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Measurement of the relative branching fractions of $\overline{B} \to D/D^*/D^{**}l^-\bar{\nu}_l$ decays in events with a fully reconstructed B meson

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We determine the relative branching fractions of semileptonic B decays to charmed final states. The measurement is performed on the recoil from a fully reconstructed B meson in a sample of 362×10^6 $B\overline{B}$ pairs collected at the $\Upsilon(4S)$ resonance with the *BABAR* detector. A simultaneous fit to a set of discriminating variables is performed on a sample of $\overline{B} \to DX\ell^- \bar{\nu}_\ell$ decays to determine the contributions from the different channels. We measure $\Gamma(B^- \to D\ell^-\bar{\nu}_\ell)/\Gamma(B^- \to DX\ell^-\bar{\nu}_\ell) = 0.227 \pm 0.014 \pm 0.016$, $\Gamma(B^- \to D^*\ell^-\bar{\nu}_\ell)/\Gamma(B^- \to DX\ell^-\bar{\nu}_\ell) = 0.582 \pm 0.018 \pm 0.030$, and $\Gamma(B^- \to D^{**}\ell^-\bar{\nu}_\ell)/\Gamma(B^- \to DX\ell^-\bar{\nu}_\ell) = 0.191 \pm 0.013 \pm 0.019$ for the charged B sample, and $\Gamma(\overline{B}^0 \to D\ell^-\bar{\nu}_\ell)/\Gamma(\overline{B}^0 \to DX\ell^-\bar{\nu}_\ell) = 0.215 \pm 0.016 \pm 0.013$, $\Gamma(\overline{B}^0 \to D^*\ell^-\bar{\nu}_\ell)/\Gamma(\overline{B}^0 \to DX\ell^-\bar{\nu}_\ell) = 0.537 \pm 0.031 \pm 0.036$, and $\Gamma(\overline{B}^0 \to D^{**}\ell^-\bar{\nu}_\ell)/\Gamma(\overline{B}^0 \to DX\ell^-\bar{\nu}_\ell) = 0.248 \pm 0.032 \pm 0.030$ for the neutral B sample, where uncertainties are statistical and systematic, respectively.

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The determination of exclusive branching fractions of $\overline{B} \to X_c\ell^-\bar{\nu}_\ell$ decays is an essential part of the B-factory program to understand the dynamics of b-quark semileptonic decays and to determine the relevant Cabibbo-Kobayashi-Maskawa matrix elements [1]. The mass of the hadronic system X_c, recoiling against the leptonic pair, is a crucial observable both in the extraction of $|V_{cb}|$, in exclusive semileptonic decays, and in isolating $\overline{B} \to X_u\ell^-\bar{\nu}_\ell$ decays to determine $|V_{ub}|$. It is also needed for the measurement of heavy quark masses and other nonperturbative operator product expansion (OPE) parameters from the distribution of spectral moments. This mass spectrum can be better understood by a study of the yields of the different D meson states in semileptonic decays. Current measurements [2–5] show a possible discrepancy between the sum of exclusive rates and the inclusive semileptonic decay width [6]. While $\overline{B} \to D\ell^-\bar{\nu}_\ell$ and $\overline{B} \to D^*\ell^-\bar{\nu}_\ell$ decays account for about 70% of this total, the contribution of other states, including resonant and nonresonant $D^{(*)}\pi$ decays, is not yet well measured and is a possible explanation of this discrepancy.

In this paper, we present a novel technique to extract the exclusive relative branching fractions for $\overline{B} \to D\ell^-\bar{\nu}_\ell$, $\overline{B} \to D^*\ell^-\bar{\nu}_\ell$, and $\overline{B} \to D^{**}\ell^-\bar{\nu}_\ell$, with $\ell = e$, μ [7], from an inclusive sample of $\overline{B} \to DX\ell^-\bar{\nu}_\ell$ events, where X can be either nothing or any particle(s) from a semileptonic B decay into a higher mass charm state, or a nonresonant state. We denote by D^{**} any hadronic final state, containing a charm meson, with total mass above that of the D^* state, thereby including both D_J excited mesons and $D^{(*)} + n\pi$ nonresonant states. This technique ensures sensitivity to all hadronic final states containing a D meson, thus helping us to understand the role of excited D states in saturating the inclusive semileptonic rate.

