

Determination of $|V_{ub}|$ in inclusive semileptonic B meson decays

The *BABAR* Collaboration

August 13, 2004

Abstract

We present a preliminary determination of the CKM matrix element $|V_{ub}|$ based on the analysis of semileptonic B decays from a sample of 88 million $\mathcal{T}(4S)$ decays collected with the *BABAR* detector at the PEP-II e^+e^- storage ring. Charmless semileptonic B decays are selected using the electron energy E_e and the invariant mass q^2 of the electron-neutrino pair. The neutrino momentum is inferred from a measurement of the visible energy and momentum in the detector and knowledge of the e^+e^- beam momenta. The partial branching fraction is determined in a region of the q^2 - E_e plane where semileptonic B decays to charm are highly suppressed. The total charmless semileptonic branching fraction is extracted using a theoretical calculation based on the heavy quark expansion. Preliminary results yield $|V_{ub}| = (4.57 \pm 0.21 \pm 0.25 \pm 0.34 \pm_{-0.29}^{+0.59} \pm 0.22) \times 10^{-3}$ where the uncertainties are from statistics (data and MC), detector modeling, background modeling, the shape function, and the heavy quark operator product expansion, respectively.

Submitted to the 32nd International Conference on High-Energy Physics, ICHEP 04,
16 August—22 August 2004, Beijing, China

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

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

The BABAR Collaboration,

B. Aubert, R. Barate, D. Boutigny, F. Couderc, J.-M. Gaillard, A. Hicheur, Y. Karyotakis, J. P. Lees,
V. Tisserand, A. Zghiche

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

A. Palano, A. Pompili

Università di Bari, Dipartimento di Fisica and INFN, I-70126 Bari, Italy

J. C. Chen, N. D. Qi, G. Rong, P. Wang, Y. S. Zhu

Institute of High Energy Physics, Beijing 100039, China

G. Eigen, I. Ofte, B. Stugu

University of Bergen, Inst. of Physics, N-5007 Bergen, Norway

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

Lawrence Berkeley National Laboratory and University of California, Berkeley, CA 94720, USA

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

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

M. Fritsch, K. Goetzen, T. Held, H. Koch, B. Lewandowski, M. Pelizaeus, M. Steinke
Ruhr Universität Bochum, Institut für Experimentalphysik 1, D-44780 Bochum, Germany

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

University of Bristol, Bristol BS8 1TL, United Kingdom

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

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

A. Khan, P. Kyberd, L. Teodorescu

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

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

Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia

D. Best, M. Bruinsma, M. Chao, I. Eschrich, D. Kirkby, A. J. Lankford, M. Mandelkern, R. K. Mommsen,
W. Roethel, D. P. Stoker

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

C. Buchanan, B. L. Hartfiel

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

S. D. Foulkes, J. W. Gary, B. C. Shen, K. Wang

University of California at Riverside, Riverside, CA 92521, USA

- D. del Re, H. K. Hadavand, E. J. Hill, D. B. MacFarlane, H. P. Paar, Sh. Rahatlou, V. Sharma
University of California at San Diego, La Jolla, CA 92093, USA
- J. W. Berryhill, C. Campagnari, B. Dahmes, O. Long, A. Lu, M. A. Mazur, J. D. Richman, W. Verkerke
University of California at Santa Barbara, Santa Barbara, CA 93106, USA
- T. W. Beck, A. M. Eisner, C. A. Heusch, J. Kroseberg, W. S. Lockman, G. Nesom, T. Schalk,
B. A. Schumm, A. Seiden, P. Spradlin, D. C. Williams, M. G. Wilson
University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, CA 95064, USA
- J. Albert, E. Chen, G. P. Dubois-Felsmann, A. Dvoretzskii, D. G. Hitlin, I. Narsky, T. Piatenko,
F. C. Porter, A. Ryd, A. Samuel, S. Yang
California Institute of Technology, Pasadena, CA 91125, USA
- S. Jayatilleke, G. Mancinelli, B. T. Meadows, M. D. Sokoloff
University of Cincinnati, Cincinnati, OH 45221, USA
- T. Abe, F. Blanc, P. Bloom, S. Chen, W. T. Ford, U. Nauenberg, A. Olivas, P. Rankin, J. G. Smith,
J. Zhang, L. Zhang
University of Colorado, Boulder, CO 80309, USA
- A. Chen, J. L. Harton, A. Soffer, W. H. Toki, R. J. Wilson, Q. Zeng
Colorado State University, Fort Collins, CO 80523, USA
- D. Altenburg, T. Brandt, J. Brose, M. Dickopp, E. Feltresi, A. Hauke, H. M. Lacker, R. Müller-Pfefferkorn,
R. Nogowski, S. Otto, A. Petzold, J. Schubert, K. R. Schubert, R. Schwierz, B. Spaan, J. E. Sundermann
Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany
- D. Bernard, G. R. Bonneaud, F. Brochard, P. Grenier, S. Schrenk, Ch. Thiebaux, G. Vasileiadis, M. Verderi
Ecole Polytechnique, LLR, F-91128 Palaiseau, France
- D. J. Bard, P. J. Clark, D. Lavin, F. Muheim, S. Playfer, Y. Xie
University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom
- M. Andreotti, V. Azzolini, D. Bettoni, C. Bozzi, R. Calabrese, G. Cibinetto, E. Luppi, M. Negrini,
L. Piemontese, A. Sarti
Università di Ferrara, Dipartimento di Fisica and INFN, I-44100 Ferrara, Italy
- E. Treadwell
Florida A&M University, Tallahassee, FL 32307, USA
- F. Anulli, R. Baldini-Ferroli, A. Calcaterra, R. de Sangro, G. Finocchiaro, P. Patteri, I. M. Peruzzi,
M. Piccolo, A. Zallo
Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy
- A. Buzzo, R. Capra, R. Contri, G. Crosetti, M. Lo Vetere, M. Macri, M. R. Monge, S. Passaggio,
C. Patrignani, E. Robutti, A. Santroni, S. Tosi
Università di Genova, Dipartimento di Fisica and INFN, I-16146 Genova, Italy
- S. Bailey, G. Brandenburg, K. S. Chaisanguanthum, M. Morii, E. Won
Harvard University, Cambridge, MA 02138, USA

