PHYSICAL REVIEW D **73,** 057101 (2006)

Search for the decay $B^+ \to \tau^+ \nu_\tau$

B. Aubert,[1] R. Barate,[1] D. Boutigny,[1] F. Couderc,[1] Y. Karyotakis,[1] J. P. Lees,[1] V. Poireau,[1] V. Tisserand,[1] A. Zghiche,[1]
E. Grauges,[2] A. Palano,[3] M. Pappagallo,[3] A. Pompili,[3] J. C. Chen,[4] N. D. Qi,[4] G. Rong,[4] P. Wang,[4] Y. S. Zhu,[4] G. Eigen,[5]
I. Ofte,[5] B. Stugu,[5] G. S. Abrams,[6] M. Battaglia,[6] A. B. Breon,[6] D. N. Brown,[6] J. Button-Shafer,[6] R. N. Cahn,[6] E. Charles,[6]
C. T. Day,[6] M. S. Gill,[6] A. V. Gritsan,[6] Y. Groysman,[6] R. G. Jacobsen,[6] R. W. Kadel,[6] J. Kadyk,[6] L. T. Kerth,[6]
Yu. G. Kolomensky,[6] G. Kukartsev,[6] G. Lynch,[6] L. M. Mir,[6] P. J. Oddone,[6] T. J. Orimoto,[6] M. Pripstein,[6] N. A. Roe,[6]
M. T. Ronan,[6] W. A. Wenzel,[6] M. Barrett,[7] K. E. Ford,[7] T. J. Harrison,[7] A. J. Hart,[7] C. M. Hawkes,[7] S. E. Morgan,[7]
A. T. Watson,[7] M. Fritsch,[8] K. Goetzen,[8] T. Held,[8] H. Koch,[8] B. Lewandowski,[8] M. Pelizaeus,[8] K. Peters,[8] T. Schroeder,[8]
M. Steinke,[8] J. T. Boyd,[9] J. P. Burke,[9] N. Chevalier,[9] W. N. Cottingham,[9] T. Cuhadar-Donszelmann,[10] B. G. Fulsom,[10]
C. Hearty,[10] N. S. Knecht,[10] T. S. Mattison,[10] J. A. McKenna,[10] A. Khan,[11] P. Kyberd,[11] M. Saleem,[11] L. Teodorescu,[11]
A. E. Blinov,[12] V. E. Blinov,[12] A. D. Bukin,[12] V. P. Druzhinin,[12] V. B. Golubev,[12] E. A. Kravchenko,[12] A. P. Onuchin,[12]
S. I. Serednyakov,[12] Yu. I. Skovpen,[12] E. P. Solodov,[12] A. N. Yushkov,[12] D. Best,[13] M. Bondioli,[13] M. Bruinsma,[13]
M. Chao,[13] S. Curry,[13] I. Eschrich,[13] D. Kirkby,[13] A. J. Lankford,[13] P. Lund,[13] M. Mandelkern,[13] R. K. Mommsen,[13]
W. Roethel,[13] D. P. Stoker,[13] C. Buchanan,[14] B. L. Hartfiel,[14] A. J. R. Weinstein,[14] S. D. Foulkes,[15] J. W. Gary,[15] O. Long,[15]
B. C. Shen,[15] K. Wang,[15] L. Zhang,[15] D. del Re,[16] H. K. Hadavand,[16] E. J. Hill,[16] D. B. MacFarlane,[16] H. P. Paar,[16]
S. Rahatlou,[16] V. Sharma,[16] J. W. Berryhill,[17] C. Campagnari,[17] A. Cunha,[17] B. Dahmes,[17] T. M. Hong,[17] M. A. Mazur,[17]
J. D. Richman,[17] W. Verkerke,[17] T. W. Beck,[18] A. M. Eisner,[18] C. J. Flacco,[18] C. A. Heusch,[18] J. Kroseberg,[18]
W. S. Lockman,[18] G. Nesom,[18] T. Schalk,[18] B. A. Schumm,[18] A. Seiden,[18] P. Spradlin,[18] D. C. Williams,[18] M. G. Wilson,[18]
J. Albert,[19] E. Chen,[19] G. P. Dubois-Felsmann,[19] A. Dvoretskii,[19] D. G. Hitlin,[19] I. Narsky,[19] T. Piatenko,[19] F. C. Porter,[19]
A. Ryd,[19] A. Samuel,[19] R. Andreassen,[20] S. Jayatilleke,[20] G. Mancinelli,[20] B. T. Meadows,[20] M. D. Sokoloff,[20] F. Blanc,[21]
P. Bloom,[21] S. Chen,[21] W. T. Ford,[21] J. F. Hirschauer,[21] A. Kreisel,[21] U. Nauenberg,[21] A. Olivas,[21] P. Rankin,[21]
W. O. Ruddick,[21] J. G. Smith,[21] K. A. Ulmer,[21] S. R. Wagner,[21] J. Zhang,[21] A. Chen,[22] E. A. Eckhart,[22] A. Soffer,[22]
W. H. Toki,[22] R. J. Wilson,[22] Q. Zeng,[22] D. Altenburg,[23] E. Feltresi,[23] A. Hauke,[23] B. Spaan,[23] T. Brandt,[24] J. Brose,[24]
M. Dickopp,[24] V. Klose,[24] H. M. Lacker,[24] R. Nogowski,[24] S. Otto,[24] A. Petzold,[24] G. Schott,[24] J. Schubert,[24]
K. R. Schubert,[24] R. Schwierz,[24] J. E. Sundermann,[24] D. Bernard,[25] G. R. Bonneaud,[25] P. Grenier,[25] S. Schrenk,[25]
