# Measurements of Higgs boson production in the di-photon decay channel at $\sqrt{s}$ = 13 TeV in pp collisions at CMS

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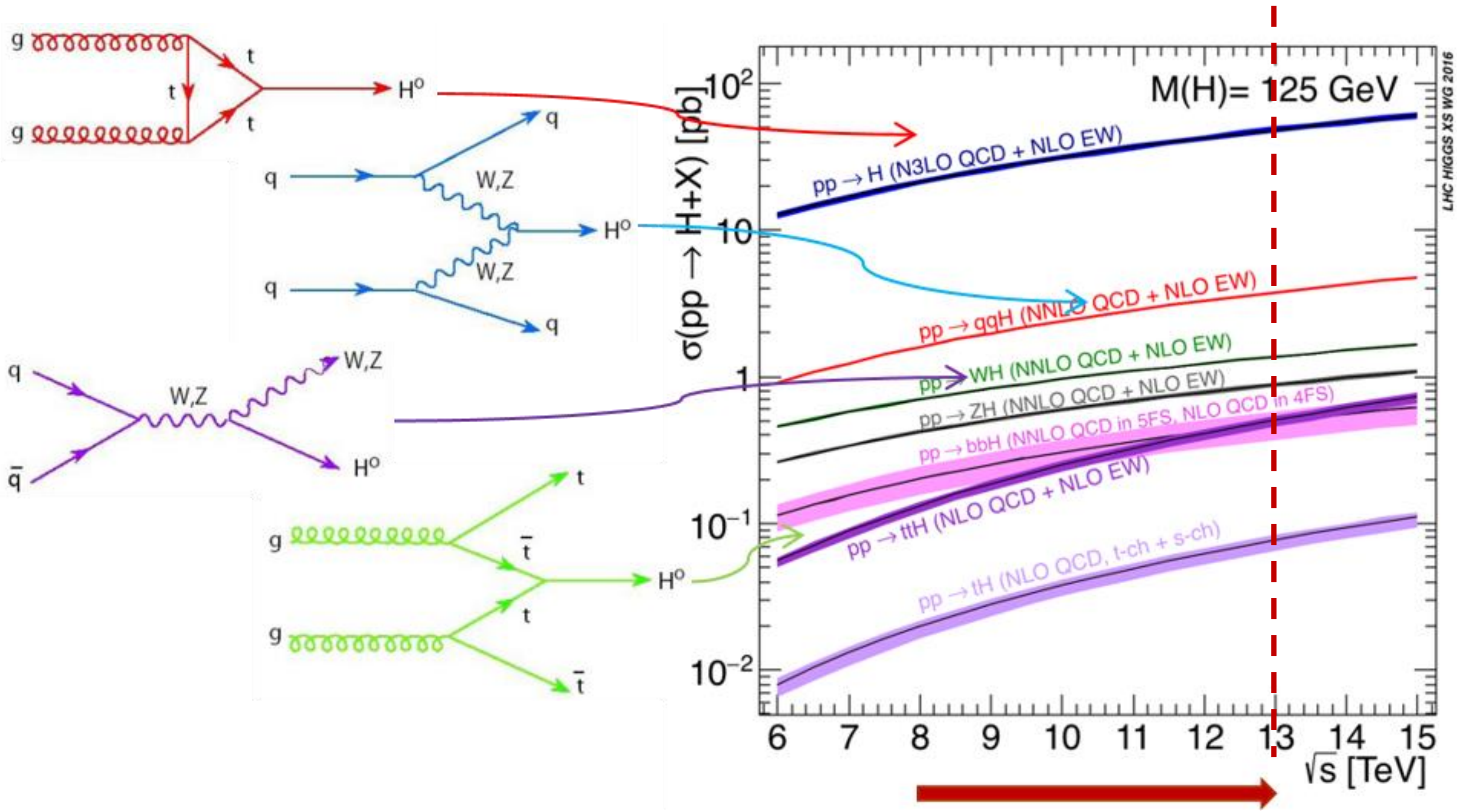
On behalf of the **CMS** Collaboration

