Measurements of the Branching Fractions of Exclusive Charmless B Meson Decays with eta-prime or omega Mesons

The *BABAR* Collaboration

Measurements of the branching fractions of exclusive charmless B meson decays with η' or ω mesons

The *BABAR* Collaboration

B. Aubert,[1] D. Boutigny,[1] J.-M. Gaillard,[1] A. Hicheur,[1] Y. Karyotakis,[1] J. P. Lees,[1] P. Robbe,[1] V. Tisserand,[1]
A. Palano,[2] G. P. Chen,[3] J. C. Chen,[3] N. D. Qi,[3] G. Rong,[3] P. Wang,[3] Y. S. Zhu,[3] G. Eigen,[4] P. L. Reinertsen,[4]
B. Stugu,[4] B. Abbott,[5] G. S. Abrams,[5] A. W. Borgland,[5] A. B. Breon,[5] D. N. Brown,[5] J. Button-Shafer,[5]
R. N. Cahn,[5] A. R. Clark,[5] M. S. Gill,[5] A. Gritsan,[5] Y. Groysman,[5] R. G. Jacobsen,[5] R. W. Kadel,[5] J. Kadyk,[5]
L. T. Kerth,[5] S. Kluth,[5] Yu. G. Kolomensky,[5] J. F. Kral,[5] C. LeClerc,[5] M. E. Levi,[5] T. Liu,[5] G. Lynch,[5]
A. B. Meyer,[5] M. Momayezi,[5] P. J. Oddone,[5] A. Perazzo,[5] M. Pripstein,[5] N. A. Roe,[5] A. Romosan,[5] M. T. Ronan,[5]
V. G. Shelkov,[5] A. V. Telnov,[5] W. A. Wenzel,[5] P. G. Bright-Thomas,[6] T. J. Harrison,[6] C. M. Hawkes,[6]
D. J. Knowles,[6] S. W. O'Neale,[6] R. C. Penny,[6] A. T. Watson,[6] N. K. Watson,[6] T. Deppermann,[7] K. Goetzen,[7]
H. Koch,[7] J. Krug,[7] M. Kunze,[7] B. Lewandowski,[7] K. Peters,[7] H. Schmuecker,[7] M. Steinke,[7] J. C. Andress,[8]
N. R. Barlow,[8] W. Bhimji,[8] N. Chevalier,[8] P. J. Clark,[8] W. N. Cottingham,[8] N. De Groot,[8] N. Dyce,[8] B. Foster,[8]
J. D. McFall,[8] D. Wallom,[8] F. F. Wilson,[8] K. Abe,[9] C. Hearty,[9] T. S. Mattison,[9] J. A. McKenna,[9] D. Thiessen,[9]
S. Jolly,[10] A. K. McKemey,[10] J. Tinslay,[10] V. E. Blinov,[11] A. D. Bukin,[11] D. A. Bukin,[11] A. R. Buzykaev,[11]
V. B. Golubev,[11] V. N. Ivanchenko,[11] A. A. Korol,[11] E. A. Kravchenko,[11] A. P. Onuchin,[11] A. A. Salnikov,[11]
S. I. Serednyakov,[11] Yu. I. Skovpen,[11] V. I. Telnov,[11] A. N. Yushkov,[11] D. Best,[12] A. J. Lankford,[12]
M. Mandelkern,[12] S. McMahon,[12] D. P. Stoker,[12] A. Ahsan,[13] K. Arisaka,[13] C. Buchanan,[13] S. Chun,[13]
J. G. Branson,[14] D. B. MacFarlane,[14] S. Prell,[14] Sh. Rahatlou,[14] G. Raven,[14] V. Sharma,[14] C. Campagnari,[15]
B. Dahmes,[15] P. A. Hart,[15] N. Kuznetsova,[15] S. L. Levy,[15] O. Long,[15] A. Lu,[15] J. D. Richman,[15] W. Verkerke,[15]
M. Witherell,[15] S. Yellin,[15] J. Beringer,[16] D. E. Dorfan,[16] A. M. Eisner,[16] A. Frey,[16] A. A. Grillo,[16] M. Grothe,[16]
C. A. Heusch,[16] R. P. Johnson,[16] W. Kroeger,[16] W. S. Lockman,[16] T. Pulliam,[16] H. Sadrozinski,[16] T. Schalk,[16]
R. E. Schmitz,[16] B. A. Schumm,[16] A. Seiden,[16] M. Turri,[16] W. Walkowiak,[16] D. C. Williams,[16] M. G. Wilson,[16]
E. Chen,[17] G. P. Dubois-Felsmann,[17] A. Dvoretskii,[17] D. G. Hitlin,[17] S. Metzler,[17] J. Oyang,[17] F. C. Porter,[17]
A. Ryd,[17] A. Samuel,[17] M. Weaver,[17] S. Yang,[17] R. Y. Zhu,[17] S. Devmal,[18] T. L. Geld,[18] S. Jayatilleke,[18]
G. Mancinelli,[18] B. T. Meadows,[18] M. D. Sokoloff,[18] T. Barillari,[19] P. Bloom,[19] M. O. Dima,[19] S. Fahey,[19]
W. T. Ford,[19] D. R. Johnson,[19] U. Nauenberg,[19] A. Olivas,[19] H. Park,[19] P. Rankin,[19] J. Roy,[19] S. Sen,[19]
J. G. Smith,[19] W. C. van Hoek,[19] D. L. Wagner,[19] J. Blouw,[20] J. L. Harton,[20] M. Krishnamurthy,[20] A. Soffer,[20]
W. H. Toki,[20] R. J. Wilson,[20] J. Zhang,[20] T. Brandt,[21] J. Brose,[21] T. Colberg,[21] G. Dahlinger,[21] M. Dickopp,[21]
R. S. Dubitzky,[21] E. Maly,[21] R. Müller-Pfefferkorn,[21] S. Otto,[21] K. R. Schubert,[21] R. Schwierz,[21] B. Spaan,[21]
L. Wilden,[21] L. Behr,[22] D. Bernard,[22] G. R. Bonneaud,[22] F. Brochard,[22] J. Cohen-Tanugi,[22] S. Ferrag,[22]
E. Roussot,[22] S. T'Jampens,[22] C. Thiebaux,[22] G. Vasileiadis,[22] M. Verderi,[22] A. Anjomshoaa,[23] R. Bernet,[23]
A. Khan,[23] F. Muheim,[23] S. Playfer,[23] J. E. Swain,[23] M. Falbo,[24] C. Borean,[25] C. Bozzi,[25] S. Dittongo,[25]
M. Folegani,[25] L. Piemontese,[25] E. Treadwell,[26] F. Anulli,[27, *] R. Baldini-Ferroli,[27] A. Calcaterra,[27] R. de
Sangro,[27] D. Falciai,[27] G. Finocchiaro,[27] P. Patteri,[27] I. M. Peruzzi,[27, *] M. Piccolo,[27] Y. Xie,[27] A. Zallo,[27]
S. Bagnasco,[28] A. Buzzo,[28] R. Contri,[28] G. Crosetti,[28] P. Fabbricatore,[28] S. Farinon,[28] M. Lo Vetere,[28]
M. Macri,[28] M. R. Monge,[28] R. Musenich,[28] M. Pallavicini,[28] R. Parodi,[28] S. Passaggio,[28] F. C. Pastore,[28]
C. Patrignani,[28] M. G. Pia,[28] C. Priano,[28] E. Robutti,[28] A. Santroni,[28] M. Morii,[29] R. Bartoldus,[30] T. Dignan,[30]
R. Hamilton,[30] U. Mallik,[30] J. Cochran,[31] H. B. Crawley,[31] P.-A. Fischer,[31] J. Lamsa,[31] W. T. Meyer,[31]
E. I. Rosenberg,[31] M. Benkebil,[32] G. Grosdidier,[32] C. Hast,[32] A. Höcker,[32] H. M. Lacker,[32] V. LePeltier,[32]
A. M. Lutz,[32] S. Plaszczynski,[32] M. H. Schune,[32] S. Trincaz-Duvoid,[32] A. Valassi,[32] G. Wormser,[32] R. M. Bionta,[33]
V. Brigljević,[33] D. J. Lange,[33] M. Mugge,[33] X. Shi,[33] K. van Bibber,[33] T. J. Wenaus,[33] D. M. Wright,[33]

