Combination of measurements of Higgs boson production and decay using up to 139/fb of p-p collision data at $\sqrt{s}$=13TeV collected with the ATLAS experiment

Speaker: Gangcheng Lu

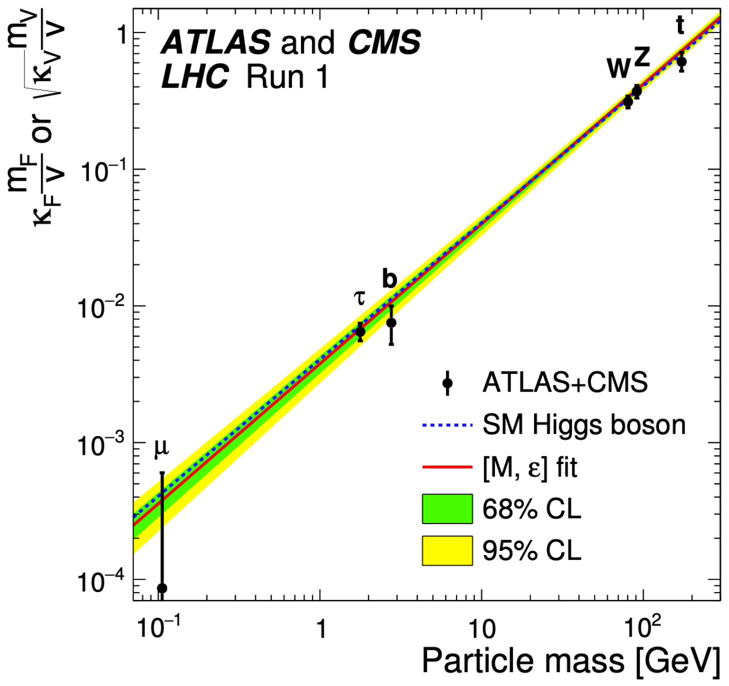
- IHEP, China
- 7. Nov. 2020

Outline

- Introduction
- Global mu measurements
- Cross-section measurements in production modes
- Simplified template cross-section(STXS) measurements
- κ framework measurements
- Two Higgs doublet models(2HDM) interpretation

Introduction

- Following the discovery of the Higgs boson, its coupling properties to other SM particles, such as its **production cross sections** and **decay branching fractions**, can be precisely computed.
- The measurements can provide stringent tests of the SM validity. The deviation from SM would an indicator of **beyond standard model physics**(BSM)



- The properties were consistent with the SM in the Run I. For this combination, the measurements have been extended using the Run 2 dataset, to probe Higgs properties more precisely.

Input channels

	ZZ	$\gamma\gamma$	bb	$\mu\mu$	$\tau\tau$	WW	multi-lep	inv
ggF	●	●		●	○	○		
VBF	●	●	○	●	○	○		●
WH	●	●	●	●				
ZH	●	●	●	●				
ttH	●	●	○	●			○	
tH		●						

●Included with full Run 2 dataset(139fb^{-1})

