ATLAS EXPERIMENT

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Measurement on the Higgs fiducial / differential cross-section in di-photon final state with the ATLAS detector at 13TeV

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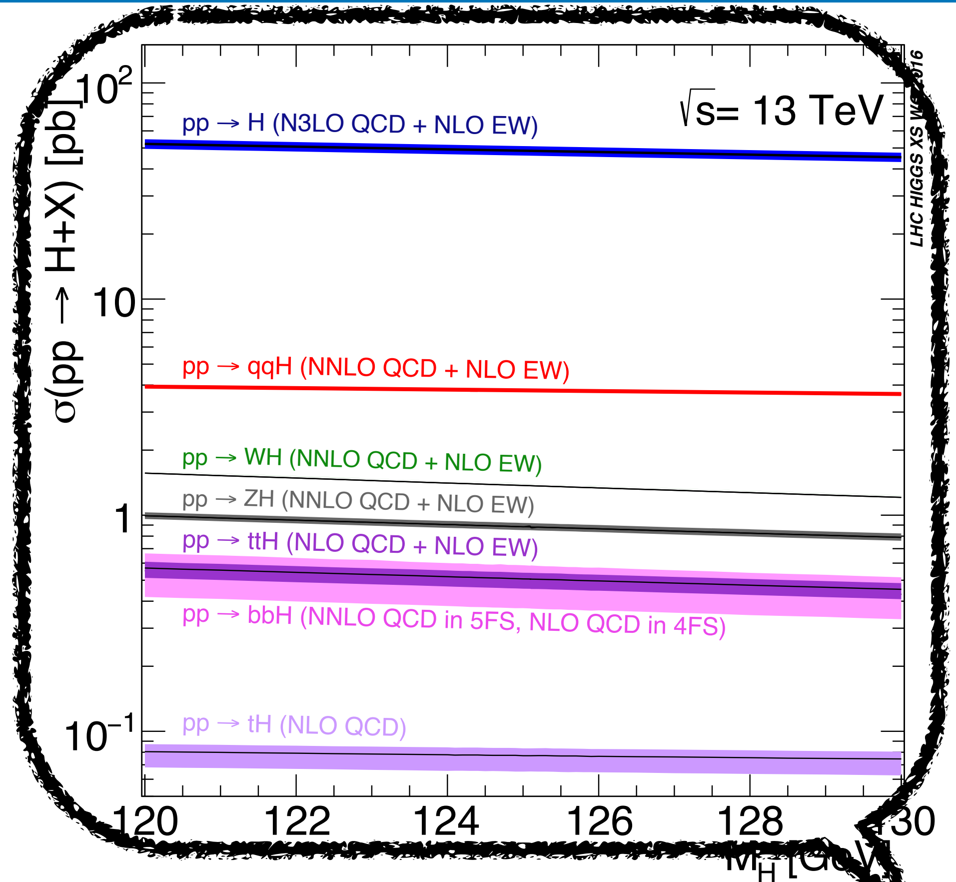
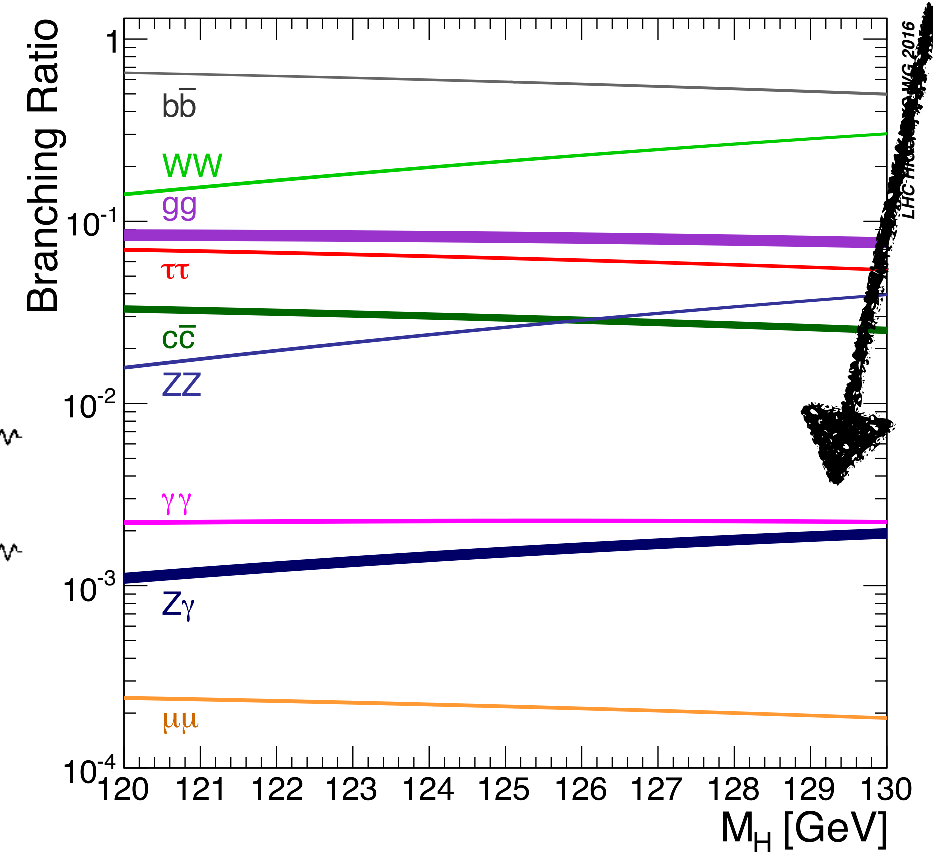
Outline

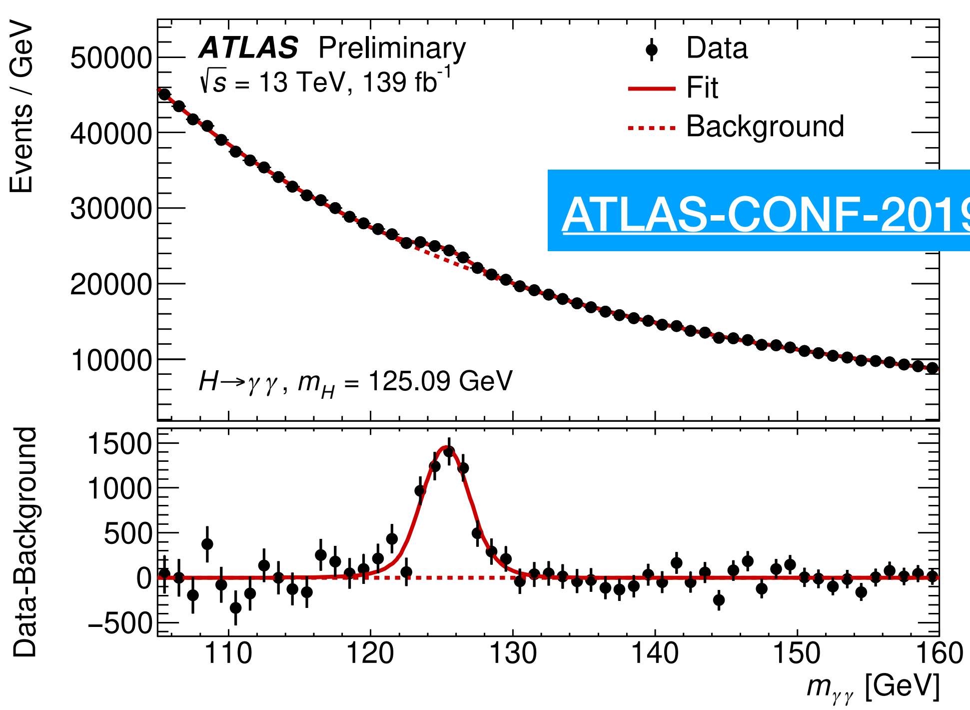
- Introduction of H->γγ
- Fiducial cross-section measurement
  - Event selection
  - Signal / background modeling
  - S+B fit and Unfolding
  - Systematic Un. And Results
- Interpretation of effective Lagrangian and charm Yukawa coupling
- Summary

Introduction of H->γγ

- ✦ SM Higgs production: ggH, VBF, VH, ttH, bbH, tH
- ✦ **H->γγ final state: loop decay that sensitive to BSM**
  - Small branching ratio (0.227%), but **high signal significance with 2 prompt-isolated photons**, good resolution (<2%)
  - Smoothly falling **background by fitting data sideband, signal is based on MC simulation** and modeled by Double-sided crystal ball function







