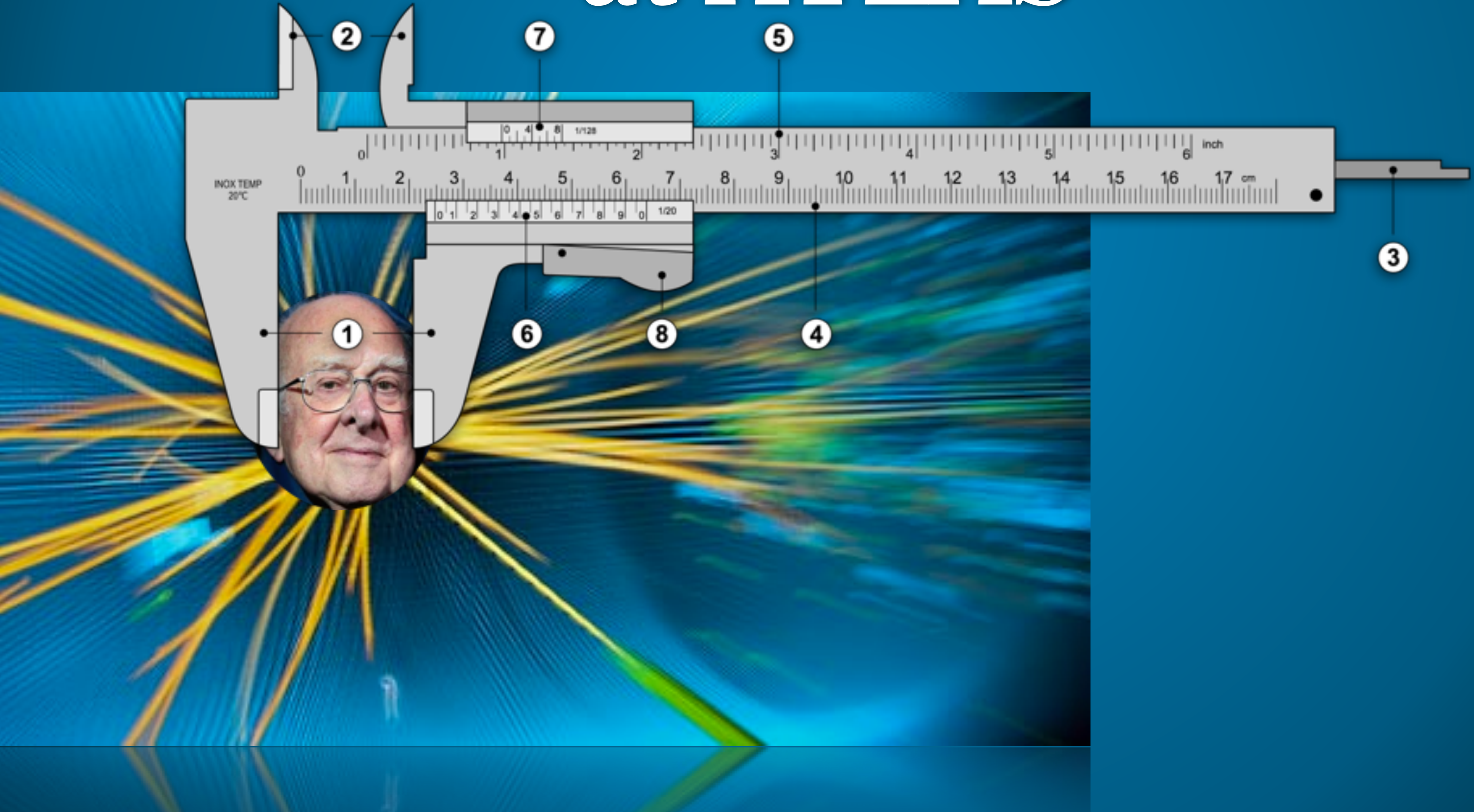
Higgs fiducial and differential cross section measurements at ATLAS

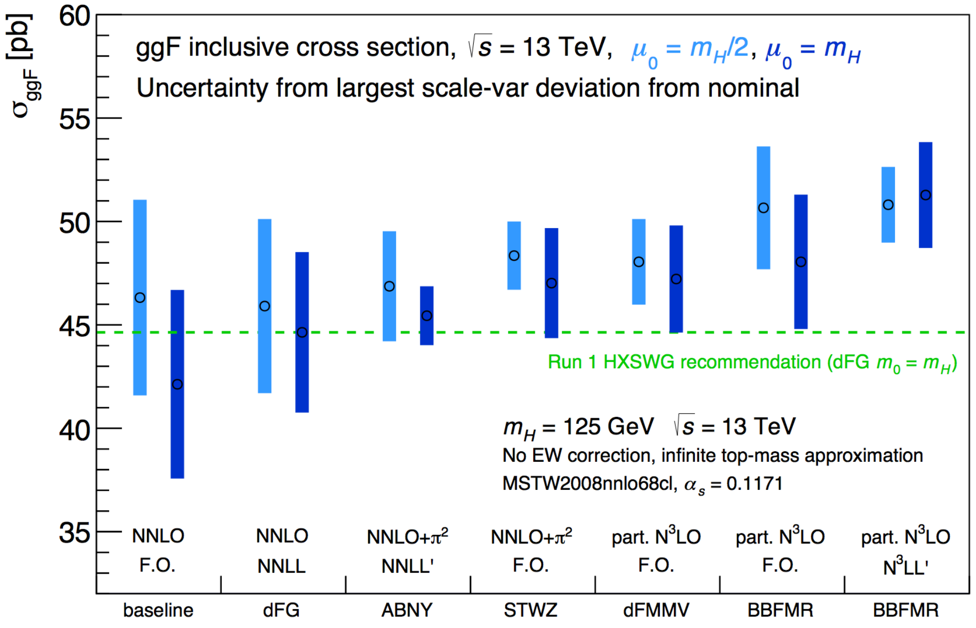


Outline

1. Why measure cross sections?
2. Definition of fiducial volume: its acceptances and NP corrections
3. Overview of the measurement
4. Signal extraction
5. Correction for detector effects
6. Uncertainties
7. Physics results:
    1. Fiducial cross sections
    2. Differential cross sections

Why cross sections?

- Cross sections offer a direct measurement of Higgs production rates in the data with minimal assumptions on the underlying model (‘model independent’).
    - Test of the compatibility of the SM with the data.
    - Can compare data to a range of different theory models now and in the future.
- The inclusive Higgs production cross section is a hot topic in the theory community
    - Lot of activity to calculate the ggF Higgs production cross section to N^{3}LO.



- Differential cross sections offer a model independent way of probing the properties of the Higgs boson.
    - ‘State-of-the-art’ MC generator predictions are now at NLO accuracy in QCD, with some steps towards NNLO.

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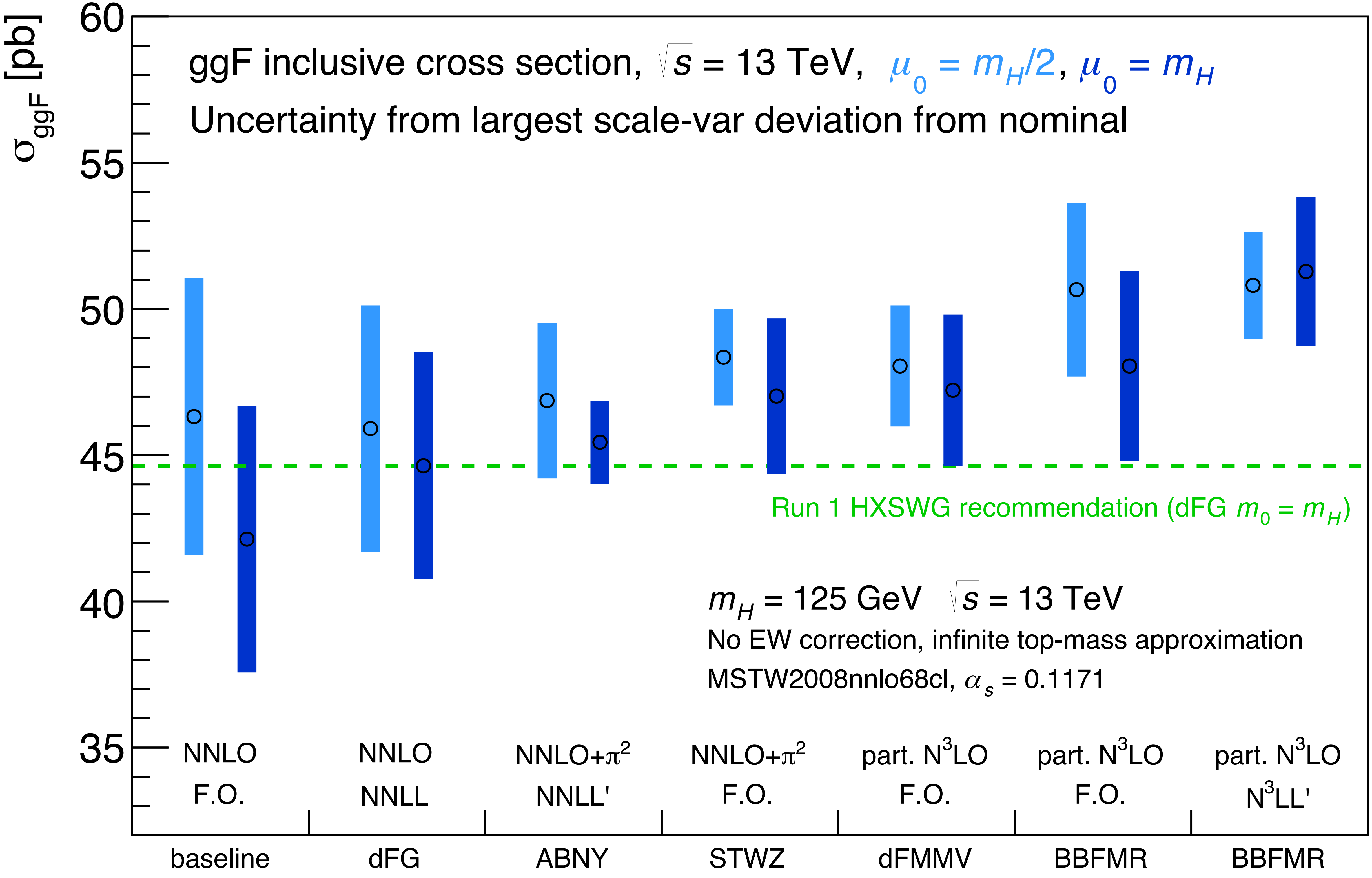
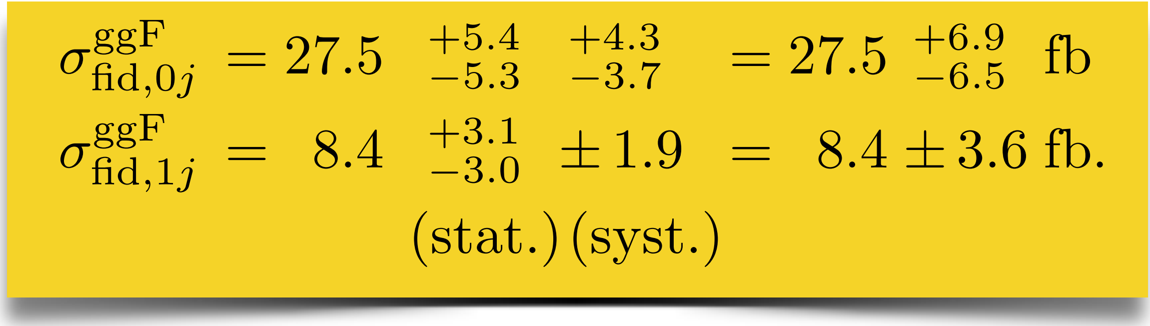
ggF inclusive cross section



Benchmark summary from ggF XS WG

A few initial remarks

- Presenting ATLAS Higgs cross section measurements
  - Measurements performed by extracting signal in the reference peak: **all Higgs production modes included** in this peak (not only ggF)
  - m_H = 125.4 GeV (ATLAS measured Higgs mass), **8 TeV data** only (20 fb^{-1})
  - Only presenting the measurements in the $\boldsymbol{\gamma\gamma}$ and ***ZZ*** channels (with focus on $\gamma\gamma$)
  - Measurements are designed to be as ***model independent*** as possible
- I'm not including the recently published $\boldsymbol{WW^{(*)}}$ fiducial cross section measurement as part of the *WW* paper: https://cds.cern.ch/record/1954714



$$\begin{aligned}\sigma^{\rm ggF}_{{\rm fid},0j} &= 27.5 \; {}^{+5.4}_{-5.3} \; {}^{+4.3}_{-3.7} = 27.5 \; {}^{+6.9}_{-6.5} \; \text{fb} \\ \sigma^{\rm ggF}_{{\rm fid},1j} &= \;\; 8.4 \; {}^{+3.1}_{-3.0} \pm 1.9 = \;\; 8.4 \pm 3.6 \; \text{fb}. \\ & \qquad\quad (\text{stat.}) \, (\text{syst.})\end{aligned}$$

  - See paper for details. The approach is a bit different from the $\gamma\gamma$ and *ZZ* results I will show. For example, the expected VBF contribution is subtracted.

Cross section measured

For γγ and ZZ

Higgs kinematics: $\boldsymbol{p_{TH}}$, $|\boldsymbol{y_H}|$

Jet activity: $\boldsymbol{N_{\mathrm{jets}}}$, $\boldsymbol{p_{\mathrm{jet1}}}$

Spin & CP: **cos** $\boldsymbol{\theta^*}$

Jet definition

jets: anti-k_t R=0.4, $|y|$<4.4

p_T > 30 GeV

ZZ only: m_{34} = dilepton-mass of offshell Z

γγ only

Higgs kinematics: $\boldsymbol{p_{Tt}}$

$\boldsymbol{N_{\mathrm{jets}}}$ **50 GeV threshold**

Jet activity: $|\boldsymbol{y_{\mathrm{jet1}}}|$, $\boldsymbol{p_{\mathrm{Tjet2}}}$, $|\boldsymbol{y_{\mathrm{jet2}}}|$, $\boldsymbol{H_{\mathrm{T,jets}}}$

VBF: $\boldsymbol{m_{\mathrm{jj}}}$, $\boldsymbol{p_{\mathrm{T}\gamma\gamma\mathrm{jj}}}$, $\boldsymbol{\Delta y_{\mathrm{jj}}}$, $\Delta\varphi(\gamma\gamma,\mathrm{jj})$

beam thrust: $\boldsymbol{\tau_{\mathrm{jet}}}$, $\boldsymbol{\sum\tau_{\mathrm{jet}}}$

2D: $\boldsymbol{p_{TH}}$ **vs** $\boldsymbol{N_{\mathrm{jets}}}$ bins: {0,1,≥2} jets, **cos** $\boldsymbol{\theta^*}$ **vs** $\boldsymbol{p_{TH}}$

Spin & CP: $\Delta\varphi_{\mathrm{jj}}$

Fiducial regions: γγ only

VBF-enhanced:

m_{jj} >400, Δy_{jj} > 2.8, $\Delta\varphi(\gamma\gamma,\mathrm{jj})$ > 2.6

Higgs + 1 lepton:
at least one e or μ with
p_T > 15 GeV, $|\eta|$<2.47

Higgs + E_T^{miss} > 80 GeV

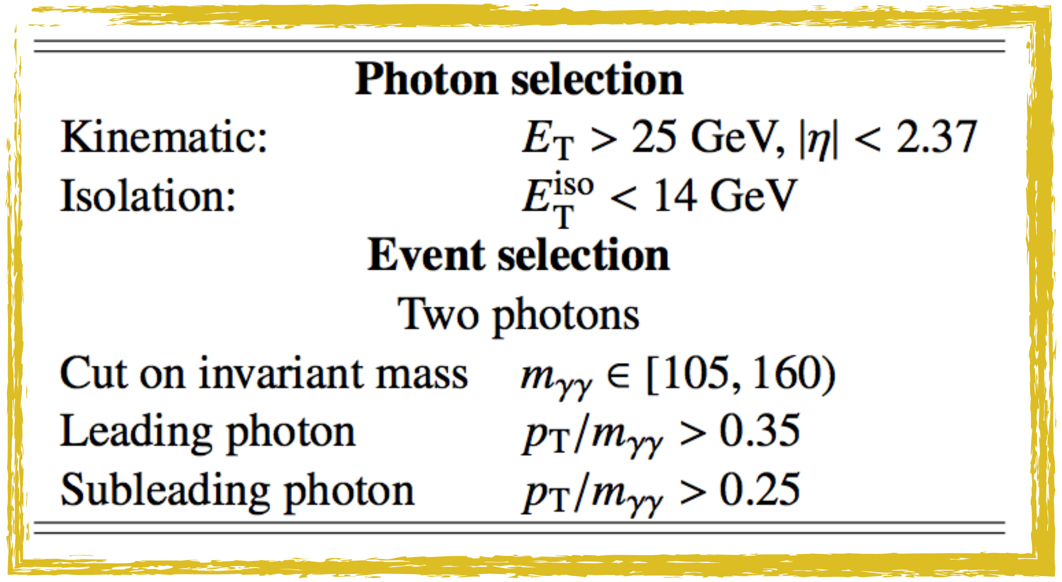
- Binning determined by available statistics

Definition of fiducial volume

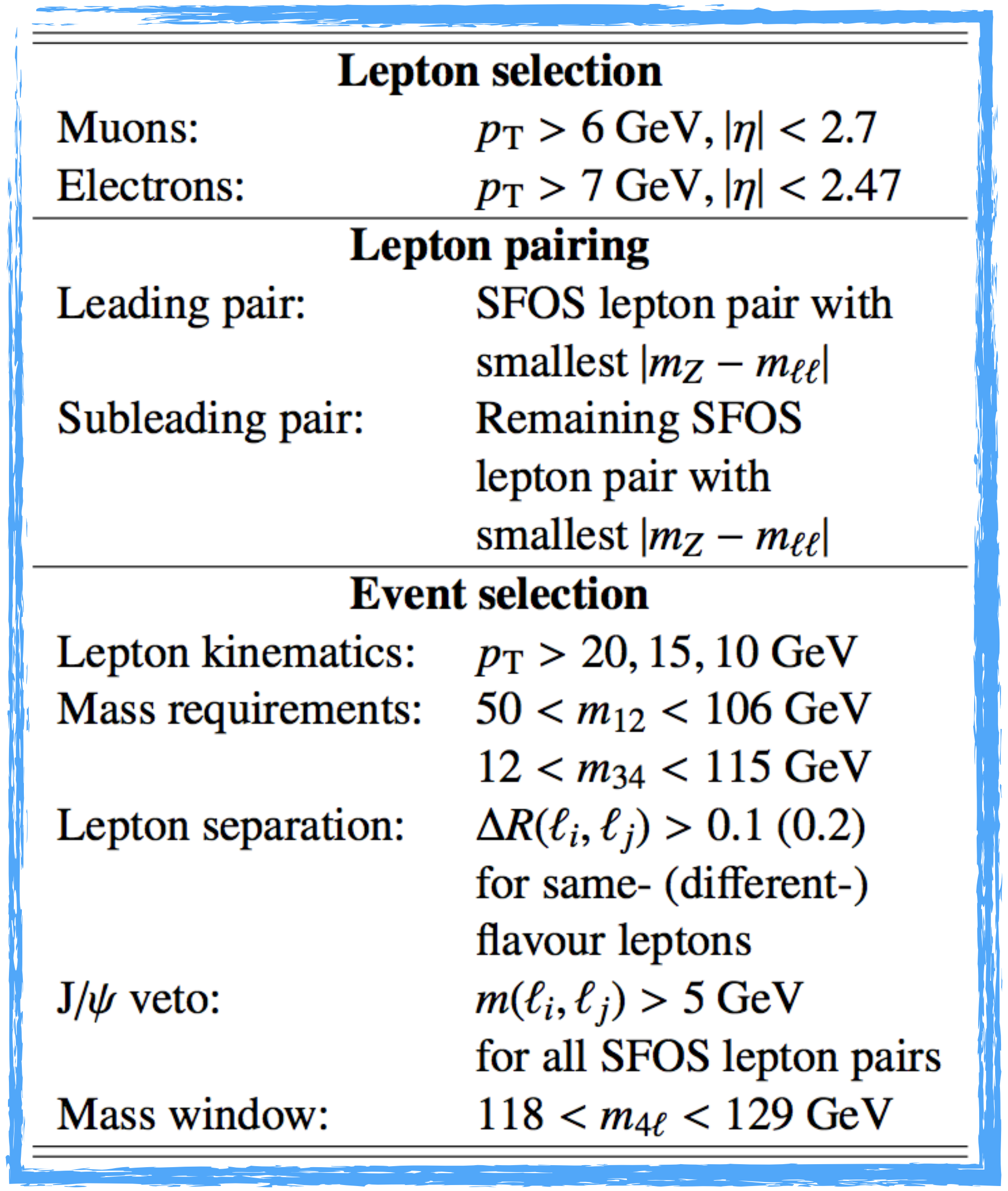
- Fiducial volume defined at truth ***particle level***
  - Particles with a mean life time longer than: $c\tau > 10$ mm
- Idea: apply **same selection criteria as applied in the data analysis**
  - Avoid model dependent extrapolation
  - “Trivial” extrapolation kept in to simplify definition (e.g. detector “crack”)
- ***H→γγ***: require the **two photons** from the Higgs to be central: **$|\eta|<2.37$**, and have **$p_T \gtrsim$ 44 GeV** and **32 GeV** (see exact def. below)
  - Reco-level: also avoid barrel-endcap transition region: $1.37<|\eta|<1.52$ (i.e. rely on MC for fraction of MC events in this region)

Z→ same-flavour-opposite-sign-pair (SFOS)

H→ZZ*



Photon selection	
Kinematic:	$E_T > 25$ GeV, $\lvert\eta\rvert < 2.37$
Isolation:	$E_T^{\text{iso}} < 14$ GeV
Event selection	
Two photons	
Cut on invariant mass	$m_{\gamma\gamma} \in [105, 160)$
Leading photon	$p_T/m_{\gamma\gamma} > 0.35$
Subleading photon	$p_T/m_{\gamma\gamma} > 0.25$



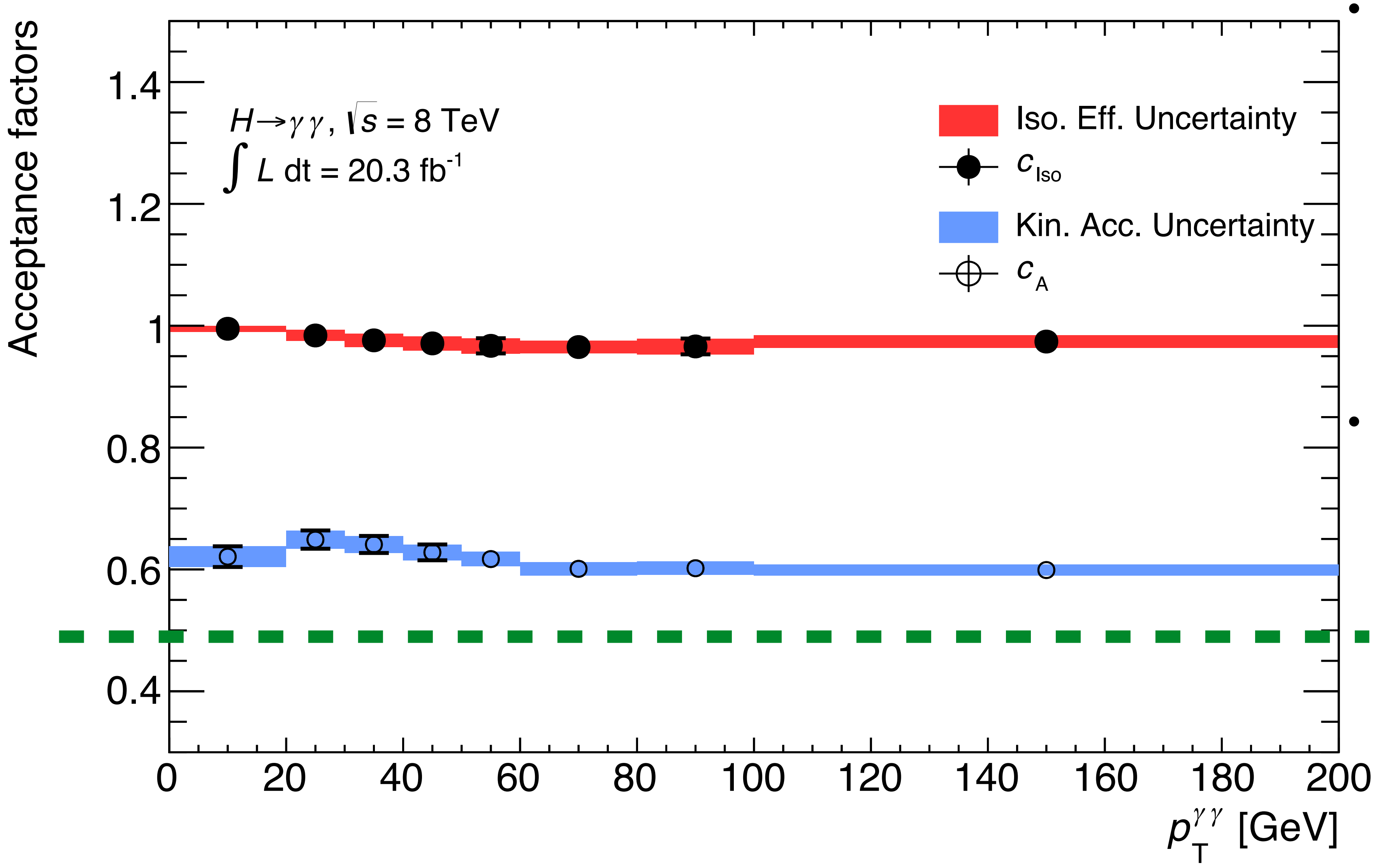
Lepton selection	
Muons:	$p_T > 6$ GeV, $\lvert\eta\rvert < 2.7$
Electrons:	$p_T > 7$ GeV, $\lvert\eta\rvert < 2.47$
Lepton pairing	
Leading pair:	SFOS lepton pair with smallest $\lvert m_Z - m_{\ell\ell}\rvert$
Subleading pair:	Remaining SFOS lepton pair with smallest $\lvert m_Z - m_{\ell\ell}\rvert$
Event selection	
Lepton kinematics:	$p_T > 20, 15, 10$ GeV
Mass requirements:	$50 < m_{12} < 106$ GeV $12 < m_{34} < 115$ GeV
Lepton separation:	$\Delta R(\ell_i, \ell_j) > 0.1\ (0.2)$ for same- (different-) flavour leptons
J/ψ veto:	$m(\ell_i, \ell_j) > 5$ GeV for all SFOS lepton pairs
Mass window:	$118 < m_{4\ell} < 129$ GeV

Acceptance

~63% **~50%**

Fiducial acceptance

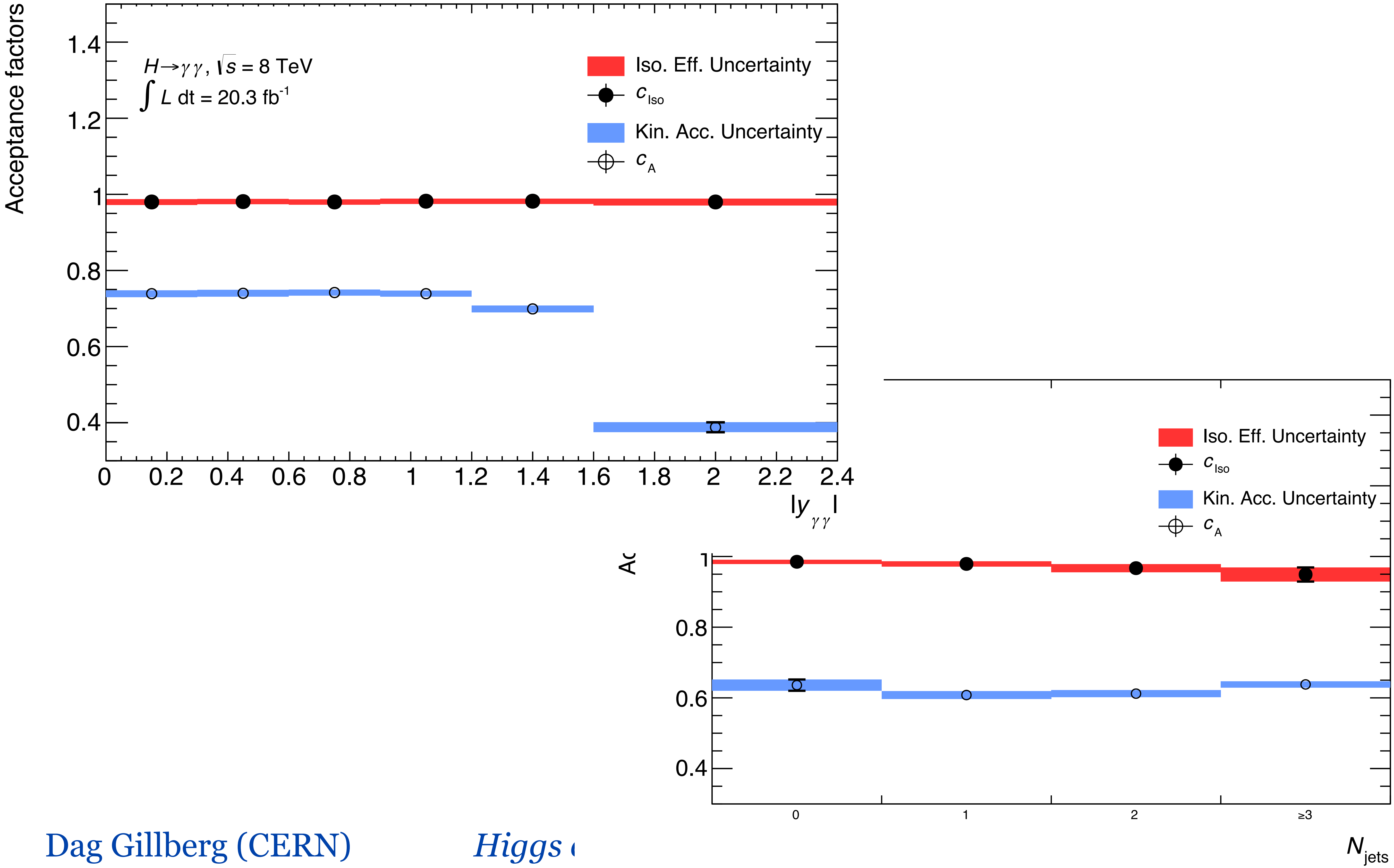
- Fiducial acceptance as a function of Higgs p_T for ggF only
  - Split into kinematic acceptance and photon isolation



H→ZZ does not apply any isolation requirements
Kinematic acceptance ~50%

- Photon isolation requirement:
  $\sum E_T < 14$ GeV
  of particles within DR<0.4, mimics ATLAS photon isolation analysis selection
  - Note: efficiency depend on amount of hadronic activity
- Kinematic acceptance:
  both photons central: $|\eta|<2.37$
  $p_{T\gamma\gamma}/m_{\gamma\gamma} > 0.35$ and 0.25
  - Quite stable (~61%) vs most variables
  - Depends on the Higgs boost along z-axis (rapidty)
    Fwd Higgs → fwd decay products

Fiducial acceptance



Comparing analytical ggF predictions with data

Note: in a differential distribution, each bin defines its own fiducial volume. Hence equation below holds bin-by-bin.

