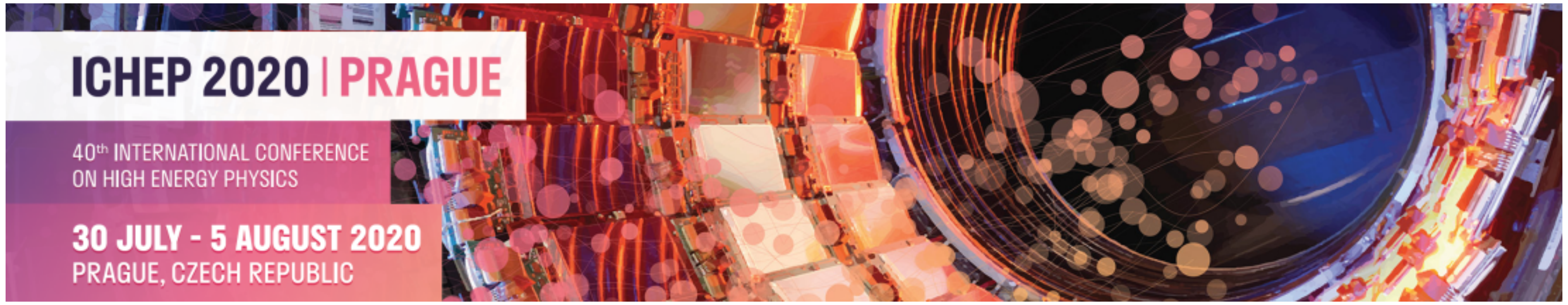
Higgs differential cross-section in H$\gamma\gamma$ and H4ℓ and mass measurement in H4ℓ

Antoine Laudrain (JGU, Mainz)

On behalf of the ATLAS collaboration

ICHEP 2020 — Higgs parallel session (2) — 30/07/2020



H4ℓ and H$\gamma\gamma$ differential cross-sections

H4ℓ: paper accepted in EPJC, arXiv:2004.03969.

Final Run-2 result!

H$\gamma\gamma$: ATLAS-CONF-2019-029 (preliminary).

Welcome to the Higgs precision measurements era!

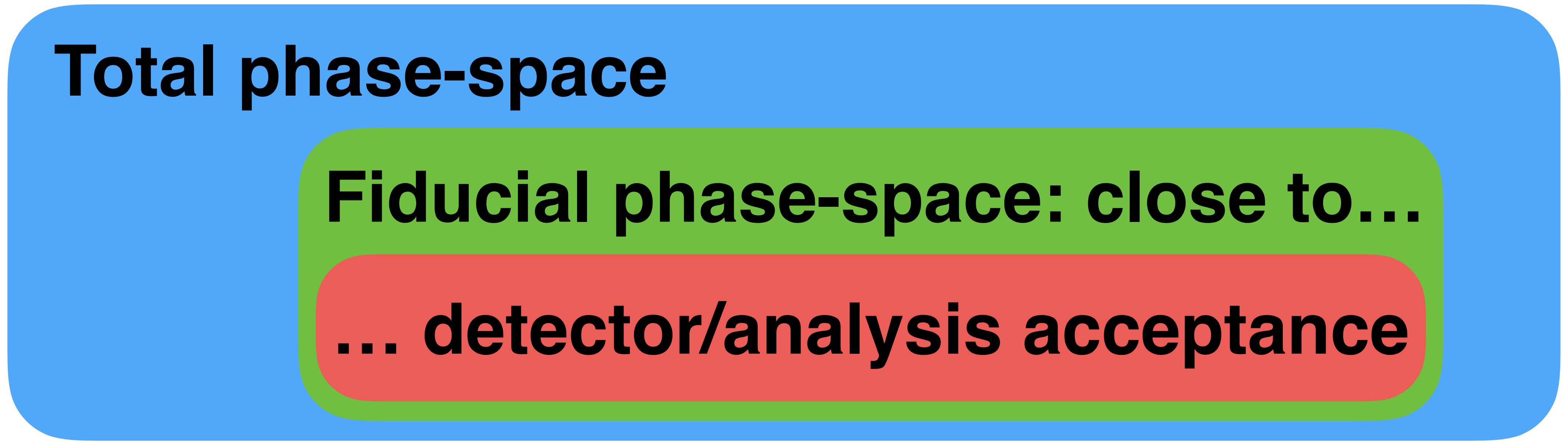
Measurements

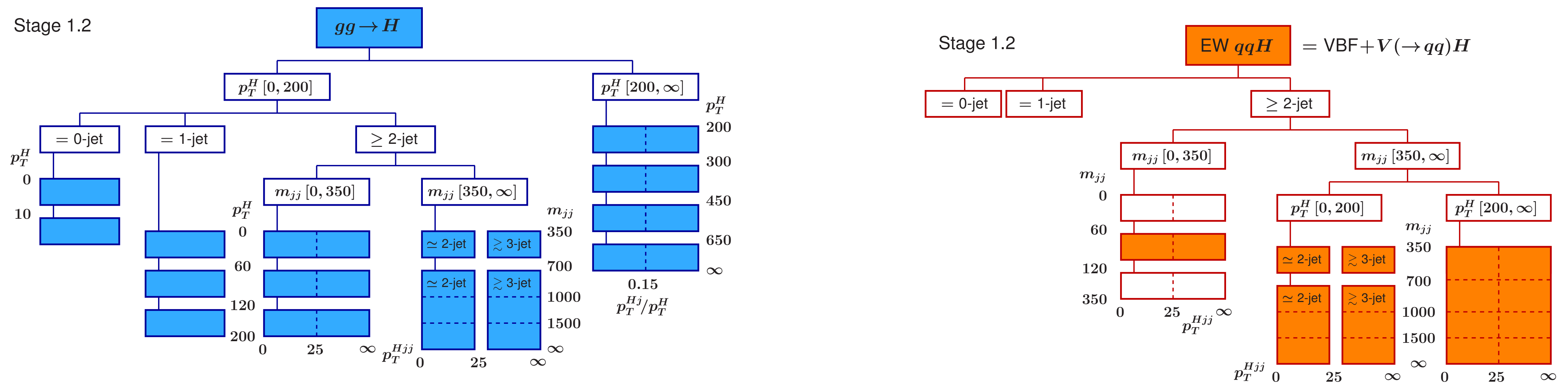
Fiducial cross-sections

- Largely **model-independent**.
- Targets **decay side**.
- Combination needs extrapolation.

Simplified Template Cross-Sections (STXS)

- Reduce theory systematics, more model-dependent.
- Targets **production side**.
- Common to all decay channels: **easy to combine**.
- Easy interpretation: isolate BSM regions.





Interpretations: BSM physics?

Model-dependency

Pseudo-observables

Effective Field Theory

κ-framework

…

Welcome to the Higgs precision measurements era!

Measurements

Fiducial cross-sections

- Largely **model-independent**.
- Targets **decay side**.
- Combination needs extrapolation.

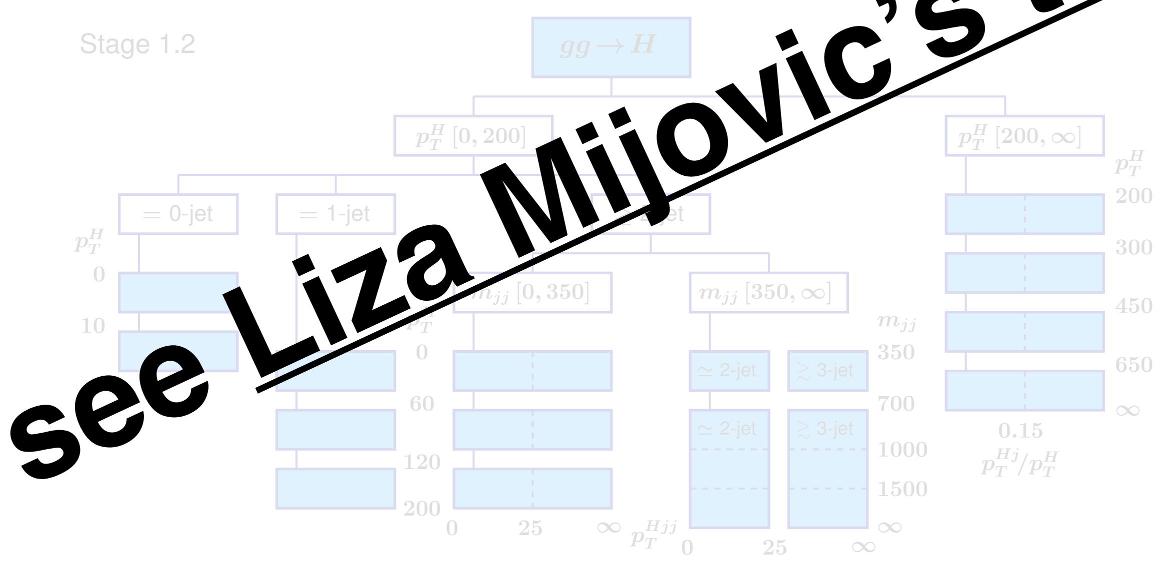
Total phase-space

Fiducial phase-space: close to…

… detector/analysis acceptance

Simplified Template Cross-Sections (STXS)

- Reduce theory systematics, more model-dependent.
- Targets **production side**.
- Common to all decay channels: **easy to combine**.
- Easy interpretation: isolate BSM regions.



see Liza Mijovic's talk in a few minutes

Interpretations: BSM physics?

Model-dependency

Pseudo-observables

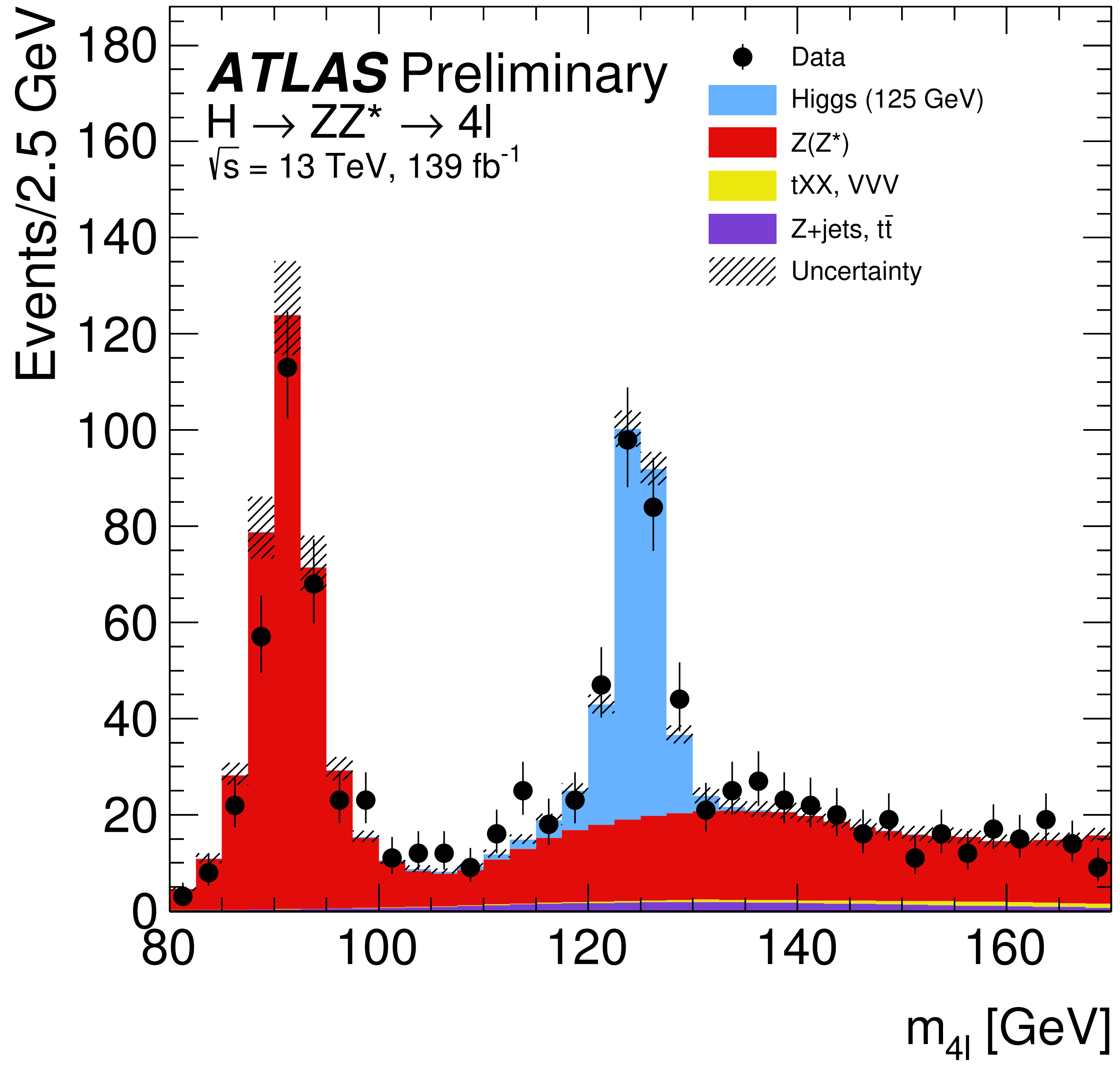
Effective Field Theory

κ-framework

…

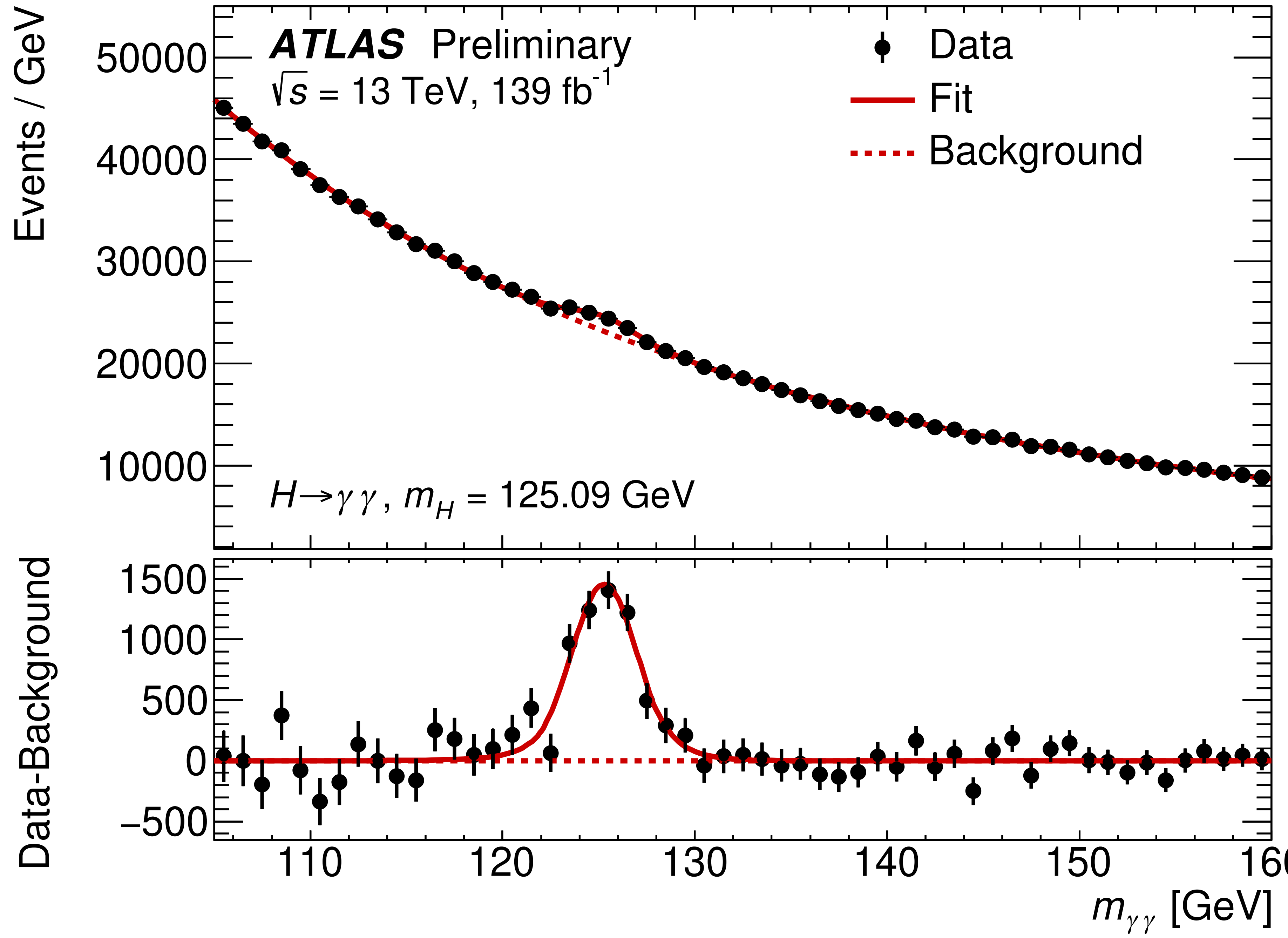
Overview of analyses

H→ZZ→4ℓ



- **Fully reconstructed final state**! **Good precision**!
- **4 low-p_T isolated leptons** (electrons / muons)
- Main **background**: **qq→ZZ continuum**, shape from MC, norm. from data sideband.
- **BR ~ 0.0124%, S/B ~ 2**.

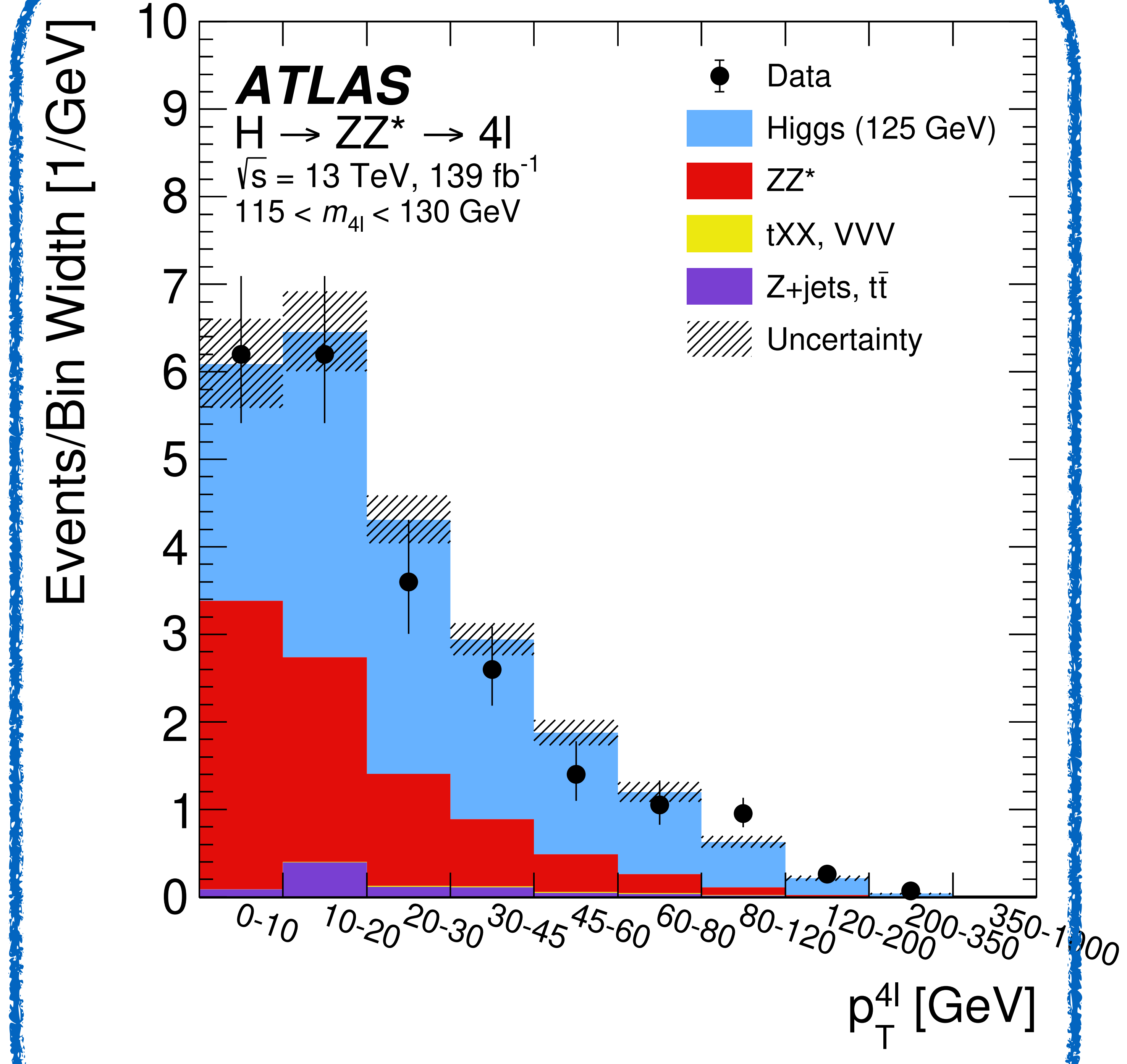
H→γγ



- **Fully reconstructed final state**! **Good precision**!
- **Two isolated photons**.
- Main **background**: **γγ continuum**, estimated from data sideband.
- **BR ~ 0.2%, S/B < 0.1**.

