Combination of the Higgs boson main property measurements using the ATLAS detector

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on behalf of the ATLAS Collaboration

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Outline

Main Higgs boson properties studied at ATLAS

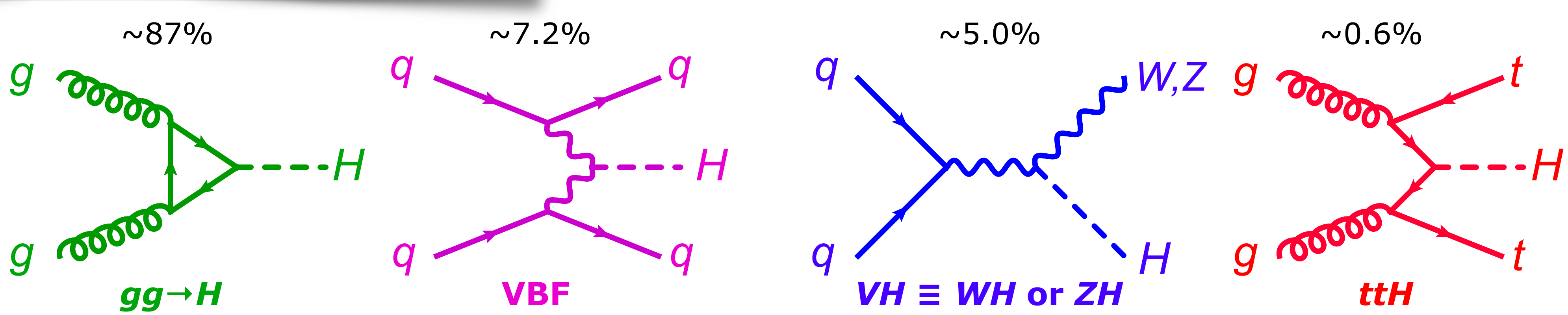
I. **mass** - *New! June 2014*
main talk by Robert Harrington

II. **production rate & couplings** to other particles
main focus of this presentation

III. **spin and parity**
main talk by Kirill Prokofiev

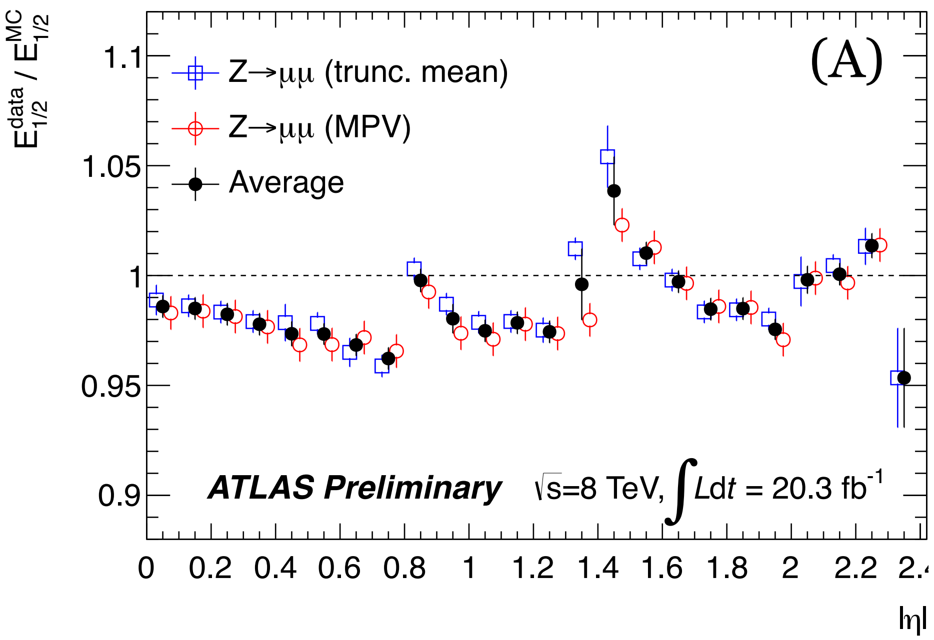
IV. **fiducial/differential cross sections**, kinematic properties; associated jet activity; BSM …
see talks by S. Laplace, G. Sciolla

coupling and spin results (II and III) not yet updated with new calibration/mass

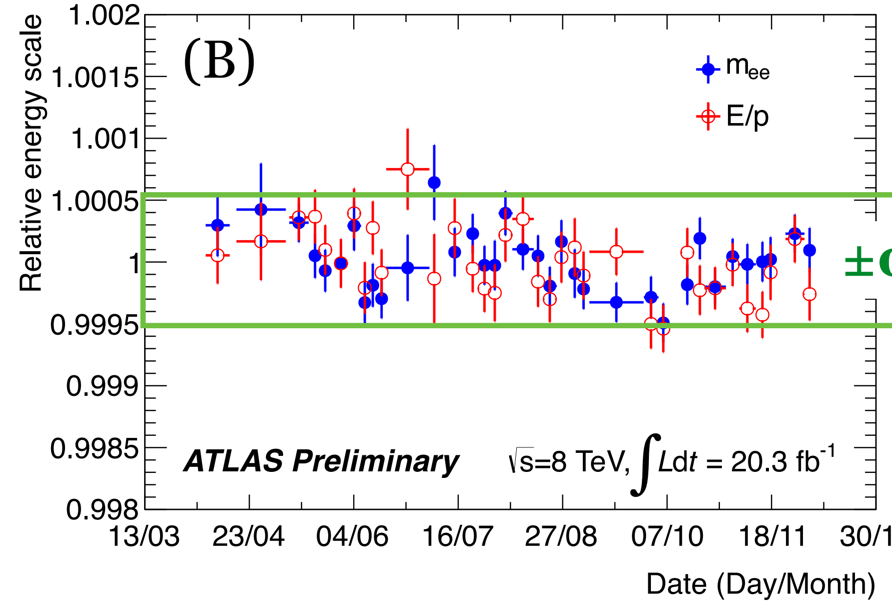


Higgs boson mass

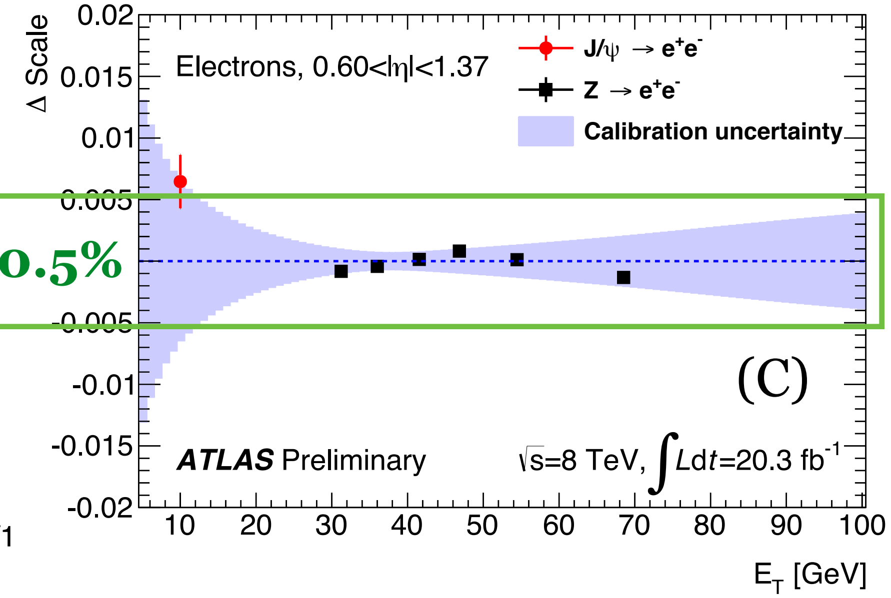
Calorimeter layer intercalibration



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:**

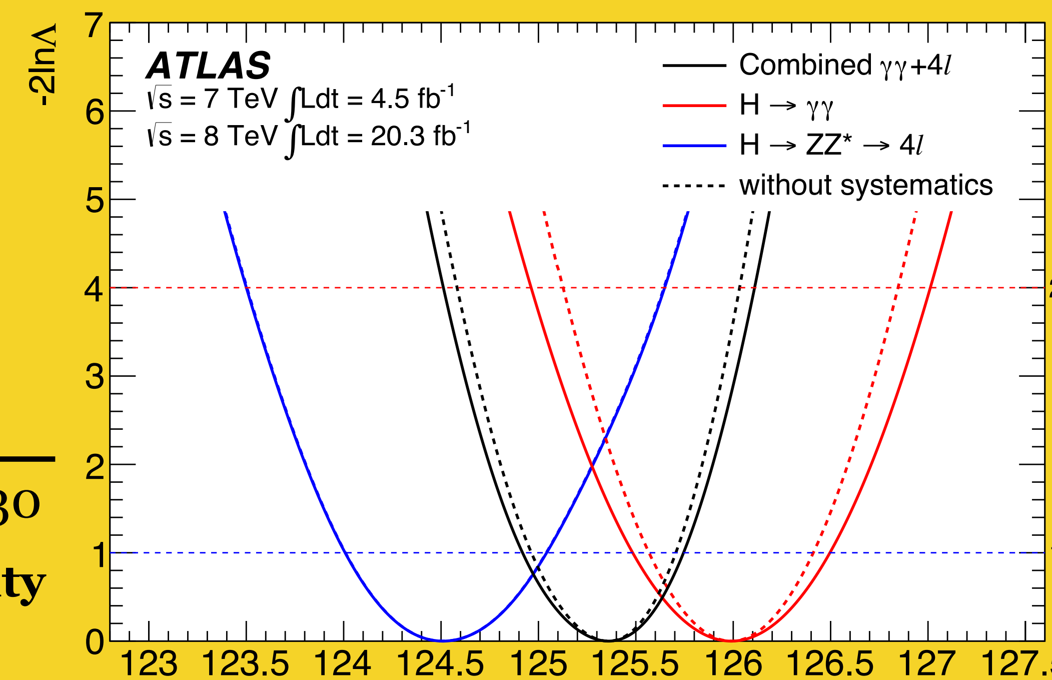
[GeV]	sys	stat
old	0.6	0.24
new	0.21	0.37

- ***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)

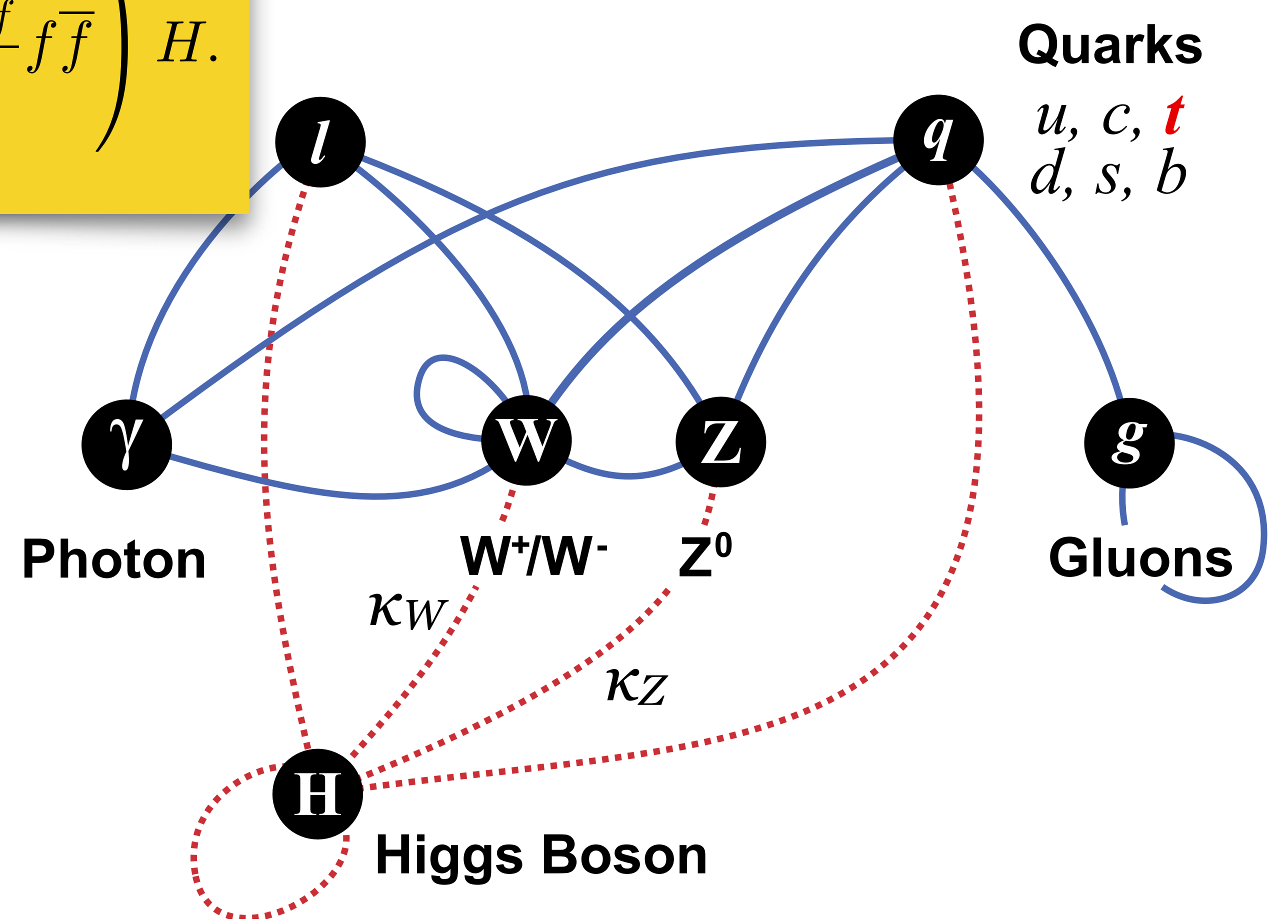
Higgs couplings

- Search for deviations from the SM Higgs coupling to other particles by introducing multipliers using a **tree-level motivated benchmark model** following the LHC Higgs XS WG recommendations: 1209.0040

$$
\begin{aligned}
\mathcal{L} = & \kappa_3 \frac{m_H^2}{2v} H^3 + \kappa_Z \frac{m_Z^2}{v} Z_\mu Z^\mu H + \kappa_W \frac{2m_W^2}{v} W_\mu^+ W^{-\mu} H \\
& + \kappa_g \frac{\alpha_s}{12\pi v} G_{\mu\nu}^a G^{a\mu\nu} H + \kappa_\gamma \frac{\alpha}{2\pi v} A_{\mu\nu} A^{\mu\nu} H + \kappa_{Z\gamma} \frac{\alpha}{\pi v} A_{\mu\nu} Z^{\mu\nu} H \\
& + \kappa_{VV} \frac{\alpha}{2\pi v} \left(\cos^2\theta_W Z_{\mu\nu} Z^{\mu\nu} + 2\, W_{\mu\nu}^+ W^{-\mu\nu}\right) H \\
& - \left(\kappa_t \sum_{f=u,c,t} \frac{m_f}{v} f\overline{f} + \kappa_b \sum_{f=d,s,b} \frac{m_f}{v} f\overline{f} + \kappa_\tau \sum_{f=e,\mu,\tau} \frac{m_f}{v} f\overline{f} \right) H.
\end{aligned}
$$

Effective Lagrangian describing the Higgs couplings in unitarity gauge

Status of Higgs boson physics (PDG), page 62



Higgs couplings

- Search for deviations from the SM Higgs coupling to other particles by introducing multipliers using a **tree-level motivated benchmark model** following the LHC Higgs XS WG recommendations: 1209.0040
- Assumptions:
  - Single, narrow, CP-even scalar resonance
    (tensor structure of couplings assumed to be those of the SM)
  - Narrow width approximation is valid:

$$\sigma\mathcal{B}(i \to H \to f) = \frac{\sigma_i \Gamma_f}{\Gamma_H}$$

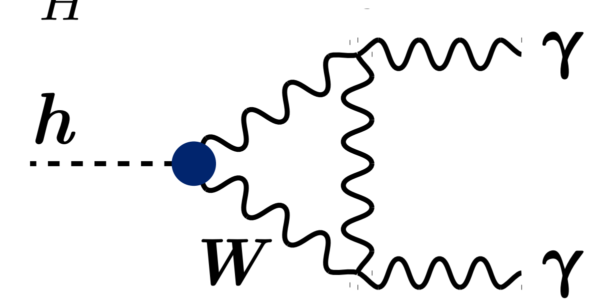
Example:

$$\sigma\mathcal{B}(gg \to H \to \gamma\gamma) = \frac{\sigma_{\mathrm{ggF}}\Gamma_{H\to\gamma\gamma}}{\Gamma_H}$$

