# Higgs boson couplings to vector bosons

Recent results from ATLAS and CMS

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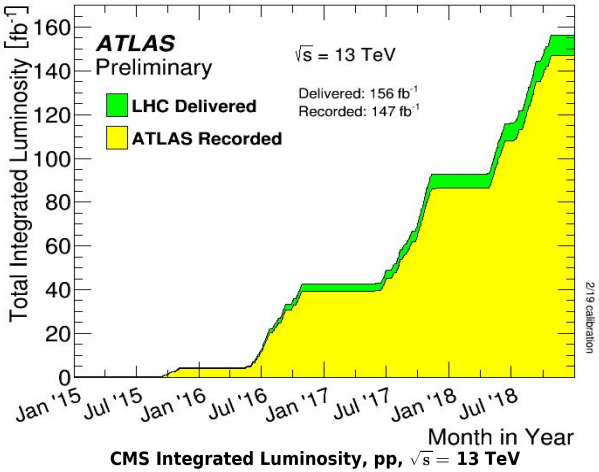
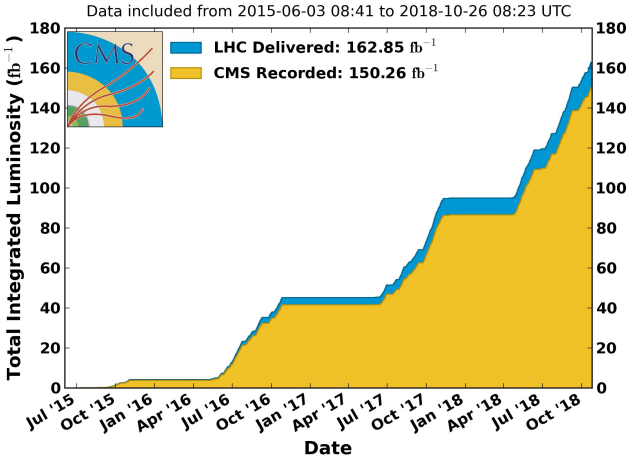
# Introduction

- Both experiments **working towards the delivery of results with the full statistics** available from the LHC Run 2 (~136/fb)
  - Some are **already available** with full statistics
- Focus on **precision measurement**s and on the extraction of as detailed information as possible, so not only inclusive observables:
  - Measurements in a **fiducial phase space**
  - Simplified template cross sections (**STXS**)
    - see talks by J. M. Langford
  - **Differential** measurements
    - see talks by D. Boerner, J. Piedra
- **Combin(-ed/-able) results**
  - See combination talks by N. Berger and M. Xiao



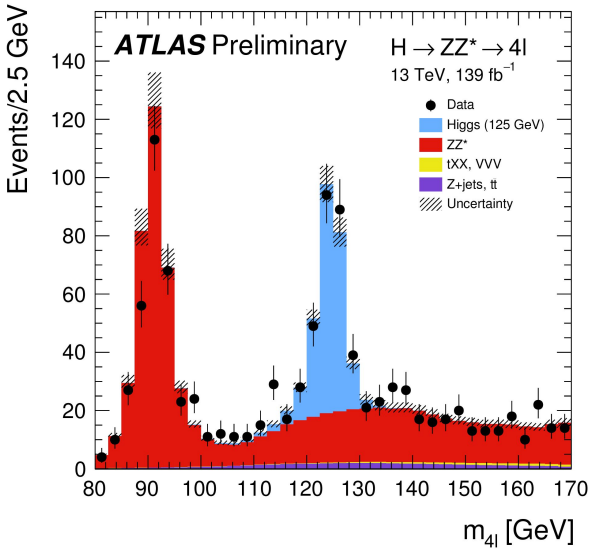

CMS Integrated Luminosity, pp, $\sqrt{s} = 13$ TeV

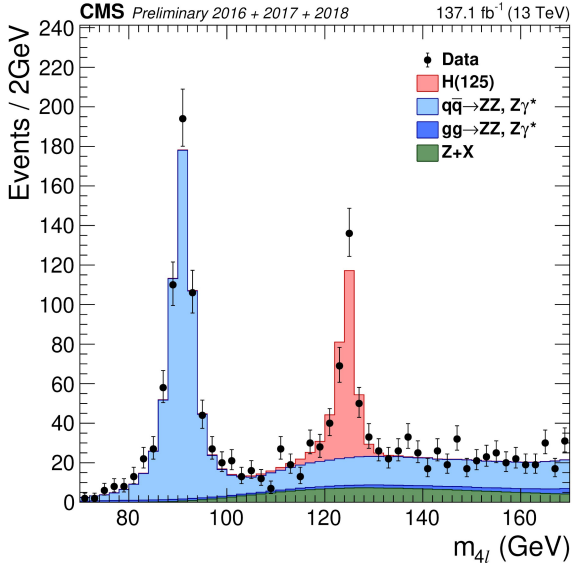


# $H \longrightarrow 4l$ ATLAS-CONF-2019-025 CMS-PAS-HIG-19-001

- Both CMS and ATLAS show **results with the full Run 2**
  - 4 leptons invariant mass as well as a **variable related to decay angles** and the scalar nature of the Higgs boson as used to discriminate against backgrounds
    - Entirely matrix element based in CMS, Neural Network based (including ME input) in ATLAS

- Backgrounds:
  - irreducible: ZZ, Zγ*
  - Reducible Z+jets
    - estimated in control regions
- **Statistically dominated measurement**
  - Main systematics from lepton efficiencies and irreducible backgrounds subtraction



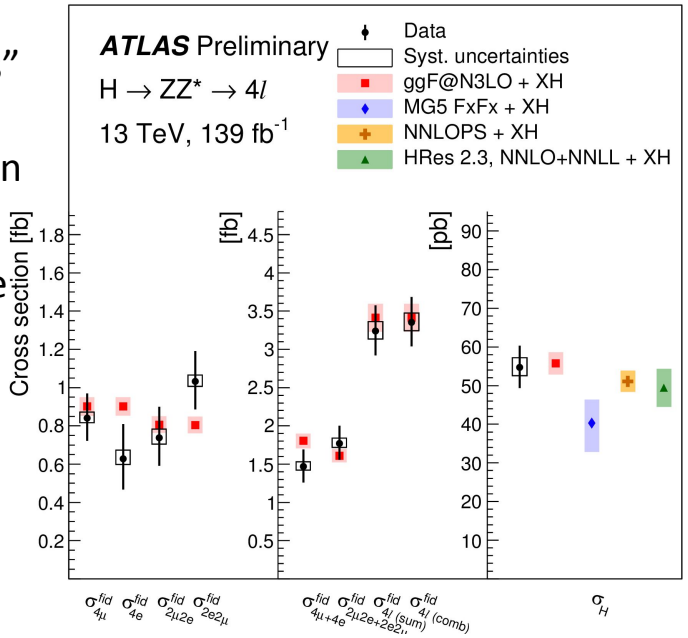
# H → 4l - Fiducial Cross Sections

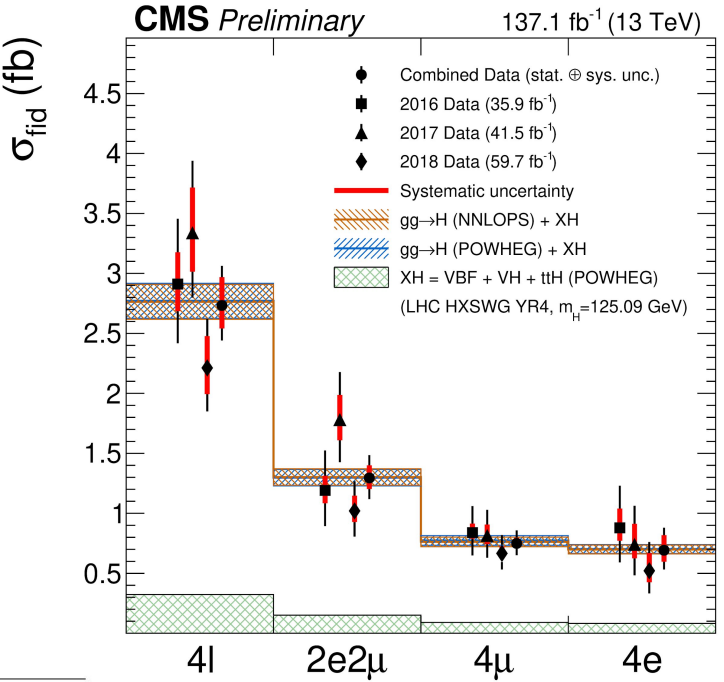
- Defined in a phase space that is **as close as possible** to the measured phase space
  - **Model independent**
  - **Small extra**

Based on “dressed-leptons”

In CMS the signal extraction is simplified removing ME discriminant, the to reduce the model dependency of the result

ATLAS floats the ZZ normalization in fit sidebands



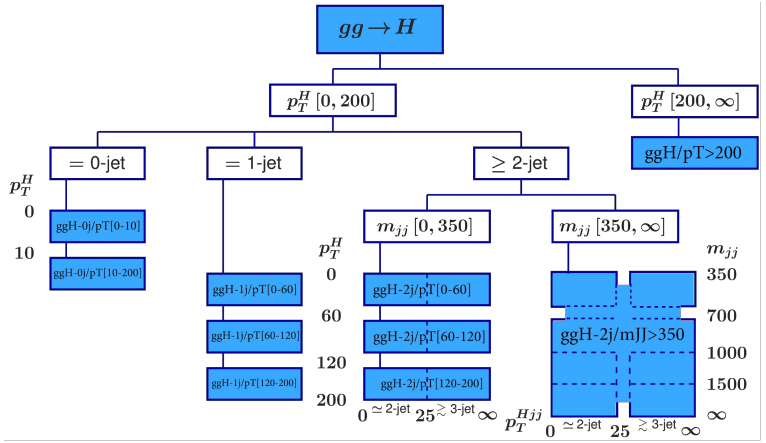



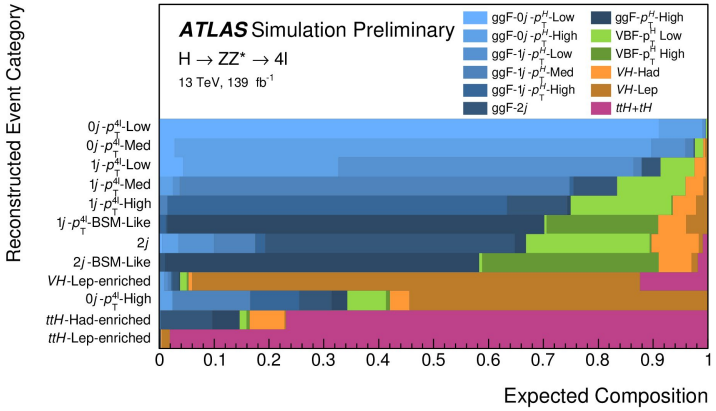

| Cross section [fb] | Data (± (stat.) | ± (syst.) ) | Standard Model prediction | | $p$-value [%] |
|---|---|---|---|---|---|
| $\sigma_{\text{comb}}$ | 3.35 | ±0.30 ±0.12 | 3.41 | ± 0.18 | 85 |

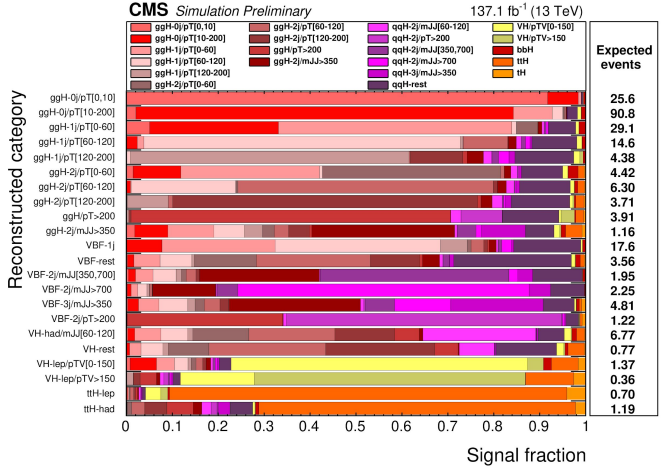
$$\sigma_{\text{fid.}} = 2.73^{+0.23}_{-0.22}(\text{stat.})^{+0.24}_{-0.19}(\text{syst.})\ \text{fb}$$

# H → 4l - STXS

Simplified template cross sections (**STXS 1.1**) are **defined phase space regions agreed between theorist and the experiments** to maximise the **sensitivity to new physics** and the **combinability of CMS and ATLAS results**.

