LHC HXSWG interim recommendations to explore the coupling structure of a Higgs-like particle

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Abstract

This document presents a framework in which the coupling structure of a Higgs-like particle can be studied. After discussing different options and approximations, recommendations on specific benchmark parametrizations to be used to fit the data are given.

Contents

1 Introduction

The recent observation of a new massive neutral boson by ATLAS and CMS [**?**, **?**], as well as corroborating evidence from the Tevatron experiments [**?**], opens a new era where characterization of this new object is of central importance.

While coarse features of the observed state can be inferred from the data that the experiments publish or make public, only a consistent and combined treatment of the data can yield the most accurate picture of the coupling structure, taking into account all the systematic and statistic uncertainties considered in the analyses.

This document oulines an interim framework which, while being far from final, should have an accuracy that matches to the statistical power of the datasets that the LHC experiments can hope to collect until the end of the 2012 LHC run.

Based on that framework, a series of benchmark parametrizations are presented. Each benchmark parametrization allows to explore specific aspects of the coupling structure of the new state. The benchmark parametrizations have varying degrees of complexity, in a bid to cover the most interesting possiblities that can be realistically tested with the LHC 7 and 8 TeV datasets.

The recommended benchmarks in this document were designed to provide a solid basis on which two aspects can be developed. On the one hand, experiments can combine their results according to clearly defined parametrizations. On the oher hand, theoretical work can be developed with knowledge of which parametrizations experiments will use to publish their results.

Finally, avenues that can be followed to improve upon this interim framework and recommendations on how to probe the tensor structure will be expounded upon in a future document.

2 Panorama of experimental measurements at the LHC

In 2011, the LHC delivered an integrated luminosity of slightly less than 6 fb^{-1} of proton–proton (pp) collisions at a center-of-mass energy of 7 TeV to the ATLAS and CMS experiments.

By July 2012, the LHC delivered more than 6 fb^{-1} of pp collisions at a center-of-mass energy of 8 TeV to both the ATLAS and CMS experiments. For this dataset, the instantaneous luminosity reached record levels of approximately $7 \cdot 10^{33}\ \text{cm}^{-2}\text{s}^{-1}$, almost double the peak luminosity of 2011 with the same 50 ns bunch spacing.

The LHC 2012 pp run will continue taking data until the end of December hopefully allowing to collect about 30 fb^{-1} per experiment.

A SM-like Higgs boson is searched for at the LHC mainly in four exclusive production processes: the predominant gluon fusion $gg \to H$, the vector boson fusion $q\bar{q} \to Hq\bar{q}$, the associated production with a vector boson $q\bar{q} \to VH$ and the associated production with a top-quark pair $gg \to t\bar{t}H$. The main search channels are determined by five decay modes of the Higgs boson. The $\gamma\gamma$, $ZZ^{(*)}$, $WW^{(*)}$, $b\bar{b}$ and $\tau^+\tau^-$ channels. Various combinations of W and Z-bosons subsequent decay modes are considered, with at least one decay to charged leptons or neutrinos.

Table 1: Summary of the individual Higgs boson search channels in the ATLAS and CMS experiments. The Higgs boson hypothesis mass range and the integrated luminosities of the datasets analyzed are indicated. The $\surd$ symbol is used to indicate in each individual channel the the analyses that are performing an explicit attempt.

Channel	m_{H} range (GeV)	L_{2011} (fb^{-1})		L_{2012} (fb^{-1})		ggH		VBF		VH		ttH	
		A	C	A	C	A	C	A	C	A	C	A	C
$H \to \gamma\gamma$	110-150	4.8	5.1	5.9	5.3	$\surd$	$\surd$	$\surd$	$\surd$	-	-	-	-
$H \to \tau^+\tau^-$	110-140	4.7	5.1	-	5.0	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	-
$H \to b\bar{b}$	110-130	4.6	5.1	-	5.0	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	-	$\surd$
$H \to ZZ^{(*)} \to \ell^+\ell^-\ell^+\ell^-$	110-600	4.8	5.1	5.8	5.3	$\surd$	$\surd$	-	-	-	-	-	-
$H \to WW^{(*)} \to \ell^+\nu\ell^-\bar{\nu}$	110-600	4.7	4.7	5.8	5.3	$\surd$	$\surd$	$\surd$	$\surd$	-	-	-	-
$H \to ZZ \to \ell^+\ell^-\nu\bar{\nu}$	200-600	4.8	4.7	-	-	$\surd$	$\surd$	$\surd$	$\surd$	-	-	-	-
$H \to ZZ \to \ell^+\ell^-q\bar{q}$	130-600	4.8	4.7	-	-	$\surd$	$\surd$	$\surd$	$\surd$	-	-	-	-
$H \to WW \to \ell\nu q\bar{q}'$	300-600	4.8	4.7	-	-	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	-	-	-

Both the ATLAS and CMS experiments observe an excess of events for a Higgs boson mass hypotheses near $\sim$125 GeV. The observed combined significances are around 5.0σ for both ATLAS and CMS, while the expected significances for a SM Higgs boson are 4.6σ and 5.9σ for ATLAS and CMS respectively. The lower sensitivity of the ATLAS searches is in part due to the smaller number of channels updated with the 2012 dataset, in particular the single most sensitive channel $H \to WW^{(*)} \to \ell^+\nu\ell^-\bar{\nu}$, and to a different analysis strategy in the $H \to ZZ^{(*)} \to \ell^+\ell^-\ell^+\ell^-$ channel where the angular distribution of the leptons is not used by the ATLAS experiment.

Both observations are primarily done in the $H \to \gamma\gamma$ and $H \to ZZ^{(*)} \to \ell^+\ell^-\ell^+\ell^-$ channels. For the $H \to \gamma\gamma$ channel excesses of 4.5σ and 4.1σ are observed at Higgs boson mass hypotheses of 126.5 GeV and 125 GeV, in agreement with the expected sensitivities of around 2.5σ, in the ATLAS and CMS experiments, respectively. For the $H \to ZZ^{(*)} \to \ell^+\ell^-\ell^+\ell^-$ channel, the significances of the excesses are 3.4σ and 3.2σ at Higgs boson mass hypotheses of 125 GeV and 125.5 GeV in the ATLAS and CMS experimentes respectively. The expected sensitivities at those masses are 2.6σ in ATLAS and 3.8σ in CMS respectively.

The other channels do not contribute significantly to the excess, but are nevertheless individually compatible with the presence of a signal.

The CMS experiment has reported a measurement of the mass of the narrow resonance yielding 125.3$\pm$0.3 (stat.) $\pm$0.4 (syst.) GeV.

The mass range within which each channel is effective, the luminosity analysed in the ICHEP 2012 run, and the production processes for which exclusive searches have been developed are indicated in Table 1.

A detailed description of the Higgs search analyses can be found in references [**?**, **?**].

