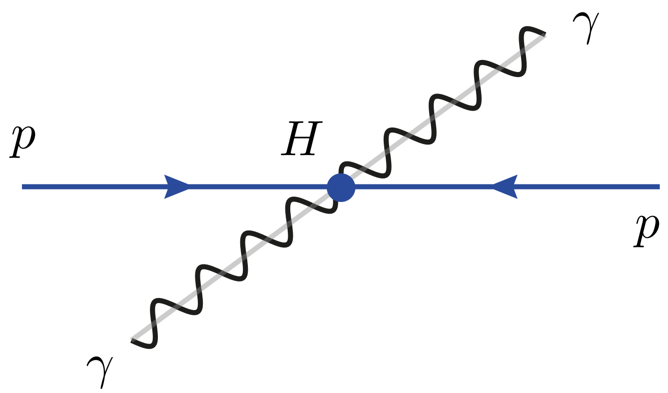
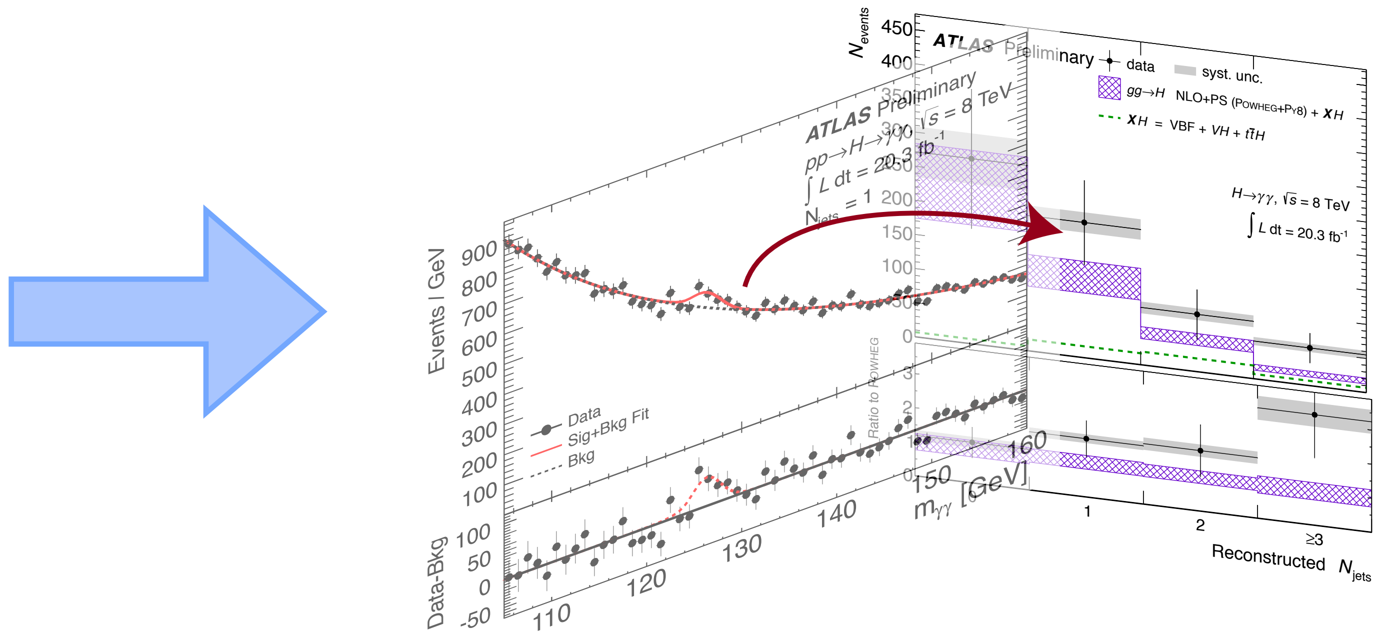
Differential cross section of the Higgs boson measured in the diphoton decay channel with the ATLAS detector
--- 8 TeV proton-proton collision data





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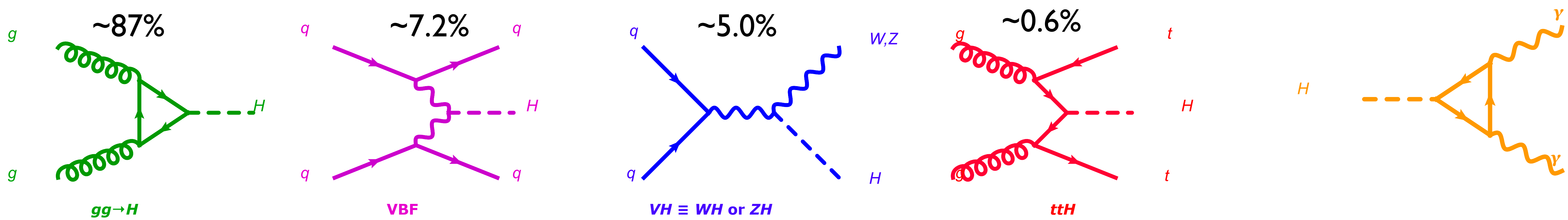
Outline

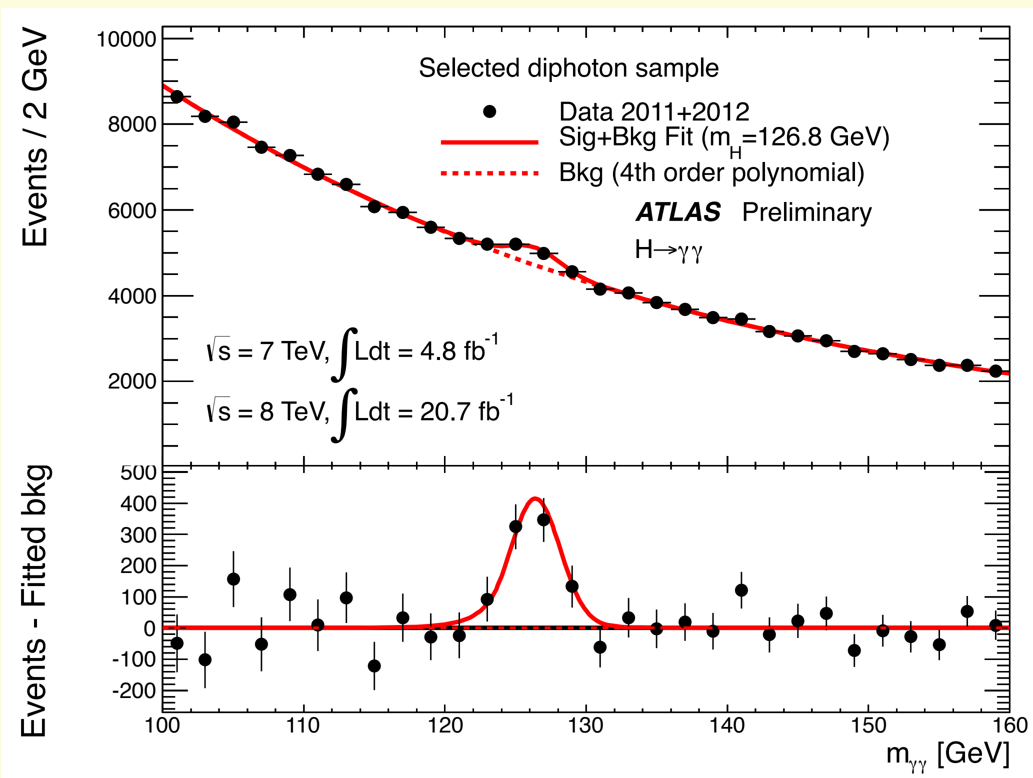
- Introduction and motivation
- Observables
- Analysis results
  - Overview
  - Systematic uncertainties
  - Signal yield at reconstructed level
  - Measurement of fiducial cross section at particle level
- Conclusion

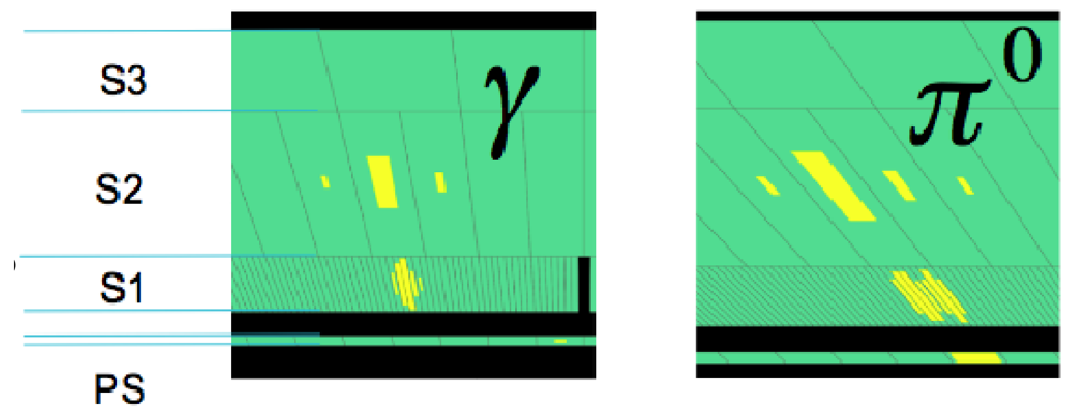
Introduction

Higgs production

Higgs decay to γγ







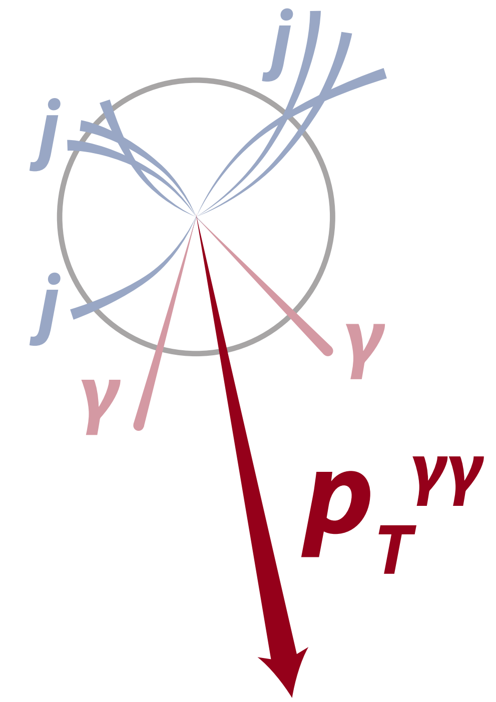
The ATLAS calorimeters are finely segmented and can effectively distinguish between isolated photons and backgrounds like $\pi^0 \rightarrow \gamma\gamma$

- **A local significance of 7.4 σ @ 126.8 GeV excess over background - Discovery!**
- **The total rate to SM : 1.55 ± 0.23 (stat) ± 0.21 (syst)**

Motivation for differential cross section measurement

For the first time, directly measure several kinematic distributions of the Higgs boson in robust and close to model independent way

- ✦ Many of the current Higgs results make assumptions on the Higgs kinematics, these results provide a cross check of the validity of these assumptions
- ✦ Correct measured spectra for detector effects to provide easy and direct comparison with theoretical predictions at particle level

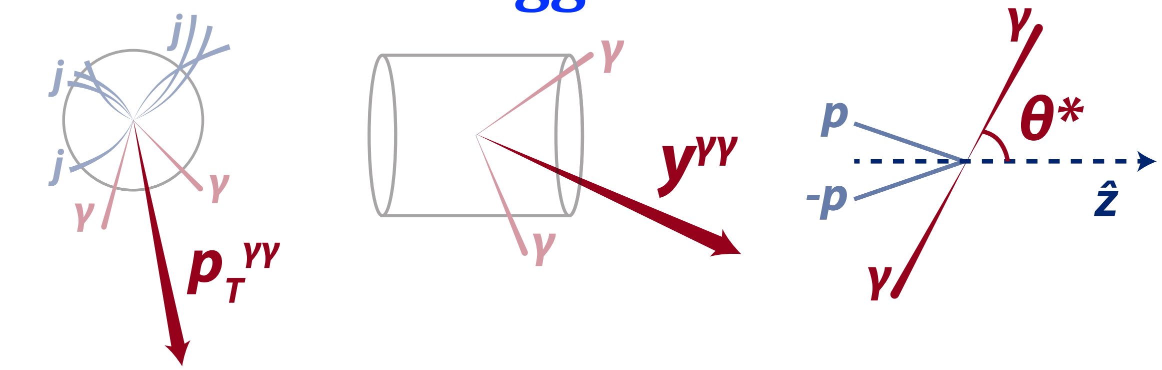


p_T of the Higgs, constructed from the two photons. The coupling measurement is sensitive to the kinematics of this variable.

In this talk, the measurement of this variable is shown!

