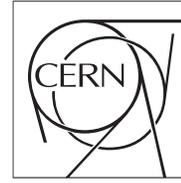


The Compact Muon Solenoid Experiment
Conference Report

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Differential measurement of signal strength of the Higgs boson in diphoton decay channel with the CMS detector

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Abstract

CMS and ATLAS collaborations have observed a Higgs-like boson at around 125 GeV. Differential measurements of signal strength(μ) of the Higgs-like boson in diphoton decay channel is reported here. The analysis uses the entire dataset collected by the CMS experiment during the years 2011 and 2012. The dataset corresponds to integrated luminosities of 5.1 fb^{-1} at $\sqrt{s} = 7 \text{ TeV}$ and 19.7 fb^{-1} at $\sqrt{s} = 8 \text{ TeV}$. Spin hypothesis tests have been performed comparing the standard model Higgs boson with a spin-2 graviton-like model with minimal couplings. The hypothesis of the signal being 2_m^+ is disfavoured.

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CMS and ATLAS collaborations have observed a Higgs-like boson at around 125 GeV. Differential measurements of signal strength(μ) of the Higgs-like boson in diphoton decay channel is reported here. The analysis uses the entire dataset collected by the CMS experiment during the years 2011 and 2012. The dataset corresponds to integrated luminosities of 5.1 fb^{-1} at $\sqrt{s} = 7 \text{ TeV}$ and 19.7 fb^{-1} at $\sqrt{s} = 8 \text{ TeV}$. Spin hypothesis tests have been performed comparing the standard model Higgs boson with a spin-2 graviton-like model with minimal couplings. The hypothesis of the signal being 2_m^+ is disfavoured.

Keywords: Higgs, Diphoton, CMS

1. Introduction

A Higgs boson [1] has been observed at around $M_H = 125 \text{ GeV}$ by both general purpose experiments, ATLAS and CMS, at LHC [3, 4]. After this observation it has become very important to measure the properties of the state to determine if they are compatible with predictions from the standard model(SM).

2. Data Samples

The data sample corresponds to integrated luminosities of 5.1 fb^{-1} at 7 TeV and 19.6 fb^{-1} at 8 TeV. Events were collected with diphoton triggers with asymmetric transverse energy thresholds and complementary photon selection criteria. One selection requires a loose calorimetric identification based on the electromagnetic shower-shape and loose isolation requirements on the photon candidates, while the other requires only that the photon candidate has a high value of the R9 shower-shape variable. The R9 variable is defined as the energy sum of 3×3 crystals centred on the most energetic crystal in the supercluster divided by the energy of the supercluster. The MC signal event samples for the gluon-

fusion and VBF processes are obtained using the next-to-leading order matrix-element generator POWHEG (version 1.0) [6] interfaced with PYTHIA [2]. The VH and ttH processes are generated at leading-order with PYTHIA, and higher order diagrams are accounted for only by PYTHIA's parton shower model. For the spin-2 graviton-like processes (gg, $q\bar{q}$) the simulation uses the JHUGEN [9] generator at leading-order, interfaced with PYTHIA. The Monte Carlo simulation of detector response employs a detailed description of the CMS detector, and uses GEANT4 [5].

3. Photon reconstruction and identification

Photon candidates are reconstructed from the energy depositions in the electromagnetic calorimeter(ECAL), grouping its channels into a supercluster. The clustering algorithms achieve a rather complete (95%) collection of the energy of photons and electrons, including those that undergo conversion and bremsstrahlung in the material in front of the ECAL. The photon candidates are required to be within the fiducial region $|\eta| < 2.5$, excluding the transition region between barrel and endcap $1.44 < |\eta| < 1.57$, where the photon reconstruction is

suboptimal. The photons entering the analysis are required to pass the following preselection requirements :

- $p_T^{\gamma 1} > 33$ GeV and $p_T^{\gamma 2} > 25$ GeV, where $p_T^{\gamma 1}$ and $p_T^{\gamma 2}$ are the transverse momenta of the leading and subleading photons, respectively.
- a selection on the hadronic leakage of the shower, measured as the ratio of energy in HCAL cells behind the ECAL supercluster to the energy deposited in the ECAL supercluster.
- a loose selection based on isolation and the electromagnetic shower-shape.
- an electron veto, which removes the photon candidate if its supercluster is matched to an electron track with no missing hits in the innermost tracker layers.