C. R. Wuest,[33] M. Carroll,[34] J. R. Fry,[34] E. Gabathuler,[34] R. Gamet,[34] M. George,[34] M. Kay,[34] D. J. Payne,[34]
R. J. Sloane,[34] C. Touramanis,[34] M. L. Aspinwall,[35] D. A. Bowerman,[35] P. D. Dauncey,[35] U. Egede,[35] I. Eschrich,[35]
N. J. W. Gunawardane,[35] J. A. Nash,[35] P. Sanders,[35] D. Smith,[35] D. E. Azzopardi,[36] J. J. Back,[36] P. Dixon,[36]
P. F. Harrison,[36] R. J. L. Potter,[36] H. W. Shorthouse,[36] P. Strother,[36] P. B. Vidal,[36] M. I. Williams,[36]
G. Cowan,[37] S. George,[37] M. G. Green,[37] A. Kurup,[37] C. E. Marker,[37] P. McGrath,[37] T. R. McMahon,[37]
S. Ricciardi,[37] F. Salvatore,[37] I. Scott,[37] G. Vaitsas,[37] D. Brown,[38] C. L. Davis,[38] J. Allison,[39] R. J. Barlow,[39]
J. T. Boyd,[39] A. C. Forti,[39] J. Fullwood,[39] F. Jackson,[39] G. D. Lafferty,[39] N. Savvas,[39] E. T. Simopoulos,[39]
J. H. Weatherall,[39] A. Farbin,[40] A. Jawahery,[40] V. Lillard,[40] J. Olsen,[40] D. A. Roberts,[40] J. R. Schieck,[40]
G. Blaylock,[41] C. Dallapiccola,[41] K. T. Flood,[41] S. S. Hertzbach,[41] R. Kofler,[41] T. B. Moore,[41] H. Staengle,[41]
S. Willocq,[41] B. Brau,[42] R. Cowan,[42] G. Sciolla,[42] F. Taylor,[42] R. K. Yamamoto,[42] M. Milek,[43] P. M. Patel,[43]
J. Trischuk,[43] F. Lanni,[44] F. Palombo,[44] J. M. Bauer,[45] M. Booke,[45] L. Cremaldi,[45] V. Eschenburg,[45] R. Kroeger,[45]
J. Reidy,[45] D. A. Sanders,[45] D. J. Summers,[45] J. P. Martin,[46] J. Y. Nief,[46] R. Seitz,[46] P. Taras,[46] A. Woch,[46]
V. Zacek,[46] H. Nicholson,[47] C. S. Sutton,[47] C. Cartaro,[48] N. Cavallo,[48, †] G. De Nardo,[48] F. Fabozzi,[48] C. Gatto,[48]
L. Lista,[48] P. Paolucci,[48] D. Piccolo,[48] C. Sciacca,[48] J. M. LoSecco,[49] J. R. G. Alsmiller,[50] T. A. Gabriel,[50]
T. Handler,[50] J. Brau,[51] R. Frey,[51] M. Iwasaki,[51] N. B. Sinev,[51] D. Strom,[51] F. Colecchia,[52] F. Dal Corso,[52]
A. Dorigo,[52] F. Galeazzi,[52] M. Margoni,[52] G. Michelon,[52] M. Morandin,[52] M. Posocco,[52] M. Rotondo,[52]
F. Simonetto,[52] R. Stroili,[52] E. Torassa,[52] C. Voci,[52] M. Benayoun,[53] H. Briand,[53] J. Chauveau,[53] P. David,[53]
C. De la Vaissière,[53] L. Del Buono,[53] O. Hamon,[53] F. Le Diberder,[53] Ph. Leruste,[53] J. Lory,[53] L. Roos,[53]
J. Stark,[53] S. Versillé,[53] P. F. Manfredi,[54] V. Re,[54] V. Speziali,[54] E. D. Frank,[55] L. Gladney,[55] Q. H. Guo,[55]
J. H. Panetta,[55] C. Angelini,[56] G. Batignani,[56] S. Bettarini,[56] M. Bondioli,[56] M. Carpinelli,[56] F. Forti,[56]
M. A. Giorgi,[56] A. Lusiani,[56] F. Martinez-Vidal,[56] M. Morganti,[56] N. Neri,[56] E. Paoloni,[56] M. Rama,[56] G. Rizzo,[56]
F. Sandrelli,[56] G. Simi,[56] G. Triggiani,[56] J. Walsh,[56] M. Haire,[57] D. Judd,[57] K. Paick,[57] L. Turnbull,[57]
