Evidence of a Broad Structure at an Invariant Mass of 4.32 GeV/c^2 in the Reaction $e^+e^- \to \pi^+\pi^-\psi(2S)$ Measured at *BABAR*

B. Aubert,[1] R. Barate,[1] M. Bona,[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] 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] D. N. Brown,[6] J. Button-Shafer,[6] R. N. Cahn,[6] E. Charles,[6] M. S. Gill,[6] Y. Groysman,[6] R. G. Jacobsen,[6] J. A. Kadyk,[6] L. T. Kerth,[6] Yu. G. Kolomensky,[6] G. Kukartsev,[6] G. Lynch,[6] L. M. Mir,[6] T. J. Orimoto,[6] M. Pripstein,[6] N. A. Roe,[6] M. T. Ronan,[6] W. A. Wenzel,[6] P. del Amo Sanchez,[7] 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] 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] W. N. Cottingham,[9] D. Walker,[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] D. J. Sherwood,[11] L. Teodorescu,[11] V. E. Blinov,[12] A. D. Bukin,[12] V. P. Druzhinin,[12] V. B. Golubev,[12] A. P. Onuchin,[12] S. I. Serednyakov,[12] Yu. I. Skovpen,[12] E. P. Solodov,[12] K. Yu Todyshev,[12] D. S. 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] S. Abachi,[14] C. Buchanan,[14] S. D. Foulkes,[15] J. W. Gary,[15] O. Long,[15] B. C. Shen,[15] K. Wang,[15] L. Zhang,[15] H. K. Hadavand,[16] E. J. Hill,[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] D. Kovalskyi,[17] J. D. Richman,[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] A. Dvoretskii,[19] F. Fang,[19] D. G. Hitlin,[19] I. Narsky,[19] T. Piatenko,[19] F. C. Porter,[19] A. Ryd,[19] A. Samuel,[19] G. Mancinelli,[20] B. T. Meadows,[20] K. Mishra,[20] M. D. Sokoloff,[20] F. Blanc,[21] P. C. Bloom,[21] S. Chen,[21] W. T. Ford,[21] J. F. Hirschauer,[21] A. Kreisel,[21] M. Nagel,[21] U. Nauenberg,[21] A. Olivas,[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] F. Winklmeier,[22] Q. Zeng,[22] D. D. Altenburg,[23] E. Feltresi,[23] A. Hauke,[23] H. Jasper,[23] A. Petzold,[23] B. Spaan,[23] T. Brandt,[24] V. Klose,[24] H. M. Lacker,[24] W. F. Mader,[24] R. Nogowski,[24] J. Schubert,[24] K. R. Schubert,[24] R. Schwierz,[24] J. E. Sundermann,[24] A. Volk,[24] D. Bernard,[25] G. R. Bonneaud,[25] P. Grenier,[25,*] E. Latour,[25] Ch. Thiebaux,[25] M. Verderi,[25] P. J. Clark,[26] W. Gradl,[26] F. Muheim,[26] S. Playfer,[26] A. I. Robertson,[26] Y. Xie,[26] M. Andreotti,[27] D. Bettoni,[27] C. Bozzi,[27] R. Calabrese,[27] G. Cibinetto,[27] E. Luppi,[27] M. Negrini,[27] A. Petrella,[27] L. Piemontese,[27] E. Prencipe,[27] F. Anulli,[28] R. Baldini-Ferroli,[28] A. Calcaterra,[28] R. de Sangro,[28] G. Finocchiaro,[28] S. Pacetti,[28] P. Patteri,[28] I. M. Peruzzi,[28,†] M. Piccolo,[28] M. Rama,[28] A. Zallo,[28] A. Buzzo,[29] R. Capra,[29] R. Contri,[29] M. Lo Vetere,[29] M. 