Co-funded by the Horizon 2020 Framework Programme of the European Union

Measurements in Higgs decays to diboson final states at the ATLAS and CMS

Giacomo Ortona (LLR)
For the ATLAS and CMS collaborations

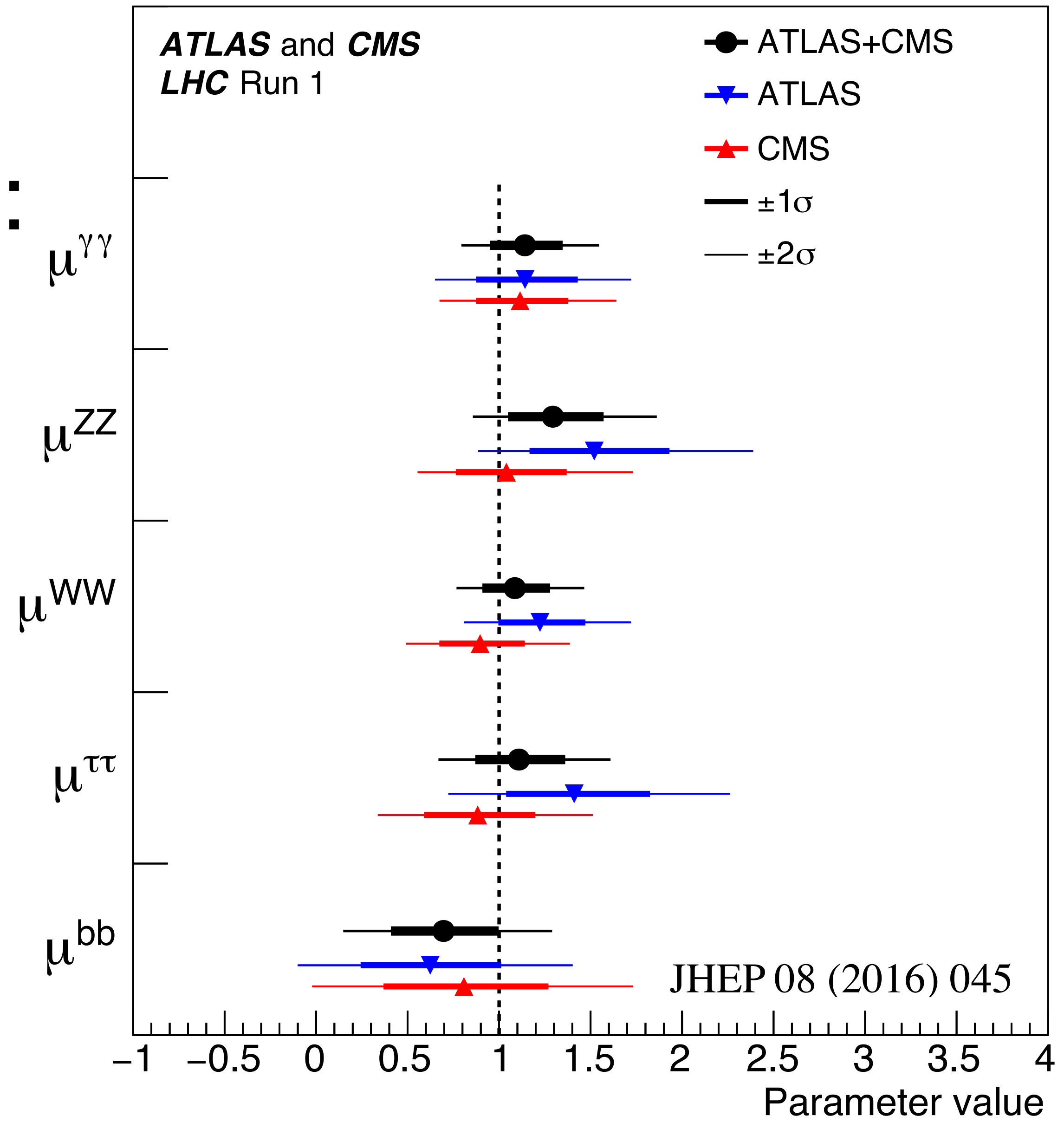
Introduction

Diboson Higgs decays are crucial for precise measurements of the Higgs properties.
Run1 most precise results for the H boson properties from ATLAS + CMS combination:

- **Mass** $m_H = 125.09 \pm 0.24$
- **Signal strength** $\mu = 1.09 \pm 0.11$ → $\mu_i = \frac{\sigma_i}{\sigma_i^{SM}}$ $\mu^f = \frac{BR^f}{BR^f_{SM}}.$
- **Couplings** to SM particles compatible with predictions

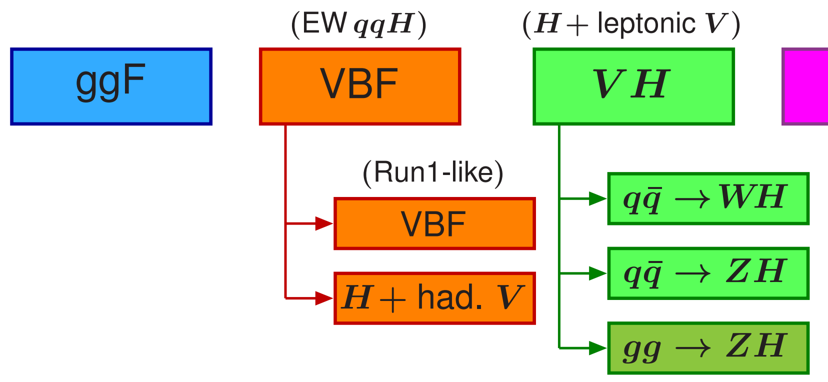
$$\kappa_j^2 = \sigma_j / \sigma_j^{SM} \qquad \kappa_j^2 = \Gamma_j / \Gamma_j^{SM} \qquad \sigma_i \cdot BR^f = \frac{\sigma_i \cdot \Gamma_f}{\Gamma_H},$$

$k_V = \{k_W, k_Z\}$; $k_F = \{k_t, k_b, k_\tau, k_\mu\}$

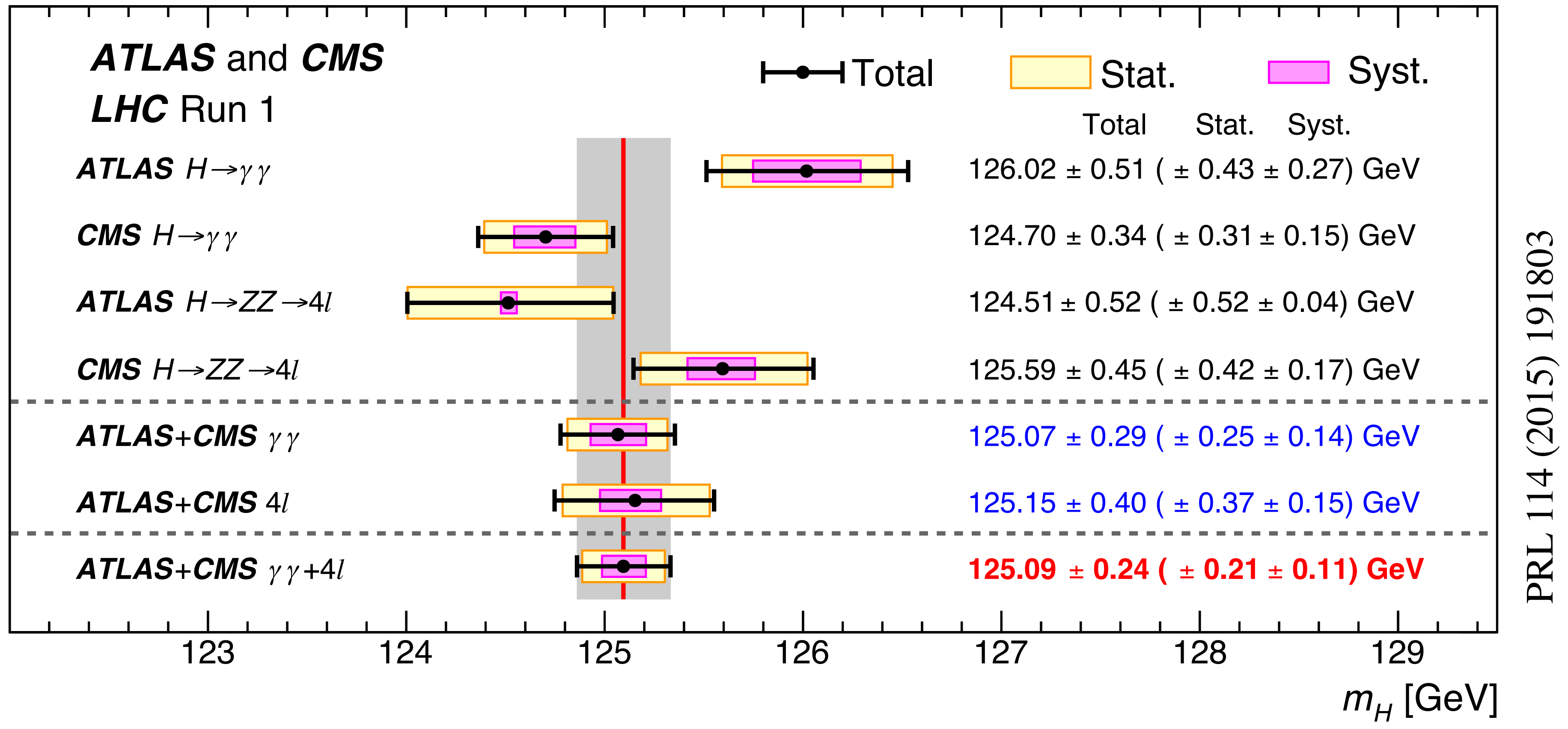


Run2: we are starting to measure cross sections and differential distributions

- **Fiducial cross-section** measurements
- **Differential cross section**
- Simplified Template Cross Sections (**STXS**)
  - Cross section split by production mode
  - Divided in **exclusive** regions of phase space
  - Abstracted fiducial volumes
  - Common abstracted object definitions



STXS tage 0



Results in this talk based on CMS and ATLAS H→WW, H→ZZ, and H→**γγ** analyses of **13TeV** data collected in 2015, 2016 **and 2017**.

$H \to WW^* \to l\nu l\nu$

Good S/B ratio, high BR, relatively large background

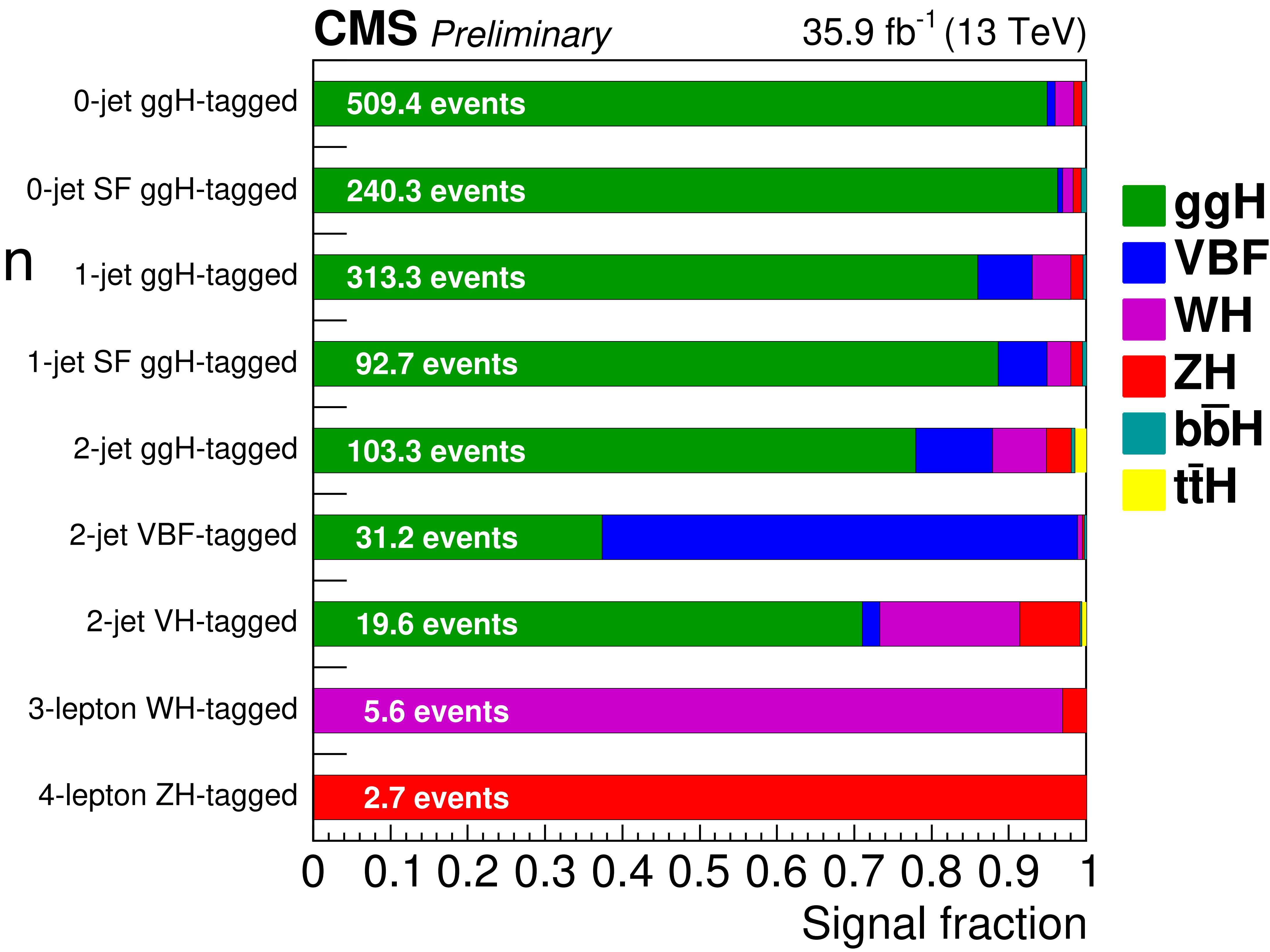
ν in the final state. Worse resolution wrt ZZ

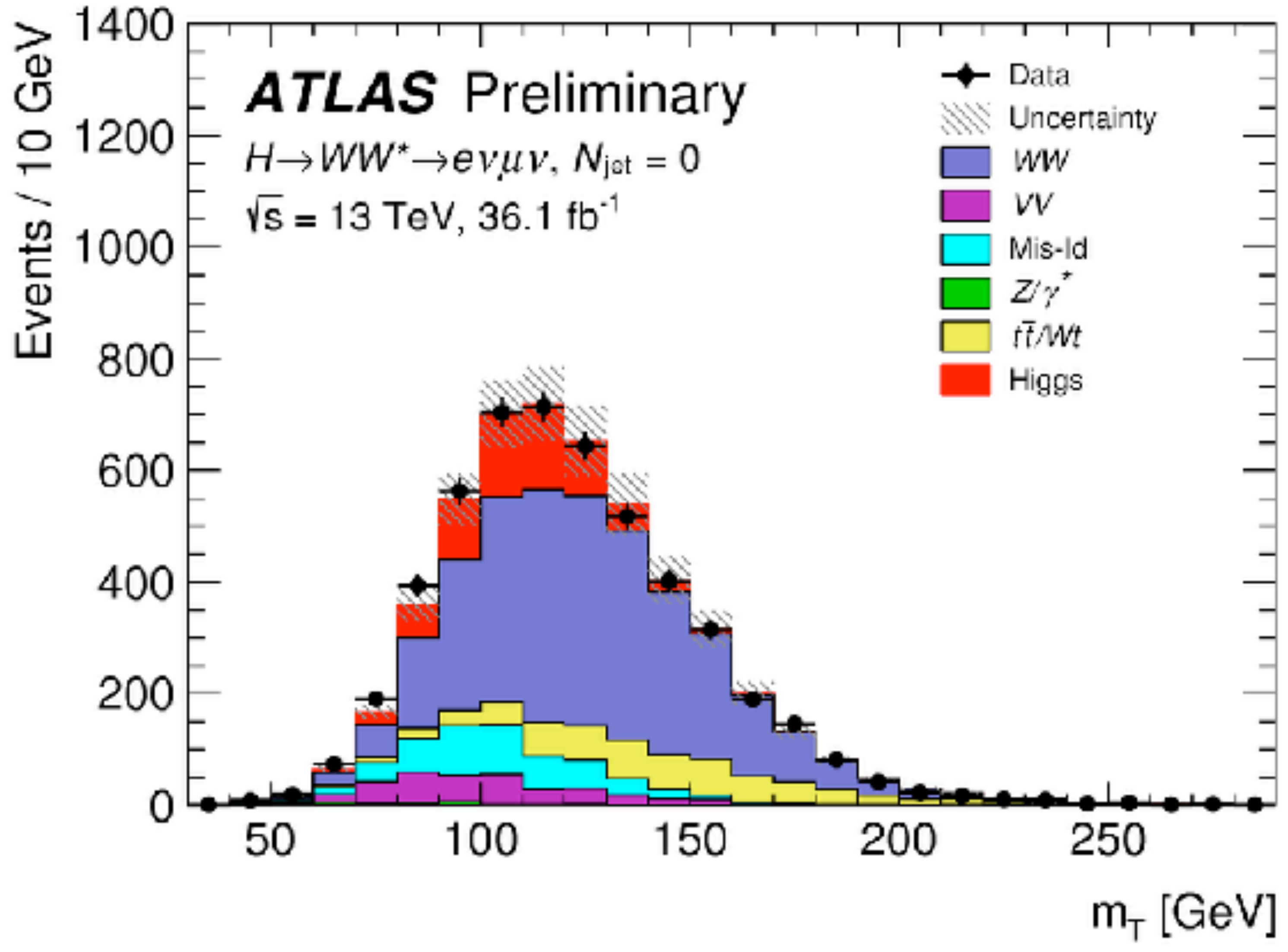
Single- and di-lepton triggers to select events

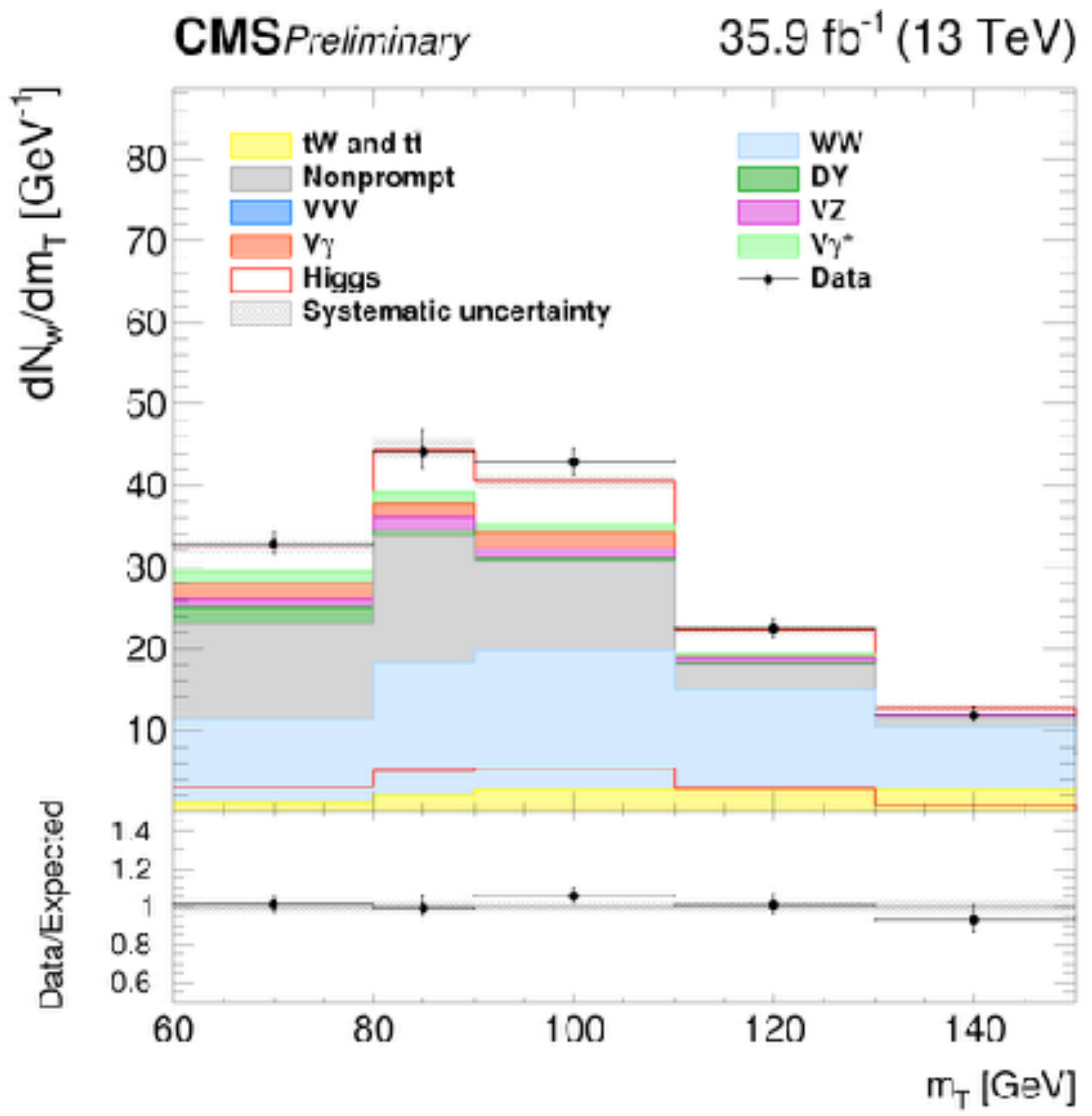
≥2 high-p_T opposite sign isolated leptons + MET. BDT selection in various categories.

Additional categorisation based on extra leptons, extra jets, and lepton flavours to target VBF and VH productions

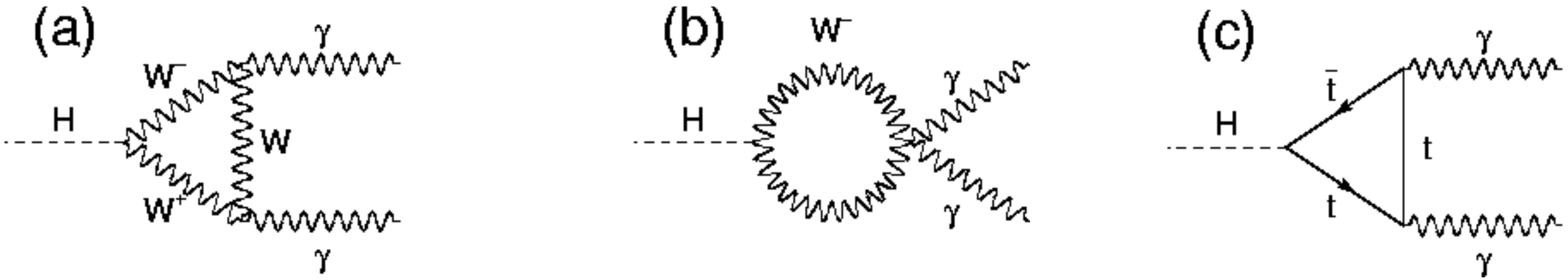
Analyses based on m_{ll} and m_T distributions







$H \to \gamma\gamma$



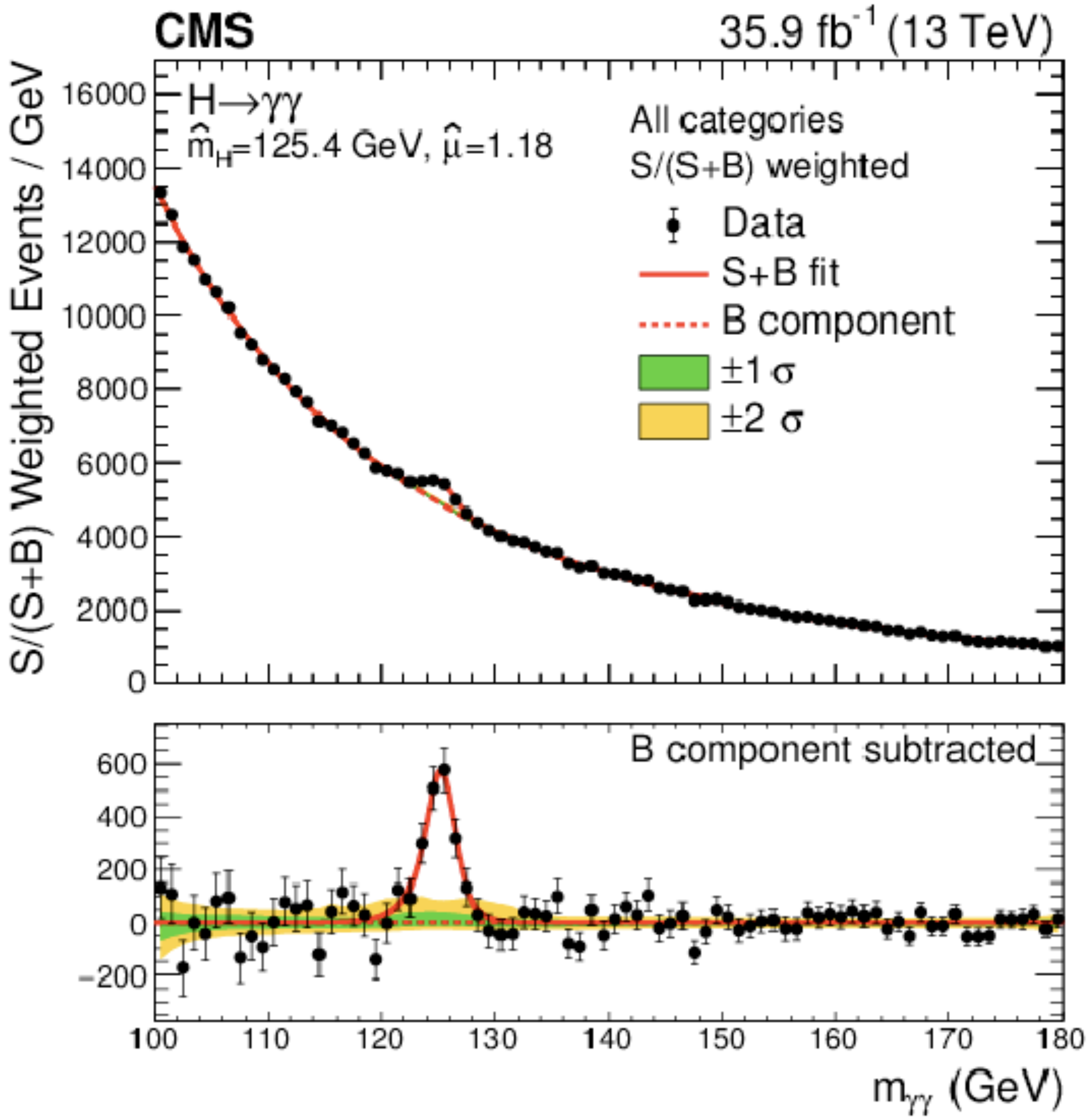
Indirect probe of coupling through production loops
- Sensitive to vector/fermion couplings (k_V, k_F)
- Can test NP in the loops

Search strategy: peak over (abundant) and regular background

Observed width dominated by detector resolution

Efficient selection (40%)
- Trigger, photon ID, E_T, isolation,…
- Abundant number of selected events allows for a large number of categories→sensitivity to different production/decay modes

Main uncertainties: photon ID/resolution, luminosity, statistical uncertainty still the largest factor

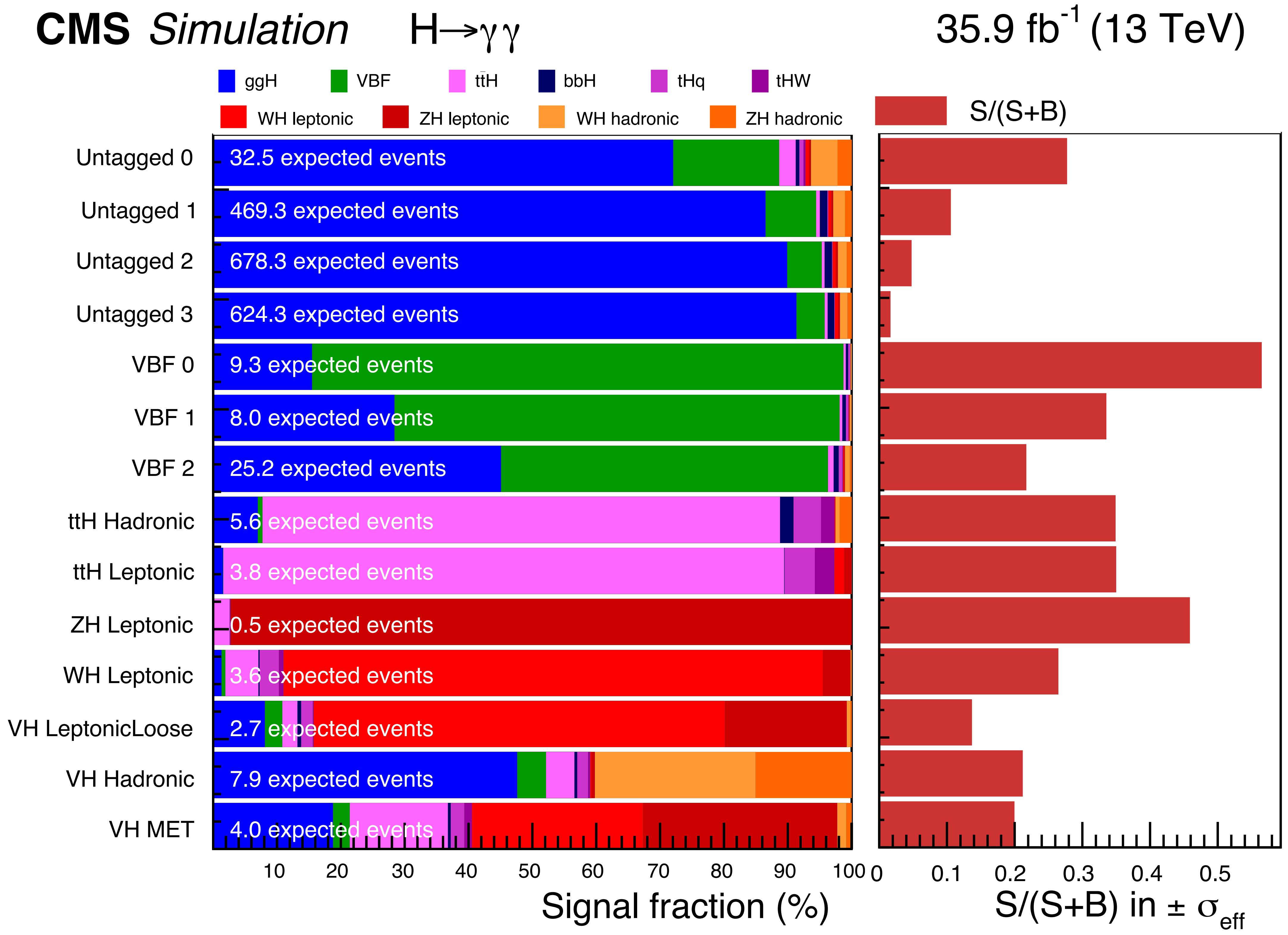


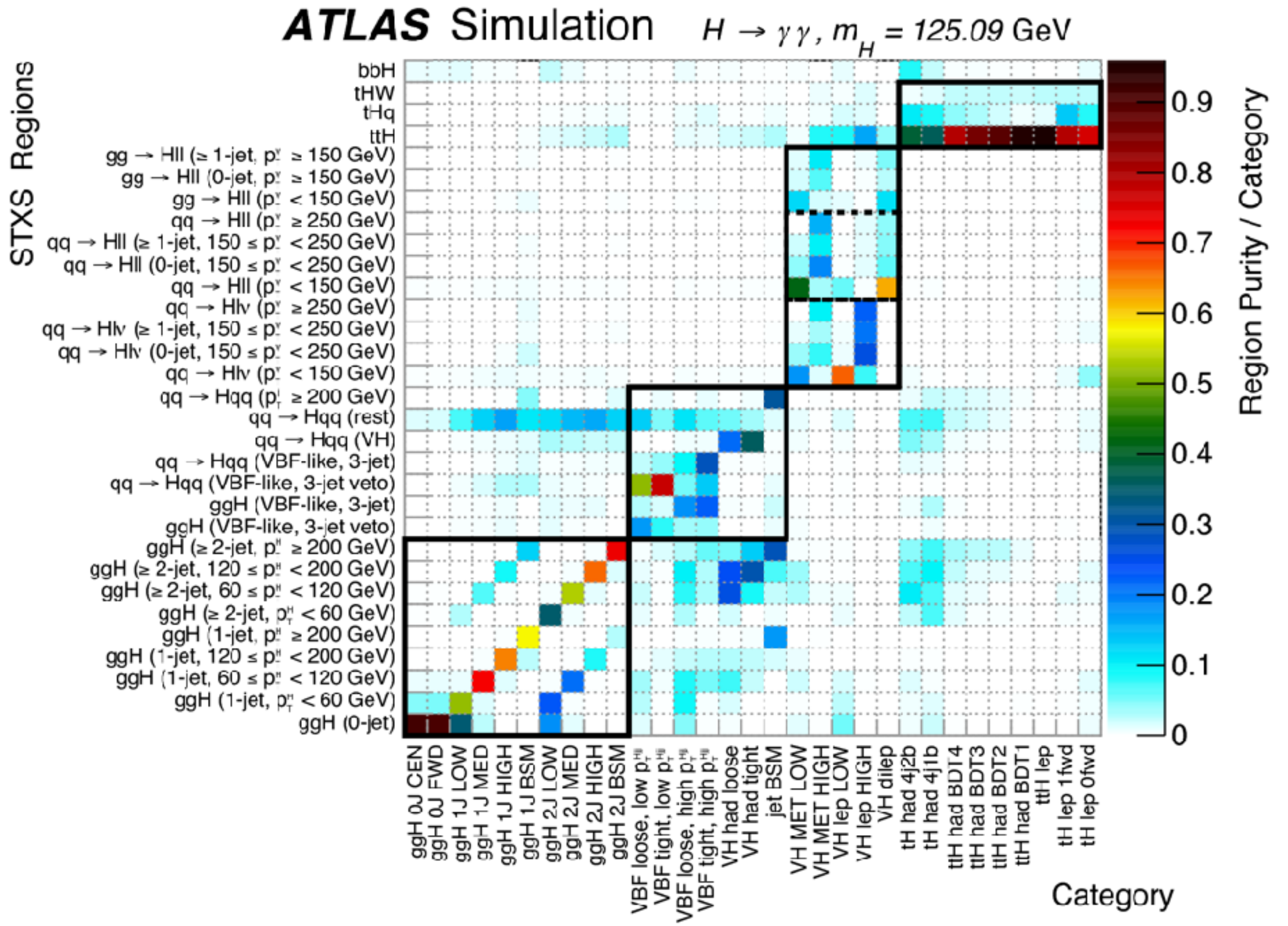
Categorisation

Vertex+photonID+kinematic BDT to select and classify the events

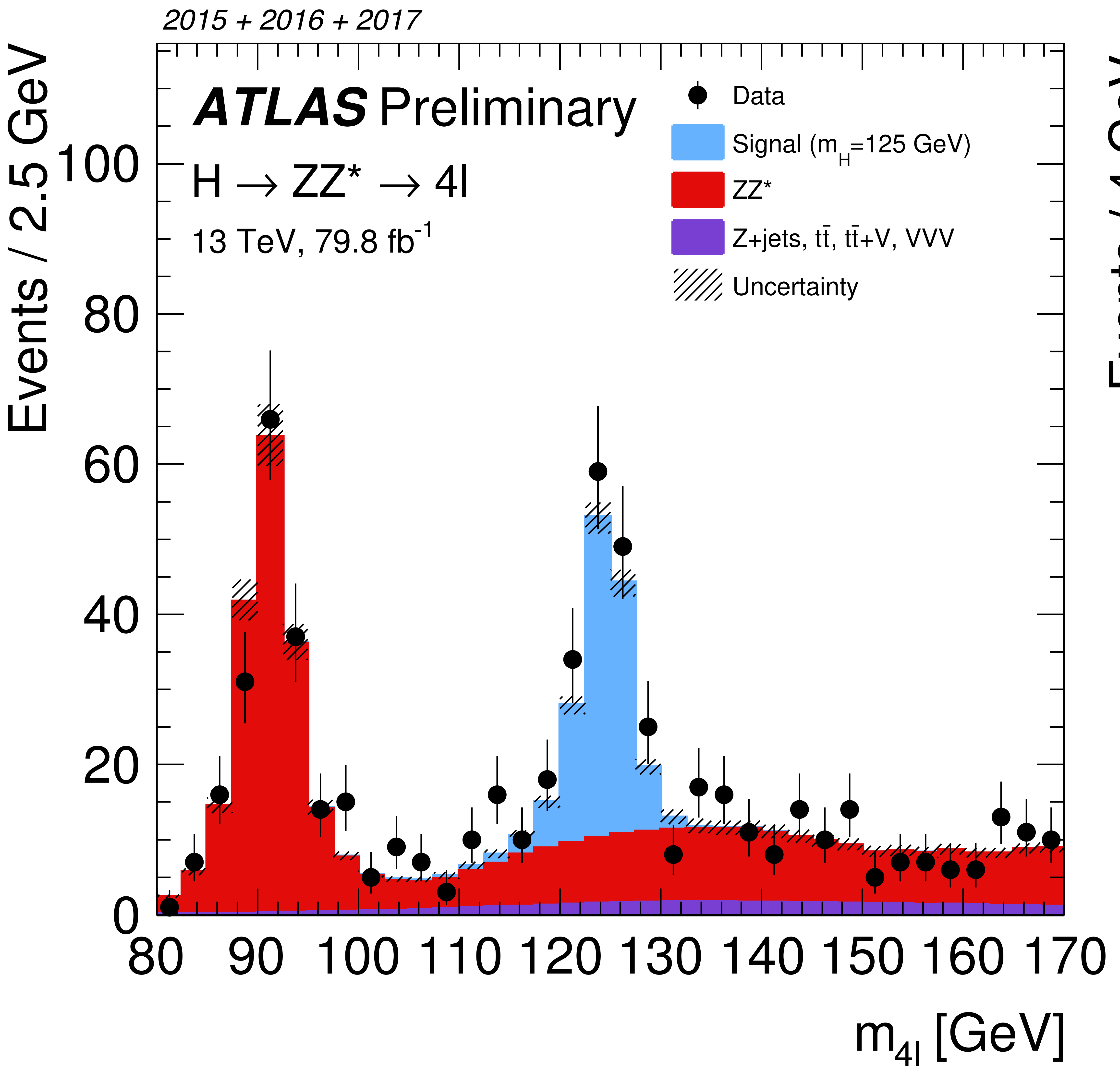
Large number of categories, with different S/B ratios and sensitive to different production modes

