

# Measurements of the CKM Matrix Element $|V_{ub}|$ with *BABAR*

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A preliminary *BABAR* measurement of the inclusive partial branching fraction  $b \rightarrow ue\nu$  is presented. We find  $\Delta\mathcal{B}(b \rightarrow ue\nu, 2.3 \dots 2.6 \text{ GeV}) = (0.152 \pm 0.014_{stat.} \pm 0.014_{syst.}) \times 10^{-3}$ . In addition, a preliminary measurement of the branching fraction  $B \rightarrow \rho e\nu$  is presented and the CKM matrix element  $|V_{ub}|$  is determined from this measurement. We find  $\mathcal{B}(B^0 \rightarrow \rho^- e^+ \nu) = (3.39 \pm 0.44_{stat.} \pm 0.52_{syst.} \pm 0.60_{theo.}) \times 10^{-4}$ , and  $|V_{ub}| = (3.69 \pm 0.23_{stat.} \pm 0.27_{syst.} \pm^{+0.40}_{-0.59}{}_{theo.}) \times 10^{-3}$ .

## 1. INTRODUCTION

The matrix element  $|V_{ub}|$  can be determined by measuring the semileptonic  $b \rightarrow ue\nu$  rate, either inclusively or exclusively. Experimentally, the main difficulty for the observation of  $b \rightarrow ue\nu$  signal events is the large background from  $b \rightarrow ce\nu$  events. The analysis will be sensitive in a lepton energy range where  $b \rightarrow ce\nu$  decays are suppressed for kinematical reasons. In the exclusive approach, additional kinematic constraints allow to include a somewhat larger lepton energy range and to reduce extrapolation uncertainties. To extract exclusive branching fractions and  $|V_{ub}|$  requires the use of hadronic form-factors which have to be obtained from theory. In the exclusive analysis presented here we use five different form factor calculations: two quark models ISGW2 [1] and Beyer/Melikhov [2], a lattice calculation by the UKQCD group [3], a model based on light cone sum rules (LCSR [4]), and one based on heavy quark and  $SU(3)$  symmetries (Ligeti/Wise [5]).

## 2. INCLUSIVE ANALYSIS

### 2.1. Data set

The data were collected with the *BABAR* detector [6] at the PEP-II  $e^+e^-$  storage ring [7]. The integrated luminosity of the sample is  $20.6 \text{ fb}^{-1}$  taken at the  $\Upsilon(4S)$  mass, corresponding to 22.6 million  $B\bar{B}$  meson pairs. An additional  $2.6 \text{ fb}^{-1}$

of data were taken 40 MeV below the  $\Upsilon(4S)$  resonance.

### 2.2. Analysis strategy

We measure the partial semileptonic branching fraction  $\Delta\mathcal{B}$  in the electron center-of-mass (CM) energy interval  $2.2 < E_e^{CM} < 2.6 \text{ GeV}$ . The continuum is subtracted by fitting a polynomial to the off-resonance data. Backgrounds from  $B \rightarrow X_c e\nu$ , electrons from  $J/\Psi \rightarrow e^+e^-$  decays, cascade decays  $B \rightarrow X_c \rightarrow e$ , and misidentified hadrons are subtracted using Monte Carlo simulation.

### 2.3. Results

The electron momentum spectrum is shown in Fig. 1. The partial  $b \rightarrow ue\nu$  branching fraction is

$$\Delta\mathcal{B} = (0.152 \pm 0.014_{stat.} \pm 0.014_{syst.}) \times 10^{-3}. \quad (1)$$

Using input from CLEO's  $b \rightarrow s\gamma$  measurement [8] this translates into

$$\mathcal{B}(b \rightarrow ue\nu) = (2.05 \pm 0.27_{exp.} \pm 0.46_{f_u}) \times 10^{-3}, \quad (2)$$

$$|V_{ub}| = (4.43 \pm 0.29_{exp.} \pm 0.25_{OPE} \pm 0.50_{f_u} \pm 0.35_{s_\gamma}) \times 10^{-3}. \quad (3)$$

The errors are experimental, from the Operator Product Expansion (OPE) [9], from the uncertainty on the fraction of events in the measured electron energy range ( $f_u$ ), and from theoretical uncertainties related to the  $b \rightarrow s(u)\gamma$  shape functions ( $s_\gamma$ ).