Differential cross-section measurements

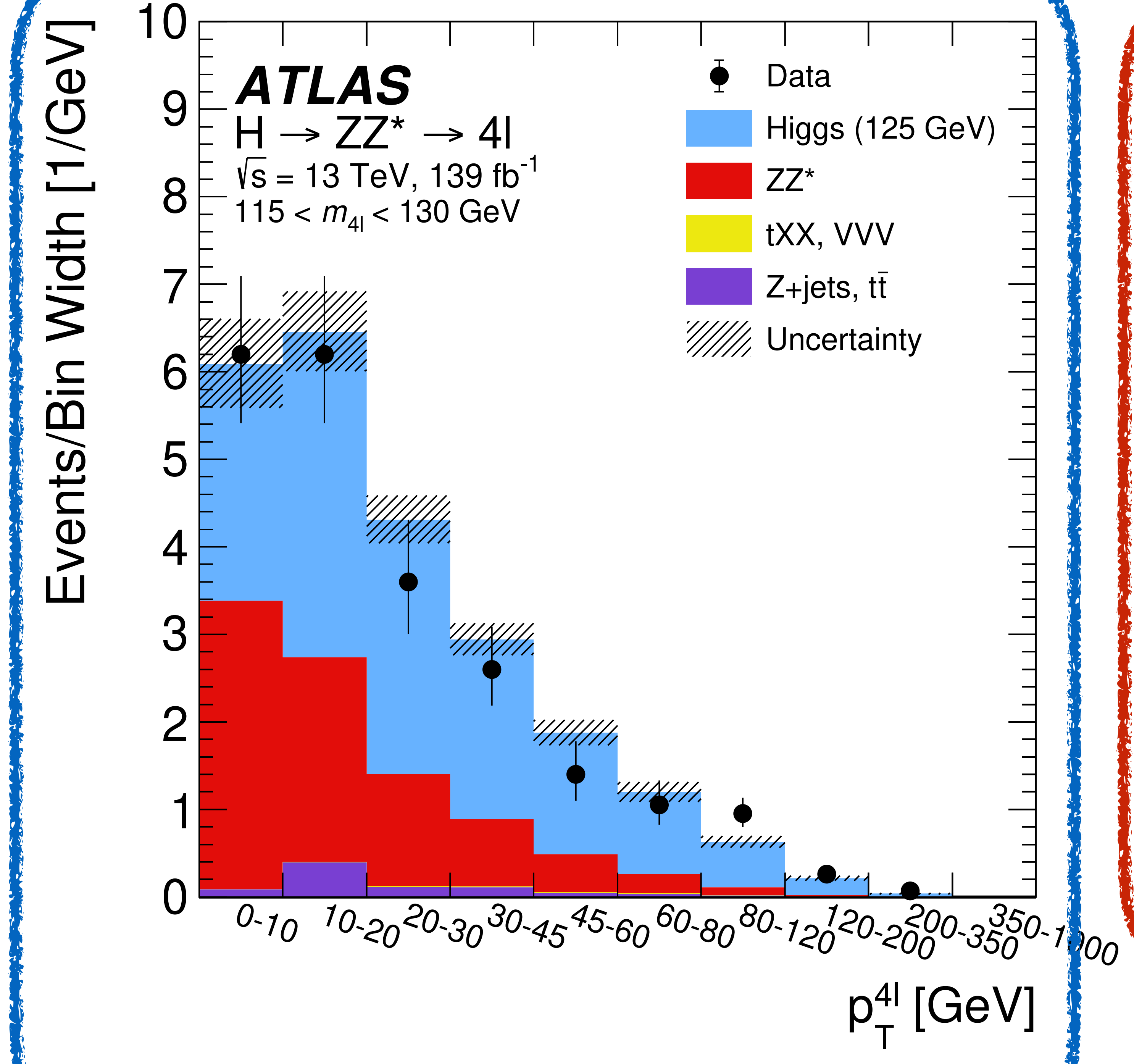
Input distribution



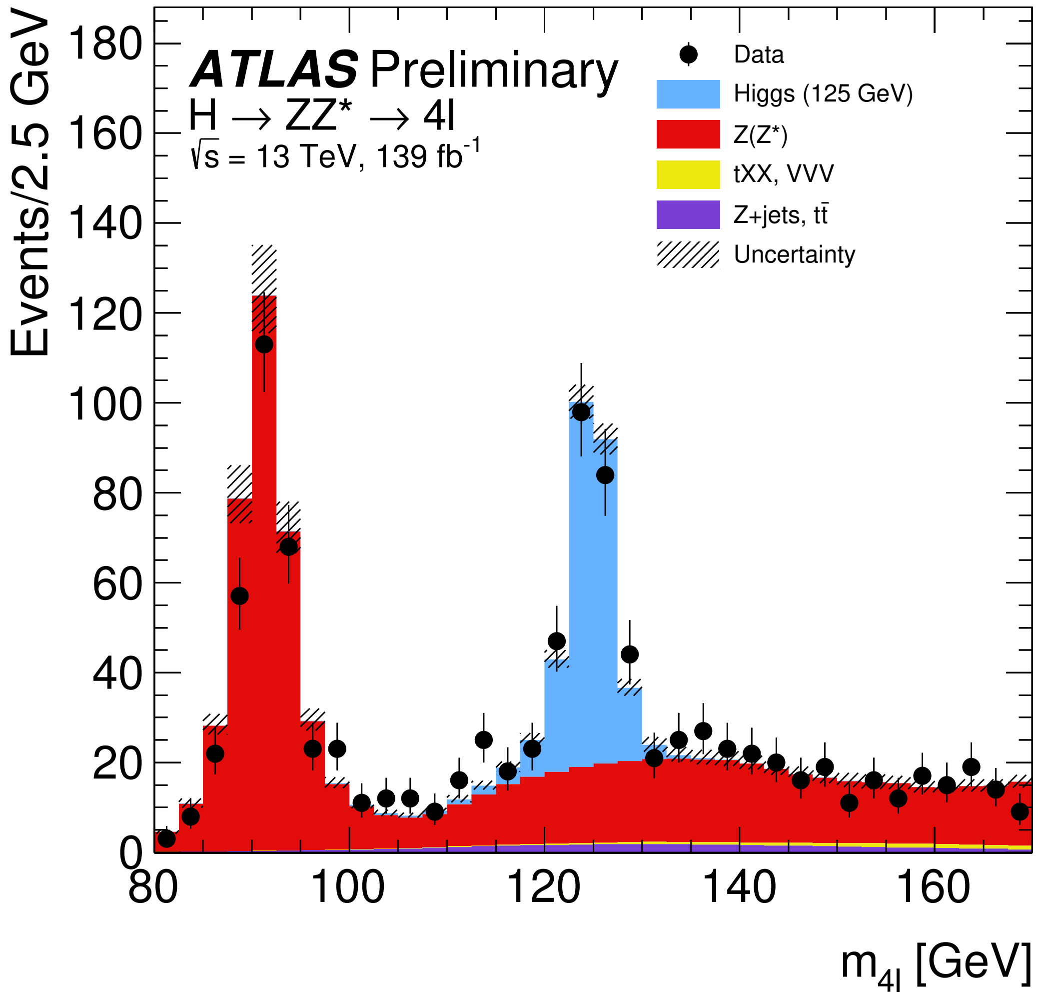
Number of events

Differential cross-section measurements

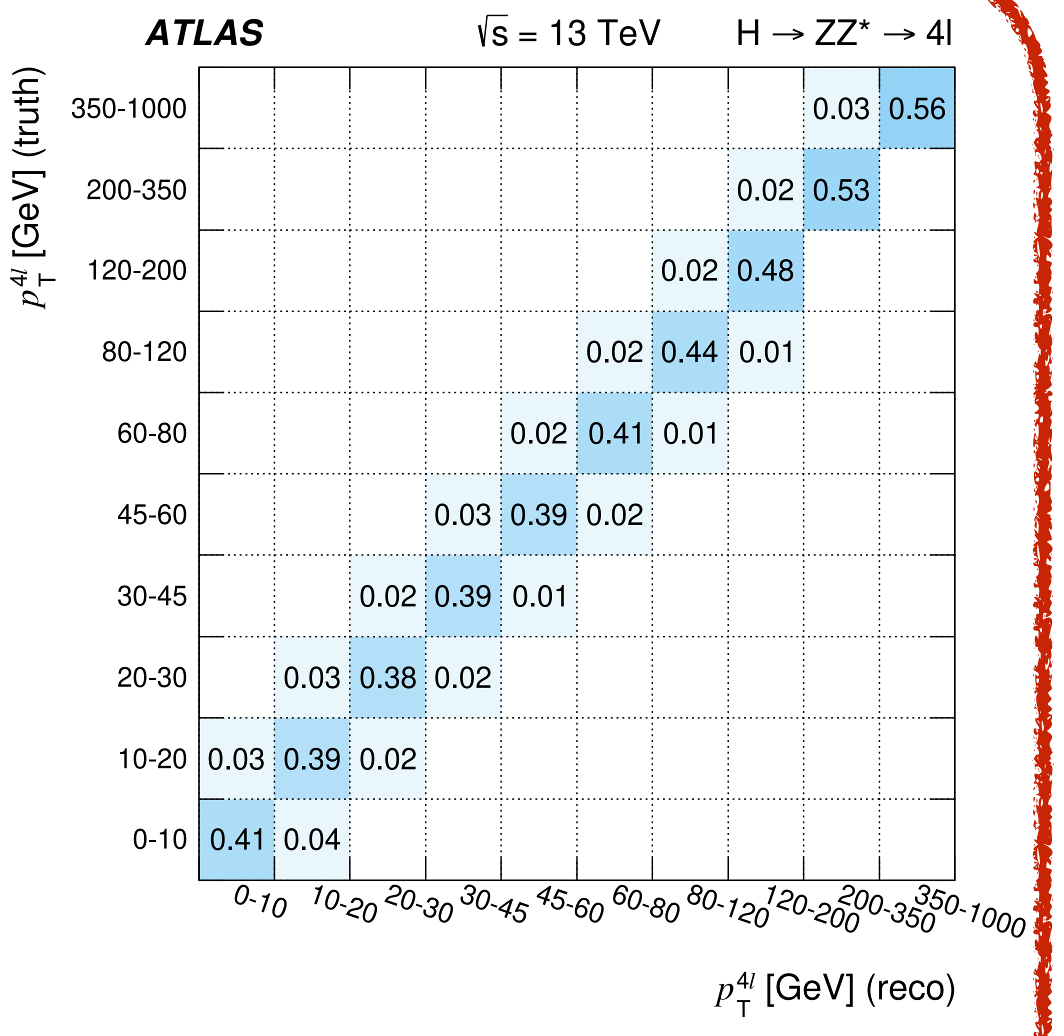
Input distribution → **Unfold**



Number of events



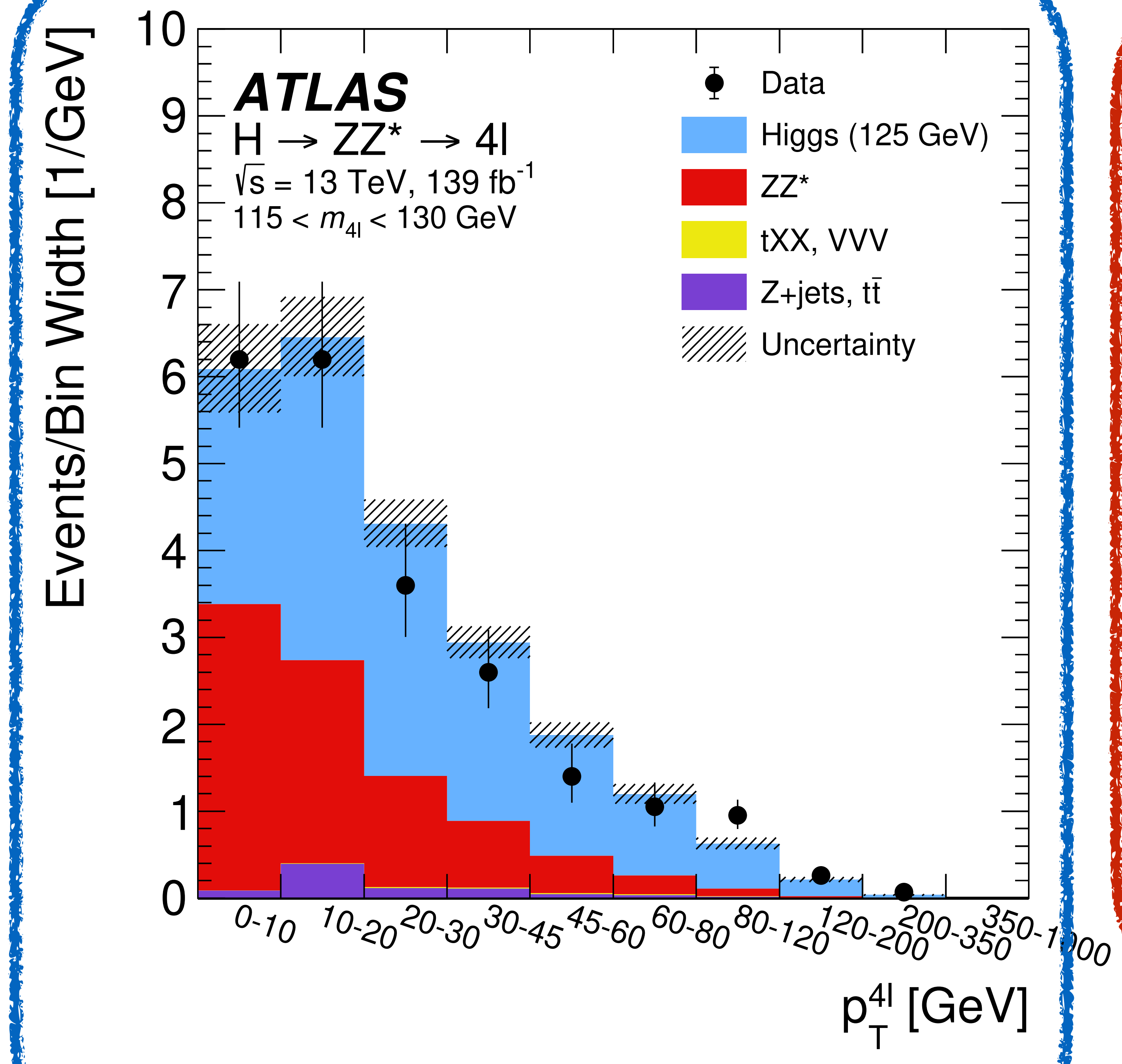
m4ℓ or mγγ



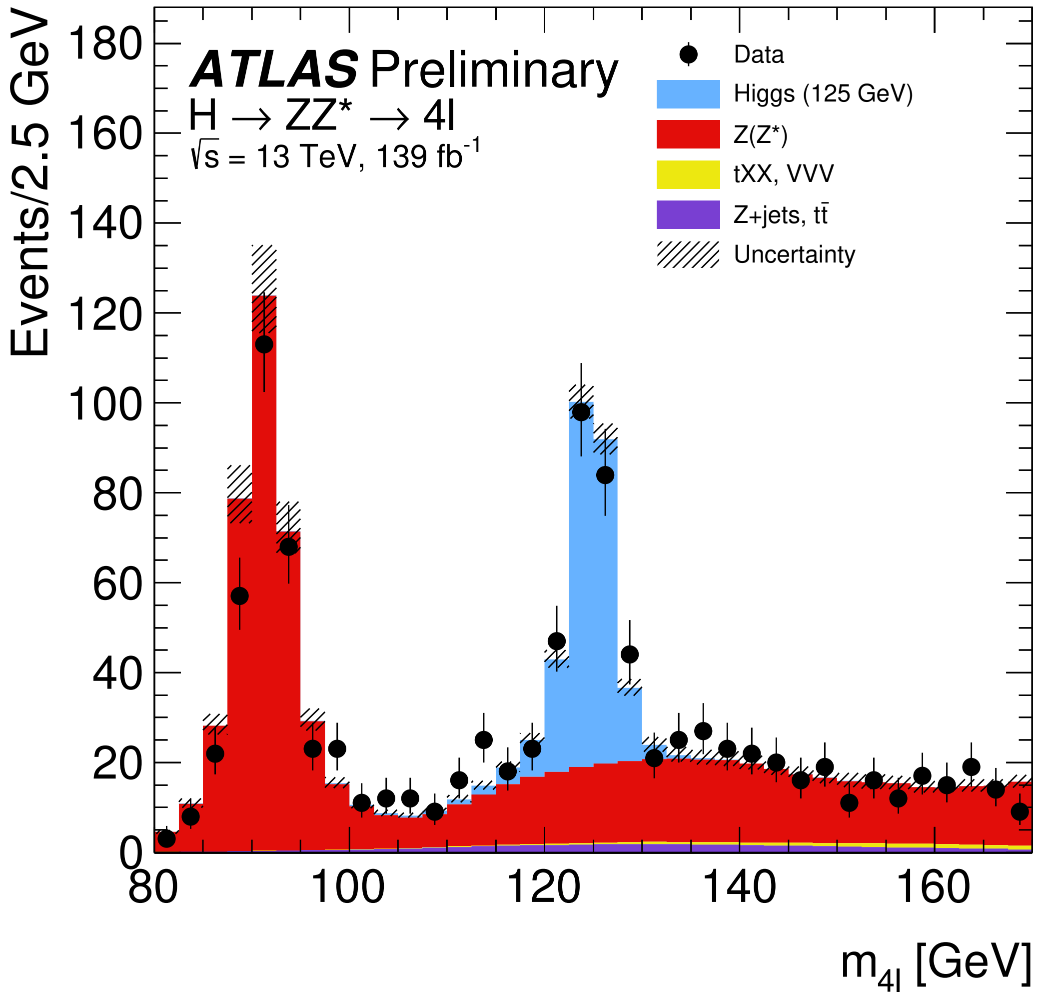
Matrix or bin-by-bin unfolding

Differential cross-section measurements

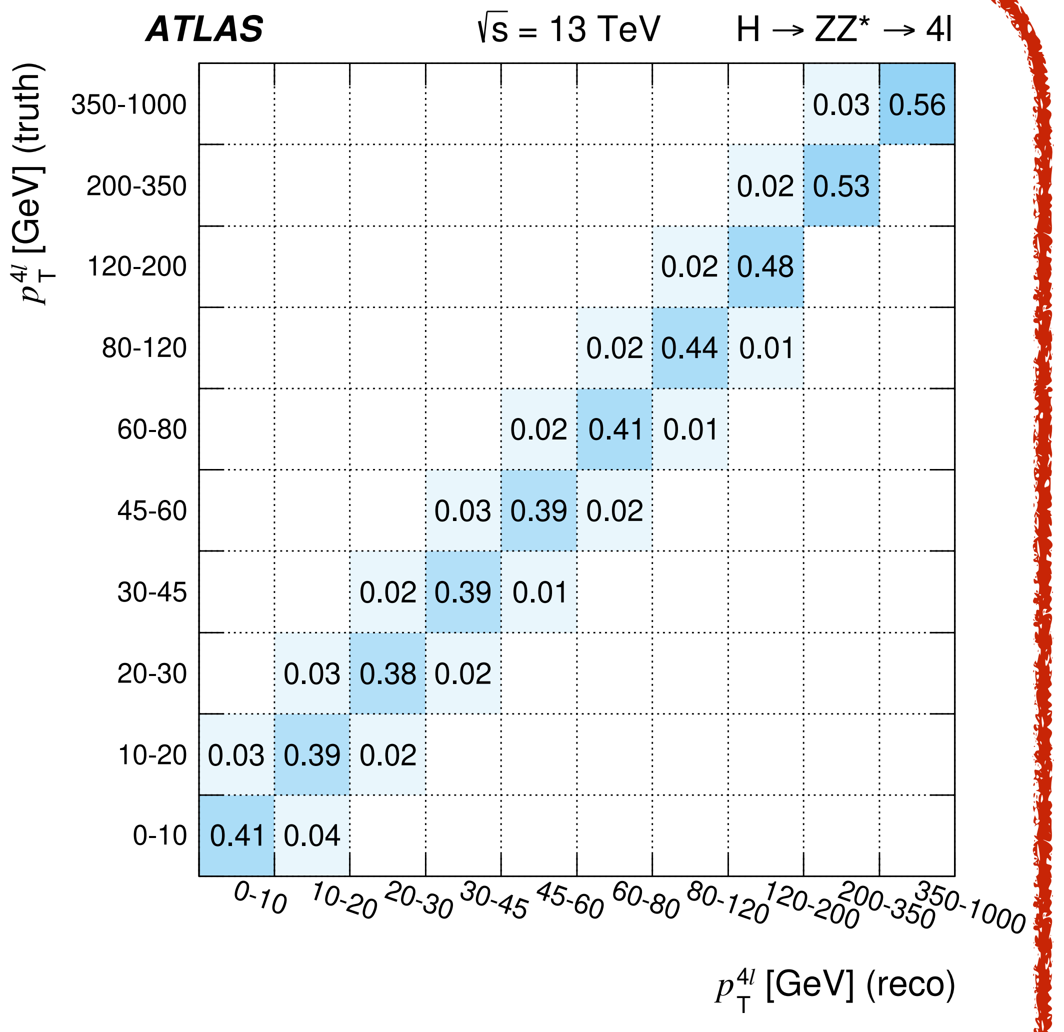
Input distribution → **Unfold** → **Fiducial XS**



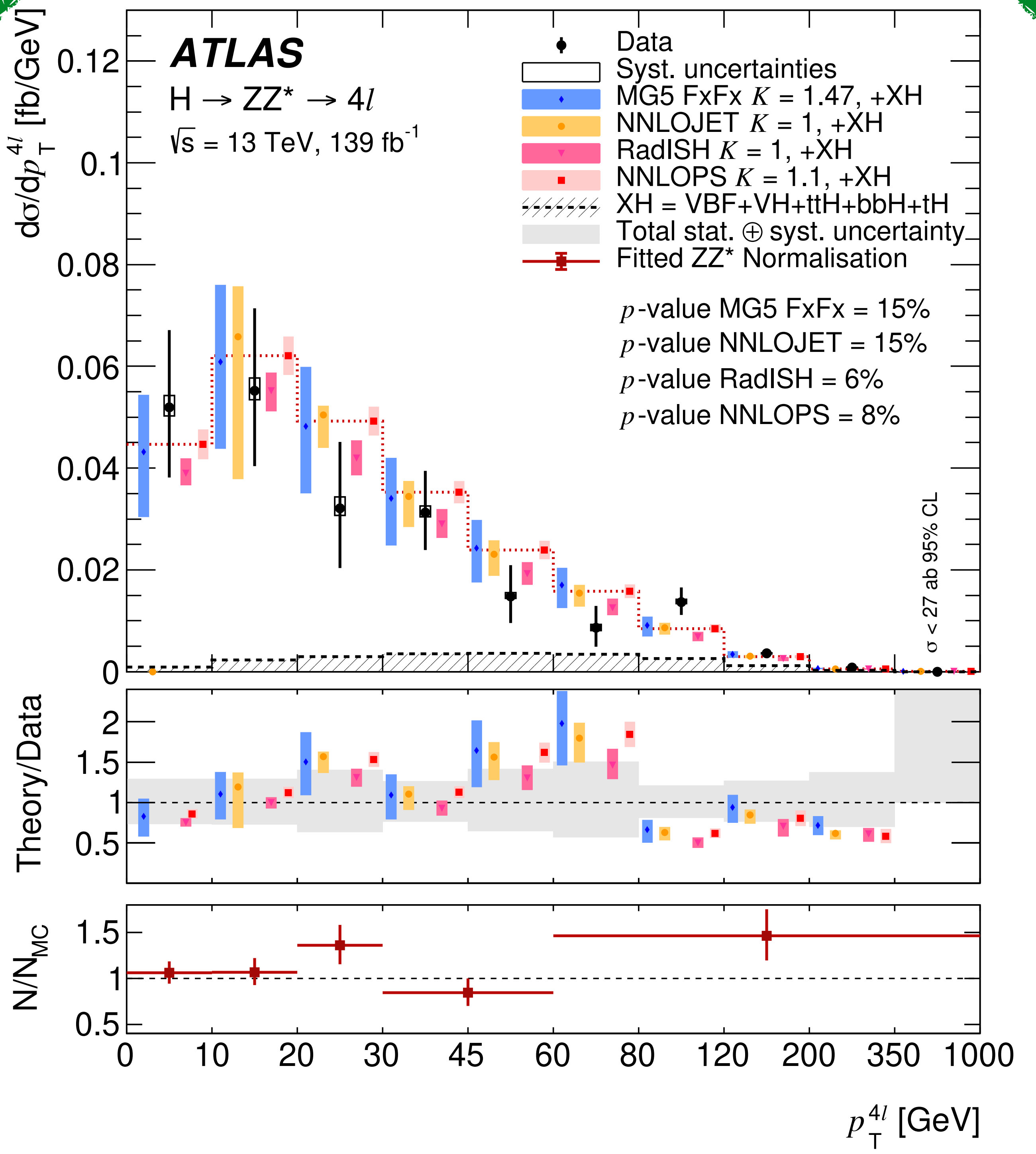
Number of events



m4ℓ or mγγ



Matrix or bin-by-bin unfolding



Compare to MC predictions (binning limited by stat)

Then provide higher-level interpretations.

H4ℓ & Hγγ differential XS: observables

H→ZZ→4ℓ

20 observables

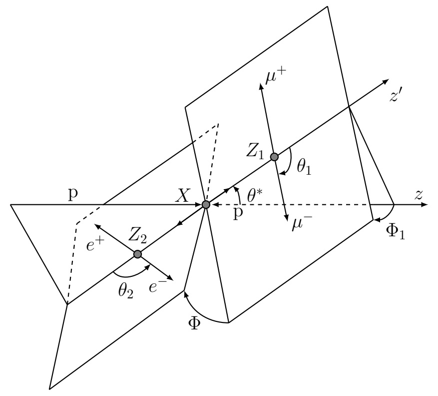
H→γγ

6 observables (preliminary)

Higgs system

H→ZZ→4ℓ:

- $p_T(4\ell)$, $y_{4\ell}$,
- m_{12}, m_{34},
- 5 final-state angular variables.



H→γγ:

- $p_T(\gamma\gamma)$, $y_{\gamma\gamma}$.

Jet variables

H→ZZ→4ℓ:

- N_{jets}, $N_{b\text{-}jets}$,
- $p_T(j_1)$, $p_T(j_2)$,
- dijet invariant mass, angular separation (ϕ, η).

H→γγ:

- N_{jets},
- $p_T(j_1)$,
- dijet invariant mass, angular separation (ϕ, η).

Higgs + 1 or 2 jets system

- p_T and invariant mass.

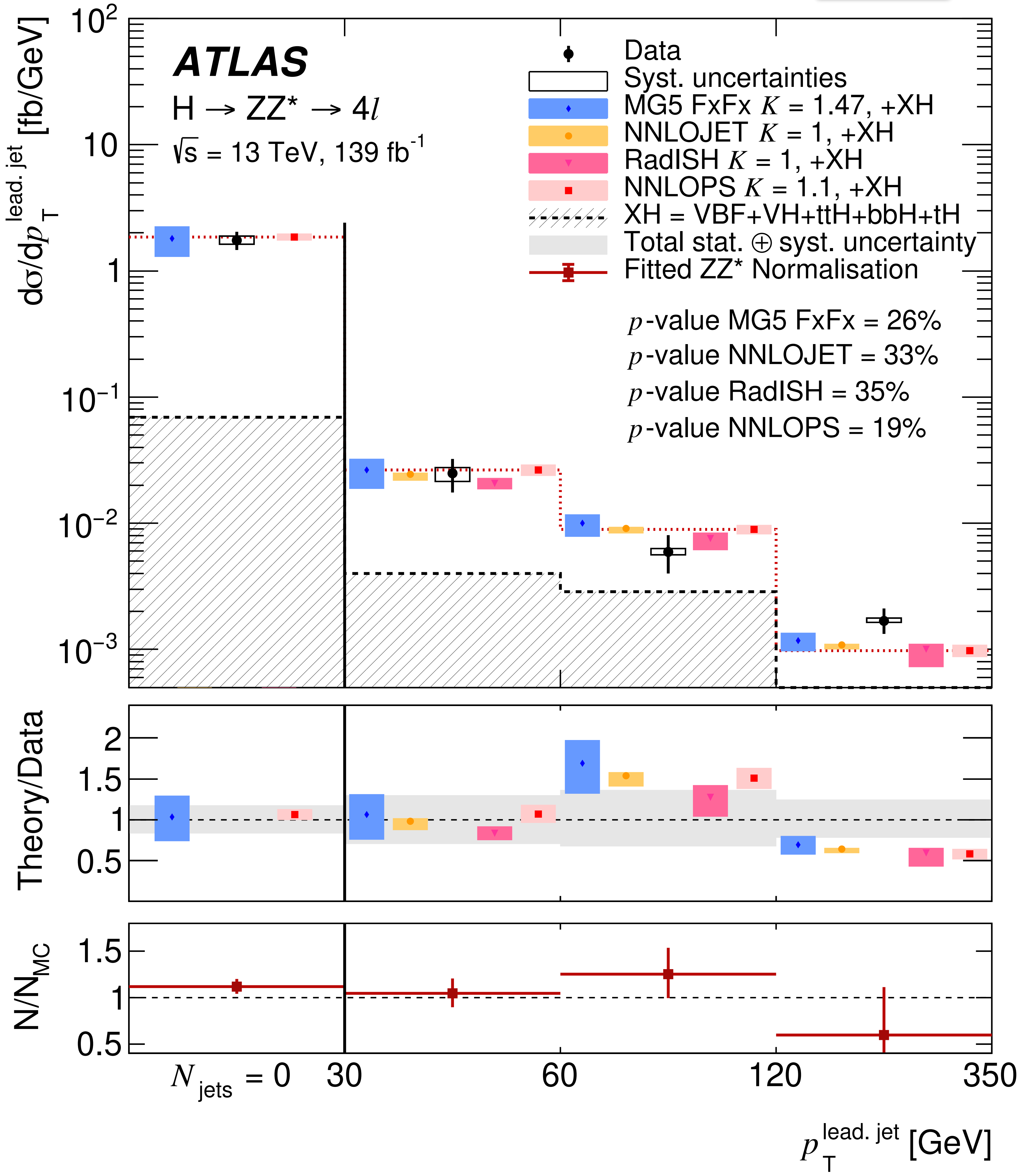
Double differential cross-section

- 8 double differential observables.

H4ℓ & Hγγ differential XS: examples

H→ZZ→4ℓ

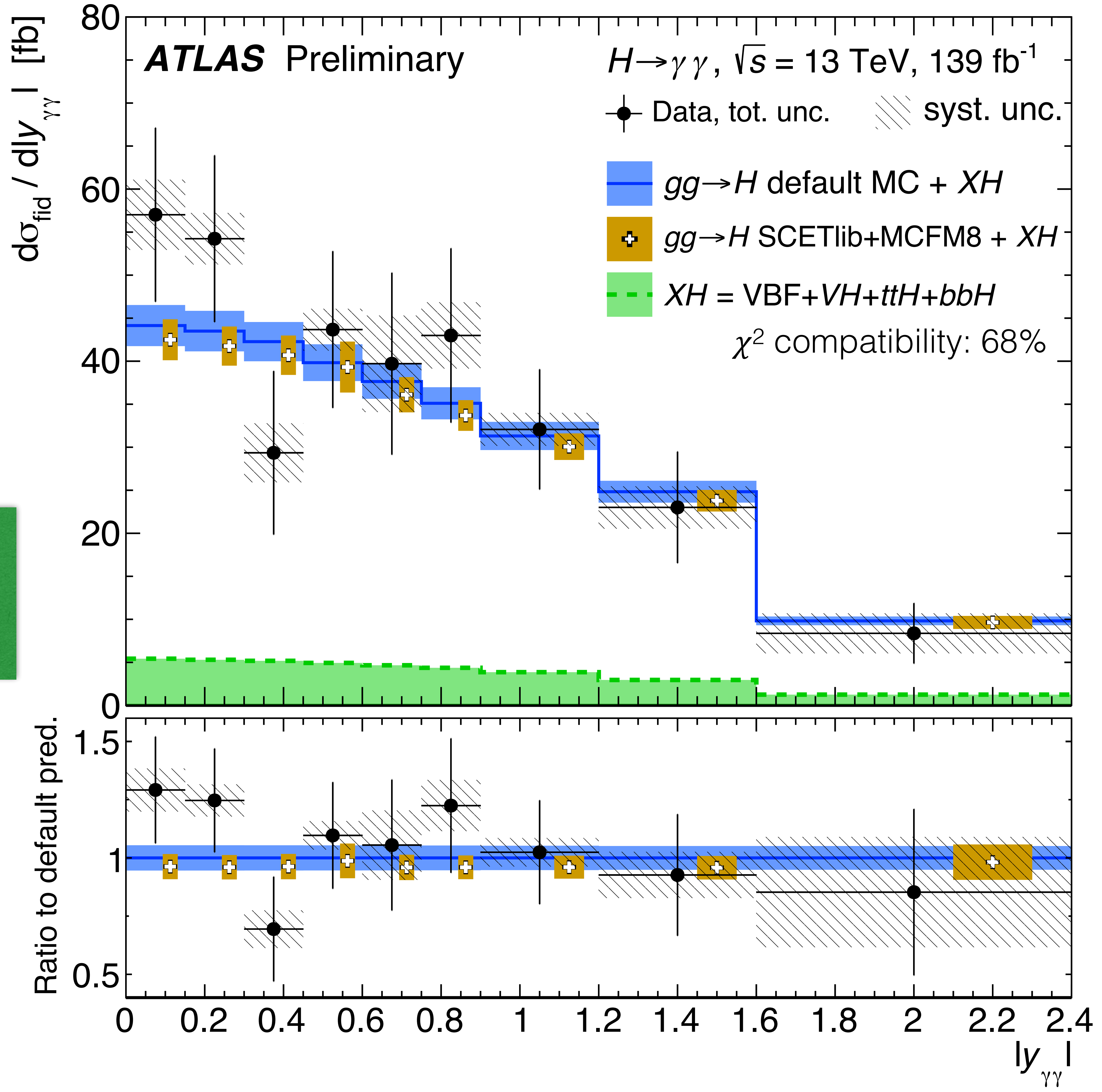
$p_T(j_1)$



Good SM compatibility

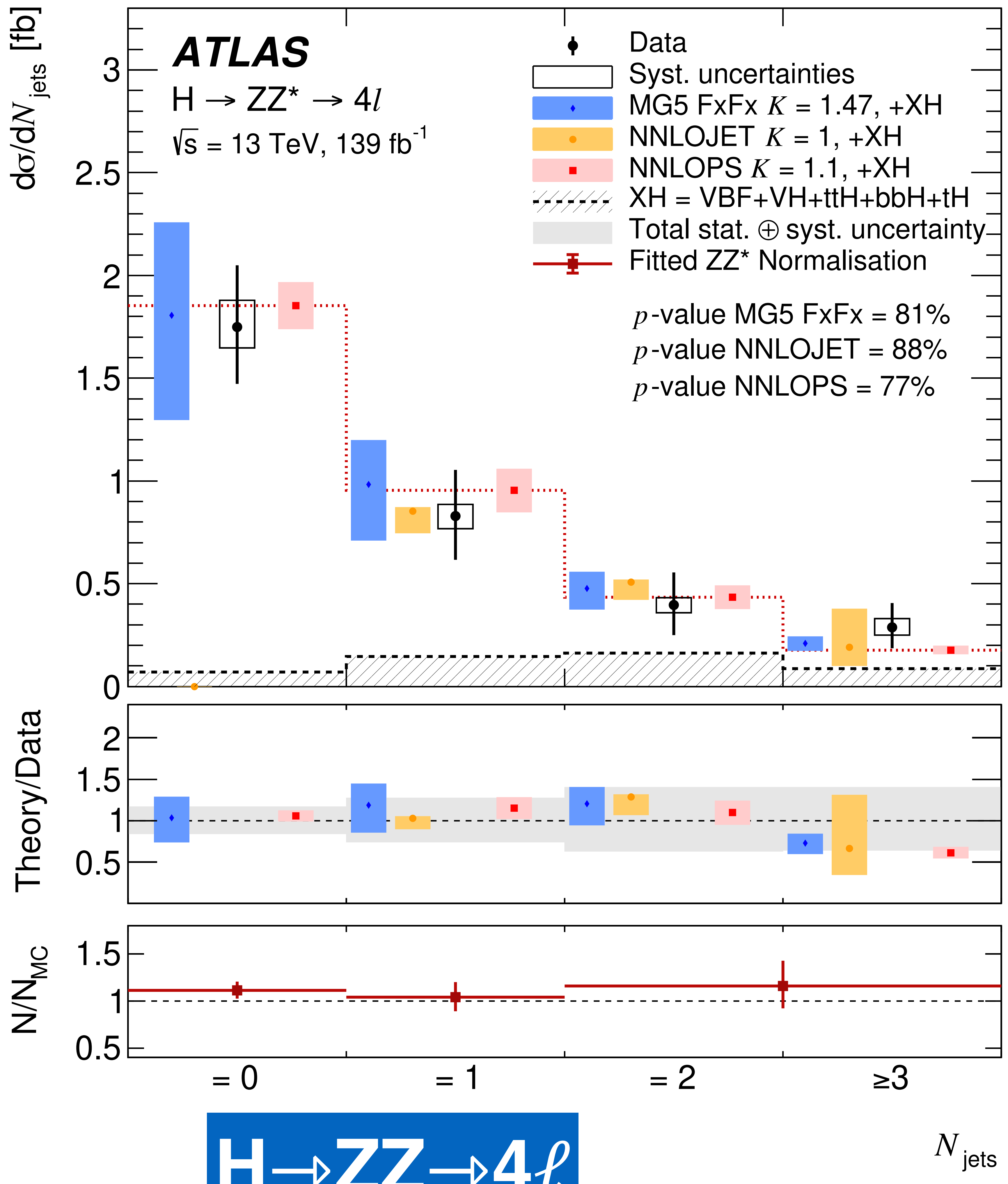
H→γγ

$y_{\gamma\gamma}$

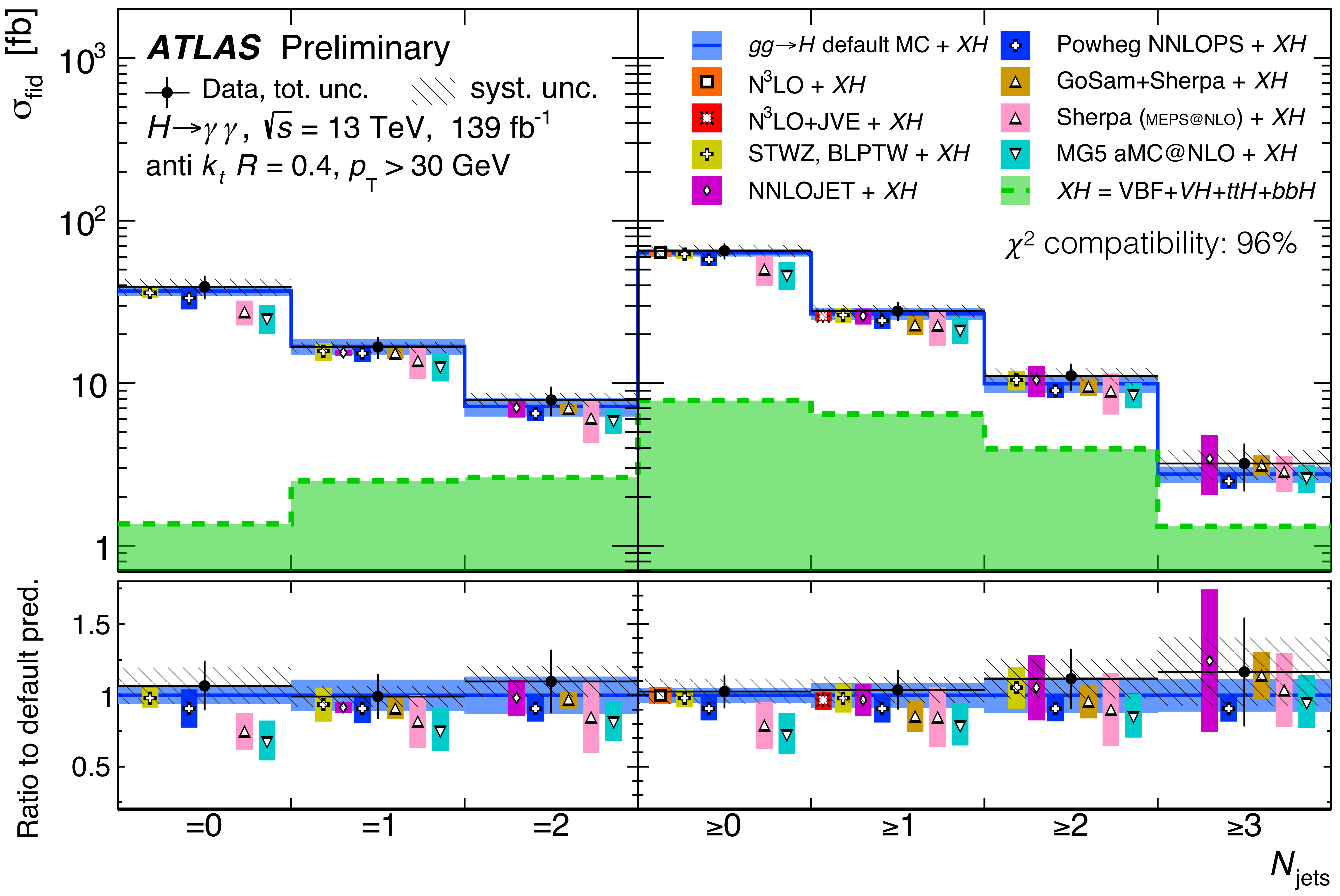


H4ℓ & Hγγ differential XS: examples

N_{jets}: sensitive to production mode composition



H→ZZ→4ℓ

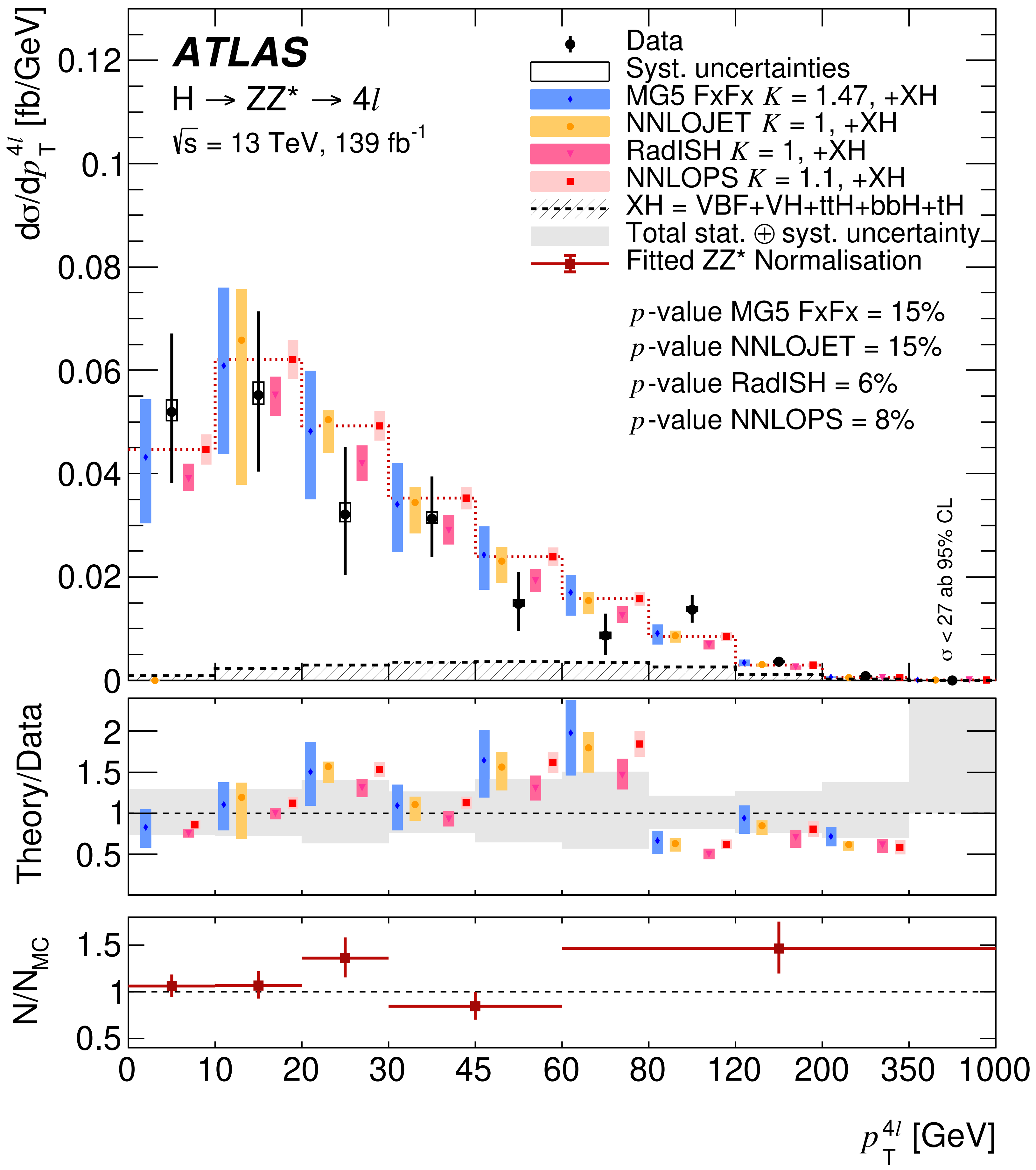


Good SM compatibility

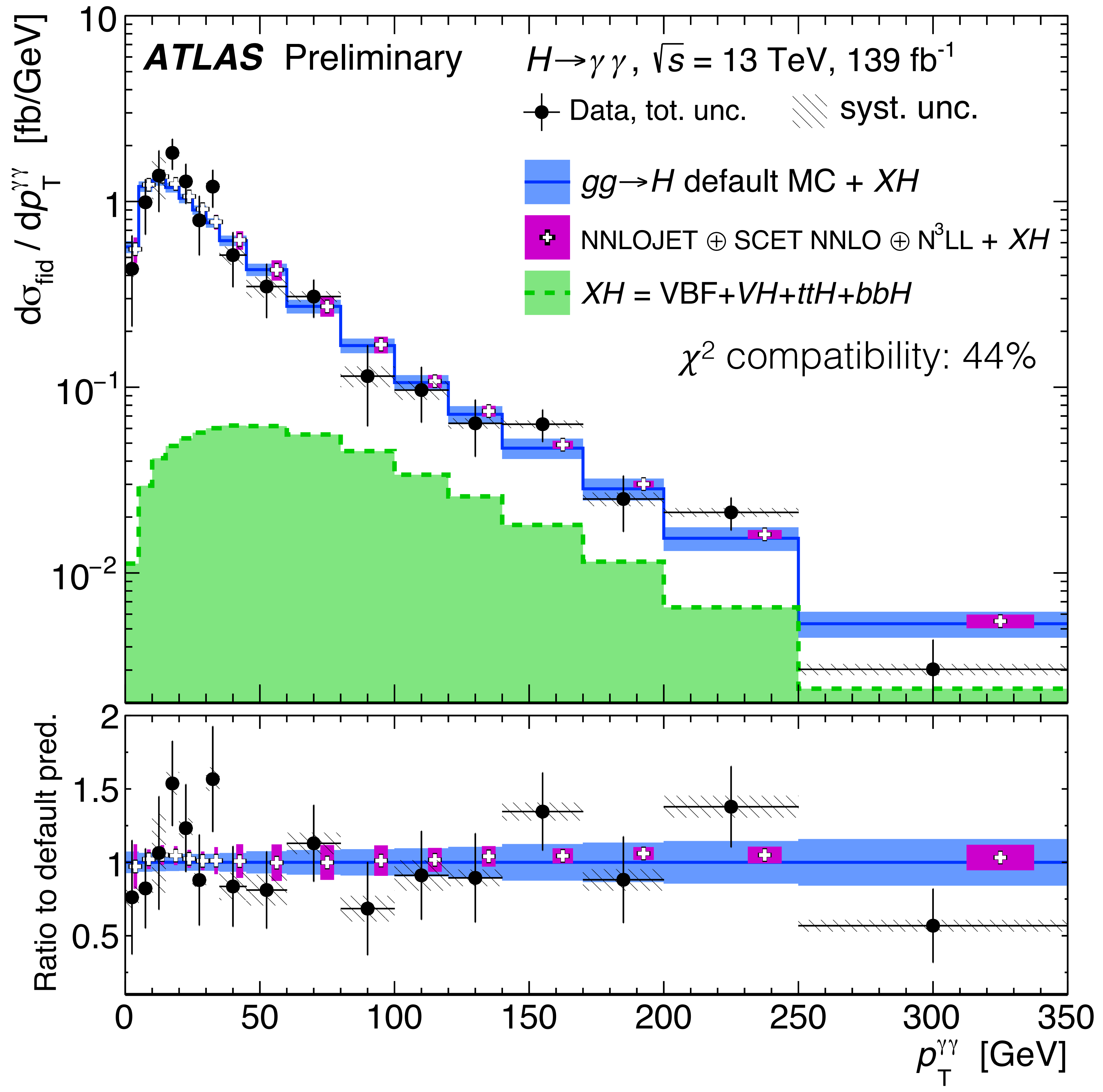
H→γγ

H4ℓ & Hγγ differential XS: probing Higgs-charm Yukawa (κ_c)

