Generic constraints on extra-fermion(s) from the Higgs global fit

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We study the fit of the Higgs boson rates, based on all the collider data, in the effective framework for any Extra-Fermion(s) [EF]. The best-fit results are presented in a generic formalism allowing to apply those for the test of any EF scenario. The variations of the fit with each one of five fundamental parameters are described.

I. INTRODUCTION

Recently, based on the combined LHC data collected at the center-of-mass energies of $\sqrt{s} = 7$ TeV and 8 TeV, the ATLAS [1] and CMS [2] Collaborations have independently announced the discovery at the $\sim 5\sigma$ level of a new resonance – with a mass close to 125 GeV – which can be identified as the missing Standard Model (SM) cornerstone: the Higgs boson [3–6]. The long list of measurements of the various Higgs boson rates provided during these last months by the two LHC Collaborations [7, 8] constitutes a new precious source of experimental results which can be exploited to test and constrain indirectly theories beyond the SM.

Most (if not all) of the proposed theories, underlying the SM, predict the existence of new fermions. In this paper, we combine all the Higgs rate measurements to constrain any model with extra-fermion(s) [of any baryon/lepton number, Yukawa/gauge coupling] that is able to induce corrections to the Higgs couplings [1]. More precisely, by using a generic parametrization, we will determine the corrections to the Higgs couplings – coming from fermion mixing or new loop-level exchanges – which are favored by the fits of the Higgs boson rates. Note that our results also apply to any model with extra scalar field(s) or vector boson(s) leading to significant Higgs interaction deviations, but not through their mixing(s) respectively with the Higgs boson or SM gauge bosons. Then the constraints will be applied to characteristic and well-motivated classes of single Extra-Fermion(s) [EF] scenarios (extra-quarks or extra-leptons) and will reveal themselves to be already quite predictive. Last but not least, the best Higgs rate fits obtained could be seen as first indirect indications of the presence of EF since those fits can be better than the SM fit; another way of seeing this indication will be to observe that the best-fit regions for the EF-induced corrections to the Higgs couplings do not contain the vanishing-correction point (SM point).

Let us note that our fits are performed over the three free parameters $c_b$, $c_gg$ and $c_{\gamma\gamma}$ (related to the $hgg$ and $h\gamma\gamma$ coupling corrections defined later) for characteristic fixed values of $c_\tau$ and $c_t$ [2]; in a second step, we fix $c_b$ for studying examples of EF scenarios ($c_\tau$, $c_b$ and $c_t$ will be defined later on).

II. THEORETICAL FRAMEWORK

A. The physical context

We consider the general framework with any EF able to modify the Higgs couplings. In our context, no other source of physics beyond the SM is responsible for deviations of the Higgs couplings; this choice allows to concentrate one’s efforts on the class of models with EF and in turn to have a deeper analysis of the parameter space. In particular, we assume the Higgs scalar field to receive no coupling modifications due to significant mixings with other scalars as it can occur e.g. in extended Higgs sectors.

[1] The extra-fermions are assumed to be heavier than the Higgs field to avoid new Higgs decay openings (in particular invisible decays into stable particles) that would require special treatments.

[2] In order to explain clearly the influences of these five relevant parameters on the Higgs rate fit, we do not marginalize any of those parameters.
B. The effective Lagrangian

In our framework, all the Higgs couplings receiving corrections can be written in the following effective Lagrangian, which allows to work out the current Higgs phenomenology at the LHC and Tevatron colliders:

\[ L_h = -c_l Y_l \bar{t}_L t_R - c_b Y_b \bar{b}_L b_R - c_t Y_t \bar{t}_L t_R + C_{h\gamma\gamma} \frac{\alpha}{\pi v} h F_{\mu\nu} F^{\mu\nu} + C_{hgg} \frac{1}{12\pi v} h G_{\mu\nu}^a G^a_{\mu\nu} + h.c. \]  

(1)

where \( Y_{t,b,\tau} \) are the SM Yukawa coupling constants of the associated fermions in the mass eigenbasis, \( v \) is the Higgs vacuum expectation value, the subscript \( L/R \) indicates the fermion chirality and the tensor fields in the \( h\gamma\gamma \) and \( hgg \) coupling terms are respectively the electromagnetic and gluon field strengths. The \( c_{t,b,\tau} \) parameters – taken real for simplicity – are defined such that the limiting case \( c_{t,b,\tau} \rightarrow 1 \) corresponds to the SM; deviations from unity of these parameters can be caused by mixings of EF (like \( t' \) states, etc.) with the SM fermions. Neglecting the mixings with the first two SM flavors, one gets, 

\[ Y_{t,b,\tau} = m_{t,b,\tau} / v \]  

where \( m_{t,b,\tau} \) are the final masses generated after EW symmetry breaking. The EF mixing effect on the Yukawa couplings enters via the \( c_{t,b,\tau} \) parameters.

