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
Beijing (China)

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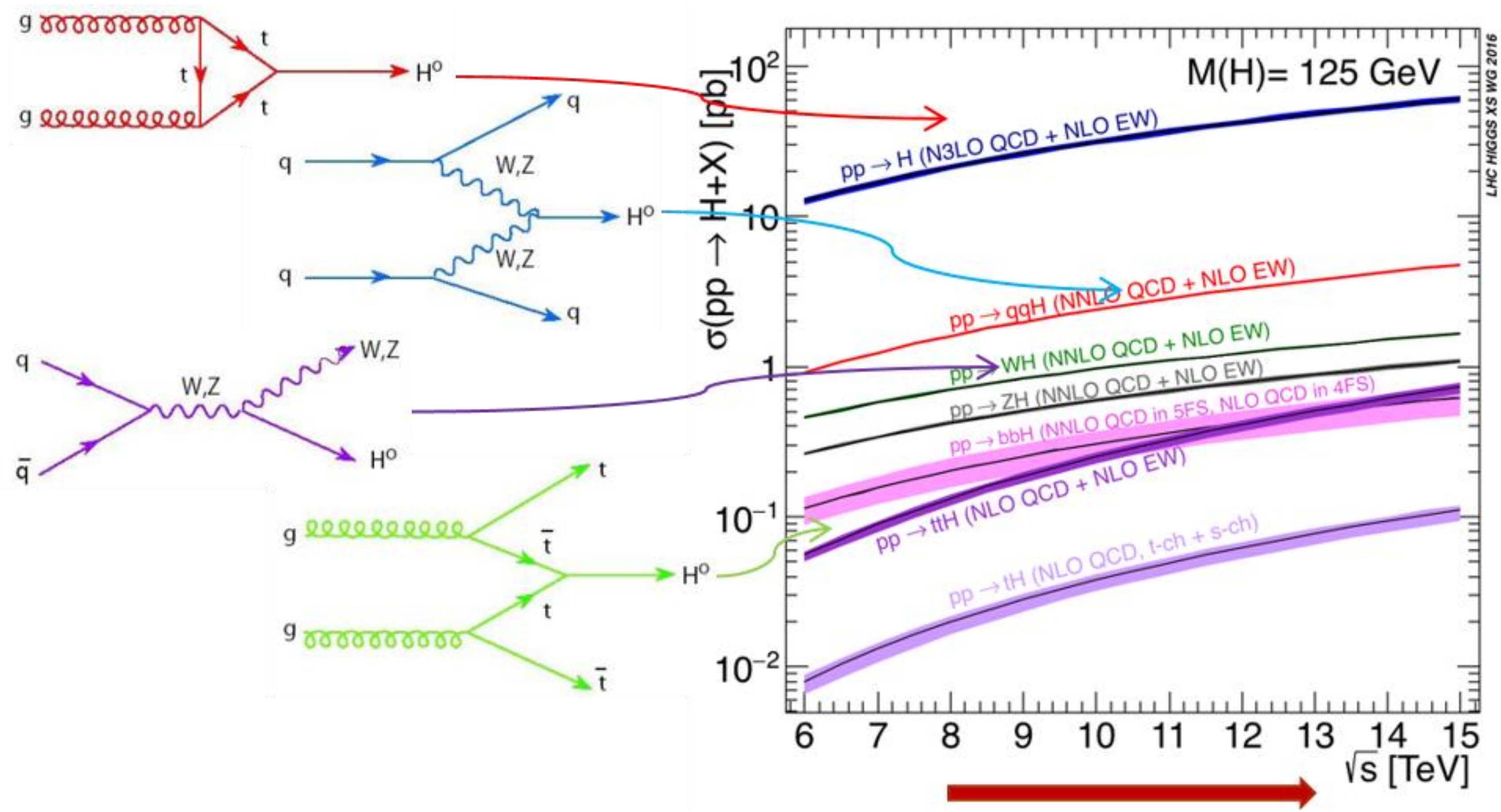
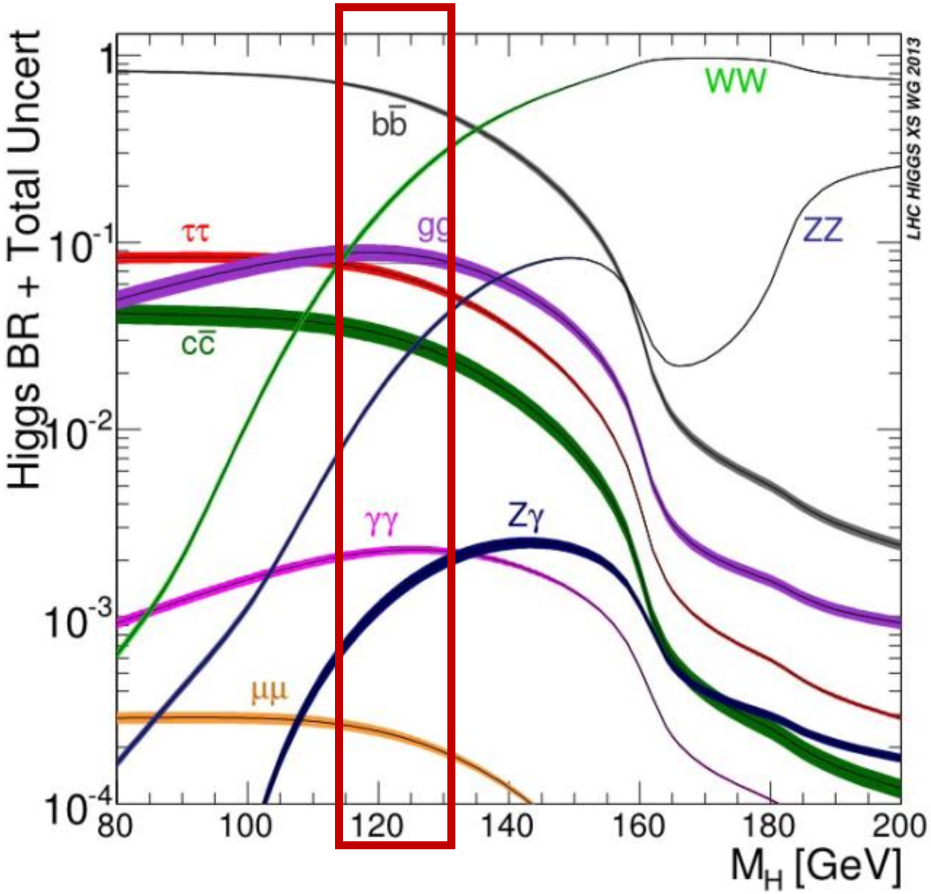
Production Modes

4 PRODUCTION MECHANISMS



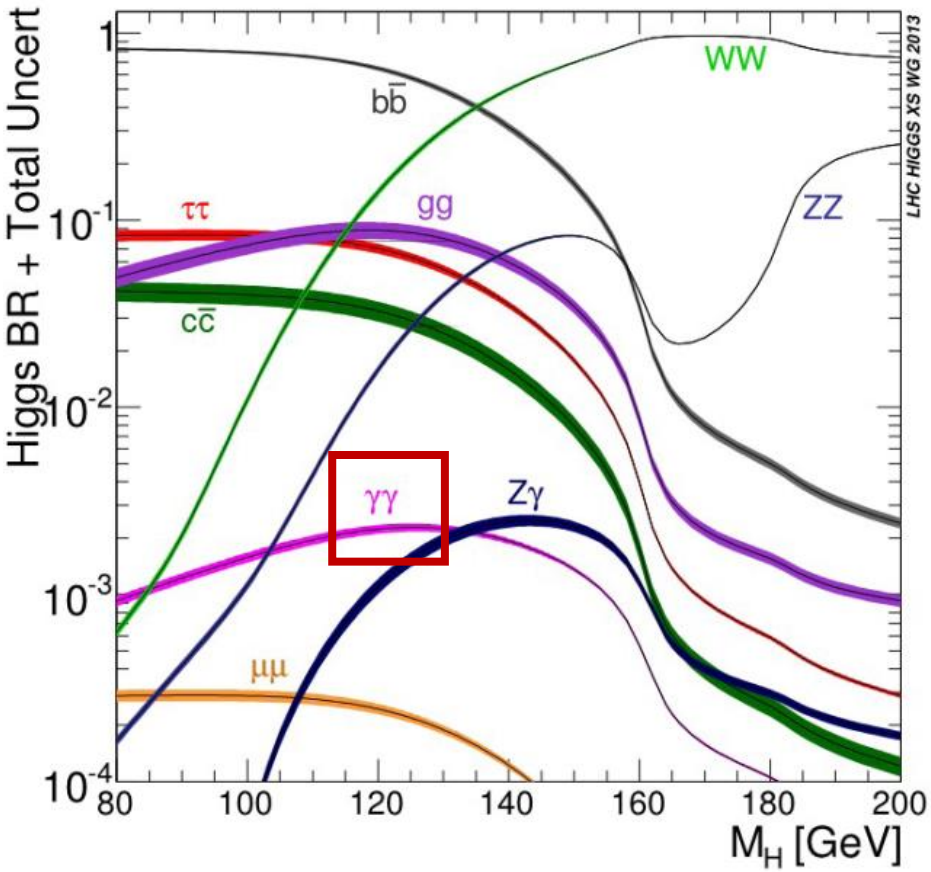
Decay Modes



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%)

