Measurement of Higgs boson cross sections and couplings in the diphoton decay channel at ATLAS at $\sqrt{s}$=13 TeV

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Outline

1) Introduction and experimental details
2) Measurement of fiducial and differential cross sections
3) Measurement of production cross sections

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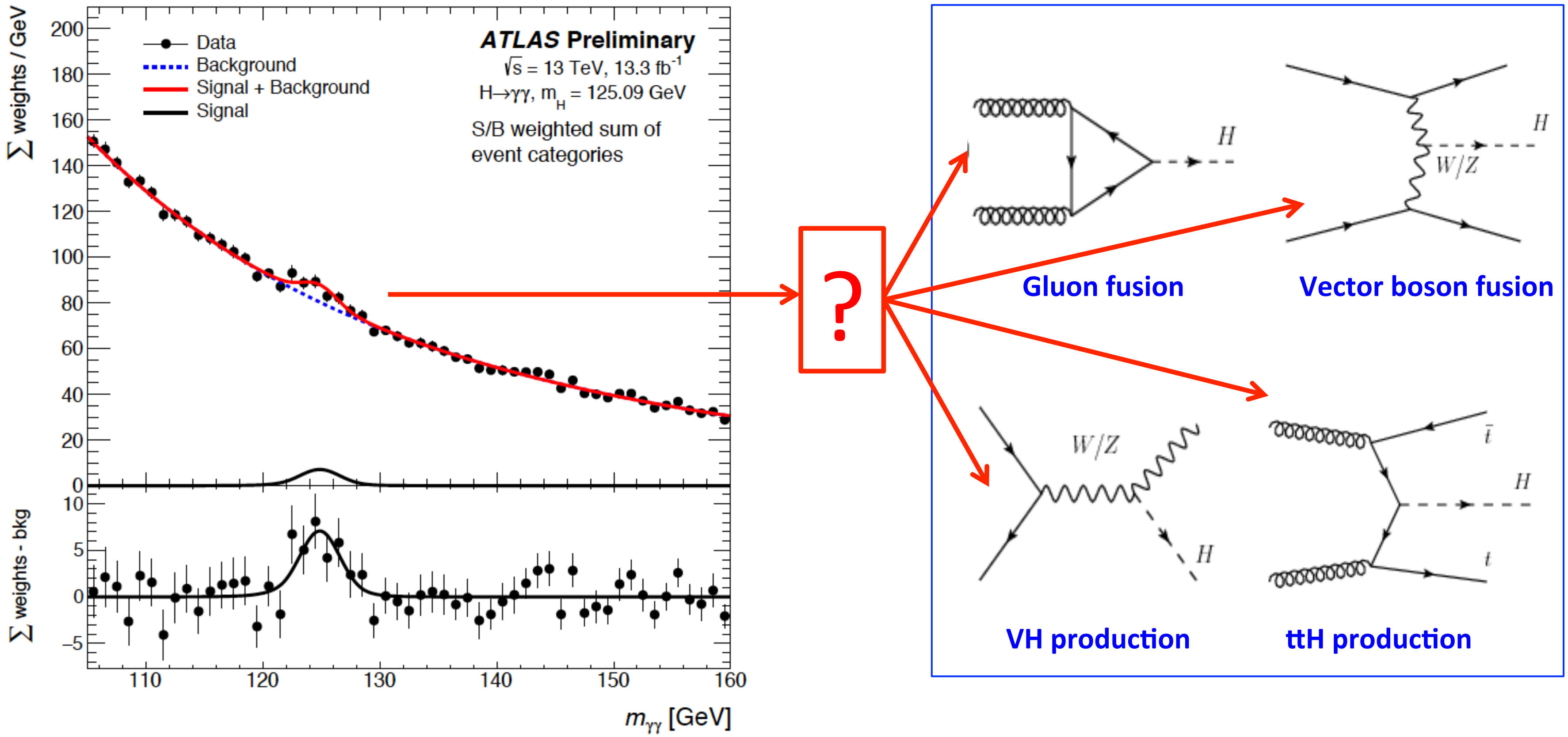
Higgs boson production at the LHC

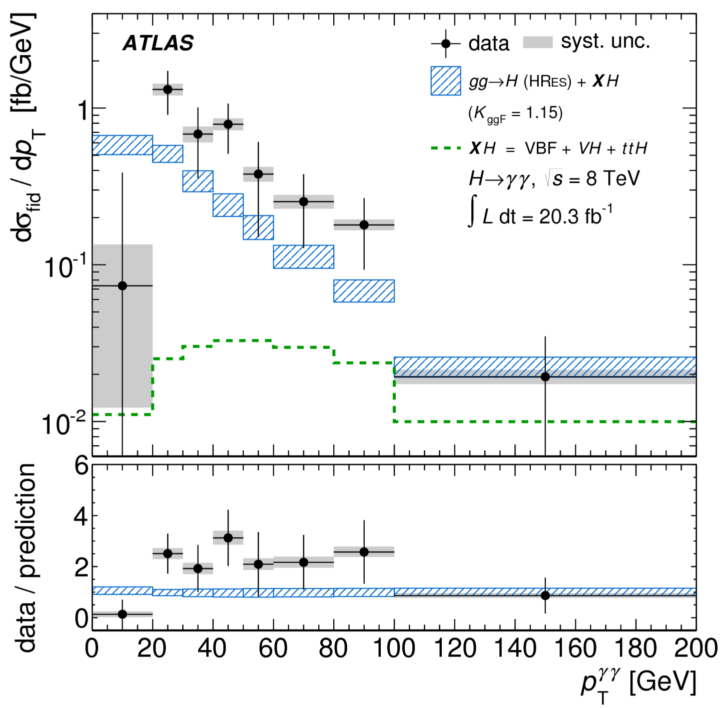


- Goal: try to extract information about the Higgs boson's couplings to other particles
  - Test the Standard Model prediction
  - Allow tests against any non-Standard Model prediction with anomalous Higgs couplings

