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Inclusive b→u decays and determination of $V_{\rm ub}$ at Belle

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The Belle measurement of $|V_{\rm ub}|$, one of Cabibbo-Kobayashi-Maskawa matrix elements, from inclusive semileptonic b→u decay was summarized. In the talk two methods are presented. One uses inclusive energy distribution of electrons from B semileptonic decays. The other features a so-called "full-reconstruction" method to get pure B meson samples with more kinematic information.

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1. Introduction

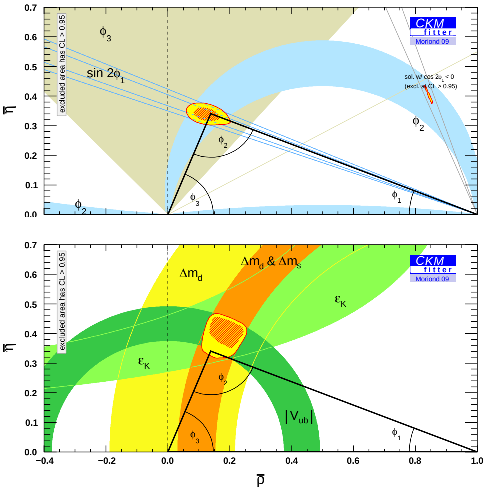

Figure 1: Result of CKM fit with angles only (top) and sides only (bottom).

The accuracies of measurements for the Cabibbo-Kobayashi-Maskawa(CKM) matrix elements have been significantly improved by experiments at B factories and hadron colliders. Recent combination of these results shows a reasonable agreement among the experiments. So far there is no significant deviation from the theory of Kobayashi and Maskawa(KM). Figure 1 shows the result of combination in two different views. One is the combination of angles measurements only and the other is that from sides. One can find that the two combinations are consistent but the agreement is not perfect. Especially the consistency between the angle ϕ_1 and the side $|V_{ub}|$ is not very good. One can also find that the accuracy of ϕ_1 measurement is quite good while the $|V_{ub}|$ is not measured very accurately. Improving the measurement of $|V_{ub}|$ is important for the test of KM mechanism.

The measurement of $|V_{ub}|$ is very straightforward. Using the relation

$$\Gamma(\mathrm{b} \to \mathrm{u}\ell^-\overline{\nu}) = \frac{G_F^2}{192\pi^2}\left|V_{\mathrm{ub}}\right|^2 m_{\mathrm{b}}^5\left(1 + \text{Correction Factor}\right)$$

you just need to count the number of b→u$\ell\nu$ events. However there are difficulties in both experimental and theoretical treatments. Experimentally, one has to distinguish b→u$\ell\nu$ events from topologically identical events from b→c$\ell\nu$ process, which has much bigger branching fraction. Theoretically, it is difficult to calculate the Correction Factor in the equation above, especially with restricting the kinematic phase space to cope with experimental kinematic selections. In order to enhance b→u$\ell\nu$ events from b→c$\ell\nu$ events, kinematic selection such as lepton energy or hadronic mass is applied. Hence what is measured experimentally is actually partial branching fraction described as,

$$\Delta B(\mathrm{B} \to \mathrm{X_u}\ell^-\overline{\nu}) = f_{\mathrm{u}} \cdot B(\mathrm{B} \to \mathrm{X_u}\ell^-\overline{\nu}),$$

where f_{u} is the fraction of phase space. The smaller the f_{u} the larger theoretical uncertainty for calculating it.

In the following sections two measurements using inclusive decay of b→u$\ell\nu$ performed in the Belle experiment are described. One analysis uses the inclusive electron energy spectrum, while the other uses the inclusive distribution of hadronic mass.

