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V_{cb}, V_{ub}, HQET at Belle

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Abstract. In this article, we review five new Belle measurements relevant to the CKM matrix elements $|V_{cb}|$ and $|V_{ub}|$: one measurement of inclusive $B \to X_c l\nu$ decays using full reconstruction of the other B, three different measurements of inclusive $B \to X_u l\nu$ decays using various experimental techniques, and finally the first evidence for the decay $B^+ \to \omega l^+ \nu$.

1 Introduction

The elements $|V_{cb}|$ and $|V_{ub}|$ play an important role in probing the unitarity of the Cabbibo-Kobayashi-Maskawa (CKM) matrix which relates quark flavor and weak eigenstates in the Standard Model [1]. In this article, we review five new Belle measurements relevant to these matrix elements: one measurement of inclusive $B \to X_c l\nu$ decays using full reconstruction of the other B, three different measurements of inclusive $B \to X_u l\nu$ decays using various experimental techniques, and finally the first evidence for the decay $B^+ \to \omega l^+ \nu$ [2].

Belle is located at KEKB, an asymmetric e^+e^- collider operating at the c.m. energy of the $\Upsilon(4S)$ resonance. The experiment has accumulated a data sample of 158.7 fb^{-1} (corresponding to about 152.0 million $B\bar{B}$ events) up to summer 2003. The main components of the detector [3] are the three-layer silicon vertex detector (SVD), the 50-layer central drift chamber (CDC), the array of aerogel threshold Čerenkov counters (ACC), and the electromagnetic calorimeter comprised of CsI(Tl) crystals (ECL) located inside a super-conducting solenoid coil that provides a 1.5 T magnetic field.

The responses of the ECL, CDC (dE/dx) and ACC detectors are combined to provide clean electron identification. Muons are identified in the instrumented iron flux-return (KLM) located outside of the coil.

2 $B \to X_c l\nu$ inclusive and extraction of $|V_{cb}|$

We have measured the semileptonic branching fraction of neutral and charged B mesons using an $\Upsilon(4S)$ data sample of 78.1 fb^{-1} (85.0 million $B\bar{B}$ events).

One B meson in the event (the tag side B) is fully reconstructed using various hadronic decay modes, and a yield of 21915 ± 202 neutral and 24529 ± 227 charged B mesons is found. The remaining particles in the event originate from the other B meson (the signal-side B), and events with an identified lepton (electron or muon) within these tracks are selected. Using the lepton charge, prompt semileptonic B decays and secondary D decays are distinguished. The prompt and secondary lepton spectra after subtraction of various backgrounds (continuum, upper vertex charm, ...) and mixing correction (for B^0 tags) are shown in Fig. 1.

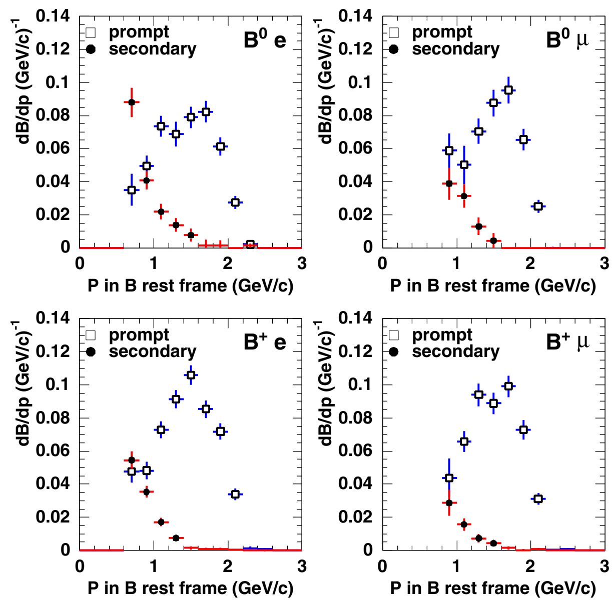

Fig. 1. Semileptonic decays with full reconstruction of the other B meson. The spectra of prompt and secondary leptons in the c.m. frame are shown

The semileptonic branching ratio of neutral (charged) B mesons is found to be $10.32 \pm 0.32(stat) \pm 0.29(syst)\%$ ($11.77 \pm 0.26(stat) \pm 0.32(syst)\%$). Combining these results