**France-China Particle Physics Laboratory**
**Marseille (France)**

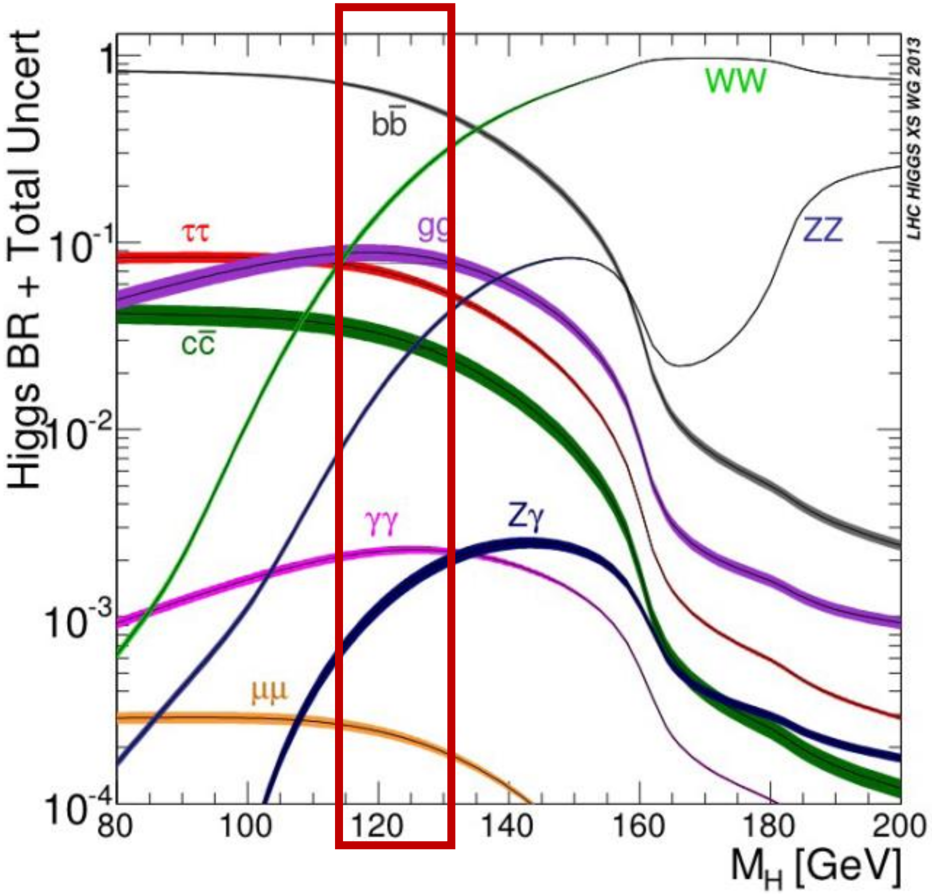
22nd May 2018

# Production Modes

**4 PRODUCTION MECHANISMS**



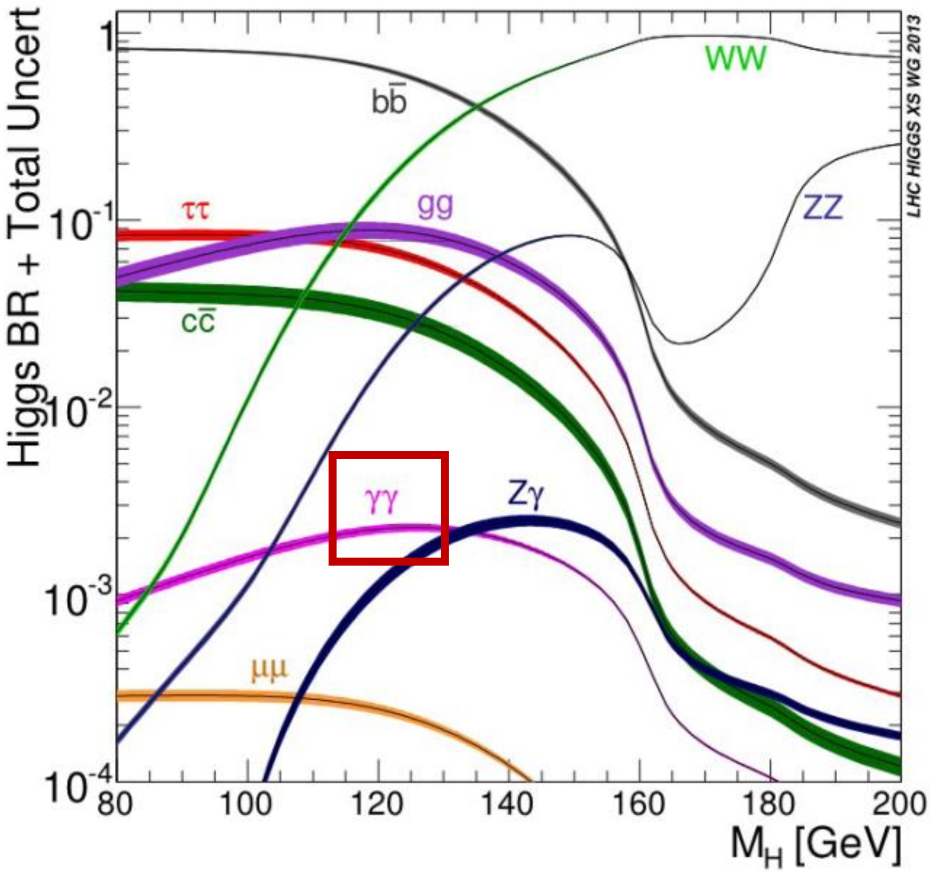
# Decay Modes




**5 MAIN DECAY MODES EXPLOITED**:

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

# Decay Modes

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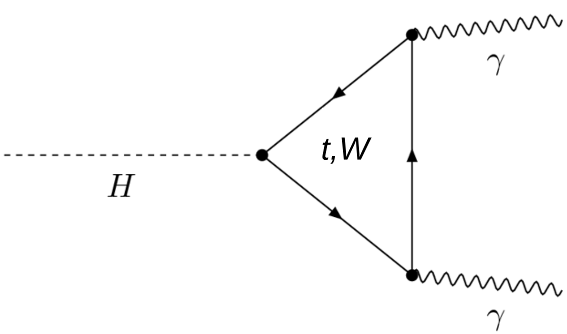
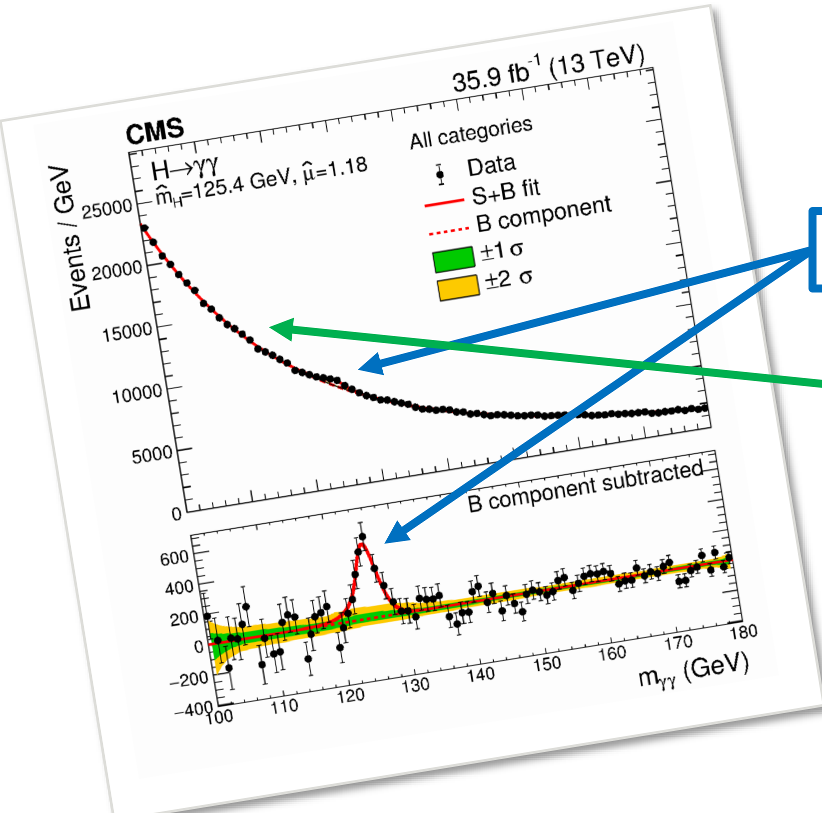


# The $H\to\gamma\gamma$ Decay Channel

- Clean signature with two **isolated and highly energetic photons**
- Final state fully reconstructed with **excellent mass resolution**
- **Large background** from QCD ($\gamma\gamma - \gamma j - jj$)




NARROW SIGNAL PEAK

LARGE FALLING BACKGROUND

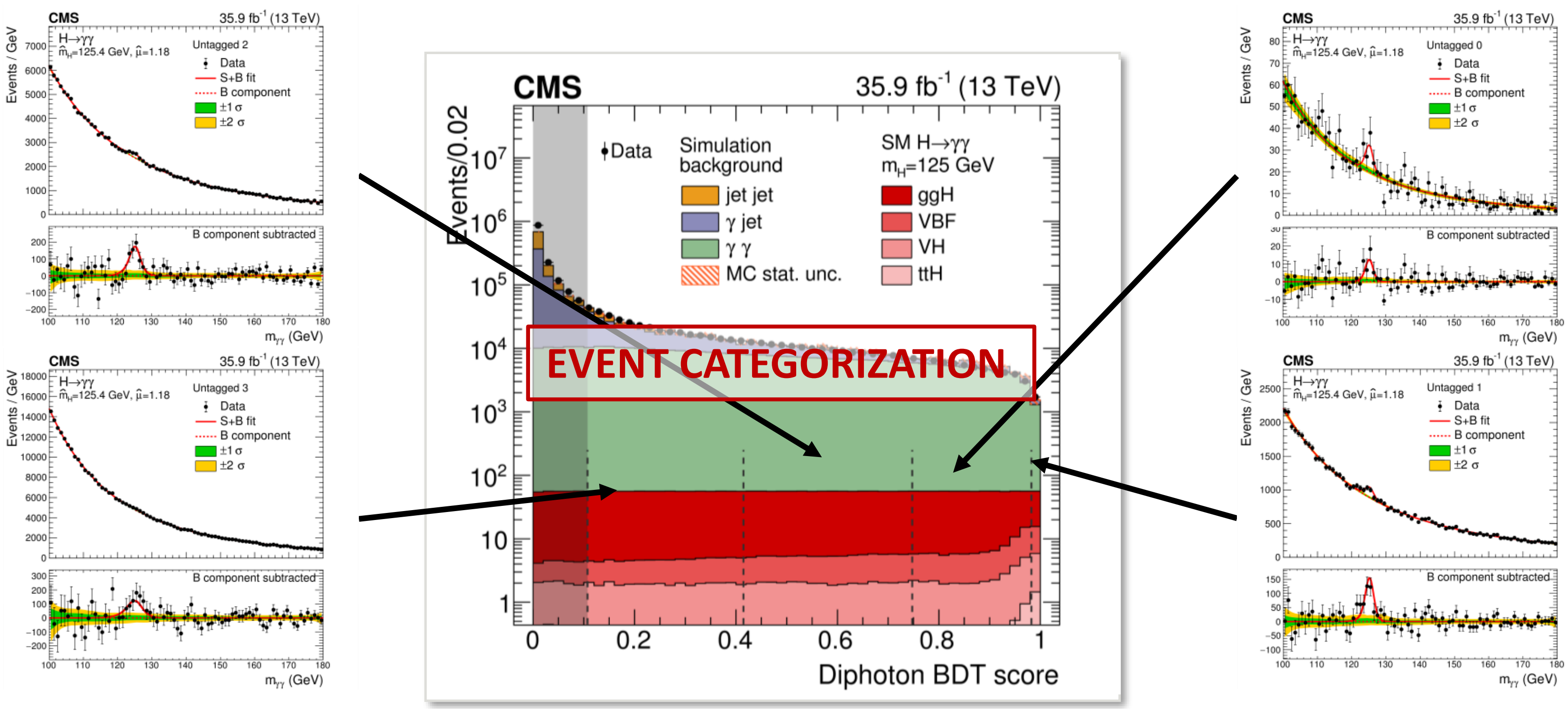
- **Total 2016** dataset analyzed, **35.9 fb$^{-1}$**, collected at 13 TeV (**HIG-16-040**, submitted to JHEP)

# Analysis Strategy

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

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

- **Event categorization** on mass resolution and S/B
- Additional event classes according to **production mechanism**
- Signal extracted from background by **fitting the observed di-photon mass distributions** in each category

