Observation and properties of a Higgs boson and search for additional Higgs bosons in the Two-Photon Decay Channel with CMS

Benoit Courbon

IPN Lyon/Universite Claude Bernard Lyon 1, on behalf of the CMS collaboration

Higgs Hunting, 30/07/2015

Overview of the Standard Model $H \rightarrow \gamma\gamma$ analysis

- Diphoton channel : **Small branching fraction** ($\sim 2.10^{-3}$ at $m_H = 125$ GeV) but **clean signature** : 2 high-p_T isolated photons
- Analysis strategy : Search for a **narrow peak** on a smoothly decreasing background in the diphoton mass spectra
- **Large diphoton background** : Reducible (jet-jet or γ-jet with jet faking photon) and irreducible (γ-γ)
- **Mass resolution** is crucial (energy corrections and vertex identification)
- **Categorization** of diphoton events to gain in sensitivity and to tag production modes

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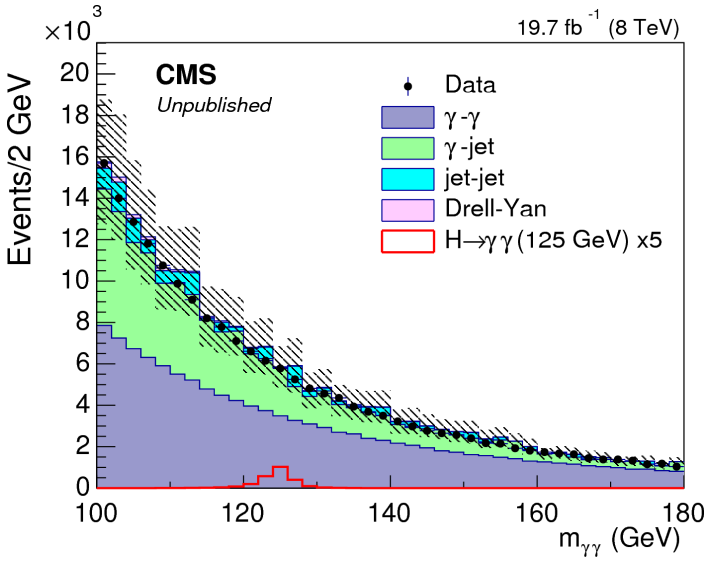


- We use the **full run 1 dataset** : 5.1 fb^{-1} (2011, 7 TeV) + 19.6 fb^{-1} (2012, 8 TeV)
- **Trigger** : $p_{T,\gamma} > 26(18)$ or $p_{T,\gamma} > 36(22)$ on the leading (trailing) photon + loose isolation, shower shape criteria and mass cut $\rightarrow$ 99.5 % efficiency
- Challenging **Pile-Up conditions** : <PU>=21, up to 40

Mass resolution

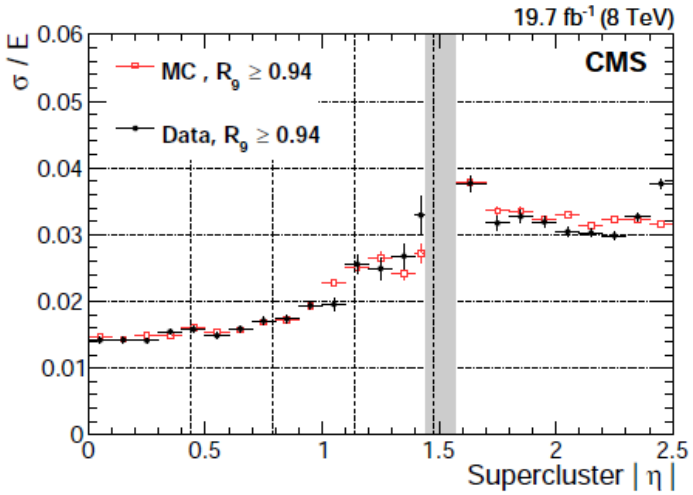
$$m_{\gamma\gamma} = \sqrt{2 E_1 E_2 \cos \alpha_{1,2}}$$

Energy measurment :

- **ECAL performance** (crystal intercalibration, response changes correction...)
- High-level correction : **Photon energy regression** method. Multivariate approach aiming to take in account showering, gap/crack effects, PU ...
- Final energy scale extraction from $Z \to ee$ events (cross-check with $Z \to \mu\mu\gamma$)

arXiv :1502.02702

Energy resolution vs η

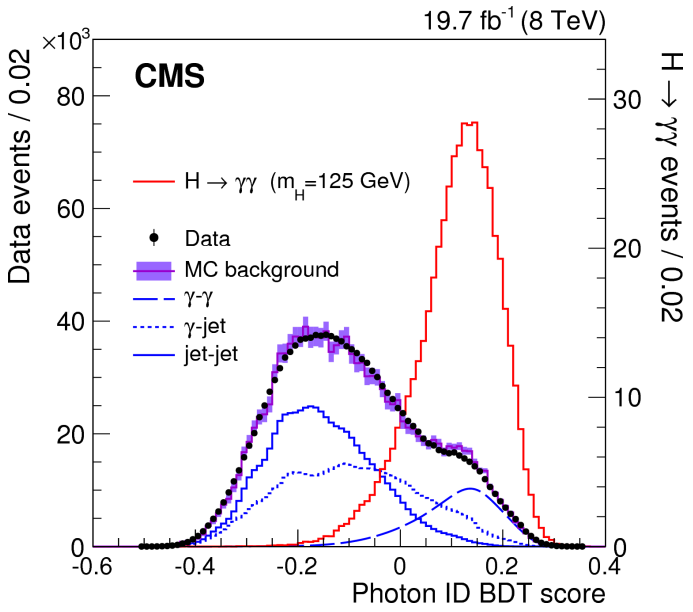


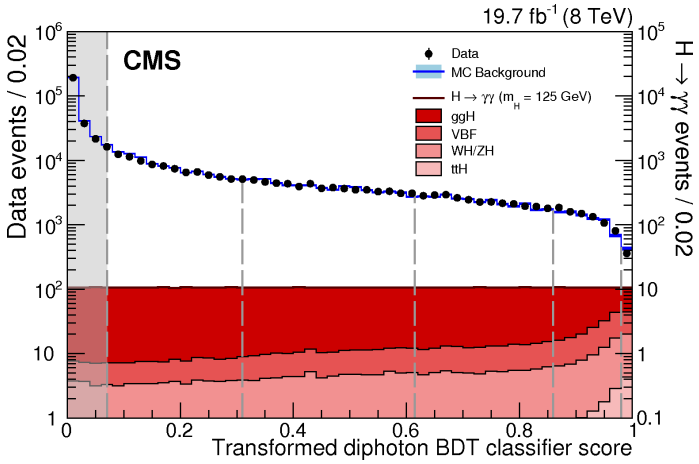
Vertex identification :

- The angular term is negligible if $\delta z < 1$ cm
- CMS has no intrisic pointing capability
- We use **Boosted Decision Trees** to identify the primary vertex, based on the kinematics of the recoiling tracks + the tracks of identified conversions
- More than 80% average vertexing efficiency

Selection and categorization

- We apply a first BDT classifier (**photon ID**) to discrimate prompt photons from fakes (neutral hadrons), based on shower shape and isolation
- Then we **categorize** diphoton events :
  - We build **exclusive classes** (1% of the events) in order to tag specific production modes, by requiring additional objects (forward jets, leptons, MET...) in the event.
  - We apply another classifier (**diphoton BDT**) to categorize the remaining diphoton events (99%) based on their mass resolution, their kinematics and the photon ID.
  - 5 (4) untagged categories + 9 (7) exclusive categories for 2012 (2011) dataset

