BABAR-PUB-05/029
SLAC-PUB-11320
hep-ex/0506081

Observation of a Broad Structure in the $\pi^+\pi^- J/\psi$ Mass Spectrum around 4.26 GeV/c^2

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]

Submitted to Physical Review Letters

Work supported in part by Department of Energy contract DE-AC02-76SF00515
SLAC, Stanford Univesity, Stanford, CA 94309

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] 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. van 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] G. Williams,[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]

(The *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, Inst. 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

(Dated: June 30, 2005)

We study initial-state radiation events, $e^+e^- \to \gamma_{\text{ISR}}\pi^+\pi^- J/\psi$, with data collected with the *BABAR* detector. We observe an accumulation of events near $4.26\,\text{GeV}/c^2$ in the invariant-mass spectrum of $\pi^+\pi^- J/\psi$. Fits of the mass spectrum indicate that a broad resonance with a mass of about $4.26\,\text{GeV}/c^2$ is required to describe the observed structure. The presence of additional narrow resonances cannot be excluded. The fitted width of the broad resonance is 50 to $90\,\text{MeV}/c^2$, depending on the fit hypothesis.

PACS numbers: 14.40.Gx 13.66.Bc, 13.25.Gv

Recent observations of a heavy but narrow state, the $X(3872)$, decaying into $\pi^+\pi^- J/\psi$ [1–4], have renewed experimental interest in charmonium spectroscopy. We have previously reported a search for direct $X(3872)$ production in e^+e^- annihilation through initial-state radiation (ISR): $e^+e^- \to \gamma_{\text{ISR}}X$ [5]. No signal is observed, suggesting that the $X(3872)$ is not a 1^{--} state, just as expected for a narrow state well above the $D\overline{D}$ threshold. In this Letter we present a study of the $e^+e^- \to \gamma_{\text{ISR}}\pi^+\pi^- J/\psi$ process across the charmonium mass range.

We use data collected with the *BABAR* detector [6] at the SLAC PEP-II asymmetric-energy e^+e^- storage ring. These data represent an integrated luminosity of $211\,\text{fb}^{-1}$ collected at $\sqrt{s} = 10.58\,\text{GeV}$, near the peak of the $\Upsilon(4S)$ resonance, plus $22\,\text{fb}^{-1}$ collected approximately $40\,\text{MeV}$ below this energy.

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) with quartz bar radiators provides charged-particle identification. A CsI electromagnetic calorimeter (EMC) is used to detect and identify photons and electrons, while muons are identified in the instrumented magnetic flux return system (IFR).

Electron candidates are identified by the ratio of the shower energy deposited in the EMC to the momentum, the shower shape, the specific ionization in the DCH, and the Cherenkov angle measured by the DIRC. Muons are identified by the depth of penetration into the IFR, the IFR cluster geometry, and the energy deposited in the EMC. Pion candidates are selected based on a likelihood calculated from the specific ionization in the DCH and SVT, and the Cherenkov angle measured in the DIRC. Photon candidates are identified with clusters in the EMC that have a shape consistent with an electromagnetic shower but without an associated charged track.

Candidate J/ψ mesons are reconstructed via their decays to e^+e^- and $\mu^+\mu^-$. The lepton tracks must be well reconstructed, and at least one must be identified as an electron or a muon. An algorithm to associate and combine the energy from bremsstrahlung photons with nearby electron tracks is used when forming $J/\psi \to e^+e^-$ candidates. An e^+e^- ($\mu^+\mu^-$) pair with an invariant mass within ${}^{+33}_{-95}$ (${}^{+33}_{-40}$) MeV/c^2 of the nominal J/ψ mass is taken as a J/ψ candidate and is combined with a pair of oppositely charged tracks that are identified as pions.

