Higgs boson coupling measurements at ATLAS experiment

Fábio Lucio Alves on behalf of the ATLAS Collaboration

Higgs Hunting 2025, July 15-17

Orsay (IJClab) and Paris (LPNHE)

Motivation

More than 10 years of the Higgs Boson discovery at LHC:

- Measurements of the Higgs Boson properties (mass, spin, width, cross sections, couplings) with increased precision
  - Consistency with SM predictions intensively tested

... that is the moment to perform the combination!

- The **combination of single Higgs analyses** allows us to test the Higgs sector and constrain the strength of the interaction between the Higgs and the SM particles
  - Higgs boson rates (cross section x BR) and $\kappa-$framework

Credit: CERN webpage

CERN 10 years HIGGS boson discovery

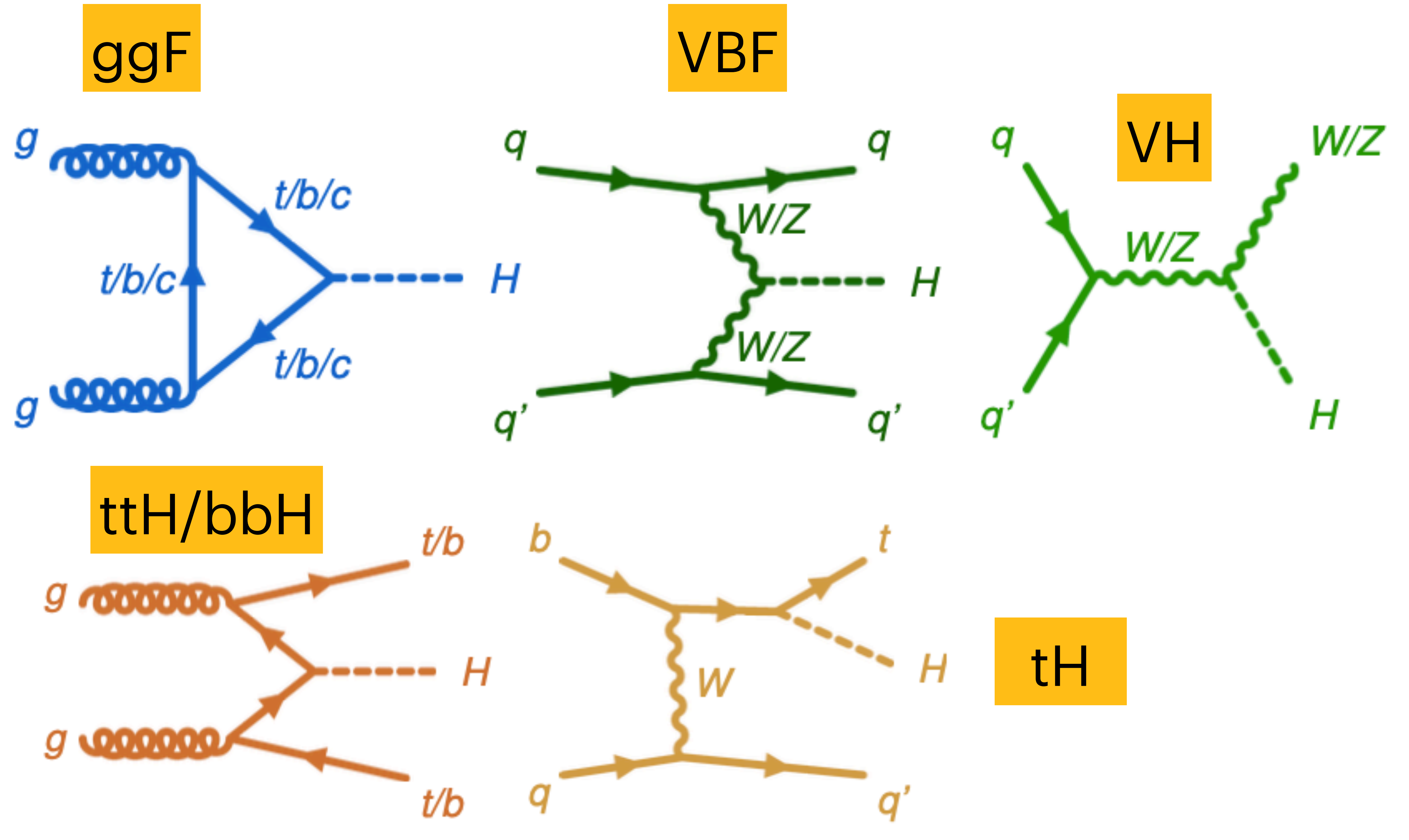
Higgs Symposium at CERN for 10 years discovery

Higgs Boson production and decay at LHC

[Nature, vol. 607, 52-59 (2022)](#)

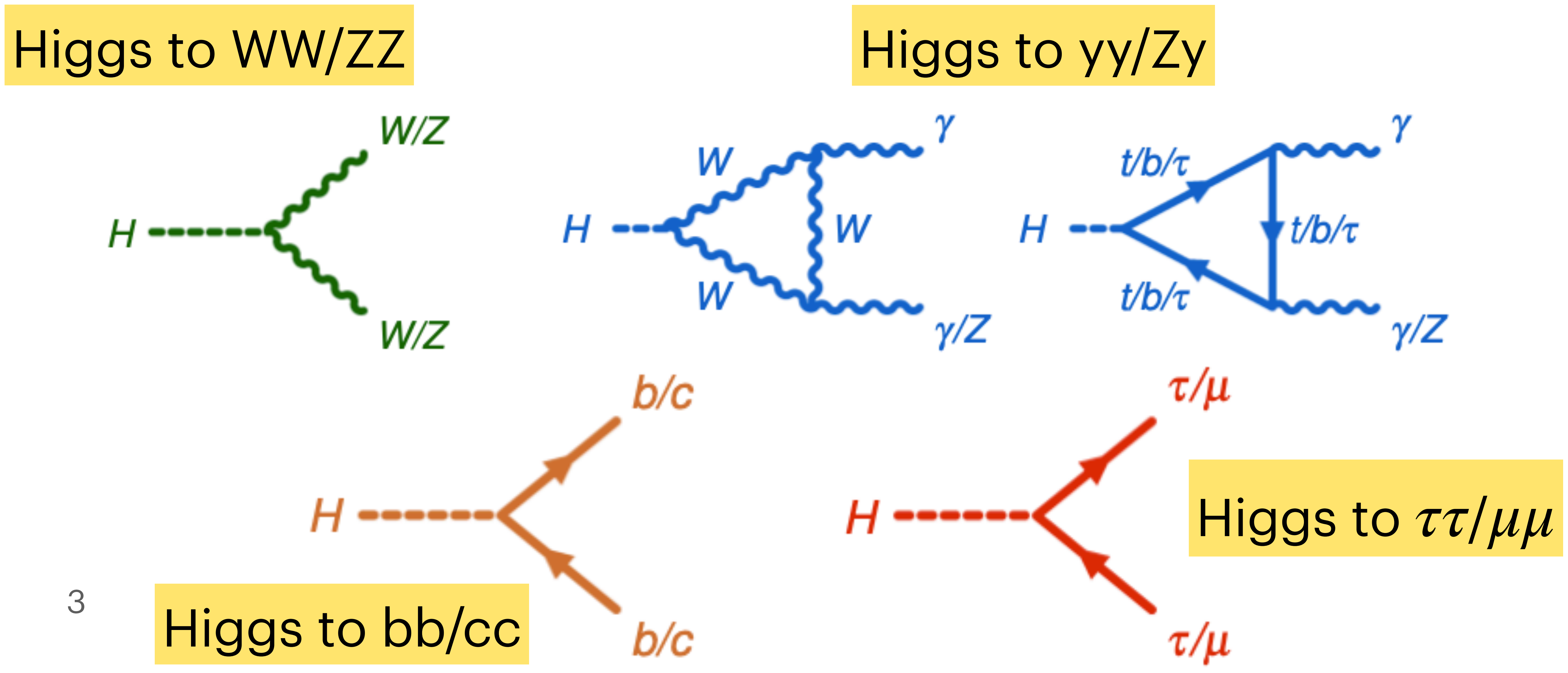
Higgs Production processes:

- Gluon-gluon fusion (ggF) (*dominant production mode*)
- Vector-boson fusion (VBF)
- Association with a vector boson (VH)
- Association with top and bottom quark pair (ttH/bbH)



Higgs Decay channels:

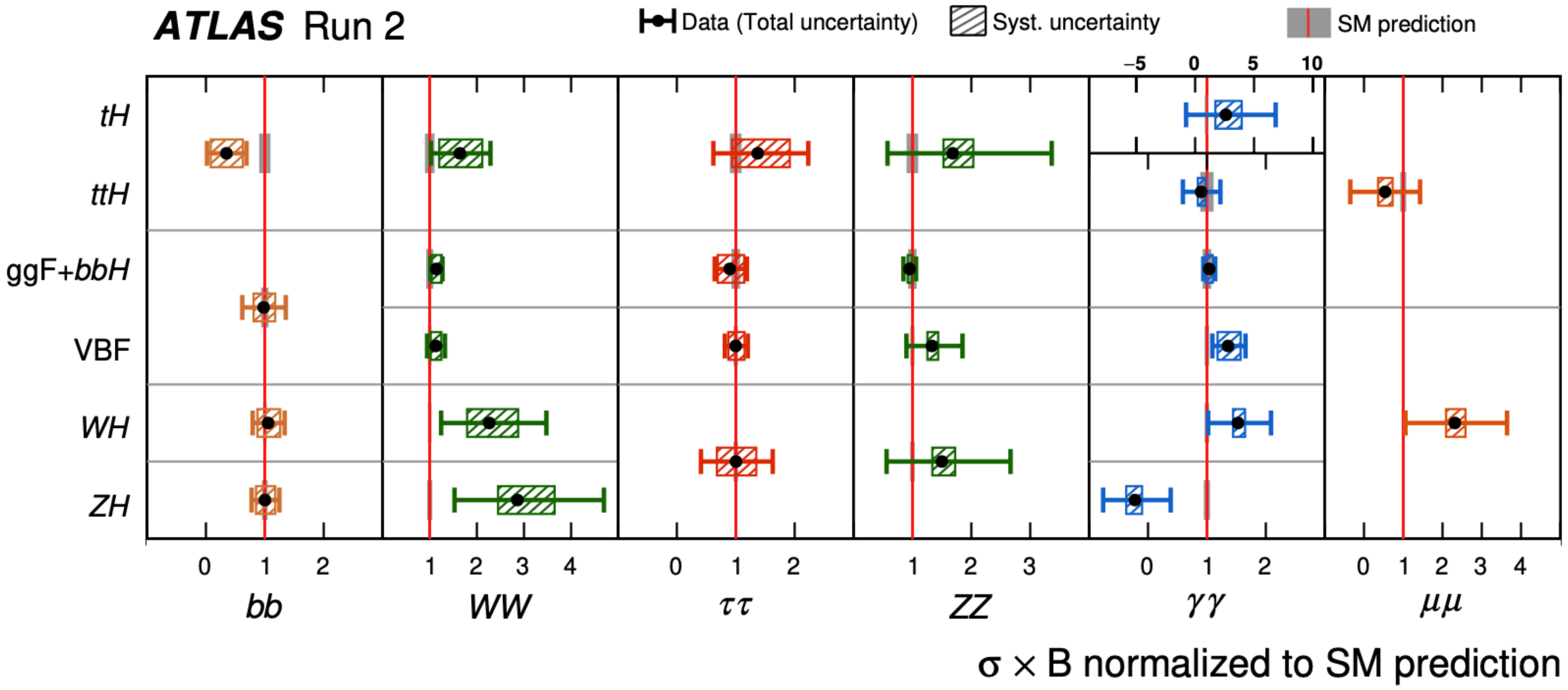
- $H \to ZZ^* \to 4l$ and $H \to \gamma\gamma$
  - Low BR and high mass resolution
- $H \to b\bar{b}, H \to W^{\pm}W^{\mp}, H \to \tau^{+}\tau^{-}$ and $H \to c\bar{c}$
  - High BR and low mass resolutions
- Rare decays: $H \to \mu^{+}\mu^{-}$ and $H \to Z\gamma$
  - BR = 2.17 × 10−4 (at mH = 125.09 GeV)
  - BR = 1.54 × 10−3 (at mH = 125.09 GeV)



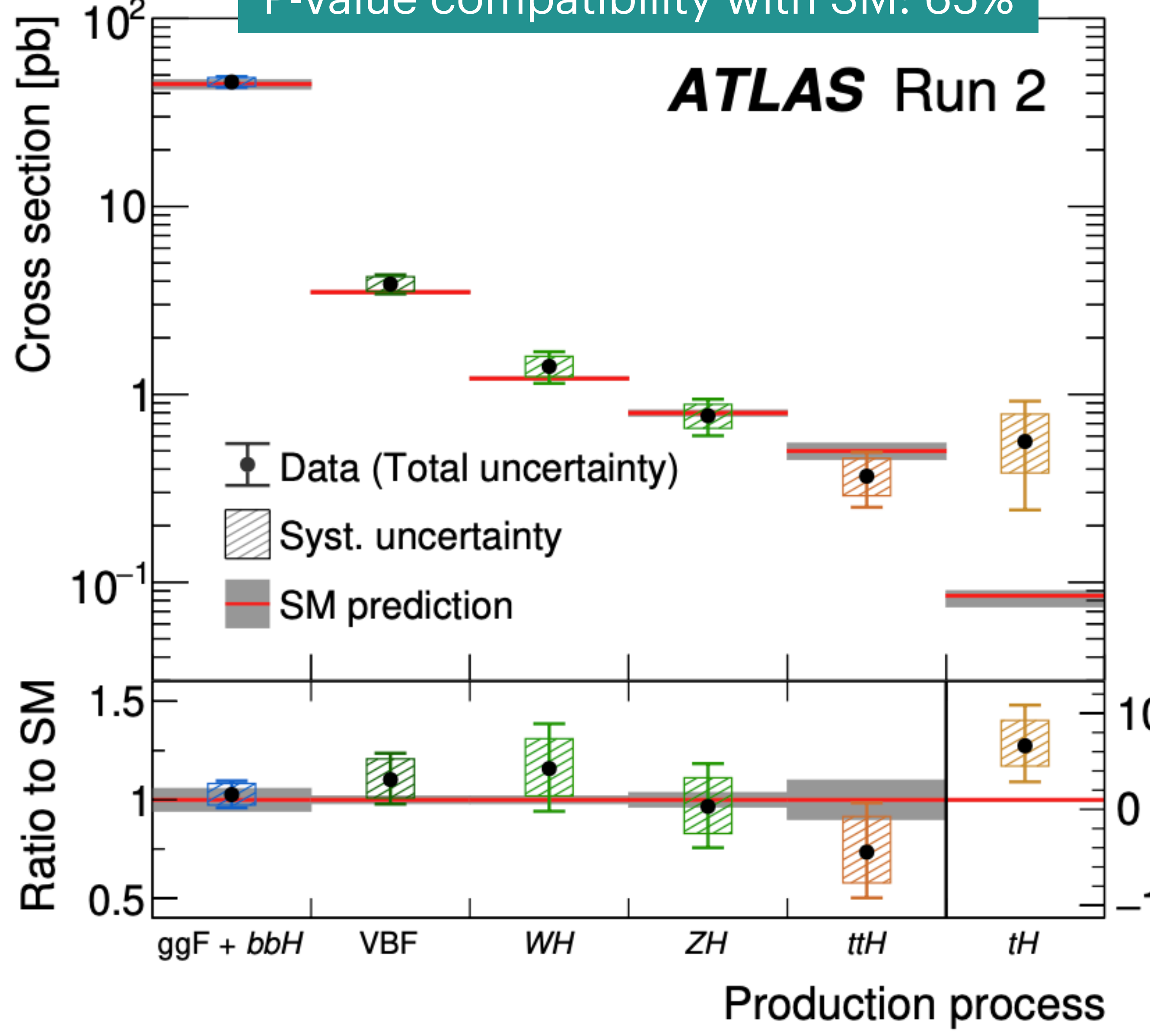
Recap of ATLAS Run2 measurements (Nature)

- **Production cross sections (free parameter in the fit, BR fixed to SM values):**
  - ggF and VBF observed in Run1, precision in Run2 7% and 12% respectively
  - Observed in Run2: WH (5.8σ), ZH (5.0σ) and $ttH + tH$ (6.4σ)
- **Branching ratio (free parameter in the fit, XS fixed to SM values):**
  - $\gamma\gamma$, ZZ, $W^{\pm}W^{\mp}$ and $\tau^{+}\tau^{-}$ already observed during Run 1, precision in Run2 ranges from 10% to 12%
  - $H \rightarrow b\bar{b}$ decay mode observed with 7.0σ, $H \rightarrow \mu^{+}\mu^{-}$ and $H \rightarrow Z\gamma$ signal significances measured to be 2.0σ and 2.3σ, respectively