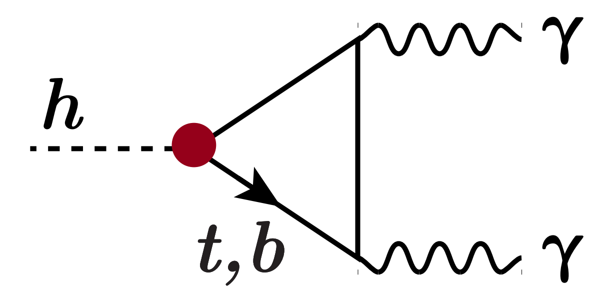
- Deviations from SM parametrized using multipliers **$\boldsymbol{\kappa}$**, e.g.

$$\sigma\mathcal{B}(gg \to H \to \gamma\gamma) = (\sigma_{\mathrm{ggF}}\mathcal{B})_{\mathrm{SM}}(gg \to H \to \gamma\gamma) \times \frac{\kappa_g^2 \kappa_\gamma^2}{\kappa_H^2}$$

where κ_g and κ_γ are effective multipliers since the Higgs boson does not directly couple to these particles,
but via loops that contains interference:

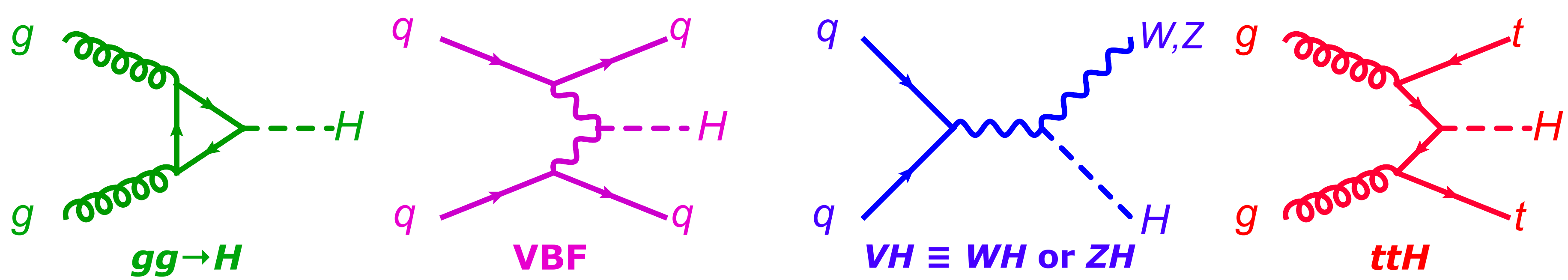


$$\kappa_\gamma^2 = 1.59\kappa_W^2 - 0.66\kappa_W\kappa_t + 0.07\kappa_t^2$$

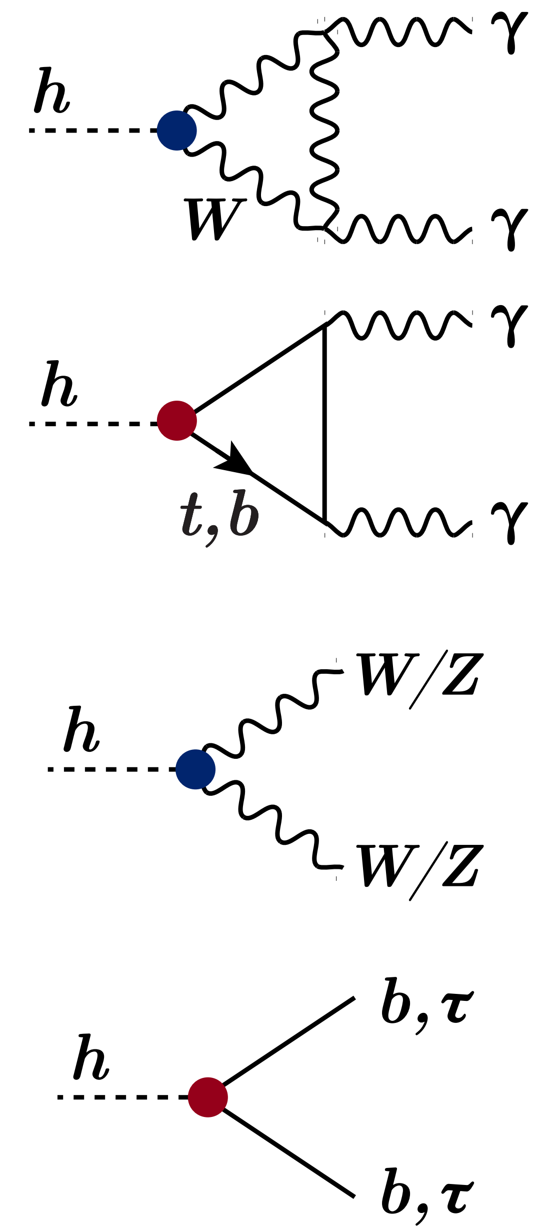


these relations are modified if non-SM particles enter the loop

Higgs couplings



Decays



- Parameters of interest
  - **Signal strength $\mu = \sigma_{\text{measured}}/\sigma_{\text{SM}}$**
    multiplier for total yield.
    Can also be defined for each production mode, e.g.:
    $\mu_{\text{VBF}} = \sigma_{\text{VBF,measured}} / \sigma_{\text{VBF,SM}}$
  - **Multiplier κ for a given coupling**
    e.g. κ_t for the Higgs-top quark coupling, or κ_F for general Higgs-fermion coupling
    - Different types of models tested by imposing different relations between kappas
- In both cases, **SM has: $\mu \equiv 1$ and $\kappa \equiv 1$**
  Deviations from unity indicate non-SM Higgs couplings

Note: κ allows for more direct accesses to coupling as μ contain complex interplay between production and decay

Datasets and analysis strategy

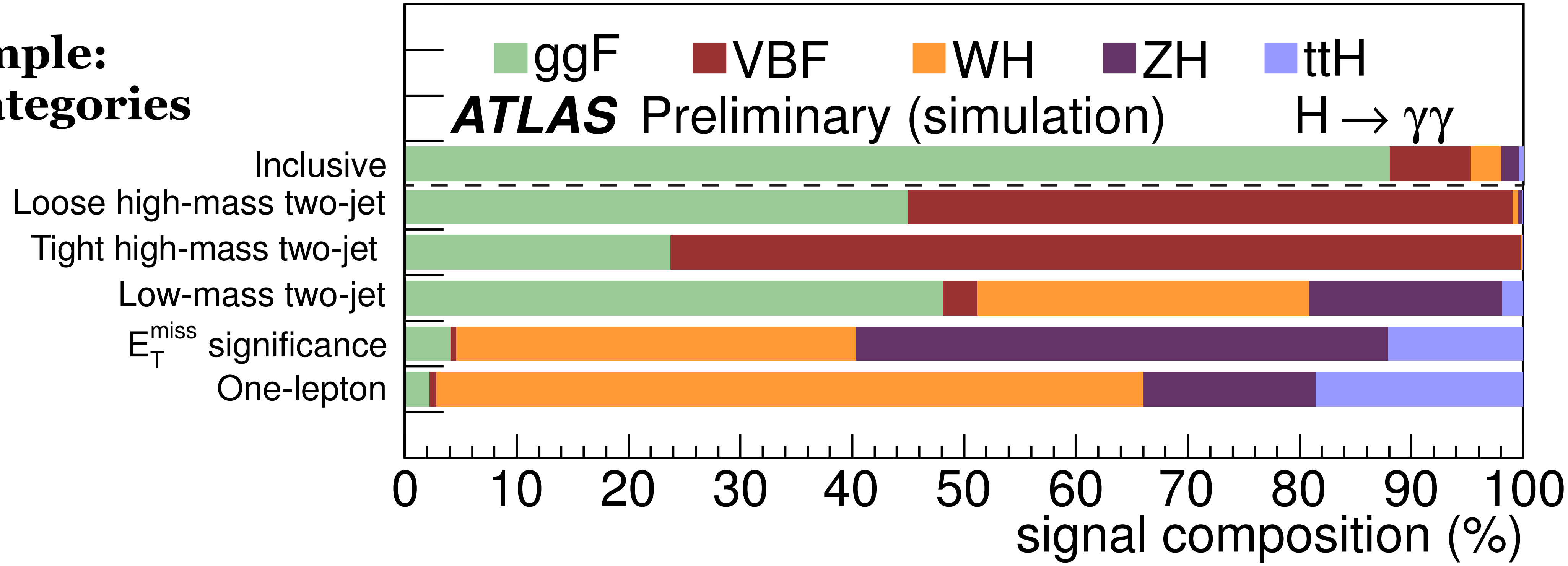
- **Combine** ATLAS Higgs measurements from **5 different channels** *γγ, ZZ, WW, bb, τ τ*
- Each analysis is **further divided into categories** that increases sensitivity:
  → different *s/b* and production mode/decay compositions
  → allows to extract Higgs couplings to different particles
- Parameter(s) of interest extracted by simultaneous maximal likelihood fit

channel	decay	categories	$\mathcal{L}$ [fb^{-1}]
$H \to \gamma\gamma$	-	low/high p_{Tt}, VBF, ℓ, $E_{\mathrm{T}}^{\mathrm{miss}}$	4.8+20.3
$H \to ZZ^*$	4ℓ	ℓ, VBF	4.6+20.3
$H \to WW*$	$\ell\nu\ell\nu$	0, 1, $\geq$ 2 jets, VBF	4.6+20.3
$VH \to Vb\bar{b}$	$Z \to \nu\nu$, $W \to \ell\nu$, $Z \to \ell\ell$	-	4.6+20.3
$H \to \tau\tau$	$\ell\ell$, ℓ-had, had-had	boosted, VBF	20.3

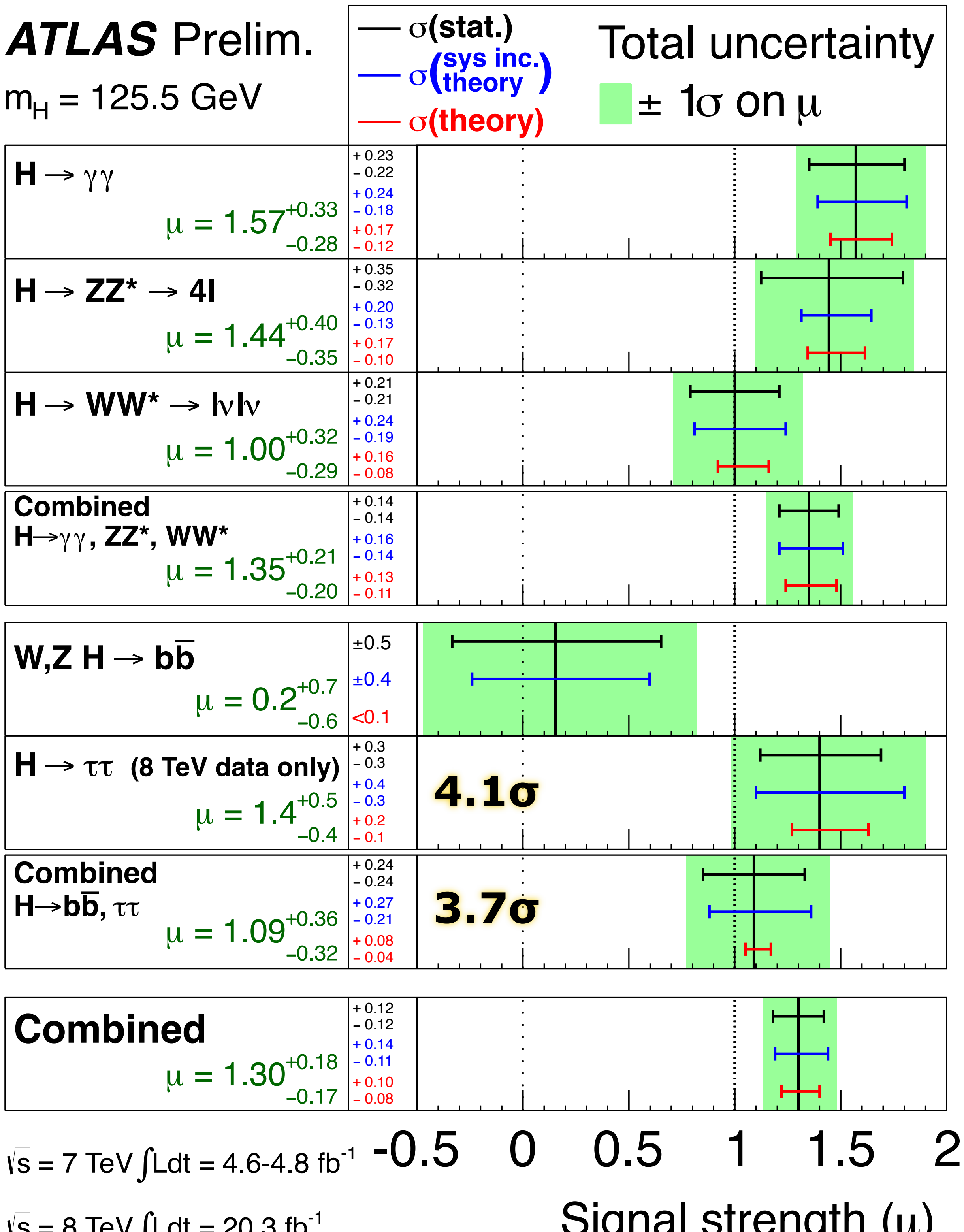
Example:
***H→γγ* categories**

VBF categories:
large fraction of VBF

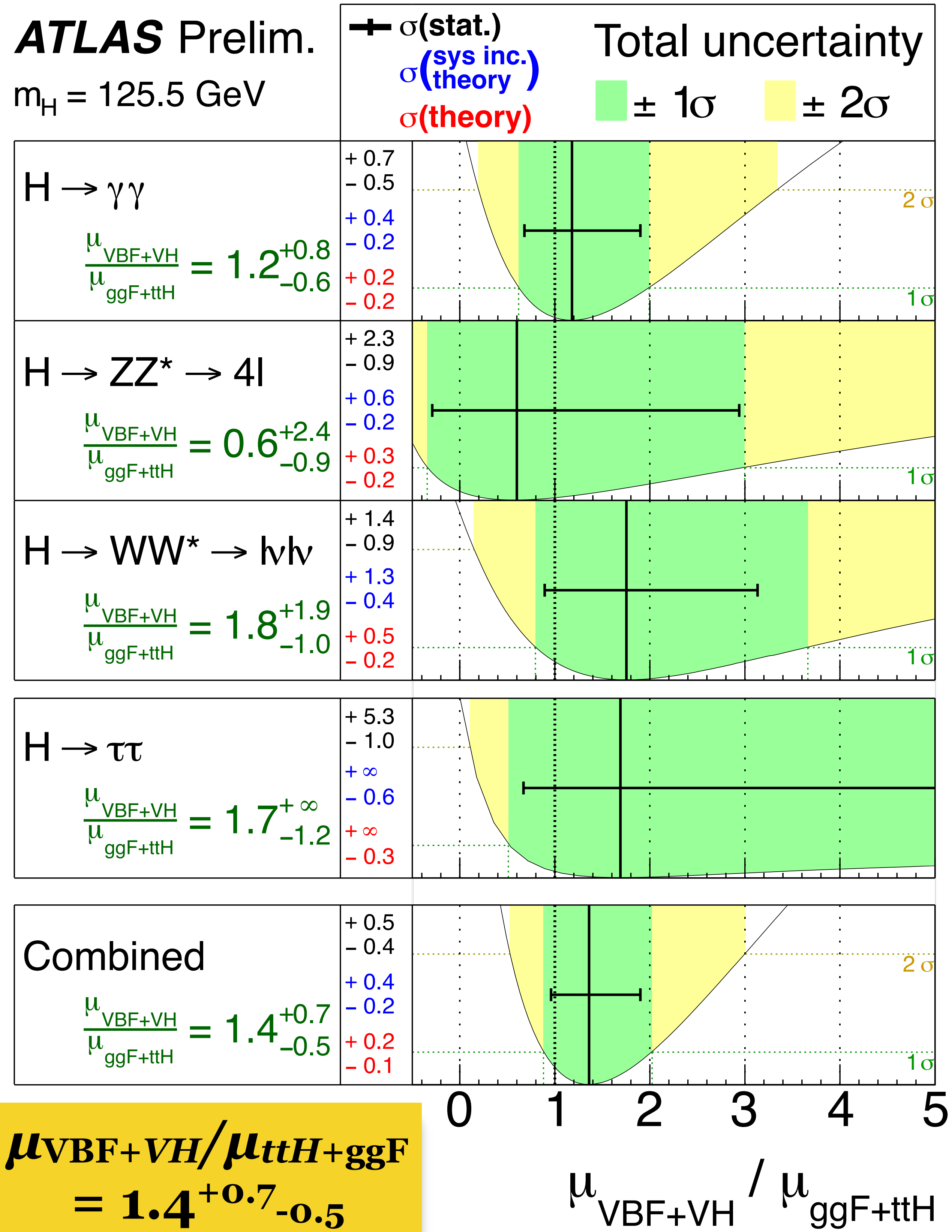
low-*m*$_{jj}$, *E*$_{\mathrm{T}}$$^{\mathrm{miss}}$ and lepton categories:
large fraction of *WH*



