Measurement of fiducial and differential cross sections of the SM Higgs boson in the di-photon and 4l decay channels using the ATLAS detector

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on behalf of ATLAS experiment

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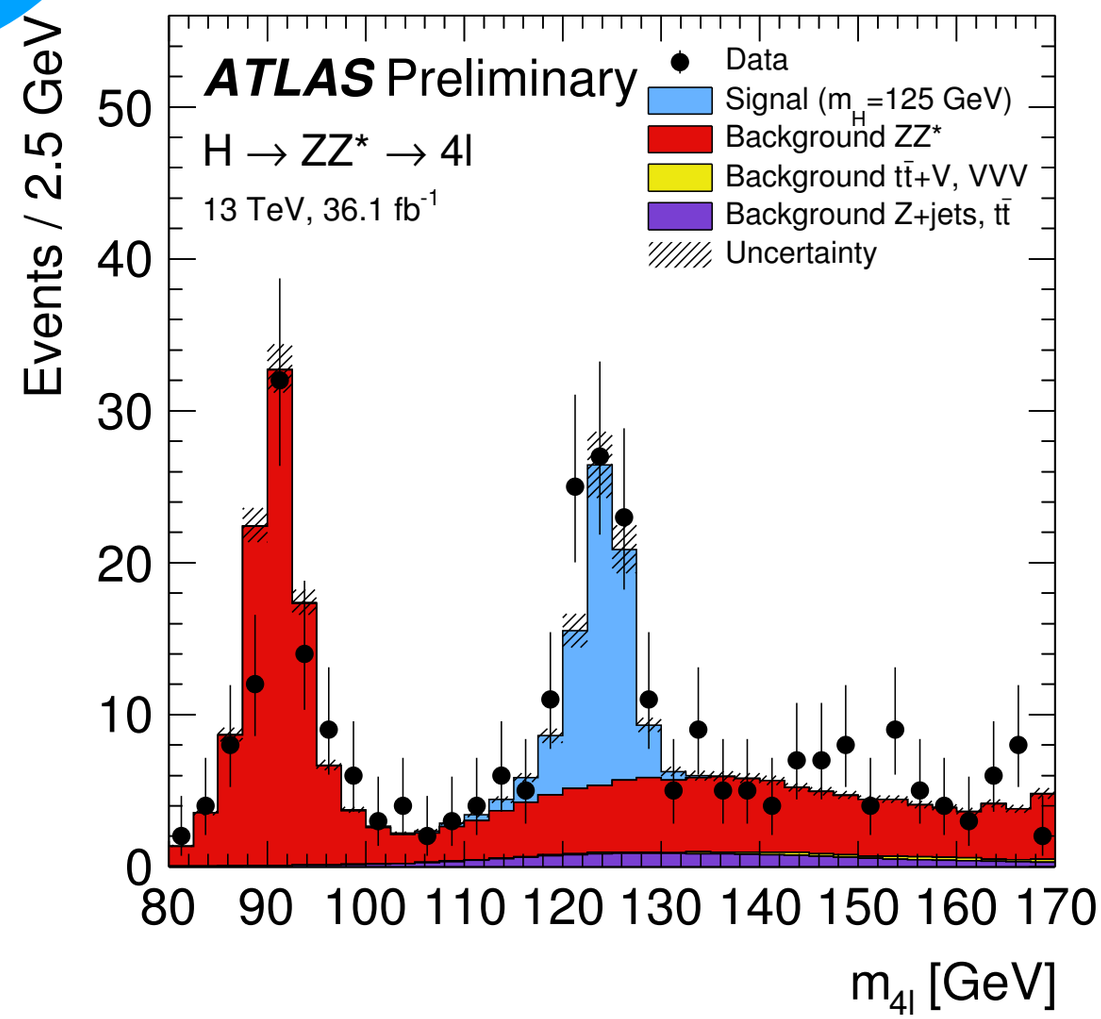
channels: 4l and γγ

LHCP

Higgs to four leptons

ATLAS-CONF-2017-032

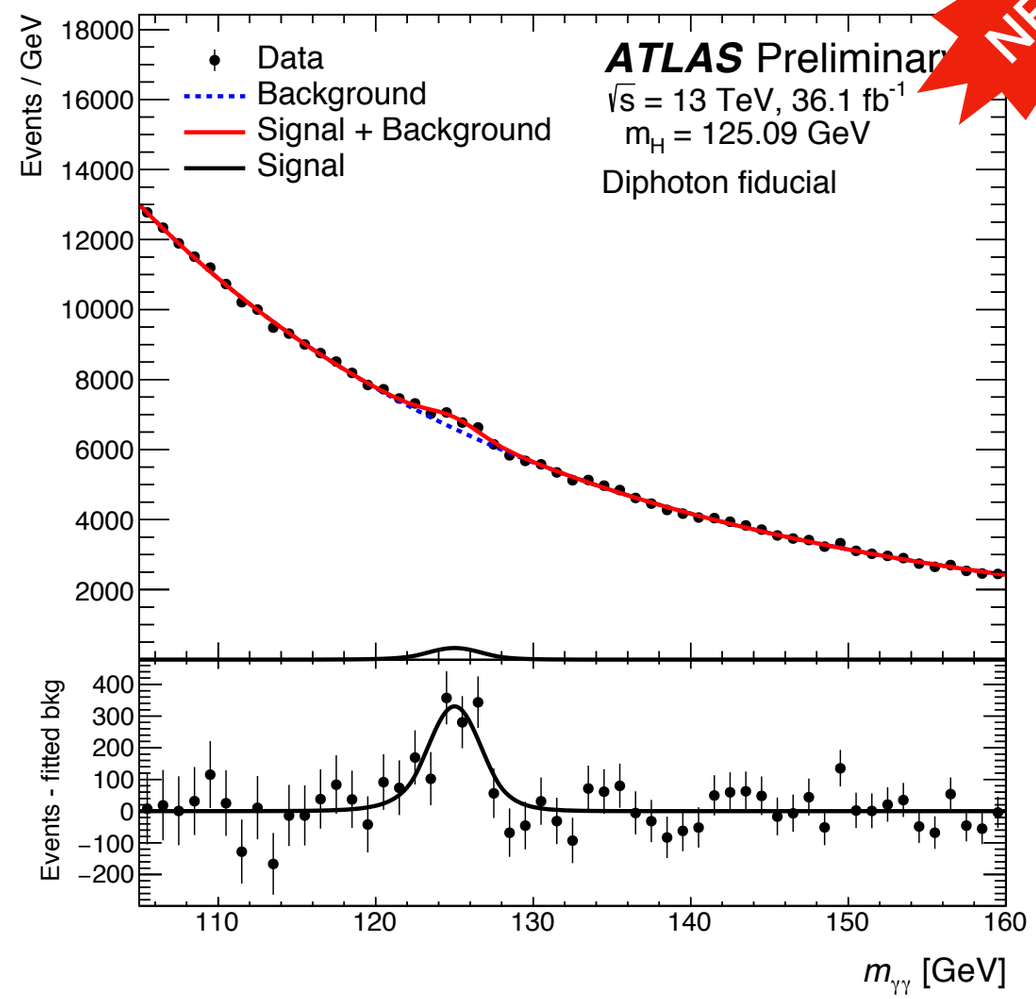


- fully reconstructible final state
- clear signal: S/B ~2.3 @13 TeV
- excellent mass resolution: 1-2% m_H
- small rate: BR ~1.3 x 10^{-4}
- virtual Z boson decays to low p_T leptons

Higgs to two photons

NEW!

ATLAS-CONF-2017-045



- rate: BR ~10^{-3}
- excellent mass resolution: 1-2% m_H
- S/B ~0.02-0.2 @13 TeV
- background evaluated from sidebands
- 5 fiducial regions: inclusive, N_{lep}, VBF, MET, ttH

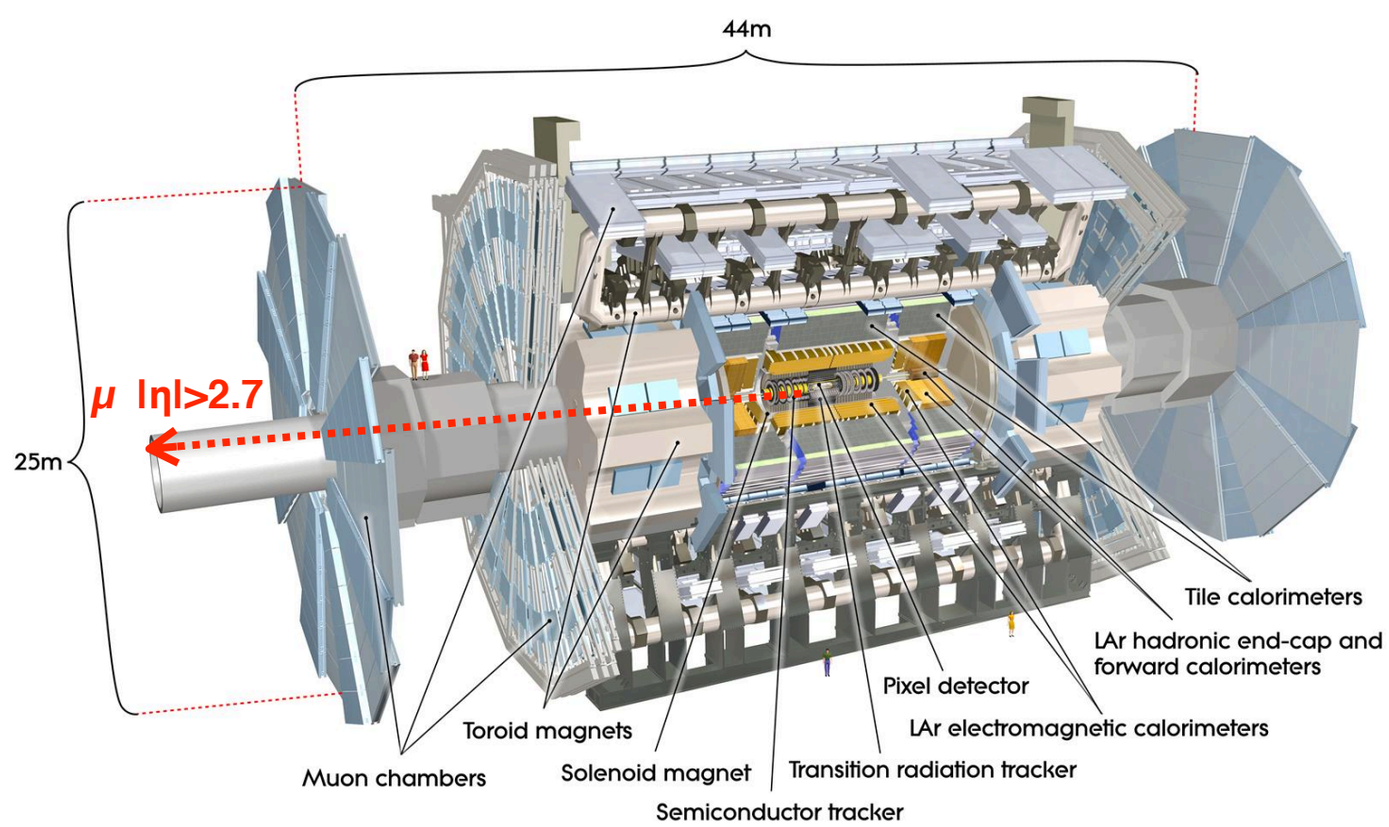
fiducial cross section

Fiducial cross section:

- cross section with kinematic and other selection cuts consistent with the sensitive detector acceptance
- **minimise extrapolation** into experimentally invisible phase space -> reduce the model dependency
- correction for detector effects (resolution and efficiencies)
- easy interpretation for theorist

event selection @particle level: "replica" of the selection criteria applied at detector level

minimise extrapolation: e.g. we cannot measure muons with |η|>2.7



selection @particle level and unfolding

Higgs to four leptons

μ	$p_T > 5$ GeV, $\lvert\eta\rvert < 2.7$
e	$E_T > 7$ GeV, $\lvert\eta\rvert < 2.47$
jet	anti-k_T, $p_T > 30$ GeV $\lvert y\rvert < 4.4$
p_T 3 lead lep	20, 15, 10 GeV
quadruplet	2 pairs same flavour
m_{12}	$50 < m_{12} < 106$ GeV
m_{34}	$12 < m_{34} < 115$ GeV
veto m_{ll}	$m_{ll} > 5$ GeV
$\Delta R_{ll} > 0.1$ (0.2)	for all same (diff) lep flavour
$\Delta R_{jet\text{-}l} > 0.1$ (0.2)	for muons (electrons)

