PROCEEDINGS OF SCIENCE

New results for semileptonic B decays from Belle

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Though the Belle experiment has stopped data taking more than a decade ago, new results on semileptonic B meson decays are still being obtained. This is in part due to new experimental tools elaborated for Belle II applied to the Belle data set, such as the FEI (Full Event Interpretation) hadronic and semileptonic tag which enables new, more precise measurements of $B \to D^* \ell \nu$ and $B \to D^{(*)}\pi(\pi)\ell\nu$ ($\ell = e, \mu$). Improved analysis methods, such as data-driven background modelling and the determination of the CKM magnitude ratio $|V_{ub}|/|V_{cb}|$ allow experimental and theoretical systematics to be cancelled. This report also covers other results on semileptonic B decay. All results in this article are based on the full data set collected by the Belle experiment at the KEKB asymmetric-energy e^+e^- collider.

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1. Introduction

The Belle experiment collected an integrated luminosity of 711 fb^{-1} at the $\Upsilon(4S)$ resonance, corresponding to 772×10^6 $B\bar{B}$-events, using the Belle detector and the KEKB asymmetric-energy e^+e^- collider. In the following, we present three recent semileptonic results and a sensitivity study of an upcoming result by the Belle collaboration.

2. Measurements of Partial Branching Fractions of Inclusive $B \to X_u \ell^+ \nu_\ell$ Decays with Hadronic Tagging

This analysis uses the Full Reconstruction [1] tagging algorithm to reconstruct the tag-side B meson, to infer the full kinematics in the event from the well-known initial state of the e^+e^- collision. The abundant $B \to X_c \ell^+ \nu_\ell$ ($\ell = e, \mu$) background and others are suppressed using a multivariate classifier whilst retaining a large fraction of the phase space and high signal efficiency. This classifier is optimized to maximize the significance considering all systematic uncertainties. The CKM matrix element $|V_{ub}|$ is extracted using the relation $|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}}{\tau_B \Delta\Gamma}}$, with the measured partial branching ratio $\Delta\mathcal{B}$, the lifetime of the B meson τ_B, and the predicted partial rate $\Delta\Gamma$ assuming $|V_{ub}| = 1$. Four different calculations for the inclusive rate have been considered: BLNP [2], DGE [3, 4], GGOU [5], and ADFR [6, 7]. The extracted values for $|V_{ub}|$ are consistent using the different theory predictions for the partial rate. The result for $|V_{ub}|$ of the analysis is shown in Fig. 1. Details of the analysis can be found in Ref. [8].

3. Measurement of Differential Branching Fractions of Inclusive $B \to X_u \ell^+ \nu_\ell$ Decays

This analysis is the first measurement of differential branching fractions of inclusive $B \to X_u \ell^+ \nu_\ell$ decays and provides and important input for future shape-function model-independent determinations of $|V_{ub}|$. Similar to the analysis in Ref. [8], the event is fully reconstructed to infer the event kinematics and a multivariate method is used to suppress backgrounds. Additional, more

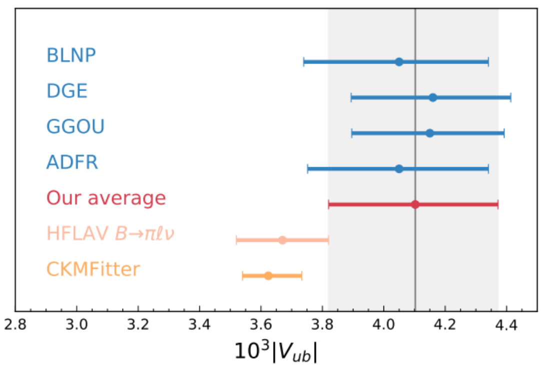

Figure 1: The obtained values of $|V_{ub}|$ from the four calculations and the arithmetic average. The extracted values for $|V_{ub}|$ are slightly larger than the determination from exclusive $B \to \pi\ell\nu$ decays, and the indirect determination from the CKM unitarity constraint.