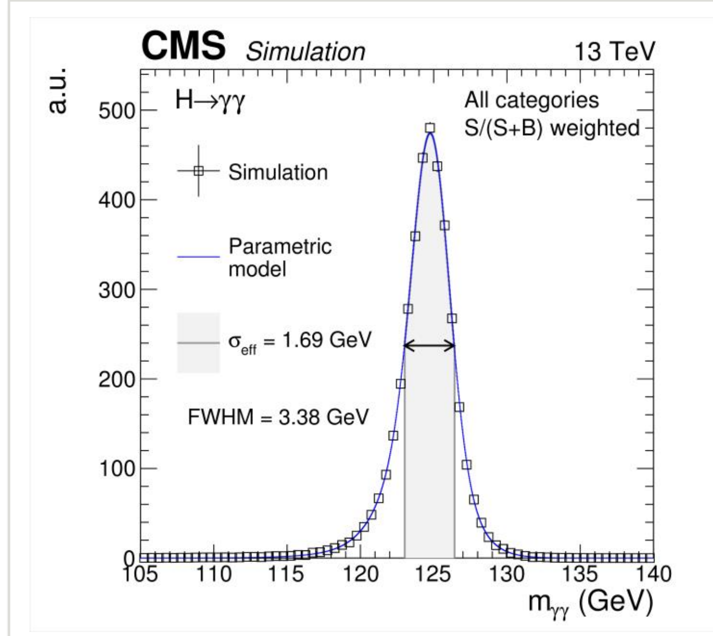


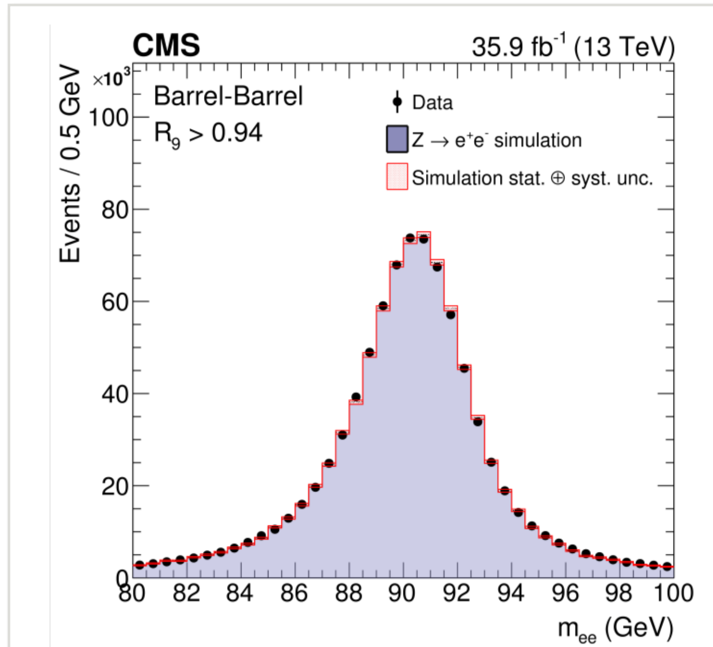
# Photon Energy

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

- 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 and EM shower width
- **Smearing** to the reconstructed photon energy in **MC** to match the resolution in data

➡ ***Z → ee* peak** used as reference

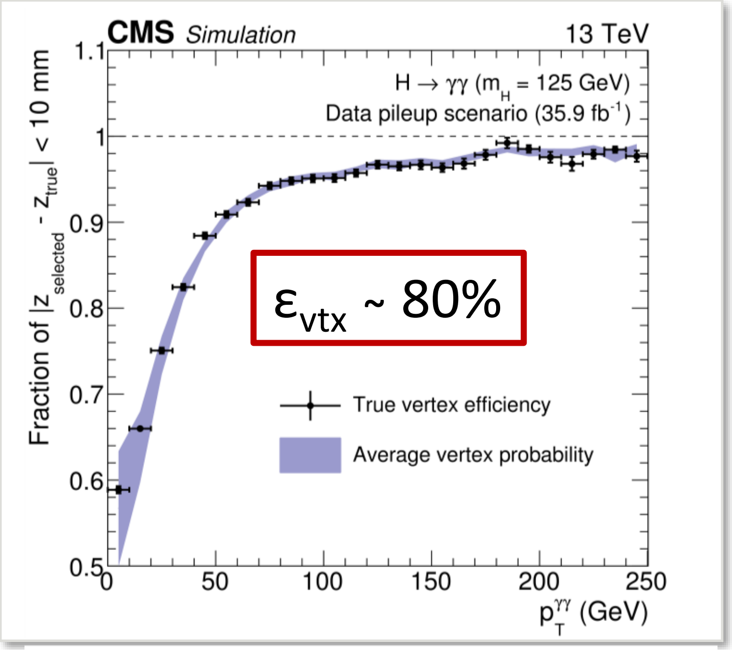


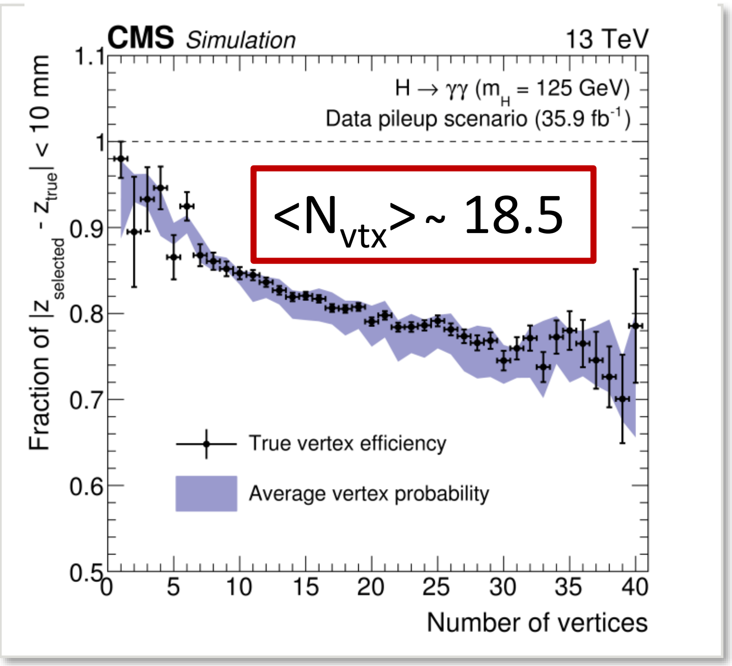



# Vertex Identification

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

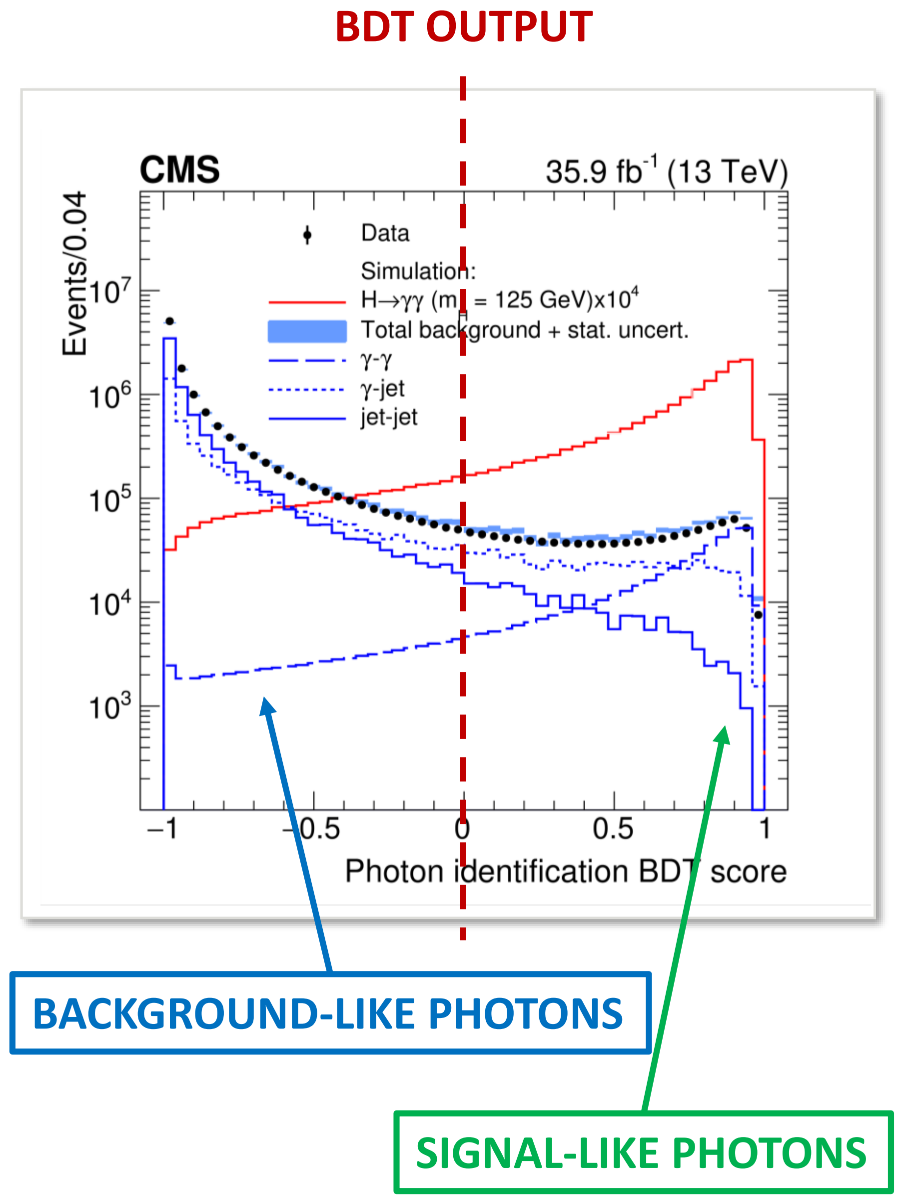
- **Vertex assignment** considered as correct within **1 cm** of the diphoton interaction point
  ➡ **negligible impact** on mass resolution
- **Multi-variate approach**:
  - Observables related **to tracks recoiling** against the diphoton system
  - direction of **conversion tracks**
- **Second MVA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



# Photon Selection

- **Trigger selection**:
  double-photon trigger path based on transverse energy, H/E, electromagnetic shower shapes and isolation variables, $m_{\gamma\gamma}$
- **Preselection**:
  similar to trigger requirements, but more stringent
- **Photon Identification**:
  - Multi-Variate approach to reject fake photon candidates (mainly from $\pi^0$ mesons produced in jets)
  - Shower shape and isolation observables, median energy density (ρ)
  - BDT output provides an estimate of the per-photon quality

