Search for a new Higgs boson-like low-mass resonance in the diphoton final state at $\sqrt{s}$ = 8 TeV in pp collisions at CMS

Linda Finco

IPN Lyon (IN2P3-CNRS)/UCB Lyon 1, France

On behalf of the CMS Collaboration

HEP 2017
Venice (Italy)

July 7th 2017

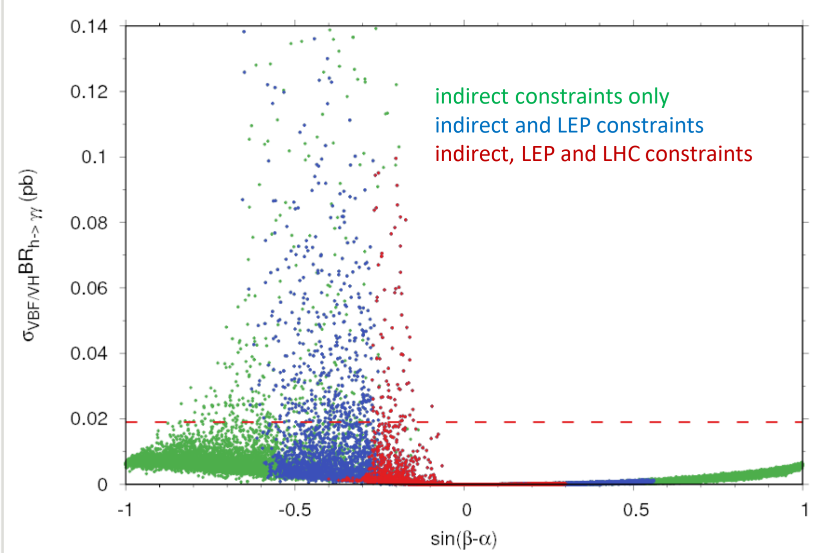
Theoretical Motivations

Is the new particle discovered in 2012 by the CMS and ATLAS Collaborations at a mass of 125 GeV really the Standard Model Higgs boson?

Some **BSM theories** predict **modified** and **extended Higgs sectors**:

- General Two Higgs Doublet Model (**2HDM**)
  - 2 Higgs Doublets ➡ 5 Higgs bosons: h, H, a, $H^{\pm}$
- Next-to-Minimal Supersymmetric Standard Model (**NMSSM**)
  - 2 Higgs Doublets + 1 singlet ➡ 7 Higgs bosons: h_1, h_2, h_3, a_1, a_2, $H^{\pm}$

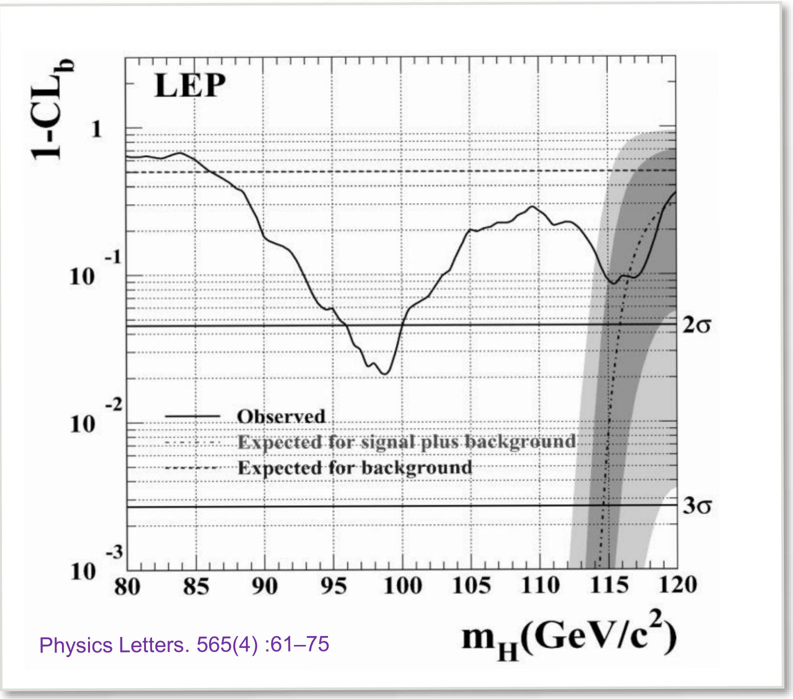
- The **Higgs boson at 125 GeV** can be identified as the **next-to-lightest scalar**, allowing to focus on a possible **lighter particle**
- Strong **interest** from the **theoretical community**

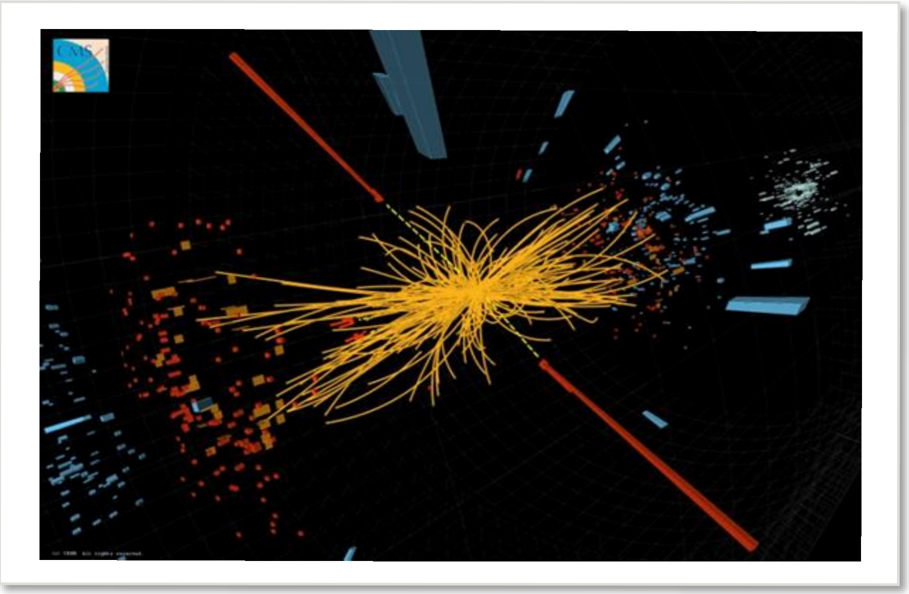


G. Cacciapagia et al., JHEP 1612 (2016) 068

Experimental Motivations

- **Small excess** of events (~2σ) at **LEP** observed by 3 of the 4 experiments in *bb*/*ττ* channels

