BABAR-CONF-03/021
SLAC-PUB-10101
hep-ex/0308017
August 2003

Measurement of $\mathcal{B}(B^0 \to D_s^{*+} D^{*-})$ and Determination of the $D_s^+ \to \phi\pi^+$ Branching Fraction with a Partial-Reconstruction Method

The *BABAR* Collaboration

August 7, 2003

Abstract

We present model-independent measurements of the branching fractions $\mathcal{B}(B^0 \to D_s^{*+} D^{*-})$ and $\mathcal{B}(D_s^+ \to \phi\pi^+)$ based on 19.3 fb^{-1} of data collected by the *BABAR* detector at the PEP-II e^+e^- B Factory. Neutral B-meson decays to the $D_s^{*+} D^{*-}$ final state are selected with a partial reconstruction of the D_s^{*+}; that is, only the D^{*-} and the soft photon from the decay $D_s^{*+} \to D_s^+ \gamma$ are reconstructed. The branching fraction $\mathcal{B}(B^0 \to D_s^{*+} D^{*-})$ is extracted from these event yields, while $\mathcal{B}(D_s^+ \to \phi\pi^+)$ is determined by combining this result with a previous measurement of the product $\mathcal{B}(B^0 \to D_s^{*+} D^{*-}) \times \mathcal{B}(D_s^+ \to \phi\pi^+)$ with partial reconstruction of the D^{*-}. We obtain the following preliminary results:

$$\mathcal{B}(B^0 \to D_s^{*+} D^{*-}) = (1.50 \pm 0.16 \pm 0.12)\%,$$
$$\mathcal{B}(D_s^+ \to \phi\pi^+) = (4.7 \pm 0.6 \pm 0.8)\%$$

where the first error is statistical, and the second systematic.

Contributed to the XXI$^{\text{st}}$ International Symposium on Lepton and Photon Interactions at High Energies, 8/11 – 8/16/2003, Fermilab, Illinois USA

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, J.-M. Gaillard, A. Hicheur, Y. Karyotakis, J. P. Lees, P. Robbe, 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, J. F. Kral, G. Kukartsev, C. LeClerc, M. E. Levi, G. Lynch, L. M. Mir, P. J. Oddone, T. J. Orimoto, M. Pripstein, N. A. Roe, A. Romosan, M. T. Ronan, V. G. Shelkov, A. V. Telnov, W. A. Wenzel

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

K. Ford, T. J. Harrison, C. M. Hawkes, D. J. Knowles, S. E. Morgan, R. C. Penny, A. T. Watson, N. K. Watson

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

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

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

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

University of Bristol, Bristol BS8 1TL, United Kingdom

K. Abe, T. Cuhadar-Donszelmann, C. Hearty, T. S. Mattison, J. A. McKenna, D. Thiessen

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

P. Kyberd, A. K. McKemey

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

V. E. Blinov, A. D. Bukin, 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, 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

B. C. Shen
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, N. Kuznetsova, S. L. Levy, 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, J. Beringer, A. M. Eisner, C. A. Heusch, W. S. Lockman, T. Schalk, R. E. Schmitz, B. A. Schumm, A. Seiden, M. Turri, W. Walkowiak, 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, 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, P. J. Clark, W. T. Ford, U. Nauenberg, A. Olivas, P. Rankin, J. Roy, J. G. Smith, W. C. van Hoek, L. Zhang
University of Colorado, Boulder, CO 80309, USA

J. L. Harton, T. Hu, A. Soffer, W. H. Toki, R. J. Wilson, J. Zhang
Colorado State University, Fort Collins, CO 80523, USA

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

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

A. Khan, D. Lavin, F. Muheim, S. Playfer, J. E. Swain
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,[1] R. Baldini-Ferroli, M. Biasini,[1] A. Calcaterra, R. Covarelli,[1] R. de Sangro, D. Falciai, G. Finocchiaro, P. Patteri, I. M. Peruzzi,[1] M. Piccolo, M. Pioppi,[1] A. Zallo
Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy

---

[1] Also with Università di Perugia, Perugia, 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, M. Morii, E. Won

