HIGGS DISCOVERY STATUS FROM ATLAS*

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An overview of the latest results of the Higgs boson search with the ATLAS experiment at the LHC, following its discovery, is presented. The various decay channels are discussed in the context of the Standard Model and Beyond Standard Model searches. Results on the properties of the boson are also provided, with focus on the mass measurement, spin, parity and production mechanisms.

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1. Introduction

During the Run I period (2010–2012) of the Large Hadron Collider (LHC) at CERN, the ATLAS experiment [1] collected 4.57 fb^{-1} at a center-of-mass energy of $\sqrt{s} = 7$ TeV and 20.3 fb^{-1} at $\sqrt{s} = 8$ TeV data, which allowed the observation of the Standard Model (SM) Higgs boson. This note summarizes the ATLAS experiment searches after the discovery concerning the decay channels and properties of the boson with focus on SM searches and references to Beyond SM (BSM) scenarios.

2. Higgs decay searches

The Higgs boson at the LHC can be produced via the mechanisms of gluon–gluon fusion (ggF), vector boson fusion (VBF), associated production with a vector boson (either W or Z, denominated as WH and ZH

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respectively) and associated production with top quarks (ttH) as shown in Fig. 1 for $\sqrt{s} = 8$ TeV [2]. The produced boson can decay in many different channels [2] as shown in Fig. 1, however not all the possible channels are discussed in this note either due to combination of small branching ratio and high background or small sensitivity in the low mass region.

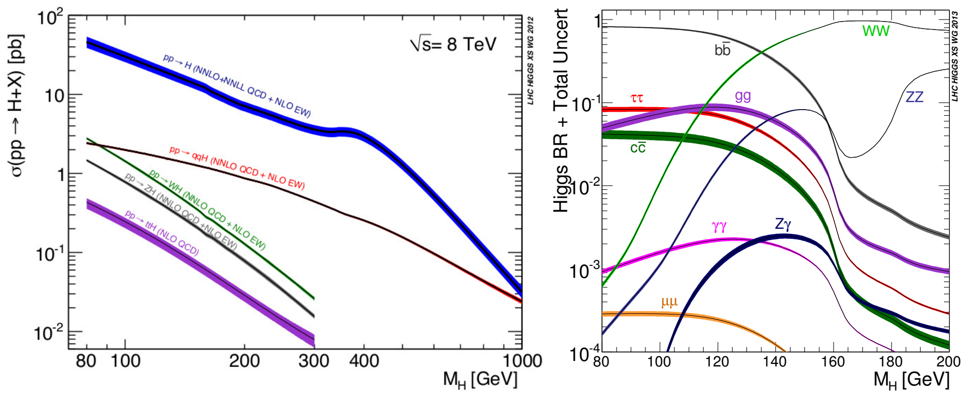

Fig. 1. Left: Production mechanisms of the SM Higgs boson at the LHC for center-of-mass energy of $\sqrt{s} = 8$ TeV [2]. Right: Branching ratios [2] of the possible Higgs decay channels.

$H \to ZZ(^*) \to 4\ell$

The signature of this channel consists of four isolated leptons originating from the primary vertex. The resonance is observed at the mass of $124.3^{+0.6}_{-0.5}$(stat.)$^{+0.5}_{-0.3}$ (syst.) GeV on top of the irreducible $ZZ(^*)$ background and the reducible Z+jets and $t\bar{t}$ backgrounds [3]. The observed significance corresponds to 6.6σ, whereas the expected significance from the SM is 4.4σ and the signal strength is $1.43^{+0.40}_{-0.35}$ [10]. The latter expresses the compatibility of the observed rate with respect to the SM expectation.

$H \to \gamma\gamma$

The Higgs decay to diphotons has an expected significance of 4.3σ [10] and the shape is expected to be a resonance on top of a continuous background. The remaining background after the requirement of isolated photons is mostly the $\gamma\gamma$ continuum and small contributions originating from jet–γ and jet–jet processes. The observed resonance has mass of 126.8 ± 0.2(stat.)$\pm$ 0.7(syst.) GeV [4], with a significance of 7.4σ and signal strength equal to $1.55^{+0.33}_{-0.28}$ [10].

$H \to WW(^*) \to \ell\nu\ell\nu$

This channel has a large production rate and has a clear signature consisting of an opposite sign dilepton pair which is discriminated from the background by means of the transverse mass ($m_{\rm T}$) and the ϕ angle between the leptons ($\Delta\phi_{\ell\ell}$), after vetoing for Z decays and Drell–Yan (DY) processes. The full mass reconstruction is not possible due to the presence of neutrinos. The expected and observed significances are 3.8σ, giving a signal strength of $0.99^{\pm+0.31}_{\pm-0.28}$ [10].