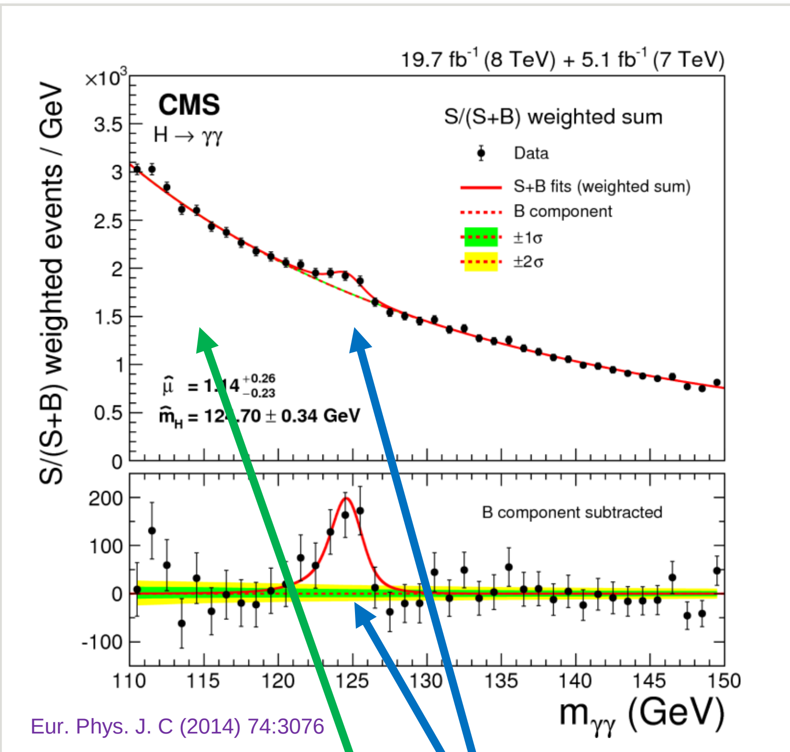




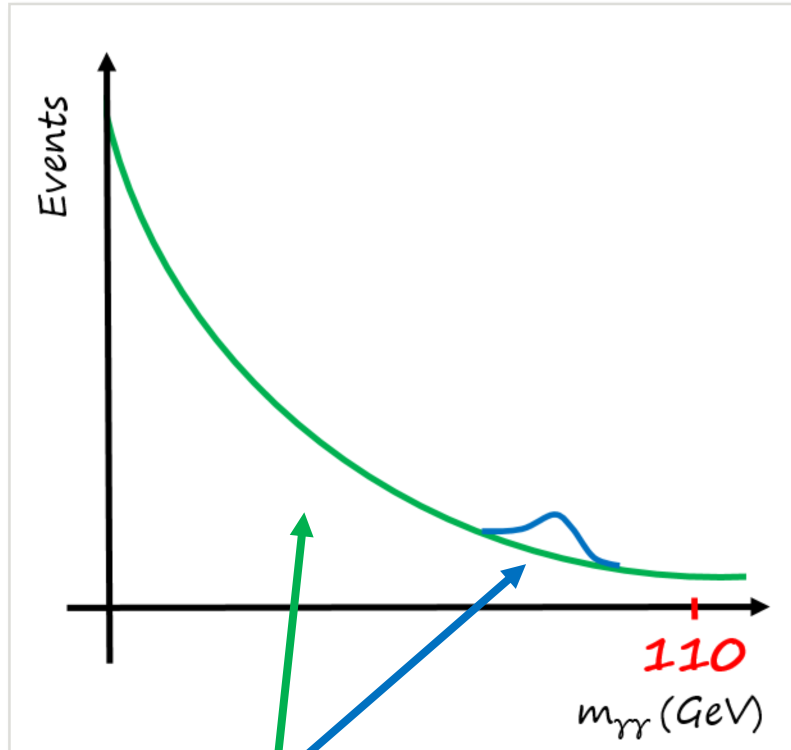
- During LHC Run I, the standard $H\to\gamma\gamma$ **search range** was **[110,150] GeV**
- Clean signature with two **isolated and highly energetic photons**
- Final state fully reconstructed with **excellent mass resolution**
- **Background** from QCD (γγ – γj – jj) large enough to be **evaluated directly on data**

The $H \to \gamma\gamma$ Decay Channel at Low Mass

STANDARD $H \to \gamma\gamma$ ANALYSIS



LOW-MASS $H \to \gamma\gamma$ ANALYSIS

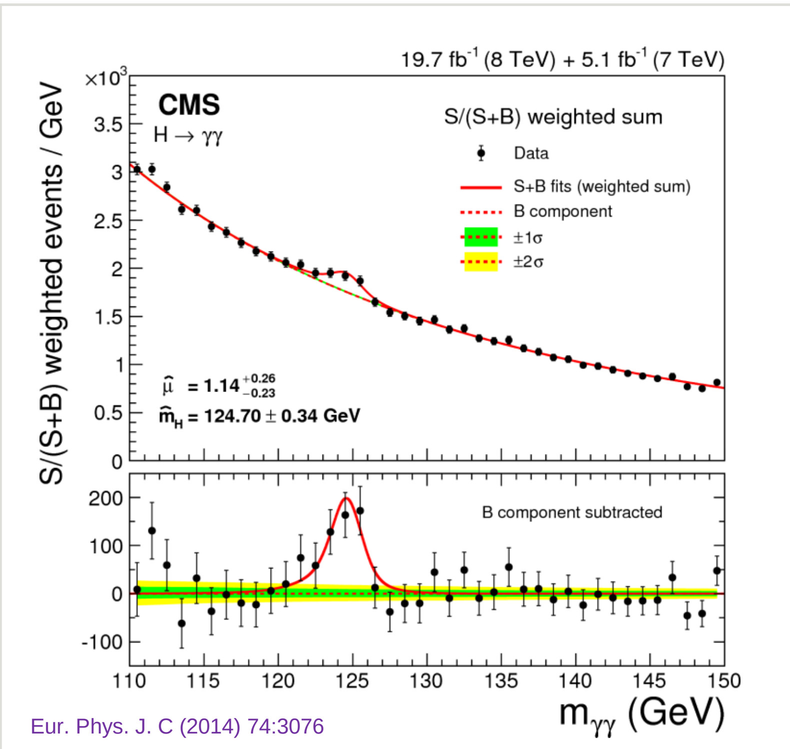


NARROW SIGNAL PEAK

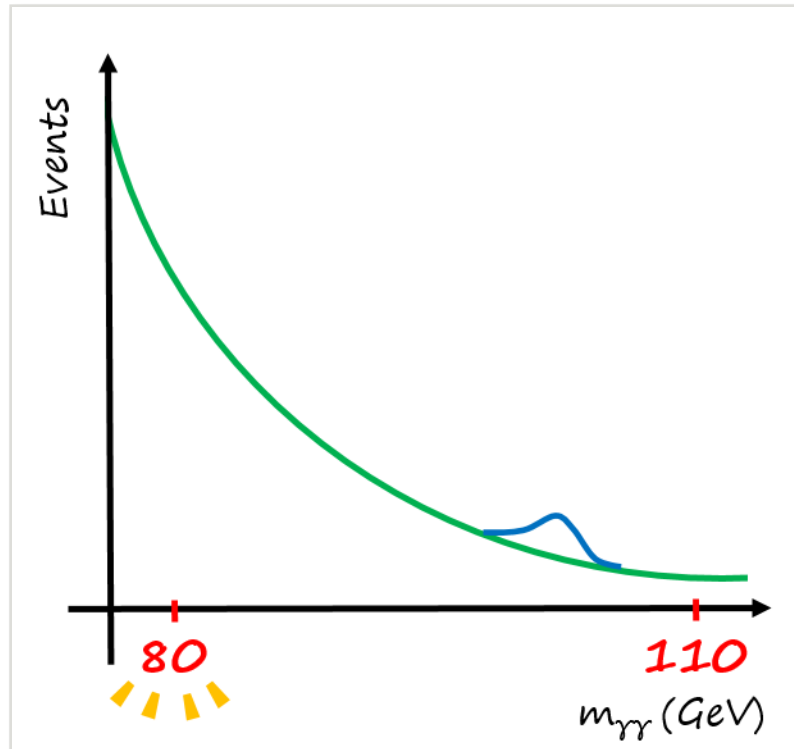
LARGE FALLING BACKGROUND

The $H \rightarrow \gamma\gamma$ Decay Channel at Low Mass

STANDARD $H \rightarrow \gamma\gamma$ ANALYSIS



LOW-MASS $H \rightarrow \gamma\gamma$ ANALYSIS



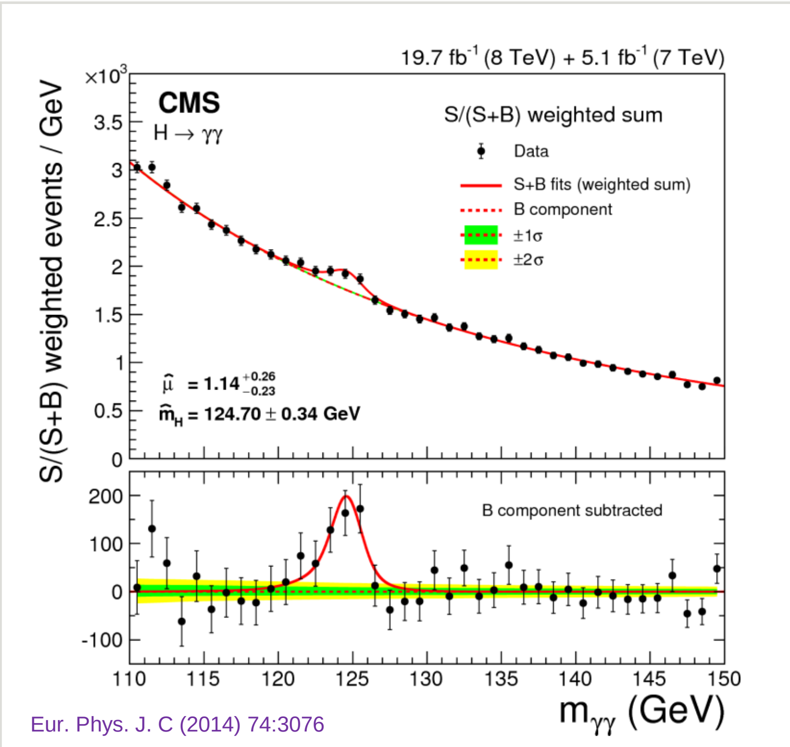
MAIN CHALLENGES:

- Difficulty to **extend the range** to very low mass values (mainly for the trigger)

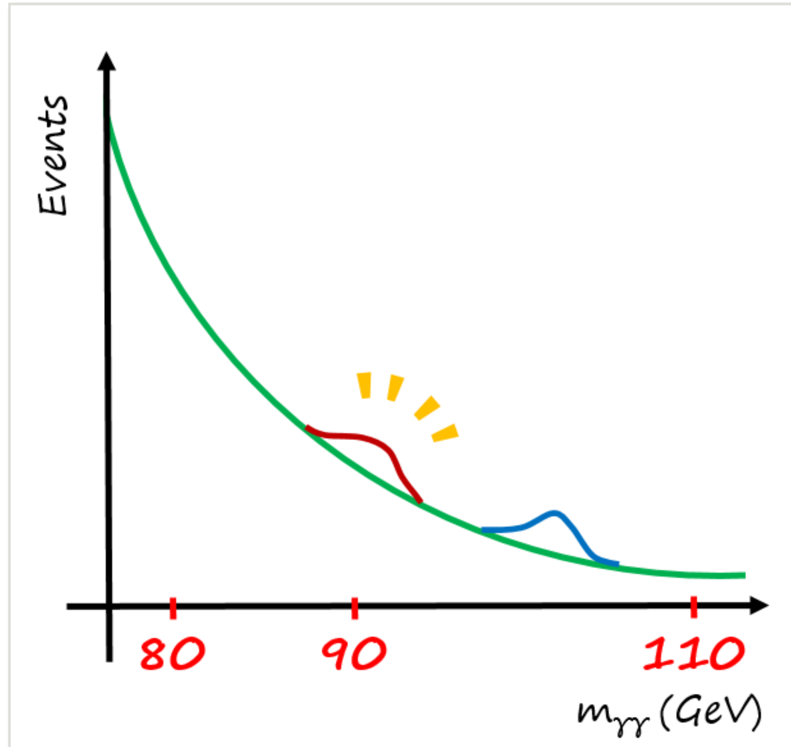
  ➡ Lower limit at 80 GeV

The $H \to \gamma\gamma$ Decay Channel at Low Mass

STANDARD *H→γγ* ANALYSIS



LOW-MASS *H→γγ* ANALYSIS



MAIN CHALLENGES:

- Additional Drell-Yan **background *Z → ee***, with electrons misidentified as photons

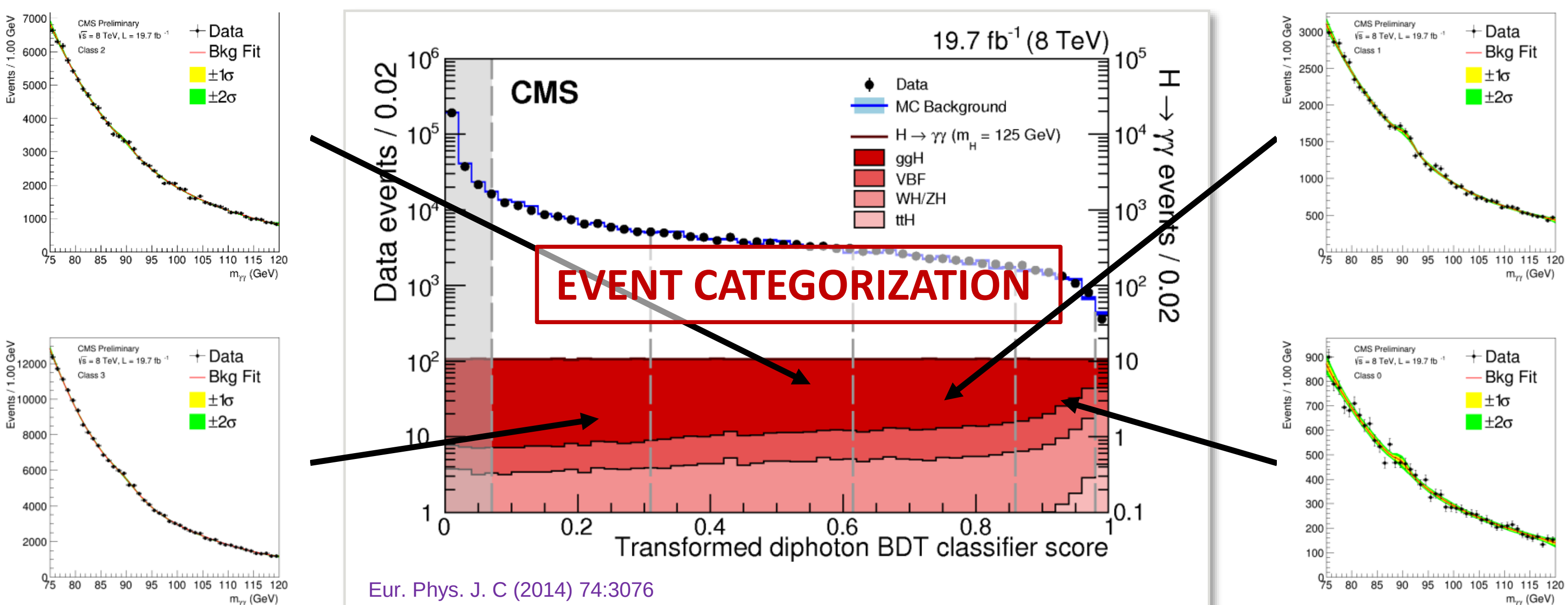
  ➡ Loss of sensitivity around 90 GeV

Analysis Strategy

$$\boxed{m_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos\theta)}}$$

- Select two **"good quality" photons**
- Measure **photon energy** precisely
- Find the **primary vertex** of the decay

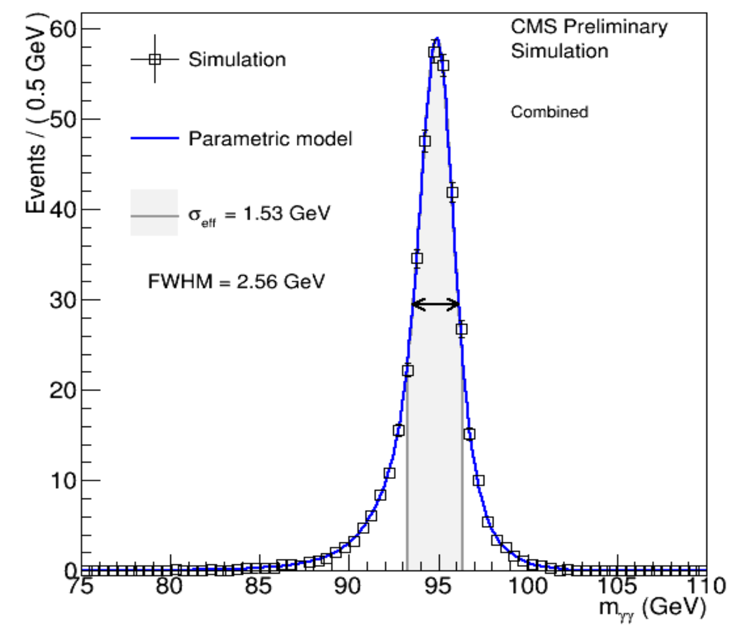
- Very **similar to the standard *H→γγ* analysis** (see Michael's talk yesterday)
- **Event categorization** defined to maximize S/B
- Signal extracted from background by **fitting the observed diphoton mass distributions** in each category



Photon Energy

$$\boxed{m_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos\theta)}}$$

- Photon energy reconstructed by building **clusters of energy deposits** in the **electromagnetic calorimeter**.
- **Energy** and **its uncertainty** corrected for local and global shower containment
  ➡ **regression technique**:
  - corrects photons' energies
  - provides an estimate of energy resolution
- **Energy scale** in data **corrected** as a function of data taking epochs, pseudorapidity, EM shower width and transverse energy
- **Smearing** to the reconstructed photon energy in **MC** to match the resolution in data
  ➡ $Z \rightarrow ee$ **peak** used as reference