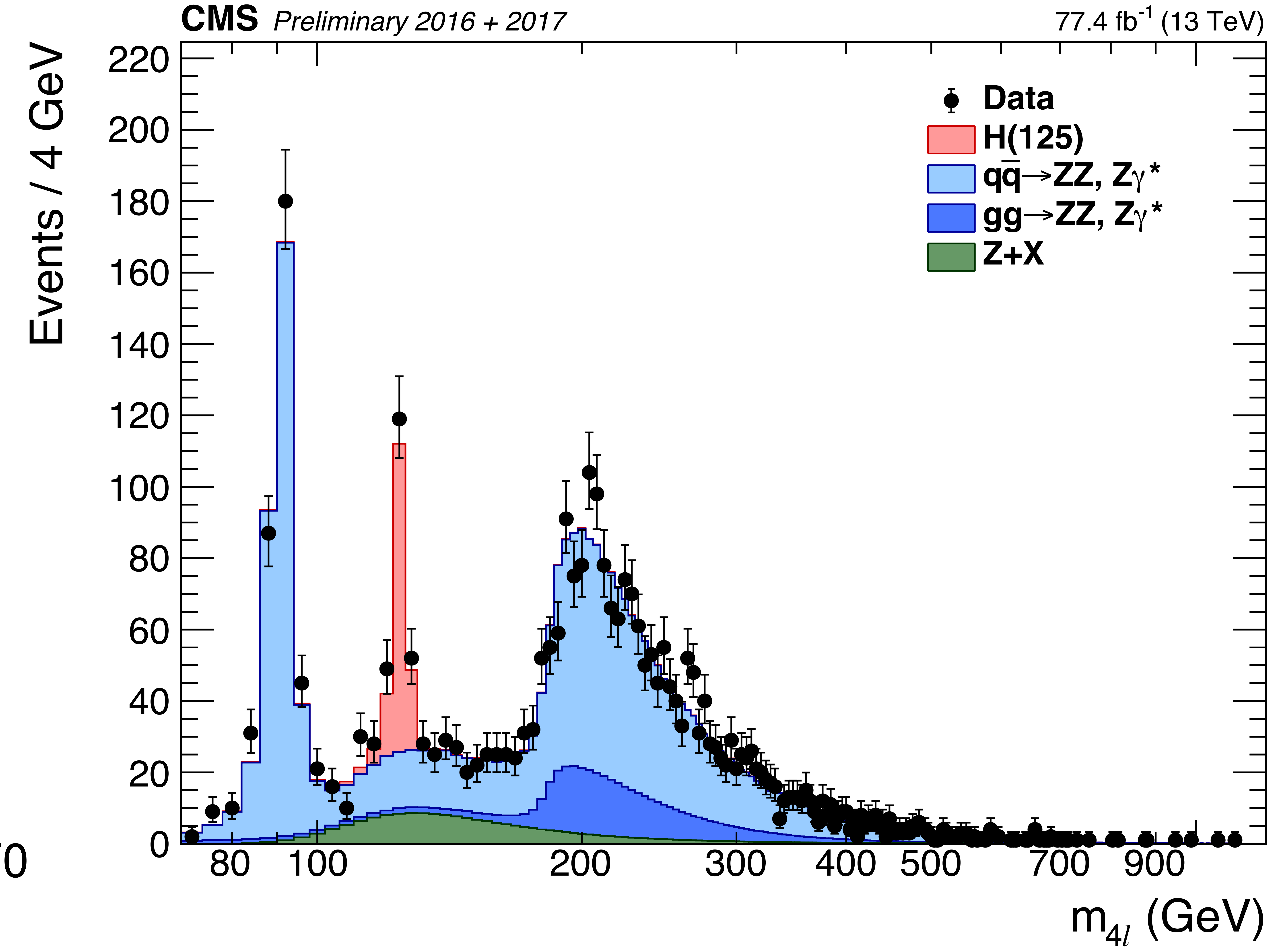
- Can be tuned to increase sensitivity to the STXS scheme (ATLAS)





H→ZZ*→4l


2015 + 2016 + 2017
ATLAS Preliminary
H → ZZ* → 4l
13 TeV, 79.8 fb-1
Data
Signal (mH=125 GeV)
ZZ*
Z+jets, tt̄, tt̄+V, VVV
Uncertainty
Events / 2.5 GeV
m4l [GeV]


CMS Preliminary 2016 + 2017
77.4 fb-1 (13 TeV)
Data
H(125)
qq̄→ZZ, Zγ*
gg→ZZ, Zγ*
Z+X
Events / 4 GeV
m4l (GeV)

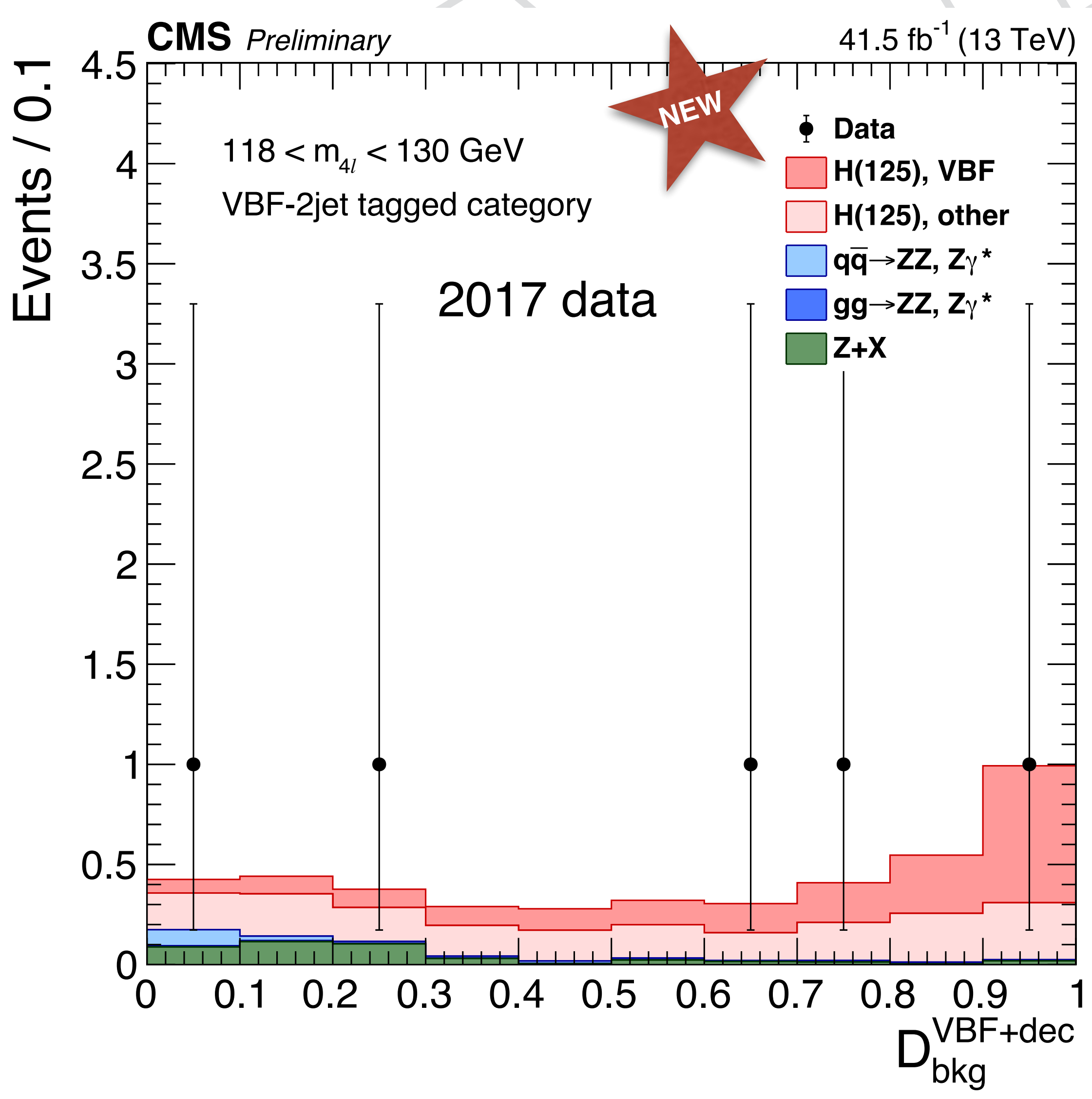
$H \rightarrow ZZ^* \rightarrow 4l$

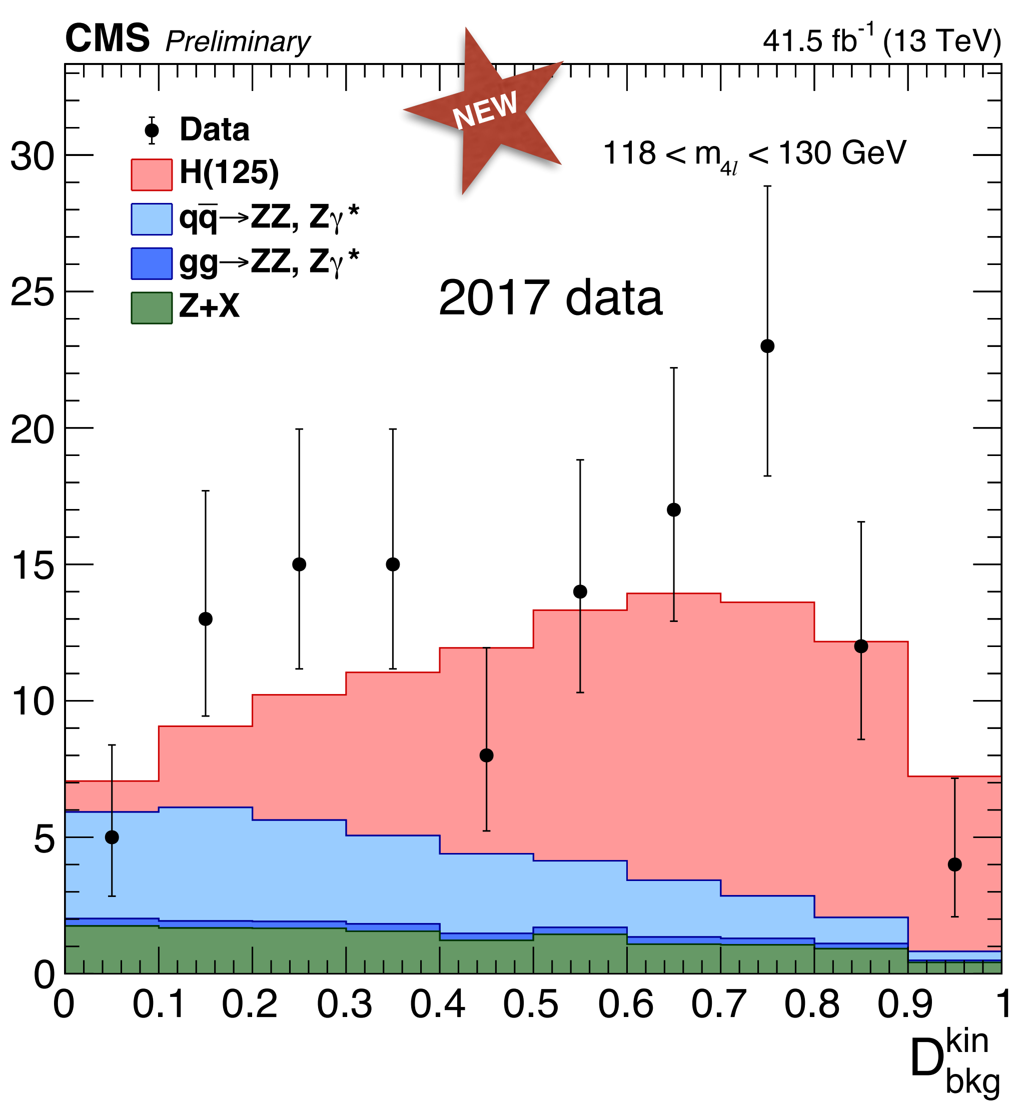
Low signal rate, but very clear signal topology over a small, flat background (mainly qqZZ, Z+jets)

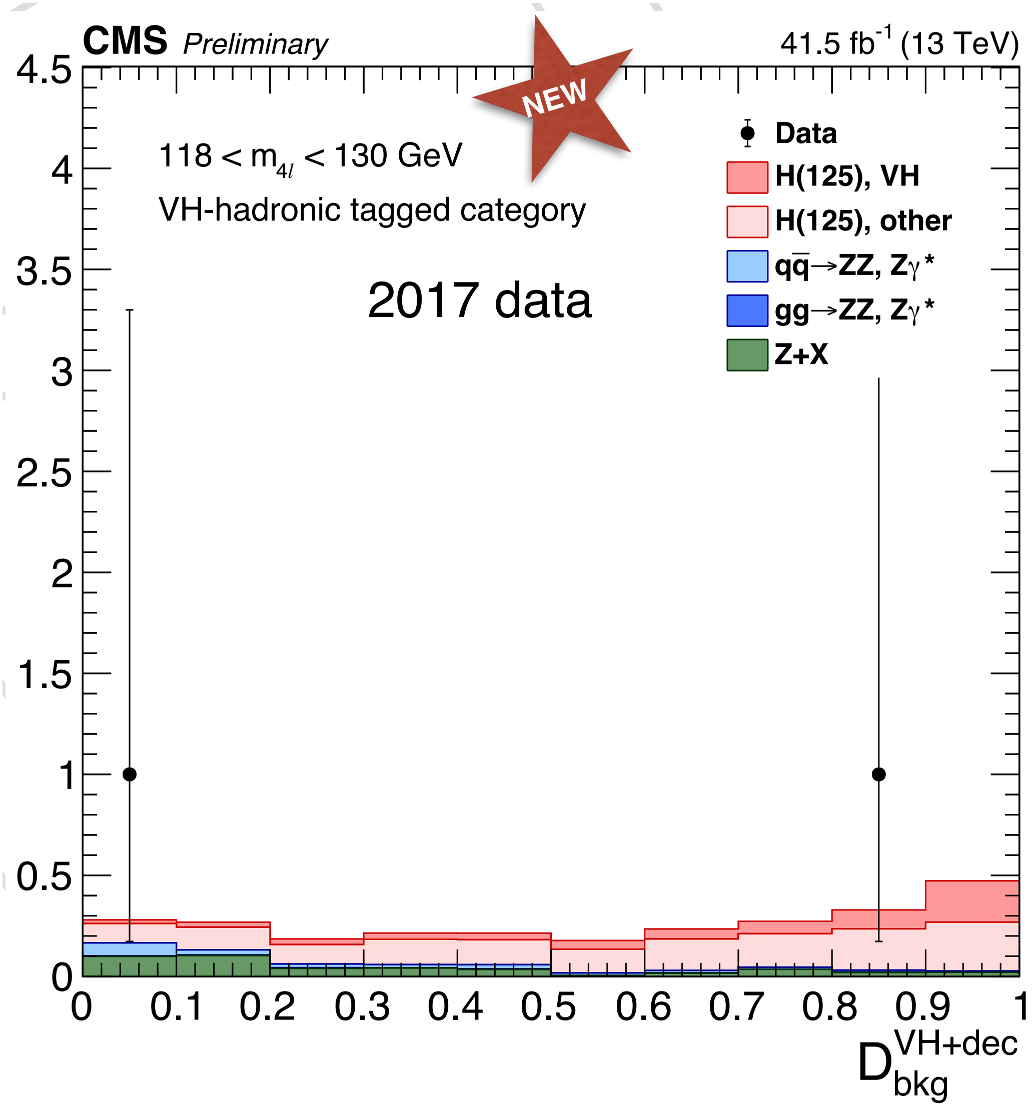
- 4 isolated leptons in final state combined in 2 Z pairs
- Kinematical information (matrix element KD discriminants) or BDT techniques to separate signal and background and categorise events

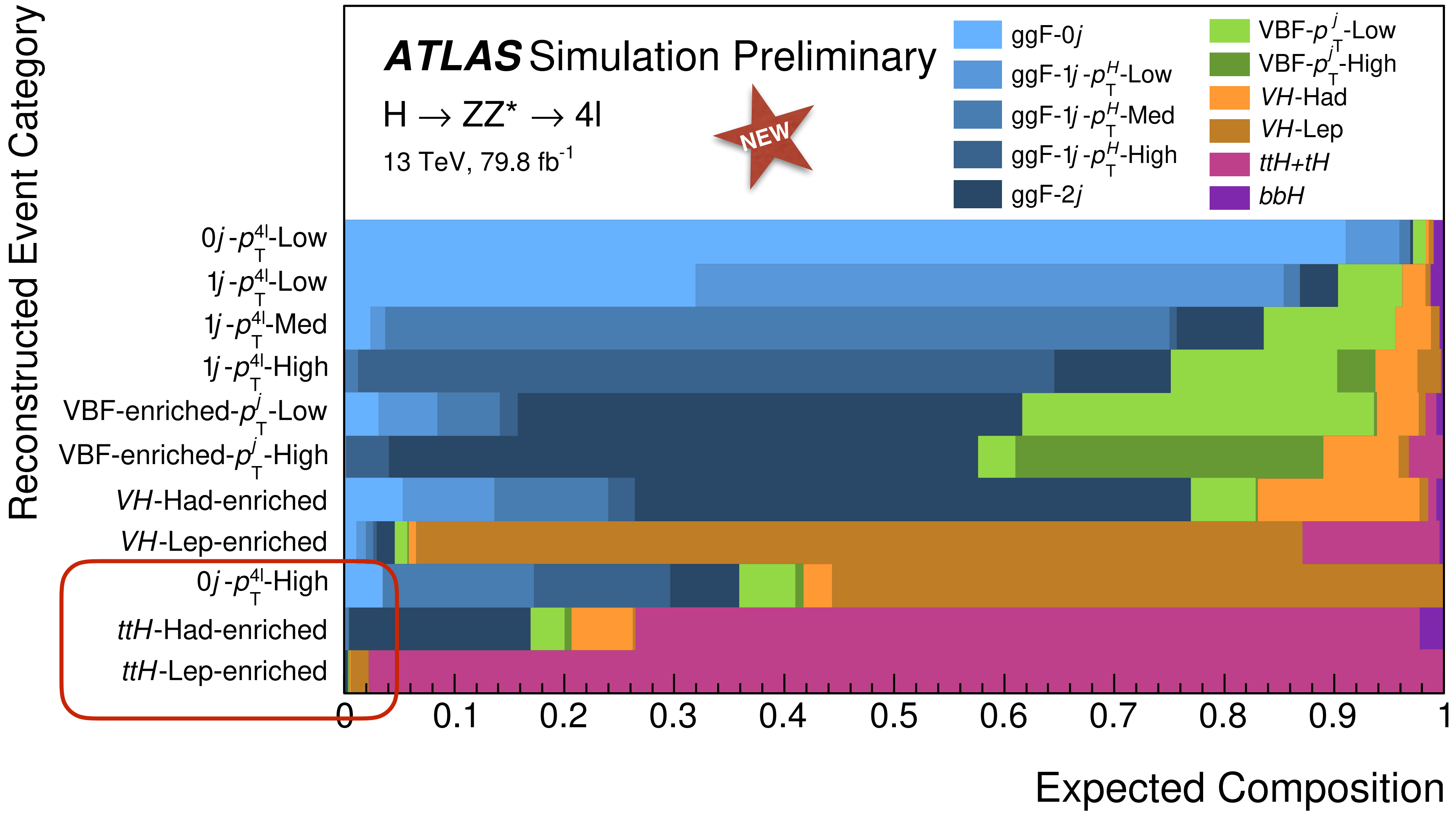
Analysis is still being improved:

- Improved event categorisation to target VH and ttH productions NEW
- CMS: dedicated discriminants to target different production modes (ggH, VBF, VH)







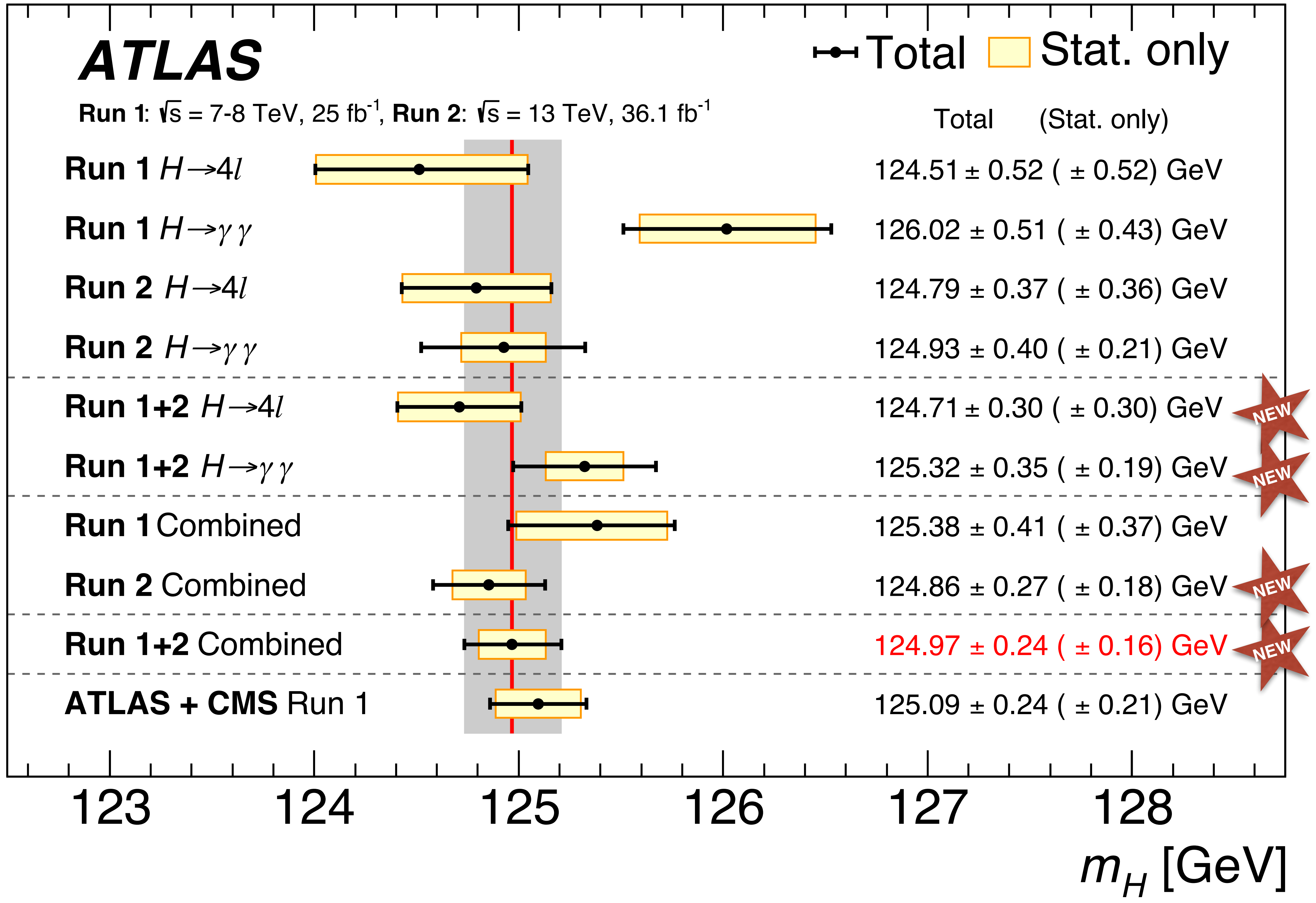


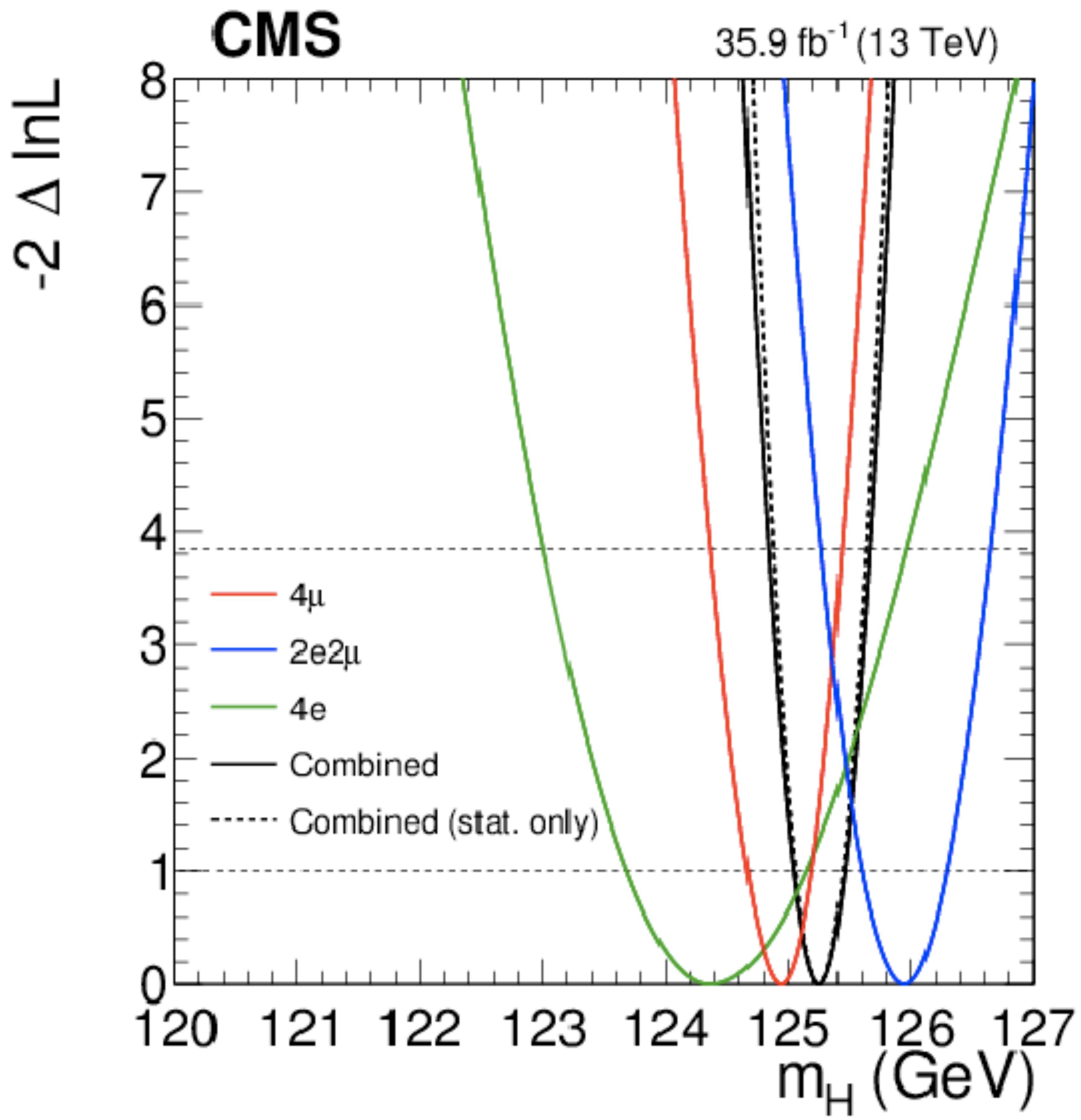
First public Higgs analyses including **2017 data**!

Mass measurement

H→ZZ→4l and H→$\gamma\gamma$ are the final states with the highest precision for the mass measurement

ATLAS performed the combined measurement of the Run1 and Run2 (2015+2016) H→ZZ→4l and H→$\gamma\gamma$ mass measurements, m_H = 124.97±0.24 GeV





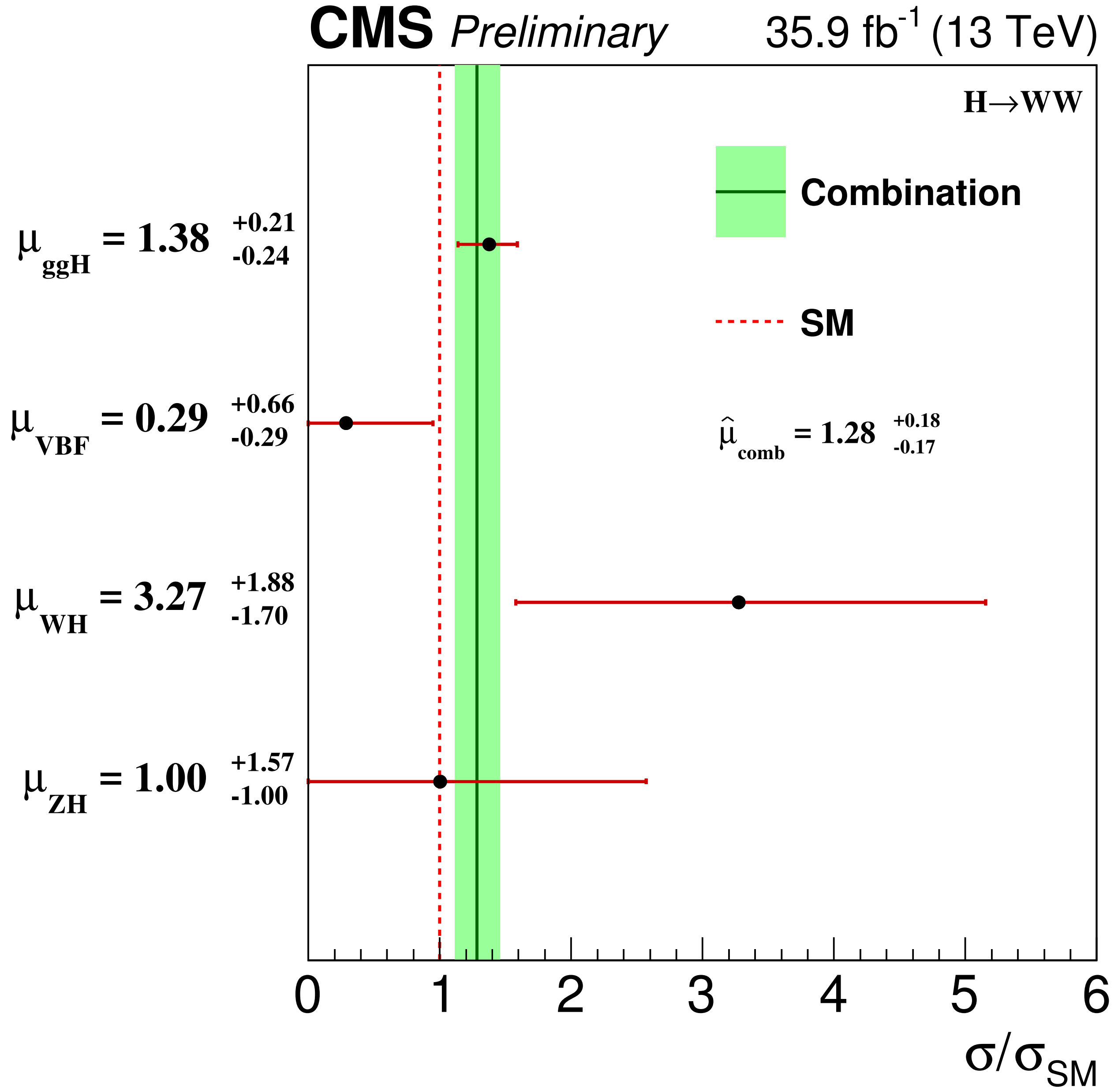
Most precise measurement at the moment comes from CMS H→ZZ→4l mass measurement with 2016 data m_H = 125.26±0.21 GeV

Signal strengths

H→WW→lνlν

Run1 CMS+ATLAS: $\mu=1.09^{+0.18}_{-0.16}$

Run2 small deficit in VBF, small excess in gluon fusion. Opposite with respect Run1



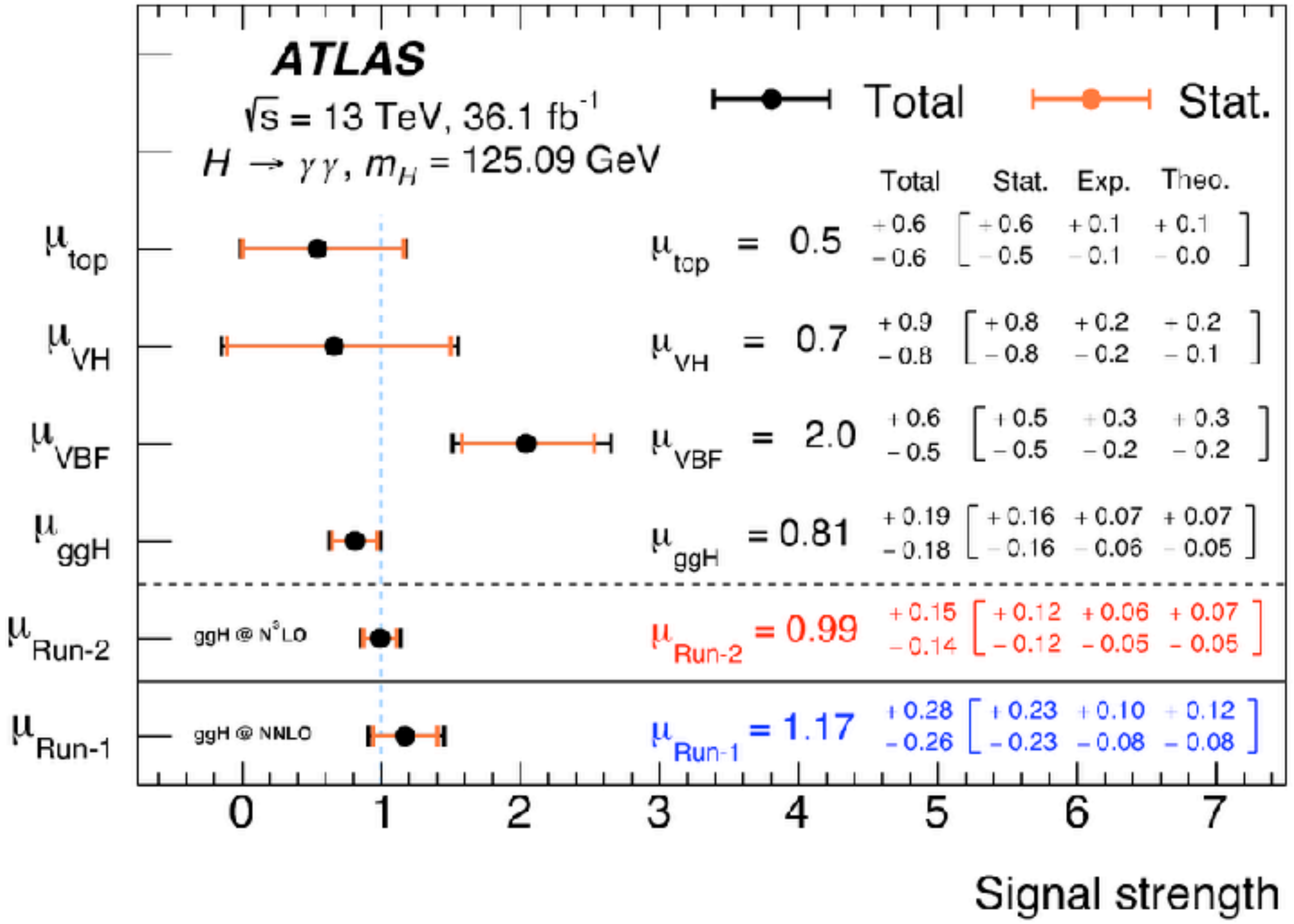
$$\mu^{\text{ATLAS}}_{\text{ggF}} = 1.21^{+0.12}_{-0.11}(\text{stat.})^{+0.18}_{-0.17}(\text{sys.})$$

$$\mu^{\text{ATLAS}}_{\text{VBF}} = 0.62^{+0.30}_{-0.28}(\text{stat.}) \pm 0.22(\text{sys.})$$

$$\mu^{\text{ATLAS}}_{WH} = 3.2^{+3.7}_{-3.2}(\text{stat})^{+2.3}_{-2.7}(\text{sys})$$ *2015 data

H→γγ

$$\hat{\mu}_{\text{CMS}} = 1.18^{+0.17}_{-0.14} = 1.18\ ^{+0.12}_{-0.11}(\text{stat})^{+0.09}_{-0.07}(\text{syst})^{+0.07}_{-0.06}(\text{theo})$$



Very good agreement between measurements and with expectations.
Run1: ATLAS excess, CMS deficit

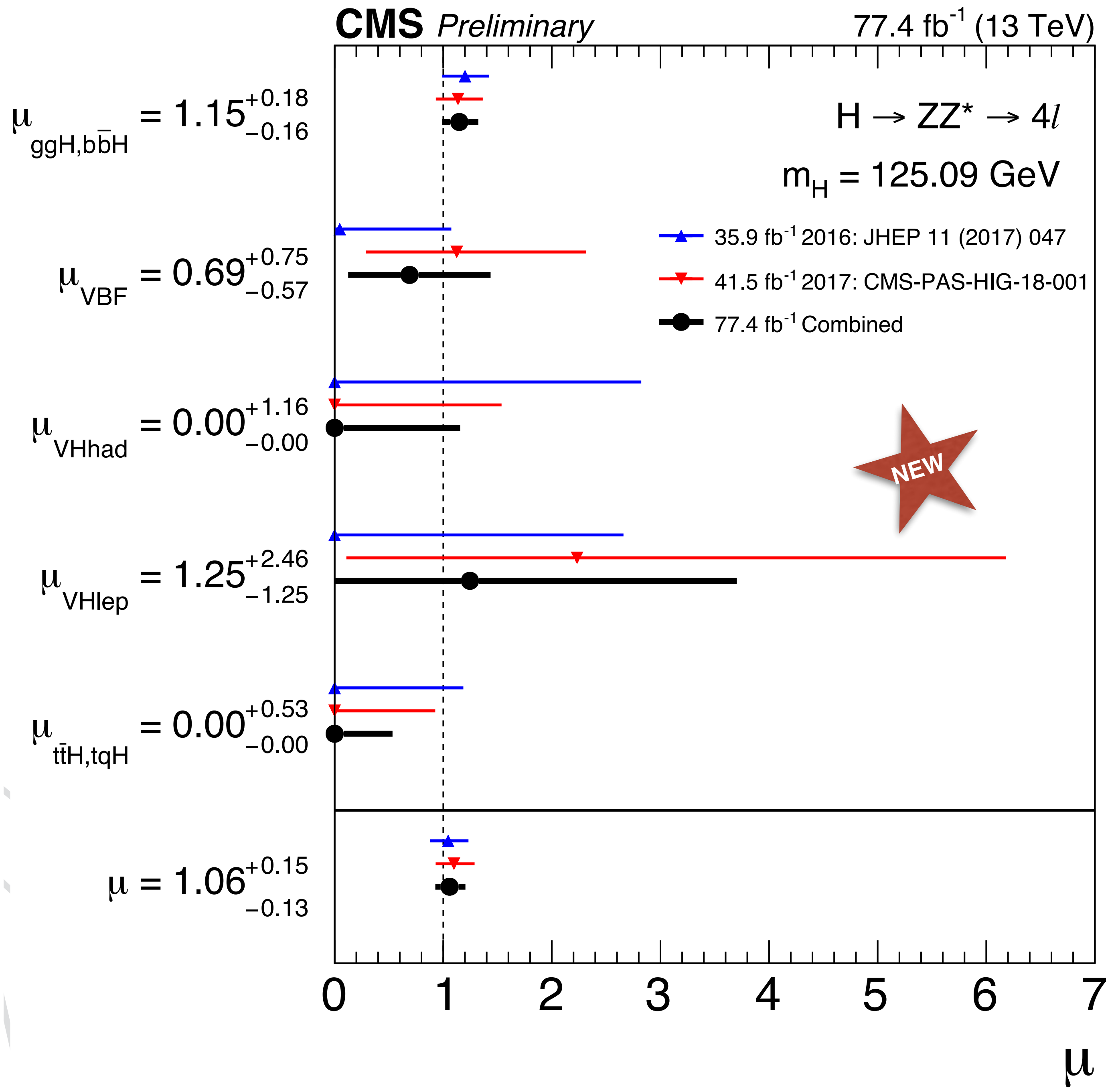
25% improvement on Run1 combination

H→ZZ→4l

ATLAS 2015+2016+2017:

$$\mu = 1.20 \pm 0.12(\text{stat.}) \pm 0.06(\text{exp.})^{+0.08}_{-0.07}(\text{th.})$$
$$= 1.20^{+0.16}_{-0.15}.$$

