# Search for a low mass Higgs boson decaying into 2 photons in CMS (CMS-HIG-14-037)

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# Outline

## Motivations

J.Fan et al.



- BSM models such as the general 2HDM and NMSSM predict an extended Higgs sector. One can identify H125 as the next-to-lightest scalar Higgs boson $h_2$, and then focus on the lightest scalar $h_1$. Strong interest from some theoreticians
  *Ellwanger et al., JHEP 1203 (2012) 044 ...*

- A scan of the NMSSM parameter space (with all the constraints on Higgs and new physics) has shown that it would be possible to have a light Higgs boson with a signal strength of up to 3.5 × the SM Higgs boson, with a mass between 85 and 95 GeV
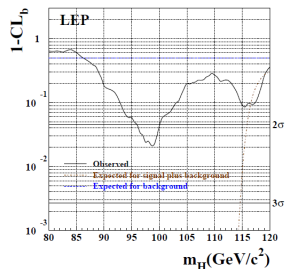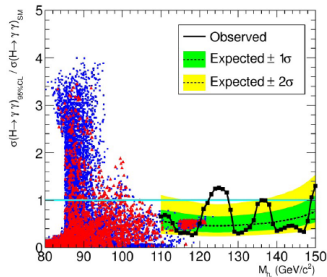  *J. Fan et al., Chinese Phys. C 38 073101*

- Small excess at LEP at $m \sim 98$ GeV in the bb channel (3 of the 4 experiments)
  *LEPHWG, Phys. Lett. B565 :61-75,2003*

- During Run 1, the standard $H \to \gamma\gamma$ analysis search range was [110,150] GeV

$\to$ **Goal : Extension of the $H \to \gamma\gamma$ analysis in the interval [80,110] GeV**

## Analysis overview

- Clear signature : 2 high-$p_T$ isolated photons
- Large smoothly-decreasing diphoton background (continuum), reducible (jet-jet and $\gamma$+jet with jet faking photon) and irreducible ($\gamma\gamma$)
- Low-mass analysis specificity : Drell-Yann background, with electrons from the Z misidentified as photons
  - Use of a stricter electron veto based on the Pixel detector
  - Include relic DY contribution in background model
- Mass resolution is crucial (calibrations, energy regression and vertex identification)
- Classification of diphoton events to gain in sensitivity
- Analysis inherited from the "standard $H \rightarrow \gamma\gamma$" analysis
  HIG-13-001 EPJC(74)3076
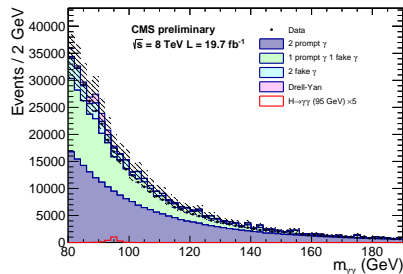


- 2012 dataset (19,7 $fb^{-1}$, 8 TeV)
- Main Trigger : $p_T > 26(18)$ GeV for the leading (trailing) photon ; $m_{\gamma\gamma} > 70$ or 60 GeV (period-dependant) ; loose isolation and shower shape criteria

# Mass resolution

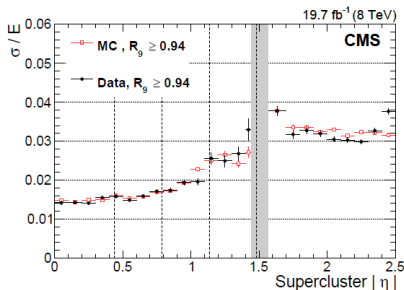$$m_{\gamma\gamma} = \sqrt{2E_1 E_2(1 - cos\alpha_{1,2})}$$

**Energy measurements** :

- ECAL performance (intercalibrations, crystal transparency changes corrections)
- High-level correction (photon energy regression)
- Final energy scale extraction from $Z \to ee$ events (cross-check with $Z \to \mu\mu\gamma$)

