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Measurement of the absolute branching fractions $B \to D\pi$, $D^{*}\pi$, $D^{**}\pi$ with a missing mass method

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We present branching fraction measurements of charged and neutral B decays to $D\pi^-$, $D^*\pi^-$, and "D^{**}"π^- with a missing mass method, based on a sample of 231×10^6 $\Upsilon(4S) \rightarrow B\bar{B}$ pairs collected by the *BABAR* detector at the PEP-II e^+e^- collider. One of the B mesons is fully reconstructed and the other one decays to a reconstructed charged π and a companion charmed meson identified by its recoil mass, inferred by kinematics. Here "D^{**}" refers to the sum of all the nonstrange charm meson states with masses in the range 2.2–2.8 GeV$/c^2$. We measure the branching fractions: $\mathcal{B}(B^- \rightarrow D^0\pi^-) = (4.49 \pm 0.21 \pm 0.23) \times 10^{-3}$, $\mathcal{B}(B^- \rightarrow D^{*0}\pi^-) = (5.13 \pm 0.22 \pm 0.28) \times 10^{-3}$, $\mathcal{B}(B^- \rightarrow \text{“}D^{**0}\text{”}\pi^-) = (5.50 \pm 0.52 \pm 1.04) \times 10^{-3}$, $\mathcal{B}(\bar{B}^0 \rightarrow D^+\pi^-) = (3.03 \pm 0.23 \pm 0.23) \times 10^{-3}$, $\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\pi^-) = (2.99 \pm 0.23 \pm 0.24) \times 10^{-3}$, $\mathcal{B}(\bar{B}^0 \rightarrow \text{“}D^{**+}\text{”}\pi^-) = (2.34 \pm 0.65 \pm 0.88) \times 10^{-3}$, and their ratios.

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Our understanding of hadronic B-meson decays has improved considerably during the past few years with the development of models based on the heavy quark effective theory (HQET), where collinear [1,2] or k_T [3,4] factorization theorems are considered. Models such as the QCD-improved factorization (QCDF) [5,6] and the soft collinear effective theory (SCET) [1,7] use the collinear factorization, while the perturbative QCD (pQCD) approach [8,9] uses the k_T factorization. In these models the amplitude of the $B \rightarrow D^{(*)}\pi$ two-body decay carries information about the difference δ between the strong-interaction phases of the two isospin amplitudes $A_{1/2}$ and $A_{3/2}$ that contribute [10,11]. A nonzero value of δ provides a measure of the departure from the heavy-quark limit and the importance of the final-state interactions in the $D^{(*)}\pi$ system. With the measurements by the *BABAR* [12] and BELLE [13] experiments of the color-suppressed B decay $\bar{B}^0 \rightarrow D^{(*)0}\pi^0$ providing evidence for a sizeable value of δ, an improved measurement of the color-favored decay amplitudes ($B^- \rightarrow D^{(*)0}\pi^-$ and $\bar{B}^0 \rightarrow D^{(*)+}\pi^-$) is of renewed interest. In addition, the study of B decays into D, D^*, and D^{**} mesons will allow tests of the spin symmetry [14–17] imbedded in HQET and of nonfactorizable corrections [18] that have been assumed to be negligible in the case of the excited states D^{**} [19].

In this paper we present new measurements of the branching fractions for the decays $B^- \rightarrow D^0\pi^-$, $D^{*0}\pi^-$, "D^{**0}" π^-, and $\bar{B}^0 \rightarrow D^+\pi^-$, $D^{*+}\pi^-$, "D^{**+}"π^- [20], based on a missing mass method previously used by *BABAR* [21]. Here "D^{**}" refers to the sum of all the nonstrange charm meson states with masses in the range 2.2–2.8 GeV$/c^2$. This analysis uses $\Upsilon(4S) \rightarrow B\bar{B}$ events in which a B^+ or a B^0 meson, denoted $B_{\rm reco}$, decays into a hadronic final state and is fully reconstructed. The decays of the recoiling $\bar{B}$ into a charged pion and a charmed meson, i.e. $\bar{B} \rightarrow \pi^- X$, are studied. The charged pion is reconstructed and the mass of the $X = D$, D^*, "D^{**}" is inferred from the kinematics of the two-body B decay. This method, unlike the previous exclusive measurements [22,23], does not assume that the $\Upsilon(4S)$ decays into B^+ and B^0 with equal rates, nor does it rely on the D, D^*, or D^{**} decay branching fractions.