R. S. Dubitzky, U. Langenegger

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

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

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

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

University of Iowa, Iowa City, IA 52242, USA

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

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

M. Biasini, R. Covarelli, M. Pioppi

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

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

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

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

Lawrence Livermore National Laboratory, Livermore, CA 94550, USA

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

University of Liverpool, Liverpool L69 7ZE, United Kingdom

J. J. Back,¹ C. M. Cormack, P. F. Harrison,¹ F. Di Lodovico, G. B. Mohanty¹

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

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

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

D. Brown, C. L. Davis

University of Louisville, Louisville, KY 40292, USA

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

University of Manchester, Manchester M13 9PL, United Kingdom

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

University of Maryland, College Park, MD 20742, USA

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

University of Massachusetts, Amherst, MA 01003, USA

¹Now at Department of Physics, University of Warwick, Coventry, United Kingdom

R. Cowan, G. Sciolla, S. J. Sekula, F. Taylor, R. K. Yamamoto
Massachusetts Institute of Technology, Laboratory for Nuclear Science, Cambridge, MA 02139, USA

D. J. J. Mangeol, P. M. Patel, S. H. Robertson
McGill University, Montréal, QC, Canada H3A 2T8

A. Lazzaro, V. Lombardo, F. Palombo
Università di Milano, Dipartimento di Fisica and INFN, I-20133 Milano, Italy

J. M. Bauer, L. Cremaldi, V. Eschenburg, R. Godang, R. Kroeger, J. Reidy, D. A. Sanders, D. J. Summers,
H. W. Zhao
University of Mississippi, University, MS 38677, USA

S. Brunet, D. Côté, P. Taras
Université de Montréal, Laboratoire René J. A. Lévesque, Montréal, QC, Canada H3C 3J7

H. Nicholson
Mount Holyoke College, South Hadley, MA 01075, USA

N. Cavallo,² F. Fabozzi,² C. Gatto, L. Lista, D. Monorchio, P. Paolucci, D. Piccolo, C. Sciacca
Università di Napoli Federico II, Dipartimento di Scienze Fisiche and INFN, I-80126, Napoli, Italy

M. Baak, H. Bulten, G. Raven, H. L. Snoek, L. Wilden
*NIKHEF, National Institute for Nuclear Physics and High Energy Physics, NL-1009 DB Amsterdam,
The Netherlands*

C. P. Jessop, J. M. LoSecco
University of Notre Dame, Notre Dame, IN 46556, USA

T. Allmendinger, K. K. Gan, K. Honscheid, D. Hufnagel, H. Kagan, R. Kass, T. Pulliam, A. M. Rahimi,
R. Ter-Antonyan, Q. K. Wong
Ohio State University, Columbus, OH 43210, USA

J. Brau, R. Frey, O. Igonkina, C. T. Potter, N. B. Sinev, D. Strom, E. Torrence
University of Oregon, Eugene, OR 97403, USA

F. Colecchia, A. Dorigo, F. Galeazzi, M. Margoni, M. Morandin, M. Posocco, M. Rotondo, F. Simonetto,
R. Stroili, G. Tiozzo, C. Voci
Università di Padova, Dipartimento di Fisica and INFN, I-35131 Padova, Italy

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

P. F. Manfredi, V. Re
Università di Pavia, Dipartimento di Elettronica and INFN, I-27100 Pavia, Italy

²Also with Università della Basilicata, Potenza, Italy

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

University of Pennsylvania, Philadelphia, PA 19104, USA

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

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

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

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

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

Princeton University, Princeton, NJ 08544, USA

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

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

S. Christ, G. Wagner, R. Waldi

Universität Rostock, D-18051 Rostock, Germany

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

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

R. Aleksan, S. Emery, A. Gaidot, S. F. Ganzhur, P.-F. Giraud, G. Hamel de Monchenault, W. Kozanecki,
M. Legendre, G. W. London, B. Mayer, G. Schott, G. Vasseur, Ch. Yèche, M. Zito

DSM/Daphnia, CEA/Saclay, F-91191 Gif-sur-Yvette, France

M. V. Purohit, A. W. Weidemann, J. R. Wilson, F. X. Yumiceva

University of South Carolina, Columbia, SC 29208, USA

D. Aston, R. Bartoldus, N. Berger, A. M. Boyarski, O. L. Buchmueller, R. Claus, M. R. Convery,
M. Cristinziani, G. De Nardo, D. Dong, J. Dorfan, D. Dujmic, W. Dunwoodie, E. E. Elsen, S. Fan,
R. C. Field, T. Glanzman, S. J. Gowdy, T. Hadig, V. Halyo, C. Hast, T. Hryn'ova, W. R. Innes,
M. H. Kelsey, P. Kim, M. L. Kocian, D. W. G. S. Leith, J. Libby, S. Luitz, V. Luth, H. L. Lynch,
H. Marsiske, S. Menke, R. Messner, D. R. Muller, C. P. O'Grady, V. E. Ozcan, A. Perazzo, M. Perl,
S. Petrak, B. N. Ratcliff, A. Roodman, A. A. Salnikov, R. H. Schindler, J. Schwiening, G. Simi, A. Snyder,
A. Soha, J. Stelzer, D. Su, M. K. Sullivan, J. Va'vra, S. R. Wagner, M. Weaver, A. J. R. Weinstein,
W. J. Wisniewski, M. Wittgen, D. H. Wright, A. K. Yarritu, C. C. Young

Stanford Linear Accelerator Center, Stanford, CA 94309, USA

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

Stanford University, Stanford, CA 94305-4060, USA

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

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

³Also with IFIC, Instituto de Física Corpuscular, CSIC-Universidad de Valencia, Valencia, Spain

⁴Also with Princeton University, Princeton, USA

W. Bugg, M. Krishnamurthy, S. M. Spanier
University of Tennessee, Knoxville, TN 37996, USA

R. Eckmann, H. Kim, J. L. Ritchie, A. Satpathy, R. F. Schwitters
University of Texas at Austin, Austin, TX 78712, USA

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

F. Bianchi, M. Bona, F. Gallo, D. Gamba
Università di Torino, Dipartimento di Fisica Sperimentale and INFN, I-10125 Torino, Italy

L. Bosisio, C. Cartaro, F. Cossutti, G. Della Ricca, S. Dittongo, S. Grancagnolo, L. Lanceri, P. Poropat,⁵
L. Vitale, G. Vuagnin
Università di Trieste, Dipartimento di Fisica and INFN, I-34127 Trieste, Italy

R. S. Panvini
Vanderbilt University, Nashville, TN 37235, USA

Sw. Banerjee, C. M. Brown, D. Fortin, P. D. Jackson, R. Kowalewski, J. M. Roney, R. J. Sobie
University of Victoria, Victoria, BC, Canada V8W 3P6

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

M. G. Greene, H. Neal
Yale University, New Haven, CT 06511, USA

⁵Deceased

1 INTRODUCTION

The study of the weak interactions of quarks has played a crucial role in the development of the Standard Model (SM), which embodies our understanding of the fundamental interactions. The increasingly precise measurements of CP-violating asymmetries in B decays allow stringent experimental tests of the SM mechanism for CP violation [1] via the non-trivial phase in the Cabibbo-Kobayashi-Maskawa (CKM) matrix. Improved determinations of $|V_{ub}|$, the coupling strength of the b quark to the u quark, will improve the sensitivity of experimental tests of the SM description of CP violation.

