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Inclusive Measurements of $|V_{ub}|$ from Belle

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Measurements of partial rates of inclusive charmless semileptonic B meson decays, $B \to X_u l \nu_l$, using the lepton endpoint and full reconstruction B-meson tag methods are presented. The lepton endpoint method yields a partial branching measurement in the momentum interval $1.9 < p_e^*/\mathrm{GeV}/c < 2.6$ as measured in the rest frame of the $\Upsilon(4S)$. The full reconstruction B-meson tag method measures partial branching fractions in three kinematic regions: the hadronic mass $M_X < 1.7\,\mathrm{GeV}/c^2$; the dilepton mass squared $q^2 < 8\,\mathrm{GeV}^2/c^2$ and $M_X < 1.7\,\mathrm{GeV}/c^2$; and the hadronic light cone variable $P_+ \equiv (E_X - |\vec{p}_X|) < 0.66\,\mathrm{GeV}/c$, all given a loose requirement on the prompt lepton momentum $p_l > 1.0\,\mathrm{GeV}/c$ measured in the rest frame of the $\Upsilon(4S)$. Using these measurements we extract values for the CKM matrix element $|V_{ub}|$ using an the BLNP [6] inclusive generator, which is constrained using data from the Belle measurement of the photon energy spectrum of $B \to X_s \gamma$. The signal region used for the endpoint method is the lowest momentum cutoff ever achieved to date. The extraction of $|V_{ub}|$ using P_+ is the first of its kind. The data used was collected by the Belle detector at the KEKB asymmetric e^+e^- collider.

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1. Introduction

The magnitude of the Cabibbo-Kobayashi-Maskawa (CKM) matrix element $|V_{ub}|$ is a fundamental parameter of the Standard Model (SM). A knowledge of its value is crucial to the understanding of CP violation within the SM, which is underpinned by knowledge of the Unitarity Triangle (UT). Recent precise measurements of UT angle $\phi_1(\beta)$ has highlighted the need to improve the precision in $|V_{ub}|$. The value of $|V_{ub}|$ can be extracted from the measured rate of charmless semileptonic B-meson decays $B \to X_u l \nu_l$ in a kinematic region that has to be chosen to negate the impact of the large background from the charmed semileptonic B-meson decays $B \to X_c l \nu_l$. We report on two new results of inclusive $|V_{ub}|$ at Belle: the endpoint and full reconstruction B tag analyses [1]. They respectively utilise ON (OFF) data samples of 27 fb^{-1}(9 fb^{-1}) and 253 fb^{-1}(28 fb^{-1}) on (60 MeV below) the $\Upsilon(4S)$ resonance collected by the Belle detector at the KEKB asymmetric energy e^+e^- collider [2].

2. Lepton endpoint

The method consists of measuring the spectrum of electron candidates with momentum in the range $1.5-3.5$ GeV$/c$, which includes both signal and sideband regions. Tracks within acceptance of the barrel calorimeter are identified as electrons using information from the various Belle subdetectors. The main background, hadronic continuum processes ($e^+e^- \to q\overline{q}$ where $q = u,d,s,c$) processes are suppressed via the use of a Fisher discriminant of virtual calorimeter type variables. The Fisher discriminant selection criteria depend on a rare decay b tag variable that exploits the presence of lepton-kaon charge correlations only evident in signal events. The variables and associated cuts were chosen to minimise the relative statistical error whilst reducing the model dependence. The Monte Carlo (MC) determined signal reconstruction efficiency is (18 ± 1)%, with main uncertainties from: event selection (4%); and model depedence (2%). The $B \to X_u e \nu_e$ signal is extracted in the momentum region $1.9-2.6$ GeV$/c$, while a lower range, from $1.5-1.9$ GeV$/c$, is examined with the aid of a large MC sample of $B\overline{B}$ events, to evaluate the contribution from $B \to X_c e \nu$, which is then extrapolated to the signal region. The continuum background is evaluated using the OFF data set, which is scaled appropiately, and cross-checked via comparison of ON and OFF spectra in the momentum interval $2.8-3.5$ GeV/c. We measure the partial branching of $\Delta\mathscr{B} = (8.98 \pm 0.39 \pm 1.62) \times 10^{-4}$ in the momentum interval 1.9-2.6 GeV/c corrected for final state radiation effects where the first error is statistical and the second is systematic. The error is dominated by the uncertainty in the $B \to X_c e \nu_e$ background, which is limited by our knowledge of the D^* form factor. Fig 1(a) shows the ON and scaled OFF momentum spectra along with the total background and Fig 1(b) shows the subsequent background subtracted and efficiency corrected spectrum, revealing the contribution of $B \to X_u e \nu_e$.

