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Search for a high mass particle decaying into two photons or Z + photon using the CMS detector and the LHC Run 1 data

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The most recent CMS results on the search for a high mass particle decaying into two photons in the high mass region [150,850] GeV and into a Z boson and a photon in the region [200,500] GeV, using the full dataset recorded at the LHC from pp collisions at the centre of mass energy of 8 TeV will be described. Results will also be presented on the search for a Higgs boson particle decaying into a photon and a Z boson using the full dataset at centre of mass energies of 7 and 8 TeV.

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Table 1: Definition of diphoton event classes

Class	η criterion	R_9 criterion
0	$\max(\|\eta\|) < 1.44$	$\min(R_9) > 0.94$
1	$\max(\|\eta\|) < 1.44$	$\min(R_9) < 0.94$
2	$1.57 < \max(\|\eta\|) < 2.50$	$\min(R_9) > 0.94$
3	$1.57 < \max(\|\eta\|) < 2.50$	$\min(R_9) < 0.94$

1. Search for diphoton resonances in the mass range from 150 to 850 GeV in pp collisions at $\sqrt{s} = 8$ TeV

The discovery of a standard model-like Higgs boson at the CERN LHC opens a new phase in the understanding of the standard model (SM) of particle physics. The search for additional Higgs-like particles provides complementary ways to test the validity of the SM and to test for the presence of physics beyond it. Several models of physics beyond the SM, such as the two-Higgs-doublet model (2HDM) [1], motivate the search for additional high-mass resonances in the $\gamma\gamma$-channel [2]. Some of those models predict a production of massive scalar particles dominated by gluon fusion. In addition, also massive spin-2 hypotheses decaying into diphoton can be tested. These particles are predicted by the Randall-Sundrum [3] and the Arkani-Hamed-Dimopoulos-Dvali [4] models which predict higher-dimensional scenarios as an alternative solution to the hierarchy problem. Despite the large non-resonant background, diphoton decay mode provides a clean final-state topology, so that the mass of the decaying object can be reconstructed with high precision, exploiting the excellent performance of the electromagnetic calorimeter [5] of the CMS experiment. Narrow and wide resonances are investigated with natural widths ranging from 100 MeV to 10% of the resonance mass.

1.1 Event selections

Photons or electrons striking the CMS ECAL detector shower through the crystals, therefore the energy of the electromagnetic showers is deposited in crystals matrices and the effect of the 3.8 T CMS magnetic field causes the energy depositions to spread along ϕ. Clustering algorithms are used to sum together energy deposits belonging to the same electromagnetic shower. The clustering algorithm first forms "basic clusters", corresponding to local maxima of energy deposits, then merges them together to form a "supercluster", which is extended in ϕ, to recover the radiated energy.

Since unconverted photons do not have associated tracks, the diphoton pair interaction vertex is identified with a Boosted Decision Tree (BDT), which exploits the debris of the recoil in the H$\rightarrow\gamma\gamma$ decay [6]. In addition, leading (subleading) photons are required to be isolated, have $p_T > m_{\gamma\gamma}/3 (m_{\gamma\gamma}/4)$ and to be inside the $|\eta| < 2.4$ fiducial region. Finally, in order to exploit the single events different kinematics and sensitivities, the events are divide in four categories based on the photons R_9 and η, as shown in Table 1, where R_9 is defined as the energy sum of the 3×3 crystals centred on the most energetic crystal in the supercluster divided by the energy of the supercluster.

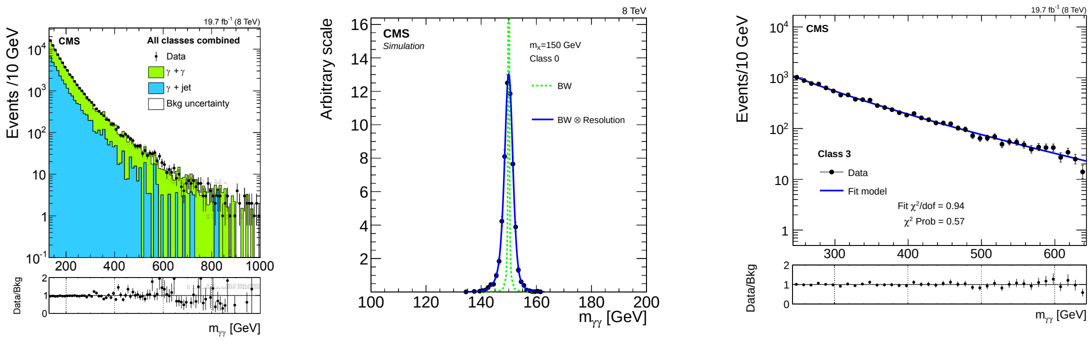

Figure 1: Left: Diphoton invariant mass distribution for the selected events in data and simulation. Middle: Parametrized signal shape for a signal with $m_X = 150$ GeV and $\Gamma_X = 0.1$ GeV. Right: Fits to the diphoton mass distributions in the third class of events in the window [240, 640] GeV chosen for searching for a peak near 350 GeV, using the $f(m)$ model.

