Fiducial/differential cross sections measured in H->γγ at ATLAS

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Presented at the LHCHXS kick-off meeting on fiducial cross sections, CERN

Overview

1) Introduction and motivation
2) Experimental details
3) Results
4) Outlook for Run-II

JHEP09 (2014) 112 [arXiv:1407.4222v2]

Fiducial/differential cross sections

Cross section in a fiducial region (or bin of differential distribution)

Number of signal events observed in the data after selection cuts

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

Correction for detector resolution and inefficiency

Integrated luminosity of the dataset

Advantages of reporting data as fiducial cross sections

- The fiducial cross sections are the physical observables associated with the Higgs boson events that we actually observe in our detector.
  - Correct for detector effects such as inefficiency and resolution
  - Minimal extrapolation across outside of phase space

- Produce nearly model-independent measurement with:
  - Small dependence on the current status of the theory predictions
  - Sensitivity to different Higgs-boson production mechanisms
  - Sensitivity to the modelling of each production mechanism
  - Sensitivity to physics beyond the Standard Model in tails of distributions.

- Detector-corrected measurement available to the theory community:
  - HEPDATA record: http://hepdata.cedar.ac.uk/view/ins1306615
  - Rivet routine: https://rivet.hepforge.org/analyses#ATLAS_2014_I1306615
  - Natural way to preserve the data for longevity.

Event and object selection

H -> γγ diphoton baseline

- Two reconstructed photons
  - $p_{T,1} > 0.35\ m_{\gamma\gamma}$
  - $p_{T,2} > 0.25\ m_{\gamma\gamma}$
  - $|\eta| < 2.37$
  - Isolated in calorimeter and tracker
  - Tight photon identification

Jet selection

- Anti-k_T algorithm with R=0.4
  - $p_T > 30$ GeV, $|y| < 4.4$
  - No muons or neutrinos
- Overlap removal with photons/leptons using ΔR cuts
- Jet vertex fraction used to reject pile-up

Electrons and muons:

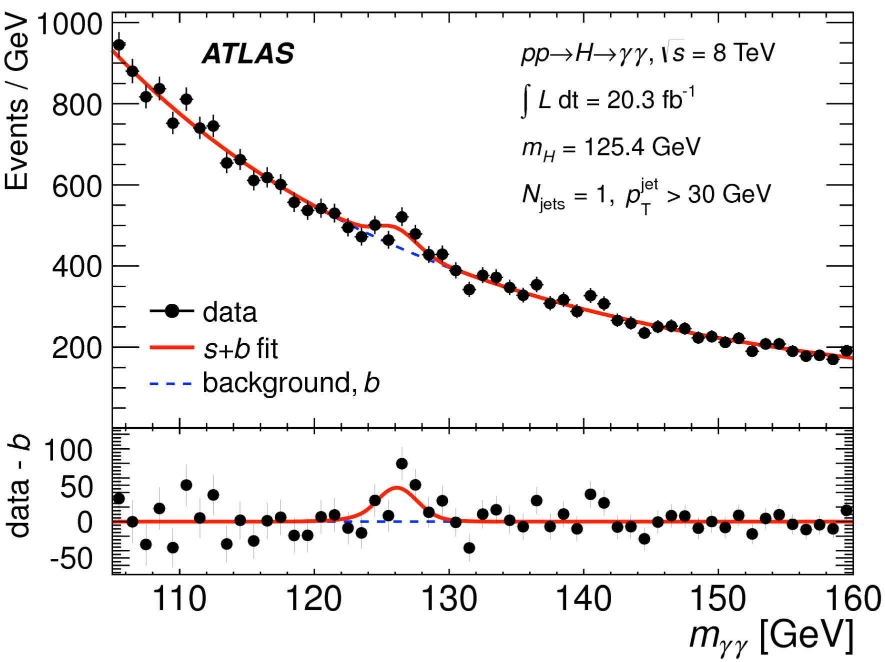
- $p_T > 15$ GeV, $|\eta| < 2.47$
- Electrons removed if overlap with photons using ΔR cuts
- Isolated in calorimeter and tracker

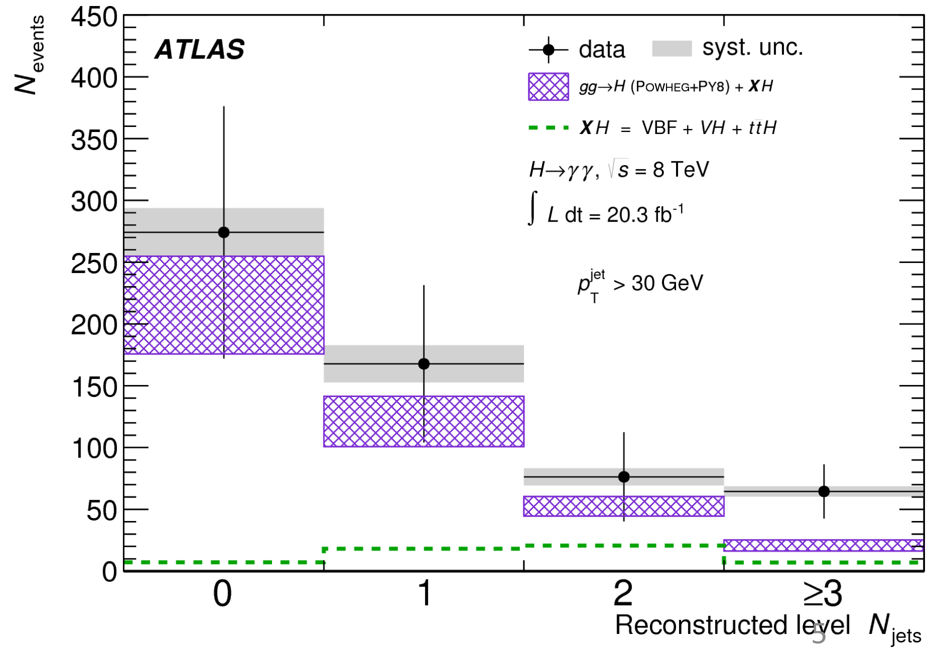
+ cuts to ensure good data quality, etc

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

Signal extraction (I)

- In each bin of a distribution:
  - unbinned maximum likelihood fit to $m_{\gamma\gamma}$
  - Signal model is a Crystal Ball plus a Gaussian (assume narrow resonance)
  - Background model an exponential of a polynomial (order 1,2 or 3), functional form chosen by minimising spurious signal extracted in background-only simulation