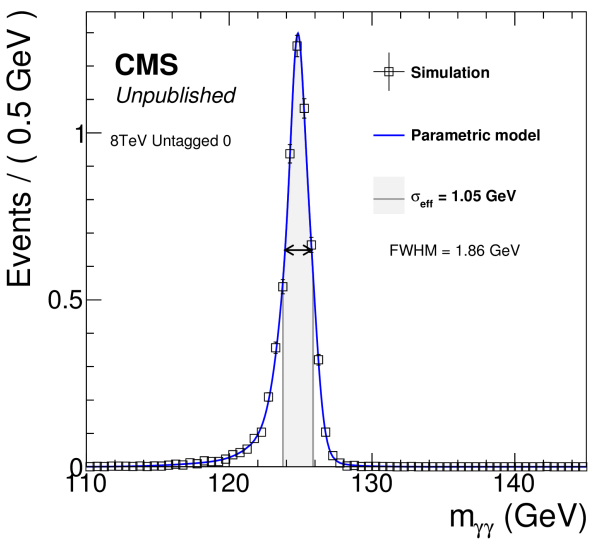




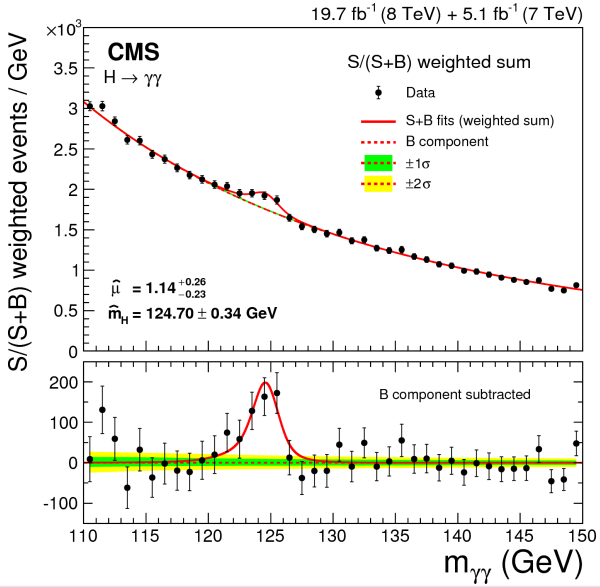
Signal and background modelling

- **Signal model** :
  - We fit MC signal samples with a sum of gaussians, with granularity of 5 GeV, for each process
  - Then the signal model is interpolated between these points.
- **Background model** :
  - It is data driven : We choose the functional form with the best fit to data, among a class of different functions (exponentials, power laws, polynomials...).
  - The choice of the bkg model is treated as a discrete nuisance parameter.
  - We make sure that the potential bias on the signal strength is negligible.

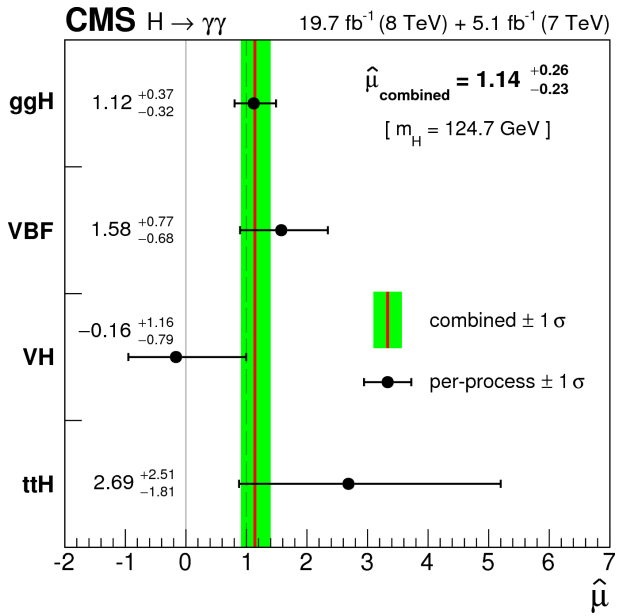
Signal model at $m_H = 125$ GeV



Results



$$\mu(m_H = 124.7\,GeV) = 1.14^{+0.26}_{-0.23}$$
$$[\pm 0.21(stat)^{+0.09}_{-0.05}(syst)^{+0.13}_{-0.09}(theo)]$$



Local significance of 5.7 σ

$$m_H = 124.70 \pm 0.34$$
$$[\pm 0.31(stat) \pm 0.15(syst)]\ \text{GeV}$$

Source of uncertainty	Uncertainty in $\hat{m}_H$ (GeV)
Imperfect simulation of electron-photon differences	0.10
Linearity of the energy scale	0.10
Energy scale calibration and resolution	0.05
Other	0.04
All systematic uncertainties in the signal model	0.15
Statistical	0.31
Total	0.35

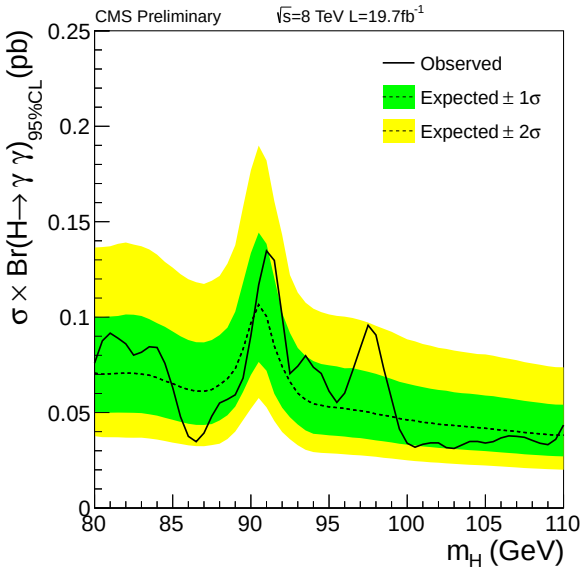
Source of uncertainty	Uncertainty in $\hat{\mu}$
Production cross sect. and branching frac.	0.11
Shower shape modelling (Section 9)	0.06
Energy scale and resolution	0.02
Other	0.04
All syst. uncert. in the signal model	0.13
Statistical	0.21
Total	0.25

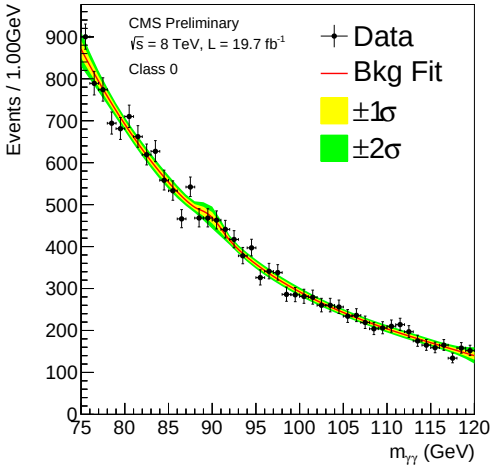
Low-mass search

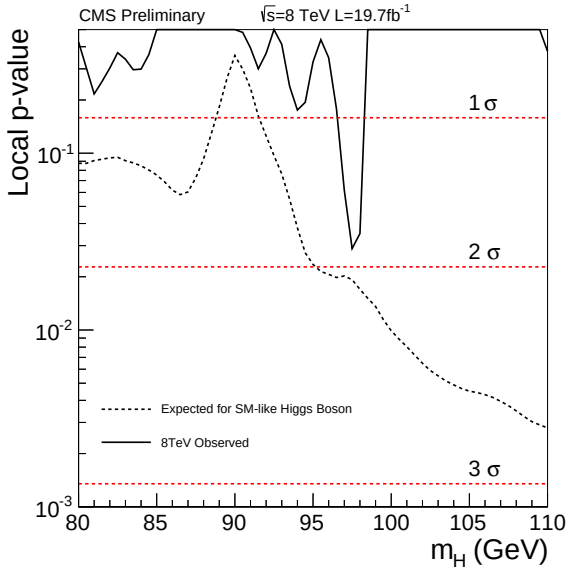
NEW

CMS-HIG-14-037

- Light scalar searches in the diphoton channel are performed in the range **[80,110] GeV**
- Motivations of this search : NMSSM, 2HDM ...
- The **Z peak contamination**, with 2 electrons misidentified as photons, needs to be added to the diphoton continuum background
- 4 categories (using the diphoton classifier from standard H$\rightarrow \gamma\gamma$ analysis)
- **No evidence** for new particle production has been observed





