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Measurement of the Semileptonic $\bar{B} \to D^{(*)}\tau\bar{\nu}_\tau$ Decays at BABAR

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Abstract. Semileptonic B meson decays into final states containing the τ lepton are of interesting as they provide information on the Standard Model as well as a window on new physics effects. We present results on $\bar{B} \to D^{(*)}\tau\bar{\nu}_\tau$ decays where the second B in the event is fully reconstructed.

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INTRODUCTION

Semileptonic decays of B mesons to the τ lepton provide a new source of information on Standard Model (SM) processes [1-3], as well as a new window on physics beyond the SM [4-10]. In the SM, semileptonic decays occur at tree level and are mediated by the W boson, but the large mass of the τ lepton provides sensitivity to additional amplitudes, such as those mediated by a charged Higgs boson. Experimentally, $b \to c\tau^-\bar{\nu}_\tau$ decays are challenging to study because the final state contains not just one, but two or three neutrinos as a result of the τ decay.

Branching fractions for semileptonic B decays to τ leptons are predicted to be smaller than those to light leptons. Calculations based on the SM predict $\mathscr{B}(\bar{B}^0 \to D^+\tau^-\bar{\nu}_\tau) = (0.69 \pm 0.04)\%$ and $\mathscr{B}(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau) = (1.41 \pm 0.07)\%$ [8-9]. In multi-Higgs doublet models [4-9], substantial departures, either positive or negative, from the SM decay rate could occur for $\bar{B} \to D\tau^-\bar{\nu}_\tau$, while smaller departures are expected for $\bar{B} \to D^*\tau^-\bar{\nu}_\tau$. The BABAR Collaboration has presented a measurement of the branching fractions for $\bar{B} \to D\tau^-\bar{\nu}_\tau$ and $\bar{B} \to D^*\tau^-\bar{\nu}_\tau$ for both charged and neutral B mesons, that is described in the following [11]. The BELLE Collaboration has also performed a similar measurement [12]. A preliminary averages of the different measurements available is also reported in this Proceeding.

EVENT RECONSTRUCTION

Semileptonic $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$ decays are selected in $B\bar{B}$ events in which a hadronic decay of the second B meson ($B_{\rm tag}$) is fully reconstructed. To reconstruct the τ , we use the decays $\tau^- \to e^-\bar{\nu}_e\nu_\tau$ and $\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$, which are experimentally the most accessible. The main challenge of the measurement is to distinguish $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$ decays, which have three neutrinos, from $\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell$ decays (where $\ell = e, \mu$), which have the same observable final-state particles but only one neutrino. This goal is achieved by using the

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missing four-momentum in the event, $p_{\rm miss} = p_{e^+e^-} - p_{\rm tag} - p_{D^{(*)}} - p_\ell$, of any particles recoiling against the observed $B_{\rm tag} + D^{(*)}\ell$ system. A large peak at zero in $m^2_{\rm miss} = p^2_{\rm miss}$ corresponds to semileptonic decays with one neutrino, whereas signal events produce a broad tail out to $m^2_{\rm miss} \simeq 8$ (GeV/c^2)^2 .

We reconstruct $B_{\rm tag}$ decays in charmed hadronic modes $\bar{B} \to D^{(*)}Y$, where Y represents a collection of hadrons, composed of $n_1\pi^\pm + n_2K^\pm + n_3K^0_S + n_4\pi^0$, where $n_1 + n_2 = 1,3,5$, $n_3 \leq 2$, and $n_4 \leq 2$, as described in [11]. For the B meson decaying semileptonically, we reconstruct $D^{(*)}$ candidates in several different decay modes [11]. We form whole-event candidates by combining $B_{\rm tag}$ candidates with $D^{(*)}\ell^-$ candidate systems.

In correctly reconstructed signal and normalization events, all of the stable final-state particles, with the exception of the neutrinos, are associated with either the $B_{\rm tag}$, $D^{(*)}$ or ℓ^- candidate. Events with additional particles in the final state must therefore have been misreconstructed, and we suppress these backgrounds by requiring that all observed charged tracks be associated with either the $B_{\rm tag}$, $D^{(*)}$ or ℓ candidate. We compute $E_{\rm extra}$, the sum of the energies of all photon candidates not associated with the $B_{\rm tag} + D^{(*)}\ell$ candidate system, and we require $E_{\rm extra} <$ 150-300 MeV, depending on the $D^{(*)}$ channel.

