Search for inclusive charmless $B \to K^+ X$ and $B \to K^0 X$ decays

The $\text{BABAR}$ Collaboration

March 25, 2022

Abstract

We present preliminary results from a search for inclusive charmless $B \to KX$ decays. These decays occur dominantly via one-loop $b \to s$ penguin transitions, and can provide useful information about these processes. Using a sample of 288.5 fb$^{-1}$ collected with the $\text{BABAR}$ detector at the PEP-II asymmetric-energy $e^+e^-$ $B$ Factory at SLAC, we search for high-energy kaons recoiling against fully reconstructed $B$ decays. We measure the partial branching fractions for kaons with momentum $p^*(K) > 2.34$ GeV in the $B$ rest frame, and obtain (in units of $10^{-6}$): $\mathcal{B}(B \to K^+ X, p^* > 2.34 \text{ GeV}) = 196_{-34}^{+37}(\text{stat.})_{-30}^{+31}(\text{syst.})$ and $\mathcal{B}(B \to K^0 X, p^* > 2.34 \text{ GeV}) = 154_{-48}^{+55}(\text{stat.})_{-41}^{+55}(\text{syst.})$ (< 266 at 90% C.L.).

Submitted to the 33rd International Conference on High-Energy Physics, ICHEP 06, 26 July—2 August 2006, Moscow, Russia.
The BABAR Collaboration,

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

Laboratoire de Physique des Particules, IN2P3/CNRS et Université de Savoie, F-74941 Annecy-Le-Vieux, France

E. Grauges

Universitat de Barcelona, Facultat de Fisica, Departament ECM, E-08028 Barcelona, Spain

A. Palano

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, Institute of Physics, N-5007 Bergen, Norway

G. S. Abrams, M. Battaglia, D. N. Brown, J. Button-Shafer, R. N. Cahn, E. Charles, M. S. Gill, Y. Groysman, R. G. Jacobsen, J. A. Kadyk, L. T. Kerth, Yu. G. Kolomensky, G. Kukartsev, G. Lynch, L. M. Mir, T. J. Orimoto, M. Pripstein, N. A. Roe, M. T. Ronan, W. A. Wenzel

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

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

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

T. Held, H. Koch, B. Lewandowski, M. Pelizaeus, K. Peters, T. Schroeder, M. Steinke

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

J. T. Boyd, J. P. Burke, W. N. Cottingham, D. Walker

University of Bristol, Bristol BS8 1TL, United Kingdom

D. J. Asgeirsson, T. Cuhadar-Donszelmann, B. G. Fulsom, C. Hearty, N. S. Knecht, T. S. Mattison, J. A. McKenna

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

A. Khan, P. Kyberd, M. Saleem, D. J. Sherwood, L. Teodorescu

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

V. E. Blinov, A. D. Bukin, V. P. Druzhinin, V. B. Golubev, A. P. Omuchin, S. I. Serednyakov, Yu. I. Skovpen, E. P. Solodov, K. Yu Todyshev

Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia

D. S. Best, M. Bondioli, M. Bruinsm, M. Chao, S. Curry, I. Eschrich, D. Kirkby, A. J. Lankford, P. Lund, M. Mandelkern, R. K. Monmsen, W. Roethel, D. P. Stoker

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

S. Abachi, C. Buchanan

University of California at Los Angeles, Los Angeles, California 90024, USA
S. D. Foulkes, J. W. Gary, O. Long, B. C. Shen, K. Wang, L. Zhang
University of California at Riverside, Riverside, California 92521, USA

H. K. Hadavand, E. J. Hill, H. P. Paar, S. Rahatlou, V. Sharma
University of California at San Diego, La Jolla, California 92093, USA

J. W. Berryhill, C. Campagnari, A. Cunha, B. Dahmes, T. M. Hong, D. Kovalskyi, J. D. Richman
University of California at Santa Barbara, Santa Barbara, California 93106, USA

T. W. Beck, A. M. Eisner, C. J. Flacco, 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, California 95064, USA

J. Albert, E. Chen, A. Dvoretskii, F. Fang, D. G. Hitlin, I. Narisky, T. Piatenko, F. C. Porter, A. Ryd,
A. Samuel
California Institute of Technology, Pasadena, California 91125, USA

G. Mancinelli, B. T. Meadows, K. Mishra, M. D. Sokoloff
University of Cincinnati, Cincinnati, Ohio 45221, USA

F. Blanc, P. C. Bloom, S. Chen, W. T. Ford, J. F. Hirschauer, A. Kreisel, M. Nagel, U. Nauenberg,
A. Olivas, W. O. Ruddick, J. G. Smith, K. A. Ulmer, S. R. Wagner, J. Zhang
University of Colorado, Boulder, Colorado 80309, USA