Higgs to γγ

γ	$p_T > 0.35(0.25) \times m_{\gamma\gamma}$ $\lvert\eta\rvert < 1.37$, $1.52 < \lvert\eta\rvert < 2.37$
jet	anti-k_T, $p_T > 30$ GeV $\lvert y\rvert < 4.4$
VBF	$m_{jj} > 400$ GeV, $\lvert\Delta y_{jj}\rvert > 2.8$ $\lvert\Delta\phi_{jj}\rvert > 2.6$
ttH	$n_{jets} \geq 3$ (1 lep) or $n_{jets} \geq 4$ (0 lep) at least 1 b-jet
leptons (VH)	$p_T > 15$ GeV, $\lvert\eta\rvert < 2.47$
MET (VH)	$E_T^{miss} > 80$ GeV, $p_T^{\gamma\gamma} > 80$ GeV

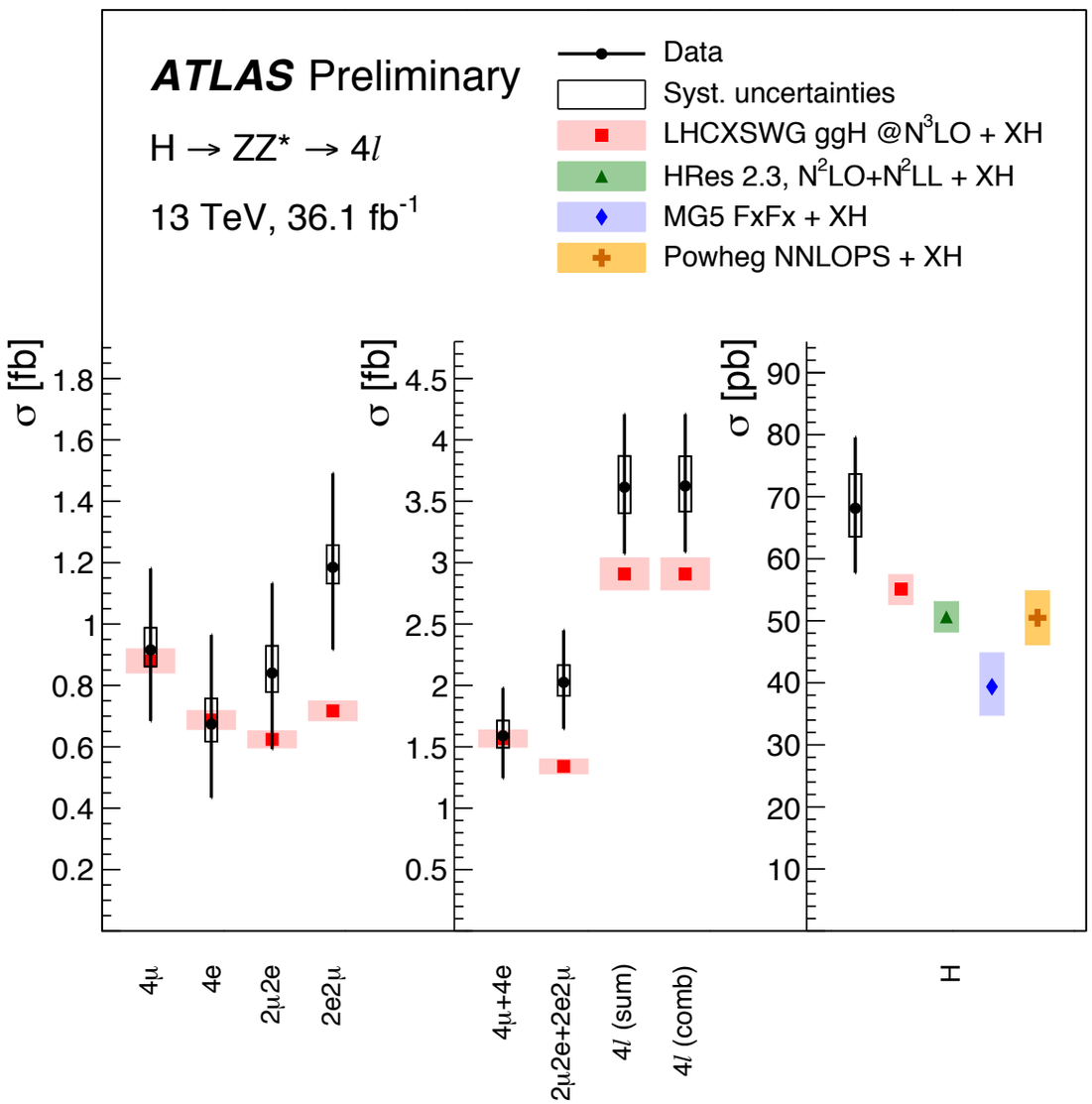
$$\sigma_{i,\mathrm{fid}} = \sigma_i \times A_i \times \mathrm{BR} = \frac{N_{i,\mathrm{fit}}}{\mathcal{L} \times C_i}$$

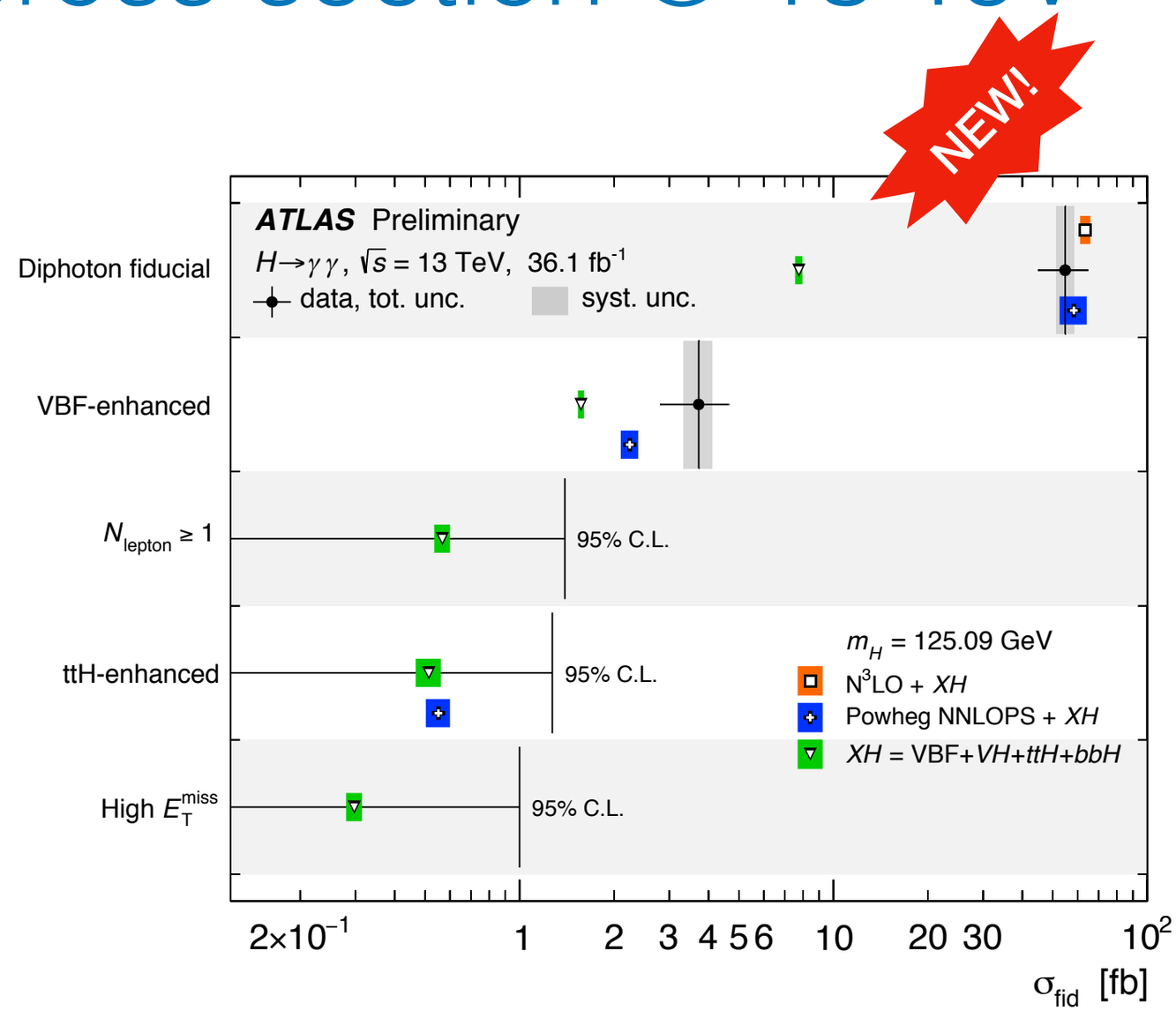
method has been cross checked with alternative techniques

the unfolding technique used is bin-by-bin correction factor:

- A_i = acceptance at particle level
- C_i = correction for detector eff. and res.
- $N_{i,fit}$ = number of signal events observed