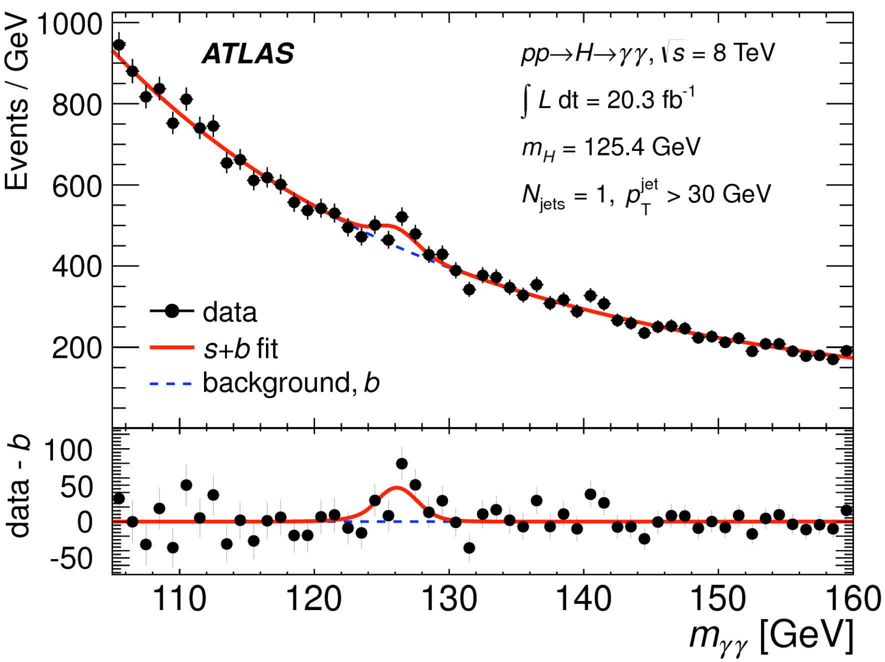


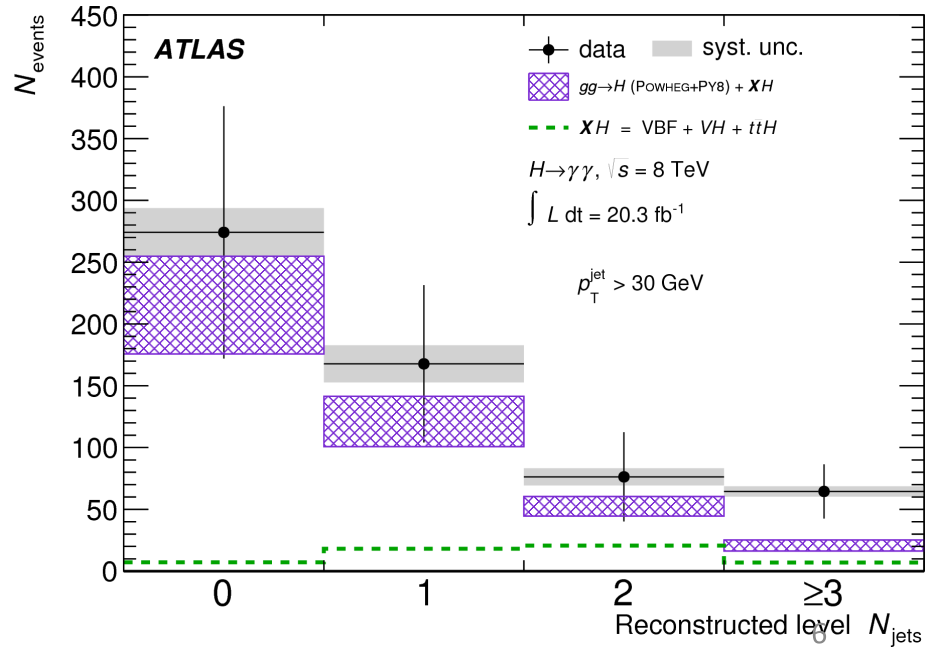
$$\sigma_i = \frac{\nu_i^{\text{sig}}}{c_i \int L\,\mathrm{d}t}$$

Signal extraction (II)

- Photon energy resolution and energy scale uncertainties included as nuisance parameters
- Choice of background modelling function affects peak position: also included in fit

- Total signal extraction uncertainty is 6.5% in the diphoton baseline region.





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

Correction for detector effects (I)

$$c_i = \frac{N_{\text{reco}}}{N_{\text{part}}}$$

Number of events selected at detector level (N_{reco})

Number of events selected at particle level (N_{part})

Particle-level definitions

- Particle level is defined using final state particles with $c\tau$ > 10mm
- Event/object selection chosen to be very close to the reconstruction-level cuts.

H -> γγ diphoton baseline

Two final state photons:

- $p_{T,1} > 0.35\, m_{\gamma\gamma}$,
- $p_{T,2} > 0.25\, m_{\gamma\gamma}$
- $|\eta| < 2.37$
- Isolated: sum of final state particle p_T in R=0.4 less than 14GeV (excluding μ, ν)

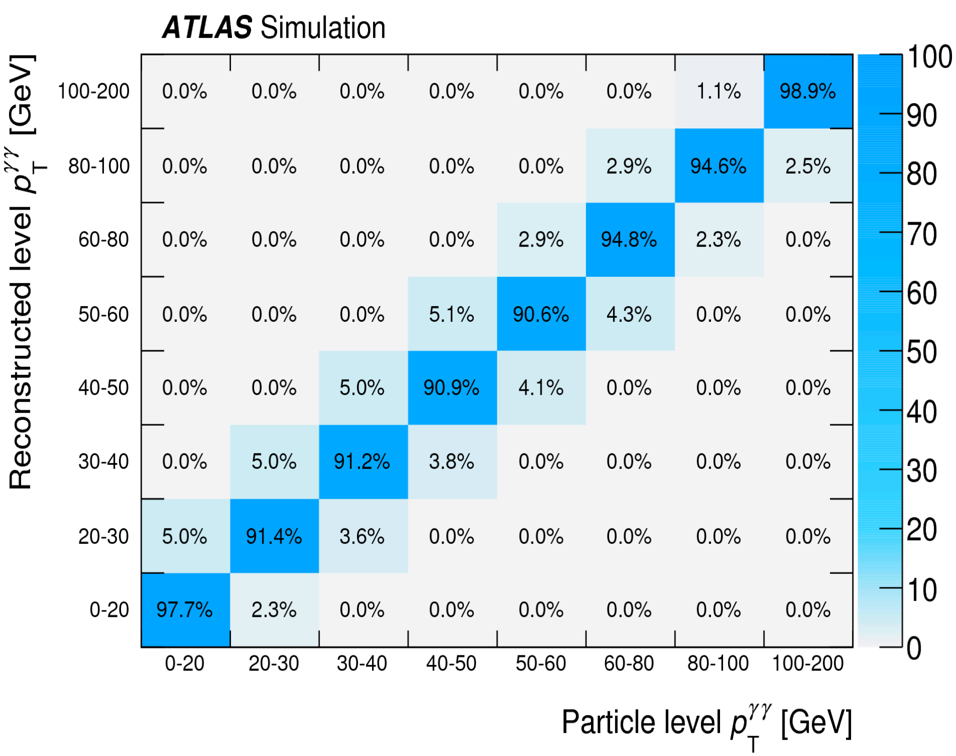
Jet selection

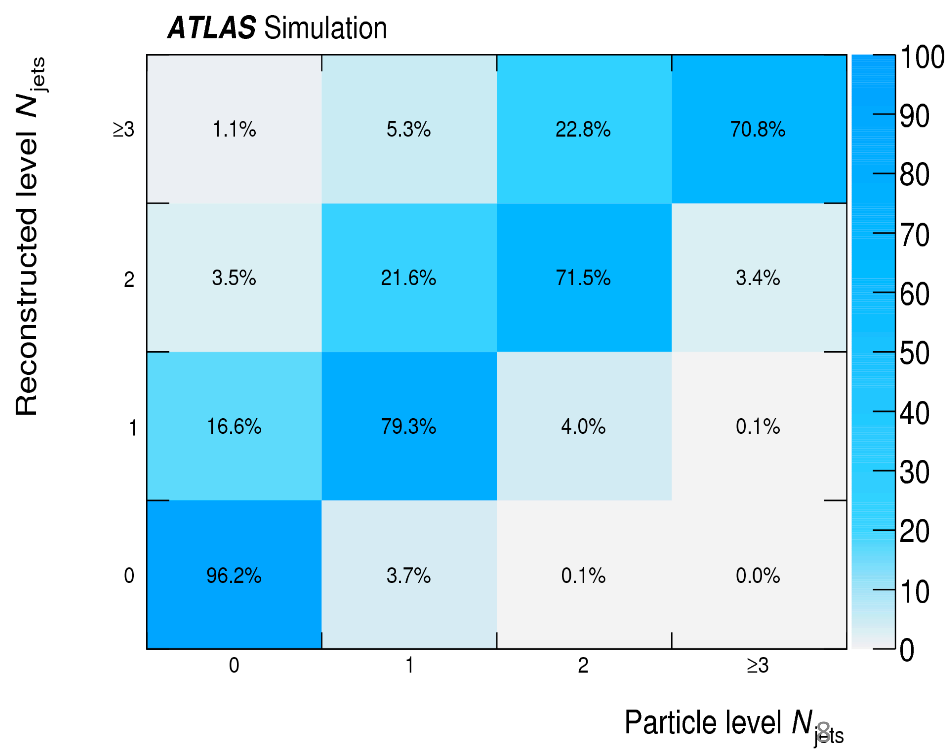
- Anti-k_T algorithm with R=0.4
  - Final state particles, no μ or ν
  - p_T > 30 GeV, $|y|$< 4.4
- Overlap removal with final-state photons and dressed leptons

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

Correction for detector effects (II)