A. Chen, E. A. Eckhart, A. Soffer, W. H. Toki, R. J. Wilson, F. Winklmeier, Q. Zeng
Colorado State University, Fort Collins, Colorado 80523, USA

D. D. Altenburg, E. Feltresi, A. Hauke, H. Jasper, J. Merkel, A. Petzold, B. Spaan
Universität Dortmund, Institut für Physik, D-44221 Dortmund, Germany

T. Brandt, V. Klose, H. M. Lacker, W. F. Mader, R. Nogowski, J. Schubert, K. R. Schubert, R. Schwierz,
J. E. Sundermann, A. Volk
Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany

D. Bernard, G. R. Bonneauad, E. Latour, Ch. Thiebaux, M. Verderi
Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, F-91128 Palaiseau, France

P. J. Clark, W. Gradl, F. Muheim, S. Playfer, A. I. Robertson, Y. Xie
University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom

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

F. Anulli, R. Baldini-Ferroli, A. Calcaterra, R. de Sangro, G. Finocchiaro, S. Pacetti, P. Patteri,
I. M. Peruzzi,1 M. Piccolo, M. Rama, A. Zallo
Laboratori Nazionali di Frascati dell’INFN, I-00044 Frascati, Italy

1Also with Università di Perugia, Dipartimento di Fisica, Perugia, Italy
A. Buzzo, R. Capra, R. Contri, M. Lo Vetere, M. 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

G. Brandenburg, K. S. Chaisanguanthum, M. Morii, J. Wu
Harvard University, Cambridge, Massachusetts 02138, USA

R. S. Dubitzky, J. Marks, S. Schenk, U. Uwer
Universität Heidelberg, Physikalisches Institut, Philosophenweg 12, D-69120 Heidelberg, Germany

D. J. Bard, W. Bhimji, D. A. Bowerman, P. D. Dauncey, U. Egede, R. L. Flack, J. A. Nash, M. B. Nikolich, W. Panduro Vazquez
Imperial College London, London, SW7 2AZ, United Kingdom

P. K. Behera, X. Chai, M. J. Charles, U. Mallik, N. T. Meyer, V. Ziegler
University of Iowa, Iowa City, Iowa 52242, USA

J. Cochran, H. B. Crawley, L. Dong, V. Eyges, W. T. Meyer, S. Prell, E. I. Rosenberg, A. E. Rubin
Iowa State University, Ames, Iowa 50011-3160, USA

A. V. Gritsan
Johns Hopkins University, Baltimore, Maryland 21218, USA

A. G. Denig, M. Fritsch, G. Schott
Universität Karlsruhe, Institut für Experimentelle Kernphysik, D-76021 Karlsruhe, Germany

N. Arnaud, M. Davier, G. Grosdidier, A. Höcker, F. Le Diberder, V. Lepeltier, A. M. Lutz, A. Oyanguren, S. Pruvot, S. Rodier, P. Roudeau, M. H. Schune, A. Stocchi, W. F. Wang, G. Wormser
Laboratoire de l’Accélérateur Linéaire, IN2P3/CNRS et Université Paris-Sud 11, Centre Scientifique d’Orsay, B.P. 34, F-91898 ORSAY Cedex, France

C. H. Cheng, D. J. Lange, D. M. Wright
Lawrence Livermore National Laboratory, Livermore, California 94550, USA

C. A. Chavez, I. J. Forster, J. R. Fry, E. Gabathuler, R. Gamet, K. A. George, D. E. Hutchcroft, D. J. Payne, K. C. Schofield, C. Touramanis
University of Liverpool, Liverpool L69 7ZE, United Kingdom

A. J. Bevan, F. Di Lodovico, W. Menges, R. Sacco
Queen Mary, University of London, E1 4NS, United Kingdom

G. Cowan, H. U. Flächer, D. A. Hopkins, P. S. Jackson, T. R. McMahon, S. Ricciardi, F. Salvatore, A. C. Wren
University of London, Royal Holloway and Bedford New College, Egham, Surrey TW20 0EX, United Kingdom

D. N. Brown, C. L. Davis
University of Louisville, Louisville, Kentucky 40292, USA
J. Allison, N. R. Barlow, R. J. Barlow, Y. M. Chia, C. L. Edgar, G. D. Lafferty, M. T. Naisbit, J. C. Williams, J. I. Yi

*University of Manchester, Manchester M13 9PL, United Kingdom*

C. Chen, W. D. Hulsbergen, A. Jawahery, C. K. Lae, D. A. Roberts, G. Simi

*University of Maryland, College Park, Maryland 20742, USA*

G. Blaylock, C. Dallapiccola, S. S. Hertzbach, X. Li, T. B. Moore, S. Saremi, H. Staengle

*University of Massachusetts, Amherst, Massachusetts 01003, USA*

R. Cowan, G. Sciolla, S. J. Sekula, M. Spitznagel, F. Taylor, R. K. Yamamoto

*Massachusetts Institute of Technology, Laboratory for Nuclear Science, Cambridge, Massachusetts 02139, USA*

