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$|V_{ub}|$ from exclusive semileptonic $B \to \rho$ decays

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ABSTRACT

We use Omnès representations of the form factors V, A_1 and A_2 for exclusive semileptonic $B \to \rho$ decays, and apply them to combine experimental partial branching fraction information with theoretical calculations of the three form factors to extract $|V_{ub}|$. We find $|V_{ub}| = (2.8 \pm 0.2_{\rm stat} \pm 0.5_{\rm sys}) \times 10^{-3}$, where we have conservatively assumed a 20% systematic error to account for the use of the quenched approximation in the lattice QCD calculations of the form factors. This value of $|V_{ub}|$ is slightly lower than the values extracted from exclusive semileptonic $B \to \pi$ decays, $(3.47 \pm 0.29 \pm 0.03) \times 10^{-3}$ [J.M. Flynn, J. Nieves, Phys. Rev. D 76 (2007) 031302], $(3.36 \pm 0.23) \times 10^{-3}$ [C. Bourrely, I. Caprini, L. Lellouch, Phys. Rev. D 79 (2009) 013008], $(3.38 \pm 0.35) \times 10^{-3}$ [J. Bailey, et al., arXiv:0811.3640 [hep-lat]], and using all other inputs in CKM fits, $(3.55 \pm 0.15) \times 10^{-3}$ [UTfit Collaboration M. Bona, et al., JHEP 0610 (2006) 081, hep-ph/0606167; UTfit Collaboration, http://utfit.roma1.infn.it/ckm-results/ckm-results.html]. The disagreement is greater when we compare to the result extracted from inclusive $B \to X_u l \nu$ decays, $|V_{ub}| = (4.10 \pm 0.30_{\rm exp} \pm 0.29_{\rm th}) \times 10^{-3}$ [M. Neubert, in: Proceedings of FPCP 2007: 5th Conference on Flavor Physics and CP Violation, Bled, Slovenia, 12–16 May 2007 (2007)].

1. Introduction

The magnitude of the element V_{ub} of the Cabibbo–Kobayashi–Maskawa (CKM) quark mixing matrix plays a critical role in testing the consistency of the Standard Model of particle physics and, in particular, the description of CP violation. Any inconsistency could be a sign of new physics beyond the Standard Model. V_{ub} is currently the least well-known element of the CKM matrix and improvement in the precision of its determination is highly desirable and topical.

$|V_{ub}|$ can be determined using inclusive or exclusive charmless semileptonic B decays. The inclusive method has historically provided a more precise result, but recent experimental [1–6] and theoretical developments [7–17] are allowing the exclusive semileptonic $B \to \pi$ method to approach the same level of precision.

Recently [18] we extracted $|V_{ub}|$ from combined experimental partial branching fraction information and theoretical [lattice QCD (LQCD) and light cone sum rules (LCSR)] information on exclusive semileptonic $B \to \pi$ decays. The Omnès representation was employed to provide parametrisations of the form factors. The extracted value turned out to be in striking agreement with that extracted using all other inputs in CKM fits and in some disagreement with $|V_{ub}|$ extracted from inclusive semileptonic decays.

The aim of this Letter is to extend the above formalism to study the exclusive semileptonic $B \to \rho$ decay and independently extract $|V_{ub}|$ from the recent measurements of the partially integrated branching fraction by BaBar [2], Belle [3] and CLEO [5,6]. We will make use of quenched LQCD form factor results [19,20] for the high q^2 region, and LCSR values [21] at $q^2 = 0$. Thanks to the Omnès representation of the form-factors, we are able to combine all these inputs, as we previously showed for $B \to \pi$ decays.

2. Fit procedure

2.1. Form-factors and differential decay width

The semileptonic decay $B^0 \to \rho^- \ell^+ \nu_l$ is determined by the matrix element of the $V - A$ weak current between a B meson and a ρ meson. The matrix element is

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$$\langle\rho(k,\eta)|\bar{b}\gamma^{\mu}(1-\gamma_5)u|B(p)\rangle=\eta^*_{\beta}T^{\mu\beta}, \tag{1}$$

with form factor decomposition

$$T_{\mu\beta}=\frac{2V(q^2)}{m_B+m_\rho}\epsilon_{\mu\gamma\delta\beta}p^{\gamma}k^{\delta}-\mathrm{i}(m_B+m_\rho)A_1(q^2)g_{\mu\beta}+\mathrm{i}\frac{A_2(q^2)}{m_B+m_\rho}(p+k)_{\mu}q_{\beta}-\mathrm{i}\frac{2A(q^2)}{q^2}m_\rho q_\mu(p+k)_\beta, \tag{2}$$

where $q=p-k$ is the four-momentum transfer and η is the ρ polarisation vector. The meson masses are $m_B=5279.5$ MeV and $m_\rho=775.5$ MeV for B^0 and ρ^-, respectively. In the helicity basis each of the form factors corresponds to a transition amplitude with definite spin-parity quantum numbers in the center of mass frame of the lepton pair. This relates the form factors V, A_1 and A_2 to the total angular momentum and parity quantum numbers of the $B\rho$ meson pair, $J^P=1^-,1^+$ and 1^+, respectively [22]. The physical region for the squared four-momentum transfer is $0\leqslant q^2\leqslant q^2_{\max}\equiv(m_B-m_\rho)^2$. If the lepton mass can be ignored ($l=e$ or μ), the total decay rate is given by

