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New results on semileptonic B decays and CKM matrix elements $|V_{cb}|$ and $|V_{ub}|$ at Belle

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Measurements of leptonic and semileptonic B meson decays are vital for the determination of CKM matrix elements $|V_{cb}|$ and $|V_{ub}|$. This article presents the measurements of semileptonic B decays $B^0 \to D^* \ell \nu_\ell$, $B \to D^{(*)} \pi \ell \nu$, $B \to \eta^{(\prime)} \ell \nu_\ell$ and the leptonic decay $B \to \mu^- \bar{\nu}_\mu$ .These analyses use entire Belle data set collected at the $\Upsilon(4S)$ resonance containing 772 million $B\bar{B}$ meson pairs.

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PoS(ICHEP2018)244

Introduction

Semileptonic B decays are a direct source to measure the CKM matrix elements $|V_{cb}|$ and $|V_{ub}|$ which eventually leads to precision tests for electroweak decays of the Standard Model (SM). These decays also probe the B meson structure and hence, the QCD form factors. In the note, $|V_{cb}|$ is calculated from the exclusive semileptonic $B^0 \to D^* \ell \nu_\ell$ decay. To measure the inclusive $B \to X \ell \nu$ rate, we must understand exclusive components where X refers to the final states $B \to \eta \ell \nu$ and $B \to \eta' \ell \nu$. The decay rates depend upon calculations of hadronic contributions to the matrix element. In the case of pure leptonic B decays such as $B \to \mu \nu$, the decay rate is proportional to $|V_{ub}|$ which governs the coupling between the u and b quarks. $B \to D^{(*)} \pi \ell \nu$ is an important background for high-multiplicity semileptonic B decays such as $B \to D^* \ell \nu_\ell$ and $B \to D^* \tau \nu_\tau$, and hence a precise measurement of this decay is very important.

1. Measurement of $|V_{cb}|$ from $B^0 \to D^{*-} \ell^+ \nu_\ell$ decay

The decay is reconstructed in the following channel: $B^0 \to D^{*-} \ell^+ \nu_\ell$ where $D^{*-} \to \bar{D}^0 \pi^-$ and $\bar{D}^0 \to K^- \pi^+$. This channel offers the best purity for the $|V_{cb}|$ measurement, which is critical as it is limited by systematic uncertainty. The experimentally most precise determination of $|V_{cb}|$ is presented in [3]. The differential decay rate of $B \to D^* \ell \nu$ decay is proportional to $|V_{cb}|$, and helicity amplitudes. The kinematics of the decay is characterised by four variables, three angular observables θ_ℓ, θ_ν, χ and $w = \frac{m_B^2 + m_{D^*}^2 - q^2}{2 m_B m_{D^*}}$. In the definition of w, q^2 is the momentum transfer between the B and the D^* meson, and m_B and m_{D^*} are their masses. Two different parameterisations of the hadronic transition form factors are used to extract $|V_{cb}|$: the model dependent Caprini-Lellouch-Neubert (CLN) form factor parameterisation [1] and the model independent Boyd-Grinstein-Lebed (BGL) parameterisation [2]. The theoretically favourable BGL parameterisation gives a higher value for $|V_{cb}|$, which is closer to the value measured by inclusive approach [4]. A simultaneous fit is performed to 1D projections of w, $\cos\theta_\ell$, $\cos\theta_\nu$ and χ to extract the form factor parameters and $|V_{cb}|$. The results from the fit are shown in Fig.[1]. The following values for $|V_{cb}|$ are extracted [3]:

$$|V_{cb}| = (38.7 \pm 0.2 \pm 0.6 \pm 0.5) \times 10^{-3} \quad \text{(CLN+LQCD) and} \tag{1.1}$$

$$|V_{cb}| = (42.5 \pm 0.3 \pm 0.7 \pm 0.6) \times 10^{-3} \quad \text{(BGL+LQCD)}. \tag{1.2}$$

Lepton flavour universality between electron and muon channels has been calculated as [3],

$$\frac{\mathscr{B}(B^0 \to D^{*+} e^- \nu_e)}{\mathscr{B}(B^0 \to D^{*+} \mu^- \nu_\mu)} = 1.01 \pm 0.01 \pm 0.03. \tag{1.3}$$

2. Measurement of the branching fraction of $B \to D^{(*)} \pi \ell \nu$ at Belle using hadronic tagging in fully reconstructed events

