

Higgs to Bosons



Comparison



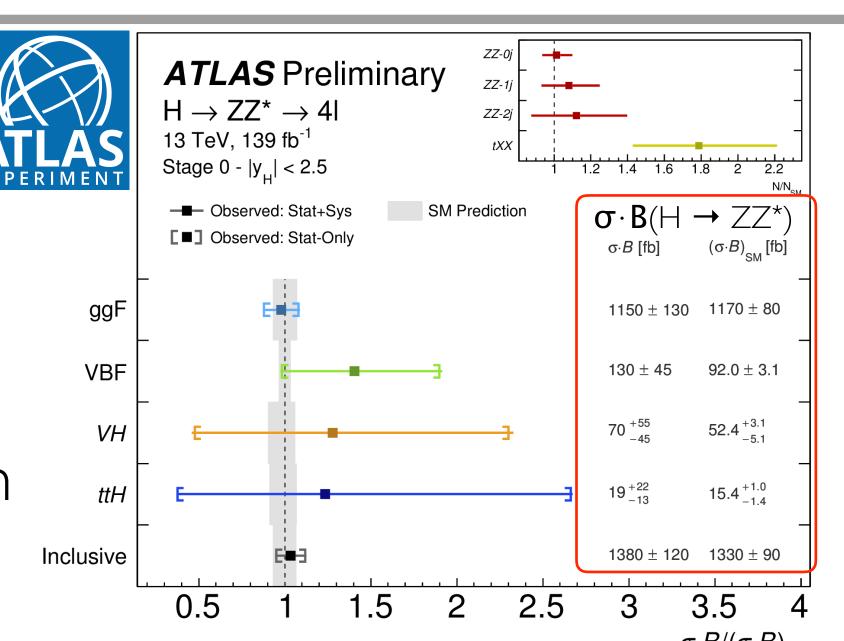
Karsten KönekeUniversity of Freiburg

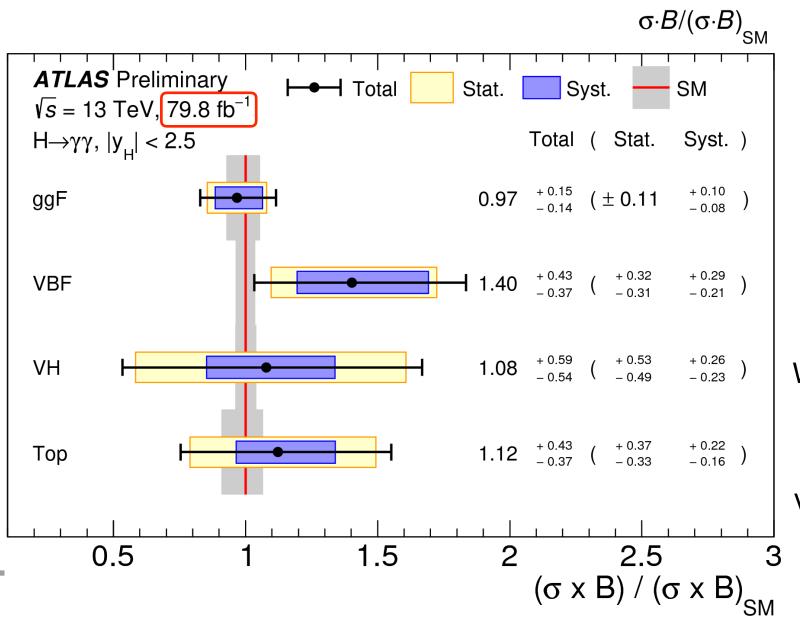
Thanks to Giada Mancini (ATLAS) and Arun Kumar (CMS) for providing me with early versions of their slides!

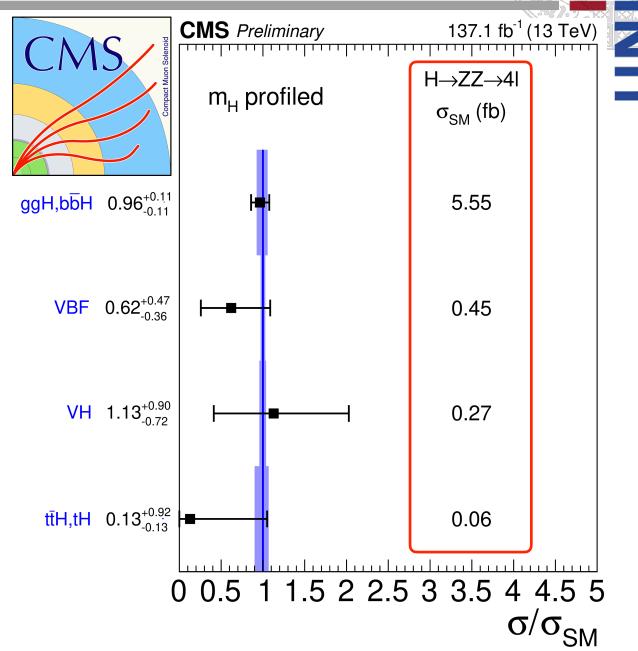


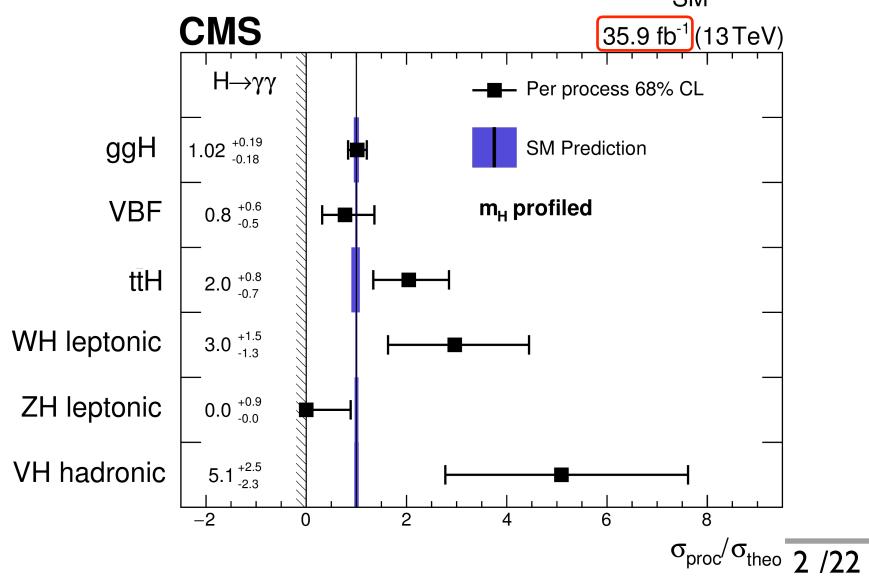
STXS Stage-0 Results

- $H \rightarrow ZZ^* \rightarrow 4\ell$
 - Still statistics limited with 140 fb-1
 - ggF measurement precision reaches precision of SM prediction
- $\bullet \quad H \longrightarrow YY$
 - Systematics for ggF and VBF similar size as 80 fb⁻¹ statistics



