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Flavour physics and CP violation / Physique de la saveur et violation de CP

Demise of CKM and its aftermath ☆

La fin de l'approche CKM . . . et ses séquelles

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Using firmly established experimental inputs such as ϵ_K, ΔM_d, ΔM_s, $\mathrm{Br}(B \to \tau\nu)$, γ, V_{cb} along with corresponding lattice matrix elements which have been well studied and are in full QCD such as B_K, SU(3) breaking ratio ξ, B_{B_s} and in particular without using V_{ub} or the pseudoscalar decay constants f_{B_d} or f_{B_s} from the lattice, we show that the CKM-paradigm now appears to be in serious conflict with the data. Specifically the SM predicted value of $\sin 2\beta$ seems too high compared to direct experimental measured value by over 3σ. Furthermore, our study shows that new physics predominantly effects B-mixings and $B_d \to \psi K_s$, and not primarily in kaon-mixing or in $B \to \tau\nu$. Model independent operator analysis suggests the scale of underlying new physics, accompanied by a BSM CP-odd phase, responsible for breaking of the SM is less than a few TeV, possibly as low as a few hundred GeV.

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R É S U M É

Sur la base de données expérimentales bien établies, comme ϵ_K, ΔM_d, ΔM_s, $\mathrm{Br}(B \to \tau\nu)$, γ, V_{cb} et d'éléments de matrice bien étudiés sur réseau, dans le cadre complet de QCD, comme B_K, la mesure ξ de la brisure de SU(3), ou B_{B_s}, nous montrons que le paradigme CKM semble en forte tension avec les données. (Nous n'utilisons à cette fin ni l'élement V_{ub} ni les constantes de désintégration f_{B_d} ou f_{B_s} tirés du réseau.) Plus spécifiquement, nous montrons que la valeur prédite par le Modèle Standard pour $\sin 2\beta$ semble plus élevée que la mesure expérimentale directe, et ce, de plus de 3σ. Notre étude montre de plus que des effets de « nouvelle physique » affectent principalement le mélange des mésons B, ainsi que la désintégration $B_d \to \psi K_s$, et pas directement le mélange des mésons K ou le processus $B \to \tau\nu$. Une analyse « indépendante des modèles », sur base d'opérateurs effectifs suggère que l'échelle pour cette « nouvelle physique », qui comprend une phase

☆ Note from the Invited Editors: This article is slightly more advanced than the basic, "well-established topics" approach of the main corpus of this issue. It also shows that, beyond the general concordance of flavour and CP physics with the minimal Cabibbo–Kobayashi–Maskawa scheme, hints for new physics may arise from discrepancies between precision measurements. These are difficult to interpret, notably due to the important role of strong interactions corrections, where input is sought from the latest lattice gauge theory simulations – hence the careful discussion and selection of channels by the authors. This contribution is thus a "frontier" one, and is included to show the current stage of research. This contribution also indicates how new experimental measurements (probably earlier than theoretical progress) will clarify the issue. The editors consider it important to include this contribution, which shows the very active (lively) nature of the field.

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brisant CP supplémentaire (au-delà du Modèle Standard) se situe en-dessous de quelques TeV, et pourrait même s'avérer de l'ordre de quelques centaines de GeV.

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1. Introduction

The next big step in our understanding of particle physics will be the uncovering of the electro-weak symmetry breaking (EWSB) mechanism. The present and upcoming collider experiments (Fermilab and LHC) will be able to test the Standard Model (SM) Higgs mechanism. New physics is widely expected at around the TeV scale if the Higgs mass is not to receive large radiative corrections and require severe fine-tuning. A stringent constraint on the SM mechanism of EWSB is the tight structure of flavor changing (FC) interactions: tree-level FC neutral currents are forbidden and charged currents are controlled by the Cabibbo–Kobayashi–Maskawa (CKM) [1] mixing matrix

$$V = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} \tag{1}$$

Within the SM, the CKM matrix is the only source of FC interactions and of CP violation. There is no reason, in general, to expect that new physics (needed to stabilize the Higgs mass) at the TeV scale will be in the basis wherein the quark mass matrix is diagonal. This reasoning gives rise to another fundamental problem in particle physics, namely the flavor puzzle, i.e. unless the scale of new physics is larger than 10^3 TeV it causes large FCNC especially for the K–$\overline{K}$ system. Thus flavor physics provides constraints on models of new physics up to scales that are much larger than what is accessible to direct searches at colliders such as the Tevatron or the LHC. Flavor physics is therefore expected to continue to provide crucial information for the interpretation of any physics that LHC may find.