Fiducial cross section that's measured in data

gluon fusion

Fiducial Acceptance

other production modes XH = VBF+VH+ttH

$$\sigma_{\mathrm{fid}} = \sigma_{\mathrm{ggF}}\, \mathcal{B}\, \alpha_{\mathrm{kinem}}\, \alpha_{\mathrm{iso}}\, f_{\mathrm{NP}} + \sigma_{\mathrm{fid},XH}$$

ggF cross section

Branching ratio

Kinematic acceptance for Higgs decay product to fulfil fiducial requirements

Efficiency for photons to fulfil particle level isolation
(part of γγ fiducial definition not used for ZZ)

Non-perturbative correction factor accounting for hadronization and underlying event activity

Example for H→γγ inclusive fiducial cross section, m_H = 125.4 GeV

$$\sigma_{\mathrm{fid}} = \underset{\text{LHC-XS: 19.15 pb}}{\sigma_{\mathrm{ggF}}}\, \underset{0.228\%}{\mathcal{B}}\, \underset{\sim 63\%}{\alpha_{\mathrm{kinem}}}\, \underset{\sim 98\%}{\alpha_{\mathrm{iso}}}\, \underset{1.00}{f_{\mathrm{NP}}} + \underset{\sim 4\ \mathrm{fb}}{\sigma_{\mathrm{fid},XH}} = \mathbf{30.5\ fb}$$

SM prediction

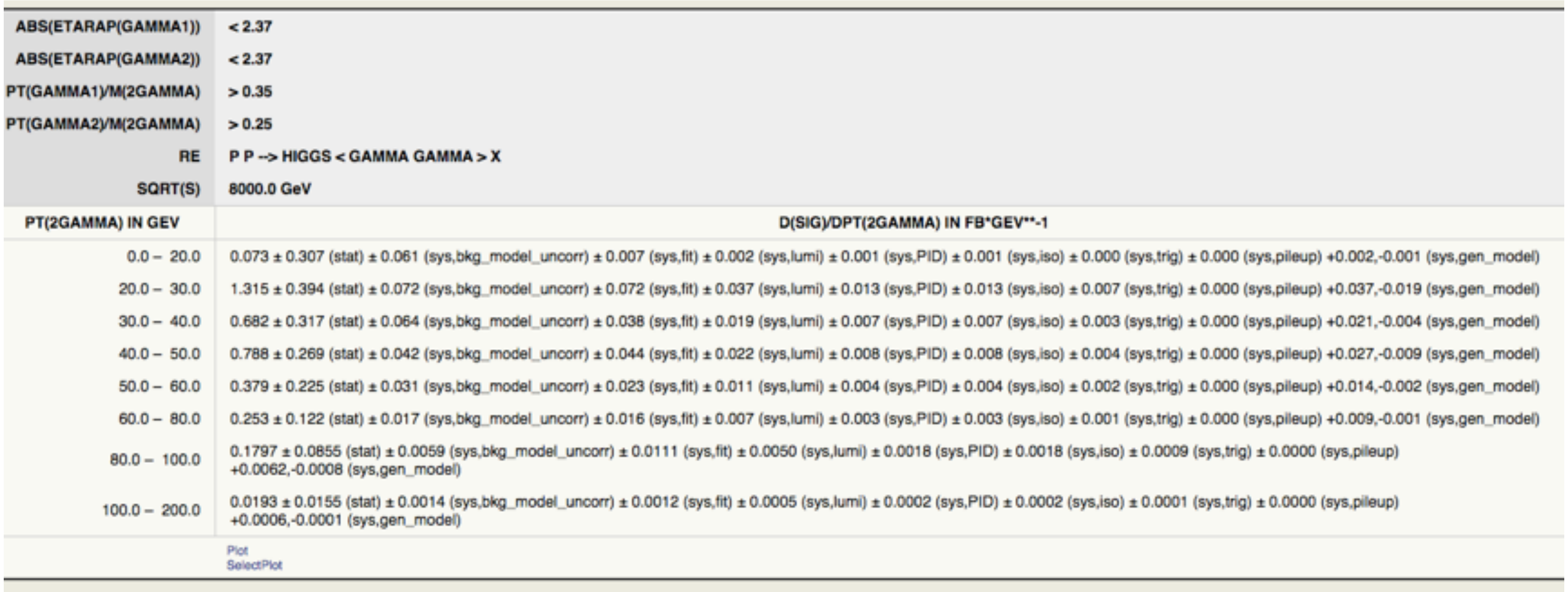
Comparing analytical ggF predictions with data

$$\sigma_{\rm fid} = \sigma_{\rm ggF}\ \mathcal{B}\ \boxed{\alpha_{\rm kinem}\ \alpha_{\rm iso}\ f_{\rm NP} + \sigma_{{\rm fid},XH}}$$

Our estimates of the above factors are in HEP data

… and the measurements of course

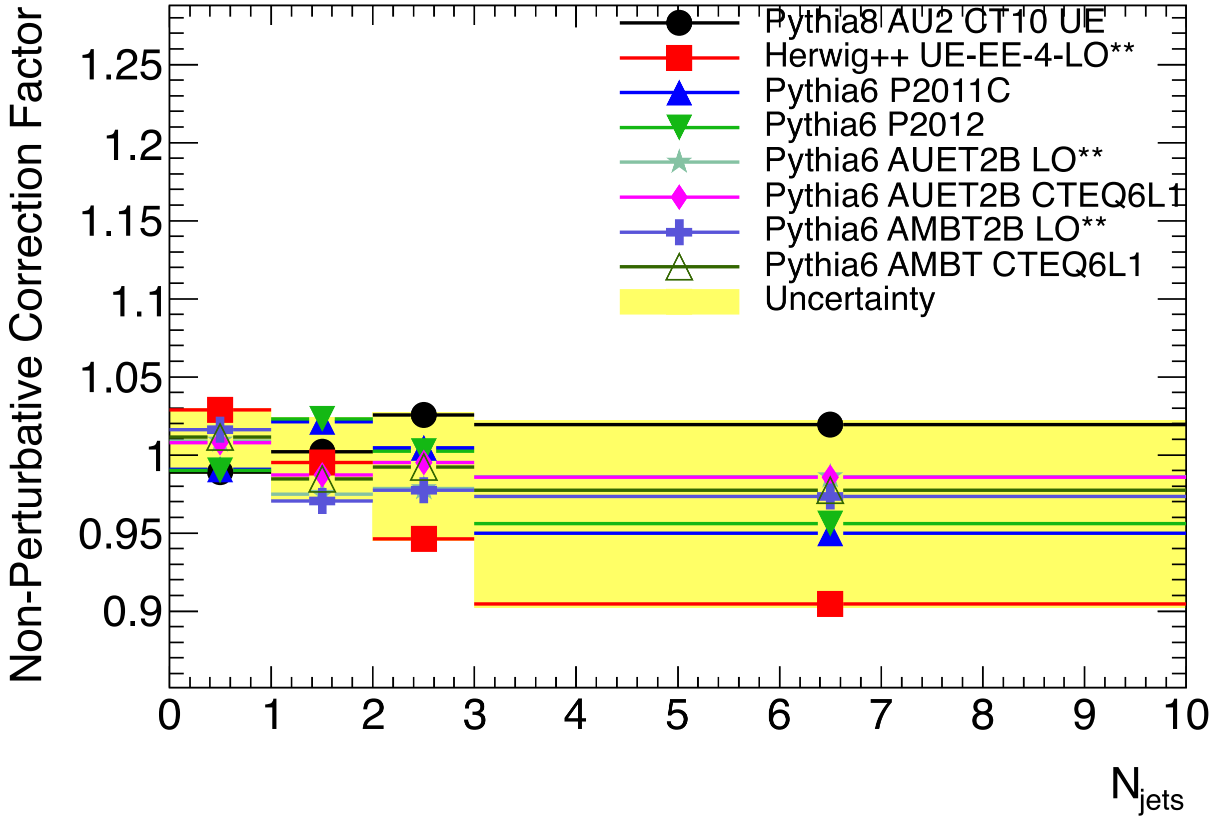
http://hepdata.cedar.ac.uk/view/ins1306615

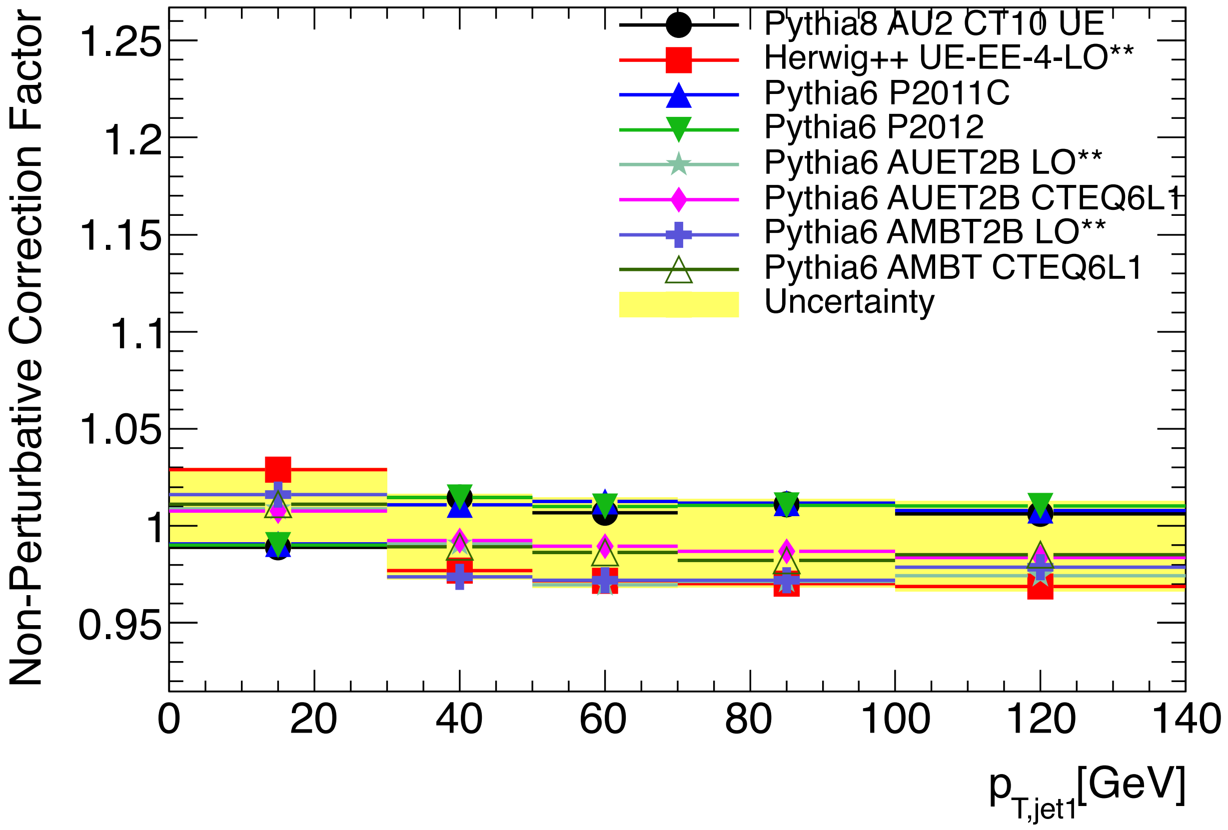


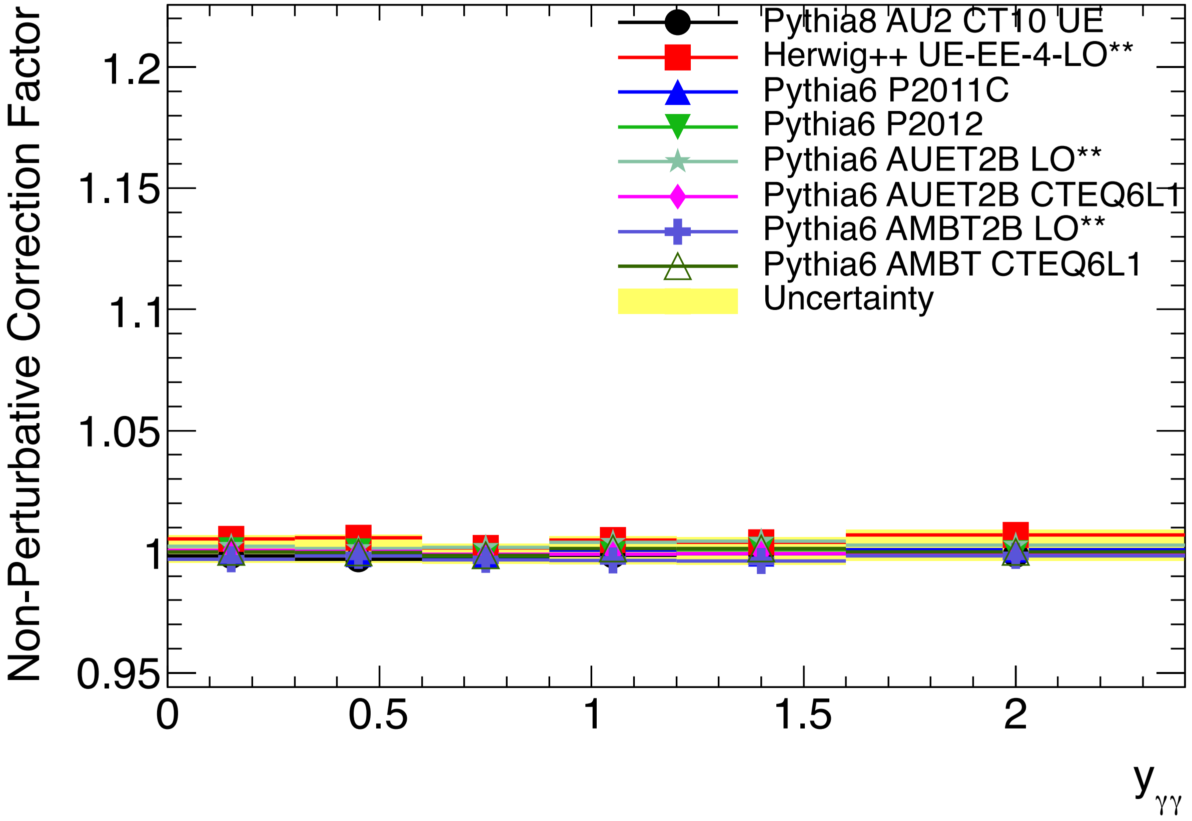
ABS(ETARAP(GAMMA1))	< 2.37
ABS(ETARAP(GAMMA2))	< 2.37
PT(GAMMA1)/M(2GAMMA)	> 0.35
PT(GAMMA2)/M(2GAMMA)	> 0.25
RE	P P --> HIGGS < GAMMA GAMMA > X
SQRT(S)	8000.0 GeV

PT(2GAMMA) IN GEV	D(SIG)/DPT(2GAMMA) IN FB*GEV**-1
0.0 – 20.0	0.073 ± 0.307 (stat) ± 0.061 (sys,bkg_model_uncorr) ± 0.007 (sys,fit) ± 0.002 (sys,lumi) ± 0.001 (sys,PID) ± 0.001 (sys,iso) ± 0.000 (sys,trig) ± 0.000 (sys,pileup) +0.002,-0.001 (sys,gen_model)
20.0 – 30.0	1.315 ± 0.394 (stat) ± 0.072 (sys,bkg_model_uncorr) ± 0.072 (sys,fit) ± 0.037 (sys,lumi) ± 0.013 (sys,PID) ± 0.013 (sys,iso) ± 0.007 (sys,trig) ± 0.000 (sys,pileup) +0.037,-0.019 (sys,gen_model)
30.0 – 40.0	0.682 ± 0.317 (stat) ± 0.064 (sys,bkg_model_uncorr) ± 0.038 (sys,fit) ± 0.019 (sys,lumi) ± 0.007 (sys,PID) ± 0.007 (sys,iso) ± 0.003 (sys,trig) ± 0.000 (sys,pileup) +0.021,-0.004 (sys,gen_model)
40.0 – 50.0	0.788 ± 0.269 (stat) ± 0.042 (sys,bkg_model_uncorr) ± 0.044 (sys,fit) ± 0.022 (sys,lumi) ± 0.008 (sys,PID) ± 0.008 (sys,iso) ± 0.004 (sys,trig) ± 0.000 (sys,pileup) +0.027,-0.009 (sys,gen_model)
50.0 – 60.0	0.379 ± 0.225 (stat) ± 0.031 (sys,bkg_model_uncorr) ± 0.023 (sys,fit) ± 0.011 (sys,lumi) ± 0.004 (sys,PID) ± 0.004 (sys,iso) ± 0.002 (sys,trig) ± 0.000 (sys,pileup) +0.014,-0.002 (sys,gen_model)
60.0 – 80.0	0.253 ± 0.122 (stat) ± 0.017 (sys,bkg_model_uncorr) ± 0.016 (sys,fit) ± 0.007 (sys,lumi) ± 0.003 (sys,PID) ± 0.003 (sys,iso) ± 0.001 (sys,trig) ± 0.000 (sys,pileup) +0.009,-0.001 (sys,gen_model)
80.0 – 100.0	0.1797 ± 0.0855 (stat) ± 0.0059 (sys,bkg_model_uncorr) ± 0.0111 (sys,fit) ± 0.0050 (sys,lumi) ± 0.0018 (sys,PID) ± 0.0018 (sys,iso) ± 0.0009 (sys,trig) ± 0.0000 (sys,pileup) +0.0062,-0.0008 (sys,gen_model)
100.0 – 200.0	0.0193 ± 0.0155 (stat) ± 0.0014 (sys,bkg_model_uncorr) ± 0.0012 (sys,fit) ± 0.0005 (sys,lumi) ± 0.0002 (sys,PID) ± 0.0002 (sys,iso) ± 0.0001 (sys,trig) ± 0.0000 (sys,pileup) +0.0006,-0.0001 (sys,gen_model)

Non perturbative correction







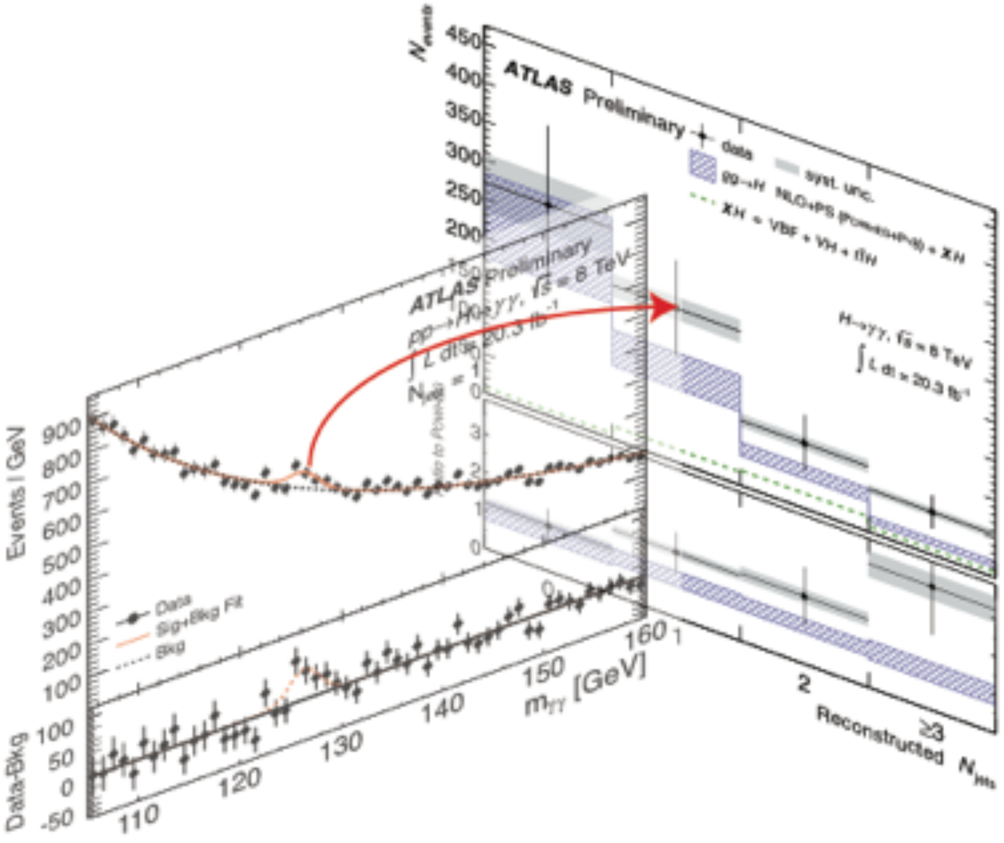
Bin-by-bin ratio:
“particle-level”/“parton-level”

“parton-level”: ME+Parton-showering

“particle-level”: adds hadronization+UE
(and beam-breakup)

Differential cross section measurement overview

1. Signal extraction



a) Spit dataset into bins of variable of interest (here 4 N_{jets} bins)

b) For each bin, extract *s* from a *s*+*b* fit to the $m_{\gamma\gamma}$ spectra

c) Large statistical uncertainty due to small *s*/*b*

2. Unfold to particle level

and divide by integrated luminosity and bin-width

$$\sigma_{\text{fid}} = \frac{n_{\text{sig},i}}{c_i\ \mathcal{L}_{\text{int}}}$$

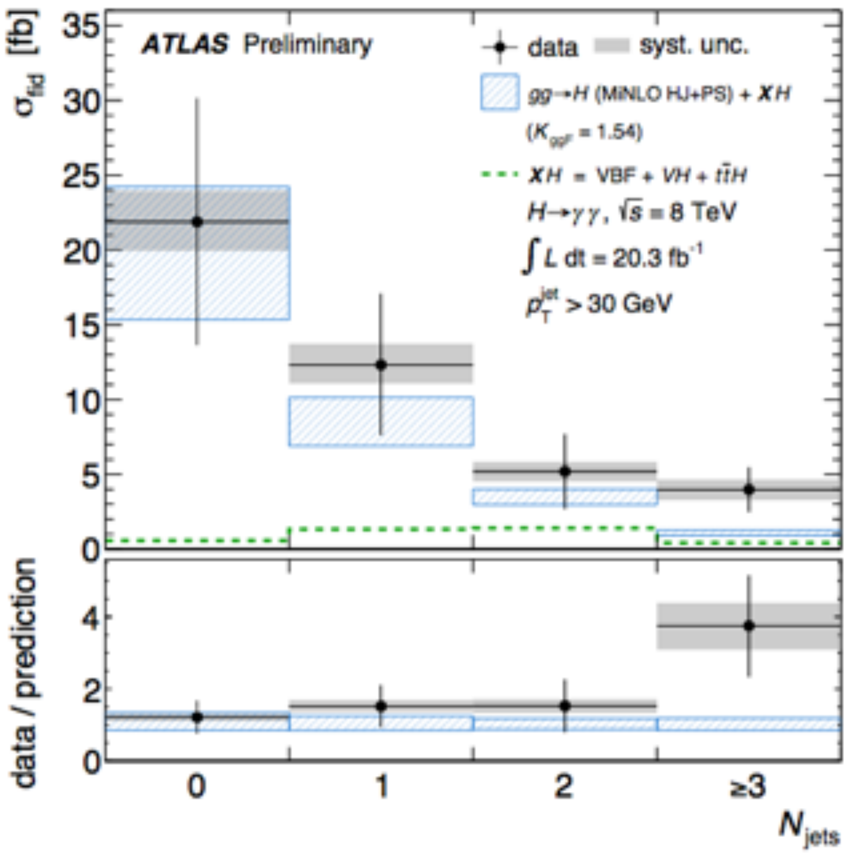
correction factor for detector effects

20.3 fb⁻¹ (±2.8%)

a) correction for detector effects with bin-by-bin unfolding

b) convert to ("differential") cross section by dividing by int. lumi (and bin-width)

