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Search for low mass Higgs-boson like resonances with $m_h < 125$ GeV in the diphoton final state with the CMS experiment

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Outline

- Introduction
- Motivations:
  - ⋆ Observations
  - ⋆ BSM models
- Results:
  - ⋆ Result of 8 TeV data
  - ⋆ Result of 13 TeV 2016 data
  - ⋆ Combined Result
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Introduction

- Will include the results of 8 TeV dataset (19.7 fb^{-1}) and 13 TeV 2016 dataset (35.9 fb^{-1})

- Documentations:
  - ◇ *CMS-PAS-HIG-17-013 (Physics Letters B 793 (2019) 320)*
    → Published in June 2019
  - ◇ *CMS-PAS-HIG-14-037 (PAS-Only)*

Available on the CERN CDS information server **CMS PAS HIG-14-037**

CMS Physics Analysis Summary

Contact: cms-pag-conveners-higgs@cern.ch 2015/10/30

Search for new resonances in the diphoton final state in the mass range between 80 and 110 GeV in pp collisions at $\sqrt{s} = 8$ TeV

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Search for a standard model-like Higgs boson in the mass range between 70 and 110 GeV in the diphoton final state in proton-proton collisions at $\sqrt{s} = 8$ and 13 TeV

The CMS Collaboration*

CERN, Switzerland

A R T I C L E I N F O

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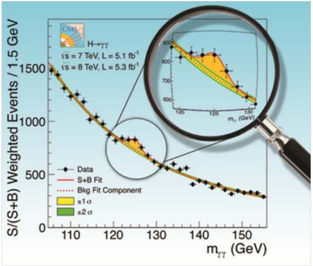
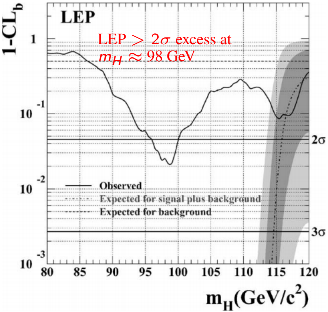
A B S T R A C T

The results of a search for a standard model-like Higgs boson in the mass range between 70 and 110 GeV decaying into two photons are presented. The analysis uses the data set collected with the CMS experiment in proton-proton collisions during the 2012 and 2016 LHC running periods. The data sample corresponds to an integrated luminosity of 19.7 (35.9) fb^{-1} at $\sqrt{s} = 8$ (13) TeV. The expected and observed 95% confidence level upper limits on the product of the cross section and branching fraction into two photons are presented. The observed upper limit for the 2012 (2016) data set ranges from 129 (161) fb to 31 (26) fb. The statistical combination of the results from the analyses of the two data sets in the common mass range between 80 and 110 GeV yields an upper limit on the product of the cross section and branching fraction, normalized to that for a standard model-like Higgs boson, ranging from 0.7 to 0.2, with two notable exceptions: one in the region around the Z boson peak, where the limit rises to 1.1, which may be due to the presence of Drell–Yan dielectron production where electrons could be misidentified as isolated photons, and a second due to an observed excess with respect to the standard model prediction, which is maximal for a mass hypothesis of 95.3 GeV with a local (global) significance of 2.8 (1.3) standard deviations.

• Is the observed 125 GeV scalar at the LHC really the SM Higgs boson?





→ Still room for BSM!

Motivations - Beyond Standard Models

• Some BSM theories predict **modified and extended** Higgs sectors, possibly with **additional low-mass (< 125 GeV)** scalars/pseudoscalars.

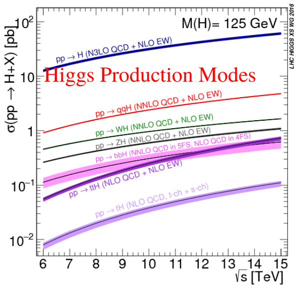
♣ General **Two Higgs Doublet Model** (2HDM):

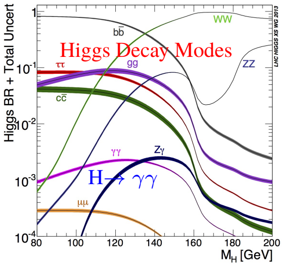
- ⋆ 2 Higgs doublets (h, H, a, $H^{\pm}$)
- ⋆ 4 types of models ($tan\beta$, α)
- ⋆ compatible with a 125 GeV SM-Like scalar (h or H) + a lighter Higgs Boson (a or h) in the "alignment limit".