D. E. Wagoner,[57] J. Albert,[58] C. Bula,[58] P. Elmer,[58] C. Lu,[58] K. T. McDonald,[58] V. Miftakov,[58] S. F. Schaffner,[58]
A. J. S. Smith,[58] A. Tumanov,[58] E. W. Varnes,[58] G. Cavoto,[59] D. del Re,[59] R. Faccini,[14, 59] F. Ferrarotto,[59]
F. Ferroni,[59] K. Fratini,[59] E. Lamanna,[59] E. Leonardi,[59] M. A. Mazzoni,[59] S. Morganti,[59] G. Piredda,[59]
F. Safai Tehrani,[59] M. Serra,[59] C. Voena,[59] S. Christ,[60] R. Waldi,[60] T. Adye,[61] B. Franek,[61] N. I. Geddes,[61]
G. P. Gopal,[61] S. M. Xella,[61] R. Aleksan,[62] G. De Domenico,[62] S. Emery,[62] A. Gaidot,[62] S. F. Ganzhur,[62]
P.-F. Giraud,[62] G. Hamel de Monchenault,[62] W. Kozanecki,[62] M. Langer,[62] G. W. London,[62] B. Mayer,[62]
B. Serfass,[62] G. Vasseur,[62] C. Yeche,[62] M. Zito,[62] N. Copty,[63] M. V. Purohit,[63] H. Singh,[63] F. X. Yumiceva,[63]
I. Adam,[64] P. L. Anthony,[64] D. Aston,[64] K. Baird,[64] E. Bloom,[64] A. M. Boyarski,[64] F. Bulos,[64] G. Calderini,[64]
R. Claus,[64] M. R. Convery,[64] D. P. Coupal,[64] D. H. Coward,[64] J. Dorfan,[64] M. Doser,[64] W. Dunwoodie,[64]
R. C. Field,[64] T. Glanzman,[64] G. L. Godfrey,[64] S. J. Gowdy,[64] P. Grosso,[64] T. Himel,[64] M. E. Huffer,[64]
W. R. Innes,[64] C. P. Jessop,[64] M. H. Kelsey,[64] P. Kim,[64] M. L. Kocian,[64] U. Langenegger,[64] D. W. G. S. Leith,[64]
S. Luitz,[64] V. Luth,[64] H. L. Lynch,[64] H. Marsiske,[64] S. Menke,[64] R. Messner,[64] K. C. Moffeit,[64] R. Mount,[64]
D. R. Muller,[64] C. P. O'Grady,[64] M. Perl,[64] S. Petrak,[64] H. Quinn,[64] B. N. Ratcliff,[64] S. H. Robertson,[64]
L. S. Rochester,[64] A. Roodman,[64] T. Schietinger,[64] R. H. Schindler,[64] J. Schwiening,[64] V. V. Serbo,[64] A. Snyder,[64]
A. Soha,[64] S. M. Spanier,[64] J. Stelzer,[64] D. Su,[64] M. K. Sullivan,[64] H. A. Tanaka,[64] J. Va'vra,[64] S. R. Wagner,[64]
A. J. R. Weinstein,[64] W. J. Wisniewski,[64] D. H. Wright,[64] C. C. Young,[64] P. R. Burchat,[65] C. H. Cheng,[65]
D. Kirkby,[65] T. I. Meyer,[65] C. Roat,[65] R. Henderson,[66] W. Bugg,[67] H. Cohn,[67] A. W. Weidemann,[67] J. M. Izen,[68]
I. Kitayama,[68] X. C. Lou,[68] M. Turcotte,[68] F. Bianchi,[69] M. Bona,[69] B. Di Girolamo,[69] D. Gamba,[69] A. Smol,[69]
D. Zanin,[69] L. Lanceri,[70] A. Pompili,[70] G. Vuagnin,[70] R. S. Panvini,[71] C. M. Brown,[72] A. De Silva,[72]
R. Kowalewski,[72] J. M. Roney,[72] H. R. Band,[73] E. Charles,[73] S. Dasu,[73] F. Di Lodovico,[73] A. M. Eichenbaum,[73]
H. Hu,[73] J. R. Johnson,[73] R. Liu,[73] J. Nielsen,[73] Y. Pan,[73] R. Prepost,[73] I. J. Scott,[73] S. J. Sekula,[73]
J. H. von Wimmersperg-Toeller,[73] S. L. Wu,[73] Z. Yu,[73] H. Zobernig,[73] T. M. B. Kordich,[74] and H. Neal[74]