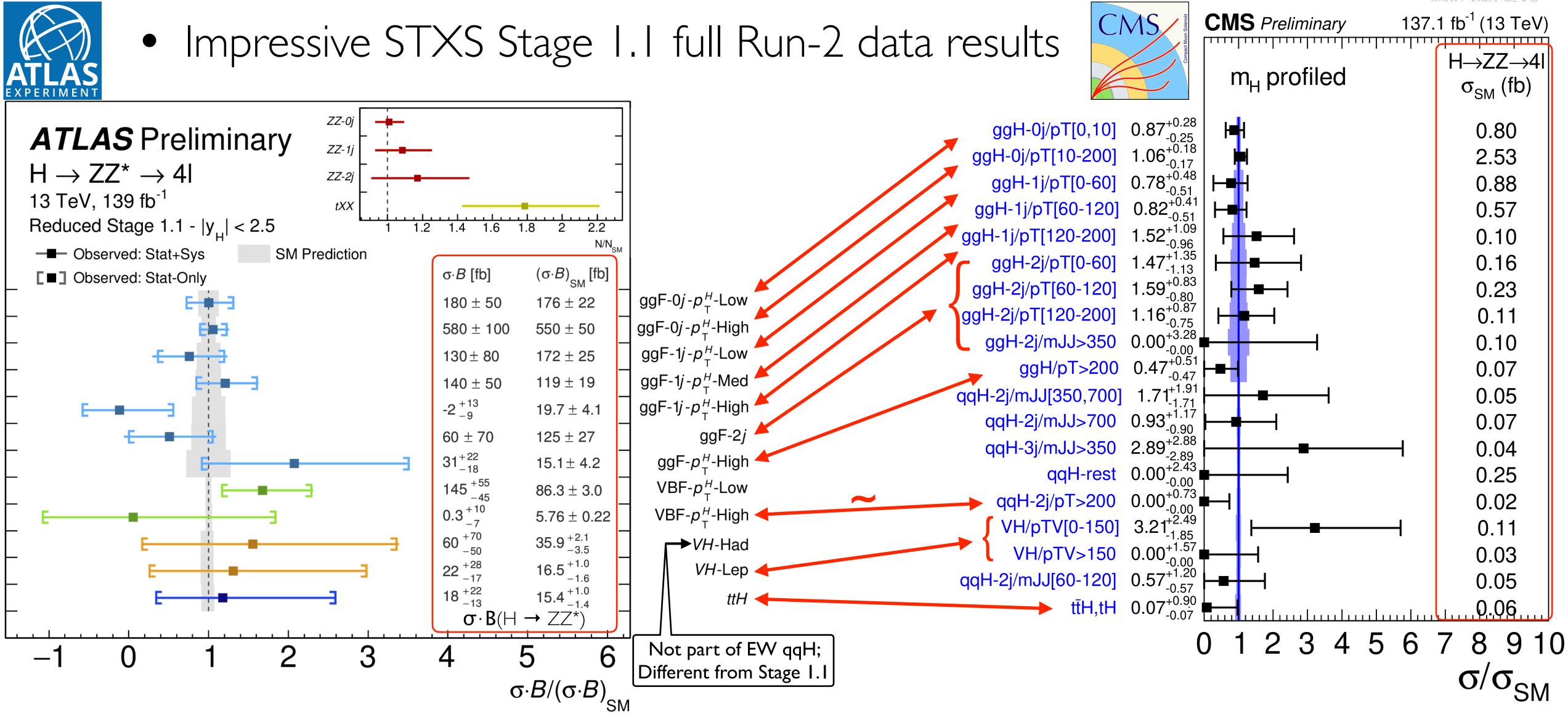






Full Run-2 H \rightarrow ZZ* \rightarrow 4 ℓ STXS Stage 1.1





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\sim 36 fb-1 H \rightarrow WW* \rightarrow $\ell\nu\ell\nu$



