Exploring the properties of the Higgs boson in the H→γγ channel with the ATLAS detector

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on behalf of the ATLAS collaboration

"Physics at the Terascale"

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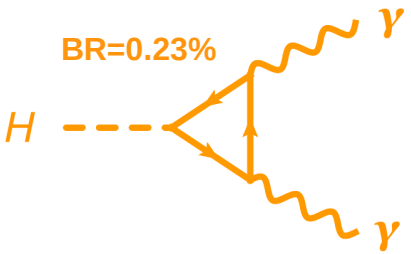
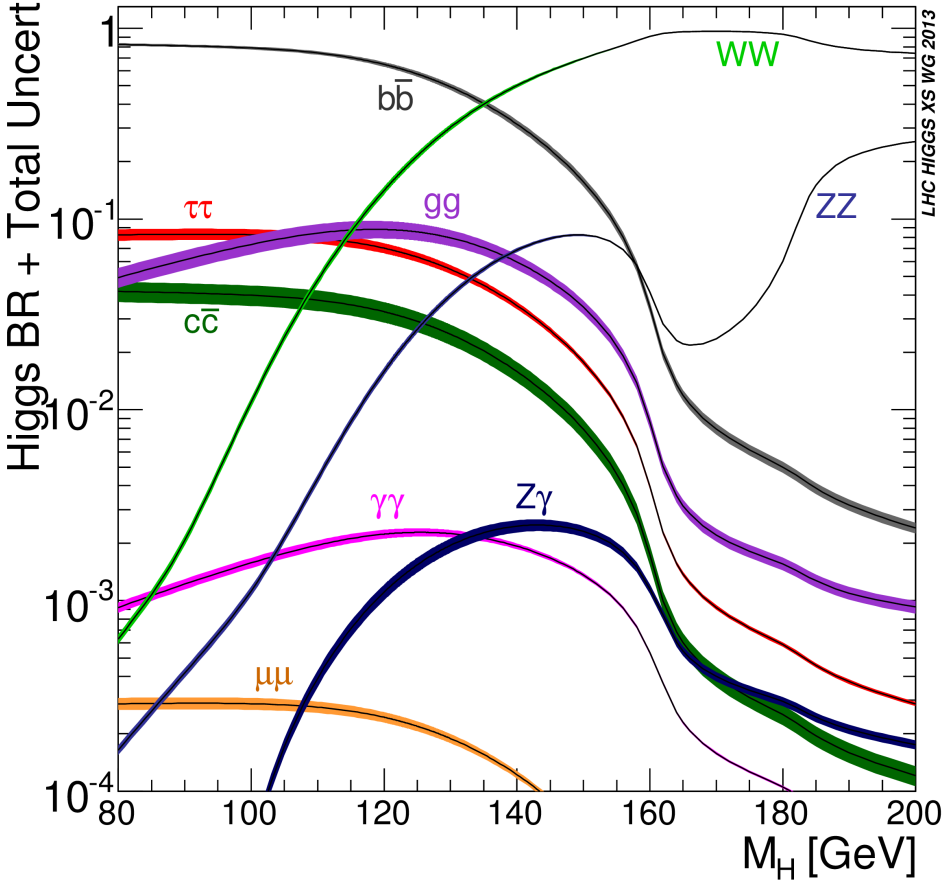
Introduction: $H \rightarrow \gamma\gamma$

- **Small branching ratio** (~0.23% for a 125 GeV Higgs)
- **Simple signature**: two isolated photons with large transverse momentum
- Number of expected events: ~475 full dataset
- **Large backgrounds**: $\gamma\gamma$, $\gamma j, jj$

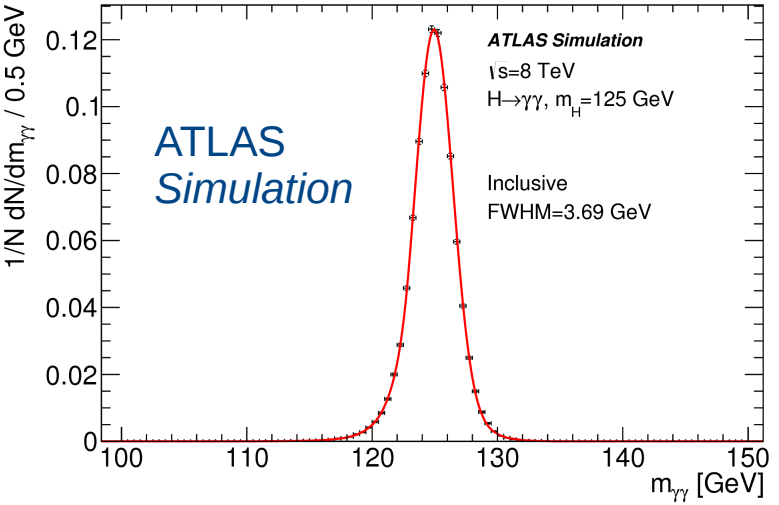


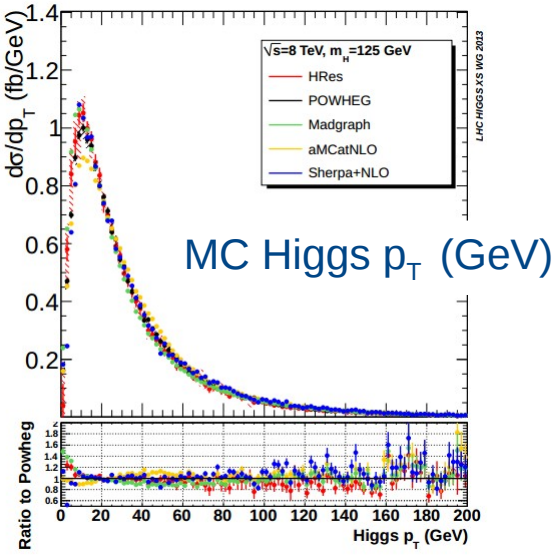


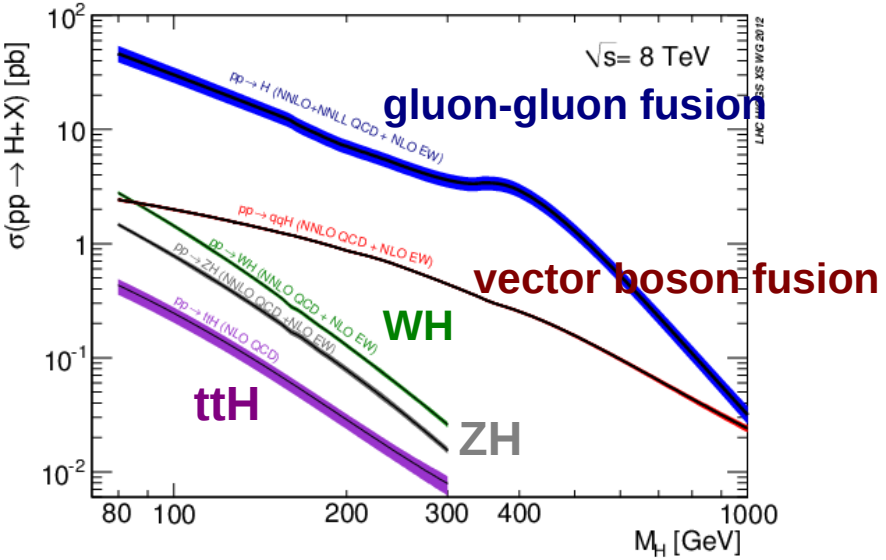
Higgs property measurements in the diphoton decay channel

H → γγ in this presentation:

- **mass** (*Phys. Rev. D. 90, 052004 (2014)*)
- **signal strength**/production modes (arXiv:1408.7084)
- fiducial and differential **cross sections** (*JHEP09(2014)112*)







Common ingredients

Common elements in these analyses:

Event and Photon selection:

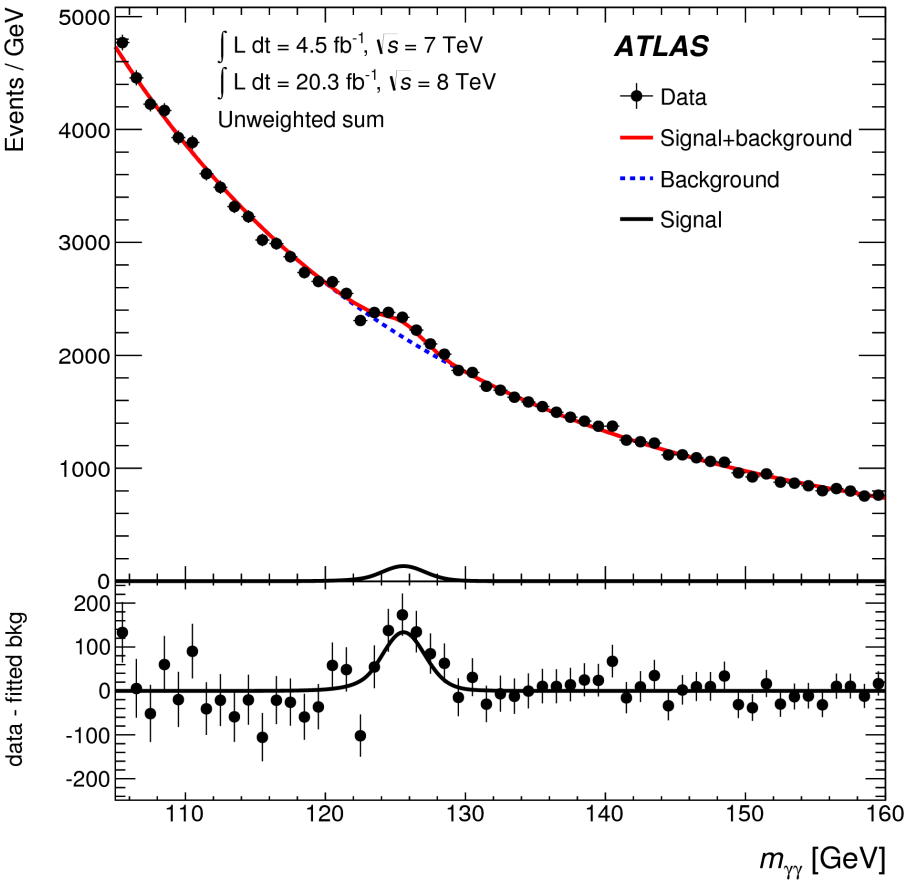
- Photons identified through shower shapes
- Two isolated photons within $|\eta| < 2.37$, excluding $1.37 < |\eta| < 1.56$
- $105\ \text{GeV} < m_{\gamma\gamma} < 160\ \text{GeV}$
- $p_{T,\gamma} / m_{\gamma\gamma} > 0.35\ (0.25)$ for leading (subleading) photon

Signal extraction:

- Simultaneous *s+b* fit

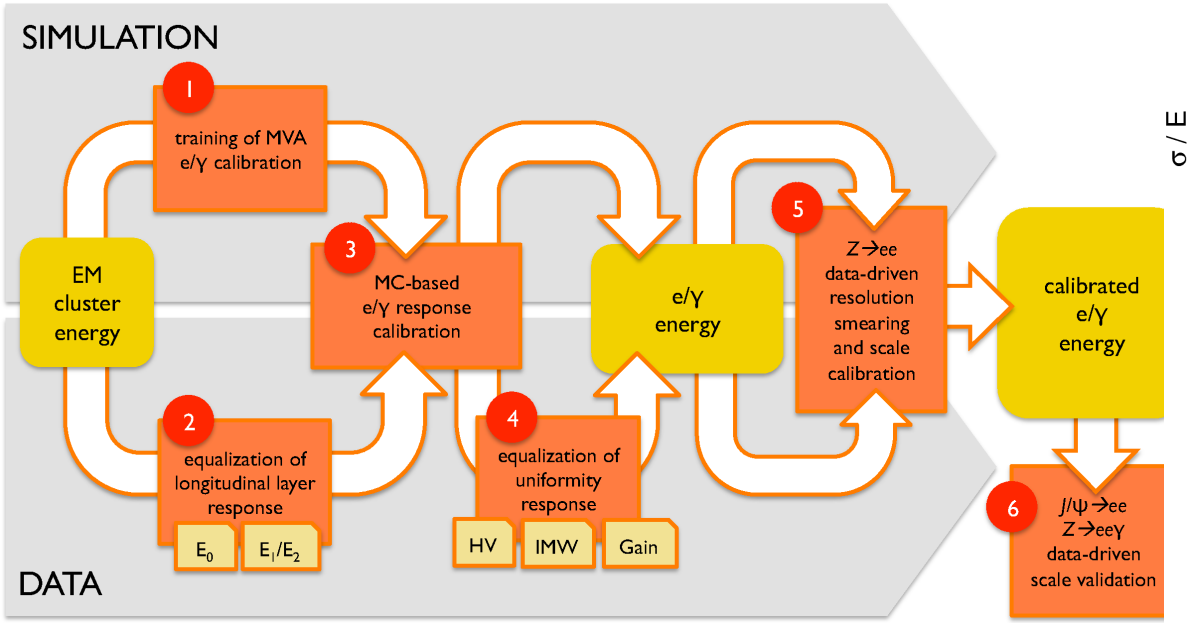
Background:

- Parametrization chosen to limit size of potential bias, require fitted signal in a s+b fit to a background-only simulation to be small



e/γ energy calibration

Final Run1 energy calibration procedure:



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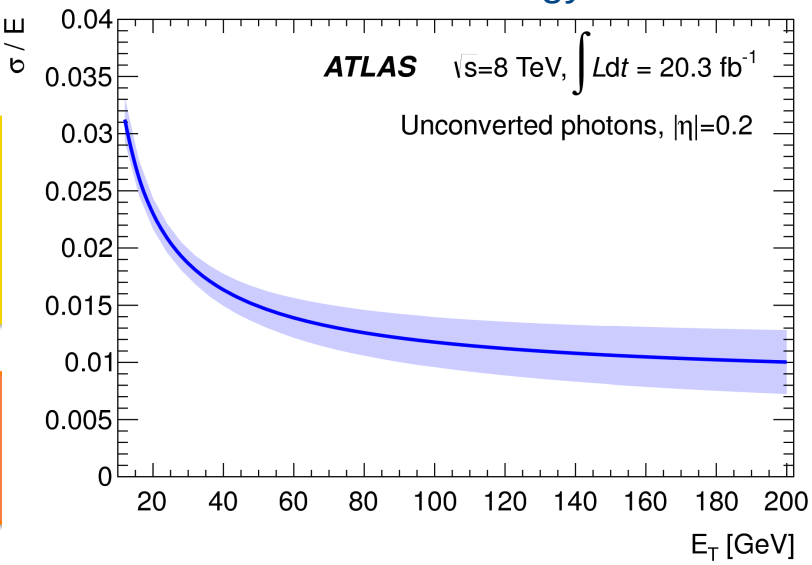
Energy resolution



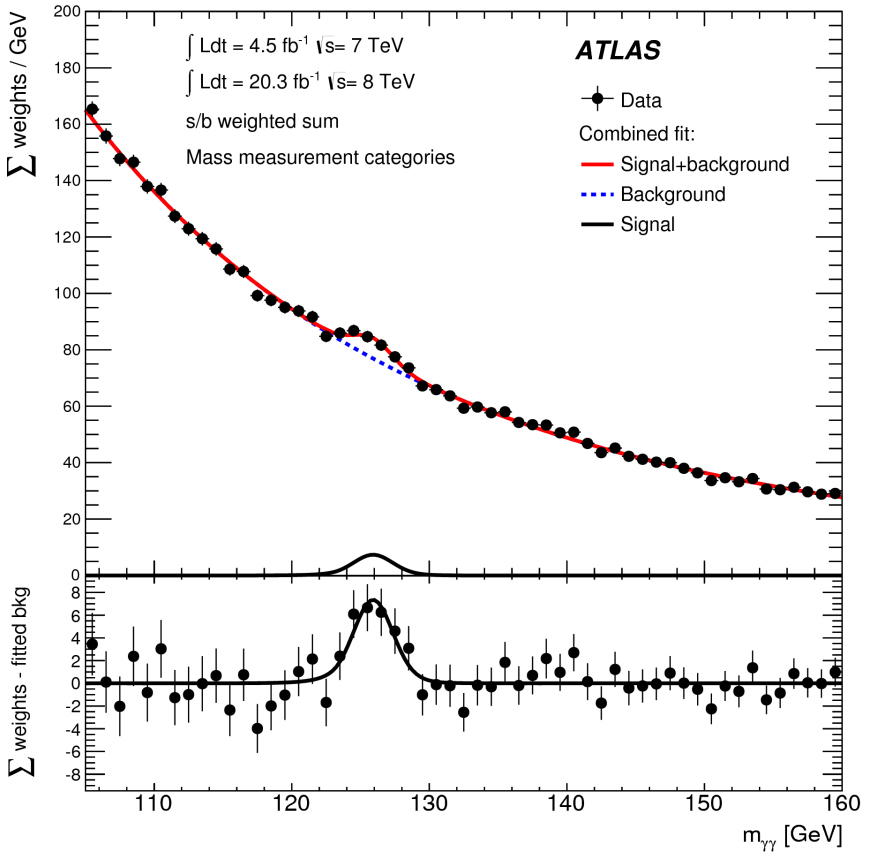
Several improvements:

- Many data driven corrections (intercalibration of the layers, non uniformities in the calorimeter)
- Better detector material simulation
- New MVA MC-based calibration (using position, shower depth, presampler, radius of conversion)

Mass measurement

$H \to \gamma\gamma$ mass measurement:

- Full Run1 dataset: 4.5 fb^{-1} @√s=7TeV, 20.3 fb^{-1} @√s=8TeV
- data divided in 10 exclusive categories based on resolution and s/b: converted/unconverted photons in the detector, η, p_{Tt}
- systematics dominated by photon energy measurement (reduced by a factor 2.5 with new e/γ calibration)

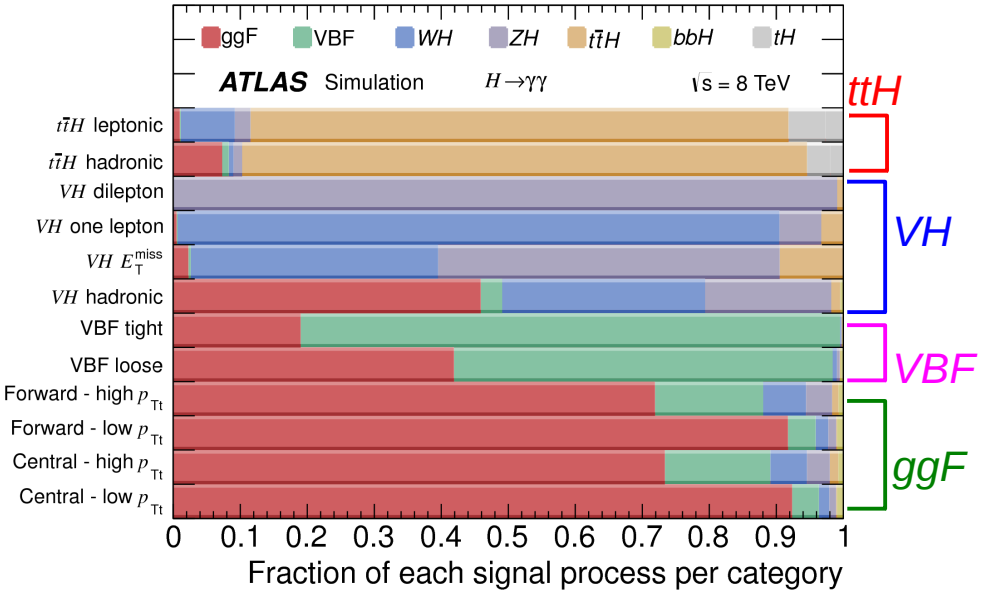


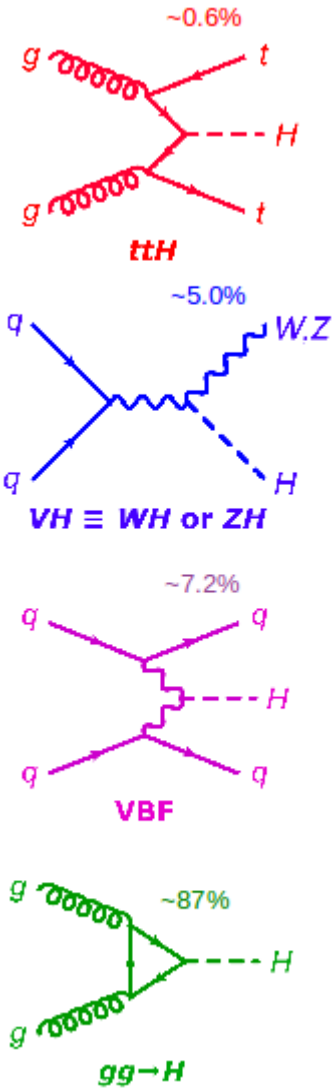
$m_H = 125.98 \pm 0.42(stat) \pm 0.28(sys)$ GeV

Separation of production modes

Analysis strategy:

- Full Run1 dataset: 4.5 fb^{-1} @√s=7TeV, 20.3 fb^{-1} @√s=8TeV
- Analysis performed at the Higgs boson mass measured by ATLAS ($\gamma\gamma$ and $4l$ combined), m_H= 125.4 GeV
- Data divided in exclusive categories optimized for the different production modes





Separation of production modes

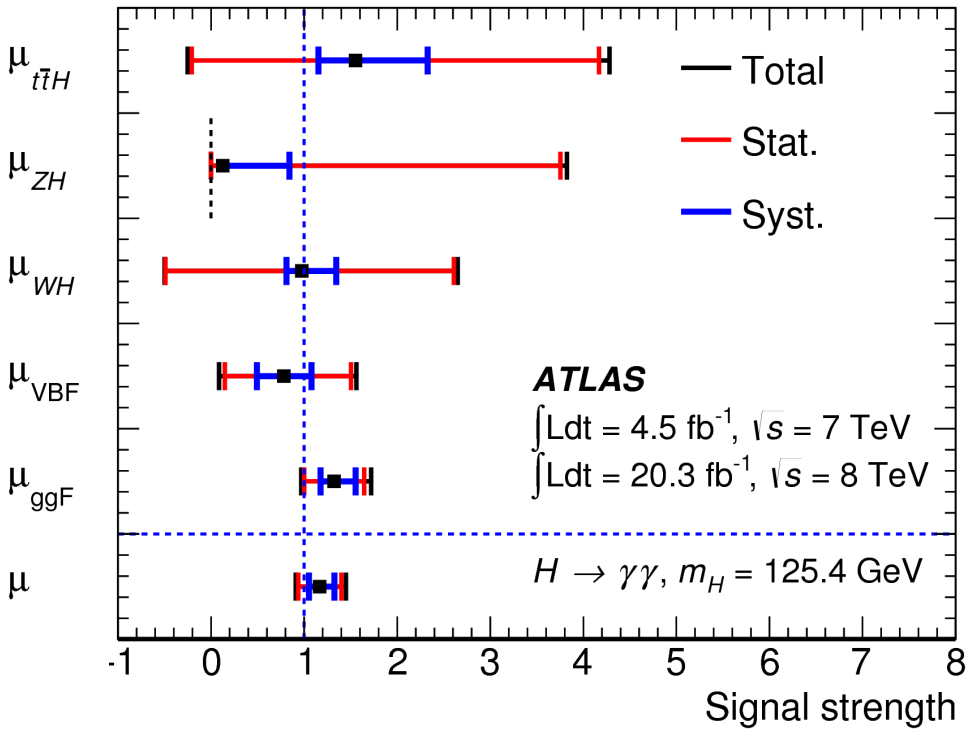
Signal strength of the primary production processes

$$\mu = \frac{\sigma^{obs}}{\sigma^{SM}}$$

Uncertainties:

- Statistics is the dominant
- Theory uncertainties of the same order of experimental systematics
- Dominant experimental systematics: luminosity, photon energy resolution

Measurement for the **five main Higgs production modes**, all consistent with the SM expectation



$$\mu = 1.17 \pm 0.23\ (\text{stat.})\ ^{+0.10}_{-0.08}\ (\text{syst.})\ ^{+0.12}_{-0.08}\ (\text{theory})$$

Fiducial and differential cross sections

Improve understanding of **kinematic properties of Higgs boson production and decay** in an almost model independent way

Measurement:

- Full 2012 data: 20.3 fb^{-1} @$\sqrt{s}$=8TeV
- 7 fiducial regions: 5 cross sections + 2 limits
- 20 differential cross sections
- all corrected for detector effects and can be used to directly compare to theory predictions (available in HepData)