This analysis is based on data collected with the *BABAR* detector [8] at the PEP-II asymmetric-energy e^+e^- storage rings. The data correspond to an integrated luminosity of 339.4 fb^{-1} recorded at the $\Upsilon(4S)$ resonance, or, equivalently, about 362×10^6 $B\overline{B}$ pairs. A detailed GEANT4-based Monte Carlo (MC) simulation [9] of $B\bar{B}$ and continuum $e^+e^- \to f\bar{f}(f = u, d, s, c, \tau)$ events has been used to study the detector response and its acceptance. The simulation models $\overline{B} \to D^*\ell^-\bar{\nu}_\ell$ decay using HQET-based calculations as in [10], $\overline{B} \to D\ell^-\bar{\nu}_\ell$ and $\overline{B} \to D^{**}(\to D^{(*)}\pi)\ell^-\bar{\nu}_\ell$ decays using the ISGW2 model [11], and $\overline{B} \to D^{(*)}\pi\ell^-\bar{\nu}_\ell$ decays using the Goity-Roberts model [12].

We select signal B-meson decays in events containing a fully reconstructed B meson ($B_{\rm tag}$), which allows us to constrain the kinematics, to reduce the combinatorial background, and to determine the charge and flavor of the signal B. We choose a set of three largely uncorrelated variables to discriminate between the different semileptonic decay modes in the reconstructed $\overline{B} \to DX\ell^-\bar{\nu}_\ell$ sample. These are: (i) the lepton momentum in the center-of-mass (CM) frame, $|\vec{p}_\ell|$; (ii) the missing mass squared reconstructed with respect to the $D\ell$ system, which corresponds to the mass of the $X\bar{\nu}_\ell$ system, $m^2_{{\rm miss},D} = (p_\Upsilon - p_{B_{\rm tag}} - p_D - p_\ell)^2$, where p_i is the four momentum in the CM frame of the reconstructed state i; and (iii) the number of reconstructed charged tracks in addition to those used for reconstructing the $D\ell$ system and the $B_{\rm tag}$, N_{trks}. In order to reduce the sensitivity to the modeling of the decays to the different charm states, the shapes of these variables are extracted from data, using exclusive samples highly enriched in the relevant decay modes. The relative D, D^*, and D^{**} contributions are then determined by a multiparameter fit to the inclusive sample.

We select semileptonic B decays that contain one fully reconstructed D meson and that recoil against a fully reconstructed $B_{\rm tag}$ decaying hadronically. To obtain a high reconstruction efficiency, the analysis exploits the presence of two charmed mesons in the final state: one used for the exclusive reconstruction of the $B_{\rm tag}$, and another in the semileptonic B decay.

The event reconstruction starts from the semileptonic B decay, selecting a charm meson and a lepton with momentum in the CM frame higher than 0.6 GeV$/c$ and the correct charge-flavor correlation. Candidate D^0 mesons are reconstructed in the $K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^-$, $K^0_S\pi^+\pi^-$, $K^0_S\pi^+\pi^-\pi^0$, $K^0_S\pi^0$, K^+K^-, $\pi^+\pi^-$, and $K^0_SK^0_S$ channels, and D^+ mesons in the $K^-\pi^+\pi^+$, $K^-\pi^+\pi^+\pi^0$, $K^0_S\pi^+$, $K^0_S\pi^+\pi^0$, $K^+K^-\pi^+$, $K^0_SK^+$, and $K^0_S\pi^+\pi^+\pi^-$ channels. In events with multiple candidates, the candidate with the largest D-ℓ vertex fit probability is selected. We then select a fully reconstructed $B_{\rm tag}$ meson candidate. We reconstruct $B_{\rm tag}$ decays of the type $\overline{B} \to DY$, where Y represents a collection of hadrons with a total charge of ± 1, composed of $n_1\pi^{\pm} + n_2K^{\pm} + n_3K_S^0 + n_4\pi^0$, where $n_1 + n_2 \leq 5$, $n_3 \leq 2$, and $n_4 \leq 2$. Using $D^0(D^+)$ and $D^{*0}(D^{*+})$ as seeds for $B^-(\overline{B^0})$ decays, we reconstruct about 1000 different decay chains.

