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Exclusive Charmless Semileptonic Decays $B \to X_u \ell \nu$ from *BABAR*

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The latest results of exclusive charmless semileptonic decays $B \to \pi \ell \nu$ and $B \to \rho \ell \nu$ from the *BABAR* Collaboration are presented. They are based on samples of $B\overline{B}$ events recorded on the $\Upsilon(4S)$ resonance. Several different experimental techniques are compared. Measurements of partial branching fractions in intervals of q^2, the four-momentum transfer squared, allow a study of the shape of the $B \to \pi \ell \nu$ form factor and a comparison with theoretical calculations. The Cabibbo-Kobayashi-Maskawa matrix element $|V_{ub}|$ is determined using the measured branching fractions combined with recent form-factor predictions.

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1. Introduction

A precise determination of the magnitude of the Cabibbo-Kobayashi-Maskawa matrix element V_{ub} provides a stringent test of the Standard Model mechanism for *CP* violation and would significantly improve constraints on the Unitarity Triangle. Charmless semileptonic decays $B \to X_u \ell \nu$ provide a clean environment to study $b \to u$ quark transitions and to determine $|V_{ub}|$.

In this talk, the latest results for exclusive charmless semileptonic decays from *BABAR* are presented. The exclusive reconstruction of the final state allows for more efficient background rejection and better kinematic constraints compared to inclusive decays and has complementary theoretical uncertainties. Exclusive decays rely on theoretical predictions of form factors, which are calculated using non-perturbative methods based on e.g. light-cone sum rules (LCSR) or lattice QCD (LQCD). Comparisons of exclusive and inclusive measurements allow us to assess the reliability of the theoretical uncertainties, which dominate the error on $|V_{ub}|$.

2. Exclusive Measurements

The *BABAR* Collaboration has presented several new measurements of $B \to \pi \ell \nu$ decays and one new measurement of $B \to \rho \ell \nu$ decays. The study of these decays is experimentally challenging due to the large background from misreconstructed $B \to X_c \ell \nu$ decays, where X_c is a hadronic system with charm content, which have similar kinematic properties. Additional background sources are continuum events from $e^+e^- \to q\overline{q}$ and cross feed from other $B \to X_u \ell \nu$ decays. The experimental approaches used in the exclusive measurements can be divided into two classes: *untagged* and *tagged*. For the untagged measurements, the kinematics of the undetected neutrino is estimated from the missing four-momentum of the whole event. For the tagged measurements, one of the two B mesons from the $\Upsilon(4S)$ decay is reconstructed in either a hadronic or semileptonic decay mode and thus the momentum and/or direction of the recoiling B meson are known.

2.1 Untagged

In the untagged technique [1], the neutrino four-momentum is inferred from the difference between the net four-momentum of the colliding-beam particles and the sum of the four-momenta of all detected particles in the event. The missing mass measured from the whole event is required to be compatible with zero. Because the resolution of the missing mass squared varies linearly with the missing energy, the quantity $|m^2_{\rm miss}/2E_{\rm miss}|$ is required to be less than 0.4 GeV. Further selection criteria are applied to improve the quality of the neutrino reconstruction by reducing the effect of losses due to the detector acceptance. To suppress the large background from $B \to X_c \ell \nu$ decays, the sum of the signal lepton and hadron momenta in the $\Upsilon(4S)$ rest frame is restricted: $|\vec{p}_\ell| + |\vec{p}_\pi| > 2.6$ GeV for $B \to \pi \ell \nu$ and $1.5|\vec{p}_\ell| + |\vec{p}_\rho| > 4.2$ GeV for $B \to \rho \ell \nu$. The continuum background is reduced to a very low level through harsh rejection of jet-like event topologies.

