B Physics: CP Violation beyond the SM

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We analyse the present experimental evidence for a complex CKM matrix, even allowing for New Physics contributions to ϵ_K, $a_{J/\Psi K_S}$, ΔM_{B_d}, ΔM_{B_s}, and the $\Delta I = 1/2$ piece of $B \to \rho\rho$ and $B \to \rho\pi$. We emphasize the crucial rôle played by the angle γ in both providing irrefutable evidence for a 3×3 complex CKM matrix and placing constraints on the size of NP contributions. It is shown that even if one allows for New Physics a real CKM matrix is excluded at a 99.92% C.L., and the probability for the phase γ to be in the interval $[-170°; -10°] \cup [10°; 170°]$ is 99.7%. Large value of the phase χ, e.g. of order λ, is only possible in models where the unitarity of the 3×3 Cabibbo-Kobayashi-Maskawa matrix is violated through the introduction of extra $Q = 2/3$ quarks. We study the allowed range for χ and the effect of a large χ on various low-energy observables, such as CP asymmetries in B meson decays. We also discuss the correlated effects which would be observable at high energy colliders, like decays $t \to cZ$, etc..

1. INTRODUCTION

As is well-known Unitarity Triangle fits indicate the prominent role of the Cabbibo-Kobayashi-Maskawa (CKM) mechanism[1] in CP violation and Flavour Physics. The huge amount and the variety of CP collected data allows for a systematic search of Physics Beyond the Standard Model (SM)[2][3].

A quite general and natural framework to go beyond the SM is:

1. Allow for New Physics in every place except in weak tree-level dominated processes.

2. Assume 3×3 unitarity.

This framework is general enough to include practically all models of New Physics (NP) except those that explicitly violate 3×3 unitarity. Going

beyond 3×3 unitarity makes the analysis almost impossible in a model independent way[4]. We will proceed in the first part with assumptions 1 and 2.

To go on with this analysis it is very important to understand the key role played by a measurement of the unitarity triangle phase γ. It is very convenient to write the CKM matrix in the following way[5][6]:

$$\begin{pmatrix} |V_{ud}| & |V_{us}|\, e^{i\chi'} & |V_{ub}|\, e^{-i\gamma} & ... \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| & ... \\ |V_{td}|\, e^{-i\beta} & |V_{ts}|\, e^{i\chi} & |V_{tb}| & ... \\ ... & ... & ... & ... \end{pmatrix} \tag{1}$$

Where the rephasing invariant CP violating phases are[7]

$$\begin{array}{lll} \beta = \arg\left(-V_{cd}V_{cb}^{*}V_{td}^{*}V_{tb}\right) & , & \gamma = \arg\left(-V_{ud}V_{ub}^{*}V_{cd}^{*}V_{cb}\right) \\ \chi = \arg\left(-V_{ts}V_{tb}^{*}V_{cs}^{*}V_{cb}\right) & , & \chi' = \arg\left(-V_{cd}V_{cs}^{*}V_{ud}^{*}V_{us}\right) \end{array} \tag{2}$$

It has been shown from 3×3 unitarity -$\lambda \sim 0.2$- that $\chi' \sim \lambda^4$ and $\chi \sim \lambda^2$ even outside the SM[8]. So χ' is too small to consider its measurement. β and χ, accompanying $|V_{td}|$ and $|V_{ts}|$ respectively, will enter only in loop processes: virtual transitions $q \to t$. Therefore processes that in the SM measure β and χ could be contaminated by NP. *Processes that measure β in the SM framework will be no longer evidence of CP violation in the CKM matrix in the presence of NP.* The unique measurable phase that can be extracted from tree-level processes and therefore not contaminated by NP is γ, because it can appear in a tree-level transition $b \to u$ [2].

We can conclude that just γ and the moduli of the first two rows are the unique parameters whose extraction from experimental data is not contaminated by NP. Or put in another way, these parameters -extracted from weak tree-level decays- are valid in all the models included in our assumptions 1 and 2.

In section II we will parametrize and clarify the NP physics contributions to the contaminated flavour and CP observables. Having seven experimental data of the CKM matrix in these general class of models, in section III we will address the question of the dominance of the CKM mechanism as the origin of CP violation in these models. At the same time, with the contaminated observables, we will set bounds on the NP contributions. Finally in section IV we will study potential large deviations of χ from its SM value in models that violates 3×3 unitarity.

2. NP CONTRIBUTIONS IN α, β AND γ MEASUREMENTS

As we have explained the measurements of β will be contaminated by NP. Also it is known that β measurements come always from the β con-

tribution to $B_d^0 - \overline{B}_d^0$ mixing. The simple reason why β contributions to B decay amplitudes cannot be measured - in a clean theoretical way- is because it always enter in the SM with a second weak phase. Therefore it is enough to parametrize the NP contributions to the $B_d^0 - \overline{B}_d^0$ mixing. We follow reference [9] to write the off diagonal mixing matrix as

$$M_{12}^{(d)} = \left(M_{12}^{(d)}\right)^{SM} r_d^2 e^{-i2\phi_d} \tag{3}$$

the SM corresponds to $r_d = 1$ and $2\phi_d = 0$. In this way we get

$$\left(\frac{q}{p}\right)_{B_d} = \left(\frac{q}{p}\right)_{B_d}^{SM} e^{2i\phi_d} = e^{-2i(\beta-\phi_d)} \tag{4}$$

and therefore, by defining

$$\overline{\beta} = \beta - \phi_d \tag{5}$$

we have for the experimental observables

$$\Delta M_{B_d} = \left(\Delta M_{B_d}\right)^{SM} r_d^2 \tag{6}$$

$$S_{J/\psi K_S} = \sin 2\left(\beta - \phi_d\right) = \sin 2\overline{\beta} \tag{7}$$

Clearly an independent knowledge of the full CKM matrix together with the $B_d^0 \to J/\psi K_S$ asymmetry $S_{J/\psi K_S}$ and the mass difference ΔM_{B_d} will give us the opportunity to test for the NP parameters r_d and ϕ_d.