Ch. Thiebaux,[25] G. Vasileiadis,[25] M. Verderi,[25] D. J. Bard,[26] P. J. Clark,[26] W. Gradl,[26] F. Muheim,[26] S. Playfer,[26] Y. Xie,[26]
M. Andreotti,[27] V. Azzolini,[27] D. Bettoni,[27] C. Bozzi,[27] R. Calabrese,[27] G. Cibinetto,[27] E. Luppi,[27] M. Negrini,[27]
L. Piemontese,[27] F. Anulli,[28] R. Baldini-Ferroli,[28] A. Calcaterra,[28] R. de Sangro,[28] G. Finocchiaro,[28] P. Patteri,[28]
I. M. Peruzzi,[28,*] M. Piccolo,[28] A. Zallo,[28] A. Buzzo,[29] R. Capra,[29] R. Contri,[29] M. Lo Vetere,[29] M. Macri,[29]
M. R. Monge,[29] S. Passaggio,[29] C. Patrignani,[29] E. Robutti,[29] A. Santroni,[29] S. Tosi,[29] G. Brandenburg,[30]
K. S. Chaisanguanthum,[30] M. Morii,[30] E. Won,[30] J. Wu,[30] R. S. Dubitzky,[31] U. Langenegger,[31] J. Marks,[31] S. Schenk,[31]
U. Uwer,[31] W. Bhimji,[32] D. A. Bowerman,[32] P. D. Dauncey,[32] U. Egede,[32] R. L. Flack,[32] J. R. Gaillard,[32] G. W. Morton,[32]
J. A. Nash,[32] M. B. Nikolich,[32] G. P. Taylor,[32] W. P. Vazquez,[32] M. J. Charles,[33] W. F. Mader,[33] U. Mallik,[33]
A. K. Mohapatra,[33] J. Cochran,[34] H. B. Crawley,[34] V. Eyges,[34] W. T. Meyer,[34] S. Prell,[34] E. I. Rosenberg,[34] A. E. Rubin,[34]
J. Yi,[34] N. Arnaud,[35] M. Davier,[35] X. Giroux,[35] G. Grosdidier,[35] A. Höcker,[35] F. Le Diberder,[35] V. Lepeltier,[35]
A. M. Lutz,[35] A. Oyanguren,[35] T. C. Petersen,[35] M. Pierini,[35] S. Plaszczynski,[35] S. Rodier,[35] P. Roudeau,[35] M. H. Schune,[35]
A. Stocchi,[35] G. Wormser,[35] C. H. Cheng,[36] D. J. Lange,[36] M. C. Simani,[36] D. M. Wright,[36] A. J. Bevan,[37] C. A. Chavez,[37]
I. J. Forster,[37] J. R. Fry,[37] E. Gabathuler,[37] R. Gamet,[37] K. A. George,[37] D. E. Hutchcroft,[37] R. J. Parry,[37] D. J. Payne,[37]
K. C. Schofield,[37] C. Touramanis,[37] C. M. Cormack,[38] F. Di Lodovico,[38] W. Menges,[38] R. Sacco,[38] C. L. Brown,[39]
G. Cowan,[39] H. U. Flaecher,[39] M. G. Green,[39] D. A. Hopkins,[39] P. S. Jackson,[39] T. R. McMahon,[39] S. Ricciardi,[39]
F. Salvatore,[39] D. Brown,[40] C. L. Davis,[40] J. Allison,[41] N. R. Barlow,[41] R. J. Barlow,[41] C. L. Edgar,[41] M. C. Hodgkinson,[41]
M. P. Kelly,[41] G. D. Lafferty,[41] M. T. Naisbit,[41] J. C. Williams,[41] C. Chen,[42] W. D. Hulsbergen,[42] A. Jawahery,[42]
D. Kovalskyi,[42] C. K. Lae,[42] D. A. Roberts,[42] G. Simi,[42] G. Blaylock,[43] C. Dallapiccola,[43] S. S. Hertzbach,[43] R. Kofler,[43]
V. B. Koptchev,[43] X. Li,[43] T. B. Moore,[43] S. Saremi,[43] H. Staengle,[43] S. Willocq,[43] R. Cowan,[44] K. Koeneke,[44] G. Sciolla,[44]
S. J. Sekula,[44] M. Spitznagel,[44] F. Taylor,[44] R. K. Yamamoto,[44] H. Kim,[45] P. M. Patel,[45] S. H. Robertson,[45] A. Lazzaro,[46]
V. Lombardo,[46] F. Palombo,[46] J. M. Bauer,[47] L. Cremaldi,[47] V. Eschenburg,[47] R. Godang,[47] R. Kroeger,[47] J. Reidy,[47]
D. A. Sanders,[47] D. J. Summers,[47] H. W. Zhao,[47] S. Brunet,[48] D. Côté,[48] P. Taras,[48] B. Viaud,[48] H. Nicholson,[49]
N. Cavallo,[50,†] G. De Nardo,[50] F. Fabozzi,[50,†] C. Gatto,[50] L. Lista,[50] D. Monorchio,[50] P. Paolucci,[50] D. Piccolo,[50]
C. Sciacca,[50] M. Baak,[51] H. Bulten,[51] G. Raven,[51] H. L. Snoek,[51] L. Wilden,[51] C. P. Jessop,[52] J. M. LoSecco,[52]
T. Allmendinger,[53] G. Benelli,[53] K. K. Gan,[53] K. Honscheid,[53] D. Hufnagel,[53] P. D. Jackson,[53] H. Kagan,[53] R. Kass,[53]

