

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

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5 *LHC Higgs Cross Section Working Group, Light Mass Higgs Subgroup*

6 *A. David, A. Denner, M. Dührssen, M. Grazzini, C. Grojean, M. Schumacher, M. Spira, G. Weiglein,*
7 *and M. Zanetti.*

8 **Abstract**

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

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32 1 Introduction

33 The recent observation of a new massive neutral boson by ATLAS and CMS [1, 2], as well as evidence
 34 from the Tevatron experiments [3], opens a new era where characterization of this new object is of central
 35 importance.

36 The Standard Model (SM), as any renormalizable theory, makes very accurate predictions for the
 37 coupling of the Higgs boson to all other known particles. These couplings directly influence the rates of
 38 production and decay of the Higgs boson. Therefore, measurement of the production and decay rates of
 39 the observed state yields information that can be used to probe whether data are compatible with the SM
 40 predictions for the Higgs boson.

41 While coarse features of the observed state can be inferred from the information that the experi-
 42 ments have made public, only a consistent and combined treatment of the data can yield the most accurate
 43 picture of the coupling structure. Such a treatment must take into account all the systematic and statistical
 44 uncertainties considered in the analyses, as well as the correlations among them.

45 This document outlines an interim framework to explore the coupling structure of the recently
 46 observed state. The framework proposed in this recommendation should be seen as a continuation of the
 47 model-independent analysis of the Higgs couplings initiated in Refs. [4–11]. It bears many resemblances
 48 to the original studies on the LHC sensitivity of the Higgs couplings [12–15] and follows closely the
 49 methodology proposed in the recent phenomenological works [16–18] which has been further extended
 50 in several directions [19–56] along the lines that are formalized in the present recommendation. While
 51 the interim framework is not final, it has an accuracy that matches the statistical power of the datasets that
 52 the LHC experiments can hope to collect until the end of the 2012 LHC run and is an explicit attempt
 53 to provide a common ground for the dialogue in the, and between the, experimental and theoretical
 54 communities.

55 Based on that framework, a series of benchmark parametrizations are presented. Each bench-

mark parametrization allows to explore specific aspects of the coupling structure of the new state. The parametrizations have varying degrees of complexity, in a bid to cover the most interesting possibilities that can be realistically tested with the LHC 7 and 8 TeV datasets. On the one hand, the framework and benchmarks were designed to provide a recommendation to experiments on how to perform coupling fits that are useful for the theory community. On the other hand the theory community can prepare for results based on the framework discussed in this document.

Finally, avenues that can be pursued to improve upon this interim framework and recommendations on how to probe the tensor structure will be discussed 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 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 2012 pp run will continue until the end of the year, hopefully delivering about 30 fb^{-1} per experiment.

At the LHC a SM-like Higgs boson is searched for mainly in four exclusive production processes: the predominant gluon fusion $gg \rightarrow H$, the vector boson fusion $qq' \rightarrow qq'H$, the associated production with a vector boson $q\bar{q} \rightarrow WH/ZH$ and the associated production with a top-quark pair $q\bar{q}/gg \rightarrow t\bar{t}H$. 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. The mass range within which each channel is effective and the production processes for which exclusive searches have been developed and made public are indicated in Table 1. A detailed description of the Higgs search analyses can be found in Refs. [1, 2].

Table 1: Summary of the Higgs boson search channels for $m_H < 130 \text{ GeV}$ in the ATLAS and CMS experiments by July 2012. The \checkmark symbol indicates exclusive searches targetting the inclusive $gg \rightarrow H$ production, the associated production processes (with a vector boson or a top quark pair) or the vector boson fusion (VBF) production process.

Channel	m_H (GeV)	ggH		VBF		VH		$t\bar{t}H$	
		ATLAS	CMS	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS
$H \rightarrow \gamma\gamma$	110–150	\checkmark	\checkmark	\checkmark	\checkmark	-	-	-	-
$H \rightarrow \tau^+\tau^-$	110–145	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	-	-
$H \rightarrow b\bar{b}$	110–130	-	-	-	-	\checkmark	\checkmark	-	\checkmark
$H \rightarrow ZZ^{(*)} \rightarrow \ell^+\ell^-\ell^+\ell^-$	110–600	\checkmark	\checkmark	-	-	-	-	-	-
$H \rightarrow WW^{(*)} \rightarrow \ell^+\nu\ell^-\bar{\nu}$	110–600	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	-	-

Both the ATLAS and CMS experiments observe an excess of events for Higgs boson mass hypotheses near $\sim 125 \text{ GeV}$. The observed combined significances are 5.9σ for ATLAS [1] and 5.0σ for CMS [2], compatible with their respective sensitivities. Both observations are primarily in the $H \rightarrow \gamma\gamma$, $H \rightarrow ZZ^{(*)} \rightarrow \ell^+\ell^-\ell^+\ell^-$ and $H \rightarrow WW^{(*)} \rightarrow \ell^+\nu\ell^-\bar{\nu}$ channels. For the $H \rightarrow \gamma\gamma$ 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 and 2.8σ , in the ATLAS and CMS experiments respectively. For the $H \rightarrow ZZ^{(*)} \rightarrow \ell^+\ell^-\ell^+\ell^-$ channel, the significances of the excesses are 3.6σ and 3.2σ at Higgs boson mass hypotheses of 125 GeV and 125.6 GeV, in the ATLAS and CMS experiments respectively. The expected sensitivities at those masses are 2.7σ in ATLAS and 3.8σ in CMS respectively. For the low mass resolution $H \rightarrow WW^{(*)} \rightarrow \ell^+\nu\ell^-\bar{\nu}$ channel ATLAS observes an excess of 2.8σ (2.3σ expected) and CMS observes 1.6σ (2.4σ expected) for a Higgs boson mass hypotheses of $\sim 125 \text{ GeV}$. The other channels do not contribute significantly to the excess, but are nevertheless individually compatible with the presence of a signal.

91 The ATLAS and CMS experiments have also reported compatible measurements of the mass of
92 the observed narrow resonance yielding:

$$93 \qquad 126.0 \pm 0.4(\text{stat.}) \pm 0.4(\text{syst.}) \text{ GeV(ATLAS)},$$

$$94 \qquad 125.3 \pm 0.4(\text{stat.}) \pm 0.5(\text{syst.}) \text{ GeV(CMS)}.$$

95 3 Interim framework for the search of deviations

96 The idea behind this framework is that all deviations from the SM are computed assuming that there is
97 only one underlying state at ~ 125 GeV. It is assumed that this state is a Higgs boson, i.e. the excitation
98 of a field whose vacuum expectation value (VEV) breaks electroweak symmetry, and that it is SM-like,
99 in the sense that the experimental results so far are compatible with the interpretation of the state in
100 terms of the SM Higgs boson. No specific assumptions are made on any additional states of new physics
101 that could influence the phenomenology of the 125 GeV state, such as additional Higgs bosons (which
102 could be heavier but also lighter than 125 GeV), additional scalars that do not develop a VEV, and new
103 fermions and/or gauge bosons that could interact with the state at 125 GeV, giving rise, for instance, to
104 an invisible decay mode.

105 The purpose of this framework is to either confirm that the light, narrow, resonance indeed matches
106 the properties of the SM Higgs, or to establish a deviation from the SM behaviour, which would rule out
107 the SM if sufficiently significant. In the latter case the next goal in the quest to identify the nature of
108 electroweak symmetry breaking (EWSB) would obviously be to test the compatibility of the observed
109 patterns with alternative frameworks of EWSB.

110 In investigating the experimental information that can be obtained on the coupling properties of
111 the new state near 125 GeV from the LHC data to be collected in 2012 the following assumptions are
112 made¹:

- 113 – The signals observed in the different search channels originate from a single narrow resonance
114 with a mass near 125 GeV. The case of several, possibly overlapping, resonances in this mass
115 region is not considered.
- 116 – The width of the assumed Higgs boson near 125 GeV is neglected, i.e. the zero-width approxima-
117 tion for this state is used. Hence the product $\sigma \times BR(ii \rightarrow H \rightarrow ff)$ can be decomposed in the
118 following way for all channels:

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

119 where σ_{ii} is the production cross section through the initial state ii , Γ_{ff} the partial decay width
120 into the final state ff and Γ_H the total width of the Higgs boson.