fiducial and total cross section @ 13 TeV

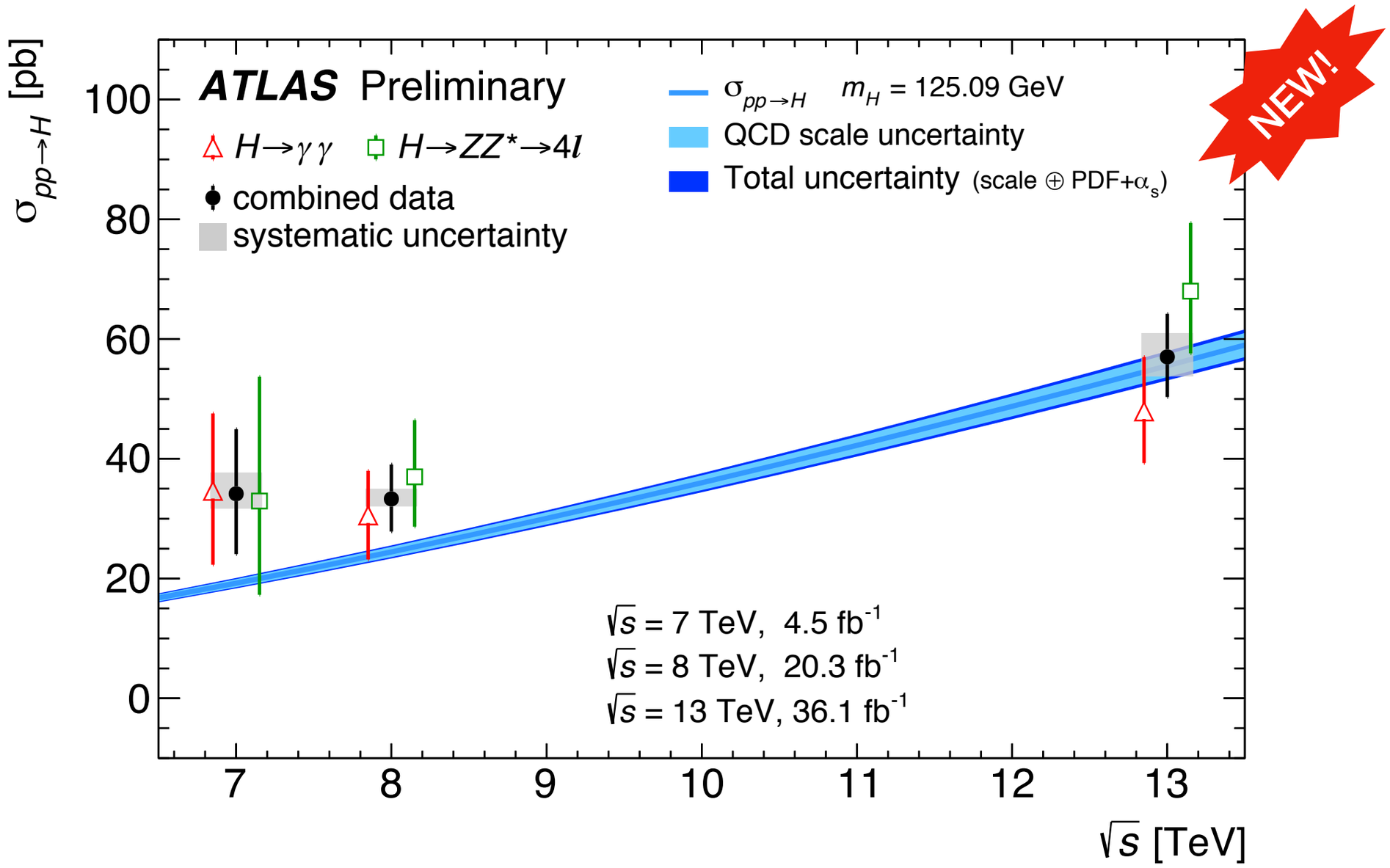




Cross section [fb]	Data (± (stat) ± (sys))	LHCXSWG prediction	p-value [%]
$\sigma_{4\mu}$	$0.92\ ^{+0.25}_{-0.23}\ ^{+0.07}_{-0.05}$	0.880 ± 0.039	88
σ_{4e}	$0.67\ ^{+0.28}_{-0.23}\ ^{+0.08}_{-0.06}$	0.688 ± 0.031	96
$\sigma_{2\mu 2e}$	$0.84\ ^{+0.28}_{-0.24}\ ^{+0.09}_{-0.06}$	0.625 ± 0.028	39
$\sigma_{2e2\mu}$	$1.18\ ^{+0.30}_{-0.26}\ ^{+0.07}_{-0.05}$	0.717 ± 0.032	7
σ_{comb}	$3.62\ ^{+0.53}_{-0.50}\ ^{+0.25}_{-0.20}$	2.91 ± 0.13	18
σ_{tot} [pb]	$69\ ^{+10}_{-9}\ \pm 5$	55.6 ± 2.5	19

Fiducial region	Measured cross section	SM prediction	
Diphoton fiducial	54.7 ± 9.1 (stat.) ± 4.5 (syst.) fb	63.5 ± 2.4 fb	[N^{3}LO + XH]
VBF-enhanced	3.7 ± 0.8 (stat.) ± 0.5 (syst.) fb	2.24 ± 0.14 fb	[NNLOPS + XH]
$N_{\text{lepton}} \geq 1$	$\leq$ 1.39 fb @ 95% CL	0.57 ± 0.03 fb	[NNLOPS + XH]
High E_T^{miss}	$\leq$ 1.00 fb @ 95% CL	0.30 ± 0.02 fb	[NNLOPS + XH]
$t\bar{t}H$-enhanced	$\leq$ 1.27 fb @ 95% CL	0.55 ± 0.05 fb	[NNLOPS + XH]

fiducial and total cross section @ 13 TeV



ATLAS-CONF-2017-047

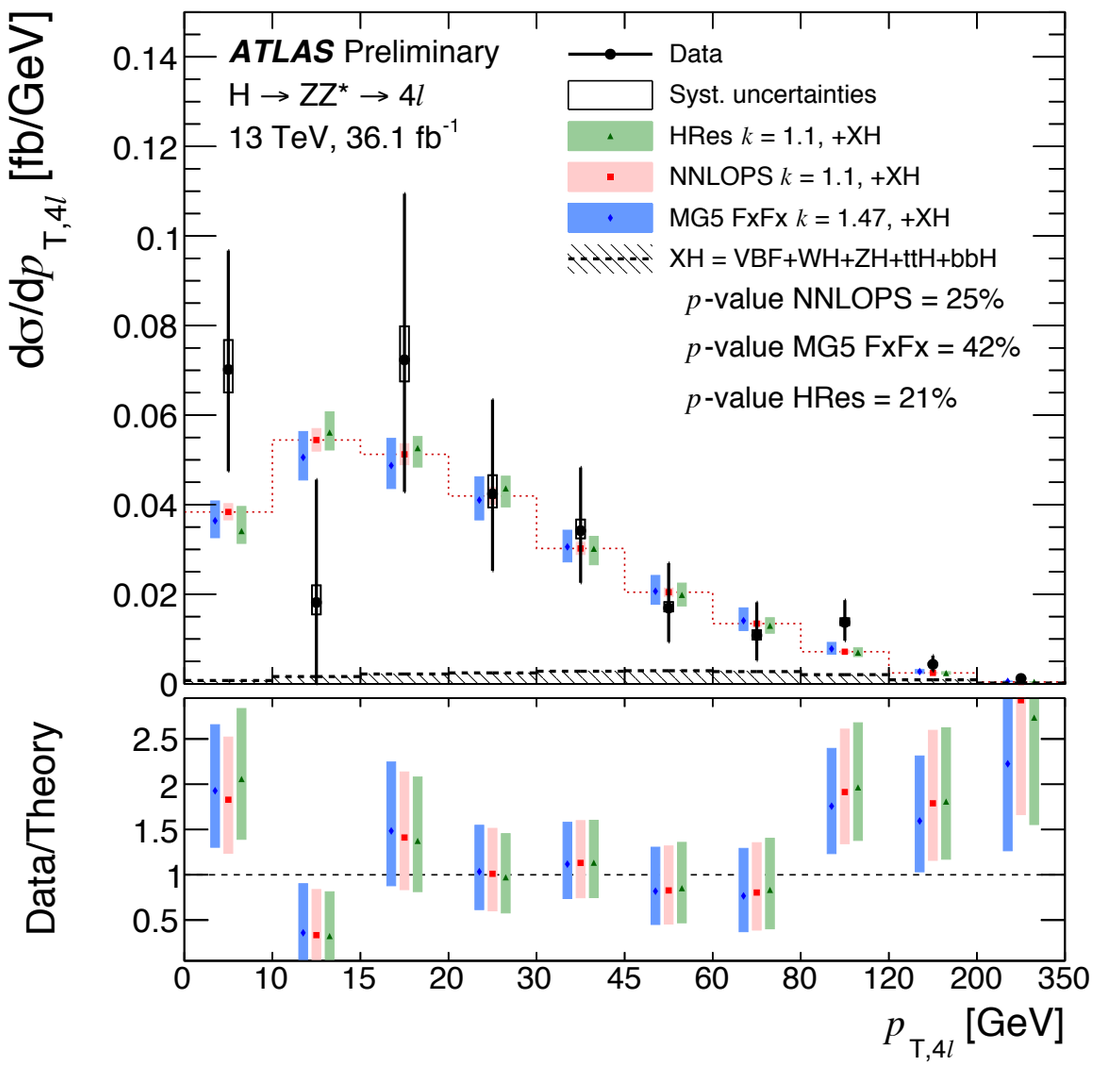
Decay channel	Total cross section ($pp \to H + X$)		
	$\sqrt{s}$ =7 TeV	$\sqrt{s}$ =8 TeV	$\sqrt{s}$ =13 TeV
$H \to \gamma\gamma$	35^{+13}_{-12} pb	$30.5^{+7.5}_{-7.4}$ pb	$47.9^{+9.1}_{-8.6}$ pb
$H \to ZZ^* \to 4\ell$	33^{+21}_{-16} pb	37^{+9}_{-8} pb	$68.0^{+11.4}_{-10.4}$ pb
Combination	34 ± 10 (stat.) $^{+4}_{-2}$ (syst.) pb	$33.3^{+5.5}_{-5.3}$ (stat.) $^{+1.7}_{-1.3}$ (syst.) pb	$57.0^{+6.0}_{-5.9}$ (stat.) $^{+4.0}_{-3.3}$ (syst.) pb
SM prediction [8]	19.2 ± 0.9 pb	24.5 ± 1.1 pb	$55.6^{+2.4}_{-3.4}$ pb

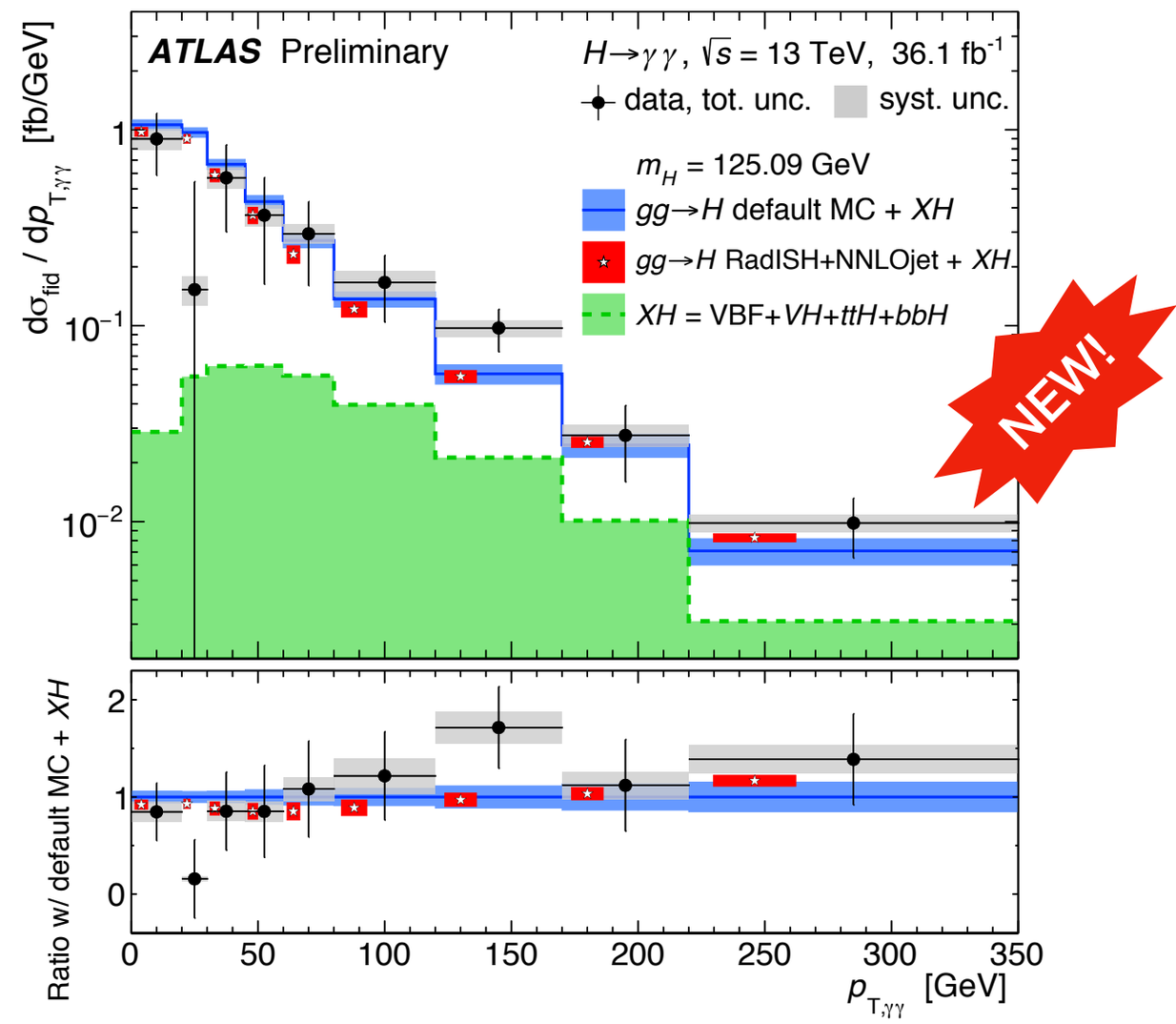
- agreement with the SM (ggF @N3LO): 84%
- compatibility between the channels: 29%

differential cross section: p_T

Higgs-boson transverse momentum p_T is sensitive to:

- perturbative QCD calculations
- heavy additional particle in the loop would change the high Higgs p_T region
- low Higgs p_T region is sensitive to the Yukawa coupling of the b and charm quark