$\underline{H \to Z + \gamma}$

This decay can provide an insight into models beyond the SM and can be produced from loops mediated from W bosons or top quarks. The channel analysis is based on the requirement of a well reconstructed Z candidate accompanied by a photon ($E_{\mathrm{T}} > 15$ GeV) in order to distinguish the signal from the $Z+\gamma$ and Z+jets background. Due to the small branching ratio [2] and limited statistics, the results are compatible with both signal and no signal hypothesis [6].

$\underline{H \to bb}$

This final state has the largest branching ratio and can provide direct constraints to Higgs coupling to quarks and fermions. Events with two b-jets are classified according to E_{T}, $P_{\mathrm{T}}(\nu)$ and discriminated according to the mass of the $b\bar{b}$ pair from the high jet background. The VH production was studied and no excess was observed ($\mu = 0.2 \pm 0.5(\text{stat.}) \pm 0.4(\text{syst.})$) [7].

$\underline{H \to \tau\tau}$

The $H \to \tau\tau$ is an important study to unveil the Higgs decays to fermions and leptons. The events are categorized according to the τ decays, which can be either hadronic or leptonic, and the signal extraction is based on the variables invariant mass $m_{\tau\tau}$, $E_{\mathrm{T}}^{\mathrm{miss}}$, system transverse momentum p_{T}^{H} and pseudorapidity gap between the jets $\Delta\eta_{jj}$. The main backgrounds are the $Z/\gamma^* \to \tau^+\tau^-$ and $Z \to \ell^+\ell^-$ decays along with small contributions from $t\bar{t}$ + single t, WW, WZ and ZZ processes. Evidence of $H \to \tau\tau$ is observed compatible with the SM prediction ($\mu = 1.4 \pm 0.3(\text{stat.})^{+0.4}_{-0.3}(\text{syst.})$) with a significance of 4.1σ [8].

$\underline{H \to \mu\mu}$

The only channel at the LHC where the Higgs couplings to second generation fermions can be measured is the $H \to \mu\mu$. The small branching ratio of this decay [2] and the amount of data collected are not sufficient for quantitative results. Specifically, no evidence of signal is observed after the analysis of data with the requirement of two isolated muons originating from the primary vertex. The data are compatible with the main background, the $Z/\gamma^* \to \mu^+\mu^-$. The observed (expected) upper limit varies between 3.5 (7.4) and 22.1 (31.3) times the SM prediction in the mass range 110–150 GeV [9].

3. Higgs channels combination

Following the decay-specific searches, the combination of the channels provides information for the nature and the properties of the discovered boson. The compatibility with the SM will be studied in the next paragraphs and simultaneously hints for new physics will be exploited.

Mass measurement

The mass measurement is performed by combining the $H \to ZZ(^*) \to 4\ell$ and $H \to \gamma\gamma$ channels, which are shown in Fig. 2, and the result corresponds to a mass of 125.5 $\pm$ 0.2 (stat.)$^{+0.5}_{-0.6}$(syst.) GeV [10]. The agreement in the mass measurement of the individual channels is estimated to be at the level of 2.4σ [10].

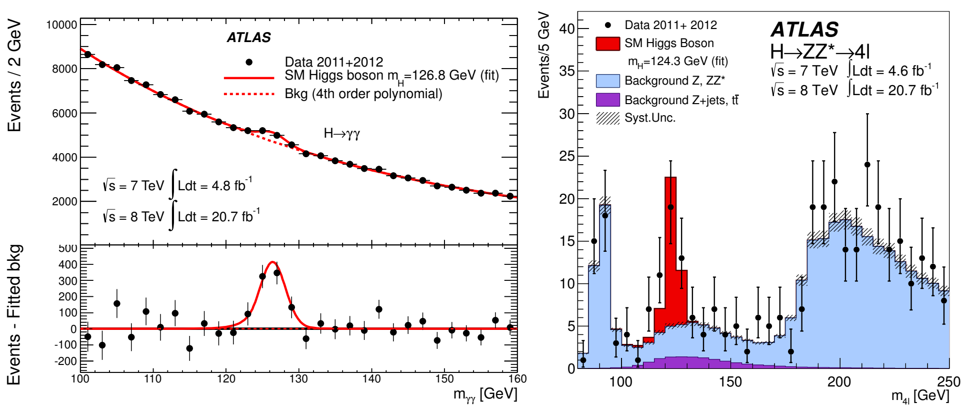

Fig. 2. Mass distributions for the $H \to \gamma\gamma$ (left) and $H \to ZZ(^*) \to 4\ell$ (right) channels [10].

