Observation of the Semileptonic Decays $B \to D^{*}\tau^{-}\bar{\nu}_{\tau}$ and Evidence for $B \to D\tau^{-}\bar{\nu}_{\tau}$


1 Laboratoire de Physique des Particules, IN2P3/CNRS et Université de Savoie, F-74941 Annecy-Le-Vieux, France
2 Universitat de Barcelona, Facultat de Fisica, Departament ECM, E-08028 Barcelona, Spain
3 Università di Bari, Dipartimento di Fisica e INFN, I-70126 Bari, Italy
4 University of Bergen, Institute of Physics, N-5007 Bergen, Norway
5 Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720, USA
6 University of Birmingham, Birmingham, B15 2TT, United Kingdom
7 Ruhr Universität Bochum, Institut für Experimentalphysik 1, D-44780 Bochum, Germany
8 University of Bristol, Bristol BS8 1TL, United Kingdom
9 University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z1
10 Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom
11 Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia
12 University of California at Irvine, Irvine, California 92697, USA
13 University of California at Los Angeles, Los Angeles, California 90024, USA
14 University of California at Riverside, Riverside, California 92521, USA
15 University of California at San Diego, La Jolla, California 92093, USA
16 University of California at Santa Barbara, Santa Barbara, California 93106, USA
17 University of California at Santa Cruz, Institute for Particle Physics, Santa Cruz, California 95064, USA
18 California Institute of Technology, Pasadena, California 91125, USA
19 University of Cincinnati, Cincinnati, Ohio 45221, USA
20 University of Colorado, Boulder, Colorado 80309, USA
21 Colorado State University, Fort Collins, Colorado 80523, USA
22 Universität Dortmund, Institut für Physik, D-44221 Dortmund, Germany
23 Technische Universität Dresden, Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany
24 Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, F-91128 Palaiseau, France
25 University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom
We present measurements of the semileptonic decays $B^+ \to D^0 \tau^+ \nu$, $B^- \to D^{*0} \tau^- \nu$, $D^+ \to D^0 \tau^- \nu$, and $D^0 \to D^{-} \tau^+ \nu$, which are potentially sensitive to non–Standard Model amplitudes. The data sample comprises $232 \times 10^6 T(4S) \to B\bar{B}$ decays collected with the BABAR detector. From a combined fit to $B^+$ and $B^0$ channels, we obtain the branching fractions $B(B \to D^0 \tau^- \nu) =$
Semileptonic decays of $B$ mesons to the $\tau$ lepton—the heaviest of the three charged leptons—provide a new source of information on Standard Model (SM) processes [1, 2, 3, 4, 5, 6, 7, 8]. In the SM, semileptonic decays occur at tree level and are mediated by the SM [4, 5, 6, 7, 8]. In the SM, semileptonic decays of $B$ mesons to $\tau$ leptons are predicted to be smaller than those for $e$ or $\mu$ [10]. Calculations based on the SM predict $\mathcal{B}(B \to D^* \tau^- \bar{\nu}_\tau) = (0.69 \pm 0.04)/%$ and $\mathcal{B}(B^0 \to D^{*+} \tau^+ \bar{\nu}_\tau) = (1.41 \pm 0.07)/%$ [8], which account for most of the predicted inclusive rate $\mathcal{B}(B \to X_c \tau^- \bar{\nu}_\tau) = (2.30 \pm 0.25)/%$ [2] (here, $X_c$ represents all hadronic final states from the $b \to c$ transition). Calculations [4, 5, 6, 7, 8] in multi-Higgs doublet models show that substantial departures, either positive or negative, from the SM decay rate could occur for $\mathcal{B}(B \to D^* \tau^- \bar{\nu}_\tau)$. Those for $\mathcal{B}(B \to D^+ \tau^- \bar{\nu}_\tau)$, however, are expected to be smaller.

Theoretical predictions for semileptonic decays to $\tau$ leptons are challenging because the final state contains not just one, but two or three neutrinos as a result of the additional form factors for light leptons. With sufficient data, one could probe the additional form factors and test the HQS relations.

