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Chinese Academy of Sciences

CMS
Compact Muon Solenoid

Measurements of Higgs production and search for an additional SM-like Higgs boson in the diphoton decay channel with the CMS detector

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Outline

- Measurement of Higgs boson production cross-section and couplings in the diphoton decay channel at 13 TeV. Published in JHEP (JHEP07(2021)027)
  - ✓ The structure of this analysis is designed to enable measurements within the simplified template cross section (STXS) framework
  - ✓ Covers STXS Stage 1.2 cross-section ($\boldsymbol{\sigma}$), signal strength (μ), and coupling modifier (κ) measurements simultaneously for all major SM processes - ggH, VBF, VH had & lep, ttH, and tH
  - ✓ Results are presented for full Run II dataset: 35.9 fb^{-1} (2016), 41.5 fb^{-1} (2017), 59.7 fb^{-1} (2018)
- Search for additional Higgs Boson in the di-photon final state at CMS
- Summary and Conclusion.

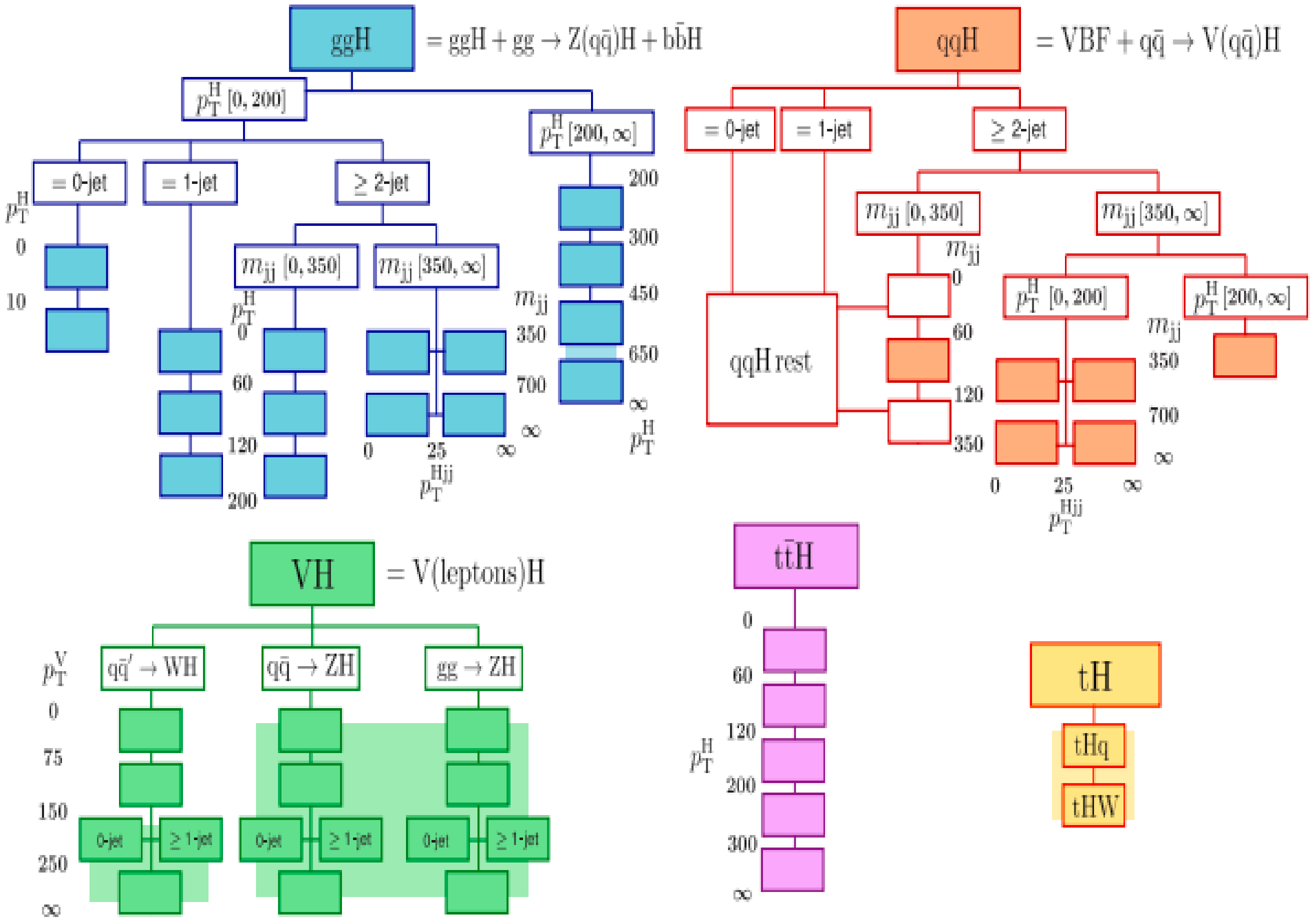
Measurements of Higgs boson production cross-sections and couplings in the diphoton decay channel at 13 TeV

Introduction

STXS Framework:

- STXS provides a framework for making measurements in increasingly finer bins of the Higgs boson phase space
- Less dependence of measurements on theory
- BSM physics is isolated in a separate bin
- Fine bins allow theorists for broader re-interpretations
- STXS framework developed in stages: stage 1.0, stage 1.1, stage 1.2

Stage 1.2

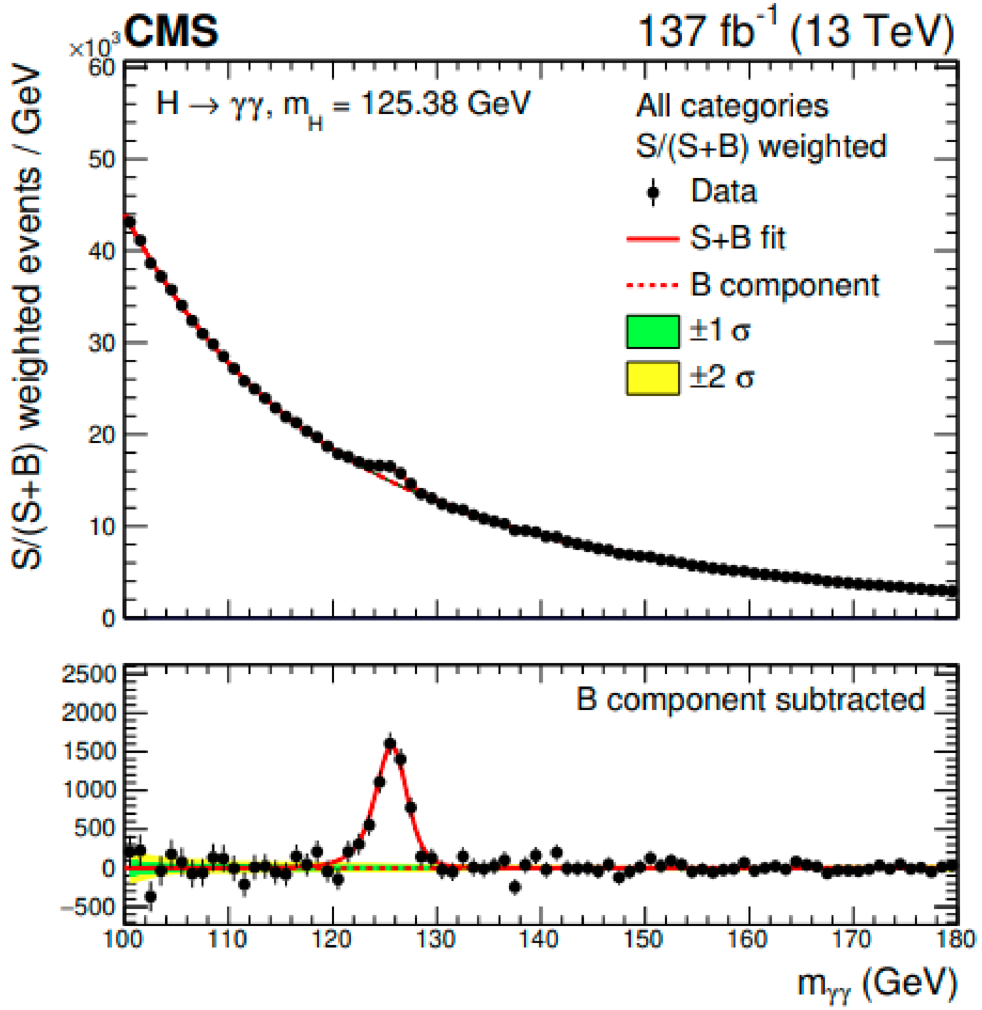


Categorisation: targeting STXS Stage 1.2 binning

- **ggH categorization:** New multiclassifier to assign most probable STXS bin
- **VBF categorization:** Data-driven technique + Three-Class BDT
- **VH hadronic categorization:** Data-driven technique + VH hadronic tag
- **VH leptonic categorization:** WH leptonic, ZH leptonic, VH MET MVA + data-driven technique for VH MET
- **ttH and tH categorization:** ttH leptonic and hadronic tags from HIG-19-013, tHq tag

