Low-mass Higgs searches at CMS via diphoton

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Outline

Motivation and previous searches

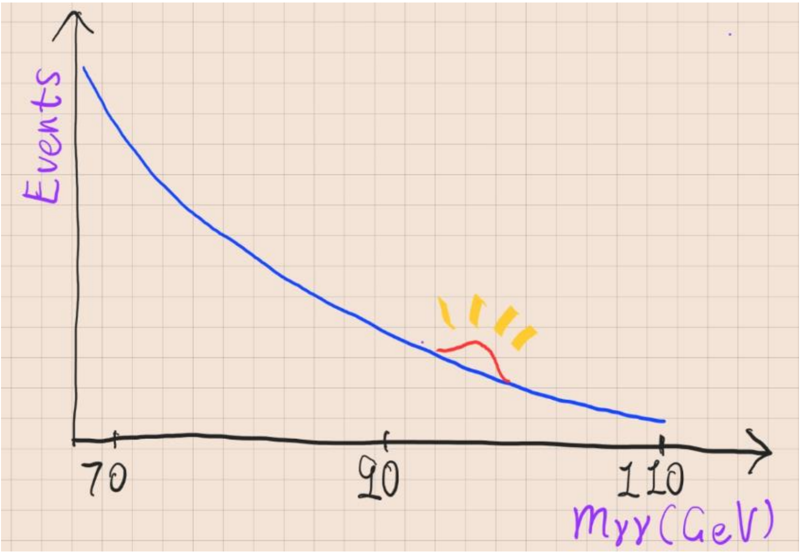
Analysis strategy for full Run2

Signal and background modeling

Full Run2 Results

Summary

Results are based on
CMS-PAS-HIG-20-002



Motivation and previous searches

Many BSM models (e.g. 2HDM, Composite Higgs) predict additional Higgs bosons

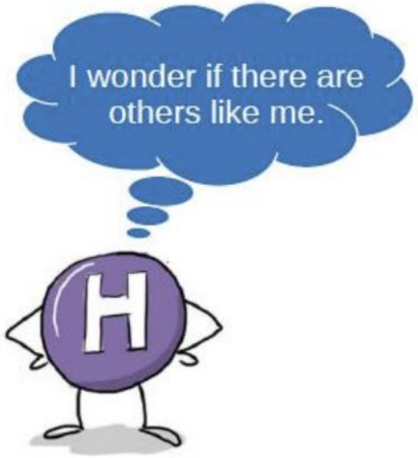
- ❖ Some of which could have **masses < 125 GeV**

Final LEP SM Higgs boson search results

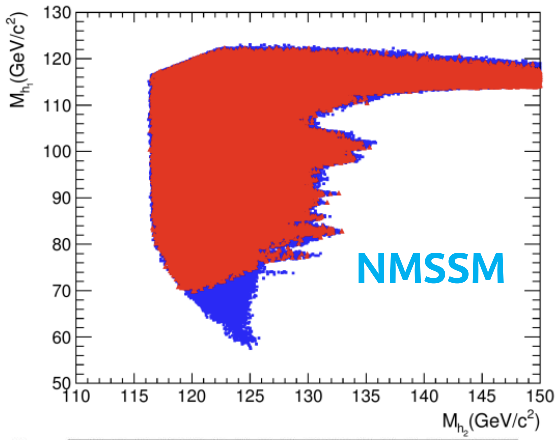
- ❖ 2.3σ local excess at m_H = 98 GeV

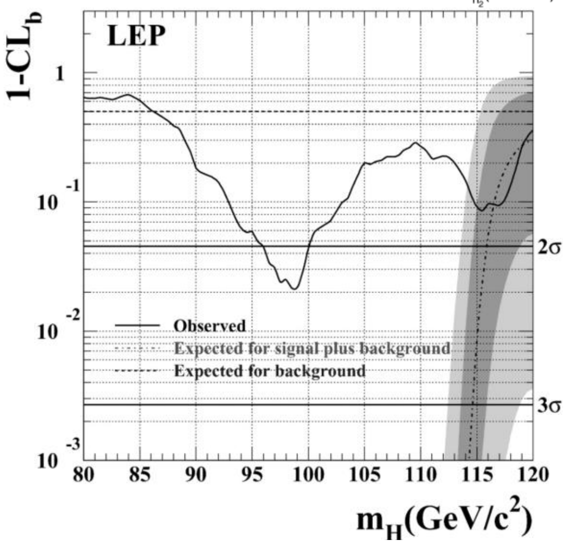
Discovery of extra Higgs boson(s) would be an unequivocal sign of new physics