Following an observation of an enhancement in the $\pi^+\pi^- J/\psi$ mass spectrum during an earlier search for ISR $X(3872)$ production in a $124\,\text{fb}^{-1}$ subsample of the available data, we choose to exclude the mass region from 4.2 to $4.4\,\text{GeV}/c^2$ from consideration during optimization of the selection criteria with the full sample to avoid the introduction of statistical or other biases in the analysis of this region. Radiative production of the $\psi(2S)$ serves as a clean benchmark process [7] for a data-driven optimization. Selection criteria are chosen to maximize $N/(3/2 + \sqrt{B})$ [8], where N is the total number of $\gamma_{\text{ISR}}\psi(2S), \psi(2S) \to \pi^+\pi^- J/\psi$ candidates in the $20\,\text{MeV}/c^2$ $\pi^+\pi^- J/\psi$ mass range that brackets the $\psi(2S)$ mass, and B is the number of events in the $\pi^+\pi^- J/\psi$ mass regions $[3.8,\ 4.2]\,\text{GeV}/c^2$ and $[4.4,\ 4.8]\,\text{GeV}/c^2$, scaled to the width of the excluded region. Simulated ISR events are validated with the $\psi(2S)$ data and are used to extrapolate the selection criteria to the excluded mass region as appropriate for small kinematic differences due to the higher mass.

Radiative $e^+e^- \to \gamma_{\text{ISR}}\pi^+\pi^- J/\psi$ events are characterized by a small mass recoiling against the $\pi^+\pi^- J/\psi$ system and by low missing transverse momentum. These properties are reflected in (1), (2), and (3) of the selection criteria: (1) there must be no additional well-reconstructed charged tracks in the event; (2) the transverse component of the visible momentum in the e^+e^- center-of-mass frame, including the ISR photon when it is reconstructed, must be less than $2.5\,\text{GeV}/c$; (3) the inferred value of the square of the mass recoiling against the $\pi^+\pi^- J/\psi$ combination (m^2_{Rec}) must be within $[-1.02, +3.27]\,\text{GeV}^2/c^4$ for $J/\psi \to e^+e^-$ candidates and $[-1.06, +1.25]\,\mathrm{GeV}^2/c^4$ for $J/\psi \to \mu^+\mu^-$ candidates; (4) $\cos\theta_\ell$, where θ_ℓ is the angle between the ℓ^+ momentum in the J/ψ rest frame and the J/ψ momentum in the e^+e^- center-of-mass frame, must satisfy $|\cos\theta_\ell| < 0.90$. In addition, (5) for the e^+e^- mode, $\cos\theta_\pi$, where θ_π is the angle between the π^- momentum and the J/ψ momentum in the $\pi^+\pi^-$ rest frame, is required to be less than 0.90 to reject background from misidentified low momentum e^- in the forward region of the detector. We do not require the ISR photon to be detected in the EMC since it is produced preferentially along the beam direction.

Candidate $\pi^+\pi^-\ell^+\ell^-$ tracks are refitted, constrained to a common vertex, while the lepton pair is kinematically constrained to the J/ψ mass. The resulting $\pi^+\pi^- J/\psi$ mass-resolution function is well-described by a Cauchy distribution [9] with a full width at half maximum of $4.2\,\mathrm{MeV}/c^2$ for the $\psi(2S)$ and $5.3\,\mathrm{MeV}/c^2$ at $4.3\,\mathrm{GeV}/c^2$.

The $\pi^+\pi^- J/\psi$ invariant mass spectrum for candidates passing all criteria is shown in Fig. 1 as points with error bars. Events that have an e^+e^- ($\mu^+\mu^-$) mass in the J/ψ sidebands [2.76, 2.95] or [3.18, 3.25] ([2.93, 3.01] or [3.18, 3.25]) GeV/c^2 but pass all the other selection criteria are represented by the shaded histogram after being scaled by the ratio of the widths of the J/ψ mass window and sideband regions. An enhancement near $4.26\,\mathrm{GeV}/c^2$ is clearly observed; no other structures are evident at the masses of the $J^{PC} = 1^{--}$ charmonium states, *i.e.*, the $\psi(4040)$, $\psi(4160)$, and $\psi(4415)$ [10], or the $X(3872)$. The Fig. 1 inset includes the $\psi(2S)$ region with a logarithmic scale for comparison; 11802±110 $\psi(2S)$ events are observed. We search for sources of backgrounds that contain a true J/ψ and peak in the $\pi^+\pi^- J/\psi$ invariant mass spectrum. The possibility that the pions candidates are misidentified kaons is checked using an analysis of the $K^+K^- J/\psi$ final state; we observe a featureless mass spectrum. Similar studies of ISR events with a $\pi^+\pi^- J/\psi$ plus one or more additional pions reveal no structure that could feed down to produce a peak in the $\pi^+\pi^- J/\psi$ mass spectrum. Two-photon events are studied directly by reversing the requirement on the missing mass; the number of events inferred for the signal region is a small fraction of those observed and their mass spectrum shows no structure. Hadronic $e^+e^- \to q\overline{q}$ events produce J/ψ at a rate that is surprisingly large [11–14], but no structure is observed for this background.

