PROCEEDINGS OF SCIENCE

Measurement of the decay $B^0 \to \pi^- \ell^+ \nu$ in untagged events and determination of $|V_{ub}|$ at Belle

Hyuncheong HA[*]
Korea University
E-mail: hcha@hep.korea.ac.kr

on behalf of the Belle collaboration

We present a measurement of the charmless semileptonic decay $B^0 \to \pi^- \ell^+ \nu$ using a large sample of untagged $\Upsilon(4S) \to B\bar{B}$ events collected with the Belle detector at the KEKB e^+e^- asymmetric collider. From the results, we determine the branching fraction of the decay and extract the Cabibbo-Kobayashi-Maskawa matrix element $|V_{ub}|$ using various approaches.

35th International Conference of High Energy Physics - ICHEP2010,
July 22-28, 2010
Paris France

[*]Speaker.

1. Introduction

Recently, there are notable improvements on the measurement of the value of $|V_{ub}|$ element of the Cabibbo-Kobayashi-Maskawa (CKM) matrix, and especially, the exclusive semileptonic decays $b \to u\ell\nu$, are studied with helps of various theoretical form factor calculations of unquenched lattice QCD [1, 2], light cone sum rule (LCSR) [3], and relativistic quark model [4].

In this study, the decay, $B^0 \to \pi^- \ell^+ \nu$ is considered since the form factor of this decay mode is well understood rather than other vector meson decay modes. For the measurement of $|V_{ub}|$ using this decay mode, two different methods, model-dependent and -independent extraction will be shown. The model dependent $|V_{ub}|$ is extracted numerically from the the form factor $f_+(q^2)$ predictions, where q^2 is the momentum transfer squared, $q^2 = (p_\ell + p_\nu)^2$, however this model-dependent method has limited understandings to a certain high or low q^2 regions and has large systematic uncertainty from that. The model-independent method uses the shapes of the distributions of lattice QCD results and experimentally measured differential branching fractions in q^2, and the $|V_{ub}|$ is a normalization and is extracted from a simultaneous fit to the these two distributions [5, 6].

For this study, we used the data sample consists of 605 fb^{-1} taken near the $\Upsilon(4S)$ resonance, corresponding to 657 $\times 10^6$ $B\bar{B}$ pair events collected with the Belle experiment at the KEKB asymmetric-energy e^+e^- collider [7, 8].

2. Exclusive $B^0 \to \pi^- \ell^+ \nu$ untagged reconstruction

The signal decay $B^0 \to \pi^- \ell^+ \nu$ is reconstructed from oppositely charged lepton and pion pairs, and from the reconstructed missing particles. The missing particle is defined from the four momenta of missing momentum in the center-of-mass (c.m.) frame, $\vec{p}_{\rm miss} \equiv -\sum_i \vec{p}_i$ where the sums include all particle candidates in a event. Then, the neutrino 4-momentum is taken to be $p_\nu = (|\vec{p}_{\rm miss}|,\ \vec{p}_{\rm miss})$. The beam-energy-constrained mass and the energy difference, $M_{\rm bc} = \sqrt{E^2_{\rm beam} - |\vec{p}_\pi + \vec{p}_\ell + \vec{p}_\nu|^2}$ and $\Delta E = E_{\rm beam} - (E_\pi + E_\ell + E_\nu)$ where $E_{\rm beam}$ is the beam energy in the c.m. frame, are used to select signal events by restricting the ranges as $M_{\rm bc} > 5.19$ GeV/c^2 and $|\Delta E| < 1$ GeV. The backgrounds are categorized $b \to u$, $b \to c$ transitions and continuum background.

We divide the q^2 range from 0 to 26.4 GeV$^2/c^2$ into 13 bins using the momenta of the B meson and the pion. The resolution is ~ 0.5 GeV$^2/c^2$ which is much improved than that of using the lepton and the neutrino. Then, the signal is extracted throughout two $(M_{\rm bc}, \Delta E)$ dimensional, binned, extended likelihood fit according to q^2 as shown in Fig. 1.

3. Extractions of $|V_{ub}|$

The q^2 distribution of signal events from the fit is unfolded using unregularization method to remove detector smearing effects. Using signal efficiencies in q^2 bins, the partial branching fractions (BF) are calculated and the distribution in true q^2 bin is shown in Fig. 2.

Various model dependent values of $|V_{ub}|$ in the CKM matrix are calculated from measured partial BFs according to the relation $|V_{ub}| = \sqrt{\Delta\mathscr{B}(q^2)/(\tau_{B^0}\Delta\zeta)}$, where ζ_{B^0} = 1.525 $\pm$ 0.009 ps is the B^0 lifetime, and $\Delta\zeta$ = Γ $|V_{ub}|^2$ is the normalized partial decay rates from theoretical form factor