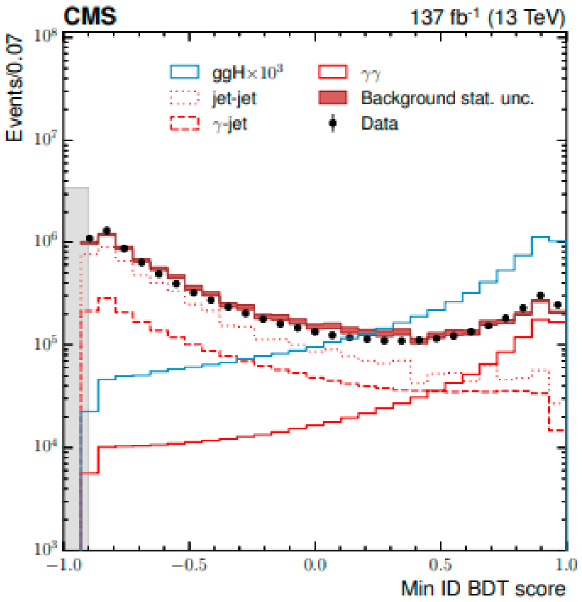
Analysis Strategy

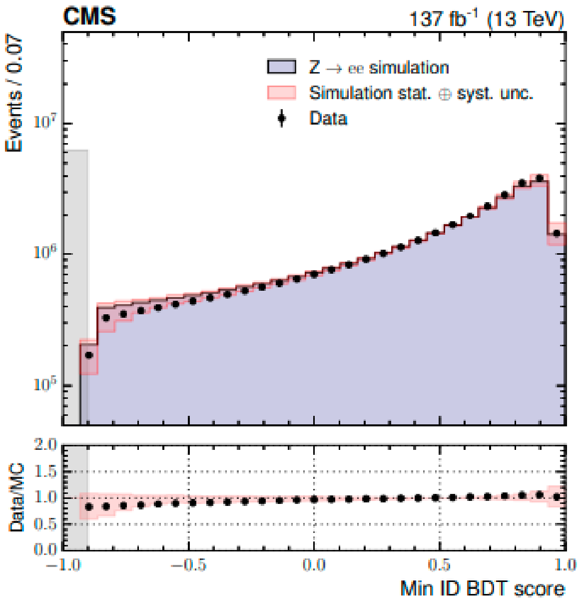
- Analysis is targeting ggH, qqH (VBF and VH hadronic), ttH and tH, VH leptonic Stage 1.2 STXS bins
- Build analysis categories to **target as many STXS bins as possible**
- **MVAs** are used to reduce the contamination from other H production modes and also for Background reduction
- Simultaneous fit to the diphoton invariant mass distributions in all categories, with the background determined from data



Photon Identification, diphoton vertex identification

- **Photon IDMVA** is used to classify prompt photons from fake photons (jets)
- **Input variables:** shower shape variables, isolation variables
- **IDMVA** validated with Z→$\mu\mu\gamma$ and Z→ee event

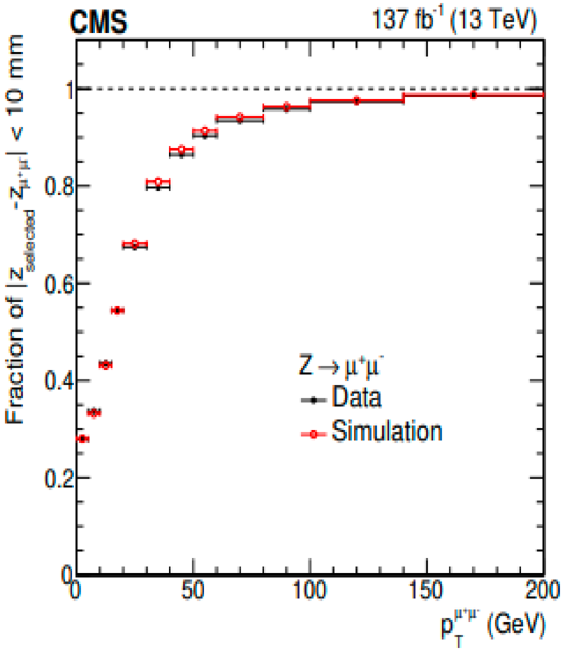


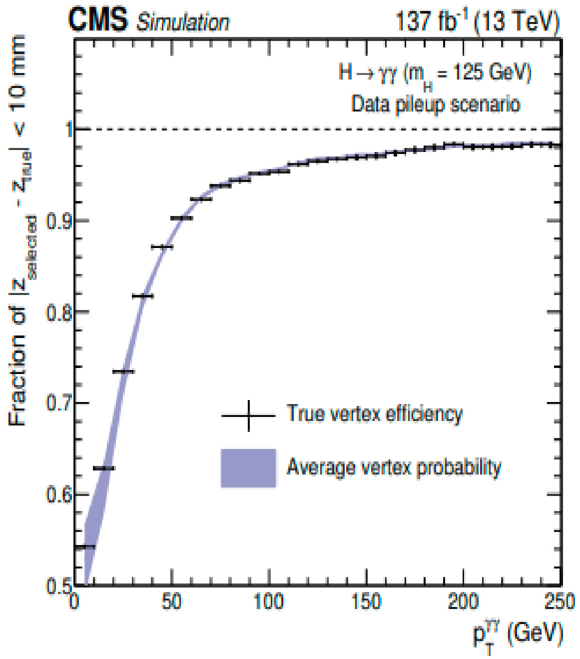


photons required to have IDMVA score > -0.9 (preselection)

- **Vertex Identification BDT:**
  - if vertex position is true within 1 cm => $m_{\gamma\gamma}$ resolution is dominated by γ energy resolution (true for ~79% events in simulation)
  - Trained on ggH events and identifies a single vertex in each event

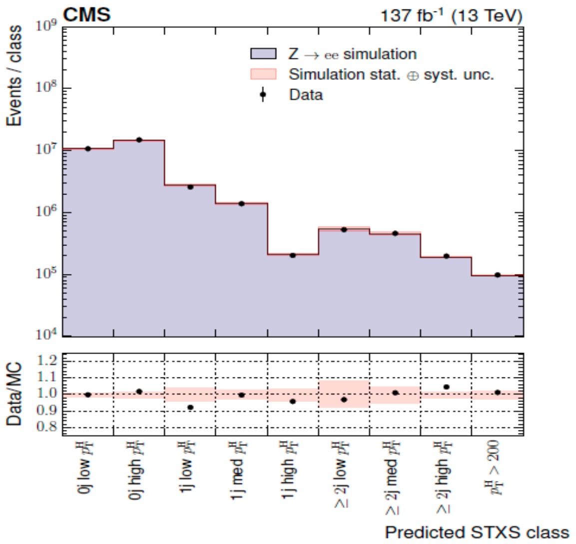
- **Vertex ID BDT validated with Z→$\mu\mu$ events:** μ tracks are omitted to mimic a diphoton system