1550-7998/2006/73(5)/057101(7)$23.00

T. Pulliam,[53] A. M. Rahimi,[53] R. Ter-Antonyan,[53] Q. K. Wong,[53] J. Brau,[54] R. Frey,[54] O. Igonkina,[54] M. Lu,[54] C. T. Potter,[54] N. B. Sinev,[54] D. Strom,[54] J. Strube,[54] E. Torrence,[54] F. Galeazzi,[55] M. Margoni,[55] M. Morandin,[55] M. Posocco,[55] M. Rotondo,[55] F. Simonetto,[55] R. Stroili,[55] C. Voci,[55] M. Benayoun,[56] H. Briand,[56] J. Chauveau,[56] P. David,[56] L. Del Buono,[56] Ch. de la Vaissière,[56] O. Hamon,[56] M. J. J. John,[56] Ph. Leruste,[56] J. Malclès,[56] J. Ocariz,[56] L. Roos,[56] G. Therin,[56] P. K. Behera,[57] L. Gladney,[57] Q. H. Guo,[57] J. Panetta,[57] M. Biasini,[58] R. Covarelli,[58] S. Pacetti,[58] M. Pioppi,[58] C. Angelini,[59] G. Batignani,[59] S. Bettarini,[59] F. Bucci,[59] G. Calderini,[59] M. Carpinelli,[59] R. Cenci,[59] F. Forti,[59] M. A. Giorgi,[59] A. Lusiani,[59] G. Marchiori,[59] M. Morganti,[59] N. Neri,[59] E. Paoloni,[59] M. Rama,[59] G. Rizzo,[59] J. Walsh,[59] M. Haire,[60] D. Judd,[60] D. E. Wagoner,[60] J. Biesiada,[61] N. Danielson,[61] P. Elmer,[61] Y. P. Lau,[61] C. Lu,[61] J. Olsen,[61] A. J. S. Smith,[61] A. V. Telnov,[61] F. Bellini,[62] G. Cavoto,[62] A. D'Orazio,[62] E. Di Marco,[62] R. Faccini,[62] F. Ferrarotto,[62] F. Ferroni,[62] M. Gaspero,[62] L. Li Gioi,[62] M. A. Mazzoni,[62] S. Morganti,[62] G. Piredda,[62] F. Polci,[62] F. Safai Tehrani,[62] C. Voena,[62] H. Schröder,[63] G. Wagner,[63] R. Waldi,[63] T. Adye,[64] N. De Groot,[64] B. Franek,[64] G. P. Gopal,[64] E. O. Olaiya,[64] F. F. Wilson,[64] R. Aleksan,[65] S. Emery,[65] A. Gaidot,[65] S. F. Ganzhur,[65] P.-F. Giraud,[65] G. Graziani,[65] G. Hamel de Monchenault,[65] W. Kozanecki,[65] M. Legendre,[65] G. W. London,[65] B. Mayer,[65] G. Vasseur,[65] Ch. Yèche,[65] M. Zito,[65] M. V. Purohit,[66] A. W. Weidemann,[66] J. R. Wilson,[66] F. X. Yumiceva,[66] T. Abe,[67] M. T. Allen,[67] D. Aston,[67] N. Bakel,[67] R. Bartoldus,[67] N. Berger,[67] A. M. Boyarski,[67] O. L. Buchmueller,[67] R. Claus,[67] J. P. Coleman,[67] M. R. Convery,[67] M. Cristinziani,[67] J. C. Dingfelder,[67] D. Dong,[67] J. Dorfan,[67] D. Dujmic,[67] W. Dunwoodie,[67] S. Fan,[67] R. C. Field,[67] T. Glanzman,[67] S. J. Gowdy,[67] T. Hadig,[67] V. Halyo,[67] C. Hast,[67] T. Hryn'ova,[67] W. R. Innes,[67] M. H. Kelsey,[67] P. Kim,[67] M. L. Kocian,[67] D. W. G. S. Leith,[67] J. Libby,[67] S. Luitz,[67] V. Luth,[67] H. L. Lynch,[67] H. Marsiske,[67] R. Messner,[67] D. R. Muller,[67] C. P. O'Grady,[67] V. E. Ozcan,[67] A. Perazzo,[67] M. Perl,[67] B. N. Ratcliff,[67] A. Roodman,[67] A. A. Salnikov,[67] R. H. Schindler,[67] J. Schwiening,[67] A. Snyder,[67] J. Stelzer,[67] D. Su,[67] M. K. Sullivan,[67] K. Suzuki,[67] S. Swain,[67] J. M. Thompson,[67] J. Va'vra,[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] P. R. Burchat,[68] A. J. Edwards,[68] S. A. Majewski,[68] B. A. Petersen,[68] C. Roat,[68] M. Ahmed,[69] S. Ahmed,[69] M. S. Alam,[69] J. A. Ernst,[69] M. A. Saeed,[69] F. R. Wappler,[69] S. B. Zain,[69] W. Bugg,[70] M. Krishnamurthy,[70] S. M. Spanier,[70] R. Eckmann,[71] J. L. Ritchie,[71] A. Satpathy,[71] R. F. Schwitters,[71] J. M. Izen,[72] I. Kitayama,[72] X. C. Lou,[72] S. Ye,[72] F. Bianchi,[73] M. Bona,[73] F. Gallo,[73] D. Gamba,[73] M. Bomben,[74] L. Bosisio,[74] C. Cartaro,[74] F. Cossutti,[74] G. Della Ricca,[74] S. Dittongo,[74] S. Grancagnolo,[74] L. Lanceri,[74] L. Vitale,[74] F. Martinez-Vidal,[75] R. S. Panvini,[76,‡] Sw. Banerjee,[77] B. Bhuyan,[77] C. M. Brown,[77] D. Fortin,[77] K. Hamano,[77] R. Kowalewski,[77] J. M. Roney,[77] R. J. Sobie,[77] J. J. Back,[78] P. F. Harrison,[78] T. E. Latham,[78] G. B. Mohanty,[78] H. R. Band,[79] X. Chen,[79] B. Cheng,[79] S. Dasu,[79] M. Datta,[79] A. M. Eichenbaum,[79] K. T. Flood,[79] M. Graham,[79] J. J. Hollar,[79] J. R. Johnson,[79] P. E. Kutter,[79] H. Li,[79] R. Liu,[79] B. Mellado,[79] A. Mihalyi,[79] Y. Pan,[79] R. Prepost,[79] P. Tan,[79] J. H. von Wimmersperg-Toeller,[79] S. L. Wu,[79] Z. Yu,[79] and H. Neal[80]

(*BaBar* Collaboration)

[1]*Laboratoire de Physique des Particules, F-74941 Annecy-le-Vieux, France*
[2]*IFAE, Universitat Autonoma de Barcelona, E-08193 Bellaterra, Barcelona, Spain*
[3]*Università di Bari, Dipartimento di Fisica and INFN, I-70126 Bari, Italy*
[4]*Institute of High Energy Physics, Beijing 100039, China*
[5]*University of Bergen, Institute of Physics, N-5007 Bergen, Norway*
[6]*Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720, USA*
[7]*University of Birmingham, Birmingham, B15 2TT, United Kingdom*
[8]*Ruhr Universität Bochum, Institut für Experimentalphysik 1, D-44780 Bochum, Germany*
[9]*University of Bristol, Bristol BS8 1TL, United Kingdom*
[10]*University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z1*
[11]*Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom*
[12]*Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia*
[13]*University of California at Irvine, Irvine, California 92697, USA*
[14]*University of California at Los Angeles, Los Angeles, California 90024, USA*
[15]*University of California at Riverside, Riverside, California 92521, USA*
[16]*University of California at San Diego, La Jolla, California 92093, USA*
[17]*University of California at Santa Barbara, Santa Barbara, California 93106, USA*
[18]*University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, California 95064, USA*
[19]*California Institute of Technology, Pasadena, California 91125, USA*
[20]*University of Cincinnati, Cincinnati, Ohio 45221, USA*

