LHC EFT WG: Flavour assumptions

Area 1, 3, 6 conveners

January 12, 2022

The aim of this working-group activity is to define consistent flavour scenarios that could realistically be adopted by the ATLAS and CMS collaborations, in the near future, for global SMEFT fits across the Higgs, electroweak and top-quark sectors. These would initially include a limited number of measurements, and progressively increase in complexity. This very preliminary note merely provides a starting point to seed and frame discussions at the 25 Jan 2022 meeting.

Scenarios

Similar in spirit to the TOP WG EFT note [1], a baseline scenario, as well as more or less restrictive variations could be defined. A proposal could be the following:

- Universal scenario[1]

  It assumes new physics only, or dominantly, couples to bosons. All possible bosonic operators are therefore potentially generated. In any specific basis, these may correspond to linear combinations of other operators. A dedicated study was for instance carried out in ref. [2] (see also Table 1 of ref. [3]). A total of 16 CP-even degrees of freedom are present in this case. See eq. (2.23) of ref. [2] for their correspondence to the Warsaw basis commonly used for Monte Carlo simulation. CP-odd degrees of freedom should be considered too. Not being symmetry-based, this scenario is not ~~strictly~~ radiatively stable (see e.g. ref. [4]). & not very motivated / exciting nowadays...

- Top-philic scenario (more restrictive)

  It is assuming new physics only, or dominantly, couples to bosons and top quarks (i.e. the left-handed quark doublet and the right-handed up-type singlet of the third generation). This scenario was defined in section 4.3 of ref. [1] and is for instance appropriate to describe composite-Higgs models where new states dominantly mix with bosons and the top quark. In addition to the degrees of freedom of the universal scenario, it includes 17 CP-even and 4 CP-odd parameters. Not being symmetry-based, this scenario is not ~~strictly~~ radiatively stable.

[1] It does not fully match to the exact $SU(3)^5$-symmetric case since, for instance, it includes the linear combination of Yukawa operators dictated by the equation of motion of the Higgs (provided the corresponding dimension-four Yukawa couplings are present) and does not allow for independent coefficients in each $SU(3)^5$-symmetric four-fermion operator like $\bar{q}\gamma_\mu q\ \bar{u}\gamma^\mu u$ or $\bar{u}\gamma^\mu u\ \bar{d}\gamma_\mu d$.

- consistent, but misses important class of effects (see below)
- why SU(2) vs. U(2) ?

- Exact $\cancel{S}\mathrm{U}(2)_q \times \cancel{S}\mathrm{U}(2)_u \times \mathrm{SU}(3)_d \times \mathrm{SU}(3)_l \times \mathrm{SU}(3)_e$ (baseline)

  Compared to the top-philic scenario, independent coefficients would for instance be allowed for light-quark $\bar{q}\gamma_\mu q$ $\bar{u}\gamma^\mu u$, or heavy-light $\bar{t}\gamma^\mu t$ $\bar{d}\gamma_\mu d$ operators.

  – The symmetry is considered exact and no breaking spurions are included.

  – It can be imposed on dimension-four SM interactions too. In high-energy Monte-Carlo simulations, off-diagonal CKM matrix elements and small Yukawa couplings are often neglected anyway. In this case, this symmetry-based scenario is exactly stable radiatively.

  – For top-quark physics, in the five-flavour scheme, a massless bottom quark is often advantageous. A full $\mathrm{SU}(3)_d$ among all three generations of down-type quarks ensures this. Note that it however forbids the bottom Yukawa which is phenomenologically relevant to describe Higgs decays. (On the other hand, $h \to \mu^+\mu^-$ probably has little interplay with other parameters in global fits.)

- Full-fledged separation of 3rd generation

  ~~One could for instance reduce the exact flavour symmetry in the lepton sector to just~~ ~~$U(1)^3_e \times U(1)^3_l$. To allow for chirality flipping interactions, one could impose the smaller~~ ~~$[U(1)_{l+e}]^3$ instead~~. One might also consider a more restrictive $\boxed{\text{full } U(2)^5 \text{ flavor symmetry,}}$ to describe the universality violation between e, μ versus τ [5]. Keeping only exact terms in the top-Higgs-EW fit, this would amount to ~~147~~ operators, see Table 6 of ref. [5]. Note that this framework allows to fit R_K (μ/e universality in B decays) by subleading operators in the spurion power counting which do not enter top-Higgs-EW fits.

  I

  less... (see below)

  II. b (b_R) vs. light quarks

  + many other BSM with "special" 3rd gen.

  Such a scenario would be motivated by current flavour anomalies. Note however that there is a limited direct interplay with top-Higgs-EW physics (i.e. different sets of operators are involved), the main point of cross-talk being high-mass Drell-Yan [6, 7]. Effects of the magnitude required to account for B anomalies would for instance be difficult to observe in top-quark decays [8]. A global fit of the Higgs, electroweak, and top-quark sectors including LFU-violating effects is thus probably overly challenging given the limited number of operators (~ 50) experiments would realistically be considering in a first iteration. Adopting such a scenario would therefore not be recommended in the near future. Analyses aiming to understand B anomalies in a wider context could be performed with a restricted set of relevant measurements (e.g. high-mass Drell-Yan data with lepton flavours distinguished).

  not only, e.g.
  - $b_R \bar{b}_R \to t\bar{t}$
  - $t\bar{t} + \cancel{E}_T$ (ν_τ)
  - ⋮

  Many ops. related to leptons (other obs.)

In practice, for Monte Carlo simulations, the above scenarios would be achieved by setting some operator coefficients to zero and by correlating others (in parameter or restriction cards). Another strategy, that could facilitate later evolutions, would be to implement the flavour assumptions as fit constraints, for SMEFT dependences computed under less restrictive assumptions.

I think the $U(2)^5$ option worth to be explored in depth

Price to pay limited compared to present "baseline"

$$U(2)_q \times U(2)_u \times SU(3)_d \to U(2)_q \times U(2)_u \times U(2)_d \times U(1)_b \to U(2)^3$$

Operators	$U(2)^5$ *Re*	*Im*	$U(2)^5\times U(1)^2_{b,\tau}$ *Re*	*Im*
Class 1–4	9	6	9	6
$\psi^2 H^3$	3	3	1	1
$\psi^2 X H$	8	8	3	3
$\psi^2 H^2 D$	15	1	14	–
$(\bar{L}L)(\bar{L}L)$	23	–	23	–
$(\bar{R}R)(\bar{R}R)$	29	–	29	–
$(\bar{L}L)(\bar{R}R)$	32	–	32	–
$(\bar{L}R)(\bar{R}L)$	1	1	–	–
$(\bar{L}R)(\bar{L}R)$	4	4	–	–
total:	124	23	111	10

(98)

$U(2)^5\times U(1)^2$ vs. $U(2)^2\times SU(3)^3$

44 vs. 33 [4-quark ops]

+11

36 vs. 19 [2-quark ops]

+5 [at given lepton spec.]

+12 [tau vs. e,μ]

80 52

Faorughi, GI, Wilsch, Yamamoto, 2005.05366