SLAC-PUB-8931
July 2001
BABAR-PUB-01/16
hep-ex-0107068

Search for the Decay B^0 --> $\gamma\gamma$

B. Aubert *et al.*

Submitted to Physical Review Letters

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

Work supported by Department of Energy contract DE–AC03–76SF00515.

BABAR-PUB-01/16
SLAC-PUB-8931
hep-ex/0107068

Search for the decay $B^0 \to \gamma\gamma$

B. Aubert,[1] D. Boutigny,[1] J.-M. Gaillard,[1] A. Hicheur,[1] Y. Karyotakis,[1] J. P. Lees,[1] P. Robbe,[1] V. Tisserand,[1] A. Palano,[2] G. P. Chen,[3] J. C. Chen,[3] N. D. Qi,[3] G. Rong,[3] P. Wang,[3] Y. S. Zhu,[3] G. Eigen,[4] P. L. Reinertsen,[4] B. Stugu,[4] B. Abbott,[5] G. S. Abrams,[5] A. W. Borgland,[5] A. B. Breon,[5] D. N. Brown,[5] J. Button-Shafer,[5] R. N. Cahn,[5] A. R. Clark,[5] M. S. Gill,[5] A. Gritsan,[5] Y. Groysman,[5] R. G. Jacobsen,[5] R. W. Kadel,[5] J. Kadyk,[5] L. T. Kerth,[5] S. Kluth,[5] Yu. G. Kolomensky,[5] J. F. Kral,[5] C. LeClerc,[5] M. E. Levi,[5] T. Liu,[5] G. Lynch,[5] A. B. Meyer,[5] M. Momayezi,[5] P. J. Oddone,[5] A. Perazzo,[5] M. Pripstein,[5] N. A. Roe,[5] A. Romosan,[5] M. T. Ronan,[5] V. G. Shelkov,[5] A. V. Telnov,[5] W. A. Wenzel,[5] P. G. Bright-Thomas,[6] T. J. Harrison,[6] C. M. Hawkes,[6] D. J. Knowles,[6] S. W. O'Neale,[6] R. C. Penny,[6] A. T. Watson,[6] N. K. Watson,[6] T. Deppermann,[7] K. Goetzen,[7] H. Koch,[7] J. Krug,[7] M. Kunze,[7] B. Lewandowski,[7] K. Peters,[7] H. Schmuecker,[7] M. Steinke,[7] J. C. Andress,[8] N. R. Barlow,[8] W. Bhimji,[8] N. Chevalier,[8] P. J. Clark,[8] W. N. Cottingham,[8] N. De Groot,[8] N. Dyce,[8] B. Foster,[8] J. D. McFall,[8] D. Wallom,[8] F. F. Wilson,[8] K. Abe,[9] C. Hearty,[9] T. S. Mattison,[9] J. A. McKenna,[9] D. Thiessen,[9] S. Jolly,[10] A. K. McKemey,[10] J. Tinslay,[10] V. E. Blinov,[11] A. D. Bukin,[11] D. A. Bukin,[11] A. R. Buzykaev,[11] V. B. Golubev,[11] V. N. Ivanchenko,[11] A. A. Korol,[11] E. A. Kravchenko,[11] A. P. Onuchin,[11] A. A. Salnikov,[11] S. I. Serednyakov,[11] Yu. I. Skovpen,[11] V. I. Telnov,[11] A. N. Yushkov,[11] D. Best,[12] A. J. Lankford,[12] M. Mandelkern,[12] S. McMahon,[12] D. P. Stoker,[12] A. Ahsan,[13] K. Arisaka,[13] C. Buchanan,[13] S. Chun,[13] J. G. Branson,[14] D. B. MacFarlane,[14] S. Prell,[14] Sh. Rahatlou,[14] G. Raven,[14] V. Sharma,[14] C. Campagnari,[15] B. Dahmes,[15] P. A. Hart,[15] N. Kuznetsova,[15] S. L. Levy,[15] O. Long,[15] A. Lu,[15] J. D. Richman,[15] W. Verkerke,[15] M. Witherell,[15] S. Yellin,[15] J. Beringer,[16] D. E. Dorfan,[16] A. M. Eisner,[16] A. Frey,[16] A. A. Grillo,[16] M. Grothe,[16] C. A. Heusch,[16] R. P. Johnson,[16] W. Kroeger,[16] W. S. Lockman,[16] T. Pulliam,[16] H. Sadrozinski,[16] T. Schalk,[16] R. E. Schmitz,[16] B. A. Schumm,[16] A. Seiden,[16] M. Turri,[16] W. Walkowiak,[16] D. C. Williams,[16] M. G. Wilson,[16] E. Chen,[17] G. P. Dubois-Felsmann,[17] A. Dvoretskii,[17] D. G. Hitlin,[17