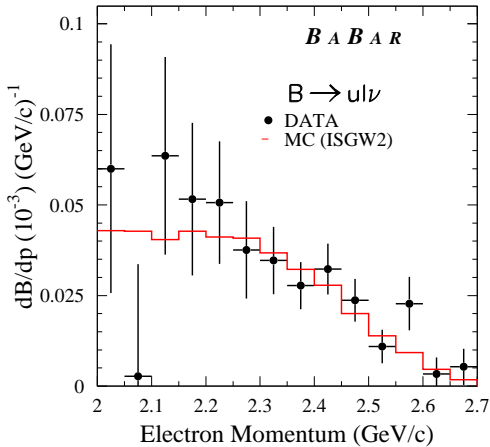


Figure 1. Inclusive electron momentum spectrum

### 3. EXCLUSIVE ANALYSIS

#### 3.1. Data set

The integrated luminosity of the data sample is  $50.5 \text{ fb}^{-1}$  taken at the  $\Upsilon(4S)$  mass, corresponding to 55.2 million  $B\bar{B}$  meson pairs. An additional  $8.7 \text{ fb}^{-1}$  of data were taken 40 MeV below the  $\Upsilon(4S)$  resonance.

#### 3.2. Analysis strategy

We reconstruct the modes  $B^+ \rightarrow \rho^0 e^+ \nu$ ,  $B^0 \rightarrow \rho^- e^+ \nu$ ,  $B^+ \rightarrow \omega e^+ \nu$ ,  $B^+ \rightarrow \pi^0 e^+ \nu$ , and  $B^0 \rightarrow \pi^- e^+ \nu$  (with  $\rho^0 \rightarrow \pi^+ \pi^-$ ,  $\rho^\pm \rightarrow \pi^0 \pi^\pm$  and  $\omega \rightarrow \pi^0 \pi^+ \pi^-$ ). The charge conjugate decays are implied throughout. The analysis is optimized for  $B \rightarrow \rho e \nu$  decays; the  $\pi$  and  $\omega$  modes are included because of the crossfeeds into the  $\rho$  modes. Isospin and quark model relations are used to effectively measure only two branching fractions, one for  $B \rightarrow \rho e \nu$  and one for  $B \rightarrow \pi e \nu$ . Three kinematic variables are used: the electron energy  $E_e^{\text{CM}}$ ; the invariant hadronic mass  $M_{\pi\pi(\pi)}$  (for the  $\rho$  and  $\omega$  modes), and the difference between the reconstructed and expected  $B$  meson energy ( $\Delta E \equiv E_{\text{hadron}} + E_e + |\vec{p}_{\text{miss}}|c - E_{\text{beam}}$ ) in the center-of-mass system. Two electron energy regions are considered:  $2.0 \leq E_e^{\text{CM}} < 2.3 \text{ GeV}$

(LOLEP), and  $2.3 \leq E_e^{\text{CM}} < 2.7 \text{ GeV}$  (HILEP). The HILEP region is most sensitive to the signal because the  $b \rightarrow ce\nu$  events are almost completely suppressed; the largest background source here is from continuum  $e^+e^- \rightarrow q\bar{q}$  events. Real data taken below the  $\Upsilon(4S)$  mass is used for the continuum subtraction. In the LOLEP region,  $b \rightarrow c$  decays dominate and provide the normalization of the background at higher electron energies.

#### 3.3. Fit method

We have performed a binned maximum-likelihood fit of the two-dimensional distributions ( $M_{\pi\pi(\pi)}$ ,  $\Delta E$ ) simultaneously in the two electron energy ranges (LOLEP, HILEP) and the five signal modes. The fit has contributions from the signal modes, other  $b \rightarrow ue\nu$  decays, and  $b \rightarrow ce\nu$  decays. Monte Carlo simulation provides the shapes of the distributions. The continuum, and a small contribution from misidentified electrons are determined using data. The decays  $B \rightarrow D^{(*)}e\nu$  have been simulated using heavy quark effective theory (HQET [10]). The modes  $B \rightarrow D^{(*)}\pi e\nu$  are simulated according to the Goity-Roberts model [11]. Resonant  $b \rightarrow ue\nu$  downfeed modes are implemented according to the ISGW2 model. Non-resonant  $b \rightarrow ue\nu$  modes are implemented according to a model by Fazio and Neubert [12]. The fit is performed five times using different form-factors for the signal modes  $B^+ \rightarrow \rho^0 e^+ \nu$ ,  $B^0 \rightarrow \rho^- e^+ \nu$ , and  $B^+ \rightarrow \omega e^+ \nu$ .

