BABAR-CONF-04/01
SLAC-PUB-10625
hep-ex/0408037
August 2004

A SEARCH FOR THE Θ^{*++} PENTAQUARK IN $B^{\pm} \to p\bar{p}K^{\pm}$

The *BABAR* Collaboration

August 11, 2004

Abstract

We report the results of a search for the Θ^{*++} pentaquark in the decay $B^{+} \to \Theta^{*++}\bar{p}$ where $\Theta^{*++} \to pK^{+}$ using $81\,\mathrm{fb}^{-1}$ of data collected on the $\Upsilon(4S)$ resonance with the *BABAR* detector at PEP-II. We find an upper limit on the branching fraction of $B^{+} \to \Theta^{*++}\bar{p}$ where $\Theta^{*++} \to pK^{+}$ to be 1.5×10^{-7} for $1.43 < m(\Theta^{*++}) < 1.85\,\mathrm{GeV/c^2}$, 2.4×10^{-7} for $1.85 < m(\Theta^{*++}) < 2.00\,\mathrm{GeV/c^2}$ and 3.3×10^{-7} for $2.00 < m(\Theta^{*++}) < 2.36\,\mathrm{GeV/c^2}$, at 90% confidence level. All results are preliminary.

Submitted to the 32$^{\mathrm{nd}}$ International Conference on High-Energy Physics, ICHEP 04,
16 August—22 August 2004, Beijing, China

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

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

The *BABAR* Collaboration,

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

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

A. Palano, A. Pompili

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

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

Institute of High Energy Physics, Beijing 100039, China

G. Eigen, I. Ofte, B. Stugu

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

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

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

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

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

M. Fritsch, K. Goetzen, T. Held, H. Koch, B. Lewandowski, M. Pelizaeus, M. Steinke

Ruhr Universität Bochum, Institut für Experimentalphysik 1, D-44780 Bochum, Germany

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

University of Bristol, Bristol BS8 1TL, United Kingdom

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

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

A. Khan, P. Kyberd, L. Teodorescu

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

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

Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia

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

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

C. Buchanan, B. L. Hartfiel

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

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

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

D. del Re, H. K. Hadavand, E. J. Hill, D. B. MacFarlane, H. P. Paar, Sh. Rahatlou, V. Sharma
University of California at San Diego, La Jolla, CA 92093, USA

J. W. Berryhill, C. Campagnari, B. Dahmes, O. Long, A. Lu, M. A. Mazur, J. D. Richman, W. Verkerke
University of California at Santa Barbara, Santa Barbara, CA 93106, USA

T. W. Beck, A. M. Eisner, C. A. Heusch, J. Kroseberg, W. S. Lockman, G. Nesom, T. Schalk, B. A. Schumm, A. Seiden, P. Spradlin, D. C. Williams, M. G. Wilson
University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, CA 95064, USA

J. Albert, E. Chen, G. P. Dubois-Felsmann, A. Dvoretskii, D. G. Hitlin, I. Narsky, T. Piatenko, F. C. Porter, A. Ryd, A. Samuel, S. Yang
California Institute of Technology, Pasadena, CA 91125, USA

S. Jayatilleke, G. Mancinelli, B. T. Meadows, M. D. Sokoloff
University of Cincinnati, Cincinnati, OH 45221, USA

T. Abe, F. Blanc, P. Bloom, S. Chen, W. T. Ford, U. Nauenberg, A. Olivas, P. Rankin, J. G. Smith, J. Zhang, L. Zhang
University of Colorado, Boulder, CO 80309, USA

A. Chen, J. L. Harton, A. Soffer, W. H. Toki, R. J. Wilson, Q. Zeng
Colorado State University, Fort Collins, CO 80523, USA

D. Altenburg, T. Brandt, J. Brose, M. Dickopp, E. Feltresi, A. Hauke, H. M. Lacker, R. Müller-Pfefferkorn, R. Nogowski, S. Otto, A. Petzold, J. Schubert, K. R. Schubert, R. Schwierz, B. Spaan, J. E. Sundermann
Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany

D. Bernard, G. R. Bonneaud, F. Brochard, P. Grenier, S. Schrenk, Ch. Thiebaux, G. Vasileiadis, M. Verderi
Ecole Polytechnique, LLR, F-91128 Palaiseau, France

D. J. Bard, P. J. Clark, D. Lavin, F. Muheim, S. Playfer, Y. Xie
University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom

M. Andreotti, V. Azzolini, D. Bettoni, C. Bozzi, R. Calabrese, G. Cibinetto, E. Luppi, M. Negrini, L. Piemontese, A. Sarti
Università di Ferrara, Dipartimento di Fisica and INFN, I-44100 Ferrara, Italy

E. Treadwell
Florida A&M University, Tallahassee, FL 32307, USA

F. Anulli, R. Baldini-Ferroli, A. Calcaterra, R. de Sangro, G. Finocchiaro, P. Patteri, I. M. Peruzzi, M. Piccolo, A. Zallo
Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy

A. Buzzo, R. Capra, R. Contri, G. Crosetti, M. Lo Vetere, M. Macri, M. R. Monge, S. Passaggio, C. Patrignani, E. Robutti, A. Santroni, S. Tosi
Università di Genova, Dipartimento di Fisica and INFN, I-16146 Genova, Italy

