial background using e^+e^- and $\mu^+\mu^-$ events, as well as lepton-flavor violating $e^+\mu^-$ and μ^+e^- events, in the $5.20 < m_{\rm ES} < 5.27\,{\rm GeV}/c^2$ sideband. The signal distribution given in equation (1) is folded with the detector acceptance as a function of $\cos\theta_K$, which is obtained from simulated signal events.

The final fit is to the cosine of the lepton helicity angle, $\cos\theta_\ell$, for events with $m_{\rm ES} > 5.27\,{\rm GeV}/c^2$. The only free parameter in this fit is $\mathcal{A}_{FB}$, with the normalizations for signal and combinatorial background events taken from the initial $m_{\rm ES}$ fit, and the value of F_L fixed from the result of the second fit. We constrain the $\cos\theta_\ell$ shape of the combinatorial background using the same sideband samples as for the $\cos\theta_K$ fit. The correlated leptons from $B \to D^{(*)}\ell\nu$, $D \to K^{(*)}\ell\nu$ give rise to a peak in the combinatorial background at $\cos\theta_\ell > 0.7$ which varies as a function of $m_{\rm ES}$. We consider this variation in our study of systematic errors. The signal distribution given in equation (2) is again folded with the detector acceptance as a function of $\cos\theta_\ell$.

TABLE I: Results for the $B \to J/\psi K^*$ control samples. ΔBF are the differences between the measured branching fractions and the world average value [9]. The previously measured K^* polarization is $F_L = 0.56 \pm 0.01$ [11], and the expected lepton asymmetry $\mathcal{A}_{FB} = 0$.

Mode	ΔBF (10^{-3})	F_L	$\mathcal{A}_{FB}$
$K^+\pi^0\mu^+\mu^-$	$+0.09 \pm 0.12$	0.54 ± 0.03	-0.04 ± 0.05
$K^0_S\pi^+\mu^+\mu^-$	$+0.02 \pm 0.11$	0.55 ± 0.02	$+0.00 \pm 0.05$
$K^+\pi^-\mu^+\mu^-$	-0.03 ± 0.07	0.56 ± 0.02	-0.02 ± 0.02
$K^+\pi^0e^+e^-$	$+0.16 \pm 0.10$	0.54 ± 0.03	$+0.02 \pm 0.03$
$K^0_S\pi^+e^+e^-$	$+0.07 \pm 0.10$	0.55 ± 0.02	-0.02 ± 0.04
$K^+\pi^-e^+e^-$	$+0.02 \pm 0.07$	0.56 ± 0.02	$+0.01 \pm 0.02$

TABLE II: Results for the fits to the $K\ell^+\ell^-$ and $K^*\ell^+\ell^-$ samples. N_S is the number of signal events in the $m_{\rm ES}$ fit. The quoted errors are statistical only.

Decay	q^2	N_S	F_L	$\mathcal{A}_{FB}$
$K\ell^+\ell^-$	low	26.0 ± 5.7		$+0.04^{+0.16}_{-0.24}$
	high	26.5 ± 6.7		$+0.20^{+0.14}_{-0.22}$
$K^*\ell^+\ell^-$	low	27.2 ± 6.3	0.35 ± 0.16	$+0.24^{+0.18}_{-0.23}$
	high	36.6 ± 9.6	$0.71^{+0.20}_{-0.22}$	$+0.76^{+0.52}_{-0.32}$

We test our fits using the large sample of vetoed charmonium events. The branching fractions (BF) and K^* polarization for $B \to J/\psi K^*$ are well known [9, 11], and $\mathcal{A}_{FB}$ is expected to be zero. The results of the fits to the six final states are all consistent with the nominal values (see Table I).

We further test our methodology by performing the $m_{\rm ES}$ and $\cos\theta_\ell$ fits on a sample of $B^+ \to K^+\ell^+\ell^-$ decays. The results are given in Table II and are consistent with $\mathcal{A}_{FB} = 0$, as expected in the SM and most new physics models.

We validate the fit model by performing ensembles of fits to datasets with events drawn from simulated signal and background event samples. The input SM values of F_L and $\mathcal{A}_{FB}$ are reproduced with the expected statistical errors. A few percent of the fits do not converge due to

TABLE III: Systematic errors on the measurements of F_L and $\mathcal{A}_{FB}$ in the $K^*\ell^+\ell^-$ samples.

Source	F_L		$\mathcal{A}_{FB}$	
of Error	low q^2	high q^2	low q^2	high q^2
$m_{\rm ES}$ fit yields	0.001	0.016	0.003	0.002
F_L fit error			0.025	0.022
Background shape	0.011	0.008	0.017	0.021
Signal model	0.036	0.034	0.030	0.038
Fit bias	0.012	0.020	0.023	0.052
Mis-reconstructed signal	0.010	0.010	0.020	0.020
Total	0.041	0.044	0.052	0.074

small signal yields. We have also performed fits using signal events generated with different values of C_7, C_9 and C_{10}, covering the physically allowed ranges of F_L and $\mathcal{A}_{FB}$, and find minimal bias in the fit values of F_L and $\mathcal{A}_{FB}$.