2. Endpoint Analysis

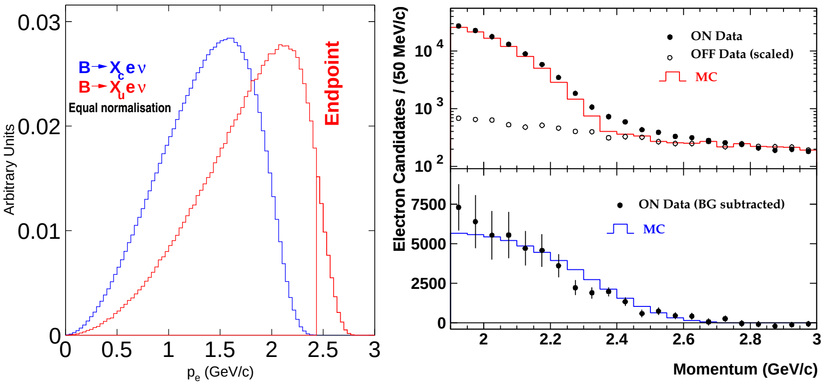

Figure 2: (Left) Electron energy distribution expected from Monte Carlo Simulation. Filled(Open) dots are data taken at (60 MeV bellow) ϒ(4S) resonance. (Right) Electron energy distribution before(top) and after (bottom) subtraction of b→c and light quark background components.

The endpoint analysis is performed using a data set corresponding to an integrated luminosity of 27 fb^{-1} and the full description of the analysis can be found in reference [1]. In this analysis, $\text{B}\to\text{X}_\text{u}e\nu$ events are selected from large $\text{X}_\text{c}e\nu$ background using endpoint of electron energy distribution in ϒ(4S) rest frame. Figure 2(left) shows distributions of electron energies in two final states expected from Monte Carlo simulation. Setting a selection cut at $E_\text{e} = 2.4$ GeV essentially kills all b→c events. However the uncertainty to calculate a fraction of phase space becomes larger as the cut is tighter. On the other hand, setting the cut smaller results in a large background. Hence uncertainty from background estimation becomes bigger. Figure 2(right) shows distributions of electron momentum in ϒ(4S) frame. In the top figure the signal corresponds to the region between data points and Monte Carlo histogram. One can see how big the background is. After subtracting b→c and light quark background contribution estimated using data taken at 60 MeV below ϒ(4S) resonance, the signal is extracted as in the bottom figure. The histogram shows the signal distribution expected from Monte Carlo simulation. The partial branching fraction is measured to be

$$\Delta B = (8.47 \pm 0.37(\text{stat.}) \pm 1.53(\text{syst.})) \times 10^{-4}$$

for electron momentum higher than 1.9 GeV. Although the analysis uses a tiny fraction of data collected by the Belle experiment, the accuracy is limited by systematic uncertainties, not by statistics. The biggest systematic uncertainty comes from the estimation of $\text{X}_\text{c}\ell\nu$ background. The partial branching fraction is then translated to $|V_{\rm ub}|$ by various theoretical calculations. Using the BLNP method [3], $|V_{\rm ub}|$ is determined as

$$|V_{\rm ub}| = \left(4.64 \pm 0.43^{+0.29}_{-0.31}\right) \times 10^{-3},$$

where the first error is experimental and the second error comes from theory.

3. Hadronic Tag Analysis

The Hadronic Tag analysis is based on so-called “full-reconstruction” method to get relatively pure B samples and to have better kinematic reconstruction of semileptonic B decay. The analysis is fully described in reference [2]. The analysis starts from fully reconstructing one of two B mesons (B_{tag}) in a event. The B decay chain is fully reconstructed exclusively. Total of about 200 exclusive decay modes are used in the analysis. Since the B_{tag} is fully reconstructed, momentum of the other B is well determined. The purity is as high as 30% while the efficiency is low as 0.3%. Using the data corresponding to the integrated luminosity of 605 fb^{-1}, more than million tagged events are available. Figure 3 shows the distribution of reconstructed B meson mass for tagged events. Hatched area in the figure corresponds to background.

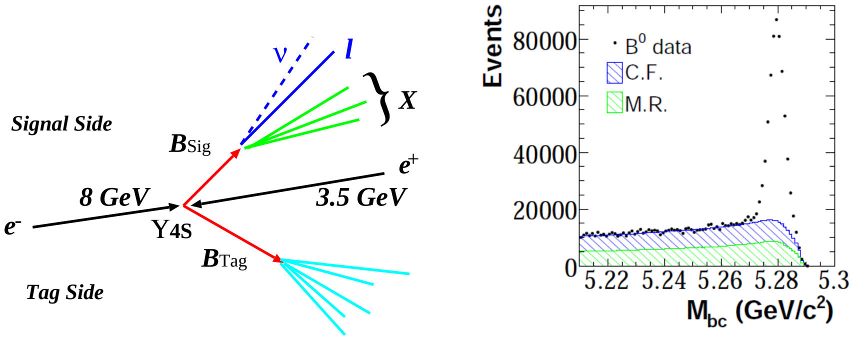

Figure 3: (Left) Event topology (Right) Reconstructed B mass distribution.