Decay Modes



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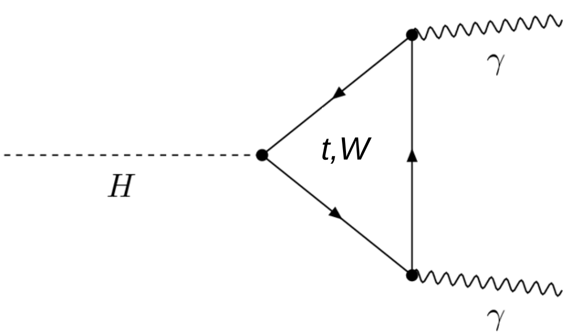
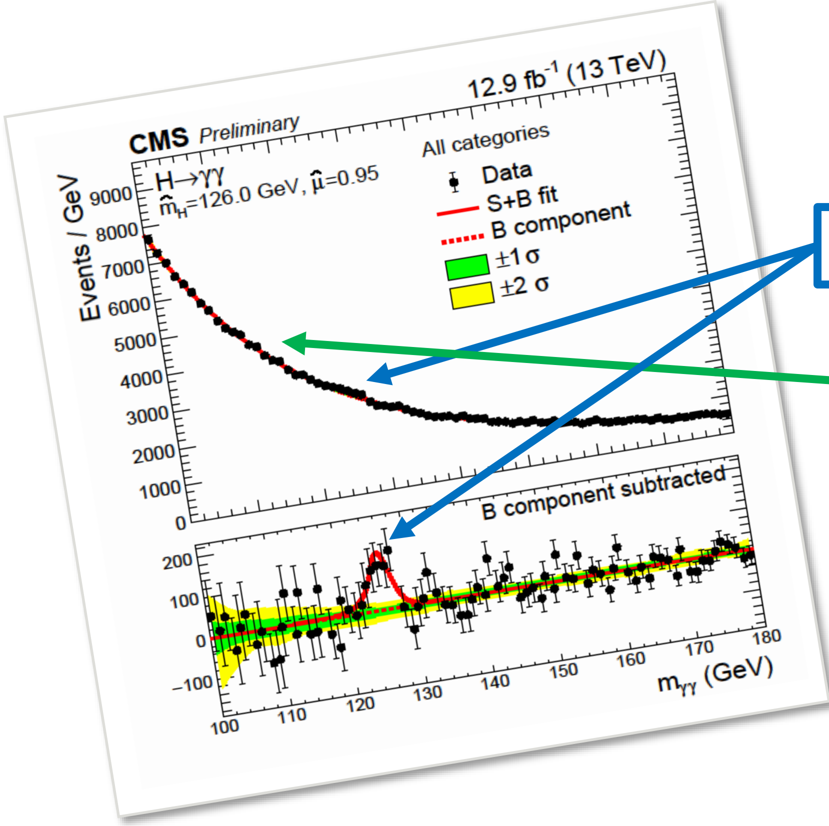


The $H \rightarrow \gamma\gamma$ Decay Channel

- 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

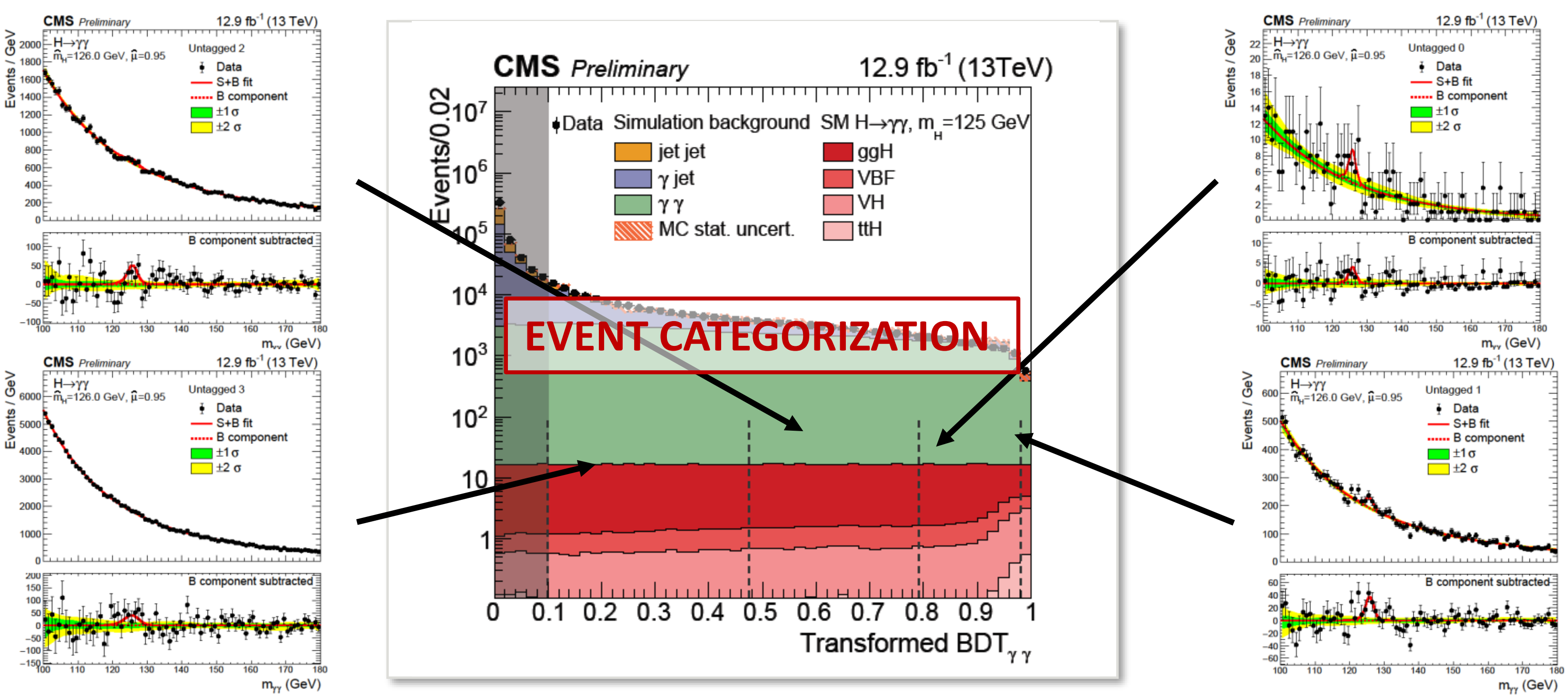
- **Partial 2016** dataset analyzed, **12.9 fb^{-1}** collected at 13 TeV for the main analysis (**HIG-16-020**)
- **Total 2016** dataset analyzed, **35.9 fb^{-1}** for the differential analysis (**HIG-17-015**)

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

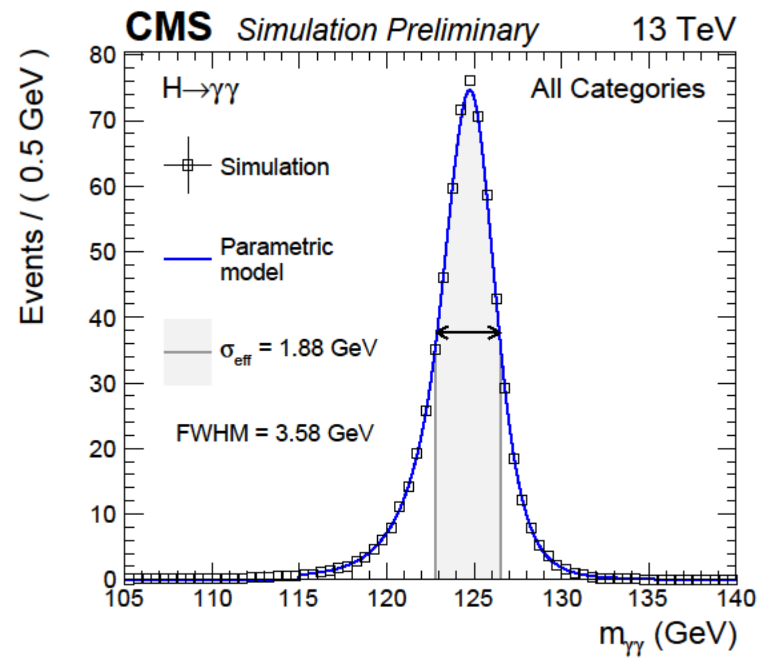
- **Event categorization** on mass resolution and S/B
- Additional event classes according to **production mechanism**
- Signal extracted from background by **fitting the observed di-photon mass distributions** in each category

