PDF hosted at the Radboud Repository of the Radboud University Nijmegen

The following full text is a publisher's version.

For additional information about this publication click this link.
http://hdl.handle.net/2066/128817

Please be advised that this information was generated on 2017-07-27 and may be subject to change.
Measurement of the branching fractions for inclusive $B^-$ and $\bar{B}^0$ decays to flavor-tagged $D, D_s, \Lambda_c$
MEASUREMENT OF THE BRANCHING FRACTIONS FOR... PHYSICAL REVIEW D 70 091106

24University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom
25Università di Ferrara, Dipartimento di Fisica and INFN, I-44100 Ferrara, Italy
26Florida A&M University, Tallahassee, Florida 32307, USA
27Laboratori Nazionali di Frascati dell’INFN, I-00044 Frascati, Italy
28Università di Genova, Dipartimento di Fisica and INFN, I-16146 Genova, Italy
29Harvard University, Cambridge, Massachusetts 02138, USA
30Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, D-69120 Heidelberg, Germany
31Imperial College London, London, SW7 2AZ, United Kingdom
32University of Iowa, Iowa City, Iowa 52242, USA
33Iowa State University, Ames, Iowa 50011-3160, USA
34Università di Perugia, Dipartimento di Fisica and INFN, I-06100 Perugia, Italy
35Laboratoire de l’Accélérateur Linéaire, F-91898 Orsay, France
36Lawrence Livermore National Laboratory, Livermore, California 94550, USA
37University of Liverpool, Liverpool L69 7E, United Kingdom
38Queen Mary, University of London, E1 4NS, United Kingdom
39University of London, Royal Holloway and Bedford New College, Egham, Surrey TW20 0EX, United Kingdom
40University of Louisville, Louisville, Kentucky 40292, USA
41University of Manchester, Manchester M13 9PL, United Kingdom
42University of Maryland, College Park, Maryland 20742, USA
43University of Massachusetts, Amherst, Massachusetts 01003, USA
44Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA
45McGill University, Montréal, QC, Canada H3A 2T8
46Università di Milano, Dipartimento di Fisica and INFN, I-20133 Milano, Italy
47University of Mississippi, University Mississippi 38677, USA
48Laboratoire René J. A. Lévesque, Université de Montréal, Montréal, QC, Canada H3C 3J7
49Mount Holyoke College, South Hadley, Massachusetts 01075, USA
50Università di Napoli Federico II, Dipartimento di Scienze Fisiche and INFN, I-80126, Napoli, Italy
51NIKHEF, National Institute for Nuclear Physics and High Energy Physics, NL-1009 DB Amsterdam, The Netherlands
52University of Notre Dame, Notre Dame, Indiana 46556, USA
53The Ohio State University, Columbus, Ohio 43210, USA
54University of Oregon, Eugene, Oregon 97403, USA
55Università di Padova, Dipartimento di Fisica and INFN, I-35131 Padova, Italy
56Laboratoire de Physique Nucléaire et de Hautes Energies, Universités Paris VI et VII, F-75252 Paris, France
57Università di Pavia, Dipartimento di Elettronica and INFN, I-27100 Pavia, Italy
58University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA
59Università di Pisa, Dipartimento di Fisica, Scuola Normale Superiore and INFN, I-56127 Pisa, Italy
60Prairie View A&M University, Prairie View, Texas 77446, USA
61Princeton University, Princeton, New Jersey 08544, USA
62Università di Roma La Sapienza, Dipartimento di Fisica and INFN, I-00185 Roma, Italy
63Universität Rostock, D-18051 Rostock, Germany
64Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, United Kingdom
65DSM/Dapnia, CEA/Saclay, F-91191 Gif-sur-Yvette, France
66University of South Carolina, Columbia, South Carolina 29208, USA
67Stanford Linear Accelerator Center, Stanford, California 94309, USA
68Stanford University, Stanford, California 94305-4060, USA
69State University of New York, Albany, New York 12222, USA
70University of Tennessee, Knoxville, Tennessee 37996, USA
71University of Texas at Austin, Austin, Texas 78712, USA
72University of Texas at Dallas, Richardson, Texas 75083, USA
73Università di Torino, Dipartimento di Fisica Sperimentale and INFN, I-10125 Torino, Italy
74Università di Trieste, Dipartimento di Fisica and INFN, I-34127 Trieste, Italy
75Vanderbilt University, Nashville, Tennessee 37235, USA
76University of Victoria, Victoria, BC, Canada V8W 3P6
77University of Wisconsin, Madison, Wisconsin 53706, USA