Measurements of cross sections and couplings

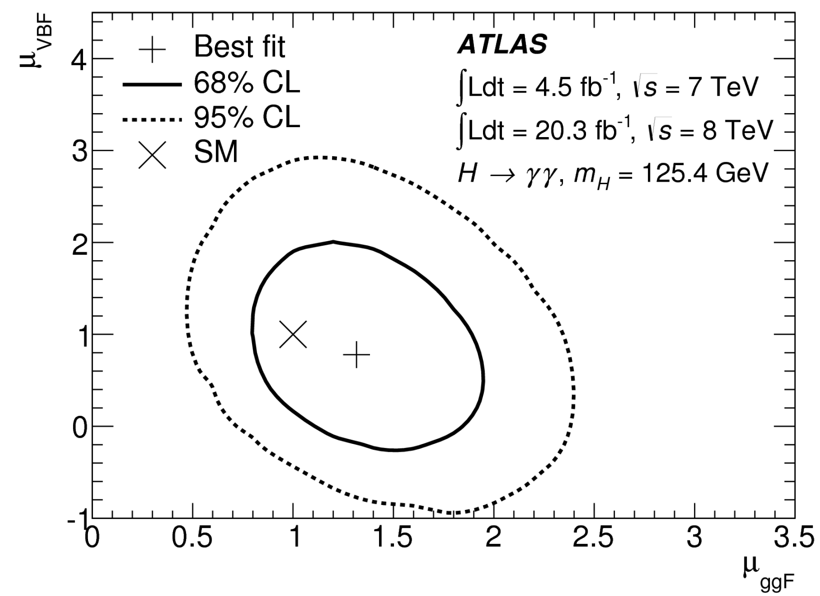
Fiducial and differential cross sections

- Event yields corrected for detector inefficiency and resolution
- Minimal dependence on theoretical modelling

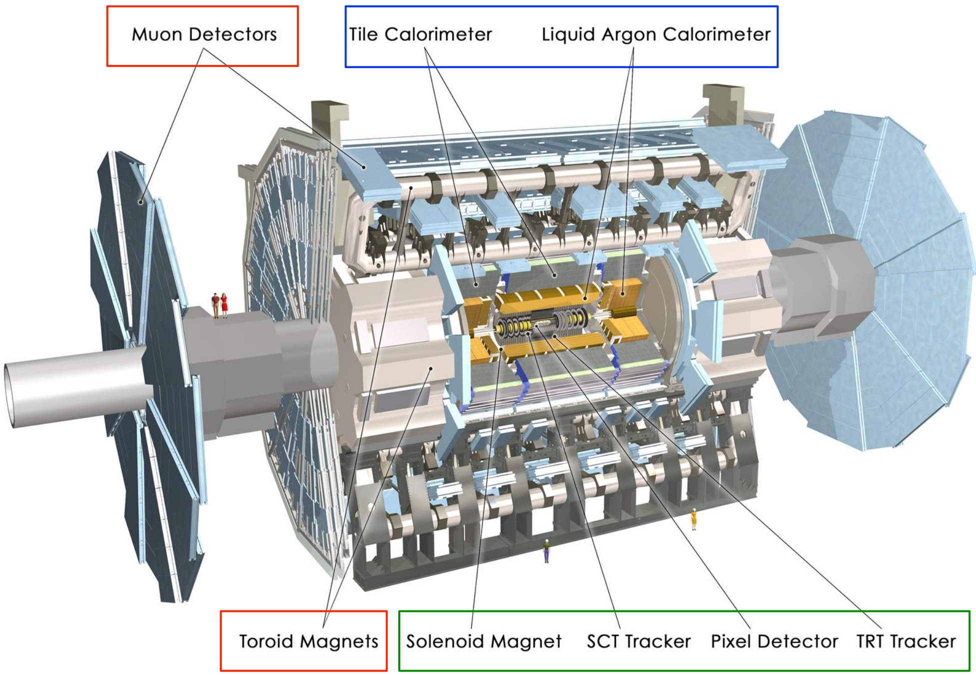


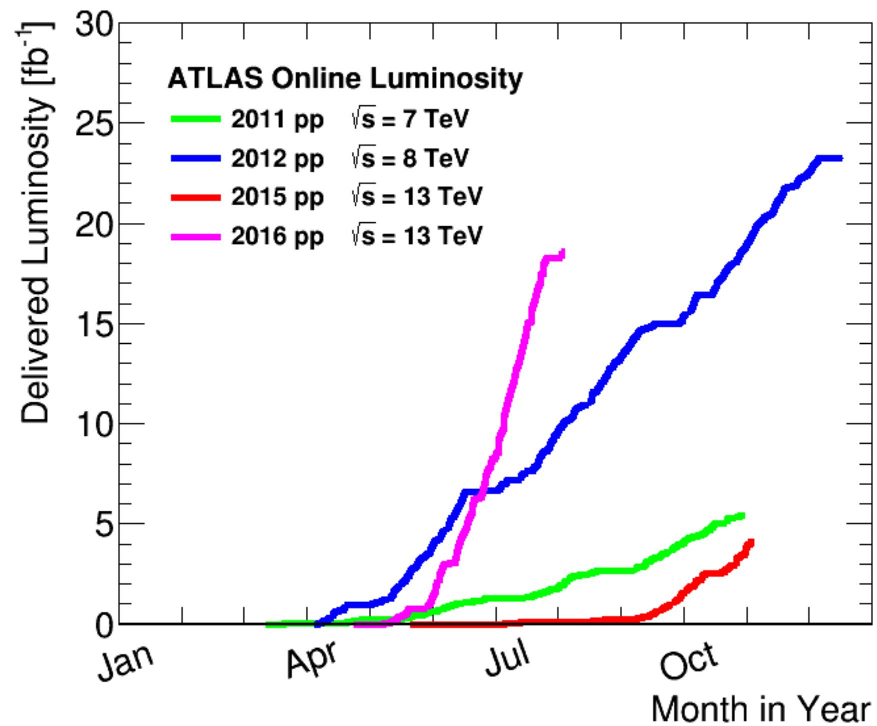
Production cross section and signal strength