] S. Metzler,[17] J. Oyang,[17] F. C. Porter,[17] A. Ryd,[17] A. Samuel,[17] M. Weaver,[17] S. Yang,[17] R. Y. Zhu,[17] S. Devmal,[18] T. L. Geld,[18] S. Jayatilleke,[18] G. Mancinelli,[18] B. T. Meadows,[18] M. D. Sokoloff,[18] T. Barillari,[19] P. Bloom,[19] M. O. Dima,[19] S. Fahey,[19] W. T. Ford,[19] D. R. Johnson,[19] U. Nauenberg,[19] A. Olivas,[19] H. Park,[19] P. Rankin,[19] J. Roy,[19] S. Sen,[19] J. G. Smith,[19] W. C. van Hoek,[19] D. L. Wagner,[19] J. Blouw,[20] J. L. Harton,[20] M. Krishnamurthy,[20] A. Soffer,[20] W. H. Toki,[20] R. J. Wilson,[20] J. Zhang,[20] T. Brandt,[21] J. Brose,[21] T. Colberg,[21] G. Dahlinger,[21] M. Dickopp,[21] R. S. Dubitzky,[21] E. Maly,[21] R. Müller-Pfefferkorn,[21] S. Otto,[21] K. R. Schubert,[21] R. Schwierz,[21] B. Spaan,[21] L. Wilden,[21] L. Behr,[22] D. Bernard,[22] G. R. Bonneaud,[22] F. Brochard,[22] J. Cohen-Tanugi,[22] S. Ferrag,[22] E. Roussot,[22] S. T'Jampens,[22] Ch. Thiebaux,[22] G. Vasileiadis,[22] M. Verderi,[22] A. Anjomshoaa,[23] R. Bernet,[23] A. Khan,[23] F. Muheim,[23] S. Playfer,[23] J. E. Swain,[23] M. Falbo,[24] C. Borean,[25] C. Bozzi,[25] S. Dittongo,[25] M. Folegani,[25] L. Piemontese,[25] E. Treadwell,[26] F. Anulli,[27,*] R. Baldini-Ferroli,[27] A. Calcaterra,[27] R. de Sangro,[27] D. Falciai,[27] G. Finocchiaro,[27] P. Patteri,[27] I. M. Peruzzi,[27,*] M. Piccolo,[27] Y. Xie,[27] A. Zallo,[27] S. Bagnasco,[28] A. Buzzo,[28] R. Contri,[28] G. Crosetti,[28] P. Fabbricatore,[28] S. Farinon,[28] M. Lo Vetere,[28] M. Macri,[28] M. R. Monge,[28] R. Musenich,[28] M. Pallavicini,[28] R. Parodi,[28] S. Passaggio,[28] F. C. Pastore,[28] C. Patrignani,[28] M. G. Pia,[28] C. Priano,[28] E. Robutti,[28] A. Santroni,[28] M. Morii,[29] R. Bartoldus,[30] T. Dignan,[30] R. Hamilton,[30] U. Mallik,[30] J. Cochran,[31] H. B. Crawley,[31] P.-A. Fischer,[31] J. Lamsa,[31] W. T. Meyer,[31] E. I. Rosenberg,[31] M. Benkebil,[32] G. Grosdidier,[32] C. Hast,[32] A. Höcker,[32] H. M. Lacker,[32] S. Laplace,[32] V. Lepeltier,[32] A. M. Lutz,[32] S. Plaszczynski,[32] M. H. Schune,[32] S. Trincaz-Duvoid,[32] A. Valassi,[32] G. Wormser,[32] R. M. Bionta,[33] V. Brigljević,[33] D. J. Lange,[33] M. Mugge,[33] X. Shi,[33] K. van Bibber,[33] T. J. Wenaus,[33] D. M. Wright,[33] C. R. Wuest,[33] M. Carroll,[34] J. R. Fry,[34] E. Gabathuler,[34] R. Gamet,[34] M. George,[34] M. Kay,[34] D. J. Payne,[34] R. J. Sloane,[34] C. Touramanis,[34] M. L. Aspinwall,[35] D. A. Bowerman,[35] P. D. Dauncey,[35] U. Egede,[35] I. Eschrich,[35] N. J. W. Gunawardane,[35] J. A. Nash,[35] P. Sanders,[35] D. Smith,[35] D. E. Azzopardi,[36] J. J. Back,[36] P. Dixon,[36] P. F. Harrison,[36] R. J. L. Potter,[36] H. W. Shorthouse,[36] P. Strother,[36] P. B. Vidal,[36] M. I. Williams,[36] G. Cowan,[37] S. George,[37] M. G. Green,[37] A. Kurup,[37] C. E. Marker,[37] P. McGrath,[37] T. R. McMahon,[37] S. Ricciardi,[37]