8Now at Department of Physics, University of Warwick, Coventry, United Kingdom.
†Also with Università della Basilicata, Potenza, Italy.
‡Also with IFIC, Instituto de Física Corpuscular, CSIC-Universidad de Valencia, Valencia, Spain.
§Deceased.
We report on the inclusive branching fractions of $B^-$ and of $\bar{B}^0$ mesons decaying to $D^0X$, $\bar{D}^0X$, $D^+X$, $D_s^+X$, $\Lambda^+_cX$, $\bar{\Lambda}^-_cX$, based on a sample of $88.9 \times 10^6$ $B\bar{B}$ events recorded with the BABAR detector at the $\Upsilon(4S)$ resonance. Events are selected by completely reconstructing one $B$ and searching for a reconstructed charmed particle in the rest of the event. We measure the number of charmed and of anticharm particles per $B$ decay and derive the total charm yield per $B^-$ decay $n_c^-=1.313\pm0.037\pm0.062^{+0.032}_{-0.038}$ and per $\bar{B}^0$ decay $n_c^0=1.276\pm0.062\pm0.058^{+0.066}_{-0.046}$, where the first uncertainty is statistical, the second is systematic, and the third reflects the charm branching-fraction uncertainties.

The dominant process for the decay of a $b$ quark is $b \rightarrow cW^+$ [1], resulting in a (flavor) correlated $c$ quark and a virtual $W$. In the decay of the $W$, the production of a $\bar{u}d$ or a $c\bar{s}$ pair are both Cabibbo-allowed and should be equal, the latter being suppressed only by a phase-space factor. The first process dominates hadronic $b$ decays, while the second can be easily distinguished as it would produce a (flavor) anticorrelated $\bar{c}$ quark. Experimentally, correlated and anticorrelated charm production can be investigated through the measurement of the inclusive $B$-decay rates to flavor-tagged charmed mesons or baryons. Current measurements [2–4] of these rates have statistically limited precision and do not distinguish among the different $B$ parent states.

Most of the charged and neutral $D$ mesons produced in $\bar{B}$ decays come from correlated production $\bar{B} \rightarrow DX$. However, a significant number of $B \rightarrow DX$ decays are expected through $b \rightarrow c\bar{s}\bar{s}$ transitions, such as $\bar{B} \rightarrow D_s^{(*)}\bar{D}^{(*)}\bar{K}^{(*)}(n\pi)$. Although the branching fractions of the three-body decays $\bar{B} \rightarrow D^{(*)}\bar{D}^{(*)}\bar{K}$ have been measured [5,6], it is not clear whether they saturate $\bar{B} \rightarrow DX$ transitions. It is therefore important to improve the precision on the branching fraction $\mathcal{B}(\bar{B} \rightarrow \bar{D}X)$.

By contrast, the anticorrelated $D_s^+$ production $B \rightarrow D_s^+D(n\pi)$ is expected to dominate $\bar{B}$ decays to $D_s$ mesons, since correlated production needs an extra $s\bar{s}$ pair created from the vacuum to give $\bar{B} \rightarrow D_s^+\bar{K}^-(n\pi)$. There is no prior published measurement of $\mathcal{B}(\bar{B} \rightarrow D_s^+X)$. All strangeless charmed baryons decay to $\Lambda_c$. Correlated $\Lambda_c$ are produced in decays such as $B^- \rightarrow \Lambda_c^+\bar{p}\pi^- (\pi)$, while anticorrelated $\bar{\Lambda}_c$ should originate from $B^- \rightarrow \Xi_c\bar{\Lambda}_c^- (\pi)$. Another possibility is $B^- \rightarrow \Lambda_c^+\bar{\Lambda}_c^-\bar{K}^-$, the baryonic analogue of the $D\bar{D}K$ decay. The rates for $\Xi_c$ production in $B$ decays [7] are unknown, but there is no absolute measurement of $\Xi_c$ decay branching fractions.