The first measurements of semileptonic $b$-hadron decays to $\tau$ leptons were performed by the LEP experiments [12] operating at the $Z^0$ resonance, yielding an average [14] inclusive branching fraction $\mathcal{B}(b_{\text{had}} \to X \tau^- \bar{\nu}_\tau) = (2.48 \pm 0.26)/%$, where $b_{\text{had}}$ represents the mixture of $b$-hadrons produced in $Z^0 \to b\bar{b}$ decays. The Belle experiment has recently obtained $\mathcal{B}(B^0 \to D^{*+} \tau^- \bar{\nu}_\tau) = (2.02^{+0.40}_{-0.37} \pm 0.37)/%$ [15].

We determine the branching fractions of four exclusive decay modes: $B^- \to D_0^0 \tau^- \bar{\nu}_\tau$, $B^- \to D^{0*} \tau^- \bar{\nu}_\tau$, $B^0 \to D^{*+} \tau^- \bar{\nu}_\tau$, and $\bar{B}^0 \to D^{*+} \tau^- \bar{\nu}_\tau$, each of which is measured relative to the corresponding $e$ and $\mu$ modes. To reconstruct the $\tau$, we use the decays $\tau^- \to e^- \bar{\nu}_e \nu_\tau$ and $\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$, which are experimentally most accessible. The main challenge of the measurement is to separate $B \to D^{(*)} \tau^- \bar{\nu}_\tau$ decays, which have three neutrinos, from $B \to D^{(*)} \ell^- \bar{\nu}_\ell$ decays, which have the same observable final-state particles but only one neutrino.

We analyze data collected with the BABAR detector [10] at the PEP-II $e^+ e^-$ storage rings at the Stanford Linear Accelerator Center. The data sample comprises 208.9 fb$^{-1}$ of integrated luminosity recorded on the $\Upsilon(4S)$ resonance, yielding $32.3 \times 10^6 BB\bar{B}$ decays.

The analysis strategy is to reconstruct the decays of both $B$ mesons in the $\Upsilon(4S) \to BB\bar{B}$ event, providing powerful constraints on unobserved particles. One $B$ meson, denoted $B_{\text{tag}}$, is fully reconstructed in a purely hadronic decay chain. The remaining charged particles and photons are required to be consistent with the products of a $b \to c$ semileptonic $B$ decay: a hadronic system, a $D^{(*)}$ meson, and a lepton ($e$ or $\mu$). The lepton may be either primary or from $\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau$. We calculate the missing four-momentum $p_{\text{miss}} = [p_e + e^- - p_{\text{tag}} - p_{D^{(*)}} - p_\ell]$ of any particles recoiling against the observed $B_{\text{tag}} + D^{(*)}\ell$ system. A large peak at zero in $m_{\text{miss}}^2 = p_{\text{miss}}^2$ corresponds to semileptonic decays with one neutrino, whereas signal events form a broad tail out to $m_{\text{miss}}^2 \sim 8$ (GeV/c$^2$)$^2$. To separate signal and background events, we perform a fit to the joint distribution of $m_{\text{miss}}^2$ and the lepton momentum ($[p_\ell^2]$) in the rest frame of the $B$ meson. In signal events, the observed lepton is the daughter of the $\tau$ and typically has a soft spectrum; for most background events, this lepton typically has higher momentum.

We reconstruct $B_{\text{tag}}$ candidates [17] in 1114 final states $B_{\text{tag}} \to D^{(*)} \Upsilon^\pm$. Tag-side $D^{(*)}$ candidates are reconstructed in 21 decay chains, and the $\Upsilon^\pm$ system may consist of up to six light hadrons ($\pi^\pm$, $\pi^0$, $K^\pm$, or $K^0_S$). $B_{\text{tag}}$ candidates are identified using two kinematic variables, $m_{\text{ES}} = \sqrt{s}/4 - |p_{\text{tag}}|^2$ and $\Delta E = E_{\text{tag}} - \sqrt{s}/2$, where $\sqrt{s}$ is the total $e^+ e^-$ energy, $|p_{\text{tag}}|$ is the magnitude of the $B_{\text{tag}}$ momentum, and $E_{\text{tag}}$ is the $B_{\text{tag}}$ energy, all defined in the $e^+ e^-$ center-of-mass frame. We require $m_{\text{ES}} > 5.27$ GeV/c$^2$ and $|\Delta E| < 72$ MeV, corresponding to $\pm 4\sigma$ (standard deviations). We reconstruct $B_{\text{tag}}$ candidates in approximately 0.3% to 0.5% of $BB\bar{B}$ events.

