Constraints on New Physics from $\gamma$ and $|V_{ub}|$

**Patricia Ball**

*IPPP, Department of Physics, University of Durham, Durham DH1 3LE, UK*

**Abstract**

The SM unitarity triangle (UT) is completely determined by the parameters $\gamma$ and $|V_{ub}|$ which can be extracted from tree-level processes and are assumed to be free of new physics. By comparison with other determinations of UT parameters one can impose constraints on new physics in loop processes, in particular $B$ mixing.

*Patricia.Ball@durham.ac.uk*
Independently of any new sources of flavour violation induced by new physics (NP), there is always a Standard Model (SM) unitarity triangle (UT). It is completely determined by two parameters, which one can choose as $|V_{ub}/V_{cb}|$ and $\gamma$ – the rationale being that these parameters can be determined from tree-level processes and hence are expected to be essentially free of new-physics effects. In this talk we discuss the impact of the presently available information on $|V_{ub}/V_{cb}|$ and $\gamma$ on possible new physics in $B$ mixing, based on Ref. [1]; we include the most recent update on $(\sin \phi_d)_{c\bar{c}s}$ presented at ICHEP2006.

Let us first discuss the status of $|V_{ub}|$ and $|V_{cb}|$. The latter quantity is presently known with 2% precision from semileptonic $B$ decays; we shall use the value obtained in Ref. [2] from the analysis of leptonic and hadronic moments in inclusive $b \rightarrow c\ell\bar{\nu}_\ell$ transitions [3]:

$$|V_{cb}| = (42.0 \pm 0.7) \cdot 10^{-3};$$

this value agrees with that from exclusive semileptonic decays.

The situation is less favourable with $|V_{ub}|$: there is more than $1\sigma$ discrepancy between the values from inclusive and exclusive $b \rightarrow u\ell\bar{\nu}_\ell$ transitions [4]:

$$|V_{ub}|_{\text{incl}} = (4.4 \pm 0.3) \cdot 10^{-3}, \quad |V_{ub}|_{\text{excl}} = (3.8 \pm 0.6) \cdot 10^{-3}.$$

The error on $|V_{ub}|_{\text{excl}}$ is dominated by the theoretical uncertainty of lattice and light-cone sum rule calculations of $B \rightarrow \pi$ and $B \rightarrow \rho$ transition form factors [3] [6], whereas for $|V_{ub}|_{\text{incl}}$ experimental and theoretical errors are at par. A recent improvement of the method used to extract $|V_{ub}|$ has been suggested in Ref. [7]; it relies on fixing the shape of the exclusive form factor from experimental data on the $q^2$-spectrum in $B \rightarrow \pi e \nu$, which helps to reduce both the experimental and theoretical error of $|V_{ub}|_{\text{excl}}$. The “low” value $|V_{ub}|_{\text{excl}}$ is in agreement with the determination of $|V_{ub}|$, by the UTfit collaboration, from only the angles of the UT [8]. In this report we shall present results for both values of $|V_{ub}|$.

As for the UT angle $\gamma$, tree-level results can be obtained from the CP asymmetries in $B \rightarrow D^{(*)}K^{(*)}$ decays. At present, the only results available come from the Dalitz-plot analysis of the CP asymmetry in $B^- \rightarrow (K_S^0\pi^+\pi^-)K^-$, with $K_S^0\pi^+\pi^-$ being a three-body final state common to both $D^0$ and $\bar{D}^0$. This method to measure $\gamma$ from a new-physics free tree-level process was suggested in Ref. [10] and has been implemented by both BaBar [11] and Belle [12], but the BaBar result currently suffers from huge errors: $\gamma_{\text{BaBar}} = (92 \pm 41 \pm 11 \pm 12)^\circ$, $\gamma_{\text{Belle}} = (53^{+15}_{-18} \pm 3 \pm 9)^\circ$. Other determinations of $\gamma$ from QCDF, $\gamma_{\text{QCDF}} = (62 \pm 8)^\circ$ [13], SCET, $\gamma_{\text{SCET}} = (73.9^{+7.4}_{-11.0})^\circ$ [14], SU(3) fits of non-leptonic $B$ decays $\gamma_{\text{SU(3)}} = (70.0^{+3.8}_{-4.3})^\circ$ [15], radiative penguin decays, $\gamma_{B\rightarrow V\gamma} = (61.0^{+13.5}_{-16.0} \pm 8.9)^\circ$ [16], and global UT fits [8] [17] all come with theoretical uncertainties and/or possible contamination by unresolved new physics. In this report we shall use $\gamma = (65 \pm 20)^\circ$, which is a fair average over all these determinations.