As we will see in the next section, the actual knowledge of the moduli of the CKM matrix in the first two rows is not enough to know the entire CKM matrix, so the measurement of gamma is of paramount importance in order to complete the knowledge of the CKM matrix and to proceed with the NP analysis. Gamma can be obtained from the phase of the rephasing invariant quartet $V_{us}V_{cb}V_{ub}^*V_{cs}^*$ [6]. A way of measuring it from pure tree-level decays is trough the interference of the two pure charged currents decay paths $b \to s\overline{u}c$ and $b \to s\overline{c}u$ [10][11]. Babar[12] and Belle[13] have presented results using the Dalitz plot analysis in $B^{\pm} \to DK^{\pm}$ with the subsequent decay $D^0, \overline{D}^0 \to K_S\pi^+\pi^-$. If any potential NP in $D^0 - \overline{D}^0$ mixing is neglected[14], as seems reasonable, these analysis provide a measurement of gamma free from NP contributions.

Other relevant ways of measuring γ are the methods to measure $\alpha = \arg\left(-V_{td}V_{tb}^*V_{ud}^*V_{ub}\right)$ [15]. By now it is well-known that using eq.(2) one has $\alpha = \pi - \beta - \gamma$ by definition[16][17]. So a measurement of α is nothing else than a measurement of $\beta + \gamma$. The main channels are $B \to \pi\pi, \rho\pi$ and $\rho\rho$. In this case, the presence of penguin pollution could become NP

pollution, so one has to be much more careful in these processes. The relevant observables are

$$\lambda_f = \left(\frac{q}{p}\right)_{B_d} \frac{A(\overline{B}_d^0 \to f)}{A(B_d^0 \to f)} \tag{8}$$

To understand the effects of NP let us first neglect the SM penguin pollution and treat the $\pi\pi$ channel as if it were a pure tree level and therefore without NP pollution in the decay amplitudes. In these case we have in the $\pi^+\pi^-$ channel

$$\lambda_{+-} = e^{-i2\overline{\beta}} e^{-i2\gamma} = e^{i2\overline{\alpha}} \tag{9}$$

where $\overline{\alpha} \equiv \pi - \overline{\beta} - \gamma = \alpha + \phi_d$. The CP asymmetry measures $\overline{\alpha}$. Once we include penguin pollution, the Gronau and London isospin analysis can be partially summarized with the following formula[16][18]

$$\lambda_{+0} \equiv \left(\frac{q}{p}\right)_{B_d} \frac{A(B^- \to \pi^-\pi^0)}{A(B^+ \to \pi^+\pi^0)} = \frac{1}{\lambda_{+-}^*} \frac{\overline{R} \pm i\sqrt{\overline{\rho}^2 - \overline{R}^2}}{R \pm i\sqrt{\rho^2 - R^2}} \tag{10}$$

where

$$\overset{(-)}{R} = \frac{|\overset{(-)}{A}_{+0}|^2 + \frac{1}{2}|\overset{(-)}{A}_{+-}|^2 - |\overset{(-)}{A}_{00}|^2}{\sqrt{2}} \tag{11}$$

$$\overset{(-)}{\rho} = |\overset{(-)}{A}_{+0}||\overset{(-)}{A}_{+-}| \tag{12}$$

that tell us that λ_{+0} can be extracted from the experimental data including branching ratios and λ_{+-}. But A_{+0} in the SM and therefore in our NP scenario is a pure tree-level amplitude with weak phase gamma - is proportional to the $\Delta I = 3/2$ piece-, so we will have that the observable λ_{+0} will be

$$\lambda_{+0} = e^{-i2\overline{\beta}} e^{-i2\gamma} = e^{-2i\overline{\alpha}} \tag{13}$$

We conclude that the usual way of measuring α in $\pi\pi$ decays provides us with a measurement of $\overline{\alpha} = \pi - \overline{\beta} - \gamma$ even in the presence of NP in the $\Delta I = 1/2$ piece[19]. Obviously the knowledge of $\overline{\beta}$ from $J/\psi K_S$ converts these α methods in another way of extracting γ from tree-level pieces. Similar results are obtained for $\rho\pi$ and $\rho\rho$.