For the $B$ meson decaying semileptonically, we reconstruct $D^{(*)}$ candidates in the modes $D^0 \to K^- \pi^+$, $K^- \pi^+ \pi^0$, $K^- \pi^+ \pi^- \pi^0$, $K^- \pi^+ \pi^- \pi^0$, $K_0^{*+} \pi^0$, $K^0_{\pi^+} \pi^-$, $D^0 \to K^- \pi^+ \pi^0$, $K^- \pi^+ \pi^0$, $K_0^{*+} \pi^0$, $K^- \pi^+ \pi^0$, $D^0 \to D^0 \pi^0$, $D^0 \pi^0$; and $D^* \to D^{0*} \pi^0$, $D^* \pi^0$. $D (D^*)$ candidates are selected within $4\sigma$ of the $D$ mass ($D^* - D$ mass difference), with $\sigma$ typically $5$–$10$ MeV/c$^2$ ($1$–$2$ MeV/c$^2$). Electron candidates must have lab-frame momentum $|p_\ell| > 300$ MeV/c; muon candidates must have an appropriate
signature in the muon detector system, effectively requiring $|p_{\mu}| \gtrsim 600$ MeV/$c$. The energy of electron candidates is corrected for bremsstrahlung energy loss if photons are found close to the electron direction.

We require that all charged tracks be associated with either the $B_{\text{tag}}$, $D^{(*)}$, or $\ell$ candidate. We compute $E_{\text{extra}}$, the sum of the energies of all photon candidates not associated with the $B_{\text{tag}} + D^{(*)} \ell$ candidate system, and we require $E_{\text{extra}} < 150$–300 MeV, depending on the $D^{(*)}$ channel. We suppress hadronic events and combinatorial backgrounds by requiring $|p_{\text{miss}}| > 200$ MeV/$c$ and $q^2 > 4$ (GeV/$c^2$)$^2$. If multiple candidate systems pass this selection, we select the one with the lowest value of $E_{\text{extra}}$. To improve the $m^2_{\text{miss}}$ resolution, we perform a kinematic fit to the event, constraining particle masses to known values and requiring tracks from $B$, $D$, and $K^0_S$ mesons to originate from appropriate common vertices. All event selection requirements and fit procedures have been defined using simulated events or using control samples in data that exclude the signal region.

Figure 1 shows the distributions of $m^2_{\text{miss}}$ for the four $D^{(*)} \ell$ channels, along with the projections of the maximum likelihood fit discussed below. We observe large peaks at $m^2_{\text{miss}} \approx 0$ as well as events in the signal region at large $m^2_{\text{miss}}$. The peaks are mainly due to $D^{(*)} \ell \rightarrow \tau_{\ell} \ell\nu_{\ell}$, which serve as normalization modes. The structure of this background is shown in the inset figures, which expand the region $-0.4 < m^2_{\text{miss}} < 1.4$ (GeV/$c^2$)$^2$. $B \rightarrow D^{\ast} \ell \tau_{\ell}$ background is the dominant feature in the two $D^{\ast} \ell$ channels (Figs. 1a, c); the two $D\ell$ channels (Figs. 1b, d) are dominated by $B \rightarrow D\ell \tau_{\ell}$ decays but also include substantial contributions from true $D^{\ast}$ mesons where the low-momentum $\pi^0$ or photon from $D^\ast \rightarrow D\pi^0$ or $D\gamma$ is not reconstructed. Similarly, $B \rightarrow D^{\ast\ast} \ell \tau_{\ell}$ events can feed down to the $D\ell$ channels. The fit therefore includes feed-down components for both the signal and normalization modes, as well as smaller feed-up contributions from $B \rightarrow D(\ell^-/\tau^-)\pi$ into the $D^{\ast} \ell$ channels. Other sources of background include $B \rightarrow D^{\ast\ast}(\ell^-/\tau^-)\pi$ events (here $D^{\ast\ast}$ represents charm resonances heavier than the $D^\ast(2010)$, as well as non-resonant $D^{(*)}n\pi$ systems with $n \geq 1$); charge-crossfeed ($B \rightarrow D^{(*)}e^-\pi^0\pi^\pm$) events reconstructed with the wrong charge for the $B_{\text{tag}}$ and $D^{(*)}$ meson, typically because a low-momentum $\pi^\pm$ is swapped between them); and combinatorial background. This last background is dominated by hadronic $B$ decays, such as $B \rightarrow D^{(*)}D_s^{(*)}$, that produce a secondary lepton, including $\tau$ leptons from $D_s$ decay.

