Constraints on new phenomena through Higgs coupling measurements with the ATLAS detector

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DOI: http://dx.doi.org/10.3204/DESY-PROC-2014-04/229

The ATLAS experiment at the Large Hadron Collider has measured the couplings of the newly found Higgs boson to other particles using about 25 fb^{-1} of proton-proton collision data at 7 and 8 TeV center-of-mass energy. These measurements have been used to contrain the parameters on new physics phenomena. In this document a short review of such studies is presented. No deviations from the Standard Model are observed. Perspectives at the High-Luminosity LHC are also discussed.

1 Introduction

The ATLAS [1] and CMS [2] Collaborations at the Large Hadron Collider (LHC) announced the discovery of a new particle in the summer of 2012 [3, 4]. The measurements of the new-found particle's mass [5, 6], coupling parameters [5, 6] and spin-parity [7, 8, 9] are compatible, within experimental uncertainties, with those of a Standard Model (SM) Higgs boson. The question remains open whether the Higgs sector is extended, and a whole family of Higgs-like bosons exists at higher mass, as predicted by many Beyond the SM (BSM) theories. At ATLAS, some BSM are tested by performing both direct searches for new particles, and indirectly by using the Higgs boson coupling measurements to put constraints. In this report, a short review of some of the indirect searches performed is described, a full discussion can be found in Ref. [10]. Perspectives at the High-Luminosity (HL) LHC [11], are also discussed.

2 Methodology and statistical treatment

The analyses presented use the full data sample collected by ATLAS during the first run of the LHC in 2011 and 2012, corresponding to about 25 fb^{-1} of proton-proton collision data at 7 and 8 TeV center-of-mass energy. The measurements of the Higgs boson couplings to bosons and fermions in all studied channels are considered: $h \to \gamma\gamma$, $h \to ZZ^{\star} \to 4\ell$, $h \to WW^{\star} \to \ell\nu\ell'\nu'$, $h \to \tau\tau$ and $h \to b\bar{b}$. The direct search for $Zh \to \ell\ell +$ invisible is also considered in the studies presented in Sec. 5. Relying on the Higgs coupling measurements confidence intervals are set on the BSM parameters based on a profile likelihood ratio test [12], following the method described in Ref. [13, 14]. The likelihood function used is defined as the product of the likelihood functions in each channel, and depend on the parameters of interest, such as the signal strength, the Higgs boson mass m_h or the couplings. Experimental and theoretical systematic uncertainties are introduced in the likelihood by means of nuisance parameters. In each decay channel, the likelihood describes the optimal observable for signal to background separation; in the $h \to \gamma\gamma$ case, for example, the discriminant observable is the di-photon invariant mass. The signal shape is extracted from Monte Carlo (MC), whereas the background shape comes from either MC or data driven estimates.

3 Two-Higgs-doublet model

A simple extension of the SM is a class of models named Two-Higgs-Doublet Models (2HDMs) [15]. These models predict the existence of an additional Higgs doublet: one neutral CP-even boson H, one neutral CP-odd boson A, and two charged bosons $H^{\pm}$. Different couplings to vector bosons and fermions are tested [10]. Limits are set on the $(\cos(\beta-\alpha), \tan(\beta))$ plane and are found to be consistent with the SM expectations for all the coupling configurations tested. In Fig. 1, limits obtained in one case considered are shown.

