The Latest CMS results on Higgs boson decaying to two photons with 13 TeV data

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Abstract: Measurements of properties of the Standard Model Higgs boson in the H→γγ decay channel are presented. The analysis uses the data collected by the CMS experiment in proton-proton collisions during the 2016 LHC running period. The data sample corresponds to an integrated luminosity of 35.9 fb^{-1}. The measured signal strength relative to the standard model prediction is $1.16^{+0.15}_{-0.14} = 1.16^{+0.11}_{-0.10}$ (stat.) $^{+0.09}_{-0.08}$ (syst.) $^{+0.06}_{-0.05}$ (theo.). Signal strengths associated with the different Higgs boson production mechanisms, coupling modifiers to bosons and fermions, and effective couplings to photons and gluons are also measured.

1. Introduction (Fig 1, 2, 3)

- Clean final state with two highly energetic photons
- Final state fully reconstructed with high resolution
- Very small branching fraction (~0.2%)
- Large backgrounds (γγ,γ-jet,jet-jet)
- Exclusive categories targeting: gluon - gluon fusion (ggH), vector boson fusion (VBF), VH and ttH production modes
- Search for a narrow peak on a falling background in mass distribution
- 2016 dataset analysed, 35.9 fb^{-1} collected at 13 TeV.

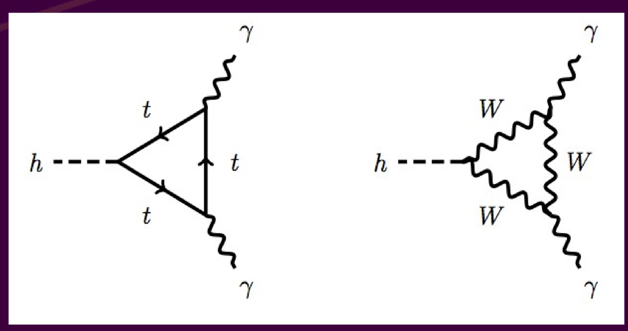


Fig 1. Dominant higgs to di-photon decay modes

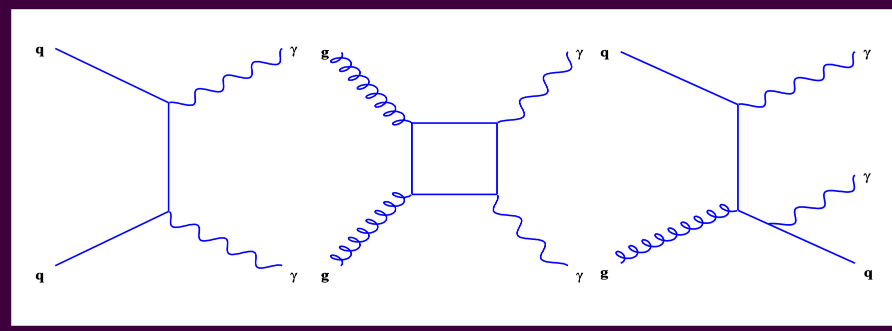


Fig 2. Dominant background processes

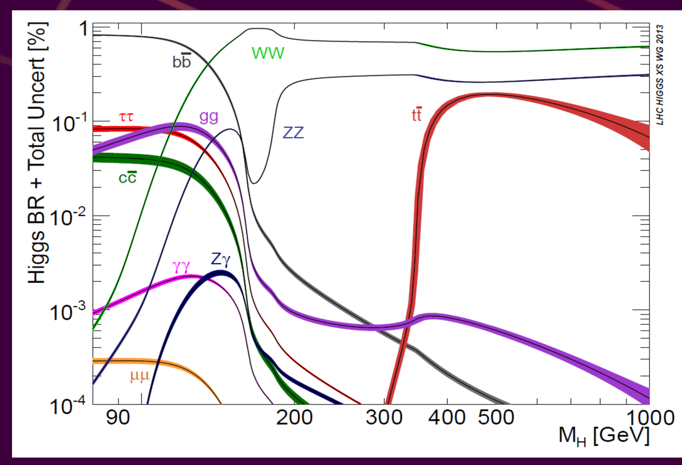


Fig 3. Higgs branching ratios in different channels

2. Vertex ID, PhotonID & diphoton ID

Vertex ID (Fig. 4, 5, 6)

- Vertex assignment important for $m_{\gamma\gamma}$ resolution. If $|z_{chosen} - z_{true}| < 1$ cm, angular contribution negligible w.r.t. energy resolution.
- Vertex ID uses Multivariate approach (Boosted Decision Tree): exploits tracks recoiling from γγ system and conversion tracks. Estimate of vertex probability extracted for use in diphoton classification.