LHC is currently the most powerful discovery machine



J. Fan, J. Tao, S. Gascon-Shotkin et. al
2014 *Chinese Phys. C* **38** 073101





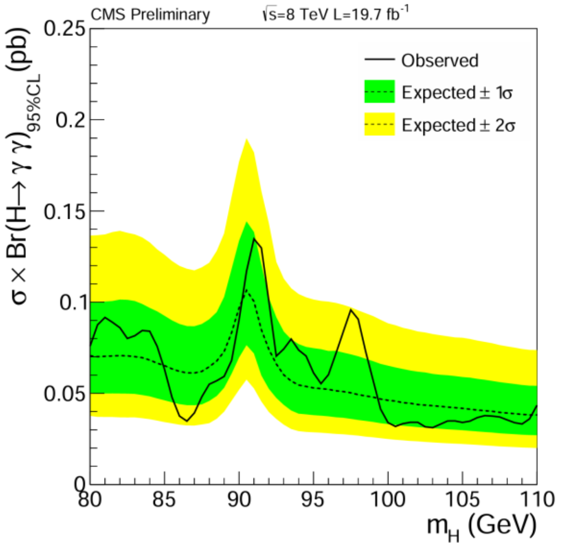
Phys.Lett.B565: 61-75, 2003

Low-mass H→γγ search before full Run2

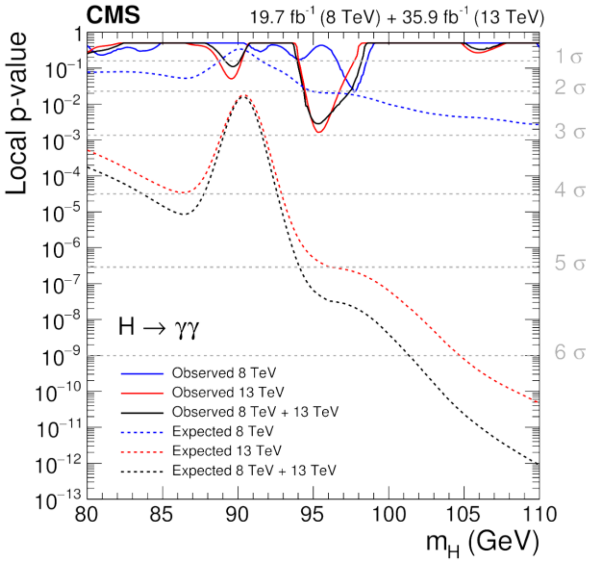
H→γγ channel provides a clean final-state topology

❖ High precision of Higgs boson reconstructed mass: 1-2%

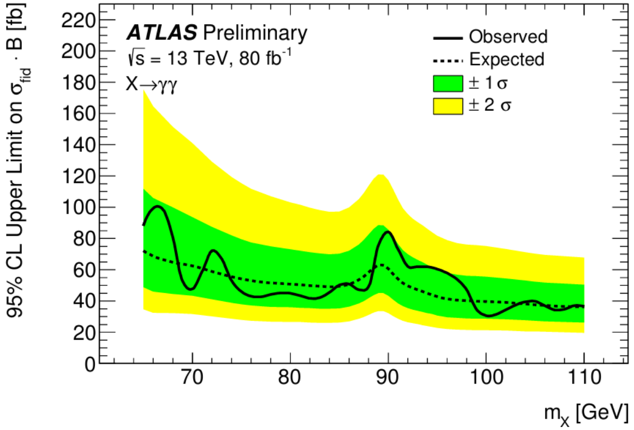
CMS-PAS-HIG-14-037
2012 data: ~2σ local significance at 97.5 GeV



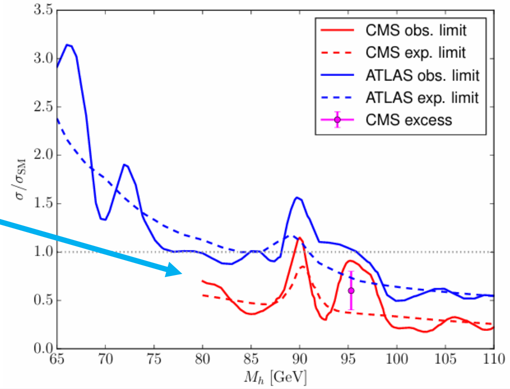
PLB 793 (2019) 320
2016+2012 data: 2.8σ local (1.3σ global) significance at 95.3 GeV



ATLAS-CONF-2018-025
2016+2017 data: Not exclude the CMS observed excess



PoS CHARGED2018(2019)016
DOI:10.22323/1.339.0016
CMS has a better sensitivity than ATLAS



