Measurement of Higgs boson differential fiducial cross sections at the LHC

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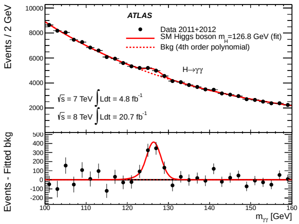
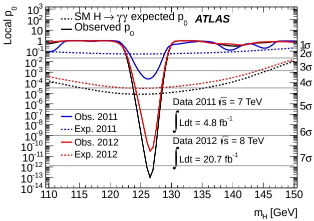
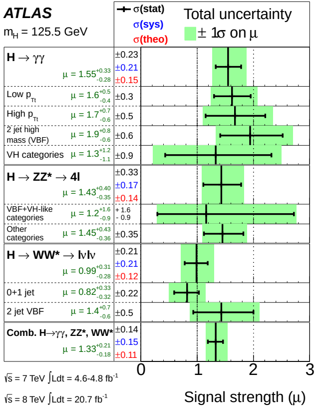
on behalf of the ATLAS Collaboration

Introduction







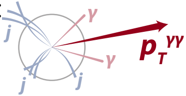
- Focus so far on discovery and signal strength
- More recently moving towards measuring properties including cross section and comparisons to NLO/NNLO predictions
- Measuring cross section within fiducial region of detector coverage reduces model dependence & theoretical uncertainties
- Differential cross sections measured in $H\to\gamma\gamma$:
  - Allow detailed checks of Higgs kinematics
  - Test QCD predictions (including of ggH cross section)
  - Compare distributions against predictions of SM and other theories

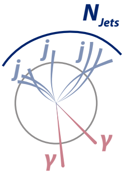
Plots from arXiv:1307.1427, Phys.Lett.B 726 (2013) 88

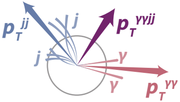
Introduction: fiducial differential cross sections

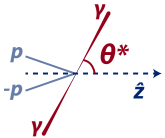
Some possible variables to measure for differential cross sections:

- p_{T}^{H}: probes perturbative QCD calculations
- y_H: sensitive to QCD radiative corrections and proton PDFs
- jet multiplicity: sensitive to relative rates of production modes (ggH, VBF/VH/ZH, ttH)
- jet veto fractions: sensitive to relative rates of production modes, and strong coupling α_s
- p_{T}^{j1}: in ggH corresponds to hardest QCD radiation, and can be compared to higher order predictions
- $\Delta\varphi_{jj}$: for ggH and VBF, sensitive to Higgs spin and CP
- p_{T}^{Hjj}: discriminates between ggH and VBF in 2-jet events
- Collins-Soper helicity angle $|\cos\theta^*|$: sensitive to spin/parity









Overview of ATLAS $\gamma\gamma$ result

First public result measuring differential cross section of the Higgs:

Differential cross sections of the Higgs boson measured in the diphoton decay channel with the ATLAS detector using 8 TeV proton-proton collision data, ATLAS-CONF-2013-072

Event selection:

- Diphoton trigger, with p_T cuts >35 GeV and >25 GeV
- Photon energy calibration from MC, with corrections from $Z \rightarrow ee$ data
- Primary Vertex selected with a neural network, using calo pointing information, photon conversion tracks, and other tracks in event
  - PV z coordinate is used to correct η and E_T of photons
- Photon $|\eta|<2.37$
  - And exclude crack between barrel/endcap calorimeter: $|\eta| \notin [1.37, 1.56]$
- Calo isolation: <6GeV in cone of 0.4; Track isolation: <2.6GeV in cone of 0.2
- $E_T/m_{\gamma\gamma} > 0.35$ and 0.25 for leading and sub-leading photons
- Require $105 < m_{\gamma\gamma} < 160$ GeV
- Jet selection: anti-k_t 0.4, with $p_T>30$GeV, $|y|<4.4$