Early determinations [2] of $|V_{ub}|$ were based on the study of the lepton momentum spectrum near the kinematic endpoint in semileptonic B decays, where the background from the dominant decay chain⁶ $b \rightarrow ce\bar{\nu}$ is kinematically forbidden. See Ref. [3] for more recent measurements using this method. This technique provides precise measurements of the partial branching fraction for lepton momenta⁷ above ~ 2.3 GeV/ c , but accepts only $\sim 10\%$ of the $b \rightarrow ue\bar{\nu}$ rate, resulting in a substantial theoretical uncertainty in the determination of $|V_{ub}|$. The major part of this uncertainty comes from limited knowledge of the “shape function” (SF), i.e. the distribution of the b quark momentum inside the B meson [4]. These uncertainties can be reduced by measuring the energy spectrum of photons from the decay $b \rightarrow s\gamma$ [4, 5], but this is very challenging [6].

Recently, measurements of $|V_{ub}|$ that use the invariant mass m_X of the hadronic system in semileptonic B decays have appeared [7, 8]. The use of m_X to select $b \rightarrow ue\bar{\nu}$ decays results in a much higher acceptance ($\sim 70\%$) of the decay rate. It is, however, experimentally challenging, since the association of particles with the semileptonic B decay is rendered difficult by the presence of the decay products of the \bar{B} in the event. These measurements also have significant SF uncertainties.

In this analysis a new approach [9] is taken to the determination of $|V_{ub}|$. Semileptonic B decays are selected using energetic electrons and simultaneously making requirements on q^2 , the invariant mass squared of the $e\bar{\nu}$ pair. The neutrino 4-momentum is reconstructed from the visible 4-momentum and knowledge of the e^+e^- initial state. The dominant charm background is then suppressed by selecting a region of the $q^2 - E_e$ phase space where properly reconstructed $b \rightarrow ce\bar{\nu}$ events are kinematically excluded. The fraction of the $b \rightarrow ue\bar{\nu}$ phase space accepted is $\sim 20\%$. The amount of background events remaining in the signal region due to resolution effects is evaluated in Monte Carlo simulations. The determination of $|V_{ub}|$ in this method is sensitive to the b quark mass through both the heavy quark operator product expansion [10] (HQE) and the SF, but has little sensitivity to Fermi motion as described below.

2 DATASET AND SIMULATION

The data used in this analysis were collected with the *BABAR* detector at the PEP-II asymmetric-energy e^+e^- storage ring between 2000 and 2002. The *BABAR* detector is described in detail elsewhere [11]. A sample of 81.4fb^{-1} collected at the $\Upsilon(4S)$ resonance, corresponding to 88.4 million $B\bar{B}$ pairs, is used along with 9.6fb^{-1} collected at center-of-mass energies approximately 40 MeV below $B\bar{B}$ threshold. The data below $B\bar{B}$ threshold, scaled in cross-section and luminosity, and whose particles are scaled in energy, are used to subtract the non- $B\bar{B}$ contributions from the data collected on the $\Upsilon(4S)$ resonance. Simulated $B\bar{B}$ events are used in estimating efficiencies and backgrounds. Branching fractions and form factors are taken from Ref. [12] in most cases.

⁶Throughout this paper, whenever a mode is given, the charge conjugate is also implied.

⁷Throughout this paper, quantities are given in the $\Upsilon(4S)$ rest frame unless stated otherwise.

Branching fractions for the semileptonic B decays to charm are adjusted as described below. The simulation of charmless semileptonic B decays is based on the model described in Ref. [13], which calculates the triple differential decay rate to order α_S and convolutes it with a shape function parameterized as

$$F(k_+) = N(1-x)^a e^{(1+a)x}, \quad x \equiv \frac{k_+}{m_B - m_b^{\text{SF}}} \leq 1,$$

where k_+ is the residual b -quark momentum, to account for the non-perturbative interactions of the b quark within the B meson. We use [14] $m_b^{\text{SF}} = 4.735 \text{ GeV}/c^2$ and $a = 1.6$. This model produces a spectrum of hadronic masses m_X down to $2m_\pi$ that does not contain any resonant states. Subsequent fragmentation of the mesons was simulated via JETSET [15]. Decays to low-mass hadrons (π , η , ρ , ω , η') are simulated separately, using the form factor model of Ref. [16], and mixed with the non-resonant states in such a way as to keep the m_X , q^2 and E_e spectral distributions the same as in the inclusive model.

3 ANALYSIS METHOD

Events are selected based on the presence of an identified electron with energy $E_e > 2 \text{ GeV}$ using the criteria given in Ref. [17]. Electrons from the decay $J/\psi \rightarrow e^+e^-$ are vetoed. The criteria given in Ref. [17] for selecting hadronic events and rejecting radiative Bhabha events are applied. Within these events the total visible 4-momentum p_{vis} is determined using charged tracks emanating from the collision point, identified pairs of charged tracks from $K_S^0 \rightarrow \pi^+\pi^-$, $\Lambda \rightarrow p\pi^-$ and $\gamma \rightarrow e^+e^-$, and energy deposits in the electromagnetic calorimeter. Each charged particle is assigned a mass hypothesis based on particle identification information. Only those calorimeter clusters unassociated with a charged track and which have a lateral energy spread consistent with photons are considered. Energy deposits due to long-lived neutral hadrons are not efficiently rejected by these criteria and are treated as coming from massless particles in the 4-vector sum. We form the missing 4-momentum $p_{\text{miss}} = p_{e^+e^-} - p_{\text{vis}}$, where $p_{e^+e^-}$ is the 4-vector of the initial state. The 4-vector $p_\nu = (\mathbf{P}_\nu, |\mathbf{P}_\nu|)$ is used as an estimate of the momentum of the neutrino from the decay $b \rightarrow ue\bar{\nu}$, where \mathbf{P}_ν is derived from \mathbf{P}_{miss} by applying a bias correction that was determined from Monte Carlo signal events. Additional requirements are made to improve the quality of the neutrino reconstruction and suppress contributions from $e^+e^- \rightarrow q\bar{q}$ continuum events. Each event must satisfy (1) no additional identified leptons, (2) $-0.95 < \cos\theta_{\text{miss}} < 0.8$, (3) $0.0 < E_{\text{miss}} - |\mathbf{P}_{\text{miss}}|c < 0.8 \text{ GeV}$, (4) $0.0 < |\mathbf{P}_{\text{miss}}| < 2.5 \text{ GeV}/c$ and (5) $|\mathbf{P}_e \cdot \mathbf{T}| < 0.75 |\mathbf{P}_e| |\mathbf{T}|$, where θ_{miss} is the angle of the missing momentum vector with respect to the beam axis, and \mathbf{T} is the thrust vector for the event, excluding the signal electron candidate. The large background from $b \rightarrow ce\bar{\nu}$ decays is then suppressed by calculating $q^2 = (p_e + p_\nu)^2$ and computing the maximum kinematically allowed hadronic mass squared, s_h^{max} , for a given E_e and q^2 . In the case where $\pm E_e > \pm \frac{\sqrt{q^2}}{2} \left(\frac{1 \pm \beta}{1 \mp \beta} \right)$, the maximum invariant hadronic mass squared is