Photon ID and di-photon pairs

- A BDT is used to separate prompt photons from photon candidates from misidentification of jet fragments.
- Multivariate approach combining shower shape and isolation variables.
- A further BDT is used to identify signal-like diphoton pairs: kinematics, high photon ID scores, correct vertex probability and good mass resolution.

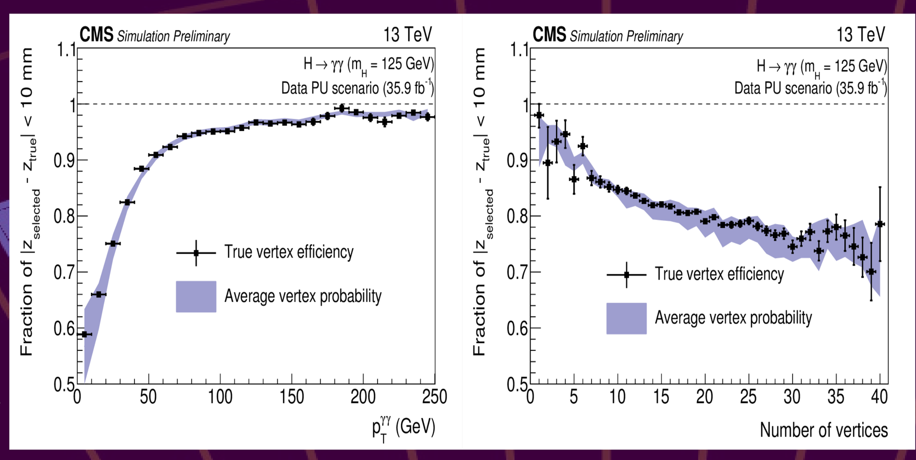


Fig 4. Comparison the true vertex identification efficiency and the average estimated vertex probability as a function of the reconstructed diphoton p_T

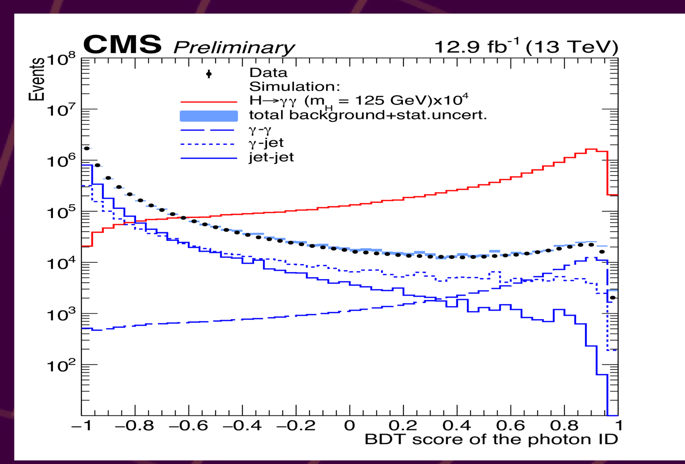


Fig 5. Photon identification BDT score of the lower-scoring photon of diphoton pairs with an invariant mass in the range 100 < m γγ < 180 GeV

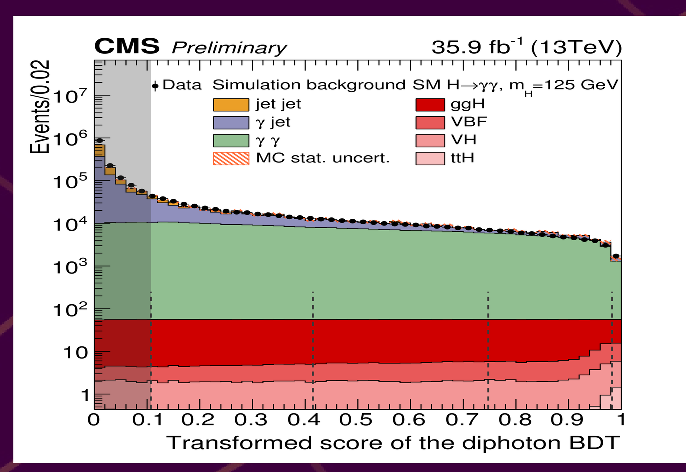


Fig 6. The shape of the BDT output variable is compared between simulation (stacked histograms) and data (black points)

3. Event categorisation (Fig. 7)

- Events with additional objects characteristic of specific production modes are tagged, and remaining events are categorised using $BDT_{\gamma\gamma}$. (Total 14 Categories)
- To a top quark pair (2 Cats.): look for hadronic or leptonic decays of tops quarks.
- Associated with a vector boson or VH(5 Cats.): split into leptonic, hadronic, MET.
- Vector Boson Fusion(3 Cats.): Distinctive 2-jet + 2-photon signature, use BDTs to identify VBF jets and split VBF Tags by mass resolution.
- Inclusive categories split by mass resolution using $BDT_{\gamma\gamma}$ output.

