

Search For $H \rightarrow Z\gamma$ and $H \rightarrow \gamma^*\gamma$ in CMS

Chiu-Ping Chang for the CMS collaboration

National Central University, Zhongli City, Taiwan

Abstract

The Higgs boson is an elementary particle predicted for why some fundamental particles have mass around 50 years ago to exist by the standard model of particle physics. In 2012 summer, a Higgs-like boson was discovered around 125 GeV [1]; its properties are still being studied to confirm whether it is the standard model Higgs boson or not. The production mechanism of $H \rightarrow Z\gamma$ and $H \rightarrow \gamma\gamma$ are the same. If the new boson which was found around 125 GeV is not the standard model Higgs boson, the channel of $H \rightarrow Z\gamma$ will be sensitive to new physics. CMS already looked into $H \rightarrow Z\gamma$ in di-electron and di-muon final state. A Higgs boson in the $H \rightarrow \gamma^*\gamma$ final-state, with the γ^* internal conversion into a muon pair, also known as Dalitz decays, at the LHC in the 120 to 150 GeV mass range is described. The search of $H \rightarrow Z\gamma$ and $H \rightarrow \gamma^*\gamma$ (the Dalitz decay) will be discussed.

1. Introduction

Within the SM, the partial width for the $H \rightarrow Z\gamma$ decay channel is rather small. A measurement of $H \rightarrow Z\gamma$ provides important information on the underlying dynamics of the Higgs sector just as for the $H \rightarrow \gamma\gamma$ decay channel.

The same diagram with the Z boson goes off-shell that $H \rightarrow \gamma^*\gamma$ final-state, with the γ^* internal conversion into a muon pair, also known as Dalitz decays would be described. In order to isolate the contribution from the Dalitz decay, the analysis is limited to the phase space $m_{\mu\mu} < 20$ GeV. The Feynman diagrams for $H \rightarrow Z\gamma$ ($\gamma^*\gamma$) are shown in Figure 1. Results are based on data samples recorded by the CMS experiment corresponding to integrated luminosities of 5.0 fb^{-1} at 7 TeV, and 19.6 fb^{-1} at 8 TeV in proton-proton collisions for $H \rightarrow Z\gamma$ and 19.7 fb^{-1} at 8 TeV for $H \rightarrow \gamma^*\gamma$.

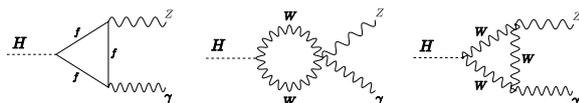


Figure 1: The photon and Z pole one-loop diagrams for $H \rightarrow Z\gamma$.

2. Event classes for $H \rightarrow Z\gamma$.

The sensitivity of the search is enhanced by 20 to 40% by dividing the selected events into mutually exclusive classes according to the expected mass resolution and the signal-to-background ratio, and then combining the results from each class as Table 1.

3. Background and signal modeling for $H \rightarrow Z\gamma$.

The dominant background is due to initial-state-radiation SM $Z\gamma$ production. The background model is obtained by fitting the observed distribution of three-body invariant mass ($m_{ll\gamma}$) with 4th order polynomial for both leptons and photon are in the barrel and with 5th order polynomial for at least one lepton and photon are in the endcap as shown in Figure 2, 3 and 4. Signal modeling is from simulated events obtained from the next-to-leading order (NLO) matrix-element generator POWHEG interfaced with PYTHIA.

4. Event selection for $H \rightarrow \gamma^*\gamma \rightarrow \mu\mu\gamma$

The observed yields at various steps of the basic event selection are listed in Table 2.

	$e^+e^- \gamma$	$\mu^+\mu^- \gamma$
	Event Class 1	
	Photon $0 < \eta < 1.44$ Both leptons $0 < \eta < 1.44$	Photon $0 < \eta < 1.44$ Both leptons $0 < \eta < 1.44$ and one lepton $0 < \eta < 1.44$
	$R_0 > 0.94$	$R_0 > 0.94$
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 leptons $0 < \eta < 1.44$	Photon $0 < \eta < 1.44$ Both leptons $0 < \eta < 1.44$ and one lepton $0 < \eta < 1.44$
	$R_0 < 0.94$	$R_0 < 0.94$
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 lepton $1.44 < \eta < 2.5$	Photon $0 < \eta < 1.44$ Both leptons in $ \eta > 0.9$ or one lepton in $2.1 < \eta < 2.4$
	No requirement on R_0	No requirement on R_0
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 leptons $0 < \eta < 2.5$ No requirement on R_0	Photon $1.57 < \eta < 2.5$ Both leptons $0 < \eta < 2.4$ No requirement on R_0
Data	31%	29%
Signal	19%	17%
σ_{eff} (GeV)	3.3 GeV	3.2 GeV
FWHM (GeV)	7.8 GeV	7.5 GeV
	VBF class	
	Photon $0 < \eta < 2.5$ Both leptons $0 < \eta < 2.5$ No requirement on R_0	Photon $0 < \eta < 2.5$ Both leptons $0 < \eta < 2.4$ No requirement on R_0
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

Table 1: Definition of the four untagged event classes and the dijet-tagged event class.

