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Latest results for the Unitary Triangle fit from the **UTfit** Collaboration.

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Flavour physics represents a unique test bench for the Standard Model (SM). New analyses performed at the LHC experiments are now providing unprecedented insights into Cabibbo-Kobayashi-Maskawa (CKM) metrology and new evidences for rare decays. The CKM picture can provide very precise SM predictions through global analyses. We present here the results of the latest global SM analysis performed by the **UTfit** collaboration including all the most updated inputs from experiments, lattice QCD and phenomenological calculations. In addition, the Unitarity Triangle (UT) analysis can be used to constrain the parameter space in possible new physics (NP) scenarios. Assuming NP, all of the available experimental and theoretical information on $\Delta F = 2$ processes is combined using a model-independent parametrisation. We determine the allowed NP contributions in the kaon, D, B_d, and B_s sectors and, in various NP scenarios, we translate them into bounds for the NP scale as a function of NP couplings.

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1. Introduction

Flavour physics represents a powerful tool to test the SM, to quantify the coherence of its picture and to explore possible departures from it. From the flavour global fit we can extract the most accurate determination of the parameters of the CKM matrix [1, 2], as well as the best SM predictions of flavour observables. The Unitarity Triangle (UT) analysis here presented is performed by the **UT***fit* Collaboration following the method described in Refs. [3, 4]. We updated the analysis with the latest determinations of the theoretical inputs and the latest measurements of the experimental observables. The basic constraints used in the global fit and contributing to the sensitivity of the CKM matrix elements are: $|V_{ub}/V_{cb}|$ from semileptonic B decays, Δm_d and Δm_s from $B^0_{d,s}$ oscillations, ε_K from neutral K mixing, α UT angle from charmless hadronic B decays, γ UT angle from charm hadronic B decays, and $\sin 2\beta$ from $B^0 \to J/\psi K^0$ decays.

The values of most experimental inputs are taken from the Heavy Flavour Averaging Group (HFAG) [5], however when most updated individual results are available the **UT***fit* collaboration performs its own averages. Below a specific update (performed for this conference) is discussed for the $|V_{ub}/V_{cb}|$ experimental input. On the theoretical side, the non-perturbative QCD parameters are taken from the most recent lattice QCD determinations: as a general prescription, we average the $N_f = 2+1+1$ and $N_f = 2+1$ FLAG numbers [6], using eq. (28) in Ref. [7] and including the results in Ref. [8]. The complete set of numerical values used as inputs can be found at URL `http://www.utfit.org/` in the Summer 2016 section, together with past and future updates.

2. Updated inputs and results of the global fit in the SM

For the inputs coming from the semileptonic B decays, we use the values shown in top-left plot in Fig. 1 and listed in Table 1. The **UT***fit* 2D average shown is calculated starting from the Summer-2016 inputs [9] with a two-dimensional procedure inspired by the skeptical method of Ref. [10] with $\sigma = 1$. A very similar result is obtained from a two-dimensional *à la* PDG [11] procedure. It is evident that exclusive and inclusive results persist in showing discrepancies at the level of about 3.3σ in the case of V_{cb} and about 3.4σ for V_{ub}. We include in the average the LHCb ratio measurement [12] that is shown in the top-left plot in Fig. 1 as a diagonal band. The top-right plot in Fig. 1 shows the predictions for $\sin 2\beta$ from the SM global fits obtained when changing the inputs relative to the semileptonic B decays, using only exclusive inputs for both V_{ub} and V_{cb}, using only inclusive inputs or not using the V_{ub} and V_{cb} inputs at all. The experimental value for $\sin 2\beta$ is also shown for comparison. These inclusive-vs-exclusive discrepancies have been highlighted and discussed by the **UT***fit* collaboration since 2006 [13].

The angle γ of the UT is extracted from V_{cb} and V_{ub} mediated transitions in $B \to D^{(*)}K^{(*)}$ decays. The Summer-2016 **UT***fit* input value for γ is $(70.5 \pm 5.7)^\circ$ [9]. The angle α of the UT is

Table 1: V_{cb} and V_{ub} experimental inputs are shown as values. The individual V_{cb} and V_{ub} exclusive and inclusive numbers are taken from the most updated HFAG averages performed for this conference [5]. The 2D average reported for comparison is obtained from the numbers used in the Summer-2016 analysis [9].