NEW



Signal strengths

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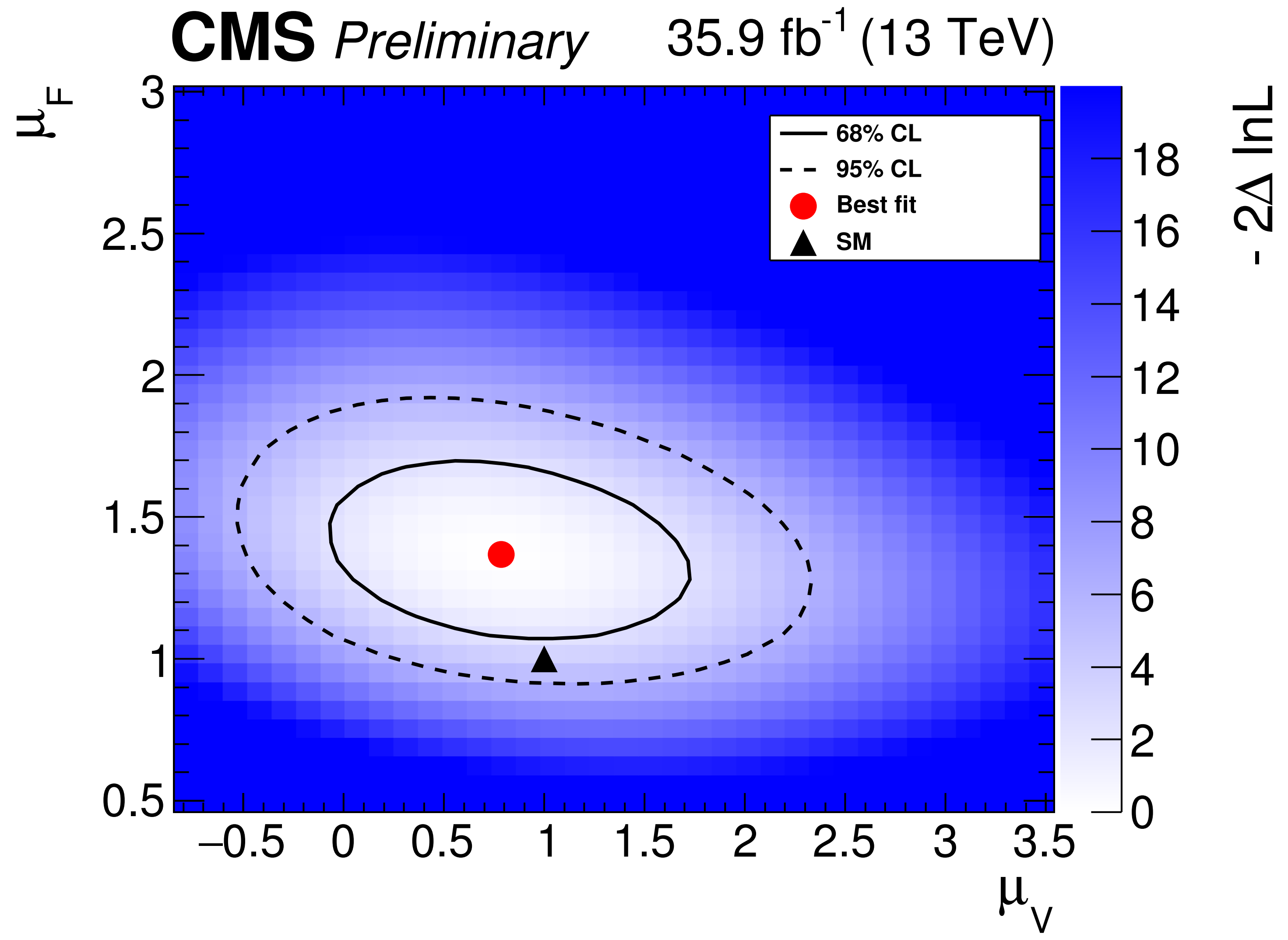

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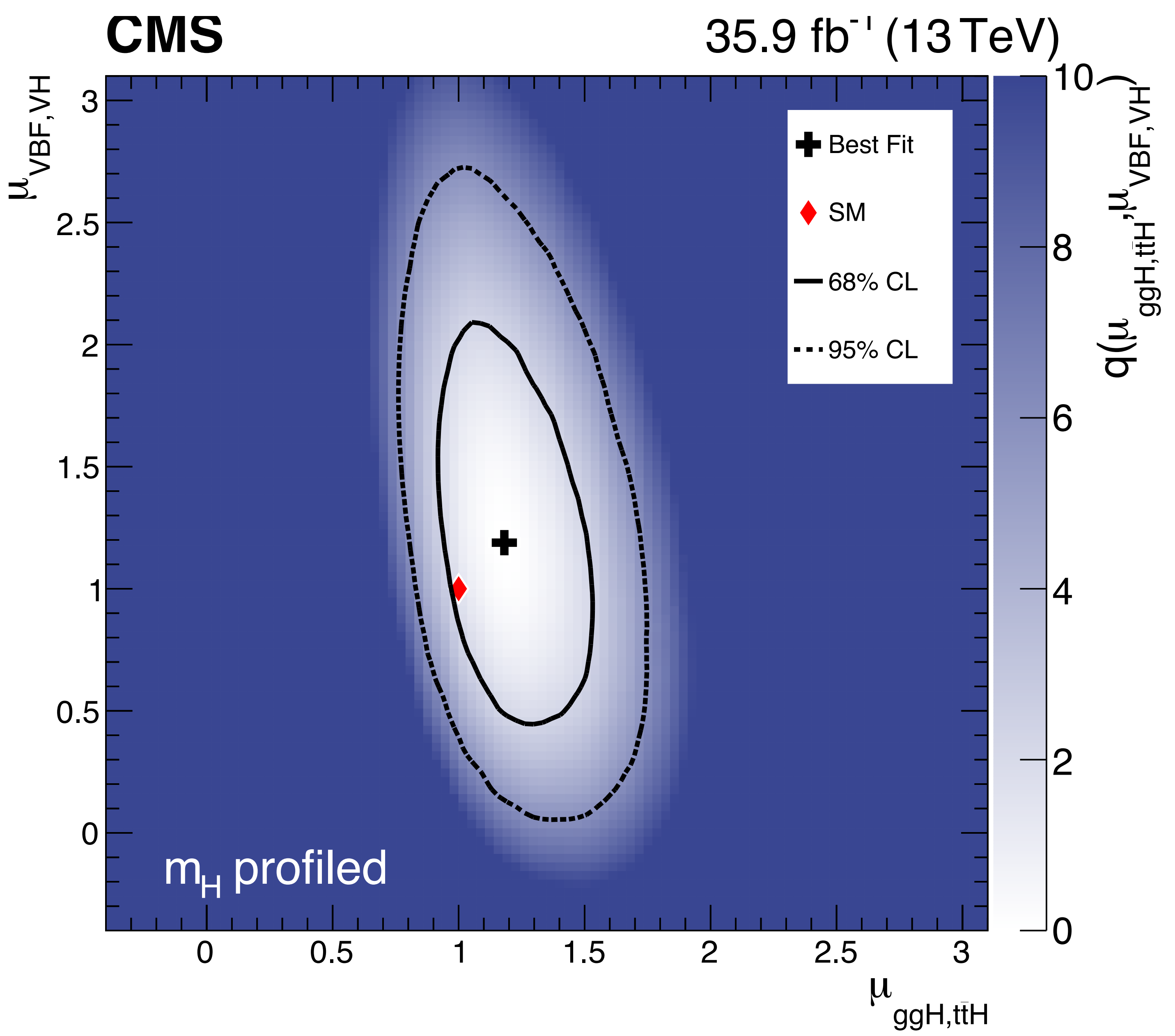

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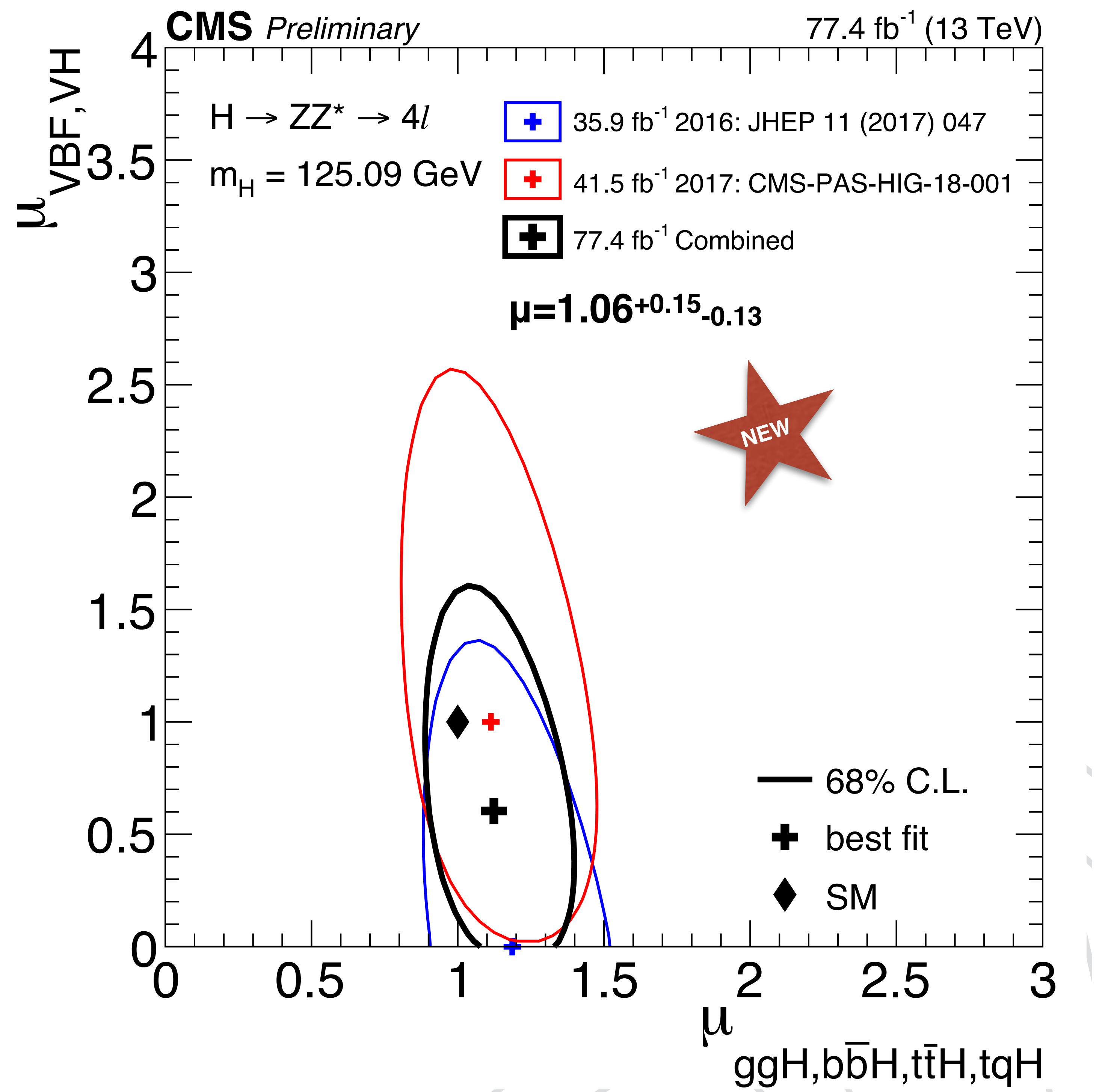
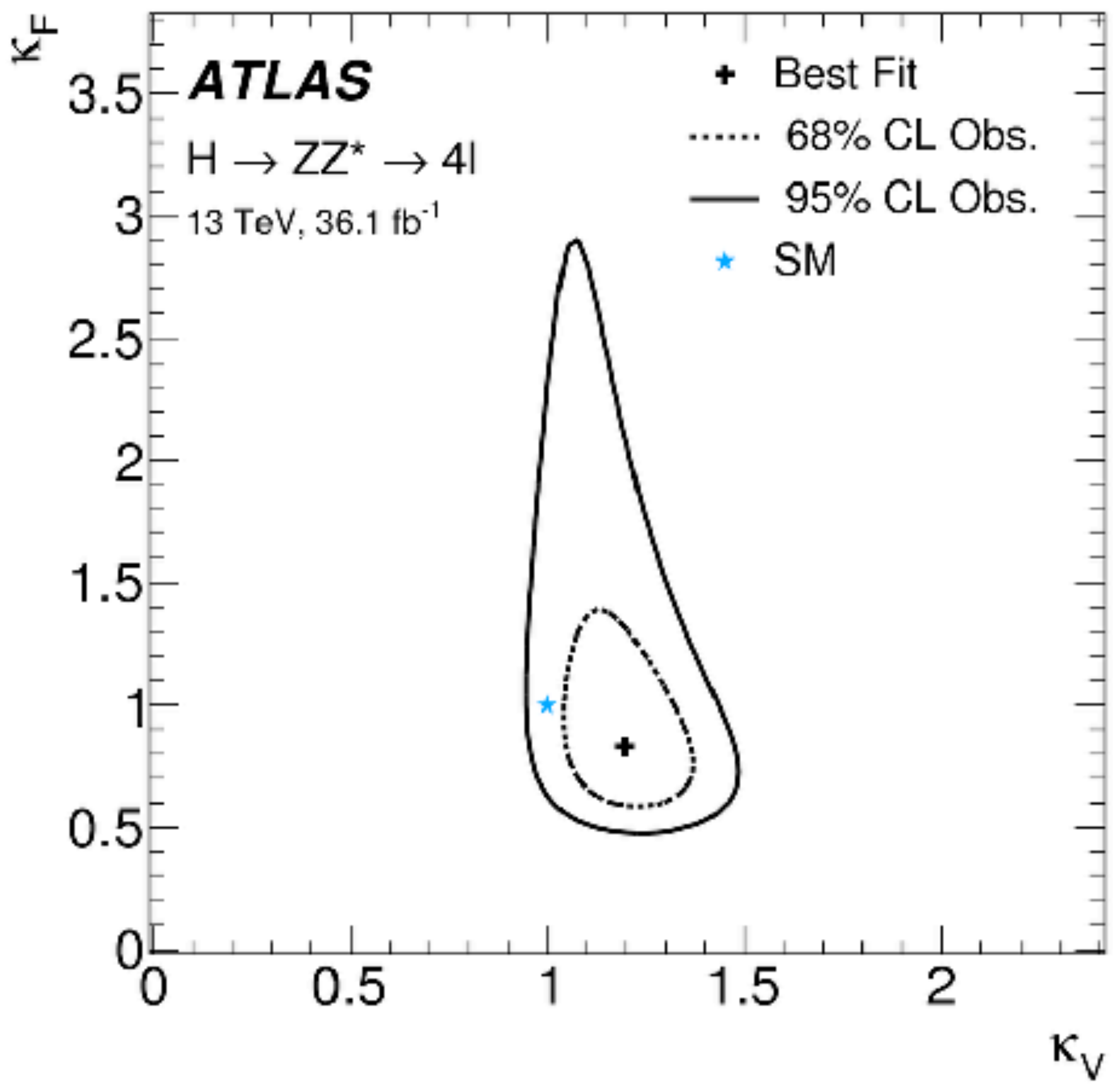
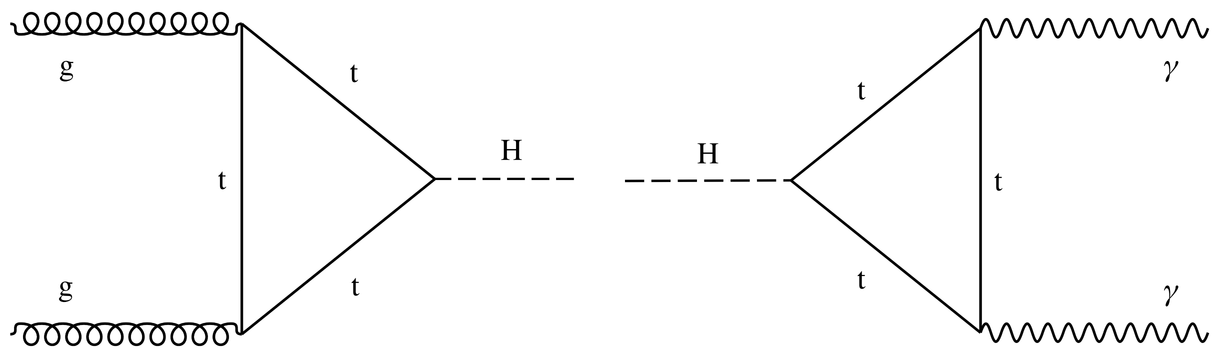
NEW



Couplings

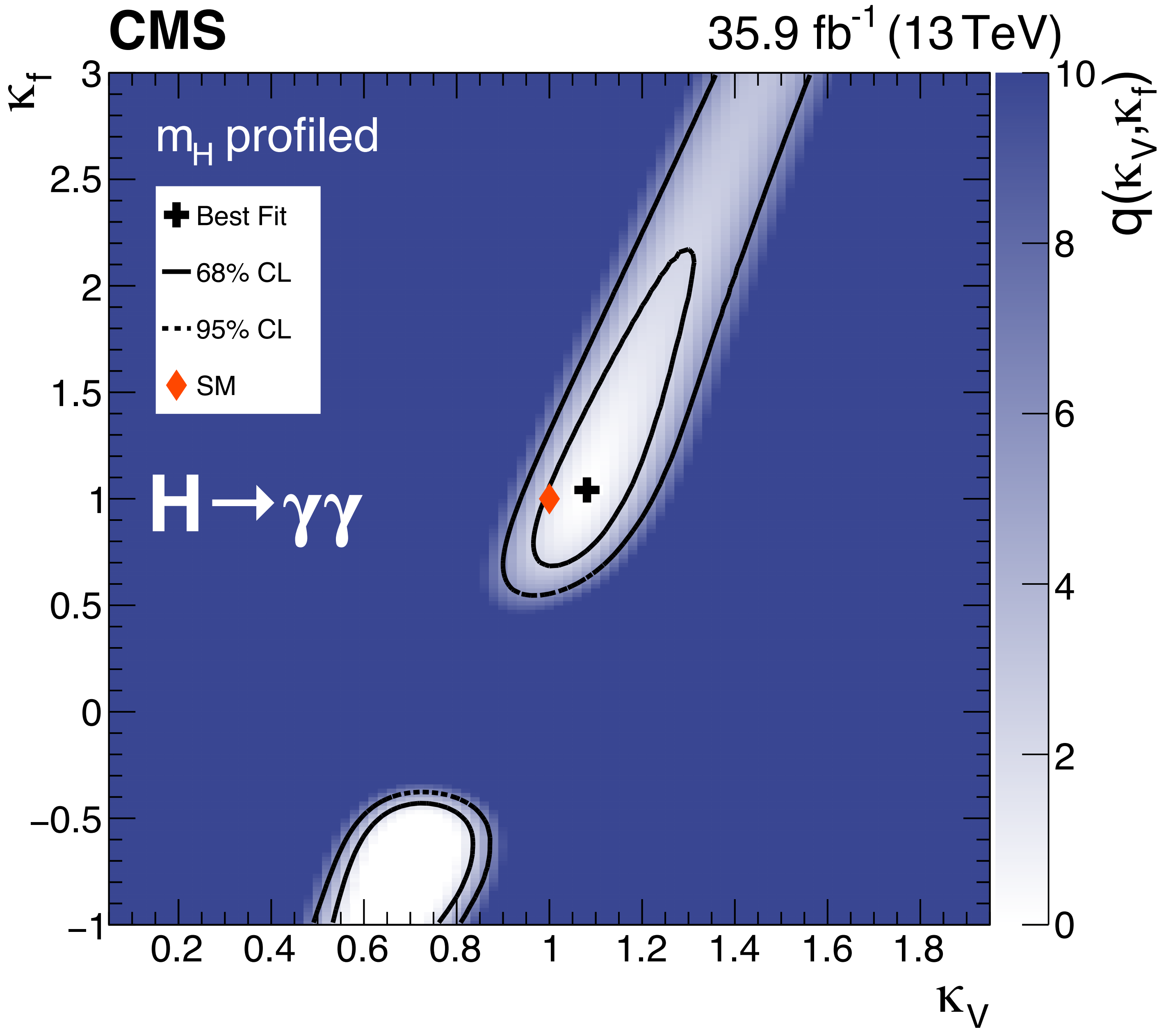


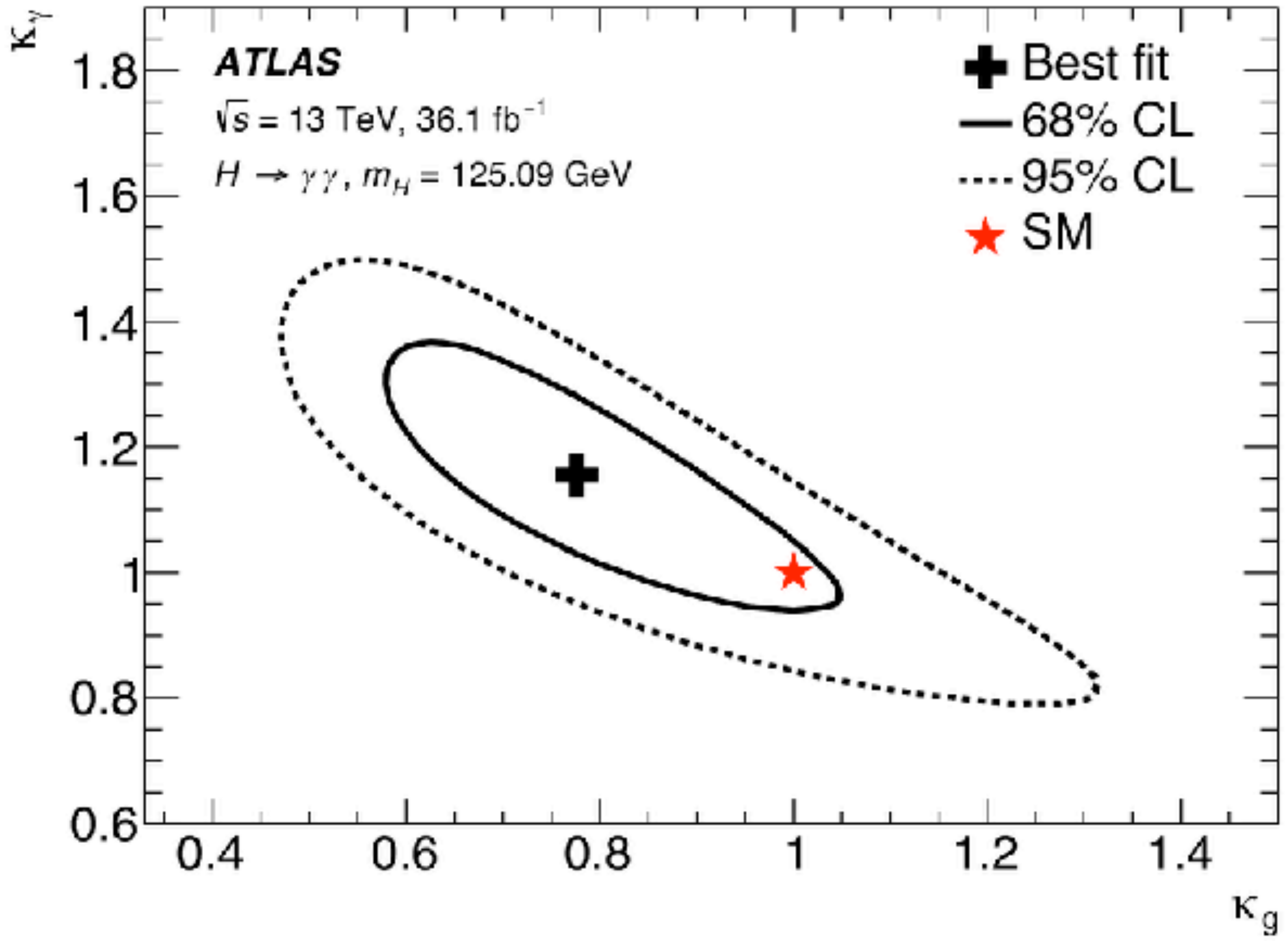


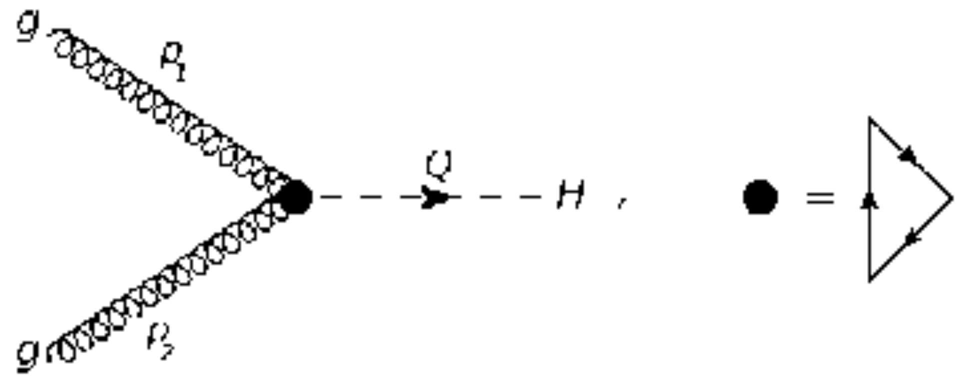
k_F/k_V: Resolved gluon and photon loops

Assumes no BSM contributions to Γ_H

Interference in H→γγ: sensitivity to the relative sign of k_F/k_V

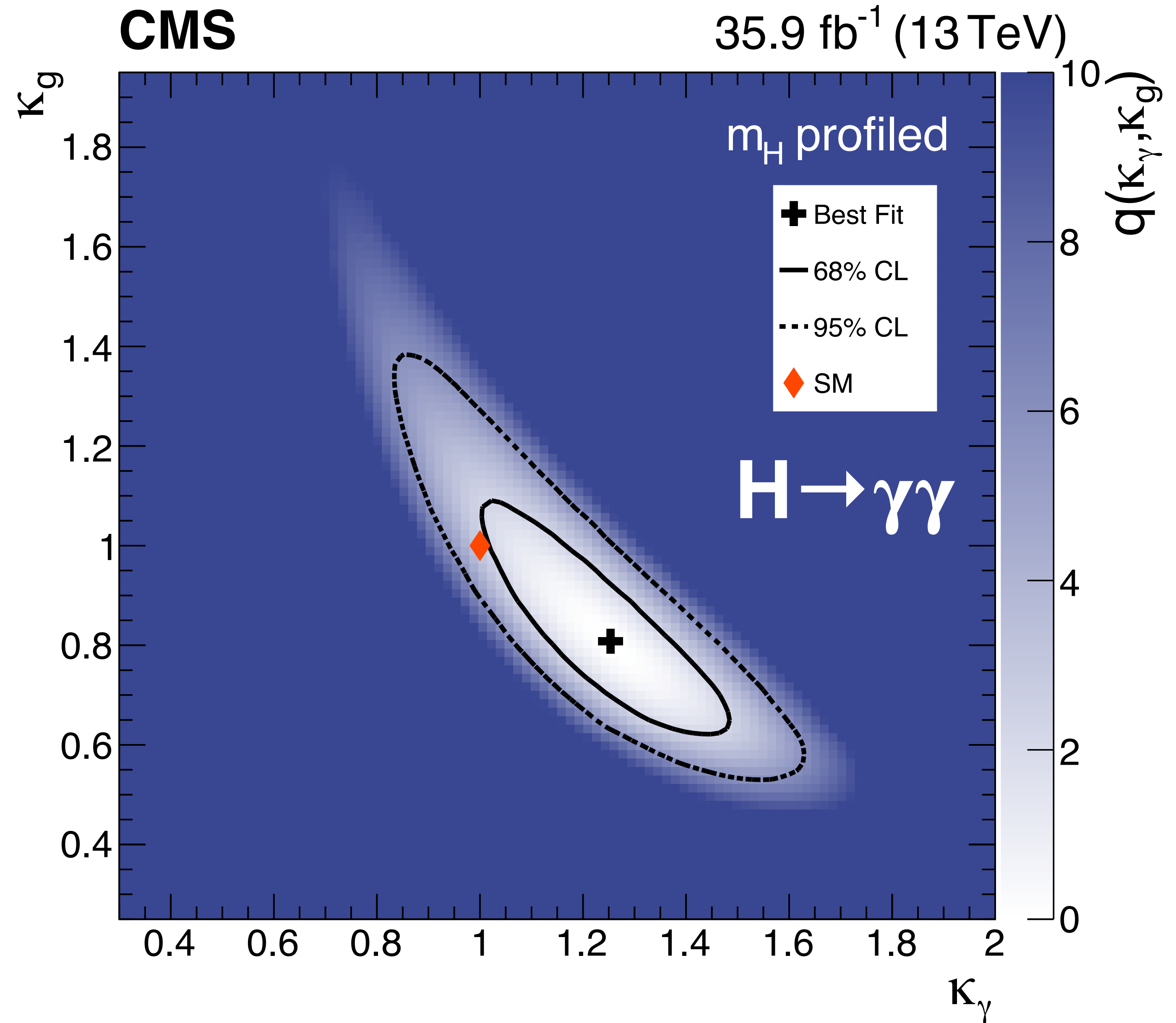




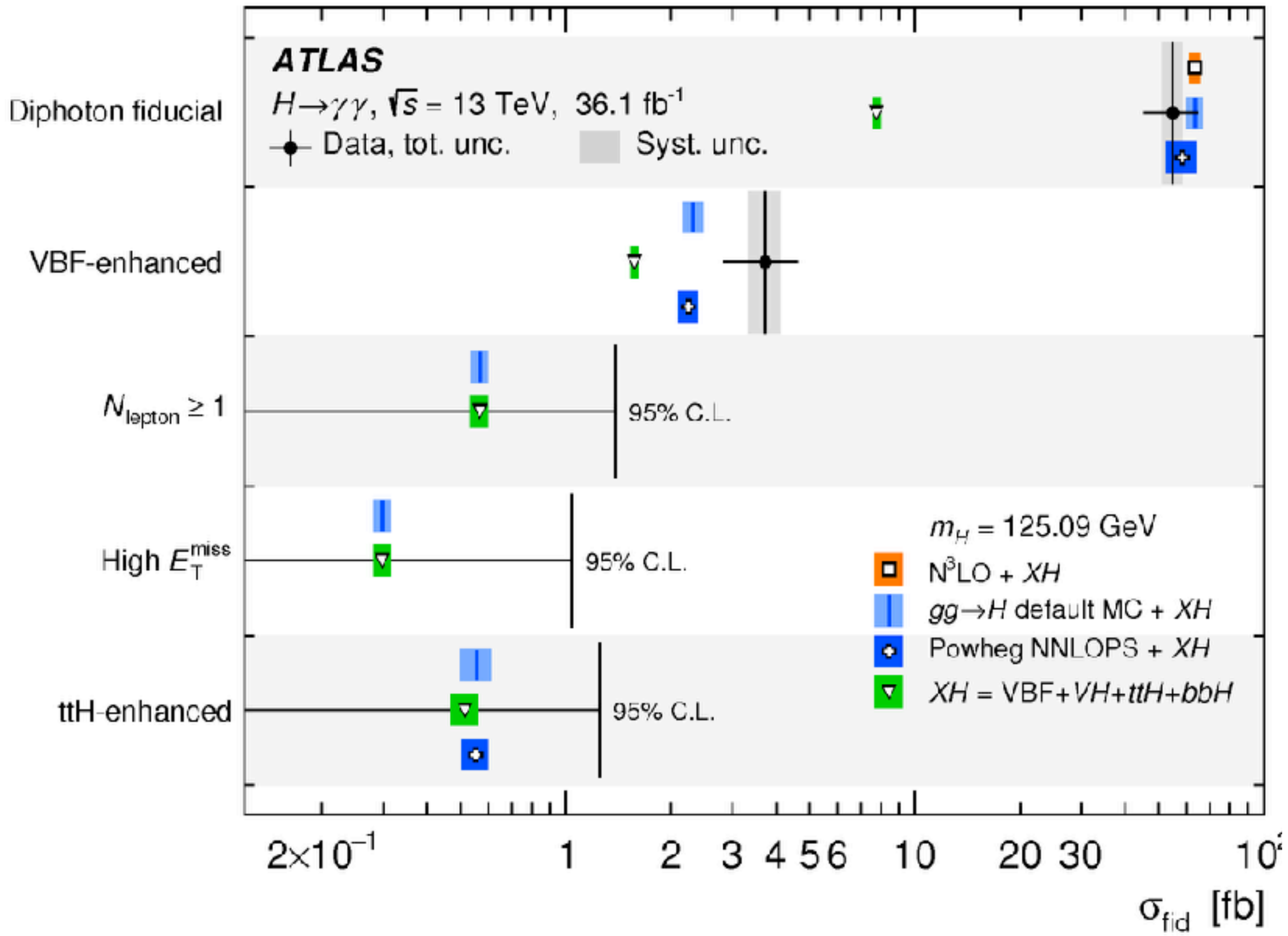


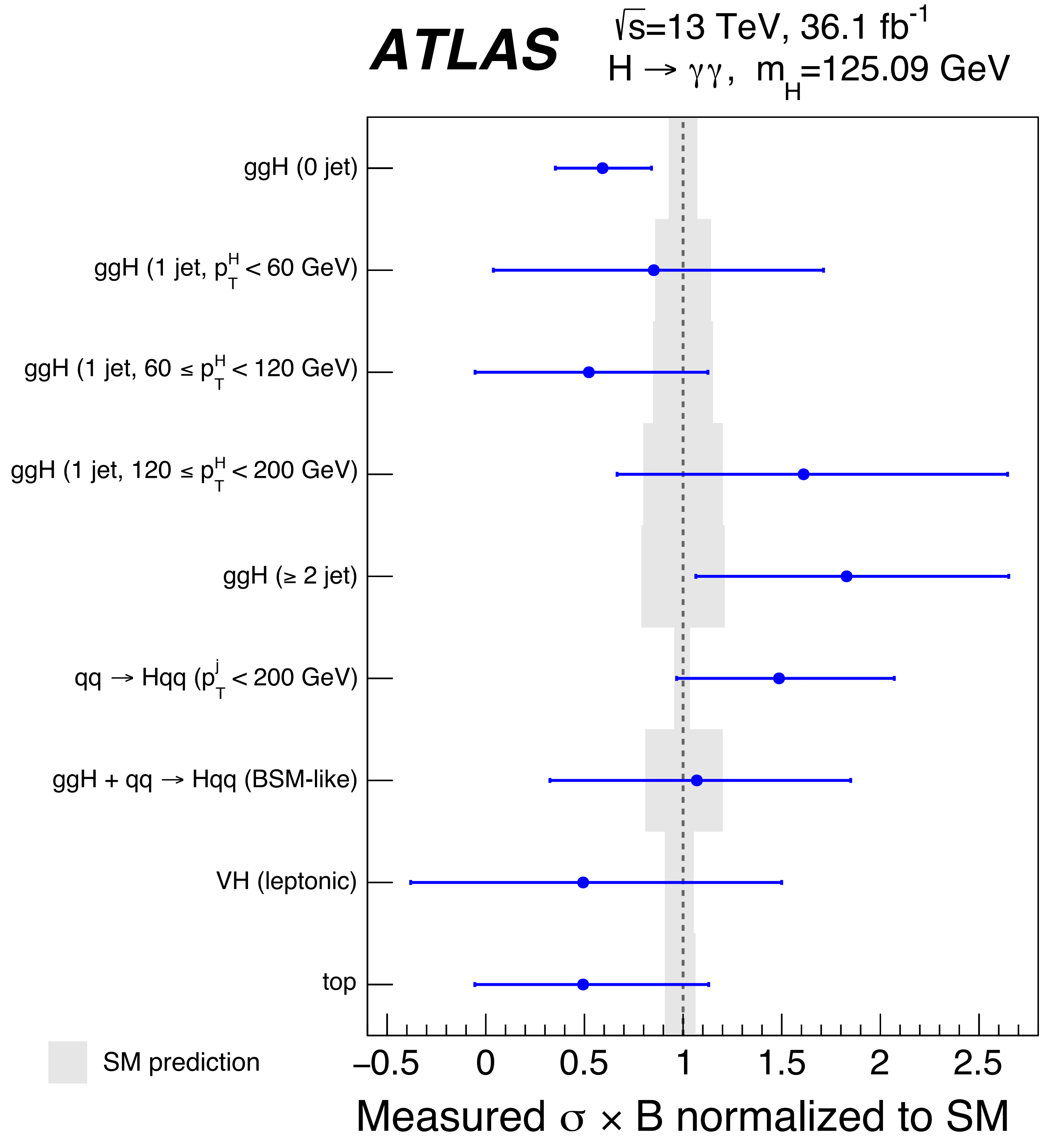
Unresolved loops.