3. Full reconstruction B-meson tag

This method relies on a sample of events where the tagging side B meson, B_{tag}, is fully reconstructed, while the semileptonic decay of the signal side B meson, B_{sig}, is identified by the presence of a high momentum electron or muon. With this sample we are able to construct kinematic variables of: the meson mass M_X, the dilepton mass squared q^2, and the hadronic light-cone

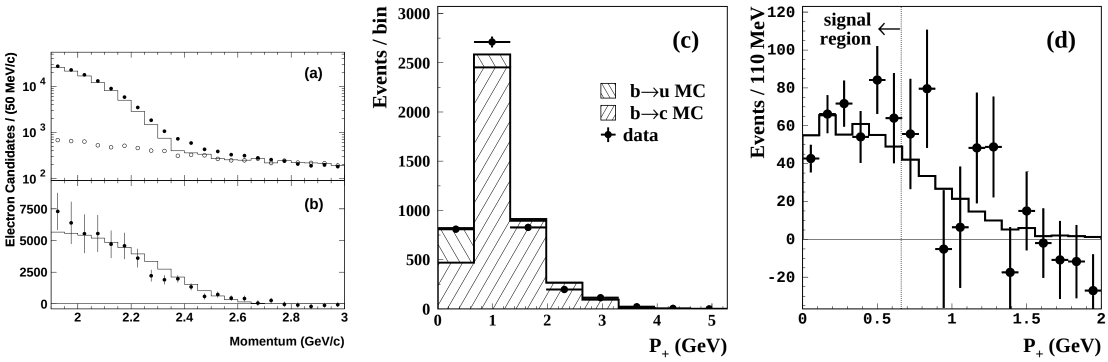

Figure 1: The electron momentum spectrum in the $\Upsilon(4S)$ rest frame: (a) ON data (filled circles), scaled OFF data (open circles), sum of scaled OFF data and estimated $B\overline{B}$ backgrounds (histogram). (b) ON data after subtraction of backgrounds and correction for efficiency (filled circles) and model spectrum of $B \to X_u e \nu_e$ decays with final state radiation (histogram, normalised to the data yield in the $1.9-2.6\,\mathrm{GeV}/c$ momentum range). (c) The P_+ distribution for the selected events, with fitted contributions from $B \to X_c \ell \nu$ and $B \to X_u \ell \nu$, (d) P_+ distribution (symbols with error bars) after subtracting $B \to X_c \ell \nu$, with fitted $B \to X_u \ell \nu$ contribution (histogram).

momentum P_+, which are the best available discriminators of signal and background in inclusive type $|V_{ub}|$ analyses. The $B_{\rm tag}$ candidates are reconstructed in the modes $B \to D^{(*)}\pi/\rho/a_1/D_s^{(*)}$, where these mesons are further reconstructed in various hadronic decay modes. The selection of $B_{\rm tag}$ candidates is based on the beam-constrained mass, $M_{\rm bc} = \sqrt{E_{\rm beam}^{*2} - p_B^{*2}}$, and the energy difference, $\Delta E = E_B^* - E_{\rm beam}^*$. Here $E_{\rm beam}^* = \sqrt{s}/2 \simeq 5.290\,\mathrm{GeV}$ is the beam energy in the e^+e^- center-of-mass system (cms), and p_B^* and E_B^* are the cms momentum and energy of the reconstructed B meson. B-meson candidates are required to satisfy $M_{\rm bc} \geq 5.27\,\mathrm{GeV}/c^2$ and $-0.2 < \Delta E < 0.05\,\mathrm{GeV}$. We require that the event contain exactly one lepton, either electron or muon, with momentum greater than $1\,\mathrm{GeV}/c$, have zero net charge and have the missing mass squared consistent with a neutrino hypothesis, $-1 \leq m_{\rm miss}^2 \leq 0.5\,\mathrm{GeV}^2/c^4$. To reduce the $B \to X_c l \nu$ background, no $K^\pm$ or K_S^0 candidates should be detected amongst remaining pariticles once the lepton and tag B-mesons have been identified. Similiarly events with a charged slow pion (π_s), consistent with having come from D^{*+} decay, are vetoed. We fit the $M_{\rm bc}$ distribution in bins of M_X and P_+ to form their respective distributions. These are fitted with MC determined functions for $B \to X_u l \nu$ and $B \to X_c l \nu$ components. The latter contribution is subtracted from the data to arrive at the number of signal events. We measure partial branching fractions in three kinematic signal regions: $P_+ < 0.66\ \mathrm{GeV}/c$, $M_X < 1.7\ \mathrm{GeV}/c^2$, and $M_X < 1.7\ \mathrm{GeV}/c^2$ & $q^2 > 8\ \mathrm{GeV}^2/c^2$. The corresponding partial branching fractions $\Delta\mathscr{B}$ are measured to be: $P_+ : (1.10 \pm 0.10 \pm 0.16) \times 10^{-3}$, $M_X : (1.24 \pm 0.11 \pm 0.12) \times 10^{-3}$ and $M_X/q^2 : (8.41 \pm 0.84 \pm 1.03) \times 10^{-4}$, respectively, where the first error is statistical and the second is systematic. The measured P_+ and corresponding background subtracted spectra are shown in Figs. 1(c)-(d) respectively.