In the tagged event a lepton with $p^B > 1$ GeV is required, where p^B is the lepton momentum in B rest frame. In order to suppress background from b→c events, 17 kinematic variables are combined with Boosted Decision Tree(BDT) method. The 17 variables are for example, number of tagged charged and neutral kaons, hadronic mass m_X, missing mass, q^2 and total charge of the event. With BDT method, single optimized cut is used to select b→u events. 5544±54 events are selected with selection efficiency of about 20 %. Using the selected events a 2D fit in $m_X - q^2$ distribution (5×4 bins) is performed to extract the b→u contribution. The background contribution not coming from B decay is estimated from off resonance data taken at 60 MeV below ϒ(4S) resonance, and is subtracted before fit. The shape of contribution coming from B_{tag} not correctly reconstructed are estimated from Monte Carlo simulation. The number of such events are obtained by scaling the shape to the sideband of reconstructed B mass distribution. This contribution is also subtracted prior to the fit. After subtracting these two components, the $m_X - q^2$ distribution is fitted with three components, $X_u\ell\nu$ (signal), $X_c\ell\nu$, and the contribution coming from events containing leptons from secondary decays or fakes. Figure 4 shows the projections of fitted $m_X - q^2$ distribution. Open histograms corresponds to 1032±91 $X_u\ell\nu$ events extracted by the fit. Background contributions subtracted prior to the fit are also shown.

The partial branching fraction is expressed by,

$$\Delta\mathcal{B}(B \to X_u \ell^- \bar{\nu}, \Delta) = \frac{N^{\Delta}_{b\to u}}{\varepsilon^{\Delta}_{b\to u} N_{tag}}(1-\delta_{rad}),$$

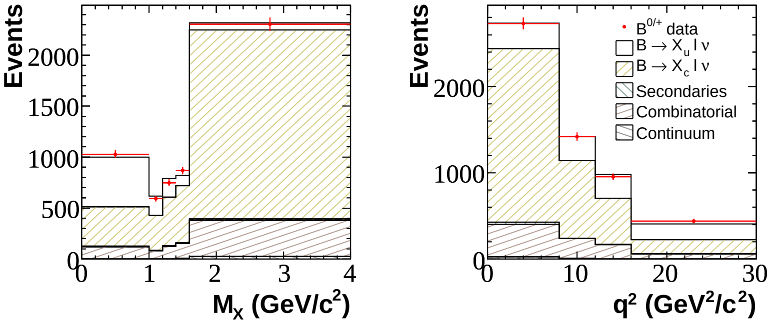

Figure 4: Projected hadronic mass(left) and q^2(right) distributions with fitted contributions.

where Δ is the kinematic selection in the analysis namely the lepton momentum requirement. $\varepsilon^{\Delta}_{b\to u}$ is the efficiency of BDT selection. δ_{rad} is correction from QED radiation of about 20%. The partial branching fraction is measured to be,

$$\Delta B = 1.963(1 \pm 0.088 \pm 0.081) \times 10^{-3},$$

for $p^{B}_{\ell} > 1$ GeV, where the first and second errors arr statistical and systematic, respectively. As described in the previous section, this partial branching fraction is converted to $|V_{\mathrm{ub}}|$ using theoretical calculation. In the Table 1 the $|V_{\mathrm{ub}}|$ values as well as their errors are summarized for three theoretical calculations, BLNP [3], DGE [4] and GGOU [5].

Theory	$\lvert V_{\mathrm{ub}}\rvert \times 10^3$	stat.	sys.	m_{b}	th.
BLNP	4.37	4.3	4.0	$^{+3.1}_{-2.7}$	$^{+4.3}_{-4.0}$
DGE	4.46	4.3	4.0	$^{+3.2}_{-3.3}$	$^{+1.0}_{-1.5}$
GGOU	4.41	4.3	4.0	1.9	$^{+2.1}_{-4.5}$

Table 1: $|V_{\mathrm{ub}}|$ and errors calculated with three theoretical method. Columns m_{b} and th. are the contribution from uncertainties of b quark mass and theories, respectively.

4. Summary

In this talk, two types of measurement of inclusive b→u decays and determination of the CKM matrix element $|V_{\mathrm{ub}}|$ performed by Belle collaboration are presented.

References

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