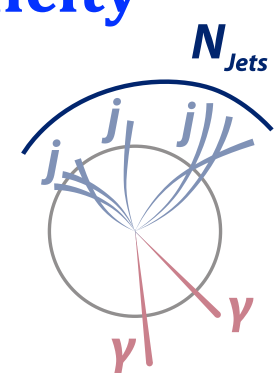
Observables

Fundamental Higgs kinematics



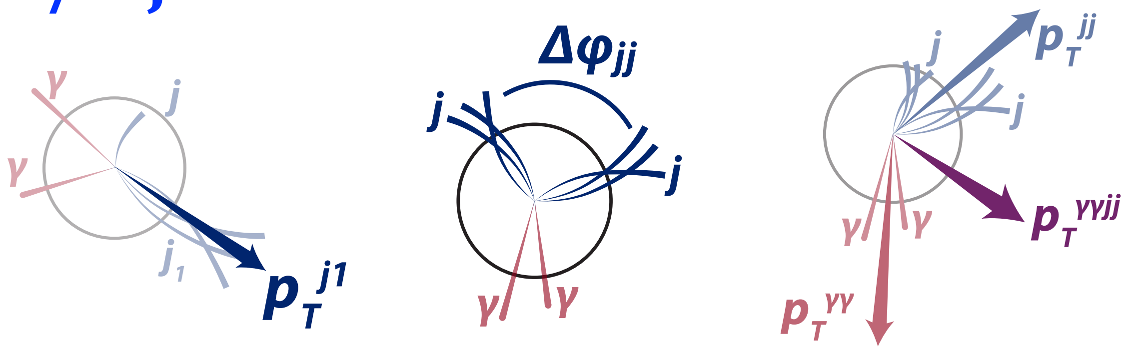
$p_{T\gamma\gamma}$	directly probe perturbative QCD calculation
$\lvert y_{\gamma\gamma}\rvert$	QCD radiative correction and parton distribution functions
$\lvert\cos\theta^*\rvert$	spin & parity

Jet multiplicity



N_{jets}	relative rate of Higgs boson production mechanisms
$\sigma_i/\sigma_{\geq i}$	strong coupling a_s, theoretical description of quark and gluon radiation (jet veto fraction)

1/2-jet observables



$p_{\text{T,jet1}}$	hardest QCD radiation (higher order predictions)
$\Delta\phi_{\text{jj}}$	spin and CP eigenvalue of the Higgs boson
$p_{T\gamma\gamma jj}$	discriminate VBF against the much more abundant ggH production

We cannot really constrain precise SM calculations yet with current data statistics, but rather test if there are significant deviations from the SM in any of the kinematic distribution.

Analysis overview

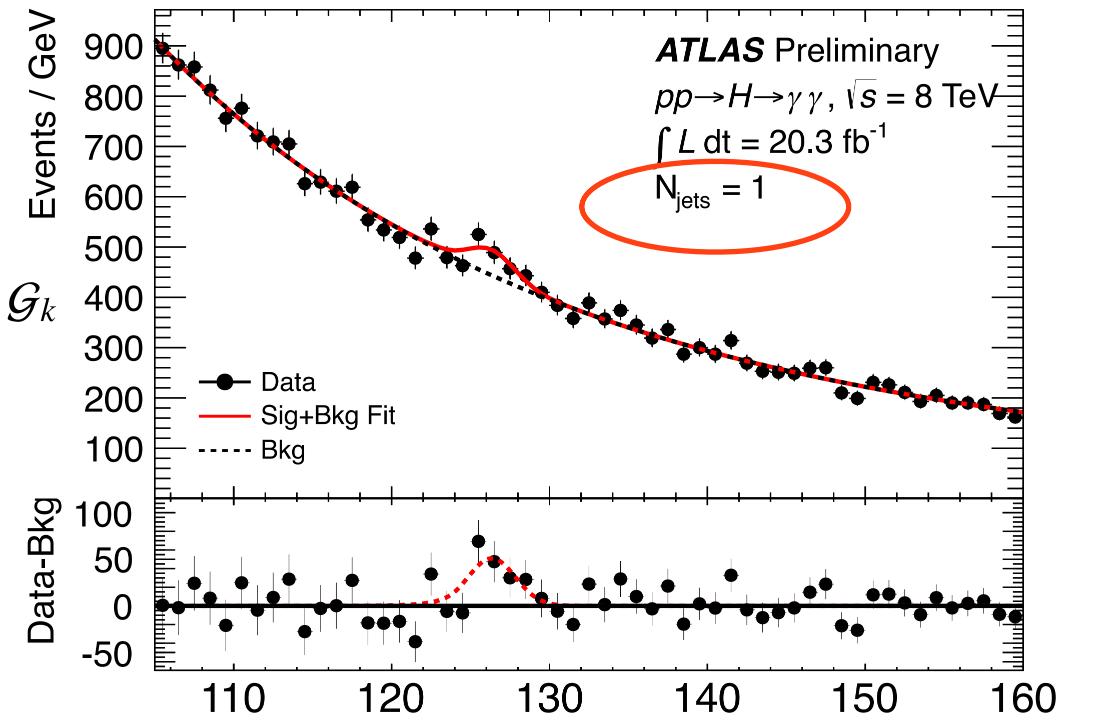
unbinned Likelihood function definition

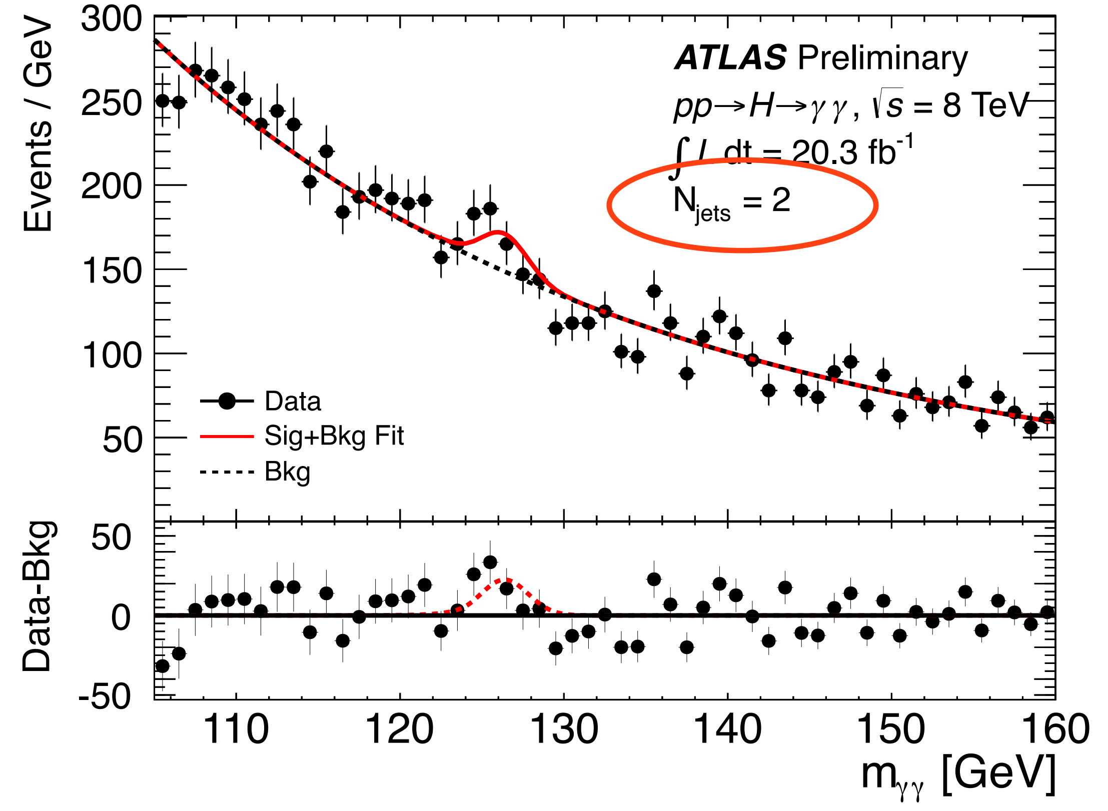
$$\mathcal{L}(\boldsymbol{m}_{\gamma\gamma};\boldsymbol{\nu}^{\mathrm{sig}},\boldsymbol{\nu}^{\mathrm{bkg}},m_H)=\prod_i\left\{\frac{e^{-\nu_i}}{n_i!}\prod_j^{n_i}\left[\nu_i^{\mathrm{sig}}\,\mathcal{S}_i(m_{\gamma\gamma}^j;m_H)+\nu_i^{\mathrm{bkg}}\,\mathcal{B}_i(m_{\gamma\gamma}^j)\right]\right\}\times\prod_k\mathcal{G}_k$$

$\nu_{\mathrm{i}}^{\mathrm{sig}}$: # of signal in i$^{\mathrm{th}}$ bin

$\nu_{\mathrm{i}}^{\mathrm{bkg}}$: # of background in i$^{\mathrm{th}}$ bin

$\mathcal{G}_k$: Constrain term of the k$^{\mathrm{th}}$ nuisance parameter





Fiducial photon definition

- $p_{\mathrm{T}}/m_{\gamma\gamma} > 0.35$ (0.25) for leading(sub-leading) photon
- $|\eta| < 2.37$ (without $1.37 \geq |\eta| \geq 1.56$ for reco)