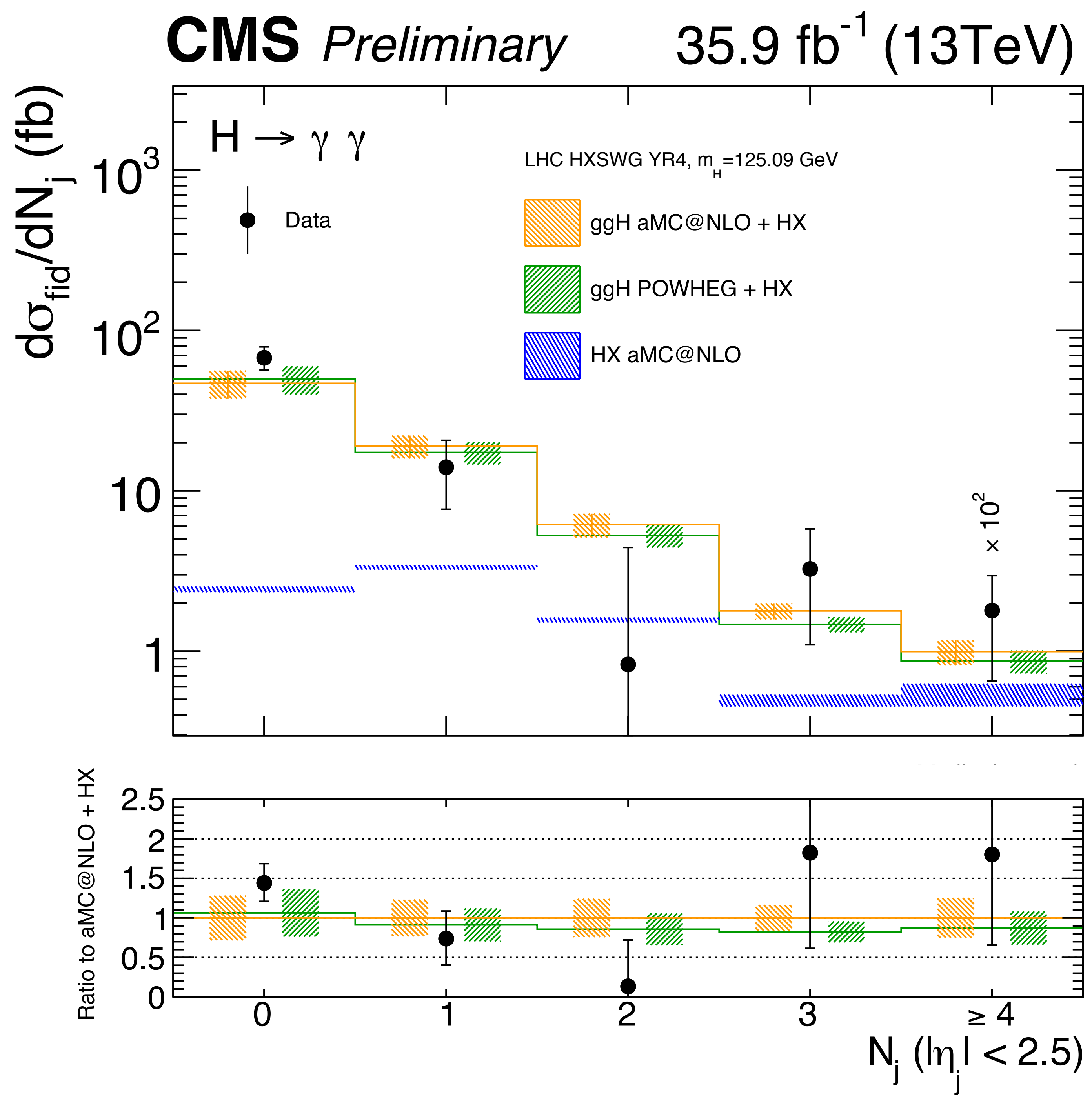
Probe effective k_g/k_γ vertices



H→γγ, Cross sections







Both fiducial (inclusive) cross section, STXS, and differential distributions show good agreement with theoretical predictions

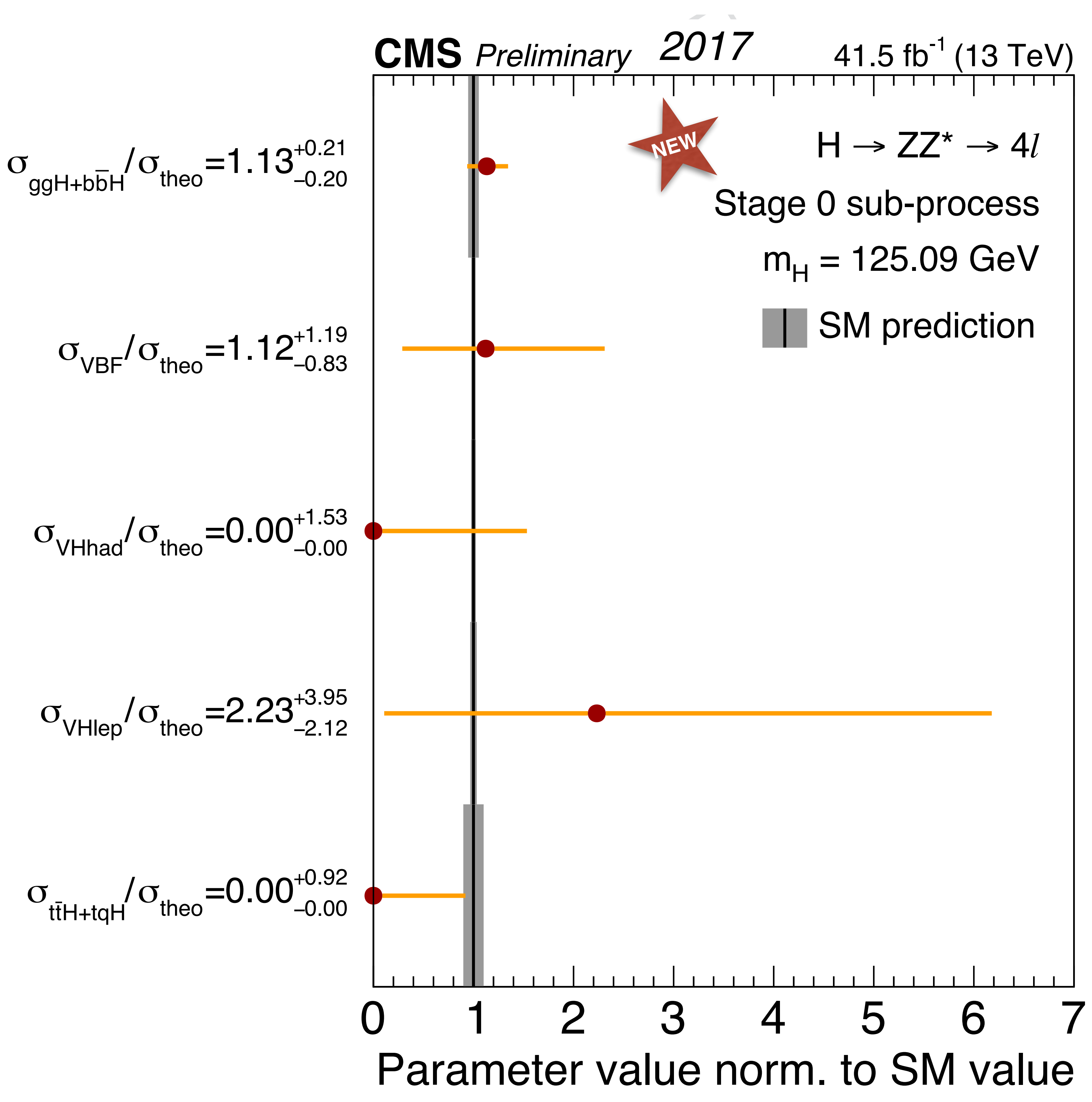
Experimental uncertainties are comparable to theoretical ones in the most populated bins (low p_T, low N_{jets})

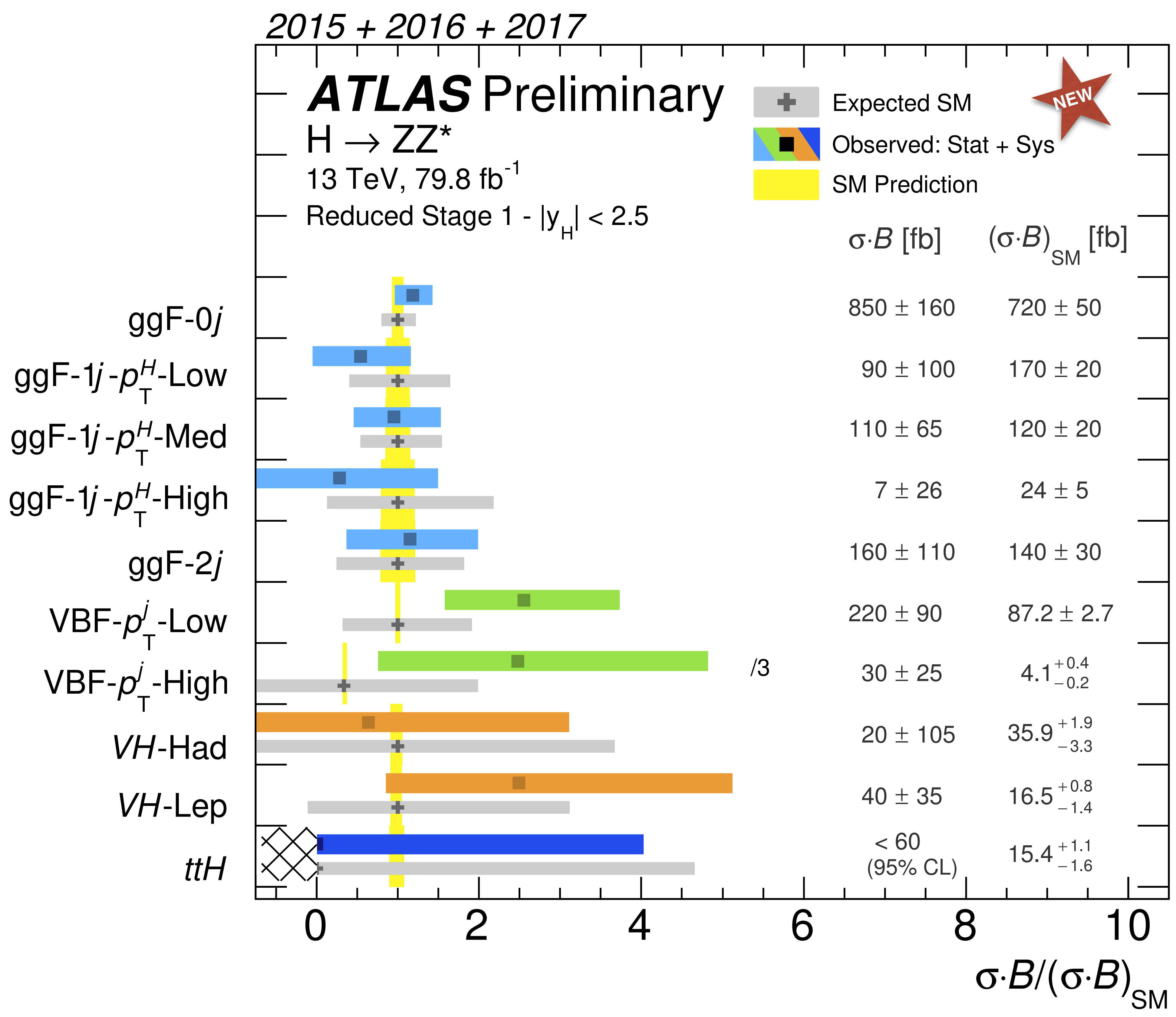
Differential cross-section as a function of $p_T(H)$, N_{jet}, y_H, $\cos\vartheta^*$ (see backup)

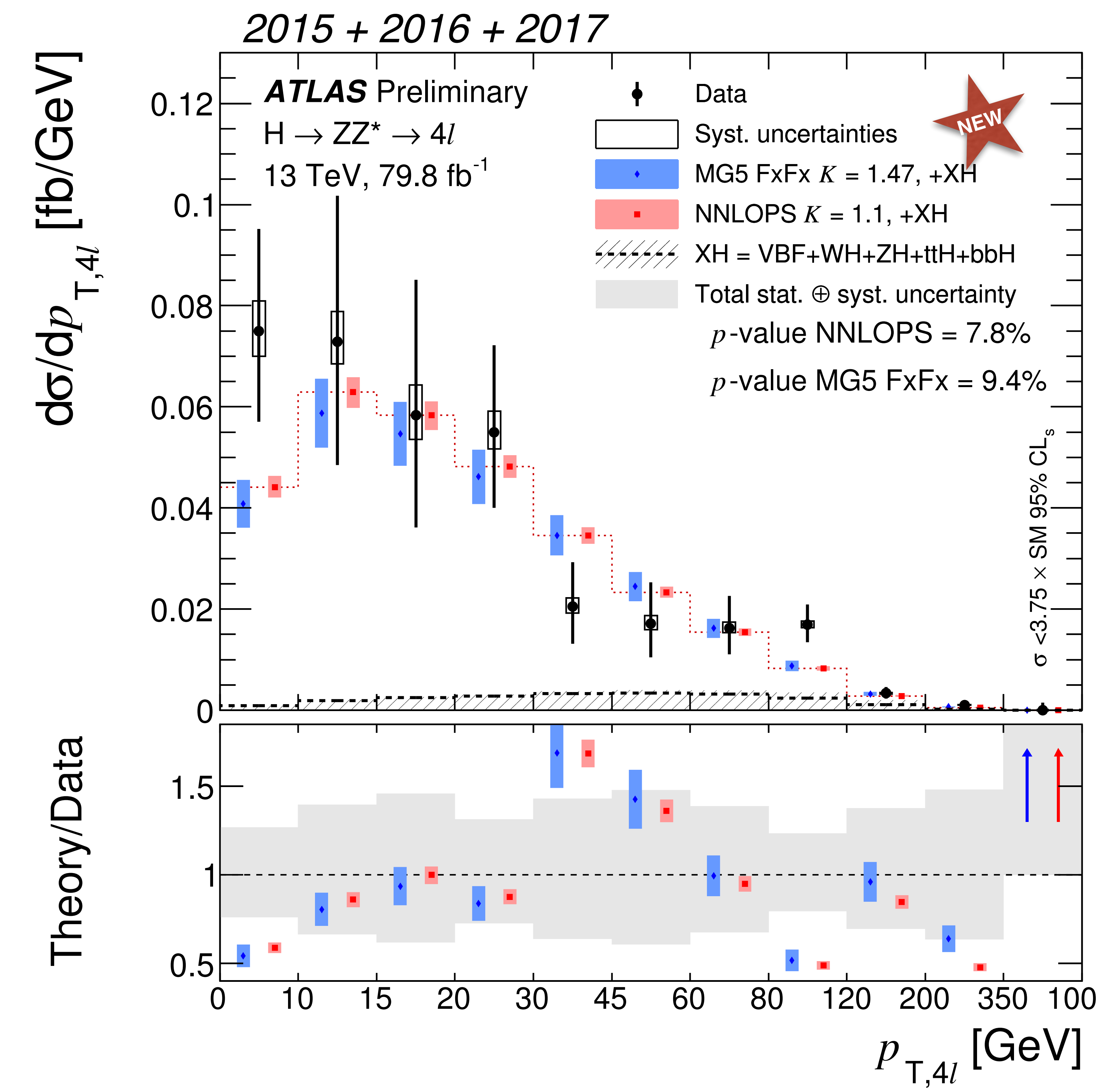
ATLAS: EFT reinterpretation to probe anomalous couplings

Phys. Lett. B 775 (2017) 1
ATLAS-CONF-2018-018

H→ZZ→4l, Cross sections







ATLAS already attempting at (simplified) stage-1 STXS subprocesses.

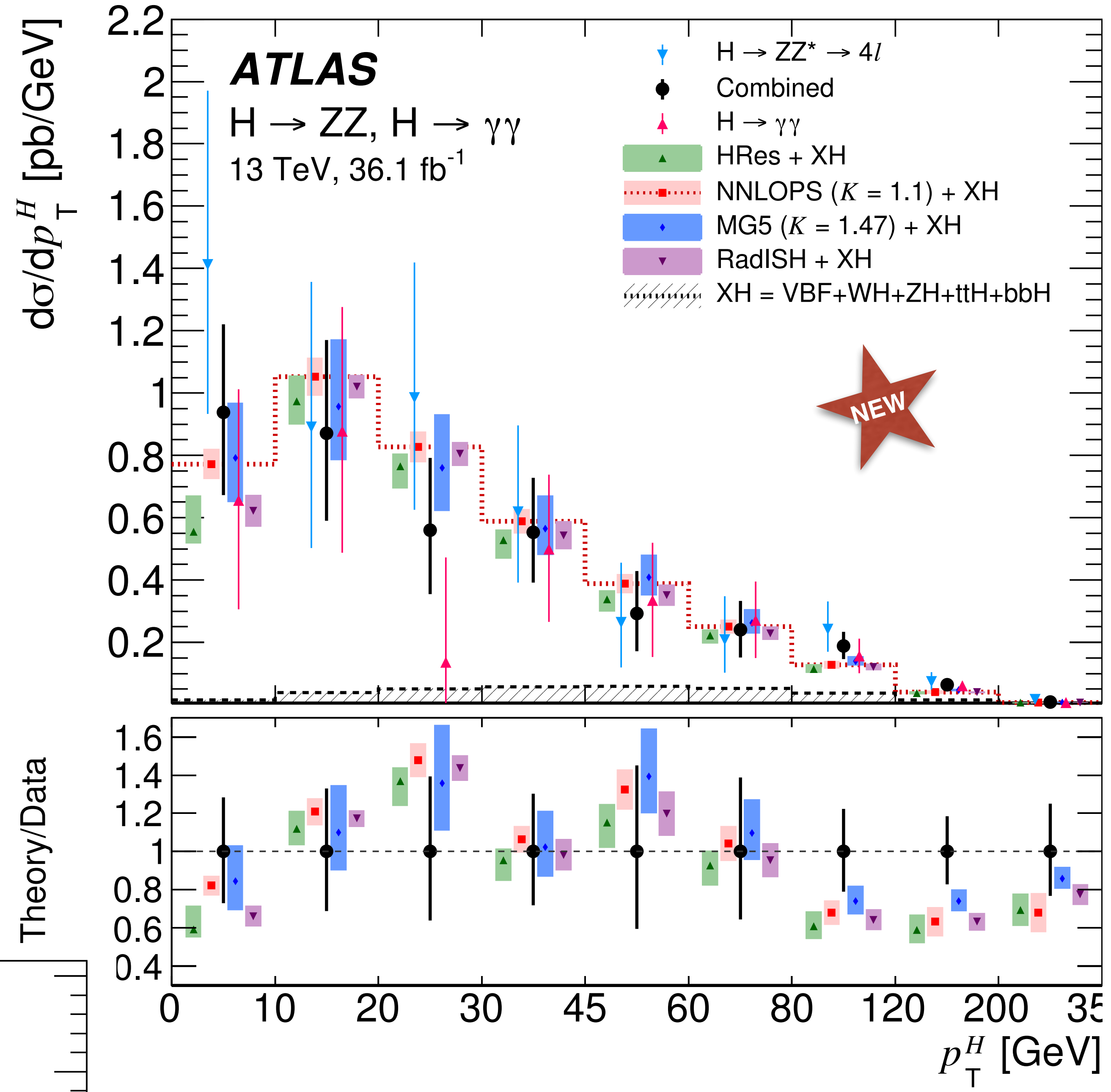
CMS show a small excess (mostly driven by excess in 2e2μ)

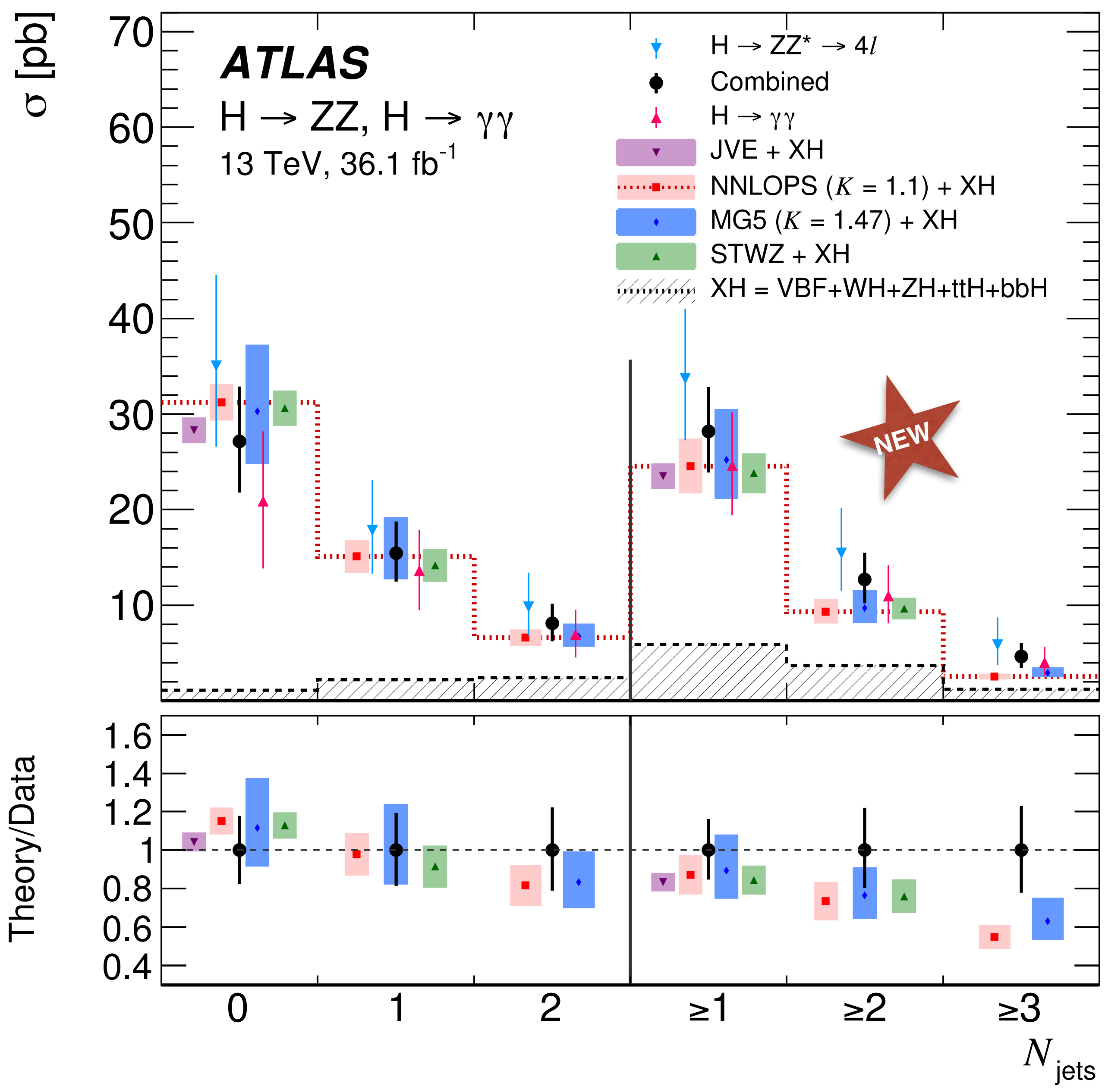
no ttH event observed yet in either of the experiments arXiv:1805.10197 NEW

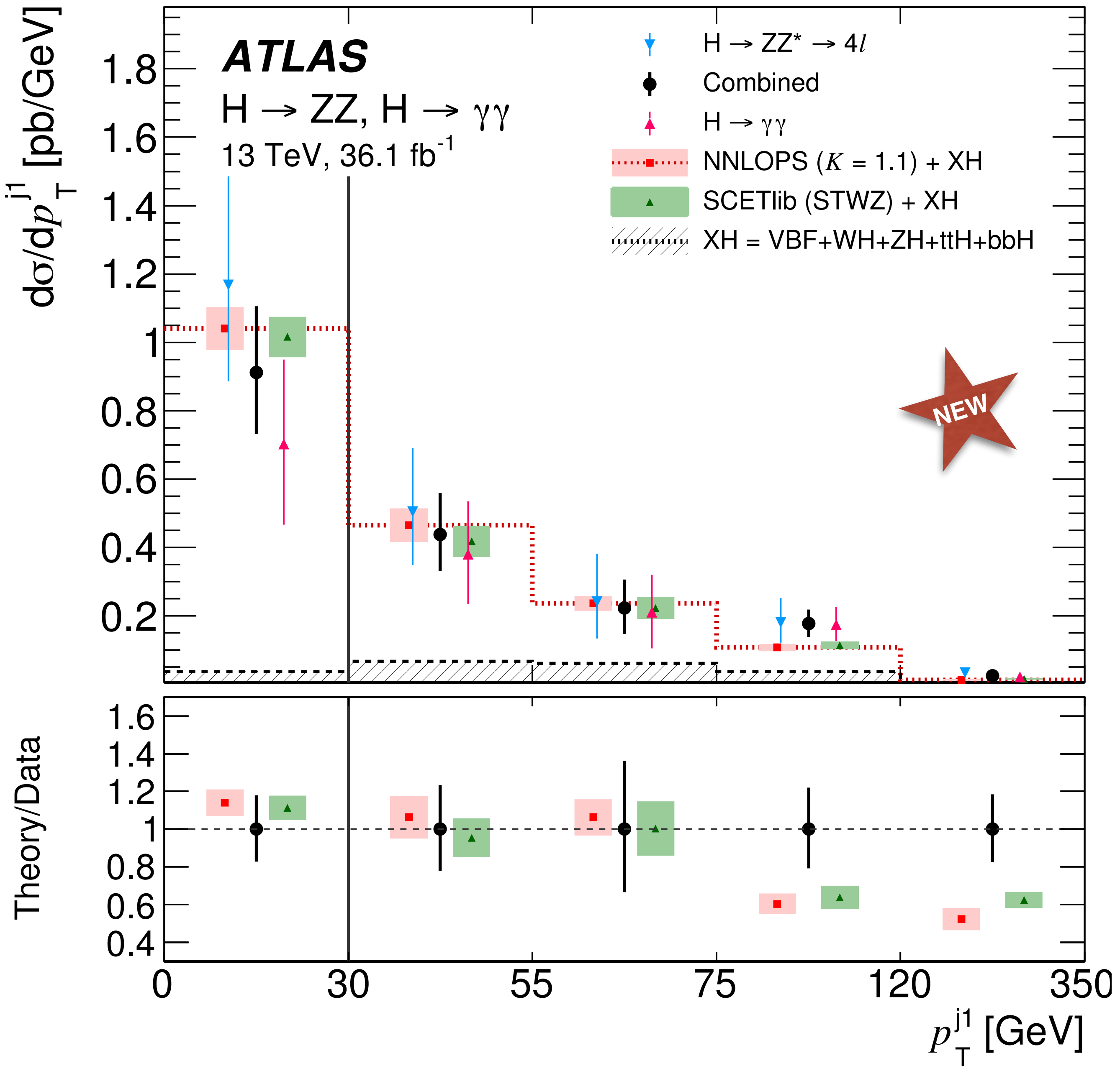
ATLAS ZZ+γγ combination

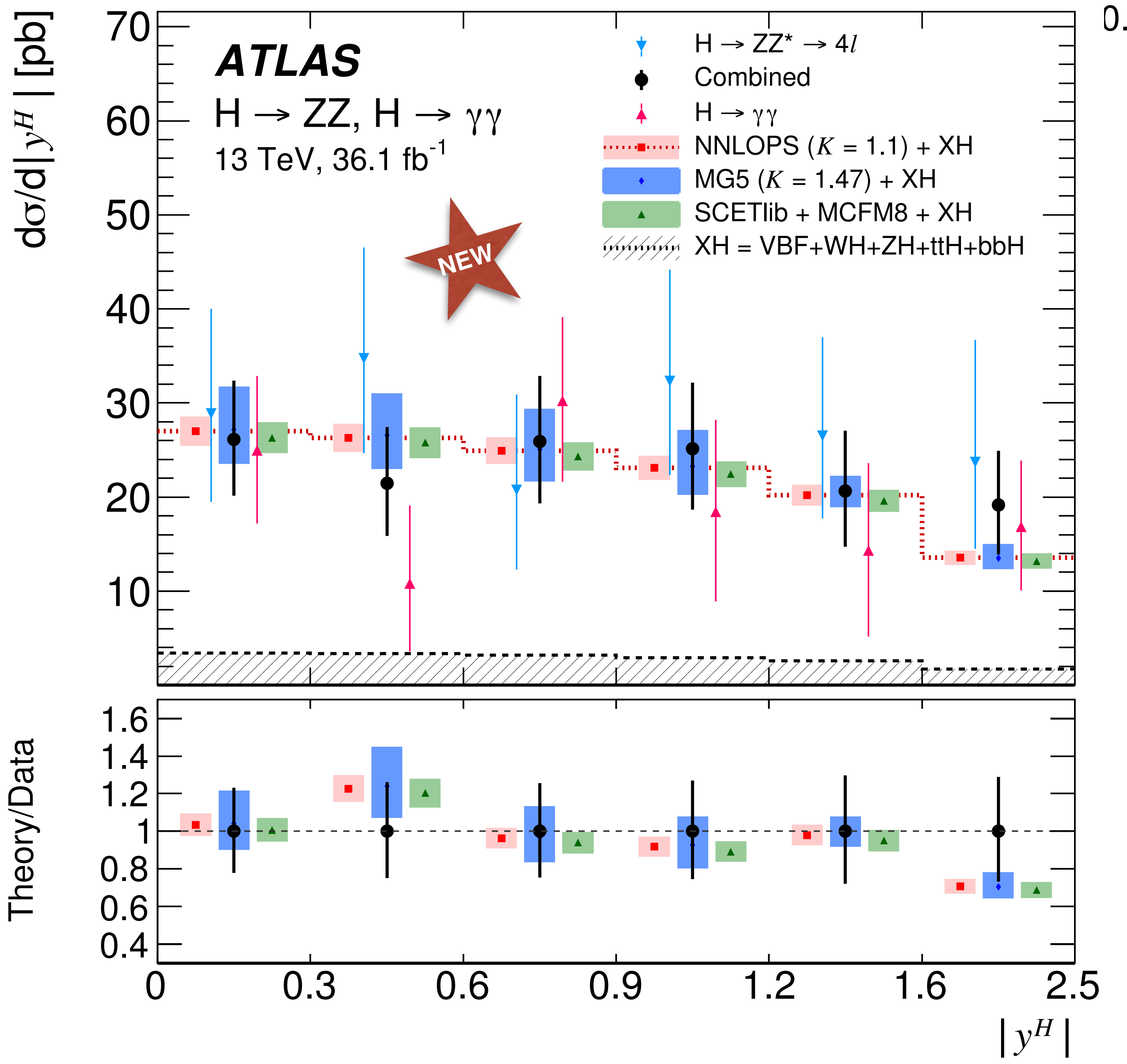
Higgs differential cross-section.

From the Hγγ and HZZ combination of the **2015+2016** dataset









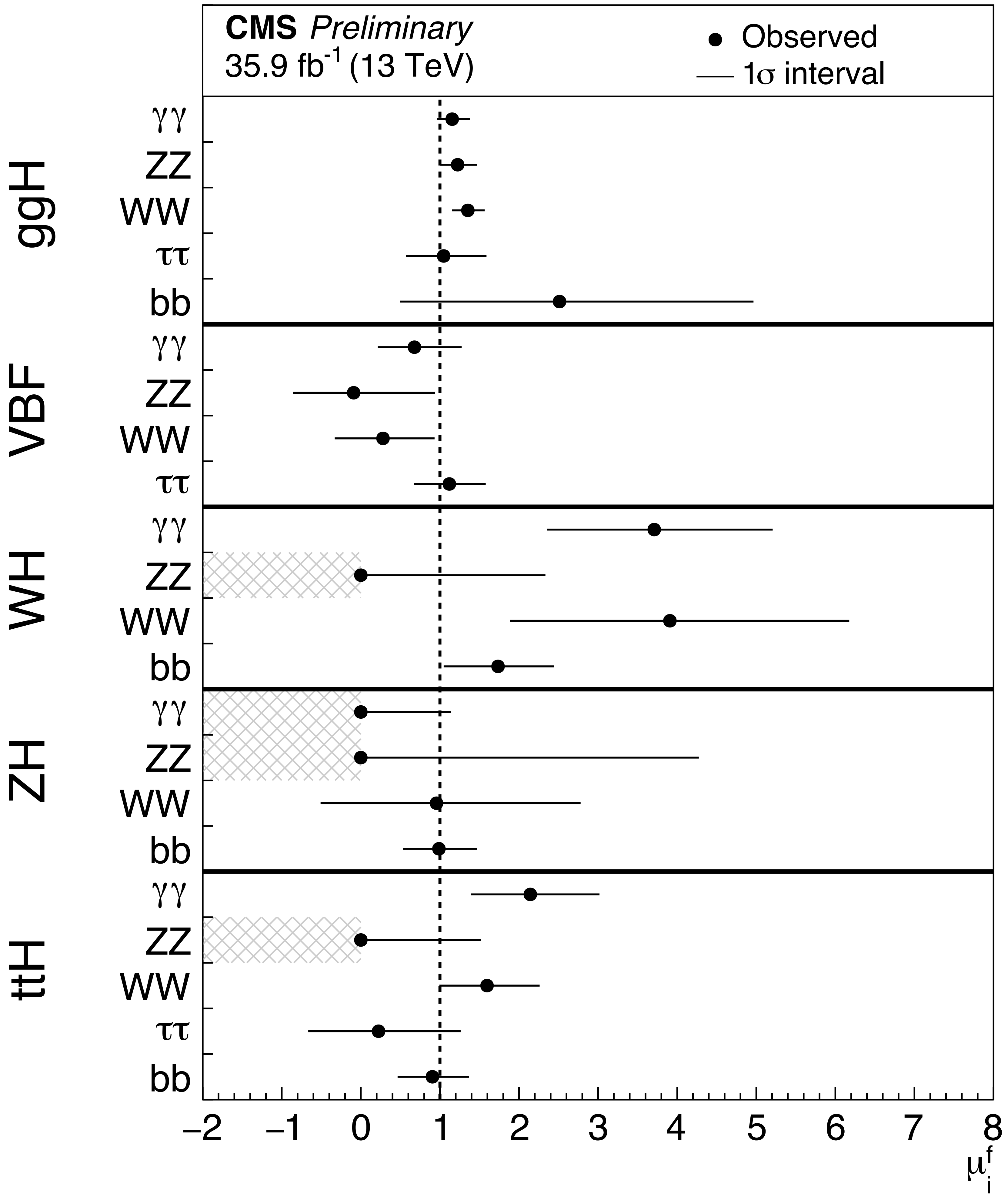
Results are largely compatible between channels and with theoretical predictions.

Combined results agree very well with predictions

Significant reduction in uncertainties from the combined results, comparable to theoretical uncertainties up to 3 jets

CMS-PAS-HIG-17-031

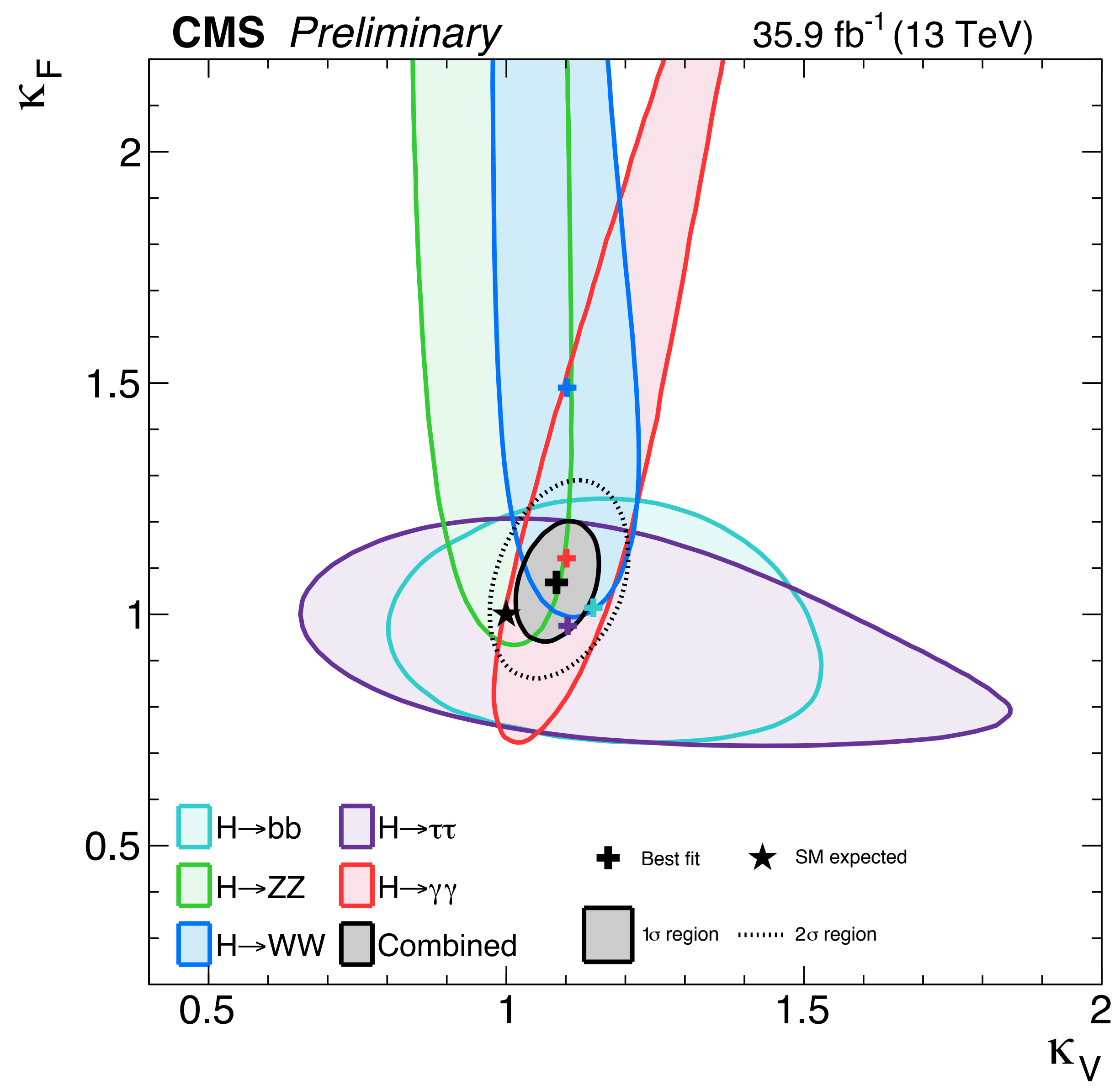
CMS single Higgs combination

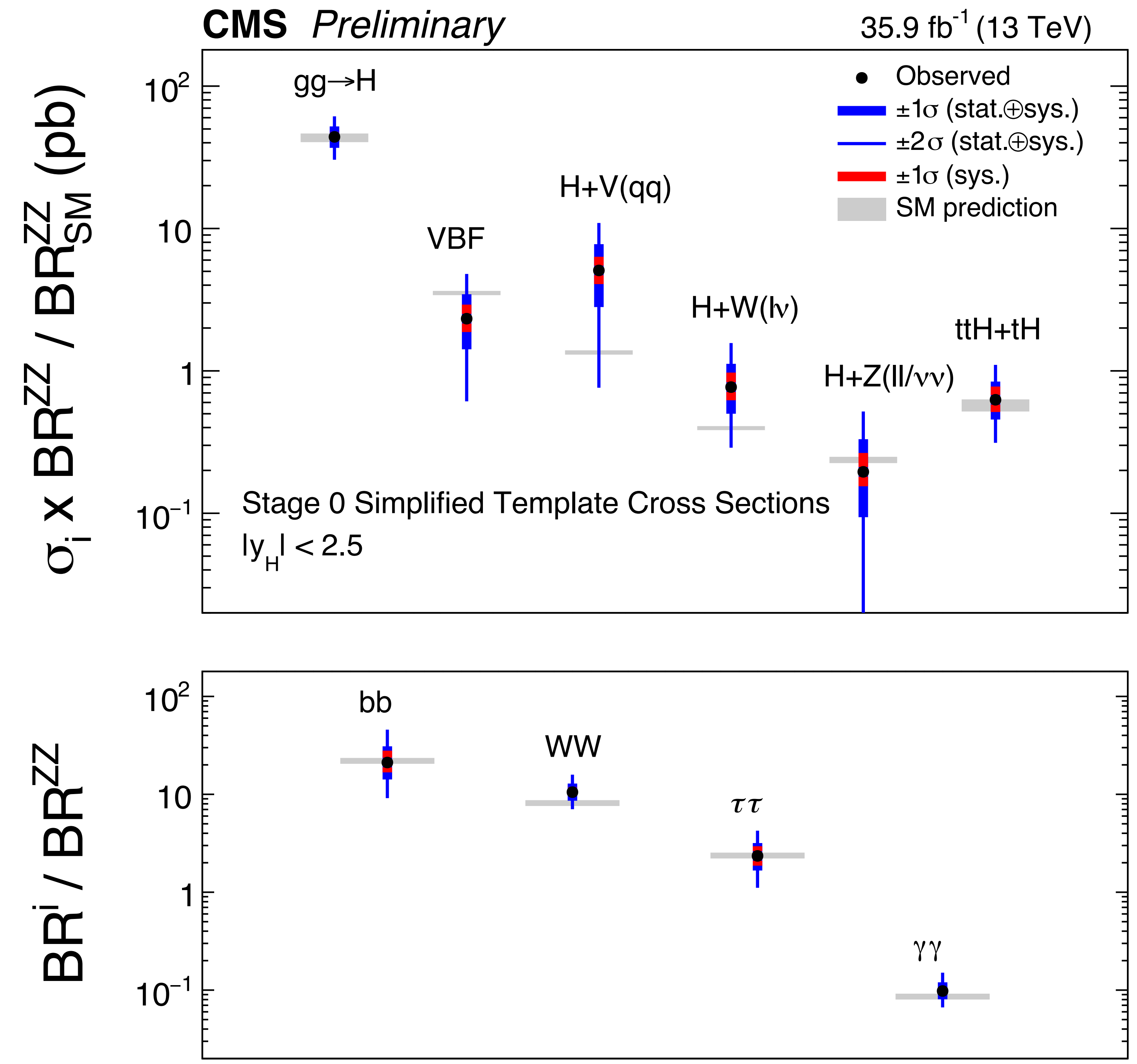


- 11 analyses
- 265 event categories
- 5500+ nuisance parameters

Most general parametrisation:
production X decay signal strength with all parameters floating

- 5x5 matrix μ_i={ggH, VBF, WH, ZH, ttH} x μ^f={**γγ**, ZZ, WW, bb, ττ}
- 22/25 measurements available





$$\mu = 1.17^{+0.10}_{-0.10} \quad = 1.17^{+0.06}_{-0.06}\,(\text{stat.})\,^{+0.06}_{-0.05}\,(\text{sig. th.})\,^{+0.06}_{-0.06}\,(\text{other sys.})$$

c.f. Run 1 CMS+ATLAS: $\mu = 1.09^{+0.11}_{-0.10} = 1.09^{+0.07}_{-0.07}(\text{stat})^{+0.07}_{-0.06}(\text{sig. th.})^{+0.05}_{-0.05}(\text{other sys.})$

Conclusions

Latest results on Higgs to diboson have been presented, from $H\to WW$, $H\to ZZ\to 4l$, $H\to\gamma\gamma$

- Precision on signal strengths and couplings already matches the one obtained at the end of Run1 in most cases
- Some of the excesses/deficits observed at the end of run1 have been mitigated by the latest results

First analyses presenting 2017 data analysis

- $H\to ZZ\to 4l$ **2017 data analysis** presented by both ATLAS and CMS

New mass measurement from ATLAS, combining $H\to ZZ\to 4l$ and $H\to\gamma\gamma$ in both run1 and run2

Collaborations are moving towards the measurement of **differential distributions and cross-sections**

- Reaching the theoretical uncertainty in the most populated bins
- **New ZZ+$\gamma\gamma$** differential cross section measurement from ATLAS, which greatly reduces uncertainties

Combination effort underway, CMS already performed full 2016 combination

Co-funded by the Horizon 2020 Framework Programme of the European Union

Thank you for the attention!

