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

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Outline

- **Motivation**

- **Lightest scalar Higgs boson $h_1 \rightarrow \gamma\gamma$ in NMSSM**

  *J. Fan, **JT**, G. Chen et al. Chin. Phys. C 38 (2014): 073101*

- **Searching results from CMS**

  CMS-HIG-14-037

- **Interpretation with 2HDM**

  *G. Cacciapagliaa, S. Le Corre, **JT** et al. arXiv:1607.08653*

- **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 : $\tan\beta$, 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)**

NMSSM scans

- Assume the next-to-lightest scalar Higgs boson h_2 corresponds to the observed 125 GeV Higgs in LHC, then focus on **the lightest Higgs boson h_1**

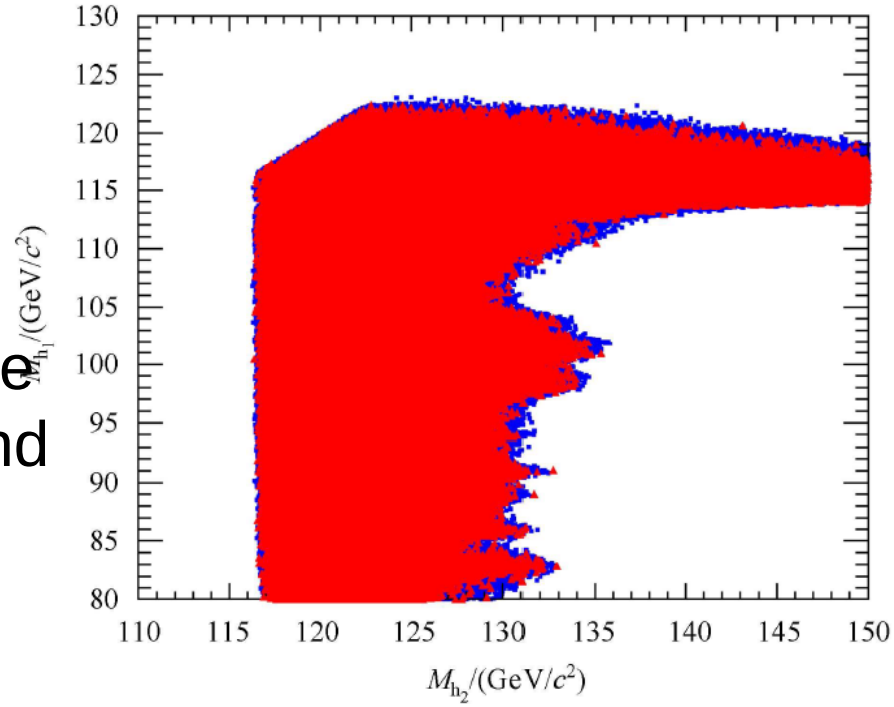
- Scans with ***NMSSMTools*** and the **constraints** from ***HiggsBounds*** and ***HiggsSignal*** on **h_2**, and **other constraints**

- **Parameter ranges** by theoretical and experimental considerations

$$0.6<\lambda<0.75, \quad 0.2<\kappa<0.3, \quad 3<\tan\beta<4,$$

$$165\ \mathrm{GeV}/c^2<\mu_{\mathrm{eff}}<190\ \mathrm{GeV}/c^2.$$

J. Fan, **JT**, G. Chen et al. Chin. Phys. C 38 (2014): 073101



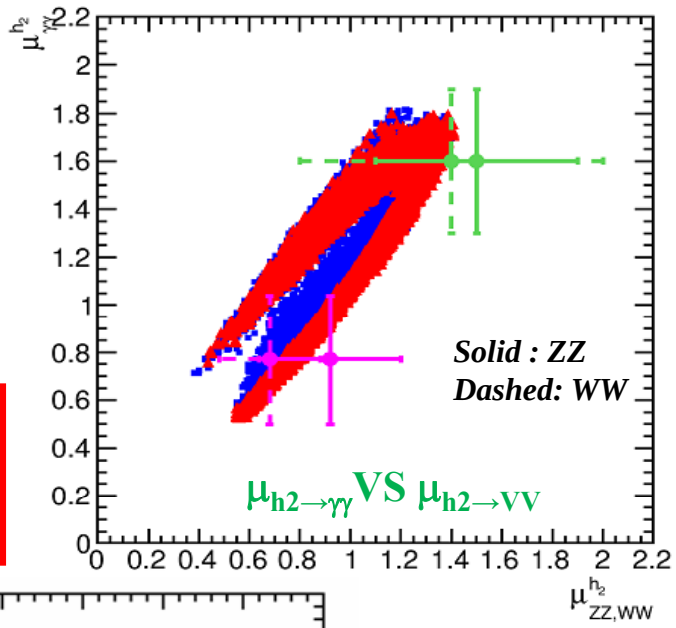
Relic density: $\Omega h^2<0.1102$
$0.1102<\Omega h^2<0.1272$ ("WMAP" window)