We evaluate the statistical significance of the enhancement using unbinned maximum likelihood fits to the $\pi^+\pi^- J/\psi$ mass spectrum. To evaluate the goodness of fit, the fit probability is determined from the χ^2 and the number of degrees of freedom for bin sizes of 5, 10, 20, 40, and $50\,\mathrm{MeV}/c^2$. Bins are combined with higher mass neighbors as needed to ensure that no bin is predicted to have fewer than seven entries. We try first-, second-, and third-order polynomials as null-hypothesis fit functions. The χ^2-probability estimates for these fits range from 10^{-16} to 10^{-11}. No substantial improvement is obtained by including $\psi(4040)$, $\psi(4160)$, or $\psi(4415)$ [10] terms in the fit. We conclude that the structure near $4.26\,\mathrm{GeV}/c^2$ is statistically inconsistent with a polynomial background. Henceforth, we refer to this structure as the $Y(4260)$.

It is important to test the ISR-production hypothesis because the $J^{PC} = 1^{--}$ assignment for the $Y(4260)$ follows from it. The ISR photon is reconstructed in (24±8)% of the $Y(4260)$ events, in agreement with the 25% observed for ISR $\psi(2S)$ events. Kinematic distributions for the signal are obtained by subtracting scaled distributions for events with $\pi^+\pi^- J/\psi$ mass in the regions [3.86, 4.06] GeV/c^2 and [4.46, 4.66] GeV/c^2 from those with $\pi^+\pi^- J/\psi$ mass in the signal region, defined as [4.16, 4.36] GeV/c^2. The distribution of m^2_{Rec} is shown in Fig. 2, along with corresponding distributions for ISR $\psi(2S)$ data events and for ISR $Y(4260)$ Monte Carlo events. Good agreement is found for these distributions, and for all other quantities studied to test that initial-state radiation is responsible for these events.

An unbinned likelihood fit to the $\pi^+\pi^- J/\psi$ mass spectrum is performed using a single relativistic Breit-Wigner signal function and a second-order polynomial background. The signal function is multiplied by a phase space factor and convoluted with the previously described resolution function. The fit gives 125±23 events with a mass of $4259 \pm 8(\mathrm{stat})^{+2}_{-6}(\mathrm{syst})\,\mathrm{MeV}/c^2$ and a width of $88 \pm 23(\mathrm{stat})^{+6}_{-4}(\mathrm{syst})\,\mathrm{MeV}/c^2$. Systematic uncertainties include contributions from the fitting procedure, the mass scale, the mass-resolution function, and dependence on the model of the $Y(4260) \to \pi^+\pi^- J/\psi$ decay. They have been added in quadrature. Under this single-resonance hypothesis we calculate a value of $\Gamma(Y(4260) \to e^+e^-) \cdot \mathcal{B}(Y(4260) \to \pi^+\pi^- J/\psi) = 5.5 \pm 1.0^{+0.8}_{-0.7}\,\mathrm{eV}$. The fit probability determined from the χ^2 and the number of degrees of freedom ranges from 0.3% to 6.6% for the same set of binning choices and background parameterizations used to evaluate the null hypothesis. To estimate the significance of the $Y(4260)$ structure conservatively, we use instead of our optimized selection criteria, the criteria developed in analyzing just the first $124\,\mathrm{fb}^{-1}$ of data. Using these, we compare fits to the remaining $109\,\mathrm{fb}^{-1}$ of data sample with and without the resonance parameters determined by the first data sample. Using the binnings described above, we find a significance in the second independent data sample alone of 5 to 7σ. The likelihood and χ^2 differences between signal and null-hypothesis fits to the full sample correspond to significances of at least 8σ.

