

Search for High-mass Resonances in $Z(\rightarrow \ell\ell)\gamma$ Final State at CMS

Kyungwook Nam^{*†}

Seoul National University

on behalf of the CMS Collaboration

E-mail: kyungwook.nam@cern.ch

A search for a heavy resonance decaying to $Z\gamma$, with the Z boson further decaying to pairs of electrons or muons is presented. The search strategy is to look for an excess above the non-resonant Standard Model background on the $\ell^+\ell^-\gamma$ invariant mass spectrum. The search is based on 13 TeV proton-proton collision data collected with the CMS detector, corresponding to the integrated luminosity of 12.9 fb^{-1} .

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^{*}Speaker.

[†]The CMS Collaboration

1. Introduction

The discovery of a Higgs boson at 125 GeV [1][2], while generally seen as the completion of the Standard Model (SM) of particle physics, can also be a first hint for a more fundamental theory of nature to which the SM might be only a low-energy approximation. A variety of models beyond the SM predict the existence of a new scalar boson, which may decay into $Z\gamma$. This paper describes the results of a search for such heavy resonances decaying to $Z\gamma$, with further decay of $Z \rightarrow e^+e^-/\mu^+\mu^-$ [3]. The search is based on 13 TeV proton-proton collision data collected by the CMS experiment [4] in 2016, corresponding to the integrated luminosity of 12.9 fb^{-1} . The search strategy measures the non-resonant SM background directly on data, and looks for localized excesses, similarly to what is done in Ref. [5] and [6].

2. Event Selection

Events are selected with exactly two opposite-sign electrons or muons with a photon. Selected events are required to pass either a double-electron trigger, a double-muon trigger, or single-muon trigger paths. All candidates must pass the CMS standard electron [7], muon [8] [9], and photon [10] identifications respectively. The leading lepton is required to have transverse momentum $p_T > 25 \text{ GeV}$, while the subleading lepton must have $p_T > 20 \text{ GeV}$, and both are required to have pseudorapidity $|\eta| < 2.4$. The chosen p_T thresholds ensure that trigger turn-on effects may be neglected. The photon is required to have $p_T > 40 \text{ GeV}$ and $|\eta| < 2.5$. In addition, the angular separation between each of the selected leptons and the photon must satisfy $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} > 0.4$ in order to minimize the effect of lepton final state radiation. Photons and electrons in the electromagnetic calorimeter gap region $1.44 < |\eta| < 1.57$ are excluded. The system of the selected dilepton is required to have an invariant mass between 50 and 130 GeV. Finally, the photon p_T has to be greater than $(40/150) \times m_{Z\gamma}$, where $m_{Z\gamma}$ is the invariant mass of the $Z\gamma$ candidate. This condition suppresses backgrounds from photon misidentification, without losing signal sensitivity nor introducing a bias in the $m_{Z\gamma}$ spectrum. $m_{Z\gamma}$ spectra of data and Monte Carlo (MC) simulations after event selection are compared in Figure 1.

3. Background Fit and Signal Modeling

The non-resonant SM background $m_{Z\gamma}$ spectrum can be extracted by an unbinned likelihood fit with a parametric function of $m_{Z\gamma}$: $f(m_{Z\gamma}) = m_{Z\gamma}^{a+b\log m_{Z\gamma}}$. The parametric coefficients are obtained from a fit to the data events, and considered as unconstrained nuisance parameters in the hypothesis test, providing a data-driven estimation for the shape of the background $m_{Z\gamma}$ spectrum. The background bias is studied using MC simulations. The signal distribution in $m_{Z\gamma}$ is taken from the MC simulation. The signal MC is used in the analysis for two parts: first, it provides the shape of the signal invariant mass spectrum, which is parametrized by a function with a Gaussian core and two power-law tails, an extended form of the Crystal Ball function [11]; second, acceptance and selection efficiency are measured using the signal MC. The best-fit values of the six parameters of the signal shape and efficiency are measured on MC samples at the benchmark resonance masses, separately for the electron and muon channels, and then interpolated through polynomial fits to generic $m_{Z\gamma}$ values.