♣ **Next-to-Minimal Supersymmetric Standard Model** (NMSSM):

- ⋆ 2 Higgs doublets & 1 singlet superfields (h_1, h_2, h_3, a_1, a_2, $H^{\pm}$)
- ⋆ solved the known "μ-problem" of MSSM;
- ⋆ compatible with a 125 GeV SM-Like scalar (h_1 or h_2) & a mostly "singlet-like" lighter Higgs Boson (a_1 or h_1).

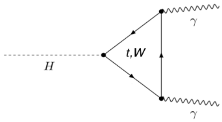
Higgs





H$\rightarrow \gamma\gamma$

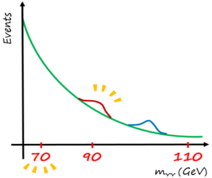
- Clean signature with **two isolated and highly energetic photons**
- Final state fully reconstructed with **excellent mass resolution**
- **Large background** from QCD ($\gamma\gamma - \gamma j - jj$)



Analysis Strategy

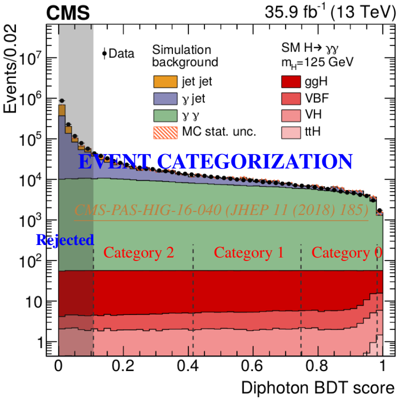
♡ Inherit **analysis strategy** from **standard H→ $\gamma\gamma$ analysis**

- **Event categorization** on mass resolution and S/B
- Signal extracted from background by **fitting the observed di-photon mass distributions** in each category



Comparisons	8 TeV	13 TeV
Luminosity	19.7 fb^{-1}	35.9 fb^{-1}
Search Range	[80, 110] GeV	[70, 110] GeV
HLT paths	2	1
Categories	4	3

- Select two **"good quality" photons**
- Measure **photon energy** precisely
- Find the **primary vertex** of the decay



Photon Energy

$$m_{\gamma\gamma} = \sqrt{2E_1E_2(1-cos\theta)}$$

- Photon energy reconstructed by building **clusters of energy deposits** in the **Electromagnetic Calorimeter**.
- **Energy** and **its uncertainty** corrected for local and global shower containment

$\Rightarrow$ **Regression Technique**:
  - Corrects photons' energies
  - Provides an estimate of energy resolution
- **Energy Scale** in data **corrected** as a function of data taking epochs, pseudorapidity and EM shower width
- **Smearing** to the reconstructed photon energy in **Mont Carlo** to match the resolution in data

$\Rightarrow$ **Z→ee peak** as reference

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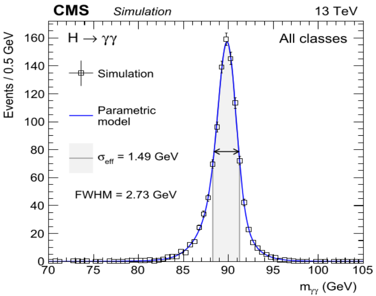
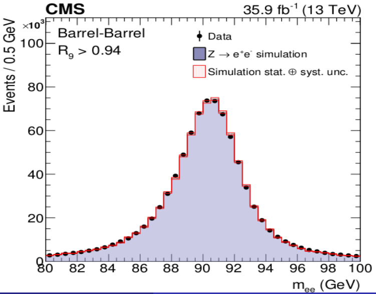




Vertex Identification

$$m_{\gamma\gamma} = \sqrt{2E_1E_2(1 - cos\theta)}$$

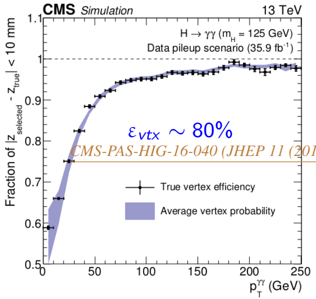
- **Vertex assignment** considered as correct within **1 cm** of the diphoton interaction point.