The measurements presented here are based on a sample of 231×10^6 $B\bar{B}$ pairs (210 fb^{-1}) recorded at the $\Upsilon(4S)$ resonance with the *BABAR* detector at the PEP-II asymmetric-energy B factory at SLAC. The *BABAR* detector is described in detail elsewhere [24]. Charged-particle trajectories are measured by a 5-layer double-sided silicon vertex tracker (SVT) and a 40-layer drift chamber (DCH), both operating in a 1.5-T solenoidal magnetic field. Charged-particle identification is provided by the average energy loss ($\mathrm{d}E/\mathrm{d}x$) in the tracking devices and by an internally reflecting ring-imaging Cherenkov detector. Photons are detected by a CsI(Tl) electromagnetic calorimeter. Muons are identified by the instrumented magnetic-flux return (IFR). We use Monte Carlo (MC) simulations of the *BABAR* detector based on GEANT4 [25] to optimize selection criteria and determine selection efficiencies.

We reconstruct B^+ and B^0 decays ($B_{\rm reco}$) in the modes $B^+ \rightarrow \bar{D}^{(*)0}\pi^+$, $\bar{D}^{(*)0}\rho^+$, $\bar{D}^{(*)0}a_1^+$, and $B^0 \rightarrow D^{(*)-}\pi^+$, $D^{(*)-}\rho^+$, $D^{(*)-}a_1^+$. $\bar{D}^0$ candidates are reconstructed in the $K^+\pi^-$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^+\pi^-$, and $K_S^0\pi^+\pi^-$ decay channels, while D^- candidates are reconstructed in the $K^+\pi^-\pi^-$ and $K_S^0\pi^-$ modes, and K_S^0 mesons are reconstructed to $\pi^+\pi^-$. D^* candidates are reconstructed in the $D^{*-} \rightarrow \bar{D}^0\pi^-$ and $\bar{D}^{*0} \rightarrow \bar{D}^0\pi^0$ decay modes. A 3σ cut is applied to the D meson mass m_D (and to the D^*-D mass difference Δm_{D^*}) where $\sigma = \sigma_{m_D}(\sigma_{\Delta m_{D^*}})$ is the resolution on m_D (Δm_{D^*}) and is determined from data. A vertex fit is performed on D (D^*) with the mass constrained to the nominal value [26]. Two nearly independent variables are defined to identify the fully reconstructed B candidates kinematically. The first one is the beam-energy substituted mass, $\mathrm{m_{ES}} = \sqrt{(s/2 + \mathbf{p}_i \cdot \mathbf{p}_B)^2/E_i^2 - \mathbf{p}_B^2}$, where $\mathbf{p}_B$ is the $B_{\rm reco}$ momentum and $(E_i, \mathbf{p}_i)$ 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

$\sqrt{s}$. The second variable is $\Delta E = E_B^* - \sqrt{s}/2$, where E_B^* is the B_{reco} candidate energy in the center-of-mass frame. To define the B_{reco} sample (Fig. 1), we require $|\Delta E| < n\sigma_{\Delta E}$, where the measured resolutions $\sigma_{\Delta E}$ range from 12 to 35 MeV and $n = 2$ or 3, both depending on the B_{reco} mode. The B_{reco} candidate multiplicity is 1.4 for data as well as for the MC simulation sample. For events with more than one candidate, we select the B_{reco} with the best χ^2 defined with the variables m_D, Δm_{D^*}, and ΔE. The MC simulation shows that the recoil variables are reconstructed well within their experimental resolution when using this selection.