Summing over the dominant loop contributions, the coefficients of the dimension-five operators in Eq. (1) can be written as,

\[ C_{hgg} = 2C(t) [\tau(m_t)] (c_l + c_g) + 2C(b) A[\tau(m_b)] c_b + 2C(c) A[\tau(m_c)], \]

\[ C_{h\gamma\gamma} = \frac{N_f^2}{6} Q_i^2 A[\tau(m_i)] (c_i + c_{\gamma\gamma}) + \frac{N_b^2}{6} Q_i^2 A[\tau(m_b)] c_b + \frac{N_c^2}{6} Q_i^2 A[\tau(m_c)] c_b + \frac{1}{8} A_1[\tau(m_W)], \]

(2)

(3)

where \( m_c \) (\( m_W \)) is the charm quark (\( W^\pm \)-boson) mass, \( C(r) \) is defined for the color representation, \( r \), by \( Tr(T^a_r T^b_r) = C(r) \delta^{ab} \) \( [T^a \) denoting the eight generators of SU(3)\( ] \), \( N_f^r \) is the number of colors for the fermion \( f \), \( Q_f \) is the electromagnetic charge for \( f \), \( A[\tau(m)] \) and \( A_1[\tau(m)] \) are respectively the form factors for spin 1/2 and spin 1 particles normalized such that \( A[\tau(m) \ll 1] \rightarrow 1 \) and \( A_1[\tau(m) \ll 1] \rightarrow -7 \) with \( \tau(m) = m_f^2 / 4m_f^2 \). The terms proportional to \( c_l, c_b \) and \( c_{\gamma\gamma} \) account for the contributions from the fermionic triangular loops involving respectively the top, bottom quark and tau lepton Yukawa coupling. The dimensionless \( c_g \) and \( c_{\gamma\gamma} \) quantities – vanishing in the SM – parametrize the EF loop-exchange contributions to the \( hgg \) and \( h\gamma\gamma \) couplings.

C. Higgs rate modifications

Within the present context, let us write explicitly certain Higgs rates, normalized to their SM prediction, which will prove to be useful in the following. The expression for the cross section of the gluon-gluon fusion mechanism of single Higgs production, over its SM prediction, reads as (for the LHC or Tevatron),

\[ \frac{\sigma_{gg\rightarrow h}}{\sigma_{SM\rightarrow h}} \simeq \left[ \frac{(c_l + c_g) A[\tau(m_t)] + c_b A[\tau(m_b)] + A[\tau(m_c)]}{A[\tau(m_i)] + A[\tau(m_b)] + A[\tau(m_c)]} \right]^2 . \]

(4)

The expression for the ratio of the diphoton partial decay width over the SM expectation is,

\[ \frac{\Gamma_{h\rightarrow \gamma\gamma}}{\Gamma_{SM\rightarrow \gamma\gamma}} \simeq \left[ \frac{1}{2} A_1[\tau(m_W)] + (\frac{1}{2})^2 A[\tau(m_t)] + (\frac{1}{2})^2 A[\tau(m_b)] + (\frac{1}{2})^2 A[\tau(m_c)] \right] \left[ \frac{1}{2} A_1[\tau(m_W)] + (\frac{1}{2})^2 A[\tau(m_t)] + (\frac{1}{2})^2 A[\tau(m_b)] + (\frac{1}{2})^2 A[\tau(m_c)] \right] \].