The process $B \to D^{(*)} \pi \ell \nu$ proceeds predominantly via $B \to D^{(**)} \ell \nu$, where D^{**} is an orbitally excited state of a charmed meson [7]. The decay is reconstructed by tagging one B meson in a hadronic mode. Since neutrinos cannot be detected in the Belle detector, the signal mode is reconstructed using rest-of-event information excluding the final state neutrino and its invariant

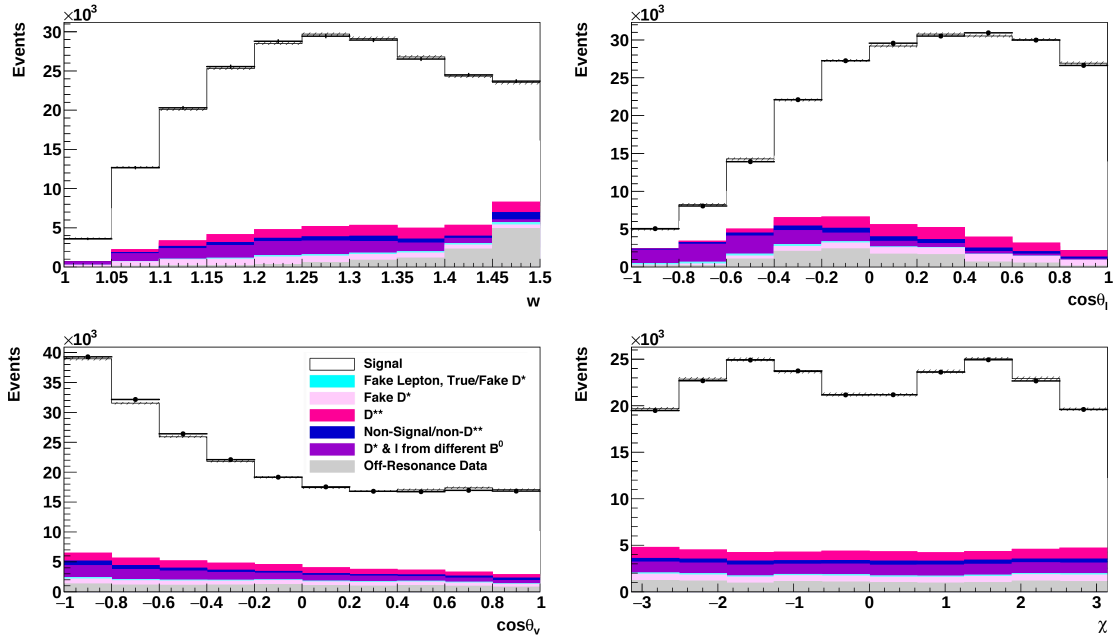

Figure 1: Results of the fit with BGL form factor parameterisation. The points with error bars are the on-resonance data. The histograms are, top to bottom, the signal component, $B \to D^{**}$ background, signal correlated background, uncorrelated background, fake ℓ component, fake D^* component and continuum.

mass, M_ν, by employing kinematic constraints. The branching fraction is extracted by performing a fit to the spectrum of

$$M_\nu^2 = ((p_{e^+} + p_{e^-}) - p_{B_{tag}} - p_{D^{(*)}} - p_\pi - p_\ell)^2/c^2, \tag{2.1}$$

where $(p_{e^+} + p_{e^-})$ is the sum of he four-momenta of the colliding beam particles. M_ν^2 is fitted with a probability density function (PDF) derived from simulation to extract the yields. Then $\mathcal{B}$ is determined using the ratios of the fitted yields to MC and the branching fractions used in MC. Neutral and charged B mesons are fitted separately where a simultaneous fit is performed to $B \to D\pi\ell\nu$ and $B \to D^*\pi\ell\nu$. The branching fractions calculated are as follows [5] ,

$$\begin{aligned}
\mathcal{B}(B^+ \to D^-\pi^+\ell^+\nu) &= (4.55 \pm 0.27_{stat.} \pm 0.39_{syst.}) \times 10^{-3} , \\
\mathcal{B}(B^0 \to \bar{D}^0\pi^-\ell^+\nu) &= (4.05 \pm 0.36_{stat.} \pm 0.41_{syst.}) \times 10^{-3} , \\
\mathcal{B}(B^+ \to D^{*-}\pi^+\ell^+\nu) &= (6.03 \pm 0.43_{stat.} \pm 0.38_{syst.}) \times 10^{-3} , \\
\mathcal{B}(B^0 \to \bar{D}^{*0}\pi^-\ell^+\nu) &= (6.46 \pm 0.53_{stat.} \pm 0.52_{syst.}) \times 10^{-3} .
\end{aligned} \tag{2.2}$$