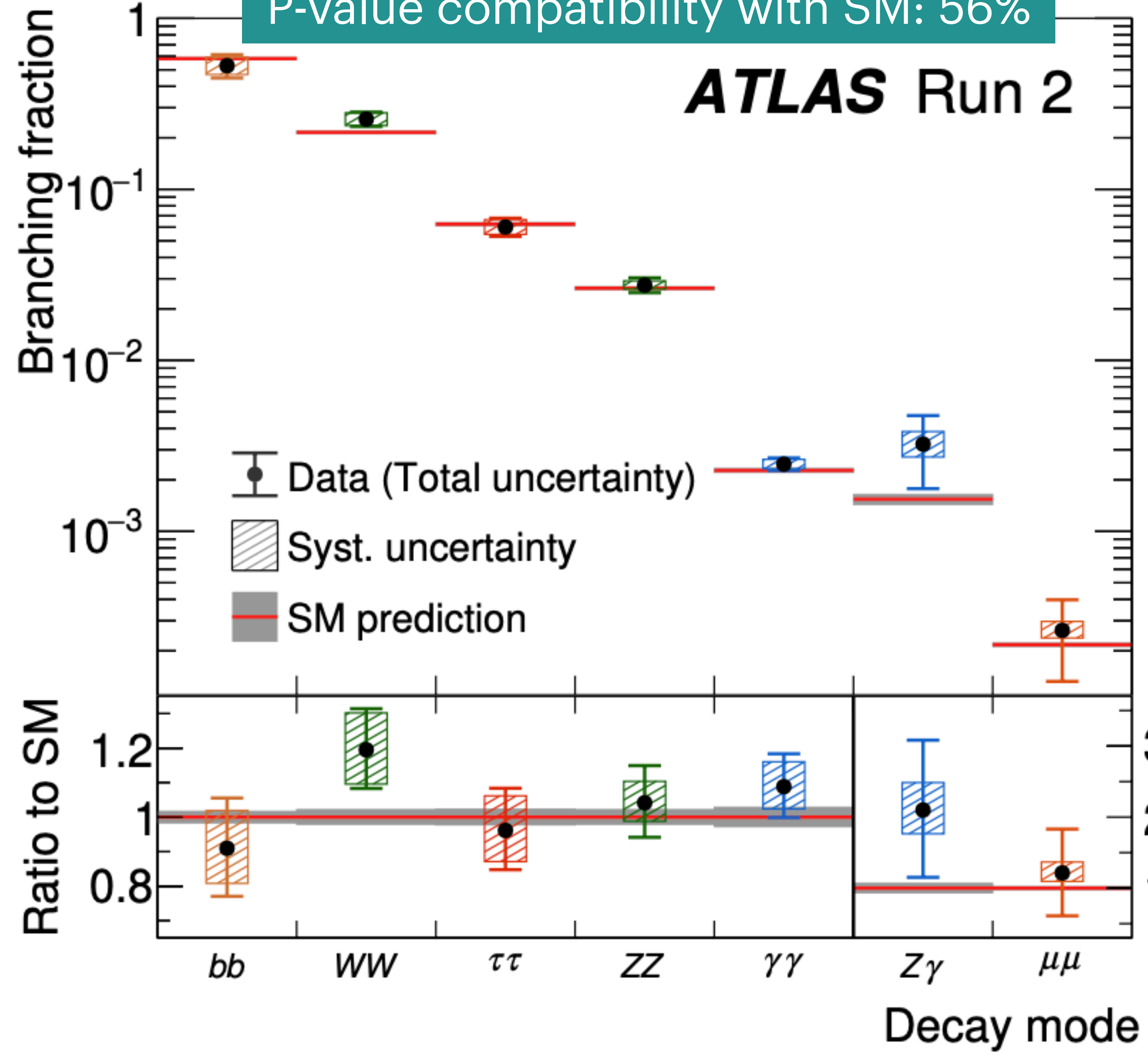
P-value compatibility with SM: 72%



P-value compatibility with SM: 65%



P-value compatibility with SM: 56%



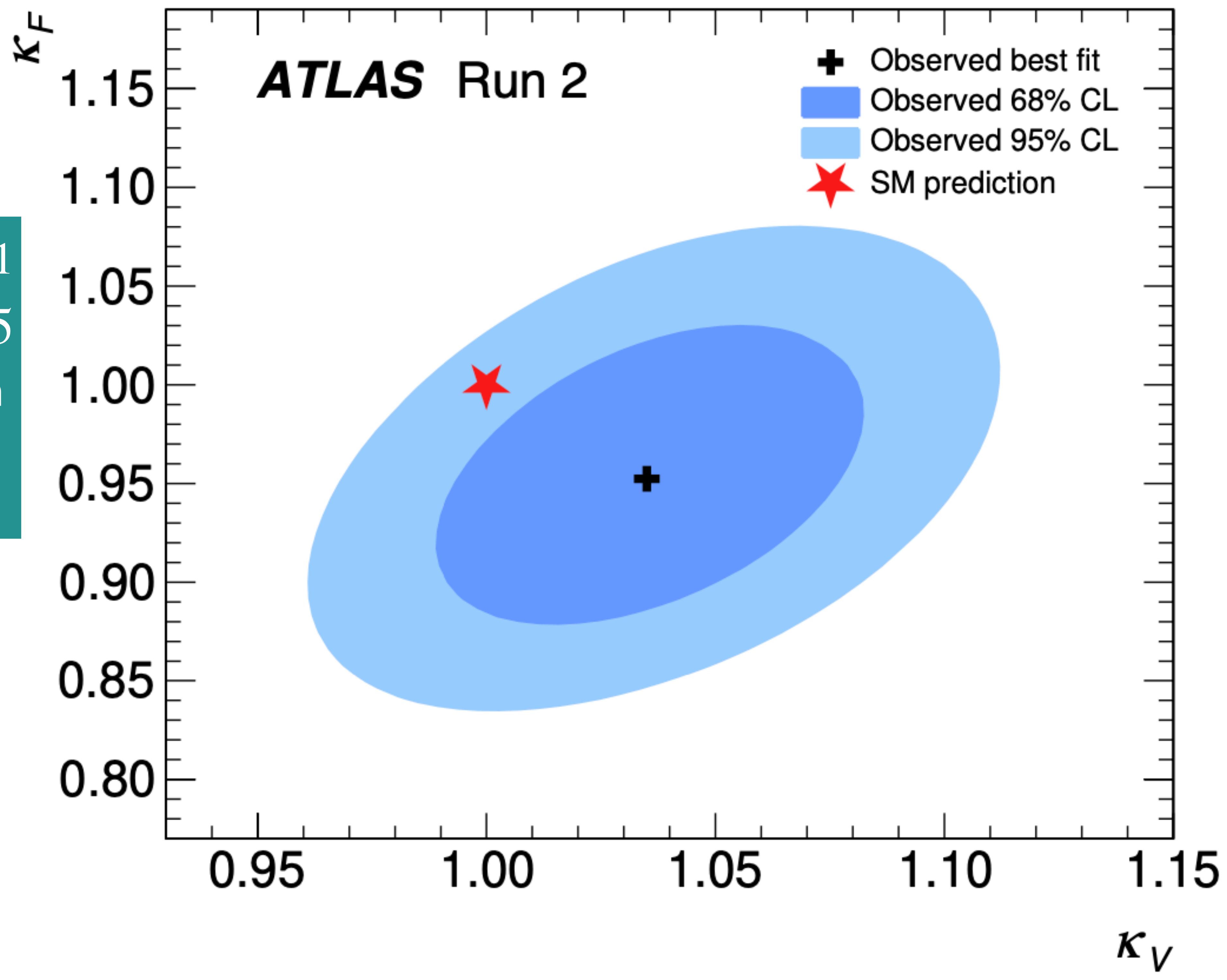
Nature, vol. 607, 52-59 (2022)

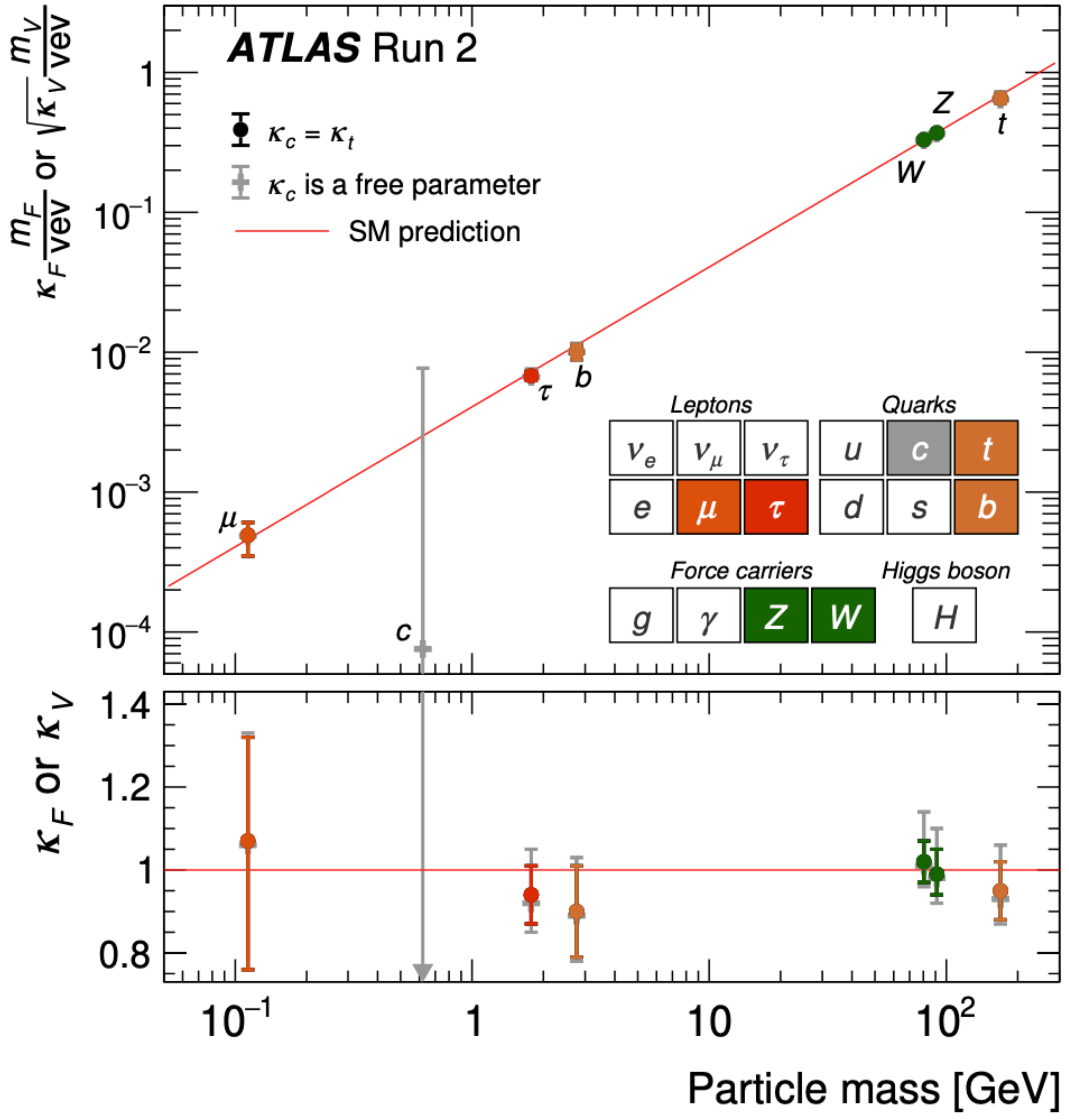
Recap of ATLAS Run2 measurements (Nature)

[Nature, vol. 607, 52-59 (2022)]

- $\sigma \times B$ **is parametrized in terms of multiplicative coupling strength modifiers (κ) (κ-framework)**
  - Total decay width accounts for all decay modes, direct/indirect decays and hypothetical decays to non-SM particles
- $\kappa_V = \kappa_Z = \kappa_W$ **(for the weak bosons),** κ_F **(all fermions)**
  - Assuming no invisible or undetected Higgs Boson decays beyond SM ($B_{inv.} = 0$ and $B_{u.} = 0$)
- **Higgs Boson coupling to SM particles as a function of their masses:** $\kappa_W, \kappa_Z, \kappa_t, \kappa_b, \kappa_c, \kappa_\tau, \kappa_\mu,$ are treated independently

$\kappa_V = 1.035 \pm 0.031$
$\kappa_F = 0.95 \pm 0.05$
Compatible with SM predictions (p-value 14%)





Compatible with SM predictions
(p-value 56% for $\kappa_c = \kappa_t$)
(p-value 65% for κ_c floating)

New single Higgs combination: input analysis channels

NEW RESULT - - ATLAS-CONF-2025-006

Analysis channel	Production mode	Luminosity (fb-1)	STXS stage	Improv. Wrt Nature
H->yy	All	140	1.2	-
H->ZZ*->4l	All	140	1.2	-
H->tautau	All	140	1.2	**Reanalysis**
H->WW*->lnulnu	ggF, VBF	140	1.2	**Reanalysis**
H->WW*->lnulnu	VH	140	1.2	**Full Run2**
H->bb	VBF	126	1.2	-
H->bb,cc	VH	140	1.2	**Reanalysis**
H->multileptons	ttH	36.1	1.2	-
H->bb	ttH	140	1.2	**Reanalysis**
H->tautau	VH	140	0	**New analysis**
H->Zy (*)	All	140	0	-
H->mumu (*)	All	140	0	-

(*) new results including Run 3 dataset

Phys. Lett. B 855 (2024) 138817

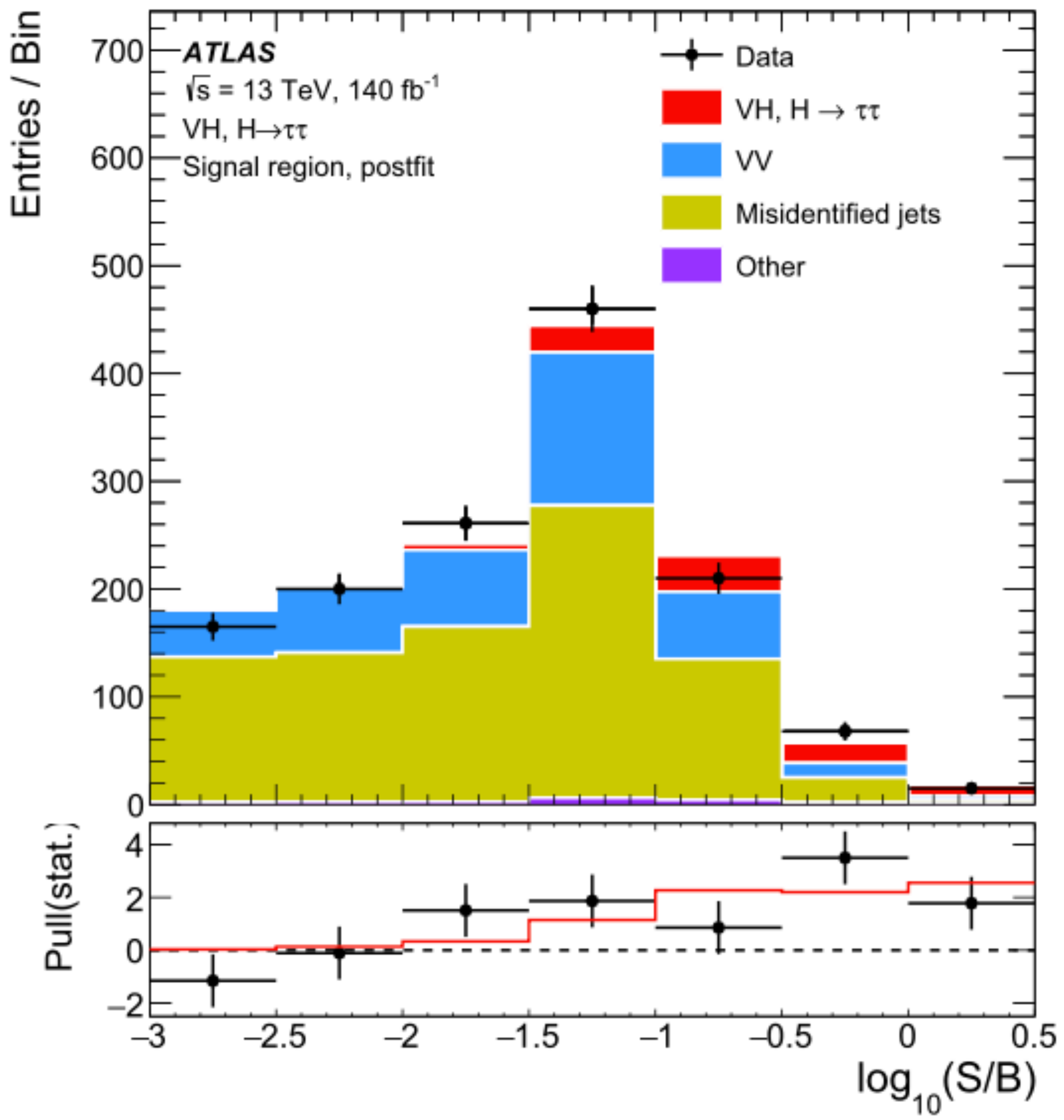
$H \rightarrow \tau\tau$ analysis

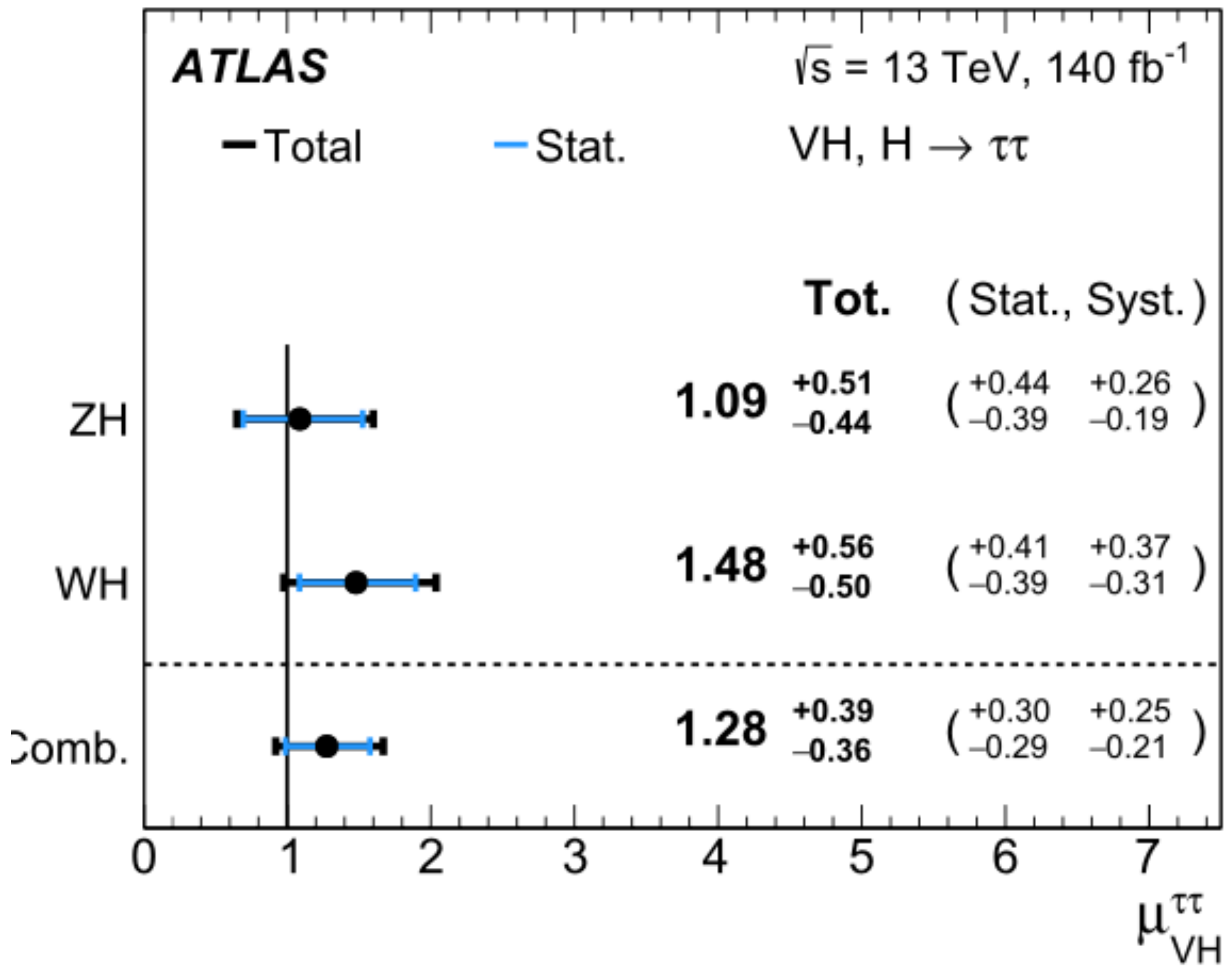
VH analysis (newly) included in the combination

- ~7x larger dataset wrt previosu analysis (Run1, 20.3 fb-1)
- NN-based for better signal and background rejection
- Better $\tau_{had-vis}$ (visible products of hadronically decaying τ-leptons) indentification algorithms

Main analysis: NN as fit discriminant

- Check with mass-based analysis (m_{MMC}), where MMC stands for Missing Mass Calculator





NN analysis:

- Observed (expected) significance 4.2σ (3.6σ)
- Signal strength: $\mu_{VH}^{\tau\tau} = 1.28^{+0.39}_{-0.36}$

Mass-based analysis:

- Observed (expected) significance 3.5σ (2.6σ)
- Signal strength: $\mu_{VH}^{\tau\tau} = 1.40^{+0.49}_{-0.45}$