F. Salvatore,[37] I. Scott,[37] G. Vaitsas,[37] D. Brown,[38] C. L. Davis,[38] J. Allison,[39] R. J. Barlow,[39] J. T. Boyd,[39] A. C. Forti,[39] J. Fullwood,[39] F. Jackson,[39] G. D. Lafferty,[39] N. Savvas,[39] E. T. Simopoulos,[39] J. H. Weatherall,[39] A. Farbin,[40] A. Jawahery,[40] V. Lillard,[40] J. Olsen,[40] D. A. Roberts,[40] J. R. Schieck,[40] G. Blaylock,[41] C. Dallapiccola,[41] K. T. Flood,[41] S. S. Hertzbach,[41] R. Kofler,[41] T. B. Moore,[41] H. Staengle,[41] S. Willocq,[41] B. Brau,[42] R. Cowan,[42] G. Sciolla,[42] F. Taylor,[42] R. K. Yamamoto,[42] M. Milek,[43] P. M. Patel,[43] J. Trischuk,[43] F. Lanni,[44] F. Palombo,[44] J. M. Bauer,[45] M. Booke,[45] L. Cremaldi,[45] V. Eschenburg,[45] R. Kroeger,[45] J. Reidy,[45] D. A. Sanders,[45] D. J. Summers,[45] J. P. Martin,[46] J. Y. Nief,[46] R. Seitz,[46] P. Taras,[46] A. Woch,[46] V. Zacek,[46] H. Nicholson,[47] C. S. Sutton,[47] C. Cartaro,[48] N. Cavallo,[48, †] G. De Nardo,[48] F. Fabozzi,[48] C. Gatto,[48] L. Lista,[48] P. Paolucci,[48] D. Piccolo,[48] C. Sciacca,[48] J. M. LoSecco,[49] J. R. G. Alsmiller,[50] T. A. Gabriel,[50] T. Handler,[50] J. Brau,[51] R. Frey,[51] M. Iwasaki,[51] N. B. Sinev,[51] D. Strom,[51] F. Colecchia,[52] F. Dal Corso,[52] A. Dorigo,[52] F. Galeazzi,[52] M. Margoni,[52] G. Michelon,[52] M. Morandin,[52] M. Posocco,[52] M. Rotondo,[52] F. Simonetto,[52] R. Stroili,[52] E. Torassa,[52] C. Voci,[52] M. Benayoun,[53] H. Briand,[53] J. Chauveau,[53] P. David,[53] Ch. de la Vaissière,[53] L. Del Buono,[53] O. Hamon,[53] F. Le Diberder,[53] Ph. Leruste,[53] J. Lory,[53] L. Roos,[53] J. Stark,[53] S. Versillé,[53] P. F. Manfredi,[54] V. Re,[54] V. Speziali,[54] E. D. Frank,[55] L. Gladney,[55] Q. H. Guo,[55] J. H. Panetta,[55] C. Angelini,[56] G. Batignani,[56] S. Bettarini,[56] M. Bondioli,[56] M. Carpinelli,[56] F. Forti,[56] M. A. Giorgi,[56] A. Lusiani,[56] F. Martinez-Vidal,[56] M. Morganti,[56] N. Neri,[56] E. Paoloni,[56] M. Rama,[56] G. Rizzo,[56] F. Sandrelli,[56] G. Simi,[56] G. Triggiani,[56] J. Walsh,[56] M. Haire,[57] D. Judd,[57] K. Paick,[57] L. Turnbull,[57] D. E. Wagoner,[57] J. Albert,[58] C. Bula,[58] P. Elmer,[58] C. Lu,[58] K. T. McDonald,[58] V. Miftakov,[58] S. F. Schaffner,[58] A. J. S. Smith,[58] A. Tumanov,[58] E. W. Varnes,[58] G. Cavoto,[59] D. del Re,[59] R. Faccini,[14, 59] F. Ferrarotto,[59] F. Ferroni,[59] K. Fratini,[59] E. Lamanna,[59] E. Leonardi,[59] M. A. Mazzoni,[59] S. Morganti,[59] G. Piredda,[59] F. Safai Tehrani,[59] M. Serra,[59] C. Voena,[59] S. Christ,[60] R. Waldi,[60] P. F. Jacques,[61] M. Kalelkar,[61] R. J. Plano,[61] T. Adye,[62] B. Franek,[62] N. I. Geddes,[62] G. P. Gopal,[62] S. M. Xella,[62] R. Aleksan,[63] G. De Domenico,[63] S. Emery,[63] A. Gaidot,[63] S. F. Ganzhur,[63] P.-F. Giraud,[63] G. Hamel de Monchenault,[63] W. Kozanecki,[63] M. Langer,[63] G. W. London,[63] B. Mayer,[63] B. Serfass,[63] G. Vasseur,[63] Ch. Yèche,[63] M. Zito,[63] N. Copty,[64] M. V. Purohit,[64] H. Singh,[64] F. X. Yumiceva,[64] I. Adam,[65] P. L. Anthony,[65] D. Aston,[65] K. Baird,[65] E. Bloom,[65] A. M. Boyarski,[65] F. Bulos,[65] G. Calderini,[65] R. Claus,[65] M. R. Convery,[65] D. P. Coupal,[65] D. H. Coward,[65] J. Dorfan,[65] M. Doser,[65] W. Dunwoodie,[65] R. C. Field,[65] T. Glanzman,[65] G. L. Godfrey,[65] S. J. Gowdy,[65] P. Grosso,[65] T. Himel,[65] M. E. Huffer,[65] W. R. Innes,[65] C. P. Jessop,[65] M. H. Kelsey,[65] P. Kim,[65] M. L. Kocian,[65] U. Langenegger,[65] D. W. G. S. Leith,[65] S. Luitz,[65] V. Luth,[65] H. L. Lynch,[65] H. Marsiske,[65] S. Menke,[65] R. Messner,[65] K. C. Moffeit,[65] R. Mount,[65] D. R. Muller,[65] C. P. O'Grady,[65] M. Perl,[65] S. Petrak,[65] H. Quinn,[65] B. N. Ratcliff,[65] S. H. Robertson,[65] L. S. Rochester,[65] A. Roodman,[65] T. Schietinger,[65] R. H. Schindler,[65] J. Schwiening,[65] V. V. Serbo,[65] A. Snyder,[65] A. Soha,[65] S. M. Spanier,[65] J. Stelzer,[65] D. Su,[65] M. K. Sullivan,[65] H. A. Tanaka,[65] J. Va'vra,[65] S. R. Wagner,[65] A. J. R. Weinstein,[65] W. J. Wisniewski,[65] D. H. Wright,[65] C. C. Young,[65] P. R. Burchat,[66] C. H. Cheng,[66] D. Kirkby,[66] T. I. Meyer,[66] C. Roat,[66] A. De Silva,[67] R. Henderson,[67] W. Bugg,[68] H. Cohn,[68] A. W. Weidemann,[68] J. M. Izen,[69] I. Kitayama,[69] X. C. Lou,[69] M. Turcotte,[69] F. Bianchi,[70] M. Bona,[70] B. Di Girolamo,[70] D. Gamba,[70] A. Smol,[70] D. Zanin,[70] L. Bosisio,[71] G. Della Ricca,[71] L. Lanceri,[71] A. Pompili,[71] P. Poropat,[71] M. Prest,[71] E. Vallazza,[71] G. Vuagnin,[71] R. S. Panvini,[72] C. M. Brown,[73] R. Kowalewski,[73] J. M. Roney,[73] H. R. Band,[74] E. Charles,[74] S. Dasu,[74] F. Di Lodovico,[74] A. M. Eichenbaum,[74] H. Hu,[74] J. R. Johnson,[74] R. Liu,[74] J. Nielsen,[74] Y. Pan,[74] R. Prepost,[74] I. J. Scott,[74] S. J. Sekula,[74] J. H. von Wimmersperg-Toeller,[74] S. L. Wu,[74] Z. Yu,[74] H. Zobernig,[74] T. M. B. Kordich,[75] H. Neal,[75]