- Exploit topological differences between Higgs boson production mechanisms
- Precision test of Higgs boson coupling strengths



ATLAS and the LHC in 2015/2016



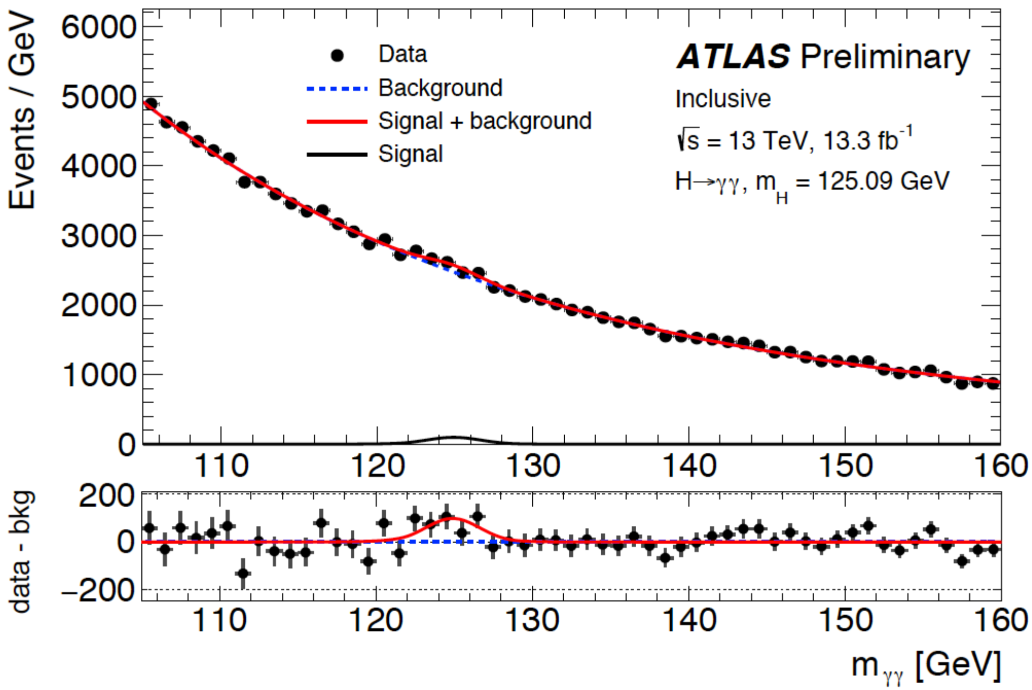


- Charged particle tracking system
- Electromagnetic and hadronic calorimetery
- Muon spectrometer

- Higher centre-of-mass energy:
  - Increased sensitivity to tails of differential distributions
  - Increased sensitivity to large partonic centre-of-mass (e.g ttH production)

Extraction of Higgs boson signal

- Signal extracted by fitting the diphoton invariant mass ($m_{\gamma\gamma}$) spectum
  - Selection: two isolated photons with $p_{T,1} > 0.35\ m_{\gamma\gamma}$, $p_{T,2} > 0.25\ m_{\gamma\gamma}$ and $|\eta| < 2.37$ (excuding $1.37 < |\eta| < 1.52$)



  - Signal model: double-sided Crystal Ball (parameters from simulation)
  - Background model: exponential of polynomial, or Bernstein polynomial
  - Dominant systematic: photon energy resolution and background choice bias.

Measurement of fiducial and differential cross sections

Fiducial and differential cross section methodology

- Aim: measure detector-corrected event yields without imposing theory assumptions

$$\sigma_i = \frac{\nu_i^{\mathrm{sig}}}{c_i \int L \, \mathrm{d}t}$$

- σ_i: Cross section in a fiducial region, or bin of a differential distribution
- ν_i^{sig}: Number of signal events observed in the data
- c_i: Correction for detector resolution and inefficiency
- $\int L \, \mathrm{d}t$: Integrated luminosity of the dataset

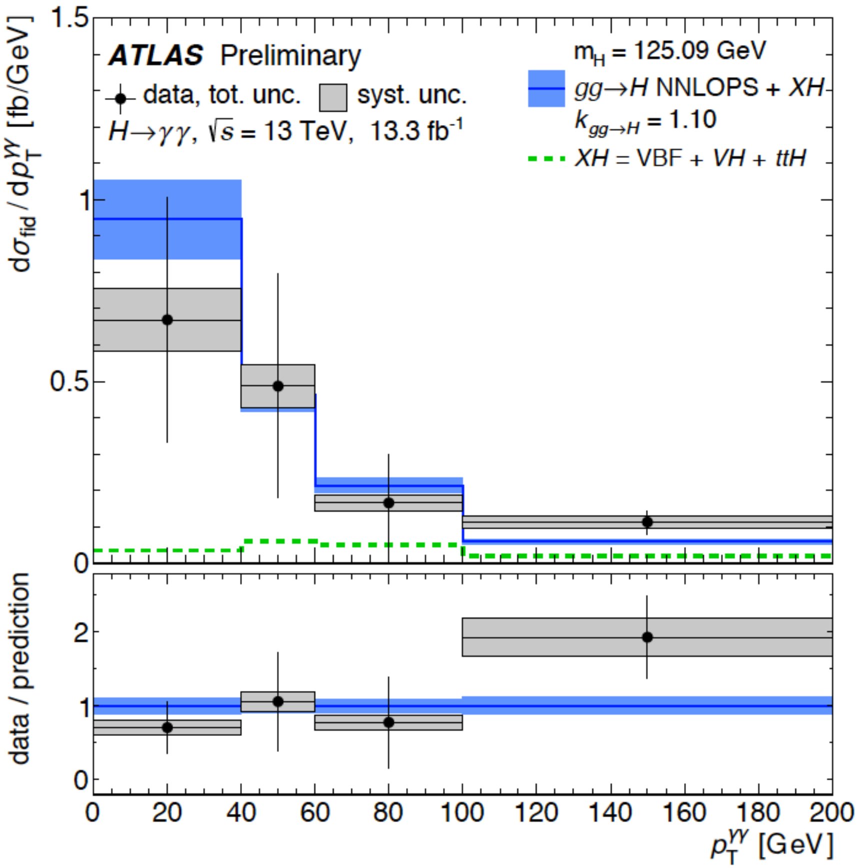
- The correction factor is the ratio of events reconstructed at detector-and particle-levels
  - model dependence minimised by applying the same object selection at particle-level
  - main experimental uncertainties from photon efficiency and jet energy scale