3. IS THE CKM MATRIX COMPLEX IN THE PRESENCE OF NP?

Within this class of models, in order to investigate whether the present experimental data already implies that CKM is complex, one has to check

whether any of the unitarity triangles is constrained by data to be non-"flat", i.e. to have a non-vanishing area. If any one of the triangles does not collapse to a line, no other triangle will collapse, due to the remarkable property that all the unitarity triangles have the same area. This property simply follows from unitarity of the 3×3 CKM matrix. The universal area of the unitarity triangles gives a measurement of the strength of CP violation mediated by a W-interaction and can be obtained from four independent moduli of V_{CKM}. The fact that one can infer about CP violation from the knowledge of CP-conserving quantities should not come as a surprise[20] . It just reflects the fact that the strength of CP violation is given by the imaginary part of a rephasing invariant quartet[21] , $J = \pm \mathrm{Im}\left(V_{i\alpha} V_{j\beta} V^*_{i\beta} V^*_{j\alpha}\right)$, with $(i \neq j, \alpha \neq \beta)$, which in turn can be expressed in terms of moduli, thanks to 3×3 unitarity. Restricting ourselves to the first two rows of V_{CKM}, to avoid any contamination from NP, a possible choice of independent moduli would be $|V_{us}|$, $|V_{cb}|$, $|V_{ub}|$ and $|V_{cd}|$. One can then use unitarity of the first two rows to evaluate J, which is given, in terms of the input moduli[2], by

$$\begin{aligned} 4J^2 \;=\; & 4\left(1 - |V_{ub}|^2 - |V_{us}|^2\right)|V_{ub}|^2\,|V_{cd}|^2\,|V_{cb}|^2 - \\ & - \left(|V_{us}|^2 - |V_{cd}|^2 + |V_{cd}|^2\,|V_{ub}|^2 - |V_{cb}|^2\,|V_{ub}|^2 - |V_{cb}|^2\,|V_{us}|^2\right)^2 \end{aligned} \quad (14)$$

Note that Eq. (14) is exact, but the actual extraction of J from the chosen input moduli, although possible in principle, it is not feasible in "practice".

To illustrate this point, let us consider the present experimental values of $|V_{us}|\,, |V_{cb}|\,, |V_{ub}|$ and $|V_{cd}|$, assuming Gaussian probability density distributions around the central values. We plot in Fig.(1) the probability density distribution of J^2, generated using a toy Monte Carlo calculation. Only 31.1% of the generated points satisfy the trivial normalization constraints and, among those, only 7.9% satisfy the condition that the unitarity triangles close $\left(J^2 > 0\right)$.

As we have mentioned, including the experimental data $S_{J/\psi K_S}$ and ΔM_{B_d} still does not give evidence of a complex V_{CKM} . We cannot conclude if V_{CKM} is the dominant contribution to CP violation, although we can set bounds on the NP parameters r_d and ϕ_d. In Fig.(2(a)) we plot 68% (black), 90% (dark grey) and 95% (grey) probability regions of the probability density function (PDF) of the apex $-V_{ud}V^*_{ub}/V_{cd}V^*_{cb}$ of the db unitarity triangle. In Fig.(2(b)) we represent joint PDF regions in the plane $(r_d^2,\, 2\phi_d)$. Because γ gives the apex of the triangle, it is clear from Fig.(2(a)) that there is essentially no restriction on γ. On the contrary, because the moduli of the first two rows put an upper bound on $|\beta|$ and upper and lower bounds on $R_t = |V_{td}V^*_{tb}|\,/\,|V_{cd}V^*_{cb}|$, we can see in Fig.(2(b)) significant constraints on $2\phi_d$ and r_d^2.

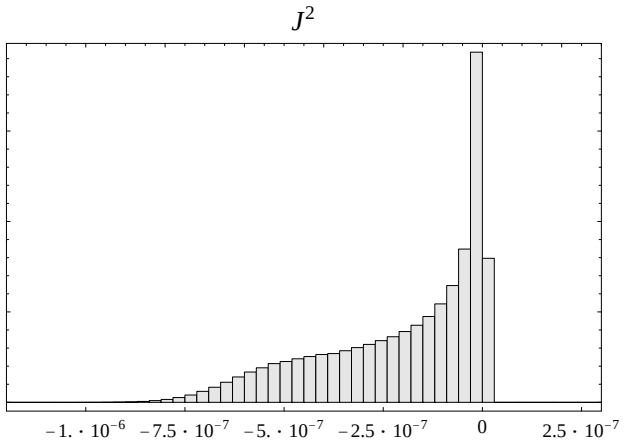
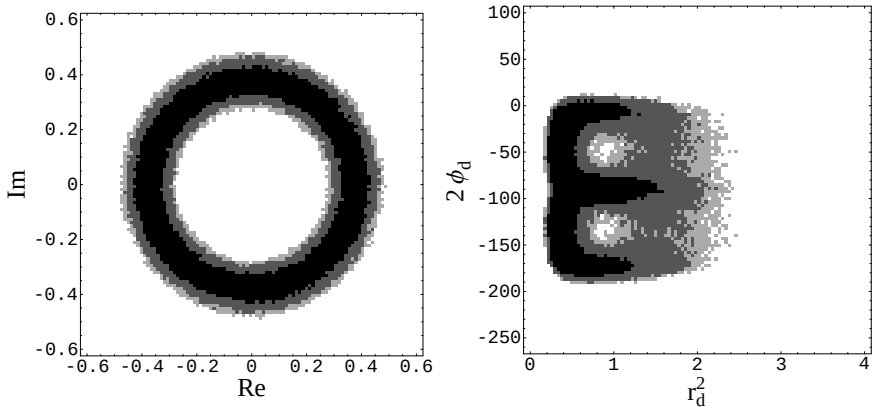


Fig. 1. J^2 distribution from $|V_{us}| = 0.2200 \pm 0.0026$, $|V_{ub}| = (3.67 \pm 0.47) \times 10^{-3}$, $|V_{cb}| = (4.13 \pm 0.15) \times 10^{-2}$ and $|V_{cd}| = 0.224 \pm 0.012$.