This analysis uses $\Upsilon(4S) \rightarrow B\bar{B}$ events in which either a $B^+$ or a $B^0$ meson (hereafter denoted $B_{\text{reco}}$) decays into a hadronic final state and is fully reconstructed. We then reconstruct $D$, $D_s$, and $\Lambda_c$ from the recoiling $B^-$ ($\bar{B}^0$) meson and compare the flavor of the charm hadron with that of the $B_{\text{reco}}$, thus allowing separate measurements of the $B^- (\bar{B}^0) \rightarrow D^0X$, $D^+X$, $D_s^+X$, $\Lambda^+_cX$ and $B^- (\bar{B}^0) \rightarrow \bar{D}^0X$, $D^-X$, $D_s^-X$, $\bar{\Lambda}^-_cX$ branching fractions. We extract $\mathcal{B}(B^- \rightarrow \Lambda_c^+\bar{\Lambda}_c^-\bar{K}^-)$ from the missing-mass spectra of the $\Lambda_c^+\bar{K}^- c\bar{u}d$ and $\bar{\Lambda}_c^-\bar{K}^- c\bar{u}d$ systems recoiling against the $B_{\text{reco}}$.

We can then evaluate indirectly $\mathcal{B}(B^- \rightarrow \Xi_cX) = \mathcal{B}(B^- \rightarrow \bar{\Xi}_cX) - \mathcal{B}(B^- \rightarrow \Lambda_c^+\bar{\Lambda}_c^-\bar{K}^-)$ and compute the average number of charm (anticharm) particles per $B^-$ decay, $N_c^- (N_c^+)$:

$$N_c^- = \sum_{X_c} \mathcal{B}(B^- \rightarrow X_cX),$$

$$N_c^+ = \sum_{X_c} \mathcal{B}(B^- \rightarrow \bar{X}_c\bar{X}_c),$$

where the sum is performed over $X_c = D^+, D_s^+, \Lambda_c^+, \Xi_c, (c\bar{s})$ or $\bar{X}_c = D^-, D_s^-, \bar{\Lambda}_c^-, (c\bar{s})$, and $(c\bar{s})$ refers to all charmonium states collectively. We neglect $\Xi_c$ production, as it requires both a $c\bar{s}$ and an $s\bar{s}$ pair in the decay to give $\Xi_c\bar{\Xi}_c$. We can sum $N_c^-$ and $N_c^+$ to obtain the average number of charm plus anticharm quarks per $B^-$ decay, $n_c^- = N_c^- + N_c^-$ (and similarly for $\bar{B}^0$ decays). In addition to the theoretical interest [8–11], the fact that anticorrelated charmed particles are a background for many studies also motivates a more precise measurement of their production rates in $B$ decays.

The measurements presented here are based on a sample of $88.9 \times 10^6$ $B\bar{B}$ pairs (81.9 fb$^{-1}$) recorded at the $\Upsilon(4S)$ resonance with the BABAR detector at the PEP-II asymmetric-energy $B$-meson factory at the Stanford Linear Accelerator Center (SLAC). The BABAR detector is described in detail elsewhere [12]. Charged-particle trajectories are measured by a 5-layer double-sided silicon vertex tracker and a 40-layer drift chamber, both operating in a 1.5-T solenoidal magnetic field. Charged-particle identification is provided by the average energy loss $(dE/dx)$ in the tracking devices and by an internally reflecting ring-imaging Cherenkov detector. Photons are detected by a CsI(Tl) electromagnetic calorimeter. We use Monte Carlo simulations of the BABAR detector based on GEANT4 [13] to optimize selection criteria and determine selection efficiencies.

