Measurement of $|V_{cb}|$ and $b \to c\ell\nu$ Transitions at BABAR

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Abstract. Three recent preliminary results on $b \to c\ell\nu$ transitions of the BABAR collaboration are presented, all using about 230 million $B\bar{B}$ events recorded on the $\Upsilon(4S)$ resonance with the BABAR detector at the SLAC e^+e^- storage rings PEP-II.

$B^- \to D^{*0}e^-\bar{\nu}_e$ decays are reconstructed using the decay chain $D^{*0} \to D^0\pi^0$ and $D^0 \to K^-\pi^+$. We obtain the preliminary results $\rho_{A_1}^2 = 1.15 \pm 0.06 \pm 0.08$, $F(1)|V_{cb}| = (36.3 \pm 0.6 \pm 1.4) \cdot 10^{-3}$, and $\mathcal{B}\left(B^- \to D^{*0}e^-\bar{\nu}_e\right) = (5.71 \pm 0.08 \pm 0.41)\%$.

We present a measurement of hadronic moments in semileptonic $\bar{B} \to X_c\ell^-\bar{\nu}$ decays. Preliminary results are reported for the moments $\langle m_X^k \rangle$ with $k = 1, \ldots, 6$ and $\langle n_X^k \rangle$ with $k = 2, 4, 6$ and $n_X^2 = m_X^2 c^4 - 2\tilde{\Lambda}E_X + \tilde{\Lambda}^2$, where m_X is the mass of the hadronic system, E_X its energy, and $\tilde{\Lambda}$ a constant of $0.65\,\mathrm{GeV}$. From a fit of HQE predictions to measured moments, we find as preliminary results $|V_{cb}| = (41.88 \pm 0.81) \cdot 10^{-3}$ and $m_b = (4.552 \pm 0.055)\,\mathrm{GeV}/c^2$.

We present preliminary measurements of branching fractions for the semileptonic decays $B \to D\tau^-\bar{\nu}_\tau$ and $B \to D^*\tau^-\bar{\nu}_\tau$. Combining B^- and $\bar{B}^0$ results, we obtain, in addition to results for the individual modes, the branching fractions $\mathcal{B}(B \to D\tau^-\bar{\nu}_\tau) = (0.90 \pm 0.26 \pm 0.11 \pm 0.06)\%$ and $\mathcal{B}(B \to D^*\tau^-\bar{\nu}_\tau) = (1.81 \pm 0.33 \pm 0.11 \pm 0.06)\%$ (quoted for the B^- lifetime), with significances of 3.5σ and 6.2σ.

1. Introduction

Semileptonic (s.l.) B-meson decays $B \to X_c\ell\nu$ provide direct access to the CKM matrix element $|V_{cb}|$ and furthermore probe the structure of B mesons through observables of these decays.

Observables of inclusive decays are sensitive to quantities such as the mass and momentum distribution of the b quark inside the B meson. These properties can be extracted from fits of predictions calculated in a Heavy Quark Expansion (HQE) to measured inclusive hadronic or leptonic moments. Exclusive decays depend on form factors for specific final states. The decay $B \to D^*\ell\nu$ is most suitable for the extraction of $|V_{cb}|$ due to its large decay rate and comparably clean experimental environment. Semileptonic decays including τ leptons provide, besides a new source of information on the Standard Model (SM), a window to physics beyond the SM, as this decay can be mediated by a charged Higgs boson.

2. Measurement of the Decay $B^- \to D^{*0}\ell^-\bar{\nu}_e$

In the case of the decay $B \to D^*\ell\nu$, the SM parameter $|V_{cb}|$ is connected to the differential decay rate in terms of w, the boost of the D^* in the B-meson rest-frame, $\mathrm{d}\Gamma/\mathrm{d}w = (G_F^2|V_{cb}|^2)/(48\pi^3) \cdot \mathcal{F}^2(w)\mathcal{G}(w)$. Here $\mathcal{G}(w)$ is a phase-space factor and $\mathcal{F}^2(w)$ is a form factor (FF), which can be calculated precisely at $w = 1$. As the phase space is empty at this point, the spectrum $\mathrm{d}\mathcal{B}/\mathrm{d}w$ is

measured and extrapolated to $w = 1$ using a parametrization with one free parameter, the slope parameter $\rho_{A_1}^2$ [1]. Measurements of the s.l. decay of B^0 mesons to $D^{*\pm}$ mesons have yielded similar results for the branching fraction but differed in the measured values of $\rho_{A_1}^2$. Therefore, the measurement of the isospin symmetric decay $B^- \to D^{*0}\ell^-\overline{\nu}_e$ can further constrain our knowledge of $\rho_{A_1}^2$ and thus $|V_{cb}|$. This section summarizes the results for the measurement of this decay presented in [2].