The number of B_{reco} is extracted from the m_{ES} spectra (Fig. 1) in the 5.27–5.29 GeV$/c^2$ signal region. The m_{ES} distribution is fitted to the sum of a broad combinatorial background and a narrow signal in the mass interval 5.21–5.29 GeV$/c^2$. The combinatorial background is described by an empirical phase-space threshold function [27] and the signal with a Crystal Ball function [28] which is a Gaussian function centered at the B meson mass modified to account for photon radiation energy loss. All of the parameters specifying the functions describing the B_{reco} signal and background distributions are determined from data. The measured yields of reconstructed B^+ and B^0 candidates, $N_{B^+} = 189\,474 \pm 7487$ and $N_{B^0} = 103\,169 \pm 3303$, are obtained by subtracting the fitted and the peaking (described below) backgrounds from the total number of events found in the signal region. These B_{reco} numbers serve as the normalization of all branching fraction measurements reported in this paper. The error is dominated by the systematic uncertainties due to the fit of the combinatorial background and to the determination of the peaking background. We assign 2.3% uncertainty to N_{B^+} and 1.8% to N_{B^0} as a fit uncertainty, obtained by varying the lower boundary of the fit interval from 5.20 to 5.23 GeV$/c^2$. The contamination of misreconstructed B^0 events in the B^+ signal (and vice versa) induces a peaking background near the B mass. From the MC simulation, the fraction of B^0 events in the reconstructed B^+ signal sample is found to be $(3.2 \pm 3.2_{\text{syst.}})\%$ and the fraction of B^+ events in the reconstructed B^0 signal sample $(2.8 \pm 2.8_{\text{syst.}})\%$. A 100% systematic uncertainty is conservatively assigned to these numbers taking into account the possible differences in the reconstruction efficiency in data and MC, as well as the branching fraction uncertainties for those B decay modes contributing to the peaking background. The total systematic uncertainties on N_{B^+} and N_{B^0} are 3.9% and 3.2%, respectively.

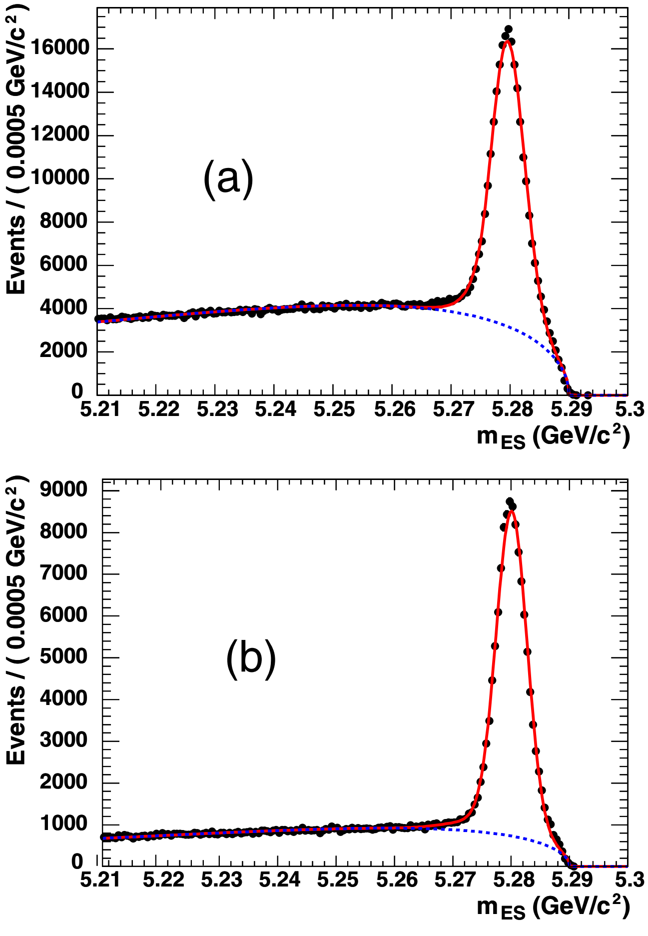

FIG. 1 (color online). m_{ES} spectra of reconstructed (a) B^+ and (b) B^0 candidates. The solid curve is the sum of the fitted signal and background whereas the dashed curve is the background component only.