In the past decade significant progress was made in our understanding of flavor physics, thanks in large part to the spectacular performance of the two asymmetric B-factories. For the first time it was experimentally established that the CKM-paradigm [1] of the Standard Model (SM) provides a quantitative description of the observed CP violation, simultaneously in the B-system as well as in the K-system with a single CP-odd phase, to an accuracy of about 20% [2]. While this success of the CKM picture is very impressive, the flip side is that an accuracy of $O(20\%)$ leaves open the possibility of quite sizable new physics contributions. In this context it is important to recall that the indirect CP violation parameter, $\varepsilon_K \sim 2\times 10^{-3}$ [3] is an asymmetry of $O(10^{-3})$ and an important reminder that if searches had been abandoned even at $O(1\%)$ the history of Particle Physics would have been completely different. Indeed, in the past few years as better data and better theoretical calculations became available some rather serious tensions have emerged [4–9].

Recently [10], we showed that the use of the latest experimental inputs along with a careful use of the latest lattice results leads to a rather strong case for a sizable contribution due to beyond the Standard Model sources of CP violation that in $\sin 2\beta$ could be around 15–25%. Clearly if this result stands further scrutiny it would have widespread and significant repercussions for experiments at the intensity as well as the high energy frontier. We also were able to isolate the presence of new physics primarily in the time dependent CP measurements via the "gold-plated" ψK_s mode which intimately involves B-mixing amplitude and the decay $B \to \psi K_s$. Our analysis does not exclude possible sub-dominant effect in kaon-mixing and/or in $B \to \tau\nu$. In particular, our analysis [10] indicates that the data does not seem to provide a consistent interpretation for the presence of large new physics contribution to the tree amplitude for $B \to \tau\nu$.

2. Some results of the fit

The complete set of lattice inputs that we use is presented in Table 1. All inputs, are taken from Refs. [11,12] (see http://www.latticeaverages.org for updates) with the exception of $\widehat{B}_K$ (see discussion above), ξ (since the statistical errors of the HPQCD and Fermilab/MILC results are 100% correlated, we decided to increase the statistical error of the HPQCD result to bring it in line with the with the more conservative Fermilab/MILC estimate), f_{B_d} (we update the HPQCD determination of f_{B_d} [13]) and $f_{B_s}\widehat{B}_s^{1/2}$ (we update the HPQCD determination of f_{B_s} [13] and combine it with the Fermilab/MILC result; we then combine the f_{B_s} average with the HPQCD determination of $\widehat{B}_s$ adding *linearly* the uncertainties).

Given the large disparity between the exclusive and inclusive determinations of V_{ub} at the level of 3.3σ, see Table 1, it is very difficult to draw reliable conclusions by using this quantity; therefore, since 2008 [5] we have been advocating not using V_{ub} for testing or constraining the UT. Consequently in this work also we will make very limited and peripheral use of V_{ub} only.

We first draw attention to the results of the fit shown in the left panel of Fig. 1. Here we use as inputs from experiments, ϵ_K, ΔM_d, ΔM_s, γ and BR($B \to \tau\nu$)[1] and from the lattice, $\widehat{B}_K$, ξ, $f_{B_s}\widehat{B}_s^1/2$ and $\widehat{B}_d$ (but not f_{B_d}) and we extract the fitted

[1] In contrast to γ, α is not used as an input since it receives appreciable contribution from penguin amplitudes which are sensitive to new physics.

Table 1
Lattice QCD and other inputs to the unitarity triangle analysis. The determination of α is obtained from a combined isospin analysis of $B \to (\pi\pi, \rho\rho, \rho\pi)$ branching ratios and CP asymmetries [15]. Statistical and systematic errors are combined in quadrature; for the error on V_{ub} [29]. We adopt the averages of Refs. [11,12] (updates at http://www.latticeaverages.org) for all quantities with the exception of ξ, $f_{B_s}\widehat{B}_s^{1/2}$, $\widehat{B}_K$ and f_{B_d} (see text).