$B^- \to D^{*0}e^-\overline{\nu}_e$ candidates [3] are selected by pairing electrons with $p^* > 1.2\,\text{GeV}/c$ in the e^+e^- rest frame with D^{*0} candidates. The analysis is restricted to the sequential decay modes $D^{*0} \to D^0\pi^0$ and $D^0 \to K^-\pi^+$, which have the smallest combinatorial background and the best resolution in $\Delta m \equiv m(K^-\pi^+\pi^0) - m(K^-\pi^+)$. The decay is distinguished from background decays through the two variables Δm and $\cos\theta_{\text{BY}}^*$, defined as $\cos\theta_{\text{BY}}^* = (2E_B^*E_Y^* - m_B^2 - m_Y^2)/(2p_B^*p_Y^*)$ with Y the D^*e system. As the direction of the B momentum is not measured, only an estimate $\tilde{w}$ for the variable w can be calculated. To extract the signal, a binned maximum likelihood fit to the 3-dimensional distribution in Δm, $\cos\theta_{\text{BY}}^*$, and $\tilde{w}$ is performed, yielding directly $\mathcal{F}(1)|V_{cb}|$ and $\rho_{A_1}^2$. The main systematic uncertainties arise from the slow π^0 reconstruction efficiency, the branching fraction $\mathcal{B}(D^{*0} \to D^0\pi^0)$ and the measured FF ratios $R_1(1)$ and $R_2(1)$ entering in the parametrization of $\text{d}\mathcal{B}/\text{d}w$ and thus the extracted value of $\rho_{A_1}^2$.

The preliminary results obtained from this analysis are $F(1)|V_{cb}| = (36.3 \pm 0.6 \pm 1.4) \cdot 10^{-3}$, $\rho_{A_1}^2 = 1.15 \pm 0.06 \pm 0.08$, and $\mathcal{B}(B^- \to D^{*0}e^-\overline{\nu}_e) = (5.71 \pm 0.08 \pm 0.41)\%$. Using $F(1) = 0.919 \pm 0.033$ from lattice QCD [4], we obtain $|V_{cb}| = (39.5 \pm 0.6 \pm 2.0) \cdot 10^{-3}$ in good agreement with the average from the exclusive neutral B decays $B^0 \to D^{*-}\ell^+\nu$ [5], and in agreement with results from the inclusive decays $B \to X_c\ell\nu$ [6].

3. Measurement of Moments of the Hadronic-Mass and -Energy Spectrum in Inclusive Semileptonic $\overline{B} \to X_c\ell^-\overline{\nu}$ Decays

Measurements of moments of the hadronic-mass and lepton-energy spectra in inclusive s.l. decays $\overline{B} \to X_c\ell^-\overline{\nu}$ have been used to determine the non-perturbative QCD parameters describing these decays and the CKM matrix element $|V_{cb}|$. We present an updated measurement of the hadronic-mass moments $\langle m_X^k \rangle$ with $k = 1, \ldots, 6$ based on a larger dataset than previously used [7]. In addition we present measurements of the mixed hadron mass-energy moments $\langle n_X^k \rangle$ with $k = 2, 4, 6$ as proposed in [8]. The moments are measured for different minimal lepton momenta between 0.8 and 1.9 GeV/c measured in the B-meson rest frame. This section summarizes these measurements reported in [9].

The measurement is performed in events tagged by a B meson fully reconstructed in hadronic modes. The s.l. decay of the signal B is selected by an identified electron or muon. All remaining tracks and neutral candidates in the event are used to reconstruct the inclusive X_c system. The moments are extracted after a kinematic fit to the whole event and correction of misreconstruction effects due to lost particles. Main systematic uncertainties of the moments measurement arise from the influence of the reconstruction efficiency on the technique of full event reconstruction.

We perform a combined fit to BABAR measurements of hadronic-mass moments, moments of the lepton-energy spectrum, and moments of the photon-energy spectrum in decays $B \to X_s\gamma$, similar to the one performed in [6]. The fit extracts values for $|V_{cb}|$, the quark masses m_b and m_c, the total s.l. branching fraction $\mathcal{B}(\overline{B} \to X_c\ell^-\overline{\nu})$, and the dominant non-perturbative HQE parameters. These are μ_π^2 and μ_G^2, parameterizing effects at $\mathcal{O}(1/m_b^2)$, and ρ_D^3 and ρ_{LS}^3, parameterizing effects at $\mathcal{O}(1/m_b^3)$. We obtain $|V_{cb}| = (41.88 \pm 0.81) \cdot 10^{-3}$, $m_b = (4.552 \pm 0.055)\,\text{GeV}/c^2$, and $m_c = (1.070 \pm 0.085)\,\text{GeV}/c^2$. The s.l. branching fraction is measured to be $\Gamma_{\text{sl}} = (10.597 \pm 0.179)\,\%$. For the HQE parameters we obtain, $\mu_\pi^2 = (0.471 \pm 0.070)\,\text{GeV}^2$, $\mu_G^2 = (0.330 \pm 0.060)\,\text{GeV}^2$, $\rho_D^3 = (0.220 \pm 0.047)\,\text{GeV}^3$ and $\rho_{LS}^3 = (-0.159 \pm 0.095)\,\text{GeV}^3$. The

values are in good agreement with previous determinations [6].