The negative search for a SM-like Higgs boson outside the range of $123\ \text{GeV} \ldots 127\ \text{GeV}$ up to $\sim 550\ \text{GeV}$ puts severe limits on models beyond the SM for Higgs bosons with reduced couplings with respect to the SM Higgs.

3 Interim framework for the search of deviations

The idea behind our framework is that all deviations from SM are computed assuming that there is only one underlying state at 125 GeV which we assume to be a SM-like Higgs boson, i.e. the excitation of a field whose vacuum expectation value (VEV) breaks electroweak symmetry. We make no specific assumption on the existence and nature of other heavy (scalar or not) degrees of freedom which can influence the SM-like Higgs boson couplings to all SM particles; furthermore no assumption is made on their decoupling as their masses increase or on the mass-mixing with the SM-like Higgs boson.

The heavy scalar degrees of freedom are Higgs-partners: they are not in the SM, but may have a rich spectrum of non-Higgs states (they do not necessarily develop a VEV). Their spectrum and couplings to fermions and vector bosons will be strongly model dependent and our frameworks are intended to be part of a larger program (the so-called inverse problem): if LHC finds evidence for physics beyond the SM, how can one determine the underlying theory? Therefore, our framework is designed for proving that the light, narrow, resonance matches the SM Higgs properties, or to establish that deviations from the SM behaviour are consistent with some other EWSB framework.

In investigating the experimental information that can be obtained on the coupling properties of the new state near 125 GeV during the 2012 run of the LHC the following assumptions are made:

- It is assumed that the signals observed in the different search channels originate from a single narrow resonance with a mass near 125 GeV. The case of several, possibly overlapping, resonances in this mass region is not considered.
- The width of the assumed Higgs boson near 125 GeV is neglected in our analysis, i.e. we work in the zero-width approximation for this state. Hence the product $\sigma \times BR(ii \to H \to ff)$ can be decomposed in the following way for all channels:

$$\sigma \times BR(ii \to H \to ff) = \frac{\sigma_{ii} \cdot \Gamma_{ff}}{\Gamma_H} \tag{1}$$

Within the context of these assumptions, in the following we outline a simplified framework for investigating the experimental information that can be obtained on the coupling properties of the new state near 125 GeV during the 2012 run of the LHC. In general, the couplings of the assumed Higgs state near 125 GeV are "pseudo-observables", i.e. they cannot be directly measured experimentally. This means that a certain "unfolding procedure" is necessary to extract information on the couplings from the actually measured quantities like cross sections times branching ratios (for specific experimental cuts and acceptances). This gives rise to a certain model dependence of the extracted information. Different options can be pursued in this context. One possibility is to confront a specific model with the experimental data. This has the advantage that all available higher-order corrections within this model can consistently be taken into account and also other experimental constraints (for instance from direct searches or from electroweak precision data) can be taken into account. On the other hand, the obtained results in this case are restricted to the interpretation within this particular model. Another possibility is to use a general parametrization of the couplings of the new state without referring to a particular model. While this approach is clearly less model-dependent, the relation between the coupling parameters extracted in this way and the couplings of actual models, for instance the SM or its minimal supersymmetric extension (MSSM), is in general non-trivial, so that the theoretical interpretation of the extracted experimental information can be difficult. It should be mentioned in this context that the results for the signal strengths of individual search channels that have been made public by ATLAS and CMS, while referring just to a particular search channel rather than to the full information available from the Higgs searches, are nevertheless very valuable for testing the predictions of possible models of physics beyond the SM.

Concerning the case of the SM, once the numerical value of the Higgs mass is specified, all the couplings of the Higgs boson to fermions, bosons and to itself are specified within the model. It is therefore in general not possible to perform a fit to experimental data within the context of the SM where

Higgs couplings are treated as free parameters. While it is possible to test the overall compatibility of the SM with the data, it is not possible in this way to extract information about deviations of the measured couplings with respect to their SM values.

A theoretically well-defined framework for probing small deviations from the SM predictions — or the predictions of another reference model — is to use the state-of-the-art predictions in this model (including all available higher-order corrections) and to supplement them with the contributions of additional terms in the Lagrangian. In such an approach in general not only the coupling strength, i.e. the absolute value of a given coupling, will be modified, but also the tensor structure of the coupling. For instance, the HW^+W^- LO coupling in the SM is proportional to the metric tensor $g^{\mu\nu}$, while anomalous couplings will in general also give rise to other tensor structures, however compatible with the SU(2)×U(1) symmetry and the corresponding Ward-Slavnov-Taylor identities. As a consequence, kinematic distributions will in general be modified as compared to the SM case.

Since the reinterpretation of searches that have been performed within the context of the SM is difficult if effects that change kinematic distributions are taken into account and since not all the necessary tools to perform this kind of analysis are available yet, we make the following assumption in our simplified framework:

– Only modifications of couplings strengths, i.e. of absolute values of couplings, are taken into account, while the tensor structure of the couplings is assumed to be the same as in the SM LO predictions. This means in particular that we assume that the observed state is a CP-even scalar.

3.1 Defintion of coupling scale factors

In order to take into account the currently best available SM predictions for Higgs cross sections as outlined in Refs. [1–3], while on the other hand introduce possible deviations from the SM values of the couplings, we dress the predicted SM Higgs cross sections and partial decay widths with leading-order motivated scale factors C_i. The scale factors C_i are defined in such a way that the cross section σ_i or the partial decay width Γ_i associated with the SM particle i scales with the factor C_i^2 compared to the relevant SM prediction. Table 2 lists all relevant cases.

The currently best available SM predictions for all $\sigma \times$ BR are recovered for all $C_i = 1$. The functions $C^2_{\text{VBF}}(C_W, C_Z, m_H)$, $C^2_g(C_b, C_t, m_H)$, $C^2_\gamma(C_W, C_t, C_b, m_H)$ and $C^2_H(C_i, m_H)$ are used for cases where there is a non-trivial relationship between scale factors C_i and cross sections or (partial) decay widths. They are defined as follows:

3.1.1 *Scale factor C^2_{VBF} for the VBF cross section*

C^2_{VBF} refers to the functional dependence of the VBF cross section on the scale factors C^2_W and C^2_Z:

$$C^2_{\text{VBF}}(C_W, C_Z, m_H) = C^2_W \cdot \frac{\sigma^{SM}_{WF}(m_H)}{\sigma^{SM}_{VBF}(m_H)} + C^2_Z \cdot \frac{\sigma^{SM}_{ZF}(m_H)}{\sigma^{SM}_{VBF}(m_H)} \tag{19}$$

$$= \frac{C^2_W + C^2_Z \cdot \frac{\sigma^{SM}_{ZF}(m_H)}{\sigma^{SM}_{WF}(m_H)}}{1 + \frac{\sigma^{SM}_{ZF}(m_H)}{\sigma^{SM}_{WF}(m_H)}} \tag{20}$$

It is assumed that the W- and Z-fusion cross sections σ^{SM}_{WF} and σ^{SM}_{ZF} add linearly to the total VBF cross section. The interference term is $< 0.1\%$ in the SM and hence ignored. The ratio $\frac{\sigma^{SM}_{ZF}(m_H)}{\sigma^{SM}_{WF}(m_H)}$ is taken from Ref. [4, 5].