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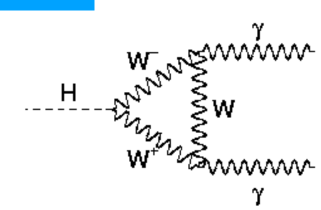
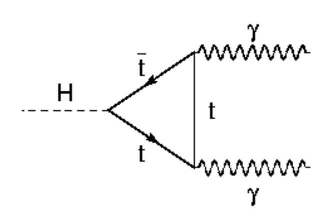
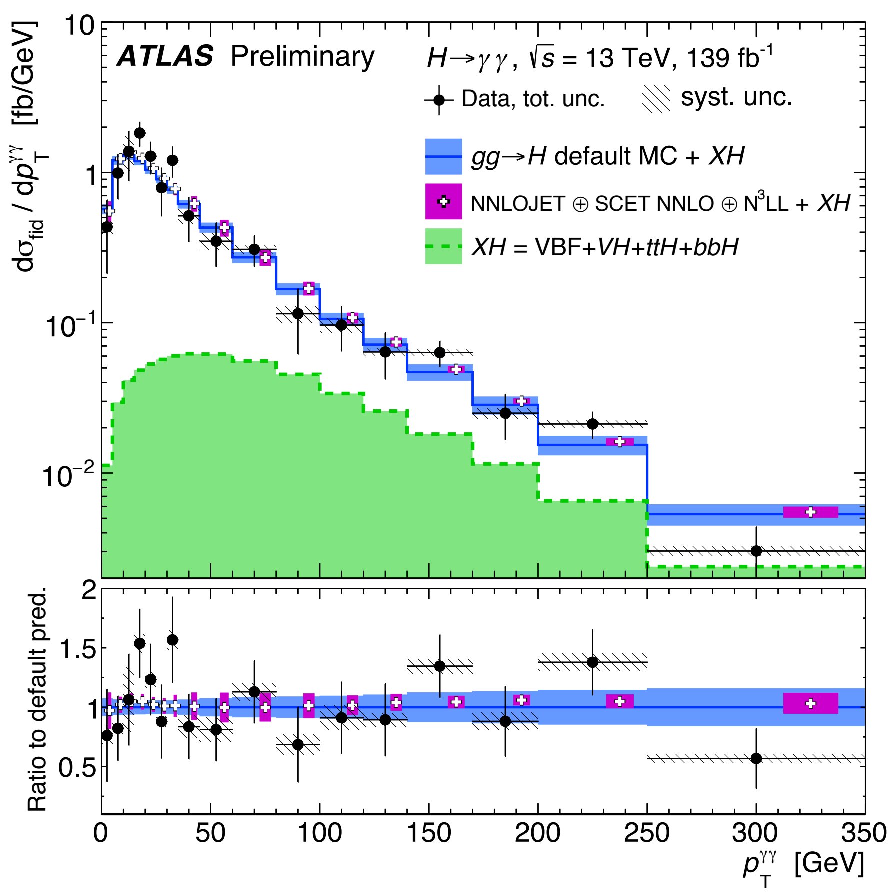




Fiducial cross section

✦ **Model independent Higgs property measurement at particle level.**

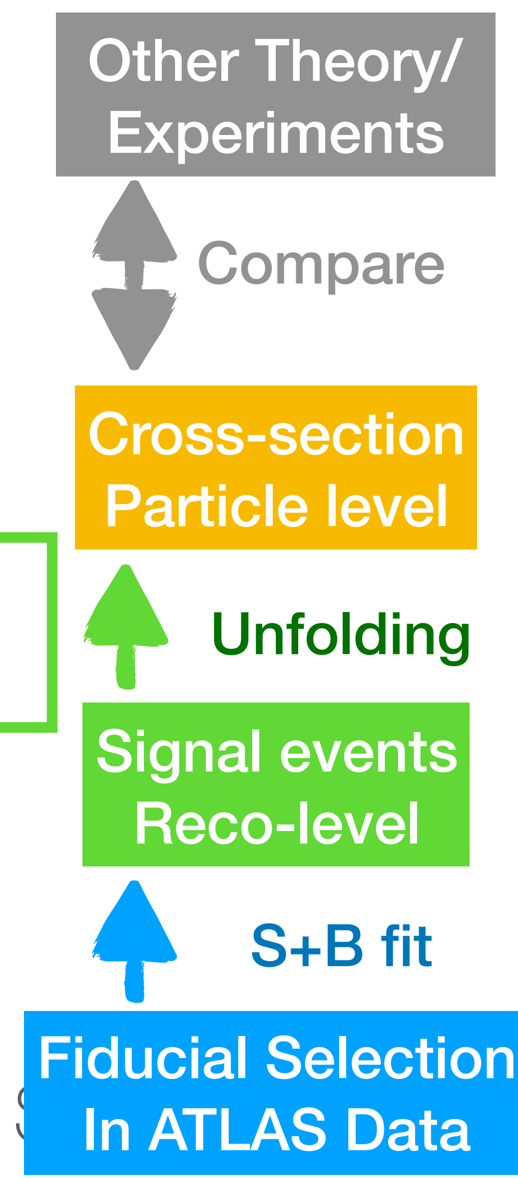
- **Fiducial cross-section:** cross-section measured in the detector acceptance
- **Differential cross-section:** measurement in the bins of Higgs kinematic or jet related observables, sensitive to enhance/weaken of couplings parameters



ATLAS-CONF-2019-029
Differential Xs. on pT_yy

Observable
$p_T^{\gamma\gamma}$ or $p_{T,\gamma\gamma}$
$\lvert y_{\gamma\gamma}\rvert$
$N_{\text{jets}}^{\geq 30\text{GeV}}$
$p_T^{j_1}$
m_{jj}
$\Delta\phi_{jj,\text{signed}}$

$$\sigma = \frac{\nu_{\text{sig}}}{c_{\text{fid}} \cdot \mathcal{L}}$$



Dataset and MC Samples

- ✦ **Full Run2 Data: 139 fb-1 2015-2018 data with ATLAS**
- ✦ **MC Signal: ggH VBF, VH ttH bbH, ttH, tH**
- ✦ **MC Background:**
  - non-resonance γγ (~80%) - large statistic fast-simulation
  - MC; γ+jet, jet+γ, jet+jet (~20%) - data-driven method;
  - Vγ、Vγγ、t¯tγγ MC (minor contribution).

Process	Generator	Cross-section normalisation	$\sigma \times$ BR[fb]
ggF	Powheg NNLOPS	N^3LO(QCD)+NLO(EW)	110
VBF	Powheg-Box	approx. NNLO(QCD)+NLO(EW)	8.58
W^+H	Powheg-Box	NNLO(QCD)+NLO(EW)	1.90
W^-H	Powheg-Box	NNLO(QCD)+NLO(EW)	1.21
$q\bar{q} \to ZH$	Powheg-Box	NNLO(QCD)+NLO(EW)	1.73
$gg \to ZH$	Powheg-Box	NLO(QCD)+NLO(EW)	0.28
$t\bar{t}H$	Powheg-Box	NLO(QCD)+NLO(EW)	1.15
$b\bar{b}H$	Powheg-Box	5FS (NNLO), 4FS (NLO)	1.10

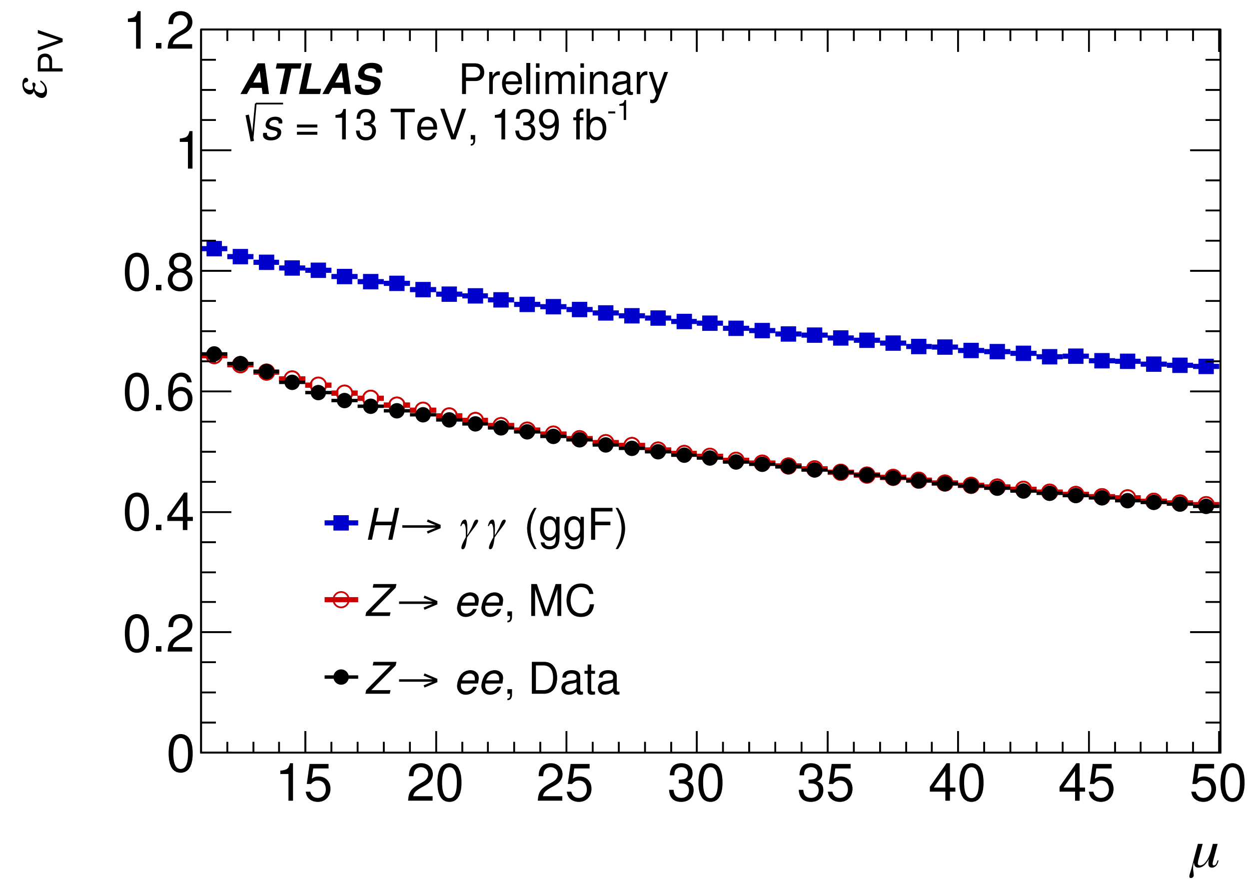
$\gamma\gamma$	Sherpa	Sherpa	CT10
$V\gamma\gamma$	Sherpa	Sherpa	CT10
$t\bar{t}\gamma\gamma$	MG5_aMC@NLO	Pythia 8	PDF4LHC15

