



The Compact Muon Solenoid Experiment
Conference Report

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08 May 2013 (v3, 13 May 2013)

CMS Measurements of a New Boson in the Gamma Gamma Channel

Chris Palmer for the CMS Collaboration

Abstract

CMS reports on the recently updated, preliminary results with the full datasets of 2011 and 2012 in the analysis of the Higgs-like Boson at 125 GeV. Utilizing $5.1 fb^{-1}$ of 7 TeV data and $19.6 fb^{-1}$ of 8 TeV data, a signal strength of $0.78^{+0.28}_{-0.26}$ times the Standard Model (SM) expectations with a mass of 125.4 ± 0.8 GeV is observed. The significance of this resonance with respect to the background only prediction is 3.2σ . The cut-based cross-check analysis observes signal strength of $1.11^{+0.32}_{-0.30}$ times the Standard Model (SM) with a significance of 3.9σ at 124.5 GeV.

Presented at *LISHEP2013 Workshop on High Energy Physics in the Near Future*

CMS Measurements of the Higgs-like Boson In the Two Photon Decay Channel

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(Dated: May 13, 2013)

CMS reports on the recently updated, preliminary results with the full datasets of 2011 and 2012 in the analysis of the Higgs-like Boson at 125 GeV. Utilizing $5.1fb^{-1}$ of 7 TeV data and $19.6fb^{-1}$ of 8 TeV data, a signal strength of $0.78_{-0.26}^{+0.28}$ times the Standard Model (SM) expectations with a mass of 125.4 ± 0.8 GeV is observed. The significance of this resonance with respect to the background only prediction is 3.2σ . The cut-based cross-check analysis observes signal strength of $1.11_{-0.30}^{+0.32}$ times the SM expectations with a significance of 3.9σ at 124.5 GeV.

I. ANALYSIS MOTIVATION

On the fourth of July, 2012, the discovery of a new particle was announced [1]. A previously unobserved particle was discovered in two channels near 125 GeV, while searching for this Higgs boson, a particle central to the SM[2–5]. One of the channels in which this particle is observed is in a two photon resonance. CMS has improved, expanded, and updated the analysis of the two photon channel, which is one of the two channels in which the discovery was made. This update contains CMS’s first preliminary results on the entire datasets from 2011 and 2012.

II. ANALYSIS DESCRIPTION

The decay signature sought in this analysis is a small, narrow resonance on top of a large, monotonically decreasing background. This analysis has two basic features: background estimates from fits to the data and, categorization of data and monte carlo signal.

Since the data is dominated by background, it is possible to fit 3rd to 5th order polynomials to the data for background estimates. A thorough bias study was performed to ensure that potential bias, calculated using numerous, varied underlying shape assumptions, would be less than 20% of the uncertainty from the polynomial fits.

The other general feature of the analysis is categorization of events. Events with different S/\sqrt{B} and resolution are best used when used with similar events. In order to optimally categorize a Boost Decision Tree (BDT) is used. The BDT takes several inputs and gives a single output, which is used to categorize events.

In addition, there are several final state signatures which are indicative of the production mechanism of the boson. These events feature extra high transverse momentum objects which can be tagged. An additional category, which has higher than normal S/\sqrt{B} , is created for each tagged class.

A. Vertex Selection and Vertex Probability

On average, events from the 2012 dataset contain 20 interactions. The challenge for this analysis is to determine the vertex accurately in order to improve the mass resolution of the reconstructed di-photon. Since there are no tracks associated to photons, except in the case of reconstructed conversions, obtaining the correct vertex is not straightforward, particularly for di-photons with low transverse momentum.

A BDT takes information from conversions, recoil between vertices’ tracks and the di-photon system, and the sum of vertices’ track transverse momentum to sort the reconstructed vertices. The one with the highest score is selected to be used in the mass calculation.

A second BDT is trained after selecting the vertex to determine the probability of having chosen the vertex correctly. This BDT uses information from the chosen vertex, as well as the second and third ranked vertices to determine a probability of accurate selection. This probability is measured from efficiency in simulation and is fully validated using Z boson events decaying to two muons where the muon tracks have been removed.

B. Photon Identification MVA (Multi-Variate Analysis)

Distinguishing real photons from fake reconstructed photons, which are mainly jets, is a very important aspect of this analysis. There are two main types of variables which are used for this purpose: shower topology and isolation. There are numerous shower topology variables, in which the profile of fake photons differs that of real photons. Isolation variables are powerful because real photons typically do not have very many particles in the immediate vicinity of the main energy deposit of the photon.