(The *BABAR* Collaboration),

[1] *Laboratoire de Physique des Particules, F-74941 Annecy-le-Vieux, France*
[2] *Università di Bari, Dipartimento di Fisica and INFN, I-70126 Bari, Italy*
[3] *Institute of High Energy Physics, Beijing 100039, China*
[4] *University of Bergen, Inst. of Physics, N-5007 Bergen, Norway*
[5] *Lawrence Berkeley National Laboratory and University of California, Berkeley, CA 94720, USA*
[6] *University of Birmingham, Birmingham, B15 2TT, United Kingdom*
[7] *Ruhr Universität Bochum, Institut für Experimentalphysik 1, D-44780 Bochum, Germany*
[8] *University of Bristol, Bristol BS8 1TL, United Kingdom*
[9] *University of British Columbia, Vancouver, BC, Canada V6T 1Z1*
[10] *Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom*
[11] *Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia*
[12] *University of California at Irvine, Irvine, CA 92697, USA*
[13] *University of California at Los Angeles, Los Angeles, CA 90024, USA*

[14] *University of California at San Diego, La Jolla, CA 92093, USA*
[15] *University of California at Santa Barbara, Santa Barbara, CA 93106, USA*
[16] *University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, CA 95064, USA*
[17] *California Institute of Technology, Pasadena, CA 91125, USA*
[18] *University of Cincinnati, Cincinnati, OH 45221, USA*
[19] *University of Colorado, Boulder, CO 80309, USA*
[20] *Colorado State University, Fort Collins, CO 80523, USA*
[21] *Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062, Dresden, Germany*
[22] *Ecole Polytechnique, F-91128 Palaiseau, France*
[23] *University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom*
[24] *Elon University, Elon University, NC 27244-2010, USA*
[25] *Università di Ferrara, Dipartimento di Fisica and INFN, I-44100 Ferrara, Italy*
[26] *Florida A&M University, Tallahassee, FL 32307, USA*
[27] *Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy*
[28] *Università di Genova, Dipartimento di Fisica and INFN, I-16146 Genova, Italy*
[29] *Harvard University, Cambridge, MA 02138, USA*
[30] *University of Iowa, Iowa City, IA 52242, USA*
[31] *Iowa State University, Ames, IA 50011-3160, USA*
[32] *Laboratoire de l'Accélérateur Linéaire, F-91898 Orsay, France*
[33] *Lawrence Livermore National Laboratory, Livermore, CA 94550, USA*
[34] *University of Liverpool, Liverpool L69 3BX, United Kingdom*
[35] *University of London, Imperial College, London, SW7 2BW, United Kingdom*
[36] *Queen Mary, University of London, E1 4NS, United Kingdom*
[37] *University of London, Royal Holloway and Bedford New College, Egham, Surrey TW20 0EX, United Kingdom*
[38] *University of Louisville, Louisville, KY 40292, USA*
[39] *University of Manchester, Manchester M13 9PL, United Kingdom*
[40] *University of Maryland, College Park, MD 20742, USA*
[41] *University of Massachusetts, Amherst, MA 01003, USA*
[42] *Massachusetts Institute of Technology, Laboratory for Nuclear Science, Cambridge, MA 02139, USA*
[43] *McGill University, Montréal, Canada QC H3A 2T8*
[44] *Università di Milano, Dipartimento di Fisica and INFN, I-20133 Milano, Italy*
[45] *University of Mississippi, University, MS 38677, USA*
[46] *Université de Montréal, Laboratoire René J. A. Lévesque, Montréal, Canada QC H3C 3J7*
[47] *Mount Holyoke College, South Hadley, MA 01075, USA*
[48] *Università di Napoli Federico II, Dipartimento di Scienze Fisiche and INFN, I-80126, Napoli, Italy*
[49] *University of Notre Dame, Notre Dame, IN 46556, USA*
[50] *Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA*
[51] *University of Oregon, Eugene, OR 97403, USA*
[52] *Università di Padova, Dipartimento di Fisica and INFN, I-35131 Padova, Italy*
[53] *Universités Paris VI et VII, LPNHE, F-75252 Paris, France*
[54] *Università di Pavia, Dipartimento di Elettronica and INFN, I-27100 Pavia, Italy*
[55] *University of Pennsylvania, Philadelphia, PA 19104, USA*
[56] *Università di Pisa, Scuola Normale Superiore and INFN, I-56010 Pisa, Italy*
[57] *Prairie View A&M University, Prairie View, TX 77446, USA*
[58] *Princeton University, Princeton, NJ 08544, USA*
[59] *Università di Roma La Sapienza, Dipartimento di Fisica and INFN, I-00185 Roma, Italy*
[60] *Universität Rostock, D-18051 Rostock, Germany*
[61] *Rutgers University, New Brunswick, NJ 08903, USA*
[62] *Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingdom*
[63] *DAPNIA, Commissariat à l'Energie Atomique/Saclay, F-91191 Gif-sur-Yvette, France*
[64] *University of South Carolina, Columbia, SC 29208, USA*
[65] *Stanford Linear Accelerator Center, Stanford, CA 94309, USA*
[66] *Stanford University, Stanford, CA 94305-4060, USA*
[67] *TRIUMF, Vancouver, BC, Canada V6T 2A3*
[68] *University of Tennessee, Knoxville, TN 37996, USA*
[69] *University of Texas at Dallas, Richardson, TX 75083, USA*
[70] *Università di Torino, Dipartimento di Fisica Sperimentale and INFN, I-10125 Torino, Italy*
[71] *Università di Trieste, Dipartimento di Fisica and INFN, I-34127 Trieste, Italy*
[72] *Vanderbilt University, Nashville, TN 37235, USA*
[73] *University of Victoria, Victoria, BC, Canada V8W 3P6*
[74] *University of Wisconsin, Madison, WI 53706, USA*
[75] *Yale University, New Haven, CT 06511, USA*

(Dated: July 24, 2001)

We present a limit on the branching fraction for the decay $B^0 \to \gamma\gamma$ using data collected at the $\Upsilon(4S)$ resonance with the *BABAR* detector at the PEP-II asymmetric–energy e^+e^- collider. Based on the observation of one event in the signal region, out of a sample of 21.3×10^6 $e^+e^- \to \Upsilon(4S) \to B\overline{B}$ decays, we establish an upper limit on the branching fraction of $\mathcal{B}(B^0 \to \gamma\gamma) < 1.7 \times 10^{-6}$ at the 90% confidence level. This result substantially improves upon existing limits.