The kinematic consistency of a $B_{\rm tag}$ candidate with a B-meson decay is checked using two variables: the beam-energy substituted mass $m_{\rm ES} = \sqrt{s/4 - \vec{p}_B^{\,2}}$, and the energy difference $\Delta E = E_B - \sqrt{s}/2$. Here $\sqrt{s}$ refers to the total CM energy, and $\vec{p}_B$ and E_B denote the momentum and energy of the $B_{\rm tag}$ candidate in the CM frame. For correctly identified $B_{\rm tag}$ decays, the $m_{\rm ES}$ distribution peaks at the B meson mass, while ΔE is consistent with zero. We select the $B_{\rm tag}$ candidate that has $m_{\rm ES}$ within the signal region defined as $5.27~{\rm GeV}/c^2 < m_{\rm ES} < 5.29~{\rm GeV}/c^2$, and the smallest $|\Delta E|$ value, excluding $B_{\rm tag}$ candidates with daughter particles in common with the charm meson or the lepton from the semileptonic B decay. Mixing effects in the $\overline{B^0}$ sample are accounted for as described in [13].

The $\overline{B} \to DX\ell^-\bar{\nu}_\ell$ decays are identified by relatively loose selection criteria. We require the reconstructed ground-state charm meson invariant mass M_{D^0} (M_{D^+}) to be in the range from $1.850(1.853)~{\rm GeV}/c^2$ to $1.880(1.883)~{\rm GeV}/c^2$ and the cosine of the angle between the directions of the D candidate and the lepton in the CM frame to be less than zero, to reduce background from non-B semileptonic decays.

After these selection criteria, the sample contains leptons from prompt B decays, as well as cascade B decays, in which the lepton does not come directly from the B. There are also background sources of leptons, such as photon conversions and Dalitz π^0 decays, combinatorial $B\overline{B}$ background and continuum events, that need to be subtracted. The contamination from cascade B decays, about 15.1 (17.8)% of the total $B^-(\overline{B^0})$ sample, is subtracted using the simulated MC distributions for these backgrounds. These events are reweighted to account for differences among the branching fractions used in our MC simulation and the latest experimental measurements [14]. The photon conversion and π^0 Dalitz decay backgrounds (less than 0.8% of the total electron sample) are removed using a dedicated algorithm, which performs the reconstruction of vertices between tracks of opposite charges whose invariant mass is compatible with a photon conversion or a π^0 Dalitz decay. The contributions of combinatorial and continuum $B_{\rm tag}$ backgrounds (respectively 16% and 11% of the sample in the $m_{\rm ES}$ signal region) are estimated from the $m_{\rm ES}$ sideband region $5.21~{\rm GeV}/c^2 < m_{\rm ES} < 5.26~{\rm GeV}/c^2$. The $m_{\rm ES}$ distribution is fitted by the sum of a Gaussian function joined to an exponential tail [15] for the signal and an empirical phase-space threshold function [16] for the background. Cross-feed effects, i.e. $B^-_{\rm tag}(\overline{B^0}_{\rm tag})$ candidates erroneously reconstructed as a neutral (charged) B, are corrected using MC simulations. We estimate the fraction of cross-feed events in the reconstructed $B^-(\overline{B^0})$ sample to be 6.8% (8.1%). A total of 6396 ± 251 (2981 ± 122) events are selected, with an estimated purity in $B^-(\overline{B^0}) \to DX\ell^-\bar{\nu}_\ell$ of 72% (73.8%).