Jet definition

- Anti-k_t $R = 0.4$, $p_{\mathrm{T}} > 30$ GeV, $|y| < 4.4$

Selected data are divided in bins of observable

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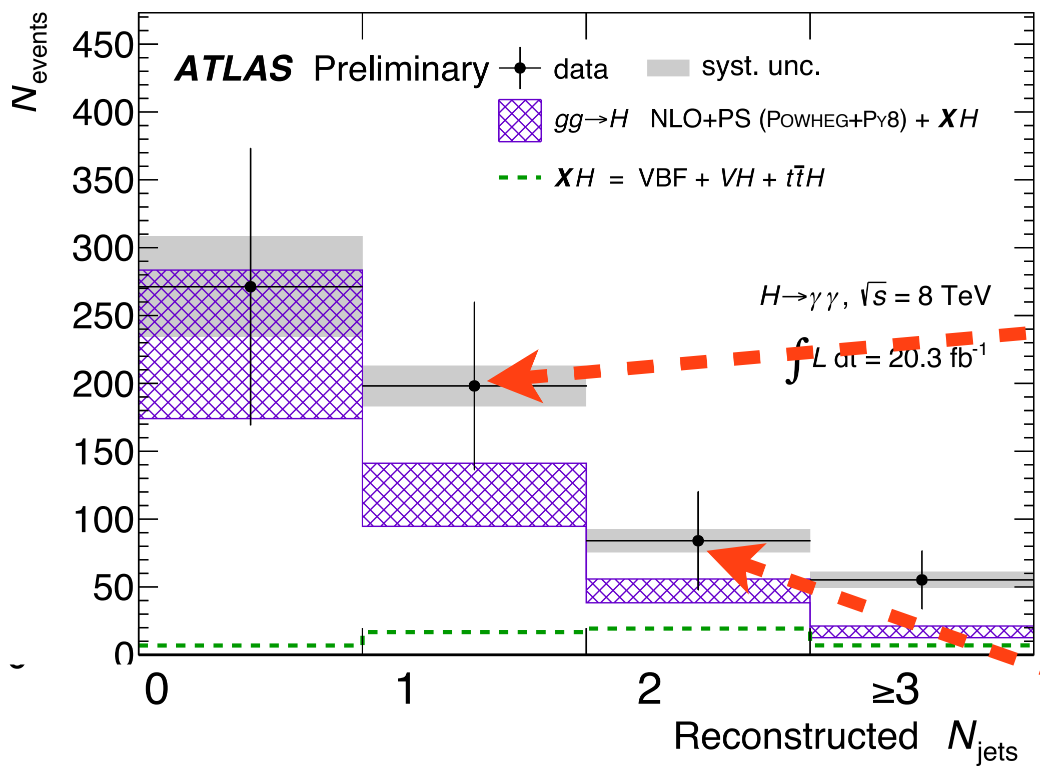
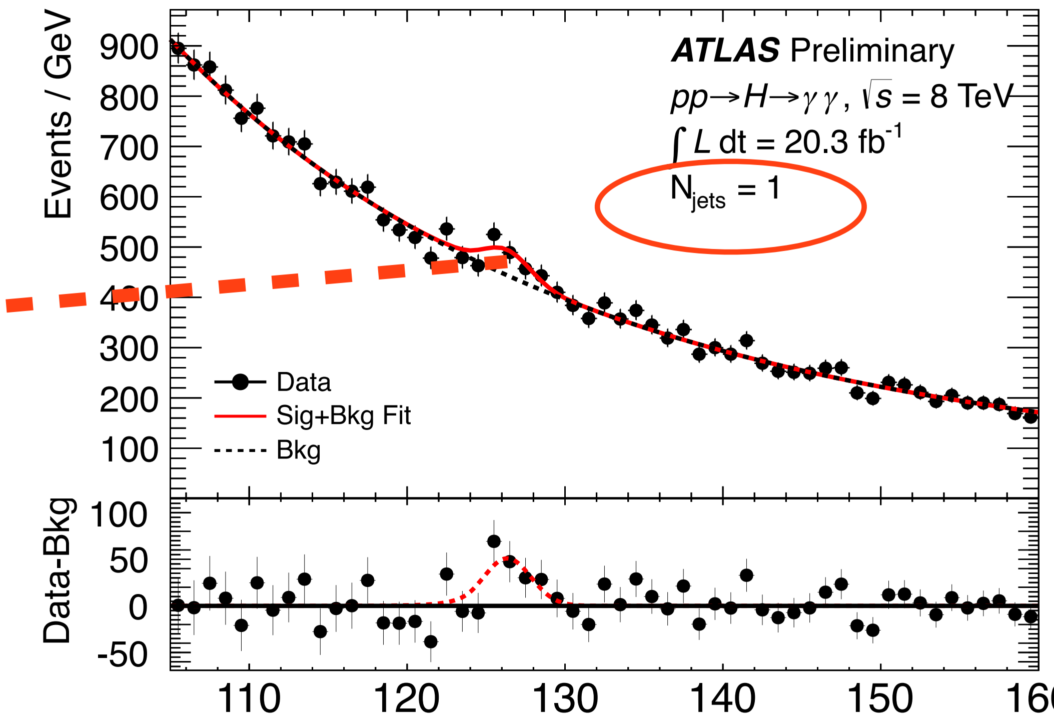
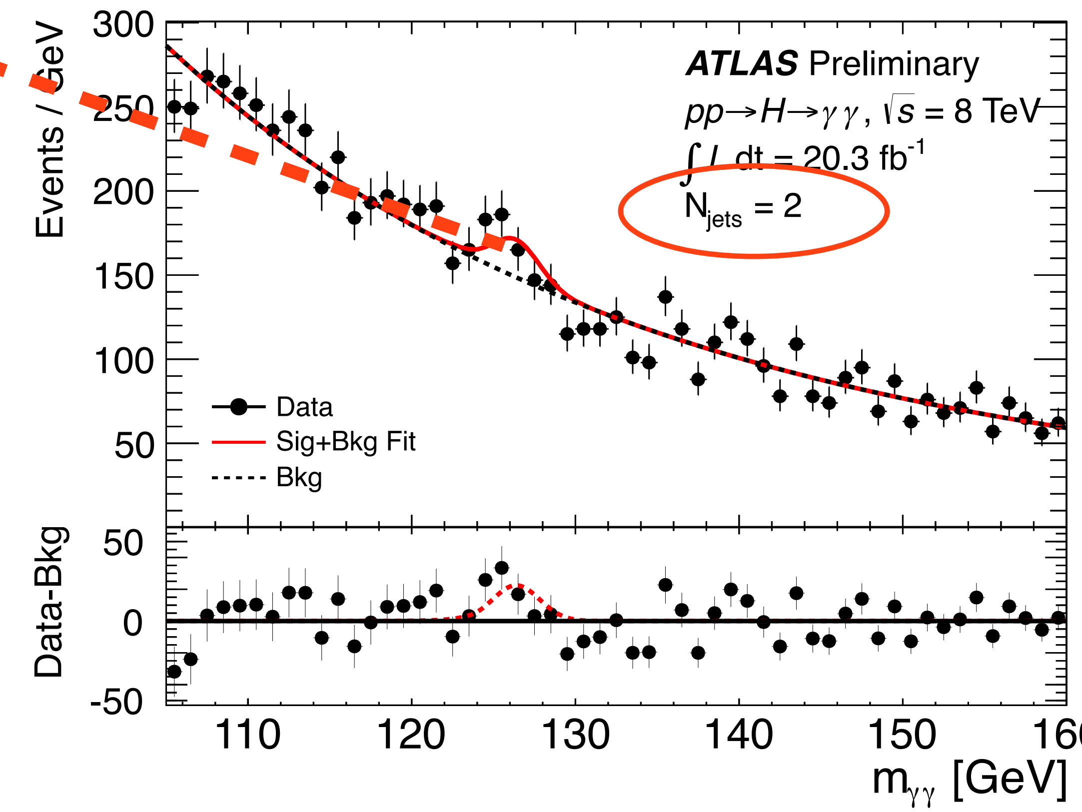
Analysis overview







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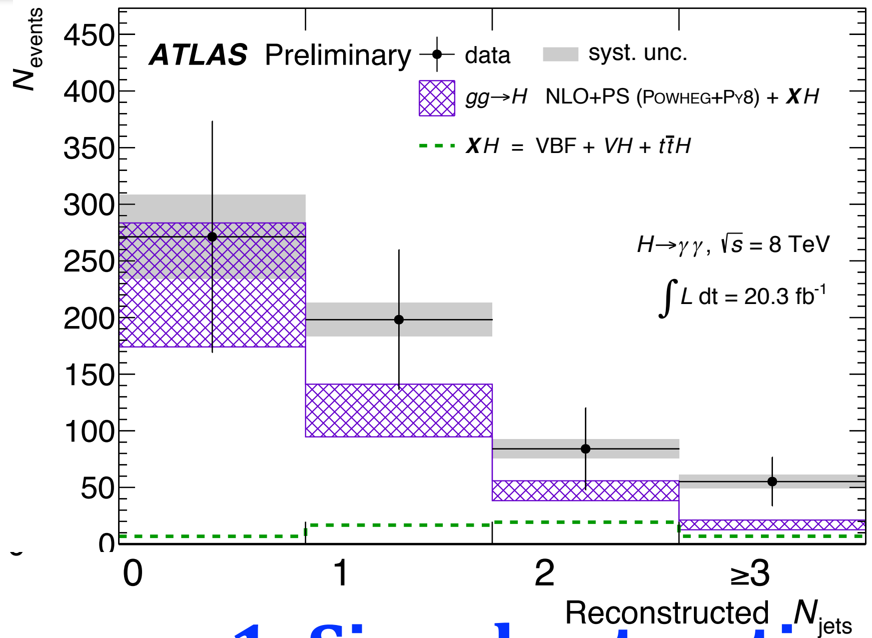

1. Signal extraction

@ reconstructed level

Signal extracted with S+B unbinned likelihood fit of $m_{\gamma\gamma}$ separately for each bin of the observable.

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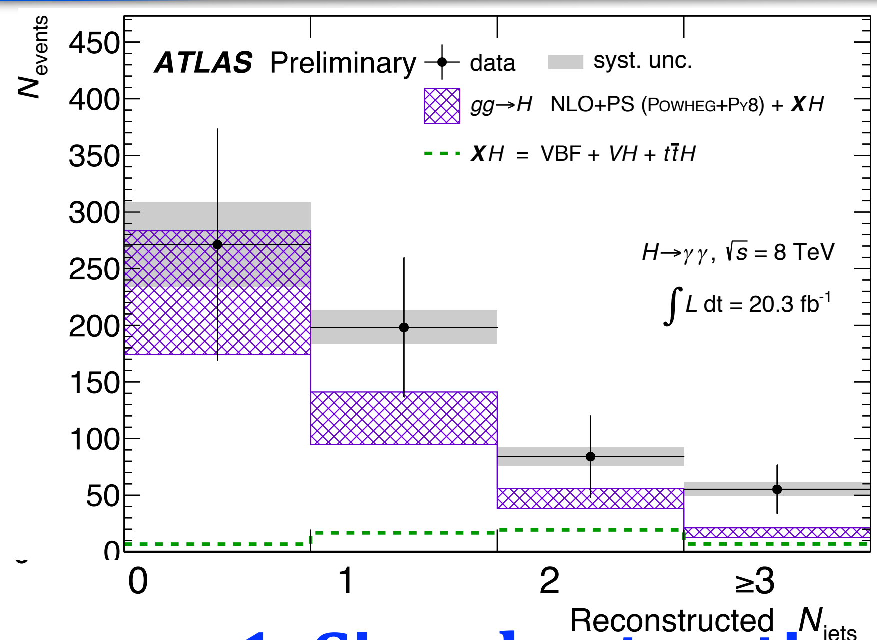
Analysis overview



1. Signal extraction

@ reconstructed level

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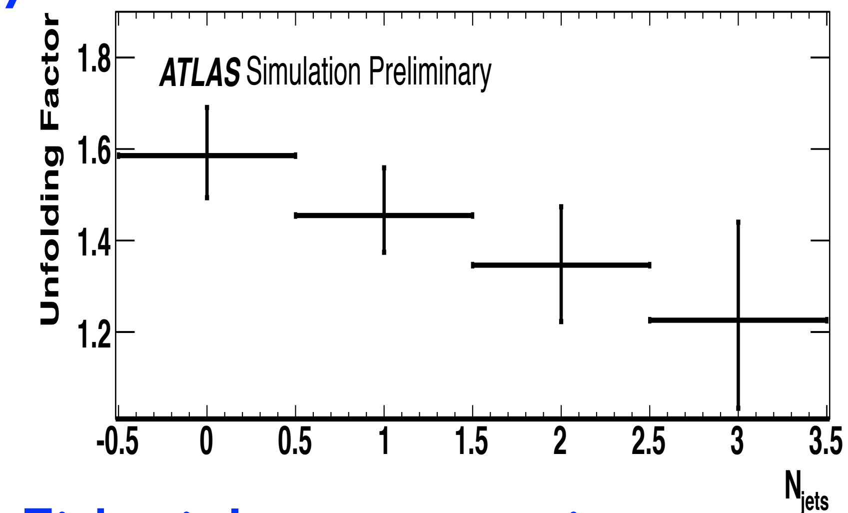
2. Bin-by-bin correction for detector effects



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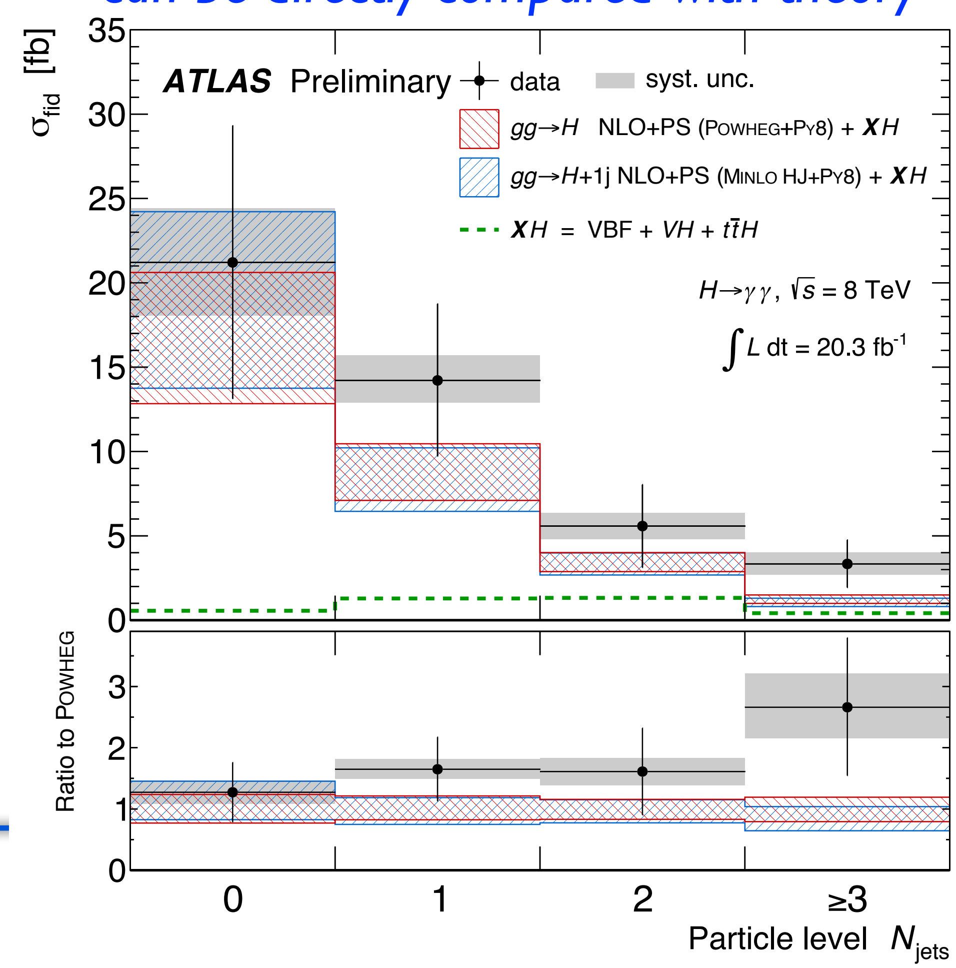
3. Fiducial cross section measurement

@ particle level

can be directly compared with theory



Signal extracted with S+B unbinned likelihood fit of $m_{\gamma\gamma}$ separately for each bin of the observable.