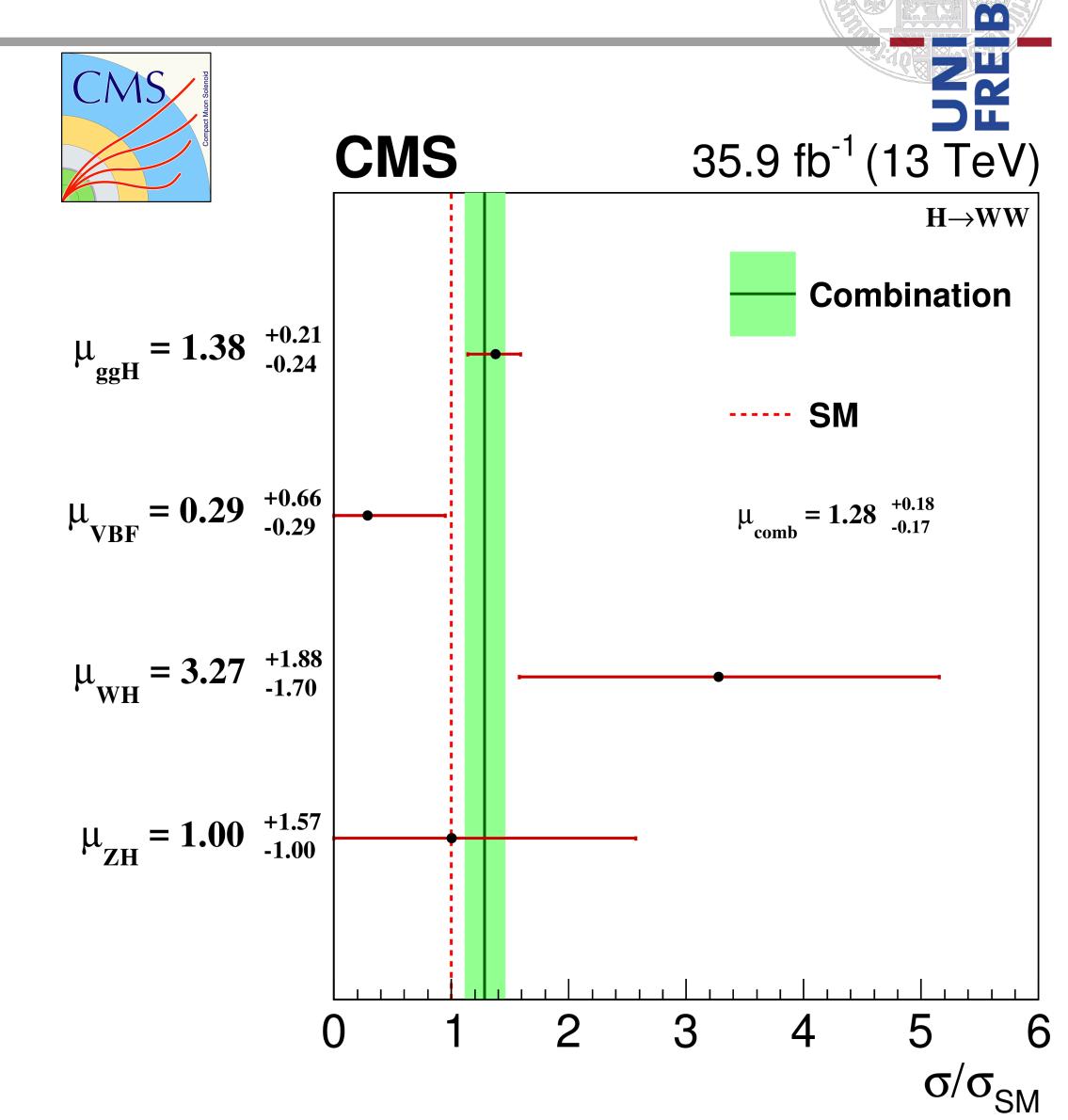
$$\mu_{\rm ggF} = 1.10^{+0.10}_{-0.09}({\rm stat.})^{+0.13}_{-0.11}({\rm theo~syst.})^{+0.14}_{-0.13}({\rm exp~syst.}) = 1.10^{+0.21}_{-0.20}$$

$$\mu_{\text{VBF}} = 0.62^{+0.29}_{-0.27}(\text{stat.})^{+0.12}_{-0.13}(\text{theo syst.}) \pm 0.15(\text{exp syst.}) = 0.62^{+0.36}_{-0.35}$$

$$\mu_{WH} = 2.3^{+1.1}_{-0.9}(\text{stat.})^{+0.41}_{-0.33}(\text{theo syst.})^{+0.49}_{-0.36}(\text{exp syst.}) = 2.3^{+1.2}_{-1.0}$$

$$\mu_{ZH} = 2.9^{+1.7}_{-1.3}(\text{stat.})^{+0.66}_{-0.27}(\text{theo syst.})^{+0.54}_{-0.28}(\text{exp syst.}) = 2.9^{+1.9}_{-1.3}$$

- Experimental and theoretical systematic ~equal
- Statistical uncertainty in ggF < systematic



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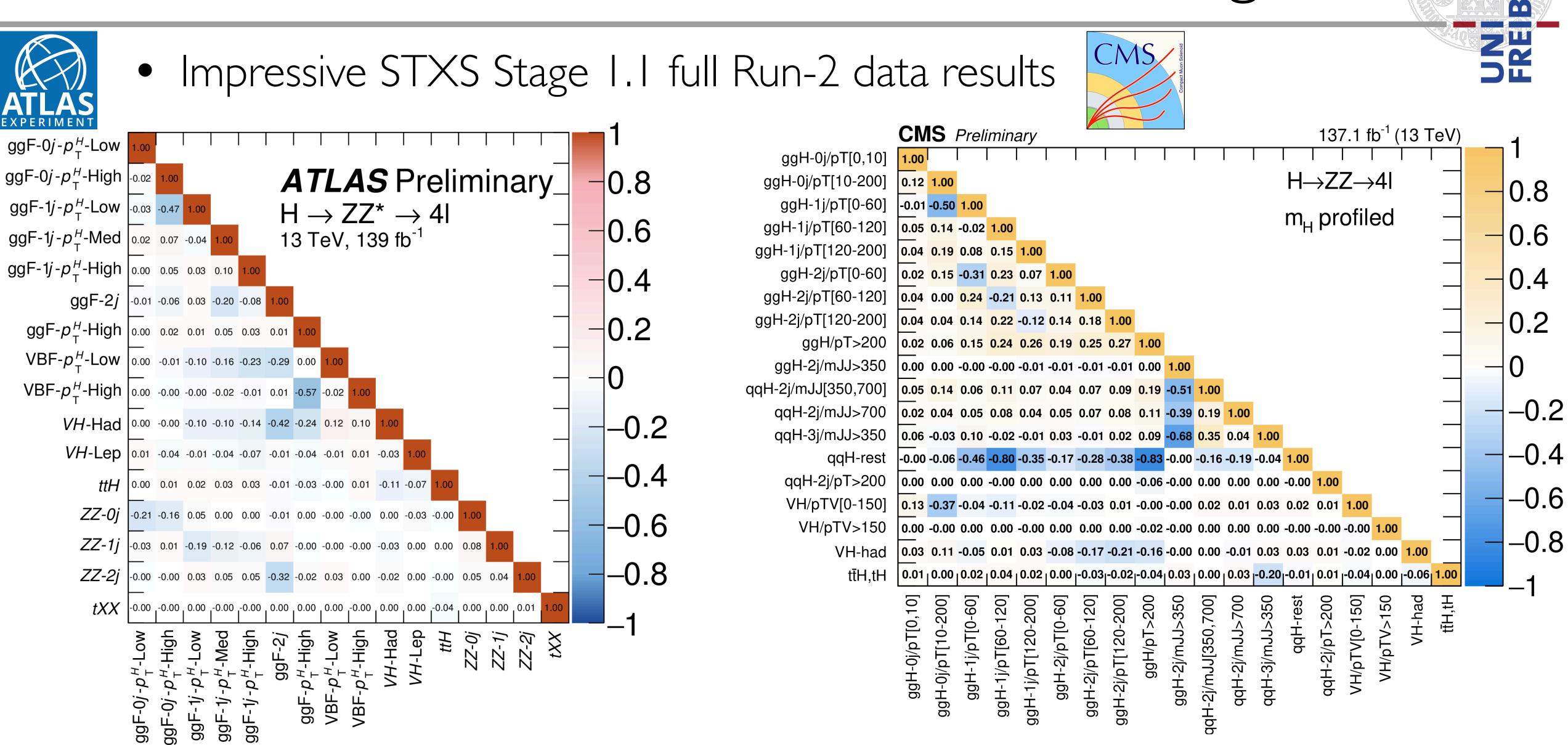
Treatment of Theory Uncertainties