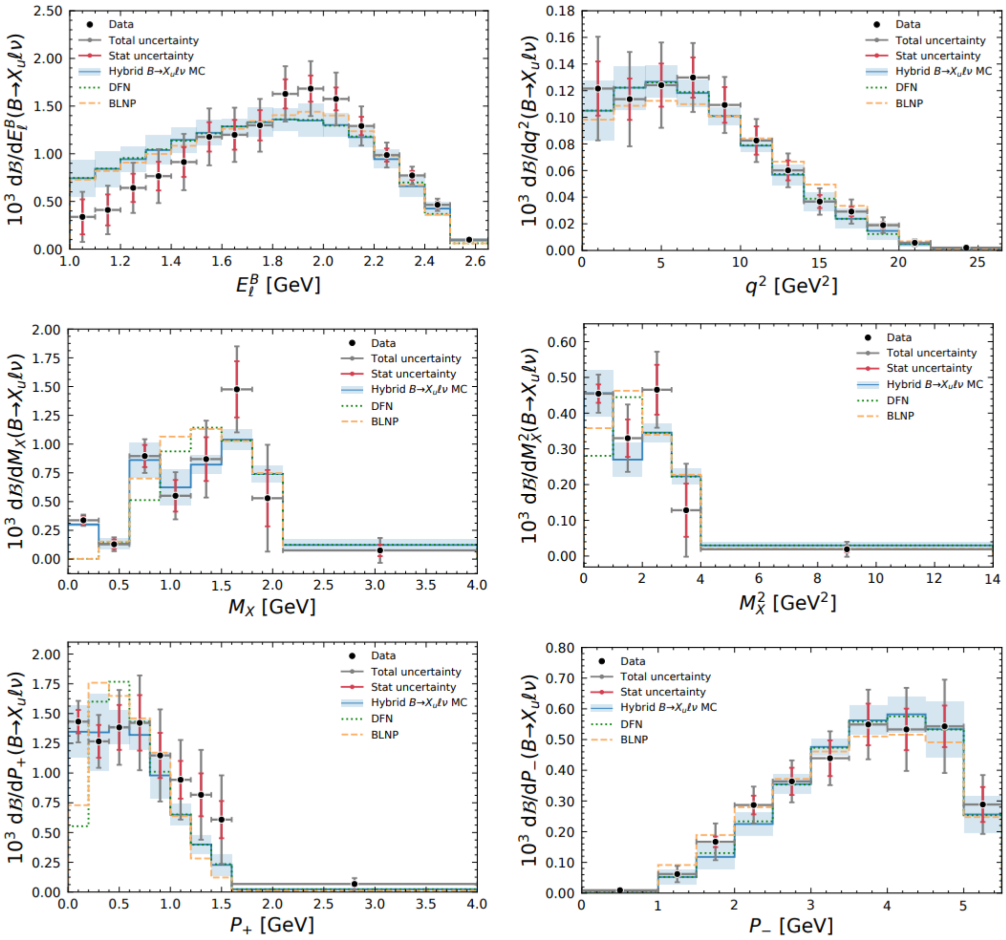

Figure 2: The measured differential $B \to X_u \ell \nu_\ell$ branching fractions are shown: The lepton energy in the B rest frame (E_ℓ^B), the four-momentum-transfer squared of the B to the X_u system, the invariant hadronic mass and mass squared of the X_u system (M_X, M_X^2), and the light-cone momenta of the hadronic X_u system $P_\pm$. Also shown are the MC prediction and two inclusive calculations.

stringent, selection criteria are applied to improve the resolution of key variables and further suppress backgrounds. Remaining backgrounds are subtracted from fits to the hadronic invariant mass distribution. The signal distributions are then unfolded using the Singular Value Decomposition (SVD) algorithm [9, 10]. The regularization parameter of the SVD algorithm was carefully tuned to minimize dependence on m_b, the shape function modelling, and the composition of the signal. The efficiency and acceptance corrections are determined from simulated events. The unfolded measured distributions of E_ℓ^B, q^2, M_X, M_X^2, P_- and P_+ (see the caption of Fig. 2 for definition) including all systematic uncertainties are shown in Fig. 2. Details of the analysis can be found in Ref. [11].