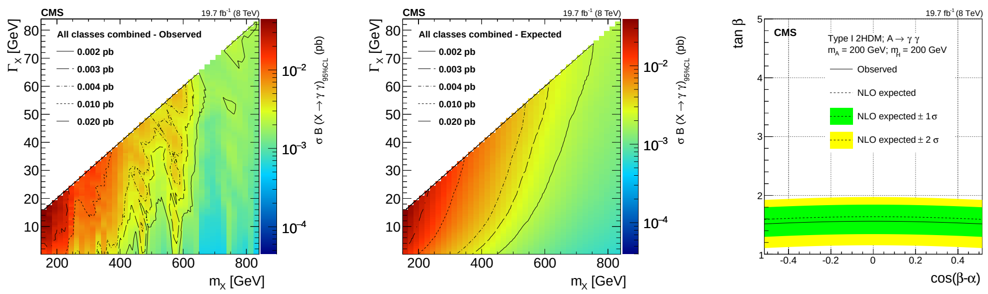

Figure 2: Combined observed (left) and expected (middle) exclusion limits at 95% CL on the cross section times branching fraction of a new, spin-0 resonance decaying into two photons as a function of the resonance mass and width hypotheses. Right: Observed and expected 95% CL exclusion regions for gluon-fusion production of a heavy scalar boson A of mass 200 GeV in the $\cos(\beta-\alpha)$-$\tan(\beta)$ parameters space.

1.2 Results

Final results are extracted fitting, for each category, the simulated signal shape with a Crystal-Ball convoluted with a Breit-Wigner, and the data background with:

$$f(m) = e^{-p_1 m} m^{-p_2} \quad (1.1)$$

which is the background function with the least bias in the fitted signal yield. Figure 1 shows the invariant mass distribution for the selected events in data and an example of signal and background fit.

The invariant mass spectrum shows no evidence for the presence of a new particle decaying to two photons, therefore the combined exclusion limits are computed. Figure 2 shows the 95% CL observed and the expected limits as a function of the signal hypothesis mass and width, and the limits as an interpretation of Type I 2HDM model in the 2D $\cos(\beta-\alpha)$-$\tan(\beta)$ parameters space.

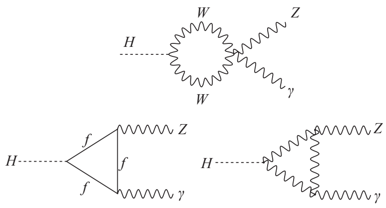

Figure 3: Contributing diagrams to $\Gamma_{Z\gamma}$.

2. Search for a Higgs boson decaying into a Z and a photon in pp collisions at $\sqrt{s} = 7$ and 8 TeV

Within the SM, even if the branching fraction of H→ $Z\gamma$ is rather small between 0.11% and 0.25% in the 120-160 GeV mass range, the measurement of $\Gamma_{Z\gamma}$ [7] provides important information on the SM mechanisms and on possible deviations, which are clear hints of physics beyond the SM. The dominant backgrounds are composed by an irreducible component of $Z\gamma$ SM production in addition with reducible components coming from final state radiation of SM Z events and Z+jets production, where a jet is misidentified as a photon. The contributing diagrams to $\Gamma_{Z\gamma}$ are shown in Figure 3 shows. The two Z→ $e^+e^-\gamma$ and Z→ $\mu^+\mu^-\gamma$ signatures are selected, where muons are identified and measured in gas-ionization detectors embedded in the steel return-yoke outside the solenoid [8].

2.1 Event selections

After passing the dielectron or the dimuon triggers, events are selected requiring isolated opposite sign and same flavour leptons (e,μ) and an isolated photon. The photon and the electrons are selected using a multivariate identification, taking as an input the superclusters shower shape and kinematic variables, while the muons identification uses the muon combined identification, which exploits the tracker [9] and the muon chambers combined measurements. In addition, in order to optimize the signal to background ratio, electrons, muons and photons are required to have: $p_T^{\ell 1} > 20$ GeV, $p_T^{\ell 2} > 10$ GeV, $p_T^{\gamma} > 15$ GeV, $|\eta| < 2.5$ (2.4 for the muons) and $m_{\ell\ell} > 50$ GeV, $100 < m_{\ell\ell\gamma} < 190$ GeV, $p_T^{\gamma}/m_{\ell\ell\gamma} > 15/110$ and $\Delta R(\ell,\gamma) > 0.4$, in order to reject events with final-state radiation. Finally, the sensitivity of the search is enhanced by 20-40% by dividing the selected events into mutually-exclusive classes, which are described in the Table 2.1. The dijet-tagged event class requires two forward jets and with large pseudorapidity separation, which are built by clustering the candidates with the anti-k_T clustering algorithm [10]. This class is chosen to enhance the Higgs bosons production via vector boson fusion.