(5)

The ratios for the partial decay widths into the bottom quark and tau lepton pairs as well as for the cross section of Higgs production in association with a top pair (LHC or Tevatron) are given by,

\[ \frac{\Gamma_{h\rightarrow bb}}{\Gamma_{SM\rightarrow bb}} \simeq |c_b|^2 , \quad \frac{\Gamma_{h\rightarrow t\bar{t}}}{\Gamma_{SM\rightarrow t\bar{t}}} \simeq |c_t|^2 , \quad \frac{\sigma_{h\rightarrow t\bar{t}}}{\sigma_{SM\rightarrow t\bar{t}}} \simeq |c_t|^2 . \]

(6)

Let us make a comment related to the mass insertion in the triangular loops of fermions inducing the \( h\gamma\gamma \) and \( hgg \) couplings. Strictly speaking, a factor \( c_l \), equal to the ratio of the sign of \( m_t \) in the SM over sign\( (m_t) \) in the EF scenario, should multiply \( c_l \) in Eq. (2)-(3) or Eq. (4)-(5) [similarly for \( c_b \) and \( c_{\gamma\gamma} \)]; in other words, if for instance \( c_l = -1 \) the values for \( c_l \) obtained below would have to be interpreted instead as values for \(-c_l \) (the observables of Eq. (6) being insensitive to the \( c_{l,b,\tau} \) signs).
D. Ratio of $c_{\gamma\gamma}$ and $c_{gg}$

For a better understanding of the above parametrization, we finally provide the examples of expressions for the $c_{gg}$ and $c_{\gamma\gamma}$ quantities, in the case of the existence of a $t'$ quark [same color number and electromagnetic charge as the top], an exotic (possibly vector-like) $q_3/3$ quark with electromagnetic charge $5/3$ and an additional $\ell'$ lepton (colorless), in terms of their physical Yukawa couplings and mass eigenvalues:

$$
c_{gg} = \frac{1}{C(t) A[\tau(m_\ell')/v]} \left[ - C(t') \frac{Y_{\ell'}}{m_{\ell'}} A[\tau(m_\ell')] - C(q_{3/3}) \frac{Y_{q_{3/3}}}{m_{q_{3/3}}} A[\tau(m_{q_{3/3}})] + \ldots \right],
$$

$$
c_{\gamma\gamma} = \frac{1}{\Lambda_5^2 Q_f^2 A[\tau(m_t)]/v} \left[ -3 \left( \frac{2}{3} \right)^2 \frac{Y_{t'}}{m_{t'}} A[\tau(m_{t'})] - \Lambda_5^2 q_{3/3} \left( \frac{5}{3} \right)^2 \frac{Y_{q_{3/3}}}{m_{q_{3/3}}} A[\tau(m_{q_{3/3}})] - Q_f^2 \frac{Y_{\ell'}}{m_{\ell'}} A[\tau(m_{\ell'})] + \ldots \right].
$$

(7)

(8)

The dots stand for any other EF loop-contributions. The mass assumption made in Footnote [1] leads to real $A[\tau(m_\ell')]$ functions and thus real $c_{gg}$, $c_{\gamma\gamma}$ values, for real masses and Yukawa coupling constants, as appears clearly in the two above expressions.

It will turn out to be instructive to express the ratio of these parameters in the simplified scenario where a new single $q'$ quark is affecting the Higgs couplings; denoting its electromagnetic charge as $Q_{q'}$ and assuming the $q'$ to have the same color representation as the top quark, this ratio reads as:

$$
\frac{c_{\gamma\gamma}}{c_{gg}} |_{q'} = \frac{Q_{q'}^2}{(2/3)^2}.
$$

(9)

This ratio takes indeed a simple form that will be exploited in Section III D. In particular, notice that $c_{\gamma\gamma}|_{q'} = c_{gg}|_{q'}$. Clearly, $q'$ should have non-vanishing Yukawa couplings to satisfy Eq. (9), otherwise $c_{\gamma\gamma}|_{q'} = c_{gg}|_{q'} = 0$.

In the specific case of a vector-like $q_{3/3}^{L/R}$, this one could for example constitute a singlet under the SU(2)$_L$ gauge group and have a Yukawa coupling with another $q_{3/3}^{R/L}$ state of same $Q_{q'}$ charge but embedded in a SU(2)$_L$ doublet; then the heaviest $q_{3/3}^{(2)}$, mass eigenstate, composed of $q_{3/3}^{L/R}$ and $q_{3/3}^{L'/R}$, could decouple from the Higgs sector so that the orthogonal $q_{3/3}^{L/R}$ composition would represent the considered unique new quark influencing significantly the Higgs couplings.

