Electroweak theory and global fit

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Abstract. We perform the fit of electroweak precision observables within the Standard Model with a 126 GeV Higgs boson, compare the results with the theoretical predictions and discuss the impact of recent experimental and theoretical improvements. We introduce New Physics contributions in a model-independent way and fit for the S, T and U parameters and for a modified Higgs coupling to vector bosons. We point out that composite Higgs models are very strongly constrained. Finally, we compute the bounds on dimension-six operators relevant for the electroweak fit.

Electroweak Precision Observables (EWPO) have played a key role in constraining New Physics (NP) for the past twenty years [1–11]. The most striking examples of the power of these indirect constraints are the prediction of the top and Higgs masses. The experimental situation improved dramatically in the past year, with the precise measurement of the Higgs mass at the LHC [12, 13]. In addition, the information on other key Standard Model (SM) parameters such as the top and W boson masses has increased considerably, leading altogether to a sizable progress in the electroweak (EW) fit. It is therefore phenomenologically relevant to reassess the constraining power of the EW fit in the light of these recent experimental improvements. To this aim, we perform the EW fit in the SM and update the constraints on oblique NP. On the theory side, the full two-loop fermionic EW contributions to the R_b^0 observable have been recently numerically calculated in ref. [14]. The implementation of this result in the global fit has a large impact but represents a nontrivial problem, as we illustrate in detail below. A very interesting question that can be tackled with present data is whether the Higgs boson is elementary or composite. Using a general effective Lagrangian for Higgs boson interactions [15–18], we analyze the constraints on the Higgs coupling to vector bosons, and find out that this coupling can be determined from the fit with an uncertainty of 5% at 95% probability, while much larger departures from the SM value are expected in generic composite Higgs models. Thus, the EW fit points to an elementary Higgs or to composite Higgs models in which additional contributions are present to restore the agreement with EWPO. Finally, we consider the most general effective Lagrangian relevant

for EWPO and compute the constraints on the coefficients of dimension six operators, which can be translated into lower bounds on the NP scale assuming a given value for the couplings.

The part of the SM Lagrangian relevant for the computation of EWPO can be defined in terms of the following free parameters: the fine structure constant α, the muon decay constant G_μ, the Z boson mass M_Z, the strong coupling $\alpha_s(M_Z^2)$, the top quark mass m_t and the Higgs mass m_h. In addition, we introduce the effective parameter $\Delta\alpha_{\text{had}}^{(5)}(M_Z^2)$ to take into account the hadronic contribution to the running of α. In terms of the seven parameters above, the SM prediction for all other EWPO can be computed. The recent measurements of m_h by the ATLAS and CMS experiments are given by

$$m_h = \begin{cases} 125.5 \pm 0.2\,(\text{stat})^{+0.5}_{-0.6}\,(\text{syst})\,\text{GeV} & \text{ATLAS,} \\ 125.7 \pm 0.3\,(\text{stat}) \pm 0.3\,(\text{syst})\,\text{GeV} & \text{CMS.} \end{cases}$$

We adopt the average $m_h = 125.6 \pm 0.3$ GeV in the current study. According to ref. [19, 20], the world average of $\alpha_s(M_Z^2)$ from the fit to various data, excluding the EW precision measurements, is given by $\alpha_s(M_Z^2) = 0.1184 \pm 0.0006$. For the hadronic contribution to the running of the electromagnetic coupling, we adopt the recent evaluation $\Delta\alpha_{\text{had}}^{(5)}(M_Z^2) = 0.02750 \pm 0.00033$ in ref. [21]. In the absence of a world average for the top pole mass, we adopt the Tevatron average $m_t = 173.18 \pm 0.56\,(\text{stat}) \pm 0.75\,(\text{syst})$ GeV $= 173.2 \pm 0.9$ GeV [22], fully compatible with the LHC result $m_t = 173.3 \pm 0.5\,(\text{stat}) \pm 1.3\,(\text{syst})$ GeV [23]. The renormalization group runnings of the strong coupling constant and the fermion masses are taken into account up to three-loop level [24–26]. The measurement of the Z boson mass is taken from LEP: $M_Z = 91.1875 \pm 0.0021$ GeV [27]. Finally, the parameters G_μ and α are fixed to be constants: $G_\mu = 1.1663787 \times 10^{-5}$ GeV^{-2} and $\alpha = 1/137.035999074$, respectively [19].