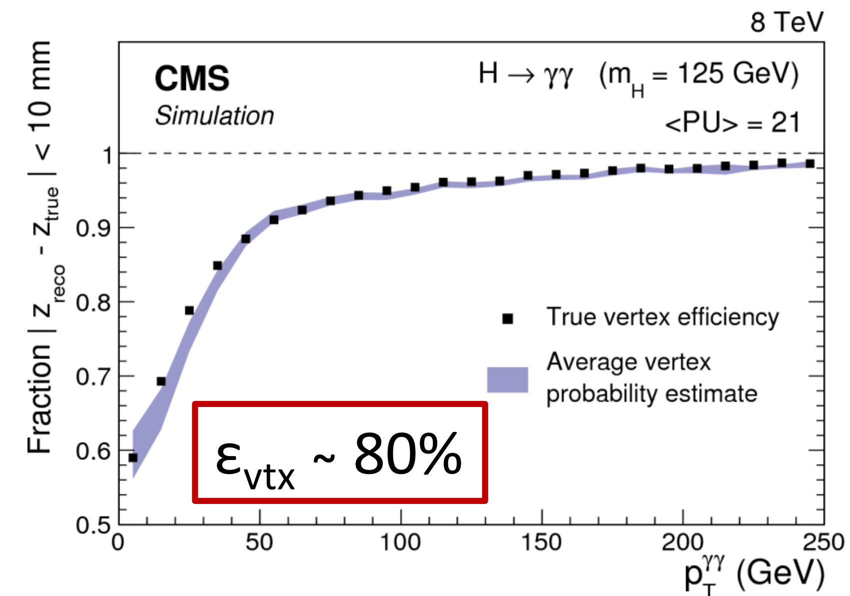


CMS PAS HIG-14-037

Vertex Identification

$$m_{\gamma\gamma} = \sqrt{2E_1E_2(1 - \cos\theta)}$$

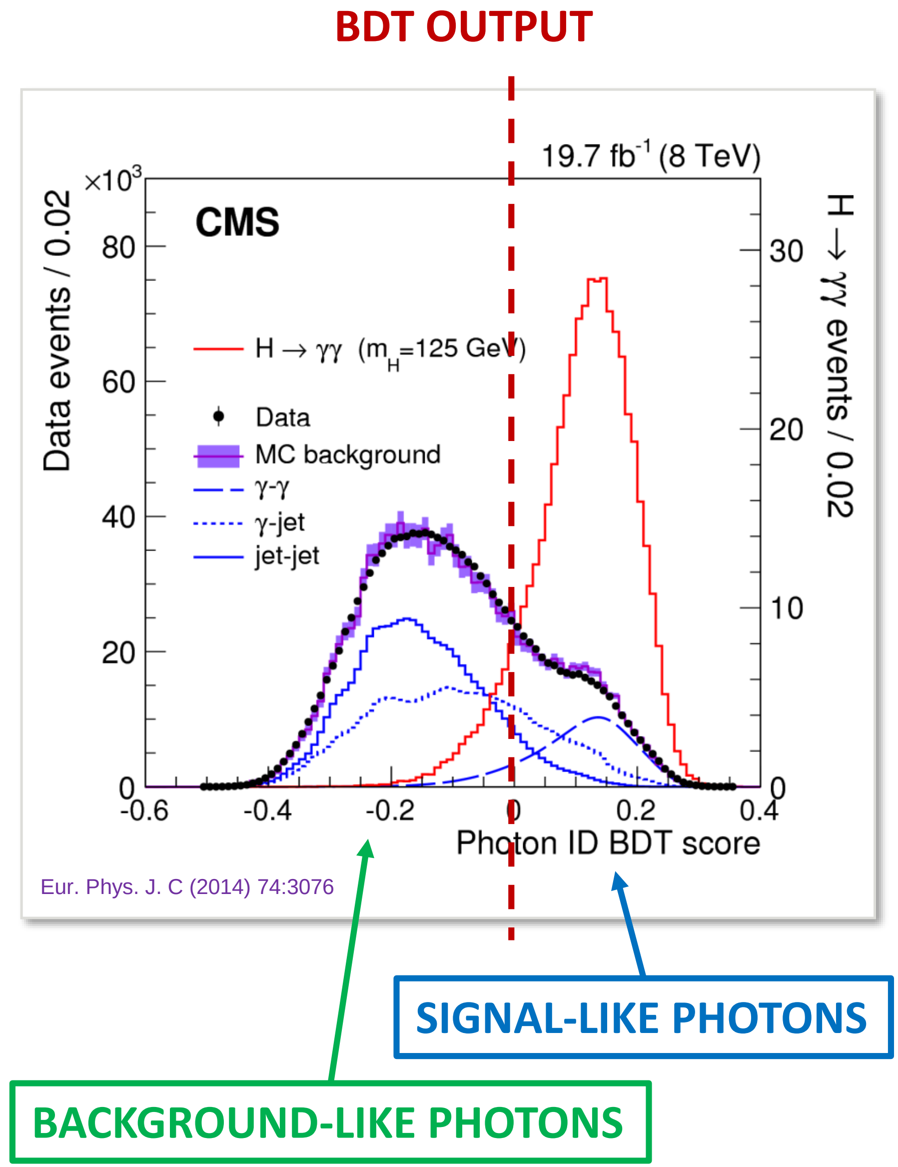
- **Vertex assignment** considered as correct within **1 cm** of the diphoton interaction point
  ➡ **negligible impact** on mass resolution
- **Multi-variate approach**:
  - Observables related **to tracks recoiling** against the diphoton system
  - direction of **conversion tracks**
- **Second MVA discriminant** to estimate the probability for the vertex assignment to be within 1 cm
  ➡ used for diphoton classification
- Method validated on $Z \to \mu\mu$ **events**, by refitting vertices ignoring the muon tracks



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

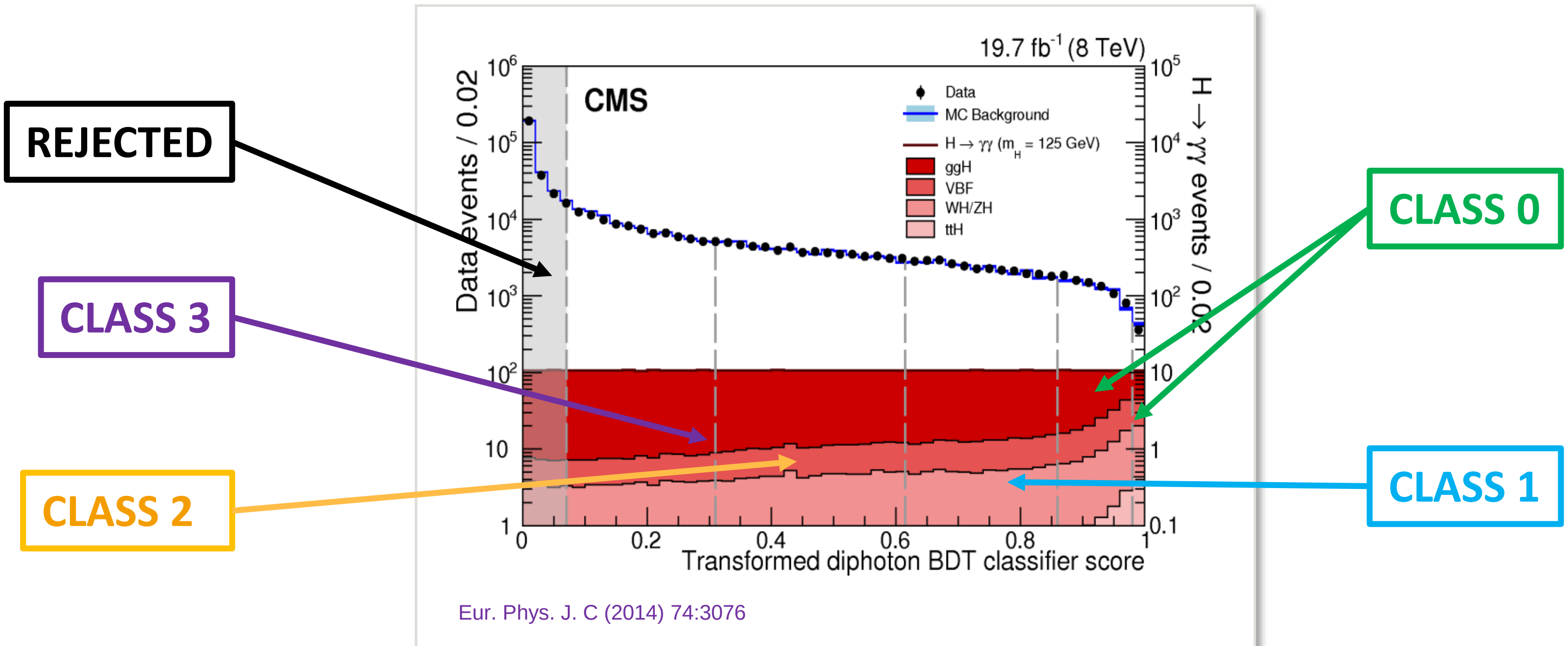
Photon Selection

- **Trigger selection**:
  Trigger paths based on transverse energy, H/E, electromagnetic shower shapes and isolation variables, $m_{\gamma\gamma}$
- **Preselection**:
  - Similar to trigger requirements, but more stringent
  - Specific cuts for the low-mass analysis
  - Electron veto based on pixel detector
- **Photon Identification**:
  - Multi-Variate approach to reject fake photon candidates (mainly from π^0 mesons produced in jets)
  - Shower shape and isolation observables, median energy density (ρ)
  - BDT output provides an estimate of the per-photon quality



Event Categorization

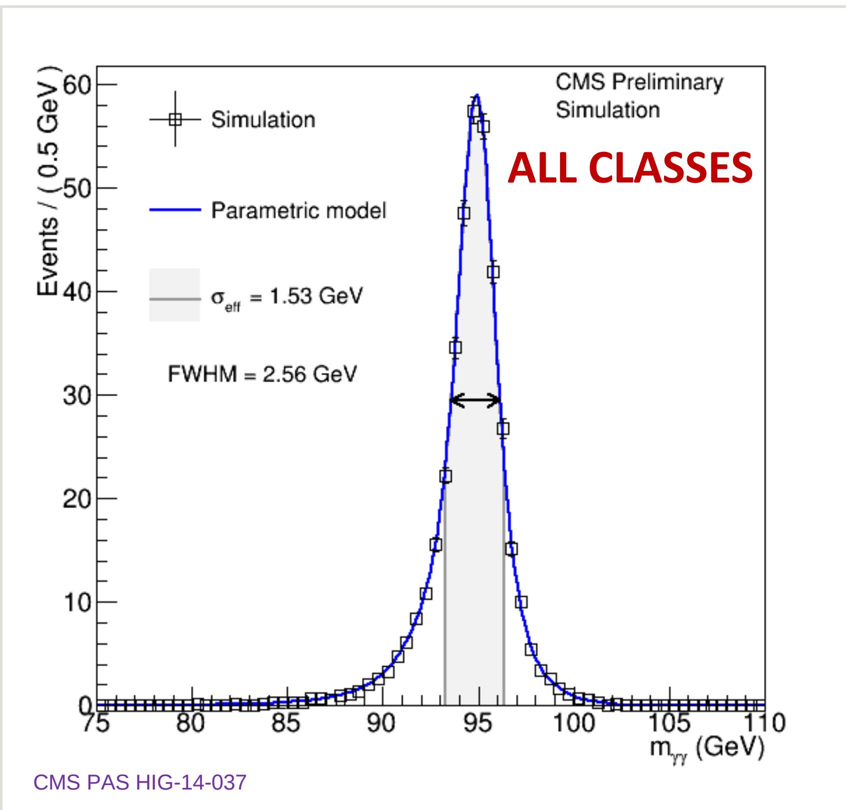
- To gain sensitivity, events are **split into classes** according to their expected signal/background ratio
- Events are categorized according to the **photon kinematics**, per-event **mass resolution, photon ID** and **good vertex probability** by a **multivariate classifier** (same as the standard $H \rightarrow \gamma\gamma$ analysis)
- **Number of classes** limited by **MC DY statistics** (4 classes, no exclusive classes tagging production modes like in standard analysis)