$\vert V_{cb}\vert_{excl} = (39.5 \pm 1.0) \times 10^{-3}$	$\eta_1 = 1.51 \pm 0.24$ [14]
$\vert V_{cb}\vert_{incl} = (41.68 \pm 0.44 \pm 0.09 \pm 0.58) \times 10^{-3}$ [15]	$\eta_2 = 0.5765 \pm 0.0065$ [16]
$\vert V_{cb}\vert_{avg} = (40.9 \pm 1.0) \times 10^{-3}$	$\eta_3 = 0.494 \pm 0.046$ [17,18]
$\vert V_{ub}\vert_{excl} = (31.2 \pm 2.6) \times 10^{-4}$	$\eta_B = 0.551 \pm 0.007$ [19]
$\vert V_{ub}\vert_{incl} = (43.4 \pm 1.6^{+1.5}_{-2.2}) \times 10^{-4}$ [15]	$\xi = 1.23 \pm 0.04$
$\vert V_{ub}\vert_{tot} = (33.7 \pm 4.9) \times 10^{-4}$	$\lambda = 0.2253 \pm 0.0009$ [20]
$\Delta m_{B_d} = (0.507 \pm 0.005)\ \text{ps}^{-1}$	$\alpha = (89.5 \pm 4.3)^\circ$
$\Delta m_{B_s} = (17.77 \pm 0.12)\ \text{ps}^{-1}$	$\kappa_\varepsilon = 0.94 \pm 0.02$ [11,21,22]
$\varepsilon_K = (2.229 \pm 0.012) \times 10^{-3}$	$\widehat{B}_d = 1.26 \pm 0.11$
$m_{t,pole} = (172.4 \pm 1.2)$ GeV	$f_{B_d} = (208 \pm 8)$ MeV [13]
$m_c(m_c) = (1.268 \pm 0.009)$ GeV	$f_K = (155.8 \pm 1.7)$ MeV
$S_{\psi K_S} = 0.668 \pm 0.023$ [23]	$\widehat{B}_K = 0.742 \pm 0.023$
$f_{B_s}\sqrt{\widehat{B}_{B_s}} = (291 \pm 16)$ MeV	$\gamma = (78 \pm 12)^\circ$ [24,25]
$\text{BR}_{B\to\tau\nu} = (1.68 \pm 0.31) \times 10^{-4}$ [26–28]	

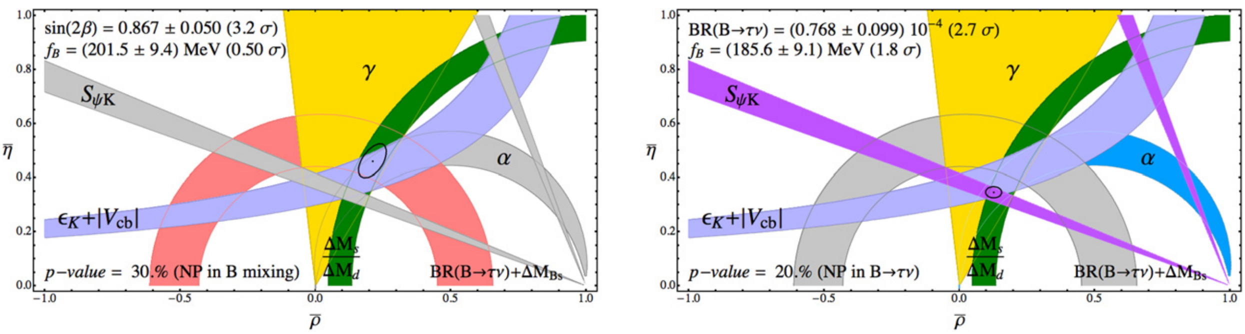

Fig. 1. Unitarity triangle fit. In each plot inputs that are grayed out are *not* used to obtain the black contour (which represents the SM allowed 1σ region), the p-value and the fit predictions presented in the upper left corners. The deviations of the fit predictions for $\sin(2\beta)$ and $\text{BR}(B \to \tau\nu)$ from the respective measurements are obtained using the actual chi-square distribution for these quantities. The p-value of the complete SM fit (i.e. including all the inputs) is $p_{SM} = 1.7\%$. In the left panel, we consider a scenario with a new phase in B_d mixing, thereby removing the $\sin(2\beta)$ and α inputs. In the right panel we consider a scenario with new physics in $B \to \tau\nu$, thereby removing the $\text{BR}(B \to \tau\nu)$ input.