CMS single Higgs combination

Tricky business

- 11 analyses
- 265 event categories
- 5500+ nuisance parameters
- Including both shape and yield systematics
- Up to 25 parameters

Need Common description of signal

- All gluon fusion signals weighted to match NNLOPS shape predictions and N^{3}LO cross-section
- Use WG1 interim ggH uncertainty scheme

Need common treatment of correlated systematic uncertainties

- Carefully check correlations

Production and decay tags		Expected tagged signal fraction	Number of categories	Mass resolution
$\mathrm{H} \to \gamma\gamma$, Section ??				
	Untagged	74-91% ggH	4	
	VBF	51-80% VBF	3	
	VH hadronic	25% WH, 15% ZH	1	
$\gamma\gamma$	WH leptonic	64-83% WH	2	$\approx$1-2%
	ZH leptonic	98% ZH	1	
	VH $p_{\mathrm{T}}^{\mathrm{miss}}$	59% VH	1	
	ttH	80-89% ttH, $\approx$8% tH	2	
$\mathrm{H} \to \mathrm{ZZ}^{(*)} \to 4\ell$, Section ??				
	Untagged	$\approx$95% ggH	3	
	VBF 1, 2-jet	$\approx$11-47% VBF	6	
	VH hadronic	$\approx$13% WH, $\approx$10% ZH	3	
4μ, $2e2\mu/2\mu2e$, 4e	VH leptonic	$\approx$46% WH	3	$\approx$1-2%
	VH $p_{\mathrm{T}}^{\mathrm{miss}}$	$\approx$56% ZH	3	
	ttH	$\approx$71% ttH	3	
$\mathrm{H} \to \mathrm{WW}^{(*)} \to \ell\nu\ell\nu$, Section ??				
$e\mu/\mu e$	ggH 0, 1, 2-jet	$\approx$55-92% ggH, up to $\approx$15% $\mathrm{H} \to \tau\tau$	17	
	VBF 2-jet	$\approx$47% VBF, up to $\approx$25% $\mathrm{H} \to \tau\tau$	2	
ee+$\mu\mu$	ggH 0, 1-jet	$\approx$84-94% ggH	6	$\approx$20%
$e\mu$+jj	VH 2-jet	22% VH, 21% $\mathrm{H} \to \tau\tau$	1	
3ℓ	WH leptonic	$\approx$80% WH, up to 19% $\mathrm{H} \to \tau\tau$	2	
4ℓ	ZH leptonic	85-90% ZH, up to 14% $\mathrm{H} \to \tau\tau$	2	
$\mathrm{H} \to \tau\tau$, Section ??				
	0-jet	$\approx$70-98% ggH, 29% $\mathrm{H} \to \mathrm{WW}$ in $e\mu$	4	
$e\mu$, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$	VBF	$\approx$35-60% VBF, 42% $\mathrm{H} \to \mathrm{WW}$ in $e\mu$	4	$\approx$10-20%
	Boosted	$\approx$48-83% ggH, 43% $\mathrm{H} \to \mathrm{WW}$ in $e\mu$	4	
VH production with $\mathrm{H} \to \mathrm{bb}$, Section ??				
$\mathrm{Z}(\nu\nu)\mathrm{bb}$	ZH leptonic	$\approx$100% VH, 85% ZH	1	
$\mathrm{W}(\ell\nu)\mathrm{bb}$	WH leptonic	$\approx$100% VH, $\approx$97% WH	2	$\approx$10%
$\mathrm{Z}(\ell\ell)\mathrm{bb}$	Low $p_{\mathrm{T}}(\mathrm{V})$ ZH leptonic	$\approx$100% ZH, of which $\approx$20% ggZH	2	
	High $p_{\mathrm{T}}(\mathrm{V})$ ZH leptonic	$\approx$100% ZH, of which $\approx$36% ggZH	2	
Boosted H Production with $\mathrm{H} \to \mathrm{bb}$, Section ??				
$\mathrm{H} \to \mathrm{bb}$	$p_{\mathrm{T}}(\mathrm{H})$ bins	$\approx$72-79% ggH	6	$\approx$10%
ttH production with $\mathrm{H} \to$ leptons, Section ??				
	2ℓss	$\mathrm{WW}/\tau\tau \approx 4.5$, $\approx$5% tH	10	
	3ℓ	$\mathrm{WW} : \tau\tau : \mathrm{ZZ} \approx 15 : 4 : 1$, $\approx$5% tH	4	
$\mathrm{H} \to \mathrm{WW}, \tau\tau, \mathrm{ZZ}$	4ℓ	$\mathrm{WW} : \tau\tau : \mathrm{ZZ} \approx 6 : 1 : 1$, $\approx$3% tH	1	
	1ℓ+$2\tau_h$	96% ttH with $\mathrm{H} \to \tau\tau$, $\approx$6% tH	1	
	2ℓss+$1\tau_h$	$\tau\tau : \mathrm{WW} \approx 5 : 4$, $\approx$5% tH	2	
	3ℓ+$1\tau_h$	$\tau\tau : \mathrm{WW} : \mathrm{ZZ} \approx 11 : 7 : 1$, $\approx$3% tH	1	
ttH production with $\mathrm{H} \to \mathrm{bb}$, Section ??				
	$\mathrm{t\bar{t}} \to$ jets	$\approx$83-97% ttH with $\mathrm{H} \to \mathrm{bb}$	6	
$\mathrm{H} \to \mathrm{bb}$	$\mathrm{t\bar{t}} \to 1\ell$+jets	$\approx$65-95% ttH with $\mathrm{H} \to \mathrm{bb}$, up to 20% $\mathrm{H} \to \mathrm{WW}$	18	
	$\mathrm{t\bar{t}} \to 2\ell$+jets	$\approx$84-96% ttH with $\mathrm{H} \to \mathrm{bb}$	3	
$\mathrm{H} \to \mu\mu$, Section ??				
$\mu\mu$	S/B bins	56-96% ggH, 1-42% VBF	15	$\approx$1-2%
Search for invisible H decays, Section ??				
	VBF	52% VBF, 48% ggH	1	
$\mathrm{H} \to$ inv.	ggH + $\geq$ 1 jet	80% ggH, 9% VBF	1	
	VH hadronic	54% VH, 39% ggH	1	
	ZH leptonic	$\approx$100% ZH, of which 21% ggZH	1	

Signal strengths

Signal strengths, μ

Parameters scale cross sections and BRs relative to SM

$$\mu_i = \frac{\sigma_i}{\sigma_i^{\mathrm{SM}}} \qquad \mu^f = \frac{\mathrm{BR}^f}{\mathrm{BR}^f_{\mathrm{SM}}}.$$

Scaling of generic i → H → f process

$$\mu_i^f \equiv \frac{\sigma_i \cdot \mathrm{BR}^f}{(\sigma_i \cdot \mathrm{BR}^f)_{\mathrm{SM}}} = \mu_i \times \mu^f$$

Most immediate quantity: ratio of observed "rate" with respect to the expected results

Production: ratio of cross-sections

Decay: ratio of branching fractions

Many systematic uncertainties and theory assumptions cancel out in the ratio

- Easy to interpret
- Deviation from SM immediately visible
- Can decouple production and decay mechanisms
- Only effects modifying the absolute normalisation are visible, no sensitivity to shapes

No immediate relation with the width, each signal strength is independent from each other, but possible reinterpretation in the k-framework

K-framework

Couplings, κ

Parameters scale cross sections and partial widths relative to SM

$$\kappa_j^2 = \sigma_j / \sigma_j^{\mathrm{SM}} \qquad \kappa_j^2 = \Gamma_j / \Gamma_j^{\mathrm{SM}}$$

$$\sigma_i \cdot \mathrm{BR}^f = \frac{\sigma_i \cdot \Gamma_f}{\Gamma_\mathrm{H}},$$

Total width determined as

$$\Gamma_\mathrm{H} = \frac{\kappa_H^2 \cdot \Gamma_H^{\mathrm{SM}}}{1 - \mathrm{BR}_{\mathrm{BSM}}}$$

Where

$$\kappa_H^2 = \sum_j \mathrm{BR}_{\mathrm{SM}}^j \kappa_j^2$$

At first, signal strengths μ (ratio of observed cross-section to SM predictions)

- Good to verify H(125) properties and to check compatibility with SM
- Not ideal parametrization when introducing NP

Second step, K-framework:

- Disentangles production and decay mechanisms. Notation $k_f = \{k_t, k_b, k_\tau\}$; $k_V = \{k_W, k_Z\}$
- Effective coupling modifiers for processes with loops (k_g, k_γ, k_H…)
- Also possible to describe as coupling modifier ratios $\lambda_{ij}=\kappa_i/\kappa_j$
- Production processes: ggF, VBF, WH, ZH, ttH
- Decay channels: HZZ,WW,$\gamma\gamma$,$\tau\tau$,bb,$\mu\mu$

Can be used to estimate the Higgs width

Next steps: PseudoObservables, cross-sections…

Fiducial and Simplified template cross-section

Fiducial cross-section

- Optimized for maximal theoretical independence
- Fiducial in Higgs decay
- Smallest acceptance corrections
- Simple signal cuts
- “Exact” fiducial volume
- Targeted object definitions
- Agnostic to production mode

Can be done with single and differential distributions

Only feasible in HZZ,H$\gamma\gamma$,HWW

Combination not straightforward

Simplified templates cross section

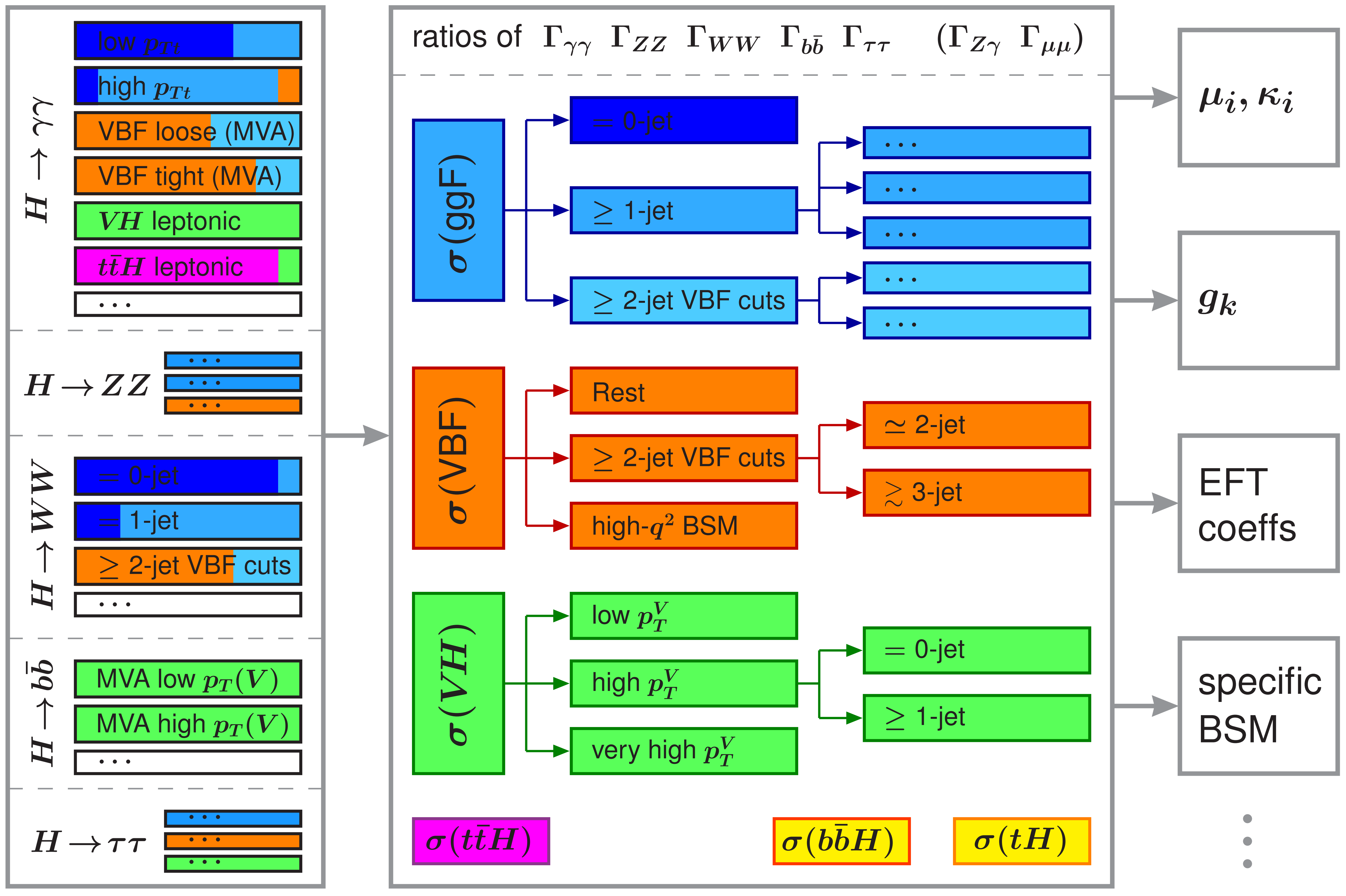
- Target maximum sensitivity, while keeping theoretical dependence as small as possible
- Cross section split by production mode
- Cross section divided in **exclusive** regions of phase space (bins)
- Larger acceptance corrections
- Abstracted fiducial volumes
- Inclusive in Higgs decay
- Allows complex event selections, categorisation

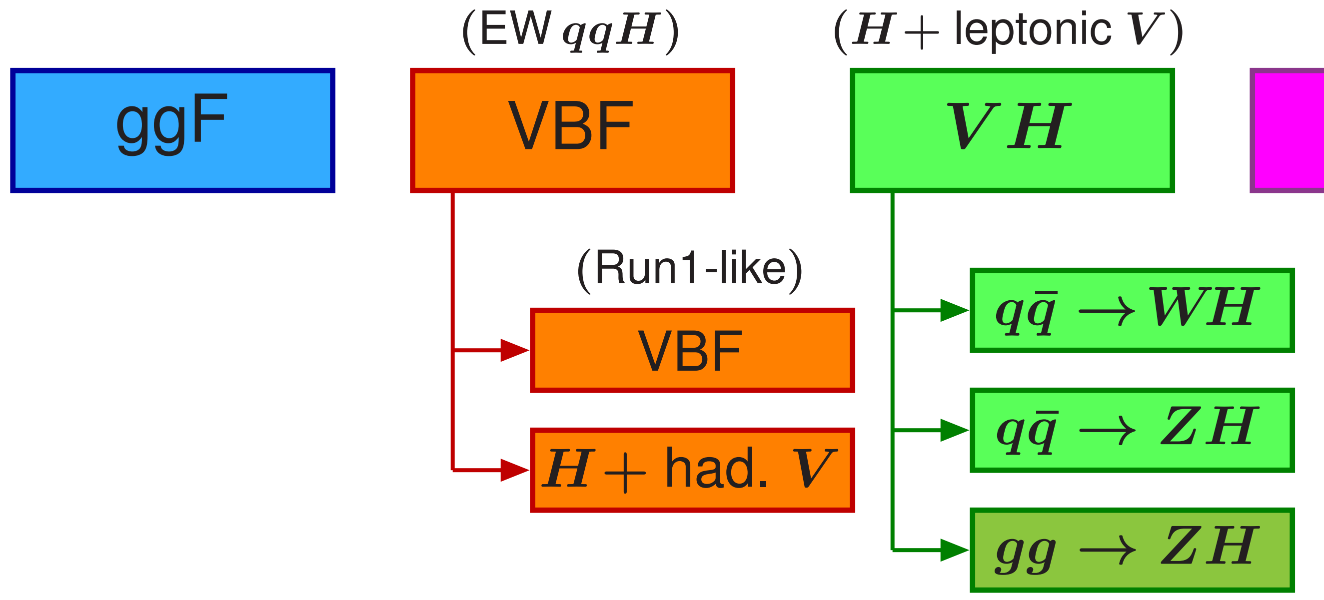
Common abstracted object definitions

Can be done in all decay modes

Explicitly designed for combination

Fiducial and Simplified template cross-section





Stage 0 bins

Simplified templates cross section

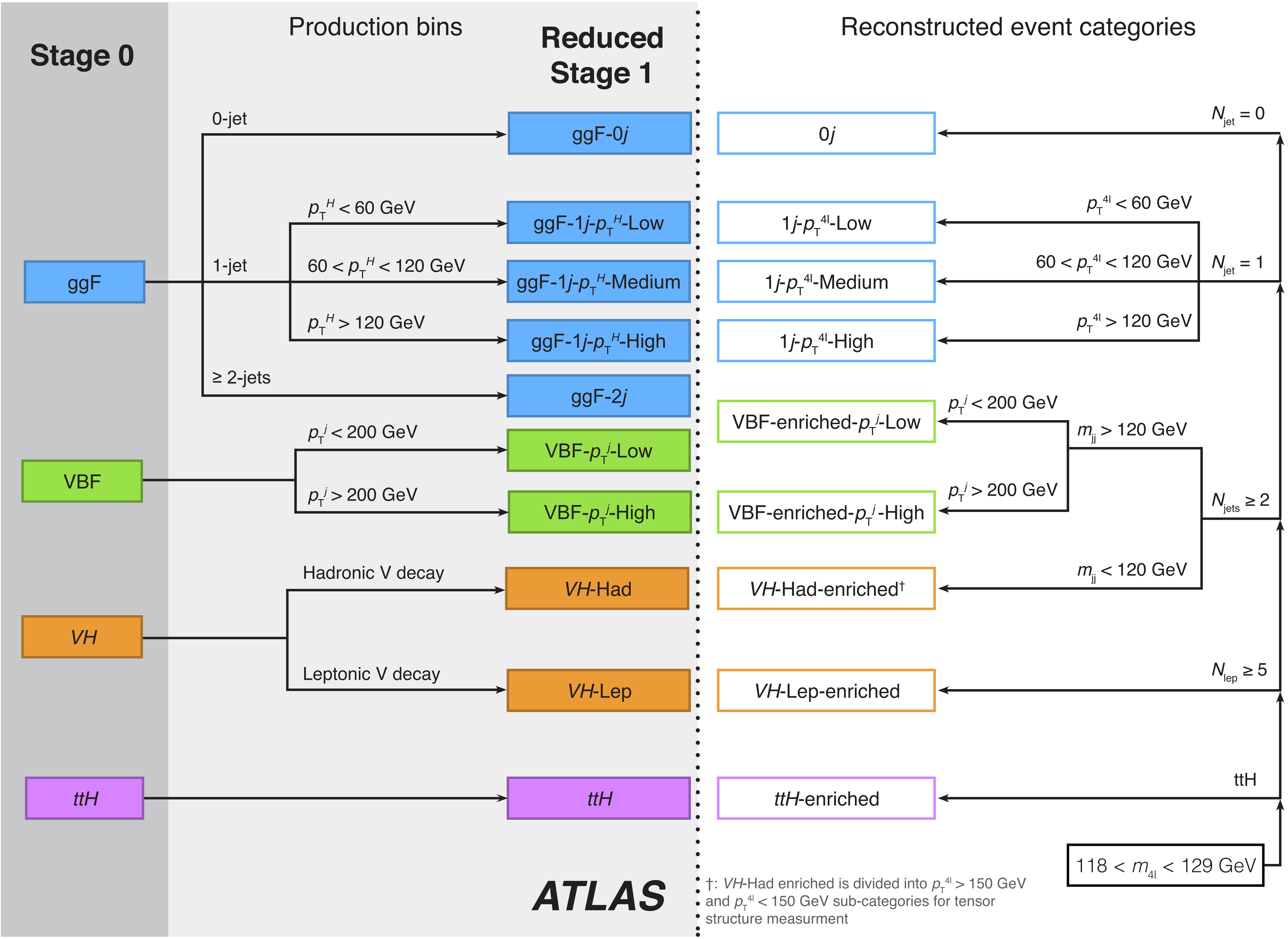
- Target maximum sensitivity, while keeping theoretical dependence as small as possible
- Cross section split by production mode
- Cross section divided in **exclusive** regions of phase space (bins)
- Larger acceptance corrections
- Abstracted fiducial volumes
- Inclusive in Higgs decay
- Allows complex event selections, categorisation

Common abstracted object definitions

Can be done in all decay modes

Explicitly designed for combination

Reduces STXS



CMS-PAS-HIG-16-042
ATLAS-CONF-2018-004
ATLAS-CONF-2016-112

Higgs to WW, Results

- CMS

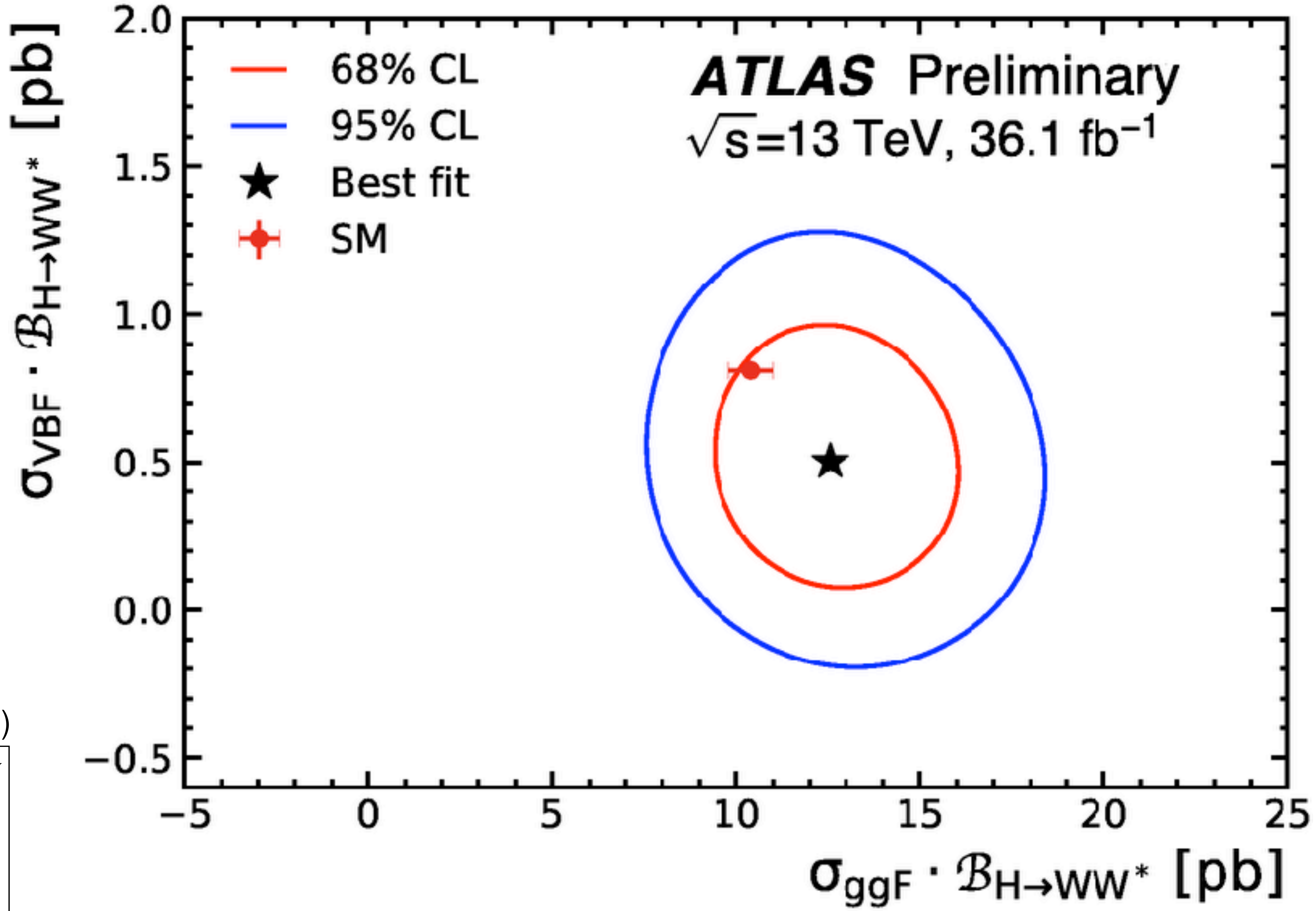
$$\boxed{\hat{\mu} = 1.28^{+0.18}_{-0.17} = 1.28 \pm 0.10(\text{stat})^{+0.11}_{-0.11}(\text{syst})^{+0.10}_{-0.07}(\text{theo.})}$$

- ATLAS

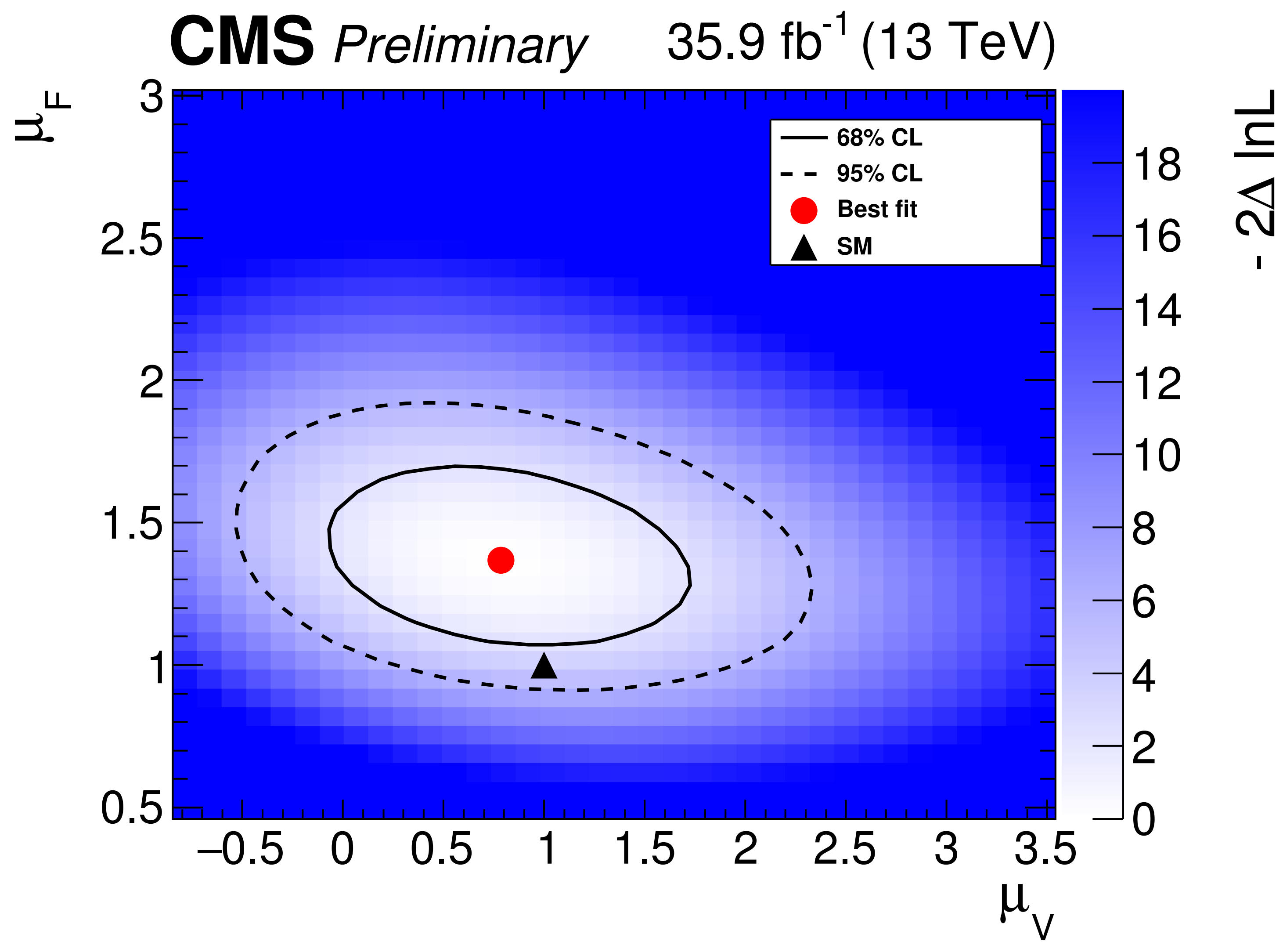
$$\boxed{\mu_{\text{ggF}} = 1.21^{+0.12}_{-0.11}(\text{stat.})^{+0.18}_{-0.17}(\text{sys.}) = 1.21^{+0.22}_{-0.21}}$$

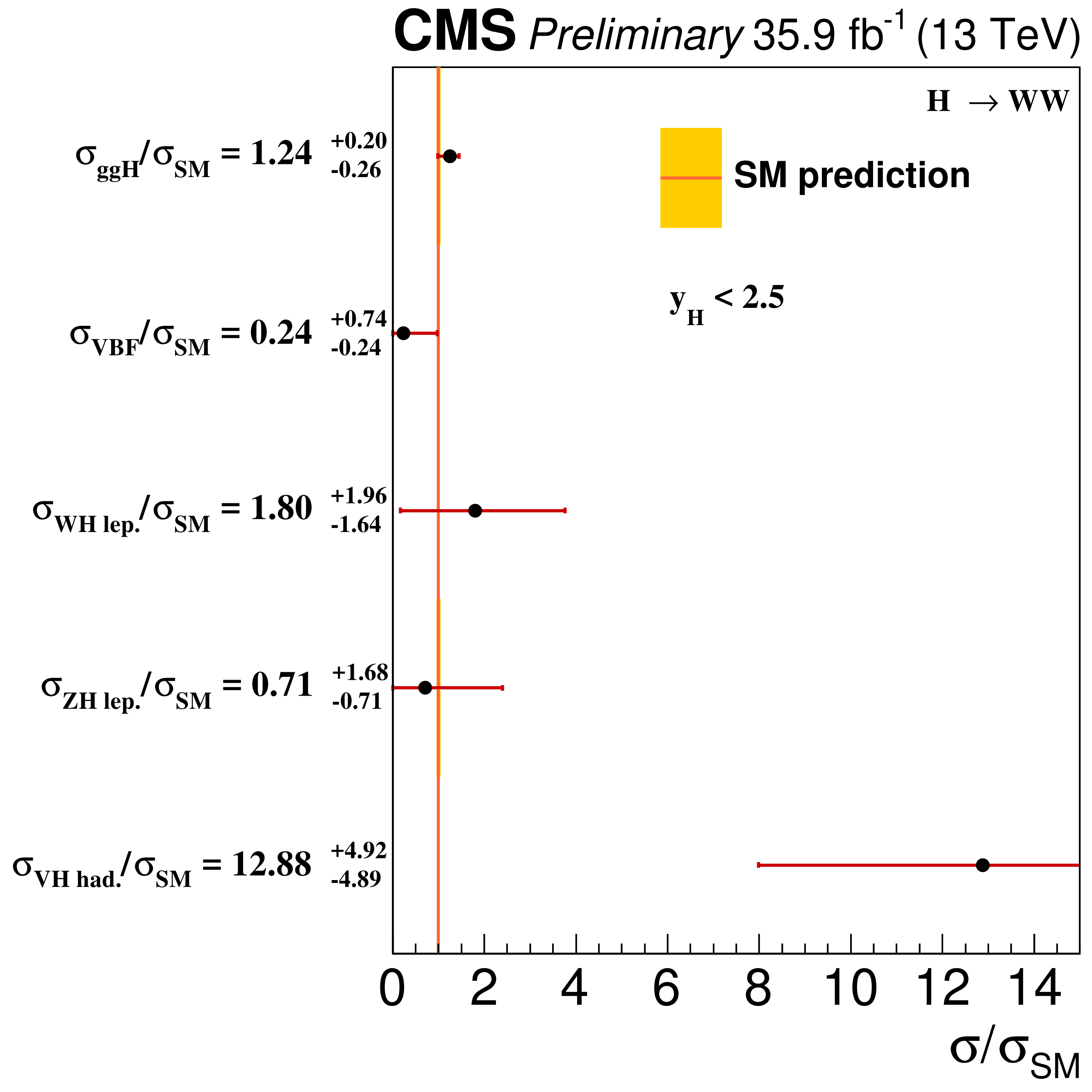
$$\boxed{\mu_{\text{VBF}} = 0.62^{+0.30}_{-0.28}(\text{stat.}) \pm 0.22(\text{sys.}) = 0.62^{+0.37}_{-0.36}}$$

* $\boxed{\mu_{WH} = 3.2^{+3.7}_{-3.2}(\text{stat})^{+2.3}_{-2.7}(\text{sys})}$ *2015 data



$$\boxed{\begin{aligned} \sigma_{\text{ggF}} \cdot \mathcal{B}_{H\to WW^*} &= 12.6^{+1.3}_{-1.2}(\text{stat.})^{+1.9}_{-1.8}(\text{sys.})\ \text{pb} = 12.6^{+2.3}_{-2.1}\ \text{pb} \\ \sigma_{\text{VBF}} \cdot \mathcal{B}_{H\to WW^*} &= 0.50^{+0.24}_{-0.23}(\text{stat.}) \pm 0.18(\text{sys.})\ \text{pb} = 0.50^{+0.30}_{-0.29}\ \text{pb.} \end{aligned}}$$



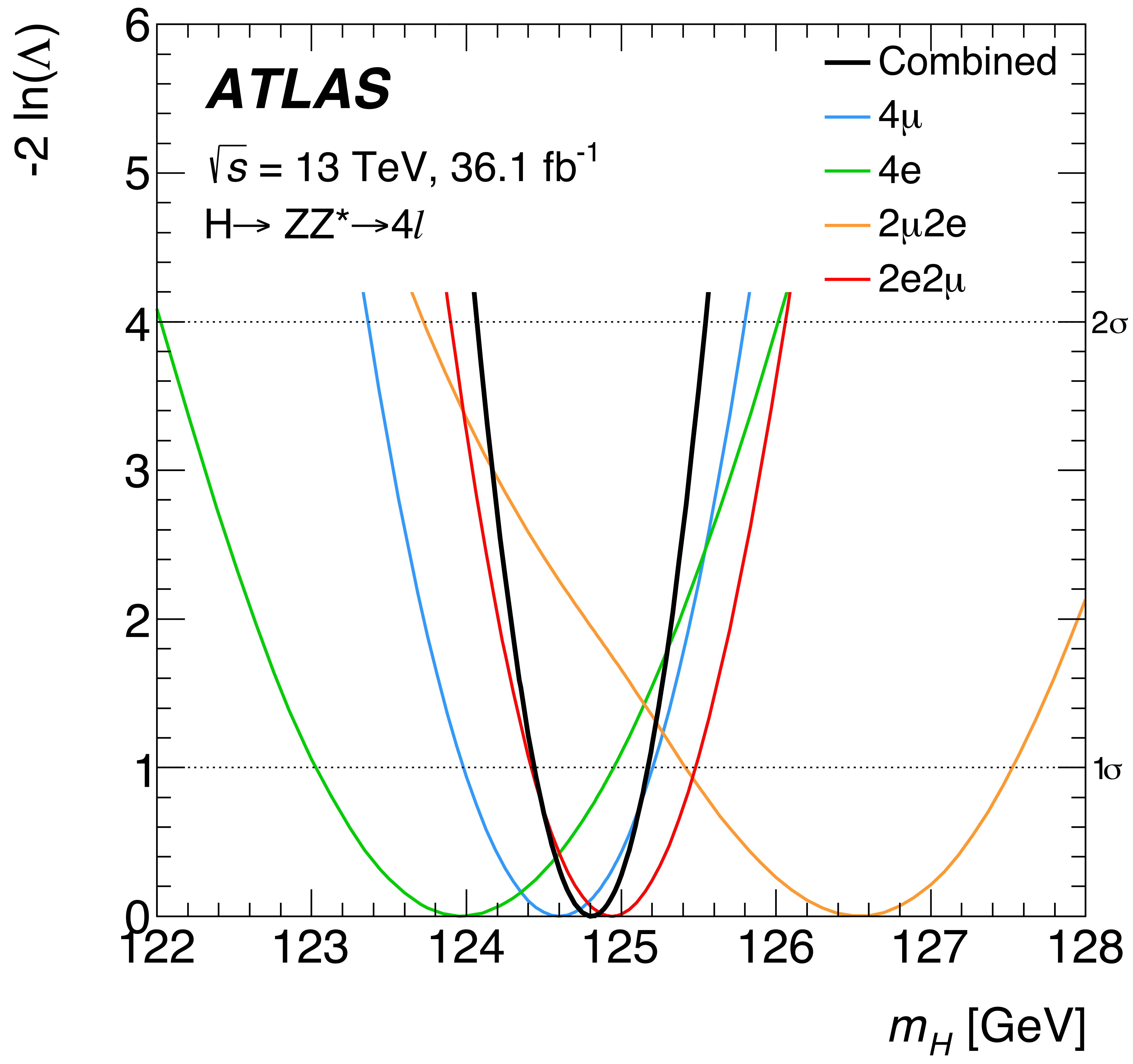


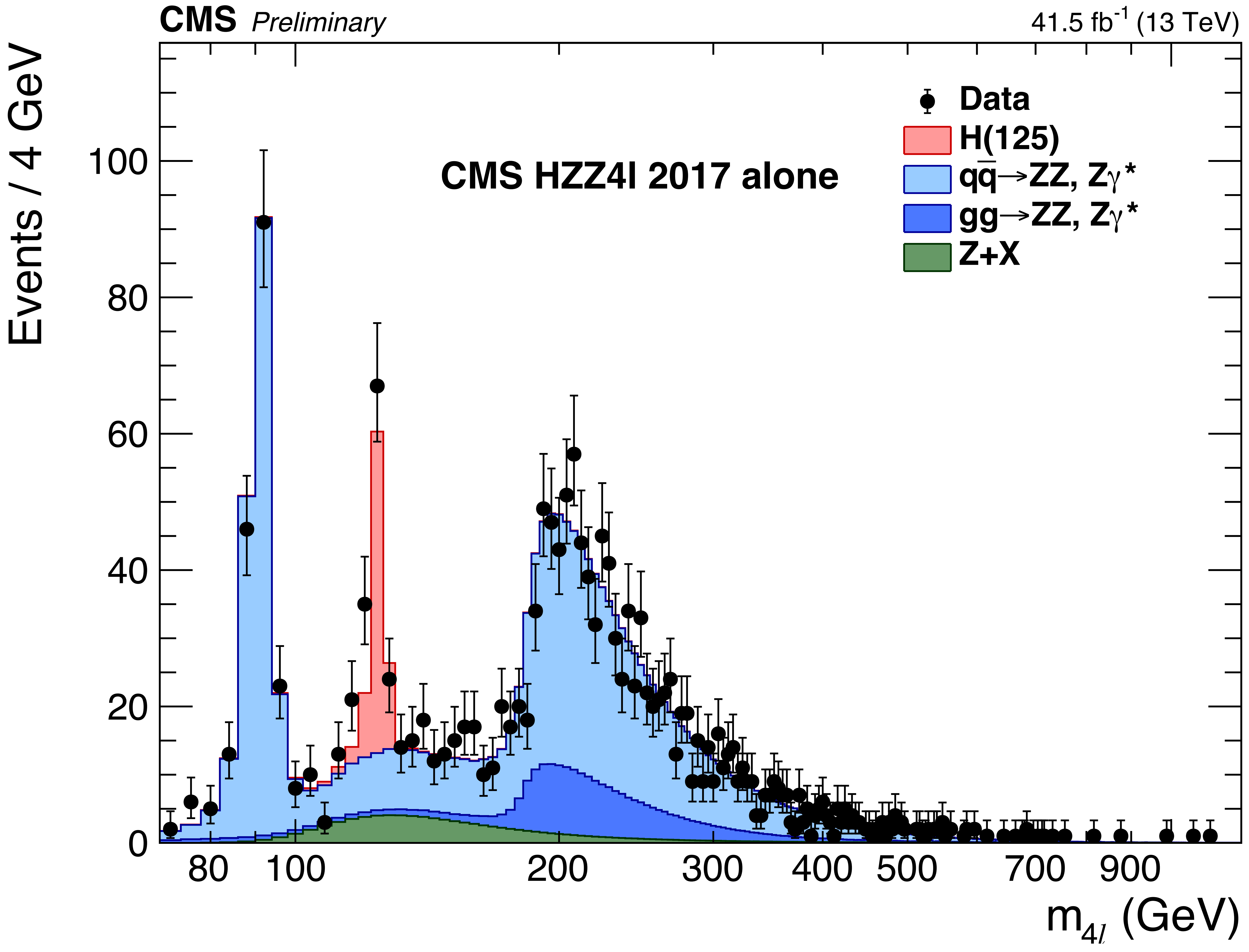
Run1 CMS+ATLAS: $\mu=1.09^{+0.18}_{-0.16}$