(a) Apex of the unitarity triangle *bd*.

(b) $\left(r_d^2, 2\phi_d\right)$ joint distribution.

Fig. 2. Probability distributions, no restriction on γ.

Including the measurement of gamma in Fig.(2(a)) will fix the unitarity triangle and the V_{CKM} matrix. The enormous effort developed at the B-factories Belle and BaBar has resulted in the first measurements of γ in tree-level decays $B^{\pm} \to DK^{\pm}$, $B^{\pm} \to D^*K^{\pm} \to \left(D\pi^0\right) K^{\pm}$, where the two paths

to D^0 or $\bar{D}^0$ interfere in the common decay channel $\bar{D}^0, D^0 \to K_S\pi^+\pi^-$. From a Dalitz-plot analysis , Belle [13] has presented $\gamma = 68^\circ \pm {}^{14^\circ}_{15^\circ} \pm 13^\circ \pm 11^\circ$ and BaBar [12] $\gamma = 70^\circ \pm 26^\circ \pm 10^\circ \pm 10^\circ$, together with the solutions obtained by changing $\gamma \to \gamma \pm \pi$.

We average conservatively both measurements to the value $\gamma = 69^\circ \pm 21^\circ$ $(-111^\circ \pm 21^\circ)$, which we take as a quantitative measurement of a complex CKM matrix *independent of the presence of NP at the one-loop weak level*.

BaBar has also presented a time-dependent analysis of the $\rho^+\rho^-$ channel [22], that once supplemented with the $\rho^+\rho^0$ and $\rho^0\rho^0$ branching ratios [23, 24] and the measurement of the final polarization, can be translated [25] into the measured value $\overline{\alpha} = 96^\circ \pm 10^\circ \pm 5^\circ \pm 11^\circ$ where the last error comes from the usual $SU(2)$ isospin bounds[1] $|\overline{\alpha}_{eff} - \overline{\alpha}| \leq 11^\circ$. Because the measurement is sensitive to $\sin(2\overline{\alpha}_{eff})$, $\overline{\alpha} = \overline{\alpha}_{eff} \pm 11^\circ$ presents a fourfold ambiguity $\left(\overline{\alpha}, \overline{\alpha} + \pi, \frac{\pi}{2} - \overline{\alpha}, -\overline{\alpha} - \frac{\pi}{2}\right)$. In the $\rho\pi$ channel the pentagon isospin analysis – from quasi-two-body decays – needs more statistics and/or additional assumptions. A time-dependent Dalitz-plot analysis in the channel $B \to \pi^+\pi^-\pi^0$ has been presented by BaBar [26], with the result $\overline{\alpha} = 113^\circ \pm {}^{27^\circ}_{17^\circ} \pm 6^\circ$.Since this analysis is sensitive to both $\sin(2\overline{\alpha}_{eff})$ and $\cos(2\overline{\alpha}_{eff})$, the resulting ambiguity is just a twofold one $(\overline{\alpha}, \overline{\alpha} + \pi)$. It is remarkable that these two solutions are in good agreement with two of the solutions coming from the $\rho\rho$ channel. This important property will be used to eliminate two of the four solutions coming from the $\rho\rho$ channel.

The situation in the $\pi\pi$ channel does not yet allow a full isospin analysis and the isospin bounds are quite poor. Furthermore BaBar and Belle measurements are still in some conflict, so that we will not use these results.

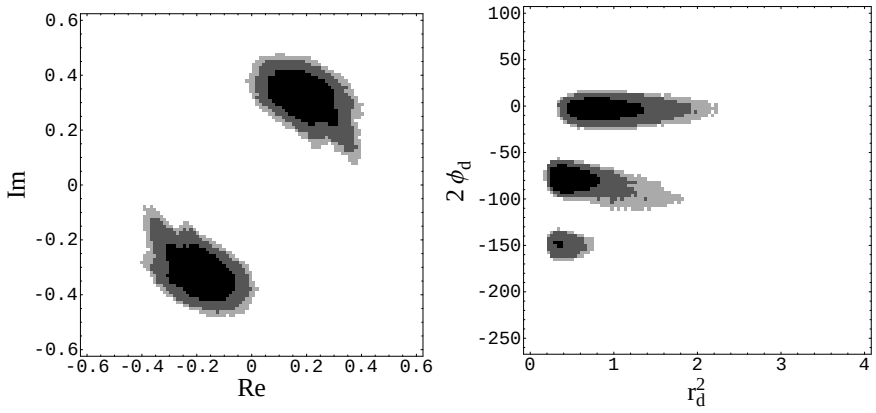
As before, we average the data from $\rho\rho$ and $\rho\pi$ but only keep the two solutions consistent with the $\rho\pi$ channel data. Our averaged values are $\overline{\alpha} = 100^\circ \pm 16^\circ$, $(-80^\circ \pm 16^\circ)$.

