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An improved Standard Model prediction of $BR(B \to \tau\nu)$ and its implications for New Physics

UTfit Collaboration

M. Bona [a], M. Ciuchini [b], E. Franco [c], V. Lubicz [b,d], G. Martinelli [c,e], F. Parodi [f], M. Pierini [a], C. Schiavi [f], L. Silvestrini [c,*], V. Sordini [g], A. Stocchi [h], C. Tarantino [b,d], V. Vagnoni [i]

[a] CERN, CH-1211 Geneva 23, Switzerland
[b] INFN, Sezione di Roma Tre, I-00146 Roma, Italy
[c] INFN, Sezione di Roma, I-00185 Roma, Italy
[d] Dipartimento di Fisica, Università di Roma Tre, I-00146 Roma, Italy
[e] Dipartimento di Fisica, Università di Roma "La Sapienza", I-00185 Roma, Italy
[f] Dipartimento di Fisica, Università di Genova and INFN, I-16146 Genova, Italy
[g] ETH Zurich, HG Raemistrasse 101, 8092 Zurich, Switzerland
[h] Laboratoire de l'Accélérateur Linéaire, IN2P3-CNRS et Université de Paris-Sud, BP 34, F-91898 Orsay Cedex, France
[i] INFN, Sezione di Bologna, I-40126 Bologna, Italy

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ABSTRACT

The recently measured $B \to \tau\nu$ branching ratio allows to test the Standard Model by probing virtual effects of new heavy particles, such as a charged Higgs boson. The accuracy of the test is currently limited by the experimental error on $BR(B \to \tau\nu)$ and by the uncertainty on the parameters f_B and $|V_{ub}|$. The redundancy of the Unitarity Triangle fit allows to reduce the error on these parameters and thus to perform a more precise test of the Standard Model. Using the current experimental inputs, we obtain $BR(B \to \tau\nu)_{\rm SM} = (0.84 \pm 0.11) \times 10^{-4}$, to be compared with $BR(B \to \tau\nu)_{\rm exp} = (1.73 \pm 0.34) \times 10^{-4}$. The Standard Model prediction can be modified by New Physics effects in the decay amplitude as well as in the Unitarity Triangle fit. We discuss how to disentangle the two possible contributions in the case of minimal flavour violation at large $\tan\beta$ and generic loop-mediated New Physics. We also consider two specific models with minimal flavour violation: the Type-II Two Higgs Doublet Model and the Minimal Supersymmetric Standard Model.

1. Introduction

Flavour physics offers the opportunity to probe virtual effects of new heavy particles using low-energy phenomena, involving Standard Model (SM) particles as external states. New Physics (NP) can generate large effects in Flavour Changing Neutral Currents (FCNC) and CP violating phenomena even for NP particle masses much above the TeV scale, if new sources of flavour and CP violation besides the Yukawa couplings are present. The strong NP sensitivity is mainly due to the Glashow–Iliopoulos–Maiani (GIM) suppression of FCNC processes in the SM [1]. However, other suppression mechanisms can be at work in the SM, making a few non-FCNC decays interesting for NP searches. In particular, the helicity suppression of the charged current decay $B \to \tau\nu$ makes it potentially sensitive to the tree-level effects of new scalar particles [2]. A typical example is given by the exchange of charged Higgs bosons in multi-Higgs extensions of the SM, such as the Type-II Two Higgs Doublet Model (2HDM-II) or the Minimal Supersymmetric Standard Model (MSSM), in the large $\tan\beta$ regime.

In the SM, the branching ratio of $B \to \tau\nu$ can be written as:

$$BR(B \to \tau\nu) = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B. \qquad (1)$$

The Fermi constant G_F, the B (τ) mass m_B (m_τ) and the B lifetime τ_B are precisely measured [3]. The decay constant of the B meson f_B is known with $\mathcal{O}(10\%)$ uncertainty. We use the lattice QCD (LQCD) average $f_B = 200 \pm 20$ MeV [4]. Concerning the error attached to lattice averages, we combine in quadrature the statistical and systematic errors, assuming Gaussian distributions. This

* Corresponding author.
E-mail address: luca.silvestrini@roma1.infn.it (L. Silvestrini).

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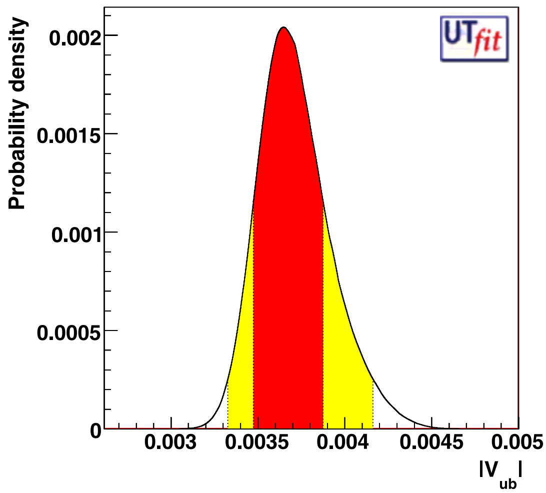

Fig. 1. P.d.f. of $|V_{ub}|$ obtained combining inclusive and exclusive measurements of the $b \to u$ semileptonic decays. The dark (light) region corresponds to the 68% (95%) probability interval.

is justified since present lattice systematic errors arise from the combination of several independent sources of uncertainty. Therefore they are well described by a Gaussian distribution, no matter what the distributions of the individual sources are.[1]