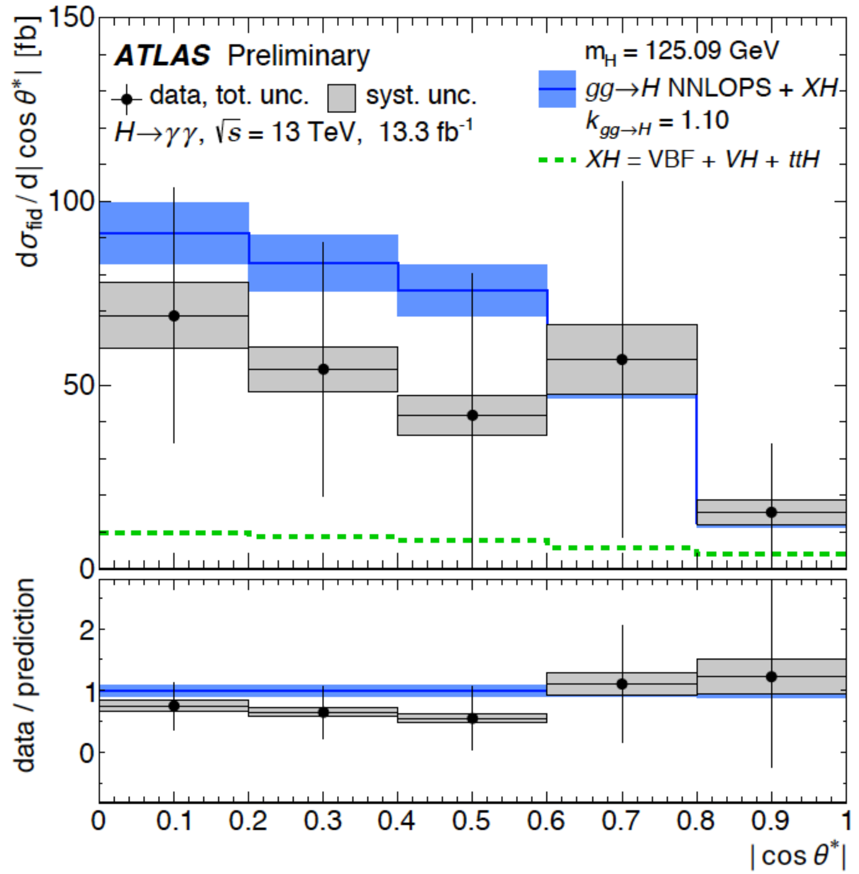
Fiducial cross sections

Fiducial region	Measured cross section (fb)	SM prediction (fb)	
Baseline	$43.2 \pm 14.9\,(\text{stat.}) \pm 4.9\,(\text{syst.})$	$62.8^{+3.4}_{-4.4}$	[N^3LO + XH]
VBF-enhanced	$4.0 \pm 1.4\,(\text{stat.}) \pm 0.7\,(\text{syst.})$	2.04 ± 0.13	[NNLOPS + XH]
single lepton	$1.5 \pm 0.8\,(\text{stat.}) \pm 0.2\,(\text{syst.})$	0.56 ± 0.03	[NNLOPS + XH]

	diphoton baseline	VBF enhanced	single lepton
Photons	$\lvert\eta\rvert < 1.37$ or $1.52 < \lvert\eta\rvert < 2.37$ $p_T^{\gamma_1} > 0.35\, m_{\gamma\gamma}$ and $p_T^{\gamma_2} > 0.25\, m_{\gamma\gamma}$		
Jets	- - -	$p_T > 30$ GeV , $\lvert y\rvert < 4.4$ $m_{jj} > 400$ GeV, $\lvert\Delta y_{jj}\rvert > 2.8$ $\lvert\Delta\phi_{\gamma\gamma,jj}\rvert > 2.6$	- - -
Leptons	-	-	$p_T > 15$ GeV $\lvert\eta\rvert < 2.47$