[21]*University of Colorado, Boulder, Colorado 80309, USA*
[22]*Colorado State University, Fort Collins, Colorado 80523, USA*
[23]*Universität Dortmund, Institut fur Physik, D-44221 Dortmund, Germany*
[24]*Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany*
[25]*Ecole Polytechnique, LLR, F-91128 Palaiseau, France*
[26]*University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom*
[27]*Università di Ferrara, Dipartimento di Fisica and INFN, I-44100 Ferrara, Italy*
[28]*Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy*
[29]*Università di Genova, Dipartimento di Fisica and INFN, I-16146 Genova, Italy*
[30]*Harvard University, Cambridge, Massachusetts 02138, USA*
[31]*Universität Heidelberg, Physikalisches Institut, Philosophenweg 12, D-69120 Heidelberg, Germany*
[32]*Imperial College London, London, SW7 2AZ, United Kingdom*
[33]*University of Iowa, Iowa City, Iowa 52242, USA*
[34]*Iowa State University, Ames, Iowa 50011-3160, USA*
[35]*Laboratoire de l'Accélérateur Linéaire, F-91898 Orsay, France*
[36]*Lawrence Livermore National Laboratory, Livermore, California 94550, USA*
[37]*University of Liverpool, Liverpool L69 72E, United Kingdom*
[38]*Queen Mary, University of London, E1 4NS, United Kingdom*
[39]*University of London, Royal Holloway and Bedford New College, Egham, Surrey TW20 0EX, United Kingdom*
[40]*University of Louisville, Louisville, Kentucky 40292, USA*
[41]*University of Manchester, Manchester M13 9PL, United Kingdom*
[42]*University of Maryland, College Park, Maryland 20742, USA*
[43]*University of Massachusetts, Amherst, Massachusetts 01003, USA*
[44]*Massachusetts Institute of Technology, Laboratory for Nuclear Science, Cambridge, Massachusetts 02139, USA*
[45]*McGill University, Montréal, Quebec, Canada H3A 2T8*
[46]*Università di Milano, Dipartimento di Fisica and INFN, I-20133 Milano, Italy*
[47]*University of Mississippi, University, Mississippi 38677, USA*
[48]*Université de Montréal, Laboratoire René J. A. Lévesque, Montréal, Quebec, Canada H3C 3J7*
[49]*Mount Holyoke College, South Hadley, Massachusetts 01075, USA*
[50]*Università di Napoli Federico II, Dipartimento di Scienze Fisiche and INFN, I-80126, Napoli, Italy*
[51]*NIKHEF, National Institute for Nuclear Physics and High Energy Physics, NL-1009 DB Amsterdam, The Netherlands*
[52]*University of Notre Dame, Notre Dame, Indiana 46556, USA*
[53]*Ohio State University, Columbus, Ohio 43210, USA*
[54]*University of Oregon, Eugene, Oregon 97403, USA*
[55]*Università di Padova, Dipartimento di Fisica and INFN, I-35131 Padova, Italy*
[56]*Universités Paris VI et VII, Laboratoire de Physique Nucléaire et de Hautes Energies, F-75252 Paris, France*
[57]*University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA*
[58]*Università di Perugia, Dipartimento di Fisica and INFN, I-06100 Perugia, Italy*
[59]*Università di Pisa, Dipartimento di Fisica, Scuola Normale Superiore and INFN, I-56127 Pisa, Italy*
[60]*Prairie View A&M University, Prairie View, Texas 77446, USA*
[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]*Vanderbilt University, Nashville, Tennessee 37235, USA*
[77]*University of Victoria, Victoria, British Columbia, Canada V8W 3P6*
[78]*Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom*
[79]*University of Wisconsin, Madison, Wisconsin 53706, USA*
[80]*Yale University, New Haven, Connecticut 06511, USA*

(Received 14 July 2005; published 10 March 2006)

We search for the rare leptonic decay $B^+ \to \tau^+ \nu_\tau$ in a sample of 232×10^6 $B\overline{B}$ pairs collected with the *BABAR* detector at the SLAC PEP-II B-Factory. Signal events are selected by examining the properties of the B meson recoiling against the semileptonic decay $B^- \to D^{*0}\ell^-\overline{\nu}_\ell$. We find no evidence for a signal and set an upper limit on the branching fraction of $\mathcal{B}(B^+ \to \tau^+ \nu_\tau) < 2.8 \times 10^{-4}$ at the 90% confidence level. We combine this result with a previous, statistically independent *BABAR* search for $B^+ \to \tau^+ \nu_\tau$ to give an upper limit of $\mathcal{B}(B^+ \to \tau^+ \nu_\tau) < 2.6 \times 10^{-4}$ at the 90% confidence level.

DOI: 10.1103/PhysRevD.73.057101 PACS numbers: 13.20.He, 14.40.Nd, 14.60.Fg

In the standard model (SM) the purely leptonic decay $B^+ \to \tau^+ \nu_\tau$ [1] proceeds via the annihilation of the $\overline{b}$ and u quarks into a virtual W boson. Its amplitude is proportional to the product of the Cabibbo-Kobayashi-Maskawa (CKM) matrix [2] element $|V_{ub}|$ and the B meson decay constant f_B. The SM branching fraction is given by [3]

$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B, \quad (1)$$

where G_F is the Fermi coupling constant, m_τ and m_B are the τ^+ lepton and B^+ meson masses, and τ_B is the B^+ lifetime. The branching fractions for $B^+ \to e^+ \nu_e$ and $B^+ \to \mu^+ \nu_\mu$ are helicity-suppressed by m_ℓ^2/m_B^2, where m_ℓ is the mass of e^+ or μ^+. Using the value of $|V_{ub}| = (3.67 \pm 0.47) \times 10^{-3}$ [4] and the lattice QCD calculation of $f_B = (0.196 \pm 0.032)$ GeV [5], we determine an expected value of $\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = (9.3 \pm 3.9) \times 10^{-5}$. Currently, our best knowledge of f_B comes from theoretical calculations, with a current theoretical uncertainty of roughly 16% [5]. Observation of $B^+ \to \tau^+ \nu_\tau$ could provide the first direct measurement of f_B. The ratio of $\mathcal{B}(B^+ \to \tau^+ \nu_\tau)$ and Δm_d, the difference in heavy and light neutral B_d masses [6], can be used to determine the ratio of CKM matrix elements $|V_{ub}|/|V_{td}|$ with roughly 4% theoretical uncertainties [4,5], dominated by the uncertainties on the square root of the bag parameter $\sqrt{B_B}$ [5].

