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Review of SM Higgs properties measured by ATLAS and CMS: couplings, spin, mass

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This proceedings present the results from the measurements of the Higgs boson properties done by ATLAS and CMS experiments using the data from proton-proton collisions provided by the LHC. The data samples were collected in 2011 and 2012 and correspond to integrated luminosities of 5 fb^{-1} of 7 TeV data and 20 fb^{-1} of 8 TeV data. The combination of high-resolution $\gamma\gamma$ and $ZZ \to 4\ell$ channels is used to measure the mass of the Higgs boson. Both collaborations reported results close to 125 GeV (125.36 GeV at ATLAS and 125.02 GeV at CMS) with uncertainties of 2-3 per mille on each result. The J^P structure of the Higgs boson has also been studied and both experiments were able to exclude scenarios where the Higgs boson has spin 1 or spin 2 with more than 99.9% confidence. Via the measurement of the anomalous couplings of the Higgs boson, CMS was also able to set the first limits on the pseudoscalar component of the new boson. All observations are consistent with the SM expectation for the Higgs boson: $J^{PC} = 0^{++}$. The best-fit values of signal strength modifiers μ in the individual search channels as well as in the combination of all channels are consistent with unity in both experiments. Finally, the couplings of the Higgs boson were probed for deviations from the SM expectations in multiple ways, including allowing new particles in the loops and invisible/undetected decays. No significant deviation from the SM predictions was found by any experiment.

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1. Introduction

The standard model (SM) is the most successful theory to describe the elementary particles and their interactions. Its key prediction is the electroweak symmetry breaking (EWSB) which is realized by a complex scalar doublet field. The existence of this field is manifested by one physical particle: the Higgs boson [1, 2, 3, 4, 5, 6].

The scalar field is indeed crucial for the validity of the SM: the gauge bosons W and Z obtain their masses via interaction with this field and its contribution to the WW scattering preserve the unitarity at higher energies. The EWSB thus provides consistent description of low-energy particle phenomenology, while keeping correct theory behavior at the energy scales that have been probed for the first time by the LHC [7]. Besides this, the SM predicts that the elementary fermions obtain their mass via interaction with the complex scalar field through so-called Yukawa mechanism.

Because the Higgs boson couples directly to all massive particles, it can be produced at colliders in many ways. The four most important mechanisms at the LHC are gluon-gluon fusion (gg$\rightarrow$ H), vector boson fusion (qq $\rightarrow$ qqH, VBF), associated production with a vector boson ("VH") and associated production with $t\bar{t}$ pair ("$t\bar{t}H$").

The production cross-section and the decay branching fractions depend on the Higgs boson mass which is a free parameter of the SM. The dominant production mode at the LHC is the gluon fusion followed by others, that are one or more orders of magnitude smaller. The Higgs boson couples more strongly to heavier particles and in general tends to decay to the heaviest particle pair that is kinematically allowed. The numerical values of cross-section and decay fractions for various masses are tabulated in [8].

In July 2012, the ATLAS [12] and CMS [13] collaborations at CERN announced a discovery of a new boson [9, 10, 11] with a mass near 125 GeV using about 5 fb^{-1} of pp collision data collected with $\sqrt{s} = 7$ TeV and about 5 fb^{-1} collected with $\sqrt{s} = 8$ TeV. Since then, additional more than 15 fb^{-1} of 8 TeV collision data have been collected and analyzed by ATLAS and CMS collaborations in order to study the properties of the new boson and assess its compatibility with the SM predictions.

This document presents mostly final results of the Higgs boson properties measurements done by the ATLAS and CMS collaborations using the almost full dataset of 7 TeV and 8 TeV pp collision data delivered by LHC during the Run I (except the minute amount of 7 TeV collision data collected in 2010). The datasets have been processed with the final alignment and calibrations of both detectors and the total amount of analyzed data were up to 4.7 (20.3) and 5.1 (19.7) fb^{-1} with $\sqrt{s}$ =7 (8) TeV in ATLAS and CMS, respectively.

