

Unitarity Triangle global fits testing the Standard Model: *Ufit* 2021 Standard Model update

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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 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 *Ufit* collaboration including all the most updated inputs from experiments, lattice QCD and phenomenological calculations.

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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 here presented is performed by the **UFit** 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 $B_{d,s}^0$ 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 $B^0 \rightarrow J/\psi K^0$ 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 **UFit** 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. Updated inputs and results of the global fit in the Standard Model

The full list of measurements used as inputs in the global fit is given in the first and second columns of Table 1.

Table 1: Full SM inputs with their predictions from the SM global fits.

Input	Measurement	Fit prediction	Pull
$\sin 2\beta$	0.688 ± 0.020	0.750 ± 0.027	~ 1.8
γ	66.1 ± 3.5	66.1 ± 2.1	< 1
α	93.6 ± 4.2	90.5 ± 2.1	< 1
$\varepsilon_K \cdot 10^3$	2.228 ± 0.001	2.00 ± 0.14	~ 1.5
$ V_{cb} \cdot 10^3$	41.1 ± 1.0	41.9 ± 0.5	< 1
$ V_{cb} \cdot 10^3$ (excl)	39.09 ± 0.68		~ 3.6
$ V_{cb} \cdot 10^3$ (incl)	42.16 ± 0.50		< 1
$ V_{ub} \cdot 10^3$	3.89 ± 0.21	3.68 ± 0.10	< 1
$ V_{ub} \cdot 10^3$ (excl)	3.73 ± 0.14		< 1
$ V_{ub} \cdot 10^3$ (incl)	4.19 ± 0.20		~ 2.2
$\text{BR}(B \rightarrow \tau\nu)[10^{-4}]$	1.09 ± 0.24	0.87 ± 0.05	< 1
$A_{SL}^d \cdot 10^3$	-2.1 ± 1.7	-0.32 ± 0.03	< 1
$A_{SL}^s \cdot 10^3$	-0.6 ± 2.8	0.014 ± 0.001	< 1

Special treatment is reserved to a few cases. Regarding the inputs coming from the semileptonic B decays, the exclusive inputs are taken from the FLAG collaboration [5], while for the inclusive values we use different sources. For the $|V_{ub}|$ inclusive value we use the latest HFLAV determination