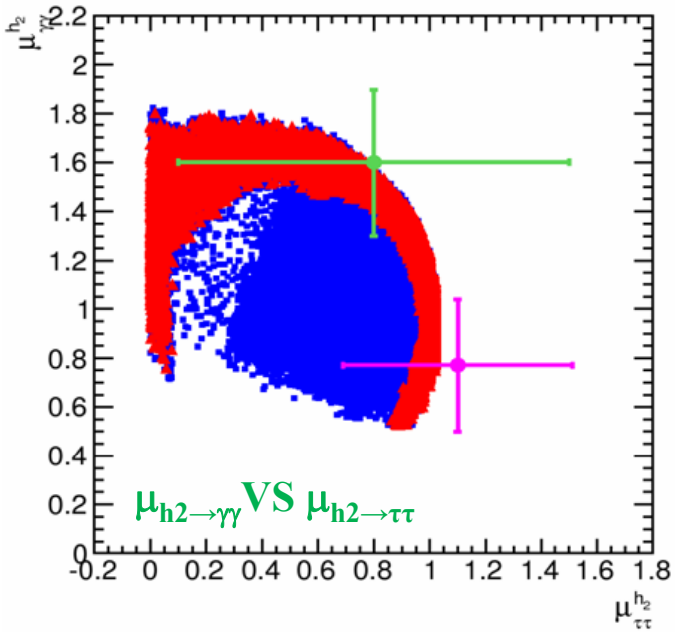
Before constraint on h_2 from *HiggsBounds* and *HiggsSignal*

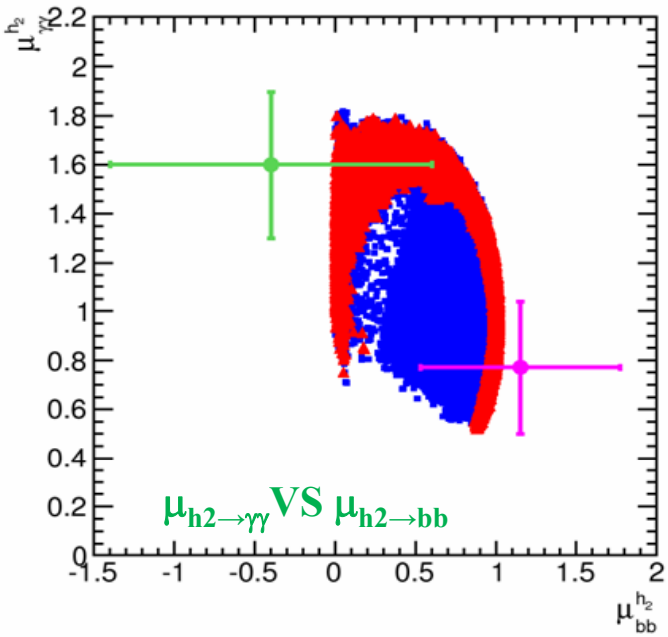
h_2 compared with LHC experiments

➢ Compare the **h2 signal strength** in **γγ, ZZ, WW, ττ and bb** decay modes with the ATLAS and CMS results: ***magenta cross for CMS and green for ATLAS in 2013***.

NMSSM h_2 is compatible with the LHC-discovered Higgs boson







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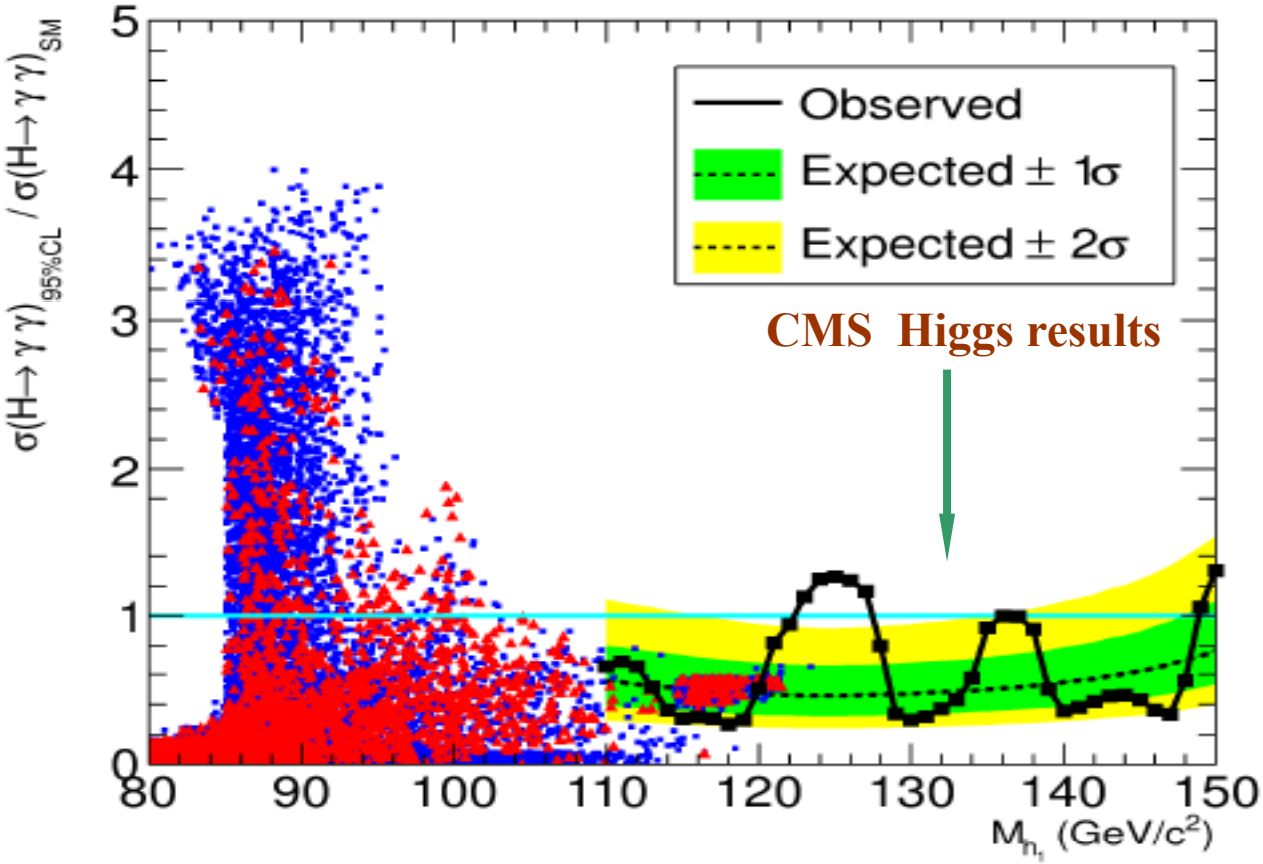
Lightest Higgs h_1 : $\sigma_{\gamma\gamma}/\ \sigma_{\gamma\gamma}^{SM}$