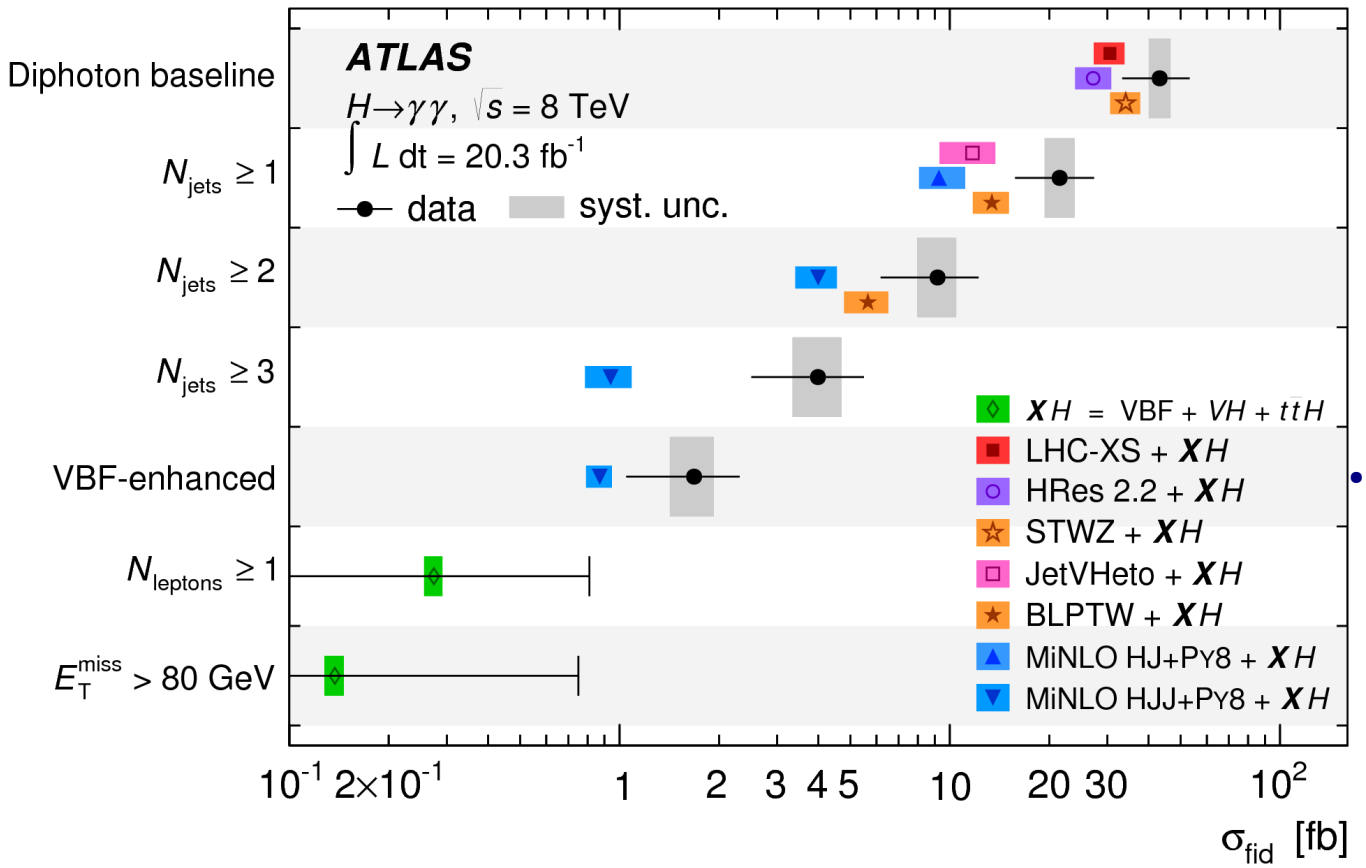
Differential fiducial cross section

$$\frac{d\sigma}{dX} = \frac{N_i^{sig} \cdot c_i}{\Delta X_i L_{int}}$$

Unfold to fiducial volume:

- Two highest photons (not coming from hadrons) with “standard” diphoton selection (slide 4)
- Mimic detector level isolation: $E_{T,iso}^{truth}(R=0.4) < 14GeV$
- bin-by-bin unfolding

Fiducial cross sections



Results show compatibility with state-of-art SM predictions and are in line with measured signal strength.

- m_{jj} >400 GeV,

  $|\Delta y_{jj}|$> 2.8, $|\Delta\phi_{\gamma\gamma,jj}|$> 2.6

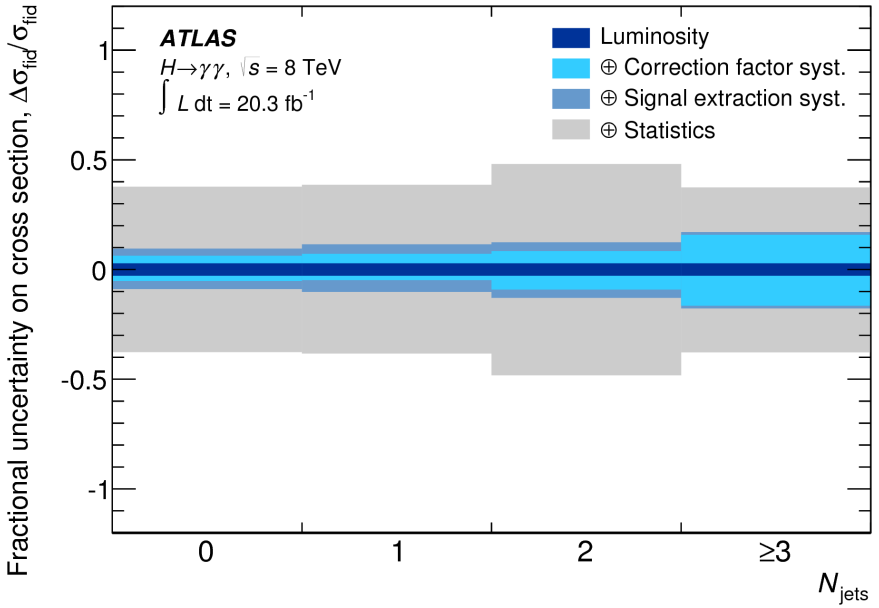
$$\sigma_{\text{fid}}(pp\to H\to\gamma\gamma) = 43.2 \pm 9.4(\text{stat.})^{+3.2}_{-2.9}(\text{syst.}) \pm 1.2(\text{lumi})\ \text{fb}$$

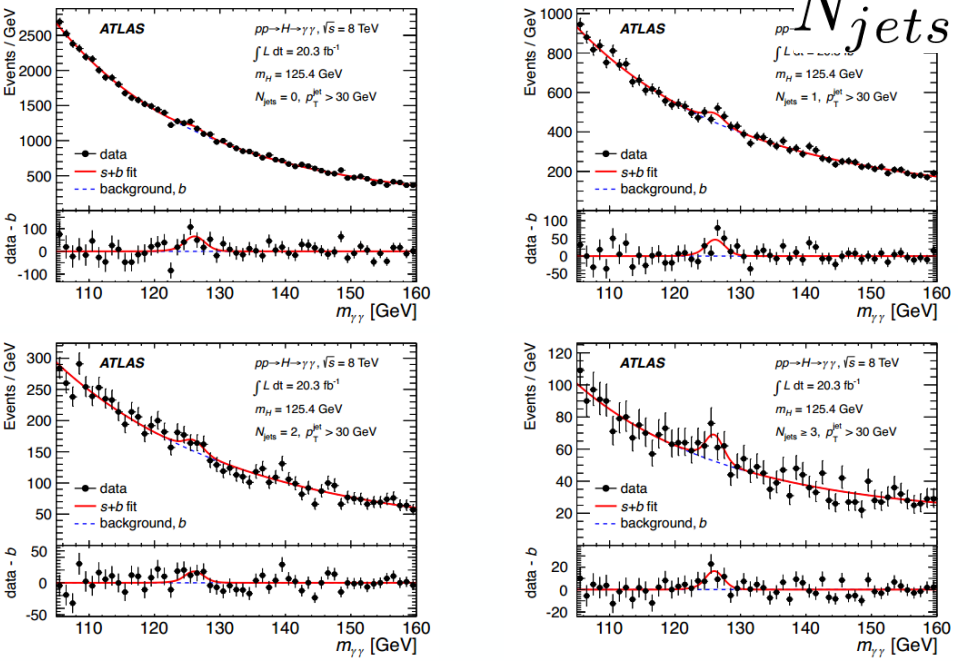
Differential cross sections

Observables sensitive to**:** Higgs kinematics, jet activity, spin-CP and VBF topology

For **each observable:**

- Partition the dataset: e.g. N_{jets}= 0, 1, 2, etc.,
- Extract the signal yields in all bins with a **simultaneous signal plus background fit**