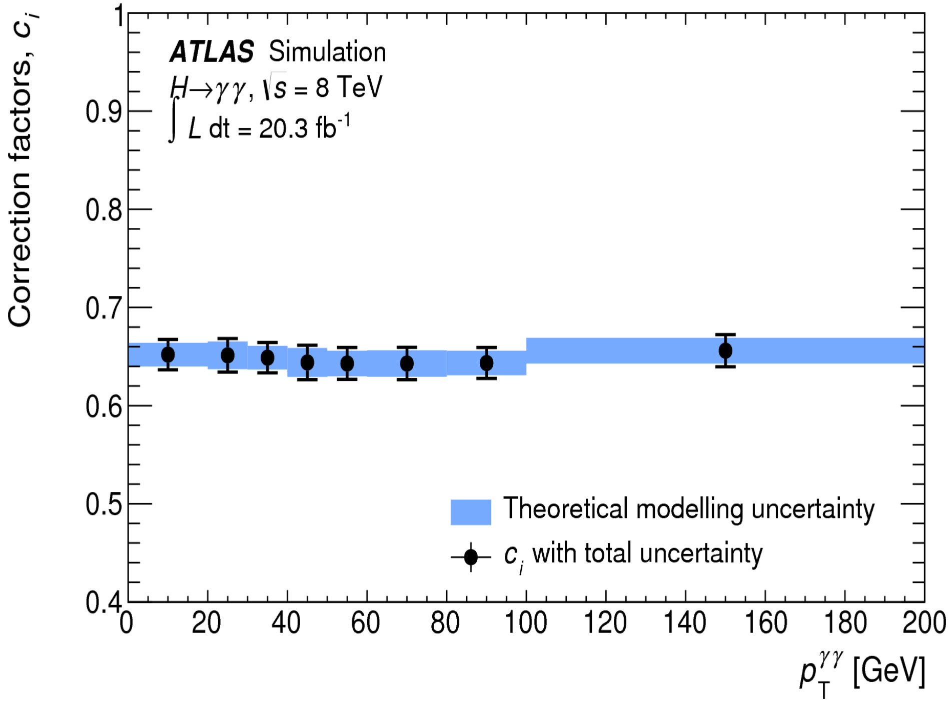
- Carefully checked the migrations and purities to justify bin-by-bin corrections
  - Inclusive variables have very little migration, purity of ~99%
  - Jet based variables have more migration, e.g. purity drops to 70% in some Njet bins

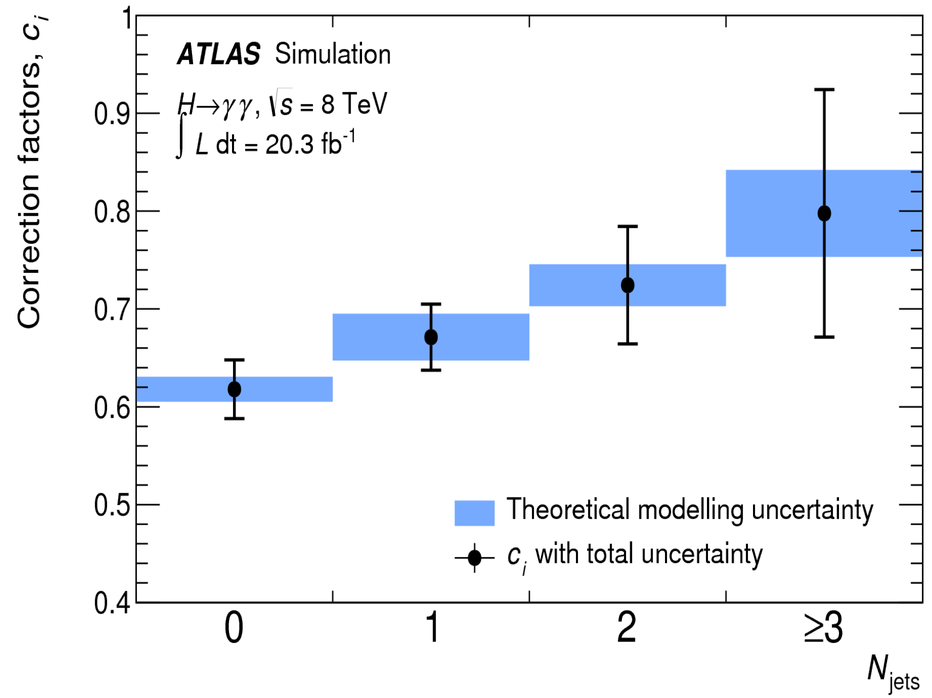




$$\sigma_i = \frac{\nu_i^{\text{sig}}}{c_i \int L\,\mathrm{d}t}$$

Correction for detector effects (III)

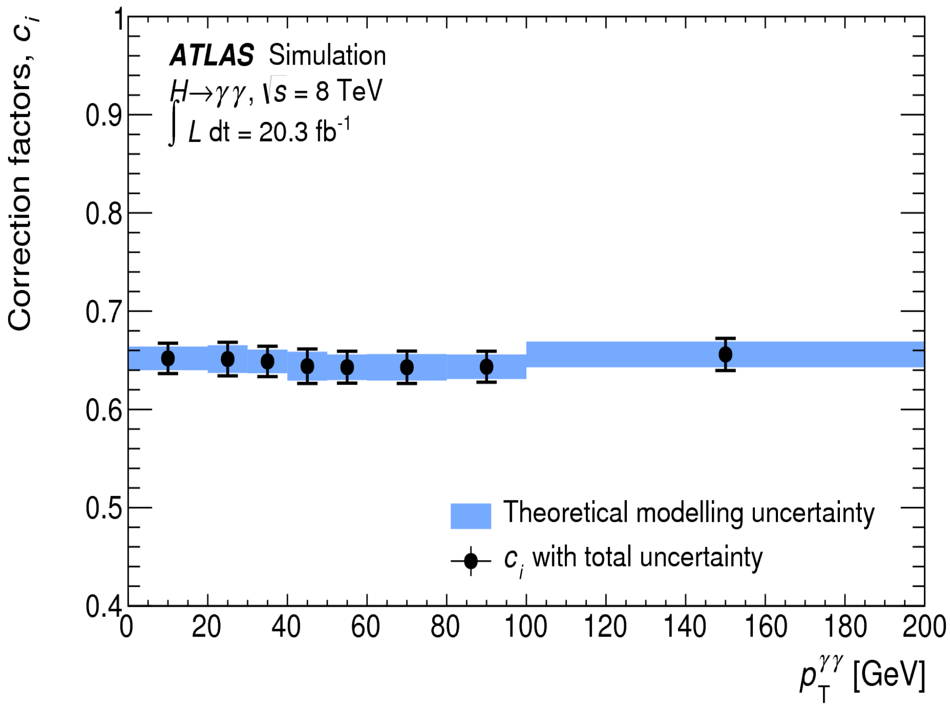


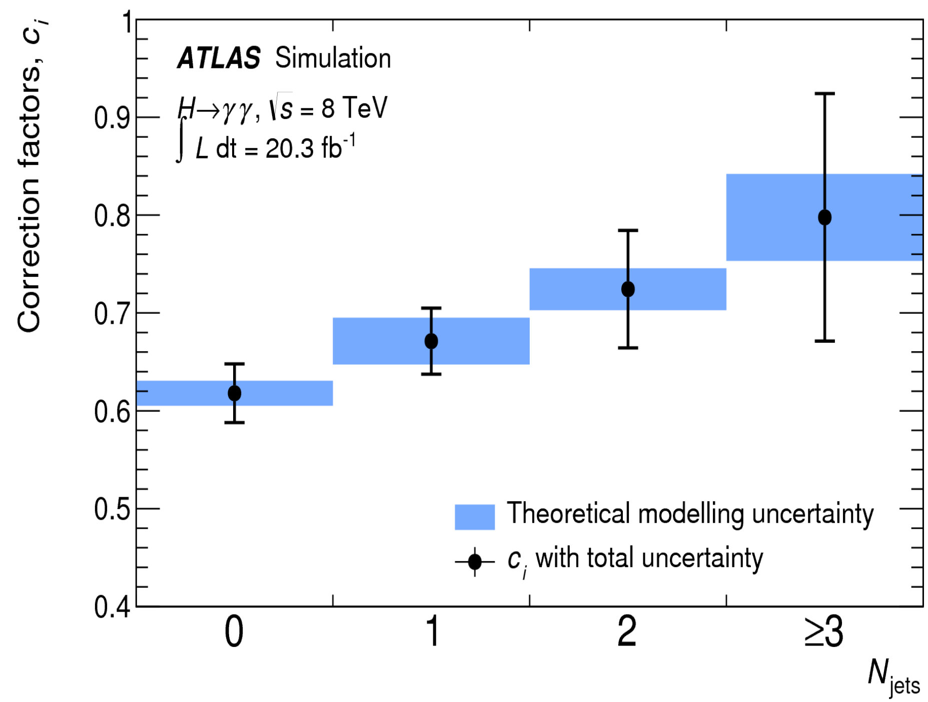


- Experimental uncertainties:
  - Photon energy scale, energy resolution, isolation and efficiency (trigger, identification)
  - Jet energy scale, resolution, jet vertex fraction efficiency and pile-up jet modelling
  - Lepton energy scale, resolution, identification