S. Bailey, G. Brandenburg, K. S. Chaisanguanthum, M. Morii, E. Won
Harvard University, Cambridge, MA 02138, USA

R. S. Dubitzky, U. Langenegger

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

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

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

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

University of Iowa, Iowa City, IA 52242, USA

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

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

M. Biasini, R. Covarelli, M. Pioppi

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

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

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

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

Lawrence Livermore National Laboratory, Livermore, CA 94550, USA

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

University of Liverpool, Liverpool L69 72E, United Kingdom

J. J. Back,[1] C. M. Cormack, P. F. Harrison,[1] F. Di Lodovico, G. B. Mohanty[1]

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

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

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

D. Brown, C. L. Davis

University of Louisville, Louisville, KY 40292, USA

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

University of Manchester, Manchester M13 9PL, United Kingdom

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

University of Maryland, College Park, MD 20742, USA

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

University of Massachusetts, Amherst, MA 01003, USA

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

[2]Also with Università della Basilicata, Potenza, Italy

P. K. Behera, L. Gladney, Q. H. Guo, J. Panetta
University of Pennsylvania, Philadelphia, PA 19104, USA

C. Angelini, G. Batignani, S. Bettarini, M. Bondioli, F. Bucci, G. Calderini, M. Carpinelli, F. Forti, M. A. Giorgi, A. Lusiani, G. Marchiori, F. Martinez-Vidal,[3] M. Morganti, N. Neri, E. Paoloni, M. Rama, G. Rizzo, F. Sandrelli, J. Walsh
Università di Pisa, Dipartimento di Fisica, Scuola Normale Superiore and INFN, I-56127 Pisa, Italy

M. Haire, D. Judd, K. Paick, D. E. Wagoner
Prairie View A&M University, Prairie View, TX 77446, USA

N. Danielson, P. Elmer, Y. P. Lau, C. Lu, V. Miftakov, J. Olsen, A. J. S. Smith, A. V. Telnov
Princeton University, Princeton, NJ 08544, USA

F. Bellini, G. Cavoto,[4] R. Faccini, F. Ferrarotto, F. Ferroni, M. Gaspero, L. Li Gioi, M. A. Mazzoni, S. Morganti, M. Pierini, G. Piredda, F. Safai Tehrani, C. Voena
Università di Roma La Sapienza, Dipartimento di Fisica and INFN, I-00185 Roma, Italy

S. Christ, G. Wagner, R. Waldi
Universität Rostock, D-18051 Rostock, Germany

T. Adye, N. De Groot, B. Franek, N. I. Geddes, G. P. Gopal, E. O. Olaiya
Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingdom

R. Aleksan, S. Emery, A. Gaidot, S. F. Ganzhur, P.-F. Giraud, G. Hamel de Monchenault, W. Kozanecki, M. Legendre, G. W. London, B. Mayer, G. Schott, G. Vasseur, Ch. Yèche, M. Zito
DSM/Dapnia, CEA/Saclay, F-91191 Gif-sur-Yvette, France

M. V. Purohit, A. W. Weidemann, J. R. Wilson, F. X. Yumiceva
University of South Carolina, Columbia, SC 29208, USA

D. Aston, R. Bartoldus, N. Berger, A. M. Boyarski, O. L. Buchmueller, R. Claus, M. R. Convery, M. Cristinziani, G. De Nardo, D. Dong, J. Dorfan, D. Dujmic, W. Dunwoodie, E. E. Elsen, S. Fan, R. C. Field, T. Glanzman, S. J. Gowdy, T. Hadig, V. Halyo, C. Hast, T. Hryn'ova, W. R. Innes, M. H. Kelsey, P. Kim, M. L. Kocian, D. W. G. S. Leith, J. Libby, S. Luitz, V. Luth, H. L. Lynch, H. Marsiske, R. Messner, D. R. Muller, C. P. O'Grady, V. E. Ozcan, A. Perazzo, M. Perl, S. Petrak, B. N. Ratcliff, A. Roodman, A. A. Salnikov, R. H. Schindler, J. Schwiening, G. Simi, A. Snyder, A. Soha, J. Stelzer, D. Su, M. K. Sullivan, J. Va'vra, S. R. Wagner, M. Weaver, A. J. R. Weinstein, W. J. Wisniewski, M. Wittgen, D. H. Wright, A. K. Yarritu, C. C. Young
Stanford Linear Accelerator Center, Stanford, CA 94309, USA

P. R. Burchat, A. J. Edwards, T. I. Meyer, B. A. Petersen, C. Roat
Stanford University, Stanford, CA 94305-4060, USA

S. Ahmed, M. S. Alam, J. A. Ernst, M. A. Saeed, M. Saleem, F. R. Wappler
State University of New York, Albany, NY 12222, USA

[3]Also with IFIC, Instituto de Física Corpuscular, CSIC-Universidad de Valencia, Valencia, Spain
[4]Also with Princeton University, Princeton, USA