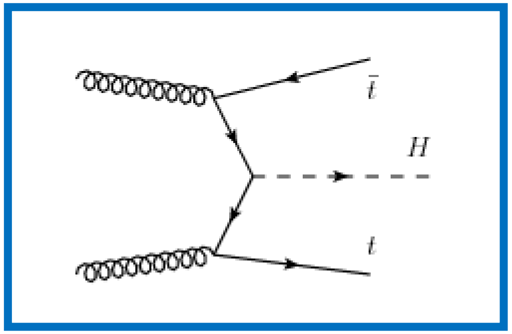


# Tagged Events

Event categories defined targeting Higgs boson production mode other than ggF, by requiring specific features in the final state

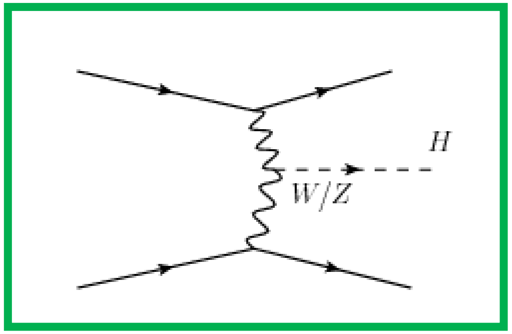
**ttH PRODUCTION MODE**:

- Higgs accompanied by two b quarks and two W bosons
    - **ttH Hadronic** (additional jets)
    - **ttH Leptonic** (additional leptons)



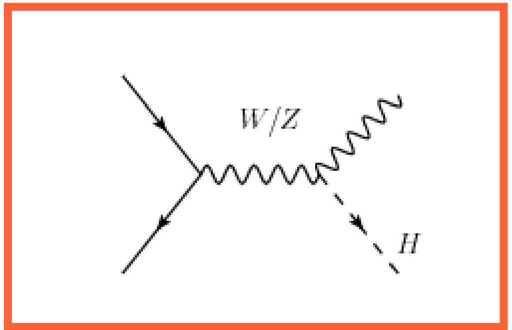

**VBF PRODUCTION MODE**:

- Higgs accompanied by 2 jets separated by a large rapidity gap
- MVA approach to identify events with 2 jets
- Combination of di-jet and di-photon BDT (**VBF tag 0**, **1** and **2**)



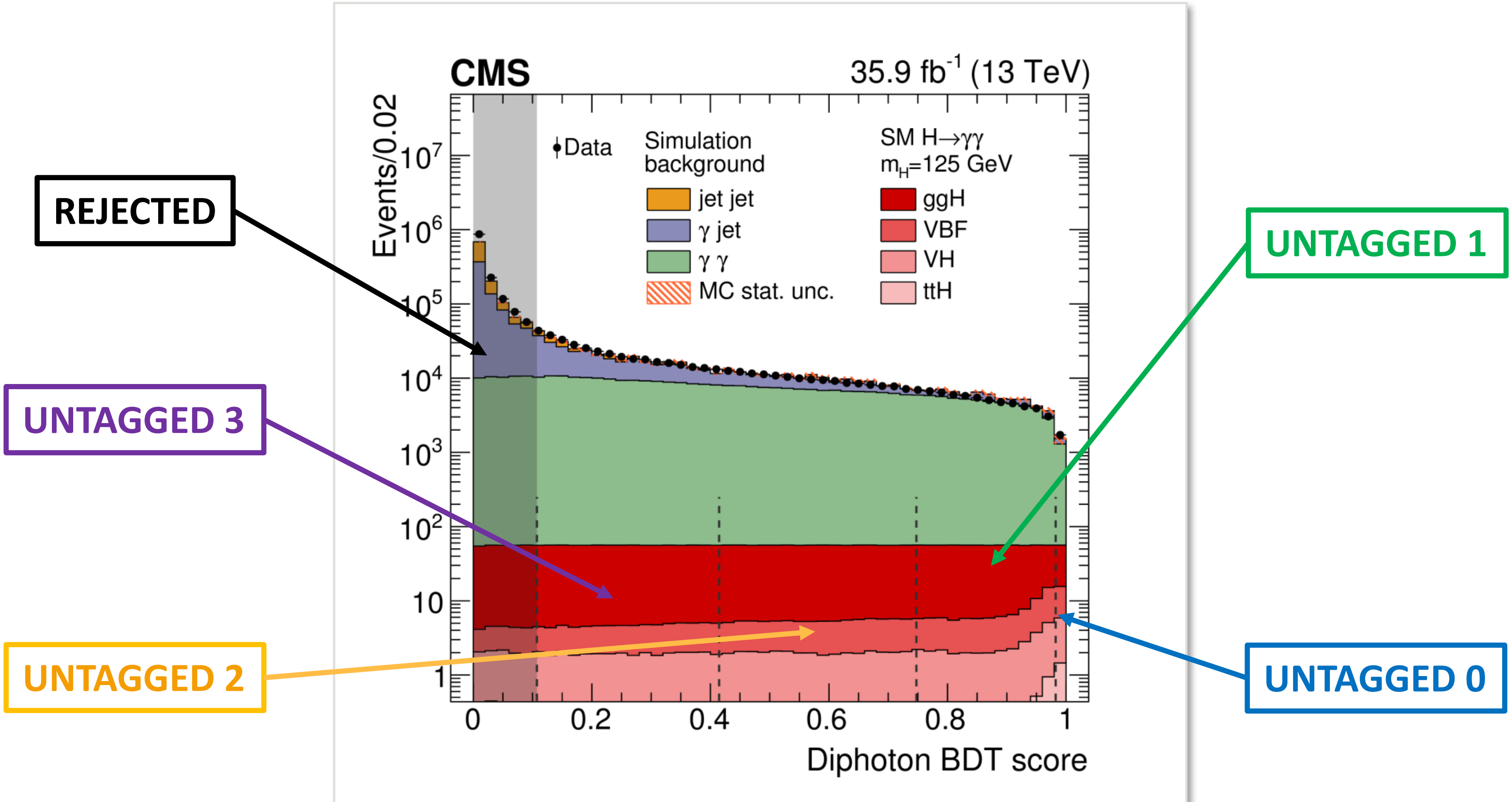

**VH PRODUCTION MODE**:

- Higgs accompanied by a vector boson (W or Z)
- 5 categories according to the presence of leptons, missing transverse momentum and jets (**ZH Leptonic**, **WH Leptonic**, **VH Leptonic Loose**, **VH MET, VH Hadronic**)



# Untagged Events

The remaining inclusive events are categorized according to the **photon kinematics**, per-event **mass resolution, photon ID** and **good vertex probability** by a **multivariate classifier**



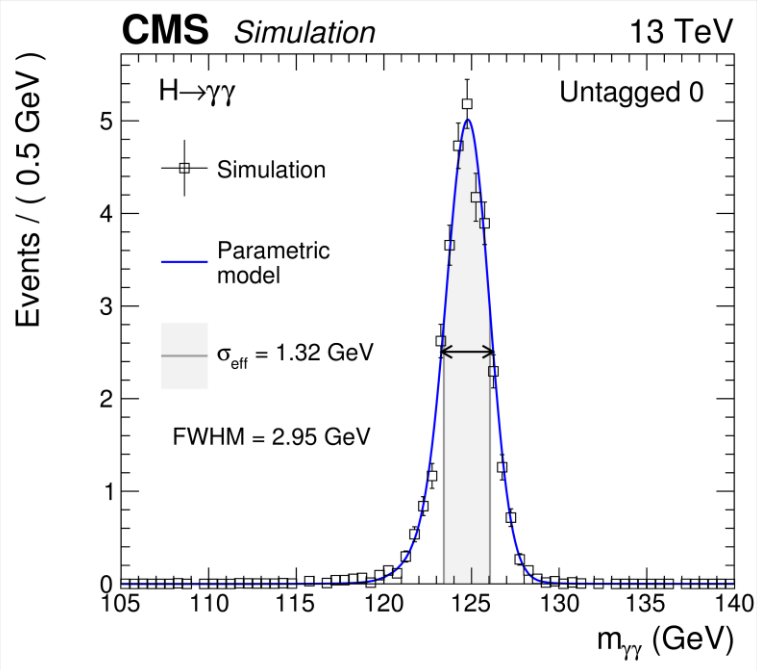

The number of categories and their boundaries are **optimized** to maximize the **expected significance**

# Signal and Background Model

**SIGNAL**

Parametrized model of Higgs boson mass shape

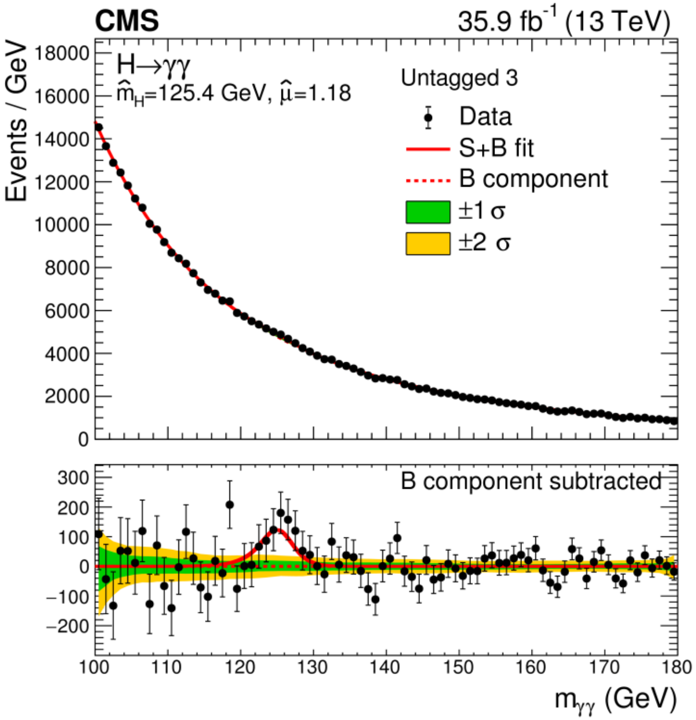
- Obtained from **simulation**
- MC tuning and data/MC efficiency scale factors applied




