Combined measurements of the properties of the Higgs boson using the ATLAS detector

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DOI: http://dx.doi.org/10.3204/DESY-PROC-2014-04/227

The combination of the measurements of the Higgs boson properties by the ATLAS detector at the LHC will be presented. Firstly, the measurements of the spin and parity CP of the observed boson will be discussed. Secondly, the results for the production of the Higgs boson in different channels through the gluon-gluon and vector-boson fusion processes will be presented. Finally, coupling fits are performed to the data and the Standard Model symmetries and mass dependence are tested and discussed. It is concluded that the observed boson is compatible with one Standard Model CP-even Higgs boson.

1 Introduction

In this paper the combination of the measurements of the properties of Higgs boson by the ATLAS detector at the LHC [1] will be discussed. The Higgs boson is observed in several final states; initially it was discovered in the $\gamma\gamma$, ZZ and WW channels [2]. Here I will summarize what is currently known about the Higgs spin and CP properties and the Higgs couplings to bosons, quarks and leptons.

The Higgs spin and CP properties have been studied in the three di-boson channels. Subsequently, the analyses probing different CP and spin hypotheses have been combined [3]. The angular and momentum distributions of the bosons and their decay products are sensitive to the spin and CP of the produced boson. By fitting these distributions to the data for the hypothesis of a Standard Model (SM) Higgs boson (0^+) and an alternative spin CP hypothesis ($\mathrm{J^P} = 2^+, 1^+, 1^-$ or 0^-), exclusion limits are obtained. The results, shown in Fig. 1, are compatible with a CP-even scalar boson and the alternative hypotheses are excluded at 97.8% CL or higher.

In the following, I will discuss in more detail the combination of Higgs measurements in the $\gamma\gamma$, ZZ, WW [2], $\tau\tau$ [4] and $b\bar{b}$ [5] channels. The Higgs can be produced in gluon-gluon fusion (ggF), vector boson fusion (VBF) and W or Z associated production (VH). The channels were divided into categories that correspond to the production mode and final states. The di-boson channels included categories enriched in ggF and VBF; the $b\bar{b}$ channel was only analyzed in the VH final state. The paper will mainly focus on the results of the Higgs boson coupling measurements and their interpretation. A detailed description of the event selection, channels, categories and fit procedure can be found in Ref. [6].

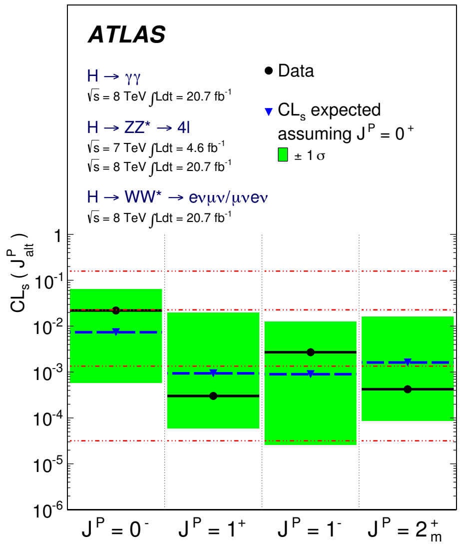

Figure 1: Expected (blue triangles/dashed lines) and observed (black circles/solid lines) confidence level CLs for alternative spin–parity hypotheses assuming a 0^+ signal. The green band represents the 68% CL expected exclusion range for a $\mathrm{J^P}$ signal. For the spin-2 hypothesis, the results for a specific 2^{+m} model, are shown.

2 Combination of the Higgs measurements

The inclusive signal strength μ normalised to the SM expectation, obtained by combining the five listed channels, is $\mu = 1.30^{+0.18}_{-0.17}$.

Because of the VBF enriched event categories, it is possible to measure the VBF fraction defined as: $\mu_{VBF}/\mu_{ggF+ttH} = 1.4^{+0.5}_{-0.4}(stat)^{+0.4}_{-0.3}$. This provides 4.1σ evidence for the production of Higgs bosons through VBF.

In the coupling fits $\kappa_i = g_i/g_i^{SM}$ is fitted, where g_i is the coupling of the Higgs boson to e.g. fermions (F) or bosons (V). The Higgs boson couplings are measured in simplified benchmark models. It is assumed that only one CP-even scalar Higgs boson with $m_H = 125.5\ GeV$ is produced. Its width is neglected, i.e. the narrow-width approximation is used.

In the first model the coupling ratios to fermions are put equal to κ_F and of all bosons to κ_V. This allows to test the SM difference of fermion and boson couplings under the assumption that there are no new physics contributions to the total width. The result is $\kappa_F = 1.15 \pm 0.08$ and $\kappa_V = 0.99^{+0.17}_{-0.15}$ as shown in Fig. 2. Note that the result is compatible with the SM, where one expects values of 1. It is possible to fit the ratio λ_{FV} defined as κ_F/κ_V. In that case no assumption on the total width is need. The result is $\lambda_{FV} = 0.86^{+0.17}_{-0.15}$ and shown in Fig. 2.