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Relic density:
Ωh^2<0.1102
0.1102<Ωh^2<0.1272

The lightest Higgs **h_1 signal strength** can be enhanced by **a factor up to ~3.5** compared to the SM predictions in the mass range 85 to 95GeV

CMS search with 8 TeV data

✓ We performed the search for new diphoton resonances with mass in the range of [80,110] GeV and with 8 TeV 19.7 fb^{-1} data .

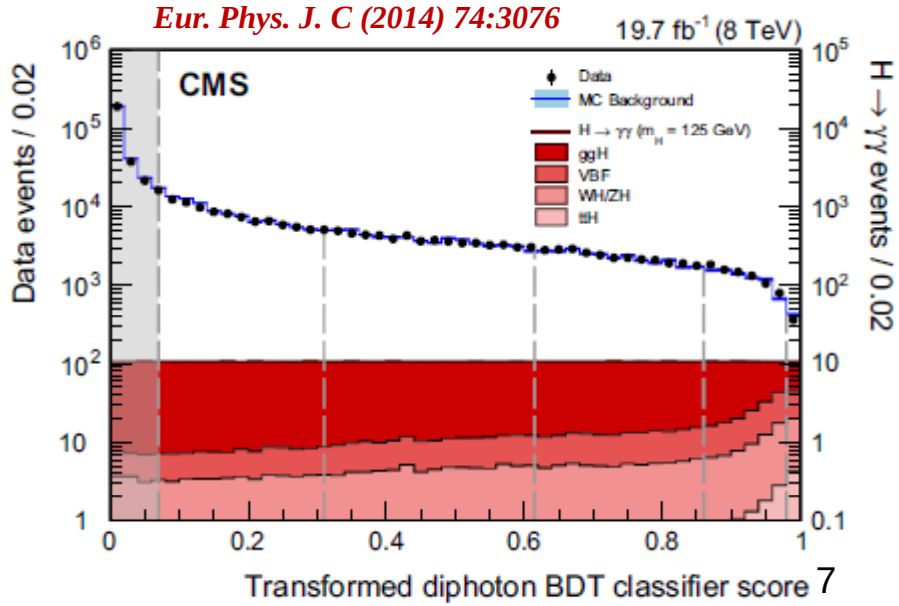
CMS PAS HIG-14-037

✓ Same **analysis strategy** as the standard CMS **H→γγ** analysis with different kinematic selections

- $pt_{lead}/m_{gg}>(hlt_{lead}+2\ GeV)/m_{\gamma\gamma min}) = 28/80$
- $pt_{trail}/m_{gg}>(hlt_{\mathbf{trail}}+2\ GeV)/m_{\gamma\gamma \mathbf{min}}) = 20/80$
- $|\eta|< 2.5$ but excluding $1.4442 < |\eta|< 1.566$

✓ Events were split into **4 classes** to improve the sensitivity, based on the **diphoton mass resolution and kinematics MVA** used in the standard CMS H→γγ analysis