#### 3.4. Systematic errors

The systematic error includes contributions from uncertainties in the detector simulation ( $\approx 8\%$ ), background modeling ( $\approx 11\%$ ) and various other sources ( $\approx 9\%$ ). The largest single systematic error comes from the uncertainty in the shape of the downfeed background.

#### 3.5. Results

The isospin-constrained branching fraction results for the five different form-factors are shown in Fig. 2. The CKM matrix element  $|V_{ub}|$  can be obtained from the branching fraction using

$$|V_{ub}| = \sqrt{\frac{\mathcal{B}(B^0 \rightarrow \rho^- e^+ \nu)}{\tilde{\Gamma}_{\text{thy}} \tau_{B^0}}}, \quad (4)$$

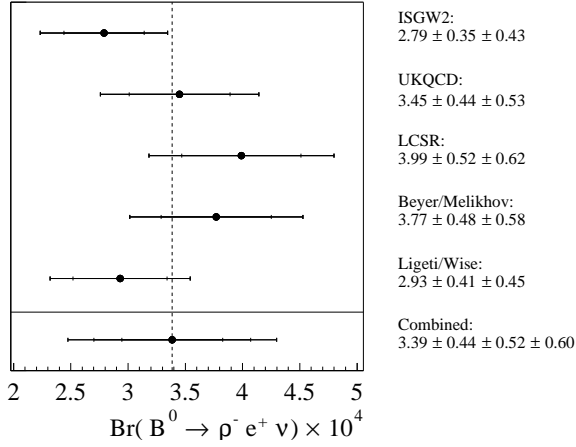


Figure 2. The  $B^0 \rightarrow \rho^- e^+ \nu$  branching fraction results for different form-factors. The errors are statistical, systematic, and theoretical (in case of the combined result), successively combined in quadrature. The combined result is the average of the 5 form-factors, the theoretical error is half of the full spread observed.

where  $\tilde{\Gamma}_{\text{thy}}$  is the predicted form-factor normalization. The calculations quote errors on  $\tilde{\Gamma}_{\text{thy}}$  between 15% and 50%. We use  $\tau_{B^0} = 1.548 \pm 0.032$  ps [13], and the branching fractions are taken separately for each form-factor as listed in Fig. 2. The combined central value is determined by taking the weighted mean of all form-factor results. The statistical and systematic errors of the combined result are determined by taking the mean of the relative errors of each individual result. The theoretical error is taken to be one half of the full spread of all fit results (including theoretical errors). The results for each form-factor and the combined result is shown in Fig. 3.

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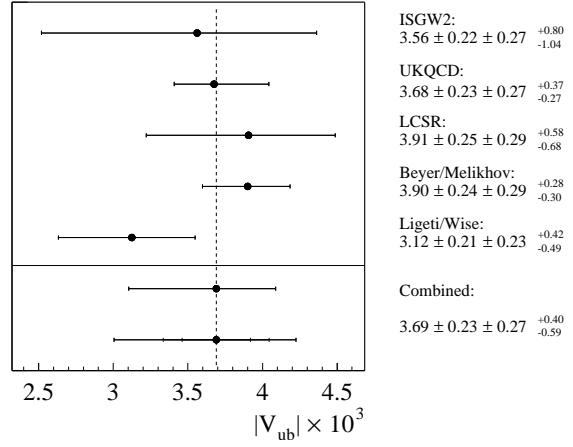


Figure 3.  $|V_{ub}|$  determined using different form-factors. The results for each form-factor are drawn with theoretical error bars only. The combined result is described in the text.

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