H→ZZ→4ℓ



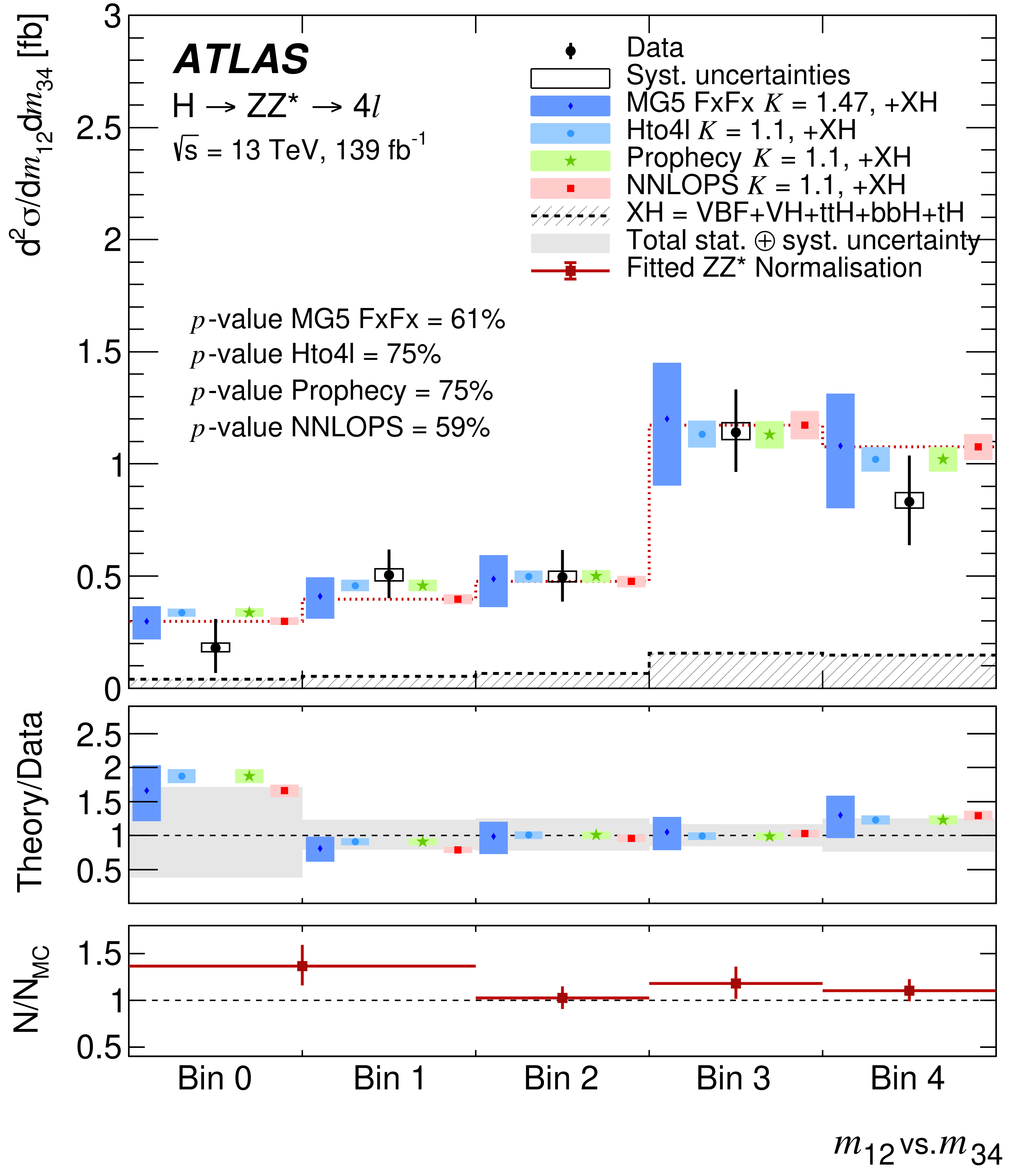
H→γγ

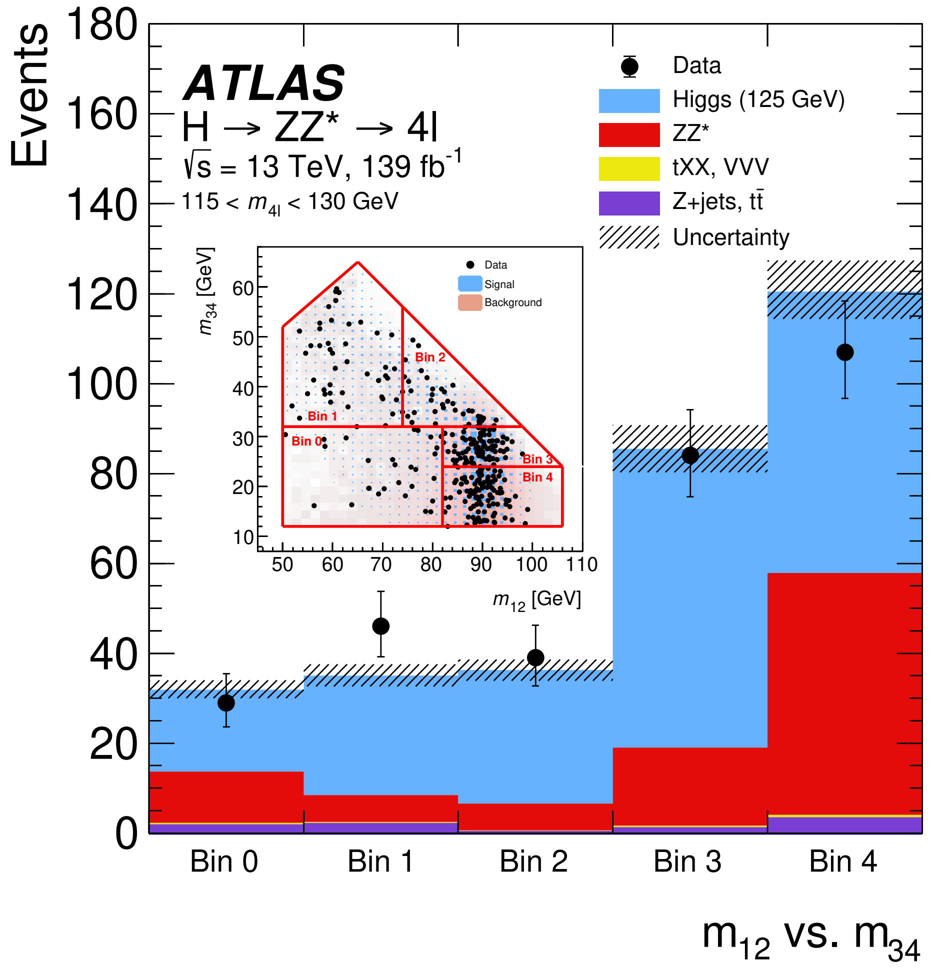


- Low-p_T: sensitive to c/b-Yukawa
- High-p_T: sensitive to new heavy particles in ggF loop

H4ℓ: [-7.5, 9.3] κ_c @ 95% CL Hγγ: [-19, 24] (shape only)

H4ℓ differential XS: Pseudo-Observable interpretation

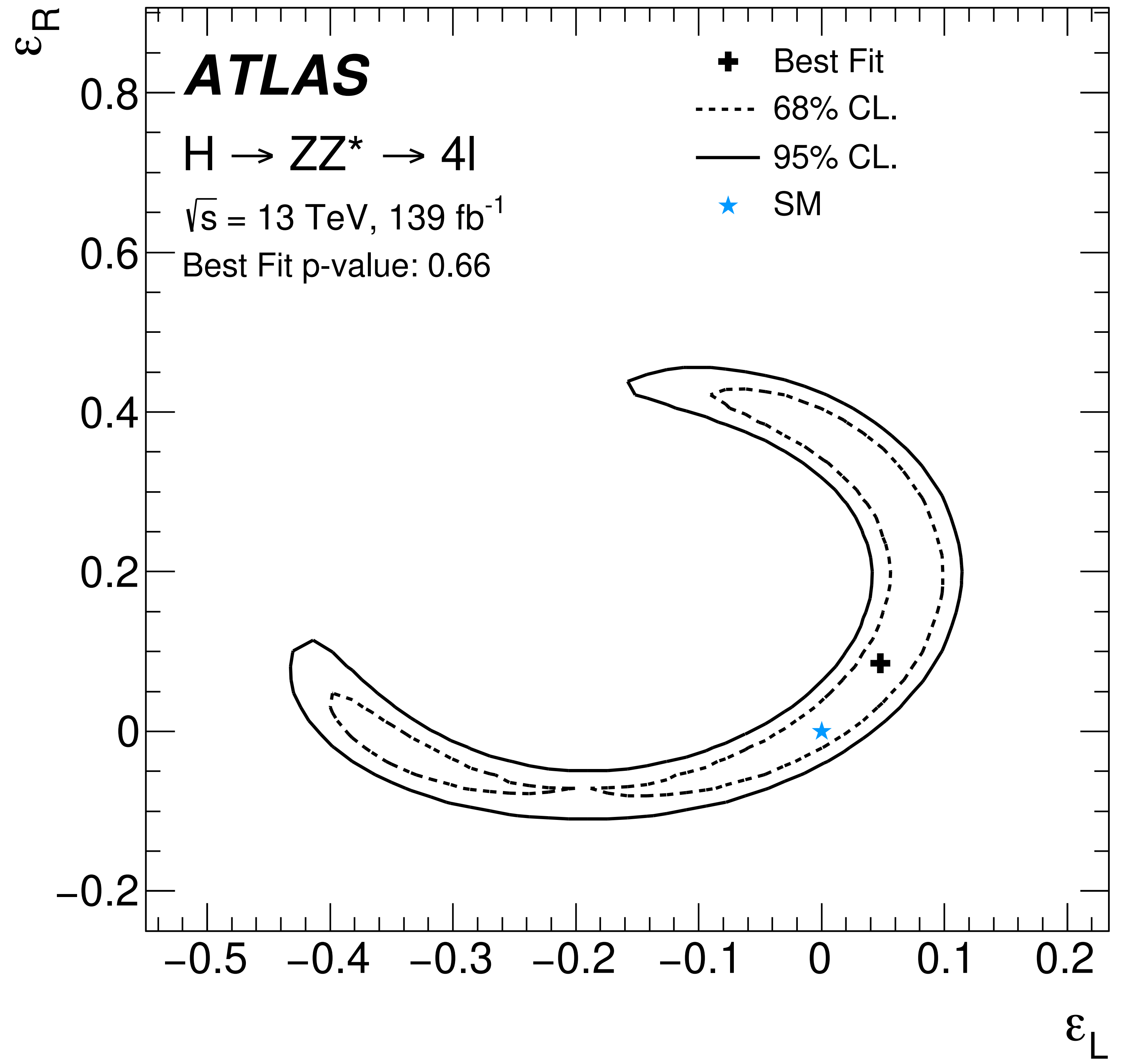




m_{12}: on-shell Z mass

m_{34}: off-shell Z mass

m_{34}: sensitive to light states



- Starts from m_{12} vs m_{34} double differential XS.
- Probes "pseudo-observables" (PO): contact terms between H, Z and ℓ_L/ℓ_R

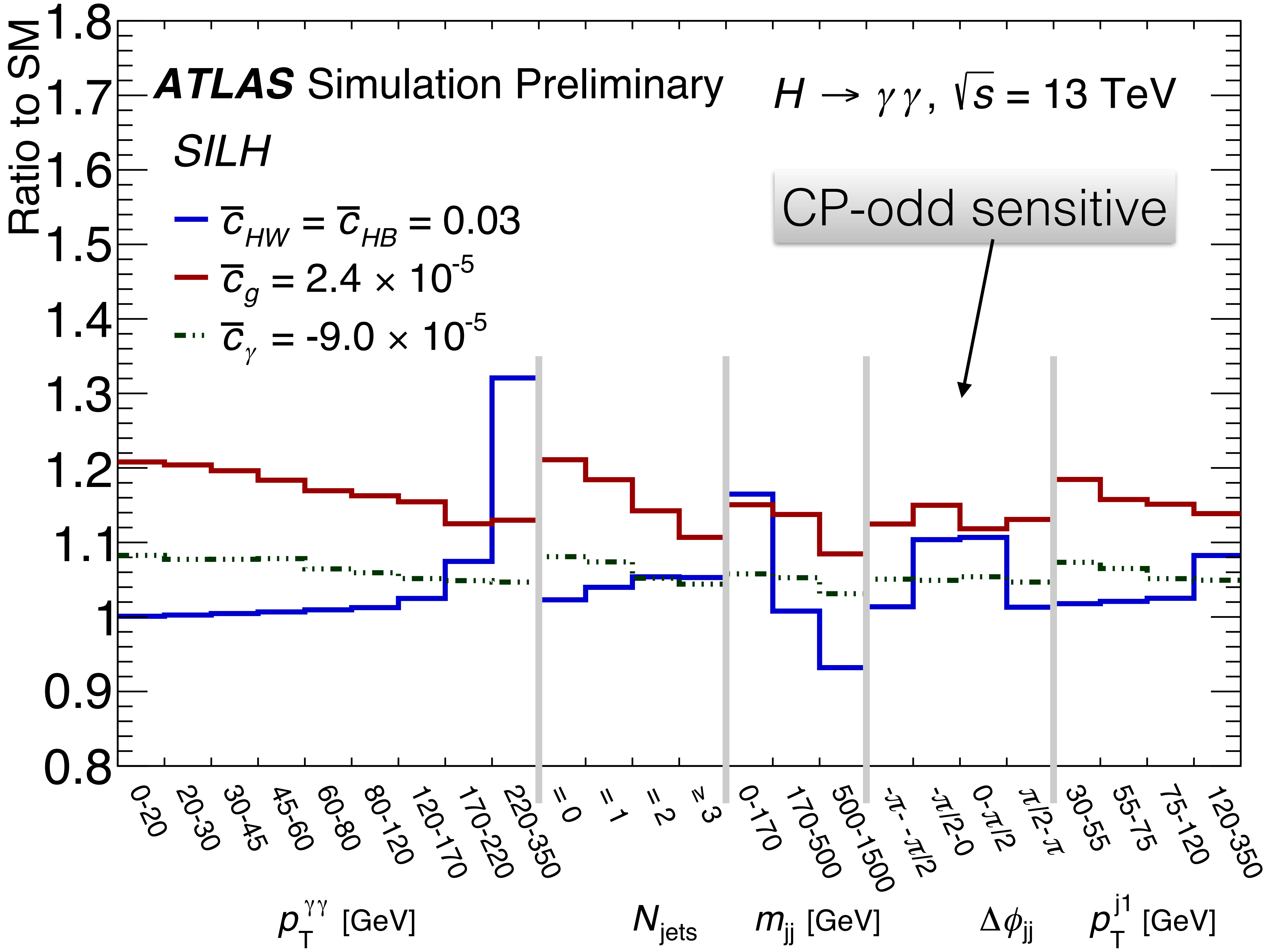
No significant deviation, good SM compatibility

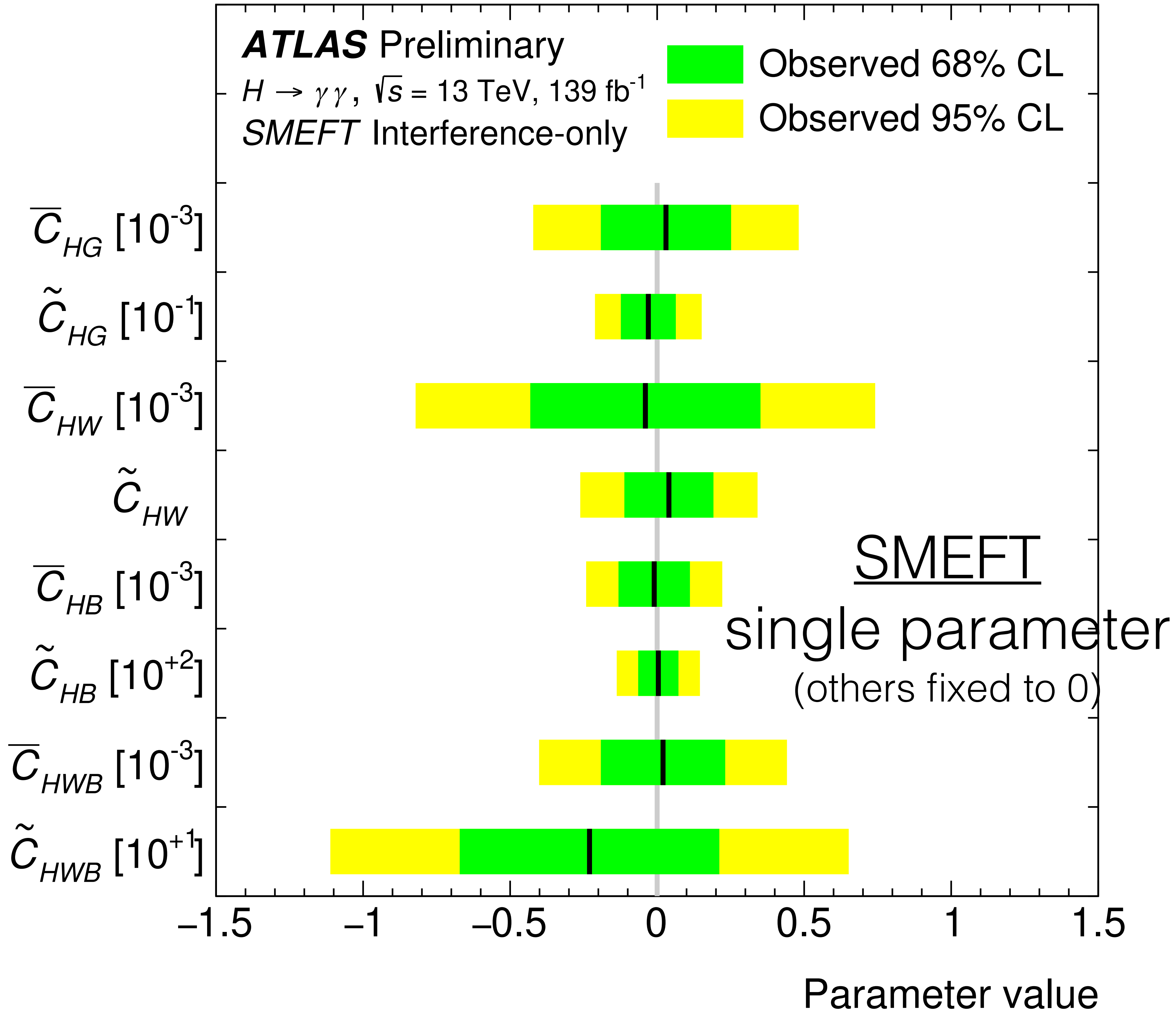
Hγγ differential XS: EFT interpretation

- **Interpretation in SILH/SMEFT basis.**
  - Dimension-6 terms: $\mathcal{L}_{\mathrm{EFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \mathcal{O}_i \cdot c_i/\Lambda^2$

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

- **Global fit to all observables.**





No significant deviation, good SM compatibility

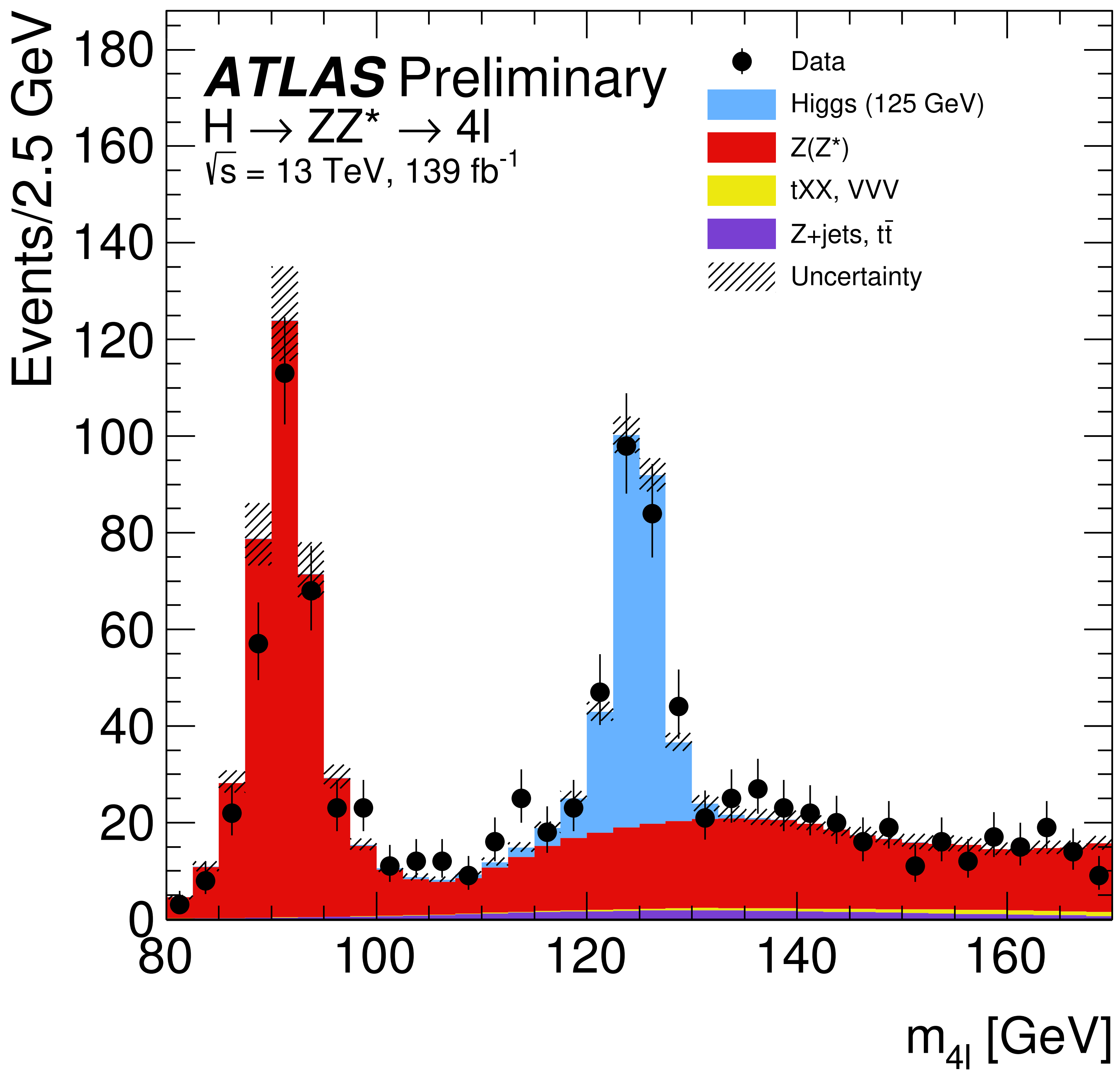
H4ℓ mass measurement

First Higgs mass measurement using full Run-2 data!

ATLAS-CONF-2020-005 (preliminary)

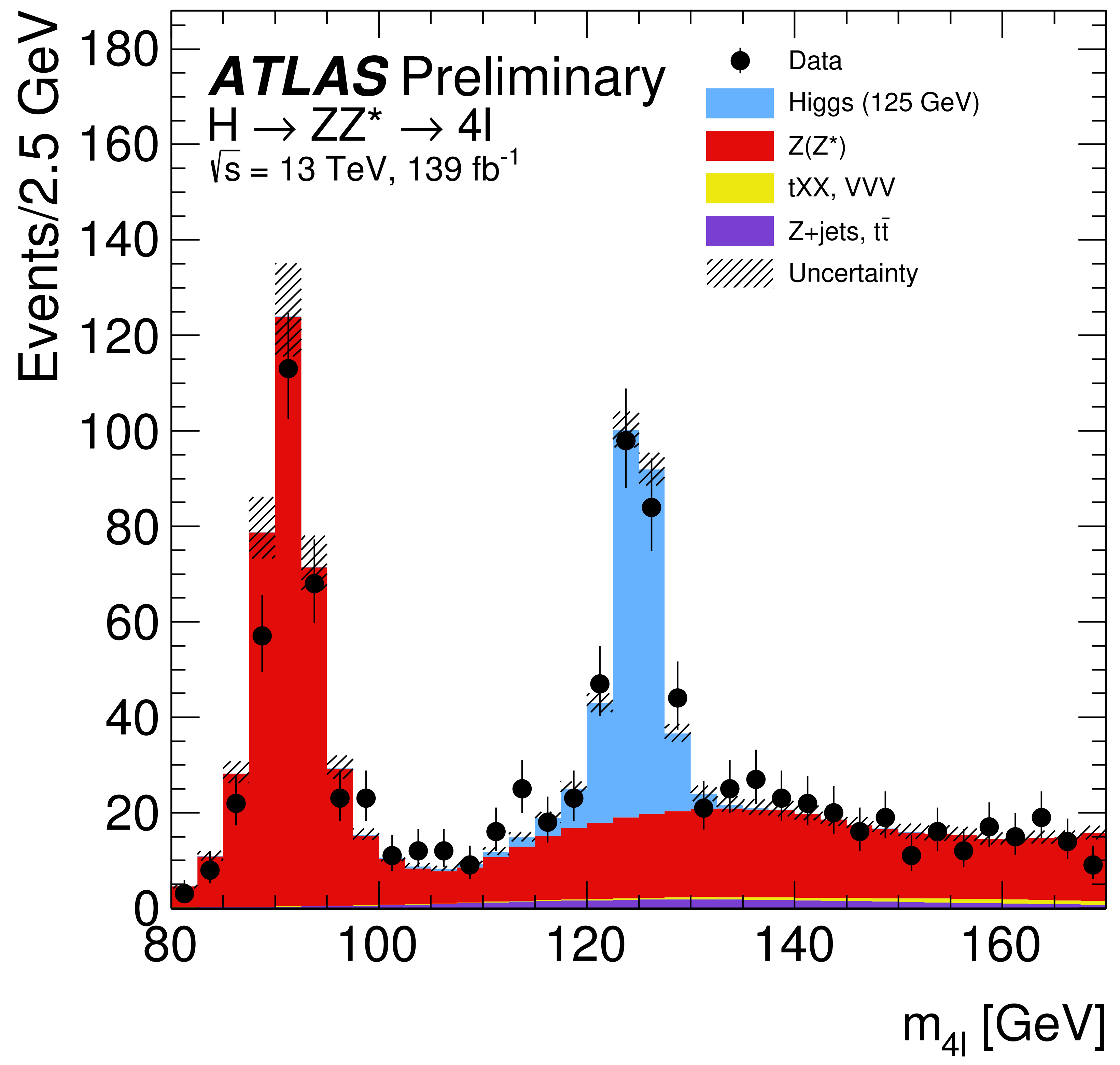
Key elements of the H4ℓ mass analysis

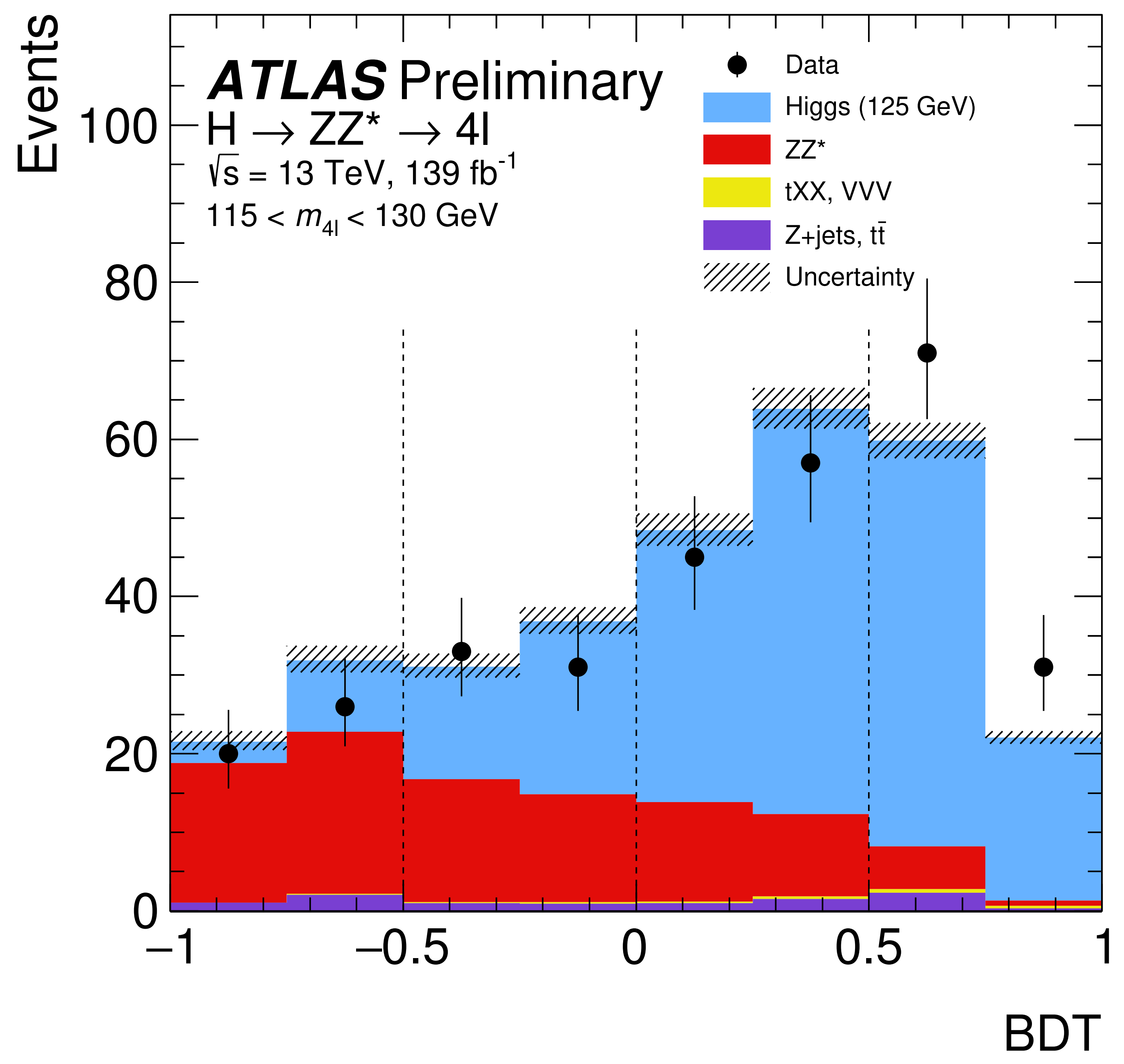
- In mass region 115-130 GeV : **314 events observed** with **S:B ratio = 2:1** (316 expected).
- Recovering **FSR**: 4% of events → improves resolution by **1%**.
- **Leading Z mass constraint** → **17%** improvement.



Key elements of the H4ℓ mass analysis

- In mass region 115-130 GeV : **314 events observed** with **S:B ratio = 2:1** (316 expected).
- Recovering **FSR**: 4% of events
  ➞ improves resolution by **1%**.
- **Leading Z mass constraint** ➞ **17%** improvement.