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] J. Wu,[30] R. S. Dubitzky,[31] J. Marks,[31] S. Schenk,[31] U. Uwer,[31] D. J. Bard,[32] W. Bhimji,[32] D. A. Bowerman,[32] P. D. Dauncey,[32] U. Egede,[32] R. L. Flack,[32] J. A. Nash,[32] M. B. Nikolich,[32] W. Panduro Vazquez,[32] P. K. Behera,[33] X. Chai,[33] M. J. Charles,[33] U. Mallik,[33] N. T. Meyer,[33] V. Ziegler,[33] J. Cochran,[34] H. B. Crawley,[34] L. Dong,[34] V. Eyges,[34] W. T. Meyer,[34] S. Prell,[34] E. I. Rosenberg,[34] A. E. Rubin,[34] A. V. Gritsan,[35] A. G. Denig,[36] M. Fritsch,[36] G. Schott,[36] N. Arnaud,[37] M. Davier,[37] G. Grosdidier,[37] A. Höcker,[37] F. Le Diberder,[37] V. Lepeltier,[37] A. M. Lutz,[37] A. Oyanguren,[37] S. Pruvot,[37] S. Rodier,[37] P. Roudeau,[37] M. H. Schune,[37] A. Stocchi,[37] W. F. Wang,[37] G. Wormser,[37] C. H. Cheng,[38] D. J. Lange,[38] D. M. Wright,[38] C. A. Chavez,[39] I. J. Forster,[39] J. R. Fry,[39] E. Gabathuler,[39] R. Gamet,[39] K. A. George,[39] D. E. Hutchcroft,[39] D. J. Payne,[39] K. C. Schofield,[39] C. Touramanis,[39] A. J. Bevan,[40] F. Di Lodovico,[40] W. Menges,[40] R. Sacco,[40] G. Cowan,[41] H. U. Flaecher,[41] D. A. Hopkins,[41] P. S. Jackson,[41] T. R. McMahon,[41] S. Ricciardi,[41] F. Salvatore,[41] A. C. Wren,[41] D. N. Brown,[42] C. L. Davis,[42] J. Allison,[43] N. R. Barlow,[43] R. J. Barlow,[43] Y. M. Chia,[43] C. L. Edgar,[43] G. D. Lafferty,[43] M. T. Naisbit,[43] J. C. Williams,[43] J. I. Yi,[43] C. Chen,[44] W. D. Hulsbergen,[44] A. Jawahery,[44] C. K. Lae,[44] D. A. Roberts,[44] G. Simi,[44] G. Blaylock,[45] C. Dallapiccola,[45] S. S. Hertzbach,[45] X. Li,[45] T. B. Moore,[45] S. Saremi,[45] H. Staengle,[45] R. Cowan,[46] G. Sciolla,[46] S. J. Sekula,[46] M. Spitznagel,[46] F. Taylor,[46] R. K. Yamamoto,[46] H. Kim,[47] S. E. Mclachlin,[47] P. M. Patel,[47] S. H. Robertson,[47] A. Lazzaro,[48] V. Lombardo,[48] F. Palombo,[48] J. M. Bauer,[49] L. Cremaldi,[49] V. Eschenburg,[49] R. Godang,[49] R. Kroeger,[49] D. A. Sanders,[49] D. J. Summers,[49] H. W. Zhao,[49] S. Brunet,[50] D. Côté,[50] M. Simard,[50] P. Taras,[50] F. B. Viaud,[50] H. Nicholson,[51] N. Cavallo,[52,‡] G. De Nardo,[52] F. Fabozzi,[52,‡] C. Gatto,[52] L. Lista,[52] D. Monorchio,[52] P. Paolucci,[52] D. Piccolo,[52] C. Sciacca,[52] M. Baak,[53] G. Raven,[53] H. L. Snoek,[53] C. P. Jessop,[54] J. M. LoSecco,[54] T. Allmendinger,[55] G. Benelli,[55] K. K. Gan,[55] K. Honscheid,[55] D. Hufnagel,[55] P. D. Jackson,[55] H. Kagan,[55] R. Kass,[55] A. M. Rahimi,[55] R. Ter-Antonyan,[55] Q. K. Wong,[55] N. L. Blount,[56] J. Brau,[56] R. Frey,[56]