3. Plot and compare with theory

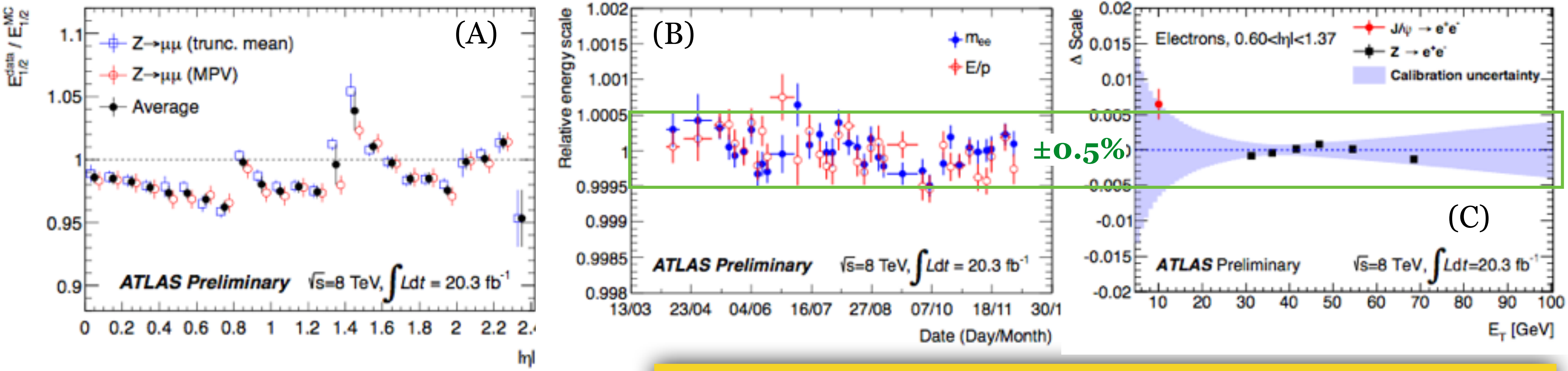


a) compare to **particle level** prediction - i.e. no need for detector simulation

b) Can also compare with analytical calculations (parton level) but then need small parton→particle level (NP) correction

Higgs boson mass

Calorimeter layer intercalibration ***Stability vs time & pileup*** ***Data vs MC & uncertainty***



New e/γ calibration (spring 2014)

- Calorimeter layers individually calibrated with *μ*, *e* and *γ* (A)
- Energy response stable within 0.5% versus time and pileup (B)
- Improved material description of the calorimeters: inactive material constrained to 2-10%X_0
- Precise MVA-based EM cluster calibration **→ 10% improved *H→γγ* $m_{\gamma\gamma}$ resolution**
- Data-MC agreement within (small!) uncertainty after calibration (C)

Final ATLAS RunI Higgs mass measurement, 1406.3827

- **Uncertainties:**

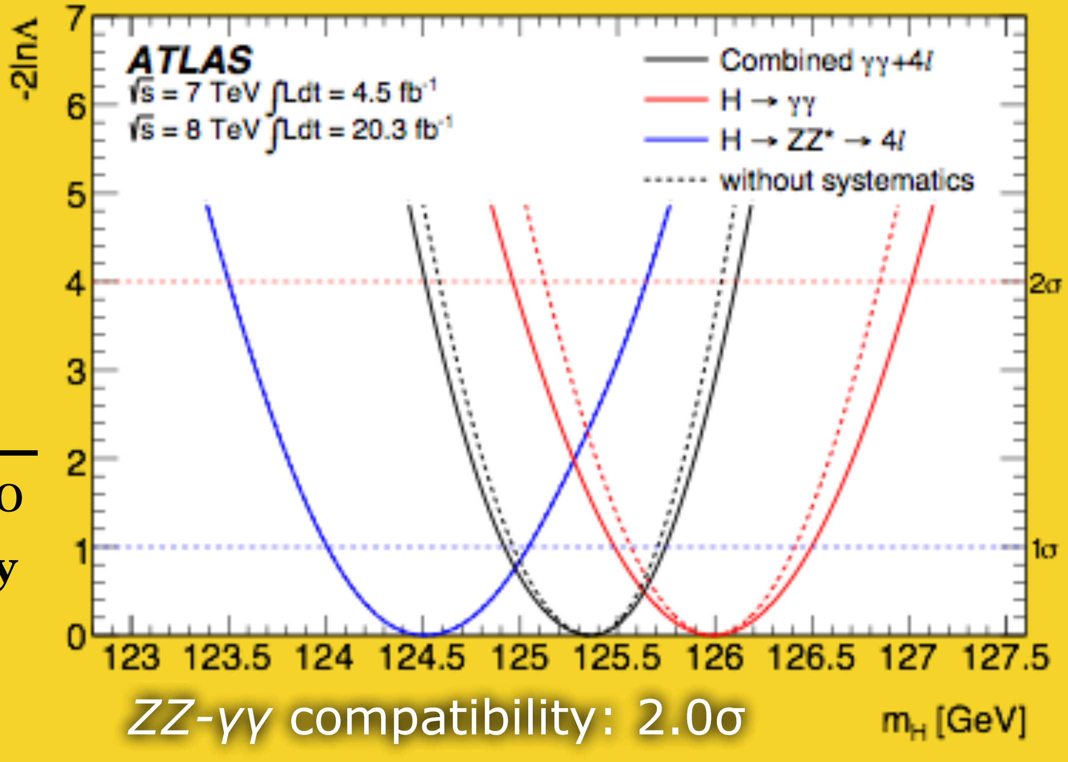
[GeV]	sys	stat
old	0.6	0.24
new	0.21	0.37

- ***μ* from *H→γγ***

old	new
1.55±0.30	1.29±0.30

- ***γγ-ZZ* compatibility**

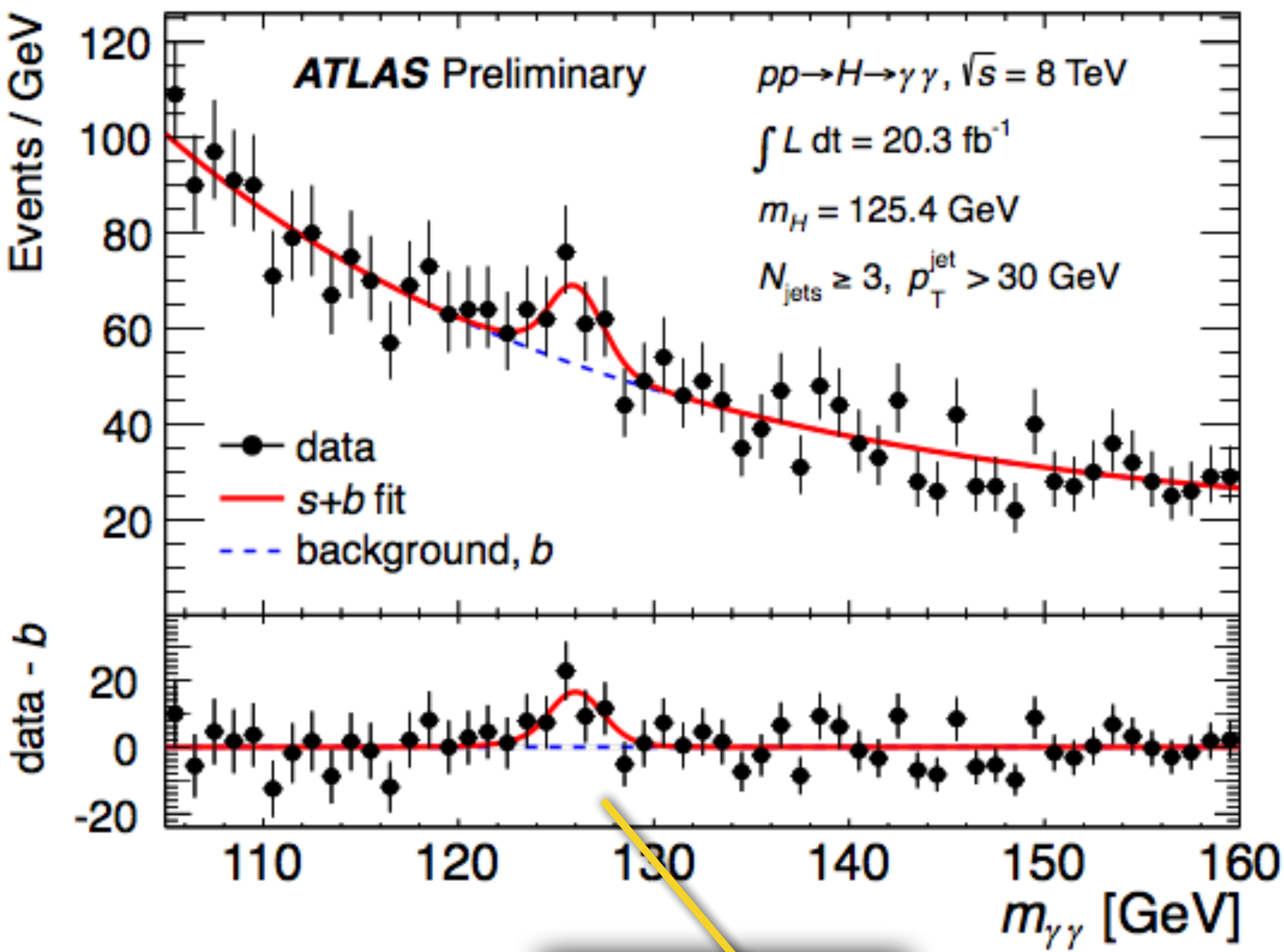
old	new
2.5 σ	2.0 σ



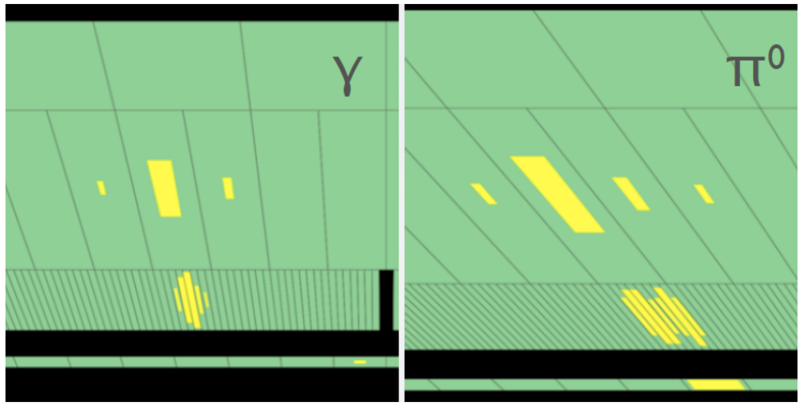
ZZ-γγ compatibility: 2.0σ

Combined Higgs mass: 125.36 ±0.37 (stat) ±0.21 (syst)

Signal extraction $\gamma\gamma$



$$\sigma_{\mathrm{fid}} = \frac{n_{\mathrm{sig},i}}{c_i\ \mathcal{L}_{\mathrm{int}}}$$



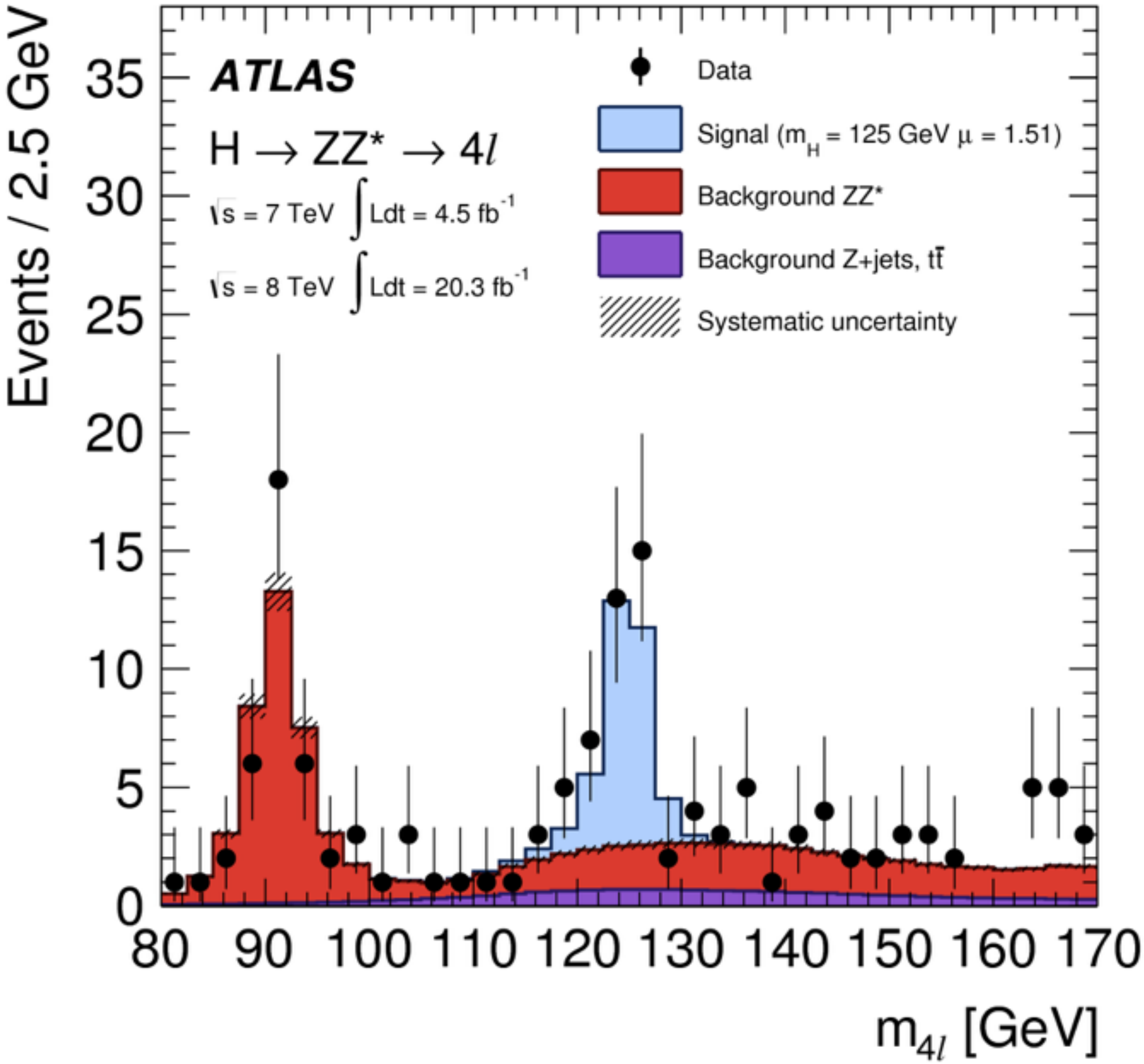
The ATLAS calorimeters are finely segmented and can effectively distinguish between isolated photons and backgrounds like $\pi^0 \to \gamma\gamma$

All diphoton events with 3-or-more jets

Nice Higgs resonance peak seen!
Background estimated by smooth fit.

Main **systematics** from photon energy resolution, i.e. **uncertainty on width** of the **resonance peak**

Signal extraction *ZZ*

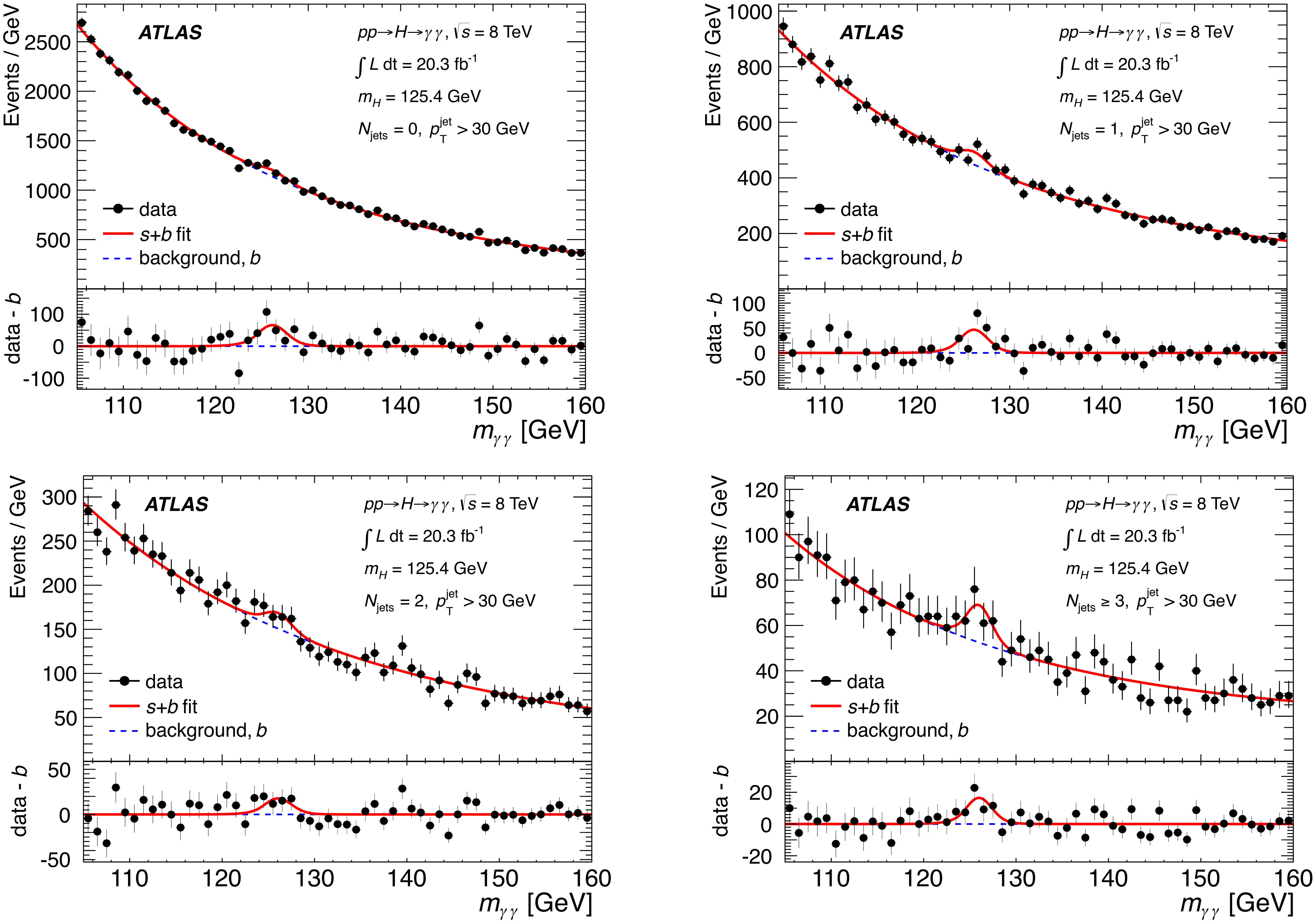


Significantly better s/b compared to γγ

Irreducible ZZ from MC
Normalization from NLO calculation.

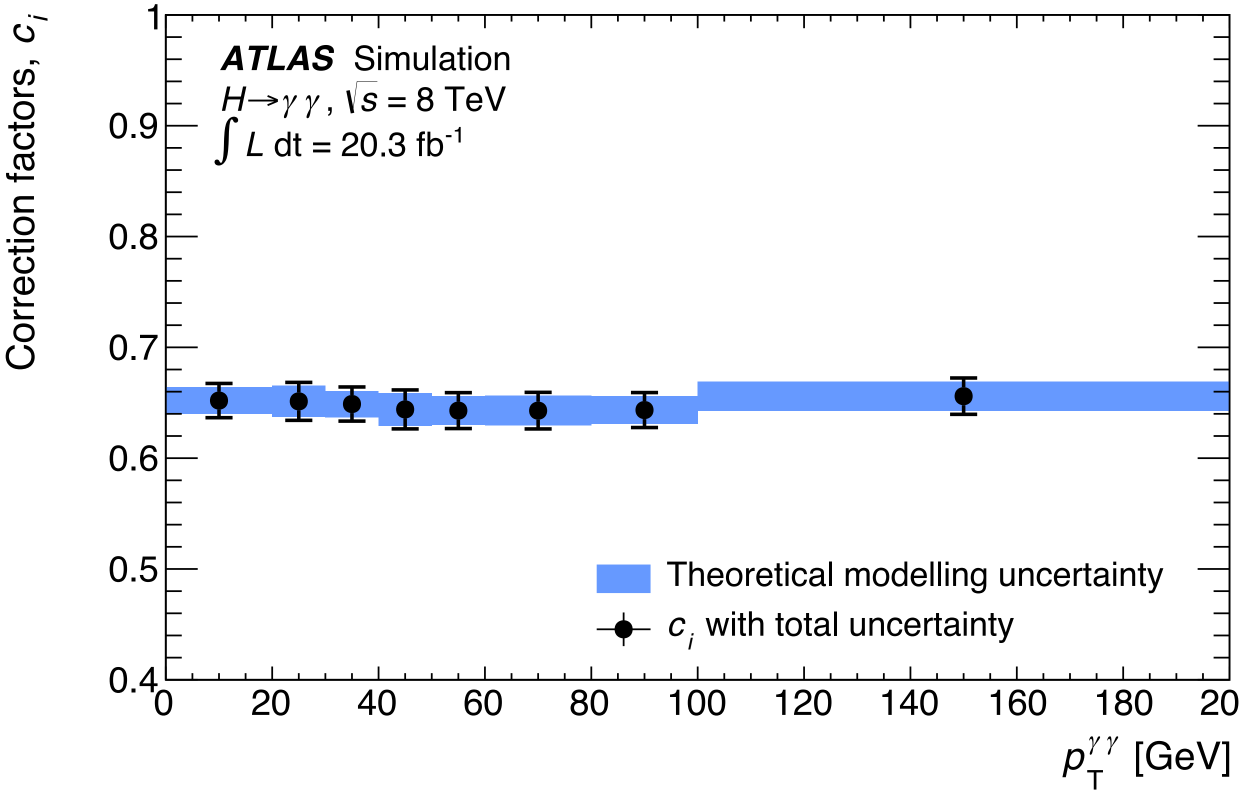
Reducible background (jets fake one or more leptons) estimated from data in control regions

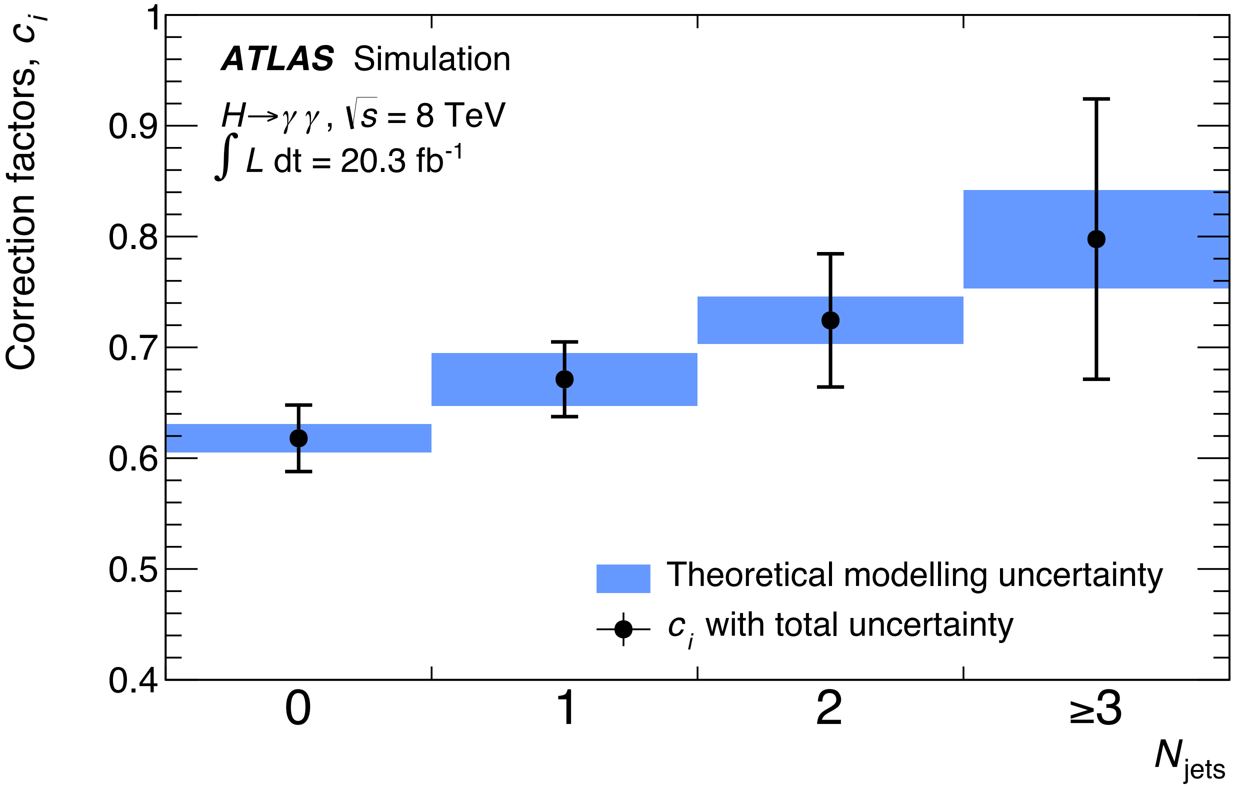
In 8 TeV data
34 data events in signal window: 118-129 GeV
After subtracting background
→ **25.1 signal events**

ATLAS
$pp \rightarrow H \rightarrow \gamma\gamma$, $\sqrt{s}$ = 8 TeV
$\int L\,dt$ = 20.3 fb^{-1}
m_H = 125.4 GeV
$N_{\rm jets}$ = 0, $p_T^{\rm jet}$ > 30 GeV
$N_{\rm jets}$ = 1, $p_T^{\rm jet}$ > 30 GeV
$N_{\rm jets}$ = 2, $p_T^{\rm jet}$ > 30 GeV
$N_{\rm jets}$ ≥ 3, $p_T^{\rm jet}$ > 30 GeV
data
s+b fit
background, b
Events / GeV
data - b
$m_{\gamma\gamma}$ [GeV]
110
120
130
140
150
160
500
1000
1500
2000
2500
200
400
600
800
1000
50
100
150
200
250
300
20
40
60
80
100
120
-100
0
100
-50
0
50
100
-50
0
50
-20
0
20

Correction for detector effects

aka unfolding



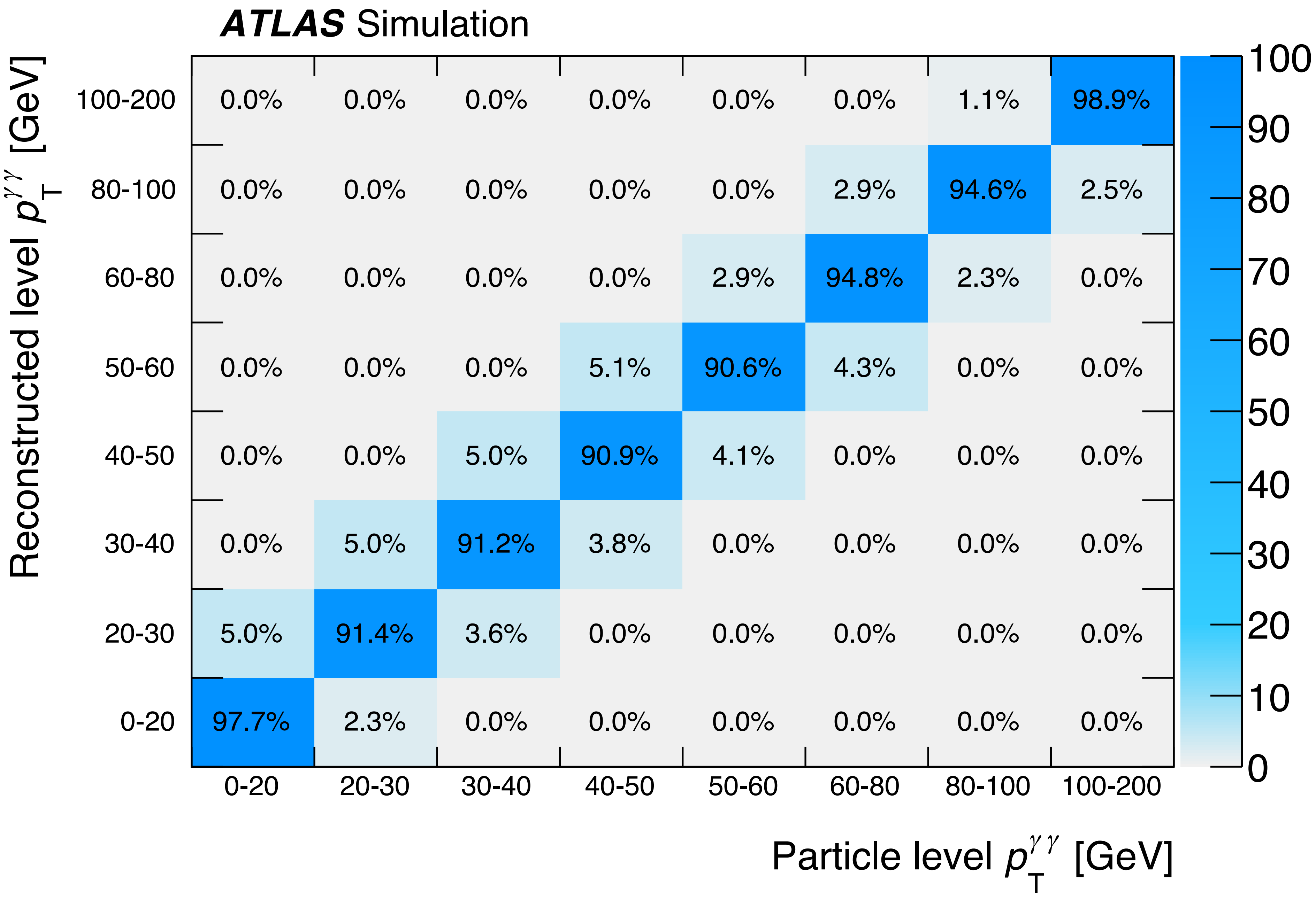


Defined as $N_{\text{reconstructed}}$ / $N_{\text{particle-level}}$ in each bin

Driven by photon reconstruction efficiency:
~80% per photon → 64% probability that both photons get reconstructed