This paper is organized as follows: Section 2 presents the results of the mass measurements, followed by section 3 which shows the outcome of the spin compatibility tests and measurements and finally section 4 contains the results from the tests of the compatibility of the H boson couplings with the SM predictions. The paper is summarized in section 5.

2. Mass measurements

The mass of the Higgs boson is a fundamental parameter of the SM. It is a crucial input for the calculation of the production cross-section and decay fractions. Therefore, the prerequisite for most of tests of the compatibility with the SM is as precise knowledge of the H boson mass as possible.

The mass is measured in “high-resolution” channels $H \to \gamma\gamma$ and $H \to ZZ \to 4\ell$ ($\ell = e$ or μ). In these two decay modes it is possible to fully reconstruct the Higgs boson decay and the mass distribution produces a narrow peak over smooth background. The mass value can therefore be extracted from this peak in a model independent way without assumptions on the Higgs boson production and decay yields. The mass peak shift due to the interference between the SM background and expected Higgs signal is small compared to the experimental resolution and thus neglected in all mass measurements. Both collaborations reported their final Higgs mass measurements from the Run I in [14, 15].

In the $H \to \gamma\gamma$, events containing a photon pair are split into several disjoint categories that have different signal-to-background ratio, diphoton mass resolution and also systematic uncertainties. The mass is determined from the simultaneous fit to $m_{\gamma\gamma}$ distribution in all categories. The ATLAS modeled the signal mass distribution as a sum of two Gaussian distributions and a Crystal Ball function, while at CMS, the signal was modeled as a sum of 3-5 Gaussian functions. The background was modeled by a smooth function and obtained directly from the fit to the data. Both experiments have studied the uncertainty arising from the choice of the background functional form. The ATLAS analysis treated this bias as systematical uncertainty and estimated its value from fits to the simulated background samples. In CMS, a discrete variable that selected which functional form was used in the fit was also profiled (i.e. set to the value that maximizes the fit value) during the likelihood maximization. The bias from the background modeling choice then contributes to the statistical uncertainty.

In the $H \to ZZ \to 4\ell$ analysis both collaborations are using kinematic discriminants based on leading order matrix elements for signal and background to measure the Higgs boson mass. The input variables to this discriminant are the masses of the 2 dilepton pairs and 5 angles that uniquely define the event configuration in the 4-lepton center-of-mass frame. Further inputs are transverse momentum and pseudorapidity (CMS uses only p_T) of the 4-lepton system in the lab frame. The ATLAS uses the two-dimensional (2D) fit to the m_{4l} and kinematic discriminants output. The CMS employs 3D fit to the m_{4l}, kinematic discriminants and per-event mass uncertainty distributions. The mass uncertainty estimator is built from single lepton momentum resolutions that have been obtained using $J/\psi \to \mu\mu$ and $Z \to \ell\ell$ data events.

Both experiments estimate the irreducible background (non resonant ZZ production) from simulation, while the reducible background (Z+jets, $t\bar{t}$, WZ+jets) is estimated from data. The main source of uncertainty in this channel is the limited amount of events in the control regions used for background estimation from data.

The results from various channels are combined using the methodology that was developed by ATLAS and CMS collaborations in the context of LHC Higgs Combination group and is described in [11, 18, 19]. The chosen test statistics is based on profile likelihood ratio and determines how signal- or background-like the data are. The systematic uncertainties are treated as nuisance parameters using frequentist paradigm. The results presented here are obtained using asymptotic formulae [20].

Figure 1 shows 68% (95%) CL confidence regions for Higgs mass and signal strength relative to SM ($\mu = \sigma/\sigma_{\mathrm{SM}}$) obtained in 2D likelihood scan, under the assumption that the relative event yields between $H \to \gamma\gamma$ and $H \to ZZ$ channels have SM values. The overall signal strength is left as a free parameter. ATLAS defined the signal strength modifier as $\sigma/\sigma_{\text{SM}}$ where σ_{SM} is evaluated the measured mass. At CMS instead the σ_{SM} is evaluated at the mass value where the likelihood is being computed. Figure 1 shows that the mass values measured in $H \to \gamma\gamma$ and $H \to ZZ$ channels are compatible with each other.