We reconstruct $B^+$ and $B^0$ decays ($B_{\text{reco}}$) in the modes $B^+ \rightarrow \bar{D}^{(*)}\pi^+$, $\bar{D}^{(*)}\rho^+$, $\bar{D}^{(*)}\omega$ and $B^0 \rightarrow D^{(*)}\pi^+$.
of the background control region (hatched), the dotted vertical line shows the upper limit of the background control region (hatched), the dotted vertical line the lower limit of the signal region. The crossed area shows the background under the B signal. The solid curve is the sum of the fitted signal and background; the dashed curve is the background component only.

$D^{(-)}\rho^+$, $D^{(-)}\pi^+$, $D^{*-}\pi^+$, $D^{*+}\pi^-$, $K^+\pi^-$, $K^{*-}\pi^0$, $K^+\pi^+\pi^0$, and $K^+\pi^-\pi^+$ ($K^+\pi^-\pi^+$) decay channels, while $D^+$ are reconstructed in the $K^+\pi^+$ and $K^+\pi^-$ modes. $D^0$ candidates are reconstructed in the $D^{(*)}\rightarrow D^{0}\pi^\pm$ and $D^{(*)}\rightarrow D^{0}\pi^\mp$, $D^{(*)}\rightarrow D^{0}\gamma$ decay modes. The first kinematic variable used to identify fully reconstructed $B$ decays is the beam-energy substituted mass, $m_{ES} = \sqrt{(s/2 + p_t^2)/E^2_{B} - p_B^2}$, where $p_B$ is the $B_{reco}$ momentum and $(E, p_t)$ is the four-momentum of the initial $e^+e^-$ system, both measured in the laboratory frame. The invariant mass of the initial $e^+e^-$ system is $s/2$. The second variable is $\Delta E = E_{B} - s/2$, where $E_{B}$ is the $B_{reco}$ candidate energy in the center-of-mass frame. We require $|\Delta E| < n\sigma_{\Delta E}$ with $n = 2$ or 3, depending on the decay mode, and using the measured resolution $\sigma_{\Delta E}$ for each decay mode.

In the $m_{ES}$ spectra (Fig. 1), we define a signal region with $5.274 < m_{ES} < 5.290$ GeV/$c^2$ and a background control region with $5.220 < m_{ES} < 5.260$ GeV/$c^2$. For each of the $B$-decay modes, the combinatorial background in the signal region is derived from a fit to the $m_{ES}$ distribution that uses an empirical phase-space threshold function [14] for the background, together with a signal function [15] peaked at the $B$ meson mass. The numbers of reconstructed $B^+$ and $B^0$ candidates, $N_{B^+} = 85840 \pm 1910$ (syst) and $N_{B^0} = 48322 \pm 590$ (syst), are then obtained by subtracting this background from the total number of events found in the signal region. These measured $B$ meson yields provide the normalization of all branching-fraction measurements reported below. The systematic uncertainties quoted above are computed by varying the boundaries of the signal and background regions and by comparing the shapes of the threshold function [14] in the data and in the simulation.

The contamination of $B^0$ events in the $B^+$ signal induces a background which peaks near the $B$ mass. From the Monte Carlo simulation, the fraction of $B^0$ events in the reconstructed $B^+$ signal sample is found to be $c_0 = 0.034$ and the fraction of $B^+$ events in the reconstructed $B^0$ signal sample to be $c_+ = 0.019$. A 100% systematic uncertainty is conservatively assigned to these numbers but they will have a small effect on the final results.

We now turn to the analysis of inclusive $D$, $D_s$, and $\Lambda_c$ production in the decays of the $B\bar{B}$s that recoil against the reconstructed $B$. Charmed particles $X_c$ (correlated production) are distinguished from anticharmed particles $X_c$ (anticorrelated production). They are reconstructed from charged tracks that do not belong to the $B_{reco}$. The decay modes considered are listed in Table I.

For charged $B$ decays, Fig. 2 shows the $D$, $D_s$, and $\Lambda_c$ mass spectra of correlated and anticorrelated candidates

![Diagram](https://example.com/diagram.png)

**TABLE I.** Charmed-particle signal yields and $B$ branching fractions per decay mode. The first uncertainty is statistical, the second is systematic (but does not include the charm branching-fraction uncertainties).

