Title

Measurements of partial branching fractions for B-->Xulnu and determination of |Vub|.

Journal

Physical review letters, 100(17)

ISSN

0031-9007

Authors

Aubert, B
Bona, M
Boutigny, D
et al.

Publication Date

2008-05-01

DOI

10.1103/physrevlett.100.171802

Measurements of Partial Branching Fractions for $\bar{B} \to X_u l \bar{\nu}$ and Determination of $|V_{ub}|$

B. Aubert,[1] M. Bona,[1] D. Boutigny,[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] Y. Groysman,[5] R. G. Jacobsen,[5] J. A. Kadyk,[5] L. T. Kerth,[5] Yu. G. Kolomensky,[5] G. Kukartsev,[5] D. Lopes Pegna,[5] G. Lynch,[5] L. M. Mir,[5] T. J. Orimoto,[5] I. L. Osipenkov,[5] M. T. Ronan,[5,*] K. Tackmann,[5] T. Tanabe,[5] W. A. Wenzel,[5] P. del Amo Sanchez,[6] C. M. Hawkes,[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] 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] S. D. Foulkes,[14] J. W. Gary,[14] F. Liu,[14] O. Long,[14] B. C. Shen,[14] G. M. Vitug,[14] L. Zhang,[14] H. P. Paar,[15] S. Rahatlou,[15] V. Sharma,[15] J. W. Berryhill,[16] C. Campagnari,[16] A. Cunha,[16] B. Dahmes,[16] T. M. Hong,[16] D. Kovalskyi,[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] M. G. Wilson,[17] L. O. Winstrom,[17] E. Chen,[18] C. H. Cheng,[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] S. Chen,[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] J. Zhang,[20] A. M. Gabareen,[21] A. Soffer,[21,†] W. H. Toki,[21] R. J. Wilson,[21] F. Winklmeier,[21] D. D. Altenburg,[22] E. Feltresi,[22] A. Hauke,[22] H. Jasper,[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] V. Lombardo,[24] Ch. Thiebaux,[24] M. Verderi,[24] P. J. Clark,[25] W. Gradl,[25] F. Muheim,[25] S. Playfer,[25] A. I. Robertson,[25] J. E. Watson,[25] Y. Xie,[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] J. Wu,[29] R. S. Dubitzky,[30] J. Marks,[30] S. Schenk,[30] U. Uwer,[30] D. J. Bard,[31] P. D. Dauncey,[31] R. L. Flack,[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] V. Eyges,[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] G. Grosdidier,[36] A. Höcker,[36] V. Lepeltier,[36] F. Le Diberder,[36] A. M. Lutz,[36] S. Pruvot,[36] S. Rodier,[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] K. C. Schofield,[38] C. Touramanis,[38] A. J. Bevan,[39] C. Clarke,[39] K. A. George,[39] F. Di Lodovico,[39] W. Menges,[39] R. Sacco,[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] J. Allison,[42] D. Bailey,[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] G. Blaylock,[44] C. Dallapiccola,[44] S. S. Hertzbach,[44] X. Li,[44] T. B. Moore,[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] Y. Zheng,[45] S. E. Mclachlin,[46,*] P. M. Patel,[46] S. H. Robertson,[46] A. Lazzaro,[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] F. Fabozzi,[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] N. Gagliardi,[56] A. Gaz,[56] M. Margoni,[56] M. Morandin,[56] A. Pompili,[56] M. Posocco,[56] M. Rotondo,[56] F. Simonetto,[56] R. Stroili,[56] C. Voci,[56] E. Ben-Haim,[57] H. Briand,[57] G. Calderini,[57] J. Chauveau,[57] P. David,[57] L. Del Buono,[57] Ch. de la Vaissière,[57] O. Hamon,[57] Ph. Leruste,[57] J. Malclès,[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] R. Cenci,[60] A. Cervelli,[60] F. Forti,[60] M. A. Giorgi,[60] A. Lusiani,[60] G. Marchiori,[60] M. A. Mazur,[60] M. Morganti,[60] N. Neri,[60] E. Paoloni,[60] G. Rizzo,[60] J. J. Walsh,[60] J. Biesiada,[61] P. Elmer,[61] Y. P. Lau,[61] C. Lu,[61] J. Olsen,[61] A. J. S. Smith,[61] A. V. Telnov,[61] E. Baracchini,[62] F. Bellini,[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] G. Castelli,[64] B. Franek,[64] E. O. Olaiya,[64] W. Roethel,[64] F. F. Wilson,[64] S. Emery,[65] M. Escalier,[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] R. Claus,[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] T. Glanzman,[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] S. Luitz,[67] V. Luth,[67] H. L. Lynch,[67] D. B. MacFarlane,[67] H. Marsiske,[67] R. Messner,[67] D. R. Muller,[67] C. P. O'Grady,[67] I. Ofte,[67] A. Perazzo,[67] M. Perl,[67] T. Pulliam,[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] W. J. Wisniewski,[67] M. Wittgen,[67] D. H. Wright,[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] V. Jain,[69] B. Pan,[69] M. A. Saeed,[69] F. R. Wappler,[69] S. B. Zain,[69] M. Krishnamurthy,[70] S. M. Spanier,[70] R. Eckmann,[71] J. L. Ritchie,[71] A. M. Ruland,[71] C. J. Schilling,[71] R. F. Schwitters,[71] J. M. Izen,[72] X. C. Lou,[72] S. Ye,[72] F. Bianchi,[73] F. Gallo,[73] D. Gamba,[73] M. Pelliccioni,[73] M. Bomben,[74] L. Bosisio,[74] C. Cartaro,[74] F. Cossutti,[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] K. Hamano,[76] R. Kowalewski,[76] I. M. Nugent,[76] J. M. Roney,[76] R. J. Sobie,[76] 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] J. J. Hollar,[78] P. E. Kutter,[78] Y. Pan,[78] M. Pierini,[78] R. Prepost,[78] S. L. Wu,[78] and H. Neal[79]