Photon identification is performed by dividing the photons into four mutually exclusive categories depending on whether the photon is in the barrel or endcap, and on whether or not it has $R_9 > 0.94$. The four event classes are :

- Both photons are in the barrel and have $R_9 > 0.94$
- Both photons are in the barrel and at least one of them fails the requirement of $R_9 > 0.94$
- At least one photon is in the endcap and both photons have $R_9 > 0.94$
- At least one photon is in the endcap and at least one of them fails the requirement $R_9 > 0.94$

The identification selection requirements are, in general, different for different categories.

4. Diphoton Vertex identification

The mean number of pp interactions per bunch crossing is 9 in the 7 TeV dataset and 21 in the 8 TeV dataset. The diphoton mass resolution is driven by photon energy resolution and photon angular resolution, which is dominated by the knowledge of the vertex from which the photons originate. Since photons are electrically neutral particles, and therefore do not leave an ionization signal in the tracker, the diphoton vertex is identified indirectly. The vertex has been identified using the kinematic properties of the diphoton system and their

correlations with the kinematic properties of the recoiling tracks. If either of the photons converts, the direction of the converted photon tracks and the conversion position can be used to identify the diphoton interaction vertex. Details of diphoton vertex identification can be found in Ref. [4].

5. Testing spin hypothesis

The Landau-Yang theorem [7, 8] forbids the direct decay of a spin-1 particle into a pair of photons. However, it is important to compare the hypothesis of a spin-2 graviton-like model with minimal couplings [9], 2_m^+ , to that of a spin-0 SM-Higgs-boson-like, 0^+ , model. As the 2_m^+ is just one of many possible realizations of the spin-2 tensor structure, an attempt has been made to make the analysis as model independent as possible. Tests have been performed for hypotheses in which the 2_m^+ resonance is produced

- entirely by gluon-fusion(gg)
- entirely by quark-antiquark annihilation ($q\bar{q}$),
- by a mixture of the two processes.

The cosine of the scattering angle in the Collins-Soper frame [10], $\cos\theta_{CS}^*$, is used to discriminate between the two hypotheses. The angle is defined, in the diphoton rest frame, as the angle between the collinear photons and the line that bisects the acute angle between the colliding protons :

$$\cos\theta_{CS}^* = 2 \times \frac{E^{\gamma 2} p_z^{\gamma 1} - E^{\gamma 1} p_z^{\gamma 2}}{m_{\gamma\gamma} \sqrt{m_{\gamma\gamma}^2 + (p_T^{\gamma\gamma})^2}} \quad (1)$$

where $E^{\gamma 1}$ and $E^{\gamma 2}$ are the energies of the leading and subleading photons, $p_z^{\gamma 1}$ and $p_z^{\gamma 2}$ are the z components of their momenta. $m_{\gamma\gamma}$ and $p_T^{\gamma\gamma}$ are the invariant mass and transverse momentum of the diphoton system.

To increase the sensitivity, the events are categorized by using the four diphoton event classes described before.

Within each diphoton class, the events are binned in $|\cos\theta_{CS}^*|$ to discriminate between the different spin hypotheses. The events are thus split into four (η, R_9) diphoton classes with five $|\cos\theta_{CS}^*|$ bins each, for both the 7 and 8 TeV datasets, giving a total of 40 event classes.

Figure 1 shows expected signal strength, μ , relative to the SM expectation in the five bins of $|\cos\theta_{CS}^*|$ for the SM, and for two 2_m^+ models : where the 2_m^+ resonance is produced entirely by gluon-fusion (gg), and where it is produced entirely by quark-antiquark annihilation ($q\bar{q}$).