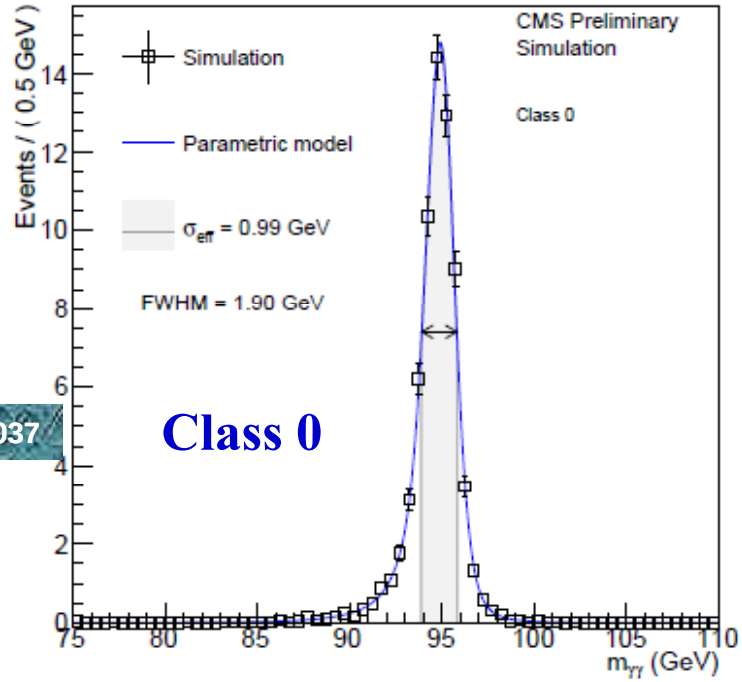
Eur. Phys. J. C (2014) 74:3076



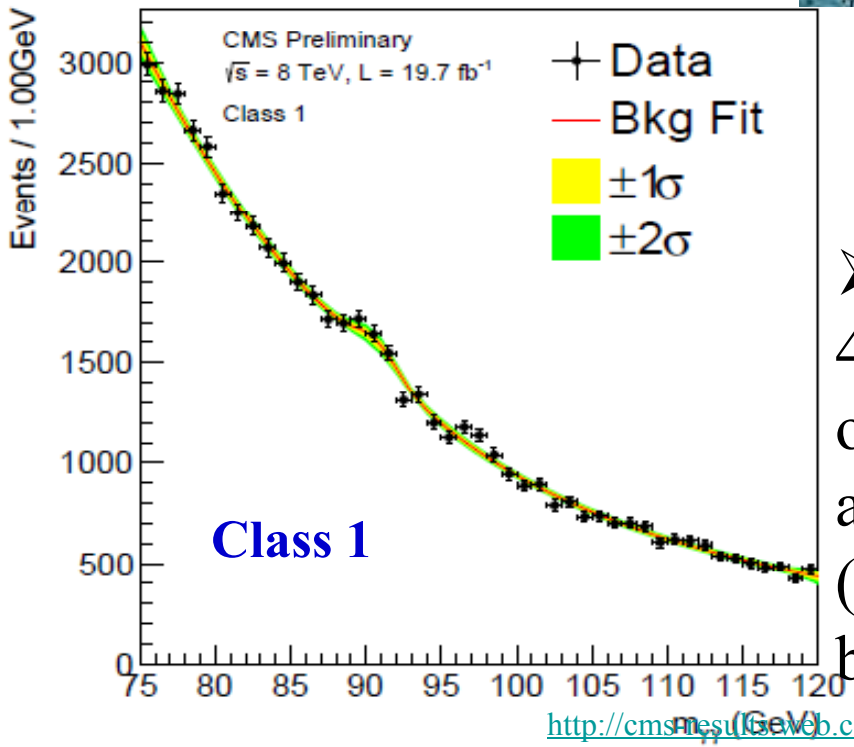
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-14-037/index.html

Signal and background modelling

➢ Parametric **signal** modelling procedure: a sum of Gaussian functions to fit signal MC at each mass point, for **each production process** in **each of the 4 event classes**



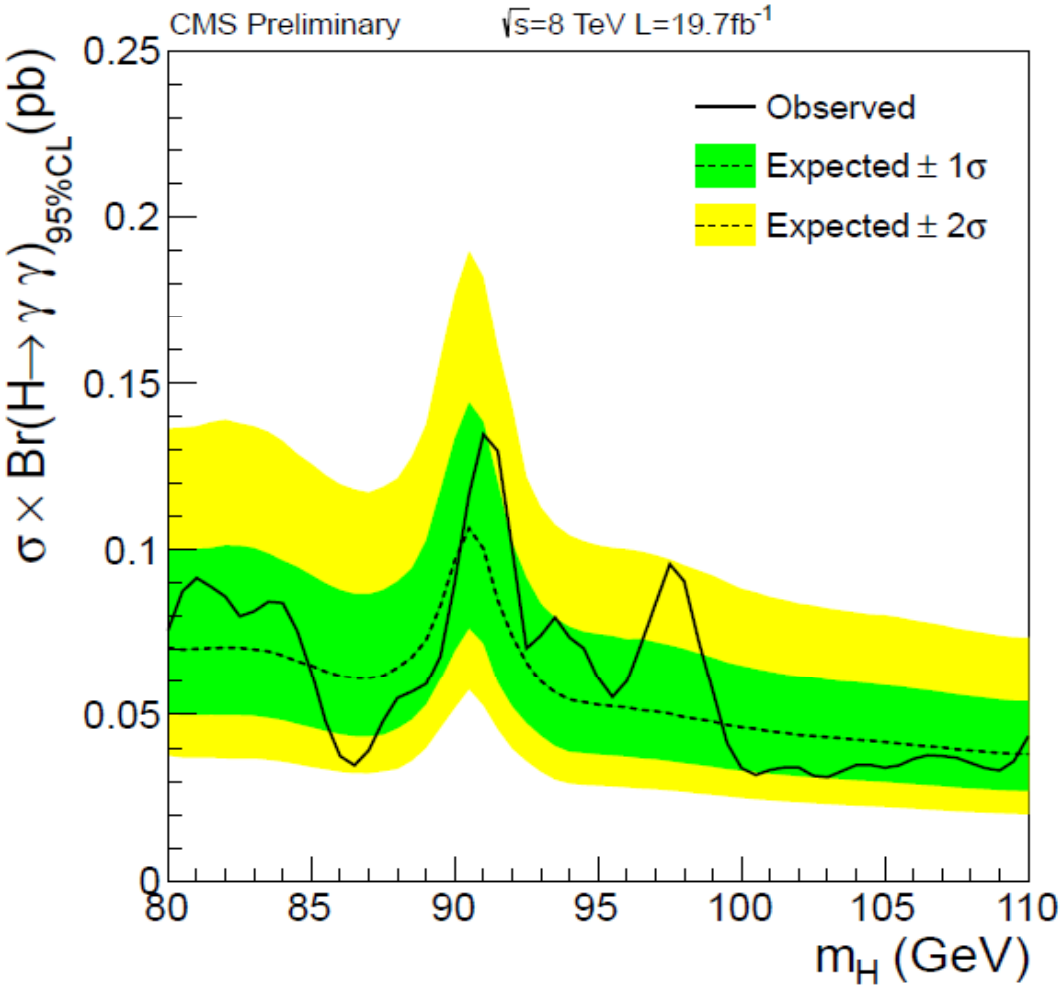
CMS PAS HIG-14-037



➢ **Background** model **fits to data** in the 4 event classes: Nth order (N = 4/5 /5/5) of **Bernstein polynomial function** plus additional **double sided Crystal Ball** (DCB) function for **Z→ee** events with both electrons identified as photons