The absolute value of the Cabibbo–Kobayashi–Maskawa (CKM) [5] matrix element V_{ub} is determined from the measurements of the branching ratios of *exclusive* and *inclusive* semileptonic $b \to u$ decays. Its precision is limited by the uncertainty of the theoretical calculations. Although inclusive determinations are systematically higher than exclusive ones, the two values are compatible, once the spread of inclusive determinations using different theoretical models is considered. For the exclusive decays, we use the HFAG averages [6,7]

$$BR(B \to \pi \ell \nu)_{q^2 < 16\,\mathrm{GeV}^2} = (0.94 \pm 0.05 \pm 0.04) \times 10^{-4},$$

$$BR(B \to \pi \ell \nu)_{q^2 > 16\,\mathrm{GeV}^2} = (0.37 \pm 0.03 \pm 0.02) \times 10^{-4},$$

together with the theoretical estimates of the relevant normalized form factors

$$FF\big(q^2 < 16\,\mathrm{GeV}^2\big) = 5.44 \pm 1.43 \quad [8],$$

$$FF\big(q^2 > 16\,\mathrm{GeV}^2\big) = 2.04 \pm 0.40 \quad [4],$$

to obtain $|V_{ub}|^{\mathrm{excl}} = (33.3 \pm 2.7) \times 10^{-4}$. For inclusive decays, we quote $|V_{ub}|^{\mathrm{incl}} = (40.0 \pm 1.5 \pm 4.0) \times 10^{-4}$, where we define the second error as a flat range accounting for the spread of the different models [9].

Our grand average of inclusive and exclusive determinations is $|V_{ub}| = (36.7 \pm 2.1) \times 10^{-4}$, obtained from the probability density function (p.d.f.) in Fig. 1. From this p.d.f. we get

$$BR(B \to \tau \nu) = (0.98 \pm 0.24) \times 10^{-4}, \tag{2}$$

compatible with $BR_{\mathrm{exp}} = (1.73 \pm 0.34) \times 10^{-4}$ [10] at $\sim 1.8\sigma$.

A few percent precision is expected to be reached by LQCD using Petaflop CPUs for f_B and the form factors entering the exclusive determination of $|V_{ub}|$ [11]. Considering how challenging the measurement of $BR(B \to \tau \nu)$ in a hadronic environment is, it is difficult to imagine a similar improvement in precision of the experimental measurement, unless a SuperB factory will be built, leading also to a better direct determination of $|V_{ub}|$ [11]. On the other hand, it has been pointed out in Ref. [12] that the indirect determination of $|V_{ub}|$ from the Unitarity Triangle (UT) fit in the SM is more accurate than the measurements, yielding a central value close to the *exclusive* determination. Therefore a more precise prediction of $BR(B \to \tau \nu)$ in the SM can be obtained combining the *direct* knowledge of $|V_{ub}|$ and f_B with the *indirect* determination from the rest of the UT fit.

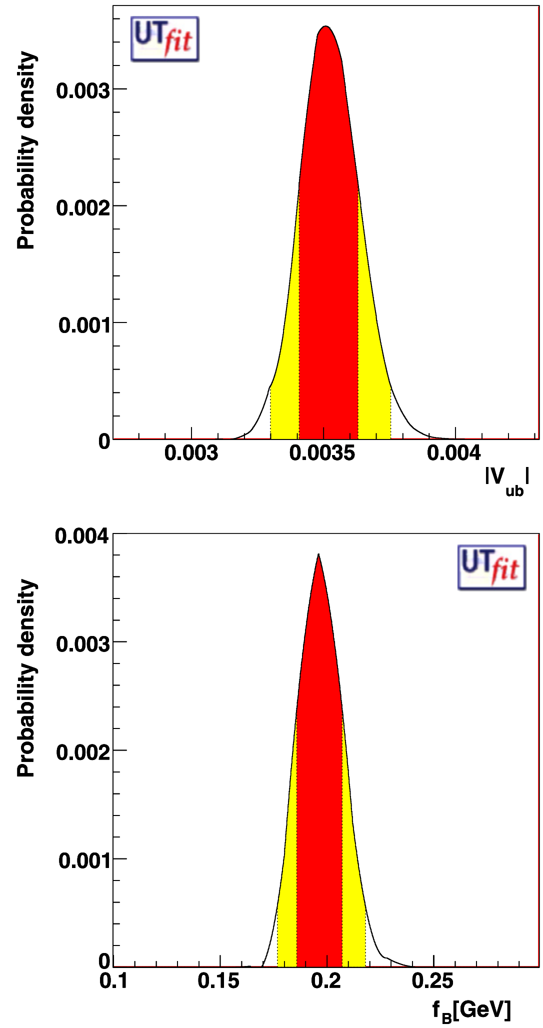

Fig. 2. Posterior p.d.f. for $|V_{ub}|$ (top) and f_B (bottom), obtained from the UT fit, without taking $BR(B \to \tau \nu)$ as input. The dark (light) region corresponds to the 68% (95%) probability interval.

2. UTfit-improved Standard Model prediction

In the UT fit [13,14], CP-conserving and CP-violating measurements are combined to constrain $\bar{\rho}$ and $\bar{\eta}$. The fit also provides an *a posteriori* determination of $|V_{ub}|$ which includes the *direct* measurement as well as the *indirect* determination from the other constraints. Similarly, an improved determination of f_B from both LQCD and experimental constraints is obtained [12].

The most accurate prediction of $BR(B \to \tau \nu)$ in the SM can then be obtained performing the SM fit without including the measurement of $BR(B \to \tau \nu)$ as a constraint. The fit gives $\bar{\rho} = 0.149 \pm 0.021$ and $\bar{\eta} = 0.334 \pm 0.013$ together with $f_B = (196 \pm 11)$ MeV and $|V_{ub}| = (35.2 \pm 1.1) \times 10^{-4}$. The posterior p.d.f.'s are shown in Fig. 2.

[1] Notice that in the past we used to assign a flat distribution to the lattice systematic errors, since they were dominated by the uncertainty associated to the quenched approximation.