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

Correction for detector effects (III)





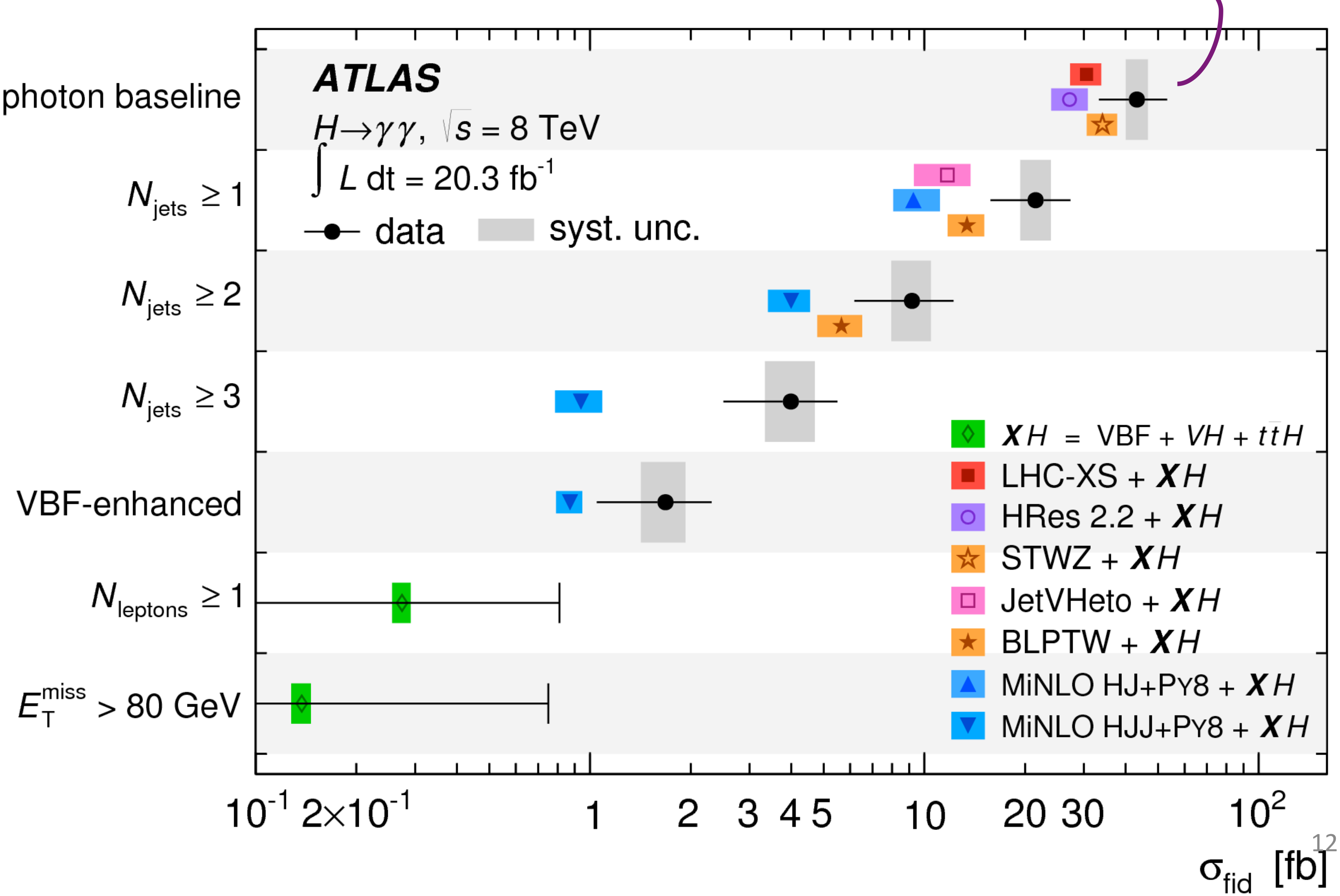
- Theoretical modelling uncertainties, estimated from
  - Uncertainty in gluon fusion modelling: choice of generator(Powheg, Minlo, Sherpa)
  - Uncertainty in signal composition (rate of VBF+VH by factor of 2, ttH by factor of 5)
  - Reweight simulation to reproduce Higgs p_T and |y| measured in the data

Example of measurement uncertainties

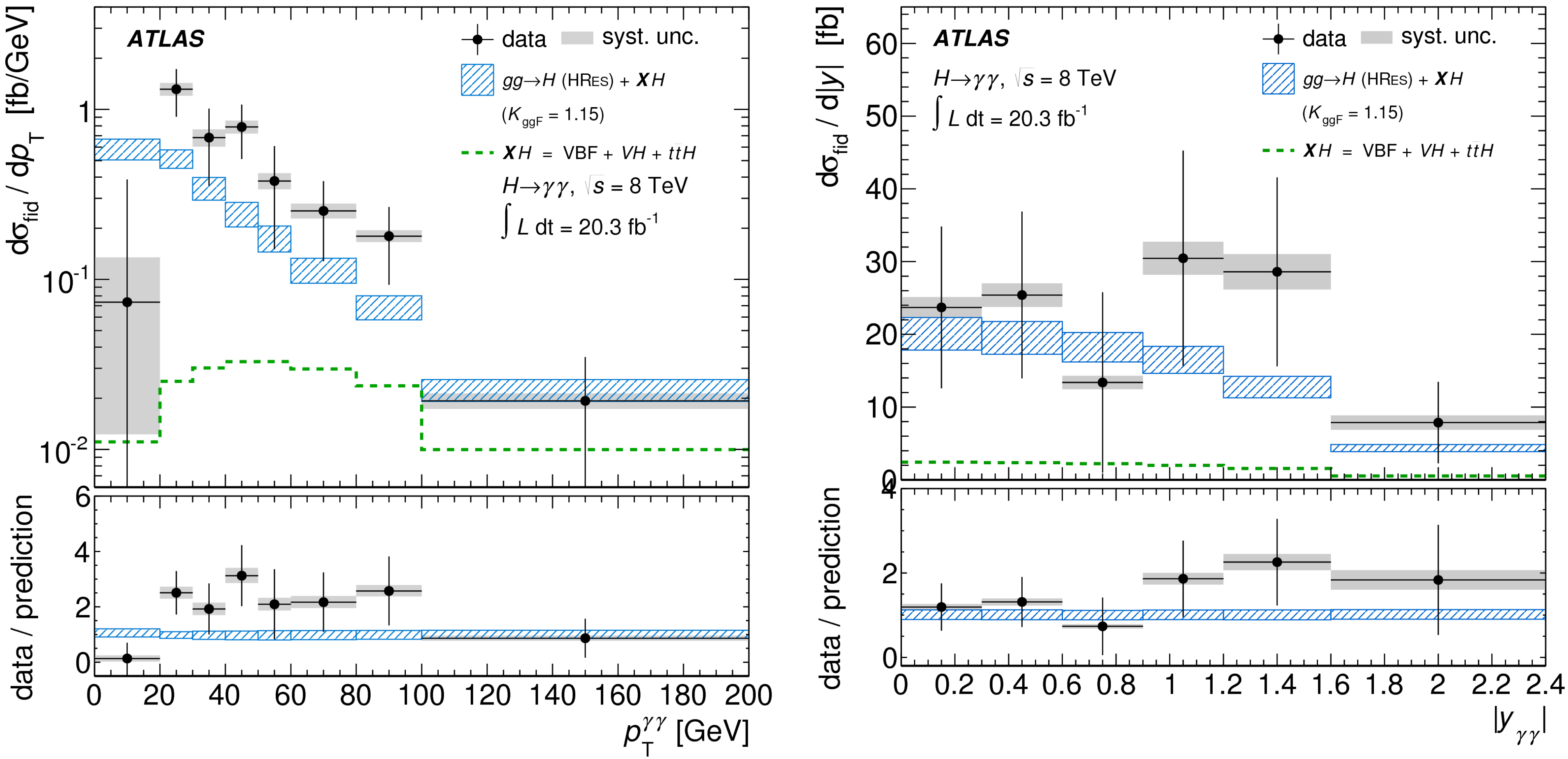
Source	Uncertainty on fiducial cross section (%)				
	Baseline	$N_{\text{jets}} \geq 1$	$N_{\text{jets}} \geq 2$	$N_{\text{jets}} \geq 3$	VBF-enhanced
Signal extraction (stat.)	± 22	± 25	± 30	± 33	± 34
Signal extraction (syst.)	± 6.5	± 7.4	± 7.1	± 6.5	± 9.0
Photon efficiency	± 1.5	± 2.1	± 3.1	± 4.2	± 2.3
Jet energy scale/resolution	-	$^{+6.2}_{-5.8}$	$^{+11}_{-10}$	$^{+15}_{-13}$	$^{+12}_{-11}$
JVF/pileup-jet	-	± 1.3	± 2.2	± 3.3	± 0.5
Theoretical modelling	$^{+3.3}_{-1.0}$	$^{+5.0}_{-2.6}$	± 4.1	$^{+6.3}_{-4.9}$	$^{+2.2}_{-3.2}$
Luminosity	± 2.8	± 2.8	± 2.8	± 2.8	± 2.8