• Example: $H \rightarrow ZZ^* \rightarrow 4\ell$

| Systematic | ATLAS EXPERIMENT | CMS pioned to the property of |
|------------|--|---|
| μR and μF | 8-point variation: Vary by 0.5 and 2.0; No further constraint | 6-point variation: Vary by 0.5 and 2.0; Constrain 0.5 $< \mu_R/\mu_F < 2.0$ |
| PDF | PDF4LHC_NLO_30 Hessian eigenvector variations: NNPDF3.0 eigenvectors + alternative nominal (MMHT2014, CT14) | NNPDF eigenvector variations |

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Full Run-2 H \rightarrow ZZ* \rightarrow 4 ℓ STXS Stage 1.1

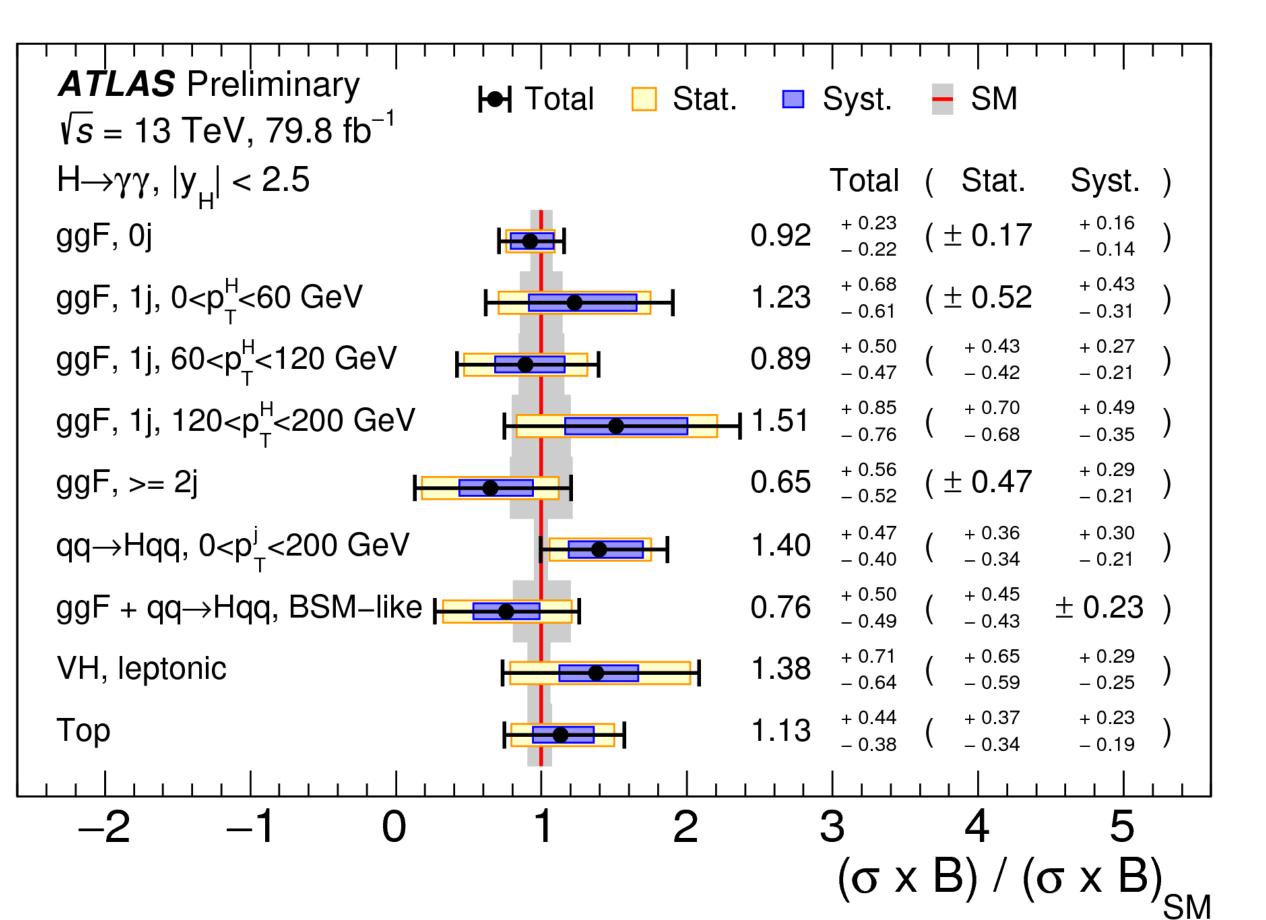


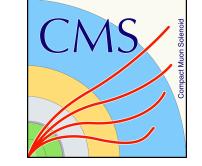
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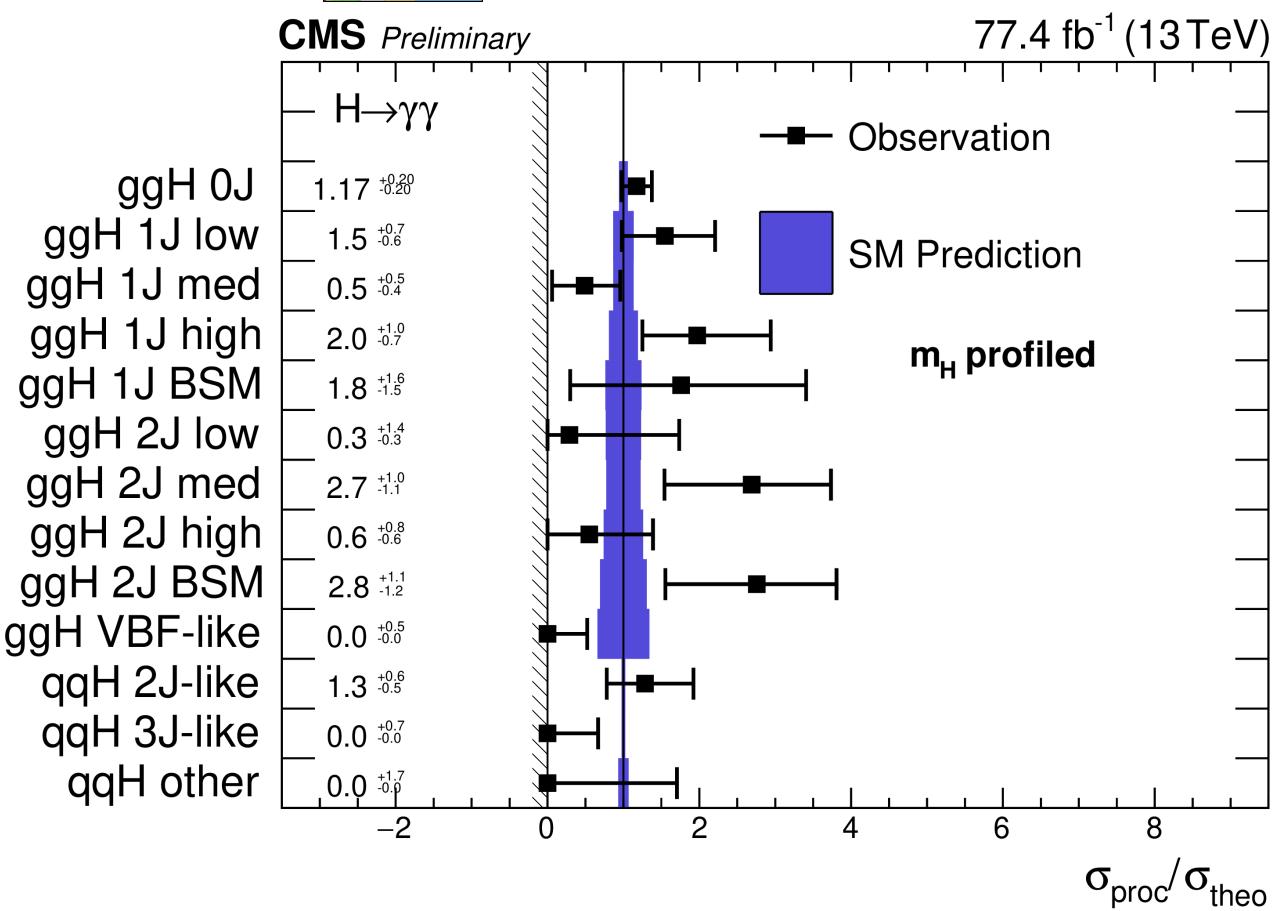
~80 fb- 1 H $\rightarrow \gamma\gamma$ STXS Stage 1.1







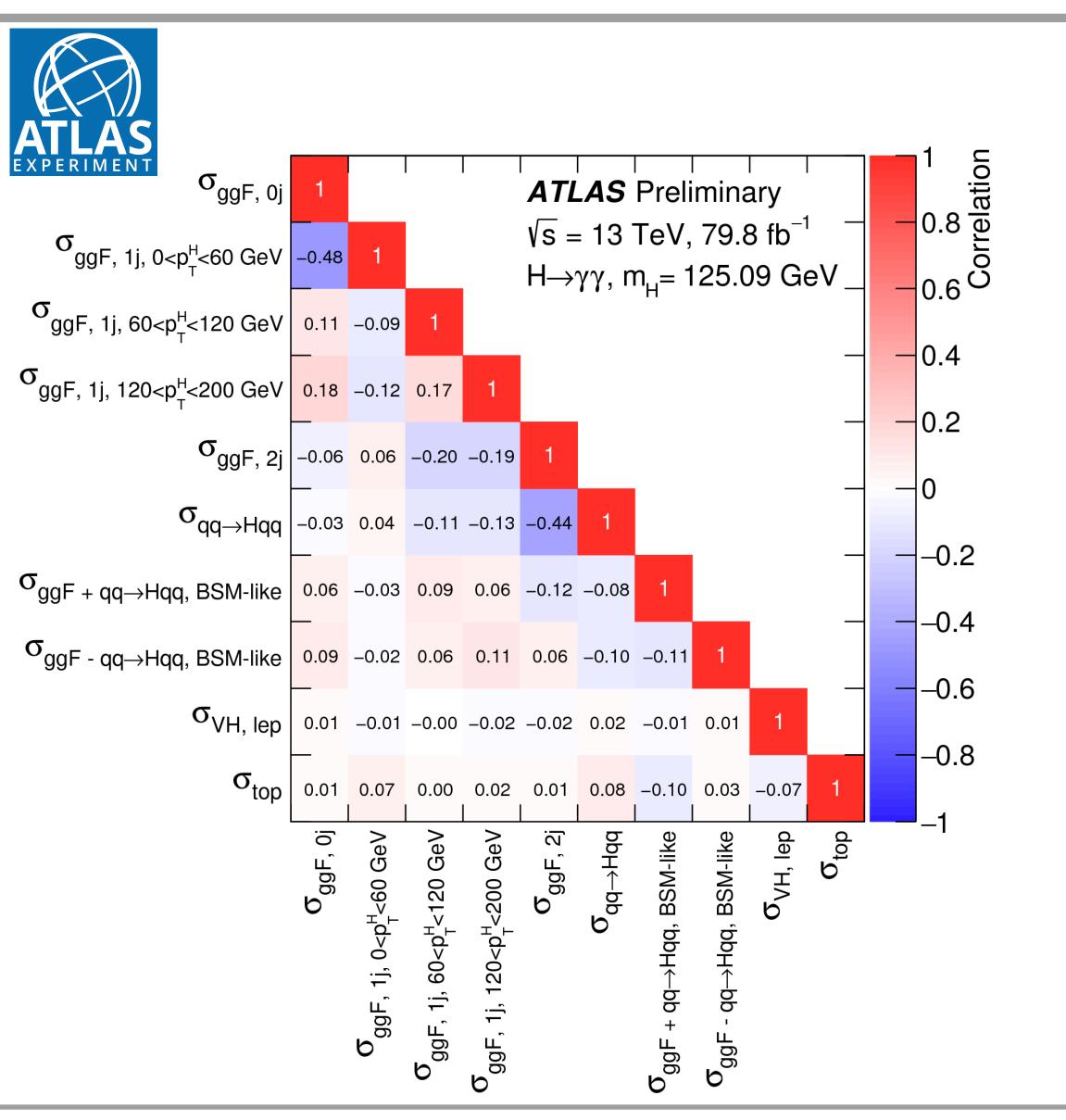




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~80 fb- 1 H $\rightarrow \gamma\gamma$ STXS Stage 1.1