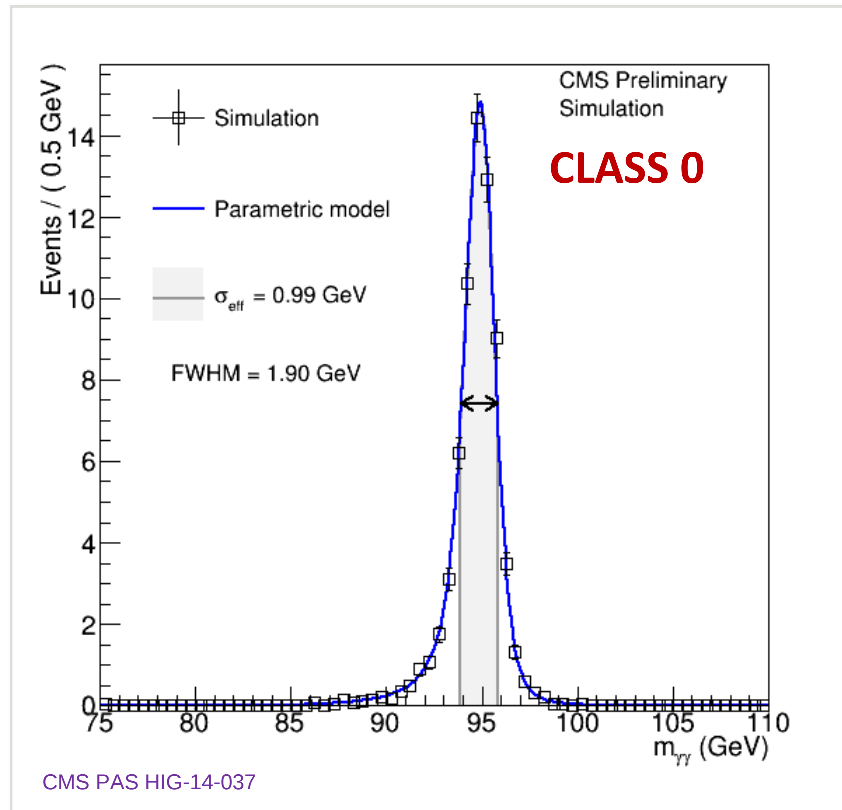


Eur. Phys. J. C (2014) 74:3076

Signal Model

- $H \to \gamma\gamma$ MC samples with m_H from **80 to 110 GeV** are used (5 GeV steps)
- The model is **interpolated between the mass points**
- The **signal shape** corresponds to a **standard Higgs boson**
- The signal is fitted by a **sum of Gaussian distributions** in each event class (then combined together)





Background Model

CONTINUUM BACKGROUND

- Modeled with Bernstein polynomials (order chosen with a p-value test)

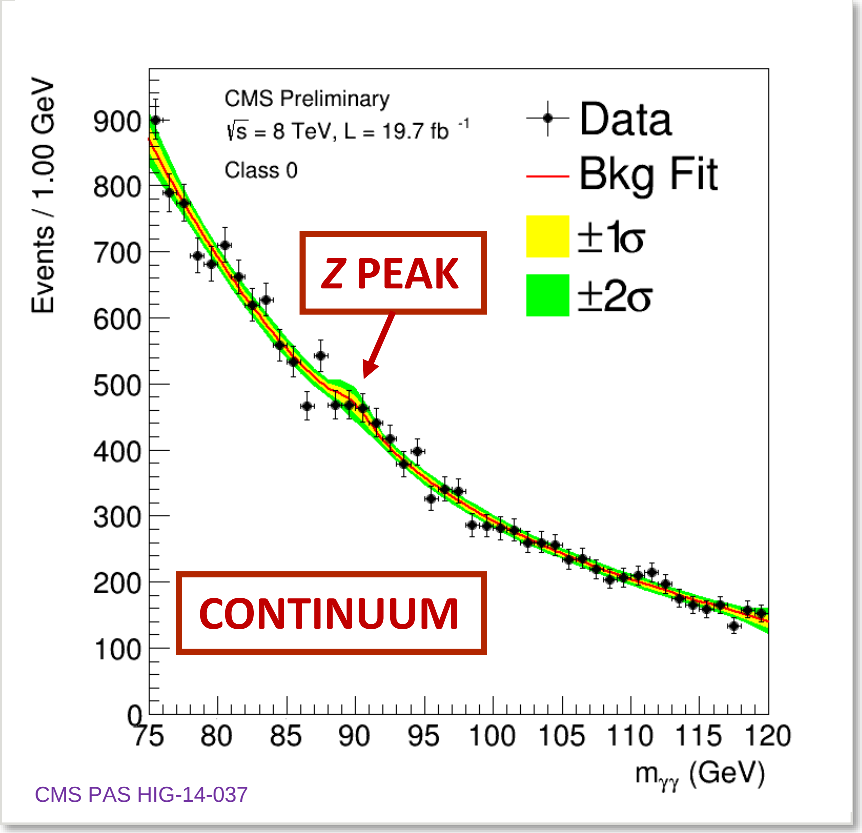
DRELL-YAN CONTRIBUTION

- Modeled with a double-sided Crystal Ball (DCB) distribution
- Shape parameters extracted by fitting MC $Z \to ee$ events passing the whole analysis selection (double-fake events)
- Data/MC systematic uncertainty estimated from single-fake $Z \to ee$ events

FINAL BACKGROUND MODEL

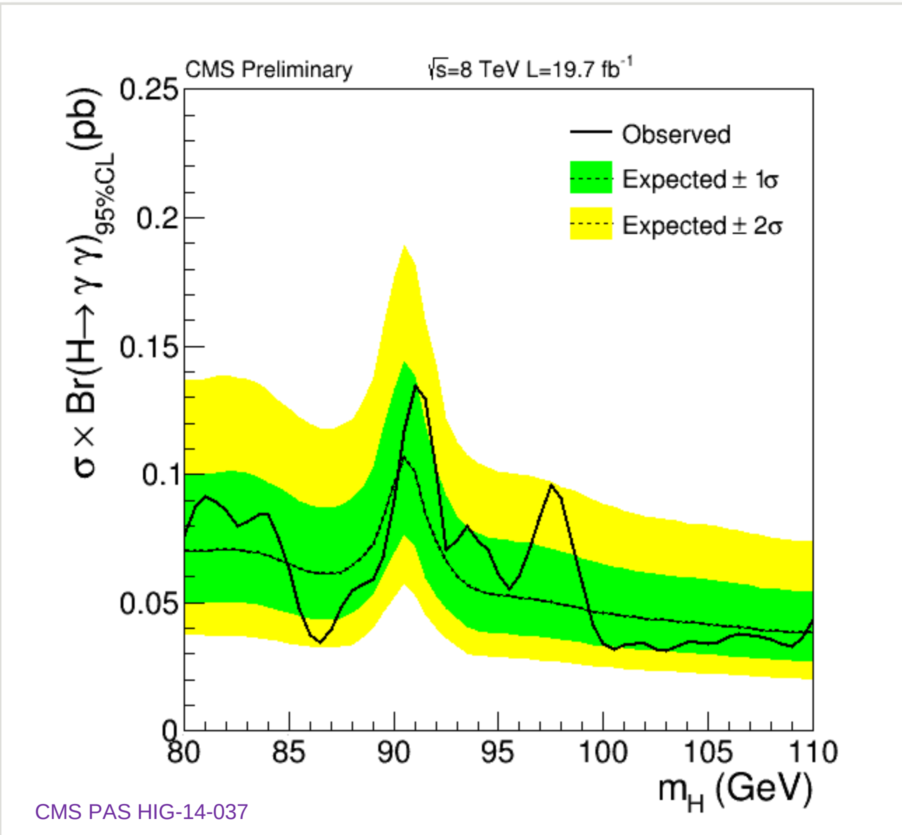
Bernstein polynomial + double-sided Crystal Ball