No evidence of the $B^+ \to \tau^+ \nu_\tau$ decay has been reported to date. The most stringent published experimental limit is $\mathcal{B}(B^+ \to \tau^+ \nu_\tau) < 4.2 \times 10^{-4}$ at the 90% confidence level (C.L.) [7]. Physics beyond the SM, such as supersymmetry or two-Higgs-doublet models, could enhance $\mathcal{B}(B^+ \to \tau^+ \nu_\tau)$ up to the current experimental limits [8].

The data used in this analysis were collected with the *BABAR* detector [9] at the PEP-II asymmetric-energy e^+e^- storage ring. The results are based on a data sample of $(231.8 \pm 2.6) \times 10^6$ $B\overline{B}$ events, in an integrated luminosity of 210.6 fb^{-1} collected at the $\Upsilon(4S)$ resonance. An additional sample of 21.6 fb^{-1} was collected at a center-of-mass (CM) energy approximately 40 MeV below the $\Upsilon(4S)$ resonance. We used the latter sample to study continuum events, $\text{e}^+\text{e}^- \to q\overline{q} (q = u, d, s, c)$ and $\text{e}^+\text{e}^- \to \tau^+\tau^-$. Charged-particle tracking and $\text{d}E/\text{d}x$ measurements for particle identification (PID) are provided by a five-layer double-sided silicon vertex tracker and a 40-layer drift chamber operated in the 1.5 T magnetic field of a superconducting solenoid. A detector of internally reflected Cherenkov light (DIRC) is used to identify charged kaons and pions. The energies of neutral particles are measured by an electromagnetic calorimeter (EMC) consisting of 6580 CsI(Tl) crystals. The magnetic flux return of the solenoid is instrumented with resistive plate chambers in order to provide muon identification. A full detector Monte Carlo (MC) simulation based on EVTGEN [10] and GEANT4 [11] is used to evaluate signal efficiencies and to identify and study background sources. Beam-related background and detector noise samples are obtained from random triggers at regular intervals. These samples are overlaid on the simulated events with appropriate luminosity weighting to model these time-varying background conditions.

Because of the presence of at least two neutrinos in the final state, the $B^+ \to \tau^+ \nu_\tau$ decay lacks the kinematic constraints that are usually exploited in B decay searches in order to reject both continuum and $B\overline{B}$ backgrounds. The strategy adopted to search for this decay is to reconstruct the B^- meson from an $\Upsilon(4S) \to B^+B^-$ event in a semileptonic final state, denoted by B_{sl}^-. All remaining charged and neutral particles in that event, referred to as the "-signal-side" particles throughout this paper, are then examined under the assumption that they are attributable to the decay of the accompanying B^+ ("signal B").

The B_{sl}^- is reconstructed in the decay modes $B_{\text{sl}}^- \to D^{*0}\ell^-\overline{\nu}_\ell$ ($\ell = e$ or μ). The D^{*0} is reconstructed in the modes $D^0\pi^0$ and $D^0\gamma$. The D^0 is reconstructed in four decay modes: $K^-\pi^+$, $K^-\pi^+\pi^-\pi^+$, $K^-\pi^+\pi^0$, and $K_S^0\pi^+\pi^-$. All kinematic variables are calculated in the CM-frame of the $\Upsilon(4S)$ unless otherwise noted.

Photon candidates are obtained from EMC clusters with laboratory-frame energy E_γ greater than 30 MeV and no associated charged track. Photon pairs with invariant mass between 115 and 150 MeV/c^2 are taken as π^0 candidates.

The D^0 candidates are reconstructed by selecting combinations of identified pions and kaons with invariant mass within 40 MeV/c^2 of the nominal D^0 mass [4], except for the $K^-\pi^+\pi^0$ mode, where this window is 70 MeV/c^2. Each D^0 candidate is combined with a soft π^0 or γ candidate to form a D^{*0}. The π^0 and γ candidates are required to have momentum less than 450 MeV/c.

---

[*] Also with Università di Perugia, Dipartimento di Fisica, Perugia, Italy.

[†] Also with Università della Basilicata, Potenza, Italy.

[‡] Deceased.

Further, the γ candidate must have $E_\gamma > 100$ MeV. The invariant mass difference ΔM between the D^{*0} and D^0 is required to be within the range 135–150 MeV/c^2 for the $D^0\pi^0$ mode, and 130–155 MeV/c^2 for the $D^0\gamma$ mode.

The $B^-_{\mathrm{sl}} \to D^{*0}\ell^-\overline{\nu}_\ell$ candidates are identified by combining a D^{*0} candidate of momentum $p_{D^{*0}} > 0.5$ GeV$/c$ with a lepton candidate of momentum $p_\ell > 1.0$ GeV$/c$. The lepton candidate must be identified as either an electron or a muon. The invariant mass $m_{D^{*0}\ell}$ of the $D^{*0}\ell$ candidate is required to be greater than 3.0 GeV$/c^2$. Under the assumption that a massless neutrino is the only missing particle, the cosine of the angle between the directions of the B^-_{sl} and the lepton-D^{*0} combination is

$$\cos\theta_{\mathrm{B,D^{*0}}\ell} \equiv \frac{2E_{\mathrm{beam}} \cdot E_{D^{*0}\ell} - m_B^2 - m_{D^{*0}\ell}^2}{2|\mathbf{p}_{D^{*0}\ell}| \cdot \sqrt{E_{\mathrm{beam}}^2 - m_B^2}}, \qquad (2)$$

where E_{beam} is the expected B^- meson energy. The energy and momentum of the $D^{*0}\ell$ candidate are $E_{D^{*0}\ell}$ and $\mathbf{p}_{D^{*0}\ell}$, respectively. Correctly reconstructed candidates populate the range $[-1, 1]$, whereas combinatorial backgrounds can take unphysical values well outside this range. We retain B^-_{sl} candidates in the wider interval $|\cos\theta_{\mathrm{B,D^{*0}}\ell}| < 1.1$, allowing for the effects of detector energy and momentum resolutions. If more than one $D^{*0}\ell$ candidate is reconstructed in an event, the best candidate is selected using a likelihood based on the simulated D^0 mass and ΔM distributions. We further require that the sum of the charges of all the particles in the event (“net charge”) must be equal to zero.