These variables, along with a variable correlated with number of simultaneously recorded interactions and the detector location of the photons, are given as input to a BDT. The output, referred to as Photon ID MVA, is validated and shape-corrected using Z boson decay to 2

electrons where the electrons are treated as photons. In figure the distributions of the Photon ID MVA for data and monte carlo for Z boson events are shown.

C. Di-Photon MVA

This BDT, referred to as Di-Photon MVA, takes several inputs: di-photon kinematics, per event resolution estimates for right and wrong vertex assumptions, the vertex probability, the Photon ID MVA scores of both selected photons, and the detector location of the photons. The Di-Photon MVA is used to categorize events into four optimized bins.

The Di-Photon MVA is validated using Z boson to two electron events where the electrons are treated like photons. In figure 1 the Di-Photon MVA is shown for the Drell-Yan samples in data and in simulation. Agreement within systematic error is shown.

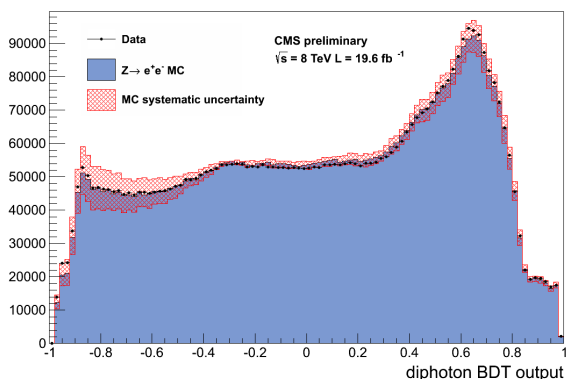


FIG. 1. Comparison of the diphoton MVA output for $Z \rightarrow ee$ events in data and Monte Carlo where the electrons are reconstructed as photons, for events passing the pre-selection of the mass-fit MVA analysis (with the electron veto condition inverted). Corrections have been applied to the MVA inputs for MC.

D. Exclusive Channels

The dominant production mechanism of SM higgs is gluon fusion. However, The SM production of higgs via Vector Boson Fusion (VBF) and Higgsstrahlung (VH) is non-negligible. Higgs produced via these mechanisms contain high transverse momentum objects, which can be tagged. In this analysis several tagged categories have been made to utilize these additional objects.

The di-jet tags and the most powerful is of these tags, which are intended to tag the two forward jets from VBF production. A BDT is used to categorize the events with two jets and there are two categories. This BDT uses mostly jet kinematics, some di-jet plus di-photon kinematics and some photon kinematics. These two cate-

gories account for nearly 20% of the sensitivity of the analysis.

In addition to the di-jet tagged categories, there are three other categories, which intend to tag the leptonic decays of vector bosons, which produce higgs via associated production (Higgsstrahlung). The three tags of muons, electrons and MET greatly reduce the uncertainty of the measured coupling of the higgs to the vector bosons.

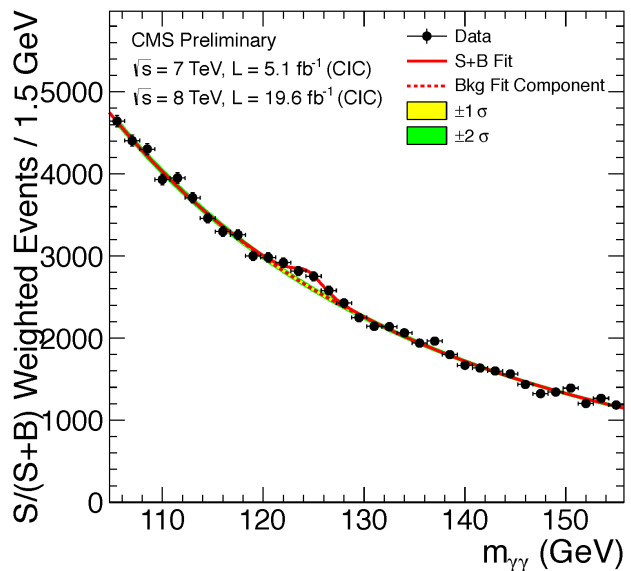
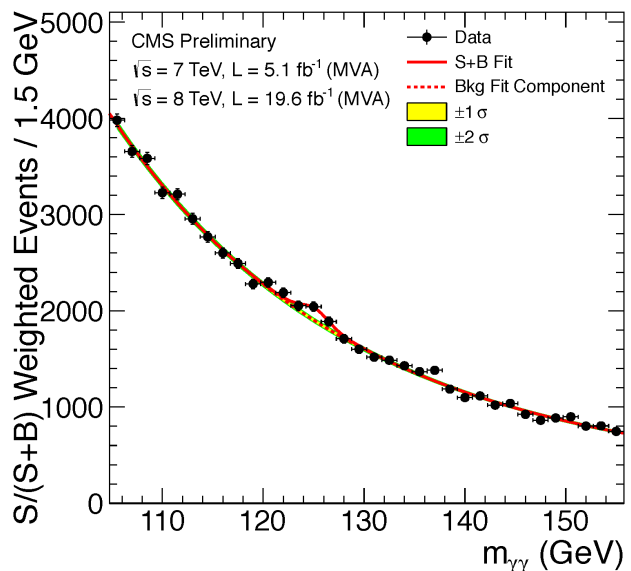