$[10^{-3}]$	**excl.**	**incl.**	$\mathbf{\lvert V_{ub}\rvert/\lvert V_{cb}\rvert}$	**2D average**
$\mathbf{\lvert V_{cb}\rvert}$	38.88 ± 0.60	42.19 ± 0.78	$(8.0 \pm 0.6)10^{-2}$	41.7 ± 1.0
$\mathbf{\lvert V_{ub}\rvert}$	3.65 ± 0.14	4.50 ± 0.20		3.74 ± 0.21

PoS(CKM2016)096

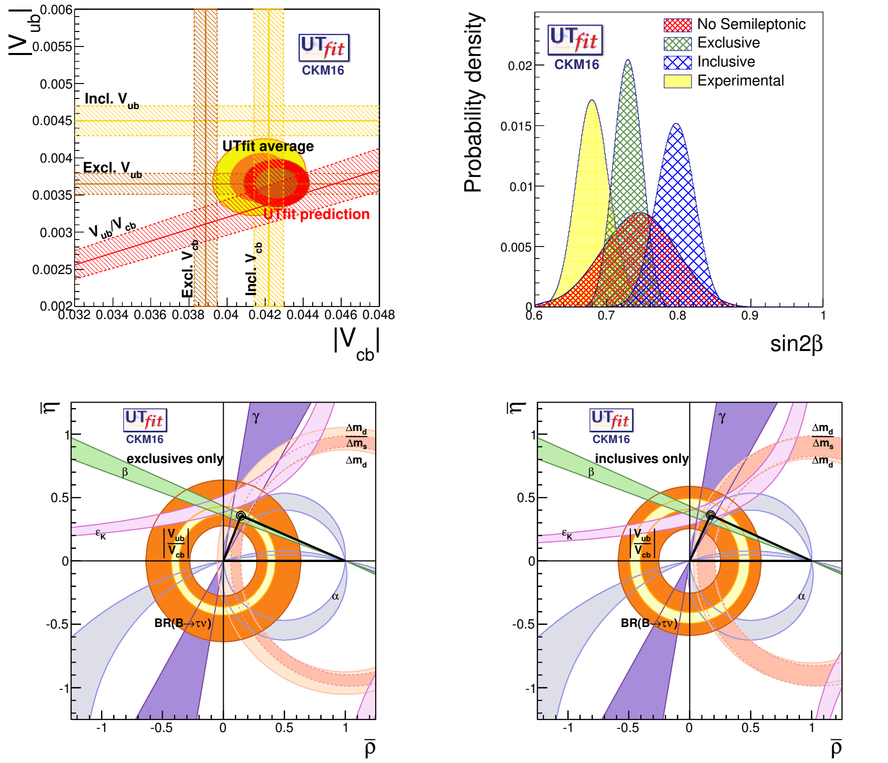

Figure 1: *Top-left*: $|V_{cb}|$ vs $|V_{ub}|$ plane showing the values reported in table 1. *Top-right*: predictions on $\sin 2\beta$ from the SM global fits obtained when changing the inputs as indicated in the legend. *Bottom*: $\bar{\rho}$-$\bar{\eta}$ plane with the SM global fit results using only exclusive inputs for both V_{ub} and V_{cb} (*left*) and using only inclusive inputs (*right*).

obtained from charmless two-body B decays in $\pi\pi$, $\rho\rho$ or $\rho\pi$ final states via isospin analyses. The Summer-2016 **UT***fit* value of the SM solution corresponds to $\alpha_{SM} = (94.2 \pm 4.5)^\circ$ [9].

Using the Summer-2016 inputs and our Bayesian framework, we perform the global fit to extract the CKM matrix parameters $\bar{\rho}$ and $\bar{\eta}$: we obtain $\bar{\rho} = 0.154 \pm 0.015$ and $\bar{\eta} = 0.344 \pm 0.013$. Left plot in Fig. 2 shows the result of the SM fit on the $\bar{\rho}$-$\bar{\eta}$ plane. The consistency of the picture is tested constraint by constraint evaluating its compatibility with all the others. The main tension still present comes from the inclusive-vs-exclusive values of the semileptonic determinations: for example, the inclusive $|V_{ub}|$ value shows a $\sim 2.9\sigma$ discrepancy with respect to the rest of the fit.

3. Result of the global fit beyond the SM

We now consider the UT analysis performed reinterpreting the experimental observables including possible model-independent NP contributions. The NP effects considered here are those entering neutral meson mixing ($\Delta F = 2$ transitions). They can be parameterised in a general way as:

$$\frac{\langle B_q | H_{\rm eff}^{\rm full} | \bar{B}_q \rangle}{\langle B_q | H_{\rm eff}^{\rm SM} | \bar{B}_q \rangle} = \left(1 + \frac{A_q^{\rm NP}}{A_q^{\rm SM}} e^{2i(\phi_q^{\rm NP} - \phi_q^{\rm SM})} \right)$$

where in the SM it is $A_q^{\rm NP} = 0$ and $\phi_q^{\rm NP} = 0$. $H_{\rm eff}^{\rm SM}$ is the SM $\Delta F = 2$ effective Hamiltonian, while $H_{\rm eff}^{\rm full}$ is its extension in a general NP model, and $q = d$ or s. The following experimental inputs