H. Kim, S. E. McLachlin, P. M. Patel, S. H. Robertson

*McGill University, Montréal, Québec, 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, D. A. Sanders, D. J. Summers, H. W. Zhao

*University of Mississippi, University, Mississippi 38677, USA*

S. Brunet, D. Côté, M. Simard, P. Taras, F. B. Viaud

*Université de Montréal, Physique des Particules, Montréal, Québec, Canada H3C 3J7*

H. Nicholson

*Mount Holyoke College, South Hadley, Massachusetts 01075, USA*

N. Cavallo,² G. De Nardo, F. Fabozzi,³ 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. A. Baak, G. Raven, H. L. Snoek

*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, Indiana 46556, USA*

T. Allmendinger, G. Benelli, L. A. Corwin, K. K. Gan, K. Honscheid, D. Hufnagel, P. D. Jackson, H. Kagan, R. Kass, A. M. Rahimi, J. J. Regensburger, R. Ter-Antonyan, Q. K. Wong

*Ohio State University, Columbus, Ohio 43210, USA*

N. L. Blount, J. Brau, R. Frey, O. Igonkina, J. A. Kolb, M. Lu, R. Rahmat, N. B. Sinev, D. Strom, J. Strube, E. Torrence

*University of Oregon, Eugene, Oregon 97403, USA*

²Also with Università della Basilicata, Potenza, Italy
³Also with Università della Basilicata, Potenza, Italy
A. Gaz, M. Margoni, M. Morandin, A. Pompili, M. Posocco, M. Rotondo, F. Simonetto, R. Stroili, C. Voci

Università di Padova, Dipartimento di Fisica and INFN, I-35131 Padova, Italy

M. Benayoun, H. Briand, J. Chauveau, P. David, L. Del Buono, Ch. de la Vaissière, O. Hamon, B. L. Hartfiel, M. J. J. John, Ph. Leruste, J. Malcles, J. Ocariz, L. Roos, G. Therin
Laboratoire de Physique Nucléaire et de Hautes Energies, IN2P3/CNRS, Université Pierre et Marie Curie-Paris6, Université Denis Diderot-Paris7, F-75252 Paris, France

L. Gladney, J. Panetta
University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA

M. Biasini, R. Covarelli
Università di Perugia, Dipartimento di Fisica and INFN, I-06100 Perugia, Italy

C. Angelini, G. Batignani, S. Bettarini, F. Bucci, G. Calderini, M. Carpinelli, R. Cenci, F. Forti, M. A. Giorgi, A. Lusiani, G. Marchiori, M. A. Mazur, M. Morganti, N. Neri, E. Paoloni, G. Rizzo, J. J. Walsh
Università di Pisa, Dipartimento di Fisica, Scuola Normale Superiore and INFN, I-56127 Pisa, Italy

M. Haire, D. Judd, D. E. Wagoner
Prairie View A&M University, Prairie View, Texas 77446, USA

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

F. Bellini, G. Cavoto, A. D’Orazio, D. del Re, E. Di Marco, R. Faccini, F. Ferrarotto, F. Ferroni, M. Gaspero, L. Li Gioi, M. A. Mazzoni, S. Morganti, G. Piredda, F. Polci, F. Safai Tehrani, C. Voena
Università di Roma La Sapienza, Dipartimento di Fisica and INFN, I-00185 Roma, Italy

M. Ebert, H. Schröder, R. Waldi
Universität Rostock, D-18051 Rostock, Germany

T. Adye, N. De Groot, B. Franek, E. O. Olaiya, F. F. Wilson
Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingdom

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

X. R. Chen, H. Liu, W. Park, M. V. Purohit, J. R. Wilson
University of South Carolina, Columbia, South Carolina 29208, USA

M. T. Allen, D. Aston, R. Bartoldus, P. Bechtle, N. Berger, R. Claus, J. P. Coleman, M. R. Convery, M. Cristinziani, J. C. Dingfelder, J. Dorfan, G. P. Dubois-Felsmann, D. Dujmic, W. Dunwoodie, R. C. Field, T. Glanzman, S. J. Gowdy, M. T. Graham, P. Grenier, V. Halyo, C. Hast, T. Hryn’ova, W. R. Innes, M. H. Kelsey, P. Kim, D. W. G. S. Leith, S. Li, S. Luitz, V. Luth, H. L. Lynch, D. B. MacFarlane, H. Marsiske, R. Messner, D. R. Muller, C. P. O’Grady, V. E. Ozcan, A. Perazzo, M. Perl, T. Pulliam, B. N. Ratcliffe, A. Roodman, A. A. Sahnikov, R. H. Schindler, J. Schwiening, A. Snyder, J. Stelzer, D. Su, M. K. Sullivan, K. Suzuki, S. K. Swain, J. M. Thompson, J. Va’vra, N. van