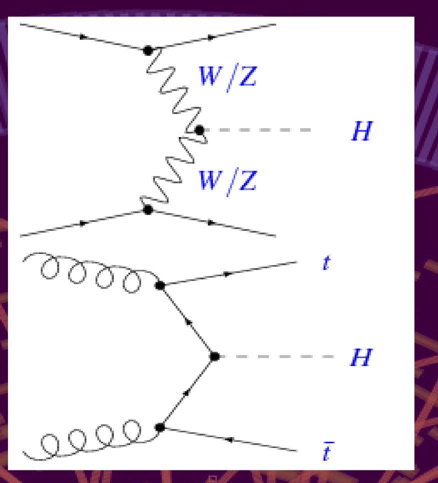


Fig 7. tth and VBF mode of higgs production

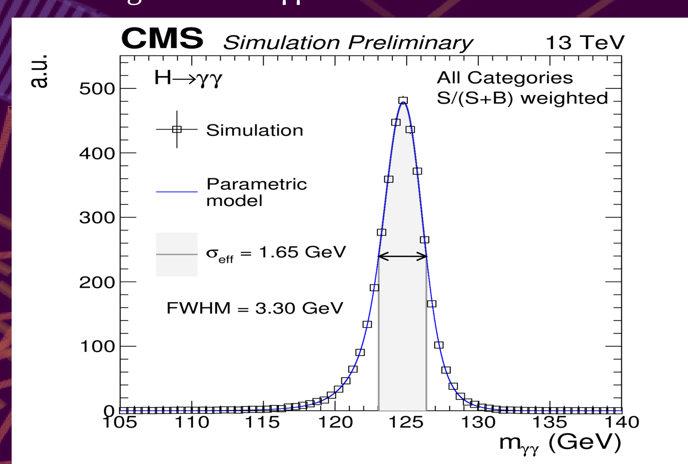


Fig 8. Full parametrized signal shape integrated over all event classes for the m_H = 125 GeV scenario at 13 TeV. The black points represent weighted simulation events and the blue lines are the corresponding model.

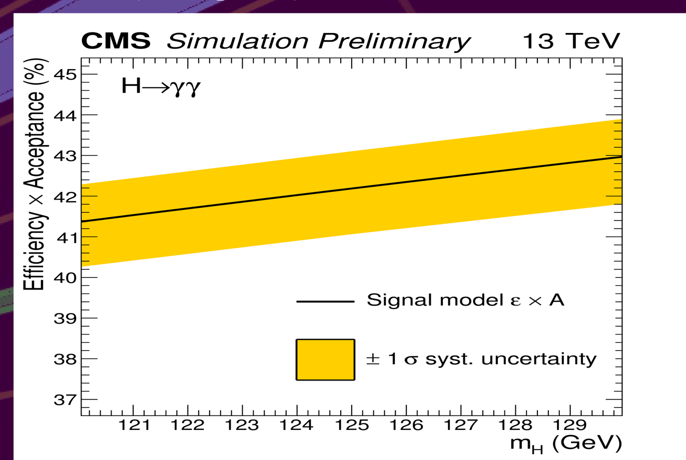


Fig 9. Efficiency X Acceptence of the signal model vs higgs mass plot

4. Signal and Background Modelling (Fig. 8, 9)

Signal Model: For each category/process, fit sum(at most 5) of Gaussians to $m_{\gamma\gamma}$ distribution, separately For: Vertex correctly identified: mass resolution dominated by energy resolution.
Vertex incorrectly identified: mass resolution dominated by uncert. on vertex position.

- For each process, category, vertex scenario, a simultaneous fit of signal samples at m_H in the range from 120 to 130 GeV is performed to obtain parametric variations of the Gaussian function parameters used in the signal model fit. Polynomials of m_H are used to describe these variations.

Background model: The model used to describe the background is extracted from data with the discrete Profiling method. A large set of candidate function families is considered, including exponentials, Bernstein polynomials, Laurent series and power law functions.