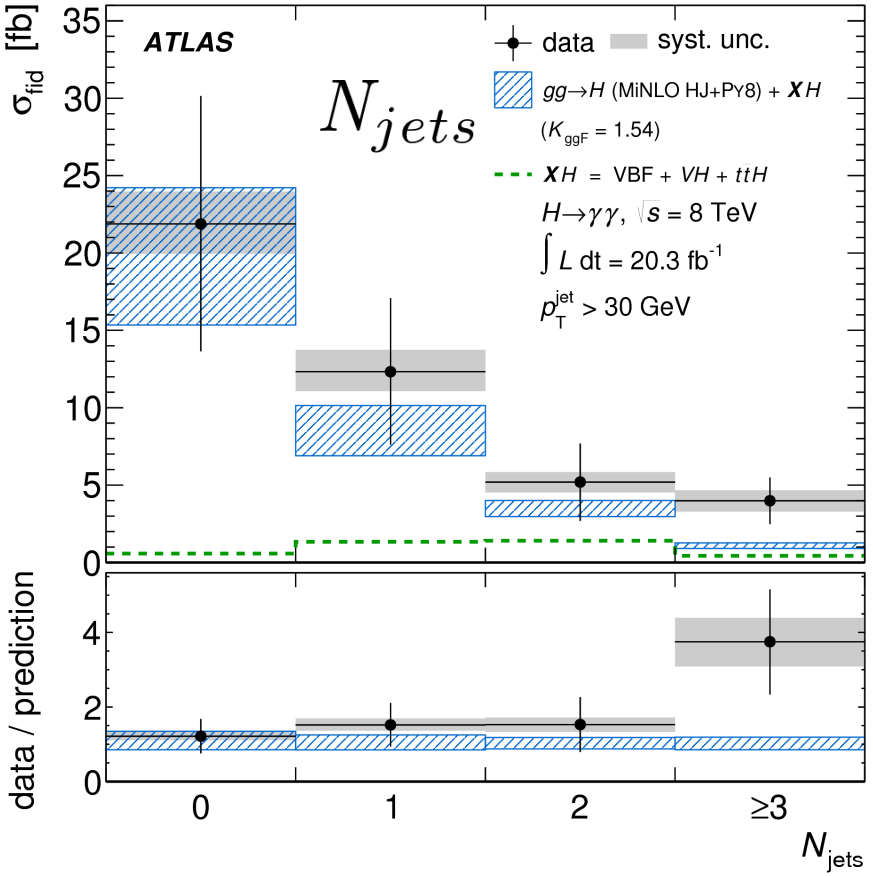


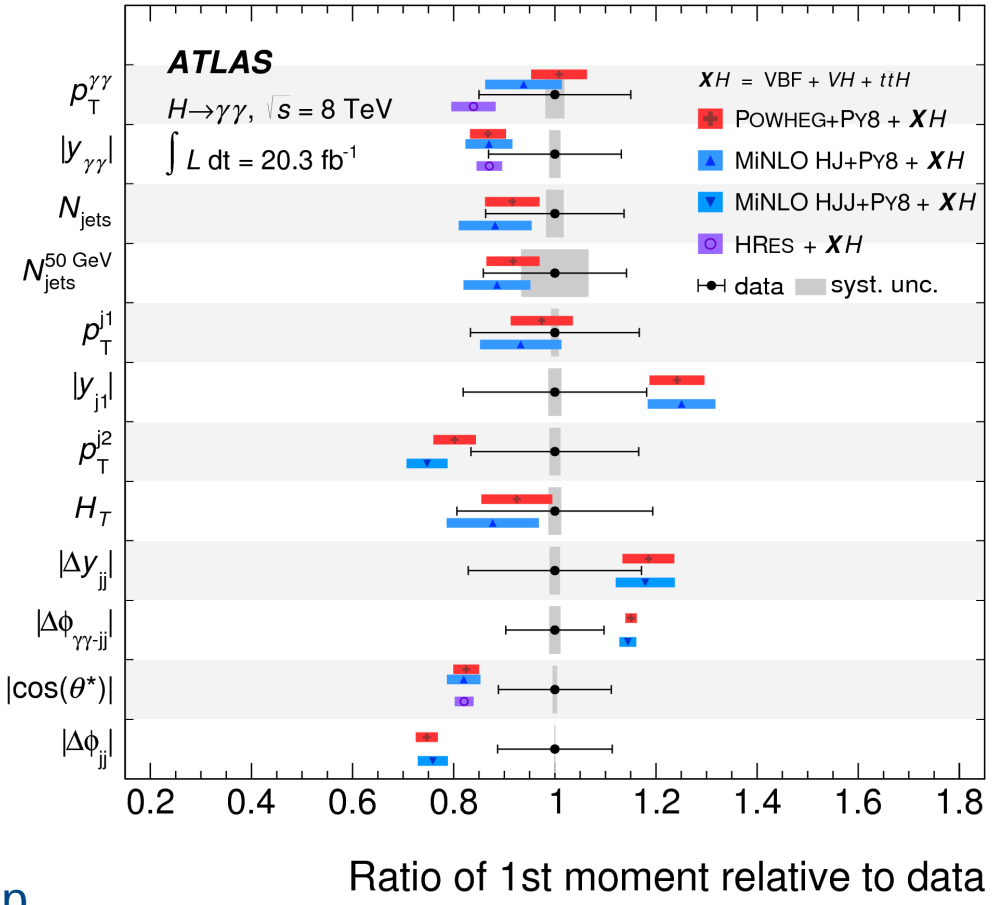
Statistical uncertainty dominates

Differential cross sections

Unfolded distribution for N_{jets}

Uncertainties dominated by statistical uncertainties





All distributions are available in the backup

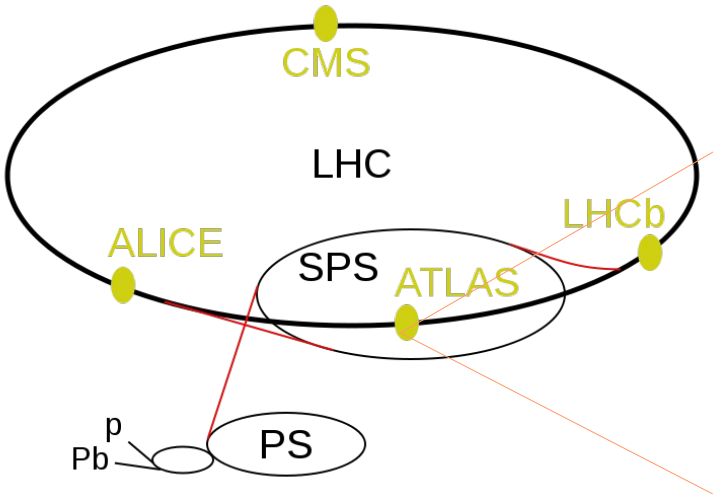
Summary

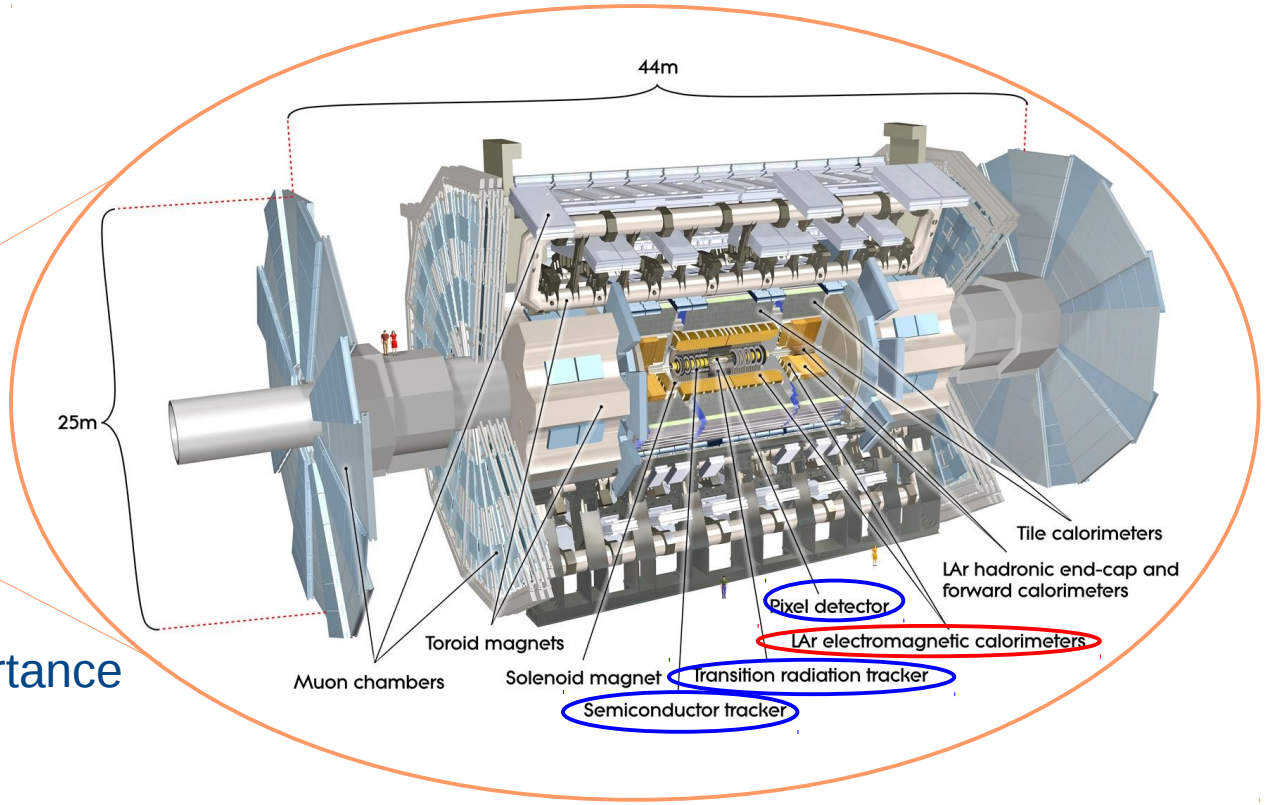
- Presented latest Run1 ATLAS measurements of the Higgs boson in the diphoton channel decay:
  - Mass
  - Signal strength
  - Fiducial and differential cross sections
- All analyses show improvements from their early publication and benefit from improved photon and electron energy calibration and identification
- Improving systematic uncertainties understanding while current measurements are limited by statistics
- Within the statistical uncertainties, good agreement between measurements and SM theory predictions is found in all cases
- Looking forward to next ATLAS data taking!!

Backup

ATLAS @ LHC

Data used in these analysis: *pp* collision data recorded with the ATLAS detector at the LHC





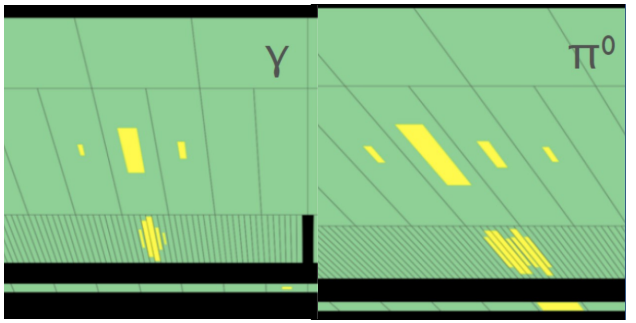
Subdetectors of particular importance

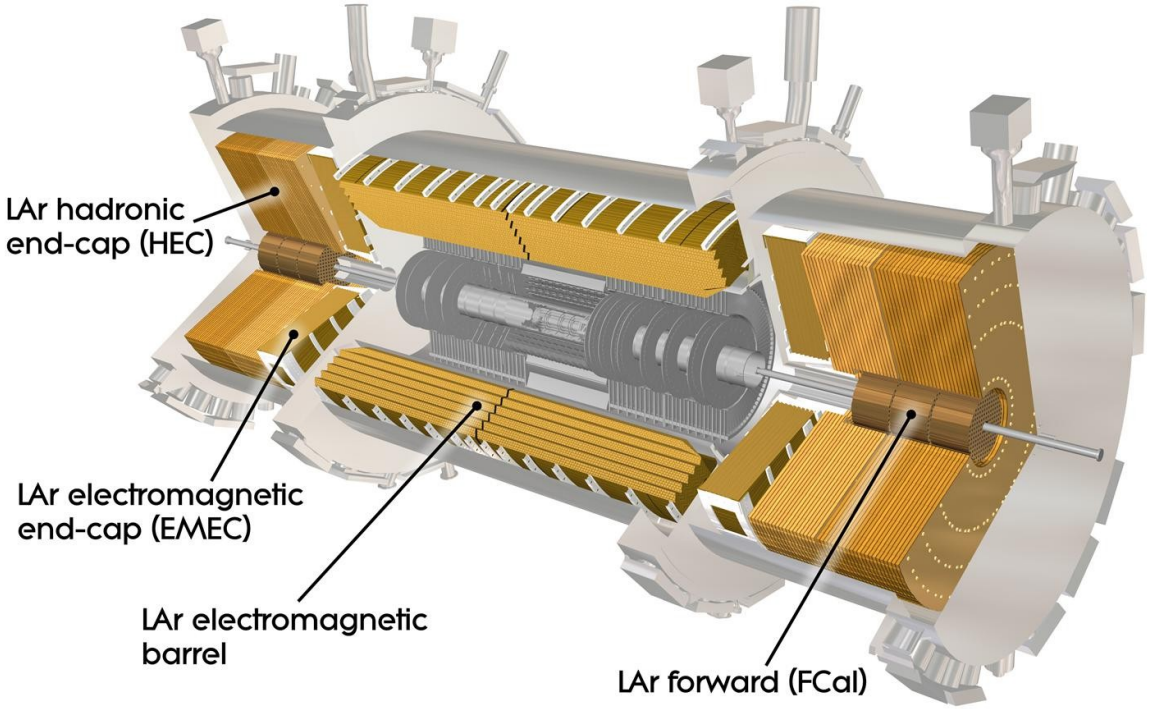
- Inner Detector
- Liquid Argon calorimeter

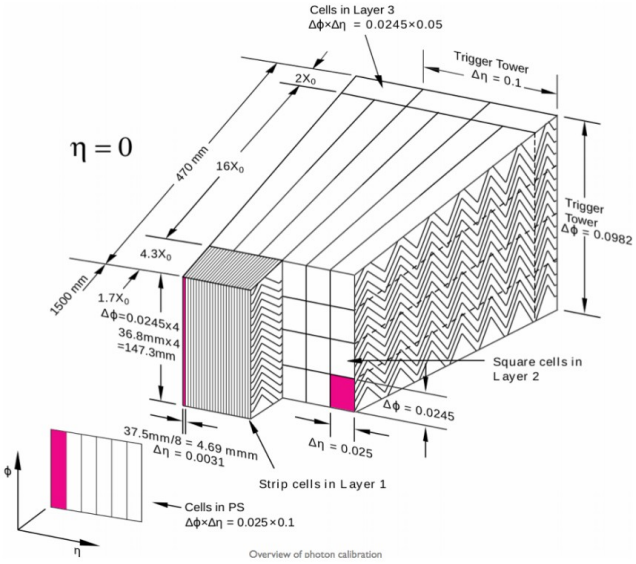
ATLAS Liquid Argon calorimeter

The main tool is the ATLAS **L**iquid **Ar**gon (LAr) calorimeter

- Longitudinal segmentation (pointing)
- Fine η granularity in first layer (γ/jet separation)



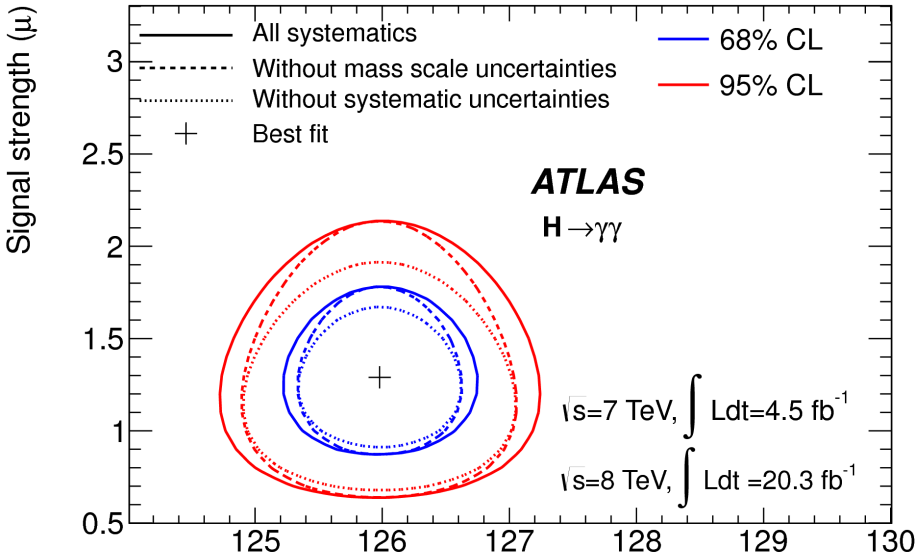




Mass measurement

Systematic uncertainties:

- energy scale dominated reduced by a factor 2.5
- most important remain: LAr cell-non linearity, material, lateral shower shape photon/electron differences



