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

Guoming Chen, Junquan Tao, Sijing Zhang

China LHC Physics Workshop, 22-24th Dcember, 2017

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences
Beijing

Outline

- Motivation
- Lightest scalar Higgs boson $h_1 \to \gamma\gamma$ in NMSSM
- Searching results with CMS 8TeV data
- Interpretation with 2HDM(8TeV data)
- The result with CMS 13TeV data and the combined result of CMS 8TeV+13TeV data New!
- Summary

Motivation

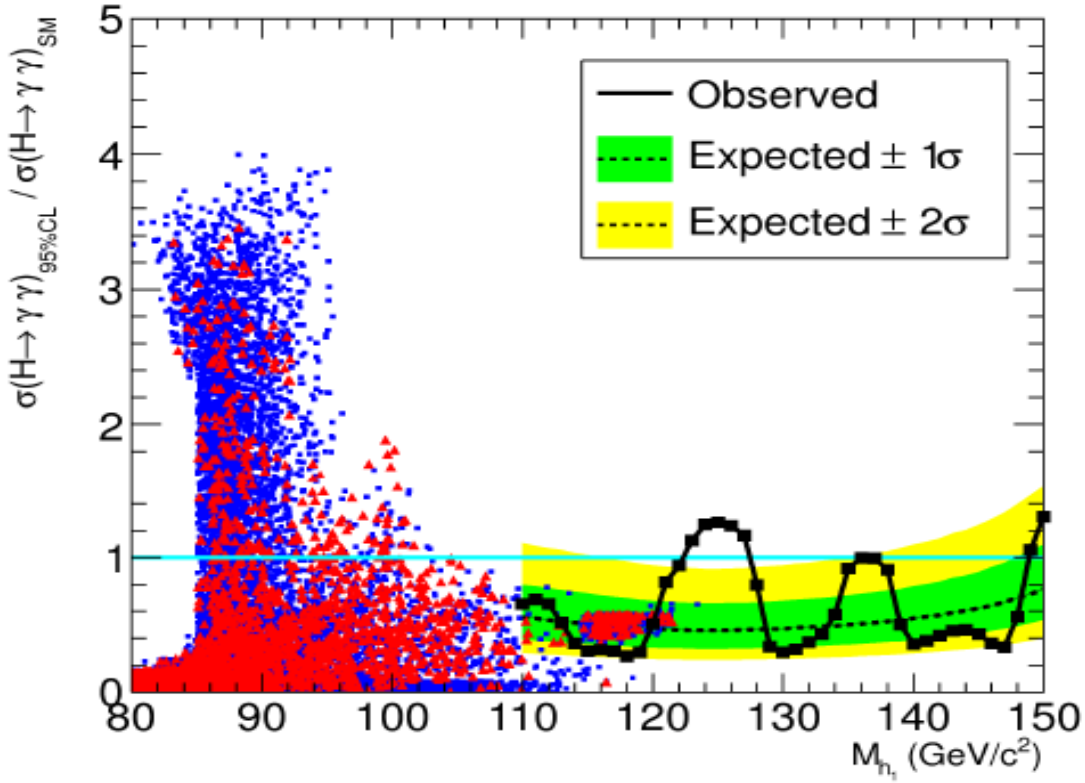
• Is the observed 125 GeV scalar at the LHC really the SM Higgs Boson ? Still room for BSM.

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

→ General Two Higgs Doublet Model (2HDM):
- 2 Higgs doublets → 5 Higgs bosons : h, H, a, $H^{\pm}$
- 4 types of models, main parameters : tanβ, α
- compatible with a 125 GeV SM-like scalar (h or H) + a light Higgs Boson (a or h) in the "alignment limit"

→ Next-to-Minimal Supersymmetric Standard Model (NMSSM):
- 2 Higgs doublets + 1 singlet superfields → 7 Higgs bosons : h1, h2, h3, a1, a2, $H^{\pm}$
- solves the known "μ-problem" of the simplest SUSY model MSSM
- compatible with a 125 GeV SM-like scalar (h1 or h2) + a mostly "singlet-like" light Higgs Boson (a1 or h1)

Lightest Higgs h1 in NMSSM



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Relic density:

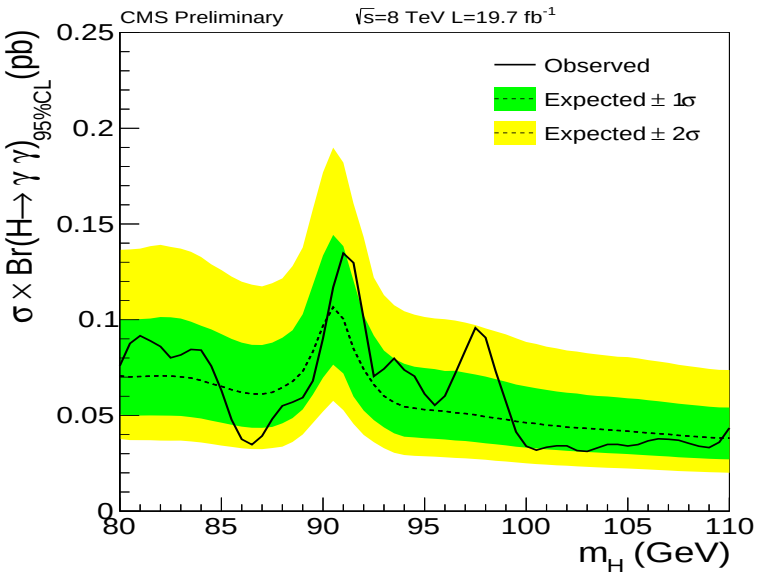
$\Omega h2<0.1102$

$0.1102< \Omega h2<0.1272$

("WMAP" window)

- Assume the next-to-lightest scalar Higgs boson h2 corresponds to the observed 125 GeV Higgs in LHC, then focus on the lightest Higgs boson h1
- Scans with NMSSMTools and the constraints from HiggsBounds and HiggsSignal on h2, and other constraints
- The lightest Higgs h1 signal strength can be enhanced by a factor up to ∼3.5 compared to the SM predictions in the mass range 85 to 95GeV.

