Differential cross sections of the Higgs boson measured in the diphoton decay channel

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Introduction

The spin and relative couplings of the Higgs boson conform to the SM.

Measure the details of its production and decay.

- Diphoton channel gives high rate and allows a clean signal extraction.
- Work described in **ATLAS-CONF-2013-072**; **new variables** below.

	Variable	Motivation
Inclusive	$p_T^{\gamma\gamma}$	Kinematics, and QCD description of *ggH*
	$\lvert y^{\gamma\gamma}\rvert$	Kinematics (and one day, PDFs)
	$\lvert\cos\theta^*\rvert$	Spin (model independent!)
	N_{jets}	Jet multiplicities vary by production mode.
	p_T^{j1}	Hardest parton emission: NNLO+NNLL comparisons!
2-jets	$\Delta\varphi_{jj}$	ggH + VBF: spin and CP; matrix element of 2nd jet.
	$p_T^{\gamma\gamma jj}$	Powerful VBF variable with large theory uncertainties.

Analysis Method

Event Selection and Fiducial Region

Photon and Event-Level Selection (= spin measurement)

- Select the two highest-E_T photons within $|\eta| < 2.37$.
  - Reconstructed: tight PID and isolation as in coupling/spin. The transition region $1.37 < |\eta| < 1.56$ is removed.
  - Particle-level: truth isolation less than 14 GeV, within $\Delta R < 0.4$.
- Mass window from $105 < m_{\gamma\gamma} < 160$ GeV.
- Require $p_T / m_{\gamma\gamma} > 0.35\,(0.25)$ for the leading (subleading) photon.
  - Simplifies background shapes (same as spin analysis).

Jet Selection (≈ coupling measurement)

- Anti-k_t ($R = 0.4$) jets with $p_T > 30$ GeV and $|y| < 4.4$.
- Remove overlap with photons and electrons.
- Reco. only: track-based pileup suppression and area-based corrections for underlying event.

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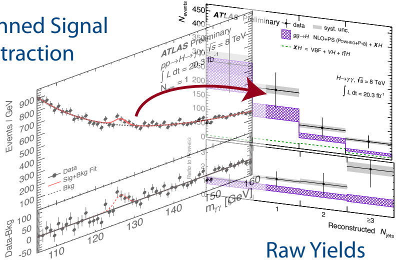
Analysis Strategy

Differential cross sections amount to different divisions of the total data sample, binned according to physical observables.

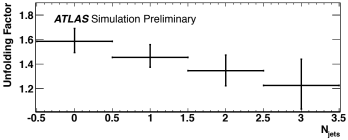
1. In each bin of each observable, the signal is extracted with a signal + background fit in the $m_{\gamma\gamma}$ spectrum.
2. The impact of the detector response on the measured yield of each bin is then unfolded with correction factors, to 'truth' level.

Binned Signal Extraction



Raw Yields

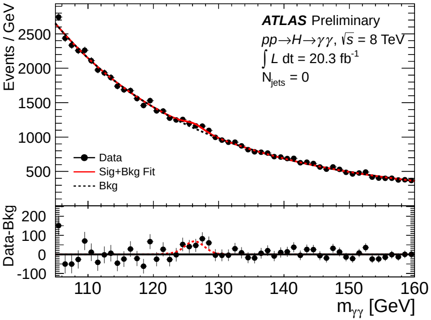
×



Correction Factors

Signal Extraction

- Signal models are derived from Monte Carlo, as a function of m_H.
- Candidate background models are tested with background-only MC, and required to have minimal bias.
  - Ultimately $\exp\{ax + bx^2\}$ is used in every bin.
- Extraction performed with a single, simultaneous fit for each observable, with shared nuisance parameters (incl. m_H) between bins.

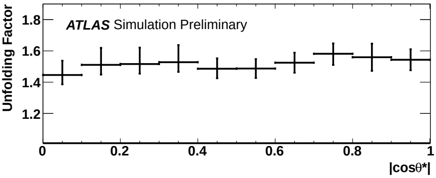


$N_{\text{jets}} = 0$, Raw Extraction

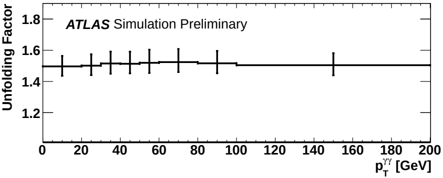
Correction Factors

The extracted yield of all bins are corrected, using factors derived from MC of $\mathbf{n_i^{Truth}/n_i^{Reco.}}$.