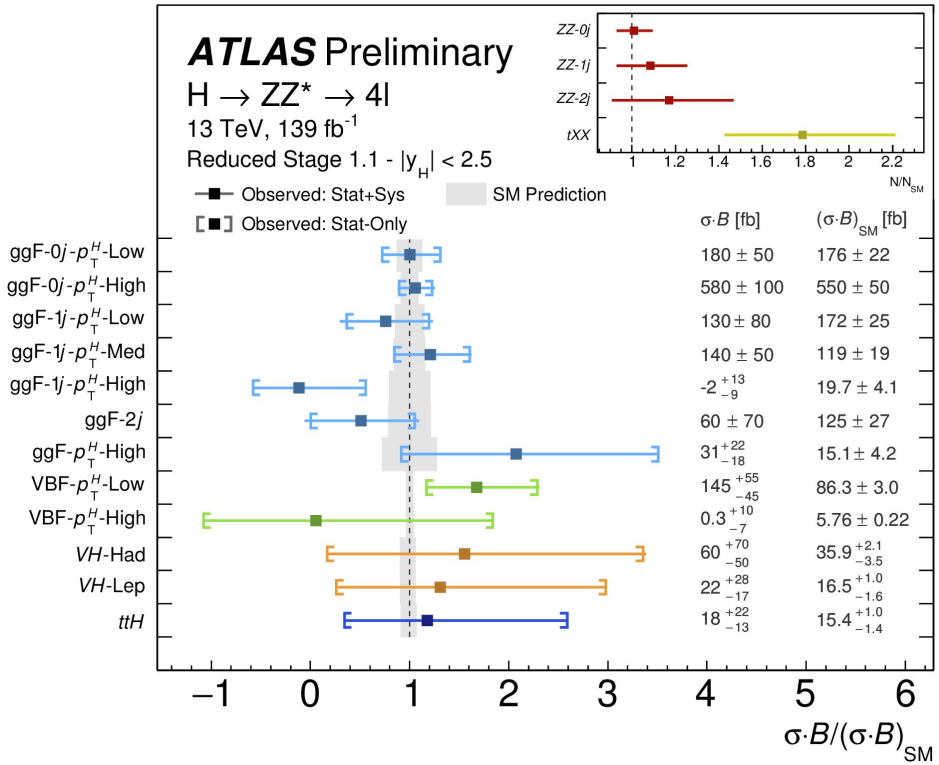


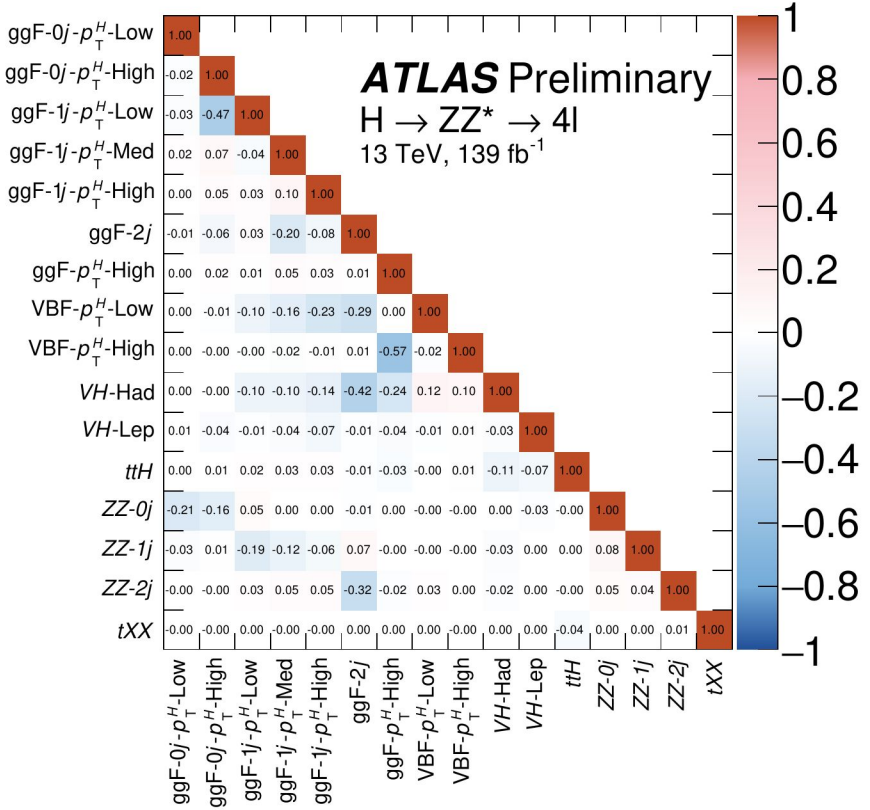



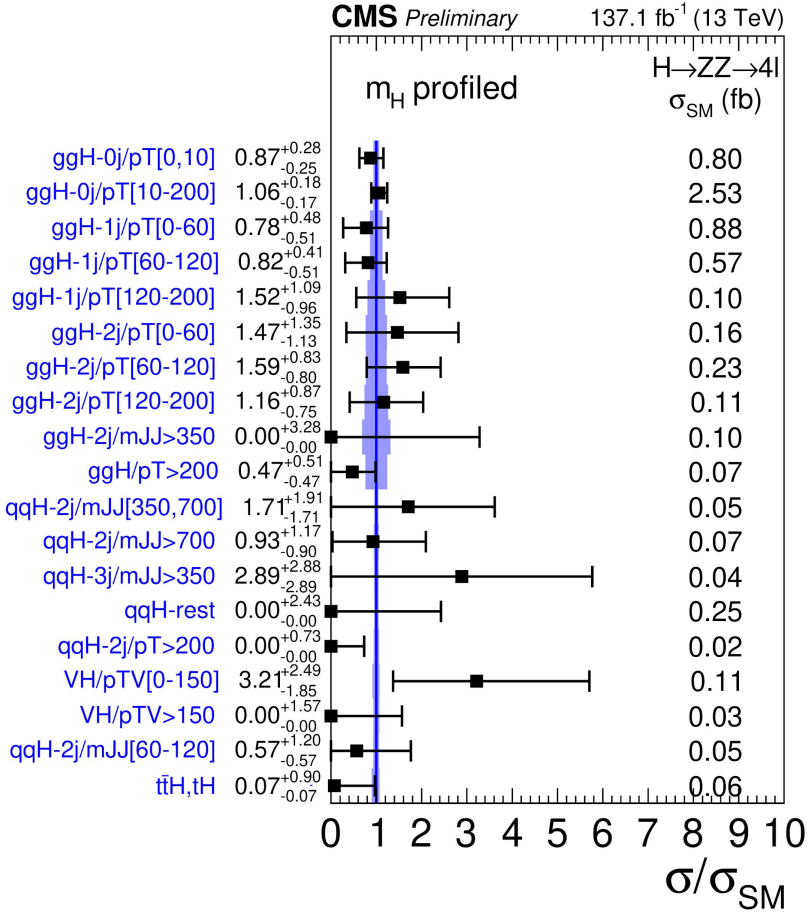
# H → 4l - STXS

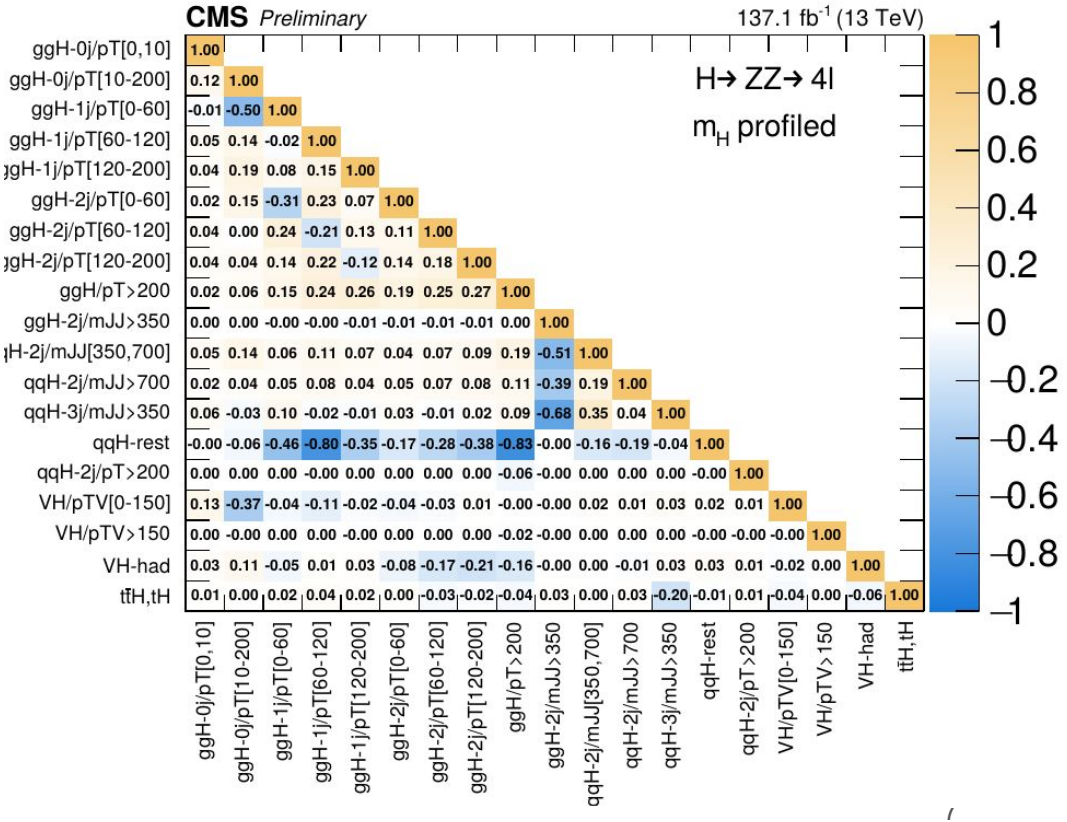
Experiments use slightly different merging of STXS bins, because current data hardly allows do be sensitive to all of the stage 1.1 bins



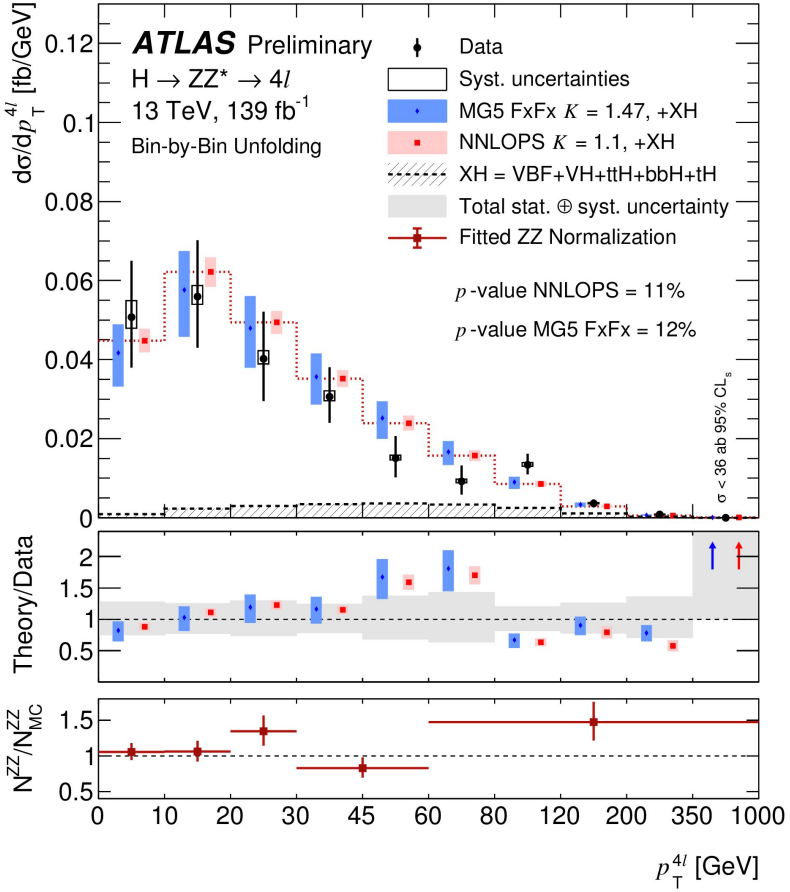



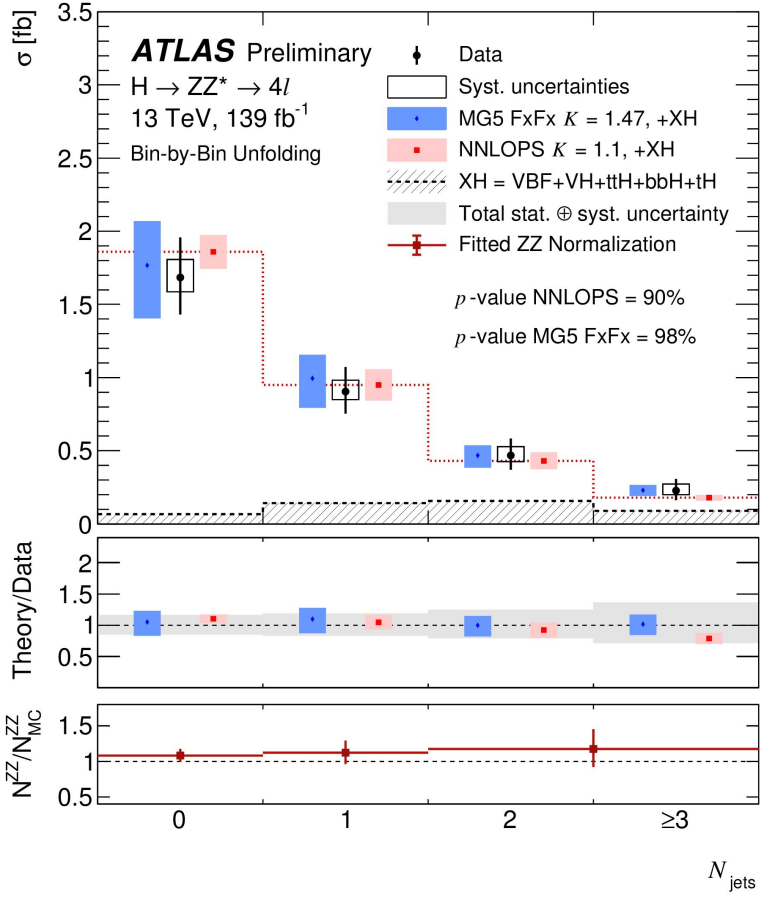
# H → 4l - STXS


CMS Preliminary
137.1 fb-1 (13 TeV)
H→ZZ→4l
mH profiled
σSM (fb)
ggH-0j/pT[0,10] 0.87+0.28-0.25 0.80
ggH-0j/pT[10-200] 1.06+0.18-0.17 2.53
ggH-1j/pT[0-60] 0.78+0.48-0.51 0.88
ggH-1j/pT[60-120] 0.82+0.41-0.51 0.57
ggH-1j/pT[120-200] 1.52+1.09-0.96 0.10
ggH-2j/pT[0-60] 1.47+1.35-1.13 0.16
ggH-2j/pT[60-120] 1.59+0.83-0.80 0.23
ggH-2j/pT[120-200] 1.16+0.87-0.75 0.11
ggH-2j/mJJ>350 0.00+3.28-0.00 0.10
ggH/pT>200 0.47+0.51-0.47 0.07
qqH-2j/mJJ[350,700] 1.71+1.91-1.71 0.05
qqH-2j/mJJ>700 0.93+1.17-0.90 0.07
qqH-3j/mJJ>350 2.89+2.88-2.89 0.04
qqH-rest 0.00+2.43-0.00 0.25
qqH-2j/pT>200 0.00+0.73-0.00 0.02
VH/pTV[0-150] 3.21+2.49-1.85 0.11
VH/pTV>150 0.00+1.57-0.00 0.03
qqH-2j/mJJ[60-120] 0.57+1.20-0.57 0.05
ttH,tH 0.07+0.90-0.07 0.06
0 1 2 3 4 5 6 7 8 9 10
σ/σSM


CMS Preliminary
137.1 fb-1 (13 TeV)
H→ ZZ→ 4l
mH profiled
ggH-0j/pT[0,10] 1.00
ggH-0j/pT[10-200] 0.12 1.00
ggH-1j/pT[0-60] -0.01 -0.50 1.00
ggH-1j/pT[60-120] 0.05 0.14 -0.02 1.00
ggH-1j/pT[120-200] 0.04 0.19 0.08 0.15 1.00
ggH-2j/pT[0-60] 0.02 0.15 -0.31 0.23 0.07 1.00
ggH-2j/pT[60-120] 0.04 0.00 0.24 -0.21 0.13 0.11 1.00
ggH-2j/pT[120-200] 0.04 0.04 0.14 0.22 -0.12 0.14 0.18 1.00
ggH/pT>200 0.02 0.06 0.15 0.24 0.26 0.19 0.25 0.27 1.00
ggH-2j/mJJ>350 0.00 0.00 -0.00 -0.00 -0.01 -0.01 -0.01 -0.01 0.00 1.00
qqH-2j/mJJ[350,700] 0.05 0.14 0.06 0.11 0.07 0.04 0.07 0.09 0.19 -0.51 1.00
qqH-2j/mJJ>700 0.02 0.04 0.05 0.08 0.04 0.05 0.07 0.08 0.11 -0.39 0.19 1.00
qqH-3j/mJJ>350 0.06 -0.03 0.10 -0.02 -0.01 0.03 -0.01 0.02 0.09 -0.68 0.35 0.04 1.00
qqH-rest -0.00 -0.06 -0.46 -0.80 -0.35 -0.17 -0.28 -0.38 -0.83 -0.00 -0.16 -0.19 -0.04 1.00
qqH-2j/pT>200 0.00 0.00 0.00 -0.00 0.00 0.00 0.00 0.00 -0.06 -0.00 0.00 0.00 0.00 -0.00 1.00
VH/pTV[0-150] 0.13 -0.37 -0.04 -0.11 -0.02 -0.04 -0.03 0.01 -0.00 -0.00 0.02 0.01 0.03 0.02 0.01 1.00
VH/pTV>150 0.00 -0.00 0.00 0.00 -0.00 0.00 0.00 0.00 -0.02 -0.00 0.00 0.00 0.00 -0.00 -0.00 -0.00 1.00
VH-had 0.03 0.11 -0.05 0.01 0.03 -0.08 -0.17 -0.21 -0.16 -0.00 0.00 -0.01 0.03 0.03 0.01 -0.02 0.00 1.00
ttH,tH 0.01 0.00 0.02 0.04 0.02 0.00 -0.03 -0.02 -0.04 0.03 0.00 0.03 -0.20 -0.01 0.01 -0.04 0.00 -0.06 1.00
ggH-0j/pT[0,10]
ggH-0j/pT[10-200]
ggH-1j/pT[0-60]
ggH-1j/pT[60-120]
ggH-1j/pT[120-200]
ggH-2j/pT[0-60]
ggH-2j/pT[60-120]
ggH-2j/pT[120-200]
ggH/pT>200
ggH-2j/mJJ>350
qqH-2j/mJJ[350,700]
qqH-2j/mJJ>700
qqH-3j/mJJ>350
qqH-rest
qqH-2j/pT>200
VH/pTV[0-150]
VH/pTV>150
VH-had
ttH,tH
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1