Fiducial photon definition

- $p_T/m_{\gamma\gamma} > 0.35$ (0.25) for leading(sub-leading) photon
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Jet definition

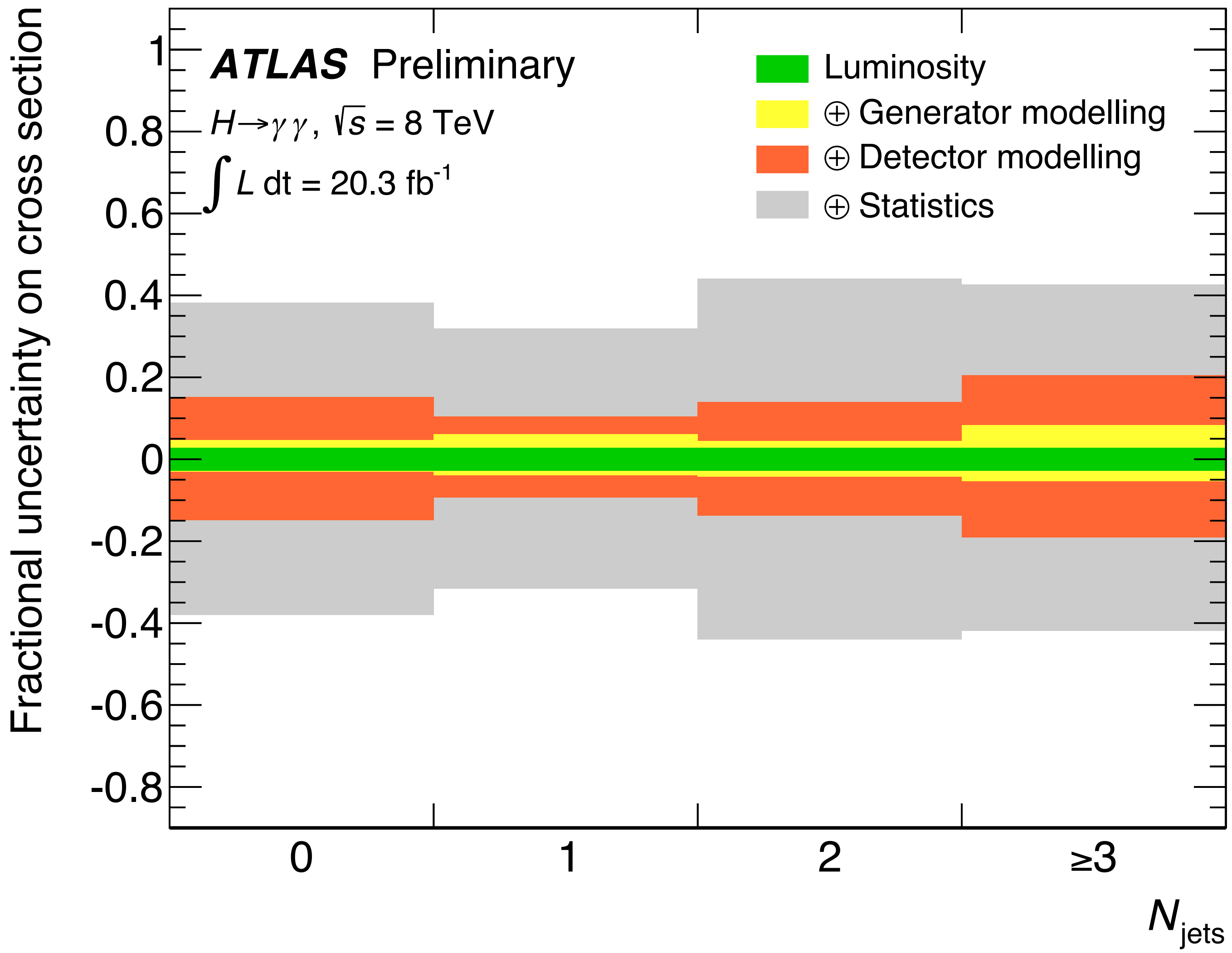
- Anti-k_t $R = 0.4$, $p_T > 30$ GeV, $|y| < 4.4$

Selected data are divided in bins of observable

Systematic Uncertainty

Potential biases of bin-by-bin correction have been carefully studied and the systematic uncertainties are evaluated.

- **Luminosity uncertainty**
- **Generator modelling uncertainty**
  - Composition of different production modes
  - Shape
- **Detector modelling uncertainty**
  - Photon object selection: *trigger efficiency, PID, isolation efficiency, photon energy resolution and scale*
  - Jet object selection: *Jet energy scale/ resolution, pileup modelling and suppression efficiency (JVF)*
  - Signal extraction in $m_{\gamma\gamma}$ fitting: *signal shape and signal/background modelling*



Statistical uncertainty dominates.

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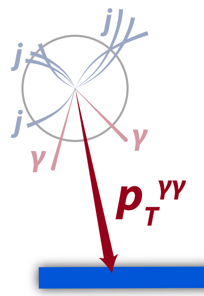
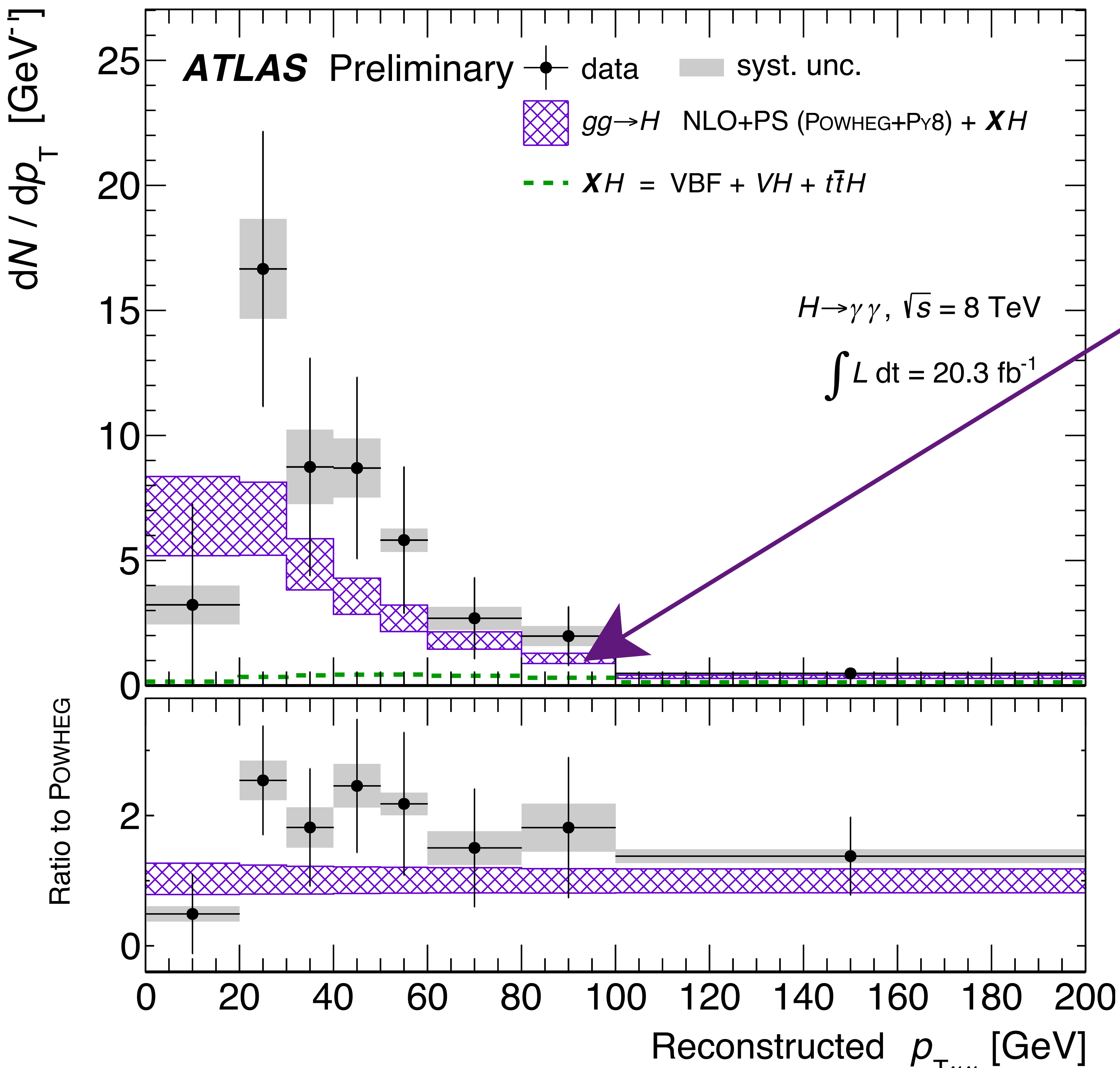


Higgs kinematic distribution

-- measured Higgs signal yield in bins of p_T



no detector unfolding applied

- *gg→H*: Powheg+Pythia8 (m_H = 125GeV)
- XH = VBF + (VH + ttH)
  (Powheg+Pythia8 and Pythia8)
- Uncertainties:
  - *theoretical prediction uncertainty:*
    including higher order pertubative corrections, PDF, underlying event modeling and branching ratio systematics
  - *detector modelling uncertainty:*
    photon/jet selection uncertainty

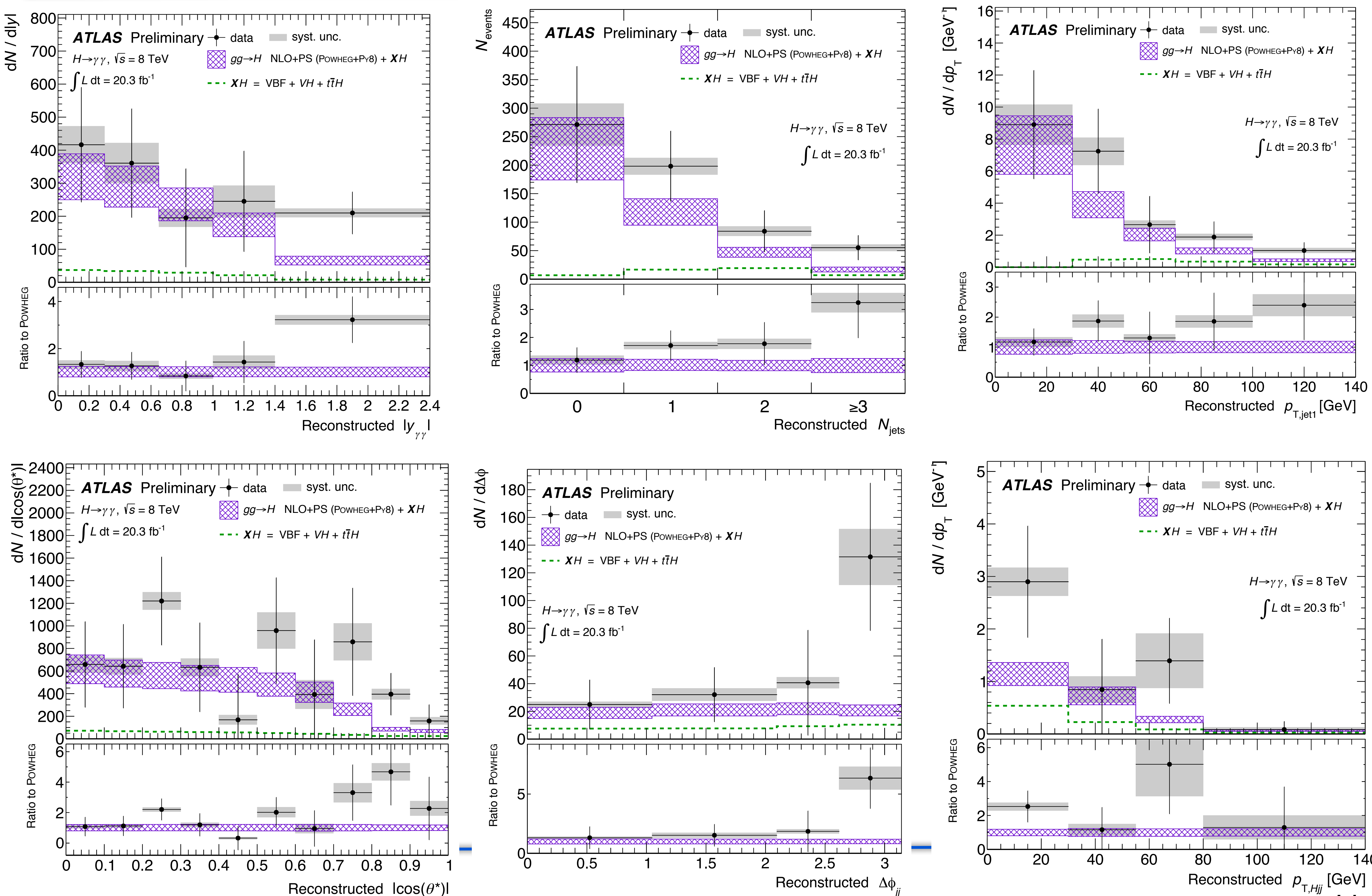
✦ Possible global excess as signal strength measurement.