(The *BABAR* Collaboration)

[1]*Laboratoire de Physique des Particules, F-74941 Annecy-le-Vieux, France*
[2]*Università di Bari, Dipartimento di Fisica and INFN, I-70126 Bari, Italy*
[3]*Institute of High Energy Physics, Beijing 100039, China*
[4]*University of Bergen, Inst. of Physics, N-5007 Bergen, Norway*
[5]*Lawrence Berkeley National Laboratory and University of California, Berkeley, CA 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, BC, 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, CA 92697, USA

[13]University of California at Los Angeles, Los Angeles, CA 90024, USA

[14]University of California at San Diego, La Jolla, CA 92093, USA

[15]University of California at Santa Barbara, Santa Barbara, CA 93106, USA

[16]University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, CA 95064, USA

[17]California Institute of Technology, Pasadena, CA 91125, USA

[18]University of Cincinnati, Cincinnati, OH 45221, USA

[19]University of Colorado, Boulder, CO 80309, USA

[20]Colorado State University, Fort Collins, CO 80523, USA

[21]Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062, Dresden, Germany

[22]Ecole Polytechnique, F-91128 Palaiseau, France

[23]University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom

[24]Elon College, Elon College, NC 27244-2010, USA

[25]Università di Ferrara, Dipartimento di Fisica and INFN, I-44100 Ferrara, Italy I-44100 Ferrara, Italy

[26]Florida A&M University, Tallahassee, FL 32307, USA

[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, MA 02138, USA

[30]University of Iowa, Iowa City, IA 52242, USA

[31]Iowa State University, Ames, IA 50011-3160, USA

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

[33]Lawrence Livermore National Laboratory, Livermore, CA 94550, USA

[34]University of Liverpool, Liverpool L69 3BX, United Kingdom

[35]University of London, Imperial College, London, SW7 2BW, United Kingdom

[36]Queen Mary, University of London, E1 4NS, United Kingdom

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

[38]University of Louisville, Louisville, KY 40292, USA

[39]University of Manchester, Manchester M13 9PL, United Kingdom

[40]University of Maryland, College Park, MD 20742, USA

[41]University of Massachusetts, Amherst, MA 01003, USA

[42]Massachusetts Institute of Technology, Lab for Nuclear Science, Cambridge, MA 02139, USA

[43]McGill University, Montréal, Canada QC H3A 2T8

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

[45]University of Mississippi, University, MS 38677, USA

[46]Université de Montréal, Lab. Rene J. A. Levesque, Montréal, Canada QC H3C 3J7

[47]Mount Holyoke College, South Hadley, MA 01075, USA

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

[49]University of Notre Dame, Notre Dame, IN 46556, USA

[50]Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA

[51]University of Oregon, Eugene, OR 97403, USA

[52]Università di Padova, Dipartimento di Fisica and INFN, I-35131 Padova, Italy

[53]Universités Paris VI et VII, LPNHE, F-75252 Paris, France

[54]Università di Pavia, Dipartimento di Elettronica and INFN, I-27100 Pavia, Italy

[55]University of Pennsylvania, Philadelphia, PA 19104, USA

[56]Università di Pisa, Scuola Normale Superiore and INFN, I-56010 Pisa, Italy

[57]Prairie View A&M University, Prairie View, TX 77446, USA

[58]Princeton University, Princeton, NJ 08544, USA

[59]Università di Roma La Sapienza, Dipartimento di Fisica and INFN, I-00185 Roma, Italy

[60]Universität Rostock, D-18051 Rostock, Germany

[61]Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingdom

[62]DAPNIA, Commissariat à l'Energie Atomique/Saclay, F-91191 Gif-sur-Yvette, France

[63]University of South Carolina, Columbia, SC 29208, USA

[64]Stanford Linear Accelerator Center, Stanford, CA 94309, USA

[65]Stanford University, Stanford, CA 94305-4060, USA

[66]TRIUMF, Vancouver, BC, Canada V6T 2A3

[67]University of Tennessee, Knoxville, TN 37996, USA

[68]University of Texas at Dallas, Richardson, TX 75083, USA

[69]Università di Torino, Dipartimento di Fiscia Sperimentale and INFN, I-10125 Torino, Italy

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

[71]Vanderbilt University, Nashville, TN 37235, USA

[72]University of Victoria, Victoria, BC, Canada V8W 3P6

[73] *University of Wisconsin, Madison, WI 53706, USA*
[74] *Yale University, New Haven, CT 06511, USA*

(Dated: August 7, 2001)

We present the results of searches for B decays to charmless two-body final states containing η' or ω mesons, based on 20.7 fb^{-1} of data collected with the *BABAR* detector. We find the branching fractions $\mathcal{B}(B^+ \to \eta' K^+) = (70 \pm 8 \pm 5) \times 10^{-6}$, $\mathcal{B}(B^0 \to \eta' K^0) = (42^{+13}_{-11} \pm 4) \times 10^{-6}$, and $\mathcal{B}(B^+ \to \omega\pi^+) = (6.6^{+2.1}_{-1.8} \pm 0.7) \times 10^{-6}$ where the first error quoted is statistical and the second systematic. We give measurements of four additional modes for which the 90% confidence level upper limits are $\mathcal{B}(B^0 \to \omega K^0) < 13 \times 10^{-6}$, $\mathcal{B}(B^+ \to \eta' \pi^+) < 12 \times 10^{-6}$, $\mathcal{B}(B^+ \to \omega K^+) < 4 \times 10^{-6}$, and $\mathcal{B}(B^0 \to \omega\pi^0) < 3 \times 10^{-6}$.