value of $\sin 2\beta$ and of f_{B_d}. We obtain:

$$\sin(2\beta)^{\text{fit}} = 0.867 \pm 0.050 \tag{2}$$

which is about 3.2σ away from the experimentally measured value of 0.668 ± 0.023. We believe this result provides a strong indication that the CKM description of the observed CP violation is breaking down.[2]

For the fitted value of f_{B_d} along with the predicted value of $\sin(2\beta)$ given above, we find:

$$f_{B_d}^{\text{fit}} = (201.5 \pm 9.4)\ \text{MeV} \tag{3}$$

This “predicted” value is in very good agreement with the one obtained by direct lattice calculation, $f_{B_d} = (208 \pm 8)$ MeV. This is a useful consistency check signifying that the SM description of the inputs used, especially of $B \to \tau\nu$, is working fairly well and that it is unlikely that the $B \to \tau\nu$ tree amplitude is receiving large contributions from new physics; most likely the dominant effect of new physics is in fact in $\sin(2\beta)$. Later we will reexamine this from an entirely different perspective and show in fact there is additional independent support to these interpretations.

In order to further scrutinize the tentative conclusion reached above, we next present an alternate scenario depicted in the right panel of Fig. 1. Here, we make one important change in the inputs used. Instead of using the measured value of $\text{BR}(B \to \tau\nu)$ we now use as input the measured value of $\sin(2\beta)$ from the “gold-plated” $B_d \to \psi K_s$ mode. Again, this fit yields two important predictions:

$$\text{BR}(B \to \tau\nu)^{\text{fit}} = (0.768 \pm 0.099) \times 10^{-4} \tag{4}$$

[2] Note that when γ is not used as an input and only ϵ_K, $\Delta M_s/\Delta M_d$ and $\text{BR}(B \to \tau\nu)$ are used, the deviation of the fitted $\sin(2\beta)$ from the measured one stays unchanged at 3.2σ, see Fig. 4.

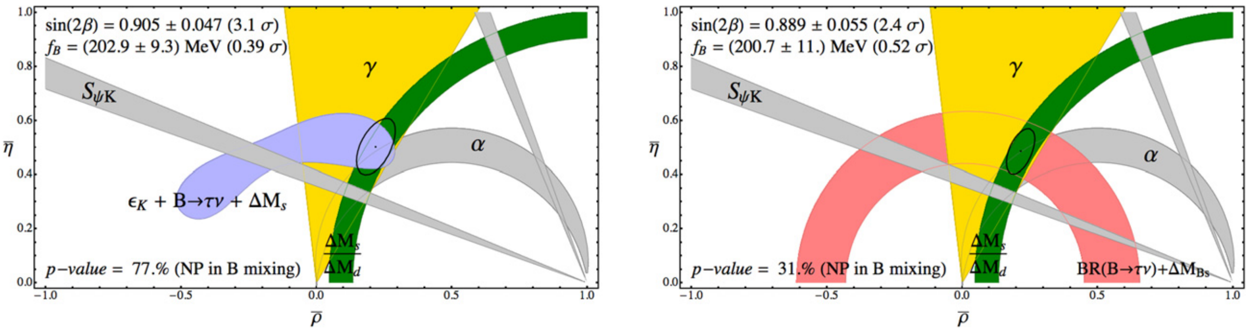

Fig. 2. Unitarity triangle fit without semileptonic decays (left panel) and without use of K mixing (right panel). See the caption of Fig. 1.

$$f_{B_d}^{\text{fit}} = (185.6 \pm 9.1)\ \text{MeV} \tag{5}$$

Eq. (4) deviates by 2.7σ from the experimental measurement, as can also be gleaned from an inspection of the left panel of Fig. 1. It is particularly interesting that also the fit prediction for f_{B_d} now deviates by about 1.8σ from the direct lattice determination given in Table 1. We believe this provides additional support that the measured value of $\sin(2\beta)$ being used here as a key input is not consistent with the SM and in fact is receiving appreciable contributions from new physics.

This leads us to conclude that while the presence of some sub-dominant contribution of new physics in $B \to \tau\nu$ is possible, a large contribution of new physics in there is not able to explain, in a consistent fashion, the tension we are observing in the unitarity triangle fit.