(*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]The 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
[79]Yale University, New Haven, Connecticut 06511, USA

(Received 28 August 2007; revised manuscript received 14 March 2008; published 29 April 2008)

We present partial branching fractions for inclusive charmless semileptonic B decays $\bar{B} \to X_u \ell \bar{\nu}$, and the determination of the Cabibbo-Kobayashi-Maskawa matrix element $|V_{ub}|$. The analysis is based on a sample of 383×10^6 $\Upsilon(4S)$ decays into $B\bar{B}$ pairs collected with the *BABAR* detector at the SLAC PEP-II e^+e^- storage rings. We select events using the invariant mass M_X of the hadronic system, the invariant mass squared, q^2, of the lepton and neutrino pair, the kinematic variable P_+, or one of their combinations. We then determine partial branching fractions in limited regions of phase space: $\Delta\mathcal{B} = (1.18 \pm 0.09_{\text{stat}} \pm 0.07_{\text{syst}} \pm 0.01_{\text{theor}}) \times 10^{-3}$ $(M_X < 1.55\ \text{GeV}/c^2)$, $\Delta\mathcal{B} = (0.95 \pm 0.10_{\text{stat}} \pm 0.08_{\text{syst}} \pm 0.01_{\text{theor}}) \times 10^{-3}$

($P_+ < 0.66$ GeV/c), and $\Delta\mathcal{B} = (0.81 \pm 0.08_{\rm stat} \pm 0.07_{\rm syst} \pm 0.02_{\rm theor}) \times 10^{-3}$ ($M_X < 1.7$ GeV/c^2, $q^2 >$ 8 GeV^2/c^4). Corresponding values of $|V_{ub}|$ are extracted using several theoretical calculations.