4Also at Laboratoire de Physique Corpusculaire, Clermont-Ferrand, France
1 INTRODUCTION

B-meson decays proceed dominantly through $b \to c$ transitions, while the tree-level $b \to u$ and one-loop $b \to s$ transitions are suppressed. In the Standard Model (SM), the branching fractions for $b \to u$ and $b \to s$ transitions are approximately $1\% - 2\%$ [1, 2, 3]. It has been suggested that loop transitions are a window on the effects of new physics, as virtual non-SM particles in the loop can couple to the quarks [4, 5]. The branching fraction for $b \to sg^*$ ($g^*$ = gluon) decays could be as large as $10\%$ in certain models [4, 5].

In recent years, exclusive $B$ decays dominated by $b \to sg^*$ ($b \to sqq$, $q = u, d, s$) have been used to measure the CKM unitarity triangle angle $\beta$. The amplitude $S$ of the sine component of the time-dependent $CP$ asymmetry in these decay modes is measured to be systematically shifted low relative to the expected values from SM calculations ($S \simeq \sin 2\beta$), although this shift is currently not statistically significant [6].

A good understanding of the dynamics of $b \to s$ transitions is needed to make accurate predictions of related quantities within the framework of the SM [7]. This understanding currently comes from branching fractions and $CP$ measurements of $b \to s$ dominated exclusive decays and from inclusive and exclusive $b \to s\gamma$ transitions. The measurement of inclusive $b \to sg^*$ decays would provide additional information to the current picture [8], and could help us understand the discrepancies seen in the measurements of $\sin 2\beta$ [7].

Previous experimental attempts to measure inclusive $b \to sg^*$ decays have been statistically limited [9, 10, 11, 12]. The $B$-factory experiments present new opportunities to make a significant measurement of this process.

In this paper, we present a preliminary result from a search for inclusive charmless $B \to K^+X$ and $B \to K^0X$ decays, which can in principle be related to the $b \to sg^*$ rate. The neutral kaon in $B \to K^0X$ is reconstructed through the decay $K^0 \to \pi^+\pi^-$. We define as signal $B \to KX$ all the charmless decays that contain at least one kaon. These decays can occur via $b \to s$ (dominant), $b \to u$, and $b \to d$ transitions. The signal yields are extracted with an unbinned maximum likelihood (ML) fit to samples of $B \to KX$ decays recoiling against fully reconstructed hadronic $B$ decays.

2 THE BaBar DETECTOR AND DATASET

The data used in this analysis were collected with the $\text{BaBar}$ detector [13] at the PEP-II asymmetric-energy $e^+e^-$ collider located at the Stanford Linear Accelerator Center (SLAC). The analysis uses an integrated luminosity of $288.5 \text{ fb}^{-1}$ recorded at the $\Upsilon(4S)$ resonance (center-of-mass energy $\sqrt{s} = 10.58 \text{ GeV}$).

In the $\text{BaBar}$ detector, charged particles are detected and their momenta measured by a combination of a vertex tracker consisting of five layers of double-sided silicon microstrip detectors and a 40-layer central drift chamber, both operating in the 1.5-T magnetic field of a superconducting solenoid. We identify photons and electrons using a CsI(Tl) electromagnetic calorimeter (EMC). Charged particle identification (PID) is provided by an internally reflecting ring imaging Cherenkov detector (DIRC) covering the central region of the detector, the average energy loss ($dE/dx$) in the tracking devices and by the EMC. Additional information that we use to identify and reject electrons and muons is provided by the EMC and the detectors of the solenoid flux return (IFR).
3 ANALYSIS METHOD AND EVENT SELECTION

The experimental identification of the inclusive $b \to s q \bar{q}$ decay is complicated by the fact that the gluon is a virtual intermediate state with no good experimental signature. We instead rely on the hadronization of the primary strange quark into a charged or neutral kaon to identify decays dominated by $b \to s$ transitions. The analysis is therefore effectively a search for the decays $B \to K^+X$ and $B \to K^0X$. The momentum $p^*(K)$ of the primary kaon in the $B$ rest frame is limited for $b \to c$ background by the $D$-meson mass, and cannot be larger than $\sim 2.3\, \text{GeV}$, while $p^*(K)$ can be as large as $\sim 2.6\, \text{GeV}$ for signal $B \to KX$ decays. We use this difference as the primary signature to look for charmless inclusive $B \to KX$ decays, as was first suggested in Ref. [14].