Most sensitive measurement of the $VH, H \rightarrow \tau\tau$

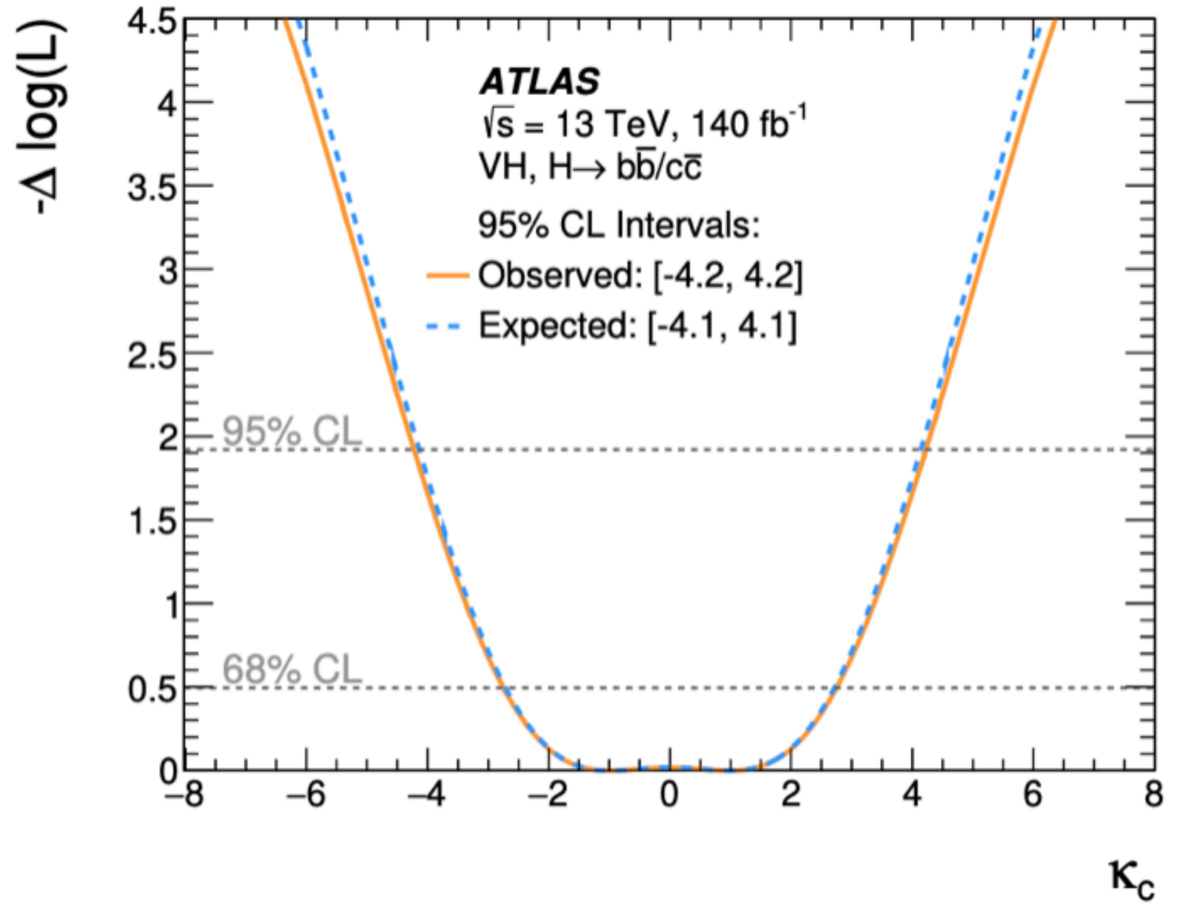
$H \to bb/cc$ **analysis**

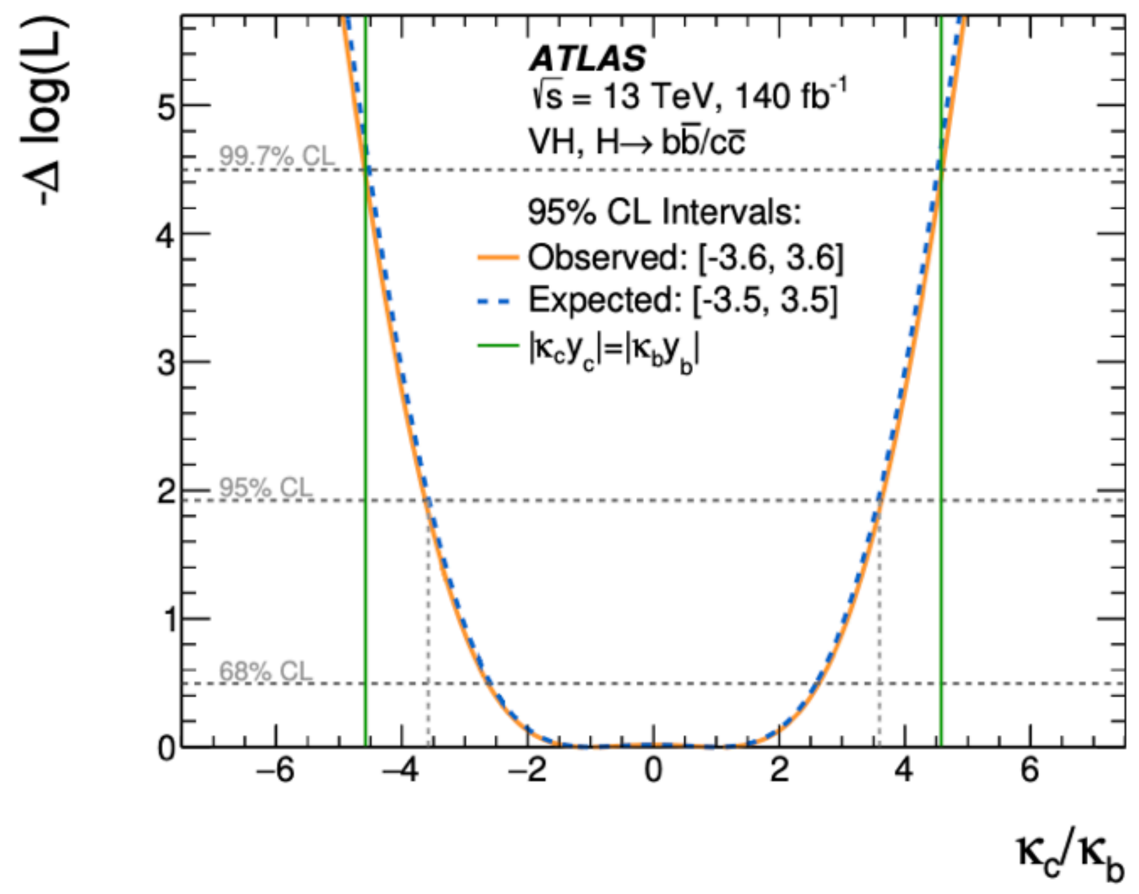
A few improvements with respect to previous analysis (VH, reanalysis):

- Better reco. and calib. of leptons and jets and FTAG algorithm
- Extended acceptance for the WH process to events with pVT < 150GeV
- First application to the H → b¯b boosted regime and H → cc¯ search
- Increased granularity of STXS measurements: high pT and as a function of jet multiplicity

- **Limits on $|\kappa_c| < 4.2$ (obs) at 95% CL and $|\kappa_c/\kappa_b|$ is 3.6 (obs) at 95% CL**

JHEP 04(2025) 075



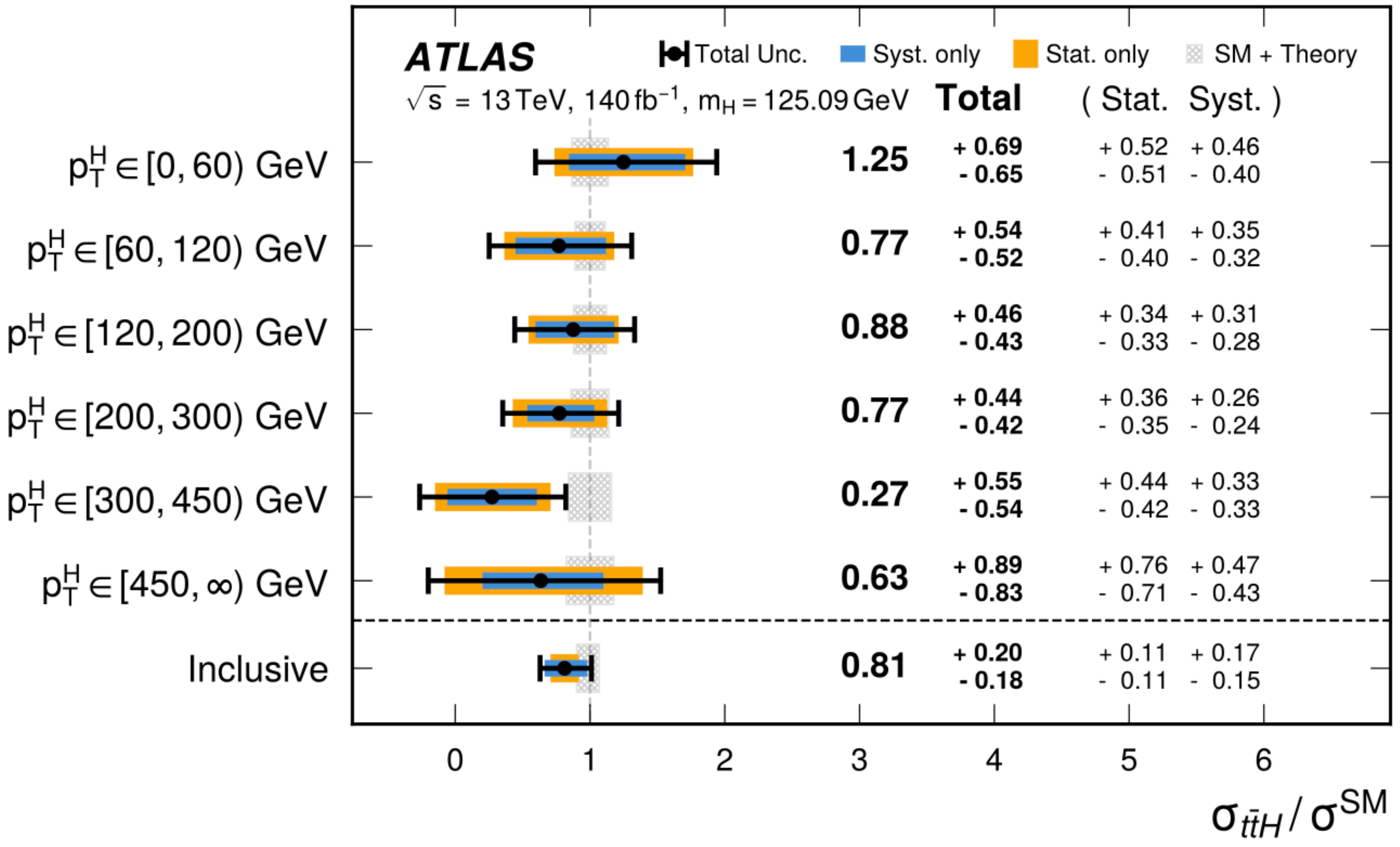


A few improvements with respect to previous analysis (ttH(bb), reanalysis):

- Looser selection requirements and improved b-jet ID that increase the $t\bar{t}H$ signal acceptance
- Control regions enriched in each of the $t\bar{t}$ + jets components defined based on a more powerful multi-class neural network
- Modelling uncertainty in $t\bar{t} + \geq 1b$ is no longer the dominant contribution to the total systematic uncertainty

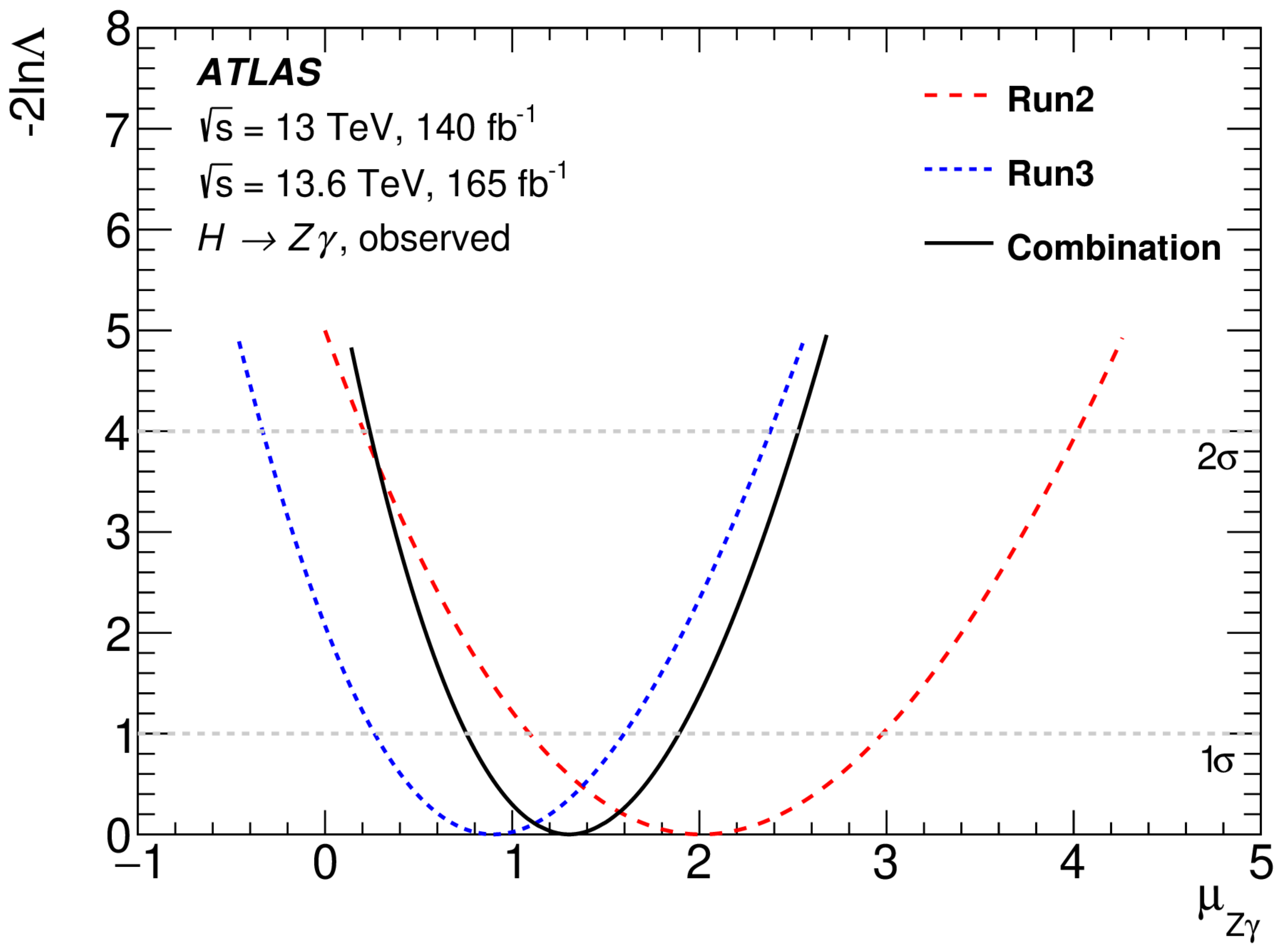
- **This analysis is the most precise *ttH* cross-section measurement in a single decay channel, inclusively and in each p_T^H bin**

Eur. Phys. J. C 85 (2025) 210



Higgs boson Rare decays

- $H \rightarrow Z\gamma$ **Run2 analysis results:**
  - Significance observed (expected) with a mass of 125.09 GeV is 2.2σ (1.2σ)
  - $\mu = 2.0^{+1.0}_{-0.9}$ (dominated by statistical uncertainty
- **Run2 ATLAS + CMS analysis results:**
  - Significance = 3.4σ (1.6σ, exp.) *(Evidence!!!!)*
  - $\mu = 2.2 \pm 0.7$ $(1.0 \pm 0.6,$ exp.)
- **New analysis: Full Run2 + partial Run 3**

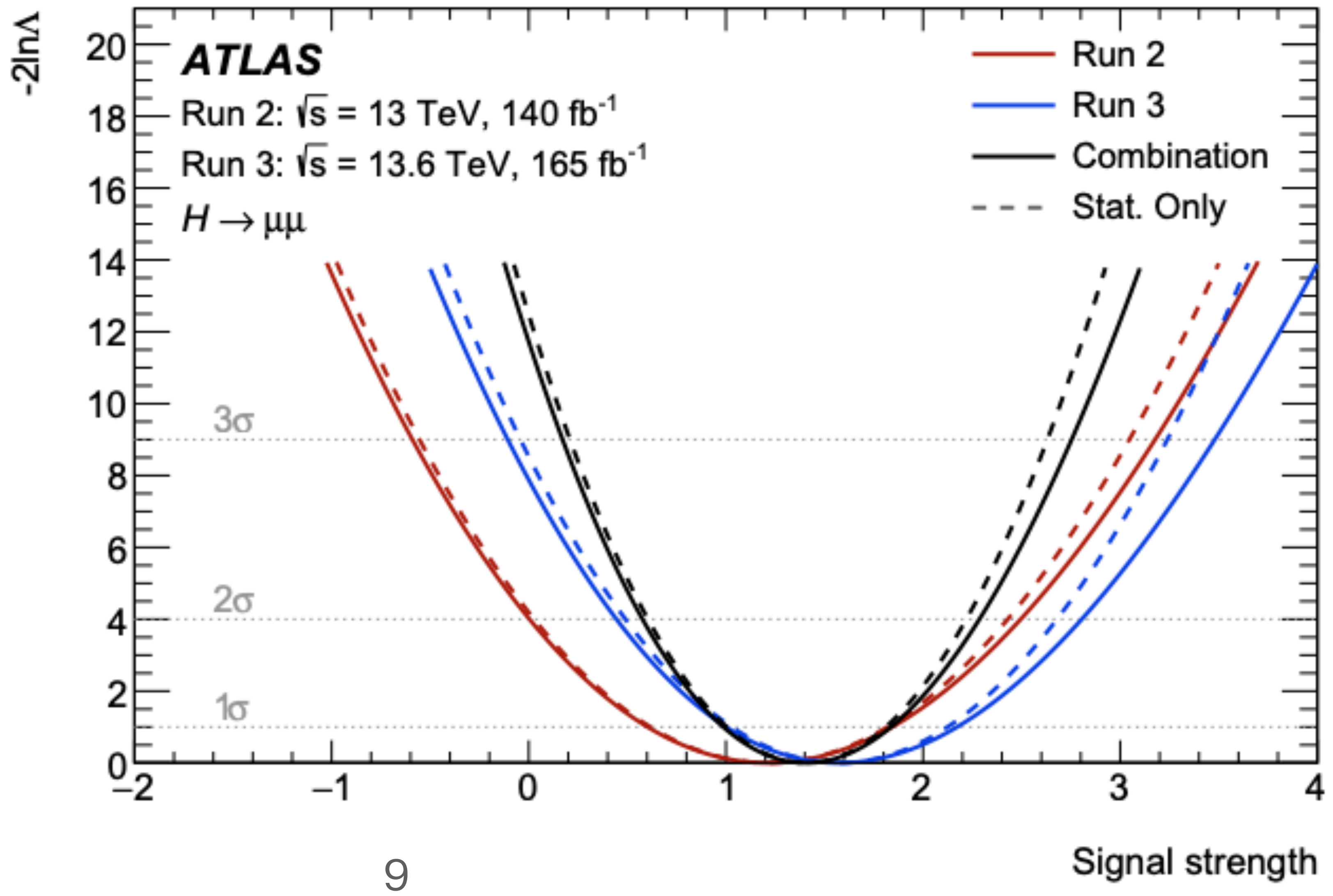


$\mu = 1.3^{+0.6}_{-0.5}$

Obs. (Exp.) significance $= 2.5\sigma$ (1.9σ)