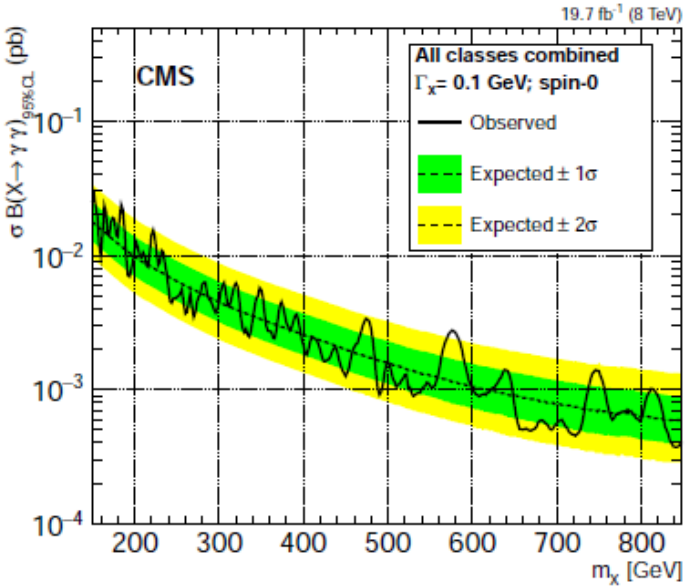


High-mass search

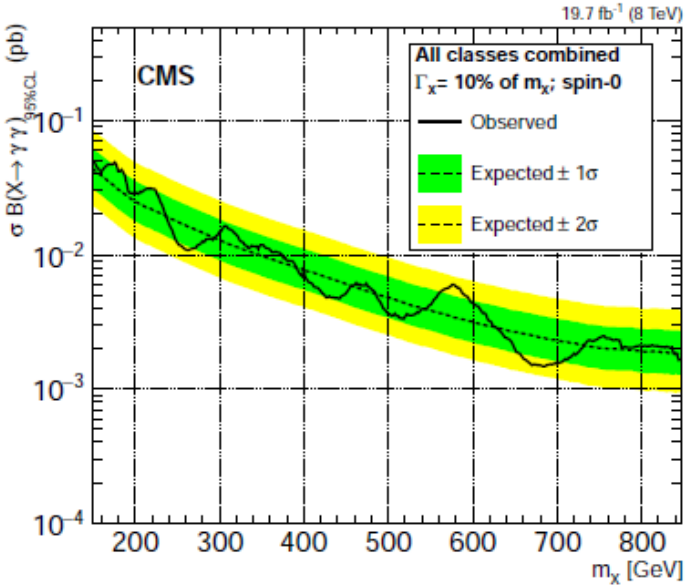
arXiv :1506.02301

- Heavy scalar searches in the diphoton channel are performed in the range **[150,850] GeV**
- These searches are motivated by several BSM scenarios, such as 2HDM
- Not only mass scan but also **width scan** (from 0.1 GeV to 10% of the scalar mass)
- 4 categories (barrel/endcap, converted/unconverted)
- **No evidence** for new particle production has been observed

$\Gamma = 0.1 GeV$

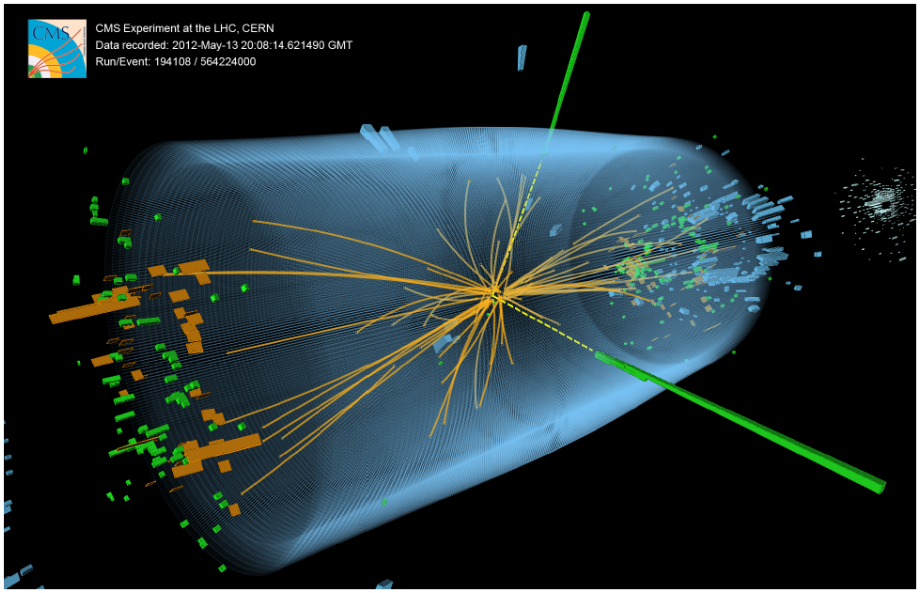


$\Gamma = 10\% m_X$



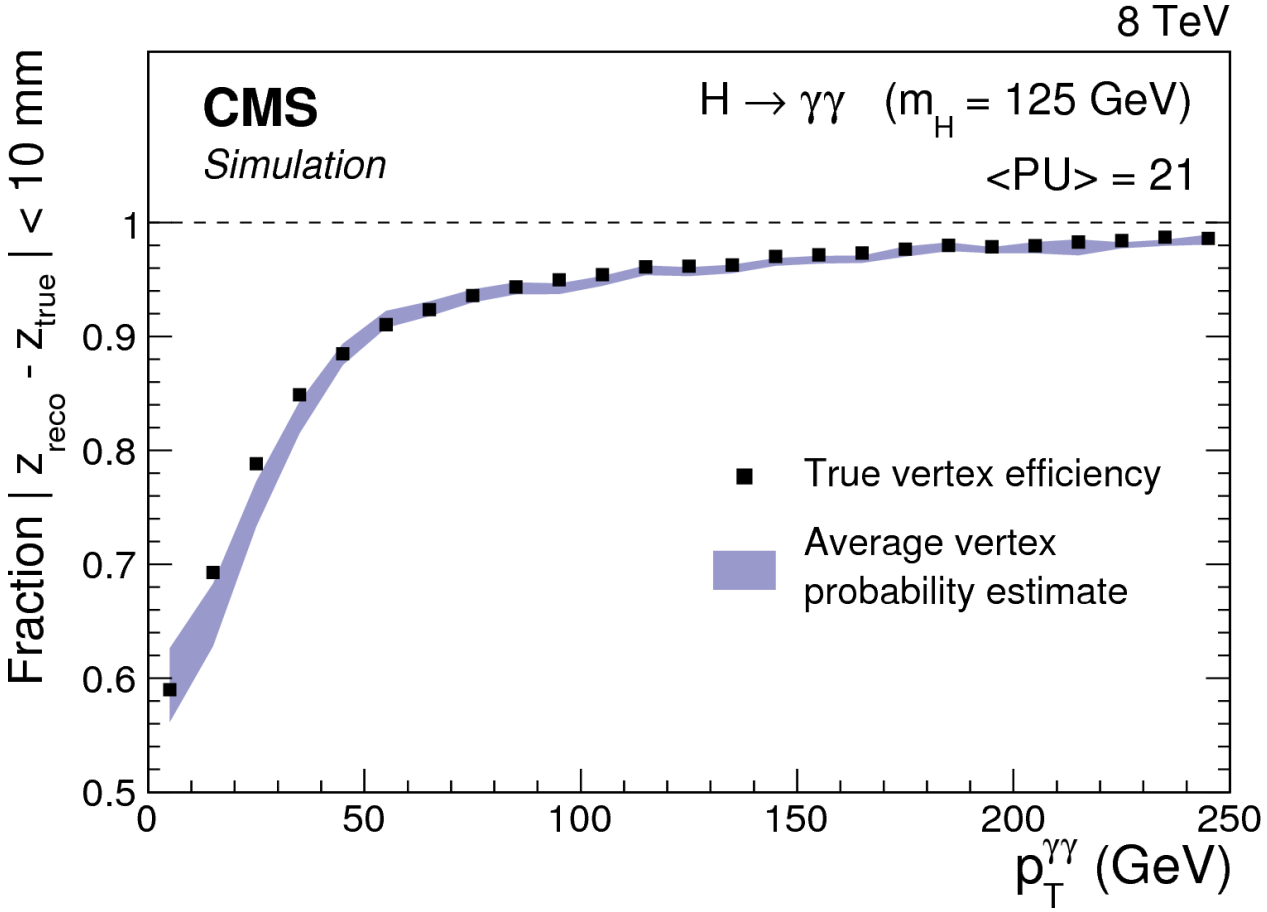
Conclusion

- H$\rightarrow \gamma\gamma$ is one of the **most sensitive channels** and allows precise measurement of the Higgs sector :
  - Observation with 5.7σ significance (single-channel discovery)
  - $m_H = 124.7 \pm 0.34$ GeV
  - $\mu = 1.14 \pm 0.24$
- All the measured properties are **compatible with the SM Higgs boson**
- Additional Higgs bosons searches, motivated by BSM scenarios, have been performed at **low and high mass**, showing no evidence of a new scalar