O. Igonkina,[56] M. Lu,[56] R. Rahmat,[56] N. B. Sinev,[56] D. Strom,[56] J. Strube,[56] E. Torrence,[56] A. Gaz,[57] M. Margoni,[57] M. Morandin,[57] A. Pompili,[57] M. Posocco,[57] M. Rotondo,[57] F. Simonetto,[57] R. Stroili,[57] C. Voci,[57] M. Benayoun,[58] J. Chauveau,[58] H. Briand,[58] P. David,[58] L. Del Buono,[58] Ch. de la Vaissière,[58] O. Hamon,[58] B. L. Hartfiel,[58] M. J. J. John,[58] Ph. Leruste,[58] J. Malclès,[58] J. Ocariz,[58] L. Roos,[58] G. Therin,[58] L. Gladney,[59] J. Panetta,[59] M. Biasini,[60] R. Covarelli,[60] C. Angelini,[61] G. Batignani,[61] S. Bettarini,[61] F. Bucci,[61] G. Calderini,[61] M. Carpinelli,[61] R. Cenci,[61] F. Forti,[61] M. A. Giorgi,[61] A. Lusiani,[61] G. Marchiori,[61] M. A. Mazur,[61] M. Morganti,[61] N. Neri,[61] G. Rizzo,[61] J. J. Walsh,[61] M. Haire,[62] D. Judd,[62] D. E. Wagoner,[62] J. Biesiada,[63] N. Danielson,[63] P. Elmer,[63] Y. P. Lau,[63] C. Lu,[63] J. Olsen,[63] A. J. S. Smith,[63] A. V. Telnov,[63] F. Bellini,[64] G. Cavoto,[64] A. D'Orazio,[64] D. del Re,[64] E. Di Marco,[64] R. Faccini,[64] F. Ferrarotto,[64] F. Ferroni,[64] M. Gaspero,[64] L. Li Gioi,[64] M. A. Mazzoni,[64] S. Morganti,[64] G. Piredda,[64] F. Polci,[64] F. Safai Tehrani,[64] C. Voena,[64] M. Ebert,[65] H. Schröder,[65] R. Waldi,[65] T. Adye,[66] N. De Groot,[66] B. Franek,[66] E. O. Olaiya,[66] F. F. Wilson,[66] R. Aleksan,[67] S. Emery,[67] A. Gaidot,[67] S. F. Ganzhur,[67] G. Hamel de Monchenault,[67] W. Kozanecki,[67] M. Legendre,[67] G. Vasseur,[67] Ch. Yèche,[67] M. Zito,[67] X. R. Chen,[68] H. Liu,[68] W. Park,[68] M. V. Purohit,[68] J. R. Wilson,[68] M. T. Allen,[69] D. Aston,[69] R. Bartoldus,[69] P. Bechtle,[69] N. Berger,[69] R. Claus,[69] J. P. Coleman,[69] M. R. Convery,[69] M. Cristinziani,[69] J. C. Dingfelder,[69] J. Dorfan,[69] G. P. Dubois-Felsmann,[69] D. Dujmic,[69] W. Dunwoodie,[69] R. C. Field,[69] T. Glanzman,[69] S. J. Gowdy,[69] M. T. Graham,[69] V. Halyo,[69] C. Hast,[69] T. Hryn'ova,[69] W. R. Innes,[69] M. H. Kelsey,[69] P. Kim,[69] D. W. G. S. Leith,[69] S. Li,[69] S. Luitz,[69] V. Luth,[69] H. L. Lynch,[69] D. B. MacFarlane,[69] H. Marsiske,[69] R. Messner,[69] D. R. Muller,[69] C. P. O'Grady,[69] V. E. Ozcan,[69] A. Perazzo,[69] M. Perl,[69] T. Pulliam,[69] B. N. Ratcliff,[69] A. Roodman,[69] A. A. Salnikov,[69] R. H. Schindler,[69] J. Schwiening,[69] A. Snyder,[69] J. Stelzer,[69] D. Su,[69] M. K. Sullivan,[69] K. Suzuki,[69] S. K. Swain,[69] J. M. Thompson,[69] J. Va'vra,[69] N. van Bakel,[69] M. Weaver,[69] A. J. R. Weinstein,[69] W. J. Wisniewski,[69] M. Wittgen,[69] D. H. Wright,[69] A. K. Yarritu,[69] K. Yi,[69] C. C. Young,[69] P. R. Burchat,[70] A. J. Edwards,[70] S. A. Majewski,[70] B. A. Petersen,[70] C. Roat,[70] L. Wilden,[70] S. Ahmed,[71] M. S. Alam,[71] R. Bula,[71] J. A. Ernst,[71] V. Jain,[71] B. Pan,[71] M. A. Saeed,[71] F. R. Wappler,[71] S. B. Zain,[71] W. Bugg,[72] M. Krishnamurthy,[72] S. M. Spanier,[72] R. Eckmann,[73] J. L. Ritchie,[73] A. Satpathy,[73] C. J. Schilling,[73] R. F. Schwitters,[73] J. M. Izen,[74] X. C. Lou,[74] S. Ye,[74] F. Bianchi,[75] F. Gallo,[75] D. Gamba,[75] M. Bomben,[76] L. Bosisio,[76] C. Cartaro,[76] F. Cossutti,[76] G. Della Ricca,[76] S. Dittongo,[76] L. Lanceri,[76] L. Vitale,[76] V. Azzolini,[77] F. Martinez-Vidal,[77] Sw. Banerjee,[78] B. Bhuyan,[78] C. M. Brown,[78] D. Fortin,[78] K. Hamano,[78] R. Kowalewski,[78] I. M. Nugent,[78] J. M. Roney,[78] R. J. Sobie,[78] J. J. Back,[79] P. F. Harrison,[79] T. E. Latham,[79] G. B. Mohanty,[79] M. Pappagallo,[79] H. R. Band,[80] X. Chen,[80] B. Cheng,[80] S. Dasu,[80] M. Datta,[80] K. T. Flood,[80] J. J. Hollar,[80] P. E. Kutter,[80] B. Mellado,[80] A. Mihalyi,[80] Y. Pan,[80] M. Pierini,[80] R. Prepost,[80] S. L. Wu,[80] Z. Yu,[80] and H. Neal[81]