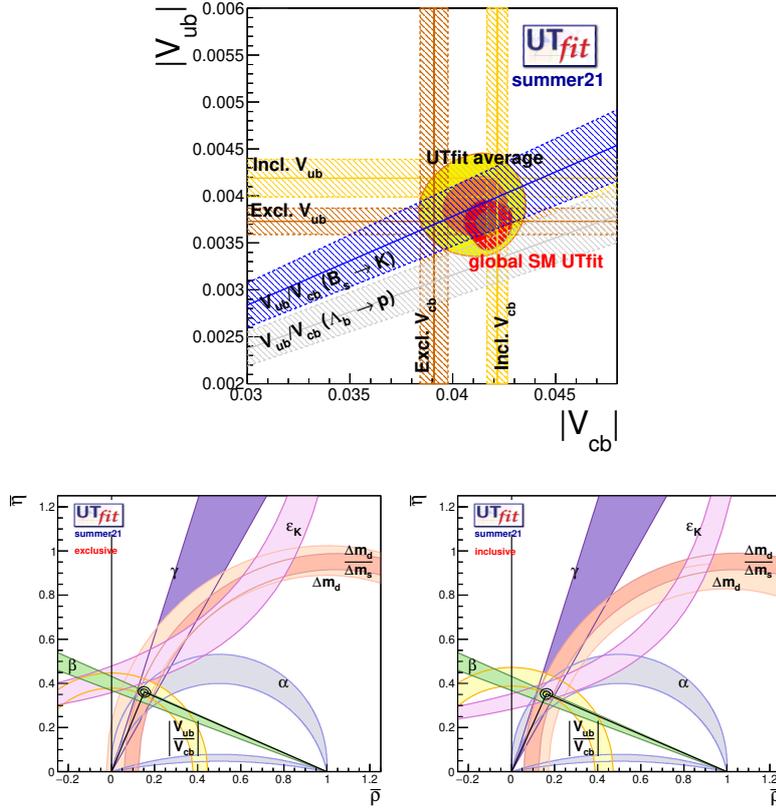


Figure 1: *Top:* $|V_{cb}|$ vs $|V_{ub}|$ plane showing the values reported in Table 1. We include in the average the LHCb ratio measurement [6] that is shown as a diagonal band. *Bottom:* $\bar{\rho}$ - $\bar{\eta}$ plane with the SM global fit results using only exclusive inputs for both V_{ub} and V_{cb} (left) and using only inclusive inputs (right).

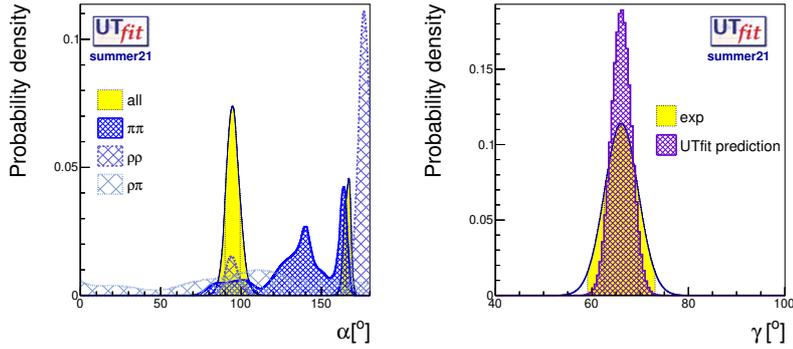


Figure 2: *Left:* global fit input distribution for the angle α (in solid yellow histogram) with the three separate distributions coming from the three contributing final states $\pi\pi$, $\rho\rho$ and $\rho\pi$. *Right:* global fit input distribution for the angle γ (in solid yellow histogram) obtained by the HFLAV [3] average compared with the global **UTfit** prediction for the same angle.

obtained via the GGOU (Gambino, Giordano, Ossola and Uraltsev [7]) calculation, and then we add a flat uncertainty covering the spread of central values from the other calculations: this results

in a value of $(4.19 \pm 0.17 \pm 0.18[\text{flat}]) \cdot 10^{-3}$. For the $|V_{cb}|$ inclusive value we use the calculation from Ref. [8]. The values used are also shown in the left plot in Fig. 1: the **UTfit** two-dimensional (2D) average shown is calculated with a 2D procedure inspired by the skeptical method of Ref. [9] with $\sigma = 1$. It is evident that exclusive and inclusive results persist in showing discrepancies in particular in the case of $|V_{cb}|$ at the level of about 3.6σ , while in the case of V_{ub} it is reduced to about 1.8σ . The effect of these deviations in the global fit results are shown in the right plots in Fig. 1. These inclusive-vs-exclusive discrepancies have been highlighted and discussed by the **UTfit** collaboration since 2006 [10].

Regarding the angle inputs, the values used are as follows:

- β (or ϕ_1): the value of $\sin 2\beta$ is taken from the latest HFLAV average [3] using exclusively the $J/\psi K^0$ final states which give $\sin 2\beta = 0.698 \pm 0.017$. We then add a correction factor of -0.01 ± 0.01 as data-driven theory uncertainty obtained with the method described in Ref. [11] with the most updated inputs.
- α (or ϕ_2): the value of the angle α is obtained by **UTfit** isospin analyses of the three contributing final states $\pi\pi$, $\rho\rho$ and $\rho\pi$. The various probability distributions are shown in Fig. 2 together with the combined one that is used as input to our global fit.
- γ (or ϕ_3): the value of the angle γ is taken from the latest HFLAV average [3] and the corresponding probability distribution is shown in Fig. 2 together with the prediction from the global fit.