121 Within the context of these assumptions, in the following a simplified framework for investigating
122 the experimental information that can be obtained on the coupling properties of the new state is outlined.
123 In general, the couplings of the assumed Higgs state near 125 GeV are “pseudo-observables”, i.e. they
124 cannot be directly measured. This means that a certain “unfolding procedure” is necessary to extract
125 information on the couplings from the measured quantities like cross sections times branching ratios
126 (for specific experimental cuts and acceptances). This gives rise to a certain model dependence of the
127 extracted information. Different options can be pursued in this context. One possibility is to confront a
128 specific model with the experimental data. This has the advantage that all available higher-order correc-
129 tions within this model can consistently be taken into account and also other experimental constraints (for
130 instance from direct searches or from electroweak precision data) can be taken into account. However,
131 the results obtained in this case are restricted to the interpretation within that particular model. Another

¹The experiments are encouraged to test the assumptions of the framework, but that lies outside the scope of this document.

possibility is to use a general parametrization of the couplings of the new state without referring to any particular model. While this approach is clearly less model-dependent, the relation between the extracted coupling parameters 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 information can be difficult. It should be mentioned 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.

In 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 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 and 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 generally also give rise to other tensor structures, however compatible with the $SU(2)\times U(1)$ symmetry and the corresponding Ward-Slavnov-Taylor identities. As a consequence, kinematic distributions will in general be modified when 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, the following additional assumption is made in this 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 prediction. This means in particular that the observed state is assumed to be a CP-even scalar.

3.1 Definition of coupling scale factors

In order to take into account the currently best available SM predictions for Higgs cross sections, which include higher-order QCD and EW corrections [57–59], while at the same time introducing possible deviations from the SM values of the couplings, the predicted SM Higgs cross sections and partial decay widths are dressed with scale factors κ_i . The scale factors κ_i are defined in such a way that the cross sections σ_{ii} or the partial decay widths Γ_{ii} associated with the SM particle i scale with the factor κ_i^2 when compared to the corresponding SM prediction. Table 2 lists all relevant cases. Taking the process $gg \rightarrow H \rightarrow \gamma\gamma$ as an example, one would use as cross section:

$$(\sigma \cdot \text{BR})(gg \rightarrow H \rightarrow \gamma\gamma) = \sigma_{\text{SM}}(gg \rightarrow H) \cdot \text{BR}_{\text{SM}}(H \rightarrow \gamma\gamma) \cdot \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2} \quad (2)$$

where the values and uncertainties for both $\sigma_{\text{SM}}(gg \rightarrow H)$ and $\text{BR}_{\text{SM}}(H \rightarrow \gamma\gamma)$ are taken from Ref. [59] for a given Higgs mass hypothesis.

By definition, the currently best available SM predictions for all $\sigma \times \text{BR}$ are recovered when all $\kappa_i = 1$. In general, this means that for $\kappa_i \neq 1$ higher-order accuracy is lost. Nonetheless, NLO

Production modes	Detectable decay modes
$\frac{\sigma_{ggH}}{\sigma_{ggH}^{SM}} = \begin{cases} \kappa_g^2(\kappa_b, \kappa_t, m_H) \\ \kappa_g^2 \end{cases} \quad (3)$	$\frac{\Gamma_{WW^{(*)}}}{\Gamma_{WW^{(*)}}^{SM}} = \kappa_W^2 \quad (8)$
$\frac{\sigma_{VBF}}{\sigma_{VBF}^{SM}} = \kappa_{VBF}^2(\kappa_W, \kappa_Z, m_H) \quad (4)$	$\frac{\Gamma_{ZZ^{(*)}}}{\Gamma_{ZZ^{(*)}}^{SM}} = \kappa_Z^2 \quad (9)$
$\frac{\sigma_{WH}}{\sigma_{WH}^{SM}} = \kappa_W^2 \quad (5)$	$\frac{\Gamma_{b\bar{b}}}{\Gamma_{b\bar{b}}^{SM}} = \kappa_b^2 \quad (10)$
$\frac{\sigma_{ZH}}{\sigma_{ZH}^{SM}} = \kappa_Z^2 \quad (6)$	$\frac{\Gamma_{\tau^-\tau^+}}{\Gamma_{\tau^-\tau^+}^{SM}} = \kappa_\tau^2 \quad (11)$
$\frac{\sigma_{t\bar{t}H}}{\sigma_{t\bar{t}H}^{SM}} = \kappa_t^2 \quad (7)$	$\frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma}^{SM}} = \begin{cases} \kappa_\gamma^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_\gamma^2 \end{cases} \quad (12)$
	$\frac{\Gamma_{Z\gamma}}{\Gamma_{Z\gamma}^{SM}} = \begin{cases} \kappa_{(Z\gamma)}^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_{(Z\gamma)}^2 \end{cases} \quad (13)$
	Currently undetectable decay modes
	$\frac{\Gamma_{t\bar{t}}}{\Gamma_{t\bar{t}}^{SM}} = \kappa_t^2 \quad (14)$
	$\frac{\Gamma_{gg}}{\Gamma_{gg}^{SM}} : \text{ see Section 3.1.2}$
	$\frac{\Gamma_{c\bar{c}}}{\Gamma_{c\bar{c}}^{SM}} = \kappa_t^2 \quad (15)$
	$\frac{\Gamma_{s\bar{s}}}{\Gamma_{s\bar{s}}^{SM}} = \kappa_b^2 \quad (16)$
	$\frac{\Gamma_{\mu^-\mu^+}}{\Gamma_{\mu^-\mu^+}^{SM}} = \kappa_\tau^2 \quad (17)$
	Total width
	$\frac{\Gamma_H}{\Gamma_H^{SM}} = \begin{cases} \kappa_H^2(\kappa_i, m_H) \\ \kappa_H^2 \end{cases} \quad (18)$

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 κ_W , κ_Z , κ_b , κ_t , and κ_τ . For partial widths that are not detectable at the LHC, scaling is performed via proxies chosen among the detectable ones. Additionally, the loop-induced vertices can be treated as a function of other κ_i or effectively, through the κ_g and κ_γ degrees of freedom which allow probing for BSM contributions in the loops. Finally, to explore invisible or undetectable decays, the scaling of the total width can also be taken as a separate degree of freedom, κ_H , instead of being rescaled as a function, $\kappa_H^2(\kappa_i)$, of the other scale factors.

174 QCD corrections essentially factorize with respect to coupling rescaling, and are accounted for wherever
 175 possible. This approach ensures that for a true SM Higgs boson no artificial deviations (caused by ignored
 176 NLO corrections) are found from what is considered the SM Higgs boson hypothesis. The functions
 177 $\kappa_{\text{VBF}}^2(\kappa_W, \kappa_Z, m_H)$, $\kappa_g^2(\kappa_b, \kappa_t, m_H)$, $\kappa_\gamma^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H)$ and $\kappa_H^2(\kappa_i, m_H)$ are used for cases where
 178 there is a non-trivial relationship between scale factors κ_i and cross sections or (partial) decay widths,
 179 and are calculated to NLO QCD accuracy. The functions are defined in the following sections and all
 180 required input parameters as well as example code can be found in Refs. [59, 60].

181 3.1.1 Scaling of the VBF cross section

182 κ_{VBF}^2 refers to the functional dependence of the VBF² cross section on the scale factors κ_W^2 and κ_Z^2 :

$$\kappa_{\text{VBF}}^2(\kappa_W, \kappa_Z, m_H) = \frac{\kappa_W^2 \cdot \sigma_{WF}(m_H) + \kappa_Z^2 \cdot \sigma_{ZF}(m_H)}{\sigma_{WF}(m_H) + \sigma_{ZF}(m_H)} \quad (19)$$

183 The W- and Z-fusion cross sections, σ_{WF} and σ_{ZF} , are taken from Refs. [61, 62]. The interference term
 184 is $< 0.1\%$ in the SM and hence ignored [63].

185 3.1.2 Scaling of the gluon fusion cross section and of the $H \rightarrow gg$ decay vertex

186 κ_g^2 refers to the scale factor for the loop-induced production cross section σ_{ggH} . Since the decay width
 187 Γ_{gg} is not observable at the LHC, its contribution to the total width is also considered.