- Uses SM composition: *ggH* (87%), VBF (7%), *VH* (5%), *ttH* (0.5%).
- This corrects acceptances, efficiencies, and migrations, at once.
- Appropriate for this very-low statistics measurement...



Correction Factors $|\cos\theta^*|$

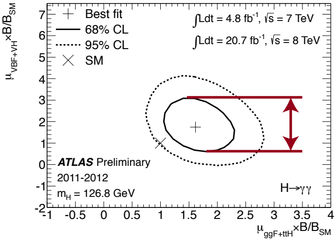


Correction Factors $p_T^{\gamma\gamma}$

Systematic Uncertainties on the Correction Factor Method

Rederive correction factors from alternate, and reweighted, MC samples.

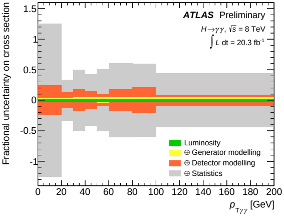
1. Different production modes have different efficiencies, so the sample composition can affect the correction factors.
   - Vary the VBF/VH and ttH components of the MC, within the errors of the coupling measurement (below).
2. For ggH: swap generators and vary scales ($2\times$, $\frac{1}{2}\times$).
3. Reweight the MC to the observation, to take into account the impact of the 'true' shape.



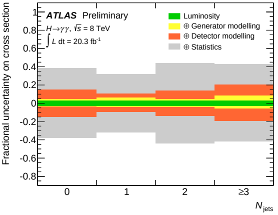
Measured μs, used to motivate composition variations.

Total Uncertainties

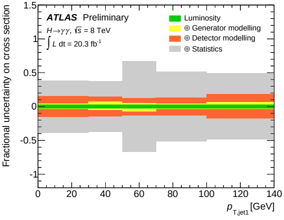
- The total uncertainty is overwhelmingly **statistical**.
  - Therefore uncorrelated between bins.
- Bin-to-bin correlations are typically $\sim 10\%$. The largest correlations between bins are found for $p_T^{\gamma\gamma jj}$, and are less than 20%.
- Additional uncertainties from **luminosity and efficiencies** and **detector modelling** (jets, pileup, etc.).



$p_T^{\gamma\gamma}$



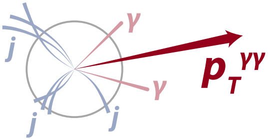
N_{jets}



p_T^{j1}

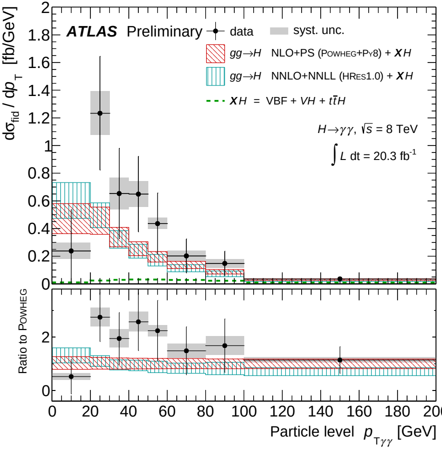
Results

Inclusive Distributions



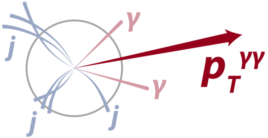
- Sensitive to QCD; theoretical interest is in resummation at low-$p_T^{\gamma\gamma}$.
- Harder spectrum, but consistent within uncertainties.
- Comparison to NLO POWHEG and NNLO+NNLL HRES1.0.

	POWHEG	HRES1.0
χ^2 *p*-value	0.55	0.39



Unfolded Differential Cross Section

Transverse Momentum of the Higgs Boson



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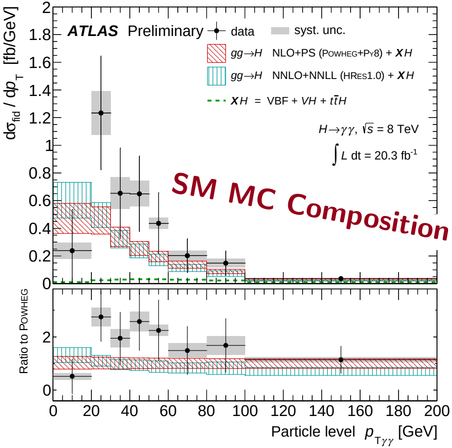