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

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

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

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

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

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

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

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

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

[5]Deceased

1 INTRODUCTION

Recently several experimental groups have reported observations of a new, manifestly exotic baryon resonance, called the $\Theta^+(1540)$ [1], with an unusually narrow width ($\Gamma < 8\,\mathrm{MeV/c^2}$). These results have prompted a surge of pentaquark searches in experimental data of many kinds [2]. In this paper we will concentrate on the exclusive search for pentaquarks in the decay of B mesons. Following the observation of the decay $B^+ \to p\bar{p}K^+$[6] [3, 4] it was suggested that this decay might include events of the form $B^+ \to \Theta^{*++}\bar{p}$ where Θ^{*++} is an $I = 1$, $I_3 = 1$ pentaquark [5]. Θ^{*++} would be a member of the baryon 27-plet with quark content $uuud\bar{s}$. It has been predicted to lie in the region $1.43 - 1.70\,\mathrm{GeV/c^2}$ in the pK^+ invariant mass of $B^+ \to p\bar{p}K^+$ candidates and to have a width of $37 - 80\,\mathrm{MeV}$ [6]. The pK^+ cross section is nearly purely elastic in the region of interest so a resonance would follow the Breit-Wigner form, with a peak cross section of about 25 mb if the resonance is at $1.7\,\mathrm{GeV/c^2}$ and even larger if the mass is less. The cross section is measured to be about 12 mb at center-of-mass energies spaced by about 15 MeV [7], so its width would need to be considerably less than 15 MeV to have escaped detection. Our limits will not depend on the Θ^{*++} width in any significant fashion. We will search for Θ^{*++} in the mass region up to $2.36\,\mathrm{GeV/c^2}$.

2 THE *BABAR* DETECTOR AND DATASET

We use data collected on the $\Upsilon(4S)$ resonance with the *BABAR* detector at PEP-II to search for Θ^{*++}. The data sample contains 89 million $B\bar{B}$ pairs, corresponding to an integrated luminosity of $81\,\mathrm{fb}^{-1}$ on the $\Upsilon(4S)$ resonance. An additional $9\,\mathrm{fb}^{-1}$ of data, collected 40 MeV below the resonance peak (referred to as off-peak data), are used to study the background from light-quark and $c\bar{c}$ production.

A detailed description of the *BABAR* detector can be found elsewhere [8]; only detector components relevant to this analysis are mentioned here. Charged-particle trajectories are measured by a five-layer double-sided silicon vertex tracker (SVT) and a 40-layer drift-chamber (DCH), operating in the magnetic field of a 1.5-T solenoid. Charged particles are identified by combining the measurements of ionization energy loss (dE/dx) in the DCH and SVT with angular information from a detector of internally reflected Cherenkov light (DIRC). Photons are identified as isolated electromagnetic showers in a CsI(Tl) electromagnetic calorimeter.

3 ANALYSIS METHOD

We require that charged tracks have a minimum transverse momentum (p_T) of 0.1 GeV/c, at least 12 hits in the DCH, and that they originate from the interaction region point within 10 cm along the beam direction and 1.5 cm in the transverse plane.

The kaon and proton particle identification is based on dE/dx information from the DCH and SVT for $p_T < 0.7\,\mathrm{GeV/c}$ or the measured Cherenkov angle and the number of photons observed in the DIRC for $p_T > 0.7\,\mathrm{GeV/c}$.

The B candidate is formed from the proton, the anti-proton and the kaon candidates. Two kinematic variables are used to isolate the $B^+ \to p\bar{p}K^+$ signal taking advantage of the kinematic constraints of B mesons produced at the $\Upsilon(4S)$. The first is the beam-energy-substituted mass, $m_{ES} = [(E_{CM}^2/2 + \mathbf{p}_i \cdot \mathbf{p}_B)^2/E_i^2 - \mathbf{p}_B^2]^{1/2}$, where E_{CM} is the total center-of-mass energy of the e^+e^-

[6]Charge-conjugates are assumed throughout the paper.

collision. Here, the four-momentum of the initial e^+e^- system is $(E_i, \mathbf{p}_i)$ and $\mathbf{p}_B$ is the momentum of the reconstructed B candidate, both measured in the laboratory frame. The second variable is $\Delta E = E_B^* - E_{CM}/2$, where E_B^* is the B-candidate energy in the center-of-mass frame.

Several topological variables provide discrimination between the large continuum background ($e^+e^- \to q\bar{q}$, where $q = u, d, s, c$), which tends to be collimated along the original quark direction, and more spherical $B\bar{B}$ events. In order to suppress the dominant continuum background we use a linear combination (a Fisher discriminant) of the following four event-shape variables: $\cos\theta^B_{thr}$, the cosine of the angle between the thrust axis of the reconstructed B and the beam axis in the center-of-mass frame; $\cos\theta^B_{mom}$, the cosine of the angle between the momentum of the reconstructed B and the beam axis in the center-of-mass frame; and zeroth- and second-order Legendre polynomial momentum moments, $L_0 = \sum_i |p_i^*|$ and $L_2 = \sum_i |p_i^*|[(3\cos^2\theta_{thr_{B,i}} - 1)/2]$, where p_i^* are the center-of-mass momenta for the tracks and neutral clusters that are not associated with the B candidate, and $\theta_{thr_{B,i}}$ are the angles between p_i^* and the thrust axis of the B candidate. We optimize the Fisher discriminant coefficients for the best background and $B^+ \to p\bar{p}K^+$ signal separation using off-resonance data and $B^+ \to p\bar{p}K^+$ simulated events that are distributed uniformly in phase-space ($B^+ \to p\bar{p}K^+$ signal Monte Carlo). These event topology requirements retain 67% of $B^+ \to p\bar{p}K^+$ signal while removing 94% of continuum background. We expect 94% of the combinatoric background to come from continuum events and the remaining 6% from $B\bar{B}$ events.