Event selection

✦ **Trigger :** single photon and di-photon trigger

✦ **Primary vertex:** di-photon vertex via NN training

- Efficiency of the NN to select the true vertex (or a vertex that is less than 0.3mm far from the true vertex) is ~76% for ggF signal events

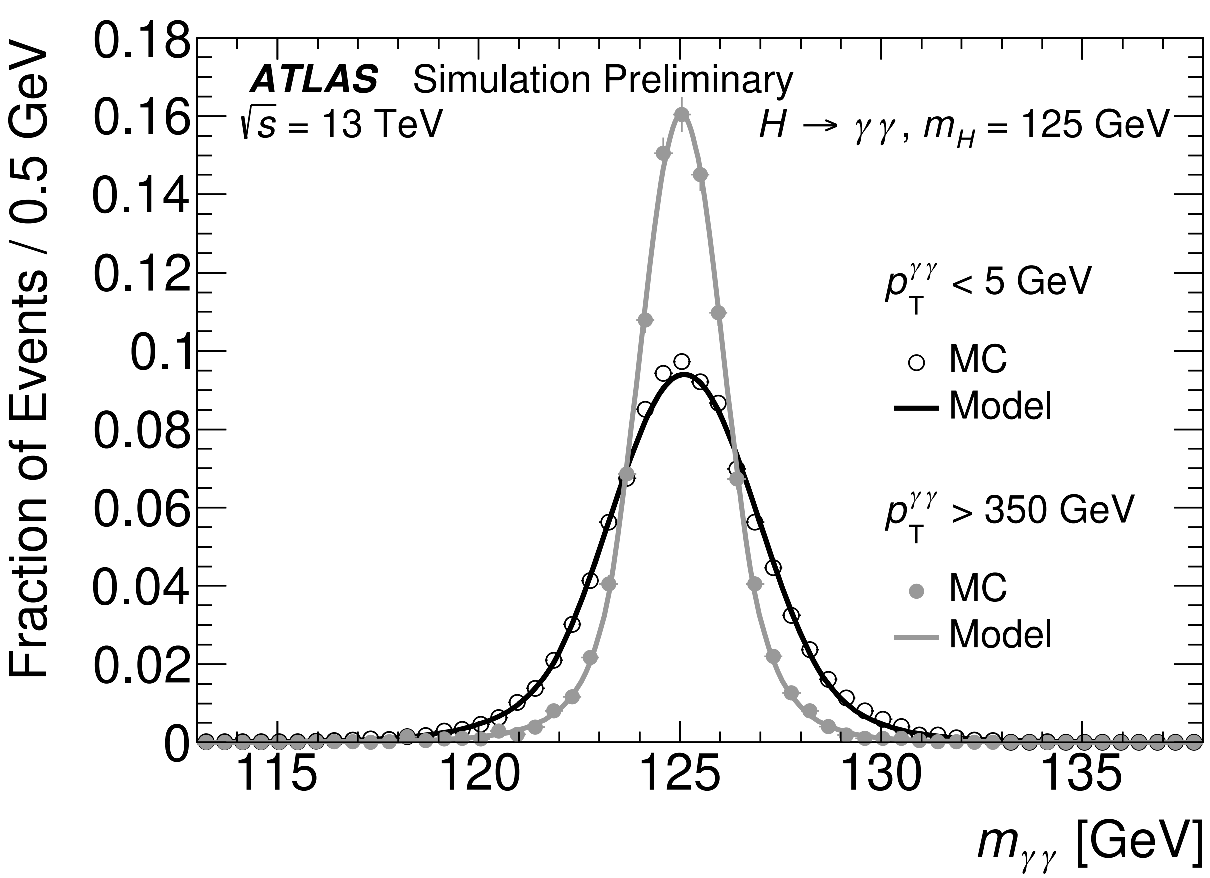


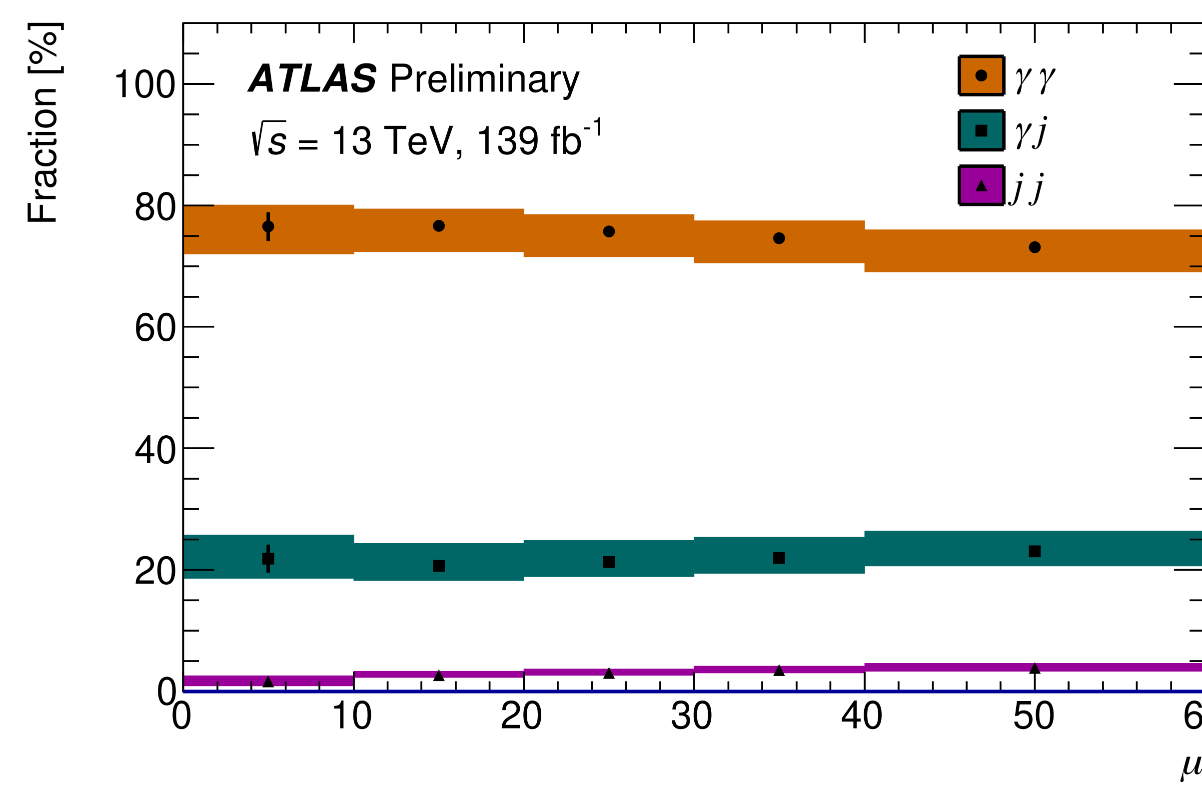
✦ **Fiducial region**

Objects	Fiducial definition
Photons	$\lvert\eta\rvert < 2.37$ (excluding $1.37 < \lvert\eta\rvert < 1.52$), $\sum p_{\mathrm{T}}^{i}/p_{\mathrm{T}}^{\gamma} < 0.05$
Jets	anti-k_t, $R = 0.4$, $p_{\mathrm{T}} > 30$ GeV, $\lvert y\rvert < 4.4$
Diphoton	$N_\gamma \geq 2$, $105\,GeV < m_{\gamma\gamma} < 160\,GeV$, $p_{\mathrm{T}}^{\gamma_1}/m_{\gamma\gamma} > 0.35$, $p_{\mathrm{T}}^{\gamma_2}/m_{\gamma\gamma} > 0.25$

