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Search for $Z\gamma$ resonances in pp collisions with the ATLAS detector

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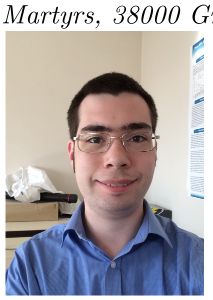

An overview of the search for $Z\gamma$ resonances using proton-proton collision data recorded by the ATLAS detector is presented. A search for evidence of the Standard Model Higgs boson undergoing the decay $H \to Z\gamma, Z \to \ell\ell$, where $\ell = e$ or μ, has been performed, and a brief summary of the most recent public results is given. A search for exotic high mass resonances decaying to a $Z\gamma$ final state has been performed using proton-proton collision data recorded at $\sqrt{s} = 13$ TeV. Leptonic decays of the Z boson ($Z \to \ell\ell$, where $\ell = e$ or μ) have been investigated, together with hadronic decay modes ($Z \to q\bar{q}$). An overview of the most recent public results is presented.

1 Introduction

Searches for evidence of resonances decaying to a $Z\gamma$ final state have been performed using proton-proton collision data recorded by the ATLAS detector [1]. The expected Standard Model (SM) Higgs boson decay $H \to Z\gamma$ has not yet been observed but is of great interest because it provides a relatively clean signal and all of the final state particles can be reconstructed. The leading order Feynman diagrams for this process are shown in Figure 1. It is possible that the loops may contain hitherto undiscovered particles. Measurements of the $H \to Z\gamma$ decay rate could therefore provide insight into models beyond the Standard Model (BSM). Many BSM models introduce additional massive bosons that decay to final states containing $W^{\pm}$, Z or γ bosons. Consequently, this analysis has also been extended to directly probe possible new high mass particles in a search for evidence of new resonances decaying to a $Z\gamma$ final state.

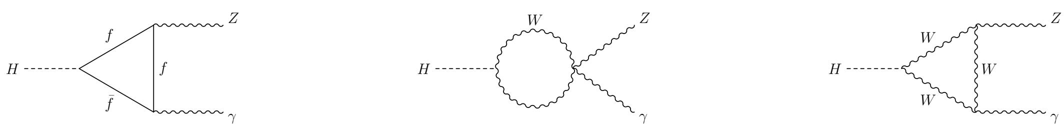

Figure 1 – Summary of the dominant $H \to Z\gamma$ decay processes.

2 Search for Standard Model $H \to Z\gamma$ Decays

A search for evidence of the SM Higgs boson undergoing the decay $H \to Z\gamma, Z \to \ell\ell$ has been performed using 4.5 fb^{-1} of data recorded at a centre-of-mass energy $\sqrt{s} = 7$ TeV and 20.3 fb^{-1} of data recorded at $\sqrt{s} = 8$ TeV [2]. Events were selected by requiring two charged leptons (e^+e^- or $\mu^+\mu^-$) with $p_T > 10$ GeV, and an isolated photon with $E_T > 15$ GeV.

In order to enhance the sensitivity of the analysis, the selected events were separated into ten categories according to the centre-of-mass collision energy, the final state ($ee\gamma$ or $\mu\mu\gamma$), the component of the p_T of the reconstructed Higgs boson candidate orthogonal to the axis defined by the difference between the Z boson and photon momenta (termed Higgs p_{Tt}), and the difference in pseudorapidity between the Z boson and the photon ($|\Delta\eta_{Z\gamma}|$).

The signal was modelled using an analytical function constructed from the combination of a Crystal Ball function and a Gaussian distribution. The background was modelled using polynomials of various order, that were fitted directly to the observed data.

No significant excess above the background was observed, and so upper limits were set on the production cross section of a SM Higgs boson decaying to $Z\gamma$ (normalised by the Standard Model expectation), as shown in Figure 2. For a Higgs boson of mass 125 GeV, the expected and observed limits were 9 and 11 times the Standard Model predictions, respectively.

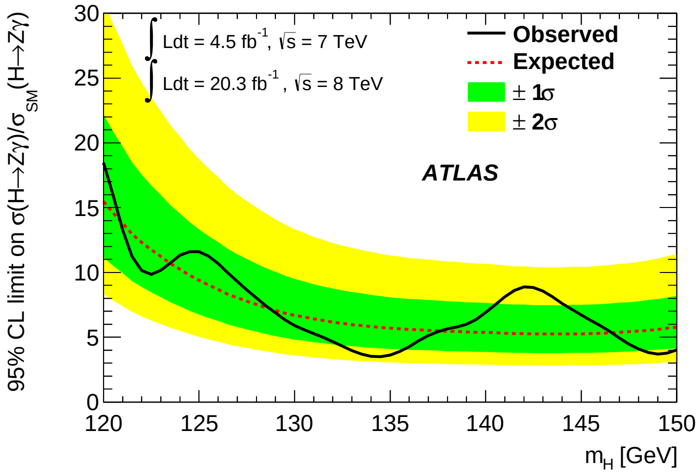

Figure 2 – Observed 95% CL limits (solid black line) on the production cross section of a SM Higgs boson decaying to $Z\gamma$ divided by the SM expectation. The limits are computed as a function of the Higgs boson mass. The median expected 95% CL exclusion limits (dashed red line), in the case of no expected signal, are also shown. The green and yellow bands correspond to the $\pm 1\sigma$ and $\pm 2\sigma$ intervals [2].