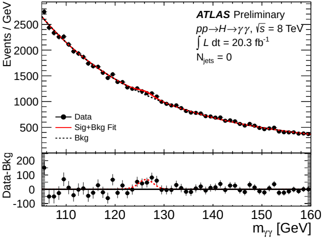
Fiducial region definition

- Photon $|\eta|<2.37$
  - Note: crack 1.37-1.56 not excluded
- Photon isolation: Sum over all stable particles (excluding muons and neutrinos) within cone of $\Delta R<0.4$ around photon: $\sum p_{\mathrm{T}}^2 < 14\,\mathrm{GeV}$
  - Corresponds closely with reconstruction-level calorimeter isolation cut at 6 GeV
  - Reduces dependence of measured cross sections on model used for unfolding
- $E_{\mathrm{T}}/m_{\gamma\gamma} > 0.35$ and 0.25 for leading and sub-leading photons
- Require $105 < m_{\gamma\gamma} < 160\,\mathrm{GeV}$

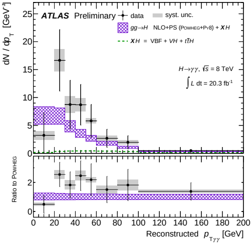
Analysis outline

- Divide dataset into bins of observables (e.g. $p_T^{\gamma\gamma}$ 0-20, 20-30, 30-40 etc.)
- Simultaneous $S + B$ fit in all bins, with m_H floated and common between bins
- Look at fitted signal yield S in each bin
  - At this stage, comparisons with theory require full simulation
- Unfold to particle level, compare with theory predictions
  - Direct comparisons with range of theories possible without full simulation

$m_{\gamma\gamma}$ distribution

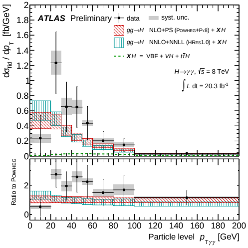


Fitted signal yield



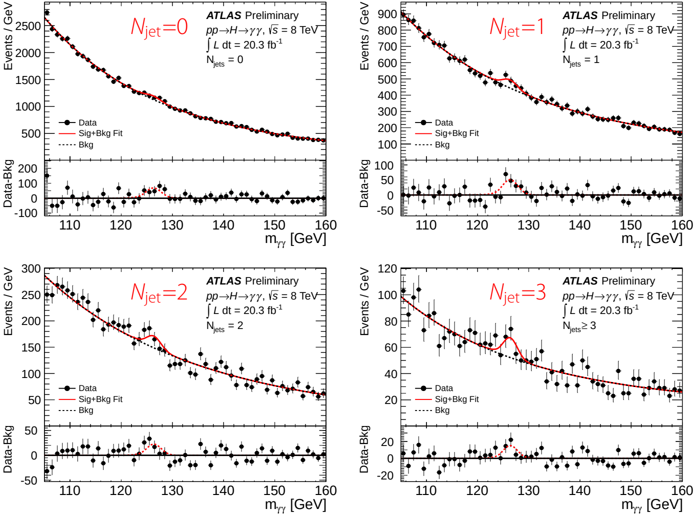
Purple hatching: $gg \to H$ signal full simulation