BACK-UP

$H \rightarrow \gamma\gamma$ vertexing efficiency

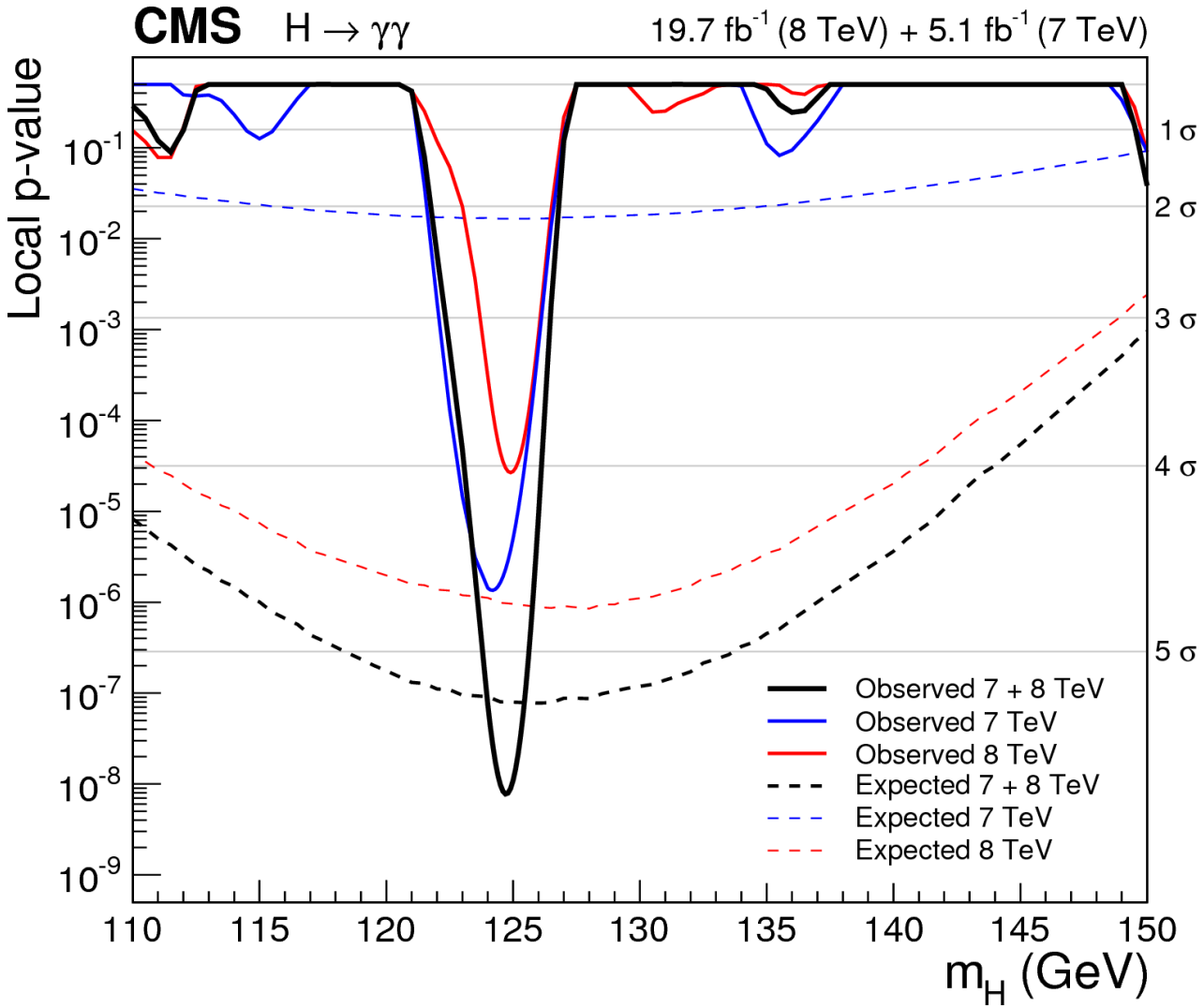


$H \to \gamma\gamma$ categories

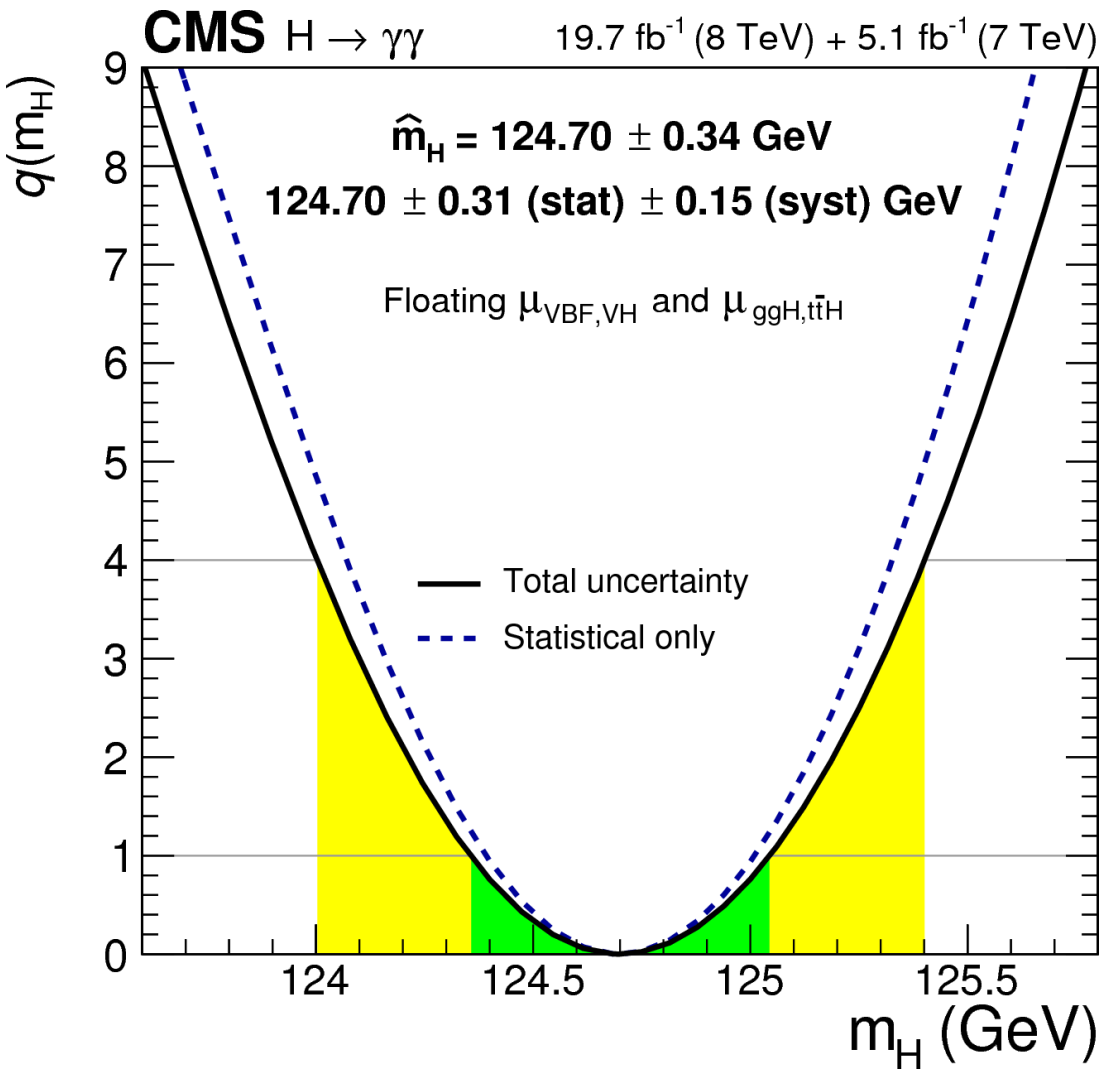
Label	No. of classes 7 TeV	8 TeV	Main requirements
$t\bar{t}H$ lepton tag	$\star$	1	$p_T^{\gamma 1} > m_{\gamma\gamma}/2$ 1 b-tagged jet + 1 electron or muon
VH tight ℓ tag	1	1	$p_T^{\gamma 1} > 3m_{\gamma\gamma}/8$ [e or μ, $p_T > 20$ GeV, and $E_T^{miss} > 45$ GeV] or [2e or 2μ, $p_T^{\ell} > 10$ GeV; $70 < m_{\ell\ell} < 110$ GeV]
VH loose ℓ tag	1	1	$p_T^{\gamma 1} > 3m_{\gamma\gamma}/8$ e or μ, $p_T > 20$ GeV
VBF dijet tag 0-2	2	3	$p_T^{\gamma 1} > m_{\gamma\gamma}/2$ 2 jets; classified using combined diphoton-dijet BDT
VH E_T^{miss} tag	1	1	$p_T^{\gamma 1} > 3m_{\gamma\gamma}/8$ $E_T^{miss} > 70$ GeV
$t\bar{t}H$ multijet tag	$\star$	1	$p_T^{\gamma 1} > m_{\gamma\gamma}/2$ 1 b-tagged jet + 4 more jets
VH dijet tag	1	1	$p_T^{\gamma 1} > m_{\gamma\gamma}/2$ jet pair, $p_T^{j} > 40$ GeV and $60 < m_{jj} < 120$ GeV
Untagged 0-4	4	5	The remaining events, classified using diphoton BDT