Signal strength

The compatibility of the results with respect to the SM expectations is investigated by fixing the mass term to the combination value of 125.5 GeV. The combined results for the $H \to \gamma\gamma$, $H \to ZZ(^*) \to 4\ell$ and $H \to WW(^*) \to \ell\nu\ell\nu$ is $\mu = 1.33^{+0.21}_{-0.18}$ [10].

Spin and parity

The study of the spin and CP properties is conducted separately for the each channel due to topological dependencies [11]. The data favors the SM prediction ($J^{\mathrm{P}} = 0^+$) by rejecting other models with confidence levels of [11]:

- 0^- : 97.8% from the $H \to ZZ(^*) \to 4\ell$,
- 1^+ : 99.97% from the $H \to ZZ(^*) \to 4\ell$ and $H \to WW(^*) \to \ell\nu\ell\nu$ combination[1],

[1] Studied for completeness since the observation of $H \to \gamma\gamma$ decays theoretically excludes the spin-1 hypothesis (Landau–Yang theorem) [11].

- 1^- : at least 99.7% from the $H \to ZZ(^*) \to 4\ell$ and $H \to WW(^*) \to \ell\nu\ell\nu$ combination[1],
- 2^+ (graviton inspired) : more than 99.9% from the $H \to \gamma\gamma$, $H \to ZZ(^*) \to 4\ell$ and $H \to WW(^*) \to \ell\nu\ell\nu$ combination.

Production mechanism

The event production mechanism is studied by identifying the production signatures. The VBF has the characteristics of two jets in opposite hemisphere, the existence of a vector boson on top of the production particles is a sign of associated production, the ttH production is revealed through the large number of b-jets stemming from the top decays. Any other case is considered to be ggF [10]. The combination result ratio is $\mu_{\mathrm{VBF+VH}}/\mu_{\mathrm{ggF}+ttH} = 1.4^{+0.4}_{-0.3}(\mathrm{stat.})^{+0.6}_{-0.4}(\mathrm{syst.})$. If the VH is profiled and the fit re-performed the result gives 3.3σ evidence of non-vanishing VBF production [10].

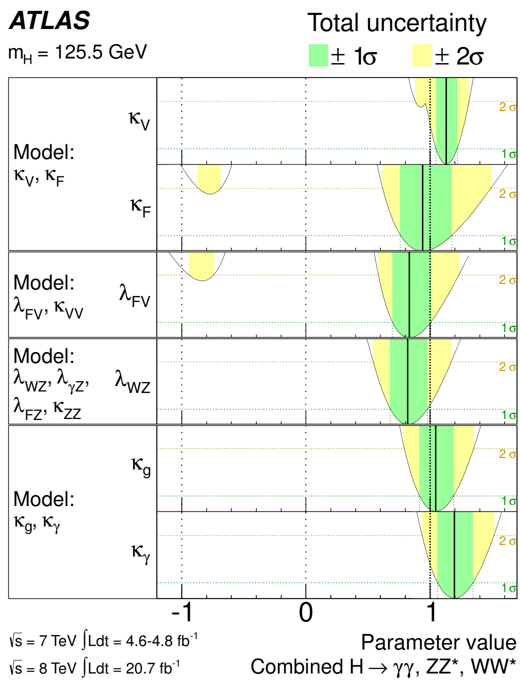

Fig. 3. Coupling tests prove no significant deviation from the SM [10].

Coupling strength studies

The signal strength of a process $ii \to H \to ff$ can be expressed as a function of the couplings (k) [10], $\mu = \sigma_{\mathrm{observed}}/\sigma_{\mathrm{SM}} = k_i^2 k_f^2 / k_H^2$. Via the couplings several models can be tested, for example couplings to fermions (k_f) and bosons (k_V), the custodial symmetry ($\lambda_{W/Z} = k_W/k_Z = 1$), production and decay loop constrains as testing for heavy BSM particles. The results of various tests are summarized in Fig. 3 and no significant deviation from the SM is observed [10].

4. Summary

The latest results for the Higgs discovery status from the ATLAS experiment at the CERN Large Hadron Collider have been presented. The individual decay channels analyzed and the properties of the boson studied using the bosonic decay channels $H \to \gamma\gamma$, $H \to ZZ(^*) \to 4\ell$ and $H \to WW(^*) \to \ell\nu\ell\nu$. All the results are consistent with the SM and no hint of new physics found.

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