In the decay $\Upsilon(4S) \to B_{\text{reco}}\bar{B}_{X\pi}$ where $\bar{B}_{X\pi}$ is the recoiling $\bar{B}$ which decays into $\pi^- X$, the invariant mass of the X system is derived from the missing 4-momentum p_X applying energy-momentum conservation:

$$p_X = p_{\Upsilon(4S)} - p_{B\text{reco}} - p_{\pi^-}.$$

The 4-momentum of the $\Upsilon(4S)$, $p_{\Upsilon(4S)}$ is computed from the beam energies and p_{π^-} and $p_{B\text{reco}}$ are the measured 4-momenta of the pion and of the reconstructed B_{reco}, respectively. The B_{reco} energy is constrained by the beam energies. The $\bar{B} \to D\pi^-$, $\bar{B} \to D^*\pi^-$, or $\bar{B} \to$ "D^{**}"π^- signal yields peak at the D, D^*, and "D^{**}" masses in the missing mass spectrum, respectively.

The charged pion candidates, chosen among the tracks that do not belong to the B_{reco}, are required to have produced at least 12 DCH hits and to have transverse momentum larger than 0.1 GeV$/c^2$. For the charged B_{reco}, the pion candidate has the opposite sign to the B_{reco}. For neutral B_{reco}, because of the $B^0 - \bar{B}^0$ mixing, the corresponding requirement is not applied. Muon tracks are rejected using the IFR information, electrons tracks using the energy loss in the SVT and the DCH, or the ratio of the candidate's EMC energy deposition to its momentum (E/p). Protons and kaons are rejected based on information from the DIRC and energy loss in the SVT and the DCH. The rejection efficiency is 97% and there is no peaking trend

TABLE I. Signal yields, efficiencies, and branching fractions for $\bar{B} \rightarrow D\pi^-$, $\bar{B} \rightarrow D^*\pi^-$, and $\bar{B} \rightarrow$ "D^{**}"π^-. The first error is statistical except for the efficiencies for which it is mainly systematic. The second error on the branching fractions is systematic. The $\bar{B} \rightarrow$ "D^{**}"π^- branching fractions are given for the 2.2–2.8 GeV/c^2 mass range which in addition to the *P*-wave states may include some yet unknown charm meson states.

Decay mode	Yield	Efficiency	$\mathcal{B}(10^{-3})$
$B^- \rightarrow D^0\pi^-$	677 ± 32	0.796 ± 0.007	4.49 ± 0.21 ± 0.23
$B^- \rightarrow D^{*0}\pi^-$	774 ± 33		5.13 ± 0.22 ± 0.28
$B^- \rightarrow$ "D^{**0}"π^-	829 ± 78		5.50 ± 0.52 ± 1.04
$\bar{B}^0 \rightarrow D^+\pi^-$	248 ± 19	0.793 ± 0.007	3.03 ± 0.23 ± 0.23
$\bar{B}^0 \rightarrow D^{*+}\pi^-$	245 ± 19		2.99 ± 0.23 ± 0.24
$\bar{B}^0 \rightarrow$ "D^{**+}"π^-	192 ± 54		2.34 ± 0.65 ± 0.88

in the missing mass distribution from remaining kaons, protons, muons, or electrons. The multiplicity of the pion candidates which give a missing mass smaller than 4.15 GeV/c^2 is 1.05 in both data and MC simulation. For events with more than one candidate the simulation shows that the contribution of the wrong candidates to the signal yields is less than 0.2%, thus negligible compared to the statistical uncertainties. The pion reconstruction efficiency is determined from the MC simulation and reported in Table I.

The signal yields for the different decay modes are extracted from the missing mass spectra. The data distributions and the $b\bar{b}$ and the $q\bar{q}$ ($q = c, u, d, s$) background expectations are shown in Figs. 2(a) and 2(b). The shape of the background is taken from MC and the normalization is scaled to match the data in the sideband region 2.8–3.2 GeV/c^2. The error on the background normalization is 2%. This is determined using the statistical errors of MC and data samples. The $b\bar{b}$ background contribution is obtained from $B\bar{B}$ MC simulation excluding the $D\pi$, $D^*\pi$, and $D^{**}\pi$ signals using the MC truth information. The background-subtracted missing mass distributions are shown in Figs. 2(c) and 2(d).