III. THE HIGGS RATE FITS

A. The data

All the Higgs rates which have been measured at the Tevatron and LHC [for $\sqrt{s} = 7$ and 8 TeV] have been summarized in Ref. [9]. The latest experimental values can be found in Ref. [7, 8]. Generically, the measured observables are the signal strengths whose theoretical predictions read as:

$$
\rho_{s,c,i}^p = \frac{\sigma_{gg-hh}^p |_{s,c,i}}{\sigma_{gg-hh}^p |_{s,c,i}^\text{SM}}, \quad \sigma_{hh}^p |_{s,c,i} = \frac{\sigma_{hh}^p |_{s,c,i}^\text{SM}}{\sigma_{hh}^p |_{s,c,i}^\text{SM}},
$$

with

$$
\sigma_{gg-hh} = \frac{\sigma_{gg-hh}^s |_{s,c,i}}{\sigma_{gg-hh}^s |_{s,c,i}^\text{SM}}, \quad \sigma_{hh}^p |_{s,c,i} = \frac{\sigma_{hh}^p |_{s,c,i}^\text{SM}}{\sigma_{hh}^p |_{s,c,i}^\text{SM}},
$$

$$
\Gamma_{h\to\gamma\gamma} = \frac{\Gamma_{h\to\gamma\gamma}^s |_{s,c,i}}{\Gamma_{h\to\gamma\gamma}^s |_{s,c,i}^\text{SM}}, \quad \Gamma_{h\to 5b} = \frac{\Gamma_{h\to 5b}^s |_{s,c,i}}{\Gamma_{h\to 5b}^s |_{s,c,i}^\text{SM}}, \quad \Gamma_{h\to 7\ell} = \frac{\Gamma_{h\to 7\ell}^s |_{s,c,i}}{\Gamma_{h\to 7\ell}^s |_{s,c,i}^\text{SM}},
$$

where the $p$-exponent labels the Higgs channel defined by its production and decay processes, the $s$-subscript represents the squared of the energy [we will note $\sqrt{s} = 1.96, 7, 8$ in TeV] of the realized measurement, the $c$-subscript stands for the experimental collaboration (CDF and D0 at the Tevatron, ATLAS or CMS at LHC) having performed the measurement and $i$ is an integer indicating the event cut category considered. $\sigma_{q_{3/3}^{L/R}}$ is the predicted cross section for the Higgs production in association with a pair of light SM quarks and $\sigma_{hL}$ is for the production in association with a gauge boson [$V = Z^0, W^\pm$ bosons]; their $s$-subscript indicates the energy and in turn which collider is considered. $c_{gg-hh}$, for the gg → h reaction example, is the experimental efficiency including the (kinematical) selection cut effects.

\[ \text{3} \]
B. The fit procedure

In order to analyze the fit of the Higgs boson data from colliders within the effective theory described above, we assume gaussian error statistics and we use the $\chi^2$ function,

$$\chi^2 = \sum_{p,s,c,i} \frac{(\mu^P_{s,c,i} - \mu^P_{s,c,i} | \text{exp})^2}{(\delta \mu^P_{s,c,i})^2},$$

(11)

where the sum is taken over all the different channel observables and $\mu^P_{s,c,i} | \text{exp}$ are the measured central values for the corresponding signal strengths. $\delta \mu^P_{s,c,i}$ are the uncertainties on these values and are obtained by symmetrizing the provided errors below and above the central values: $(\delta \mu^P_{s,c,i})^2 = [(\delta \mu^P_{s,c,i} | ^{+})^2 + (\delta \mu^P_{s,c,i} | ^{-})^2] / 2$. $\mu^P_{s,c,i} | \text{exp}$ and $\delta \mu^P_{s,c,i}$ are given in the experimental papers.

C. Numerical results and discussions

Having the three free parameters, $c_{bg}, c_{\gamma\gamma}, c_t$, we now determine the best-fit domains in this three-dimensional space at 68.27%C.L. (1$\sigma$), 95.45%C.L. (2$\sigma$) and 99.73%C.L. (3$\sigma$) which correspond to established values of $\Delta \chi^2 = \chi^2 - \chi^2_{\text{min}}$ ($\chi^2_{\text{min}}$ being the minimum $\chi^2$ value reached in the $\{c_{bg}, c_{\gamma\gamma}, c_t\}$ space).