$$s_h^{\text{max}} = m_B^2 + q^2 - 2m_B E_e \sqrt{\frac{1 \mp \beta}{1 \pm \beta}} - 2m_B \left(\frac{q^2}{4E_e} \right) \sqrt{\frac{1 \pm \beta}{1 \mp \beta}}, \quad (1)$$

otherwise

$$s_h^{\text{max}} = m_B^2 + q^2 - 2m_B \sqrt{q^2},$$

where $\beta = 0.06$ is the boost of the B meson in the $\Upsilon(4S)$ frame. We require $s_h^{\text{max}} < 3.5 \text{ GeV}^2/c^4 \simeq m_D^2$. Figure 1 shows the distribution of generated $b \rightarrow ce\bar{\nu}$ and $b \rightarrow ue\bar{\nu}$ decays in the q^2 - E_e plane

and indicates the contour corresponding to $s_h^{\max} = m_D^2$. The requirements for E_e and s_h^{\max} as well as criteria (1)–(5) were optimized to minimize the total (experimental and theoretical) uncertainty on $\mathcal{B}(b \rightarrow ue\bar{\nu})$.

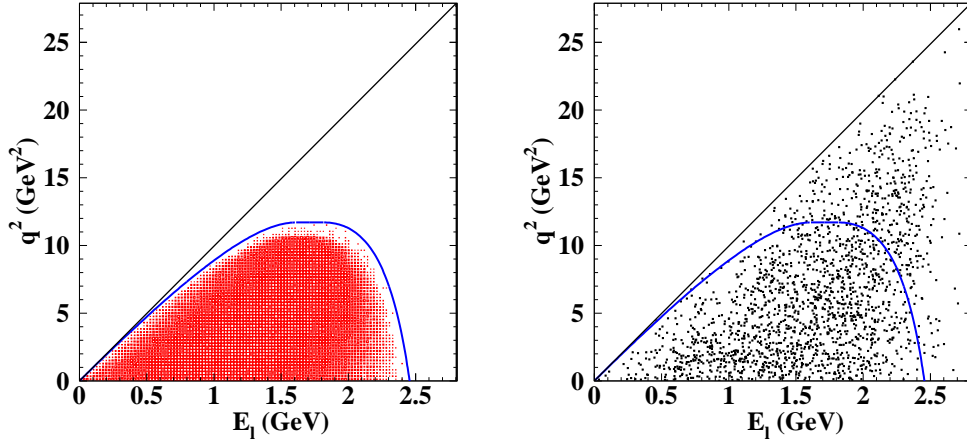


Figure 1: Distribution of q^2 versus E_e for generated $b \rightarrow ce\bar{\nu}$ (left) and $b \rightarrow ue\bar{\nu}$ (right) events in the $\Upsilon(4S)$ rest frame. The curved contour corresponds to $s_h^{\max} = m_D^2$ and the diagonal line to $s_h^{\max} = 0 \text{ GeV}^2/c^4$.

The quality of the neutrino reconstruction was evaluated using a control sample ($De\bar{\nu}$) consisting of $\sim 90,000$ decays of the type $\bar{B} \rightarrow D^0 e\bar{\nu}(X)$ where the D^0 is reconstructed in the $K^-\pi^+$ decay mode and satisfies $|\mathbf{P}_{D^0}| > 0.5 \text{ GeV}/c$ and the electron satisfies $E_e > 1.4 \text{ GeV}$. The D^0 - e combination must satisfy $-2.5 < \cos\theta_{B-D^0e} < 1.1$ where $\cos\theta_{B-D^0e} = (2E_B E_{D^0e} - m_B^2 - m_{D^0e}^2)/(2|\mathbf{P}_B||\mathbf{P}_{D^0e}|)$ is the cosine of the angle between the vector momenta of the B and the D^0 - e system under the assumption that the only missing particle in the B decay is a single neutrino. This criterion selects both $\bar{B} \rightarrow D^0 e\bar{\nu}$ and $\bar{B} \rightarrow D^{*} e\bar{\nu}$, $D^{*} \rightarrow D^0(\pi, \gamma)$ decays with high efficiency while rejecting other sources of D^0 - e combinations. The additional requirements made on the semileptonic B decay in the control sample selection differ from the signal selection, where only the electron is required. However, in neither case are any requirements made on the decay of the other B , leaving its properties the same in both samples. An estimate of the neutrino energy can be formed from the known B energy and the measured D^0 and electron energies. A second estimate of the neutrino energy is given by the $|\mathbf{P}_\nu|$ defined above. In simulation the first (second) estimate for the true neutrino energy has a bias of 0.014 (0.271) GeV and an r.m.s. of 0.202 (0.359) GeV for $De\bar{\nu}$ events. Subtracting the first estimate from the second gives the distribution shown in Figure 2, from which we find a mean (sigma) of 0.109 (0.433) GeV on data and 0.107 (0.427) GeV on MC, indicating that the missing energy from the other B decay is well modeled. The distribution of $|\mathbf{P}_{\text{miss}}|$, also shown in Figure 2, is sensitive to both the modeling of the semileptonic $b \rightarrow ce\bar{\nu}$ decays and of missing energy, and shows good agreement with the simulation.

The $De\bar{\nu}$ control sample was also used to improve the modeling of the $b \rightarrow ce\bar{\nu}$ decays as follows. A binned χ^2 fit in the variables $|\mathbf{P}_D|$, E_e and $\cos\theta_{B-D^0e}$ ⁸ is performed on the $De\bar{\nu}$ sample after subtracting continuum and combinatorial background. The fit determines scale factors for the MC components $\bar{B} \rightarrow De\bar{\nu}$, $\bar{B} \rightarrow D^{*} e\bar{\nu}$ and other contributions, of which 85% are $\bar{B} \rightarrow D^{**} e\bar{\nu}$

⁸The $\cos\theta_{B-D^0e}$ requirements were relaxed to $-10 < \cos\theta_{B-D^0e} < 5$.