In this analysis we reject the large $e^+e^- \to q\bar{q}$ ($q = u, d, s, c$) continuum background very efficiently by reconstructing one of the two $B$ mesons ($B_{\text{reco}}$) in $e^+e^- \to \Upsilon(4S) \to B\bar{B}$, and searching for the $B \to KX$ signal ($B_{\text{signal}}$) recoiling against $B_{\text{reco}}$. We select a large sample of events containing a $B_{\text{reco}}$ meson which decays into a hadronic final state as $B_{\text{reco}} \to \Upsilon(4S)Y^\pm$, and is fully reconstructed. The system $Y^\pm$ consists of a combination of hadrons containing one, three, or five charged pions or kaons, up to two neutral pions, and at most two $K_S^0 \to \pi^+\pi^-$ candidates. We reconstruct $D^{*-} \to \Upsilon(4S)\pi^-$; $D^{*0} \to \Upsilon(4S)\pi^0$; $D^0 \to K^+\pi^-$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^+\pi^-$, $K^0_s\pi^+\pi^-$; and $D^- \to K^+\pi^-\pi^-$, $K^+\pi^-\pi^0$, $K^0_s\pi^-$, $K^0_s\pi^-\pi^0$, $K^0_s\pi^-\pi^+\pi^-$. The $B_{\text{reco}}$ candidates are characterized kinematically by the energy-substituted mass $m_{\text{ES}} = \left(\frac{1}{2} s - p_B^2\right)^{\frac{1}{2}}$ and energy difference $\Delta E = E_B - \frac{1}{2} \sqrt{s}$, where $(E_B, \mathbf{p}_B)$ is the $B$-meson 4-momentum vector, and all values are expressed in the $\Upsilon(4S)$ frame. We require the value of $\Delta E$ to be consistent with zero within three standard deviations ($\sigma$), as measured for each decay mode ($10$ to $35\, \text{MeV}$). We require $5.25 < m_{\text{ES}} < 5.29\, \text{GeV}$, and use this variable in the ML fit described below. We define the purity for each $B_{\text{reco}}$ decay mode as the ratio $S/(S + B)$ measured in control samples, where $S$ is the number of reconstructed signal $B_{\text{reco}}$ and $B$ is the number of background events. We require the purity of the selected $B_{\text{reco}}$ candidates to be at least $20\%$. In events containing more than one $B_{\text{reco}}$ candidate, we select the decay mode with the highest purity.

To further reject $q\bar{q}$ continuum background, we make use of the angle $\theta_T$ between the thrust axis of the $B_{\text{reco}}$ candidate in the $\Upsilon(4S)$ frame and that of the rest of the charged tracks and neutral clusters in the event. The distribution of $|\cos \theta_T|$ is sharply peaked near 1 for combinations drawn from jet-like $q\bar{q}$ pairs, and nearly uniform for the almost isotropic $B$-meson decays; we require $|\cos \theta_T| < 0.9$. Further discrimination from continuum in the ML fit is obtained from a Fisher discriminant $\mathcal{F}$, which is an optimized linear combination of four variables: the angles with respect to the beam axis of the $B$ momentum and $B$ thrust axis (in the $\Upsilon(4S)$ frame), and the zeroth and second angular moments $L_{0,2}$ of the energy flow about the $B$ thrust axis. The moments are defined by $L_j = \sum_i p_i \times |\cos \theta_i|^j$, where $\theta_i$ is the angle with respect to the $B$ thrust axis of track or neutral cluster $i$, $p_i$ is its momentum, and the sum excludes the $B_{\text{reco}}$ candidate.

We select $2.99 \times 10^6$ $B_{\text{reco}}$ candidates with the above criteria, and apply an unbinned ML fit to the $m_{\text{ES}}$ and $\mathcal{F}$ variables to separate $B\bar{B}$ events from $q\bar{q}$ continuum background. We find $N(B_{\text{reco}}) = (1.78 \pm 0.09) \times 10^6$, where the uncertainty includes a conservative preliminary estimate of the systematics due to the modeling of the data.

We search for the signal $B$ meson ($B_{\text{signal}}$) using the charged tracks and the neutral clusters that are not part of the $B_{\text{reco}}$ candidate. We reject $B_{\text{signal}}$ candidates containing charged tracks compatible with an electron or muon hypothesis, or that contain a reconstructed $D$ meson candidate with mass within $30\, \text{MeV}$ of the nominal mass. We also require $m_{\text{ES}}(B_{\text{signal}}) > 5.1\, \text{GeV}$. 

9
The measured $\Upsilon(4S)$ and $B_{\text{reco}}$ 4-momentum vectors are used to determine accurately the 4-momentum vector of $B_{\text{signal}}$, independently of its decay products. We then select charged $K^+$ and neutral $K_S^0 \to \pi^+\pi^-$ candidates with momentum $p^* (K)$ larger than 2.34 GeV, calculated in the $B_{\text{signal}}$ rest frame.