http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-14-037/index.html

Upper limits on σ×BR



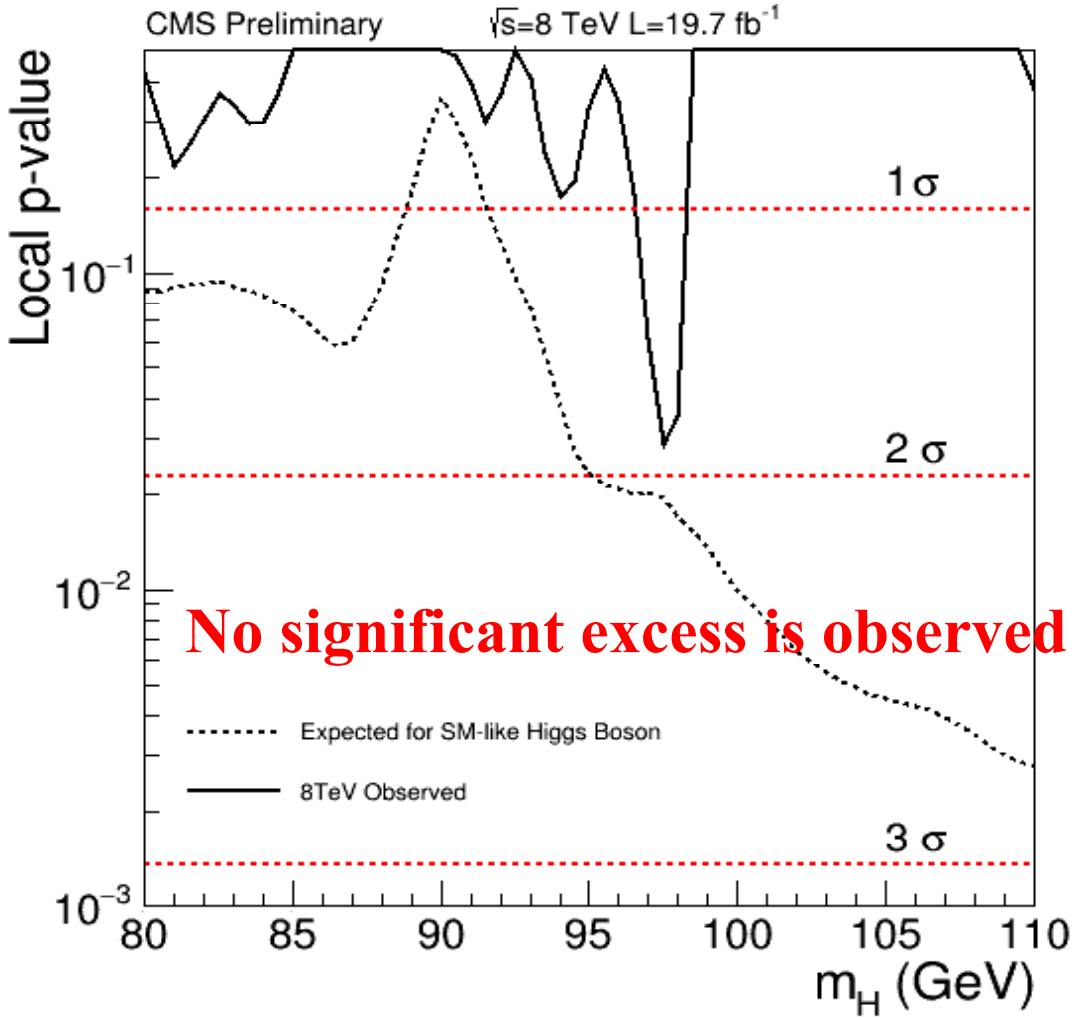
CMS PAS HIG-14-037

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

- **Observed limit ranges from 40-75 fb**
- **Exclude scalars with σ×BR(h→γγ) from 0.8- 3 times the SM**

http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-14-037/index.html

Combined Local p-value



CMS PAS HIG-14-037

Maximum significance: ~1.9σ at m_H=97.5 GeV

http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-14-037/index.html

Interpretation with 2HDM

Is CMS 8 TeV h→γγ result sensitive to a lighter Higgs in 2HDM?

- Reminder: Two doublets - ϕ_1 and ϕ_2, 5 Higgses - h, H, A, $H^{\pm}$

- Parameters in the **physical basis** : m_H=125 GeV in our case

$$m_h,\ m_H,\ m_A,\ m_{H^\pm},\ \tan\beta,\ \sin(\beta-\alpha),\ v,\ m_{12}^2$$

- **4 types of 2HDM** : different ways to couple ϕ_1 and ϕ_2 to fermions : focus on **Type I**