<table>
<thead>
<tr>
<th>$X_c$ decay mode</th>
<th>$B^- \rightarrow X_cX$ Yield</th>
<th>$B^- \rightarrow X_cX$ $\mathcal{B}$ (%)</th>
<th>$B^0 \rightarrow X_cX$ Yield</th>
<th>$B^0 \rightarrow X_cX$ $\mathcal{B}$ (%)</th>
<th>$\bar{B}^0 \rightarrow X_cX$ Yield</th>
<th>$\bar{B}^0 \rightarrow X_cX$ $\mathcal{B}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0 [16] \rightarrow K^-\pi^+$</td>
<td>$1273 \pm 42$</td>
<td>$79.2 \pm 2.6 \pm 3.9$</td>
<td>$160 \pm 16$</td>
<td>$9.3 \pm 1.0 \pm 0.5$</td>
<td>$397 \pm 24$</td>
<td>$50.3 \pm 3.4 \pm 2.4$</td>
</tr>
<tr>
<td>$D^+ \rightarrow K^-\pi^+$</td>
<td>$998 \pm 65$</td>
<td>$80.6 \pm 5.3 \pm 7.5$</td>
<td>$173 \pm 30$</td>
<td>$13.4 \pm 2.4 \pm 1.3$</td>
<td>$332 \pm 36$</td>
<td>$56.2 \pm 6.8 \pm 5.4$</td>
</tr>
<tr>
<td>$D_s^+ \rightarrow \phi \pi^+$</td>
<td>$262 \pm 29$</td>
<td>$9.8 \pm 1.2 \pm 1.2$</td>
<td>$98 \pm 20$</td>
<td>$3.8 \pm 0.9 \pm 0.4$</td>
<td>$452 \pm 31$</td>
<td>$39.7 \pm 3.0 \pm 2.8$</td>
</tr>
<tr>
<td>$\Lambda_c^+ \rightarrow pK^-\pi^+$</td>
<td>$11 \pm 5$</td>
<td>$2.2 \pm 1.1 \pm 0.3$</td>
<td>$82 \pm 11$</td>
<td>$16.5 \pm 2.6 \pm 1.7$</td>
<td>$24 \pm 6$</td>
<td>$8.3 \pm 2.8 \pm 0.8$</td>
</tr>
<tr>
<td>$\Lambda_c^+ \rightarrow K^-p\pi^+$</td>
<td>$0 \pm 3$</td>
<td>$0.0 \pm 1.1 \pm 0.2$</td>
<td>$55 \pm 11$</td>
<td>$18.0 \pm 3.5 \pm 1.7$</td>
<td>$3 \pm 4$</td>
<td>$0.0 \pm 2.8 \pm 0.1$</td>
</tr>
<tr>
<td>$\Lambda_c^+ \rightarrow pK^-\pi^+$</td>
<td>$0 \pm 3$</td>
<td>$0.0 \pm 0.9 \pm 0.2$</td>
<td>$31 \pm 9$</td>
<td>$9.2 \pm 2.7 \pm 0.8$</td>
<td>$12 \pm 5$</td>
<td>$5.0 \pm 3.4 \pm 0.4$</td>
</tr>
</tbody>
</table>
recoiling against $B^*$'s reconstructed in the $m_{ES}$ signal region, for some selected decay modes. These spectra are fitted with the sum of a Gaussian signal and a linear background (including a satellite peak for some channels [17]). The shaded areas correspond to well reconstructed $D, D_s, \text{or } \Lambda_c$ in the $B^+$ combinatorial background. They are obtained from data in the $m_{ES}$ background control region, normalized to the number of combinatorial background events expected under the $B_{\text{rec}}$ peak. The background-subtracted reconstructed signal yields are listed in Table I. The reconstruction efficiencies for each charmed (anticharmed) final state $X_c \rightarrow f$ $(\bar{X}_c \rightarrow \bar{f})$ are computed from the simulation as a function of the charmed-particle momentum in the $B^-$ center-of-mass frame and are applied event by event to obtain the efficiency-corrected charm signal yields $N(X_c \rightarrow f) \ [N(\bar{X}_c \rightarrow \bar{f})]$. The final branching fractions are computed from these yields, the number of $B_{\text{rec}}$, and the intermediate branching fractions $\mathcal{B}(X_c \rightarrow f)$ taken from Ref. [18]. They are given by

$$\mathcal{B}(B^- \rightarrow X_c X) = \frac{N(X_c \rightarrow f)}{N_{B^-} \times \mathcal{B}(X_c \rightarrow f)} - c_0 \mathcal{B}_0. \quad (3)$$