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[a] representing the Belle Collaboratio;
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we obtain a semileptonic B meson branching fraction of $11.19 \pm 0.20(stat) \pm 0.31(syst)\%$ corresponding to $|V_{cb}| = (4.13 \pm 0.07(exp) \pm 0.25(theor)) \times 10^{-2}$ [4]. The ratio of the charged and the neutral branching fraction, $\mathcal{B}(B^+ \to Xl\nu)/\mathcal{B}(B^0 \to Xl\nu) = 1.14 \pm 0.04(stat) \pm 0.01(syst)$, is consistent with the lifetime ratio. The main experimental systematics are particle identification and upper vertex charm. All these results are preliminary.

3 $B \to X_u l\nu$ inclusive and extraction of $|V_{ub}|$

We have measured inclusive $B \to X_u l\nu$ decays at the endpoint of the electron momentum spectrum, using $B \to D^{(*)} l\nu$ decays for tagging and using a neutrino reconstruction technique based on simulated annealing.

The electron endpoint analysis is based on 27.1 fb^{-1} of $\Upsilon(4S)$ data and examines the electron yield in a c.m. momentum window between 2.3 and 2.6 GeV/c. The challenges of this analysis arise from the significant backgrounds in the signal window, mainly from $B \to X_c l\nu$ decays (suppressed by the hard lepton momentum cut) and from hadronic continuum (suppressed using various event shape variables). The raw electron yield is found to be 7497 events. The largest background component, the continuum, is subtracted using real data taken below the $\Upsilon(4S)$ resonance. Other backgrounds are estimated using the simulation, and a signal yield of 1616 ± 165 events is found (Fig. 2).

The partial $B \to X_u l\nu$ branching fraction in the momentum window between 2.3 and 2.6 GeV/c is found to be $(1.19 \pm 0.11(stat) \pm 0.10(syst)) \times 10^{-4}$. The main experimental systematics are the model dependence of the selection efficiency and the uncertainty in the $B \to X_c e\nu$ background. Extrapolating the electron spectrum using HQET parameters determined from the $B \to X_s\gamma$ spectrum [5], the $B \to X_u l\nu$ branching fraction is obtained to be $(1.66 \pm 0.14(stat) \pm 0.13(syst) \pm 0.37(f_u) \pm 0.28(s\gamma)) \times 10^{-3}$, corresponding to $|V_{ub}| = (3.99 \pm 0.17(stat) \pm 0.16(syst) \pm 0.45(f_u) \pm 0.22(theor) \pm 0.32(s\gamma)) \times 10^{-3}$ [6]. These results are preliminary.

The different steps in the $B \to X_u l\nu$ analysis using $B \to D^{(*)} l\nu$ decays for tagging are as follows. Starting from 78 fb^{-1} of $\Upsilon(4S)$ data, events with one reconstructed $D^{(*)}$ meson and a pair of oppositely charged leptons are selected. In signal events one B meson decays to $D^{(*)} l\nu$ and the other to $X_u l\nu$, and one can show that the B direction lies on two cones of given opening angle around the Dl and the opposite $X_u l$ direction. The cones intersect and the kinematics can be solved. A large fraction of the background fails this requirement, and the signal can thus be selected. Additional requirements are: no identified charged kaons in the X_u system, and event charge $Q_{tot} = 0$. A signal yield of 82 ± 19 (92 ± 21) events is found in the phase space region $m(X_u) < 1.5$ GeV/c^2 and $p_l > 1$ GeV/c if only charged (charged and π^0) particles are allowed in the X_u system. This corresponds to a $B \to X_u l\nu$ branching ratio of $(2.62 \pm 0.63(stat) \pm 0.23(syst) \pm 0.05(b \to c) \pm 0.41(b \to u)) \times 10^{-3}$ (preliminary).

