Testing New Physics with Unitarity Triangle Fit

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We review here the status of the Unitarity Triangle beyond the Standard Model. Within the Standard Model (SM), all flavour and CP violating quark weak interactions are governed by the CKM matrix, which can be parameterized in terms of three angles and one phase, or, more conveniently, in terms of the parameters λ, A, $\bar{\rho}$ and $\bar{\eta}$. This implies very strong correlations among flavour and CP violating observables within the SM. The Unitarity Triangle (UT) is a very useful tool to analyze these correlations. With the recent data on B decays, the UT fit has become strongly overconstrained, thus it is now possible to test the CKM mechanism within the SM and to derive constraints on New Physics (NP). In this talk, we will review the latter aspect, while the first is contained in ref. [1]. More details on the procedure and on the results can be found in ref. [2]. We analyze the determination of the unitarity triangle and the model-independent constraints on new physics that can be derived from this analysis. We find stringent bounds on new contributions to $K - \bar{K}$ and $B_d - \bar{B}_d$ mixing, pointing either to models of minimal flavour violation or to models with new sources of flavour and CP violation in $b \to s$ transitions. We also discuss the status of the universal unitarity triangle in minimal flavour violation. Finally, we perform a combined fit of the Unitarity Triangle and of new physics contributions in Minimal Flavour Violation, reaching a sensitivity to a new physics scale of about 5 TeV. More details on these analyses and on the results can be found in ref. [3].

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1. Constraints on New Physics from the Unitarity Triangle

Thanks to the measurements of the UT angles recently performed at *B* factories, the UT fit is at present time overconstrained. Therefore, it has become possible to add NP contributions to all quantities entering the UT analysis and to perform a combined fit of both NP and SM parameters. In general, NP models introduce a large number of new parameters whose specific list and the actual values can only be determined within a given model. Nevertheless, each of the meson-antimeson mixing processes is described by a single amplitude and can be parameterized, without loss of generality, in terms of two parameters, which quantify the difference between the full amplitude and the SM one. Thus, in the case of $B_q^0 - \bar{B}_q^0$ mixing we define $C_{B_q} e^{2i\phi_{B_q}} = \langle B_q^0 | H_{\text{eff}}^{\text{full}} | \bar{B}_q^0 \rangle / \langle B_q^0 | H_{\text{eff}}^{\text{SM}} | \bar{B}_q^0 \rangle$ with $q = d, s$, and where $H_{\text{eff}}^{\text{SM}}$ includes only the SM box diagrams, while $H_{\text{eff}}^{\text{full}}$ includes also the NP contributions. In $K^0 - \bar{K}^0$ mixing, we find it convenient to introduce a single parameter relating the imaginary part of the amplitude to the SM one: $C_{\varepsilon_K} = \text{Im}[\langle K^0 | H_{\text{eff}}^{\text{full}} | \bar{K}^0 \rangle] / \text{Im}[\langle K^0 | H_{\text{eff}}^{\text{SM}} | \bar{K}^0 \rangle]$. Therefore, all NP effects in $\Delta F = 2$ transitions are parameterized in terms of three real quantities, C_{B_d}, ϕ_{B_d} and C_{ε_K}. NP in the B_s sector is not considered, due to the lack of experimental information.
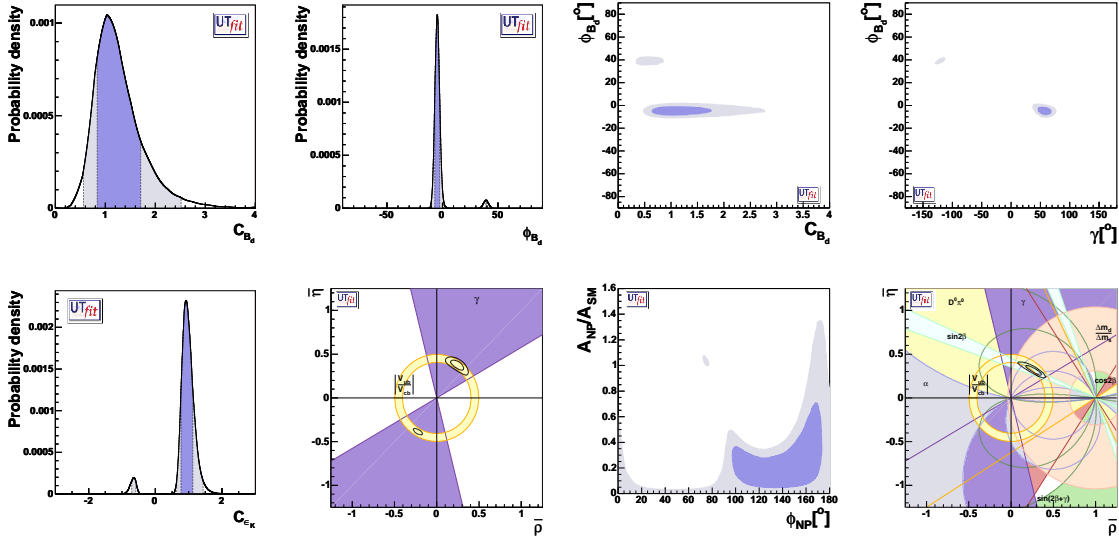
Figure 1: From top to bottom and from left to right, p.d.f.'s for C_{B_d}, ϕ_{B_d}, ϕ_{B_d} *vs.* C_{B_d}, ϕ_{B_d} *vs.* γ, C_{ε_K}, the resulting selected region on the $\bar{\rho} - \bar{\eta}$ plane obtained from the NP analysis, P.d.f. in the $(A_{\text{NP}}/A_{\text{SM}})$ vs. ϕ_{NP} plane for NP in the $|\Delta B| = 2$ sector, and the selected region on $\bar{\rho}$-$\bar{\eta}$ plane obtained from the determination of the UUT analysis [3].