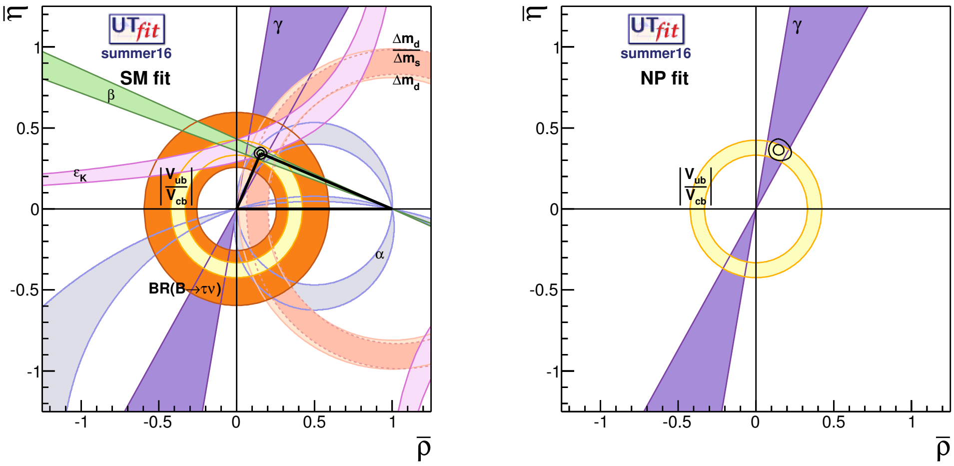

Figure 2: *Left:* $\bar{\rho}-\bar{\eta}$ plane showing the result of the SM fit. *Right:* $\bar{\rho}-\bar{\eta}$ plane showing the result of the NP fit. The black contours display the 68% and 95% probability regions selected by the given global fit. The 95% probability regions selected are also shown for those constraints not affected by NP in $\Delta F = 2$ transitions, however all the constraints are used in the fit selecting the $\bar{\rho}-\bar{\eta}$ area.

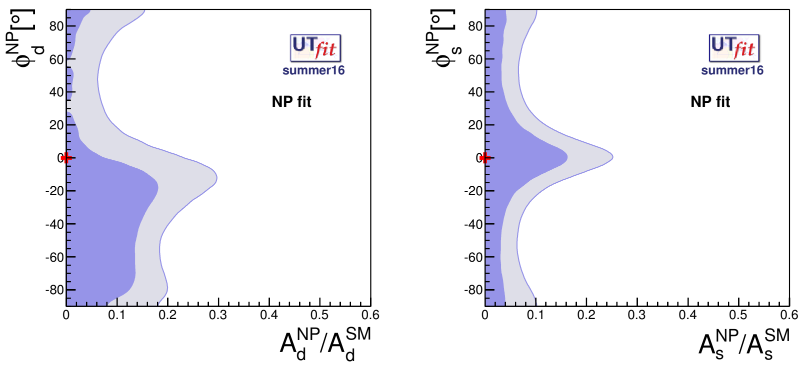

Figure 3: NP parameters in the B_d system (*left*) and B_s system (*right*), where 68% (dark) and 95% (light) probability regions are shown in the $A_q^{NP}/A_q^{SM} - \phi_q^{NP}$ planes. The red cross represents the SM expectation.

are added to the NP global fit to extract information on the B_s system: the semileptonic asymmetry in B_d and B_s decays, the di-muon charge asymmetry, the B_s lifetime from flavour-specific final states, and the CP-violating phase and the decay-width difference for B_s mesons from the time-dependent angular analysis of $B_s \to J/\psi\phi$ decays. The values used as inputs are mostly taken from the HFAG [5], except for the B_s semileptonic asymmetry where we are using the updated average available in Ref. [14].

Using the above inputs and our Bayesian framework, we perform the full NP analysis and the result of this global fit selects a region of the $(\bar{\rho},\bar{\eta})$ plane which is consistent with the result of the SM analysis. This can be seen in the two $\bar{\rho}-\bar{\eta}$ plots in Fig. 2. The $\bar{\rho}$ and $\bar{\eta}$ value extracted from the NP global fit are $\bar{\rho} = 0.150 \pm 0.027$ and $\bar{\eta} = 0.363 \pm 0.025$. Simultaneously, the NP parameters are extracted and their allowed ranges are shown in Fig. 3. The good consistency of the SM picture constrains the amount of NP that can still be allowed to contribute: however a $15-25\%$ effect is still allowed given the current sensitivities. For more details see Ref. [15].