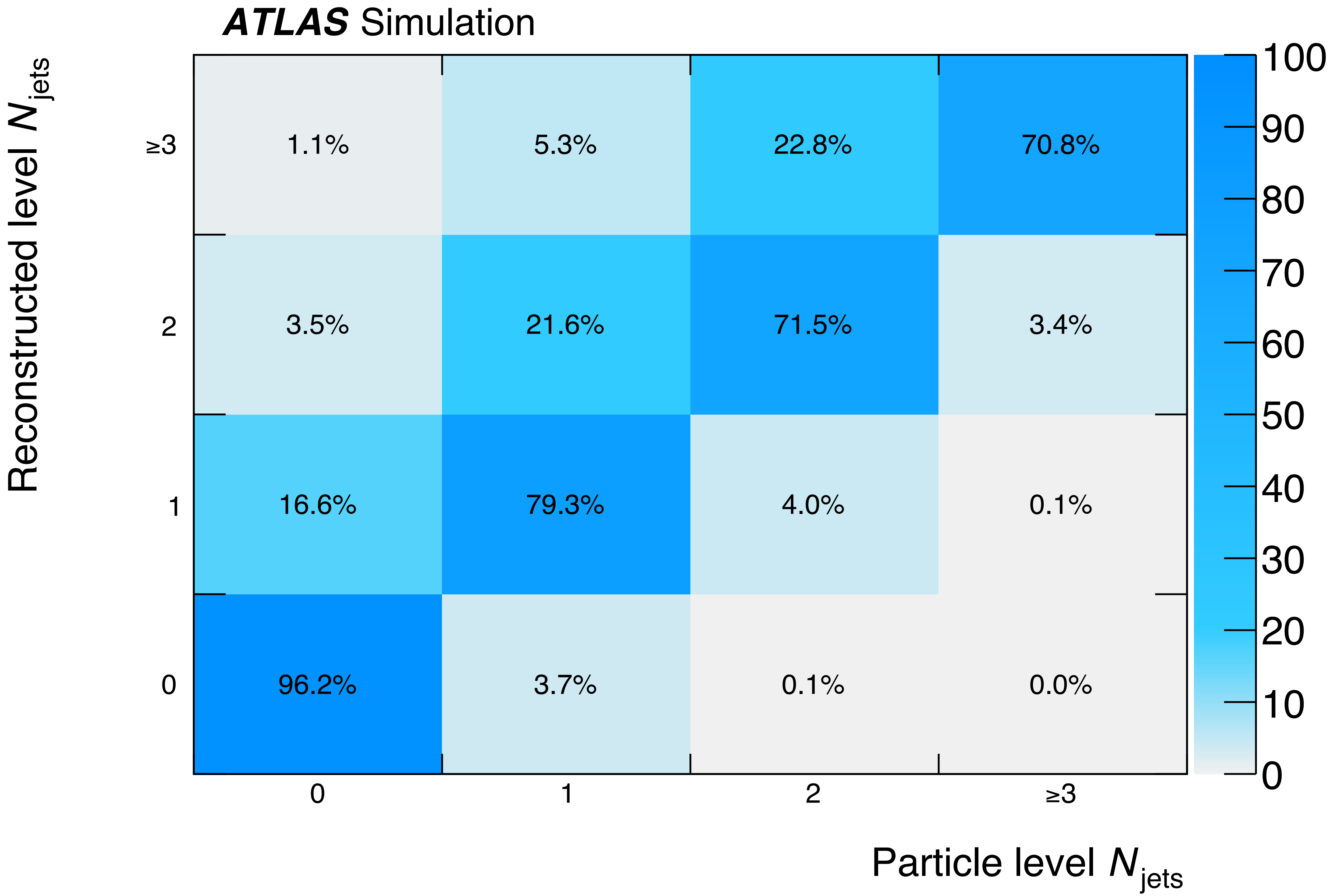
Also account for bin-migration.
→ Very small effect for photon/lepton defined variables
→ Sizeable for jet-based observables due to JES/JER and pileup
(see larger to the right)

Correction for detector effects

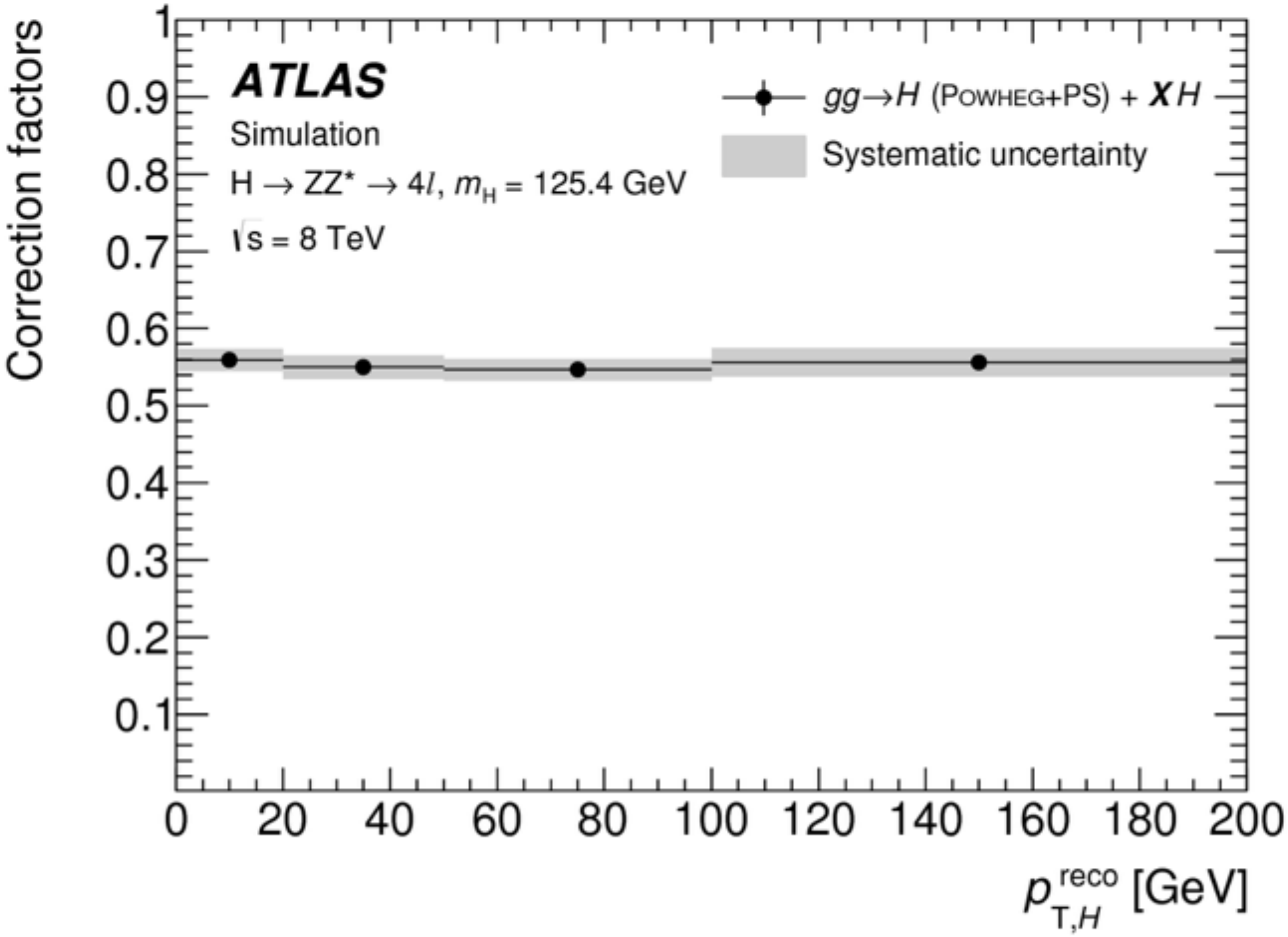


100-200	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.1%	98.9%
80-100	0.0%	0.0%	0.0%	0.0%	0.0%	2.9%	94.6%	2.5%
60-80	0.0%	0.0%	0.0%	0.0%	2.9%	94.8%	2.3%	0.0%
50-60	0.0%	0.0%	0.0%	5.1%	90.6%	4.3%	0.0%	0.0%
40-50	0.0%	0.0%	5.0%	90.9%	4.1%	0.0%	0.0%	0.0%
30-40	0.0%	5.0%	91.2%	3.8%	0.0%	0.0%	0.0%	0.0%
20-30	5.0%	91.4%	3.6%	0.0%	0.0%	0.0%	0.0%	0.0%
0-20	97.7%	2.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	0-20	20-30	30-40	40-50	50-60	60-80	80-100	100-200

Correction for detector effects

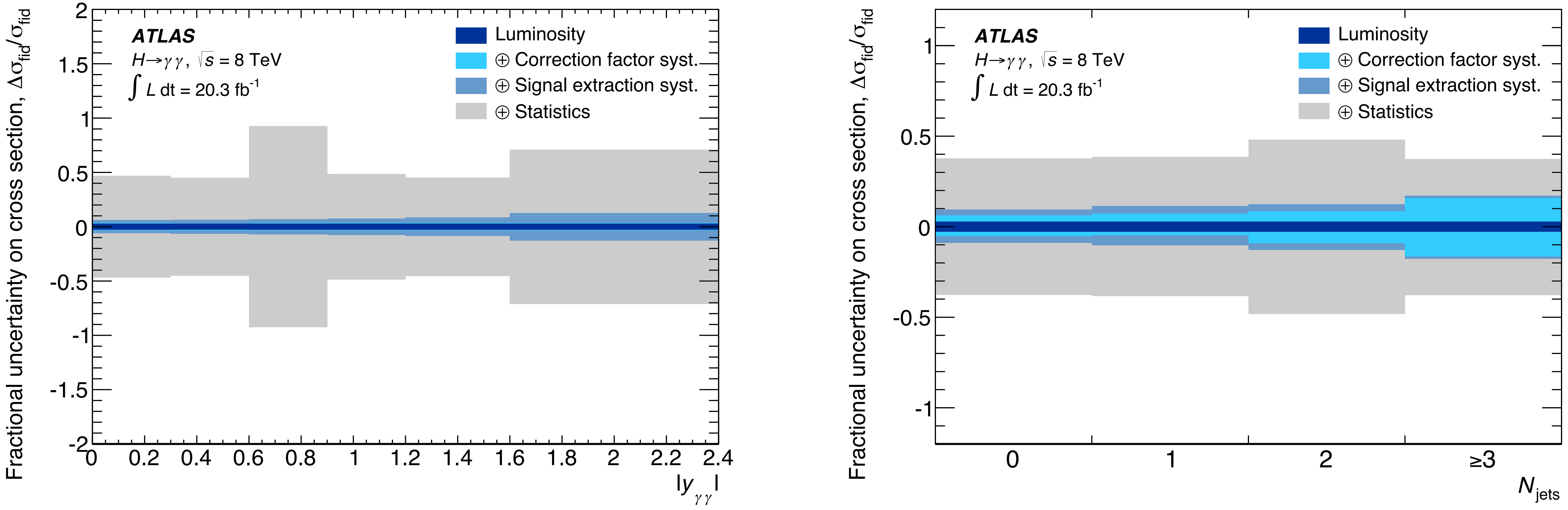


Correction for detector effects



Similar for ZZ: higher reconstruction efficiency per lepton but there are 4 of them, hence slightly larger overall correction for dector effects

Uncertainties

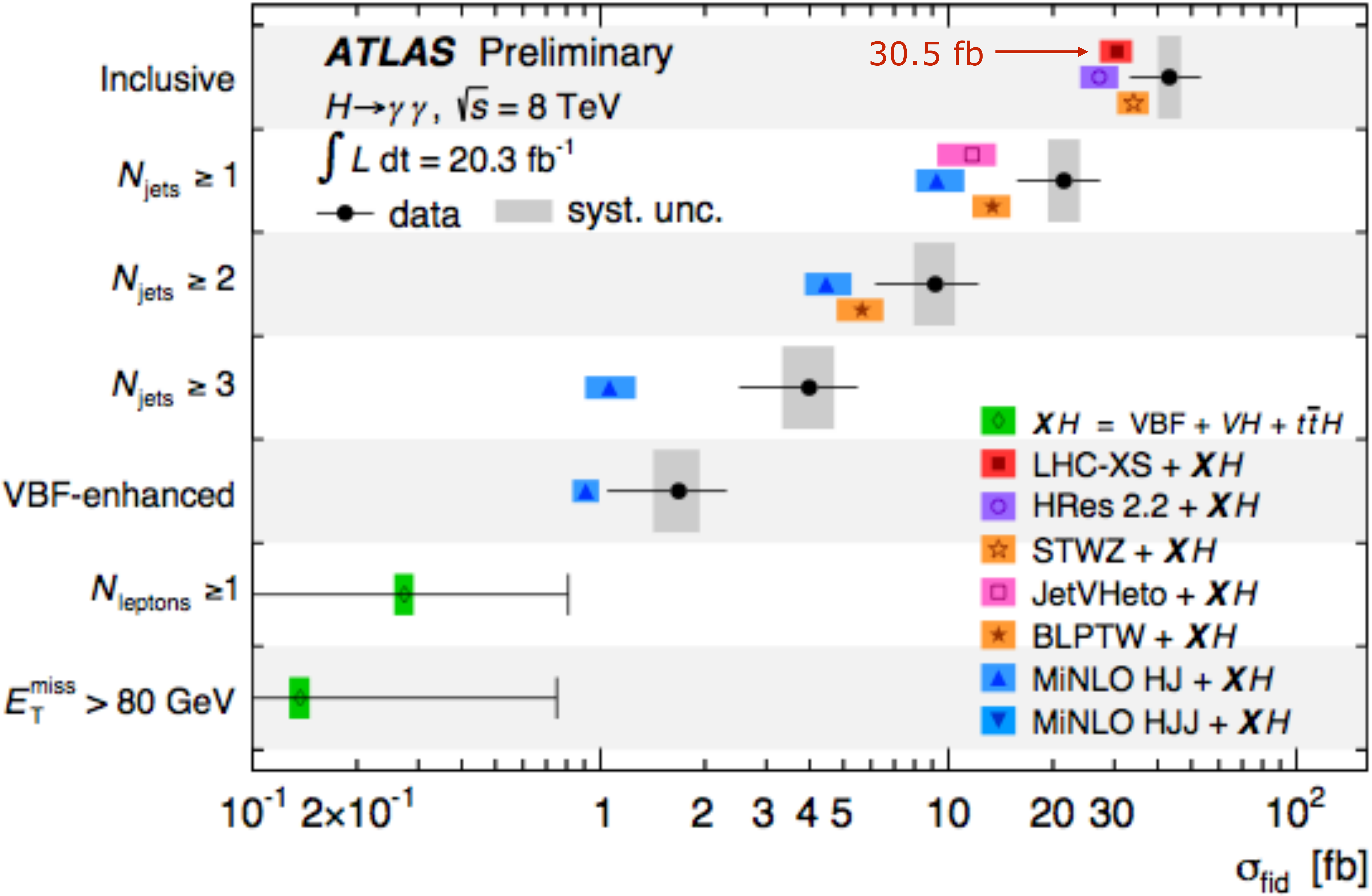


Completely dominated by the statistical uncertainty.
This picture will change in Run II…

Now. Let’s jump to the results!

$H\to\gamma\gamma$ fiducial cross sections

Our measurement: 43.2 +/-9.4 +/-3.2 pb

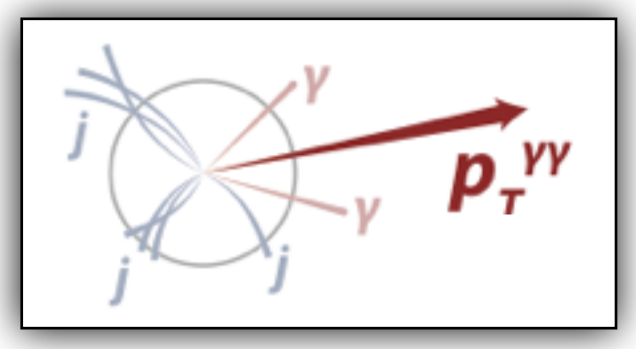


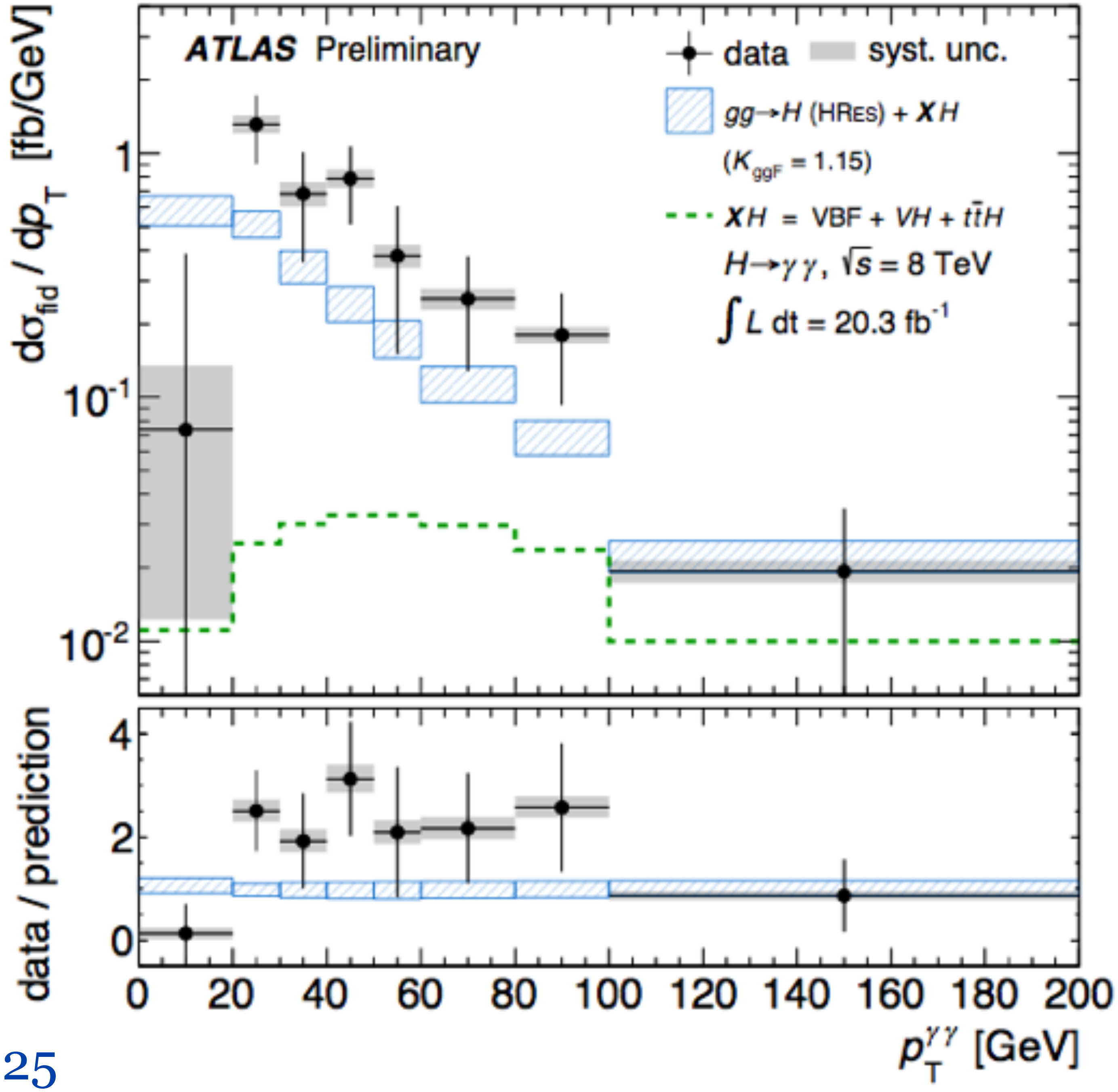
Fiducial region	Measured cross section (fb)
Baseline	$43.2 \pm 9.4\,(\text{stat.})\,^{+3.2}_{-2.9}\,(\text{syst.}) \pm 1.2\,(\text{lumi})$
$N_{\text{jets}} \geq 1$	$21.5 \pm 5.3\,(\text{stat.})\,^{+2.4}_{-2.2}\,(\text{syst.}) \pm 0.6\,(\text{lumi})$
$N_{\text{jets}} \geq 2$	$9.2 \pm 2.8\,(\text{stat.})^{+1.3}_{-1.2}\,(\text{syst.}) \pm 0.3\,(\text{lumi})$
$N_{\text{jets}} \geq 3$	$4.0 \pm 1.3\,(\text{stat.}) \pm 0.7\,(\text{syst.}) \pm 0.1\,(\text{lumi})$
VBF-enhanced	$1.68 \pm 0.58\,(\text{stat.})^{+0.24}_{-0.25}\,(\text{syst.}) \pm 0.05\,(\text{lumi})$
$N_{\text{leptons}} \geq 1$	< 0.80
$E_{\text{T}}^{\text{miss}} > 80$ GeV	< 0.74

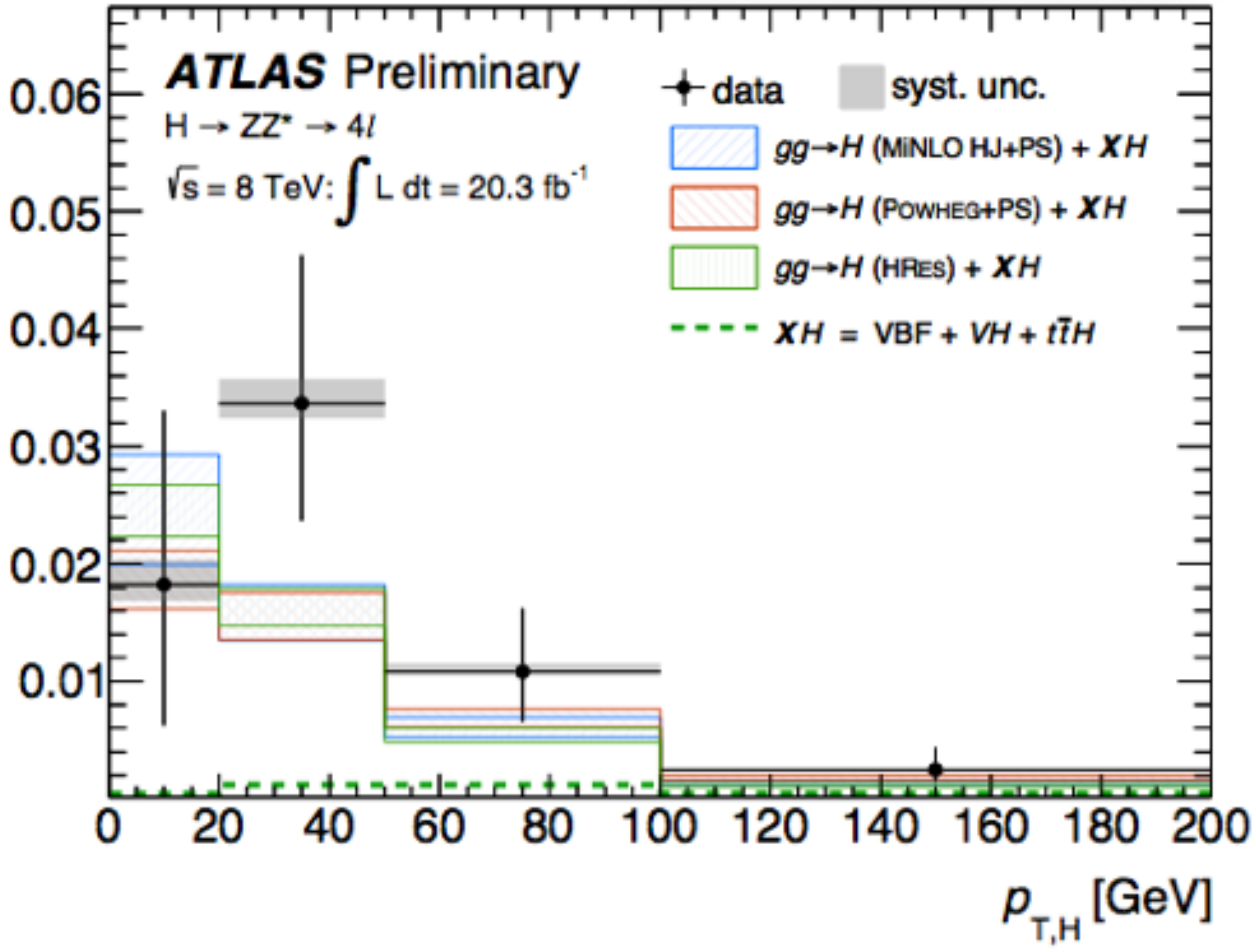
Fiducial region	Theoretical prediction (fb)	Source
Baseline	30.5 ± 3.3	LHC-XS [56] + XH
	$34.1\,^{+3.6}_{-3.5}$	STWZ [98] + XH
	$27.2\,^{+3.6}_{-3.2}$	HRES [102] + XH
$N_{\text{jets}} \geq 1$	13.8 ± 1.7	BLPTW [105] + XH
	$11.7\,^{+2.0}_{-2.4}$	JetVHeto [106]+ XH
	$9.3\,^{+1.8}_{-1.2}$	MINLO HJ+ XH
$N_{\text{jets}} \geq 2$	5.65 ± 0.87	BLPTW + XH
	$3.99\,^{+0.56}_{-0.59}$	MINLO HJJ+ XH
$N_{\text{jets}} \geq 3$	0.94 ± 0.15	MINLO HJJ+ XH
VBF-enhanced	0.87 ± 0.08	MINLO HJJ+ XH
$N_{\text{leptons}} \geq 1$	0.27 ± 0.02	XH
$E_{\text{T}}^{\text{miss}} > 80$ GeV	0.14 ± 0.01	XH

Transverse momentum

- Differential cross sections as a function of transverse momentum of the Higgs-like resonance compared with theory for the γγ (left) and ZZ (right) fiducial regions