Fiducial cross sections for H -> γγ

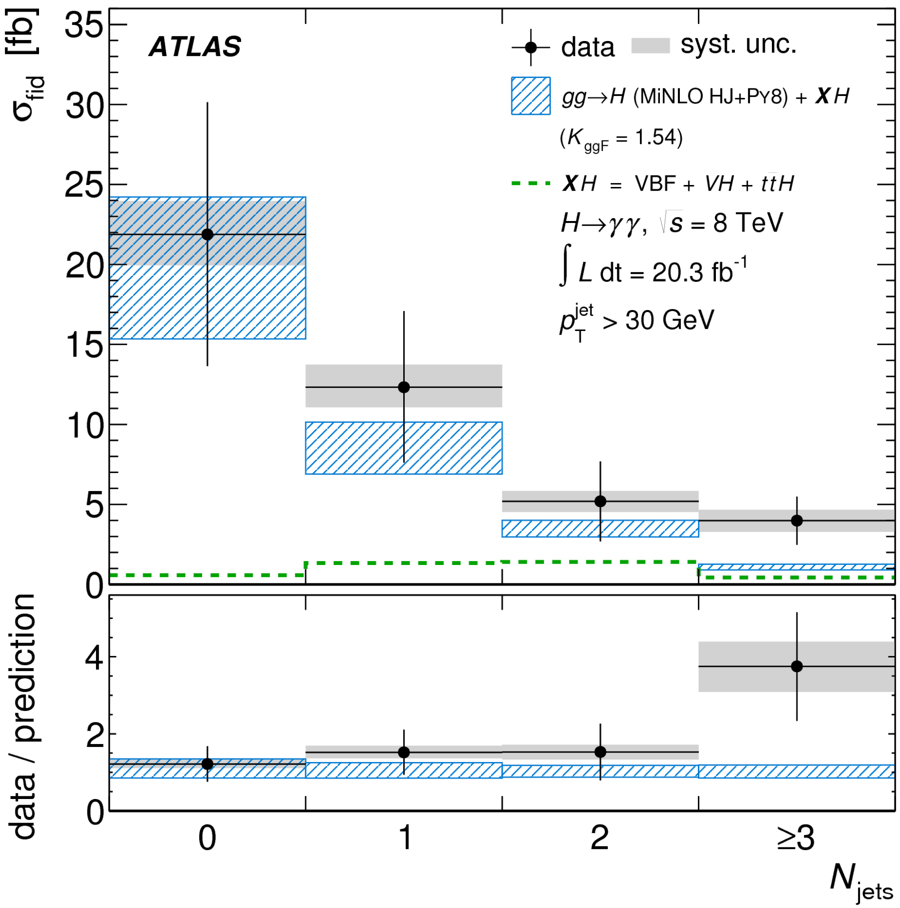
$$\sigma_{\rm fid}(pp \to H \to \gamma\gamma) = 43.2 \pm 9.4\,({\rm stat.})\,^{+3.2}_{-2.9}\,({\rm syst.}) \pm 1.2\,({\rm lumi})\ {\rm fb.}$$