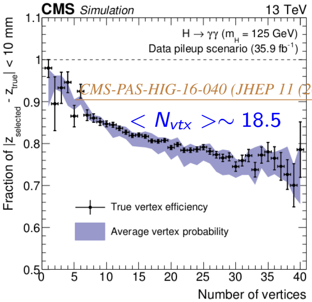
⇒ **negligible impact** on mass resolution:

- **Multi-variate approach**:
  - Observables related to **tracks recoiling** against the diphoton system
  - direction of **conversion tracks**
- **Second MVA discriminant** to estimate the probability for the vertex assignment to be within 1 cm

⇒ used later for **diphoton classification**

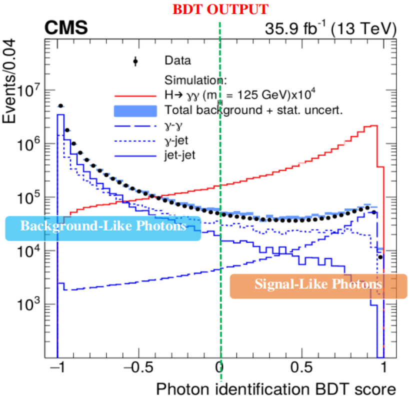
- Method validated with **$Z \to \mu\mu$ events**, by refitting vertices ignoring the muon tracks





Photon Selection

- **Trigger selection**:
  - **double-photon trigger paths** based on transverse energy, H/E, electromagnetic shower shapes and isolation variables, $m_{\gamma\gamma}$
- **Preselection**:
  - Similar to trigger requirements, but more stringent
- **Photon Identification**:
  - **Multi-Variate approach** to reject fake photon candidates (mainly from π^0 **mesons** produced in jets)
  - **Shower shape and isolation** observables, median energy density (ρ)
  - **BDT output** provides an estimate of the per-photon quality



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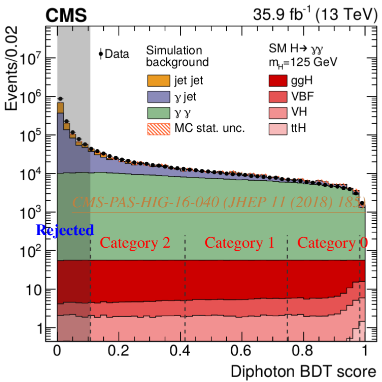
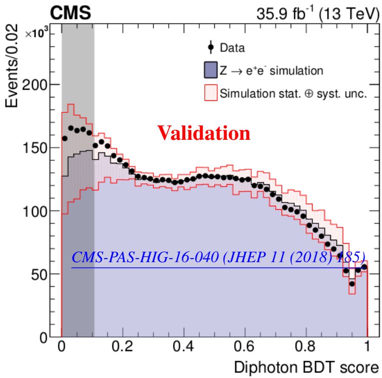
Untagged Events

- All the inclusive events are categorized according to the **photon kinematics**, per-event **mass resolution, photon ID** and **good vertex probability** by a **MultiVariate Classifier**
- The number of categories and their boundaries are **optimized** to maximize the **expected significance**
- Method validated with **Z →ee events**, where the electrons are reconstructed as photons



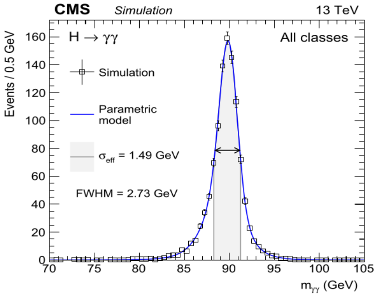


Signal and Background Model

Signal

Parametrized model of Higgs boson mass shape

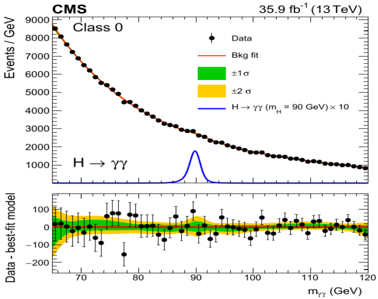
- Obtained from **Simulation**
- MC tuning and data/MC efficiency scale factors applied