We suppress hadronic events and combinatorial backgrounds by requiring $|p_{\rm miss}| >$ 200 MeV/c to reject hadronic events such as $B \to D^{(*)}\pi^-$, where the π^- is misidentified as a μ^-. We further suppress background by requiring $q^2 > 4$ (GeV/c^2)^2 , where q^2 is calculated as $q^2 = [p_{e^+e^-} - p_{B_{\rm tag}} - p_{D^{(*)}}]^2$. This requirement preferentially rejects combinatorial backgrounds from two-body B decays such as $B \to D^{(*)}D$, where one D meson decays semileptonically. If multiple candidate systems pass our selection in a given event, we select the one with the lowest value of $E_{\rm extra}$.

We also select four control samples to constrain the poorly known $\bar{B} \to D^{**}\ell^-\bar{\nu}_\ell$ background. The selection is identical to that of the signal channels, but we require the presence of a π^0 meson, with momentum greater than 400 MeV/c, in addition to the $B_{\rm tag} + D^{(*)}\ell$ system. The event must satisfy $E_{\rm extra} <$ 500 MeV, where the two photons from $\pi^0 \to \gamma\gamma$ are excluded from the calculation of $E_{\rm extra}$.

SIGNAL YIELD EXTRACTION

To separate signal and background events, we perform an extended unbinned maximum likelihood fit to the joint distribution of $m^2_{\rm miss}$ and the lepton momentum (p^*_ℓ) in the rest frame of the B meson. The fit is performed simultaneously in eight channels (the four $D^{(*)}\ell$ selected samples and the four $D^{**}\ell$ control samples), with a set of constraints relating the event yields between the channels.

Figure 1 shows the projections of the fit to data in $m^2_{\rm miss}$ for the four signal channels, showing both the low $m^2_{\rm miss}$ region, which is dominated by the normalization modes $\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\tau$, and the high $m^2_{\rm miss}$ region, which is dominated by the signal modes $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$.

In order to minimize the systematic uncertainties due to the $B_{\rm tag}, D^{(*)}$ and ℓ

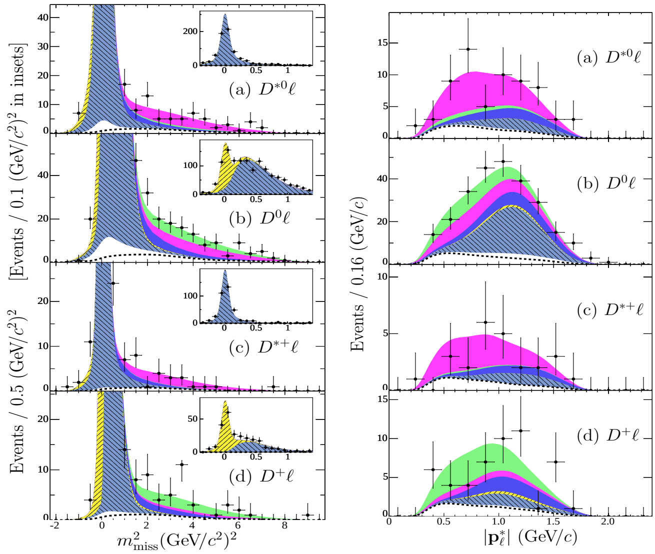

FIGURE 1. Left: distributions of events and fit projections in m^2_{miss} for the four final states: $D^{*0}\ell^-$, $D^0\ell^-$, $D^{*+}\ell^-$ and $D^+\ell^-$. The normalization region $m^2_{miss} \approx 0$ is shown with finer binning in the insets. The fit components are combinatorial background (white), the $\bar{B} \to D\ell^-\bar{\nu}_\ell$ normalization mode (yellow), the $\bar{B} \to D^*\ell^-\bar{\nu}_\ell$ normalization mode (light blue), $\bar{B} \to D^{**}\ell^-\bar{\nu}_\ell$ background (dark, or blue), the $\bar{B} \to D\tau^-\bar{\nu}_\tau$ signal (light grey, green), and the $\bar{B} \to D^*\tau^-\bar{\nu}_\tau$ signal (medium grey, magenta). Right: Distributions of events and fit projections in $|p^*_\ell|$ in the signal region, $m^2_{miss} > 1(\mathrm{GeV}/c^2)^2$.

reconstruction, we measure the relative branching fractions $R(D^{(*)}) = \mathscr{B}(\bar{B} \to D^*\tau^-\bar{\nu}_\tau)/\mathscr{B}(\bar{B} \to D^*\ell^-\bar{\nu}_\ell)$, as reported in Table 1.

