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The Unitarity Triangle Analysis within and beyond the Standard Model

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We present the status of the Unitarity Triangle Analysis (UTA) performed by the UTfit Collaboration, with experimental and theoretical inputs updated for the last summer conferences. Several analyses are presented, corresponding to different assumptions for the theoretical model, that is either the Standard Model, or Minimal Flavour Violation or completely generic New Physics.

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1. Introduction

The Cabibbo-Kobayashi-Maskawa (CKM) matrix, V_{CKM}, is a 3×3 unitary matrix which originates from the misalignment in flavour space of the up and down components of the $SU(2)_L$ quark doublet of the Standard Model (SM). The CKM matrix elements are the only flavour-non-diagonal and CP-violating couplings present in the SM. The CKM matrix can be parameterized using three rotation angles and one phase. The popular Wolfenstein parameterization allows for a transparent expansion of the CKM matrix in terms of the sine of the small Cabibbo angle, λ, with the other three parameters being A, ρ and η. In this parameterization, because of the non-vanishing η parameter, V_{CKM} is complex and as a consequence the CP-symmetry is violated. The relations induced by the unitarity of the CKM matrix include six *triangular* relations in the (ρ, η)-plane, among which

$$V^*_{ub} V_{ud} + V^*_{cb} V_{cd} + V^*_{tb} V_{td} = 0 \,, \tag{1.1}$$

is referred to as the Unitarity Triangle (UT). This triangle is of great phenomenological interest as it is a privileged framework for studying CP-violation. Eq. (1.1), indeed, represents a relation among the CKM parameters which is sensitive to the η contribution.

The main aim of the Unitarity Triangle Analysis (UTA) is the determination of the values of the CKM parameters, by comparing experimental measurement and theoretical prediction for several observables depending on the CKM itself. The parameters λ and A are accurately measured from the decays $K \to l\nu$, $K \to \pi l \nu$, and $B \to D l \nu$, and are known with a precision of 0.5% and 1.2%, respectively [1, 2]. The essential role of the UTA, then, is the determination of the ρ and η parameters. Actually, the UTA is performed in terms of the parameters $\bar{\rho} \equiv \rho \cdot (1 - \lambda^2/2)$ and $\bar{\eta} \equiv \eta \cdot (1 - \lambda^2/2)$, in order to add to the original Wolfenstein expansion some $\mathcal{O}(\lambda^5)$ corrections, which are required by the present accuracy of the constraints.

In these proceedings we present the results of the different UT analyses performed by the UTfit collaboration, following the methods described in refs. [3]-[8], with experimental and theoretical inputs updated for the last summer conferences. These UT analyses, which are based on different assumptions for the theoretical model, are:

- The SM fit
  The validity of the SM is assumed. As NP effects cannot appear in any process, all the experimental constraints are used.

- The indirect determination of the hadronic parameters
  It is the same as the SM Fit but with the exclusion of one hadronic input at a time, which turns out to be predicted by the UTA itself.

- The Tree-level Fit
  Completely generic NP effects are allowed in loop processes (whereas in tree-level processes they are very unlikely to show up). Only tree-level constraints are unaffected by these contributions and can be used.

- The Universal Unitarity Triangle (UUT) Fit
  NP is assumed to be Minimal Flavour Violating (MFV) [9, 10] (i.e. ruled by the CKM couplings). Only the constraints not affected by MFV NP are included.

- The New Physics Fit
  Generic NP effects are allowed and parameterized in $\Delta F = 2$ processes (where visible effects can be expected). In addition to the usual constraints, also the recent CDF and D0 measurements of the CP-asymmetries in $B_s \to \psi\phi$ are included. Both the CKM and the NP parameters are determined from the fit.

2. The UTA within the SM

In this section we present the results of the SM Fit, where NP effects are not allowed and all the available constraints are included. They are

$$\varepsilon_K \,, \Delta m_d \,, \frac{\Delta m_d}{\Delta m_s} \,, \frac{|V_{ub}|}{|V_{cb}|} \,, BR(B \to \tau\nu) \,, \\ \sin 2\beta \,, \cos 2\beta \,, \alpha \,, \gamma \,, (2\beta + \gamma) \,, \tag{2.1}$$

where the constraints in the first row rely on the theoretical calculation of hadronic matrix elements, at variance with those in the second row. In ε_K we have included the contributions of ξ and $\phi_\varepsilon \neq \pi/4$ which, as pointed out in [11], decrease the SM prediction for ε_K by $\sim 8\%$. We have also included the long-distance contribution calculated more recently in [12], which softens the 8% reduction to 6%. In a new paper [13] the perturbative calculation of the NNLO QCD corrections to the box diagram involving a top and a charm quark has been computed and found to increase the theoretical prediction of ε_K by 3%. This contribution, which is a part of the NNLO QCD corrections, is not yet included in the UTA.

