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V_{ub} inclusive

Nicola Gagliardi[*]
INFN sezione di Padova
E-mail: `nicola.gagliardi@pd.infn.it`

In this article, the status of the determination of the CKM magnitude $|V_{ub}|$ from inclusive semileptonic B decays at the B-factories experiments *BABAR* and *BELLE*, is reviewed.

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[*] Speaker.

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1. Introduction

The principal physic goal of the B-factories experiments is to study CP violation in B mesons and test if the observed effects are consistent with the Standard Model (SM) predictions. CP violation effects arise in the SM from an irreducible phase in the Cabibbo-Kobayashi-Maskawa (CKM) matrix which describe the couplings of the charged weak current to quarks. In the Unitary Triangle picture, the CKM matrix element $|V_{ub}|$, the strength of the coupling of the b quark to u quark, plays a peculiar role because its magnitude is connected with the length of the side of the UT opposite to the angle β. This means that a precise determination of $|V_{ub}|$ is crucial to enhance the constraints of the unitarity of the CKM matrix and the Standard Model consistency. $|V_{ub}|$ can be measured from semileptonic B decays either using an exclusive hadronic final states (e.g. $B \to \pi\ell\nu$), or by considering the inclusive rate, summing over all hadron final states (e.g. $B \to X_u\ell\nu$). Both approaches need inputs from the theory to describe the hadronization 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 hight precision in inclusive $B \to X_u\ell\nu$ decays is suppressing the background from $B \to X_c\ell\nu$, which is 50 times larger. All previous inclusive measurements have been performed in restricted phase space regions (i.e. fraction of $b \to u\ell\nu$ decays of about 30-40%) in order to exploit the different behavior between $b \to u$ and $b \to c$ transitions. In particular for these analyses theoretical parameterizations (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. Therefore, to reduce model uncertainties one must access as much kinematic phase space as possible.

BABAR has previously published [1] a determination of $|V_{ub}|$ from measurements of the inclusive charmless semileptonic branching fractions $\Delta\mathscr{B}(B \to X_u\ell\nu)$ based on the study of the recoil of fully reconstructed B mesons and applying some particular kinematic cuts. At ICHEP2010 *BABAR* presented a preliminary analysis which extends the same analysis strategy on a larger data set. In addition an analysis that selects about 90% of the phase space have been performed.

BELLE has recently published an analysis [2] relies on a multivariate technique to reduce the larger $B \to X_c\ell\nu$ background accessing at the about 90% of the $B \to X_u\ell\nu$ available phase space (the same analyzed by *BABAR*).