To analyze the implications for the dominance of the CKM mechanism for CP violation and the presence of NP, we add both measurements γ and $\overline{\alpha}$ to the previous analysis presented in Figs.(2(a)) and (2(b)).

In Fig.(3(a)) we represent the analogue of Fig.(2(a)). We conclude [2] that a real CKM matrix is excluded at a 99.92% C.L. and the probability of $\gamma \in [10^\circ; 170^\circ] \cup [-170^\circ; -10^\circ]$ is 99.7%.

In Fig(3(b)) we can see three solutions in the $\left(r_d^2, 2\phi_d\right)$ plane with $2\phi_d \sim 0^o, -75^o$ and -150^o. In these plots one has in general four solutions corresponding to the two values of γ $(\overline{\alpha})$ and to the two signs of $\cos\left(2\overline{\beta}\right)$ The last solution corresponds to $\cos\left(2\overline{\beta}\right) < 0$. It is the inclusion of both γ and $\overline{\alpha}$ constraints that almost eliminates the $\cos\left(2\overline{\beta}\right) < 0$ solutions. The

[1] In our notation $\overline{\alpha}_{eff}$ is the usual α_{eff} but where we have introduced $\overline{\beta}$ instead of β as the phase in the B_d^0–$\bar{B}_d^0$ mixing.



(a) Apex of the unitarity triangle *bd*.

(b) $\left(r_d^2, 2\phi_d\right)$ joint distribution.

Fig. 3. Probability distributions including γ and $\overline{\alpha}$ experimental data.

first solution is obviously the SM one, and the semileptonic asymmetry A_{SL} - not included here - is starting to play an important role[27] in the exclusion of the solution $2\phi_d \sim -75^o$.

It is important to stress that having an irrefutable piece of evidence for a complex CKM matrix, in a framework where the presence of NP is allowed, has profound implications for models of CP violation. In the particular case of models with spontaneous CP violation, a complex CKM matrix favours the class of models where, although Yukawa couplings are real, the vacuum phase responsible for spontaneous CP violation also generates CP violation in charged-current weak interactions. Conversely, the evidence for a complex CKM matrix, even allowing for the presence of NP, excludes the class of models with spontaneous CP violation and a real CKM matrix at a 99.92% C.L..

4. THE SIZE OF $\chi = \arg\left(-V_{ts}V_{tb}^*V_{cs}^*V_{cb}\right)$ AND DEVIATION FROM 3×3 UNITARITY

Within the SM and any extension where $V_{3\times3}$ is unitary, like supersymmetric or multi Higgs doublet models, we have the relation[7]

$$\sin\chi = \frac{|V_{ub}||V_{us}|}{|V_{cb}||V_{cs}|}\sin(\gamma + \chi' - \chi) \tag{15}$$

which shows that $|\chi| \lesssim \lambda^2$ in any model where 3×3 CKM unitarity holds. In particular, within the SM one obtains at 90% CL

$$0.015 \leq \chi \leq 0.022 \quad \text{(SM)} \tag{16}$$

The only models in which χ can be significantly larger than λ^2 are those in which $V_{3\times3}$ is not unitary, what can only be achieved by enlarging the quark sector. The most simple way of doing this is with the introduction of new quark singlets [28][2] .Quark singlets often arise in grand unified theories and models with extra dimensions at the electroweak scale [29]. They have both their left- and right-handed components transforming as singlets under $SU(2)_L$, thus their addition to the SM particle content does not spoil the cancellation of triangle anomalies. In these models, the charged and neutral current terms of the Lagrangian in the mass eigenstate basis are

$$\mathcal{L}_W = -\frac{g}{\sqrt{2}}\,\bar{u}_L\gamma^\mu V d_L\,W^+_\mu + \text{h.c.} \tag{17}$$

$$\mathcal{L}_Z = -\frac{g}{2c_W}\left(\bar{u}_L\gamma^\mu X u_L - \bar{d}_L\gamma^\mu U d_L - 2s^2_W J^\mu_{em}\right) Z_\mu \tag{18}$$

where $u = (u, c, t, T, \dots)$ and $d = (d, s, b, B, \dots)$, V denotes the extended CKM matrix and $X = VV^\dagger$, $U = V^\dagger V$ are hermitian matrices. X and U are not necessarily diagonal and thus flavour-changing neutral couplings (FCNC) exist at the tree level, although they are naturally suppressed by the ratio of the standard quark over the heavy singlet masses. Moreover, the diagonal Zqq couplings, which are given by the diagonal entries of X and U plus a charge-dependent term, are also modified. Within the SM $X_{uu} = X_{cc} = X_{tt} = 1$, $X_{qq'} = 0$ for $q \neq q'$, $U_{dd} = U_{ss} = U_{bb} = 1$ and $U_{qq'} = 0$ for $q \neq q'$. The addition of up-type $Q = 2/3$ singlets modifies the first two of these equalities, while the addition of down-type $Q = -1/3$ ones modifies the last two.