CMS piounous unmu solemon

CMS Supplementary H→γγ

77.4 fb⁻¹ (13 TeV)

| , | | | | | | | | | | | | | | 1 I |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|
| qqH other | -0.11 | -0.41 | -0.68 | -0.64 | -0.54 | -0.48 | -0.64 | -0.77 | -0.82 | -0.00 | -0.14 | -0.03 | 1.00 | 1 |
| qqH 3J-like | -0.26 | 0.12 | 0.12 | -0.18 | -0.06 | 0.51 | 0.35 | 0.33 | -0.01 | -0.96 | 0.74 | 1.00 | -0.03 | 8.0 |
| qqH 2J-like | -0.22 | 0.12 | 0.16 | -0.10 | -0.00 | 0.48 | 0.35 | 0.36 | 0.07 | -0.83 | 1.00 | 0.74 | -0.14 | 0.6 |
| ggH VBF-like | 0.29 | -0.10 | -0.10 | 0.21 | 80.0 | -0.52 | -0.34 | -0.32 | 0.03 | 1.00 | -0.83 | -0.96 | -0.00 | 0.4 |
| ggH 2J BSM | 0.13 | 0.34 | 0.56 | 0.57 | 0.36 | 0.37 | 0.58 | 0.66 | 1.00 | 0.03 | 0.07 | -0.01 | -0.82 | |
| ggH 2J high | -0.00 | 0.36 | 0.56 | 0.33 | 0.40 | 0.53 | 0.64 | 1.00 | 0.66 | -0.32 | 0.36 | 0.33 | -0.77 | 0.2 |
| ggH 2J med | 0.00 | 0.33 | 0.30 | 0.33 | 0.31 | 0.47 | 1.00 | 0.64 | 0.58 | -0.34 | 0.35 | 0.35 | -0.64 | 0 |
| ggH 2J low | -0.07 | 0.03 | 0.39 | 0.21 | 0.22 | 1.00 | 0.47 | 0.53 | 0.37 | -0.52 | 0.48 | 0.51 | -0.48 | -0.2 |
| ggH 1J BSM | 0.11 | 0.21 | 0.37 | 0.40 | 1.00 | 0.22 | 0.31 | 0.40 | 0.36 | 0.08 | -0.00 | -0.06 | -0.54 | |
| ggH 1J high | 0.16 | 0.26 | 0.43 | 1.00 | 0.40 | 0.21 | 0.33 | 0.33 | 0.57 | 0.21 | -0.10 | -0.18 | -0.64 | -0.4 |
| ggH 1J med | 0.03 | 0.29 | 1.00 | 0.43 | 0.37 | 0.39 | 0.30 | 0.56 | 0.56 | -0.10 | 0.16 | 0.12 | -0.68 | -0.6 |
| ggH 1J low | -0.24 | 1.00 | 0.29 | 0.26 | 0.21 | 0.03 | 0.33 | 0.36 | 0.34 | -0.10 | 0.12 | 0.12 | -0.41 | -0.8 |
| ggH 0J | 1.00 | -0.24 | 0.03 | 0.16 | 0.11 | -0.07 | 0.00 | -0.00 | 0.13 | 0.29 | -0.22 | -0.26 | -0.11 | _1 |

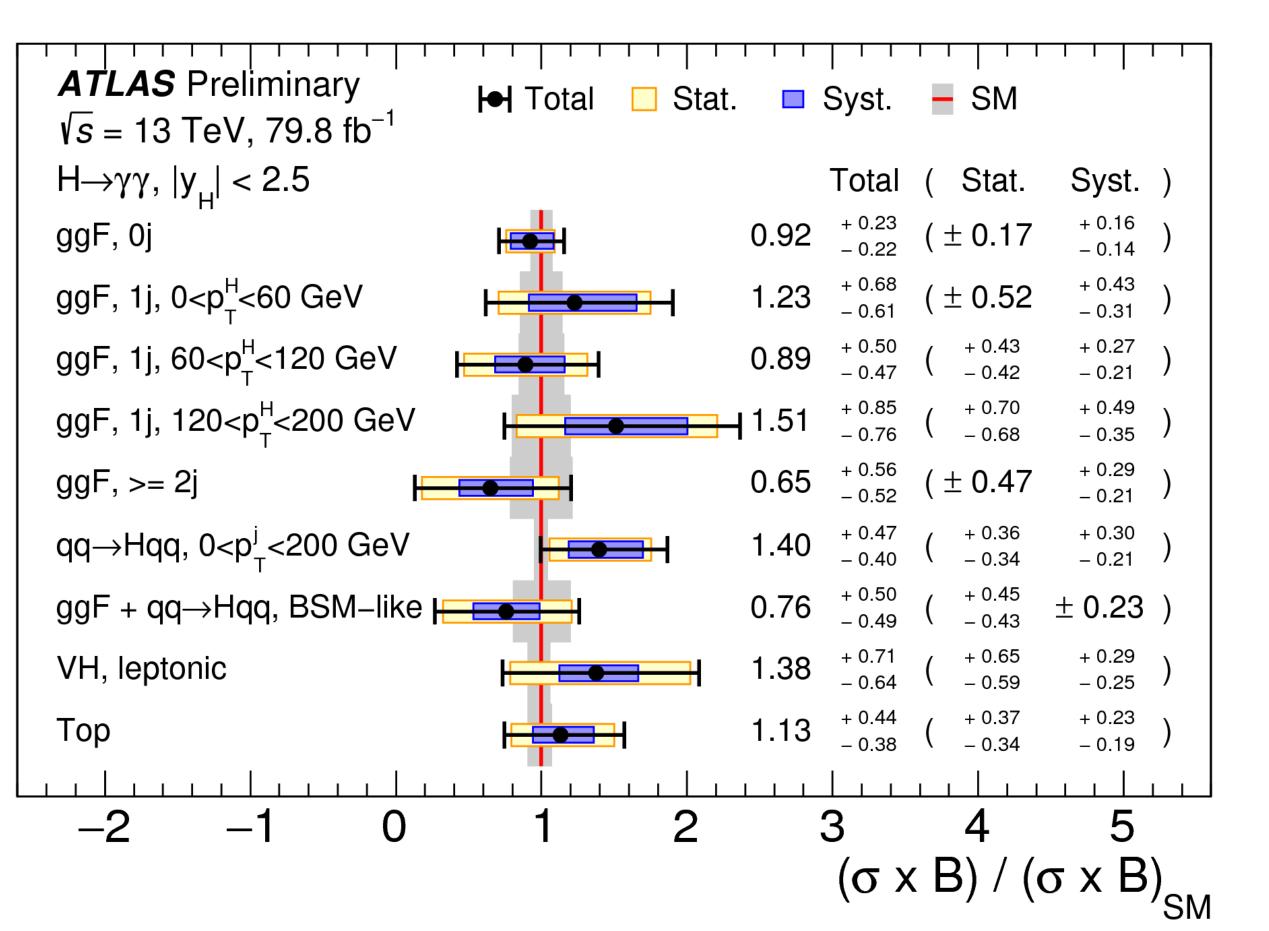
99H 0J99H 1J99H 1J99H 1J99H 1J99H 2J99H 2J99H 2J99H 2J99H 2J99H 2J99H 3J99H 3J99H 3J99H 0ther