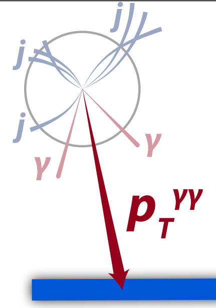
✦ Data tend to be slightly harder.

✦ Agreement within uncertainties with the SM prediction

First measurements of Higgs kinematic distributions

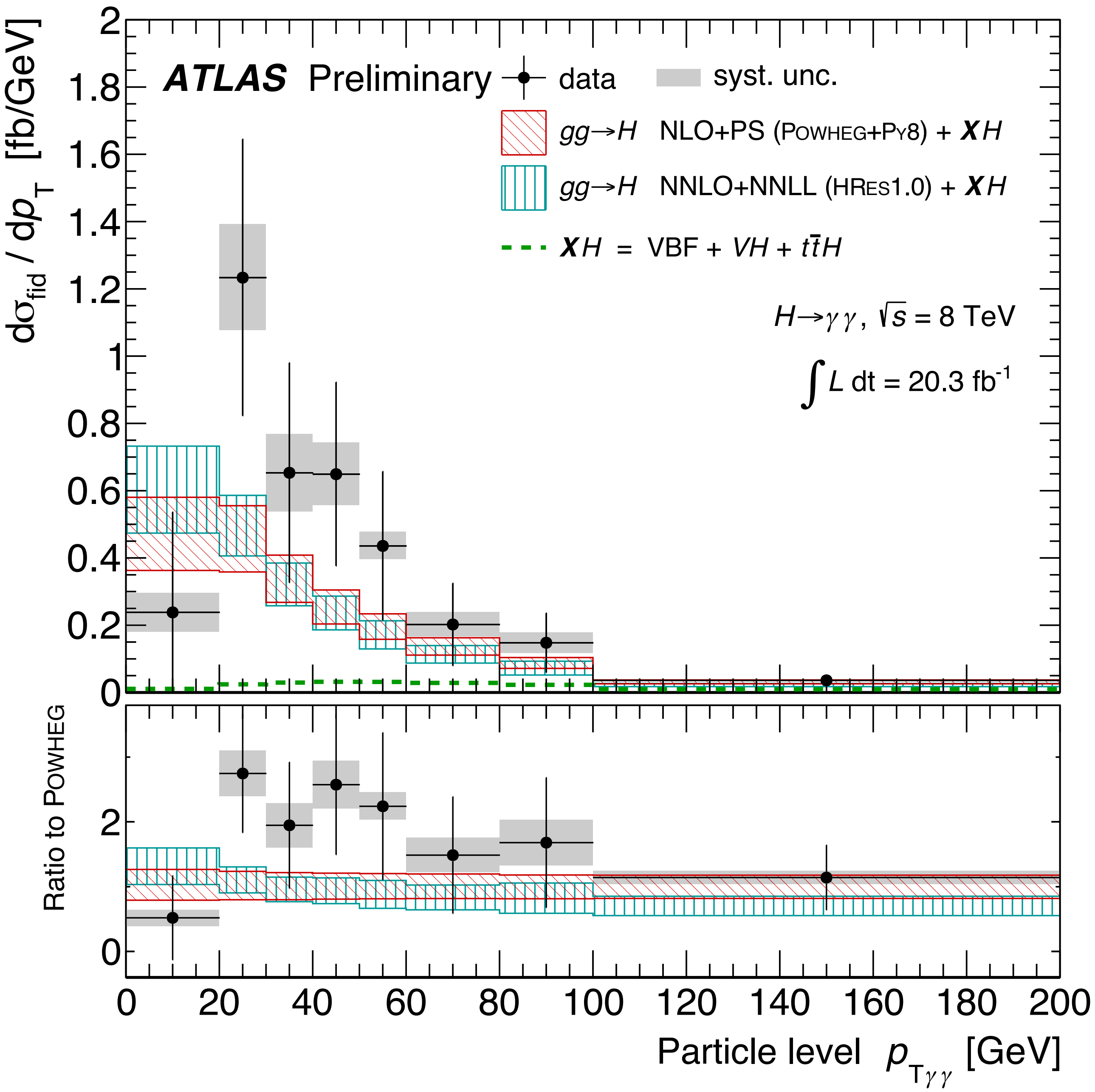
-- Higgs signal yield in bins of other observables





Fiducial differential cross section

-- Higgs p_T

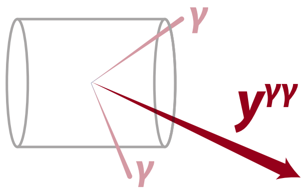


Probabilities from χ^2 test, taking into account the full covariance between bins

	N_{jets}	$p_T^{\gamma\gamma}$	$\lvert y^{\gamma\gamma}\rvert$	$\lvert\cos\theta^*\rvert$	$p_T^{j_1}$	$\Delta\phi_{jj}$	$p_T^{\gamma\gamma jj}$
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	–	–	–	–

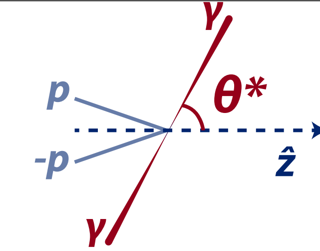
No significant difference between the predicted shapes and the observation.

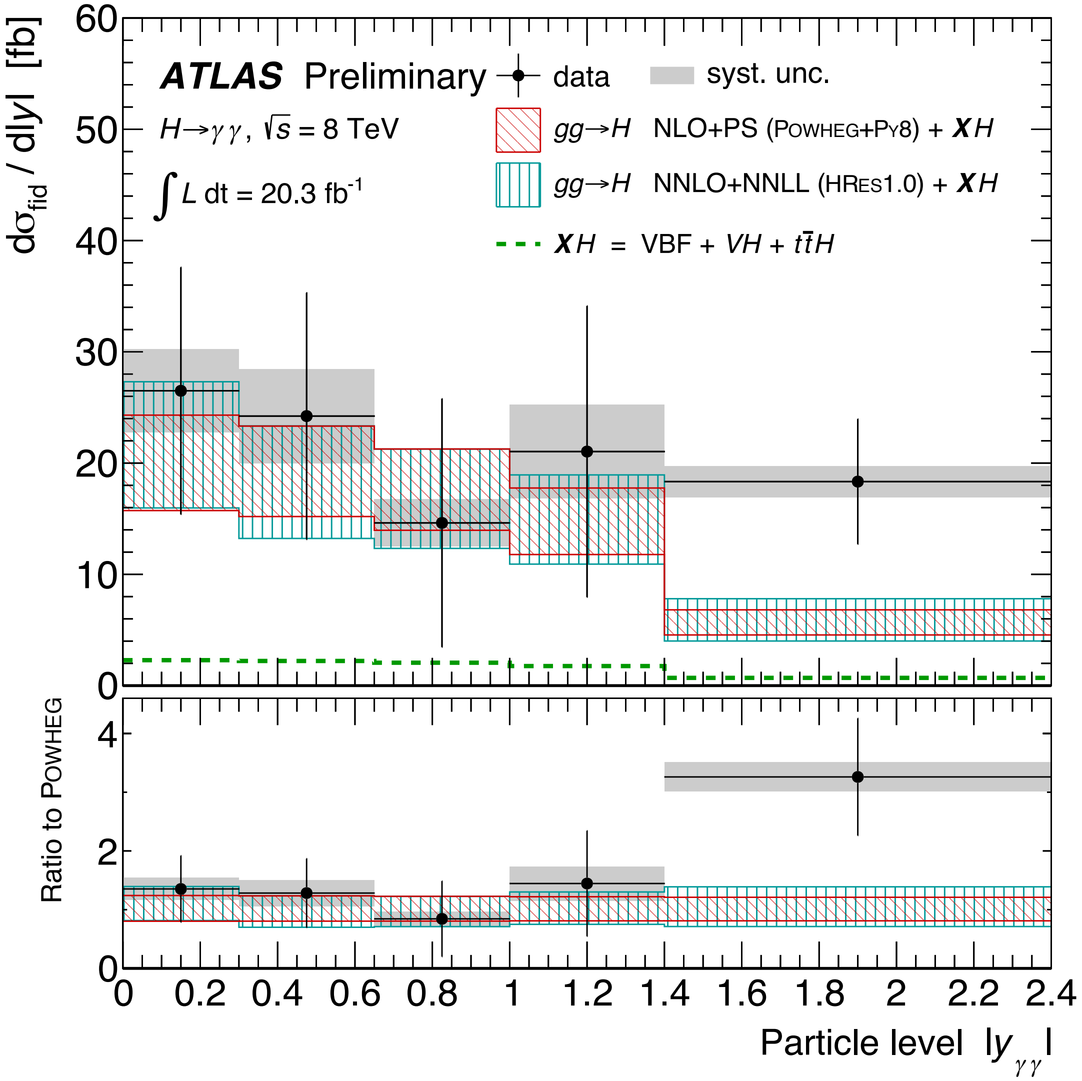
full detector unfolding applied brings the measurements to particle level