With $\gamma$ and $|V_{ub}/V_{cb}|$ fixed, let us first have a closer look at the $B^0_d - \bar{B}^0_d$ mixing parameters. In the presence of NP, the matrix element $M_{12}^d$ can be written, in a model-independent way, as

$$M_{12}^d = M_{12}^{d,\text{SM}} (1 + \kappa_d e^{i\sigma_d}),$$

where $M_{12}^{d,\text{SM}}$ is determined by two parameters, which one can choose as $(\sin \phi_d)_{c\bar{c}s}$ and $(\cos \phi_d)_{c\bar{c}s}$.
where the real parameter $\kappa_d \geq 0$ measures the “strength” of the NP contribution with respect to the SM, whereas $\sigma_d$ is a new CP-violating phase; analogous formulae apply to the $B_s$ system. The $B_d$ mixing parameters then read

$$\Delta M_d = \Delta M_d^{SM} \left[ 1 + \kappa_d e^{i\sigma_d} \right],$$

$$\phi_d = \phi_d^{SM} + \phi_d^{NP} = \phi_d^{SM} + \text{arg}(1 + \kappa_d e^{i\sigma_d}).$$

Experimental constraints on $\kappa_d$ and $\sigma_d$ are provided by $\Delta M_d$ and $\phi_d$, the mass difference and mixing phase in the $B_d$ system. While the interpretation of the very accurately known experimental value of $\Delta M_d$ depends crucially on hadronic matrix elements provided by lattice calculations, $\phi_d$ can be measured directly as mixing-induced CP asymmetry in $b \to c \bar{c}s$ transitions [4]:

$$\sin \phi_d = 0.675 \pm 0.026,$$

which yields the twofold solution

$$\phi_d = (42.5 \pm 2.0)^\circ \quad \vee \quad (137.5 \pm 2.0)^\circ,$$

where the latter result is in dramatic conflict with global CKM fits and would require a large NP contribution to $B_0^d - \bar{B}_d^0$ mixing. However, experimental information on the sign of $\cos \phi_d$ rules out a negative value of this quantity at greater than 95% C.L. [18], so that we are left with $\phi_d = (42.5 \pm 2.0)^\circ$.

The SM prediction of the mixing phase, $\phi_d^{SM} = 2\beta$, can easily be obtained in terms of the tree-level quantities $R_b$ and $\gamma$, as

$$\sin \beta = \frac{R_b \sin \gamma}{\sqrt{1 - 2R_b \cos \gamma + R_b^2}}, \quad \cos \beta = \frac{1 - R_b \cos \gamma}{\sqrt{1 - 2R_b \cos \gamma + R_b^2}}.$$

Here the quantity $R_b$ is given by

$$R_b \equiv \left( 1 - \frac{\lambda^2}{2} \right) \frac{1}{\lambda} \left| \frac{V_{ub}}{V_{cb}} \right|.$$

Using Eq. (11), the experimental value of $\phi_d$ can immediately be converted into a result for the NP phase $\phi_d^{NP}$, which depends on both $\gamma$ and $R_b$. It turns out that the dependence of $\phi_d^{NP}$ on $\gamma$ is very small and that $R_b$ plays actually the key rôle for its determination. With our range of values for $\gamma$ and $|V_{ub}|$ we find

$$\phi_d^{SM} \big|_{\text{incl}} = (53.5 \pm 3.8)^\circ, \quad \phi_d^{SM} \big|_{\text{excl}} = (45.9 \pm 7.6)^\circ,$$

corresponding to

$$\phi_d^{NP} \big|_{\text{incl}} = -(11.0 \pm 4.3)^\circ, \quad \phi_d^{NP} \big|_{\text{excl}} = -(3.4 \pm 7.9)^\circ;$$

results of $\phi_d^{NP} \approx -10^\circ$ were also recently obtained in Refs. [19, 20, 9]. Note that the emergence of a non-zero value of $\phi_d^{NP}$ is caused by the large value of $|V_{ub}|$ from inclusive semileptonic decays, but that $\phi_d^{NP}$ is compatible with zero for $|V_{ub}|$ from exclusive decays.
We can now combine the constraints from both $\Delta M_d$ and $\phi_d$ to constrain the allowed region in the $\sigma_d$--$\kappa_d$ plane. These constraints depend on hadronic input for $\Delta M_d$ in terms of the parameter $f_{B_d} \hat{B}_{B_d}^{1/2}$ for which there exist two independent unquenched lattice results, one by the JLQCD collaboration with $N_f = 2$ active flavours [21], and one by the HPQCD collaboration with $N_f = 2 + 1$ active flavours [22]. We also give the corresponding results for the $B_s$ which we will need below:

$$f_{B_d} \hat{B}_{B_d}^{1/2} \big|_{\text{JLQCD}} = (0.215 \pm 0.019^{+0}_{-0.023}) \text{ GeV},$$

$$f_{B_s} \hat{B}_{B_s}^{1/2} \big|_{\text{JLQCD}} = (0.245 \pm 0.021^{+0.003}_{-0.002}) \text{ GeV},$$

$$f_{B_d} \hat{B}_{B_d}^{1/2} \big|_{\text{(HP+JL)QCD}} = (0.244 \pm 0.026) \text{ GeV},$$

$$f_{B_s} \hat{B}_{B_s}^{1/2} \big|_{\text{HPQCD}} = (0.281 \pm 0.021) \text{ GeV}.$$  \hspace{1cm} (11)  

The last but one entry is a combination of both HPQCD and JLQCD results, as the HPQCD collaboration is yet to provide results on $B_{B_d}$.

The corresponding constraints in the $\sigma_d$--$\kappa_d$ plane are shown in Fig. [1]. We see that a non-vanishing value of $\phi_d^{\text{NP}}$, even as small as $\phi_d^{\text{NP}} \approx -10^\circ$, has a strong impact on the allowed space in the $\sigma_d$--$\kappa_d$ plane. In both scenarios with different lattice results and different values for $|V_{ub}|$, the upper bounds of $\kappa_d \lesssim 2.5$ on the NP contributions following from the experimental value of $\Delta M_d$ are reduced to $\kappa_d \lesssim 0.5$. In order to determine $\kappa_d$ more precisely, it is mandatory to reduce the errors of $\Delta M_d^{\text{latt}}$, which come from both $\gamma$ and lattice calculations. The value of $\gamma$ can be determined -- with impressive accuracy -- at the LHC, whereas progress on the lattice side is much harder to predict.

Let us now have a closer look at the $B_s$-meson system. The big news in 2006 was the
Figure 2: The allowed regions (yellow/grey) in the $\kappa_s$-$\sigma_s$ plane. Left panel: JLQCD lattice results \cite{11}. Right panel: HPQCD lattice results \cite{12}.

The first measurement, by the CDF collaboration, of $\Delta M_s$ \cite{23}:

$$\Delta M_s = (17.77 \pm 0.10 \pm 0.07) \text{ps}^{-1}. \quad (13)$$

In order to describe NP effects in $B_s$ mixing in a model-independent way, we parametrize them analogously to (3) and (4). The relevant CKM factor is $|V^*_t s V_{tb}|$. Using the unitarity of the CKM matrix and including next-to-leading order terms in the Wolfenstein expansion, we have

$$\left| \frac{V_{ts}}{V_{cb}} \right| = 1 - \frac{1}{2} (1 - 2 R_b \cos \gamma) \lambda^2 + \mathcal{O}(\lambda^4). \quad (14)$$

Consequently, apart from the tiny correction in $\lambda^2$, the CKM factor for $\Delta M_s$ is independent of $\gamma$ and $R_b$, which is an important advantage in comparison with the $B_d$-meson system. The accuracy of the SM prediction of $\Delta M_s$ is hence limited by the hadronic mixing parameter $f_{B_s} \delta_{B_s}^{1/2}$. In Fig. 2, we show the constraints in the $\sigma_s$-$\kappa_s$ plane. We see that upper bounds of $\kappa_s \lesssim 2.5$ arise from the measurement of $\Delta M_s$. Consequently, the CDF measurement of $\Delta M_s$ leaves ample space for the NP parameters $\sigma_s$ and $\kappa_s$. This situation will change significantly as soon as precise information about CP violation in the $B_s$-meson system becomes available.

To date, the CP-violating phase associated with $B^0_s$-$\bar{B}^0_s$ mixing is not very well constrained. In the SM, it is doubly Cabibbo-suppressed, and can be written as follows:

$$\phi_s^{\text{SM}} = -2 \lambda^2 \eta = -2 \lambda^2 R_b \sin \gamma \approx -2^\circ. \quad (15)$$