The Fisher discriminant, m_{ES}, and ΔE cuts are optimized to maximize the statistical sensitivity of the $B^+ \to p\bar{p}K^+$ signal, defined as $S/\sqrt{S+B}$, with S and B being estimated numbers of $B^+ \to p\bar{p}K^+$ signal and background yields in the Monte Carlo simulation respectively. We assumed the $B^+ \to p\bar{p}K^+$ signal branching fraction of $(5.66^{+0.67}_{-0.57} \pm 0.62) \times 10^{-6}$ [3] in the optimization. The $B^+ \to p\bar{p}K^+$ signal region is defined to be $5.276 < m_{ES} < 5.286\,\mathrm{GeV/c^2}$ and $|\Delta E| < 0.029\,\mathrm{GeV}$ (signal box) and the m_{ES} sideband region is taken to be $5.20 < m_{ES} < 5.26\,\mathrm{GeV/c^2}$ and $|\Delta E| < 0.029\,\mathrm{GeV}$ for the combinatoric background studies.

The main source of $B\bar{B}$ backgrounds is the $b \to c\bar{c}s$ transitions, where $B^+ \to X_{c\bar{c}}K^+$, $X_{c\bar{c}} \to p\bar{p}$ and $X_{c\bar{c}} = \eta_c$, J/ψ, $\psi(2S)$, $\chi_{c0,1,2}$ (so-called "charmonium background"). We expect 72 ± 10 events of this type in the signal box region. To check for additional $B\bar{B}$ backgrounds that might peak in the $B^+ \to p\bar{p}K^+$ signal region, we study generic $B\bar{B}$ Monte Carlo as well as a set of samples of exclusive B decay simulated events for potential charmoniumless backgrounds. The expected $B\bar{B}$ "charmoniumless" background contribution is less than one event in the signal box region.

4 SYSTEMATIC STUDIES

Systematic uncertainties in the analysis are described below and are summarized in Table 1.

The $B^+ \to \Theta^{*++}(pK^+)\bar{p}$ signal efficiency is computed with $B^+ \to p\bar{p}K^+$ simulated events, reconstructed and selected using the same procedure as for the data. We apply small corrections determined from data to the efficiency calculation to account for the overestimation of the tracking and particle-identification systems performance. The resulting efficiency, as a function of m_{pK^+}, is shown in Fig. 1. A systematic uncertainty is assigned to each correction to account for the limited size and purity of the control sample used in computing that correction. For example, for the kaon identification, we correct the simulation using a pure sample of $D^{*+} \to \pi^+ D^0$ decays with $D^0 \to K^-\pi^+$ and for the proton identification we use a sample of $\Lambda \to p\pi^-$. Conservatively, we take the size of the correction applied as our systematic error.

In addition, after all the corrections, we compare our $B^+ \to p\bar{p}K^+$ signal simulation to a control sample with similar kinematics and final state topology ($B^+ \to J/\psi(e^+e^-)K^+$), in order

Table 1: Systematic uncertainties for the branching fraction of $B^+ \to \Theta^{*++}(pK^+)\bar{p}$ without(with) background subtraction.

Type	% BF
B-counting	1.1
Tracking	2.4
PID	6.0
Event Shape	2.0
Signal Box Cut	2.5
Monte Carlo Statistics	1.1
Background subtraction	(1.1)
Total	7.4(7.5)

to quantify the ability of the simulation to model the kinematic and event-shape variables used in the event selection. The small residual differences in the efficiencies at the cut value are assigned as systematic uncertainties affecting the selection procedure.

For the calculation of the systematic error due to the background subtraction we decrease the B-backgrounds by the uncertainties in their branching fractions [7]. The change in the upper limit for the new background estimation is 1.1% which we take as a systematic error.

The systematic error also comprises the uncertainties from the determination of the number of $B\bar{B}$ pairs. We assume that the branching fraction of the $\Upsilon(4S)$ into $B\bar{B}$ is 100%, with an equal admixture of charged and neutral B final states. We do not include any additional uncertainty due to these assumptions.

5 RESULTS

The distribution of events in the $m_{ES} - \Delta E$ plane is shown in Fig. 2. We see 212 events in the signal box region. To extract the number of $B^+ \to p\bar{p}K^+$ signal events we loosen signal box cuts on ΔE and fit the ΔE projection for $5.276 < m_{ES} < 5.286\,\mathrm{GeV/c^2}$ and $|\Delta E| < 400\,\mathrm{MeV}$ with a single-Gaussian distribution for $B^+ \to p\bar{p}K^+$ signal and a first-order polynomial for the background. From that fit we estimate that the 212 total events comprise 40±2 combinatoric background events and 188±17 $B^+ \to p\bar{p}K^+$ signal events, including 68±10 events originating from charmonium decays to $p\bar{p}$.