Combined signal strength



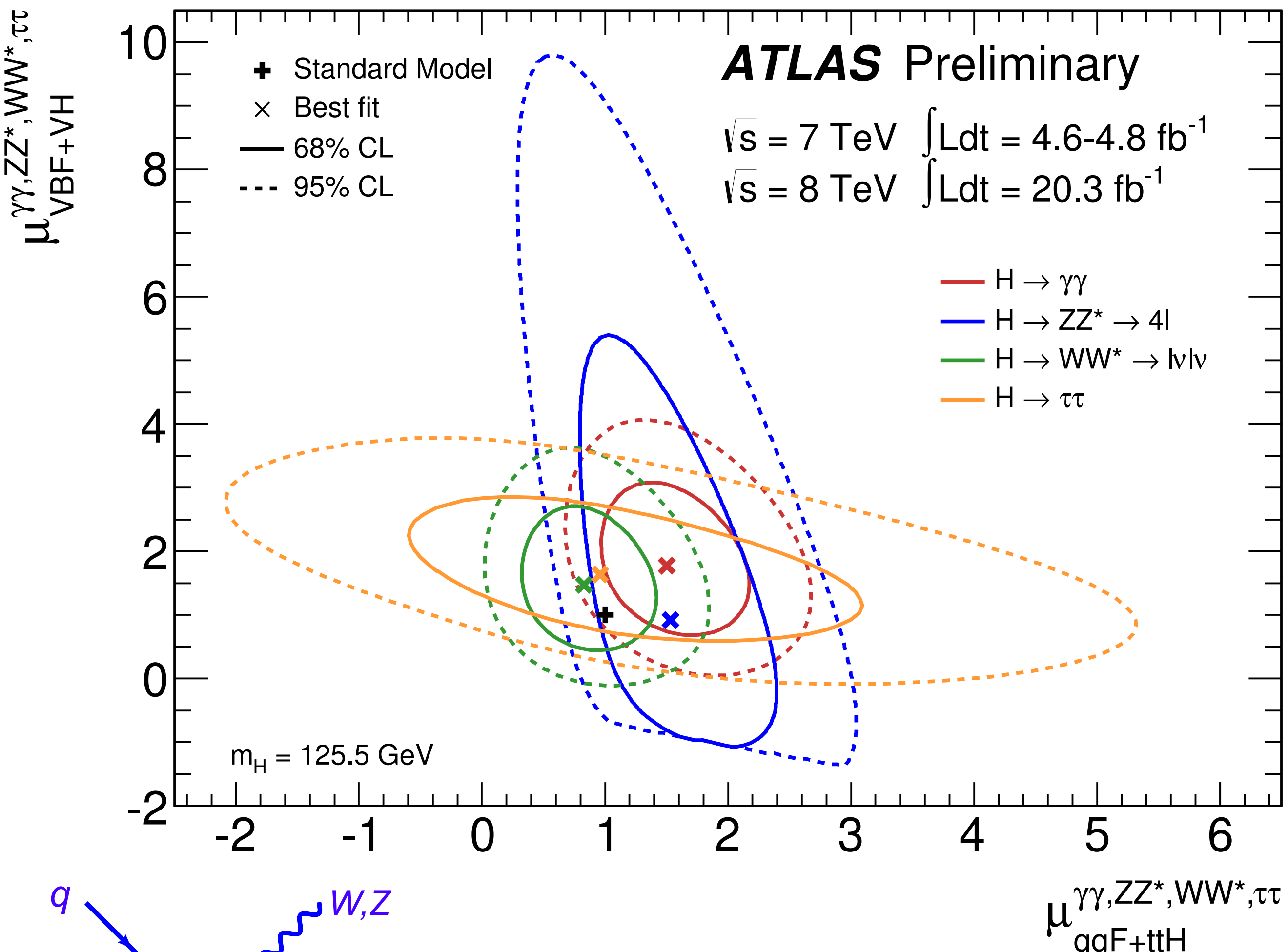
Combined $\mu = 1.30^{+0.18}_{-0.17}$



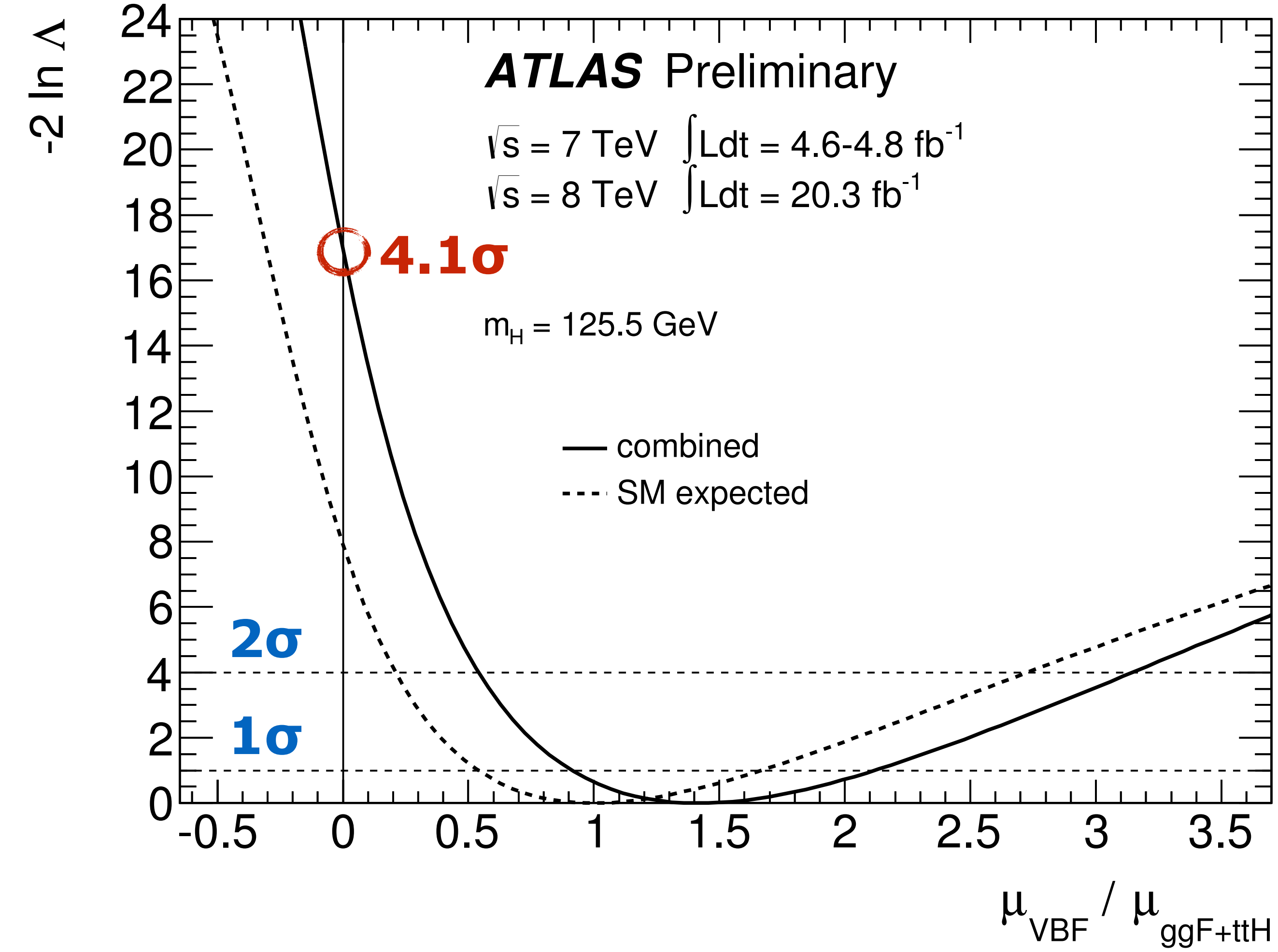
$\mu_{VBF+VH}/\mu_{ttH+ggF} = 1.4^{+0.7}_{-0.5}$

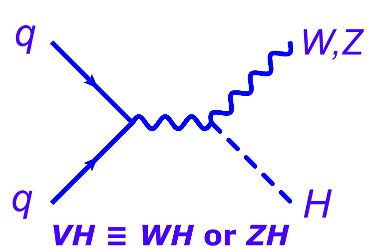
Evidence for VBF Higgs production

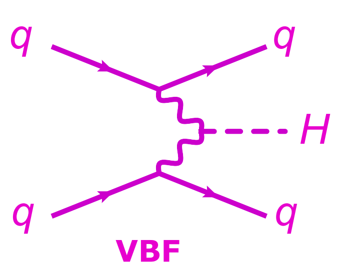
Split between Higgs production via vector bosons vs quark-loop



Higgs production via **vector boson fusion** vs quark-loop





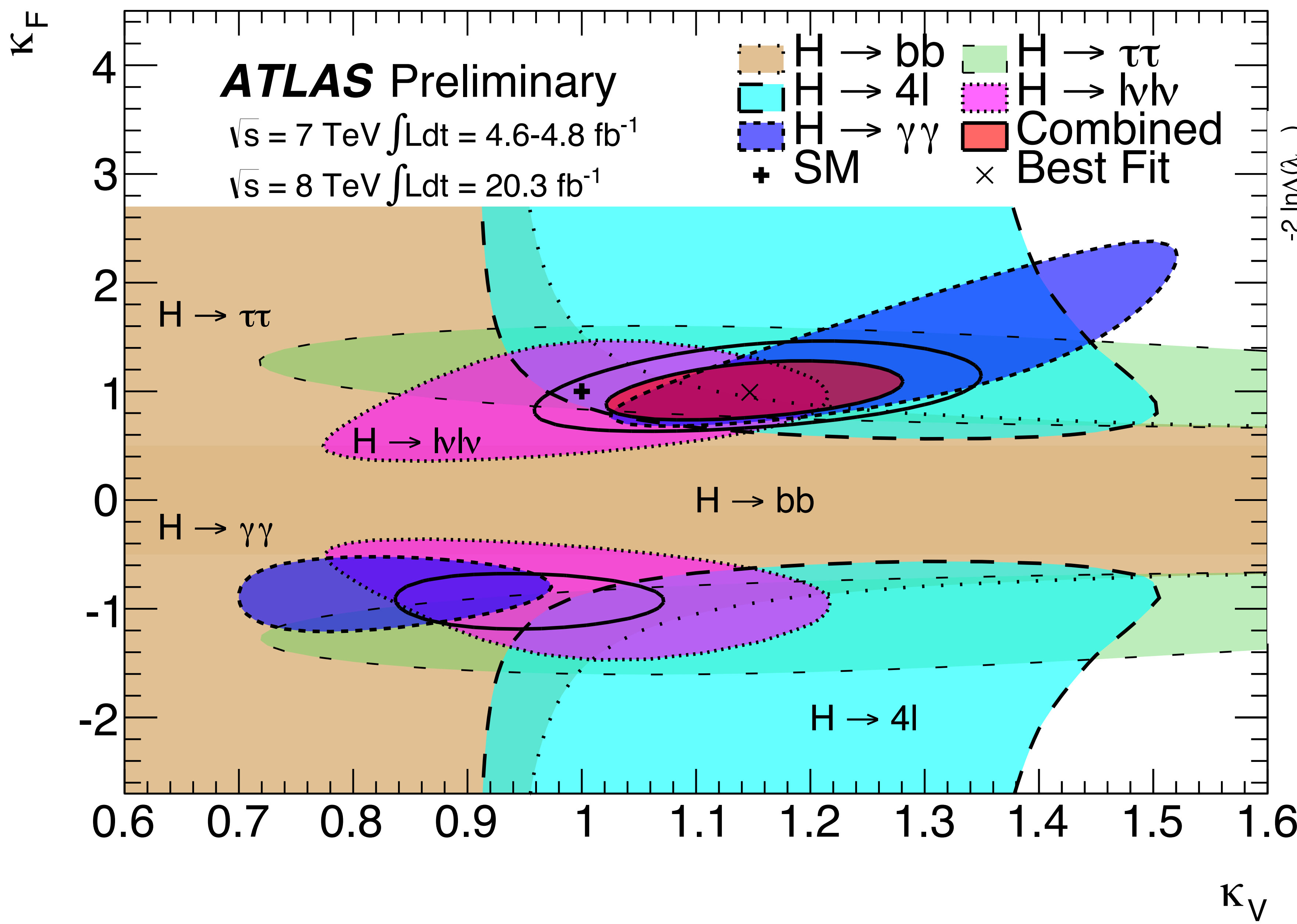


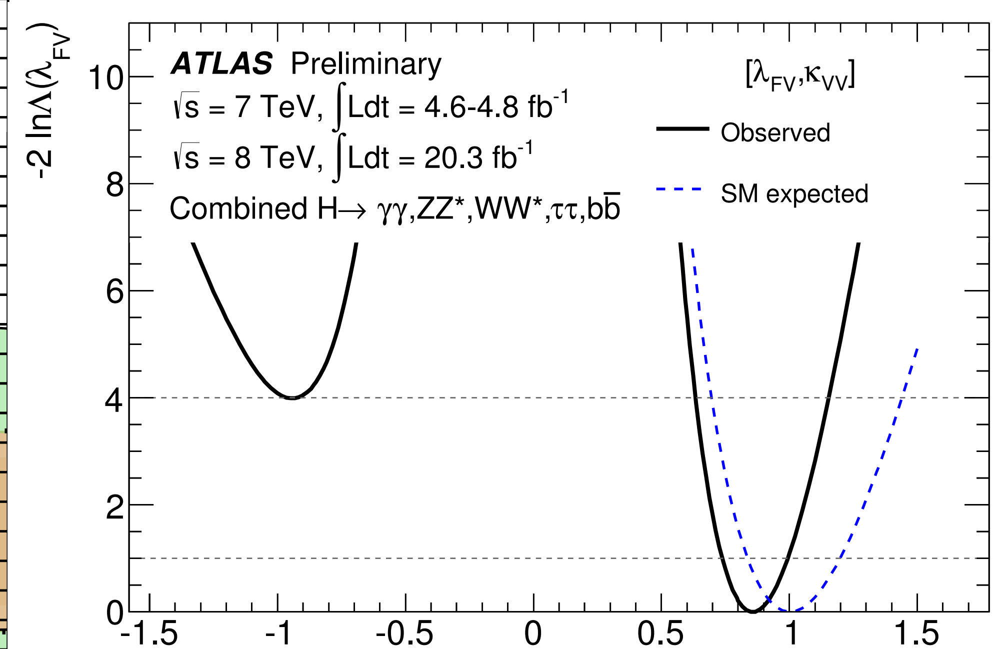
Coupling ratio for VBF production only: $\mu_{\mathrm{VBF}}/\mu_{\mathrm{ggF+ttH}} = 1.4^{+0.5\,+0.4}_{-0.4\,-0.3}$

$\rightarrow$ Evidence at 4.1σ for VBF production!