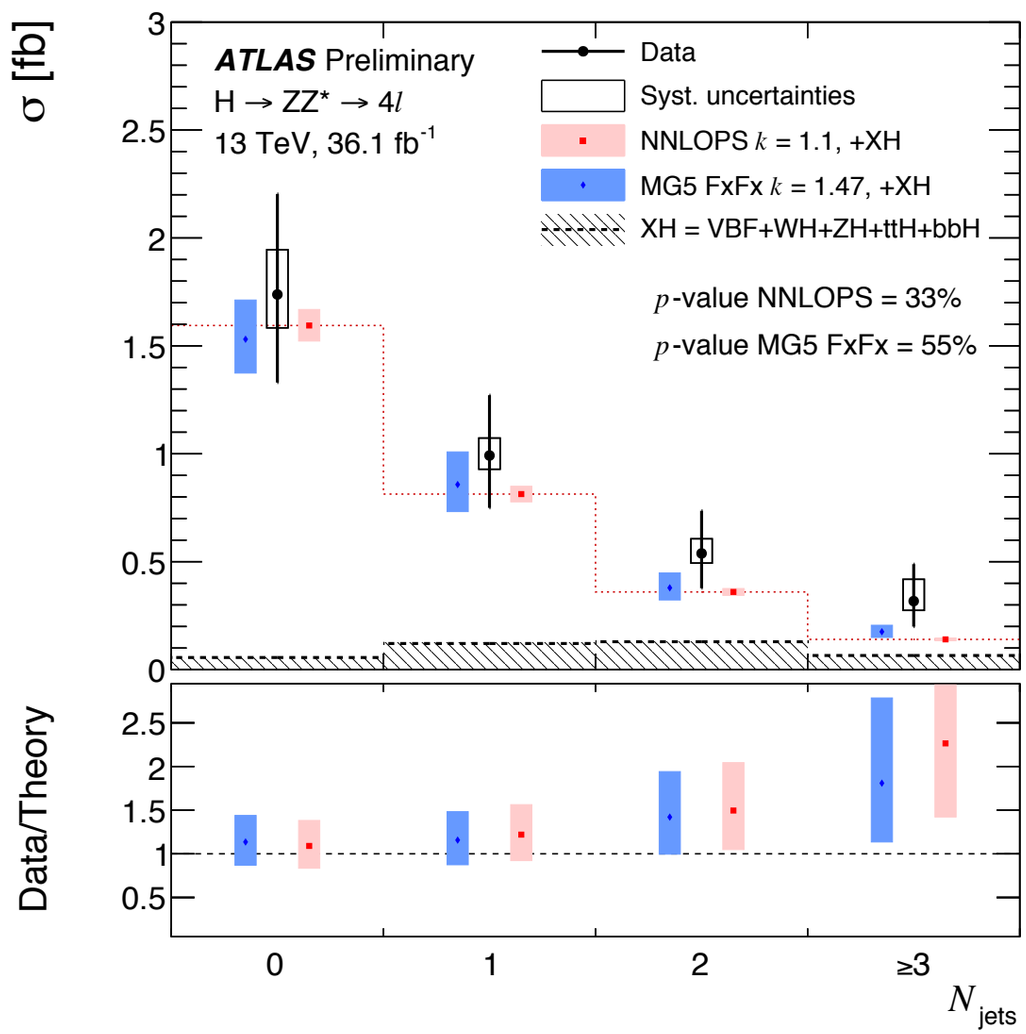


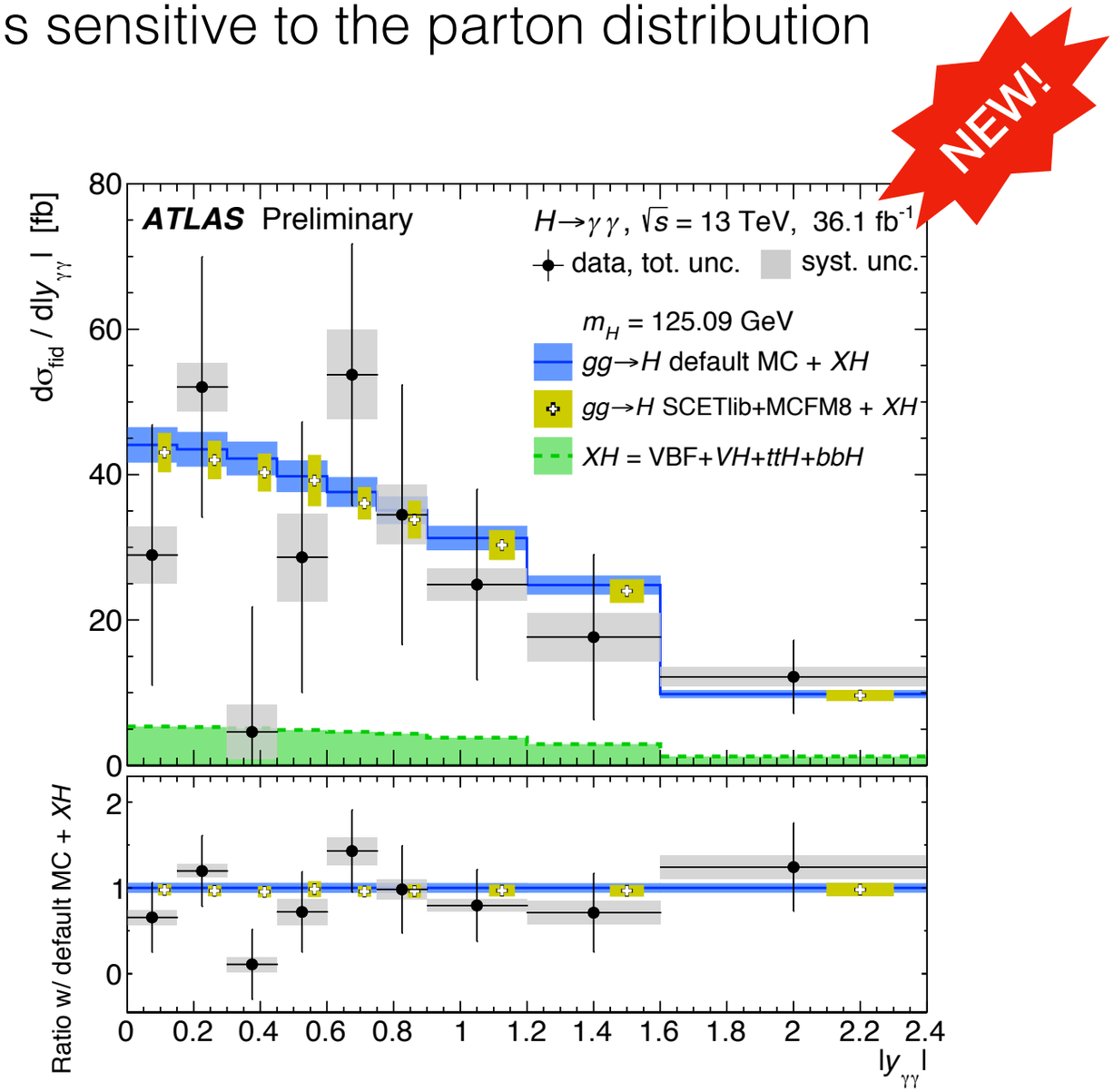
agreement with the Standard Model prediction (NNLOPS):

- 4l: p-value 25% γγ: p-value 51%

differential cross sections: y, n_{jet}

- number of jets n_{jets} is sensitive to: production mode composition and gluon emission
- the Higgs-boson rapidity distribution |y| is sensitive to the parton distribution functions (PDFs) of the colliding protons



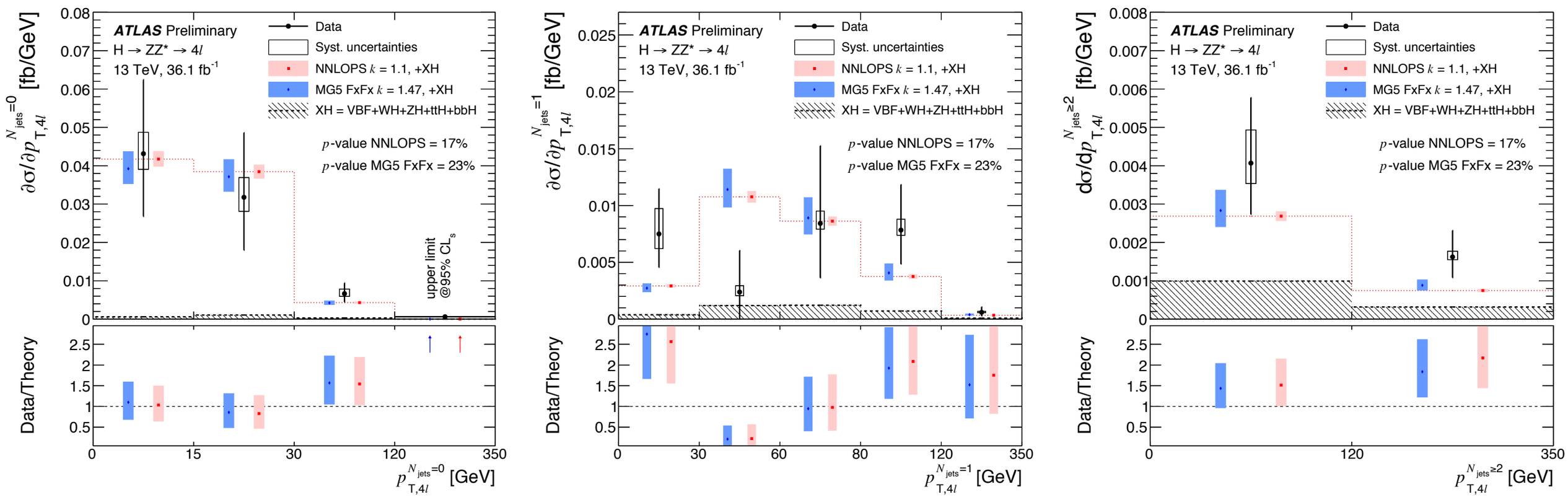


agreement with the Standard Model prediction (NNLOPS):
- 4l (n_{jets}): p-value 33% γγ (y): p-value 57%

double differential cross section: p_T vs n_{jets}

Higgs-boson transverse momentum p_T when separated into exclusive jet multiplicities is sensitive to:

- perturbative QCD, production modes composition and BSM couplings
- low p_T 0-jets sensitive to ggF
- high p_T 0-jets sensitive to VH
- 2 jets sensitive to VBF



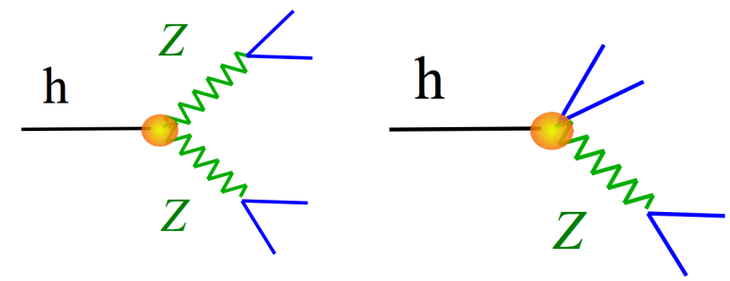
agreement with the Standard Model prediction (NNLOPS):

- 4l: p-value 17% (2-dim)