Signal / background modeling

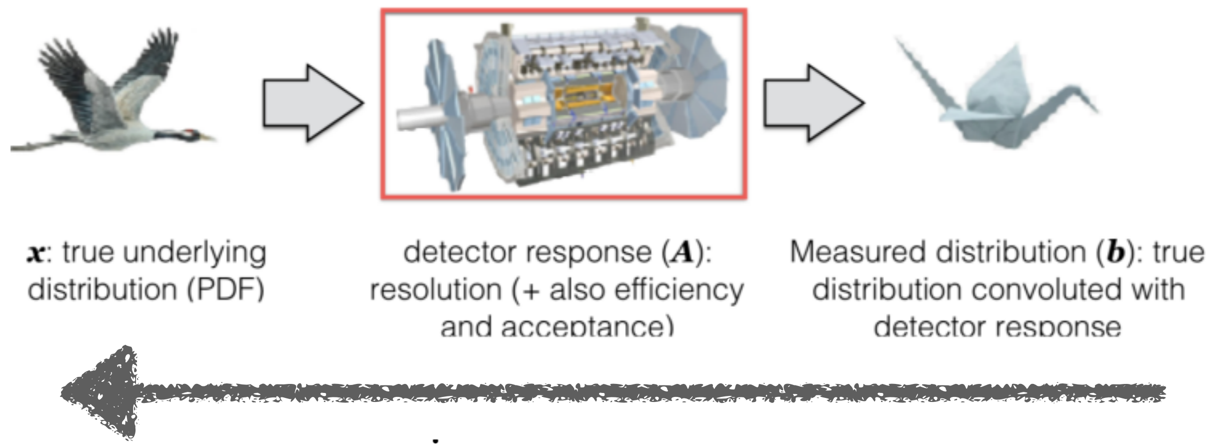
- **Signal:** individual **DSCB fit based on MC** @ 125 GeV, shift the signal model to 125.09 GeV
- **Background: γγ γj jγ and jj (**purity from **2x2D sideband** method**),** very few Vγ / Vγγ
  - Shape: **linear re-weighting γγ MC to the total background** by fitting non-γγ/γγ ratio
- **Function decision: spurious signal** tests scan in 121-129 GeV
  - **GPR smoothing** is minimizing the spurious signal uncertainty by 0-20%





S+B fit and unfolding

- The **number of signal events** from S+B fit is **bin by bin unfolded** to particle level **cross-section**



Particle - Reco level (folding)

$$\sigma_i = \frac{\nu_i^{\mathrm{sig}}}{C_i \cdot \mathcal{L}_{\mathrm{int}}} \quad C_i = \frac{n_i^{\mathrm{det}}}{n_i^{\mathrm{ptcl}}}$$

"Correction factor"

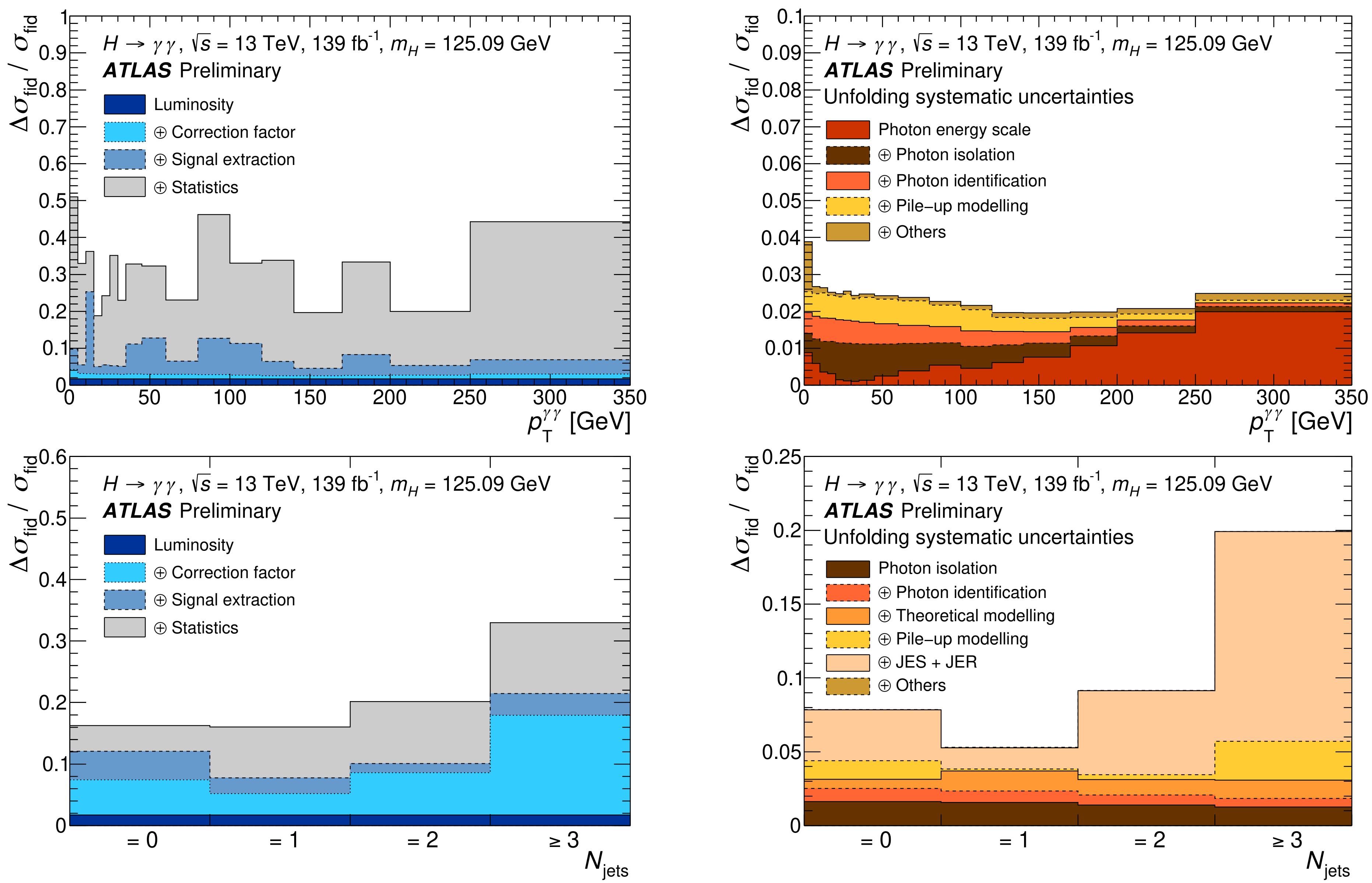
- **Toy study** is done to estimate the **bias of each method** (matrix inversion, Bayesian, IDS, SVD..), **bin by bin has small statistic uncreftainty with acceptable bias**

Statistic Un. And bias from each unfolding method

					$p_T^{\gamma\gamma}$
method	$\sqrt{\Sigma_i^{bins}\sigma_{stat,i}^2}$	$\Sigma_i^{bins} b_i$	$\Sigma_i^{bins}\lvert b_i\rvert$	$\Sigma_i^{bins}\sqrt{b_i^2+\sigma_{stat,i}^2}$	$\sqrt{\Sigma_i^{bins}(b_i^2+\sigma_{stat,i}^2)}$
					bias: nominal
bayes k2	658.90	46.65	61.54	2428.92	659.20
bin by bin	627.58	45.05	58.30	2313.46	627.88
matrix	770.82	45.72	64.87	2796.33	771.13

Systematic Un.

- **Correction factor:** photon energy scale, photon ID/ISO, Jet energy scale/resolution
- **Signal extraction:** mainly from spurious signal
- **Theoretical uncertainties:** QCD scale, PDF, signal composition, Underlying event…
- Statistic uncertainty is still **dominant in most of the differential bins, and similar contribution to total uncertainty in the fiducial region.**