188 Gluon fusion cross-section scaling

189 As NLO QCD corrections factorize with the scaling of the electroweak couplings with κ_t and κ_b , the
 190 function $\kappa_g^2(\kappa_b, \kappa_t, m_H)$ can be calculated in NLO QCD:

$$\kappa_g^2(\kappa_b, \kappa_t, m_H) = \frac{\kappa_t^2 \cdot \sigma_{ggH}^{\text{tt}}(m_H) + \kappa_b^2 \cdot \sigma_{ggH}^{\text{bb}}(m_H) + \kappa_t \kappa_b \cdot \sigma_{ggH}^{\text{tb}}(m_H)}{\sigma_{ggH}^{\text{tt}}(m_H) + \sigma_{ggH}^{\text{bb}}(m_H) + \sigma_{ggH}^{\text{tb}}(m_H)} \quad (20)$$

191 Here, σ_{ggH}^{tt} , σ_{ggH}^{bb} and σ_{ggH}^{tb} denote the square of the top-quark contribution, the square of the
 192 bottom-quark contribution and the top-bottom interference, respectively. The interference term (σ_{ggH}^{tb}) is
 193 negative for a light mass Higgs, $m_H < 200$ GeV. Within the LHC Higgs Cross Section Working Group
 194 (for the evaluation of the MSSM cross section) these contributions were evaluated, where for σ_{ggH}^{bb} and
 195 σ_{ggH}^{tb} the full NLO QCD calculation included in *HIGLU* [64] was used. For σ_{ggH}^{tt} the NLO QCD result
 196 of *HIGLU* was supplemented with the NNLO corrections in the heavy-top-quark limit as implemented in
 197 *GGH@NNLO* [65], see Ref. [57, Sec. 6.3] for details.

198 Partial width scaling

199 In a similar way, NLO QCD corrections for the $H \rightarrow gg$ partial width are implemented in *HDECAY* [66–
 200 68]. This allows to treat the scale factor for Γ_{gg} as a second order polynomial in κ_b and κ_t :

$$\frac{\Gamma_{gg}}{\Gamma_{gg}^{\text{SM}}(m_H)} = \frac{\kappa_t^2 \cdot \Gamma_{gg}^{\text{tt}}(m_H) + \kappa_b^2 \cdot \Gamma_{gg}^{\text{bb}}(m_H) + \kappa_t \kappa_b \cdot \Gamma_{gg}^{\text{tb}}(m_H)}{\Gamma_{gg}^{\text{tt}}(m_H) + \Gamma_{gg}^{\text{bb}}(m_H) + \Gamma_{gg}^{\text{tb}}(m_H)} \quad (21)$$

201 The terms Γ_{gg}^{tt} , Γ_{gg}^{bb} and Γ_{gg}^{tb} are defined like the σ_{ggH} terms in Eq. (20). The Γ_{gg}^{ii} correspond to the
 202 partial widths that are obtained for $\kappa_i = 1$ and all other $\kappa_j = 0, j \neq i$. The cross-term Γ_{gg}^{tb} can then be
 203 derived by calculating the SM partial width by setting $\kappa_b = \kappa_t = 1$ and subtracting Γ_{gg}^{tt} and Γ_{gg}^{bb} from it.

²Vector Boson Fusion is also called Weak Boson Fusion, as only the weak bosons W and Z contribute to the production.

204 *Effective treatment*

205 In the general case, without the assumptions above, possible non-zero contributions from additional
 206 particles in the loop have to be taken into account and κ_g^2 is then treated as an effective coupling scale
 207 factor parameter in the fit: $\sigma_{ggH}/\sigma_{ggH}^{\text{SM}} = \kappa_g^2$. The effective scale factor for the partial gluon width
 208 Γ_{gg} should behave in a very similar way, so in this case the same effective scale factor κ_g is used:
 209 $\Gamma_{gg}/\Gamma_{gg}^{\text{SM}} = \kappa_g^2$. As the contribution of Γ_{gg} to the total width is <10% in the SM, this assumption is
 210 believed to have no measurable impact.

211 **3.1.3 Scaling of the $H \rightarrow \gamma\gamma$ partial decay width**

212 Like in the previous section, κ_γ^2 refers to the scale factor for the loop-induced $H \rightarrow \gamma\gamma$ decay. Also for
 213 the $H \rightarrow \gamma\gamma$ decay NLO QCD corrections exist and are implemented in *HDECAY*. This allows to treat
 214 the scale factor for the $\gamma\gamma$ partial width as a second order polynomial in κ_b , κ_t , κ_τ , and κ_W :

$$\kappa_\gamma^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) = \frac{\sum_{i,j} \kappa_i \kappa_j \cdot \Gamma_{\gamma\gamma}^{ij}(m_H)}{\sum_{i,j} \Gamma_{\gamma\gamma}^{ij}(m_H)} \quad (22)$$

215 where the pairs (i, j) are bb, tt, $\tau\tau$, WW, bt, b τ , bW, t τ , tW, τ W. The $\Gamma_{\gamma\gamma}^{ii}$ correspond to the partial
 216 widths that are obtained for $\kappa_i = 1$ and all other $\kappa_j = 0$, ($j \neq i$). The cross-terms $\Gamma_{\gamma\gamma}^{ij}$, ($i \neq j$) can then
 217 be derived by calculating the partial width by setting $\kappa_i = \kappa_j = 1$ and all other $\kappa_l = 0$, ($l \neq i, j$), and
 218 subtracting $\Gamma_{\gamma\gamma}^{ii}$ and $\Gamma_{\gamma\gamma}^{jj}$ from them.

219 *Effective treatment*

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

223 **3.1.4 Scaling of the $H \rightarrow Z\gamma$ decay vertex**

224 Like in the previous sections, $\kappa_{(Z\gamma)}^2$ refers to the scale factor for the loop-induced $H \rightarrow Z\gamma$ decay for
 225 which NLO QCD corrections exist and are implemented in *HDECAY*. This allows to treat the scale
 226 factor for the $Z\gamma$ partial width as a second order polynomial in κ_b , κ_t , κ_τ , and κ_W :

$$\kappa_{(Z\gamma)}^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) = \frac{\sum_{i,j} \kappa_i \kappa_j \cdot \Gamma_{Z\gamma}^{ij}(m_H)}{\sum_{i,j} \Gamma_{Z\gamma}^{ij}(m_H)} \quad (23)$$

227 where the pairs (i, j) are bb, tt, $\tau\tau$, WW, bt, b τ , bW, t τ , tW, τ W. The $\Gamma_{Z\gamma}^{ij}$ are calculated in the same
 228 way as for Eq. (22).

229 *Effective treatment*

230 In the general case, without the assumption above, possible non-zero contributions from additional parti-
 231 cles in the loop have to be taken into account and $\kappa_{(Z\gamma)}^2$ is then treated as an effective coupling parameter
 232 in the fit.

233 **3.1.5 Scaling of the total width**

234 The total width Γ_H is the sum of all Higgs partial decay widths. Under the assumption that no additional
 235 BSM Higgs decay modes (into either invisible or undetectable final states) contribute to the total width,

236 Γ_H is expressed as the sum of the scaled partial Higgs decay widths to SM particles, which combine to
 237 a total scale factor κ_H^2 compared to the SM total width Γ_H^{SM} :

$$\kappa_H^2(\kappa_i, m_H) = \sum_{j = \text{WW}^{(*)}, \text{ZZ}^{(*)}, \text{b}\bar{\text{b}}, \tau^-\tau^+, \gamma\gamma, \text{Z}\gamma, \text{gg}, \text{t}\bar{\text{t}}, \text{c}\bar{\text{c}}, \text{s}\bar{\text{s}}, \mu^-\mu^+} \frac{\Gamma_j(\kappa_i, m_H)}{\Gamma_H^{\text{SM}}(m_H)} \quad (24)$$

238 *Effective treatment*

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

241 The total width Γ_H for a light Higgs with $m_H \sim 125$ GeV is not expected to be directly observable
 242 at the LHC, as the SM expectation is $\Gamma_H \sim 4$ MeV, several orders of magnitude smaller than the experi-
 243 mental mass resolution. There is no indication from the results observed so far that the natural width is
 244 broadened by new physics effects to such an extent that it could be directly observable. Furthermore, as
 245 all LHC Higgs channels rely on the identification of Higgs decay products, there is no way of measuring
 246 the total Higgs width indirectly within a coupling fit without using assumptions. This can be illustrated
 247 by assuming that all cross sections and partial width are increased by a common factor $\kappa_i^2 = r > 1$. If
 248 simultaneously the Higgs total width is increased by the square of the same factor $\kappa_H^2 = r^2$ (for example
 249 by postulating some BSM decay mode) the experimental visible signatures in all Higgs channels would
 250 be indistinguishable from the SM.