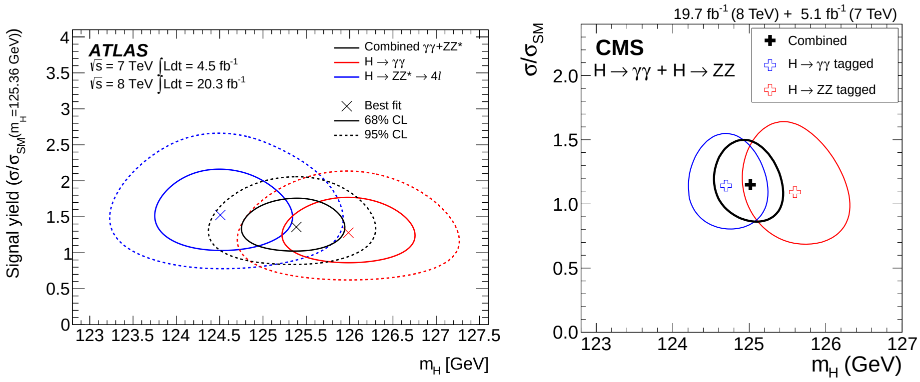

Figure 1: The CL confidence regions for the signal strength $\sigma/\sigma_{\text{SM}}$ versus the Higgs boson mass m_H for the $\gamma\gamma$ and 4ℓ final states, and their combination. In this combination, the relative signal strength for the two decay modes is set to the expectation for the SM Higgs boson. (left) ATLAS results that include 68% (solid) and 95% (dashed) CL confidence contours. (right) 68% CL confidence contours from CMS. Figures are taken from [14, 15].

To obtain the mass value in the most model-independent way as possible, it is assumed that $H \to \gamma\gamma$ and $H \to ZZ \to \ell\ell$ processes are independent (i.e. their signal strengths modifiers are not tied to SM expectations) and the signal in all channels is due to the single resonance H. The best mass value is then obtained from 1D profile likelihood scan where all observables except the m_H are profiled. Note that CMS uses 2 signal strength modifiers in $H \to \gamma\gamma$ channel - one for gg and $t\bar{t}H$ production and one for VBF and VH production. The results are shown on Fig. 2 and tabulated in Tab. 1.

Experiment	Combined mass
ATLAS	125.36 ± 0.37 (stat.) ± 0.18 (syst.) GeV
CMS	$125.02\ ^{+0.26}_{-0.27}$ (stat.) $^{+0.14}_{-0.15}$ (syst.) GeV

Table 1: Results of combined mass measurement in $\gamma\gamma$ and $ZZ \to 4\ell$ channels in ATLAS and CMS.

In order to quantify in each experiment the compatibility of the $\gamma\gamma$ and $ZZ \to 4\ell$ mass measurements, a test statistics $q(\Delta m_H)$ where $\Delta m_H = m_H^{\gamma\gamma} - m_H^{4\ell}$ is used. The Δm_H, $m_H^{\gamma\gamma}$ as well as signal strength modifiers μ are taken all as independent parameters and except for the first one are all profiled in the likelihood fit. The results are $\Delta m_H = 1.47 \pm 0.72$ GeV $(-0.87^{+0.54}_{-0.59})$ at ATLAS (CMS). The results in the $\gamma\gamma$ and 4ℓ channels thus agree with each other at the 1.98σ (1.6σ) level at ATLAS (CMS). Note, however, that the sign of the Δm_H is opposite in the two experiments.