DOI: 10.1103/PhysRevLett.100.171802 PACS numbers: 13.20.He, 12.15.Hh, 14.40.Nd

In the standard model the element V_{ub} of the Cabibbo-Kobayashi-Maskawa (CKM) quark-mixing matrix [1] plays a critical role in tests of the prediction of CP violation. Since the rate for charmless semileptonic decays, $\bar{B} \to X_u \ell \bar{\nu}$ [2], is proportional to $|V_{ub}|^2$, and the hadronic and leptonic currents are factorizable, the best method to extract this quantity is to measure branching fractions for such decays [3]. Experimentally, the principal challenge is to separate the rare $\bar{B} \to X_u \ell \bar{\nu}$ decays from the approximately 50 times larger $\bar{B} \to X_c \ell \bar{\nu}$ background. Given that the u quark is much lighter than the c quark, regions of phase space can be defined where the background is suppressed. To relate the decay rate of the B meson to $|V_{ub}|$, parton level calculations have to be corrected for perturbative and nonperturbative QCD effects. A variety of QCD calculations are available to determine these corrections [4–6].

In this Letter, we present a measurement of partial branching fractions for inclusive charmless semileptonic decays, $\bar{B} \to X_u \ell \bar{\nu}$ [7]. $\Upsilon(4S) \to B\bar{B}$ events are tagged by the full reconstruction of a hadronic decay of one of the B mesons ($B_{\rm reco}$). The semileptonic decay of the second B meson ($B_{\rm recoil}$) is identified by the presence of an electron or a muon. This technique results in a low event selection efficiency but allows the determination of the momentum, charge, and flavor of the B mesons.

We use three kinematic variables to separate $\bar{B} \to X_u \ell \bar{\nu}$ decays from the dominant $\bar{B} \to X_c \ell \bar{\nu}$ background: M_X, the invariant mass of the hadronic system $X_{u,c}$; q^2, the invariant mass squared of the lepton-neutrino system; and $P_+ \equiv E_X - |\vec{P}_X|$ [4,5], where E_X and $\vec{P}_X$ are the energy and momentum of the hadronic system $X_{u,c}$ calculated in the B rest frame. We measure the fraction of partial rates of charmless semileptonic decays $\Delta R_{u/\rm sl} = \Delta\mathcal{B}(\bar{B} \to X_u \ell \bar{\nu})/\mathcal{B}(\bar{B} \to X \ell \bar{\nu})$ in restricted phase-space regions, corrected for resolution effects. The resulting partial branching fractions are used to calculate $|V_{ub}|$ following theoretical prescriptions.

The analysis uses a sample of 383×10^6 $\Upsilon(4S)$ decays into $B\bar{B}$ pairs, corresponding to an integrated luminosity of 347.4 fb^{-1}, collected with the *BABAR* detector [8]. Charmless semileptonic $\bar{B} \to X_u \ell \bar{\nu}$ decays are simulated as a combination of three-body decays ($X_u = \pi, \eta, \eta'$, $\rho, \omega, \ldots$) [9] and decays to nonresonant hadronic final states X_u [10]. The motion of the b quark inside the B meson is modeled with the shape function parametrization given in Ref. [10]. The simulation of the $\bar{B} \to X_c \ell \bar{\nu}$ background uses a heavy quark effective theory parametrization of form factors for $B \to D^* \ell \nu$ [11,12], and models for $\bar{B} \to D\pi \ell \bar{\nu}$, $D^* \pi \ell \bar{\nu}$ [13], and for $\bar{B} \to D \ell \bar{\nu}$, $D^{**} \ell \bar{\nu}$ [9]. The simulation of the hadronization is performed by JETSET 7.4 [14]. We use GEANT4 [15] to simulate the detector response.