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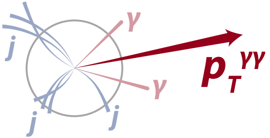

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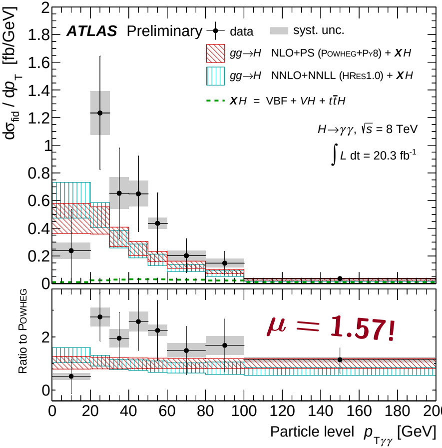

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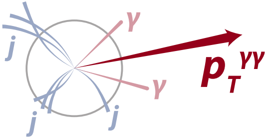

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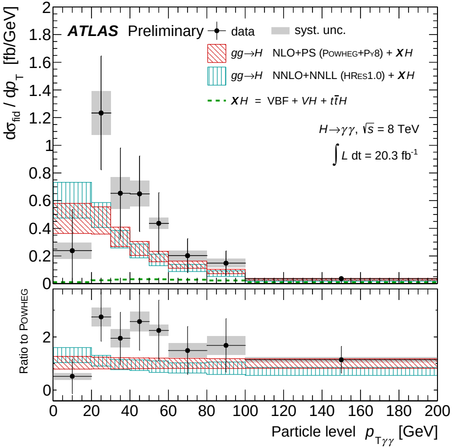
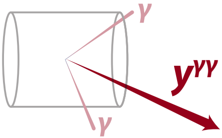
Using All Correlations!



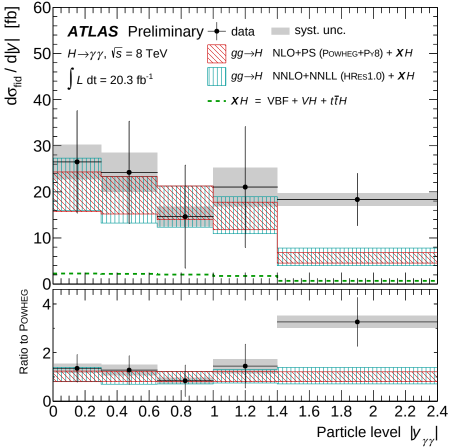
Unfolded Differential Cross Section

Rapidity of the Higgs Boson



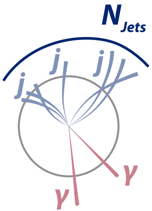
- With m_H and $p_T^{\gamma\gamma}$ this uniquely defines the kinematics.
- One bin high at large $|y^{\gamma\gamma}|$.
- Eventually, sensitive to incoming PDFs, though there are better ways to measure this.

	POWHEG	HRES1.0
χ^2 *p*-value	0.38	0.44



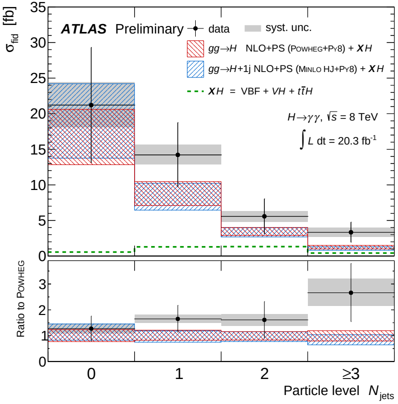
Unfolded Differential Cross Section

Partial Cross Sections, by Number of Jets



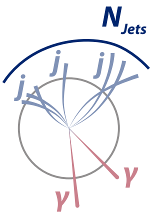
- Quite consistent, allowing for normalization ($\mu = 1.57$).
- Scale variations fail, because order changes for each bin.
  - Tests Pythia parton shower! $\Longrightarrow$
  - For SM comparison, use 'standard' LHC recommendations.