In models with a down quark singlet, from orthogonality of the second and third columns of V, one obtains the generalization of Eq.(15)

$$\sin\chi = \frac{|V_{ub}||V_{us}|}{|V_{cb}||V_{cs}|}\sin(\gamma + \chi' - \chi) - \frac{\text{Im}\left(U_{bs}e^{-i\chi}\right)}{|V_{cb}||V_{cs}|} \tag{19}$$

From the present bound on $b \to s\ell^+\ell^-$, one obtains[30][31] that at most $|U_{bs}| \simeq 10^{-3} \sim \lambda^4$, thus implying that in this class of models χ cannot be significantly larger than λ^2.

[2] The addition of a sequential fourth generation is another possibility, but it is disfavoured by two facts: (i) the experimental value of the oblique correction parameters only leave a small range for the masses of the new quarks; (ii) anomaly cancellation requires the introduction of a new lepton doublet, in which the new neutrino should be very heavy, in contrast with the small masses of the presently known neutrinos.

In model with an up quark singlet, from orthogonality of the second and third rows of V, one gets[8]

$$\sin\chi = \frac{\text{Im } X_{ct}}{|V_{cs}||V_{ts}|} + O(\lambda^2) \tag{20}$$

In contrast with models containing down-type singlets, where the size of all FCNC is very restricted by experiment, present limits on X_{ct} are rather weak. The most stringent one, $|X_{ct}| \leq 0.41$ with a 95% CL, is derived from the non-observation of single top production at LEP, in the process $e^+e^- \to t\bar{c}$ and its charge conjugate. This bound does not presently provide an additional restriction on the size of χ. In models with extra up singlets $|X_{ct}|$ can be of order λ^3, yielding $\chi \sim \lambda$. From Eq.(20), one derives some important phenomenological consequences. First, we observe that a sizeable χ is associated to a FCNC $X_{ct} \sim 10^{-2}$, which *leads to FCNC decays* $t \to cZ$ *at rates observable at LHC*. In addition, the modulus of X_{ct} obeys the equality [32]

$$|X_{ct}|^2 = (1 - X_{cc})(1 - X_{tt}) \tag{21}$$

This relation shows that conditions for achieving $X_{ct} \sim 10^{-2}$ are to have a small deviation $O(\lambda^4)$ of X_{cc} from unity (which is allowed by the measurement of R_c and $A_{FB}^{0,c}$ [31]) and a deviation of $X_{tt} \sim |V_{tb}|^2$ from unity of order λ^2. This deviation is only possible if the mass of new top quark T is bellow 1 TeV, again testable at LHC. Finally the $D^0 - \overline{D}^0$ mass difference sets bounds on X_{uc} that for large χ - $(1 - X_{cc}) \sim O(\lambda^4)$ - translate into bounds on $(1 - X_{uu})$ in such a way that deviations of unitarity in the first row are not observable. By the same token, large values of χ will be correlated with an important contribution to $D^0 - \overline{D}^0$ mixing [8].

The shaded area in Fig.(4) represents the allowed interval of χ for a given X_{tt}. Note that lower values of X_{tt} are allowed for lighter T quarks[31]. The Fig.(4) has been obtained incorporating all the relevant constraints: the correction to the oblique parameter ΔT, R_c and $A_{FB}^{(0,c)}$ in the charm sector, $D^0 - \overline{D}^0$ mixing and several bounds from rare K and B decays.

Because χ is the phase of V_{ts}, important effects will appear in $b \to s$ transition in the piece $V_{ts}V_{tb}^*$, nevertheless the presence of the new T quark will introduce a contribution proportional to $V_{Ts}V_{Tb}^*$ and dependent on the mass m_T of this quark. For the CP asymmetry of $B_d^0 \to \phi K_S$ we get[8]

$$S_{\phi K_S} = \sin(2\bar{\beta} + 2\bar{\chi}) \tag{22}$$

where

$$\bar{\chi} = \chi - \frac{1}{2}\arg\left(\frac{1 + f(m_T, m_t)V_{Tb}V_{Ts}^*/V_{tb}V_{ts}^*}{1 + f(m_T, m_t)V_{Tb}^*V_{Ts}/V_{tb}^*V_{ts}}\right) \tag{23}$$

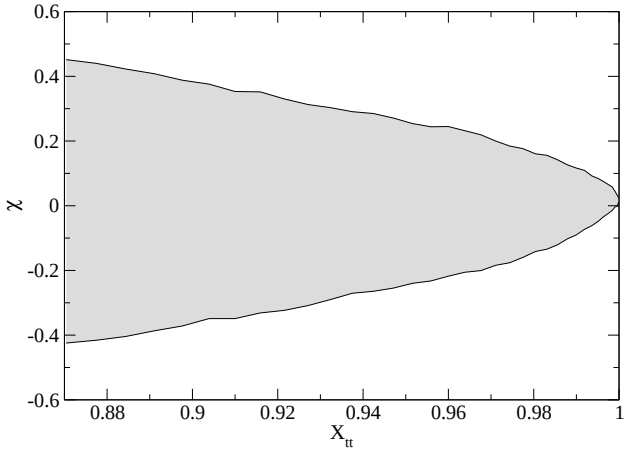


Fig. 4. Allowed interval of χ (shaded area) as function of X_{tt}

gets contributions from χ and the new T quark. $f(m_T, m_t)$ is in general a complex function fixed by Wilson coefficients and matrix elements[8]. By scanning all the allowed range of parameters we get $S_{\phi K_S} \in [0.57, 0.93]$.