The Dalitz plots for the events in the signal box (212 events) and the sideband region (368 events) are shown in Fig. 3. Note that the relative phase-space, or the fraction of Fig. 3(bottom) in the signal box, is 0.104. The distributions in Fig. 3 are not efficiency-corrected. The Dalitz plot for the events in the signal box (Fig. 3) shows a threshold enhancement in the $p\bar{p}$ mass spectrum, as well as three clear bands corresponding to η_c, J/ψ and $\psi(2S)$ events. The background events tend to lie on the edges of the Dalitz plot because they are dominated by inclusion of random soft tracks.

As we are interested only in the low m_{pK^+} region the following figures will be limited to m_{pK^+} up to $3.4\,\mathrm{GeV/c^2}$ or the total of 75 events in the signal box region. It is convenient to represent data in two different ways: in Fig. 4 we separate the events into those inside the charmonium

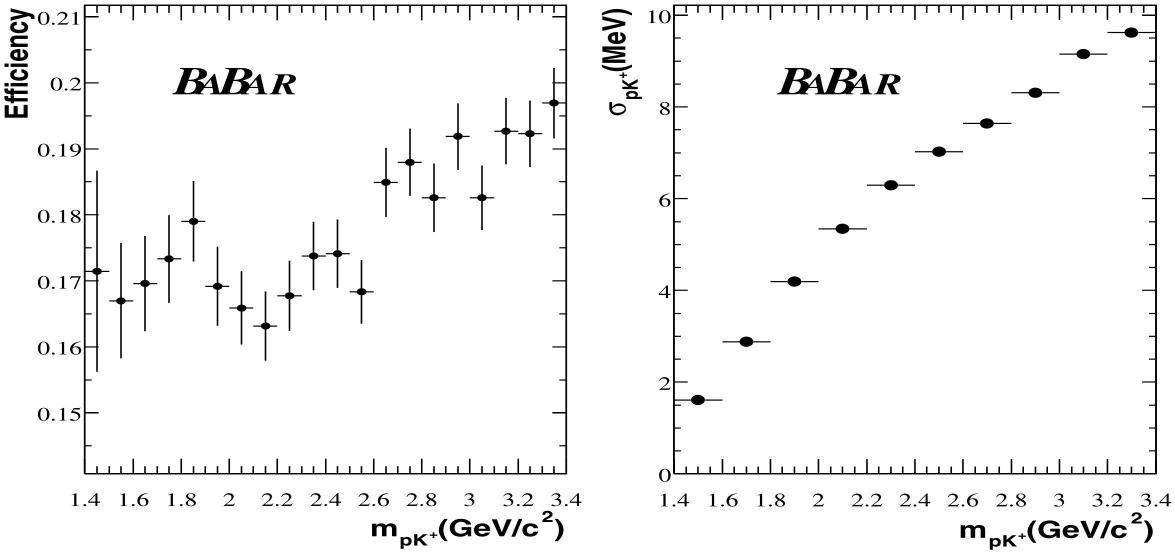

Figure 1: The $B^+ \to p\bar{p}K^+$ signal reconstruction efficiency(left) and the detector resolution(right) as functions of m_{pK^+}

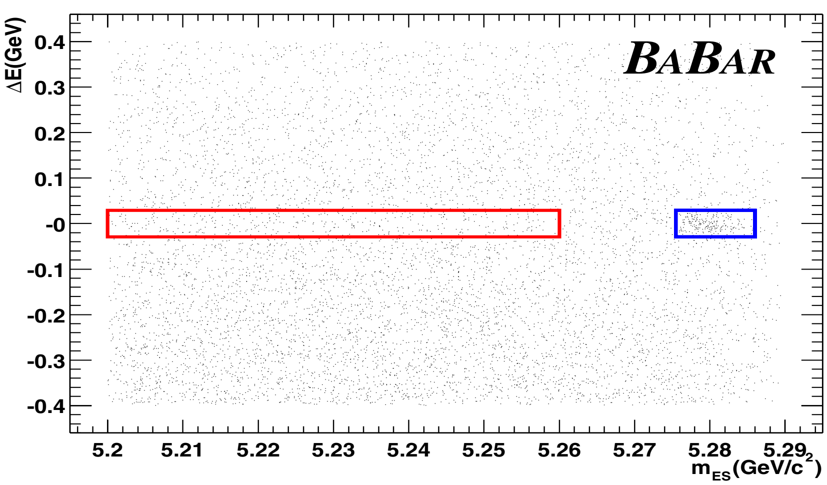

Figure 2: $m_{ES} - \Delta E$ distribution of on-peak data reconstructed in the $B^+ \to p\bar{p}K^+$ mode. The small box (blue) is "signal" box: $5.276 < m_{ES} < 5.286\,\mathrm{GeV/c^2}$ and $|\Delta E| < 29\,\mathrm{MeV}$; and the large box (red) is "sideband": $5.20 < m_{ES} < 5.26\,\mathrm{GeV/c^2}$ and $|\Delta E| < 29\,\mathrm{MeV}$.