(*BABAR* Collaboration)

[1]*Laboratoire de Physique des Particules, F-74941 Annecy-le-Vieux, France*
[2]*Universitat de Barcelona, Facultat de Fisica Dept. ECM, E-08028 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 für Physik, D-44221 Dortmund, Germany*

[24]*Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany*
[25]*Ecole Polytechnique, Laboratoire Leprince-Ringuet, 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]*Johns Hopkins University, Baltimore, Maryland 21218, USA*
[36]*Universität Karlsruhe, Institut für Experimentelle Kernphysik, D-76021 Karlsruhe, Germany*
[37]*Laboratoire de l'Accélérateur Linéaire, IN2P3-CNRS et Université Paris-Sud 11, Centre Scientifique d'Orsay, B.P. 34, F-91898 ORSAY Cedex, France*
[38]*Lawrence Livermore National Laboratory, Livermore, California 94550, USA*
[39]*University of Liverpool, Liverpool L69 7ZE, United Kingdom*
[40]*Queen Mary, University of London, E1 4NS, United Kingdom*
[41]*University of London, Royal Holloway and Bedford New College, Egham, Surrey TW20 0EX, United Kingdom*
[42]*University of Louisville, Louisville, Kentucky 40292, USA*
[43]*University of Manchester, Manchester M13 9PL, United Kingdom*
[44]*University of Maryland, College Park, Maryland 20742, USA*
[45]*University of Massachusetts, Amherst, Massachusetts 01003, USA*
[46]*Massachusetts Institute of Technology, Laboratory for Nuclear Science, Cambridge, Massachusetts 02139, USA*
[47]*McGill University, Montréal, Québec, Canada H3A 2T8*
[48]*Università di Milano, Dipartimento di Fisica and INFN, I-20133 Milano, Italy*
[49]*University of Mississippi, University, Mississippi 38677, USA*
[50]*Université de Montréal, Physique des Particules, Montréal, Québec, Canada H3C 3J7*
[51]*Mount Holyoke College, South Hadley, Massachusetts 01075, USA*
[52]*Università di Napoli Federico II, Dipartimento di Scienze Fisiche and INFN, I-80126, Napoli, Italy*
[53]*NIKHEF, National Institute for Nuclear Physics and High Energy Physics, NL-1009 DB Amsterdam, The Netherlands*
[54]*University of Notre Dame, Notre Dame, Indiana 46556, USA*
[55]*Ohio State University, Columbus, Ohio 43210, USA*
[56]*University of Oregon, Eugene, Oregon 97403, USA*
[57]*Università di Padova, Dipartimento di Fisica and INFN, I-35131 Padova, Italy*
[58]*Universités Paris VI et VII, Laboratoire de Physique Nucléaire et de Hautes Energies, F-75252 Paris, France*
[59]*University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA*
[60]*Università di Perugia, Dipartimento di Fisica and INFN, I-06100 Perugia, Italy*
[61]*Università di Pisa, Dipartimento di Fisica, Scuola Normale Superiore and INFN, I-56127 Pisa, Italy*
[62]*Prairie View A&M University, Prairie View, Texas 77446, USA*
[63]*Princeton University, Princeton, New Jersey 08544, USA*
[64]*Università di Roma La Sapienza, Dipartimento di Fisica and INFN, I-00185 Roma, Italy*
[65]*Universität Rostock, D-18051 Rostock, Germany*
[66]*Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingdom*
[67]*DSM/Dapnia, CEA/Saclay, F-91191 Gif-sur-Yvette, France*
[68]*University of South Carolina, Columbia, South Carolina 29208, USA*
[69]*Stanford Linear Accelerator Center, Stanford, California 94309, USA*
[70]*Stanford University, Stanford, California 94305-4060, USA*
[71]*State University of New York, Albany, New York 12222, USA*
[72]*University of Tennessee, Knoxville, Tennessee 37996, USA*
[73]*University of Texas at Austin, Austin, Texas 78712, USA*
[74]*University of Texas at Dallas, Richardson, Texas 75083, USA*
[75]*Università di Torino, Dipartimento di Fisica Sperimentale and INFN, I-10125 Torino, Italy*
[76]*Università di Trieste, Dipartimento di Fisica and INFN, I-34127 Trieste, Italy*
[77]*IFIC, Universitat de Valencia-CSIC, E-46071 Valencia, Spain*
[78]*University of Victoria, Victoria, British Columbia, Canada V8W 3P6*
[79]*Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom*
[80]*University of Wisconsin, Madison, Wisconsin 53706, USA*
[81]*Yale University, New Haven, Connecticut 06511, USA*

(Received 21 October 2006; revised manuscript received 31 January 2007; published 24 May 2007)

We present a measurement of the cross section of the process $e^+e^- \to \pi^+\pi^-\psi(2S)$ from threshold up to 8 GeV center-of-mass energy using events containing initial-state radiation, produced at the SLAC PEP-II e^+e^- storage rings. The study is based on 298 fb^{-1} of data recorded with the *BABAR* detector. A structure is observed in the cross section not far above threshold, near 4.32 GeV. We also investigate the compatibility of this structure with the $Y(4260)$ previously reported by this experiment.

DOI: 10.1103/PhysRevLett.98.212001 PACS numbers: 14.40.Gx, 13.25.Gv, 13.66.Bc

Until recently, charmonium spectroscopy has been well described by potential models. Observations of the $X(3872)$ [1] and the $Y(4260)$ [2] decaying into $\pi^+\pi^-J/\psi$ complicate this picture, and have stimulated both experimental and theoretical interest in this area. The $Y(4260)$ can be produced by direct e^+e^- annihilation and is therefore known to have $J^{PC} = 1^{--}$. Weak evidence for the $Y(4260)$ structure in B decays was also reported by *BABAR* [3]. In addition, the $Y(4260)$ has been confirmed by the CLEO-c experiment in direct $e^+e^- \to Y(4260)$ interactions where the $Y(4260)$ is detected in decays to $\pi^+\pi^-J/\psi$ and $\pi^0\pi^0J/\psi$ [4]; the observation of the latter mode and the measured ratio $\mathcal{B}(Y(4260) \to \pi^0\pi^0J/\psi)/\mathcal{B}(Y(4260) \to \pi^+\pi^-J/\psi) \approx 0.5$ implies that the $Y(4260)$ has isospin zero, as expected for a charmonium state.

It is peculiar that the $Y(4260)$ is wide and yet has a large branching fraction into the hidden charm mode $\pi^+\pi^-J/\psi$, and that at the $Y(4260)$ mass the cross section for $e^+e^- \to$ hadrons exhibits a local minimum. Many theoretical interpretations for the $Y(4260)$ have been proposed, including unconventional scenarios: quark-antiquark gluon hybrids [5] and hadronic molecules [6]. We undertook this study with the intent of clarifying the nature of the $Y(4260)$.