3 Search for High Mass Resonances with a $Z\gamma$ Final State

A search for evidence of new high mass resonances decaying to a $Z\gamma$ final state has been performed using 13.3 fb^{-1} of data recorded at a centre-of-mass energy $\sqrt{s} = 13$ TeV [3]. Events were selected by requiring two charged leptons (e^+e^- or $\mu^+\mu^-$) with $p_T > 10$ GeV, and an isolated photon with $E_T > 15$ GeV. The reconstructed Z boson was required to be within 15 GeV of the Z mass pole, and was then combined with the highest E_T photon to form the $m_{\ell\ell\gamma}$ candidate.

Events were separated into two categories based on the final state of $ee\gamma$ or $\mu\mu\gamma$, in order to exploit their different invariant mass resolutions. Muons with a very high p_T suffer from a loss of resolution, as can be seen when comparing simulated signal at 300 GeV and 1.5 TeV in Figure 3. The signal is modelled using a double-sided Crystal Ball function, which consists of a core Gaussian distribution with asymmetric power-law tails.

The background is dominated by non-resonant $Z + \gamma$ production that accounts for around

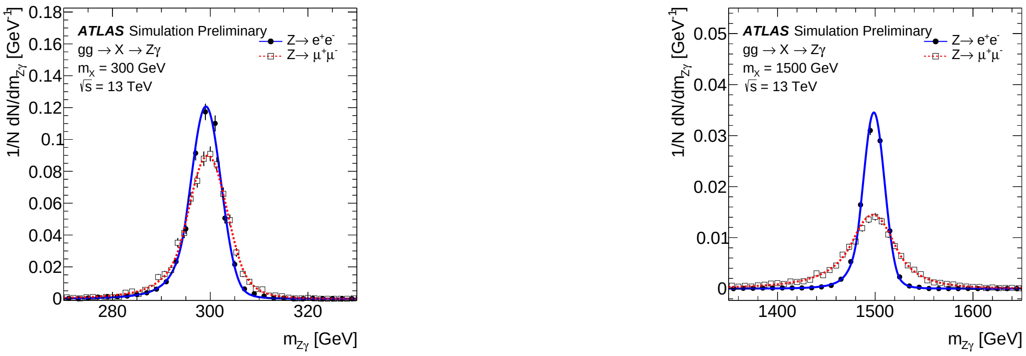

Figure 3 – Invariant mass distribution for $X \to Z\gamma, Z \to e^+e^-$ (full circles) or $Z \to \mu^+\mu^-$ events (open squares) in a simulation of a narrow resonance X with a mass of 300 GeV (left) and 1.5 TeV (right) produced in a gluon-fusion process in $\sqrt{s} = 13$ TeV pp collisions. All selection requirements have been applied. The lines represent the fits of the points with a double-sided Crystal Ball function [3].

90% of the total, while the remaining 10% comes from production of a Z boson in association with a hadronic jet that is then misreconstructed as a photon. The background was modelled using an analytical function that was fitted directly to the data, with the functional form determined by assessing the level of spurious signal and by performing an F-Test. Spurious signal represents a bias on the signal yield arising from the choice of background model - fitting a combined signal and background model to a sample of background events will return a non-zero signal yield, and the ratio of this fitted yield to its uncertainty is required to be less than 20%. The F-Test is a means of identifying the simplest functional form for which introducing an additional parameter does not significantly improve the quality of the fit. The selected background model used in both categories has the form:

$$f_{k=0;d=1/3}(x; b, d, \{a_k\}) = (1 - x^{1/3})^b x^{a_0}, \tag{1}$$

where $x = \frac{m_{ll\gamma}}{\sqrt{s}}$, and b and a_0 are free parameters. The results of fitting this function in each category are shown in Figure 4.