Because of the small SM phase in (15), $B^0_s$-$\bar{B}^0_s$ mixing is particularly well suited to search for NP effects, which may well lead to a sizeable value of $\phi_s$. The presently available information on $\phi_s$ stems from measurements of $\Delta \Gamma_s$ and the semileptonic CP asymmetry $a^s_{fs}$; they have been re-analysed very recently in Ref. \cite{24} with the result

$$\sin \phi_s = -0.77 \pm 0.04 \pm 0.34 \quad \text{or} \quad \sin \phi_s = -0.67 \pm 0.05 \pm 0.29, \quad (16)$$

depending on the value of $\Delta M_{s}^{\text{latt}}$; both results would imply a 2$\sigma$ deviation from the SM prediction $\sin \phi_s^{\text{SM}} \approx -0.04$, but are heavily theory dependent. In order to test the SM
and probe CP-violating NP contributions to $B^0_s - \bar{B}^0_s$ mixing in a less theory-dependent way, the decay $B^0_s \rightarrow J/\psi \phi$, which is very accessible at the LHC, plays a key rôle and allows the measurement of

$$ \sin \phi_s = \sin(-2\lambda^2 R_b \sin \gamma + \phi_s^{NP}), \tag{17} $$

in analogy to the determination of $\sin \phi_d$ through $B^0_d \rightarrow J/\psi K_S$.

In order to illustrate the possible impact of NP effects, let us assume that the NP parameters satisfy the simple relation

$$ \sigma_d = \sigma_s, \quad \kappa_d = \kappa_s, \tag{18} $$

i.e. that in particular $\phi_d^{NP} = \phi_s^{NP}$. To illustrate the impact of CP violation measurements on the allowed region in the $\sigma_s - \kappa_s$ plane, let us consider two cases:

i) $(\sin \phi_s)_{\text{exp}} = -0.04 \pm 0.02$, i.e. the SM prediction;

ii) $(\sin \phi_s)_{\text{exp}} = -0.20 \pm 0.02$, i.e. the above NP scenario $\phi_d = \phi_s \approx -11^\circ$.

In Fig. 3, we show the situation in the $\sigma_s - \kappa_s$ plane. The constraints on the NP parameters are rather strong, although $\kappa_s$ could still assume sizeable values, with the upper bound $\kappa_s \approx 0.5$. In the SM-like scenario (i), values of $\sigma_s$ around $180^\circ$ would arise, i.e. a NP contribution with a sign opposite to the SM. However, due to the absence of new CP-violating effects, the accuracy of lattice results would have to be considerably improved in order to allow the extraction of a value of $\kappa_s$ incompatible with 0. On the other hand, a measurement of $(\sin \phi_s)_{\text{exp}} = -0.20 \pm 0.02$ would give a NP signal at the 10 $\sigma$ level, with $\kappa_s \gtrsim 0.2$.

Let us conclude with a few remarks concerning the prospects for the search for NP through $B^0_s - \bar{B}^0_s$ mixing at the LHC. This task will be very challenging if essentially no CP-violating effects will be found in $B^0_s \rightarrow J/\psi \phi$ (and similar decays). On the other hand, as
we demonstrated above, even a small phase $\phi_{NP}^{s} \approx -10^\circ$ (inspired by the $B_d$ data) would lead to CP asymmetries at the $-20\%$ level, which could be unambiguously detected after a couple of years of data taking, and would not be affected by hadronic uncertainties. Conversely, the measurement of such an asymmetry would allow one to establish a lower bound on the strength of the NP contribution -- even if hadronic uncertainties still preclude a direct extraction of this contribution from $\Delta M_s$ -- and to dramatically reduce the allowed region in the NP parameter space. In fact, the situation may be even more promising, as specific scenarios of NP still allow large new phases in $B^0_s - \bar{B}^0_s$ mixing, also after the measurement of $\Delta M_s$, see, for instance, Refs. [25] [26].

In essence, the lesson to be learnt from the CDF measurement of $\Delta M_s$ is that NP may actually be hiding in $B^0_s - \bar{B}^0_s$ mixing, but is still obscured by parameter uncertainties, some of which will be reduced by improved statistics at the LHC, whereas others require dedicated work of, in particular, lattice theorists. The smoking gun for the presence of NP in $B^0_s - \bar{B}^0_s$ mixing will be the detection of a non-vanishing value of $\phi_{NP}^{s}$ through CP violation in $B^0_s \to J/\psi \phi$. Let us finally emphasize that the current $B$-factory data may show -- in addition to $\phi_{NP}^{d} \approx -10^\circ$ -- other first indications of new sources of CP violation through measurements of $B^0_d \to \phi K_S$ and $B \to \pi K$ decays, which may point towards a modified electroweak penguin sector. All these examples are yet another demonstration that flavour physics is not an optional extra, but an indispensable ingredient in the pursuit of NP, also and in particular in the era of the LHC.

References

[1] P. Ball and R. Fleischer, Eur. Phys. J. C 48 (2006) 413 [arXiv:hep-ph/0604249].