To reconstruct a large sample of hadronically decaying B mesons, $B_{\rm reco} \to \bar{D}^{(*)} Y^{\pm}$ are selected. Here, the system $Y^{\pm}$ consists of hadrons with a total charge of ± 1, composed of $n_1 \pi^{\pm} n_2 K^{\pm} n_3 K^0_S n_4 \pi^0$, where $n_1 + n_2 \leq 5$, $n_3 \leq 2$, and $n_4 \leq 2$. The kinematic consistency of $B_{\rm reco}$ candidates is checked with two variables, $m_{\rm ES} = \sqrt{s/4 - \vec{p}_B^{\,2}}$ and $\Delta E = E_B - \sqrt{s}/2$. Here $\sqrt{s}$ is the total energy in the $\Upsilon(4S)$ center of mass frame, and $\vec{p}_B$ and E_B denote the momentum and energy of the $B_{\rm reco}$ candidate in the same frame. We require $\Delta E = 0$ within 3 standard deviations as measured for each decay mode. For each of the $B_{\rm reco}$ decay modes, the purity $\mathcal{P}$ is estimated using Monte Carlo (MC) simulation. $\mathcal{P}$ is defined as the ratio of signal over background events with $m_{\rm ES} \geq 5.27$ GeV/c^2. Only modes for which $\mathcal{P}$ exceeds 20% are used. On average, we reconstruct at least one B candidate in 0.3% (0.5%) of the $B^0\bar{B}^0$ (B^+B^-) events. For events with more than one reconstructed B decay, the decay mode with the highest purity is selected.

We determine the number of $B_{\rm reco}$ candidates from an unbinned maximum likelihood fit to the $m_{\rm ES}$ distribution. The data are fit to the sum of three contributions: signal $B_{\rm reco}$ decays, combinatorial background from $B\bar{B}$ events, and continuum ($e^+e^- \to q\bar{q}$, $q = u$, d, s, c) events. A threshold function [16] is used to describe the combinatorial and continuum backgrounds. To obtain a good description of the signal $m_{\rm ES}$ distribution, we adopt the modified Gaussian function used in Ref. [17] to account for energy losses of photons in the detector. Fits to the $m_{\rm ES}$ distribution are shown in Fig. 1. Semileptonic decays $\bar{B} \to X \ell \bar{\nu}$ of

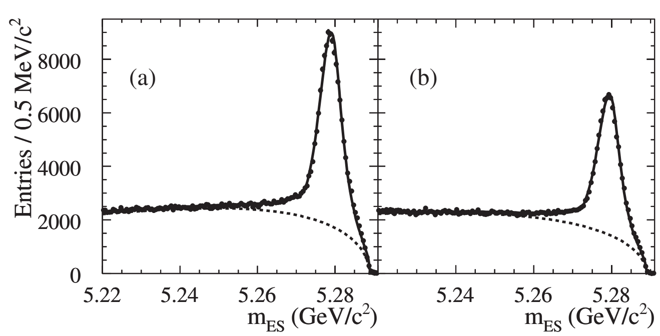

FIG. 1. The $m_{\rm ES}$ distribution for data (full circles) is shown together with the results of the fit (solid line) for selected semileptonic decays from B^+B^- events (a) and $B^0\bar{B}^0$ events (b). The dashed line shows the contribution from combinatorial and continuum background.

the $B_{\rm recoil}$ candidate are identified by an electron or muon with momentum, p^*_ℓ, defined in the $\bar{B}$ rest frame, greater than 1 GeV/c. For charged $B_{\rm reco}$ candidates, we require the charge of the lepton to be consistent with a prompt semileptonic $\bar{B}$ decay. For neutral $B_{\rm reco}$ candidates, both charge-flavor combinations are retained and the known average B^0-$\bar{B}^0$ mixing rate [18] is used to extract the prompt lepton yield.

The hadronic system X in the decay $\bar{B} \to X\ell\bar{\nu}$ is reconstructed from charged tracks and energy depositions in the calorimeter that are not associated with the $B_{\rm reco}$ candidate or the identified lepton. We reconstruct K^0_S by performing a mass-constrained fit to $\pi^+\pi^-$ pairs with an invariant mass in the range 0.473–0.523 GeV/c^2. The neutrino four-momentum p_ν is estimated from the missing momentum four-vector $p_{\rm miss} = p_{\Upsilon(4S)} - p_{B_{\rm reco}} - p_X - p_\ell$, where all momenta are measured in the laboratory frame and $p_{\Upsilon(4S)}$ refers to the $\Upsilon(4S)$ meson.