The robustness of the $Y(4260)$ signal is tested with single-resonance fits to the $\pi^+\pi^- J/\psi$ mass spectrum for e^+e^- and $\mu^+\mu^-$ modes separately, which yield 49±16 and 76±13 signal events, respectively. Fits give 76±18

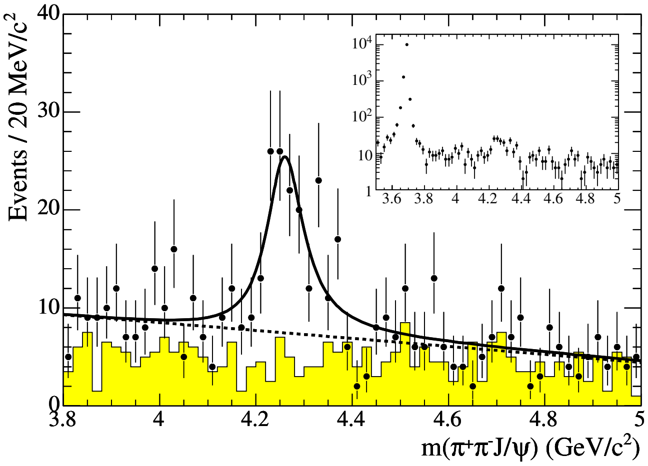

FIG. 1: The $\pi^+\pi^- J/\psi$ invariant mass spectrum in the range $3.8-5.0\,\mathrm{GeV}/c^2$ and (inset) over a wider range that includes the $\psi(2S)$. The points with error bars represent the selected data and the shaded histogram represents the scaled data from neighboring e^+e^- and $\mu^+\mu^-$ mass regions (see text). The solid curve shows the result of the single-resonance fit described in the text; the dashed curve represents the background component.

events for the original $124\,\mathrm{fb}^{-1}$ data set and 56 ± 13 events for the next, independent $109\,\mathrm{fb}^{-1}$ data set. Fitting samples with and without reconstructed ISR photons gives 30 ± 11 and 96 ± 15 events, respectively. We find consistent values for the $Y(4260)$ and the $\psi(2S)$ when determining the fraction of the total signal found in each of these subsets.

Several additional systematic checks have been performed. Each selection criterion has been tightened (loosened) and the decrease (increase) in the signal yield is consistent with that for the $\psi(2S)$ data. Events selected when the selection criteria are reversed, individually or in pairs, are studied; in no case is there a significant dip in the signal-mass region that might indicate a bias in the selection procedure.

Since the single-resonance fit probability is low we consider the possibility that the observed signal is due to two interfering resonances. Two-resonance fits with an interference term find one resonance mass close to the mass from the single-resonance fit, but with a width as low as $50\,\mathrm{MeV}/c^2$, plus a second narrow resonance around $4.33\,\mathrm{GeV}/c^2$. However, the fit probabilities are not significantly improved by two-resonance hypotheses. The size of our sample does not allow a statistically significant discrimination; we can neither exclude nor establish a multi-resonance hypothesis.

The dipion invariant mass distribution for the $Y(4260)$ is shown in Fig. 3. Each point represents the yield of a single-resonance fit to the $\pi^+\pi^- J/\psi$ mass distribution for that $\pi^+\pi^-$ mass bin.

No enhancement has been observed in the cross section

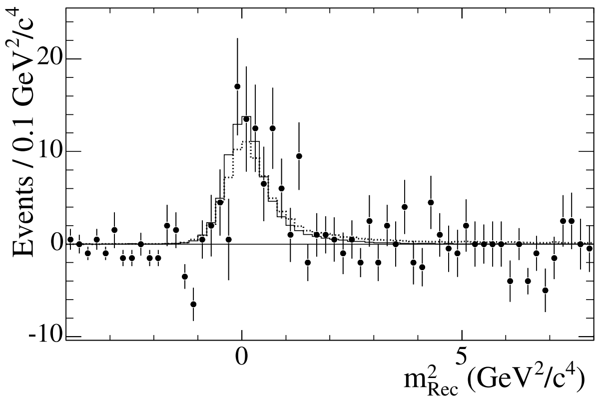

FIG. 2: The distribution of m^2_{Rec}. The points represent the data events passing all selection criteria except that on m^2_{Rec} and having a $\pi^+\pi^- J/\psi$ mass near $4260\,\mathrm{MeV}/c^2$, minus the scaled distribution from neighboring $\pi^+\pi^- J/\psi$ mass regions (see text). The solid histogram represents ISR Y Monte Carlo events, and the dotted histogram represents the ISR $\psi(2S)$ data events.