ATLAS-CONF-2025-007

- $H \rightarrow \mu\mu$ **Run2 analysis results:**
  - Significance observed (expected) with a mass of 125.09 GeV is 2.0σ (1.7σ)
  - $\mu = 1.2 \pm 0.6$
- **New analysis (Full Run2 + partial Run 3):** ***Evidence!!!!***



$\mu = 1.4 \pm 0.4$

Obs. (Exp.) significance $= 3.4\sigma$ (2.5σ) (bkg-only hypothesis)

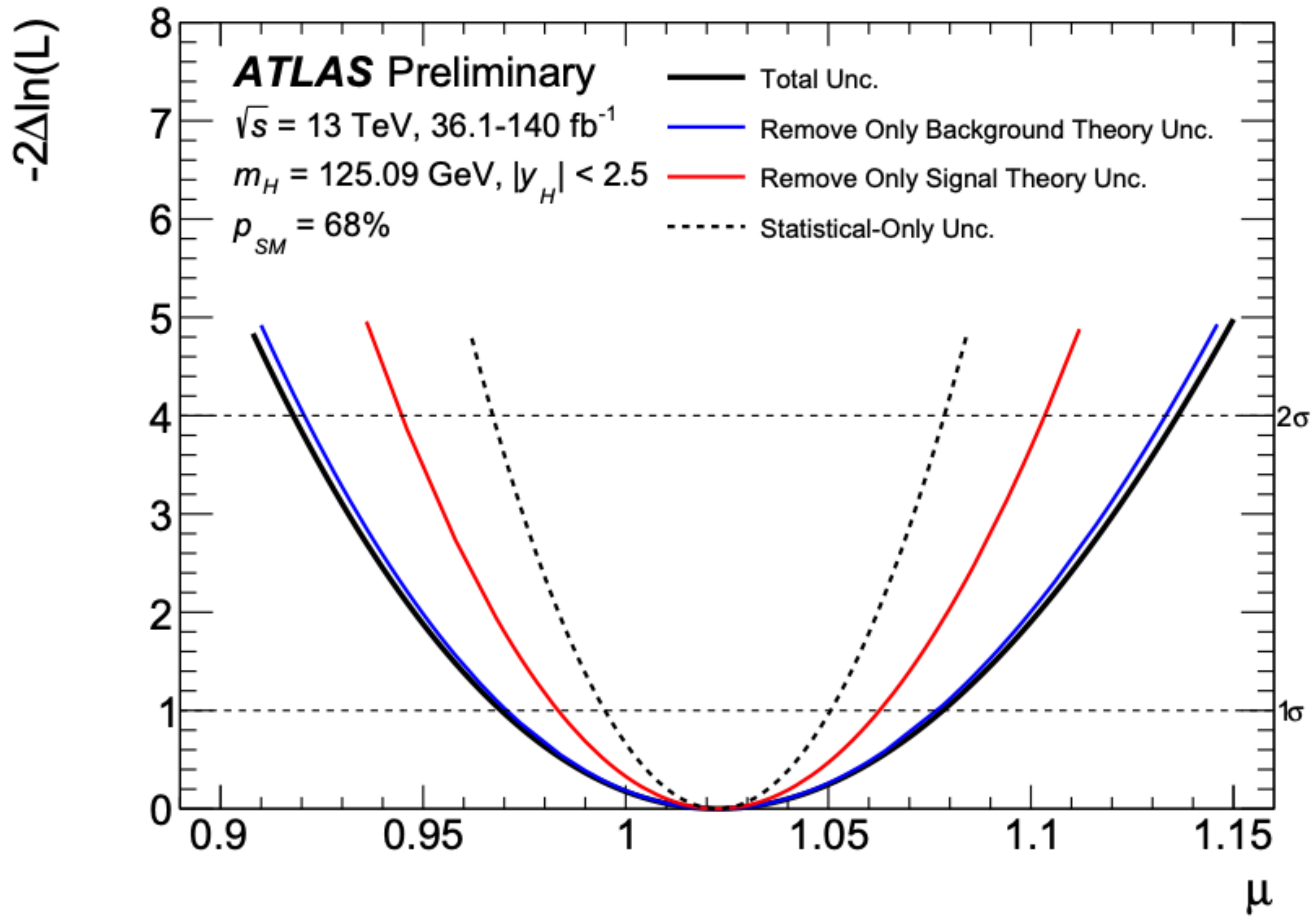
arXiv:2507.03595

Global Signal strength (μ)

- Rate of Higgs boson production and decay processes:

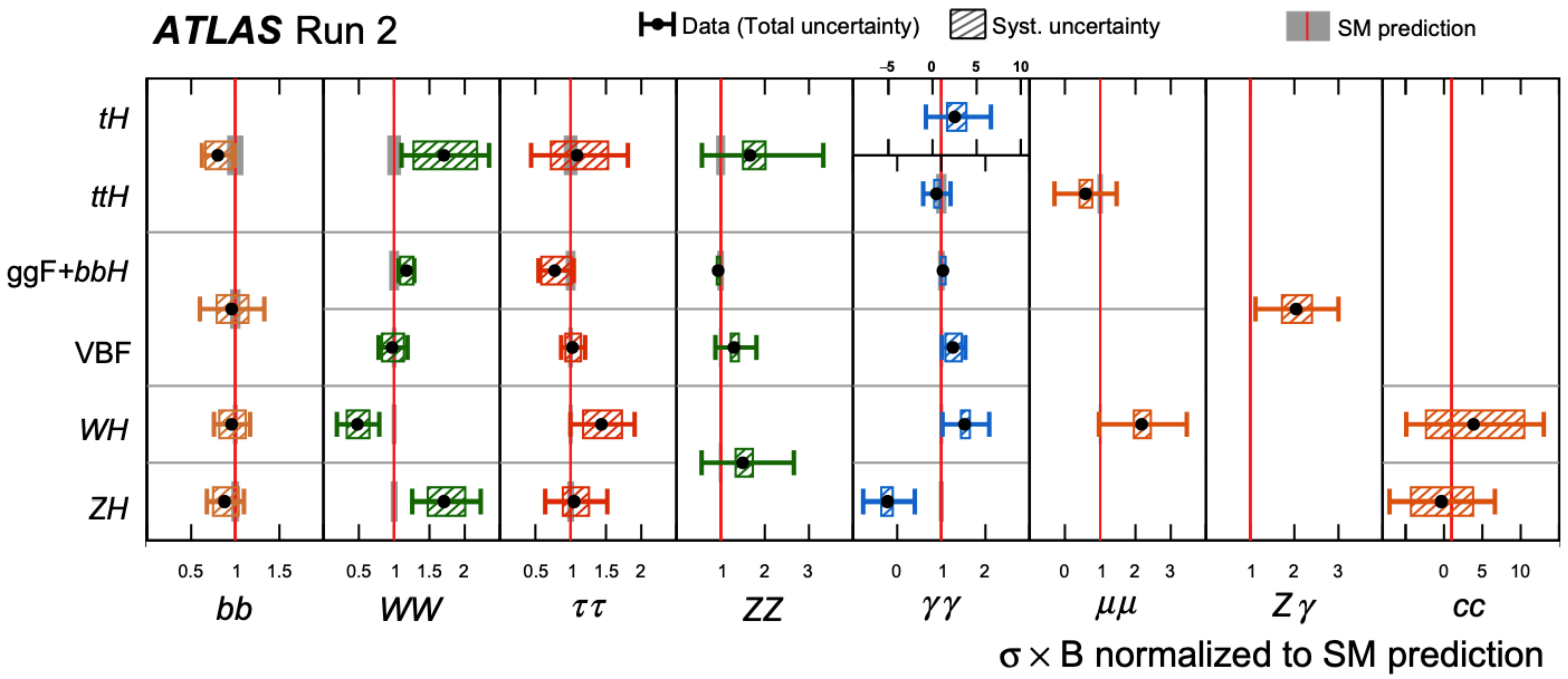
- $$\mu_{if} = \frac{(\sigma_i \times B_f)}{(\sigma_i^{SM} \times B_f^{SM})} = 1.023 \pm 0.028\ (\text{stat.})\ ^{+0.026}_{-0.025}\ (\text{exp.})\ ^{+0.039}_{-0.036}\ (\text{sig. theo.})\ \pm 0.012\ (\text{bkg. theo.})$$

- Around <u>10% reduction</u> in the total uncertainty with respect to Nature result (1.05 ± 0.06)
- Measurement in good agreement with respect to SM:
  - P-value compatibility at 68%



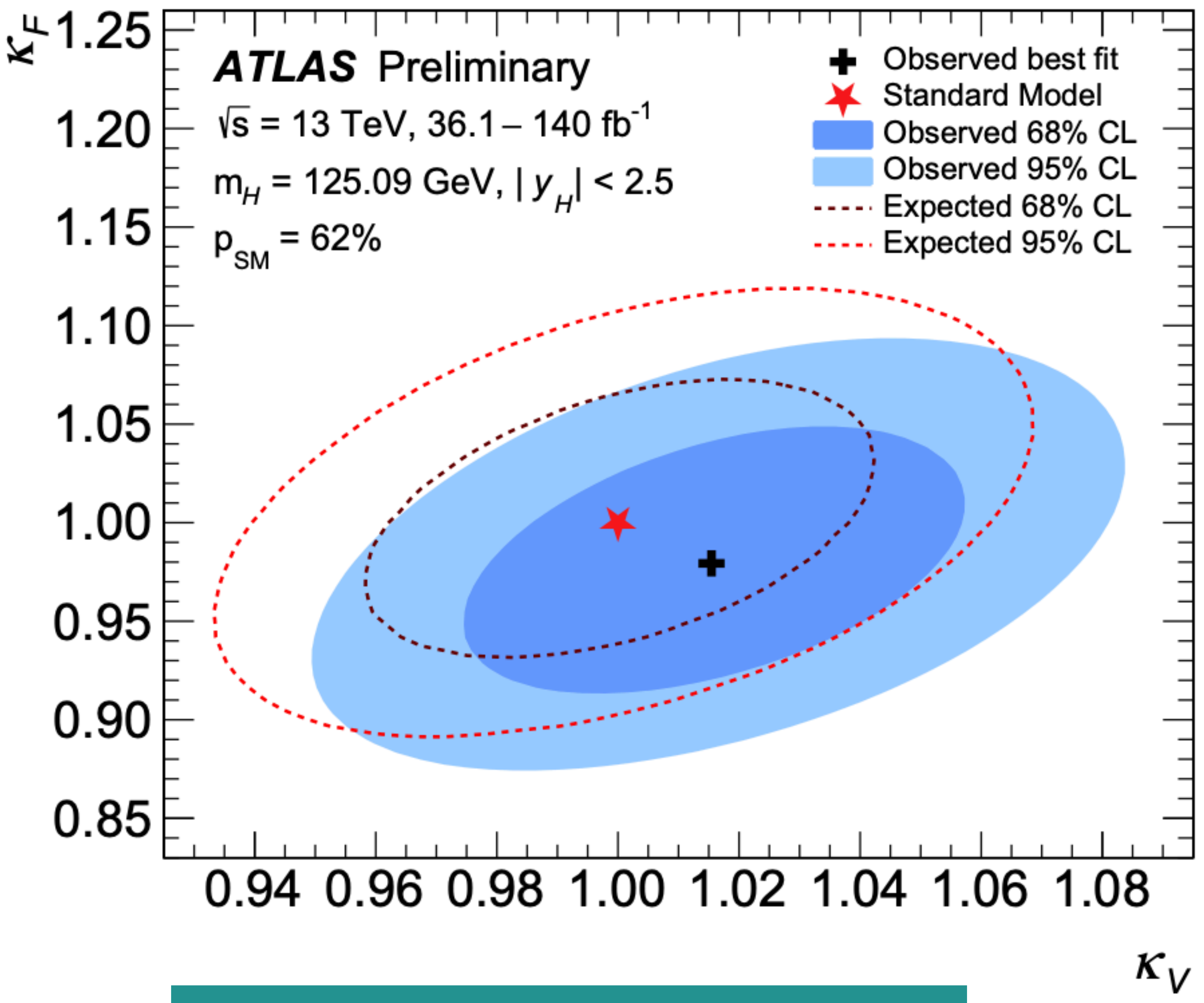
Higgs Boson production rates measurements

- Measurements for different combinations of production and decay processes
  - Relaxed assumptions by measuring the $\sigma \times B$
- Combine or separating production modes:
  - driven by experimental sensitivity and ability to distinguish different process in a given decay channel
- **Good agreement between the measurements and SM predictions**



P-value compatibility with SM: 85%

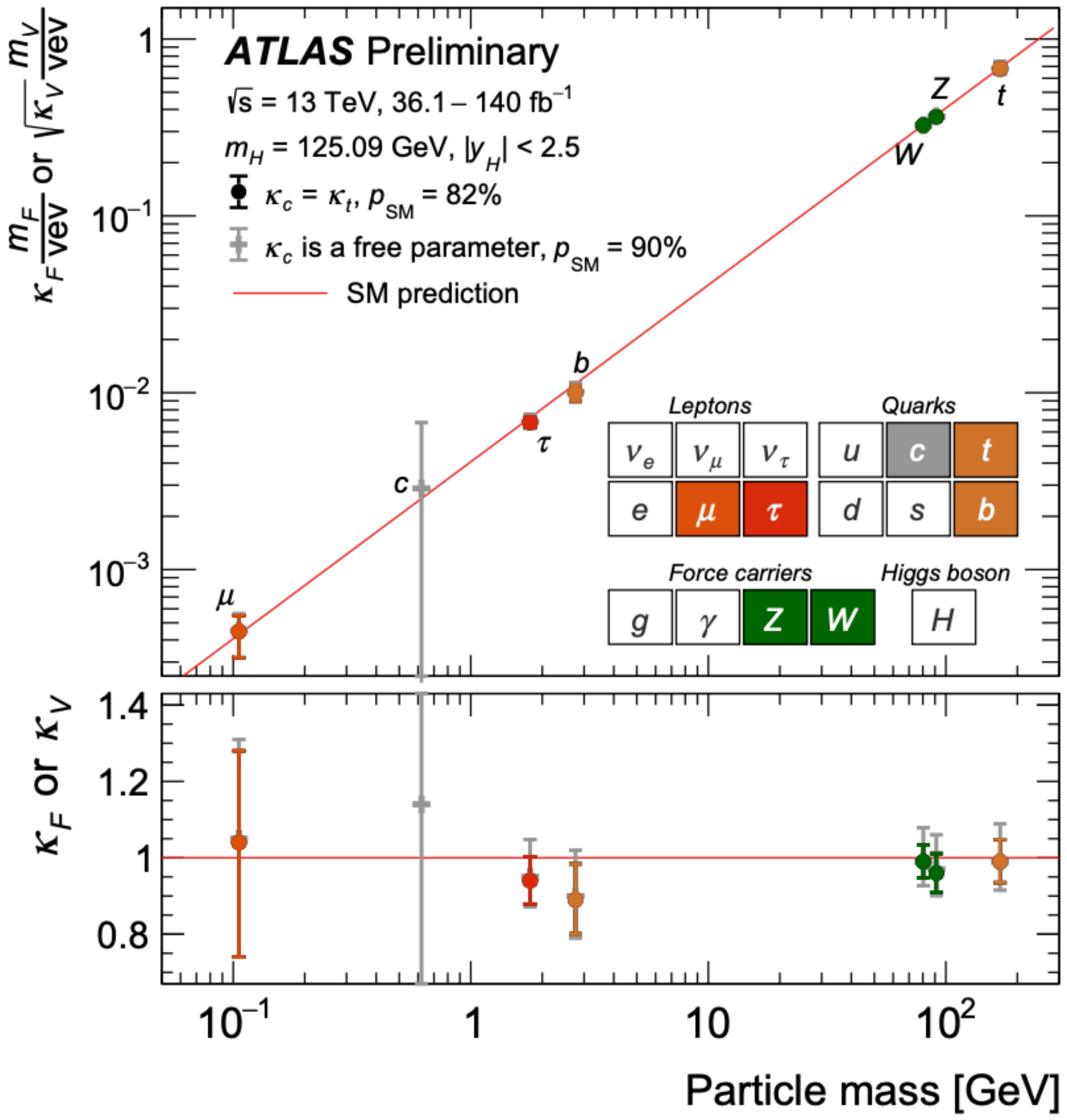
Higgs Boson coupling measurements



$\kappa_V = 1.015^{+0.028}_{-0.027}$

$\kappa_F = 0.979^{+0.044}_{-0.045}$

Compatible with SM predictions (p-value 62%)



Compatible with SM predictions (p-value 90%) for resolved parametrization

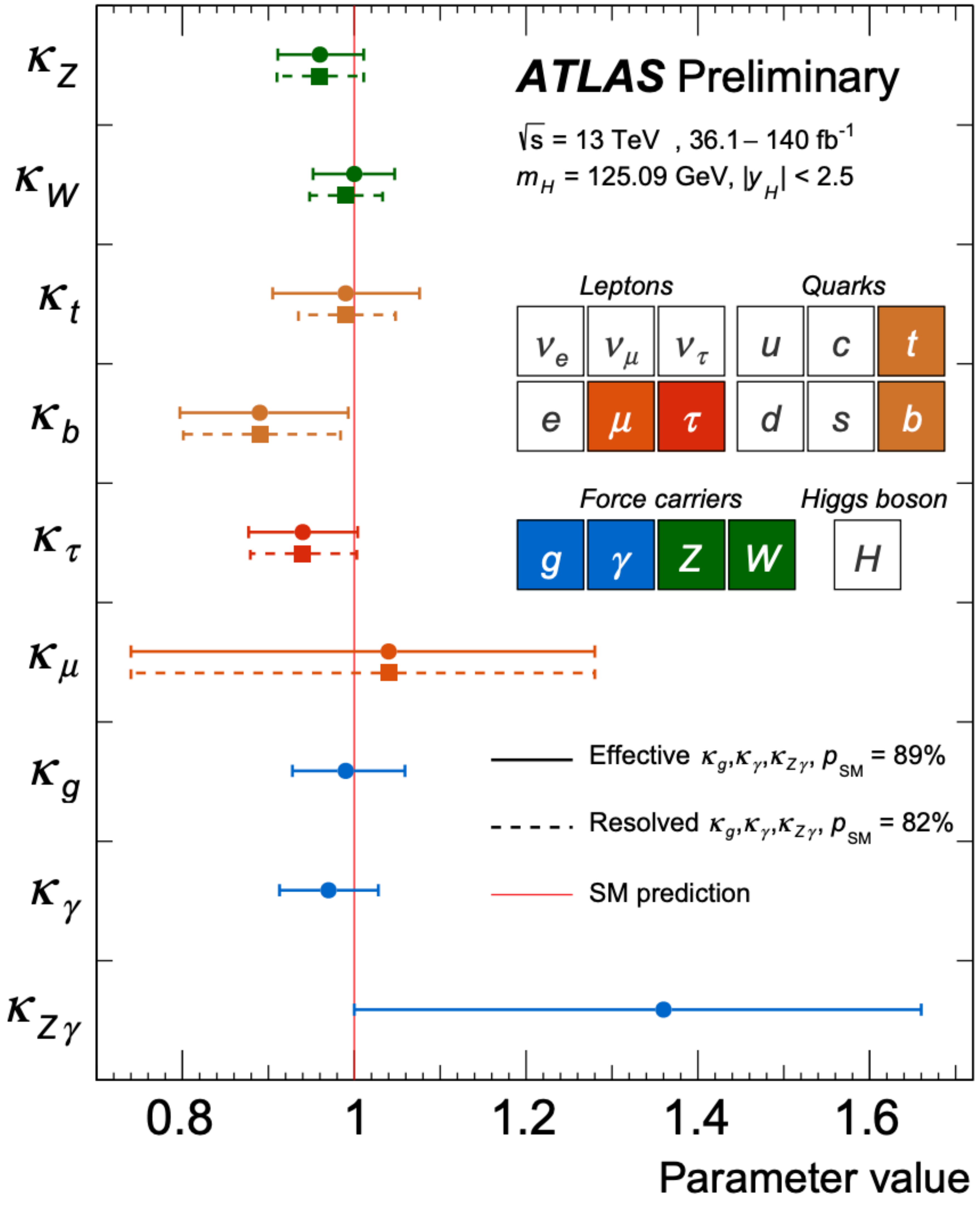
Improvements: VH, H(WW*) with lower kV and ttH(bb), with higher kF

Improved VH, H(cc) constraints halved uncertainty on κ_c; uncertainty on κ_t improved 15% (vs. Nature).