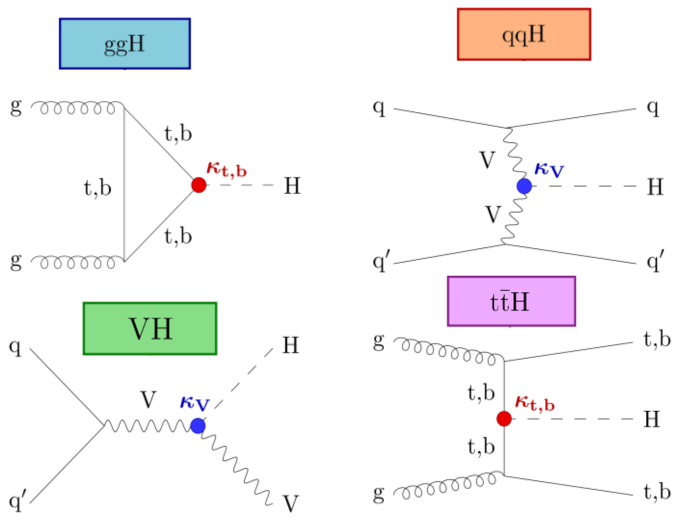
Low-mass H→γγ full Run2 analysis

Full Run2 data

- ❖ Corresponding luminosity 132.2 fb^{-1}

Main production modes included

- ❖ ggH, VBF, VH, and ttH
- ❖ Coupling ratios between different production modes are the same as the SM



Extract signal events by fitting to the diphoton invariant mass

- ❖ Signal search region: 70-110 GeV
- ❖ Background fitting range: 65-120 GeV

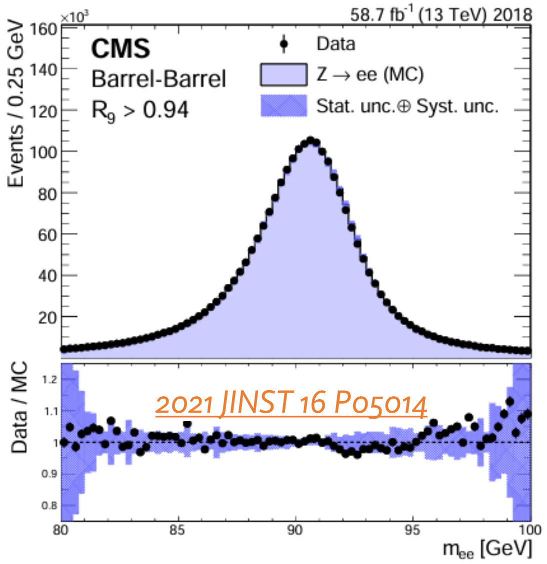
Background components

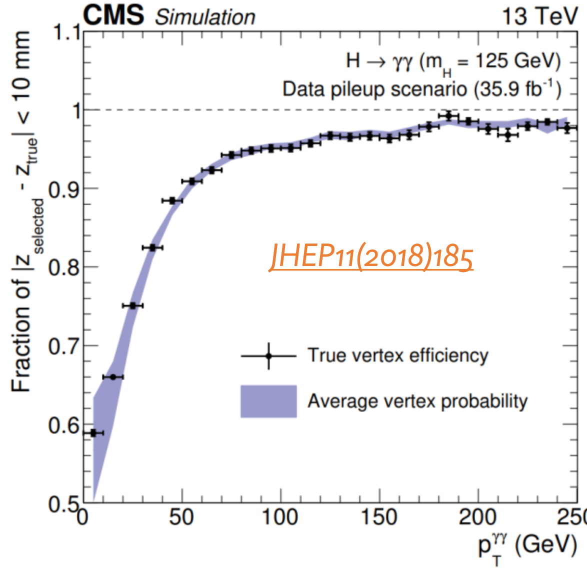
- ❖ Irreducible direct QCD γγ production
- ❖ Reducible γ+jet process and jet+jet processes
- ❖ Reducible Drell-Yan Z→ee events

Analysis strategy of the full Run2 analysis

Share and inherit many elements from the SM H→γγ Run2 analyses

- Photon reconstruction and correction, Vertex ID, Signal and background modeling techniques, …





Dedicated updates and optimizations for low-mass H→γγ full Run2

- New triggers and pre-selections for 2017 & 2018
- Updated photon ID and di-photon candidate classifier for the low-mass case in 2017 & 2018
- Dedicated classifiers for tagging VBF events in 2017 & 2018
- DY suppression strategy (next page)

Analysis strategy for full Run2

CMS-PAS-HIG-20-002

DY suppression strategy

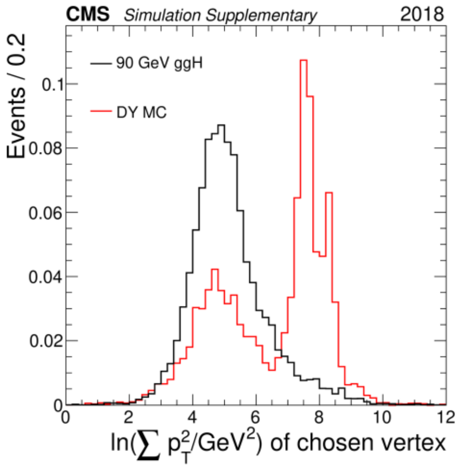
- Electron-veto without pixel detector hits
  - Used in previous 2016+2012 paper: *PLB 793 (2019) 320*
- Two additional selections
  - **No matched electron**
  - **Linear cut**: maximum value of ln (Σp_T^2) as function of $p_T^{\gamma\gamma}$