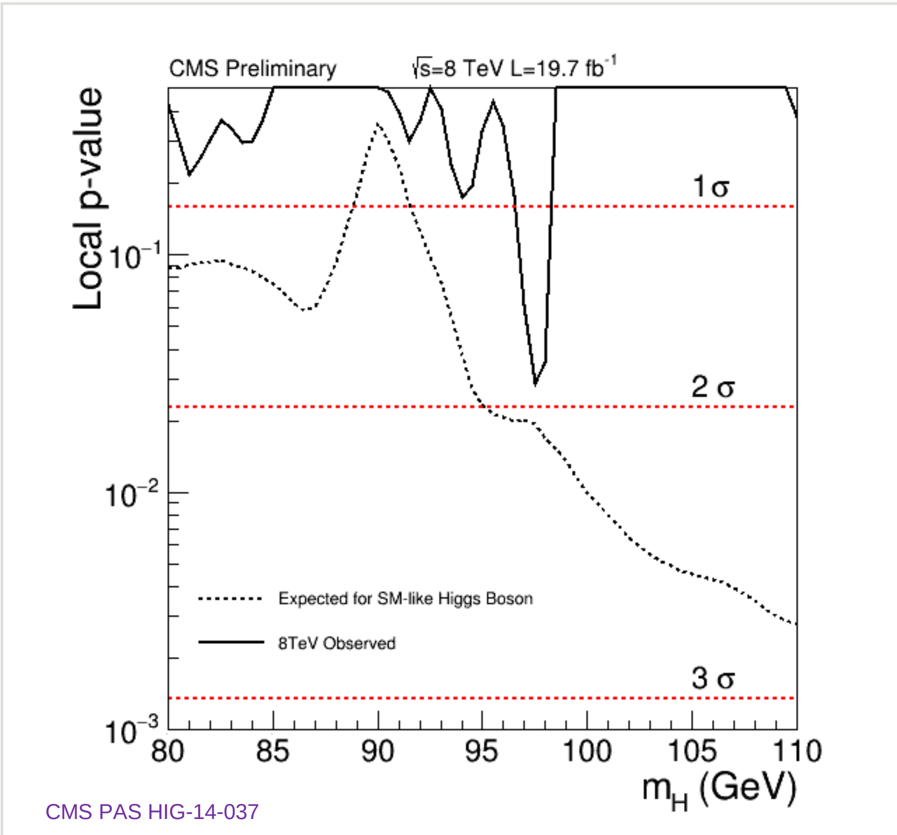
- Fitted to the data
- DCB fraction let floating



Results

- **No significant excess** is observed
- Maximum significance of **1.9 σ** (no Look-Elsewhere Effect) at **97.5 GeV**, about the same value observed at LEP
- **Worse sensitivity** around the ***Z* boson mass**





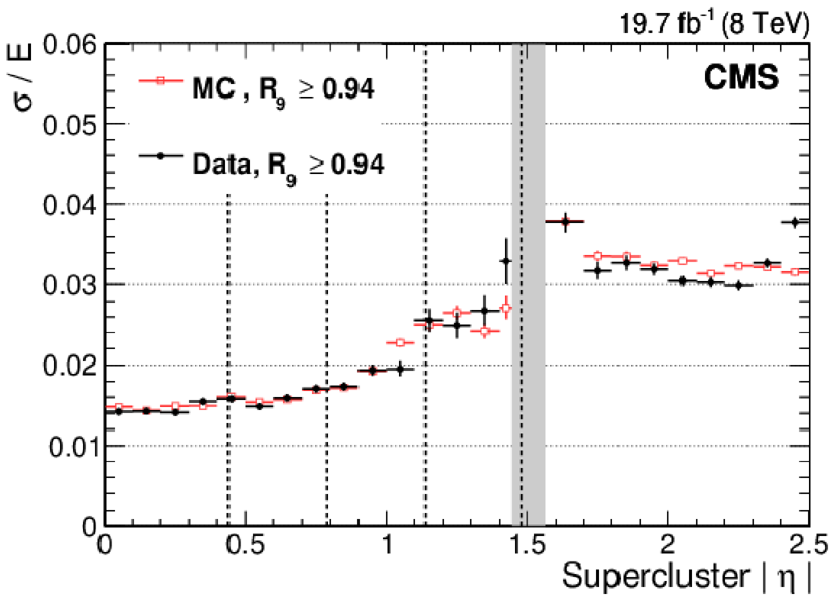
Conclusions

- The search for a **Higgs boson at low mass** values is strongly motivated by **theoretical predictions** (2HDM, NMSSM)
- The **standard $H \rightarrow \gamma\gamma$ analysis** has been **extended** to the mass range **[80, 110] GeV**, analyzing Run I data collected by CMS
- The low-mass analysis has **specific features**, in particular the Drell-Yan contribution
- **No evidence for new particle** has been observed

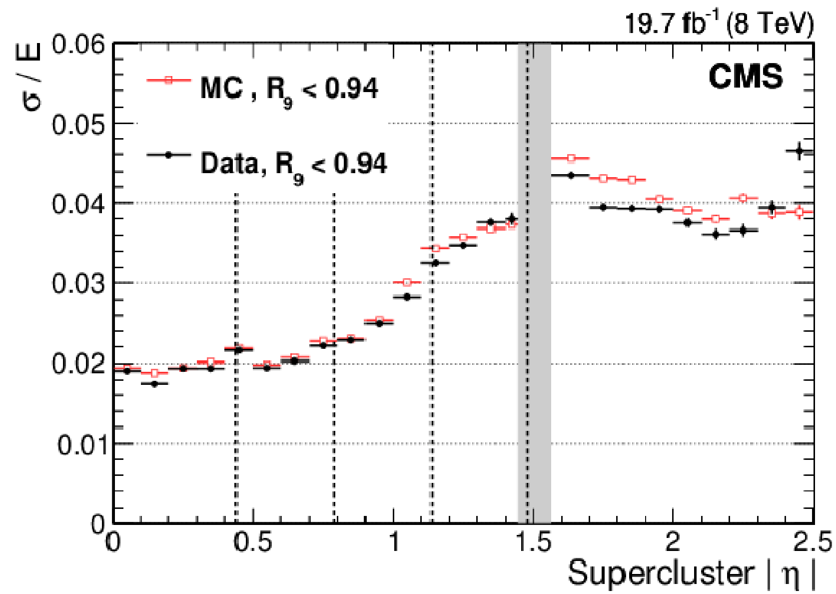
Looking forward to seeing the results at 13 TeV!

