SLAC-PUB-15528

SNSN-xxx-xx
January 13, 2011

Studies of exclusive charmless semileptonique B decays and extraction of $|V_{ub}|$ at BABAR

Martin Simard[1]

Department of Physics
Université de Montréal, Montréal, CANADA

We report on recent measurements of the branching fractions (BFs) for the decay channels $B^0 \to \pi^- \ell^+ \nu$, $B^+ \to \pi^0 \ell^+ \nu$, $B^+ \to \eta \ell^+ \nu$, $B^+ \to \eta' \ell^+ \nu$, $B^0 \to \rho^- \ell^+ \nu$ and $B^+ \to \rho^0 \ell^+ \nu$. We obtain very precise values of the total branching fractions for these decays, as well as partial branching fractions as a function of q^2 for the decay channels $B^0 \to \pi^- \ell^+ \nu$, $B^+ \to \eta \ell^+ \nu$ and $B^0 \to \rho^- \ell^+ \nu$. In particular, we use the partial branching fractions of the $B^0 \to \pi^- \ell^+ \nu$ decay channel and form-factor calculations to extract several values of $|V_{ub}|$. When we compared these values of $|V_{ub}|$ to the one measured in inclusive semileptonic B decay, we find that two of them are consistent, within large theoretical uncertainties.

PRESENTED AT

Proceedings of CKM2010, the 6th International Workshop
on the CKM Unitarity Triangle
University of Warwick, UK
6-10 September 2010

---

[1] On behalf of the BABAR Collaboration

Work supported in part by US Department of Energy under contract DE-AC02-76SF00515.

SLAC National Accelerator Laboratory, Menlo Park, CA 94025

1 Introduction

Semileptonic decays are best to measure $|V_{ub}|$ [1] because they are much easier to understand theoretically than hadronic decays and they are far more abundant than leptonic decays. In particular, the decay rate of $B \to \pi\ell\nu$ is proportional to $|V_{ub}f_+(q^2)|^2$, where $f_+(q^2)$ is the theoretical form-factor calculation as a function of q^2, the momentum transferred squared. A precise value of $|V_{ub}|$ from the exclusive $B \to \pi\ell\nu$ decay can be performed to test the QCD calculations and to constrain the description of weak interactions and CP violation in the Standard Model.

We present two recent analyses in *BABAR* where $|V_{ub}|$ is obtained in the study of the exclusive $B \to \pi\ell\nu$ decay. In the $\pi - \eta$ analysis [2], we study three decay modes: $B^0 \to \pi^-\ell^+\nu$, $B^+ \to \eta\ell^+\nu$ and $B^+ \to \eta'\ell^+\nu$. In the $\pi - \rho$ analysis [3], we study four decay modes: $B^0 \to \pi^-\ell^+\nu$, $B^+ \to \pi^0\ell^+\nu$, $B^0 \to \rho^-\ell^+\nu$ and $B^+ \to \rho^0\ell^+\nu$. These decays involve a $b \to u$ transition via the coupling of a W gauge boson. The value of $|V_{ub}|$ can be extracted from the partial branching fraction, $\Delta\mathcal{B}(q^2)$, measured as a function of q^2:

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(q^2)}{\tau_{B^0}\Delta\zeta(q^2)}}, \quad \Delta\zeta(q^2) = \frac{G_F^2}{24\pi^3}\int_{q^2_{min}}^{q^2_{max}} |\vec{p}_\pi|^3|f_+(q^2)|^2 dq^2, \tag{1}$$

where $\tau_{B^0} = 1.525 \pm 0.009$ ps [4] is the B^0 lifetime. As can be seen in Eq. 1, $\Delta\zeta(q^2)$ depends on the $f_+(q^2)^2$ form factor that is provided by QCD calculations from light cone sum rules at low q^2 values and lattice QCD at high q^2 values.

2 Experimental method

The main differences between the $\pi - \eta$ and the $\pi - \rho$ analyses are summarized in Table 1. Both analyses use an untagged technique. This means that only one of the B mesons of the $B\overline{B}$ pair is reconstructed. Values of q^2 are determined using different methods which do lead to some variations in their values. The two-dimensional distribution of true versus reconstructed values of q^2 yields a detector response matrix which is used to unfold the measured q^2 distribution onto the true q^2 one.

Backgrounds can be broadly grouped into three main categories: decays arising from $b \to u\ell\nu$ transitions, decays in other $B\overline{B}$ events and decays in continuum events. Given the sufficient number of events in the $\pi - \eta$ analysis for the $\pi^-\ell^+\nu$ decay mode, the data samples can be subdivided in 12 bins of q^2 for the signal. For the $\pi - \rho$ analysis and the other decay modes, a smaller number of events leads us to restrict the number of bins used in the fit. We use the ΔE-$m_{\rm ES}$ histograms, obtained from the Monte Carlo (MC) simulation, as two-dimensional probability density functions (PDFs), to extract the yields of the signal and backgrounds as a function of q^2 in our fit to the data.