EGM-14-001, JINST 10 (2015) P08010



**Vertex ID** :

- Angular term contribution negligible if $\delta z < 1cm$
- CMS ECAL has no intrinsic pointing capability
- We use Boosted Decision Trees (BDT) to identify the primary vertex, based on the kinematics of the recoiling tracks + the tracks of identified conversions
- Then a second BDT estimates the probabilty of correct vertex assignment
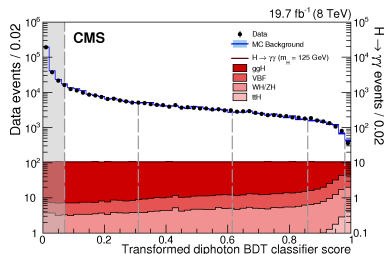- More than 80% average probability of correct vertex assignment

# Selection et classification

## Photon Selection

- To reject neutral mesons (reducible background), we apply a BDT classifier ("photon ID") inherited from the standard analysis
- Based on shower shape and isolation variables

## Event classification

- To gain in sensitivity, we split events into classes according to their expected signal / background ratio
- We use the "diphoton BDT" classifier from the standard analysis
- Based on the mass resolution of the events and their kinematics (+ photon ID)
- We define 4 event classes
- Number of classes limited by DY statistic ($\rightarrow$ no exclusive classes tagging production modes like standard analysis)



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

# Signal Model

- We use $H \to \gamma\gamma$ MC samples with Higgs boson mass from 80 to 110 GeV, with a 5 GeV step.
- The signal shape correspond to that of a standard Higgs boson
- We fit the signal by a sum of gaussians in each event class for each process, and then combine them
- Between the mass points, the model is interpolated
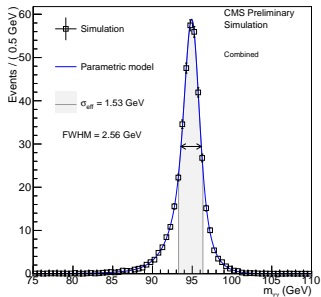


all classes
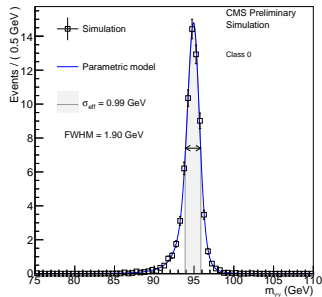


class 0

# Background model

- We model the DY contribution with a double-sided Crystal Ball function
- We extract the values of its parameters by fitting $Z \to ee$ MC events passing all our selection



- We model the continuum background with Bernstein polynomials (order chosen with a p-value test)
- Final background model : Bernstein polynomial + double-sided Crystal Ball, fitted to the data
- In the statistical interpretation the DCB fraction is let floating
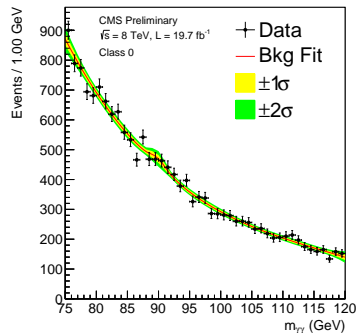
## Systematics uncertaincies following the standard analysis

- Per event :

  | Sources of systematic uncertainty | Uncertainty |
  |---|---|
  | Integrated luminosity | 2.6% |
  | Vertex finding efficiency | 1.02% |
  | Trigger efficiency | 1.0% |

  - PDF uncertaincies : up to 2% (VBF, class 0), otherwise below 1%.
  - QCD scale uncertaincies : up to 7.5% (ggh, class 0), otherwise below 1%

- Per photon :

  | Sources of systematic uncertainty | Uncertainty | |
  |---|---|---|
  | | Barrel | Endcap |
  | Photon preselection efficiency | 1.0% | 2.6% |
  | Photon identification BDT distribution | $\pm 0.01$ (shape shift) | |
  | Photon energy resolution distribution | $\pm 10\%$ (shape scaling) | |

  - The uncertaincy on the energy scale in data ranges from 0.05% for unconverted photons in the barrel, to 0.1% for converted photons in the endcaps.