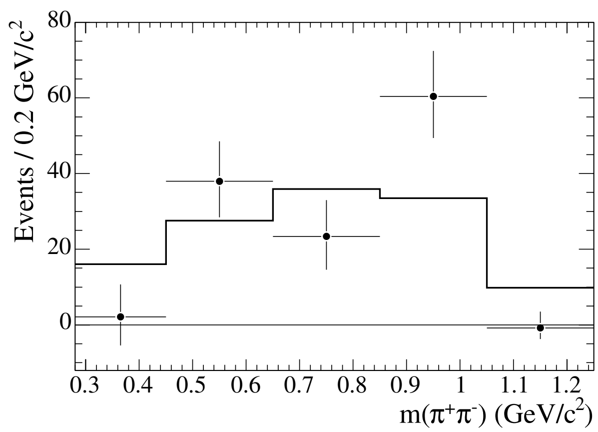

FIG. 3: The dipion mass distribution for $Y(4260) \to \pi^+\pi^- J/\psi$ data is shown as points with error bars. The histogram shows the distribution for Monte Carlo events where $Y(4260) \to \pi^+\pi^- J/\psi$ is generated according to an S-wave phase space model.

for $e^+e^- \to$ hadrons [10] at energies corresponding to the $Y(4260)$. We compute the cross section for $e^+e^- \to \pi^+\pi^- J/\psi$ production at 4.25 GeV, corresponding to the highest bin in our data, to be about 50 pb. The inclusive hadronic cross section at $\sqrt{s} = 4.25\,\mathrm{GeV}$ is 14.2 nb [10]. The ratio, approximately 0.34%, is smaller than the 4% experimental uncertainty for the hadronic cross section, so this mode would not have been visible. However, if the branching fraction of $Y(4260)$ to $\pi^+\pi^- J/\psi$ is very small, decays to other hadronic modes like $D\overline{D}$ would have been observable. This indicates that the branching fraction to $\pi^+\pi^- J/\psi$ must be large compared to that for $\psi(3770)$ [15].

In summary, we have used initial-state radiation events to study the process $e^+e^- \to \pi^+\pi^- J/\psi$ across the charmonium mass range. In addition to the expected $\psi(2S)$ events, we observe an excess of 125±23 events centered at a mass of ∼4.26 GeV/c^2, signifying the presence of one or more previously unobserved $J^{PC} = 1^{--}$ states containing hidden charm. At the current level of statistics we are unable to distinguish the number of new states; the data can be characterized by a single resonance of mass ∼4.26 GeV/c^2 and of width ∼90 MeV/c^2.

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.

---

* Also with Università di Perugia, Dipartimento di Fisica, Perugia, Italy

† Also with Università della Basilicata, Potenza, Italy

‡ Deceased

[1] Belle Collaboration, S. K. Choi *et al.*, Phys. Rev. Lett. **91**, 262001 (2003).

[2] CDF Collaboration, D. Acosta *et al.*, Phys. Rev. Lett. **93**, 072001 (2004).

[3] D0 Collaboration, V. M. Abazov *et al.*, Phys. Rev. Lett. **93**, 162002 (2004).

[4] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. D **71**, 071103(R) (2005).

[5] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. D **71**, 052001 (2005).

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

[7] X.C. Lou, Int. J. Mod. Phys., Vol. 16, No. supp01B, 486 (2001).

[8] G. Punzi, in *Proceedings of the Conference on Statistical Problems in Particle Physics, Astrophysics and Cosmology (PHYSTAT2003), Stanford, California, 2003,* eConf **C030908** (2003) MODT002 [arXiv: physics/0308063]. The value of 3/2 corresponds to an optimization for a signal of 3σ significance.

[9] A non-relativistic Breit-Wigner shape.

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

[11] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. Lett. **87**, 162002 (2001)

[12] Belle Collaboration, K. Abe *et al.*, Phys. Rev. Lett. **88**, 052001 (2002)

[13] Belle Collaboration, K. Abe *et al.*, Phys. Rev. D **70**, 071102 (2004).

[14] *BABAR* Collaboration, B. Aubert *et al.*, arXiv:hep-ph/0506062, submitted to Phys. Rev. D.

[15] BES Collaboration, J. Z. Bai *et al.*, Phys. Lett. B **605**, 63 (2005).