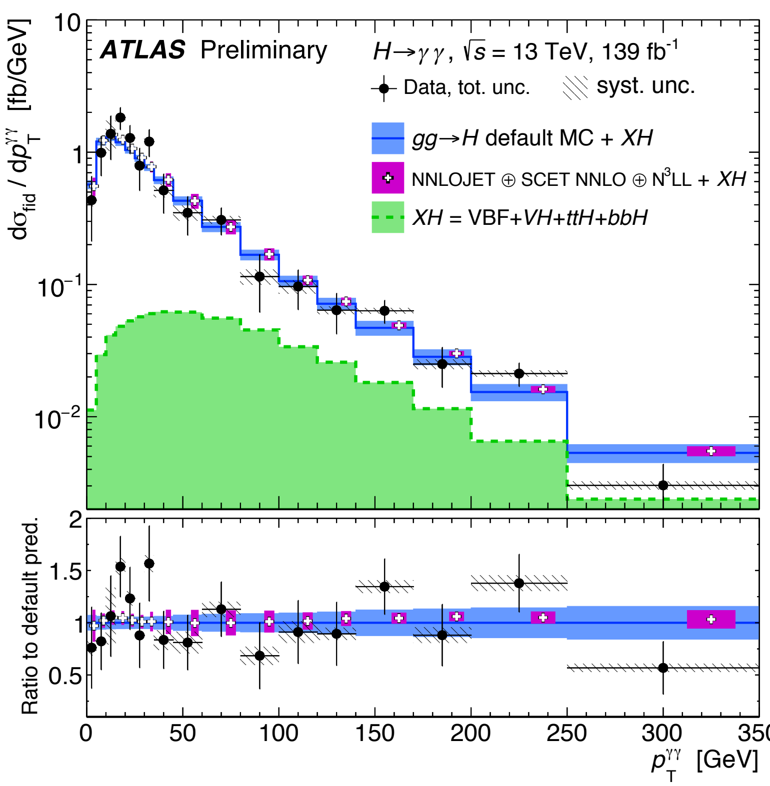


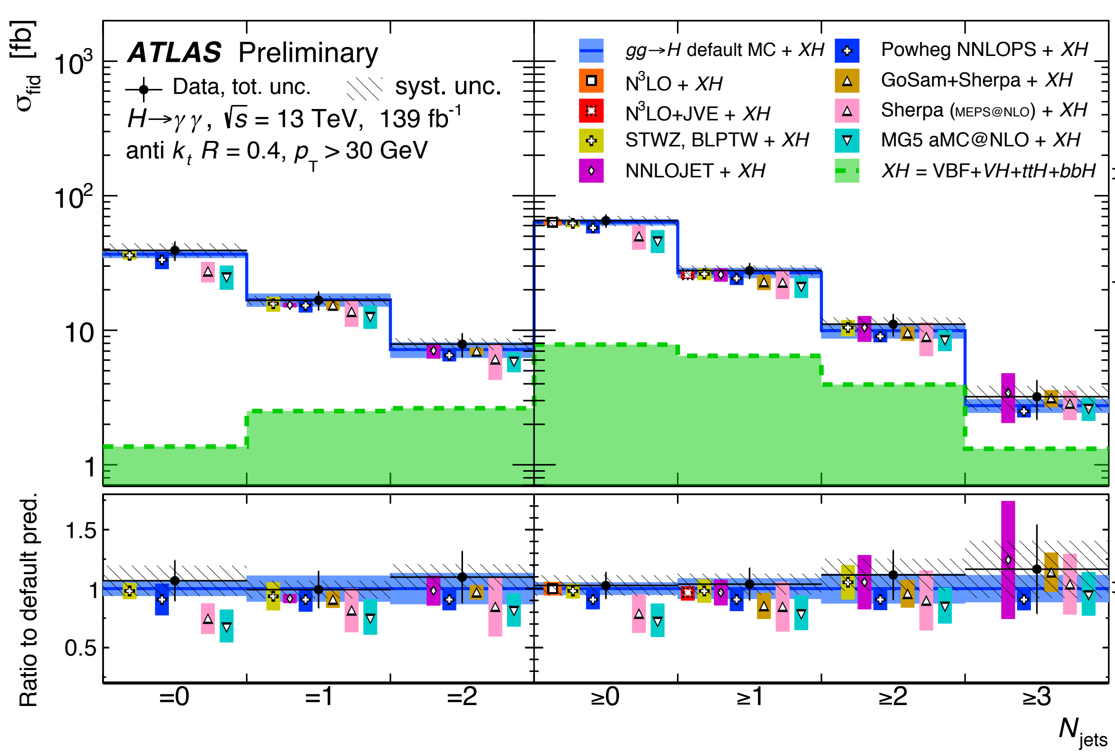
Results

- **Full Run2 (139 fb-1) fiducial cross-section** (SM: 63.6±3.3 fb)

$$\sigma_{\text{fid}} = 65.2 \pm 4.5\,(\text{stat.}) \pm 5.6\,(\text{syst.}) \pm 0.3\,(\text{theo.})\,\text{fb}\,, \ \text{SM: } 63.6 \pm 3.3 \text{ fb}$$

- Default SM expectation: **ggH N3LO, VBF WH qqZH NNLO, ggZH ttH bbH NLO**
- **Compatibility** is calculated comparing to SM expectation, no obvious excess found beyond SM.
- Full-Run2 publication: ATLAS-CONF-2019-029
- Previous publication: ATLAS-CONF-2018-028 (79.9 fb-1), PhysRevD.98.052005 (36.1fb-1)



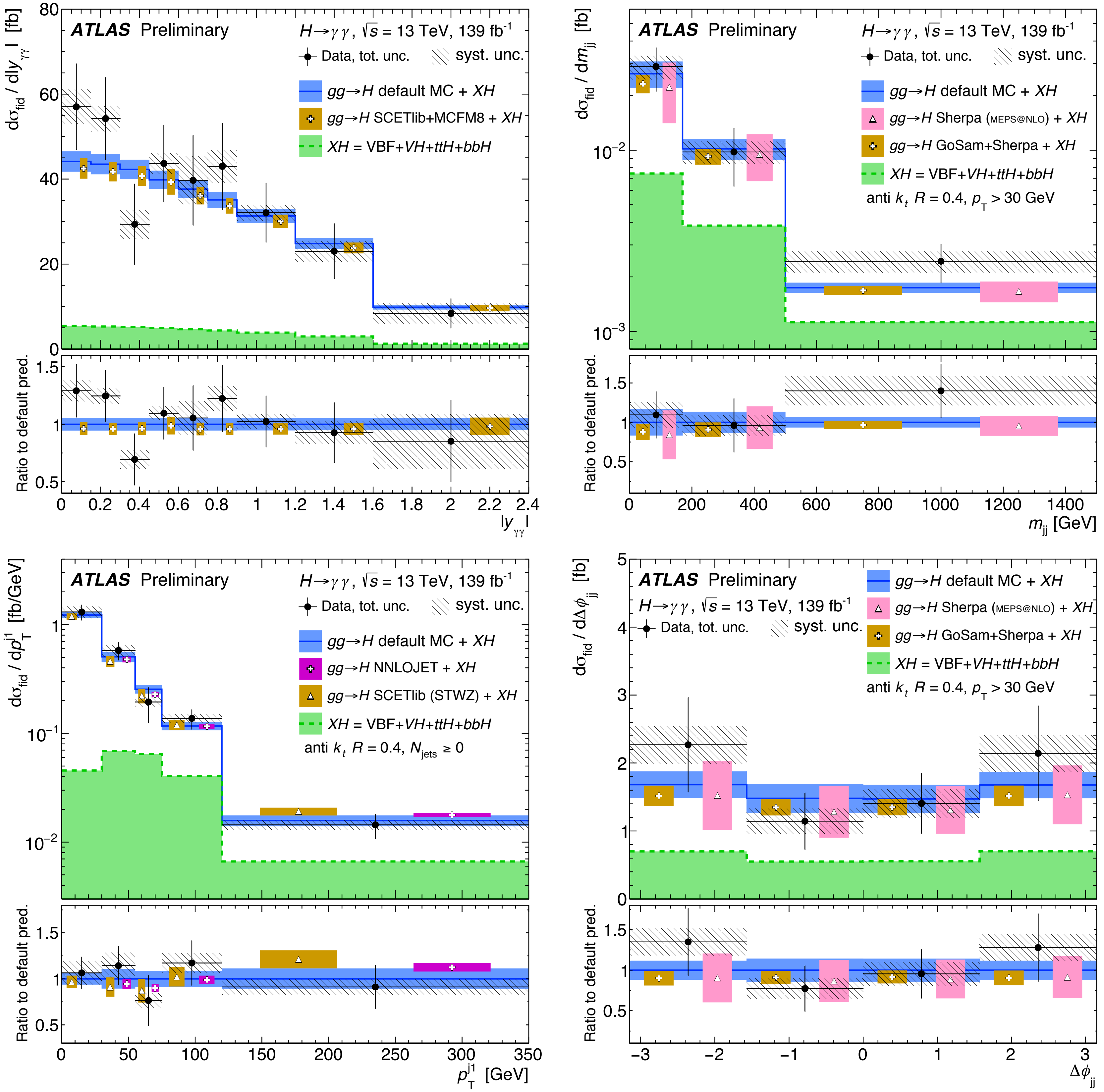


Consistency to SM

Distribution	$p(\chi^2)$ with Default MC Prediction
$p_T^{\gamma\gamma}$	44%
$\lvert y_{\gamma\gamma}\rvert$	68%
$p_T^{j_1}$	77%
N_{jets}	96%
$\Delta\phi_{jj}$	82%
m_{jj}	75%

Results

✦ Various of expectations compared, more consistent with N3LO QCD calculations



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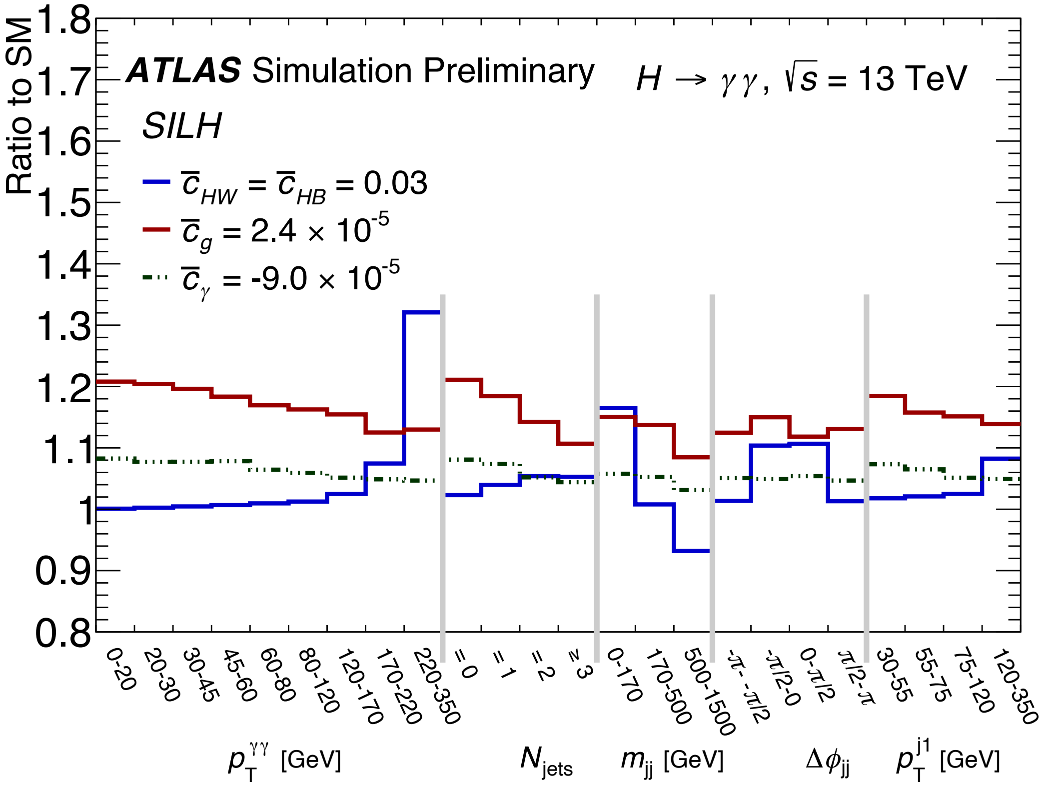
Effective Lagrangian interpretation