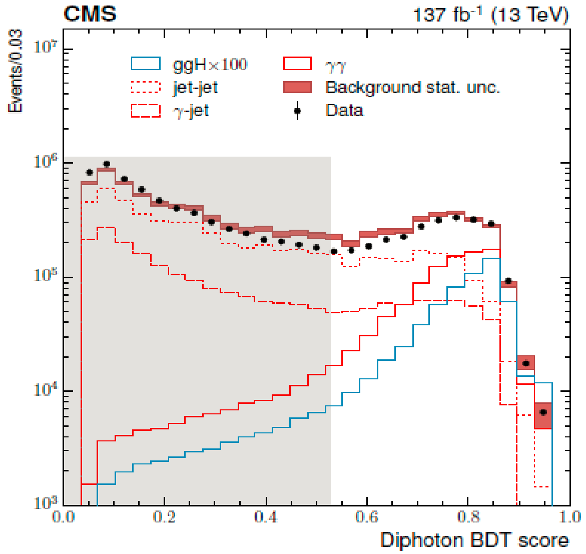




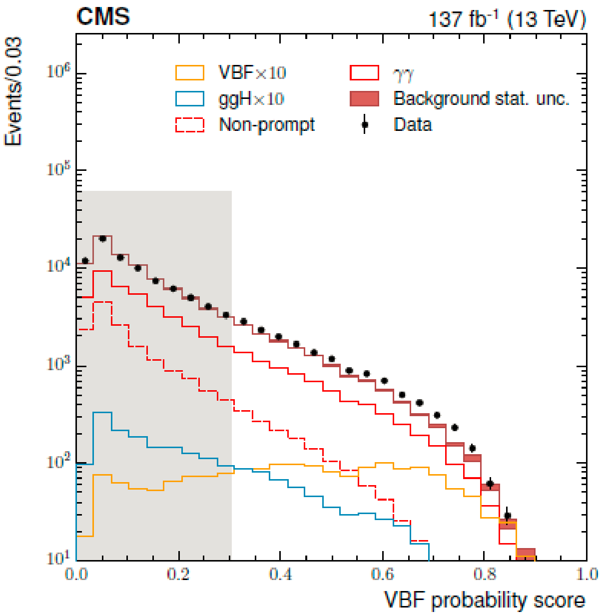
ggH event categorization and other production modes

- Use a multi-class BDT (9 Classes): Predicts the probability that an event belongs to a given ggH STXS bin
- After being classified by the ggH BDT, events are divided into analysis categories using the diphoton BDT

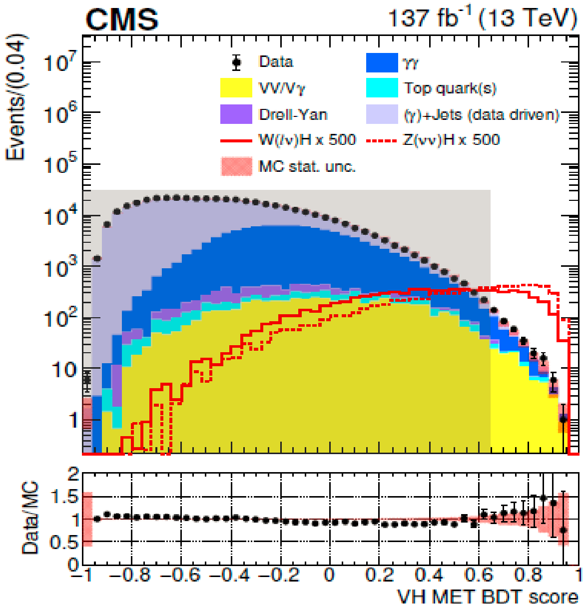




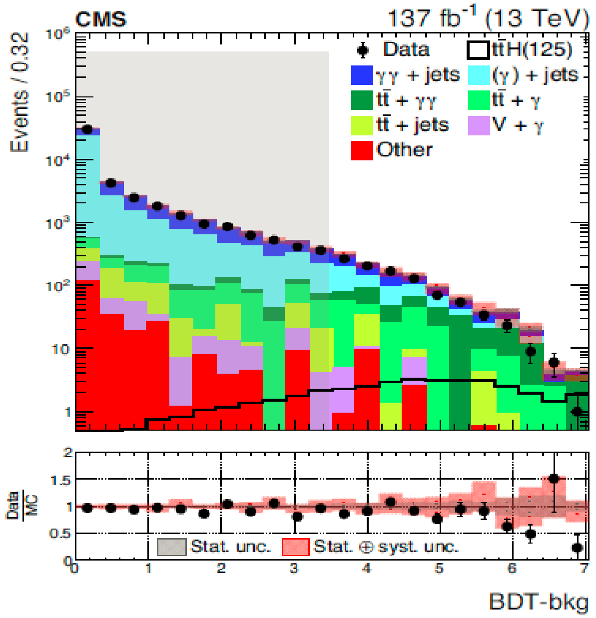
- Dedicated categorization for **tHq events (tHq Leptonic)**
- Data-driven estimation of key backgrounds for MVA training i.e. **VBF, VH MET, ttH Hadronic**