Here the raw branching fraction for $B^- \rightarrow X_c X$ is modified by a small corrective term $c_0 \mathcal{B}_0$ that accounts for the $B^0$ contamination in the reconstructed $B^+$ sample. The factor $\mathcal{B}_0$ depends on the measured $B^0 \rightarrow X_c X$ and $B^0 \rightarrow X_c X$ branching fractions and on the $B^0 - B^+$ mixing parameter $\chi_d$ [18]. It ranges from less than 3% for $\Lambda_c$ to as much as 50% for correlated $D^0$ and $D_s^+$. Doubly Cabibbo-suppressed $D^0$ decays are also taken into account. The branching fractions and their errors are given in Table I. The statistical and systematic uncertainties are computed separately for each channel. For example, the 3.9% absolute systematic uncertainty on $\mathcal{B}(B^- \rightarrow D^0 (K^- \pi^+) X)$ reflects the quadratic sum of 1.8% attributed to $N_{B^+}$, 1.3% to the error on the rate of true $D$s in the $B$ combinatorial background, 0.8% to the Monte Carlo statistics, 1.2% to the track-finding efficiency, 2.5% to the particle identification, 1.2% to $c_0$, and 0.1% to $\mathcal{B}_0$. We combine the results from the different $D^0$ and $D_s$ decay modes to extract the final branching fractions listed in Table II.

To extract $N_c$ from these numbers, we need to evaluate the contribution of $B^- \rightarrow \Lambda_c^+ \bar{X}_c K^-$. Combining the four-momenta of the recoiling $B^-$, of a $K^-$, and of the reconstructed $\Lambda_c^+$ or $\bar{X}_c$ candidate, we compute the missing mass: the absence of signal at the $\Lambda_c$ mass excludes a significant contribution of this process. We therefore take $\mathcal{B}(B^- \rightarrow \Xi_c X) = \mathcal{B}(B^- \rightarrow \Xi_c X)$ in the computation of $N_c$. Using Eqs. (1) and (2) and taking $\mathcal{B}(B^- \rightarrow (c\bar{c})X) = (2.3 \pm 0.3)\%$ [19,20], one obtains:

$$N_c^- = 0.983 \pm 0.030 \pm 0.046^{+0.028}_{-0.023},$$

$$N_c^z = 0.330 \pm 0.022 \pm 0.020^{+0.051}_{-0.031},$$

$$n_c = 1.313 \pm 0.037 \pm 0.063^{+0.063}_{-0.042}.$$

**TABLE II.** Combined $B^-$ branching fractions. The first uncertainty is statistical, the second is systematic, and the third reflects charm branching-fraction uncertainties [18].