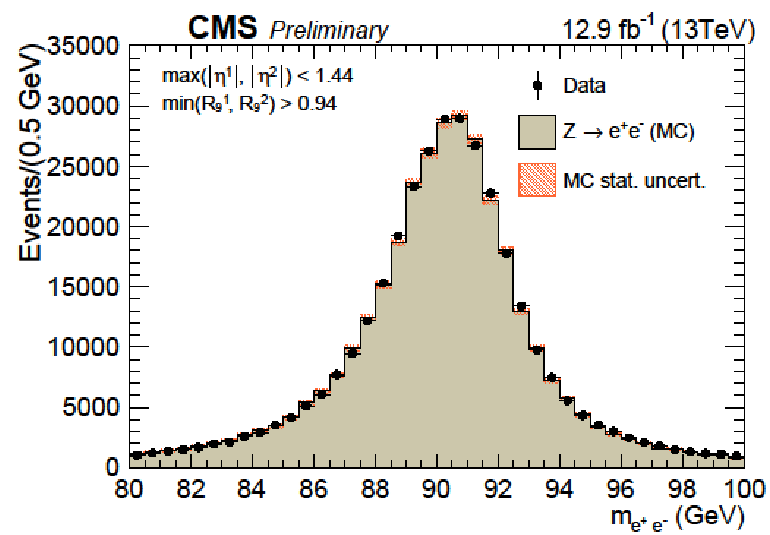


Photon Energy

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

- 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

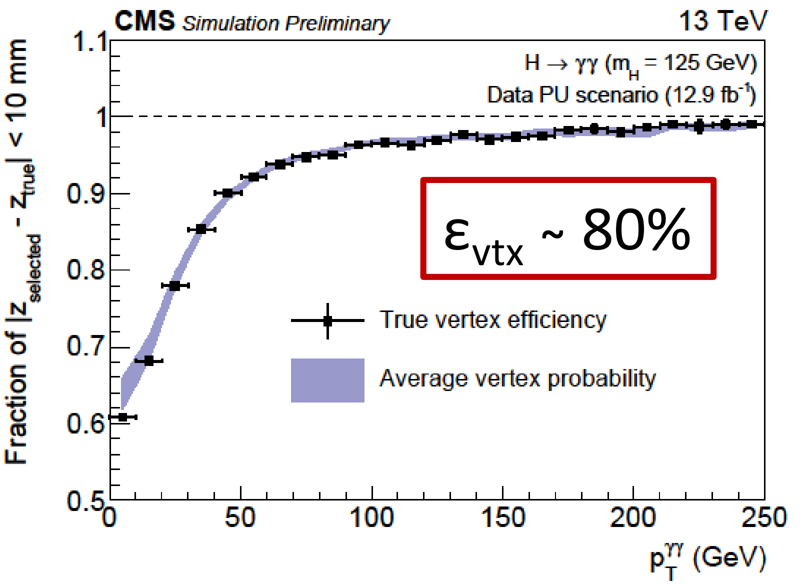


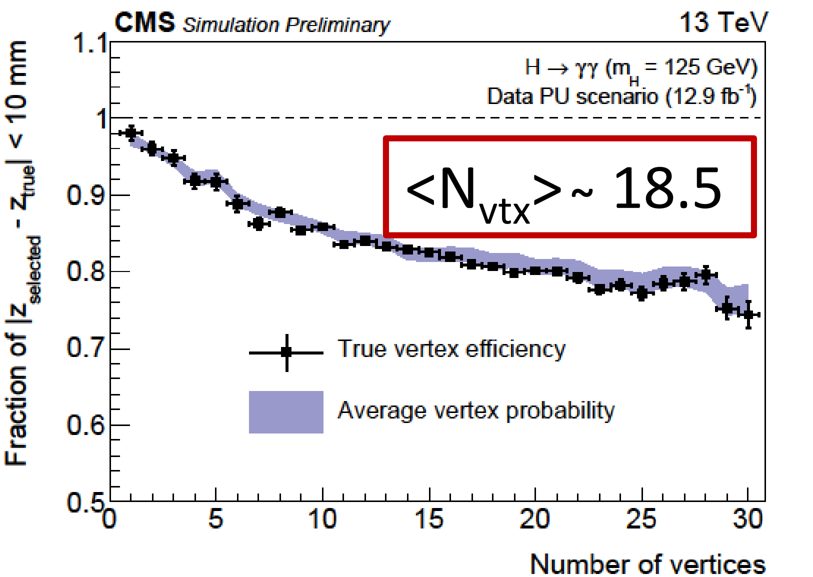


Vertex Identification

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

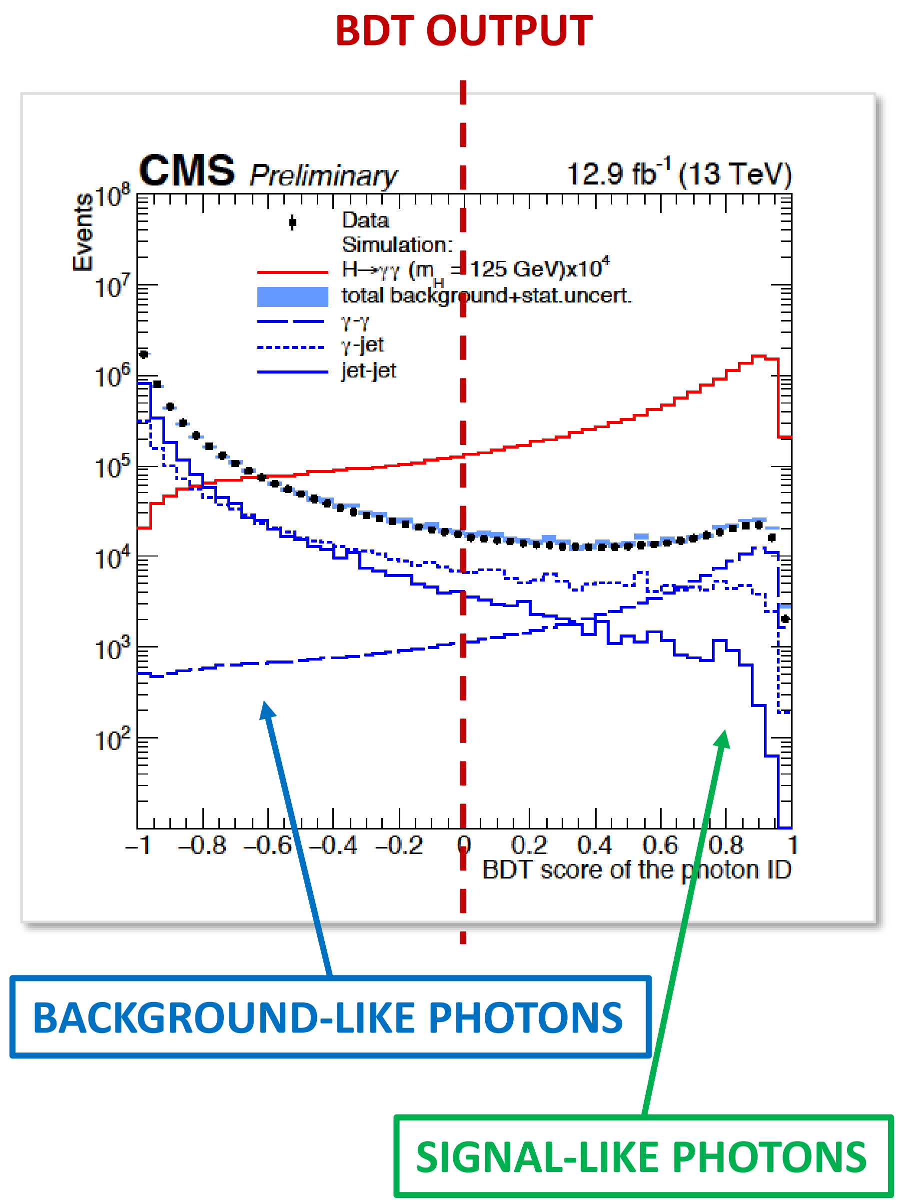
- **Vertex assignment** considered as correct within **1 cm** of the di-photon interaction point
  ➡ **negligible impact** on mass resolution
- **Multi-variate approach**:
  - Observables related **to tracks recoiling** against the di-photon system
  - direction of **conversion tracks**
- **Second MVA discriminant** to estimate the probability for the vertex assignment to be within 1 cm
  ➡ used for di-photon 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 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



