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Status of V_{ub} measurement with BELLE detector

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Abstract. Semileptonic decays of $B \to X_u \ell \nu$ have great importance both from theoretical and experimental point of view, as they are useful for extracting the magnitude of V_{ub}, one of the tiniest elements of CKM matrix. Similarly measurement of $B \to D_s X_u$ can be used to calculate V_{ub}. The Belle Collaboration has measured these branching ratios and extracted V_{ub} for various theoretical models.

Keywords. BELLE; Cabibbo–Kobayashi–Maskawa matrix; V_{ub}.

1. Introduction

In the standard model, the mechanism of CP violation has been explained in the framework of Cabibbo–Kobayashi–Maskawa (CKM) [1] matrix. But, the elements of the CKM matrix are free parameters in theory and need to be determined from experimental results. V_{ub}, one of the tiniest elements of this matrix can be measured from $B \to X_u \ell \nu$ decay modes.

There are mainly two approaches to measure $|V_{ub}|$, the inclusive and the exclusive methods. Inclusive methods provide less theoretical uncertainty on $|V_{ub}|$. On the other hand, exclusive decay mode has small background due to the fact that the final hadronic system (π, ω etc.) can be reconstructed very clearly. But the hadronic form factor has a very large uncertainty. The differential decay rate as a function of q^2, four-momentum transfer from b quark to W^*, can put some constraints for form factor model. Only exclusive analysis is discussed here.

$B \to D_s^{(*)+} \pi$ decays are expected to be dominated by the $b \to u$ transition without any penguin contribution. It also provides an opportunity to determine $|V_{ub}|$. Predicted branching ratios varies over a wide range, 3×10^{-6}–10^{-4}.

The decays $B^+ \to \ell^+ \nu_\ell$ are allowed through annihilation into virtual W bosons, where branching ratio is a function of $f_B |V_{ub}|$.

Similarly $B^+ \to D^{*+} \gamma$ decay mode is also possible through W-annihilation diagram (expected branching ratio $\sim 10^{-7}$). All these annihilation modes have only upper limits.

This talk is based on $\int \mathcal{L}\ \mathrm{d}t = 29$–$78\ \mathrm{fb}^{-1}$ (different decay mode uses different data set) data collected on the $\Upsilon(4S)$ resonance by the BELLE detector at the KEKB asymmetric $e^+ e^-$ collider.

The BELLE detector has been described elsewhere [2]. Charge tracks are selected with requirements based on the average hit residual, impact parameter relative to $e^+ e^-$ interaction point (IP) and threshold on track momentum to reduce fake tracks. For charged hadron identification (PID), the combined information from specific ionisation in the central drift chamber ($\mathrm{d}E/\mathrm{d}x$), time-of-flight (TOF) scintillation counter and aerogel Čerenkov counter (ACC) is used. Electrons are identified with the shower shape in the electromagnetic calorimeter (ECL), matching between charged tracks and ECL shower, the ratio of the shower energy to the matched track momentum, $\mathrm{d}E/\mathrm{d}x$ and light yield in the ACC. Muons are identified by comparing the measured range and hit position in the K_L and muon detection system (KLM).

γ candidates are identified from the isolated ECL shower with electromagnetic shower shape again with 30(50) MeV threshold for barrel(endcap) region to reduce background noise. Pair of ECL photons are identified as π^0 candidate provided the invariant mass, $M_{\gamma\gamma}$ lies within 15 MeV ($\approx 3\sigma$) of the nominal π^0 mass. Neutral kaons are identified with the decay $K_S^0 \to \pi^+\pi^-$. The two-pion invariant mass is required to be within 6 MeV ($\sim 2.5\sigma$) of the nominal K_S^0 mass and the displacement of $\pi^+\pi^-$ vertex from the IP.

2. Search for $b \to X_u \ell \nu$ decay chains ($X_u = \pi, \rho, \omega$)

The most difficult task of this search is reconstruction of the elusive neutrino momentum from the energy momentum conservation with the concept of hermetic BELLE detector. But, due to asymmetric energy of the beams, there is a possibility that the low momentum particles are missing along the forward beam direction. All possible efforts are made to reject those events. After confirming that there is only one lepton (one neutrino) in the events, the conservation of charge $\mid Q \mid \leq 2$, neutrino four-momenta are reconstructed from

$$\vec{P}_\nu = \vec{P}_{\text{miss}} = \vec{P}_{e^+} + \vec{P}_{e^-} - \textstyle\sum_i \vec{P}^i_{\text{charged}} - \sum_i \vec{P}^i_{\text{neutral}},$$
$$E_\nu = E_{\text{miss}} = E_{e^+} + E_{e^-} - \textstyle\sum_i E^i_{\text{charged}} - \sum_i E^i_{\text{neutral}}.$$

In addition, the missing mass square is required to be consistent with the neutrino ($M^2_{\text{miss}} \leq 3\,\text{GeV}^2$), $\hat{P}_{\text{miss}}$ lies within the detector acceptance region. Due to better momentum resolution (with respect to energy) of the BELLE detector, for the rest of the analysis, E_ν is replaced by $|\vec{P}_{\text{miss}}|$.

