PHENOMENOLOGY OF A $U(2)^3$ FLAVOUR SYMMETRY

FILIPPO SALA
Scuola Normale Superiore and INFN, Piazza dei Cavalieri 7, 56126 Pisa, Italy
Theoretical Physics Group, Lawrence Berkeley National Laboratory, Berkeley, CA 94720

The approximate $U(2)^3$ symmetry exhibited by the quark sector of the Standard Model, broken in specific directions dictated by minimality, can explain the current success of the CKM picture of flavour and CP violation while allowing for large deviations from it at foreseen experiments. The embedding of this symmetry in specific models also leaves space to satisfy collider and precision bounds without spoiling the naturalness of the theory.

1 Introduction

The Standard Model (SM) description of flavour and CP violation (CPV) in the quark sector, encoded in the Cabibbo Kobayashi Maskawa (CKM) matrix, is in very good agreement with any experimental data, leaving in several cases little room for new physics (NP) contributions. In other words if NP effects in flavour and CP violation are parameterized via the effective Lagrangian

$$\Delta\mathcal{L} = \sum_i \frac{1}{\Lambda_i^2}\mathcal{O}_i + \text{h.c.}\,, \tag{1}$$

where $\mathcal{O}_i$ are generic dimension 6 gauge invariant operators obtained by integrating out the new degrees of freedom appearing above the scale Λ_i, one finds that lower limits on the scales Λ_i are in many cases of the order of $10^3 \div 10^4$ TeV [1]. If one believes some new physics has to appear at a scale Λ_{NP} in the TeV range, for example to provide a natural solution to the hierarchy problem, then the flavour and CP structure of the NP theory has to be highly non trivial. A possibility is the requirement for this new theory to respect some flavour symmetry, so that the effective Lagrangian

$$\Delta\mathcal{L} = \sum_i \frac{c_i}{\Lambda_{\text{NP}}^2}\xi_i\,\mathcal{O}_i + \text{h.c.}\,, \tag{2}$$

where ξ_i are small parameters controlled by the symmetry, is in agreement with all current data for coefficients c_i of $O(1)$. Such a goal is achieved if one considers the flavour symmetry $U(2)^3 = U(2)_q \times U(2)_u \times U(2)_d$, which is indeed a symmetry of the SM if one neglects the masses of the first two generation quarks, as well as their small mixing with the third generation ones.

The aim of this short contribution is to let the reader get an idea of how the framework is built, what its main phenomenological features are, and finally of its most interesting experimental and theoretical aspects. A more thorough exposition can be found in [2,3], where we built on previous work in the specific context of Supersymmetry [4,5].

2 Construction of the framework

The logic we follow is assuming that some small parameters in the Yukawa matrices have definite transformation properties under $U(2)^3$, and control at the same time its breaking in any extension of the SM. In order to reproduce the light quark masses, we introduce two spurions $\Delta Y_u \sim (2,\bar{2},1)$ and $\Delta Y_d \sim (2,1,\bar{2})$. We introduce another spurion $\boldsymbol{V} \sim (2,1,1)$ to let the first two generations communicate with the third one. This is the minimal choice that reproduces the correct pattern of masses and mixing angles of the quark sector of the SM. It is dubbed Minimal $U(2)^3$ as opposite to the Generic $U(2)^3$ case [3], where one completes the list of spurions to all the possible breaking terms entering the quark masses, a possibility that will not be further explored here. By appropriate $U(2)^3$ transformations the spurions can be put in the form

$$\boldsymbol{V} = \begin{pmatrix} 0 \\ \epsilon \end{pmatrix}, \qquad \Delta Y_u = L_{12}^u \, \Delta Y_u^{\rm diag}, \qquad \Delta Y_d = \Phi L_{12}^d \, \Delta Y_d^{\rm diag} \tag{3}$$

where ϵ is a real parameter, $\Phi = \mathrm{diag}\big(e^{i\phi}, 1\big)$ and $L_{12}^{u,d}$ are two dimensional rotations. At first order in the spurions the Yukawa matrices read

$$Y_u = y_t \left(\begin{array}{c|c} \Delta Y_u & x_t \boldsymbol{V} \\ \hline 0 & 1 \end{array} \right), \qquad Y_d = y_b \left(\begin{array}{c|c} \Delta Y_d & x_b \boldsymbol{V} \\ \hline 0 & 1 \end{array} \right), \tag{4}$$

so that they are formally invariant under $U(2)^3$ [a].

The diagonalization to the mass basis, which is done perturbatively by taking into account the smallness of the parameters, results in a unique form for the CKM matrix V which depends only on the four $U(2)^3$ parameters: they can then be determined by a direct fit to tree level observables, with the assumption that they are not influenced by NP.