Backup

Mass Resolution



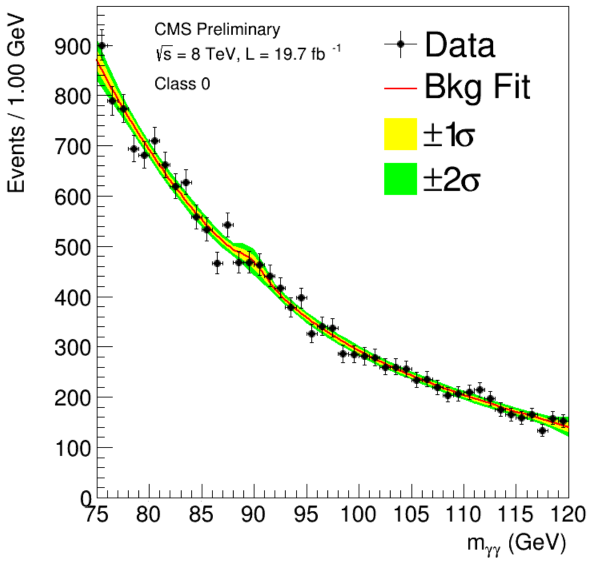
CMS-EGM-14-001



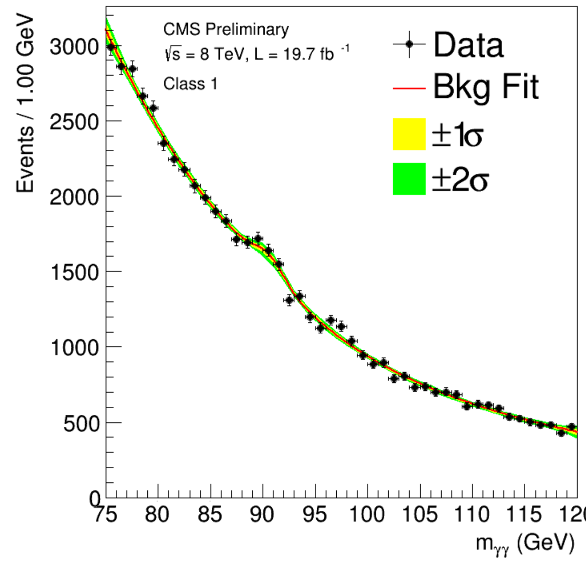
CMS-EGM-14-001

Mass Spectra

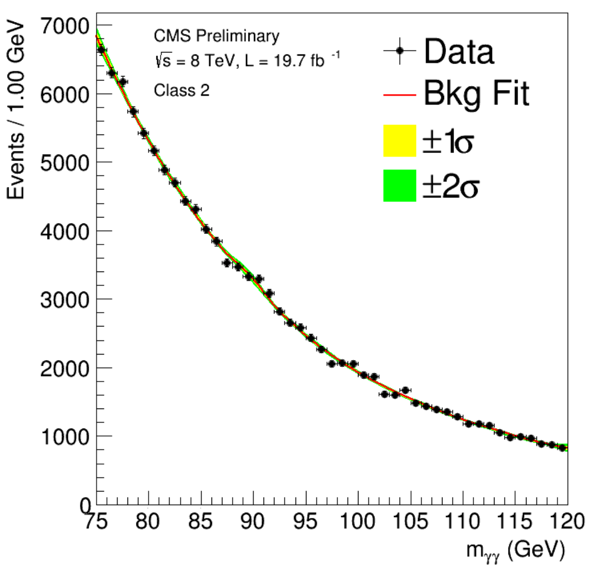
CLASS 0



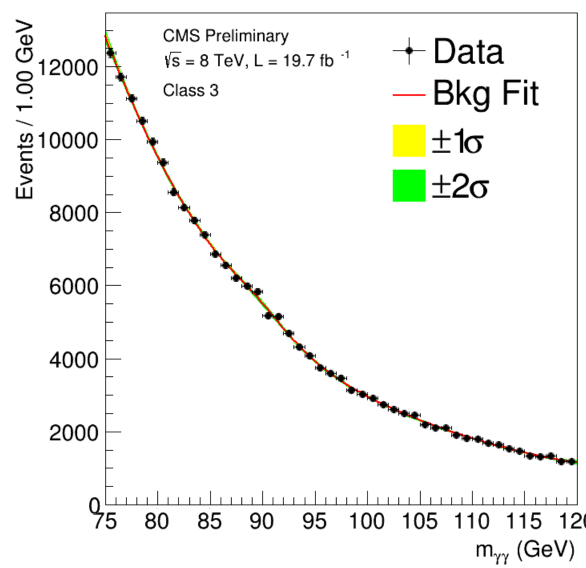
CLASS 1



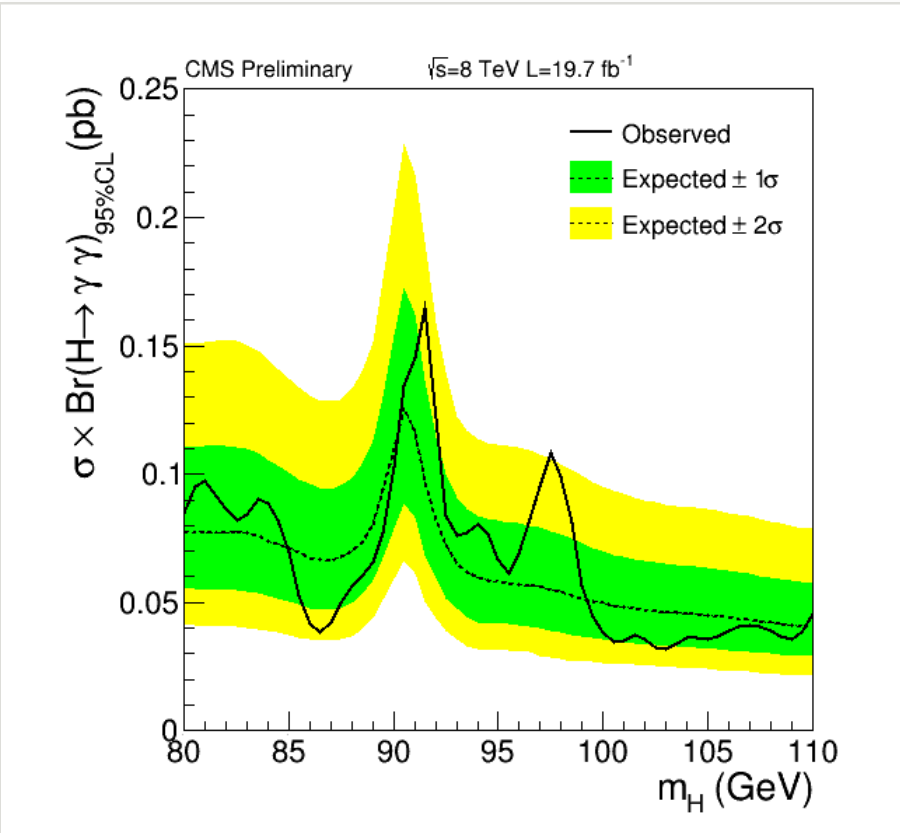
CLASS 2

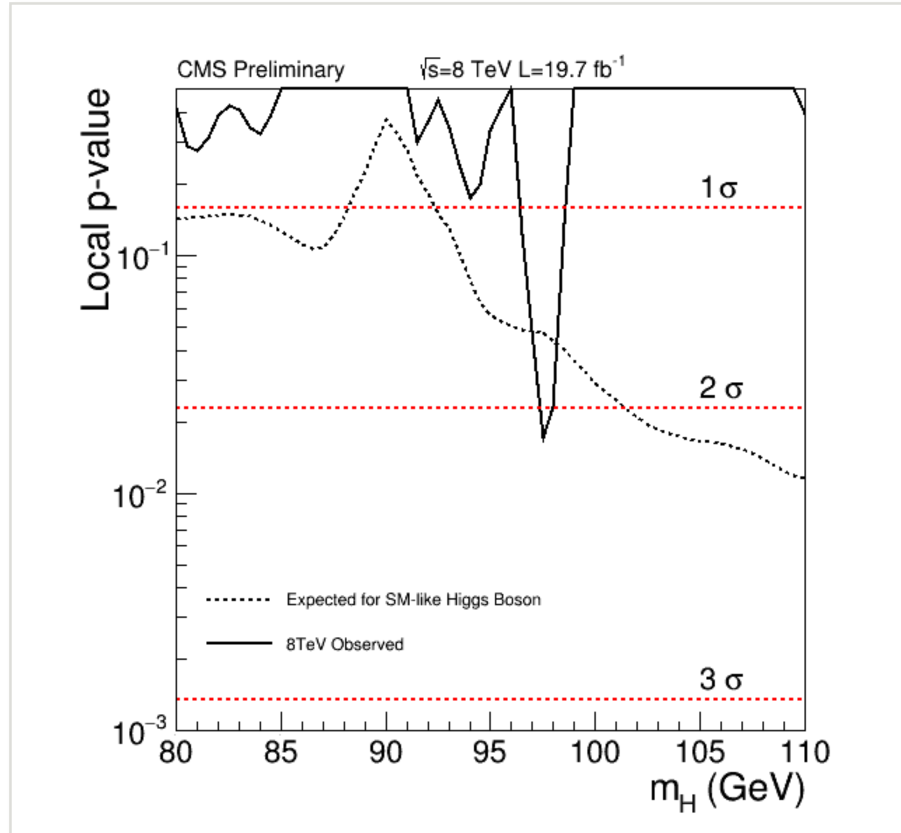


CLASS 3

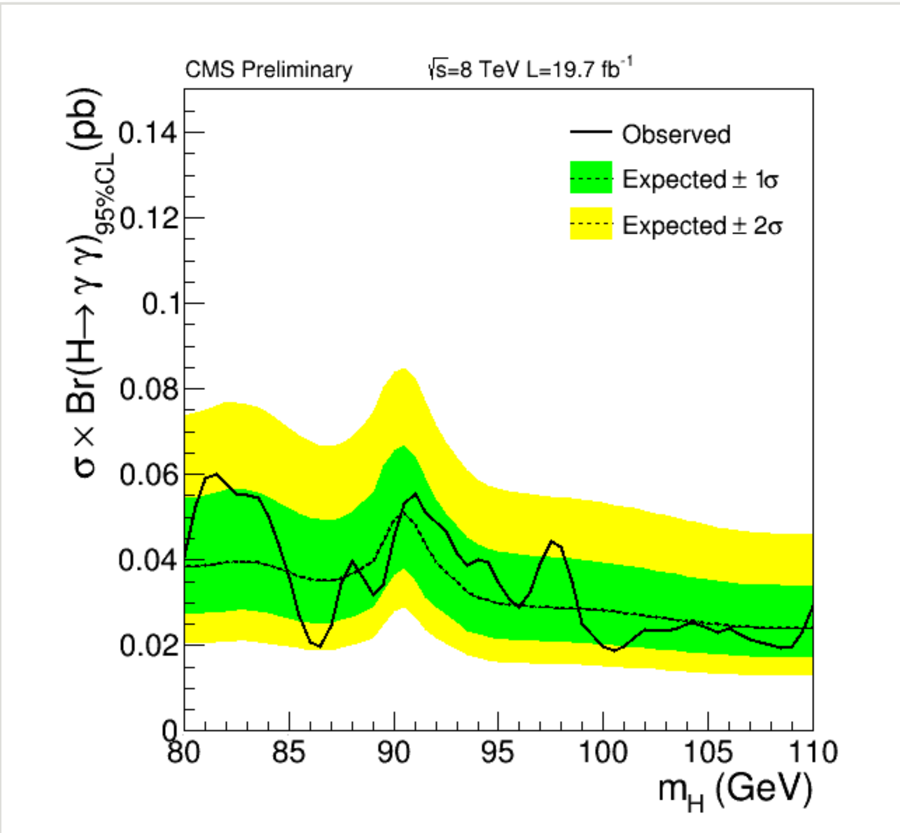