Production modes

$$\frac{\sigma_{ggH}}{\sigma_{ggH}^{SM}} = \begin{cases} C_g^2(C_b, C_t, m_H) \\ C_g^2 \end{cases} \quad (2)$$

$$\frac{\sigma_{\text{VBF}}}{\sigma_{\text{VBF}}^{SM}} = C_{\text{VBF}}^2(C_W, C_Z, m_H) \quad (3)$$

$$\frac{\sigma_{WH}}{\sigma_{WH}^{SM}} = \frac{\Gamma_{WW}}{\Gamma_{WW}^{SM}} = C_W^2 \quad (4)$$

$$\frac{\sigma_{ZH}}{\sigma_{ZH}^{SM}} = \frac{\Gamma_{ZZ}}{\Gamma_{ZZ}^{SM}} = C_Z^2 \quad (5)$$

$$\frac{\sigma_{t\bar{t}H}}{\sigma_{t\bar{t}}^{SM}} = C_t^2 \quad (6)$$

Detectable decay modes

$$\frac{\Gamma_{WW}}{\Gamma_{WW}^{SM}} = C_W^2 \quad (7)$$

$$\frac{\Gamma_{ZZ}}{\Gamma_{ZZ}^{SM}} = C_Z^2 \quad (8)$$

$$\frac{\Gamma_{b\bar{b}}}{\Gamma_{b\bar{b}}^{SM}} = C_b^2 \quad (9)$$

$$\frac{\Gamma_{\tau\tau}}{\Gamma_{\tau\tau}^{SM}} = C_\tau^2 \quad (10)$$

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma}^{SM}} = \begin{cases} C_\gamma^2(C_b, C_t, C_W, m_H) \\ C_\gamma^2 \end{cases} \quad (11)$$

$$\frac{\Gamma_{Z\gamma}}{\Gamma_{Z\gamma}^{SM}} \sim C_W^2 \quad (12)$$

Undetectable decay modes

$$\frac{\Gamma_{t\bar{t}}}{\Gamma_{t\bar{t}}^{SM}} = \frac{\sigma_{t\bar{t}H}}{\sigma_{t\bar{t}}^{SM}} = C_t^2 \quad (13)$$

$$\frac{\Gamma_{gg}}{\Gamma_{gg}^{SM}} = \frac{\sigma_{ggH}}{\sigma_{ggH}^{SM}} \quad (14)$$

$$\frac{\Gamma_{c\bar{c}}}{\Gamma_{c\bar{c}}^{SM}} = C_t^2 \quad (15)$$

$$\frac{\Gamma_{s\bar{s}}}{\Gamma_{s\bar{s}}^{SM}} = C_b^2 \quad (16)$$

$$\frac{\Gamma_{\mu\mu}}{\Gamma_{\mu\mu}^{SM}} = C_\tau^2 \quad (17)$$

Total width

$$\frac{\Gamma_H}{\Gamma_H^{SM}} = \begin{cases} C_H^2(C_i, m_H) \\ C_H^2 \end{cases} \quad (18)$$

Table 2: LO coupling scale factor relations for Higgs boson cross sections and partial decay widths relative to the SM. For a given m_H hypothesis, the smallest set of degrees of freedom in this framework comprises C_W, C_Z, C_b, C_t, and C_τ. Additionally, the gluon and photon loops can be treated effectively, thus allowing for BSM contributions in the loops, by adding the C_g and C_γ degrees of freedom. Finally, to explore invisible or undetectable decay widths, the scaling of the total width can also be taken as a separate degree of freedom, C_H.

3.1.2 Scale factor C_g^2 for the gluon fusion cross section and the gluon decay width

C_g^2 refers to the scaling factor for the loop induced production cross section σ_{ggH} and the decay width Γ_{gg}. Under the assumption that the only relevant contributions to σ_{ggH} and Γ_{gg} are from top and bottom loops, $C_g^2(C_b, C_t, m_H)$ is a scaling function depending on the scale factors C_b and C_t:

$$C_g^2(C_b, C_t, m_H) = \frac{|C_b A_b'(m_H) + C_t A_t'(m_H)|^2}{|A_b'(m_H) + A_t'(m_H)|^2} \quad (21)$$

where $A'_{b,t}$ denotes the bottom and top amplitudes in the SM [6]. As QCD NLO corrections factorize with the scaling of the electroweak couplings with C_t and C_b, the function $C_g^2(C_b, C_t, m_H)$ can be calculated in NLO:

$$C_g^2(C_b, C_t, m_H) \;=\; \frac{C_t^2 \cdot \sigma_{tt}(m_H) + C_b^2 \cdot \sigma_{bb}(m_H) - C_t C_b \cdot |\sigma_{tb}(m_H)|}{\sigma_{tt}(m_H) + \sigma_{bb}(m_H) - |\sigma_{tb}(m_H)|} \tag{22}$$

Here, σ_{tt}, σ_{bb} and σ_{tb} denote the square of the top-quark contribution, the square of the bottom-quark contribution and the top-bottom interference, respectively. Within the LHC Higgs Cross Section Working Group (for the evaluation of the MSSM cross section) these contributions were evaluated, where for σ_{bb} and σ_{tb} the full NLO QCD calculation included in Higlu [7] was used. For σ_{tt} the NLO QCD result of Higlu was supplemented with the NNLO corrections in the heavy-top-quark limit as implemented into GGH@NNLO [8], see [1] for details.

Since the corrections are large, the use of the QCD NLO corrected function is recommended.

In the general case, without the assumption above, possible non-zero contributions from additional particles in the loop have to be taken into account and C_g^2 is then treated as an effective coupling parameter in the fit.

3.1.3 Scale factor C_γ^2 for the $H \to \gamma\gamma$ decay loop

Analogous to the previous section, C_γ^2 refers to the scaling factor for the loop induced $H \to \gamma\gamma$ decay. Under the assumption that the only relevant contributions to $\Gamma_{\gamma\gamma}$ are from W, top and bottom loops, $C_\gamma^2(C_b, C_t, C_W, m_H)$ is a scaling function depending on the scale factors C_b, C_t and C_W:

$$C_\gamma^2(C_b, C_t, C_W, m_H) \;=\; \frac{|C_b A_b(m_H) + C_t A_t(m_H) + C_W A_W(m_H)|^2}{|A_b(m_H) + A_t(m_H) + A_W(m_H)|^2} \tag{23}$$

where $A\prime_{b,t,W}$ denotes the bottom, top and W amplitudes in the SM [6].