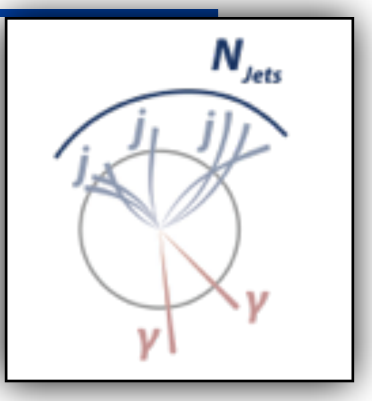




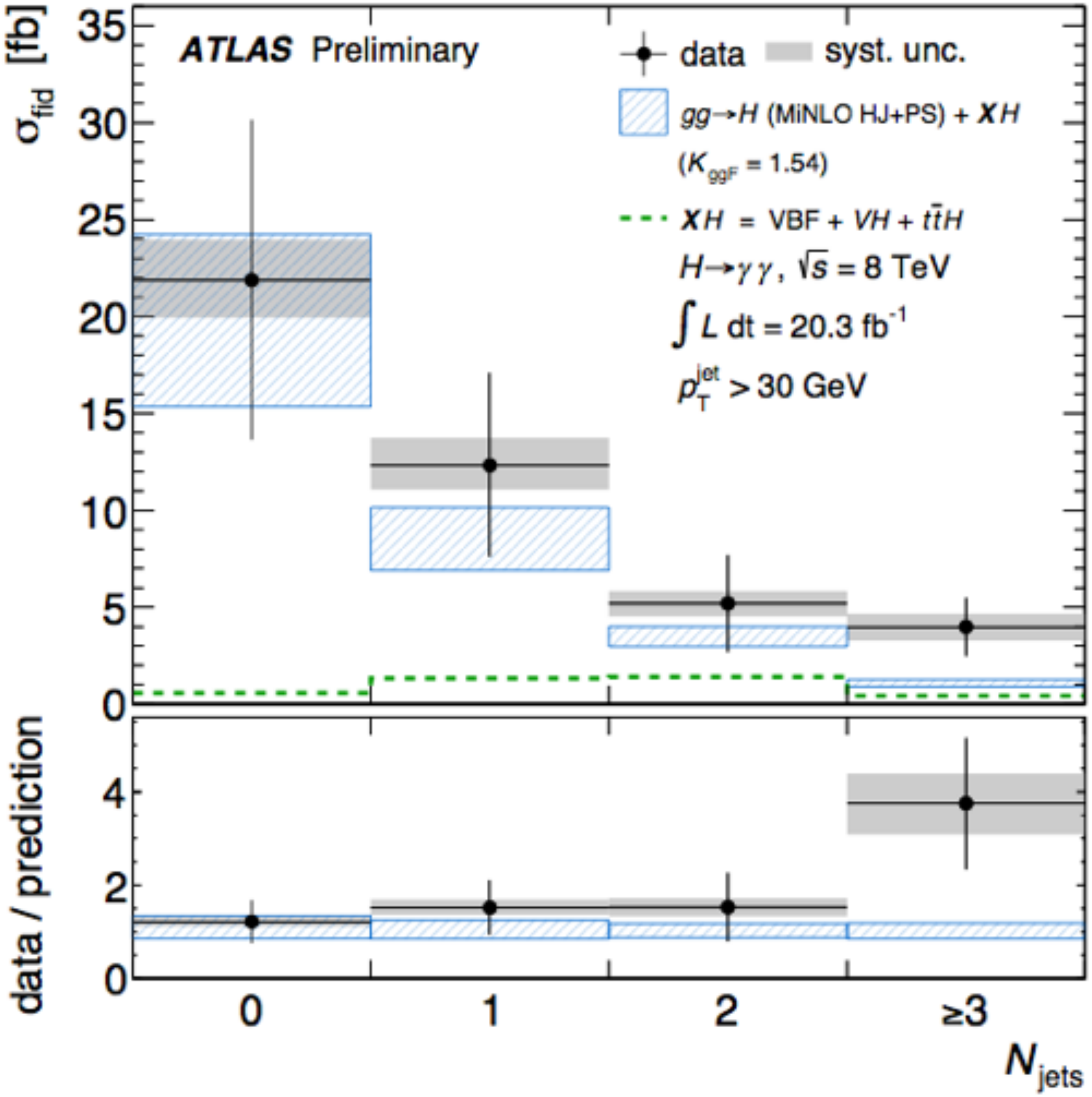
Consistent with SM theory predictions

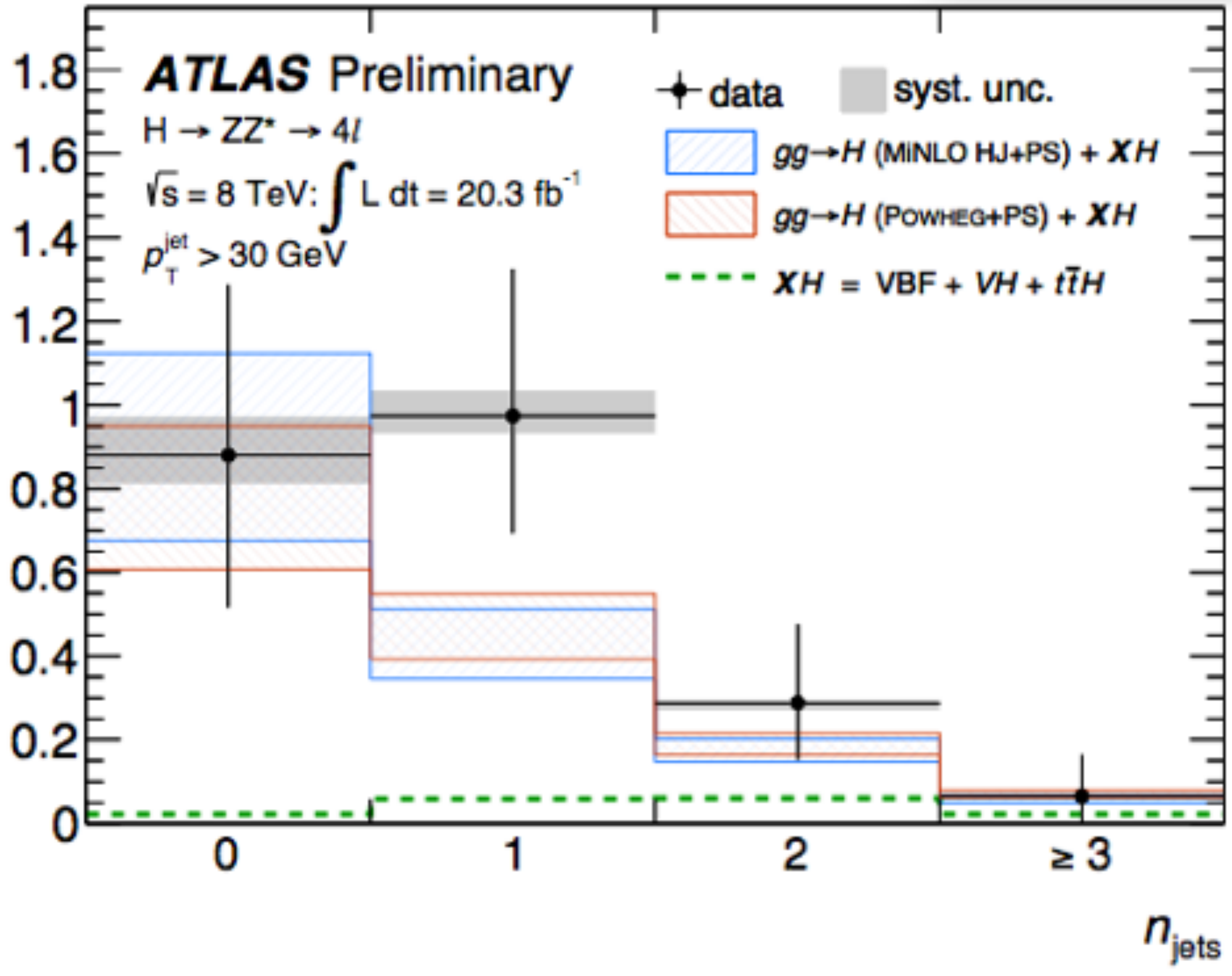
p-values 0.09-0.12 (γγ) 0.16-0.30 (ZZ)

Jet multiplicity



- Number of jets (anti-k_t $R = 0.4$) with $p_T > 30$ GeV and $|y|<4.4$ produced in association with the Higgs-like resonance
- ≥3 jets bin for *ZZ* only contain 1 event

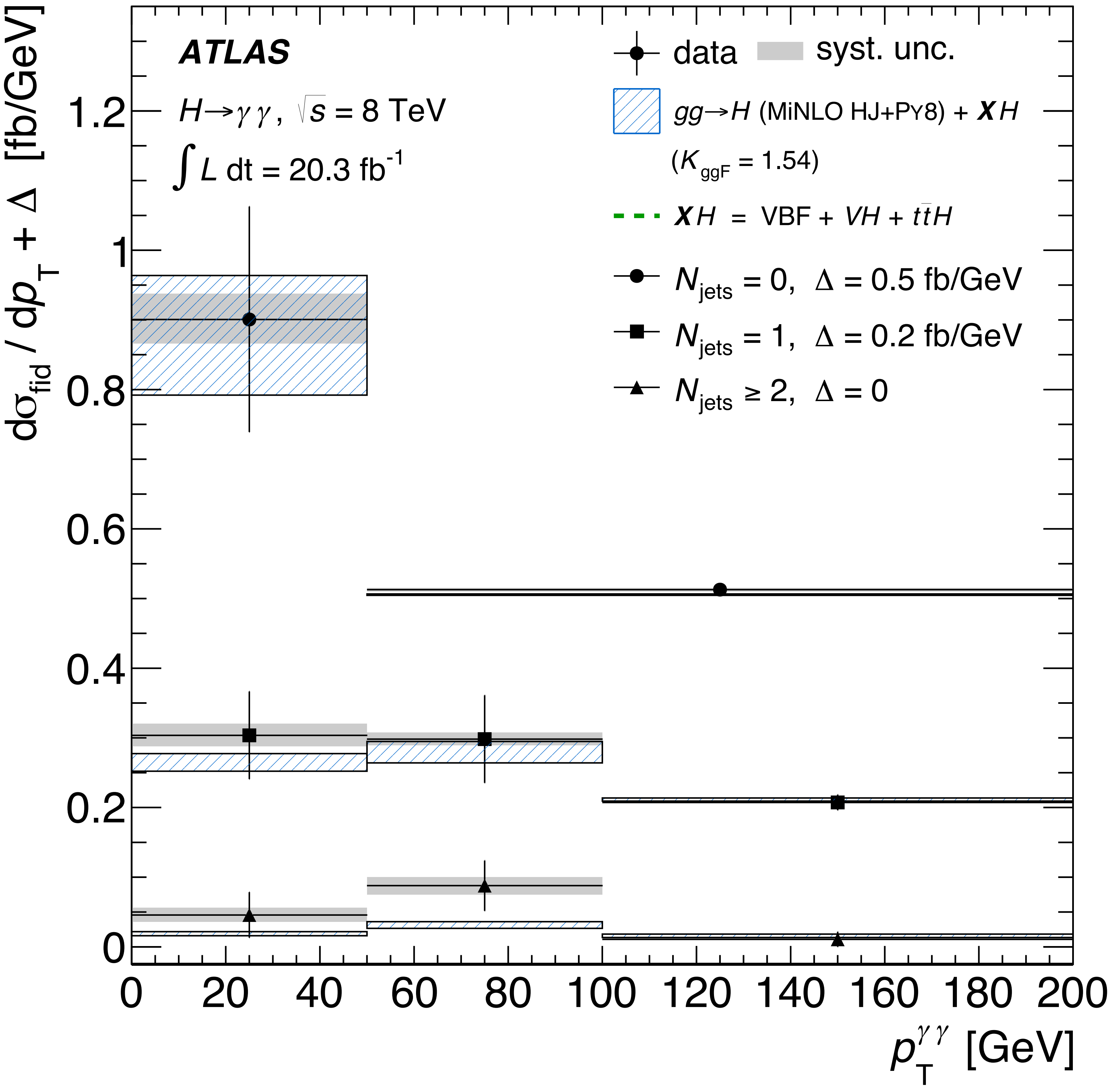




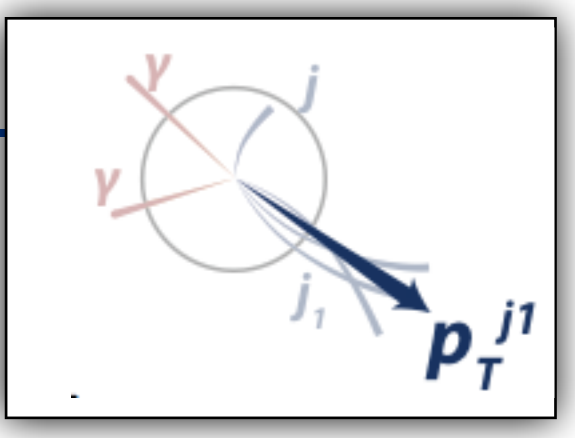
Consistent with SM theory predictions

p-values 0.30-0.42 (γγ) 0.28-0.37 (ZZ)

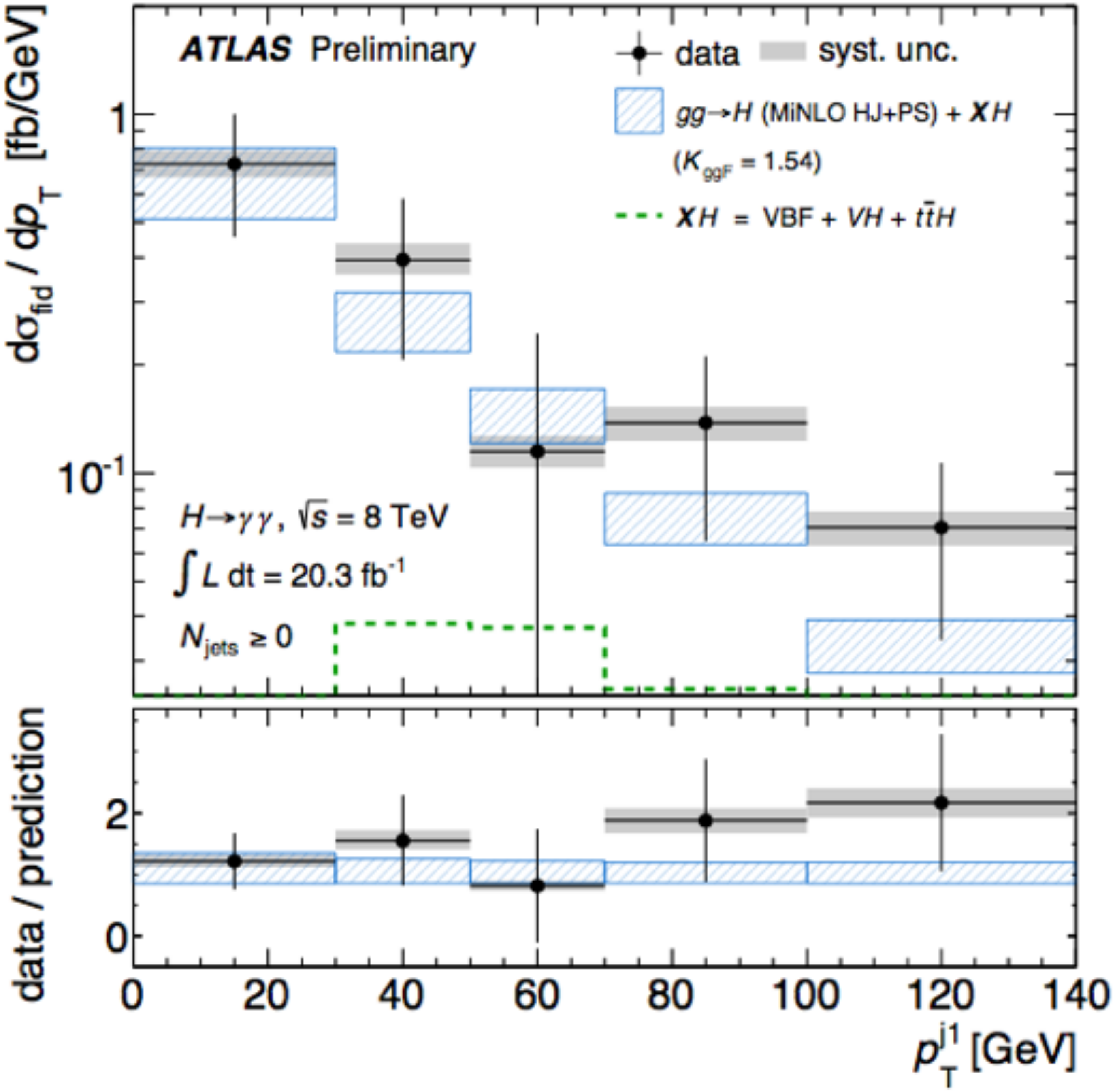
Higgs p_T in bins of N_{jets}

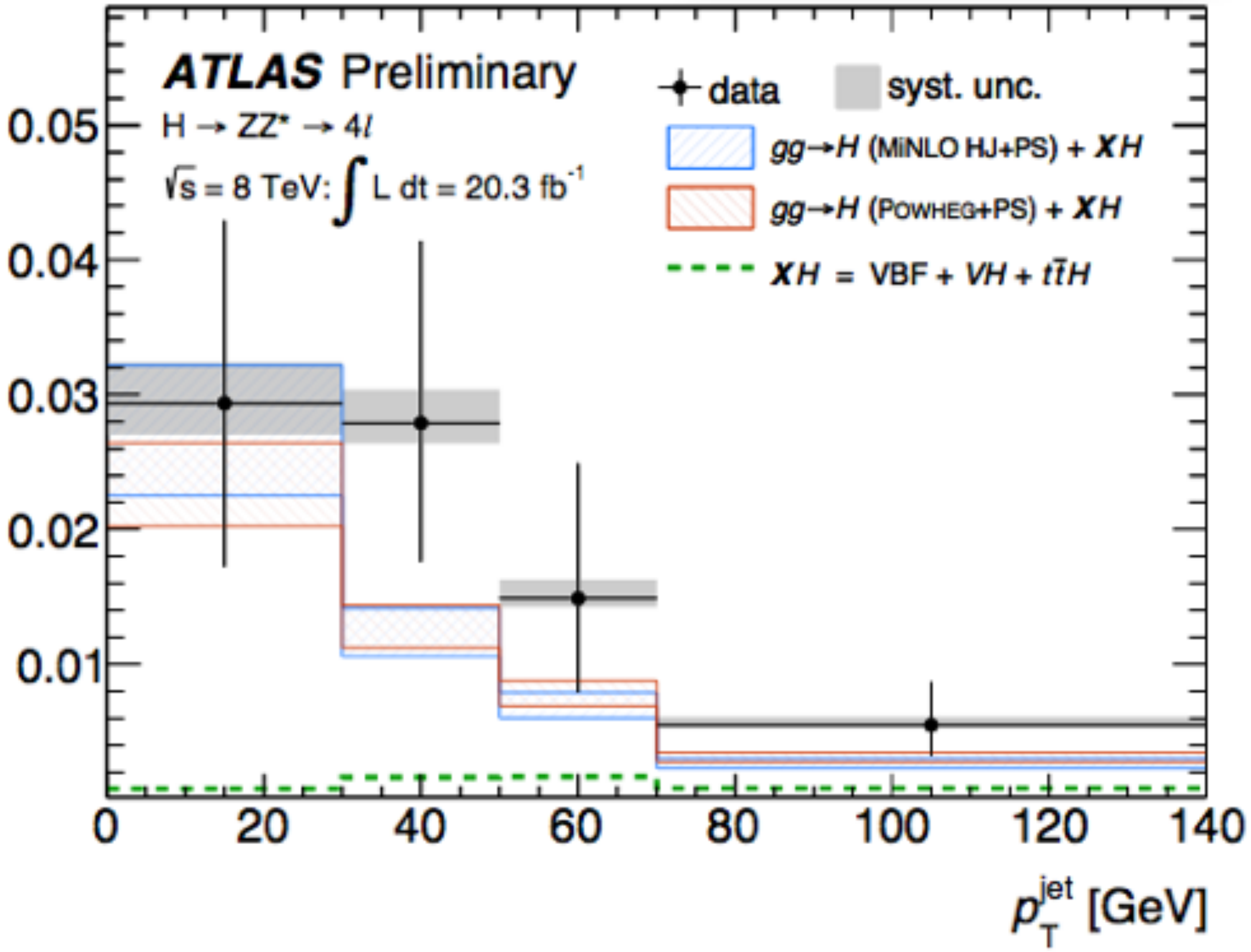


Leading jet p_T



- Transverse momentum of the leading jet produced in association with the Higgs boson (anti-k_t R = 0.4, $|y|<4.4$)
- The first bin contains the events with no jet with p_T > 30 GeV

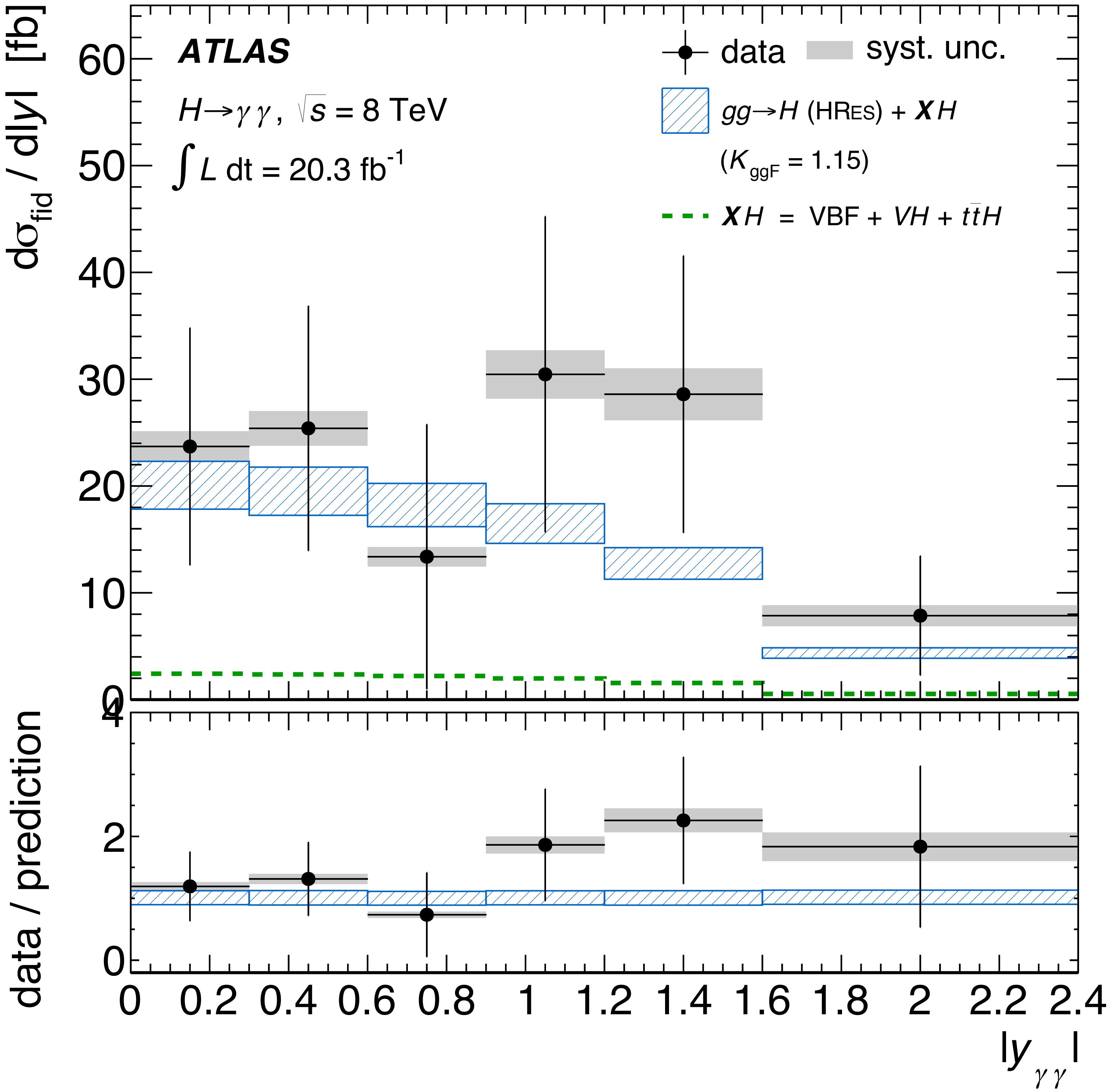


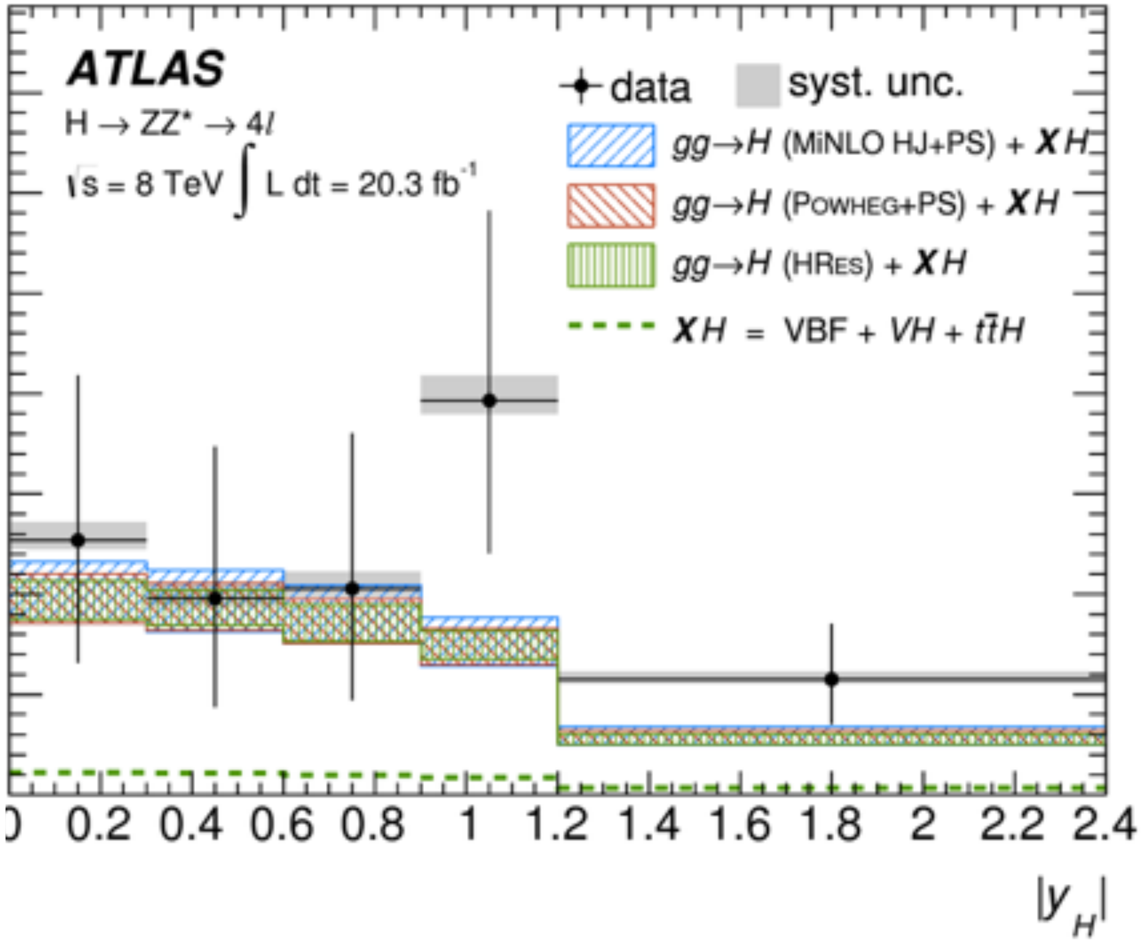


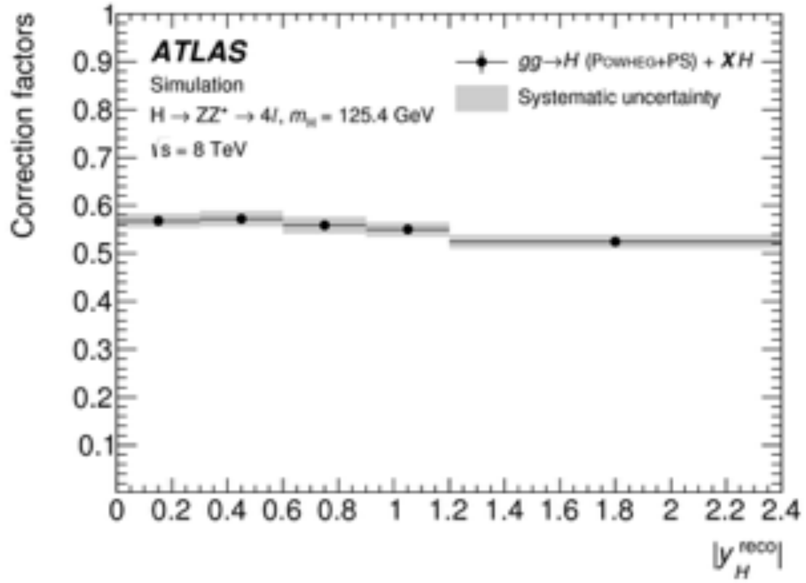
Consistent with SM theory predictions

p-values 0.79-0.84 (γγ) 0.26-0.33 (ZZ)