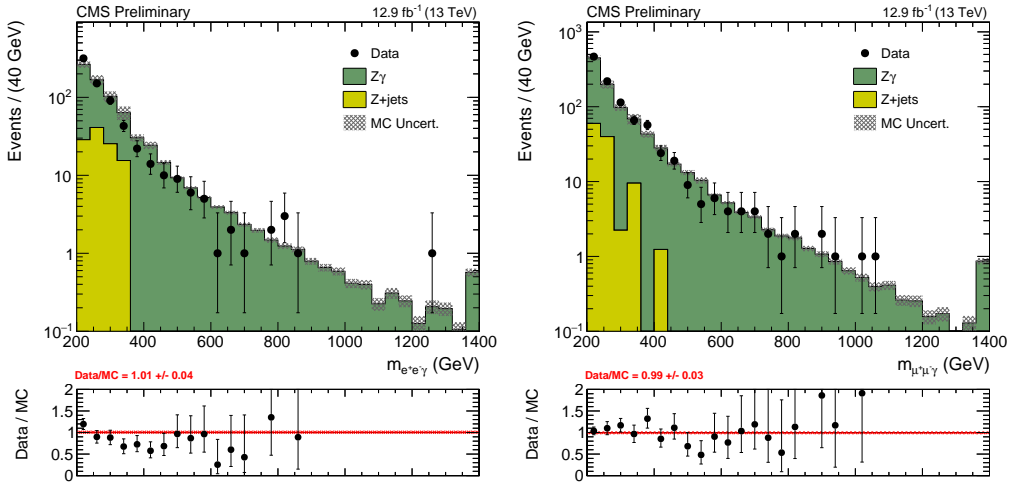


Figure 1: $m_{Z\gamma}$ distributions of data and the MC simulation in $e^+e^-\gamma$ (left) and $\mu^+\mu^-\gamma$ (right) channels after event selection. They are in good agreement in both search channels.

4. Results

No significant excess above expected backgrounds is observed in $m_{Z\gamma}$ spectrum. Therefore, we set upper limits on the production cross section of heavy scalar resonances in the narrow width (0.014% of the resonance mass) scenario, using the modified frequentist method, commonly known as CLs following the prescription in Ref. [12]. Asymptotic formulae [13] are used in the calculation. Figure 2 shows 95% confidence level upper limits on $\sigma \times BR$, where σ is the signal production cross section and BR is branching fraction. The expected limit for the background-only hypothesis is represented by a dashed black line, and its 1σ and 2σ standard deviations are shown with green and yellow bands, respectively. The observed limit is represented by a solid black line. Only small statistical fluctuations of significance less than 2σ are observed at around 370 GeV.

5. Conclusion

A search for high-mass scalar resonances in the $X \rightarrow Z\gamma \rightarrow e^+e^-\gamma/\mu^+\mu^-\gamma$ channel has been performed, using 12.9 fb^{-1} 13 TeV pp collision data collected with the CMS detector. No significant excess is observed above the background-only hypothesis. Upper limits are placed in the $300 < m_{Z\gamma} < 2000$ GeV range.

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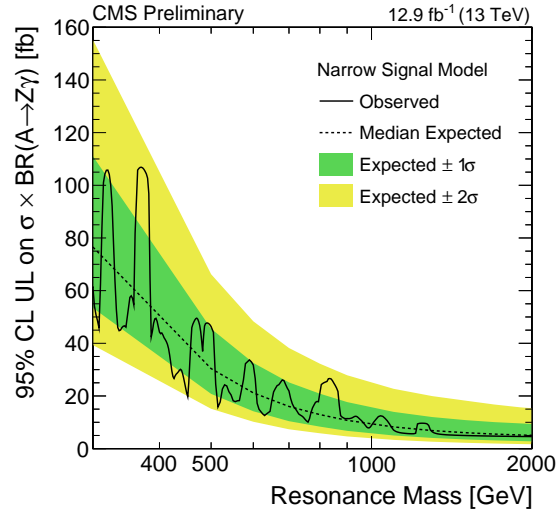


Figure 2: Limits on $\sigma \times BR(Z\gamma)$ obtained by combining $e^+e^-\gamma$ and $\mu^+\mu^-\gamma$ channels.

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