In the general case, without the assumption above, possible non-zero contributions from additional particles in the loop have to be taken into account and C_γ^2 is then treated as an effective coupling parameter in the fit.

3.1.4 Scale factor C_H^2 for the total width

The total width Γ_H is the sum of all partial Higgs decay widths. Under the assumption that no additional BSM Higgs decay modes (either into invisible or undetectable final states) contribute to the total width, Γ_H is expressed as the sum of the scaled partial Higgs decay widths to SM particles, which combine to a total scale factor C_H^2 compared to the SM total width Γ_H^{SM}:

$$C_H^2(C_i, m_H) \;=\; \sum_{\substack{k = WW, ZZ, b\bar{b}, \tau\tau, \gamma\gamma, \\ Z\gamma, gg, t\bar{t}, c\bar{c}, s\bar{s}, \mu\mu}} \frac{\Gamma_k(C_i, m_H)}{\Gamma_H^{SM}(m_H)} \tag{24}$$

In the general case, additional Higgs decay modes to BSM particles cannot be excluded and the total width scale factor C_H^2 is treated as free parameter.

The total width Γ_H for a light Higgs with $m_H \sim 125$ GeV is not expected to be directly observable at the LHC, as the SM expectation is $\Gamma_H \sim 4$ MeV and hence several orders of magnitude smaller than the experimental mass resolution. There is no indication from the results observed so far that the natural width could be broadened by new physics effects to such an extent that it would be directly observable. Furthermore, as all LHC Higgs channels rely on the identification of Higgs decay products, there is no way of measuring the total Higgs width indirectly within a coupling fit without using assumptions.

This can be illustrated by assuming that all couplings are increased by the same factor $C_i^2 = C^2 > 1$ compared to the SM. If simultaneously the Higgs total width is increased by the square of the same factor $C_H^2 = C^4$ (for example by postulating some BSM decay mode) the experimental visible signature in all Higgs channels would be indistinguishable from the SM.

Hence without further assumptions only ratios of scale factors C_i can be measured at the LHC, where at least one of the ratios needs to include the total width scale factor C_H^2. Such a definition of ratios absorbs two degrees of freedom (e.g. a common scale factor to all couplings and a scale factor to the total width) into one ratio that can be measured at the LHC. In order to go beyond the measurement of ratios of coupling scaling factors to the determination of absolute coupling scale factors C_i additional assumptions are necessary to remove one degree of freedom. Possible assumptions are:

– No new physics in Higgs decay modes (Eq. 24).
– $C_W \leq 1$, $C_Z \leq 1$. Since all Higgs partial decay widths are positive definite, this condition is sufficient to give a lower and upper bound on all C_i and also determine a possible branching ratio $\mathrm{BR}_{\mathrm{inv.,undet.}}$ into invisible or, at the LHC, undetectable final states. However, depending on the accuracy on the $b\bar{b}$-decay measurement in particular, uncertainties can be very large.

In the following benchmark parametrizations always two versions are given: one without assumptions on the total width and one assuming no new unkown physics Higgs decay modes.

3.2 Further assumptions

3.2.1 Limit of the zero-width approximation

Concerning the zero-width approximation (ZWA), it should be noted that in the mass range of the narrow resonance the width of the Higgs boson of the Standard Model (SM) is more than four orders of magnitude smaller than its mass. Thus, the zero-width approximation is in principle expected to be an excellent approximation not only for a SM-like Higgs boson at about 125 GeV but also for a wide range of BSM scenarios that are compatible with the present data. However, it has been shown in Ref. [9] that this is not always the case even in the SM. The inclusion of off-shell contributions is essential to obtain an accurate Higgs signal normalization at the 1% precision level. For $\mathrm{gg}\ (\to \mathrm{H}) \to \mathrm{VV}$, $\mathrm{V} = \mathrm{W}, \mathrm{Z}$, $\mathcal{O}(10\%)$ corrections occur due to an enhanced Higgs signal in the region $M_{\mathrm{VV}} > 2\,M_{\mathrm{V}}$, where also sizeable Higgs-continuum interference occurs. However, with the accuracy anticipated to be reached in the 2012 data these effects play a minor role.

3.2.2 Signal interference effects

A source of uncertainty is related to interference effects in $\mathrm{H} \to 4$ fermion decay. We refer to Chapter 2 of Ref. [2]. There it is shown that the ratio of the ZWA

$$\mathrm{BR}(\mathrm{H} \to \mathrm{VV}) \times \mathrm{BR}^2(V \to \overline{f}f) \tag{25}$$

over the complete result [10] for $\mathrm{H} \to \mathrm{e}^+\mathrm{e}^-\mathrm{e}^+\mathrm{e}^-$ or $\mathrm{e}^+\mathrm{e}^-\mu^+\mu^-$ is large, due to the interference (below WW, ZZ thresholds), about 11% difference.

The experimental analyses take into account the full NLO 4 fermion partial decay width. The partial width of the 4 lepton final state (usually described as $H \to ZZ^* \to 4l$ or $H \to ZZ^* \to 2l2j$ depending on decay mode) is scaled with C_Z^2. The partial width of the low mass 2 lepton, 2 neutrino final state (usually described as $H \to WW^* \to l\nu\, l\nu$) is scaled with C_W^2.

3.2.3 Treatment of $\Gamma_{c\bar{c}}$, $\Gamma_{s\bar{s}}$, $\Gamma_{\mu\mu}$

When calculating $C_H^2(C_i, m_H)$ in a benchmark parametrization, the final states $c\bar{c}$, $s\bar{s}$ and $\mu^+\mu^-$ (unobservable at the LHC) are tied to C_i scale factors which can be determined from the experimental data.

The following choices are made:

$$\frac{\Gamma_{c\bar{c}}}{\Gamma^{SM}_{c\bar{c}}(m_H)} = C_c^2 = C_t^2 \quad (26)$$

$$\frac{\Gamma_{s\bar{s}}}{\Gamma^{SM}_{s\bar{s}}(m_H)} = C_s^2 = C_b^2 \quad (27)$$

$$\frac{\Gamma_{\mu\mu}}{\Gamma^{SM}_{\mu\mu}(m_H)} = C_\mu^2 = C_\tau^2 \quad (28)$$

3.2.4 Treatment of $\Gamma_{Z\gamma}$

Until the $Z\gamma$ final state is experimentally observable, the scaling of its width is taken as proportional to C_W^2, which is accurate to within 10% in the SM. The correct functional dependence, following Ref. [11], will be used once the channel becomes observable.

3.2.5 Treatment of m_b

Wherever the b-quark mass, m_b, appears in the C_g^2 and C_γ^2 functions in Section 3.1, the running mass $m_b(\mu)$ is used. Based on Ref. [6], the recommendation is to use $m_b(m_b)$ for C_g^2 (Eq. 21) and $m_b(m_H)$ for C_γ^2 (Eq. 23).