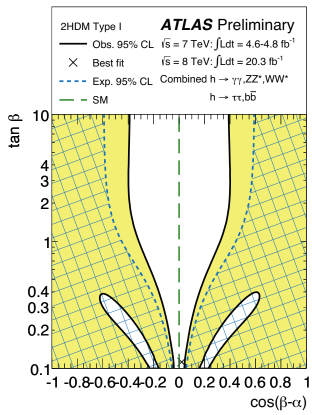

Figure 1: Regions of the $(\cos(\beta-\alpha), \tan(\beta))$ plane for a coupling configuration of 2HDMs excluded by fits to the measured rates of the Higgs boson production and decays. The cross marks the best fit value, the light shaded and hashed regions indicate the observed and expected 95% confidence level exclusions. [10]

4 Simplified minimal supersymmetric model

Supersymmetry [16] was introduced to solve the hierarchy problem, and provides Weakly Interacting Massive Particles (WIMPs) that are good candidates for dark matter. In this study, limits have been set, within the simplified Minimal SuperSymmetric Model (MSSM) formalism, in the (m_A, $\tan(\beta)$) plane. Results are shown in Fig. 2 (left). The observed (expected) lower limit at 95% Confidence Level (CL) on m_A is 400 GeV (280 GeV) for $2 \leq \tan(\beta) \leq 10$. Everything is consistent with the SM, although there is still a large unexplored region for $\tan(\beta) > 1$.

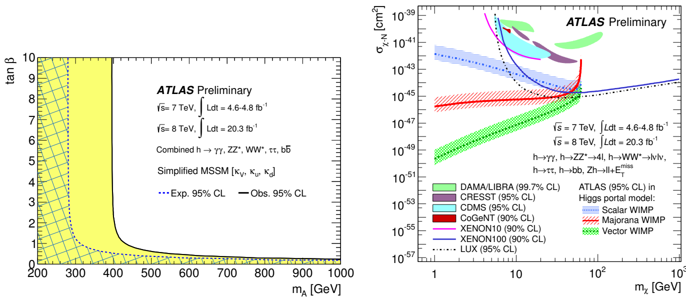

Figure 2: Left: regions of the $(\mathrm{m_A}, \tan(\beta))$ plane excluded in a simplified MSSM model via fits to the Higgs boson production and decay rates. The light shaded and hashed regions indicate the observed and expected 95% CL exclusions respectively. [10] Right: ATLAS 95% CL upper limit on the WIMP-nucleon scattering cross section in a Higgs portal model as a function of the dark matter candidate's mass for different spin configurations. Excluded and allowed regions from direct detection experiments are also shown. [10]

5 Higgs portal to dark matter

In the "Higgs portal to dark matter" models [17, 18] a WIMP is introduced as a dark matter candidate, that interacts very weakly with all SM particles except the Higgs boson. From the Higgs boson coupling measurements, and from direct searches of $Zh \to \ell\ell +$invisible, the upper limit at 95% CL on the Branching Ratio of the Higgs boson to invisible final states ($\mathrm{BR_{inv}}$) is found to be $\mathrm{BR_{inv}} < 0.37$, where the expectation is 0.39. The upper limit is then transformed into constraints on the coupling of the WIMP to the Higgs boson as a function of its mass [18] to allow for comparison with direct searches for dark matter [19]. The results are shown in Fig. 2 (right) for different spin configurations of the WIMP. The ATLAS experiment results dominate in a broad region at low mass.

6 Perspectives at HL LHC

The LHC is expected to be brought to the high luminosity phase in 2023. Five to ten times the nominal luminosity will be reached in the HL-LHC collisions, and about 3000 fb^{-1} of proton-proton data will be collected by 2030 at 14 TeV of center-of-mass energy. Experimental precisions of 1.5% and 3% are expected on the couplings of the Higgs boson to vector bosons and fermions respectively. In the Higgs portal to dark matter studies expected limits on $\mathrm{BR_{inv}}$ will be set at the level of 8 to 16% in direct $Zh \to \ell\ell +$ invisible searches, and of 12 to 15% in indirect searches from coupling measurements.

7 Summary

The data collected during the first phase of the operation at the LHC have been used to extract a first measurement of the Higgs boson couplings. Such measurements allow to perform indirect searches for new physics at high energy. The results presented show an impressive consistency with the SM, and allow to set limits on the parameters of the BSM models studied.

Acknowledgements

This report was supported by the European Research Council, Grant Agreement N^o 279170 DIBOSON.

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