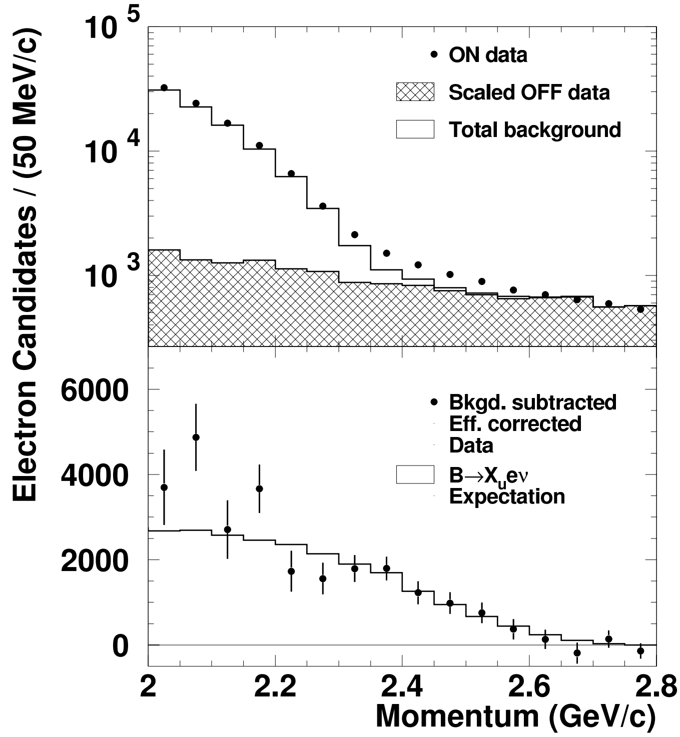

Fig. 2. Electron spectrum endpoint analysis. In the upper plot, the data (data points) and the estimated background (histogram) are shown. The lower plot shows the background subtracted data (data points) together with the Monte Carlo expectation (histogram) for $B \to X_u l\nu$

The $B \to X_u l\nu$ analysis using an advanced neutrino reconstruction technique is also based on an $\Upsilon(4S)$ data set of 78 fb^{-1}. Events with a hard lepton ($p_l > 1.2$ GeV/c) are selected and the missing energy and momentum in the event is used as a first estimate of the neutrino four-momentum. Then, using different discriminant variables and so called simulated annealing [7] each particle in the event is assigned to either one or the other B meson. In this way, the X_u system recoiling against the $l\nu$ pair is determined and the neutrino reconstruction is improved. In the phase space region $q^2 = (p_l + p_\nu)^2 > 7$ GeV$^2/c^2$ and $m(X_u) < 1.5$ GeV/c^2 1148 ± 98 signal events are found, corresponding to a $B \to X_u l\nu$ branching fraction of $(1.64 \pm 0.14(stat) \pm 0.36(syst) \pm 0.28(b \to c) \pm 0.22(b \to u)) \times 10^{-3}$. This result is also preliminary.

4 First evidence for $B^+ \to \omega l^+\nu$

The matrix element $|V_{ub}|$ can also be determined from exclusive semileptonic decays $B \to X_u l\nu$. Belle has previously obtained preliminary results for the decays $B^0 \to \pi^- l^+\nu$ and $B^+ \to \rho^0 l^+\nu$ [8]. Here, the first evidence for the decay $B^+ \to \omega l^+\nu$ is reviewed.

Using an $\Upsilon(4S)$ dataset of 78 fb^{-1}, events with a single lepton (electron or muon) are selected ($p_l > 1.8$ GeV/c). The missing energy and momentum in each event is calculated, and different cuts are applied to suppress events in