The result with 8TeV data: Upper limits on σxBR



- Observed limit ranges from 40-75 fb.
- Statistical treatment for extraction of limits and p-values is the same as that used by all CMS Higgs boson search channels as well as for the combination of channels.

CMS-HIG-14-037

Interpretation with 2HDM

Is CMS 8 TeV h$\rightarrow \gamma\gamma$ result sensitive to a lighter Higgs in 2HDM?

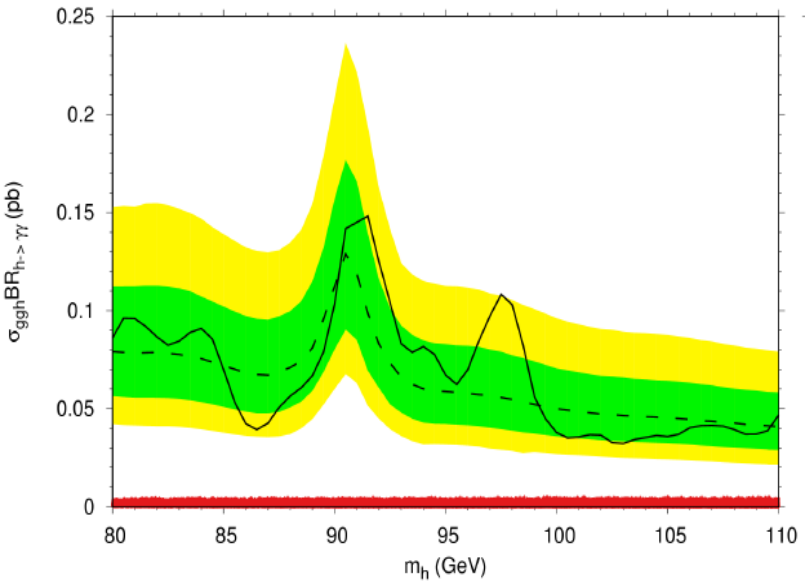
- Reminder: Two doublets - $\Phi 1$ and $\Phi 2$, 5 Higgses - h, H, A, $H^{\pm}$
- Parameters in the physical basis : mH=125 GeV in our case

  m_h, m_H, m_A, $m_{H^{\pm}}$, $\sin(\beta - \alpha)$, ν, m_{12}^2
- 4 types of 2HDM: different ways to couple Φ_1 and Φ_2 to fermions : focus on Type I
- Extension of 2HDM predictions from gluon fusion and bb production modes in SusHi+2HDMC : VBF/VH production
- First comparison of 2HDM with the LHC (CMS) low mass di-photon analysis at 8 TeV

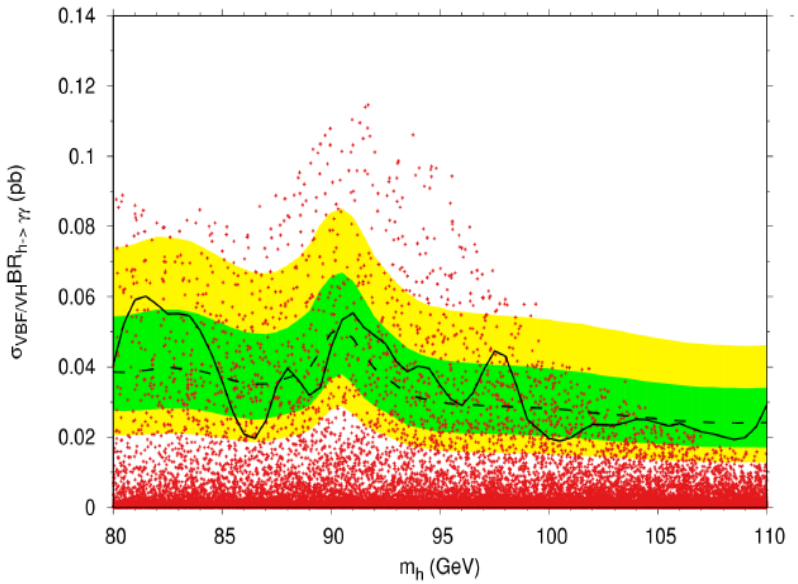
	Type I	Type II	Flipped(Type Y)	Lepton Specific(Type X)
Up-type quark	Φ_2	Φ_2	Φ_2	Φ_2
Down-type quark	Φ_2	Φ_1	Φ_1	Φ_2
Leptons	Φ_2	Φ_1	Φ_2	Φ_1

A lighter scalar Higgs : Sensitivity

$\sigma_{gg\to h}$ X $\mathrm{BR}_{h\to\gamma\gamma}$



$\sigma_{VBF/VH\to h}$ X $\mathrm{BR}_{h\to\gamma\gamma}$



G. Cacciapagliaa, J. Tao et al JHEP12(2016)068

- No sensitivity in the gluon fusion production channel
- Red points passing the indirect, LEP and LHC Run1 constraints
- Many points are above the CMS observed limit in the VBF/VH production mode for light Higgs boson with mass below 105 GeV

A lighter scalar Higgs : Constraints

- An exclusion zone in the plane tanβ vs m_h in the particular case
- Violet points passing the indirect, LEP and LHC Run1 constraints
- Orange points are excluded by the CMS low mass di-photon analysis at 95% C.L..
- But the exclusion zone depends on the value of the different free parameters.