**BACKGROUND**

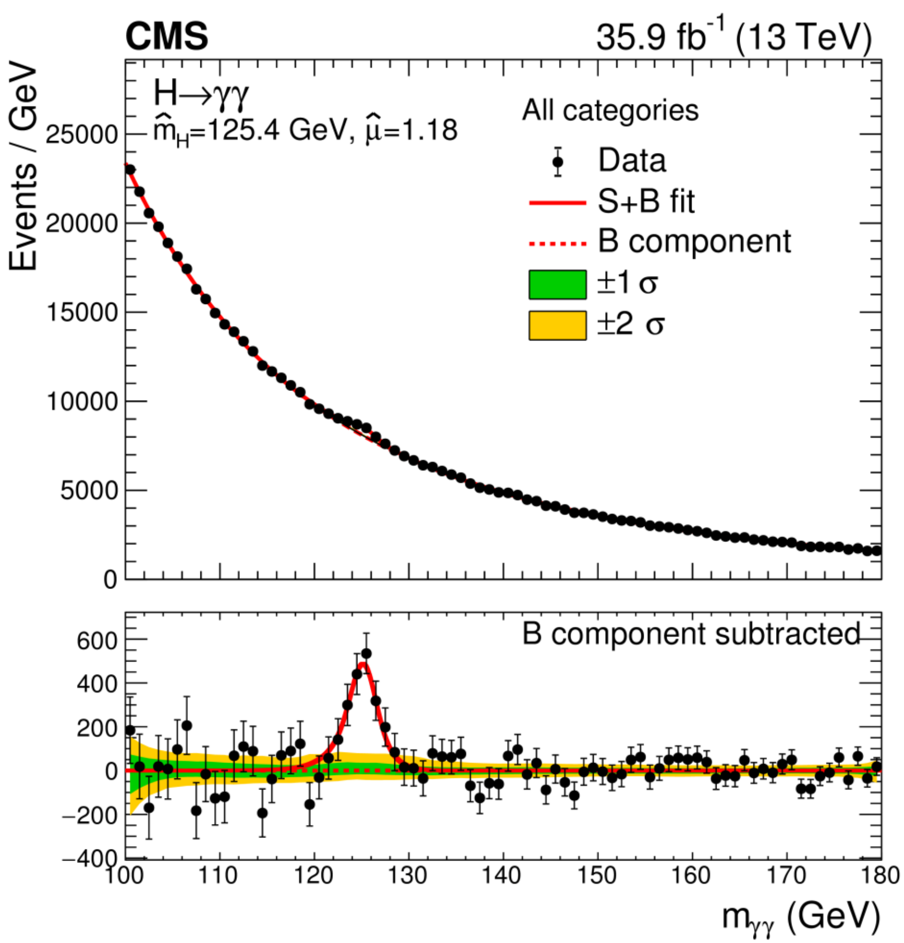
Background model extracted from **data**

- Different functional forms used for each category
- Choice of function treated as a discrete nuisance parameter

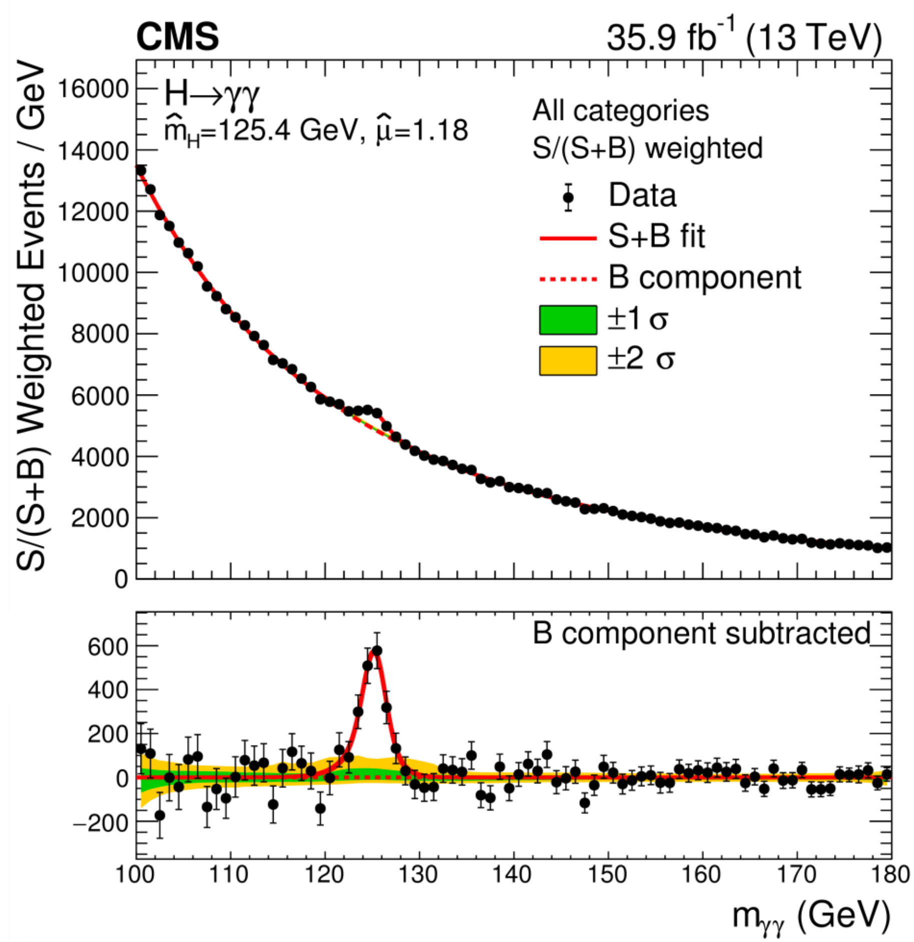


# Mass Spectra (All Categories)

**All Categories**




**All Categories weighted by sensitivity**



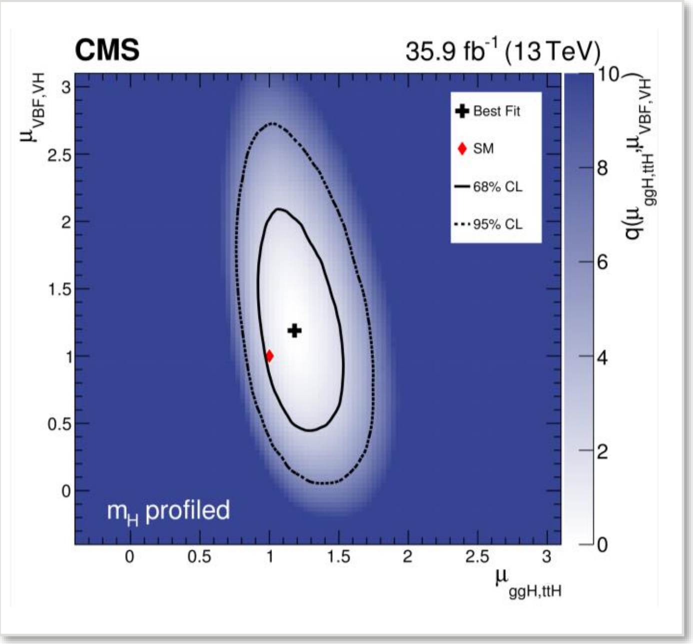
# Results

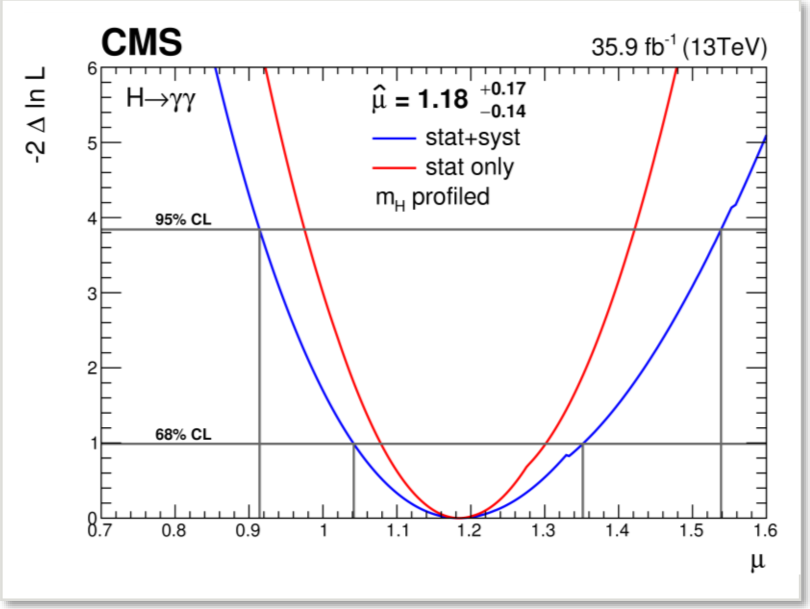
- Best-fit **signal strength**:

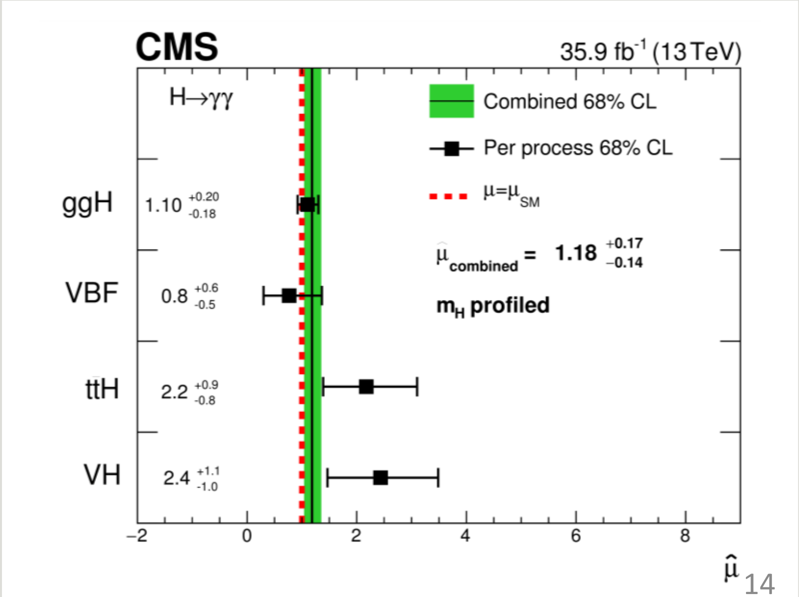
  $\hat{\mu} = 1.18^{+0.17}_{-0.14} = 1.18^{+0.12}_{-0.11}\,(\text{stat.})\,^{+0.09}_{-0.07}\,(\text{syst.})^{+0.07}_{-0.06}\,(\text{theo.})$

- **Signal strength** measured in **bosonic** and **fermionic** components:
  - $\mu_{VBF/VH} = 1.21^{+0.58}_{-0.51}$
  - $\mu_{ggH/ttH} = 1.19^{+0.22}_{-0.18}$
- **Signal strength** measured for each **production modes (compatible** with the **Standard Model)**
- Best fit **mass**

  $\hat{m}_H$ = 125.4 ± 0.3 GeV = 125.4 ± 0.2 (stat.) ± 0.2 (syst.)



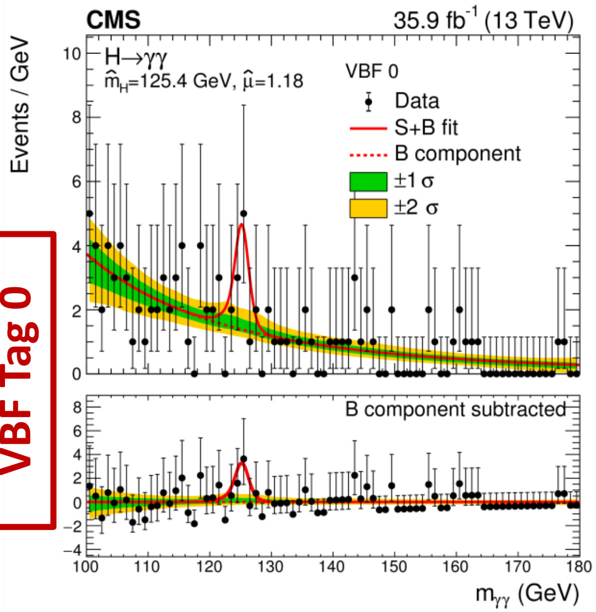
# Conclusions

- Results of the CMS **$\mathbf{H \to \gamma\gamma}$ analysis** have been reported, using **35.9 $\mathbf{fb^{-1}}$** of collision data collected in 2016 at 13 TeV
- The **$\mathbf{H \to \gamma\gamma}$ channel** is one of the **most sensitive** for the **precise characterization** of the **Higgs boson**
- The best fit signal strength modifier is $\hat{\mu} = 1.18^{+0.17}_{-0.14}$
- The best-fit values for the signal strength modifiers associated with bosonic and fermionic components are found to be $m_{ggH/ttH} = 1.19^{+0.22}_{-0.18}$ and $m_{VBF/VH} = 1.21^{+0.58}_{-0.51}$
- All results are up-to-now compatible with the Standard Model