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

- 257 – No new physics in Higgs decay modes (Eq. 24).
- 258 – $\kappa_W \leq 1, \kappa_Z \leq 1$. If one combines this assumption with the fact that all Higgs partial decay widths
 259 are positive definite and the total width is bigger than the sum of all (known) partial decay width,
 260 this is sufficient to give a lower and upper bound on all κ_i and also determine a possible branching
 261 ratio $\text{BR}_{\text{inv., undet.}}$ into final states invisible or undetectable at the LHC. This is best illustrated with
 262 the $\text{VH}(\text{H} \rightarrow \text{VV})$ process:

$$\sigma_{\text{VH}} \cdot \text{BR}(\text{H} \rightarrow \text{VV}) = \frac{\kappa_V^2 \cdot \sigma_{\text{VH}}^{\text{SM}} \cdot \kappa_V^2 \cdot \Gamma_V^{\text{SM}}}{\Gamma_H} \quad \text{and} \quad \Gamma_H > \kappa_V^2 \cdot \Gamma_V^{\text{SM}} \quad (25)$$

$$\text{give combined:} \quad \sigma_{\text{VH}} \cdot \text{BR}(\text{H} \rightarrow \text{VV}) < \frac{\kappa_V^2 \cdot \sigma_{\text{VH}}^{\text{SM}} \cdot \kappa_V^2 \cdot \Gamma_V^{\text{SM}}}{\kappa_V^2 \cdot \Gamma_V^{\text{SM}}} \quad \Rightarrow \quad \kappa_V^2 > \frac{\sigma_{\text{VH}} \cdot \text{BR}(\text{H} \rightarrow \text{VV})}{\sigma_{\text{VH}}^{\text{SM}}} \quad (26)$$

263 If more final states are included in Eq. (25), the lower bounds become tighter and together with the
 264 upper limit assumptions on κ_W and κ_Z , absolute measurements are possible. However, uncertain-
 265 ties on all κ_i can be very large depending on the accuracy of the $\text{b}\bar{\text{b}}$ decay channels that dominate
 266 the uncertainty of the total width sum.

267 In the following benchmark parametrizations always two versions are given: one without assump-
 268 tions on the total width and one assuming no beyond SM Higgs decay modes.

3.2 Further assumptions

3.2.1 Theoretical uncertainties

The quantitative impact of theory uncertainties in the Higgs production cross sections and decay rates is discussed in detail in Ref. [57].

Such uncertainties will directly affect the determination of the scale factors. In particular, the uncertainty from missing higher-order contributions can be larger than what was estimated in Ref. [57].

In practice, the cross section predictions with their uncertainties as tabulated in Ref. [57] are used as such so that for $\kappa_i = 1$ the recommended SM treatment is recovered. Without a consistent electroweak NLO calculation for deviations from the SM, electroweak corrections and their uncertainties for the SM prediction ($\sim 5\%$ in gluon fusion production and $\sim 2\%$ in the di-photon decay) are naively scaled together. In the absence of explicit calculations this is the currently best available approach in a search for deviations from the SM Higgs prediction.

3.2.2 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 below ~ 150 GeV but also for a wide range of BSM scenarios which are compatible with the present data. However, it has been shown in Ref. [69] 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 $gg (\rightarrow H) \rightarrow VV$, $V = W, Z$, $\mathcal{O}(10\%)$ corrections occur due to an enhanced Higgs signal in the region $M_{VV} > 2 M_V$, 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.

3.2.3 Signal interference effects

A possible source of uncertainty is related to interference effects in $H \rightarrow 4$ fermion decay. For a light Higgs boson the decay width into 4 fermions should always be calculated from the complete matrix elements and not from the approximation

$$\text{BR}(H \rightarrow VV) \times \text{BR}^2(V \rightarrow f\bar{f}) \quad (27)$$

This approximation, based on the ZWA, neglects both off-shell effects and interference between diagrams where the intermediate gauge bosons couple to different pairs of final-state fermions. As shown in Chapter 2 of Ref. [58], the interference effects not included in Eq. (27) amount to 10% for the decay $H \rightarrow e^+e^-e^+e^-$ for a 125 GeV Higgs. Similar interference effects of the order of 5% are found for the $e^+e^-e^+e^-$ and $q\bar{q}q\bar{q}$ final states.

The experimental analyses take into account the full NLO 4-fermion partial decay width [70–72]. The partial width of the 4-lepton final state (usually described as $H \rightarrow ZZ^{(*)} \rightarrow 4l$) is scaled with κ_Z^2 . Similarly, the partial width of the 2-lepton, 2-jet final state (usually described as $H \rightarrow ZZ^{(*)} \rightarrow 2l2q$) is scaled with κ_Z^2 . The partial width of the low mass 2-lepton, 2-neutrino final state (usually described as $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$, although a contribution of $H \rightarrow Z^{(*)}Z \rightarrow ll\nu\nu$ exists and is taken into account) is scaled with κ_W^2 .

3.2.4 Treatment of $\Gamma_{c\bar{c}}$, $\Gamma_{s\bar{s}}$, $\Gamma_{\mu^-\mu^+}$ and light fermion contributions to loop-induced processes

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

310 weak isospin symmetry considerations, the following choices are made:

$$\frac{\Gamma_{c\bar{c}}}{\Gamma_{c\bar{c}}^{\text{SM}}(m_H)} = \kappa_c^2 = \kappa_t^2 \quad (28)$$

$$\frac{\Gamma_{s\bar{s}}}{\Gamma_{s\bar{s}}^{\text{SM}}(m_H)} = \kappa_s^2 = \kappa_b^2 \quad (29)$$

$$\frac{\Gamma_{\mu^-\mu^+}}{\Gamma_{\mu^-\mu^+}^{\text{SM}}(m_H)} = \kappa_\mu^2 = \kappa_\tau^2 \quad (30)$$

311 Following the rationale of Ref. [57, Sec. 9], the widths of e^-e^+ , $u\bar{u}$, $d\bar{d}$ and neutrino final states are
312 neglected.

313 Through interference terms, these light fermions also contribute to the loop-induced $gg \rightarrow H$ and
314 $H \rightarrow gg, \gamma\gamma, Z\gamma$ vertices. In these cases, the assumptions $\kappa_c = \kappa_t$, $\kappa_s = \kappa_b$ and $\kappa_\mu = \kappa_\tau$ are made.

315 3.2.5 Approximation in associated ZH production

316 When scaling the associated ZH production mode, the contribution from $gg \rightarrow ZH$ through a top-
317 quark loop is neglected. This is estimated to be around 5% of the total associated ZH production cross
318 section [57, Sec. 4.3].

319 4 Benchmark parametrizations

320 In putting forward a set of benchmark parametrizations based on the framework described in the pre-
321 vious section several considerations were taken into account. One concern is the stability of the fits
322 which typically involve several hundreds of nuisance parameters. With that in mind, the benchmark
323 parametrizations avoid quotients of parameters of interest. Another constraint that heavily shapes the
324 exact choice of parametrization is consistency among the uncertainties that can be extracted in different
325 parametrizations. Some coupling scale factors enter linearly in loop-induced photon and gluon vertices.
326 For that reason, all scale factors are defined at the same power, leading to what could be misconstrued
327 as an abundance of squared expressions. Finally, the benchmark parametrizations are chosen such that
328 some potential physics cases can be probed and the parameters of interest are chosen so that at least some
329 are expected to be determined.

330 For every benchmark parametrization, two variations are provided:

- 331 1. The total width is scaled assuming that there are no invisible or undetected widths. In this case
332 $\kappa_H^2(\kappa_i)$ is a function of the free parameters.
- 333 2. The total width scale factor is absorbed into the parametrization. In this case no assumption is
334 done and there will be a parameter of the form $\kappa_{ij} = \kappa_i \cdot \kappa_j / \kappa_H$.

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

337 For every benchmark parametrization, a list of the free parameters and their relation to the frame-
338 work parameters is provided. To reduce the amount of symbols in the tables, m_H is omitted throughout.
339 In practice, m_H can either be fixed to a given value or profiled together with other nuisance parameters.

340 4.1 One common scale factor

341 The simplest way to look for a deviation from the predicted SM Higgs coupling structure is to leave
342 the overall signal strength as a free parameter. This is presently done by the experiments, with ATLAS
343 finding $\mu = 1.4 \pm 0.3$ at 126.0 GeV [1] and CMS finding $\mu = 0.87 \pm 0.23$ at 125.5 GeV [2].

344 In order to perform the same fit in the context of the coupling scale factor framework, the only
 345 difference is that $\mu = \kappa^2 \cdot \kappa^2/\kappa^2 = \kappa^2$, where the three terms κ^2 in the intermediate expression account
 346 for production, decay and total width scaling, respectively (Table 3).

Common scale factor					
Free parameter: $\kappa(= \kappa_t = \kappa_b = \kappa_\tau = \kappa_W = \kappa_Z)$.					
	$H \rightarrow \gamma\gamma$	$H \rightarrow ZZ^{(*)}$	$H \rightarrow WW^{(*)}$	$H \rightarrow b\bar{b}$	$H \rightarrow \tau^-\tau^+$
ggH	κ^2				
t \bar{t} H					
VBF					
WH					
ZH					

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

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

350 4.2 Scaling of vector boson and fermion couplings

351 In checking whether an observed state is compatible with the SM Higgs boson, one obvious question
 352 is whether it fulfills its expected role in EWSB which is intimately related to the coupling to the vector
 353 bosons (W, Z).