- Treats the choice of the background function as a discrete nuisance parameter in the likelihood fit to the data.

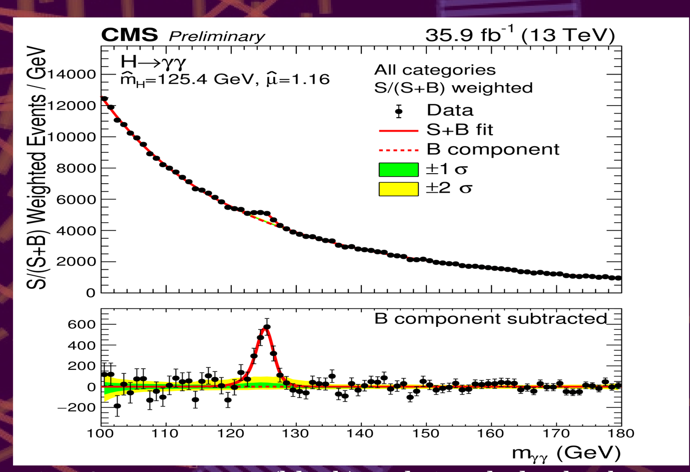


Fig 10. Data points (black) and signal plus background model fits for all categories summed. The 1 standard deviation (green) and 2 standard deviation bands (yellow) include the uncertainties of the fit. The bottom plot shows the residuals after background subtraction.

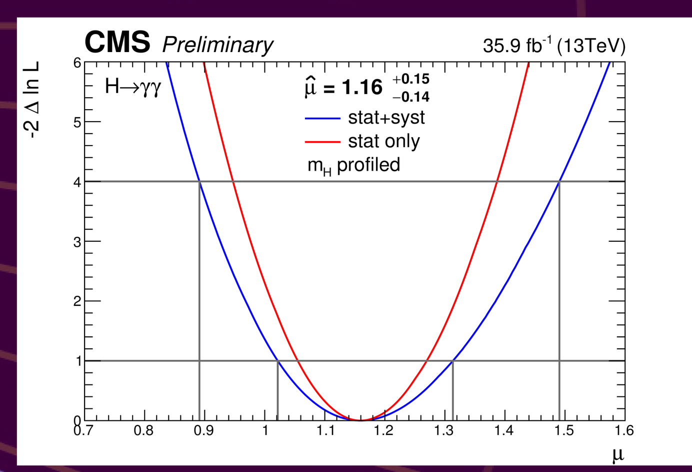


Fig 11. The likelihood scan for the signal strength where the value of the standard model Higgs boson mass is profiled in the fit.

5. Diphoton mass spectrum All categories summed (Fig. 10)

- Observed best fit is at m_H =125.4 GeV, obtained from prompt-reconstructed data.
- Statistical uncertainty ~0.15 GeV.
- Systematic uncertainty ~0.2-0.3 GeV and still under study.

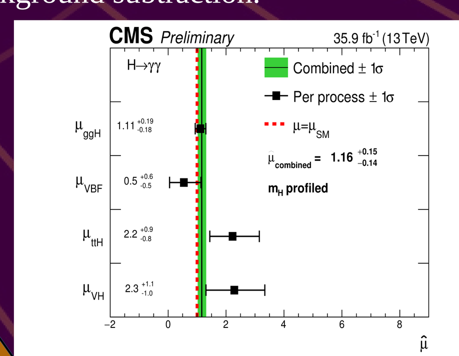


Fig 12. Signal strength modifiers measured for each process (black points) for profiled m H , compared to the overall signal strength (green band) and to the SM expectation (dashed red line).

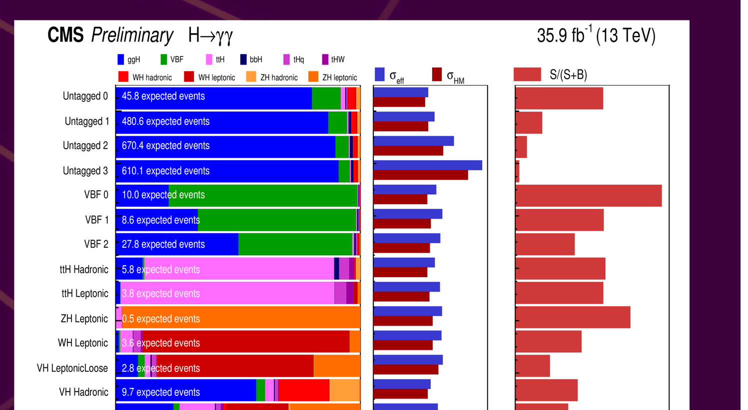


Fig 13. Expected fraction of signal events per production mode in the different categories. For each category, the σ_{eff} and σ_{HM} of the signal model are given. The ratio of the number of signal events (S) to the number of signal plus background events (S+B) is shown on the right hand side.