We observe that the CKM matrix turns out to be consistently overconstraint and the CKM parameters $\bar{\rho}$ and $\bar{\eta}$ are accurately determined: $\bar{\rho} = 0.132 \pm 0.020$, $\bar{\eta} = 0.358 \pm 0.012$ [14]. The UTA has thus established that the CKM matrix is the dominant source of flavour mixing and CP-violation and that New Physics (NP) effects can at most represent a small correction to this picture. As shown in fig. 1, however, the new contributions in ε_K generate some tension in particular between the constraints provided by the experimental measurements of ε_K and $\sin 2\beta$. As a consequence, the indirect determination of $\sin 2\beta$ turns out to be larger than the experimental value by $\sim 2.6\sigma$, as shown by the compatibility plot in fig. 2. We observe that the updated lattice average of the bag-parameter B_K [15] further enhances this ε_K-$\sin 2\beta$ tension. This is due to the fact that new unquenched results, though compatible with older quenched results, tend to lie below them. An equivalent way to point it out is from the comparison of the input lattice average and the indirect determination of B_K from the UTA. The difference is found at the 1.5σ level. We do not further discuss the results of the indirect determination of the hadronic parameters from the (overconstraint) SM UTA. We just observe that the overall consistency provides additional evidence of the SM success in describing flavour physics and of the reliability of Lattice QCD. For a detailed discussion on the status of Lattice calculations of the hadronic parameters which enter the UTA we refer to the conference proceedings of Vittorio Lubicz [16].

Recently, we have shown [17] how to use the UTA to improve the prediction of $\mathrm{BR}(B \to \tau\nu)$ in the SM, thanks to a better determination of $|V_{ub}|$ and f_B. Within the SM the UTA prediction for $\mathrm{BR}(B \to \tau\nu)$ is found to deviate from the experimental measurement [2, 18] by $\sim 3.2\sigma$ (see fig. 3).

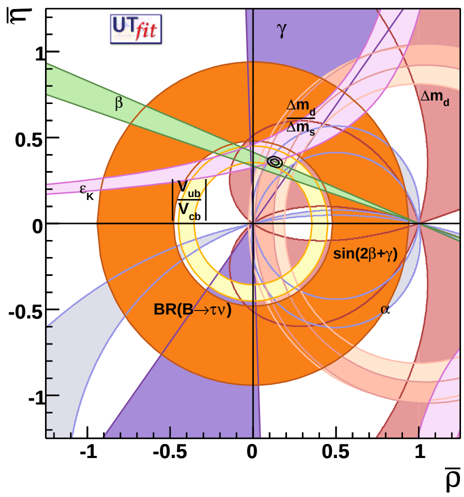

Figure 1: Results of the UTA within the SM. The contours display the selected 68% and 95% probability regions in the $(\bar{\rho}, \bar{\eta})$-plane. The 95% probability regions selected by the single constraints are also shown.

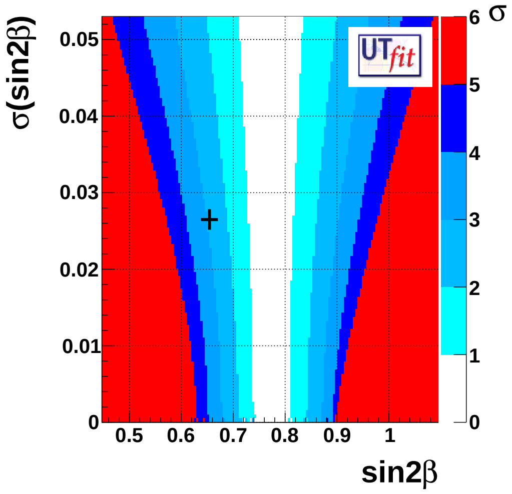

Figure 2: Compatibility plot for $\sin 2\beta$. Different colors denote the number of standard deviations from the indirect UTA result for $\sin 2\beta$. The experimental measurement is represented by the cross.