In Fig. (1), we present slices at several $c_t$ values of the best-fit regions at 68.27%C.L., 95.45%C.L. and 99.73%C.L. in the plane $c_{\gamma\gamma}$ versus $c_{bg}$, in the case $c_t = 1$ and for different fixed values of $c_t$.

The best-fit points reachable, when varying the three free parameters, $c_t, c_{bg}, c_{\gamma\gamma}$, for fixed values $c_t = 1$ and $c_t = 1$, are at $c_t = 2.08$ and the $c_{bg}, c_{\gamma\gamma}$ values corresponding to the four crosses drawn in Fig. (1)[c]. Since there are exact symmetries along the $c_{bg}$ and $c_{\gamma\gamma}$ axes (see discussion below), those four cross-points are all associated to the same $\chi^2_{\text{min}} = 52.36$.

This minimal $\chi^2$ value is smaller than the SM one, $\chi^2_{\text{SM}} = 57.10$ [from taking all the strength predictions at unity in Eq. (11)]. The regions at 68.27%C.L. in Fig. (1)[b] do not even contain the SM point $\{c_t = 1; c_{bg} = 1; c_{\gamma\gamma} = 0\}$. We observe on Fig. (1)[a,b,c] that a $c_t$ variation of amount, $\delta c_t$, leads in a good approximation to a translation (no shape modification) of $-\delta c_t$ along both the $c_{\gamma\gamma}$ and $c_{bg}$ axes, for each one of the three best-fit regions. It is particularly clear in Fig.(1)[b] where a large $\delta c_t$ is exhibited. This strong parameter interdependence implies that in order to determine experimentally the $c_{\gamma\gamma}$ and $c_{bg}$ quantities, it is crucial to determine as well the $c_t$ Yukawa correction.

Concerning the $c_t$ variation (for fixed $c_t = c_t$ = 1), we first explain the impact of the $c_t$ increase on the typical $c_{\gamma\gamma}$ values – starting from the best-fit domains around the best-fit point, $c_t = 2.08; c_{bg} = 0.66; c_{\gamma\gamma} = -1.09$, in Fig.(1)[c] – and the reasons why huge values up to $c_t \approx 50$ could still agree with present Higgs rate fits. For such a $c_t$ increase, the strengths are reduced via $\Gamma_{h \rightarrow f \bar{f}b}$, a reduction which has to be compensated by a $\sigma_{gg \rightarrow h b}$ increase through a $c_{gg}$ enhancement to conserve a satisfactory $\chi^2$ (or equivalently here, $\Delta \chi^2$). This explains the shift of the considered best-fit domains, around $c_t = 2.08; c_{bg} = 0.66; c_{\gamma\gamma} = -1.09$ in Fig.(1)[c], to higher $c_{bg}$ values in the plot [d] where $c_t = 10$ (still with $c_t = 1$). This necessary compensation between the $\Gamma_{h \rightarrow f \bar{f}b}$ and $\sigma_{gg \rightarrow h b}$ increases also guarantees the stability of diphoton rates (there is also a significant gluon-gluon fusion contribution in the three dijet-tagged final states) letting the $\chi^2$ at the same level, without $c_{\gamma\gamma}$ modifications – explaining nearly identical $c_{\gamma\gamma}$ values for the studied regions in Fig.(1)[c] and [d]. The $\Gamma_{h \rightarrow f \bar{f}b}$ increase leads to enhancements of the strengths without major consequences on the fit; a $c_t$ increase up to $\sim 50$ (leading to $\Gamma_{h \rightarrow f \bar{f}b} \lesssim 5$ GeV) would still leave existing domains at 68.27%C.L. since in the theoretical limit, $c_b \rightarrow \infty$, $B_{h \rightarrow f \bar{f}b}$ tends obviously to a finite value compatible with data : $B_{h \rightarrow f \bar{f}b} \rightarrow 1$.