$\star$ For the 7 TeV dataset, events in the $t\bar{t}H$ lepton tag and multijet tag classes are selected first, and combined to form a single event class.

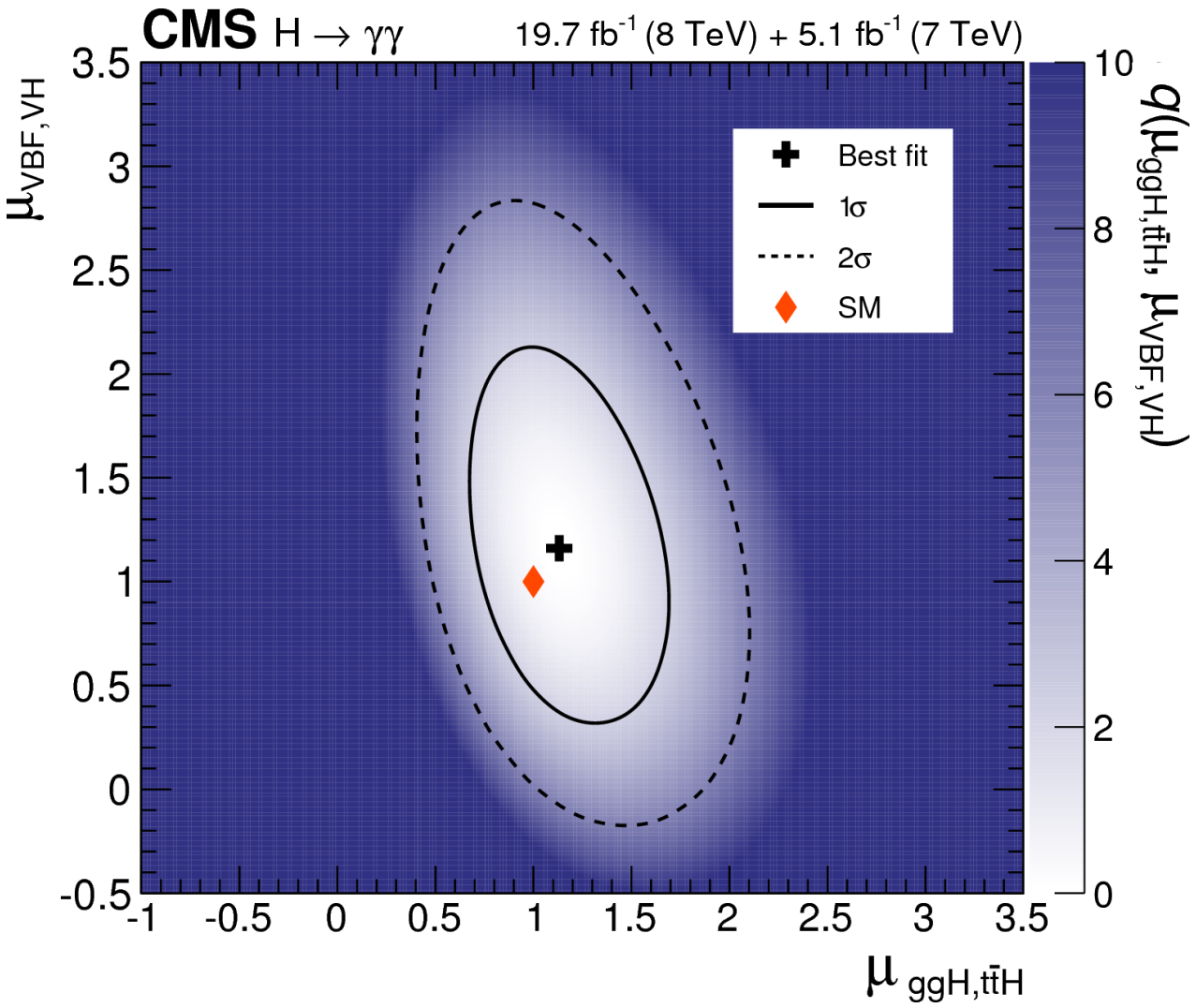
$H \rightarrow \gamma\gamma$ significance plot