The NP Lagrangian $\Delta\mathcal{L}$ is built using the same spurions, so that its building blocks are bilinears like e.g. $\bar{\boldsymbol{q}}_{\boldsymbol{L}} \boldsymbol{V} \gamma_\mu q_{3L}$ and $y_b \bar{\boldsymbol{q}}_{\boldsymbol{L}} \Delta Y_d \boldsymbol{d}_{\boldsymbol{R}}$, where $\boldsymbol{q}_{\boldsymbol{L}}$ and $\boldsymbol{d}_{\boldsymbol{R}}$ stand for doublets under $U(2)_q$ and $U(2)_d$ respectively. In the mass basis we give as an example, to a sufficient level of approximation, the form of some relevant NP flavour-violating operators [in parentheses the processes they contribute to]:

$$c_{LL}^K \, (V_{ts} V_{td}^*)^2 \, \big(\bar{d}_L \gamma_\mu s_L\big)^2 \qquad \big[K - \bar{K} \text{ mixing}\big], \tag{5}$$

$$c_{LL}^B e^{i\phi_B} \, (V_{tb} V_{ti}^*)^2 \, \big(\bar{d}_L^i \gamma_\mu b_L\big)^2 \qquad \big[B_{d,s} - \bar{B}_{d,s} \text{ mixing}\big], \tag{6}$$

$$c_{7\gamma} e^{i\phi_{7\gamma}} m_b V_{tb} V_{ti}^* \, \big(\bar{d}_L^i \sigma_{\mu\nu} b_R\big) \, e F_{\mu\nu} \qquad \big[b \to s(d)\gamma\big], \tag{7}$$

where c_{LL}^K, c_{LL}^B, $c_{7\gamma}$ are real coefficient, in principle of order one, and in each operator we understood a factor $1/\Lambda^2$. Note that: (i) flavour-violating operators are suppressed by products of the CKM matrix elements, as it happens also in Minimal Flavour Violation [6,7,8] (i.e. considering a $U(3)^3$ symmetry as a starting point and the Yukawa matrices as the spurions); (ii) as in $U(3)^3$, flavour violating operators involving right handed currents are suppressed, for example they do not generate too large dangerous contributions to ϵ_K.

---

[a] In (4) we have extracted out the bottom Yukawa coupling y_b as a common factor, which in principle requires an explanation due to its smallness. One could consider for this pourpose a symmetry, either continuous or discrete, acting in the same way on all the right-handed down-type quarks, broken by the small parameter y_b.

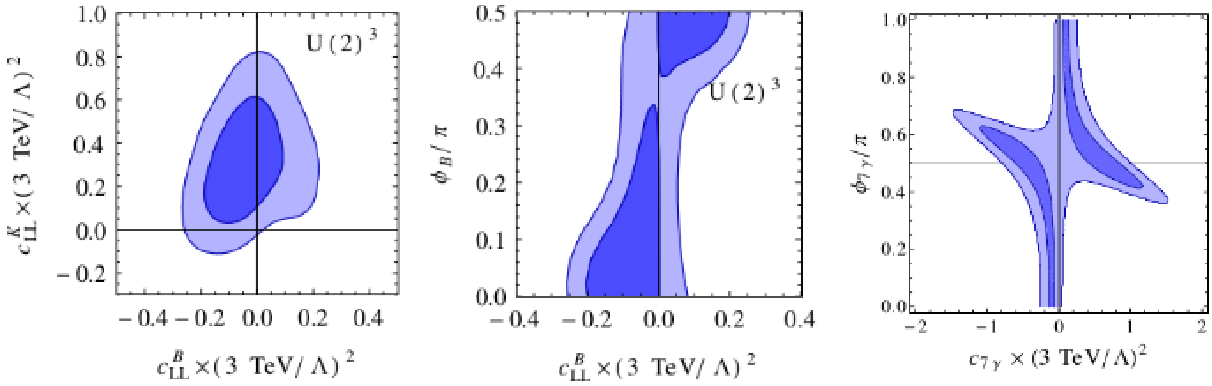

Figure 1: 68 and 95% C.L. allowed regions for some $\Delta F = 2$ (left and centre) and $\Delta F = 1$ (right) coefficients.

3 Bounds and new effects

In Minimal $U(2)^3$ we performed a global fit to the experimental data, the resulting allowed regions for the coefficients of the operators defined in (5), (6) and (7) are shown in Fig. 1. In this derivation we fixed the energy scale Λ to the value of 3 TeV $\simeq 4\pi v$, which can be either the typical scale of a new strong interaction or the one associated with new weakly interacting particles of mass $\simeq v = 246$ GeV circulating in loops.

The constraints on the other operators are similar to those we showed here, so that the picture that emerges is consistent with an effective Lagrangian like (2), with the coefficients $|c_i|$ ranging between 0.2 and 1. Since the NP operators are less constrained than in $U(3)^3$, there is space for larger deviations from the SM at foreseen experiments. As a relevant example we mention that MFV implies $c^B_{LL} = c^K_{LL}$ and $\phi_B = 0$, and that this extra freedom of $U(2)^3$ can also be used to solve the CKM unitarity fit tensions. Many correlations among flavour violating observables emerge when considering $U(2)^3$ in specific BSM theories, see [5] and [9] for detailed discussions in the cases of Supersymmetry and composite Higgs models respectively.