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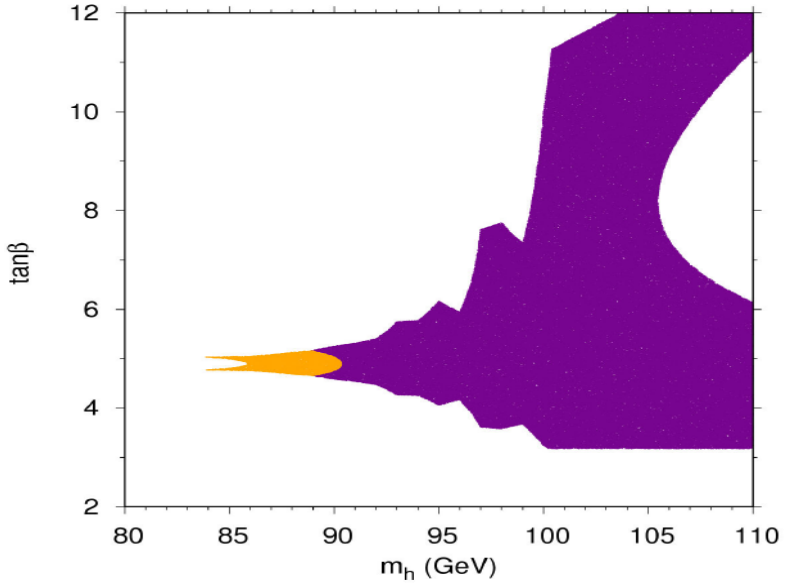

$m_H = 125 GeV, m_A = m_{H_\pm} = 80$ GeV
$\sin(\beta - \alpha)$ =-0.2 and $m_{12} = 30$ GeV

A lighter pseudo-scalar Higgs

- Similar kinematic behavior of the two photons coming from a pseudo-scalar particle and a scalar particle
- So can directly apply the CMS study as for the scalar case to constrain a possible light pseudo-scalar
- Restrict ourselves to Type I only in the gluon fusion production channel
- No sensitivity to a light pseudo-scalar at the LHC Run 1 in the di-photon final state

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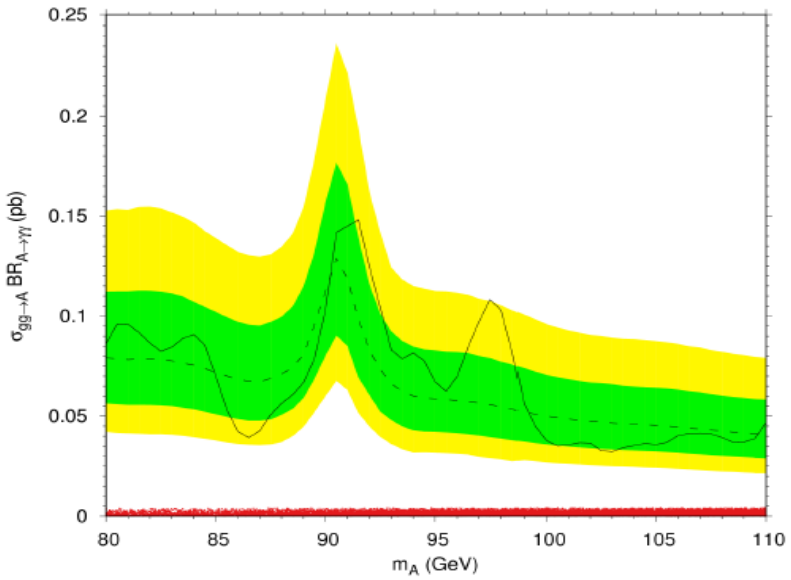


Red points passing the indirect, LEP and LHC Run1 constraints

Search with 2016 13TeV data

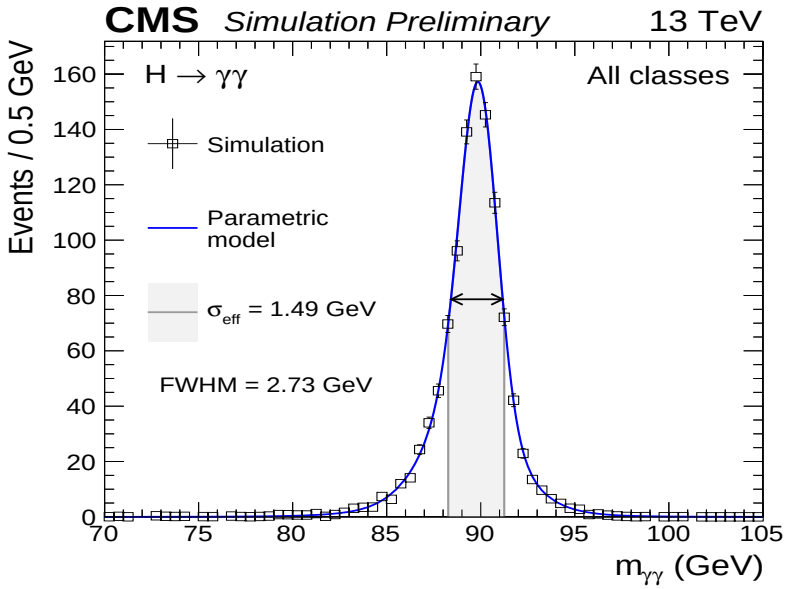
CMS-HIG-17-013

• Dedicated Run 2 "low-mass" diphoton triggers: Cope with increased rate with stricter isolation/shower shape requirements + reject endcap photons compatible with conversions

• Enables extension of lower limit of search zone : 80→70 GeV< m_h¡110GeV

• As in Run 1, inherit photon and event reconstruction/selection techniques from standard H→ $\gamma\gamma$ analysis (photon ID and kinematic event selection BDTs...)