The systematic errors on the fitted values of F_L and $\mathcal{A}_{FB}$ are summarized in Table III. The uncertainties in the fitted signal yields N_S, due to variations in the ARGUS shape in the $m_{\rm ES}$ fits, are propagated into the angular fits. The errors on the fitted F_L values are propagated into the $\mathcal{A}_{FB}$ fits. We vary the combinatorial background shapes by dividing the sideband sample into two disjoint regions in $m_{\rm ES}$. We vary the signal model using simulated events generated with different form factors [5, 12], and with a range of values of C_7, C_9 and C_{10}, to determine an average fit bias. Finally the modeling of mis-reconstructed signal events is constrained by the fits to the charmonium samples (Table I).

The final fits to the $K^*\ell^+\ell^-$ samples are shown in Fig. 2. The results for F_L and $\mathcal{A}_{FB}$ are given in Table II and are shown in Fig. 3. In the low q^2 region, where we expect $\mathcal{A}_{FB} = -0.03 \pm 0.01$ [13] and $F_L = 0.63 \pm 0.03$ [3] from the SM, we measure $\mathcal{A}_{FB} = 0.24^{+0.18}_{-0.23} \pm 0.05$ and $F_L = 0.35 \pm 0.16 \pm 0.04$, where the first error is statistical and the second is systematic. In the high q^2 region, the SM expectation is $\mathcal{A}_{FB} = 0.26 \pm 0.01^{+0.00}_{-0.05}$ (where the first and second errors are due to uncertainties arising from perturbative and non-perturbative sources, respectively) [4, 7] and $F_L = 0.40 \pm 0.03$ [3], and we measure $\mathcal{A}_{FB} = 0.76^{+0.52}_{-0.32} \pm 0.07$ and $F_L = 0.71^{+0.20}_{-0.22} \pm 0.04$. The $\mathcal{A}_{FB}$ results exclude a wrong-sign C_9C_{10} from purely right-handed weak currents at more than 3 standard deviations significance. Our results are consistent with measurements by Belle [14], and replace the earlier *BABAR* results in which only a lower limit on $\mathcal{A}_{FB}$ was set in the low q^2 region [15].

We are grateful for the excellent luminosity and machine conditions provided by our PEP-II colleagues, and for the substantial dedicated effort from the computing organizations that support *BABAR*. The collaborating institutions wish to thank SLAC for its support and

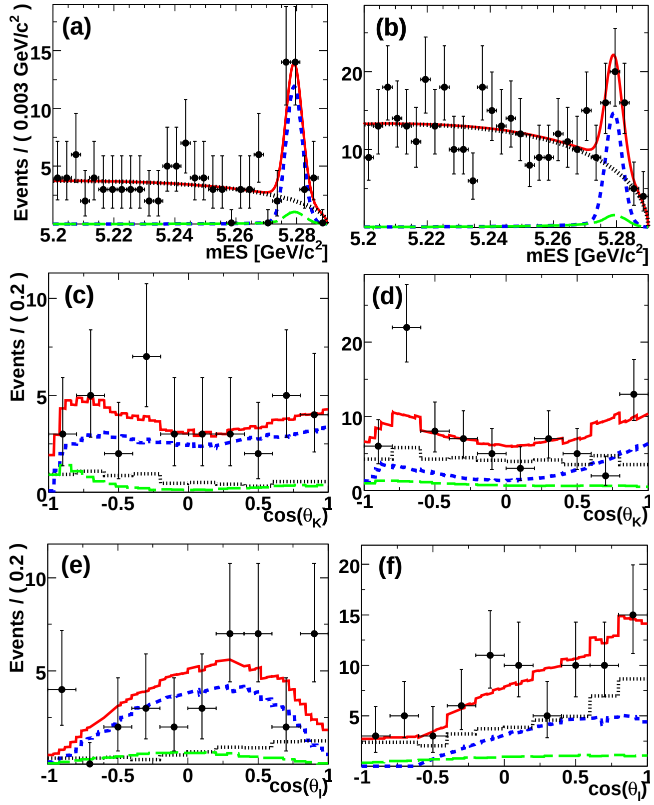

FIG. 2: $K^*\ell^+\ell^-$ fits: (a) low q^2 $m_{\rm ES}$, (b) high q^2 $m_{\rm ES}$, (c) low q^2 $\cos\theta_K$, (d) high q^2 $\cos\theta_K$, (e) low q^2 $\cos\theta_\ell$, (f) high q^2 $\cos\theta_\ell$; with combinatorial (dots) and peaking (long dash) background, signal (short dash) and total (solid) fit distributions superimposed on the data points.

kind hospitality. This work is supported by DOE and NSF (USA), NSERC (Canada), CEA and CNRS-IN2P3 (France), BMBF and DFG (Germany), INFN (Italy), FOM (The Netherlands), NFR (Norway), MES (Russia), MEC (Spain), and STFC (United Kingdom). Individuals have received support from the Marie Curie EIF (European Union) and the A. P. Sloan Foundation.