2.2 Results

In order to extract the final results, the peaking signal is fitted with a sum of a Crystal-Ball and a Gaussian. Regarding the background, the data are fitted with a convolution between a Gaussian

Table 2: Definition of the four untagged event classes and the dijet-tagged event class, the fraction of selected events for a gluon-gluon produced signal with $m_H = 125$ GeV and data in a narrow region in the $m_{\ell\ell\gamma}$ phase space centred at 125 GeV.

	$e^+e^-\gamma$	$\mu^+\mu^-\gamma$
	Event class 1	
	Photon $0 < \|\eta\| < 1.44$ Both electrons $0 < \|\eta\| < 1.44$ $R_9 > 0.94$	Photon $0 < \|\eta! < 1.44$ Both muons $0 < \|\eta\| < 2.1$ and one muon $0 < \|\eta\| < 0.9$ $R_9 > 0.94$
Data	17%	20%
Signal	29%	33%
σ_{eff} (GeV)	1.9 GeV	1.6 GeV
FWHM (GeV)	4.5 GeV	3.7 GeV
	Event class 2	
	Photon $0 < \|\eta\| < 1.44$ Both electrons $0 < \|\eta\| < 1.44$ $R_9 < 0.94$	Photon $0 < \|\eta\| < 1.44$ Both muons $0 < \|\eta\| < 2.1$ and one muon $0 < \|\eta\| < 0.9$ $R_9 < 0.94$
Data	26%	31%
Signal	27%	30%
σ_{eff} (GeV)	2.1 GeV	1.9 GeV
FWHM (GeV)	5.0 GeV	4.6 GeV
	Event class 3	
	Photon $0 < \|\eta\| < 1.44$ At least one electron $1.44 < \|\eta\| < 2.5$ No requirement on R_9	Photon $0 < \|\eta\| < 1.44$ Both muons in $\|\eta\| > 0.9$ or one muon in $2.1 < \|\eta\| < 2.4$ No requirement on R_9
Data	26%	20%
Signal	23%	18%
σ_{eff} (GeV)	3.1 GeV	2.1 GeV
FWHM (GeV)	7.3 GeV	5.0 GeV
	Event class 4	
	Photon $1.57 < \|\eta\| < 2.5$ Both electrons $0 < \|\eta\| < 2.5$ No requirement on R_9	Photon $1.57 < \|\eta\| < 2.5$ Both muons $0 < \|\eta\| < 2.4$ No requirement on R_9
Data	31%	29%
Signal	19%	17%
σ_{eff} (GeV)	3.3 GeV	3.2 GeV
FWHM (GeV)	7.8 GeV	7.5 GeV
	Dijet tagged class	
	Photon $0 < \|\eta\| < 2.5$ Both electrons $0 < \|\eta\| < 2.5$ No requirement on R_9	Photon $0 < \|\eta\| < 2.5$ Both muons $0 < \|\eta\| < 2.4$ No requirement on R_9
Data	0.1%	0.2%
Signal	1.8%	1.7%
σ_{eff} (GeV)	2.6 GeV	2.2 GeV
FWHM (GeV)	4.4 GeV	3.8 GeV

and a polynomial, where the order is chosen so that the function gives the least bias to the signal yield. The spectrum shows no clear evidence of the H$\rightarrow$ Zγ decay, therefore an exclusion limit is performed. The expected exclusion limits at 95% CL are between 5 and 16 times the SM cross section and the observed limit ranges between about 4 and 25 times the SM cross section. The data background fit and the final 95% CL exclusion limits are shown in Figure 4.