5. Background and signal modeling for $H \rightarrow \gamma^* \gamma \rightarrow \mu\mu\gamma$

The background model is obtained by fitting the observed $m_{\mu\mu\gamma}$ distribution, which is shown in Figure 5. The description of the Higgs boson signal used in the search is obtained from simulated events produced at leading-order using the Madgraph matrix-element generator interfaced with PYTHIA 6.4.

6. Results

The expected and observed 95% confidence level limits of $H \rightarrow Z\gamma$ are shown in Figure 6. The limits are calculated at 0.5 GeV intervals in the 120 to 160 GeV mass range. The expected exclusion limits at 95% confidence level 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 observed and expected limits for $m_{ll\gamma}$ at 125 GeV are within one order of magnitude of the SM prediction. The data excludes models predicting $\sigma(pp \rightarrow H) \times \beta(H \rightarrow Z\gamma)$ to be larger than

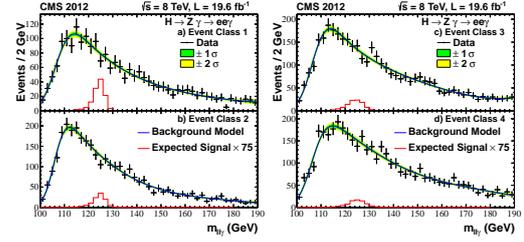


Figure 2: The background model fit to the $m_{ll\gamma}$ distributions for event classes 1 to 4 for $H \rightarrow Z\gamma \rightarrow ee\gamma$.

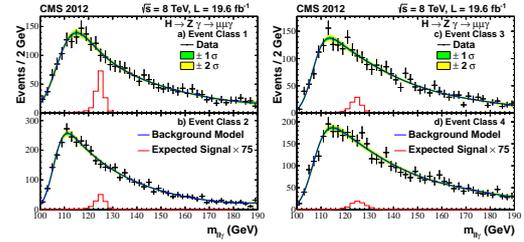


Figure 3: The background model fit to the $m_{ll\gamma}$ distributions for event classes 1 to 4 for $H \rightarrow Z\gamma \rightarrow \mu\mu\gamma$.

one order of magnitude of the SM prediction for most of the 125 to 157 GeV mass range. The expected and observed limits of $H \rightarrow \gamma^* \gamma$ are shown in Figure 7. The limits are calculated at 0.5 GeV intervals in the 120 to 150 GeV mass range. The expected exclusion limits at 95% confidence level are between 8 and 13 times the SM cross section and the observed limit ranges between about 4 and 19 times the SM cross section.

7. Summary

The search for a Higgs boson decaying into a Z boson and a photon has been performed a dataset from proton-proton collisions at a center-of-mass energy of 7 and 8

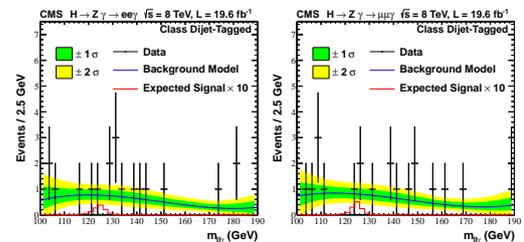


Figure 4: The background model fit to the $m_{ll\gamma}$ distributions for event classes 1 to 4 for the dijet-tagged event class.

Requirements	Observed event yield	Expected number of signal events for $m_H=125$ GeV
Trigger, photon selection, $P_T^\gamma > 25$ GeV	0.6M	6.2
Muon selection, $P_T^{\mu 1} > 23$ GeV, $P_T^{\mu 2} > 4$ GeV	55836	4.7
110 GeV $< m_{\mu\mu\gamma} < 170$ GeV	7800	4.7
$m_{\mu\mu} < 20$ GeV	1142	3.9
$\Delta R(\gamma, \mu) > 1$	1138	3.9
Removal of resonances	1020	3.7
$P_T^{\mu 1}/m_{\mu\mu\gamma} > 0.3$ and $P_T^{\mu 2}/m_{\mu\mu\gamma} > 0.3$	665	3.3
122 GeV $< m_{\mu\mu\gamma} < 128$ GeV	99	2.9

Table 2: Event yield in data, and for a 125 GeV SM Higgs boson signal, after application of successive selection requirements.