Using isospin relations, the yields of four signal modes $X_u = \pi^-, \pi^0, \rho^-,$ and ρ^0 are extracted simultaneously in a fit to the ΔE vs. m_{ES} distributions in intervals of q^2, the four-momentum transfer squared. Here ΔE is the difference between the reconstructed and expected B-meson energies and m_{ES} is the beam-energy substituted B-meson mass. Fig. 1 shows the result of this fit for $B \to \pi \ell \nu$ for a sample of 83 million $B\overline{B}$ events. Table 1 gives the measured total branching

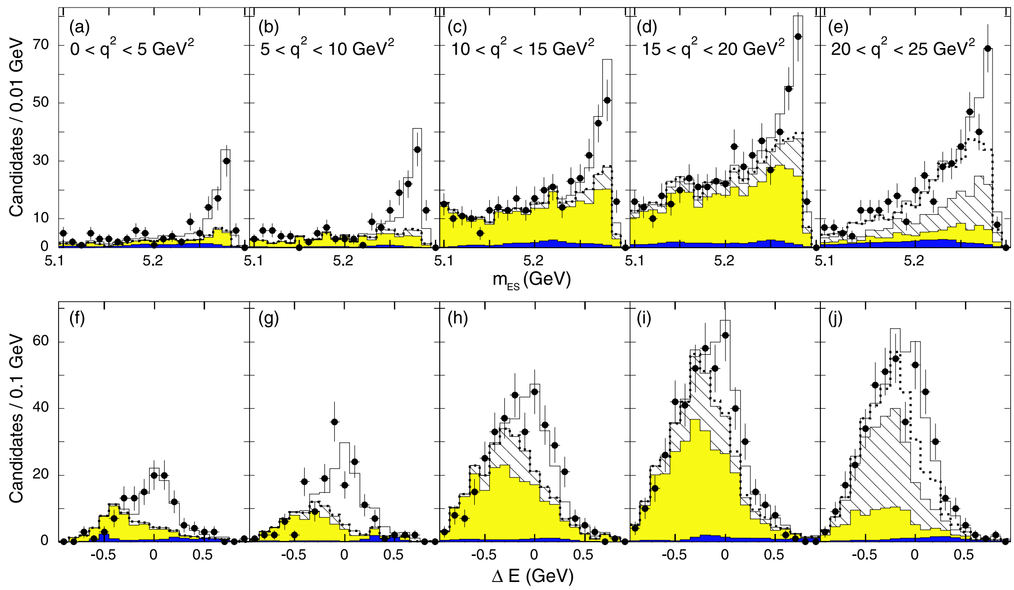

Figure 1: Projected m_{ES} and ΔE distributions for $B \to \pi \ell \nu$ decays in five intervals of q^2. The histograms are signal (white), combinatoric signal (white, dotted) where the signal hadron is incorrectly selected or the lepton comes from the isospin conjugate decay, cross feed from other $B \to X_u \ell \nu$ decays (hatched), $B \to X_c \ell \nu$ decays (light shaded), and non-$B\overline{B}$ background (dark shaded).

fractions. The dominant systematic error contribution is due to the uncertainties in the neutrino reconstruction.

The q^2 dependence of the fit allows a determination of the shape of the $B \to \pi \ell \nu$ form factor $f_+(q^2)$. A comparison of the measured form-factor shape with theoretical predictions shows that the data agree well with recent LCSR [2] and unquenched LQCD [3, 4] results, but disfavor the widely used ISGW2 quark model [5]. Using the Becirevic-Kaidalov (BK) parametrization [6] with one shape parameter, α, to fit the q^2 spectrum yields $\alpha = 0.61 \pm 0.09$, which is the most precise measurement of the $B \to \pi \ell \nu$ form-factor shape to date. For $B \to \rho \ell \nu$, the experimental uncertainties are still too large to study the three form factors needed to describe the decay to a vector meson.

2.2 Hadronic *B* tags

To allow for more kinematic constraints and a better background reduction, one B meson from the $\Upsilon(4S)$ decay is fully reconstructed in a hadronic decay mode. The hadronic-tag technique [7] allows a study of the recoiling B decay with high purity and very low background. However, the signal efficiency is about 20 times lower than for the untagged measurement. This method yields 36.1 ± 7.1 $B^0 \to \pi^- \ell^+ \nu$ and 34.1 ± 6.2 $B^+ \to \pi^0 \ell^+ \nu$ decays in a sample of 232 million $B\overline{B}$ events. A number of other signal modes, $X_u = \rho^-, \rho^0, \omega, \eta,$ and η', have previously been studied [8]. The hadronic-tag measurements will clearly benefit from the larger data samples expected in the next few years.