The DIRC Cherenkov angle $\theta_c$ for charged kaon candidates must satisfy $-5\sigma_c < \theta_c < +2\sigma_c$, where $\sigma_c$ is the resolution on $\theta_c$, and the upper limit is designed to reject contamination from charged pions. To exclude secondary kaons, the distance of closest approach of the tracks recoiling against $K^+$ is the yield of events in the decay of $B^{+}X$, which can produce kaons of momentum higher than 2.34 GeV in the decay of $D$ mesons. Contamination from unflavored $b \to u$ and $b \to d$ transitions is negligible for $B \to K^0_S X$, and estimated to contribute to 2.4% of the $B \to K^+ X$ sample via $K/\pi$ mis-identification.

4 MAXIMUM LIKELIHOOD FIT

We obtain yields for each decay from an extended unbinned ML fit with the following input observables: $m_{ES}$, $F$, and $p^* (K)$. As described below, the fit is first applied with several probability density function (PDF) parameters floating to samples obtained with $p^* (K) > 1.8$ GeV. The signal yield is then extracted from a fit to the $p^* (K) > 2.34$ GeV samples, in which the $B\bar{B}$ background yield and $p^* (K)$ PDF are fixed to the results of the first fit.

For each event $i$ and hypothesis $j$ (signal $B \to KX$, $B\bar{B}$ background, continuum background), we define the probability density function (PDF)

$$P_j^i = P_j (m_{ES}^i) P_j (F^i) P_j (p^* i).$$  

(1)

The likelihood function is

$$\mathcal{L} = \exp \left(- \sum_j Y_j \prod_i^N \left[ \sum_j P_j^i \right] \right),$$  

(2)

where $Y_j$ is the yield of events of hypothesis $j$, to be found by maximizing $\mathcal{L}$. $N$ is the number of events in the sample.

The $m_{ES}$ and $F$ variables discriminate between $B\bar{B}$ and $q\bar{q}$ continuum events. For these variables, the same PDF is used for the $B \to KX$ signal and $B\bar{B}$ background components. The $m_{ES}$ PDF for $q\bar{q}$ continuum is parametrized by an empirical phase-space function [13] of the form

$$f(x) \propto x \sqrt{1 - x^2} \exp \left[ -\xi (1 - x^2) \right]$$  

(3)

where $x = 2m_{ES}/\sqrt{s}$, and $\xi$ is a parameter determined by the fit. For $B$ decays, $m_{ES}$ is modeled by the sum of two Gaussians and the function of Eq. [3] with a different value of $\xi$. The $F$ PDF is parametrized as a bifurcated Gaussian plus a Gaussian for $B\bar{B}$ events, and as two Gaussians for
continuum. The $p^*(K)$ PDF is defined over the wider range $p^*(K) > 1.8$ GeV. For the signal $B \to KX$, the PDF is the sum of a phase-space function given by Eq. (4) with $x \equiv p^*(K)/2.62$ GeV, and a Gaussian to account for the contribution from exclusive 2-body decays such as $B \to \eta'K$. The parameters of the signal $p^*(K)$ PDF will be varied in the evaluation of the systematic errors, as the $p^*(K)$ spectrum is not well known. The $B\bar{B}$ background PDF is the sum of three Gaussians, two of them used to model the $B \to D\bar{K}$ and $B \to D^*\bar{K}$ contributions. The $q\bar{q}$ component is described by the sum of an exponential and a Gaussian. All the PDF distributions are illustrated in Figs. 1 and 2.

The PDF for each variable and each component is initially determined from Monte Carlo (MC) simulation. A preliminary ML fit with several free PDF parameters is applied to the sample obtained with the relaxed requirement $p^*(K) > 1.8$ GeV. This range of $p^*(K)$ includes too much background for an accurate determination of the signal yield, but it allows the measurement of the yield and the $p^*(K)$ PDF for the $B\bar{B}$ component. The free parameters of this fit are the three yields, the fractions of neutral $B_{\text{reco}}$ candidates for each component, the size of the $p^*(K)$ secondary Gaussians for the signal and $B\bar{B}$ components, the width of the $p^*(K)$ main Gaussian for the $B\bar{B}$ component, and the $m_{ES}$ exponent parameter for the $q\bar{q}$ component. The results are illustrated in Fig. 1 which shows the projections onto $p^*(K^+)$ and $p^*(K^0_S)$ of subsamples enriched with a threshold requirement on the signal likelihood computed without the variable plotted.

![Figure 1](image-url)  

Figure 1: Projection plots for the $p^*(K^+)$ (left) and $p^*(K^0_S)$ (right) variables from the fits to the $p^*(K) > 1.8$ GeV samples. The projections are obtained with a cut on the signal likelihood (see text) retaining about 80% of the signal events. The points are from the data, the full line shows the full fit, the dotted line the signal, the short-dashed line the $B\bar{B}$ background, and the long-dashed line the $q\bar{q}$ continuum background.