• 3 inclusive event classes based on DiPhoton BDT scores



• Entire 2016 dataset (35.9 fb^{-1})*analyzed*
• Signal model: Sums of Gaussian functions (same as Run1)

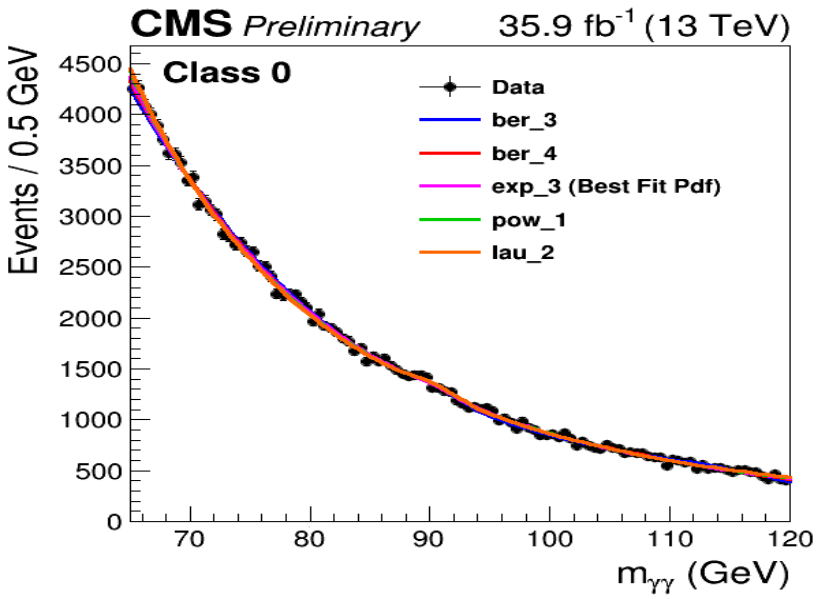
Background modelling

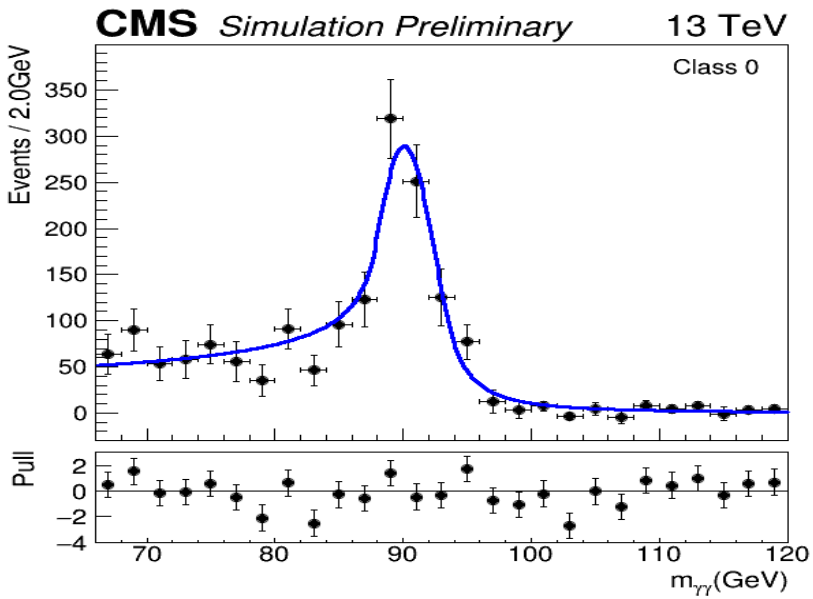
CMS-HIG-17-013

• Background Model(data driven): Sum of polynomial (chosen from 4 families) + Double-sided Crystal Ball (DCB) function for relic Z→ee component

• Chosen polynomials: 3d-order sum of exponentials (classes 0,2), 1st-order power law (class1)

• DCB: shape parameters from MC "double-fake" events, syst. uncertainty from "single-fake" events, normalization floating





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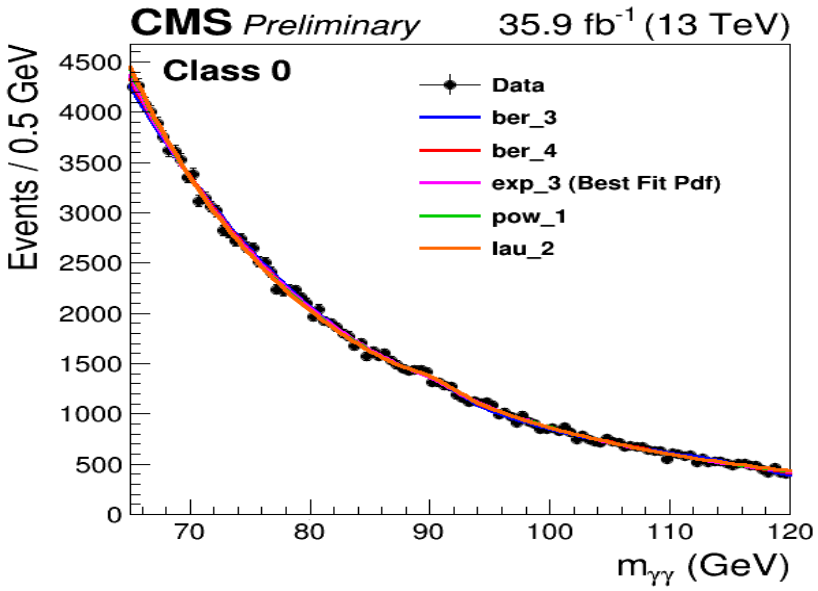
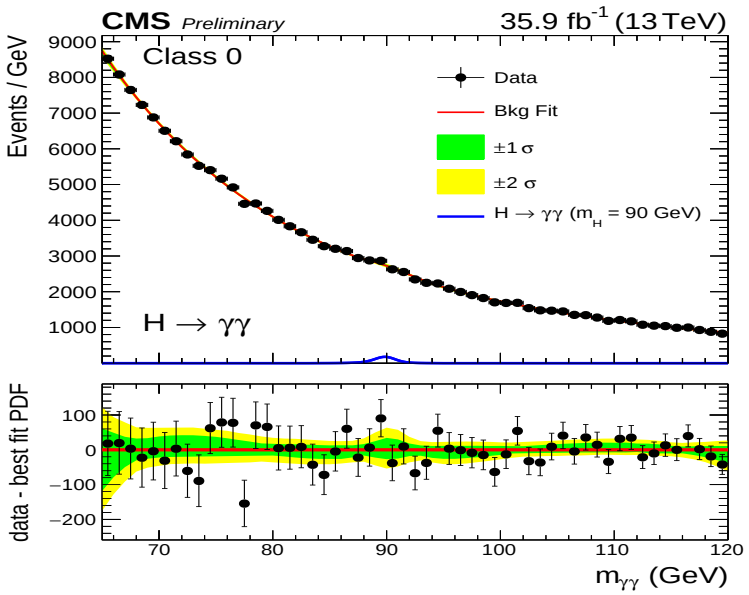
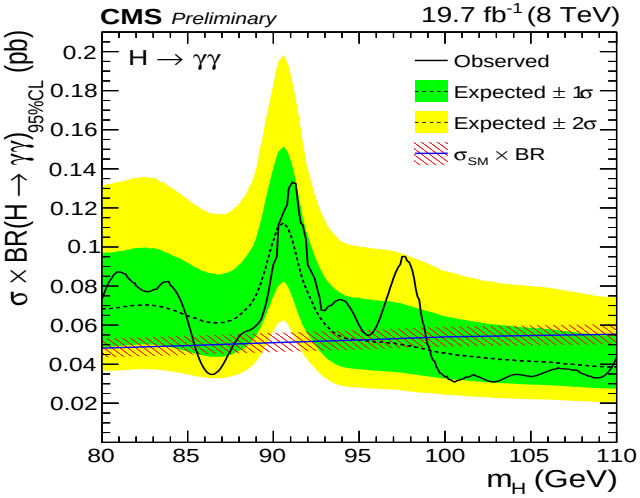


