

Recent CKM Element Results from BaBar and Belle

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We review the latest measurements of the Cabibbo-Kobayashi-Maskawa quark mixing matrix elements at the B -factories. Determinations of $|V_{ub}|$, $|V_{cb}|$, $|V_{td}/V_{ts}|$ from B decays and $|V_{us}|$ from τ decays will be discussed.

1. INTRODUCTION

In the standard model the strong eigenstates are related to the weak eigenstates through a unitary transformation described by Cabibbo-Kobayashi-Maskawa matrix (CKM) [1,2]. This matrix is an SU(3) transformation which has four free parameters that can be expressed in terms of three angles and one irremovable complex phase. A general element of the CKM matrix V_{ij} express the coupling strength between the quark flavor i and j . The irremovable phase in the CKM matrix allows possible CP violation. In the following, a review of the latest measurements of the absolute values of the CKM matrix elements from the B -factory is presented.

2. $|V_{ub}|$

$|V_{ub}|$ can be measured from semileptonic B decays either using an exclusive hadronic final states ($B \rightarrow \pi \ell \nu$), or by considering the inclusive rate, summing over all hadron final states applying some kinematical constraints ($B \rightarrow X_u \ell \nu$). Both approaches need inputs from the theory to model the hadronization process and they are complementary, since the description of the QCD part from the theory comes from independent calculations. The leading difficulty in $|V_{ub}|$ extraction with high precision in inclusive $B \rightarrow X_u \ell \nu$ decays is suppressing the background from $B \rightarrow X_c \ell \nu$, which is 50 times larger. All previous inclusive measurements have been performed in restricted phase space regions in order to exploit the different behavior between $b \rightarrow u$ and $b \rightarrow c$ transitions. In particular for these anal-

yses theoretical parametrizations (called shape functions SF) need to be introduced to describe the unmeasured region of phase space. At present the main contribute on $|V_{ub}|$ uncertainty is due to SF. Belle reports a measurement [3] of the partial branching fraction of $B \rightarrow X_u \ell \nu$ decays with a lepton momentum threshold of 1 GeV/c using a multivariate data mining technique, and derives $|V_{ub}|$ using several theoretical calculations [4–6]. The measurement is performed studying events where one B from $\Upsilon(4S)$ decay is fully reconstructed in hadronic decay modes (B_{tag}), which make possible to infer its flavor and four-momentum. A semi-leptonic decay of the other B meson (B_{recoil}) is identified by the presence of a charged lepton (e or μ). In addition, the detection of missing energy and momentum in the event is taken as evidence for the presence of a neutrino. The signal selection is based on a *non-linear* multivariate analysis technique, the boosted decision tree (BDT) method, which uses 17 discriminating variable to separate $B \rightarrow X_u \ell \nu$ decays from other kinds of B decays. The signal yields is extracted using a binned maximum likelihood fit to the two dimensional distributions of the variable M_X (the hadronic invariant mass of the system X) and q^2 (the momentum transfer squared). The partial branching fraction measured is $\Delta B(B \rightarrow X_u \ell \nu; p_{lep} > 1 \text{ GeV}/c) = 1.963 \times (1 \pm 0.088_{stat} \pm 0.081_{syst})$ and the respective value of $|V_{ub}|$ is $4.41 \times 10^{-3} \times (1 \pm 0.043_{stat} \pm 0.040_{syst} \pm 0.038)$ using the GGOU theoretical model [6]. With this analysis the total error on $|V_{ub}|$ is only 7% and is primarily due to the increase in the measured phase space,

which decrease the power dependence of $|V_{ub}|$ on the b quark mass. For the extraction of $|V_{ub}|$ using exclusive approach, the decay $B \rightarrow \pi \ell \nu$ is the most promising for both, experimentally and theoretically reasons. Its rate is proportional to $|V_{ub} \times f_+(q^2)|^2$ where the form factor $f_+(q^2)$ depends on q^2 . BaBar recently presented an update [7] of an earlier measurement [8] that was based on a significantly smaller data set. In this analysis a study of four exclusive charmless semileptonic decay modes, $B^{0/+} \rightarrow \pi^{-/0} \ell^+ \nu$, and $B^{0/+} \rightarrow \rho^{-/0} \ell^+ \nu$, and a determination of $|V_{ub}|$ has been performed. The reconstruction of the signal decays in $\Upsilon(4S) \rightarrow B\bar{B}$ requires the identification of three kinds of particles, the hadronic state X_u , the charged lepton (e or μ), and the neutrino. The presence of the neutrino is inferred from missing energy considerations. The event yields for each of the four signal decays modes are extracted from a binned maximum-likelihood fit to the three-dimensional distributions of the variable m_{ES} , the energy-substituted B -meson mass, ΔE , the difference between the reconstructed and the expected B -meson energy, and q^2 . Assuming isospin symmetry is possible combine the two $\pi \ell \nu$ samples and measure the branching ratio $B(B^0 \rightarrow \pi^- \ell^+ \nu) = (1.41 \pm 0.05_{stat} \pm 0.07_{syst}) \times 10^{-4}$. The measured branching ratio for $B \rightarrow \pi \ell \nu$ is more precise than any previous measurement and agree well with the current world average [9]. $|V_{ub}|$ can be extracted using two different approaches. First combining the measured partial branching ratio with the form factor computed using different QCD calculations [10,11] and gives a total error on $|V_{ub}|$ of about 16%. Second, using a simultaneous fit to $B \rightarrow \pi \ell \nu$ data and FNAL/MILC lattice QCD [12]. In this case $|V_{ub}|$ is $(2.95 \pm 0.31) \times 10^{-3}$ where the total uncertainty is only 11%. A summary of the $|V_{ub}|$ status is shown in figure 1. Currently, there is about 1.5σ discrepancy in the respective world average, and it increases if we consider the latest $B \rightarrow \pi \ell \nu$ measurement [7].