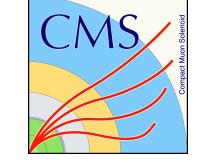
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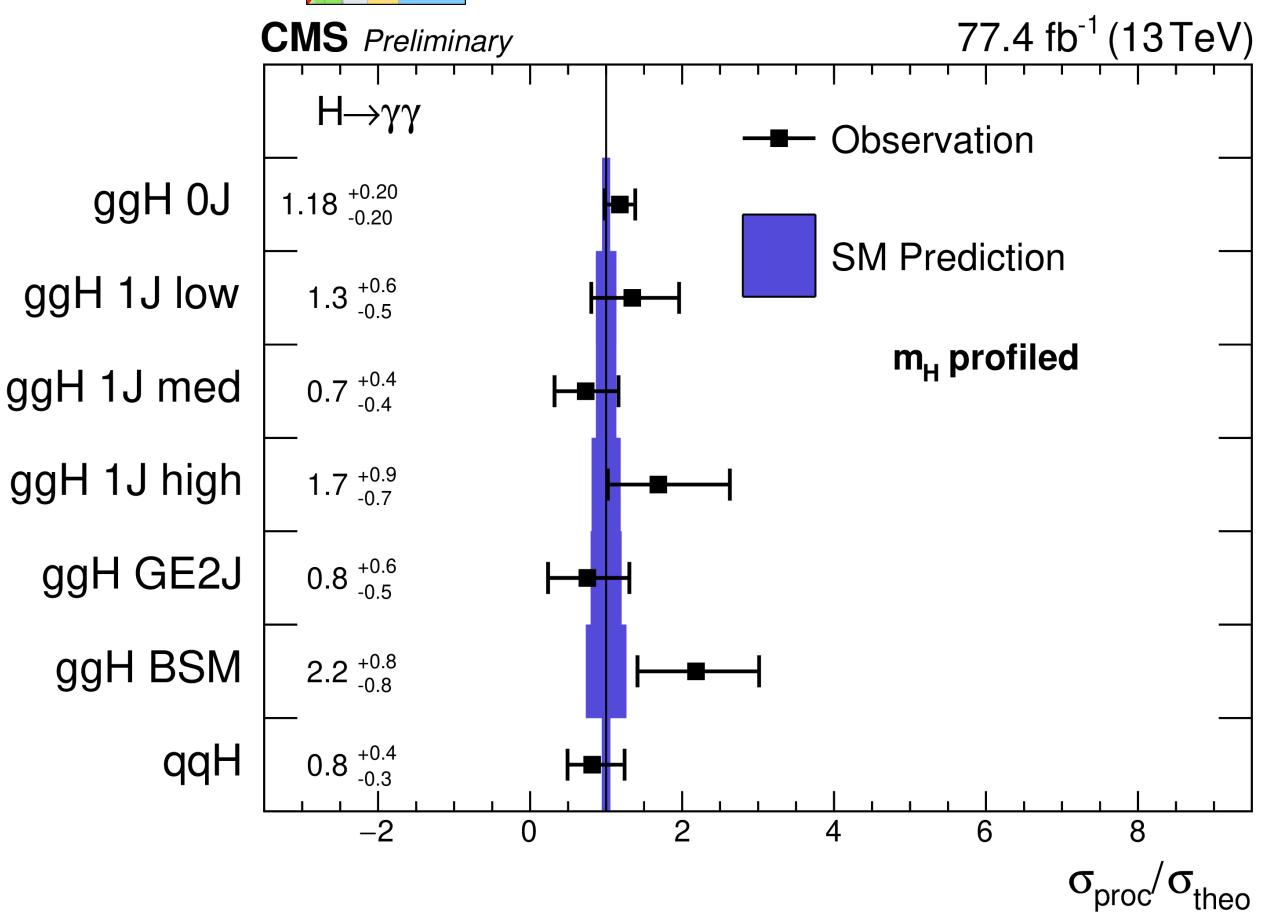
~80 fb- 1 H \rightarrow $\gamma\gamma$ STXS Stage 1.1