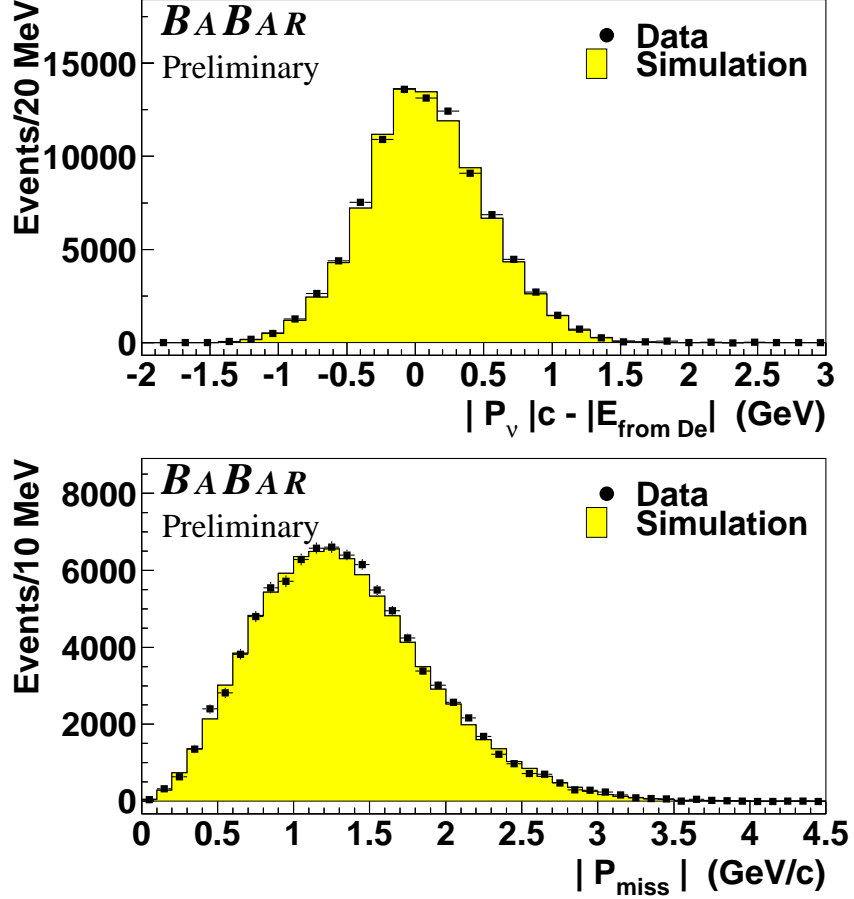


Figure 2: The top plot shows the difference between the two neutrino energy estimates described in the text for continuum-subtracted data and $B\bar{B}$ MC. The bottom plot shows the $|\mathbf{P}_{\text{miss}}|$ distribution for the $De\bar{\nu}$ control sample.

(P-wave charm mesons) or $\bar{B} \rightarrow D^{(*)}\pi e\bar{\nu}$; the remainder comes from $\bar{B} \rightarrow D\bar{D}$ decays and from misidentified electrons. Updated branching fractions are obtained by requiring the total $b \rightarrow ce\bar{\nu}$ branching fraction to equal the measured value [18]. The fit raises the branching fractions relative to those of Ref. [12] for $\bar{B} \rightarrow De\bar{\nu}$ and $\bar{B} \rightarrow D^*e\bar{\nu}$ and lowers the remaining contributions. Given the large uncertainty in the composition of the high mass charm states in semileptonic B decay, this procedure cannot be considered a measurement of the branching fractions, but rather a means of improving the simulation of inclusive quantities in $b \rightarrow ce\bar{\nu}$ decays. We find an improved agreement between data and MC in kinematic distributions (E_e , \mathbf{P}_{miss} , q^2 , s_h^{max}) in the inclusive electron sample using the fitted branching fractions. These revised branching fractions are used to determine the $b \rightarrow ce\bar{\nu}$ background in the inclusive electron sample.

The signal region $E_e > 2$ GeV and $s_h^{\text{max}} < 3.5$ GeV²/c⁴ was not examined until all selection criteria were fixed based on studies of simulated data and of control samples. Two control samples are used to reduce the sensitivity of the efficiency and background estimates to details of the simulation: (a) the $De\bar{\nu}$ control sample described above; and (b) events satisfying the normal selection criteria but having $s_h^{\text{max}} > 4.25$ GeV²/c⁴ (high- s_h^{max} sideband), a sample dominated by

background. Efficiencies can be calculated, separately in data and MC, from the ratio of $De\bar{\nu}$ candidates satisfying cuts (1)-(5) to the total number of selected $De\bar{\nu}$ candidates having $E_e > 2.0$ GeV. The sensitivity of the $b \rightarrow ue\bar{\nu}$ signal efficiency to details of the simulation is reduced by multiplying it by the data/simulation ratio of $De\bar{\nu}$ efficiencies. The high- s_h^{\max} sideband is used to normalize the Monte Carlo s_h^{\max} distribution to the data, reducing sensitivity to background normalization uncertainties. The total charmless semileptonic branching fraction is calculated as

$$\mathcal{B}(b \rightarrow ue\bar{\nu}) = \frac{N_{\text{cand}}^{\text{data}} - M_{\text{bkg}}^{\text{MC}} \frac{N_{\text{side}}^{\text{data}}}{M_{\text{side}}^{\text{MC}}}}{2 \epsilon_u^{\text{MC}} \frac{\epsilon_{De\bar{\nu}}^{\text{data}}}{\epsilon_{De\bar{\nu}}^{\text{MC}}} N_{B\bar{B}}}, \quad (2)$$

where $N_{\text{cand}}^{\text{data}}$ and $N_{\text{side}}^{\text{data}}$ refer to the number of candidates in the signal and high- s_h^{\max} sideband regions of the data after subtraction of non- $B\bar{B}$ contributions determined on data taken below the $B\bar{B}$ threshold, $M_{\text{bkg}}^{\text{MC}}$ and $M_{\text{side}}^{\text{MC}}$ refer to background in the signal region and the yield in the sideband region in simulated events, $\epsilon_{De\bar{\nu}}^{\text{data}}$ and $\epsilon_{De\bar{\nu}}^{\text{MC}}$ are the efficiencies calculated on the corresponding $De\bar{\nu}$ samples, pseudo-efficiency of the event selection determined from the data and Monte Carlo $De\bar{\nu}$ control sample events, $N_{B\bar{B}}$ is the number of $\Upsilon(4S) \rightarrow B\bar{B}$ decays analyzed. The total efficiency times acceptance for $b \rightarrow ue\bar{\nu}$ decays in the simulation is given by $\epsilon_u^{\text{MC}} = \epsilon_{\text{sig}} f_u + \epsilon_{\overline{\text{sig}}} (1 - f_u)$, where f_u is the fraction of $b \rightarrow ue\bar{\nu}$ decays generated in the signal region, and ϵ_{sig} ($\epsilon_{\overline{\text{sig}}}$) is the efficiency for an event inside (outside) the signal region to be reconstructed and pass our selection requirements.