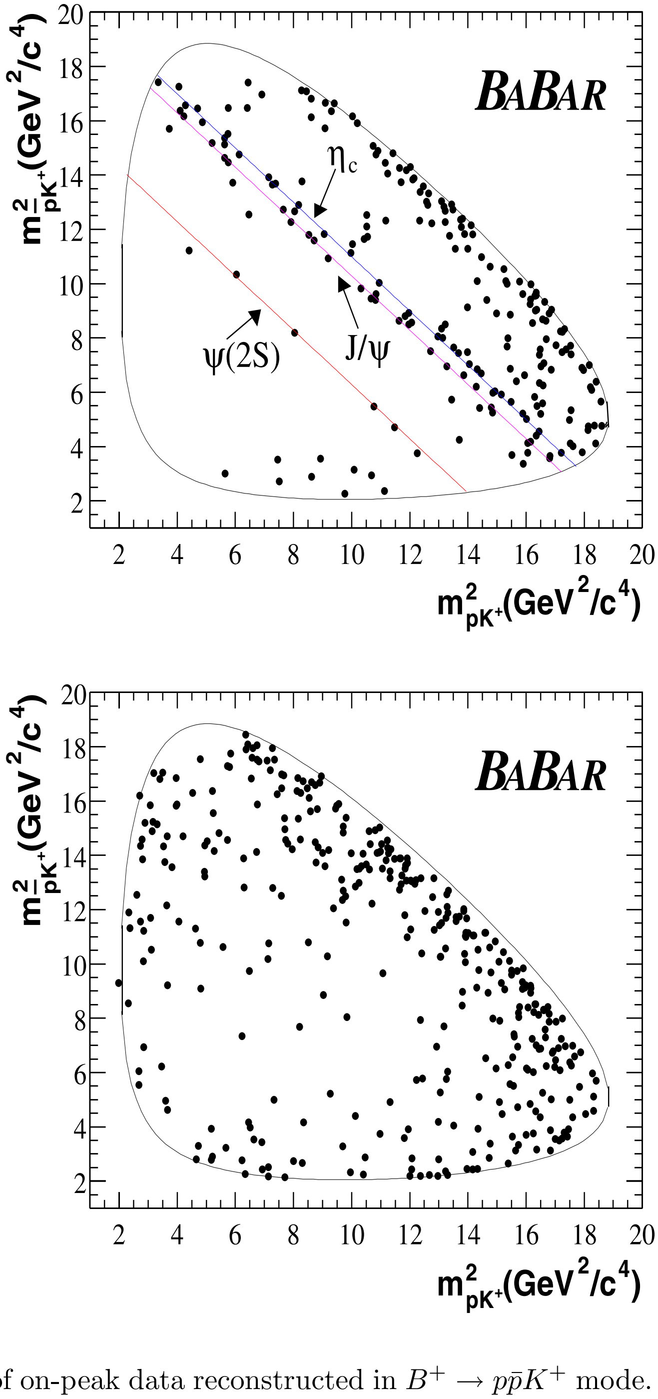

Figure 3: Dalitz plot of on-peak data reconstructed in $B^+ \to p\bar{p}K^+$ mode. Events in the signal box region (top), sideband region (bottom). Note that these distributions are not efficiency-corrected.

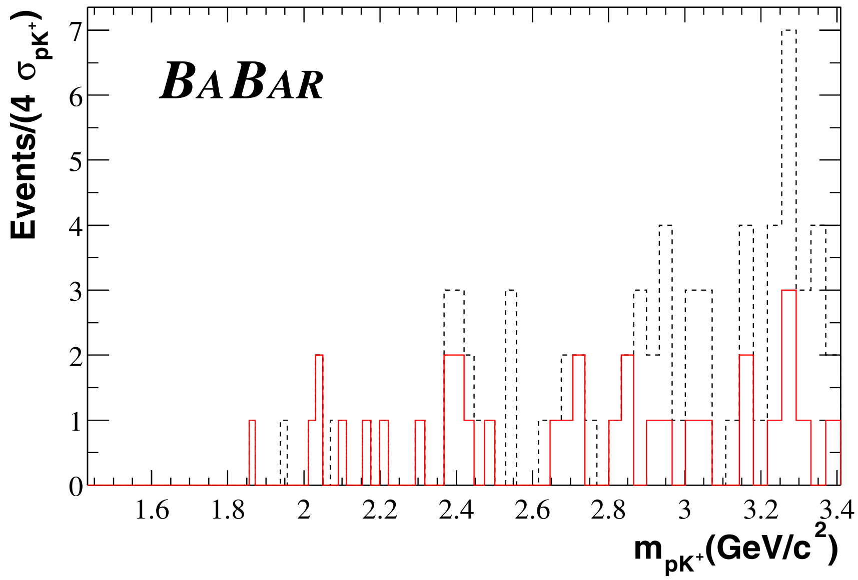

Figure 4: The m_{pK^+} distribution for data events in $B^+ \to p\bar{p}K^+$ signal box: events in the charmonium region $2.85 < m_{p\bar{p}} < 3.15\,\mathrm{GeV/c^2}$ (solid), events outside the charmonium region (dashed). Note that these distributions are not efficiency-corrected.