The B^-_{sl} reconstruction efficiency for events containing a $B^+ \to \tau^+\nu_\tau$ decay is determined from signal simulation after verifying that the simulated $B\overline{B}$, $u\overline{u}$, $d\overline{d}$, $s\overline{s}$, $c\overline{c}$, and $\tau^+\tau^-$ events are consistent with data. This procedure compensates for differences in the B^-_{sl} reconstruction efficiency in the low-multiplicity environment of $B^+ \to \tau^+\nu_\tau$ events compared with the generic B^+B^- environment. The simulated efficiency is further cross-checked by comparing the yield of events in which a $B^+ \to \overline{D}^{*0}\ell^+\nu_\ell$ decay has been reconstructed in addition to a B^-_{sl} (“double semileptonic decay”). In the signal simulation the B^-_{sl} reconstruction efficiency is $\varepsilon_{\mathrm{sl}} = (1.75 \pm 0.07(\mathrm{stat.}) \pm 0.05(\mathrm{syst.}))\times 10^{-3}$. The $D^{*0}\ell^-\overline{\nu}_\ell$, D^{*0}, and D^0 branching fractions are factored in $\varepsilon_{\mathrm{sl}}$.

Events that contain a B^-_{sl} are examined for evidence of a $B^+ \to \tau^+\nu_\tau$ decay. Charged tracks and EMC clusters not already utilized for the B^-_{sl} reconstruction are assumed to originate from the signal candidate B^+ decay. We identify the τ lepton in six mutually exclusive channels: $e^+\nu_e\overline{\nu}_\tau$, $\mu^+\nu_\mu\overline{\nu}_\tau$, $\pi^+\overline{\nu}_\tau$, $\pi^+\pi^0\overline{\nu}_\tau$, $\pi^+\pi^-\pi^+\overline{\nu}_\tau$, and “misidentified lepton.” The misidentified-lepton channel selects signal events from the $e^+\nu_e\overline{\nu}_\tau$ or $\mu^+\nu_\mu\overline{\nu}_\tau$ signal decays in which the momentum of the e^+ or μ^+ from the signal τ^+ is too low to pass the lepton identification criteria. The identified τ^+ modes all together correspond to approximately 81% of all τ^+ decays [4].

Signal candidates are searched in events that are required to possess exactly one signal-side charged track, except for $\pi^+\pi^-\pi^+\overline{\nu}_\tau$ candidate events, which must have three signal-side charged tracks. The signal track from the $e^+\nu_e\overline{\nu}_\tau$ ($\mu^+\nu_\mu\overline{\nu}_\tau$) channel is required to be identified as an electron (a muon), and not to satisfy either muon (electron) or kaon PID criteria. In the $\pi^+\overline{\nu}_\tau$, $\pi^+\pi^0\overline{\nu}_\tau$, $\pi^+\pi^-\pi^+\overline{\nu}_\tau$, and misidentified-lepton channels the signal track(s) must not satisfy electron, muon, or kaon PID. In addition, each signal track from the $\pi^+\pi^-\pi^+\overline{\nu}_\tau$ channel has to be identified as a pion. For the $\pi^+\pi^0\overline{\nu}_\tau$ channel the signal track is combined with a signal-side π^0 candidate, reconstructed from a signal-side photon pair ($E_\gamma >$ 50 MeV for each photon) with invariant mass between 100 and 160 MeV$/c^2$. If several signal-side π^0 candidates are reconstructed in an event, the candidate with $\gamma\gamma$ invariant mass closest to the nominal π^0 mass [4] is chosen. We require that the events in the $\pi^+\overline{\nu}_\tau$ and misidentified-lepton channels contain no signal-side π^0 candidates. Events in the $\pi^+\overline{\nu}_\tau$ and misidentified-lepton channels are distinguished by requiring the momentum of the signal track to be greater than 1.2 GeV$/c$ in the former, and less than 1.2 GeV$/c$ in the latter.

Further requirements are made on the (total) momentum of the signal track(s) for some channels: $p_{e^+} < 1.4$ GeV$/c$ for $e^+\nu_e\overline{\nu}_\tau$, and $p_{\pi^+\pi^-\pi^+} > 1.0$ GeV$/c$ for $\pi^+\pi^-\pi^+\overline{\nu}_\tau$. We apply constraints on the missing mass M_{miss} of the event, which is determined by subtracting the total four-momentum of reconstructed tracks and neutrals from that for the $\Upsilon(4S)$ system. This quantity tends to be larger for events with more neutrinos. Signal events must satisfy $M_{\mathrm{miss}} > 4$ GeV$/c^2$ for $e^+\nu_e\overline{\nu}_\tau$ and $\mu^+\nu_\mu\overline{\nu}_\tau$, $M_{\mathrm{miss}} >$ 3 GeV$/c^2$ for $\pi^+\overline{\nu}_\tau$, $\pi^+\pi^0\overline{\nu}_\tau$, and misidentified lepton, and $M_{\mathrm{miss}} > 2$ GeV$/c^2$ for $\pi^+\pi^-\pi^+\overline{\nu}_\tau$.

Additional kinematic constraints are applied on the $\pi^+\pi^0\overline{\nu}_\tau$ ($\pi^+\pi^-\pi^+\overline{\nu}_\tau$) channel, which proceeds mainly via intermediate ρ^+ (a_1^+ and ρ^0) resonance(s). In the $\pi^+\pi^0\overline{\nu}_\tau$ channel the invariant mass of the $\pi^+\pi^0$ must be between 0.55 and 1.0 GeV$/c^2$. For the $\pi^+\pi^-\pi^+\overline{\nu}_\tau$ channel the invariant mass of the three-pion system is required to be within the range 1.0–1.6 GeV$/c^2$. The $\pi^+\pi^-$ combination of the three-pion system, with invariant mass closest to the nominal ρ^0 mass [4], is required to have momentum greater than 0.5 GeV$/c$ and invariant mass between 0.55 and 1.0 GeV$/c^2$. We further require that the cosine of the angle between the directions of the τ^+ and the $\pi^+\pi^0$ ($\pi^+\pi^-\pi^+$),

$$\cos\theta_{\tau,\mathrm{had}} \equiv \frac{2E_\tau \cdot E_{\mathrm{had}} - m_\tau^2 - m_{\mathrm{had}}^2}{2|\mathbf{p}_\tau| \cdot |\mathbf{p}_{\mathrm{had}}|}, \qquad (3)$$

is within $[-1.1, 1.1]$. Here E_{had}, $\mathbf{p}_{\mathrm{had}}$, and m_{had} are the energy, momentum, and invariant mass, respectively, of the $\pi^+\pi^0$ ($\pi^+\pi^-\pi^+$). The energy E_τ and momentum $\mathbf{p}_\tau$

of the τ^+ from $B^+ \to \tau^+ \nu_\tau$ decay are calculated under the assumption that the B^+ is at rest in the CM frame.