Differential cross section



Red & Blue hatching: particle-level simulations

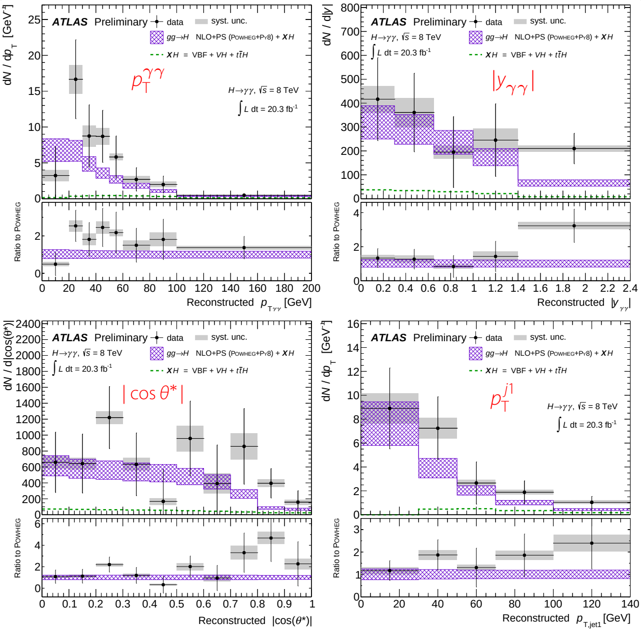
Distributions of $m_{\gamma\gamma}$



- Categorize events according to number of selected jets

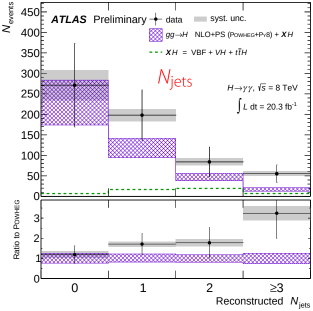
  (for the example of jet multiplicity differential cross section)

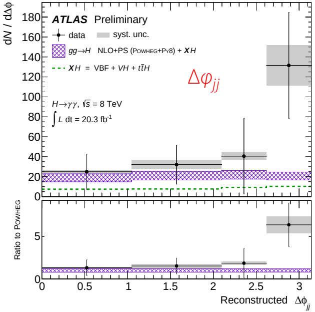
Fitted event yields

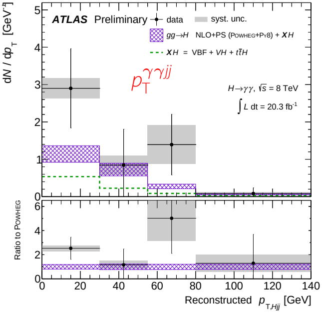


- Fitted signal yield at reconstruction level: $p_T^{\gamma\gamma}$, $|y_{\gamma\gamma}|$, $|\cos\theta^*|$, p_T^{j1}
- Unbinned fit in $m_{\gamma\gamma}$ for each bin of observable
- Note: SM predictions here (purple hatching) require full detector simulation

Fitted event yields







- Fitted signal yield: N_{jets}, $\Delta\varphi_{jj}$, $p_T^{\gamma\gamma jj}$

Uncertainties:

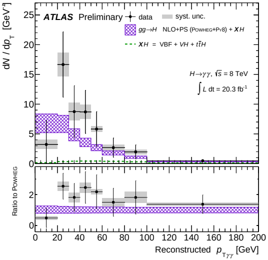
- Systematics from signal extraction in grey (fit and background subtraction)
- Signal uncertainties in purple hatching:
  - Theoretical (QCD scale, PDF, $H\to\gamma\gamma$ branching, underlying event);
  - Jet bin migration (from jet energy scale & resolution)

Unfolding to particle level

- Calculate yields in simulation, in each bin of each observable, at particle level and at reconstruction level
- Apply bin-by-bin multiplicative correction factor:

$$c_{\mathrm{bin},i} = n_{\mathrm{bin},i}^{\mathrm{particle-level}} / n_{\mathrm{bin},i}^{\mathrm{reconstructed}}$$

- Define fiducial region at particle level (close to reconstruction level):
  - Same kinematic cuts as reconstruction level
  - Include calorimeter crack ($1.37<|\eta|<1.56$)
- Using unfolded distributions allows for direct comparison with predictions