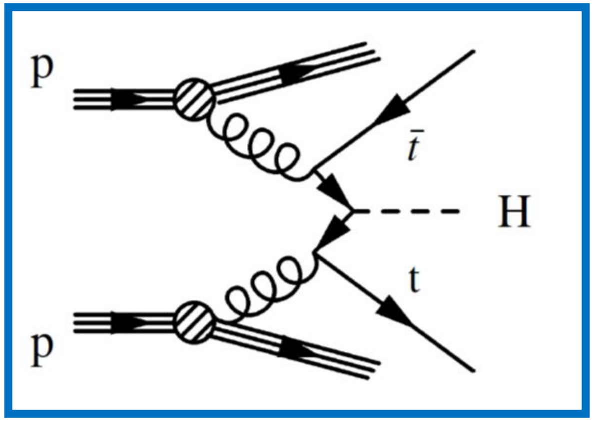
Tagged Events

Specific event categories defined targeting Higgs boson production mode other than ggF

ttH PRODUCTION MODE:

Higgs accompanied by two b quarks and two W bosons

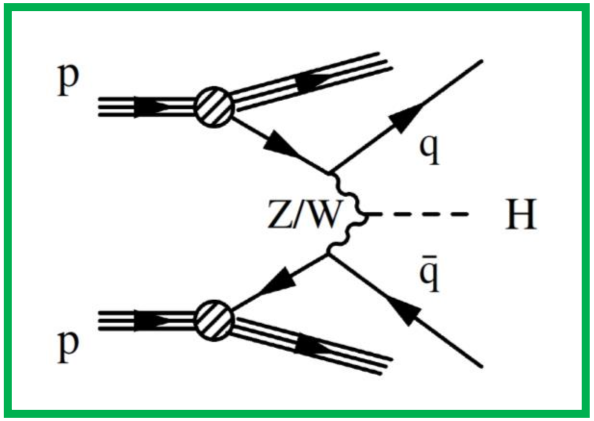
- **ttH Hadronic** (additional jets):
  - (sub)lead $p_T/m_{\gamma\gamma} > 1/2(1/4)$
  - at least one lepton (ℓ = e,μ), away from Z peak
  - ≥ 2 jets
  - ≥ 1 b-jet
- **ttH Leptonic** (additional leptons):
  - (sub)lead $p_T/m_{\gamma\gamma} > 1/2(1/4)$
  - 0 leptons
  - ≥ 5 jets
  - ≥ 1 b-jet



VBF PRODUCTION MODE:

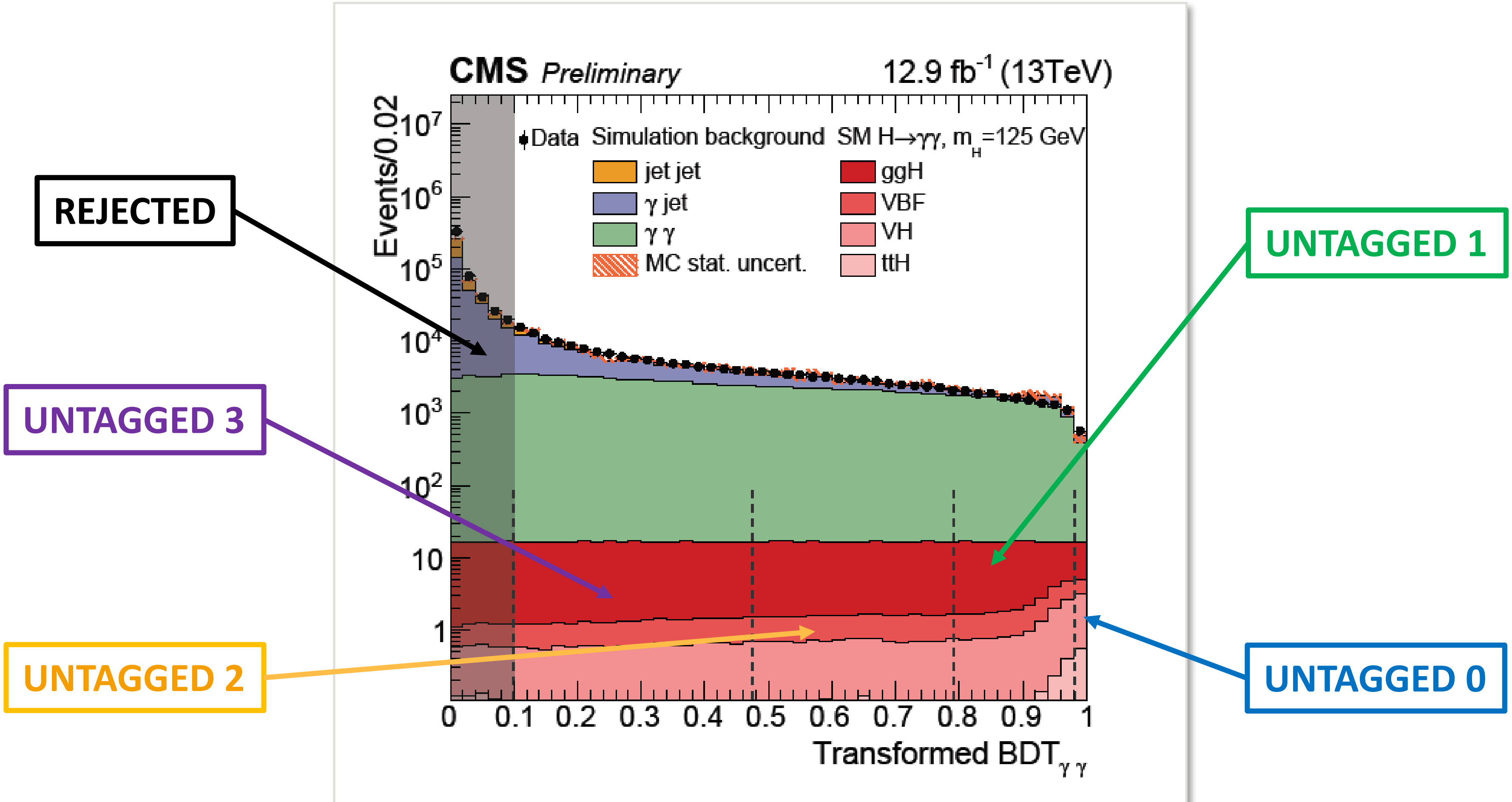
Higgs accompanied by 2 jets separated by a large rapidity gap

- MVA approach to identify events with 2 jets
- 2 jets with $p_{T1} > 30$GeV, $p_{T2} > 20$ GeV, $|\eta| < 4.7$, $m_{jj} > 250$ GeV
- Combination of di-jet and di-photon BDT (**VBF tag 0-1**)



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**



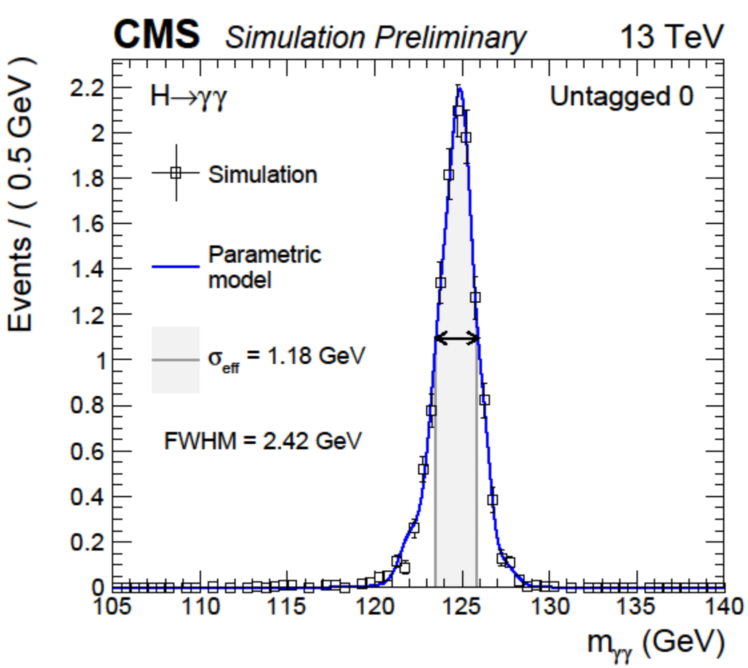
The number of categories and their boundaries are **optimized** to maximize the **expected significance**