Analysis	$\pi - \eta$	$\pi - \rho$
Luminosity on $\Upsilon(4S)$ peak	422.6 fb^{-1}	349.0 fb^{-1}
Number of $B\overline{B}$ pair events	464 millions	377 millions
q^2 evaluation	$(P_B - P_{meson})^2$	$(P_\ell + P_\nu)^2$
Cut strategy	cuts, q^2 dependent	NN, q^2 dependent
Cut selection	loose ν cuts	tighter ν cuts
Signal efficiency	8% to 15%	6% to 7%
Background/signal	11.5	6.3
$B^0 \to \pi^- \ell^+ \nu$ yield	11778 ± 435	10604 ± 376
Number of q^2 bins in π mode	12	6
Systematic uncertainties	full gaussian	$\pm 1\sigma$

Table 1: Comparison of various characteristics for the two recent analyses in BABAR.

In each analysis, the systematic uncertainties are estimated from the variations of the resulting partial BF values when the data are re-analyzed with different simulation parameters. In the $\pi - \eta$ analysis, for each parameter, we produce new PDFs by varying randomly the parameter value over a complete gaussian distribution whose standard deviation is given by the parameter uncertainty. One hundred such variations are done for each parameter. The systematic uncertainty of a parameter is given by its RMS value of the resulting partial BF distribution from these one hundred variations. In the $\pi - \rho$ analysis, the systematic uncertainties are evaluated by $\pm 1\sigma$ variation for each parameter.

3 Results

The experimental $\Delta\mathcal{B}(q^2)$ distributions for $B^0 \to \pi^- \ell^+ \nu$ decays are displayed in Fig. 1 in the $\pi - \eta$ analysis, together with two parametrizations and three QCD calculations, and in Fig 2 in the $\pi - \rho$ analysis, combining the charged and neutral pion channels assuming isospin symmetry. From the BGL expansion extrapolated to $q^2 = 0$, we obtain the value of $|V_{ub} f_+(0)|$ in both analysis as shown in Table 2. These values differs from both analysis since the experimental distributions do look different. However, the individual values of the partial branching fractions are indeed consistent with each other for the two analyses. The comparison between theory and experiment in their q^2 ranges of validity shows that all three QCD calculations are compatible with the data as we can see in Table 2.

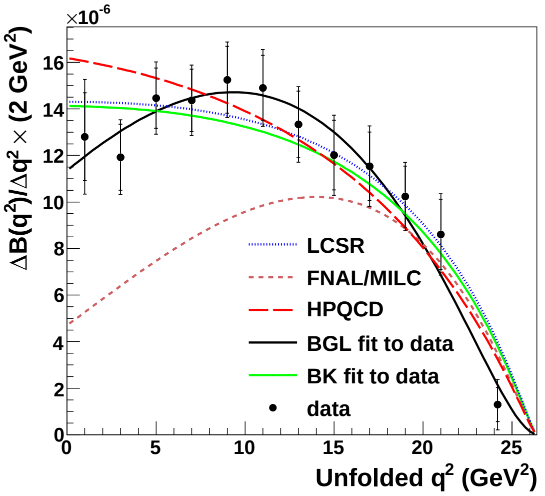

Figure 1: Partial $\Delta\mathcal{B}(q^2)$ spectrum in 12 bins of q^2 for $B^0 \to \pi^-\ell^+\nu$ decays in the $\pi-\eta$ analysis. The solid green and black curves show the result of the fit to the data of the BK [5] and BGL [6] parametrizations, respectively. The data are also compared to unquenched LQCD calculations (HPQCD [7], FNAL [8]) and an LCSR calculation [9].

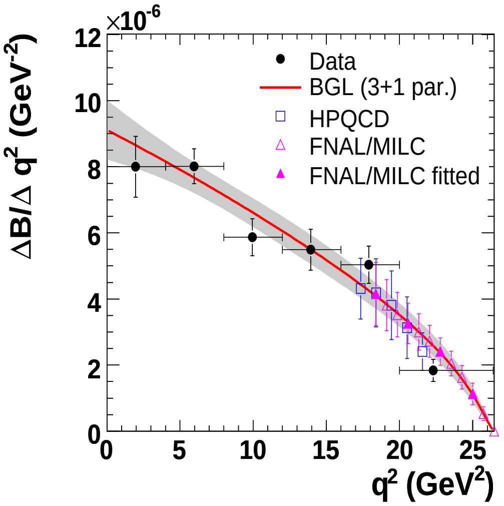

Figure 2: Partial $B \to \pi\ell\nu$ spectrum in 6 bins of q^2 for $B \to \pi\ell\nu$ decays in the $\pi-\rho$ analysis. The red curve represents the simultaneous fit to the data points and four theoretical points produced with the FNAL LQCD calculation (magenta, closed triangles).