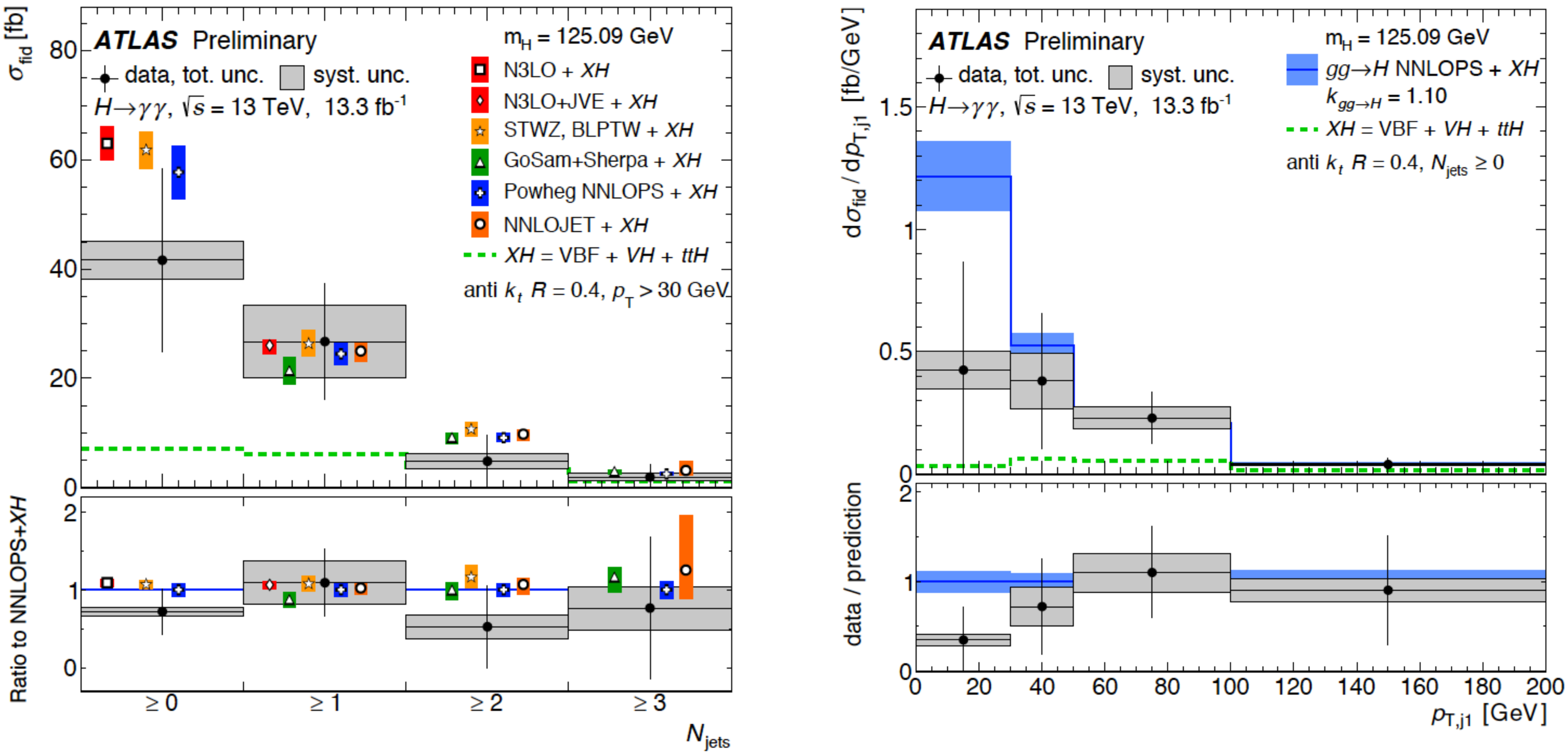
Higgs boson kinematics





- Good agreement between data and theory
  - very slightly harder Higgs p_T spectrum in data as in Run-I (left)
  - data in agreement with theory expectation for scalar CP-even particle (right)