Exclusive samples enriched in $D\ell^-\bar{\nu}_\ell$, $D^*\ell^-\bar{\nu}_\ell$, and $D^{(*)}\pi\ell^-\bar{\nu}_\ell$ are then selected. Contributions from other semileptonic B decays into charm final states, where one or more particles from a higher mass charm state are missing (feed-down) or random particles are erroneously associated with the charm candidate (feed-up) are removed. This is done by selecting signal regions in the missing mass squared distributions $m^2_{{\rm miss},D^{(*,**)}} = (p_{\Upsilon} - p_{B_{\rm tag}} - p_{D^{(*,**)}} - p_\ell)^2$ corresponding to the exclusive decay being reconstructed. The selection criteria are chosen to maximize the sample purity. We select D^{*+} and D^{*0} candidates by requiring the invariant mass difference between the D^* and the D to satisfy the selection criteria in Table I. The $B^- \to D^{*0}\ell^-\bar{\nu}_\ell$ and $\overline{B^0} \to D^{*+}\ell^-\bar{\nu}_\ell$ decays are selected by requiring the missing mass squared $m^2_{{\rm miss},D^{*0}}$ to be between $-0.35~{\rm GeV}^2/c^4$ and $0.5~{\rm GeV}^2/c^4$ and $|m^2_{{\rm miss},D^{*+}}|$ to be smaller than $0.55~{\rm GeV}^2/c^4$, respectively. Feed-down events from decays to D^{**} states are removed by requiring $m^2_{{\rm miss},D^{**0}}$ and $m^2_{{\rm miss},D^{**+}}$ to be incompatible with zero. The $B^- \to D^0\ell^-\bar{\nu}_\ell$ and $\overline{B^0} \to D^+\ell^-\bar{\nu}_\ell$ decays are selected by removing feed-down events from D^* and D^{**} states. Similar selection criteria are applied for $B^- \to D^{**0}\ell^-\bar{\nu}_\ell$ decays, with $D^{**0} \to D^{(*)+}\pi^-$, and $\overline{B^0} \to D^{**+}\ell^-\bar{\nu}_\ell$ decays, with $D^{**+} \to D^{(*)0}\pi^+$.

The probability density functions (PDFs) of the discriminating variables, $|\vec{p}_\ell|$, $m^2_{{\rm miss},D}$, and N_{trks} are determined using the exclusive samples. In order to test for possible selection biases in the PDF shapes, the inclusive distributions for MC samples of $\bar{B} \to D\ell^-\bar{\nu}_\ell$, $D^*\ell^-\bar{\nu}_\ell$, and $D^{(*)}\pi\ell^-\bar{\nu}_\ell$ events have been compared to those obtained after the exclusive event selection. Good agreement is found after accounting for the residual background from feed-down and feed-up from other modes. The PDFs are parametrized as sums of analytic functions, such as Gaussians and polynomials, with the exception of N_{trks} which is described using histograms.

The relative fractions of D, D^*, and D^{**} decays in the selected inclusive sample of $\overline{B} \to DX\ell^-\bar{\nu}_\ell$ events are obtained by a simultaneous χ^2 fit to the inclusive and ex-

TABLE I. Invariant mass ranges for D^{*0} and D^{*+} selection.