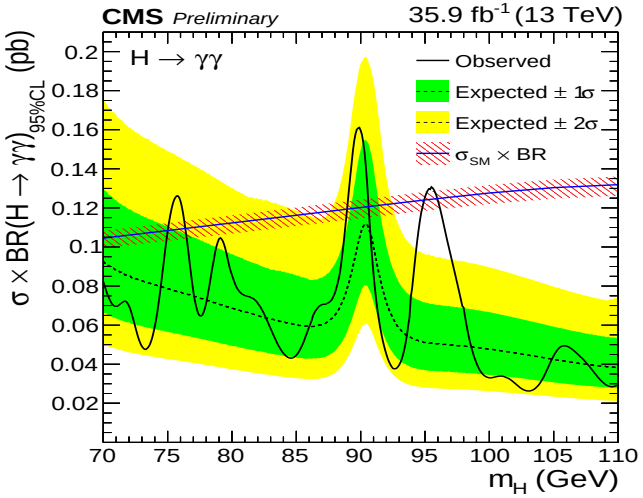


• Choice of background function discrete parameter in lh fit to data, systematic error associated with each possible choice (discrete profiling or "envelope" method)

Upper limits on σxBR

CMS-HIG-17-013



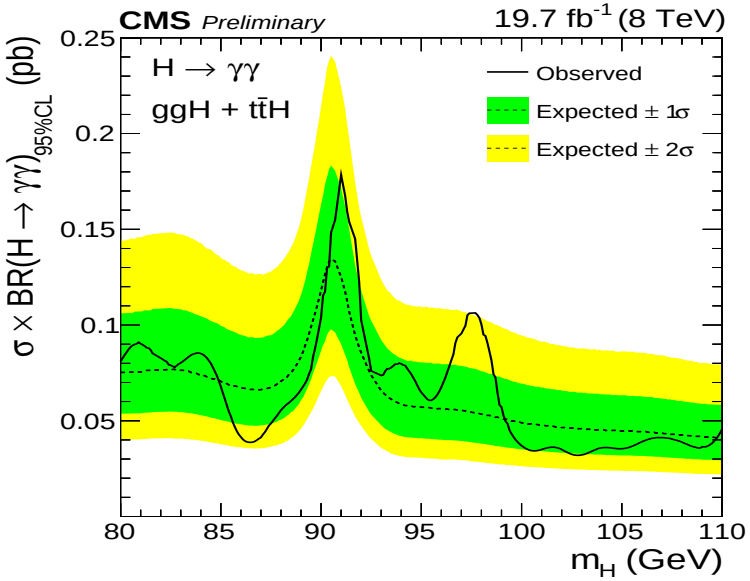


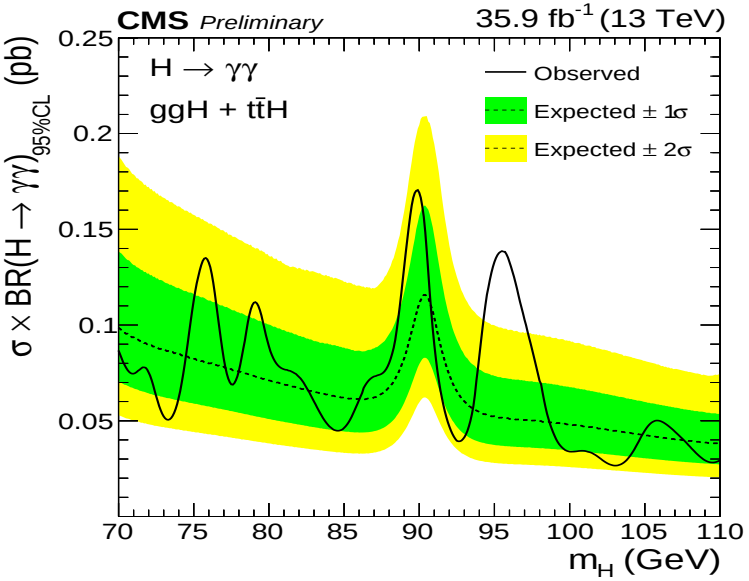
→ 8 TeV: minimum(maximum) limit on σ X Br : 31(133) fb at m=102.8(91.1)GeV
→ 13 TeV: minimum(maximum) limit on σ X Br : 26(161) fb at m=103.0(89.9)GeV

• 8 TeV limits on σ X Br redone with 0.1 GeV step. Production processes assumed in SM proportions.

