

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



Chiu-Ping Chang for CMS collaboration

Department of Physics, National Central University, Jhongli, 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 125GeV [1]; its properties are still being studied to confirm whether it is the SM 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 125GeV is not the SM 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. In this poster, the search of  $H \rightarrow Z\gamma$  and  $H \rightarrow \gamma^*\gamma$  (the Dalitz decay) will be presented.

## 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 goes off-shell that  $H \rightarrow \gamma^*\gamma$  final-state, with the  $\gamma^*$  internal conversion into a muon pair, also known as Dalitz decays would be described. The Feynman diagrams for  $H \rightarrow Z\gamma$  ( $\gamma^*\gamma$ ) are shown in Fig. 1. Results are based on data samples recorded by the CMS experiment corresponding to integrated luminosities of  $5.0 \text{ fb}^{-1}$  at 7 TeV, and  $19.6 \text{ fb}^{-1}$  at 8 TeV in proton-proton collisions for  $H \rightarrow Z\gamma$  and  $19.7 \text{ fb}^{-1}$  at 8 TeV for  $H \rightarrow \gamma^*\gamma$ .

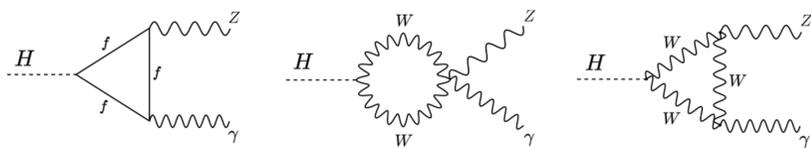


Figure 1: The photon and Z pole one-loop diagrams for  $H \rightarrow Z\gamma$ .

## Event selection for $H \rightarrow \gamma^*\gamma \rightarrow \mu\mu\gamma$

This table shows event yield in data, and for a 125 GeV SM Higgs boson signal, after application of successive selection requirements.

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

## 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. The fitting is unbinned and is performed over the 110–170 GeV mass range which is shown in Fig. 4.

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

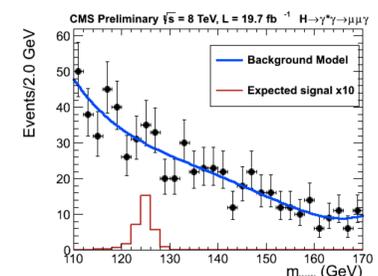


Figure 4: The  $m_{\mu\mu\gamma}$  spectrum for 8 TeV data (points with error bars). Also shown is the simulated SM Higgs boson signal events,  $m_H = 125 \text{ GeV}$ , (histogram), scaled by 10.

## Event classes for $H \rightarrow Z\gamma$

The sensitivity of the search is enhanced by 20–40% 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.

	$e^+e^-\gamma$	$\mu^+\mu^-\gamma$
	Event class 1	Event class 1
	Photon $0 <  \eta  < 1.44$ Both leptons $0 <  \eta  < 1.44$	Photon $0 <  \eta  < 1.44$ Both leptons $0 <  \eta  < 2.1$ and one lepton $0 <  \eta  < 0.9$
	$R_0 > 0.94$	$R_0 > 0.94$
Data	17%	20%
Signal	29%	33%
$\sigma_{\text{eff}}$ (GeV)	1.9 GeV	1.6 GeV
FWHM (GeV)	4.5 GeV	3.7 GeV
	Event class 2	Event class 2
	Photon $0 <  \eta  < 1.44$ Both leptons $0 <  \eta  < 1.44$	Photon $0 <  \eta  < 1.44$ Both leptons $0 <  \eta  < 2.1$ and one lepton $0 <  \eta  < 0.9$
	$R_0 < 0.94$	$R_0 < 0.94$
Data	26%	31%
Signal	27%	30%
$\sigma_{\text{eff}}$ (GeV)	2.1 GeV	1.9 GeV
FWHM (GeV)	5.0 GeV	4.6 GeV
	Event class 3	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%
$\sigma_{\text{eff}}$ (GeV)	3.1 GeV	2.1 GeV
FWHM (GeV)	7.3 GeV	5.0 GeV
	Event class 4	Event class 4
	Photon $1.57 <  \eta  < 2.5$ Both leptons $0 <  \eta  < 2.5$	Photon $1.57 <  \eta  < 2.5$ Both leptons $0 <  \eta  < 2.4$
	No requirement on $R_0$	No requirement on $R_0$
Data	31%	29%
Signal	19%	17%
$\sigma_{\text{eff}}$ (GeV)	3.3 GeV	3.2 GeV
FWHM (GeV)	7.8 GeV	7.5 GeV
	VBF class	VBF class
	Photon $0 <  \eta  < 2.5$ Both leptons $0 <  \eta  < 2.5$	Photon $0 <  \eta  < 2.5$ Both leptons $0 <  \eta  < 2.4$
	No requirement on $R_0$	No requirement on $R_0$
Data	0.1%	0.2%
Signal	1.8%	1.7%
$\sigma_{\text{eff}}$ (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.