Fermion vs vector couplings

- One multiplier for the Higgs coupling to fermions: $\boldsymbol{\kappa_F = \kappa_b = \kappa_t = \kappa_\tau}$
- One multiplier for the Higgs coupling to vector bosons: $\boldsymbol{\kappa_V = \kappa_W = \kappa_Z}$
- Assumes no new particles coupling to the Higgs in loops or decays





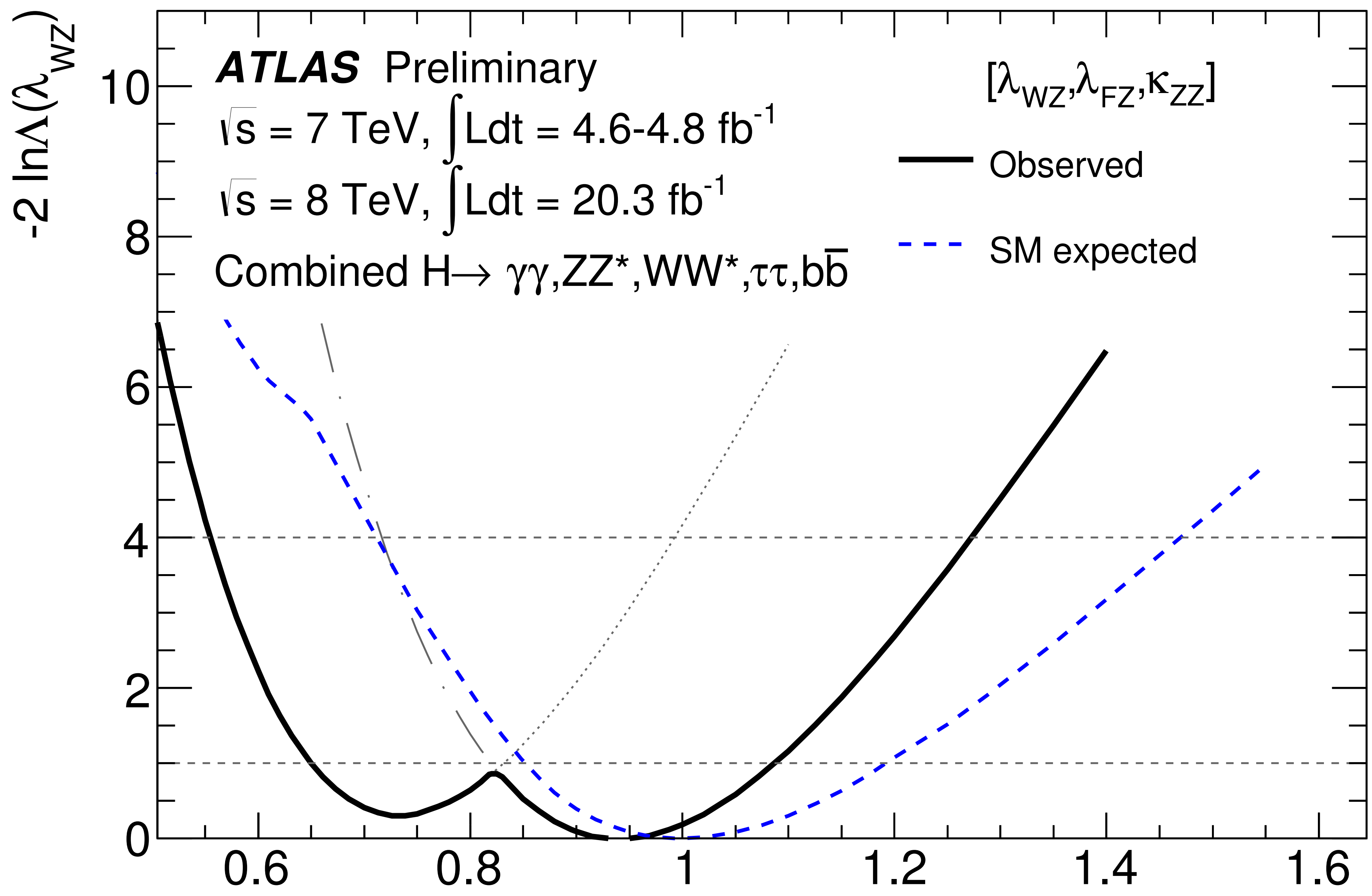
$\boldsymbol{\lambda_{FV} = \kappa_F / \kappa_V}$'

Consistent with SM expectation

p-value = 0.10

Custodial symmetry

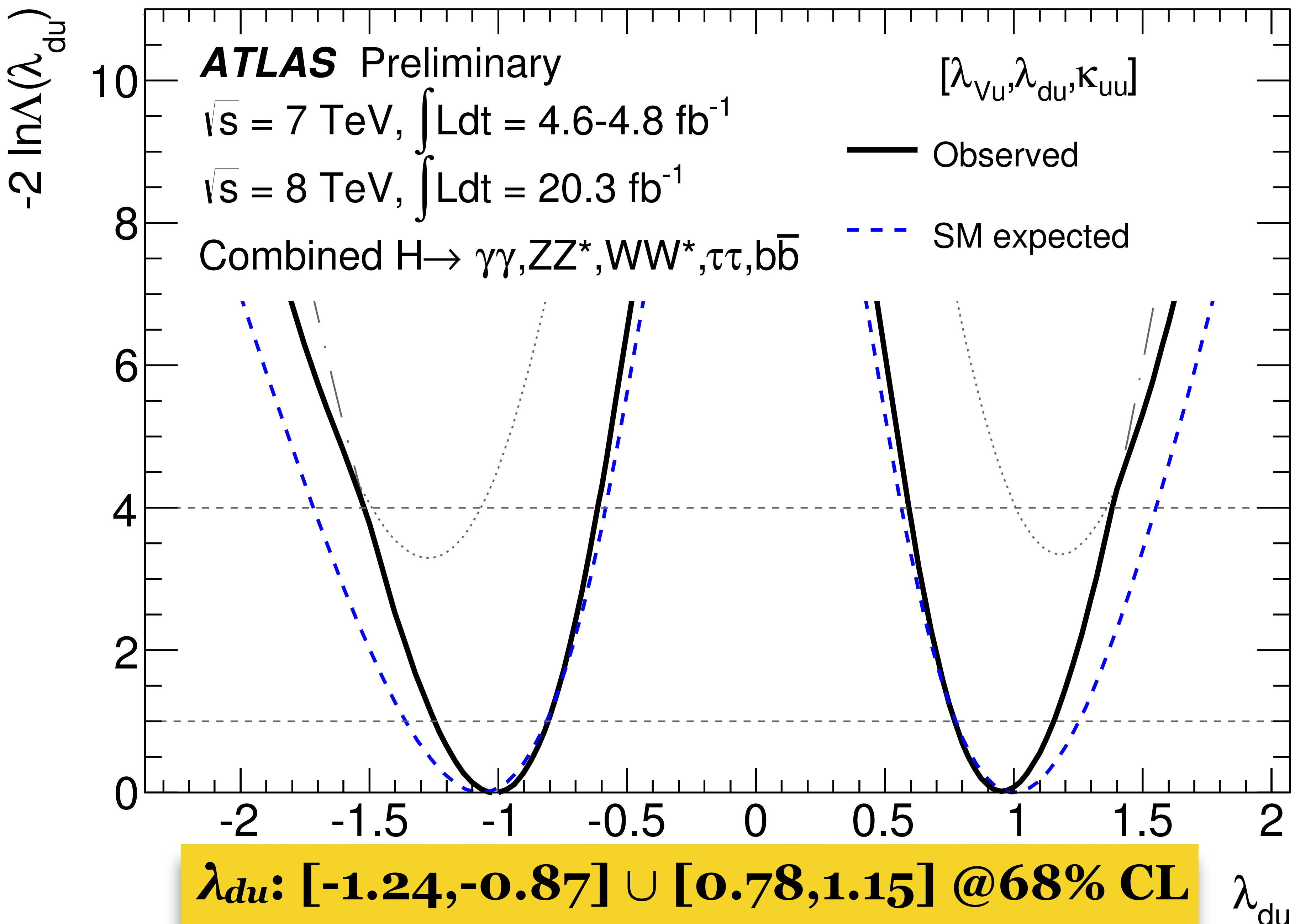
- Parameter of interest: $\boldsymbol{\lambda_{WZ} = \kappa_W/\kappa_Z}$
- Constrained by direct inputs from $H \rightarrow WW$ and $H \rightarrow ZZ$, but also from VBF measurements (~3/4 WW and ~1/4 ZZ fusion)
- Measured to be consistent with unity to high precision at LEP and Tevatron.



λ_{WZ}: [0.65,1.08] @68% CL

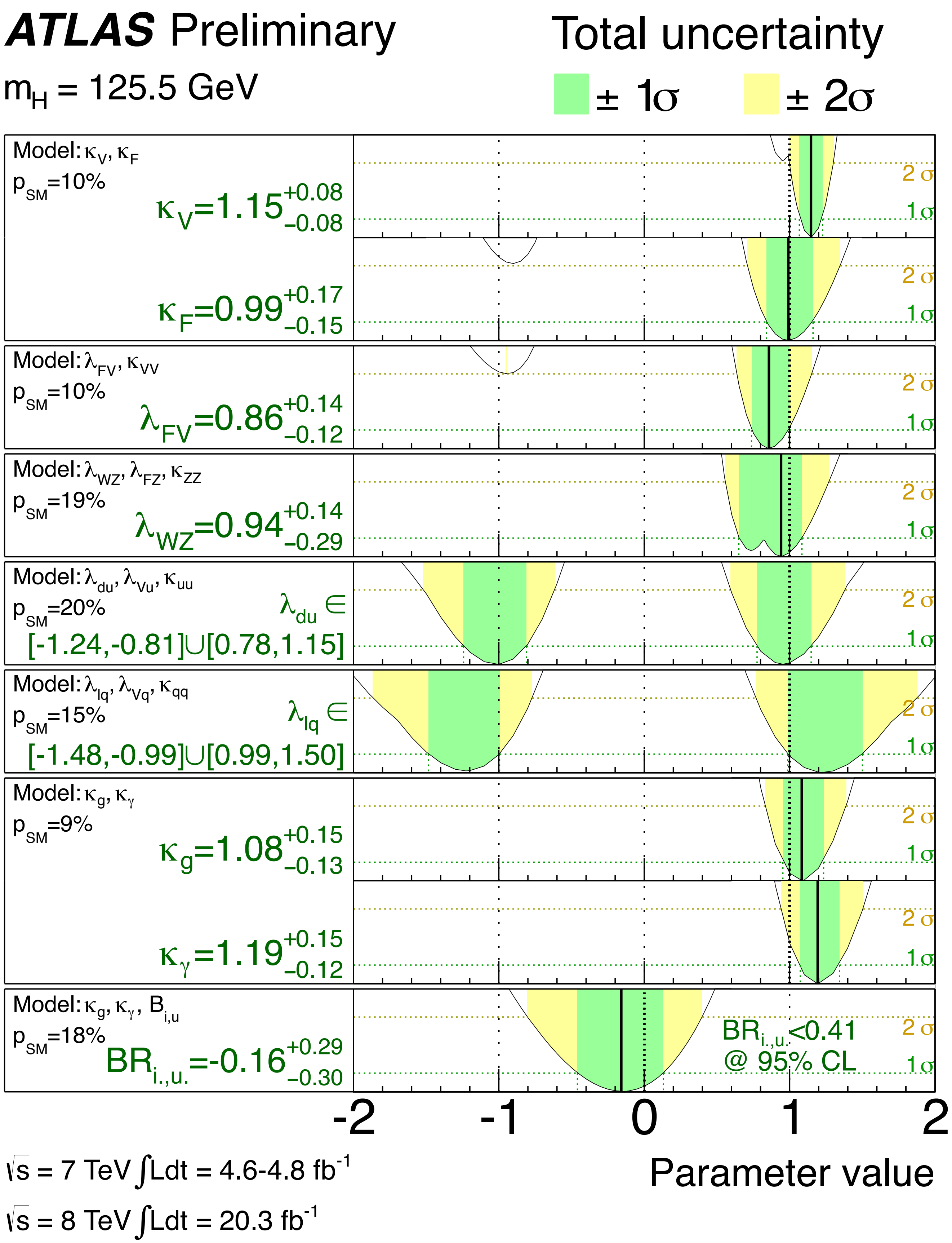
Up- vs down-type couplings

- Several **Higgs doublet models** (e.g. MSSM) predict different Higgs couplings to up and down-type fermions, hence introducing:
- One multiplier for up-type fermions: $\boldsymbol{\kappa_u = \kappa_t}$, and one for down-type $\boldsymbol{\kappa_d = \kappa_b = \kappa_\tau}$
- Parameter of interest: $\boldsymbol{\lambda_{du} = \kappa_d/\kappa_u}$



$\boldsymbol{\lambda_{du}}$: [-1.24,-0.87] ∪ [0.78,1.15] @68% CL

Summary of coupling measurements



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Higgs couplings …

… to vector bosons, κ_V

… to fermions, κ_F

coupling ratio κ_F/κ_V

Custodial symmetry: κ_W/κ_Z

up vs down-type couplings

quark vs lepton couplings

sensitive to SUSY

Additional particles in loops?
$gg \rightarrow H$, $H \rightarrow \gamma\gamma$

Unobserved or invisible particles

All measurements consistent with SM
p-values 0.09-0.20

Combined Higgs spin hypothesis tests

Spin & CP can be inferred by angular correlation of Higgs decay products:

Channels used for combination: $H \to \gamma\gamma$ $H \to ZZ^*$, $H \to WW^*$.

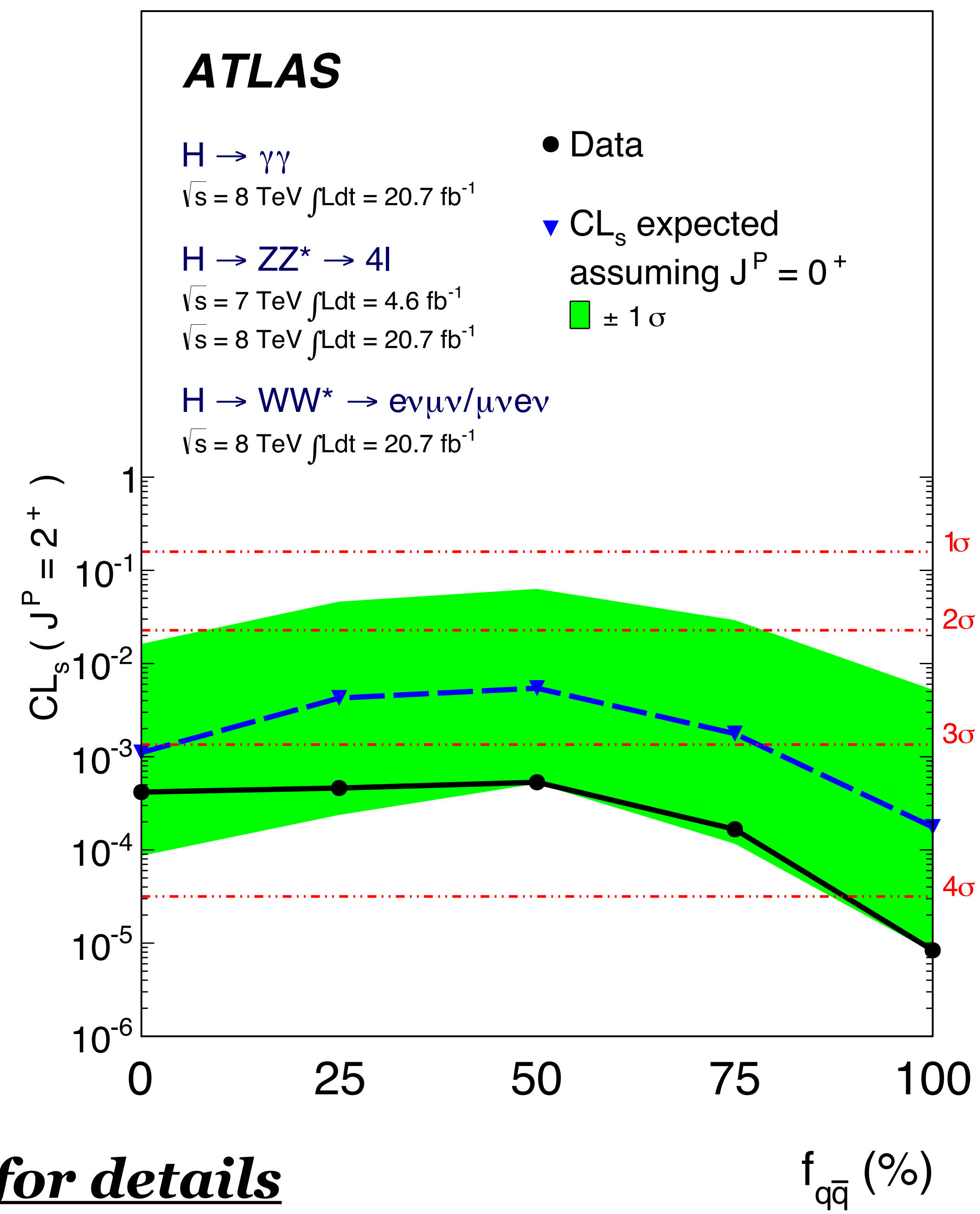
$\downarrow$

Hypothesis test: Spin 0^+ **(SM)** versus Spin 2^+

Test spin 2 admixture of leading order $q\bar{q} \to X$ & $gg \to X$ production: $f_{q\bar{q}}$

$\downarrow$

Entire Spin 2^+ configuration space excluded at **99.9%** CL_s.