	Unconverted					Converted				
	Central		Rest		Transition	Central		Rest		Transition
Class	low p_{Tt}	high p_{Tt}	low p_{Tt}	high p_{Tt}		low p_{Tt}	high p_{Tt}	low p_{Tt}	high p_{Tt}	
$Z \to e^+e^-$ calibration	0.02	0.03	0.04	0.04	0.11	0.02	0.02	0.05	0.05	0.11
LAr cell nonlinearity	0.12	0.19	0.09	0.16	0.39	0.09	0.19	0.06	0.14	0.29
Layer calibration	0.13	0.16	0.11	0.13	0.13	0.07	0.10	0.05	0.07	0.07
ID material	0.06	0.06	0.08	0.08	0.10	0.05	0.05	0.06	0.06	0.06
Other material	0.07	0.08	0.14	0.15	0.35	0.04	0.04	0.07	0.08	0.20
Conversion reconstruction	0.02	0.02	0.03	0.03	0.05	0.03	0.02	0.05	0.04	0.06
Lateral shower shape	0.04	0.04	0.07	0.07	0.06	0.09	0.09	0.18	0.19	0.16
Background modeling	0.10	0.06	0.05	0.11	0.16	0.13	0.06	0.14	0.18	0.20
Vertex measurement	0.03									
Total	0.23	0.28	0.24	0.30	0.59	0.21	0.25	0.27	0.33	0.47

m_H = 125.98 ± 0.42(stat) ± 0.28(sys) GeV

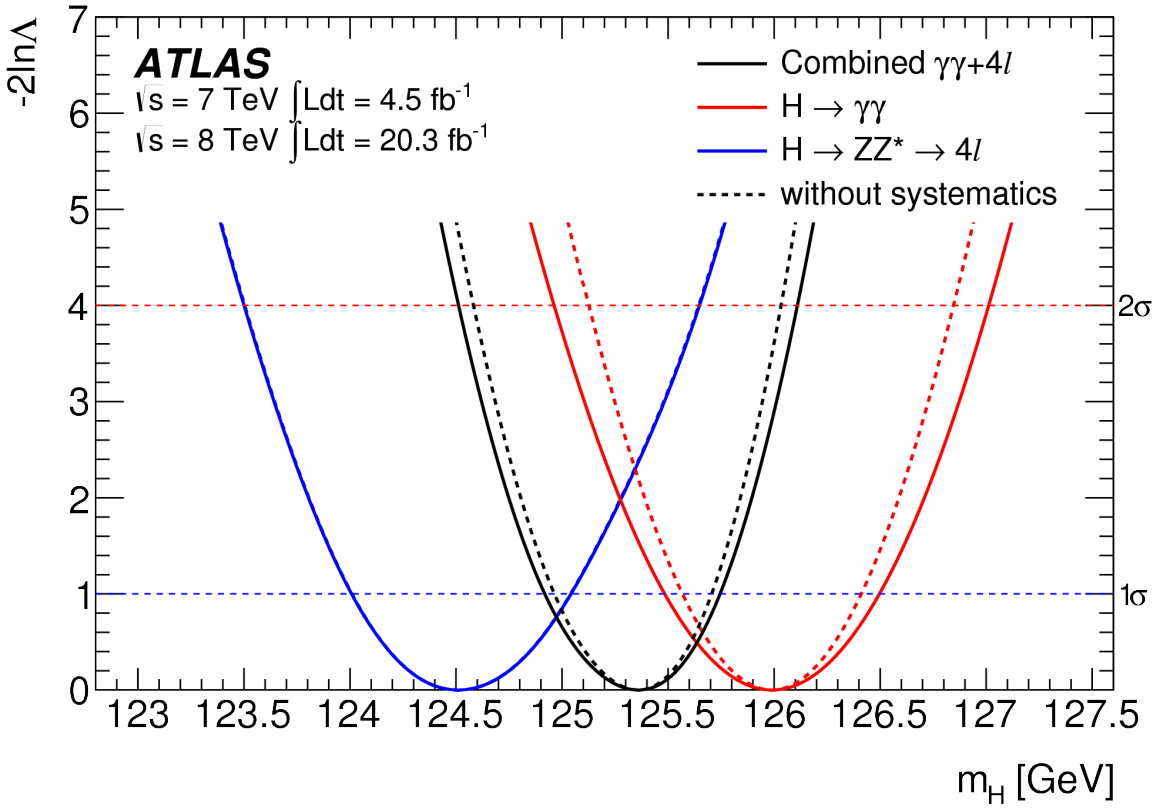
Mass measurement

Mass measurement combination:

- Previous value was

$m_H = 125.49 \pm 0.24(\text{stat})\ ^{+0.50}_{-0.58}(\text{sys})$ GeV

- compatibility between $H \to \gamma\gamma$ and $H \to 4l$ measurements is 1.98σ



$m_H = 125.36 \pm 0.37(\text{stat}) \pm 0.18(\text{sys})$ GeV

Differential cross sections

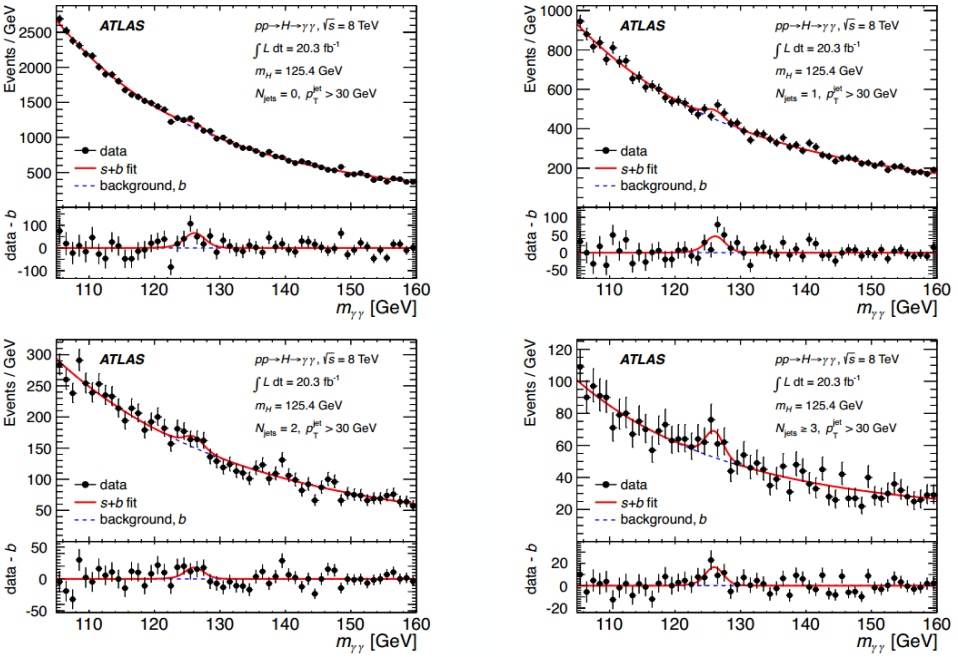
Observables:

- Higgs kinematics: p_T, $|y|$, of the di-photon system
- Jet activity: N_{jets}, p_T, $|y|$, of the (sub-)leading jet, scalar sum of jet momenta H_T
- Spin-CP sensitive: $|cos\theta^*|$ of the Higgs, $|\Delta\phi_{jj}|$ between the two leading jets
- VBF sensitive: $|\Delta y_{jj}|$, $|\Delta\phi_{\gamma\gamma,jj}|$

N_{jets}

For **each observable:**

- Partition the dataset: e.g. N_{jets}= 0, 1, 2, etc., or 20 < $p_{T,\gamma\gamma}$ < 30 GeV, etc.
- Extract the signal yields in all bins with a **simultaneous signal plus background fit**
- This correlates systematic uncertainties and the Higgs boson mass m_H across bins (for each observable).



Bin-by-bin unfolding using correction factors $\mathbf{c_i = n_i^{Particle} / n_i^{Reconstructed}}$ (forced by low statistics)

Uncertainties

The measured differential cross sections are subject to uncertainties on the overall yield and on migrations between bins of the observables.

Luminosity uncertainty:

- Flat 2.8% affecting fiducial and differential cross sections

Correction factors uncertainties:

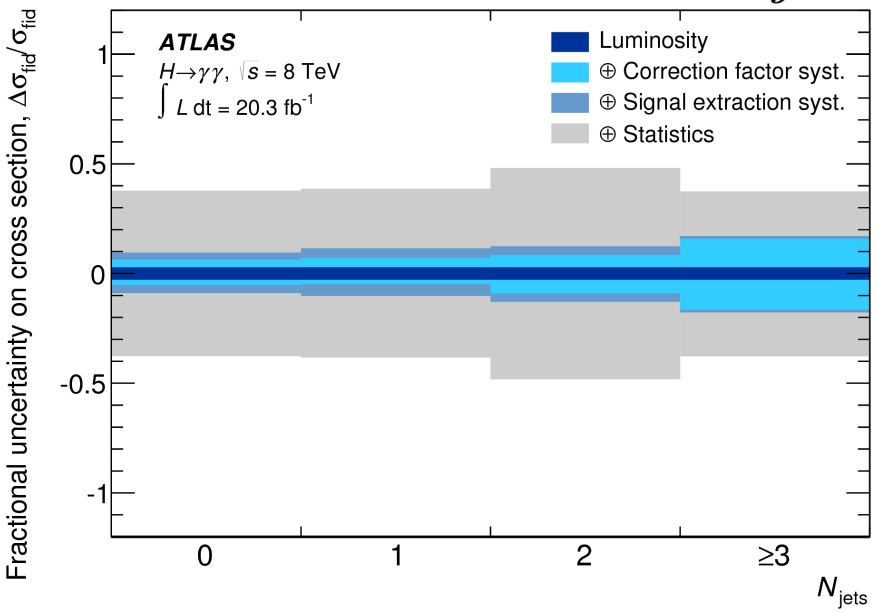
- Trigger efficiency, photon energy scale and resolution, photon identification and isolation efficiency
- Gluon fusion modelling and signal composition
- jet energy scale and resolution, jet vertex fraction and pileup mismodelling

Signal extraction uncertainty:

- photon energy scale and resolution, background modelling

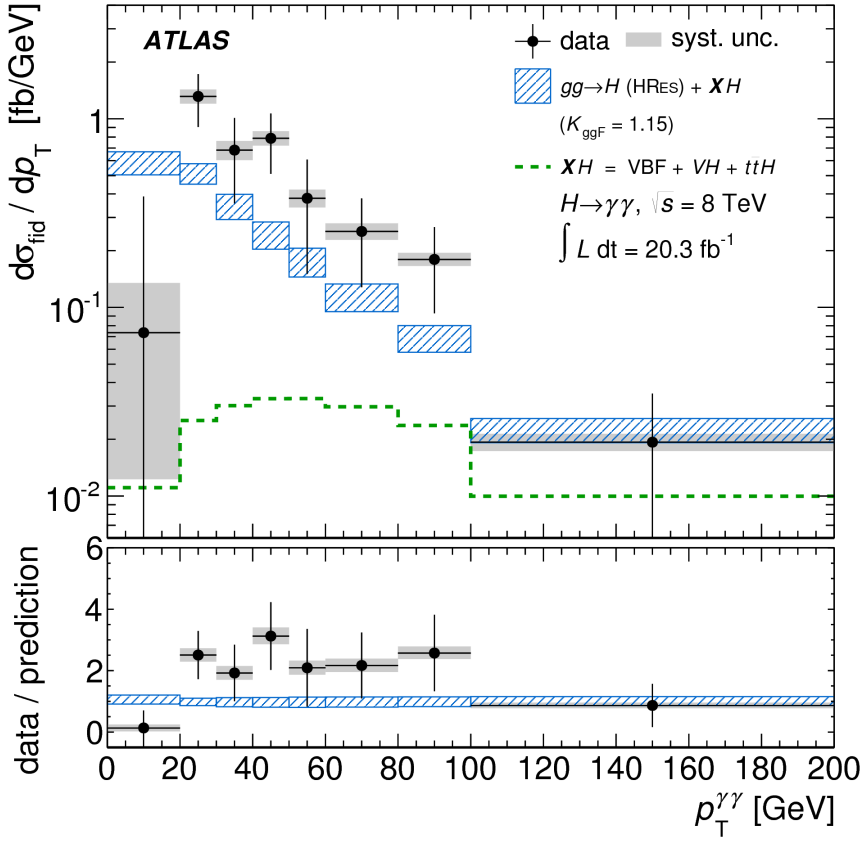
Statistical uncertainty dominates

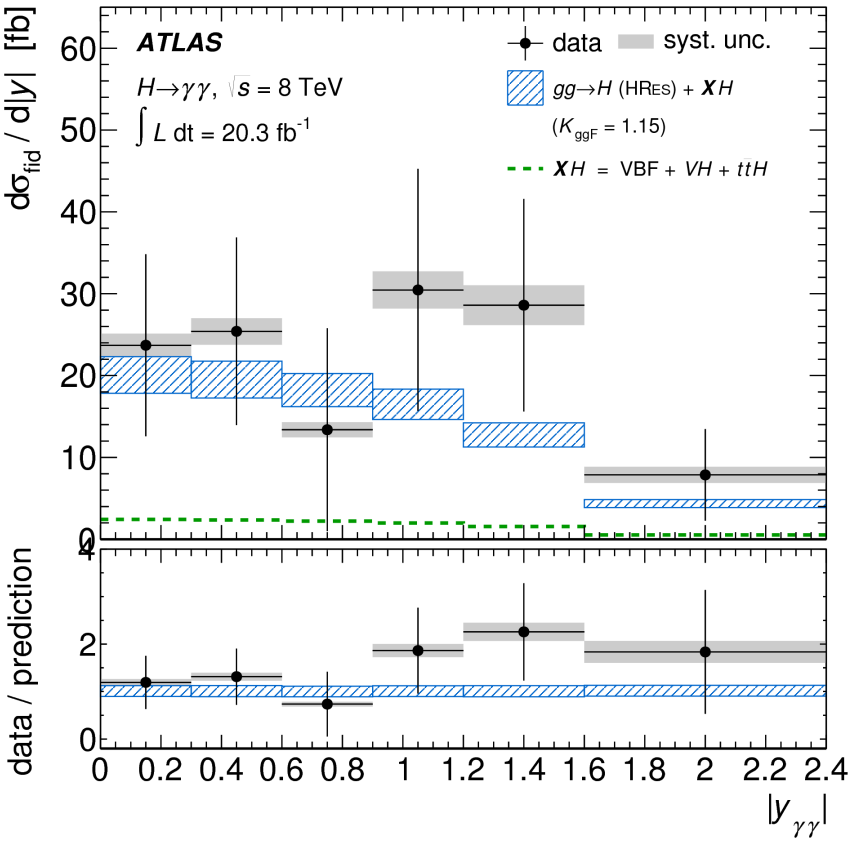
N_{jets}



Differential cross sections

The unfolded distributions for the described variables are presented. As seen in the previous slide, the results are limited by statistics.