Concerning the up quark sector, one does not expect any sizeable effect neither in CPV in D meson decays nor in flavour changing neutral current (FCNC) top decays at near future experiments.

4 Final messages

A suitably broken $U(2)^3$ flavour symmetry acting on the first two generations of quarks [b] can be consistent with the SM explanation of current experimental data, while allowing from sizeable deviations from it at near future experiments.

Suppose now some NP effect is observed at foreseen experiment: how could one tell if it is compatible with an approximate $U(2)^3$ symmetry of Nature? The most promising way would be to look for correlations in d and s final states of B decays, which would have to be SM-like. This could be actually reproduced by $U(3)^3$ in the presence of two Higgs doublets and at large values of $\tan\beta$ [11,12], but it would in turn imply other peculiar effects which are not necessarily present in $U(2)^3$. In the absence of an extra Higgs doublet (or in the case of small $\tan\beta$) MFV could be distinguished by $U(2)^3$ by means of new CP violating effects in B decays, and/or non SM-like correlations between semileptonic B and K decays. Furthermore, as first noted in [13], this framework also implies a stringent triple correlation $S_{\psi K_S} - S_{\psi\phi} - |V_{ub}|$, where $S_{\psi K_S}$ and $S_{\psi\phi}$ are observables related to CPV in $B - \bar{B}$ mixing that LHCb is measuring with unprecedented

[b] For a possible extension of $U(2)^3$ to the charged lepton sector, both from an EFT point of view and in composite Higgs models, see [2]. For a discussion in Supersymmetry with the inclusion of both charged leptons and neutrinos see [10].

precision.

We conclude by mentioning some virtues of the embedding of $U(2)^3$ in specific *natural* extensions of the SM:

- In Supersymmetry it leaves space to satisfy collider bounds on the masses of the first two generations of squarks, while keeping the third one lighter. Another advantage of the same mass difference is the suppression of undesired EDMs.

- In specific composite Higgs models fermion partners lighter than a TeV, as preferred by naturalness, can be accomodated respecting all flavour and electroweak precision constraints, a possibility that is instead absent if one opts for an anarchic or a $U(3)^3$ flavour structure [14].

Acknowledgments

I thank R. Barbieri, D. Buttazzo, D. M. Straub and A. Tesi for the pleasant collaborations. I also thank the organizers of Moriond EW 2013 for the opportunity to give a talk and for the very nice hospitality.

References

1. Gino Isidori, Yosef Nir, and Gilad Perez. Flavor Physics Constraints for Physics Beyond the Standard Model. *Ann.Rev.Nucl.Part.Sci.*, 60:355, 2010.
2. Riccardo Barbieri, Dario Buttazzo, Filippo Sala, and David M. Straub. Flavour physics from an approximate $U(2)^3$ symmetry. *JHEP*, 1207:181, 2012.
3. Riccardo Barbieri, Dario Buttazzo, Filippo Sala, and David M. Straub. Less Minimal Flavour Violation. *JHEP*, 1210:040, 2012.
4. Riccardo Barbieri, Gino Isidori, Joel Jones-Perez, Paolo Lodone, and David M. Straub. U(2) and Minimal Flavour Violation in Supersymmetry. *Eur.Phys.J.*, C71:1725, 2011.
5. Riccardo Barbieri, Paolo Campli, Gino Isidori, Filippo Sala, and David M. Straub. B-decay CP-asymmetries in SUSY with a $U(2)^3$ flavour symmetry. *Eur.Phys.J.*, C71:1812, 2011.
6. R. Sekhar Chivukula and Howard Georgi. Composite Technicolor Standard Model. *Phys.Lett.*, B188:99, 1987.
7. L.J. Hall and Lisa Randall. Weak scale effective supersymmetry. *Phys.Rev.Lett.*, 65:2939–2942, 1990.
8. G. D'Ambrosio, G.F. Giudice, G. Isidori, and A. Strumia. Minimal flavor violation: An Effective field theory approach. *Nucl.Phys.*, B645:155–187, 2002.
9. David M. Straub. Anatomy of flavour-changing Z couplings in models with partial compositeness. 2013.
10. Gianluca Blankenburg, Gino Isidori, and Joel Jones-Perez. Neutrino Masses and LFV from Minimal Breaking of $U(3)^5$ and $U(2)^5$ flavor Symmetries. *Eur.Phys.J.*, C72:2126, 2012.
11. Thorsten Feldmann and Thomas Mannel. Large Top Mass and Non-Linear Representation of Flavour Symmetry. *Phys.Rev.Lett.*, 100:171601, 2008.
12. Alexander L. Kagan, Gilad Perez, Tomer Volansky, and Jure Zupan. General Minimal Flavor Violation. *Phys.Rev.*, D80:076002, 2009.
13. Andrzej J. Buras and Jennifer Girrbach. On the Correlations between Flavour Observables in Minimal $U(2)^3$ Models. *JHEP*, 1301:007, 2013.
14. Riccardo Barbieri, Dario Buttazzo, Filippo Sala, David M. Straub, and Andrea Tesi. A 125 GeV composite Higgs boson versus flavour and electroweak precision tests. 2012.