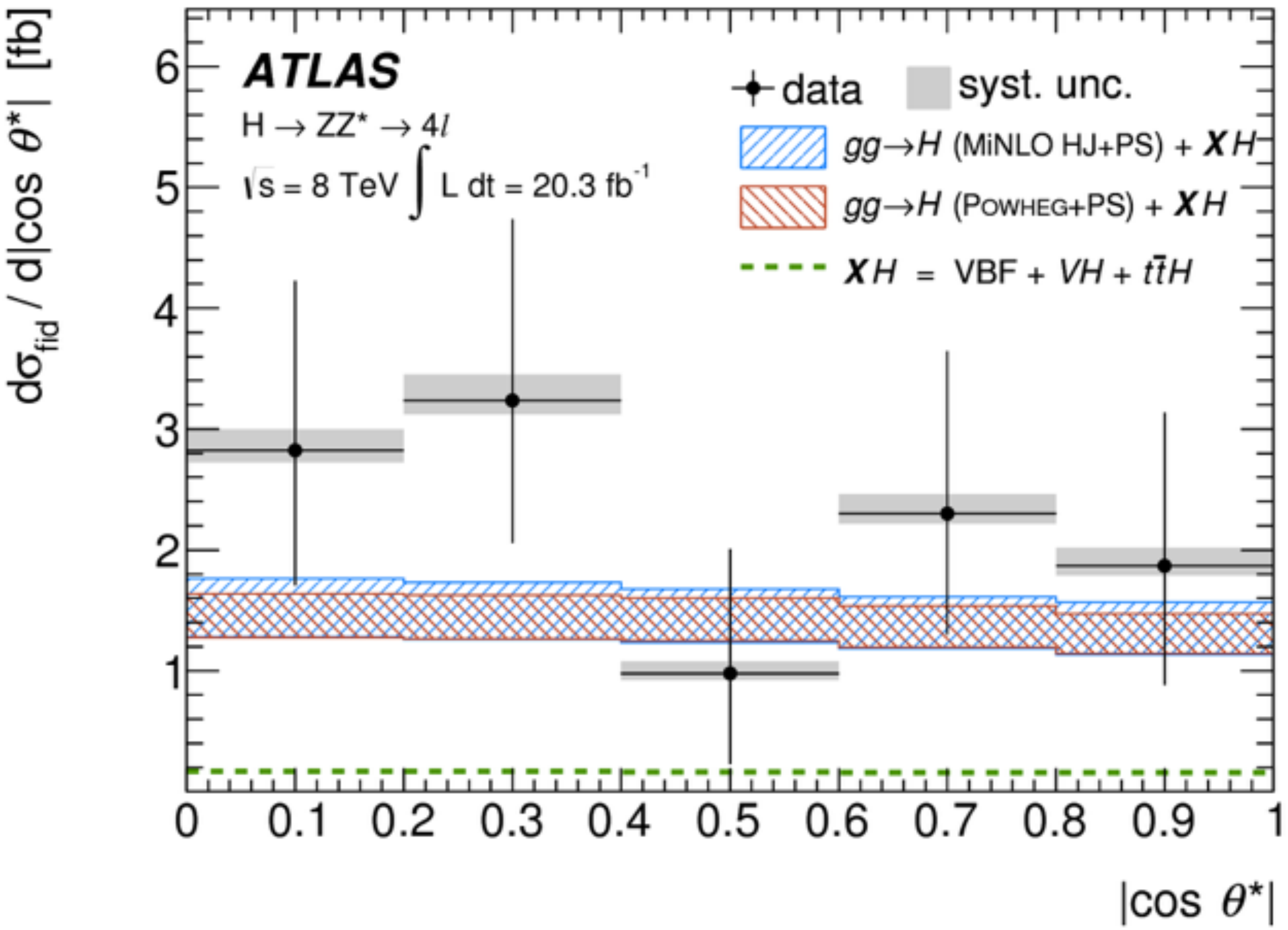
Higgs rapidity



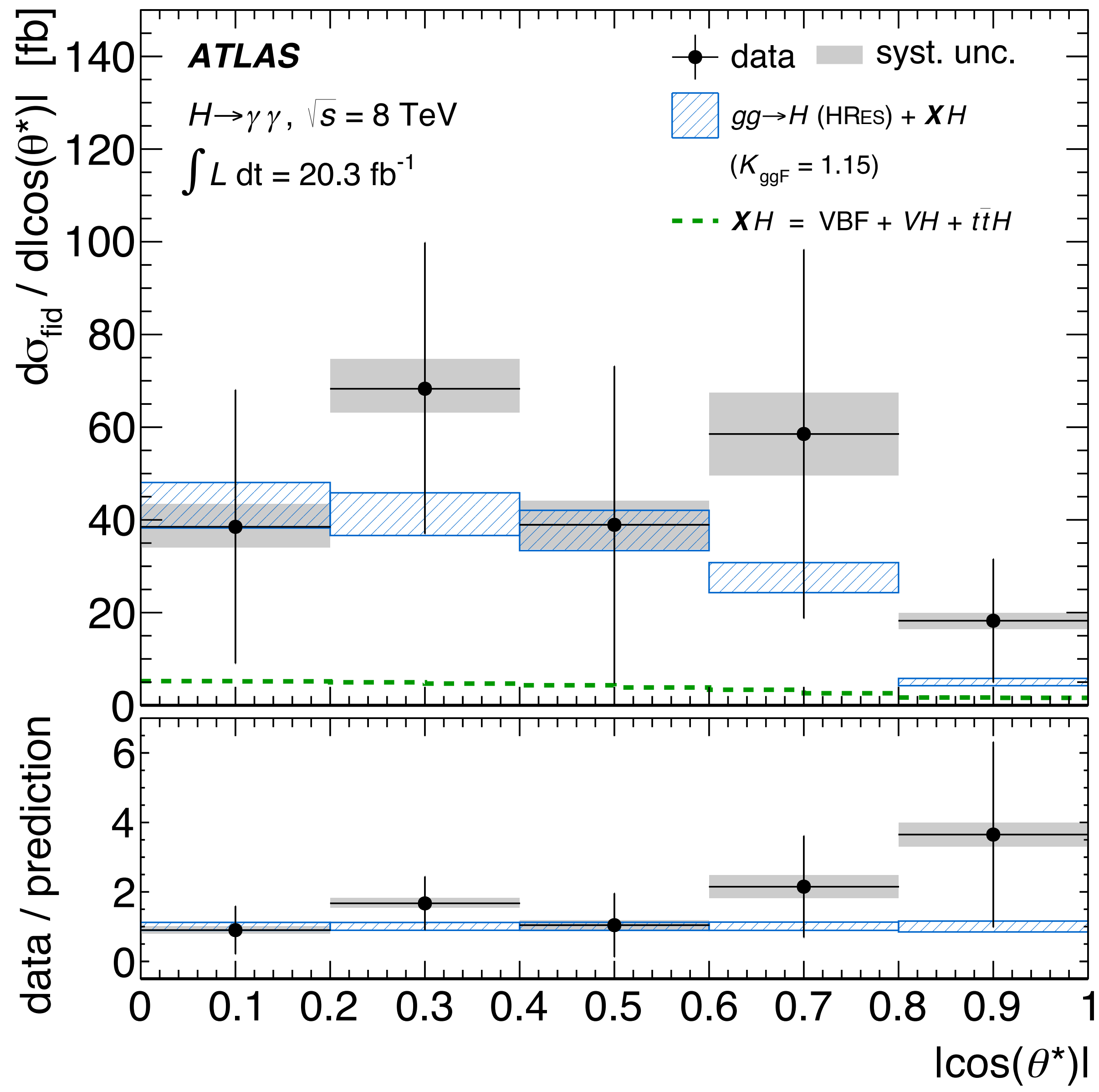


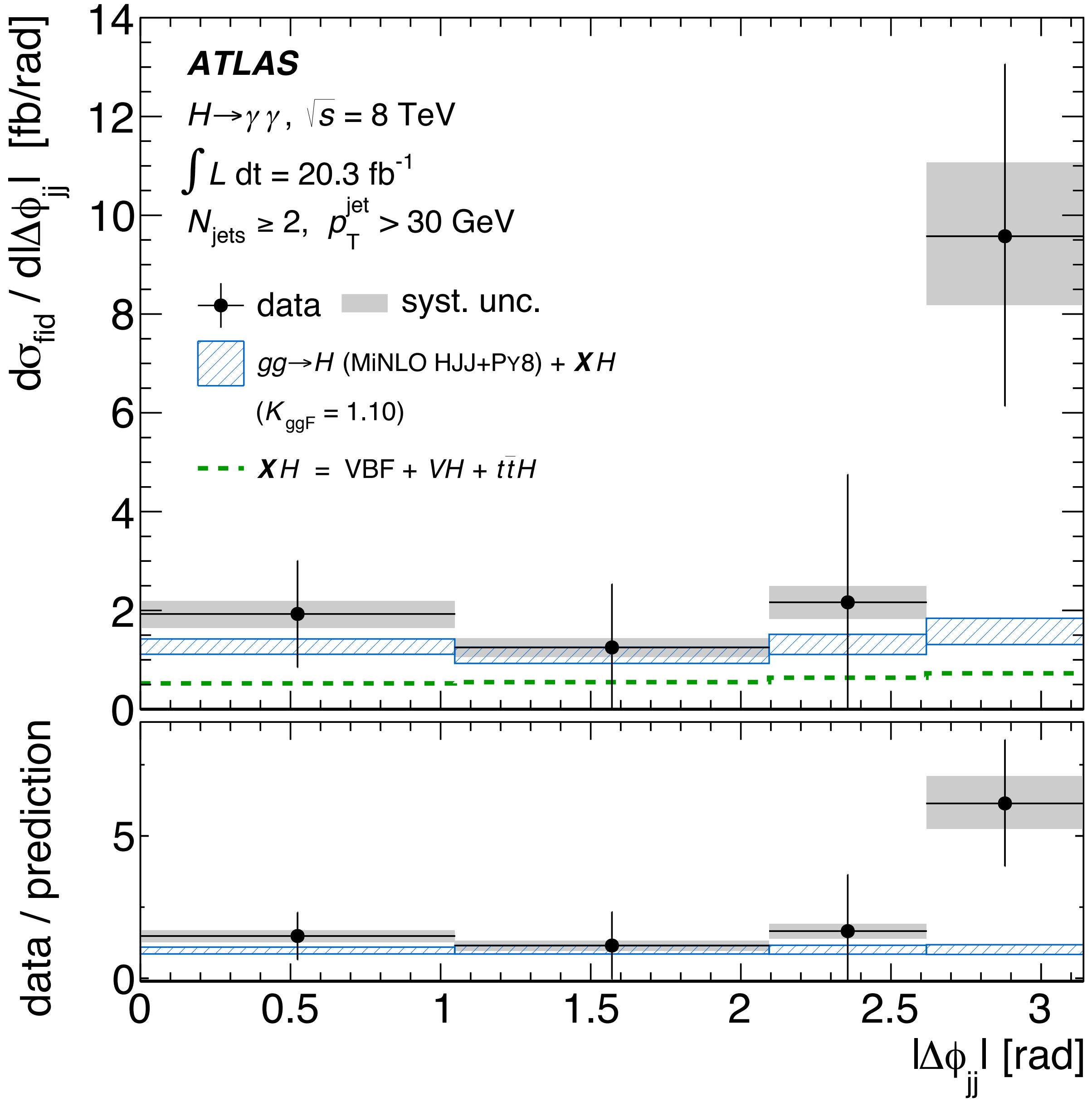


Spin-CP: cos θ^*

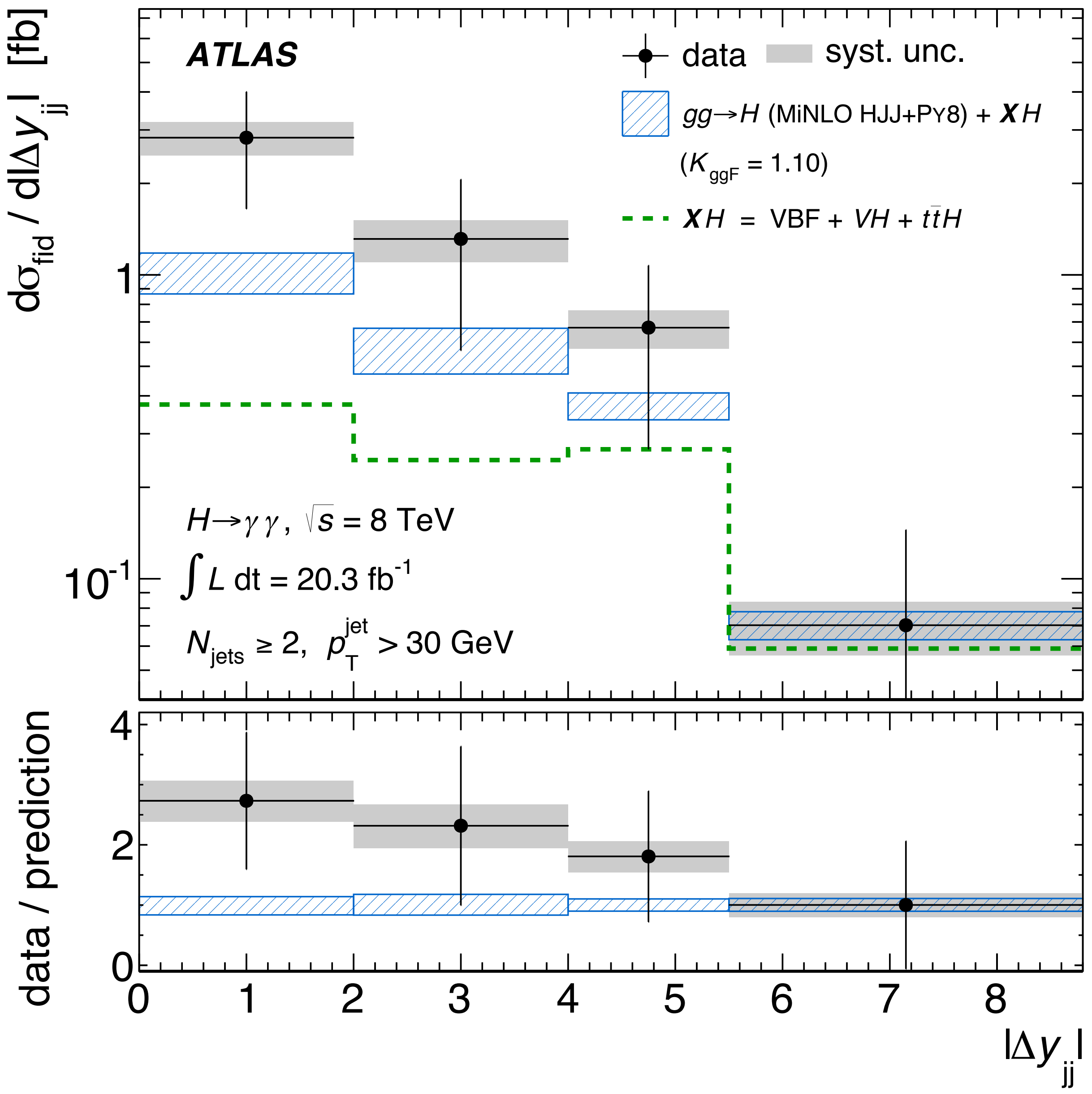


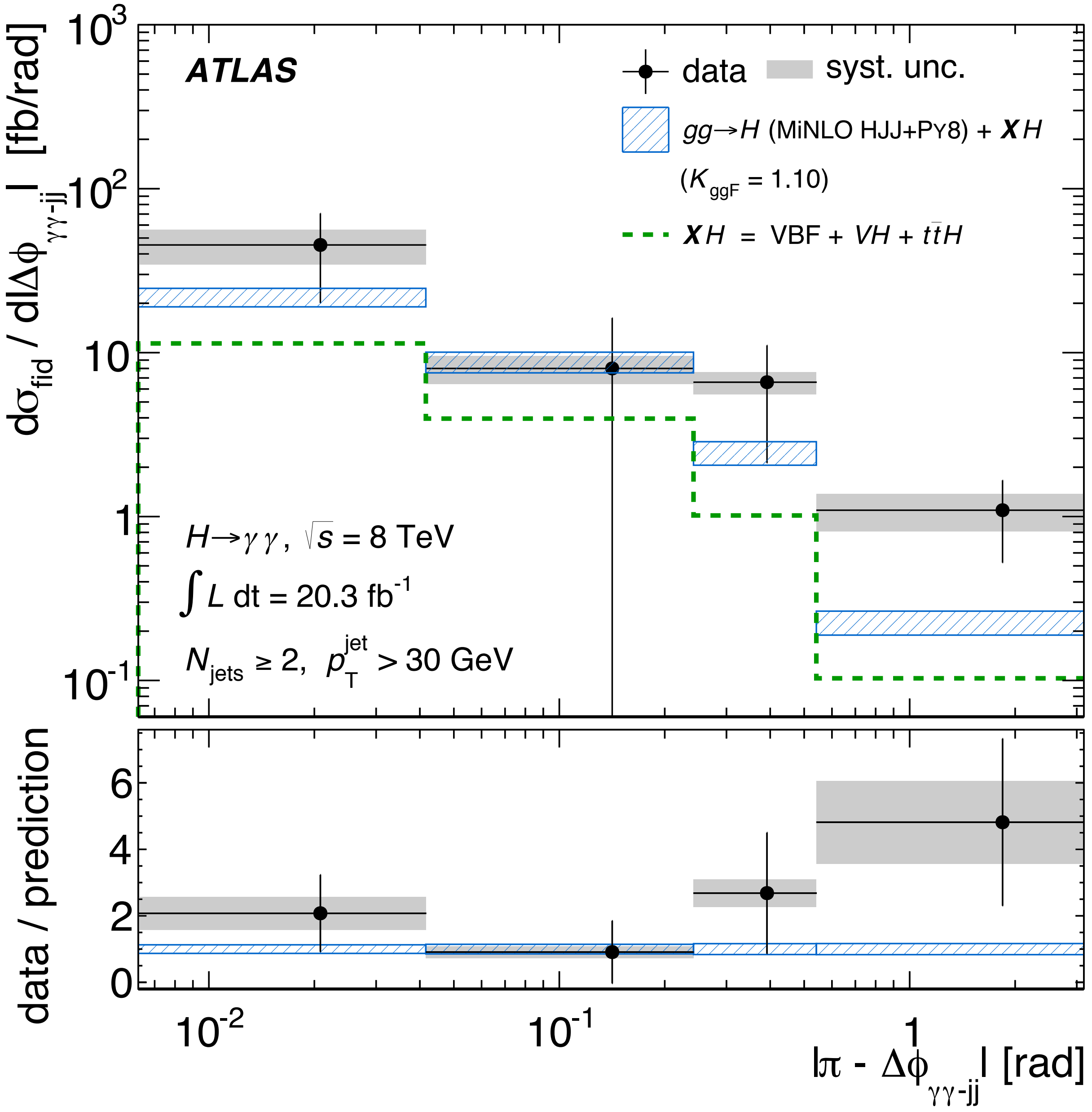
Spin-CP: cos θ* and Dphi(j,j)



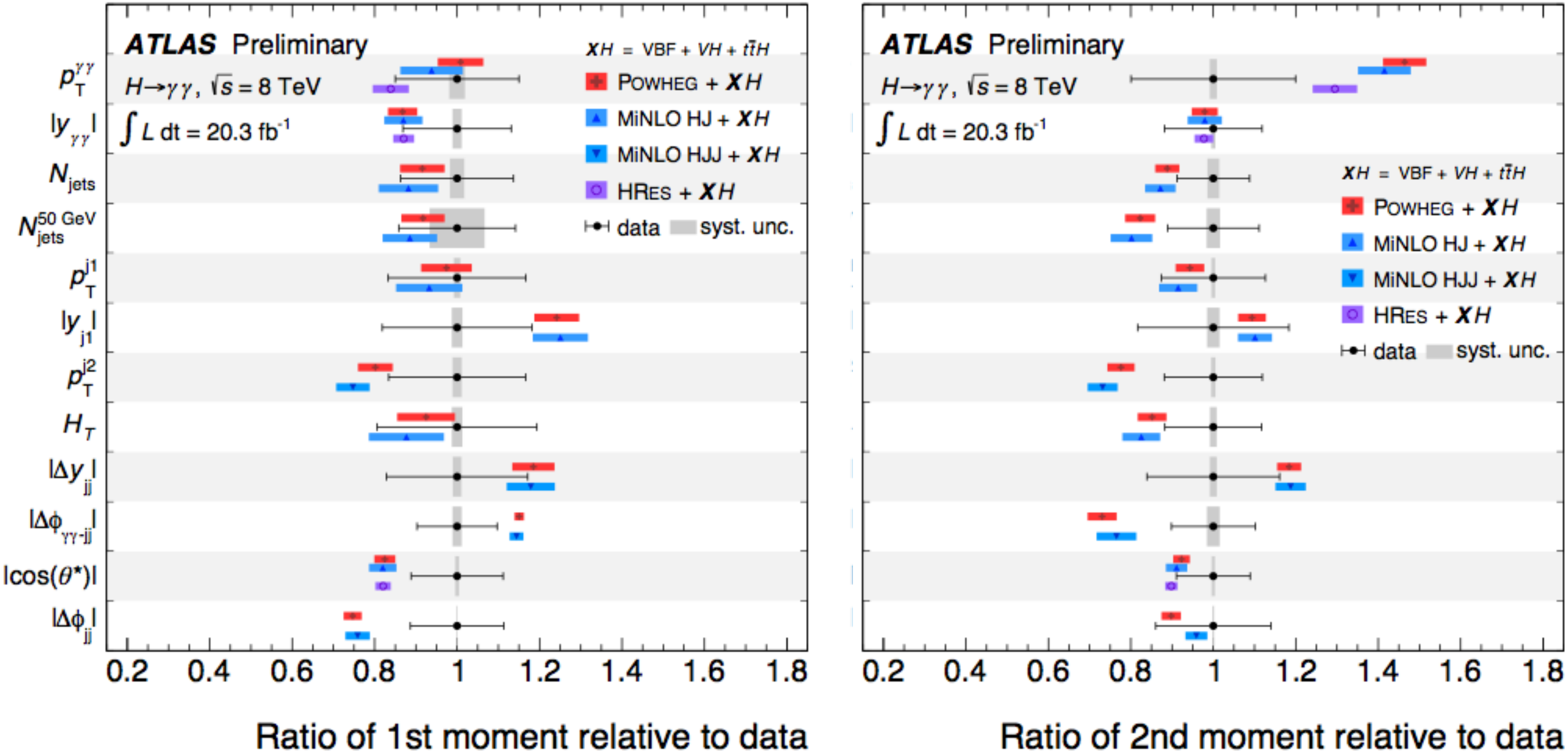


VBF variables





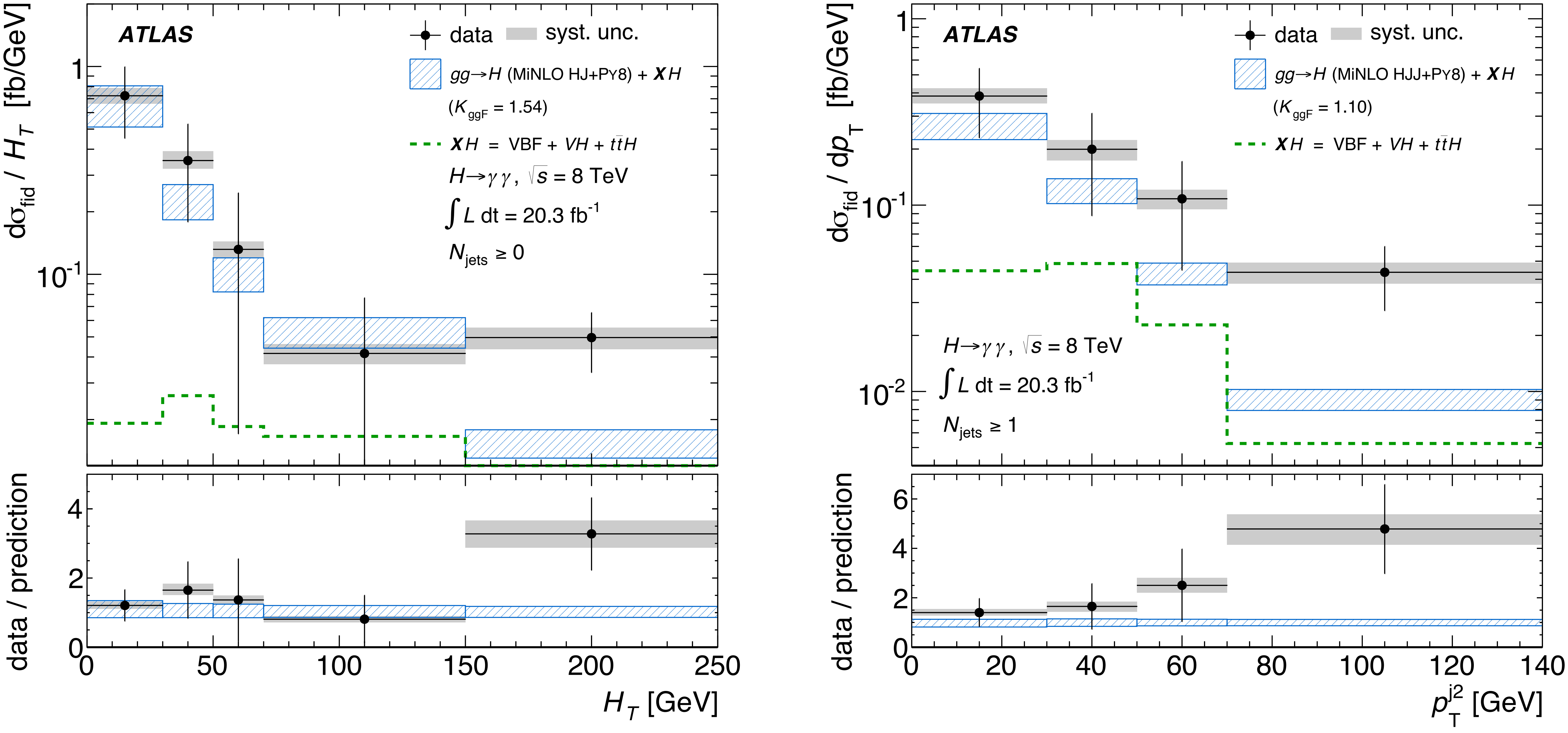
MC/data ratio of mean and mode of differential distributions