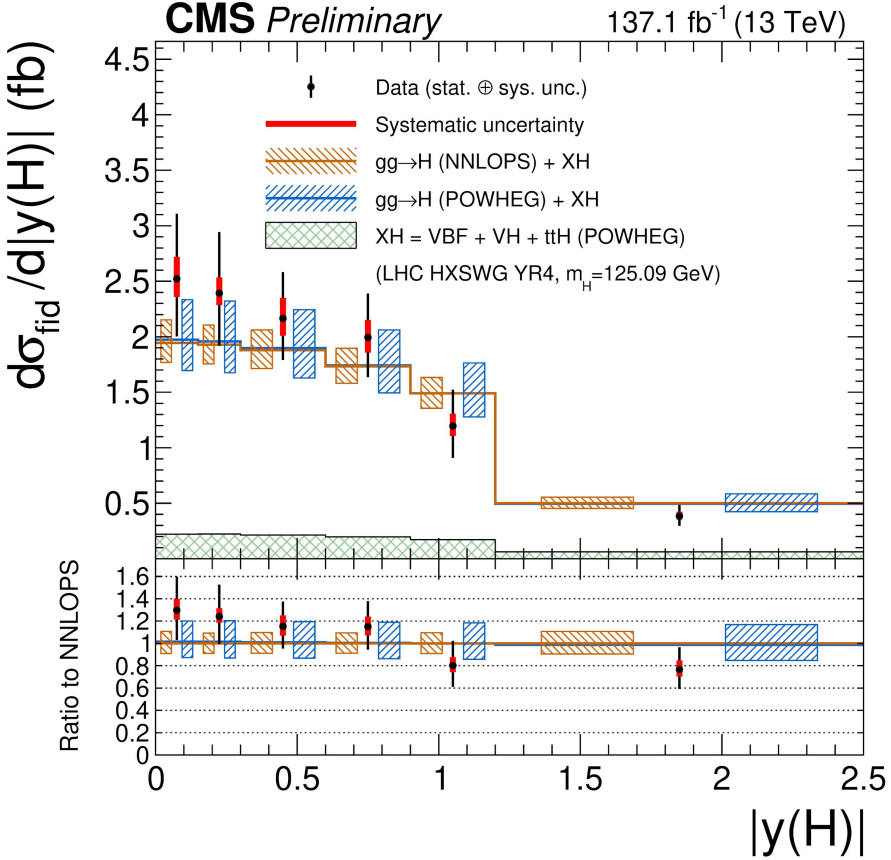
# H → 4l Differential Measurements

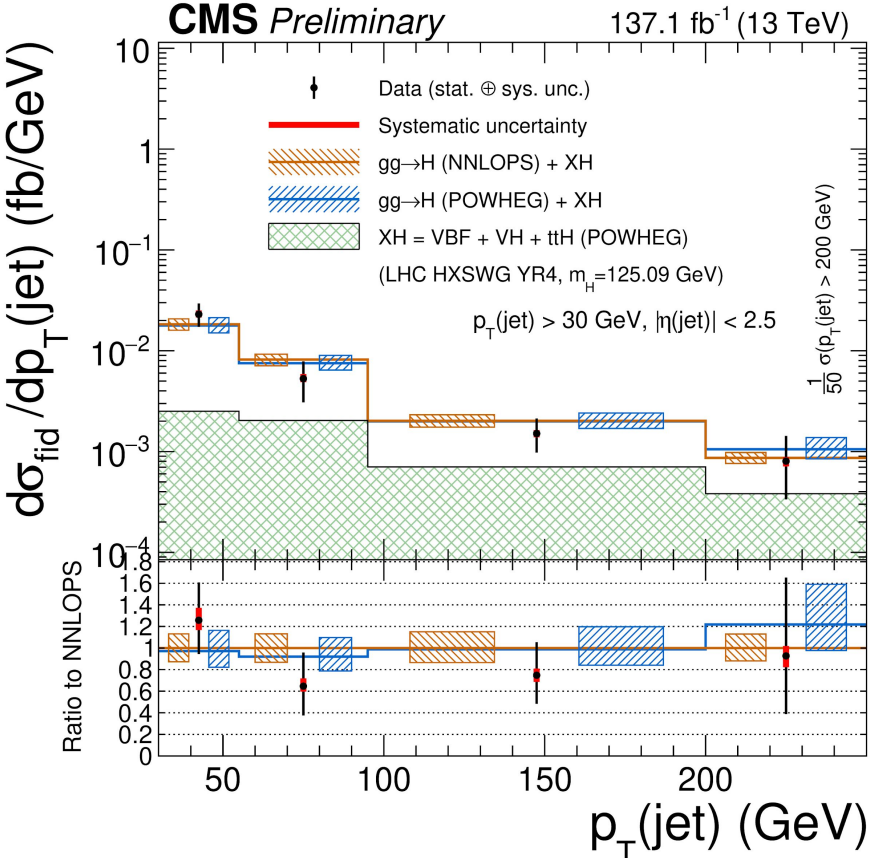


# H → 4l Differential Measurements

## Unfolding with matrix inversion

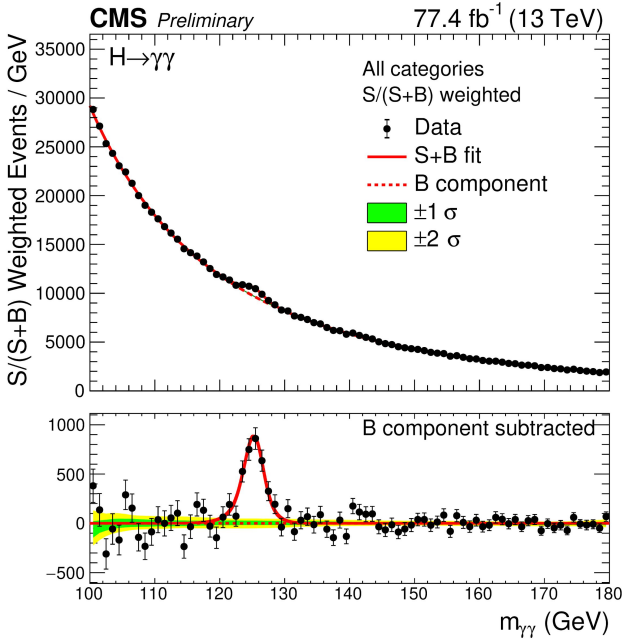


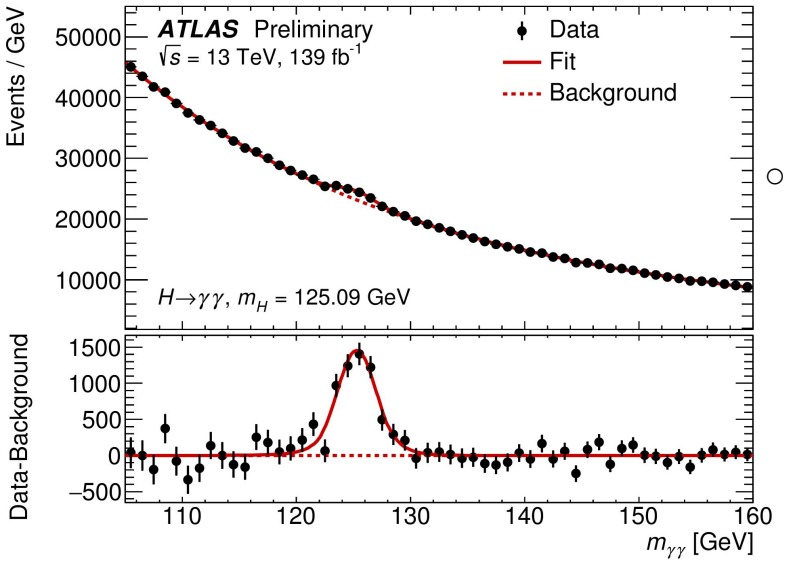
# H→ γγ ATLAS-CONF-2018-028, ATLAS-CONF-2019-029 CMS-HIG-18-029

**ATLAS result exploits the full Run 2** statistics, **CMS uses 2016 and 2017** dataset

- Main challenges:
  - Photon to vertex association
  - Huge backgrounds



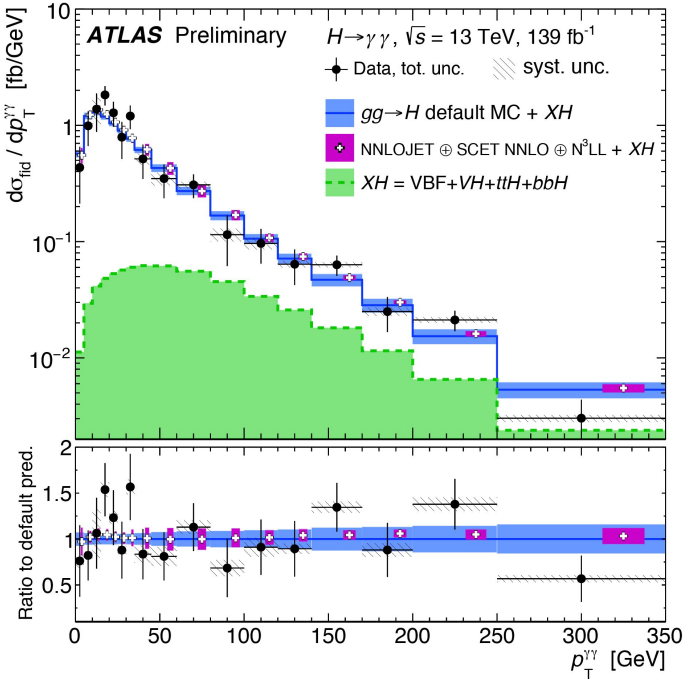

- Similar strategies:
  - Fit a signal on top of a smoothly falling background
    - Slightly different treatment of the systematics associated with the function ansatz for background fit
  - CMS uses a discrete parameter in the fit, ranging across different background models
  - ATLAS uses the model that minimizes the bias based on MC studies

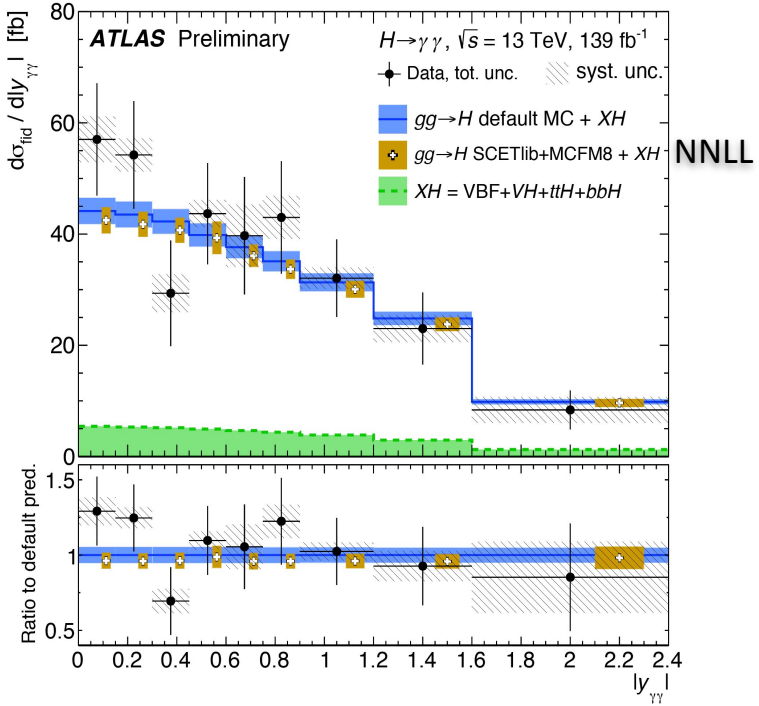


# H→ γγ - Differential measurements

Good agreement with NNLO + PS predictions (POWHEG) as well as with predictions in which the resummation effects are described to higher precision

$$\sigma_{\text{fid}} = 65.2 \pm 4.5\,(\text{stat.}) \pm 5.6\,(\text{syst.}) \pm 0.3\,(\text{theo.})\ \text{fb}$$



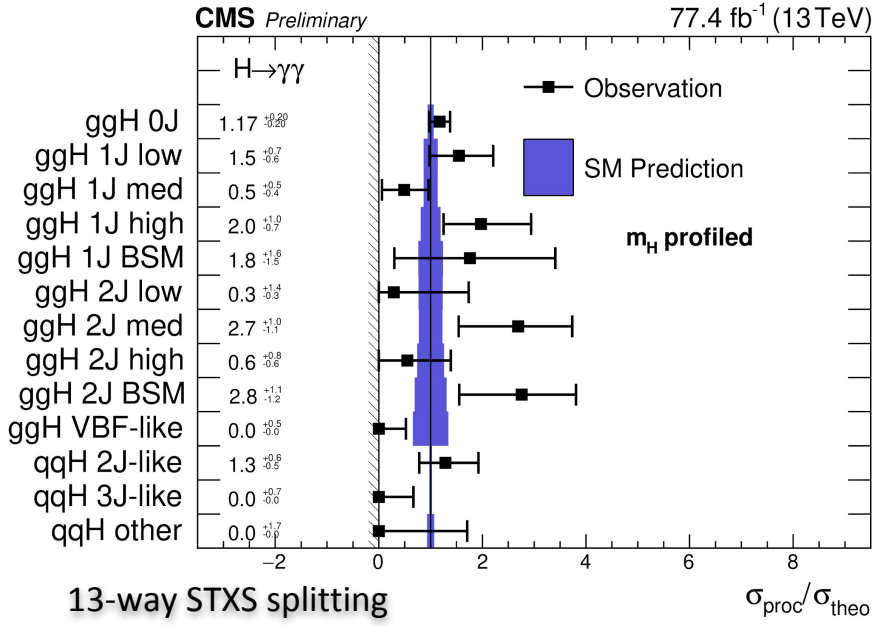




NNLL

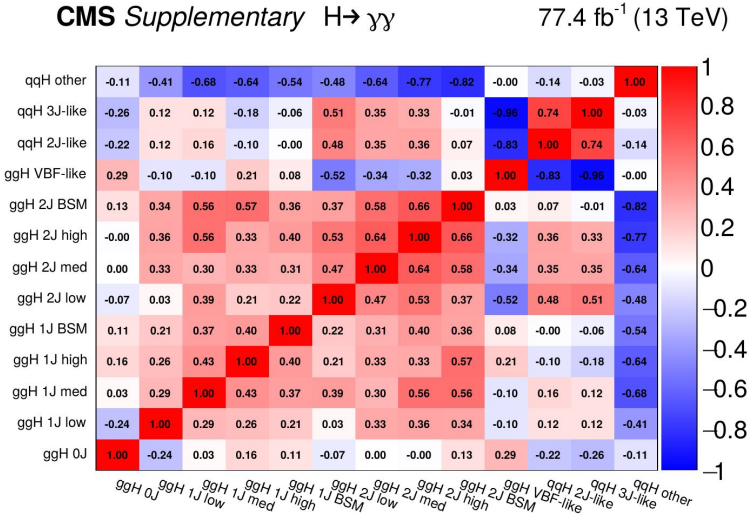
# H→ γγ - STXS stage 1

- Focus of the CMS preliminary result
  - Two splittings explored, with different granularity for gluon fusion and VBF
  - No significant deviation w.r.t. the SM prediction

| Region | Definition | Fraction | Cross section (pb) |
|---|---|---|---|
| 0J | Exactly zero jets, any $p_T^H$ | 60.0% | 26.49 |
| 1J low | Exactly one jet, $p_T^H < 60$ GeV | 15.4% | 6.79 |
| 1J med | Exactly one jet, 60 GeV $< p_T^H < 120$ GeV | 10.4% | 4.61 |
| 1J high | Exactly one jet, 120 GeV $< p_T^H < 200$ GeV | 1.7% | 0.76 |
| 1J BSM | Exactly one jet, $p_T^H > 200$ GeV | 0.4% | 0.16 |
| 2J low | $\geq$ two jets, $p_T^H < 60$ GeV | 2.9% | 1.26 |
| 2J med | $\geq$ two jets, 60 GeV $< p_T^H < 120$ GeV | 4.5% | 2.00 |
| 2J high | $\geq$ two jets, 120 GeV $< p_T^H < 200$ GeV | 2.3% | 1.00 |
| 2J BSM | $\geq$ two jets, $p_T^H > 200$ GeV | 1.0% | 0.43 |
| VBF-like 2J | $\geq$ two jets, $p_T^H < 200$ GeV, $\lvert\Delta\eta\rvert > 2.8$, $m_{jj} > 400$ GeV, $p_T^{Hjj} < 25$ GeV | 0.6% | 0.27 |
| VBF-like 3J | $\geq$ two jets, $p_T^H < 200$ GeV, $\lvert\Delta\eta\rvert > 2.8$, $m_{jj} > 400$ GeV, $p_T^{Hjj} > 25$ GeV | 0.9% | 0.38 |