354 Therefore, assuming that the $SU(2)$ custodial symmetry holds, in the simplest case two parameters
 355 can be defined, one scaling the coupling to the vector bosons, $\kappa_V(= \kappa_W = \kappa_Z)$, and one scaling the
 356 coupling common to all fermions, $\kappa_f(= \kappa_t = \kappa_b = \kappa_\tau)$. Loop-induced processes are assumed to scale as
 357 expected from the SM structure.

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

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

365 4.3 Probing custodial symmetry

366 One of the best motivated symmetries in case the new state is responsible for electroweak symmetry
 367 breaking is that which links its coupling to the W and Z bosons. Since $SU(2)_V$ or custodial symmetry is
 368 an approximate symmetry of the SM (e.g. $\Delta\rho \neq 0$), it is important to test whether data are compatible
 369 with the amount of violation allowed by the SM at NLO.

370 In this parametrization, presented in Table 5, $\lambda_{WZ}(= \kappa_W/\kappa_Z)$ is the main parameter of interest.
 371 Though providing interesting information, both κ_Z and κ_f can be thought of as nuisance parameters when
 372 performing this fit. In addition to the photon vertex loop not having a trivial scaling, in this parametriza-
 373 tion also the individual W and Z boson fusion contributions to the vector boson fusion production process
 374 need to be resolved.

Boson and fermion scaling without invisible or undetectable widths					
Free parameters: $\kappa_V (= \kappa_W = \kappa_Z)$, $\kappa_f (= \kappa_t = \kappa_b = \kappa_\tau)$.					
	$H \rightarrow \gamma\gamma$	$H \rightarrow ZZ^{(*)}$	$H \rightarrow WW^{(*)}$	$H \rightarrow b\bar{b}$	$H \rightarrow \tau^-\tau^+$
ggH t \bar{t} H	$\frac{\kappa_f^2 \cdot \kappa_\gamma^2(\kappa_f, \kappa_f, \kappa_f, \kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_f^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_f^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_f^2 \cdot \kappa_f^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_f^2 \cdot \kappa_f^2}{\kappa_H^2(\kappa_i)}$
VBF WH ZH	$\frac{\kappa_V^2 \cdot \kappa_f^2(\kappa_f, \kappa_f, \kappa_f, \kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2 \cdot \kappa_f^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2 \cdot \kappa_f^2}{\kappa_H^2(\kappa_i)}$
Boson and fermion scaling without assumptions on the total width					
Free parameters: $\kappa_{VV} (= \kappa_V \cdot \kappa_V / \kappa_H)$, $\lambda_{fV} (= \kappa_f / \kappa_V)$.					
	$H \rightarrow \gamma\gamma$	$H \rightarrow ZZ^{(*)}$	$H \rightarrow WW^{(*)}$	$H \rightarrow b\bar{b}$	$H \rightarrow \tau^-\tau^+$
ggH t \bar{t} H	$\kappa_{VV}^2 \cdot \lambda_{fV}^2 \cdot \kappa_\gamma^2(\lambda_{fV}, \lambda_{fV}, \lambda_{fV}, 1)$	$\kappa_{VV}^2 \cdot \lambda_{fV}^2$	$\kappa_{VV}^2 \cdot \lambda_{fV}^2$	$\kappa_{VV}^2 \cdot \lambda_{fV}^2 \cdot \lambda_{fV}^2$	$\kappa_{VV}^2 \cdot \lambda_{fV}^2 \cdot \lambda_{fV}^2$
VBF WH ZH	$\kappa_{VV}^2 \cdot \kappa_f^2(\lambda_{fV}, \lambda_{fV}, \lambda_{fV}, 1)$	κ_{VV}^2	κ_{VV}^2	$\kappa_{VV}^2 \cdot \lambda_{fV}^2$	$\kappa_{VV}^2 \cdot \lambda_{fV}^2$
$\kappa_i^2 = \Gamma_{ii} / \Gamma_{ii}^{\text{SM}}$					

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

375 4.4 Probing the fermion sector

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

378 Given how the gluon-gluon fusion production process is dominated by the top-quark coupling,
379 and how there are two decay modes involving fermions, one way of splitting fermions that is within
380 experimental reach is to consider up-type fermions (top quark) and down-type fermions (bottom quark
381 and tau lepton) separately. In this parametrization, presented in Table 6, the relevant parameter of interest
382 is $\lambda_{du} (= \kappa_d / \kappa_u)$, the ratio of the scale factors of the couplings to down-type fermions, $\kappa_d = \kappa_\tau (= \kappa_\mu) =$
383 $\kappa_b (= \kappa_s)$, and up-type fermions, $\kappa_u = \kappa_t (= \kappa_c)$.

384 Alternatively one can consider quarks and leptons separately. In this parametrization, presented
385 in Table 7, the relevant parameter of interest is $\lambda_{lq} (= \kappa_l / \kappa_q)$, the ratio of the coupling scale factors to
386 leptons, $\kappa_l = \kappa_\tau (= \kappa_\mu)$, and quarks, $\kappa_q = \kappa_t (= \kappa_c) = \kappa_b (= \kappa_s)$.

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

390 4.5 Probing the loop structure and invisible or undetectable decay of new particles

391 It is possible that in nature there are particles not predicted by the SM. Depending on their properties,
392 new particles may influence the partial width of the gluon and/or photon vertices.

393 In this parametrization, presented in Table 8, each of the loop-induced vertices is represented by
394 an effective scale factor, κ_g and κ_γ .

395 Particles not predicted by the SM may also give rise to invisible or undetectable decays. Invisible
396 decays might show up as a MET signature and could potentially be measured at the LHC with dedicated
397 analyses. An example of an undetectable final state would be a multi-jet signature that cannot be sepa-
398 rated from QCD backgrounds at the LHC and hence not detected. With sufficient data it can be envisaged
399 to disentangle the invisible and undetectable components.