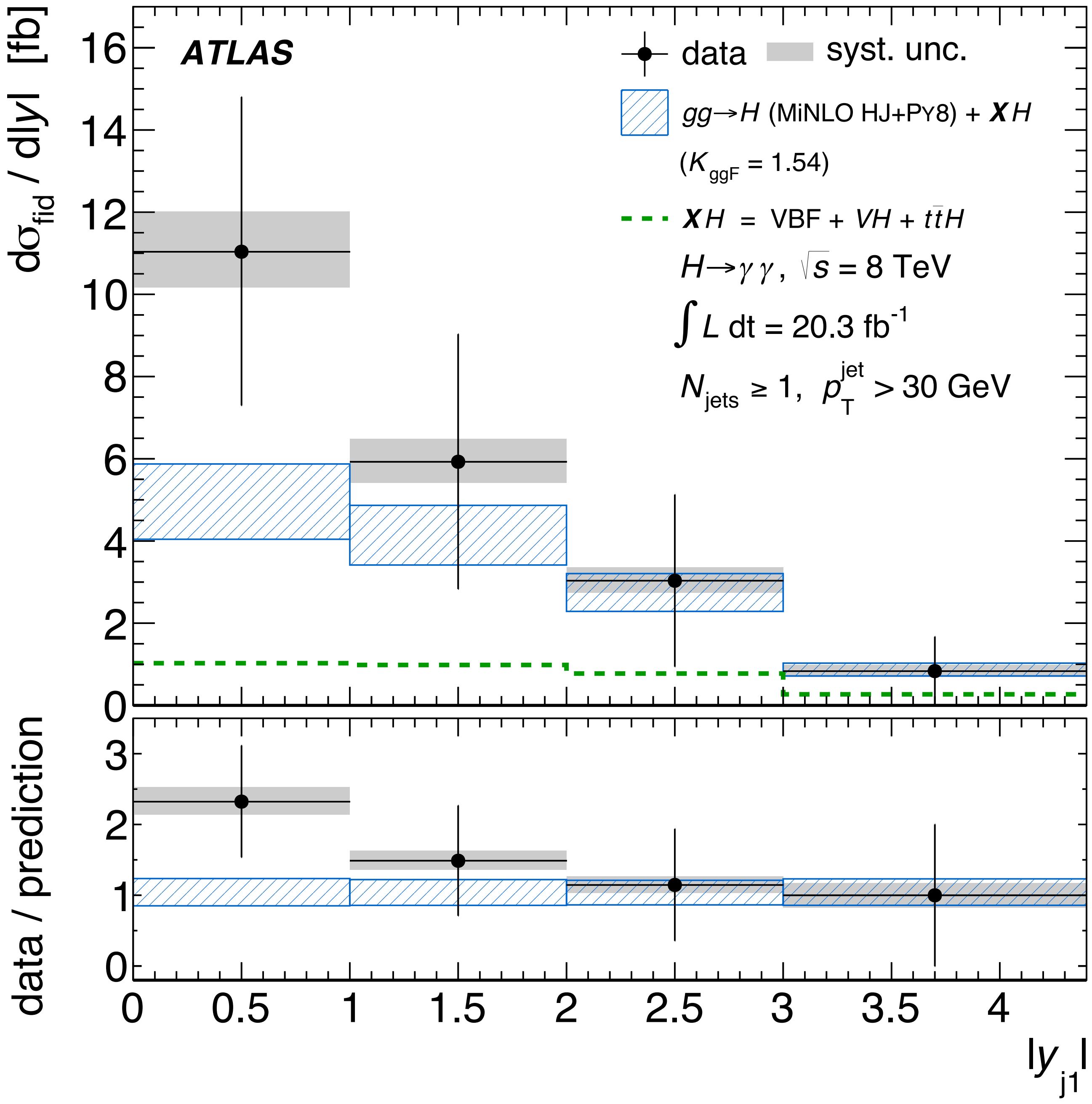
Summary

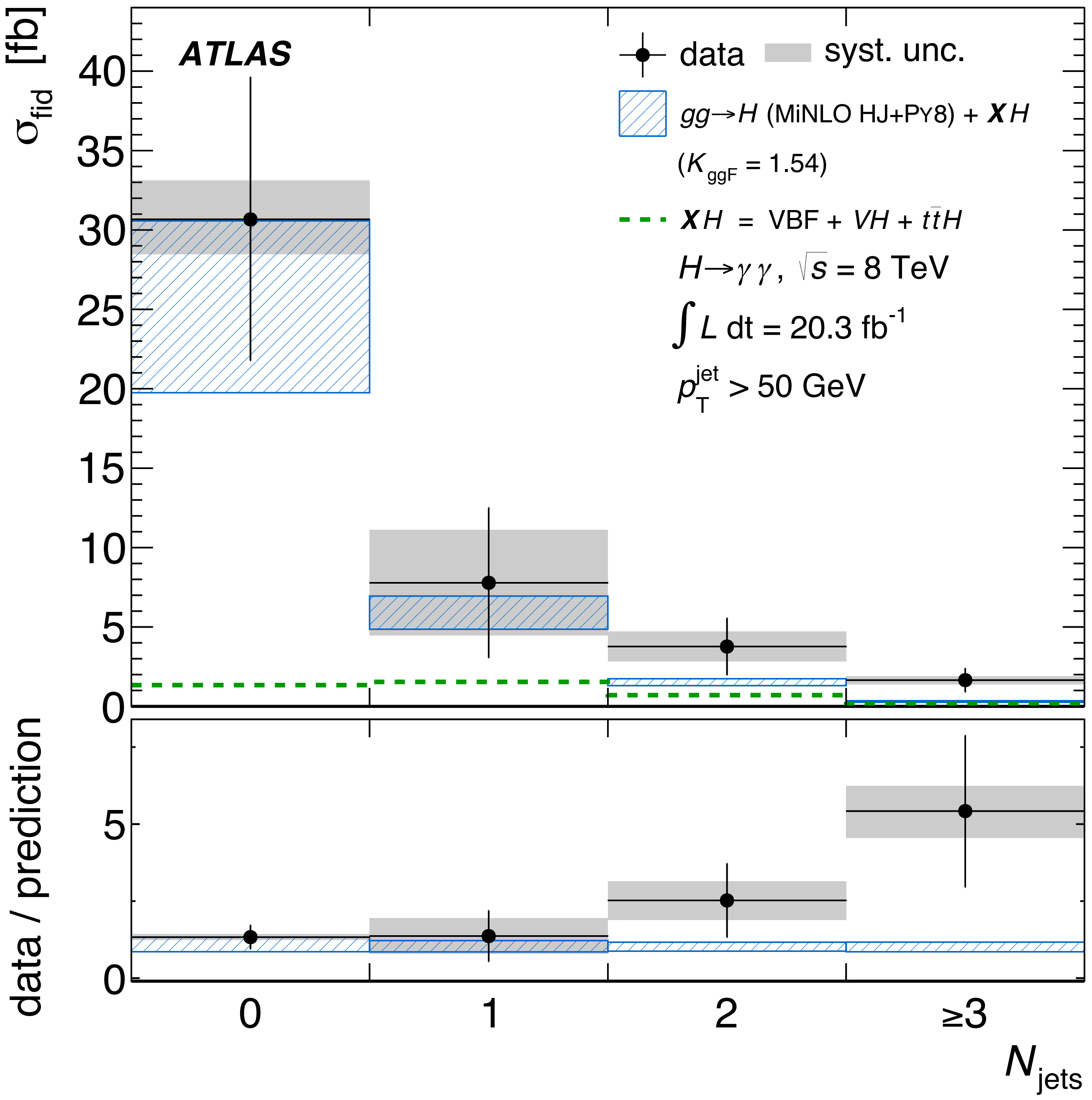
- Presented ATLAS 8 TeV γγ and ZZ differential measurements
- Can be directly compared with theory predictions: now and in the future
- (*γγ*, *ZZ* soon) Available in **HEPdata** and + dedicated **Rivet** routine
- Statistical uncertainty dominant. Expect about equal statistical precision with full 2015 dataset (10 fb^{-1} @ 13 TeV). By the end of Run II expect 100 fb^{-1} and x3 smaller uncertainties
- *γγ* and *ZZ* use the same bin edges, and can be combined if one adjust for the channel dependent a) branching ratio and b) the fiducial acceptance
- Can use measurements to constrain theory, see talk by …
- Happy birthday Florian!

Scalar pT sum and second jet pT



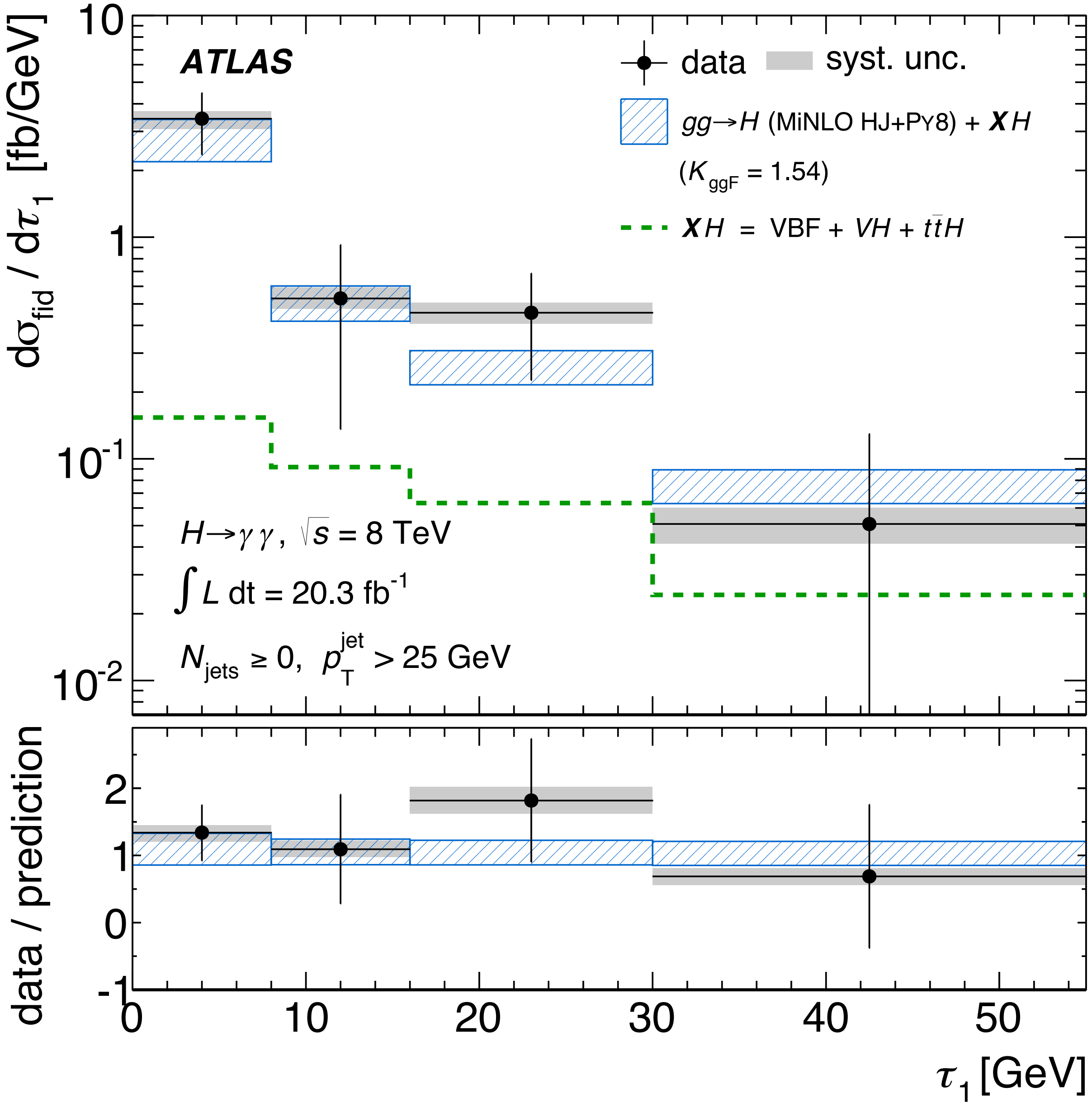
Leading jet rapidity, $N_{\text{jets}}(p_T>50)$

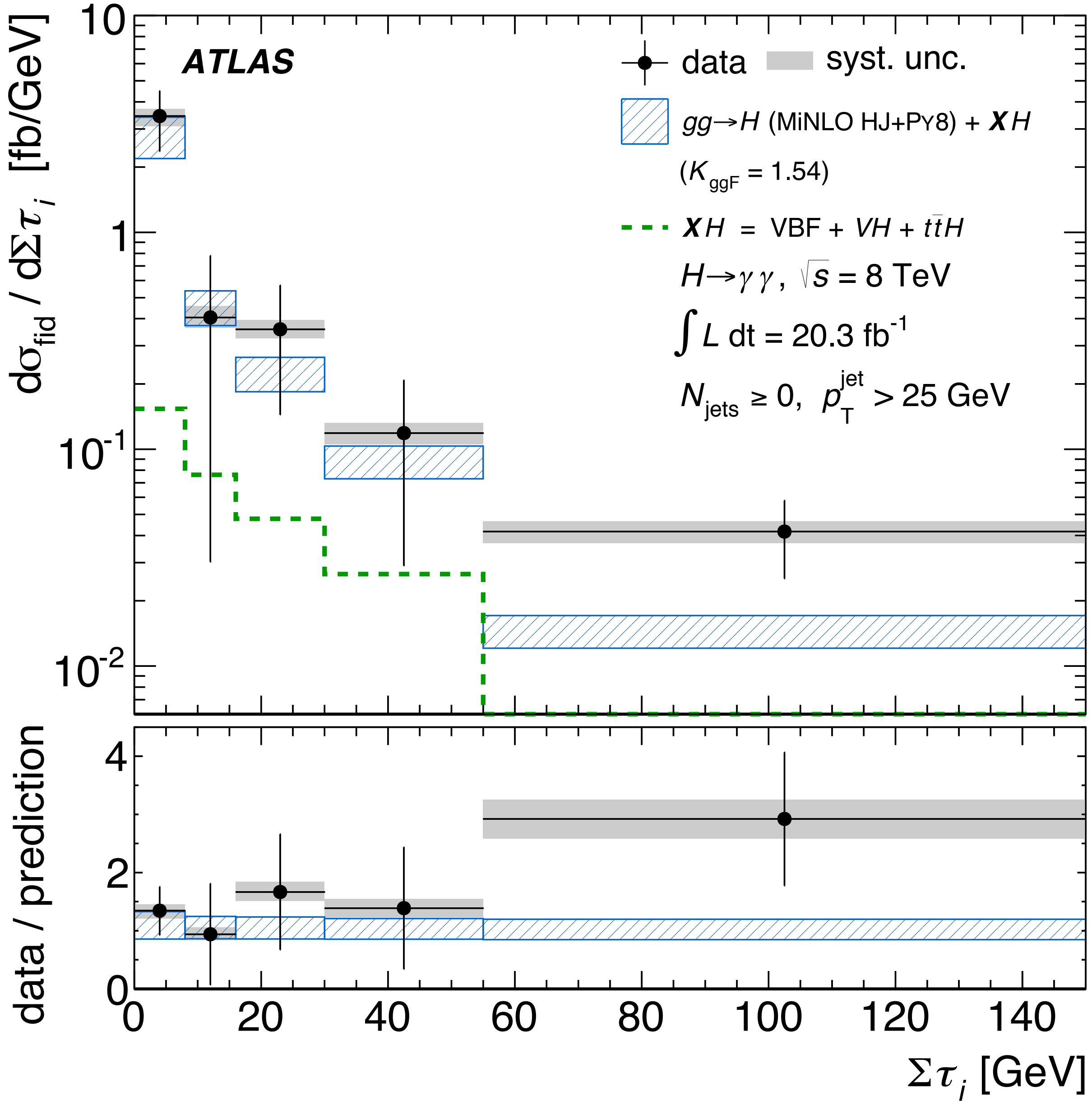




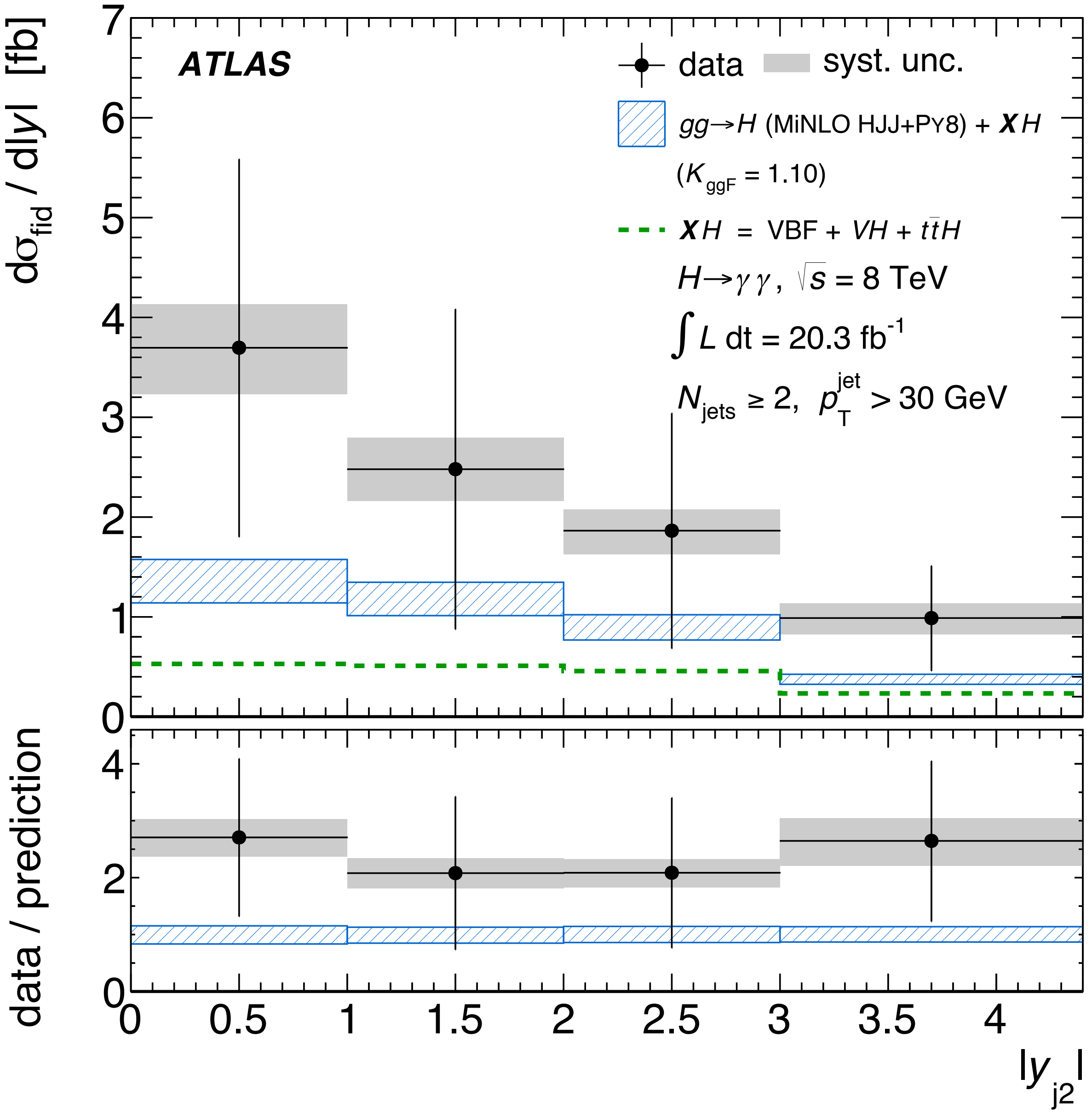
Beam-thrust variables

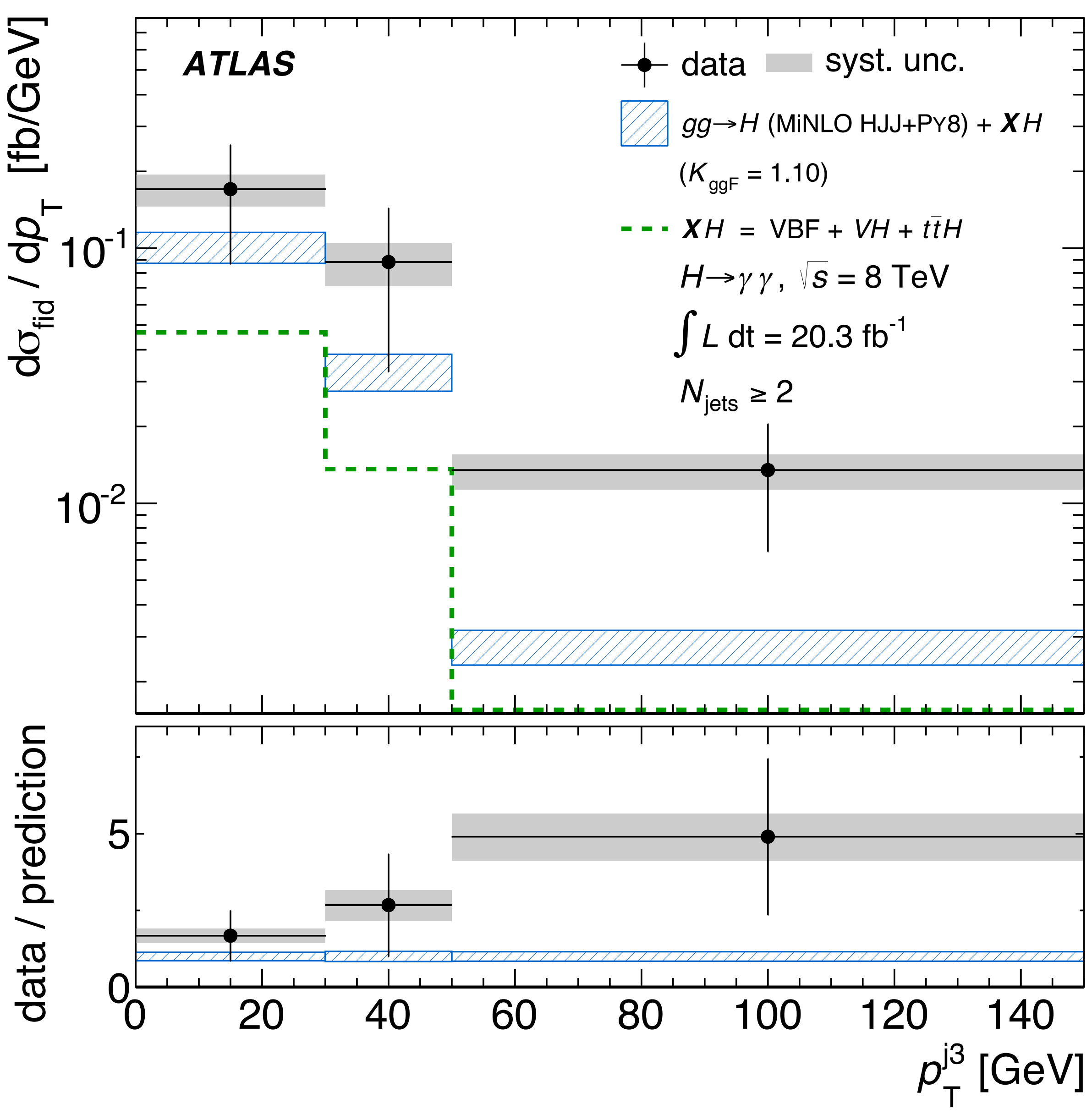
$$\tau = \frac{m_{\mathrm{T}}}{2\cosh y^*}, \quad y^* = y - y_{\gamma\gamma}, \quad m_{\mathrm{T}} = \sqrt{p_{\mathrm{T}}^2 + m^2},$$