The separation between the two models is extracted using a test statistic(q) defined as twice the negative logarithm of the ratio of the likelihoods for the 0^+ signal plus background hypothesis and the 2^+ signal plus background hypothesis when performing a simultaneous fit of all forty event classes together : $q = -2\ln(\mathcal{L}_{2_m^+ + bkg} / \mathcal{L}_{0^+ + bkg})$. The test is built under the assumption that the 2_m^+ state is produced entirely by either gluon-fusion, or entirely by quark-antiquark annihilation, or by three intermediate mixtures of gg and $q\bar{q}$ spin-2 production. The fraction of the spin-2 state produced by $q\bar{q}$ annihilation is parameterized by the variable $f_{q\bar{q}}$, so that the total signal plus background, $f(m_H)$, is given by :

$$f(m_H) = \mu[(1 - f_{q\bar{q}}) \times S_{gg}^{2_m^+}(m_H) + f_{q\bar{q}} \times S_{q\bar{q}}^{2_m^+}(m_H)] + B(m_H)$$

where $S_{gg}^{2_m^+}(m_H)$ is the gg -produced 2_m^+ signal, $S_{q\bar{q}}^{2_m^+}(m_H)$ the $q\bar{q}$ -produced 2_m^+ signal, μ is a signal strength modifier, and $B(m_H)$ is the background. Figure 2 shows the values of the test statistic as a function of $f_{q\bar{q}}$.

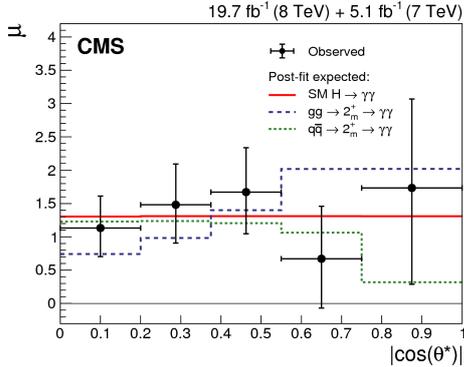


Figure 1: Signal strength in five bins of $|\cos\theta_{CS}^*|$ expected for SM, for 2_m^+ produced by gg and for 2_m^+ produced by $q\bar{q}$. The signal strength observed in the data is shown by the black points.

When produced entirely by gluon fusion, the spin-2 model is disfavoured with a CLs value of 94% (92% expected). When produced entirely by $q\bar{q}$ annihilation it is disfavoured with a CLs value of 85% (83% expected). Intermediate mixtures are less disfavoured because of less sensitivity to distinguish between the models.

6. Summary

We report the measurement of some of the properties of the recently discovered Higgs boson. The analysis uses the entire dataset collected by the CMS experiment

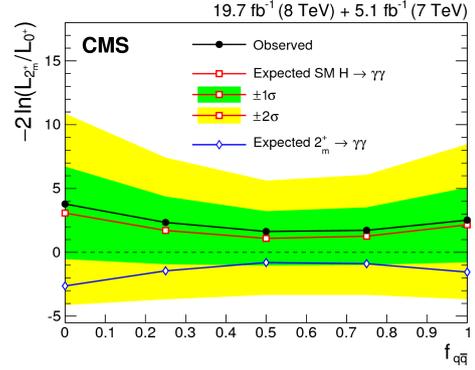


Figure 2: The test statistic for pseudo-experiments generated under the SM(0^+) hypothesis (open squares) and the graviton-like (2_m^+) hypothesis (open diamonds), as a function of the fraction $f_{q\bar{q}}$ of $q\bar{q}$ production. The observed distribution in the data is shown by the black points.

in pp collisions during the 2011 and 2012 LHC running periods. The SM spin-0 hypothesis for the observed state is compared to a graviton-like spin-2 hypothesis with minimal couplings. The hypothesis of the signal being 2_m^+ is disfavoured by data.

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