We report results of searches for B decays to the charmless two-body final states [1] $B^+ \to \omega\pi^+$, $B^+ \to \omega K^+$, $B^+ \to \eta' \pi^+$, $B^+ \to \eta' K^+$, $B^0 \to \omega K^0$, $B^0 \to \omega\pi^0$, and $B^0 \to \eta' K^0$. These processes are manifestations of penguin or suppressed tree amplitudes proportional to small couplings in hadronic flavor mixing (CKM matrix [2]). As more of these rare B decay modes are measured, their phenomenological description will improve, and with it the sensitivity to any contributions through virtual particles in loops or interference terms of heretofore undetected physics.

The data were collected with the *BABAR* detector [3] at the PEP-II asymmetric e^+e^- collider [4] located at the Stanford Linear Accelerator Center. The results presented in this paper are based on data taken in the 1999–2000 run. An integrated luminosity of 20.7 fb^{-1} was recorded at the $\Upsilon(4S)$ resonance, corresponding to 22.7 million $B\overline{B}$ pairs ("on-resonance"), with an additional 2.6 fb^{-1} about 40 MeV below this energy ("off-resonance") for the study of continuum backgrounds.

The asymmetric beam configuration in the laboratory frame provides a boost to the $\Upsilon(4S)$ increasing the momentum range of the B-meson decay products up to 4.3 GeV/c. Charged particles are detected and their momenta are measured by a combination of a silicon vertex tracker (SVT) consisting of five double-sided layers and a 40-layer central drift chamber (DCH), both operating in a 1.5 T solenoidal magnetic field. Photons and electrons are detected by a CsI(Tl) electromagnetic calorimeter (EMC), which provides excellent angular and energy resolution with high efficiency for energies above 20 MeV [3].

Charged particle identification (PID) is provided by the average energy loss (dE/dx) in the tracking devices and by a unique, internally reflecting ring imaging Cherenkov detector (DIRC) covering the central region. A Cherenkov angle K–π separation of better than 4 standard deviations (σ) is achieved for tracks below 3 GeV/c momentum, decreasing to 2.5σ at the highest momenta in the final states considered here [5]. Electrons are identified with the use of the EMC.

We reconstruct a B meson candidate by combining an ω or η' candidate with a charged track, $\pi^0 \to \gamma\gamma$, or $K_S^0 \to \pi^+\pi^-$. The resonance decays R we reconstruct are $\omega \to \pi^+\pi^-\pi^0$, $\eta' \to \eta\pi^+\pi^-$ ($\eta'_{\eta\pi\pi}$), or $\eta' \to \rho^0\gamma$ ($\eta'_{\rho\gamma}$), with $\eta \to \gamma\gamma$ and $\rho^0 \to \pi^+\pi^-$. These modes are kinematically distinct from the dominant B decays to heavier charmed states. Backgrounds come primarily from combinatorics among continuum events in which a light quark pair is produced instead of an $\Upsilon(4S)$.

Monte Carlo (MC) simulations [6] of the target decay modes and of continuum background are used to establish the event selection criteria. The selection is designed to achieve high efficiency and retain sidebands sufficient to characterize the background for subsequent fitting. Photons must satisfy $E_\gamma > 50$ (100) MeV for π^0 (η) candidates, and $E_\gamma > 200$ (100) MeV for $\eta' \to \rho^0\gamma$ candidates from $\eta'_{\rho\gamma}K^+$ ($\eta'_{\rho\gamma}K^0$) B decays. We select ω, η', η, and ρ candidates with the following requirements on the invariant masses in MeV/c^2 of their final states: $735 < m(\pi^+\pi^-\pi^0) < 830$, $930 < m(\eta\pi^+\pi^-) < 990$, $900 < m(\rho\gamma) < 1000$, $490 < m(\gamma\gamma) < 600$, and $500 < m(\pi^+\pi^-) < 995$. For π^0 and K_S^0 candidates we require $120 < m(\gamma\gamma) < 150$ and $488 < m(\pi^+\pi^-) < 508$.

Tracks in ω or η' candidates must have DIRC, dE/dx, and EMC responses consistent with pions. For charged B decays, the B primary track must have an associated DIRC Cherenkov angle within 3.5σ of the expected value for a kaon or pion. For modes with K_S^0 the three-dimensional flight distance from the production point must exceed 2 mm, and the angle between the flight and momentum vectors projected perpendicular to the beam must be less than 40 mrad.

A B meson candidate is characterized by two kinematic observables. The minimally correlated pair we use are the energy constrained mass $m_{\rm EC}$ and energy difference ΔE. In the $\Upsilon(4S)$ frame the B meson energy E^* equals the beam energy $E^*_{\rm beam}$. A kinematic fit of the measured candidate four momentum in this frame with the constraint $E^* = E^*_{\rm beam}$ yields $m_{\rm EC}$, while $\Delta E \equiv E^* - E^*_{\rm beam}$ measures the consistency of this constraint. We require $|\Delta E| \leq 0.2$ GeV, and $m_{\rm EC} \geq 5.2$ GeV/c^2. The resolutions on these quantities are mode dependent but average about 30 MeV and 2.8 MeV/c^2, respectively.