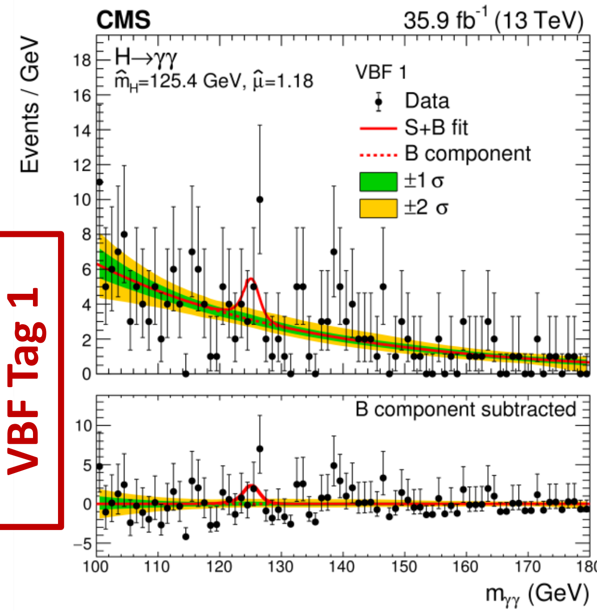
# Backup

# Mass Spectra (Tagged Events)

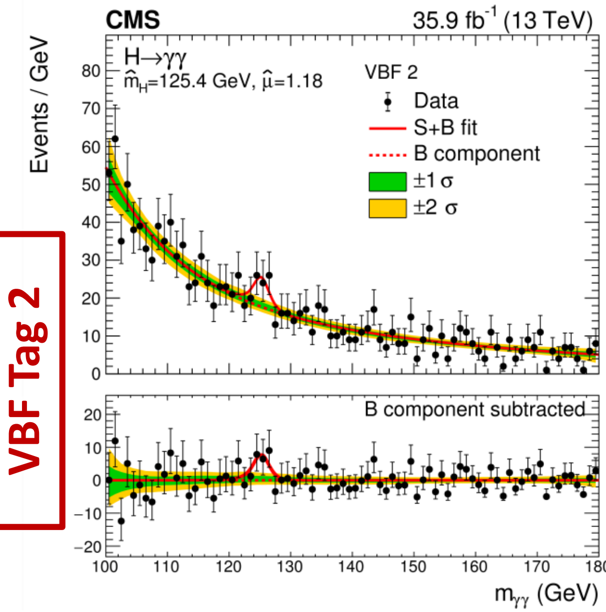
**VBF Tag 0**



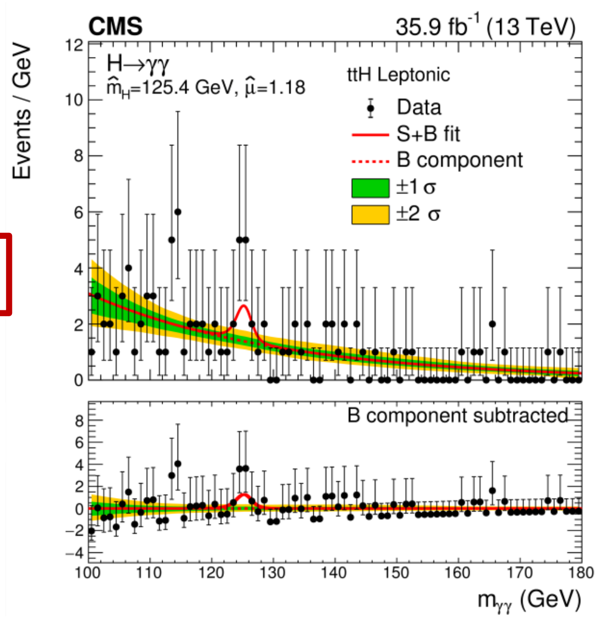

**VBF Tag 1**

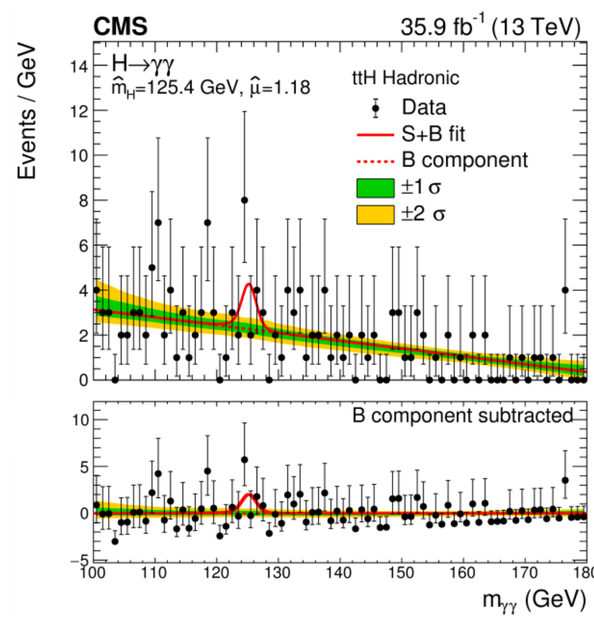



**VBF Tag 2**




**TTH Leptonic**

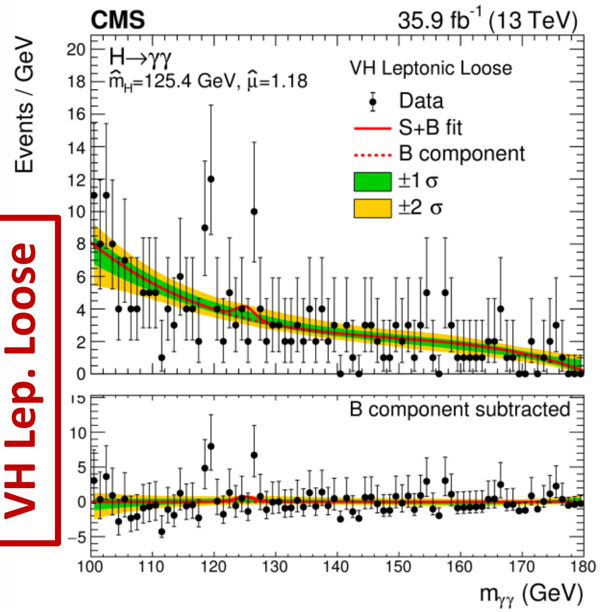


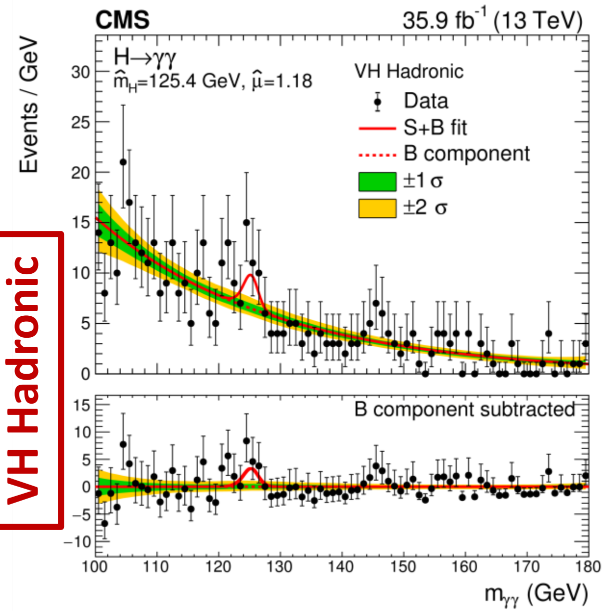

**TTH Hadronic**

# Mass Spectra (Tagged Events)

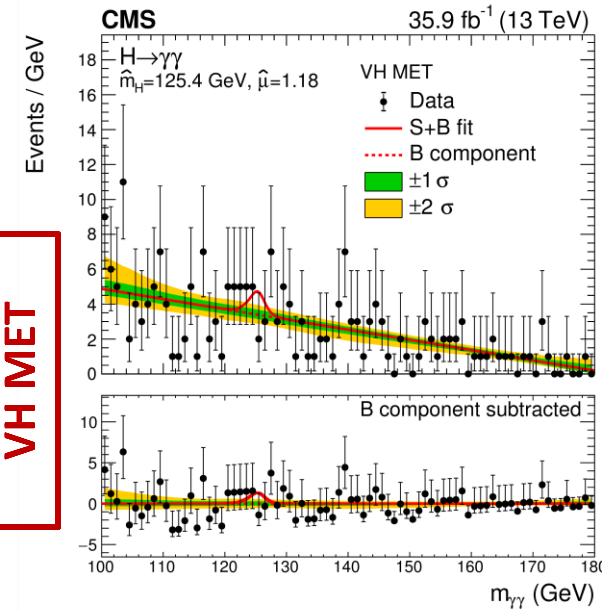