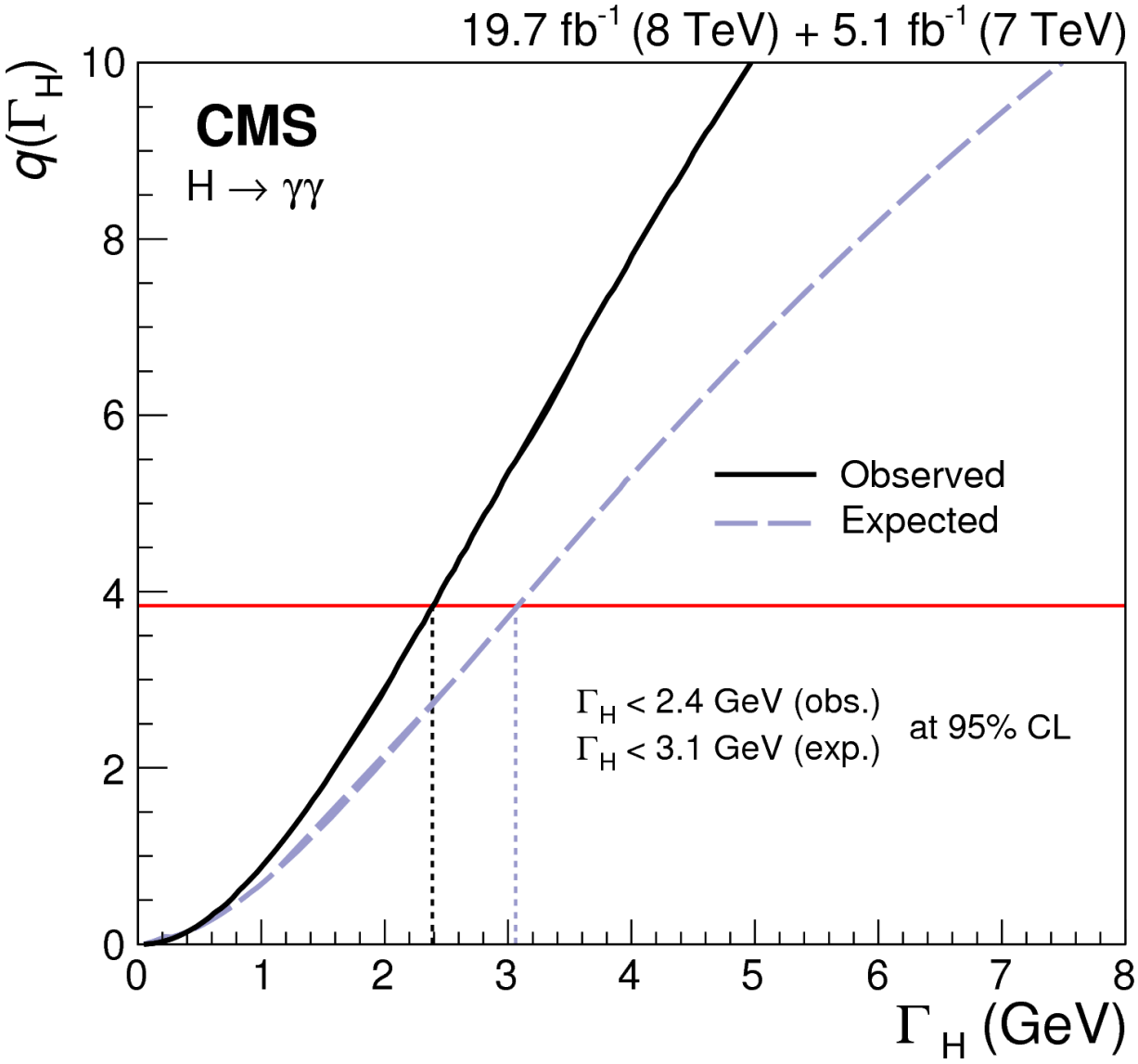
$H \rightarrow \gamma\gamma$ mass measurment



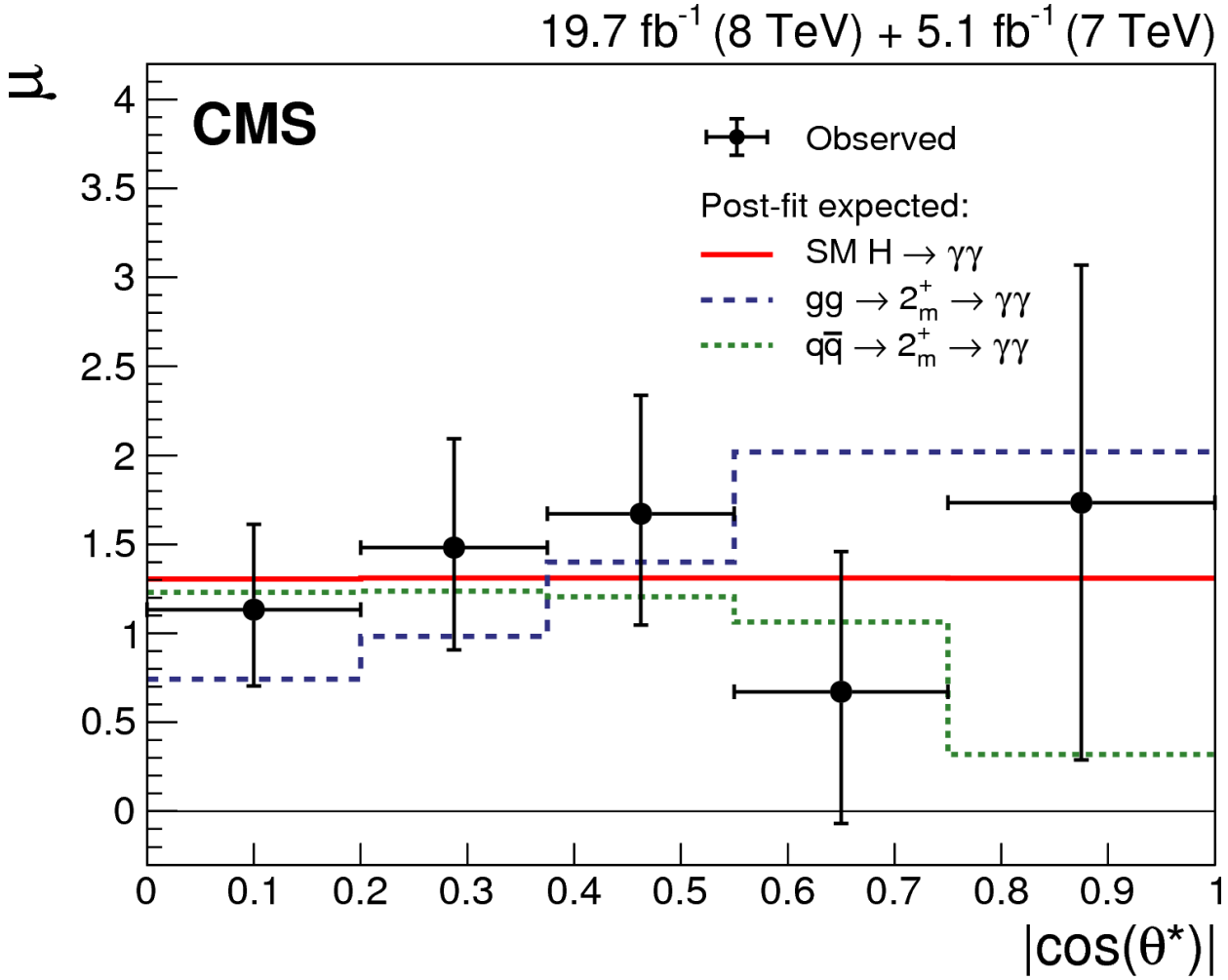
$H \rightarrow \gamma\gamma$ reduced couplings