PACS numbers: 12.15.Hh, 11.30.Er, 13.25.Hw

In the Standard Model the decay $B^0 \to \gamma\gamma$ proceeds via a second order weak transition, including gluonic penguins, followed by annihilation (Fig. 1). Standard Model predictions for the branching fraction of these effective flavor–changing weak neutral current processes range from 0.1 to 2.3×10^{-8} [1].

Physics beyond the Standard Model can enhance this branching fraction by as much as two orders of magnitude, particularly in the case of two–Higgs models [2]. Other particles from the supersymmetric spectrum can further modify the Standard Model expectation [1]. The current best limit on the branching fraction for $B^0 \to \gamma\gamma$, from the L3 experiment [3] at the CERN LEP collider, is $\mathcal{B}(B^0 \to \gamma\gamma) < 3.9 \times 10^{-5}$ (90% confidence level).

In this Letter we present an analysis based on data taken with the *BABAR* detector [4], which operates at the PEP–II asymmetric–energy e^+e^- collider at the Stanford Linear Accelerator Center [5]. The sample consists of 19.4 fb^{-1} taken at the $\Upsilon(4S)$ resonance, corresponding to 21.3×10^6 $e^+e^- \to \Upsilon(4S) \to B\overline{B}$ events. An additional sample of 2.2 fb^{-1} accumulated approximately 40 MeV below the $\Upsilon(4S)$ resonance is used to estimate non–$B\overline{B}$ background.

Charge conjugation invariance is assumed for all channels quoted in this paper, and the charge conjugate reactions are included in the analysis. Quantities evaluated in the $\Upsilon(4S)$ rest frame are denoted by an asterisk; *e.g.*, E_b^* is the energy of the e^+ and e^- beams in the $\Upsilon(4S)$ rest frame.

The *BABAR* detector, a general purpose solenoidal magnetic spectrometer, is described in detail elsewhere [4]. A silicon vertex detector and a cylindrical drift chamber in a 1.5 T solenoidal magnetic field are used to measure momenta and ionization energy loss of charged particles. Electrons and photons are identified by a CsI electromagnetic calorimeter (EMC).

This analysis exploits in particular the information provided by the EMC consisting of 6580 CsI crystals, covering 90% of 4π in the $\Upsilon(4S)$ rest frame. The energy resolution has been measured directly with a radioactive source at low energy and with electrons from Bhabha scattering at high energy. The mass resolution of π^0 and η candidates in which the two photons in the decay have approximately equal energy can be used to infer the energy resolution at an energy less than 1 GeV, the decay $\chi_{c1} \to J/\psi\gamma$ provides an additional measurement at 500 MeV. A fit to the energy dependence results in $\sigma_E/E = (2.3 \pm 0.3)\%/\sqrt[4]{E} \oplus (1.9 \pm 0.1)\%$ [4].

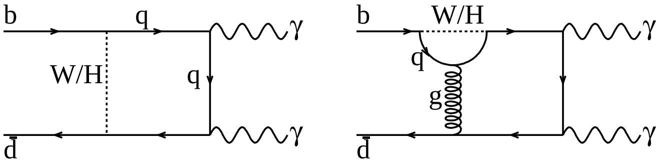

FIG. 1: Examples of possible diagrams responsible for the decay $B^0 \to \gamma\gamma$. In these diagrams q = u, c, or t, and H is a hypothetical charged non-Standard Model Higgs boson.

Energy deposits in the EMC are reconstructed by grouping adjacent crystals with energy deposits greater than 1 MeV into *clusters*. Clusters with more than one local energy maximum are then split into *bumps*. The energy of each crystal is divided among the bumps by an iterative adjustment of the centers and energies of the bumps assuming electromagnetic shower shapes [4]. Next, all tracks reconstructed in the tracking volume are extrapolated to the electromagnetic calorimeter entrance and a track–bump matching probability is calculated for each pair.

All bumps with a matching probability smaller than 10^{-6} are treated as photon candidates. Photons are selected by requiring the bump shape to be compatible with an electromagnetic shower, and by requiring the bump to have a minimum energy of 30 MeV. In addition we accept only photon candidates which are isolated from any other bump in the event. This requirement selects against background from high–energy π^0 mesons, where the two photons from the decay of the π^0 meson strike the calorimeter in close proximity (*merged* π^0).

The *BABAR* detector is simulated by a `GEANT`–based Monte Carlo procedure [6] that includes beam–related background by mixing random trigger events into the Monte Carlo generated events. The simulated events are processed in the same manner as data. The simulation is used to study background and optimize selection criteria, but only enters the analysis directly through the calculation of the signal efficiency.

In order to select $B\overline{B}$ events, we require at least three tracks of good quality in the event. The quality requirements for these tracks include a small impact parameter with respect to the collision point along the beam direction (10 cm) and transverse to it (1.5 cm), a minimum number of 13 hits in the drift chamber and a momentum of $p < 10\,\mathrm{GeV}/c$ in the laboratory frame. To help reject continuum background, the ratio of the second Fox–Wolfram moment to the zeroth Fox–Wolfram moment [7] must be less than 0.9. We further require that there be two high–energy photon candidates with an energy in the $\Upsilon(4S)$ rest frame between 1.5 and 3.5 GeV. At this point, all remaining pairs of photons are considered candidates for the decay $B^0 \to \gamma\gamma$. If the event contains more than one such B candidate all of them are kept for further analysis.

After this preselection additional requirements are imposed on the $B^0 \to \gamma\gamma$ candidates. Photon bumps from the B candidate must not contain noisy crystals or crystals which produce no signals. The second moment of the energy distribution around the cluster's centroid [8] must be smaller than 0.002. This value has been optimized to reject remaining background from merged π^0 mesons.