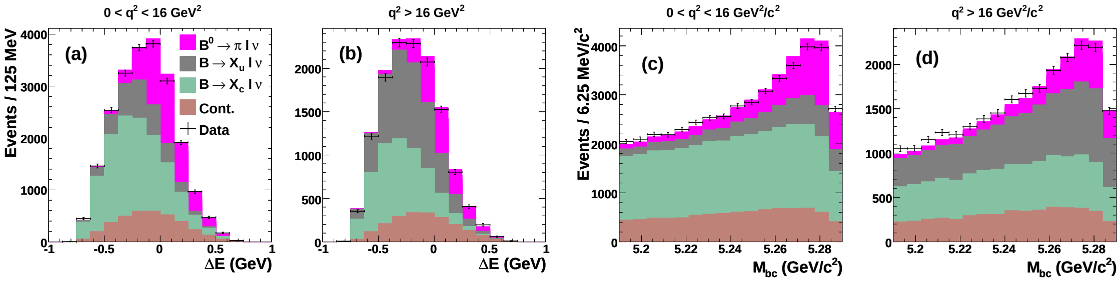

Figure 1: The fit projections to ΔE in (a) and (b) with $M_{\rm bc} > 5.27$ GeV, and to $M_{\rm bc}$ with $|\Delta E| < 0.125$ GeV in (c) and (d). The fit projections in (a) and (c) are for $0 < q^2 < 16$ GeV^2, (b) and (d) are for $q^2 > 16$ GeV^2, respectively. From top to bottom, each component refers $B^0 \to \pi^- \ell^+ \nu$ signal, $b \to u \ell \nu$ background, $b \to c \ell \nu$ background, and continuum background.

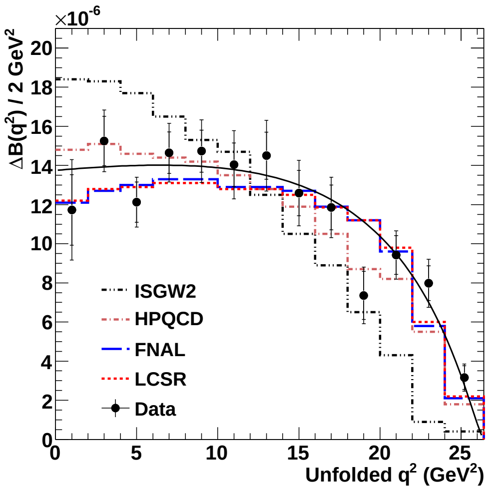

Figure 2: The partial BFs distribution in unfolded q^2 bins. The smaller error bar is for statistical error only and the large error bar means the total uncertainty including systematics. The curve is the fit result with BK form factor parameterization.

predictions. Measured values of $|V_{ub}|$ and its errors are presented in Table 1 and contain large size uncertainties from the form factor calculation.

An extraction of $|V_{ub}|$ is obtained by fitting simultaneously experimental data and lattice QCD calculated data by taking into account its correlation matrices. In this fit, the q^2 distribution of $f_+(q^2)$ is transformed into a z distribution in order to remove well-understood QCD effects. Then the f_+ distribution in terms of z can be expressed as a simple polynomial function. The experimental data and the lattice QCD calculation of the z distribution of f_+ are shown in Fig. 3. In this figure, f_+ is multiplied by the known Φ_+ and P_+ functions.

4. Conclusions

We measure the total branching fraction of the decay, $\mathscr{B}(B^0 \to \pi^- \ell^+ \nu) = (1.49 \pm 0.04_{\rm stat} \pm 0.07_{\rm syst}) \times 10^{-4}$, and extract the Cabibbo-Kobayashi-Maskawa matrix element $|V_{ub}|$ based on var-

$f_+(q^2)$	q^2 (GeV$^2/c^2$)	$\Delta\zeta$ (ps^{-1})	$\lvert V_{ub}\rvert$ (10^{-3})
HPQCD [1]	> 16	2.07 ± 0.57	$3.55 \pm 0.13^{+0.62}_{-0.41}$
FNAL [2]	> 16	1.83 ± 0.50	$3.78 \pm 0.14^{+0.65}_{-0.43}$
LCSR [3]	< 16	5.44 ± 1.43	$3.64 \pm 0.11^{+0.60}_{-0.40}$
ISGW2 [4]	all	9.6 ± 4.8	$3.19 \pm 0.08^{+1.32}_{-0.59}$

Table 1: Value of $|V_{ub}|$ element from various form factor predictions. The first two errors are estimated from the statistical and systematic uncertainties of the partial BFs, respectively. The third error arise from the uncertainty on $\Delta\zeta$.

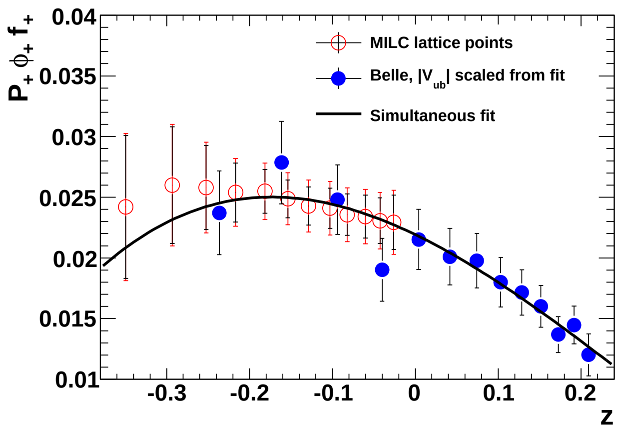

Figure 3: $|V_{ub}|$ extraction from simultaneous fit to experiment data and lattice QCD form factor data [**?**]. The 13-bin experimental data and 12-bin lattice QCD results are transformed to a new variable z and the experimental data are re-scaled by the $|V_{ub}|$ fit result. The curve is the third order polynomial fit function.

ious f_+ predictions, for the the LCSR model, $|V_{ub}| = (3.64 \pm 0.11^{+0.60}_{-0.40}) \times 10^{-3}$ is obtained, and based on a simultaneous fit with the lattice QCD results to be $|V_{ub}| = (3.43 \pm 0.33) \times 10^{-3}$.

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