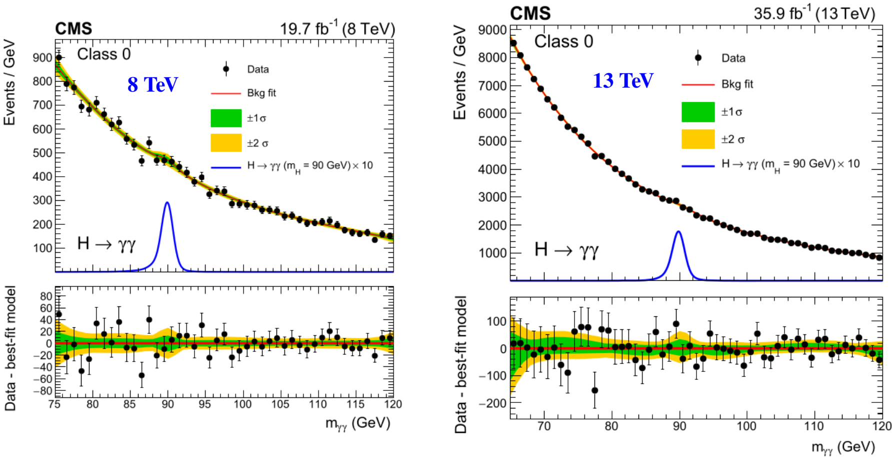
Background

Background model extracted from **data**

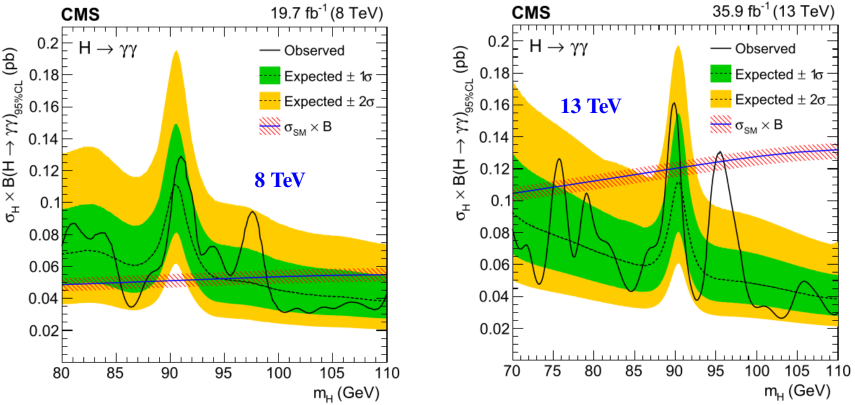
- Different functional forms used for each category
  - **Sum of polynomial** (chosen from 4 families) + **Double-sided Crystal Ball (DCB)** functions for relic $Z \to ee$ component;
- Choice of function treated as a **discrete nuisance parameter**
- DCB: shape parameters from MC **"double-fake"** events, syst. uncertainty from **"single-fake"** events



Mass Spectrum



Results

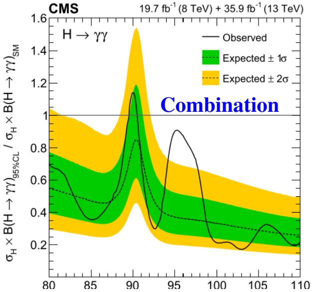


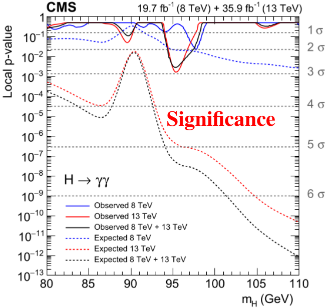
→ **8 TeV**: Minimum (Maximum) limit on $\sigma \times$ **Br**: 31 (133) fb at m_H = 102.8 (91.1) GeV

→ **13 TeV**: Minimum (Maximum) limit on $\sigma \times$ **Br**: 26 (161) fb at m_H = 103.0 (89.9) GeV

- Production processes assumed in **SM proportions**.

Results





- Normalized **Upper limits on $\sigma \times$ Br**:

  → Minimum (Maximum) Limit: 0.17(1.13) at m_H = 103.0 (90.0) GeV

- Expected and observed **local p-values**:

  → **8 TeV**: Excess with ∼2.0σ local significance at m_H **= 97.6 GeV**

  → **13 TeV**: Excess with ∼ 2.9σ local (1.47σ global) significance at m_H **= 95.3 GeV**

  → **8TeV+13 TeV**: Excess with ∼ 2.8σ local (1.3σ global) significance at m_H **= 95.3 GeV**

♣ More data are required to ascertain the origin of this excess.

Conclusions

- Results of the CMS **low mass H$\rightarrow\gamma\gamma$ analysis** have been reported, using 35.9 (19.7) fb^{-1} of collision data collected in 2016 (2012) at 13 (8) TeV;
- **No significant (>3σ) excess** with respect to the expected number of background events is observed:
  - **CMS Run I (8 TeV)**: Modest excess with maximum local significance **2.0σ** at m_H = **97.6GeV**;
  - **CMS Run II (13 TeV 2016 data)**: Modest excess with maximum local significance **2.9σ** at m_H = **95.3GeV**;
  - **Combination results (Run I and Run II)**: Modest excess with maximum local significance **2.8σ** at m_H = **95.3GeV**;

⋆⋆ Looking forward to the results of ***13TeV 2017 data*** or ***full RunII data*** !