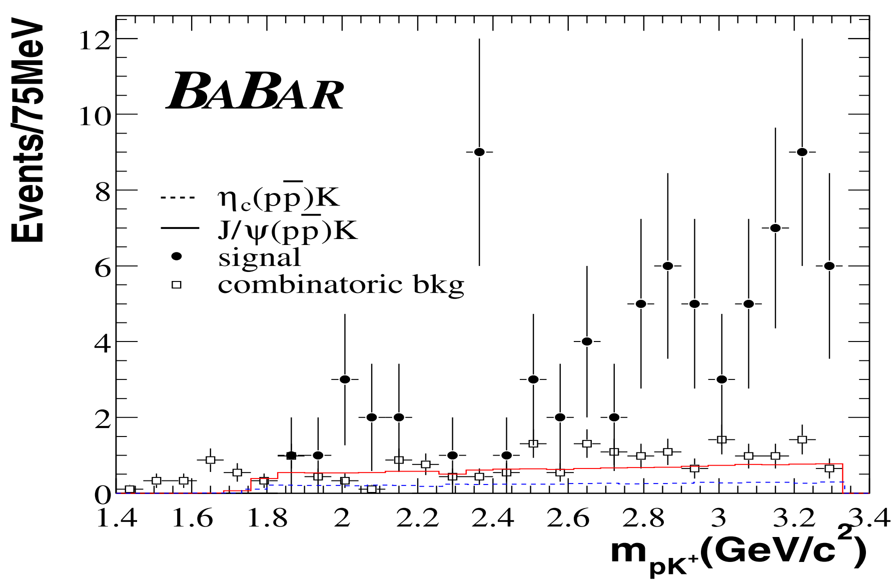

Figure 5: The m_{pK^+} distributions for data reconstructed as $B^+ \to p\bar{p}K^+$ (dots), m_{ES} sideband (empty squares) and, Monte Carlo, $B^+ \to \eta_c(p\bar{p})K^+$(dashed line) and $B^+ \to J/\psi(p\bar{p})K^+$(solid line). Note that these distributions are not efficiency-corrected.

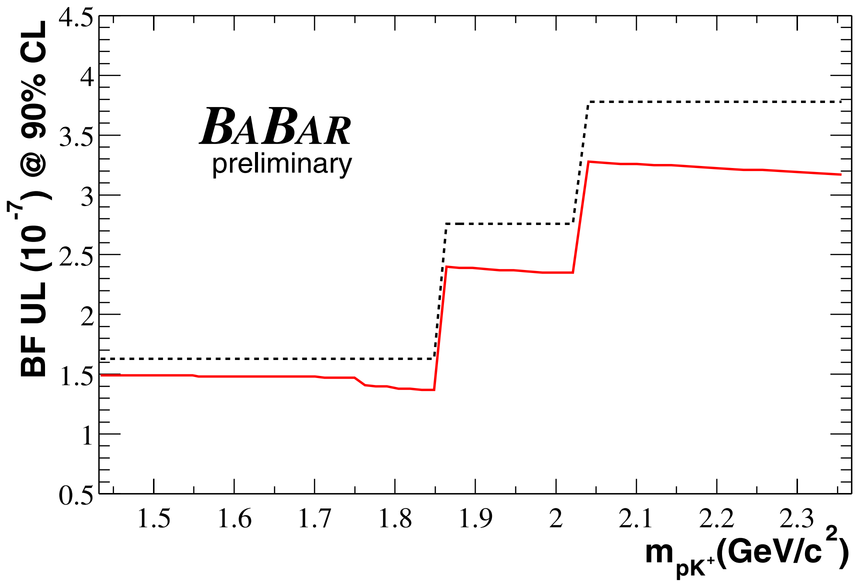

Figure 6: Upper Limit on the branching fraction of $B^+ \to \Theta^{*++}(pK^+)\bar{p}$ at 90% confidence level with the assumption of no background(dashed), with background as determined from data and Monte Carlo (solid). The systematic error correction is included in the limits.

window and those outside, where as in Fig. 5 we emphasize the different background contributions to the data.

We search for Θ^{*++} pentaquark in the pK^+ mass spectrum, shown in Fig. 4. The binning corresponds to $4 \cdot \sigma_{pK^+}$, where σ_{pK^+} is the detector resolution shown in Fig. 1(right). The average $B^+ \to \Theta^{*++}(pK^+)\bar{p}$ signal efficiency is $(17.0 \pm 0.2)\%$ for $1.43 < m_{pK^+} < 2.40\,\mathrm{GeV/c^2}$. We observe no events for $m_{pK^+} < 1.85\,\mathrm{GeV/c^2}$.