3. Spin measurements

The SM predicts that the Higgs boson is CP-even and has zero spin ($J^P = 0^+$). The measure-

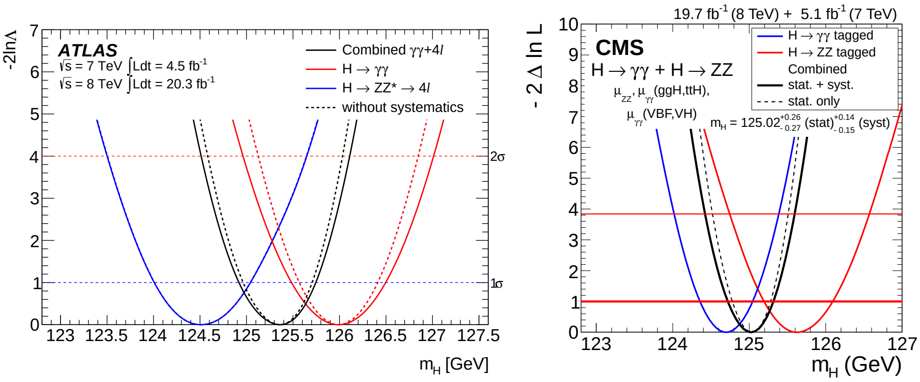

Figure 2: Scan of the test statistic $q(m_H) = 2\Delta \ln \mathrm{L}$ versus the Higgs boson mass m_H for the $H \to \gamma\gamma$ and $H \to ZZ \to 4\ell$ final states separately and for their combination. Dashed lines show statistics profile without including systematics. The signal strength modifiers are profiled together with all nuisance parameters (left) ATLAS result, using 2 independent signal strength modifiers (ZZ and $\gamma\gamma$ channels). (right) CMS result using 3 independent signal strength modifiers (ZZ, (VBF,VH)$\to \gamma\gamma$, (ggH, $t\bar{t}H$)$\to \gamma\gamma$). Figures are taken from [14, 15].

ment of spin and parity properties of the new resonance is therefore a crucial test of the validity of the SM. The first analyses focused on testing the compatibility of data with the SM and with various alternative J^P hypotheses ([16, 17, 21, 22]). The decay channels used for these tests were the $\gamma\gamma$ and $ZZ \to 4\ell$ where full event reconstruction is possible. On top of those 2 high-purity high-precision channels, both collaboration exploited also the $WW \to 2\ell 2\nu$ decays: although the full event reconstruction is not possible in this case due to presence of neutrinos, some kinematical observables can be successfully used to distinguish between the SM and models where Higgs boson has different parity and/or spin.

In order to test the compatibility of data with SM or alternative hypotheses, a value of test statistics $q = \ln(\mathscr{L}(J^P = 0^+)/\mathscr{L}(J^P_{alt}))$ is used. $\mathscr{L}(J^P = 0^+)$ and $\mathscr{L}(J^P_{alt})$ are the best-fit likelihood values for the SM and alternative hypothesis, respectively. The likelihood model used in these fit is the same as in the SM Higgs searches. The signal strength is an independent parameter in both fits to be independent of the yield and be only sensitive to spin/parity. The frequentist $\mathrm{CL_s}$ criterion is then used to quantify the compatibility of a given hypothesis with data. The alternative spin hypotheses were simulated using a modified framework that was first outlined in [23].

3.1 Spin 0

The comparison of the value of test statistics obtained for data with the values obtained from simulation of scalar and pseudoscalar particle clearly shows that data strongly prefers scalar to pseudoscalar and the latter hypothesis is excluded at 97.8 % (99.5%) CL_s at ATLAS (CMS). In addition to this, CMS also tested the compatibility of data with the 0^+_h model, where the H boson is a scalar which does not participate in the EWSB, but rather involves higher-dimension operators. That hypothesis was excluded at 95.5% level [17].