Mode	Selection criteria
$D^{*0} \to D^0\pi^0$	$0.139 < M(D^{*0}) - M(D^0) < 0.145~{\rm GeV}/c^2$
$D^{*0} \to D^0\gamma$	$0.133 < M(D^{*0}) - M(D^0) < 0.151~{\rm GeV}/c^2$
$D^{*+} \to D^0\pi^+$	$0.141 < M(D^{*+}) - M(D^0) < 0.149~{\rm GeV}/c^2$
$D^{*+} \to D^+\pi^0$	$0.138 < M(D^{*+}) - M(D^+) < 0.143~{\rm GeV}/c^2$

clusive $|\vec{p}_\ell|$, $m^2_{\mathrm{miss},D}$, and N_{trks} distributions. The relative fractions are floated, constraining their sum to be one, together with the parameters of the functions describing the shapes of the discriminating variables. This results in a 35-parameter fit, which ensures that statistical correlations between the different samples are properly taken into account and the uncertainties in the exclusive shapes, obtained from samples of significantly smaller size compared to that of the inclusive sample, are correctly propagated into the statistical uncertainties on the D, D^*, and D^{**} relative fractions. Since this analysis does not reconstruct D^{**} states with neutral pions, the N_{trks} distribution for states with the same charged-track multiplicity is used to model these decays: e.g. the $B^- \to D^{*0}\ell^-\bar{\nu}_\ell$ N_{trks} distribution is used for modeling $D^{**0}(\to D^{*0}\pi^0)\ell^-\bar{\nu}_\ell$ decays. For the modes involving a soft charged pion, such as $\overline{B^0} \to D^{*+}\ell^-\bar{\nu}_\ell$, the MC prediction for the additional charged-track multiplicity distribution is used to account for inefficiencies in the reconstruction of the low-momentum particle. MC studies show that the PDFs for the $\overline{B} \to D^{**}\ell^-\bar{\nu}_\ell$ component, obtained by the exclusive reconstruction of $\overline{B} \to D^{(*)}\pi\ell^-\bar{\nu}_\ell$ decays, can also be used to parametrize $\overline{B} \to D^{(*)}n\pi\ell^-\bar{\nu}_\ell$ decays in the inclusive $\overline{B} \to DX\ell^-\bar{\nu}_\ell$ sample. The fit also accounts for feed-down and feed-up decays in the exclusive shapes, fixing the relative contributions to the predictions from the simulation. The fit performance has been extensively tested using simulated samples with varying fractions of the different decay modes. These tests show that the procedure adopted in this analysis is able to extract the decay fractions without any significant bias. The statistical uncertainty obtained by the fit reproduces the scatter of the results from independent samples, where the bin contents of the distributions have been fluctuated according to their statistical uncertainty. The fit results for the $\overline{B^0} \to DX\ell^-\bar{\nu}_\ell$ and $B^- \to DX\ell^-\bar{\nu}_\ell$ distributions of the three variables $|\vec{p}_\ell|$, $m^2_{\mathrm{miss},D}$, and N_{trks} are shown in Fig. 1. The fit has a χ^2 value of 200 for 212 degrees of freedom for the B^- sample and 204 for 168 degrees of freedom for the $\overline{B^0}$ sample.

Several stability checks have been performed. First the sample has been split into subsamples based on the lepton flavor and the run period and the fit has been repeated for each one of them. Results are consistent within the statistical uncertainties. As another check, the $\overline{B} \to D\ell^-\bar{\nu}_\ell$ and $\overline{B} \to D^*\ell^-\bar{\nu}_\ell$ branching fractions have been determined by a binned likelihood fit to the $m^2_{\mathrm{miss},D}$ and m^2_{miss,D^*} distributions, respectively, where simulated events are used to model the shape of the missing mass squared variables for the D, D^*, and D^{**} exclusive decays and the combinatorial and continuum background. The results are in good agreement with the relative branching fractions obtained from the fit to the inclusive $\overline{B} \to DX\ell^-\bar{\nu}_\ell$ sample, once we normalize them to the total semileptonic B branching fraction.