To select $\bar{B} \to X_u\ell\bar{\nu}$ candidates, we require exactly one charged lepton with $p^*_\ell > 1$ GeV/c, charge conservation ($Q_X + Q_\ell + Q_{B_{\rm reco}} = 0$), and a missing mass consistent with zero ($m^2_{\rm miss} < 0.5$ GeV$^2/c^4$). These criteria suppress the dominant $\bar{B} \to X_c\ell\bar{\nu}$ decays, many of which contain additional leptons or an undetected K^0_L meson. We suppress the $B \to D^*\ell\nu$ background by reconstructing the low momentum π^+ from the $D^{*+} \to D^0\pi^+$ decay. Since the momentum of the π^+ is almost collinear with the D^{*+} momentum $p_{D^{*+}}$, we can approximate the D^{*+} energy as $E_{D^{*+}} \simeq m_{D^{*+}} \times E_\pi/145$ MeV/c^2. The neutrino mass $m^2_{\rm veto} = (p_B - p_{D^{*+}} - p_\ell)^2$ is peaked at zero for background events. The requirement $m^2_{\rm veto} < -3$ GeV$^2/c^4$ reduces the $B \to D^*\ell\nu$ background by about 36% while keeping more than 90% of signal events. We reject events with charged kaons or K^0_S in the $B_{\rm recoil}$ to reduce the background from $\bar{B} \to X_c\ell\bar{\nu}$ decays.

To extract the distribution in the variables M_X, P_+, and the combination of M_X and q^2, we perform fits to the $B_{\rm reco}$ $m_{\rm ES}$ distributions for subsamples of events in individual bins for each of the variables, and subsequently separate the signal from the combinatorial and continuum backgrounds for the three distributions. The resulting distributions are presented in Fig. 2. To reduce the systematic uncertainties in the derivation of the branching fractions, we determine the ratios of the partial branching fractions to the total semileptonic branching fraction. This is done for restricted regions of phase space, $M_X < 1.55$ GeV/c^2, $P_+ < 0.66$ GeV/c, and ($M_X < 1.7$ GeV/c^2, $q^2 > 8.0$ GeV$^2/c^4$). Specifically, we define this ratio as

$$\frac{\Delta\mathcal{B}(X_u\ell\bar{\nu}_\ell)}{\mathcal{B}(X\ell\bar{\nu}_\ell)} = \frac{(N_u - N_u^{\rm out} - BG_u)/(\epsilon^u_{\rm sel}\epsilon^u_{\rm kin})}{(N_{\rm sl} - BG_{\rm sl})}\frac{\epsilon^{\rm sl}_\ell\epsilon^{\rm sl}_t}{\epsilon^u_\ell\epsilon^u_t}, \quad (1)$$

where N_u refers to the number of observed events, BG_u to the estimated number of background events, and $N_u^{\rm out}$ to the signal events that migrate from outside the kinematic region into the signal region. They are determined by a χ^2 fit to the measured spectra with signal and background shapes determined from MC simulation. $N_{\rm sl} = 181074 \pm 706$ and $BG_{\rm sl} = 12185 \pm 78$ are the number of semileptonic events, extracted with a $m_{\rm ES}$ fit, and the corresponding background, determined from simulation. The efficiency $\epsilon^u_{\rm sel}$ denotes the fraction of selected $B_{\rm reco}$-tagged signal events with a high-energy lepton. The model-dependent efficiency $\epsilon^u_{\rm kin}$ accounts for the loss of selected events generated in the kinematic region that migrate outside this region. The efficiency of the tag and lepton selection, ϵ_t and ϵ_ℓ, differ slightly for the signal and the semileptonic samples, due to differences in the lepton momentum distribution and the multiplicity of the recoiling B meson. To convert the ratio in Eq. (1) to partial branching fractions, we use the total semileptonic branch-