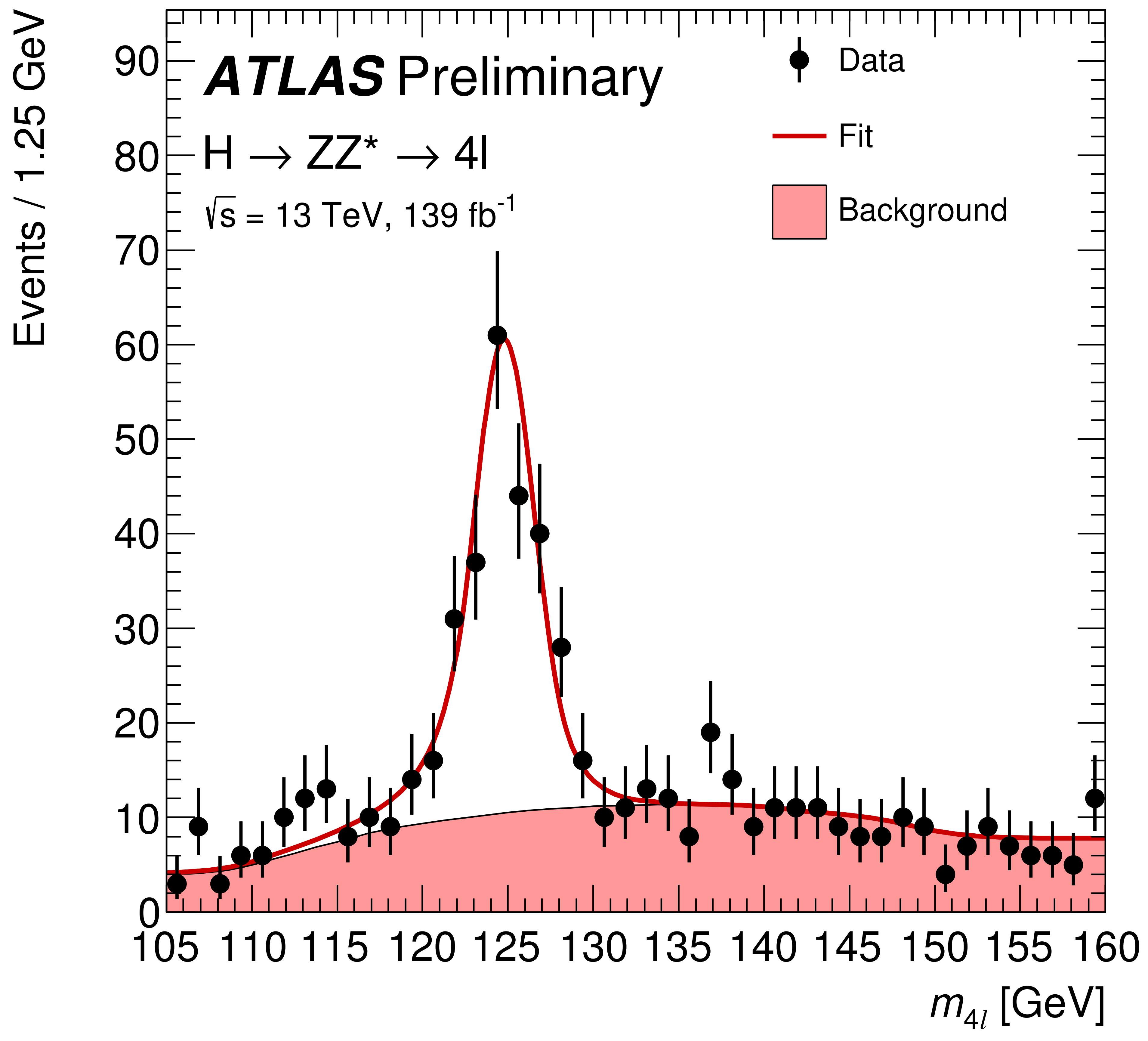


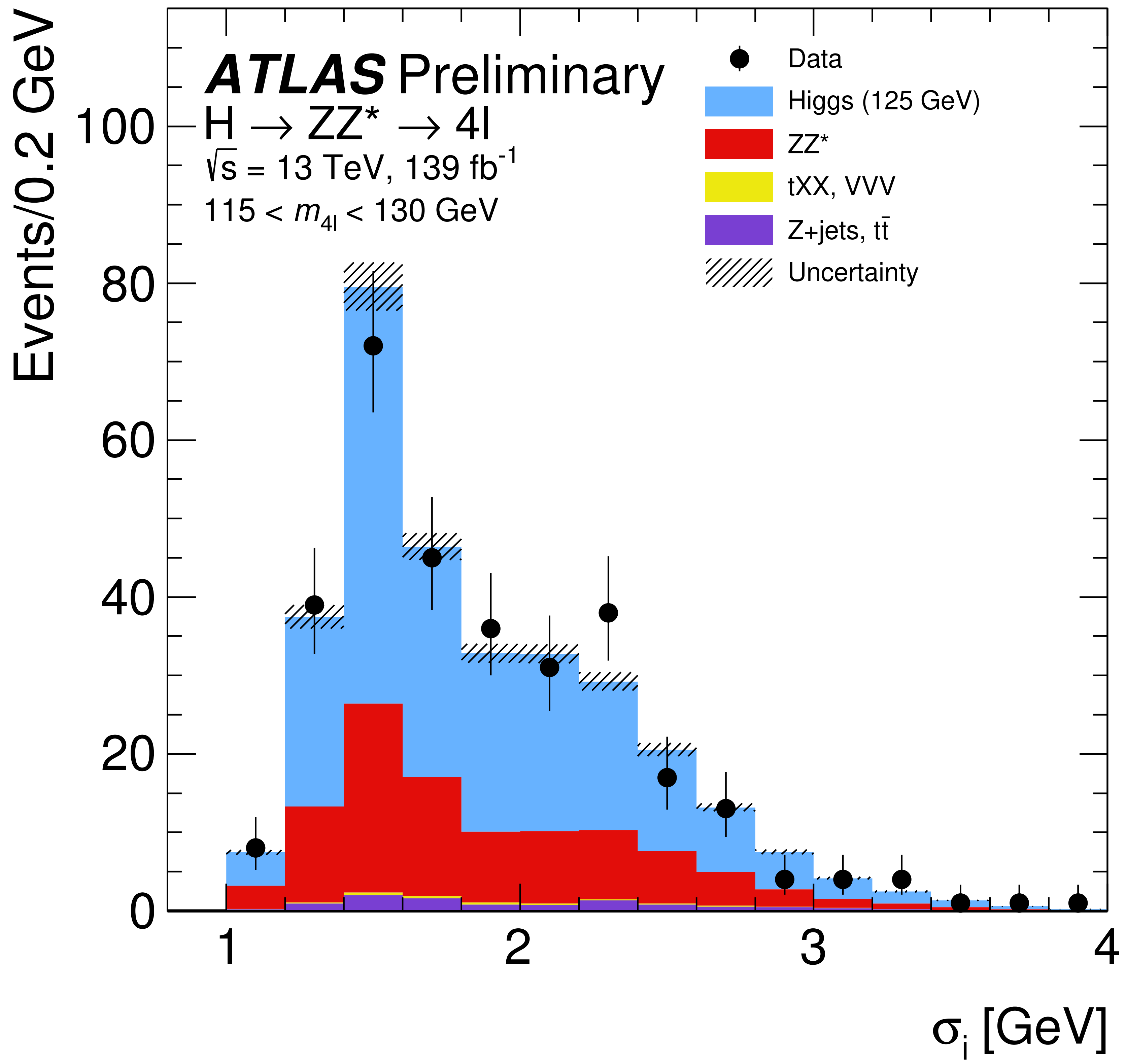


- Signal purity enhanced with BDT:
  - Discriminate Higgs signal vs ZZ* continuum.
  - **4 BDT bins ➞ 2%** improvement.
- Total 16 analysis categories: 4 BDT bins x 4 final states.

Key elements of the H4ℓ mass analysis

- **Signal modelling**: **double-sided Crystal-Ball**.
- **Per-event resolution** ➞ **2%** improvement.

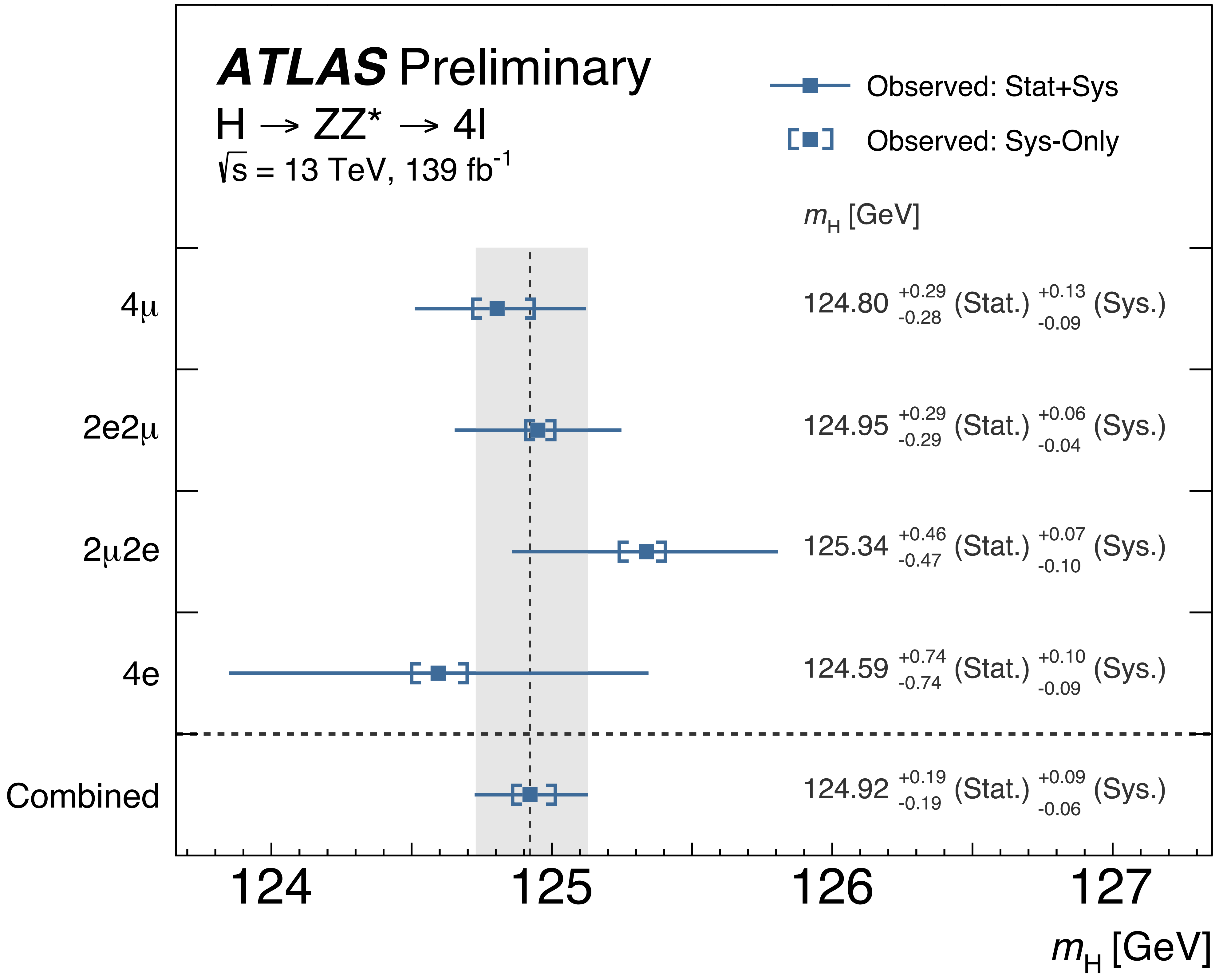




- Lepton resolution ➞ $m_{4\ell}$ resolution not straightforward.
- **Use NN to predict $m_{4\ell}$ resolution** based on lepton kinematics and uncertainties.

H4ℓ mass measurement: result & comparisons

- **This measurement**:
  - mH = 124.92 ± **0.21** (**±0.19 stat** ±0.08 sys)
  - Good compatibility between channels.
  - Largely **statistically dominated**.



Systematic Uncertainty	Impact (GeV)
Muon momentum scale	+0.08,−0.06
Electron energy scale	±0.02
Muon momentum resolution	±0.01
Muon sagitta bias correction	±0.01

H4ℓ mass measurement: result & comparisons

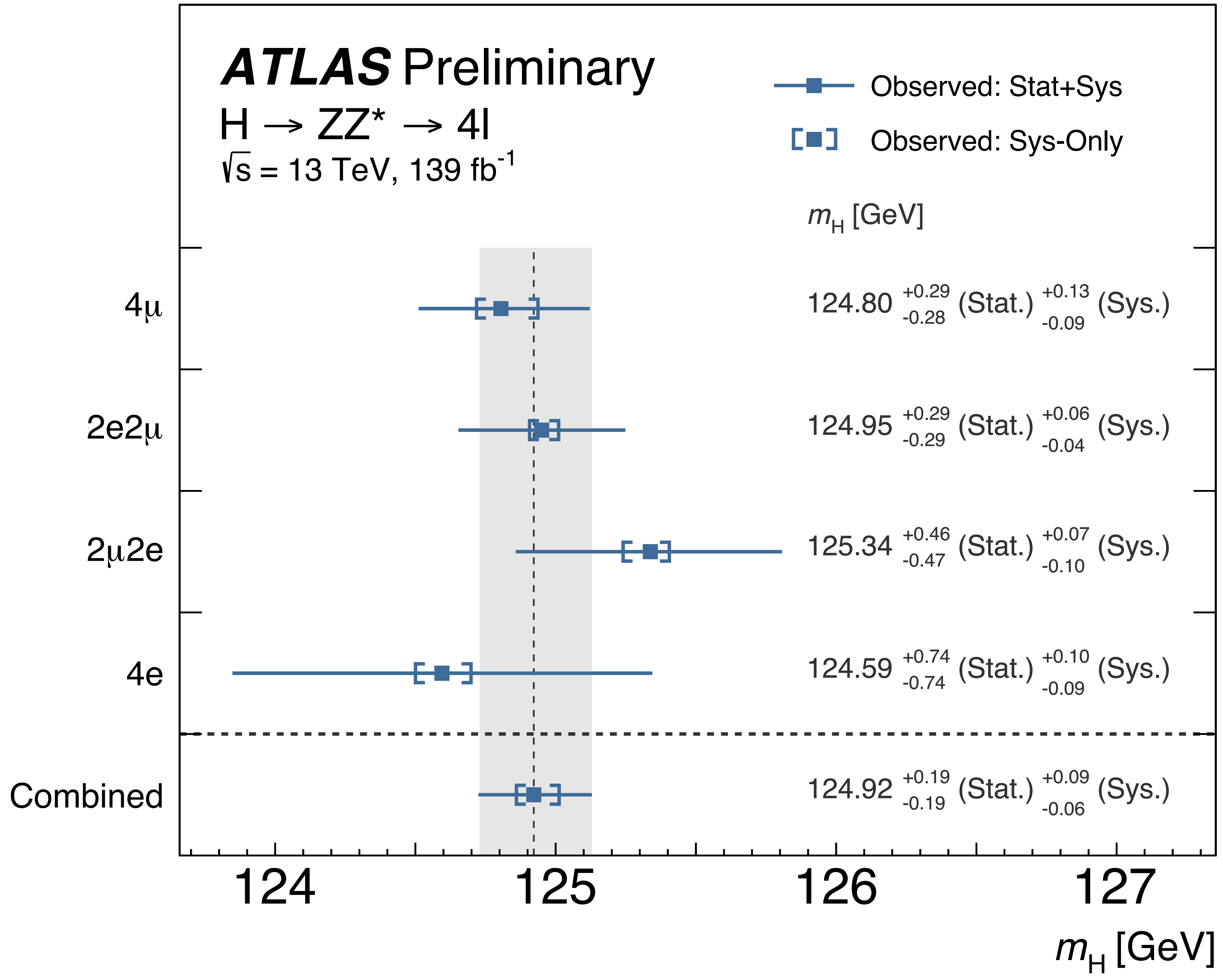
- **This measurement**:

  mH = 124.92 ± **0.21** (**±0.19 stat** ±0.08 sys)

  - Good compatibility between channels.
  - Largely **statistically dominated**.

- **Previous ATLAS result**: PLB. 784 (2018) 345
  Hγγ + H4ℓ (Run1 + Run2 @ 36/fb):

  mH = 124.97 ± **0.24** GeV



Systematic Uncertainty	Impact (GeV)
Muon momentum scale	+0.08,−0.06
Electron energy scale	±0.02
Muon momentum resolution	±0.01
Muon sagitta bias correction	±0.01

H4ℓ mass measurement: result & comparisons

- **This measurement**:

  mH = 124.92 ± **0.21** (**±0.19 stat** ±0.08 sys)

  - Good compatibility between channels.
  - Largely **statistically dominated**.

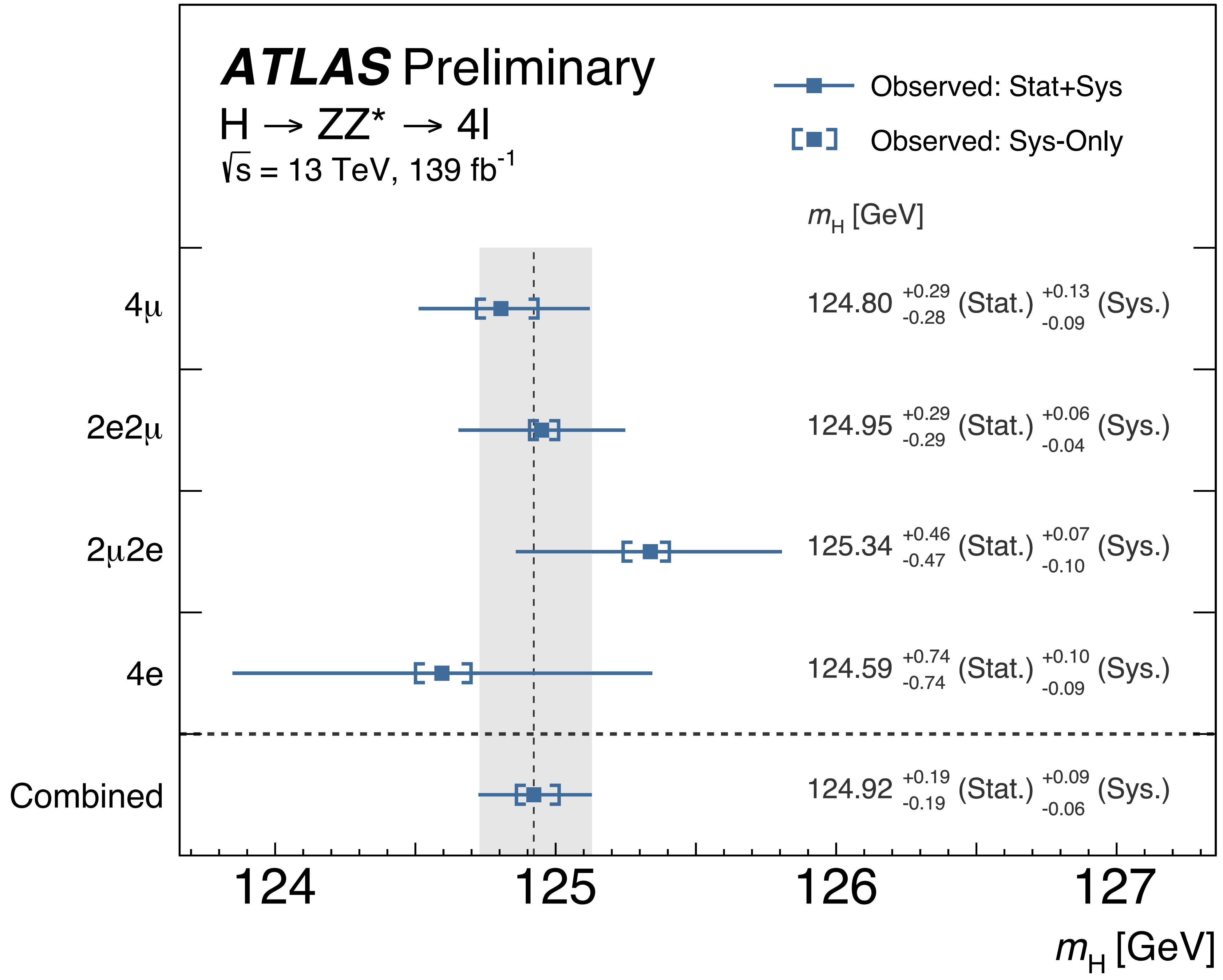
- **Previous ATLAS result**: PLB. 784 (2018) 345
  Hγγ + H4ℓ (Run1 + Run2 @ 36/fb):

  mH = 124.97 ± **0.24** GeV

- **Comparable CMS result**: JHEP 11 (2017) 047
  H4ℓ (36/fb):

  mH = 125.26 ± **0.21** GeV

All results compatible!



Systematic Uncertainty	Impact (GeV)
Muon momentum scale	+0.08,−0.06
Electron energy scale	±0.02
Muon momentum resolution	±0.01
Muon sagitta bias correction	±0.01

Conclusion

H4ℓ — Differential cross-sections — Hγγ

- H4ℓ **final Run-2 result**:
  - σ_{fid} = 3.28 ± 0.30 (stat) ± 0.11 (syst) fb.
  - SM: σ_{fid} = 3.41 ± 0.18 fb.
  - **Improves last result by 40%**.
  - Statistically dominated.
- κ_c @ 95% CL: [-7.5, 9.3].
- **Interpretation with pseudo-observables**.

10% precision level

- Hγγ **using all Run-2 data**:
  - σ_{fid} = 65.2 **± 4.5 (stat) ± 5.6 (syst)** ± 0.3 (theo) fb.
  - SM: σ_{fid} = 63.6 ± 3.3 fb.
  - **Best Hγγ up to now**.
  - Inclusive XS: now systematics-dominated.
- κ_c @ 95% CL: [-19, 24] (shape only).
- **Interpretation with EFT** (SILH/SMEFT).

No significant deviation, well compatible with Standard Model.

Conclusion

H4ℓ — Differential cross-sections — Hγγ

- H4ℓ **final Run-2 result**:
  - σ_{fid} = 3.28 ± 0.30 (stat) ± 0.11 (syst) fb.
  - SM: σ_{fid} = 3.41 ± 0.18 fb.
  - **Improves last result by 40%**.
  - Statistically dominated.
- κ_c @ 95% CL: [-7.5, 9.3].
- **Interpretation with pseudo-observables**.

10% precision level

- Hγγ **using all Run-2 data**:
  - σ_{fid} = 65.2 **± 4.5 (stat) ± 5.6 (syst)** ± 0.3 (theo) fb.
  - SM: σ_{fid} = 63.6 ± 3.3 fb.
  - **Best Hγγ up to now**.
  - Inclusive XS: now systematics-dominated.
- κ_c @ 95% CL: [-19, 24] (shape only).
- **Interpretation with EFT** (SILH/SMEFT).

No significant deviation, well compatible with Standard Model.

Higgs mass measurement in H4ℓ channel

- **First Higgs mass measurement using full Run-2 dataset**: mH = 124.92 ± 0.21 (0.19 stat)
  - **15% better than previous ATLAS measurement** & **same precision as CMS H4ℓ** (but with more data).
  - **Compatible with previous measurements**.

Thank you for your attention

Stay tuned: other ATLAS SM single Higgs talks @ ICHEP !!

- **Higgs → bosons**:
  - This talk:
    - **Differential cross-sections** in H4ℓ and Hγγ.
    - **Mass measurement** in H4ℓ.
  - **Production couplings and STXS**: see Liza Mijovic's in a few minutes.

- **Higgs → fermions**:
  - **H→bb / H→cc**: see Marco Battaglia's talk yesterday.
  - **H→ττ**: see Christian Grefe's talk in a few minutes.
  - **ttH**: see Jelena Jovicevic's talk after the break.

- **Higgs combination**: see Matthew Klein's talk after the break.

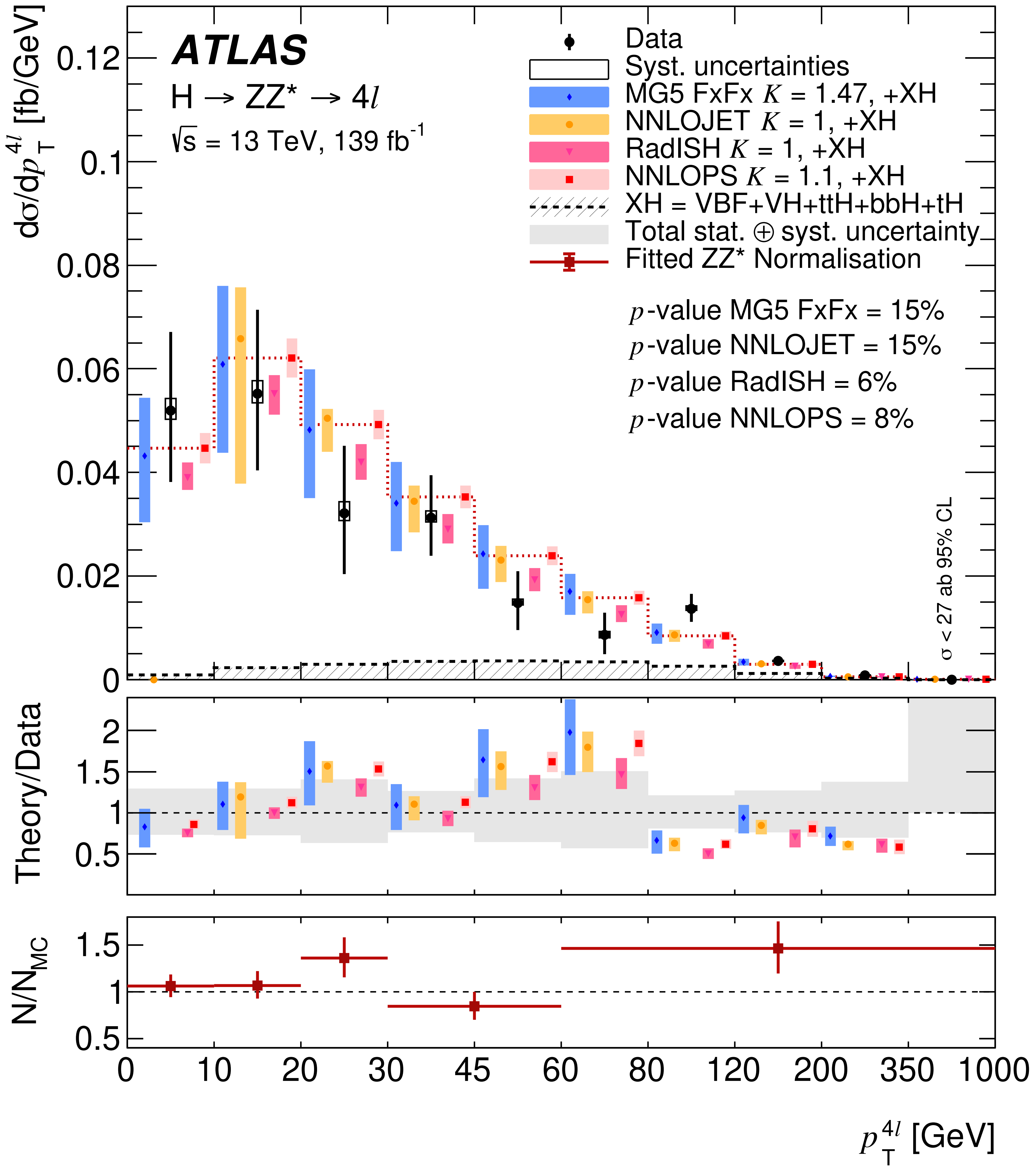
BACKUP

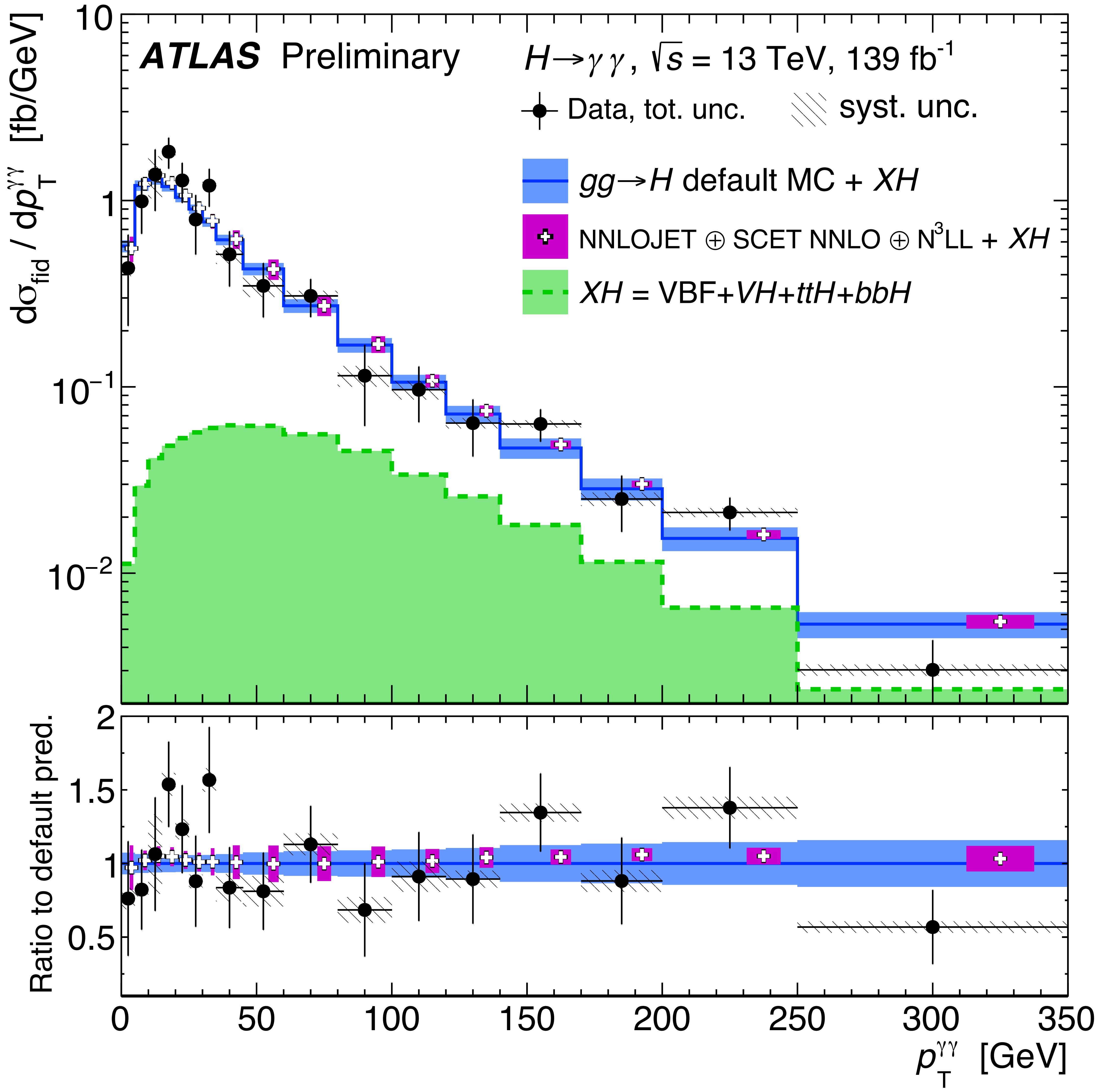
More questions?