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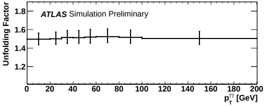
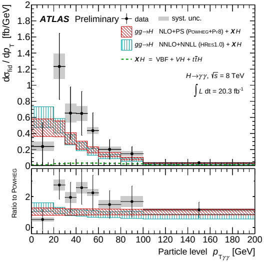
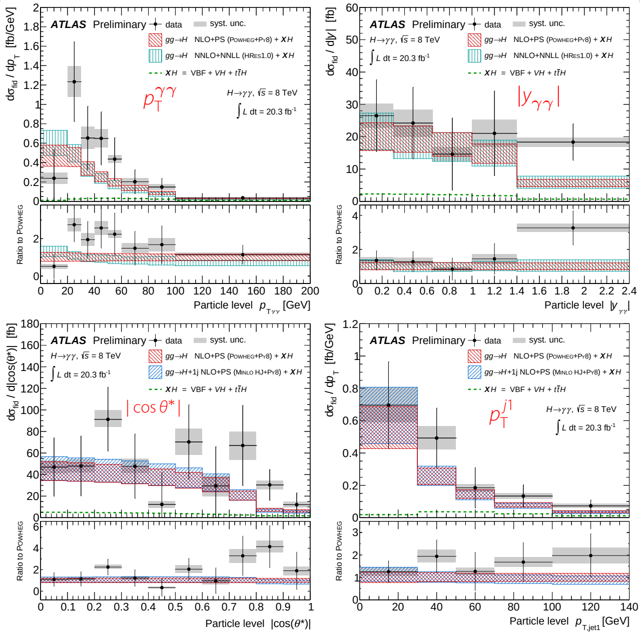


$/\int \mathcal{L}dt \Rightarrow$

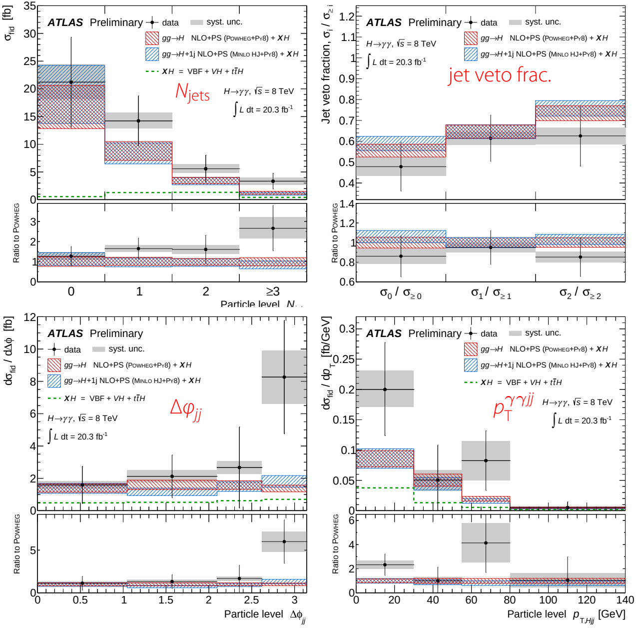


Differential cross section results



- Differential cross sections: $p_{\mathrm{T}}^{\gamma\gamma}$, $|y_{\gamma\gamma}|$, $|\cos\theta^{*}|$, p_{T}^{j1}
- All detector effects corrected for here
- Any external theory prediction can be directly compared (without needing to simulate the ATLAS detector)

Differential cross section results



- Differential cross sections: N_{jets}, Jet Veto Fraction, $\Delta\varphi_{jj}$, $p_T^{\gamma\gamma jj}$
- All detector effects corrected for here
- Any external theory prediction can be directly compared (without needing to simulate the ATLAS detector)

Comparison with Standard Model predictions

- Current uncertainties are dominated by low statistics
- Agreement with SM is good within current uncertainties, with χ^2 probabilities:

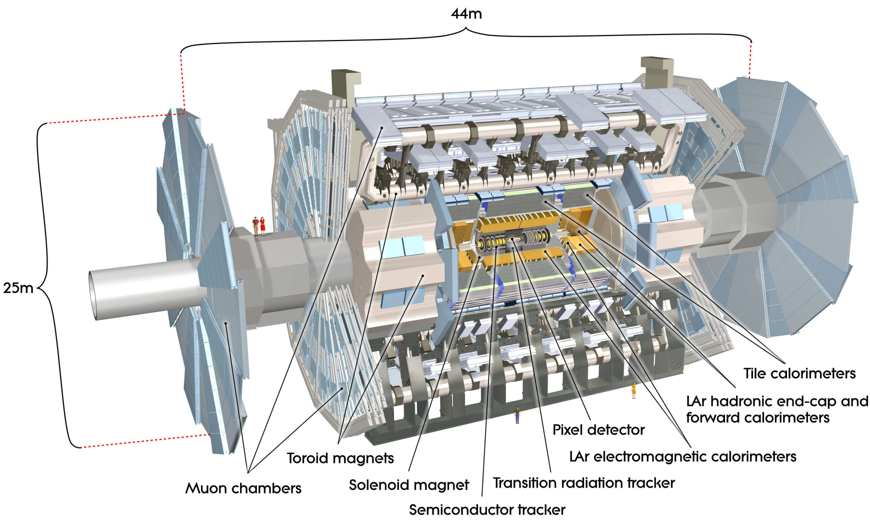
	N_{jets}	$p_T^{\gamma\gamma}$	$\lvert y_{\gamma\gamma}\rvert$	$\lvert\cos\theta^*\rvert$	p_T^{j1}	$\Delta\varphi_{jj}$	$p_T^{\gamma\gamma jj}$
POWHEG	0.54	0.55	0.38	0.69	0.79	0.42	0.50
MINLO	0.44	–	–	0.67	0.73	0.45	0.49
HRes 1.0	–	0.39	0.44	–	–	–	–

- Notes on generators:
  - POWHEG+PYTHIA8: norm. to NNLO QCD + NLO EW
  - POWHEG+MINLO: H+1jet NLO, showered with PYTHIA8, using CT10 PDFs
  - HRes 1.0: NNLO + NNLL, using MSTW 2008 NNLO PDFs and infinite top quark mass approximation

Summary

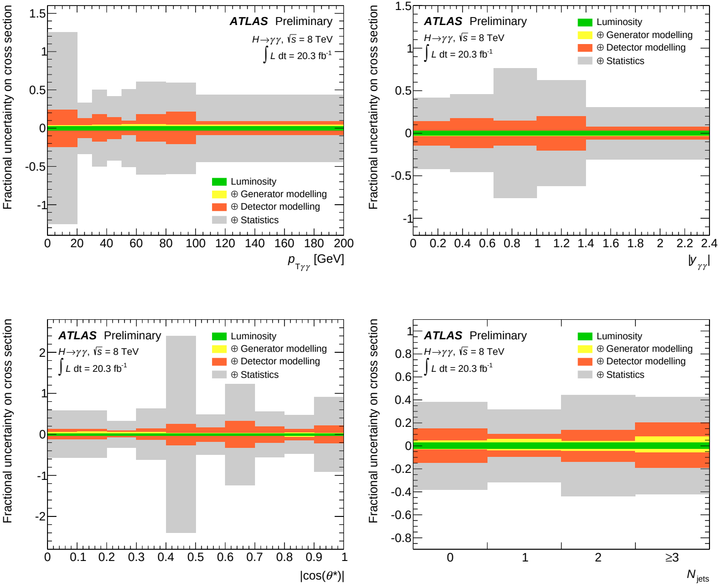
- First differential cross sections of the Higgs boson, measured in $H \to \gamma\gamma$ with 20.3 fb^{-1} of $\sqrt{s}$=8 TeV data
- Unfolded distributions can be compared to any particle-level predictions, without needing full detector simulation
  - Paper in preparation, and data will be released in HepData together with Rivet code
  - Released data will include full experimental covariance in each bin, usable for external hypothesis tests
- Look forward to new 13-14 TeV data in 2015
  - Higher statistics will reduce uncertainties, allow us to probe effects at $\sim$10% level, including NLO/NNLO differences, quark mass effects

The ATLAS detector



(from JINST **3** S08003)

Fractional uncertainty on differential cross sections



Fractional uncertainty on differential cross sections