Higgs Boson coupling measurements

- **$\sigma \times B$ is parametrized in terms of multiplicative coupling strength modifiers (κ) (κ-framework)**
  - Total decay width accounts for all decay modes, direct/indirect decays and hypothetical decays to non-SM particles
- **Higgs boson coupling modifiers in the effective parameterization:**
  - κ_g, κ_γ and $\kappa_{Z\gamma}$ are treated as independent parameters
  - Assuming $\kappa_c = \kappa_t$
  - Assuming no invisible or undetected Higgs Boson decays beyond SM

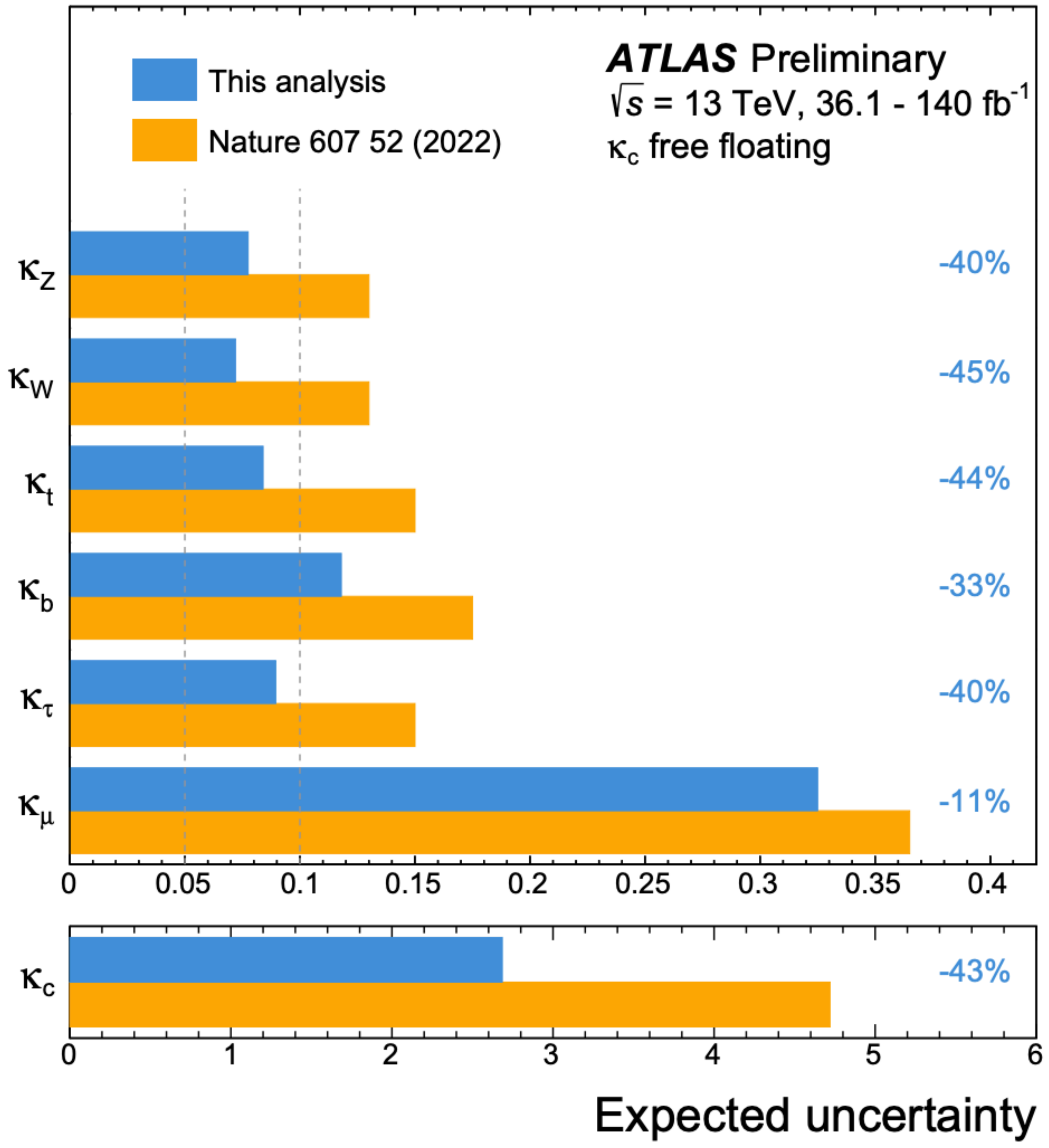
Compatible with SM predictions (p-value 89%) for effective parametrization



Coupling modifiers: expected uncertainties

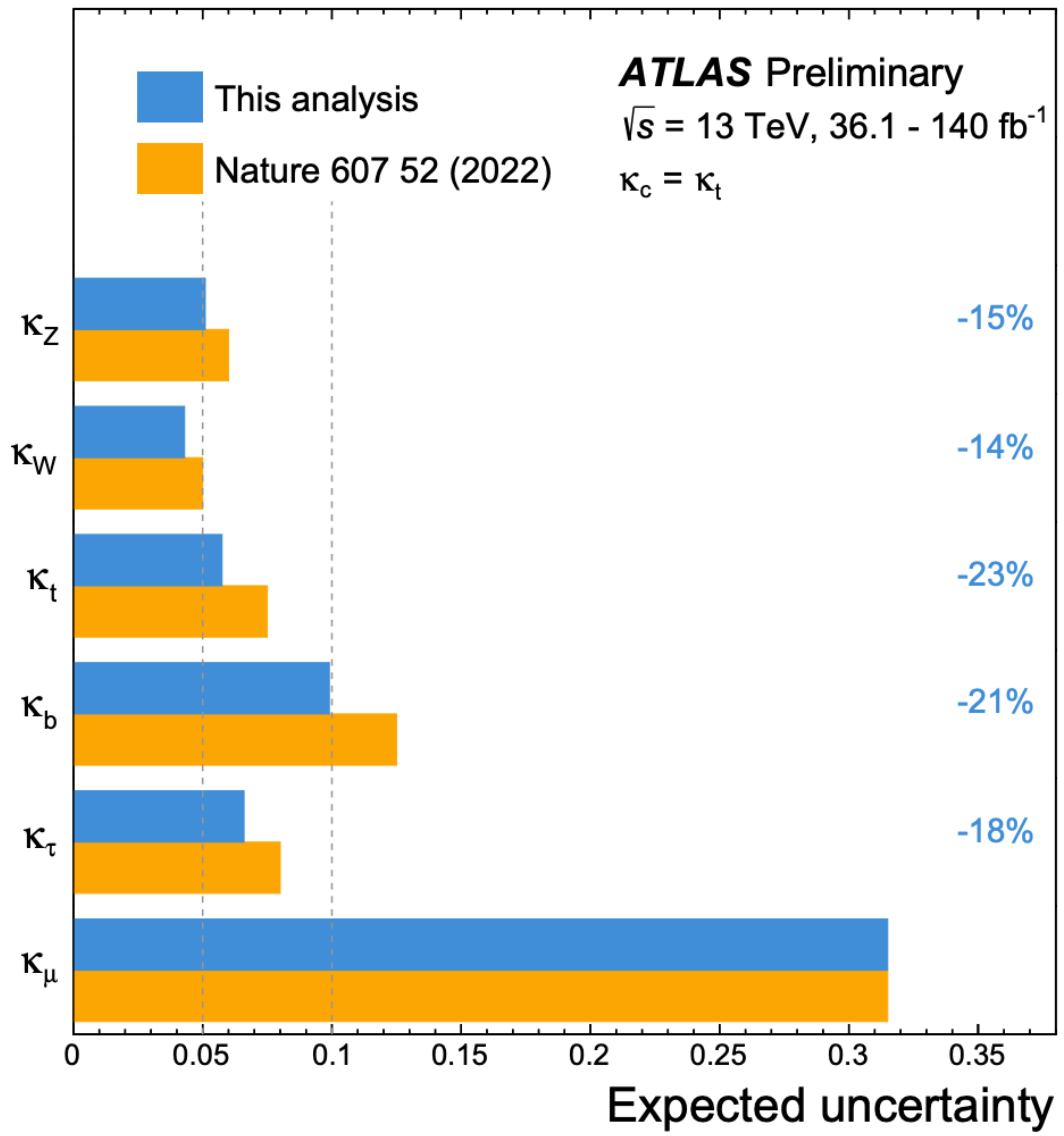
Resolved parametrization

κ_c as fit parameter



Reduction of 43% on exp. κ_c uncertainty (improved VH, H(cc) constraints)

Assuming $\kappa_c = \kappa_t$

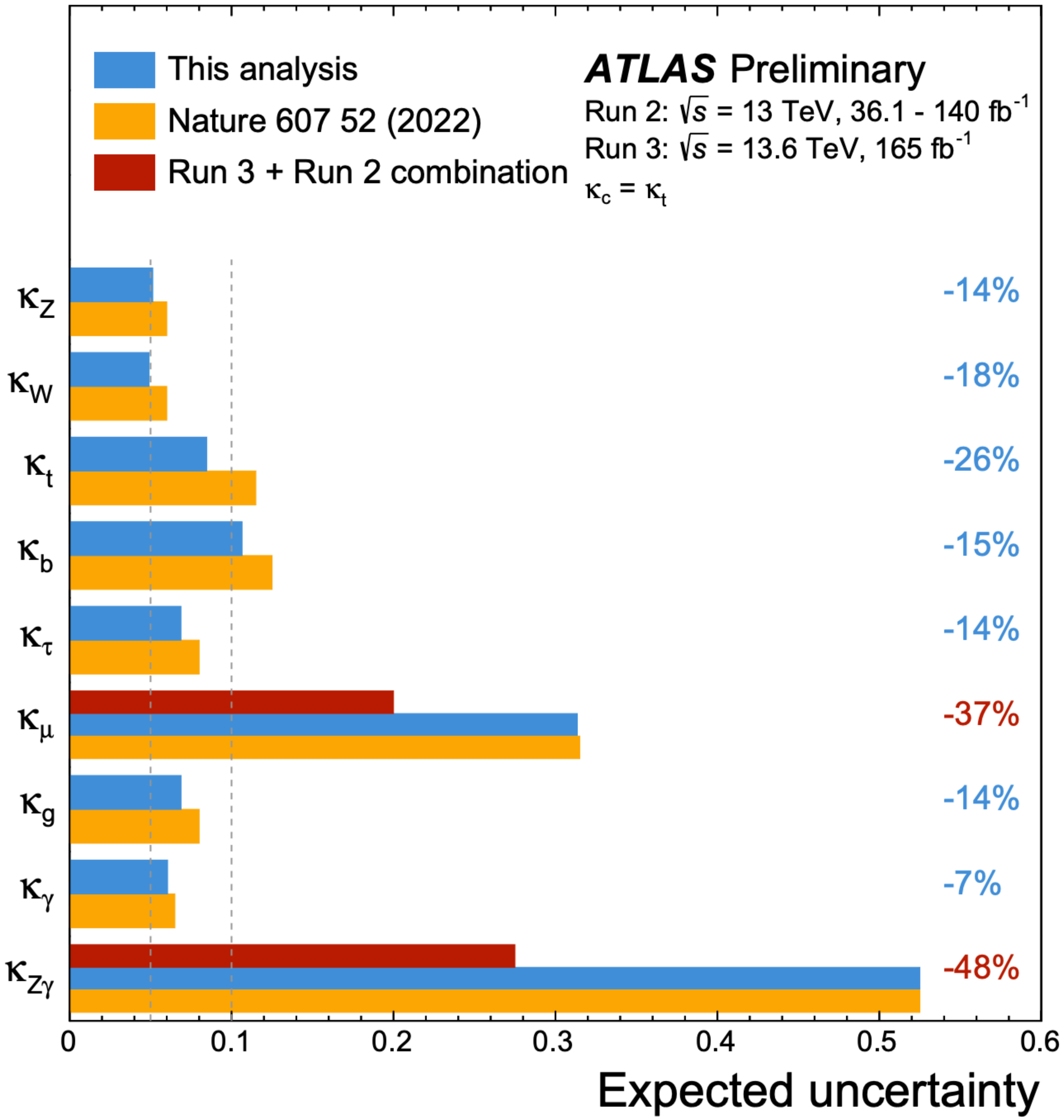


Reduction of 23% on exp. κ_t uncertainty

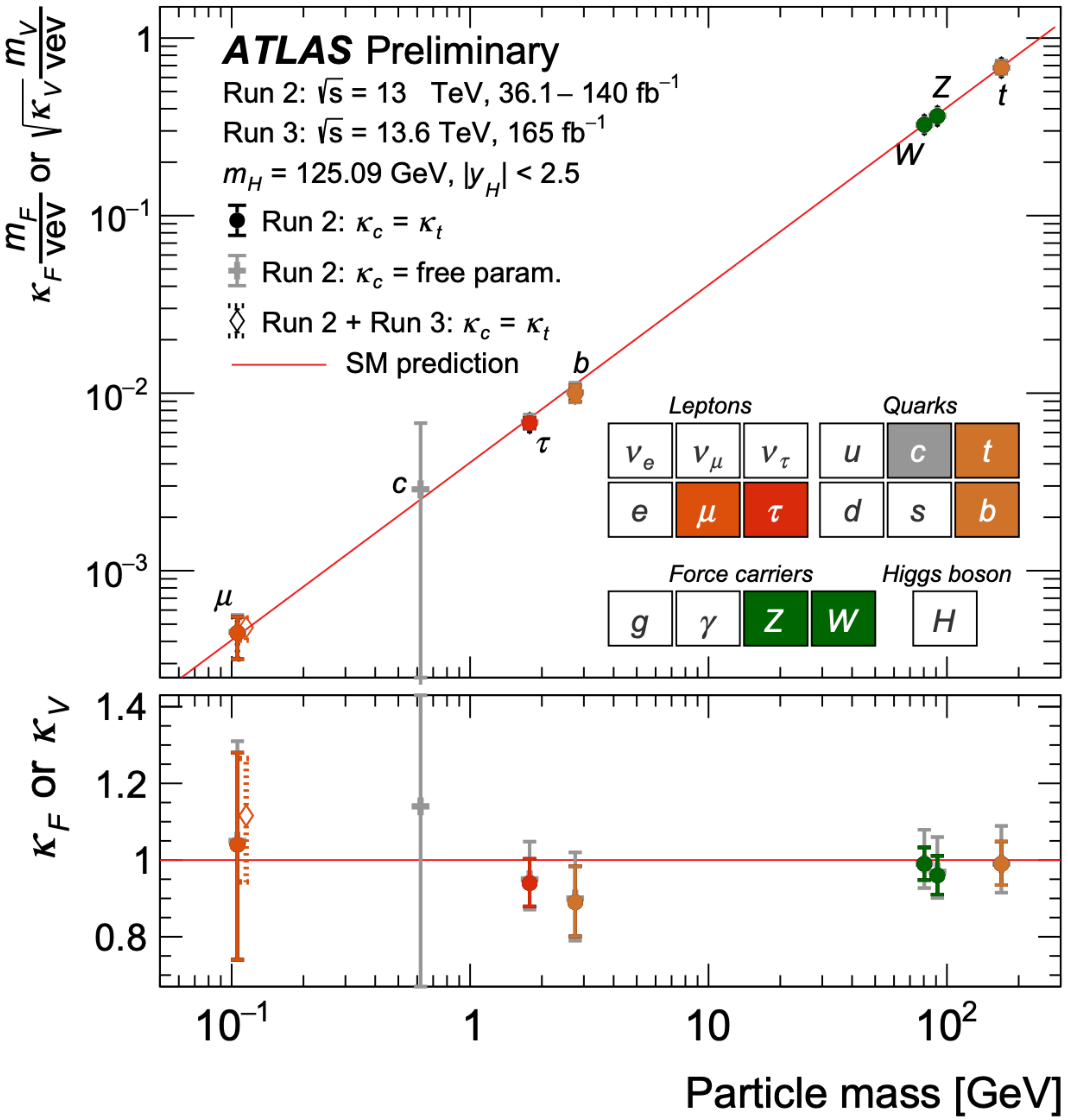
Run 2 + Run 3 Expected Uncertainties

Effective parametrization

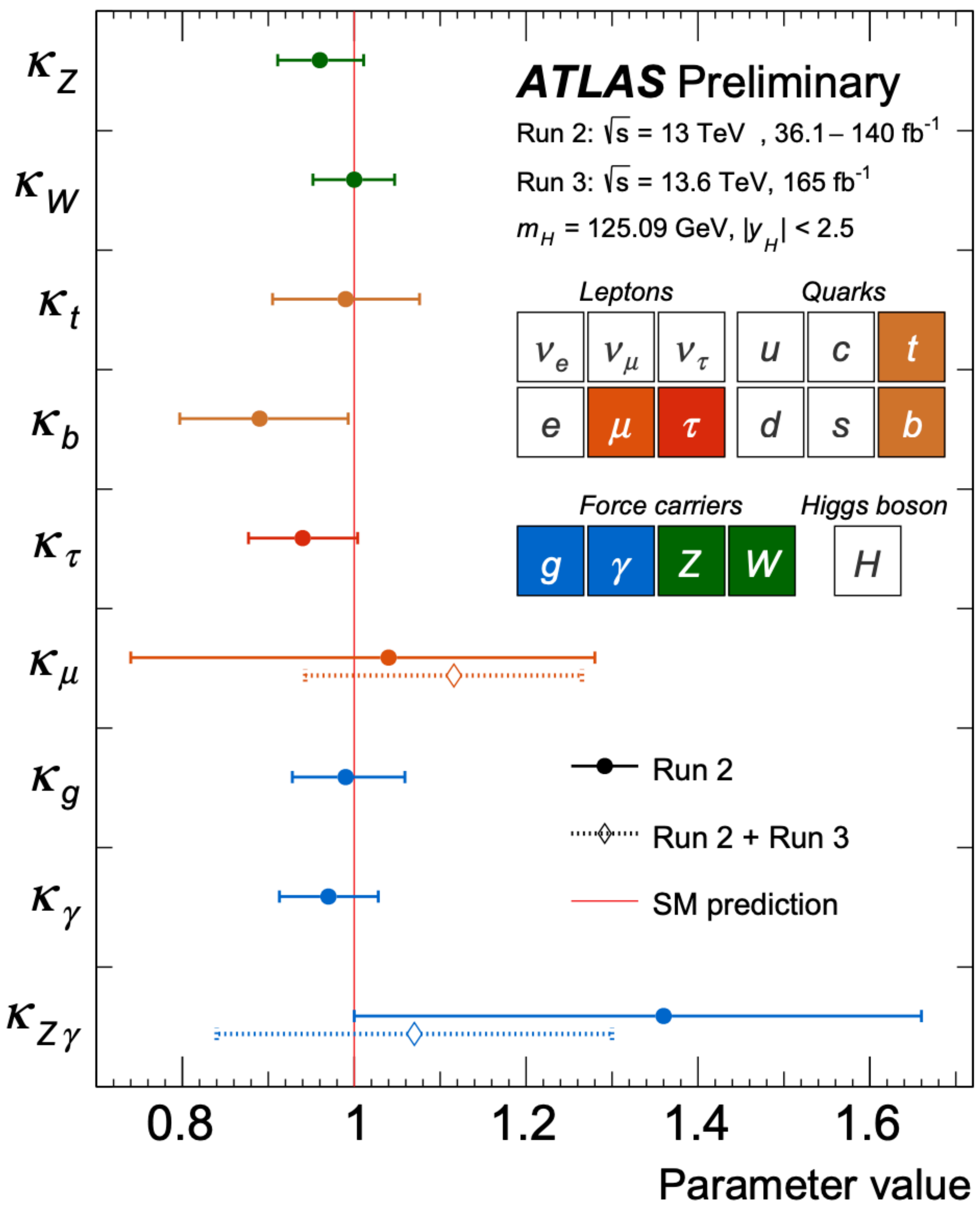
- Run3 dataset (2022, 2023 and 2024 = 165 fb-1) is used for analysis of H($\mu\mu$) and H($Z\gamma$)
- **Reduction on the expected uncertainty for κ_μ of about 37% while 48% reduction is expected for $\kappa_{Z\gamma}$**