FIG. 2. The data and background plus signal fits for the categories in the main (above) and cut-based (below) analyses have weighted by $S/(S+B)$ and summed. The normalization is such that the signal yield is same as the best fit.

E. Cut-based Analysis

In addition to the full analysis outlined already, a simple, robust, cut-based analysis is performed in parallel. It utilizes the main features of the main analysis, which are categorization and polynomial background fits to the data, but it uses cut-based photon selection and categorization based on the detector location of the photons and their shower shapes.

There are analogous exclusive tags in the cut-based analysis. The di-jet tag categories use a cut-based approach with the same inputs as the di-jet MVA in the main analysis. The muon, electron, and MET tags are nearly identical except for the cut-based selection of the photons.

F. 2011 Data Analysis

The 2011 dataset is analyzed separately and is identical to that in the discovery paper [1]. For the untagged categories, the same strategy is used with a BDT trained on 7 TeV monte carlo. The only exclusive channel is a single, cut-based, di-jet tag. The cut-based analysis also uses an analogous strategy and uses the same cut-based, di-jet tag as the MVA analysis.

III. RESULTS - 2011 AND 2012 DATA

The $S/(S+B)$ weighted distributions of data in the MVA and cut-based analyses are shown in figure 2. The expected and observed significance is in figure 3 for the two analyses. At 125 GeV, the expected significance is 4.2σ and the observed is 3.2σ in the main analysis. At 124.5 GeV, the expected significance is 3.5σ and the observed is 3.9σ in the cut-based analysis.