We also include in the fit NP effects in $\Delta B = 1$ transitions that can also affect some of the measurements entering the UT analysis, in particular the measurements of α and A_{SL}[3]. The results obtained in a global fit for the NP parameters are shown in Fig. 1, together with the corresponding regions in the $\bar{\rho}$–$\bar{\eta}$ plane. Writing $C_{B_d} e^{2i\phi_{B_d}} = (A_{\text{SM}} e^{2i\beta} + A_{\text{NP}} e^{2i(\beta + \phi_{\text{NP}})})/(A_{\text{SM}} e^{2i\beta})$ and given the p.d.f. for C_{B_d} and ϕ_{B_d}, we can derive the p.d.f. in the $(A_{\text{NP}}/A_{\text{SM}})$ vs. ϕ_{NP} plane as seen in Fig. 1. We see that the NP contribution can be substantial if its phase is close to the SM phase, while for arbitrary phases its magnitude has to be much smaller than the SM one.[1] Assuming that the small

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[1]Notice that, with the latest data, the SM ($\phi_{B_d} = 0$) is disfavoured at 68% probability due to a slight disagreement

but non-vanishing value for ϕ_{B_d} we obtained is just due to a statistical fluctuation, the result of our analysis points either towards models with no new source of flavour and CP violation beyond the ones present in the SM (Minimal Flavour Violation, MFV [5, 6]), or towards models in which new sources of flavour and CP violation are only present in $b \to s$ transitions. In the rest of this talk we will concentrate on the former possibility.

2. Minimal Flavour Violation models

We now specialize to the case of MFV. Making the basic assumption that the only source of flavour and CP violation is in the Yukawa couplings[4], it can be shown that the phase of $|\Delta B| = 2$ amplitudes is unaffected by NP, and so is the ratio $\Delta m_s / \Delta m_d$. This allows the determination of the Universal Unitarity Triangle independent on NP effects in the context of MFV models: it is based on $|V_{ub}/V_{cb}|$, γ, $A_{CP}(B \to J/\Psi K^{(*)})$, β from $B \to D^0 h^0$, α, and $\Delta m_s / \Delta m_d$[6]. In the bottom-right plot in Fig. 1 we show the allowed region in the $\bar{\rho} - \bar{\eta}$ plane for the UUT analysis. The corresponding values and ranges are reported in Tab. 1.

	UUT analysis		Minimal Flavour Violation analysis			
			low/moderate $\tan\beta$		large $\tan\beta$	
	68%	95%	68%	95%	68%	95%
$\bar{\rho}$	0.259 ± 0.068	[0.107, 0.376]	0.216 ± 0.058	[0.109, 0.361]	0.231 ± 0.067	[0.112, 0.375]
$\bar{\eta}$	0.320 ± 0.042	[0.241, 0.399]	0.351 ± 0.032	[0.265, 0.406]	0.347 ± 0.036	[0.254, 0.404]
$\sin 2\beta$	0.728 ± 0.031	[0.668, 0.778]	0.733 ± 0.027	[0.679, 0.781]	0.731 ± 0.027	[0.673, 0.781]
$\alpha[°]$	105 ± 11	[81, 124]	98.6 ± 9.5	[81.6, 121.7]	101 ± 11	[82, 124]
$\gamma[°]$	51 ± 10	[33, 75]	57.6 ± 9.1	[35.7, 79.1]	55 ± 11	[34, 74]
$(2\beta + \gamma)[°]$	98 ± 12	[77, 123]	104 ± 10	[80, 122]	102 ± 12	[77, 121]
$\Delta m_s\,[ps^{-1}]$	20.6 ± 5.6	[10.6, 32.6]	19.5 ± 2.6	[15.0, 31.7]	22.6 ± 5.4	[15.5, 35.1]

Table 1: Results for UT parameters from both the UUT and the MFV generalized analyses [3].