Run 2 + Run 3 Coupling modifiers



Addition of Run3 data significantly reduces total uncertainty for κ_μ wrt Run2



Effective parametrization

Rel. improvement on the precision of κ_μ (~38%) and $\kappa_{Z\gamma}$ (~30%) adding Run3 data wrt Run2 measurements

Summary

The combination of the single Higgs measurements has been <u>updated</u> with the LHC Run 2 dataset:

- It allows to test the Higgs sector by measuring the Higgs production and decay rates and the its couplings to the SM particles
  - ***All measurement show excellent agreement with the SM predictions***
  - ***Uncertainty reduction of the order of 10% for the signal strength and as 43% for the expected uncertainty on κ_c***
- Addition of channels with partial Run3 significantly improves precision on couplings:
  - **Sensitivity is enhanced by the combination**
  - **Precision of ~17% for κ_μ and ~23% for $\kappa_{Z\gamma}$**

Precision on the event rates, cross sections and couplings are expected to further improve with the Run 3 dataset collected so far

<u>Run 3 Analysis</u> are on-going! There are much more to come!
Stay tuned!

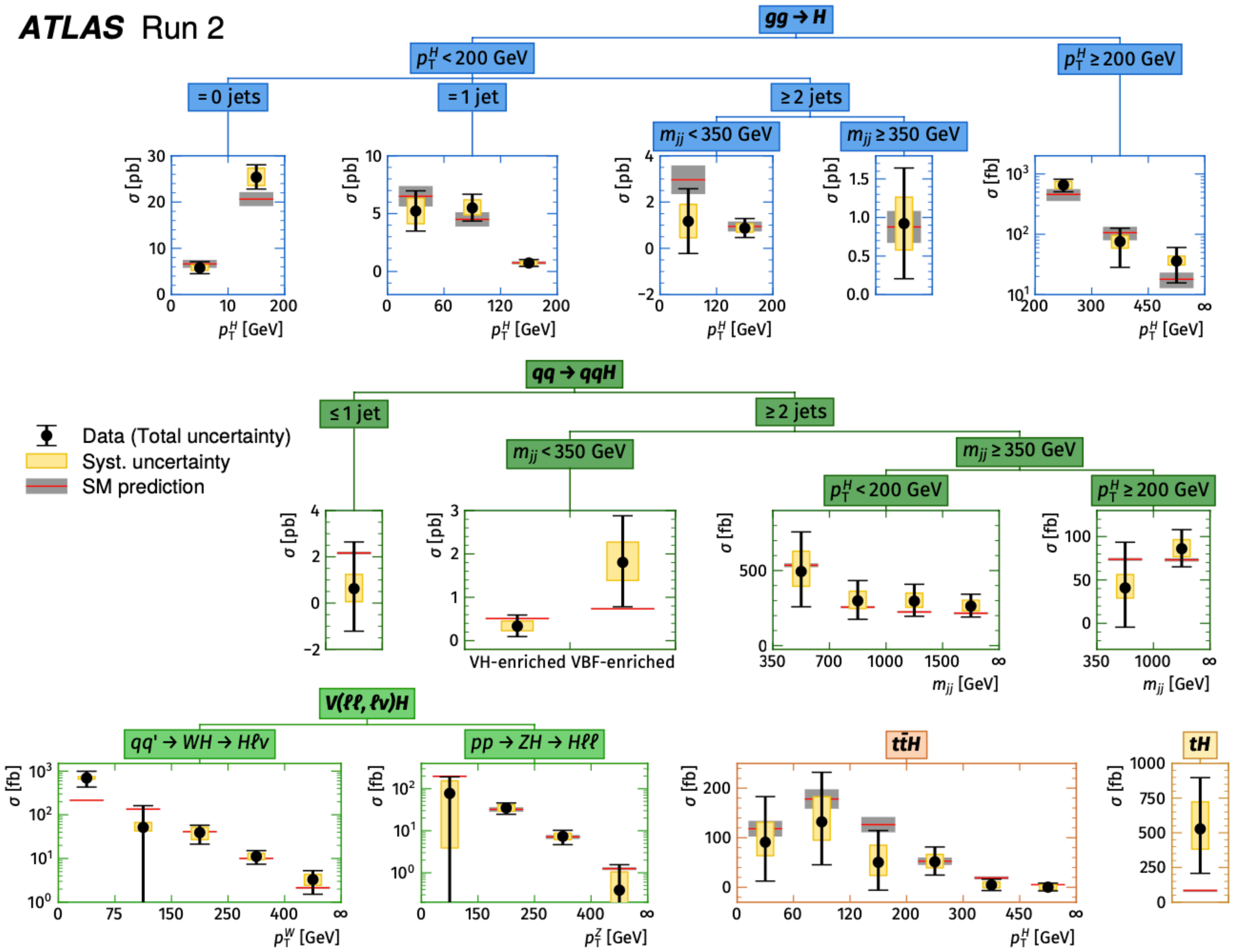
Back-up slides

Recap of ATLAS Run2 measurements

[Nature, vol. 607, 52-59 (2022)]

- **Simplified template cross section framework**:
  - Mutually exclusive regions (36) of the phase space split based on Higgs kinematics (+ W or Z bosons and associated jets)
  - Sensitive to SM deviations; reduce large theory uncertainties and minimize model-dependence when extrapolating to accessible signal regions
  - More regions are probed compared to previous result [1], specially for High Pt Higgs Boson
- *Good compatibility between the measurements and the SM predictions!*

P-value compatibility of combined measurement and SM: 94%



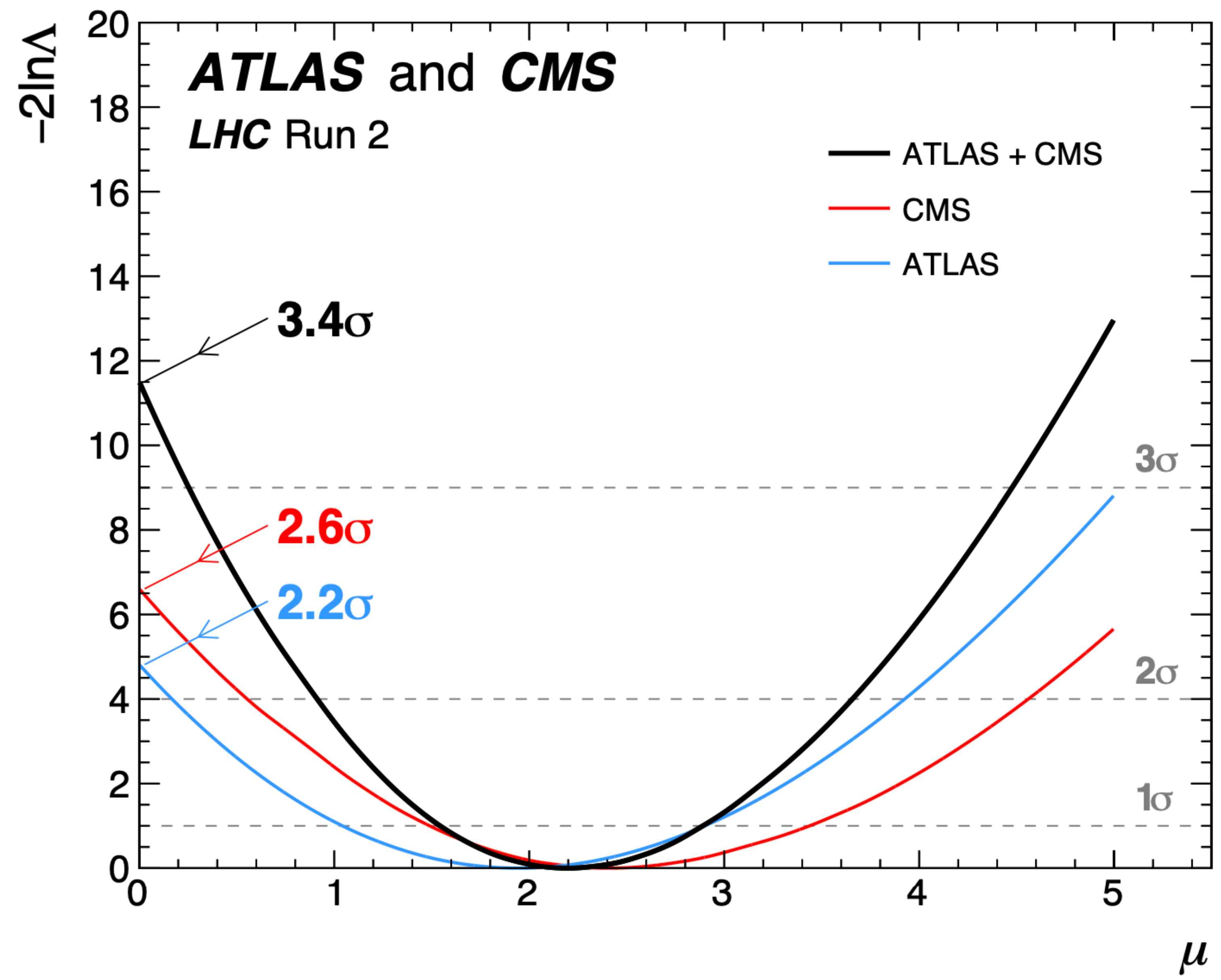
[1]: PhysRevD.101.012002

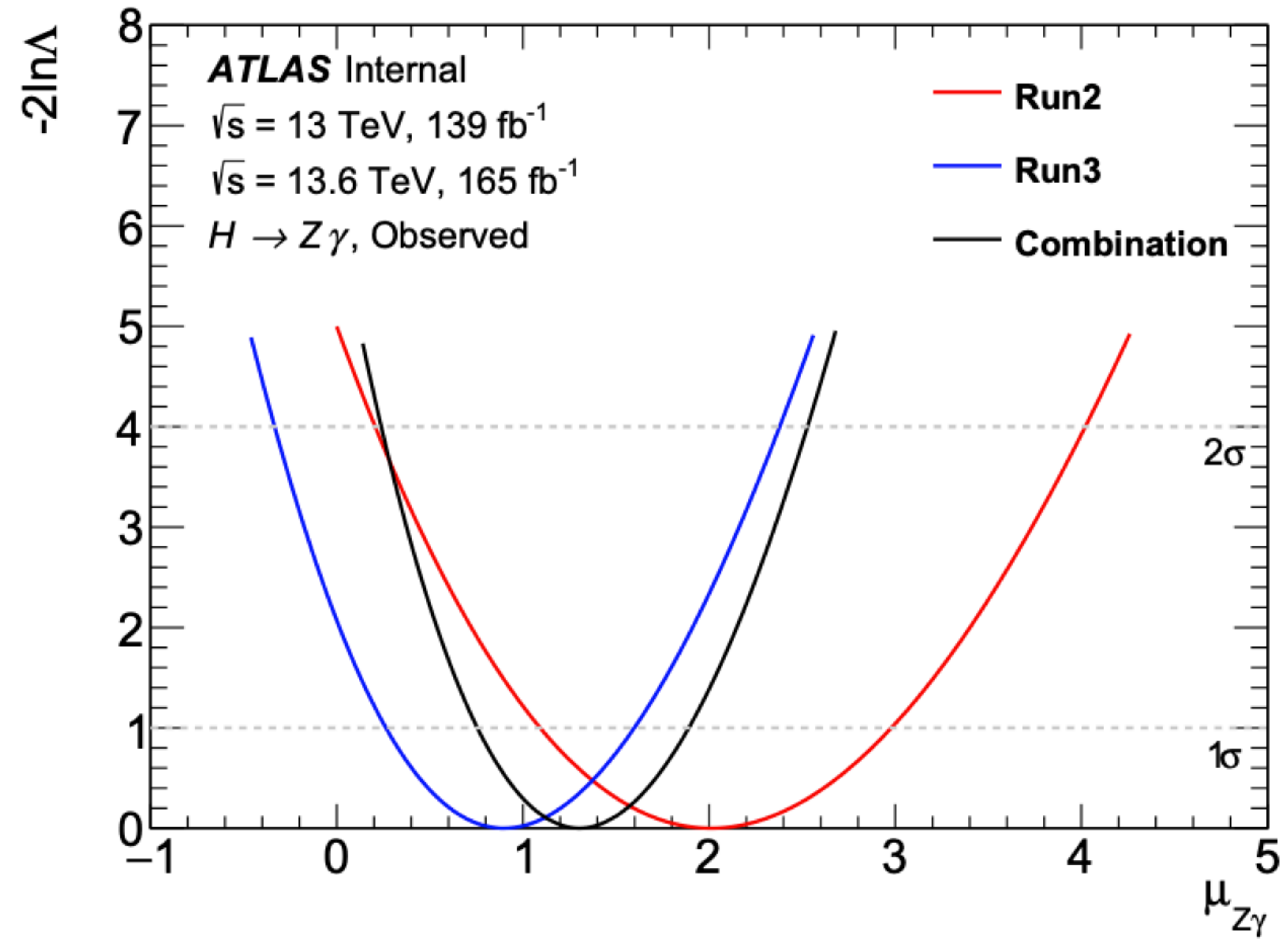
$H \rightarrow Z\gamma$ analysis

Phys. Rev. Lett. 132, 021803

- Rare decay in the SM via loop-induced processes with BR = 1.54 × 10−3 (at mH = 125.09 GeV)
- **Run2 analysis results:**
  - Significance observed (expected) with a mass of 125.09 GeV is 2.2σ (1.2σ)
  - $\mu = 2.0^{+1.0}_{-0.9}$ (dominated by statistical uncertainty)
- **Run2 ATLAS + CMS analysis results:**
  - Significance = 3.4σ $(1.6\sigma$, exp.) *(Evidence!!!!)*
  - $\mu = 2.2 \pm 0.7$ $(1.0 \pm 0.6,$ exp.)
- **New analysis (Full Run2 + partial Run 3) enhancements:**
  - Higher Higgs cross-section and larger datasets
  - Relaxed pT thresholds for muons and photons
  - 13 exclusive categories, including a new multi-lepton one
  - XGBoost classifier replaces cut-based selections
  - Combined with Run 2 for improved sensitivity

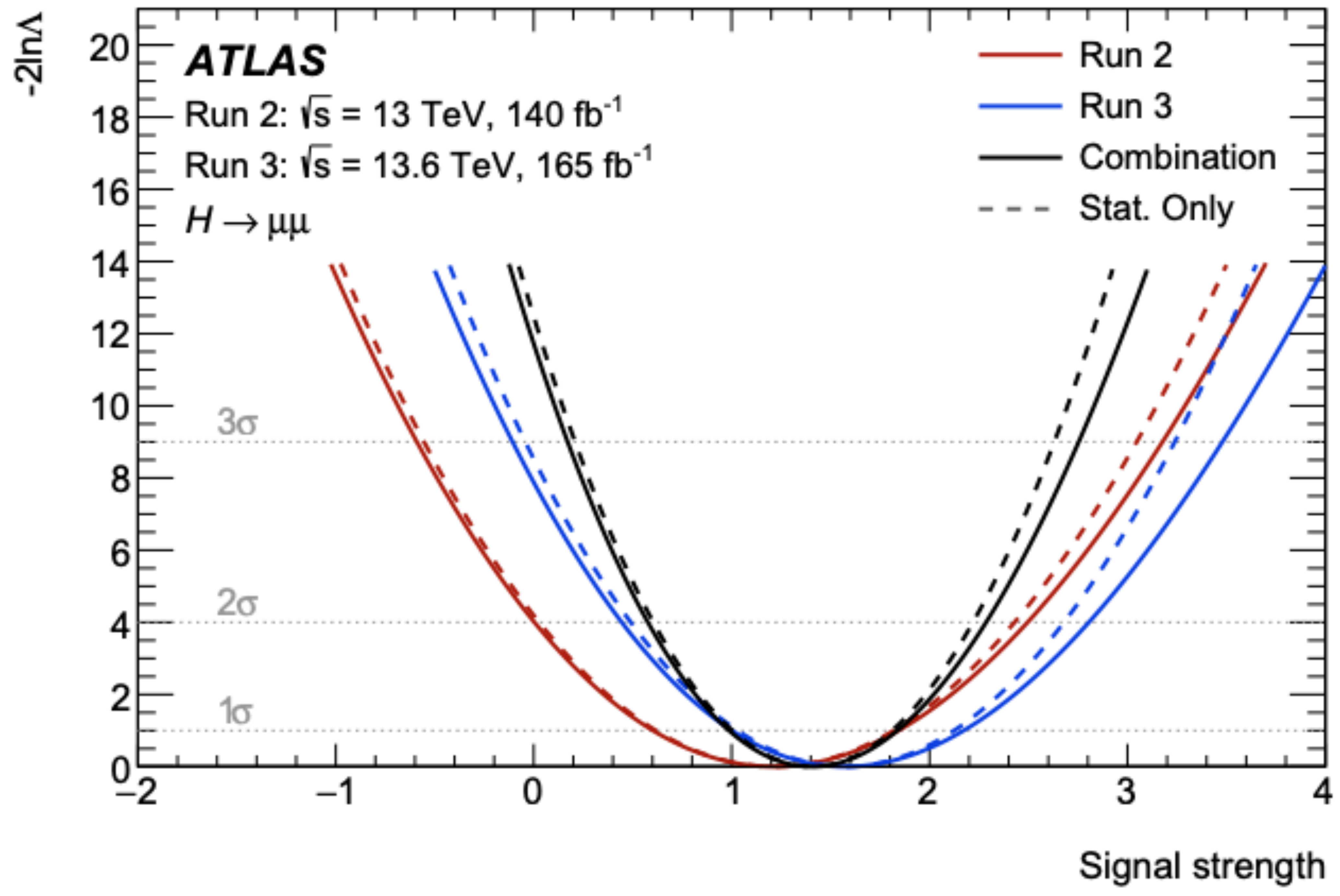
$\mu = 1.3^{+0.6}_{-0.5}$ Observed (expected) significance = 2.5σ (1.9σ)