This conclusion receives corroboration by the observation that even without using $B \to \tau\nu$ at all, and using as input only ϵ_K, $\Delta M_{B_s}/\Delta M_{B_d}$ and $|V_{cb}|$ (see Fig. 4), the predicted value of $\sin(2\beta)$ deviates by 1.8σ from its measurement (in this case we find $\sin(2\beta)^{\text{fit}} = 0.814 \pm 0.081$). Thus, possible new physics in $B \to \tau\nu$ can alleviate but not remove completely the tension in the fit.

We recall that the fit above is actually the simple fit we had reported some time ago (now with updated lattice inputs) with its resulting $\approx 2\sigma$ deviation [5]. This fit is somewhat special as primarily one is only using $\Delta F = 2$ box graphs from ϵ_K and $\Delta M_{B_s}/\Delta M_{B_d}$ in conjunction with lattice inputs for B_K and the SU(3) breaking ratio ξ. The experimental input from box graphs is clearly short-distance dominated and for the lattice these two inputs are particularly simple to calculate as the relevant 4-quark operators have no mixing with lower-dimensional operators and also require no momentum injection. The prospects for further improvements in these calculations are high and the method should continue to provide an accurate and clean "prediction" for $\sin(2\beta)$ in the SM. So even if the current tensions get resolved, this type of fit should remain a viable way to test the SM as lattice calculations and experimental inputs continue to improve.

2.1. Roles of V_{cb}, ε_K, V_{ub} and of hadronic uncertainties

The fit described above does use V_{cb} where again the inclusive and exclusive methods differ mildly (about 1.7σ). Of greater concern here is that ϵ_K scales as $|V_{cb}|^4$ and therefore is very sensitive to the error on V_{cb}. We address this in two ways. First in the left panel of Fig. 2 we study a fit wherein no semileptonic input from $b \to c$ or $b \to u$ is being used. Instead, in this fit $\text{BR}(B \to \tau\nu)$ and ΔM_{B_s} along with ϵ_K, $\Delta M_{B_s}/\Delta M_{B_d}$ and γ are used. Interestingly this fit gives

$$\sin(2\beta)^{\text{fit}} = 0.905 \pm 0.047 \tag{6}$$

$$f_{B_d}^{\text{fit}} = (202.9 \pm 9.3)\ \text{MeV} \tag{7}$$

Thus, once again, $\sin(2\beta)$ is off by 3.1σ whereas f_{B_d} is in very good agreement with directly measured value which we again take to mean that the *bulk* of the discrepancy is in $\sin(2\beta)$ rather than in $B \to \tau\nu$ or in V_{cb}.

Next we investigate the role of ϵ_K. In the right panel of Fig. 2 we show a fit where only input from B-physics, namely $\Delta M_{B_s}/\Delta M_{B_d}$, ΔM_{B_s}, γ, $|V_{cb}|$ and $\text{BR}(B \to \tau\nu)$ are used. This fit yields,

$$\sin(2\beta)^{\text{fit}} = 0.889 \pm 0.055 \tag{8}$$

$$f_{B_d}^{\text{fit}} = (200.7 \pm 11)\ \text{MeV} \tag{9}$$

Thus, $\sin(2\beta)^{\text{fit}}$ is off by $\approx 2.4\sigma$ and again $f_{B_d}^{\text{fit}}$ is in good agreement with its direct determination. We are, therefore, led to conclude that the role of ϵ_K in the discrepancy is subdominant and that the bulk of the new physics contribution is likely to be in B-physics. As before, the fact that the fitted value of f_{B_d} is in good agreement with its direct determination seems to suggest that the input $\text{BR}(B \to \tau\nu)$ is most likely not in any large conflict with the SM, though, obviously we cannot rule out the possibility of it receiving a sub-dominant contribution from new physics.

For completeness, we present in Fig. 3 the results we obtain when including V_{ub} in the fit. Note that inclusive and exclusive determinations of $|V_{ub}|$ differ at 3.3σ (see Table 1) and, for this reason, are presented separately in the plot.

