Contributed to 32nd International Conference on High-Energy Physics (ICHEP 04),
08/16/2004--8/22/2004, Beijing, China

SLAC-PUB-11525

STUDY OF INCLUSIVE AND EXCLUSIVE $B \to X_u \ell \nu$ DECAYS AND MEASUREMENT OF $|V_{ub}|$ WITH THE *BABAR* DETECTOR

DANIELE DEL RE
(representing the BABAR collaboration)
University of California, San Diego, Department of Physics, La Jolla, CA 92093, USA

We report studies of $B \to X_u \ell \nu$ decays, based on a sample of 88 million $B\overline{B}$ events recorded with the *BABAR* detector. From both tagged and untagged $B\overline{B}$ events we have isolated inclusive charmless decays in kinematic regions for which the dominant background from $B \to X_c \ell \nu$ is reduced by making requirements on different variables: the electron energy E_l, the momentum transfer q^2, and the hadronic mass m_X. Using theoretical calculations we extrapolate to the total decay rate to determine the CKM matrix element $|V_{ub}|$. In addition, we have measured the branching fraction for exclusive semileptonic decays, such as $B \to \pi(\rho, \omega, \eta, a_0)\ell\nu$. A high signal purity is achieved by selecting events in which a decay of the second B meson is either fully or partially reconstructed.

1 Introduction

The precise determination of the magnitude of the CKM element $|V_{ub}|$ is one of the most important goals in the heavy flavor physics. In the unitarity triangle the uncertainty in $|V_{ub}|$ dominates the error of the length of the side opposite to the angle β. As a consequence a precise measurement of $|V_{ub}|$ represents a strong constraint and tests the compatibility between angles and sides measurements, where any disagreement can be interpreted as new physics. The measurement of $|V_{ub}|$ is a challenge. The main experimental problem is the separation of $b \to u\ell\bar{\nu}$ events from the more abundant (approximately 50 times larger) $b \to c\ell\bar{\nu}$ events, that have also very similar kinematic properties. Selection criteria to achieve this separation generally make the theoretical extrapolation to the full decay rate more difficult. This problem affects both inclusive and exclusive approaches, even though the sources of theoretical uncertainties are very different.

In this paper we report recent results on the study of inclusive and exclusive $b \to u\ell\bar{\nu}$ decays based on data recorded by the *BABAR* detector[1] at the PEP-II asymmetric-energy e^+e^- storage ring at SLAC. We used a sample of about 88 million $B\overline{B}$ pairs that corresponds to an integrated luminosity of $81\,\mathrm{fb}^{-1}$ collected at the $\Upsilon(4S)$ resonance.

2 Inclusive $b \to u\ell\bar{\nu}$

The dynamics in the inclusive charmless semileptonic decays depends on the b quark mass and on its motion within the B meson. Calculations of the decay rate rely on operator product expansion (OPE). They include non-perturbative contributions, resummed into the so-called shape function. These contributions introduce model uncertainties when the extrapolation to the full decay rate is performed. In order to reduce these uncertainties, the challenge in inclusive measurements is to keep as much as possible decay rate, using loose kinematic cuts. Moreover it is important to apply cuts that minimize the dependence of the selection on non-perturbative parameters. Finally if we use different observables and approaches we can test the stability of the result and the robustness of the models.

In order to accomplish these requirements, we have studied $b \to u\ell\bar{\nu}$ decays with the three different techniques described in the following. In all these measurements the non-perturbative parameters ($\bar{\Lambda}^{SF}$ and λ_1^{SF}) used for the extrapolation are taken from the photon energy spectrum in $b \to s\gamma$ measurement performed by CLEO[2].

Work supported in part by Department of Energy contract DE-AC02-76SF00515
SLAC, Stanford University, Stanford, CA 94309

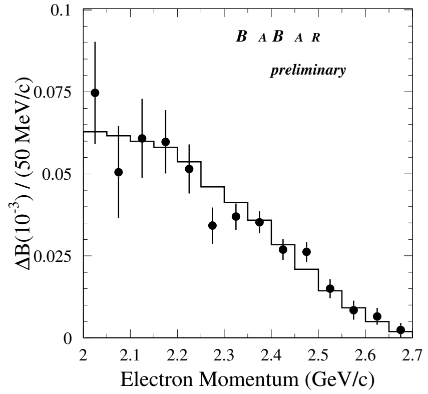

Figure 1. The differential branching fraction for $b \to u\ell\bar{\nu}$ decays (data points) as a function of the electron momentum (in the $\Upsilon(4S)$ rest frame) after background subtraction and corrections for bremsstrahlung and final state radiation, compared to the Monte Carlo simulation (histogram).