<table>
<thead>
<tr>
<th></th>
<th>Correlated</th>
<th>Anticorrelated</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_c$</td>
<td>$\mathcal{B}(B^- \rightarrow X_c X)(%)$</td>
<td>$\mathcal{B}(B^- \rightarrow X_c X)(%)$</td>
</tr>
<tr>
<td>$D^0$</td>
<td>79.3 $\pm$ 2.5 $\pm$ 4.0$^{+0.29}_{-0.19}$</td>
<td>9.8 $\pm$ 0.9 $\pm$ 0.5$^{+0.3}_{-0.3}$</td>
</tr>
<tr>
<td>$D^+$</td>
<td>9.8 $\pm$ 1.2 $\pm$ 1.2$^{+0.8}_{-0.7}$</td>
<td>3.8 $\pm$ 0.9 $\pm$ 0.4$^{+0.3}_{-0.3}$</td>
</tr>
<tr>
<td>$D_s^+$</td>
<td>0.5 $\pm$ 0.6 $\pm$ 0.2$^{+0.2}_{-0.1}$</td>
<td>14.3 $\pm$ 1.6 $\pm$ 1.5$^{+0.9}_{-0.3}$</td>
</tr>
<tr>
<td>$&lt;2.2$ at 90% C.L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Lambda_c^+$</td>
<td>3.5 $\pm$ 0.8 $\pm$ 0.3$^{+1.3}_{-0.8}$</td>
<td>2.9 $\pm$ 0.8 $\pm$ 0.3$^{+1.1}_{-0.6}$</td>
</tr>
</tbody>
</table>
TABLE III. Combined \( \overline{B} \) branching fractions. The first uncertainty is statistical, the second is systematic, and the third reflects charm branching-fraction uncertainties [18].

<table>
<thead>
<tr>
<th>Correlated ( X_c )</th>
<th>( \mathcal{B}(\overline{B} \rightarrow X_c \overline{X}) ) (%)</th>
<th>Anticorrelated ( X_c )</th>
<th>( \mathcal{B}(\overline{B} \rightarrow X_c \overline{X}) ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D^0 )</td>
<td>51.1 ± 3.1 ± 2.5^{+1.3}_{-1.3}</td>
<td>6.3 ± 1.9 ± 0.5^{+0.2}_{-0.2}</td>
<td></td>
</tr>
<tr>
<td>( D^+ )</td>
<td>39.7 ± 3.0 ± 2.8^{+0.8}_{-2.5}</td>
<td>2.3 ± 1.8 ± 0.3^{+0.2}_{-0.2}</td>
<td></td>
</tr>
<tr>
<td>( D_s^+ )</td>
<td>3.9 ± 1.7 ± 0.4^{+1.3}_{-0.8}</td>
<td>10.9 ± 2.1 ± 0.8^{+3.8}_{-2.3}</td>
<td></td>
</tr>
<tr>
<td>( \Lambda_c^+ )</td>
<td>4.9 ± 1.7 ± 0.4^{+1.8}_{-1.0}</td>
<td>2.0 ± 1.2 ± 0.2^{+0.7}_{-0.4}</td>
<td></td>
</tr>
</tbody>
</table>

The reconstruction of \( D, D_s \), and \( \Lambda_c \) from \( \overline{B} \) decays is performed in the same way as in the \( B^- \) analysis. The corresponding yields are listed in Table I. We then compute for each decay channel \( X_c \rightarrow f \) the efficiency-corrected signal yields \( N(X_c ightarrow f) = N(X_c \rightarrow \overline{f}) \) and define the raw branching fractions \( \mathcal{B}_c \) and \( \overline{\mathcal{B}_c} \) as

\[
\mathcal{B}_c = N(X_c \rightarrow f)/[N_{B^0} \times \mathcal{B}(X_c \rightarrow f)],
\]

\[
\overline{\mathcal{B}_c} = N(X_c \rightarrow \overline{f})/[N_{B^0} \times \mathcal{B}(X_c \rightarrow f)].
\]

After correcting these numbers for \( B^0 \overline{B} \) mixing, we obtain the final branching fraction for \( \overline{B} \rightarrow X_c X \):

\[
\mathcal{B}(\overline{B} \rightarrow X_c X) = \frac{\mathcal{B}_c - \chi_d (\mathcal{B}_c + \overline{\mathcal{B}_c}) - c + \overline{\mathcal{B}_c}}{1 - 2 \chi_d},
\]

where \( \chi_d = 0.181 ± 0.004 \) is the \( B^0 - \overline{B} \) mixing parameter [18]. The correcting factor \( \chi_d \) accounts for \( B^+ \) contamination in the \( B^0 \) sample and depends on \( \mathcal{B}(B^- \rightarrow X_c X) \) and \( \mathcal{B}(B^+ \rightarrow X_c X) \). The results are given in Table I. Combining the different \( D^0 \) or \( D_s \) modes, we obtain the final branching fractions listed in Table III.