The $D\pi$ and $D^*\pi$ signal yields are extracted by a χ^2 fit to the background-subtracted missing mass distribution in the range 1.65–2.20 GeV/c^2. The $D\pi$ and $D^*\pi$ components are each modeled by a sum of two Gaussian functions $G_{i=1,2}$ to account for tails in the mass distributions. The resulting ten parameters (two yield fractions $f(D^{(*)}) = \| G_2(D^{(*)}) \| / \| G_1(D^{(*)}) \|$, four central values $m_i(D^{(*)})$, and four widths $\sigma_i(D^{(*)})$) are constrained in order to improve the convergence of the fit, using assumptions that have been tested with MC simulation: we fix the fractions $f(D) = f(D^*)$ and the mass differences $m_i(D^*) - m_i(D) = \Delta m$, where $\Delta m = 0.1421$ GeV/c^2 (0.1406 GeV/c^2) is the world average $D^{*0} - D^0$ ($D^{*+} - D^+$) mass difference [26]. Simultaneously, we apply

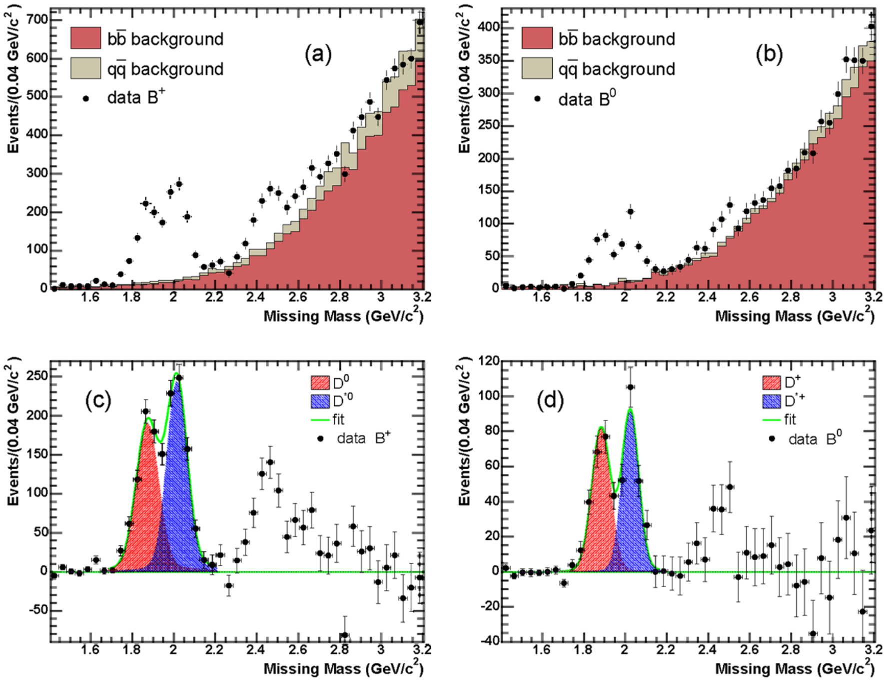

FIG. 2 (color online). Top: missing mass distributions obtained in the recoil of B^+ (a) and B^0 (b). The points with error bars show the data and the histograms show the background contributions ($b\bar{b}$ and $q\bar{q}$ ($q = c, u, d, s$)) predicted by the MC simulation. Bottom: background-subtracted missing mass spectra for B^+ (c) and B^0 (d). The curves show the result of the fits to the $D\pi$ and $D^*\pi$ components.

Gaussian constraints to the width ratios $\sigma_i(D^*)/\sigma_i(D) = 0.900 \pm 0.015$.

The "D^{**}" yields are defined as the excess of candidates in the missing mass range 2.2–2.8 GeV/c^2, and the $\bar{B} \to$ "D^{**}"π^- branching fractions refer to the contributions of all nonstrange charm meson states in the same region. The range is chosen in order to maximize the acceptance to the four P-wave D^{**} states predicted by the theory given the 34 MeV/c^2 mass resolution, determined from MC simulation, in the same region. The well-known narrow D_1 and D_2^* states [26] are fully contained in this range, and more than 90% of the broad D_0 and D_1', are covered if measured masses and widths [29,30] are used. The event yields, the efficiencies, and the resulting branching fractions are reported in Table I.