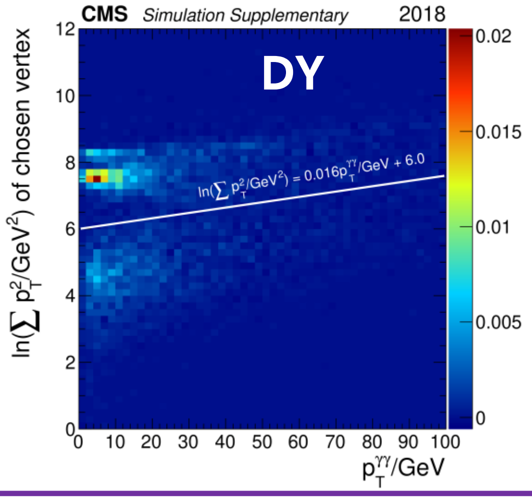
Event categorization

- 2016
  - 3 untagged event classes
- 2017 & 2018
  - 3 untagged event classes
  - 1 VBF tagged event class

On top of pixel seed e-veto, the two additional cuts can:

- reject **~60%-70%** of the relic DY events
- keep **~92%** 90GeV signal efficiency in 2016-2018





Signal modeling

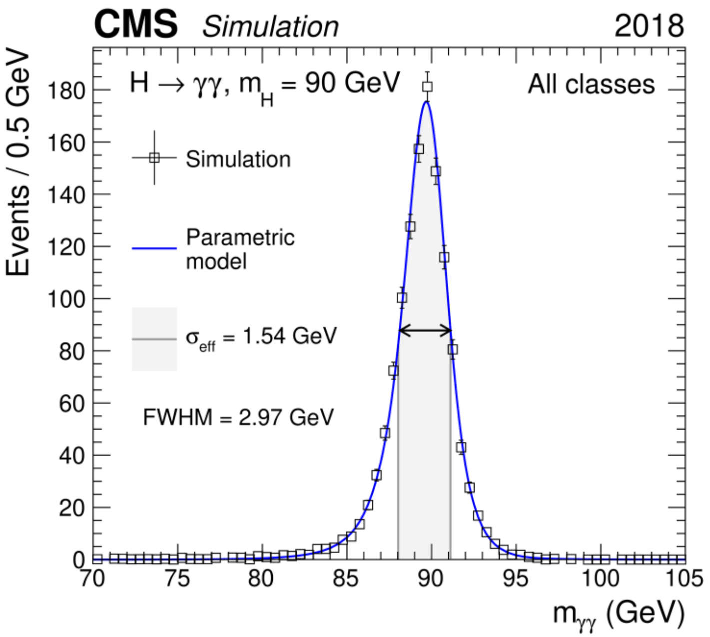
Signal modeling

- ❖ Use a parametric model (sum of Gaussian functions)
- ❖ Fit to the shape of the signal in each event class

All production modes together

- ❖ From 70 GeV to 110 GeV with a 5 GeV granularity
- ❖ Different production modes weighted by SM-like Higgs boson cross sections evaluated at $70 < m_H < 110$ GeV

CMS-PAS-HIG-20-002



Fully parametrized signal shape in simulated signal events with m_H = 90 GeV for 2018

Background modeling

Continuum background

- Estimated with the envelope method (discrete profiling method)
  - Built from the diphoton mass spectrum (65-120 GeV) of data
  - Fit with four analytic function families (Power law, Exponential, Laurent, Bernstein)