Since B mesons at the $\Upsilon(4S)$ resonance are produced nearly at rest, the decay $B^0 \to \gamma\gamma$ will contain two nearly back–to–back photons with $E^*_\gamma \approx 2.6\,\mathrm{GeV}$ in the $\Upsilon(4S)$ rest frame. This represents a clean signature and makes this channel relatively easy to study experimentally. We exploit this feature by considering only $B^0 \to \gamma\gamma$ candidates which have at least one photon with $2.3 < E^*_\gamma < 3.0\,\mathrm{GeV}$.

In order to reject photons from $\pi^0(\eta)$ decays we combine each photon from the B candidate with all the other photons in the event having energy greater than 50(250) MeV. The resulting $\pi^0(\eta)$ candidates are required to have an invariant mass beyond three standard deviations, or $3 \times 8.8(18)\,\mathrm{MeV}/c^2$, of the nominal $\pi^0(\eta)$ mass [9].

Reconstruction of exclusive final states from B mesons produced at the $\Upsilon(4S)$ resonance benefits from the beam energy constraint $E^*_B = E^*_b$. Thus, in the $\Upsilon(4S)$ rest frame the energies of the B meson decay products must add up to the beam energy. We calculate the energy difference $\Delta E \equiv E^*_{\gamma,1} + E^*_{\gamma,2} - E^*_b$ between the candidate B^0 meson and the beam energy in the $\Upsilon(4S)$ rest frame. The distribution of this quantity peaks at 0 GeV for true B mesons, and has a tail towards negative ΔE due to shower leakage in the EMC. The resolution in ΔE is obtained from signal Monte Carlo events with a fit of the ΔE distribution to an empirical function [10] and is $\sigma_{\Delta E} = 73\,\mathrm{MeV}$.

The B meson mass resolution is improved with the use of the beam energy constraint. We use the beam energy substituted mass $m_{\mathrm{ES}} \equiv \sqrt{E^{*2}_b - (\mathbf{p}^*_{\gamma,1} + \mathbf{p}^*_{\gamma,2})^2}$. The resolution on m_{ES} is obtained from signal Monte Carlo events with a fit of the m_{ES} distribution to an empirical function [10] and is $\sigma_{m_{\mathrm{ES}}} = 3.9\,\mathrm{MeV}/c^2$.

For the purpose of determining numbers of events and efficiencies a rectangular signal region is defined. This region extends 2σ in ΔE about $0\,\mathrm{MeV}$ and 2σ in m_{ES} about the nominal mass m_{B^0} of the B^0 meson. The overall efficiency for $B^0 \to \gamma\gamma$ decays is determined from the Monte Carlo simulation to be $(10.7 \pm 0.2)\%$, where the error is purely statistical.

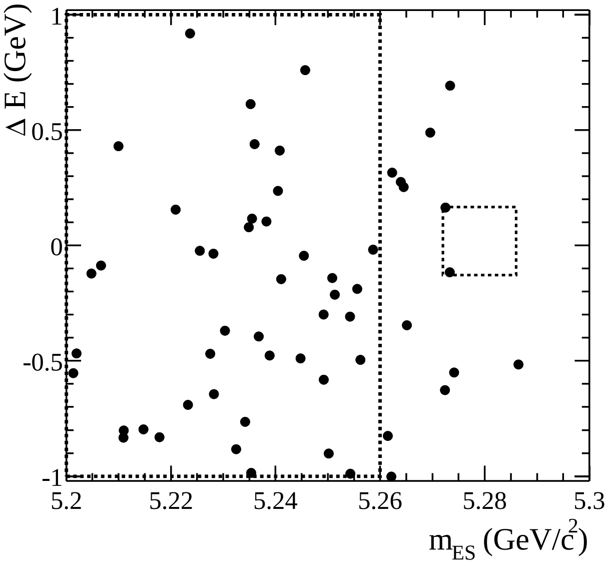

FIG. 2: Energy difference ΔE between the candidate B^0 meson and the beam energy in the $\Upsilon(4S)$ rest frame versus beam energy substituted mass m_{ES} for on–resonance data. We observe one event in the signal region, outlined as a black dashed box about $\Delta E = 0$ GeV, consistent with the expected background. The dashed box on the left shows the side band used for background estimation.

The search for $B^0 \to \gamma\gamma$ was performed as a blind analysis by hiding a 3σ region in ΔE and m_{ES} in on–resonance data until the development of the selection procedure was complete. This allows optimization of the selection and estimation of the background without the bias of knowing the number of events in the signal region.

Monte Carlo studies indicate that the main background arises from the process $e^+e^- \to q\overline{q}$ ($q = u$, d, s), referred to as continuum background and modeled with the JETSET event generator [11]. Such events usually exhibit a two–jet structure and contain high momentum, approximately back–to–back tracks. One source of background includes photons from initial state radiation, others are photons from $\pi^0 \to \gamma\gamma$ and $\eta \to \gamma\gamma$ decays which decay very asymmetrically in the final state photon energy. Background from merged π^0 mesons is negligible.

To reduce continuum background, we calculate the angle θ^*_T between one of the photons (chosen randomly) of the B^0 candidate and the thrust axis of the remaining tracks and neutral bumps in the event. The distribution of $|\cos\theta^*_T|$ is uniform for signal events and strongly peaked at 1 for continuum background events. We also calculate the angle θ^*_B between the momentum vector of the B^0 candidate and the beam axis in the $\Upsilon(4S)$ rest frame. The distribution of $|\cos\theta^*_B|$ is uniform for continuum background and follows a $\sin^2\theta^*_B$ distribution