Harvard University, Cambridge, MA 02138, USA

W. Bhimji, D. A. Bowerman, P. D. Dauncey, U. Egede, I. Eschrich, J. R. Gaillard, G. W. Morton,
J. A. Nash, P. Sanders, G. P. Taylor

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

G. J. Grenier, S.-J. Lee, 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, J. Yi

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

M. Davier, 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

V. Brigljević , C. H. Cheng, D. J. Lange, D. M. Wright

Lawrence Livermore National Laboratory, Livermore, CA 94550, USA

A. J. Bevan, J. P. Coleman, J. R. Fry, E. Gabathuler, R. Gamet, M. Kay, R. J. Parry, D. J. Payne,
R. J. Sloane, C. Touramanis

University of Liverpool, Liverpool L69 3BX, United Kingdom

J. J. Back, P. F. Harrison, H. W. Shorthouse, P. Strother, P. B. Vidal

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

C. L. Brown, G. Cowan, R. L. Flack, H. U. Flaecher, S. George, M. G. Green, A. Kurup, C. E. Marker,
T. R. McMahon, S. Ricciardi, F. Salvatore, G. Vaitsas, 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, R. J. Barlow, A. C. Forti, P. A. Hart, M. C. Hodgkinson, F. Jackson, G. D. Lafferty, A. J. Lyon,
J. H. Weatherall, J. C. Williams

University of Manchester, Manchester M13 9PL, United Kingdom

A. Farbin, 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

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

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

A. Lazzaro, 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. Cote-Ahern, C. Hast, 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

C. Cartaro, N. Cavallo,[2] G. De Nardo, F. Fabozzi,[2] C. Gatto, L. Lista, 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
NIKHEF, National Institute for Nuclear Physics and High Energy Physics, NL-1009 DB Amsterdam, The Netherlands

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

T. A. Gabriel
Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA

B. Brau, K. K. Gan, K. Honscheid, D. Hufnagel, H. Kagan, R. Kass, T. Pulliam, Q. K. Wong
Ohio State University, Columbus, OH 43210, USA

J. Brau, R. Frey, 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. Ocariz, M. Pivk, L. Roos, J. Stark, S. T'Jampens, G. Therin
Universités Paris VI et VII, Lab de Physique Nucléaire H. E., 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, V. Del Gamba, 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, C. Lu, V. Miftakov, J. Olsen, A. J. S. Smith, H. A. Tanaka E. W. Varnes
Princeton University, Princeton, NJ 08544, USA

F. Bellini, G. Cavoto,[4] R. Faccini,[5] F. Ferrarotto, F. Ferroni, M. Gaspero, 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, S. M. Xella
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. Langer, M. Legendre, G. W. London, B. Mayer, G. Schott, G. Vasseur, Ch. Yeche, M. Zito
DSM/Dapnia, CEA/Saclay, F-91191 Gif-sur-Yvette, France

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

D. Aston, R. Bartoldus, N. Berger, A. M. Boyarski, O. L. Buchmueller, M. R. Convery, D. P. Coupal, D. Dong, J. Dorfan, D. Dujmic, W. Dunwoodie, R. C. Field, T. Glanzman, S. J. Gowdy, E. Grauges-Pous, T. Hadig, V. Halyo, T. Hryn'ova, W. R. Innes, C. P. Jessop, M. H. Kelsey, P. Kim, M. L. Kocian, U. Langenegger, D. W. G. S. Leith, 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, S. H. Robertson, 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, D. H. Wright, 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. Saleem, F. R. Wappler
State Univ. 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

[5] Also with University of California at San Diego

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

R. Eckmann, H. Kim, J. L. Ritchie, 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

C. Borean, L. Bosisio, G. Della Ricca, S. Dittongo, S. Grancagnolo, L. Lanceri, P. Poropat,[6] 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
University of Victoria, Victoria, BC, Canada V8W 3P6

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

H. Neal
Yale University, New Haven, CT 06511, USA

---

[6] Deceased

1 INTRODUCTION

We present a measurement of the branching fractions $\mathcal{B}(B^0 \to D_s^{*+} D^{*-})$ and $\mathcal{B}(D_s^+ \to \phi\pi^+)$ using a partial-reconstruction technique[1] [1]. A precise measurement of the branching fraction for this mode is important because nearly all D_s^+ branching fractions are determined by normalizing the measurements to $\mathcal{B}(D_s^+ \to \phi\pi^+)$ [2]. The present uncertainty on $\mathcal{B}(D_s^+ \to \phi\pi^+)$ thus affects many of the results regarding D_s^+ mesons, including the determination of the decay constant by means of purely leptonic decays and the measurement of the $D_s^+ \to K$ inclusive decay rate, as well as b-physics analyses where a D_s^+ or a D_s^{*+} is fully reconstructed.