To discriminate against tau-pair and two-photon background we require the event to contain at least five

charged tracks. To reject continuum background we make use of the angle θ_T between the thrust axes of the B candidate and the rest of the tracks and neutral clusters in the event, calculated in the center-of-mass frame. The distribution of $\cos\theta_T$ is sharply peaked near ± 1 for combinations drawn from jetlike $q\bar{q}$ pairs, and nearly uniform for the isotropic B meson decays.

The yields are obtained from extended unbinned maximum likelihood (ML) fits, with two variants. The first, which provides our results for all modes except $B^0 \to \omega\pi^0$, uses several uncorrelated variables representing the B decay kinematics and a Fisher discriminant representing the production and energy flow; we require $|\cos\theta_T| \le 0.9$. The second is applied to all channels with an ω meson, with a fit of ΔE and the output of a neural network built from the remaining inputs; we relax the preliminary requirements to $100 < m(\gamma\gamma) < 160$ MeV/c^2 and $|\Delta E| < 0.3$ GeV. Comparisons for the $\omega\pi^+$, ωK^+, and ωK^0 modes show that the central values and errors for the yields obtained by the two approaches are in very good agreement. Simple cut-based analyses are performed as checks for each final state. Agreement of central values is good in all cases, although, as expected, errors are larger than for the ML analyses, particularly for modes having high background.

The ML fit input observables are ΔE, m_{EC}, the invariant mass m_R of the intermediate resonance, the Fisher discriminant $\mathcal{F}$, and, where relevant, the η mass m_η, the measured DIRC Cherenkov angle for the B primary track, and the cosine $\mathcal{H}$ of the helicity angle, the angle in the ω rest frame between the normal to the ω decay plane and the B flight direction. The Fisher discriminant [7] combines eleven variables: the angles with respect to the beam axis in the $\Upsilon(4S)$ frame of the B momentum and B two-body decay axis, and a nine bin representation of the energy flow about the B decay axis. The neural network is constructed with the B momentum p^*, a χ^2 for resonance masses, $\mathcal{H}$, and variables representing energy flow and angular distributions, including θ_T.

We use MC to estimate backgrounds from other B decays, including final states with and without charm. For most of our modes we find contributions that are negligible. For the $\eta' \to \rho^0\gamma$ modes we account for small cross feed contributions in the systematic error estimate.

The likelihood function for N events is

$$\mathcal{L} = \frac{e^{-(\sum n_j)}}{N!} \prod_{i=1}^{N} \mathcal{L}_i, \quad \mathcal{L}_i = \sum_{j=1}^{m} n_j \mathcal{P}_j(\mathbf{x}_i).$$

Here n_j is the population size for species j (e.g., signal, background) and $\mathcal{P}_j(\mathbf{x}_i)$ the corresponding probability distribution function (PDF), evaluated with the observables $\mathbf{x}_i$ of the ith event.

For the fits of charged B decays $\mathcal{L}_i$ becomes

$$\begin{aligned} \mathcal{L}_i &= n_\pi \mathcal{P}_{\pi S}(\mathbf{x}_i) + n_K \mathcal{P}_{KS}(\mathbf{x}_i) + \\ &\quad n_C \left[f_{KC} \mathcal{P}_{KC}(\mathbf{x}_i) + (1 - f_{KC}) \mathcal{P}_{\pi C}(\mathbf{x}_i) \right], \end{aligned}$$

where $n_\pi (n_K)$ is the number of $B^+ \to R\pi^+ (B^+ \to RK^+)$ signal events, n_C is the number of continuum background events, and f_{KC} is the fraction of continuum background events for which the B primary track is identified as a kaon. These quantities are the free parameters of the ML fit. The probabilities for the components are $\mathcal{P}_{\pi S}$ $(\mathcal{P}_{KS})$ for $B^+ \to R\pi^+ (B^+ \to RK^+)$ signal and $\mathcal{P}_{\pi C}$ $(\mathcal{P}_{KC})$ for background where the primary track is a pion (kaon). Since we measure the correlations among the observables in the data to be small, we take each $\mathcal{P}_j$ to be a product of the PDFs for the separate observables. The analyses involving a K_S^0 are treated identically except that there is only one component of signal and of continuum background.

A second B candidate satisfying the preliminary cuts occurs in about 10–20% of the events. In this case the "best" combination is selected according to a χ^2 quantity computed with m_{EC}, m_R, m_η (for $\eta' \to \eta\pi^+\pi^-$ modes), and the Fisher discriminant.
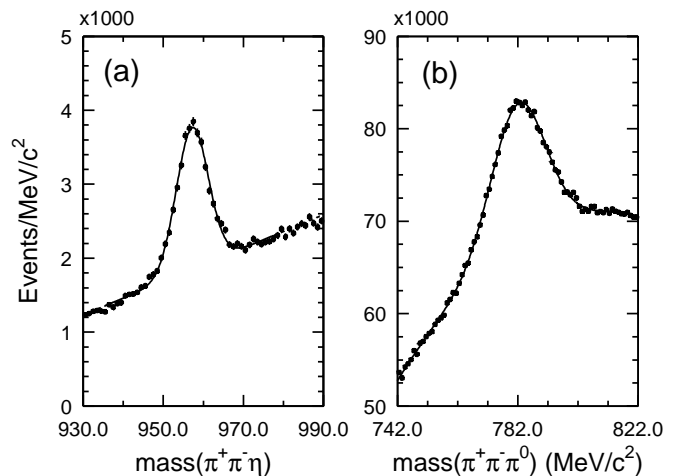

FIG. 1: Invariant mass distributions for inclusive data samples for (a) η', (b) ω candidates, with fit curves overlaid. The Gaussian peak widths are 4 and 10 MeV/c^2, respectively.