To constrain $B \rightarrow D^{\ast\ast}(\ell^-/\tau^-)\pi$ background, we select four control samples, identical to the signal channels but in which an extra $\pi^0$ meson is observed. Most of the $D^{\ast\ast}$ background in the signal channels occurs when the $\pi^0$ from $D^{\ast\ast} \rightarrow D^{(*)}\pi^0$ is not reconstructed, so these control samples provide a normalization of the background source. $D^{\ast\ast}$ decays in which a $\pi^0$ is lost do not have the correct charge correlation between the $B_{\text{tag}}$ and $D^{(*)}$, and decays with two missing charged pions are rare. The feed-down probabilities for the $D^{\ast\ast}(\ell^-/\tau^-)\pi$ background are determined from simulation, with uncertainties in the $D^{\ast\ast}$ content treated as a systematic error.

We perform a relative measurement, extracting both signal $B \rightarrow D^{(*)}\tau^-\pi_\tau$ and normalization $B \rightarrow D^{(*)}\ell^-\tau_\ell$ yields from the fit to obtain the four branching ratios $R(D^0)$, $R(D^+)$, $R(D^{*0})$, and $R(D^{*+})$, where, for exam-
ple, \( R(D^*) \equiv B(B^- \rightarrow D^{**0} \tau^- \nu_\tau) / B(B^- \rightarrow D^{*0} \ell^- \nu_\ell) \). These ratios are normalized such that \( \ell \) represents only one of \( e \) or \( \mu \); however, both light lepton species are included in the measurement. Signal and background yields are extracted using an extended, unbinned maximum likelihood fit to the joint \((m_{\text{miss}}^2, |p_T^\ell|)\) distribution. The 18-parameter fit is performed simultaneously in the four signal channels and the four \( D^{**} \) control samples. In each of the four signal channels, we describe the data as the sum of seven components (shown in Fig. 1): \( D^+ \rightarrow \tau^+ \nu_\tau \), \( D^0 \rightarrow \tau^- \nu_\tau \), \( D^0 \rightarrow \ell^- \nu_\ell \), \( D^{**} \rightarrow (\ell^-/\tau^-) \nu_\tau \) charge crossfeed, and combinatorial background. The four \( D^{**} \) control samples are described as the sum of five components: \( D^{**} \rightarrow (\ell^-/\tau^-) \nu_\tau \), \( D^+ \rightarrow \ell^- \nu_\ell \), \( D^+ \rightarrow 2 \ell^- \nu_\ell \), charge crossfeed, and combinatorial background. Probability distribution functions (PDFs) are primarily determined from simulated event samples. Both the signal and normalization modes are described using HQET-based form factors [18] for which the parameters and their uncertainties are determined by experimental measurements [11]. Parameters describing the amount of the dominant feed-down components—\( D^+ \) feed-down into the \( D \) channels—are determined directly by the fit.

Table I summarizes the results from two fits, one in which all four signal yields can vary independently, and a second fit in which we constrain \([19]\). \( R(D^+) = R(D^0) \) and \( R(D^{**}) = R(D^{*0}) \). The \( m_{\text{miss}}^2 \) projections shown in Fig. 1 are those from this \( B^- \rightarrow B^- \) constrained fit.

The features of the event sample have been extensively checked. The observed lepton spectra are well described by the fit both in signal- and in background-dominated regions. The properties of reconstructed \( B_{\text{tag}} \) mesons, such as charged and neutral daughter multiplicities, are consistent with expectations. Control samples of \( B \rightarrow D^+(s) \ell^- \nu_\ell \) events, kinematically selected without a cut on \( m_{\text{miss}}^2 \), provide checks of numerous distributions, including the \( m_{\text{miss}}^2 \) tails.