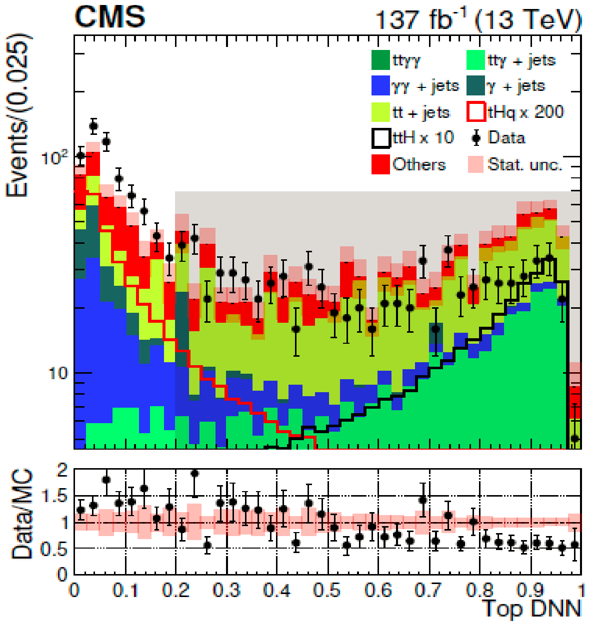
VBF



VH MET

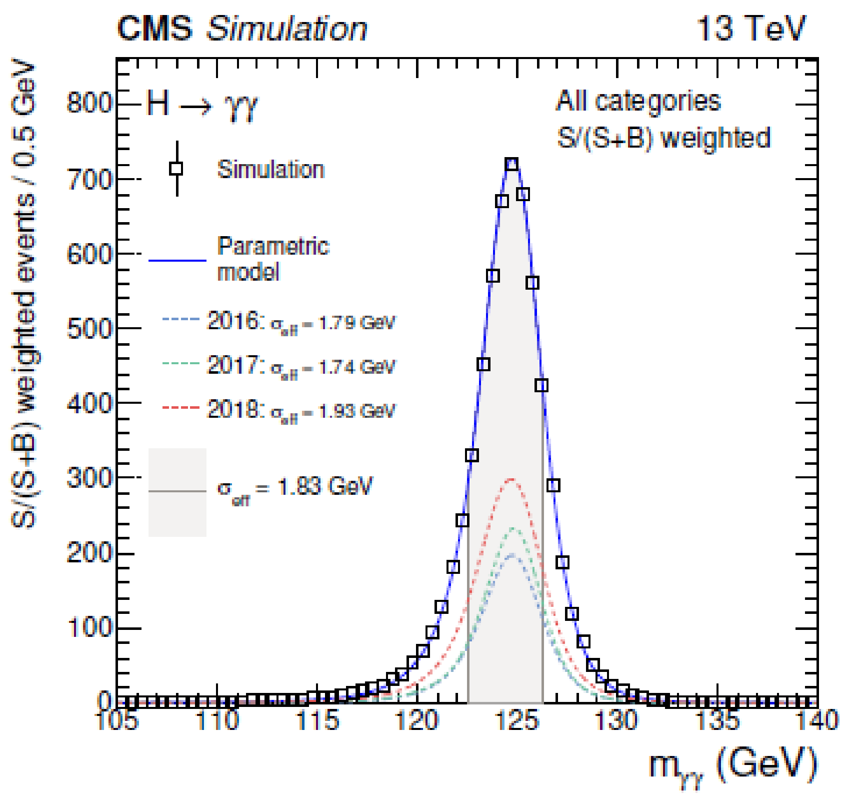


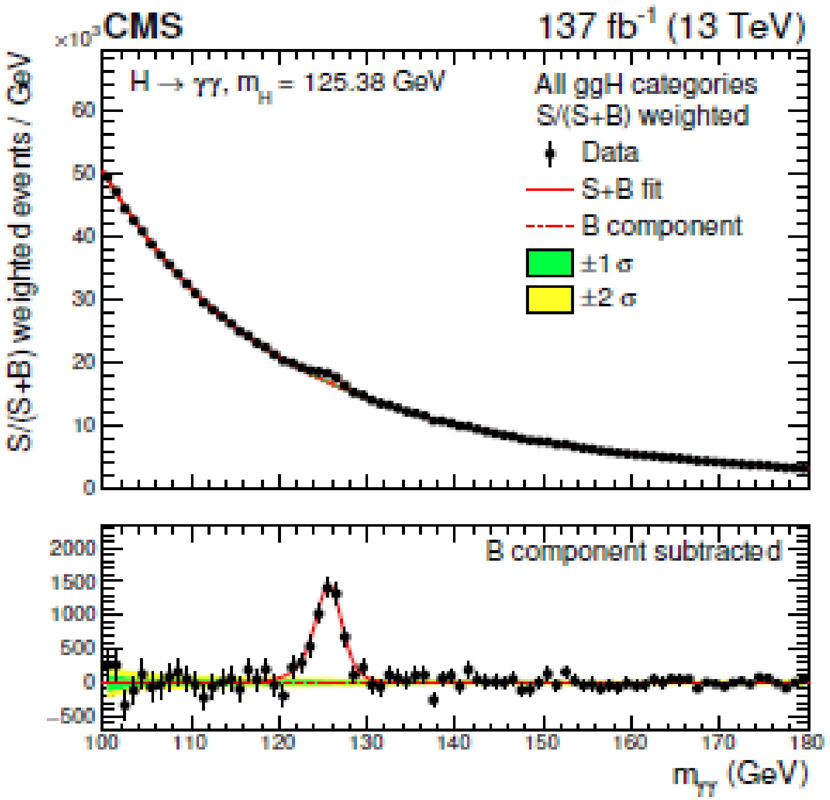
ttH Hadronic



tHq Leptonic

Signal & Background Modelling





- Shape of the **parametric signal model** for each year of simulated data, and for the sum of all years together
- MC tuning and **Data/MC** scale factors have been applied
- Better resolution in 2017 using Ultra-Legacy 2017 data set

- Model used to describe the background is extracted from data using the discrete profiling method
- A large set of candidate function families is considered, including **exponential functions, Bernstein polynomials, Laurent series** and **power law functions**

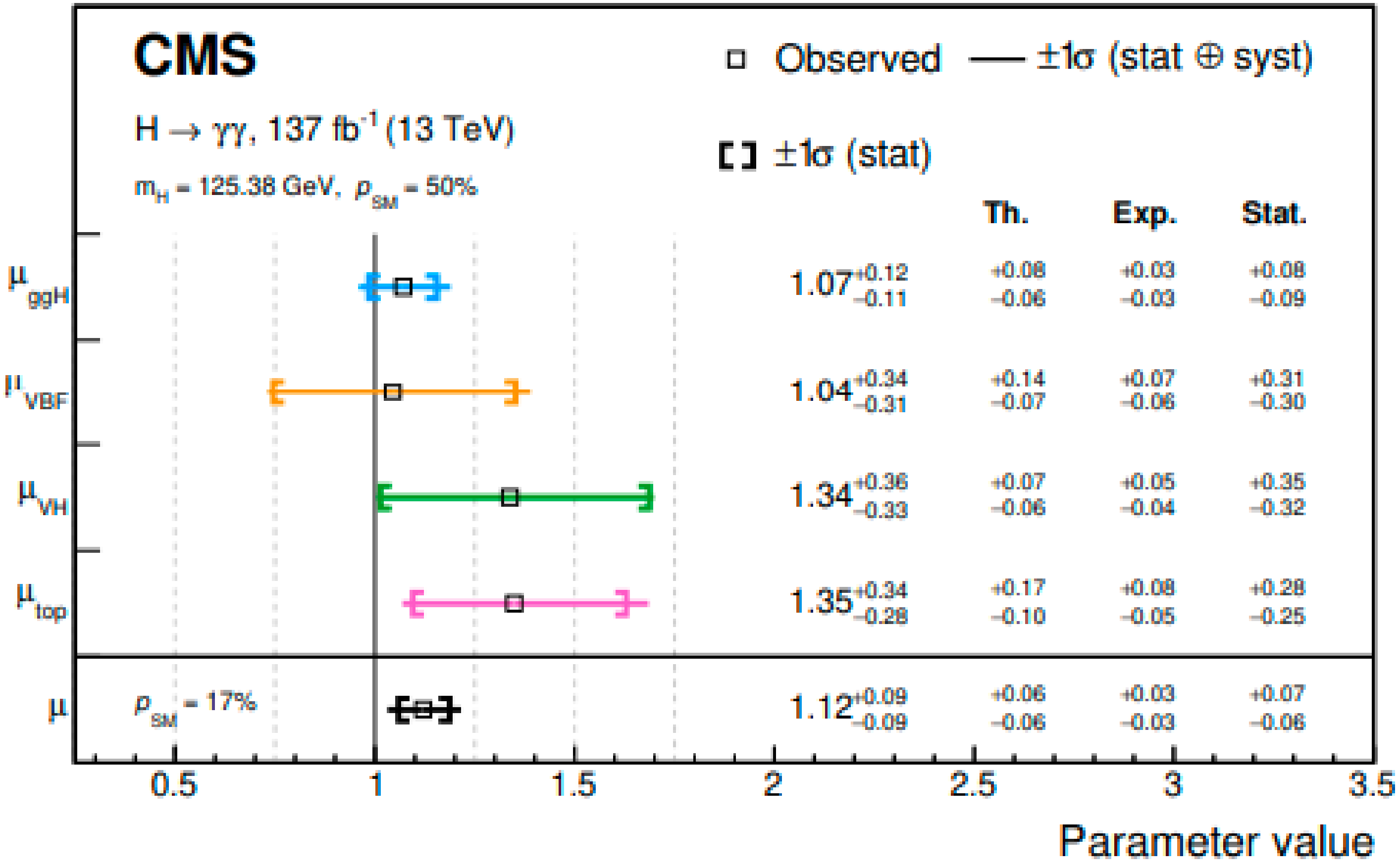
Signal Strength modifiers

$$\mu_i^f = \frac{\sigma_i \mathcal{B}^f}{(\sigma_i)_{\rm SM} (\mathcal{B}^f)_{\rm SM}}$$

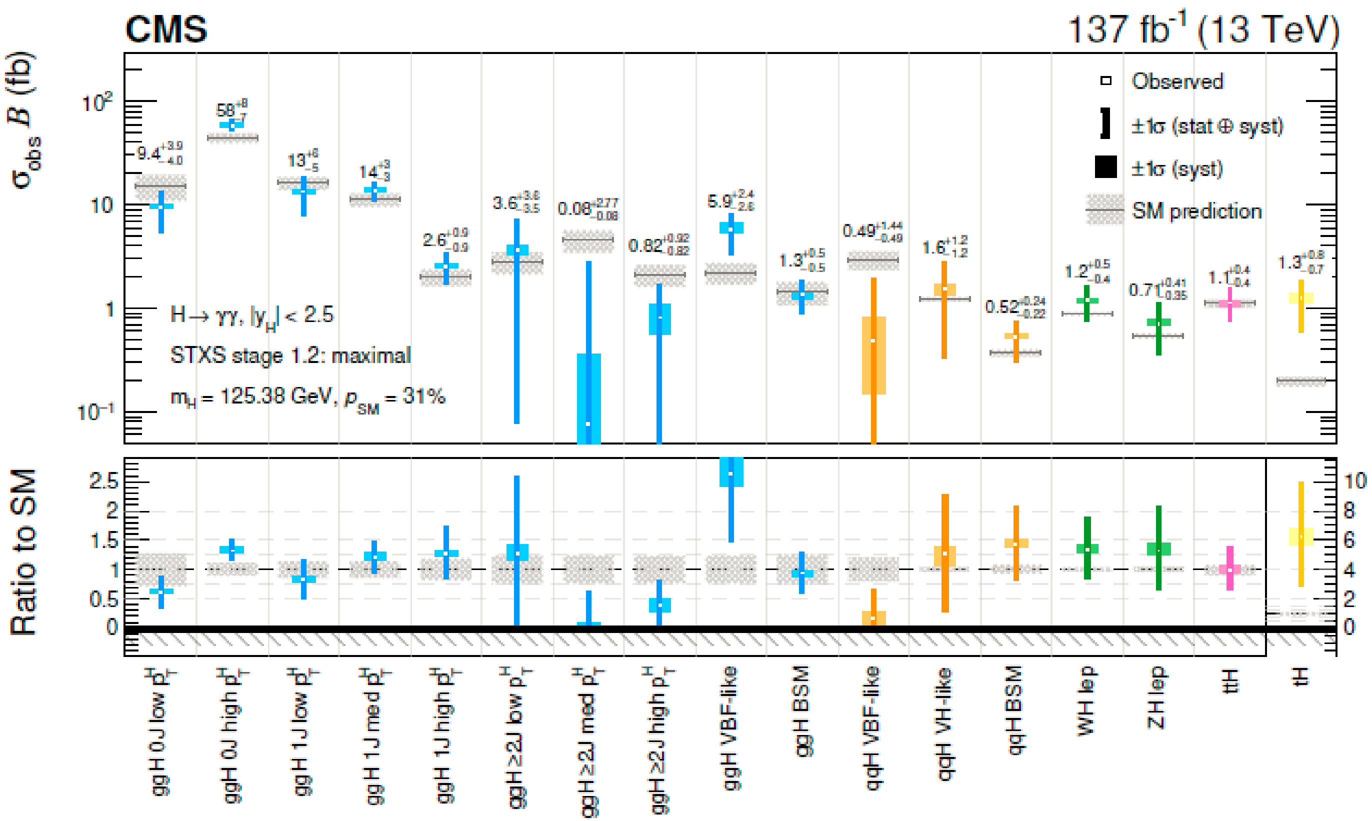
- Best-fit signal + background model shown with data for sum of all categories
- common signal strength modifier (μ): ratio of observed ($\boldsymbol{\sigma}_{\rm H}$ x diphoton BR) to SM prediction
- The overall precision is about 8%