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The SM contributions to the EWPO have been calculated very precisely including higher-order radiative corrections. For a recent discussion of the theoretical status of EWPO we refer the reader to ref. [28]; here we focus on the discussion of the calculation of fermionic two-loop corrections to the $Zb\bar{b}$ vertex. The complete two-loop formulæ for the coupling ρ_Z^f are currently missing. Recently, the complete fermionic two-loop EW corrections have been calculated for $R_b^0 = \Gamma_b/\Gamma_h$ in ref. [14], where an approximate formula has been presented. However, from this approximate formula alone we cannot extract the values of ρ_Z^f including fermionic two-loop corrections, that are necessary to compute other ρ_Z^f-dependent observables such as R_ℓ^0, R_c^0, Γ_Z and the hadronic cross section. The authors of ref. [14] have kindly provided us with the approximate formulæ for Γ_u/Γ_b and Γ_d/Γ_b [29], which allow us to use the experimental information on one more observable in addition to R_b^0. To illustrate the impact of these two-loop corrections, we present our results for the SM fit in two scenarios. First, we use only the previously known leading and (where available) next-to-leading two-loop EW contributions of $O(G_\mu^2 m_t^4)$ and $O(G_\mu^2 m_t^2 M_Z^2)$ in the large-m_t expansion, together with the leading three-loop corrections of $O(G_\mu^2 \alpha_s m_t^4)$ and $O(G_\mu^3 m_t^6)$. Second, we use the approximate formulæ for Γ_u/Γ_b and Γ_d/Γ_b adding three free parameters to the fit, which represent the unknown corrections to ρ_Z^ν, ρ_Z^ℓ and ρ_Z^b. The corrections to $\rho_Z^{u,d}$ can then be determined using the formulæ for Γ_u/Γ_b and Γ_d/Γ_b. This is the optimal use we can make of the presently available theoretical information. It will be interesting to compare the fitted values of $\delta\rho_Z^\nu$, $\delta\rho_Z^\ell$ and $\delta\rho_Z^b$ with the theoretical expressions, once these will be available. As we shall see below, the corrections computed in ref. [14, 29] are surprisingly large, so that an independent check of the computation would be very useful.

The latest Tevatron average of the W-boson mass is $M_W = 80.385 \pm 0.015$ GeV [30]. We use the results for Γ_Z, σ_h^0, P_τ^{pol}, $\mathcal{A}_f$, $A_{\mathrm{FB}}^{0,f}$ and R_f^0 from SLD/LEP-I [27, 31] and Γ_W from LEP-II/Tevatron [32]. All experimental inputs are summarized in the second column of table 1, where we take into account the correlations among the inputs that can be found in ref. [31].

In the third column of table 1 we present the results of the SM fit obtained using the top pole mass and the expressions for Γ_u/Γ_b and Γ_d/Γ_b from refs. [14, 29]. As discussed above, in this case we do not have enough information to compute Γ_Z, σ_h^0 and R_ℓ^0 at the same level of accuracy of R_b^0 and R_c^0. We therefore add three free parameters to the fit, representing the fermionic two-loop corrections $\delta\rho_Z^\nu$, $\delta\rho_Z^\ell$ and $\delta\rho_Z^b$. These parameters affect only the observables Γ_Z, σ_h^0 and R_ℓ^0. In this way, while we cannot predict Γ_Z, σ_h^0 and R_ℓ^0, we obtain a posterior for the parameters $\delta\rho_Z^\nu$, $\delta\rho_Z^\ell$ and $\delta\rho_Z^b$, which can be compared to the theoretical expressions once they become available. The other parameters $\delta\rho_Z^u$ and $\delta\rho_Z^d$ are determined from $\delta\rho_Z^b$ through Γ_u/Γ_b and Γ_d/Γ_b, respectively. Notice that fits performed using the formula for R_b^0 from ref. [14] and the formulæ for ρ_Z^f from ref. [34] are inconsistent, since the change in R_b^0 implies a change in $R_{c,\ell}^0$, Γ_Z and σ_h^0. Furthermore, the
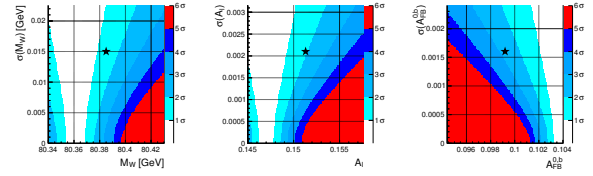