**VH Lep. Loose**



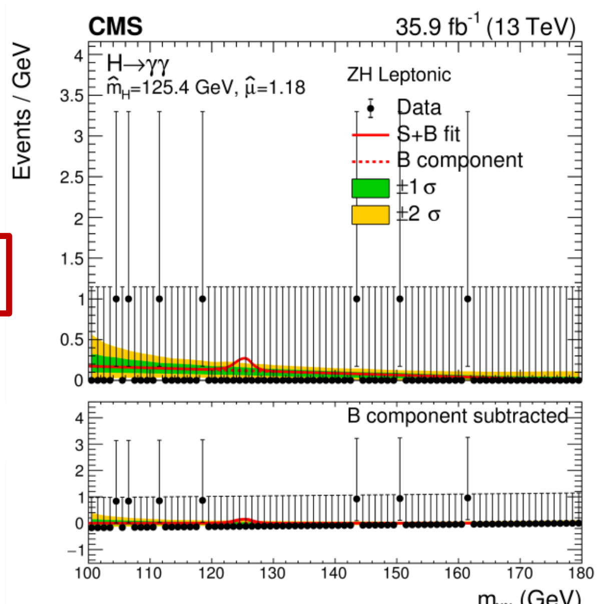

**VH Hadronic**

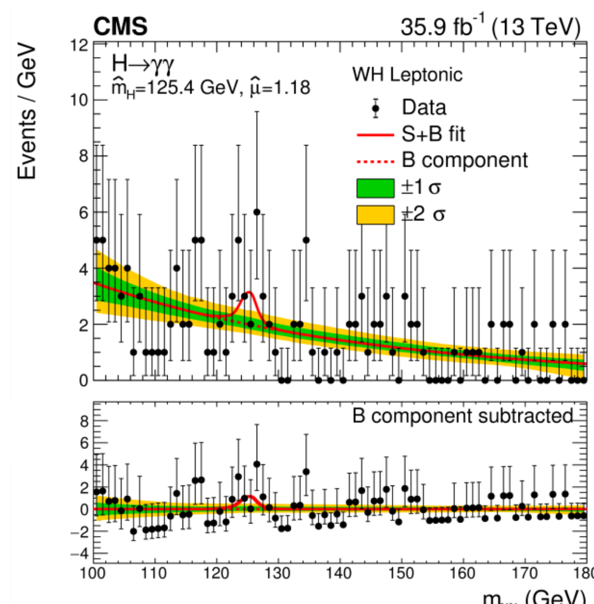



**VH MET**



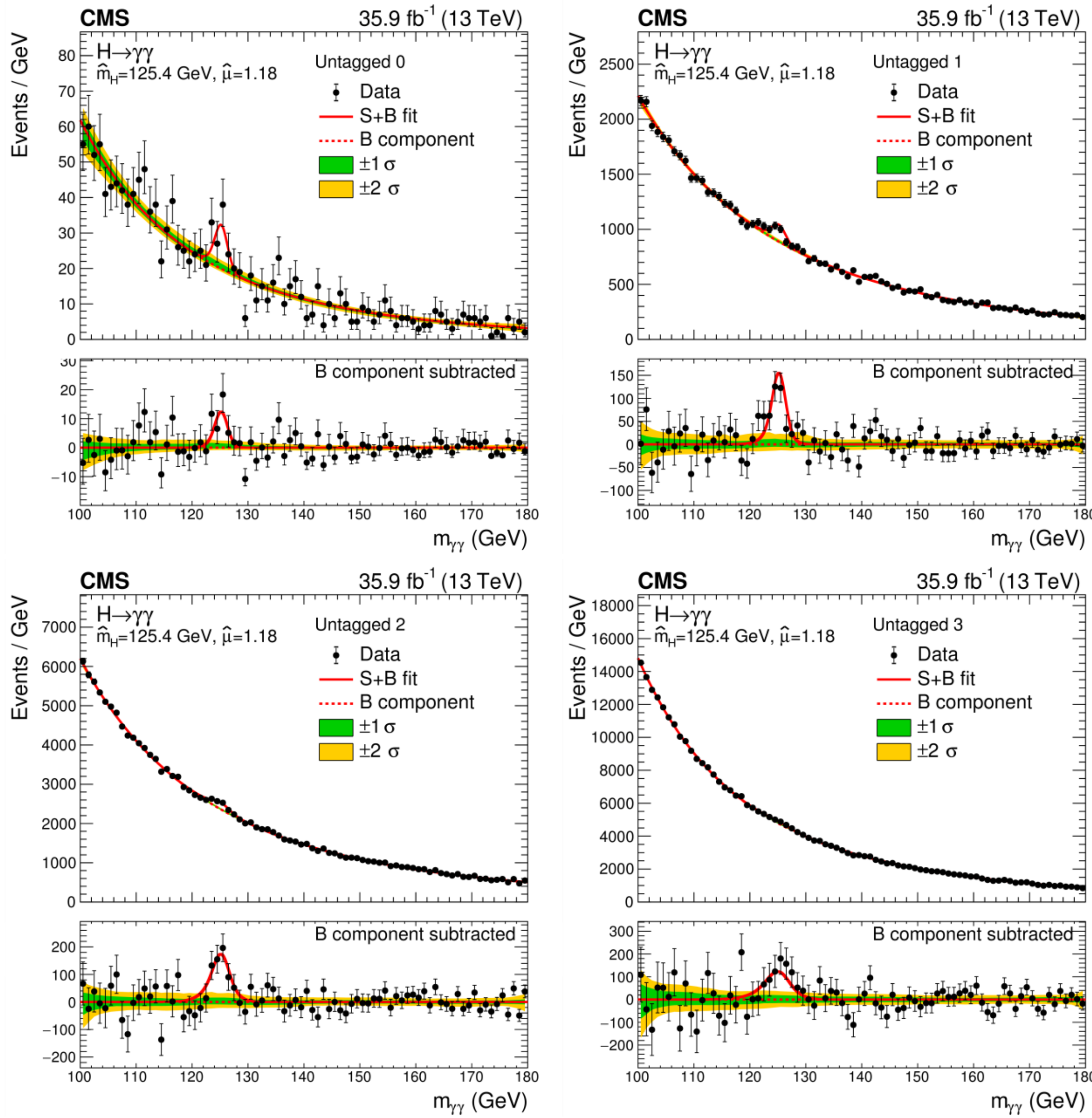

**ZH Leptonic**




**WH Hadronic**

# Mass Spectra (Untagged Events)



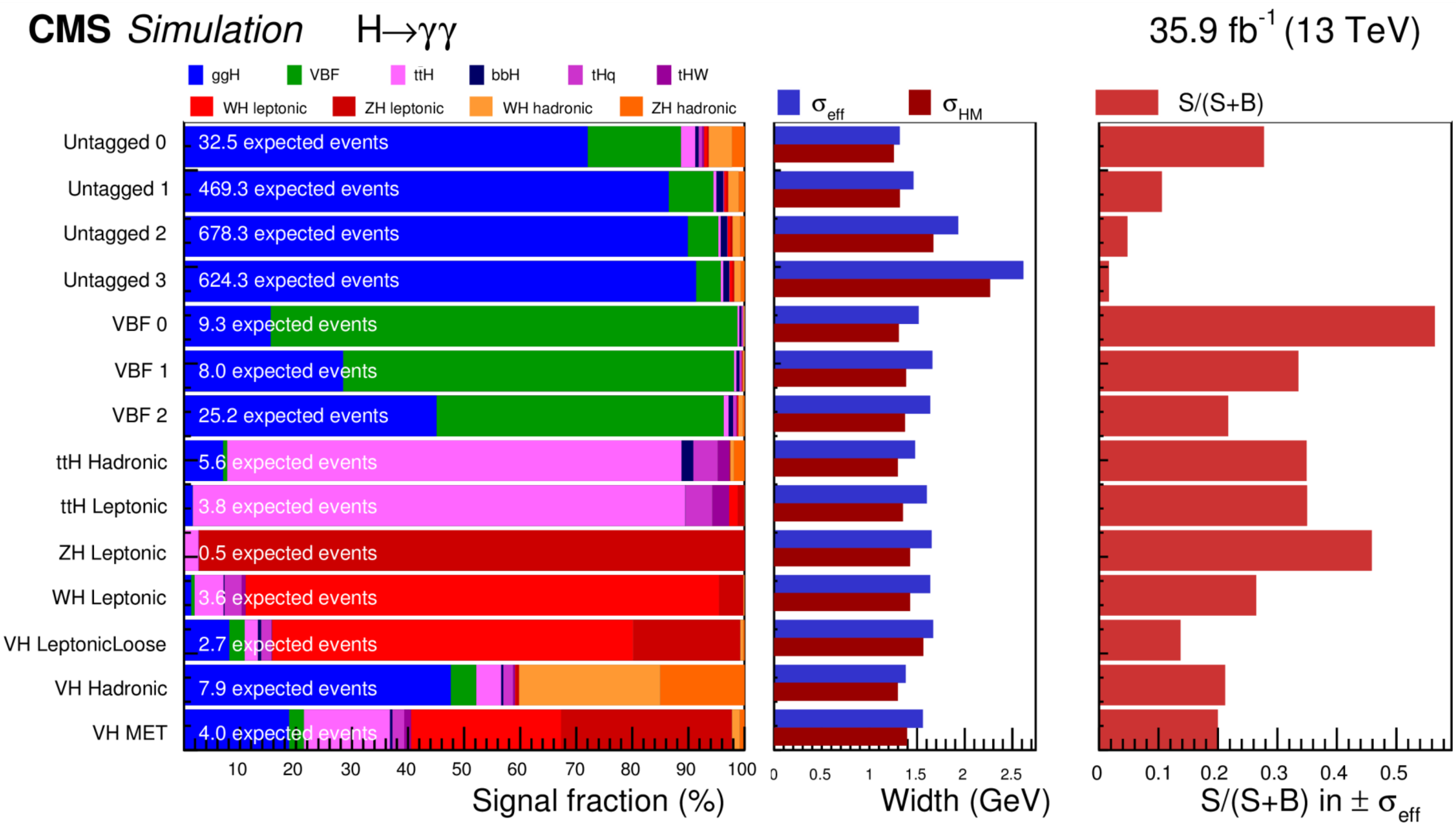

**Untagged 0**

**Untagged 1**

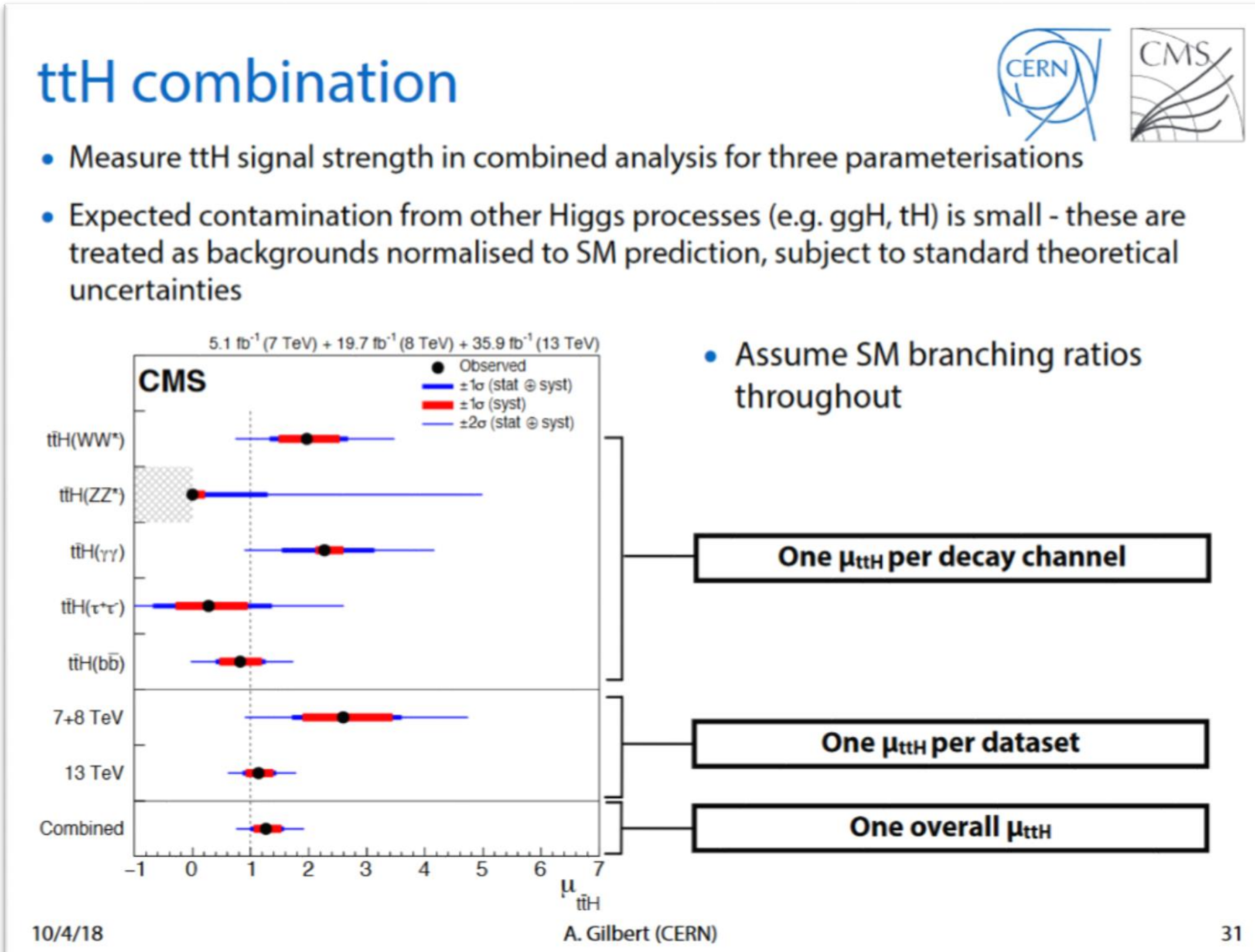
**Untagged 2**

**Untagged 3**

# Category Signal Events



# ttH Combination




From A. Gilbert's seminar at CERN