In the factorization model for two-body decay rates, it is assumed that each contribution to the transition amplitude of the process is the product of two currents that can be evaluated separately. This model has been successful [3] in describing the measured branching fractions and polarizations for B meson decays such as $B^0 \to D^{*-}\pi^+$ [4], $B^0 \to D^{*-}\rho^+$ and $B^0 \to D^{*-}a_1^+$ [5], in which the momentum transfer in the process is low ($q^2 \simeq M_\pi^2, M_\rho^2$). Measurements of decay rates for modes such as $B^0 \to D_s^{*+}D^{*-}$ (Fig. 1(a)) allow tests of the predictions made [6] using the factorization model when the W emits a light and a heavy quark and so the momentum transfer is high ($q^2 \simeq M_{D_s^*}^2$).

The Feynman diagram for the decay $\mathcal{B}(D_s^+ \to \phi\pi^+)$ is shown in Fig. 1(b).

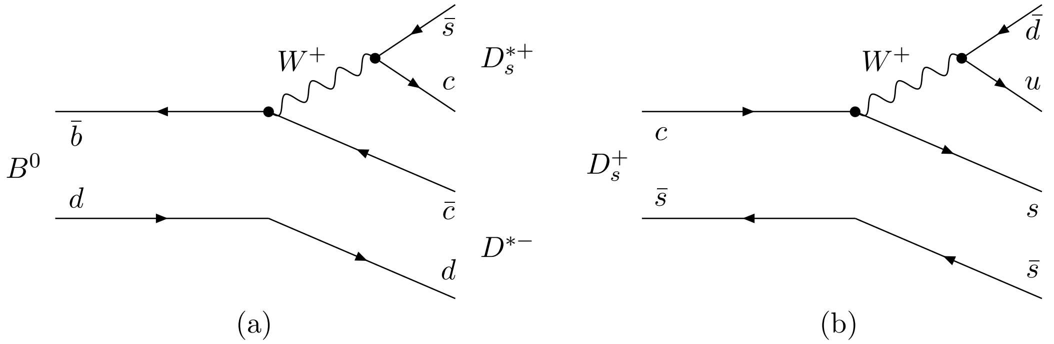

Figure 1: Tree-level Feynman diagrams for the decays (a) $B^0 \to D_s^{*+}D^{*-}$ and (b) $D_s^+ \to \phi\pi^+$.

2 THE *BABAR* DETECTOR AND DATASETS

The data used in this analysis were collected with the *BABAR* detector at the PEP-II storage ring and correspond to an integrated luminosity of $19.3\,\mathrm{fb}^{-1}$. A detailed description of the detector can be found in Ref. [7].

In addition to this data sample, several simulated event samples were used in order to study efficiency and backgrounds. For background studies, we used Monte Carlo samples of $B^0\overline{B}^0$ events (equivalent to an integrated luminosity of $270\,\mathrm{fb}^{-1}$), B^+B^- ($150\,\mathrm{fb}^{-1}$), $e^+e^- \to c\overline{c}$ ($70\,\mathrm{fb}^{-1}$) and $e^+e^- \to u\overline{u}$, $d\overline{d}$, $s\overline{s}$ ($70\,\mathrm{fb}^{-1}$). We used two signal samples in which the $B^0 \to D_s^{*+}D^{*-}$ decay proceeds either with completely longitudinal or transverse polarization; an additional signal sample

---

[1] Here and in the following, charge-conjugate processes are implicitly considered.

was extracted from the $B^0\overline{B}{}^0$ by selecting only $B^0 \to D_s^{*+}D^{*-}$ decays, with no further restriction on the D^{*-} and D_s^{*+} decays.

