

SEMILEPTONIC B -MESON DECAYS AT $BABAR$ Michael Sigamani^a*Department of Physics, Queen Mary, University of London,
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Abstract. Presented are selected results of semileptonic B decays at $BaBar$. Two measurements of the Cabibbo-Kobayashi-Maskawa matrix element $|V_{cb}|$ are reported. One using moments of the hadronic-mass spectrum in inclusive $\bar{B} \rightarrow X_c \ell^- \bar{\nu}$ decays, and the other, exclusive $\bar{B} \rightarrow D \ell^- \bar{\nu}_\ell$ decays. These results are based on data samples of 232 (inclusive $\bar{B} \rightarrow X_c \ell^- \bar{\nu}$) and 460 (exclusive $\bar{B} \rightarrow D \ell^- \bar{\nu}_\ell$) million $\Upsilon(4S) \rightarrow B\bar{B}$ decays, recorded by the $BaBar$ detector at the PEP-II e^+e^- -storage rings. Semileptonic B decays are identified by requiring a lepton (e or μ) in events tagged with a full reconstruction of one of the B mesons in the $B\bar{B}$ pair.

1 Introduction

In the Standard Model of electroweak interactions, the coupling strength of the b to the c quark in the weak interaction is described by the Cabibbo-Kobayashi-Maskawa (CKM) [1] matrix element $|V_{cb}|$. A precise determination of $|V_{cb}|$ is therefore crucial for probing the CKM mechanism for quark mixing.

Experimentally, $|V_{cb}|$ is obtained using $\bar{B} \rightarrow X_c \ell^- \bar{\nu}$ decays with two distinct approaches: An exclusive analysis, where the hadronic system X_c is reconstructed in a specific mode. Or, an inclusive analysis where X_c is not reconstructed, but rather summed over all possible hadronic final states. Theoretically, inclusive determinations rely on an Operator Product Expansion in inverse powers of the b -quark mass [2], which relates the total $\bar{B} \rightarrow X_c \ell^- \bar{\nu}$ rate to $|V_{cb}|$. Whereas exclusive determinations use Form Factors (FF) to describe the hadronization process. Current measurements of $|V_{cb}|$ using inclusive and exclusive determinations generally differ by around two standard deviations, with the inclusive result being twice as precise as the exclusive [3].

2 Hadronic Reconstruction for the tagged B sample

The semileptonic sample for both exclusive and inclusive measurements are selected using $B\bar{B}$ events whereby a full reconstruction for one of the B mesons is required (referred to as the B_{tag}). The B_{tag} [4] candidate is reconstructed using hadronic modes of the type $\bar{B} \rightarrow D^{(*)}Y$, where Y represents a collection of charmed hadrons. The remaining particles in the event are assumed to belong to the other B (referred to as the B_{recoil}), which leaves a very clean sample of semileptonic events.

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*Presented to the 14th Lomonosov Conference on Elementary Particle Physics
Moscow, Russia, August 19-25, 2009*

Published in arXiv:1103.0562.

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

3 Exclusive determination of $|V_{cb}|$ using $\bar{B} \rightarrow D\ell^-\bar{\nu}_\ell$ decays

The $\bar{B} \rightarrow D\ell^-\bar{\nu}_\ell$ decay rate is proportional to the square of $|V_{cb}|$, and in the limit of very small lepton masses we use the following relation:

$$\frac{d\Gamma(\bar{B} \rightarrow D\ell\nu)}{dw} = \frac{G_F^2}{48\pi^3\hbar} M_D^3 (M_B + M_D)^2 (w^2 - 1)^{3/2} |V_{cb}|^2 \mathcal{G}^2(w), \quad (1)$$