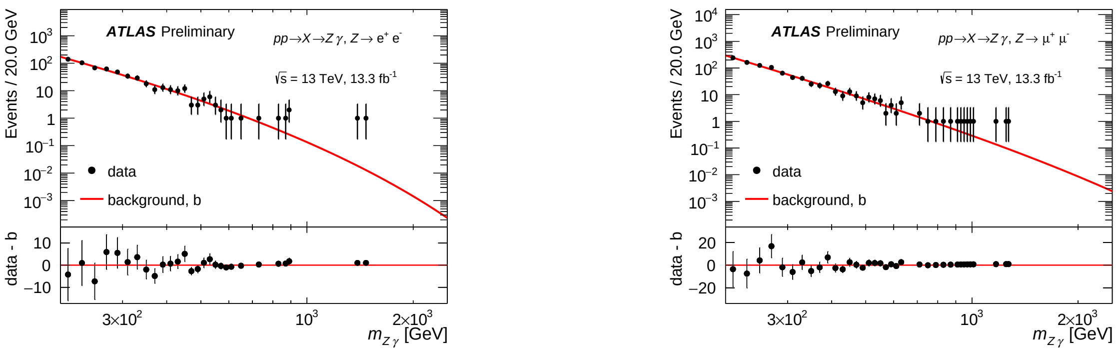

Figure 4 – Distribution of the reconstructed $Z\gamma$ invariant mass in events in which the Z boson decays to electrons (left) or to muons (right). The solid lines show the results of background-only fits to the data. The residuals of the data points with respect to the fit are also shown [3].

No significant excesses were identified and so limits were placed on $\sigma(pp \to X) \times BR(X \to Z\gamma)$ at 95% CL, as shown in Figure 5. The expected limits range from 103 fb ($m_X = 250$ GeV) to 5 fb ($m_X = 2.4$ TeV), while the observed limits range from 215 fb ($m_X = 270$ GeV) to 5 fb ($m_X = 2.4$ TeV).

Consideration is also given to hadronic decays of the Z boson, where the resultant quarks form the seeds of highly boosted hadronic jets [4]. An analysis was performed using 3.2 fb^{-1} of data recorded at $\sqrt{s} = 13$ TeV that examined both leptonic and hadronic decays of the

Z boson. Hadronic Z boson decays suffer from poor sensitivity at low masses due to a large associated background, but provided greater sensitivity than the leptonic decays when probing $m_{\ell\ell\gamma} > 1.5$ TeV. The resultant limits are also shown in Figure 5.

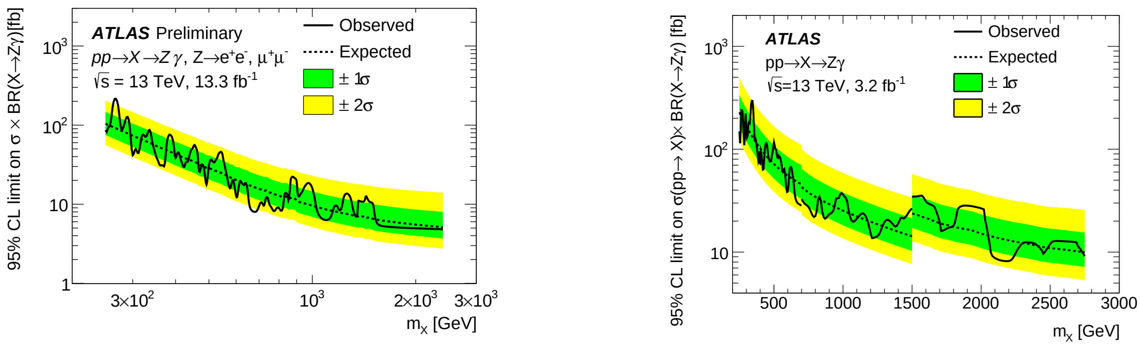

Figure 5 – Observed (solid lines) and median expected (dashed lines) 95% CL limits on the product of the production cross section times the branching ratio for the decay to a Z boson and a photon of a narrow scalar boson X, $\sigma(pp \to X) \times BR(X \to Z\gamma)$, as a function of the boson mass m_X. The green and yellow solid bands correspond to the $\pm 1\sigma$ and $\pm 2\sigma$ intervals for the expected upper limit, respectively. Left: results obtained using 13.3 fb^{-1} of $\sqrt{s}$ = 13 TeV data, from leptonic Z decays only. Right: results obtained using 3.2 fb^{-1} of $\sqrt{s}$ = 13 TeV data, from leptonic Z decays (m_X < 700 GeV), hadronic Z decays (m_X > 1.5 TeV) and a combination ($700 < m_X < 1500$ GeV)[3,4].

4 Conclusions

A search for evidence of the Standard Model Higgs boson decaying to a $Z\gamma$ final state, where the Z boson decays leptonically, has been performed using data recorded at centre-of-mass energies $\sqrt{s} = 7$ and 8 TeV. No significant excesses were observed and so limits have been set on production cross section normalised by the Standard Model expectation. A search for evidence of a new high-mass resonance decaying to a $Z\gamma$ final state has been performed using 13.3 fb^{-1} of data recorded at $\sqrt{s} = 13$ TeV. No significant excesses have been observed, and limits have been set on the production cross-section times the branching ratio. Both of these analyses have since been reproduced using 36.1 fb^{-1} of data that had been recorded at $\sqrt{s} = 13$ TeV by the end of the 2016 data-taking period. The increased integrated luminosity and the larger Higgs boson production cross-section due to the higher centre of mass energy, 13 TeV, wereexpected to improvethe $H \to Z\gamma$ decay limit by about 40%. Further improvements were also expected through re-optimisation of the event categories. The results of these updated studies are to be published in JHEP.

Acknowledgments

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