The PDFs determined in the first fit are then used in a second ML fit to the sample obtained with $p^*(K) > 2.34$ GeV. Free parameters are the signal and $q\bar{q}$ continuum background yields, while the $B\bar{B}$ yield is fixed to the fraction of the value measured in the first fit ($p^*(K) > 1.8$ GeV). Systematic errors account for the uncertainties in the fixed $B\bar{B}$ yield, as determined in the first fit and which include the affect of correlations with the signal component.

Monte Carlo simulated experiments are used to validate the fit procedure, and to evaluate possible biases in the yields due to our neglect of small residual correlations among discriminating
variables. The bias is determined by fitting ensembles of simulated $q\bar{q}$ experiments drawn from the PDF into which we have embedded the expected number of signal and $B\bar{B}$ background events, randomly extracted from the fully simulated MC samples. The measured biases are listed in Table 1.

5 RESULTS

The partial branching fractions are calculated as

$$\mathcal{B}(B \rightarrow KX, p^*(K) > 2.34\, \text{GeV}) = \frac{Y_{KX} - Y_b}{\epsilon \cdot N(B_{\text{reco}})},$$

where $Y_{KX}$ is the measured yield, $Y_b$ is the fit bias, and $\epsilon$ is the reconstruction efficiency. The results of the fits to the $p^*(K) > 2.34\, \text{GeV}$ samples and the quantities used in the determination of the branching fractions are presented in Table 1. The significance is taken as the square root of the difference between the value of $-2 \ln \mathcal{L}$ (with additive systematic uncertainties included) for zero signal and the value at its minimum. In Fig. 2 we show projections onto $m_{ES}$, $F$ and $p^*(K)$ of

Table 1: Number of events to fit $N_{\text{cand}}$, fitted signal yield $Y_{KX}$ in events (ev.), measured bias $Y_b$ (see text), detection efficiency $\epsilon$, significance $S$ (with systematic uncertainties included), and measured partial branching fraction $\mathcal{B}$ for each mode. The first errors are statistical and the second are systematic. The quantity in parentheses is the 90% C.L. upper limit for the branching fraction $\mathcal{B}(B \rightarrow K^0X)$.

| Mode       | $N_{\text{cand}}$ | $Y_{KX}$ (ev.) | $Y_b$ (ev.) | $\epsilon$ (%) | $S$ ($\sigma$) | $\mathcal{B}$ ($10^{-6}$) |
|------------|-------------------|----------------|-------------|-----------------|---------------|-------------------------|
| $B \rightarrow K^+X$ | 246               | 58.4$^{+10.5}_{-9.7}$ | 2.2        | 16.1            | 6.0           | 196$^{+37+31}_{-34-30}$ |
| $B \rightarrow K^0X$ | 76                | 21.1$^{+6.5}_{-5.7}$  | 2.8        | 6.7             | 3.1           | 154$^{+55+55}_{-48-41}$ (< 266) |

subsamples enriched with a threshold requirement on the signal likelihood computed without the variable plotted.

6 SYSTEMATIC STUDIES

We determine systematic uncertainties affecting the measurement of the yields, the estimation of the selection efficiencies, and the measurement of the number of $B_{\text{reco}}$ candidates. The systematic uncertainties are summarized in Table 2.

The signal yield systematic errors arise from the fixed $B\bar{B}$ yields (31.0 ± 6.8 events for the charged decay mode and 13.8 ± 4.2 events for the neutral mode), which are varied within their uncertainties; the fit bias correction, for which we assign as systematic error the quadratic sum of the statistical uncertainty on the correction and one half of the correction itself; and the PDF parameter uncertainties, which are left free one by one in the fit and the variation in signal yield recorded. The dominant contribution to the PDF parameter uncertainties arises from the poorly known signal $p^*(K)$ spectrum. We evaluate this uncertainty by floating in the fit the relative size and the mean of the Gaussian used in the description of the signal $p^*(K)$ PDF.
Figure 2: Projection plots for $m_{ES}$ (left), $F$ (center), and $p^*(K)$ (right) from the fits to the $p^*(K) > 2.34$ GeV samples. The top plots are for the $B \to K^+X$ decay, and the bottom plots for $B \to K^0_SX$. The projections are obtained with a cut on the signal likelihood (see text) retaining about 85% of the $B \to K^+X$ signal events and 75% of the $B \to K^0_SX$ signal events. The points are from the data, the full line shows the full fit, the dotted line the signal, the short-dashed line the $B\bar{B}$ background, and the long-dashed line the $q\bar{q}$ continuum background.

Uncertainties on the selection efficiencies are dominated by the statistics of the inclusive $B \to KX$ Monte Carlo samples. We also include 0.5% uncertainty per track, 2.1% for the $K^0_S$, and 2.4% for the $K^+$ particle identification criteria.

The uncertainty in the number of fitted $B_{\text{reco}}$ candidates is taken from the results of that fit (5%).