$H \to \mu\mu$ analysis

- Rare decay in the SM with BR = 2.17 × 10−4 (at mH = 125.09 GeV)
- **Run2 analysis results:**
  - Significance observed (expected) with a mass of 125.09 GeV is 2.0σ (1.7σ)
  - μ=1.2 ± 0.6
- **New analysis (Full Run2 + partial Run 3) enhancements:**
  - The statistics increased by over a factor of 2
  - 5B-event NLO Drell–Yan simulation
  - Mass resolution improvement due to $H \to \mu\mu$ vertex fit
  - Addition of 2-lepton VH category; ttH fully hadronic decays
  - Recategorization of ttH (distance-correlation NN)



Evidence for $H \to \mu\mu$ decay

$\mu = 1.4 \pm 0.4$ Observed (expected) significance = 3.4σ (2.5σ) (bkg-only hypothesis)

$H \to \mu\mu$ analysis

All selections

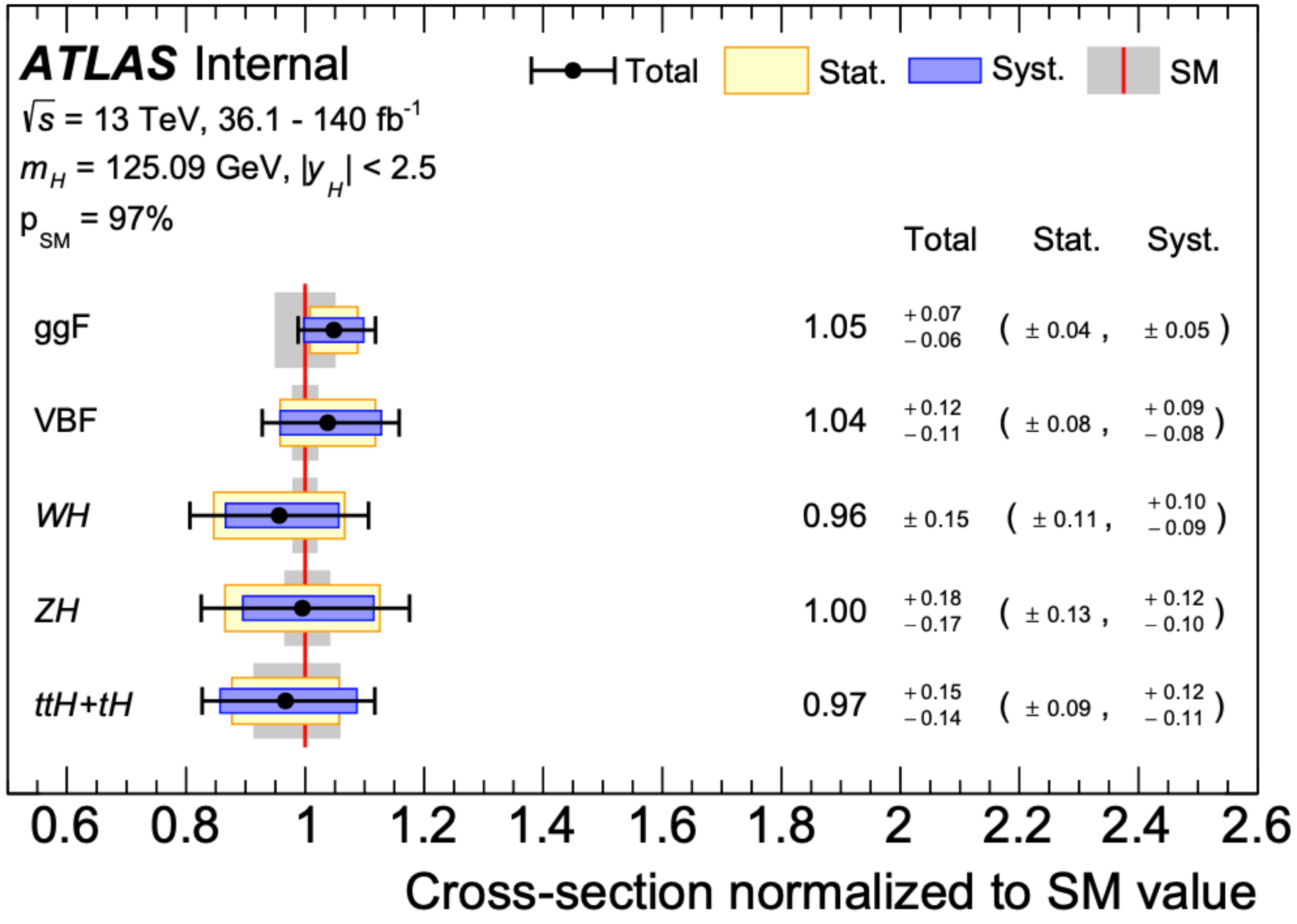
Triggers: at least one high pT muon (pT > 24 GeV) and isolated or pT > 50 GeV without isolation

	Selection
Common preselection	Primary vertex Two opposite-charge muons Muons: $\lvert\eta\rvert < 2.5$, $p_T^{\text{lead}} > 27$ GeV, $p_T^{\text{sublead}} > 15$ GeV
Fit region	$m_{\mu\mu} = 110 - 160$ GeV
Jets	$p_T > 25$ GeV and $\lvert\eta\rvert < 2.4$ or with $p_T > 30$ GeV and $2.4 < \lvert\eta\rvert < 4.5$
b-tagged jets	$p_T > 25$ GeV and $\lvert\eta\rvert < 2.4$ or with $p_T > 30$ GeV and $2.4 < \lvert\eta\rvert < 2.5$ Tagging efficiency working point of 85%
$t\bar{t}H$ categories	At least one b-jet
VH 4-lepton category	Exactly two additional e or μ with $p_T > 8$ GeV, 5 GeV (μ) / 7 GeV (e), no b-jets
VH 3-lepton categories	Exactly one additional e or μ with $p_T > 15$ GeV, no b-jets
VH 2-lepton categories	No additional lepton, no b-jets, $E_T^{\text{miss}} > 120$ GeV
VBF and ggF categories	No additional lepton, no b-jets, $E_T^{\text{miss}} < 120$ GeV

Higgs boson production cross sections

- Production cross section for main production modes (*BR are fixed to their SM expectations*)
  - bbH mode considered together with ggF (acceptance for both processes are similar in all channels considered)
  - Fiducial volume: $|y_H| < 2.5$;
- Excellent agreement with SM (predictions): **p-value of 97%**

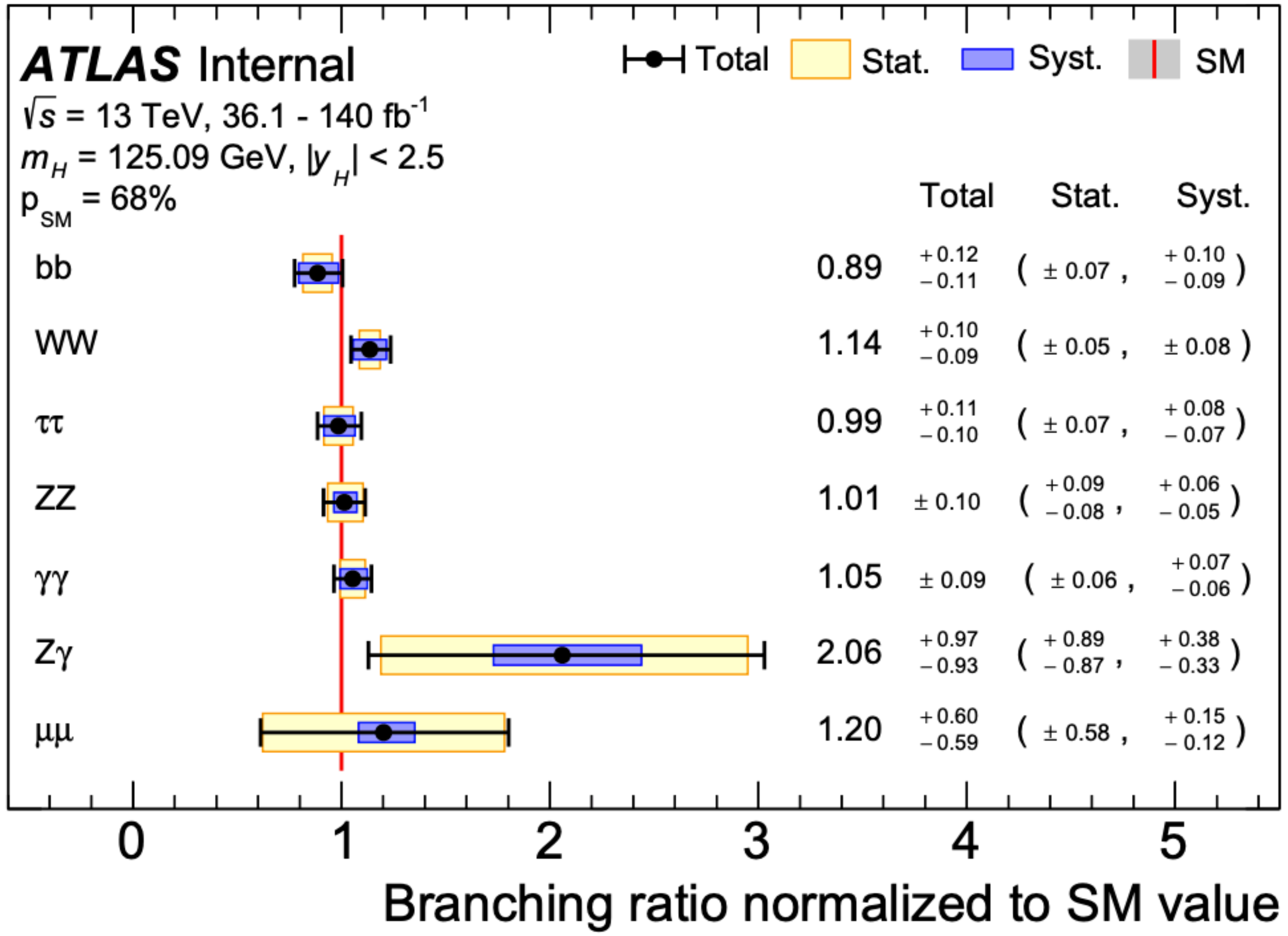
- **Comparison wrt Nature paper 2022:**
  - Reduction of about 30% on the uncertainty of σ_{WH} and σ_{ZH}
    - Due to updates on VH(bb,cc) analysis
  - Reduction of about 40% on the uncertainty of σ_{ttH}
    - Due to updates on ttH(bb) analysis



Decay branching ratio measurements

- Branching ratio measurements (*production cross sections are fixed to their SM expectations*)
  - Fiducial volume: $|y_H| < 2.5$;
- Good agreement with SM (predictions): **p-value of 68%**

- **Comparison wrt Nature paper 2022:**
  - Reduction of about 20% on the uncertainty of BR_{bb}
    - Due to higher sensitivity of updated VH(bb,cc) analysis
  - Reduction of about 20% on the uncertainty of BR_{WW} and 10% for $BR_{\tau\tau}$
    - Due to updates on H(WW*) and H($\tau\tau$) analysis



Higgs Boson production rates measurements

Decay mode	Prod. mode	Measurement	SM prediction	Ratio to SM
$H \to bb$	$\mathrm{ggF} + b\bar{b}H + \mathrm{VBF}$	27 ± 10 pb	28.0 ± 1.5 pb	1.0 ± 0.4
	WH	$0.68^{+0.15}_{-0.14}$ pb	0.706 ± 0.016 pb	$0.96^{+0.21}_{-0.20}$
	ZH	$0.41^{+0.10}_{-0.09}$ pb	0.462 ± 0.018 pb	$0.88^{+0.22}_{-0.20}$
	$ttH + tH$	0.27 ± 0.06 pb	$0.340^{+0.029}_{-0.030}$ pb	$0.80^{+0.19}_{-0.18}$
$H \to WW^*$	$\mathrm{ggF} + b\bar{b}H$	11.3 ± 1.1 pb	9.6 ± 0.6 pb	1.17 ± 0.11
	VBF	$0.73^{+0.17}_{-0.14}$ pb	0.753 ± 0.018 pb	$0.97^{+0.22}_{-0.19}$
	WH	0.13 ± 0.08 pb	0.262 ± 0.006 pb	$0.48^{+0.31}_{-0.29}$
	ZH	$0.29^{+0.09}_{-0.08}$ pb	0.171 ± 0.007 pb	$1.7^{+0.5}_{-0.4}$
	$ttH + tH$	0.21 ± 0.08 pb	0.126 ± 0.011 pb	1.7 ± 0.6
$H \to \tau\tau$	$\mathrm{ggF} + b\bar{b}H$	$2.2^{+0.8}_{-0.6}$ pb	2.80 ± 0.17 pb	$0.77^{+0.27}_{-0.23}$
	VBF	$0.226^{+0.040}_{-0.035}$ pb	0.219 ± 0.005 pb	$1.03^{+0.18}_{-0.16}$
	WH	$0.110^{+0.040}_{-0.033}$ pb	0.0761 ± 0.0018 pb	$1.4^{+0.5}_{-0.4}$
	ZH	$0.052^{+0.023}_{-0.020}$ pb	0.0498 ± 0.0020 pb	$1.1^{+0.5}_{-0.4}$
	$ttH + tH$	$0.040^{+0.026}_{-0.024}$ pb	0.0366 ± 0.0032 pb	$1.1^{+0.7}_{-0.6}$
$H \to ZZ^*$	$\mathrm{ggF} + b\bar{b}H$	$1.11^{+0.13}_{-0.12}$ pb	1.18 ± 0.07 pb	$0.94^{+0.11}_{-0.10}$
	VBF	$0.12^{+0.05}_{-0.04}$ pb	0.0924 ± 0.0022 pb	$1.3^{+0.5}_{-0.4}$
	VH	$0.08^{+0.06}_{-0.05}$ pb	0.0321 ± 0.0008 pb	$1.5^{+1.2}_{-0.9}$
	$ttH + tH$	$0.026^{+0.026}_{-0.017}$ pb	$0.0154^{+0.0013}_{-0.0014}$ pb	$1.7^{+1.7}_{-1.1}$
$H \to \gamma\gamma$	$\mathrm{ggF} + b\bar{b}H$	106 ± 10 fb	102 ± 6 fb	1.04 ± 0.10
	VBF	$10.0^{+2.2}_{-2.0}$ fb	7.94 ± 0.20 fb	$1.26^{+0.28}_{-0.25}$
	WH	$4.2^{+1.5}_{-1.4}$ fb	2.76 ± 0.07 fb	$1.5^{+0.6}_{-0.5}$
	ZH	$-0.4^{+1.1}_{-1.0}$ fb	1.81 ± 0.07 fb	-0.2 ± 0.6
	ttH	$1.01^{+0.40}_{-0.34}$ fb	1.13 ± 0.11 fb	$0.89^{+0.32}_{-0.30}$
	tH	$0.5^{+0.8}_{-0.6}$ fb	$0.192^{+0.013}_{-0.025}$ fb	$2.5^{+4.0}_{-3.3}$
$H \to \mu\mu$	$\mathrm{ggF} + b\bar{b}H + ttH + tH$	6 ± 9 fb	9.8 ± 0.6 fb	0.6 ± 0.9
	$\mathrm{VBF} + VH$	$2.6^{+1.5}_{-1.4}$ fb	$1.196^{+0.026}_{-0.027}$ fb	$2.2^{+1.3}_{-1.2}$
$H \to Z\gamma$	All	160^{+80}_{-70} fb	78 ± 6 fb	$2.0^{+1.0}_{-0.9}$
$H \to cc$	WH	135^{+320}_{-310} fb	35.1 ± 2.0 fb	3.8 ± 9.0
	ZH	-8^{+160}_{-150} fb	23.0 ± 1.5 fb	-0.4 ± 7.0

- Granular measurement of ttH and tH in the $H(\gamma\gamma)$ channel (cleaner channel)
- ggF+bbH and VBF are combined in H(bb) for improving sensitivity
- In $H(\mu\mu)$, ggF+bbH, ttH+tH, and VBF+VH; while in $H(Z\gamma)$, all production modes are grouped together