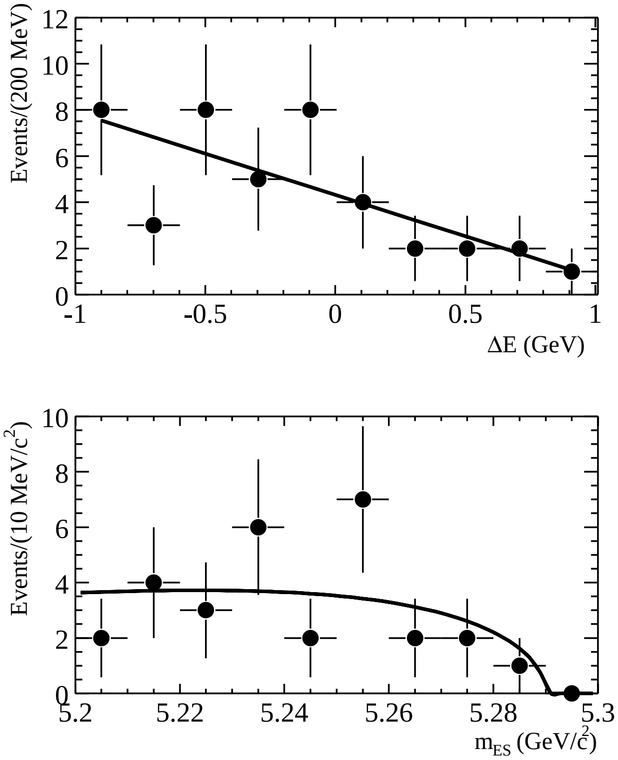

FIG. 3: Fit to the ΔE distribution in the grand side band to a first order polynomial (top panel). The bottom panel shows a fit of the $m_{\rm ES}$ distribution in the lower side band to the ARGUS function [12]. See text for the definition of the side bands.

for signal events. The cut values for both $|\cos\theta^*_T|$ and $|\cos\theta^*_B|$ have been optimized to maximize the statistical significance $N_S^2/(N_S+N_B)$, where N_S is the number of signal candidates expected assuming for the branching fraction $\mathcal{B}(B^0 \to \gamma\gamma) = 1\times10^{-8}$ [1] and N_B is the expected number of background candidates determined from continuum background Monte Carlo events and off–resonance data. We require $|\cos\theta^*_T| < 0.57$ and $|\cos\theta^*_B| < 0.81$. If more than one B meson candidate per event remains after this selection, which occurs in less than 0.1% of the events analyzed, we select the candidate with the smallest $|\Delta E|$.

A single event in the on–resonance data meets these selection criteria, as shown in Fig. 2. A number of exclusive decay modes which can mimic $B^0 \to \gamma\gamma$ decays have been studied with high statistics (equivalent to $1.2-1.7\times10^4\,{\rm fb}^{-1}$ assuming branching fractions of the order of 10^{-6}). We expect negligible contributions from $B^0\to\eta\eta$, $K^{*0}\gamma$, $\rho^0\gamma$, and $\pi^0\pi^0$, and a combined contribution of 0.7×10^{-3} events from $B^\pm\to\rho^\pm(\pi^\pm\pi^0)\gamma$ and $B^0\to\omega(\pi^0\gamma)\gamma$. To further explore the question of remaining background in the signal region, we define the *grand side band* consisting of a rectangular region within the limits $-1.0 < \Delta E < 1.0\,{\rm GeV}$ and $5.20 < m_{\rm ES} < 5.26\,{\rm GeV}/c^2$ (see Fig. 2, left dashed box). In this region we find a prediction of 34 ± 9 events from continuum background Monte Carlo simulations, in good agreement with the observation of 43 ± 7 (44 ± 20) events from on–resonance data (off-resonance data of 2.2 ${\rm fb}^{-1}$ scaled to the full analyzed luminosity of $19.4\,{\rm fb}^{-1}$). We parameterize the background using on–resonance data. The background in ΔE is parameterized in the grand side band with a first order polynomial (see Fig. 3, top panel), the background in $m_{\rm ES}$ is parameterized in the *lower side band*, which is a rectangular region within the limits $-1.0 < \Delta E < -0.2\,{\rm GeV}$ and $5.20 < m_{\rm ES} < 5.29\,{\rm GeV}/c^2$, using an empirical threshold function first employed by the ARGUS collaboration [12] (see Fig. 3, bottom panel). Both parameterizations describe the corresponding distribution very well with a χ^2 normalized to the number of degrees of freedom of about 0.8. Using this parameterization we are able to extrapolate the on–resonance grand side band data into the signal region and find an expectation of $0.9^{+0.4}_{-0.3}$ events. This is consistent with the hypothesis that the observed event in the signal region is due to continuum background. Nevertheless, we choose to quote a conservative upper limit, assuming that the observed event in the signal region is in fact due to the decay $B^0\to\gamma\gamma$. We use Poisson statistics to set an upper limit on the branching fraction. The upper limit on the branching fraction $\mathcal{B}$ is obtained from $\mathcal{B} = N_{UL}/(\epsilon\cdot(N_{B^0}+N_{\overline{B}^0}))$, where N_{UL} is the upper limit on the number of observed events, ϵ the signal reconstruction efficiency of (10.7 ± 0.2)% and $N_{B^0}+N_{\overline{B}^0}$ is the number of produced B^0 and $\overline{B}^0$ mesons. $N_{B^0}+N_{\overline{B}^0}$ is equal to the number of $\Upsilon(4S)$ events since we assume the number of B^0 $\overline{B}^0$ events to be 50 % of the number of produced $\Upsilon(4S)$ events. This yields an upper limit on the branching fraction, based on statistics alone, of $\mathcal{B}(B^0\to\gamma\gamma) < 1.7\times10^{-6}$ at the 90% confidence level.

TABLE I: Summary of systematic uncertainties on the signal efficiency and the number of produced $\Upsilon(4S)$ as an error on the branching fraction determination. The total systematic uncertainty is the sum of the individual contributions added in quadrature.

systematic uncertainty	$(\Delta\mathcal{B}/\mathcal{B})$%
Number of produced $\Upsilon(4S)$	1.6
Photon detection efficiency	6.5
η veto	2.0
π^0 veto	2.0
ΔE selection	5.3
$m_{\rm ES}$ selection	2.6
Track finding efficiency	1.8
Number of signal Monte Carlo events	2.0
Total	9.6

Systematic effects arise from the modeling of the signal efficiency and the estimation of the number of B mesons

TABLE II: Summary of results and branching fraction upper limit. The number of expected signal events assuming a branching fraction of 1×10^{-8} is $N_{\rm exp}$, the number of observed events $N_{\rm obs}$, with the upper limit on 1 of $N_{\rm UL}$ and a signal efficiency ϵ we derive the upper limit on the branching fraction $\mathcal{B}$.