The background contributions are shown in Fig. 5. The m_{pK^+} distribution of the combinatoric background is obtained from the events in the data m_{ES} sideband region and is scaled to the expected number of the combinatoric background events in the signal box. The shape and amount of $B^+ \to \eta_c(p\bar{p})K^+$ and $B^+ \to J/\psi(p\bar{p})K^+$ background contributions are determined from the simulation and scaled by their respective branching fractions [7]. There is no contribution to the background from $B^+ \to \eta_c(p\bar{p})K^+$ for $m_{pK^+} < 1.80\,\mathrm{GeV/c^2}$ and $B^+ \to J/\psi(p\bar{p})K^+$ for $m_{pK^+} < 1.75\,\mathrm{GeV/c^2}$.

To set an upper limit at 90% confidence level on the branching fraction of $B^+ \to \Theta^{*++}(pK^+)\bar{p}$ we count events in each of the m_{pK^+} mass bins in Fig. 4 assuming that all the events observed are $B^+ \to \Theta^{*++}(pK^+)\bar{p}$ signal events. To simplify the presentation of the upper limit on the branching fraction as a function m_{pK^+} we assume that number of events in each of the bins in m_{pK^+} is equal to the maximum number of events per bin for each of the m_{pK^+} regions (see Table 2).

We use two methods to determine the upper limit. In the first one we assume that there is no background contribution. We calculate from Table 31.3 [7] the Bayesian upper limit for 90% confidence level as a function of m_{pK^+} assuming Poisson-distributed events in the absence of background. The resulting values are shown in Fig. 6 and given in Table 2. To account for systematic errors we increase the upper limit by the total systematic error (7.5%).

Table 2: The upper limit for the branching fraction of $B^+ \to \Theta^{*++}(pK^+)\bar{p}$ as a function m_{pK^+} without(with) background subtraction.

Mass Region, GeV/c^2	Maximum Events Observed in any m_{pK^+} bin	BF UL (10^{-7}) @ 90% CL without bkg	BF UL (10^{-7}) @ 90% CL with bkg
1.43< m_{pK^+} <1.85	0	1.63	1.49
1.85< m_{pK^+} <2.00	1	2.76	2.40
2.00< m_{pK^+} <2.36	2	3.78	3.28

To calculate the upper limit in the presence of background we use a tool described in [9]. It uses toy Monte Carlo technique to calculate an upper limit in presence of uncertainties on the efficiency and the number of expected background events. We assume all the systematic errors but the systematics on background and B-counting to contribute to the uncertainty on the efficiency (7.3%). To estimate the number of expected background events we fit a first-order polynomial to the pK^+ mass spectrum of the combinatoric background events as well as $B^+ \to \eta_c(p\bar{p})K^+$ and $B^+ \to J/\psi(p\bar{p})K^+$ Monte Carlo events (so-called peaking B-background). The uncertainty on the background comes from the statistical error on the fit as well as the systematic error on the background. The resulting values of the upper limit as a function of m_{pK^+} increased by the systematic error on B-counting (1.1%) are given in Table 2 and shown in Fig. 6.

6 SUMMARY

Using $81\,\mathrm{fb}^{-1}$ of on-peak data accumulated by the *BABAR* detector, we set an upper limit at 90% confidence level on the branching fraction of $B^+ \to \Theta^{*++}(pK^+)\bar{p}$ to be 1.49×10^{-7} for $1.43 < m(\Theta^{*++}) < 1.85\,\mathrm{GeV/c}^2$, 2.40×10^{-7} for $1.85 < m(\Theta^{*++}) < 2.00\,\mathrm{GeV/c}^2$ and 3.28×10^{-7} for $2.00 < m(\Theta^{*++}) < 2.36\,\mathrm{GeV/c}^2$.

7 ACKNOWLEDGMENTS

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

References

[1] LEPS Collaboration, T. Nakano *et al.*, Phys. Rev. Lett. **91**, 012002 (2003); SAPHIR Collaboration, J. Barth *et al.*, Phys. Lett. **B 572**, 127 (2003); DIANA Collaboration, V.V. Barmin *et al.*, Phys. Atom. Nucl **66**, 1715 (2003).

[2] See, e.g., J. Pochodzalla, hep-ex/0406077 (2004) and references therein.

[3] The Belle Collaboration, Phys. Rev. Lett., **88**, 181803 (2002); Phys. Rev. Lett., **92**, 131801 (2004).

[4] T. Hryn'ova (for the *BABAR* Collaboration), APS, April 2004, TALK-04/067, https://oraweb.slac.stanford.edu:8080/pls/slacquery/BABAR_DOCUMENTS.DetailedIndex?P_BP_ID=3754.

[5] T. Browder *et al.*, Phys.Lett.B, **587** 62 (2004).

[6] J. Ellis *et al.*, JHEP 0405:002, 2004; B.Wu and B.Q.Ma, Phys. Rev. D, **69** 077501 (2004); H. Walliser *et al.*, J. Exp. Theor. Phys. **97** 433 (2003); D. Borisyuk *et al.*, hep-ph/0307370.

[7] Particle Data Group, K. Hagiwara *et al.*, Phys. Rev. **D66**, 010001 (2002).

[8] The *BABAR* Collaboration, B. Aubert *et al.*, Nucl. Instr. Meth. A **479**, 1 (2002).

[9] R. Barlow, Computer Physics Communications **149**, 97 (2002).