See talk by Kirill Prokovfiev for details

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

correction factor for detector effects

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

20.3 fb^{-1} (±2.8%)

differential cross section of bin *i*

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

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 $\Delta R<0.4$

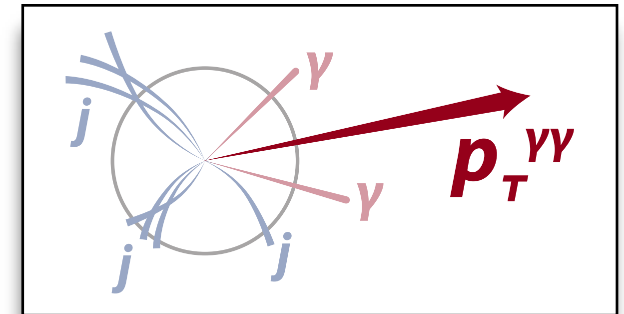
- *H→γγ* inclusive cross section: $n_{\mathrm{sig}} = 570\pm130$, $c_i = 0.65\pm0.02$:

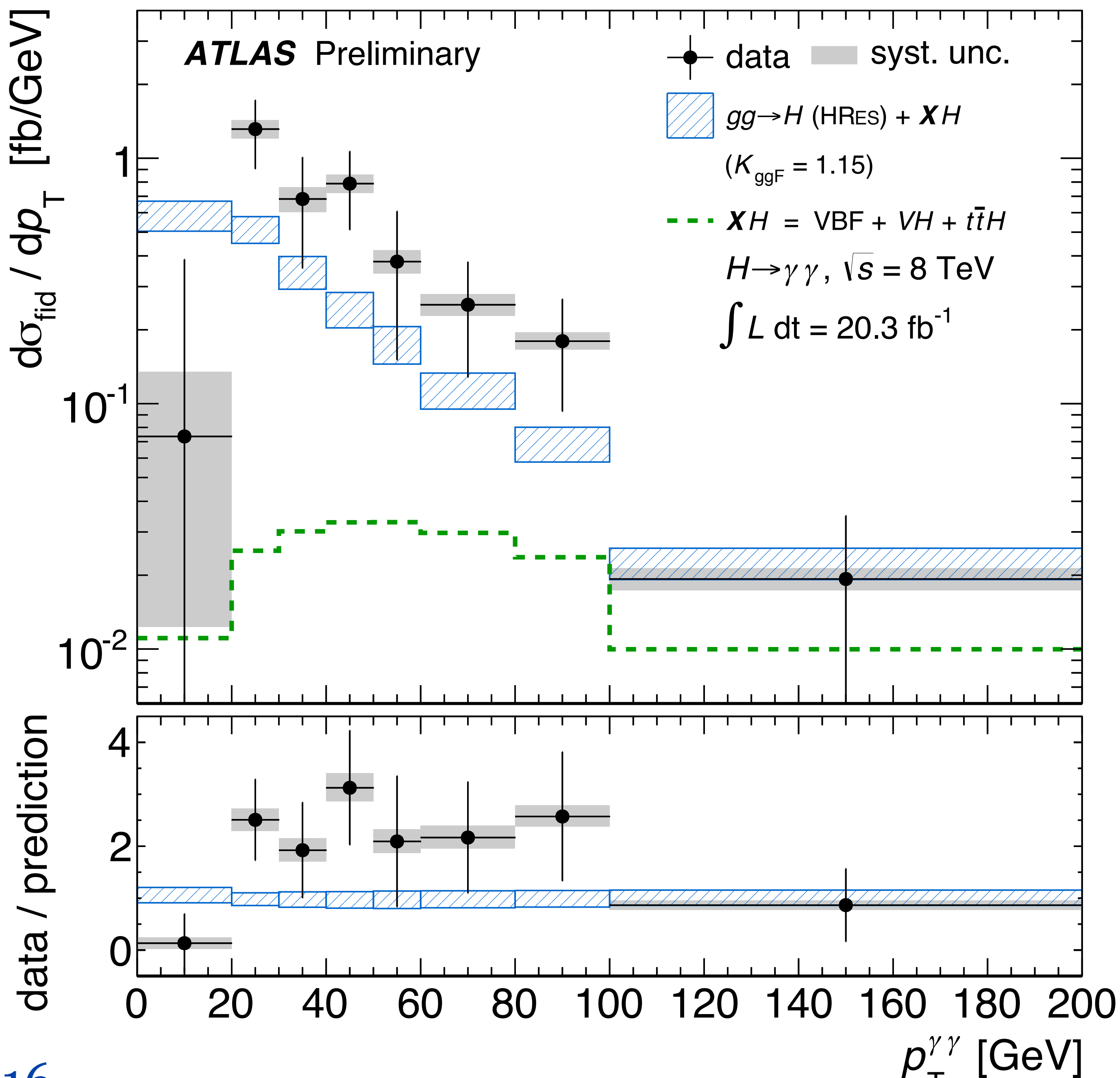
$$\sigma_{\mathrm{fid}}(pp \to H \to \gamma\gamma) = 43.2 \pm 9.4\,(\mathrm{stat})\ ^{+3.2}_{-2.9}\,(\mathrm{syst}) \pm 1.2\,(\mathrm{lumi})\ \ \mathrm{fb}$$

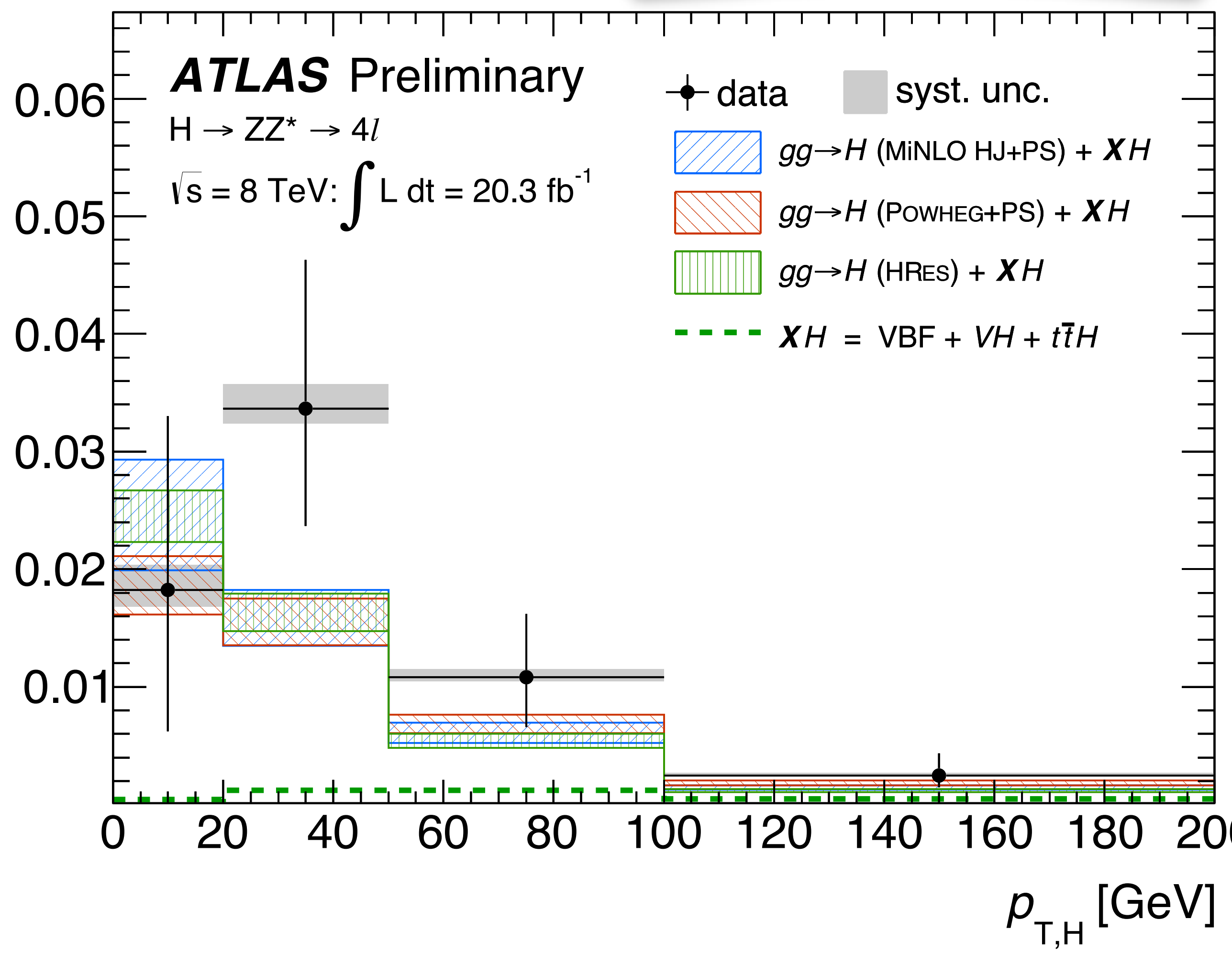
- *H→ZZ* inclusive cross section: $2.11^{+0.53}_{-0.47}(\mathrm{stat})^{+0.16}_{-0.10}(\mathrm{syst}) \quad \mathrm{fb}$

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



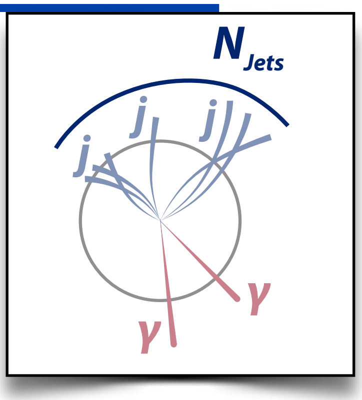


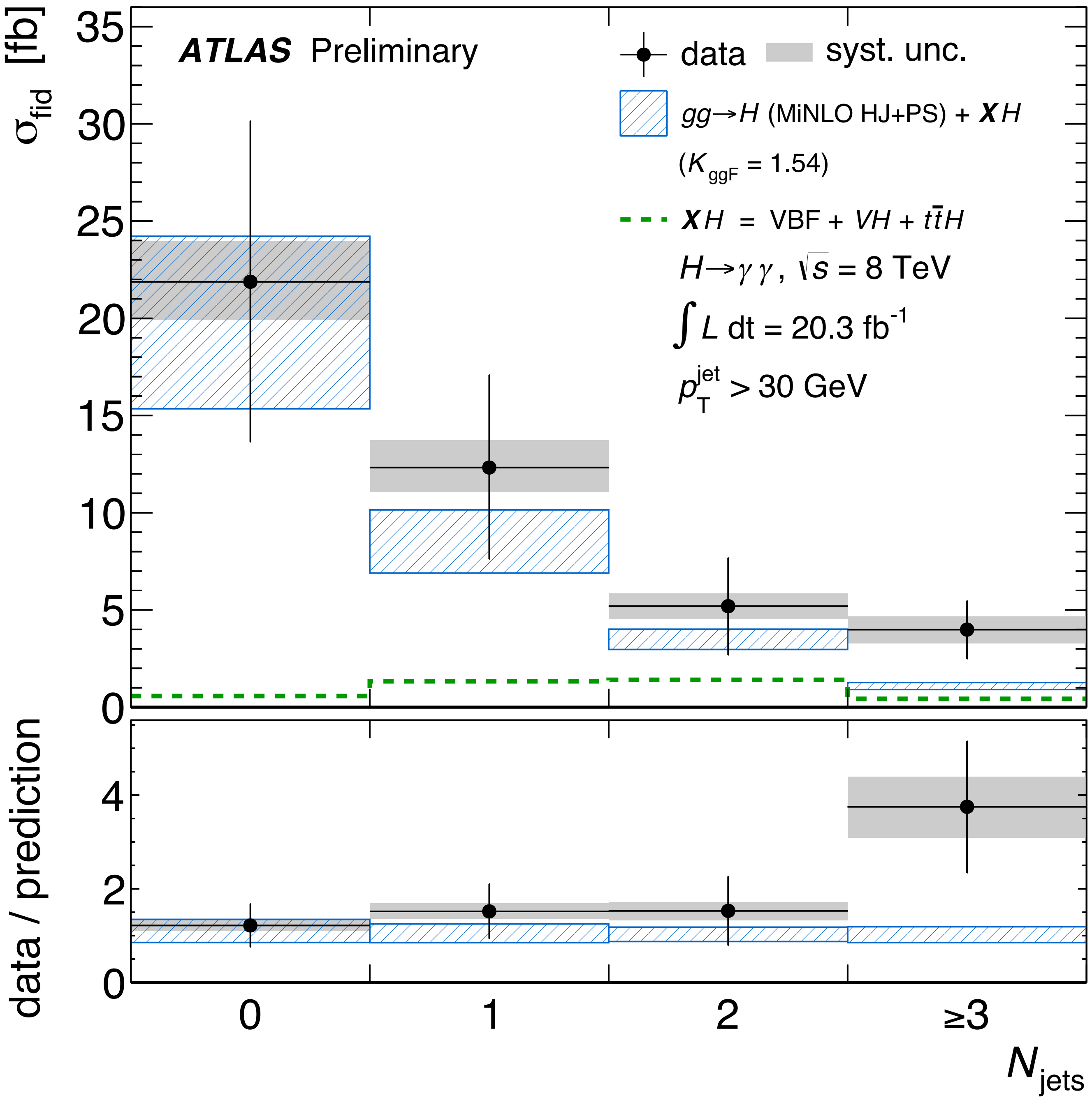


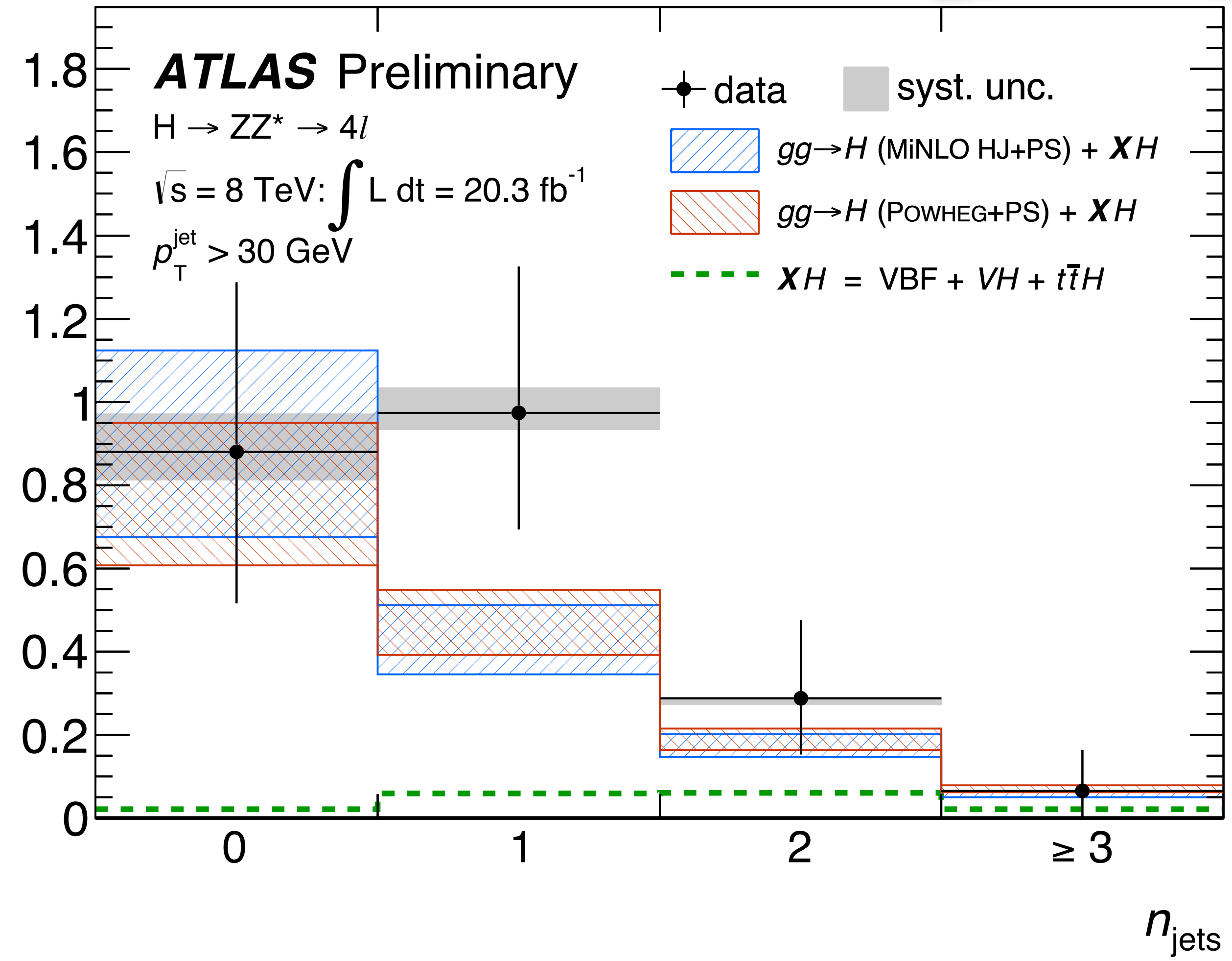
Consistent with SM theory predictions
p-values 0.09-0.12 (γγ) 0.16-0.30 (ZZ)