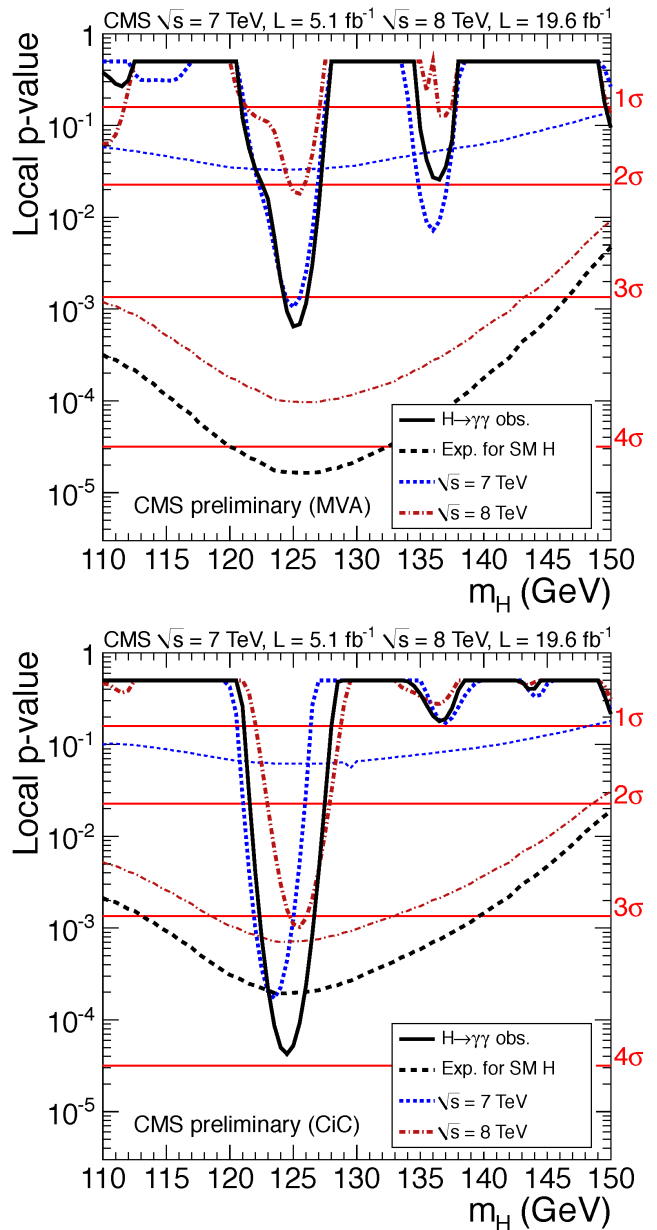


FIG. 3. Observed local p-values as a function of m_H obtained with the mass fit MVA analysis for the 7 and 8 TeV datasets. The main analysis is above and the cut-based is below.

In figure 4 is the channel compatibility of each of the categories and the combination is in green. In the 2011 data one can see the large excess in untagged 0 and di-jet tag. In the 2012 data a large excess is visible in untagged 0 as well.

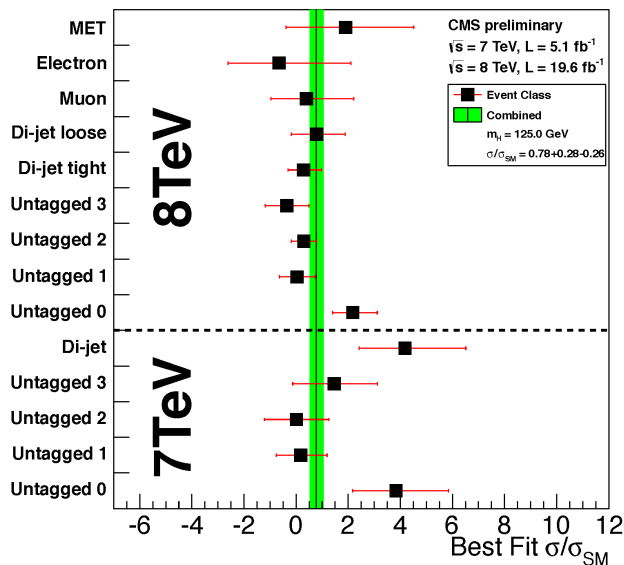


FIG. 4. The best fit signal strength, (σ/σ_{SM}) , obtained in the mass-fit-MVA analysis for the combined fit to the five classes used for the 7 TeV data set and the nine classes used for the 8 TeV data set (vertical line) and for the individual contributing classes (points) for the hypothesis of a SM Higgs boson mass of 125.0 GeV.

An important property of the observed boson is its mass. In this decay channel there is very good mass resolution. The two main systematics that limit this measurement are the differences between electrons and photons, and the uncertainty in energy scale which is extrapolated from the mass of the Z boson to the mass of the observation. The combined systematic from these two has been estimated to be 0.47%. The mass of the higgs-like particle has been measured to be $125.4 \pm 0.5(stat.) \pm 0.6(syst.)$ GeV and the measurement is shown in figure 5.

Finally, a two dimensional scan of the signal strength was performed. One dimension is the signal strength of gluon fusion production plus $t\bar{t}H$ production, and the other is the VBF plus VH production. In figure 6 the scan shows best fit values of $(\mu_{ggH+t\bar{t}H} = 0.52, \mu_{VBF+VH} = 1.48)$ with the SM prediction being $(\mu_{ggH+t\bar{t}H} = 1.0, \mu_{VBF+VH} = 1.0)$ which is within 1σ of the best fit. Thus, the observed boson is compatible with a SM higgs boson.

IV. CONCLUSIONS

The results of the search for a Standard Model Higgs Boson decaying into two photons have been updated using data obtained from $5.1fb^{-1}$ and $19.6fb^{-1}$ of pp collisions at $\sqrt{s} = 7\text{TeV}$ and at $\sqrt{s} = 8\text{TeV}$, respectively. The selected events have been subdivided into classes according to indicators of mass resolution and predicted signal-to-background ratio, and the results of a search in

each class have been combined.

An excess of events above the expected SM background has been observed for a Higgs boson mass hypothesis of 125 GeV, where the expected limit is 0.48 times the SM expectation. The local significance of this excess is 3.2σ . This result constitutes further evidence for the existence of a new massive state that decays into two photons. The mass of the observed boson is measured to be $125.4 \pm 0.5(stat.) \pm 0.6(syst.)$ GeV. For a Higgs boson mass hypothesis of 125.0 GeV, the best fit signal strength is $0.78^{+0.28}_{-0.26}$ times the SM Higgs boson cross-section.