Jet activity

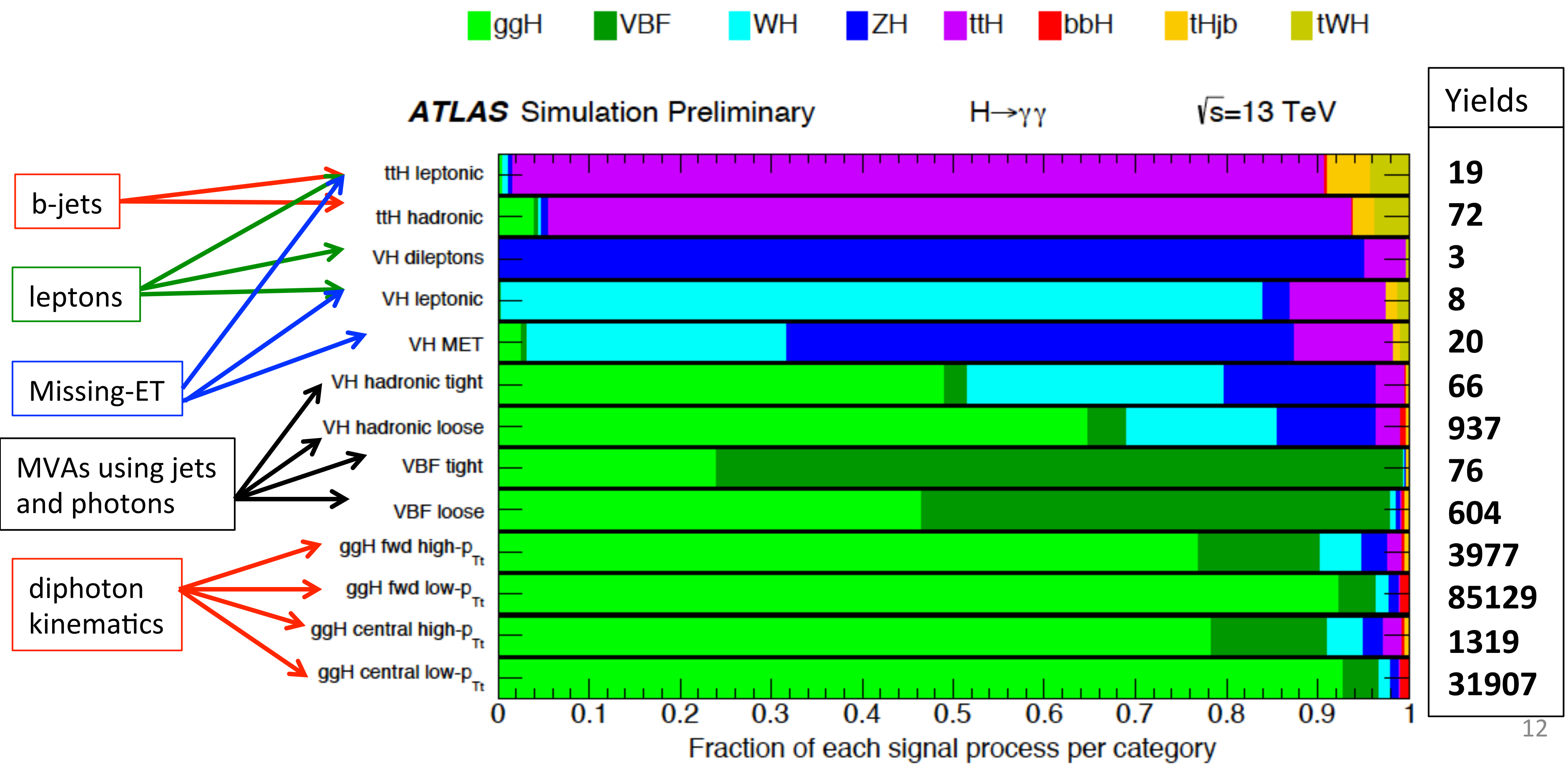


- Good agreement between data and theory
  - Data in agreement with state-of-art theory predictions

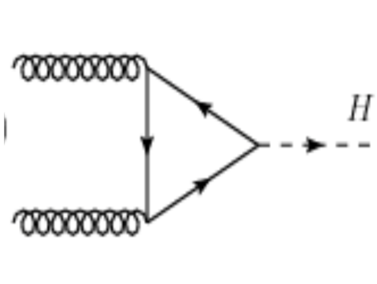
Measurement of production cross sections

Production cross section and signal strength methodology (I)

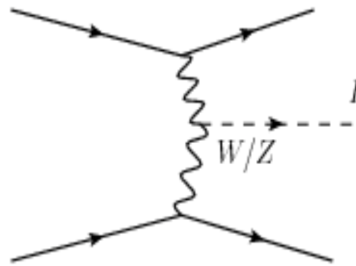
- Events are split into 13 orthogonal categories that exploit topological differences between production mechanisms



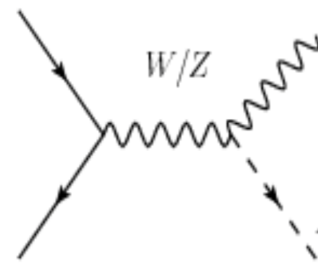
Production cross section and signal strength methodology (II)



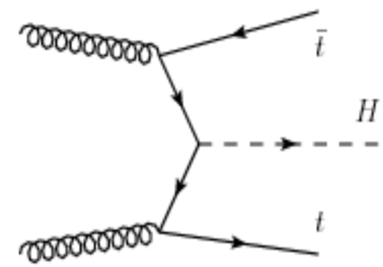
Gluon fusion



Vector boson fusion



VH production



ttH production

- Production cross section extracted by a combined fit to $m_{\gamma\gamma}$ specta

$$N_k^{\mathrm{sig}} = \sum_i \sigma_i \cdot \mathcal{B}(H \to \gamma\gamma) \cdot \epsilon_{ik} \cdot A_{ik} \cdot \int L\,\mathrm{d}t$$

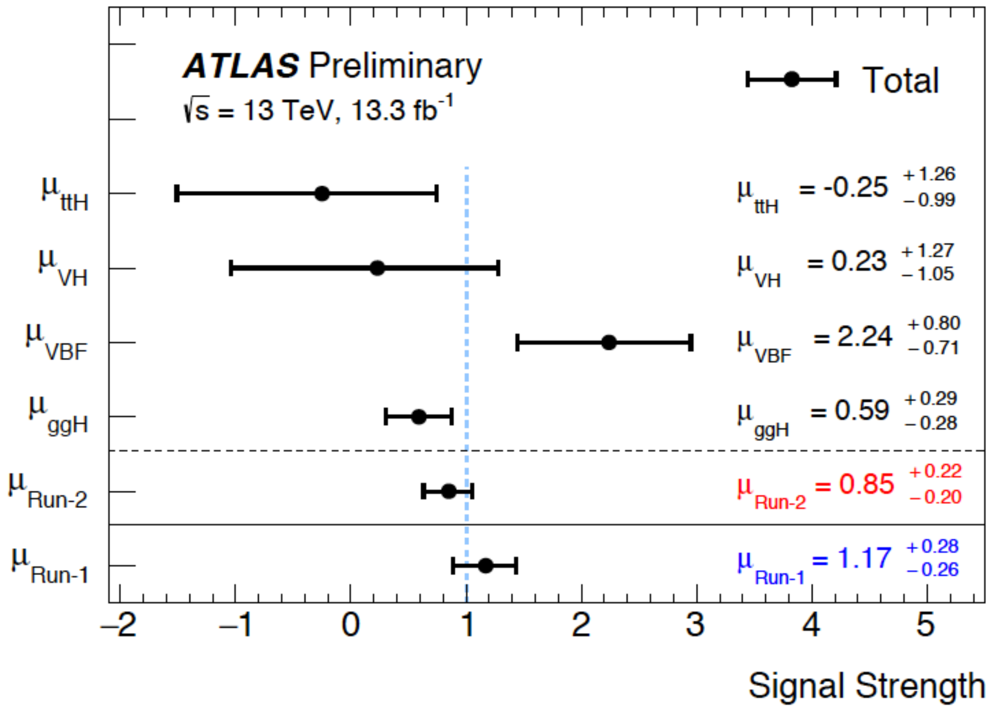
Signal yield in specified category

Production cross section times branching ratio for given process

Acceptance predicted by SM for given process in specified category

- Dominant uncertainty again from photon energy scale/resolution in fit
- Large uncertainty from theoretical modelling of acceptances, especially for gluon fusion in VBF-enriched categories

