PROCEEDINGS OF SCIENCE

Exotic production and decays of the 125 GeV Higgs – ATLAS

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Since its discovery in 2012, the Higgs boson has been recognized as a promising candidate for exploring new physics beyond the Standard Model. The ATLAS collaboration has undertaken extensive efforts to investigate various potential scenarios for new physics. A substantial portion of the ATLAS physics program is devoted to the thorough examination of exotic Higgs phenomena. This paper presents recent studies conducted by the ATLAS collaboration in this endeavor.

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1. Introduction

The unique place that the Higgs boson occupies within the Standard Model (SM) makes it especially well-suited as a potential conduit to unexplored realms of physics beyond the standard model (BSM). The remarkably narrow width of the Higgs implies that even a slight coupling to another lightweight state can readily introduce significant additional decay modes. Therefore, the search for non-standard Higgs interactions, commonly referred to as "Exotic production and decays of Higgs" forms an integral part of the experimental program at the Large Hadron Collider (LHC) at CERN.

This paper offers a comprehensive overview of recent studies carried out by the ATLAS collaboration in this domain. The exploration of exotic Higgs phenomena can be systematically categorized into three groups as discussed below in the subsequent sections.

2. Exotic Higgs decays involving rare SM particles

The Higgs boson is hypothesized to undergo decay into various rare SM final states. The following studies provide an overview of the current status of these searches within ATLAS:

2.1 $H \to Z\gamma$

The combined search [1] conducted by the ATLAS and CMS collaborations has established an evidence of the $H \to Z\gamma$ decay with an observed significance of 3.4σ.

2.2 $H \to J/\psi\gamma$ or $\psi(2s)\gamma$ or $\Upsilon(1s,2s,3s)\gamma \to \mu^+\mu^-\gamma$

A search [2] for the exclusive decays of Higgs or Z bosons into a vector quarkonium state and a photon in a $\mu^+\mu^-\gamma$ final state has been conducted using Run II proton-proton collision data. The observed data is found to be compatible with expected background and 95% Confidence Level (CL) upper limits on the branching ratio of H/Z boson into these final states are presented (Table 1).

95% CL upper limits				
Channel	Higgs boson [10^{-4}]		Z boson [10^{-6}]	
	Expected	Observed	Expected	Observed
$J/\psi\gamma$	$1.8^{+0.8}_{-0.5}$	2.0	$0.7^{+0.3}_{-0.2}$	1.2
$\psi(2S)\gamma$	$8.1^{+3.6}_{-2.3}$	10.5	$3.0^{+1.3}_{-0.8}$	2.4
$Y(1S)\gamma$	$2.7^{+1.2}_{-0.8}$	2.5	$1.6^{+0.6}_{-0.4}$	1.1
$Y(2S)\gamma$	$3.4^{+1.5}_{-1.0}$	4.2	$2.1^{+0.8}_{-0.6}$	1.3
$Y(3S)\gamma$	$3.0^{+1.3}_{-0.8}$	3.4	$1.9^{+0.8}_{-0.5}$	2.4
$\omega\gamma$	$10.4^{+3.8}_{-2.9}$	5.5	$4.7^{+2.0}_{-1.3}$	3.9
$K^*\gamma$	$3.7^{+1.5}_{-1.0}$	2.2	–	–

Table 1: 95% CL branching fraction upper limits for the Higgs and Z boson decays into different SM final states.

2.3 H/Z $\rightarrow \omega\gamma \rightarrow \pi^+\pi^-\pi^0\gamma$ or H $\rightarrow k^*\gamma \rightarrow k^+\pi^-\gamma$

This study [3] presented a search for the decays $H/Z \rightarrow \omega\gamma$ and $H \rightarrow k^*\gamma$ with Run II ATLAS data. Given the absence of a significant excess above the SM background expectation, 95% CL upper limits on the H/Z branching ratio into different final states are set as presented in Table 1.

3. Exotic Higgs decays in new BSM final states

The ATLAS collaboration has conducted a series of studies investigating the decay of the SM Higgs into new BSM final states, as detailed below.

3.1 Associated ZH production with subsequent decays $Z \rightarrow l^+l^-$ and H $\rightarrow \gamma\gamma_d$

This paper [4] explores Run II LHC data to search for dark photons (γ_d) in the decays of the Higgs ($H \rightarrow \gamma\gamma_d$) produced through ZH production modes. As no excess is observed w.r.t. the SM prediction, 95% CL upper limits are set on the branching ratio of the $H \rightarrow \gamma\gamma_d$ decay for different dark photon mass hypotheses as presented in Figure 1.

3.2 Lepton flavour violating decays of the Higgs boson, H $\rightarrow e\tau/\mu\tau$

Direct searches [5] for lepton flavor violation in Higgs boson decays have been conducted using ATLAS Run II data and an agreement with background expectation is observed. Therefore, the results are interpreted as upper limits on lepton-flavour-violating branching ratios of the Higgs boson as presented in Figure 2.

