PROCEEDINGS OF SCIENCE

Unitarity Triangle global fits beyond the Standard Model: UT*fit* 2021 new physics update

Marcella Bona,[a,*] **Marco Ciuchini,**[b] **Denis Derkach,**[c] **Fabio Ferrari,**[d] **Enrico Franco,**[e] **Vittorio Lubicz,**[f] **Guido Martinelli,**[g] **Maurizio Pierini,**[h] **Luca Silvestrini,**[i] **Cecilia Tarantino,**[f] **Vincenzo Vagnoni,**[j] **Mauro Valli**[k] **and Ludovico Vittorio**[l]

[a] *Queen Mary University of London*
[b] *INFN Sezione di Roma Tre*
[c] *Yandex/Higher School of Economics*
[d] *University of Bologna and INFN Sezione di Bologna*
[e] *INFN Sezione di Roma*
[f] *University of Roma Tre*
[g] *University of Roma La Sapienza*
[h] *CERN*
[i] *INFN Sezione di Roma*
[j] *INFN Sezione di Bologna*
[k] *Stony Brook University*
[l] *Scuola normale Superiore, Pisa and INFN Sezione di Pisa*

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 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 results from **UT***fit* new physics analysis: the Unitarity Triangle (UT) analysis can be used to constrain the parameter space in possible new physics (NP) scenarios. All of the available experimental and theoretical information on $\Delta F = 2$ processes is reinterpreted including a model-independent NP 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.

**** The European Physical Society Conference on High Energy Physics (EPS-HEP2021), ****
**** 26-30 July 2021 ****
**** Online conference, jointly organized by Universität Hamburg and the research center DESY ****

[*]Speaker

PoS(EPS-HEP2021)500

Flavour physics can test the Standard Model (SM) with high precision to quantify the coherence of its picture and to explore possible departures from it. Performing a global fit of flavour results, we can extract the most accurate determination of the parameters of the Cabibbo-Kobayashi-Maskawa (CKM) matrix [1], as well as the best SM predictions for a wide range of flavour observables. The Unitarity Triangle (UT) analysis is performed by the **UT***fit* Collaboration following the method described in Refs. [2]. 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 the sine of 2β UT angle from $B^0 \to J/\psi K^0$ decays.

The values of most experimental inputs are taken from the Heavy Flavour Averaging Group (HFLAV) (in Ref. [3] and online update at the `hflav.web.cern.ch`, mostly for the Particle Data Group 2021 update [4]). However, in the cases detailed in the text below, the **UT***fit* Collaboration performs its own averages. On the theoretical side, the non-perturbative QCD parameters are mostly taken from the recent lattice QCD determinations as in Ref. [5]. The continuously updated set of numerical values used as inputs can be found at `www.utfit.org`.

1. Results from the global fit beyond the Standard Model

We perform a full analysis of the UT reinterpreting the experimental observables including possible model-independent new physics (NP) contributions. The possible NP effects considered in the analysis are those entering neutral meson mixing ($\Delta F = 2$ transitions) and they can be parameterised in a model-independent way as:

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

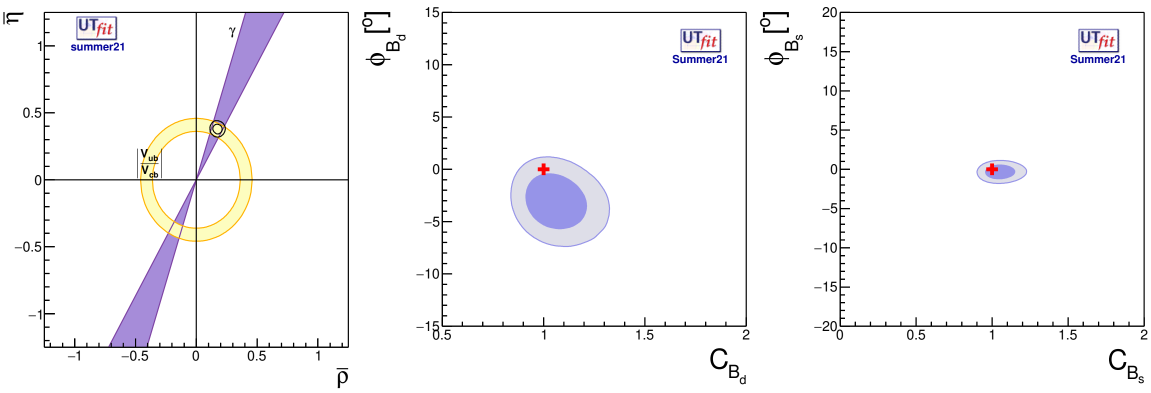

Figure 1: *Left*: $\bar{\rho} - \bar{\eta}$ plane showing the result of the NP fit. The black contours display the 68% and 95% probability regions selected by the given global fit. The 95% probability regions selected are also shown for those constraints not affected by NP in $\Delta F = 2$ transitions; *Middle*: NP $\phi_{B_d} - C_{B_d}$ parameters in the B_d system, with 68% (dark) and 95% (light) probability regions; *Right*: NP $\phi_{B_s} - C_{B_s}$ parameters in the B_s system, with 68% (dark) and 95% (light) probability regions. The red cross represents the SM expectation.

PoS(EPS-HEP2021)500

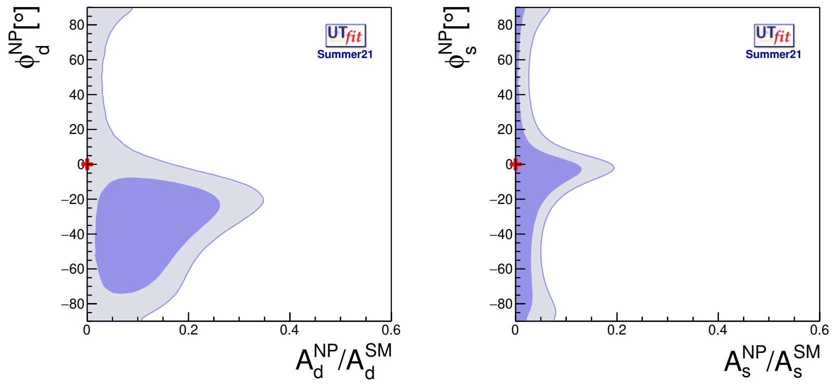

Figure 2: $A_q^{NP}/A_q^{SM} - \phi_q^{NP}$ NP-parameter plane as selected from the NP fit for the B_d system (*left*) and for the B_s system (*right*), where 68% (dark) and 95% (light) probability regions are shown. The red cross represents the SM expectation.

where in the SM $C_{B_{d,s}} = 1$ and $\phi_{B_{d,s}} = 0$, or equivalently $A_q^{NP} = 0$ and $\phi_q^{NP} = 0$, with $q = d$ or s. $H_{\rm eff}^{SM}$ is the SM $\Delta F = 2$ effective Hamiltonian, and $H_{\rm eff}^{\rm full}$ is its extension in a general NP model.

The following experimental inputs are added to the fit to extract information on the B_s system: the semileptonic asymmetry in B_s decays, the di-muon charge asymmetry, the B_s lifetime from flavour-specific final states, and CP-violating phase and the decay-width difference for B_s mesons from the time-dependent angular analyses of $B_s \to J/\psi\phi$ decays [3].

The result of the NP global fit selects a region in the $(\bar\rho, \bar\eta)$ plane which is consistent with the result of the SM analysis. This is shown in Fig. 1 with numerical results given in Table 1. Simultaneously, the NP parameters are extracted and their allowed ranges are shown in Figs. 1

Table 1: Results for the $\bar\rho$ and $\bar\eta$ values as extracted from the NP fit together with the NP parameters.

CKM parameters	$\bar\rho = 0.174 \pm 0.026$	$\bar\eta = 0.380 \pm 0.025$
Kaon parameter	$C_{\varepsilon_K} = 1.08 \pm 0.10$	
B_d parameters	$C_{B_d} = 1.07 \pm 0.10$	$\phi_{B_d} = (-3.1 \pm 1.7)^\circ$
B_s parameters	$C_{B_s} = 1.05 \pm 0.07$	$\phi_{B_s} = (-0.3 \pm 0.6)^\circ$

and 2. A 30% (18%) NP effect is allowed at 95% probability, given the current sensitivities in the B_d (B_s) system.