3. Measurement of the decays in $B \to \eta\ell\nu_\ell$ and $B \to \eta^{'}\ell\nu_\ell$ fully reconstructed events at Belle

Precise measurements of $B \to \eta\ell\nu_\ell$ and $B \to \eta^{'}\ell\nu_\ell$ decay rates will improve the inclusive determination of $|V_{ub}|$ because lack of knowledge on all exclusive $B \to u\ell\nu$ decays are the primary contributions to the systematic uncertainty [8]. The branching fraction for $\mathscr{B}(B^+ \to \eta \ell^+ \nu_\ell)$ and $\mathscr{B}(B^+ \to \eta^{'} \ell^+ \nu_\ell)$ is calculated. The decay is reconstructed by identifying B_{tag} using the beam-constrained mass, $M_{\rm bc} = \sqrt{E^*_{beam} - |\vec{p}_{B_{tag}}|^2}$, and the energy difference, $\Delta E = E^*_{B_{tag}} - E^*_{beam}$, where E^*_{beam} is the energy of the colliding beam particles in the c.m. frame and $E^*_{B_{tag}}$ and $\vec{p}_{B_{tag}}$ are the reconstructed energy and three-momentum of the B_{tag} candidate respectively. B_{sig}, is reconstructed using all charged particles and neutral clusters not associated with the B_{tag} candidate. The $B \to \eta^{(')} \ell \nu_\ell$ yield is extracted from the distribution of the missing mass squared, defined as $M^2_{miss} = (p_{B_{tag}} - p_{\eta^{(')}} - p_\ell)^2$, where $p_{B_{tag}}$, $p_{\eta^{(')}}$ and p_ℓ are the four-momenta of the B_{tag}, $\eta^{(')}$, and charged lepton candidates, respectively.

The results for the $B \to \eta \ell \nu_\ell$ branching fractions are [6],

$$\mathscr{B}(B^+ \to \eta \ell^+ \nu_\ell) = (4.2 \pm 1.1_{\rm stat.} \pm 0.3_{\rm syst.}) \times 10^{-5},$$
$$\mathscr{B}(B^+ \to \eta^{'} \ell^+ \nu_\ell) = (3.6 \pm 2.7_{\rm stat.} \pm {}^{+0.3}_{-0.4}{\rm syst.}) \times 10^{-5}. \quad (3.1)$$

4. Search for $B \to \mu^- \bar{\nu}_\mu$ decays at the Belle Experiment

In the Standard Model, the branching fraction for the purely leptonic decay of a B meson is

$$\mathscr{B}(B^- \to \ell^- \bar{\nu}_\ell) = \frac{G_F^2 m_B m_\ell^2}{8\pi} \left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B. \quad (4.1)$$

The signal B meson is reconstructed without the neutrino while the rest-of-event information is used in reconstructing the other B meson. Neural networks (NN) are used to separate signal and background components. A fit is performed between μ momentum in the c.m. frame, p^*_μ and the NN output. The resulting branching fraction is [9],

$$\mathscr{B}(B^+ \to \mu^+ \nu_\mu) = (6.46 \pm 2.22 \pm 1.60) \times 10^{-7},$$
$$\mathscr{B}(B^+ \to \mu^+ \nu_\mu) \in [2.9, 10.7] \times 10^{-7} \text{ at 90\% C.L.} \quad (4.2)$$

References

[1] I. Caprini, L. Lellouch and M. Neubert, Nucl. Phys. B **530** (1998) 153.

[2] C. G. Boyd, B. Grinstein, and R. F. Lebed, Phys. Rev. D **56**, 6895 (1997).

[3] Belle Collaboration, A. Abdesselam et al., Measurement of CKM Matrix Element |Vcb| from $B^0 \to D^{*-} \ell^+ \nu_\ell$, arXiv:1809.03290.

[4] Y. Amhis *et al.* (HFLAV Collab.), Eur. Phys. J. C **77**, no. 12, 895 (2017).

[5] Collaboration (Vossen, A. et al.) Phys.Rev. D98 (2018) no.1, 012005 arXiv:1803.06444

[6] Phys.Rev. D96 (2017) no.9, 091102 arXiv:1703.10216

[7] N. Isgur and M. B. Wise, Phys. Rev. Lett. 66, 1130 (1991).

[8] P. Ball and G.W. Jones, J. High Energy Phys. 08, 25 (2007).

[9] Belle Collaboration (Sibidanov, A. et al.) Phys.Rev.Lett. 121 (2018) no.3, 031801 arXiv:1712.04123

PoS(ICHEP2018)244