Continuum background events contribute to the $\pi^+\overline{\nu}_\tau$, misidentified-lepton, $\pi^+\pi^0\overline{\nu}_\tau$, and $\pi^+\pi^-\pi^+\overline{\nu}_\tau$ channels. To suppress this background we combine five variables in a linear Fisher discriminant [12]: $p_{D^{*0}}$, p_ℓ, $\cos\theta_{\mathrm{B},D^{*0}\ell}$, the cosine of the angle between the thrust axis of the decay products of B_{sl}^- and the thrust axis of the rest of the event, and the ratio of the second and zeroth Fox-Wolfram moments using all the particles in the event [13]. The requirement placed on the output of the Fisher discriminant selects about 93% of signal events and rejects about 37% of continuum background events. After this requirement the continuum background in each channel is less than 40% of the total background.

The sum of the laboratory-frame energies of the neutral EMC clusters with $E_\gamma > 30$ MeV, which are not associated with either the B_{sl}^- or the π^0 candidate from the $\pi^+\pi^0\overline{\nu}_\tau$ channel, is denoted by E_{extra} (Fig. 1). For signal events the neutral clusters contributing to E_{extra} come only from hadronic shower fragments, bremsstrahlung, and beam-related background. This variable peaks near zero for signal while for background, which contains additional sources of neutral clusters, it takes on larger values. Signal events are required to have E_{extra} less than 250 MeV for $e^+\nu_e\overline{\nu}_\tau$, 150 MeV for $\mu^+\nu_\mu\overline{\nu}_\tau$, 300 MeV for $\pi^+\overline{\nu}_\tau$, 170 MeV for misidentified lepton, 250 MeV for $\pi^+\pi^0\overline{\nu}_\tau$, and 200 MeV for $\pi^+\pi^-\pi^+\overline{\nu}_\tau$, which are selected based on a MC study to provide the tightest branching fraction upper limit. The E_{extra} selection region defines the "signal region" for each channel. The $350 < E_{\mathrm{extra}} < 1000$ MeV region is defined as the "sideband" for all the channels.

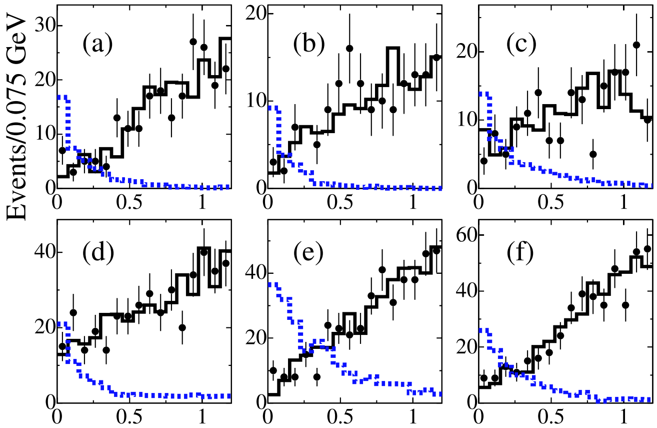

FIG. 1 (color online). The distribution of E_{extra} after applying all other selection criteria, plotted for (a) $e^+\nu_e\overline{\nu}_\tau$, (b) $\mu^+\nu_\mu\overline{\nu}_\tau$, (c) $\pi^+\overline{\nu}_\tau$, (d) misidentified lepton, (e) $\pi^+\pi^0\overline{\nu}_\tau$, and (f) $\pi^+\pi^-\pi^+\overline{\nu}_\tau$ channels. The data and background MC samples are represented by the points with error bars and solid histograms, respectively. The dotted lines indicate the $B^+ \to \tau^+\nu_\tau$ signal distribution from MC. The signal MC events for the $e^+\nu_e\overline{\nu}_\tau$, $\mu^+\nu_\mu\overline{\nu}_\tau$, $\pi^+\overline{\nu}_\tau$, and misidentified-lepton ($\pi^+\pi^0\overline{\nu}_\tau$ and $\pi^+\pi^-\pi^+\overline{\nu}_\tau$) channels are normalized assuming a branching fraction of 10^{-3} (10^{-2}) for $B^+ \to \tau^+\nu_\tau$ decay.

The efficiencies ε_i for each τ selection channel i are determined using simulated events. Cross-feeds among the τ decay channels are taken into account. The systematic uncertainties in the selection efficiency arise from tracking efficiency (1.4% per track), particle identification (0.2%–2.0%), E_{extra} simulation (3.0%–8.0%), π^0 reconstruction (3.3%), and data and MC differences in the output of the Fisher discriminant (1.0%). Systematic uncertainties due to the E_{extra} simulation are determined by evaluating the effect of varying the MC E_{extra} distribution within a range representing the observed level of agreement with data in samples containing B_{sl}^- and up to seven additional tracks. For a further cross-check the E_{extra} distributions of the data and MC events for the double semileptonic decays are compared. The signal selection efficiencies for the six selection channels are listed in Table I. The total $B^+ \to \tau^+\nu_\tau$ selection efficiency is roughly 31%.

The remaining background consists primarily of B^+B^- events with correctly reconstructed B_{sl}^-. For these events the signal side contains K_L^0('s), neutrino(s), or particles that pass outside the detector acceptance. For each channel we estimate the background b_i in the signal region using events in the data sideband and the simulated E_{extra} distribution:

$$b_i = N_{\mathrm{SideB}}^{\mathrm{data}} \times (N_{\mathrm{SigR}}^{\mathrm{MC}}/N_{\mathrm{SideB}}^{\mathrm{MC}}). \tag{4}$$

Here $N_{\mathrm{SideB}}^{\mathrm{data}}$ is the number of data events in the sideband, and $N_{\mathrm{SigR}}^{\mathrm{MC}}$ and $N_{\mathrm{SideB}}^{\mathrm{MC}}$ are the numbers of MC background events in the signal region and sideband, respectively. Background estimation is cross-checked using data and MC events that satisfy the full signal selection, with the exception of having two signal-side tracks, or nonzero net charge, or the ΔM of the D^{*0} outside the selection region. The uncertainties in the background estimations are predominantly statistical; smaller systematic uncertainties arise from the simulation of the E_{extra} shape in the background MC.