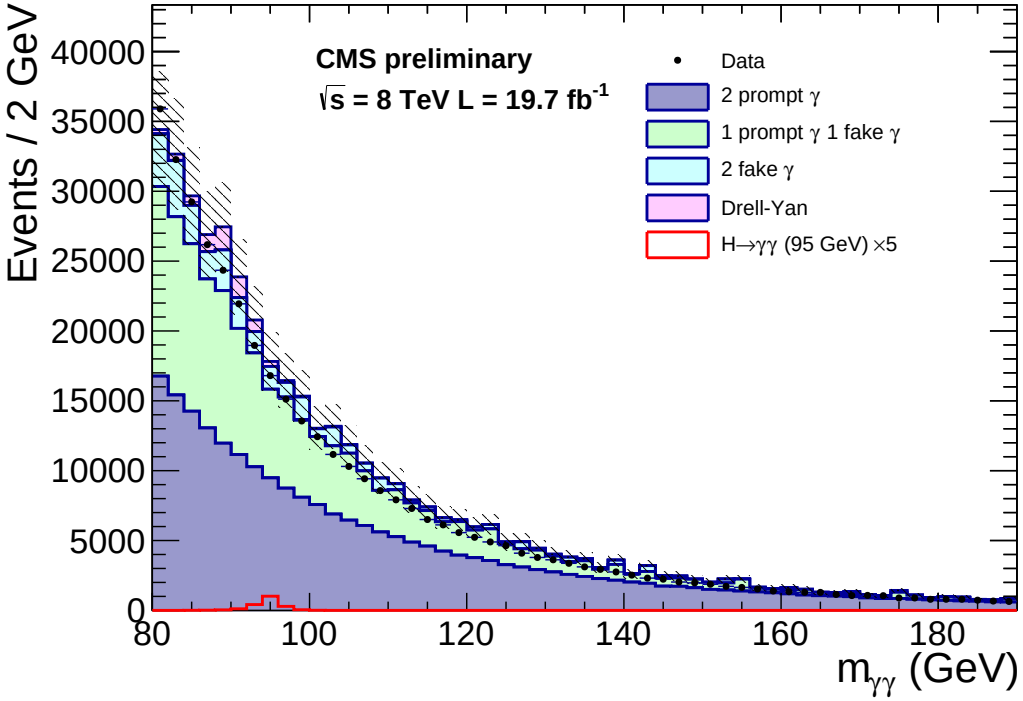
$H \to \gamma\gamma$ width



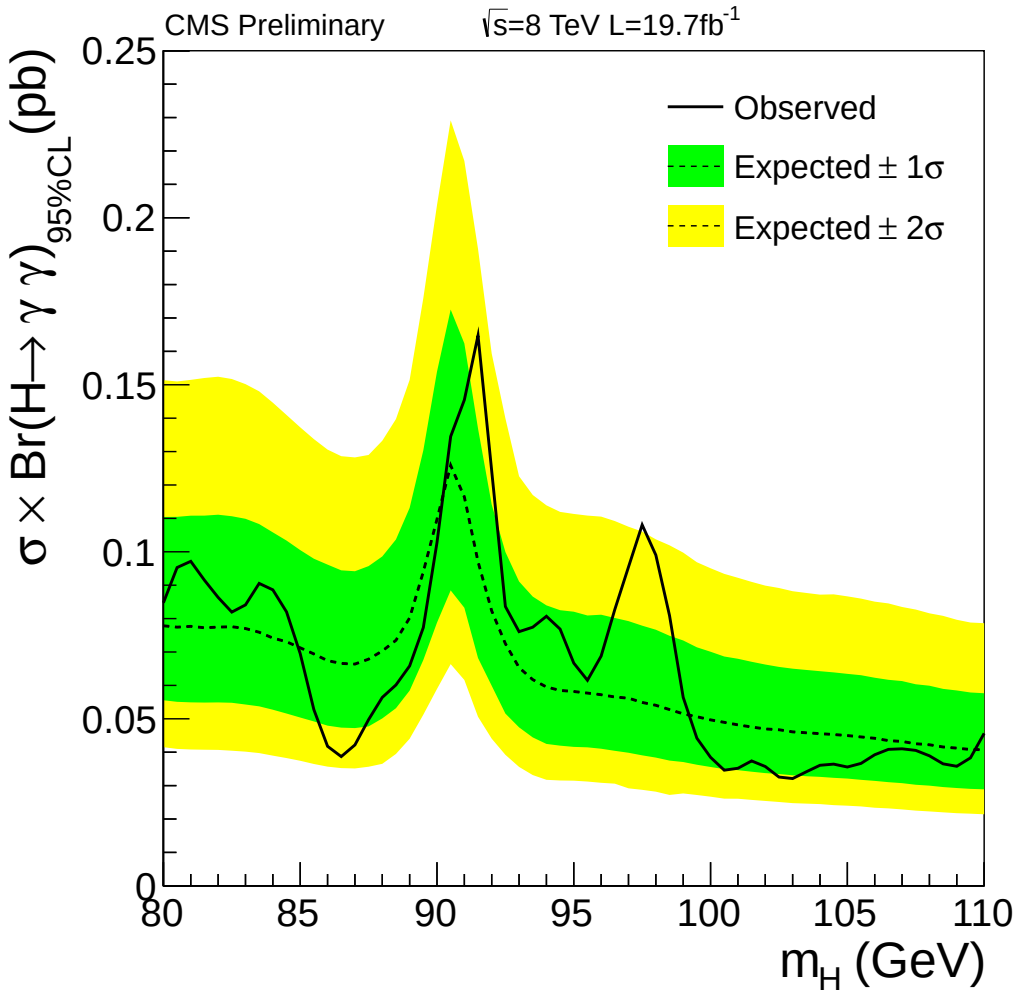
$H \rightarrow \gamma\gamma$ spin



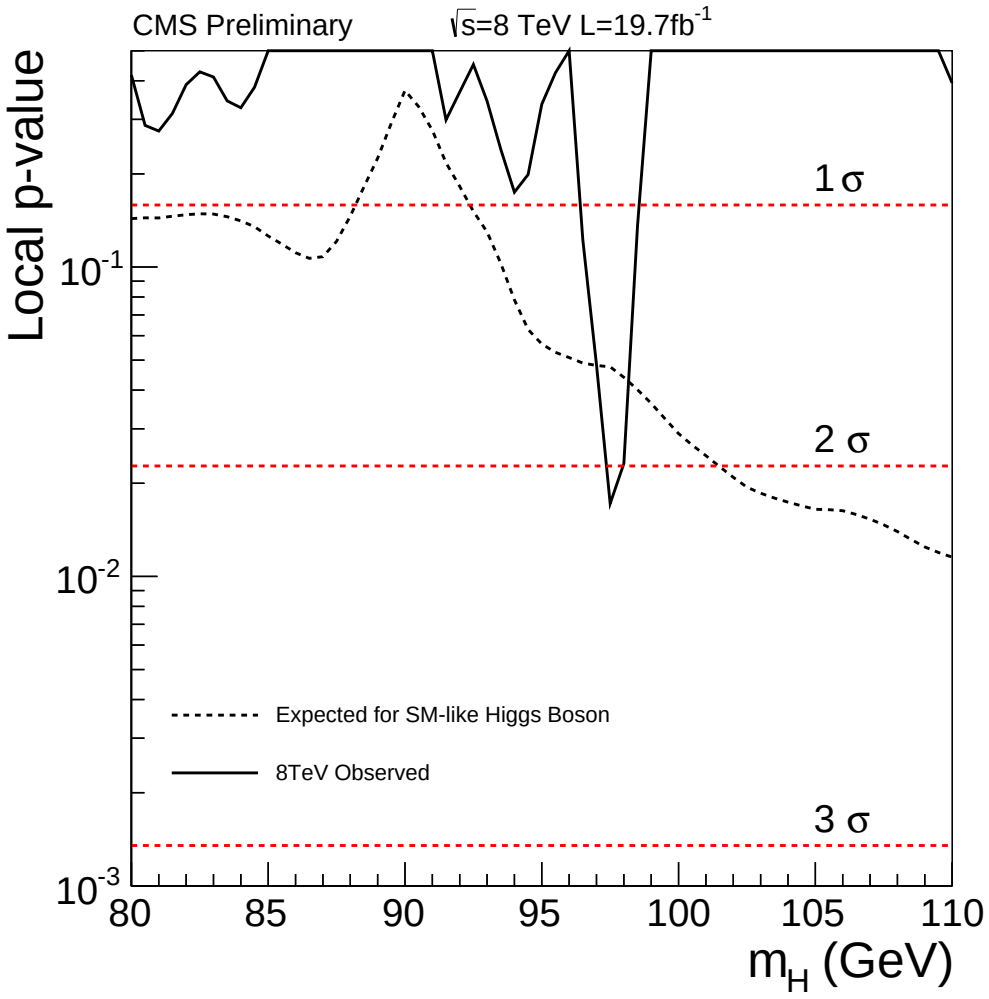
Low-mass Data/MC comparison



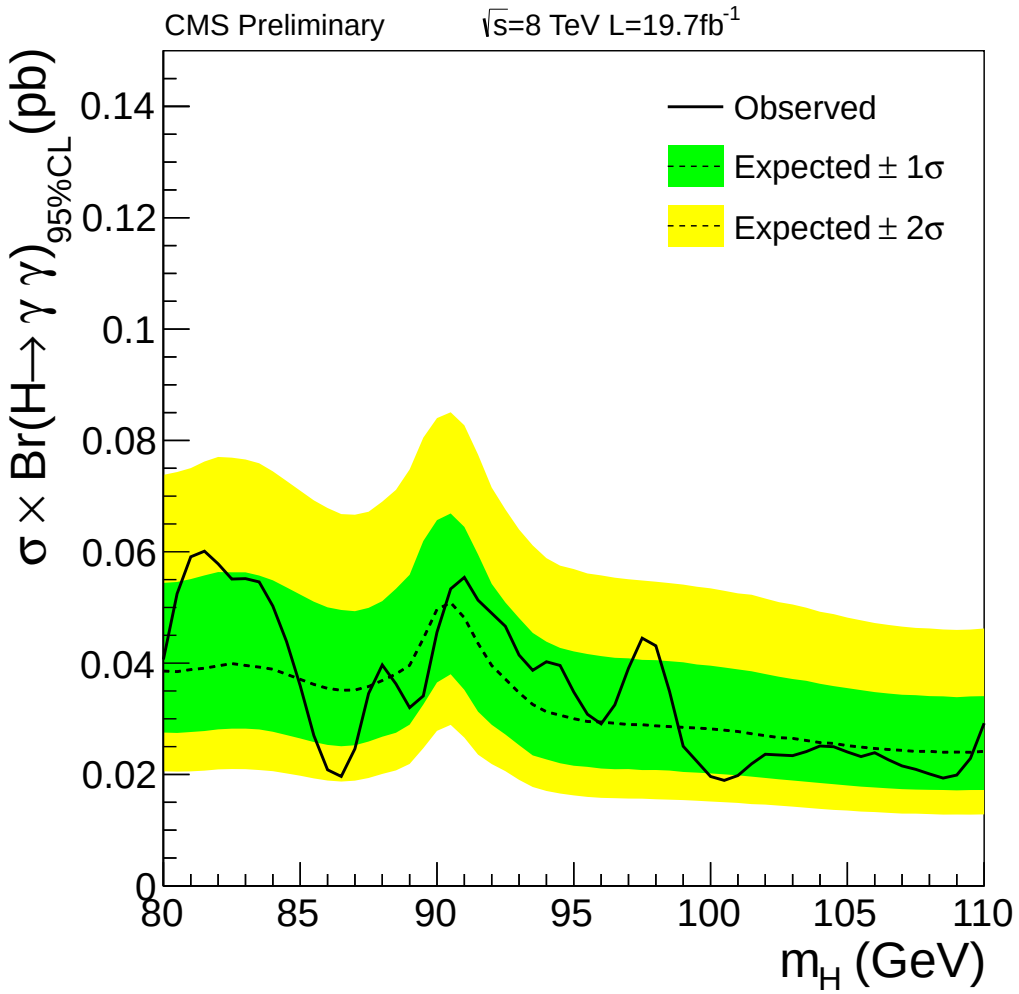
Low-mass exclusion limits (ggh+tth)