# Systematics from Z peak modelling

- We choose a region with no signal : "single-fake" selection (1 photon candidate passing selection including electron veto and 1 photon candidate passing selection but failing electron veto)
- We calculate the differences in the fitted mean ($\mu$) and width ($\sigma$) of the DCB between 'single-fake' data and MC, retain for each parameter the maximum difference among the 4 event classes
- We add these contributions in quadrature with the purely statistical error from the fits used to extract the final uncertainty values on these parameters

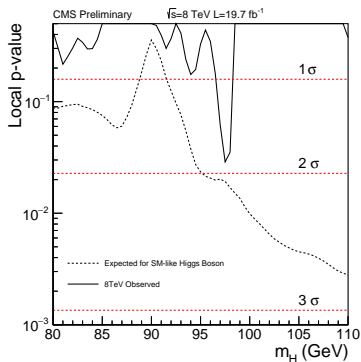| Event Class | $\mu$ (GeV) | $\Delta\mu_{stat}$ (GeV) | $\Delta\mu_{data-MC_{all}}$ (GeV) | $\Delta\mu_{MC_{all}-MC_{DY}}$ (GeV) | $\Delta\mu_{tot}$ (GeV) |
|---|---|---|---|---|---|
| 0 | 89.9 | 0.3 | 0.64 | 0.40 | 0.81 |
| 1 | 90.6 | 0.2 | 0.64 | 0.40 | 0.78 |
| 2 | 89.6 | 0.1 | 0.64 | 0.40 | 0.76 |
| 3 | 89.24 | 0.08 | 0.64 | 0.40 | 0.76 |

| Event Class | $\sigma$ (GeV) | $\Delta\sigma_{stat}$ (GeV) | $\Delta\sigma_{data-MC_{all}}$ (GeV) | $\Delta\sigma_{MC_{all}-MC_{DY}}$ (GeV) | $\Delta\sigma_{tot}$ (GeV) |
|---|---|---|---|---|---|
| 0 | 1.5 | 0.3 | 1.46 | 1.70 | 2.26 |
| 1 | 1.8 | 0.2 | 1.46 | 1.70 | 2.25 |
| 2 | 1.8 | 0.2 | 1.46 | 1.70 | 2.25 |
| 3 | 3.22 | 0.08 | 1.46 | 1.70 | 2.24 |

## Results (all production processes)



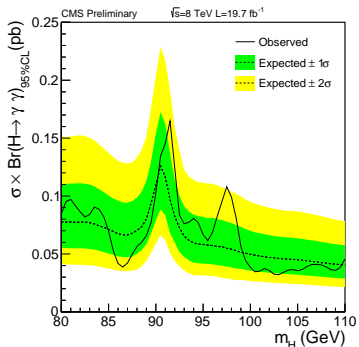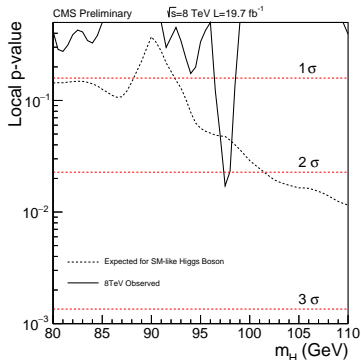**Limits on the Higgs cross section**
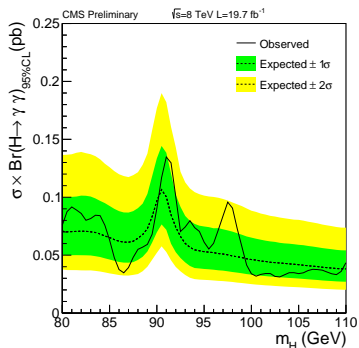
**Local P-value**

- Small excess (1.9 $\sigma$, without Look Elsewhere Effect) at 97.5 GeV, approximately the same mass as LEP excess
- Worsening of the sensitivity around the Z peak