No deviations observed with respect the SM expectations

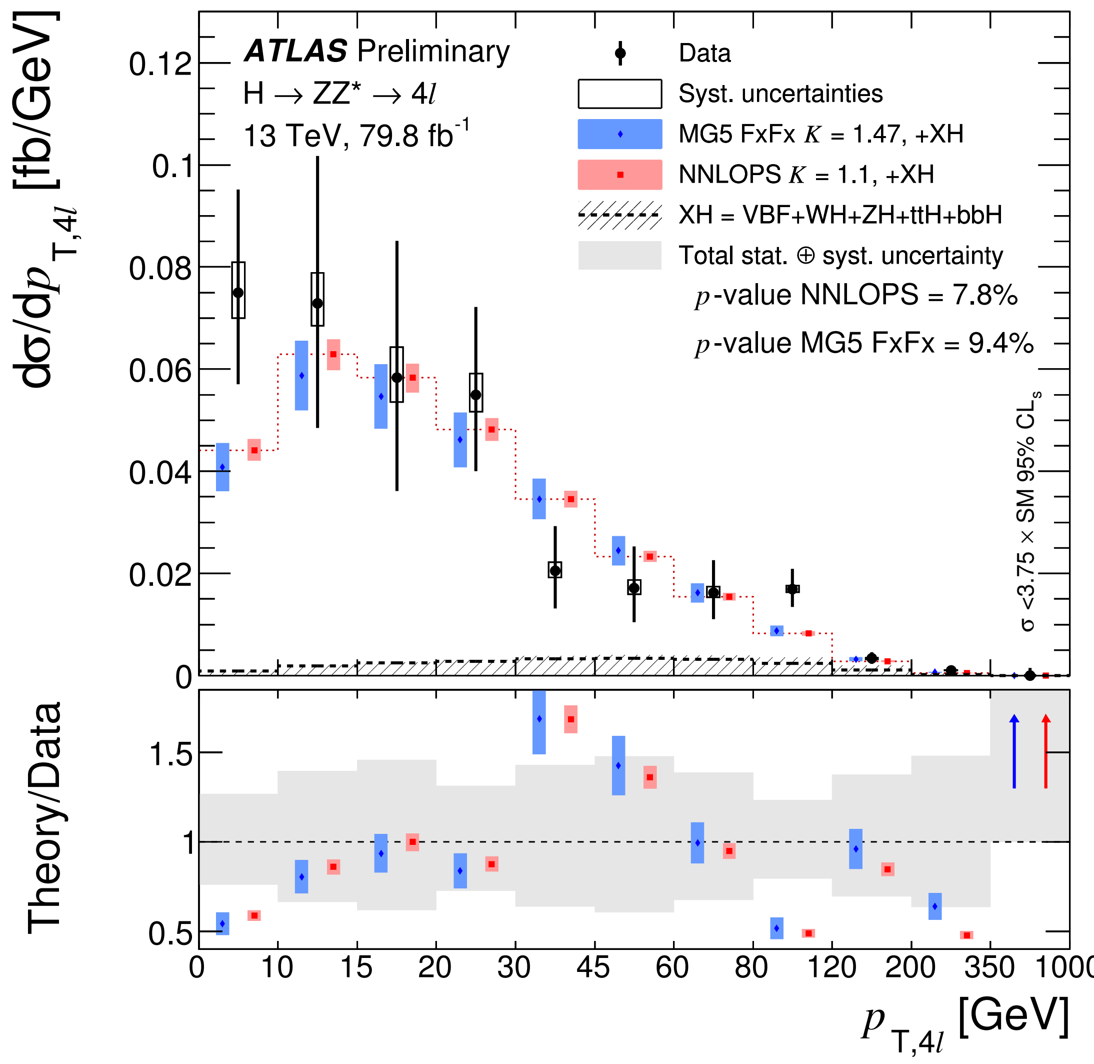
Small deficit in VBF, small excess in gluon fusion, opposite with respect Run1

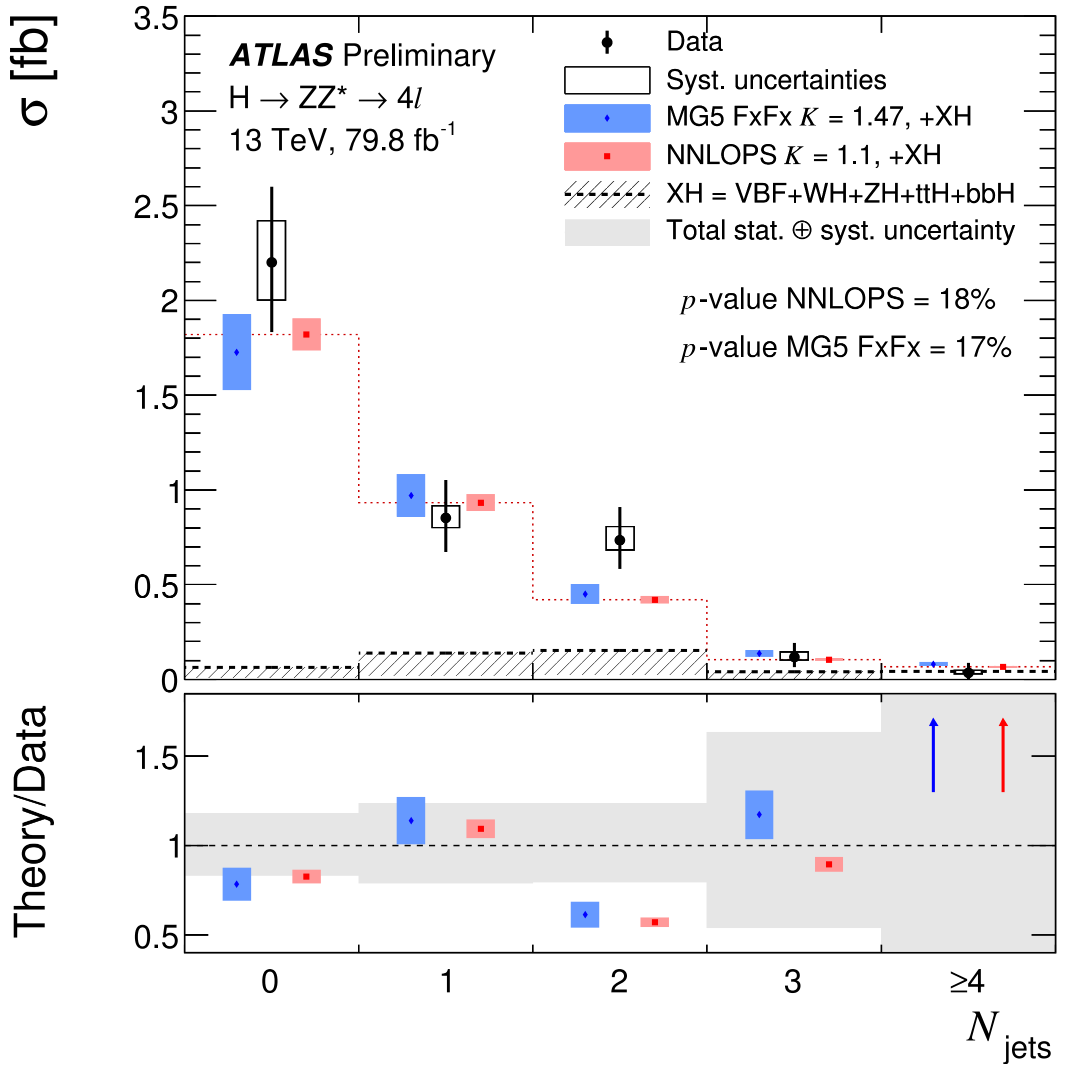
HZZ4l additional material

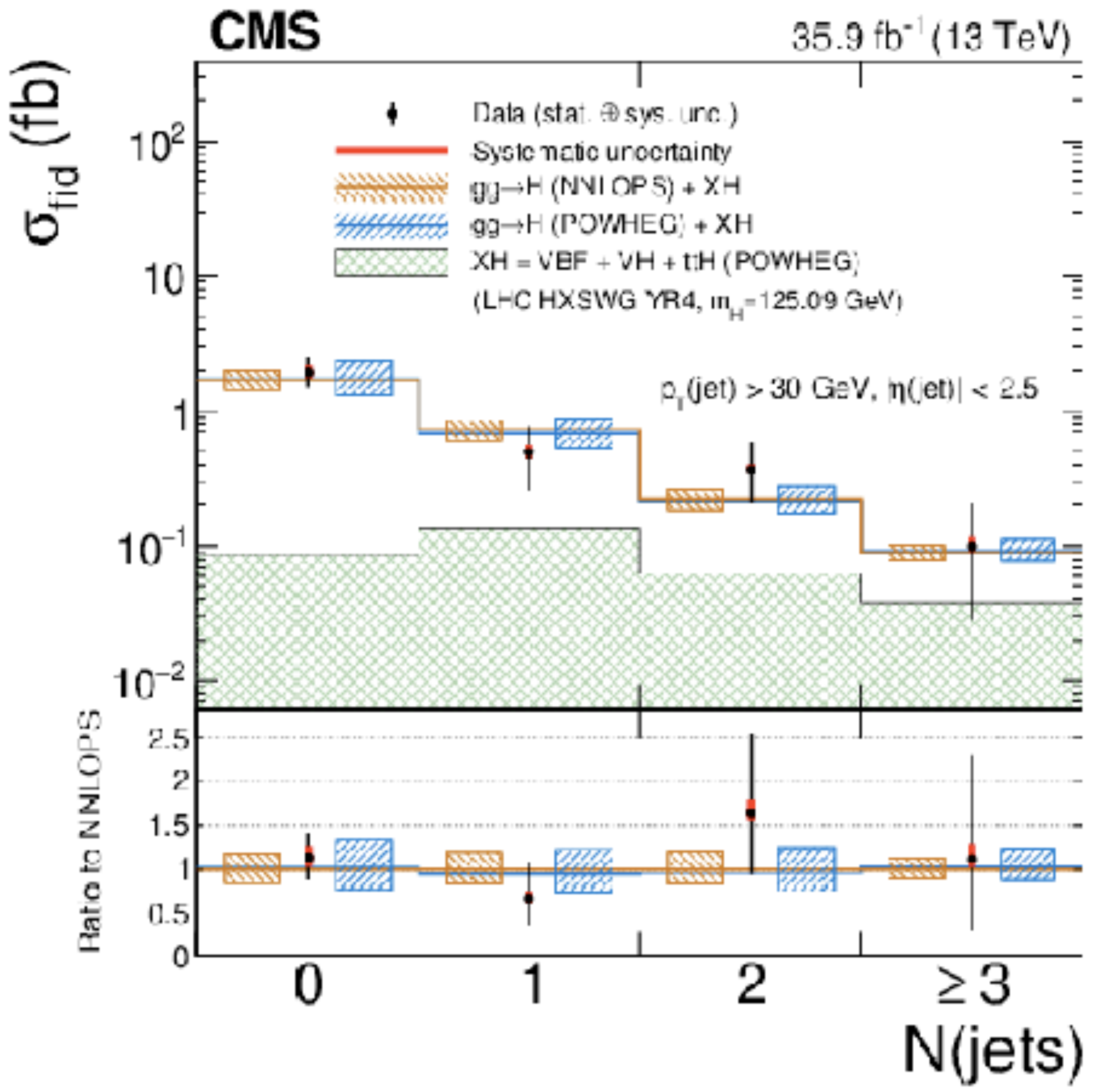


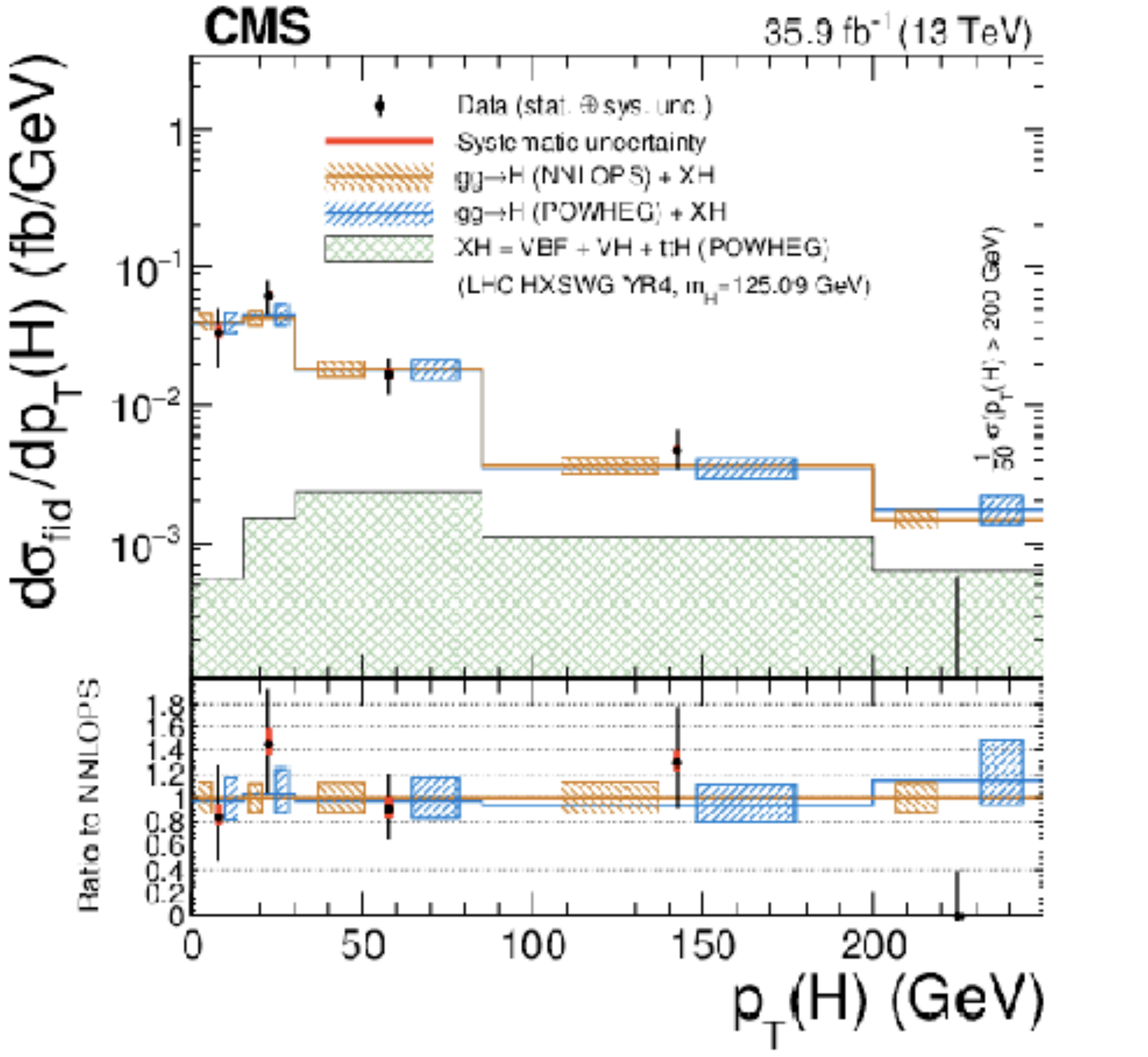


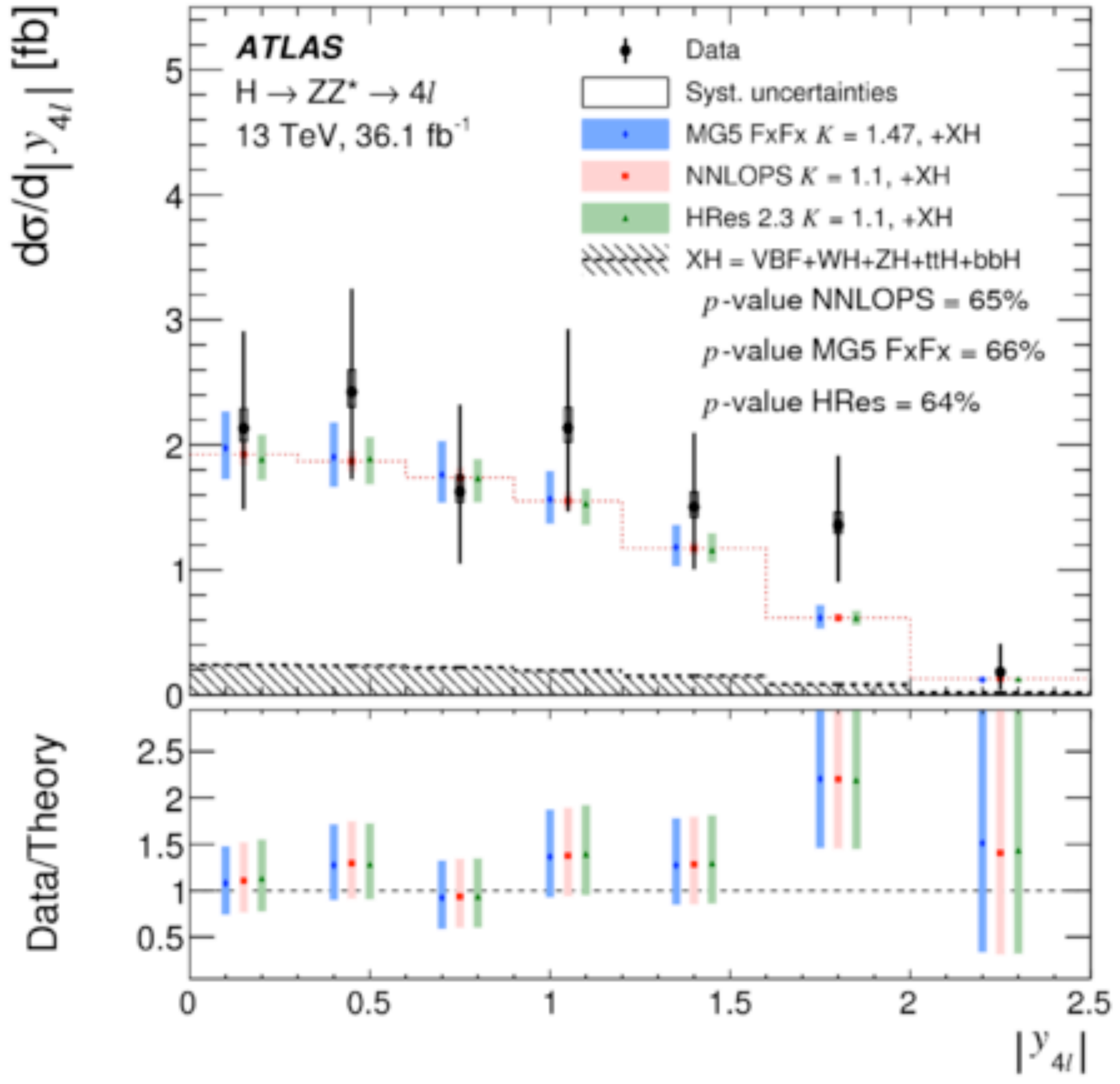
Cross sections







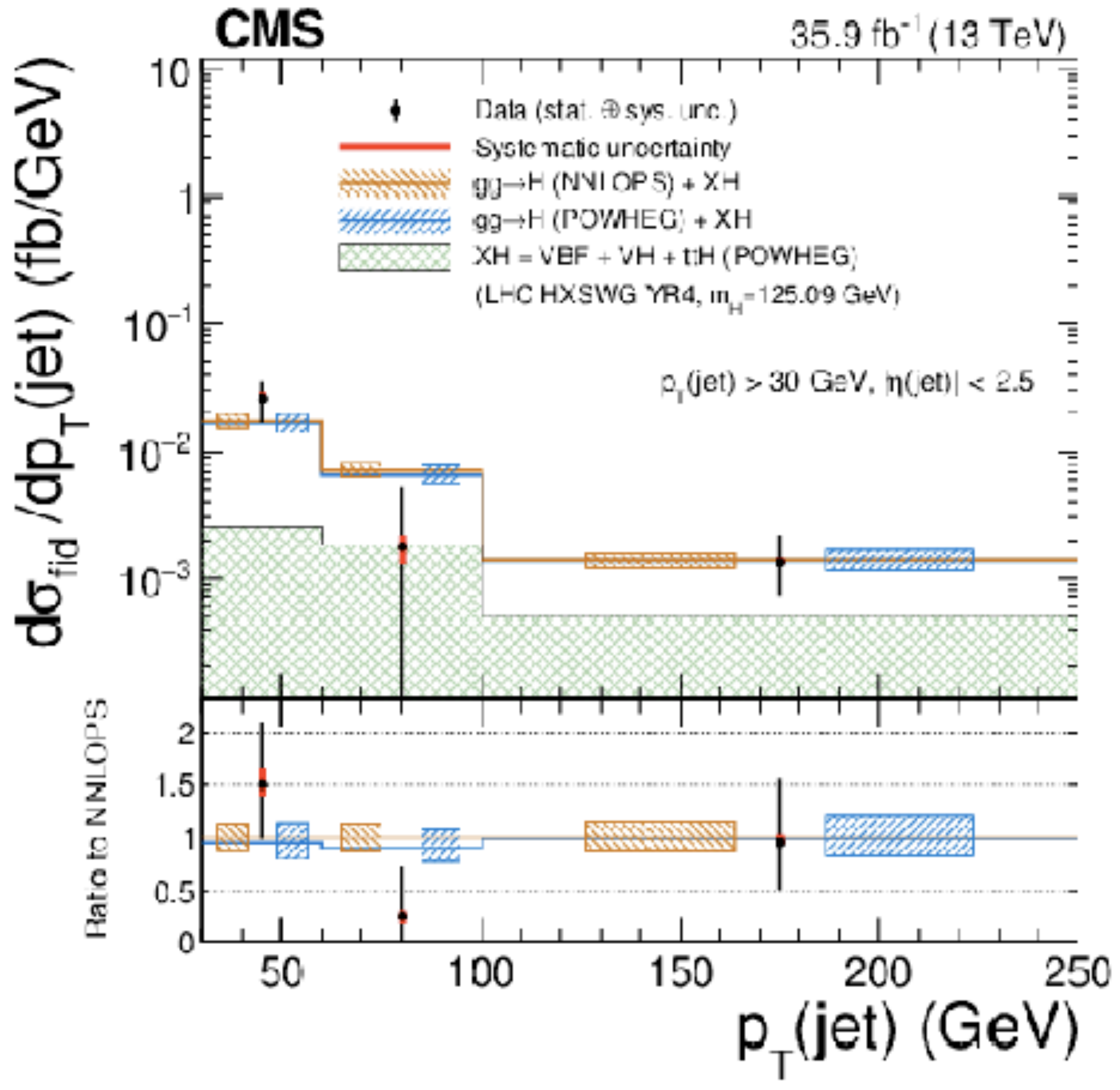




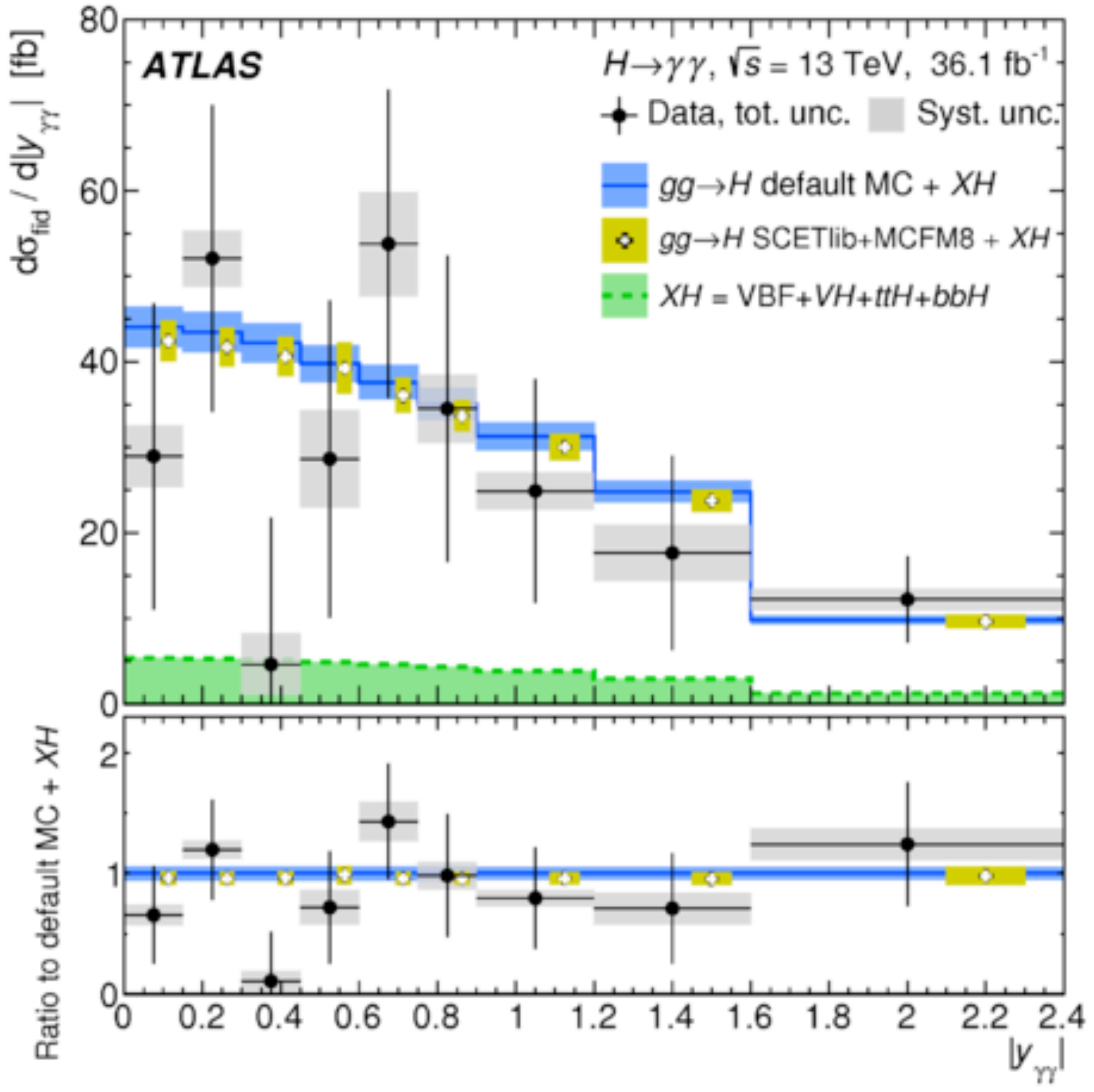
Still large uncertainties on the tails

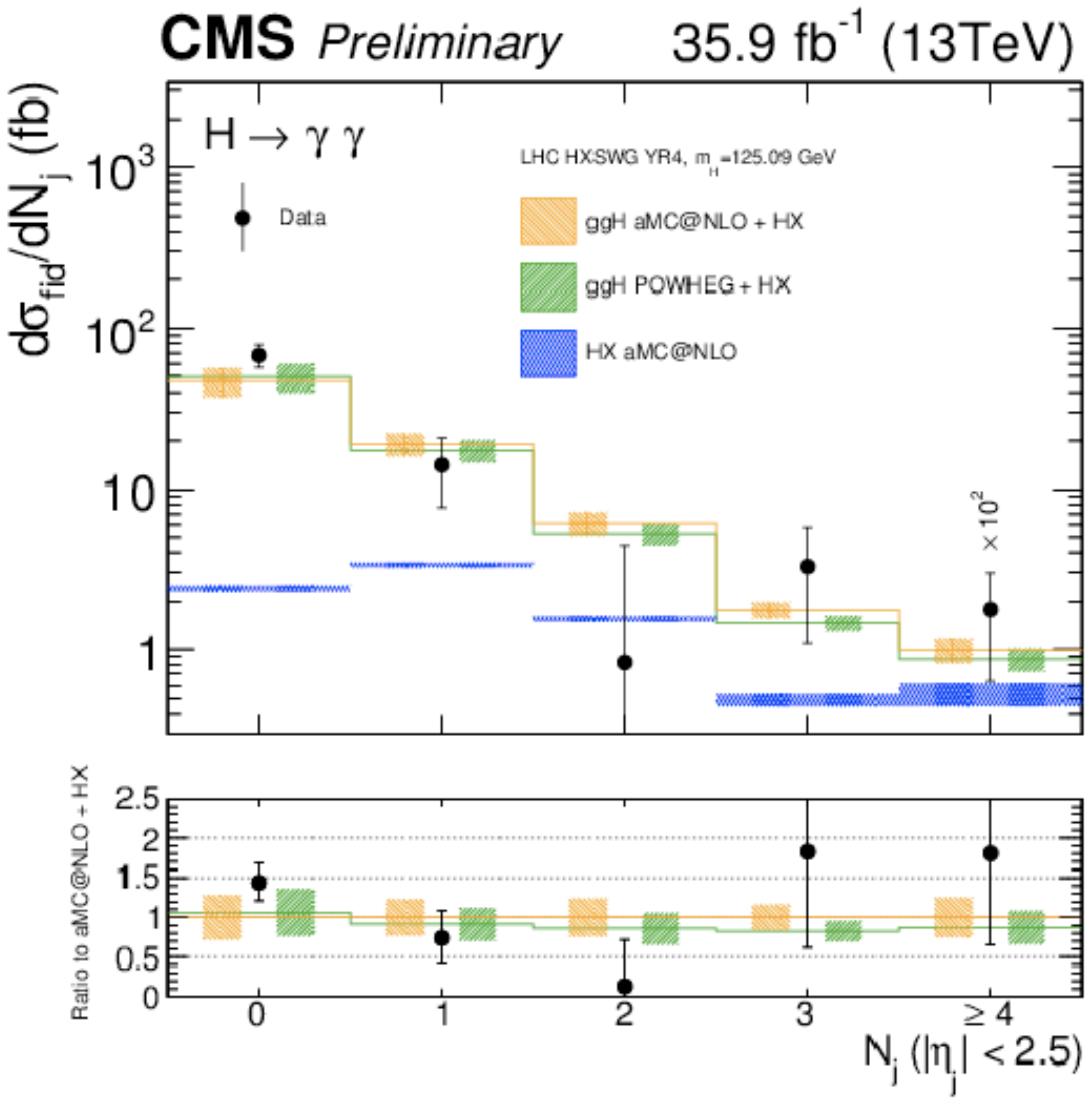
Approaching theoretical uncertainties in the low n-jets bins

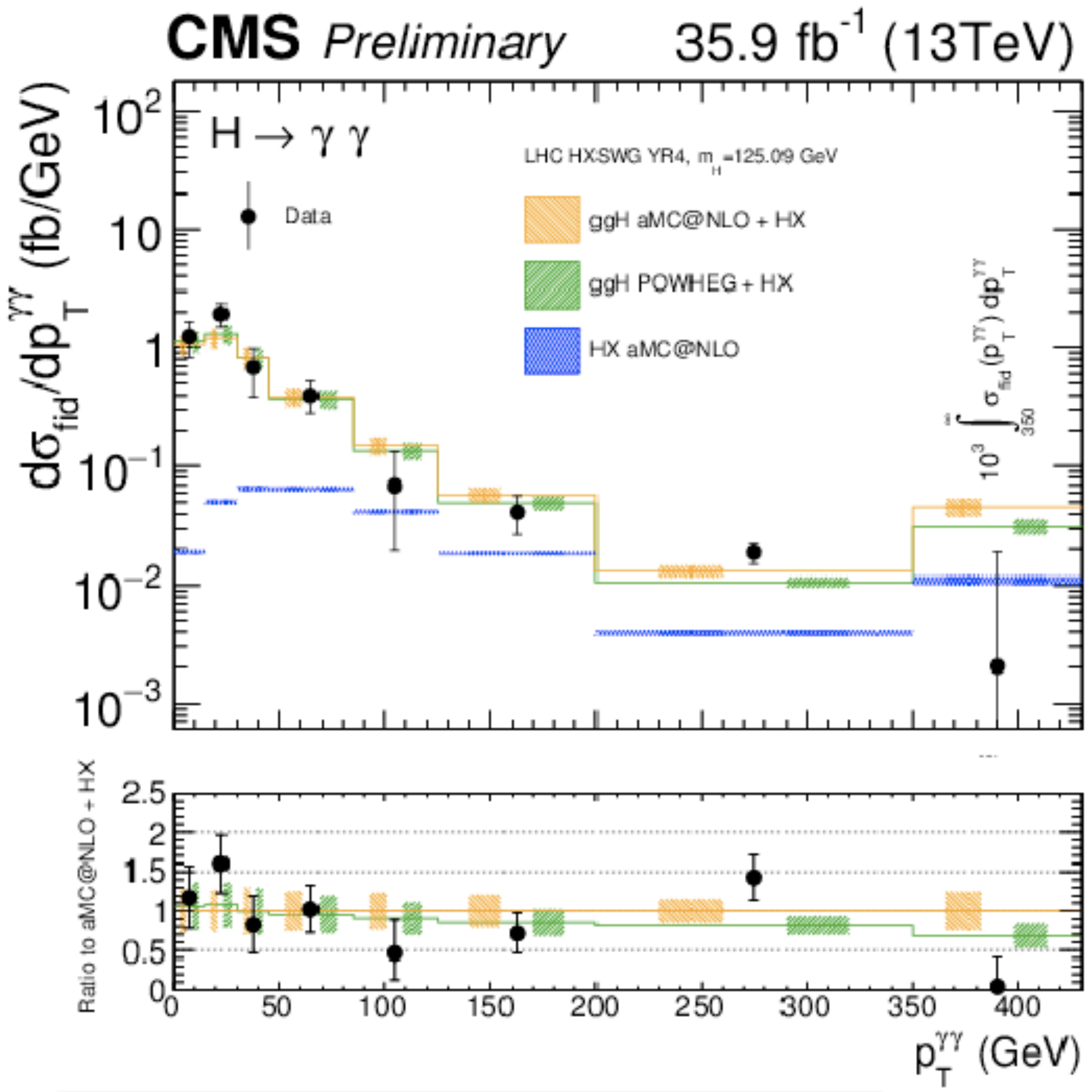
No large deviations observed at the moment