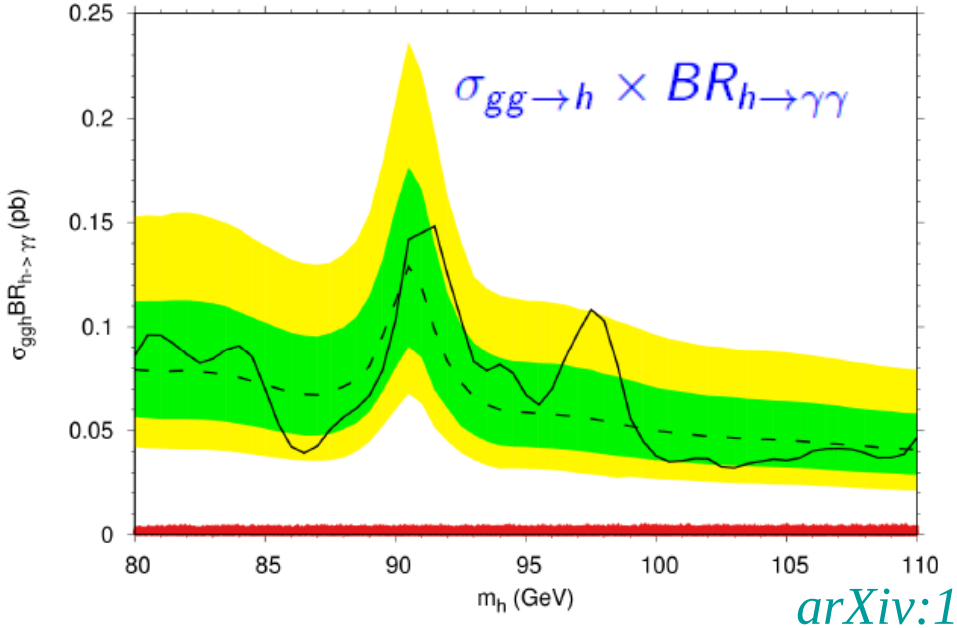
	Type I	Type II	Flipped (Type Y)	Lepton Specific (Type X)
Up-type quark	ϕ_2	ϕ_2	ϕ_2	ϕ_2
Down-type quark	ϕ_2	ϕ_1	ϕ_1	ϕ_2
Leptons	ϕ_2	ϕ_1	ϕ_2	ϕ_1

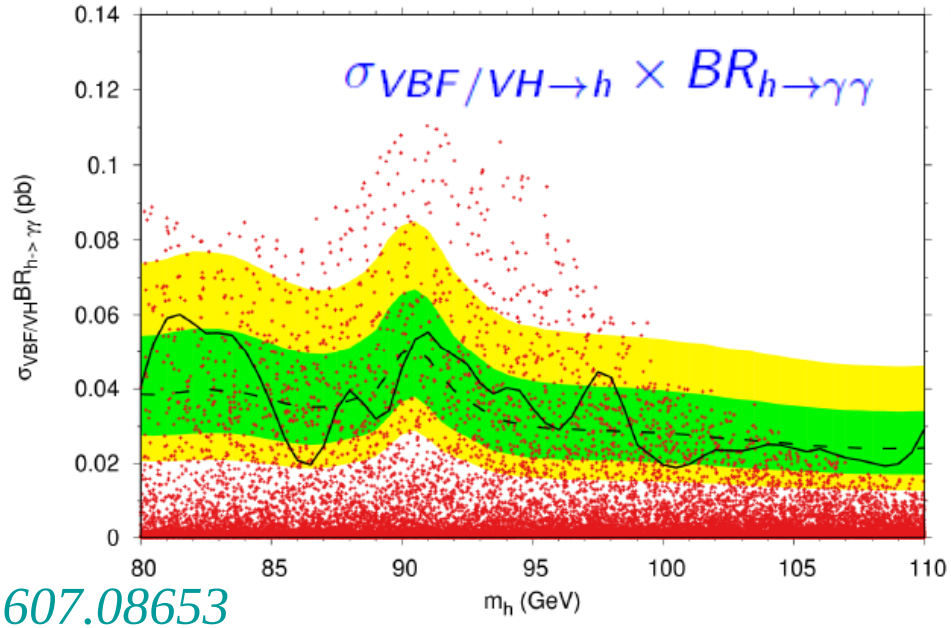
- **Extension** of 2HDM predictions from **gluon fusion and bb production** modes in SusHi+2HDMC : **VBF/VH production**

G. Cacciapagliaa, A. Deandrea , S. Gascon-Shotkin, M. Lethuilliera , S. Le Corre, **JT** *arXiv:1607.08653* *(28 Jul 2016)*

- **First comparison of 2HDM** with the LHC (CMS) low mass di-photon analysis at 8 TeV

A lighter scalar Higgs : Sensitivity





arXiv:1607.08653

Red points passing the indirect, LEP and LHC Run1 constraints

- **No sensitivity** in the **gluon fusion** production channel

- **Many points** are above the CMS observed limit in the **VBF/VH production** mode for light Higgs boson with **mass below 105 GeV**

m_h (GeV)	m_H (GeV)	m_A (GeV)	$m_{H^\pm}$ (GeV)	$\sin(\beta-\alpha)$	$\tan\beta$	$m12^2$
[80;110]	125	[60;650]	[60;630]	[-0.3;-0.05]	[2;12]	[-(100)^2;+(100)^2]