Systematic uncertainties on \( R \) associated with the fit, \((\Delta R/R)_{\text{fin}}\) in Table II, are determined by running ensembles of fits in which input parameters are distributed according to our knowledge of the underlying source, and include the PDF parametrization (2% to 12%); the composition of combinatorial backgrounds (2% to 11%); the mixture of \( D^{**} \) states in \( B \rightarrow D^{**} \ell^- \nu_\ell \) decays (0.3% to 6%); the \( B \rightarrow D^* \) form factors (0.2% to 1.9%); the \( \pi^0 \) reconstruction efficiency, which affects the \( D^* \) and \( D^{**} \) feed-down rates (0.5% to 1.1%); and the \( m_{\text{miss}}^2 \) resolution for \( B \rightarrow D^+ \ell^- \nu_\ell \) events (0.1% to 1.6%). Uncertainties on the \( B \rightarrow D^* \) form factors contribute less than 1%. Uncertainties on \( R \) propagated from the ratio of efficiencies, \((\Delta R/R)_{\text{eff}}\) in Table II, are typically small due to cancellations, and include the limited statistics in the simulation (0.8% to 1.5%) and systematic errors related to detector performance (0.2% to 0.7%). Uncertainties from modeling final-state radiation are 0.3% to 0.5%; uncertainties on the branching fractions of the reconstructed modes contribute 0.3% or less. Finally, the uncertainty on \( B(\tau^- \rightarrow \ell^- \nu_\ell \nu_\tau) \) [14] contributes 0.2% to all modes.

Table II gives the significances of the signal yields. The statistical significance is determined from \( \sqrt{2\Delta (\ln L)} \), where \( \Delta (\ln L) \) is the change in log-likelihood between the nominal fit and the no-signal hypothesis. The total significance is determined by including \((\Delta R/R)_{\text{fin}}\) in quadrature with the statistical error.

We have presented measurements of the decays \( B \rightarrow D^+ \ell^- \nu_\ell \) and \( B \rightarrow D^* \ell^- \nu_\ell \), relative to the corresponding decays to light leptons. We find \( R(D) = (41.6 \pm 11.7 \pm 5.2)\% \) and \( R(D^*) = (29.7 \pm 5.6 \pm 1.8)\% \), where the first error is statistical and the second is systematic. Normalizing to known \( B^0 \) branching fractions [20], we obtain

\[
B(B \rightarrow D^+ \ell^- \nu_\ell) = (0.86 \pm 0.24 \pm 0.11 \pm 0.06)\%
\]

\[
B(B \rightarrow D^* \ell^- \nu_\ell) = (1.62 \pm 0.31 \pm 0.10 \pm 0.05)\%
\]

where the third error is from that on the normalization mode branching fraction. The significances of the signals are 3.6\( \sigma \) and 6.2\( \sigma \), respectively. The modes \( B^- \rightarrow D^0 \ell^- \nu_\ell \), \( B^- \rightarrow D^{*0} \ell^- \nu_\ell \), and \( B^- \rightarrow D^0 \tau^- \nu_\tau \) have not been studied previously, while the measurement of \( B^0 \rightarrow D^{**} \ell^- \nu_\ell \) is consistent with the Belle result [15].

The averaged branching fractions are about 1\( \sigma \) higher than the SM predictions but, given the uncertainties, there is still room for a sizeable non-SM contribution.

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), CEA and CNRS-IN2P3 (France), BMBF and DFG (Germany), INFN (Italy), FOM (The Netherlands), NFR (Norway), MIST (Russia), MEC (Spain), and STFC (United Kingdom). Individuals have received support from the Marie Curie EIF (European Union) and the A. P. Sloan Foundation.

* Deceased
1 Now at Tel Aviv University, Tel Aviv, 69978, Israel
2 Also with Università di Perugia, Dipartimento di Fisica, Perugia, Italy
3 Also with Università della Basilicata, Potenza, Italy
4 Also with Universita’ di Sassari, Sassari, Italy
5 Also with Universitat de Barcelona, Facultat de Fisica, Departament ECM, E-08028 Barcelona, Spain
Table 1: Results from fits to data: the signal yield \(N \text{sig}\), the yield of normalization \(B \rightarrow D^{(*)} \ell^- \overline{\nu}_\ell\) events \(N \text{norm}\), the ratio of signal and normalization mode efficiencies \(\varepsilon \text{sig}/\varepsilon \text{norm}\), the relative systematic error due to the efficiency ratios \((\Delta R/R) \text{rel}\), the relative systematic error due to the fit yields \((\Delta R/R) \text{fit}\), the branching fraction relative to the normalization mode \(R\), the absolute branching fraction \(B\), and the total and statistical signal significances \((\sigma \text{tot}, \sigma \text{stat})\). The last two rows show the results of the fit with the \(B^- \overline{B}^+\) constraint applied, where \(B\) is expressed for the \(\overline{B}^+\). The statistical correlation between \(R(D)\) and \(R(D^*)\) in this fit is \(-0.51\).