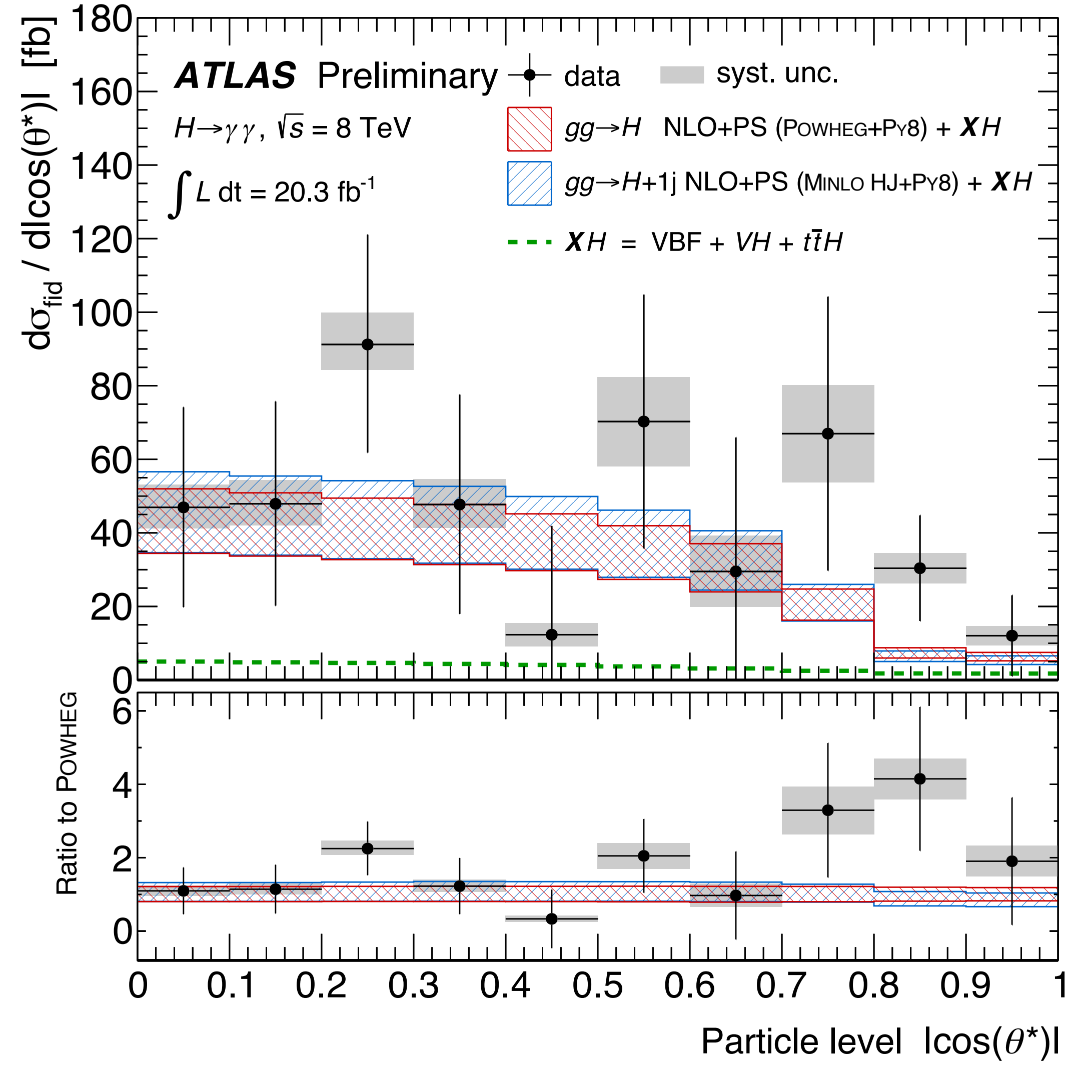


Fiducial differential cross section

-- Higgs rapidity and cosθ*



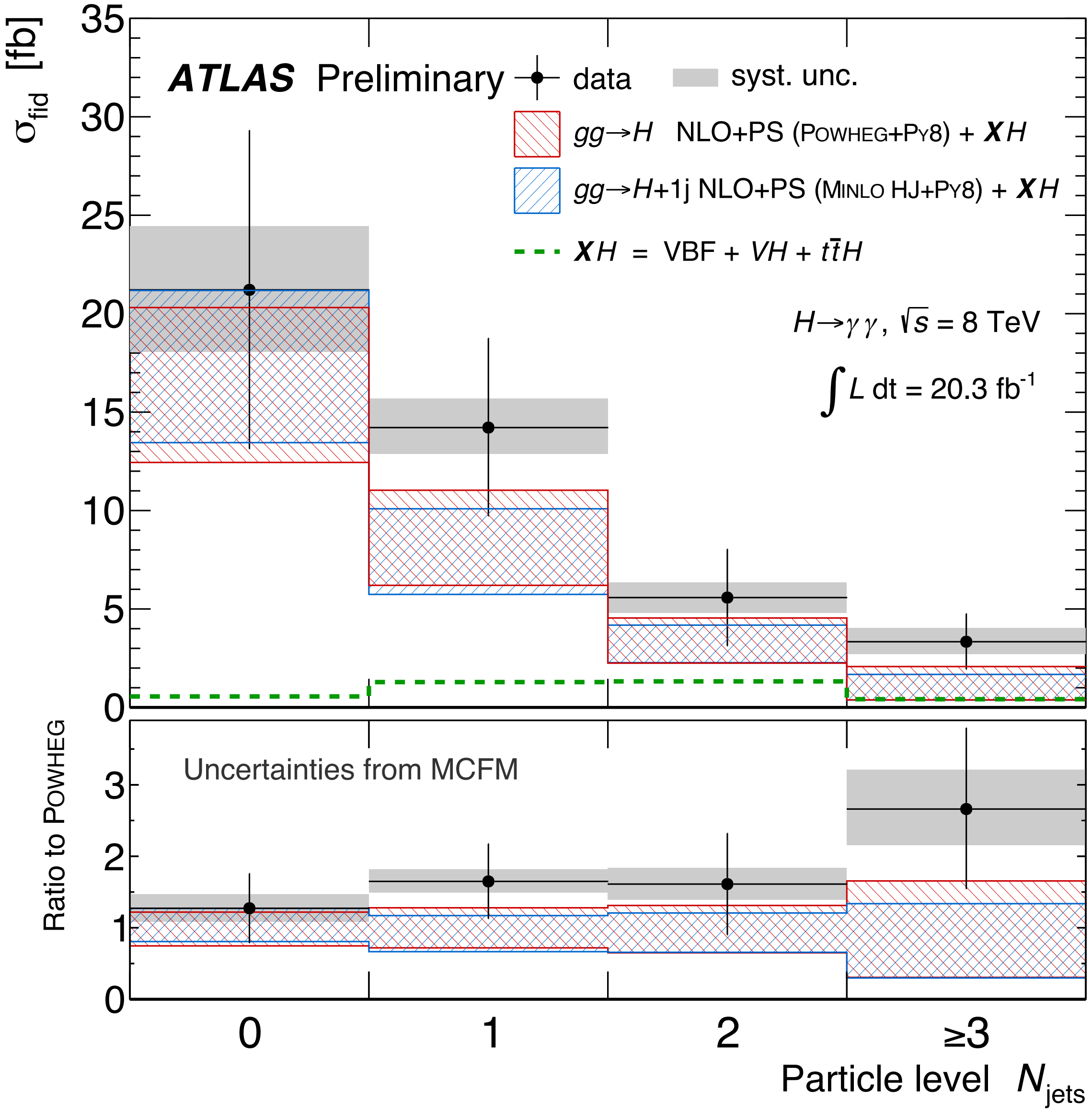


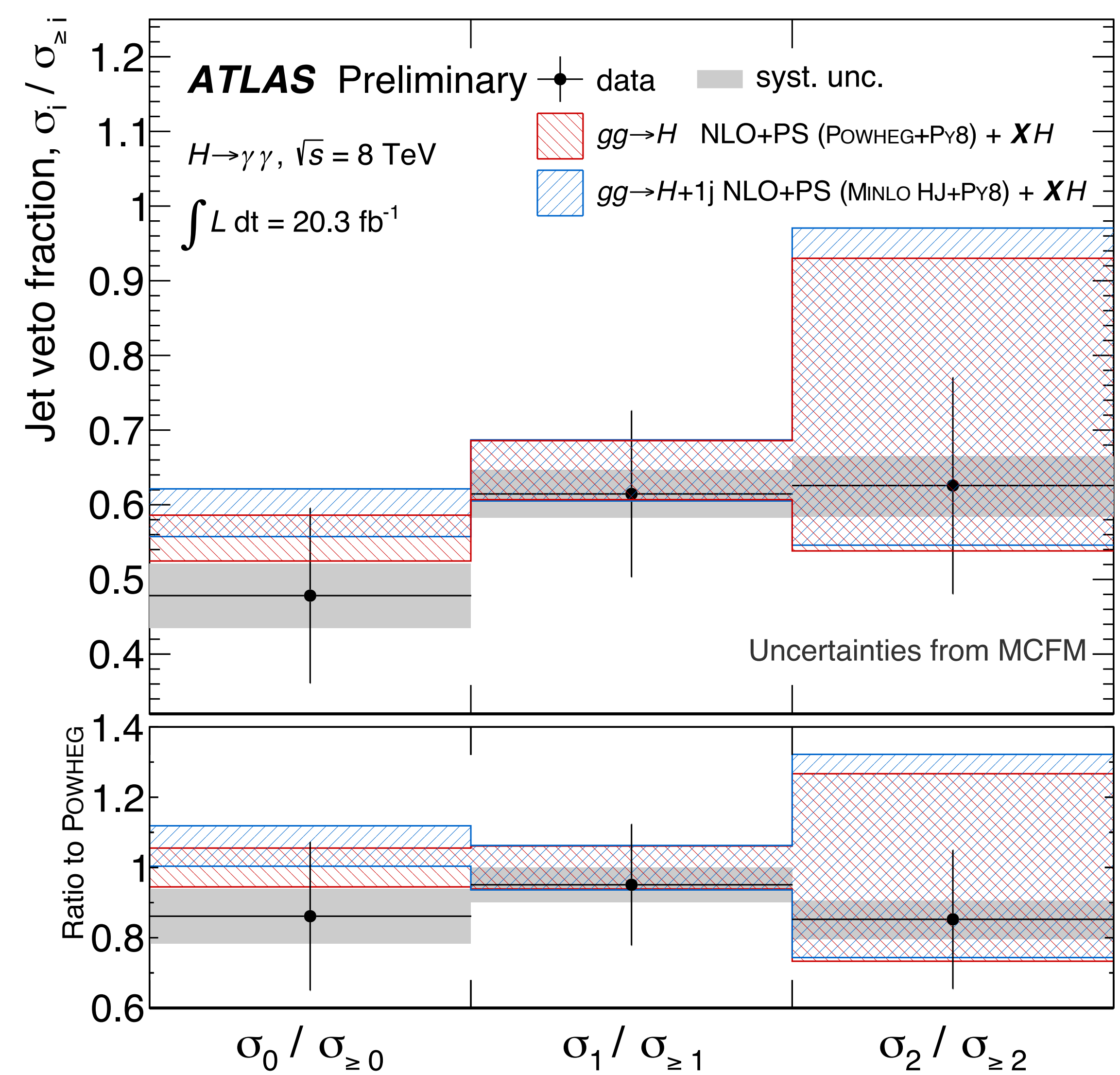


- Agreement within uncertainties with the SM prediction.
- The measurement of cosθ* is complementary to what is determined in the dedicated spin analysis, and the individual yields are extracted in a model independent way.

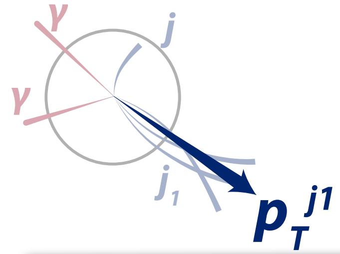
Fiducial differential cross section

--Jet multiplicity





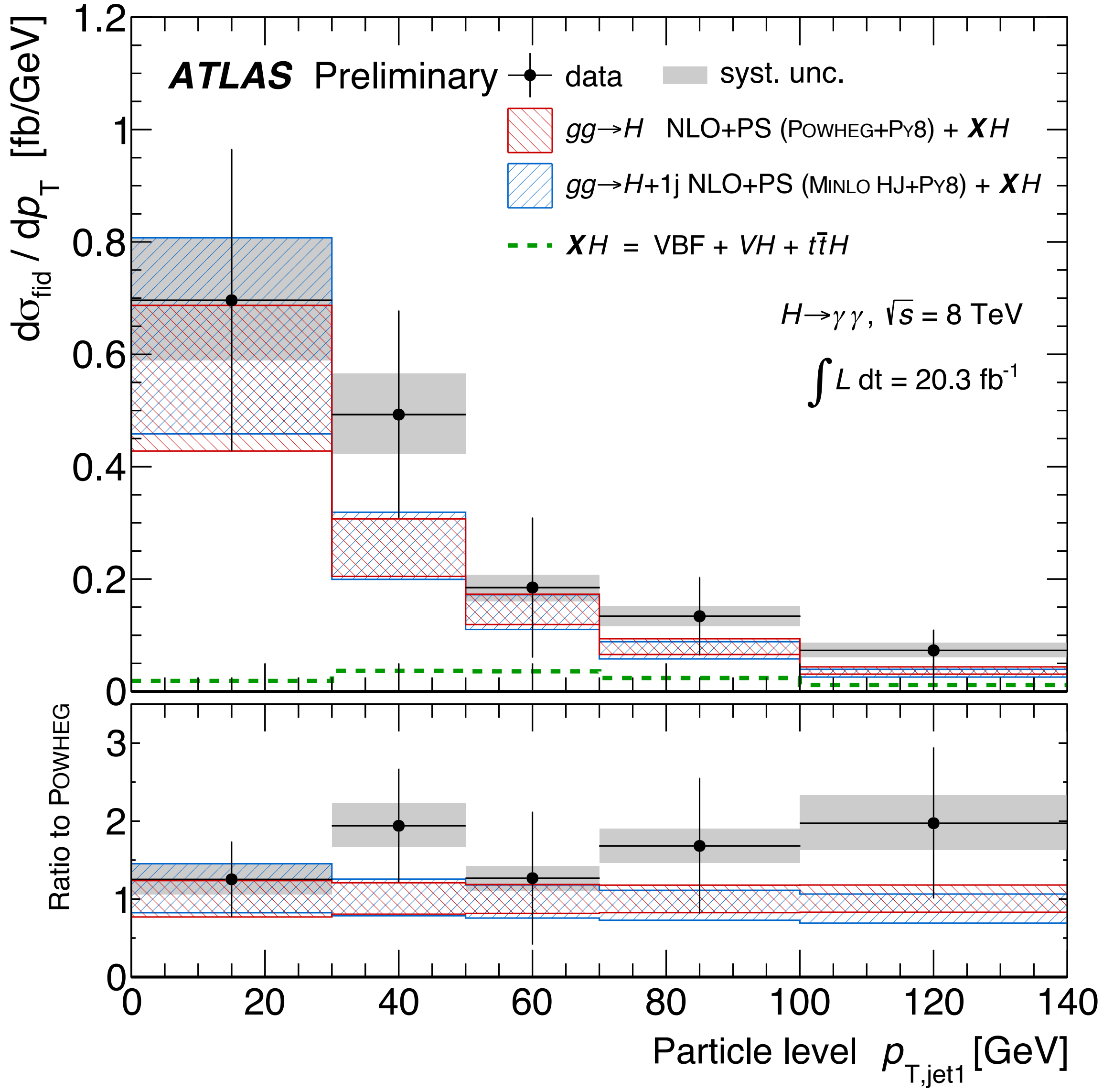
- More conservative uncertainty estimation with the procedure of reference **[Phys. Rev. D 85, 034011 (2012)]** using input uncertainties from MCFM.
- Good agreement on the jet veto fraction distribution indicates that we have a fair understanding.