(w/ Scale Vars.)	POWHEG	MINLO
χ^2 *p*-value	0.54	0.44



Partial Cross Section
with Uncertainties from Scale Variations
(model breaks down, since PS is not affected)

Partial Cross Sections, by Number of Jets



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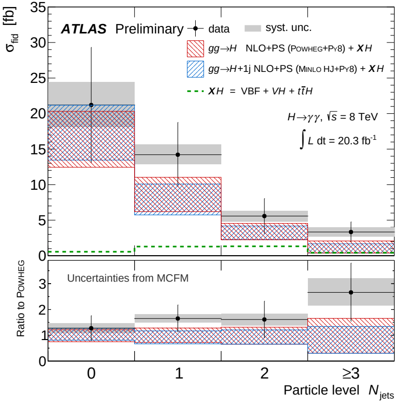
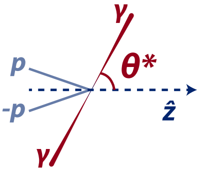


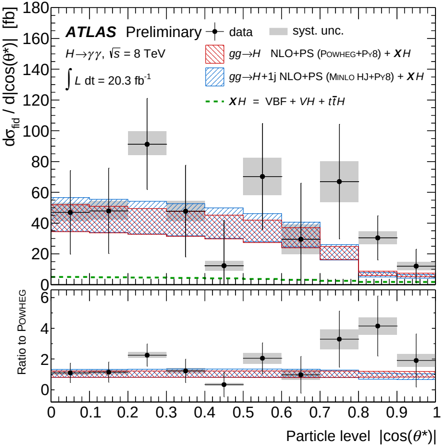
Partial Cross Section
with **Stewart-Tackmann/MCFM Errors**
(more conservative, for SM comparisons.)

Helicity Angle $\cos\theta^*$ of the Higgs Boson



- Spin-sensitive variable.
- Uncorrelated extraction for each bin $\Longrightarrow$ less model-dependence (and less powerful) than spin measurement.
- Large statistical fluctuations.

	POWHEG	MINLO
χ^2 p-value	0.69	0.67



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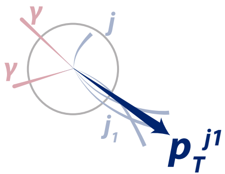
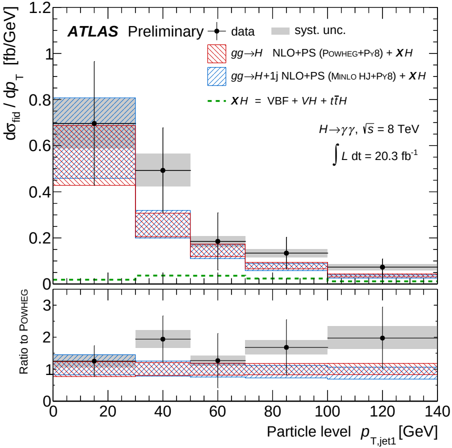


- Hardest radiation in Higgs events; first bin from $N_{\text{jets}} = 0$.
- Consistent with NLO – and also with NNLO+NNLL theory!

	POWHEG	MINLO
χ^2 p-value	0.79	0.73



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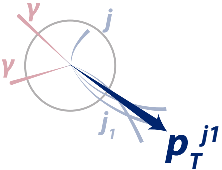

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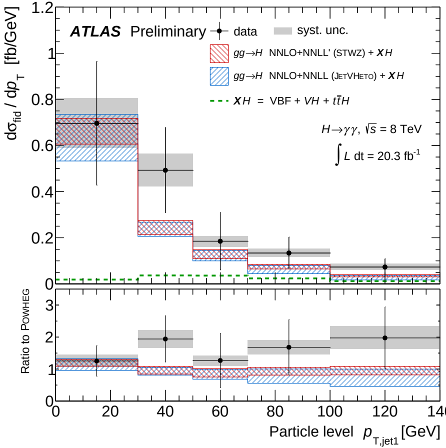
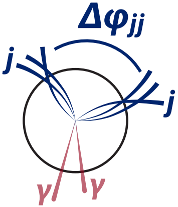


Unfolded Differential Cross Section, compared to NNLO+NNLL from Jet Veto (arXiv:1206.4998) and STWZ (arXiv:1307.1808)