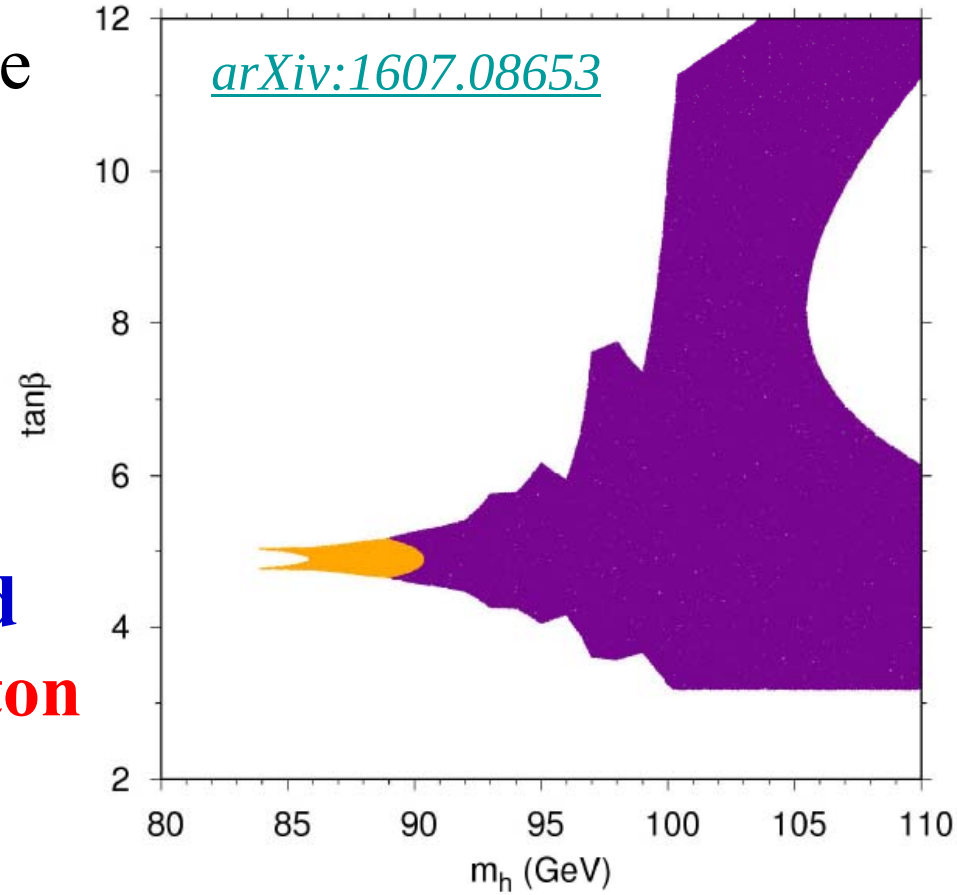
A lighter scalar Higgs : Constraints

- 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.



m_H = 125 GeV, $m_A = m_{H^\pm}$ =80 GeV

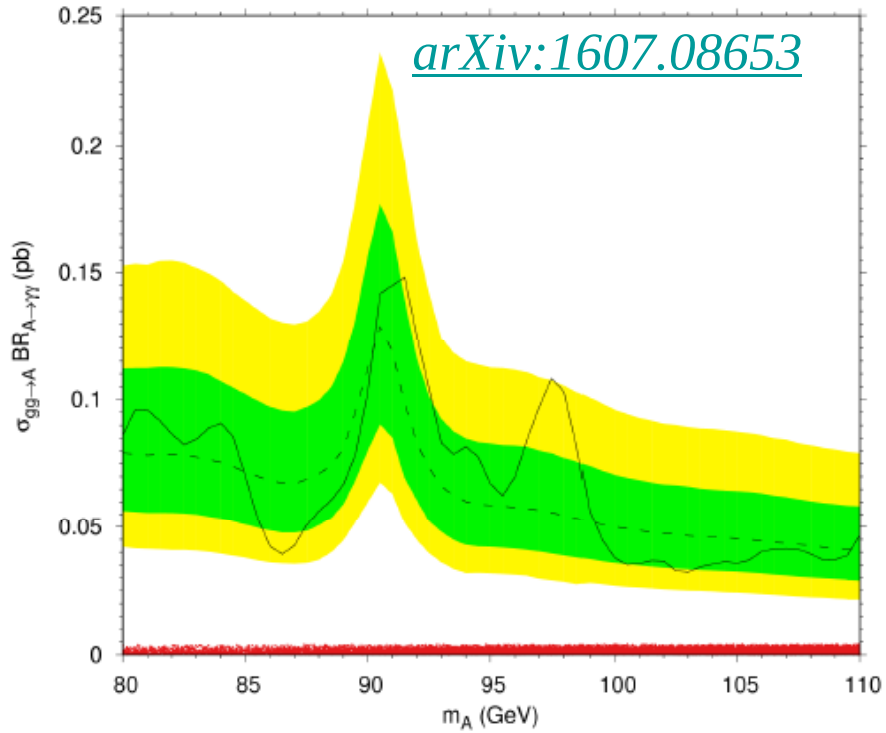
$\sin(\beta - \alpha)$=-0.2 and m_{12} =30 GeV.

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



Red points passing the indirect, LEP and LHC Run1 constraints

No sensitivity to a light pseudo-scalar at the LHC Run 1 in the di-photon final state

m_h (GeV)	m_H (GeV)	m_A (GeV)	$m_{H^\pm}$ (GeV)	$\sin(\beta-\alpha)$	$\tan\beta$	m_{12} (GeV)
[80; 110]	125	[80; 110]	[60; 630]	[-0.4; 0.3]	[1.5; 50]	[-(300)^2; +(100)^2]