3.2.6 Approximation in associated ZH production

When scaling the associated ZH production mode, the contribution from $gg \to ZH$ through a top-quark loop is neglected. This is estimated to be around 5% of the total associated ZH production cross section.

4 Benchmark parametrizations

In putting forward a set of benchmark parametrizations based on the framework described in the previous section several considerations were taken into account. One first concern is the stability of the fits which typically involve several hundreds of nuisance parameters. With that in mind, the benchmark parametrizations avoid division of parameters of interest. Another constraint that heavily shapes the exact choice of parametrization is consistency among the uncertainties that can be extracted in different parametrizations. Some coupling scaling factors enter linearly in the photon and gluon loop amplitudes. For that reason, all scaling factors are defined at the same power, leading to what could be miscronstrued as an abundance of squared expressions. Finally, the benchmark parametrizations are chosen such that some potential physics cases can be probed and the parameters of interest are chosen so that at least some can be expected to not be undetermined.

For every benchmark parametrization, two variations are provided:

1. The total width is scaled assuming that there is no invisible or undetected width. In this case $C_H^2(C_i)$ is a function of the free parameters.
2. The total width scaling factor is absorbed into the parametrization. In this case no assumption is done and there will be a parameter of the form $C_{ij} = C_i \cdot C_j / C_H$.

The benchmark parametrizations are given in tabular form where each cell corresponds to the scaling factor to be applied to a given combination of production and decay mode.

For every benchmark parametrization, a list of the free parameters and their relation to the framework parameters is provided.

4.1 One common scaling factor

The simplest way to look for a deviation from the predicted SM Higgs coupling structure is to leave the overall signal strength as a free parameter. This is presently done by the experiments, with ATLAS finding 1.2x at 126 GeV [**?**] and CMS 0.8x at 125 GeV [**?**].

In order to perform the same fit in the context of the coupling scaling factor framework, the only difference is that $\mu = C^2 \cdot C^2/C^2 = C^2$, where the three terms in the intermediate expression account for production, decay and total width scaling, respectively.

Common scaling factor
Free parameter: $C(= C_t = C_b = C_\tau = C_W = C_Z)$.

	H$\to\gamma\gamma$	H$\to ZZ$	H$\to WW$	H$\to b\bar{b}$	H$\to\tau\tau$
ggH					
$t\bar{t}$H					
VBF			C^2		
WH					
ZH					

Table 3: The simplest possible benchmark parametrization where a single scaling factor applies to all production and decay modes.

This parametrization, despite providing the highest experimental precision, has several clear shortcomings, such as ignoring that the role of the Higgs boson in providing the masses of the vector bosons is very different from the role it has in providing the masses of fermions.

4.2 Scaling of vector boson and fermion couplings

When asking the question of whether an observed state is compatible with the SM Higgs boson, one obvious question is whether it fulfills its expected role in electroweak symmetry breaking and which is intimately related to the coupling to the vector bosons (W,Z).

Therefore, assuming that the SU(2) custodial symmetry holds, in the simplest case two parameters can be defined, one scaling the coupling to the vector bosons, $C_V(= C_W = C_Z)$, and one scaling the coupling common to all fermions, $C_F(= C_t = C_b = C_\tau)$. Loop-induced processes are assumed to scale as expected in the SM.

In this parametrization, presented in table 4, the gluon loop is effectively a fermion loop and only the photon loop requires a non-trivial scaling, given the contribution of the top-quark, bottom-quark, and W-boson, as well as their (destructive) interference.

This parametrization, though exceptionally succint, makes a number of assumptions, which are expected to be object of further scrutiny with the accumulation of data at the LHC. The assumptions naturally relate to the grouping of different individual couplings or to assuming that the loop amplitudes are those predicted by the SM.

4.3 Probing custodial symmetry

One of the most well founded symmetries in case the new state is responsible for electroweak symmetry breaking is that which links the coupling to the W and Z bosons.

In this parametrization, presented in table 5, $R_{WZ}(= C_W/C_Z)$ is the main parameter of interest. Though providing interesting information, both C_Z and C_F can be thought of as a nuisance parameters when performing this fit. In addition to the photon loop not having a trivial scaling, in this parametrization also the individual W and Z bonson fusion contributions to the vector boson fusion production process need to be resolved.

Boson and fermion scaling without invisible or undetectable widths Free parameters: $C_V(= C_W = C_Z), C_F(= C_t = C_b = C_\tau)$.					
	H$\to\gamma\gamma$	H$\to ZZ$	H$\to WW$	H$\to b\bar{b}$	H$\to\tau\tau$
ggH $t\bar{t}$H	$\frac{1}{C_H^2(C_i)} C_F^2 C_\gamma^2(C_F, C_F, C_V)$	$\frac{1}{C_H^2(C_i)} C_F^2 C_V^2$		$\frac{1}{C_H^2(C_i)} C_F^2 C_F^2$	
VBF WH ZH	$\frac{1}{C_H^2(C_i)} C_V^2 C_\gamma^2(C_F, C_F, C_V)$	$\frac{1}{C_H^2(C_i)} C_V^2 C_V^2$		$\frac{1}{C_H^2(C_i)} C_V^2 C_F^2$	
Boson and fermion scaling without assumptions on the total width Free parameters: $C_{VV}(= C_V \cdot C_V / C_H), R_{FV}(= C_F/C_V)$.					
	H$\to\gamma\gamma$	H$\to ZZ$	H$\to WW$	H$\to b\bar{b}$	H$\to\tau\tau$
ggH $t\bar{t}$H	C_{VV}^2 R_{FV}^2 $C_\gamma^2(R_{FV}, R_{FV}, 1)$	C_{VV}^2 R_{FV}^2 1		C_{VV}^2 R_{FV}^2 R_{FV}^2	
VBF WH ZH	C_{VV}^2 1 $C_\gamma^2(R_{FV}, R_{FV}, 1)$	C_{VV}^2 1 1		C_{VV}^2 1 R_{FV}^2	

$C_i^2 = \Gamma_i/\Gamma_i(SM)$

Table 4: A benchmark parametrization where custodial symmetry is assumed and vector boson couplings scaled together (C_V) and fermions are assumed to scale with a single parameter (C_F).

4.4 Probing the fermion sector

There are extensions of the SM where different Higgs bosons couple differently to different types of fermions.

Given how the gluon-gluon fusion production process is dominated by the top-quark coupling, and how there are two decays modes involving fermions, one way of splitting fermions that is within experiemtnal reach is to consider up-type fermions (top quark) and down-type fermions (bottom quark and tau lepton) separately. In this parametrization, presented in table 6, the relevant parameter of interest is $R_{du}(= C_d/C_u)$, the ratio of the scaling factors of the couplings to down-type fermions, $C_d = C_\tau(= C_\mu) = C_b(= C_s)$, and up-type fermions, $C_u = C_t(= C_c)$.