- Dim-6 extension of the SM Lagrangian in the SILH (Higgs Effective Lagrangian) and Warsaw (SMEFT) bases $\mathcal{L}_{\mathrm{EFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{c_i}{\Lambda^2} O_i^{(6)}$
  - *Wilson* coefficients c_i quantify the strength of the new interactions (CP-even/odd)

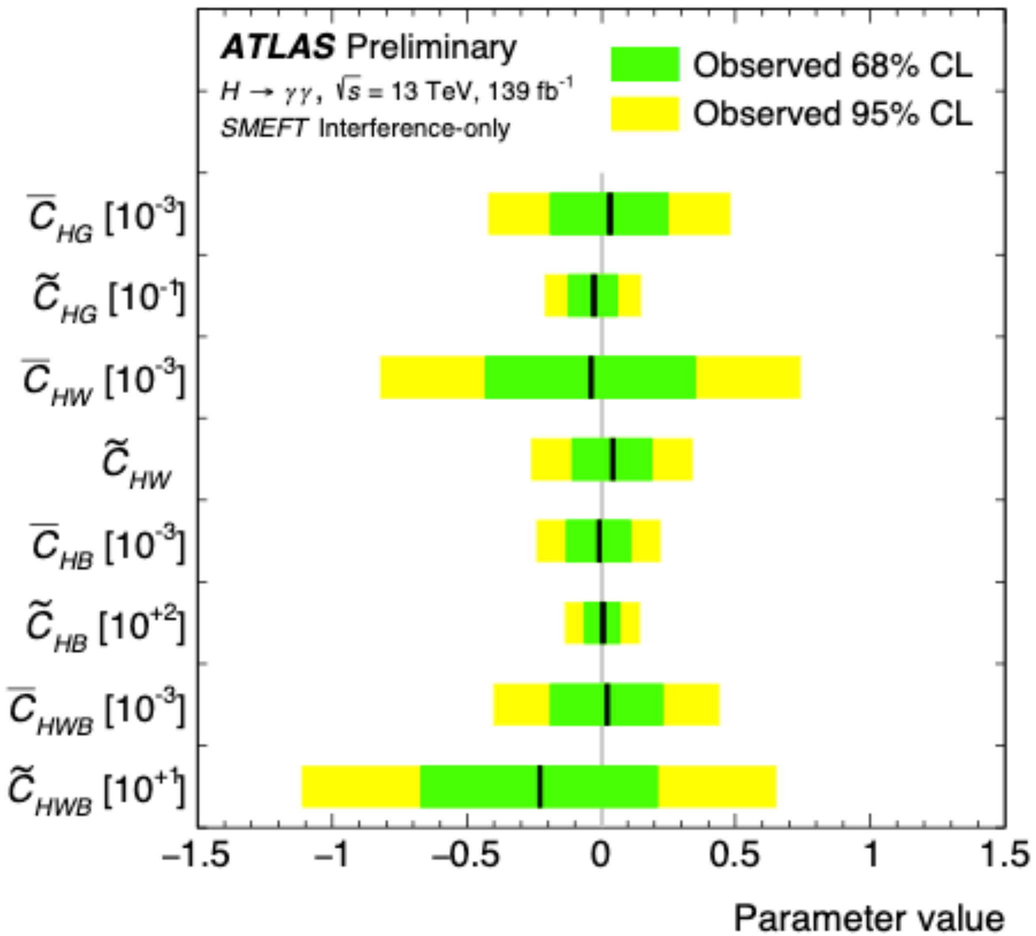
$$\mathcal{L}_{\mathrm{eff}}^{\mathrm{SILH}} \supset \bar{c}_g O_g + \bar{c}_\gamma O_\gamma + \bar{c}_{HW} O_{HW} + \bar{c}_{HB} O_{HB} + \tilde{c}_g \tilde{O}_g + \tilde{c}_\gamma \tilde{O}_\gamma + \tilde{c}_{HW} \tilde{O}_{HW} + \tilde{c}_{HB} \tilde{O}_{HB}$$

$$\mathcal{L}_{\mathrm{eff}}^{\mathrm{SMEFT}} \supset \bar{C}_{HG} O'_g + \bar{C}_{HW} O'_{HW} + \bar{C}_{HB} O'_{HB} + \bar{C}_{HWB} O'_{HWB} + \tilde{C}_{HG} \tilde{O}'_g + \tilde{C}_{HW} \tilde{O}'_{HW} + \tilde{C}_{HB} \tilde{O}'_{HB} + \tilde{C}_{HWB} \tilde{O}'_{HWB}$$