Besides the compatibility test, CMS studied also possible scalar-pseudoscalar mix states that can manifest themselves as anomalous couplings of the H boson [24]. The results are statistically limited, but for example the pseudoscalar contribution to HZZ coupling larger than 43% has been excluded at 2 σ level (in the SM, the CP-odd contribution to this coupling is a 3-loop effect). In the $\gamma\gamma$ channel, this limit is slightly stronger: there a contribution larger than 35% has been excluded.

3.2 Spin 1

The spin-1 hypothesis is strongly disfavored due to observation of $\gamma\gamma$ decay that is forbidden by the Landau-Yang theorem for spin-1 particles. Nevertheless, it is in principle possible that $\gamma\gamma$ and ZZ/WW decays came from different resonances, so the spin-1 hypothesis was tested as well. ATLAS and CMS used ZZ and WW decays to check the compatibility of data with spin 1 hypothesis [21, 24]. ATLAS and CMS excluded both the 1^- and 1^+ hypotheses at 99.7% or higher confidence level. CMS additionally also excluded 3 various 1^+ and 1^- mixtures at confidence levels above 99.9% using ZZ channel only.

It might also be possible that there is additional resonance which cannot be separated from the dominant 0^+ state due to limited mass resolution. For example, composite particles can have multiple narrow states with different spin-parity quantum numbers and nearly degenerate masses. The presence of these additional resonances can influence the kinematics and this it is possible to set limits on them.

CMS conducted search for non-interfering degenerate spin 1 states [24] under the assumption that the decay widths of the dominant 0^+ state as well as of the other state are much smaller than their mass difference which itself should be smaller than 1 GeV. The limits were set using ZZ channel for various mixtures of 1^+ and 1^-. Depending on the production mode and $1^\pm$ ratio, the cases where non-interfering exotic spin case contributes more than 37%-57% to the total observed Higgs cross-section are excluded at 95% confidence level.

3.3 Spin 2

There is no elementary particle with spin 2, however there are many BSM scenarios, that include such particles - some of them were tested by the ATLAS and CMS collaborations [21, 24]. The historically first one to be tested was 2^+_m model which represents a massive graviton-like boson as suggested in models with warped extra dimensions with minimal couplings. This model was explored using the combination of $\gamma\gamma$, ZZ and WW channels. ATLAS excluded this model at 99.99% confidence, while CMS exclusion is at 99.87% CL.

CMS in addition tested spin 2 models where SM fields were allowed to propagate to extra dimensions and also models with higher dimensional operators. Again, all of those models have been excluded at more than 99.9% confidence.

Similarly to the case of spin 1 non-interfering states CMS carried out also a search for spin 2 non-interfering states. However, due to the lack of data, the limits in these cases are quite weak and most of the studied models can contribute by more than 60% to the observed Higgs decays via the non-interfering degenerate spin 2 states.

4. Compatibility with SM Higgs couplings

4.1 Overall signal strength modifiers

The previous section showed that all observations in ATLAS and CMS are consistent with the SM expectation of $J^P = 0^+$ and that alternative spin hypotheses are excluded or strongly disfavored. Using the measured mass of the Higgs boson (cf. section 2), it is possible to derive the SM predictions for all the other properties of the Higgs boson.

The first quantity to test is the overall signal strength modifier $\mu = \sigma/\sigma_{\text{SM}}$. ATLAS has provided final Run I results in four out of five main search channels ([27, 28, 29, 30]) and preliminary results in the $H \to \tau\tau$ channel [31]. All of them are compatible with the SM expectation ($\mu = 1$) within 1-2σ. The overall signal strength result of $1.3^{+0.18}_{-0.17}$ is based on the combination of the earlier round of analyses [32]. The final Run I CMS result is provided in [15]. At the measured mass of 125.0 GeV (see Tab. 1), the measured overall signal strength modifier is $1.00^{+0.14}_{-0.13}$, consistent with the SM expectation. The signal strength modifiers for individual channels and the combination are shown in Figure 3.