Comparison of Run1 and Run2 results(ggH+ttH)

CMS-HIG-17-013

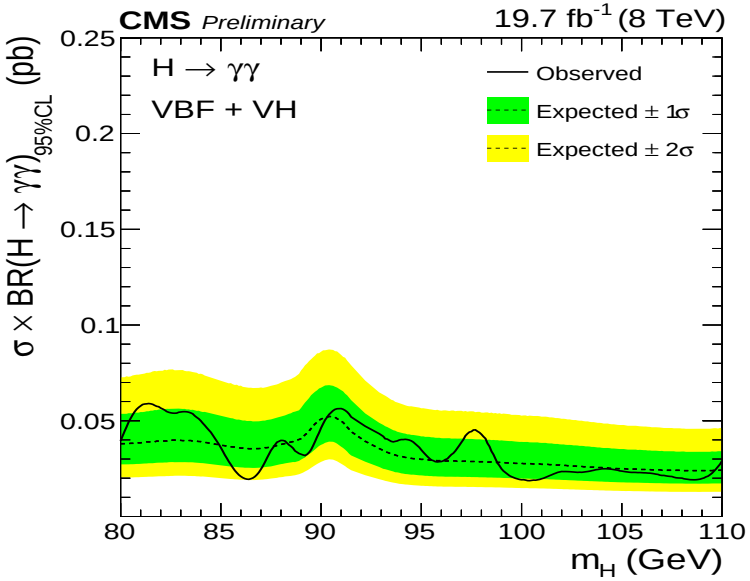


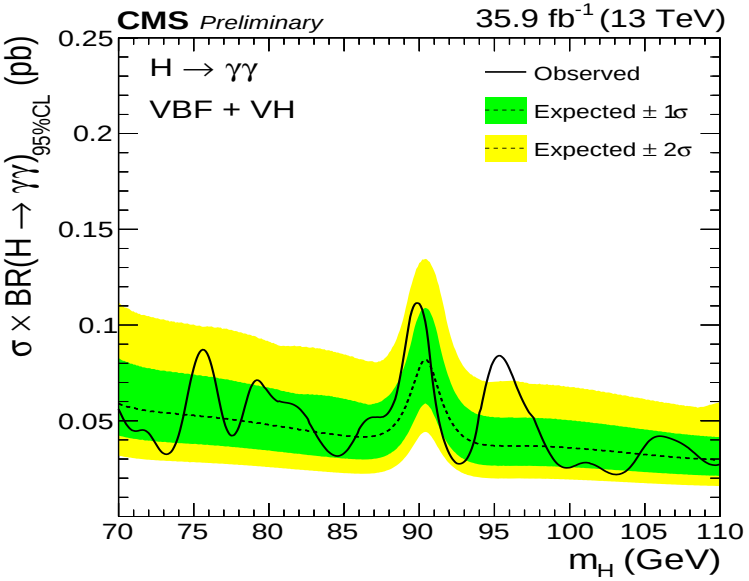


- Per-process limits on σ X Br assuming 100% gluon-induced processes (ggH, ttbarH in SM proportions)

Comparison of Run1 and Run2 results(VBF+VH)

CMS-HIG-17-013





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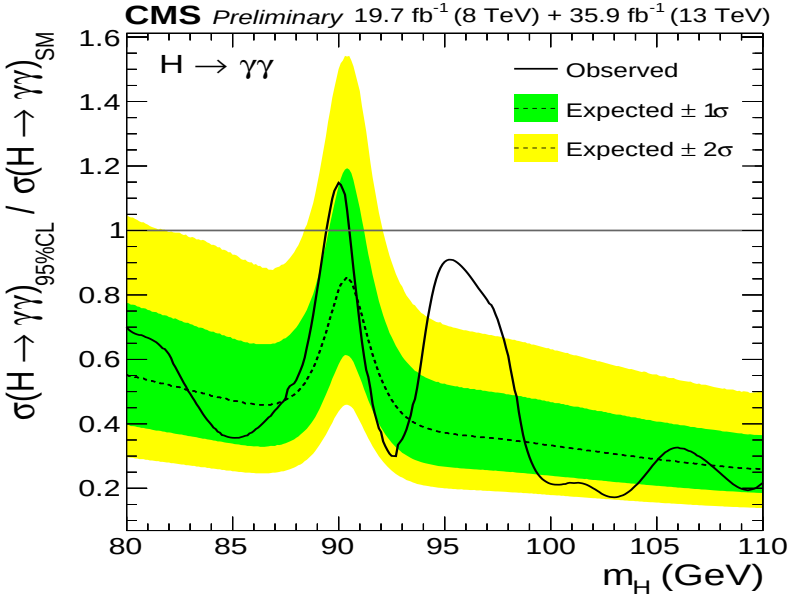
Run1+Run2: Combined limit results

CMS-HIG-17-013

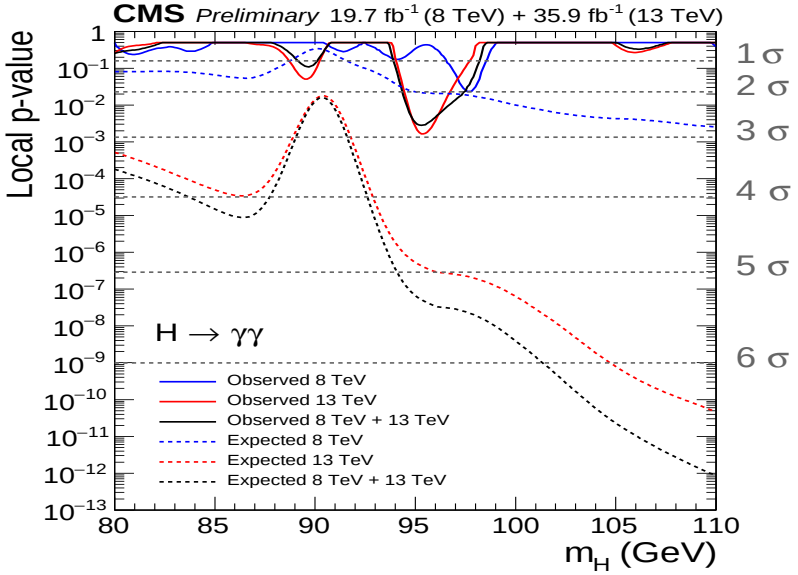


→ 8 TeV+13TeV: minimum(maximum) limit on (σ X Br)/ (σ X Br)$_{SM}$: 0.17(1.15) at m=103.0(90.0)GeV

• Combined 8 TeV+13 TeV s X BR limit normalized to SM expectation (production processes assumed in SM proportions). No significant excess with respect to expected limits observed.