Different sources of systematic uncertainties have been investigated and are given in Table II. The first source is due to detector effects, where the size of the uncertainties in the detector response are determined from data control samples. Uncertainties related to the reconstruction of charged tracks are determined by evaluating the fit stability using different track selection criteria and by a MC study in which we vary the track multiplicity according to the tracking efficiency uncertainty. The systematic error due to the reconstruction of neutral particles is studied by varying the simulated calorimeter resolution and efficiency. The systematic uncertainty from lepton identifica-

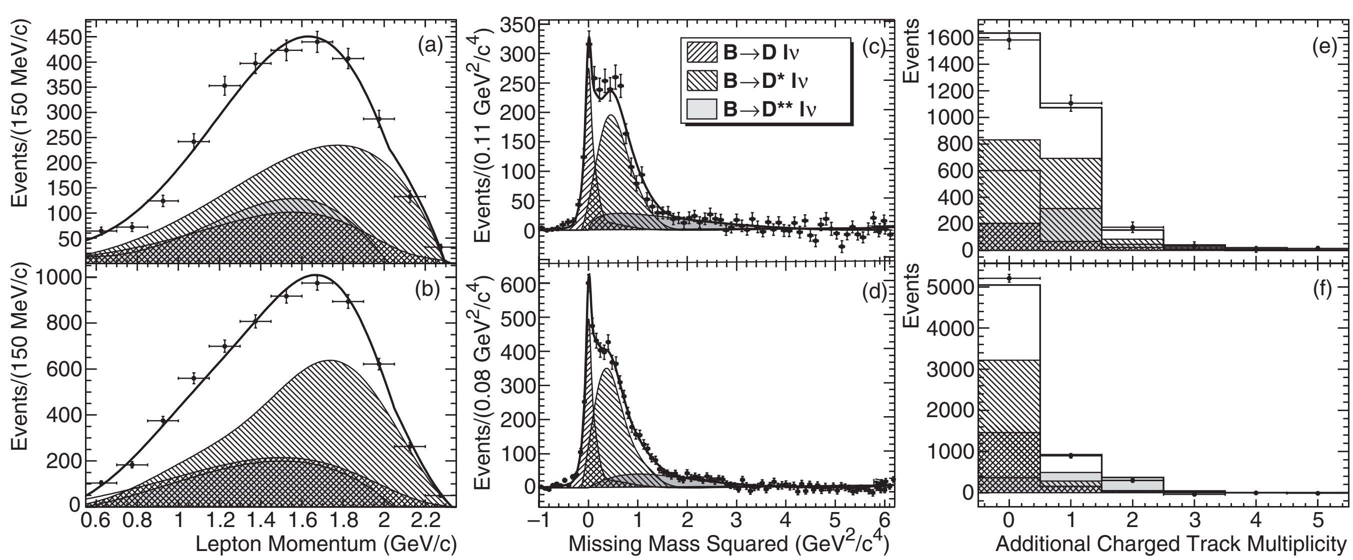

FIG. 1. Fitted $|\vec{p}_\ell|$ (a,b), $m^2_{\mathrm{miss},D}$, (c,d), and N_{trks} (e,f) distributions for $\overline{B^0} \to DX\ell^-\bar{\nu}_\ell$ (top) and $B^- \to DX\ell^-\bar{\nu}_\ell$ (bottom). The PDFs corresponding to the different exclusive components are superposed with different filling styles. The solid line is the sum of the three PDFs.

TABLE II. Relative systematic uncertainties (%) in the determination of $\Gamma(\overline{B} \to D^{(*,**)}\ell^- \bar{\nu}_\ell)/\Gamma(\overline{B} \to DX\ell^- \bar{\nu}_\ell)$.