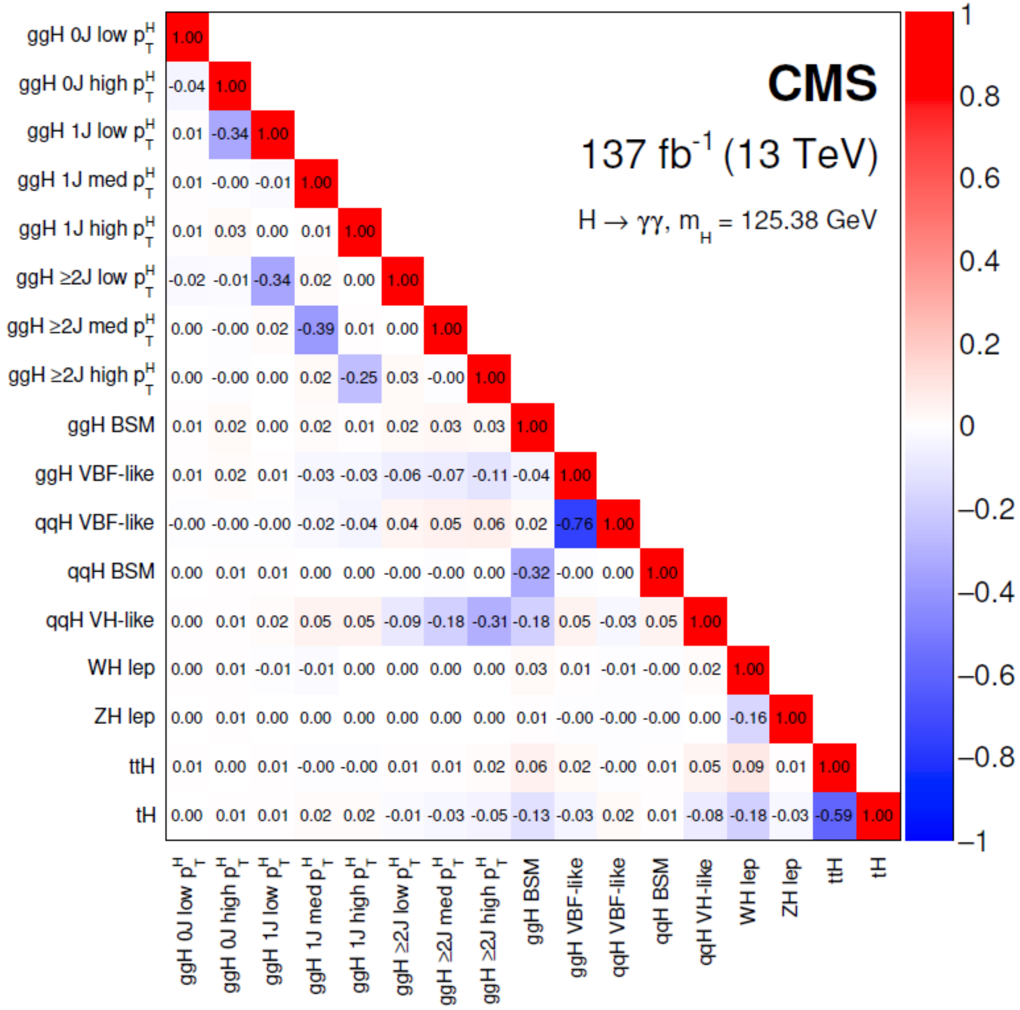
$$\mu = 1.12^{+0.09}_{-0.09} = 1.12^{+0.06}_{-0.06}\,({\rm theo})^{+0.03}_{-0.03}\,({\rm syst})^{+0.07}_{-0.06}\,({\rm stat})$$

- **Signal strength modifiers per production mode**
  - $\mu_{\rm VH}$ (VH hadronic + VH leptonic)
  - $\mu_{\rm VBF}$ (VBF production)
  - $\mu_{\rm top}$ (ttH + tHq + tHW)
  - $\mu_{\rm ggH}$ (ggH + bbH)



“Maximal” Merging Scenario (17 parameters of interest)



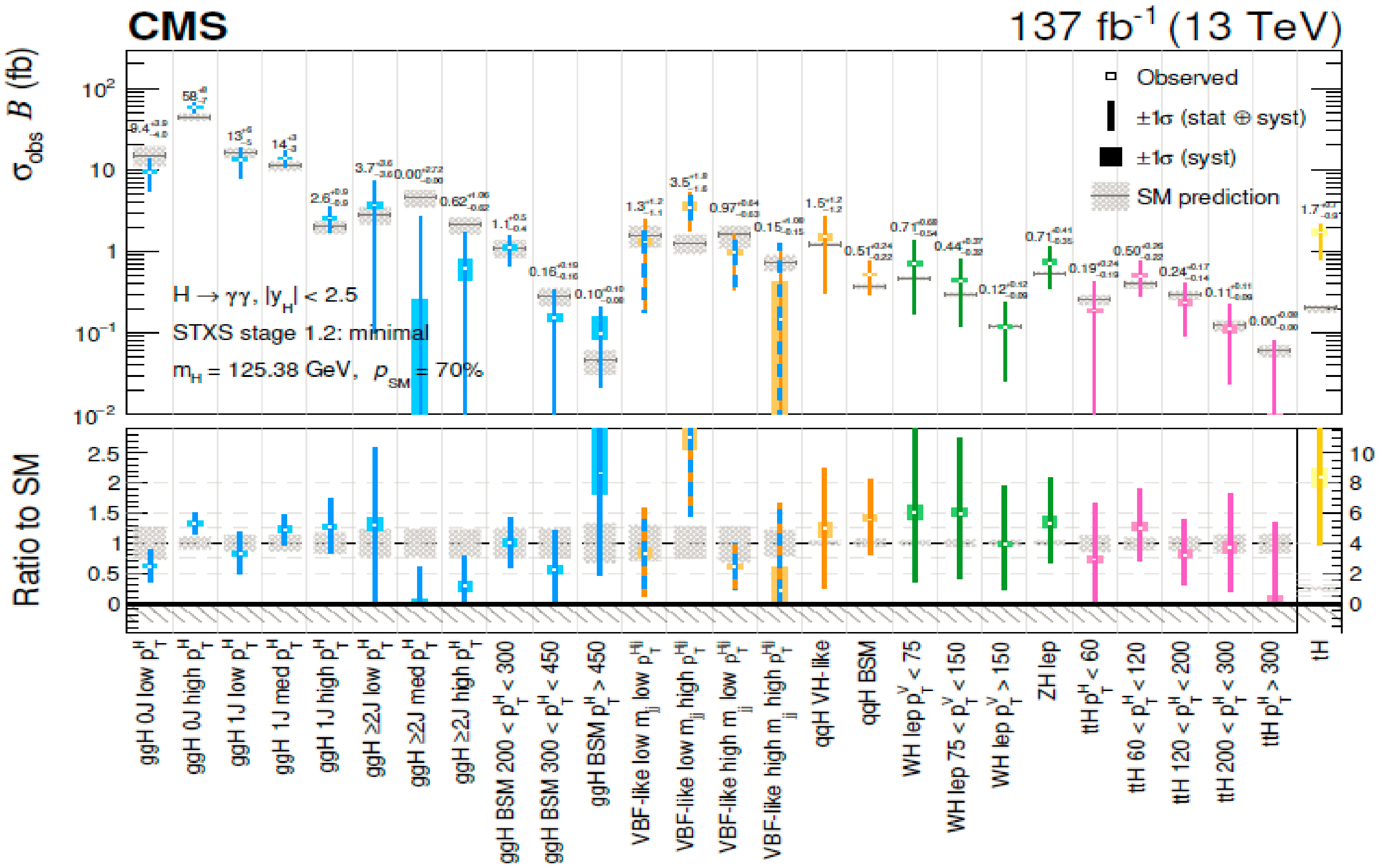


- STXS bins are merged until their expected uncertainty is less than **150%** of the SM prediction
- Measurement of **ttH** and **tH** simultaneously
- Best **tH** measurement: rate of **tH** production of **14 (8)** times the SM expectation is **observed (expected)** to be excluded at the 95% CL , **σxB** is $1.27^{+0.76}_{-0.69}$ fb