The uncertainty related to π reconstruction efficiency is due to the MC sample statistics and the systematic uncertainty on track reconstruction and particle identification algorithms. The uncertainty due to the yield extraction is estimated by fitting the MC sample. The difference between the generated and the fitted yield is found to be consistent with zero for each signal component and the MC sample statistical uncertainty is taken as a systematic uncertainty. We evaluate the uncertainty on the missing mass resolution in the $D\pi$ and $D^*\pi$ yield extraction by varying by 1 standard deviation the ratio $\sigma_i^{D^*}/\sigma_i^D$ while $\sigma_2^{D^*}$ and $m_2^{D^*}$ are allowed to vary in the fit. The difference in the yield is taken as systematic uncertainty. The uncertainty related to the background subtraction is dominated by the contribution of the $D^{(*)}\rho$ decay channels. We varied the branching fractions of these background components within the uncertainties of the most recent measurements [26] and the changes in the fitted yields are taken as systematic uncertainties. The effect of the 2% error in the background normalization is also included in the systematic uncertainties. Because of the threshold shape of $D^{(*)}\rho$ contribution and to the fast varying combinatorial background, $B \to$ "D^{**}"π branching fractions have larger systematic errors than $B \to D\pi$ and $B \to D^*\pi$ branching fractions. The summary of these systematic uncertainties is reported in Table II.

Using the measured branching fractions we compute the following ratios:

$$\mathcal{B}(B^- \to D^{*0}\pi^-)/\mathcal{B}(B^- \to D^0\pi^-) = 1.14 \pm 0.07 \pm 0.04,$$

$$\mathcal{B}(B^- \to \text{“}D^{**0}\text{”}\pi^-)/\mathcal{B}(B^- \to D^0\pi^-) = 1.22 \pm 0.13 \pm 0.23,$$

$$\mathcal{B}(\bar{B}^0 \to D^{*+}\pi^-)/\mathcal{B}(\bar{B}^0 \to D^+\pi^-) = 0.99 \pm 0.11 \pm 0.08,$$

$$\mathcal{B}(\bar{B}^0 \to \text{“}D^{**+}\text{”}\pi^-)/\mathcal{B}(\bar{B}^0 \to D^+\pi^-) = 0.77 \pm 0.22 \pm 0.29.$$

The first uncertainty is statistical and the second is systematic. In addition to the cancellation of many of the systematic errors, the ratios are insensitive to the absolute normalization scale.

In summary, we have measured the branching fractions for the decays $B^- \to D^0\pi^-$, $B^- \to D^{*0}\pi^-$, $B^- \to$ "D^{**0}"π^-, $\bar{B}^0 \to D^+\pi^-$, $\bar{B}^0 \to D^{*+}\pi^-$, and $\bar{B}^0 \to$ "D^{**+}"π^-, using a missing mass method. This measurement does not assume that the $\Upsilon(4S)$ decays into B^+ and B^0 with equal rates, nor does it rely on the D, D^*, or "D^{**}" intermediate branching fractions. The results for $\mathcal{B}(B \to D\pi^-)$ and $\mathcal{B}(B \to D^*\pi^-)$ are compatible with previous world averages [26]. We have extracted a new result for $\mathcal{B}(B \to$ "D^{**}"$\pi^-)$ branching fractions where "D^{**}" excited states correspond to the yield measured in the mass range 2.2–2.8 GeV/c^2. The isospin study [10,11] will become competitive with the exclusive measurements [23] if the statistical error is reduced by a factor of 2. With regard to spin symmetry, the values measured for the ratios $\mathcal{B}(B^- \to D^{*0}\pi^-)/\mathcal{B}(B^- \to D^0\pi^-)$ and $\mathcal{B}(\bar{B}^0 \to D^{*+}\pi^-)/\mathcal{B}(\bar{B}^0 \to D^+\pi^-)$ are close to 1, as predicted by different theoretical models [14–18], and their precision is comparable or better than the current world averages [26].

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

TABLE II. Total relative systematic uncertainties for the branching fractions $\mathcal{B}(B^- \to (D^0, D^{*0}, \text{“}D^{**0}\text{”})\pi^-)$ and $\mathcal{B}(\bar{B}^0 \to (D^+, D^{*+}, \text{“}D^{**+}\text{”})\pi^-)$.