✉️ **mail**: antoine.laudrain [at] cern.ch

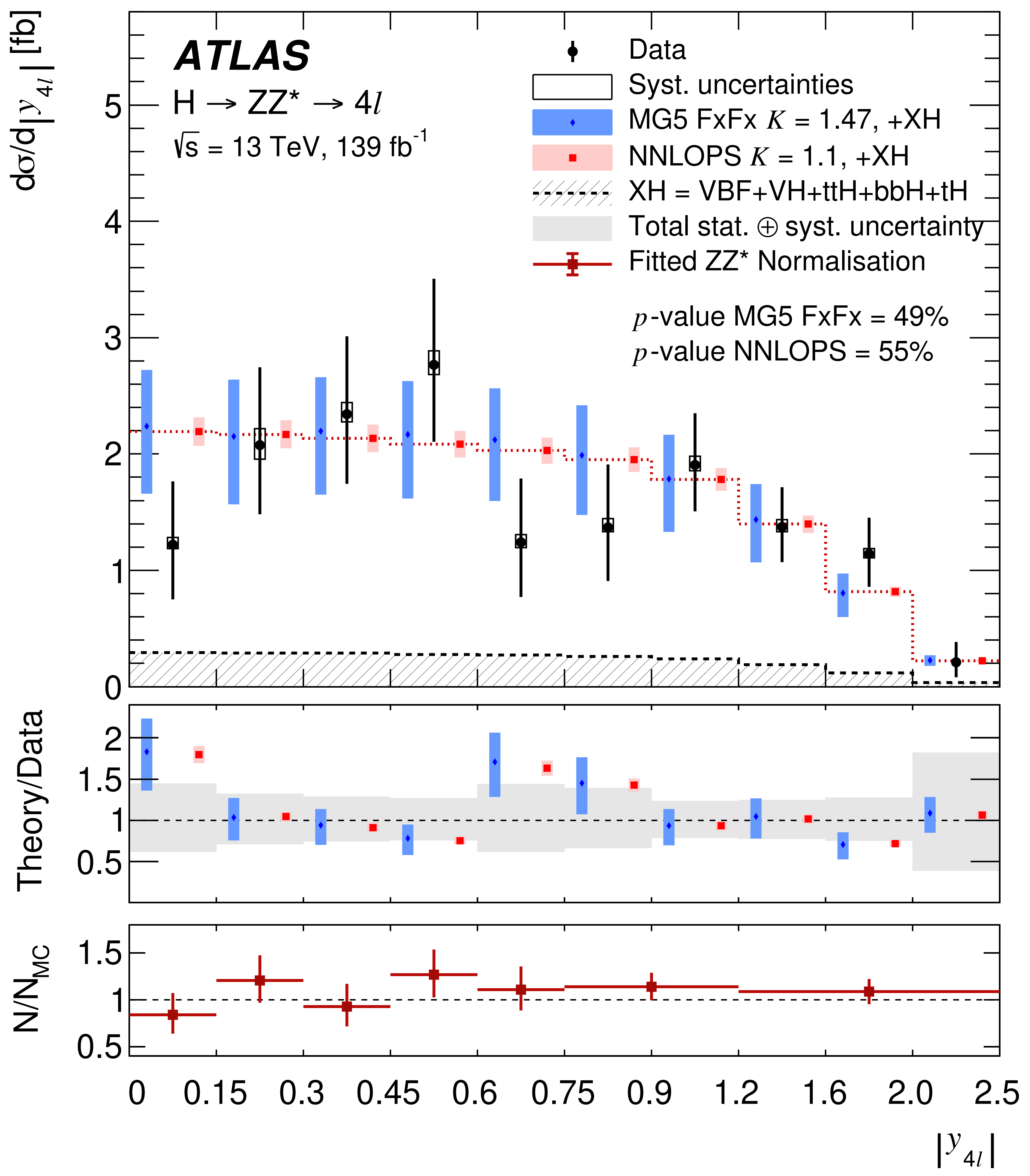
Mattermost: @anlaudra

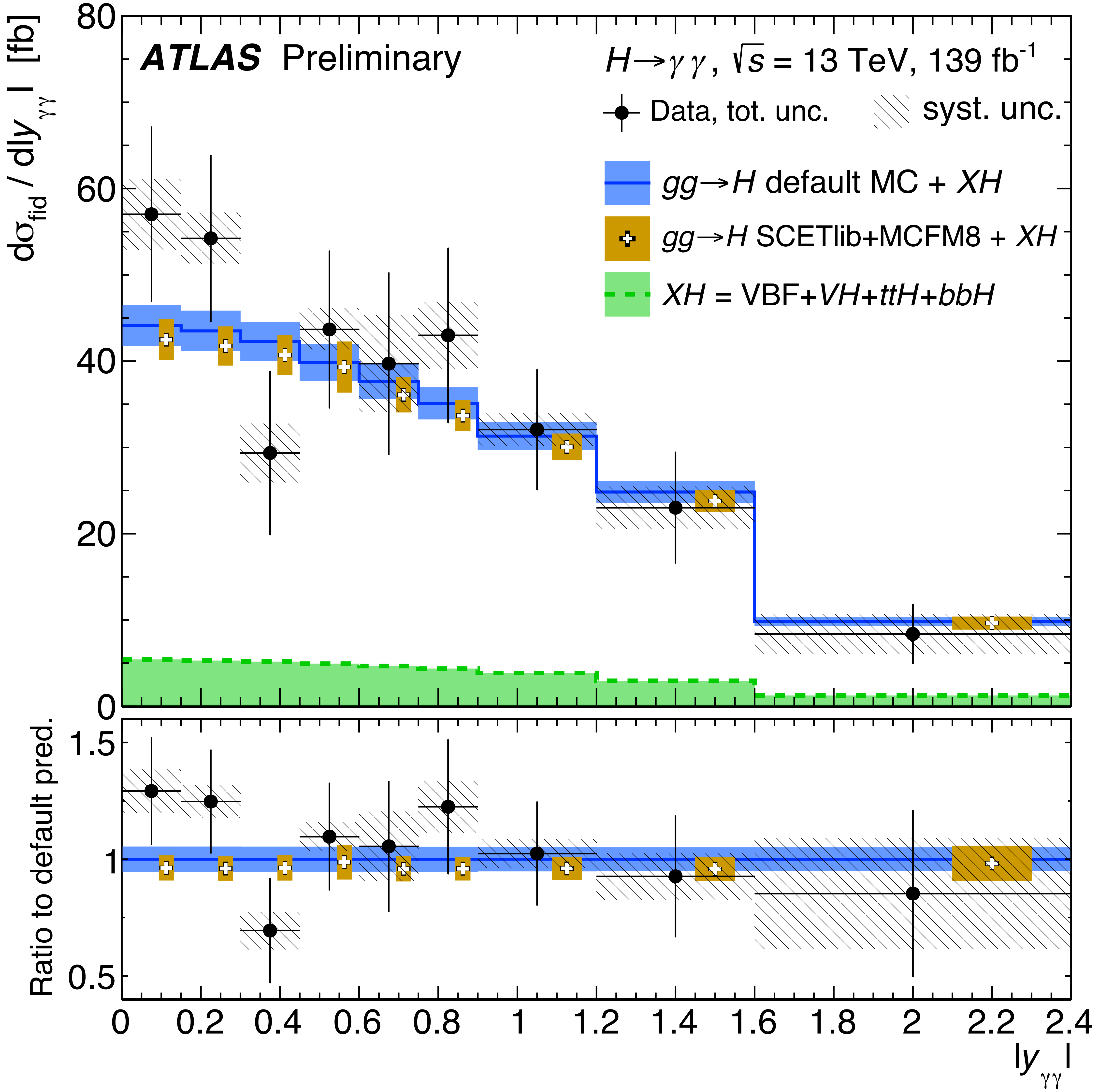
A few more differential XS results



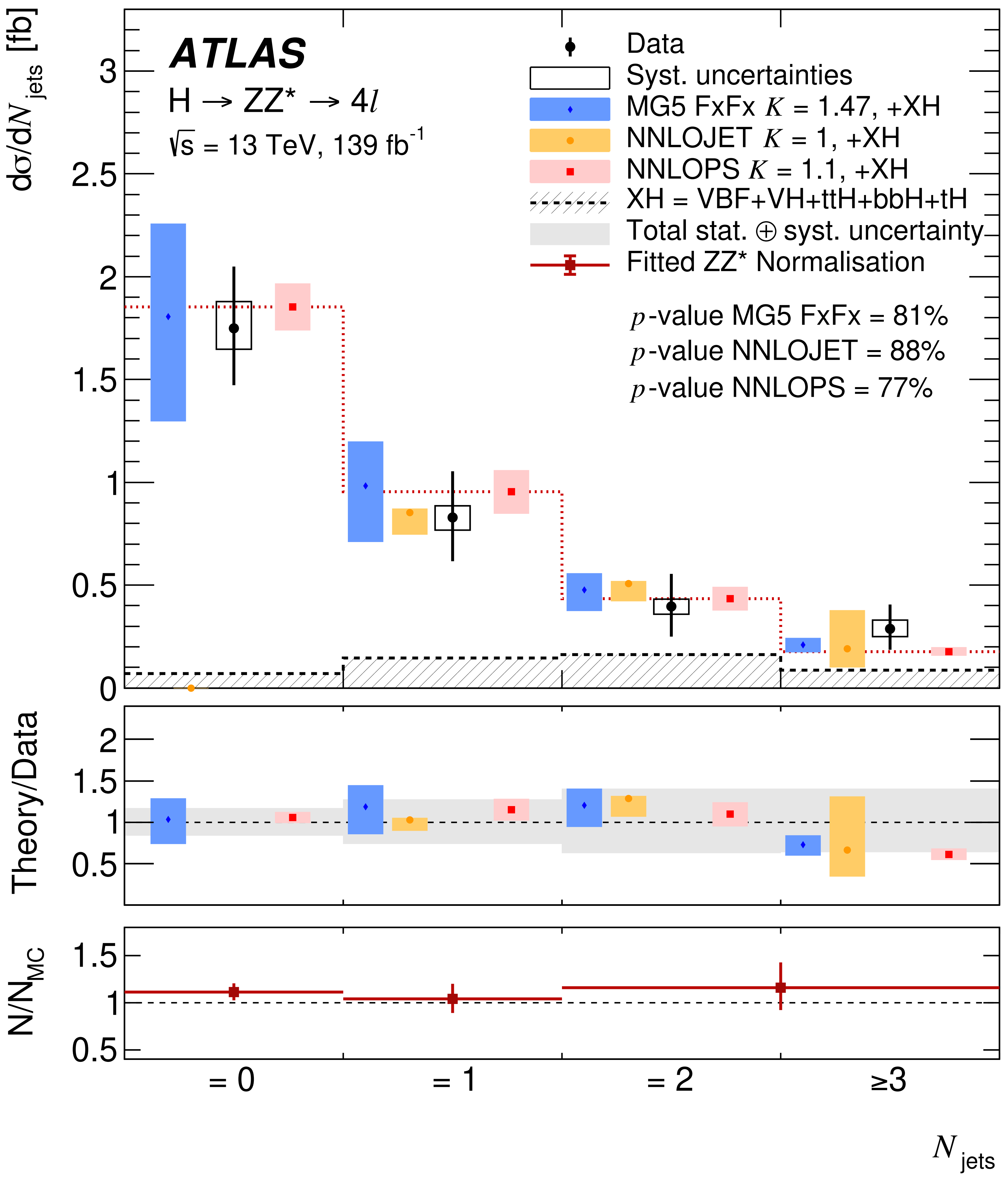


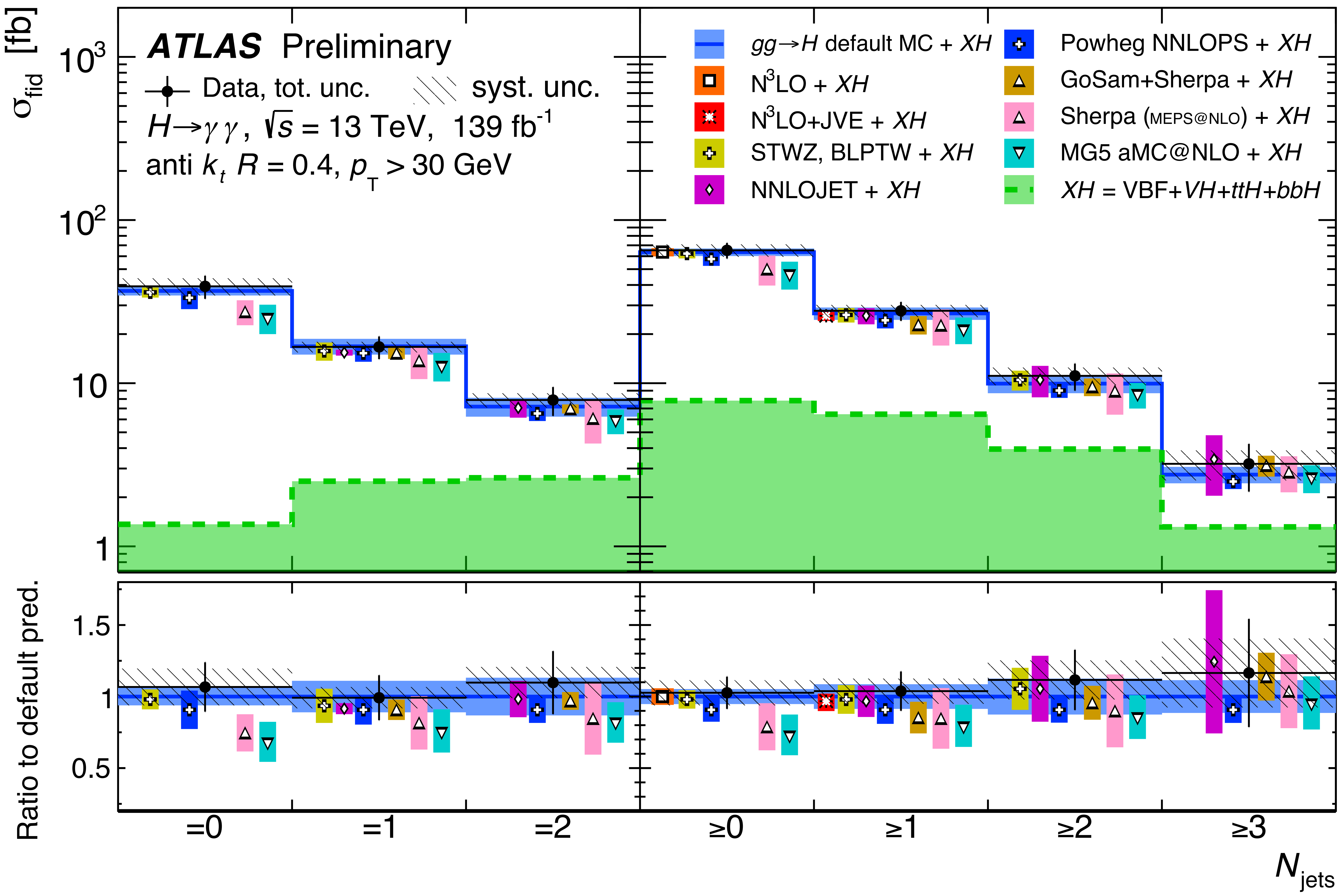
A few more differential XS results



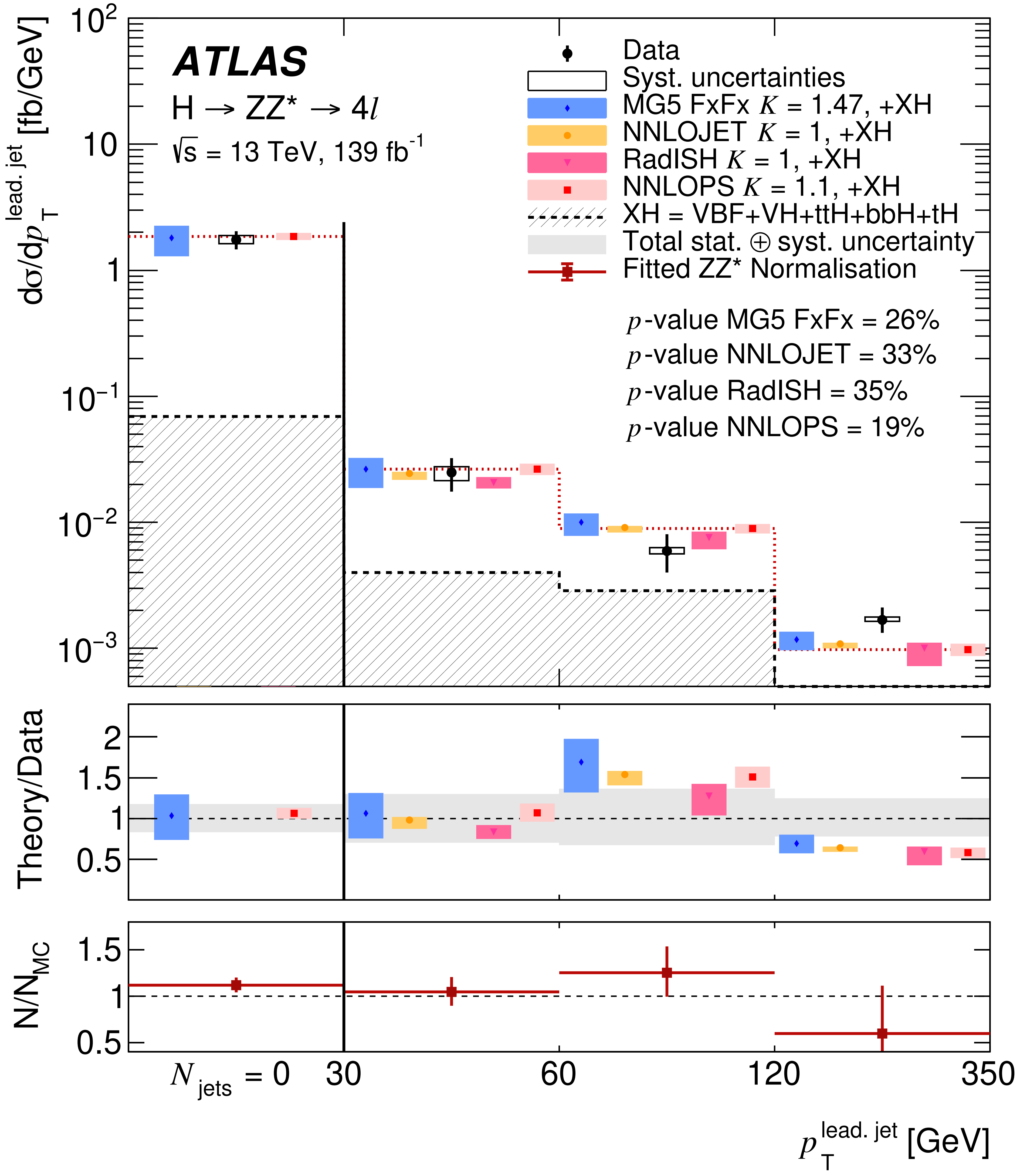


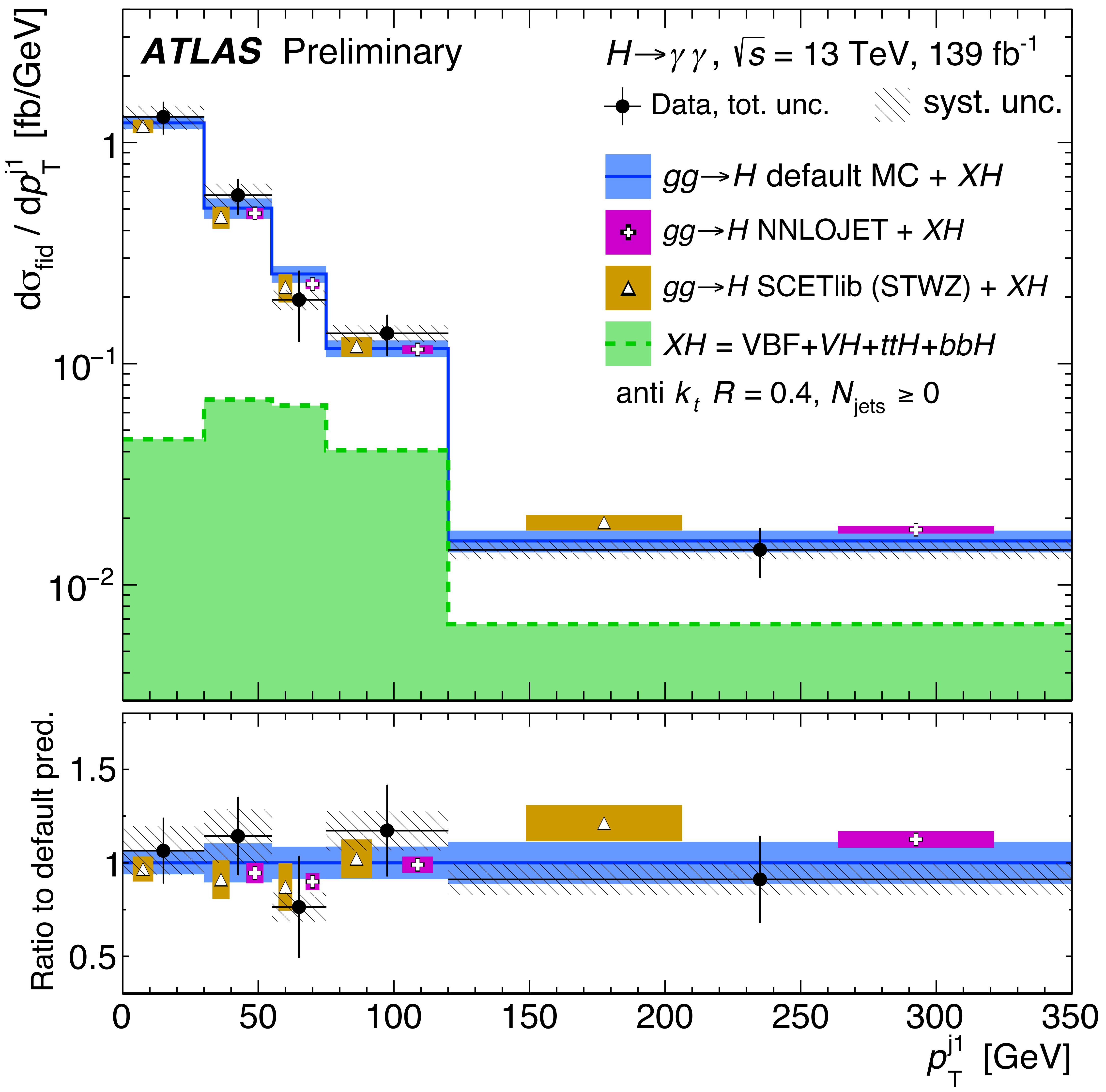
A few more differential XS results



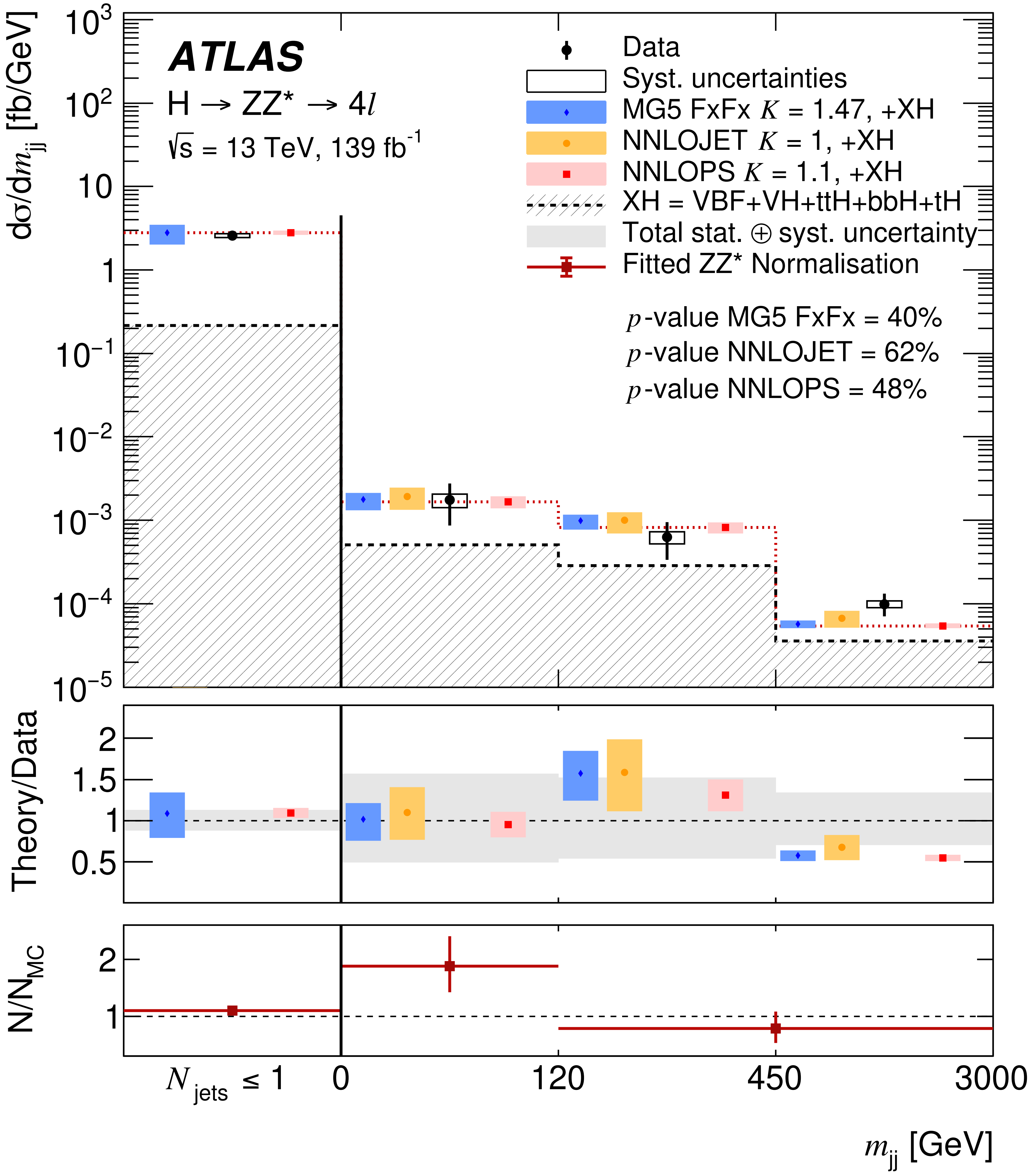


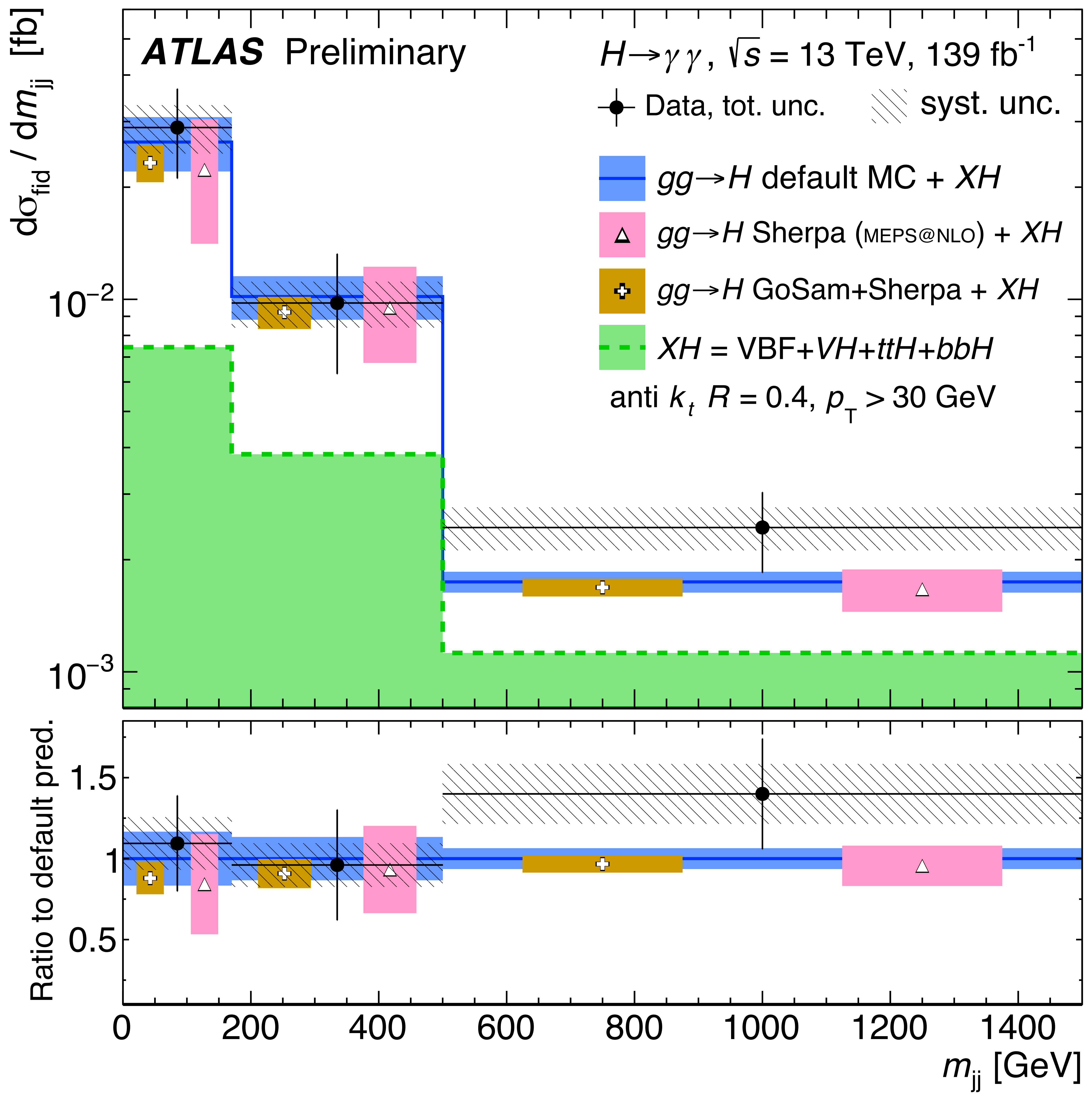
A few more differential XS results



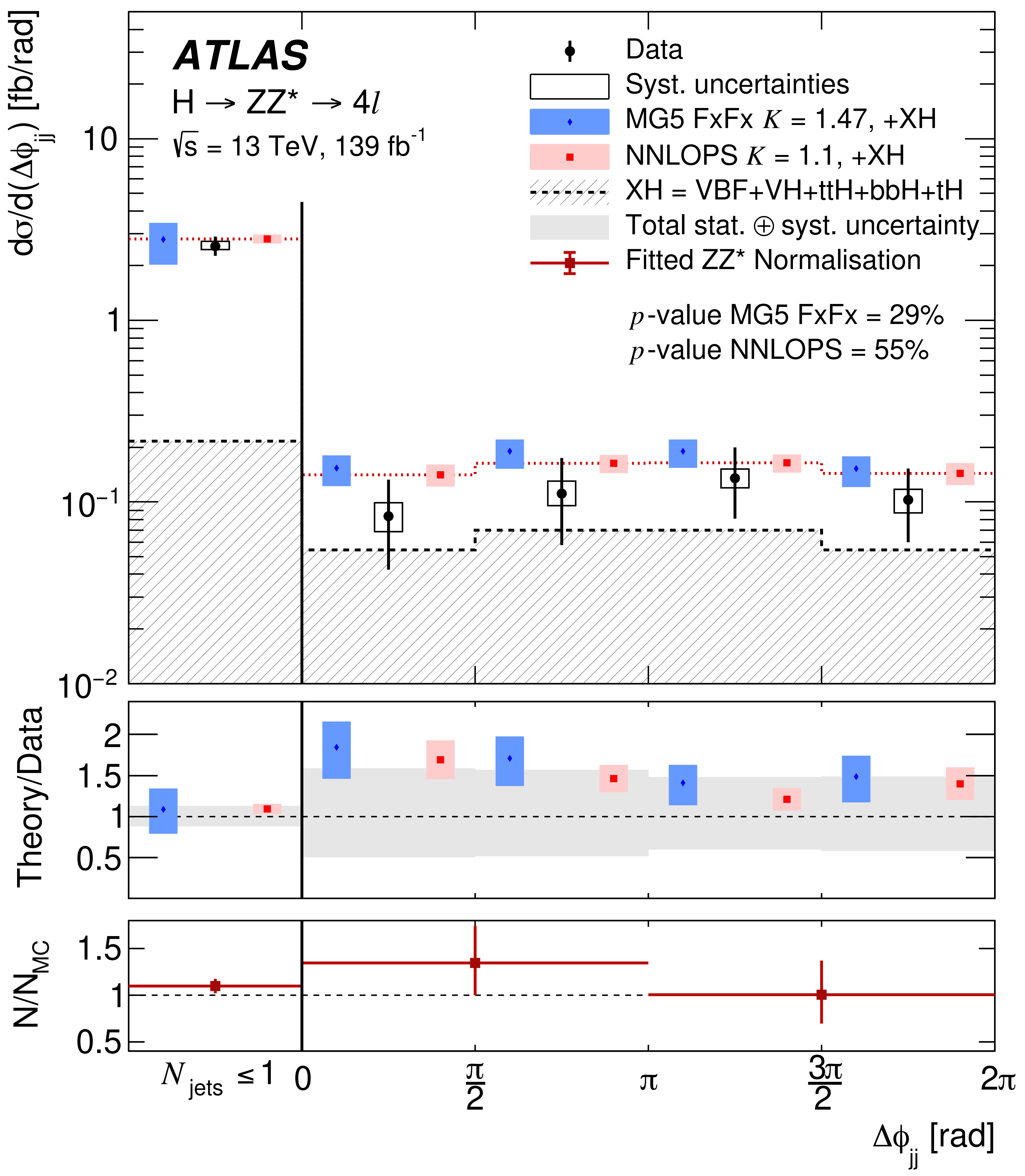


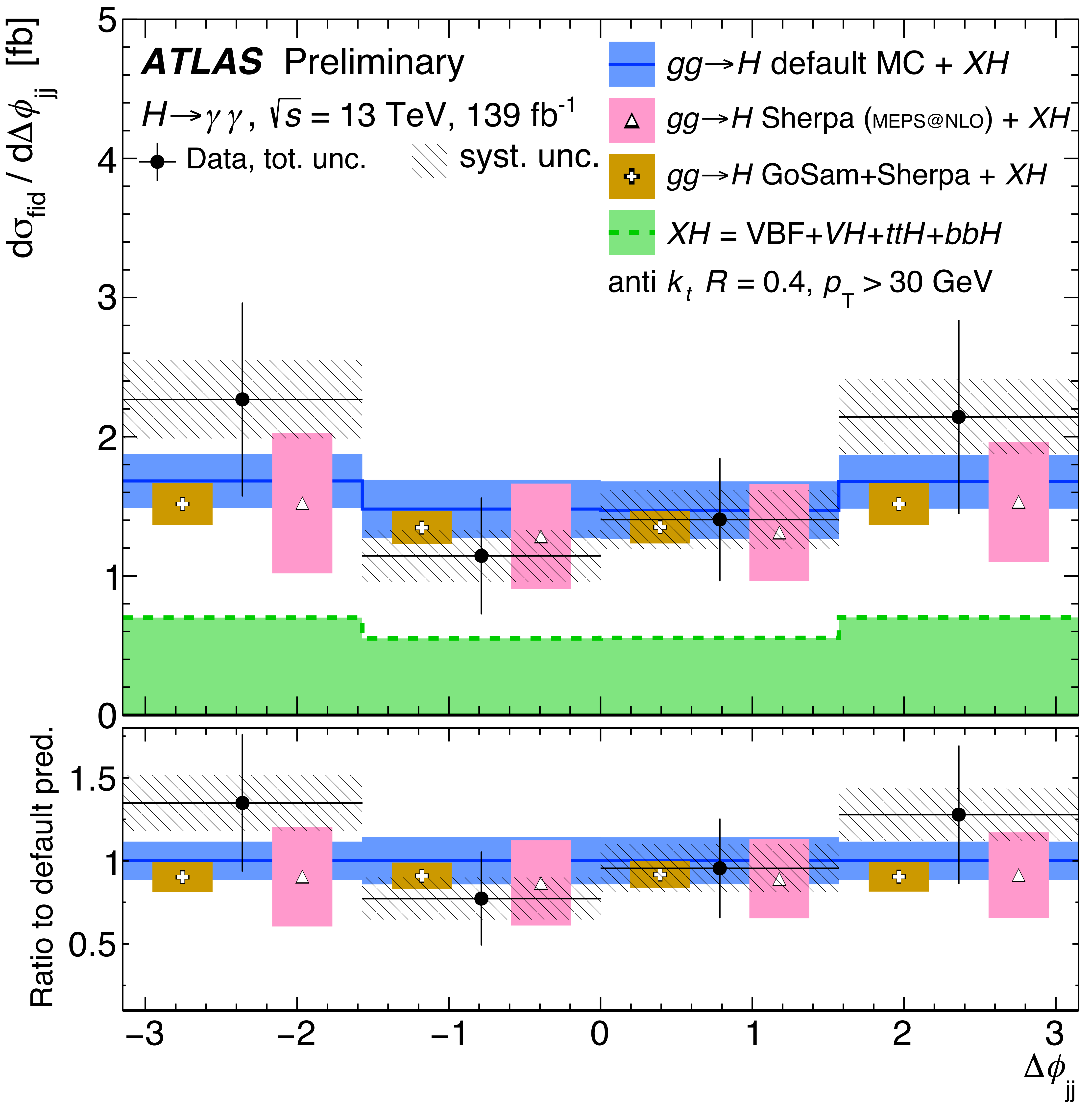
A few more differential XS results



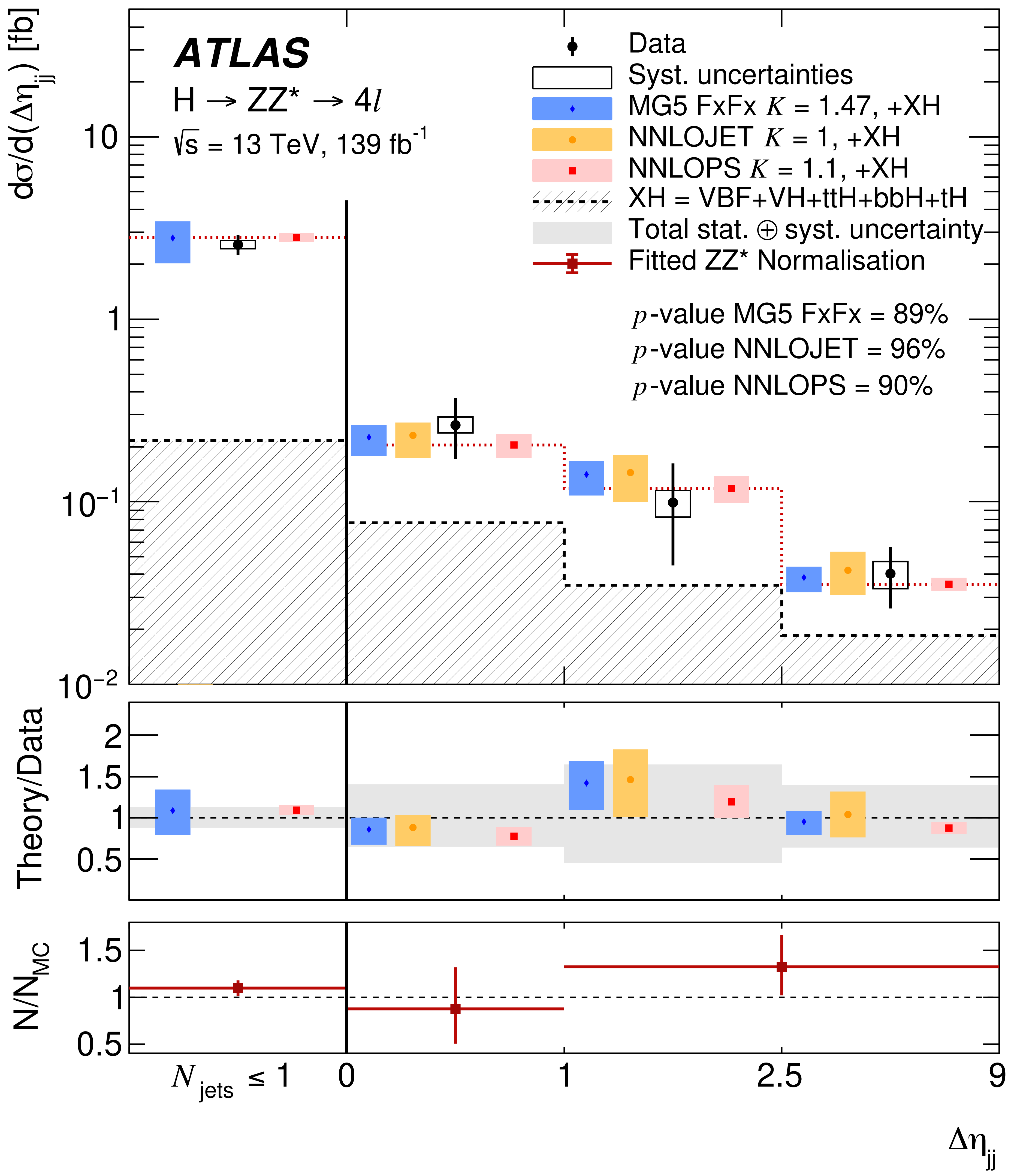


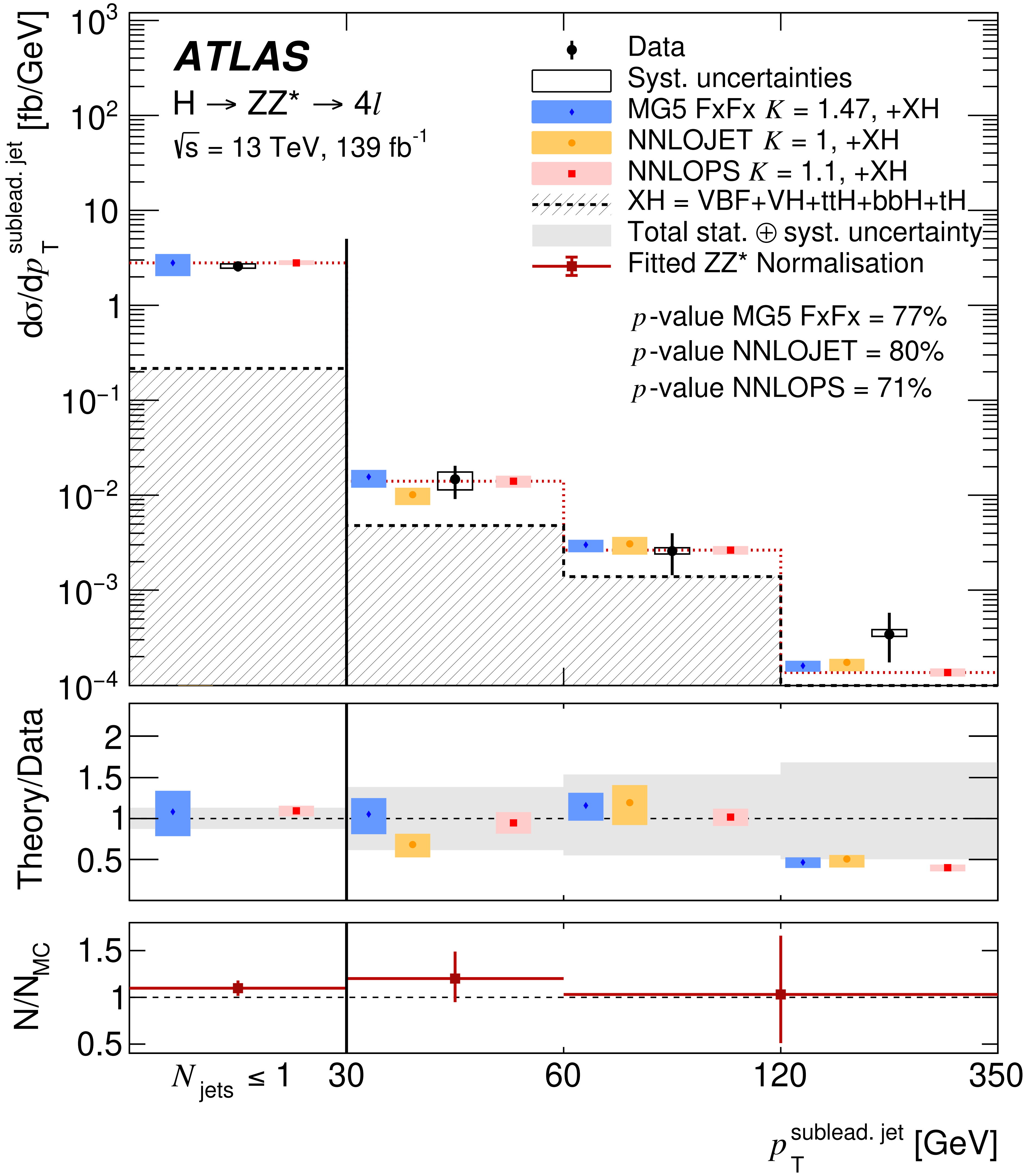
A few more differential XS results



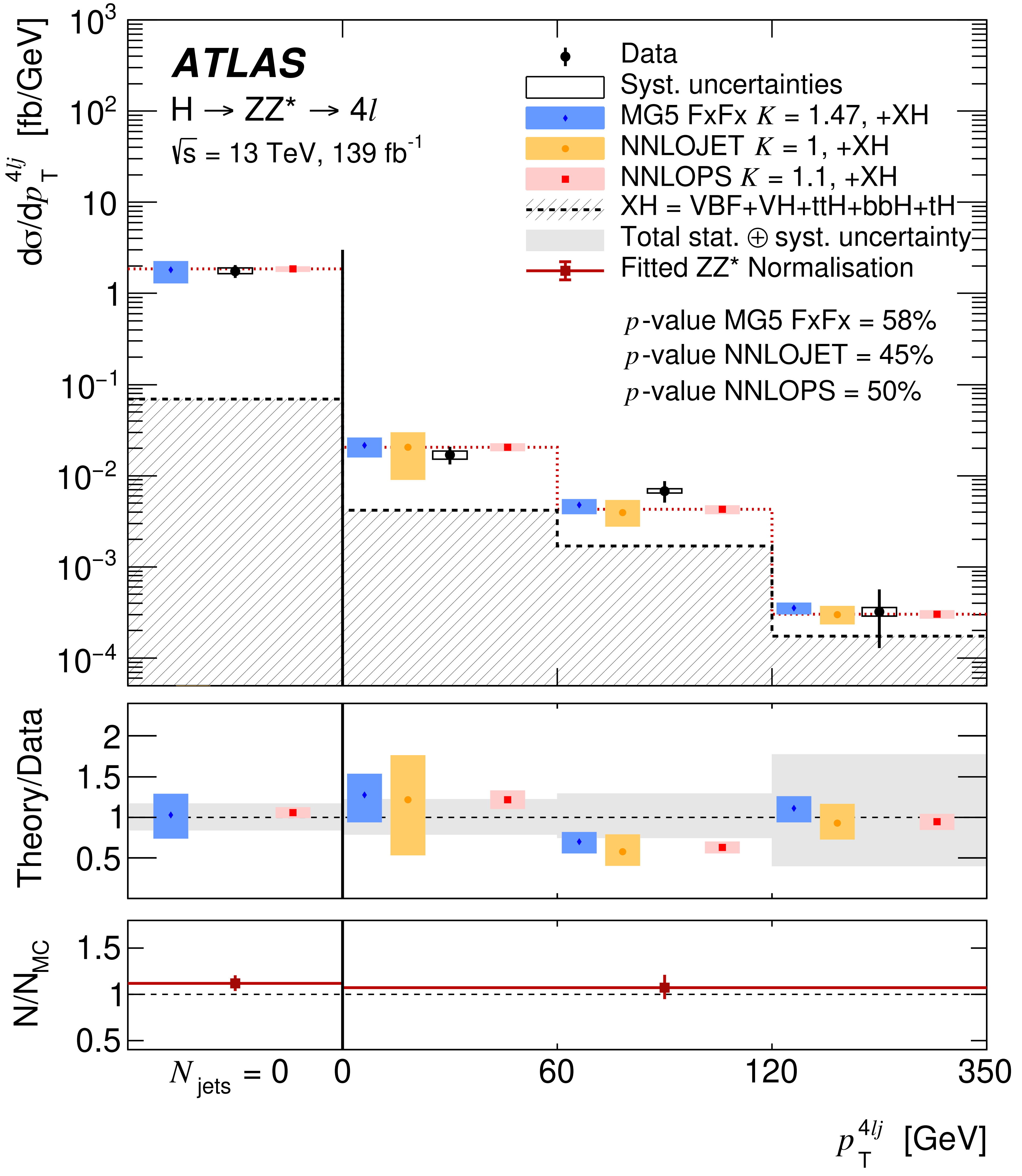


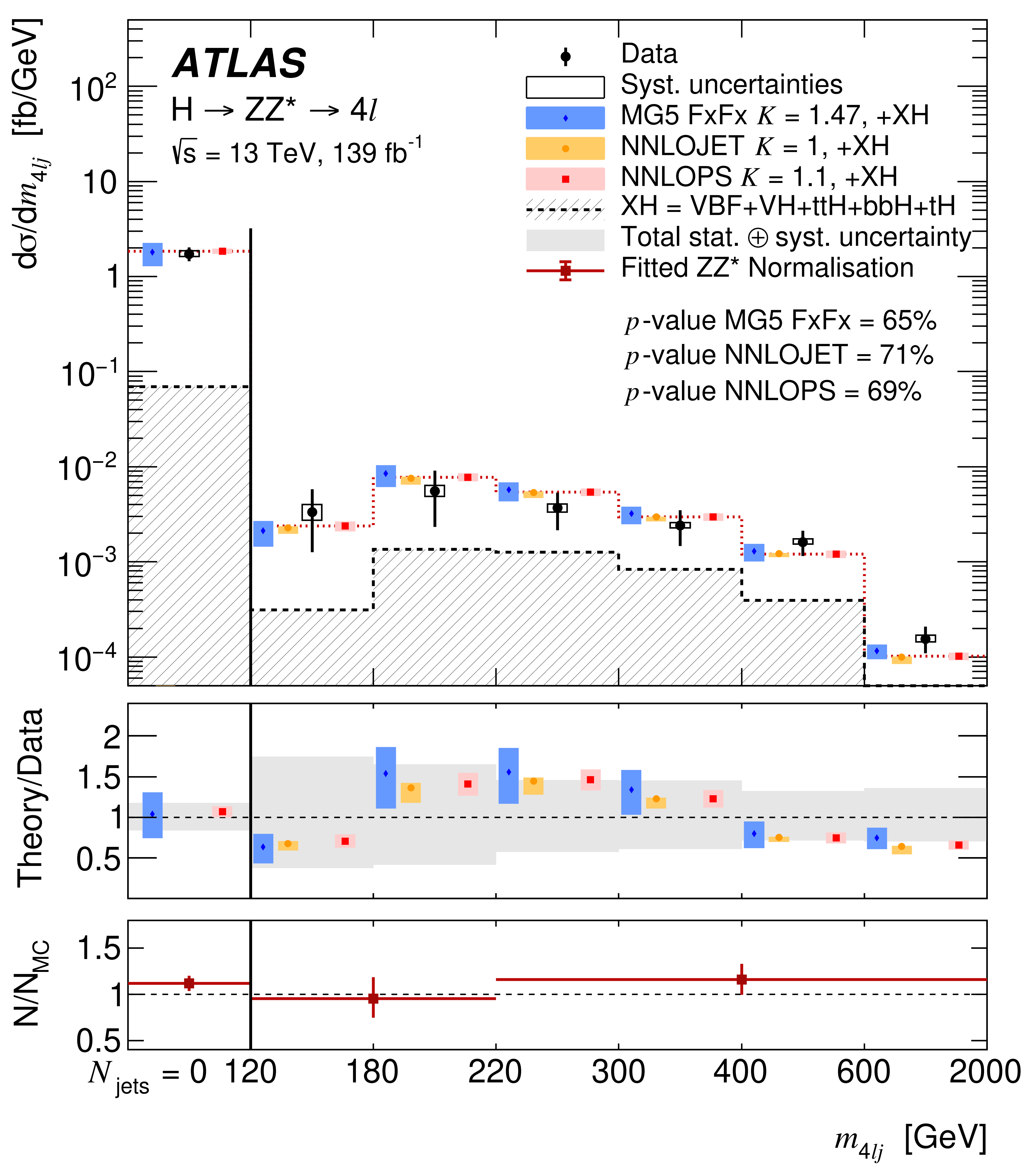
A few more differential XS results



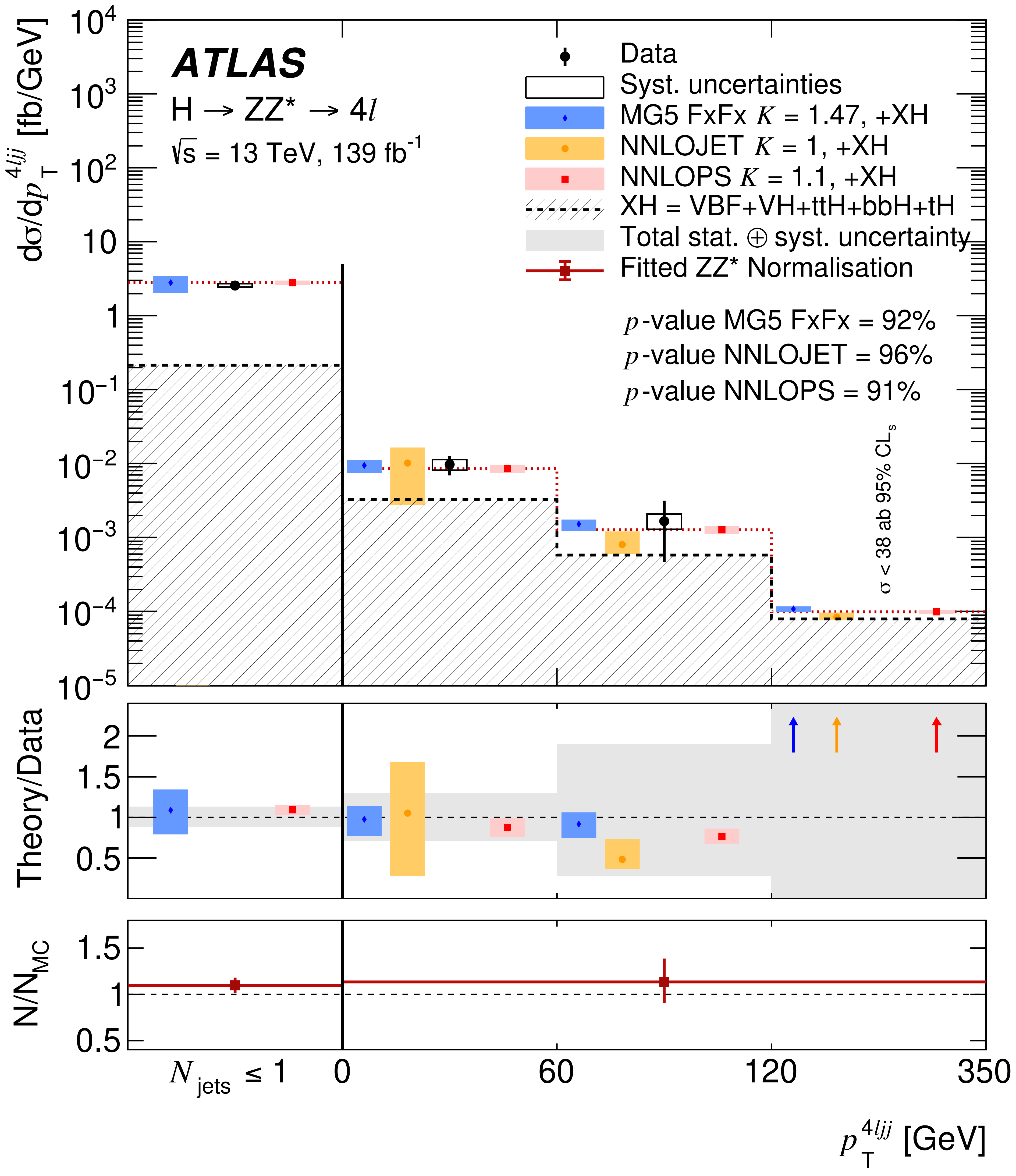


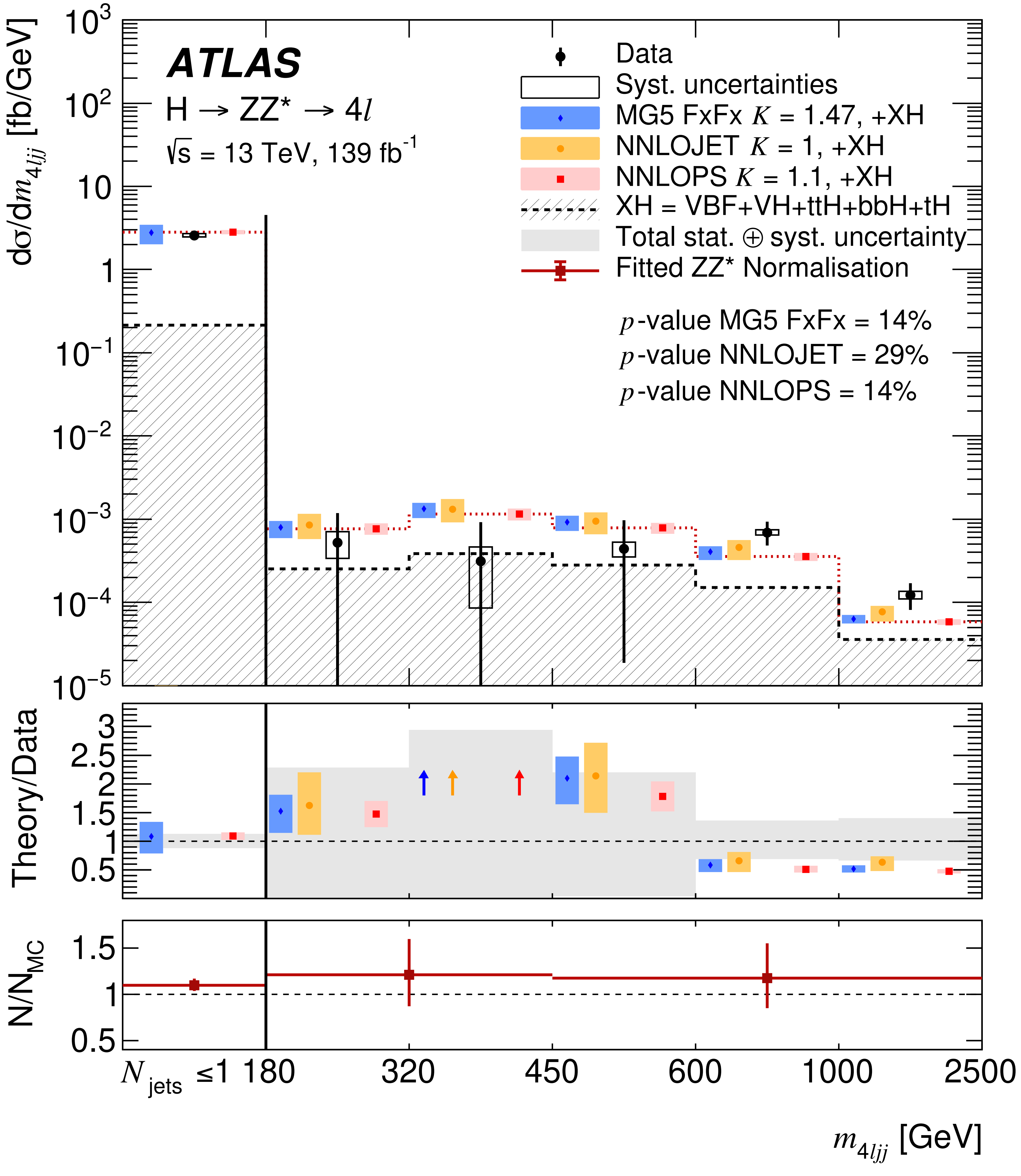
A few more differential XS results



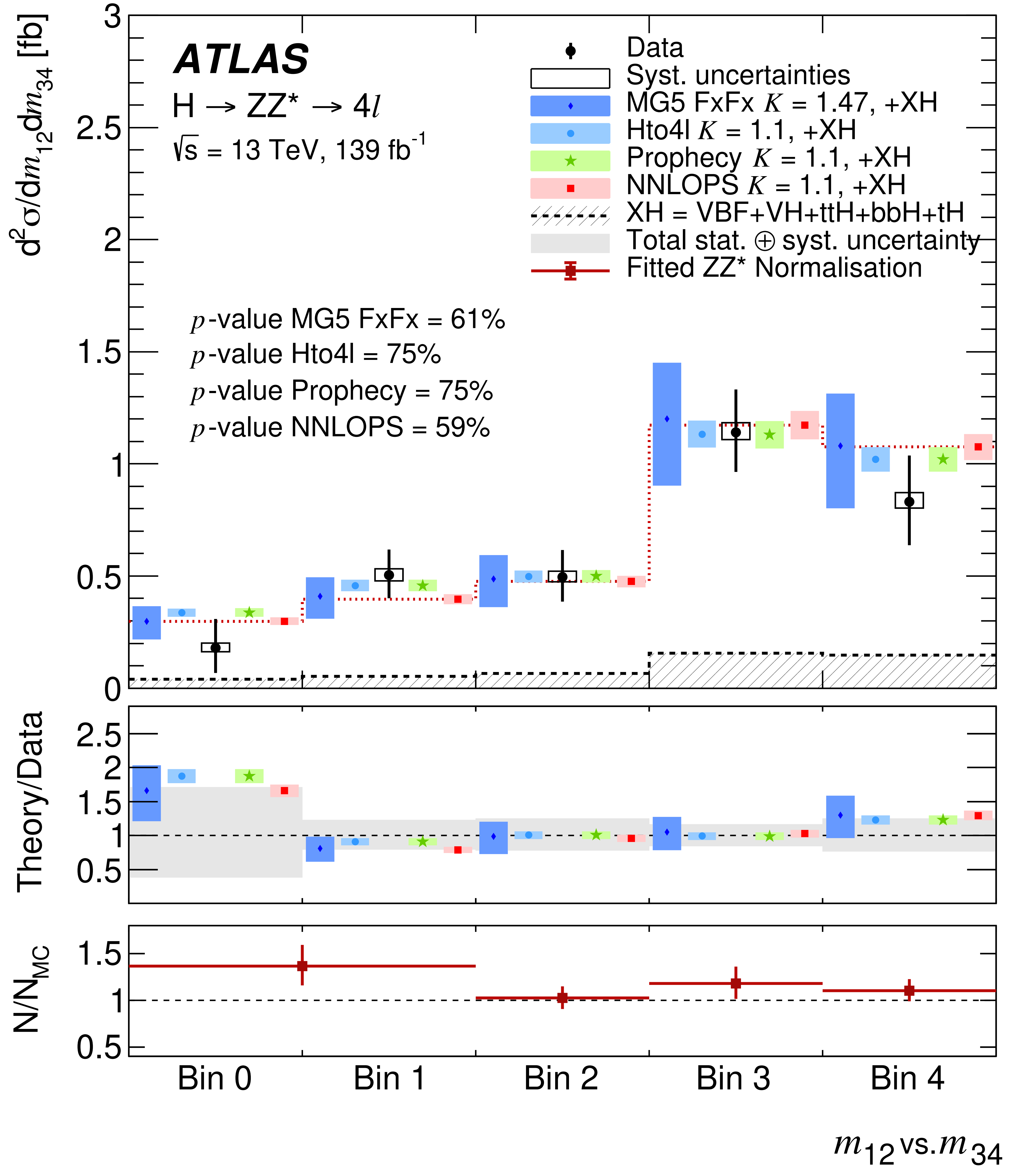


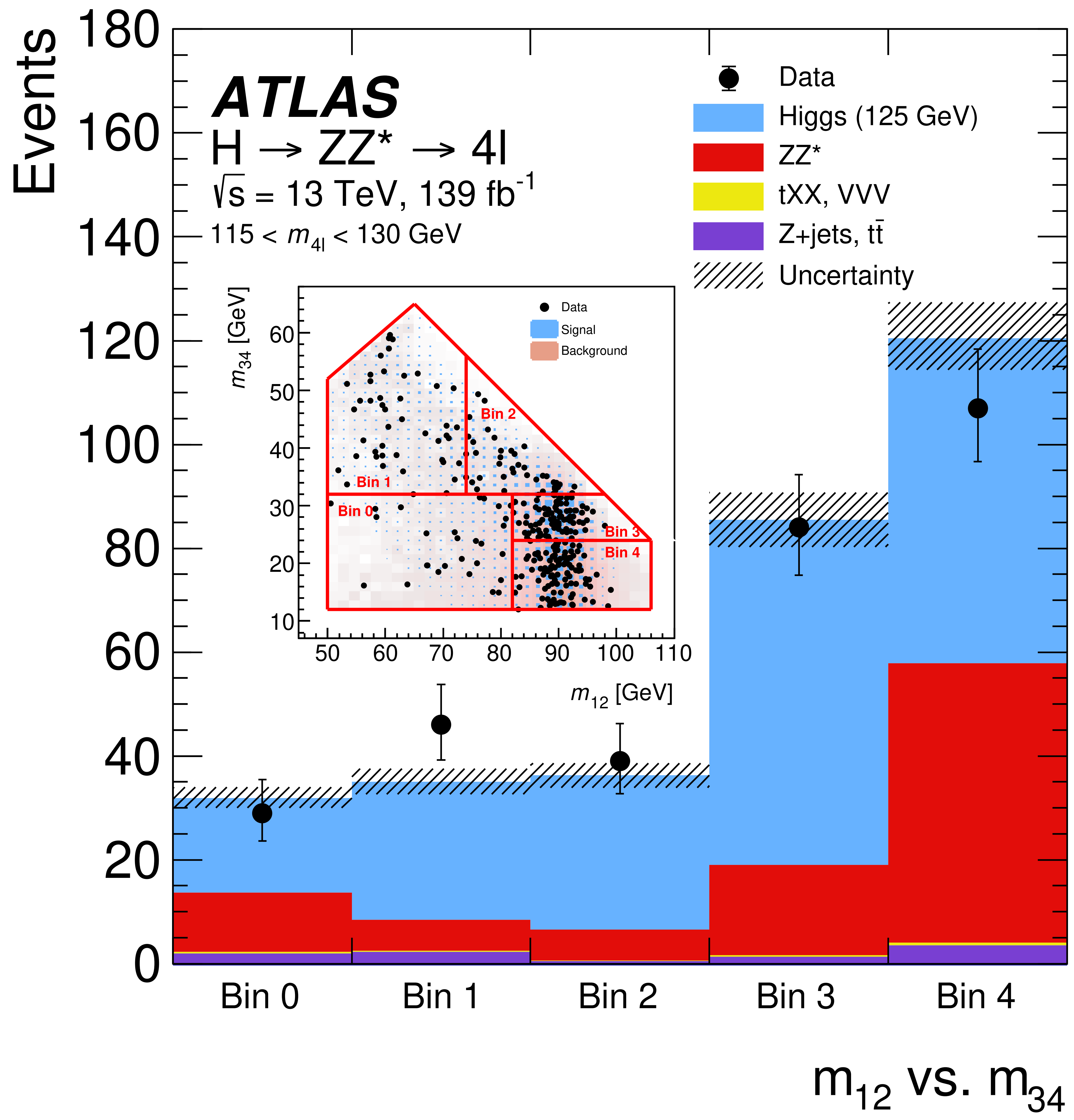
A few more differential XS results





A few more differential XS results



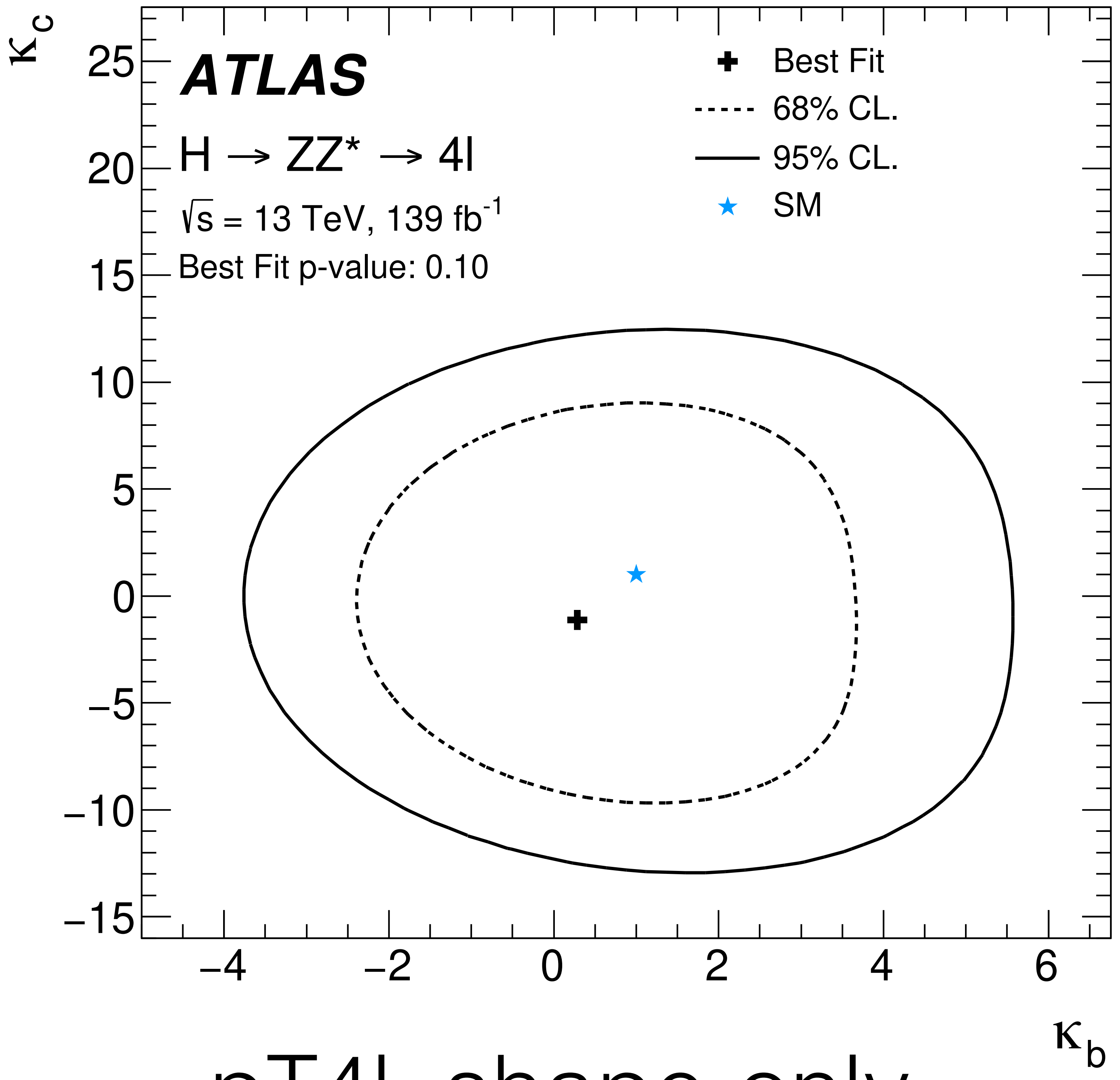


Hγγ differential XS: data/MC compatibility

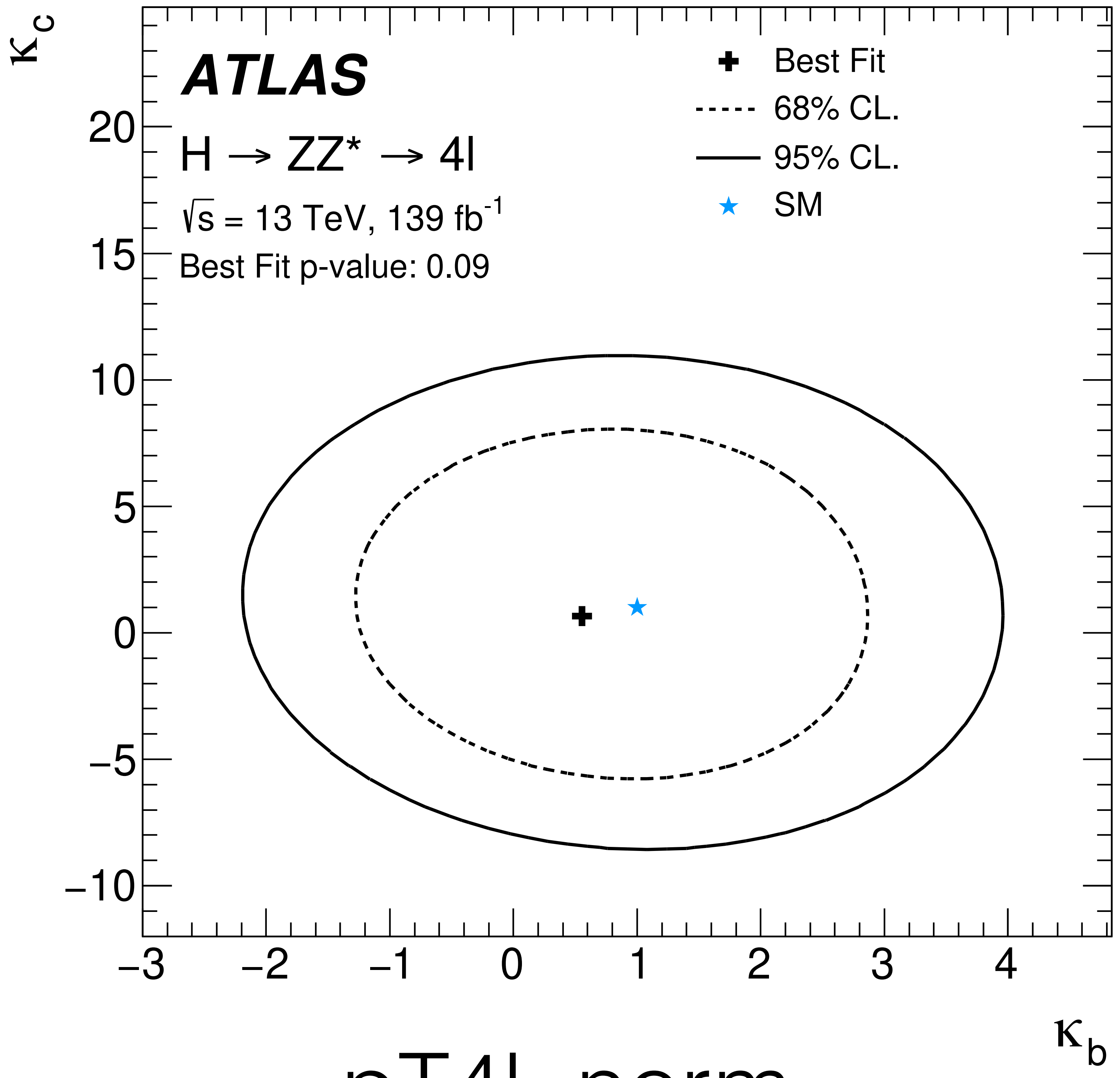
Distribution	$p(\chi^2)$ with Default MC Prediction
$p_{\mathrm{T}}^{\gamma\gamma}$	44%
$\lvert y_{\gamma\gamma}\rvert$	68%
$p_{\mathrm{T}}^{j_1}$	77%
N_{jets}	96%
$\Delta\phi_{jj}$	82%
m_{jj}	75%

κ_b and κ_c results in $H4\ell$ and $H\gamma\gamma$

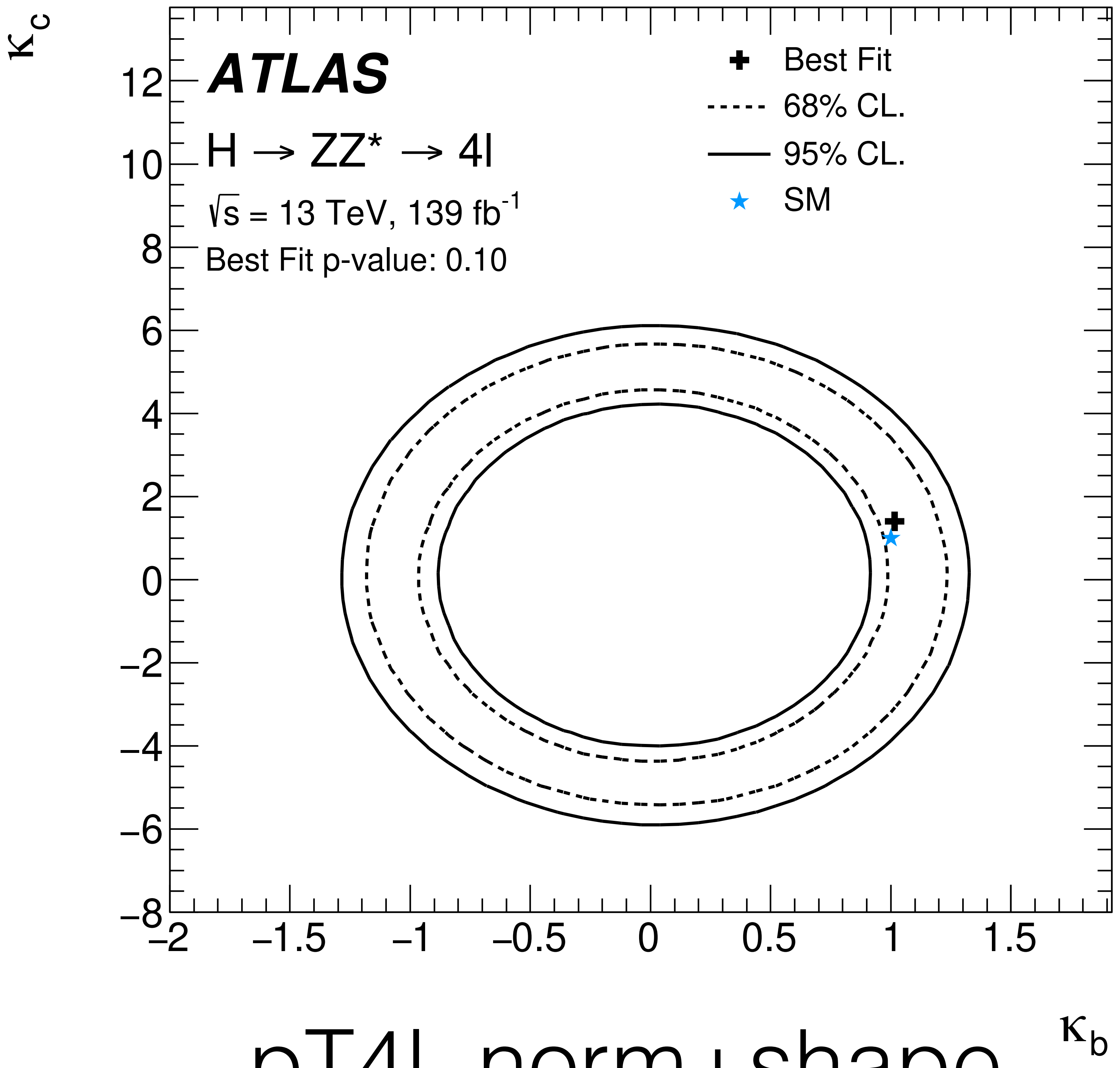
κ_b vs κ_c in H4ℓ



pT4l, shape-only



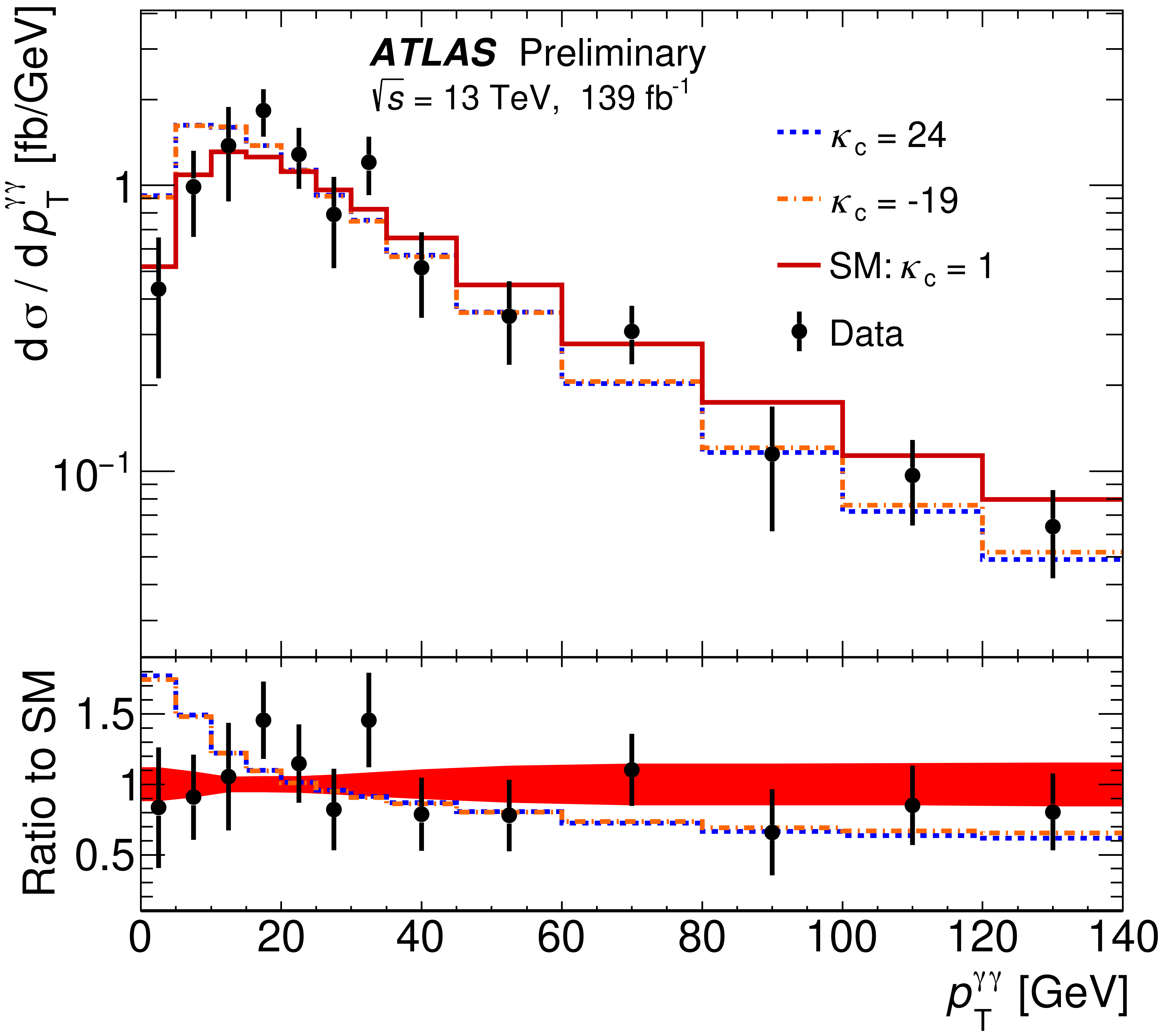
pT4l, norm

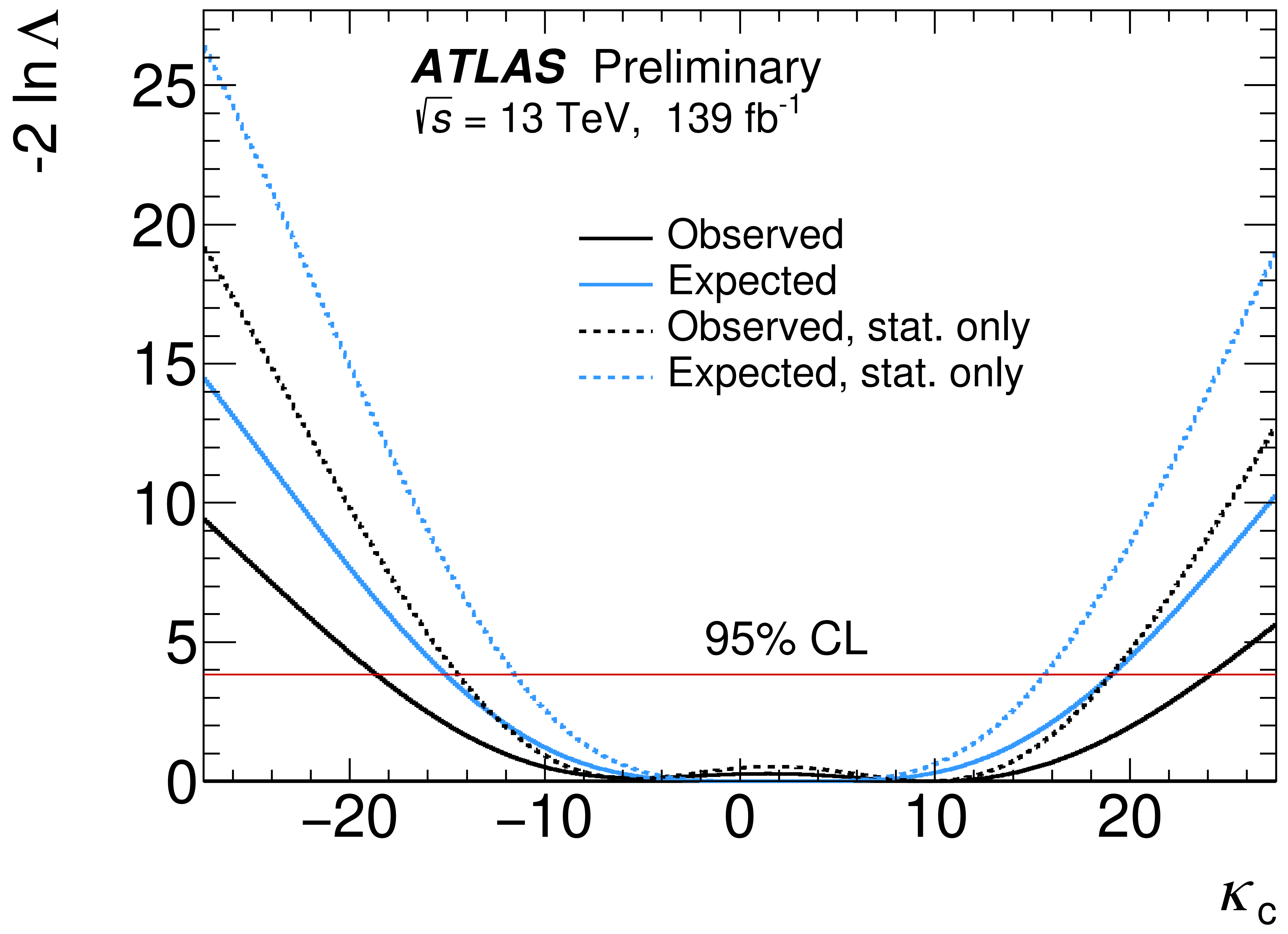


pT4l, norm+shape

Interpretation	Parameter best-fit value	95% confidence interval
Modifications to only $p_{\mathrm{T}}^{4\ell}$ shape	$\kappa_c = -1.1$	$[-11.7,\ 10.5]$
	$\kappa_b = 0.28$	$[-3.21,\ 4.50]$
Modifications to $p_{\mathrm{T}}^{4\ell}$ predictions	$\kappa_c = 0.66$	$[-7.46,\ 9.27]$
	$\kappa_b = 0.55$	$[-1.82,\ 3.34]$

κ_b vs κ_c in Hγγ





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

H4ℓ differential cross-sections and interpretations

H4ℓ phase space definition: analysis

Leptons and jets	
Muons	$p_T > 5$ GeV, $\|\eta\| < 2.7$
Electrons	$E_T > 7$ GeV, $\|\eta\| < 2.47$
Jets	$p_T > 30$ GeV, $\|\eta\| < 4.5$