where G_F is the Fermi coupling constant, $\mathcal{G}(w)$ is a FF which describes the effects of strong interactions in $\bar{B} \rightarrow D$ transitions, and M_B and M_D are the masses of the B and D mesons respectively. The variable w denotes the product of the B and D meson four-velocities, V_B and V_D , $w = V_B \cdot V_D = (M_B^2 + M_D^2 - q^2)/(2M_B M_D)$, where $q^2 \equiv (p_B - p_D)^2$, and p_B and p_D are the four-momenta of the B and D mesons. In the limit of infinite quark masses, $\mathcal{G}(w)$ coincides with the Isgur-Wise function [5]. This function is normalized to unity at zero recoil, where q^2 is maximum. Thus $|V_{cb}|$ can be extracted by extrapolating the differential decay rate to $w = 1$ using $\bar{B}^0 \rightarrow D^+\ell^-\bar{\nu}_\ell$ and $B^- \rightarrow D^0\ell^-\bar{\nu}_\ell$ decays [6]. Using the B_{tag} sample, the B_{recoil} is reconstructed by selecting a lepton (e or μ) with momentum in the CM frame $p_{\ell,min}^*$ above 0.6 GeV. Signal events are then identified using a missing-mass squared value,

$$m_{miss}^2 = [p(\Upsilon(4S)) - p(B_{tag}) - p(D) - p(\ell)]^2, \quad (2)$$

defined in terms of the measured particle four-momenta. Signal events will peak at zero in the m_{miss}^2 distribution as there is only one associated missing particle (left: Fig. 1). Other semileptonic B decays, such as $\bar{B} \rightarrow D^{(*,**)}\ell^-\bar{\nu}_\ell$ (feed-down) will yield larger values of m_{miss}^2 due to higher numbers of missing particles generated from secondary semi-leptonic decays of the $D^{(*,**)}$. A measurement of $|V_{cb}|$ is made using a fit to the w distribution, where data and MC events are evaluated in ten equal-size bins in the interval $1 < w < 1.6$ (right: Fig. 1). Data samples are assumed to contain four different contributions: $\bar{B} \rightarrow D\ell^-\bar{\nu}_\ell$ signal events, feed-down from other semileptonic B decays, combinatorial $B\bar{B}$ and continuum background, and fake lepton events (predominantly from hadronic B decays with hadrons misidentified as leptons). From the fit to the combined $\bar{B} \rightarrow D\ell^-\bar{\nu}_\ell$ sample, a measurement of $\mathcal{G}(1)|V_{cb}| = (43.0 \pm 1.9 \pm 1.4) \times 10^{-3}$ is made. Using an unquenched lattice calculation, corrected by a factor of 1.007 for QED effects, a value of $|V_{cb}| = (39.8 \pm 1.8 \pm 1.3 \pm 0.9_{FF}) \times 10^{-3}$ is extracted, where the third error is due to the theoretical uncertainty from $\mathcal{G}(1)$.

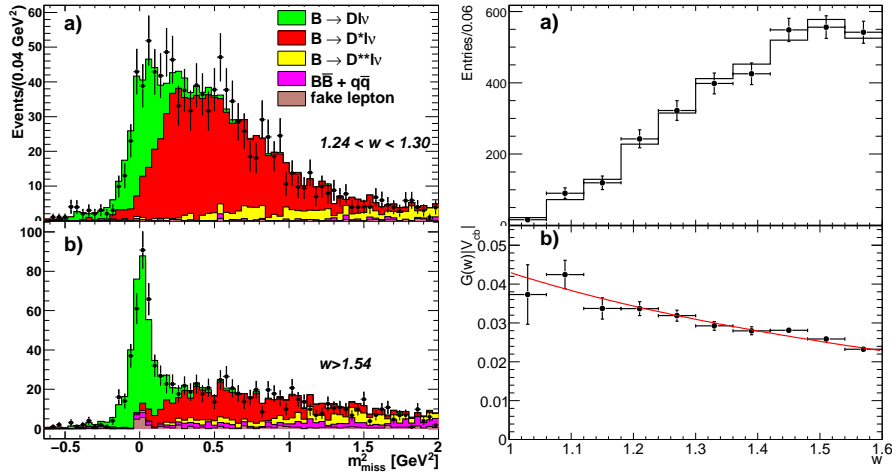


Figure 1: Left: Fit to the m_{miss}^2 distribution, in two different w intervals, for $B^- \rightarrow D^0\ell^-\bar{\nu}_\ell$: the data (points with error bars) are compared to the results of the overall fit (sum of the solid histograms). The PDFs for the different fit components are stacked in the order shown in the legend. Right: (a) The w distribution obtained by summing the $B^- \rightarrow D^0\ell^-\bar{\nu}_\ell$ and $\bar{B}^0 \rightarrow D^+\ell^-\bar{\nu}_\ell$ yields. Data (points) are compared to the results of the overall fit (solid histogram). (b) The $\mathcal{G}(w)|V_{cb}|$ distribution corrected for the reconstruction efficiency, with the fit result superimposed.