Since, in the $\pi-\rho$ analysis, the number of data points is limited to two above $q^2 = 16\ \mathrm{GeV}^2$, it was deemed desirable to undertake a simultaneous fit of theoretical and experimental points to extract a value of $|V_{ub}|$. We obtain the total BFs $\mathcal{B}(B^0 \to \pi^-\ell^+\nu) = (1.42 \pm 0.05_{stat} \pm 0.07_{syst}) \times 10^{-4}$, $\mathcal{B}(B^+ \to \eta\ell^+\nu) = (0.36 \pm 0.05_{stat} \pm 0.04_{syst}) \times 10^{-4}$ and $\mathcal{B}(B^+ \to \eta'\ell^+\nu) = (0.24 \pm 0.08_{stat} \pm 0.03_{syst}) \times 10^{-4}$ in the $\pi-\eta$ analysis, and $\mathcal{B}(B^0 \to \pi^-\ell^+\nu) = (1.41 \pm 0.05_{stat} \pm 0.07_{syst}) \times 10^{-4}$ and $\mathcal{B}(B^0 \to \rho^-\ell^+\nu) = (1.75 \pm 0.15_{stat} \pm 0.27_{syst}) \times 10^{-4}$ in the $\pi-\rho$ analysis. Values of $|V_{ub}|$ obtained in our two analyses are given in Table 2. They range from $(3.0-3.8) \times 10^{-3}$.

4 Summary

It is estimated that there is less than 20% overlap in the selected event samples between the two analyses for the $B^0 \to \pi^-\ell^+\nu$ decay channel. It is thus very satisfying to note that there is excellent agreement between the results of the two analyses. The values of the total BFs obtained in our work are the most precise total BFs to date.

Analysis	$\pi - \eta$	$\pi - \rho$
HPQCD [7] ($q^2 > 16$ GeV^2)	$3.24 \pm 0.13 \pm 0.16^{+0.57}_{-0.37}$	$3.21 \pm 0.17^{+0.55}_{-0.36}$
FNAL [8] ($q^2 > 16$ GeV^2)	$3.14 \pm 0.12 \pm 0.16^{+0.35}_{-0.29}$	2.95 ± 0.31
LCSR [9] ($q^2 < 12$ GeV^2)	$3.70 \pm 0.07 \pm 0.09^{+0.54}_{-0.39}$	$3.78 \pm 0.13^{+0.55}_{-0.40}$
$\|V_{ub} f_+(0)\|$	$(8.6 \pm 0.3_{stat} \pm 0.3_{syst}) \times 10^{-4}$	$(10.8 \pm 0.6) \times 10^{-4}$

Table 2: Values of $|V_{ub}| \times 10^{-3}$ derived from the form-factor calculations for the $B^0 \to \pi^- \ell^+ \nu$ decays.

Our value of the total BF for $B^+ \to \eta' \ell^+ \nu$, with a significance of 3.0σ, is an order of magnitude smaller than the CLEO result [10]. The three values of $|V_{ub}|$ are all acceptable according to the data. Two of them [7, 9] are consistent, within large theoretical uncertainties, with the value measured in inclusive semileptonic B decays: $|V_{ub}| = (4.27 \pm 0.38) \times 10^{-3}$ [4].

References

[1] M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973).

[2] P. del Amo Sanchez *et al.* (*BaBar* Collaboration), arXiv:1010.0987, submitted to Phys. Rev. **D**.

[3] P. del Amo Sanchez *et al.* (*BaBar* Collaboration), arXiv:1005.3288, accepted by Phys. Rev. **D**.

[4] K. Nakamura *et al.* (Particle Data Group), Jour. of Phys. **G37**, 075021 (2010); see also "Determination of $|V_{cb}|$ and $|V_{ub}|$", ibidem.

[5] D. Becirevic and A. B. Kaidalov, Phys. Lett. **B478**, 417 (2000).

[6] C. G. Boyd and M. J. Savage, Phys. Rev. **D56**, 303 (1997).

[7] E. Gulez *et al.* (HPQCD Collaboration), Phys. Rev. **D73**, 074502 (2006); Erratum ibid. **D75**, 119906 (2007).

[8] C. Bernard *et al.* (FNAL/MILC Collaboration), Phys. Rev. **D80**, 034026 (2009); R. Van de Water, private communication.

[9] G. Duplancic *et al.*, JHEP **804**, 14 (2008); A. Khodjamirian, private communication.

[10] S. B. Athar *et al.* (CLEO Collaboration), Phys. Rev. **D68**, 072003 (2003).