In this Letter we study the process $e^+e^- \to \pi^+\pi^-\psi(2S)$, $\psi(2S) \to \pi^+\pi^-J/\psi$, for e^+e^- center-of-mass (c.m.) energies from threshold up to 8 GeV using initial-state radiation (ISR) events. The ISR cross section for a particular hadronic final state f is given by

$$\frac{d\sigma_f(s,x)}{dx} = W(s,x)\sigma_f(s(1-x)), \qquad (1)$$

where s is the square of the e^+e^- c.m. energy, $x \equiv 2E_\gamma/\sqrt{s}$ is the ratio of the photon energy to the beam energy in the e^+e^- c.m. frame, and $W(s,x)$ is the spectrum for ISR photon emission for which we use a calculation good to $\mathcal{O}(\alpha^2)$; the effective c.m. energy $\sqrt{s'}$ is the invariant mass of the final state $m = \sqrt{s(1-x)}$.

We use data recorded with the *BABAR* detector [7] at the PEP-II asymmetric-energy e^+e^- storage rings, located at the Stanford Linear Accelerator Center. These data represent an integrated luminosity of 272 fb^{-1} recorded at $\sqrt{s} = 10.58$ GeV, near the $\Upsilon(4S)$ resonance, and 26 fb^{-1} recorded near 10.54 GeV.

Charged-particle momenta are measured in a tracking system consisting of a five-layer double-sided silicon vertex tracker (SVT) and a 40-layer central drift chamber (DCH), both situated in a 1.5-T axial magnetic field. An internally reflecting ring-imaging Cherenkov detector (DIRC) provides charged-particle identification. A CsI(Tl) electromagnetic calorimeter (EMC) is used to detect and identify photons and electrons, while muons are identified in the instrumented magnetic-flux return system (IFR).

Optimized selection criteria are chosen based on a simulated sample of $e^+e^- \to \gamma_{ISR}\pi^+\pi^-\psi(2S)$ events and a sample of $e^+e^- \to \gamma_{ISR}\psi(2S)$, $\psi(2S) \to \pi^+\pi^-J/\psi$ candidates in data, which serve as a clean control sample [8].

A candidate J/ψ meson is reconstructed via its decay to e^+e^- or $\mu^+\mu^-$. The lepton tracks must be well reconstructed, and at least one must be identified as an electron or a muon candidate. An algorithm to recover energy lost to bremsstrahlung is applied to electron candidates. An e^+e^- pair with its invariant mass within the interval of $(-100, +40)$ MeV/c^2 of the nominal J/ψ mass is taken as a J/ψ candidate. For a $\mu^+\mu^-$ pair, the interval is $(-60, +40)$ MeV/c^2. The J/ψ candidate is then kinematically constrained to the nominal J/ψ mass and combined with a pair of oppositely charged tracks identified as pion candidates. The $\pi^+\pi^-J/\psi$ combinations with invariant mass within 10 MeV/c^2 of the nominal $\psi(2S)$ mass are taken as $\psi(2S)$ candidates. Another pair of oppositely charged pion candidates (primary pions) is then combined with the $\psi(2S)$ candidate. The $\pi^+\pi^-\psi(2S)$ mass-resolution function is well described by a Cauchy distribution [9] with a FWHM of about 7 MeV/c^2. We do not require observation of the ISR photon (γ_{ISR}) as it is preferentially produced along the beam directions.

We select $e^+e^- \to \gamma_{ISR}\pi^+\pi^-\psi(2S)$ events with the following criteria: (1) there must be no additional well-reconstructed charged tracks in the event; (2) there must be no well-reconstructed π^0 or $\eta \to \gamma\gamma$ in the event; (3) the transverse component of the visible momentum in the e^+e^- c.m. frame, including that of the γ_{ISR} when it is reconstructed, must be less than 2 GeV/c; (4) the difference (Δp^*) between the measured $\pi^+\pi^-\psi(2S)$ momentum and the value expected for it in an ISR $\pi^+\pi^-\psi(2S)$ event, that is, $(s - m^2)/(2\sqrt{s})$, where m is the $\pi^+\pi^-\psi(2S)$ invariant mass, must be within $[-0.10, +0.06]$ GeV/c; (5) $\cos\theta_\ell$, where θ_ℓ is the angle between the lepton ℓ^+ momentum in the J/ψ rest frame and the J/ψ momentum in the e^+e^- c.m. frame, must satisfy $|\cos\theta_\ell| < 0.90$; and (6) the invariant mass of the $\pi^+\pi^-$ pair in $\psi(2S)$ decay must be greater than 0.4 GeV/c^2 in order to suppress the combinatorial $\pi^+\pi^-J/\psi$ background.

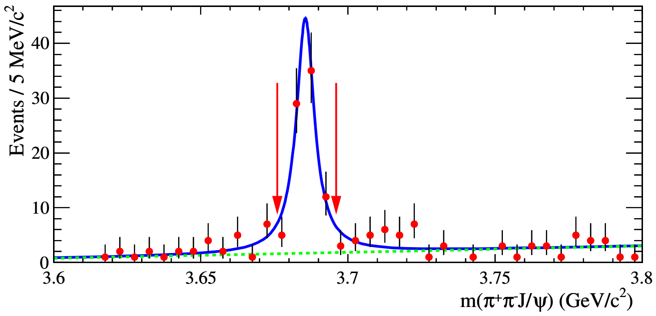

FIG. 1 (color online). The invariant-mass distribution for all $\pi^+\pi^- J/\psi$ candidates where more than one entry per event is allowed. The solid curve is a fit to the distribution in which the $\psi(2S)$ signal is described by a Cauchy function and the background by a quadratic function (represented by the dashed curve). The arrows indicate the $\psi(2S)$ mass window.