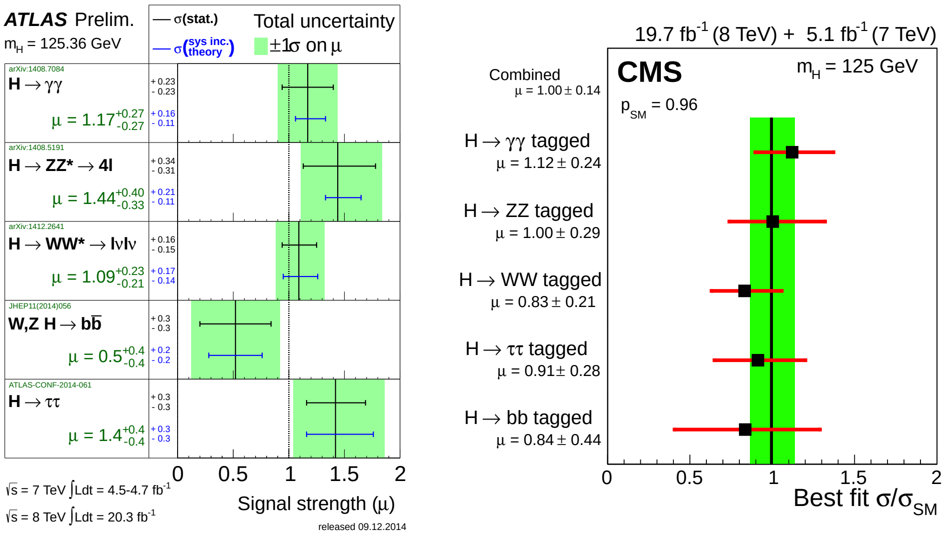

Figure 3: The measured production strengths for a Higgs boson, normalized to the SM expectations, for the $H \to \gamma\gamma$, $H \to ZZ \to 4\ell$, $H \to WW \to \ell\nu\ell\nu$, $H \to \tau\tau$, and $H \to bb$ final states at ATLAS (left) and CMS (right). Both experiments assumed the mass they obtained in the combined measurement. The ATLAS figure shows the breakdown of the total uncertainty in the statistical and systematical component. The CMS plot indicates also the value of the overall signal strength obtained from all channels. Its value is shown by the thick black line, and the one σ uncertainty is depicted by the green band. The figures are taken from [15, 33].

In the SM, the Higgs coupling to gauge bosons and fermions are linked via the Yukawa mechanism. The four main production mechanisms can be split into 2 groups in order to test the relative coupling strengths: fermion-mediated (ggH, $t\bar{t}H$) and boson-mediated (VBF, VH). Then the μ_{VBF+VH} and $\mu_{ggH+ttH}$ are treated independently in order to find the best fit values for both. The fitted minima for all channels are consistent with the SM expectation ($\mu_{VBF+VH} = \mu_{ggH+ttH} = 1$) within 2$\sigma$.

4.2 Couplings compatibility with the SM

The amount of data collected in Run I does not allow to measure the value of the Higgs boson couplings precisely enough to establish the SM beyond all doubts, however it is possible to test the compatibility of data with the SM prediction for the coupling strength. In order to test the observed data for possible deviation from the SM, scale factors κ_i are introduced. They are defined for production ($\kappa_i^2 = \sigma_i/\sigma_i^{\rm SM}$), decays ($\kappa_j^2 = \Gamma_{jj}/\Gamma_{jj}^{\rm SM}$) as well as for the total width ($\kappa_H^2 = \Gamma_{\rm tot}/\Gamma_{\rm SM}$). Significant deviation of any κ parameter from unity would indicate the presence of BSM physics.