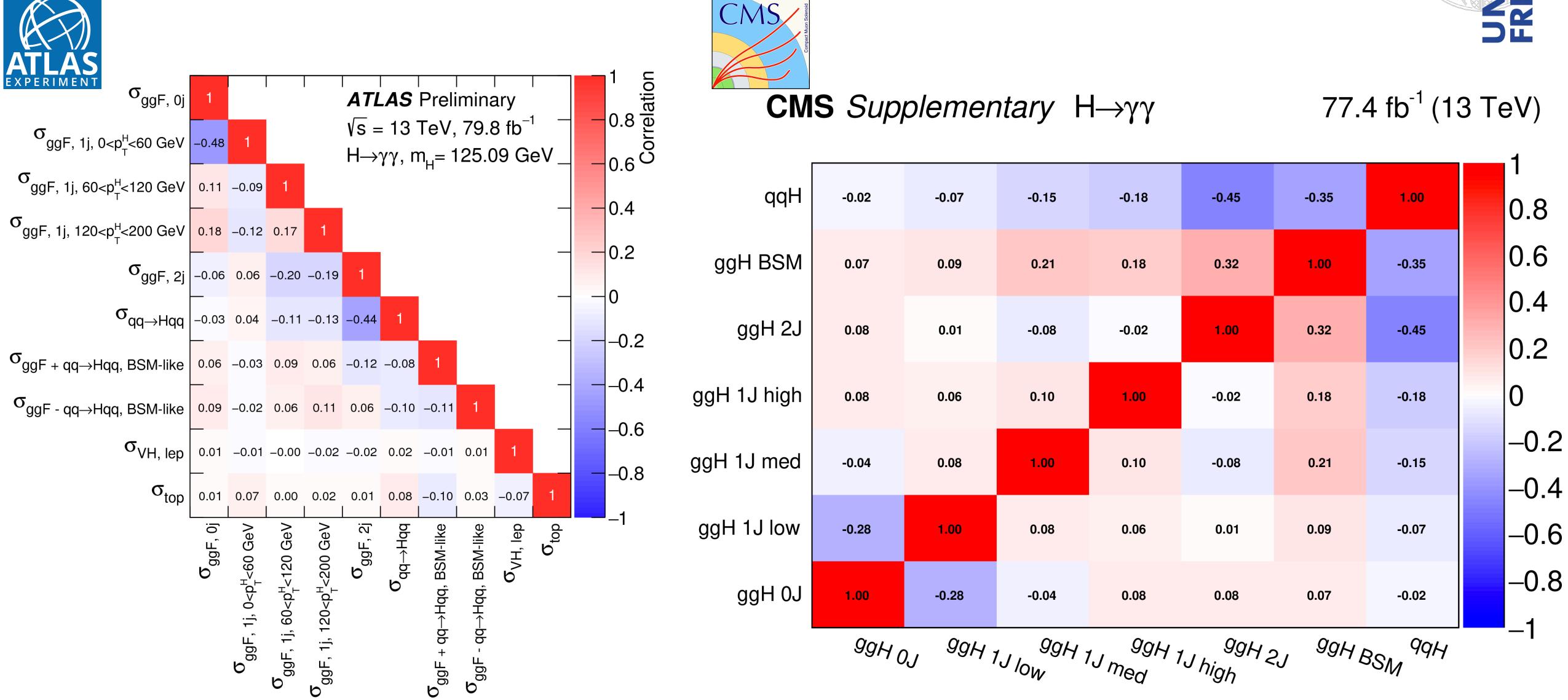




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~80 fb⁻¹ H $\rightarrow \gamma\gamma$ STXS Stage 1.1





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(Fiducial) Cross-Sections and μ



• Different definitions of fiducial phase space

Channel





$$H \rightarrow ZZ^* \rightarrow 4\ell$$

$$\sigma_{
m fid.} = 2.73^{+0.30}_{-0.29} = 2.73^{+0.23}_{-0.22} ({
m stat.})^{+0.24}_{-0.19} ({
m syst.}) {
m fb}$$
 $\sigma_{
m fid.}^{
m SM} = 2.76 \pm 0.14 {
m fb}$

$$H \rightarrow \gamma \gamma$$

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

SM prediction: 63.3 +- 3.3 fb

$$\sigma_{ggH}/\sigma_{ggH}^{SM} = 1.15^{+0.15}_{-0.15}$$

$$\sigma_{ggH}/\sigma_{ggH}^{SM} = 0.8^{+0.4}_{-0.3}$$

$$H \rightarrow WW^* \rightarrow \ell \nu \ell \nu$$

$$\sigma_{ggF} \cdot \mathcal{B}_{H \to WW^*} = 11.4^{+1.2}_{-1.1}(\text{stat.})^{+1.2}_{-1.1}(\text{theo syst.})^{+1.4}_{-1.3}(\text{exp syst.}) \text{ pb}$$

$$= 11.4^{+2.2}_{-2.1} \text{ pb} \quad (\text{SM:} 10.4 \pm 0.6 \text{ pb})$$

$$\sigma_{VBF} \cdot \mathcal{B}_{H \to WW^*} = 0.50^{+0.24}_{-0.22}(\text{stat.}) \pm 0.10(\text{theo syst.})^{+0.12}_{-0.13}(\text{exp syst.}) \text{ pb}$$

$$= 0.50^{+0.29}_{-0.28} \text{ pb} \quad (\text{SM:} 0.81 \pm 0.02 \text{ pb})$$

$$\sigma_{WH} \cdot \mathcal{B}_{H \to WW^*} = 0.67^{+0.31}_{-0.27}(\text{stat.})^{+0.11}_{-0.09}(\text{theo syst.})^{+0.14}_{-0.11}(\text{exp syst.}) \text{ pb}$$

$$(\text{SM:} 0.293 \pm 0.007 \text{ pb})$$

$$\sigma_{ZH} \cdot \mathcal{B}_{H \to WW^*} = 0.54^{+0.31}_{-0.24}(\text{stat.})^{+0.11}_{-0.05}(\text{theo syst.})^{+0.10}_{-0.05}(\text{exp syst.}) \text{ pb}$$

$$(\text{SM:} 0.189 \pm 0.007 \text{ pb})$$

$$\mu = 1.28 \pm 0.10 \text{ (stat)} \pm 0.11 \text{ (syst)}_{-0.07}^{+0.10} \text{ (theo)}$$

$$= 1.28_{-0.17}^{+0.18}$$

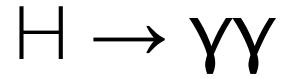
Example of different fiducial definitions





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

| Requirements for the $H 	o 4\ell$ fiducial phase space | | | | | |
|---|--|--|--|--|--|
| Lepton kinematics and isolation | | | | | |
| Leading lepton $p_{\rm T}$ | $p_{\mathrm{T}} > 20\mathrm{GeV}$ | | | | |
| Next-to-leading lepton p_T | $p_{\mathrm{T}} > 10\mathrm{GeV}$ | | | | |
| Additional electrons (muons) $p_{\rm T}$ | $p_{\rm T} > 7(5) { m GeV}$ | | | | |
| Pseudorapidity of electrons (muons) | $ \eta < 2.5(2.4)$ | | | | |
| Sum of scalar p_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 Z_1 candidate | $40\text{GeV} < m_{Z_1} < 120\text{GeV}$ | | | | |
| Inv. mass of the Z_2 candidate | $12\text{GeV} < m_{Z_2} < 120\text{GeV}$ | | | | |
| 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 | $105{ m GeV} < m_{4\ell} < 140{ m GeV}$ | | | | |



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

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