3 ANALYSIS METHOD

3.1 Analysis Strategy

The partial reconstruction technique results in a significantly larger sample of events than full reconstruction. Moreover, the $B^0 \to D_s^{*+}D^{*-} \to (D_s^+\gamma)(\overline{D}{}^0\pi^-)$ decay is interesting from an experimental point of view since it can be partially reconstructed in two ways: the D_s^{*+} can be fully reconstructed and combined with the slow pion from the decay $D^* \to \overline{D}{}^0\pi^-$, or the D^{*-} can be fully reconstructed and combined with the soft photon from the decay $D_s^{*+} \to D_s^+\gamma$.

The former technique has been used in *BABAR* [8] to measure $\mathcal{B}(B^0 \to D_s^{*+}D^{*-})$. However, the precision one can achieve through this technique is limited by uncertainty on $\mathcal{B}(D_s^+ \to \phi\pi^+)$. By applying this method, the $B^0 \to D_s^{*+}D^{*-}$ branching fraction can be expressed as

$$\mathcal{B}(B^0 \to D_s^{*+}D^{*-}) = \frac{1}{2N_{B\overline{B}}} \frac{N_{D_s^{*+}\pi^-}}{\mathcal{B}(D^{*-} \to \overline{D}{}^0\pi^-)\mathcal{B}(D_s^{*+} \to D_s^+\gamma)\sum_i(\varepsilon_i \cdot \mathcal{B}_i^{D_s^+})}, \tag{1}$$

where $N_{D_s^{*+}\pi^-}$ is the number of partially reconstructed D^{*-} candidates, $N_{B\overline{B}}$ is the number of neutral B meson pairs, $\mathcal{B}_i^{D_s^+}$ are the D_s^+ branching fractions, ε_i are the total reconstruction efficiencies[2] computed separately for each D_s^+ decay mode, and the index i runs over all D_s^+ decay modes used in the reconstruction (in Ref. [8], $D_s^+ \to \phi\pi^+$, $D_s^+ \to K^{*+}K^0$, and $D_s^+ \to K^{*0}K^+$). Partial D_s^{*+} reconstruction similarly yields

$$\mathcal{B}(B^0 \to D_s^{*+}D^{*-}) = \frac{1}{2N_{B\overline{B}}} \frac{N_{D^{*-}\gamma}}{\mathcal{B}(D_s^{*+} \to D_s^+\gamma)\mathcal{B}(D^{*-} \to \overline{D}{}^0\pi^-)\sum_j(\varepsilon_j \cdot \mathcal{B}_j^{D^0})}, \tag{2}$$

where $N_{D^{*-}\gamma}$ is the number of partially reconstructed D_s^{*+} candidates. The result now depends on $\mathcal{B}_j^{D^0}$, the branching fractions for the D^0 modes, which are measured much more precisely than those of the D_s^+.

The $D_s^+ \to \phi\pi^+$ branching fraction can be extracted by combining the two methods. Dividing Eq. 1 by Eq. 2 and solving for $\mathcal{B}(D_s^+ \to \phi\pi^+)$, this last quantity can be expressed as

$$\mathcal{B}(D_s^+ \to \phi\pi^+) = \frac{N_{D_s^{*+}\pi^-}}{\sum_i(\varepsilon_i \cdot R_i^{D_s^+})} \frac{\sum_j(\varepsilon_j \cdot \mathcal{B}_j^{D^0})}{N_{D^{*-}\gamma}}, \tag{3}$$

where $R_i^{D_s^+} \equiv \mathcal{B}_i^{D_s^+}/\mathcal{B}(D_s^+ \to \phi\pi^+)$ is the branching fraction of each D_s^+ mode relative to the $D_s^+ \to \phi\pi^+$ mode, and the $D_s^{*+}\pi^-$ ($D^{*-}\gamma$) yields are normalized to the same luminosity. In the systematic uncertainty determination the contributions given by $\mathcal{B}(D^{*-} \to \overline{D}{}^0\pi^-)$ and $\mathcal{B}(D_s^{*+} \to D_s^+\gamma)$ are clearly cancelled according to Eq. 3.