To compute \( N_c \), we neglect \( \overline{B} \rightarrow \Lambda_c^+, \overline{\Lambda}_c^+, K^0 \) production and assume that \( \mathcal{B}(\overline{B} \rightarrow \Xi_c^+ \overline{X}) = \mathcal{B}(\overline{B} \rightarrow \overline{X}_c X) \). Substituting \( \overline{B} \) for \( B^+ \) in Eqs. (1) and (2) and taking \( \mathcal{B}[B^0 \rightarrow (c \overline{c})X] = (2.3 ± 0.3)\% \) [19,20], we obtain:

\[
N_c^0 = 1.039 ± 0.051 ± 0.049^{+0.039}_{-0.031},
\]

\[
N_c^0 = 0.237 ± 0.036 ± 0.012^{+0.039}_{-0.024},
\]

\[
n_c^0 = 1.276 ± 0.062 ± 0.058^{+0.066}_{-0.046}.
\]

We also compute the fraction of anticorrelated charm production in \( B^- \) decays, \( w(X_c) = \mathcal{B}(B^- \rightarrow X_c \overline{X})/[\mathcal{B}(B^- \rightarrow X_c X) + \mathcal{B}(\overline{B} \rightarrow X_c \overline{X})] \). Here, many systematic uncertainties cancel (tracking, \( K \) identification, \( B \) branching fractions, \( B \) counting). The results are given in Table IV. We obtain an upper limit on the correlated \( D_s^+ \) fraction in \( B^- \) decays:

\[
\mathcal{B}(B^- \rightarrow D_s^+ X)/\mathcal{B}(B^- \rightarrow D_s^+ X) < 0.126 \text{ at 90\% C.L.}
\]

In conclusion, we have measured for the first time the branching fractions for inclusive decays of \( B \) mesons to flavor-tagged \( D, D_s, \) and \( \Lambda_c \), separately for \( B^- \) and \( \overline{B} \). We observe significant production of anticorrelated \( D^0 \) and \( D^+ \) mesons in \( B \) decays (Table IV), with the branching fractions detailed in Tables II and III. The correlated \( D_s \) production in \( B^- \) decays is measured to be small.

As expected, the sum of all correlated charm branching fractions \( N_c \) is compatible with 1, for charged as well as for neutral \( B \)’s. The numbers of charmed particles per \( B^- \) decay (\( n_c = 1.313 ± 0.037 ± 0.062^{+0.046}_{-0.042} \)) and per \( \overline{B} \) decay (\( n_c^0 = 1.276 ± 0.062 ± 0.058^{+0.086}_{-0.046} \)) are consistent with previous measurements [2,19,21] and with theoretical expectations [8–10].

We are grateful for the excellent luminosity and machine conditions provided by our PEP-II colleagues and for the substantial dedicated effort from the computing organizations that support BABAR. The collaborating institutions wish to thank SLAC for its support and kind hospitality. This work is supported by DOE and NSF (USA), NSERC (Canada), IHEP (China), CEA and CNRS-IN2P3 (France), BMBF and DFG (Germany), INFN (Italy), FOM (The Netherlands), NFR (Norway), MIST (Russia), and PPARC (United Kingdom). Individuals have received support from CONACyT (Mexico), A.P. Sloan Foundation, Research Corporation, and Alexander von Humboldt Foundation.

[1] Throughout this paper, the named reaction refers also to its complex conjugate.


[16] Only $D^0 \to K^- \pi^+$ and $D^0 \to K^- \pi^+ \pi^+ \pi^-$ are used for the charm counting because $D^0 \to K^- \pi^+ \pi^0$ has a lower significance and $D^0 \to K_S^0 \pi^+ \pi^-$ is not self-tagging (one cannot distinguish between $D^0$ and $D^\ast_0$).

[17] Satellite contributions include a reflection from $D^0 \to K^- K^+$ in the $D^0 \to K^- \pi^+$ mass spectrum and a signal at the $D^+$ mass (from $D^+ \to \phi \pi^+$ decays) in the $D^+_c \to \phi \pi^+$ mass spectrum.