Probing custodial symmetry without invisible or undetectable widths					
Free parameters: $\kappa_Z, \lambda_{WZ}(= \kappa_W / \kappa_Z), \kappa_t(= \kappa_t = \kappa_b = \kappa_\tau)$.					
	$H \rightarrow \gamma\gamma$	$H \rightarrow ZZ^*$	$H \rightarrow WW^*$	$H \rightarrow b\bar{b}$	$H \rightarrow \tau^-\tau^+$
ggH	$\frac{\kappa_t^2 \cdot \kappa_\gamma^2 (\kappa_t, \kappa_t, \kappa_t, \kappa_Z \lambda_{WZ})}{\kappa_H^2 (\kappa_t)}$	$\frac{\kappa_t^2 \cdot \kappa_Z^2}{\kappa_H^2 (\kappa_t)}$	$\frac{\kappa_t^2 \cdot (\kappa_Z \lambda_{WZ})^2}{\kappa_H^2 (\kappa_t)}$	$\frac{\kappa_t^2 \cdot \kappa_t^2}{\kappa_H^2 (\kappa_t)}$	
t \bar{t} H	$\frac{\kappa_t^2 \cdot \kappa_\gamma^2 (\kappa_Z, \kappa_Z \lambda_{WZ}) \cdot \kappa_t^2 (\kappa_t, \kappa_t, \kappa_t, \kappa_Z \lambda_{WZ})}{\kappa_H^2 (\kappa_t)}$	$\frac{\kappa_t^2 \cdot \kappa_Z^2 (\kappa_Z, \kappa_Z \lambda_{WZ}) \cdot \kappa_t^2}{\kappa_H^2 (\kappa_t)}$	$\frac{\kappa_{\text{VBF}}^2 (\kappa_Z, \kappa_Z \lambda_{WZ}) \cdot (\kappa_Z \lambda_{WZ})^2}{\kappa_H^2 (\kappa_t)}$	$\frac{\kappa_{\text{VBF}}^2 (\kappa_Z, \kappa_Z \lambda_{WZ}) \cdot \kappa_t^2}{\kappa_H^2 (\kappa_t)}$	$\frac{\kappa_t^2 \cdot \kappa_t^2}{\kappa_H^2 (\kappa_t)}$
VBF	$\frac{(\kappa_Z \lambda_{WZ})^2 \cdot \kappa_t^2 (\kappa_t, \kappa_t, \kappa_t, \kappa_Z \lambda_{WZ})}{\kappa_H^2 (\kappa_t)}$	$\frac{(\kappa_Z \lambda_{WZ})^2 \cdot \kappa_Z^2}{\kappa_H^2 (\kappa_t)}$	$\frac{(\kappa_Z \lambda_{WZ})^2 \cdot (\kappa_Z \lambda_{WZ})^2}{\kappa_H^2 (\kappa_t)}$	$\frac{(\kappa_Z \lambda_{WZ})^2 \cdot \kappa_t^2}{\kappa_H^2 (\kappa_t)}$	$\frac{(\kappa_Z \lambda_{WZ})^2 \cdot \kappa_t^2}{\kappa_H^2 (\kappa_t)}$
WH	$\frac{\kappa_Z^2 \cdot \kappa_\gamma^2 (\kappa_t, \kappa_t, \kappa_t, \kappa_Z \lambda_{WZ})}{\kappa_H^2 (\kappa_t)}$	$\frac{\kappa_Z^2 \cdot \kappa_Z^2}{\kappa_H^2 (\kappa_t)}$	$\frac{\kappa_Z^2 \cdot (\kappa_Z \lambda_{WZ})^2}{\kappa_H^2 (\kappa_t)}$	$\frac{\kappa_Z^2 \cdot \kappa_t^2}{\kappa_H^2 (\kappa_t)}$	$\frac{\kappa_Z^2 \cdot \kappa_t^2}{\kappa_H^2 (\kappa_t)}$
ZH	$\frac{\kappa_Z^2 \cdot \kappa_\gamma^2 (\kappa_t, \kappa_t, \kappa_t, \kappa_Z \lambda_{WZ})}{\kappa_H^2 (\kappa_t)}$	$\frac{\kappa_Z^2 \cdot \kappa_Z^2}{\kappa_H^2 (\kappa_t)}$	$\frac{\kappa_Z^2 \cdot (\kappa_Z \lambda_{WZ})^2}{\kappa_H^2 (\kappa_t)}$	$\frac{\kappa_Z^2 \cdot \kappa_t^2}{\kappa_H^2 (\kappa_t)}$	$\frac{\kappa_Z^2 \cdot \kappa_t^2}{\kappa_H^2 (\kappa_t)}$
Probing custodial symmetry without assumptions on the total width					
Free parameters: $\kappa_{ZZ}(= \kappa_Z \cdot \kappa_Z / \kappa_H), \lambda_{WZ}(= \kappa_W / \kappa_Z), \lambda_{FZ}(= \kappa_t / \kappa_Z)$.					
	$H \rightarrow \gamma\gamma$	$H \rightarrow ZZ^*$	$H \rightarrow WW^*$	$H \rightarrow b\bar{b}$	$H \rightarrow \tau^-\tau^+$
ggH	$\kappa_{ZZ}^2 \lambda_{FZ}^2 \cdot \kappa_\gamma^2 (\lambda_{FZ}, \lambda_{FZ}, \lambda_{FZ}, \lambda_{WZ})$	$\kappa_{ZZ}^2 \lambda_{FZ}^2$	$\kappa_{ZZ}^2 \lambda_{FZ}^2 \cdot \lambda_{WZ}^2$	$\kappa_{ZZ}^2 \lambda_{FZ}^2 \cdot \lambda_{FZ}^2$	$\kappa_{ZZ}^2 \lambda_{FZ}^2 \cdot \lambda_{FZ}^2$
t \bar{t} H	$\kappa_{ZZ}^2 \lambda_{FZ}^2 \cdot \kappa_\gamma^2 (\lambda_{FZ}, \lambda_{FZ}, \lambda_{FZ}, \lambda_{WZ})$	$\kappa_{ZZ}^2 \lambda_{FZ}^2$	$\kappa_{ZZ}^2 \lambda_{FZ}^2 \cdot \lambda_{WZ}^2$	$\kappa_{ZZ}^2 \lambda_{FZ}^2 \cdot \lambda_{FZ}^2$	$\kappa_{ZZ}^2 \lambda_{FZ}^2 \cdot \lambda_{FZ}^2$
VBF	$\kappa_{ZZ}^2 \lambda_{WZ}^2 \cdot \kappa_\gamma^2 (\lambda_{FZ}, \lambda_{FZ}, \lambda_{FZ}, \lambda_{WZ})$	$\kappa_{ZZ}^2 \lambda_{WZ}^2$	$\kappa_{ZZ}^2 \lambda_{WZ}^2 \cdot \lambda_{WZ}^2$	$\kappa_{ZZ}^2 \lambda_{WZ}^2 \cdot \lambda_{FZ}^2$	$\kappa_{ZZ}^2 \lambda_{WZ}^2 \cdot \lambda_{FZ}^2$
WH	$\kappa_{ZZ}^2 \lambda_{WZ}^2 \cdot \kappa_\gamma^2 (\lambda_{FZ}, \lambda_{FZ}, \lambda_{FZ}, \lambda_{WZ})$	$\kappa_{ZZ}^2 \lambda_{WZ}^2$	$\kappa_{ZZ}^2 \lambda_{WZ}^2 \cdot \lambda_{WZ}^2$	$\kappa_{ZZ}^2 \lambda_{WZ}^2 \cdot \lambda_{FZ}^2$	$\kappa_{ZZ}^2 \lambda_{WZ}^2 \cdot \lambda_{FZ}^2$
ZH	$\kappa_{ZZ}^2 \cdot \kappa_\gamma^2 (\lambda_{FZ}, \lambda_{FZ}, \lambda_{FZ}, \lambda_{WZ})$	κ_{ZZ}^2	$\kappa_{ZZ}^2 \cdot \lambda_{WZ}^2$	$\kappa_{ZZ}^2 \cdot \lambda_{FZ}^2$	$\kappa_{ZZ}^2 \cdot \lambda_{FZ}^2$

$$\kappa_t^2 = \Gamma_{ii} / \Gamma_{ii}^{\text{SM}}$$

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

Probing up-type and down-type fermion symmetry without invisible or undetectable widths					
Free parameters: $\kappa_V (= \kappa_Z = \kappa_W)$, $\lambda_{du} (= \kappa_d/\kappa_u)$, $\kappa_u (= \kappa_t)$.					
	$H \rightarrow \gamma\gamma$	$H \rightarrow ZZ^{(*)}$	$H \rightarrow WW^{(*)}$	$H \rightarrow b\bar{b}$	$H \rightarrow \tau^-\tau^+$
ggH	$\frac{\kappa_g^2(\kappa_u\lambda_{du},\kappa_u)\cdot\kappa_\gamma^2(\kappa_u\lambda_{du},\kappa_u,\kappa_u\lambda_{du},\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_g^2(\kappa_u\lambda_{du},\kappa_u)\cdot\kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_g^2(\kappa_u\lambda_{du},\kappa_u)\cdot(\kappa_u\lambda_{du})^2}{\kappa_H^2(\kappa_i)}$	
t \bar{t} H	$\frac{\kappa_u^2\cdot\kappa_\gamma^2(\kappa_u\lambda_{du},\kappa_u,\kappa_u\lambda_{du},\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_u^2\cdot\kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_u^2\cdot(\kappa_u\lambda_{du})^2}{\kappa_H^2(\kappa_i)}$	
VBF WH ZH	$\frac{\kappa_V^2\cdot\kappa_\gamma^2(\kappa_u\lambda_{du},\kappa_u,\kappa_u\lambda_{du},\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2\cdot\kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_V^2\cdot(\kappa_u\lambda_{du})^2}{\kappa_H^2(\kappa_i)}$	

Probing up-type and down-type fermion symmetry without assumptions on the total width					
Free parameters: $\kappa_{uu} (= \kappa_u \cdot \kappa_u/\kappa_H)$, $\lambda_{du} (= \kappa_d/\kappa_u)$, $\lambda_{Vu} (= \kappa_V/\kappa_u)$.					
	$H \rightarrow \gamma\gamma$	$H \rightarrow ZZ^{(*)}$	$H \rightarrow WW^{(*)}$	$H \rightarrow b\bar{b}$	$H \rightarrow \tau^-\tau^+$
ggH	$\kappa_{uu}^2\kappa_g^2(\lambda_{du}, 1) \cdot \kappa_\gamma^2(\lambda_{du}, 1, \lambda_{du}, \lambda_{Vu})$	$\kappa_{uu}^2\kappa_g^2(\lambda_{du}, 1) \cdot \lambda_{Vu}^2$		$\kappa_{uu}^2\kappa_g^2(\lambda_{du}, 1) \cdot \lambda_{du}^2$	
t \bar{t} H	$\kappa_{uu}^2 \cdot \kappa_\gamma^2(\lambda_{du}, 1, \lambda_{du}, \lambda_{Vu})$	$\kappa_{uu}^2 \cdot \lambda_{Vu}^2$		$\kappa_{uu}^2 \cdot \lambda_{du}^2$	
VBF WH ZH	$\kappa_{uu}^2\lambda_{Vu}^2 \cdot \kappa_\gamma^2(\lambda_{du}, 1, \lambda_{du}, \lambda_{Vu})$	$\kappa_{uu}^2\lambda_{Vu}^2 \cdot \lambda_{Vu}^2$		$\kappa_{uu}^2\lambda_{Vu}^2 \cdot \lambda_{du}^2$	