3.2 Signal Extraction

We reconstruct the $B^0 \to D_s^{*+}D^{*-} \to (D_s^+\gamma)(\overline{D}{}^0\pi^-)$ decay by combining photons in the event with fully reconstructed D^{*-} mesons, without requiring reconstruction of the D_s^+ from the D_s^{*+} decay.

---

[2] Both exclusive D_s^{*+} reconstruction and partial reconstruction efficiencies are included in ε_i.

In order to extract the signal, we compute the missing mass M_{miss} recoiling against the D^{*-}-γ system

$$M_{\mathrm{miss}} = \sqrt{(E_{\mathrm{beam}} - E_{D^*} - E_\gamma)^2 - (\overrightarrow{p}_B - \overrightarrow{p}_{D^*} - \overrightarrow{p}_\gamma)^2}. \tag{4}$$

For signal events, this must be the D_s^+ mass within experimental resolution. The kinematics of the event are not fully constrained with this procedure and one of the decay parameters must be chosen in an arbitrary way. In particular, approximating the energy of the B meson in the e^+e^- center-of-mass (CM) to the CM beam energy, the opening angle between the B momentum vector and the measured D^* momentum vector can be calculated from 4-momentum conservation in the $B^0 \to D_s^{*+} D^{*-}$ decay

$$\cos\vartheta_{BD^*} = \frac{m_B^2 - m_{D_s^{*+}}^2 - 2E_B E_{D^*}}{2|\vec{p}_B||\vec{p}_{D^*}|}. \tag{5}$$

The B four-momentum is therefore determined up to the azimuthal angle around the D^* direction. However, an arbitrary choice of the azimuthal angle ($\cos\phi_{BD^*} = 0$) introduces only a negligible spread (less than 1.5 MeV/c^2) in the missing mass distribution.

3.3 Event Selection

To reject events from continuum, we require the ratio of the second to the zeroth Fox-Wolfram moment (R_2) [9] to be less than 0.3.

Candidates for D^{*-} are reconstructed in the $\overline{D}^0\pi^-$ mode, using $\overline{D}^0$ decays to $K^+\pi^-$, $K^+\pi^-\pi^+\pi^-$ $K^+\pi^-\pi^0$, and $K_S^0\pi^+\pi^-$, here listed in order of decreasing purity. The χ^2 probabilities of both the D^0 and D^* vertex fits are required to be greater than 1%. The D^* momentum in the $\Upsilon(4S)$ frame must satisfy $1.4\,\mathrm{GeV}/c < p^{\mathrm{CMS}}(D^{*-}) < 1.8\,\mathrm{GeV}/c$. Moreover, we require the reconstructed mass of the D^0 particle to be within 2.5 standard deviations of the D^0 nominal mass, and the D^{*-} Q-value ($Q(D^{*-}) \equiv M(D^{*-}) - M(D^0) - M(\pi^-)$) to satisfy $Q_{\mathrm{lo}} < Q(D^{*-}) < Q_{\mathrm{hi}}$, where $Q_{\mathrm{lo}} = 4.00$ to 5.25 MeV/c^2 and $Q_{\mathrm{hi}} = 6.75$ to 8.00 MeV/c^2, depending on the D^0 decay mode. Kaon identification is required for the modes $K^+\pi^-\pi^0$ and $K^+\pi^-\pi^+\pi^-$. For the mode $K_S^0\pi^+\pi^-$, the invariant mass of the $\pi^+\pi^-$ from the K_S^0 decay is required to lie within $15\,\mathrm{MeV}/c^2$ of the K_S^0 nominal mass and its flight length must be greater than 3 mm. If more than one D^* candidate is found, for each D^0 decay mode we first select the candidates in which the pion from the decay $D^{*-} \to \overline{D}^0\pi^-$ has hits in the drift chamber. Among these, the one with the minimum value of $\chi^2 = [(Q(D^{*-}) - Q_{PDG}(D^{*-}))/\sigma_{Q(D^{*-})}]^2 + [(M(D^0) - M_{PDG}(D^0))/\sigma_{M(D^0)}]^2$ is retained. Finally, if candidates from different D^0 decay modes are present, we select the one with the best average purity.