4. Measurements of q^2 Moments of Inclusive $B \to X_c \ell \nu_\ell$ Decays with Hadronic Tagging

This analysis is the first measurement of the first to fourth order moments of the four-momentum transfer squared (q^2) of inclusive $B \to X_c \ell \nu_\ell$ decays. The determination of these moments opens new ways to determine the absolute value of the CKM matrix element $|V_{cb}|$ [12]. Similar to the measurements above, the event is reconstructed with the Full Reconstruction algorithm. Backgrounds are subtracted by determining event weights in a fit to the hadronic invariant mass distribution. The background-subtracted events are then calibrated to recover the true q^2 moments, free from effects due to the reconstruction of the X_c system and to the selection criteria. The recovered true q^2 moments with different cut-offs are shown in Fig. 3. Details of the analysis can be found in Ref. [13].

5. Measurement of Differential Distributions of $B \to D^* \ell \bar{\nu}_\ell$ and Determination of $|V_{cb}|$ with Hadronic Tagging

This analysis uses the Full Event Interpretation [14], the successor algorithm of the Full Reconstruction, to fully reconstruct the event. In contrast to previous tagged measurements of this decay, the B^+ mode is also considered, significantly increasing the available statistic in the low hadronic recoil phase-space, which is most sensitive to the $|V_{cb}|$ extraction. In this analysis, the marginal distributions of the hadronic recoil w and the three helicity angles $\cos\theta_\ell$, $\cos\theta_V$, and χ are determined, taking into account the statistical and systematic correlations. A projection of the expected uncertainties based on an Asimov data sample is shown in Fig 4. The determination of the shapes allows for extraction of the form factors describing the exclusive decay and the CKM matrix element $|V_{cb}|$. Additionally, the lepton flavor universality ratio $R_{e\mu}(D^*)$ can be determined, as well as the forward-backward asymmetry in the full w phase space A_{FB}, and the longitudinal polarization fraction $F_L(D^*)$.

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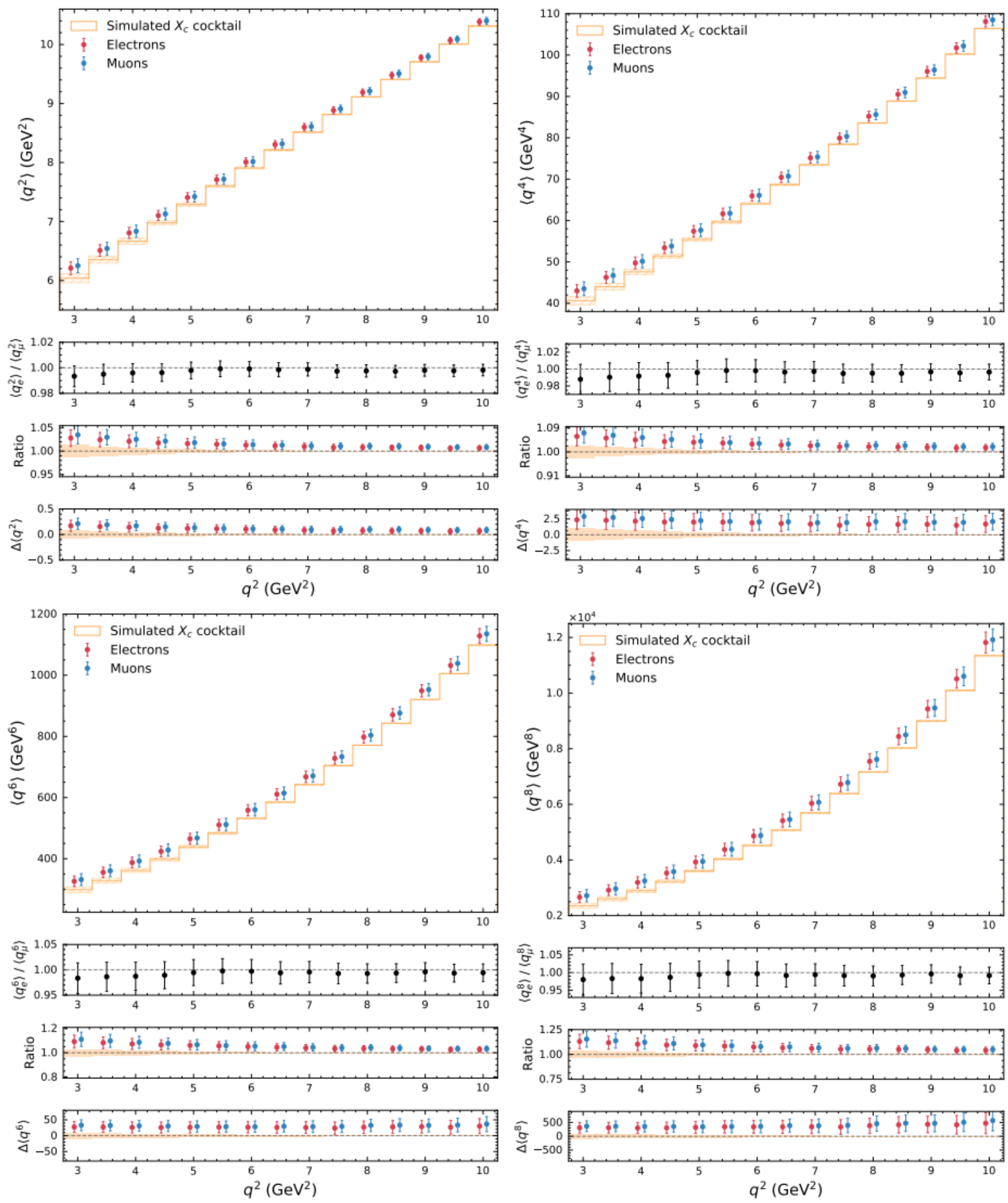