2. Inclusive $B \to X_u\ell\nu$ from *BABAR*

BABAR recently presented a preliminary analysis [3] which measures partial branching fractions for inclusive charmless semileptonic B decays $B \to X_u\ell\nu$ and extracts the CKM matrix element $|V_{ub}|$. The analysis is based on a sample of 467 million $\Upsilon(4S)$ decays into $B\bar{B}$ pairs collected with the *BABAR* detector at the PEP-II e^+e^- storage rings. Only events where one of the B mesons is fully reconstructed in a hadronic decay mode and the other decays semileptonically into either an electron or a muon are selected. Knowing the kinematic of one of the two B mesons is possible to infer the flavour and the four-momentum of the the B meson. In addition, the detection of missing energy and momentum in the event is taken as evidence for the presence of a neutrino. In inclusive measurements of the $B \to X\ell\nu$ decays restrictions on various kinematic variables are used to separated the small signal from the dominant backgrounds: the lepton momentum (P_l), the hadronic invariant mass (m_X), the dilepton invariant mass squared (q^2) and $P_+ = E_X - |\vec{P}_X|$, where E_X and $\vec{P}_X$ are the energy and momentum of the hadronic system X in the B-meson rest frame. One of the two B mesons coming from $\Upsilon(4S)$ is reconstructed looking for decays of the type $B \to DY$, where D is a generic charmed meson (D^0, $D^+, D^{*0}, D^{*\pm}$) and Y is a charged system composed of charged pions, charged kaons, K^0_S and neutral pions. The kinematic consistency of a reconstructed B meson (called B_{reco}) with a true B meson decay is checked using the beam energy substitute mass $m_{\mathrm{ES}} = \sqrt{s/4 - \vec{p}_B^{\,2}}$, and the energy difference, $\Delta E = E_B - \sqrt{s}/2$, where $\sqrt{s}$ is the total energy in the $\Upsilon(4S)$ center of mass frame, and p_B and E_B are respectively the momentum and energy of the B_{reco} candidate in the same frame. $m_{\mathrm{ES}} > 5.22\ GeV/c^2$ and $\Delta E = 0$ within approximately three standard deviations are required to reduce fake B mesons. On average one B candidate is reconstructed in 0.3% of the $B^0\bar{B}^0$ events and in 0.5% of the B^+B^- events. The hadronic system X in the decay $B \to X_u \ell \nu$ is reconstructed from charged tracks and energy depositions in the calorimeter that are not associated with B_{reco} candidate or the identified lepton. The neutrino four-momentum p_ν is estimated from the missing momentum four-vector $p_{miss} = p_{\Upsilon(4S)} - p_{B_{reco}} - p_X - p_l$. To derive the charmless semileptonic branching ratio, the observed number of signal events in the kinematics region considered, corrected for background and efficiency, is normalized to the total number of semileptonic decays $B \to X \ell \nu$ observed in the decays recoiling against a B_{reco} events sample. In this way the systematic uncertainties in the reconstruction of the B_{reco} side are canceled and others are strongly reduced. The events based selection criteria can be divided into loose ones, used to measure the number of semileptonic $B \to X \ell \nu$ events in the sample, and the tight selection used to identify well reconstructed $B \to X_u \ell \nu$ events. Semileptonic events are selected by the presence of at least one well identified electron or muon. The angular acceptance for tracks associated to leptons is reduced to $0.450 < \theta < 2.473$ in order to exclude regions where the particle identification is not well known. We require the momentum of this lepton in the B_{recoil} rest frame (P_l) to be greater than 1 GeV/c in order to suppress backgrounds from secondary charm or $\tau^\pm$ decays and from fake leptons, while retaining about 90% of signal. The theoretical uncertainty in the small fraction of the spectrum lost by this cut is expected to be small. Boosting to the rest frame of the recoiling B is possible since the momentum of the $\Upsilon(4S)$ and the reconstructed B are known. $B \to X_u \ell \nu$ candidates are selected requiring exactly one charged lepton with $p_l > 1 GeV/c$, charge conservation ($Q_X + Q_l + Q_{B_{reco}} = 0$), and a missing mass consistent with zero($m^2_{miss} < 0.5 GeV^2/c^4$). These criteria suppress the dominant $B \to X_c \ell \nu$ decays, many of which contain additional leptons or undetected K^0_L meson. $B \to D^* \ell \nu$ background have been suppressed by using the partial reconstruction method with neutral and charged soft pions. Events with charged kaons or K^0_S in the B_{recoil} have been rejected to reduce the background from $B \to X_c \ell \nu$ decays. To extract the distribution in the kinematic variables m_X, P_+, q^2, p_l and the combination of m_X and q^2 fits to the B_{reco} m_{ES} distributions for subsamples of events in individual bins for each of the variables have been performed in order to separate the signal from the combinatorial and continuum backgrounds.The resulting distributions are presented in figures 1. The number of fitted events and the relative $\Delta\mathscr{B}(B \to X_u \ell \nu)$ for the different phase space analyzed are reported in Table 1.In these fits, the $B \to X_u \ell \nu$ MC component is divided in events with the true value of the considered variable inside the kinematic region under examination (inner region) and signal events in which the considered variable is outside the kinematics region. These separation allows to account for the finite resolution of the reconstructed