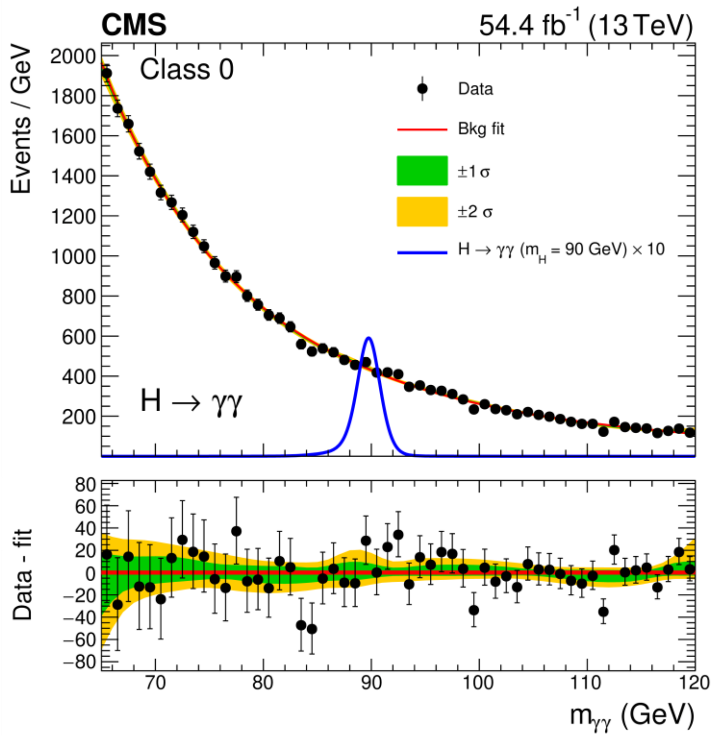
Relic Drell-Yan Z→ee contribution

- Estimated by fitting with a double-sided Crystal Ball (DCB) function + an exponential
  - *(1.0-frac)*DCB(x) + frac*exp(p1*x)*

Total background model

- Sum of the two components
  - Continuous functions for the continuum background
  - DCB+exponential (normalization floating) function for Z→ee contribution

CMS-PAS-HIG-20-002



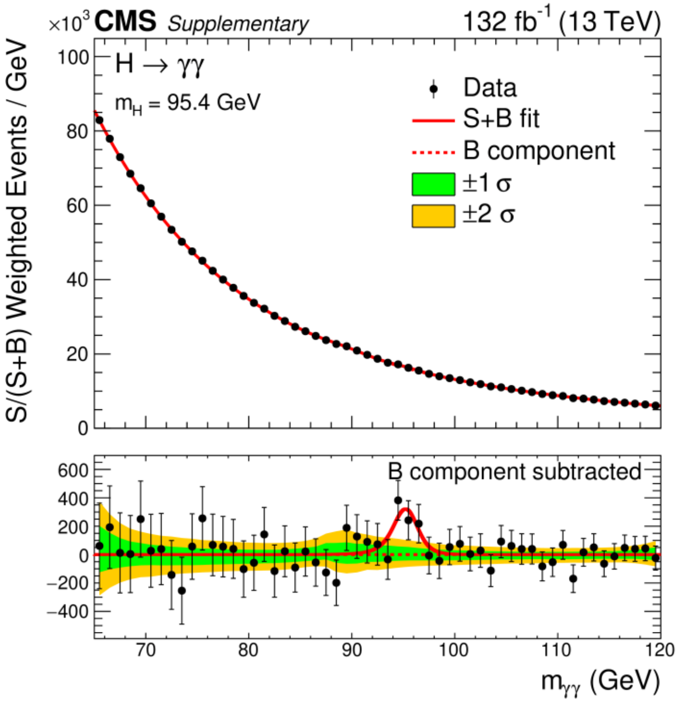
Background model fits using best-fit parametrization to the 2018 data in event class 0 (stat. uncertainty only)

Full Run2 results: inclusive significance

CMS-PAS-HIG-20-002

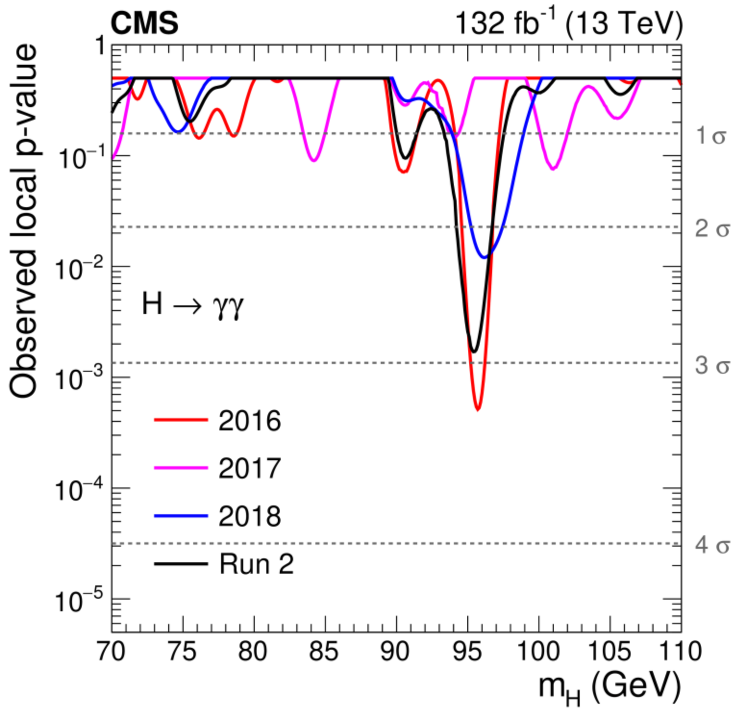
The $m_{\gamma\gamma}$ distribution with Signal+Background model fit

- The mass hypothesis here is m_H = 95.4 GeV
- Each event is weighted by the ratio S/(S+B) for its event class