Figure 1. Compatibility plots of M_W, $\mathcal{A}_\ell$ and $A_{\mathrm{FB}}^{0,b}$. Any direct measurement corresponds to a point in the (central value, experimental error) plane, and its compatibility with the indirect determination is given in numbers of standard deviations by the color coding. The present experimental result is indicated by a star.

results of ref. [14] imply much larger two-loop fermionic corrections than expected from the expansion in ref. [34]. In fact, we can estimate the size of the unknown two-loop corrections as follows:

$$\delta\rho_Z^q - \delta\rho_Z^b \approx \frac{\Gamma_q/\Gamma_b - \Gamma_q'/\Gamma_b'}{\Gamma_q'/\Gamma_b'} = \begin{cases} 4.8 \times 10^{-3} & \text{for } q = u\,, \\ 4.4 \times 10^{-3} & \text{for } q = d\,, \end{cases}$$

where Γ_f (Γ_f') denotes a partial width including (omitting) the contribution from $\delta\rho_Z^f$, and the approximation $\rho_Z^f \approx 1$ has been used. Since these corrections are comparable in size to one-loop contributions, it would be desirable to have an independent confirmation of the calculation of ref. [14].

From the fit we also obtain posteriors for the SM parameters $\alpha_s(M_Z^2)$, $\Delta\alpha_{\mathrm{had}}^{(5)}(M_Z^2)$, M_Z, m_t and m_h (see table 1).

To show the impact on the fit of the new calculation of R_b^0 [14], we present in table 2 the results obtained using instead refs. [34–40] for the leading and next-to-leading terms in the large-m_t expansion for two-loop fermionic EW corrections to ρ_Z^f. As can be seen by comparing with the full results, the tension in R_b^0 is reduced. Notice that the indirect determination of $\alpha_s(M_Z^2)$ is much more precise in this case since we are not considering large unknown fermionic corrections to ρ_Z^f.

Let us now discuss the compatibility of the SM prediction with experimental data. To this aim, we use the compatibility plots introduced in ref. [33], where the difference in standard deviations between the fit prediction and the experimental result is given by the color coding.

The compatibility of M_W, $\mathcal{A}_\ell$ and $A_{\mathrm{FB}}^{0,b}$ is shown in figure 1. While these results are stable against the inclusion of the recently calculated two-loop fermionic corrections to R_b^0, the compatibility of R_b^0 is worsened by the inclusion of the results in ref. [14], as can be seen by comparing the plots in figure 2.

Our numerical results agree with those obtained using the ZFITTER package [41–44]. Our fit results are compatible with the ones obtained by the LEP Electroweak Working Group [32] and also with the ones in refs. [45, 46]. A comparison with the recent Gfitter group fits [47, 48] is not straightforward since the result for R_b^0 of ref. [14] has been used without correspondingly modifying other Γ_q-related observables and without accounting for other possibly large fermionic two-loop corrections.

Table 1. Summary of experimental data and fit results in the SM, including the subleading two-loop fermionic EW corrections to ρ_Z^f with the results of ref. [14, 29] and introducing the parameters $\delta\rho_Z^{\nu,\ell,b}$. The values in the column "Indirect" are determined without using the corresponding experimental information. The last column shows the pulls in units of standard deviations evaluated from the p.d.f.'s of "Data" and "Indirect" as explained in ref. [33]. For completeness we also report the fit result for $\delta\rho_Z^{u,d}$ computed from $\delta\rho_Z^b$ using $\Gamma_{u,d}/\Gamma_b$.