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



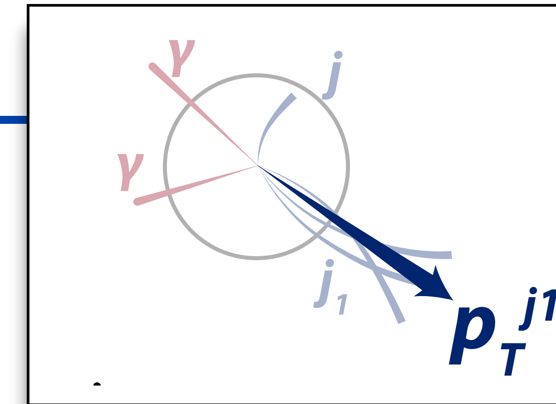




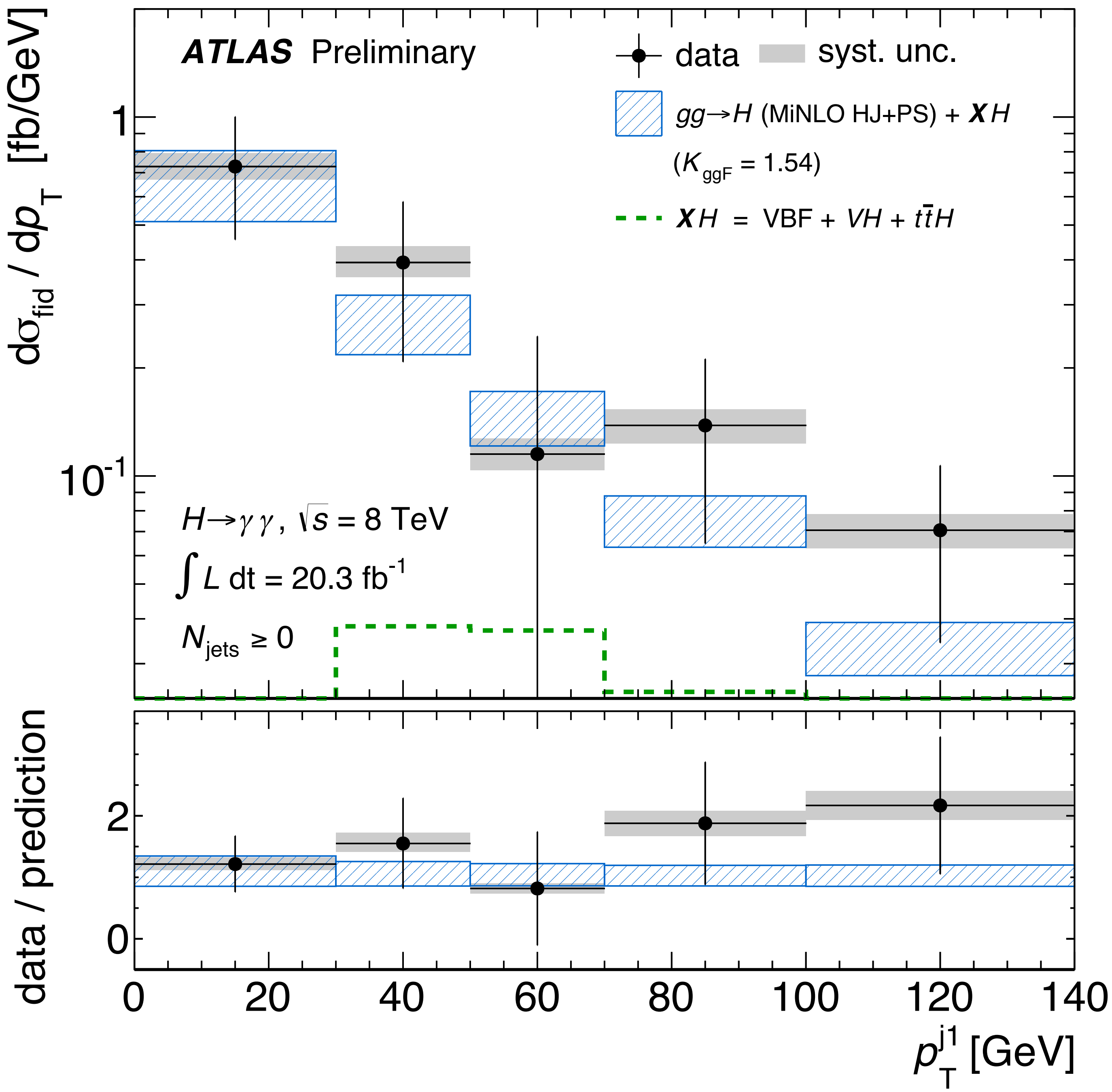
Consistent with SM theory predictions

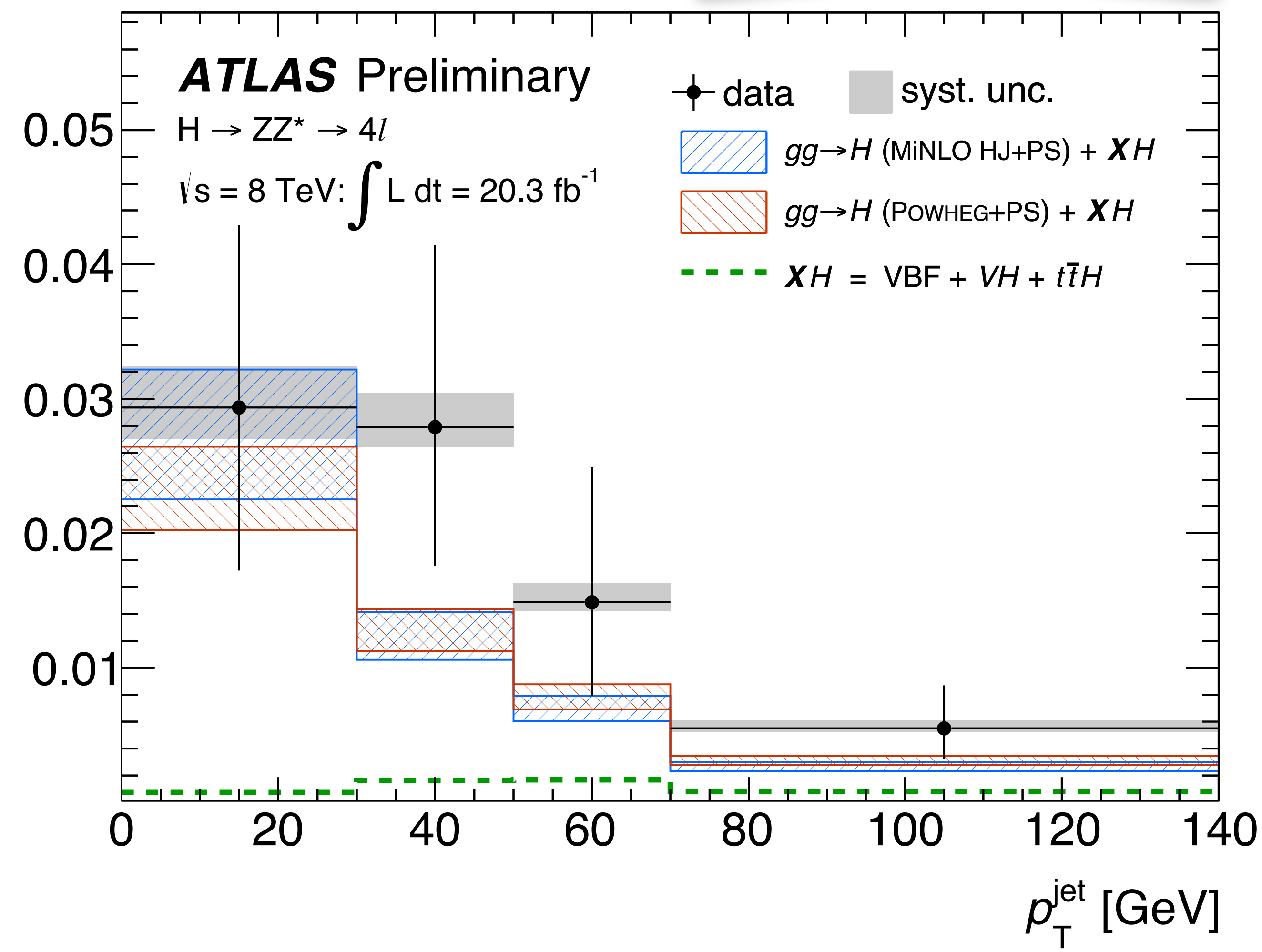
p-values 0.30-0.42 (γγ) 0.28-0.37 (ZZ)

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)

Summary

Highlights of ATLAS Higgs boson main property measurements:

- **Mass**, benefits from new calibration+simulation:
  $\boldsymbol{m_H = 125.36 \pm 0.37\ (\mathrm{stat}) \pm 0.21\ (\mathrm{syst})}$
- **Signal strength**
  $\boldsymbol{\mu = 1.30\ ^{+0.18}_{-0.17}}$
- 4.1σ evidence that a fraction of Higgs is produced via VBF
  $\boldsymbol{\mu_{\mathrm{VBF}}/\mu_{ttH+\mathrm{ggF}} = 1.4^{+0.7}_{-0.5}}$
- A long list of **coupling scenarios** have been tested, and **no significant deviations from the SM Higgs is observed**
  - *p*-values of SM compatibility range from 10 to 20% (within 2σ)
- Combined spin measurement favour the SM spin-0 nature of the particle and exclude various alternative spin models at 98% CL or more
- Differential and fiducial cross section have been measured separately for $\gamma\gamma$ and ZZ as a function of several variables.
  Results are compatible with the SM Higgs boson.

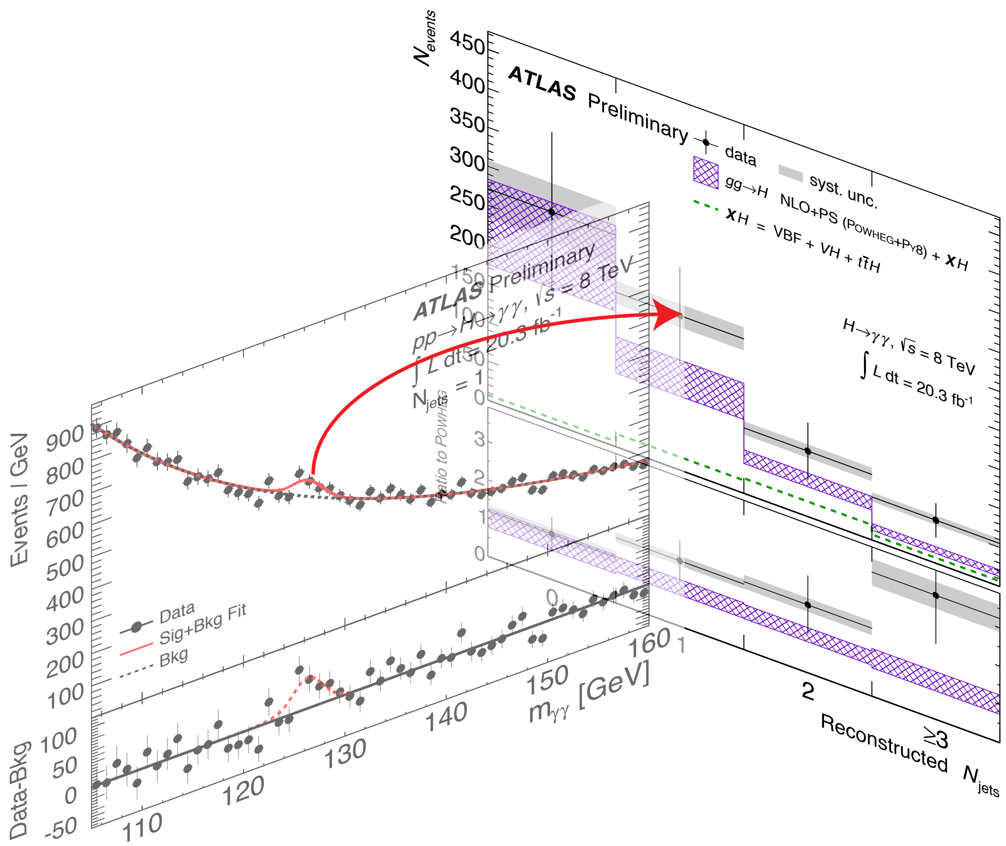
Is this the SM Higgs boson, or something more interesting?