It is possible to test the custodial symmetry of the SM directly in the Higgs sector by fitting λ_{WZ} thus allowing different couplings to the W and Z bosons. The result is shown in Fig. 2: $\lambda_{WZ} = 0.94^{+0.14}_{-0.29}$, compatible with the SM expectation.

Many extensions of the SM predict different couplings to up- and down-type fermions. In that case λ_{ud} is constrained to the range 0.78 - 1.15 at 68% CL as shown in Fig. 2. It can be further shown that there is 3.6σ evidence for the coupling of the Higgs boson to down-type fermions.

Another test is the measurement of the lepton and quark couplings. Here λ_{lq} is constrained to the range 0.99 - 1.5 at 68% CL, shown in Fig. 2. A vanishing coupling of the Higgs boson to leptons is excluded at 4σ.

The loop contributions in SM processes are sensitive to possible new physics processes. To quantify this sensitivity, the couplings to gluons κ_g and photons κ_γ are measured to be: $\kappa_g = 1.08^{+0.15}_{-0.13}$ and $\kappa_\gamma = 1.19^{+0.15}_{-0.12}$. It is assumed that the $\kappa_{F,V}$ values are 1 and only SM particles contribute to the total width.

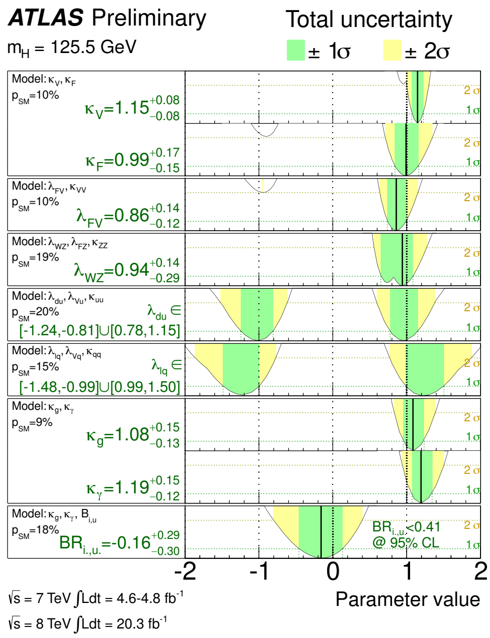

Figure 2: Summary of the coupling scale factor measurements for $m_H = 125.5\ GeV$. The best-fit values are represented by the solid black vertical lines. The measurements in the different benchmark models, separated by double lines in the figure, are strongly correlated, as they are obtained from fits to the same experimental data. For each model the compatibility of the SM hypothesis with the best-fit point is given by $\mathrm{p_{SM}}$.

Finally, the mass scaling of the couplings is tested by parametrising deviations from the SM prediction in terms of two additional parameters ϵ and M in the formulae: $\kappa_{f,i} = v\frac{m_{f,i}^{\epsilon}}{M^{1+\epsilon}}$ and $\kappa_{V,j} = v\frac{m_{V,j}^{2\epsilon}}{M^{2+\epsilon}}$, where v is the vacuum expectation value of 246 GeV and $m_{f,V}$ denote to the fermion and boson masses. In the SM ϵ is zero and M equals v. The result of the fit is shown in Fig. 3. The deviation of the Higgs boson couplings to fermions (bosons) from a linear (quadratic) scaling with the particle masses is less than 10% [7].

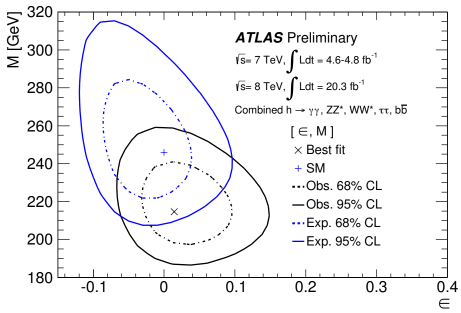

Figure 3: Two-dimensional likelihood scan of ϵ and M. The likelihood contours corresponding approximately to 68% CL (1σ) and 95% CL (2σ) respectively, are shown for both the data and the prediction for a SM Higgs boson. The best fit to the data and the SM expectation are indicated as $\times$ and $+$ respectively.

3 Conclusions

The spin and CP of the observed particle is consistent with a CP-even scalar boson. The boson is produced in ggF and VBF processes with cross sections and branching ratios that are consistent with a SM Higgs boson. The measured couplings are consistent with the SM predictions and the underlying symmetries and mass scalings have been measured. In the near future the final Run-1 Higgs analysis results will be published. We look forward to higher statistics Run-2 results for which the projections can be found in Ref. [8].

References

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