	Data	Fit	Indirect	Pull
$\alpha_s(M_Z^2)$	0.1184 ± 0.0006	0.1184 ± 0.0006	0.078 ± 0.024	-1.9
$\Delta\alpha_{\mathrm{had}}^{(5)}(M_Z^2)$	0.02750 ± 0.00033	0.02742 ± 0.00026	0.02728 ± 0.00043	-0.4
M_Z [GeV]	91.1875 ± 0.0021	91.1878 ± 0.0021	91.204 ± 0.013	$+1.2$
m_t [GeV]	173.2 ± 0.9	173.5 ± 0.8	175.7 ± 2.6	$+0.9$
m_h [GeV]	125.6 ± 0.3	125.6 ± 0.3	98.5 ± 27.7	-0.8
$\delta\rho_Z^\nu$	—	-0.0052 ± 0.0031	—	—
$\delta\rho_Z^\ell$	—	-0.0002 ± 0.0010	—	—
$\delta\rho_Z^b$	—	-0.0021 ± 0.0011	—	—
$\delta\rho_Z^u$	—	0.0026 ± 0.0012	—	—
$\delta\rho_Z^d$	—	0.0023 ± 0.0012	—	—
M_W [GeV]	80.385 ± 0.015	80.366 ± 0.007	80.361 ± 0.007	-1.4
Γ_W [GeV]	2.085 ± 0.042	2.0890 ± 0.0006	2.0890 ± 0.0006	$+0.1$
Γ_Z [GeV]	2.4952 ± 0.0023	2.4952 ± 0.0023	—	—
σ_h^0 [nb]	41.540 ± 0.037	41.539 ± 0.037	—	—
$\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}(Q_{\mathrm{FB}}^{\mathrm{had}})$	0.2324 ± 0.0012	0.23145 ± 0.00009	0.23145 ± 0.00009	-0.8
P_τ^{pol}	0.1465 ± 0.0033	0.1476 ± 0.0007	0.1476 ± 0.0007	$+0.3$
$\mathcal{A}_\ell$ (SLD)	0.1513 ± 0.0021	0.1476 ± 0.0007	0.1470 ± 0.0008	-1.9
$\mathcal{A}_c$	0.670 ± 0.027	0.6681 ± 0.0003	0.6681 ± 0.0003	-0.1
$\mathcal{A}_b$	0.923 ± 0.020	0.93466 ± 0.00006	0.93466 ± 0.00006	$+0.6$
$A_{\mathrm{FB}}^{0,\ell}$	0.0171 ± 0.0010	0.0163 ± 0.0002	0.0163 ± 0.0002	-0.8
$A_{\mathrm{FB}}^{0,c}$	0.0707 ± 0.0035	0.0739 ± 0.0004	0.0740 ± 0.0004	$+0.9$
$A_{\mathrm{FB}}^{0,b}$	0.0992 ± 0.0016	0.1034 ± 0.0005	0.1038 ± 0.0005	$+2.7$
R_ℓ^0	20.767 ± 0.025	20.768 ± 0.025	—	—
R_c^0	0.1721 ± 0.0030	0.17247 ± 0.00002	0.17247 ± 0.00002	$+0.1$
R_b^0	0.21629 ± 0.00066	0.21492 ± 0.00003	0.21492 ± 0.00003	-2.1

Table 2. Same as table 1, but using the large-m_t expansion for the two-loop fermionic EW corrections to ρ_Z^f.