What is the experimental impact of the above $c_t$ analysis? The present experimental results do not prevent $c_t$ from taking extremely large values – due in particular to Higgs rate compensations. In order to put a more stringent experimental upper limit on it, one could of course if possible improve the accuracies on the signal strengths involving $\sigma_{gg \rightarrow h b}$ and $\Gamma_{h \rightarrow f \bar{f}b}$. A new possibility to measure $c_b$ (or equivalently the bottom Yukawa coupling constant) would be to investigate the processes, $q_q \rightarrow h b b$ and $g g \rightarrow h b b$ (or $b b \rightarrow h$ and $b q \rightarrow h b$), followed by the decay, $h \rightarrow b b$. Indeed, here both the production and decay rates should increase with $c_b$ ($\Gamma_{h \rightarrow f \bar{f}b}$ being the dominant partial width) so that compensations should not occur; then too large $c_b$ values would be experimentally ruled out. This Higgs production in association with bottom quarks could have
FIG. 1: Best-fit regions at 68.27% C.L., 95.45% C.L. and 99.73% C.L. in the plane \( c_{\gamma\gamma} \) versus \( c_{\gamma\gamma} \), for \( c_\tau = 1 \). Each one of the four figures is associated to a certain \( c_b \) amount written on the figure itself. In each figure, the regions are drawn for three \( c_\tau \) values, the corresponding value being indicated nearby the relevant region; the regions for the lowest, intermediate, highest \( c_\tau \) values are respectively shown by plain contours, filled domains, dotted contours. The SM point at, \( c_\tau = c_b = c_\tau = 1 \), \( c_{\gamma\gamma} = c_{\gamma\gamma} = 0 \), is shown. Also represented are the predicted lines for a \( b' \) and a \( t' \) extra-quark. Finally, the four best-fit point locations are indicated by crosses in the plot [c].

significant cross sections for high LHC luminosities and enhanced \( c_b \) values compared to the SM as the present fit points out. The sensitivity to such a reaction relies deeply on the b-tagging capability. This reaction suffers from large QCD backgrounds but new search strategies have been developed for such a bottom final state topology, as in Ref. [10].

D. Effective EF scenarios

In this last section, we apply the above constraints from the Higgs rate fit to examples of simple scenarios where a unique EF state significantly affects the Higgs interactions. For instance, a \( b' \) state [same color representation and electromagnetic charge as the bottom quark], that could be a light custodian top-partner in warped/composite frameworks, would lead to a ratio in Eq. (9), \( (c_{\gamma\gamma}/c_{\gamma\gamma})b' = 1/4 \), corresponding to the straight line drawn on Fig.(1)[c,d]. Generically, a \( b' \) would be mixed with the SM bottom so that possibly, \( c_b \neq 1 \), whereas one would have, \( c_\tau = c_\tau = 1 \) – like in Fig.(1)[c,d]. These figures show that there exist \( c_{\gamma\gamma} \), \( c_{\gamma\gamma} \) and \( c_b \) values for which the predicted \( b' \) line crosses the 68.27% C.L. region. The simultaneous knowledge of the exact position on the \( b' \) line and the \( c_b \) value fixing the C.L. regions, necessary to determine the goodness of fit, requires the specification of the bottom mass matrix and hence of the considered model.
The other example of EF candidate able to be mixed with SM quarks is the $t'$ state, possibly constituted e.g. by a light top-partner in little Higgs models. For a dominant $t'$ state, the ratio of Eq. (9) tends to one which corresponds to the straight line on Fig.(1)[b]. Since a $t'$ field can mix with the top quark, $c_t \neq 1$, but in the context of a single $t'$ one should have, $c_b = c_t = 1$, as in Fig.(1)[b]. The predicted $t'$ line crosses two 95.45%C.L. regions e.g. for, $c_t = 0.5$, as well as two 68.27%C.L. regions exclusively in the range, $c_t \sim 1.1 \leftrightarrow 2.6$ (above $\sim 2.6$ the region sizes decrease as explained in previous section).

For a single extra-lepton with charge, $Q_{\ell'} = -1$, potentially mixed with the $\tau$-lepton, the parameters, $c_b = c_t = 1, c_{gg} = 0$ [see Eq. (7)], are fixed and there remain two free effective parameters, namely $c_{\gamma\gamma}$ and $c_{\tau}$. The best-fit regions for such a two-dimensional fit are presented in Fig.(2). The two best-fit points shown in this figure correspond to $\chi^2_{\min} = 52.54$.