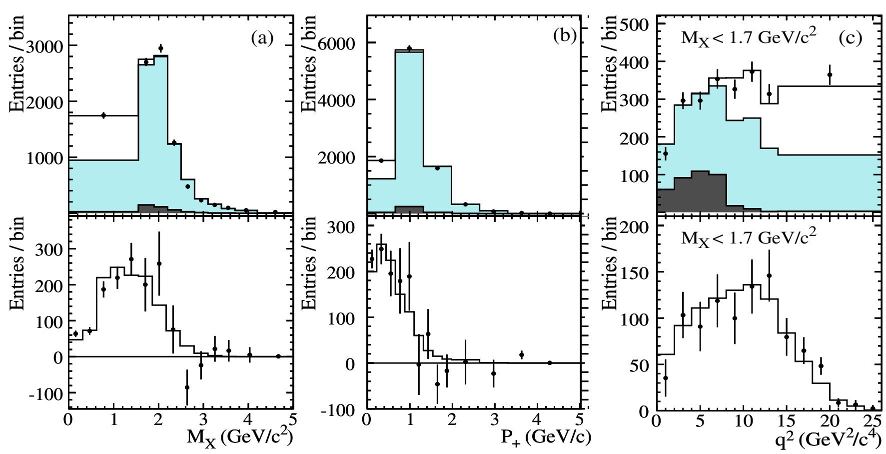

FIG. 2 (color online). Upper row: measured M_X (a), P_+ (b), and q^2 with $M_X < 1.7$ GeV/c^2 (c) spectra (data points). The result of the fit to the sum of three MC contributions is shown in the histograms: $\bar{B} \to X_u\ell\bar{\nu}$ decays generated inside (no shading) and outside (dark shading) the selected kinematic region, and $\bar{B} \to X_c\ell\bar{\nu}$ and other background (light shading). Lower row: corresponding spectra for $\bar{B} \to X_u\ell\bar{\nu}$ after $\bar{B} \to X_c\ell\bar{\nu}$ and other background subtraction; they have been rebinned in order to show the shape of the kinematic variables.

TABLE I. Summary of the fitted number of events and efficiencies, $\Delta\mathcal{B}(\bar{B}\to X_u\ell\bar{\nu})$, and extracted $|V_{ub}|$ for the three kinematic cuts. The first uncertainty is statistical, the second systematic. For $\Delta\mathcal{B}$, the third uncertainty is due to the theoretical knowledge of the signal efficiency; for the $|V_{ub}|$ values, it comes from the theoretical uncertainty on $\Delta\zeta$. For Ref. [4] we use the exponential parametrization of the shape function.

Method	N_u	$N_u^{\rm out}$	BG_u	$\epsilon^u_{\rm sel}\epsilon^u_{\rm kin}$	$\frac{\epsilon^{\rm sl}_\ell\epsilon^{\rm sl}_t}{\epsilon^u_\ell\epsilon^u_t}$	$\Delta\mathcal{B}(\bar{B}\to X_u\ell\bar{\nu})(10^{-3})$	$\lvert V_{ub}\rvert\times(10^{-3})$
M_X	803 ± 60	27 ± 2	923 ± 21	0.331 ± 0.003	0.76 ± 0.02	$1.18\pm0.09\pm0.07\pm0.01$	$4.27\pm0.16\pm0.13\pm0.30$ [4] $4.56\pm0.17\pm0.14\pm0.32$ [5]
P_+	633 ± 63	48 ± 5	1183 ± 27	0.344 ± 0.003	0.81 ± 0.02	$0.95\pm0.10\pm0.08\pm0.01$	$3.88\pm0.19\pm0.16\pm0.28$ [4] $3.99\pm0.20\pm0.16\pm0.24$ [5]
M_X, q^2	562 ± 55	32 ± 2	789 ± 9	0.353 ± 0.005	0.79 ± 0.03	$0.81\pm0.08\pm0.07\pm0.02$	$4.57\pm0.22\pm0.19\pm0.30$ [4] $4.64\pm0.23\pm0.19\pm0.25$ [5] $4.93\pm0.24\pm0.20\pm0.36$ [6]