Considering the most general effective Hamiltonian for $\Delta F = 2$ processes ($H_{\rm eff}^{\Delta F=2}$), we 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 [6]. These coefficients have the general form $C_i(\Lambda) = F_i\, L_i/\Lambda^2$, 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 $F_i \sim L_i \sim 1$. Specific assumptions on the flavour structure of NP, for example Next-to-Minimal [7] Flavour Violation (NMFV), correspond to particular choices of the F_i functions. In the case of the general NP scenario, we have arbitrary NP flavour structures ($|F_i| \sim 1$) with arbitrary phase and $L_i = 1$ corresponding to strongly-interacting and/or tree-level NP, while in the case of NMFV, we have $|F_i| = F_{\rm SM}$ with an arbitrary phase [7].

PoS(EPS-HEP2021)500

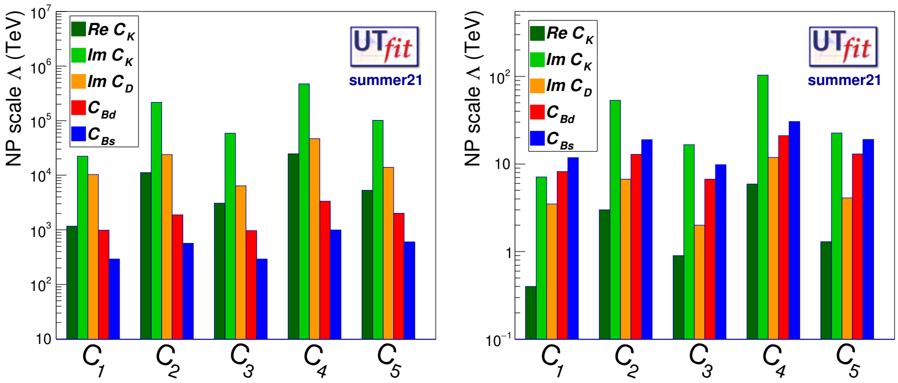

Figure 3: Summary of the 95% probability lower bound on the NP scale Λ for strongly-interacting NP in the general NP scenario (*left*) and in the NMFV scenario (*right*). Results from all the neutral meson systems are shown.

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 overall strongest constraints on the NP scale come from the kaon sector and are translated into $\Lambda_{\text{gen}} > 4.7 \cdot 10^5$ TeV and $\Lambda_{\text{NMFV}} > 103$ TeV. The B_s system also provides quite stringent constraints in the case of the NMFV scenario. In conclusion, a loop suppression is needed in all scenarios to obtain NP scales that can be reached at the LHC. For example, in case of loop coupling through weak interactions, hence considering $L_i \sim \alpha_W$, the constraints on the NP scale become $\Lambda_{\text{gen}} > 1.4 \cdot 10^4$ TeV and $\Lambda_{\text{NMFV}} > 3.1$ TeV, respectively.

References

[1] N. Cabibbo, *Unitary symmetry and leptonic decays*, *Phys. Rev. Lett.* **10** (Jun, 1963) 531–533; M. Kobayashi and T. Maskawa, *CP Violation in the Renormalizable Theory of Weak Interaction*, *Prog.Theor.Phys.* **49** (1973) 652–657.

[2] M. Ciuchini et al., *2000 CKM triangle analysis: A Critical review with updated experimental inputs and theoretical parameters*, *JHEP* **0107** (2001) 013, [hep-ph/0012308]; UTfit collaboration, M. Bona et al., *The 2004 UTfit collaboration report on the status of the unitarity triangle in the standard model*, *JHEP* **0507** (2005) 028, [hep-ph/0501199].

[3] HFLAV collaboration, Y. S. Amhis et al., *Averages of b-hadron, c-hadron, and τ-lepton properties as of 2018*, *Eur. Phys. J. C* **81** (2021) 226, [1909.12524].

[4] Particle Data Group collaboration, P. Zyla et al., *Review of Particle Physics*, *PTEP* **2020** (2020) 083C01.

[5] Flavour Lattice Averaging Group collaboration, S. Aoki et al., *FLAG Review 2019: Flavour Lattice Averaging Group (FLAG)*, *Eur. Phys. J. C* **80** (2020) 113, [1902.08191].

[6] UTfit collaboration, M. Bona et al., *Model-independent constraints on $\Delta F = 2$ operators and the scale of new physics*, *JHEP* **0803** (2008) 049, [0707.0636].

[7] K. Agashe et al., *Next to minimal flavor violation*, hep-ph/0509117.