	$B^-/\overline{B^0} \to D\ell^- \bar{\nu}_\ell$	$B^-/\overline{B^0} \to D^*\ell^- \bar{\nu}_\ell$	$B^-/\overline{B^0} \to D^{**}\ell^- \bar{\nu}_\ell$
Tracking reconstruction	3.5/2.4	1.3/0.3	4.6/3.1
Neutral reconstruction	0.4/0.3	0.4/0.3	0.4/0.3
Lepton identification	3.5/3.2	3.7/3.6	3.5/3.3
Inclusive selection			
Backgrounds	0.5/0.8	1.7/4.1	5.1/7.2
Reconstruction efficiency	2.4/3.5	1.5/2.6	3.4/6.4
Cross-feed corrections	0.2/0.5	0.1/0.6	0.7/1.0
Exclusive selection			
Backgrounds	1.8/1.5	1.0/1.4	1.9/2.3
Feed-down and feed-up corrections	2.0/1.5	1.3/1.3	1.8/2.0
Cross-feed corrections	0.7/0.6	0.1/0.2	1.3/0.7
$\lvert\vec{p}_\ell\rvert$ and $m^2_{\rm miss}$ PDFs	3.3/1.7	1.0/1.8	1.6/4.8
N_{trks} PDF	0.4/0.9	0.9/0.2	3.7/0.9
$\bar{B} \to D^{(*)}n\pi\ell^- \bar{\nu}_\ell$	0.9/0.7	1.1/0.9	0.9/0.7
Total syst.	7.1/6.2	5.2/6.7	9.9/12.2

tion is estimated by varying the tagging efficiency by 2% (3%) for electrons (muons) and the misidentification probability by 15%.

The second main source of systematic uncertainty is related to the selection of the inclusive sample. A major contribution is due to background processes, where the estimated systematic error is dominated by the uncertainty on the weighting factors used to subtract B cascade decays. The uncertainty in the subtraction of the background from the fully reconstructed $B_{\rm tag}$ decays is evaluated from the differences in the shapes of this background in the side-band and in the signal region using MC predictions. The systematic error due to the uncertainty in the amount of flavor cross feed is computed by varying its fraction by a conservative 30%. The third source of systematic uncertainty is due to the selection of the exclusive samples and is evaluated in a similar way. The analysis, relying on decay classification in an inclusive sample, is not sensitive, at first order, to reconstruction efficiencies. There remains an uncertainty arising from possible differences in efficiencies for the various channels, which is estimated from simulation.

Systematic uncertainties due to the PDFs are estimated by replacing the shapes extracted from the exclusive samples with those predicted by our simulation and repeating the fit. Additionally the uncertainty in the relative $D^{**0} \to D^{(*)+}\pi^-$ to $D^{**0} \to D^{(*)0}\pi^0$ reconstruction efficiency is accounted for by varying the N_{trks} distribution for the D^{**0} component.

TABLE III. Fitted ratios of branching fractions with statistical and systematic uncertainties.

Ratio	B^- (%)	$\overline{B^0}$ (%)
$\frac{\Gamma(\overline{B} \to D\ell^- \bar{\nu}_\ell)}{\Gamma(\overline{B} \to DX\ell^- \bar{\nu}_\ell)}$	22.7 ± 1.4 ± 1.6	21.5 ± 1.6 ± 1.3
$\frac{\Gamma(\overline{B} \to D^*\ell^- \bar{\nu}_\ell)}{\Gamma(\overline{B} \to DX\ell^- \bar{\nu}_\ell)}$	58.2 ± 1.8 ± 3.0	53.7 ± 3.1 ± 3.6
$\frac{\Gamma(\overline{B} \to D^{**}\ell^- \bar{\nu}_\ell)}{\Gamma(\overline{B} \to DX\ell^- \bar{\nu}_\ell)}$	19.1 ± 1.3 ± 1.9	24.8 ± 3.2 ± 3.0

Systematic effects due to $\overline{B} \to D^{(*)}n\pi\ell^- \bar{\nu}_\ell$ events not well parametrized by the $\overline{B} \to D^{**}\ell^- \bar{\nu}_\ell$ PDFs are estimated by repeating the fit with an additional component for these events. The corresponding PDFs are built from a sample of simulated $\overline{B} \to D^{(*)}\pi\pi\ell^- \bar{\nu}_\ell$ events. The observed difference in the fit results is taken as an additional systematic error.