3. $|V_{cb}|$

$|V_{cb}|$ can be extracted from inclusive semileptonic B decays [13] and exclusive decays $\bar{B} \rightarrow$

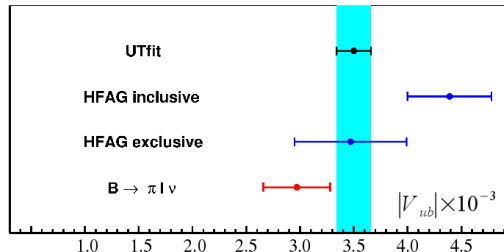


Figure 1. Summary of the measured values of $|V_{ub}|$ using different techniques. The blue line shows the average values of $|V_{ub}|$ reported from HFAG [14] for both, inclusive and exclusive approaches. In the exclusive average calculation the latest measurement of $|V_{ub}|$ from $B \rightarrow \pi \ell \nu$ is not considered. Its value is shown by red line.

$D\ell^- \bar{\nu}_l$ and $\bar{B} \rightarrow D^* \ell^- \bar{\nu}_l$ [15]. At present the inclusive determinations of $|V_{cb}|$ are more precise than exclusive ones. Improvements in the measurements of the exclusive decay rates are strongly desirable and, in particular, for $\bar{B} \rightarrow D\ell^- \bar{\nu}_l$ which is dominated by experimental uncertainties. In the limit of very small lepton mass (e or μ), the $\bar{B} \rightarrow D\ell^- \bar{\nu}_l$ differential decay rate depends on a single factor $G(w)$, where w is the product of the B and D meson 4-velocities. If we consider the limit of infinite heavy quark mass, $G(w)$ is equal to the Isgur-Wise function [16] which is normalized to unity at zero recoil (where q^2 is maximum, i.e. $w = 1$). Corrections to the heavy quark limit arise from unquenched [17] and quenched [18] QCD. $|V_{cb}|$ can be extracted by extrapolating the $\bar{B} \rightarrow D\ell^- \bar{\nu}_l$ differential decay rate to $w = 1$. The form factor is parametrized using a function described in references [20]. BaBar recently presents a measurement of $|V_{cb}|$ using $\bar{B} \rightarrow D\ell \bar{\nu}_l$ decays [19]. Semileptonic decays are selected in $B\bar{B}$ events where one of the two B mesons is fully reconstructed from its hadronic decays. From the measured particle 4-momenta of all other tracks the missing mass square ($m_{miss}^2 = [p_{\Upsilon(4S)} - p_{B_{tag}} - p_D - p_l]^2$) is computed and semileptonic B decays are identified. The $\bar{B} \rightarrow D\ell \bar{\nu}_l$ signal yields are obtained from the m_{miss}^2 distribution in data by an extended binned maximum likelihood in ten bins of

w ($1 < w < 1.6$). From another χ^2 fit $G(1)|V_{cb}|$ is $(4.2 \pm 1.9_{stat} \pm 1.4_{syst}) \times 10^{-3}$, where $G(w=1)$ is the hadronic form factor at the point of *zero recoil* and it's predicted from Lattice QCD. Using unquenched [17] and quenched [18] lattice calculations $|V_{cb}|$ is $(39.8 \pm 1.8 \pm 1.3 \pm 0.9_{FF}) \times 10^{-3}$ and $(41.6 \pm 1.8 \pm 1.4 \pm 0.7_{FF}) \times 10^{-3}$ respectively. This result is compatible with the determination of $|V_{cb}|$ from both, inclusive and exclusive from $\bar{B} \rightarrow D^* \ell \bar{\nu}_l$. A summary of the $|V_{cb}|$ status is shown in figure 2.

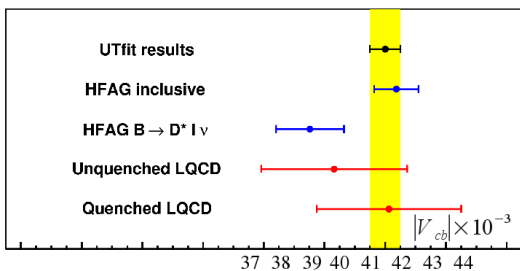


Figure 2. Summary of the measured values of $|V_{cb}|$ using different technique. The blue lines shown the average values of $|V_{cb}|$ reported from HFAG [14] for both, inclusive and exclusive approaches from $B \rightarrow D^* \ell \nu$ decays. In red are reported the $|V_{cb}|$ measurements [19] using $\bar{B} \rightarrow D \ell \bar{\nu}_l$ decays with unquenched and quenched lattice QCD calculation. If we compare the exclusive determination of $|V_{cb}|$ using $\bar{B} \rightarrow D^* \ell \bar{\nu}$ decays with respect to the inclusive one there is about 2σ discrepancy.