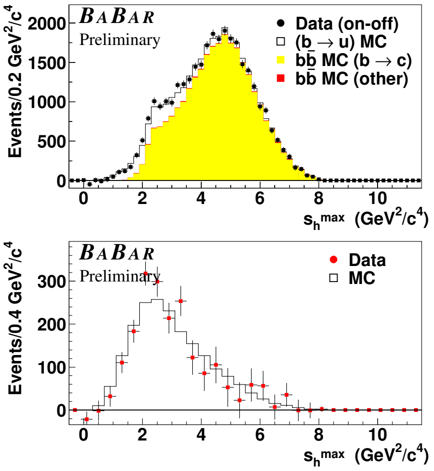

Figure 2. s_h^{max} distribution after cuts have been applied to all variables except the one being plotted. Top: signal and background components are shown. Bottom: background subtracted distribution.

Endpoint of the electron energy spectrum: In the rest frame of the B meson, the kinematic endpoint of the electron spectrum for the dominant $B \to X_c e\nu$ decays is around $2.3\,\mathrm{GeV}/c$ while for $B \to X_u e\nu$ decays corresponds to approximately $2.6\,\mathrm{GeV}/c$. A narrow interval of about $300\,\mathrm{MeV}/c$ remains dominated by electrons from $B \to X_u e\nu$ transitions. In this analysis[3] we extend the interval for signal extraction down to $2.0\,\mathrm{GeV}/c$ covering about 30% of the total electron spectrum, thus reducing errors related to extrapolation. We use event shape variables to suppress the non-$B\overline{B}$ background. We further require the missing momentum in the event as an evidence of the presence of the neutrino coming from the semileptonic decay. Non-$B\overline{B}$ background is estimated by using off-resonance data, collected below $B\overline{B}$ production threshold, and using on-resonance data above 2.8 GeV/c, *i.e.,* above the endpoint for electrons from B decays. The $B\overline{B}$ background is estimated from simulated data with the normalization of the individual contributions determined by a fit to the observed electron energy spectrum requiring $E_l > 1.1\,\mathrm{GeV}$. The resulting background subtracted distribution is shown in Fig. 1. The value of $|V_{ub}|$ obtained is reported in Tab. 1.

Neutrino reconstruction technique: This technique[4] is a refinement of the endpoint analysis. Events are selected by requiring $p_e > 2.0\,\mathrm{GeV}/c$ in the $\Upsilon(4S)$ rest frame. The measurement of the missing momentum is improved eliminating fake charged tracks, as well as low-energy beam-generated photons and energy depositions in the calorimeter from charged and neutral hadrons. The estimated neutrino four-momentum is used to compute the maximum kinematically allowed hadronic mass squared, s_h^{max}[5], for a given E_e and momentum transfer q^2. In the case where $\pm E_e > \pm\frac{\sqrt{q^2}}{2}\left(\frac{1\pm\beta}{1\mp\beta}\right)$, the maximum invariant hadronic mass squared is $s_h^{max} = m_B^2 + q^2 - 2m_B E_e\sqrt{\frac{1\mp\beta}{1\pm\beta}} - 2m_B\left(\frac{q^2}{4E_e}\right)\sqrt{\frac{1\pm\beta}{1\mp\beta}}$, otherwise $s_h^{max} = m_B^2 + q^2 - 2m_B\sqrt{q^2}$. This variable helps to suppress the large background from $b \to c\ell\bar{\nu}$ decays. The q^2 resolution for the neutrino reconstruc-

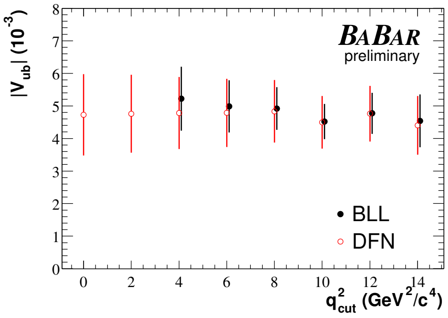

Figure 3. Measured value of $|V_{ub}|$ for $m_X < 1.7\,\mathrm{GeV}/c^2$ as a function of the q^2 cut applied when using acceptances from DFN (open points) and BLL (solid points). The error bars include all uncertainties.