|	Data	Fit	Indirect	Pull
$\alpha_s(M_Z^2)$	0.1184 ± 0.0006	0.1184 ± 0.0006	0.1193 ± 0.0027	$+0.3$
$\Delta\alpha_{\mathrm{had}}^{(5)}(M_Z^2)$	0.02750 ± 0.00033	0.02740 ± 0.00026	0.02725 ± 0.00042	-0.5
M_Z [GeV]	91.1875 ± 0.0021	91.1878 ± 0.0021	91.197 ± 0.012	$+0.8$
m_t [GeV]	173.2 ± 0.9	173.5 ± 0.8	176.3 ± 2.5	$+1.1$
m_h [GeV]	125.6 ± 0.3	125.6 ± 0.3	97.3 ± 26.9	-0.9
M_W [GeV]	80.385 ± 0.015	80.367 ± 0.007	80.362 ± 0.007	-1.4
Γ_W [GeV]	2.085 ± 0.042	2.0891 ± 0.0006	2.0891 ± 0.0006	$+0.1$
Γ_Z [GeV]	2.4952 ± 0.0023	2.4953 ± 0.0004	2.4953 ± 0.0004	$+0.0$
σ_h^0 [nb]	41.540 ± 0.037	41.484 ± 0.004	41.484 ± 0.004	-1.5
$\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}(Q_{\mathrm{FB}}^{\mathrm{had}})$	0.2324 ± 0.0012	0.23145 ± 0.00009	0.23144 ± 0.00009	-0.8
P_τ^{pol}	0.1465 ± 0.0033	0.1476 ± 0.0007	0.1477 ± 0.0007	$+0.3$
$\mathcal{A}_\ell$ (SLD)	0.1513 ± 0.0021	0.1476 ± 0.0007	0.1471 ± 0.0008	-1.9
$\mathcal{A}_c$	0.670 ± 0.027	0.6682 ± 0.0003	0.6682 ± 0.0003	-0.1
$\mathcal{A}_b$	0.923 ± 0.020	0.93466 ± 0.00006	0.93466 ± 0.00006	$+0.6$
$A_{\mathrm{FB}}^{0,\ell}$	0.0171 ± 0.0010	0.0163 ± 0.0002	0.0163 ± 0.0002	-0.8
$A_{\mathrm{FB}}^{0,c}$	0.0707 ± 0.0035	0.0740 ± 0.0004	0.0740 ± 0.0004	$+0.9$
$A_{\mathrm{FB}}^{0,b}$	0.0992 ± 0.0016	0.1035 ± 0.0005	0.1039 ± 0.0005	$+2.8$
R_ℓ^0	20.767 ± 0.025	20.735 ± 0.004	20.734 ± 0.004	-1.3
R_c^0	0.1721 ± 0.0030	0.17223 ± 0.00002	0.17223 ± 0.00002	$+0.0$
R_b^0	0.21629 ± 0.00066	0.21575 ± 0.00003	0.21575 ± 0.00003	-0.8
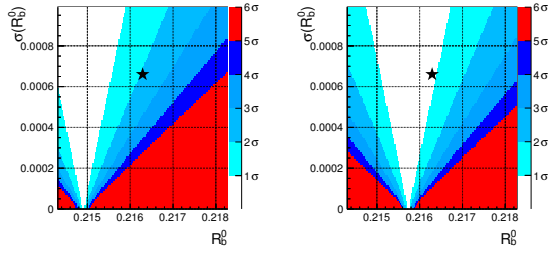
Figure 2. Compatibility plot of R_b^0 computed using the results of ref. [14] (left) or the large m_t expansion for the two-loop fermionic EW corrections to ρ_Z^f (right).

Let us now discuss the EW fit beyond the SM, using several widely adopted model-independent parameterizations of NP contributions. Before dwelling into the details of the different analyses, a discussion on the inclusion of the results of ref. [14, 29] is mandatory. In our SM fit, we parameterized the unknown two-loop fermionic EW corrections to ρ_Z^f with three free parameters. The fit result selects values of these corrections that are as large as the ones computed by Freitas and Huang, and much larger than naively expected from the large-m_t expansion. Waiting for a complete calculation of these corrections, we cannot use consistently the results of ref. [14, 29] in NP fits where the use of R_ℓ^0, Γ_Z and σ_h^0 is necessary to constrain NP contributions. Thus, in these cases we only present results obtained using the large-m_t expansion for the two-loop fermionic EW corrections to ρ_Z^f, while in other cases we present results using both the large-m_t expansion and the expressions in ref. [14, 29], leaving the choice of the preferred option to the reader. In the latter case, we do not use the observables Γ_Z, R_ℓ^0 and R_c^0 in the fit. In all the NP fits reported below, the fit result for SM parameters practically coincides with the input reported in table 1.

In several NP scenarios, the dominant NP effects appear in the gauge-boson vacuum-polarization corrections, called oblique corrections [49, 50]. If the NP scale is sufficiently higher than the weak scale, the oblique corrections are effectively described by the three independent parameters S, T and U [4, 51]. NP contributions to an observable, parameterized by the above oblique parameters, add up to the SM contribution:

$$O = O_{\rm SM} + O_{NP}(S, T, U)\,, \qquad (1)$$

where $S = T = U = 0$ in the SM, and we linearize the NP contribution in terms of the oblique parameters [4, 51–54]. For S, T and U all different from zero, Γ_Z is necessary to obtain bounds on the NP parameters, so in this case we only use the large-m_t expansion. We fit the three oblique parameters together with the SM parameters to the EW precision data in table 1. The fit results are summarized in the second column of table 3. The two-dimensional probability distribution for S and T is shown in the left plot of figure 3.

If one fixes $U = 0$, which is the case in many NP models where $U \ll S, T$, the fit yields the results in the third

Table 3. Fit results for the oblique parameters with floating U or fixing $U = 0$, using the large-m_t expansion or with the results of ref. [14, 29] for the two-loop fermionic EW corrections to ρ_Z^f.