$$\bar{C}_i \equiv C_i v^2 / \Lambda^2$$

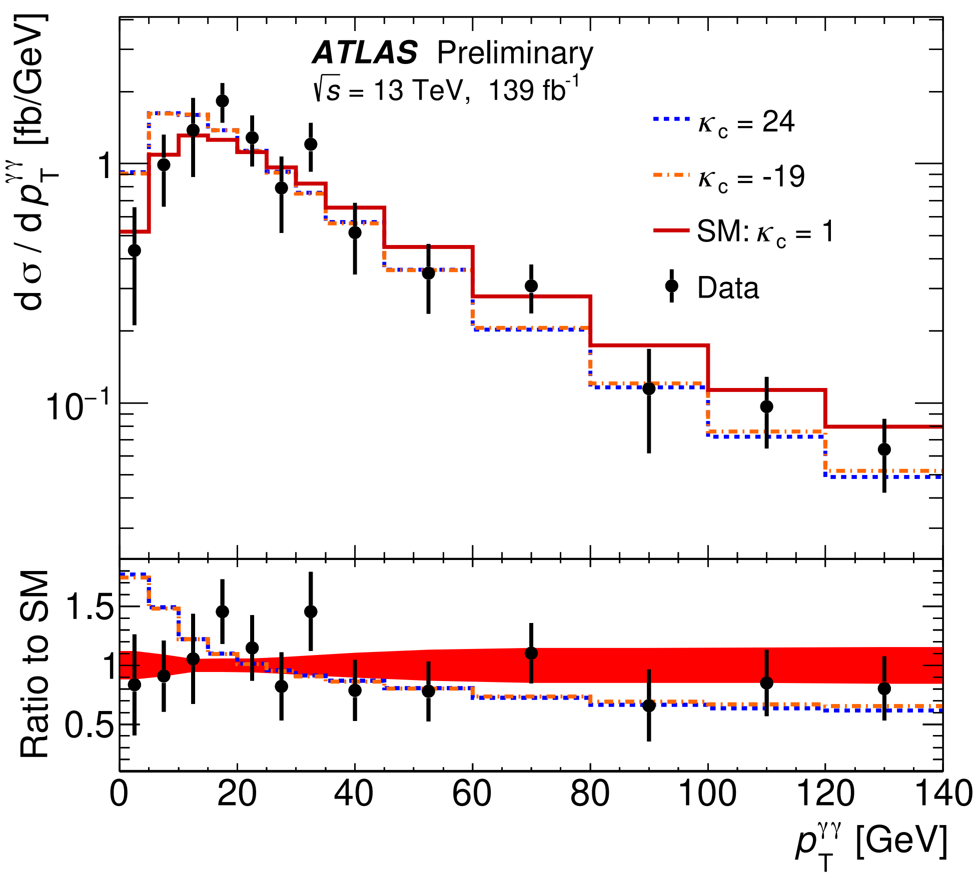


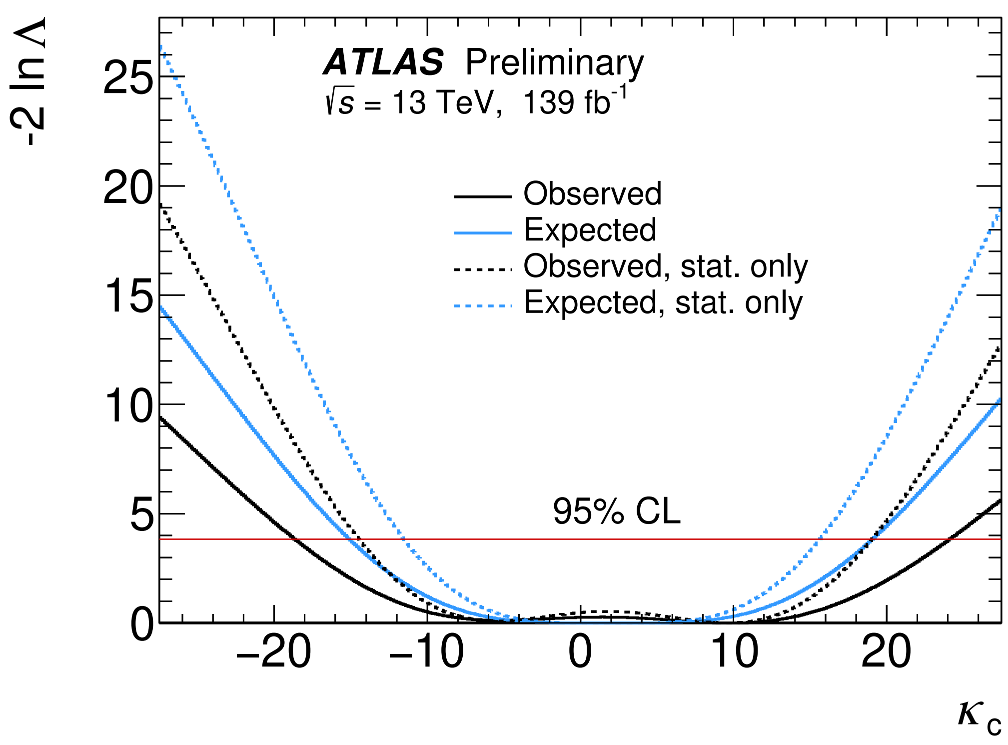
Coefficient	Observed 95% CL limit	Expected 95% CL limit
$\bar{c}_g$	$[-0.26, 0.26] \times 10^{-4}$	$[-0.25, 0.25] \cup [-4.7, -4.3] \times 10^{-4}$
$\tilde{c}_g$	$[-1.3, 1.1] \times 10^{-4}$	$[-1.1, 1.1] \times 10^{-4}$
$\bar{c}_{HW}$	$[-2.5, 2.2] \times 10^{-2}$	$[-3.0, 3.0] \times 10^{-2}$
$\tilde{c}_{HW}$	$[-6.5, 6.3] \times 10^{-2}$	$[-7.0, 7.0] \times 10^{-2}$
$\bar{c}_\gamma$	$[-1.1, 1.1] \times 10^{-4}$	$[-1.0, 1.2] \times 10^{-4}$
$\tilde{c}_\gamma$	$[-2.8, 4.3] \times 10^{-4}$	$[-2.9, 3.8] \times 10^{-4}$



Charm-Yukawa interpretation of pT_γγ

- Limit on the $\kappa_c = Y_c/Y_c^{SM}$ modification of the charm coupling
- Indirect limit using $p_T^{\gamma\gamma}$, exploiting only shape information
  - Assuming only modifications on gg→H and cc/cg→H cross-sections
  - Predictions from Radish (ggF) and Madgraph (cc/cg→H)



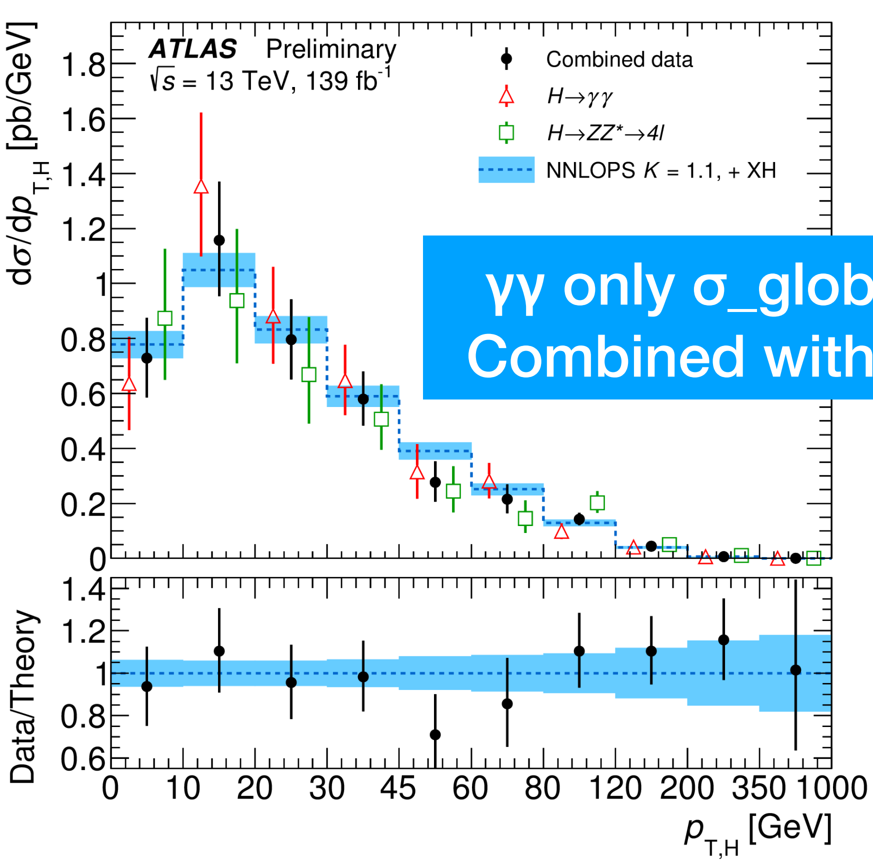


Coefficient	Observed 95% CL limit	Expected 95% CL limit
κ_c	$[-19, 24]$	$[-15, 19]$

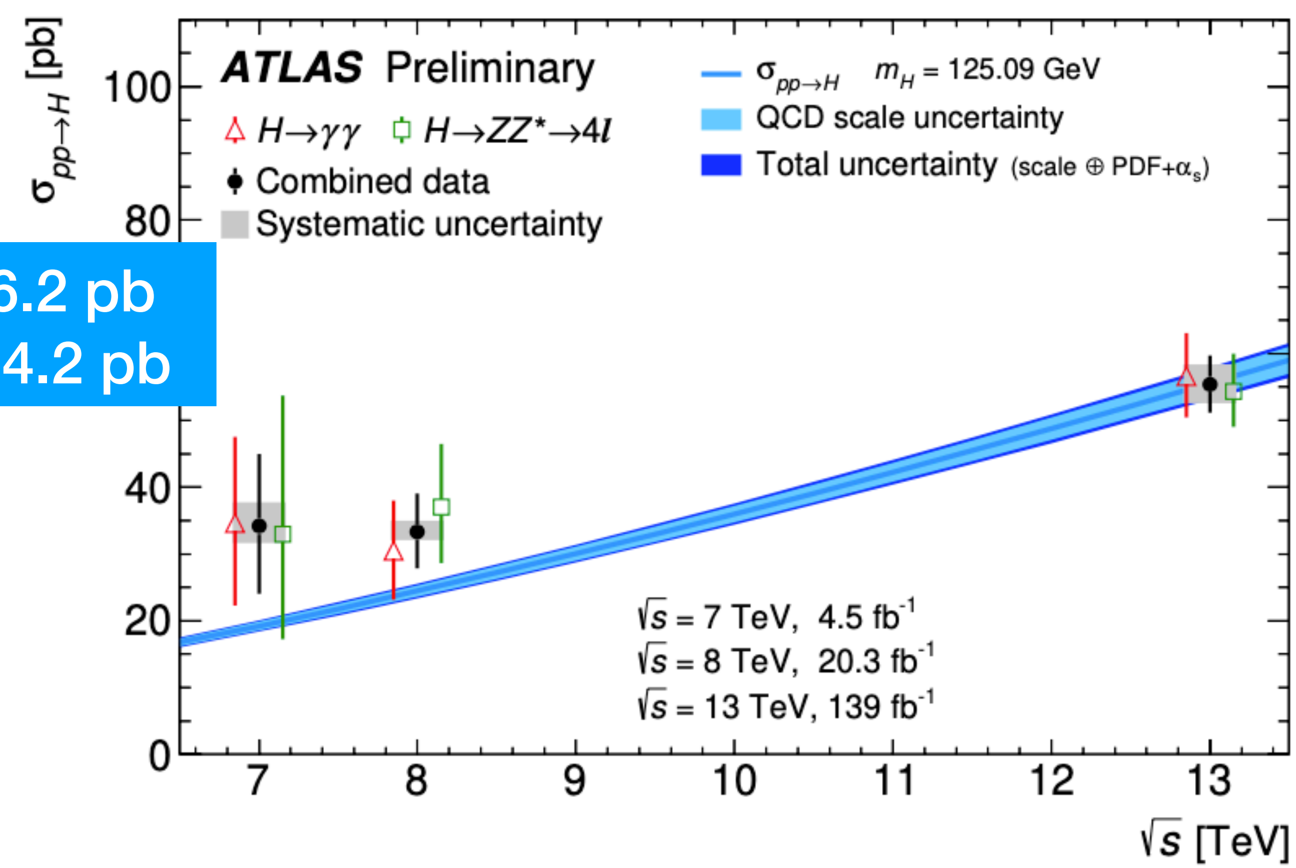
Similar precision as CMS 36fb-1 Hγγ and HZZ
arXiv:1812.06504