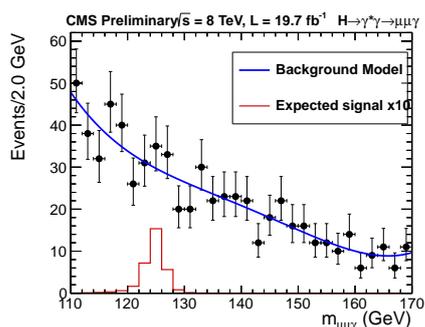


Figure 5: The $m_{\mu\mu\gamma}$ spectrum for 8 TeV data (points with error bars). Also shown is the simulated SM Higgs boson signal events, $m_H = 125$ GeV, (histogram), scaled by 10.

TeV, corresponding to an integrated luminosity of 5.0 and $19.6 fb^{-1}$, respectively. The observed and expected limits for $m_{l\gamma}$ of $H \rightarrow Z\gamma$ at 125 GeV are within one order of magnitude of the SM prediction. [2]

The first search for a Higgs boson decaying into a photon and a muon pair for $m_{\mu\mu} < 20$ GeV has been performed. The analysis used a dataset from proton-proton collisions at a center-of-mass energy of 8 TeV, corresponding to an integrated luminosity of $19.7 fb^{-1}$. The observed and expected limits for $m_{\mu\mu\gamma}$ of $H \rightarrow \gamma^*\gamma \rightarrow \mu\mu\gamma$ at 125 GeV and $m_{\mu\mu} < 20$ GeV are about ten times of the SM prediction. [3]

References

- [1] CMS collaboration, *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC*, Phys. Lett. B 716 (2012) 30-61.
- [2] CMS Collaboration, *Search for a Higgs boson decaying into a Z and a photon in pp collisions at 7 and 8 TeV*, Phys. Lett. B (2013).
- [3] CMS Collaboration, *Search for a Higgs boson decaying into $\gamma^*\gamma \rightarrow \mu\mu\gamma$ to $\mu\mu\gamma$ with dilepton mass below 20 GeV in pp collisions at 8 TeV*, CMS PAS-HIG-14-003.

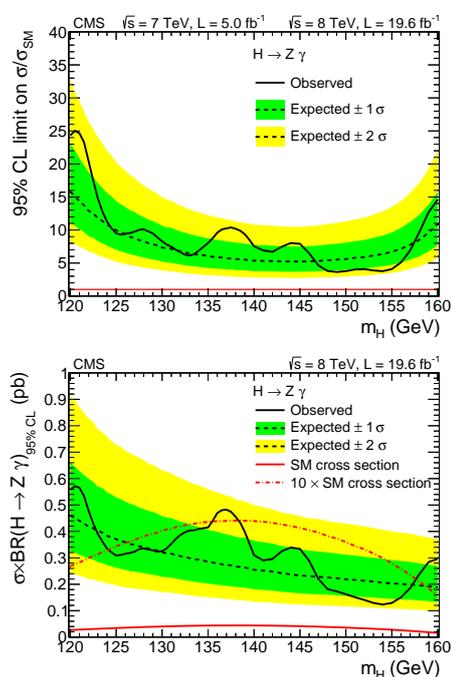


Figure 6: (a) The exclusion limit on the cross section times the branching fraction of $H \rightarrow Z\gamma$ divided by the SM value. (b) Exclusion limit on the inclusive cross section alone, where the theoretical uncertainties on the cross section have been excluded in the limit setting.

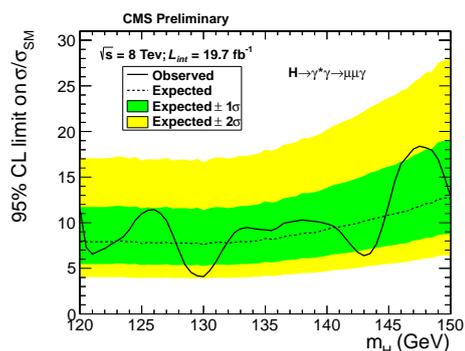


Figure 7: Exclusion limit on the cross section of a $H \rightarrow \gamma^*\gamma \rightarrow \mu\mu\gamma$ with $m_{\mu\mu} < 20$ GeV.