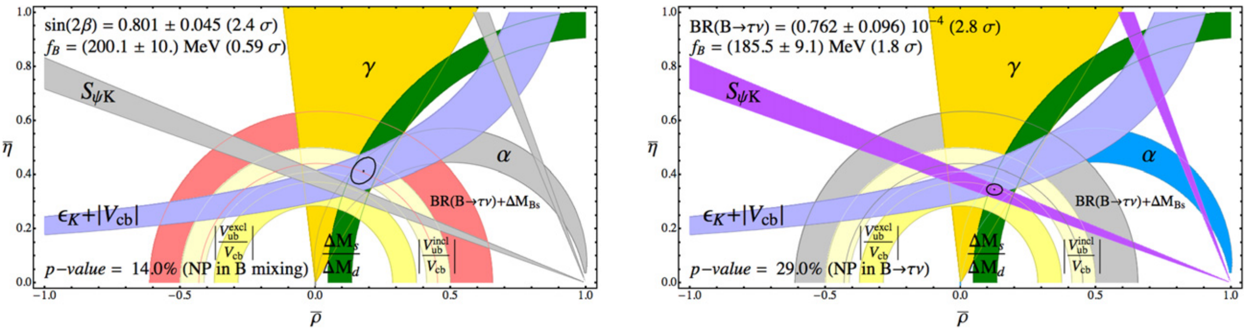

Fig. 3. Unitarity triangle fit with V_{ub}. We plot separately the constraints from inclusive and exclusive semileptonic B decays. The contour, p-value and fit predictions are obtained using the $|V_{ub}|_{\text{tot}}$. See the caption of Fig. 1.

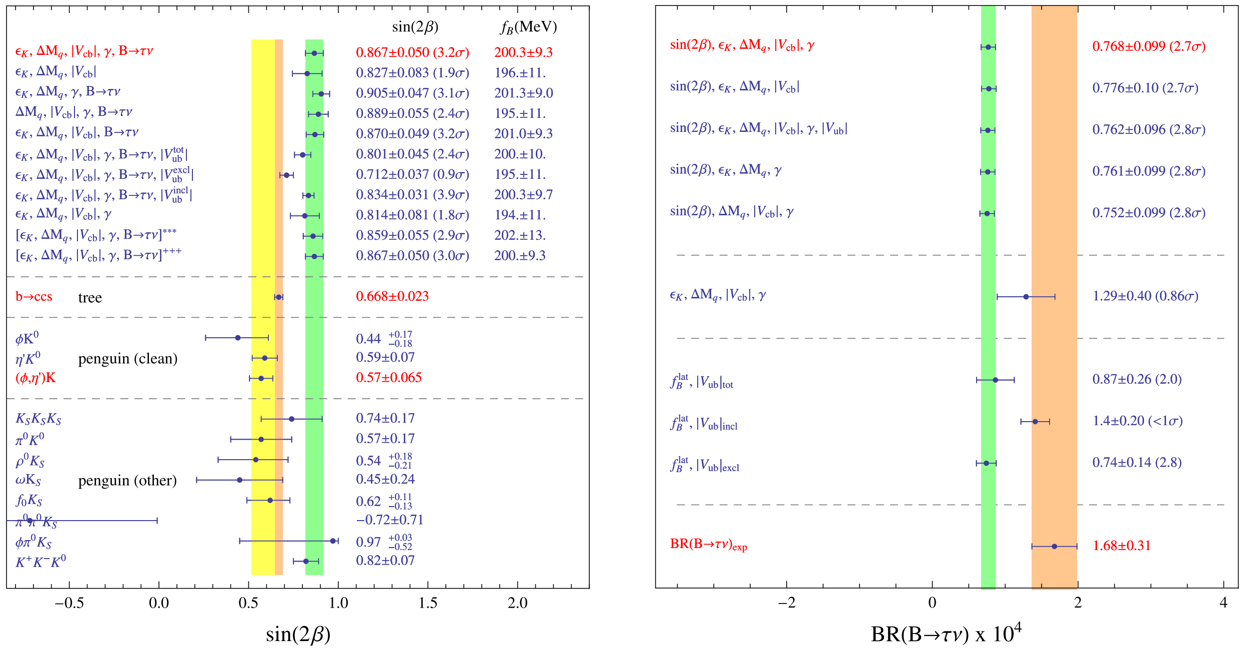

Fig. 4. Summary of $\sin(2\beta)$ and $\text{BR}(B \to \tau\nu)$ determinations. The entry marked *** (tenth from the top) is obtained with lattice errors increased by 50% over those given in Table 1 for each of the input quantities that we use and the entry marked +++ (eleventh from the top) corresponds to adding a hadronic uncertainty $\delta\Delta S_{\psi K} = 0.021$ to the relation between $\sin(2\beta)$ and $S_{\psi K}$. See the text for further explanations.