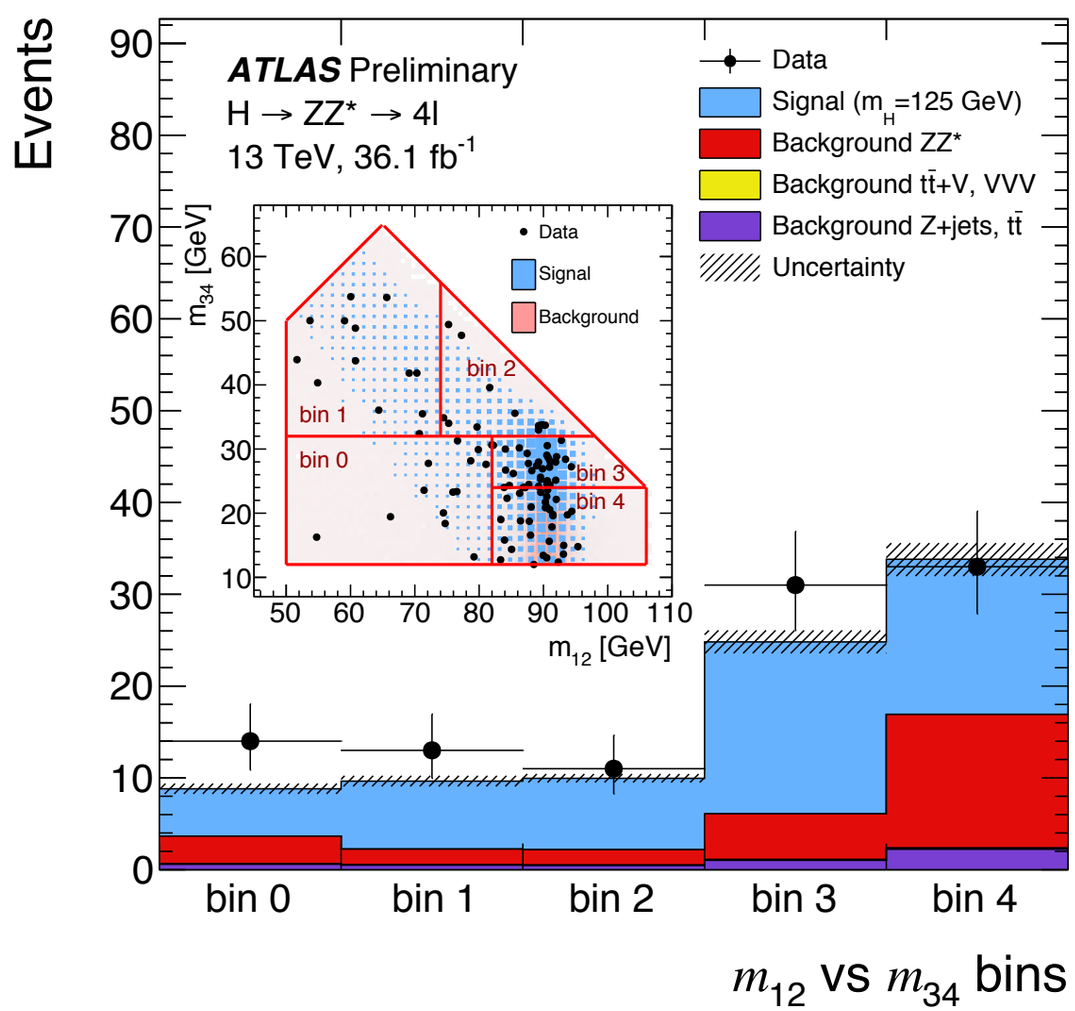
Higgs pseudo-observables

Double differential cross section m_{12} vs m_{34} is used put limits on anomalous couplings within the pseudo-observables framework [Eur. Phys. J. C (2015) 75: 128]

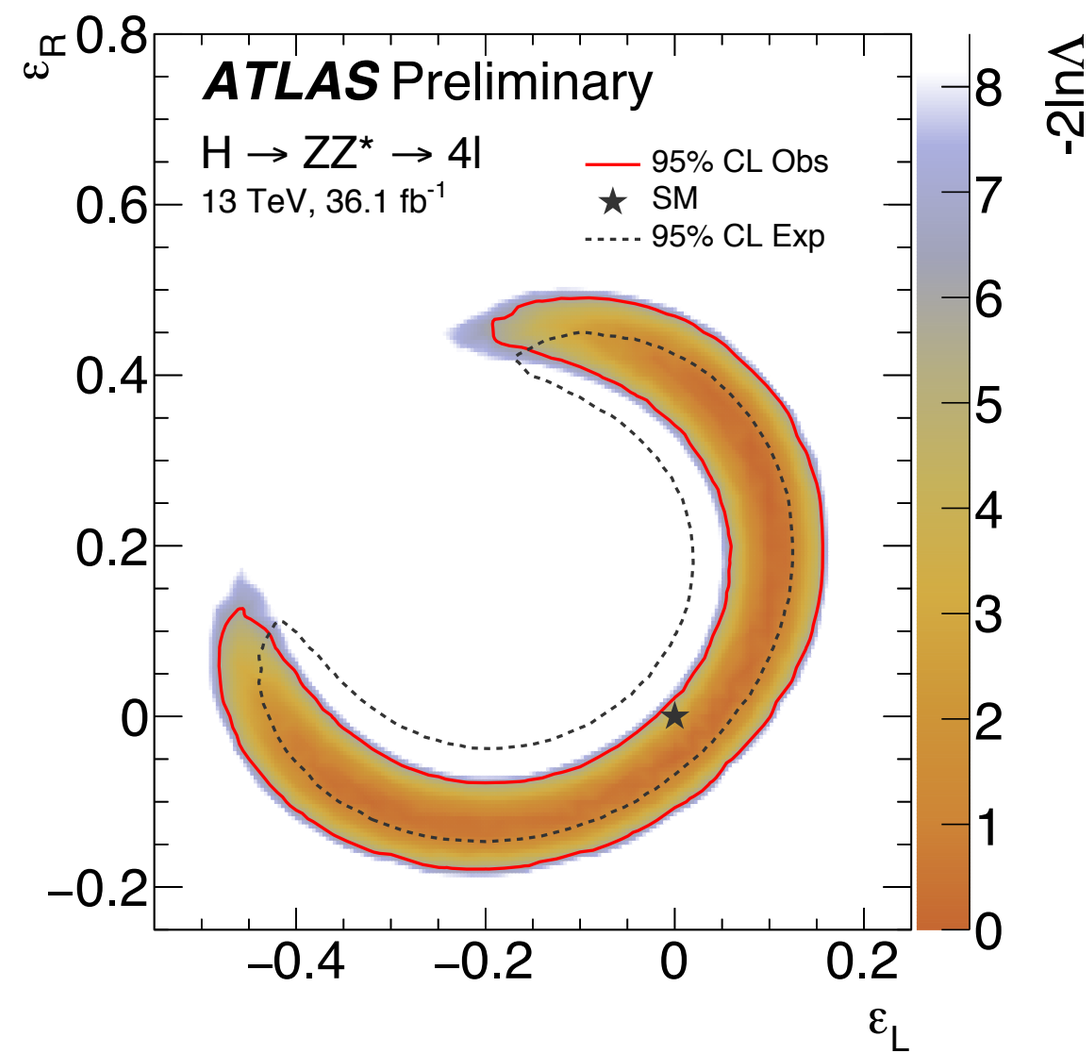
Limits on contact terms interaction between Higgs and leptons left(right)-handed $\varepsilon_L(\varepsilon_R)$ assuming lepton flavour universality



reconstructed distribution
m_{12} vs m_{34}

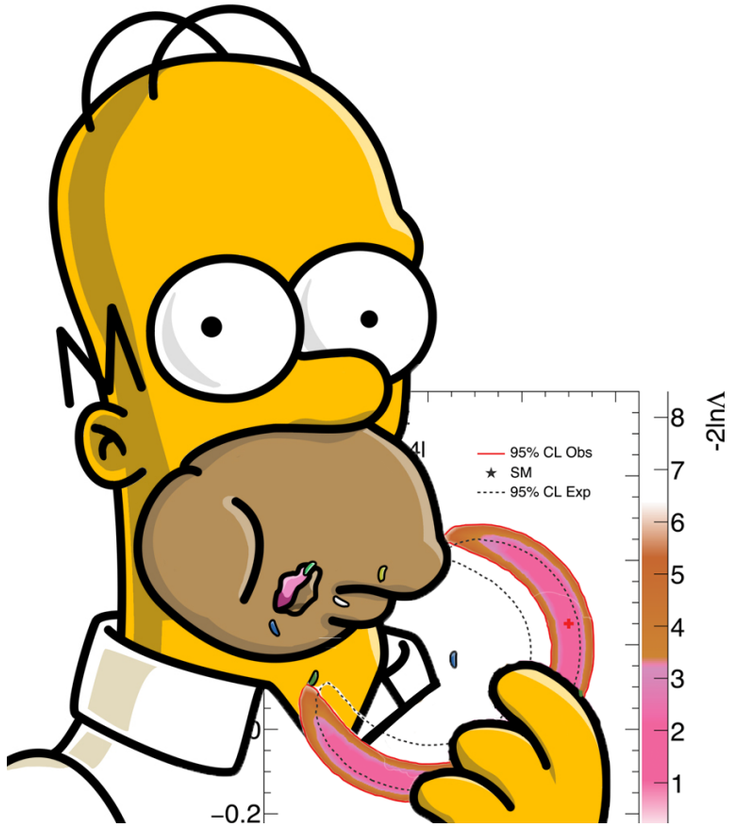


ε_R VS ε_L



conclusions

- presented fiducial and differential measurements in the $H \to ZZ^* \to 4\ell$ and $H \to \gamma\gamma$ channels
- differential cross section measurements demonstrate a high resolution way to measure many Higgs properties and to put limits on BSM couplings
- no significant deviations from SM predictions observed… **but many results are limited by statistical uncertainties**
- with the LHC Run 2 dataset we enter the precision measurement era!
  waiting for more data to improve the measurements