Observed local p-values for 2016, 2017, 2018, and the combination

- Modest excess with **~2.9σ** local (**1.3σ** global) significance at $m_{\gamma\gamma}$ = **95.4 GeV**

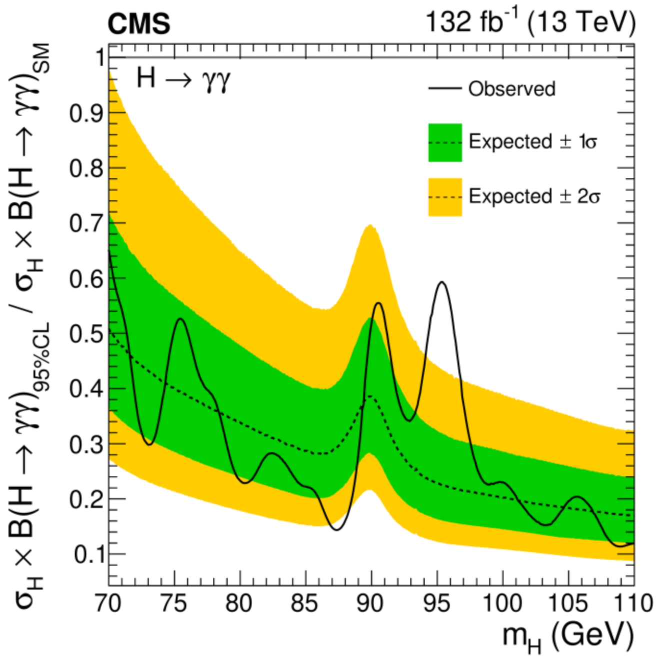


Full Run2 results: inclusive limits

CMS-PAS-HIG-20-002

95% CL upper limits on $\sigma \times BR$

- Relative to SM-like expectation (production processes assumed in SM proportions)