TABLE 1. Results from fits to data: the signal yield ($N_{\rm sig}$), the yield of normalization $\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell$ events ($N_{\rm norm}$), the branching-fraction ratio (R), and the absolute branching fraction ($\mathscr{B}$). The first two errors on R and $\mathscr{B}$ are statistical and systematic, respectively; the third error on $\mathscr{B}$ represents the uncertainty on the normalization mode. The last two rows show the results of the fit with the B^-–$\bar{B}^0$ constraint applied, where $\mathscr{B}$ is expressed for the $\bar{B}^0$.

Decay Mode	N_{sig}	N_{norm}	R[%]	$\mathscr{B}$[%]
$B^- \to D^0\tau^-\bar{\nu}_\tau$	35.6 ± 19.4	347.9 ± 23.1	$31.4 \pm 17.0 \pm 4.9$	$0.67 \pm 0.37 \pm 0.11 \pm 0.07$
$B^- \to D^{*0}\tau^-\bar{\nu}_\tau$	92.2 ± 19.6	1629.9 ± 63.6	$34.6 \pm 7.3 \pm 3.4$	$2.25 \pm 0.48 \pm 0.22 \pm 0.17$
$\bar{B}^0 \to D^+\tau^-\bar{\nu}_\tau$	23.3 ± 7.8	150.2 ± 13.3	$48.9 \pm 16.5 \pm 6.9$	$1.04 \pm 0.35 \pm 0.15 \pm 0.10$
$\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$	15.5 ± 7.2	482.3 ± 15.5	$20.7 \pm 9.5 \pm 0.8$	$1.11 \pm 0.51 \pm 0.04 \pm 0.04$
$\bar{B} \to D\tau^-\bar{\nu}_\tau$	66.9 ± 18.9	497.8 ± 26.4	$41.6 \pm 11.7 \pm 5.2$	$0.86 \pm 0.24 \pm 0.11 \pm 0.06$
$\bar{B} \to D^*\tau^-\bar{\nu}_\tau$	101.4 ± 19.1	2111.5 ± 68.1	$29.7 \pm 5.6 \pm 1.8$	$1.62 \pm 0.31 \pm 0.10 \pm 0.05$

The main sources of systematic uncertainty are due to the parameterization of the probability density functions used in the 2-d fit, and the background modeling, in addition to the $\mathscr{B}(\bar{B} \to D^*\ell^-\bar{\nu}_\ell)$ for the branching fraction measurement.

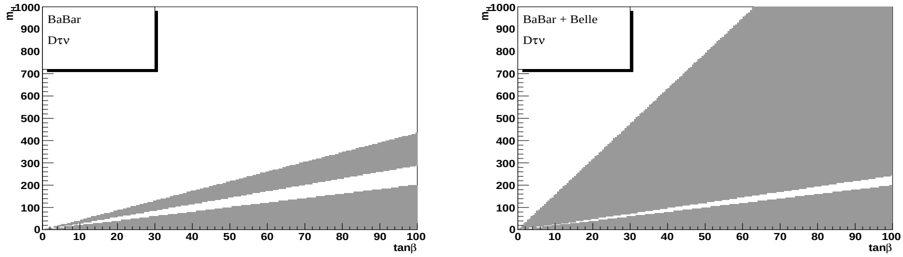

FIGURE 2. Left: 2-d exclusion region in the $m_H - \tan\beta$ space for the $R(D)$ *BABAR* measurement. Right: 2-d exclusion region in the $m_H - \tan\beta$ space for the $R(D)$ average from the *BABAR* and BELLE measurements.

NEW PHYSICS CONSTRAINTS

The branching ratios $R(D)$ and $R(D^*)$ can be calculated as function of m_H and $\tan\beta$ type-II 2HDM models involving charged Higgs doublets [5]. The measured $R(D)$ and $R(D^*)$ values can therefore be used to compute the probability that a given point in the $m_H - \tan\beta$ space is allowed or excluded.

The *BABAR* results for $R(D)$ and $R(D^*)$ can also be averaged with recent results on the same branching fractions by BELLE [12]. The author's personal averages for $R(D)$ and $R(D^*)$ give $R(D) = (49.8 \pm 10.2)\%$ and $R(D^*) = (34.8 \pm 4.8)\%$. The 2-d exclusion regions in the $m_H - \tan\beta$ space for the *BABAR* and the combined *BABAR* + BELLE averages are shown in Fig. 2.

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