- Observed correlations between 17 parameters considered in the maximal merging STXS fit

- BSM bins (in **qqH** and **ggH**) : in agreement with SM

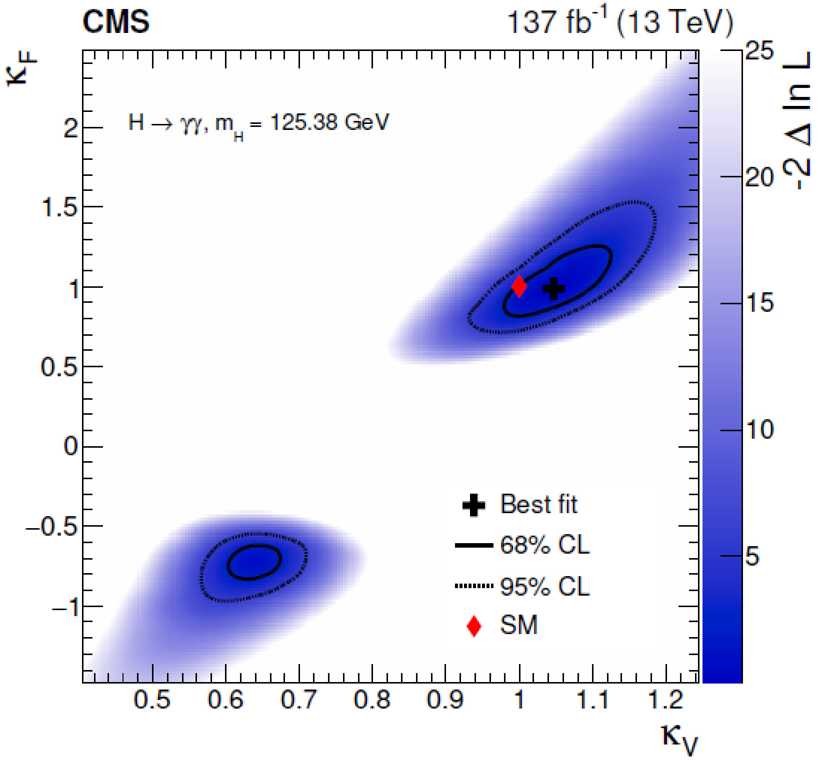
"Minimal" Merging Scenario (27 parameters of interest)

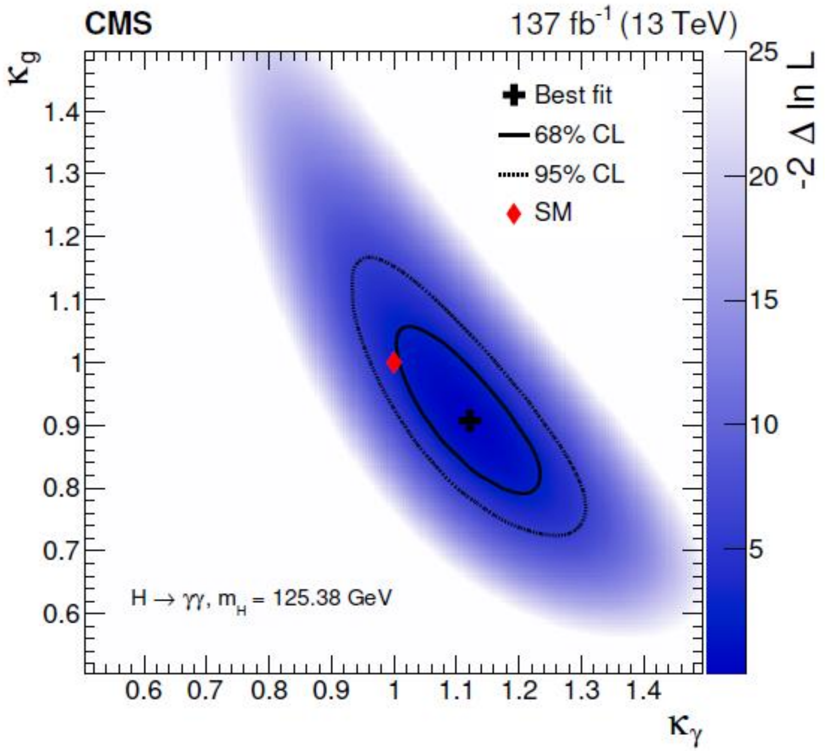


- Merges as few bins as possible that parameters do not become too anti-correlated (values of less than around 90%)
- Measurement with additional stage 1.2 splitting (**ttH** and **ggH BSM**)
  - Splitting **ttH** production into five separate parameters introduces larger correlations into the measurement
- All ***σ*** results are in agreement with the SM predictions
- Merged **ggH** and **VBF** bins (blue/orange lines): less model dependence and reduced correlations

Coupling Modifiers

- The κ-framework defines coupling modifiers to directly parametrize deviations from the SM expectation in the couplings of the Higgs boson to other particles





- **Resolved κ model** is used: Here the scaling factors of loops present in Higgs boson production and decay are resolved into their SM components, in terms of the other parameters
- Exclude negative κ_f with **0.5 (2.4) σ** confidence

- **Unresolved κ model** is used: parameterise deviations in ggH and H→γγ loops using effective coupling modifiers (κ_g, κ_γ)
- The g and γ parameters are particularly sensitive to additional BSM states, that contribute towards the rate of Higgs boson production and decay via loop processes

Search for an additional SM-like Higgs boson in the diphoton decay channel (2012+2016)

Analysis Strategy

- Analysis strategy is mainly inherited from Standard **H→γγ** analysis

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

- **MVA based BDT** is used to separate diphoton candidates with signal-like kinematics, high photon ID scores and good mass resolution from background

- The major difference in **low-mass** is the **Relic DY** as compared to standard **H→γγ**

- In low-mass: standard **H→γγ** 4 Untagged event classes -> Low-mass 3 Untagged classes (2016) by merging class0 and class1 in standard **H→γγ** , to be the class0 in **LM**

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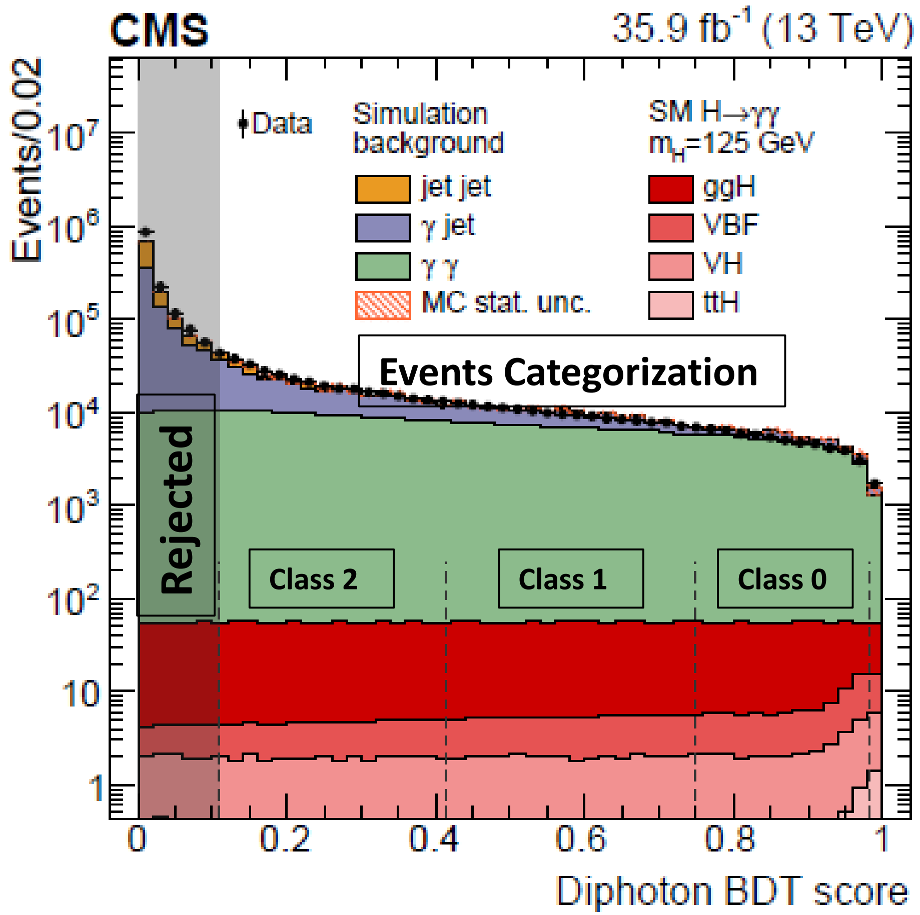