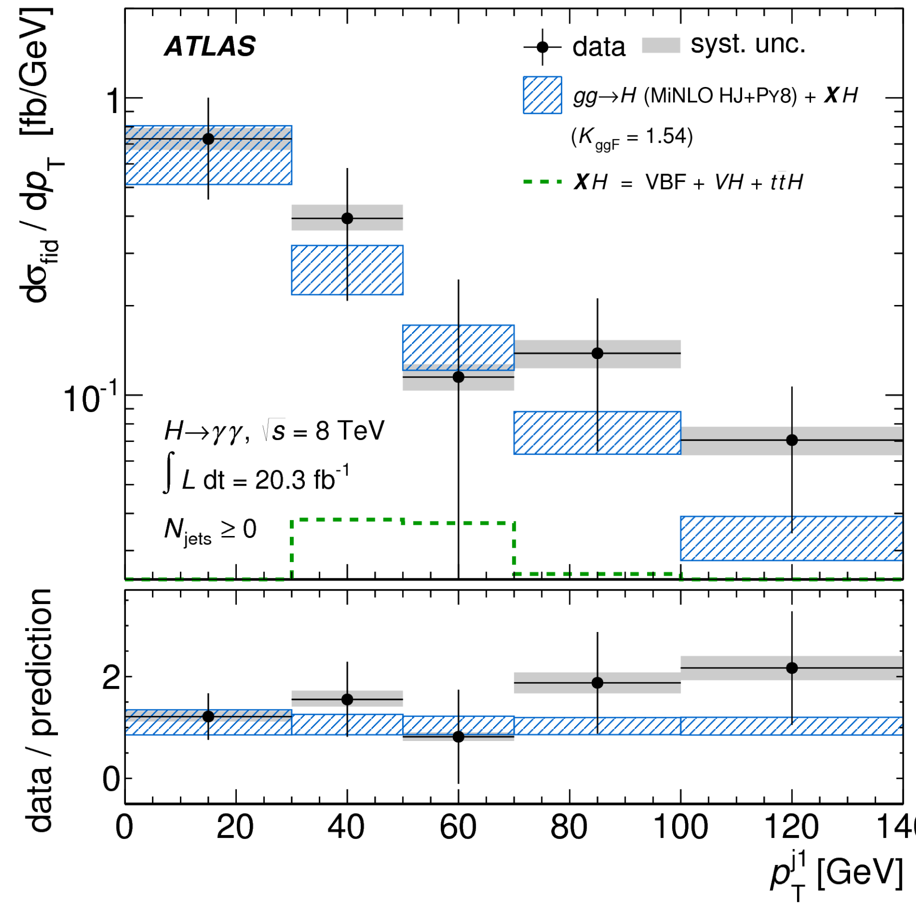


Higgs boson kinematics

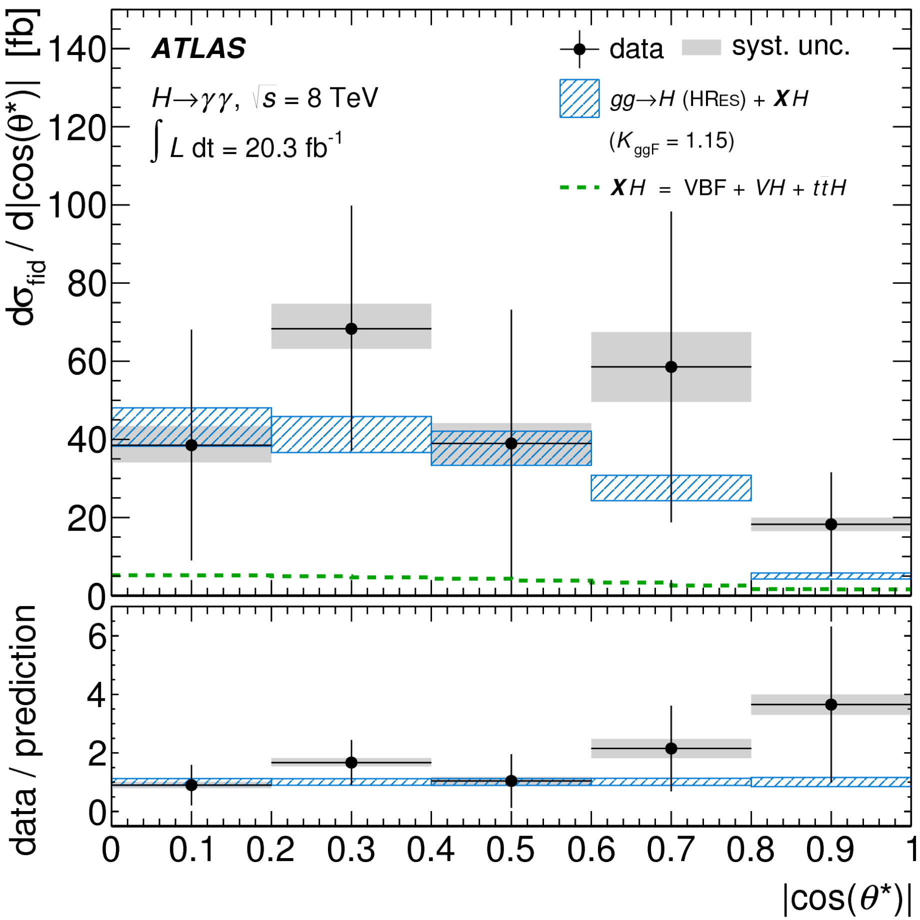


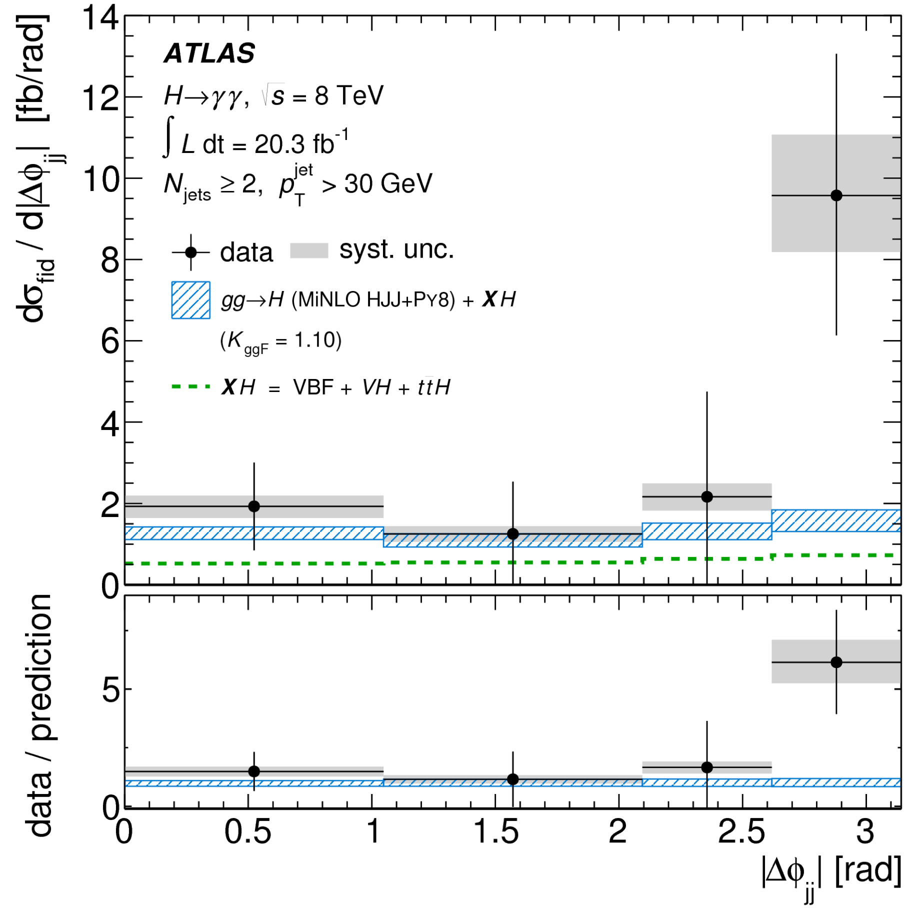
Associated jet activity



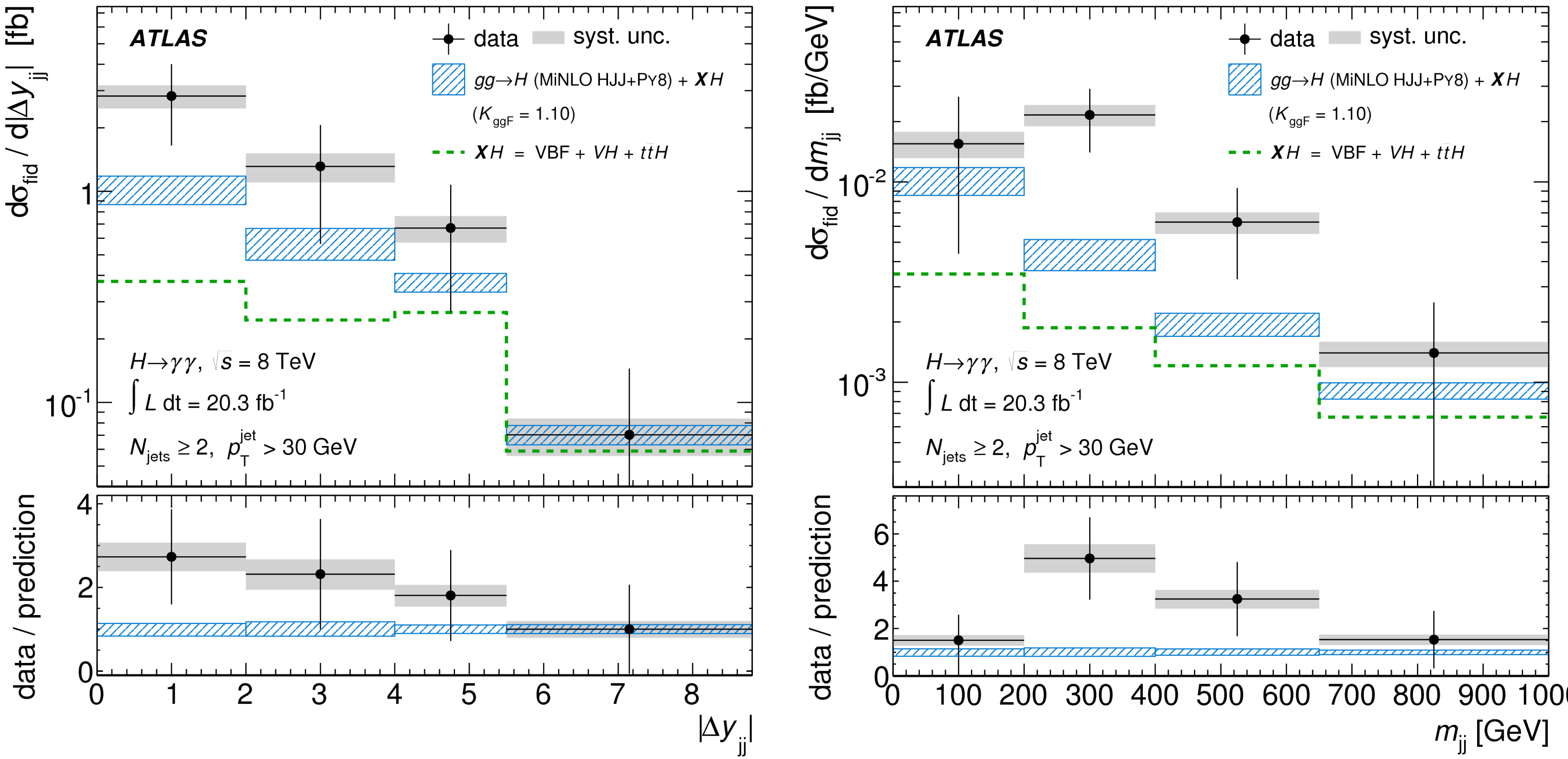


Spin-CP sensitive variables





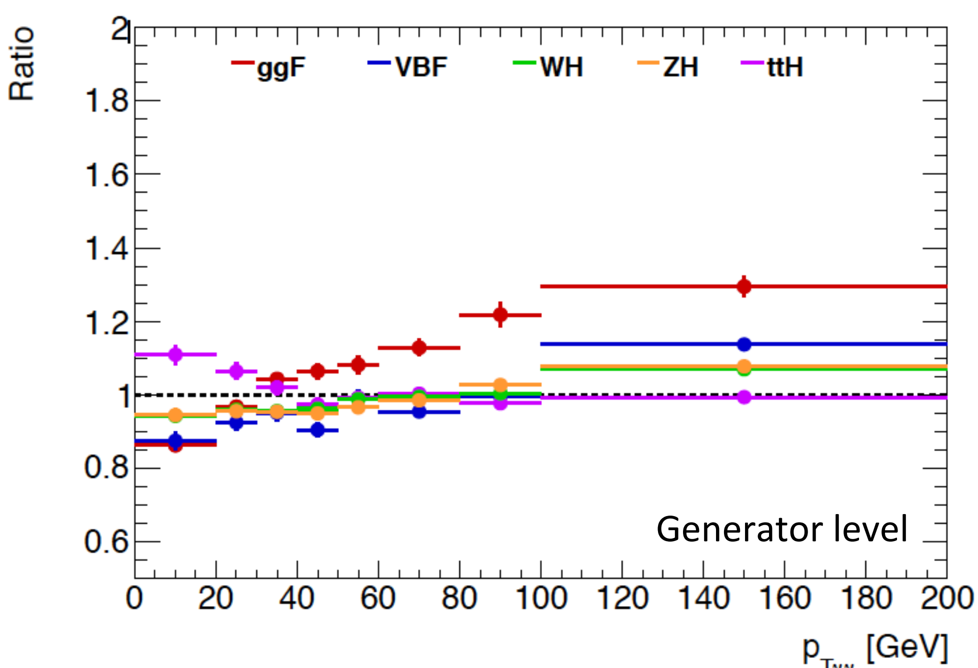
VBF-sensitive variables



Outlook for Run II measurements: statistical improvement (I)

- Cross section for each production mechanism increases as the centre-of-mass energy increases

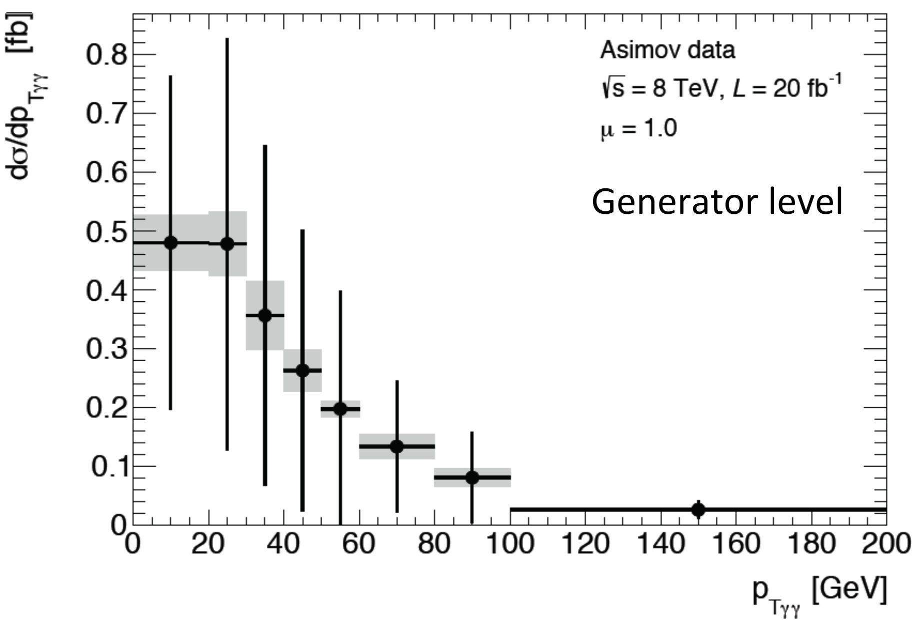