Before taking the average, we add a 10% model uncertainty to the inclusive determination. This reduces the discrepancy to 2.1σ. We finally rescale the error on the average by the square root of the reduced chi-square (following the PDG recipe). In Table 1 we report the result we obtain and that we use in the fit.

A compilation of all the eleven fits that we studied for $\sin 2\beta$ are shown in the left panel of Fig. 4. Notice that there is only one case in here (8th from the top) where the discrepancy in $\sin 2\beta$ is only $O(1\sigma)$. We believe this is primarily a reflection of the large ($\approx 14.4\%$) uncertainty with our combined V_{ub} fit originating from the large disparity between inclusive and exclusive determinations. This is again a reminder of the fact that till this discrepancy gets removed, we cannot use V_{ub} to draw any reliable conclusion.

3. $B \to \tau\nu$ and new physics

Now with regard to $B \to \tau\nu$, the right panel of Fig. 4 shows a summary of predictions versus the measured BR. Notice that whenever the measured value of $\sin(2\beta)$ is used as an input, the predicted BR is $\approx 2.7\sigma$ from the measured one. In the preceding discussion we have emphasized that this seems to us to be a consequence of new physics largely in B mixings and/or in $B_d \to \psi K_s$ decay. This conclusion receives further strong support when we try determine the $B \to \tau\nu$ branching ratio without using $\sin 2\beta$. Indeed as shown in the right panel of Fig. 4 when we use ϵ_K, ΔM_{B_q}, V_{cb} and γ only, the fitted value of $\text{BR}(B \to \tau\nu)$ is in very good agreement with the measured value.

In principle, of course, the prediction for BR($B \to \tau\nu$) only needs the values of f_{B_d} and of V_{ub}. Fixing now $f_{B_d} = 208 \pm 8$ MeV as directly determined on the lattice (see Table 1) we show the corresponding two predictions for the BR using separately the values of V_{ub} determined in inclusive and in exclusive decays. It is clear that the inclusive determination yields results that are within one σ of experiment (see also Fig. 1); however with V_{ub} from exclusive modes (that makes use of the semileptonic form factor as determined on the lattice), the BR deviates by $\approx 2.8\sigma$ from experiment. This may be a hint that lattice based exclusive methods have some intrinsic difficulty or that the exclusive modes are sensitive to some new physics that the inclusive modes are insensitive to, *e.g.* right-handed currents [30,31]. In either case, this reasoning suggests that we try using the value of V_{ub} given by inclusive methods only in our fit for determining $\sin 2\beta$. This line of reasoning is also supported by the analysis presented in Ref. [32] in which the discrepancy between the experimental determination and the SM prediction of ratio $R_{s/l} = \mathrm{BR}(B \to \pi\ell\nu)/\mathrm{BR}(B \to \tau\nu)$ is considered. Note that the authors of Ref. [32] find that the experimental value of this ratio is about a factor of 2 smaller than the SM prediction and that this discrepancy is independent of whether lattice QCD or Light-Cone QCD Sum Rules are used to determine the $B \to \pi$ form factor and the B decay constant. This result can be seen as a solid consistency check of the lattice QCD calculation of the $B \to \pi$ form factor. Within the SM this ratio is independent of short distance physics (the $|V_{ub}|^2$ factors cancel out) and measures the ratio of the $B \to \pi$ form factor to the B decay constant. New physics in right-handed currents affects differently the $B \to \pi\ell\nu$ and $B \to \tau\nu$ transitions and might be responsible for the observed discrepancy.