Signal & Background Modelling

- The shape of the diphoton mass distribution is parameterized separately for each event category and production process

- The signal modeling strategy is inherited from standard **H→γγ** analysis

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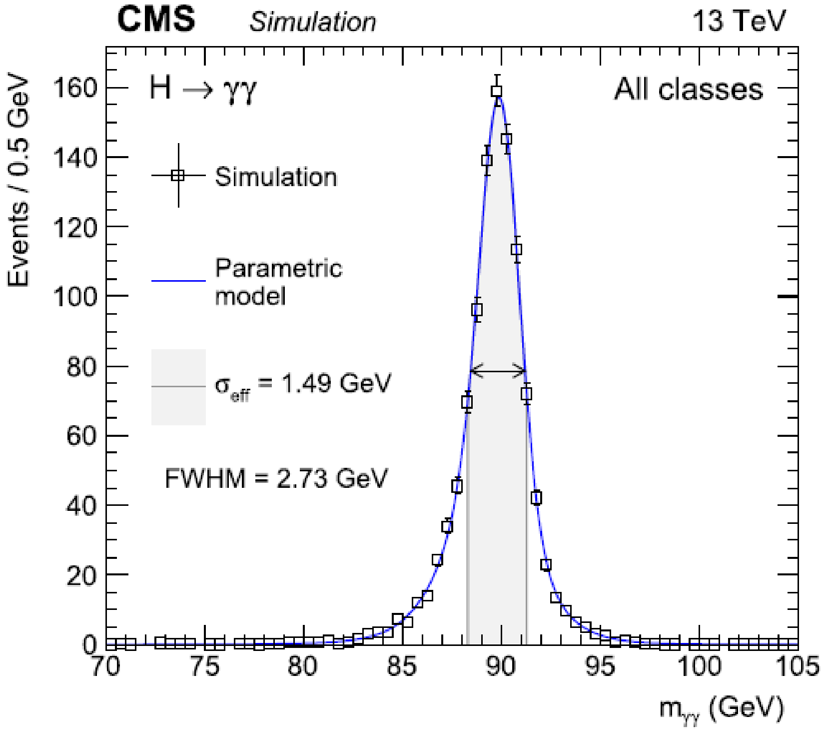
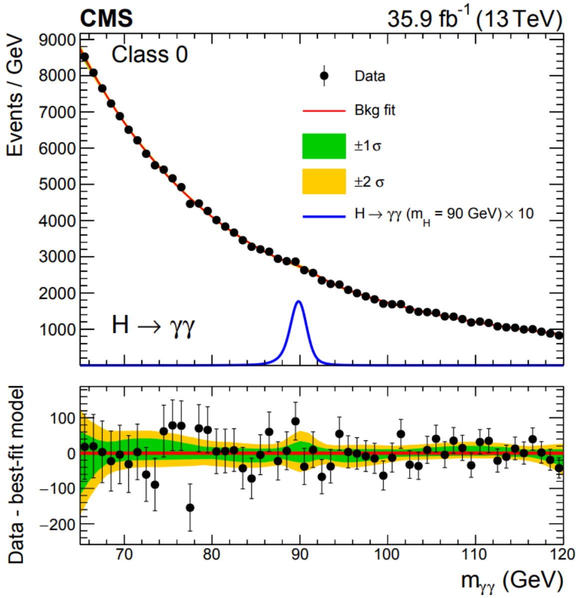
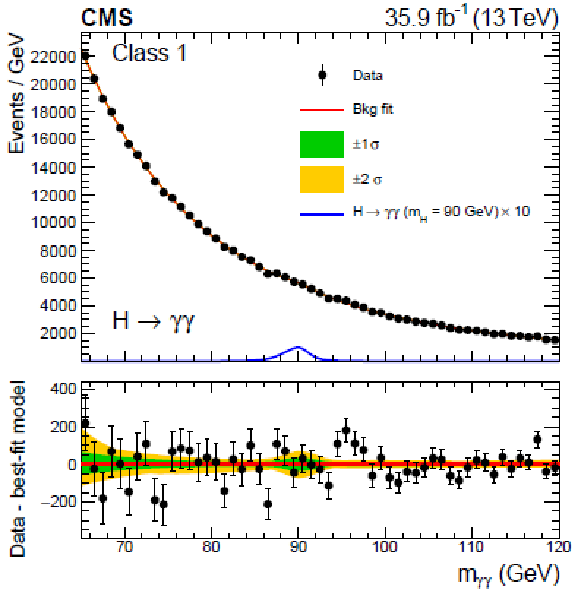


- Background: **γγ, j-j, γ-jet, ee**
- The background is modeled by fitting analytic functions to the observed diphoton mass distributions, in each of the event classes, over the range **65 < $m_{\gamma\gamma}$ < 120** GeV
- **Drell-Yan di-electron production** is significant potential background estimation source since the mass search range includes the Z boson peak region
  - ✓ Background source (**Relic Z->ee, double fake)** events where 'e' misidentified as 'γ'.
  - ✓ **Double Crystal ball (DCB)** function to fit the double fake 'DY' MC events.
  - ✓ Systematics uncertainties on shape parameters estimated by using single fake events





Results (2012 (8TeV), 2016 (13TeV))

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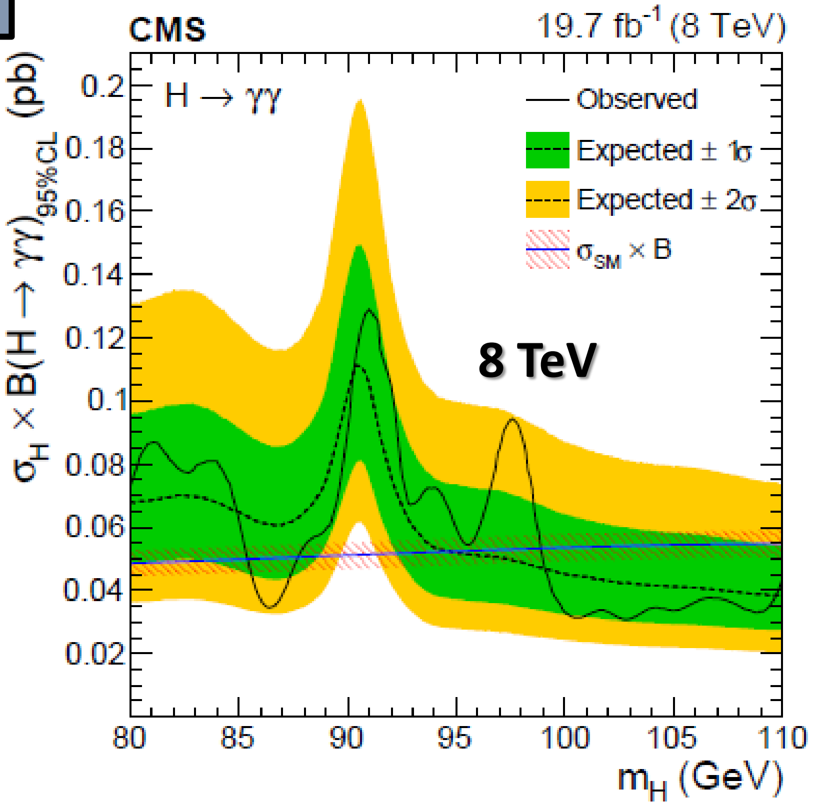