4. $|V_{ub}|$ Extraction

$|V_{ub}|$is obtained directly from the partial branching fraction using $|V_{ub}|^2 = \Delta\mathscr{B}(B \to X_u \ell \nu)/(R \cdot$

Table 1: Predicted partial rates, *R*, and subsequent extracted values of $|v_{ub}|$ using measurements of the partial branching fraction for various signal regions defined in the text.

Method	$R\,(\lvert V_{ub}\rvert^2\mathrm{ps}^{-1})$	$\lvert V_{ub}\rvert\,(10^{-3})$(BLNP)						
			STAT	SYS	$b \to c$	$b \to u$	SF	Theory
Endpoint p_e^*	$21.7 \pm 3.6^{+2.2}_{-2.0}$	5.08	± 0.11	± 0.14	± 0.44	± 0.04	± 0.42	$^{+0.26}_{-0.23}$
B tag:M_X	$40.9 \pm 7.5^{+3.2}_{-2.9}$	4.35	± 0.20	± 0.15	± 0.13	± 0.05	± 0.40	$^{+0.16}_{-0.17}$
B tag:M_X&q^2	$21.6 \pm 4.0^{+2.4}_{-2.3}$	4.93	± 0.25	± 0.22	± 0.15	± 0.13	± 0.46	$^{+0.25}_{-0.27}$
B tag:P_+	$33.2 \pm 6.8^{+2.3}_{-2.3}$	4.56	± 0.21	± 0.21	± 0.15	± 0.20	± 0.47	$^{+0.16}_{-0.16}$

τ_B), where $\tau_B = (1.604 \pm 0.011)$ ps is the average B lifetime. R is the theoretical prediction of the partial rate and is calculated for a given signal region by using an inclusive $B \to X_u \ell \nu$ decay generator [6] based on the latest theoretical studies [3, 4]. The values of R are given in Table 1, its errors (SF) are calculated using the shape function scheme [6] parameters $m_b(\mathrm{SF}) = 4.52 \pm 0.07$ GeV$/c^2$ and $\mu_\pi^2(\mathrm{SF}) = 0.27 \pm 0.13$ GeV$^2/c^2$ and their correlation [5] with the predicted shapes of the $B \to X_s\gamma$ photon energy distributions from Ref. [6]. The theoretical error on R (th.) is estimated by varying the subleading shape functions (four models), the matching scales μ_h, μ_i, $\bar{\mu}$ and weak annihilation [6]. The extracted values of $|V_{ub}|$ are given in Table 1, the relative uncertainties are 13%, 13%, 12% and 14% for p_e^*, M_X/q^2, M_X and P_+ regions, respectively.

5. Summary

The precision of the $|V_{ub}|$determination is better than previous measurements [7], owing to the use of both a larger data sample and improved theoretical predictions [3, 4]. The endpoint method is a competitive avenue for $|V_{ub}|$ extraction as is the full reconstruction B-meson tag method using the recently touted P_+ variable [3].

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