$N_{\rm exp}$	$N_{\rm obs}$	$N_{\rm UL}$	$N_{\rm bkg}$	ϵ [%]	$\mathcal{B}(B^0 \to \gamma\gamma)$ upper limit
0.02	1	3.89	$0.9^{+0.4}_{-0.3}$	10.7 ± 0.2	1.7×10^{-6} (90% CL)

in the *BABAR* data sample. The systematic uncertainties we have considered in this study are listed in Table I in terms of their effect on the branching fraction determination. The most significant systematic uncertainties are introduced by the photon detection efficiency and by the ΔE selection as a consequence of the uncertainty in the photon energy scale and photon energy resolution. The photon detection efficiency has been determined from hadronic τ lepton decays. The study compares the rate of $\tau \to \pi\pi^0\nu_\tau$ relative to that of $\tau \to \pi\pi^0\pi^0\nu_\tau$, which is precisely known [9], in Monte Carlo events and data. The uncertainty in the energy scale was estimated in a study of symmetric $\eta \to \gamma\gamma$ decays, in which both photons were within a narrow energy range. Systematic shifts of the reconstructed η mass from the nominal mass measure the uncertainty in the energy scale in this energy range.

In order to include our systematic uncertainty in the determination of the upper limit, we follow a prescription given by [13]. The branching fraction $\mathcal{B}$ is calculated as $\mathcal{B} = n/S$, where n is the number of observed events and $S = 2.3 \times 10^6$ is the sensitivity, given by the product of the number of $B^0\overline{B}^0$ events and the overall $B^0 \to \gamma\gamma$ selection efficiency. Assuming a normal distribution for the uncertainty in $1/S$, the systematic uncertainty is accounted for by convoluting the Poisson probability distribution for the assumed branching fraction with a Gaussian error distribution for $1/S$. Our total systematic uncertainty of 9.6 % included in this way has a negligible effect on the upper limit. The results of this analysis are summarized in Table II.

In summary, we have performed a search for the decay $B^0 \to \gamma\gamma$. We observe one event in the signal region and infer an upper limit on the branching fraction of

$$\mathcal{B}(B^0 \to \gamma\gamma) < 1.7 \times 10^{-6}$$

at the 90% confidence level. This result improves the existing limit from the L3 collaboration [3] by over a factor of 20.

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 collaborating institutions wish to thank SLAC for its support and the kind hospitality extended to them. This work is supported by DOE and NSF (USA), NSERC (Canada), IHEP (China), CEA and CNRS-IN2P3 (France), BMBF (Germany), INFN (Italy), NFR (Norway), MIST (Russia), and PPARC (United Kingdom). Individuals have received support from the Swiss NSF, A. P. Sloan Foundation, Research Corporation, and Alexander von Humboldt Foundation.

---

[*] Also with Università di Perugia, I-06100 Perugia, Italy

[†] Also with Università della Basilicata, I-85100 Potenza, Italy

[1] G. G. Devidze and G. R. Jibuti, Phys. Lett. B **429**, 48 (1998).

[2] T. M. Aliev and G. Turan, Phys. Rev. D **48**, 1176 (1993).

[3] L3 Collaboration, M. Acciarri *et al.*, Phys. Lett. B **363**, 137 (1995).

[4] *BABAR* Collaboration, B. Aubert *et al.*, hep-ex/0105044, submitted to Nucl. Instr. Methods A.

[5] PEPII – An Asymmetric B Factory, Conceptual Design Report SLAC-0418.

[6] GEANT – Detector Description and Simulation Tool, CERN Program Library Long Writeup W5013, 1994.

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

[8] The second moment of a cluster is defined as $\frac{1}{\sum_{i=1}^{n} E_i} \times \sum_{i=1}^{n} E_i \, (\Delta\theta_i^2 + \Delta\phi_i^2)$; $\Delta\theta_i$ and $\Delta\phi_i$ are the angular distances between the center of crystal i and the cluster centroid in θ and ϕ, E_i is the energy deposited in crystal i, where i runs from 1 to n, the total number of crystals contained in the EMC cluster.

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

[10] For signal Monte Carlo events the ΔE and $m_{\rm ES}$ distribution are fitted with the Crystal Ball function

$$f(x) = N \cdot \begin{cases} \exp(-\frac{(x-\bar{x})^2}{2\,\sigma^2}) & ; (x-\bar{x})/\sigma > \alpha \\ A \times (B - \frac{x-\bar{x}}{\sigma})^{-n} & ; (x-\bar{x})/\sigma \leq \alpha \end{cases}$$

where $A \equiv \left(\frac{n}{|\alpha|}\right)^n \times \exp(-|\alpha|^2/2)$ and $B \equiv \frac{n}{|\alpha|} - |\alpha|$. N is a normalization factor, $\bar{x}$ and σ are the fitted peak position and width of the Gaussian portion of the function, and α and n are the fitted point at which the function transitions to the power function and the exponent of the power function, respectively. A and B are defined such as to maintain the continuity of the function and it first derivative at α. More details can be found in D. Antreasyan, Crystal Ball Note 321 (1983).

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

[12] The $m_{\rm ES}$ distribution is parameterized using the ARGUS function $f(x) = N\,x\,\sqrt{1-x^2}\,\exp(-\zeta\,(1-x^2))$ with $x = 2\,m_{ES}/\sqrt{s}$ and $\sqrt{s}$ the center of mass energy. N is a normalization factor and ζ a fit parameter. More details can be found in Argus Collaboration, H. Albrecht *et al.*, Z. Phys. **C48**, 543 (1990).

[13] R. D. Cousins and V. L. Highland, Nucl. Instr. and Methods A **320**, 331 (1992).