Process	σ_{8TeV} [pb]	σ_{14TeV} [pb]	$\sigma_{14TeV}/\sigma_{8Te}$
ggF	19.27	49.47	2.57
VBF	1.578	4.233	2.68
WH	0.7046	1.522	2.16
ZH	0.4153	0.9690	2.33
ttH	0.1293	0.6113	4.73

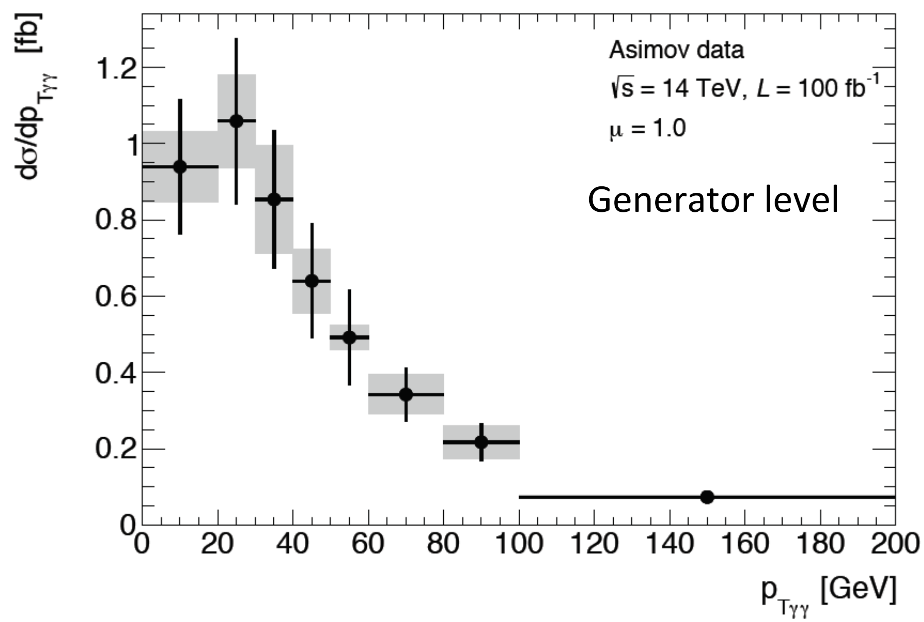


.....harder distributions due to increase in available phase space.

Outlook for Run II measurements: statistical improvement (II)

- Estimate of sensitivity in 100 fb-1 of Run-II data
- Assume that systematic uncertainties not improved.



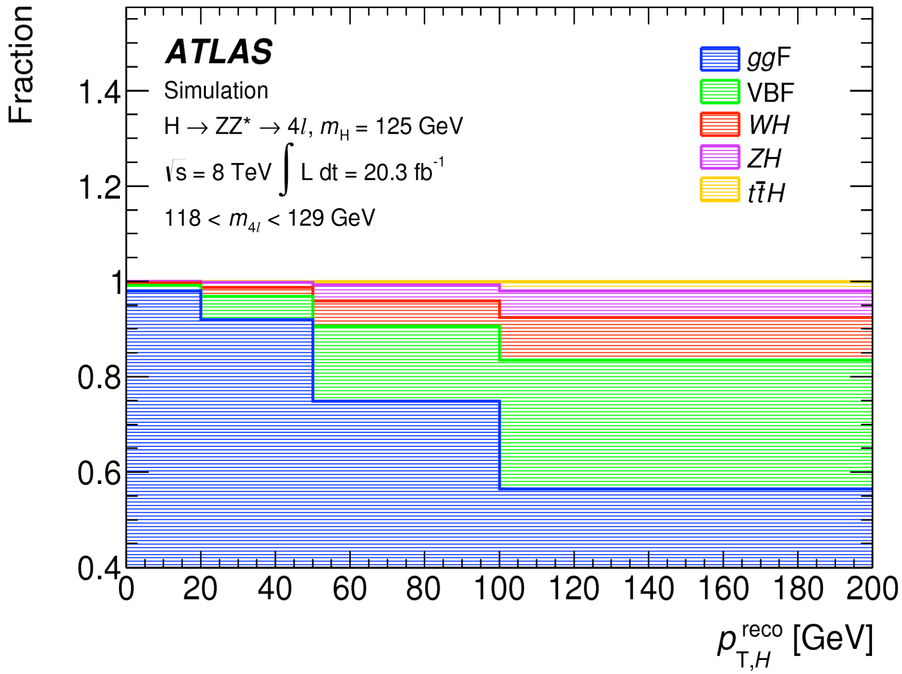


[plots from Michaela Queitsch-Maitland]