Signal and Background Model

SIGNAL

Parametrized model of Higgs boson mass shape

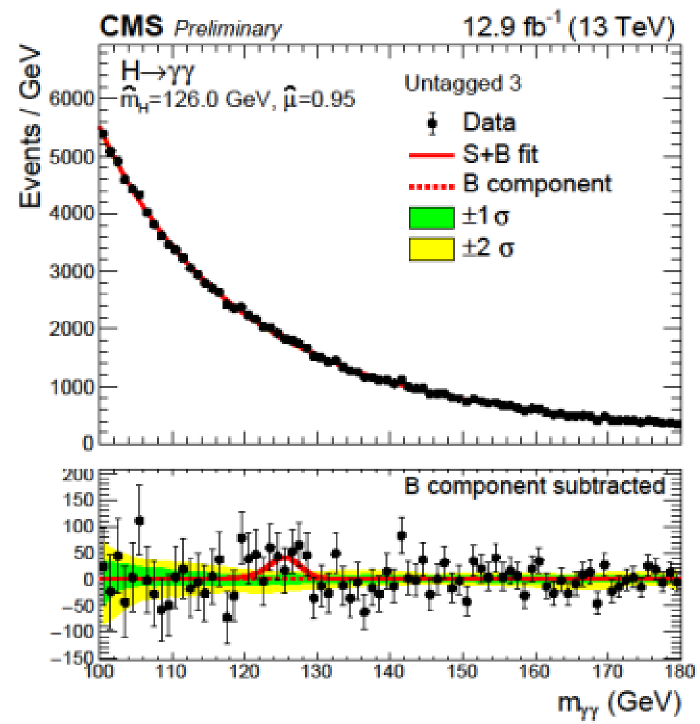
- Obtained from **simulation**
- MC tuning and data/MC efficiency scale factors applied



BACKGROUND

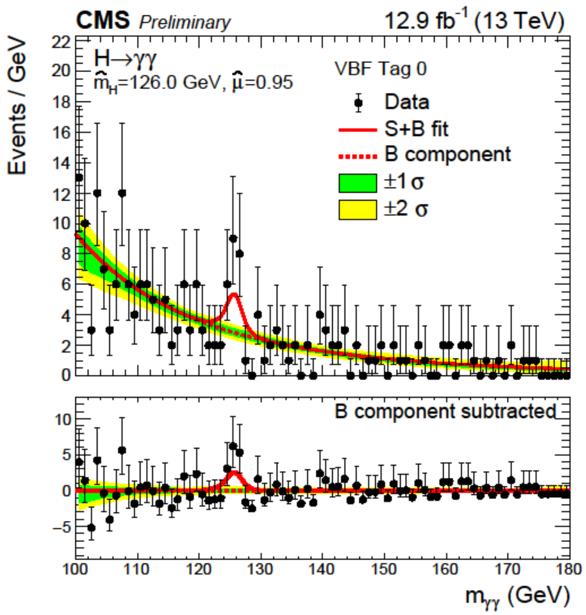
Background model extracted from **data**

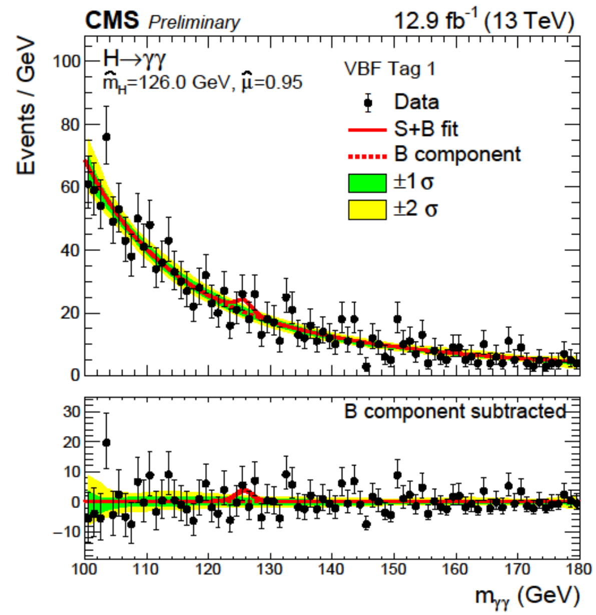
- Different functional forms used for each category
- Choice of function treated as a discrete nuisance parameter



Mass Spectra (Tagged Events)