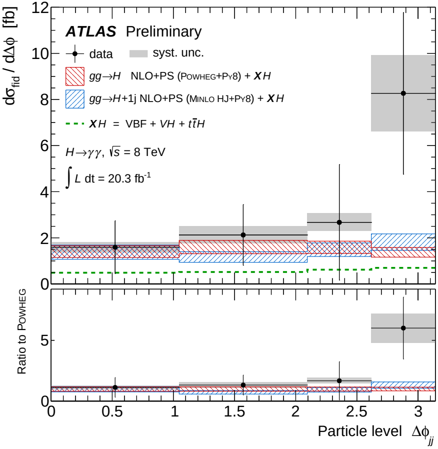
Events ≥ 2 Jets

Angular Separation of the Two Leading Jets



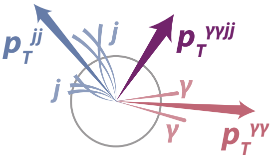
- Sensitive to spin and CP (with more data).
- Is the $\Delta\varphi_{jj} \approx \pi$ bin pileup?
    1. Low/high pileup samples: consistent.
    2. Pileup unc. is ~4%.
    3. Higgs + dijet DPI is ~1%.

	POWHEG	MINLO
χ^2 *p*-value	0.42	0.45



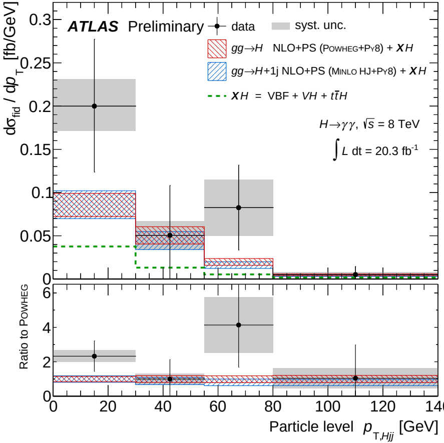
Unfolded Differential Cross Section

Transverse Momentum of the Higgs Boson + Dijet System



- Important variable for VBF analyses, but plagued by *ggH* theory uncertainties.
  - Same 'pole' as $\Delta\varphi(\gamma\gamma, jj)$.
- Begin measurements!

	POWHEG	MINLO
χ^2 *p*-value	0.50	0.49



Unfolded Differential Cross Section

Conclusions

Entering a new era of Higgs physics!

Direct measurements of differential cross sections of the Higgs boson.

- Full kinematics of Higgs production: m_H, $p_T^{\gamma\gamma}$, $|y^{\gamma\gamma}|$!
- Begin to provide experimental feedback for QCD in Higgs production ($p_T^{\gamma\gamma}$, N_{jets}, p_T^{j1}, etc.), and in particular for variables with theoretical challenges in current measurements ($p_T^{\gamma\gamma jj}$).

Overall good agreement, within large statistical uncertainties.

	N_{jets}	$p_T^{\gamma\gamma}$	$\|y^{\gamma\gamma}\|$	$\|\cos\theta^*\|$	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	–	–	–	–

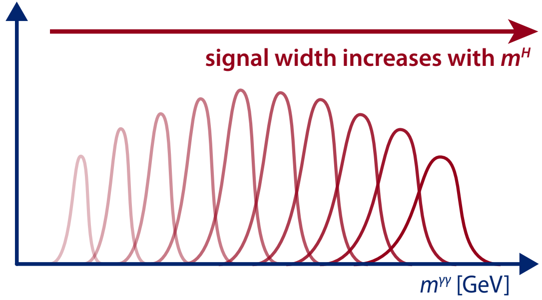
Questions?

Backup

Signal Model

Analytic descriptions of the signal and background shapes are used in the yield extraction fit. These shapes must be accurate!

- The signal model evolves predictably as a function of m_H.
- Fitting an array of masses furnishes us with a parameterization of the analytic shape for arbitrary m_H, and allows us to **float $\mathbf{m_H}$** in our fits.
  - Also used for determining background model (next slide).



Background Model

- Each candidate background model is validated using signal + background fits to high-statistics background-only MC.
- Models are rejected if the (spurious) fitted signal exceeds 20% of the background uncertainty.
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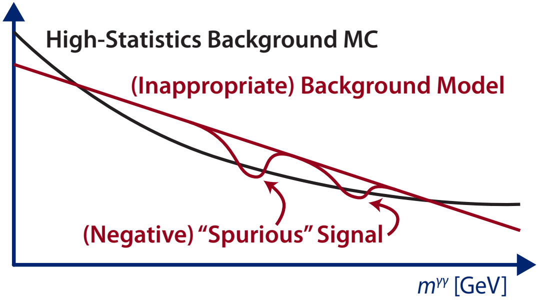
- In practice, the function $\exp\{am_{\gamma\gamma} + bm_{\gamma\gamma}^2\}$ is used in every bin.



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