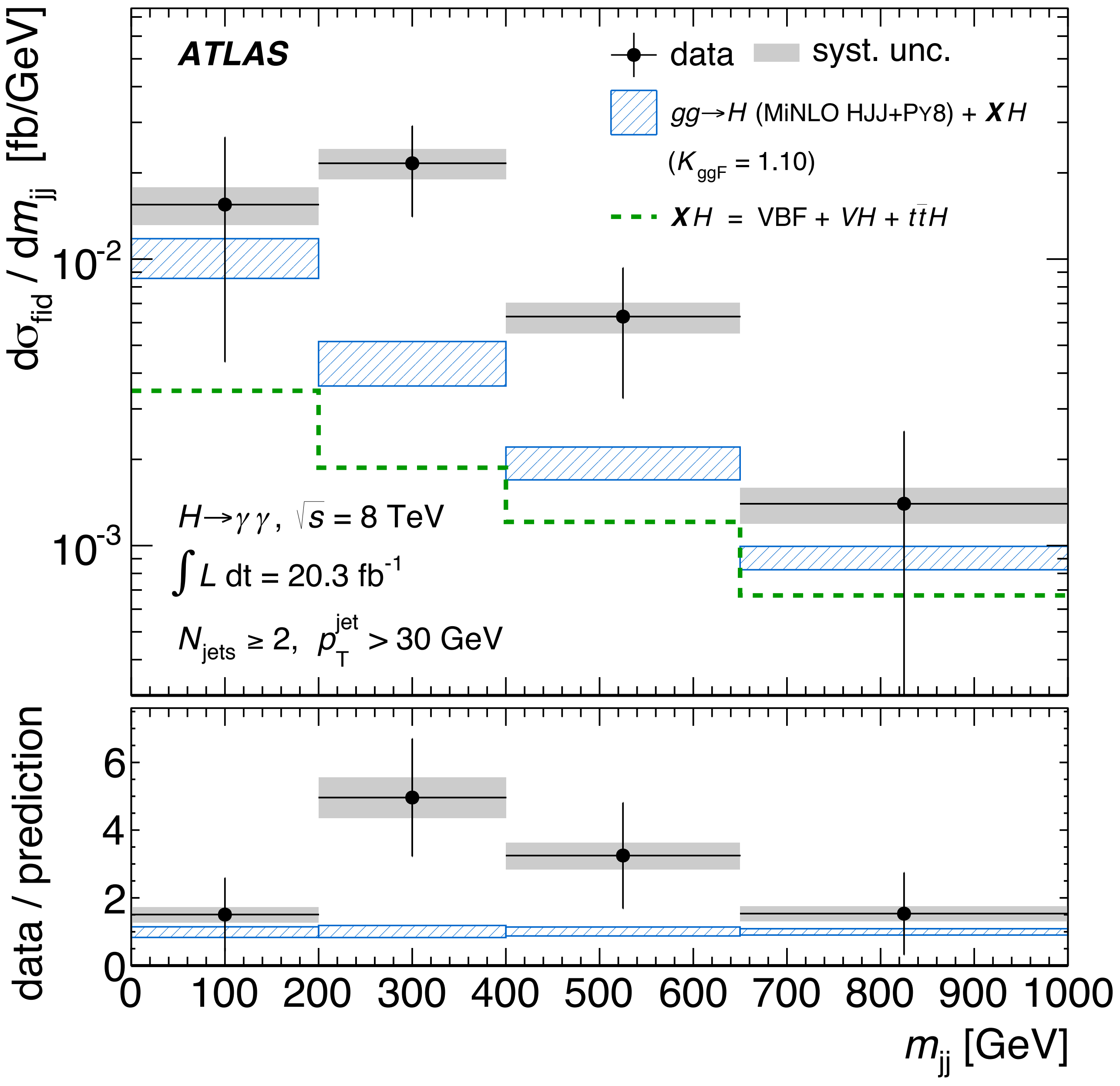


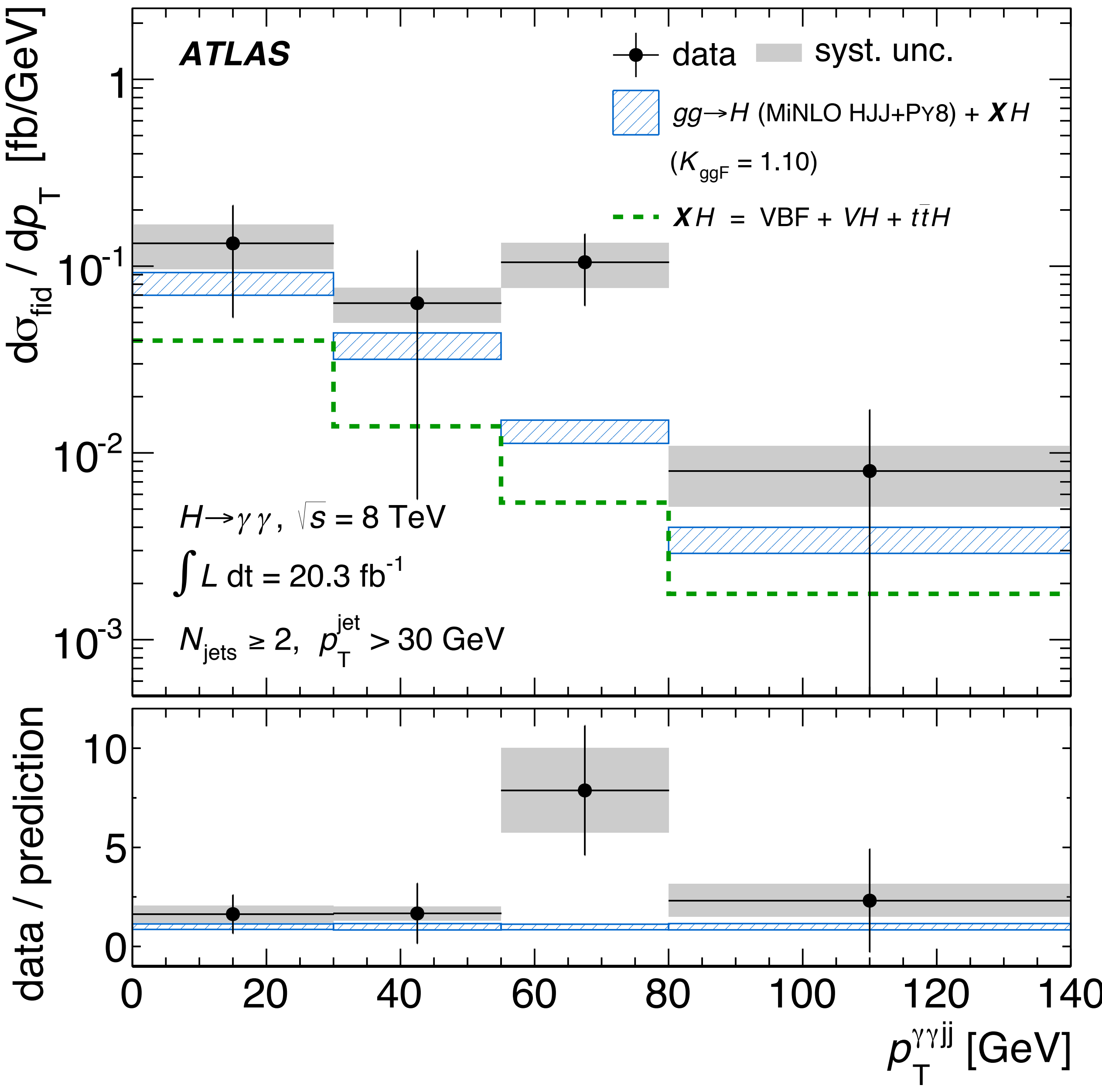
More jet variables



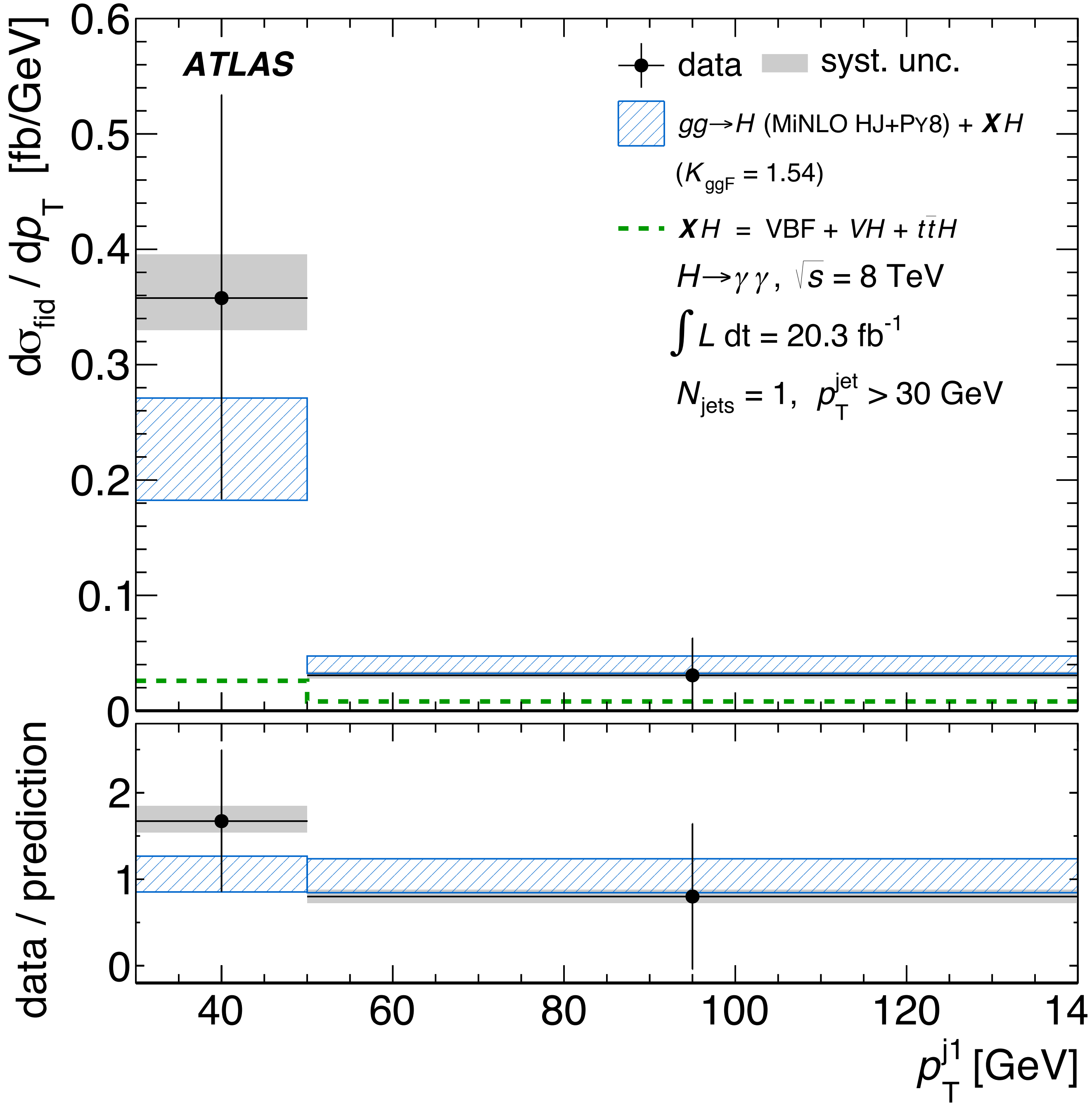


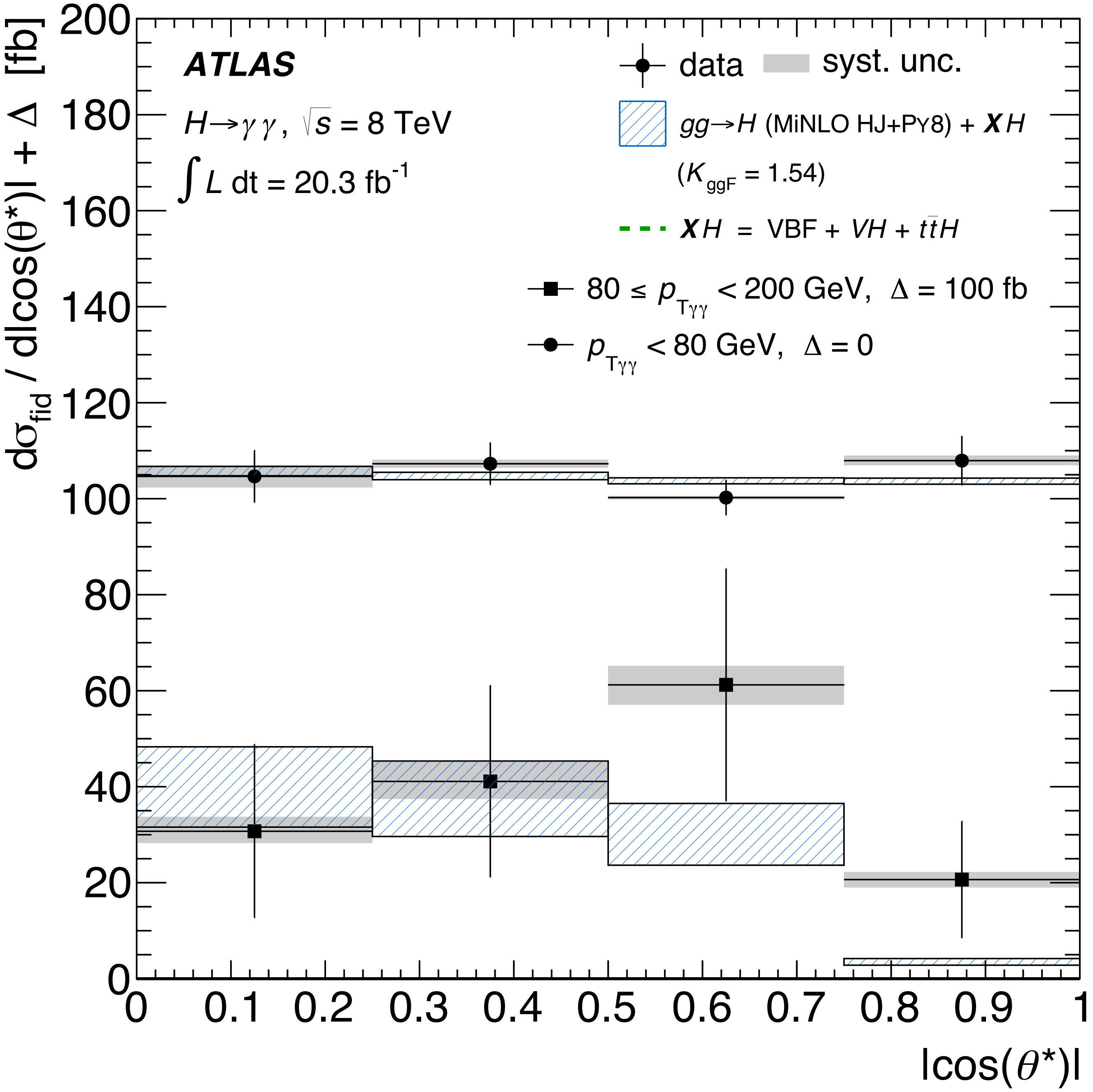
More VBF variables





Exclusive jet p_T





Fiducial differential cross sections

- Measurement of ***fiducial*** and differential cross sections are ***corrected for detector effects*** and designed to be as ***model independent*** as possible

number of extracted signal events

$$\sigma_{\text{fid}} = \frac{n_{\text{sig},i}}{c_i\ \mathcal{L}_{\text{int}}}$$

correction factor for detector effects

20.3 fb^{-1} (±2.8%)

differential cross section of bin *i*

$$d\sigma/dX = \frac{n_{\text{sig},i}}{c_i\ \mathcal{L}_{\text{int}}\ \Delta X_i}$$

bin width

- Corrected measured distributions can be
  - direct comparison with theory (without the need of detector simulation)
  - used to probe a variety of physics: fiducial cross section; kinematic properties; QCD; associated jet activity; spin/CP; BSM Higgs scenarios …
- Fiducial definitions chosen to closely replicate analysis selection to minimize model dependence:

H→ZZ 4*e*, 4*μ* or *eeμμ*

- e: $p_T > 7$ GeV, $|\eta|<2.47$
- μ: $p_T > 6$ GeV, $|\eta|<2.7$

H→γγ two isolated photons:

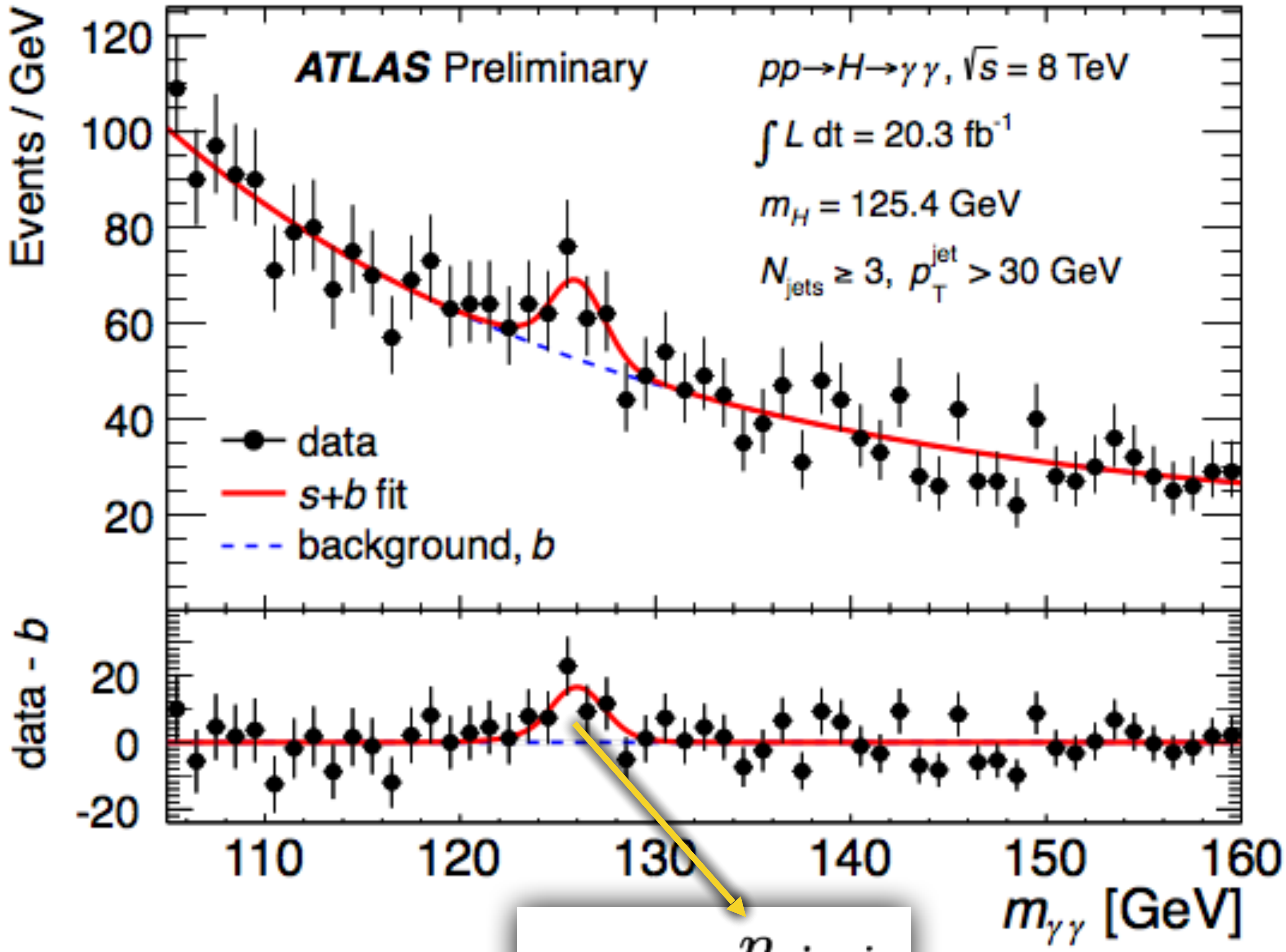
- $p_{T\gamma1} / m_{\gamma\gamma} > 0.35$, $p_{T\gamma2} / m_{\gamma\gamma} > 0.25$
- $|\eta|<2.37$
- isolation criteria: $E_T < 14$ GeV of particles in $\Delta R<0.4$

- *H*→*γγ* inclusive cross section: $n_{\text{sig}} = 570\pm130$, $c_i = 0.65\pm0.02$:

$$\sigma_{\text{fid}}(pp \to H \to \gamma\gamma) = 43.2 \pm 9.4\,(\text{stat})\,^{+3.2}_{-2.9}\,(\text{syst}) \pm 1.2\,(\text{lumi})\ \text{fb}$$

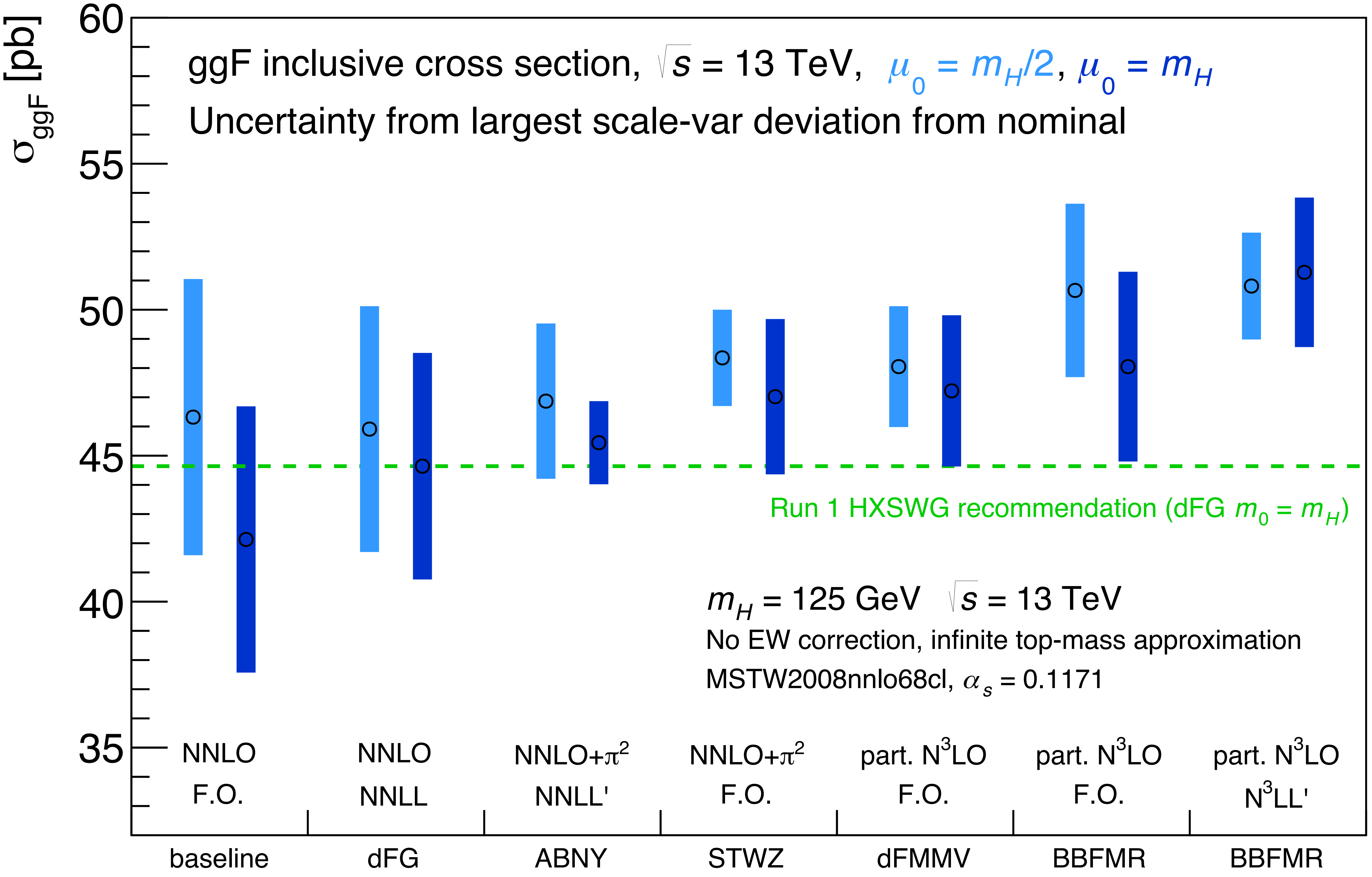
- *H*→*ZZ* inclusive cross section: $2.11^{+0.53}_{-0.47}(\text{stat})^{+0.16}_{-0.10}(\text{syst})\ \ \text{fb}$

Example $m_{\gamma\gamma}$ spectra for an N_{jets} bin

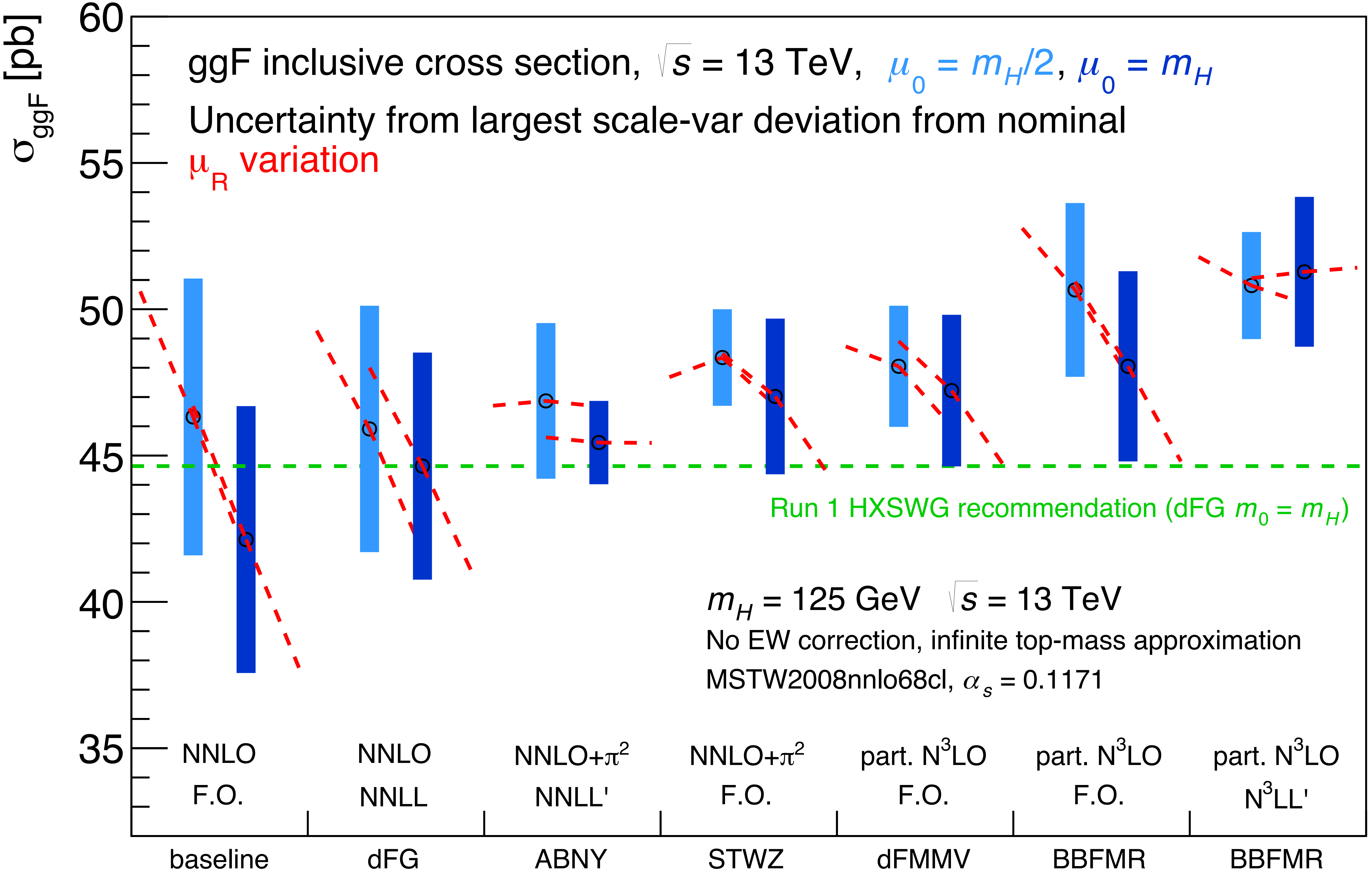


$$\sigma_{\text{fid}} = \frac{n_{\text{sig},i}}{c_i\ \mathcal{L}_{\text{int}}}$$

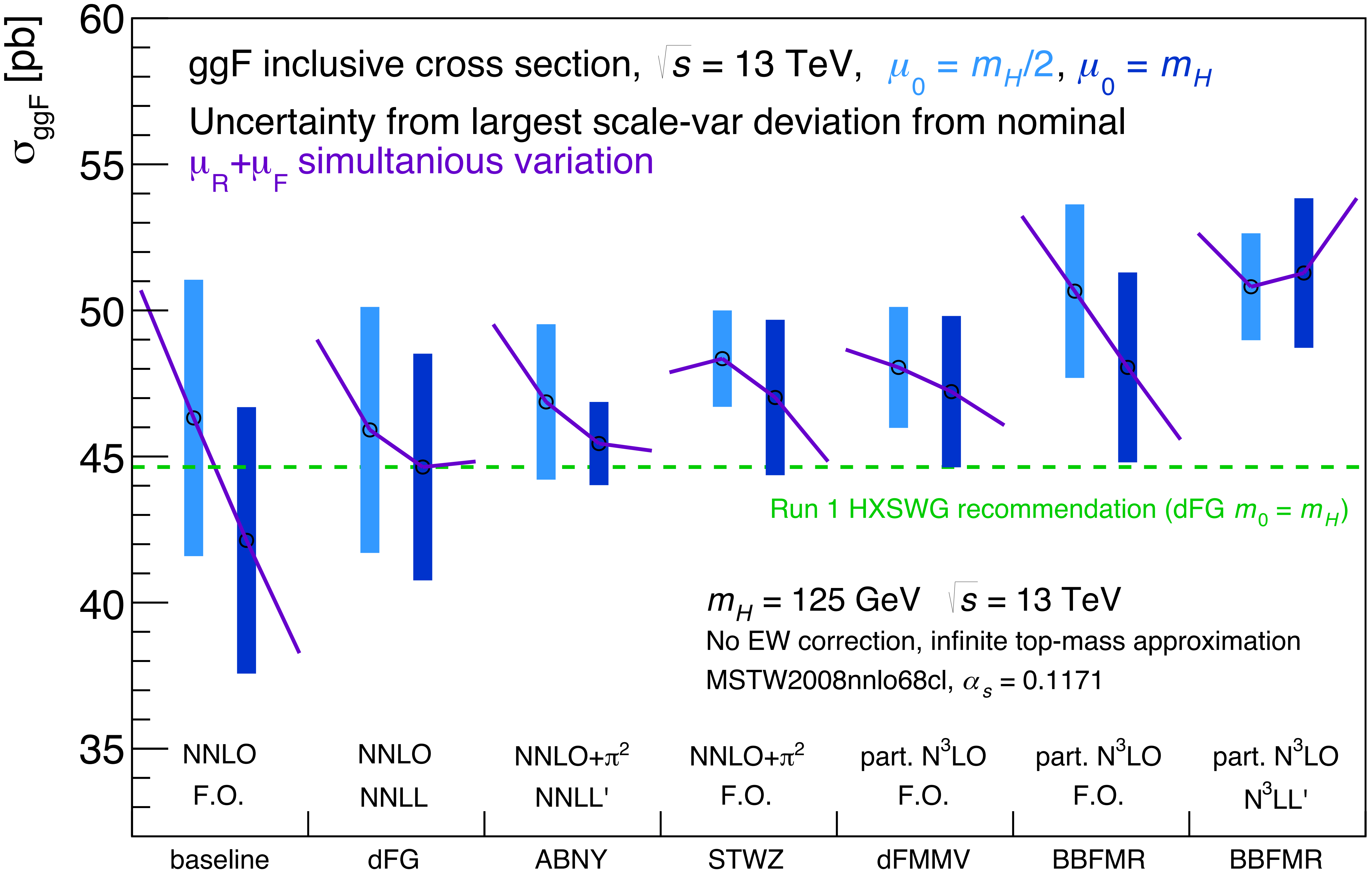
ggF inclusive cross sections



ggF inclusive cross sections



ggF inclusive cross sections



ggF inclusive cross sections