2.3 Semileptonic *B* tags

In the semileptonic-tag technique, one B meson is tagged through a semileptonic decay $B \to D^{(*)} \ell \nu$.

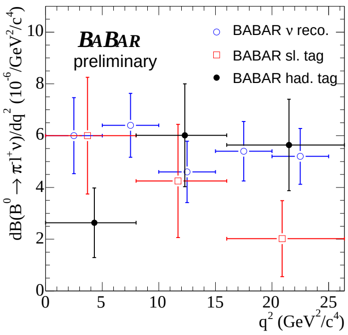

Figure 2: Partial branching fractions as functions of q^2 for the $B \to \pi\ell\nu$ measurements.

	$\mathscr{B}(B^0 \to \pi^-\ell^+\nu)/10^{-4}$	$\mathscr{B}(B^0 \to \rho^-\ell^+\nu)/10^{-4}$
Untagged [1] $\pi^-, \pi^0 / \rho^-, \rho^0$	$1.38 \pm 0.10 \pm 0.18$	$2.14 \pm 0.21 \pm 0.56$
Hadronic tag [7, 8] $\pi^-, \pi^0 / \rho^-, \rho^0$	$1.28 \pm 0.23 \pm 0.16$	$2.57 \pm 0.52 \pm 0.59$
Semileptonic tag π^- [10]	$1.03 \pm 0.25 \pm 0.13$	–
Semileptonic tag π^0 [11]	$3.31 \pm 0.68 \pm 0.42^*$	–

Table 1: Measured branching fractions for $B \to \pi\ell\nu$ and $B \to \rho\ell\nu$. The errors are statistical and systematic. * The result for $B^+ \to \pi^0\ell^+\nu$ has been scaled by a factor $2\tau_{B^0}/\tau_{B^+}$.

This method was pioneered by the Belle Collaboration, which has also presented new results [9] for $B \to \pi\ell\nu$ and $B \to \rho\ell\nu$ at this conference. The efficiency for semileptonic tags is about four times higher than for hadronic tags due to the larger branching fractions of the decay channels on the tag side. However, the presence of the additional neutrino in the event reduces the kinematic constraints, which results in less efficient background suppression. The *BABAR* $B^0 \to \pi^-\ell^+\nu$ analysis uses the fact that the two B mesons are back-to-back in the $\Upsilon(4S)$ frame to construct the discriminating variable $\cos^2\phi_B$ [10], which peaks around zero for signal events and shows a broad distribution for background. The signal is extracted in a fit to the $\cos^2\phi_B$ distribution in three bins of q^2. The $B^+ \to \pi^0\ell^+\nu$ analysis makes use of the variable $\cos\theta_{B,\pi^0\ell}$ [11] to extract the signal yield over the whole q^2 range. The total branching fractions measured in a sample of 232 (88) million $B\overline{B}$ events for $B^0 \to \pi^-\ell^+\nu$ ($B^+ \to \pi^0\ell^+\nu$) are given in Table 1.

3. Extraction of $|V_{ub}|$

The branching fraction measurements can be converted to $|V_{ub}|$ using the relation $|V_{ub}| = \sqrt{\Delta\mathscr{B}/(\tau_B\Delta\zeta)}$, where $\Delta\mathscr{B}$ is the measured partial branching fraction, τ_B is the B lifetime, and $\Delta\zeta$ denotes the form-factor normalization predicted by theory. The LCSR calculations predict $\Delta\zeta$ for $q^2 < 14$ GeV^2, whereas the LQCD calculations are valid for $q^2 > 15$ GeV^2. To extract $|V_{ub}|$ from the total branching fraction, extrapolations to the full q^2 range are necessary which introduce additional uncertainties. Table 2 shows the results for $|V_{ub}|$ for the different form-factor predictions in their validity ranges and for the whole q^2 range. The errors are statistical, systematic, and due to form-factor uncertainties. There are notable differences between the form-factor calculations, especially between LCSR and LQCD, but the theoretical uncertainties are still large.