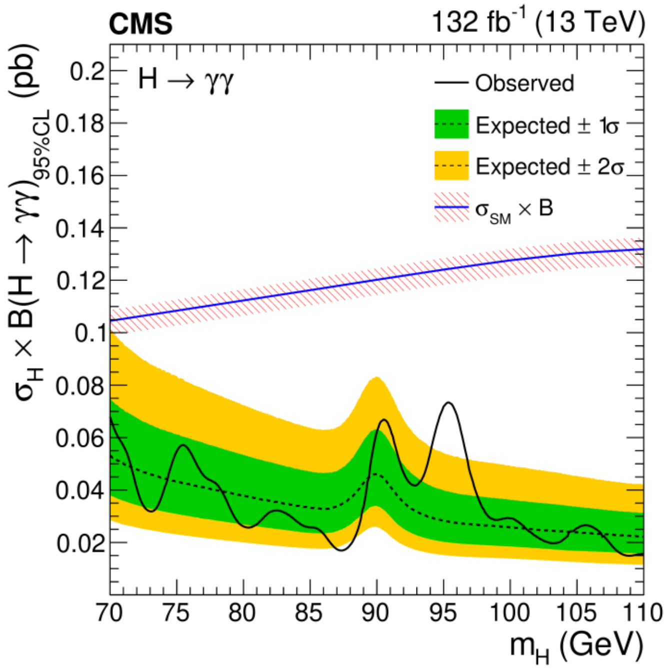


Observed upper limits

- 0.11 ~ 0.65 × SM-like

Absolute 95% CL upper limits on $\sigma \times BR$

- Between 15-73 fb



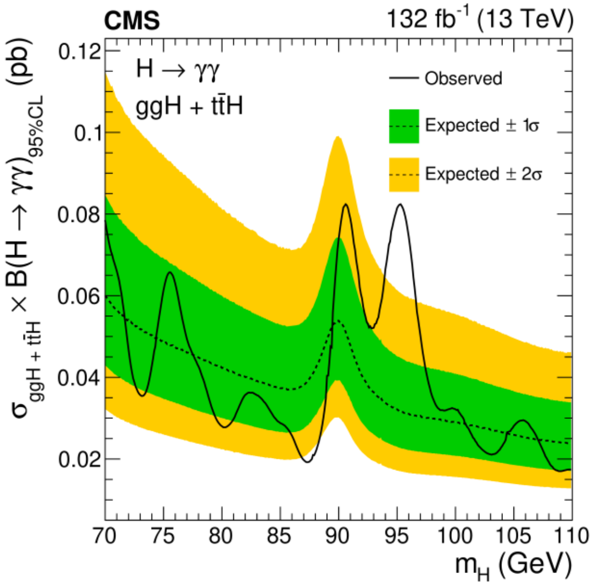
Observed upper limits

- 15~ 73 fb

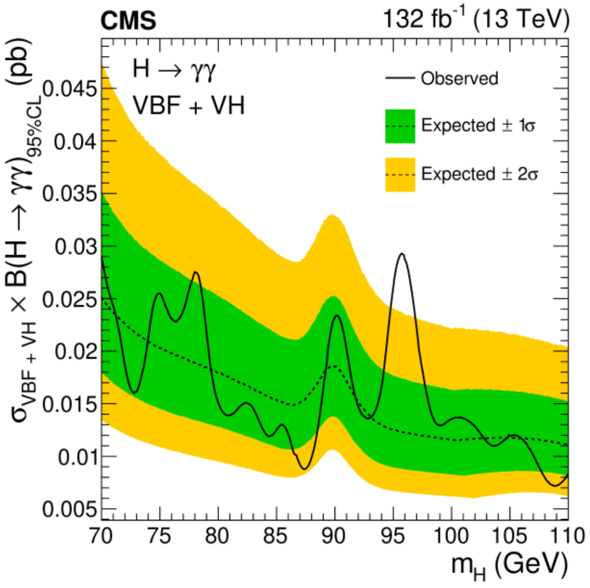
Full Run2 results: limits by production mode

Observed and expected 95% CL limits on $\sigma \times BR$ by production process (integrated over all event classes)

CMS-PAS-HIG-20-002



100% production via gluon-induced processes (**ggH, ttH** in SM proportions) 17-83 fb observed



100% production via vector boson coupling (**VBF, VH** in SM proportions) 7-29 fb observed

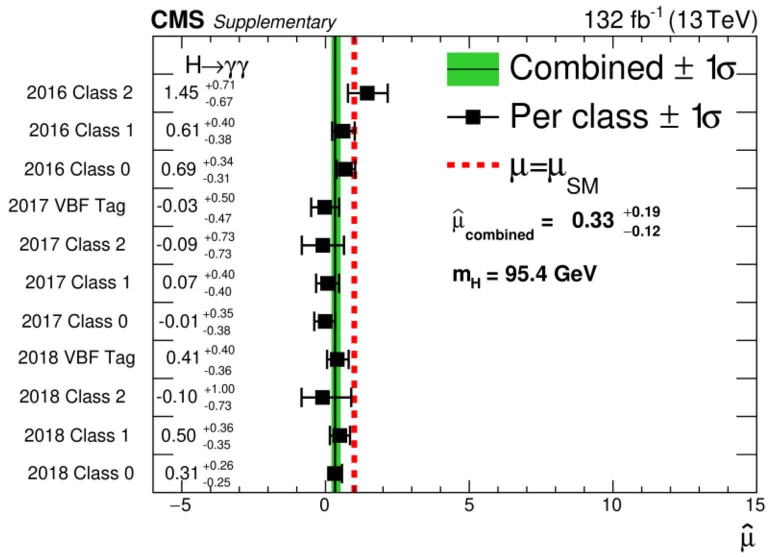
Full Run2 results: Channel compatibility

CMS-PAS-HIG-20-002

Signal strength μ

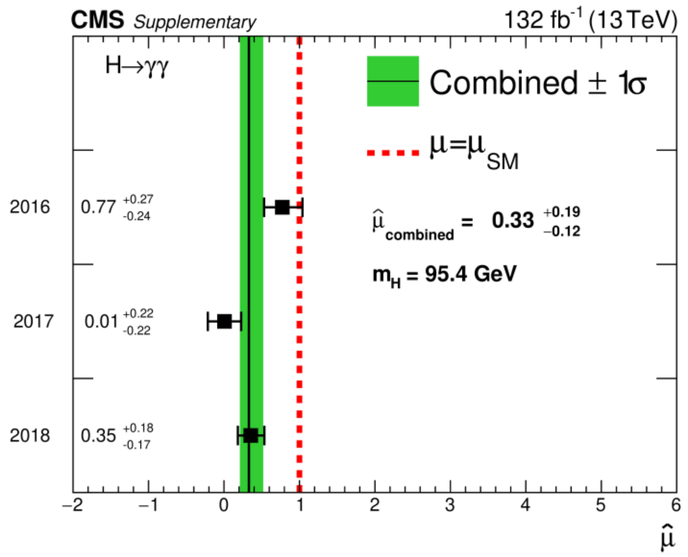
- m_H fixed to max. significance value of 2016+2017+2018 (95.4GeV)

Channel compatibility 11 event classes



χ^2 probability of the values for the eleven event classes being compatible with the overall best-fit signal strength is 68%

Channel compatibility per year



χ^2 probability of the values for the three years being compatible with the overall best-fit signal strength is 6%

Summary

Results of search for a standard model-like Higgs boson in the mass range between 70 and 110 GeV in the diphoton final state at 13 TeV with full Run 2 data has been presented

- CMS-PAS-HIG-20-002: Accepted for publication in Phys. Lett. B

No hint for the existence of new Higgs boson so far

- The maximum local significance corresponds to 2.9σ at 95.4 GeV for all production mechanisms and event classes combined (1.3σ global significance)