The first test was for the custodial symmetry (ratios m_W/m_Z and g_W/g_Z are protected from the large radiative corrections due to the symmetries of the SM). The parameter of interest in this measurement was $\lambda_{\rm WZ} = \kappa_{\rm W}/\kappa_{\rm Z}$. The value of this parameter was extracted from the combined analysis of all channels. Besides $\lambda_{\rm WZ}$, two additional parameters were fitted simultaneously: κ_Z (scaling factor for $H \to ZZ$ coupling) and κ_f (common scaling factor for all couplings to fermions which influences also the ggH and $H \to \gamma\gamma$ processes, due to presence of fermions in the loops). Both ATLAS [32] and CMS [15] results are compatible with unity ($\lambda_{\rm WZ} = 0.94^{+0.14}_{-0.29}$ and $\lambda_{\rm WZ} = 0.91^{+0.14}_{-0.12}$, respectively). In all the subsequent measurements, it is therefore assumed that $\lambda_{\rm WZ} = 1$ and a common scaling factor κ_V is used for W and Z bosons.

Next test was checking the relationship between fermion and W/Z boson coupling which are linked by the Yukawa mechanism in the SM. In this measurement, it was assumed that there are two independent scaling factors κ_f and κ_V. Additionally, it was assumed that $\Gamma_{\rm BSM}$ (non SM decay width to non-SM particles or to SM particles via non-SM decay) is zero. Note that $\kappa_\gamma \sim 1.59\kappa_V^2 - 0.66\kappa_V\kappa_f + 0.07\kappa_f^2$ due to W and t present in the loop which makes $\gamma\gamma$ decays sensitive to the relative sign of κ_V and κ_f. The results of this test at ATLAS and CMS [32, 15] demonstrated that the best value of the 2D fit for (κ_V, κ_f) is within 1-2σ from the SM expectation.

In some models (e.g. 2HDM [34]), the interaction with different types of fermions can be mediated by different (pseudo)scalar fields, so the data were also tested for possible asymmetry in fermion couplings. The parameters of interest were $\lambda_{du} = \kappa_d/\kappa_u$ (assuming that there is a common scaling factor for all up-/down-type fermions) and $\lambda_{lq} = \kappa_l/\kappa_q$ (assuming that there is one common scaling factor for all quarks and one for all leptons). Assuming that both λ_{du} and λ_{lq} are positive, CMS measured that $\lambda_{du} \in [0.65, 1.39]$ and $\lambda_{lq} \in [0.62, 1.5]$ at 95% CL [15]. ATLAS did not have any assumptions on the sign of the λ parameters, so its 95% CL confidence intervals are $\lambda_{du} \in [-1.24, -0.81] \bigcup [0.78, 1.15]$ and $\lambda_{lq} \in [-1.48, -0.99] \bigcup [0.99, 1.50]$.

Although no BSM particles have been observed, they could contribute to the loops and thus affect the scalar sector phenomenology. The processes that are loop-induced, such as ggH production and $H \to \gamma\gamma$ decay are particularly sensitive to this type of phenomena. In order to test for the presence of new particles in the loop a 2D fit of κ_g and κ_γ was performed using the combination of all search channels. Additionally, it was assumed that all other scaling factors have SM values ($\kappa_i = 1$) and that $\Gamma_{BSM} = 0$. At both experiments, the best fit values were within 1-2σ from the SM expectation [32, 15].

The other way to search for BSM effects is to look for the direct decay of the Higgs boson to the BSM particles by releasing the assumption that $\Gamma_{\rm BSM} = 0$. A new parameter ${\rm BR}_{\rm BSM} = \Gamma_{\rm BSM}/\Gamma_{\rm tot}$ is introduced (the SM expectation value for this parameter is zero) and profiled together with κ_γ and κ_g. The upper 95% CL bound on the BR to BSM particles is 0.41 at ATLAS [32] and 0.35 at CMS [15].