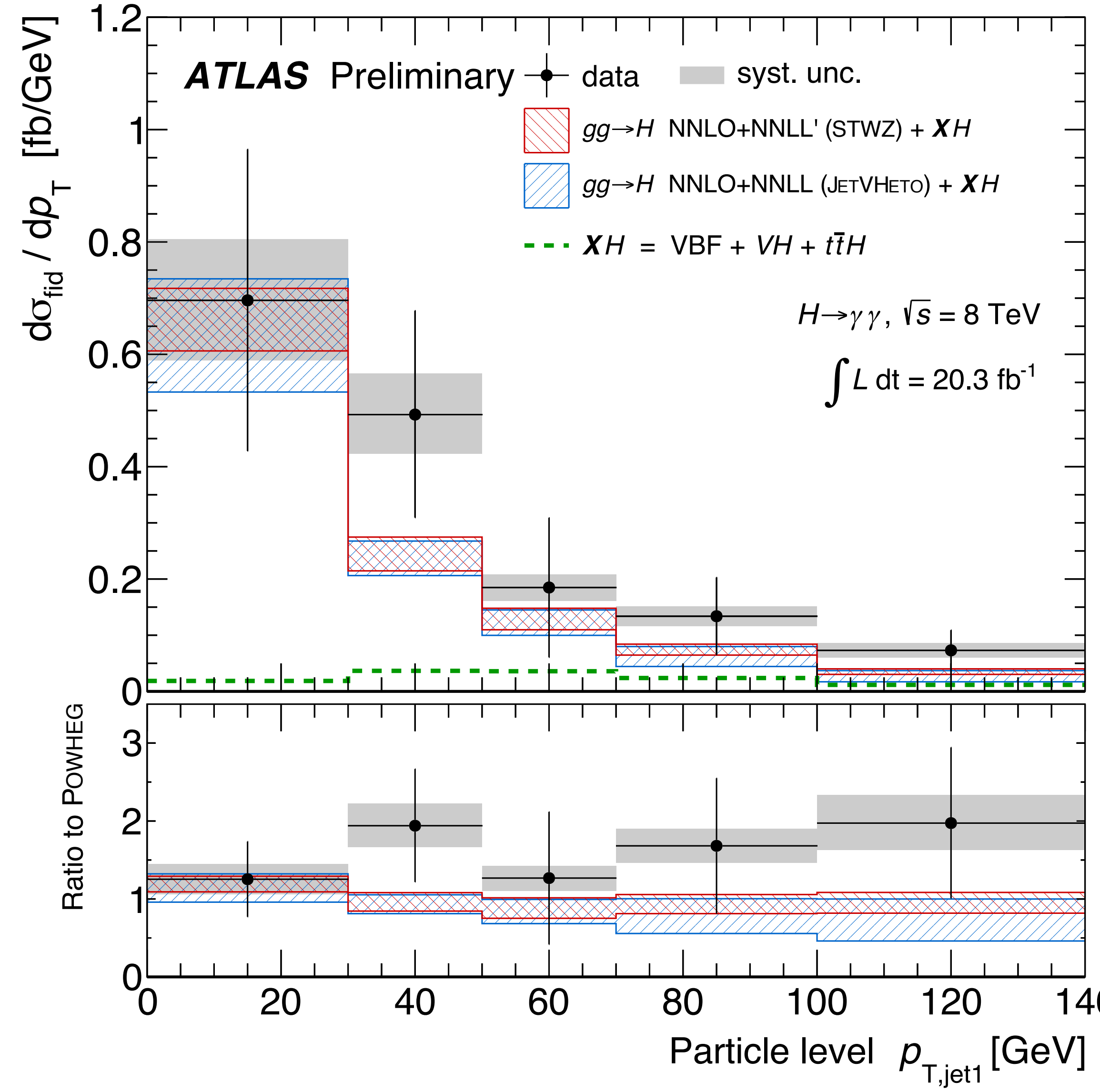


Fiducial differential cross section -- leading jet p_T

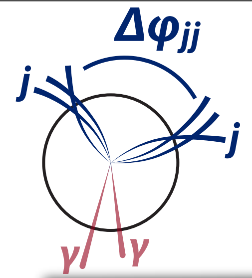
The 0-30 GeV bin contains the cross section for events without any jet above 30 GeV

Same data points but different more precise theoretical prediction!



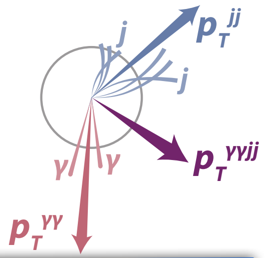


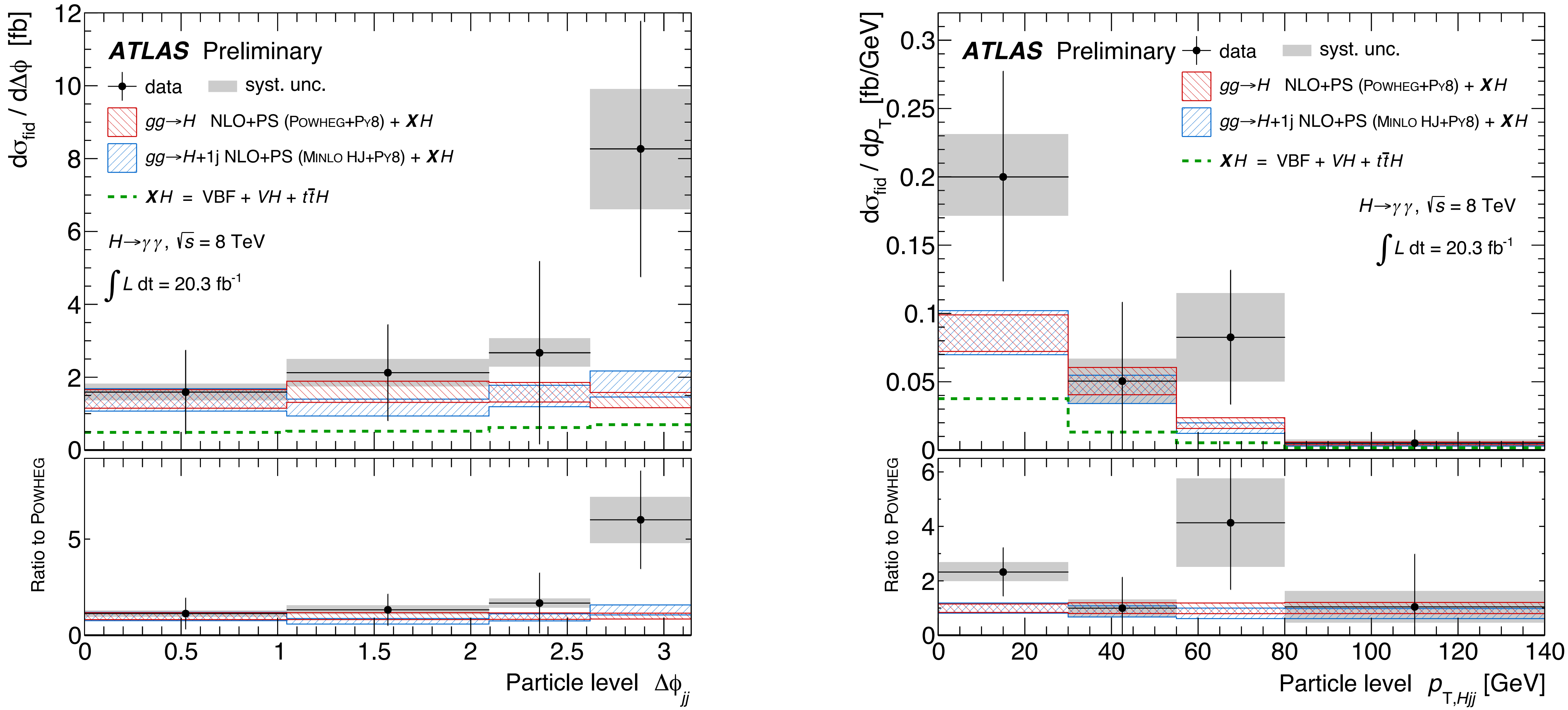
- Theory predictions describe the spectrum well
- Comparison is made with the predictions with STWZ [PRL. 109, 202001 (2012)] and JETVHETO [hep-ph:1307.1808] calculation, which are precise to NNLO +NNLL' and NNLO+NNLL respectively.



Fiducial differential cross section

-- di-jet observables





- Largest excess in last $\Delta\phi_{jj}$ bin. Carefully checked for systematic biases.
- Predictions for both distributions are consistent with the observed spectra.

Conclusion

- First measurements of Higgs differential cross sections with the full 2012 dataset and comparisons with several MC predictions are presented.
- The measured spectra of 7 observables and the jet veto fraction are sensitive to the fundamental kinematic properties of Higgs boson, probe its spin and parity and test the QCD theoretical prediction.
- Except for possible global excess as signal strength measurement, with the limited statistics of the measurement, the predicted shapes agree with the observation, and no significant deviation from the SM expectation is observed.

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More interesting observable will be measured
With more statistics in RunII, more meaningful conclusion may be drawn from these measurements.
Exciting times ahead :)

Comparison with theoretical predictions

ggH prediction:

- POWHEG H @ NLO + Py8
- MINLO H + 1jet @ NLO + Py8
- HRES H & NNLO + approx. NNLL.
- JetVheto H @ NNLO/NNLL
- STWZ H + 1jet @NNLO/NNLL'

XH prediction:

- VBF: POWHEG H @ NLO + Py8
- Other: Py8 @ LO
- All scaled with k-factor of the Higgs

❖Theoretical prediction uncertainties

(Stat. ⊕ (Scale+PDF) ⊕ UE ⊕ BR):

- *Sum in quadrature of PDF+ α_s variations*
- *Envelop of Renormalization/factorization/ resummation*
- *Underlying event modeling*
- *Branching ratio of Higgs decay*

Probabilities from chi2 test, taking into account the full covariance between bins

	N_{jets}	$p_T^{\gamma\gamma}$	$\lvert y^{\gamma\gamma}\rvert$	$\lvert\cos\theta^*\rvert$	$p_T^{j_1}$	$\Delta\phi_{jj}$	$p_T^{\gamma\gamma jj}$
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MINLO	0.44	–	–	0.67	0.73	0.45	0.49
HRES 1.0	–	0.39	0.44	–	–	–	–

Predicted shapes mostly agree well with the observation.

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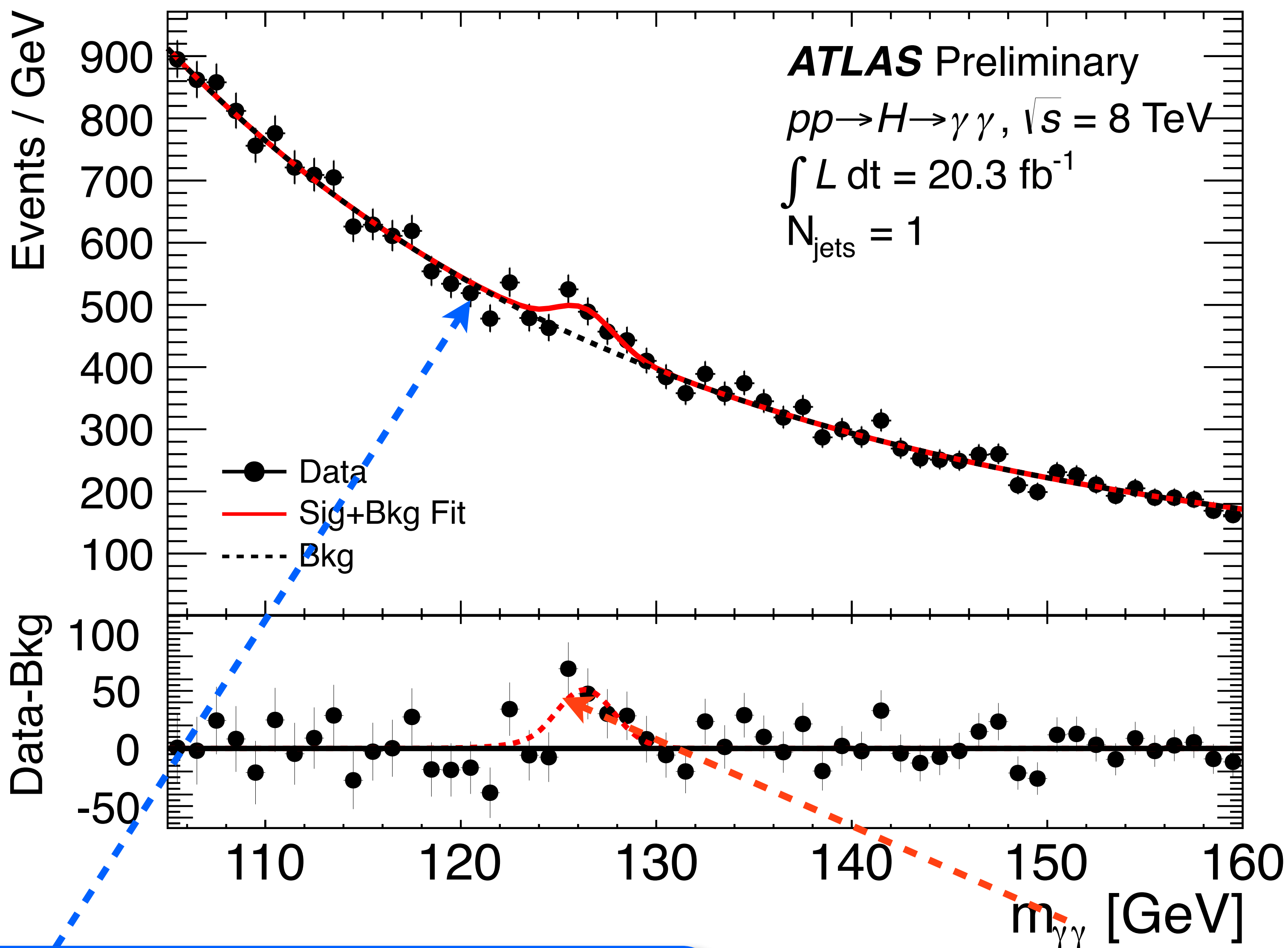
Signal extraction