4. Summary of fits, perspective and outlook

The result of our analysis strongly suggests that the SM predicted value of $\sin(2\beta)$ is around 0.85 whereas the value measured experimentally via the gold plated ψK_s mode is around 0.66 constituting a deviation of about 3σ from the SM (see Fig. 4). To put this result in a broader perspective let us now recall that in fact in the SM $\sin(2\beta)$ can also be measured via the penguin dominated modes (see Fig. 4) [33–36]. Unfortunately several of these modes suffer from a potentially large tree pollution, though there are good reasons to believe that the $\eta' K_s$, ϕK_s and $3K_s$ modes are rather clean [37–39] wherein the deviations from $\sin 2\beta$ are expected to be only O(few %). The striking aspect of these three clean modes as well as many others penguin dominated modes (see Fig. 4) is that the central values of almost all of them tend to be even smaller than the value (0.66), measured in ψK_s, and consequently tend to exhibit even a larger deviation from the SM prediction of around 0.85. Thus, seen in the light of our analysis, the deviation in these penguin modes suggests the presence of new CP-violating physics not just in B-mixing but also in $b \to s$ penguin transitions.

Moreover, the large difference ($\approx (14.4 \pm 2.9)\%$) [3] in the direct CP asymmetry measured in $B^0 \to K^+\pi^-$ versus that in $B^+ \to K^+\pi^0$ provides another hint that $b \to s$ penguin transitions may be receiving the contribution from a beyond the SM source of CP-violation (for alternate explanation see Refs. [40–42]). To briefly recapitulate, in the SM one naively expects this difference to be vanishingly small and careful estimates based on QCD factorization ideas suggest that it is very difficult to get a difference much larger than $(2.2 \pm 2.4)\%$ [7].

Of course, if $b \to s$ penguin transitions ($\Delta \mathit{Flavor} = 1$) are receiving contributions from new physics, then it is quite unnatural for B_s mixing amplitudes ($\Delta \mathit{Flavor} = 2$) to remain unaffected. Therefore, this reasoning suggests that we should expect non-vanishing CP asymmetries in $B_s \to \psi\phi$ as well as a non-vanishing di-lepton asymmetry in $B_s \to X_s l\nu$. As is well known, at Fermilab, in the past couple of years CDF and D0 experiments have been studying CP asymmetry in $B_s \to \psi\phi$. The latest result with about 6 fb^{-1} from each experiment seems to reveal a reduction from $\sim 1.8\sigma$ tension to $\sim 1\sigma$ from the SM [15,43,44]. Thus, findings in $B_s \to \psi\phi$ from Fermilab and from LHCb are eagerly awaited.

Another interesting and potentially very important development with regard to non-standard CP in B_s is that last year D0 announced the observation of a large dimuon asymmetry in B-decays amounting to a deviation of ($\approx 3.2\sigma$) from the minuscule asymmetry predicted in the SM [45,46]. They attribute this largely to originate from B_s mixing. While this is a very exciting development, their experimental analysis is extremely challenging and a confirmation is highly desirable before their findings can be safely assumed. Note, though, HFAG [15] has combined CDF and D0 results on $B_s \to \psi\phi$ and on the dimuon asymmetry, A^s_{sl} and finds the deviation from the SM to be around 2.7σ.

Be that as it may, we reiterate that our analysis suggests that the deviation from the SM in $\sin(2\beta)$ is difficult to reconcile with errors in the inputs from the lattice that we use, and strongly suggests the presence of a non-standard source of CP violation largely in B/B_s mixings, thereby predicting that non-standard signals of CP violation in $S(B_d \to \eta' K_s, \phi K_s, 3K_s,$ etc.) as well as in $S(B_s \to \psi\phi)$, and the semileptonic and di-lepton asymmetries in B_s, and possibly also in B_d, decays will persist and survive further scrutiny in experiments at the intensity frontiers such as Fermilab (CDF, D0), LHCb and the Super-B factories. Lastly, the fact that our analysis rules out the possibility that new physics exclusively in kaon mixing is responsible for the deviations in $\sin(2\beta)$, has the very important repercussions for the mass scale of the underlying new physics contributing to these deviations: model independent analysis then imply that the relevant mass scale of the new physics is necessarily relatively low, i.e. below $O(2\ \mathrm{TeV})$ [7].[3] Thus, collider experiments at the high energy frontier at LHC and possibly even at Fermilab should see direct signals of the underlying degrees of freedom appearing in any relevant beyond the Standard Model scenario.

[3] The reason that the presence of new physics in kaon mixings can shift the relevant scale to much larger energies ($O(20\ \mathrm{TeV})$) is the possible presence of left-right 4-quark operators whose matrix elements for kaon mixing and RG running are significantly enhanced as emphasized in Ref. [49] (see also, Refs. [7,50]).

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