ing fraction, $\mathcal{B}(\bar{B}\to X\ell\bar{\nu}_\ell) = (10.75\pm0.15)\%$ [18]. The resulting partial branching fractions for the three selected kinematic regions, along with parameters in Eq. (1), are listed in Table I. The statistical correlations between the M_X and (M_X, q^2), P_+ analyses are 65%, 67%, 38%, respectively.

We consider several sources of systematic uncertainties. Detector-related uncertainties take into account particle (e, μ, K) identification (efficiency, misidentification), charged particle tracking efficiency, photon reconstruction efficiency, and K_L^0 interactions. We estimate the uncertainty due to signal and background modeling. The uncertainty on the signal modeling is due to the modeling of exclusive charmless semileptonic decays and gluon splitting into $s\bar{s}$-quark pairs. We also calculate the uncertainties due to the nonperturbative parameters and the functional form of the shape function. The background simulation depends on the B and D branching fractions and $B\to D^*\ell\nu$ form factors; the corresponding systematic uncertainties are calculated by varying all these quantities within their experimental errors. We estimate the error due to $m_{\rm ES}$ fits, coming from the uncertainty in the parametrization ansatz. Finally, we estimate the error due to MC statistics. The fractional contribution of each uncertainty is shown in Table II together with the total error.

The results of the partial branching fractions are translated into $|V_{ub}|$ in the context of recent QCD calculations [4–6], including estimates of theoretical uncertainties (see Table I). The hadronic input parameters, the b-quark mass m_b and the kinetic energy expectation value μ_π^2, are extracted from moment measurements in $B\to X_s\gamma$ and $\bar{B}\to X_c\ell\bar{\nu}$. Their values in the kinetic scheme [19] are $m_b = (4.59\pm0.04)\ \mathrm{GeV}/c^2$ and $\mu_\pi^2 = (0.40\pm0.04)\ \mathrm{GeV}^2/c^2$ [20] and are translated into values in different schemes, as needed [4–6]. The partial branching fraction $\Delta\mathcal{B}(\bar{B}\to X_u\ell\bar{\nu})$ is related directly to $|V_{ub}|$ by the relation $|V_{ub}| = [\Delta\mathcal{B}(\bar{B}\to X_u\ell\bar{\nu})/\tau_b\Delta\zeta]^{1/2}$, where τ_b is the average B lifetime [18], and $\Delta\zeta$ is the prediction for the partial rate for $\bar{B}\to X_u\ell\bar{\nu}$ in the given phase-space region [4–6].

In summary, we have measured the branching fractions for inclusive charmless semileptonic B decays $\bar{B}\to X_u\ell\bar{\nu}$ in three overlapping regions of phase space. Relying on theoretical predictions, we extract values for the CKM matrix element $|V_{ub}|$ from our measured $\Delta\mathcal{B}$.

We find that the determinations of $|V_{ub}|$ agree at 1σ level in the BNLP [4] framework for the M_X and combined (M_X, q^2) analyses. The analysis based on P_+ differs from the two others at a 2.5σ level, as indicated also by other experiments [21]. The M_X analysis captures the largest portion of phase space and gives the most precise determination of $|V_{ub}|$. Within their stated theoretical uncertainties, the results based on BLNP and DGE [5] give consistent results. The result, based on the hadronic mass spectrum, supersedes our previously published measurement [3], reducing the relative uncertainty by 40%. These values are in good agreement with other inclusive $|V_{ub}|$ determinations, and they are somewhat higher, though compatible, than the results based on exclusive charmless semileptonic decays [18].