The selection of photon candidates is based on the optimization of the statistical significance of the observed signal ($S/\sqrt{S+B}$, where S and B are the number of signal and background photons), using generic Monte Carlo events. We apply a π^0 veto on photon candidates, rejecting them if their invariant mass, calculated with any other photon candidate in the event, is between 115 and $155\,\mathrm{MeV}/c^2$. The following additional cuts are applied on the photon energy in the $\Upsilon(4S)$ CMS (E^{CMS}), the cluster lateral moment (LAT) [10] and Zernike moments [11] of order $\{2,0\}$ (Z_{20}) and $\{4,2\}$ (Z_{42}): $E^{\mathrm{CMS}} > 142\,\mathrm{MeV}$, $0.016 < LAT < 0.509$, $Z_{20} > 0.85$, $Z_{42} < 0.14$. If more than one photon is found in the event, we choose the one which maximizes the value of a likelihood ratio based on four photon variables (E, E^{CMS}, N_{cry}, LAT), where E is the photon energy in the laboratory frame and N_{cry} is the number of calorimeter crystals involved in the electromagnetic shower.

3.4 Selection efficiency and Monte Carlo validation

To effect the partial D_s^{*+} reconstruction in Monte Carlo events, the Monte Carlo sample is split in two parts. The signal reconstruction efficiency is determined from $B^0 \to D_s^{*+} D^{*-}$ events extracted from the first half of the sample by performing a minimum-χ^2 fit to the missing mass distribution. The signal peak, centered on the nominal D_s^+ mass, is well described by a Gaussian probability density function (p.d.f.), while the background, which is mainly due to random $D^*-\gamma$ combinations, is parametrized with the function $B(m) = a\left(1 - e^{-b(m - m_{\max})}\right)\left(\frac{m}{m_{\max}}\right)^c$, where $m \equiv M_{\text{miss}}$ and $m_{\max}$ is the end point of the missing mass distribution. We perform a single fit to all D^0 decay modes; the sum of the branching fraction-weighted efficiencies for the four reconstruction modes is computed from the number of signal events fitted in the range $|m - M(D_s^+)| < 41\,\text{MeV}/c^2$, and found to be $\langle \varepsilon \mathcal{B} \rangle = \sum_j (\varepsilon_j \cdot \mathcal{B}_j^{D^0}) = (7.14 \pm 0.16) \times 10^{-3}$.

We have validated the fitting technique and the method of extracting the signal on the other half of our Monte Carlo sample. The distribution of the missing mass of partially reconstructed B^0 candidates is shown in Fig. 2 for $B^0\overline{B}^0$ (including signal), B^+B^-, and continuum Monte Carlo events. The signal yield is extracted from a minimum-χ^2 fit of the missing mass distribution to a sum of the signal, described by a Gaussian function, and the background, described by the p.d.f. introduced above. From the signal yield, using Eq. 2, we obtain $\mathcal{B}(B^0 \to D_s^{*+} D^{*-}) = (1.43 \pm 0.04)\%$, which is consistent with the value of 1.41% used in the generation of the Monte Carlo.

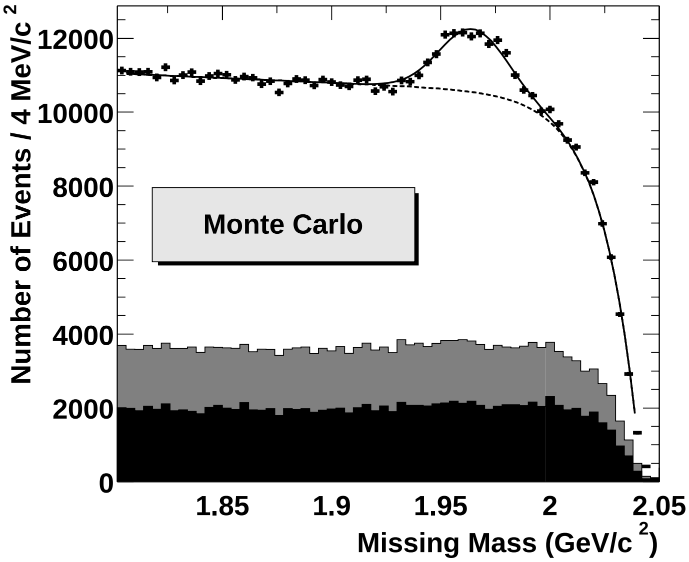

Figure 2: Monte Carlo simulation of missing mass distributions. The missing mass is defined by Eq. 4. Contributions of continuum (black), B^+B^- (grey) and $B^0\overline{B}^0$ (points) are added. The solid line shows the fit to the signal plus the sum of all backgrounds. The dashed line is the fit to the background component only.