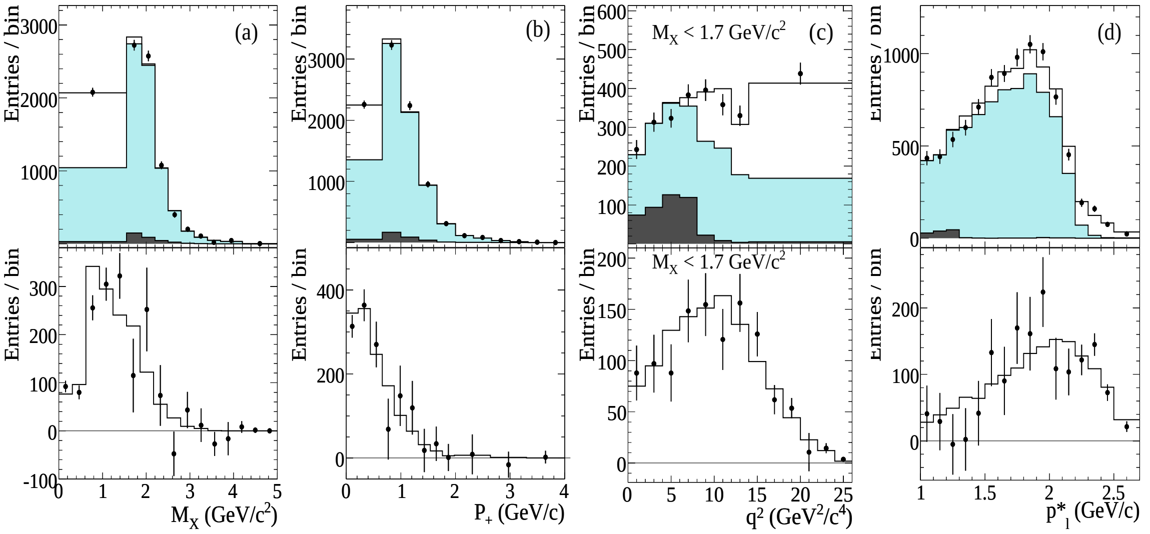


Figure 1: Upper row: measured m_X (a), P_+ (b), q^2 with $m_X < 1.7$ GeV/c^2 (c) and P_l spectra (data points). The result of the fit to the sum of three MC contributions is shown in the histograms: $B \to X_u \ell \nu$ decays generated inside (no shading) and outside (dark shading) the selected kinematic region, and $B \to X_c \ell \nu$ and other background (light shading). Lower row: corresponding spectra for $B \to X_u \ell \nu$ after $B \to X_c \ell \nu$ and other background subtraction; they have been rebinned in order to show the shape of the kinematic variables. Background-subtracted distributions are not efficiency corrected.

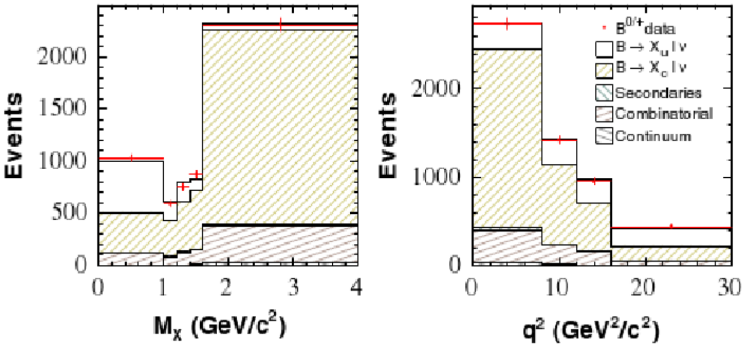
Table 1: Summary of the measurements of the fitted numbers of events and $\Delta\mathscr{B}(B \to X_u \ell \nu)$ for the different phase spaces analyzed. The first error is statistical, the second systematic. The $P_l > 1\,\mathrm{GeV}/c$ requirement is implicitly assumed, unless otherwise noted. The two results for $P_l > 1\,\mathrm{GeV}/c$ have been obtained by fitting the two dimensional (m_X, q^2) and P_l distributions, respectively.

Regions of phase space	N_u	$\Delta\mathscr{B}(B \to X_u \ell \nu)$ (10^{-3})
$m_X < 1.55\,\mathrm{GeV}/c^2$	1033 ± 73	$1.08 \pm 0.08_{stat} \pm 0.06_{syst}$
$m_X < 1.70\,\mathrm{GeV}/c^2$	1089 ± 82	$1.15 \pm 0.10_{stat} \pm 0.08_{syst}$
$P_+ < 0.66\,\mathrm{GeV}$	902 ± 80	$0.98 \pm 0.09_{stat} \pm 0.08_{syst}$
$m_X < 1.70\,\mathrm{GeV}/c^2, q^2 > 8\mathrm{GeV}^2/\mathrm{c}^4$	665 ± 53	$0.68 \pm 0.06_{stat} \pm 0.04_{syst}$
(m_X, q^2), $P_l > 1\,\mathrm{GeV}/c$	1441 ± 102	$1.80 \pm 0.13_{stat} \pm 0.15_{syst}$
$P_l > 1.0\,\mathrm{GeV}/c$	1470 ± 133	$1.80 \pm 0.16_{stat} \pm 0.19_{syst}$
$P_l > 1.3\,\mathrm{GeV}/c$	1329 ± 123	$1.52 \pm 0.13_{stat} \pm 0.14_{syst}$

kinematic variables.The result of the fit to P_l distribution requiring just $P_l > 1.0\,\mathrm{GeV}/c$ can be directly compared with the results of the 2-dimensional fit to the $m_X - q^2$ distribution because the events are exactly the same but fitted on different kinematic variables. The agreement is good, and as expected the results obtained from the 2-dimensional fit are affected by smaller statistical and theoretical uncertainty. This cross check shows that MC describes fairly well the background and signal events. The total experimental error for these analyses goes from 9 to 13% where the leading systematic uncertainty arises by signal model(6-8%).