TABLE II. Contributions to the systematic uncertainty on the measured $\Delta\mathcal{B}(\bar{B}\to X_u\ell\bar{\nu})$, shown in percent (%) for the three kinematic cuts, from detector, shape function (input parameters and functional form), exclusive $\mathcal{B}(\bar{B}\to X_u\ell\bar{\nu})$, gluon splitting, exclusive $\mathcal{B}(\bar{B}\to X_c\ell\bar{\nu})$, $B\to D^*\ell^-\bar{\nu}$ form factors, $\mathcal{B}(D)$, $m_{\rm ES}$ fit, MC statistics. The last column gives the total systematic uncertainty.

Method	Detector	Shape function	$\mathcal{B}(\bar{B}\to X_u\ell\bar{\nu})$ $X_u=\pi,\rho,\ldots$	Gluon splitting	$\mathcal{B}(\bar{B}\to X_c\ell\bar{\nu})$	$B\to D^*\ell^-\bar{\nu}$ form factors	$\mathcal{B}(D)$	$m_{\rm ES}$ fit	Monte Carlo statistics	Total
M_X	1.92	0.90	2.08	1.62	0.87	0.21	0.44	3.71	3.22	6.07
P_+	3.88	1.31	2.22	1.47	2.80	0.39	0.73	3.98	4.62	8.38
M_X, q^2	3.83	2.43	2.71	1.02	1.17	0.55	0.79	5.17	4.29	8.81

We would like to thank the many theorists with whom we have had valuable discussions, in particular, J.R. Andersen, E. Gardi, B. Lange, Z. Ligeti, M. Neubert, and G. Paz. 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 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), MIST (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.

†Present address: Tel Aviv University, Tel Aviv, 69978, Israel.

‡Also at Università di Perugia, Dipartimento di Fisica, Perugia, Italy.

§Also at Università della Basilicata, Potenza, Italy.

‖Also at Universitat de Barcelona, Facultat de Fisica, Departament ECM, E-08028 Barcelona, Spain.

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

[2] We indicate with X the hadronic system in semileptonic B decays. We use the notation X_u and X_c when referring, respectively, to a charmless and charmed hadronic system.

[3] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **92**, 071802 (2004).

[4] B. O. Lange, M. Neubert, and G. Paz, Phys. Rev. D **72**, 073006 (2005).

[5] J.R. Andersen and E. Gardi, J. High Energy Phys. 01 (2006) 097.

[6] C. W. Bauer, Z. Ligeti, and M. Luke, Phys. Rev. D **64**, 113004 (2001).

[7] Charge-conjugate modes are implied throughout this Letter unless explicitly stated.

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

[9] D. Scora and N. Isgur, Phys. Rev. D **52**, 2783 (1995).

[10] F. De Fazio and M. Neubert, J. High Energy Phys. 06 (1999) 017.

[11] I. Caprini, L. Lellouch, and M. Neubert, Nucl. Phys. **B530**, 153 (1998).

[12] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **77**, 032002 (2008).

[13] J.L. Goity and W. Roberts, Phys. Rev. D **51**, 3459 (1995).

[14] T. Sjöstrand, Comput. Phys. Commun. **82**, 74 (1994).

[15] S. Agostinelli *et al.* (GEANT4 Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).

[16] H. Albrecht *et al.* (ARGUS Collaboration), Phys. Lett. B **318**, 397 (1993).

[17] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **74**, 091105 (2006).

[18] W. M. Yao *et al.* (Particle Data Group), J. Phys. G **33**, 1 (2006), and 2007 partial update for edition 2008.

[19] D. Benson, I. I. Bigi, and N. Uraltsev, Nucl. Phys. **B710**, 371 (2005).

[20] O.L. Buchmüller and H.U. Flächer, Phys. Rev. D **73**, 073008 (2006).

[21] I. Bizjak *et al.* (Belle Collaboration), Phys. Rev. Lett. **95**, 241801 (2005).