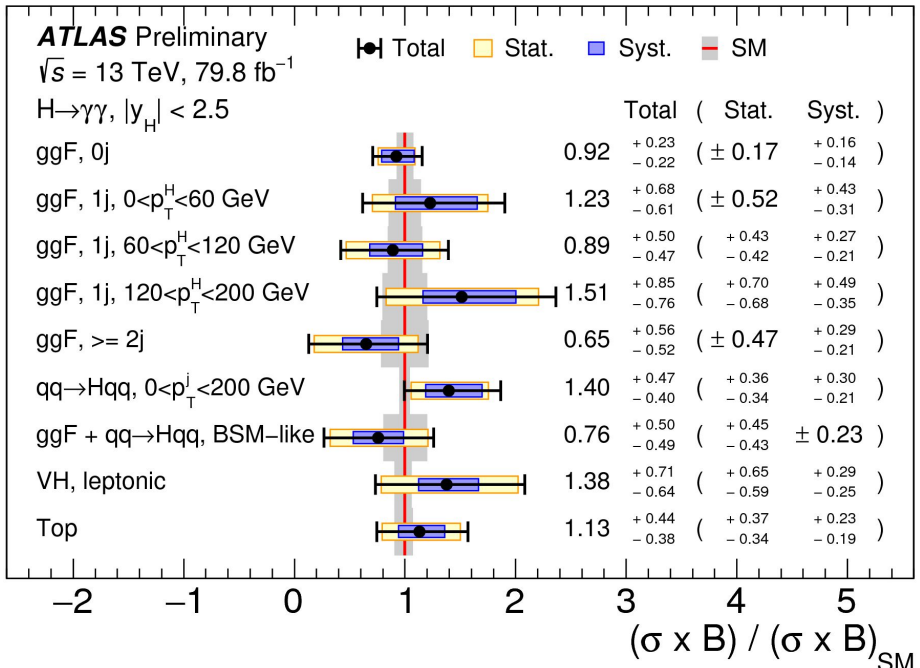


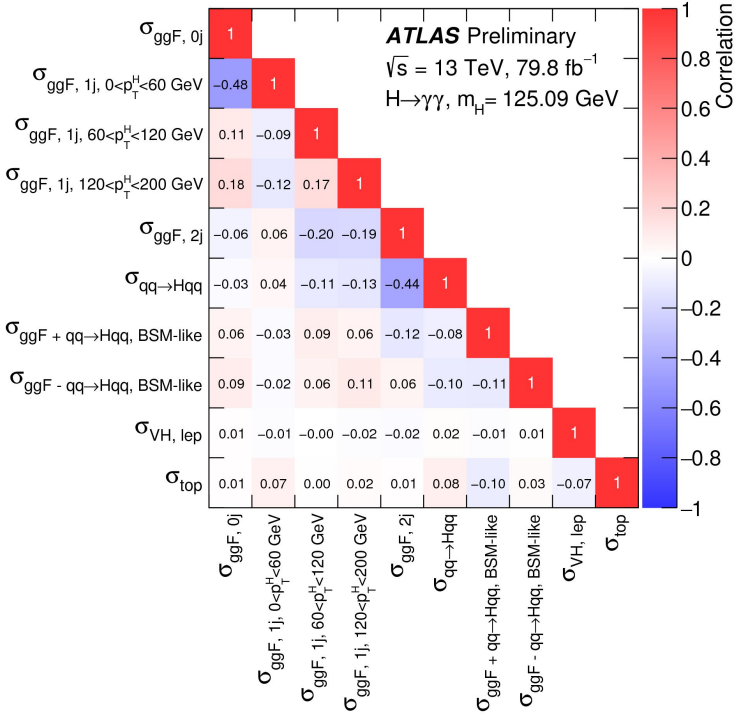

13-way STXS splitting



# H→ γγ - STXS

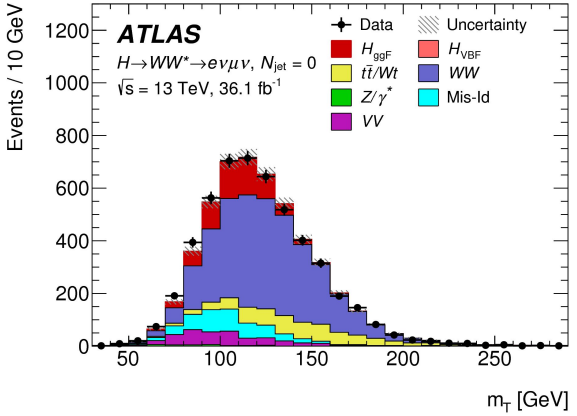
- STXS stage 1 analysis in ATLAS with 2016+2017
- Interesting to notice the correlation matrix, several strong correlations, some mainly coming from theoretical uncertainties, some from experimental



# H→ WW ATLAS-HIGG-2017-14, ATLAS-HIGG-2016-07 CMS_HIG-16-042

- **2016 results** from ATLAS and CMS
- Complicated final state which requires detailed knowledge of **nearly all physics objects**
- Large signal, moderate to large background
- Analyses **binned in number of jets to control** $t\bar{t}$

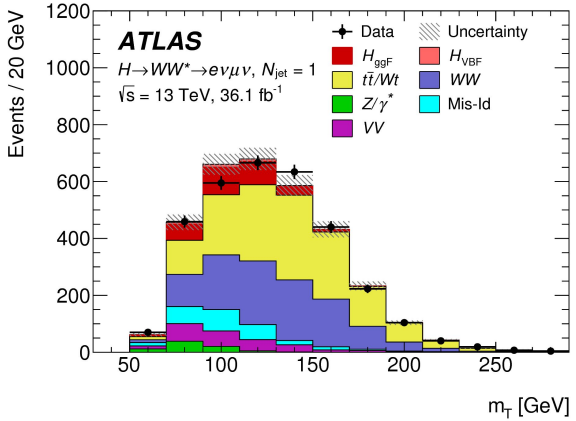



**ATLAS:**

- **e/μ final state**
- Control regions to normalize top and WW
- Discriminating variable

$$m_T = \sqrt{(E_T^{ll} + E_t^{miss})^2 + |\mathbf{p_T^{ll}} + \mathbf{E_T^{miss}}|^2}$$

$$E_T^{ll} = \sqrt{m_{ll}^2 + |\mathbf{p_T^{ll}}|^2}$$



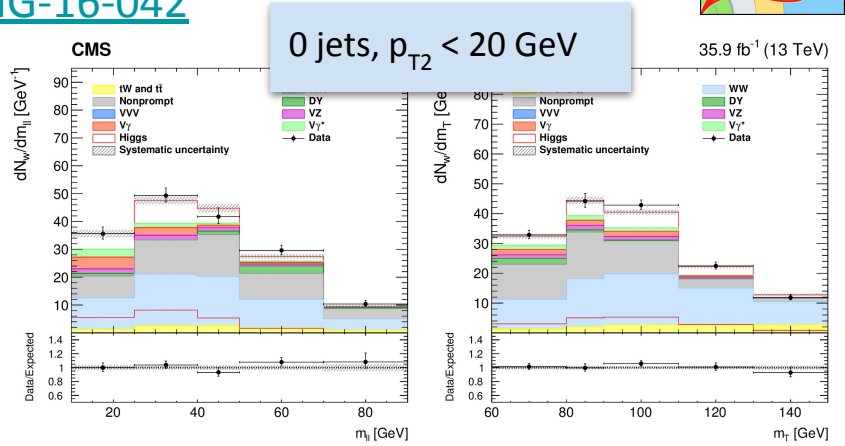
# H→ WW [ATLAS-HIGG-2017-14](), [ATLAS-HIGG-2016-07]() [CMS_HIG-16-042]()

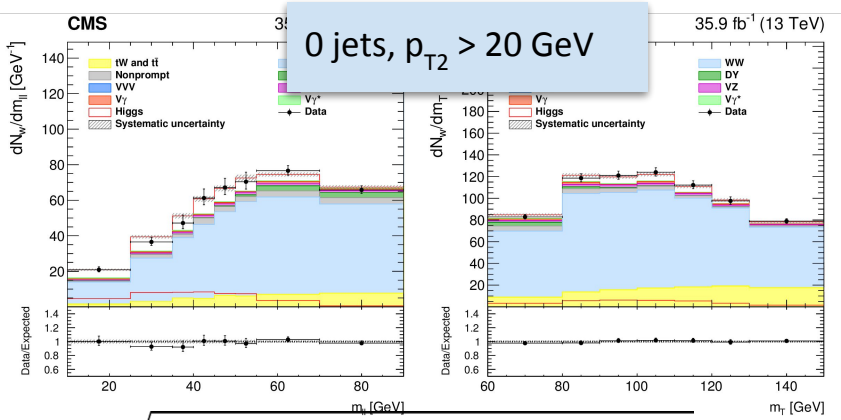
- **2016 results** from ATLAS and CMS
- Complicated final state which requires detailed knowledge of **nearly all physics objects**
- Large signal, moderate to large background
- Analyses **binned in number of jets to control** $t\bar{t}$

**CMS:**

- **e/μ final state (shape based) and same flavor (cut and count)**
- Control region for top, WW is normalized in the signal region
- Discriminating variable

$$m_{ll} \; vs \; m_T$$



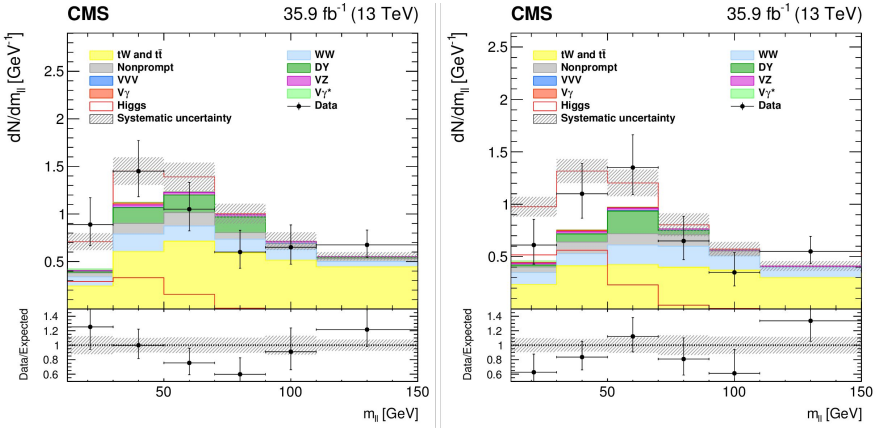

$$m_T = \sqrt{2p_T^{ll}E_T^{miss}[1 - cos\Delta\Phi(ll, \mathbf{E_T^{miss}})]}$$

# H→ WW

- Dedicated categories for VBF. Challanges:
  - **large backgrounds and gluon fusion contamination with large theoretical systematics**

CMS: two di-jet invariant mass windows.

DIscriminating variable: di-lepton invariant mass

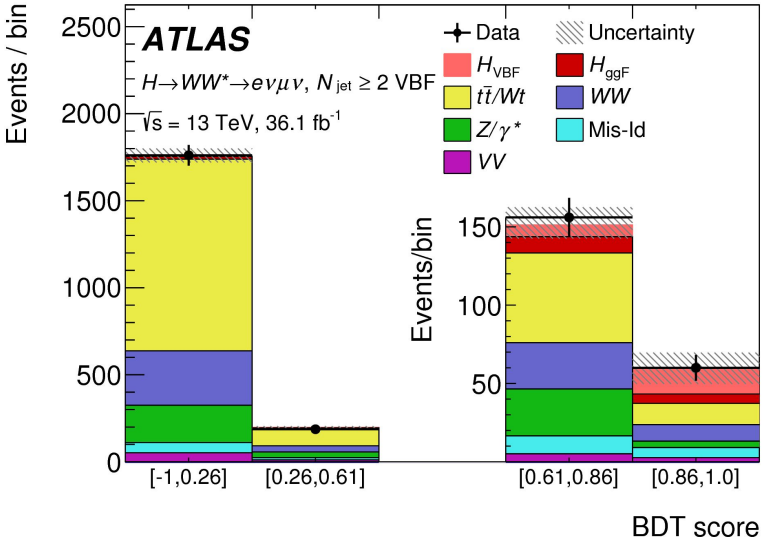



400 GeV <$m_{jj}$<700 GeV




$m_{jj}$>700 GeV

ATLAS: BDT based discriminant based on tagging jets and lepton kinematics



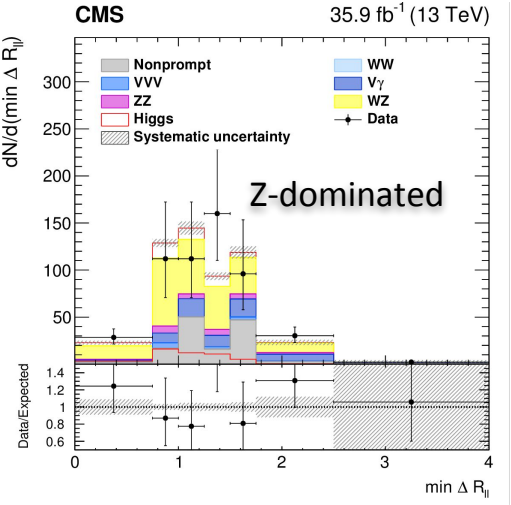
# H→ WW

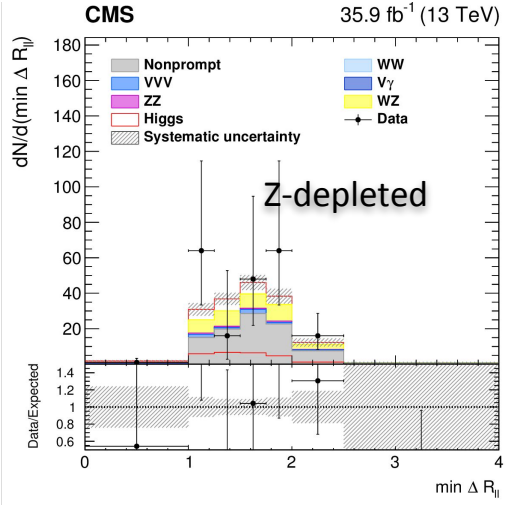
CMS: WH with 3 leptons, ZH with 4 leptons, VH with hadronic V decay