	q^2 (GeV^2)	Untagged	Hadronic tag	Semileptonic tag
Ball-Zwicky [2]	<15 (<16)	$3.3 \pm 0.2 \pm 0.2^{+0.5}_{-0.4}$	$2.9 \pm 0.5 \pm 0.1^{+0.5}_{-0.3}$	$3.1 \pm 0.4 \pm 0.2^{+0.5}_{-0.3}$
HPQCD [3]	>15 (>16)	$4.9 \pm 0.3 \pm 0.3^{+0.8}_{-0.5}$	$5.4 \pm 0.7 \pm 0.5^{+0.8}_{-0.6}$	$3.3 \pm 1.1 \pm 0.5^{+0.5}_{-0.3}$
FNAL/MILC [4]	>15 (>16)	$4.2 \pm 0.2 \pm 0.2^{+0.7}_{-0.5}$	$4.6 \pm 0.6 \pm 0.4^{+0.8}_{-0.5}$	$2.7 \pm 0.9 \pm 0.4^{+0.5}_{-0.3}$
Ball-Zwicky [2]	full	$3.4 \pm 0.1 \pm 0.2^{+0.7}_{-0.4}$	$3.3 \pm 0.3 \pm 0.2^{+0.6}_{-0.4}$	$2.9 \pm 0.4 \pm 0.2^{+0.6}_{-0.4}$
HPQCD [3]	full	$4.0 \pm 0.1 \pm 0.2^{+0.8}_{-0.5}$	$3.8 \pm 0.3 \pm 0.2^{+0.7}_{-0.5}$	$3.4 \pm 0.4 \pm 0.2^{+0.7}_{-0.4}$
FNAL/MILC [4]	full	$3.8 \pm 0.1 \pm 0.2^{+0.9}_{-0.5}$	$3.7 \pm 0.3 \pm 0.2^{+0.8}_{-0.5}$	$3.3 \pm 0.4 \pm 0.2^{+0.8}_{-0.4}$

Table 2: Results for $|V_{ub}|$ extracted from the measured partial and full branching fractions. Due to different q^2 binnings the untagged measurement splits the q^2 range at 15 GeV^2 and the tagged ones at 16 GeV^2.

4. Conclusions and Outlook

The current world average [12] of $|V_{ub}|$ from $B \to \pi \ell \nu$ decays has reached an experimental precision of about 4% for the full q^2 range, but the theoretical uncertainties are dominant. The untagged *BABAR* measurement with its relatively large signal statistics is the currently most precise single measurement. The prospects for improvement of the experimental results with the rapidly increasing *B*-factory data samples are good. The tagged measurements in particular will profit from larger statistics. Progress in the determination of $|V_{ub}|$ depends critically on further improvements in form-factor calculations. The leading error contributions are due to lattice spacing and matching between lattice and continuum QCD operators. A reduction of the theoretical uncertainty to the 5 – 6% level may be feasible in the next few years, which would allow an exclusive determination of $|V_{ub}|$ with a precision of better than 8%.

Acknowledgments

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References

[1] *BABAR* Collaboration, *Phys. Rev.* **D 72**, 051102 (2005) [hep-ex/0507003].

[2] P. Ball and R. Zwicky, *Phys. Rev.* **D 71**, 014015 (2005) [hep-ph/0406232].

[3] J. Shigemitsu *et. al.* (HPQCD), *Nucl. Phys. Proc. Suppl.* **140**, 464 (2005) [hep-lat/0408019].

[4] M. Okamoto *et. al.* (FNAL/MILC), *Nucl. Phys. Proc. Suppl.* **140**, 461 (2005) [hep-lat/0409116].

[5] D. Scora and N. Isgur, *Phys. Rev.* **D 52**, 2783 (1995) [hep-ph/9503486].

[6] D. Becirevic and A. B. Kaidalov, *Phys. Lett.* **B 478**, 417 (2000) [hep-ph/9904490].

[7] *BABAR* Collaboration, HEP 2005 conference contribution [hep-ex/0507085].

[8] *BABAR* Collaboration, ICHEP 2004 conference contribution [hep-ex/0408068].

[9] Belle Collaboration, HEP 2005 conference contribution [hep-ex/0508018].

[10] *BABAR* Collaboration, Lepton-Photon 2005 conference contribution [hep-ex/0506064].

[11] *BABAR* Collaboration, Lepton-Photon 2005 conference contribution [hep-ex/0506065].

[12] Report from the Heavy Flavor Averaging Group, to appear in hep-ex.