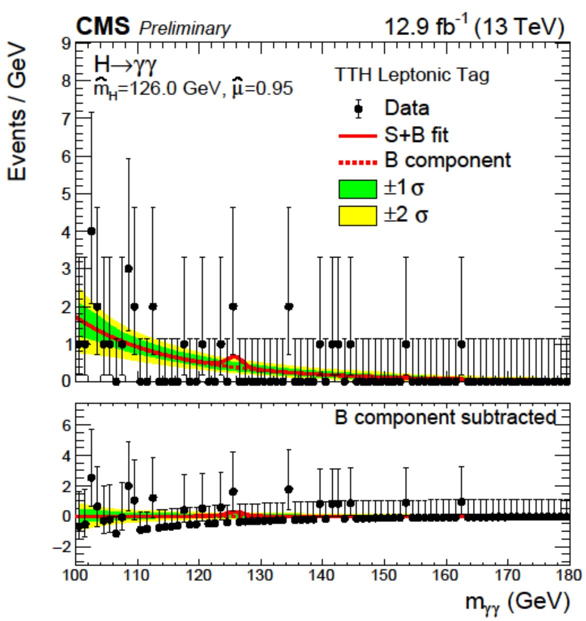
VBF Tag 0

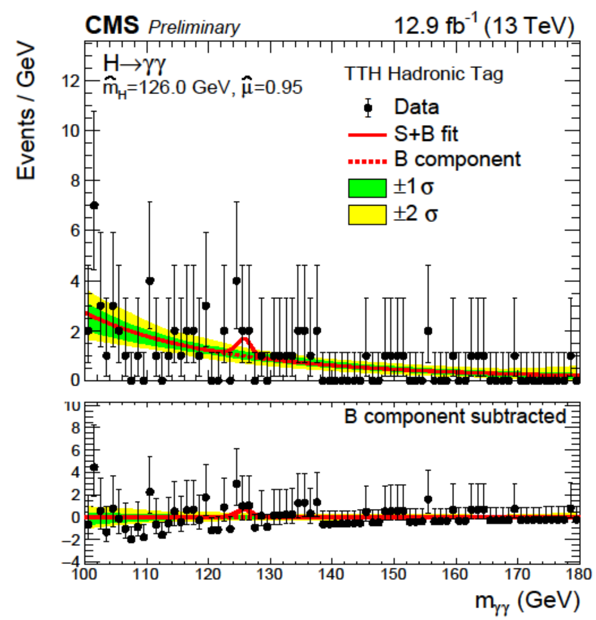




VBF Tag 1

TTH Leptonic

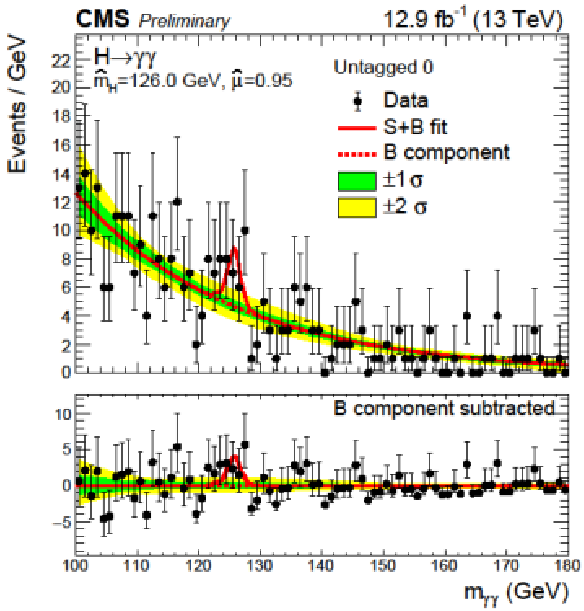




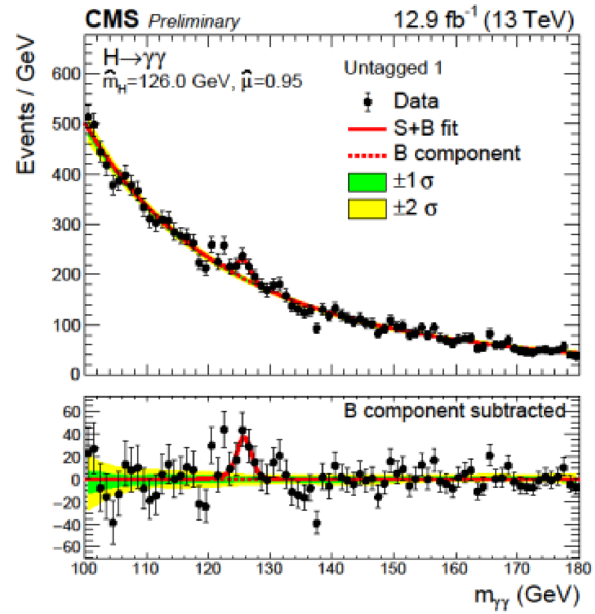
TTH Hadronic

Mass Spectra (Untagged Events)

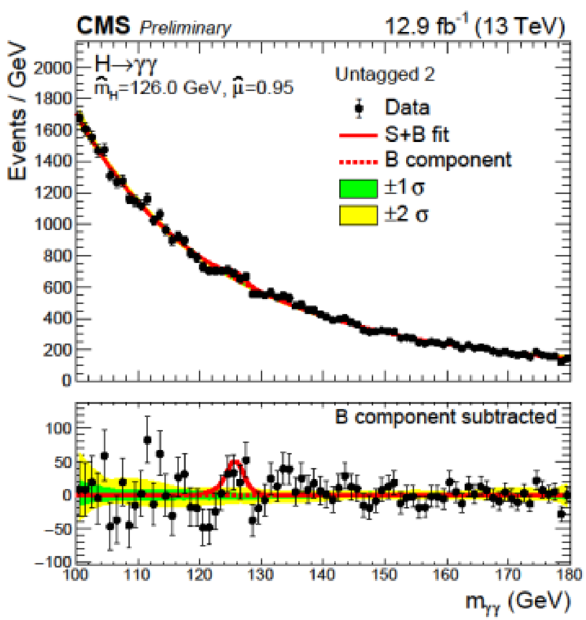
Untagged 0



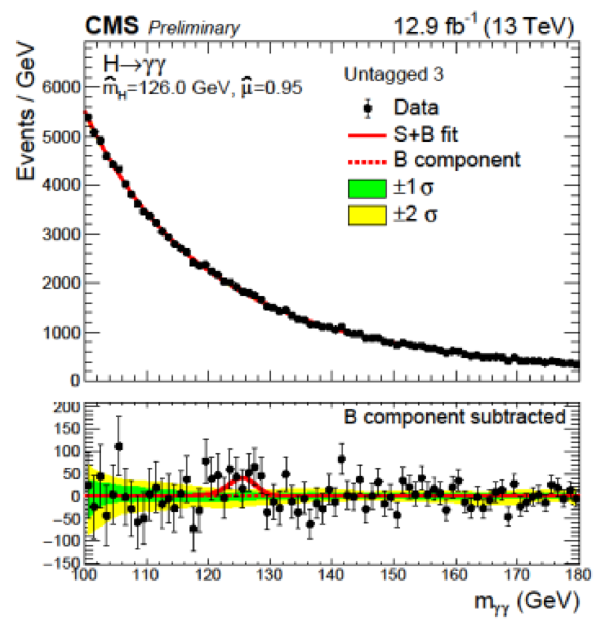
Untagged 1



Untagged 2

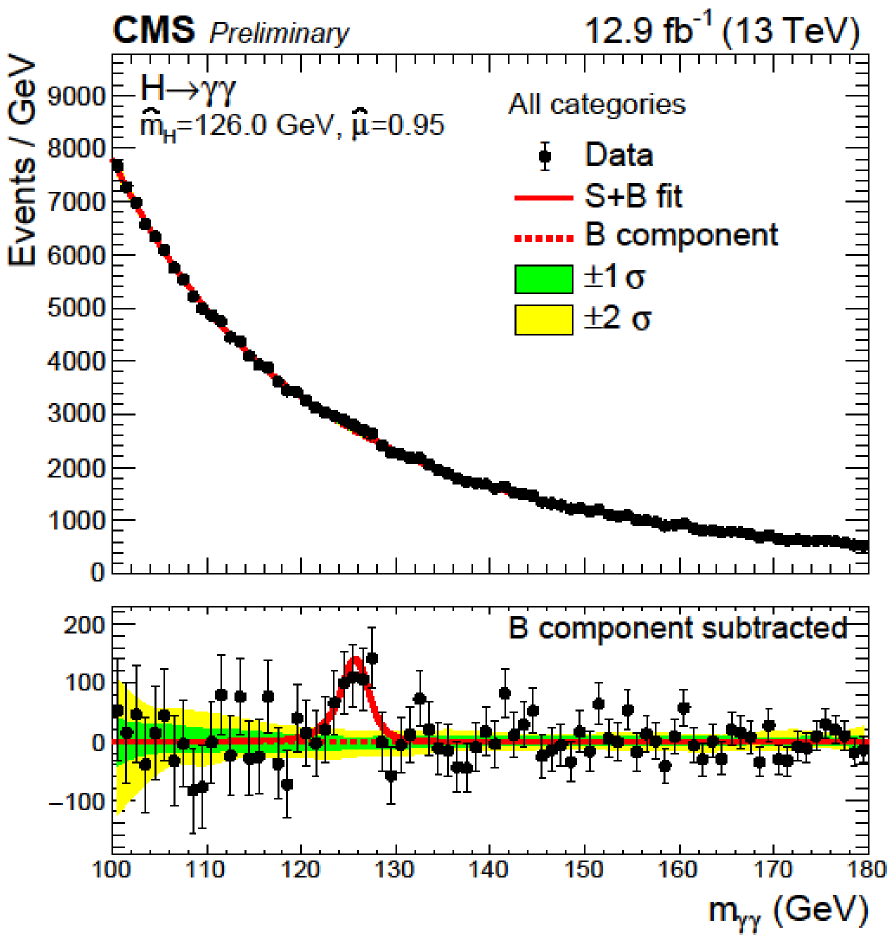


Untagged 3

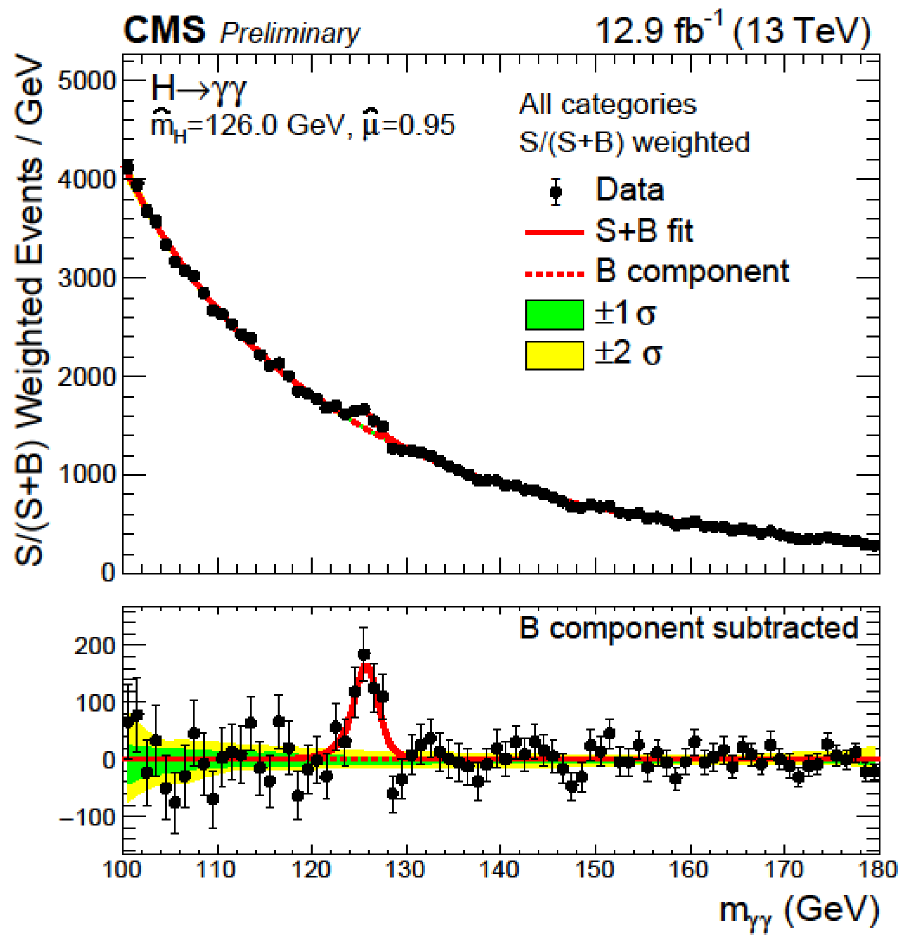


Mass Spectra (All Categories)