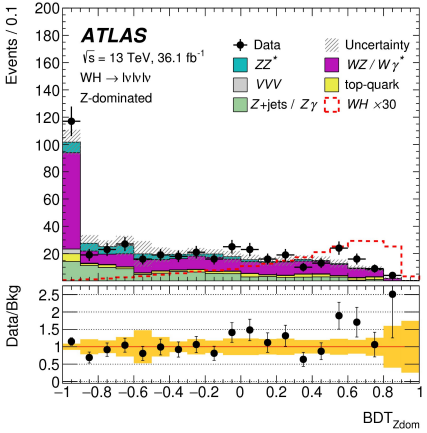
Shape based or cut & count

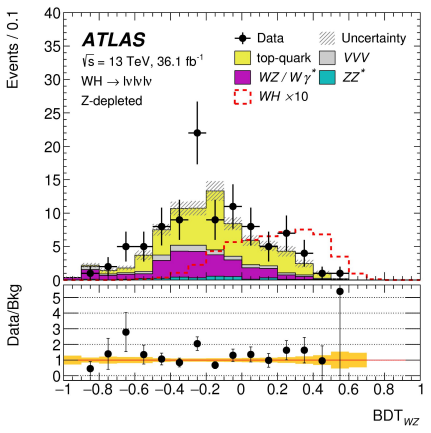
ATLAS: WH with 3 leptons, ZH with 4 leptons

BDT based

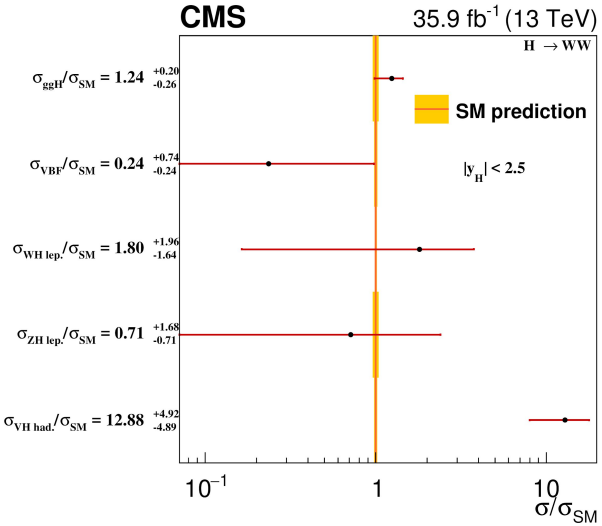


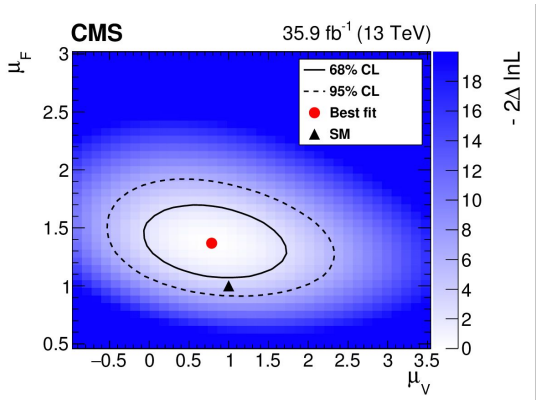



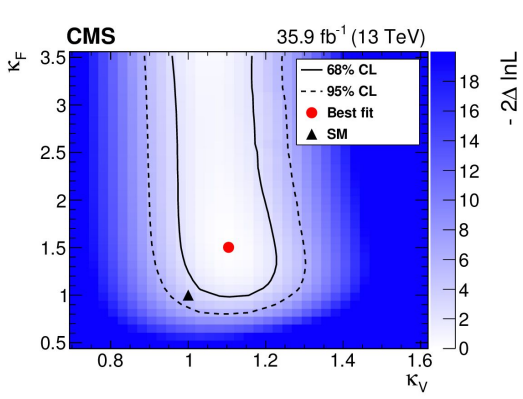



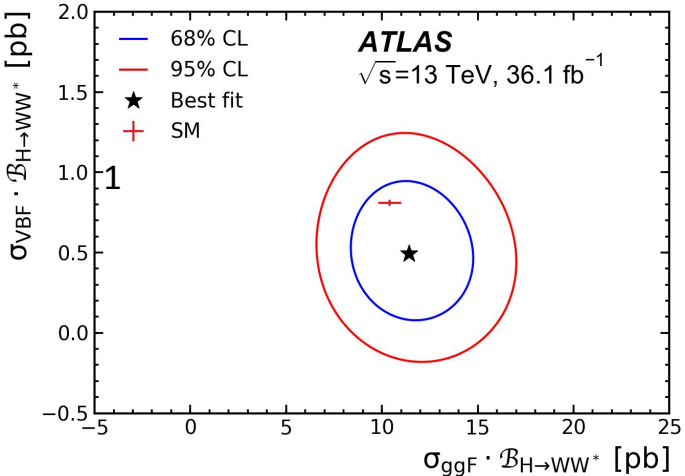
# H → WW

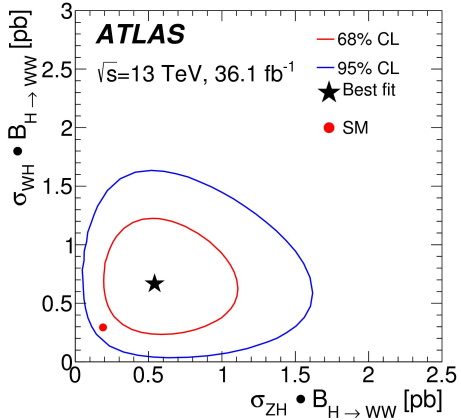



Stage-0 STXS performed in CMS. The channel has potential given the large signal



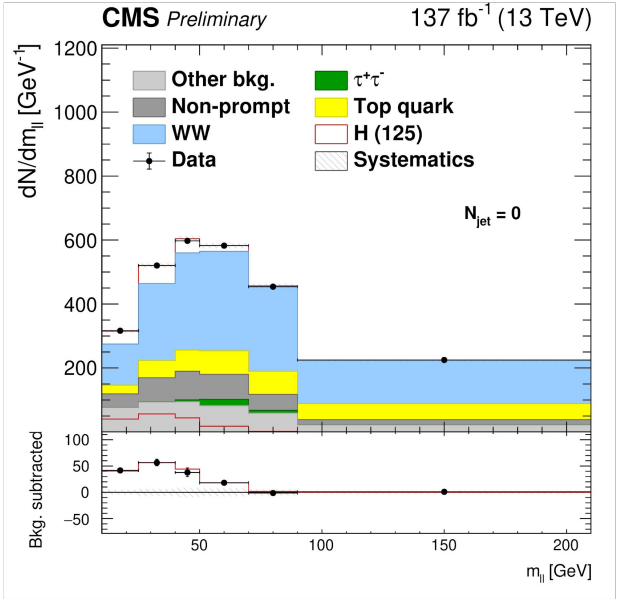



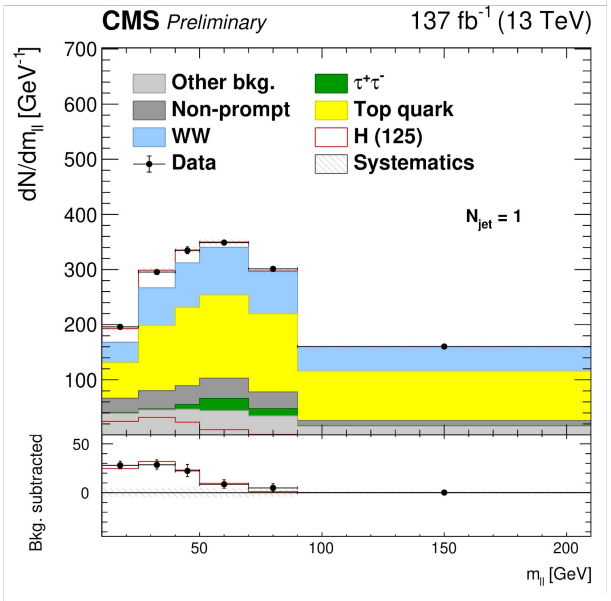
# Full run 2 H → WW Differential analysis

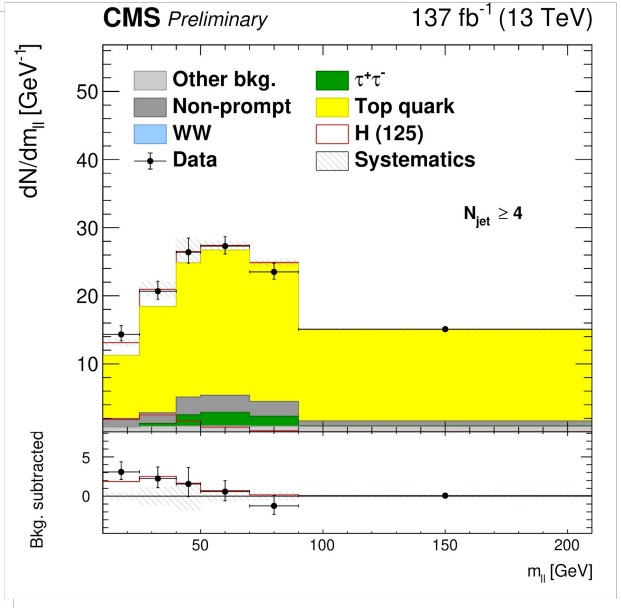
CMS-PAS-HIG-19-002

- Fiducial cross sections with 137/fb in H → WW
- Main challenges: taming the top and fake lepton backgrounds

NEW



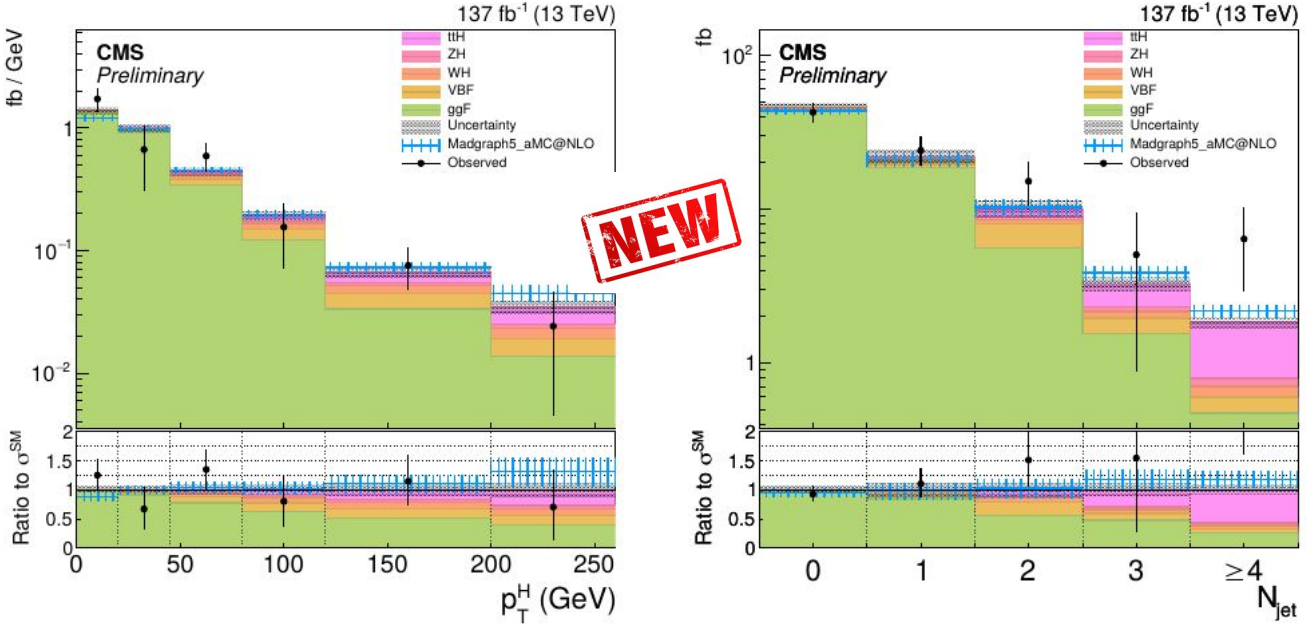



# Full run 2 H → WW Differential analysis

Fiducial and differential cross sections with 137/fb in H → WW

$$\mu^{\text{fid}} = 1.03^{+0.12}_{-0.11}\ \left(^{+0.05}_{-0.05}\,(\text{stat.})\ ^{+0.08}_{-0.07}\,(\text{theo.})\ ^{+0.03}_{-0.03}\,(\text{lumi.})\ ^{+0.07}_{-0.07}\,(\text{exp.})\right)$$

$$\sigma^{\text{fid}} = 85.0^{+9.9}_{-9.3}\ \text{fb}.$$




Uncertainties of the same order as di-photon analyses in #jets and similar in high ptH.

Unfolding with Tichonov regularization embedded as a constraint in the likelihood function

Overall fiducial measurement competitive with di-photon (with larger theoretical uncertainties)

# Conclusion

- Full Run 2 results becoming available
- Mature analyses providing results within a coherent framework
  - Fiducial results
    - 4-leptons is still statistically dominated (in ATLAS, in CMS stat and syst are of the same order)
    - γγ is beginning to be systematically dominated
    - WW is systematically dominated, but some of the main systematics are statistical in nature
  - STXS, agreed-upon differential distributions
    - Theoretical uncertainties play a significant role in the well populated bins
    - Still not enough statistics to populate all STXS bins (at least with single channels)

# ZZ backup

## Fiducial volume definitions

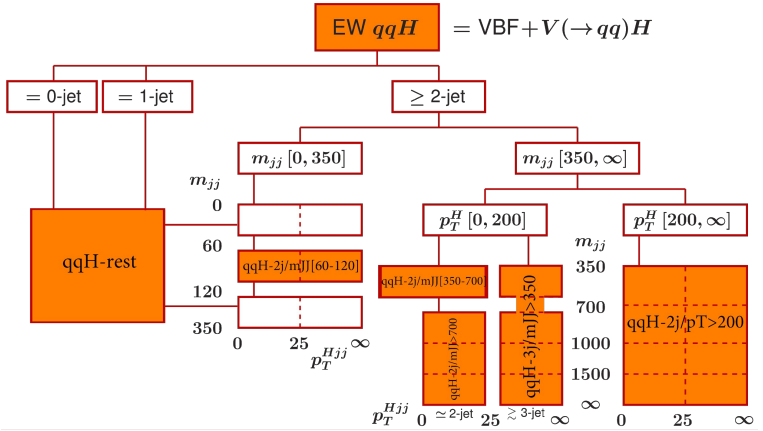
ATLAS

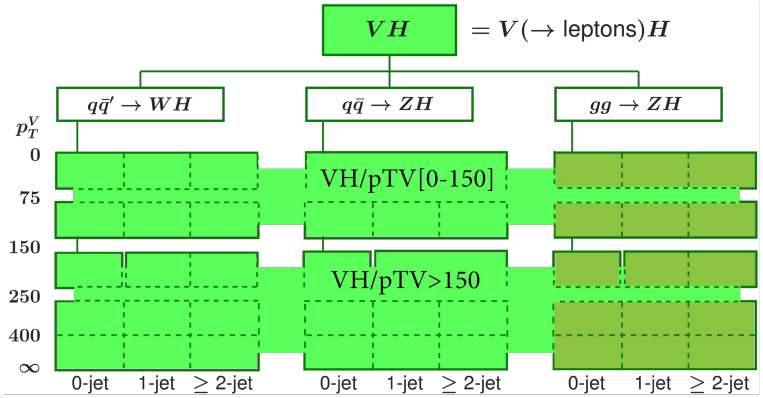
| | |
|---|---|
| **Leptons and jets** | |
| Leptons | $p_{\mathrm{T}} > 5$ GeV, $\lvert\eta\rvert < 2.7$ |
| Jets | $p_{\mathrm{T}} > 30$ GeV, $\lvert y\rvert < 4.4$ |
| remove jets with | $\Delta R(\mathrm{jet}, \ell) < 0.1$ |
| **Lepton selection and pairing** | |
| Lepton kinematics | $p_{\mathrm{T}} > 20, 15, 10$ GeV |
| Leading pair ($m_{12}$) | SFOS lepton pair with smallest $\lvert m_Z - m_{\ell\ell}\rvert$ |
| Subleading pair ($m_{34}$) | remaining SFOS lepton pair with smallest $\lvert m_Z - m_{\ell\ell}\rvert$ |
| **Event selection (at most one quadruplet per event)** | |
| Mass requirements | 50 GeV$< m_{12} <$ 106 GeV and 12 GeV $< m_{34} <$ 115 GeV |
| Lepton separation | $\Delta R(\ell_i, \ell_j) > 0.1$ |
| $J/\psi$ veto | $m(\ell_i, \ell_j) > 5$ GeV for all SFOS lepton pairs |
| Mass window | 105 GeV $< m_{4\ell} <$ 160 GeV |
| If extra leptons with $p_{\mathrm{T}} > 12$ GeV | Quadruplet with the largest ME |