Alternatively, given the distinct experimental signatures of bottom-quark and tau-lepton decays, one can consider quarks and leptons separately. In this parametrization, presented in table 7, the relevant parameter of interest is $R_{\ell q}(= C_\ell/C_q)$, the ratio of the coupling scaling factors to leptons, $C_\ell = C_\tau(= C_\mu)$, and quarks, $C_q = C_t(= C_c) = (C_b = C_s)$.

One further combination of top-quark, bottom-quark and tau-lepton, namely scaling the top-quark and tau-lepton with a common parameter and the bottom-quark with another parameter, can be envisaged and readily parametrized based on the interim framework but is not put forward as a benchmark.

4.5 Probing the loop structure and invisible or undetectable decay of new particles

It is possible that in nature there are particles not predicted by the SM. Depending on their properties, as long as they have color charge or electric charge they may influence the partial width of the gluon and photon loops.

In this parametrization, presented in table 8, each of the loops is represented by an effective scaling factor, C_g and C_γ.

Particles not predicted by the SM may also give rise to invisible or undetectable decays. In order to probe this, instead of absorbing the total width into another parameter, a different parameter is introduced, $\mathrm{BR}_{\mathrm{inv.,undet.}}$. This can then be interepreted as the invisble or undetectable fraction of the total width.

Probing custodial symmetry without invisible or undetectable widths

Free parameters: C_Z, $R_{WZ}(=C_W/C_Z)$, $C_F(=C_t=C_b=C_\tau)$.

	H$\to\gamma\gamma$	H$\to ZZ$	H$\to WW$	H$\to b\bar{b}$	H$\to\tau\tau$
ggH $t\bar{t}$H	$\frac{C_F^2 \cdot C_\gamma^2(C_F, C_F, C_Z R_{WZ})}{C_H^2(C_i)}$	$\frac{C_F^2 \cdot C_Z^2}{C_H^2(C_i)}$	$\frac{C_F^2 \cdot (C_Z R_{WZ})^2}{C_H^2(C_i)}$	$\frac{C_F^2 \cdot C_F^2}{C_H^2(C_i)}$	
VBF	$\frac{C_{\text{VBF}}^2(C_Z, C_Z R_{WZ}) \cdot C_\gamma^2(C_F, C_F, C_Z R_{WZ})}{C_H^2(C_i)}$	$\frac{C_{\text{VBF}}^2(C_Z, C_Z R_{WZ}) \cdot C_Z^2}{C_H^2(C_i)}$	$\frac{C_{\text{VBF}}^2(C_Z, C_Z R_{WZ}) \cdot (C_Z R_{WZ})^2}{C_H^2(C_i)}$	$\frac{C_{\text{VBF}}^2(C_Z, C_Z R_{WZ}) \cdot C_F^2}{C_H^2(C_i)}$	
WH	$\frac{(C_Z R_{WZ})^2 \cdot C_\gamma^2(C_F, C_F, C_Z R_{WZ})}{C_H^2(C_i)}$	$\frac{(C_Z R_{WZ})^2 \cdot C_Z^2}{C_H^2(C_i)}$	$\frac{(C_Z R_{WZ})^2 \cdot (C_Z R_{WZ})^2}{C_H^2(C_i)}$	$\frac{(C_Z R_{WZ})^2 \cdot C_F^2}{C_H^2(C_i)}$	
ZH	$\frac{C_Z^2 \cdot C_\gamma^2(C_F, C_F, C_Z R_{WZ})}{C_H^2(C_i)}$	$\frac{C_Z^2 \cdot C_Z^2}{C_H^2(C_i)}$	$\frac{C_Z^2 \cdot (C_Z R_{WZ})^2}{C_H^2(C_i)}$	$\frac{C_Z^2 \cdot C_F^2}{C_H^2(C_i)}$	

Probing custodial symmetry without assumptions on the total width

Free parameters: $C_{ZZ}(=C_Z \cdot C_Z/C_H)$, $R_{WZ}(=C_W/C_Z)$, $R_{FZ}(=C_F/C_Z)$.

	H$\to\gamma\gamma$	H$\to ZZ$	H$\to WW$	H$\to b\bar{b}$	H$\to\tau\tau$
ggH $t\bar{t}$H	$C_{ZZ}^2 R_{FZ}^2 \cdot C_\gamma^2(R_{FZ}, R_{FZ}, R_{WZ})$	$C_{ZZ}^2 R_{FZ}^2$	$C_{ZZ}^2 R_{FZ}^2 \cdot R_{WZ}^2$	$C_{ZZ}^2 R_{FZ}^2 \cdot R_{FZ}^2$	
VBF	$C_{ZZ}^2 C_{\text{VBF}}^2(1, R_{WZ}^2) \cdot C_\gamma^2(R_{FZ}, R_{FZ}, R_{WZ})$	$C_{ZZ}^2 C_{\text{VBF}}^2(1, R_{WZ}^2)$	$C_{ZZ}^2 C_{\text{VBF}}^2(1, R_{WZ}^2) \cdot R_{WZ}^2$	$C_{ZZ}^2 C_{\text{VBF}}^2(1, R_{WZ}^2) \cdot R_{FZ}^2$	
WH	$C_{ZZ}^2 R_{WZ}^2 \cdot C_\gamma^2(R_{FZ}, R_{FZ}, R_{WZ})$	$C_{ZZ}^2 \cdot R_{WZ}^2$	$C_{ZZ}^2 R_{WZ}^2 \cdot R_{WZ}^2$	$C_{ZZ}^2 R_{WZ}^2 \cdot R_{FZ}^2$	
ZH	$C_{ZZ}^2 \cdot C_\gamma^2(R_{FZ}, R_{FZ}, R_{WZ})$	C_{ZZ}^2	$C_{ZZ}^2 \cdot R_{WZ}^2$	$C_{ZZ}^2 \cdot R_{FZ}^2$	

$C_i^2 = \Gamma_i/\Gamma_i(SM)$

Table 5: A benchmark parametrization where custodial symmetry is probed through the R_{WZ} parameter.