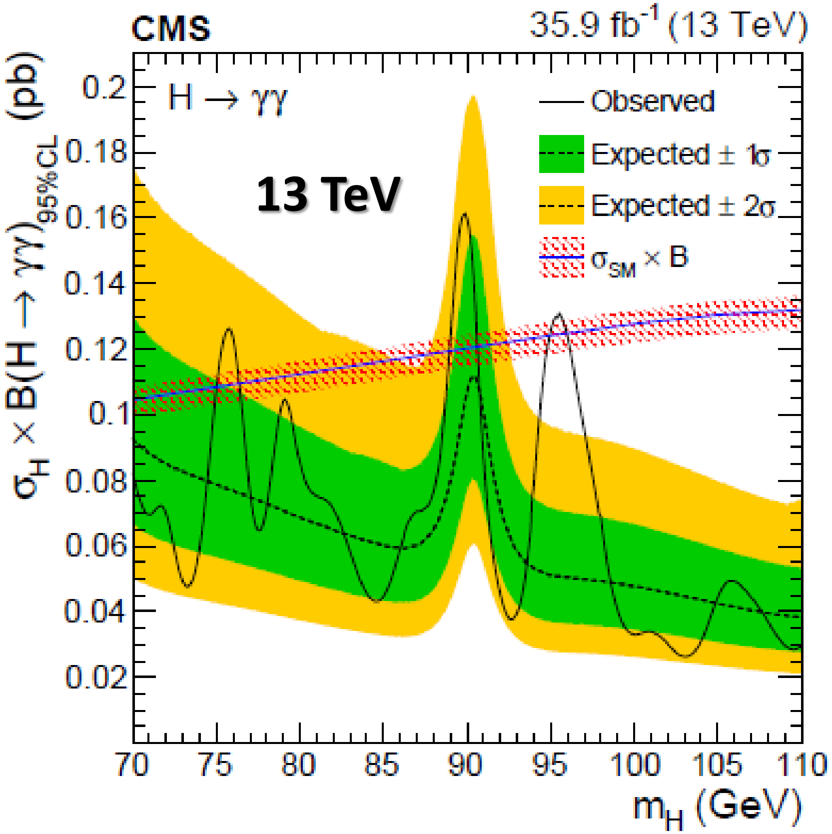

- No significant **(>3 σ)** excess w.r.t. the expected number of background events
- For the **8 TeV** data: **Min. (Max.)** observed UL on **σxB** is approx. **31 (129) fb**, corresponding to the mass **102.8 (91.0) GeV**
- For the **13 TeV data**, **Min. (Max.)** observed UL on **σxB** is approx. **26 (161) fb**, corresponding to the mass **103.0 (89.8) GeV**

Results (2012+2016)

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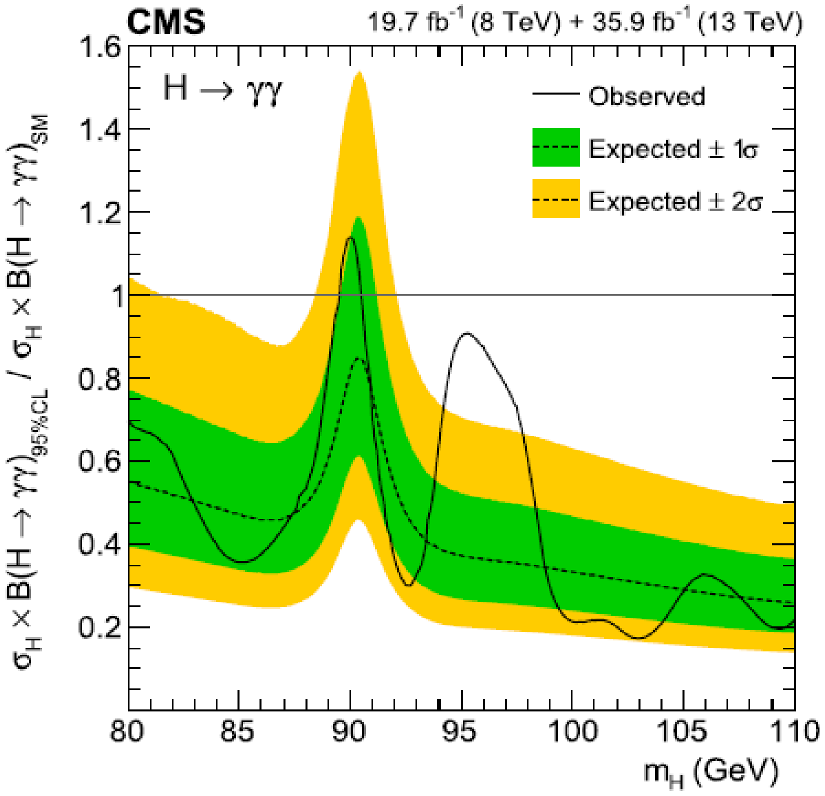

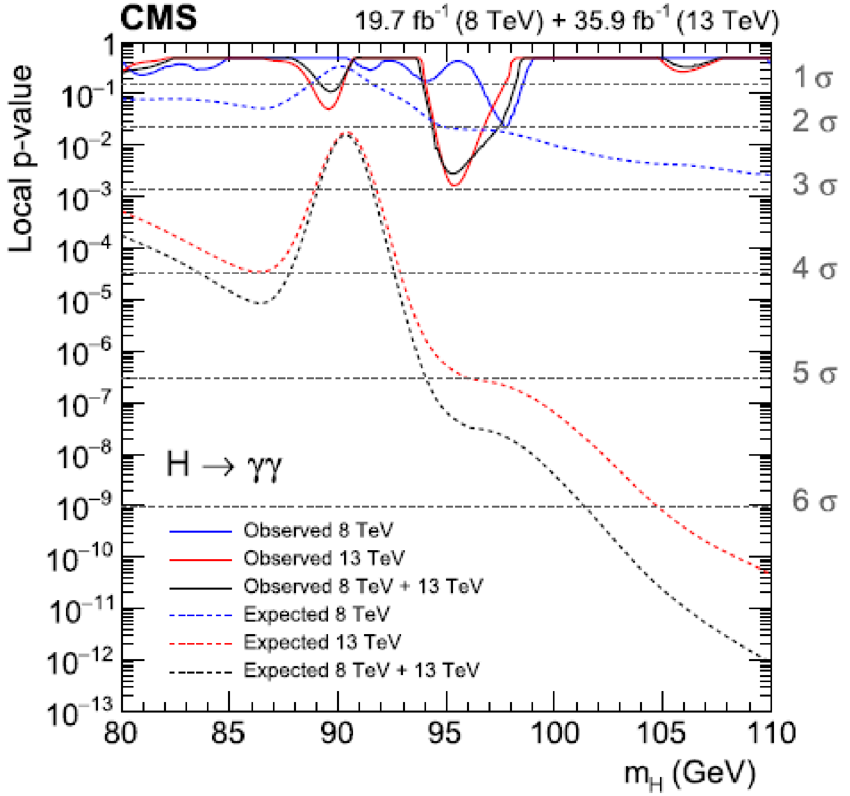

- Limit on **σ x BR (H-> γγ)** normalized to that of SM.
  - ✓ Min. (Max.) limit: **0.17 (1.13)** pb at m_H = **103.0 (90.0) GeV**
- Observed significance:
  - ✓ **8 TeV: ~2.0 σ** local significance at m_H = **97.6 GeV**
  - ✓ **13 TeV: ~2.9 σ** local **(1.47 σ global)** significance at m_H = **95.3 GeV**
  - ✓ **8 TeV + 13 TeV: ~2.8 σ** local **(1.3 σ global)** significance at m_H = **95.3 GeV**
- Need more data to ascertain the origin of this excess.

Summary and Conclusion

- Measurements of Higgs boson properties with the Higgs boson decaying into a pair of photons are reported
- The total Higgs boson signal strength, relative to the standard model **(SM)** prediction, is measured to be **1.12 ± 0.09**
- Two different measurements are performed within the simplified template cross section framework, in which **17** and **27** independent kinematic regions are measured simultaneously
- Several additional measurements are the most precise made in a single channel to date
- Measurements of the Higgs boson's couplings to vector bosons and to fermions, are also in agreement with the SM expectations

- Searches for low mass Higgs bosons are strongly motivated by several theories
- Direct searches for additional Higgs bosons (m<125) with various decay channels have been presented
- Most results presented here have been performed with **2016** data and combination of **2012** and **2016**
- No evidence for the moment has been found for the presence of BSM Higgs bosons
- Looking forward to new results with **Full Run II** data **(Ongoing…)**

Thanks

Backup

“Minimal” Merging Scenario