We determine the PDFs for the likelihood fit from simulation for the signal component, and from off-resonance and sideband data for the continuum background. Peaking distributions (signal masses, ΔE, $\mathcal{F}$) are parameterized as Gaussians, with or without a second Gaussian or asymmetric width as required to describe the distributions. Slowly varying distributions (combinatoric background under mass or energy peaks, $\mathcal{H}$, or $\mathcal{F}$) have first or second order polynomial shapes. The combinatoric background in m_{EC} is described by a phase space motivated empirical function [8]. Control samples of B decays to charmed final states of similar topology are used to verify the simulated resolutions in ΔE and m_{EC}. Inclusive resonance production samples such as those shown in Fig. 1 are used similarly for the relevant B daughter mass spectra.

We compute the branching fractions from the fitted

TABLE I: Signal event yield with statistical uncertainty, detection efficiency ϵ, daughter branching fractions that were forced to 100% in our signal mode simulations, significance S (defined in the text), and branching fraction result for each decay chain or mode, with the final (combined) result given in bold type.

Mode	Signal yield	ϵ %	$\prod \mathcal{B}_i$ %	S σ	$\mathcal{B}$ 10^{-6}
$\eta'_{\eta\pi\pi}K^+$	$49.5^{+8.1}_{-7.3}$	20	17.4	15	63^{+10}_{-9}
$\eta'_{\rho\gamma}K^+$	$87.6^{+13.4}_{-12.5}$	18	29.5	11	80^{+12}_{-11}
$\eta' K^+$				17	$\mathbf{70 \pm 8 \pm 5}$
$\eta'_{\eta\pi\pi}K^0$	$6.3^{+3.3}_{-2.5}$	16	6.0	4.7	28^{+15}_{-11}
$\eta'_{\rho\gamma}K^0$	$20.8^{+7.4}_{-6.5}$	16	10.1	4.2	61^{+22}_{-19}
$\eta' K^0$				5.9	$\mathbf{42^{+13}_{-11} \pm 4}$
$\eta'_{\eta\pi\pi}\pi^+$	$5.7^{+3.8}_{-2.8}$	20	17.4	3.2	$7.1^{+4.8}_{-3.5}$
$\eta'_{\rho\gamma}\pi^+$	$-0.9^{+7.8}_{-6.2}$	19	29.5	0.1	$-0.7^{+6.7}_{-5.3}$
$\eta' \pi^+$				2.8	$\mathbf{5.4^{+3.5}_{-2.6} \pm 0.8}$
ωK^+	$6.4^{+5.6}_{-4.4}$	22	88.8	1.3	$\mathbf{1.4^{+1.3}_{-1.0} \pm 0.3}$
ωK^0	$8.1^{+4.6}_{-3.6}$	18	30.5	3.2	$\mathbf{6.4^{+3.6}_{-2.8} \pm 0.8}$
$\omega \pi^+$	$27.6^{+8.8}_{-7.7}$	21	88.8	4.9	$\mathbf{6.6^{+2.1}_{-1.8} \pm 0.7}$
$\omega \pi^0$	$-0.9^{+5.0}_{-3.2}$	18	88.8	–	$\mathbf{-0.3 \pm 1.1 \pm 0.3}$

FIG. 2: B candidate m_{EC} and ΔE for $B^+ \to \eta' K^+$(a, b), $B^0 \to \eta' K^0$(c, d), and $B^+ \to \omega \pi^+$(e, f). Histograms represent data, with the $\eta' \to \eta\pi\pi$ subset shaded, solid curves represent the full fit functions, and dashed curves the background functions.

signal event yields, reconstruction efficiency, daughter branching fractions, and the number of produced B mesons, assuming equal production rates of charged and neutral pairs. To determine the reconstruction efficiency, including any yield bias of the likelihood fit, we apply the method to simulated samples with the signal and continuum background populations expected in the data. Table I shows for each decay chain the branching fraction we measure, together with the quantities entering into its computation. The statistical error on the number of events is taken as the shift from the central value that changes the quantity $\chi^2 \equiv -2\log\left(\mathcal{L}/\mathcal{L}_{\max}\right)$ by one unit. We also give the significance S, computed as the square root of the difference between the value of χ^2 for zero signal and the value at its minimum. The χ^2 used for significance includes a term that accounts for the additive systematic error. Where the significance is less than four standard deviations, we quote also (Bayesian) 90% CL upper limits, defined by the solution B to the condition $\int_0^B \mathcal{L}(b)db / \int_0^\infty \mathcal{L}(b)db = 0.9$.

In Fig. 2 we show projections of m_{EC} and ΔE for the modes with significant yields. The projections are made by selecting events with signal likelihood (computed without the variable plotted) exceeding a mode-dependent threshold that optimizes the expected sensitivity.