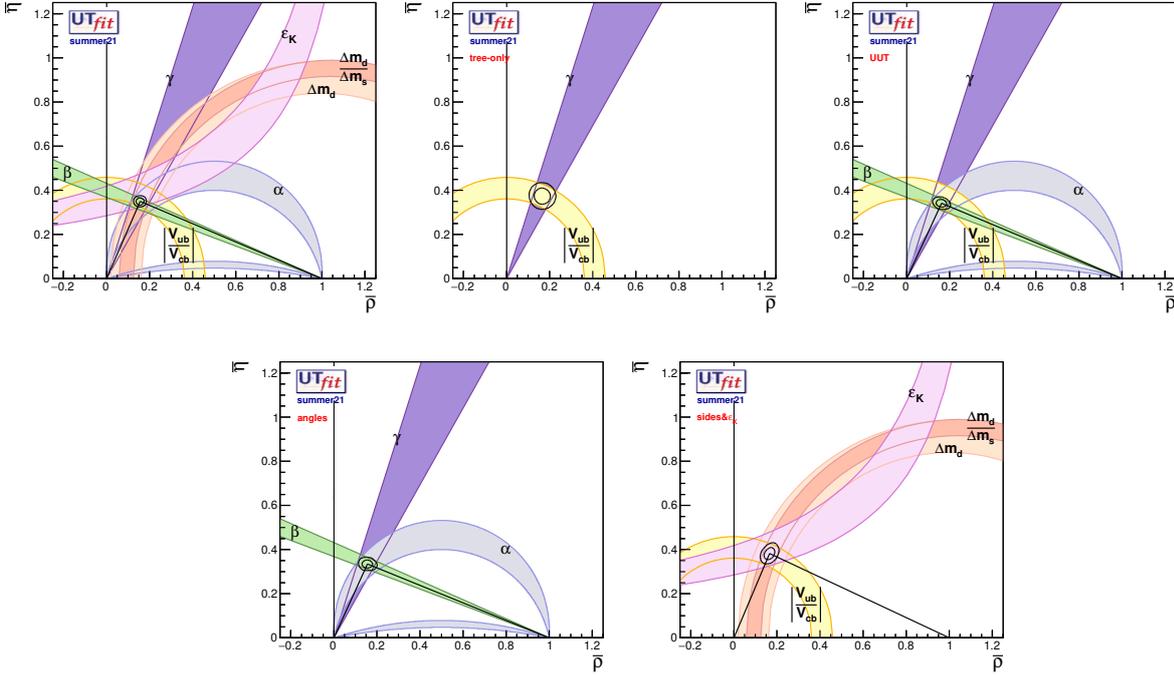


Figure 3: $\bar{\rho}$ - $\bar{\eta}$ planes with the SM global fit results in various configurations. The black contours display the 68% and 95% probability regions selected by the given global fit. The 95% probability regions selected are also shown for each constraint considered. *Top-Left:* full SM fit; *Top-Centre:* fit using as inputs the “tree-only” constraints; *Top-Right:* Universal Unitarity Triangle fit; *Bottom-Left:* fit using as inputs only the angle measurements; *Bottom-Right:* fit using as inputs only the side measurements and the mixing parameter ε_K in the kaon system.