Lepton selection and pairing	
Lepton kinematics	$p_T > 20, 15, 10$ GeV
Leading pair (m_{12})	SFOC lepton pair with smallest $\|m_Z - m_{\ell\ell}\|$
Subleading pair (m_{34})	Remaining SFOC lepton pair with smallest $\|m_Z - m_{\ell\ell}\|$
Event selection (at most one Higgs boson candidate per channel)	
Mass requirements	50 GeV$< m_{12} <$ 106 GeV and $m_{\text{threshold}} < m_{34} <$ 115 GeV
Lepton separation:	$\Delta R(\ell_i, \ell_j) > 0.1$
Lepton/Jet separation	$\Delta R(\mu_i(e_i), \text{jet}) > 0.1(0.2)$
J/ψ veto	$m(\ell_i, \ell_j) > 5$ GeV for all SFOC lepton pairs
Impact parameter	$\|d_0\|/\sigma(d_0)$ ¡ 5 (3) for electrons (muons)
Mass window	105 $GeV < m_{4\ell} <$ 160 GeV
Vertex selection:	χ^2/N_{dof} ¡ 6 (9) for 4μ (other channels)
If extra lepton with $p_T > 12$ GeV	Quadruplet with largest matrix element (ME) value

H4ℓ phase space definition: fiducial

Leptons and jets	
Leptons	$p_{\mathrm{T}} > 5$ GeV, $\lvert\eta\rvert < 2.7$
Jets	$p_{\mathrm{T}} > 30$ GeV, $\lvert y\rvert < 4.4$
Lepton selection and pairing	
Lepton kinematics	$p_{\mathrm{T}} > 20, 15, 10$ GeV
Leading pair (m_{12})	SFOC lepton pair with smallest $\lvert m_Z - m_{\ell\ell}\rvert$
Subleading pair (m_{34})	remaining SFOC lepton pair with smallest $\lvert m_Z - m_{\ell\ell}\rvert$
Event selection (at most one quadruplet per event)	
Mass requirements	50 GeV$< m_{12} <$ 106 GeV and 12 GeV $< m_{34} <$ 115 GeV
Lepton separation	$\Delta R(\ell_i, \ell_j) > 0.1$
Lepton/Jet separation	$\Delta R(\ell_i, \mathrm{jet}) > 0.1$
J/ψ veto	$m(\ell_i, \ell_j) > 5$ GeV for all SFOC lepton pairs
Mass window	105 GeV $< m_{4\ell} <$ 160 GeV
If extra lepton with $p_{\mathrm{T}} > 12$ GeV	Quadruplet with largest matrix element value

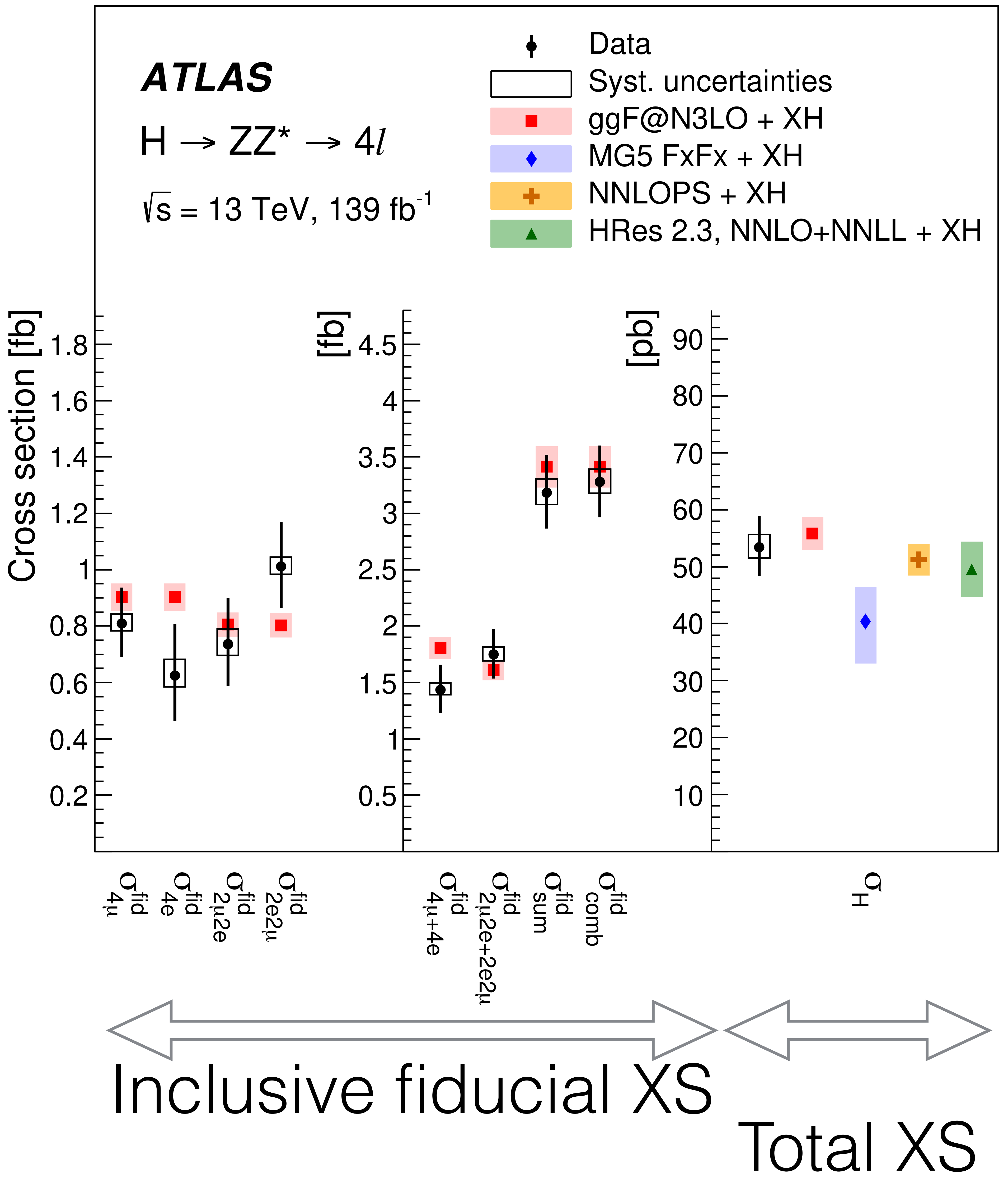
H4ℓ systematics

Observable	Stat. unc. [%]	Syst. unc. [%]	Dominant systematic components [%] Lumi.	e/μ	Jets	Other Bkg.	ZZ^* Th.	Sig. Th.	Comp.
$d\sigma$ / $dp_T^{4\ell}$	20–46	2–8	1.7	1–3	1–2	< 0.5	1–6	1–2	< 1
$d\sigma$ / dm_{12}	12–42	3–6	1.7	2–3	< 1	< 0.5	1–2	1–2	< 1
$d\sigma$ / dm_{34}	20–82	3–12	1.7	2–3	< 1	1–2	1–8	1–3	< 1
$d\sigma$ / $d\|y_{4\ell}\|$	22–81	3–6	1.7	2–3	< 1	< 0.5	1–5	1–3	< 1
$d\sigma$ / $d\|\cos\theta^*\|$	23–113	3–6	1.7	2–3	< 1	1–2	1–7	1–3	< 0.5
$d\sigma$ / $d\cos\theta_1$	23–44	3–6	1.7	2–3	< 1	< 0.5	1–3	1–2	< 1
$d\sigma$ / $d\cos\theta_2$	22–39	3–6	1.7	2–3	< 1	< 0.5	1–3	1–3	< 1
$d\sigma$ / $d\phi$	20–29	2–5	1.7	2–3	< 1	< 0.5	1–3	1–2	< 0.5