We have evaluated systematic errors, which are dominated in most cases by the PDF uncertainties (3–18%, depending on the decay mode). To determine these we
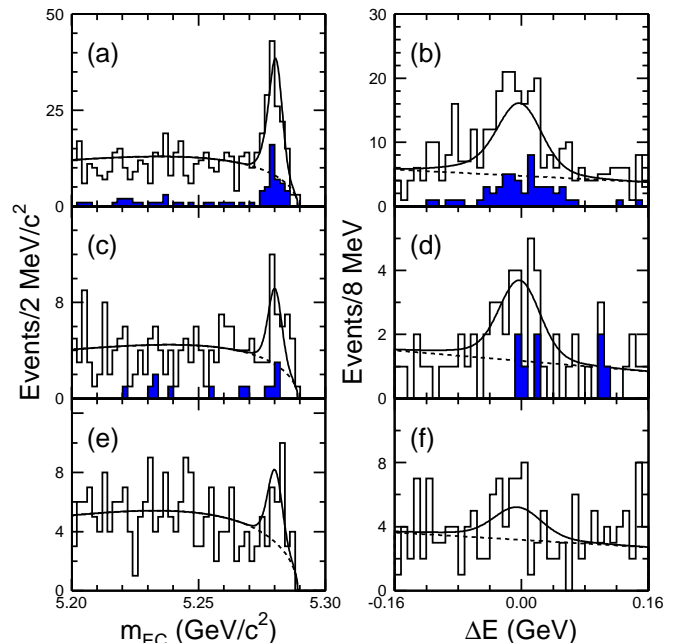
vary parameters of the PDFs within their uncertainties and observe the impact on the fit yield. We include them in upper limits by convolution with the likelihood function. This is the only additive systematic error; all others are multiplicative. The estimate of any systematic bias from the fitter itself (1–4%) comes from fits of simulated samples with varying background populations.

Auxiliary studies lead to systematic errors of 1%, 1.25%, and 5% respectively reflecting our knowledge of track, photon, and K_s^0 efficiencies. These errors are summed linearly for the B daughters and the unreconstructed B, which must contribute tracks to achieve the event multiplicity requirement. Our estimate of the B production systematic error is 1.6%. Published world averages [9] provide the B daughter branching fraction uncertainties.

Systematic errors associated with the event selection are minimal given the generally loose requirements. We account explicitly for $\cos\theta_{\mathrm{T}}$ (1%), for which we observe a nearly uniform distribution in the signal simulation. We also include errors of 4% from those PID requirements that are imposed via cuts rather than the fit.

We have observed signals of at least 4σ in five of the decay chains studied here, as reported in Table I. Where we have multiple chains for a given mode we combine the results by adding the χ^2 distributions that represent them and their uncorrelated statistical and systematic errors. For the measurements that are consistent with zero we also derive

90% CL upper limits $\mathcal{B}(B^0 \to \omega K^0) < 13 \times 10^{-6}$, $\mathcal{B}(B^+ \to \eta'\pi^+) < 12 \times 10^{-6}$, $\mathcal{B}(B^+ \to \omega K^+) < 4 \times 10^{-6}$, and $\mathcal{B}(B^0 \to \omega\pi^0) < 3 \times 10^{-6}$.

The final results are generally in agreement with those previously reported [10, 11], with somewhat smaller errors. In particular, we confirm the expected $\mathcal{B}(B^+ \to \omega\pi^+) > \mathcal{B}(B^+ \to \omega K^+)$, and the rather larger than predicted [12] rate for $B \to \eta'K$ obtained by the CLEO Collaboration [10]. Conjectured sources of η' enhancement include flavor singlet [13], charm enhanced [14], and constructively interfering internal penguin diagrams [12, 15]. Our results in combination with expected measurements of related modes involving η and K^* should help clarify this situation.

---

* Also with Università di Perugia, Perugia, Italy.

† Also with Università della Basilicata, Potenza, Italy.

[1] Charge conjugate states are implied throughout this paper.

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

[3] *BABAR* Collaboration, B. Aubert *et al.*, SLAC-PUB-8569, hep-ex/0105044, Nucl. Instr. and Methods A (in press).

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

[5] See Fig. 1(b) in *BABAR* Collaboration, B. Aubert *et al.*, SLAC-PUB-8838, hep-ex/0105061, Phys. Rev. Lett. (in press).

[6] The *BABAR* detector Monte Carlo simulation is based on GEANT: R. Brun *et al.*, CERN DD/EE/84-1.

[7] CLEO Collaboration, D. M. Asner *et al.*, Phys. Rev. D **53**, 1039 (1996).

[8] With $x \equiv m_{\mathrm{EC}}/E_b$ and ξ a parameter to be fit, $f(x) \propto x\sqrt{1-x^2}\exp\left[-\xi(1-x^2)\right]$. See ARGUS Collaboration, H. Albrecht *et al.*, Phys. Lett. B **241**, 278 (1990); **254**, 288 (1991).

[9] Particle Data Group, D. E. Groom *et al.*, Eur. Phys. Jour. C **15**, 1 (2000).

[10] CLEO Collaboration, S. J. Richichi *et al.*, Phys. Rev. Lett. **85**, 520 (2000).

[11] CLEO Collaboration, C. P. Jessop *et al.*, Phys. Rev. Lett. **85**, 2881 (2000).

[12] A. Ali, G. Kramer, and C. D. Lü, Phys. Rev. D **58**, 094009 (1998); Y. H. Chen *et al.*, Phys. Rev. D **60**, 094014 (1999).

[13] M. Gronau and J. L. Rosner, Phys. Rev. D **53**, 2516 (1996); A. S. Dighe, M. Gronau, and J. L. Rosner, Phys. Rev. Lett. **79**, 4333 (1997); M. R. Ahmady, E. Kou, and A. Sugamoto, Phys. Rev. D **58**, 014015 (1998); D. Du, C. S. Kim, and Y. Yang, Phys. Lett. **B419**, 369 (1998).

[14] I. Halperin and A. Zhitnitsky, Phys. Rev. D **56**, 7247 (1997); E. V. Shuryak and A. Zhitnitsky, *ibid.* **57**, 2001 (1998).

[15] H. J. Lipkin, Phys. Lett. B **254**, 247 (1991).