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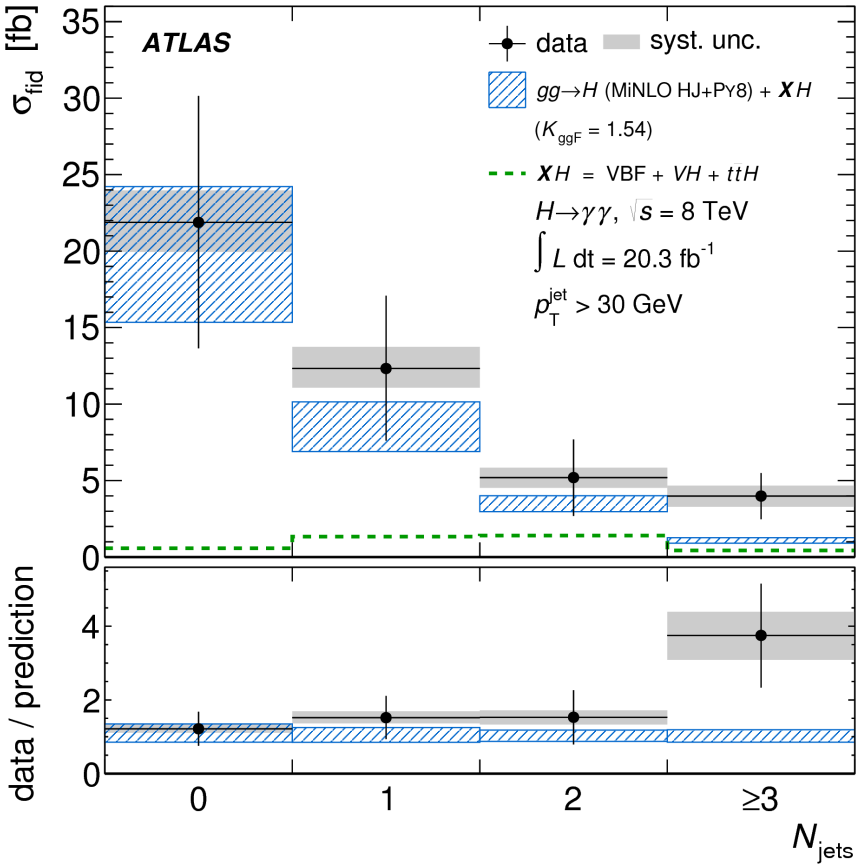

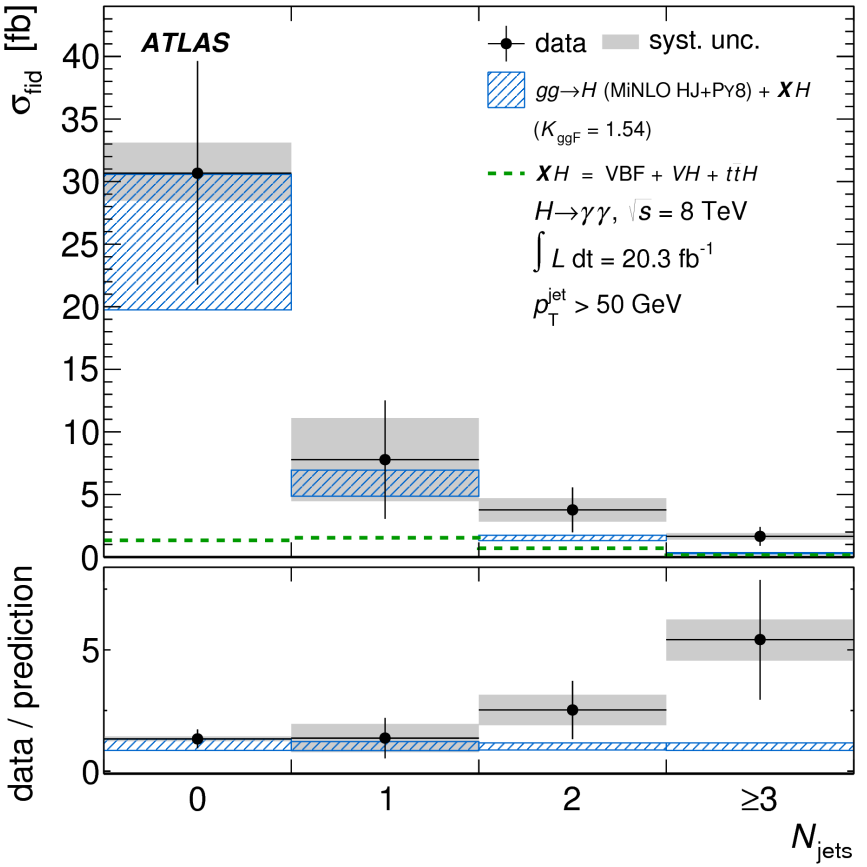

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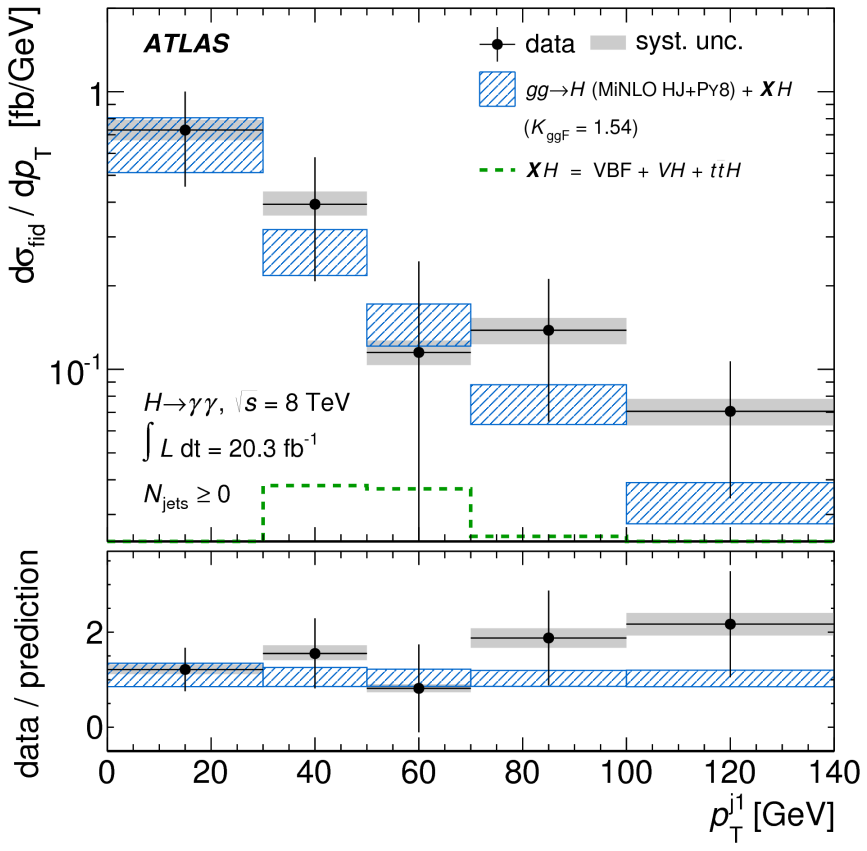

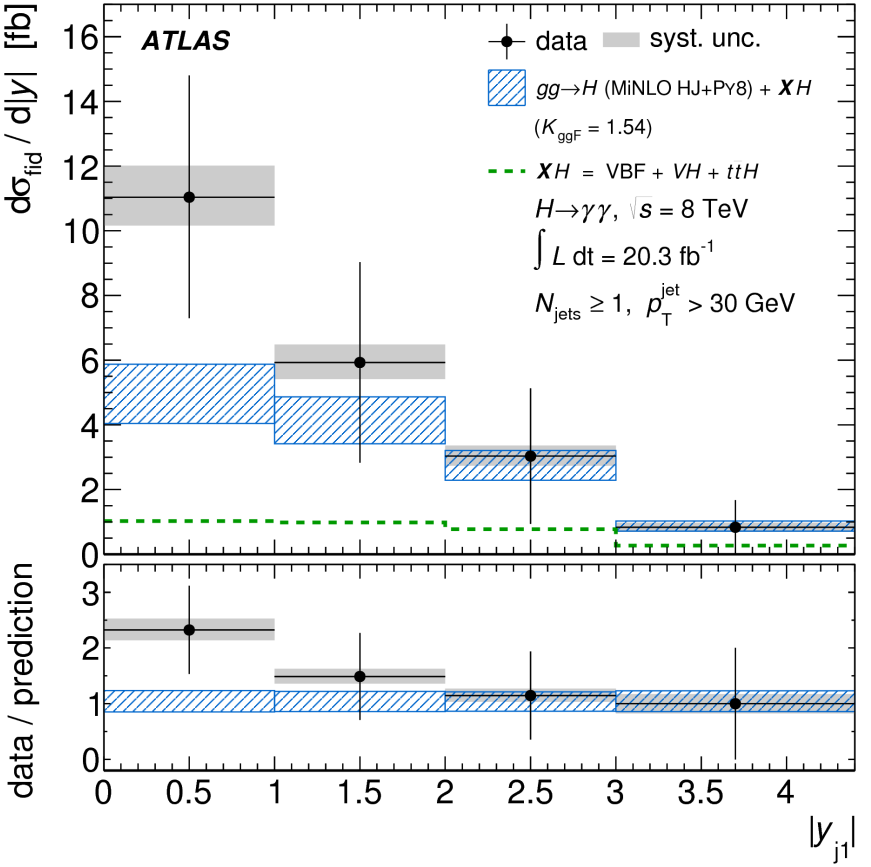

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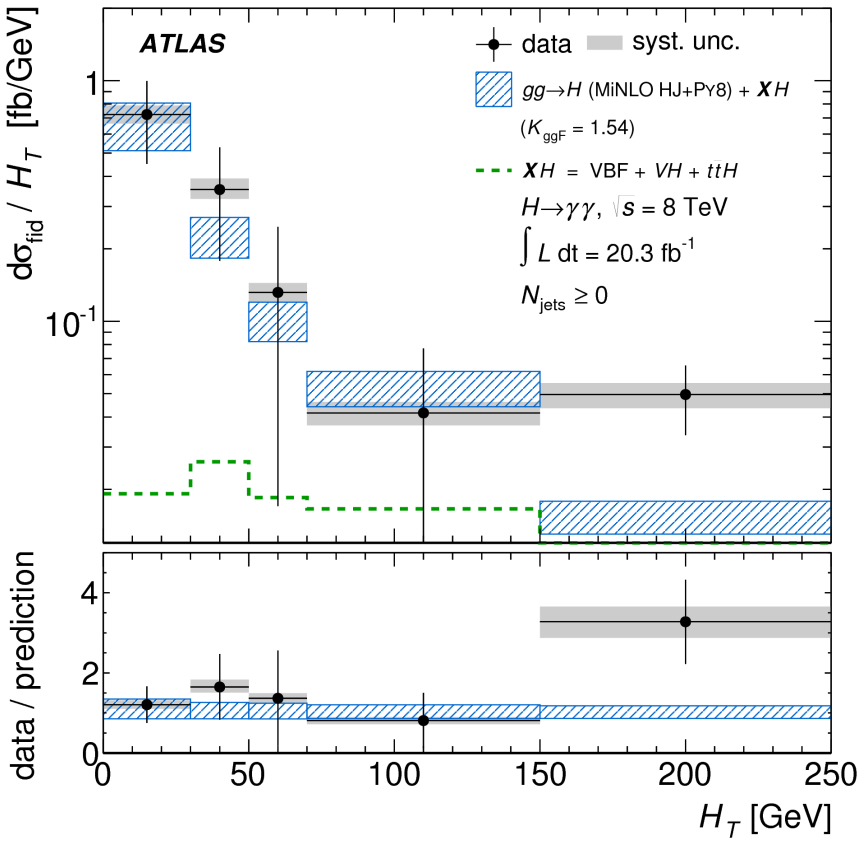