All the previous tests were done by fixing most of the κ parameters to the SM values and let few of them float in the fit. Therefore both collaborations explored also the generic models where more parameters (5-7) were considered to be independent. The most generic probed model with 7 free parameters dropped the assumption on the total width and the likelihood scan was performed for each of the parameters κ_{gZ}, λ_{WZ}, λ_{Zg}, λ_{bZ}, $\lambda_{\gamma Z}$, $\lambda_{\tau Z}$ and λtg, while other 6 were profiled in

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the fit. The parameters λ are defined as $\lambda_{ij} = \kappa_i/\kappa_j$ and $\kappa_{gZ} = \kappa_g \kappa_Z/\kappa_H$. The results obtained at ATLAS [32] and CMS [15] are presented in Fig. 4. With one exception (λ_{tg} at CMS), all the results are within 2σ from SM expectation of 1.

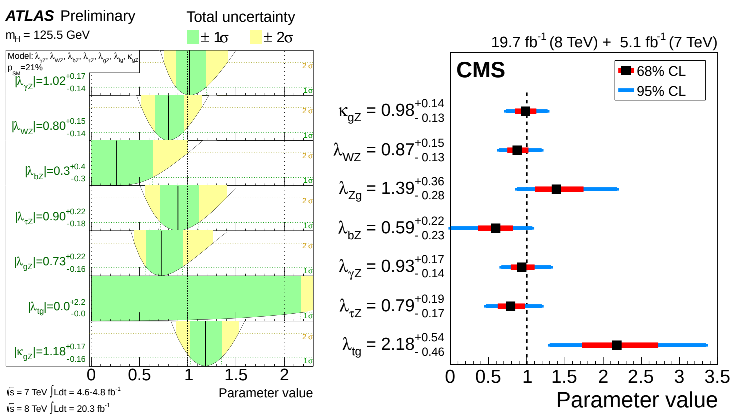

Figure 4: Likelihood scans for parameters in a generic model with 7 independent parameters: 6 SM coupling scaling factors and no assumption on total width. The likelihood scan is always done for one parameter at a time, while the 6 others are profiled together with other nuisance parameters. ATLAS results are on the left, CMS on the right. The best fit values are represented by solid lines (black squares) in the left (right) plot. The 68% CL confidence intervals are represented by green bands (inner red bars) in the left (right). The 95% CL confidence intervals are represented by yellow bands (outer blue bars) in the left (right). The numerical values for all parameters with 1σ uncertainty are indicated on both figures. The SM expectation (one for all parameters) is shown as well. Figures are taken from [15, 32].

5. Conclusions

This document presented mostly final results regarding the properties of the Higgs boson obtained by the ATLAS and CMS collaborations in the Run I of the LHC. The mass, the only free parameter of the SM in the Higgs sector, has been measured with 2-3 per mille precision and is slightly above 125 GeV (125.36 GeV at ATLAS and 125.02 GeV at CMS) and results of both central values are compatible within approx. 1σ of the quoted mass uncertainty. Both experiments also demonstrated that the mass values obtained in $\gamma\gamma$ and $ZZ \to 4\ell$ channels are compatible within 2σ.

Furthermore, in section 3 it has been shown that all examined scenarios in which the discovered boson was pure spin 1 or spin 2 particle have been excluded with more than 99% confidence and in most cases even more than 99.9%. The CMS has also set an upper limit of 0.43 on the possible contribution of pseudoscalar component to the total cross-section. However, many other studied scenarios (non-interfering degenerate spin 1 or spin 2 states, contribution of another scalar field that is not involved in EWSB) have been constrained only weakly and leave room for possible BSM physics.

Finally, section 4 presented the result of the test of the possible deviation of the Higgs couplings and signal strength modifiers from the SM expectations, using the combination of all search channels. The study also included search for invisible and undetected decays. The parameters were tested in many ways and no significant deviation from the SM expectation has been observed. Some couplings have been measured with precision of 10-20%, nevertheless, the uncertainties are still quite large (up to 50%) and thus leave a lot of space for possible BSM surprises.

The structure of the scalar sector is one of the distinguishing features of the SM. It is therefore clear that tightening the constraints on the Higgs boson couplings and J^P mixtures will be one of the main goals of the upcoming Run II of the LHC as well as one of the motivations for the LHC upgrade.

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