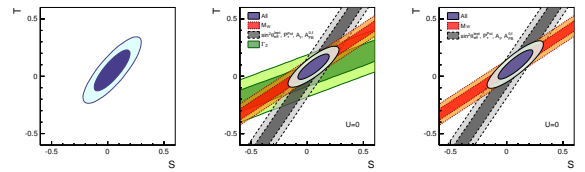|	Large-m_t expansion		Using ref. [14, 29]
	STU fit	ST fit with $U = 0$	ST fit with $U = 0$
S	0.04 ± 0.10	0.06 ± 0.09	0.08 ± 0.10
T	0.05 ± 0.12	0.08 ± 0.07	0.10 ± 0.08
U	0.03 ± 0.09	—	—

Figure 3. Left: Two-dimensional probability distribution for the oblique parameters S and T obtained from the fit with S, T, U and the SM parameters, with the large-m_t expansion for the two-loop fermionic EW corrections to ρ_Z^f. The dark (light) regions correspond to 68% (95%) probability. Center: Two-dimensional probability distribution for the oblique parameters S and T obtained from the fit with S, T and the SM parameters with $U = 0$, with the large-m_t expansion for the two-loop fermionic EW corrections to ρ_Z^f. Right: Same as center, but using the results of ref. [14, 29].

(fourth) column of table 3 omitting (using) the formulæ of ref. [14, 29]. The corresponding two-dimensional distribution is given in the center and right plots in figure 3. As expected, the results in the case $U = 0$ do not depend sizably on the choice made for the two-loop fermionic EW corrections.

A key question to understand the mechanism of EWSB is whether the underlying dynamics is weak or strong. As we shall see below, EWPO strongly constrain the Higgs coupling to vector bosons, and this hints either at a weakly interacting Higgs or at a non-trivial strongly interacting sector in which additional contributions to EWPO are present and restore the agreement with experimental data. To investigate the question above, it is useful to consider a general Lagrangian for a light Higgs-like scalar field h [15–18]. Under the assumption of an approximate custodial symmetry, the longitudinal W and Z polarizations can be described by the two-by-two matrix $\Sigma(x) = \exp(i\tau^a \chi^a(x)/v)$, with τ^a the Pauli matrices and $v^2 = 1/(\sqrt{2}G_\mu)$. Then, assuming that there are no other light states and no new sources of flavour violation, the dominant contribution to EWPO is given by the coupling a defined by [16, 17]:

$$\mathcal{L}_a = \frac{v^2}{4}\,{\rm Tr}(D_\mu\Sigma^\dagger D^\mu\Sigma)\left(1 + 2a\,\frac{h}{v} + \cdots\right)$$

The SM corresponds to the choice $a = 1$. The dominant deviations from the SM in EWPO are induced by the non-standard coupling $a \neq 1$. This generates extra contribu-
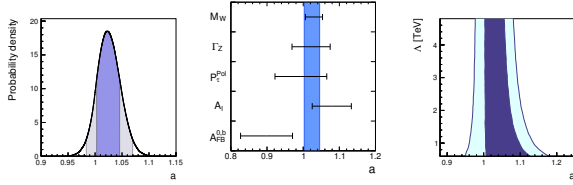
Figure 4. Left: Probability distribution for the coupling a. Center: Indirect determinations of the coupling a, excluding the observables M_W, Γ_Z, $P_\tau^{\rm pol}$, A_l^0 and $A_{\rm FB}^{0,b}$, except for the one specified in each row. The vertical blue band represents the one obtained from the the the fit with all the observables. Right: Probability regions in the a–Λ plane.

tions to the S and T parameters [55]:

$$S = \frac{1}{12\pi}(1-a^2)\ln\left(\frac{\Lambda^2}{m_h^2}\right), \quad T = -\frac{3}{16\pi c_W^2}(1-a^2)\ln\left(\frac{\Lambda^2}{m_h^2}\right),$$

where $\Lambda = 4\pi v/\sqrt{|1-a^2|}$ is the cutoff of the light Higgs effective Lagrangian. A sum rule for $1-a^2$ can be written in terms of the total cross sections in different isospin channels of longitudinal EW gauge boson scattering [56], implying $a^2 \leq 1$ unless the $I = 2$ channel dominates the cross section. Thus, we expect in general a positive S and a negative T. We fit the coupling a together with the five SM parameters to the precision observables using the large-m_t expansion for the two-loop fermionic EW corrections to ρ_Z^f, and obtain the results shown in the left plot in figure 4.