A clean $\psi(2S)$ signal is apparent in Fig. 1. An examination of the $\pi^+\pi^-\psi(2S)$ combinations reveals that about half the background results from recombinations within the same $2(\pi^+\pi^-)J/\psi$ system where at least one of the primary pions is combined with the J/ψ to form a $\pi^+\pi^- J/\psi$ candidate. After subtracting the self-combinatorial background, we estimate 3.8 ± 1.1 non-$\psi(2S)$ background events in the final sample of 78 events within the $\psi(2S)$ mass window.

In Fig. 2 the distributions of (a) Δp^* and (b) $\cos\theta^*$ for $2(\pi^+\pi^-)J/\psi$ candidates, where θ^* is the angle between the positron beam and the $(\pi^+\pi^-\pi^+\pi^- J/\psi)$ momentum in the e^+e^- c.m. frame, are shown and compared to expectations from simulations. There are 16 events that have a well-reconstructed gamma with energy greater than 3 GeV, while the Monte Carlo simulation predicts 16.4 for the same total number of ISR $\pi^+\pi^-\psi(2S)$ candidates. Furthermore, all events within $|\cos\theta^*| < 0.9$ are accompanied by a reconstructed gamma with energy greater than 3.0 GeV. We find excellent agreement in the ISR characteristics between the data and signal Monte Carlo sample. The good agreement in the Δp^* distribution rules out any significant feed down from higher mass charmonia decaying to the $\psi(2S)$ with one or more undetected particles. As an example, the Δp^* distribution for $\psi(4415) \to \pi^+\pi^-\pi^0\psi(2S)$ events would peak around -0.2 GeV/c with a long tail extending to well below -0.2 GeV/c. We estimate the non-ISR $\pi^+\pi^-\psi(2S)$ background to be less than 1 event.

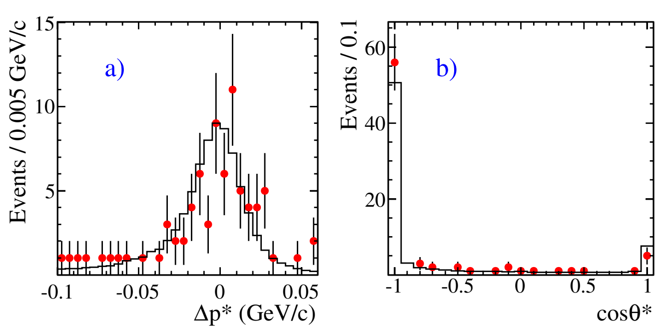

FIG. 2 (color online). The distributions of (a) Δp^* and (b) $\cos\theta^*$ of the $2(\pi^+\pi^-)J/\psi$ combination in the e^+e^- c.m. frame are shown for data (solid dots) and Monte Carlo simulation of the signal (histogram) normalized to the total number of the observed data events.

The track quality, particle identification information, and kinematic variables of all pion candidates are examined, and displays of the events are scanned visually to check for possible track duplications and other potential problems. No evidence for improper reconstruction or event quality problems is found.

The $2(\pi^+\pi^-)J/\psi$ invariant-mass spectrum up to 5.7 GeV/c^2 for the final sample is represented as data points in Fig. 3. A structure around 4.32 GeV/c^2 is observed in the mass spectrum.

To clarify the peaking structure observed in Fig. 3, we perform an unbinned maximum likelihood fit to the mass spectrum up to 5.7 GeV/c^2 in terms of a single resonance with the following probability density function (PDF):

$$P(m) = Na\varepsilon(m)(W(s,x)2m/s)\frac{12\pi}{m^2} \times \frac{M^2\Gamma_{ee}\Gamma_f(\Phi(m)/\Phi(M))}{(M^2 - m^2)^2 + (M\Gamma_{\rm tot})^2} + B(m), \quad (2)$$

where $M, \Gamma_{\rm tot}, \Gamma_{ee}, \Gamma_f, N$ are the nominal mass, total width, partial width to e^+e^-, partial width to $\pi^+\pi^-\psi(2S)$, and yield for a resonance, respectively, and m is the $2(\pi^+\pi^-)J/\psi$ invariant mass, $\varepsilon(m)$ is the mass-dependent efficiency, $\Phi(m)$ is the mass-dependent phase-space factor for a S-wave three-body $\pi^+\pi^-\psi(2S)$ system, a is a normalization factor, and $B(m)$ is the PDF (the shaded histogram in Fig. 3) for the non-$\psi(2S)$ background. The shape of B was obtained from $\psi(2S)$ sideband events with its

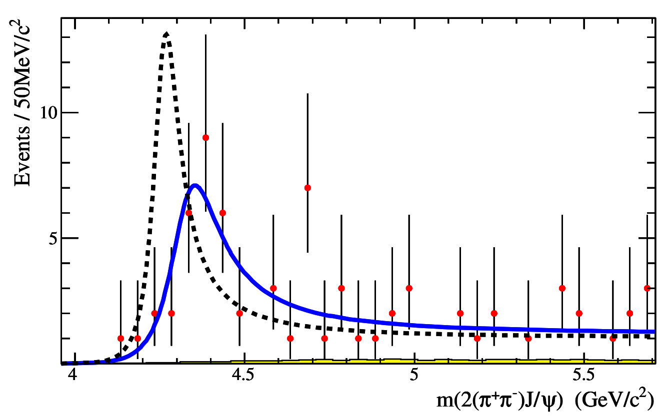

FIG. 3 (color online). The $2(\pi^+\pi^-)J/\psi$ invariant-mass spectrum up to 5.7 GeV/c^2 for the final sample. The shaded histogram represents the fixed background and the curves represent the fits to the data (see text).

integral fixed to 3.1 events corresponding to the mass region in the fit, where the total number of events is 68. The mass dependence of Γ_{tot} is ignored in the fit.