The effects of detector response and the boost of the B meson in the $\Upsilon(4S)$ frame are unfolded to produce a partial branching fraction that can be compared directly to theoretical calculations. We define

$$\Delta\mathcal{B}(b \rightarrow ue\bar{\nu}) \equiv \mathcal{B}(b \rightarrow ue\bar{\nu}) f_u \quad (3)$$

$$\begin{aligned} &= \frac{N_{\text{cand}}^{\text{data}} - M_{\text{bkg}}^{\text{MC}} \frac{N_{\text{side}}^{\text{data}}}{M_{\text{side}}^{\text{MC}}}}{2 \frac{\epsilon_{De\bar{\nu}}^{\text{data}}}{\epsilon_{De\bar{\nu}}^{\text{MC}}} N_{B\bar{B}}} \frac{f_u}{(\epsilon_{\text{sig}} f_u + \epsilon_{\overline{\text{sig}}} (1 - f_u))} \\ &= \frac{N_{\text{cand}}^{\text{data}} - M_{\text{bkg}}^{\text{MC}} \frac{N_{\text{side}}^{\text{data}}}{M_{\text{side}}^{\text{MC}}}}{2 \epsilon_{\text{sig}} \frac{\epsilon_{De\bar{\nu}}^{\text{data}}}{\epsilon_{De\bar{\nu}}^{\text{MC}}} N_{B\bar{B}}} \left[1 + \left(\frac{1}{f_u} - 1 \right) \frac{\epsilon_{\overline{\text{sig}}}}{\epsilon_{\text{sig}}} \right]^{-1}. \end{aligned} \quad (4)$$

Whereas the extraction of the total branching fraction $\mathcal{B}(b \rightarrow ue\bar{\nu})$ has a strong dependence on the signal modeling due to the theoretical uncertainty on f_u , this dependence is suppressed in computing the unfolded partial branching fraction $\Delta\mathcal{B}(b \rightarrow ue\bar{\nu})$ since the ratio $\epsilon_{\overline{\text{sig}}}/\epsilon_{\text{sig}} \approx 0.029$ is much smaller than 1 (see Table 1).

Figure 3 shows the electron energy and s_h^{\max} distributions after cuts have been applied to all variables except the one being plotted. The yields and efficiencies are given in Table 1; these correspond to a branching fraction of $(2.37 \pm 0.22_{\text{(stat)}}) \times 10^{-3}$ using Eq. 2. We calculate the partial branching fraction $\Delta\mathcal{B}$ for $E_e > 1.9$ GeV in the B rest frame, which corresponds to $E_e > 2.0$ GeV in the $\Upsilon(4S)$ rest frame, and $s_h^{\max}(\beta = 0) < 3.5$ GeV²/c⁴, unfolded for detector effects. We find $\Delta\mathcal{B}(b \rightarrow ue\bar{\nu}) = (4.51 \pm 0.42_{\text{(stat)}}) \times 10^{-4}$.

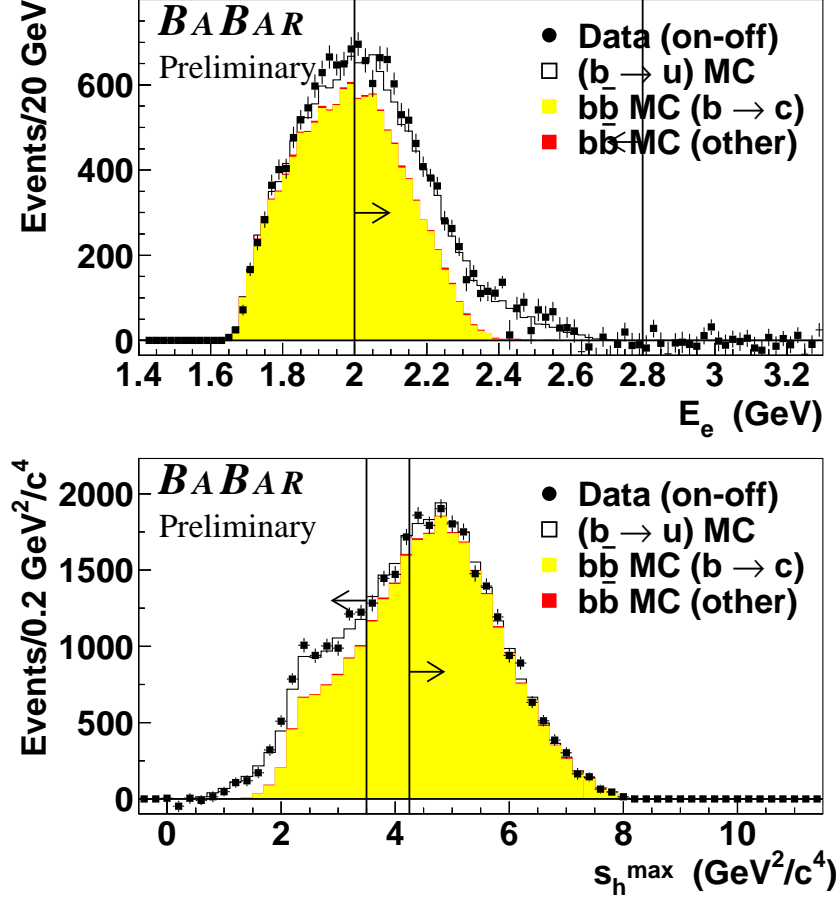


Figure 3: The electron energy distribution (top) and s_h^{\max} distribution (bottom) after cuts have been applied to all variables except the one being plotted. The arrows denote the signal region and also the high- s_h^{\max} sideband region (above $4.25 \text{ GeV}^2/c^4$). The number of background events from cascade decays and mis-identified electrons is small (events denoted as other).

Table 1: Yields and efficiencies. All uncertainties are statistical except for on $N_{B\bar{B}}$.

