Search for the Higgs boson decaying to two photons in CMS

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A search for Higgs bosons has been carried out in the Higgs to two photons decay channel with the CMS detector at the Large Hadron Collider. The analysis is based on proton-proton collision data collected in 2011-2012 at centre of mass energies of 7 and 8 TeV corresponding to integrated luminosities of 5.1 fb^{-1} and 19.7 fb^{-1}, respectively. The analysis strategy and measurements of the mass, couplings, and spin-parity are reported.

1 Introduction

In 2012, the ATLAS and CMS collaborations observed a new particle compatible with the Higgs boson postulated by the standard model (SM) [1, 2]. Here, the search through its decay to two photons is presented. Results based on the full CMS Run I dataset collected in 2011-2012 at centre of mass energies of 7 and 8 TeV are reported [3].

2 Analysis strategy

Despite the small branching ratio (0.23% for $m_{\mathrm{H}} = 125$ GeV), the $H \to \gamma\gamma$ decay channel is characterized by a clean experimental signature, with two high transverse momentum isolated photons, which allow high precision for mass reconstruction. Photon candidates are reconstructed starting from energy deposits in the CMS electromagnetic calorimeter (ECAL). The ECAL single channel response is monitored and corrected for crystal transparency losses and is equalized between the different channels exploiting the $\phi-$simmetry of the energy flow, $\pi^0 \to \gamma\gamma$, $W \to e\nu$ and $Z \to ee$ decays [4]. Higher level corrections for shower containment, material and pileup effects are implemented through a multivariate regression, which provides also an estimate of the per photon energy resolution. Residual corrections, estimated from data to Monte Carlo (MC) comparisons in $Z \to ee$ events, are applied to correct the photon energy scale in data and to match the resolution of simulated events to the one observed in data.

A boosted decision tree (BDT), employing shower shapes and isolation variables, is used to discriminate prompt photons from jets misidentified as photons.

The di-photon vertex assignment is based on a multivariate approach with the transverse momenta of the tracks associated to the vertex, their correlation with the di-photon kinematics and the information from conversions as inputs. A further BDT is trained to estimate the per event probability to assign the correct vertex (∼80% for an average pileup of about 20 interactions per bunch crossing).

To achieve the maximum sensitivity, events are splitted in categories exploiting their different mass resolution and signal-over-background ratio. The event information, including the kinematics, photon quality, mass resolution and probability to assign the correct vertex, is combined in a multivariate classifier (referred to as di-photon BDT), which is built in such a way to be mass independent and to have high values for events with good di-photon mass resolution and high probability of being signal rather than background. The output of the di-photon BDT is used to define untagged event classes. The boundary of the untagged categories are chosen to minimize the expected uncertainty on the signal strength measurement. In addition, categories tagged by the presence of additional objects in the final state are defined to target specific production modes: Higgs boson events produced via Vector Boson Fusion (VBF) have two jets with large rapidity gap; events from the associated VH (V = W, Z) production are tagged by the presence of one or more charged leptons, large missing transverse energy, or jets from the decay of the W or Z boson; and those from $\mathrm{t\bar{t}H}$ production are characterized by the presence of b-jets and additional leptons or jets from the top decay. In total, 25 mutually exclusive event classes are defined: 14 in the 8 TeV dataset and 11 in the 7 TeV dataset.

For each event category, a signal and a background model are built. The signal model is obtained from a parametric fit of the simulated invariant mass of the two photons after having applied all the corrections derived from data to MC comparisons in $Z \to ee$ and $Z \to \mu\mu\gamma$ events. The background model is fitted from data. A smoothly falling background is expected, but the shape is *a priori* unknown. A discrete profiling method in which the choice of the function is included as discrete nuisance parameter in the likelihood to extract results is used. All reasonable families of functions are considered (exponentials, power laws, polynomials, Laurent series) and data are allowed to select the one which fits the best. The uncertainty resulting from the envelope around the negative log-likelihood curve of all the different functions takes therefore into account the model assumption.

3 Results

The inclusive di-photon invariant mass spectrum for all the selected events in the 7 and 8 TeV datasets is shown in Fig. 1-left. An excess of events is observed at a mass of 124.7 GeV with a significance of 5.7σ (Fig. 1-right). The corresponding measured signal strenght μ relative to the standard model expectation is $\mu = 1.14^{+0.26}_{-0.23} = 1.14 \pm 0.21(\mathrm{stat.})\ ^{+0.09}_{-0.05}(\mathrm{syst.})\ ^{+0.13}_{-0.09}(\mathrm{theo.})$. The main sources of systematic uncertainties on the signal yield are the theoretical uncertainty on the production cross section and branching ratio, the shower shape modeling and the energy scale and resolution uncertainties.

The mass of the observed boson is determined via a 1-dimensional likelihood scan (Fig. 2-left) in which the relative signal strengths for couplings to fermions and bosons are floated to make the measurement less model dependent. The measured mass is $m_\mathrm{H} = 124.70 \pm 0.31$ (stat.) $\pm$ 0.15 (syst.) GeV, where the main systematic uncertainties are due to the non-linearity in the extrapolation from the m_Z scale to the m_H scale and to imperfections in the modeling of the differences between electrons and photons in the MC simulation.

The measured signal strengths when considering different production modes separately are $\mu_{\mathrm{ggH,t\bar{t}H}} = 1.13^{+0.37}_{-0.31}$ and $\mu_{\mathrm{VBF,VH}} = 1.16^{+0.63}_{-0.58}$ (Fig. 2-right).