6. Event yields and Signal strength (Fig. 11, 12, 13, 14)

- Fig. 13 shows the expected number of signal events for each category. The total number is broken down by percentage contribution of each production mode to any particular event category.
- A two-dimensional likelihood scan of the signal strength $\mu_{ggH,ttH}$ for fermionic production modes (ggH and ttH) and $\mu_{VBF,VH}$ for vector boson production modes (VBF, ZH, WH), with the value of the parameter m_H profiled in the fit, is performed.
- Best fit signal strength (XS*BR) relative to SM, for profiled M_H, is found to be: $\hat{\mu} = 1.16^{+0.15}_{-0.14} = 1.16^{+0.11}_{-0.10}$ (stat.) $^{+0.09}_{-0.08}$ (syst.) $^{+0.06}_{-0.05}$ (theo.)

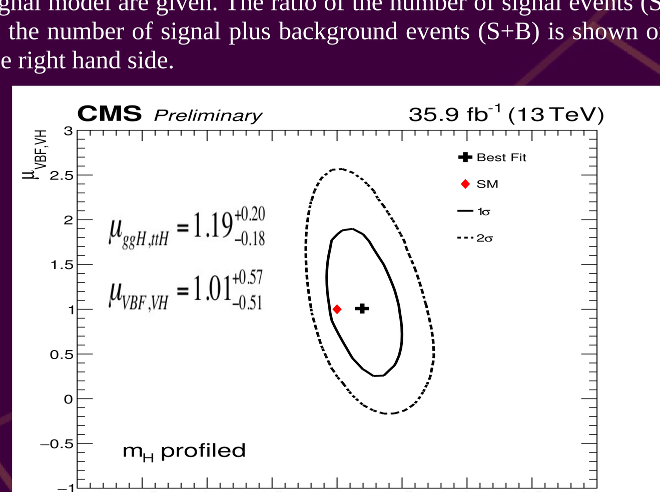
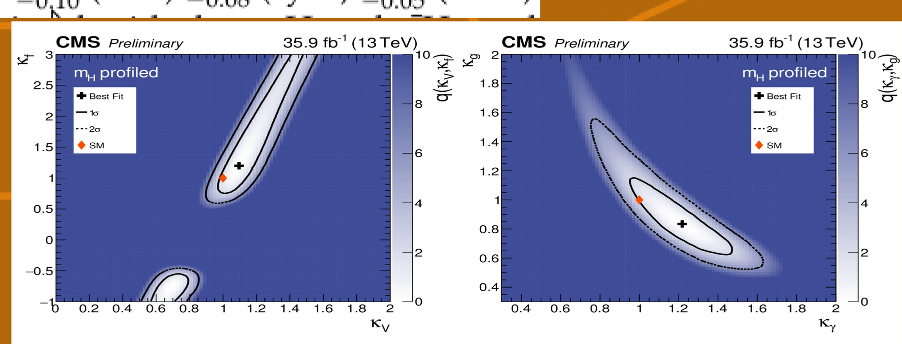


Fig 14. The two-dimensional best-fit (black cross) of the signal strengths for fermionic (ggH,t tH) and bosonic (VBF, ZH, WH) production modes compared to the SM expectations (red diamond). The Higgs boson mass is profiled in the fit. The solid (dashed) line represents the 1(2) standard deviation confidence region.

7. Coupling Constants

- Two-dimensional likelihood scans of the Higgs boson coupling modifiers are produced.
  - κ_f versus κ_V, the coupling modifiers to bosons and fermions and
  - κ_γ versus κ_g, the effective coupling modifiers to photons and gluons.
- The κ parameters other than those varied are fixed to 1 in each case.
- Figure shows the 1σ and 2σ contours for each scan and shows the test statistic q, equal to twice the negative log likelihood ratio. The results are compatible with SM.



8. Conclusions

- We report the measurements of several properties of the standard model Higgs boson using it's diphoton decay.
- The measured signal strength is consistent with the SM expectation.

9. References:

Public analysis summary: CMS PAS-HIG-16-040