TABLE I. Efficiency (ε_i) with statistical and systematic errors, expected background (b_i), and observed data candidates (n_i) for each reconstructed τ selection channels. The cross-feeds among the τ decay modes are taken into account. The ε_i values include the branching fractions of the τ decay modes.

Selection	ε_i(%)	b_i	n_i
$e^+\nu_e\overline{\nu}_\tau$	7.5 ± 0.4 ± 0.2	13.4 ± 2.4	17
$\mu^+\nu_\mu\overline{\nu}_\tau$	2.9 ± 0.2 ± 0.1	6.2 ± 1.7	5
$\pi^+\overline{\nu}_\tau$	8.0 ± 0.4 ± 0.3	27.7 ± 5.0	26
$\pi^+\pi^0\overline{\nu}_\tau$	2.5 ± 0.2 ± 0.1	28.6 ± 4.3	31
$\pi^+\pi^-\pi^+\overline{\nu}_\tau$	1.4 ± 0.2 ± 0.1	21.6 ± 3.0	26
Misidentified lepton	9.0 ± 0.4 ± 0.4	33.4 ± 5.1	45

We determine the $B^+ \to \tau^+ \nu_\tau$ branching fraction from the number of signal candidates s_i expected for each τ selection channel, where $s_i \equiv N_B^\pm \varepsilon_{\rm sl} \varepsilon_i \mathcal{B}(B^+ \to \tau^+ \nu_\tau)$. $N_B^\pm = (231.8 \pm 2.6) \times 10^6$ is the estimated number of $B^\pm$ mesons in the data sample. The results for each channel are combined using the estimator $Q \equiv \mathcal{L}(s + b)/\mathcal{L}(b)$ [14,15], where

$$\mathcal{L}(s+b) \equiv \prod_{i=1}^{6} \int_{-\infty}^{+\infty} \mathrm{d}b'_i \frac{e^{-[(b'_i - b_i)^2/2\sigma_i^2]}}{\sqrt{2\pi\sigma_i^2}} \times \frac{e^{-(s_i + b'_i)}(s_i + b'_i)^{n_i}}{n_i!} \tag{5}$$

is the likelihood function for signal-plus-background hypotheses, n_i is the observed number of data events in each τ selection channel, and σ_i is the uncertainty in the background estimate b_i (Table I). The likelihood function for background-only hypotheses $\mathcal{L}(b)$ can be obtained from Eq. (5) by setting s_i to zero.

The measured branching fraction, which is the value that maximizes the likelihood ratio estimator, is $(1.3^{+1.2}_{-1.1}) \times 10^{-4}$. This value is compatible with a zero branching fraction. The n_i and b_i values (Table I) do not indicate any significant excess of observed events. Therefore, we set an upper limit on the branching fraction [15] of $\mathcal{B}(B^+ \to \tau^+ \nu_\tau) < 2.8 \times 10^{-4}$ (90% C.L.). The expected branching fraction upper limit for background-only hypotheses is $\mathcal{B}(B^+ \to \tau^+ \nu_\tau) < 1.8 \times 10^{-4}$ (90% C.L.).

BABAR Collaboration has previously performed a search for the $B^+ \to \tau^+ \nu_\tau$ decay based on a sample of 88.9×10^6 $B\overline{B}$ pairs, where the B^- meson accompanying the signal B^+ is reconstructed in a variety of hadronic or semileptonic modes [7]. The hadronic B^- selection is mutually exclusive with the current $B^-_{\rm sl}$ selection. Therefore the two samples are statistically independent and may be combined. The hadronic reconstruction analysis obtained a limit $\mathcal{B}(B^+ \to \tau^+ \nu_\tau) < 4.2 \times 10^{-4}$ at the 90% C.L. To combine the results from the previous hadronic and current semileptonic samples, we create a combined estimator from the product of the semileptonic ($Q_{\rm sl}$) and hadronic ($Q_{\rm had}$) likelihood ratio estimators, $Q \equiv Q_{\rm sl} \times Q_{\rm had}$. The measured branching fraction from the combined sample is $(1.3^{+1.0}_{-0.9}) \times 10^{-4}$. This value is compatible with a zero branching fraction, and we set a combined upper limit,

$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) < 2.6 \times 10^{-4} \text{ (90\% C.L.)}. \tag{6}$$

These results represent the most stringent limits on $B^+ \to \tau^+ \nu_\tau$ reported to date.

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), IHEP (China), CEA and CNRS-IN2P3 (France), BMBF and DFG (Germany), INFN (Italy), FOM (The Netherlands), NFR (Norway), MIST (Russia), and PPARC (United Kingdom). Individuals have received support from CONACyT (Mexico), A. P. Sloan Foundation, Research Corporation, and Alexander von Humboldt Foundation.

---

[1] Charge-conjugate modes are included implicitly throughout this paper.

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

[3] D. Boutigny *et al.* (*BABAR* Collaboration), in *The BABAR Physics Book*, edited by P.F. Harrison and H.R. Quinn, Report No. SLAC-R-504, 1998.

[4] S. Eidelman *et al.* (Particle Data Group), Phys. Lett. B **592**, 1 (2004).

[5] A.S. Kronfeld, Nucl. Phys. B, Proc. Suppl. **129**, 46 (2004).

[6] A.J. Buras and R. Fleischer, in *Heavy Flavours II*, edited by A.J. Buras and M. Lindner (World Scientific, Singapore, 1997); A.J. Buras and R. Fleischer, Adv. Ser. Dir. High Energy Phys. **15**, 65 (1998).

[7] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **95**, 041804 (2005).

[8] W.-S. Hou, Phys. Rev. D **48**, 2342 (1993).

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

[10] D.J. Lange, Nucl. Instrum. Methods Phys. Res., Sect. A **462**, 152 (2001).

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

[12] R.A. Fisher, Ann. Eugenics **7**, 179 (1936).

[13] G.C. Fox and S. Wolfram, Phys. Rev. Lett. **41**, 1581 (1978).

[14] T. Junk, Nucl. Instrum. Methods Phys. Res., Sect. A **434**, 435 (1999).

[15] L. Lista, Nucl. Instrum. Methods Phys. Res., Sect. A **517**, 360 (2004).