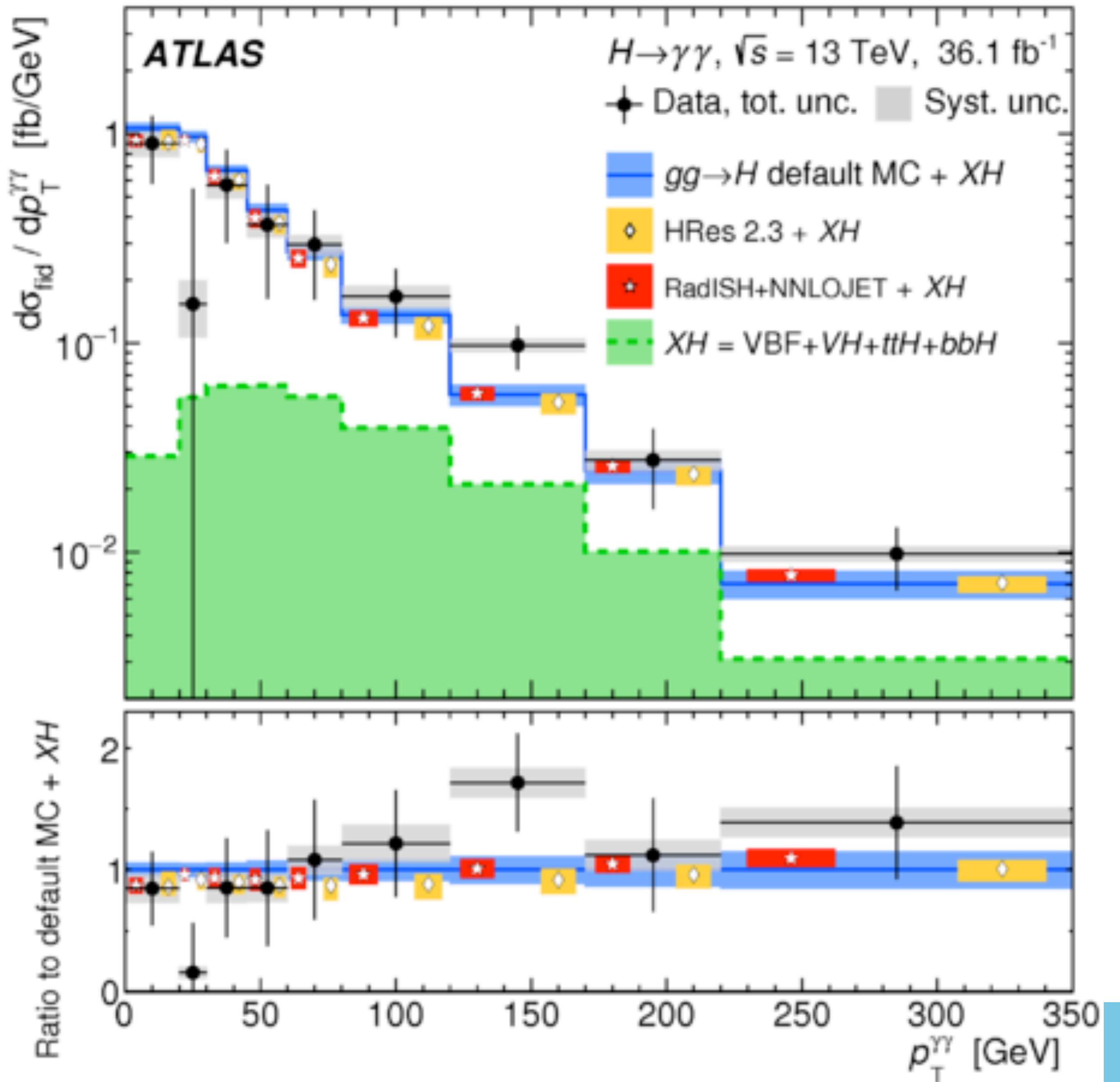


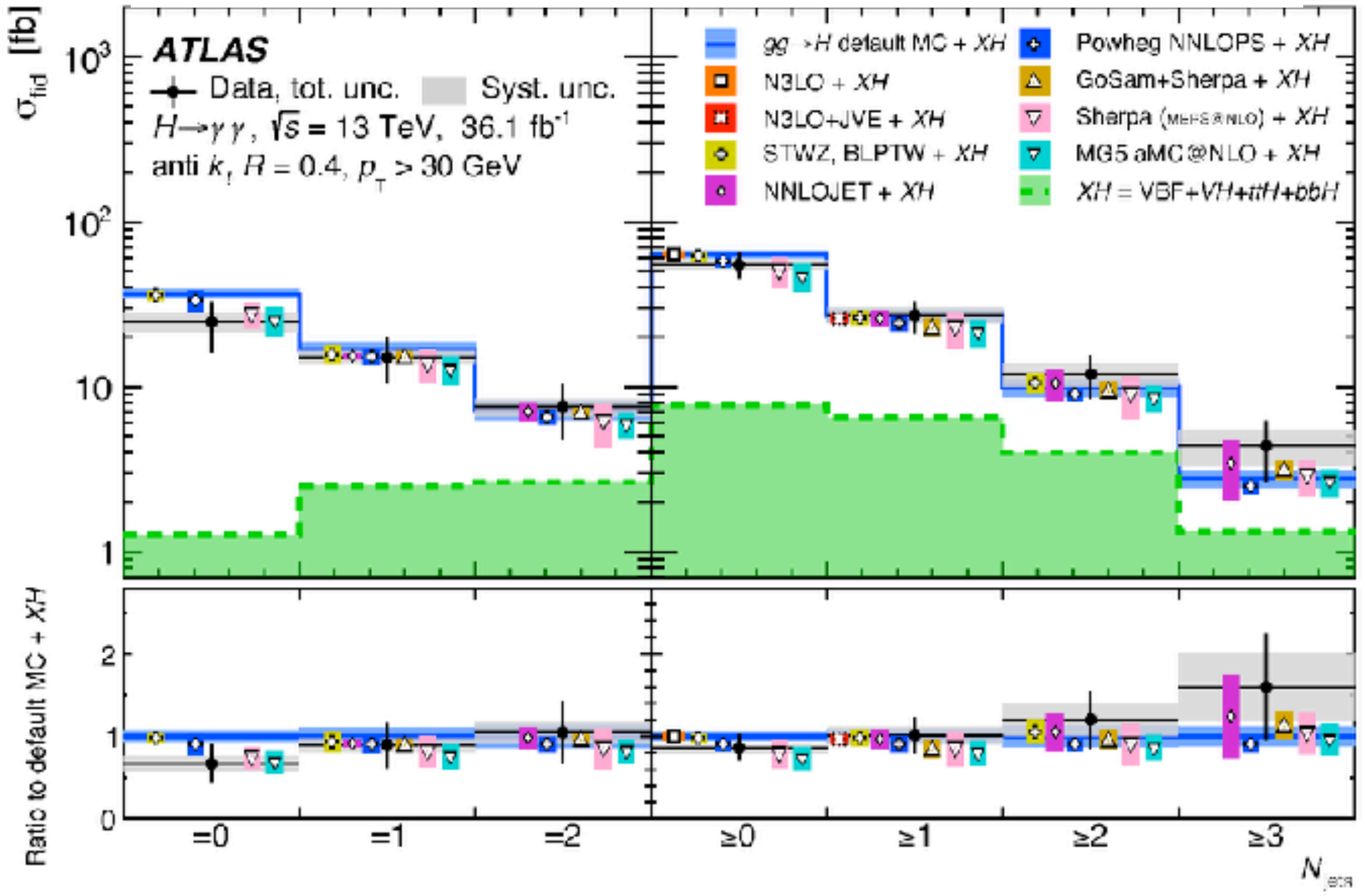
Differential cross sections

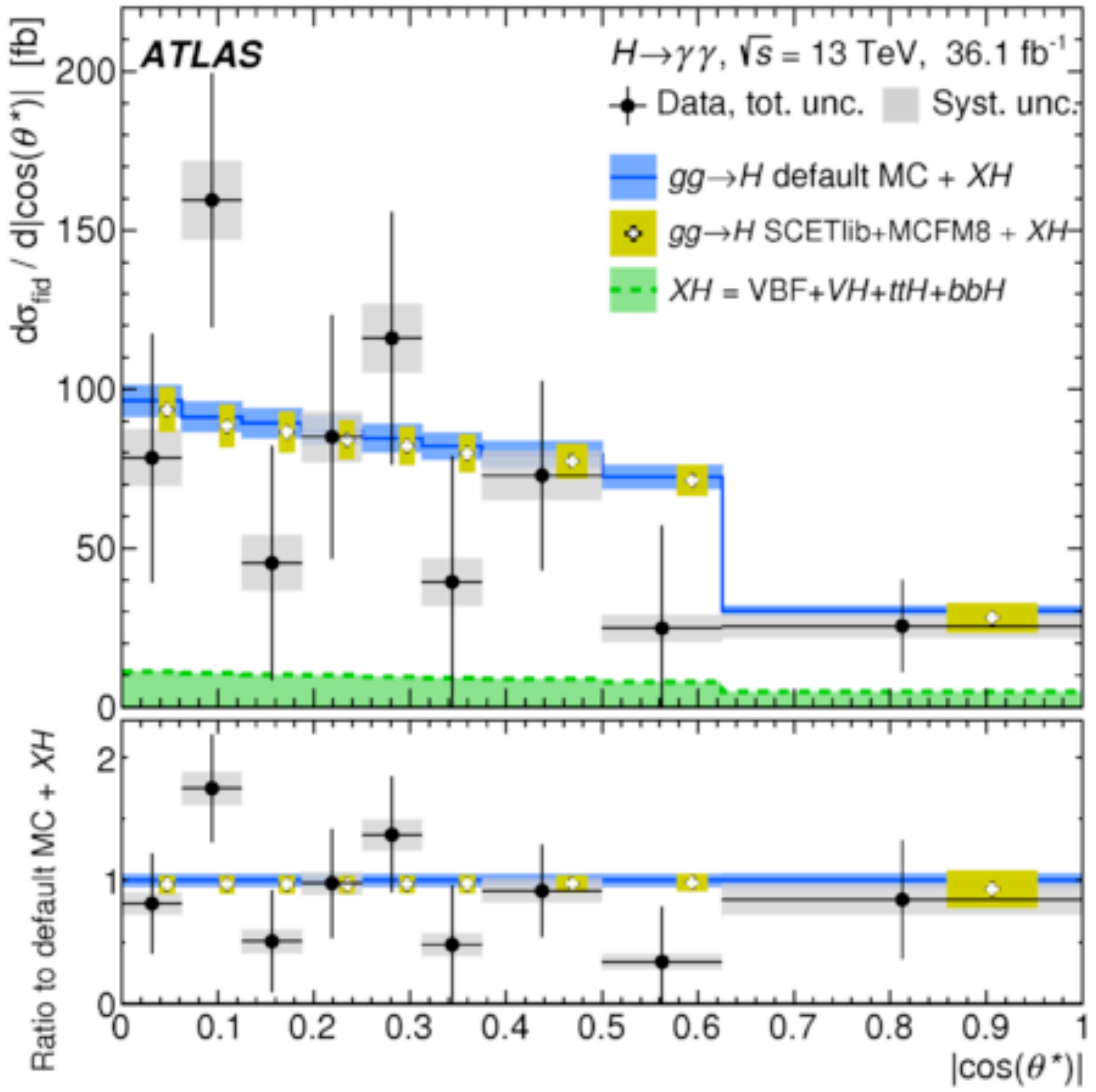




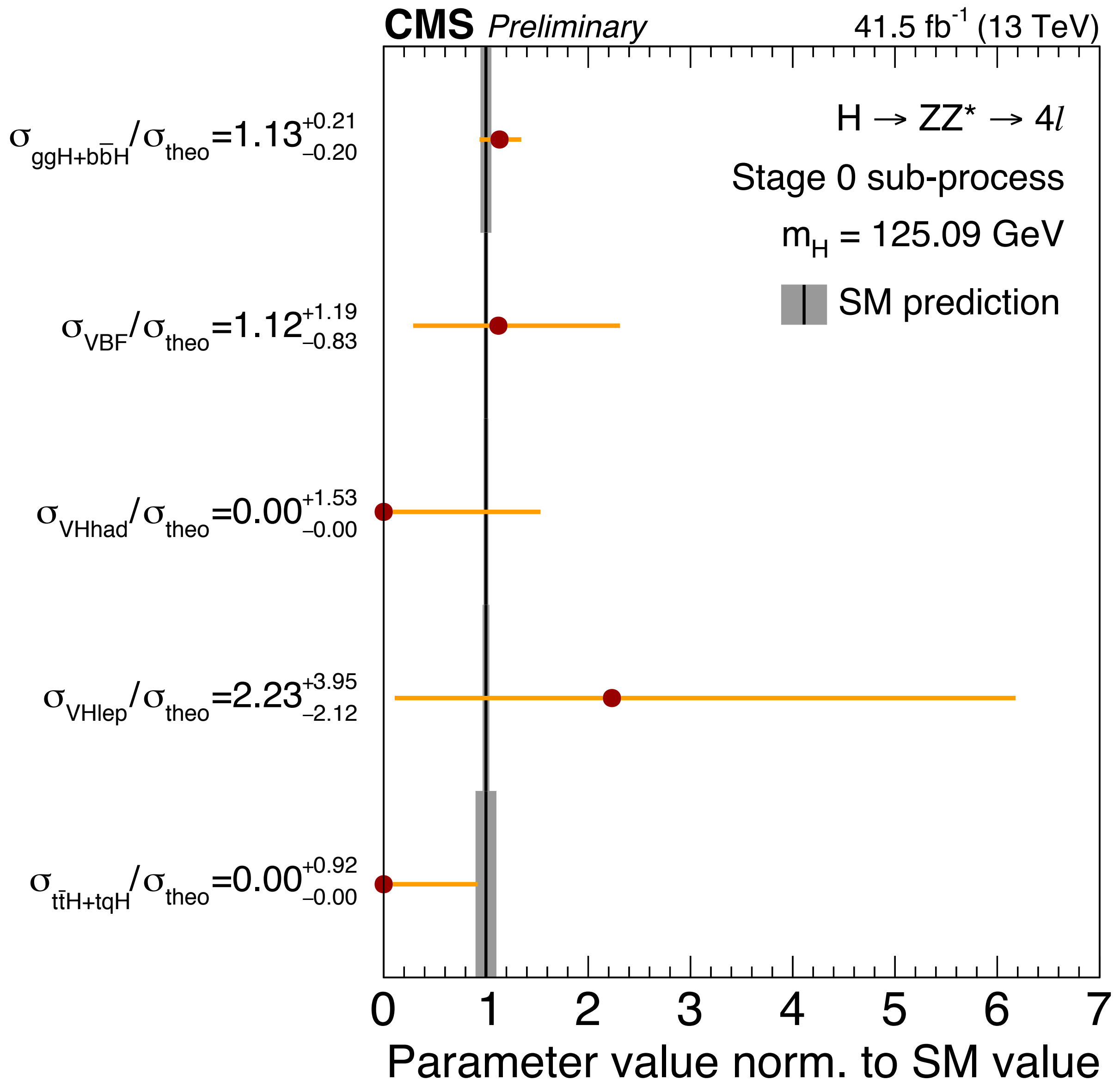


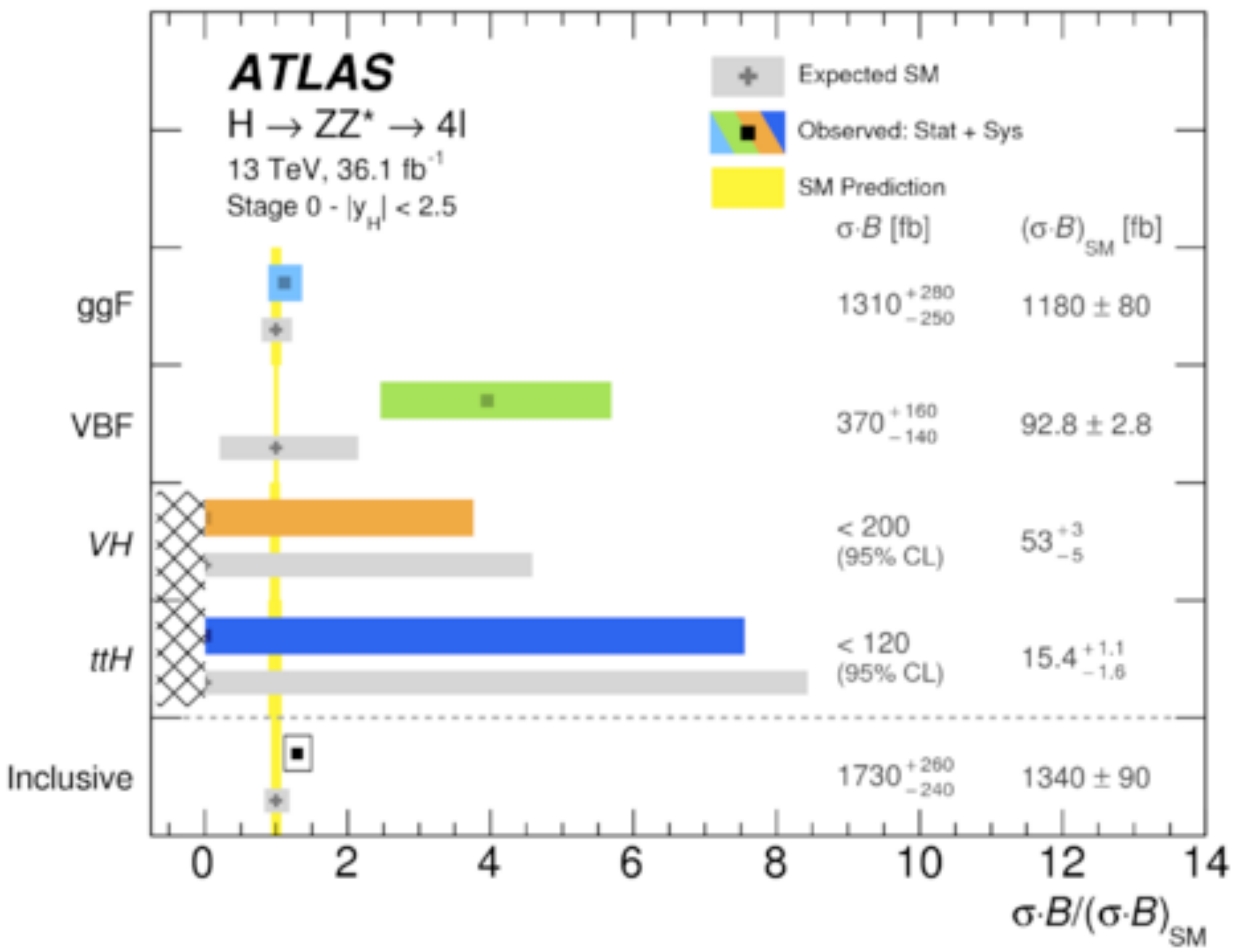


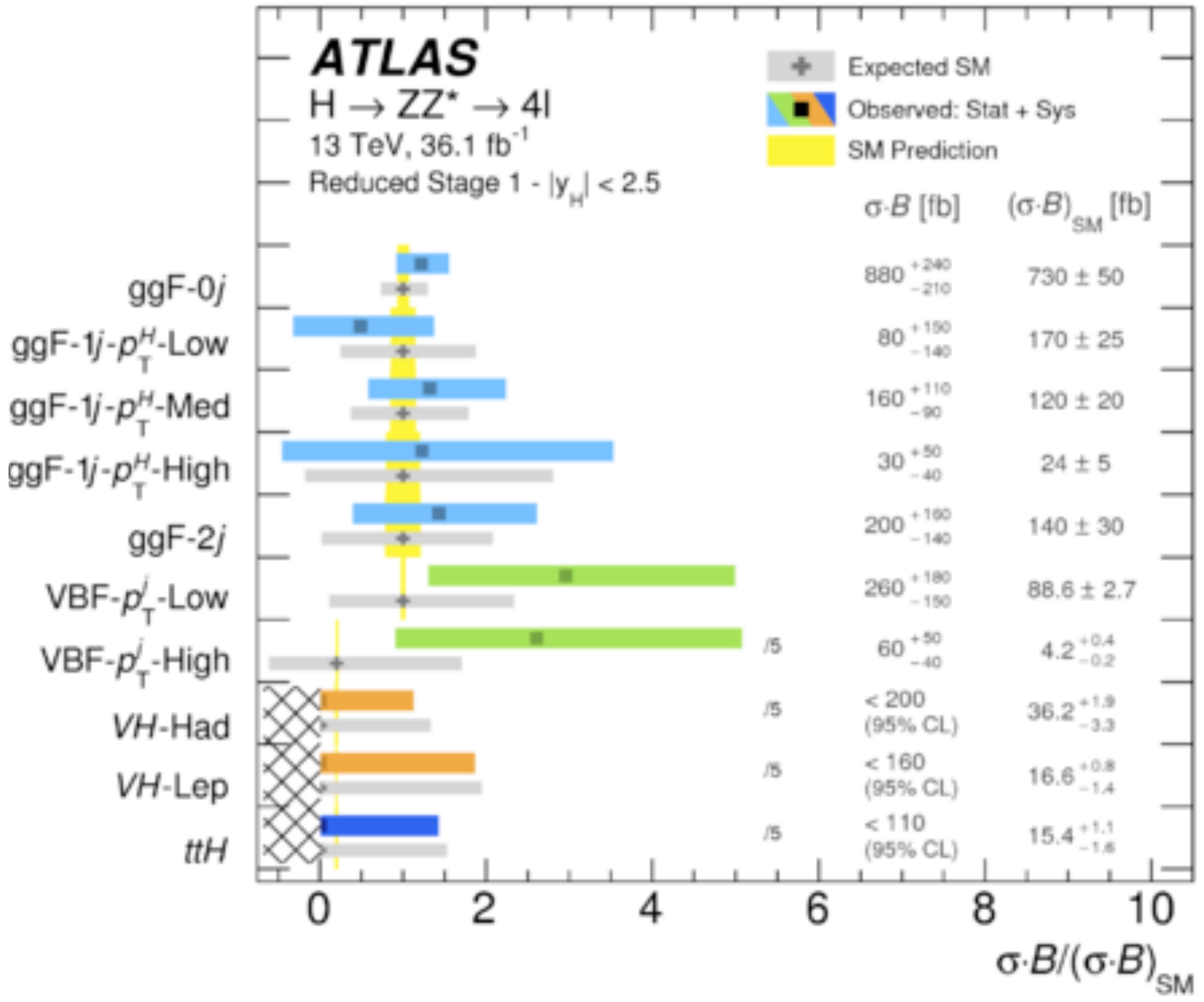


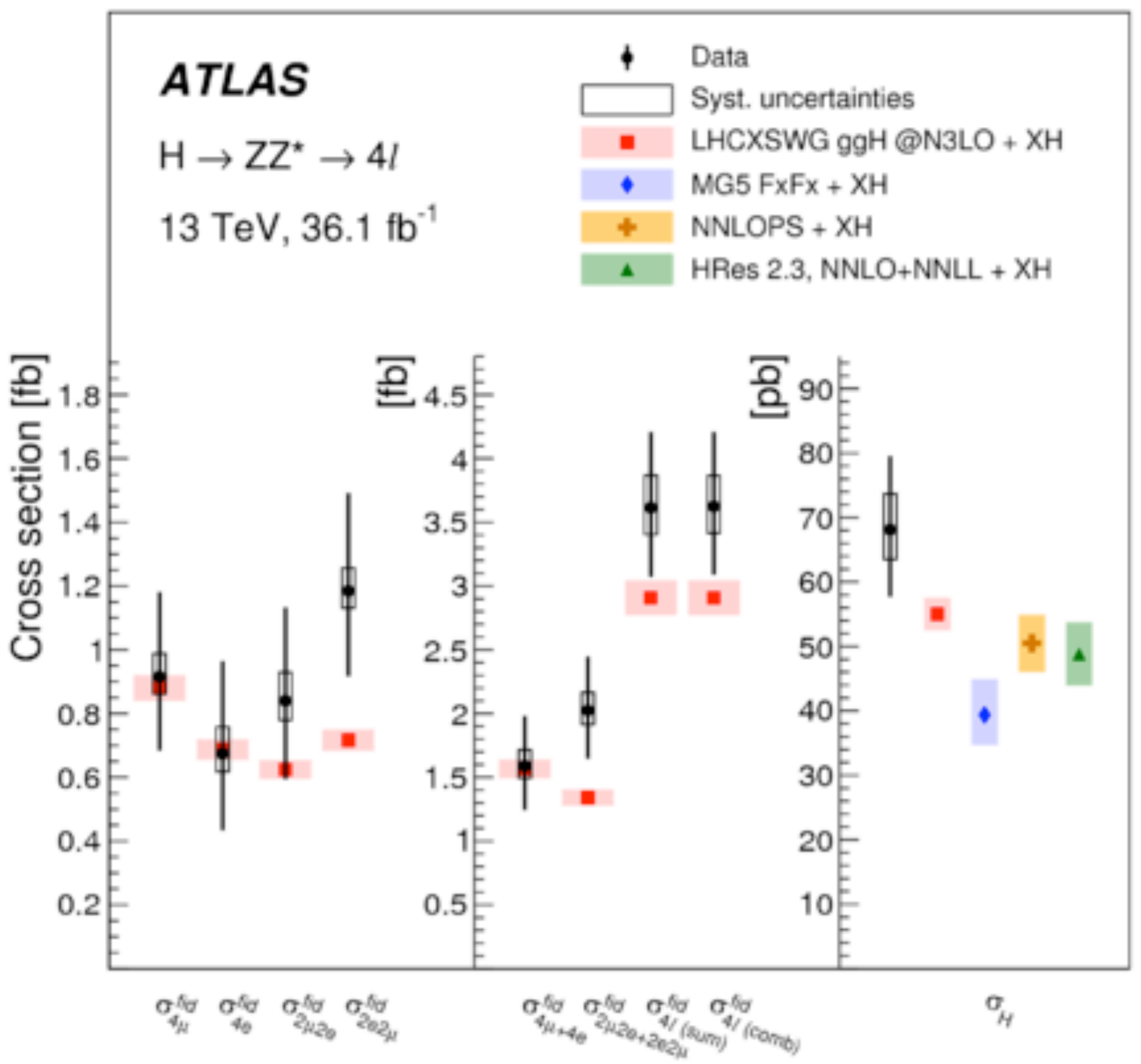


Cross sections





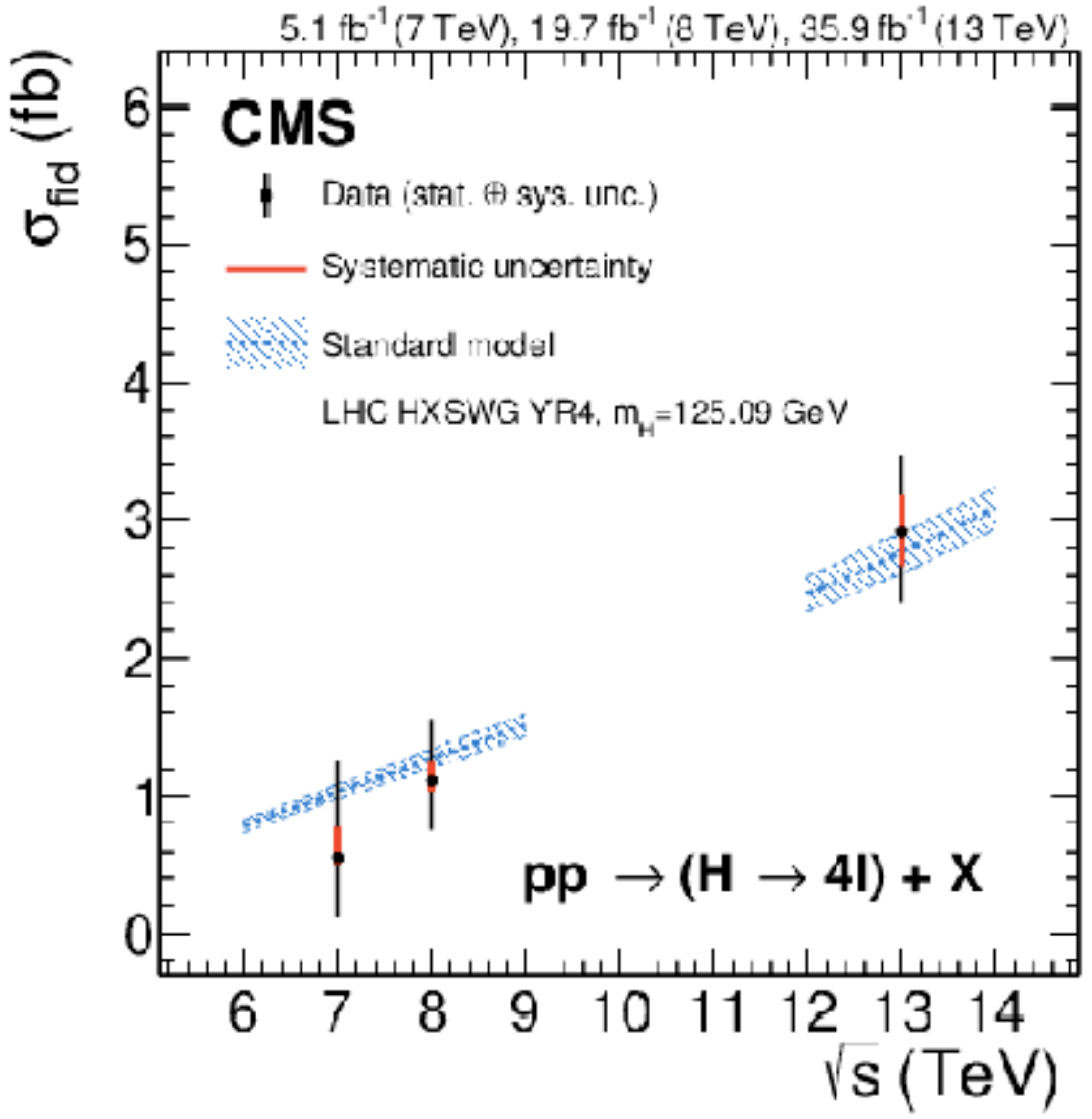




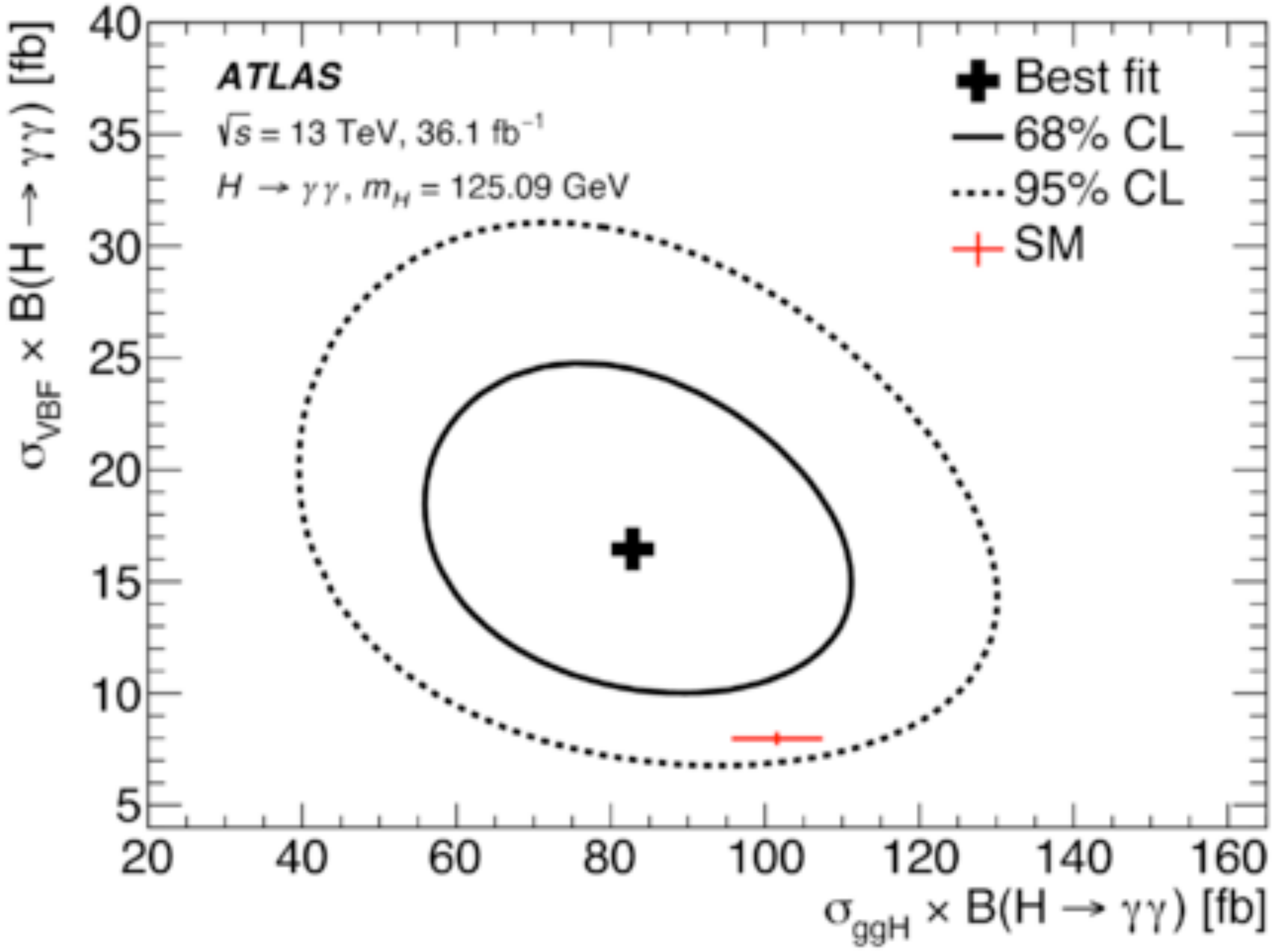
ATLAS already attempting at (simplified) stage-1 STXS subprocesses.

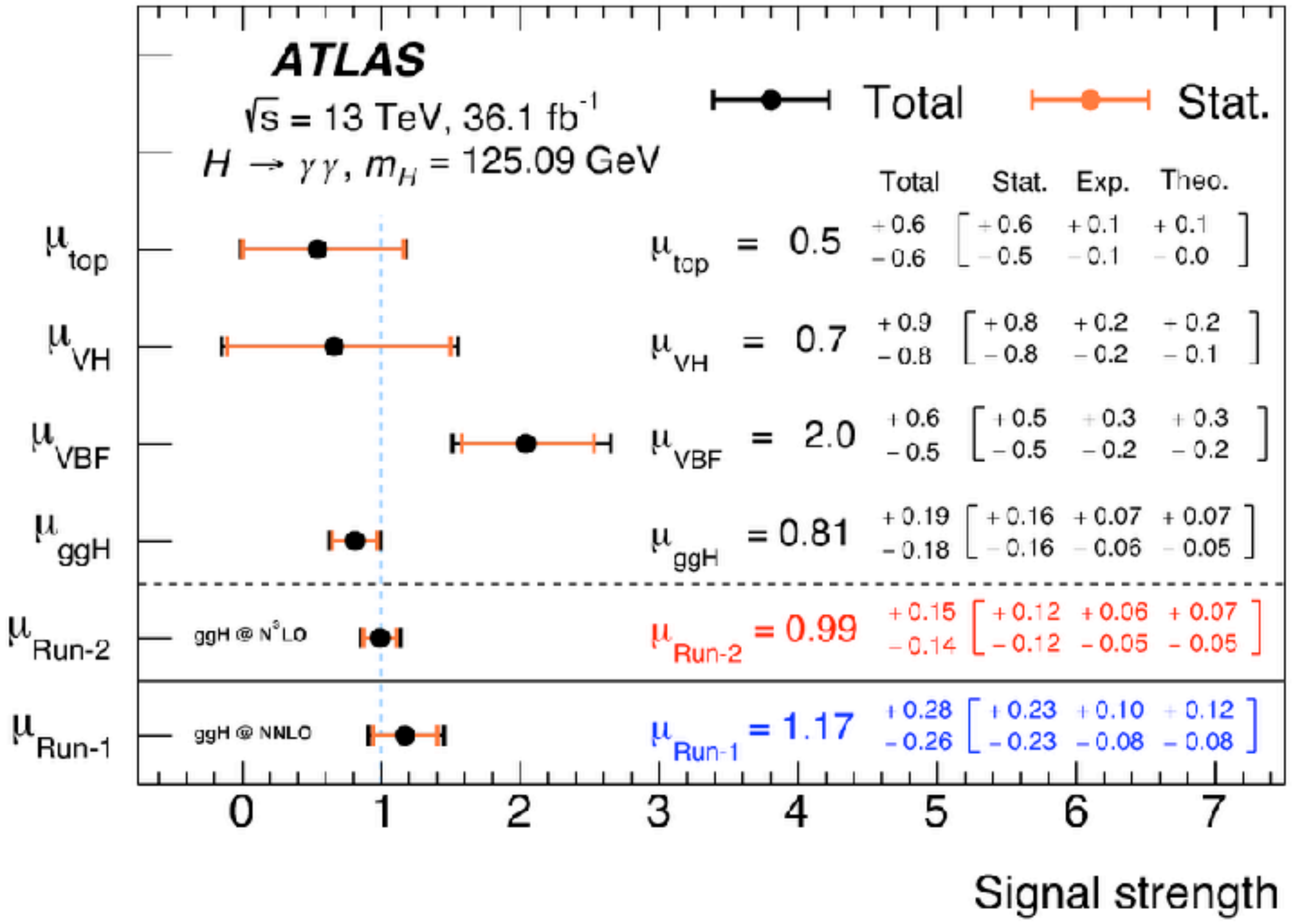
Fiducial cross section show a small upward fluctuation (mostly driven by fluctuations in 2e2μ)