4. $|V_{td}/V_{ts}|$

In the SM the inclusive rate for $b \rightarrow d\gamma$ is suppressed relative to $b \rightarrow s\gamma$ by a factor $|V_{td}/V_{ts}|^2$. These are one-loop electroweak penguin processes, and are a good probe for new physics. The best measurement of $|V_{td}/V_{ts}|$ (total error about 4%) arise from B_d and B_s mixing frequency [21]. It's important to confirm the consistency of the two methods of determining $|V_{td}/V_{ts}|$, since new physics would enter in different ways in mixing and radiative decays.

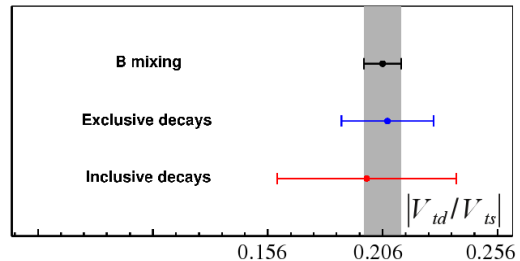


Figure 3. Summary of the measured values of $|V_{td}/V_{ts}|$. The best measurement arises from B_d and B_s mixing ([21]) (black line). Exclusive [24, 25] (blue line) and inclusive determinations [22] (red line) are also reported.

BaBar reports a measurement [22] of the inclusive $B \rightarrow X_{s(d)}\gamma$ transition rates using a sum of seven final states in the hadronic mass range up to $2.0 \text{ GeV}/c^2$. This analysis presents the first significant observation of the $b \rightarrow d\gamma$ transition in the hadronic mass range larger than $1.0 \text{ GeV}/c^2$, providing significant improvements in the determination of $|V_{td}/V_{ts}|$. After correction for unobservable decay modes the ratio of branching ratio measured is $B(b \rightarrow d\gamma)/B(b \rightarrow s\gamma) = (0.040 \pm 0.009_{stat} \pm 0.005_{syst} \pm 0.010_{extrap})$. Conversion of the ratio of inclusive branching fractions to the ratio $|V_{td}/V_{ts}|$ is done according to [23]. The relative value of $|V_{td}/V_{ts}|$ derived from this procedure is $(0.199 \pm 0.022_{stat} \pm 0.012_{syst} \pm 0.027_{extrap} \pm 0.012_{theo})$ and it's compatible with the result from B oscillations, but with an error about 4.8σ larger. A summary of the $|V_{td}/V_{ts}|$ status is shown in figure 3.

5. $|V_{us}|$

Measurements of hadronic τ decays provide a new test for the determination of $|V_{us}|$, although affected by a higher statistical error respect to the kaon decays (see figure 4). The extraction of $|V_{us}|$ from hadronic τ decays is related to moments of the invariant mass distributions of the final states hadrons as described in [26]. Considering two recent measurements [27,28], the averaged value of $|V_{us}|$ from inclusive τ decays is (0.2151 ± 0.0026) and it's about 3σ lower than the

value extracted from kaon decays (see figure 3). A recent result presented by *BaBar* [29] uses an alternative way to extract $|V_{us}|$ and relies on the ratio of the branching fractions for $\tau^- \rightarrow K^- \nu$ and $\tau^- \rightarrow \pi^- \nu$. Using this method $|V_{us}|$ is (0.2255 ± 0.0023) and it's compatible with the one from kaon decays.

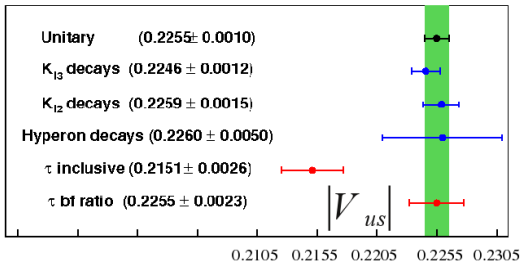


Figure 4. Summary of the measured values of $|V_{us}|$ using different techniques.

6. Summary

A review of the current status of the CKM matrix elements performed at the B-factory is given. The inclusive determinations of $|V_{ub}|$ and $|V_{cb}|$ provide the most precise measurements but a discrepancy of at least 2σ with respect to exclusive determination indicate an incomplete scenario. $|V_{td}|/|V_{ts}|$ obtained from $b \rightarrow d(s)\gamma$ decays is compatible with the result from B oscillations. $|V_{us}|$ from inclusive τ decays is 3σ lower than the value extracted from kaon decays. $|V_{us}|$ from ratio of branching fractions for $\tau^- \rightarrow K^- \nu$ and $\tau^- \rightarrow \pi^- \nu$ is compatible with the one from kaon decays.

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