To suppress the large $e^+e^- \to q\bar{q}$ continuum process, which are jet-like events in the CM system, event shape variables e.g., ratio of second and zeroth Fox–Wolfram variable, energy flow around lepton etc., are used.

$$\theta_{Y-B}(\cos\theta_{Y-B}) = \frac{2\,E_B\,E_Y - M_B^2 - M_Y^2}{2\,|\vec{P}_B||\vec{P}_Y|},$$

$E_B(P_B)$ is the energy(momentum) of B in the CM frame, the angle between the B direction and the reconstructed lepton and hadron system ($Y = X_u + \ell$) in the CM frame is the most effective kinematic variable to discriminate background from signal events. Most of the signal events lie within $-1 \leq \cos\theta_{Y-B} \leq 1$.

Finally, signal events are selected from the distribution of the momentum of lepton (P_ℓ), beam constraint mass, $M_{\rm bc}$ ($\sqrt{E_B^2 - |\vec{P}_u + \vec{P}_\ell + \vec{P}_\nu|^2}$), energy difference, ΔE ($E_B - E_u - E_\ell - E_\nu$) and the invariant mass of X_u (for ρ, ω).

Measured branching ratios are $(1.33 \pm 0.11 \pm 0.21) \times 10^{-4}$, $(1.4 \pm 0.4 \pm 0.3) \times 10^{-4}$ and $(1.44 \pm 0.18 \pm 0.23) \times 10^{-4}$ for $B^0 \to \pi^- \ell^+ \nu_\ell$ (60 $\rm fb^{-1}$), $B^+ \to \omega e^+ \nu_e$ (60 $\rm fb^{-1}$) and $B^+ \to \rho^0 \ell^+ \nu_\ell$ (29 $\rm fb^{-1}$) decay mode respectively, where the first error is statistical and second is systematic. Systematic uncertainties come from background estimation, signal fitting, MC statistics, track finding efficiency, PID etc. Extracted value of $|V_{ub}|$ from $B^0 \to \pi^- \ell^+ \nu_\ell$ are $(3.11 \pm 0.13 \pm 0.24 \pm 0.56) \times 10^{-3}$ (UKQCD) [3] and $(3.58 \pm 0.15 \pm 0.28 \pm 0.63) \times 10^{-3}$ (LCSR) [4], where errors are statistical, systematic and theoretical.

3. Search for $B^0 \to D_s^+ \pi^-$ decays

D_s^+ mesons are reconstructed from these three decay modes, $D_s^+ \to \phi\pi^+, \bar{K}^{*0} K^+$ and $K_S^0 K^+$. $\phi(\bar{K}^{*0})$ mesons are formed from the K^+K^- ($K^-\pi^+$) combinations with invariant mass within 10 (50) MeV of the nominal ϕ ($\bar{K}^{*0}$) mass. Same event shape variables are used to reduce continuum events. M_{bc}, ΔE and mass of D_s^+, $M_{D_s^+}$ are used to extract signal from the large background. Special selection criteria are used to reject background from (i) $q\bar{q}$ events containing real D_s^+ mesons, (ii) B decay chains containing D^+, such as $B^0 \to D^- \pi^+$, $D^- \to K^+ \pi^- \pi^-$ and $B^0 \to D^- \pi^+$, $D^- \to K_S^0 \pi^-$, (iii) charmless $B^0 \to K^+ K^- K^+ \pi^- (K_S^0 K^+ K^-)$. These background contributions may peak in the signal region $M_{D_s^+}$ or of ΔE (and $M_{\rm bc}$) but not in both simultaneously.

Simultaneous fit of these three D_s^+ decay modes gives a signal yield of $10.1^{+4.4}_{-3.7}$ (78 $\rm fb^{-1}$), which is an evidence for $B^0 \to D_s^+ \pi^-$ with $\mathcal{B}(B^0 \to D_s^+ \pi^-) = (2.4^{+1.0}_{-0.8} \pm 0.7) \times 10^{-5}$ (3.6σ statistical significance). Dominant systematic uncertainty comes from the branching ratio of D_s^+ decay modes. Using $\Gamma(B \to D_S^{(*)} \pi)/\Gamma(B \to D_S^{(*)} D) = (0.424 \pm 0.041) \times |V_{ub}/V_{cb}|^2$ [5], the extracted model dependent value of $|V_{ub}/V_{cb}| = (8.2^{+3.5}_{2.9} \pm 3.4) \times 10^{-2}$, where no error on the factorisation assumption or other source of model dependence are included.

4. Decay modes of W-annihilation diagram

$B^+ \to \tau^+ \nu$ is the dominant decay mode of $B^+ \to \ell^+ \nu$. But $B^+ \to e^+(\mu^+)\nu$ channels were searched for because of the narrow momentum range of ℓ in CM frame.

Event selection requires a lepton with CM momentum (P_ℓ) ranging from 2.2 GeV to 2.9 GeV, the sum of the energies of all charged and neutral particles, except for the signal lepton must be consistent with E_B and their beam constraint mass also must be consistent with the B meson mass. The signal yield is obtained by fitting the P_ℓ distribution and there was no evidence of any signal. 90% CL upper limits of branching fractions are 5.4 $\times 10^{-6}$ and 6.8 $\times 10^{-6}$ for $B^+ \to e^+ \nu_e$ and $B^+ \to \mu^+ \nu_\mu$ channels respectively (60 $\rm fb^{-1}$).

To select $B^+ \to D_s^{+*}\gamma$ signal events, $D_s^{+*} \to D_s^+\gamma$ mode is used with the same three decay modes of D_s^+. Signals are looked for in $M_{\rm bc}$ and ΔE distributions. Absence of any signal in this decay chain gives $\mathcal{B}(B^+ \to D_s^{+*}\gamma) < 2.6 \times 10^{-5}$ at 90% CL (60 fb^{-1}).

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