# Results (sum of ggh + tth production processes)
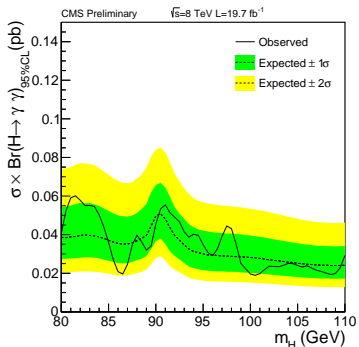


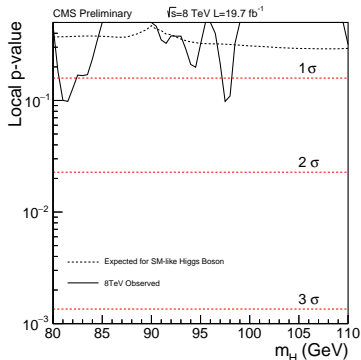**Limits on the Higgs cross section**
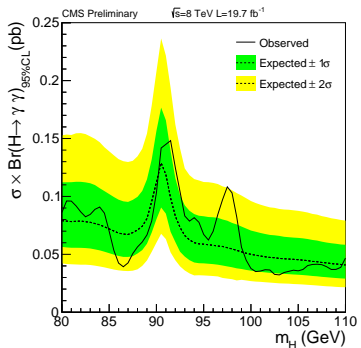
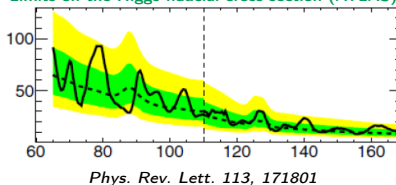**Local P-value**

## Results (sum of vbf + vh production processes)

# CMS and ATLAS results

**Limits on the Higgs total cross section (CMS)**



**Limits on the Higgs fiducial cross section (ATLAS)**



*Phys. Rev. Lett. 113, 171801*

- These plots consider only ggh production mode
- CMS : total cross section
- ATLAS : fiducial cross section
- ATLAS does not observe any excess around 98 GeV

# Summary and plans

- Strong motivations for the search for a low mass Higgs boson predicted by some BSM models (2HDM, NMSSM)
- Extension of the standard $H \to \gamma\gamma$ analysis to the interval [80,110] GeV with run 1 data
- Special feature of the analysis : additional DY contribution to reduce and model
- No evidence for new particle
- Looking forward to redoing the analysis with Run 2 13 TeV data !

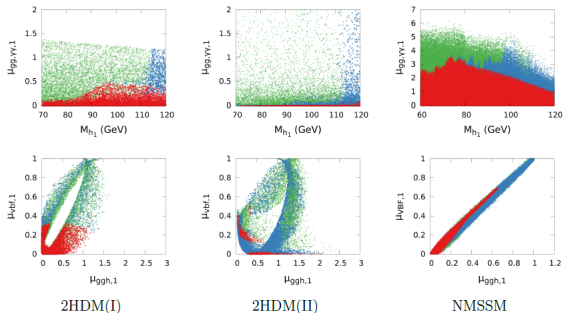# BACK-UP

# $h_1$ signal strength vs mass in 2HDM and NMSSM



Figure 1: Top: signal strength in the $gg \to h_1 \to \gamma\gamma$ channel. Bottom: ggh production mode versus VBF, both normalised to the SM. The colour code is the following: 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 $h_1$ and red (dark grey) points pass in addition the LHC couplings constraint on $h_2$.

● *Cacciapaglia, Deandrea, Drieu La Rochelle, Flament ; Phys.Rev. D91 (2015) 1, 015012*

# Low-mass Higgs boson searches with LEP data
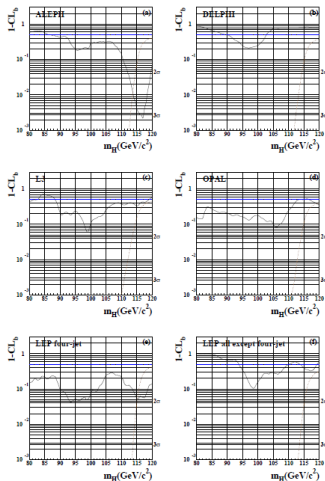


- *LEPHWG, Phys. Lett. B565 :61-75, 2003*

Figure 8: The background confidence $1 - CL_b$ as a function of the test mass $m_H$ for subsets of the LEP data. The same notation as in Figure 7 is used. Plots (a) to (d): individual experiments; (e): the four-jet and (f): all but the four-jet final state, with the data of the four experiments combined.