Production cross section and signal strength measurements



Total Higgs production cross section

$$\sigma_{ggH} \times \mathcal{B}(H \to \gamma\gamma) = 65\ ^{+32}_{-31}\ \text{fb}$$

$$\sigma_{\text{VBF}} \times \mathcal{B}(H \to \gamma\gamma) = 19.2\ ^{+6.8}_{-6.1}\ \text{fb}$$

$$\sigma_{\text{VH}} \times \mathcal{B}(H \to \gamma\gamma) = 1.2\ ^{+6.5}_{-5.4}\ \text{fb}$$

$$\sigma_{t\bar{t}H} \times \mathcal{B}(H \to \gamma\gamma) = -0.28\ ^{+1.44}_{-1.12}\ \text{fb}$$

Higgs production cross section ($|y_H|<2.5$)

$$\sigma_{ggH} \times \mathcal{B}(H \to \gamma\gamma) = 63\ ^{+30}_{-29}\ \text{fb}$$

$$\sigma_{\text{VBF}} \times \mathcal{B}(H \to \gamma\gamma) = 17.8\ ^{+6.3}_{-5.7}\ \text{fb}$$

$$\sigma_{\text{VHlep}} \times \mathcal{B}(H \to \gamma\gamma) = 0.96\ ^{+2.52}_{-1.90}\ \text{fb}$$

$$\sigma_{\text{VHhad}} \times \mathcal{B}(H \to \gamma\gamma) = -2.3\ ^{+6.8}_{-5.8}\ \text{fb}$$

$$\sigma_{t\bar{t}H} \times \mathcal{B}(H \to \gamma\gamma) = -0.28\ ^{+1.43}_{-1.12}\ \text{fb}$$

Summary

- Higgs boson properties measured at $\sqrt{s}$=13 TeV in the H->γγ decay channel
  - Data in reasonable agreement with the Standard Model predictions

- Two different but complementary approaches:
  - Fiducial and differential cross sections are the most model independent characterisation of the events we see in the detector
  - Production cross section and signal strengths probe the Higgs couplings directly

- Run-II has only just started in earnest!
  - O(100fb^{-1}) of data by end of 2018 (=factor of 3 reduction in statistical uncertainty)

- Additional ATLAS H->γγ results at ICHEP 2016:
  - Combination with other decay channels: Bertrand La Forge (talk)
  - More fiducial/differential cross section information: Cong Peng (poster)
  - Higgs coupling to dark matter: Steven Schramm (talk) Andrew Hard (poster)

Backup

Selection of diphoton candidate events

H -> γγ candidates

Two reconstructed photons with:

- $p_{T,1} > 0.35\ m_{\gamma\gamma}$ and $p_{T,2} > 0.25\ m_{\gamma\gamma}$
- $|\eta| < 2.37$ (excuding $1.37 < |\eta| < 1.52$)
- $105 < m_{\gamma\gamma} < 160$ GeV
- Isolated in tracker can calorimeter

In total 124137 diphoton events selected

Additional object selection

Jets (anti-k_T, R=0.4):

- $p_T > 25$ GeV for $|\eta| < 2.4$
- $p_T > 30$ GeV for $2.4 < |\eta| < 4.4$
- Jet vertex tagger used to reject pile-up
- b-jet tagger to identify heavy-flavour

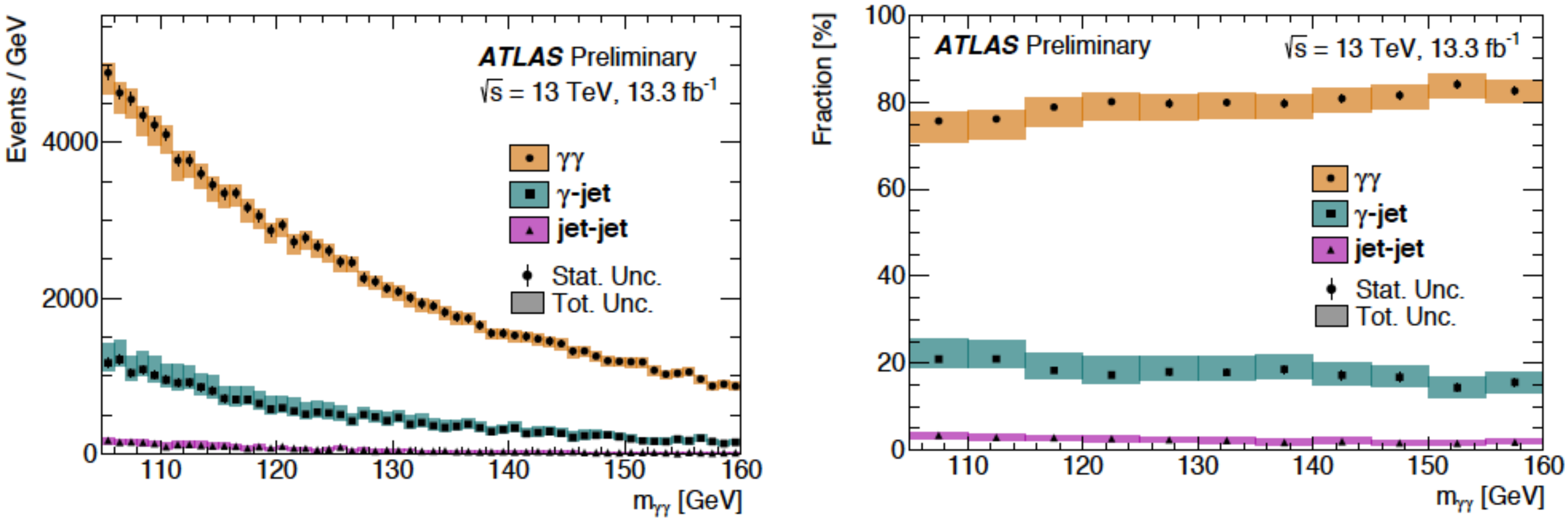
Muons: $p_T > 10$ GeV and $|\eta| < 2.7$