$$\Gamma(B^0\to\rho^-\ell^+\nu_l)=\frac{G_F^2|V_{ub}|^2}{192\pi^3m_B^3}\int_0^{q^2_{\max}}dq^2\,q^2\left[\lambda(q^2)\right]^{\frac{1}{2}}\left(|H^+(q^2)|^2+|H^-(q^2)|^2+|H^0(q^2)|^2\right), \tag{3}$$

where $G_F=1.16637\times10^{-5}$ GeV^{-2} is the Fermi constant and $\lambda(q^2)=(m_B^2+m_\rho^2-q^2)^2-4m_B^2m_\rho^2$. H^0 comes from the contribution of the longitudinally polarised ρ and is given by

$$H^0(q^2)=-\frac{1}{2m_\rho\sqrt{q^2}}\left\{(m_B^2-m_\rho^2-q^2)(m_B+m_\rho)A_1(q^2)-\frac{4m_B^2|\vec{k}|^2}{m_B+m_\rho}A_2(q^2)\right\}, \tag{4}$$

where $\vec{k}$ is the momentum of the ρ in the B-meson rest frame. $H^{\pm}$ correspond to the contribution of the transverse polarisations of the vector meson and are given by[1]

$$H^{\pm}=-\left\{(m_B+m_\rho)A_1(q^2)\mp\frac{2m_B|\vec{k}|}{m_B+m_\rho}V(q^2)\right\}. \tag{5}$$

The CLEO Collaboration has also measured partial branching fractions of the differential distribution [5,6]

$$\frac{d\Gamma(B^0\to\rho^-\ell^+\nu)}{dq^2\,d\cos\theta_{W\ell}}=\frac{G_F^2|V_{ub}|^2}{512\pi^3m_B^3}q^2\left[\lambda(q^2)\right]^{\frac{1}{2}}\left\{2\sin^2\theta_{W\ell}|H^0(q^2)|^2+(1-\cos\theta_{W\ell})^2|H^+(q^2)|^2+(1+\cos\theta_{W\ell})^2|H^-(q^2)|^2\right\} \tag{6}$$

with $\theta_{W\ell}$ the angle between the charged lepton direction in the virtual W-gauge boson rest frame and the virtual W in the B-meson rest frame.

2.2. Omnès parametrisations

We have previously [10,11,13,14,18] used a multiply subtracted Omnès dispersion relation [25,26], based on unitarity and analyticity properties, to describe $B\to\pi$ semileptonic decays. Here, we apply these ideas to $B\to\rho$ decays and use for $(n+1)$ subtractions [14]

$$F(q^2)=\frac{1}{s_0-q^2}\prod_{i=0}^{n}\left[F(s_i)(s_0-s_i)\right]^{\alpha_i(q^2)},\quad \alpha_i(s)\equiv\prod_{j=0,\,j\neq i}\frac{s-s_j}{s_i-s_j},\quad F=V,A_1,A_2, \tag{7}$$

where s_0 corresponds to a pole of the form factor F. We fix $s_0=m^2_{B^*}$ and $s_0=s_{\text{th}}=(m_B+m_\rho)^2$ for the V and A_1, A_2 form factors, respectively. In principle, for the axial form factors one should use the square of the 1^+ B-meson mass. The mass of this latter hadron is not well established yet, but it appears to be heavier than the 1^- B^* resonance. Thus and for the purposes of this exploratory work, since it would be reasonably far from $\sqrt{q^2_{\max}}$, it is sufficient to employ s_{th}. The parametrisation of Eq. (7) amounts to finding an interpolating polynomial for $\ln[(s_0-q^2)F(q^2)]$ passing through the points $(s_0-s_i)F(s_i)$. While one could always propose a parametrisation using an interpolating polynomial for $\ln[g(q^2)F(q^2)]$ for a suitable function $g(q^2)$, the derivation using the Omnès representation shows that taking $g(q^2)=s_0-q^2$ is physically motivated [14].

2.3. Theoretical and experimental inputs

We have used experimental partial branching fraction data from CLEO [5,6], Belle [3] and BaBar [2]. CLEO and BaBar combine results for neutral and charged B-meson decays using isospin symmetry, while Belle give separate values for $B^0\to\rho^-\ell^+\nu_l$ and $B^+\to\rho^0\ell^+\nu_l$ decays. Belle use three q^2 intervals, and we have added in quadrature the two different systematic errors quoted for each q^2 bin, and combined charged and neutral B-meson results. We take the resulting systematic errors to be fully correlated. BaBar's untagged analysis also uses three q^2 bins and we have assumed that the quoted percentage systematic errors for the partial branching fractions divided by total branching fraction are representative for the partial branching fractions alone and, following BaBar, took them to be fully correlated. CLEO determines partial branching fractions as a function of both q^2 and of $\cos\theta_{W\ell}$ (see Eq. (6)) and complete correlation matrices are given in [5] for both statistical uncertainties and systematic errors that we have used in our fits.

When computing partial branching fractions, we have used $\tau_{B^0}=1/\Gamma_{\text{Tot}}=(1.527\pm0.008)\times10^{-12}$ s [27] for the B^0 lifetime. All the branching fraction inputs are listed in Table 1.

[1] Note a typo in Eq. (1.7) of Ref. [19], the $\pm$ sign should be $\mp$, as used in previous papers of the UKQCD Collaboration [23,24].