3.5 Results on data

Figure 3 shows the missing mass distribution in our data sample. The same fitting procedure

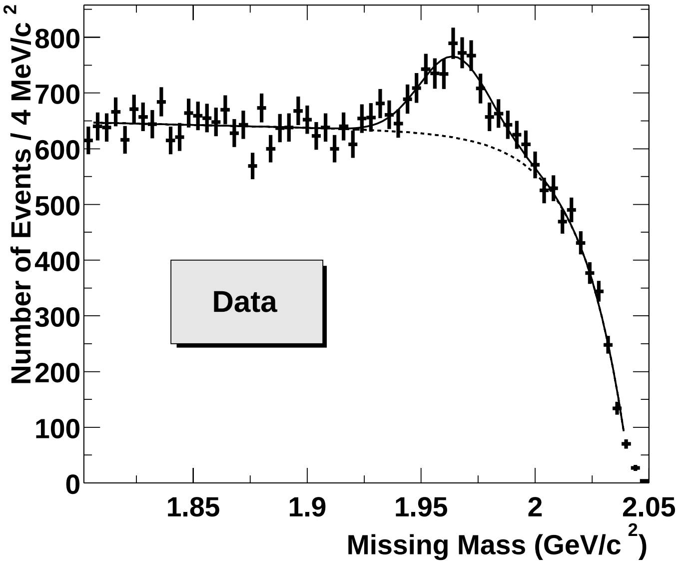

Figure 3: Missing mass distribution in the data sample. The solid line shows the fit to the signal plus background, the dashed line is the fit to the background component only.

applied in the previous section to the Monte Carlo sample is used to extract the number of signal events in the data sample. In the fit we let all parameters float except the mean and the stantard deviation of the Gaussian signal, which are fixed to their Monte Carlo values. The result of the fit to the missing mass distribution is shown in Fig. 3 as well. The signal yield in the data sample is $N_{D_s^+} = 1382 \pm 145$ events. The χ^2 of the fit is 53.3 for 54 degrees of freedom, corresponding to a probability of 50.1%.

From this yield we obtain $\mathcal{B}(B^0 \to D_s^{*+} D^{*-}) = (1.50 \pm 0.16)\%$, where the error is just statistical.

4 SYSTEMATIC STUDIES

The main sources of systematic uncertainties on the $B^0 \to D_s^{*+} D^{*-}$ branching fraction measurement are listed in Table 1. The Monte-Carlo-statistics uncertainty is due to the statistical error on the efficiency determination. The uncertainty on the background shape is evaluated by fitting the missing mass distribution using a different p.d.f. for the background[3], and assigning the relative signal yield difference as systematics. The systematic uncertainty due to tracking efficiency is evaluated applying a random inefficiency of 0.8% per track (1.6% for the soft pions from D^* decays). We assign as an uncertainty the difference between the yield obtained in this way and the one described in Sec. 3.4. The systematics associated to photon reconstruction efficiency and particle identification are evaluated in a similar way. We find a 7% difference in the overall selection efficiency between our samples with complete longitudinal or transverse polarization in the $B^0 \to D_s^{*+} D^{*-}$ decay. The uncertainty due to the dependence on polarization is computed taking into account the measured value [8] of the fraction of longitudinal polarization and its uncertainty

---

[3] The alternative background p.d.f. has the following functional form: $B(m) = \dfrac{a(m - m_{\max})^b}{c + (m - m_{\max})^b}$.

Table 1: Fractional systematic uncertainties (%) for the $B^0 \to D_s^{*+} D^{*-}$ branching fraction measurement.