It is interesting to note that a large value of $|V_{ub}|$ (which is closer to some inclusive determinations) would reduce this deviation but it would enhance the tension in $\sin 2\beta$.

3. The UTA beyond the SM

In this section we consider the UT analyses where NP effects are allowed for.

In the Tree-level Fit, NP effects are allowed to affect in the most general way all loop processes. Therefore, only the tree-level constraints can be used in the analysis, namely $|V_{ub}|/|V_{cb}|$ and γ. The former comes from (tree-level) B semileptonic decays and the latter from the (tree-level) non-

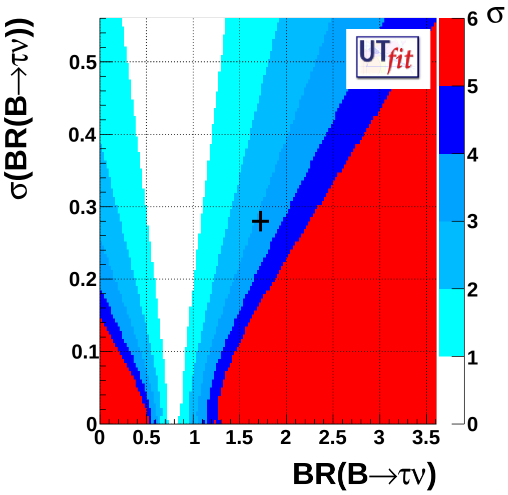

Figure 3: Compatibility plot for BR$(B \to \tau\nu)$.

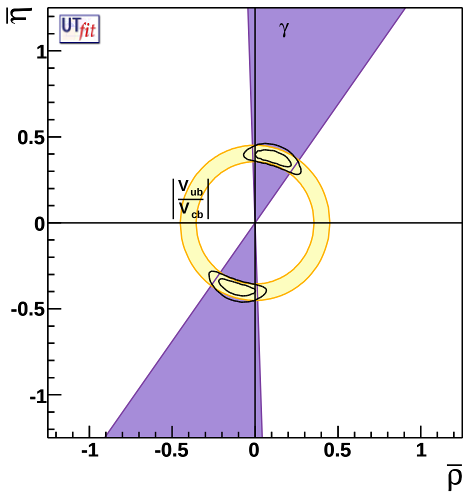

Figure 4: Results of the Tree-level Fit. The contours display the selected 68% and 95% probability regions in the $(\bar{\rho},\bar{\eta})$-plane. The 95% probability regions selected by the two constraints are also shown.

leptonic decays $B \to D^{(*)}K$. Within this analysis, the CKM parameters $\bar{\rho}$ and $\bar{\eta}$ are found to be: $\bar{\rho} = 0.111 \pm 0.070$, $\bar{\eta} = 0.381 \pm 0.030$ [14]. They are compatible with the results of the SM Fit, with larger uncertainties due to the use of only two constraints (see fig. 4).

A different scenario is considered in the UUT Fit, where NP is assumed to be Minimal Flavour Violating [9, 10], i.e. with quark mixing ruled only by the Standard Model CKM couplings. In this case no additional weak phases are generated and several observables entering into the Standard Model fit (the tree-level processes and the measurement of angles through the use of time-dependent CP-asymmetries) are not affected by the presence of NP. The sizeable effect one is sensitive to is a shift of the Inami-Lim function of the top contribution in meson mixing. This means that that the constraints on ε_K and Δm_d cannot be used, nor the ratio $\Delta m_d/\Delta m_s$, as Δm_s can get additional NP contributions at large $\tan\beta$ (e.g. in some SUSY models). The $BR(B \to \tau\nu)$ constraint could also receive a MFV NP contribution and is thus excluded from the fit. From the UUT Fit we find $\bar{\rho} = 0.143 \pm 0.030$, $\bar{\eta} = 0.342 \pm 0.015$ [14], which are in good agreement with the results of the SM Fit, with similar uncertainties. It is also interesting to note the the indirect determination of BR$(B \to \tau\nu)$ from th UUT Fit differs from the experimental value by $\sim 3.0\sigma$, showing that in a NP model of MFV type a significant deviation would still be present.