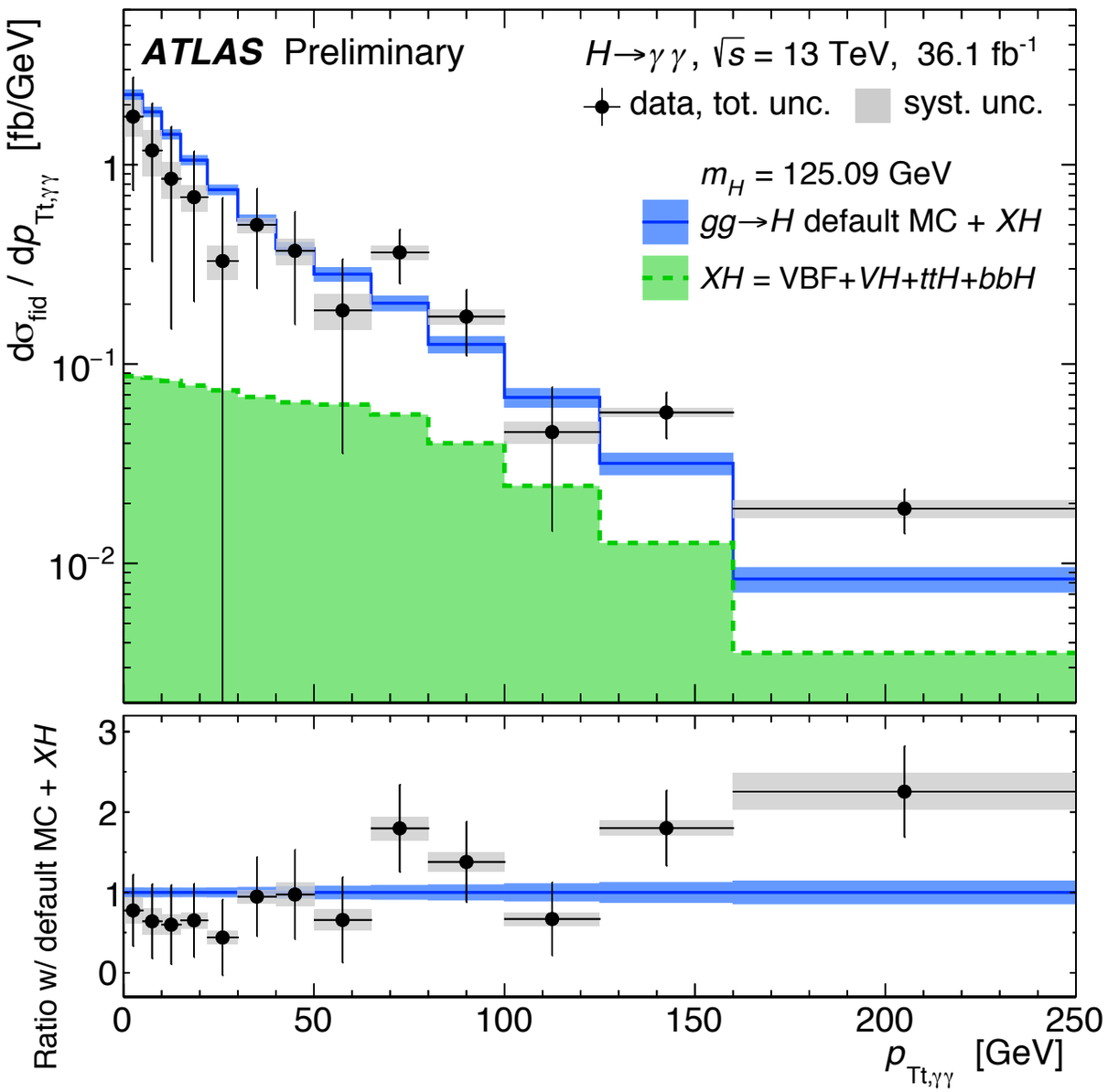


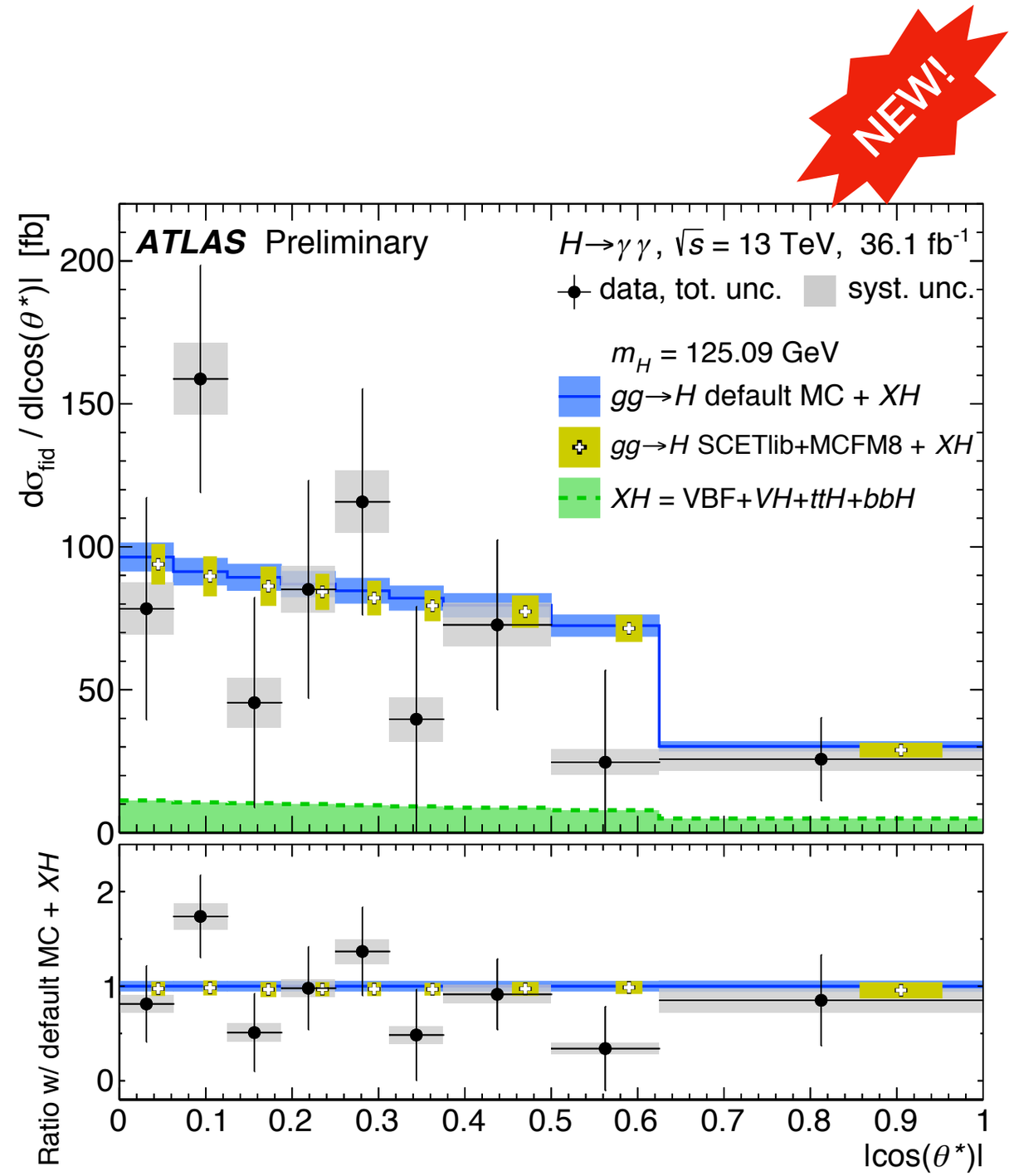
other Higgs results from ATLAS

- couplings : Ruchi Gupta
- ttH: Judith Katzy
- mass measurement : Karolos Potamianos
- combination results : Tamara Vazquez Schroeder