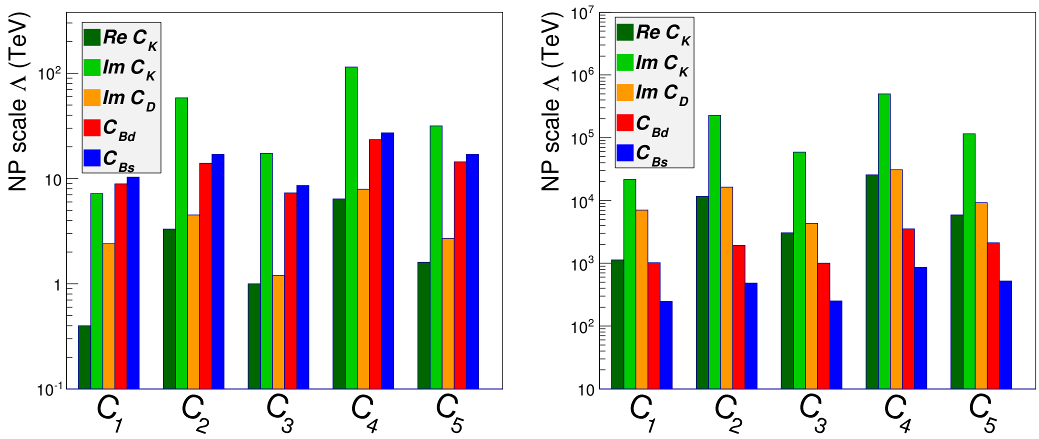

Figure 4: Summary of the 95% probability lower bound on the NP scale Λ for strongly-interacting NP in the NMFV scenario (*left*) and in the general NP scenario (*right*). Results from all the neutral meson systems are shown.

4. New-physics scale analysis

If we now consider the most general effective Hamiltonian for $\Delta F = 2$ processes ($H_{\rm eff}^{\Delta F=2}$), we can translate the current constraints into allowed ranges for the Wilson coefficients of $H_{\rm eff}^{\Delta F=2}$. The full procedure and analysis details are given in [16]. These coefficients have the general form

$$C_i(\Lambda) = \frac{F_i\, L_i}{\Lambda^2} \tag{4.1}$$

where F_i is a function of the (complex) NP flavour couplings, L_i is a loop factor that is present in models with no tree-level Flavour Changing Neutral Currents, and Λ is the scale of NP, *i.e.* the typical mass of the new particles mediating $\Delta F = 2$ transitions. For a generic strongly-interacting theory with arbitrary flavour structure, one expects $F_i \sim L_i \sim 1$ so that the allowed range from the fit for each of the $C_i(\Lambda)$ can be immediately translated into a lower bound on Λ. Specific assumptions on the flavour structure of NP, for example Next-to-Minimal [17] Flavour Violation (NMFV), corresponds to particular choices of the F_i functions.

In the latter case of NMFV, we have $|F_i| = F_{\rm SM}$ with an arbitrary phase [17]. The left plot in Fig. 4 shows the lower bounds on Λ in a NMFV scenario, assuming strongly interacting and/or tree-level NP contributions. To obtain the lower bound on Λ for loop-mediated contributions, one simply multiplies the bounds we quote in the following by $\alpha_s \sim 0.1$ or by $\alpha_W \sim 0.03$. The strongest bound is obtained from Im C_K^4 as $\Lambda_{\rm NMFV} > 114$ TeV. In the current scenario, the B_s system also provides quite stringent constraints.

For arbitrary NP flavour structures, we expect $|F_i| \sim 1$ with arbitrary phase. In this case, the constraints on the NP scale are much tighter due to the absence of the CKM suppression. The right plot in Fig. 4 shows the results for the lower bounds on Λ coming from all the C_i's in this case of the general NP scenario, with arbitrary NP flavour structures ($|F_i| \sim 1$) with arbitrary phase and $L_i = 1$ corresponding to strongly-interacting and/or tree-level NP. Again, the overall constraint on the NP scale comes from Im C_K^4 as $\Lambda_{\rm gen} > 5.0 \cdot 10^5$ TeV.

In conclusion, a loop suppression is needed in all scenarios to obtain NP scales that can be reached at the LHC. For NMFV models, an α_W loop suppression might not be sufficient, since the resulting NP scale is still of the order of 11 TeV. The general model is out of reach even for α_W (or stronger) loop suppression. Finally, the reader should keep in mind the possibility of accidental cancellations among the contribution of different operators, that might weaken the bounds we obtained.

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