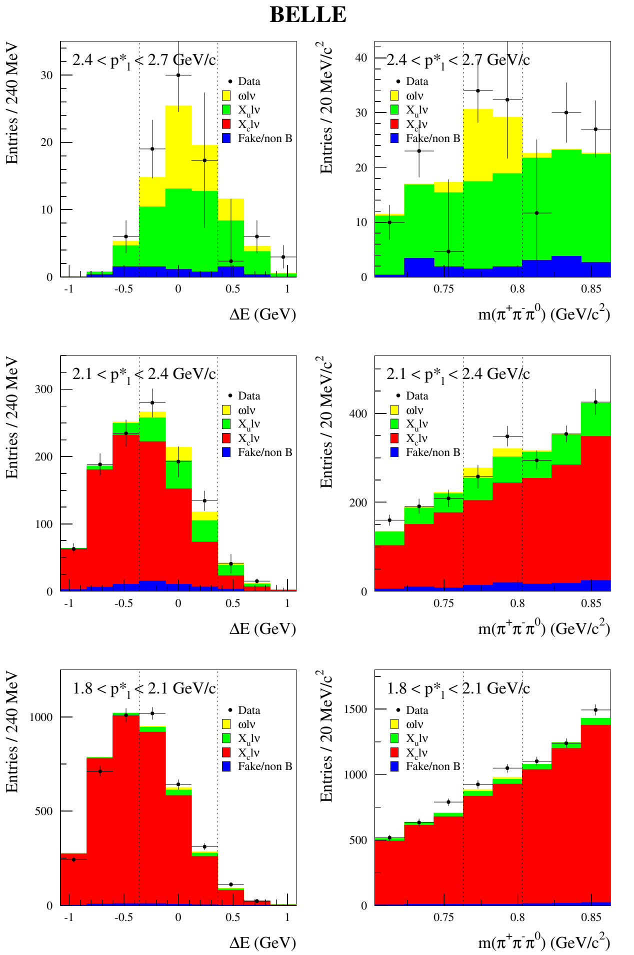

Fig. 3. First evidence for the decay $B^+ \to \omega l^+ \nu$. The result of the fit assuming ISGW2 form-factors for $B^+ \to \omega l^+ \nu$ is shown

which the missing four-momentum misrepresents the neutrino momentum: total charge $Q_{tot} < 3$, missing momentum within the ECL acceptance, and $m^2_{miss} < 3\ \mathrm{GeV}^2/c^4$. After applying these cuts a missing momentum resolution of about 140 MeV/c is found.

Then, the ω is reconstructed using its decay to $\pi^+\pi^-\pi^0$, and the signal yield and the remaining background are determined using a maximum likelihood fit in the $\Delta E = E(\omega l \nu) - E_{beam}$ vs. $m(\pi^+\pi^-\pi^0)$ plane in three bins of lepton momentum (Fig. 3). The fit is repeated for three different $\omega l \nu$ form factor models [9,10,11], and an average yield of $155 \pm 47(stat) \pm 15(model)$ signal events is found (4.0σ significance). This result corresponds to a $B^+ \to \omega l^+ \nu$ branching fraction of $(1.3 \pm 0.4(stat) \pm 0.2(syst) \pm 0.3(model)) \times 10^{-4}$ (prelimimary).

5 Conclusion

Five new Belle results relevant to the CKM matrix elements $|V_{cb}|$ and $|V_{ub}|$ have been reviewed. A comparison of these analyses with other results can be found in Figs. 4 and 5.

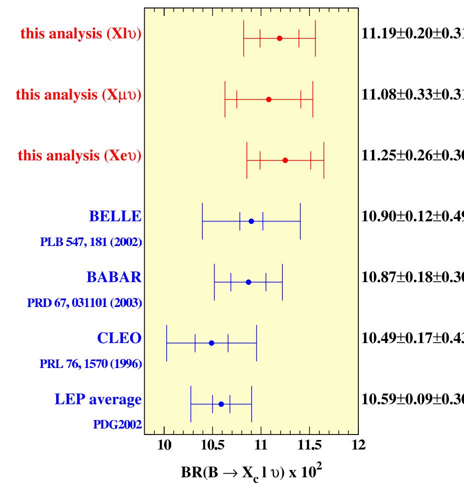

Fig. 4. The semileptonic B branching fraction. The Belle full reconstruction analysis is compared to other results

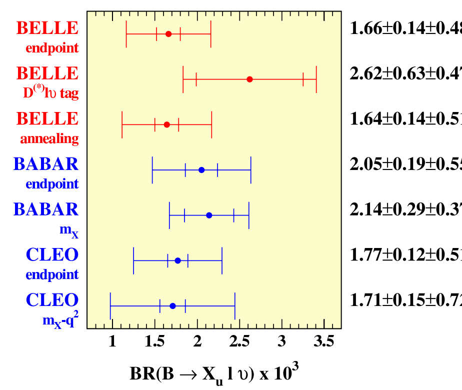

Fig. 5. The $B \to X_u l \nu$ branching fraction. The analyses reviewed in this article are compared to other results

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