Data	N_{cand} 8417 ± 164	N_{side} 17776 ± 195	$\epsilon_{De\bar{\nu}}^{\text{data}}(\%)$ 8.72 ± 0.52	$N_{B\bar{B}} (10^6)$ 88.35 ± 0.97		
MC	M_{bkg} 5687 ± 47	M_{side} 17904 ± 81	$\epsilon_{De\bar{\nu}}^{\text{MC}}(\%)$ 9.18 ± 0.22	$\epsilon_{\text{sig}}(\%)$ 3.26 ± 0.03	$\epsilon_{\text{sig}}^{-1}(\%)$ 0.095 ± 0.003	f_u 0.1907 ± 0.0002

4 SYSTEMATIC STUDIES

Systematic uncertainties are assigned for the modeling of the signal $b \rightarrow ue\bar{\nu}$ decays and background decays, and the modeling of detector response. The leading sources of uncertainty are listed in Table 2. Detector modeling for charged particle tracking, neutral reconstruction and charged

particle identification was evaluated by comparing data and MC in control samples. The simulated production rate of K_L^0 was verified by comparing data and MC momentum distributions for K_S^0 in semileptonic decays, and the energy deposition of K_L^0 in the calorimeter was varied by a generous amount ($\pm 50\%$) to assess the corresponding uncertainty. The uncertainty due to Bremsstrahlung in the detector was based on the method used in Ref. [18]. QED final state radiation was simulated using PHOTOS [19]; comparisons with the analytical result of Ref. [20] were used to assess the systematic uncertainty. The uncertainty in the background was evaluated by varying the form factors and branching fractions of the $b \rightarrow ce\bar{\nu}$ decays. An additional uncertainty of 12% was added to account for the variation in the extracted branching fraction when the cut on E_e was varied from 1.8 GeV to 2.2 GeV. The modeling of signal decays is sensitive to the resonant structure at low mass. The exclusive branching fractions $\mathcal{B}(\bar{B} \rightarrow h e \bar{\nu})$, where $h = \pi, \eta, \rho, \omega, \eta'$, were varied coherently by $\pm 30\%$ to evaluate the uncertainty which proved to be negligible. The sensitivity of the branching fraction to the parameters m_b^{SF} and a of the De Fazio–Neubert model [13] was evaluated using uncertainties based on fits [14] to the $b \rightarrow s\gamma$ spectrum [6], leading to $f_u = 0.190^{+0.048}_{-0.024}$.

Table 2: Systematic uncertainties on $\mathcal{B}(b \rightarrow ue\bar{\nu})$ and $\Delta\mathcal{B}(b \rightarrow ue\bar{\nu})$.

Source of Systematics	$\delta\mathcal{B}$ (%)	$\delta(\Delta\mathcal{B})$ (%)
1a) Tracking efficiency	± 2.7	± 2.6
2a) Electron ID efficiency	$+3.1$ -2.7	$+3.1$ -2.7
3a) Charged particle ID	$+2.0$ -2.7	$+2.0$ -2.6
4a) Bremsstrahlung	$+2.2$ -1.3	$+2.6$ -0.7
5a) Neutrals reconstruction	± 6.3	± 6.4
6a) Energy from K_L^0	$+7.1$ -7.6	$+7.1$ -7.6
7a) B counting	± 1.1	± 1.1
A) Experimental systematics	± 10.9	± 11.0
1b) $B \rightarrow X_c \ell \nu$ simulation	$+6.5$ -7.5	± 7.5
2b) Radiative corrections	$+4.0$ -3.1	$+4.5$ -2.6
3b) Stability scans	± 12	± 12
B) Background simulation	± 14.4	± 14.6
C) Signal simulation	$+25.4$ -12.5	± 4.6
Total (A \oplus B \oplus C)	$+31.2$ -22.0	± 18.8

5 RESULTS

Using 88 million $\Upsilon(4S)$ decays collected with the *BABAR* detector at the PEP-II e^+e^- storage ring, the charmless semileptonic branching fraction is determined using the method of Ref. [9]. The unfolded partial branching fraction is determined in the B rest frame for $E_e > 1.9$ GeV and $s_h^{\text{max}}(\beta = 0) < 3.5$ GeV $^2/c^4$:

$$\Delta\mathcal{B}(b \rightarrow ue\bar{\nu}) = (4.51 \pm 0.42 \pm 0.50 \pm 0.66 \pm 0.19) \times 10^{-4} \text{ (preliminary).}$$

The uncertainties are from statistics (data and MC), detector modeling, background modeling and the modeling of $b \rightarrow ue\bar{\nu}$ decays, respectively. This partial branching fraction can be directly compared with theoretical calculations. We also determine

$$\mathcal{B}(b \rightarrow ue\bar{\nu}) = \left(2.37 \pm 0.22 \pm 0.26 \pm 0.34_{-0.30}^{+0.60}\right) \times 10^{-3} \text{ (preliminary),}$$

where the uncertainties are from statistics (data and MC), detector modeling, background modeling and the SF parameters m_b^{SF} and a , respectively. The uncertainty due to the modeling of resonant states in $b \rightarrow ue\bar{\nu}$ decays is negligible compared to the other uncertainties.

We extract $|V_{ub}|$ from our measurement using [21]

$$|V_{ub}| = 0.00424 \sqrt{\frac{\mathcal{B}_{b \rightarrow ue\bar{\nu}}}{0.002} \frac{1.61 \text{ ps}}{\tau_B}} (1 \pm 0.028_{\text{pert}} \pm 0.039_{1/m_b^3}),$$

where the first coefficient and the uncertainties quoted in Ref. [21] have been updated using the experimental input from the moment measurements obtained in Refs. [18, 22, 23]. The first coefficient takes also into account electroweak radiative corrections [24].

Taking $\tau_B = 1.604 \pm 0.012 \text{ ps}$ from [25] we find

$$|V_{ub}| = (4.57 \pm 0.21 \pm 0.25 \pm 0.34_{-0.29}^{+0.59} \pm 0.22) \times 10^{-3} \text{ (preliminary),}$$

where the first four uncertainties are as for the total branching fraction and the last comes from the HQE relating $|V_{ub}|$ to the full branching fraction.

The theoretical uncertainty is dominated by the SF parameter m_b^{SF} . The variation taken in this analysis is large [14]: $m_b^{\text{SF}} = 4.735_{-0.255}^{+0.110} \text{ GeV}/c^2$. A more precise estimate of the SF parameters has been determined from the $B \rightarrow X_s \gamma$ photon energy spectrum measured by Belle only recently [26] from which we obtain the following preliminary results:

$$\Delta \mathcal{B}(b \rightarrow ue\bar{\nu}) = (4.46 \pm 0.42 \pm 0.49 \pm 0.64 \pm 0.19) \times 10^{-4},$$

$$\mathcal{B}(b \rightarrow ue\bar{\nu}) = \left(2.76 \pm 0.26 \pm 0.30 \pm 0.40_{-0.16}^{+0.20} \pm 0.05\right) \times 10^{-3} \text{ } (f_u = 0.1628 \pm 0.0002),$$

where the uncertainties are from statistics (data and MC), detector modeling, background modeling, the SF parameters m_b^{SF} and a , and the uncertainty due to the modeling of resonant states in $b \rightarrow ue\bar{\nu}$ decays, respectively, and

$$|V_{ub}| = (4.99 \pm 0.23 \pm 0.25 \pm 0.34_{-0.14}^{+0.18} \pm 0.04_{-0.18} \pm 0.22) \times 10^{-3},$$

where the first five uncertainties are as for the total branching fraction and the last comes from the HQE relating $|V_{ub}|$ to the full branching fraction. Note that all of the above results are preliminary.