3. Inclusive $B \to X_u \ell \nu$ from BELLE

BELLE reports a measurements [2] of the partial branching fraction of $B \to X_u \ell \nu$ decays with lepton momentum threshold of 1 GeV/c using a multivariate data mining technique. The analysis strategy is exactly the same of the BABAR ones in section 2. The leading differences arise from the $B \to X_u \ell \nu$ selection criteria procedure. It is based on a non-linear multivariate analysis technique, the Boosted Decision Tree (BDT) method, which takes into account various observables used to form a BDT classifier, separating $B \to X_u \ell \nu$ decays from other kinds of B decays. The signal yields is extracted using a binned maximum likelihood fit to the two dimensional distribution of the variable m_X and q^2. A total of 1032 ± 91 events remain after background subtraction. The partial branching ratio measured is $\Delta\mathscr{B}(B \to X_u \ell \nu, P_l > 1GeV/C) = 1.963 \times (1 \pm 0.088_{stat} \pm 0.081_{syst})$ and it's compatible with the preliminary results presented by BABAR and described in section 1. The fit result and the breakdown of the errors are shown in figure 2. The dominant source of uncertainty is due to Monte Carlo signal modeling (6.5%). The total error on $\Delta\mathscr{B}(B \to X_u \ell \nu)$ is about 12%.



$p_\ell^{*B} > 1.0$ GeV	$\Delta\mathcal{B}/\mathcal{B}$ (%)
$\mathcal{B}(D^{(*)}\ell\nu)$	1.2
$(D^{(*)}\ell\nu)$ form factors	1.2
$\mathcal{B}(D^{**}e\nu)$ & form factors	0.2
$B \to X_u\ell\nu$ (SF)	3.6
$B \to X_u\ell\nu$ ($g \to s\bar{s}$)	1.5
$\mathcal{B}(B \to \pi/\rho/\omega\ell\nu)$	2.3
$\mathcal{B}(B \to \eta,\ \eta'\ell\nu)$	3.2
$\mathcal{B}(B \to X_u\ell\nu)$ un-meas.	2.9
Cont./Comb.	1.8
Sec./Fakes/Fit.	1.0
PID/Reconstruction	3.1
BDT	3.1
Systematics	8.1
Statistics	8.8

Figure 2: Projection of the $m_X - q^2$ fit in bins of m_X(left) and q^2(middle). Breakdown of the errors(right) for the partial charmless semileptonic branching fraction (in percent)

4. Weak Annihilation

One of the effects that is not included in current calculations of the partial decay rate is the Weak Annihilation which is expected to contribute at level of a few percent. Simply speaking Weak Annihilation refers to the annihilation of b-$\bar{u}$ pair to a virtual W boson and the results is an enhancement of the decay rate near the q^2 endpoint spectrum($q^2 > 18\ GeV^2/c^4$).

The values for $\Delta\mathscr{B}(B \to X_u \ell \nu)$ for neutral and charged B mesons, presented for the first time in the preliminary results reported from BABAR in 2, can be used to test isospin invariance, using the ratio:

$$R^{+/0} = \frac{\Delta\Gamma^+}{\Delta\Gamma^0} = \frac{\tau^0}{\tau^+} \cdot \frac{\Delta\mathscr{B}(B^+ \to X_u \ell \nu)}{\Delta\mathscr{B}(B^0 \to X_u \ell \nu)}, \tag{4.1}$$

where τ^+/τ^0 = 1.071± 0.009 [4] is the ratio of the lifetimes for B^+ and B^0. The result for $R^{+/0}$ -1 for the analysis with the smallest systematic error on the partial branching fractions($M_X <$ 1.55 GeV/c^2) is $-0.020 \pm 0.066_{stat} \pm 0.033_{syst}$. This value is compatible with zero and there is no evidence for a difference in partial decay rates between B^+ and B^0. Defining $\Delta\gamma_{WA} = \Delta\Gamma^+ - \Delta\Gamma^0$ the contribution of Weak Annihilation, is possible to compute its relative contribution to the relative decay width $\Delta\Gamma$ for $B \to X_u \ell \nu$ decays, as $\Delta\gamma_{WA}/\Delta\Gamma = R^{+/0} - 1$. If f_{WA} is the fraction of Weak Annihilation contribution for the kinematic cut considered, and f_u the fraction of $B \to X_u \ell \nu$ predicted in that region, is possible to write the following expression $\Delta\Gamma = f_u \Gamma$, where Γ is the total decay width of $B \to X_u \ell \nu$ decays and the relative contribution of the Weak Annihilation can be written as:

$$\frac{\gamma_{WA}}{\Gamma} = \frac{f_u}{f_{WA}} \cdot R^{+/0}, \tag{4.2}$$

Taken f_u from the signal model and considering $f_{WA} = 1.0$ (Weak Annihilation is expected to be confined in the high q^2 region) is possible set a limit $-0.13 < \gamma_{WA}/\Gamma < 0.09$ at 90% of C.L.