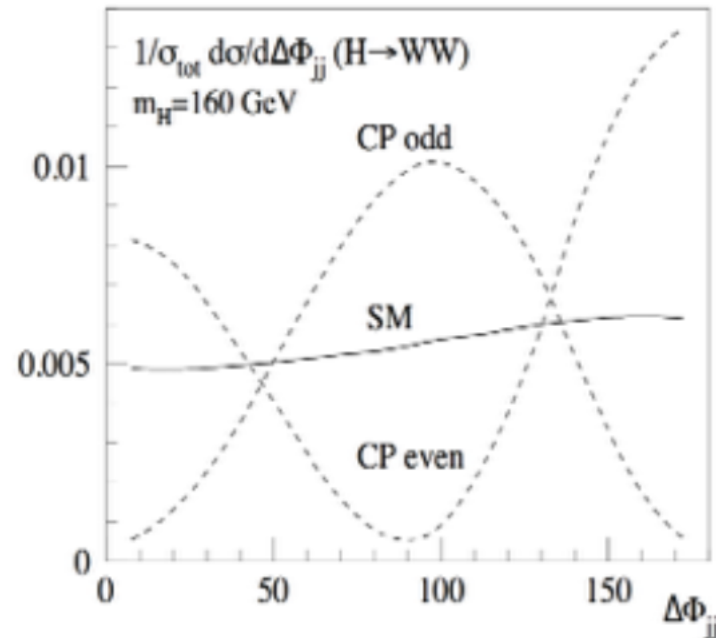
Summary

- First fiducial and differential cross section measurements for the Higgs boson measured in the H->γγ decay channel (JHEP09 2014 112)
  - Not all results shown in this talk: many more differential distributions.
- Data is publicly available for testing theoretical modelling and BSM possibilities
  - See: http://hepdata.cedar.ac.uk/view/ins1306615
  - Use: https://rivet.hepforge.org/analyses#ATLAS_2014_I1306615
- Combination with H->ZZ* channel has been published as well
  - See talks by Sarah Heim and Michaela Queitsch-Maitland
- Fiducial cross-section measurements will be a crucial part of the Run-II programme
  - Statistical uncertainties reduced by a factor of ~4
  - Increased opportunity to use fiducial detector-corrected data for interpretations: EFT, pseudo-observables, specific BSM models….

Example: sensitivity to production channel and new physics



Example of sensitivity to production Mechanism: Higgs p_T



Example of sensitivity to new CP-even and CP-odd interactions: $\Delta\phi_{jj}$

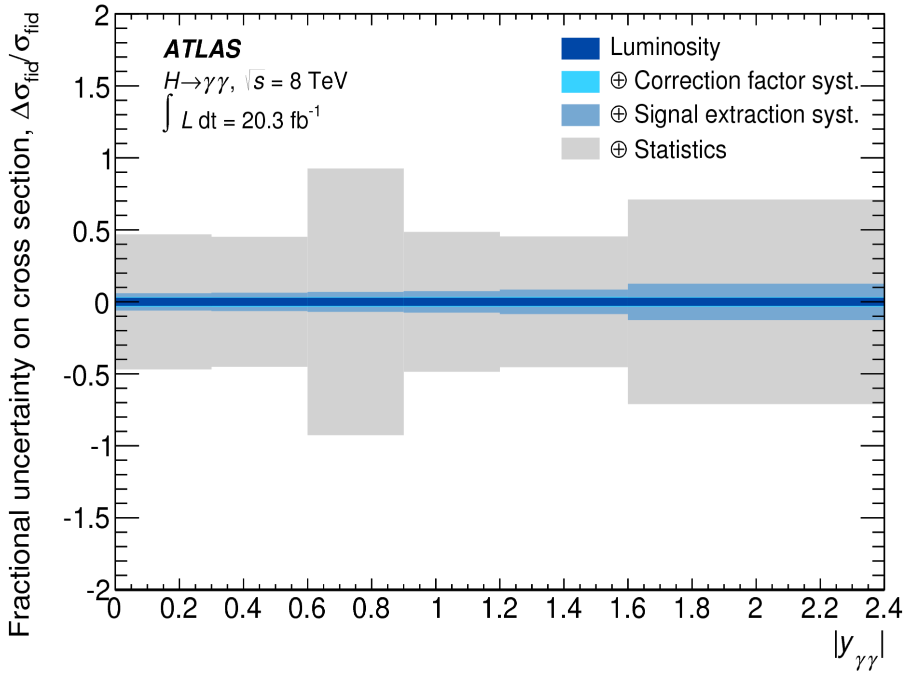
Phys.Rev.Lett. 88 (2002) 051801

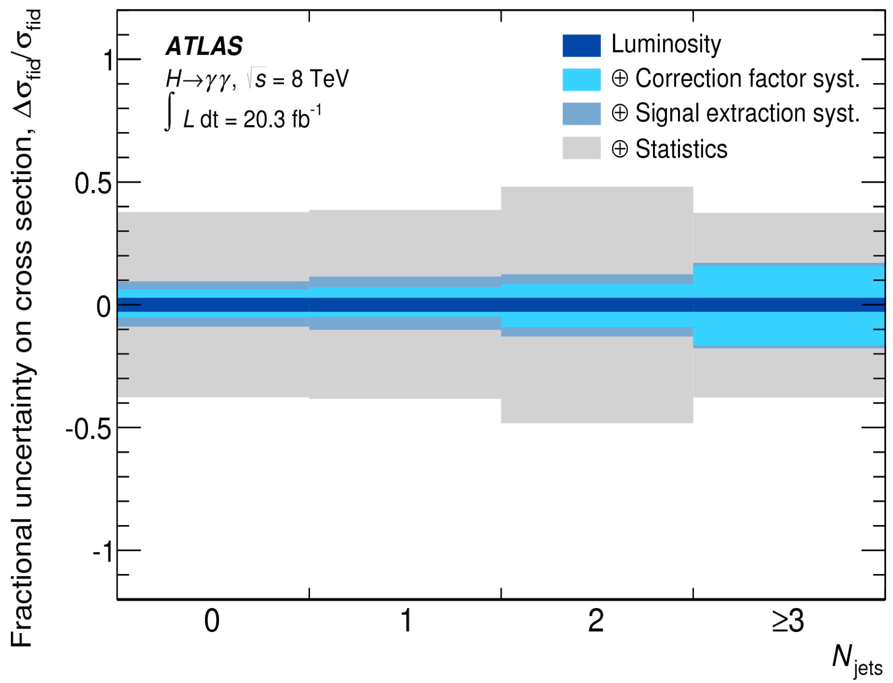
Theoretical predictions for gluon fusion

Name	Parton Shower	fiducial region	diff. XS	QCD Precision	Quark mass in loop	EW Prec.
Powheg+Py8	Pythia 8	inclusive	all	NLO(0j) + PS	$m_t=\infty$, $m_b=0$	-
MINLO HJ	Pythia 8	inclusive 1 jet	all	NLO(0,1j) + PS	$m_t=\infty$, $m_b=0$	-
MINLO HJJ	Pythia 8	inclusive 2 jets	all	NLO(2j) + PS	$m_t=\infty$, $m_b=0$	-
LHC XS	-	inclusive		NNLO+NNLL	finite m_t,m_b,m_c	NLO
STWZ (SCET)	-	inclusive		NNLO+NNLL'	$m_t=\infty$, $m_b=0$	-
HRes	-	inclusive	kinematics of Higgs + decay	NNLO+NNLL	finite m_t,m_b	-
BLPTW (SCET)	-	1 jet 2 jets		NLO + NNLL' approx. NLO +	$m_t=\infty$, $m_b=0$	-
JetVHeto	-	1 jet		(N)NLO + NNLL	finite m_t,m_b	-

Single MC-based prediction for VBF, VH (normalised to NNLO) and ttH (normalised to NLO)

Example of measurement uncertainties





- Signal extraction systematic dominated by photon energy resolution effects
- Correction factor systematic contains both experimental and theoretical modelling effects
  - Jet energy scale dominant uncertainty at large jet multiplicities

Seven fiducial phase space regions