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SEMILEPTONIC B DECAYS FROM BABAR: $|V_{UB}|$ AND $|V_{CB}|$

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We report results from the BaBar Collaboration on the semileptonic B decays, highlighting the measurements of the magnitude of the Cabibbo-Kobayashi-Maskawa matrix elements V_{ub} and V_{cb}. We describe the techniques used to obtain the matrix element $|V_{cb}|$ using the measurement of the inclusive $B \to X_c \ell\nu$ process and a large sample of exclusive $B \to D^* \ell\nu$ decays. The $|V_{ub}|$ matrix elements has been measured studying the hadronic mass distribution M_X and the lepton spectra at the endpoint for the $B \to X_u \ell\nu$ process.

1. Introduction

The measurement of the parameters $|V_{cb}|$ and $|V_{ub}|$ provide important inputs to test the unitarity of the CKM matrix. To determine these parameters we have to measure the decay rates of the $b \to c$ and $b \to u$ transitions. The weak parameters are obscured by the hadronization effects and by the interaction between initial and final state. The common approach is to use the semileptonic decays $B \to X_{u,c}\ell\nu$ which reduce strongly the non calculable hadronic effects compared to the fully hadronic B decays. The parameters $|V_{cb}|$ and $|V_{ub}|$ are extracted in many different way to get a better control of the remaining non-perturbative effects, which still limit the precision of their measurements.

2. Measurement of $|V_{cb}|$

The measurement of the partial decay width for the process $B \to X_c\ell\nu$ can be used to determine $|V_{cb}|$ throw the relation $|V_{cb}|^2 = \Gamma(B \to X_c\ell\nu)/\gamma_{th}$, where $\Gamma(B \to X_c\ell\nu)$ is the semileptonic Cabibbo favored partial width. The Operator Product Expansion (OPE) allow to write the γ_{th} as a double series in α_s and $1/m_b$, where m_b is the b quark mass, which is the key

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parameter of these kind of expansions. The leading non-perturbative corrections appears at the $1/m_b{}^2$ order and are parameterized by the quantity λ_1 (or $-\mu_\pi^2$), related to the Fermi motion of the b quark inside the B meson, and λ_2, (or μ_G^2), related to the expectation value of the chromomagnetic operator [1]. The quark-hadron duality is essential in these calculations. Other experimental quantities, like the moments of the invariant mass M_X of the hadronic system recoiling against the lepton-ν pair and the moment of the lepton energy spectra, can be written as a function of the same non-perturbative λ_1 and λ_2 parameters. Therefore we have the opportunity to extract these parameters from the data itself.

BABAR exploit the high statistics data sample collected by performing the M_X study on the recoil of fully reconstructed B decays. We use a sample of $B \to D^{(*)}Y$ (B_{reco}) where Y denoted a collection of hadrons with total charge ±1 composed of $n_1\pi^\pm+n_2K^\pm+n_3K_S+n_4\pi^0$ where $n_1+n_2 < 6$, $n_3 < 3$ and $n_4 < 3$. On the signal side a lepton with momentum $p_\ell^* > 0.9$ GeV/c is required. All remaining tracks and neutral showers are combined into the hadronic system X. Fig.1 (left) shows the extracted $< M_X^2 >$ as a function of the minimum lepton momentum cut. The results are also consistent with a recent preliminary measurement performed by DELPHI without any lepton momentum cut [2]. The CLEO result of the first hadronic mass moment at $p_{min}^* = 1.5$ GeV is also consistent [3], but in combination with the mean photon energy from $b \to s\gamma$ [4] shows a different p_{min}^* dependence. The recent CLEO measurement of the hadronic moments [5] as a function of the lepton momentum cut is in good agreement with the BABAR measurement (Fig.1). A fit to all BABAR hadronic moments is performed in the $1S$ scheme. The results are $m_b^{1S} = 4.638 \pm 0.094_{exp} \pm 0.062_{theo} \pm 0.065_{1/m_B^3}$ GeV and $\lambda_1 = -0.26 \pm 0.06_{exp} \pm 0.04_{the} \pm 0.04_{1/m_B^3}$ GeV^2. The fit also utilizes the semileptonic width $\Gamma_{sl} = (4.37 \pm 0.18) \times 10^{-11}$, determined from BABAR data, to obtain $|V_{cb}| = (42.10 \pm 1.04_{exp} \pm 0.52_{theo} \pm 0.50_{1/m_B^3}) \times 10^{-3}$.