Most measurements currently statistically limited: ***Run II will be a lot of fun!***

BACKUP SLIDES

$H \rightarrow \gamma\gamma$ differential cross section overview

1. Signal extraction



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

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

c) Large statistical uncertainty due to small s/b

2. Unfold to particle level

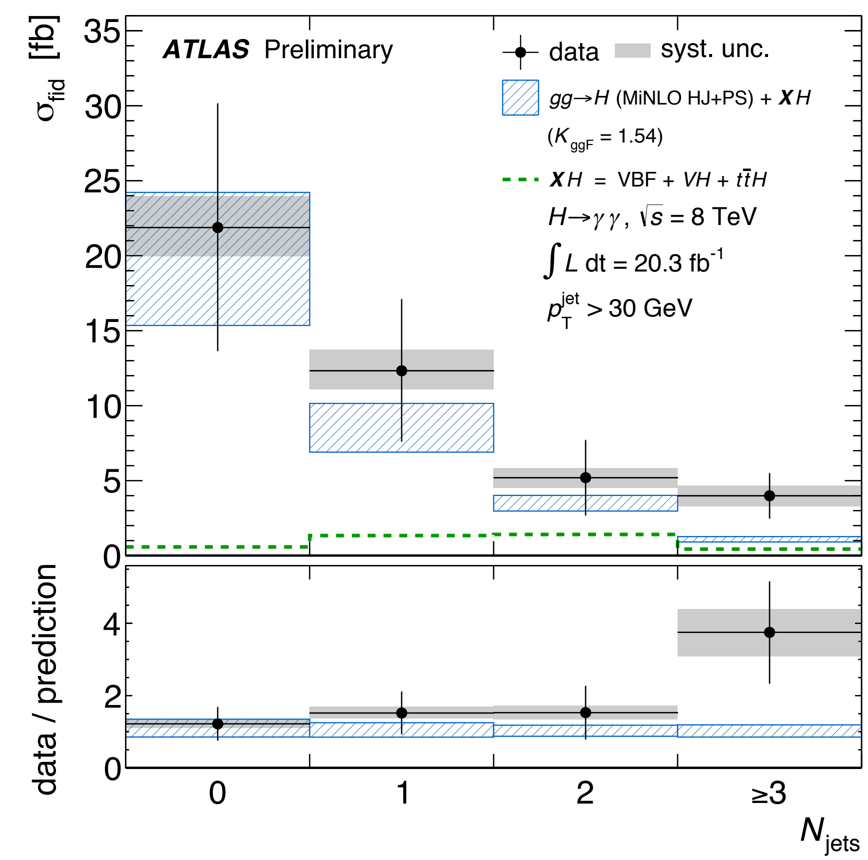
and divide by integrated luminosity and bin-width

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

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

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

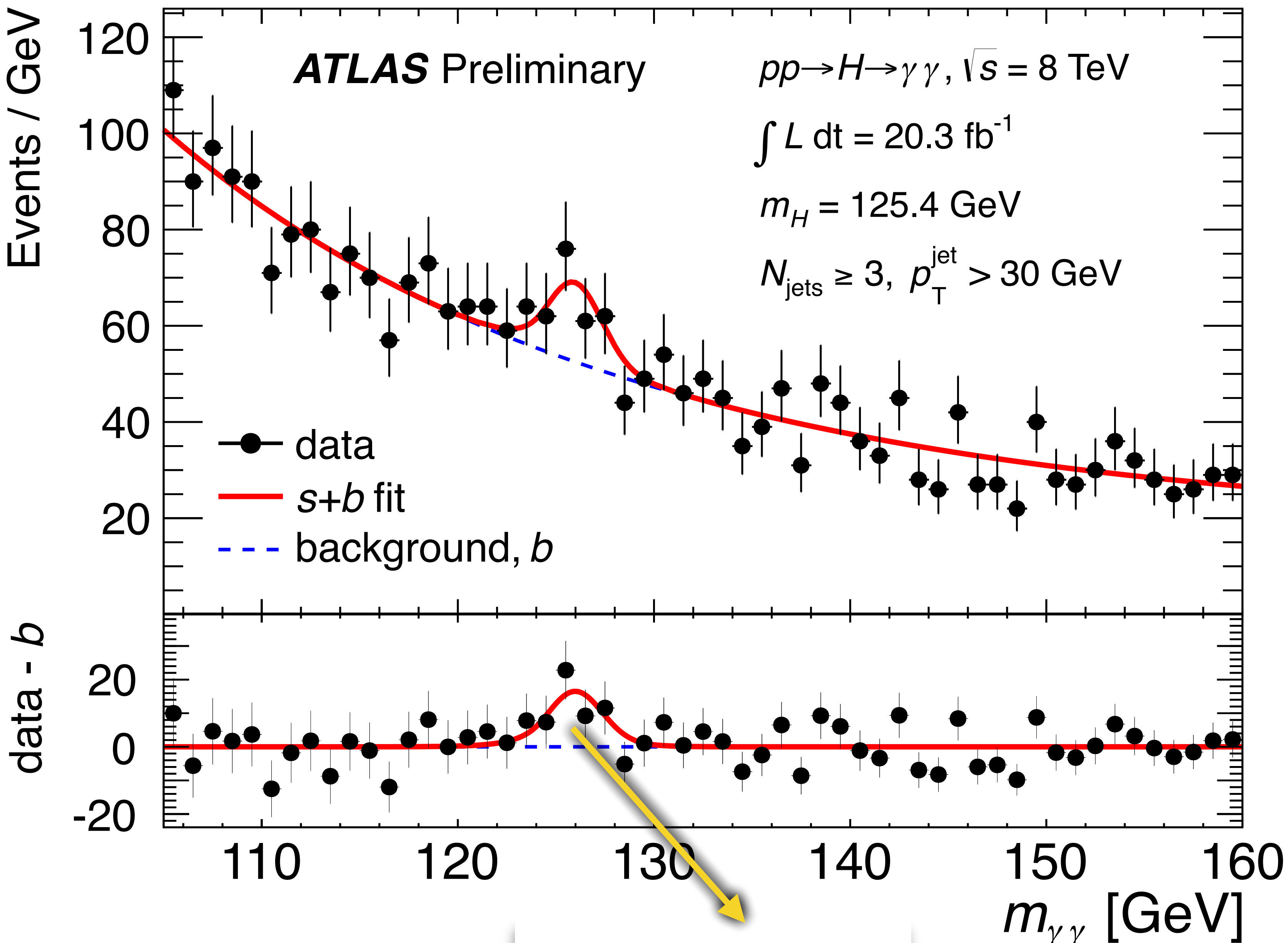
3. Plot and compare with theory



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

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



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

Comparing analytical ggF predictions with data

Analytical calculated cross sections can be corrected for acceptances and non-perturbative effects using provided correction factors for each fiducial region/bin of differential cross section
SM is assumed for provided values. Uncert. from QCD-scale, PDF, MPI/fragm. tune variations

gluon fusion

other production modes
XH = VBF+VH+ttH

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

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

$$\sigma_{\text{fid}} = \sigma_{\text{ggF}}\ \mathcal{B}\ \alpha_{\text{kinem}}\ \alpha_{\text{iso}}\ f_{\text{NP}} + \sigma_{\text{fid},XH} \quad \mathbf{= 30.5\ fb}$$

LHC-XS: 19.15 pb

0.228%

~63%

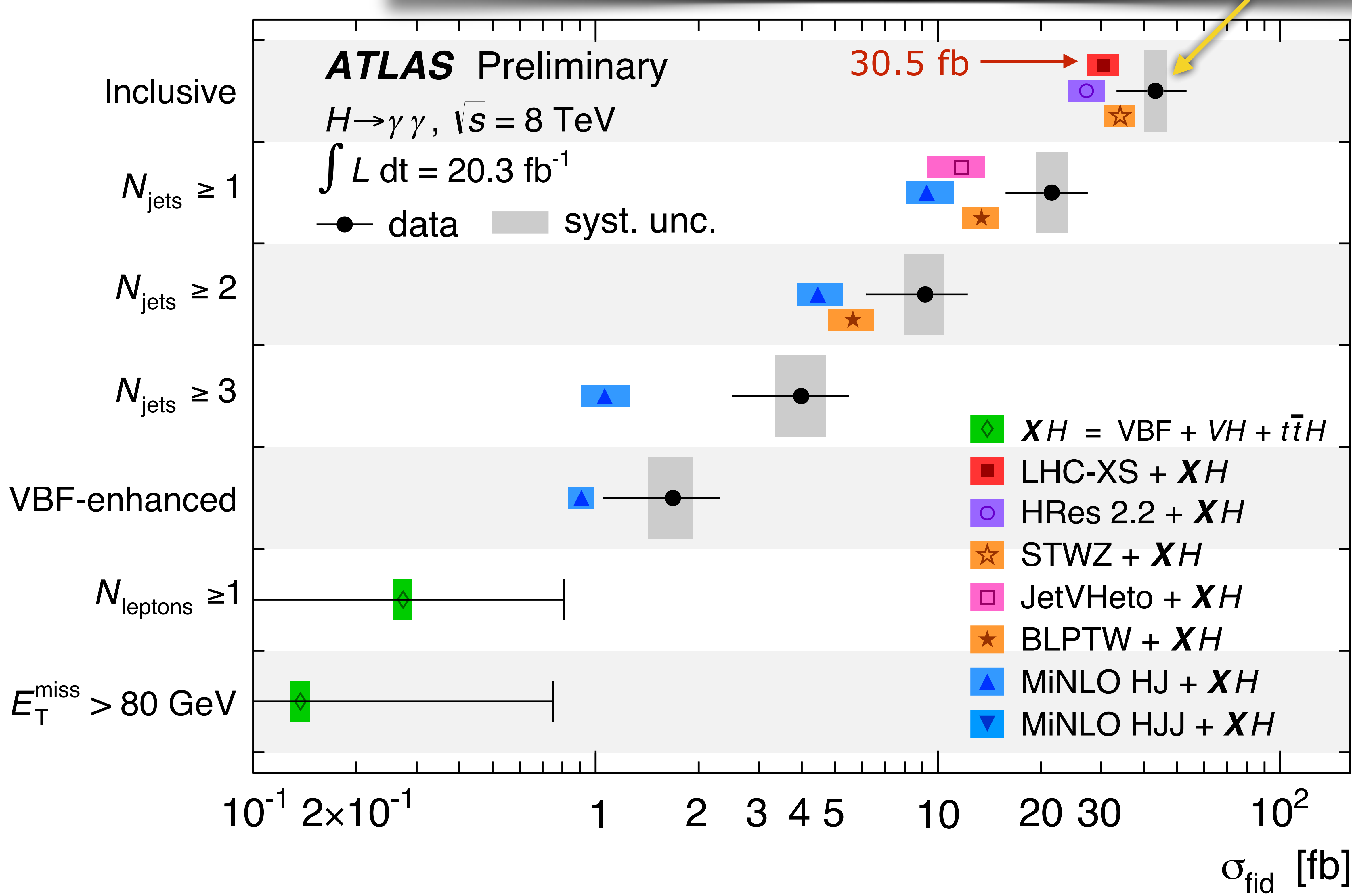
~98%

1.00

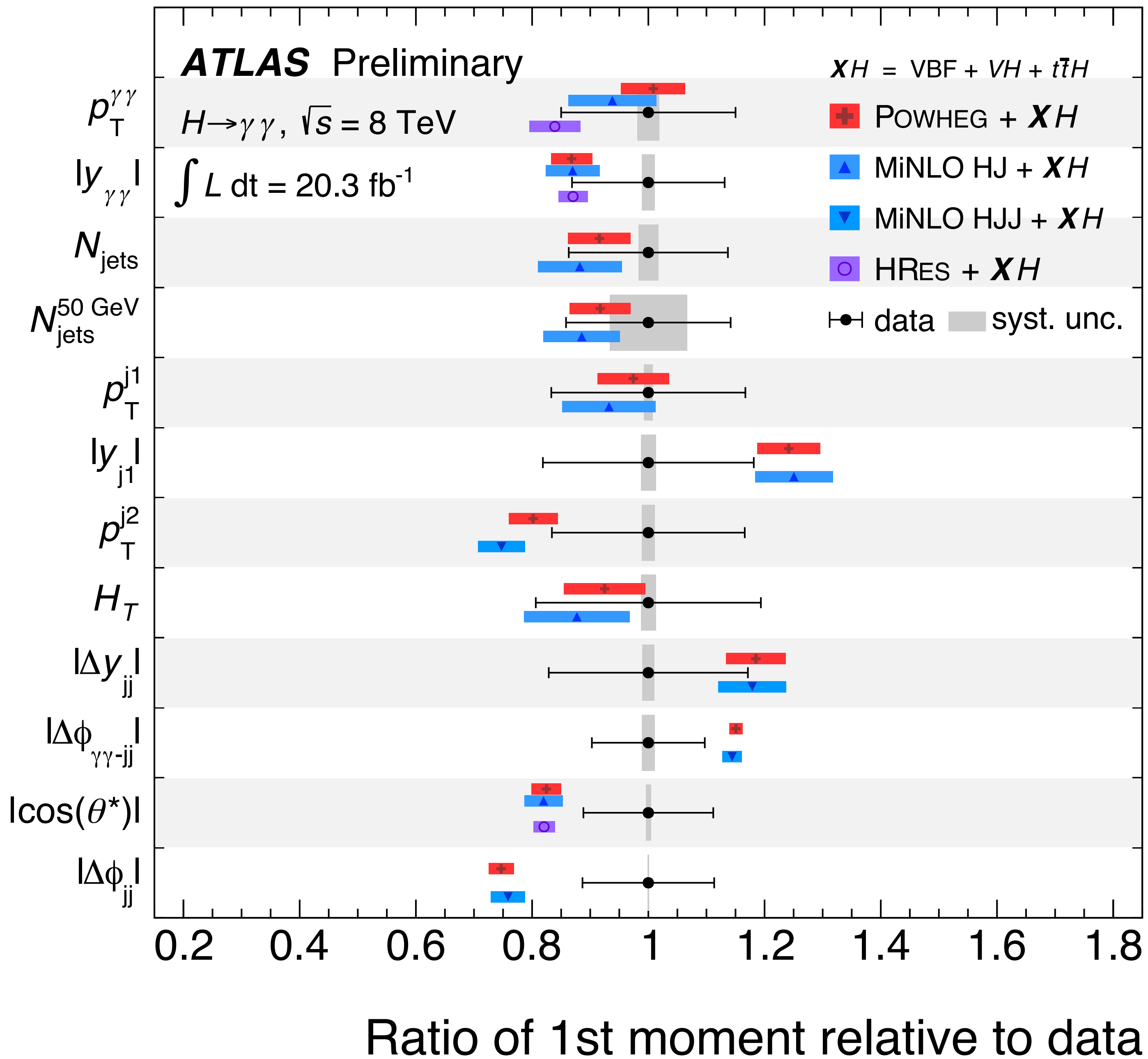
~4 fb

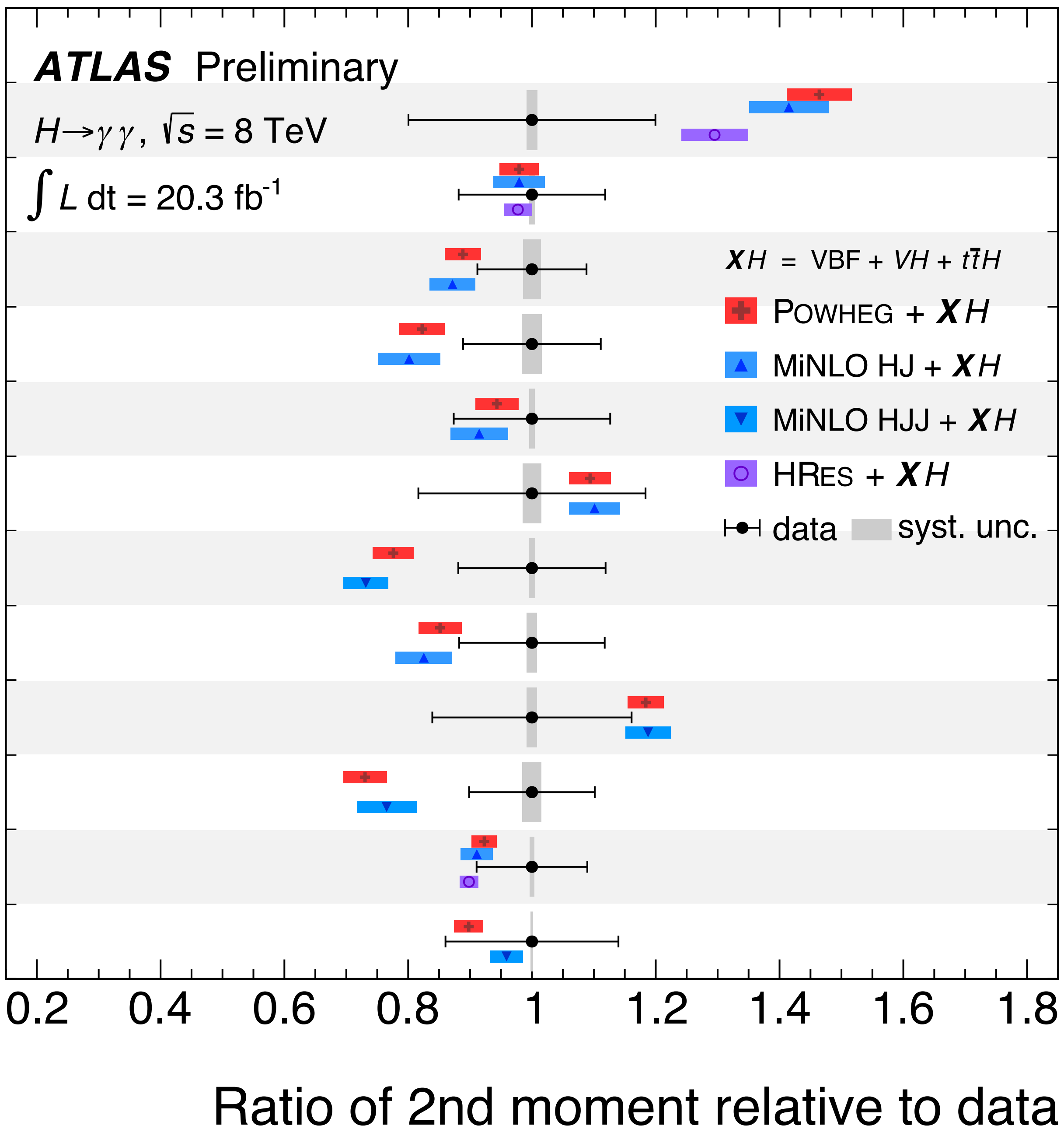
$H \to \gamma\gamma$ fiducial cross sections