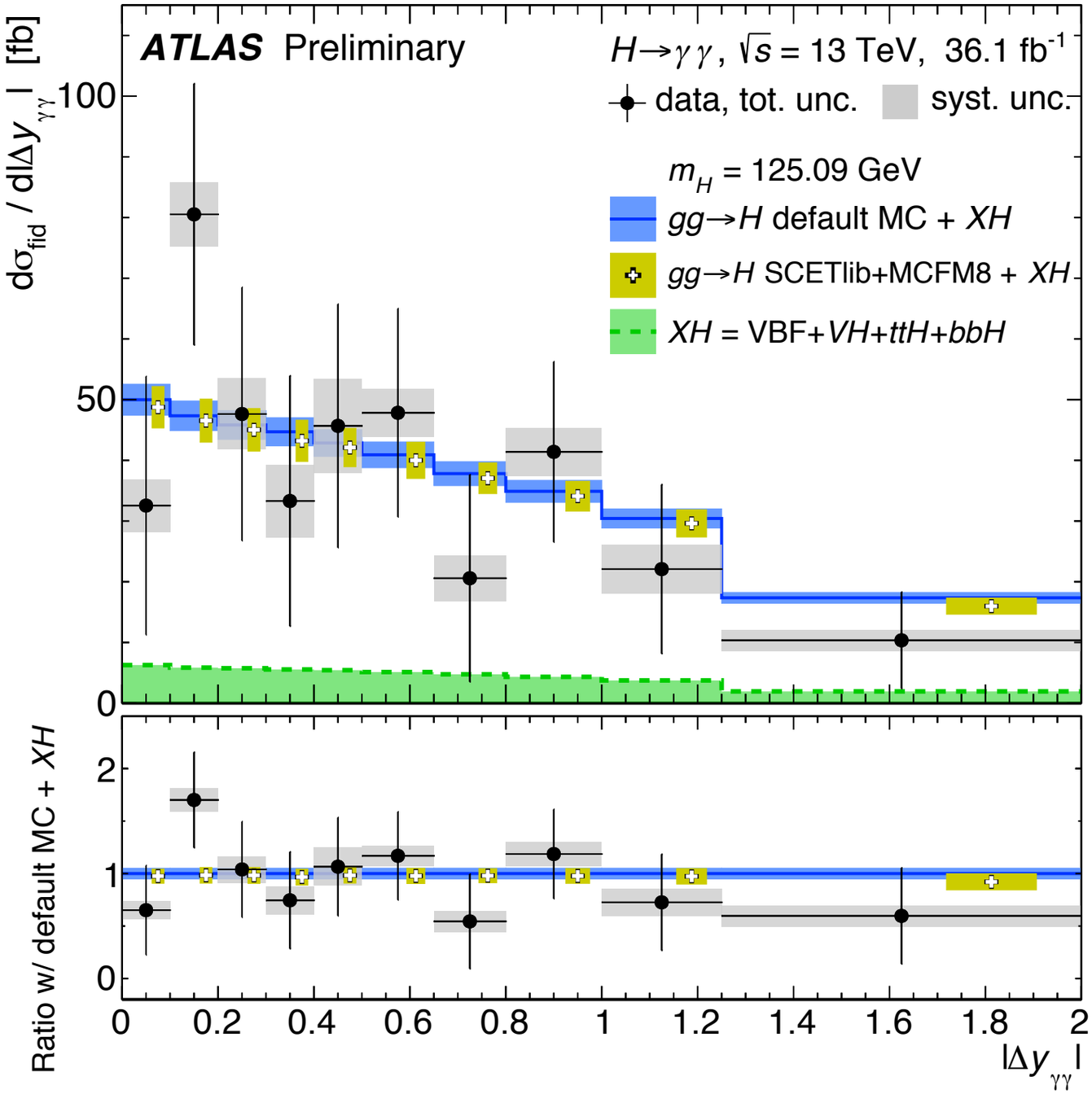
backup

differential XS



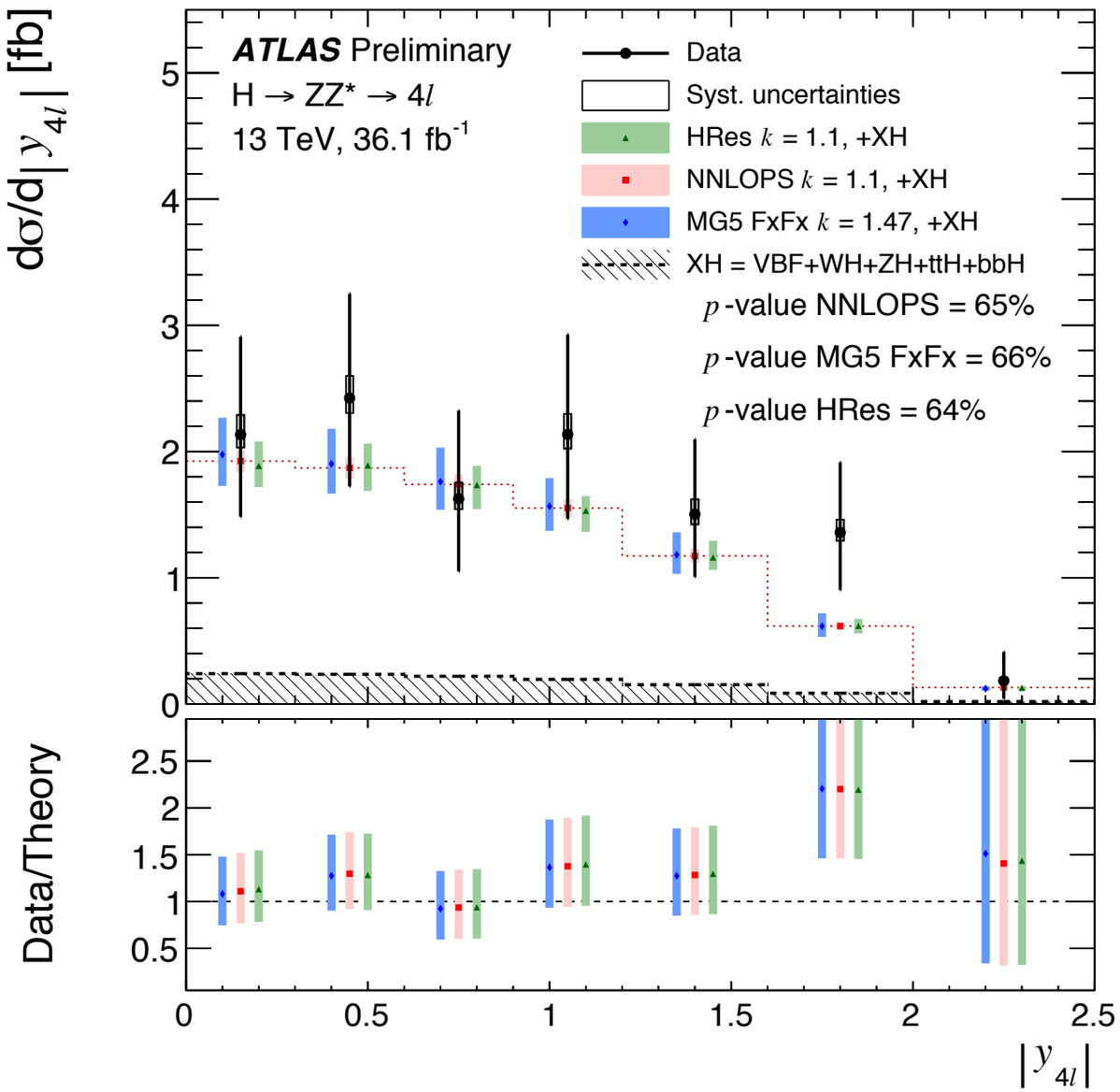


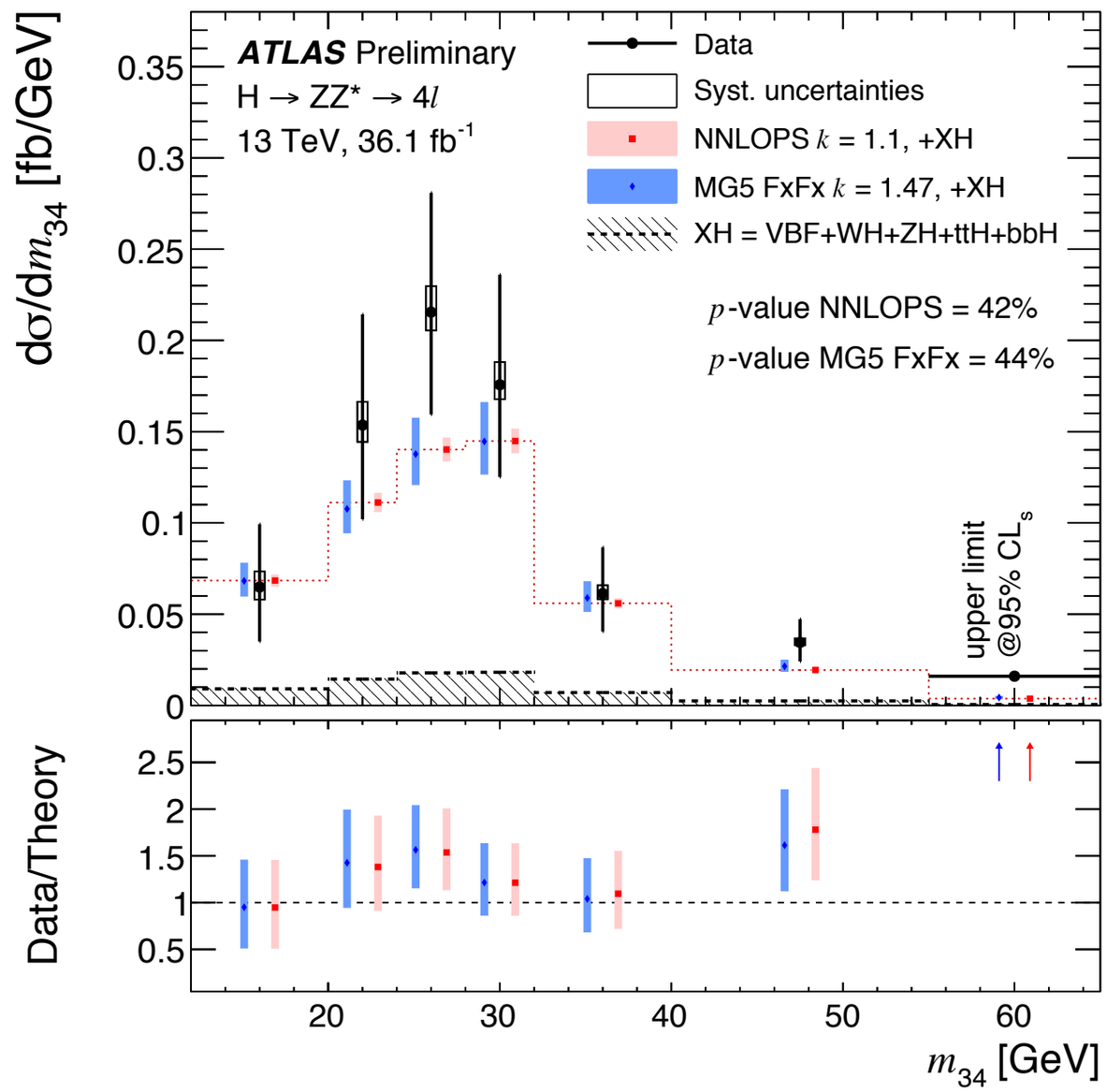
differential XS



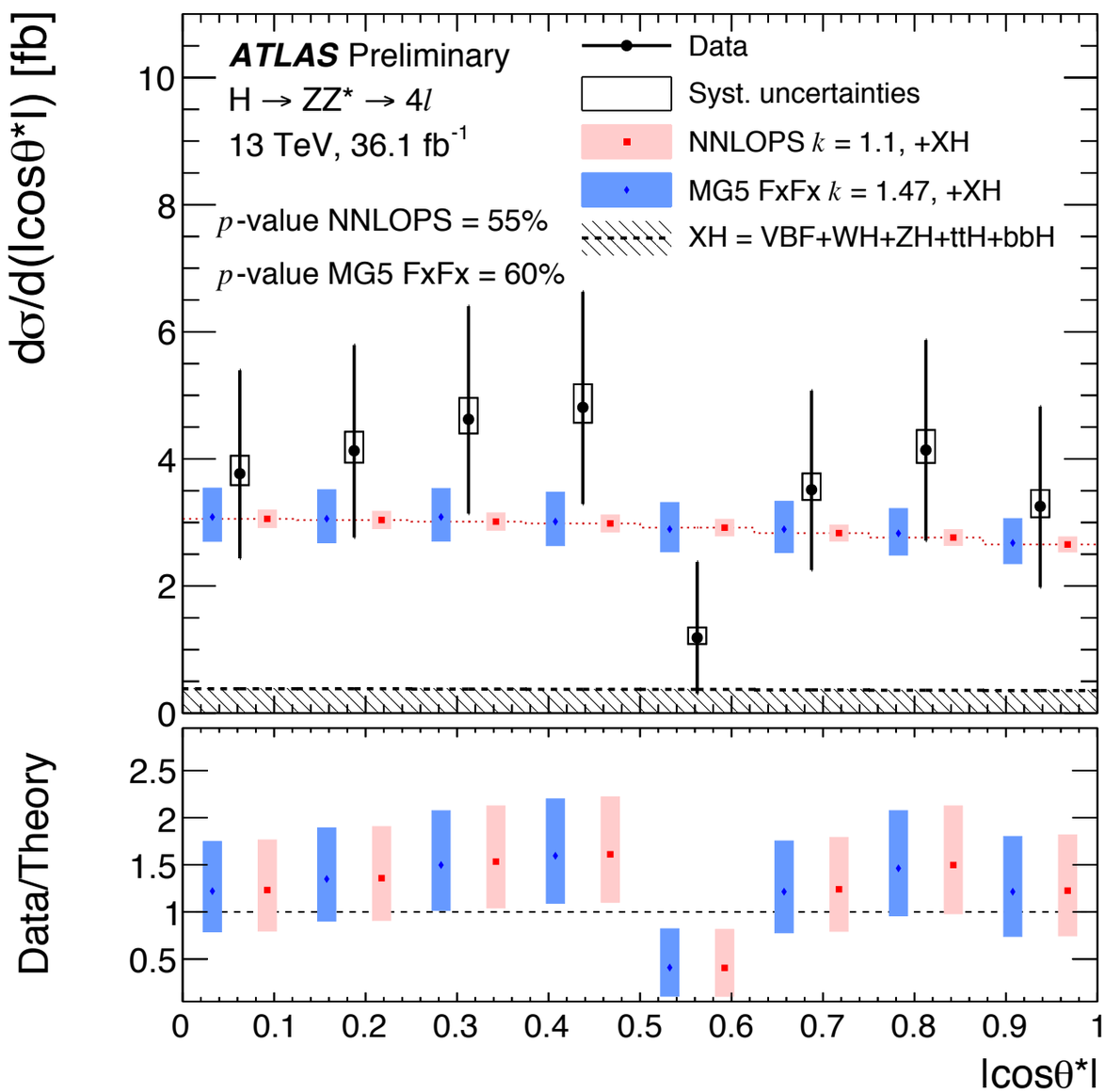
Variable	POWHEG NNLOPS + XH
$p_{\mathrm{T}}^{\gamma\gamma}$	57%
$p_{\mathrm{Tt}}^{\gamma\gamma}$	38%
$\lvert y_{\gamma\gamma}\rvert$	57%
$\lvert\cos\theta^*\rvert$	46%
$\lvert\Delta y_{\gamma\gamma}\rvert$	82%