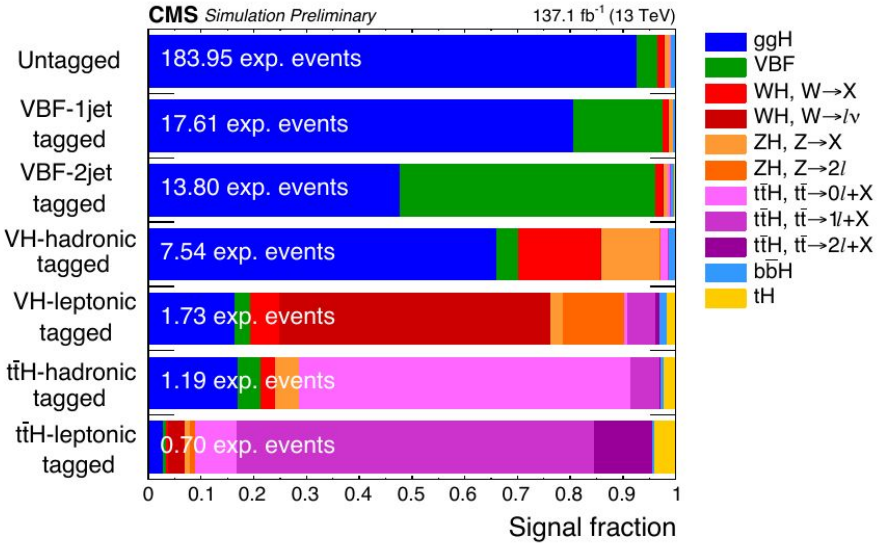
CMS

| **Requirements for the $\mathrm{H} \to 4\ell$ fiducial phase space** | |
|---|---|
| Lepton kinematics and isolation | |
| Leading lepton $p_{\mathrm{T}}$ | $p_{\mathrm{T}} > 20$ GeV |
| Next-to-leading lepton $p_{\mathrm{T}}$ | $p_{\mathrm{T}} > 10$ GeV |
| Additional electrons (muons) $p_{\mathrm{T}}$ | $p_{\mathrm{T}} > 7(5)$ GeV |
| Pseudorapidity of electrons (muons) | $\lvert\eta\rvert < 2.5(2.4)$ |
| Sum of scalar $p_{\mathrm{T}}$ of all stable particles within $\Delta R < 0.3$ from lepton | $< 0.35 \cdot p_{\mathrm{T}}$ |
| Event topology | |
| Existence of at least two same-flavor OS lepton pairs, where leptons satisfy criteria above | |
| Inv. mass of the $\mathrm{Z}_1$ candidate | $40\,\mathrm{GeV} < m_{\mathrm{Z}_1} < 120\,\mathrm{GeV}$ |
| Inv. mass of the $\mathrm{Z}_2$ candidate | $12\,\mathrm{GeV} < m_{\mathrm{Z}_2} < 120\,\mathrm{GeV}$ |
| Distance between selected four leptons | $\Delta R(\ell_i, \ell_j) > 0.02$ for any $i \neq j$ |
| Inv. mass of any opposite sign lepton pair | $m_{\ell^+\ell^-} > 4\,\mathrm{GeV}$ |
| Inv. mass of the selected four leptons | $105\,\mathrm{GeV} < m_{4\ell} < 140\,\mathrm{GeV}$ |

# ZZ backup


EW $qqH$ = VBF+$V(\to qq)H$
= 0-jet
= 1-jet
≥ 2-jet
$m_{jj}$ [0, 350]
$m_{jj}$ [350, ∞]
qqH-rest
qqH-2j/mJJ[60-120]
$p_T^H$ [0, 200]
$p_T^H$ [200, ∞]
qqH-2j/mJJ[350-700]
qqH-2j/mJJ>700
qqH-3j/mJJ>350
qqH-2j/pT>200
$p_T^{Hjj}$
≃ 2-jet
≳ 3-jet


$VH$ = $V(\to$ leptons$)H$
$q\bar{q}' \to WH$
$q\bar{q} \to ZH$
$gg \to ZH$
$p_T^V$
VH/pTV[0-150]
VH/pTV>150
0-jet
1-jet
≥ 2-jet

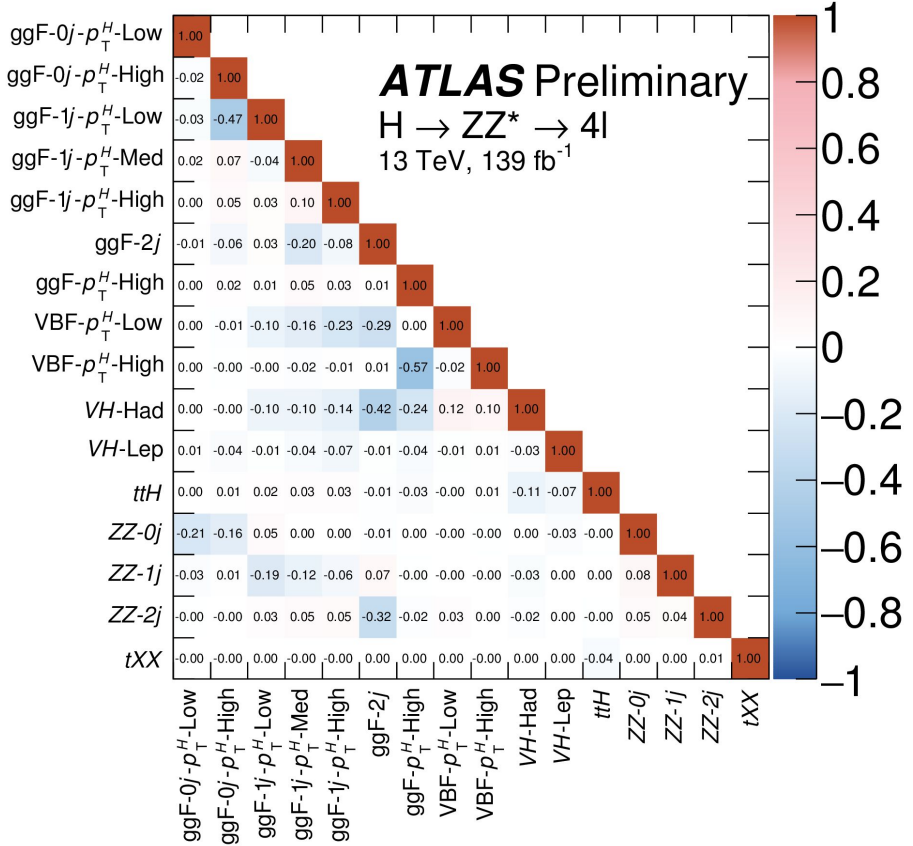

CMS Simulation Preliminary
137.1 fb-1 (13 TeV)
Untagged
183.95 exp. events
VBF-1jet tagged
17.61 exp. events
VBF-2jet tagged
13.80 exp. events
VH-hadronic tagged
7.54 exp. events
VH-leptonic tagged
1.73 exp. events
ttH-hadronic tagged
1.19 exp. events
ttH-leptonic tagged
0.70 exp. events
Signal fraction
ggH
VBF
WH, W→X
WH, W→lν
ZH, Z→X
ZH, Z→2l
ttH, tt→0l+X
ttH, tt→1l+X
ttH, tt→2l+X
bbH
tH

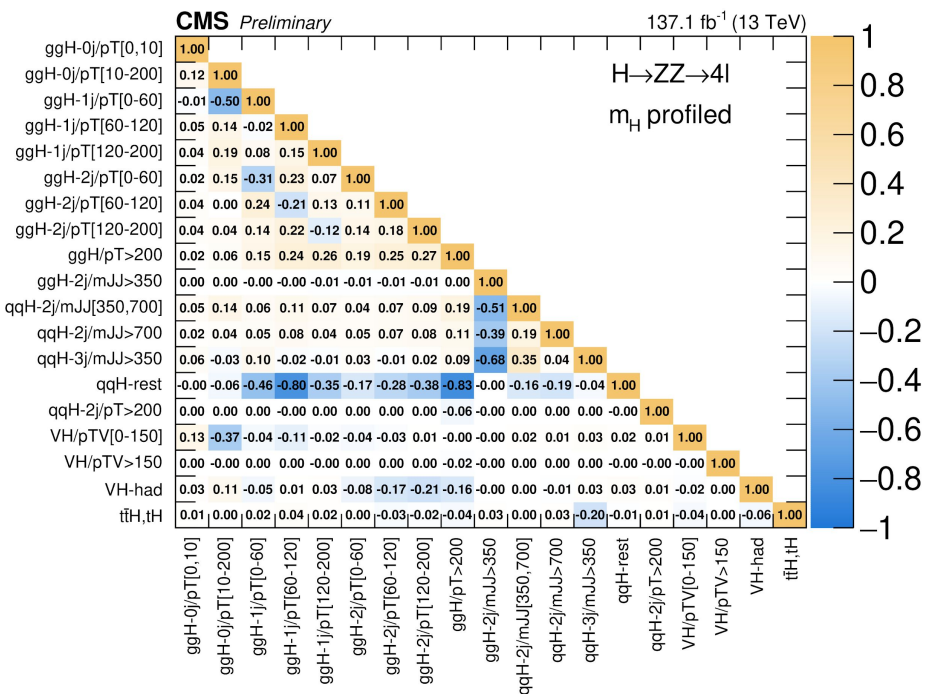
# ATLAS 4l NNs

Single or multiclass networks used in the different categories

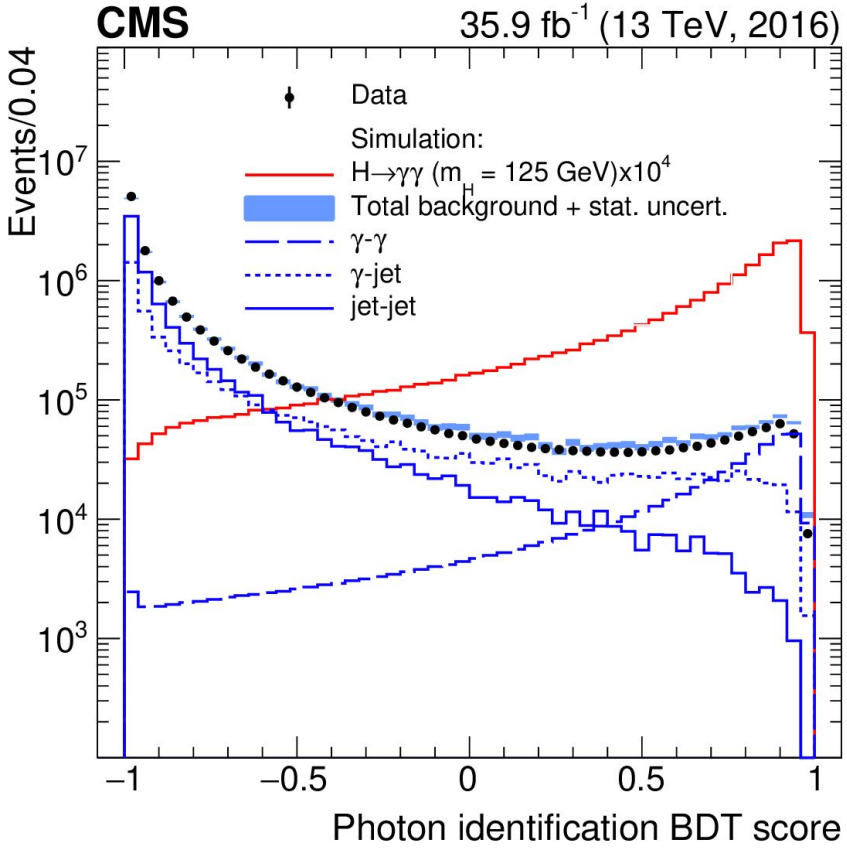
| Category | Processes | MLP | Lep rNN | Jet rNN |
|---|---|---|---|---|
| $0j$ | ggF,$ZZ$ | $p_{\mathrm{T}}^{4\ell}$, $D_{ZZ^*}$, $m_{12}$, $m_{34}$, $\cos\theta^*$, $\cos\theta_1$, $\phi_{ZZ}$ | $p_{\mathrm{T},\ell}$, $\eta_\ell$ | n/a |
| $1j$-$p_{\mathrm{T}}^{4\ell}$-Low | ggF,VBF,$ZZ$ | $p_{\mathrm{T}}^{4\ell}$, $p_{\mathrm{T},j}$, $\eta_j$, $\Delta R_{4\ell j}$, $D_{ZZ^*}$ | $p_{\mathrm{T},\ell}$, $\eta_\ell$ | n/a |
| $1j$-$p_{\mathrm{T}}^{4\ell}$-Med | ggF, VBF, $ZZ$ | $p_{\mathrm{T}}^{4\ell}$, $p_{\mathrm{T},j}$, $\eta_j$, $E_{\mathrm{T}}^{\mathrm{miss}}$ $\Delta R_{4\ell j}$, $D_{ZZ^*}$, $\eta_{4\ell}$ | - | n/a |
| $1j$-$p_{\mathrm{T}}^{4\ell}$-High | ggF, VBF | $p_{\mathrm{T}}^{4\ell}$, $p_{\mathrm{T},j}$, $\eta_j$, $\Delta R_{4\ell j}$, $\eta_{4\ell}$, $E_{\mathrm{T}}^{\mathrm{miss}}$ | $p_{\mathrm{T},\ell}$ | n/a |
| $2j$ | ggF, VBF, $VH$ | $m_{\mathrm{jj}}$, $\Delta\eta_{\mathrm{jj}}$, $p_{\mathrm{T},4\ell jj}$ | $p_{\mathrm{T},\ell}$, $\eta_\ell$ | $p_{\mathrm{T},j}$, $\eta_j$ |
| $2j$-BSM-like | ggF, VBF | $\Delta\eta_{\mathrm{jj}}$, $\Delta\eta_{4\ell jj}$, $p_{\mathrm{T},4\ell jj}$ | $p_{\mathrm{T},\ell}$, $\eta_\ell$ | $p_{\mathrm{T},j}$, $\eta_j$ |
| $VH$-Lep-enriched | $ttH$, $VH$ | $N_{\mathrm{jets}}$, $N_{b-\mathrm{jets}}$, $E_{\mathrm{T}}^{\mathrm{miss}}$, HT, $\ln(\lvert\mathcal{M}_{sig}\rvert^2)$ | $p_{\mathrm{T},\ell}$ | n/a |
| $ttH$-Had-enriched | $ttH$, $tXX$, ggF | $p_{\mathrm{T}}^{4\ell}$, $m_{\mathrm{jj}}$, $\Delta\eta_{\mathrm{jj}}$, $p_{\mathrm{T},jj}$, $\min(\Delta R_{Zj})$, $\Delta\eta_{4\ell jj}$, $N_{\mathrm{jets}}$, $N_{b-\mathrm{jets}}$, $E_{\mathrm{T}}^{\mathrm{miss}}$, $\min(\Delta R_{4\ell j})$, HT, $\ln(\lvert\mathcal{M}_{sig}\rvert^2)$ | $p_{\mathrm{T},\ell}$, $\eta_\ell$ | $p_{\mathrm{T},j}$, $\eta_j$ |