It would also be possible theoretically that the new $t'$ and $b'$ particles do not mix with the SM top and bottom quarks. It would be the case also for additional $q'$ quarks with exotic electric charges. For illustration, let us first concentrate on the components of possible extensions of the SM quark multiplets under $SU(2)_L$, as in warped/composite frameworks where SM multiplets are promoted to representations of the custodial symmetry [11–18]. The charges for such $q'$ components obey the relation, $Y_{q'} = Q_{q'} - I_{3L}^q$ ($Y \equiv \text{hypercharge}, I_{3L} \equiv SU(2)_L$ isospin). We will consider the electric charges of smallest absolute values, $Q_{q'} = -1/3, 2/3, -4/3, 5/3, -7/3$ and 8/3, keeping in mind that the naive perturbative limit on the electric charge reads as, $|Q_{q'}| \lesssim \sqrt{4\pi/\alpha} \simeq 40$ ($\alpha \equiv$ line-structure constant). The $q'$ states are in the same color representation as the SM quarks.

In the case of the presence of such a $q'$ quark, unmixed with SM quarks, while $c_t = c_b = c_{\tau} = 1$, one has $c_{\gamma\gamma} \neq 0$ and $c_{gg} \neq 0$ if the $q'$ state possesses non-zero Yukawa couplings. The best-fit domains for a two-dimensional fit keeping the fixed parameters, $c_t = c_b = c_{\tau} = 1$, are shown in Fig.(2) together with the four best-fit points associated to $\chi^2_{\min} = 55.04$. On this plot, we also represent the theoretically predicted regions in the cases of a single $q'$ quark with electric charge $Q_{q'}$ : these regions are the straight lines defined by Eq. (9). All the predicted lines – whatever is the $Q_{q'}$ charge – cross the SM point which is reached in the decoupling limit, $c_{\gamma\gamma} \rightarrow 0, c_{gg} \rightarrow 0$. The first result is that the upper-left best-fit regions, around $c_{\gamma\gamma} \sim 8, c_{gg} \sim -1.8$, cannot be explored in single $q'$ models [no line can reach it]. We also observe on Fig.(2) that the predicted line being the closest to a best-fit point is for, $Q_{q'} = -7/3$. This result means that, among any possible SM multiplet extension component, the fit prefers the $q-7/3$ state compared for example to a $t'$ or $q_5/3$ state. This prediction is independent of the $Y_{q'}$ Yukawa coupling constants, the $q'$ mass values and the $q'$ representations under $SU(2)_L$.

Now we determine the physical parameters corresponding typically to an overlap between a given line in

FIG. 2: Left - Best-fit regions at 68.27%C.L., 95.45%C.L. and 99.73%C.L. in the plane $c_{\gamma\gamma}$ versus $c_{\tau}$, for the case of an extra-lepton with electric charge, $Q_{\ell'} = -1$, corresponding to $c_t = c_b = 1, c_{gg} = 0$. The two best-fit points are indicated. Right - Best-fit regions at 68.27%C.L., 95.45%C.L. and 99.73%C.L. in the plane $c_{\gamma\gamma}$ versus $c_{gg}$, for $c_t = c_b = c_{\tau} = 1$. Also represented are the predicted (plain) lines for extra-quarks with the several electric charges, $Q_{q'} = -1/3, 2/3, -4/3, 5/3, -7/3$ and 8/3. The extreme (dashed) lines for, $Q_{q'} = 0$, and, $|Q_{q'}| = |Q_{q'}|_{\text{pert.}} = \sqrt{4\pi/\alpha}$, are shown as well. The four best-fit points are indicated.
As described at the end of Section II C, strictly speaking the $\epsilon_{t,b,\tau}$ parameters entering Eq. (4)-(5) – whose values...

Fig. (2) and the best-fit regions; we consider the characteristic examples of the charges, $Q_{q'} = -1/3$, 5/3 and 8/3. More precisely, we plot in Fig. (3) the regions in the plane $|m_{q'}|$ versus $\tilde{Y}_{q'} = -Y_{q'}/\text{sign}(m_{q'})$ which correspond [see Eq. (7)-(8)] to $c_{\gamma\gamma}$, $c_{\gamma g}$ quantities giving rise to the best $\Delta \chi^2$ values in the case of one free effective parameter, say $c_{\gamma g}$ (related to $c_{\gamma \gamma}$ through the fixed ratio $c_{\gamma \gamma}/c_{\gamma g} |q'| \sim Q_{q'}^2$).

In Fig. (3), we also illustrate the case of a single additional $\ell'$-lepton (colorless) without significant mixing to SM leptons $[c_{\tau} = 1]$, as may be justified by exotic $Q_{\ell'}$ charges or the large mass difference between the SM and extra-leptons. Here we choose, $Q_{\ell'} = -1$, being quite common for extra-lepton scenarios. There is, again, a unique free effective parameter, $c_{\gamma \gamma}$, since $c_{\gamma g} = 0$.