Probing up-type and down-type fermion symmetry without invisible or undetectable widths					
Free parameters: $C_V(= C_Z = C_W)$, $R_{du}(= C_d/C_u)$, $C_u(= C_t)$.					
	H$\to \gamma\gamma$	H$\to ZZ$	H$\to WW$	H$\to b\bar{b}$	H$\to \tau\tau$
ggH	$\frac{C_g^2(C_uR_{du},C_u)\cdot C_\gamma^2(C_uR_{du},C_u,C_V)}{C_H^2(C_i)}$	$\frac{C_g^2(C_uR_{du},C_u)\cdot C_V^2}{C_H^2(C_i)}$		$\frac{C_g^2(C_uR_{du},C_u)\cdot(C_uR_{du})^2}{C_H^2(C_i)}$	
$t\bar{t}$H	$\frac{C_u^2\cdot C_\gamma^2(C_uR_{du},C_u,C_V)}{C_H^2(C_i)}$	$\frac{C_u^2\cdot C_V^2}{C_H^2(C_i)}$		$\frac{C_u^2\cdot(C_uR_{du})^2}{C_H^2(C_i)}$	
VBF WH ZH	$\frac{C_V^2\cdot C_\gamma^2(C_uR_{du},C_u,C_V)}{C_H^2(C_i)}$	$\frac{C_V^2\cdot C_V^2}{C_H^2(C_i)}$		$\frac{C_V^2\cdot(C_uR_{du})^2}{C_H^2(C_i)}$	
Probing up-type and down-type fermion symmetry without assumptions on the total width					
Free parameters: $C_{uu}(= C_u \cdot C_u/C_H)$, $R_{du}(= C_d/C_u)$, $R_{Vu}(= C_V/C_u)$.					
	H$\to \gamma\gamma$	H$\to ZZ$	H$\to WW$	H$\to b\bar{b}$	H$\to \tau\tau$
ggH	$C_{uu}^2 C_g^2(R_{du},1)\cdot C_\gamma^2(R_{du},1,R_{Vu})$	$C_{uu}^2 C_g^2(R_{du},1)\cdot R_{Vu}^2$		$C_{uu}^2 C_g^2(R_{du},1)\cdot R_{du}^2$	
$t\bar{t}$H	$C_{uu}^2\cdot C_\gamma^2(R_{du},1,R_{Vu})$	$C_{uu}^2\cdot R_{Vu}^2$		$C_{uu}^2\cdot R_{du}^2$	
VBF WH ZH	$C_{uu}^2 R_{Vu}^2\cdot C_\gamma^2(R_{du},1,R_{Vu})$	$C_{uu}^2 R_{Vu}^2\cdot R_{Vu}^2$		$C_{uu}^2 R_{Vu}^2\cdot R_{du}^2$	

$C_i^2 = \Gamma_i/\Gamma_i(SM)$, $C_d = C_b = C_\tau$

Table 6: A benchmark parametrization where the up-type and down-type symmetry of fermions is probed through the R_{du} parameter.

Probing quark and lepton fermion symmetry without invisible or undetectable widths					
Free parameters: $C_V(= C_Z = C_W)$, $R_{\ell q}(= C_\ell/C_q)$, $C_q(= C_t = C_b)$.					
	H$\to \gamma\gamma$	H$\to ZZ$	H$\to WW$	H$\to b\bar{b}$	H$\to \tau\tau$
ggH $t\bar{t}$H	$\frac{C_q^2\cdot C_\gamma^2(C_q,C_q,C_V)}{C_H^2(C_i)}$	$\frac{C_q^2\cdot C_V^2}{C_H^2(C_i)}$		$\frac{C_q^2\cdot C_q^2}{C_H^2(C_i)}$	$\frac{C_q^2\cdot(C_qR_{\ell q})^2}{C_H^2(C_i)}$
VBF WH ZH	$\frac{C_V^2\cdot C_\gamma^2(C_q,C_q,C_V)}{C_H^2(C_i)}$	$\frac{C_V^2\cdot C_V^2}{C_H^2(C_i)}$		$\frac{C_V^2\cdot C_q^2}{C_H^2(C_i)}$	$\frac{C_V^2\cdot(C_qR_{\ell q})^2}{C_H^2(C_i)}$
Probing quark and lepton fermion symmetry without assumptions on the total width					
Free parameters: $C_{qq}(= C_q \cdot C_q/C_H)$, $R_{\ell q}(= C_\ell/C_q)$, $R_{Vq}(= C_V/C_q)$.					
	H$\to \gamma\gamma$	H$\to ZZ$	H$\to WW$	H$\to b\bar{b}$	H$\to \tau\tau$
ggH $t\bar{t}$H	$C_{qq}^2\cdot C_\gamma^2(1,1,R_{Vq})$	$C_{qq}^2\cdot R_{Vq}^2$		C_{qq}^2	$C_{qq}^2\cdot R_{\ell q}^2$
VBF WH ZH	$C_{qq}^2 R_{Vq}^2\cdot C_\gamma^2(1,1,R_{Vq})$	$C_{qq}^2 R_{Vq}^2\cdot R_{Vq}^2$		$C_{qq}^2\cdot R_{Vq}^2$	$C_{qq}^2 R_{Vq}^2\cdot R_{\ell q}^2$

$C_i^2 = \Gamma_i/\Gamma_i(SM)$, $C_\ell = C_\tau$

Table 7: A benchmark parametrization where the quark and lepton symmetry of fermions is probed through the $R_{\ell q}$ parameter.

One particularity of this benchmark parametriation is that it should allow any theoretical prediction involving new particles to be projected into the (C_g, C_γ) or $(C_g, C_\gamma, \mathrm{BR}_{\mathrm{inv.,undet.}})$ spaces.

4.6 A minimal parametrization without assumptions on new physics contributions

Finally, the following parametrization gathers the most important degrees of freedom considered before, namely C_g, C_γ, C_V, C_F. The parametrization, presented in table 9, is chosen such that some parameters are expected to be reasonably constrained by the LHC data in the near term, while other parameters are not expected to be as well constrained in the same time frame.

It should be noted that this is a parametrization which only includes trivial scaling factors.

With the presently available analyses and data, $C_{gV}^2 = C_g^2 \cdot C_V^2 / C_H^2$ seems to be a good choice for the common C_{ij} parameter.

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Probing loop structure without invisible or undetectable widths Free parameters: C_g, C_γ.					
	H$\to \gamma\gamma$	H$\to ZZ$	H$\to WW$	H$\to b\bar{b}$	H$\to \tau\tau$
ggH	$\frac{C_g^2 \cdot C_\gamma^2}{C_H^2(C_i)}$	$\frac{C_g^2}{C_H^2(C_i)}$			
$t\bar{t}$H VBF WH ZH	$\frac{C_\gamma^2}{C_H^2(C_i)}$	$\frac{1}{C_H^2(C_i)}$			

Probing loop structure allowing for invisible or undetectable widths Free parameters: $C_g, C_\gamma, \mathrm{BR}_{\mathrm{inv.,undet.}}$.					
	H$\to \gamma\gamma$	H$\to ZZ$	H$\to WW$	H$\to b\bar{b}$	H$\to \tau\tau$
ggH	$\frac{C_g^2 \cdot C_\gamma^2}{C_H^2(C_i)/(1-\mathrm{BR}_{\mathrm{inv.,undet.}})}$	$\frac{C_g^2}{C_H^2(C_i)/(1-\mathrm{BR}_{\mathrm{inv.,undet.}})}$			
$t\bar{t}$H VBF WH ZH	$\frac{C_\gamma^2}{C_H^2(C_i)/(1-\mathrm{BR}_{\mathrm{inv.,undet.}})}$	$\frac{1}{C_H^2(C_i)/(1-\mathrm{BR}_{\mathrm{inv.,undet.}})}$			

$C_i^2 = \Gamma_i/\Gamma_i(SM)$

Table 8: A benchmark parametrization where effective loop couplings are allowed to float through the C_g and C_γ parameters. Instead of absorbing C_H, explicit allowance is made for a contribution from invisible or undetectable widths via the $\mathrm{BR}_{\mathrm{inv.,undet.}}$ parameter.