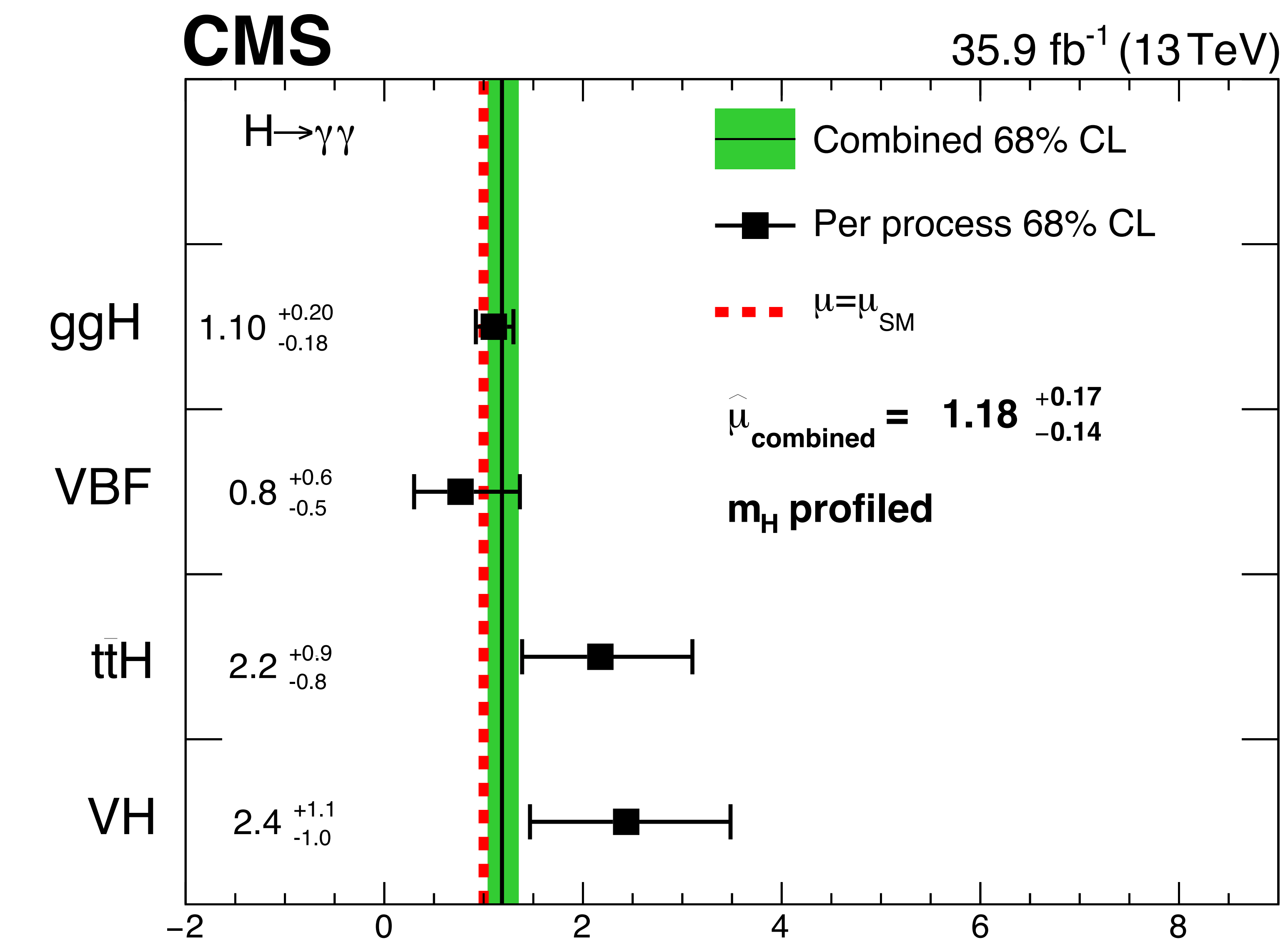
no ttH event observed yet

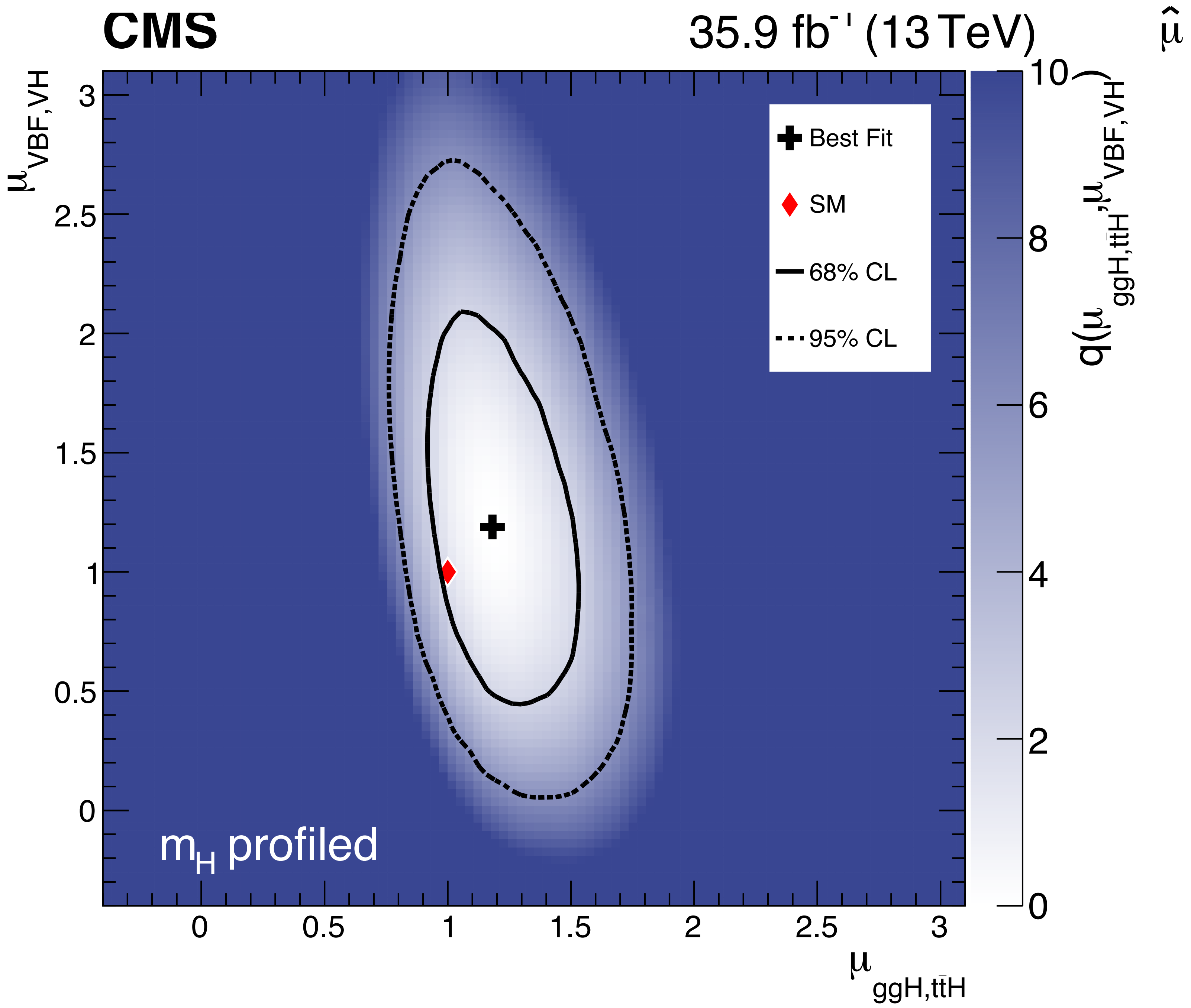


H→γγ, signal strengths

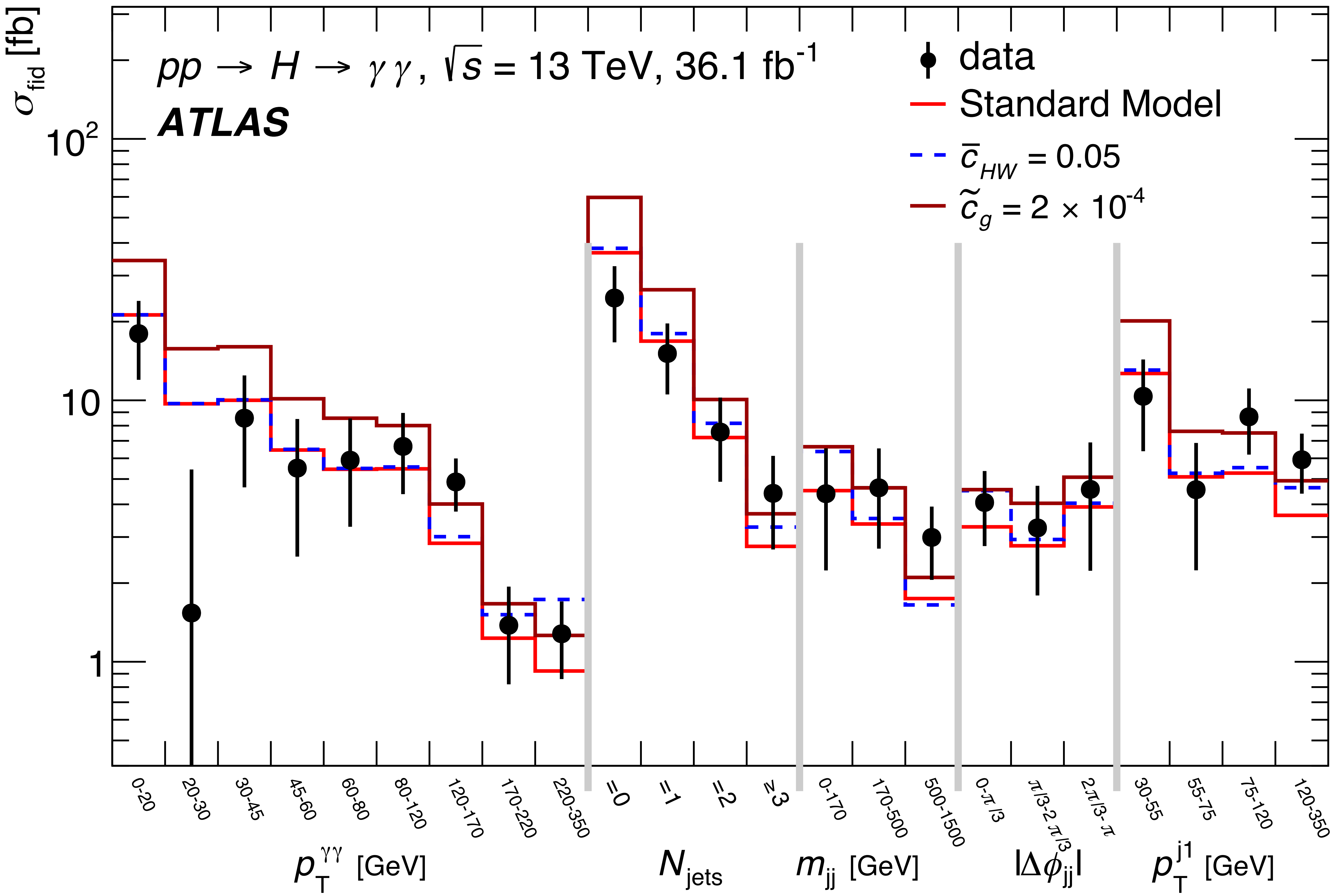


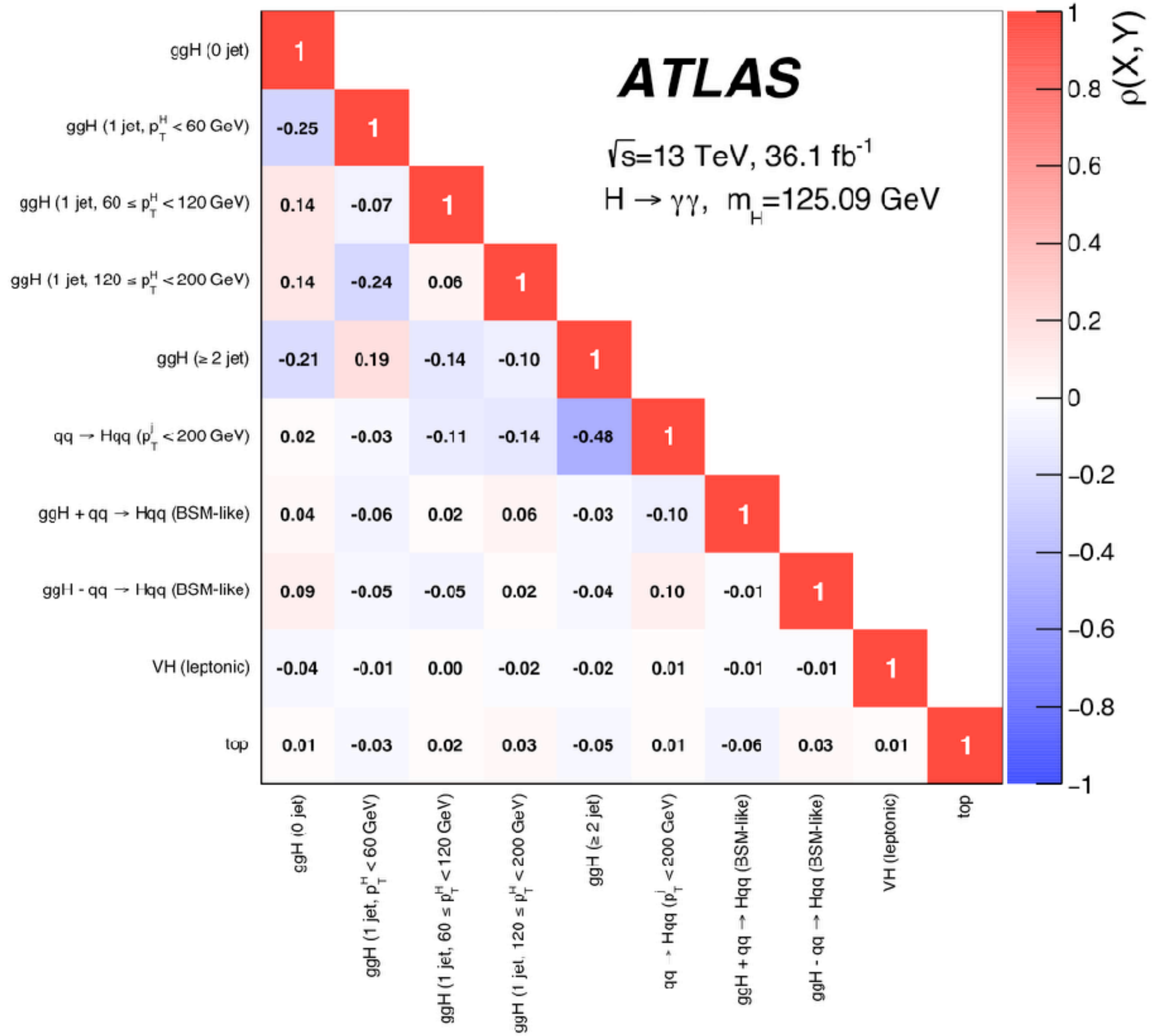






H→γγ, Cross sections





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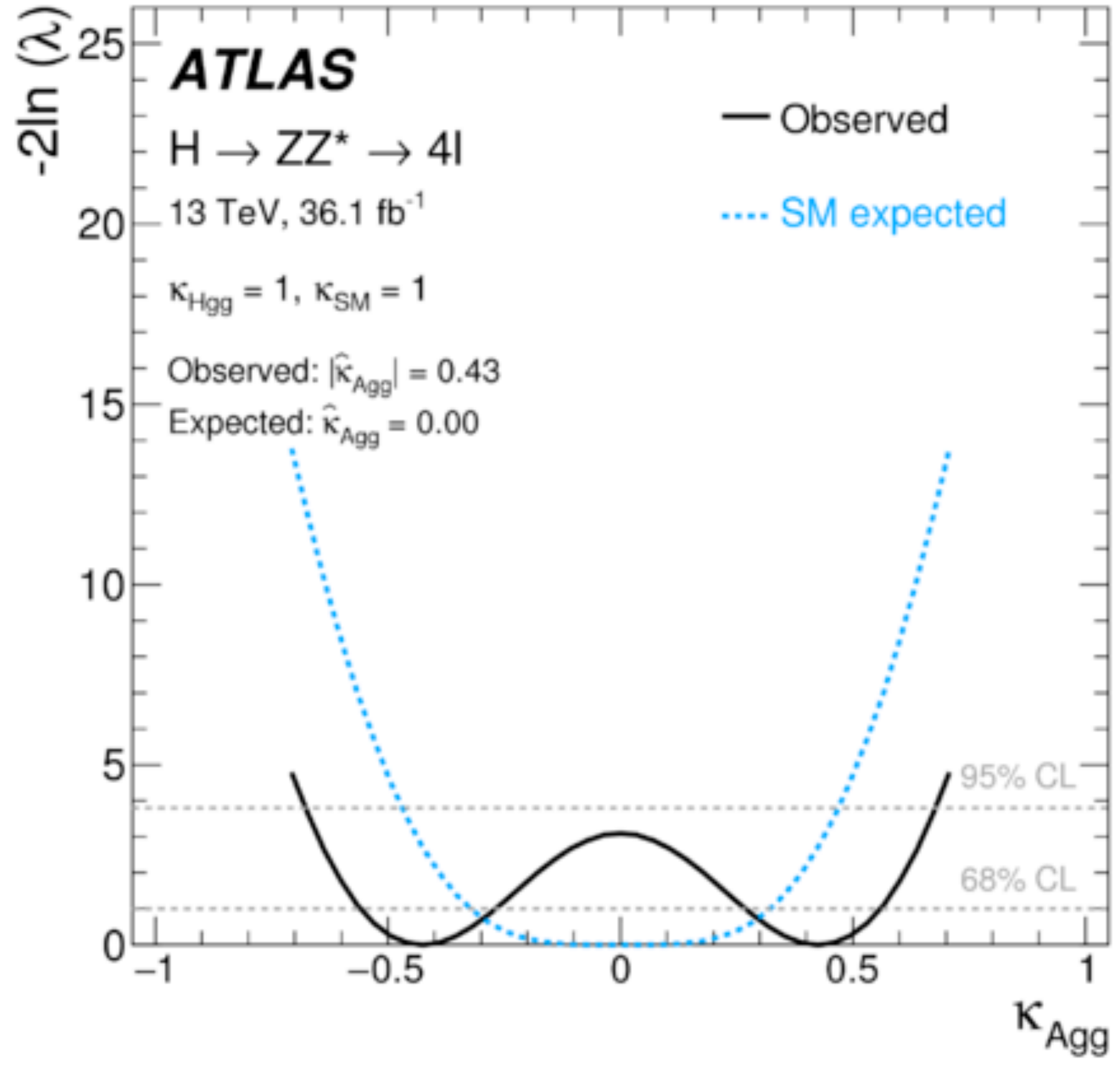
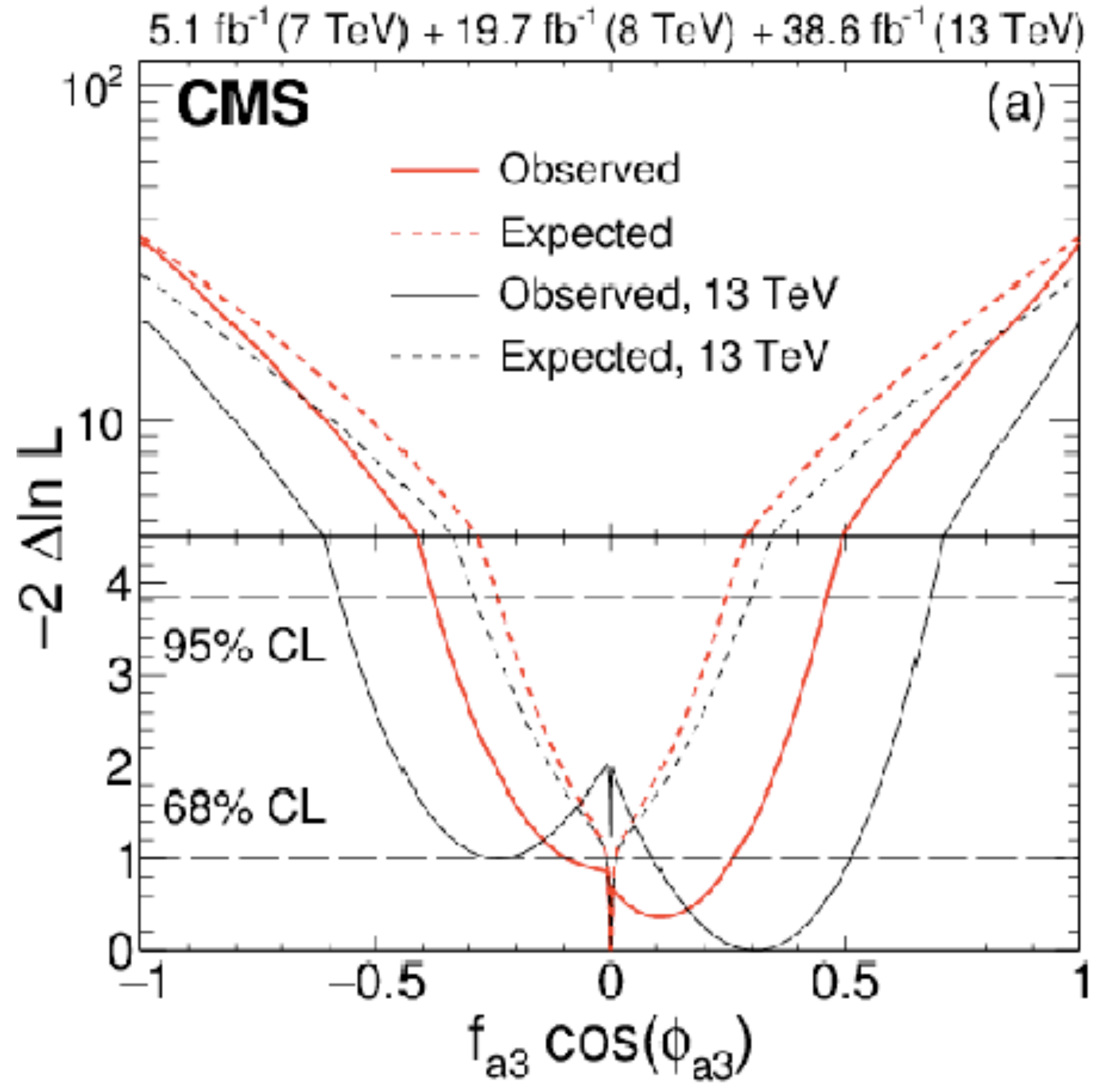
HVV Tensor Structure





Expanded HVV amplitude to include anomalous coupling in the tensor structure.

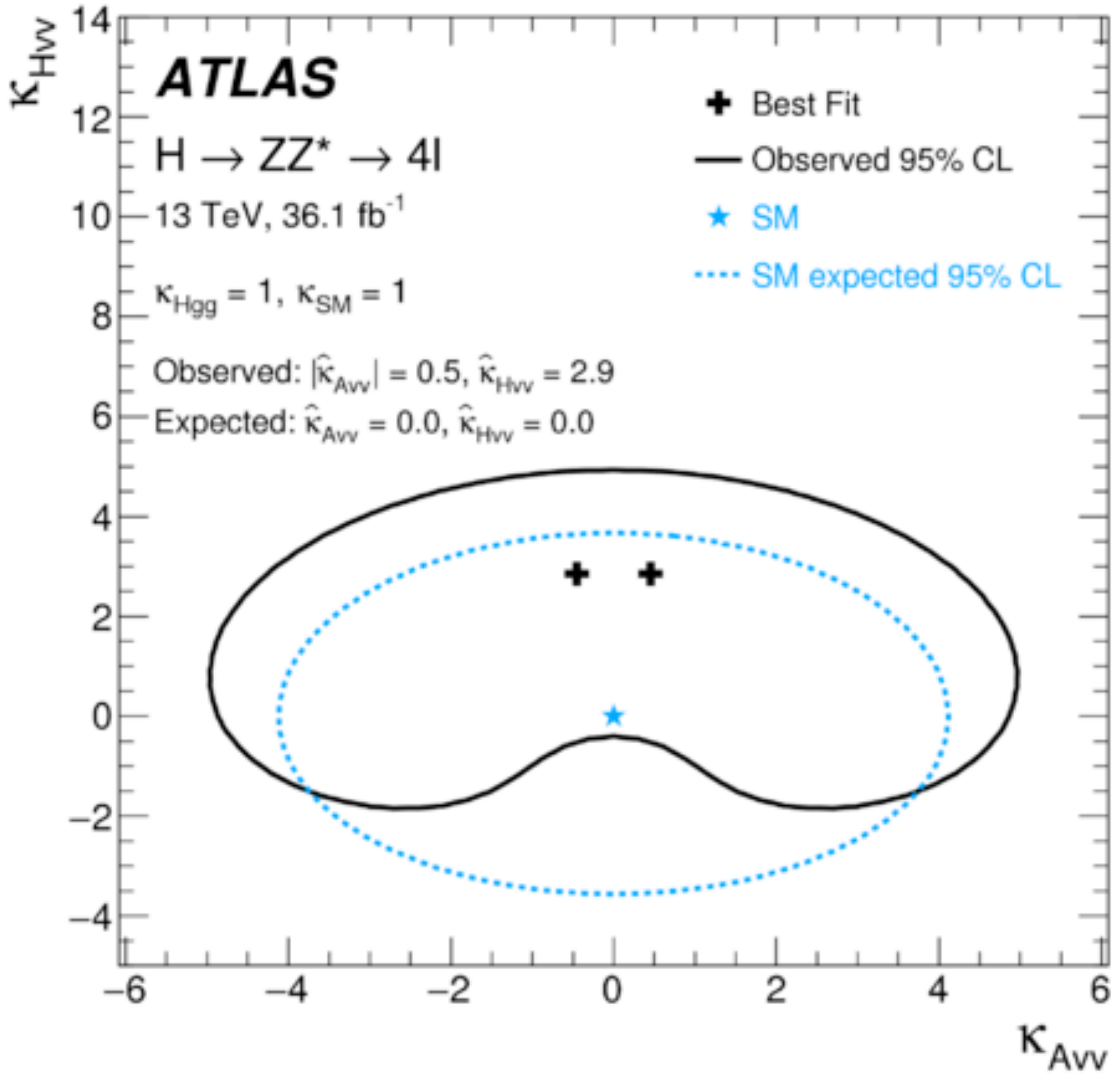
CMS:

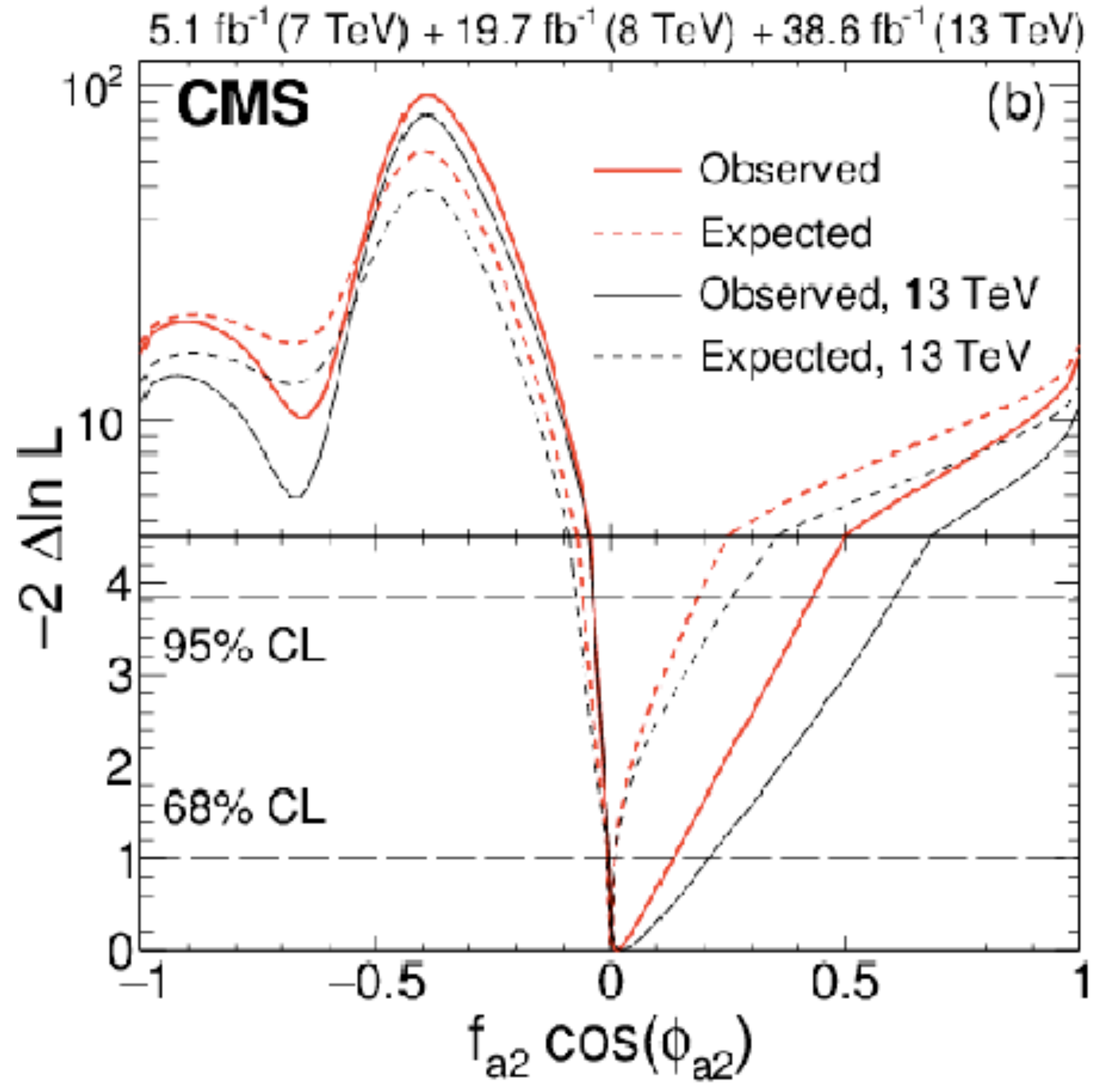
$$f_{a3} = \frac{|a_3|^2\sigma_3}{|a_1|^2\sigma_1 + |a_2|^2\sigma_2 + |a_3|^2\sigma_3 + \tilde{\sigma}_{\Lambda 1}/(\Lambda_1)^4 + \ldots}, \qquad \phi_{a3} = \arg\left(\frac{a_3}{a_1}\right),$$

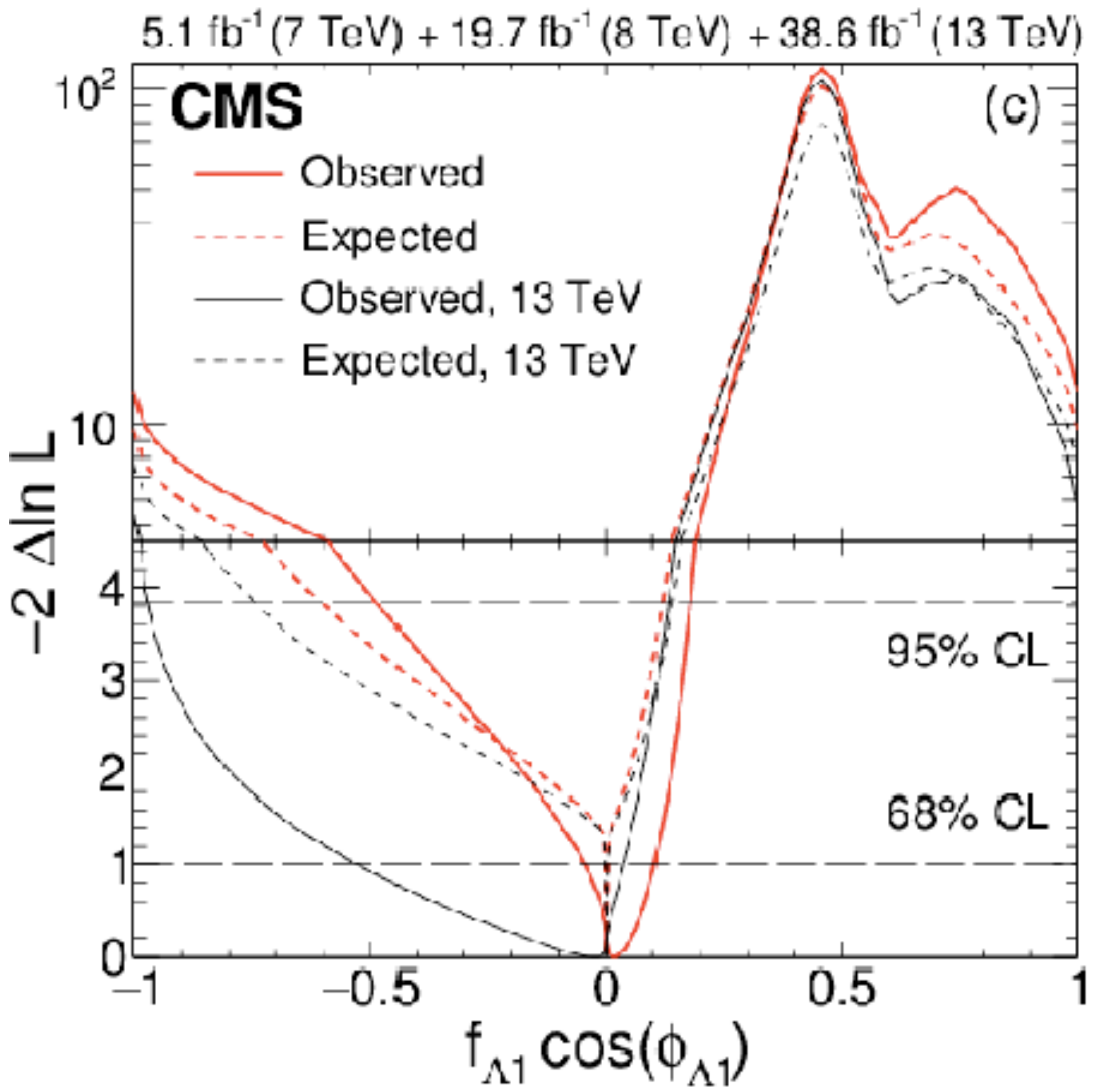
$$f_{a2} = \frac{|a_2|^2\sigma_2}{|a_1|^2\sigma_1 + |a_2|^2\sigma_2 + |a_3|^2\sigma_3 + \tilde{\sigma}_{\Lambda 1}/(\Lambda_1)^4 + \ldots}, \qquad \phi_{a2} = \arg\left(\frac{a_2}{a_1}\right),$$

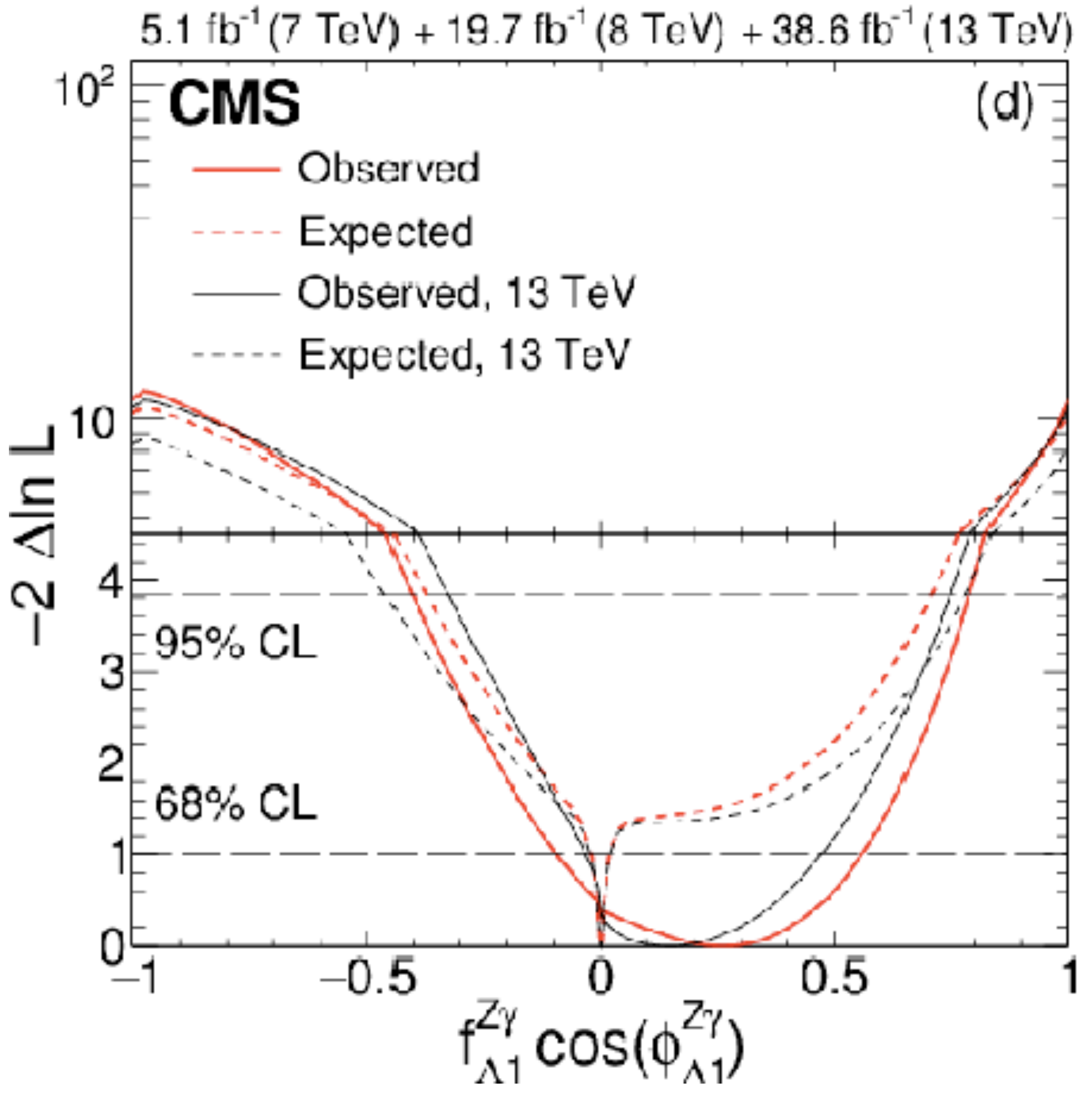
$$f_{\Lambda 1} = \frac{\tilde{\sigma}_{\Lambda 1}/(\Lambda_1)^4}{|a_1|^2\sigma_1 + |a_2|^2\sigma_2 + |a_3|^2\sigma_3 + \tilde{\sigma}_{\Lambda 1}/(\Lambda_1)^4 + \ldots}, \qquad \phi_{\Lambda 1},$$

ATLAS: morphing function to introduce anomalous couplings in the signal model

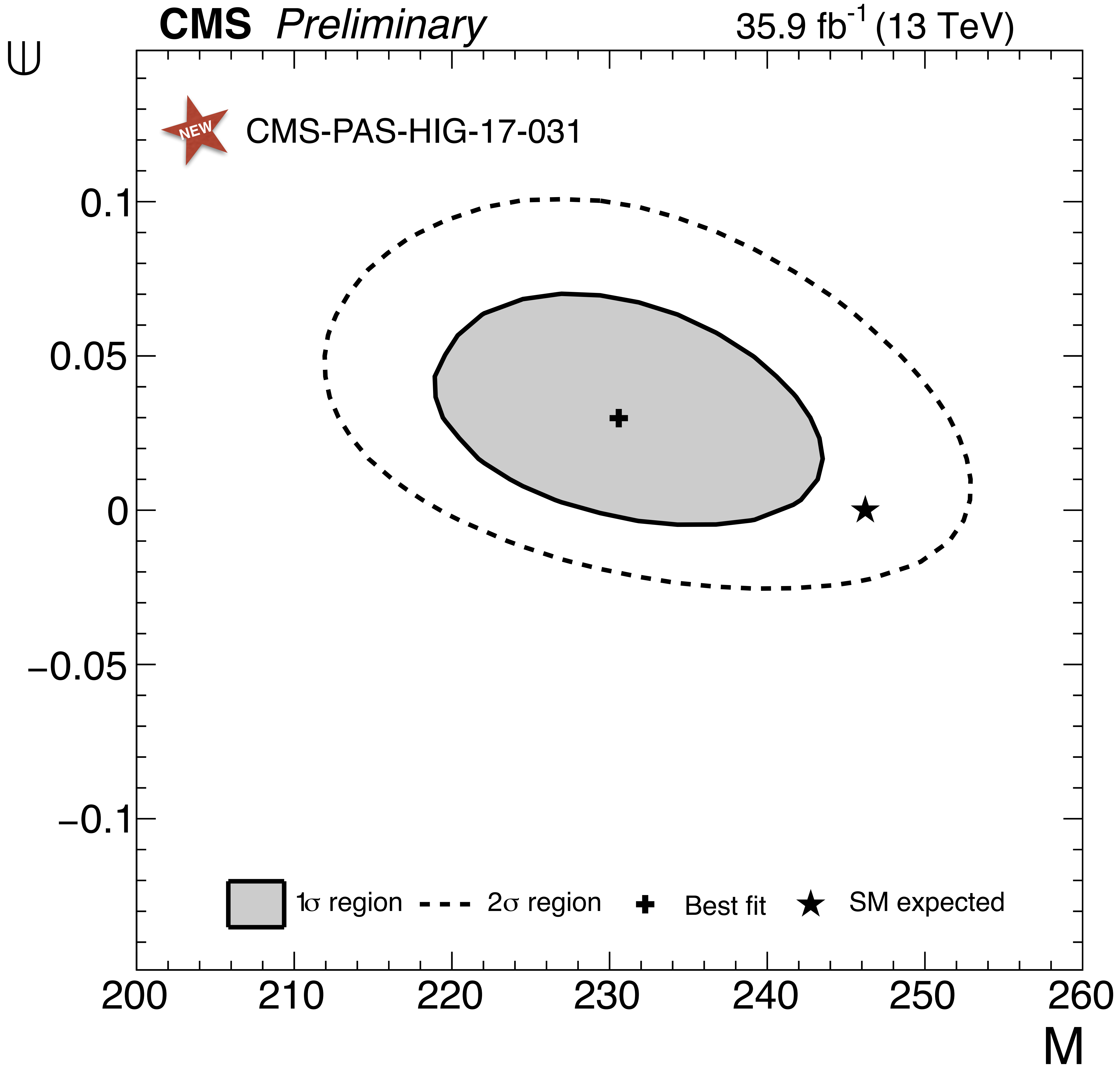


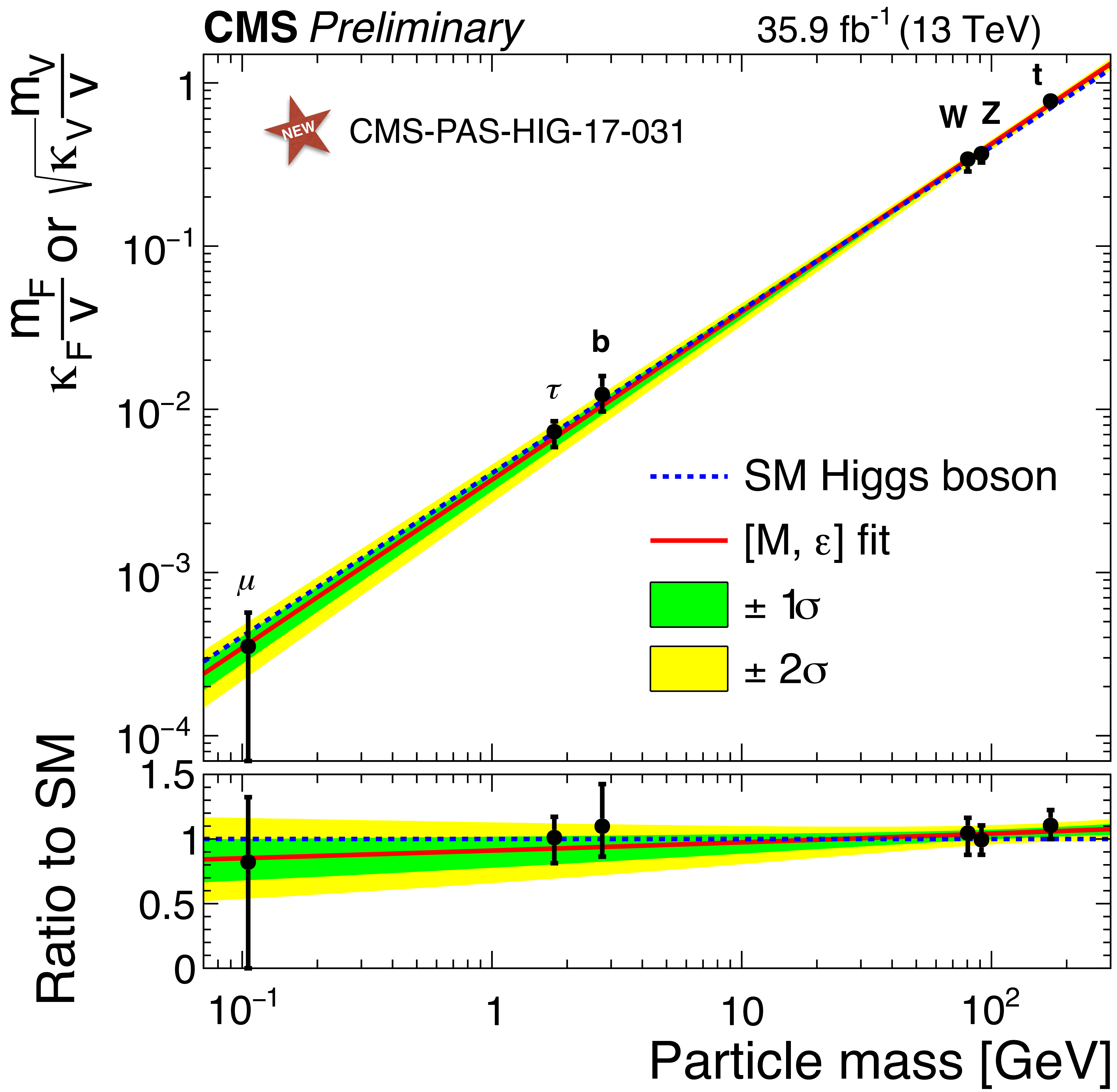






Combinations





H→ZZ


CMS Experiment at LHC, CERN
Data recorded: Sun Jun 25 16:21:14 2017 CEST
Run/Event: 297486 / 804651304
Lumi section: 503
CMS

H→WW


Longitudinal View
muon
electron
jet
MET
jet
Projected η-φ view
E_T [GeV]
75
65
55
45
35
25
15
5
4
2
0
-2
-4
η
0°
90°
180°
270°
360°
φ
ATLAS
EXPERIMENT
Run Number: 280673, Event Number: 2811124938
September 30, 2015, 05:55:03 CEST


CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000
H→γγ