Local P-value of Run1, Run2 and Run1+Run2(2016) Combination

CMS-HIG-17-013



- Expected and observed local p-values for 8 TeV, 13 TeV and their combination

→ 8 TeV: Excess with 2.0σ local significance at m=97.6 GeV

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

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

→ More data are required to ascertain the origin of this excess

Summary

• From NMSSM (Chin. Phys. C 38 (2014): 073101), signal strength of the lightest scalar Higgs boson h1 can be up to up to a factor $\sim$3.5 compared to SM with m_H 85-95GeV;
• Performed the searches for new resonances in $\gamma\gamma$ channel (CMS PAS HIG-14-037) in the range of [80,110] GeV with 19.7 fb^{-1} of data at $\sqrt{s}$=8TeV: No obvious excess; maximum local significance 1.9σ at m=97.7GeV
• Performed the searches for new resonances in $\gamma\gamma$ channel (CMS PAS HIG-17-013) in the range of [70,110] GeV with 35.9fb^{-1} of data at $\sqrt{s}$=13TeV: No obvious excess; maximum local significance 2.9σ at m=95.3GeV
• Interpreted with 2HDM(JHEP12(2016)068) : no sensitivity in ggh but VBF/VH;
• Looking forward to 13TeV 2017 data!

BackUp

NMSSM scans

- Assume the next-to-lightest scalar Higgs boson h2 corresponds to the observed 125 GeV Higgs in LHC, then focus on the lightest Higgs boson h1

- Scans with NMSSMTools and the constraints from HiggsBounds and HiggsSignal on h2, and other constraints

- Parameter ranges by theoretical and experimental considerations

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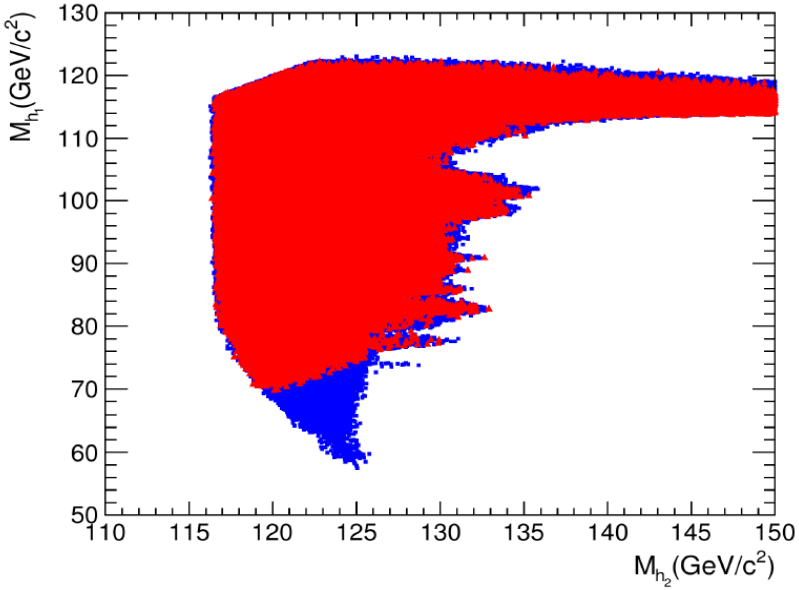


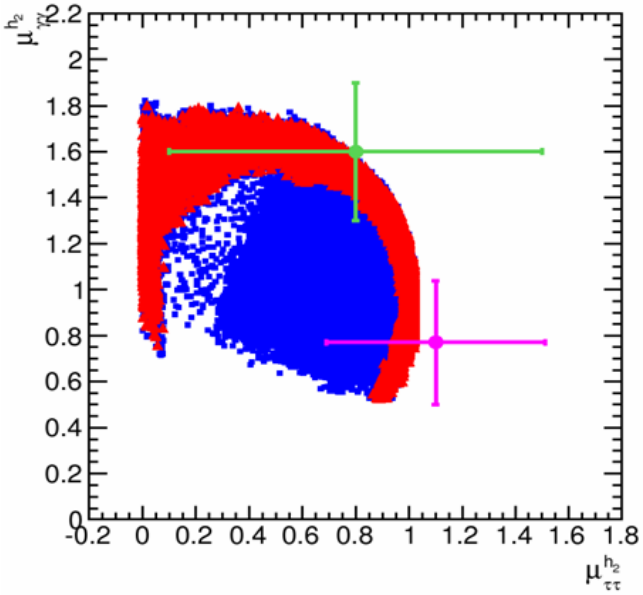
$0.1102 < \Omega h^2 < 0.1272$("WMAP" window)

Before constraint on h2 from Higgs Bounds and Higgs Signal

h2 compared with LHC experiments

- Compare the h2 signal strength in $\gamma\gamma$, ZZ, WW, $\tau\tau$ and bb decay modes with the ATLAS and CMS results: magenta cross for CMS and green for ATLAS in 2013.