Current theoretical work (e.g., see Ref. [27]) is aimed at connecting the m_b^{SF} parameter in the SF with determinations of m_b^{SF} from moments in $b \rightarrow ce\bar{\nu}$ decays or from the $\mathcal{T}(1S)$ mass, and may significantly reduce this uncertainty. The results obtained in this analysis have very little dependence on the SF parameter a and are complementary to those obtained from studies of the electron endpoint and of the mass of the recoiling hadron in semileptonic decays.

6 ACKNOWLEDGMENTS

We are grateful for the extraordinary contributions of our PEP-II colleagues in achieving the excellent luminosity and machine conditions that have made this work possible. The success of this project also relies critically on the expertise and dedication of the computing organizations that support *BABAR*. The collaborating institutions wish to thank SLAC for its support and the kind hospitality extended to them. This work is supported by the US Department of Energy and National Science Foundation, the Natural Sciences and Engineering Research Council (Canada), Institute of High Energy Physics (China), the Commissariat à l’Energie Atomique and Institut National de Physique Nucléaire et de Physique des Particules (France), the Bundesministerium für Bildung und Forschung and Deutsche Forschungsgemeinschaft (Germany), the Istituto Nazionale di Fisica Nucleare (Italy), the Foundation for Fundamental Research on Matter (The Netherlands), the Research Council of Norway, the Ministry of Science and Technology of the Russian Federation, and the Particle Physics and Astronomy Research Council (United Kingdom). Individuals have received support from CONACyT (Mexico), the A. P. Sloan Foundation, the Research Corporation, and the Alexander von Humboldt Foundation.

References

- [1] M. Kobayashi and T. Maskawa, *Prog. Theor. Phys.* **49**, 652 (1973).
- [2] R. Fulton *et al.* (CLEO Collab.), *Phys. Rev. Lett.* **64**, 16, (1990); J. Bartelt *et al.* *Phys. Rev. Lett.* **71**, 4111, (1993); H. Albrecht *et al.* (ARGUS Collab.), *Phys. Lett. B* **B234**, 409 (1990); and *Phys. Lett. B* **255**, 297 (1991).
- [3] A. Bornheim *et al.* (CLEO Collab.), *Phys. Rev. Lett.* **88**, 231803 (2002); B. Aubert *et al.* (*BABAR* Collab.), “Measurement of the inclusive electron spectrum in charmless semileptonic B decays near the kinematic endpoint,” hep-ex/0207081 (2002).
- [4] M. Neubert, *Phys. Rev. D* **49**, 4623 (1994).
- [5] I. Bigi *et al.*, *Int. Jour. Mod. Phys.* **A9**, 2467 (1994).
- [6] S. Chen *et al.* (CLEO Collab.), *Phys. Rev. Lett.* **87**, 251807 (2001); P. Koppenburg *et al.* (Belle Collab.), “An Inclusive Measurement of the Photon Energy Spectrum in $b \rightarrow s$ gamma Decays,” hep-ex/0403004 (2004).
- [7] B. Aubert *et al.* (*BABAR* Collab.), *Phys. Rev. Lett.* **92**, 071802 (2004).
- [8] H. Kakuno *et al.* (Belle Collab.), *Phys. Rev. Lett.* **92**, 101801 (2004).
- [9] R. Kowalewski and S. Menke, *Phys. Lett. B* **541**, 34 (2002).
- [10] I.I. Bigi, N.G. Uraltsev and A.I. Vainshtein, *Phys. Lett. B* **293**, 430 (1992) [E **297**, 477 (1993)]; I.I. Bigi, M.A. Shifman, N.G. Uraltsev and A.I. Vainshtein, *Phys. Rev. Lett.* **71**, 496 (1993); A.F. Falk and M. Neubert, *Phys. Rev. D* **47**, 2965 and 2982 (1993). A.V. Manohar and M.B. Wise, *Phys. Rev. D* **49**, 1310 (1994);
- [11] B. Aubert *et al.* (*BABAR* Collab.), *Nucl. Instr. Meth. A* **479**, 116 (2002).

- [12] K. Hagiwara *et al.*, Phys. Rev. D **66**, 010001 (2002).
- [13] De Fazio, F. and Neubert, M., JHEP **9906**, 017 (1999).
- [14] L. Gibbons, “The status of $|V_{ub}|$ ”, hep-ex/0402009 (2004).
- [15] T. Sjöstrand, Comp. Phys. Communications **82**, 74 (1994).
- [16] N. Isgur, D. Scora, B. Grinstein and M. Wise, Phys. Rev. D **39**, 799 (1989).
- [17] B. Aubert *et al.* (BABAR Collab.), Phys. Rev. D **67**, 031101 (2003).
- [18] B. Aubert *et al.* (BABAR Collab.), Phys. Rev. D **69**, 111104 (2004).
- [19] E. Richter-Was, Phys. Lett. B **303**, 163 (1993).
- [20] E.S. Ginsberg, Phys. Rev. **142**, 1035 (1966).
- [21] N. Uraltsev, Int. Jour. Mod. Phys. **A14**, 4641 (1999); A.H. Hoang, Z. Ligeti, A.V. Manohar, Phys. Rev. D **59**, 074017 (1999).
- [22] B. Aubert *et al.* (BABAR Collab.), Phys. Rev. D **69**, 111103 (2004).
- [23] B. Aubert *et al.* (BABAR Collab.), Phys. Rev. Lett. **93**, 011803 (2004).
- [24] A. Sirlin, Nucl. Phys. B **71**, 29 (1974), and Rev. Mod. Phys. **50**, 573 (1978).
- [25] S. Eidelman *et al.*, Phys. Lett. B **592**, 1 (2004).
- [26] A. Limosani and T. Nozaki, “Extraction of the b-quark shape function parameters using the Belle $B \rightarrow X_s \gamma$ photon energy spectrum”, hep-ex/0407052 (2004).
- [27] S.W. Bosch, B.O. Lange, M. Neubert and G. Paz, “Factorization and Shape-Function Effects in Inclusive B-Meson Decays” hep-ph/0402094 (2004).