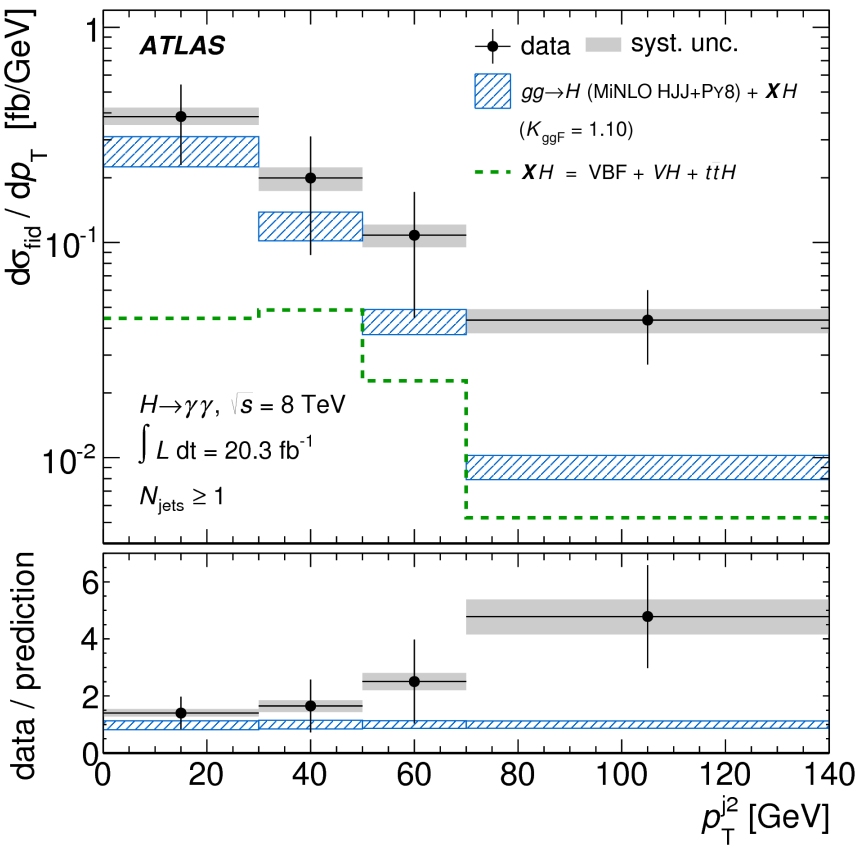

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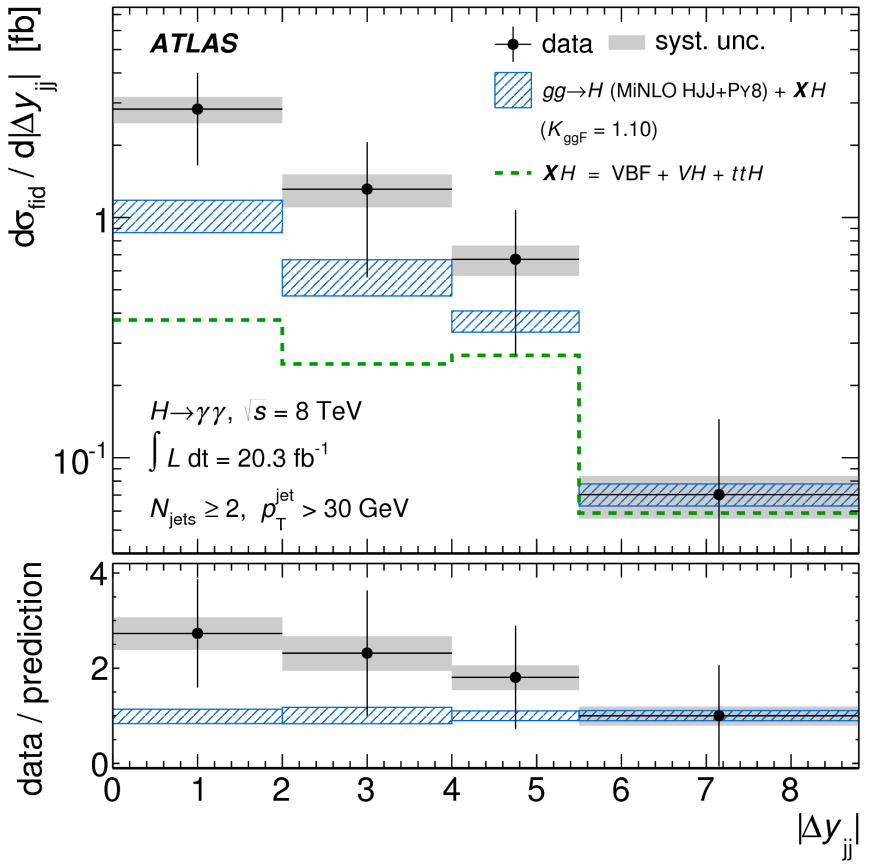

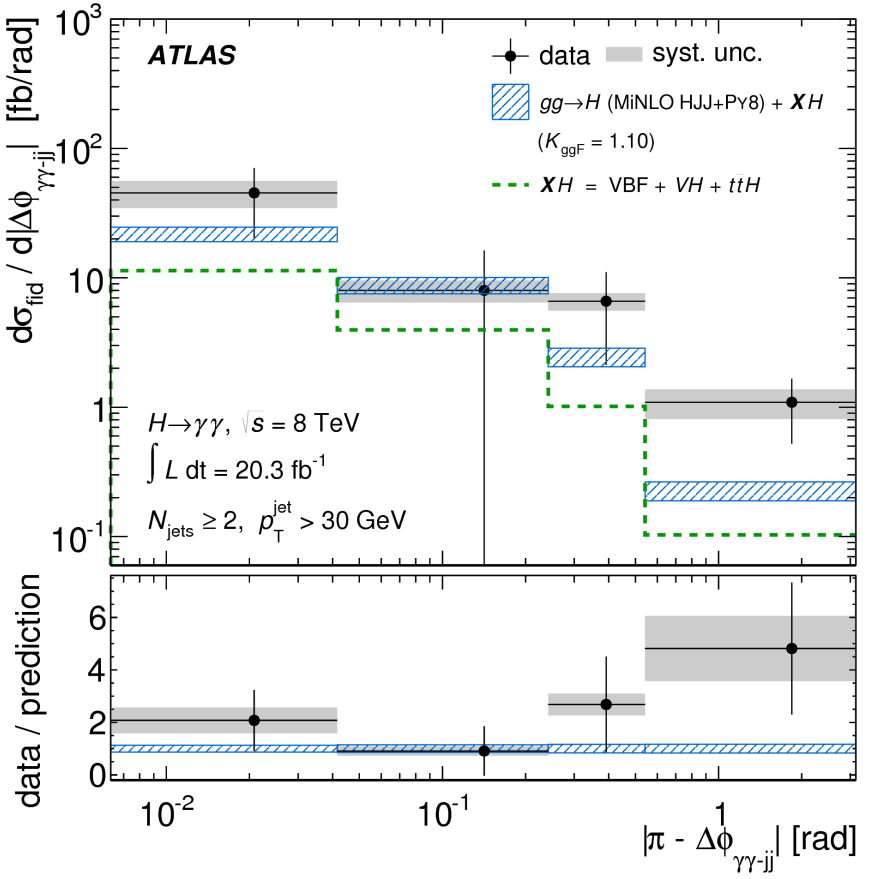

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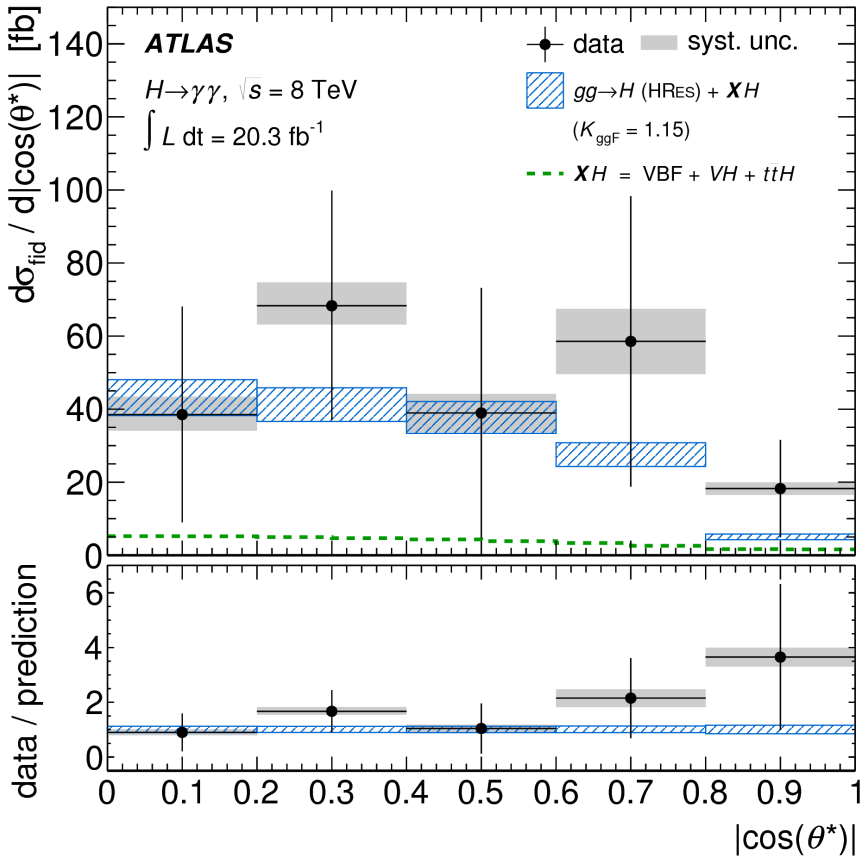

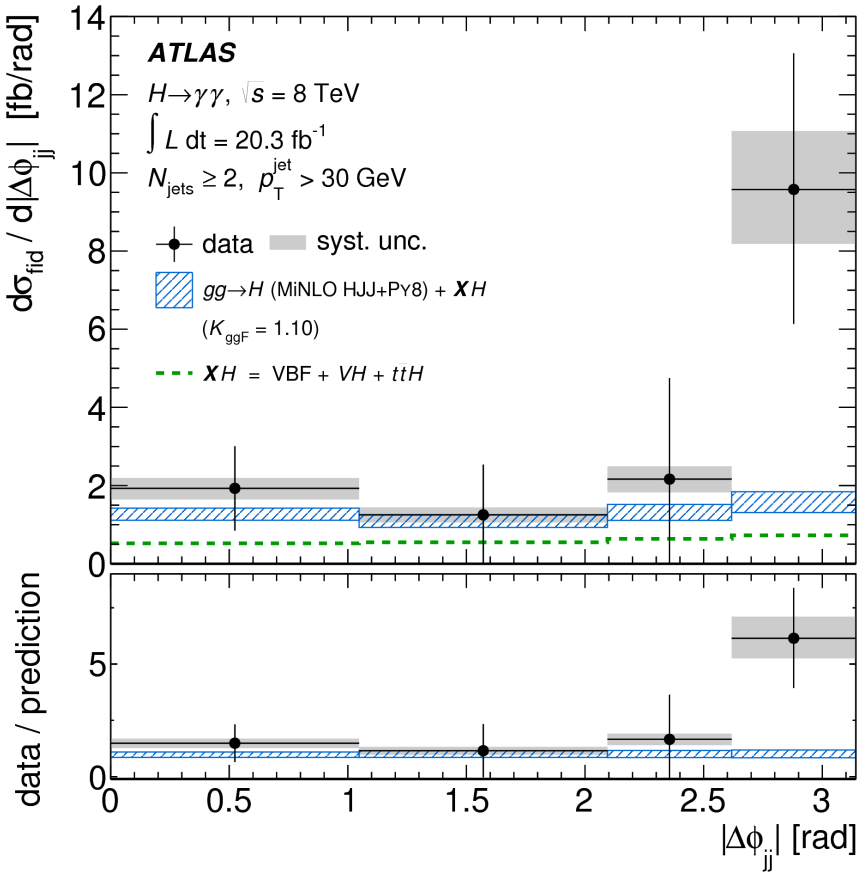

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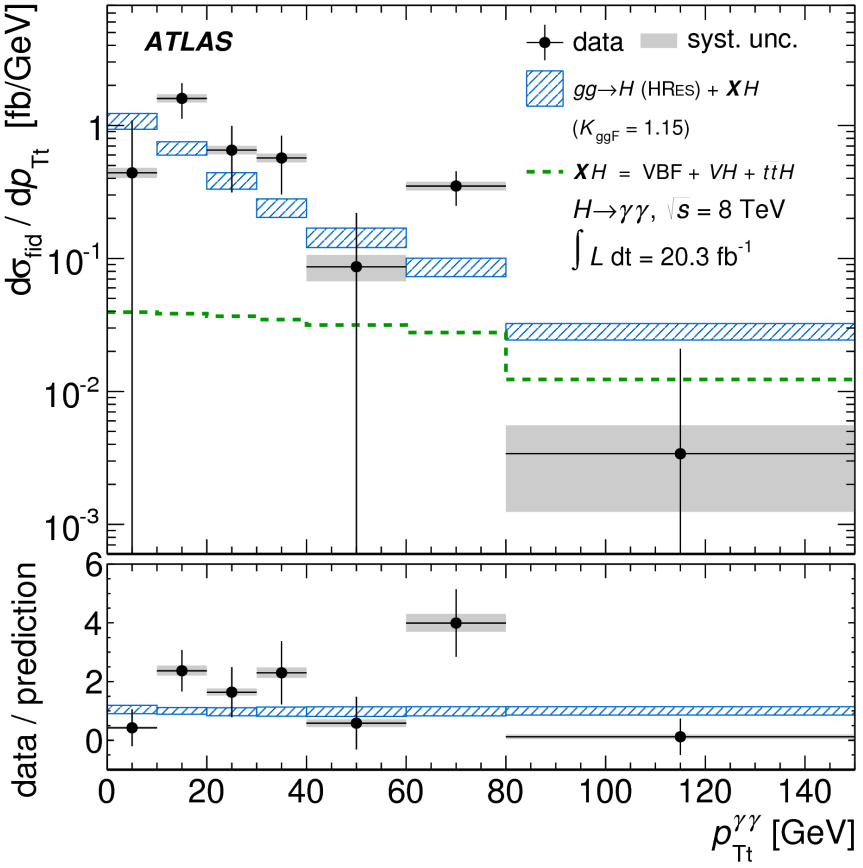