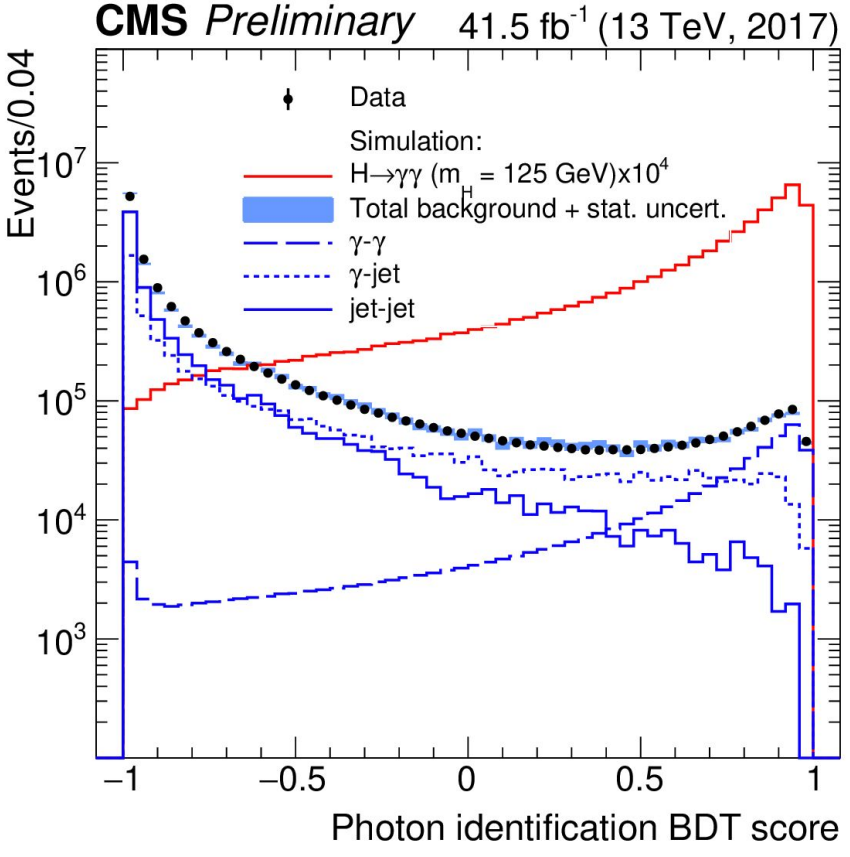
# ZZ backup


ATLAS Preliminary
H → ZZ* → 4l
13 TeV, 139 fb-1
ggF-0j-pTH-Low
ggF-0j-pTH-High
ggF-1j-pTH-Low
ggF-1j-pTH-Med
ggF-1j-pTH-High
ggF-2j
ggF-pTH-High
VBF-pTH-Low
VBF-pTH-High
VH-Had
VH-Lep
ttH
ZZ-0j
ZZ-1j
ZZ-2j
tXX

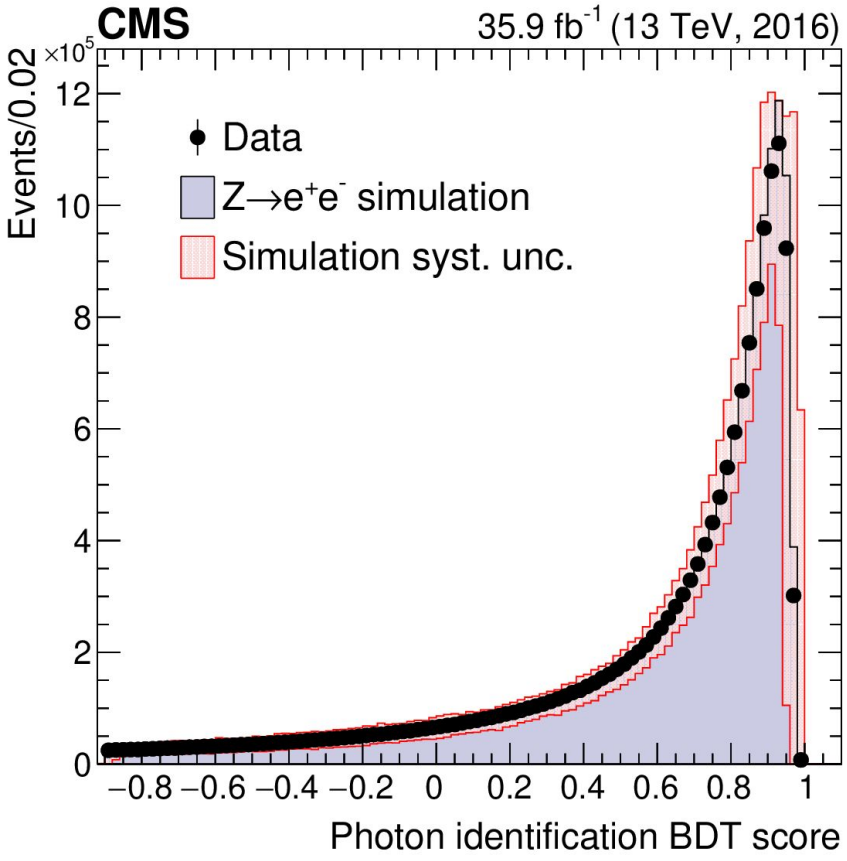

CMS Preliminary
137.1 fb-1 (13 TeV)
H→ZZ→4l
mH profiled
ggH-0j/pT[0,10]
ggH-0j/pT[10-200]
ggH-1j/pT[0-60]
ggH-1j/pT[60-120]
ggH-1j/pT[120-200]
ggH-2j/pT[0-60]
ggH-2j/pT[60-120]
ggH-2j/pT[120-200]
ggH/pT>200
ggH-2j/mJJ>350
qqH-2j/mJJ[350,700]
qqH-2j/mJJ>700
qqH-3j/mJJ>350
qqH-rest
qqH-2j/pT>200
VH/pTV[0-150]
VH/pTV>150
VH-had
ttH,tH

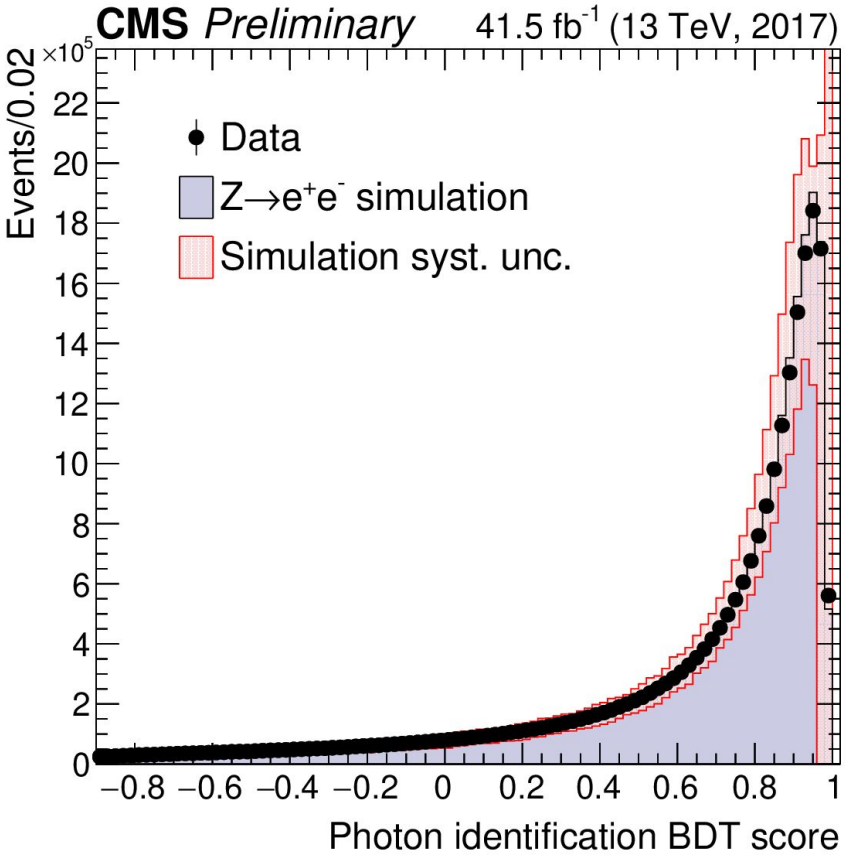
# H→ γγ


CMS
35.9 fb-1 (13 TeV, 2016)
Data
Simulation:
H→γγ (mH = 125 GeV)x10^4
Total background + stat. uncert.
γ-γ
γ-jet
jet-jet
Events/0.04
Photon identification BDT score

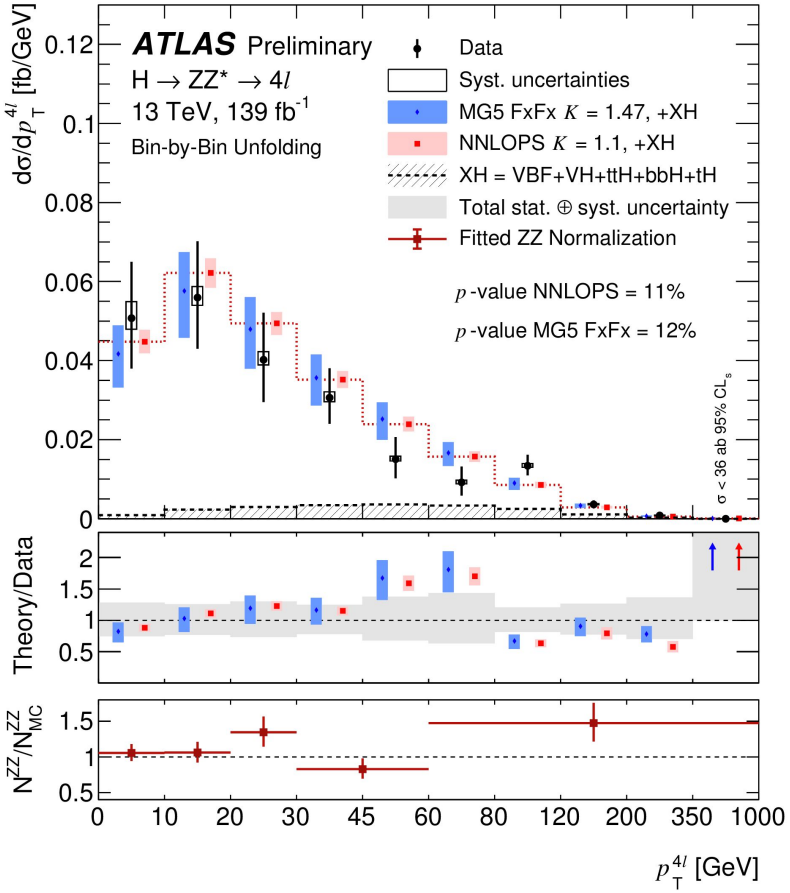

CMS Preliminary
41.5 fb-1 (13 TeV, 2017)
Data
Simulation:
H→γγ (mH = 125 GeV)x10^4
Total background + stat. uncert.
γ-γ
γ-jet
jet-jet
Events/0.04
Photon identification BDT score

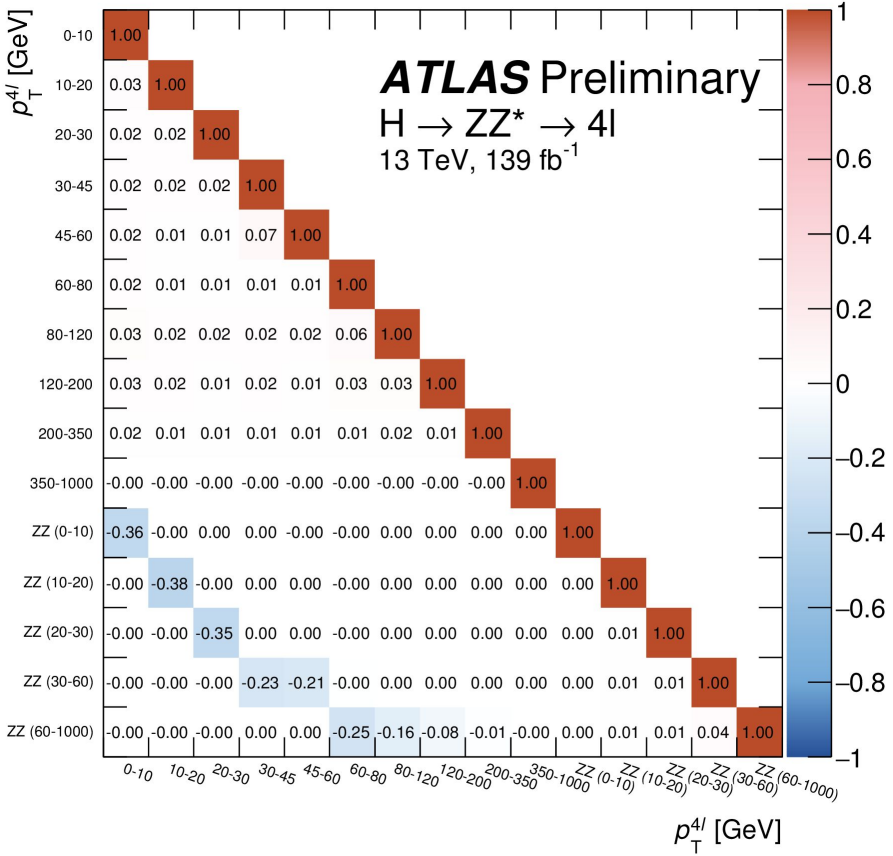
# H→ γγ


CMS
35.9 fb-1 (13 TeV, 2016)
Events/0.02
×10^5
Data
Z→e+e- simulation
Simulation syst. unc.
Photon identification BDT score

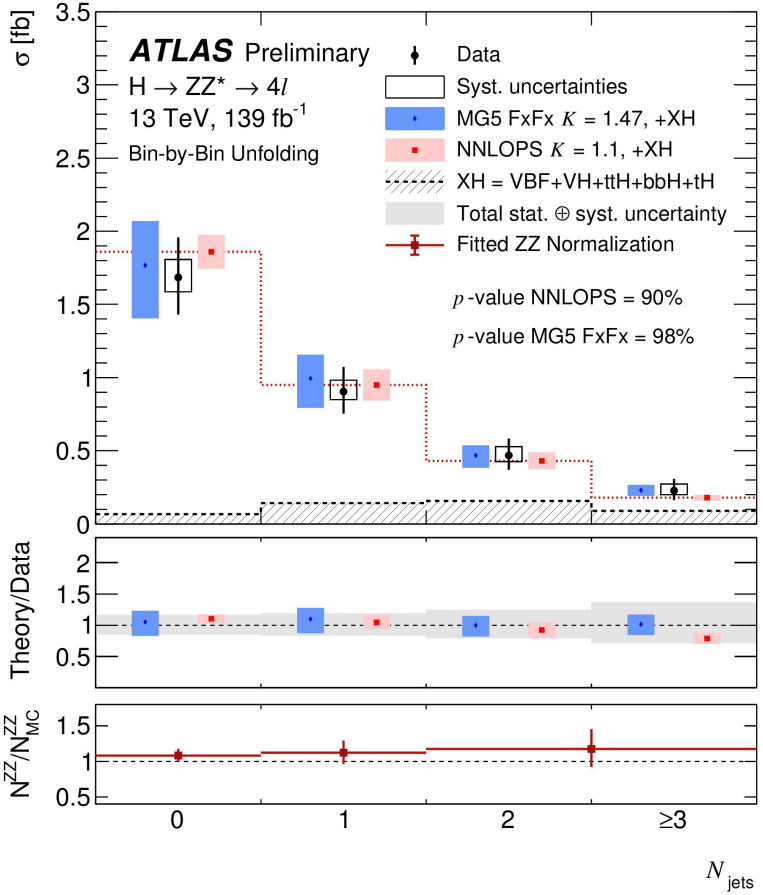

CMS Preliminary
41.5 fb-1 (13 TeV, 2017)
Events/0.02
×10^5
Data
Z→e+e- simulation
Simulation syst. unc.
Photon identification BDT score