Background $m_{\gamma\gamma}$ modelling

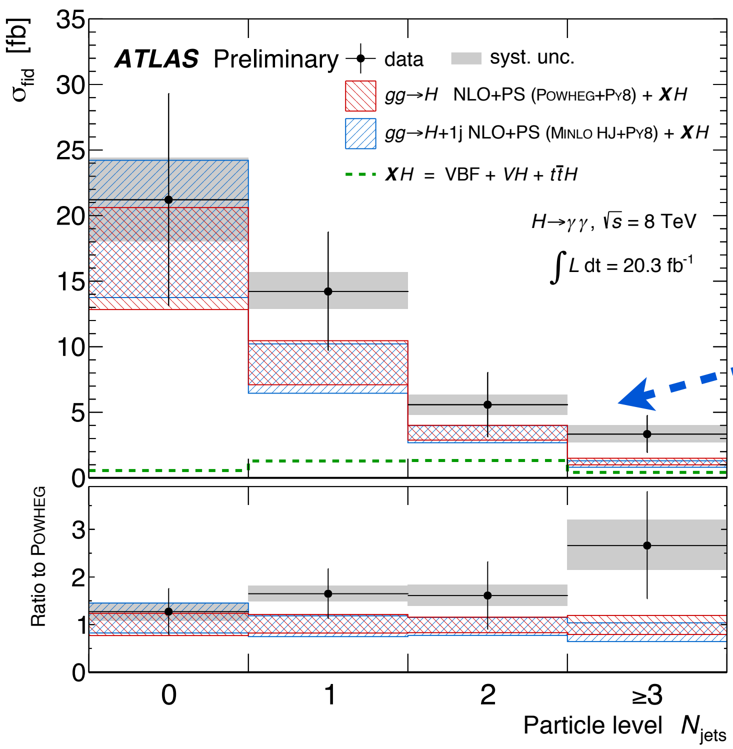
- smooth function used
- validated using the same procedure as used in main analysis (ATLAS-CONF-2013-029)

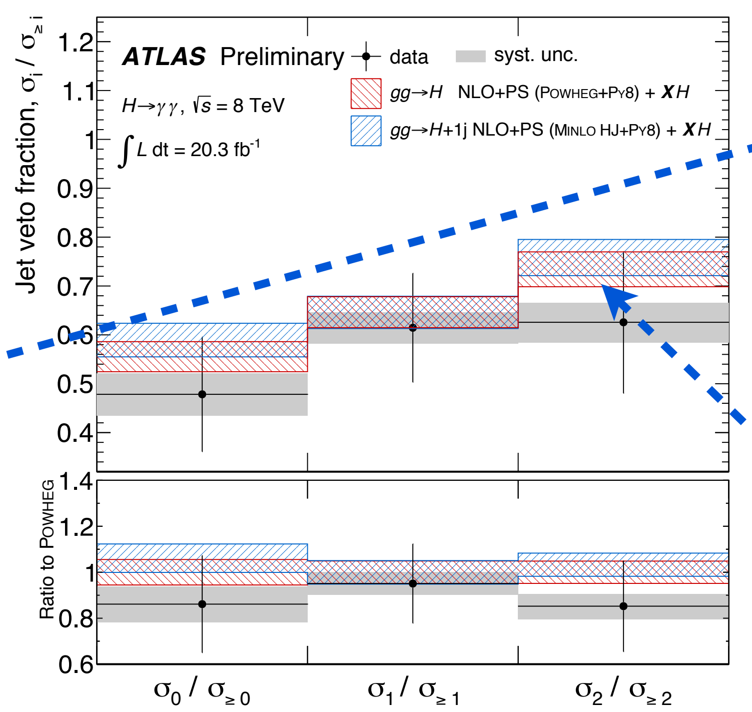
Signal $m_{\gamma\gamma}$ shape modelling

- Crystal Ball function + a wide gaussian, parameterized as a function of mH

Fiducial differential cross section

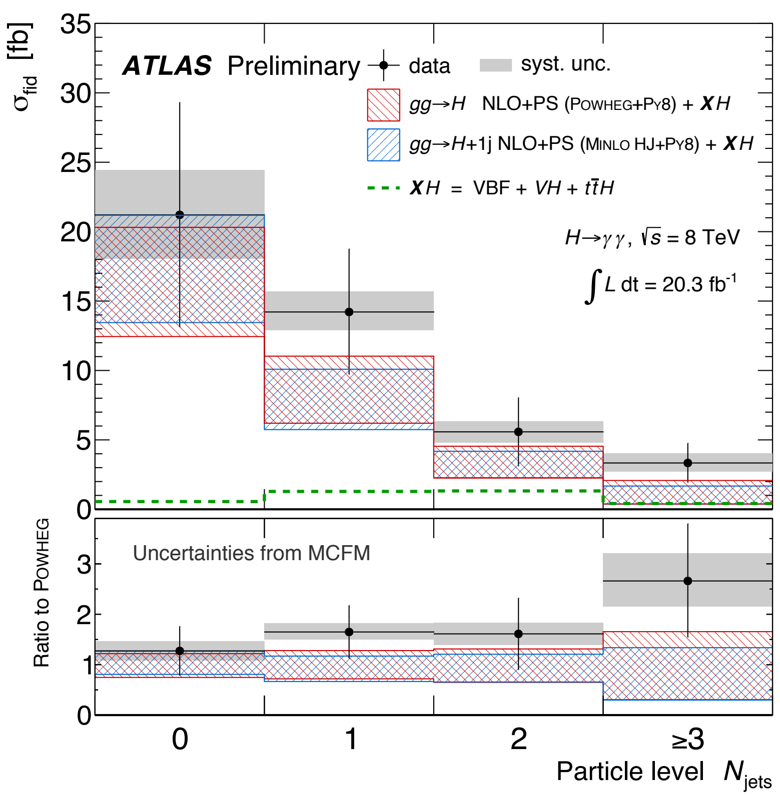
--Jet multiplicity

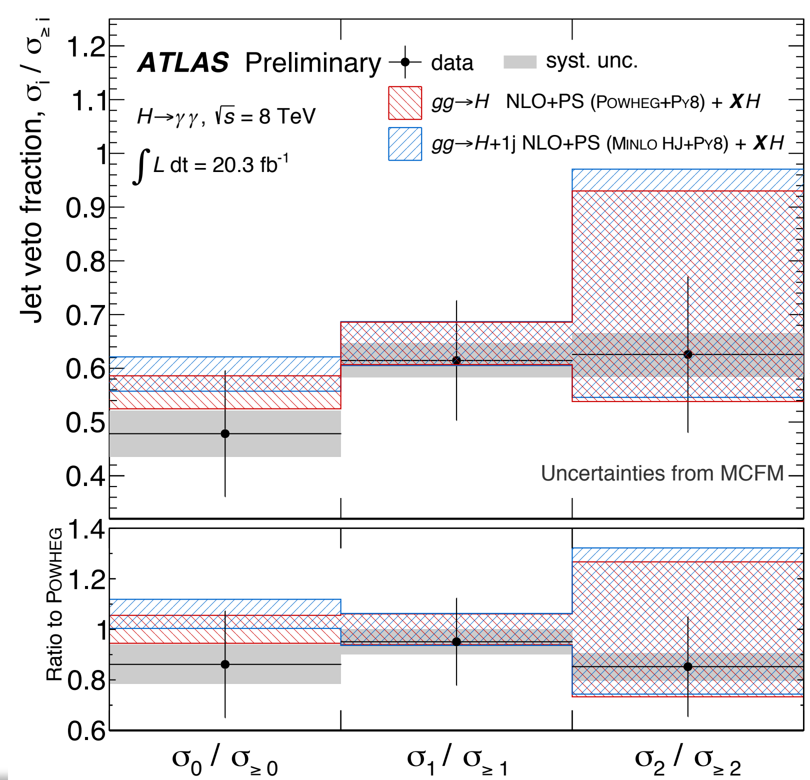




Theory unc. of large N_{jets} are unnaturally small, because scale variations do not significantly shift the predictions from the parton shower algorithm

Good agreement indicates that we have a fair understanding of this.

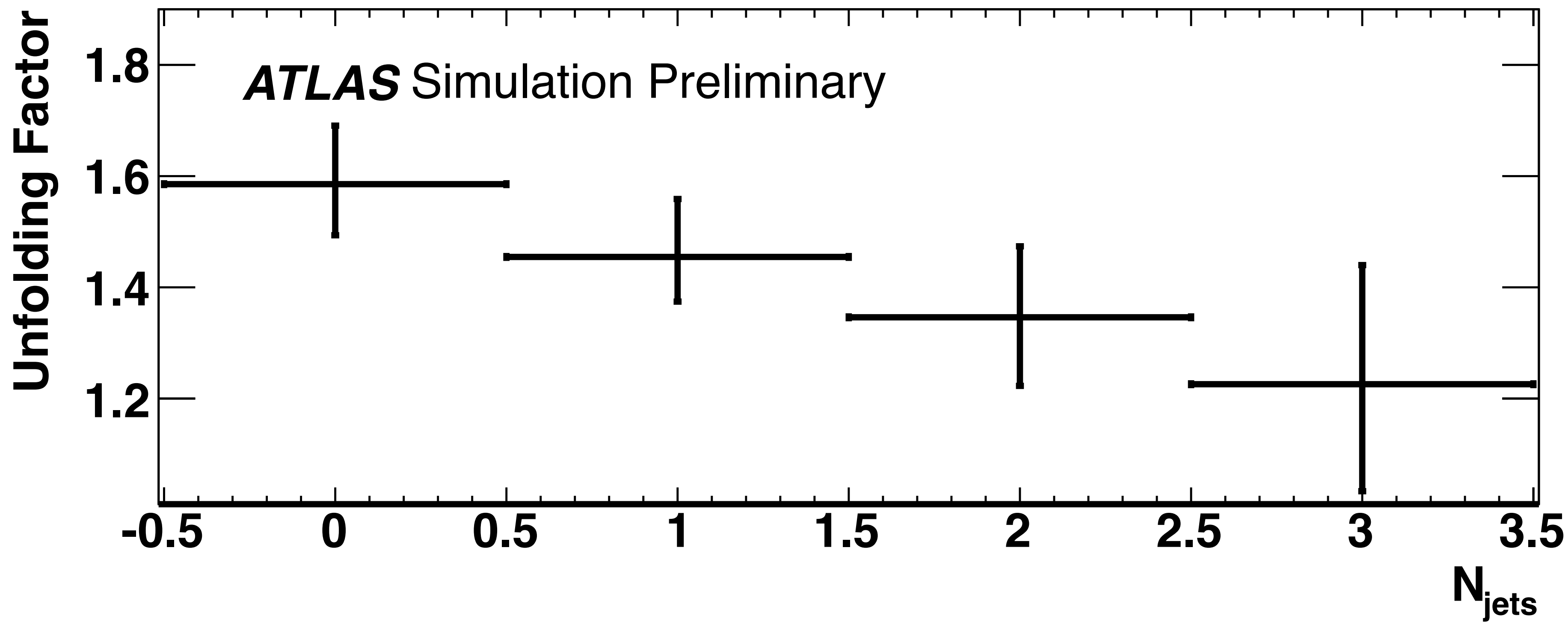




More conservative uncertainty estimation with the ST procedure [Phys. Rev. D 85, 034011 (2012)] using input uncertainties from MCFM.

Unfolding treatment

- Bin-by-bin unfolding method is used to correct for detector effect.
- Unfolding factor : $C_i = n_i^{particle}/n_i^{reconstructed}$, is derived bin-by-bin. This unfolding procedure corrects for all efficiencies, acceptances and resolution effects.



✦ The distributions at particle level are restored by multiplying the extracted binned signal yield by unfolding factor.

✦ Potential biases have been carefully studied and systematic uncertainties are evaluated.