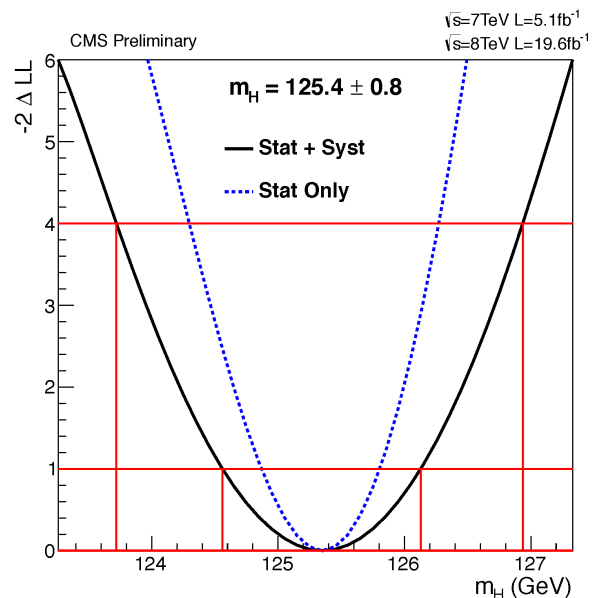


FIG. 5. The 1D test statistic $2 \ln Q$ vs Higgs boson mass hypothesis, m_H . The solid line is obtained with all nuisance parameters profiled and so includes both statistical and systematic uncertainties. The dashed line is obtained with all nuisance parameters fixed to their best-fit values and thus includes only statistical uncertainties. The crossings with the thick (thin) horizontal lines define the 68% (95%) CL interval for the measured mass. To reduce model-dependency, two production cross-section scaling factors $(\mu_{ggH+t\bar{t}H}$ and $\mu_{VBF+VH})$ are introduced as nuisance parameters and profiled in this measurement.

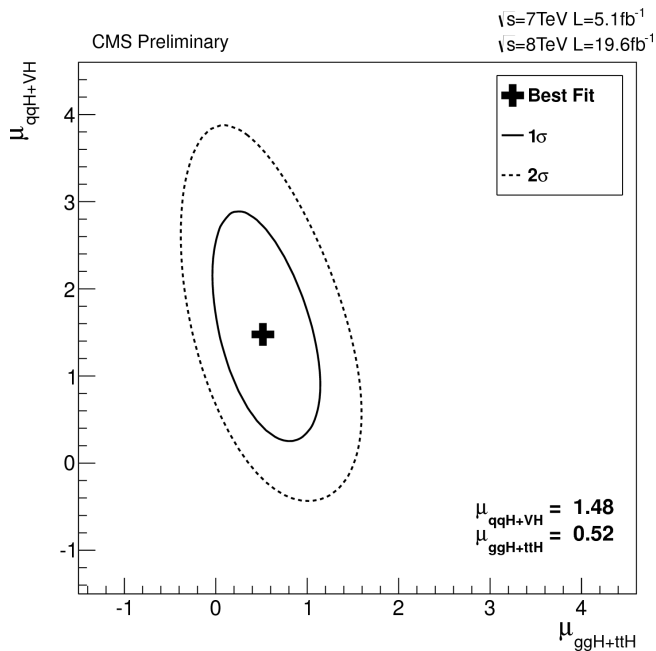


FIG. 6. The 68% CL (solid line) and 95% CL (dashed line) intervals for signal strength in the gluon-gluon-fusion-plus- ttH and in VBF-plus-VH production mechanisms: μ_{gg+ttH} and μ_{VBF+VH} , respectively.

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- [1] CMS Collaboration, CMS-PAS-HIG-12-020 *Observation of a new boson with a mass near 125 GeV*, CERN, 2012.
- [2] S. Weinberg, “A Model of Leptons”, *Phys. Rev. Lett.* **19** (1967) 1264.
- [3] A. Salam, “Elementary Particle Theory”, p. 367. Almquist and Wiksells, Stockholm, 1968.
- [4] F. Englert and R. Brout, “Broken symmetries and the masses of gauge bosons”, *Phys. Rev. Lett.* **13** (1964) 321.
- [5] P. W. Higgs, “Broken symmetry and the mass of gauge vector mesons”, *Phys. Rev. Lett.* **13** (1964) 508.
- [6] CMS Collaboration, *Updated Measurements of the Higgs-like Boson at 125 GeV in the Two Photon Decay Channel* CMS-PAS-HIG-13-001 (2013).