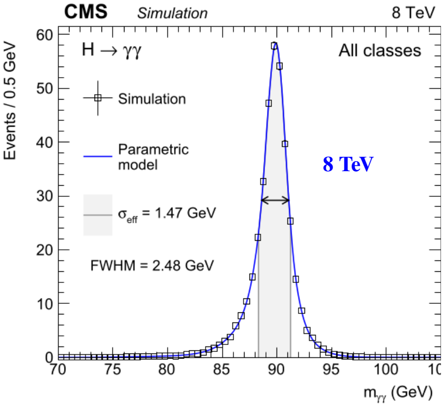
BackUp

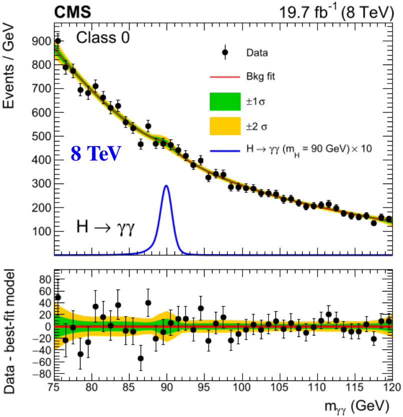
μ problem

- MSSM:
  $\rightarrow$ 2 Higgs doublets(2 CP-even, 1 CP-odd and 2 charged Higgs bosons)
  $\rightarrow$ μ problem: There's a mass term μ in the low energy Higgs which seems unrelated to the electroweak scale;

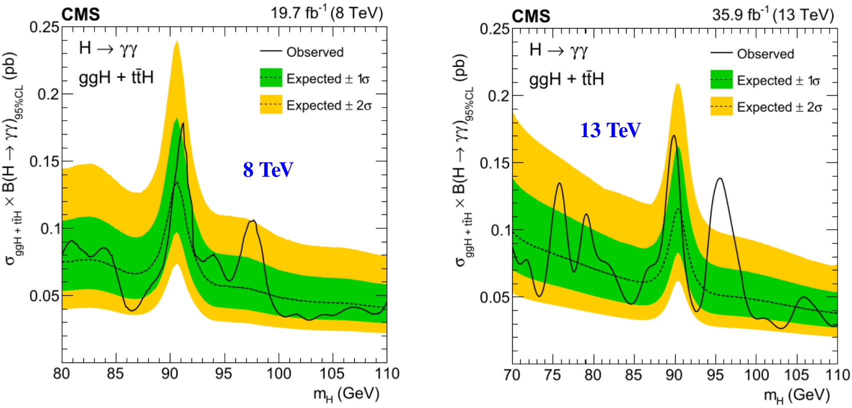
- Solution of μ problem in NMSSM:
  $\rightarrow$ NMSSM introduces a new gauge singlet superfield which only couples to the Higgs sector in a similar way as the Yukawa coupling and give rise to a effective μ-term to solve the "μ problem";
  $\rightarrow$ The new singlet adds additional degrees of freedom to the NMSSM particle spectrum.
  $\rightarrow$ 2 Higgs doublets (3 CP-even, 2 CP-odd and 2 charged Higgs bosons).

Signal and Background Model (8 TeV)



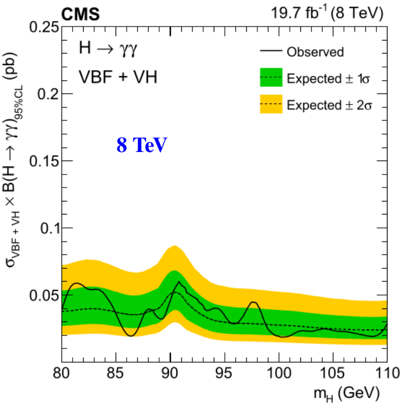


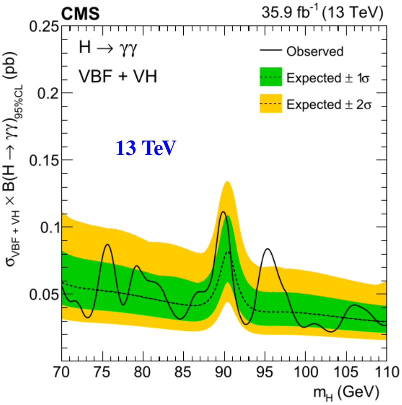
Results: Upper limits on $\sigma \times$ Br



- Per-process limits on $\sigma \times$ Br assuming 100% **gluon-induced** processes (ggH, ttbarH in SM proportions)

Results: Upper limits on $\sigma \times$ Br





- Per-process limits on $\sigma \times$ Br assuming 100% **fermion-induced** processes (VBF, VH in SM proportions)