Source	Error (%)
Monte Carlo statistics	2.3
Background shape	2.9
B counting	1.1
Tracking efficiency	2.4
Soft pion efficiency	1.6
Photon efficiency	4.2
Particle identification	1.5
Polarization uncertainty	0.8
D^0 branching fractions	3.2
$\mathcal{B}(D^{*-} \to \overline{D}^0 \pi^-)$	0.7
$\mathcal{B}(D_s^{*+} \to D_s^+ \gamma)$	2.7
Total systematic error	7.9

$\Gamma_L/\Gamma = (51.9 \pm 5.7)\%$. Finally, the uncertainties on D^0, D^{*-} and D_s^{*+} branching fractions [2] are propagated through the analysis.

5 PRELIMINARY BRANCHING FRACTION RESULTS

The $B^0 \to D_s^{*+} D^{*-}$ branching fraction is found to be:

$$\mathcal{B}(B^0 \to D_s^{*+} D^{*-}) = (1.50 \pm 0.16 \pm 0.12)\%, \tag{6}$$

where the first error is statistical, and the second systematic. The $D_s^+ \to \phi\pi^+$ branching fraction can be extracted by comparing this result with the measurement of the $B^0 \to D_s^{*+} D^{*-}$ decay with partial D^{*-} reconstruction [8]: $\mathcal{B}(B^0 \to D_s^{*+} D^{*-}) = (1.97 \pm 0.15_{\text{stat}} \pm 0.30_{\text{syst}} \pm 0.49_{D_s^+ \to \phi\pi^+})\%$. In this measurement the world average branching fraction $\mathcal{B}(D_s^+ \to \phi\pi^+) = (3.6 \pm 0.9)\%$ was used. From Eq. 6 we obtain therefore:

$$\mathcal{B}(D_s^+ \to \phi\pi^+) = (4.7 \pm 0.6 \pm 0.8)\%, \tag{7}$$

where the first error is statistical, the second systematic. The systematic uncertainty on this branching fraction is dominated by the measurement using partial D^{*-} reconstruction.

6 SUMMARY

A measurement of the $B^0 \to D_s^{*+} D^{*-}$ branching fraction is performed, using data corresponding to an integrated luminosity of $19.3\,\text{fb}^{-1}$, with a partial reconstruction technique of B meson:

$$\mathcal{B}(B^0 \to D_s^{*+} D^{*-}) = (1.50 \pm 0.16 \pm 0.12)\%.$$

This result is compatible with, and improves on the precision of previously published experimental results [2, 8], and should be compared with the most recent theoretical results based on the factorization assumption [6]: $\mathcal{B}(B^0 \to D_s^{*+} D^{*-})_{\text{theor}} = (2.4 \pm 0.7)\%$.

The $D_s^+ \to \phi\pi^+$ branching fraction result is

$$\mathcal{B}(D_s^+ \to \phi\pi^+) = (4.7 \pm 0.6 \pm 0.8)\%.$$

This new determination is compatible with the published CLEO result [1] and a preliminary measurement from Belle [12].

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 the A. P. Sloan Foundation, the Research Corporation, and the Alexander von Humboldt Foundation.

References

[1] The CLEO Collaboration, M. Artuso *et al.*, Phys. Lett. **B378**, 364 (1996).

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

[3] J. L. Rosner, Phys. Rev. **D42**, 3732 (1990).

[4] The CLEO Collaboration, G. Brandenburg *et al.*, Phys. Rev. Lett. **80**, 2762 (1998).

[5] The CLEO Collaboration, M. S. Alam *et al.*, Phys. Rev. **D50**, 43 (1994).

[6] Z. Luo and J. L. Rosner, Phys. Rev. **D64**, 094001 (2001).

[7] The *BABAR* Collaboration, B. Aubert *et al.*, Nucl. Instrum. Methods **A479**, 1 (2002).

[8] The *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. Lett. **D67**, 092003 (2003).

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

[10] P. F. Harrison and H. R. Quinn, *"The BABAR Physics Book"*, SLAC-R-504 (1998), p. 134.

[11] S. P. Prismall, M. S. Nixon and J. N. Carter, submitted to the *British Machine Vision Conference, Cardiff, United Kingdom, 2002*, 74-82 (2002).

[12] A. Limosani, submitted to the *XXXVIII Rencontres de Moriond on Electroweak Interactions and Unified Theories, Les Arcs, France, 2003*, `hep-ex/0305037` (2003).