Signal strengths at 95.4 GeV are compatible among 2016, 2017, 2018 and for all the event classes

First diphoton resonance search in this mass range with full Run2 data

Looking forward to more LHC Run3 data to conclude on the nature of this excess

Backup

Systematic uncertainties

Uncertainties evaluated at the per-event level

- Total integrated luminosity
- 2016 and 2017 pre-firing
- Underlying event and parton shower
- 2018 HEM issue
- 2017 and 2018, VBF additional jet radiation issue
- Linear cut SF

Uncertainties evaluated at the per-photon level

- Shape of the photon identification BDT distribution
- Photon energy scale and resolution
- Trigger efficiencies SF
- Preselection SF
- Electron veto SF and NMatchedEle=0 SF
- Minimum photon identification BDT
- Non-uniformity of light collection (FNUF)
- Photon energy scale non-linearity
- Vertex selection uncertainty

Dedicated systematics for VBF class

- Jet energy correction and resolution
- PUJID
- Tight Jet ID

Theoretical uncertainties

- PDF uncertainty
- QCD scale and strong coupling strength (α_s) uncertainty
- Cross-section uncertainties (for normalized limit and p-value)

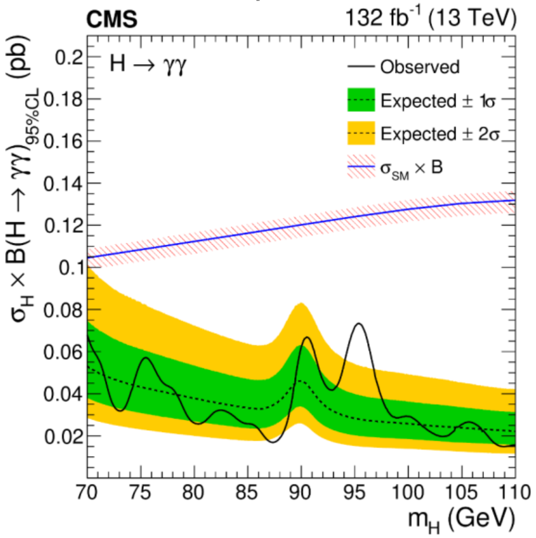
Major systematic uncertainties

- Per-photon energy resolution < 20%
- Renormalization and factorization scales < 14%
- UE modeling < 27%
- Parton shower < 16%
- JES corrections (VBF class) < 16%

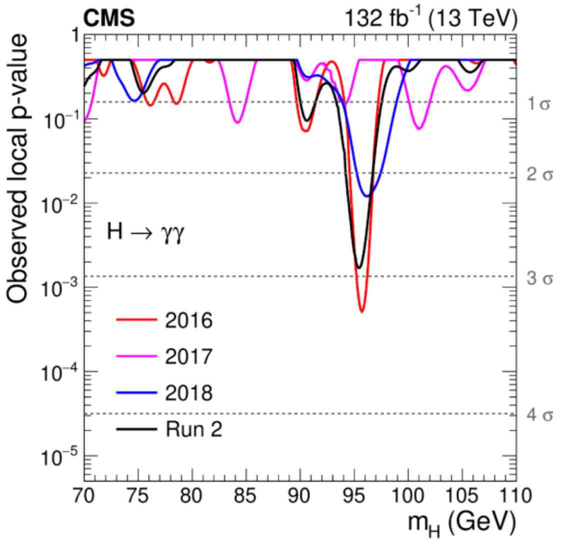
Comparison with ATLAS full Run2

CMS-PAS-HIG-20-002

95% CL upper limits on σ×B
- ❖ 15-73 fb observed
- ❖ 22-53 fb expected



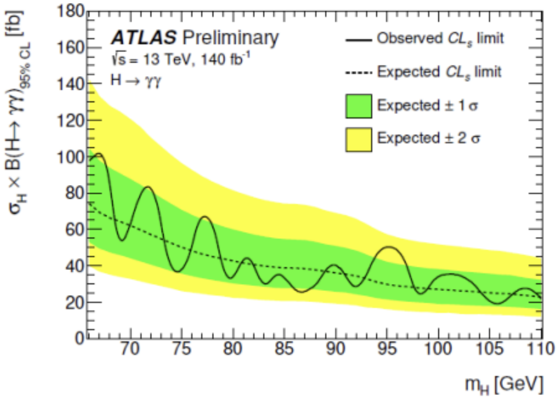
Observed local p-values
- ❖ Maximum significance: **2.9σ @ 95.4 GeV**



ATLAS full Run2 results

ATLAS-CONF-2023-035 **(June 6, 2023)**

Upper limit of σ×B:
- ❖ [19, 102] fb @ 95 % CL



Observed local p-values
- ❖ Maximum significance: **1.7σ @ 95.4 GeV**