$d\sigma$ / $d\phi_1$	22–33	3–6	1.7	2–3	< 1	< 0.5	1–2	1–3	< 0.5
$d\sigma$ / dN_{jets}	15–37	6–14	1.7	1–3	4–10	< 0.5	1–4	3–7	1–4
$d\sigma$ / $dN_{b-\text{jets}}$	15–67	6–15	1.7	1–3	4–5	1–3	1–2	3–9	1–4
$d\sigma$ / $dp_T^{\text{lead. jet}}$	15–34	3–13	1.7	1–3	4–10	< 0.5	1–2	1–5	< 0.5
$d\sigma$ / $dp_T^{\text{sublead. jet}}$	11–67	5–22	1.7	1–3	2–12	< 1	1–3	2–15	1–5
$d\sigma$ / dm_{jj}	11–50	5–18	1.7	1–3	1–11	< 0.5	1–3	2–15	1–2
$d\sigma$ / $d\eta_{jj}$	11–57	5–17	1.7	1–3	2–10	< 0.5	1–2	2–14	1–4
$d\sigma$ / $d\phi_{jj}$	11–50	4–18	1.7	1–3	2–9	< 0.5	1–3	2–14	1–6
$d\sigma$ / $dm_{4\ell\text{j}}$	15–66	4–19	1.7	1–3	3–9	< 0.5	1–6	3–14	1–8
$d\sigma$ / $dm_{4\ell\text{jj}}$	11–182	5–67	1.7	1–3	4–24	< 0.5	1–5	2–35	1–9
$d\sigma$ / $dp_T^{4\ell\text{j}}$	15–76	6–13	1.7	1–3	2–8	< 1	1–5	3–9	1–3
$d\sigma$ / $dp_T^{4\ell\text{jj}}$	11–76	5–27	1.7	2–3	2–9	1–2	1–4	3–17	1–12

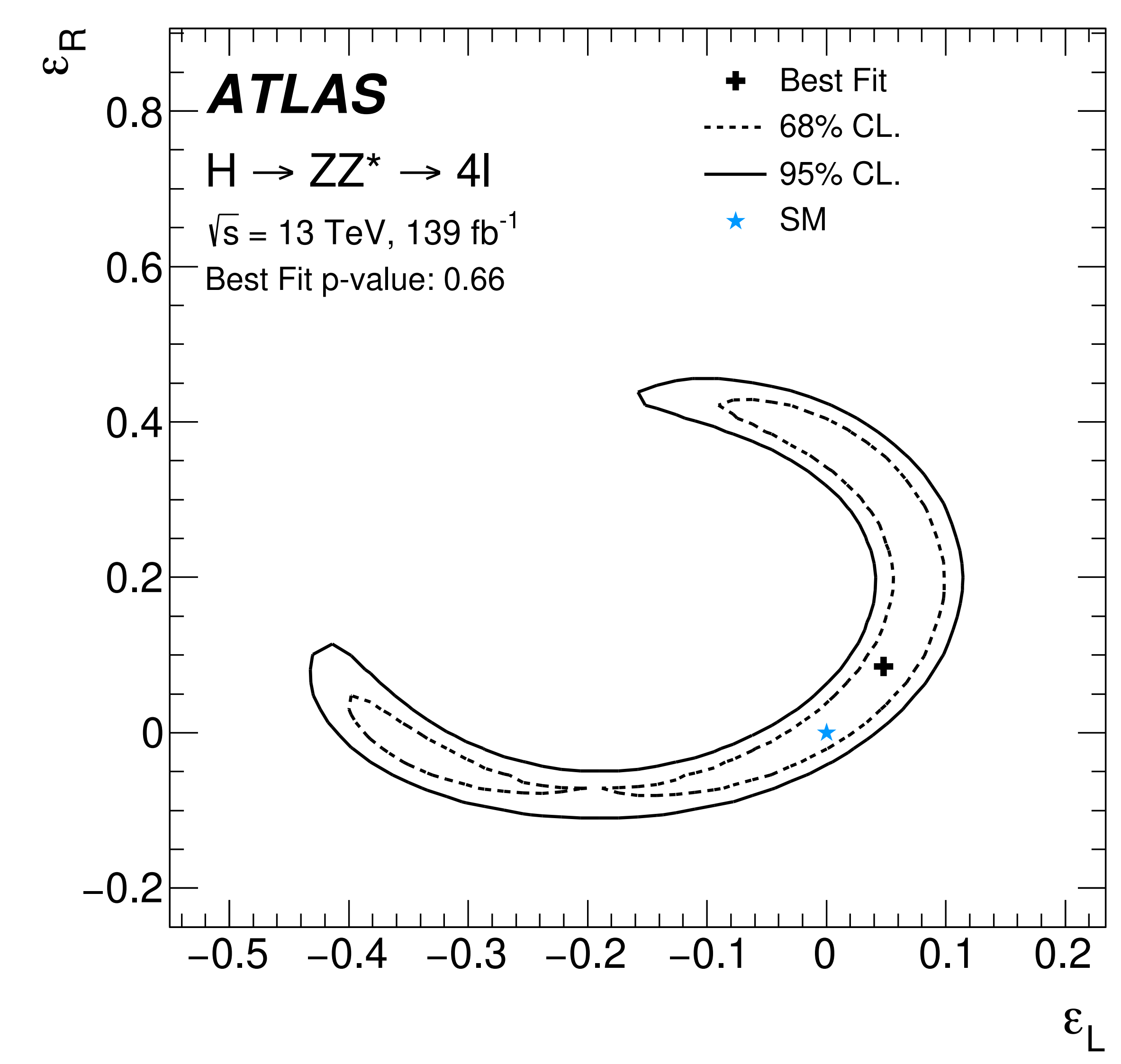
H4ℓ systematics

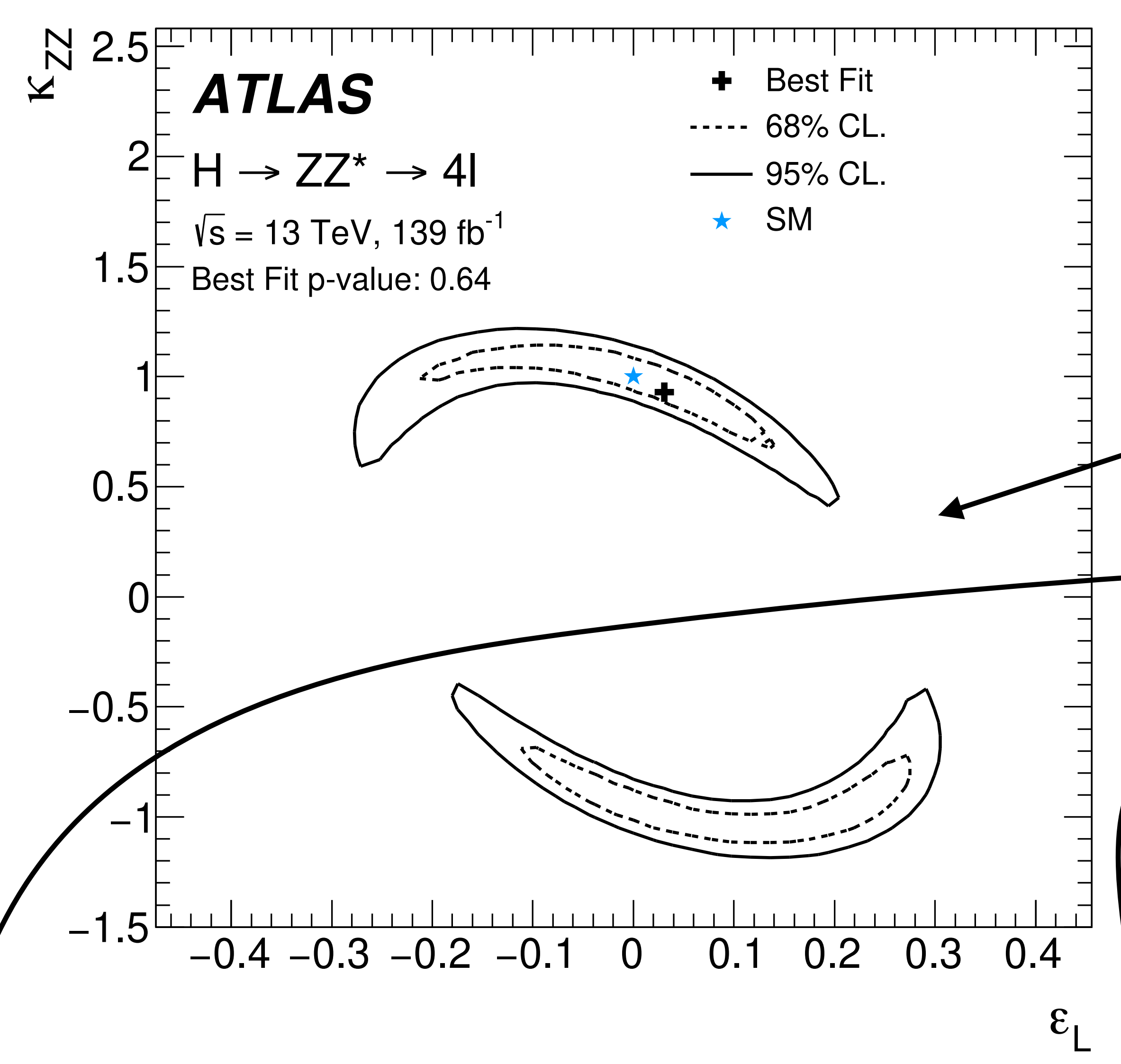
Observable	Stat. unc. [%]	Syst. unc. [%]	Dominant systematic components [%] Lumi.	e/μ	Jets	Other Bkg.	ZZ^* Th.	Sig. Th.	Comp.
σ_{comb}	9	3	1.7	2	< 0.5	< 0.5	1.0	1.5	< 0.5
$\sigma_{4\mu}$	15	4	1.7	3	< 0.5	< 0.5	1.5	1.0	< 0.5
$\sigma_{4\text{e}}$	26	8	1.7	7	< 0.5	< 0.5	1.5	1.5	< 0.5
$\sigma_{2\mu 2\text{e}}$	20	7	1.7	5	< 0.5	< 0.5	2	1.5	< 0.5
$\sigma_{2\text{e}2\mu}$	15	3	1.7	2	< 0.5	< 0.5	1	1.5	< 0.5
$\text{d}^2\sigma\ /\ \text{d}m_{12}\ \text{d}m_{34}$	16–65	3–11	1.7	2–3	< 1	1–2	1–9	1–3	1–2
$\text{d}^2\sigma\ /\ \text{d}p_{\text{T}}^{4\ell}\ \text{d}\lvert y_{4\ell}\rvert$	23–63	2–13	1.7	1–3	1–2	< 1	1–6	1–5	1–2
$\text{d}^2\sigma\ /\ \text{d}p_{\text{T}}^{4\ell}\ \text{d}N_{\text{jets}}$	23–93	4–193	1.7	2–14	2–25	1–3	1–7	1–12	1–92
$\text{d}^2\sigma\ /\ \text{d}p_{\text{T}}^{4\ell\text{j}}\ \text{d}m_{4\ell\text{j}}$	15–41	4–12	1.7	1–3	2–8	< 0.5	1–5	2–9	< 1
$\text{d}^2\sigma\ /\ \text{d}p_{\text{T}}^{4\ell}\ \text{d}p_{\text{T}}^{4\ell\text{j}}$	15–53	3–10	1.7	1–3	2–8	< 1	1–2	2–6	1–2
$\text{d}^2\sigma\ /\ \text{d}p_{\text{T}}^{4\ell}\ \text{d}p_{\text{T}}^{\text{lead. jet}}$	15–84	3–21	1.7	1–3	2–18	1–10	1–3	2–9	1–3
$\text{d}^2\sigma\ /\ \text{d}p_{\text{T}}^{\text{lead. jet}}\ \text{d}\lvert y^{\text{lead. jet}}\rvert$	15–38	3–11	1.7	1–3	2–9	< 0.5	1–2	1–4	1–2
$\text{d}^2\sigma\ /\ \text{d}p_{\text{T}}^{\text{lead. jet}}\ \text{d}p_{\text{T}}^{\text{sublead. jet}}$	15–63	5–22	1.7	1–3	4–15	< 0.5	1–4	3–11	1–7