A test of the SM 0^+ hypothesis against a spin-2 graviton-like model with mininimal cou-

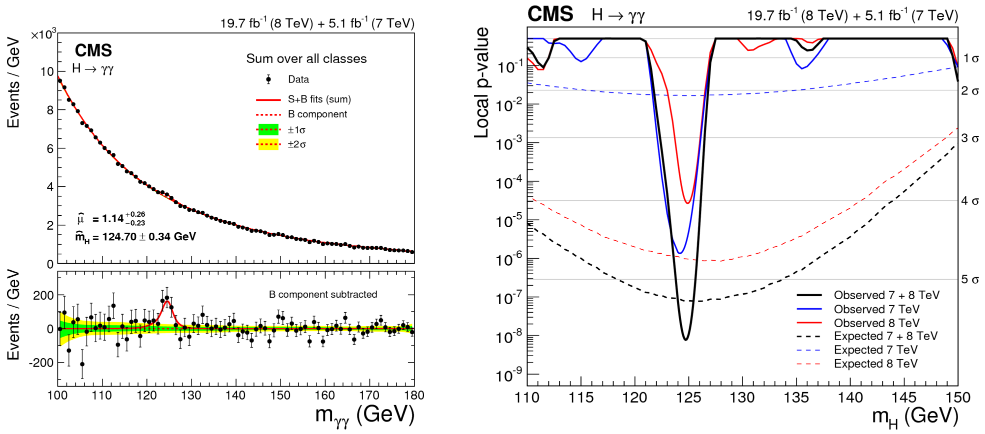

Figure 1: Left: invariant mass of the two photons for all the events selected in the 7 and 8 TeV datasets. Right: local p-values as a function of $m_{\rm H}$ for the 7 TeV, 8 TeV, and the combined dataset.

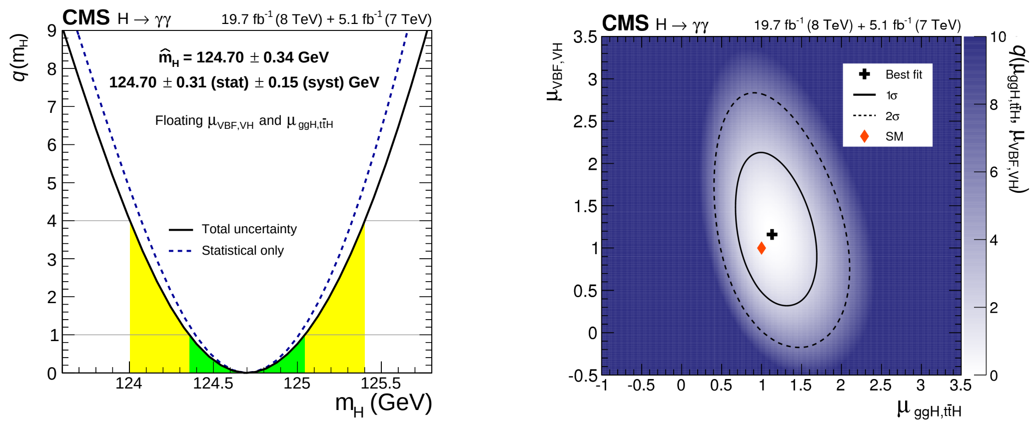

Figure 2: Left: likelihood scan as a function of the mass with $\mu_{\rm ggH,t\bar{t}H}$ and $\mu_{\rm VBF,VH}$ floated independently. Right: likelihood scan as a function of $\mu_{\rm ggH,t\bar{t}H}$ and $\mu_{\rm VBF,VH}$; the 1σ and 2σ uncertainty contours are shown, the cross indicates the best-fit values and the diamond represents the standard model expectation.

plings, 2^+_m [5], was performed. The variable used to discriminate between the two hypothesis is the cosine of the scattering angle in the Collins-Soper frame [6]. Figure 3 shows the test statistic $-2\ln(L_{2^+_m}/L_{0^+})$ as function of the fraction $f_{q\bar{q}}$ of $q\bar{q}$ production. The hypothesis 2^+_m is disfavoured at a 94% C.L. for pure gluon fusion production.

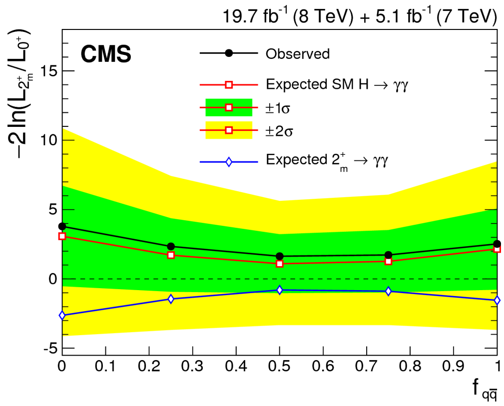

Figure 3: Test statistic for pseudo-experiments generated under the standard model 0^+ hypothesis (open squares) and the graviton-like 2^+_m hypothesis (open diamonds), as a function of the fraction $f_{q\bar{q}}$ of $q\bar{q}$ production. The full dots correspond to the observed distribution in the data.

4 Conclusions

The search for the Higgs boson through its decay to two photons in CMS was reported. The analysis is based on the full CMS Run I dataset collected at 7 and 8 TeV. A clear signal, with a local significance of 5.7σ, is observed at a mass of 124.7 GeV and the measured properties are consistent with the expectations from a standard model Higgs boson.

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