Less dependent on hadronic matrix elements is the contribution to $B_s^0 - \overline{B}_s^0$ mixing:

$$M_{12}^{B_s} = K \sum_{i,j=t,T'} (V_{is}^* V_{ib})(V_{js}^* V_{jb}) S(m_i, m_j) = K S(m_t, m_t) |V_{ts}|^2 |V_{tb}|^2 r_s^2 e^{-2i\chi_{eff}} \tag{24}$$

$$\begin{aligned} r_s^2 e^{-2i\chi_{eff}} \;=\; & e^{-2i\chi} \left\{ \left[1 + \frac{S(m_t, m_T) V_{Ts}^* V_{Tb}}{S(m_t, m_t) V_{ts}^* V_{tb})} \right]^2 \right. \\ & \left. + \left[\frac{S(m_T, m_T)}{S(m_t, m_t)} - \left(\frac{S(m_t, m_T)}{S(m_t, m_t)} \right)^2 \right] \left(\frac{V_{Ts}^* V_{Tb}}{V_{ts}^* V_{tb}} \right)^2 \right\} \end{aligned} \tag{25}$$

with K a constant factor and S the usual Inami-Lim box function[33]. In any channel without a weak phase in the decay amplitude, for example in the $B_s^0 \to D_s^+ D_s^-$ and $\psi\,\phi$ channels, the time dependent CP asymmetry is

$$S_{D_s^+ D_s^-} = \sin 2\chi_{eff} \tag{26}$$

again χ_{eff} is equal to χ plus a T dependent contribution. The range of both contributions goes in opposite direction as m_T changes.

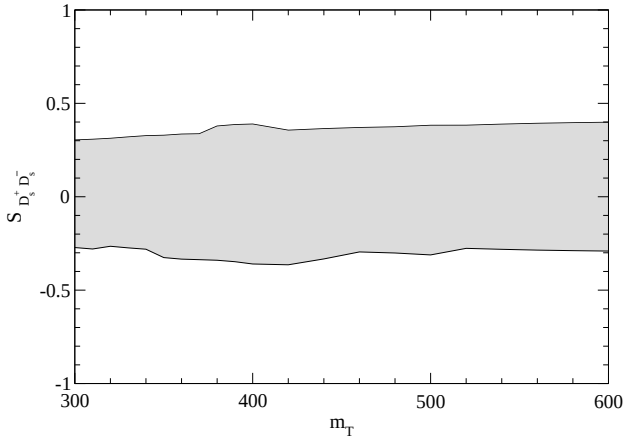


Fig. 5. Range of variation of the asymmetry $S_{D_s^+ D_s^-}$ in terms of m_T

In Fig.(5), we present the range of variation of $S_{D_s^+ D_s^-}$ in terms of m_T. A potential spectacular departure from the SM could be seen at LCH.

5. CONCLUSIONS

The first measurements of γ clearly points towards the CKM mechanism as the dominant source of CP violation in the quark sector, even in the presence of NP in all loops. A real CKM matrix is excluded at the 99.92% C.L. Including $\overline{\alpha}$ data, there are still alive three solutions: the most robust is the SM, one with $\cos\left(2\overline{\beta}\right) < 0$ is almost excluded and it remains another NP solution where the semileptonic asymmetry can do a relevant job. Future improvements of the data will be crucial to left just very small deviations of the SM.

A large deviation of the SM value of the phase χ is only possible in models that violates 3×3 unitarity. More precisely, in models with an up singlet quark, χ can be order λ. Moderates effects appear in $B_d^0 \to \phi K_S$, more spectacular effects can be present in CP asymmetries in the B_s^0 system. Correlated effects of this scenario would be: rare top decays $t \to cZ$ at a rate observable at LHC, production of a heavy top T at LHC and important deviations from 1 of $X_{tt} \sim |V_{tb}|^2$, measurable at ILC.

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REFERENCES

[1] N.Cabibbo, Phys. Rev. Lett. **10**, 531 (1963).
M. Kobayashi and T.Maskawa, Prog. Theor. Phys. **49**, 652 (1973).

[2] F.J. Botella, G.C. Branco, M. Nebot and M.N. Rebelo. Nucl.Phys.B725:155-172, hep-ph/0502133.

[3] UTfit, M.Bona *et al.*, hep-ph/0501199, `http://www.utfit.org` . CKMfitter Group, J. Charles *et al.*, hep-ph/0406184, `http://ckmfitter.in2p3.fr` . A. J. Buras, F. Parodi, and A. Stocchi, JHEP **01**, 029 (2003), hep-ph/0207101 .

[4] J. P. Silva and L. Wolfenstein, Phys. Rev. D **55** (1997) 5331

[5] R. Aleksan, B. Kayser and D. London, Phys. Rev. Lett. **73** (1994) 18

[6] G. C. Branco, L. Lavoura and J. P. Silva, *"CP violation,"*, (Oxford University Press, Oxford, 1999)

[7] F. J. Botella, G. C. Branco, M. Nebot and M. N. Rebelo, Nucl. Phys. B **651** (2003) 174 .

[8] J. A. Aguilar-Saavedra, F. J. Botella, G. C. Branco, and M. Nebot, Nucl. Phys. **B706**, 204 (2005), hep-ph/0406151 .

[9] G. C. Branco, F. Cagarrinho, and F. Kruger, Phys. Lett. **B459**, 224 (1999), hep-ph/9904379.