H4ℓ inclusive fiducial and total cross-sections

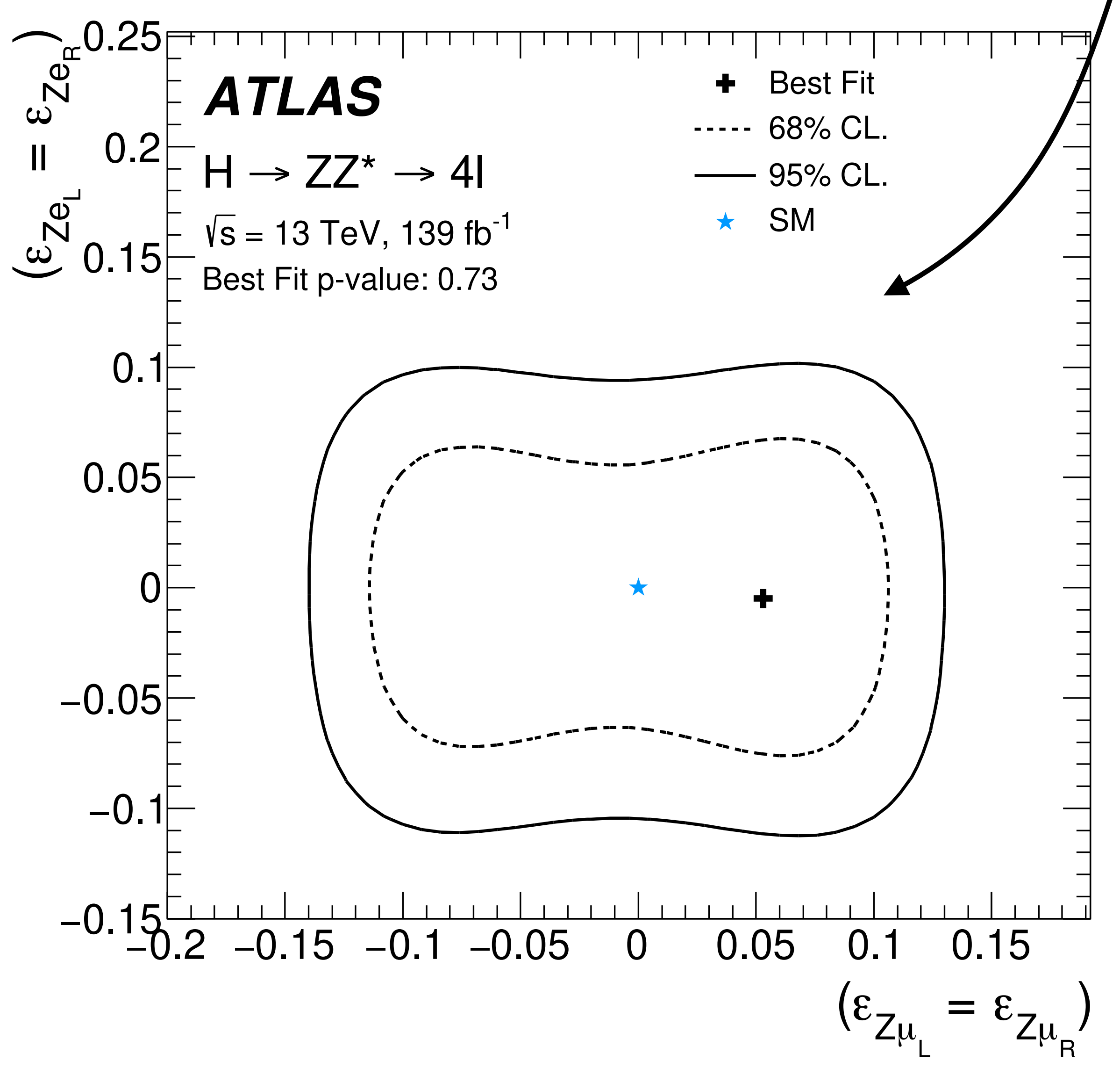


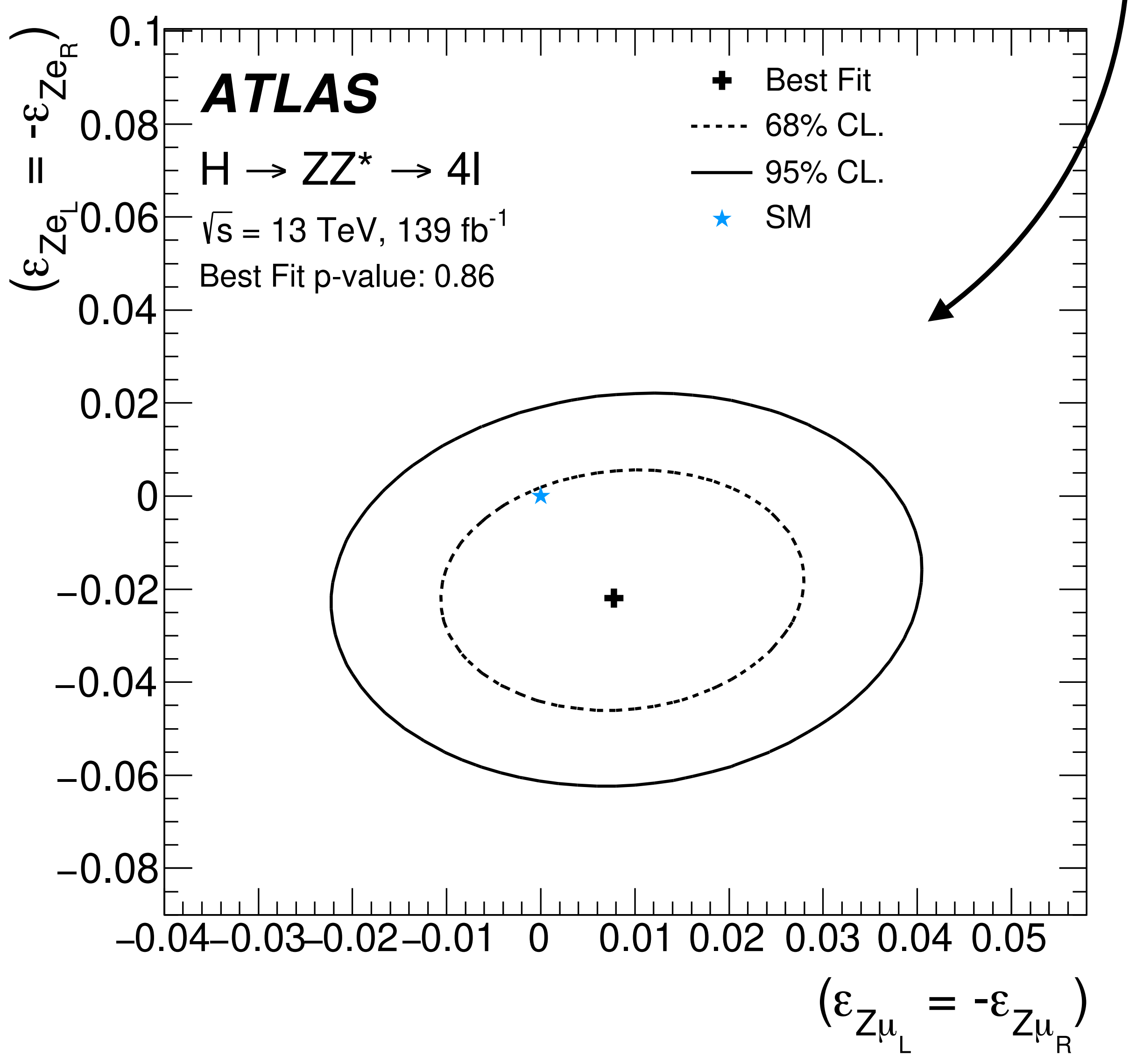
All H4ℓ Pseudo-Observables results





Interpretation	Parameter best-fit value	95% confidence interval
EFT-inspired eR = 0.48 eL	$\epsilon_L = 0.03$	$[-0.25, 0.17]$
	$\kappa_{ZZ} = 0.93$	$[0.51, 1.16]$
Flavour non-universal vector	ϵ_{Ze} = -0.005	$[-0.097, 0.082]$
	$\epsilon_{Z\mu} = 0.054$	$[-0.131, 0.114]$
Flavour non-universal axial-vector	ϵ_{Ze} = -0.022	$[-0.056, 0.012]$
	$\epsilon_{Z\mu} = 0.008$	$[-0.016, 0.033]$





Hγγ differential cross-sections and interpretations

Hγγ phase space definition: fiducial

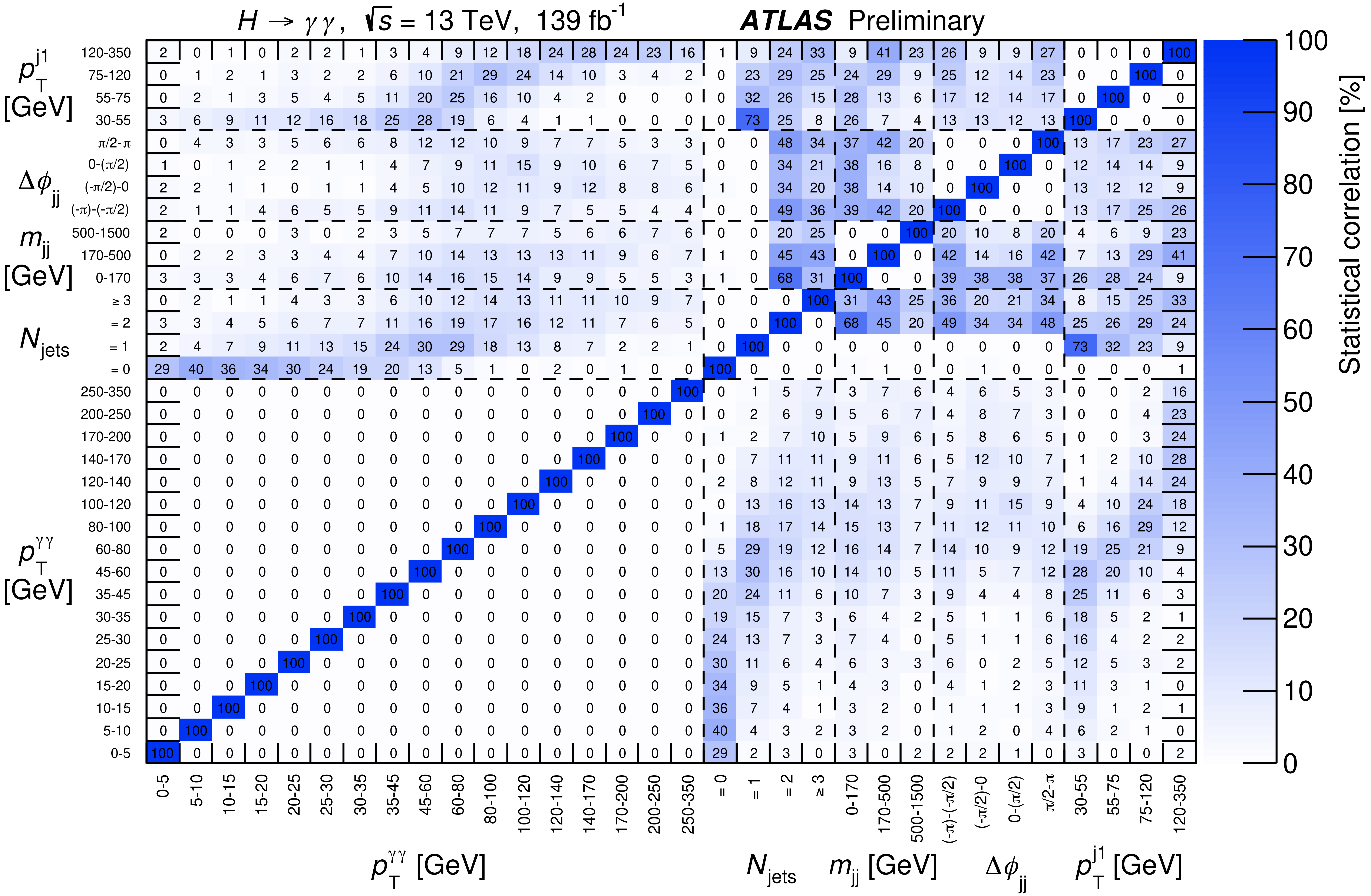
Objects	Fiducial definition
Photons	$\lvert\eta\rvert < 2.37$ (excluding $1.37 < \lvert\eta\rvert < 1.52$), $\sum p_{\mathrm{T}}^{i}/p_{\mathrm{T}}^{\gamma} < 0.05$
Jets	anti-k_t, $R = 0.4$, $p_{\mathrm{T}} > 30$ GeV, $\lvert y\rvert < 4.4$
Diphoton	$N_{\gamma} \geq 2$, $105\,GeV < m_{\gamma\gamma} 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

Hγγ inclusive fiducial XS systematics ranking

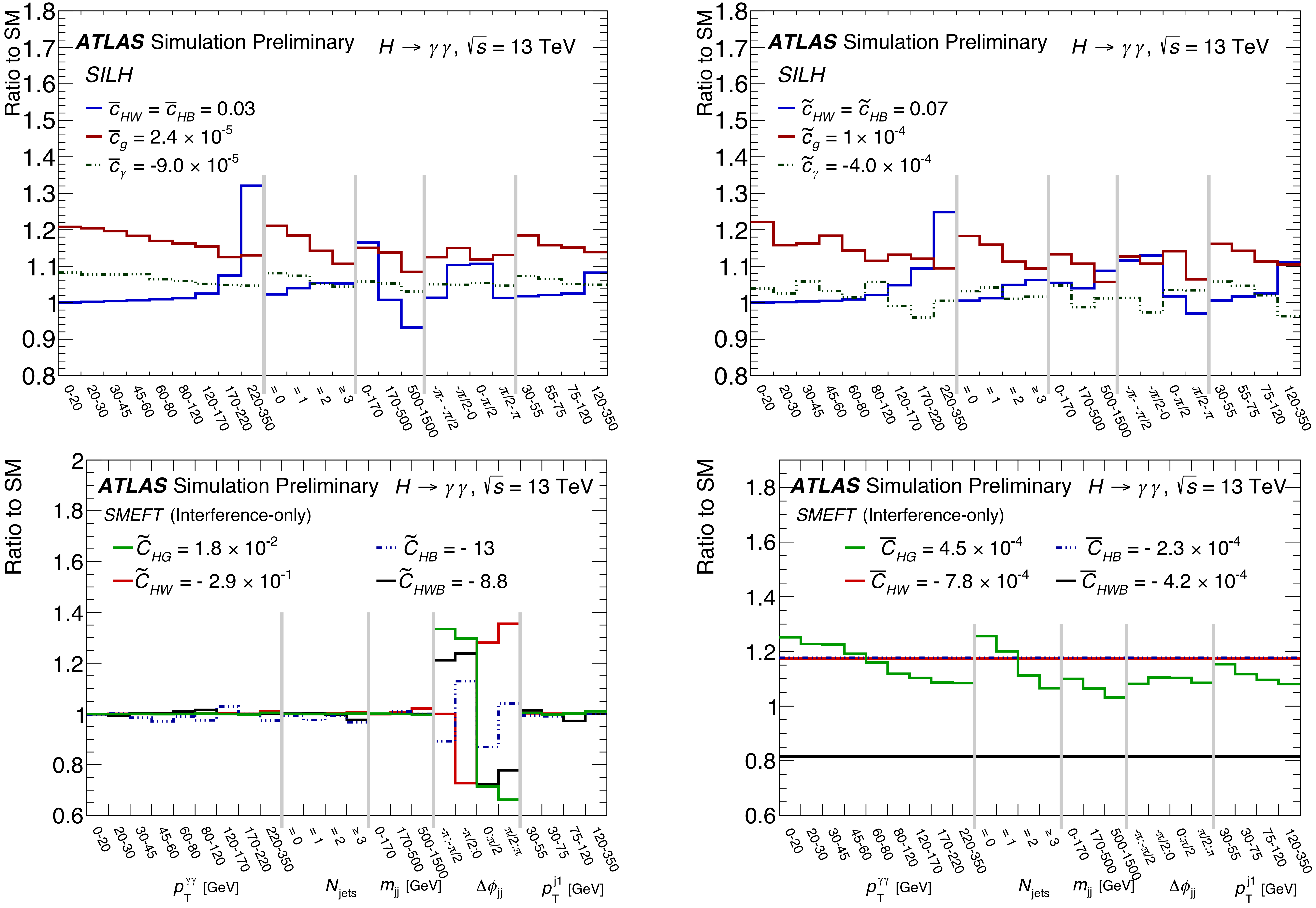
Source	Uncertainty (%)
Statistics	6.9
Signal extraction syst.	7.9
Photon energy scale & resolution	4.6
Background modelling (spurious signal)	6.4
Correction factor	2.6
Pile-up modelling	2.0
Photon identification efficiency	1.2
Photon isolation efficiency	1.1
Trigger efficiency	0.5
Theoretical modelling	0.5
Photon energy scale & resolution	0.1
Luminosity	1.7
Total	11.0

- Exponential of order 1 or 2 polynomial
- Power law
- Bernstein polynomial of order 3 or 4

Bin-correlations in Hγγ differential XS



EFT limits in Hγγ



SILH

right: CP-even
left: CP-odd

SMEFT

EFT limits in Hγγ

SILH

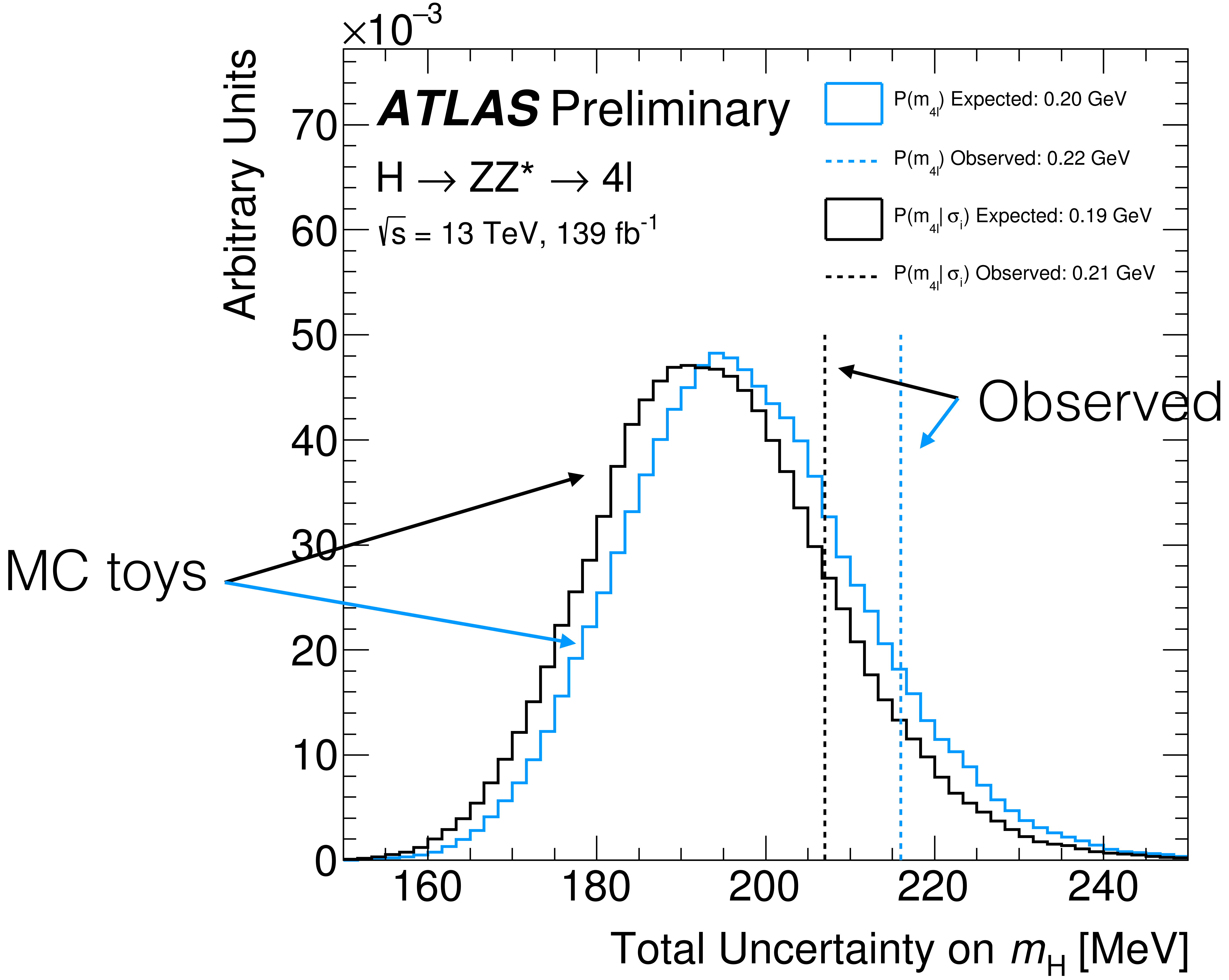
Coefficient	Observed 95% CL limit	Expected 95% CL limit
$\bar{c}_g$	$[-0.26, 0.26] \times 10^{-4}$	$[-0.25, 0.25] \cup [-4.7, -4.3] \times 10^{-4}$
$\tilde{c}_g$	$[-1.3, 1.1] \times 10^{-4}$	$[-1.1, 1.1] \times 10^{-4}$
$\bar{c}_{HW}$	$[-2.5, 2.2] \times 10^{-2}$	$[-3.0, 3.0] \times 10^{-2}$
$\tilde{c}_{HW}$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

SMEFT

Coefficient	95% CL, interference-only terms	95% CL, interference and quadratic terms
$\overline{C}_{HG}$	$[-4.2, 4.8] \times 10^{-4}$	$[-6.1, 4.7] \times 10^{-4}$
$\widetilde{C}_{HG}$	$[-2.1, 1.6] \times 10^{-2}$	$[-1.5, 1.4] \times 10^{-3}$
$\overline{C}_{HW}$	$[-8, 2, 7.4] \times 10^{-4}$	$[-8.3, 8.3] \times 10^{-4}$
$\widetilde{C}_{HW}$	$[-0.26, 0.33]$	$[-3.7, 3.7] \times 10^{-3}$
$\overline{C}_{HB}$	$[-2.4, 2.3] \times 10^{-4}$	$[-2.4, 2.4] \times 10^{-4}$
$\widetilde{C}_{HB}$	$[-13.0, 14.0]$	$[-1.2, 1.1] \times 10^{-3}$
$\overline{C}_{HWB}$	$[-4.0, 4.4] \times 10^{-4}$	$[-4.2, 4.2] \times 10^{-4}$
$\widetilde{C}_{HWB}$	$[-11.1, 6.5]$	$[-2.0, 2.0] \times 10^{-3}$

Mass measurement

Resolution on mH with or without Per-Event Resolution

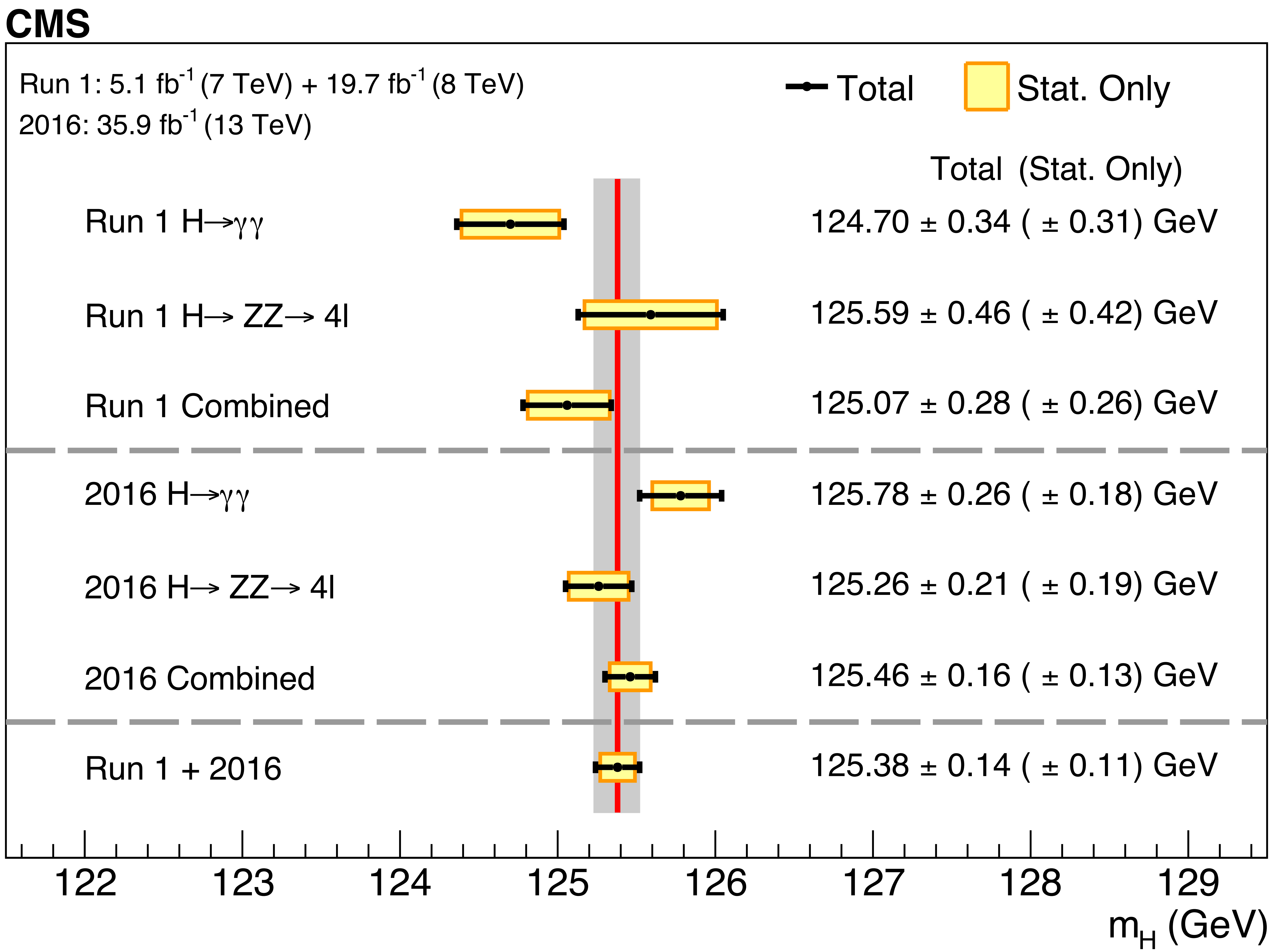


- **Blue**: without PER
- **Black**: with PER

- Central value with/without PER: 50 MeV (p-value = 26%).
- Observed/expected resolution: p-value = 17%.

Latest CMS Higgs mass result

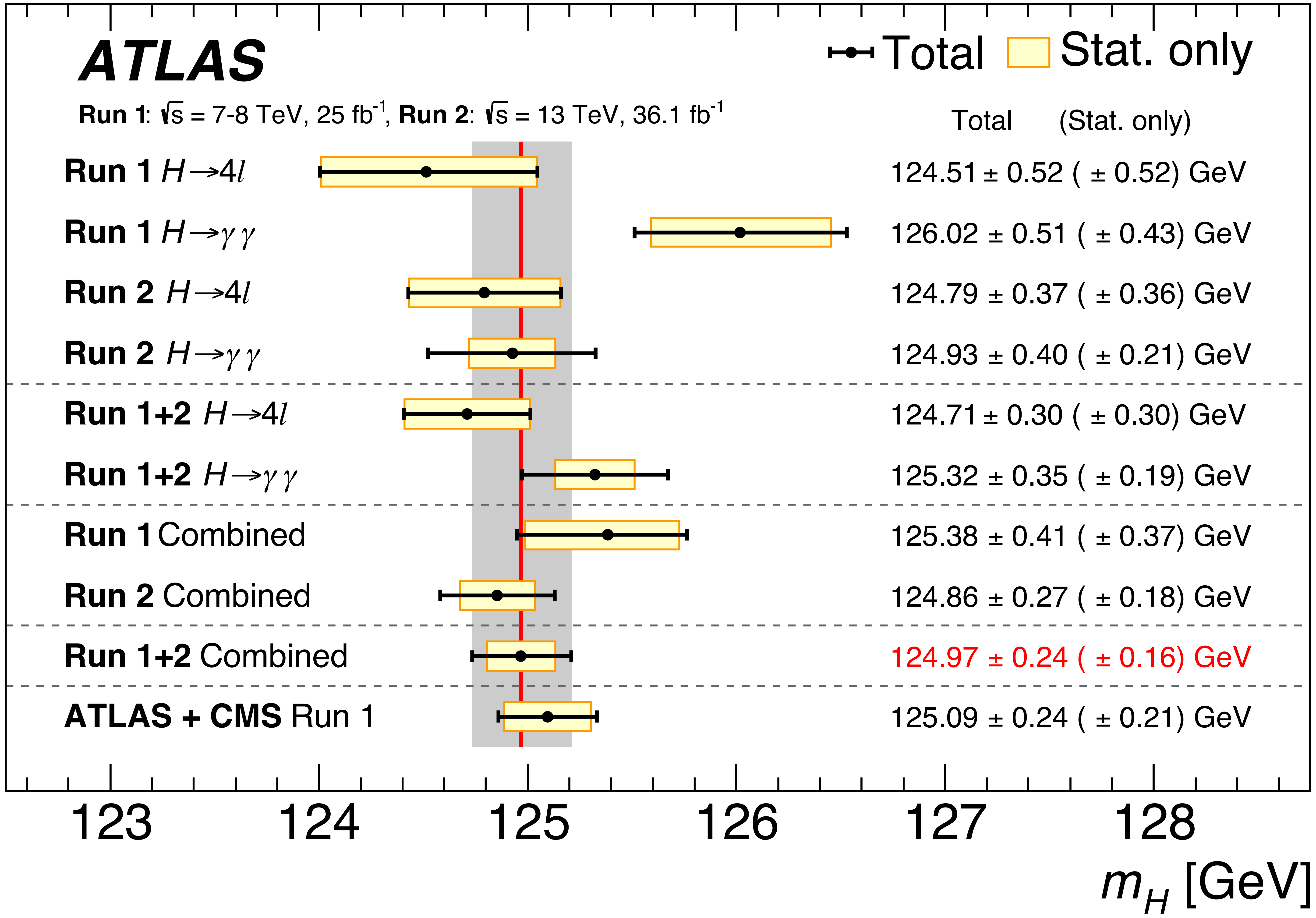
Phys. Lett. B 805 (2020) 135425



CMS record

Previous ATLAS Higgs mass result

Phys. Lett. B 784 (2018) 345



ATLAS record