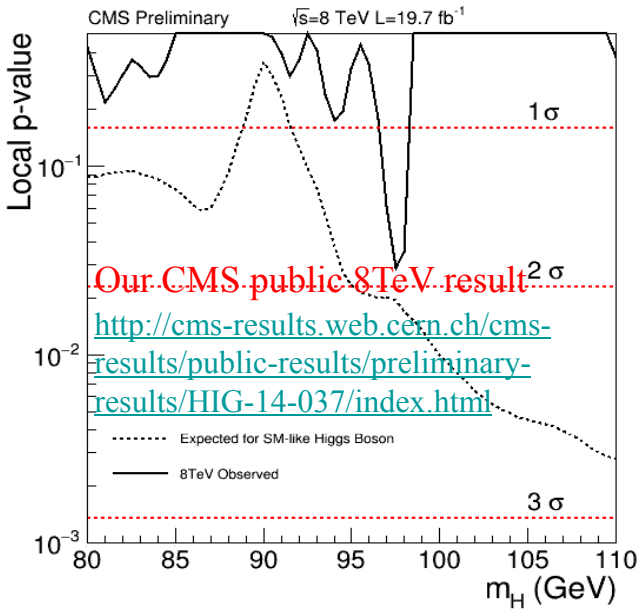
Summary

- From **NMSSM** (**Chin. Phys. C 38 (2014): 073101**), signal strength of the lightest scalar Higgs boson h_1 can be up to **up to a factor ~3.5** compared to SM

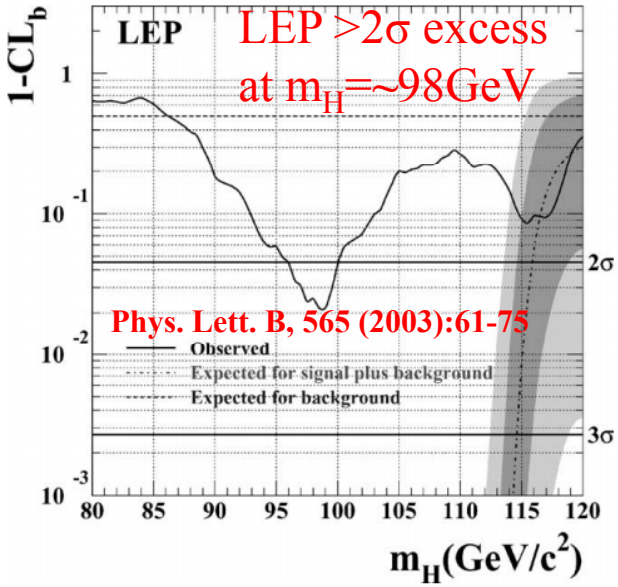
- Performed the **searches** for new resonances in γγ channel (**CMS PAS HIG-14-037**) in the range of **[80,110] GeV** with **19.7 fb^{-1} of data at √s=8TeV**: ***No obvious excess***

- Interpreted with **2HDM**(*arXiv:1607.08653*) : *no sensitivity in ggh but VBF/VH*

- **Looking forward to 13TeV results**!



Our CMS public 8TeV result
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-14-037/index.html



LEP >2σ excess at m_H=~98GeV

Phys. Lett. B, 565 (2003):61-75

Thanks for your attention!

EXTRA

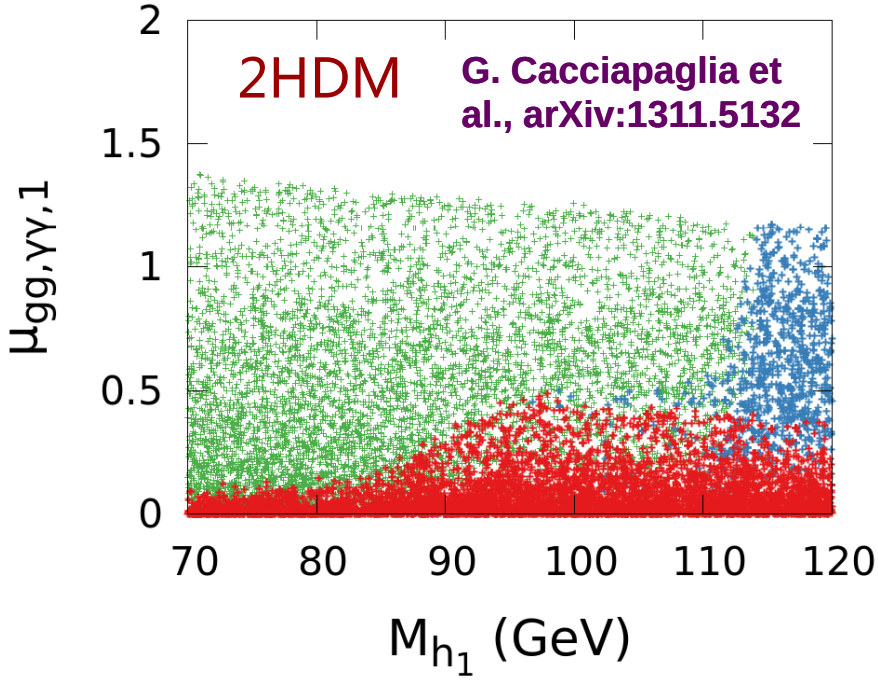
Motivation : Additionally in 2HDM

➢ Additionally, general Two-Higgs-Doublet-Models (2HDM) postulate the existence of additional light Higgs bosons and even admit the possibility that the observed H(125) is only the next-to-lightest Higgs.

Green (light grey) points are all points passing flavour and theoretical constraints

Blue points (grey) are a subset of those which also pass **LEP constraints** on h_1

Red (dark grey) points pass in addition the LHC couplings constraint on h_2



➢ So, we extend the CMS data analysis to the low- mass range down to 80 GeV, to search for possible additional Higgs bosons.

ATLAS Result

Phys. Rev. Lett. 113, 171801

- Both low- and high-mass extensions to the SM search.
- Limits on σxBR quoted in fiducial region: ET >22 GeV for both leading and subleading photons, $|\eta| < 2.37$ but excluding $1.37 < |\eta| < 1.56$
- No evidence for signal, **largest excess <2σ at m~80 GeV**