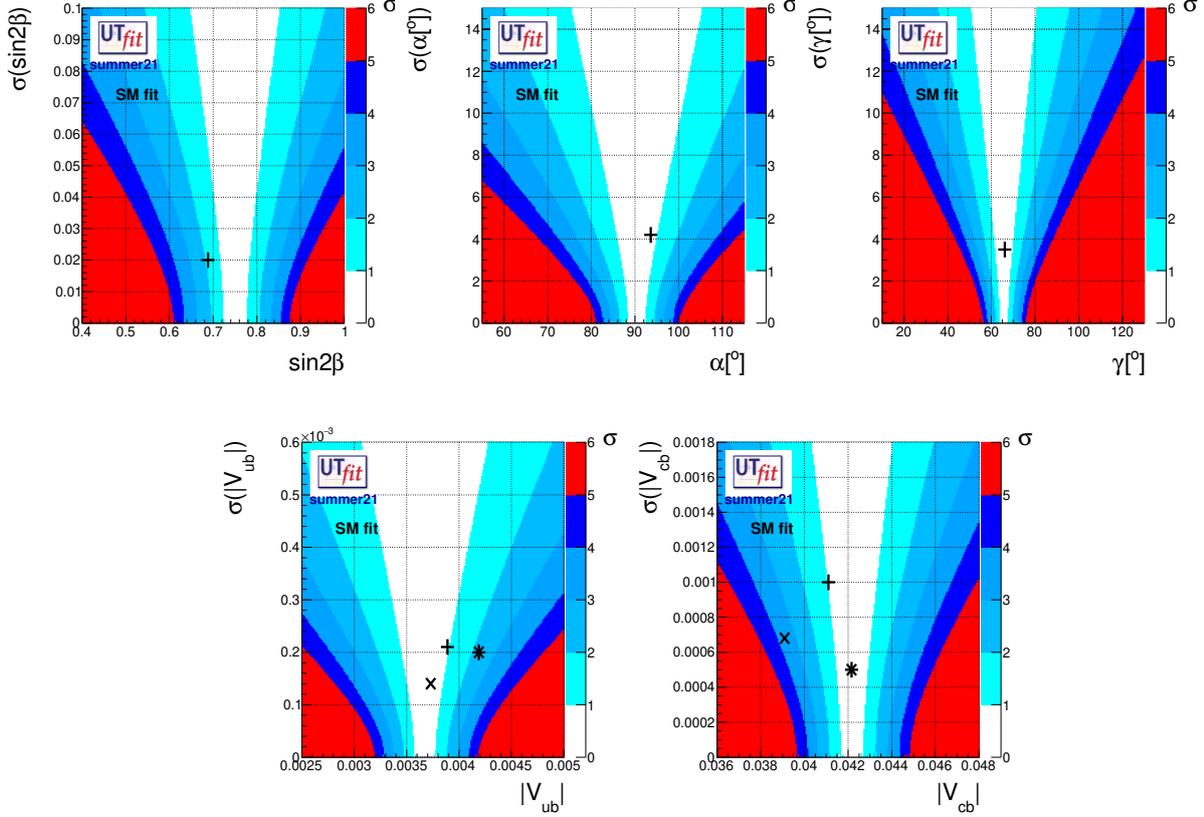


Figure 4: Pull plots (see text) for $\sin 2\beta$ (top-left), α (top-centre), γ (top-right), $|V_{ub}|$ (bottom-left) and $|V_{cb}|$ (bottom-right) inputs.

The results of the global SM fit are given as two-dimensional probability distributions in the plan of CKM parameters $\bar{\rho}$ and $\bar{\eta}$ and shown in Fig. 3. The numerical results are in Table 2.

Table 2: Results for the $\bar{\rho}$ and $\bar{\eta}$ values as extracted from the various fit configurations. The Universal Unitarity Triangle (UUT) fit includes the three angles inputs and the semileptonic $|V_{ub}/V_{cb}|$ [12].

fit configuration	$\bar{\rho}$	$\bar{\eta}$
full SM fit	0.156 ± 0.012	0.350 ± 0.010
tree-only fit	$\pm 0.166 \pm 0.025$	$\pm 0.374 \pm 0.025$
UUT fit	0.162 ± 0.017	0.341 ± 0.011
angle-only fit	0.156 ± 0.017	0.334 ± 0.012
Sides+ ε_K fit	0.166 ± 0.018	0.382 ± 0.020

The so-called ‘‘pull plots’’ in Fig. 4 are used to assess the agreement of a given measurement with the indirect determination from the fit using all the other inputs. The coloured areas represent the level of agreement between the predicted values and the measurements at better than 1, 2, . . . $n\sigma$. The markers have the coordinates $(x, y) = (\text{central value}, \text{error})$ of the direct measurements considered. These plots allow to visualise the tensions between each input and the rest of them as in the pull column of Table 1. It is clear that inputs like α and γ show perfect agreement with the rest

of the fit, while $\sin 2\beta$ and $|V_{xb}|$ present various degrees of tension either directly or with respect to the different exclusive or inclusive determinations.

However, overall, the global fit proves a remarkable internal consistency with a better than 7% precision in the determination of the fundamental CKM parameters $\bar{\rho}$ and $\bar{\eta}$.

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