Figure 3: The expectation of lepton flavor universality of the moments are tested for the first to fourth q^2 moments: in the ratio of electron to muon moments many of the associated systematic uncertainties cancel and all reported moments are compatible with the expectation of lepton flavor universality (bottom top). Note that the individual electron and muon moments are highly correlated. Furthermore, the measured and generated-level moments for all the threshold selections on q^2 are compared as a ratio (bottom middle) and difference (bottom lower) for both electrons and muons.

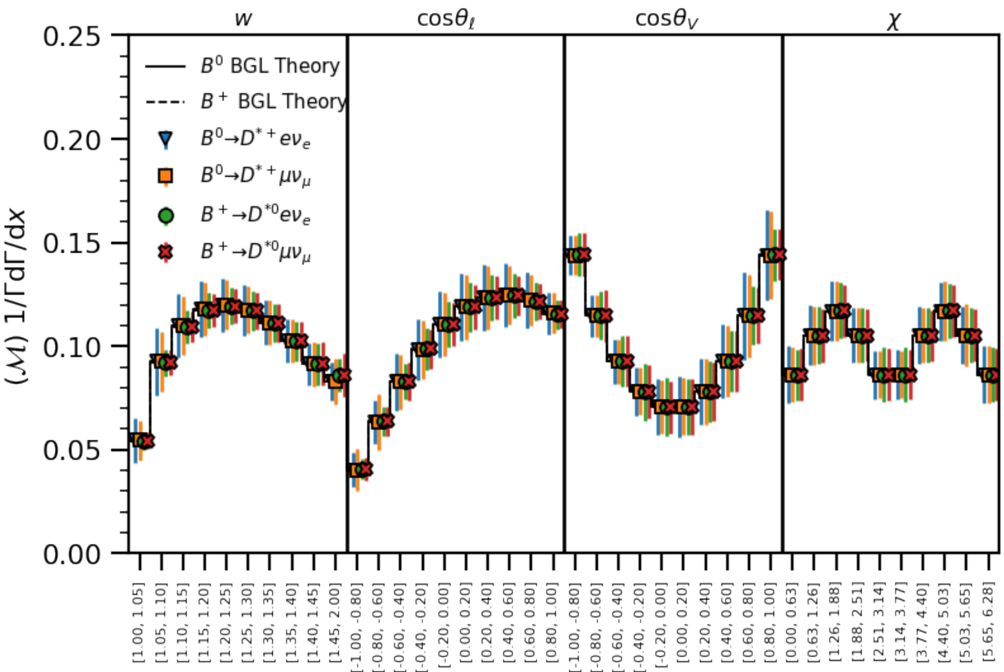

Figure 4: The determined shape after unfolding and acceptance correction for the four different decay modes considered in this analysis. Data points shown here are Asimov data.

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