Finally, we discuss the NP Fit, which is based on a generalization of the relations among the experimental observables and the elements of the CKM matrix, introducing effective model-independent parameters that quantify the deviation of the experimental results from the SM expectations. The possible NP effects considered in the analysis are those entering the NP-sensitive processes of neutral meson mixing, where a significant experimental progress has been achieved. In the case of $B_{d,s}$-$\bar{B}_{d,s}$ mixing, a complex effective parameter is introduced, defined as

$$C_{B_{d,s}} e^{2i\phi_{B_{d,s}}} = \frac{\langle B_{d,s}|H_{eff}^{full}|\bar{B}_{d,s}\rangle}{\langle B_{d,s}|H_{eff}^{SM}|\bar{B}_{d,s}\rangle}\,, \qquad (3.1)$$

being H_{eff}^{SM} the SM $\Delta F = 2$ effective Hamiltonian and H_{eff}^{full} its extension in a general NP model, and with $C_{B_{d,s}} = 1$ and $\phi_{B_{d,s}} = 0$ within the SM. All the mixing observables are then expressed as a function of these parameters and the SM ones (see refs. [5, 6, 7] for details). In a similar way, for the K-$\bar{K}$ system one can introduce two parameters, C_{ε_K} and $C_{\Delta m_K}$ (equal to one in the SM)

$$C_{\varepsilon_K} = \frac{Im[\langle K|H_{eff}^{full}|\bar{K}\rangle]}{Im[\langle K|H_{eff}^{SM}|\bar{K}\rangle]}\,, \qquad C_{\Delta m_K} = \frac{Re[\langle K|H_{eff}^{full}|\bar{K}\rangle]}{Re[\langle K|H_{eff}^{SM}|\bar{K}\rangle]}\,. \qquad (3.2)$$

For Δm_K, a possible long-distance contribution with a uniform distribution between zero and the experimental value of Δm_K is conservatively added to the short-distance one. The combined fit of all the experimental observables selects the region ($\bar{\rho} = 0.135 \pm 0.040$, $\bar{\eta} = 0.374 \pm 0.026$) which is consistent with the results of the SM analysis, with larger uncertainties as the NP parameters are simultaneously determined. For a more detailed discussion of the status of this analysis and for the results of the NP parameters we refer to the conference proceedings of Luca Silvestrini [19].

References

[1] M. Antonelli *et al.* [for the FlaviaNet Working Group on Kaon Decays], arXiv:1005.2323 [hep-ph].

[2] The Heavy Flavour Averaging Group (HFAG), http://www.slac.stanford.edu/xorg/hfag/.

[3] M. Ciuchini *et al.*, JHEP **0107** (2001) 013 [hep-ph/0012308].

[4] M. Bona *et al.* [UTfit Collaboration], JHEP **0507** (2005) 028 [hep-ph/0501199].

[5] M. Bona *et al.* [UTfit Collaboration], JHEP **0603** (2006) 080 [hep-ph/0509219].

[6] M. Bona *et al.* [UTfit Collaboration], Phys. Rev. Lett. **97** (2006) 151803 [hep-ph/0605213].

[7] M. Bona *et al.* [UTfit Collaboration], JHEP **0803** (2008) 049 [0707.0636 [hep-ph]].

[8] M. Bona *et al.* [UTfit Collaboration], JHEP **0610** (2006) 081 [arXiv:hep-ph/0606167].

[9] G. D'Ambrosio *et al.*, Nucl. Phys. B **645** (2002) 155 [hep-ph/0207036].

[10] A. J. Buras *et al.*, Phys. Lett. B **500** (2001) 161 [hep-ph/0007085].

[11] A. J. Buras and D. Guadagnoli, Phys. Rev. D **78** (2008) 033005 [0805.3887 [hep-ph]].

[12] A. J. Buras, D. Guadagnoli and G. Isidori, Phys. Lett. B **688** (2010) 309 [arXiv:1002.3612 [hep-ph]].

[13] J. Brod and M. Gorbahn, arXiv:1007.0684 [hep-ph].

[14] The UTfit Collaboration, http://www.utfit.org/.

[15] V. Lubicz, PoS **LAT2009** (2009) 013 [arXiv:1004.3473 [hep-lat]].

[16] V. Lubicz, these proceedings.

[17] M. Bona *et al.* [UTfit Collaboration], Phys. Lett. B **687** (2010) 61 [arXiv:0908.3470 [hep-ph]].

[18] G. De Nardo on behalf of the BaBar Collaboration, proceedings of ICHEP'10.

[19] L. Silvestrini, these proceedings.

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