If we now consider MFV models with one Higgs doublet or low/moderate $\tan\beta$, all NP effects in $|\Delta F| = 2$ transitions are due to the effective Hamiltonian[2] $(a/2\Lambda^2)(\bar{Q}_L \lambda_{FC} \gamma_\mu Q_L)^2$ with $(\lambda_{FC})_{ij} = Y_t^2 V_{ti}^* V_{tj}$ for $i \neq j$ and zero otherwise, Y_t the top quark Yukawa coupling, Λ the scale of NP and a an unknown (but real) Wilson coefficient. The value of a can range from order one for strongly interacting extensions of the SM to much smaller values for weakly interacting theories and/or symmetry suppressions analogous to the GIM mechanism in the SM. To project this onto the SM $|\Delta F| = 2$ effective Hamiltonian, only a modification of the top quark contribution to box diagrams has to be applied. Normalizing the NP Wilson coefficient to the SM effective electroweak scale $\Lambda_0 = Y_t \sin^2 \theta_W M_W / \alpha \approx 2.4$ TeV, we obtain $S_0(x_t) \to S_0(x_t) + \delta S_0$ and $\delta S_0 = 4a(\Lambda_0/\Lambda)^2$. We can therefore determine simultaneously the shape of the UT and δS_0 from the standard UT analysis. Then, choosing as reference values $a = \pm 1$, we can translate the constraints on δS_0 into a lower bound on Λ. At 95% probability we obtain (see Fig. 2): $\Lambda > 3.6(5.1)$ TeV for $\delta S_0 > 0$ ($\delta S_0 < 0$).

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between $\sin 2\beta$ and $|V_{ub}/V_{cb}|$. This requires $A_{NP} \neq 0$ and $\phi_{NP} \neq 0$. For the same reason, $\phi_{NP} > 90°$ at 68% probability and the plot is not symmetric around $\phi_{NP} = 90°$.

[2]Here and in the rest of this section we follow the notation of Ref. [4].

Also in this case, we can obtain predictions for UT parameters, together with a constraint on NP contributions (see Tab. 1).

In the case of large $\tan\beta$, the situation changes since the bottom Yukawa coupling is not negligible anymore, and it can distinguish transitions involving b quarks from those involving only light quarks. This spoils the correlation of $|\Delta B| = 2$ with $|\Delta S| = 2$ amplitudes, so that two uncorrelated parameters δS_0^B and δS_0^K are required in this case, to take into account NP contributions to $B_{d,s}$–$\bar{B}_{d,s}$ and K–$\bar{K}$ mixing. In a global fit, made by using all the available inputs, Δm_d and $\Delta m_d/\Delta m_s$ determine the value of δS_0^B, ε_K fixes δS_0^K, while $\bar{\rho}$ and $\bar{\eta}$ are given by the combination of all the other constraints.

Performing this analysis, we bound the UT parameters as given in Tab. 1 and we limit the NP scale to be, from $B_{d,s} - \bar{B}_{d,s}$ mixing $\Lambda > 2.6(4.9)$ TeV for $\delta S_0^B > 0$ ($\delta S_0^B < 0$) at 95% probability, and from $K - \bar{K}$ mixing $\Lambda > 3.2(4.9)$ TeV for $\delta S_0^K > 0$ ($\delta S_0^K < 0$) at 95% probability. The output distributions for δS_0^B and δS_0^K are given in Fig. 2.
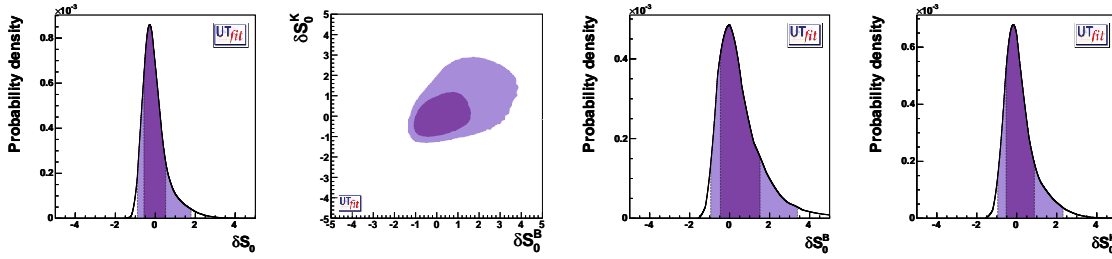

Figure 2: From left to right: P.d.f. of δS_0, δS_0^K vs δS_0^B, δS_0^B and δS_0^K. See the text for details.

It is instructive to observe the two-dimensional plot of δS_0^B vs. δS_0^K in Fig. 2: within models with only one Higgs doublet or with small $\tan\beta$, the two δ's are bound to lie on the line $\delta S_0^B = \delta S_0^K$. The correlation coefficient R provides a measure of this relation. We find $R = 0.52$ giving no compelling indication on the value of $\tan\beta$.

References

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