3. Search for scalar resonances in the 200-500 GeV mass range decaying into a Z and a photon in pp collisions at $\sqrt{s} = 8$ TeV

The search for the SM Higgs boson decaying into a Z boson and a photon lacks the sensitivity to confirm or reject the SM Higgs hypothesis [7]. However, beyond the SM theoretical models exist that predict the existence of a pseudo-scalar boson A [12], in which the coupling to heavier

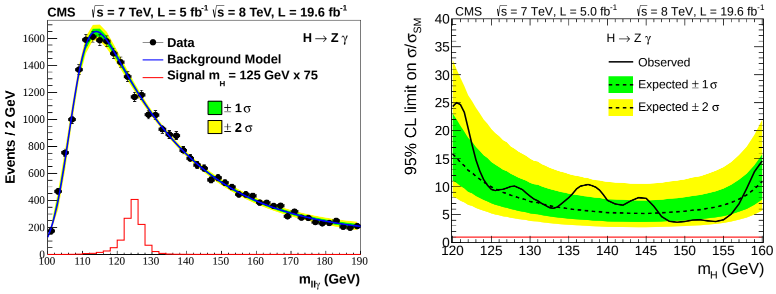

Figure 4: Left: The $m_{\ell\ell\gamma}$ spectrum in the electron and the muon channels for the 7 and 8 TeV data combined. Also shown the sum of the individual fits made to the data for each channel and event class. Right: The exclusion limit on the cross section times the branching fraction of a Higgs boson decaying into a Z boson and a photon divided by the SM value

bosons is more favourable for the Z and photon decay mode, i.e. branching fraction for A$\rightarrow Z\gamma$ is enhanced up to 500 times the SM value. The background components and the Z decay channels are similar to the SM analysis [7], Z$\rightarrow e^+e^-\gamma$ and Z$\rightarrow \mu^+\mu^-\gamma$. Broad and narrow width, from 1% to 5%, signals are tested.

3.1 Event selections

In this analysis the events reconstruction and identification is similar to those used for the SM analysis. Once the electrons, muons and photons are identified, they are required to also have: $p_T^{\ell 1} > 20$ GeV, $p_T^{\ell 2} > 10$ GeV, $p_T^{\gamma} > 15$ GeV, $|\eta| < 2.5$ (2.4 for the muons) and $m_{\ell\ell} > 50$ GeV, $m_{\ell\ell\gamma} > 150$ GeV, $p_T^{\gamma}/m_{\ell\ell\gamma} > 40/150$ and $\Delta R(\ell,\gamma) > 0.4$, in order to reject events with final-state radiation.

3.2 Results

The final results are extracted fitting the signal with a Crystal-Ball for the broad width case, and with the sum of a Crystal-Ball and a Gaussian for the narrow width. The background is fitted to the data with a function that minimize the bias to the signal yield, which is a sum of 3 exponential, as shown in Figure 5. No evidence of a new particle is present in the spectrum within the 200-500 GeV mass range. A cross section times branching fraction for broad (narrow) A$\rightarrow Z\gamma$ production of 0.4-1.4 fb (0.2-1.2 fb) is excluded at 95% CL, as shown in Figure 6.

4. Conclusions

The results of the diphoton search for high mass candidates, in addition with the SM and the non-SM H$\rightarrow Z\gamma$ searches are presented, using CMS data at $\sqrt{s} = 7$ and 8 TeV. During Run 1 no evidence of these phenomena has been found.

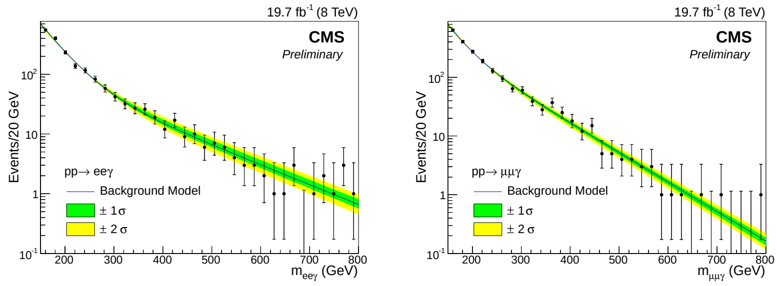

Figure 5: The $m_{\ell\ell\gamma}$ distribution from data, compared to the background model fit, for electron (left) and muon (right) channels. The statistical uncertainty bands shown are computed from a fit to data.

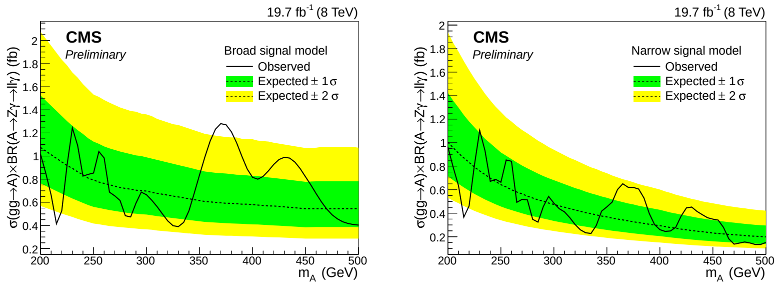

Figure 6: Exclusion limits at 95% confidence level on the cross section times branching ratio for A$\rightarrow Z\gamma\rightarrow\ell\ell\gamma$ for (left) the broad and (right) the narrow signal model.

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