Since the fit prefers values of $a > 1$, while the sum rule of ref. [56] gives in general $a < 1$, additional contributions to the EWPO, for example from additional light fermions [55, 57], are required in order to restore the agreement with experimental data in composite Higgs models. If one takes literally the model with no new particles below the cutoff and assuming $a \leq 1$, from the 95% probability range $a \in [0.984, 1.070]$ ([0.981, 1.071]) one can derive a lower bound on Λ:

$$\Lambda > 17\,(16)\;\text{TeV @95\% probability}, \tag{2}$$

using the large-m_t expansion (using the results of ref. [14, 29]). One can generalise the analysis allowing for $\Lambda < 4\pi v/\sqrt{|1-a^2|}$ and assuming that the dynamics at the cutoff does not contribute sizably to S and T. In this case one can determine regions in the a–Λ plane as shown in right plot of figure 4. Clearly the value of a is tightly constrained for values of Λ compatible with direct searches.

Before concluding, let us take a more general approach and consider the contributions to the EW fit of arbitrary dimension-six NP-induced operators [11, 18, 58]:

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \sum_i \frac{C_i}{\Lambda^2} O_i. \tag{3}$$

For concreteness, let us use the operator basis of ref. [11]. For fermions, we do not consider generation mixing, and assume lepton-flavour universality: $C'_{HL} = C'_{HL_i}$, $C_{HL} = C_{HL_i}$ and $C_{HE} = C_{HE_i}$ for $i = 1, 2, 3$. Switching on one

operator at a time (thus barring accidental cancellations), one can constrain the coefficient of each of the above operators using the EW fit. Clearly, as is the case for all indirect constraints, one can either interpret this as a bound on the NP scale fixing the coupling or as a bound on the coupling for fixed NP scale. In table 4, we list for all the operators the 95% probability regions of the coefficients and the lower bound on the NP scale in TeV obtained by setting $C_i = \pm 1$, assuming quark-flavour universality for the operators. Results obtained relaxing the quark-flavour universality assumption, and also allowing several operators to contribute simultaneously, can be found in ref. [28]. Our fit results are also compatible with the ones of ref. [59], considering that in the latter work m_h was not yet available and that in the fit the other SM parameters were not floated. While the results we obtained are consistent with the non-observation of NP at the 7 and 8-TeV runs, the possibility of weakly-interacting NP hiding behind the corner remains unscathed.

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Table 4. Fit results for the coefficients of the dimension six operators at 95% probability in units of $1/\Lambda^2$ TeV^{-2}, with quark-flavour universality in NP contribution. The fit is performed switching on one operator at a time. The corresponding lower bounds on the NP scale in TeV obtained by setting $C_i = \pm 1$ are also presented.

Coefficient	Large-m_t expansion			Using ref. [14, 29]		
	C_i/Λ^2 [TeV^{-2}] at 95%	Λ [TeV] $C_i=-1$	$C_i=1$	C_i/Λ^2 [TeV^{-2}] at 95%	Λ [TeV] $C_i=-1$	$C_i=1$
C_{WB}	[−0.0096, 0.0042]	10.2	15.4	[−0.0095, 0.0045]	10.3	15.0
C_H	[−0.030, 0.007]	5.8	12.1	[−0.031, 0.008]	5.7	11.5
C_{LL}	[−0.011, 0.019]	9.5	7.2	[−0.016, 0.023]	8.0	6.6
C'_{HL}	[−0.012, 0.005]	9.2	14.1	[−0.017, 0.009]	7.6	10.8
C'_{HQ}	[−0.010, 0.015]	10.2	8.2	[−0.40, 0.20]	1.6	2.2
C_{HL}	[−0.007, 0.010]	12.2	10.0	[−0.034, 0.022]	5.5	6.7
C_{HQ}	[−0.023, 0.046]	6.6	4.7	[−0.01, 0.11]	11.7	3.0
C_{HE}	[−0.014, 0.008]	8.4	11.1	[−0.029, 0.019]	5.9	7.2
C_{HU}	[−0.061, 0.087]	4.0	3.4	[−0.37, 0.08]	1.6	3.5
C_{HD}	[−0.15, 0.05]	2.6	4.6	[−1.1, −0.2]	1.0	—

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