7 CONCLUSIONS

We have presented preliminary results for a study of inclusive charmless $B \to K^+X$ and $B \to K^0X$ decays, recoiling against fully reconstructed hadronic $B$ decays from $\Upsilon(4S)$ decays. We measure the partial branching fractions for charged and neutral kaons with momentum above the end-point for $b \to c$ backgrounds ($p^*(K) > 2.34$ GeV):

$$B(B \to K^+X, p^* > 2.34 \text{ GeV}) = (196^{+37}_{-34} \text{(stat.)}^{+31}_{-30} \text{(syst.)}) \times 10^{-6}, \text{ and}$$

$$B(B \to K^0X, p^* > 2.34 \text{ GeV}) = (154^{+55}_{-43} \text{(stat.)}^{+55}_{-41} \text{(syst.)}) \times 10^{-6} (~< 266 \times 10^{-6} \text{ at 90\% C.L.})$$
Table 2: Systematic uncertainties for the $B \rightarrow K^+X$ and $B \rightarrow K^0X$ decay modes. The multiplicative errors are fractional, and apply to the efficiency and to the $B_{\text{reco}}$ counting, while the additive errors are in units of events and apply to the signal yields.

|                      | $B \rightarrow K^+X$ | $B \rightarrow K^0X$ |
|----------------------|----------------------|----------------------|
| Multiplicative errors (%) |                      |                      |
| MC eff               | 9.4                  | 16.1                 |
| Tracking eff/qual    | 0.5                  | 1.0                  |
| $K^0_S$ eff          | –                    | 2.1                  |
| Kaon PID             | 2.4                  | –                    |
| Number $B_{\text{reco}}$ | 5.0                  | 5.0                  |
| Total multiplicative (%) | 10.9                  | 17.0                 |
| Additive errors (events) |                    |                      |
| Fixed $b \rightarrow c$ yield | +6.0                | +4.1                  |
| PDF parametrization  | –5.6                 | –3.5                 |
| Fit bias             | +2.6                 | +3.9                 |
|                      | –2.4                 | –0.8                 |
| Total additive (events) |                  |                      |
|                      | +6.6                 | +5.8                 |
|                      | –6.2                 | –3.9                 |

Known exclusive charmless two-body decays, dominated by the decays $B^+ \rightarrow \eta'K^+$ and $B^0 \rightarrow \eta/K^0$, account for approximately 60% of these branching fractions. Similar two-body decays with a $K^*$ meson and three-body decays, such as $B^+ \rightarrow K^+K^-K^+$ and $B^0 \rightarrow K^+K^-K^0$, probably account for much of the remainder.

A theoretical model is necessary to extrapolate these results to the full $p^*(K)$ spectrum, and ultimately to extract a measurement of the inclusive $b \rightarrow s\gamma^*$ branching fraction. Completing this extrapolation and assigning the theoretical systematic error from the shape of the $p^*(K)$ spectrum is the focus of ongoing effort.

8 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, Ministerio de Educación y Ciencia (Spain), and the Particle Physics and Astronomy Research
Council (United Kingdom). Individuals have received support from the Marie-Curie IEF program (European Union) and the A. P. Sloan Foundation.

References

[1] W.-S. Hou, A. Soni, H. Steger, Phys. Rev. Lett. 59, 1521 (1987).
[2] C. Greub, P. Liniger, Phys. Rev. D 63, 054025 (2001).
[3] A. Lenz, U. Nierste, G. Ostermaier, Phys. Rev. D 56, 7228 (1997).
[4] I. Bigi et al., Phys. Lett. B 323, 408 (1994).
[5] A. Goksu, E.O. Iltan, L. Solmaz, Phys. Rev. D 64, 054006 (2001).
[6] Heavy Flavor Averaging Group, Winter 2006 averages:
   http://www.slac.stanford.edu/xorg/hfag/triangle/moriond2006/index.shtml#qq
[7] G. Buchalla et al., JHEP 0509, 074 (2005).
[8] G. Hiller and F. Krüger, Phys. Rev. D 69, 074020 (2004).
[9] H. Albrecht et al. (ARGUS Collaboration), Phys. Lett. B353, 554 (1995).
[10] T.E. Coan et al. (CLEO Collaboration), Phys. Rev. Lett. 80, 1150 (1998).
[11] P. Abreu et al. (DELPHI Collaboration), Phys. Lett. B426, 193 (1998).
[12] SLD Collaboration, “Inclusive search for $b \rightarrow sg$”, SLAC-PUB-7896 (1998).
[13] B. Aubert et al. (BABAR Collaboration), Nucl. Instrum. Methods A479, 1 (2002).
[14] T.E. Browder et al., Phys. Rev. D 57, 6829 (1998).
[15] H. Albrecht et al. (ARGUS Collaboration), Phys. Lett. B 241, 278 (1990); ibid 254, 288 (1991).