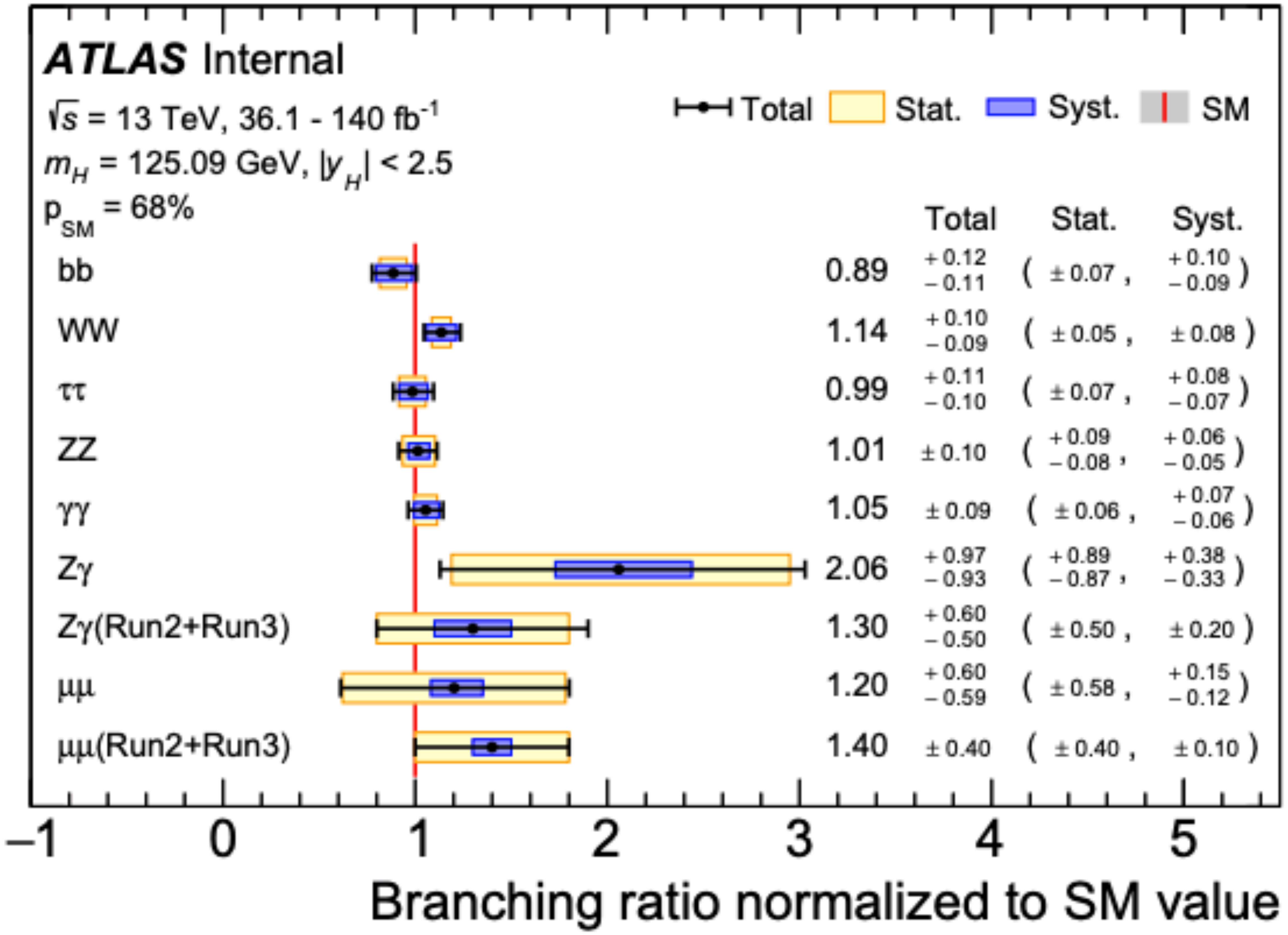
Resolved and effective parametrization

Higgs boson coupling modifiers

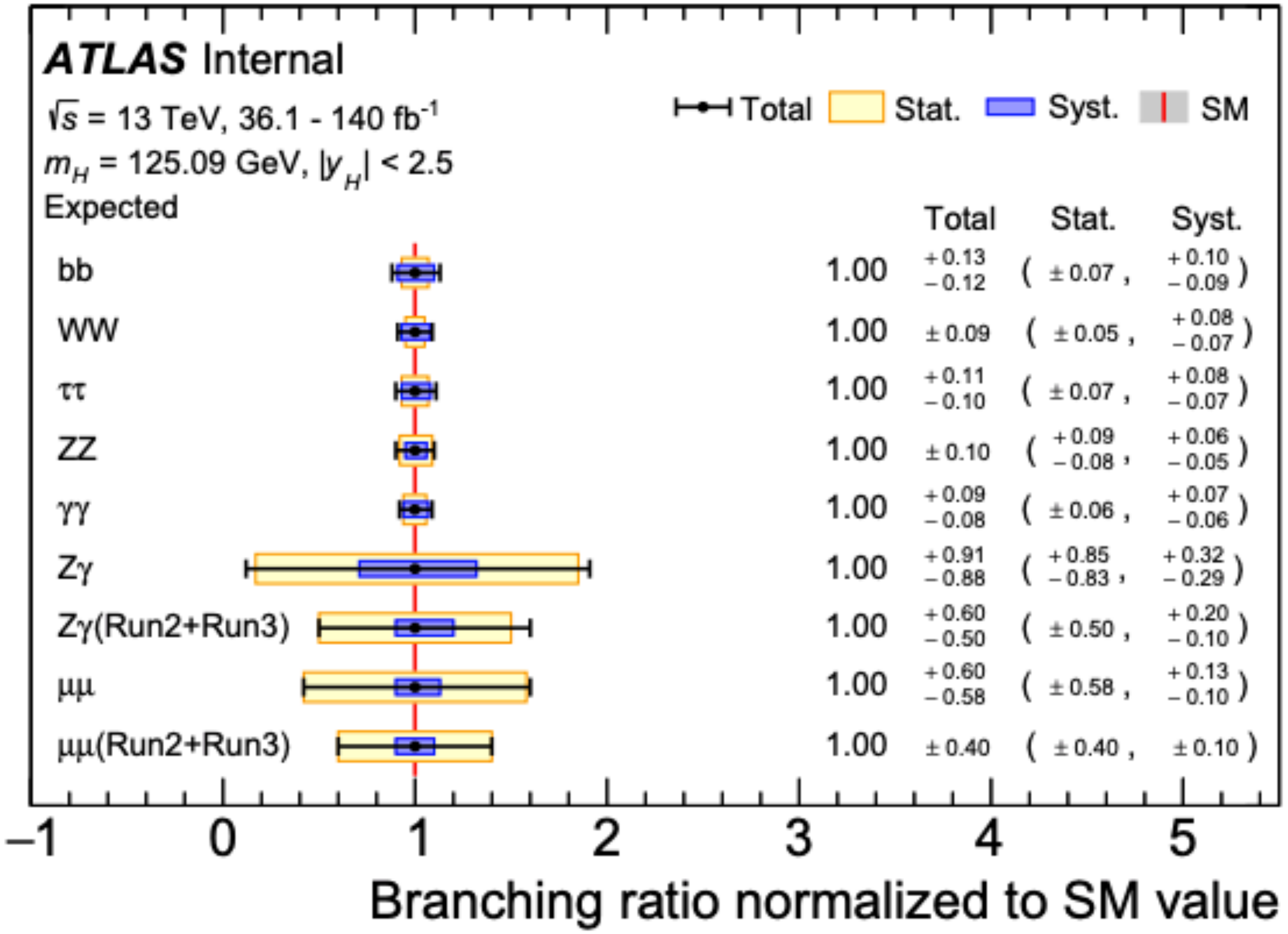
Parameter	Resolved $\kappa_g, \kappa_\gamma, \kappa_{Z\gamma}$		Effective $\kappa_g, \kappa_\gamma, \kappa_{Z\gamma}$
	Free κ_c	$\kappa_c = \kappa_t$	$\kappa_c = \kappa_t$
κ_Z	$0.97^{+0.09}_{-0.07}$	0.96 ± 0.05	0.96 ± 0.05
κ_W	$0.99^{+0.09}_{-0.06}$	0.99 ± 0.04	1.00 ± 0.05
κ_t	$0.99^{+0.10}_{-0.08}$	$0.99^{+0.06}_{-0.05}$	0.99 ± 0.09
κ_b	$0.90^{+0.12}_{-0.11}$	0.89 ± 0.09	$0.89^{+0.10}_{-0.09}$
κ_c	$1.1^{+1.6}_{-3.8}$	—	—
κ_τ	$0.95^{+0.10}_{-0.08}$	0.94 ± 0.06	0.94 ± 0.06
κ_μ	$1.05^{+0.25}_{-0.31}$	$1.04^{+0.24}_{-0.30}$	$1.04^{+0.23}_{-0.30}$
κ_g	—	—	$0.99^{+0.07}_{-0.06}$
κ_γ	—	—	0.97 ± 0.06
κ_{Z/γ^*}	—	—	$1.36^{+0.30}_{-0.36}$

Run 2 + Run 3 Decay branching rations

Observed



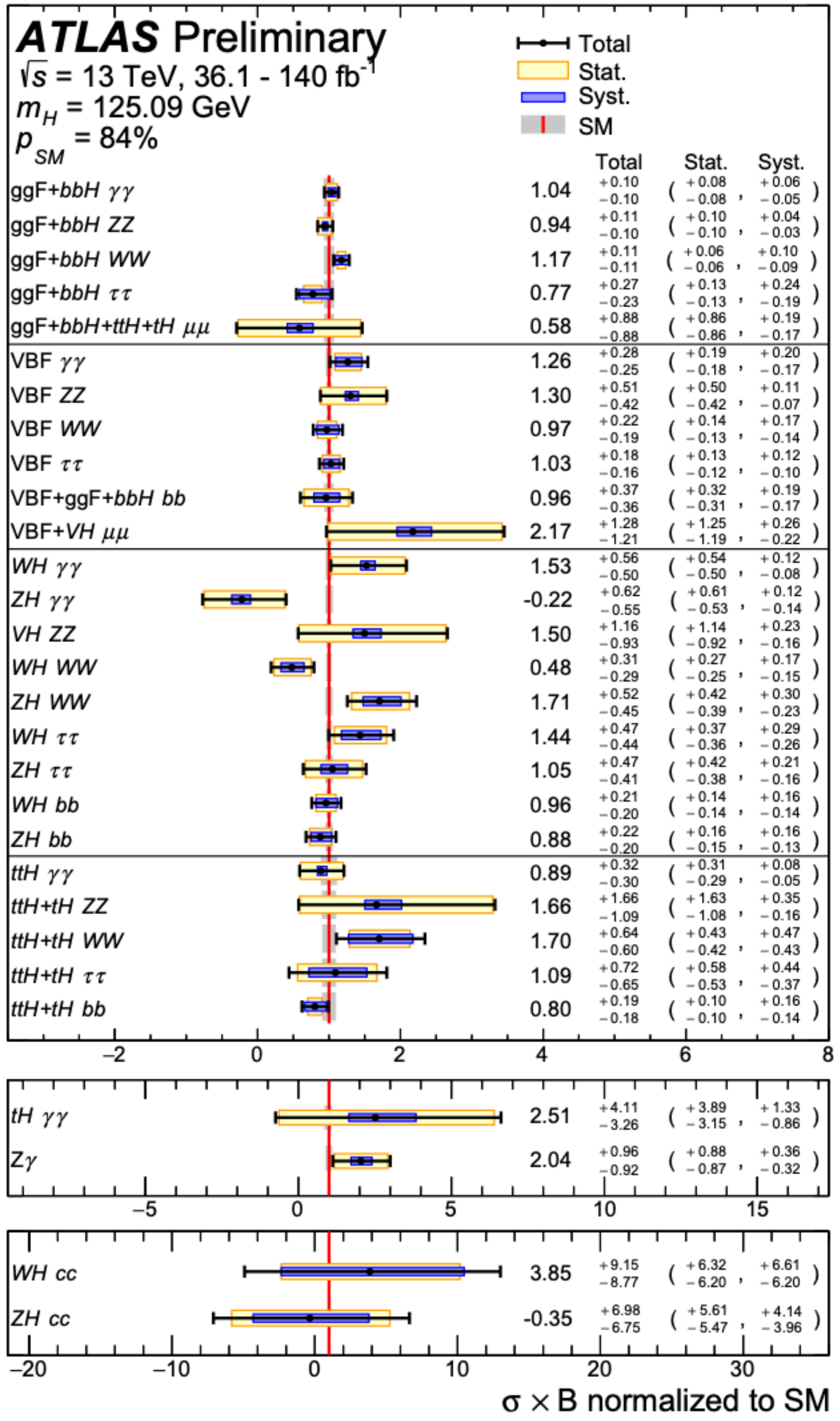
Expected



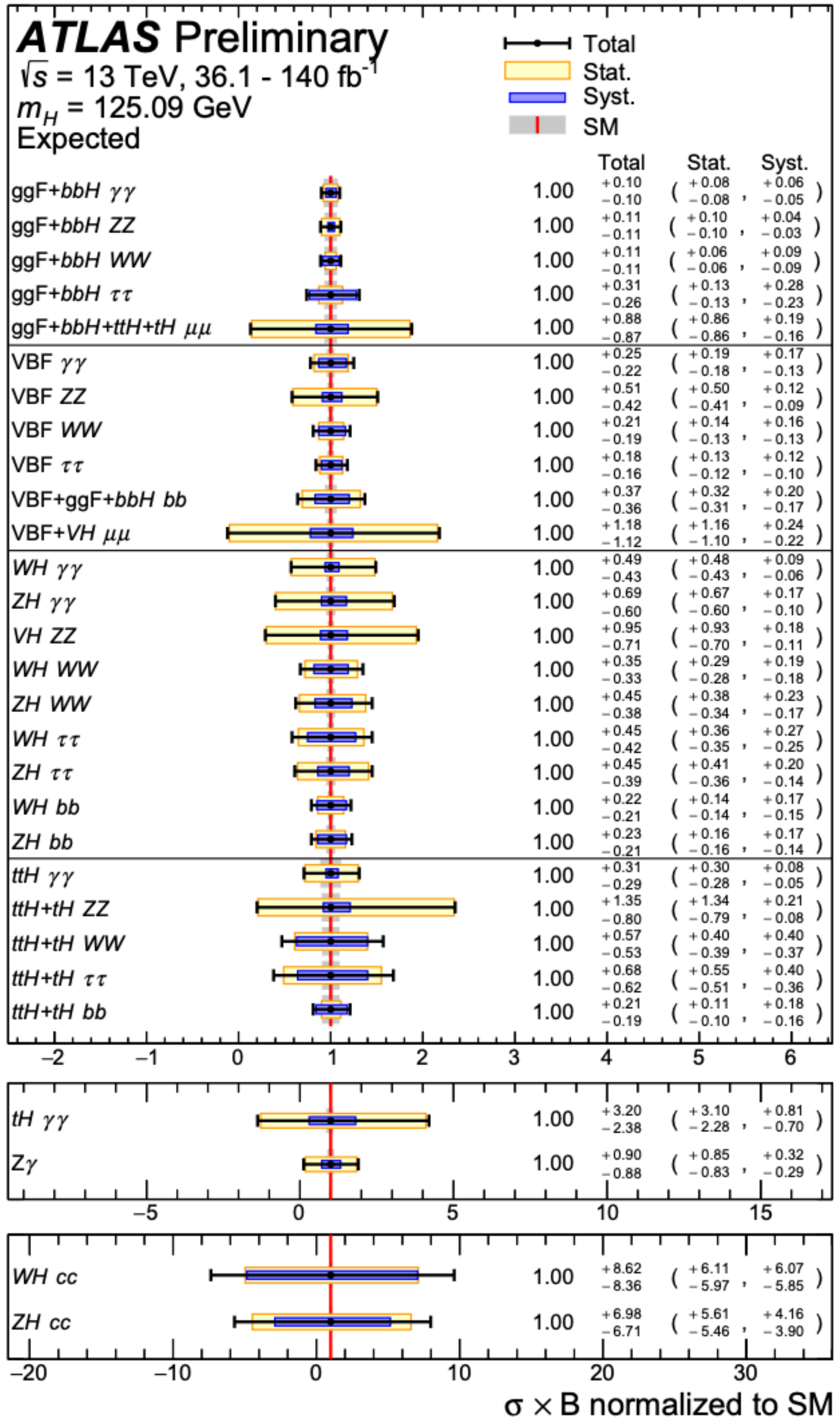
$H \rightarrow \mu\mu$ and $H \rightarrow Z\gamma$ BR includes Run3 dataset

Higgs Boson production rates measurements

Observed

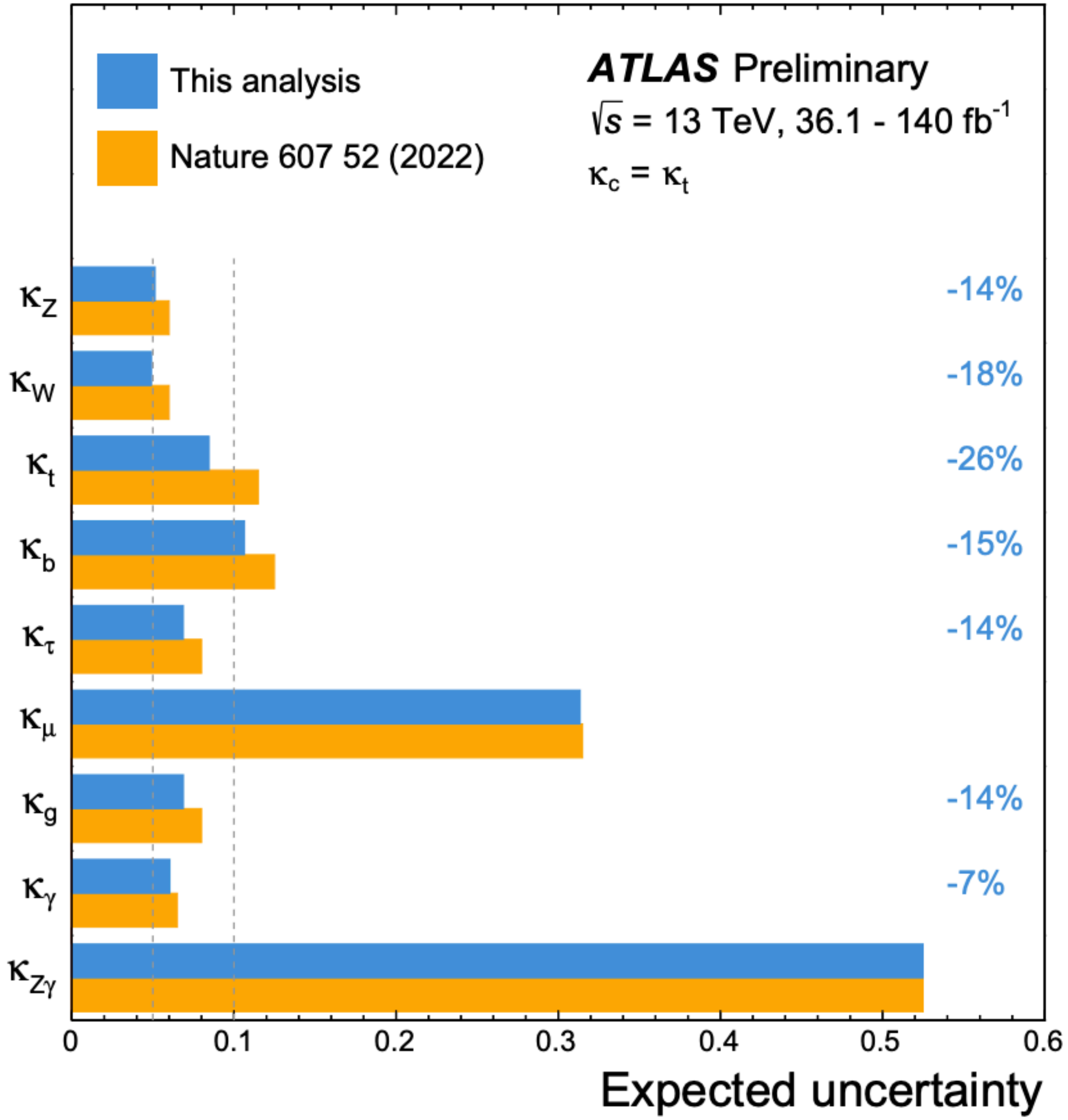


Expected



Coupling modifiers: expected uncertainties

Effective parametrization



Summary of the new combination results

- **Higgs boson production cross-sections** are consistent with the Standard Model (SM), exhibiting 6-18% uncertainties, with notable reductions of 30% for WH/ZH and 40% for $t\bar{t}$H/tH rates compared to Ref. [3]. **Branching fractions for major decay modes ($H \to \gamma\gamma$, $H \to ZZ^* \to 4\ell$, $H \to WW^* \to \ell\nu\ell\nu$, $H \to b\bar{b}$, $H \to \tau\tau$)** also align with SM predictions, having 8-13% uncertainties. Specifically, uncertainties for $H \to b\bar{b}$ and $H \to WW^*$ are reduced by 20%, and for $H \to \tau\tau$ by 10%, relative to Ref. [3]. Results for 29 combined production and decay channels are also provided.

- **Higgs boson coupling modifiers** are also presented, assuming only Standard Model (SM) loop and unprobed Higgs processes. Couplings to **W, Z, t, b, and τ** are measured with **5-12% uncertainties, improving by 10-20% compared to Ref. [3]**. The muon coupling uncertainty is about 25%, while the charm quark coupling has a +1.6–3.8 uncertainty, a factor of 2 improvement over Ref. [3]. All results align with SM predictions.