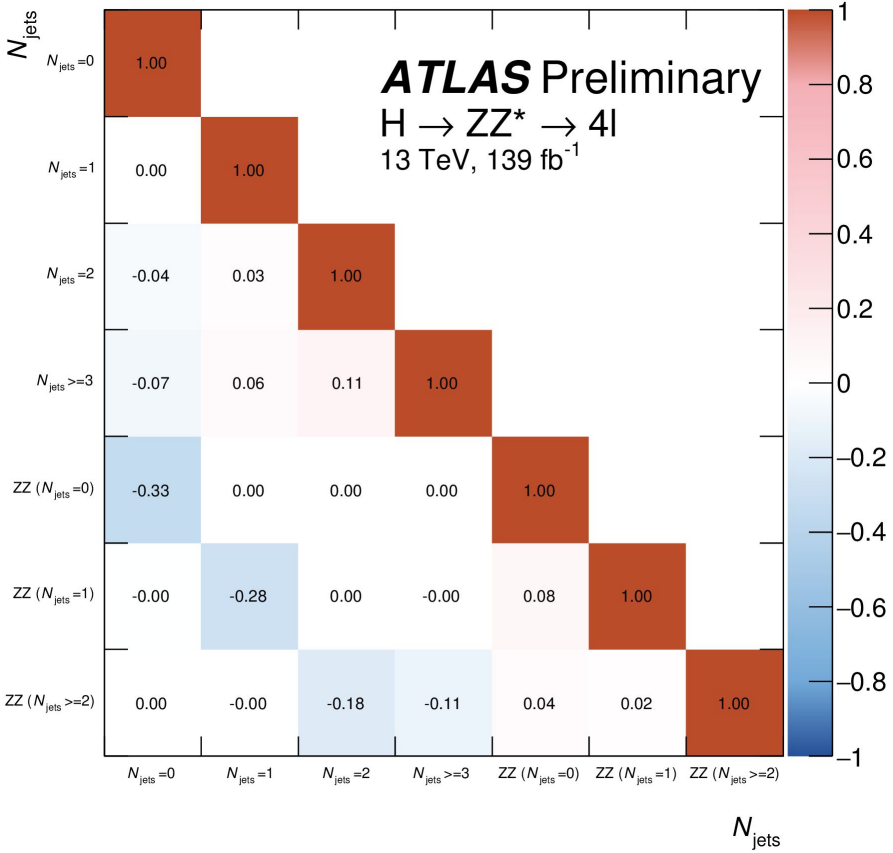
# ZZ → 4l Differential Measurements



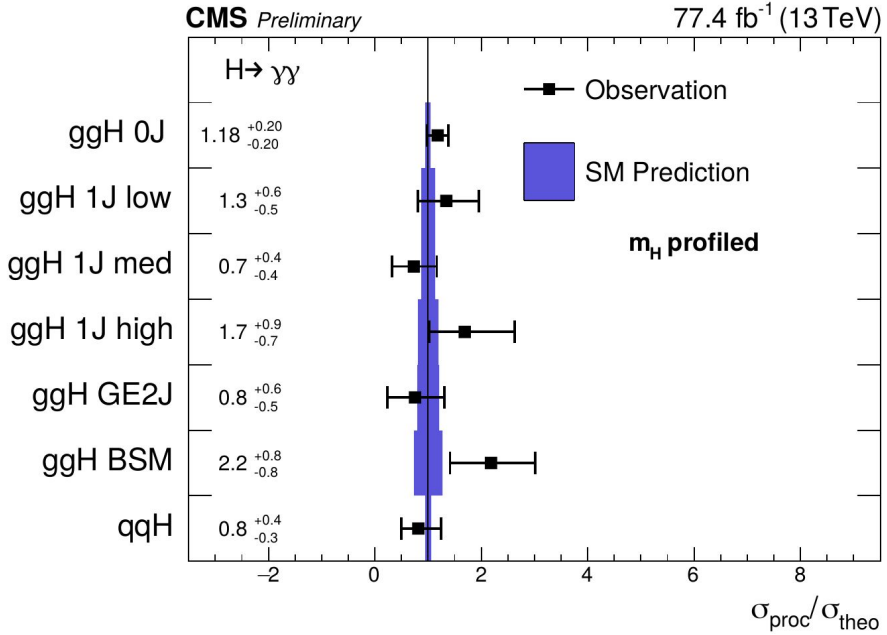



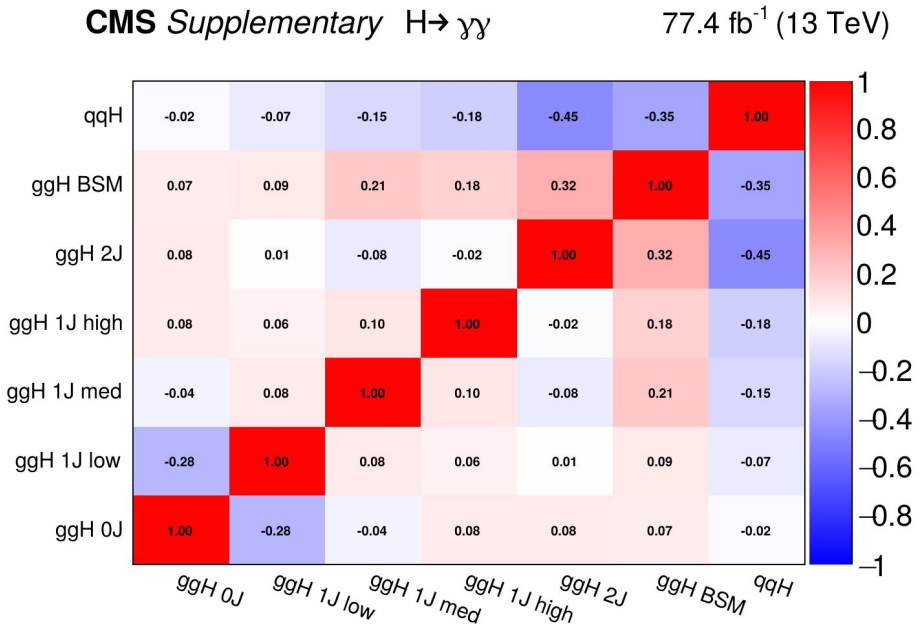
# ZZ → 4l Differential Measurements



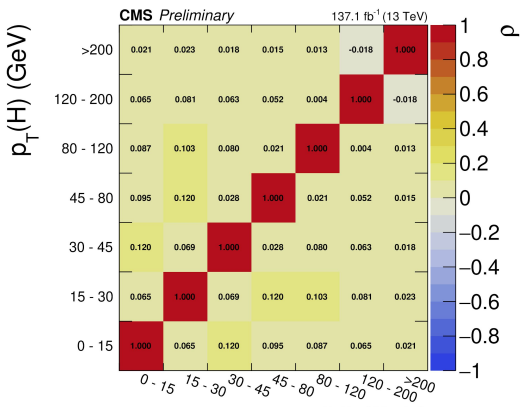



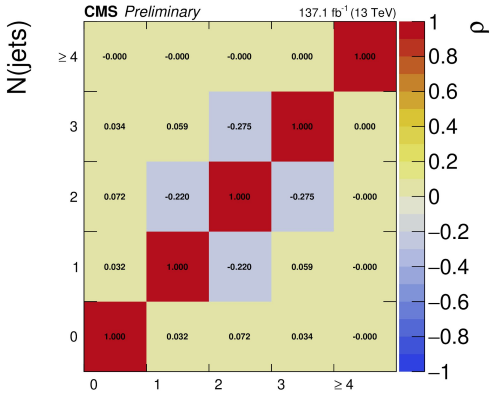
# H→ γγ

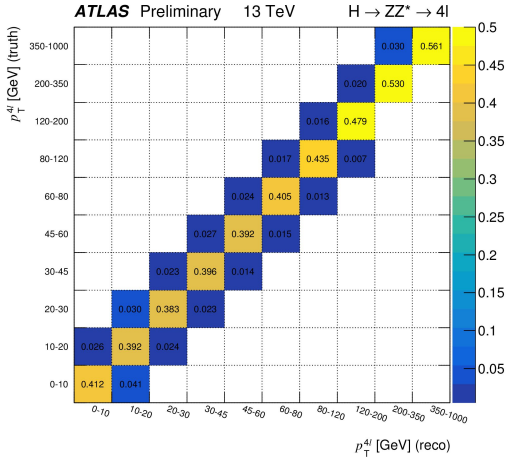

CMS Preliminary
77.4 fb-1 (13 TeV)
H→ γγ
Observation
SM Prediction
mH profiled
ggH 0J
1.18 +0.20 -0.20
ggH 1J low
1.3 +0.6 -0.5
ggH 1J med
0.7 +0.4 -0.4
ggH 1J high
1.7 +0.9 -0.7
ggH GE2J
0.8 +0.6 -0.5
ggH BSM
2.2 +0.8 -0.8
qqH
0.8 +0.4 -0.3
−2
0
2
4
6
8
σproc/σtheo

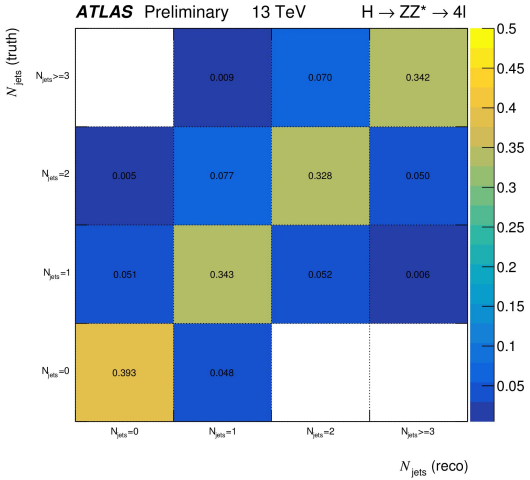

CMS Supplementary H→ γγ
77.4 fb-1 (13 TeV)
qqH -0.02 -0.07 -0.15 -0.18 -0.45 -0.35 1.00
ggH BSM 0.07 0.09 0.21 0.18 0.32 1.00 -0.35
ggH 2J 0.08 0.01 -0.08 -0.02 1.00 0.32 -0.45
ggH 1J high 0.08 0.06 0.10 1.00 -0.02 0.18 -0.18
ggH 1J med -0.04 0.08 1.00 0.10 -0.08 0.21 -0.15
ggH 1J low -0.28 1.00 0.08 0.06 0.01 0.09 -0.07
ggH 0J 1.00 -0.28 -0.04 0.08 0.08 0.07 -0.02
ggH 0J
ggH 1J low
ggH 1J med
ggH 1J high
ggH 2J
ggH BSM
qqH
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1

# Response matrices 4l



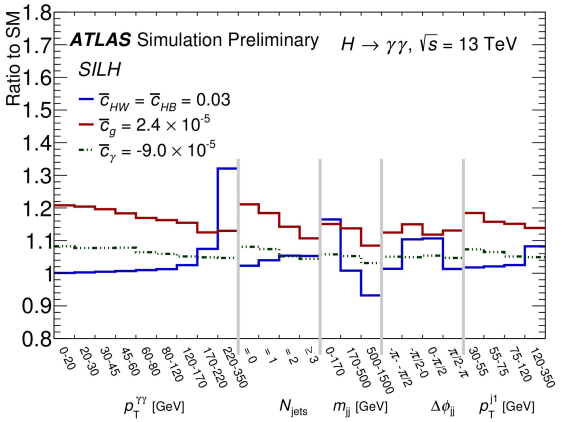



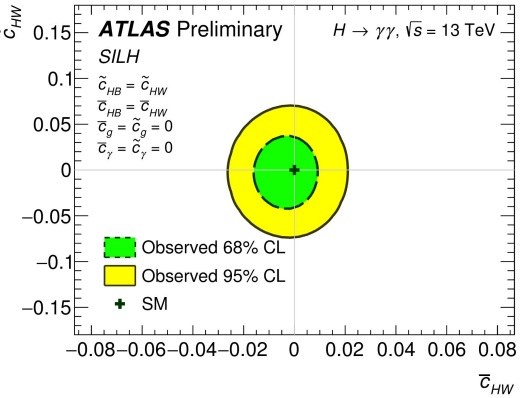



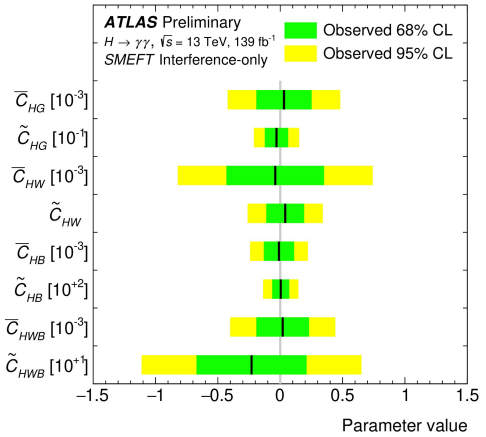



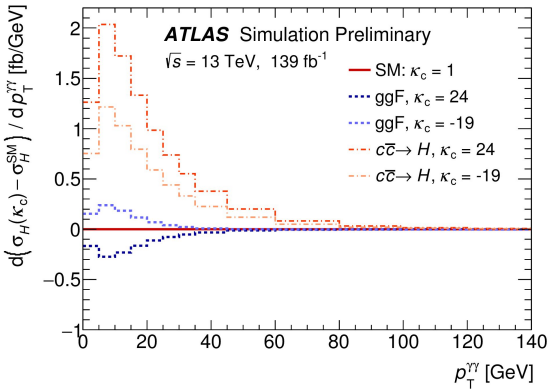
# H→ γγ - Differential measurements

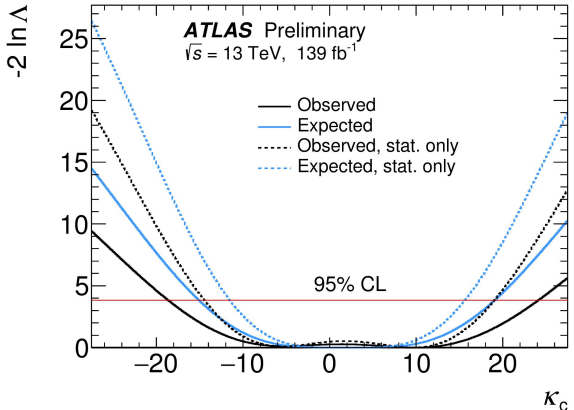
Differential measurements exploited to study c-quark couplings and EFT (dimension 6)



# H⟶ γγ - Differential measurements

ATLAS

Table 2: Particle-level selections for the fiducial measurements. The photon isolation, $\sum p_{\mathrm{T}}^{i}/p_{\mathrm{T}}^{\gamma}$, is defined as the sum of the $p_{\mathrm{T}}$ of charged particles within $\Delta r < 0.2$ of the photon.

| Objects | Fiducial definition |
|---|---|
| Photons | $\lvert\eta\rvert < 2.37$ (excluding $1.37 < \lvert\eta\rvert < 1.52$), $\sum p_{\mathrm{T}}^{i}/p_{\mathrm{T}}^{\gamma} < 0.05$ |
| Jets | anti-$k_t$, $R = 0.4$, $p_{\mathrm{T}} > 30$ GeV, $\lvert y\rvert < 4.4$ |
| Diphoton | $N_\gamma \geq 2$, $105\,\mathrm{GeV} < m_{\gamma\gamma} < 160\,\mathrm{GeV}$, $p_{\mathrm{T}}^{\gamma_1}/m_{\gamma\gamma} > 0.35$, $p_{\mathrm{T}}^{\gamma_2}/m_{\gamma\gamma} > 0.25$ |