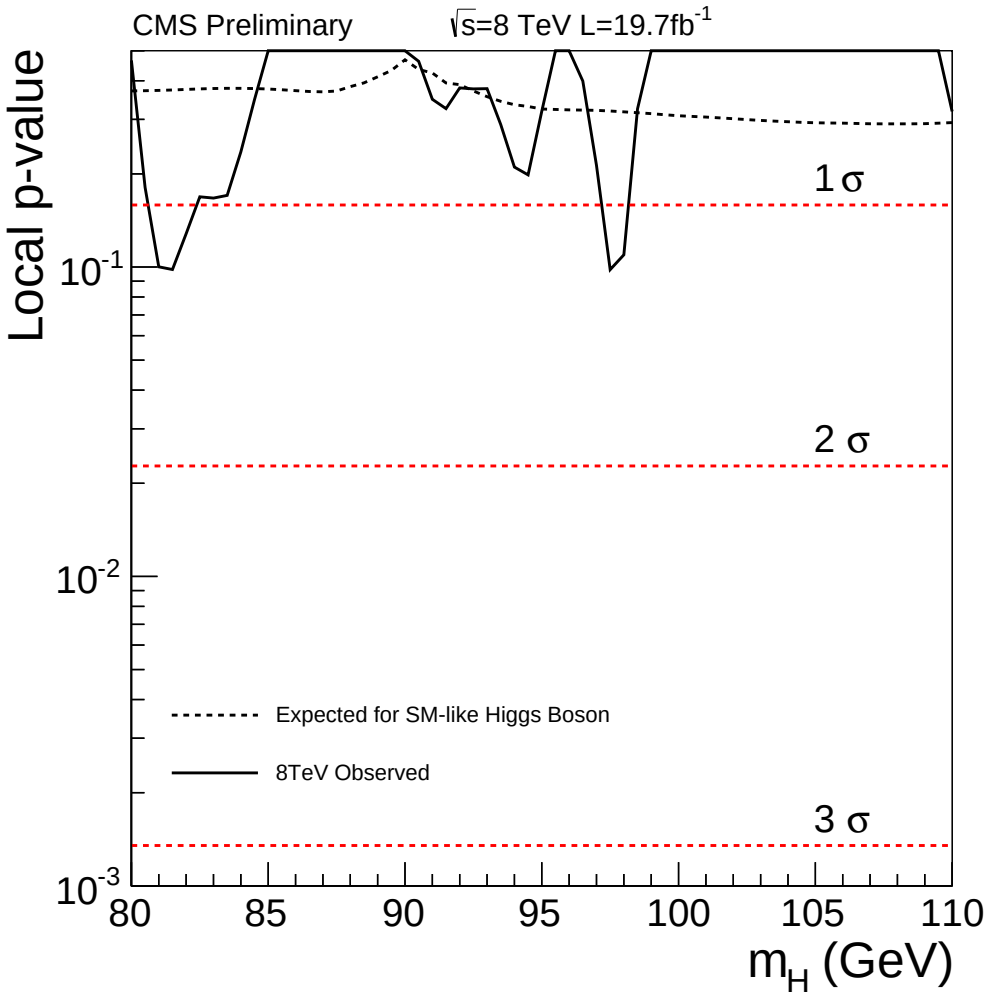
Low-mass significance plot (ggh+tth)



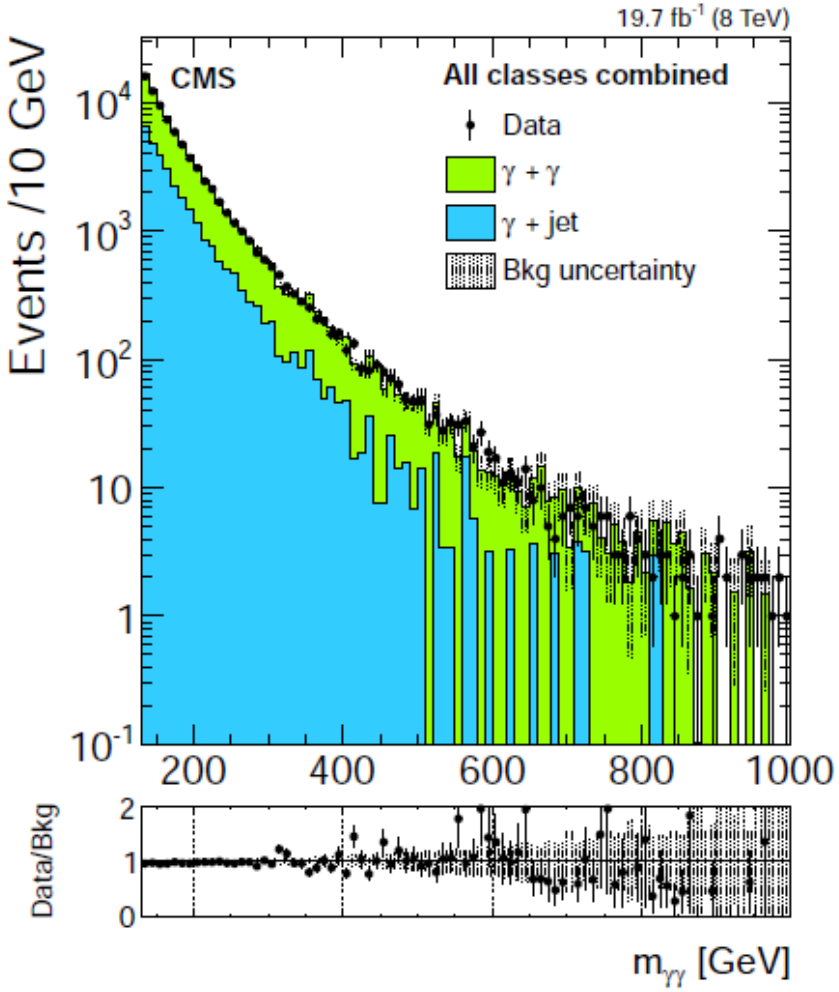
Low-mass exclusion limits (vbf+vh)



Low-mass significance plot (vbf+vh)



High-mass Data/MC comparison



High-mass exclusion limits in spin 2 interpretation