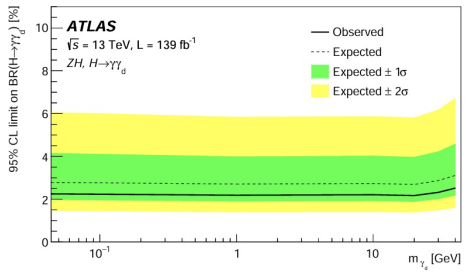

Figure 1: Observed and expected exclusion limits at 95% CL on BR($H \rightarrow \gamma\gamma_d$) as a function of the γ_d mass.

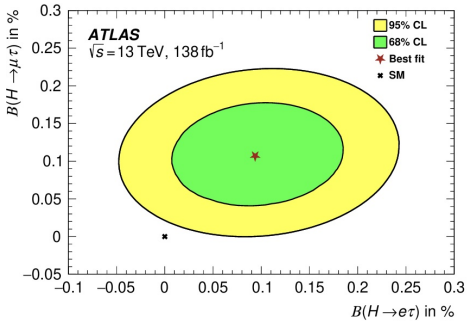

Figure 2: Best fit value (red star) of the BR($H \rightarrow e\tau$) and BR($H \rightarrow \mu\tau$) and likelihood contours at 68% and 95% CL.

4. SM Higgs production in association with new exotic final states

A number of theoretical models motivate the SM Higgs production along with new BSM final states. The latest studies performed in this direction by the ATLAS collaboration are discussed below.

4.1 SM Higgs production along with a vector boson, W'/Z'/A $\rightarrow$ VH $\rightarrow llbb/\nu\nu bb/l\nu bb$

A search [6] for Z'/W' bosons and for a CP-odd Higgs boson A has been performed in final states with leptons and b-quarks using Run II data from ATLAS. No significant excess of events is

observed above the SM predictions in the three channels, and upper limits are set on the respective production cross-sections.

4.2 SM Higgs production along with a new heavy resonance, Y → XH → $qqbb$

An anomaly detection search [7] for a new heavy resonance X produced in association with a Higgs boson has been presented. In the absence of any significant deviation from SM, 95% CL upper limits on the cross section have been set as shown in Figure 3.

4.3 SM Higgs production along with a dark matter candidate, A → aH → $\tau\tau + E^{T}_{\text{miss}}$

A search [8] for dark matter produced in association with a Higgs boson in final states with two hadronically decaying leptons and missing transverse momentum is presented and exclusion limits at 95% confidence level are derived as shown in Figure 4.

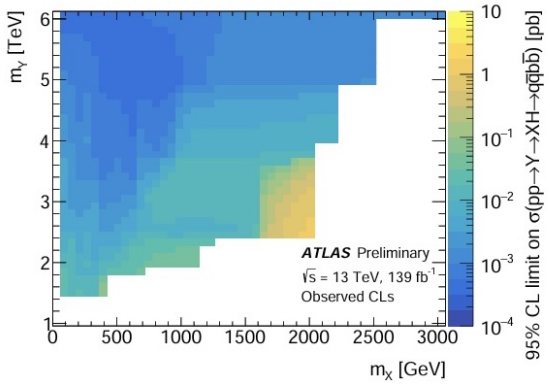

Figure 3: Observed exclusion limits at 95% CL on the cross section $\sigma(pp \to Y \to XH \to qqbb)$ in the m_Y vs. m_X plane.

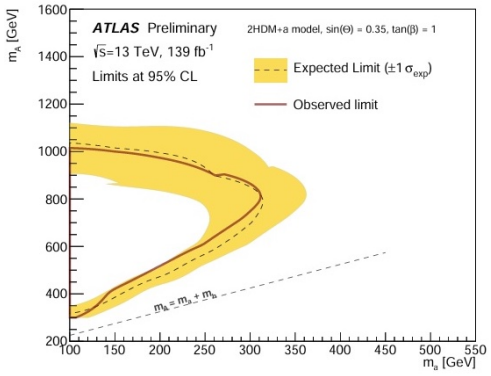

Figure 4: Observed and expected exclusion contours at 95% CL 2HDM+a model with sin(Θ) = 0.35 and tan(β) = 1.

4.4 New physics in 22 different signal final states produced along with H → $\gamma\gamma$

This paper [9] presents a model-independent search for new physics in $H \to \gamma\gamma$ ATLAS Run II data. This search examines 22 final states categorized by the objects that are produced in association with the Higgs boson. These objects include isolated electrons or muons, hadronically decaying τ-leptons, additional photons, missing transverse momentum, and hadronic jets, as well as jets that are tagged as containing a b-hadron. No significant excesses above SM expectations are observed and limits on the production cross-sections at 95% CL are set.

5. Conclusions

This paper offers an overview of recent investigations into exotic Higgs searches conducted by the ATLAS collaboration. The exploration of exotic Higgs phenomena is categorized into three distinct groups, each of which is thoroughly examined and presented through various studies. The aim is to provide a comprehensive review of the diverse research efforts undertaken by the ATLAS collaboration in the realm of exotic Higgs searches.

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