$\kappa_i^2 = \Gamma_{ii}/\Gamma_{ii}^{SM}$, $\kappa_d = \kappa_b = \kappa_t$

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

Probing quark and lepton fermion symmetry without invisible or undetectable widths					
Free parameters: $\kappa_V (= \kappa_Z = \kappa_W)$, $\lambda_{lq} (= \kappa_l/\kappa_q)$, $\kappa_q (= \kappa_t = \kappa_b)$.					
	$H \rightarrow \gamma\gamma$	$H \rightarrow ZZ^{(*)}$	$H \rightarrow WW^{(*)}$	$H \rightarrow b\bar{b}$	$H \rightarrow \tau^-\tau^+$
ggH t \bar{t} H	$\frac{\kappa_q^2\cdot\kappa_\gamma^2(\kappa_q,\kappa_q,\kappa_q\lambda_{lq},\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_q^2\cdot\kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_q^2\cdot\kappa_q^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_q^2\cdot(\kappa_q\lambda_{lq})^2}{\kappa_H^2(\kappa_i)}$
VBF WH ZH	$\frac{\kappa_V^2\cdot\kappa_\gamma^2(\kappa_q,\kappa_q,\kappa_q\lambda_{lq},\kappa_V)}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2\cdot\kappa_V^2}{\kappa_H^2(\kappa_i)}$		$\frac{\kappa_V^2\cdot\kappa_q^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2\cdot(\kappa_q\lambda_{lq})^2}{\kappa_H^2(\kappa_i)}$

Probing quark and lepton fermion symmetry without assumptions on the total width					
Free parameters: $\kappa_{qq} (= \kappa_q \cdot \kappa_q/\kappa_H)$, $\lambda_{lq} (= \kappa_l/\kappa_q)$, $\lambda_{Vq} (= \kappa_V/\kappa_q)$.					
	$H \rightarrow \gamma\gamma$	$H \rightarrow ZZ^{(*)}$	$H \rightarrow WW^{(*)}$	$H \rightarrow b\bar{b}$	$H \rightarrow \tau^-\tau^+$
ggH t \bar{t} H	$\kappa_{qq}^2 \cdot \kappa_\gamma^2(1, 1, \lambda_{lq}, \lambda_{Vq})$	$\kappa_{qq}^2 \cdot \lambda_{Vq}^2$		κ_{qq}^2	$\kappa_{qq}^2 \cdot \lambda_{lq}^2$
VBF WH ZH	$\kappa_{qq}^2\lambda_{Vq}^2 \cdot \kappa_\gamma^2(1, 1, \lambda_{lq}, \lambda_{Vq})$	$\kappa_{qq}^2\lambda_{Vq}^2 \cdot \lambda_{Vq}^2$		$\kappa_{qq}^2 \cdot \lambda_{Vq}^2$	$\kappa_{qq}^2\lambda_{Vq}^2 \cdot \lambda_{lq}^2$

$\kappa_i^2 = \Gamma_{ii}/\Gamma_{ii}^{SM}$, $\kappa_l = \kappa_\tau$

Table 7: A benchmark parametrization where the quark and lepton symmetry of fermions is probed through the λ_{lq} parameter.

400 In order to probe this possibility, instead of absorbing the total width into another parameter or
 401 leaving it free, a different parameter is introduced, $\text{BR}_{\text{inv.,undet.}}$. The definition of $\text{BR}_{\text{inv.,undet.}}$ is relative
 402 to the rescaled total width, $\kappa_{\text{H}}^2(\kappa_i)$, and can thus be interpreted as the invisible or undetectable fraction of
 403 the total width.

404 One particularity of this benchmark parametrization is that it should allow any theoretical predic-
 405 tion involving new particles to be projected into the $(\kappa_g, \kappa_\gamma)$ or $(\kappa_g, \kappa_\gamma, \text{BR}_{\text{inv.,undet.}})$ spaces.

406 It can be noted that the benchmark parametrization including $\text{BR}_{\text{inv.,undet.}}$ can be recast in a form
 407 that allows for an interpretation in terms of a tree-level scale factor and the loop-induced scale factors
 408 with the following substitutions: $\kappa_j \rightarrow \kappa'_j/\kappa_{\text{tree}}$ (with $j = g, \gamma$) and $(1 - \text{BR}_{\text{inv.,undet.}}) \rightarrow \kappa_{\text{tree}}^2$.

409 4.6 A minimal parametrization without assumptions on new physics contributions

410 Finally, the following parametrization gathers the most important degrees of freedom considered before,
 411 namely $\kappa_g, \kappa_\gamma, \kappa_V, \kappa_f$. The parametrization, presented in Table 9, is chosen such that some parameters
 412 are expected to be reasonably constrained by the LHC data in the near term, while other parameters are
 413 not expected to be as well constrained in the same time frame.

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

415 With the presently available analyses and data, $\kappa_{gV}^2 = \kappa_g^2 \cdot \kappa_V^2/\kappa_{\text{H}}^2$ seems to be a good choice for
 416 the common κ_{ij} parameter.

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Probing loop structure without invisible or undetectable widths					
Free parameters: κ_g, κ_γ .					
	$H \rightarrow \gamma\gamma$	$H \rightarrow ZZ^{(*)}$	$H \rightarrow WW^{(*)}$	$H \rightarrow b\bar{b}$	$H \rightarrow \tau^-\tau^+$
ggH	$\frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_g^2}{\kappa_H^2(\kappa_i)}$			
$t\bar{t}H$ VBF WH ZH	$\frac{\kappa_\gamma^2}{\kappa_H^2(\kappa_i)}$	$\frac{1}{\kappa_H^2(\kappa_i)}$			

Probing loop structure allowing for invisible or undetectable widths					
Free parameters: $\kappa_g, \kappa_\gamma, BR_{inv.,undet.}$.					
	$H \rightarrow \gamma\gamma$	$H \rightarrow ZZ^{(*)}$	$H \rightarrow WW^{(*)}$	$H \rightarrow b\bar{b}$	$H \rightarrow \tau^-\tau^+$
ggH	$\frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2(\kappa_i)/(1-BR_{inv.,undet.})}$	$\frac{\kappa_g^2}{\kappa_H^2(\kappa_i)/(1-BR_{inv.,undet.})}$			
$t\bar{t}H$ VBF WH ZH	$\frac{\kappa_\gamma^2}{\kappa_H^2(\kappa_i)/(1-BR_{inv.,undet.})}$	$\frac{1}{\kappa_H^2(\kappa_i)/(1-BR_{inv.,undet.})}$			

$\kappa_i^2 = \Gamma_{ii}/\Gamma_{ii}^{SM}$

Table 8: A benchmark parametrization where effective vertex couplings are allowed to float through the κ_g and κ_γ parameters. Instead of absorbing κ_H , explicit allowance is made for a contribution from invisible or undetectable widths via the $BR_{inv.,undet.}$ parameter.

Probing loops while allowing other couplings to float without invisible or undetectable widths					
Free parameters: $\kappa_g, \kappa_\gamma, \kappa_V (= \kappa_W = \kappa_Z), \kappa_f (= \kappa_t = \kappa_b = \kappa_\tau)$.					
	$H \rightarrow \gamma\gamma$	$H \rightarrow ZZ^{(*)}$	$H \rightarrow WW^{(*)}$	$H \rightarrow b\bar{b}$	$H \rightarrow \tau^-\tau^+$
ggH	$\frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_g^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$			$\frac{\kappa_g^2 \cdot \kappa_f^2}{\kappa_H^2(\kappa_i)}$
$t\bar{t}H$	$\frac{\kappa_f^2 \cdot \kappa_\gamma^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_f^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$			$\frac{\kappa_f^2 \cdot \kappa_f^2}{\kappa_H^2(\kappa_i)}$
VBF WH ZH	$\frac{\kappa_V^2 \cdot \kappa_\gamma^2}{\kappa_H^2(\kappa_i)}$	$\frac{\kappa_V^2 \cdot \kappa_V^2}{\kappa_H^2(\kappa_i)}$			$\frac{\kappa_V^2 \cdot \kappa_f^2}{\kappa_H^2(\kappa_i)}$