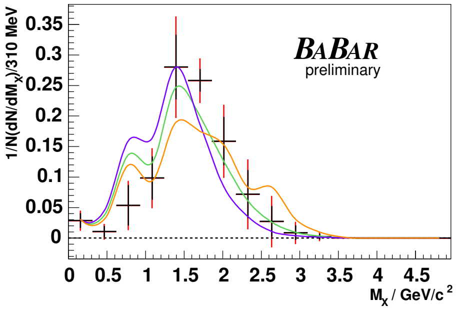

Figure 4. The unfolded m_X spectrum normalized to unit area compared with the Monte Carlo expectations. The green curve is obtained with the non-perturbative paramenter obtained with CLEO $b \to s\gamma$ best fit. Orange and violet curves corresponds to the two extreme points of the CLEO's 68% C.L. $\bar{\Lambda}^{SF}$, λ_1^{SF} contour.

tion is checked by using a large control sample consisting of $\overline{B} \to D^0 e\overline{\nu}(X)$ decays and comparing with Monte Carlo simulation. In Fig.3 the s_h^{max}distribution obtained on data is displayed. The value of $|V_{ub}|$ is shown is in Tab. 1.

Study on the recoil of fully reconstructed B mesons:

These studies extend the analysis of the invariant mass of the X system m_X[6] and they are motivated by the recent discussion on the theoretical uncertainties to be assigned to the $|V_{ub}|$ measurement. They are based on events in which one B meson decays into hadrons and is fully reconstructed and the semileptonic decay of the recoiling B meson is identified by the presence of an electron or muon ($p^* > 1.0\,\mathrm{GeV}$ in the B rest frame). The hadronic system in the $b \to u\ell\bar{\nu}$ decay is reconstructed from charged tracks and energy depositions not associated with the fully reconstructed B. Further cuts on the missing momentum and on the total charge of the event are applied. We perform[7] two different approaches to extract $|V_{ub}|$. The first one uses a cut on m_X ($m_X < 1.55\,\mathrm{GeV}$) to separate the $b \to c\ell\bar{\nu}$ background where the extrapolation to the full phase space is performed using De Fazio-Neubert parametrization (DFN)[8]. The second one is based on a method proposed by Bauer et al.(BLL)[9], that emphasizes a region in $m_X - q^2$ where the uncertainties due to non-perturbative parameters are reduced and the OPE calculations are robust. The results are summarized in Tab.1 and in Fig.3 where DFN and BLL methods are compared for different cuts in q^2. In addition we used this sample to unfold the m_X distribution and we compared it to the signal shapes expected with different non-perturbative parameters (see Fig.4). m_X moments have been also extracted[7].

A summary of all four $|V_{ub}|$ measurements is in Tab.1.

Table 1. Summary of inclusive $|V_{ub}|$ results. The first uncertainty is experimental, the second is theoretical.

	$\lvert V_{ub}\rvert$ $[10^{-3}]$
endpoint	$3.94 \pm 0.25 \pm 0.42$
ν reco	$4.63 \pm 0.47 \pm 0.49$
m_X	$4.77 \pm 0.40^{+0.65}_{-0.39}$
$m_X$vs q^2	$4.92 \pm 0.53 \pm 0.46$

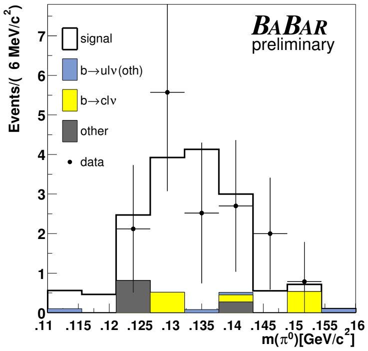

Figure 5. Projection of the fit result onto the $m(\gamma\gamma)$ variable for the $B \to \pi^0 \ell \nu$ analysis.