We perform fits to the distribution in Fig. 3 to test hypotheses that the data are a result of the decay of the $Y(4260)$ (dashed curve) using resonance parameters fixed to those of Ref. [2], and alternatively those of the $\psi(4415)$ (not shown) with the mass and width taken from Ref. [10]. In the third fit (solid curve) we assume a single resonance whose mass and width are free parameters, which are then found to be $(4324 \pm 24)\ \mathrm{MeV}/c^2$ and (172 ± 33) MeV (after unfolding mass resolution) by the fit. We calculate the χ^2/dof value for each fit to test these hypotheses. In the calculation the events in Fig. 3 are regrouped so that at least seven events are expected in each bin. The χ^2/dof values are found to be 21.3/8, 54.4/7, and 7.3/7 for hypotheses of the $Y(4260)$, the $\psi(4415)$, and a new resonance, respectively, corresponding to χ^2-probabilities of 6.5×10^{-3}, 2.0×10^{-9}, and 29%. The low probabilities associated with the $Y(4260)$ and the $\psi(4415)$ indicate that the structure is not consistent with the $\psi(4415)$, and is not well described by the $Y(4260)$ either. We also perform a fit including both the $Y(4260)$ and $\psi(4415)$ plus their interference, and find the χ^2/dof value to be 17.8/6, corresponding to a χ^2-probability of 6.7×10^{-3}, but no much improvement from the fit to the $Y(4260)$ only. In order to further compare the structure reported here with the $Y(4260)$ reported in Ref. [2], we perform simultaneous fits to both the $\pi^+\pi^-\psi(2S)$ mass spectrum in Fig. 3 and the $\pi^+\pi^- J/\psi$ mass distribution in [2] under the hypotheses that (1) both signals are a single resonance and (2) these signals are manifestations of two independent resonances, with a single resonance for each signal. The PDF as used in Ref. [2] is applied to the fit to the $\pi^+\pi^- J/\psi$ mass distribution. The logarithmic likelihood obtained from the single-resonance hypothesis (1) is 5.4 units less than that obtained from the two-resonance hypothesis (2), which corresponds to a χ^2 probability of 4.5×10^{-3} for the single-resonance hypothesis assuming a χ^2 distribution for the difference in the logarithmic likelihood between the two hypotheses. However, none of the probabilities associated with the $Y(4260)$ can exclude the possibility that the structure observed is a manifestation of a new decay mode for the $Y(4260)$.

The primary $\pi^+\pi^-$ invariant-mass distribution for the selected events within $m(2(\pi^+\pi^-)J/\psi) < 5.7\ \mathrm{GeV}/c^2$ is shown in Fig. 4. For the two events having more than one $\psi(2S)$ candidates, the dipion invariant mass is only included for the $\psi(2S)$ candidate closest to its nominal mass. The Monte Carlo distribution is also shown in Fig. 4 for a single resonance decaying to $\pi^+\pi^-\psi(2S)$ in a S-wave three-body phase space using the resonance parameters obtained in the above paragraph.

We extract the energy-dependent cross section for $e^+e^- \to \pi^+\pi^-\psi(2S)$ up to 8 GeV for the final sample.

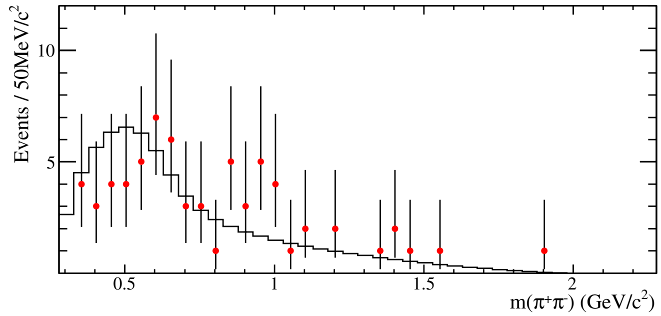

FIG. 4 (color online). The primary $\pi^+\pi^-$ invariant-mass spectrum within region $m(2(\pi^+\pi^-)J/\psi) < 5.7\ \mathrm{GeV}/c^2$ for the final sample. Only one entry per event is included in the plot, as described in the text. The histogram shows the distribution for Monte Carlo events (see text).

The average cross section over a mass range of width Δm is calculated as

$$\overline{\sigma(m)} \equiv \int_{m-\Delta m/2}^{m+\Delta m/2} \sigma(x)dx/\Delta m \approx \frac{1}{\mathcal{L}\mathcal{B}\Delta m}\sum_i \left(\frac{1}{2m_i/sW(s, 1 - m_i^2/s)\varepsilon_i}\right), \quad (4)$$

where $\mathcal{L}$ is the integrated luminosity, $\mathcal{B}$ is the product of $\mathcal{B}(\psi(2S) \to \pi^+\pi^- J/\psi)$ and $\mathcal{B}(J/\psi \to \ell^+\ell^-)$, the sum is over all events within the mass range, m_i is the $2(\pi^+\pi^-)J/\psi$ invariant mass, and ε_i is the estimated efficiency at that mass. The measured cross section is shown in Fig. 5 and the numerical results can be found in [11], where the background has been subtracted from bins with nonzero content. The energy-dependent selection efficiency (solid histogram in Fig. 5) is determined from Monte Carlo events for which the $\psi(2S)$ polarization has been properly considered while the primary $\pi^+\pi^-$ is generated in S-wave phase space. The uncertainty in the selection efficiency due to model dependence is estimated