<table>
<thead>
<tr>
<th>Mode</th>
<th>(N \text{sig})</th>
<th>(N \text{norm})</th>
<th>(\varepsilon \text{sig}/\varepsilon \text{norm})</th>
<th>((\Delta R/R) \text{fit})</th>
<th>((\Delta R/R) \text{rel})</th>
<th>(R)</th>
<th>(B)</th>
<th>(\sigma \text{tot})</th>
<th>(\sigma \text{stat})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(B^- \rightarrow D^+ \tau^- \overline{\nu}_\tau)</td>
<td>35.6±19.4</td>
<td>347.9±23.1</td>
<td>1.85</td>
<td>15.5</td>
<td>1.6</td>
<td>31.4±17.0±4.9</td>
<td>0.67±0.37±0.11±0.07</td>
<td>1.8 (1.8)</td>
<td></td>
</tr>
<tr>
<td>(B^- \rightarrow D^{0} \tau^- \overline{\nu}_\tau)</td>
<td>92.2±19.6</td>
<td>1629.9±63.6</td>
<td>0.99</td>
<td>9.7</td>
<td>1.5</td>
<td>34.6±7.3±3.4</td>
<td>2.25±0.48±0.22±0.17</td>
<td>5.3 (5.8)</td>
<td></td>
</tr>
<tr>
<td>(\overline{B}^0 \rightarrow D^+ \tau^- \overline{\nu}_\tau)</td>
<td>23.3±7.8</td>
<td>150.2±13.3</td>
<td>1.83</td>
<td>13.9</td>
<td>1.8</td>
<td>48.9±16.5±6.9</td>
<td>1.04±0.35±0.15±0.10</td>
<td>3.3 (3.6)</td>
<td></td>
</tr>
<tr>
<td>(\overline{B}^0 \rightarrow D^{+} \tau^- \overline{\nu}_\tau)</td>
<td>15.5±7.2</td>
<td>482.3±25.5</td>
<td>0.91</td>
<td>3.6</td>
<td>1.4</td>
<td>20.7±9.5±0.8</td>
<td>1.11±0.51±0.04±0.04</td>
<td>2.7 (2.7)</td>
<td></td>
</tr>
<tr>
<td>(B \rightarrow D \tau^- \overline{\nu}_\tau)</td>
<td>66.9±18.9</td>
<td>497.8±26.4</td>
<td>—</td>
<td>12.4</td>
<td>1.4</td>
<td>41.6±11.7±5.2</td>
<td>0.86±0.24±0.11±0.06</td>
<td>3.6 (4.0)</td>
<td></td>
</tr>
<tr>
<td>(B \rightarrow D^+ \tau^- \overline{\nu}_\tau)</td>
<td>101.4±19.1</td>
<td>2111.5±68.1</td>
<td>—</td>
<td>5.8</td>
<td>1.3</td>
<td>29.7±5.6±1.8</td>
<td>1.62±0.31±0.10±0.05</td>
<td>6.2 (6.5)</td>
<td></td>
</tr>
</tbody>
</table>

[9] Charge-conjugate modes are implied throughout.
[10] Throughout this letter, we use the symbol \(\ell\) to refer only to the light charged leptons \(e\) and \(\mu\). The symbol \(D^{(*)}\) refers either to a \(D\) or a \(D^*\) meson.
[19] This constraint follows from isospin symmetry in both the signal and normalization modes but is more general.
[20] We use [14] to normalize the four individual branching fractions. For the \(B^- \overline{B}^+\)-constrained measurement, we use our own averages of the values in [14]: \(B(\overline{B}^0 \rightarrow D^+ \ell^- \overline{\nu}_\ell) = (2.07 \pm 0.14)\%\) and \(B(\overline{B}^0 \rightarrow D^{+} \ell^- \overline{\nu}_\ell) = (5.46 \pm 0.18)\%\).