4. Measurement of the Semileptonic Decays $B \to D\tau\nu$ and $B \to D^*\tau\nu$

Semileptonic decays of B mesons to τ leptons provide a new source of information on SM processes [10], as well as an access to physics beyond the SM [11], as, due to the large τ mass, this decay at tree level can be mediated by a charged Higgs boson. This section summarizes the results presented in [12], which have already been submitted for publication [13].

The branching fractions of four exclusive decay modes are measured [3], $B^- \to D^0\tau^-\bar{\nu}_\tau$, $B^- \to D^{*0}\tau^-\bar{\nu}_\tau$, $\bar{B}^0 \to D^+\tau^-\bar{\nu}_\tau$, and $\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$. The determination of the branching fractions is performed relative to the corresponding e and μ modes (normalization modes). To reconstruct the τ, the decays $\tau^- \to e^-\bar{\nu}_e\nu_\tau$ and $\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$ are used. The analysis is performed in events tagged by a B meson fully reconstructed in hadronic modes. From the remaining particles, D and D^* candidates are reconstructed in various decay modes and an identified lepton is required. Important selection criteria are an upper bound for the energy deposited by additional photons, $E_{\text{extra}} < 150 - 300\,\text{MeV}$, and the requirement of no additional charged tracks in the event. The signal is extracted by an extended unbinned maximum likelihood fit to the variables $m_{\text{miss}}^2 = [P_{e^+e^-} - P_{B_{\text{tag}}} - P_{D^{(*)}} - P_\ell]^2$, with P_x the four-momentum of the corresponding particle(s), and the lepton momentum in the rest frame of the B meson, $|\vec{p}_\ell^{\,*}|$. A large peak at zero in m_{miss}^2 corresponds to semileptonic decays with one neutrino, whereas signal events form a broad tail out to $m_{\text{miss}}^2 \sim 8\,(\text{GeV}/c^2)^2$. The fit extracts both signal $B \to D^{(*)}\tau^-\bar{\nu}_\tau$ and normalization $B \to D^{(*)}\ell^-\bar{\nu}_\ell$ yields, thereby measuring the four branching ratios $R(D^0)$, $R(D^+)$, $R(D^{*0})$, and $R(D^{*+})$. Here, for example, $R(D^{*0}) \equiv \mathcal{B}(B^- \to D^{*0}\tau^-\bar{\nu}_\tau)/\mathcal{B}(B^- \to D^{*0}\ell^-\bar{\nu}_\ell)$, where ℓ represents only one of e or μ. Background contributions from s.l. decays to D^{**} states (i.e. resonances heavier than the $D^*(2010)$ and states $D^{(*)}n\pi$), which, with an unmeasured π^0 and neutrino, accumulate in the signal region in m_{miss}^2, are included in the fit procedure by adding π^0 candidates to the reconstructed $D^{(*)}$ candidate. Main systematic uncertainties arise from the parametrization of the fit pdfs, crossfeed constrains, and the composition of the combinatorial background.

We obtain the branching fractions, $\mathcal{B}(B^- \to D^0\tau^-\bar{\nu}_\tau) = (0.63\pm0.38\pm0.10\pm0.06)\%$, $\mathcal{B}(B^- \to D^{*0}\tau^-\bar{\nu}_\tau) = (2.35 \pm 0.49 \pm 0.22 \pm 0.18)\%$, $\mathcal{B}(\bar{B}^0 \to D^+\tau^-\bar{\nu}_\tau) = (1.03 \pm 0.35 \pm 0.14 \pm 0.10)\%$, and $\mathcal{B}(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau) = (1.15 \pm 0.33 \pm 0.04 \pm 0.04)\%$, where the uncertainties are statistical, systematic, and normalization, respectively. A combined fit to B^- and $\bar{B}^0$ results in $\mathcal{B}(B \to D\tau^-\bar{\nu}_\tau) = (0.90 \pm 0.26 \pm 0.11 \pm 0.06)\%$ and $\mathcal{B}(B \to D^*\tau^-\bar{\nu}_\tau) = (1.81 \pm 0.33 \pm 0.11 \pm 0.06)\%$ (quoted for the B^- lifetime), with significances of 3.5σ and 6.2σ. The results are consistent with a previous measurement [14] and with the SM within 1σ.

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