[10] M. Gronau and D. London, Phys. Lett. **B253**, 483 (1991). M. Gronau and D. Wyler, Phys. Lett. **B265**, 172 (1991). I. Dunietz, Phys. Lett. **B270**, 75 (1991). R. Aleksan, I. Dunietz, and B. Kayser, Z. Phys. **C54**, 653 (1992).D. Atwood, G. Eilam, M. Gronau, and A. Soni, Phys. Lett. **B341**, 372 (1995), hep-ph/9409229. D. Atwood, I. Dunietz, and A. Soni, Phys. Rev. Lett. **78**, 3257 (1997), hep-ph/9612433. A. Bondar and T. Gershon, Phys. Rev. **D70**, 091503 (2004), hep-ph/0409281.

[11] A. Giri, Y. Grossman, A. Soffer, and J. Zupan, Phys. Rev. **D68**, 054018 (2003), hep-ph/0303187.

[12] BaBar, B. Aubert *et al.*, hep-ex/0408088.

[13] Belle, K. Abe *et al.*, hep-ex/0411049.

[14] A. Amorim, M. G. Santos, and J. P. Silva, Phys. Rev. **D59**, 056001 (1999), hep-ph/9807364. C. C. Meca and J. P. Silva, Phys. Rev. Lett. **81**, 1377 (1998), hep-ph/9807320. J. P. Silva and A. Soffer, Phys. Rev. **D61**, 112001 (2000), hep-ph/9912242.

[15] M. Gronau and D. London, Phys. Rev. Lett. **65**, 3381 (1990). Y. Grossman and H. R. Quinn, Phys. Rev. **D58**, 017504 (1998), hep-ph/9712306. J. Charles, Phys. Rev. **D59**, 054007 (1999), hep-ph/9806468. M. Gronau, D. London, N. Sinha, and R. Sinha, Phys. Lett. **B514**, 315 (2001), hep-ph/0105308.

[16] J. P. Silva, hep-ph/0410351.

[17] G. Barenboim, F. J. Botella, G. C. Branco, and O. Vives, Phys. Lett. **B422**, 277 (1998), hep-ph/9709369.

[18] F.J. Botella and J. Silva, Phys. Rev. **D71**, 094008 (2005), hep-ph/0503136

[19] Seungwon Baek, F.J. Botella, David London, Joao P. Silva. Phys. Rev. D72:036004,2005. hep-ph/0506075 .

[20] F. J. Botella and L.-L. Chau, Phys. Lett. **B168**, 97 (1986). G. C. Branco and L. Lavoura, Phys. Lett. **B208**, 123 (1988).

[21] C. Jarlskog, Phys. Rev. Lett. **55**, 1039 (1985).

[22] BaBar, B. Aubert *et al.*, Phys. Rev. Lett. **93**, 231801 (2004), hep-ex/0404029.

[23] BaBar, B. Aubert *et al.*, Phys. Rev. Lett. **91**, 201802 (2003), hep-ex/0306030.

[24] Belle, J. Zhang *et al.*, Phys. Rev. Lett. **91**, 221801 (2003), hep-ex/0306007.

[25] BaBar, A. Bevan, hep-ex/0411090

[26] BaBar, B. Aubert *et al.*, hep-ex/0408099

[27] UTfit Collaboration (M. Bona et al.). hep-ph/0509219 .

[28] F. del Aguila and M. J. Bowick, Nucl. Phys. B **224**, 107 (1983); G. C. Branco and L. Lavoura, Nucl. Phys. B **278**, 738 (1986)

[29] P. Langacker and D. London, Phys. Rev. D **38**, 886 (1988); D. London, hep-ph/9303290; R. Barbieri and L. J. Hall, Nucl. Phys. B **319**, 1 (1989); Y. Nir and D. J. Silverman, Phys. Rev. D **42**, 1477 (1990); G. C. Branco, T. Morozumi, P. A. Parada and M. N. Rebelo, Phys. Rev. D **48** (1993) 1167; E. Nardi, E. Roulet and D. Tommasini, Nucl. Phys. B **386**, 239 (1992); V. D. Barger, M. S. Berger and R. J. Phillips, Phys. Rev. D **52**, 1663; (1995) F. del Aguila, J. A. Aguilar-Saavedra and G. C. Branco, Nucl. Phys. **B510**, 39 (1998); G. Barenboim and F. J. Botella, Phys. Lett. **B433**, 385 (1998); P. H. Frampton, P. Q. Hung and M. Sher, Phys. Rept. **330**, 263 (2000)

[30] G. Barenboim, F. J. Botella and O. Vives, Nucl. Phys. B **613** (2001) 285; D. Hawkins and D. Silverman, Phys. Rev. **D66**, 016008 (2002); T. Yanir, JHEP **0206**, 044 (2002);

[31] J. A. Aguilar-Saavedra, Phys. Rev. D **67** (2003) 035003 [Erratum-ibid. D **69** (2004) 099901]

[32] F. del Aguila, J. A. Aguilar-Saavedra and R. Miquel, Phys. Rev. Lett. **82**, 1628 (1999)

[33] T. Inami and C. S. Lim, Prog. Theor. Phys. **65** (1981) 297 [Erratum-ibid. **65** (1981) 1772]