Electrons: $p_T > 10$ GeV and $|\eta| < 2.47$
(excluding $1.37 < |\eta| < 1.52$)

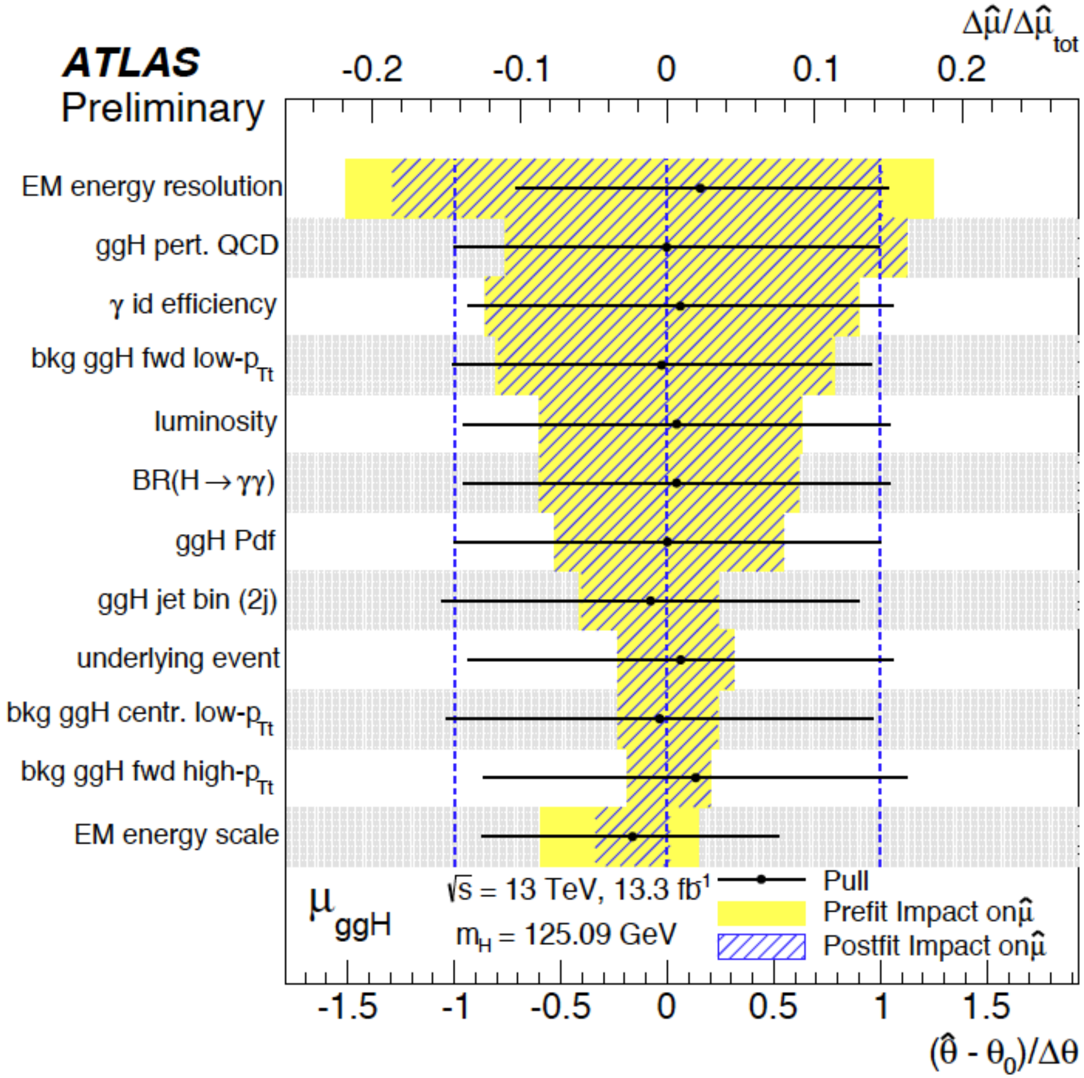
Missing transverse momentum reconstructed from photons, jets, leptons and tracks

Background decomposition

- Studied using a 2Dx2D sideband method -> 15 control regions and 1 signal region



Uncertainty in signal strength measurements



All uncertainties included as nuisance parameters in the fit to $m_{\gamma\gamma}$

Uncertainties in the fiducial cross section measurements

- Dominant systematic uncertainty is due to photon energy resolution, which changes the shape of the signal model
- Correction factor uncertainties include experimental sources (e.g photon ID, jet energy scale) and theoretical sources (e.g. production mode composition)

Source	Uncertainty on fiducial cross section (%)		
	Baseline	VBF-enhanced	single-lepton
Fit (stat.)	34.5	35.0	52.9
Fit (syst.)	9.0	11.1	9.3
Photon efficiency	4.4	4.4	4.4
Jet energy scale/resolution	-	9.4	-
Lepton selection	-	-	0.8
Pileup	1.1	2.0	1.4
Theoretical modelling	4.3	9.4	8.4
Luminosity	2.9	2.9	2.9