[2] O. Buchmüller and H. Flächer, Phys. Rev. D 73 (2006) 073008 [arXiv:hep-ph/0507253].

[3] P. Gambino and N. Uraltsev, Eur. Phys. J. C 34 (2004) 181 [arXiv:hep-ph/0401063].

[4] E. Barberio et al. [HFAG], hep-ex/0603003, updated results available at http://www.slac.stanford.edu/xorg/hfag/.

[5] M. Okamoto et al., Nucl. Phys. Proc. Suppl. 140 (2005) 461 [arXiv:hep-lat/0409116]; E. Gulez et al., Phys. Rev. D73 (2006) 074502 [arXiv:hep-lat/0601021].

[6] P. Ball, JHEP 9809 (1998) 005 [arXiv:hep-ph/9802394]; A. Khodjamirian et al., Phys. Rev. D62 (2000) 114002 [arXiv:hep-ph/0001297]; P. Ball and R. Zwicky, JHEP 0110 (2001) 019 [arXiv:hep-ph/0110115]; Phys. Rev. D71 (2005) 014015 [arXiv:hep-ph/0406232]; Phys. Rev. D71 (2005) 014029 [arXiv:hep-ph/0412079]; A. Khodjamirian, T. Mannel and N. Offen, arXiv:hep-ph/0611193.
[7] P. Ball and R. Zwicky, Phys. Lett. B625 (2005) 225 [arXiv:hep-ph/0507076];
P. Ball, Phys. Lett. B 644 (2007) 38 [arXiv:hep-ph/0611108] and talk at this conference [arXiv:hep-ph/0612190].

[8] M. Bona et al. [UTfit Collaboration], JHEP 0610 (2006) 081 [arXiv:hep-ph/0606167];
updated results available at http://www.utfit.org/.

[9] M. Blanke, A. J. Buras, D. Guadagnoli and C. Tarantino, JHEP 0610 (2006) 003 [arXiv:hep-ph/0604057].

[10] A. Giri, Y. Grossman, A. Soffer and J. Zupan, Phys. Rev. D 68 (2003) 054018 [arXiv:hep-ph/0303187].

[11] B. Aubert et al. [BABAR Collaboration], arXiv:hep-ex/0507101;
D. Marciano [BaBar Collaboration], talk given at ICHEP06, Moscow, August 2006.

[12] A. Poluektov et al. [Belle Collaboration], Phys. Rev. D 73 (2006) 112009 [arXiv:hep-ex/0604054].

[13] M. Neubert, talk at this conference.

[14] I. Stewart, talk at this conference.

[15] R. Fleischer, talk at this conference.

[16] P. Ball and R. Zwicky, JHEP 0604 (2006) 046 [arXiv:hep-ph/0603232];
P. Ball, G. W. Jones and R. Zwicky, arXiv:hep-ph/0612081;
P. Ball, talk at this conference [arXiv:hep-ph/0612264].

[17] J. Charles et al. [CKMfitter Group], Eur. Phys. J. C41 (2005) 1; for the most recent updates, see http://ckmfitter.in2p3.fr/.

[18] G. Cavoto et al., hep-ph/0603019.

[19] A.J. Buras, R. Fleischer, S. Recksiegel and F. Schwab, Eur. Phys. J. C45 (2006) 701 [arXiv:hep-ph/0512032].

[20] M. Bona et al. [UTfit Collaboration], JHEP 0603 (2006) 080 [arXiv:hep-ph/0509219].

[21] S. Aoki et al. [JLQCD Collaboration], Phys. Rev. Lett. 91 (2003) 212001 [arXiv:hep-ph/0307039].

[22] A. Gray et al. [HPQCD Collaboration], Phys. Rev. Lett. 95 (2005) 212001 [arXiv:hep-lat/0507015];
E. Dalgic et al. [HPQCD Collaboration], arXiv:hep-lat/0610104.

[23] A. Abulencia et al. [CDF Collaboration], Phys. Rev. Lett. 97 (2006) 062003 [arXiv:hep-ex/0606027];
A. Abulencia et al. [CDF Collaboration], arXiv:hep-ex/0609040.
[24] A. Lenz and U. Nierste, arXiv:hep-ph/0612167.

[25] P. Ball, S. Khalil and E. Kou, Phys. Rev. D 69 (2004) 115011 [arXiv:hep-ph/0311361].

[26] P. Ball, J. M. Frere and J. Matias, Nucl. Phys. B 572 (2000) 3 [arXiv:hep-ph/9910211];
P. Ball and R. Fleischer, Phys. Lett. B 475 (2000) 111 [arXiv:hep-ph/9912319].