3 Exclusive $b \to u\ell\overline{\nu}$

Exclusive decays can be also used to extract $|V_{ub}|$. The theoretical uncertainties involved in these decays are related to the form factors determination. The measured rates depend on the variation of the form factors with q^2 and their relative normalization while the extraction of $|V_{ub}|$ depends on their variation and absolute normalization. The uncertainty due to q^2 variation can be reduced by loosening the acceptance cuts and the extrapolation errors. To address this issue we developed the new techniques described below that result in better signal to noise ratios than in previous measurements. As a consequence the hard kinematic requirements used to reject $b \to c\ell\overline{\nu}$ events are not needed and almost the full phase space is analyzed.

The first technique uses events where one of the two B mesons decays into $B^0 \to D^{*-}l^+\nu$ and the recoiling B decays semileptonically. $B^0 \to D^{*-}l^+\nu$ decays are partially reconstructed using only the charged lepton and the soft π^- (from $D^{*-} \to \pi^- \overline{D}^0$) and inferring the direction of the D^{*-}. On the recoil we study $\overline{B}^0 \to \pi^+\ell\overline{\nu}$ decays and extract the branching fraction in three bins of q^2.

The second technique[7] studies the recoil of fully reconstructed B mesons as in the inclusive analysis described before. The semileptonic decay is identified by a charged lepton and the hadronic state is exclusively reconstructed. We analyze and measure individual branching ratio for the following decay modes: $\overline{B}^0 \to \pi^+\ell\overline{\nu}$, $B^- \to \pi^0\ell\overline{\nu}$, $\overline{B}^0 \to \rho^+\ell\overline{\nu}$, $B^- \to \rho^0\ell\overline{\nu}$, $B^- \to \omega\ell\overline{\nu}$, $B^- \to \eta\ell\overline{\nu}$, $B^- \to \eta'\ell\overline{\nu}$, $B^- \to a_0^0\ell\overline{\nu}$ and $\overline{B}^0 \to a_0^+\ell\overline{\nu}$. As an example, the $m(\gamma\gamma)$ distribution for $B^- \to \pi^0\ell\overline{\nu}$ is displayed in Fig.5 and it shows the high purity achieved by the recoil technique.

Averaging the results of the two techniques and using isospin and quark model relations we obtain:

$$\mathcal{B}(\overline{B}^0 \to \pi^+\ell\overline{\nu}\ ) = (1.22 \pm 0.19_{stat} \pm 0.18_{sys})10^{-4}$$
$$\mathcal{B}(\overline{B}^0 \to \rho^+\ell\overline{\nu}\ ) = (2.57 \pm 0.52_{stat} \pm 0.59_{sys})10^{-4}$$

4 Conclusions

With the *BABAR* detector, we have studied $b \to u\ell\overline{\nu}$ transitions with different methods. Inclusive analyses give a consistent picture but theoretical uncertainties are still dominant, mainly because of the poor knowledge of non-perturbative parameters. With higher statistics, that error can decrease by using more precise independent measurements on $b \to s\gamma$ transitions. Moreover with better precisions the measurement of m_X moments in $b \to u\ell\overline{\nu}$ decays will be used to constrain shape function parameters.

The recoil techniques provide very clean samples of exclusive $b \to u\ell\overline{\nu}$ decays and smaller theoretical uncertainties are obtained by analyzing the full phase space. These measurements are still statistically limited but with rapidly increasing accumulated data they will allow precise measurements of $|V_{ub}|$.

References

1. B. Aubert *et al.* (*BABAR* Collab.), Nucl. Instr. and Methods A **479**, 116 (2002).
2. S. Chen *et al.* (CLEO Collab.), Phys. Rev. Lett. **87**, 251807 (2001).
3. B. Aubert *et al.* (*BABAR* Collab.), arXiv:hep-ex/0408075.

4. B. Aubert *et al.* (*BABAR* Collab.), arXiv:hep-ex/0408045.
5. R. Kowalewski and S. Menke, Phys. Lett. B **541**, 34 (2002).
6. B. Aubert *et al.* (*BABAR* Collab.), Phys. Rev. Lett. **(**92), 071802 (2004)
7. B. Aubert *et al.* (*BABAR* Collab.), arXiv:hep-ex/0408068.
8. De Fazio, F. and Neubert, M., JHEP 9906, 017 (1999).
9. C. W. Bauer, Z. Ligeti and M. Luke, arXiv:hep-ph/0111387.