## Background and signal modeling for $H \rightarrow Z\gamma$

The background model is obtained by fitting the observed distribution of  $m_{ll\gamma}$  with 4<sup>th</sup> order polynomial for both leptons and photon are in the barrel and with 5<sup>th</sup> order polynomial for at least one lepton and photon are in the endcap.

Signal modeling is from simulated events obtained from the next-to-leading order (NLO) matrix-element generator POWHEG interfaced with PYTHIA.

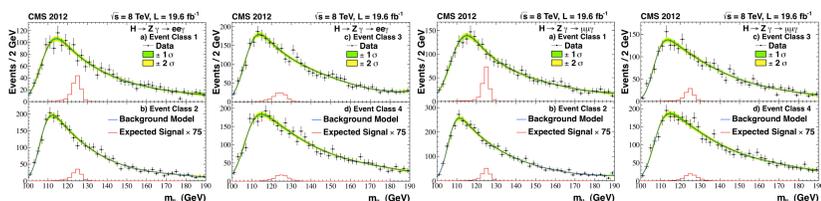
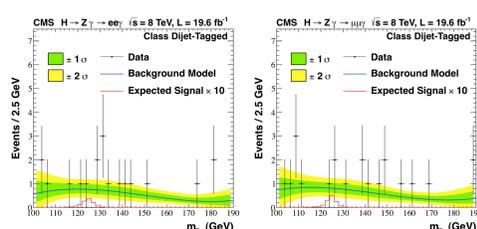


Figure 2: The background model fit to the  $m_{ll\gamma}$  distributions for event classes 1–4 for the two data samples.

Figure 3: The background model fit to the  $m_{ll\gamma}$  distributions for event classes 1–4 for the dijet-tagged event class.



## Results

The expected and observed limits of  $H \rightarrow Z\gamma$  are shown in Fig. 5. The limits are calculated at 0.5 GeV intervals in the 120–160 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 expected and observed limits of  $H \rightarrow \gamma^*\gamma$  are shown in Fig. 6. The limits are calculated at 0.5 GeV intervals in the 120–150 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.

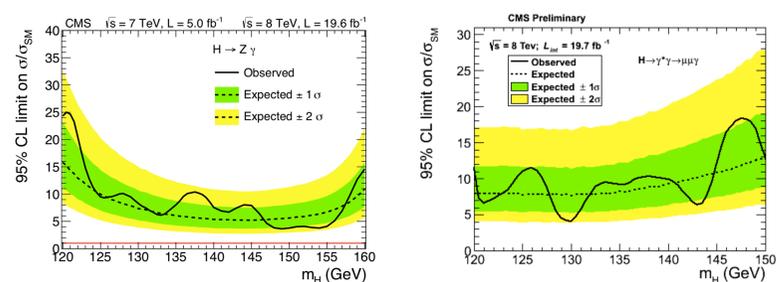


Figure 5 (left): The exclusion limit on the cross section of  $H \rightarrow Z\gamma$ . Figure 6 (right): Exclusion limit on the cross section of a  $H \rightarrow \gamma^*\gamma \rightarrow \mu^+\mu^-\gamma$  with  $m_{\mu\mu} < 20 \text{ GeV}$ .

## Summary

- The observed and expected limits for  $m_{ll\gamma}$  of  $H \rightarrow Z\gamma$  at 125 GeV are within one order of magnitude of the SM prediction. [2]
- The observed and expected limits for  $m_{\mu\mu\gamma}$  of  $H \rightarrow \gamma^*\gamma$  at 125 GeV and  $m_{\mu\mu} < 20 \text{ GeV}$  are about ten times of the SM prediction. [3]

## Reference

- [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  $\sqrt{s} = 7$  and 8 TeV", Phys. Lett. B (2013)
- [3] CMS Collaboration, "Search for a Higgs boson decaying into  $\gamma^*\gamma \rightarrow \mu\mu\gamma$  with dilepton mass below 20 GeV in pp collisions at  $\sqrt{s} = 8 \text{ TeV}$ , CMS PAS HIG-14-003