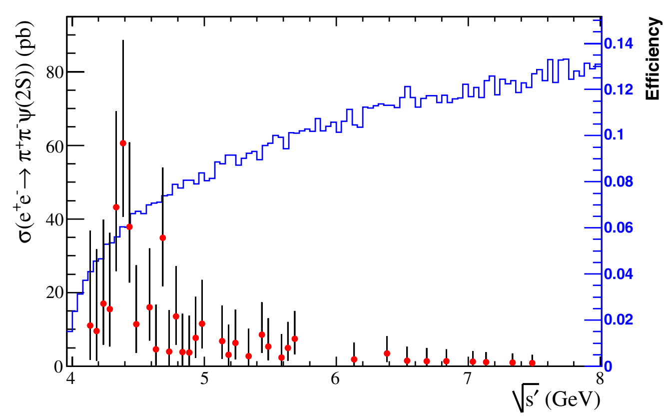

FIG. 5 (color online). The measured c.m. energy dependence of the cross section (points with error bars) for $e^+e^- \to \pi^+\pi^-\psi(2S)$ after background subtraction. The solid histogram shows the energy-dependent selection efficiency.

TABLE I. Summary of main systematic uncertainties for the $e^+e^- \to \pi^+\pi^-\psi(2S)$ cross section measurements.

Source	Systematic error
Model-dependent acceptance	$\pm 9.0\%$
Tracking efficiency	$\pm 7.6\%$
$\mathcal{B}(\psi(2S) \to \pi^+\pi^- J/\psi)\mathcal{B}(J/\psi \to \ell^+\ell^-)$	$\pm 3.5\%$
Total	$\pm 12.3\%$

from the efficiency difference between S-wave phase space model and multipole model [12] in the primary $\pi^+\pi^-$ generation. The main systematic uncertainties are listed in Table I, and are added in quadrature, resulting in a total systematic uncertainty of 12.3%.

In summary, we have used ISR events to study the exclusive process $e^+e^- \to \pi^+\pi^-\psi(2S)$ and to measure its energy-dependent cross section from threshold to 8 GeV c.m. energy. A structure is observed at $\sim$4.32 GeV/c^2 in the $\pi^+\pi^-\psi(2S)$ invariant-mass spectrum that is not consistent with the decay $\psi(4415) \to \pi^+\pi^-\psi(2S)$. A fit to the mass spectrum with a single resonance yields a mass of (4324 ± 24) MeV/c^2 and a width of (172 ± 33) MeV, where the errors are statistical only. The structure in Fig. 3 has a mass that differs somewhat from that reported for the $Y(4260)$ in Ref. [2]. However, the possibility that it represents evidence for a new decay mode for the $Y(4260)$ cannot be ruled out at this time.

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 the Marie Curie EIF (European Union) and the A. P. Sloan Foundation.

*Also at Laboratoire de Physique Corpusculaire, Clermont-Ferrand, France.
†Also with Università di Perugia, Dipartimento di Fisica, Perugia, Italy.
‡Also with Università della Basilicata, Potenza, Italy.

[1] S. K. Choi *et al.* (Belle Collaboration), Phys. Rev. Lett. **91**, 262001 (2003); D. Acosta *et al.* (CDF Collaboration), Phys. Rev. Lett. **93**, 072001 (2004); V. M. Abazov *et al.* (D0 Collaboration), Phys. Rev. Lett. **93**, 162002 (2004); B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **71**, 071103(R) (2005).
[2] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **95**, 142001 (2005).
[3] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **73**, 011101(R) (2006).
[4] T. E. Coan *et al.* (CLEO Collaboration), Phys. Rev. Lett. **96**, 162003 (2006).
[5] S. L. Zhu, Phys. Lett. B **625**, 212 (2005); E. Kou and O. Pene, Phys. Lett. B **631**, 164 (2005); F. E. Close and P. R. Page, Phys. Lett. B **628**, 215 (2005).
[6] L. Maiani, V. Riquer, F. Piccinini, and A. D. Polosa, Phys. Rev. D **72**, 031502 (2005); X. Liu, X. Q. Zeng, and X. Q. Li, Phys. Rev. D **72**, 054023 (2005); C. F. Qiao, Phys. Lett. B **639**, 263 (2006).
[7] B. Aubert *et al.* (*BABAR* Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **479**, 1 (2002).
[8] X. C. Lou, Int. J. Mod. Phys. A **16S1B**, 486 (2001).
[9] A nonrelativistic Breit-Wigner shape.
[10] W.-M. Yao *et al.* (Particle Data Group), J. Phys. G **33**, 1 (2006).
[11] See EPAPS Document No. E-PRLTAO-98-016722 for a supplementary table, corresponding to Fig. 5 in the Letter, which is a numerical representation of the cross section for $e^+e^- \to \pi^+\pi^-\psi(2S)$ at different center-of-mass energies using ISR events. For more information on EPAPS, see http://www.aip.org/pubservs/epaps.html.
[12] T.-M. Yan, Phys. Rev. D **22**, 1652 (1980).