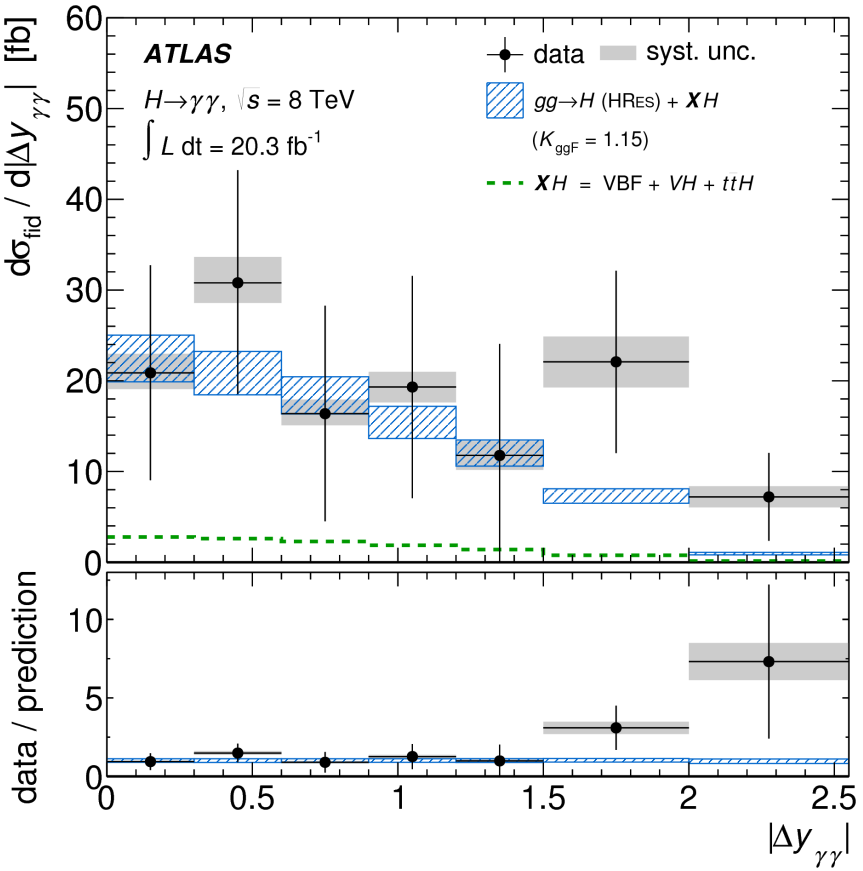

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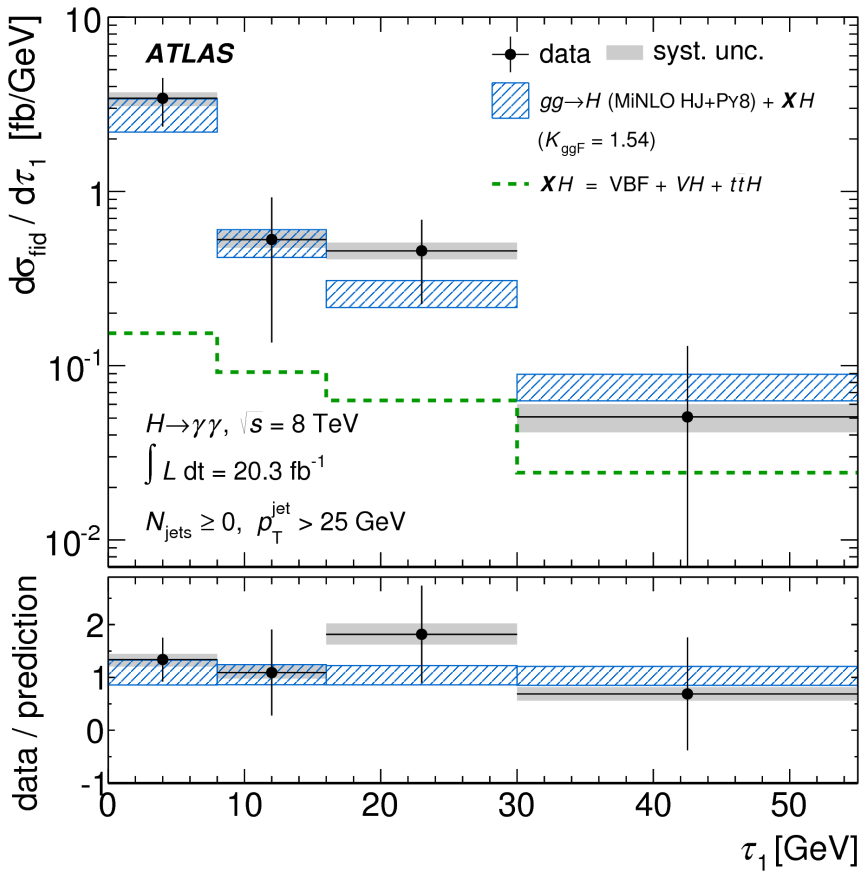

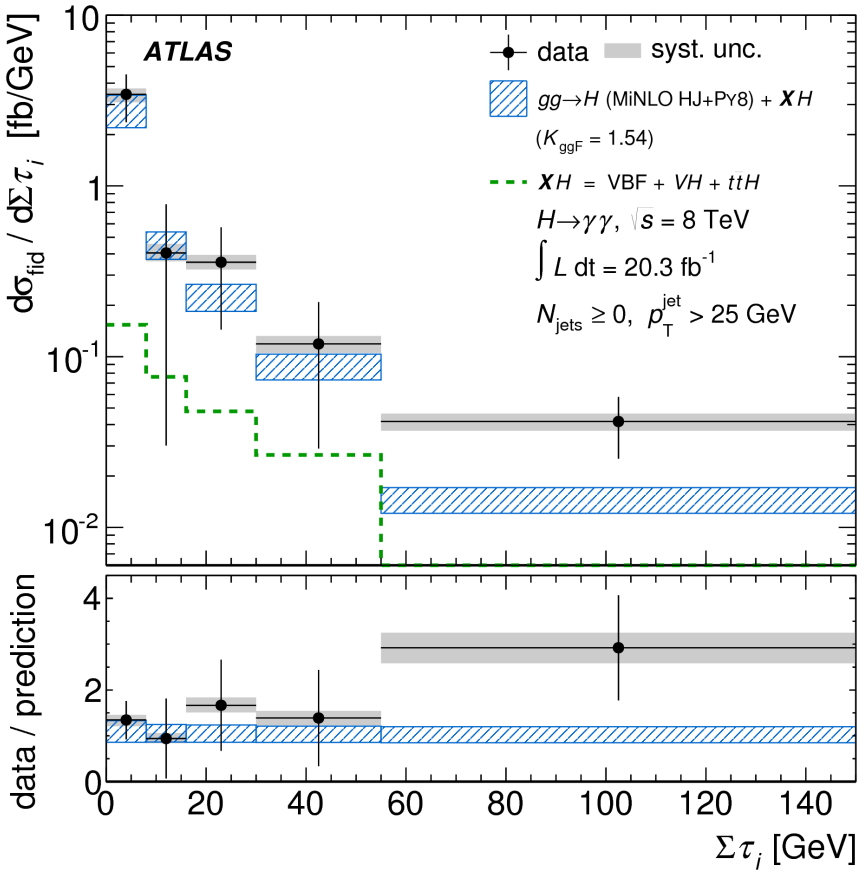

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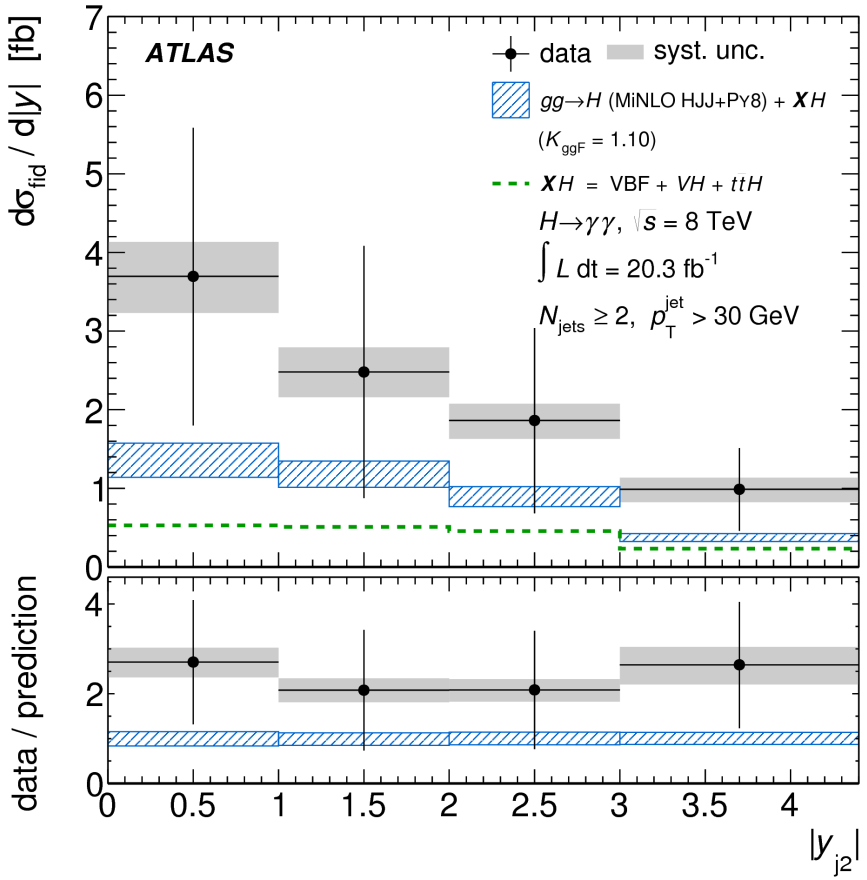

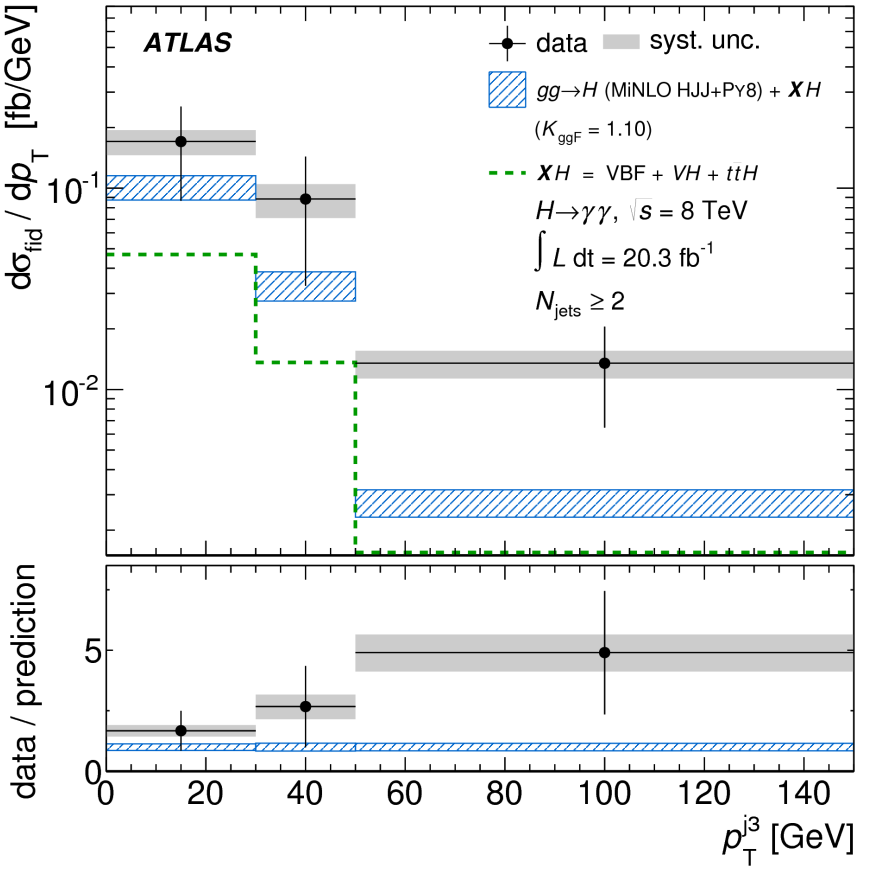

Differential cross sections

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