Probing loops while allowing other couplings to float without invisible or undetectable widths Free parameters: $C_g, C_\gamma, C_V(= C_W = C_Z), C_F(= C_t = C_b = C_\tau)$.					
	H$\to \gamma\gamma$	H$\to ZZ$	H$\to WW$	H$\to b\bar{b}$	H$\to \tau\tau$
ggH	$\frac{C_g^2 \cdot C_\gamma^2}{C_H^2(C_i)}$	$\frac{C_g^2 \cdot C_V^2}{C_H^2(C_i)}$		$\frac{C_g^2 \cdot C_F^2}{C_H^2(C_i)}$	
$t\bar{t}$H	$\frac{C_F^2 \cdot C_\gamma^2}{C_H^2(C_i)}$	$\frac{C_F^2 \cdot C_V^2}{C_H^2(C_i)}$		$\frac{C_F^2 \cdot C_F^2}{C_H^2(C_i)}$	
VBF WH ZH	$\frac{C_V^2 \cdot C_\gamma^2}{C_H^2(C_i)}$	$\frac{C_V^2 \cdot C_V^2}{C_H^2(C_i)}$		$\frac{C_V^2 \cdot C_F^2}{C_H^2(C_i)}$	

Probing loops while allowing other couplings to float allowing for invisible or undetectable widths Free parameters: $C_{gV}(= C_g \cdot C_V/C_H), R_{Vg}(= C_V/C_g), R_{\gamma V}(= C_\gamma/C_V), R_{FV}(= C_F/C_V)$.					
	H$\to \gamma\gamma$	H$\to ZZ$	H$\to WW$	H$\to b\bar{b}$	H$\to \tau\tau$
ggH	$C_{gV}^2 \cdot R_{\gamma V}^2$	C_{gV}^2		$C_{gV}^2 \cdot R_{FV}^2$	
$t\bar{t}$H	$C_{gV}^2 R_{Vg}^2 R_{FV}^2 \cdot R_{\gamma V}^2$	$C_{gV}^2 R_{Vg}^2 R_{FV}^2$		$C_{gV}^2 R_{Vg}^2 R_{FV}^2 \cdot R_{FV}^2$	
VBF WH ZH	$C_{gV}^2 R_{Vg}^2 \cdot R_{\gamma V}^2$	$C_{gV}^2 R_{Vg}^2$		$C_{gV}^2 R_{Vg}^2 \cdot R_{FV}^2$	

$C_i^2 = \Gamma_i/\Gamma_i(SM), C_V = C_W = C_Z, C_F = C_t = C_b = C_\tau$

Table 9: A benchmark parametrization where effective loop couplings are allowed to float through the C_g and C_γ parameters and the gauge and fermion couplings through the unified parameters C_V and C_F.

Appendices

A Maximal parametrization

The following parametrization gives the relations in a fit without assumptions. It should be noted that the number of degrees of freedom is too large to make such a fit feasible within the near future.

Several choices are possible for C_{ij}. With the currently available channels, $C_{gZ} = C_g \cdot C_Z/C_H$ seems most appropriate, as shown in table A.1. The more appealing choice using vector boson scattering $C_{WW} = C_W{\cdot}C_W/C_H$ or $C_{ZZ} = C_Z{\cdot}C_Z/C_H$ will not be a good choices until more data is accumulated.

Maximal parametrization allowing other couplings to float

Free parameters: $C_{gZ}(=C_g \cdot C_Z/C_H)$, $R_{\gamma Z}(=C_\gamma/C_Z)$, $R_{WZ}(=C_W/C_Z)$, $R_{bZ}(=C_b/C_Z)$, $R_{\tau Z}(=C_\tau/C_Z)$, $R_{Zg}(=C_Z/C_g)$, $R_{tg}(=C_t/C_g)$.

	H→ $\gamma\gamma$			H→ ZZ			H→ WW			H→ $b\bar{b}$			H→ $\tau\tau$		
ggH	C^2_{gZ}	1	$R^2_{\gamma Z}$	C^2_{gZ}	1	1	C^2_{gZ}	1	R^2_{WZ}	C^2_{gZ}	1	R^2_{bZ}	C^2_{gZ}	1	$R^2_{\tau Z}$
$t\bar{t}$H	C^2_{gZ}	R^2_{tg}	$R^2_{\gamma Z}$	C^2_{gZ}	R^2_{tg}	1	C^2_{gZ}	R^2_{tg}	R^2_{WZ}	C^2_{gZ}	R^2_{tg}	R^2_{bZ}	C^2_{gZ}	R^2_{tg}	$R^2_{\tau Z}$
VBF	C^2_{gZ}	$R^2_{Zg} C^2_{\mathrm{VBF}}(1, R_{WZ})$	$R^2_{\gamma Z}$	C^2_{gZ}	$R^2_{Zg} C^2_{\mathrm{VBF}}(1, R_{WZ})$	1	C^2_{gZ}	$R^2_{Zg} C^2_{\mathrm{VBF}}(1, R_{WZ})$	R^2_{WZ}	C^2_{gZ}	$R^2_{Zg} C^2_{\mathrm{VBF}}(1, R_{WZ})$	R^2_{bZ}	C^2_{gZ}	$R^2_{Zg} C^2_{\mathrm{VBF}}(1, R_{WZ})$	$R^2_{\tau Z}$
WH	C^2_{gZ}	$R^2_{Zg} R^2_{WZ}$	$R^2_{\gamma Z}$	C^2_{gZ}	$R^2_{Zg} R^2_{WZ}$	1	C^2_{gZ}	$R^2_{Zg} R^2_{WZ}$	R^2_{WZ}	C^2_{gZ}	$R^2_{Zg} R^2_{WZ}$	R^2_{bZ}	C^2_{gZ}	$R^2_{Zg} R^2_{WZ}$	$R^2_{\tau Z}$
ZH	C^2_{gZ}	R^2_{Zg}	$R^2_{\gamma Z}$	C^2_{gZ}	R^2_{Zg}	1	C^2_{gZ}	R^2_{Zg}	R^2_{WZ}	C^2_{gZ}	R^2_{Zg}	R^2_{bZ}	C^2_{gZ}	R^2_{Zg}	$R^2_{\tau Z}$

$C^2_i = \Gamma_i/\Gamma_i(SM)$

Table A.1: A benchmark parametrization without assumptions and maximum degrees of freedom.