NMSSM h2 is compatible with the LHC-discovered Higgs boson



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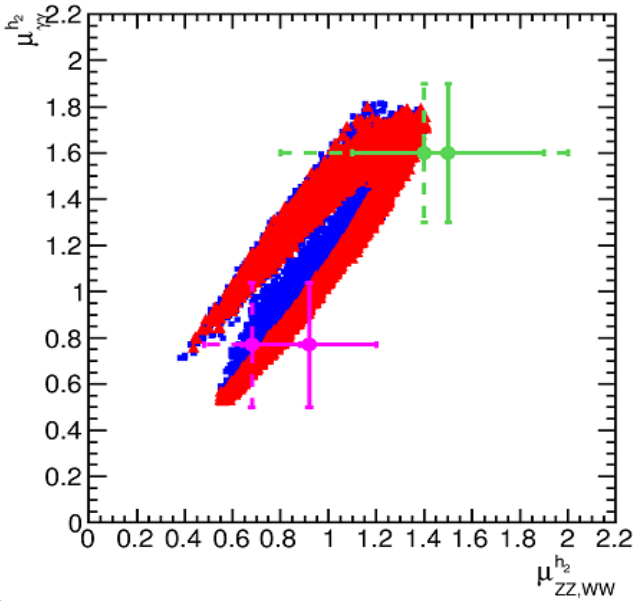
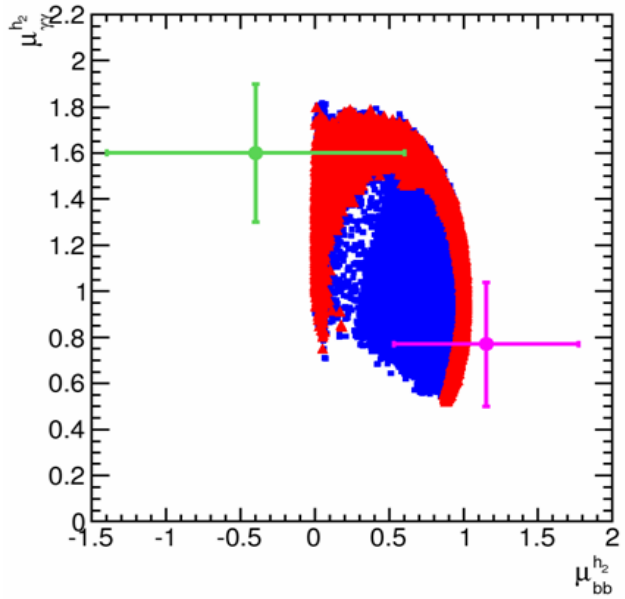
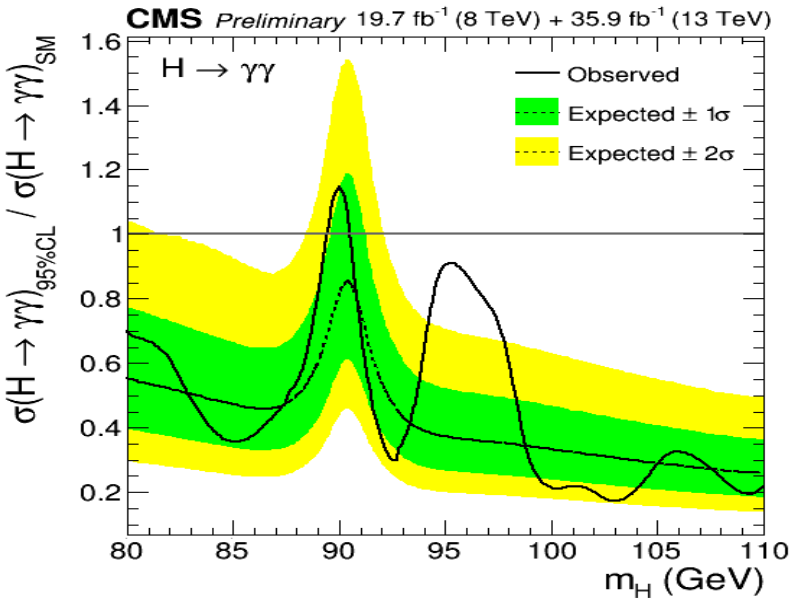




Run1+Run2: Combined results

CMS-HIG-17-013

All experimental + theoretical systematic uncertainties assumed uncorrelated except for those on signal acceptance due to scale variations + those on production cross sections (assumed 100% correlated).



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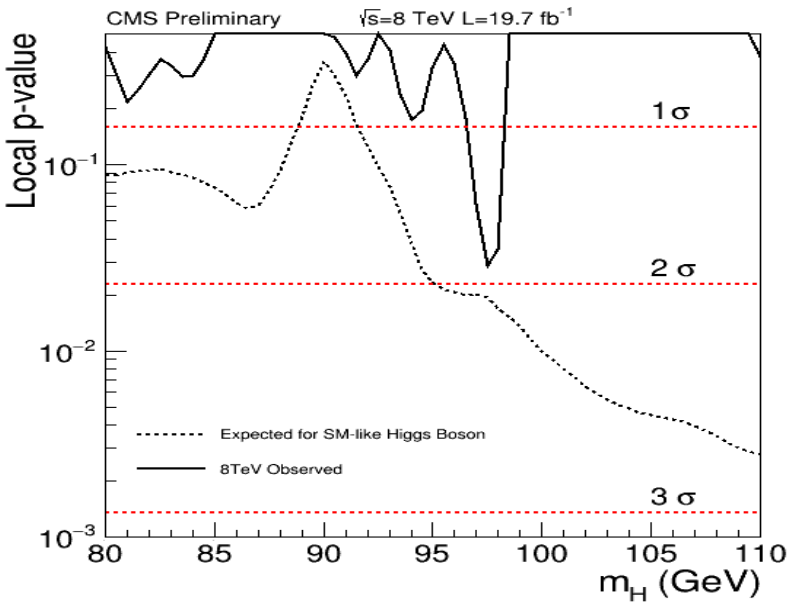
The result with 8TeV data: Local p-value

CMS PAS HIG-14-037



- Maximum significance: 1.9σ at $m_H = 97.5$ GeV