In summary, the relative branching fractions for the $B^- \to D^0$, D^{*0}, $D^{**0}\ell^- \bar{\nu}_\ell$ and $\overline{B^0} \to D^+$, D^{*+}, $D^{**+}\ell^- \bar{\nu}_\ell$ decays have been determined by a multiparameter fit to three discriminating variables in an inclusive sample of $\overline{B} \to DX\ell^- \bar{\nu}_\ell$ events recoiling against a fully reconstructed B meson. The results are given in Table III. Apart from possible isospin violation effects, which are thought to be small, these three ratios are expected to be equal for B^-_u and $\overline{B}^0_d$ mesons. The results for charged and neutral B mesons are compatible within their uncorrelated uncertainties. Therefore the relative fractions have been averaged, accounting for correlated errors. The results are: $\Gamma(\overline{B} \to D\ell^- \bar{\nu}_\ell)/\Gamma(\overline{B} \to DX\ell^- \bar{\nu}_\ell) = 0.221 \pm 0.012(\text{stat.}) \pm 0.006(\text{uncorr. syst.}) \pm 0.010(\text{corr. syst.})$, $\Gamma(\overline{B} \to D^*\ell^- \bar{\nu}_\ell)/\Gamma(\overline{B} \to DX\ell^- \bar{\nu}_\ell) = 0.572 \pm 0.017(\text{stat.}) \pm 0.016(\text{uncorr. syst.}) \pm 0.022(\text{corr. syst.})$, $\Gamma(\overline{B} \to D^{**}\ell^- \bar{\nu}_\ell)/\Gamma(\overline{B} \to DX\ell^- \bar{\nu}_\ell) = 0.197 \pm 0.013(\text{stat.}) \pm 0.013(\text{uncorr. syst.}) \pm 0.012(\text{corr. syst.})$, where the first uncertainty is statistical, the second the uncorrelated systematic, and the third the correlated systematic error. The accuracy of these measurements is comparable to that of the current world average [6].

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[1] M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973).
[2] D. Buskulic *et al.* (ALEPH Collaboration), Z. Phys. C **73**, 601 (1997).
[3] P. Abreu *et al.* (DELPHI Collaboration), Phys. Lett. B **475**, 407 (2000).
[4] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **71**, 051502 (2005).
[5] D. Liventsev *et al.* (Belle Collaboration), Phys. Rev. D **72**, 051109 (2005).
[6] W. M. Yao *et al.* (Particle Data Group), J. Phys. G **33**, 1 (2006).
[7] Charge conjugate states are always implied unless stated otherwise.
[8] B. Aubert *et al.* (*BABAR* Collab.), Nucl. Instrum. Methods Phys. Res., Sect. A **479**, 1 (2002).
[9] S. Agostinelli *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).
[10] J. Dubosq *et al.* (CLEO Collaboration), Phys. Rev. Lett. **76**, 3898 (1996).
[11] D. Scora and N. Isgur, Phys. Rev. D **52**, 2783 (1995). See also N. Isgur *et al.*, Phys. Rev. D **39**, 799 (1989).
[12] J. L. Goity and W. Roberts, Phys. Rev. D **51**, 3459 (1995).
[13] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **69**, 111104 (2004).
[14] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **74**, 091105 (2006).
[15] M. J. Oreglia, SLAC, Report No. SLAC-236 1980; J. E. Gaiser, SLAC, Report No. SLAC-255 1982; T. Skwarnicki, Report No. DESY F31-86-02 1986.
[16] H. Albrecht *et al.* (ARGUS Collaboration), Z. Phys. C **48**, 543 (1990).