Concerning the constraints on the signs, as shown in Fig. (3) based on the present Higgs data, the sign, $\tilde{Y}_{q'} < 0$ [leading to $c_{\gamma \gamma} < 0$], is preferred at 68.27% C.L. [except with absolute charges, $|Q_{q'}| \gtrsim 7$, i.e. in a range close to the $|Q_{q'}|_{\text{pert}}$ limit as illustrated in Fig. (2)] for any single extra-quark as it creates a constructive interference with the $W^\pm$-boson exchange increasing the diphoton rates. The specific sign configuration, $\tilde{Y}_{q'} < 0$, is selected by the two relevant best-fit points which pin down, $c_{\gamma \gamma} < 0$, as obtained for extra-quarks in Fig. (2). This predicted condition means that the Yukawa coupling constant $[-Y_{q'}$ in our conventions] must have a sign opposite to $m_{q'}$ which could be written,

$$\text{sign}(\frac{-Y_{q'}}{m_{q'}}) < 0.$$  \hspace{1cm} (12)

Related to this condition, there are comments on the configuration denoted as dysfermiophilia in the literature.
are generally given in best-fit plots such as the present ones in Fig.(1) – should in fact be understood as being,

$$c_t c_\ell = \frac{\text{sign}(m_t)}{\text{sign}(m_{t}^{\text{EF}})} c_t = \frac{\text{sign}(m_t)}{\text{sign}(m_{t}^{\text{EF}})} \frac{\text{sign}(-Y_{t}^{\text{EF}})}{\text{sign}(Y_{t})} |c_t| = \frac{\text{sign}(-Y_{t}^{\text{EF}})}{\text{sign}(Y_{t})} |c_t| = \left(\frac{-Y_{t}^{\text{EF}}}{m_{t}^{\text{EF}}} \right) \left| Y_{t}^{\text{EF}} \right| \frac{1}{Y_t},$$

in our conventions of Lagrangian (1), and similarly for $c_b, c_{b}\tau, c_{t}\tau$; here the EF-exponent indicates that the parameter is considered within the context of an EF model (and remind that $m_t, Y_t$ are in the SM). Therefore, the **dysfermiophilia** property of increasing, $\Gamma_{h \rightarrow \gamma\gamma}/\Gamma_{h \rightarrow \gamma\gamma}^{\text{SM}}$, via changing the top Yukawa sign is in fact relying on the possibility to have, $c_t c_\ell < 0$, or equivalently, $\text{sign}(-Y_t^{\text{EF}}/m_{t}^{\text{EF}}) < 0$. This makes sense as it is the sign of, $-Y_{t}^{\text{EF}}/m_{t}^{\text{EF}}$, which has a physical meaning and appears in $\Gamma_{h \rightarrow \gamma\gamma}$ [see Eq. (8) for an analogy with the $t'$-loop]. The other comment is that the **dysfermiophilia** possibility of having, $c_t c_\ell < 0$, can indeed gives rise to an acceptable agreement with the Higgs data (see e.g. Fig.(1)[d]) but it is not necessary to achieve a good agreement (c.f. Fig.(2) where $c_t c_\ell = 1$) since the constructive interference with the $W^\pm$-loop increasing the diphoton rates can be realized with an EF-loop inducing, $c_{\gamma \gamma} < 0$.

Hence the above condition (12) can be called an **extra-dysfermiophilia** as it is exactly the same as for the top quark transposed to an EF. Besides, this condition (12) leads to a decrease of, $\sigma_{gg \rightarrow h}/\sigma_{gg \rightarrow h}^{\text{SM}}$, for a single EF [see Eq. (7)] through negative $c_{gg}$ values [c.f. Fig.(2)].

IV. CONCLUSIONS

We have studied the behaviour of the global Higgs fit with the variations of fundamental parameters in the simplified scenario with extra-fermions and have learnt in particular that the determination of the Higgs couplings is difficult and sometimes suffers from correlations. We have also shown that the global fit allows quite simply to constrain the electric charge (and color) of EF. The **extra-dysfermiophilia** has also been clearly defined and pointed out as a present general prediction (for more details, see Ref. [19]).

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