The study of the decay $B \to D^{*+}\ell^-\bar{\nu}$ can also be used to extract $|V_{cb}|$. The differential decay rate for the process $B \to D^{*+}\ell^-\bar{\nu}$ is determined as a function of the four-velocity product, $w = v_B \cdot v_D^* = (m_B^2 + m_{D^*}^2 - q^2)/2m_B m_D^*$ where q^2 is the square of the 4-momentum transfered to the two leptons. The theoretical tool to extract the hadronic matrix element is the Heavy Quark Effective Theory (HQET) [6]. The relation $d\Gamma/dw \propto |V_{cb}|^2\mathcal{F}^2(w)\mathcal{K}(w)$ expresses the decay width as the product of the phase space factor $\mathcal{K}(w)$ times the hadronic form factor $\mathcal{F}(w)$ square, which corresponds to the Isgur-Wise function in the limit of infinite b and c masses. This form factor can be expressed as $\mathcal{F}(w) = \mathcal{F}(1)g(w)$,

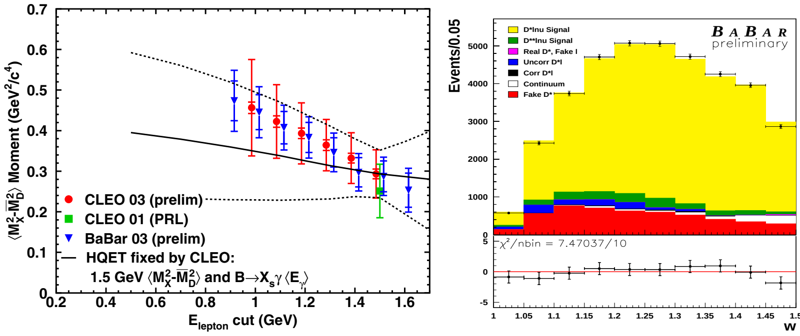

Figure 1. Left: measured hadronic mass momentum for different lepton threshold momenta cut. For comparison the measurements by CLEO are also shown. The solid curve is the dashed curve is the OPE prediction based on the CLEO result at $p^*_min > 1.5$ GeV combined with information from the $b \to s\gamma$ decay. Right: comparison of the w distribution for $B \to D^*\ell\nu$ in data and the result of the fit. The fit residuals are shown in the bottom plot.

where the shape function $g(w)$ is an almost linear function. Using some general analytical constraints by QCD [7], the shape $g(w)$ can written as a function depending on just one single parameter (ρ^2), which is usually determined from data. In the limit $w \to 1$ the HQET predict $\mathcal{F}(1) = 1$, some recent quenched lattice QCD calculations gives $\mathcal{F} \approx 0.913\ ^{+0.030}_{-0.035}$ [11], which is compatible with other calculations. The product $\mathcal{F}(1)|V_{cb}|$ is measured by extrapolating $d\Gamma/dw$ at the point of zero recoil $w \to 1$, where the phase space $\mathcal{K}(w)$ is null. The measurement of $|V_{cb}|$ using this technique has been performed both at the B-Factories and LEP experiments. In BaBar we select events with a lepton with $p^* > 1.2$ GeV and a reconstructed $D^{*+0} \to D^0\pi$, where the D^0 is reconstructed in the $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^+\pi^-\pi+$ and $D^0 \to K^-\pi^+\pi^0$ modes. A sample of ~ 57.000 signal events are selected. Kinematics constraints are used to extract from the data the amount of the decay $B \to D^* X\ell\nu$, which is the most dangerous physics background, (often called simply D^{**} background). The result of the fit to the w distribution, combined with the value of $\mathcal{F}(1)$ showed above, is $|V_{cb}| = (37.27 \pm 0.26_{stat} \pm 1.43_{syst}\ ^{+1.48}_{-1.23}{}_{theo})$. The dN/dw distribution with the results of the fit is reported in Fig.1 (right). The branching fraction $\mathcal{B}(B\to D^{*+}\ell^-\bar{\nu}) = (4.68 \pm 0.03 \pm 0.29)\%$ is determined by integrating the differential w distribution. This measurement is lower than other measurement [8], especially the recent one by CLEO [9].