Syst. Source	$B^- \to D^0\pi^-$	$B^- \to D^{*0}\pi^-$	$B^- \to$ "D^{**0}"π^-	$\bar{B}^0 \to D^+\pi^-$	$\bar{B}^0 \to D^{*+}\pi^-$	$\bar{B}^0 \to$ "D^{**+}"π^-
N_B	3.9%	3.9%	3.9%	3.2%	3.2%	3.2%
Efficiency	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%
Yield extraction	2.7%	2.7%	5.1%	5.4%	5.1%	5.9%
Missing mass resolution	0.9%	0.8%	···	1.9%	1.1%	···
Background subtraction	1.6%	2.3%	17.7%	3.7%	5.4%	37.1%
Total	5.2%	5.4%	18.9%	7.6%	8.2%	37.7%

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[1] C. W. Bauer, D. Pirjol, and I. W. Stewart, Phys. Rev. Lett. **87**, 201806 (2001).
[2] M. Bauer, B. Stech, and M. Wirbel, Z. Phys. C **34**, 103 (1987).
[3] J. Botts and G. Sterman, Nucl. Phys. **B325**, 62 (1989).
[4] H-n. Li and G. Sterman, Nucl. Phys. **B381**, 129 (1992).
[5] M. Beneke *et al.*, Nucl. Phys. **B591**, 313 (2000).
[6] M. Neubert and B. Stech in *Heavy Flavors* edited by A. J. Buras and M. Lindner (World Scientific, Singapore, 1998), 2nd ed.
[7] C. W. Bauer, D. Pirjol, and I. W. Stewart, Phys. Rev. D **65**, 054022 (2002).
[8] Y. Y. Keum *et al.*, Phys. Rev. D **69**, 094018 (2004).
[9] T. Kurimoto, Phys. Rev. D **74**, 014027 (2006).
[10] J. L. Rosner, Phys. Rev. D **60**, 074029 (1999).
[11] C. W. Chiang and J. L. Rosner, Phys. Rev. D **67**, 074013 (2003).
[12] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **69**, 032004 (2004).
[13] K. Abe *et al.* (Belle Collaboration), Phys. Rev. Lett. **88**, 052002 (2002); S. Blyth *et al.*, Phys. Rev. D **74**, 092002 (2006).
[14] T. Mannel *et al.*, Phys. Lett. B **259**, 359 (1991).
[15] M. Neubert, W. Rieckert, B. Stech, and Q. P. Xu, in *Heavy Flavors* edited by A. J. Buras and M. Lindner (World Scientific, Singapore, 1992).
[16] S. Mantry, D. Pirjol, and I. W. Stewart, Phys. Rev. D **68**, 114009 (2003).
[17] F. Jugeau, A. Le Yaouanc, L. Oliver, and J.-C Raynal, Phys. Rev. D **72**, 094010 (2005).
[18] B. Blok, and M. Shifman, Nucl. Phys. **B389**, 534 (1993).
[19] M. Neubert, Phys. Lett. B **418**, 173 (1998).
[20] Charge conjugate relations are assumed throughout this paper.
[21] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **96**, 052002 (2006).
[22] S. Ahmed *et al.*, Phys. Rev. D **66**, 031101(R) (2002); M. S. Alam *et al.*, Phys. Rev. D **50**, 43 (1994).
[23] G. Calderini (*BABAR* Collaboration), in Proceedings of the XXXIII International Conference on High Energy Physics (ICHEP'06), Moscow, 2006 (unpublished).
[24] B. Aubert *et al.* (*BABAR* Collaboration) Nucl. Instrum. Methods Phys. Res., Sect. A **479**, 1 (2002).
[25] S. Agostinelli *et al.* (GEANT4 Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).
[26] W.-M. Yao *et al.* (Particle Data Group Collaboration), J. Phys. G **33**, 1 (2006).
[27] H. Albrecht *et al.* (ARGUS Collaboration), Z. Phys. C **48**, 543 (1990).
[28] T. Skwarnicki (CRYSTAL BALL Collaboration), DESY Report No. DESY F31-86-02, 1986; J. E. Gaiser *et al.*, Phys. Rev. D **34**, 711 (1986).
[29] K. Abe *et al.* (Belle Collaboration), Phys. Rev. D **69**, 112002 (2004).
[30] J. M. Link *et al.* (FOCUS Collaboration), Phys. Lett. B **586**, 11 (2004).