Combination of differential cross-section

- ✦ Combination is done with Full-Run2 dataset between Hγγ and H-ZZ-4l ATLAS-CONF-2019-032
  - ✦ Only **pT_H and total** cross section were calculated, using **bin by bin unfolding**
  - ✦ **Acceptance** and corresponding uncertainties were included for the **global cross-section**
  - ✦ All results **consistent with SM expectation** (global Xs compatibility 96%, on pT_H 78%)
  - ✦ **Stat. And Syst.** Uncertainties are with the **similar size**. γγ background modeling have large impact

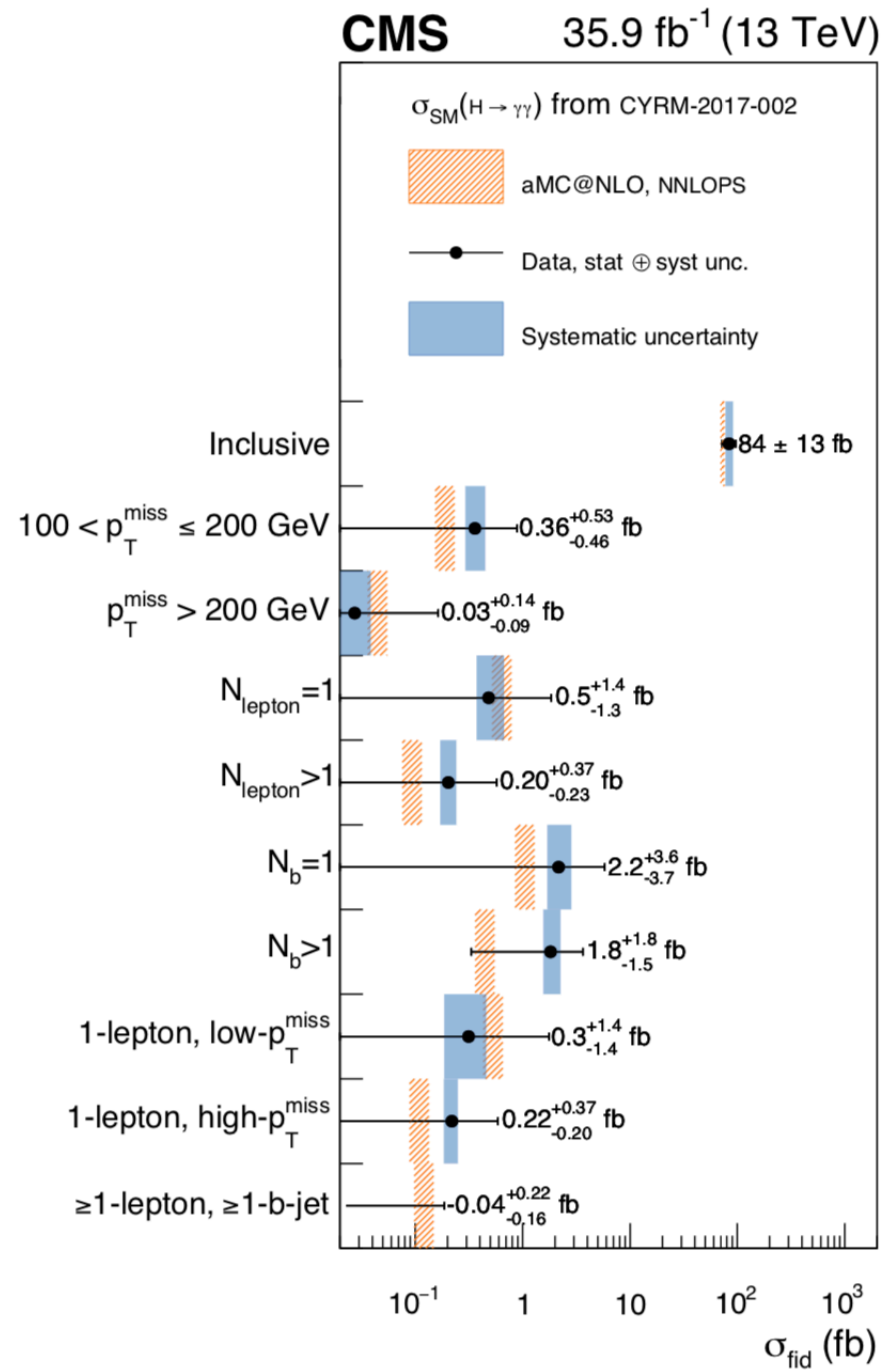


γγ only σ_global = 56.7+6.4-6.2 pb
Combined with 4l = 55.4+4.3-4.2 pb



CMS 2015+2016 result

- ✦ CMS 35.9 fb-1 result: CERN-EP-2018-166 https://arxiv.org/pdf/1807.03825.pdf
- ✦ CMS Hγγ Fiducial: 84 ± 13 fb
  - **Global: 62 ± 10 pb, With acceptance ~0.60**
- ✦ ATLAS Hγγ Fiducial : 65.2 ± 7.2 fb
  - **Global : 56.7 ± 6.4 pb, With acceptance ~0.51**
  - Combined with H4l: 55.4±4.3 pb
- ✦ **Still match in uncertainty, will be improved with CMS full Run2 result**



Summary

- **Fiducial and differential cross section measurement with ATLAS full Run2 dataset (140 fb-1), the result is consistent with SM expectation** (Fiducial Xs. : 65.2±7.2 fb)
  - Fiducial cross-section is **more limited by systematic uncertainties**
  - Model independent differential fiducial cross section are **mostly statistical limited,** good agreement with high order QCD (N3LO) calculations
- Interpretations:
  - **Effective Lagrangian: SILH** (more accurate than 36.1fb-1 publication) and **SMEFT** (new) models, Including Dphi_jj that is sensitive to the EFT interpretation
  - **Charm-Yukawa coupling**, Set limit on kappa_c **using pT_γγ**, similar precision as CMS 36.1fb-1 Hγγ and HZZ.
- Combination is done between Hγγ and HZZ channels with full Run2 dataset,
  - **On pT_H and fiducial, bin by bin method, for the global cross section, consistent with SM** (Global Xs. : 55.4±4.3 pb, Hγγ only: 56.7±6.4 pb)

backup

Combination of differential cross-section

- ✦ The Hγγ is measuring with a **2-step strategy that dividing mass-fitting and unfolding**
- ✦ For combination, we do **1-step** implementing bin_by_bin correction factor into the workspace.
- ✦ **Cross-check is done to make sure the 2 strategies agree with each other**

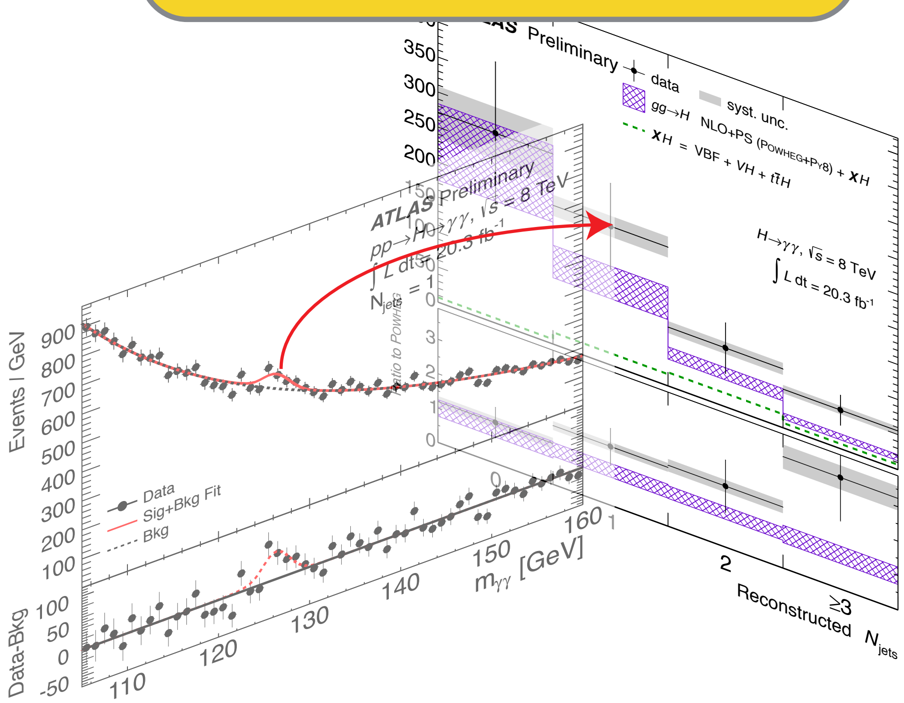
$$N_s^i = \sigma^i_{SM,global} \times acc.^i \times Br_{\gamma\gamma} \times eff^i \times Lumi\,.$$

One-Step: merge signal extraction and unfolding

Signal extraction

Two-Step

Unfolding extraction



$$\sigma_i^{fid} = \frac{n_i^{sig}}{c_i \mathcal{L}}$$