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



MC/data ratio of mean and mode of differential distributions





Coupling multipliers κ

… the Higgs couplings are described, in unitarity gauge, by the following effective Lagrangian:

$$
\begin{aligned}
\mathcal{L} = {} & \kappa_3 \frac{m_H^2}{2v} H^3 + \kappa_Z \frac{m_Z^2}{v} Z_\mu Z^\mu H + \kappa_W \frac{2m_W^2}{v} W_\mu^+ W^{-\mu} H \\
& + \kappa_g \frac{\alpha_s}{12\pi v} G_{\mu\nu}^a G^{a\mu\nu} H + \kappa_\gamma \frac{\alpha}{2\pi v} A_{\mu\nu} A^{\mu\nu} H + \kappa_{Z\gamma} \frac{\alpha}{\pi v} A_{\mu\nu} Z^{\mu\nu} H \\
& + \kappa_{VV} \frac{\alpha}{2\pi v} \left(\cos^2\theta_W Z_{\mu\nu} Z^{\mu\nu} + 2\, W_{\mu\nu}^+ W^{-\mu\nu} \right) H \\
& - \left(\kappa_t \sum_{f=u,c,t} \frac{m_f}{v} f\overline{f} + \kappa_b \sum_{f=d,s,b} \frac{m_f}{v} f\overline{f} + \kappa_\tau \sum_{f=e,\mu,\tau} \frac{m_f}{v} f\overline{f} \right) H.
\end{aligned}
$$

From: Status of Higgs boson physics (PDG), page 62

Coupling modifier	Wilson coefficient dependence
κ_3	$1 + \bar{c}_6 - 3\bar{c}_H/2$
κ_V	$1 - \bar{c}_H/2$
κ_f	$1 - \bar{c}_f - \bar{c}_H/2$
κ_γ	$(2\pi/\alpha)\,\sin^2\theta_W\,(4\bar{c}_{BB} + \bar{c}_{WW})$
$\kappa_{Z\gamma}$	$(\pi/\alpha)\,\sin 2\theta_W\,\bar{c}_{WW}$
κ_{VV}	$(\pi/\alpha)\,\bar{c}_{WW}$
κ_g	$(48\pi/\alpha)\,\sin^2\theta_W\,\bar{c}_{GG}$

Table 11: Correspondence between the κ's and the Wilson coefficients of the dimension-6 operators of the Higgs EFT Lagrangian constrained only by Higgs physics.

Coupling multipliers

From ATLAS-CONF-2014-009

To a very good approximation, the relevant expressions for m_H = 125.5 GeV are:

$$\kappa_\gamma^2 \sim 1.59 \cdot \kappa_W^2 - 0.66 \cdot \kappa_W \kappa_t + 0.07 \cdot \kappa_t^2 \tag{2}$$

$$\kappa_g^2 \sim 1.06 \cdot \kappa_t^2 - 0.07 \cdot \kappa_t \kappa_b + 0.01 \cdot \kappa_b^2 \tag{3}$$

$$\kappa_{VBF}^2 \sim 0.74 \cdot \kappa_W^2 + 0.26 \cdot \kappa_Z^2 \tag{4}$$

$$\kappa_H^2 \sim 0.57 \cdot \kappa_b^2 + 0.22 \cdot \kappa_W^2 + 0.09 \cdot \kappa_g^2 + 0.06 \cdot \kappa_\tau^2 + 0.03 \cdot \kappa_Z^2 + 0.03 \cdot \kappa_c^2. \tag{5}$$

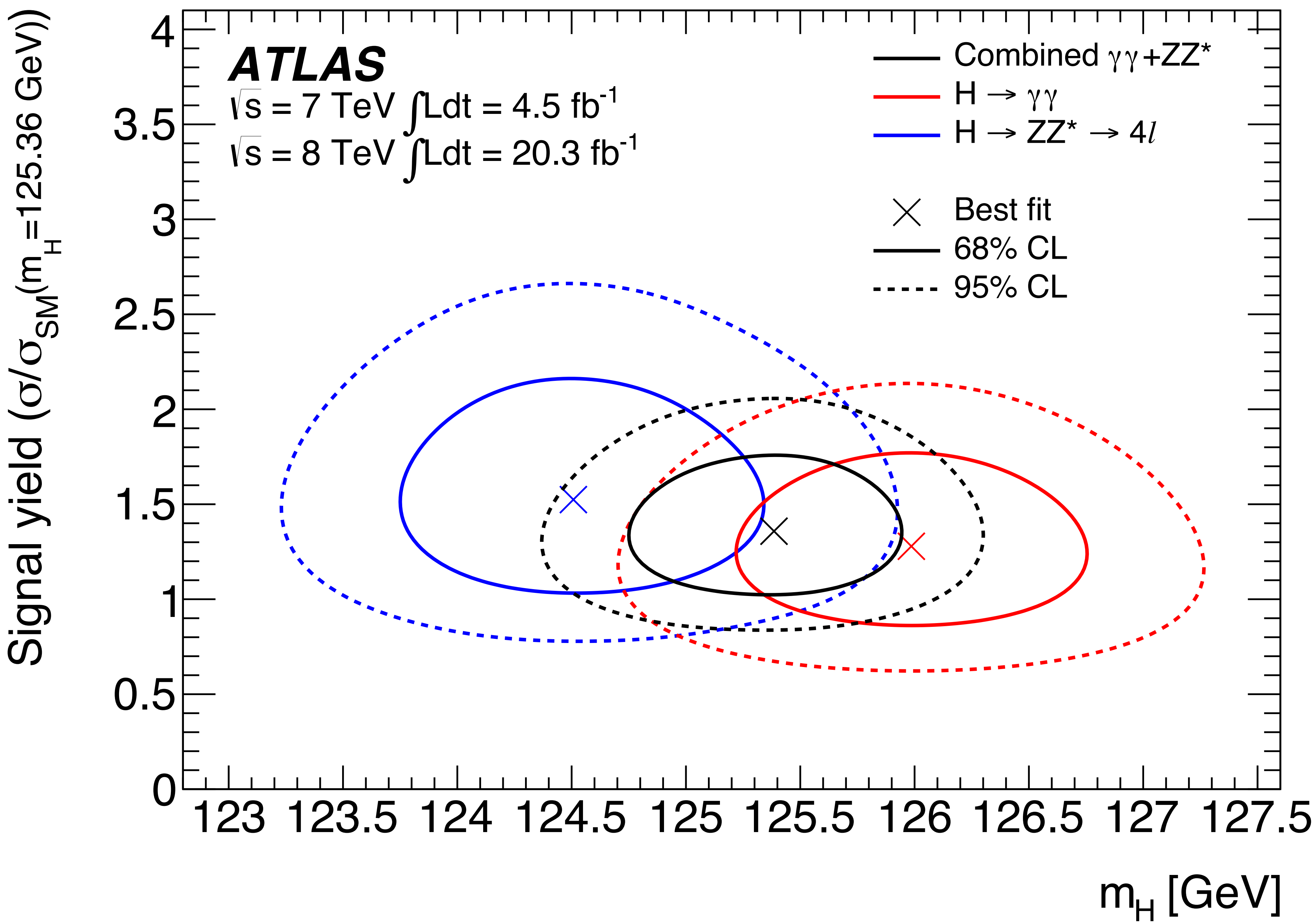
- **Note:** The interference terms allows to check the sign of the couplings multipliers κ

Channels included in coupling combination

Higgs boson Decay	Subsequent Decay	Sub-Channels	$\int L\,dt$ [fb^{-1}]	Ref.
		2011 $\sqrt{s}$ =7 TeV		
$H \to \gamma\gamma$	–	10 categories $\{p_{\mathrm{Tt}} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet VBF}\}$	4.8	[3]
$H \to ZZ^*$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu, \text{2-jet VBF}, \ell\text{-tag}\}$	4.6	[3]
$H \to WW^*$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu e, \mu\mu\} \otimes \{\text{0-jet, 1-jet, 2-jet VBF}\}$	4.6	[3]
$VH \to Vbb$	$Z \to \nu\nu$	$E_{\mathrm{T}}^{\mathrm{miss}} \in \{120-160, 160-200, \geq 200\ \mathrm{GeV}\} \otimes \{\text{2-jet, 3-jet}\}$	4.6	[5]
	$W \to \ell\nu$	$p_{\mathrm{T}}^{W} \in \{< 50, 50-100, 100-150, 150-200, \geq 200\ \mathrm{GeV}\}$	4.7	
	$Z \to \ell\ell$	$p_{\mathrm{T}}^{Z} \in \{< 50, 50-100, 100-150, 150-200, \geq 200\ \mathrm{GeV}\}$	4.7	
		2012 $\sqrt{s}$ =8 TeV		
$H \to \gamma\gamma$	–	14 categories: $\{p_{\mathrm{Tt}} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus$ $\{\text{loose, tight 2-jet VBF}\} \oplus \{\ell\text{-tag}, E_{\mathrm{T}}^{\mathrm{miss}}\text{-tag, 2-jet VH}\}$	20.3	[3]
$H \to ZZ^*$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu, \text{2-jet VBF}, \ell\text{-tag}\}$	20.3	[3]
$H \to WW^*$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu e, \mu\mu\} \otimes \{\text{0-jet, 1-jet, 2-jet VBF}\}$	20.3	[3]
$VH \to Vbb$	$Z \to \nu\nu$	$E_{\mathrm{T}}^{\mathrm{miss}} \in \{120-160, 160-200, \geq 200\ \mathrm{GeV}\} \otimes \{\text{2-jet, 3-jet}\}$	20.3	[5]
	$W \to \ell\nu$	$p_{\mathrm{T}}^{W} \in \{<90, 90\text{-}120, 120\text{-}160, 160\text{-}200, \geq 200\ \mathrm{GeV}\} \otimes \{\text{2-jet, 3-jet}\}$	20.3	
	$Z \to \ell\ell$	$p_{\mathrm{T}}^{Z} \in \{<90, 90\text{-}120, 120\text{-}160, 160\text{-}200, \geq 200\ \mathrm{GeV}\} \otimes \{\text{2-jet, 3-jet}\}$	20.3	
$H \to \tau\tau$	$\tau_{\mathrm{lep}}\tau_{\mathrm{lep}}$	$\{ee, e\mu, \mu\mu\} \otimes \{\text{boosted, 2-jet VBF}\}$	20.3	[6]
	$\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$	$\{e, \mu\} \otimes \{\text{boosted, 2-jet VBF}\}$	20.3	
	$\tau_{\mathrm{had}}\tau_{\mathrm{had}}$	$\{\text{boosted, 2-jet VBF}\}$	20.3	

Signal yield vs m_H

Results with new calibration



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

CMS Combined mass: 125.03 ±0.27 (stat) ±0.15 (syst)

Higgs coupling measurements

Selection of benchmark models with focus on different observables:

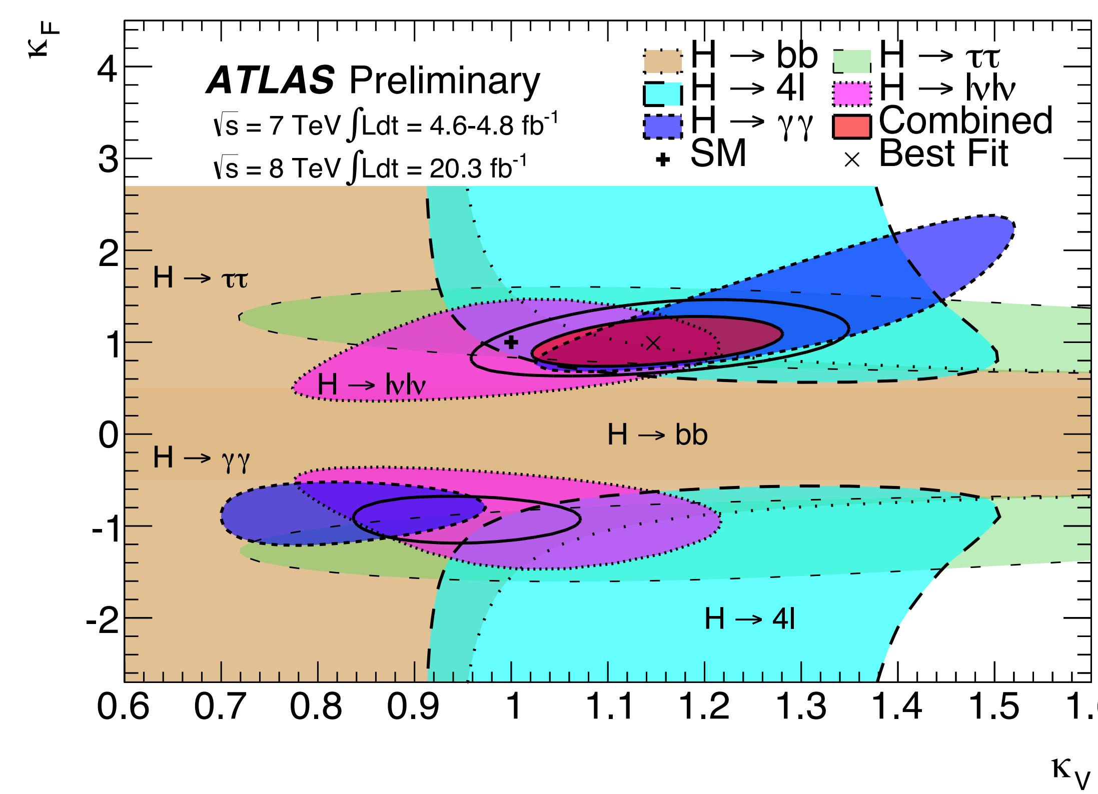
Model	Probed couplings	Parameters of interest	Functional assumptions κ_V	κ_F	κ_g	κ_γ	κ_H	Example: $gg \to H \to \gamma\gamma$
1	Couplings to fermions and bosons	κ_V, κ_F	√	√	√	√	√	$\kappa_F^2 \cdot \kappa_\gamma^2(\kappa_F, \kappa_V)/\kappa_H^2(\kappa_F, \kappa_V)$
2		$\lambda_{FV}, \kappa_{VV}$	√	√	√	√	-	$\kappa_{VV}^2 \cdot \lambda_{FV}^2 \cdot \kappa_\gamma^2(\lambda_{FV}, \lambda_{FV}, \lambda_{FV}, 1)$
3	Custodial symmetry	$\lambda_{WZ}, \lambda_{FZ}, \kappa_{ZZ}$	-	√	√	√	-	$\kappa_{ZZ}^2 \cdot \lambda_{FZ}^2 \cdot \kappa_\gamma^2(\lambda_{FZ}, \lambda_{FZ}, \lambda_{FZ}, \lambda_{WZ})$
4		$\lambda_{WZ}, \lambda_{FZ}, \lambda_{\gamma Z}, \kappa_{ZZ}$	-	√	√	-	-	$\kappa_{ZZ}^2 \cdot \lambda_{FZ}^2 \cdot \lambda_{\gamma Z}^2$
5	Vertex loops	κ_g, κ_γ	=1	=1	-	-	√	$\kappa_g^2 \cdot \kappa_\gamma^2/\kappa_H^2(\kappa_g, \kappa_\gamma)$

The ticks correspond to a certain fixed functional dependence – more details in backup

Model 1: One coupling factors for fermions and one coupling factor for bosons: κ_F, κ_V

Model 2: Removing the constraint on the Higgs boson width (i.e. that the measured partial widths have to saturate the total width) only the rato $\lambda_{FV} = \kappa_F/\kappa_V$ and $\kappa_{VV} = \kappa_V^2/\kappa_H$ can be measured.

Model 1	Model 2
$\kappa_F = 0.99^{+0.17}_{-0.15}$	$\lambda_{FV} = 0.86^{+0.14}_{-0.12}$
$\kappa_V = 1.15^{+0.08}_{-0.08}$	$\kappa_{VV} = 1.28^{+0.16}_{-0.15}$



Compatibility of SM with both model fits: 10%.