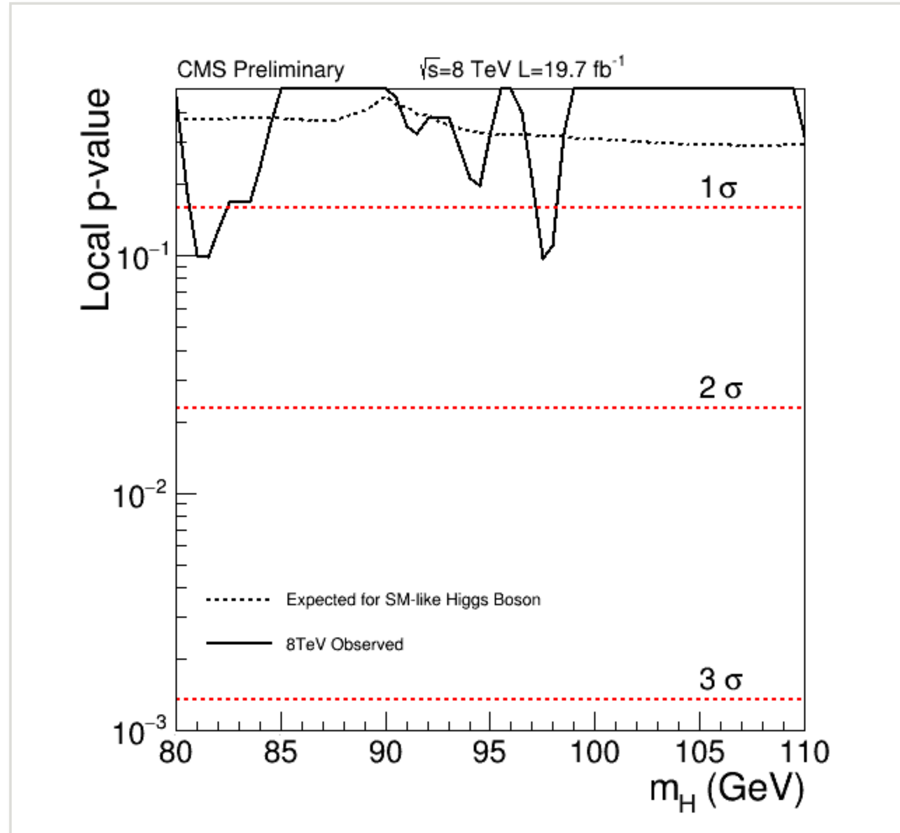
Results – ggH + ttH Production Modes





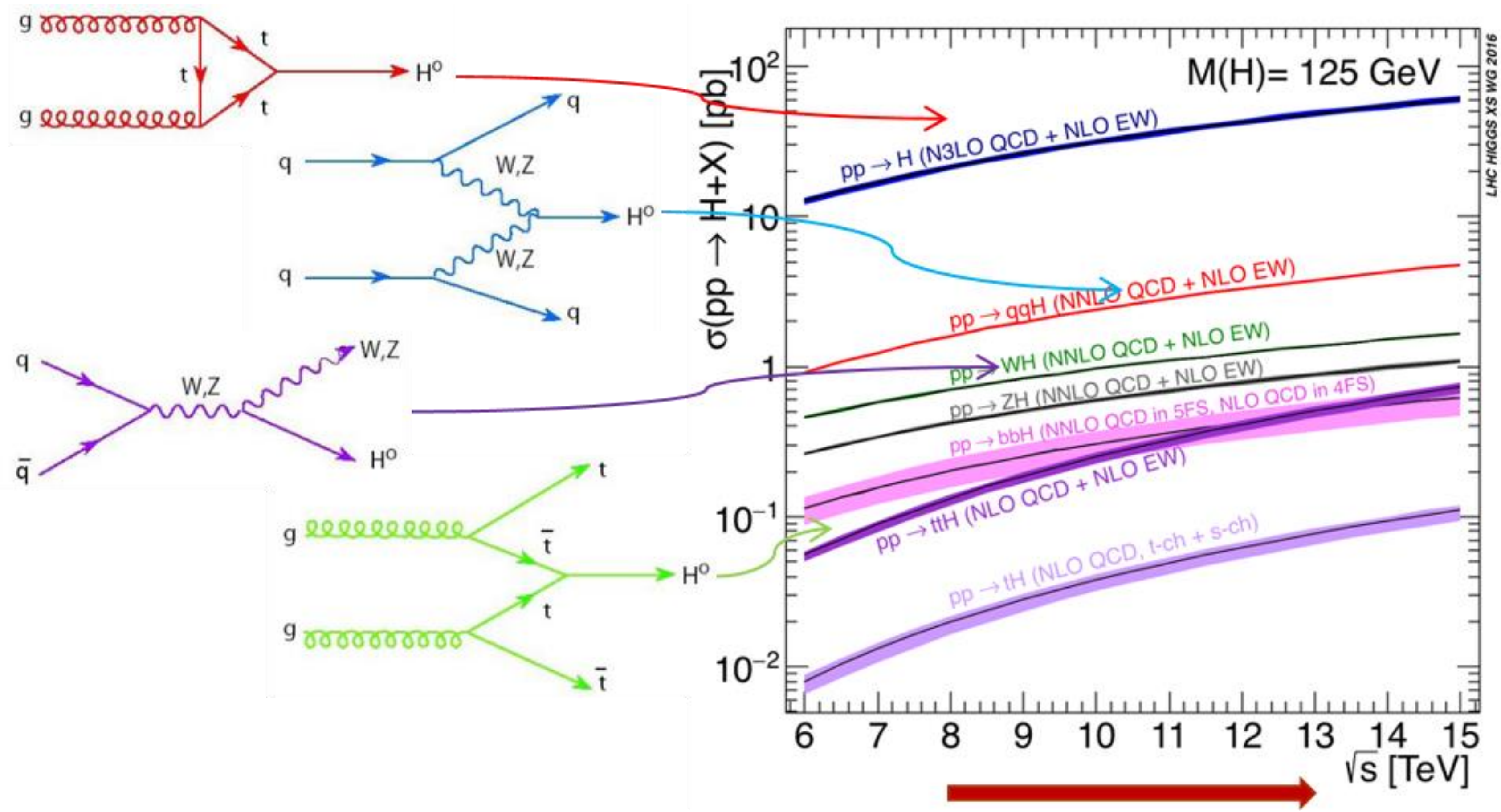
Results – VBF + VH Production Modes



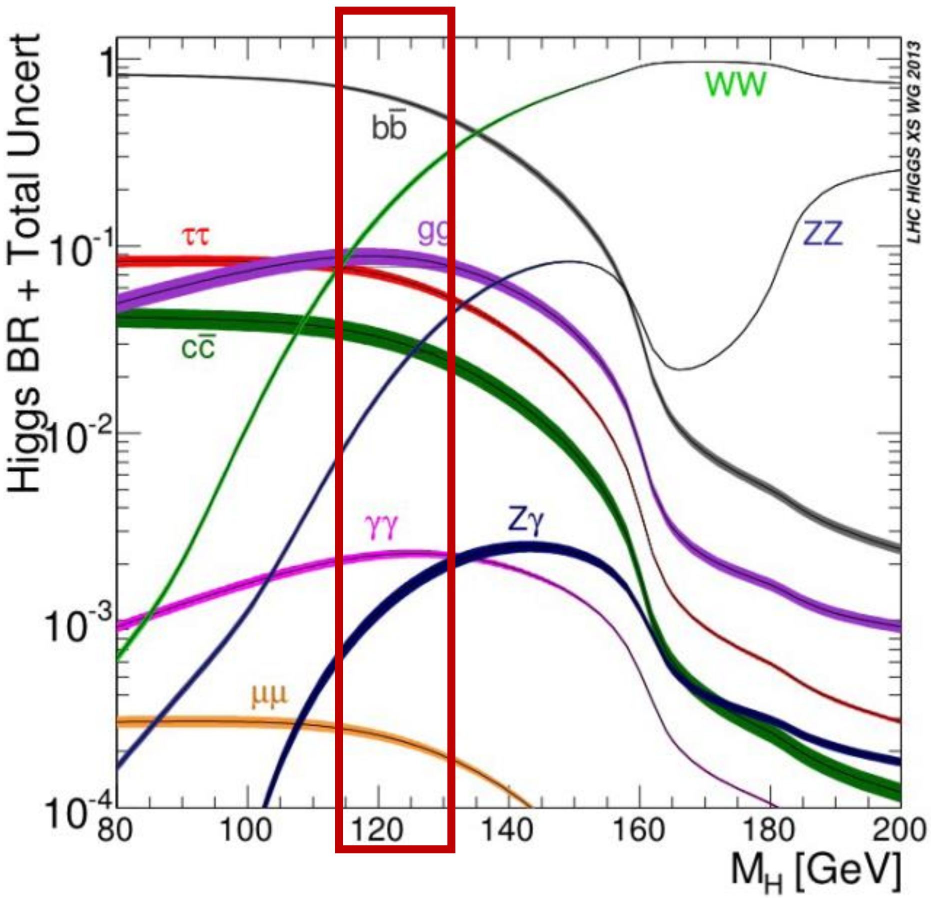


Production Modes

4 PRODUCTION MECHANISMS



Decay Modes



5 MAIN DECAY MODES EXPLOITED:

- H → bb (~58%)
- H → WW → 2l2ν (~22%)
- H → gg (~8.5%)
- H → ττ (~6%)
- H → ZZ → 4l (~3%)
- H → γγ (~0.2%)