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

The measurement of $B \to X_u \ell \nu$ decays is a difficult experimental task due to the high $B \to X_c \ell \nu$ background. This kind of background have to be reduced by restricting the phase space in the analysis. One approach is to measure the lepton spectrum beyond the kinematic cutoff for $B \to X_c \ell \nu$ decays, which is at $p^*_\ell > 2.3$ GeV. The disadvantage is that only about 10% of all charmless semileptonic decays are detected, therefore the extrapolation to the full phase space is significant with corresponding uncertainties. In the endpoint range ($2.3 < p^*_\ell < 2.6$ GeV) the partial branching fraction is determined to be $\Delta\mathcal{B}(B \to X_u \ell \nu) = (0.152 \pm 0.014_{stat} \pm 0.014_{syst}) \times 10^{-3}$ (see Fig.2 (left)). The extrapolation to the full phase space is done as in the CLEO analysis [10], where the shape function parameters are determined by a fit to the $b \to s\gamma$ photon energy spectrum. The result is $\mathcal{B}(B \to X_u \ell \nu) = (2.05 \pm 0.27_{exp} \pm 0.46_{fu})$, where the last error is due to the extrapolation. Using the relation from the Ref.[12] we obtain $|V_{ub}| = (4.43 \pm 0.29_{exp} \pm 0.50_{fu} \pm 0.35_{s\gamma} \pm 0.25_{\Gamma}) \times 10^{-3})$, the last error is the uncertainty in the extraction of $|V_{ub}|$ from the total decay rate.

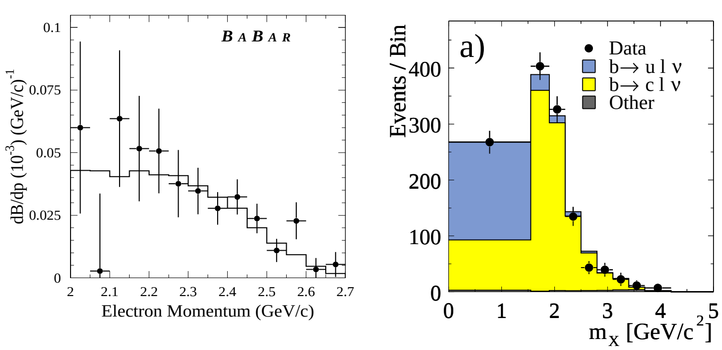

Figure 2. Left: differential branching fraction as a function of the electron momentum, after efficiency and bremsstrahlung corrections. Right: the χ^2 fit to the M_X distribution.

A different approach uses the invariant mass M_X of the hadron system recoiling against the lepton-ν pair to identify the charmless component which typically involve lighter M_X. The cuts on the M_X retain $50-80\%$ of all $B \to X_u \ell \nu$ decays, depending which cut is used. BaBar has exploited the high statistics using the B_{reco} sample described before. A lepton with minimum momentum in the B rest frame $p_\ell^* > 1$ GeV/c is required in the signal side. In order to reduce experimental systematic errors the ratio of branching fraction $R_u = \mathcal{B}(B \to X_u \ell\nu)/\mathcal{B}(B \to X\ell\nu)$ is extracted from the number N_u of observed events with $M_X < 1.55$ GeV/c^2. N_u is obtained from a fit to the M_X distribution. Fig.2(right) shows the results of the χ^2 fit to the M_X distribution for the $B \to X_u \ell\nu$ enriched sample.

By using 82 fb^{-1} integrated luminosity, $|V_{ub}| = (4.62 \pm 0.28_{stat} \pm 0.27_{syst} \pm 0.40_{theo} \pm 0.26_{\Gamma})$, where the theoretical model uncertainty is due to shape function that parameterize the Fermi motion. This result is compatible with previous inclusive measurements [8], but the systematics error is smaller due to the large acceptance and high sample purity.

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