Probing loops while allowing other couplings to float allowing for invisible or undetectable widths					
Free parameters: $\kappa_{gV} (= \kappa_g \cdot \kappa_V / \kappa_H), \lambda_{Vg} (= \kappa_V / \kappa_g), \lambda_{\gamma V} (= \kappa_\gamma / \kappa_V), \lambda_{fV} (= \kappa_f / \kappa_V)$.					
	$H \rightarrow \gamma\gamma$	$H \rightarrow ZZ^{(*)}$	$H \rightarrow WW^{(*)}$	$H \rightarrow b\bar{b}$	$H \rightarrow \tau^-\tau^+$
ggH	$\kappa_{gV}^2 \cdot \lambda_{\gamma V}^2$	κ_{gV}^2			$\kappa_{gV}^2 \cdot \lambda_{fV}^2$
$t\bar{t}H$	$\kappa_{gV}^2 \lambda_{Vg}^2 \lambda_{fV}^2 \cdot \lambda_{\gamma V}^2$	$\kappa_{gV}^2 \lambda_{Vg}^2 \lambda_{fV}^2$			$\kappa_{gV}^2 \lambda_{Vg}^2 \lambda_{fV}^2 \cdot \lambda_{fV}^2$
VBF WH ZH	$\kappa_{gV}^2 \lambda_{Vg}^2 \cdot \lambda_{\gamma V}^2$	$\kappa_{gV}^2 \lambda_{Vg}^2$			$\kappa_{gV}^2 \lambda_{Vg}^2 \cdot \lambda_{fV}^2$

$\kappa_i^2 = \Gamma_{ii}/\Gamma_{ii}^{SM}, \kappa_V = \kappa_W = \kappa_Z, \kappa_f = \kappa_t = \kappa_b = \kappa_\tau$

Table 9: A benchmark parametrization where effective vertex couplings are allowed to float through the κ_g and κ_γ parameters and the gauge and fermion couplings through the unified parameters κ_V and κ_f .

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574 Appendices

575 A Maximal parametrization

576 Table A.1 presents the relations in a fit only with simple scale factors. It should be noted that the number
577 of degrees of freedom is too large to make such a fit feasible in the near future.

578 Several choices are possible for κ_{ij} . With the currently available channels, $\kappa_{gZ} = \kappa_g \cdot \kappa_Z / \kappa_H$ seems
579 most appropriate, as shown in table A.1. The more appealing choices using vector boson scattering
580 $\kappa_{WW} = \kappa_W \cdot \kappa_W / \kappa_H$ or $\kappa_{ZZ} = \kappa_Z \cdot \kappa_Z / \kappa_H$ will not be as good until more data is accumulated.

581 B LO SM-inspired loop parametrizations

582 This appendix collects LO SM-inspired relations that can be used as scale factors of couplings involving
583 loops.

584 These are not recommended and are considered obsolete.

585 B.1 Gluon vertex loop

586 Under the assumption that the only relevant contributions to $\sigma_{g\bar{g}H}$ and $\Gamma_{g\bar{g}}$ are from top-quark and
587 bottom-quark loops, $\kappa_g^2(\kappa_b, \kappa_t, m_H)$ is a scaling function depending on the scale factors κ_b and κ_t :

$$\kappa_g^2(\kappa_b, \kappa_t, m_H) = \frac{|\kappa_b A_b(m_H) + \kappa_t A_t(m_H)|^2}{|A_b(m_H) + A_t(m_H)|^2} \quad (\text{B.1})$$

588 where $A_{b,t}$ denotes the bottom-quark and top-quark amplitudes in the SM [73, Eq. (21)].

589 B.2 Photon vertex loop

590 Under the assumption that the only relevant contributions to $\Gamma_{\gamma\gamma}$ are from W-boson, top-quark, and
591 bottom-quark loops, $\kappa_\gamma^2(\kappa_b, \kappa_t, \kappa_W, m_H)$ is a scaling function depending on the scale factors κ_b , κ_t and
592 κ_W :

$$\kappa_\gamma^2(\kappa_b, \kappa_t, \kappa_W, m_H) = \frac{|\kappa_b A'_b(m_H) + \kappa_t A'_t(m_H) + \kappa_W A'_W(m_H)|^2}{|A'_b(m_H) + A'_t(m_H) + A'_W(m_H)|^2} \quad (\text{B.2})$$

593 where $A'_{b,t,W}$ denotes the bottom-quark, top-quark, and W-boson amplitudes in the SM, including color
594 and charge factors [73, Eq. (1)].

595 B.3 $Z\gamma$ vertex loop

596 Under the assumption that the only relevant contributions to $\Gamma_{Z\gamma}$ are from W-boson, top-quark, and
597 bottom-quark loops, $\kappa_{(Z\gamma)}^2(\kappa_b, \kappa_t, \kappa_W, m_H)$ is a scaling function depending on the scale factors κ_b , κ_t
598 and κ_W :

$$\kappa_{(Z\gamma)}^2(\kappa_b, \kappa_t, \kappa_W, m_H) = \frac{|\kappa_b B_b(m_H) + \kappa_t B_t(m_H) + \kappa_W B_W(m_H)|^2}{|B_b(m_H) + B_t(m_H) + B_W(m_H)|^2} \quad (\text{B.3})$$

599 where $B_{b,t,W}$ denotes the bottom-quark, top-quark, and W-boson amplitudes in the SM [74, Eq. (7)]. In
600 the SM $\kappa_{(Z\gamma)}^2 \sim \kappa_W^2$ to within 10%.

601 B.4 Treatment of m_b

602 Wherever the b-quark mass, m_b , appears in the κ_g^2 and $\kappa_{(Z\gamma)}^2$ above (Eqs. (B.1) and (B.3), respectively),
603 the pole mass $M_b = 4.49$ GeV is used.

604 Based on the results of Ref. [73], for κ_γ^2 , Eq. (B.2), the running mass $m_b(\mu)$, $\mu = m_H/2$ is used.

Maximal parametrization allowing other couplings to float					
Free parameters: $\kappa_{gZ} (= \kappa_g \cdot \kappa_Z / \kappa_H)$, $\lambda_{\gamma Z} (= \kappa_\gamma / \kappa_Z)$, $\lambda_{WZ} (= \kappa_W / \kappa_Z)$, $\lambda_{bZ} (= \kappa_b / \kappa_Z)$, $\lambda_{\tau Z} (= \kappa_\tau / \kappa_Z)$, $\lambda_{Zg} (= \kappa_Z / \kappa_g)$, $\lambda_{tZ} (= \kappa_t / \kappa_g)$.					
	$H \rightarrow \gamma\gamma$	$H \rightarrow ZZ^{(*)}$	$H \rightarrow WW^{(*)}$	$H \rightarrow b\bar{b}$	$H \rightarrow \tau^-\tau^+$
ggH	κ_{gZ}^2	κ_{gZ}^2	κ_{gZ}^2	κ_{gZ}^2	κ_{gZ}^2
	1	1	1	1	1
$\lambda_{\gamma Z}^2$	$\lambda_{\gamma Z}^2$				
t \bar{t} H	λ_{tZ}^2	λ_{tZ}^2	λ_{tZ}^2	λ_{tZ}^2	λ_{tZ}^2
VBF	$\kappa_{gZ}^2 \lambda_{Zg}^2 \kappa_{VBF}^2 (1, \lambda_{WZ}) \lambda_{\gamma Z}^2$	$\kappa_{gZ}^2 \lambda_{Zg}^2 \kappa_{VBF}^2 (1, \lambda_{WZ}) 1$	$\kappa_{gZ}^2 \lambda_{Zg}^2 \kappa_{VBF}^2 (1, \lambda_{WZ}) \lambda_{WZ}^2$	$\kappa_{gZ}^2 \lambda_{Zg}^2 \kappa_{VBF}^2 (1, \lambda_{WZ}) \lambda_{bZ}^2$	$\kappa_{gZ}^2 \lambda_{Zg}^2 \kappa_{VBF}^2 (1, \lambda_{WZ}) \lambda_{\tau Z}^2$
WH	$\lambda_{Zg}^2 \lambda_{WZ}^2$	$\lambda_{Zg}^2 \lambda_{WZ}^2$	$\lambda_{Zg}^2 \lambda_{WZ}^2$	$\lambda_{Zg}^2 \lambda_{WZ}^2$	$\lambda_{Zg}^2 \lambda_{WZ}^2$
ZH	λ_{Zg}^2	λ_{Zg}^2	λ_{Zg}^2	λ_{Zg}^2	λ_{Zg}^2

$$\kappa_i^2 = \Gamma_{ii} / \Gamma_{ii}^{\text{SM}}$$

Table A.1: A benchmark parametrization without assumptions and maximum degrees of freedom. The colors denote the common factor (black) and the factors related to the production (blue) and decay modes (red). Ones are used to denote the trivial factor.