4 Inclusive determination of $|V_{cb}|$ using hadronic-mass moments in $\bar{B} \rightarrow X_c\ell^-\bar{\nu}$ decays

We are able to extract $|V_{cb}|$ using measurements of the hadronic mass moments $\langle m_X^k \rangle$ [7], with $k = 1, \dots, 6$ in semileptonic $\bar{B} \rightarrow X_c\ell\nu$ decays. These moments are measured as functions of $p_{\ell, min}^*$ between 0.8 GeV/c and 1.9 GeV/c. The measured hadronic mass moments $\langle m_X^k \rangle$ are shown in Fig. 2 with $k = 1 \dots 6$ as functions $p_{\ell, min}^*$. The statistical uncertainty consists of contributions from the data statistics, and the statistics of the MC. The fit method designed to extract the $|V_{cb}|$ from the moments measurements has been reported in [8] and is based on a χ^2 minimization technique. There are eight fit parameters in total namely: $|V_{cb}|$, the quark masses m_b and m_c , the total semileptonic branching fraction $\mathcal{B}(\bar{B} \rightarrow X_c\ell\nu)$, and the dominant non-perturbative HQE parameters μ_G^2 and ρ_{LS}^3 . Combined fits to these moments and moments of the photon-energy spectrum in $B \rightarrow X_s\gamma$ decays [9] have resulted in: $|V_{cb}| = (42.07 \pm 0.45 \pm 0.70) \times 10^{-3}$.

5 Summary and Conclusion

Presented are measurements of $|V_{cb}|$ using exclusive $\bar{B} \rightarrow D\ell^-\bar{\nu}_\ell$ decays, and the moments of the hadronic mass distribution in inclusive $\bar{B} \rightarrow X_c\ell^-\bar{\nu}$ decays.

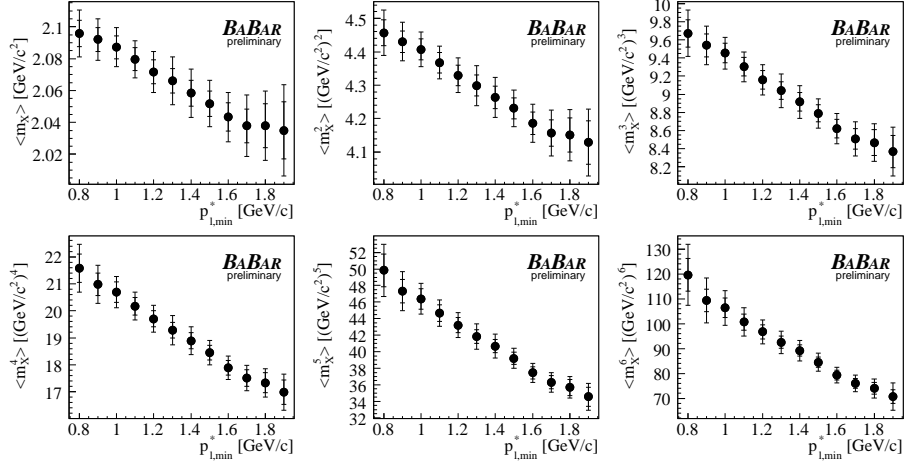


Figure 2: Measured hadronic mass moments $\langle m_X^k \rangle$ with $k = 1..6$ for different values of $p_{L,min}^*$. The inner error bars correspond to the statistical uncertainties while the full error bars correspond to the total uncertainties. All the moments are highly correlated since they share subsets of selected events.

Using the exclusive determination, the fit to the combined sample and an unquenched lattice calculation yields: $|V_{cb}| = (39.8 \pm 1.8 \pm 1.3 \pm 0.9_{FF}) \times 10^{-3}$. Using hadronic mass moments in the inclusive determination yields: $|V_{cb}| = (42.05 \pm 0.45 \pm 0.70) \times 10^{-3}$.

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