This result is consistent with the previous limits measured from CLEO [5] and BABAR [6].

5. $|V_{ub}|$ extractions

Measured values of $\Delta\mathscr{B}(B \to X_u \ell \nu)$ are translated into $|V_{ub}|$ using all the available QCD predictions [7, 8, 9, 10, 11]. All calculations use hadronic input parameters which can extracted from data, by combining a global fit to a set of measurements, performed by several collaborations, of the moments of the lepton energy and hadronic invariant mass in semileptonic B decays, and of the photon energy in radiative $B \to X_s \gamma$ inclusive decays [12]. The fit has been performed by using only published results; the fit parameters useful to determine $|V_{ub}|$ are the b-quark mass $m_b^{KIN} = 4.59 \pm 0.03\,\mathrm{GeV}/c^2$ and the mean value of the b-quark momentum operator $\mu_\pi^{2(KIN)} = 0.45 \pm 0.04\mathrm{GeV}^2/\mathrm{c}^4$. Both parameters are determined in the kinetic renormalization scheme, and need to be translated in other schemes, depending on the calculation used to determine $|V_{ub}|$ from the partial branching fraction measurements. The measured $\Delta\mathscr{B}(B \to X_u \ell \nu)$ are related to $|V_{ub}|$ via the following equation

$$|V_{ub}| = \sqrt{\frac{\Delta\mathscr{B}(B \to X_u \ell \nu)}{\tau_B \cdot \Delta\Gamma_{theory}}} \tag{5.1}$$

where values of $\Delta\Gamma_{theory}$ (the theoretical $B \to X_u \ell \nu$ width according to the applied cuts) is based on different QCD calculations [7, 8, 9, 10, 11]. A preliminary summary of the measured values of $|Vub|$ computed by HFAG[13] are shown in figure 3. These preliminary $|V_{ub}|$ values are consistent within one σ of each other, and also consistent within one σ of previous measurements of $|V_{ub}|$ [1].

6. Conclusions

We have reviewed the current status of the $|V_{ub}|$ determination using inclusive semileptonic B decays. The most precise result arises from the preliminary analysis on the two-dimensional fit on $m_X - q^2$ plane with no cuts other than $p_l > 1GeV/c$ presented by BABAR at ICHEP2010. The total

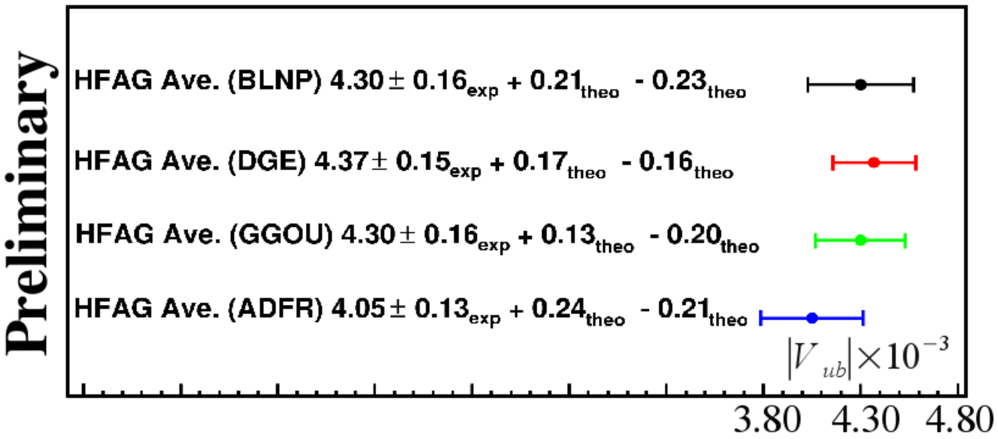


Figure 3: Preliminary summary of the measured values of $|Vub|$ obtained using different theoretical calculations [7, 8, 9, 10, 11]. The preliminary $|V_{ub}|$ average values have been provided by HFAG[13].

uncertainty is about 7.6% comparable in precision with the result recently published by *BELLE* [2] on a similar analysis that use a multivariate discriminants to reduce the large background.

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