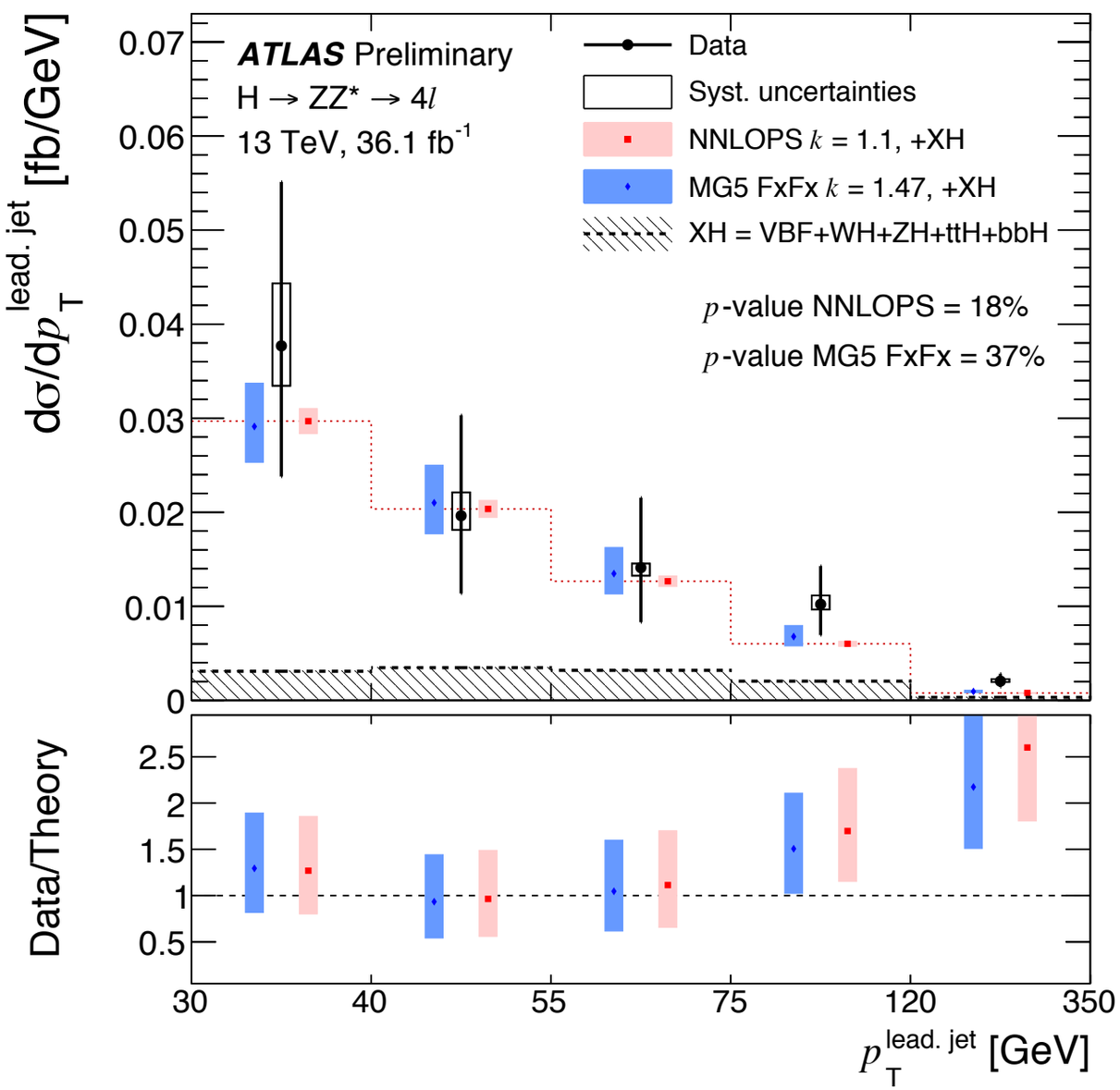
differential XS



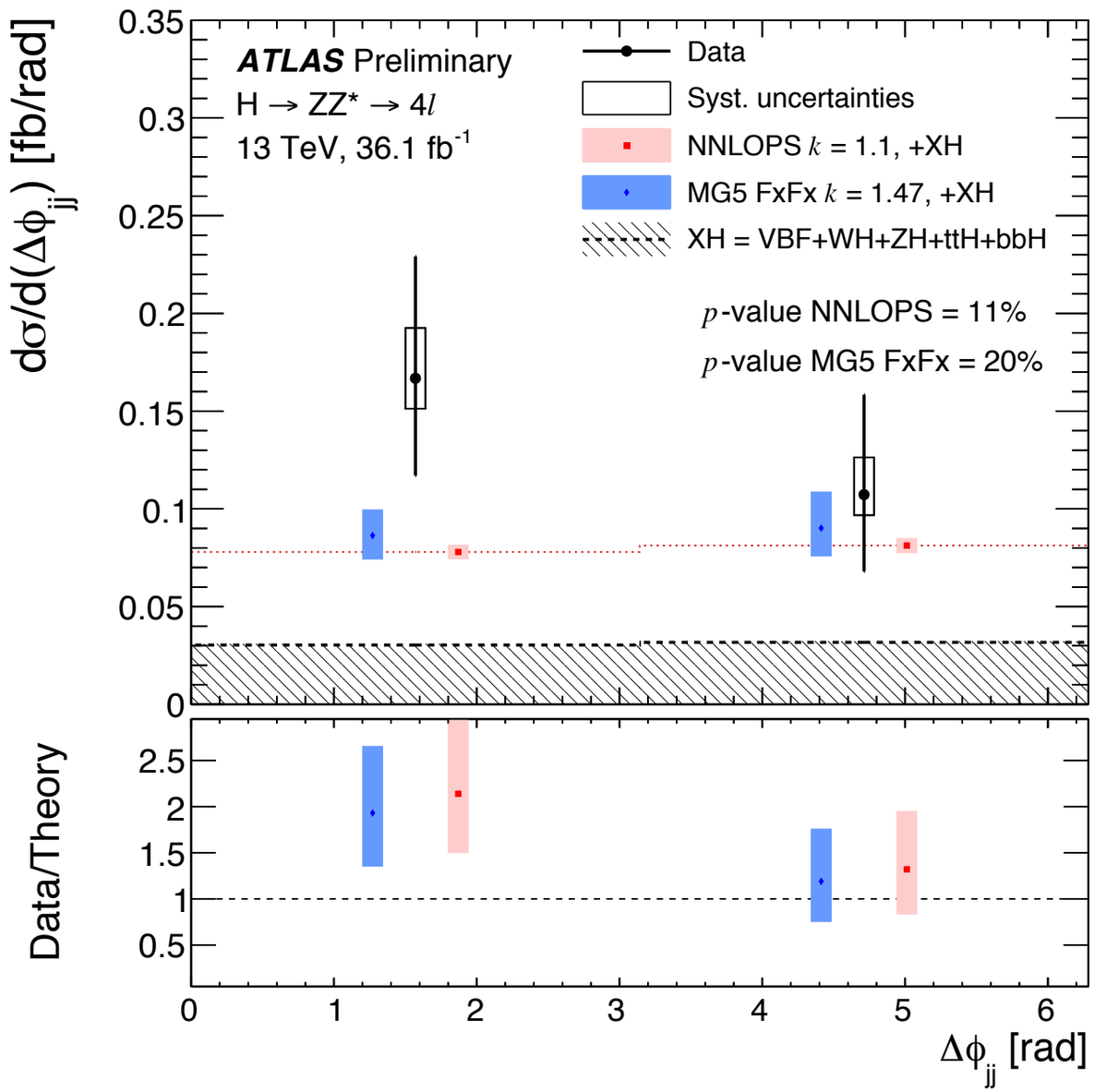


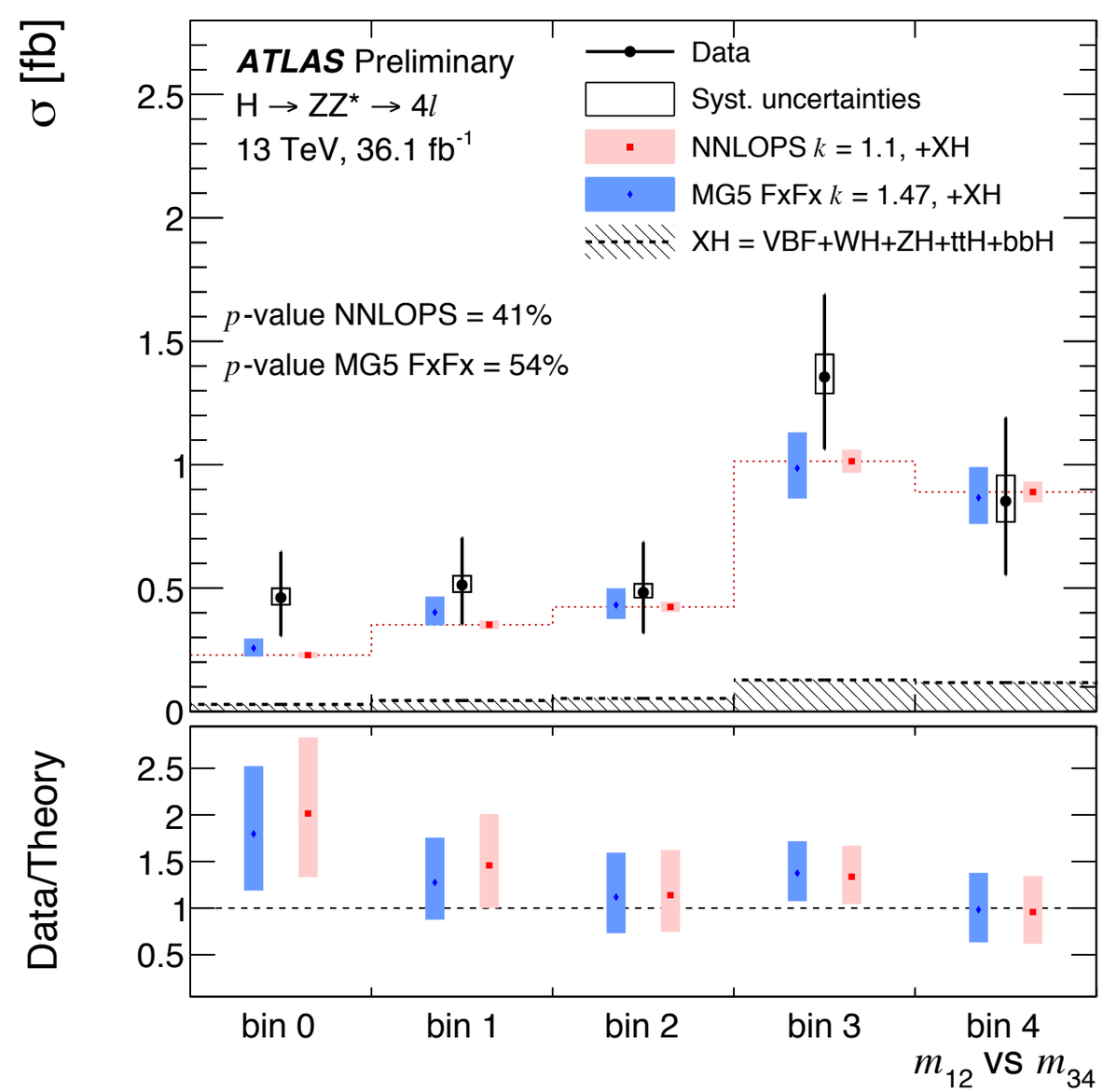
differential XS





differential XS





systematic uncertainties for di-photon

Source	Uncertainty on fiducial cross section (%)				
	Diphoton	VBF-enhanced	$N_{\text{lepton}} \geq 1$	$t\bar{t}H$-enhanced	High $E_{\text{T}}^{\text{miss}}$
Fit (stat.)	17%	22%	72%	150%	53%
Fit (syst.)	6%	8%	28%	170%	13%
Photon efficiency	1.8%	1.8%	1.8%	1.8%	1.9%
Jet energy scale/resolution	-	8.9%	-	4.5%	6.9%
b-jet flavour tagging	-	-	-	3%	-
Lepton selection	-	-	0.8%	0.2%	-
Pileup	1.1%	2.9%	1.3%	4.4%	2.5%
Theoretical modeling	4.2%	8.2%	8.7%	12.7%	30%
Luminosity	3.2%	3.2%	3.2%	3.2%	3.2%

systematic uncertainties for 4l

Observable	Stat unc. [%]	Systematic unc. [%]	Dominant systematic components [%] e	jets	μ	ZZ^* theo	Model	$Z+\text{jets}+t\bar{t}$	Lumi
σ_{comb}	14	7	3	< 0.5	3	2	0.8	0.8	4
$\mathrm{d}\sigma/\mathrm{d}p_{\mathrm{T},4\ell}$	$30-150$	$3-11$	$1-4$	< 0.5	$1-3$	$0-7$	$0-6$	$1-6$	$3-5$
$\partial\sigma/\partial p_{\mathrm{T},4\ell}$ (0j)	$31-52$	$10-18$	$2-5$	$3-16$	$1-4$	$3-8$	1	$2-3$	$3-5$
$\partial\sigma/\partial p_{\mathrm{T},4\ell}$ (1j)	$35-15$	$6-30$	$1-4$	$2-29$	$1-3$	$1-4$	$1-11$	$1-2$	$3-5$
$\partial\sigma/\partial p_{\mathrm{T},4\ell}$ (2j)	$30-41$	$5-21$	$1-3$	$2-19$	$1-3$	$1-5$	$1-7$	$1-2$	$3-5$
$\mathrm{d}\sigma/\mathrm{d}\lvert y_{4\ell}\rvert$	$29-120$	$5-8$	$2-4$	< 0.5	$2-3$	$1-2$	$0-1$	$1-1$	$3-5$
$\mathrm{d}\sigma/\mathrm{d}\lvert\cos\theta^*\rvert$	$31-100$	$5-8$	$2-4$	< 0.5	$2-3$	$1-2$	$0-2$	$1-4$	$3-5$
$\mathrm{d}\sigma/\mathrm{d}m_{34}$	$26-53$	$4-13$	$2-5$	< 0.5	$1-5$	$1-6$	$0-1$	$1-3$	$3-5$
$\partial^2\sigma/\ \partial m_{12}\ \partial m_{34}$	$21-40$	$4-12$	$2-4$	< 0.5	$1-4$	$1-6$	$0-1$	$1-4$	$3-5$
$\mathrm{d}\sigma/\mathrm{d}N_{\mathrm{jets}}$	$22-44$	$6-31$	$1-4$	$4-22$	$1-3$	$2-4$	$1-22$	$1-2$	$3-5$
$\mathrm{d}\sigma/\mathrm{d}p_{\mathrm{T}}^{\mathrm{lead.jet}}$	$30-53$	$5-18$	$1-4$	$3-16$	$1-3$	$2-3$	$1-8$	$1-2$	$3-5$
$\mathrm{d}\sigma/\mathrm{d}\Delta\phi_{\mathrm{jj}}$	$29-43$	$9-17$	$1-3$	$8-14$	$1-3$	$3-4$	$1-7$	$1-1$	$3-5$
$\mathrm{d}\sigma/\mathrm{d}m_{jj}$	$23-100$	$9-27$	$1-4$	$8-24$	$1-4$	$3-8$	$1-7$	$0-3$	$3-5$

Higgs pseudo-observables

$\varepsilon_R = 0.48 * \varepsilon_L$
from TGC measurements