* Deceased
† Now at Temple University, Philadelphia, Pennsylvania 19122, USA
‡ Now at Tel Aviv University, Tel Aviv, 69978, Israel
§ Also with Università di Perugia, Dipartimento di Fisica, Perugia, Italy
¶ Also with Universita' di Sassari, Sassari, Italy

[1] G. Buchalla, A. J. Buras and M. E. Lautenbacher, Rev. Mod. Phys. **68**, 1125 (1996).

[2] G. Burdman, Phys. Rev. D **52**, 6400 (1995); J. L. Hewett and J. D. Wells, Phys. Rev. D **55**, 5549 (1997); T. Feldmann and J. Matias, JHEP **0301**, 074 (2003); W. J. Li, Y. B. Dai and C. S. Huang, Eur. Phys. J. C **40**, 565

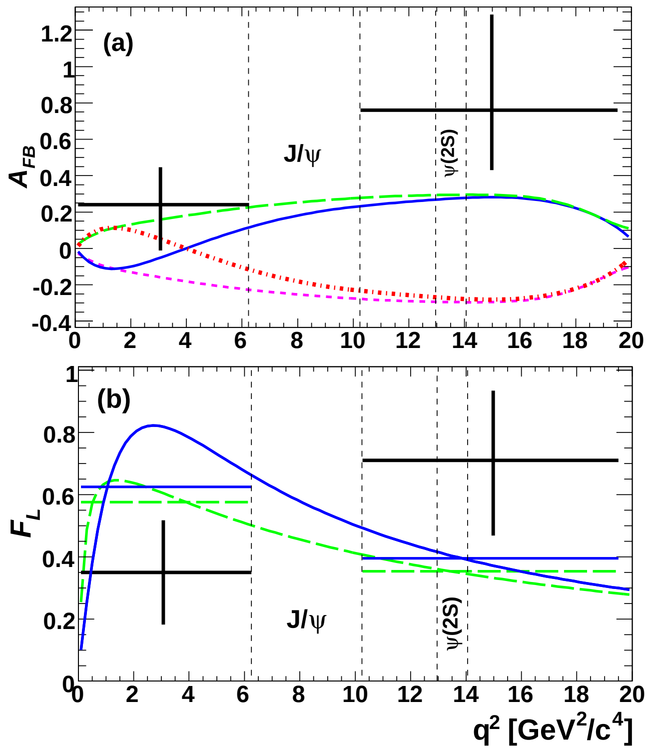

FIG. 3: Plots of our results for (a) $\mathcal{A}_{FB}$ and (b) F_L for the decay $B \to K^* \ell^+ \ell^-$ showing comparisons with SM (solid); $C_7 = -C_7^{SM}$ (long dash); $C_9 C_{10} = -C_9^{SM} C_{10}^{SM}$ (short dash); $C_7 = -C_7^{SM}, C_9 C_{10} = -C_9^{SM} C_{10}^{SM}$ (dash-dot). Statistical and systematic errors are added in quadrature. Expected F_L values integrated over each q^2 region are also shown. The F_L curves with $C_9 C_{10} = -C_9^{SM} C_{10}^{SM}$ are nearly identical to the two curves shown.

(2005); Y. G. Xu, R. M. Wang and Y. D. Yang, Phys. Rev. D **74**, 114019 (2006); P. Colangelo, F. De Fazio, R. Ferrandes and T. N. Pham, Phys. Rev. D **73**, 115006 (2006).

[3] F. Kruger and J. Matias, Phys. Rev. D **71**, 094009 (2005).

[4] A. Ali, P. Ball, L. T. Handoko and G. Hiller, Phys. Rev. D **61**, 074024 (2000).

[5] F. Kruger, L. M. Sehgal, N. Sinha and R. Sinha, Phys. Rev. D **61**, 114028 (2000) [Erratum-ibid. D **63**, 019901 (2001)]; A. Ali, E. Lunghi, C. Greub and G. Hiller, Phys. Rev. D **66**, 034002 (2002); K. S. M. Lee, Z. Ligeti, I. W. Stewart and F. J. Tackmann, Phys. Rev. D **75**, 034016 (2007).

[6] E. Barberio *et al.* [Heavy Flavor Averaging Group (HFAG) Collaboration], arXiv:0704.3575 [hep-ex].

[7] A. Hovhannisyan, W. S. Hou and N. Mahajan, Phys. Rev. D **77**, 014016 (2008).

[8] B. Aubert *et al.* [BABAR Collaboration], Nucl. Instrum. Meth. A **479**, 1 (2002).

[9] W. M. Yao *et al.* [Particle Data Group], J. Phys. G **33** (2006) 1.

[10] H. Albrecht *et al.* [ARGUS Collaboration], Z. Phys. C **48**, 543 (1990).

[11] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. D **76**, 031102 (2007).

[12] P. Ball and R. Zwicky, Phys. Rev. D **71**, 014029 (2005).

[13] T. Huber, T. Hurth and E. Lunghi, arXiv:0712.3009 [hep-ph], submitted to Nucl.Phys.B.

[14] A. Ishikawa *et al.*, Phys. Rev. Lett. **96**, 251801 (2006).

[15] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. D **73**, 092001 (2006).