All Categories

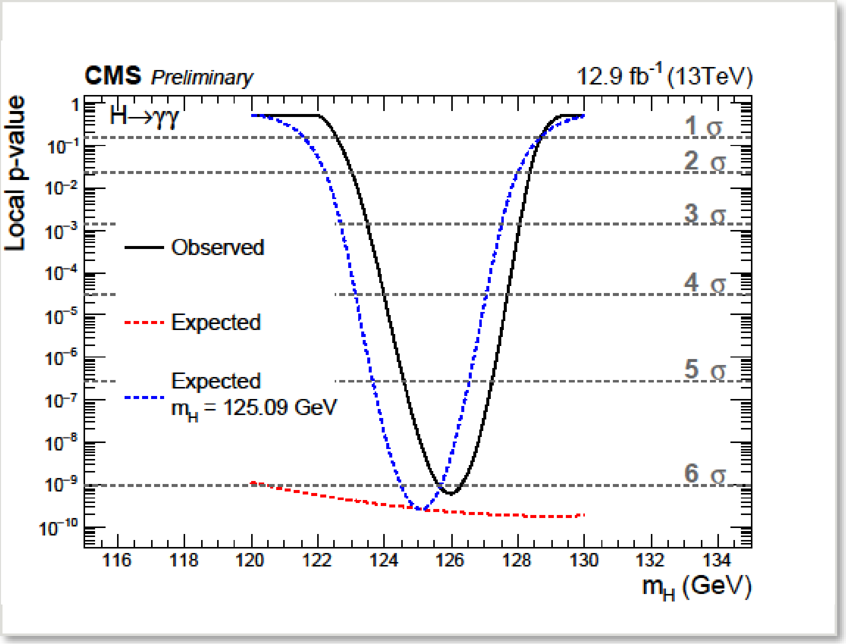


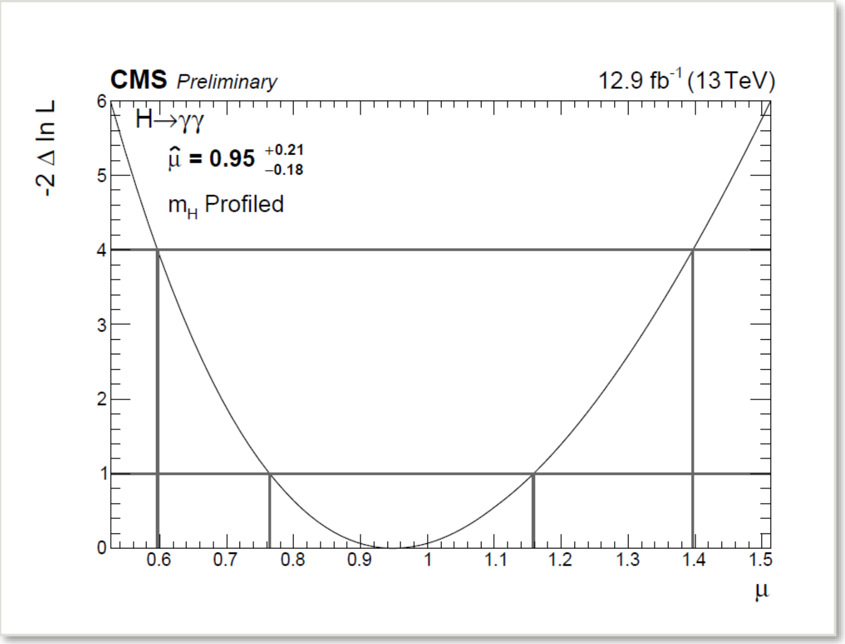
All Categories weighted by sensitivity



Results

- **Significance** at 125.09 GeV: **5.6σ observed** (6.2σ expected)
- **Maximum observed** significance is **6.1σ** at 126.0 GeV
- Best-fit signal strength $\hat{\mu} = 0.95 \pm 0.20 = 0.95 \pm 0.17\ (\text{stat.})\ ^{+0.10}_{-0.07}\ (\text{syst.})\ ^{+0.08}_{-0.05}\ (\text{theo.})$

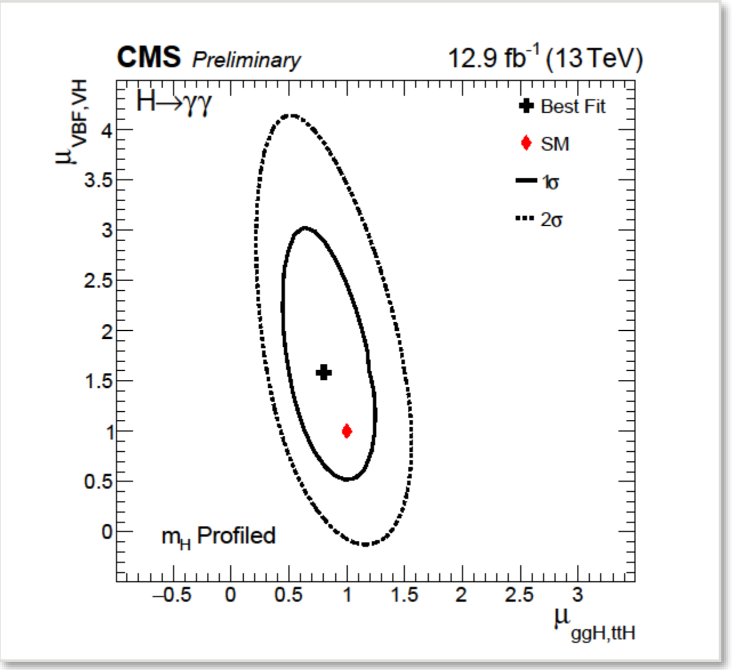




Results

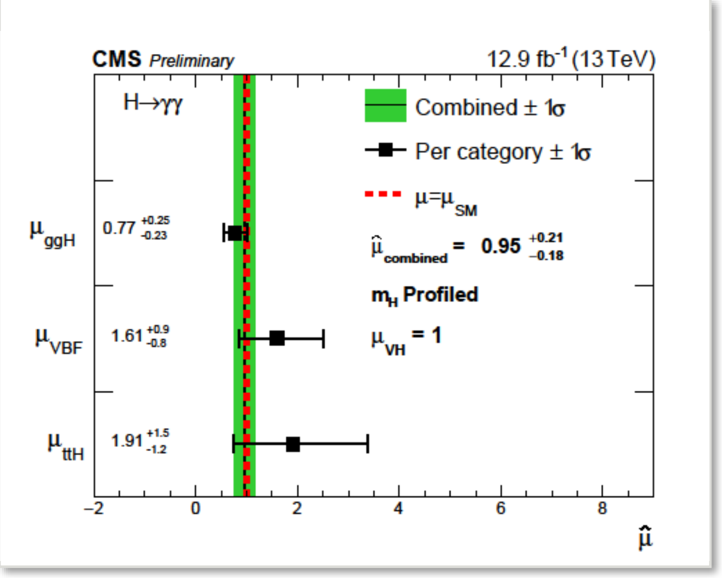
Signal strength measured in **bosonic** and **fermionic** components:

- $\mu_{ggH/ttH} = 0.80^{+0.14}_{-0.18}$
- $\mu_{VBF/VH} = 1.59^{+0.73}_{-0.45}$



Signal strength measured for each **production modes**

➡ **compatible** with the **Standard Model**



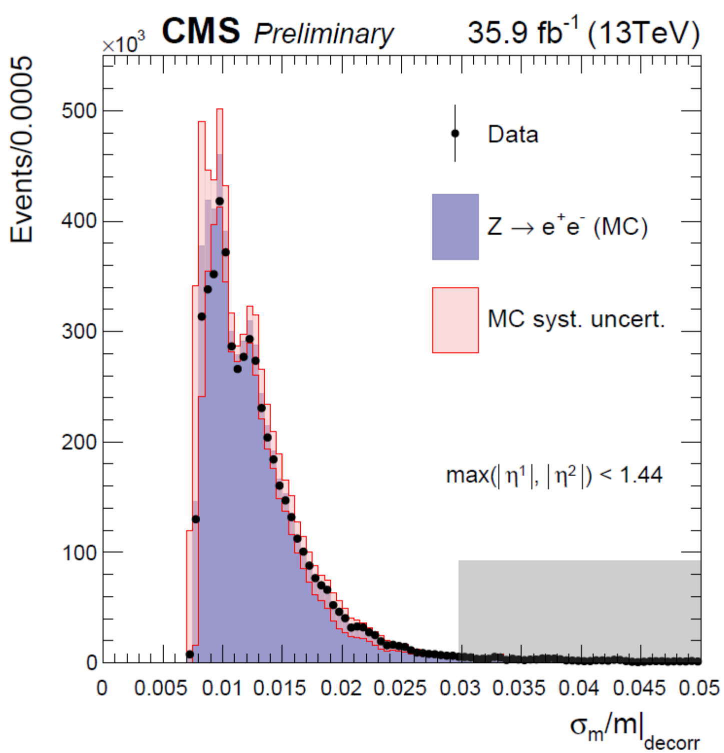
Fiducial Cross-Section

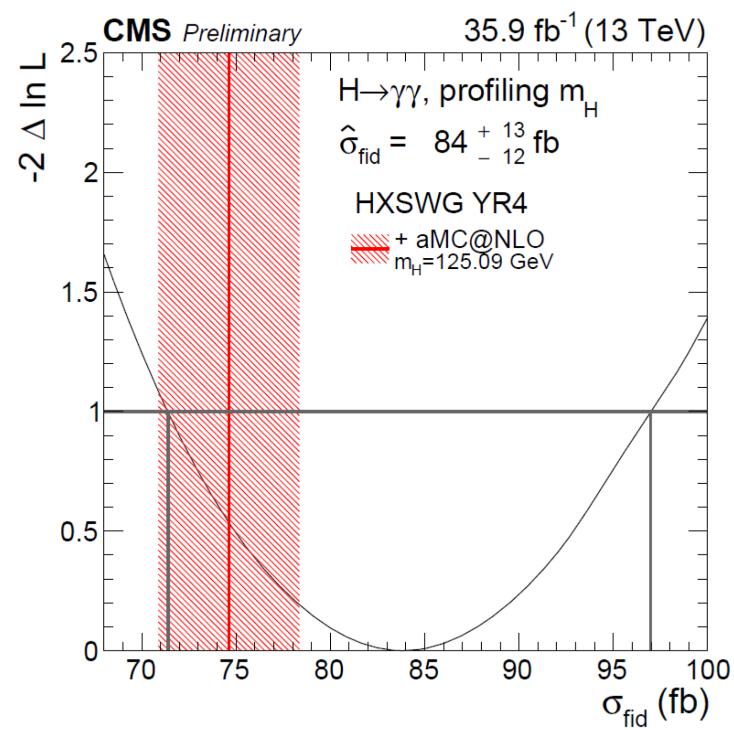
LAST MINUTE

- **Full 2016 dataset** (35.9 fb^{-1})
- Different categorization:
  - Di-photon **mass estimator**
  - 3 events categories
- Fiducial cross-section measured profiling m_H

$$\hat{\sigma}_{fid} = 84 \pm 11\,(\text{stat.}) \pm 7\,(\text{syst.})\ \text{fb}$$

$$\sigma_{fid}^{th} = 75 \pm 4\ \text{fb}$$

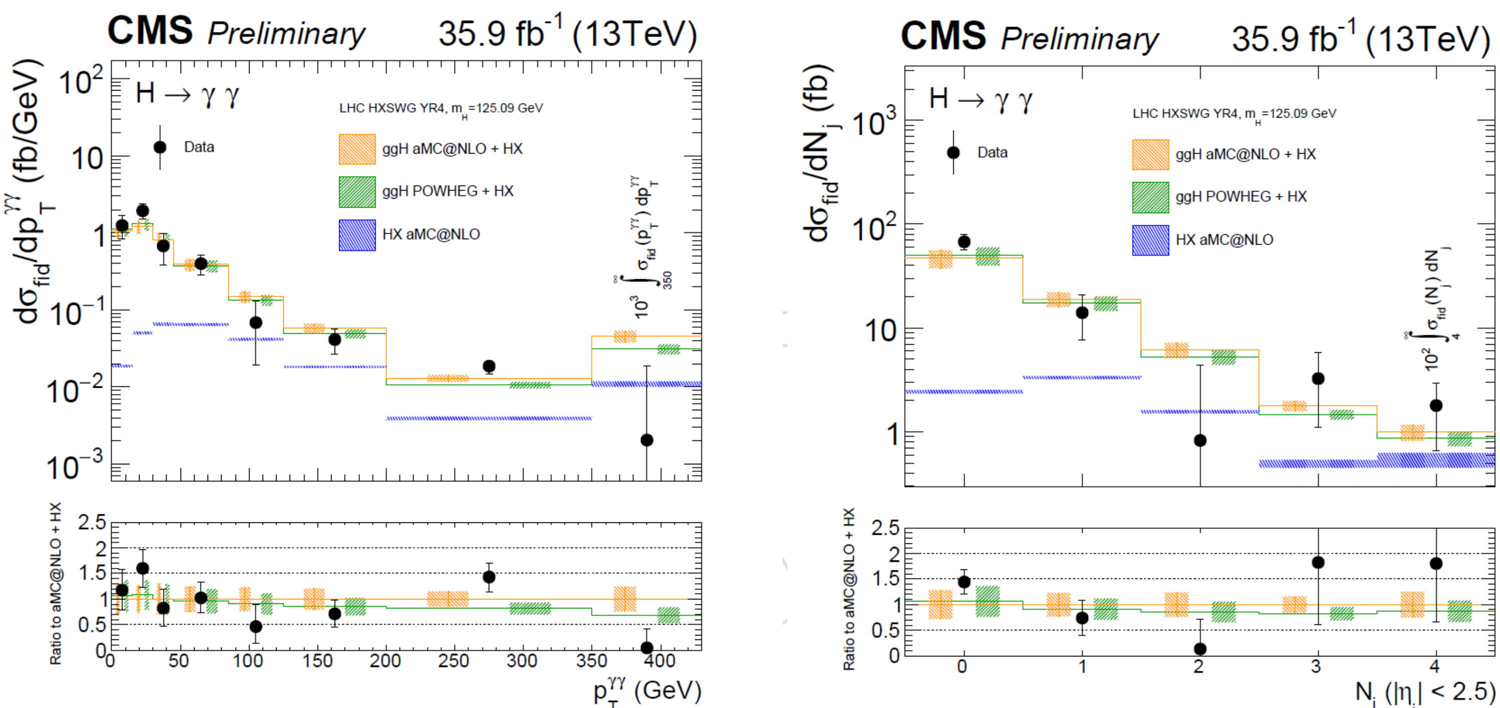




Differential Cross-Section

LAST MINUTE

- **Full 2016 dataset** ($35.9\ fb^{-1}$)
- Different categorization:
  - Di-photon **mass estimator**
  - 3 events categories
- Differential cross-section measured as a function of **di-photon p_T** and **N_j**



Conclusions

- Results of the CMS **$\mathbf{H \rightarrow \gamma\gamma}$ analysis** have been reported, using **12.9 fb^{-1}** of collision data collected in 2016 at 13 TeV

- The Higgs boson has been observed with a peak **significance** of **6.1σ** at **m_H = 126.0 GeV**

- The best fit signal strength is $\hat{\mu} = 0.95^{+0.21}_{-0.19}$

- The best-fit values for the signal strength modifiers associated with bosonic and fermionic components are found to be $m_{ggH/ttH} = 0.80^{+0.14}_{-0.18}$ and $m_{VBF/VH} = 1.59^{+0.73}_{-0.45}$

NEW RESULTS

- The fiducial cross-section is measured to be $\hat{\sigma}_{fid} = 84 \pm 11\ (\text{stat.}) \pm 7\ (\text{syst.})\ \text{fb}$

- **Differential distributions** have been reported as a function of **di-photon p_T** and the **number of jets**

FULL 2016 DATASET

Backup