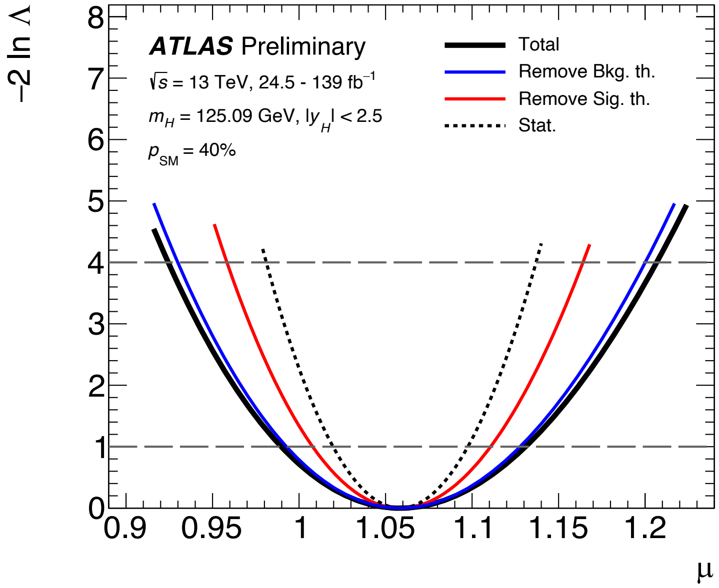
○Included with 2015-2016 data only

- $H \rightarrow \gamma\gamma$, $H \rightarrow ZZ \rightarrow 4l$ and $VH, H \rightarrow bb$ analyses are included in the STXS measurements
- $H \rightarrow \mu\mu$ and VBF $Hinv$ are only used for κ framework with $\boldsymbol{\kappa_\mu}$ and $\boldsymbol{B_{i.}}$, $\boldsymbol{B_{u.}}$ respectively
- For more detailed not covered in the presentation, please refer to the CONF-NOTE.

Global mu results

$$\mu = 1.06^{+0.07}_{-0.07} = 1.06^{+0.04}_{-0.04}(stat.)^{+0.03}_{-0.03}(exp.)^{+0.05}_{-0.04}(sig.th.)^{+0.02}_{-0.02}(bkg.th.)$$

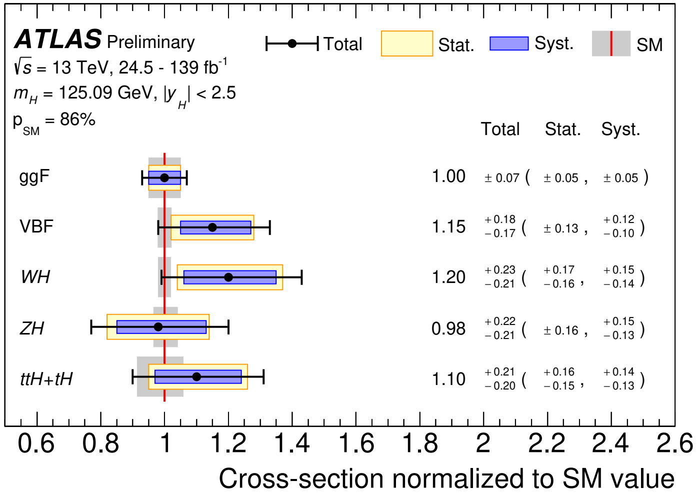
- The global μ is defined as the ratio of observed yields to its SM expectation, a measurement of potential deviation from SM.
- Observed result is **1.06**, a little larger then SM expected, with a precision of 7%
- The measurement is consistent with SM prediction with a p-value of $p_{SM} = 40\%$

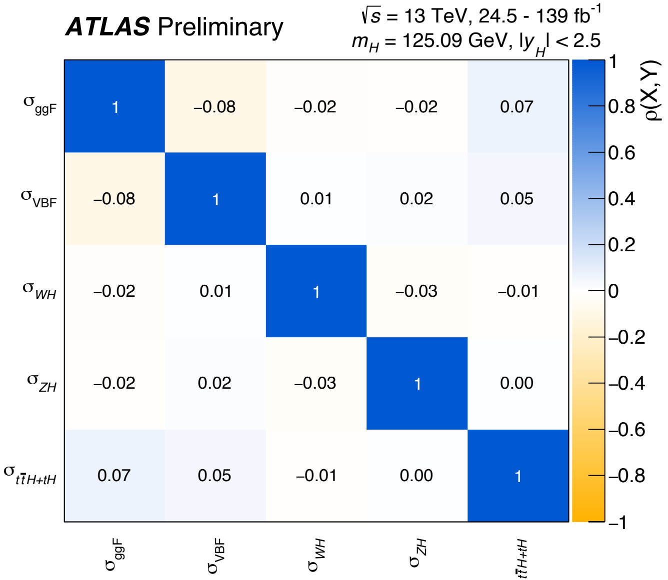


Cross-section measurements in production modes

Production cross sections

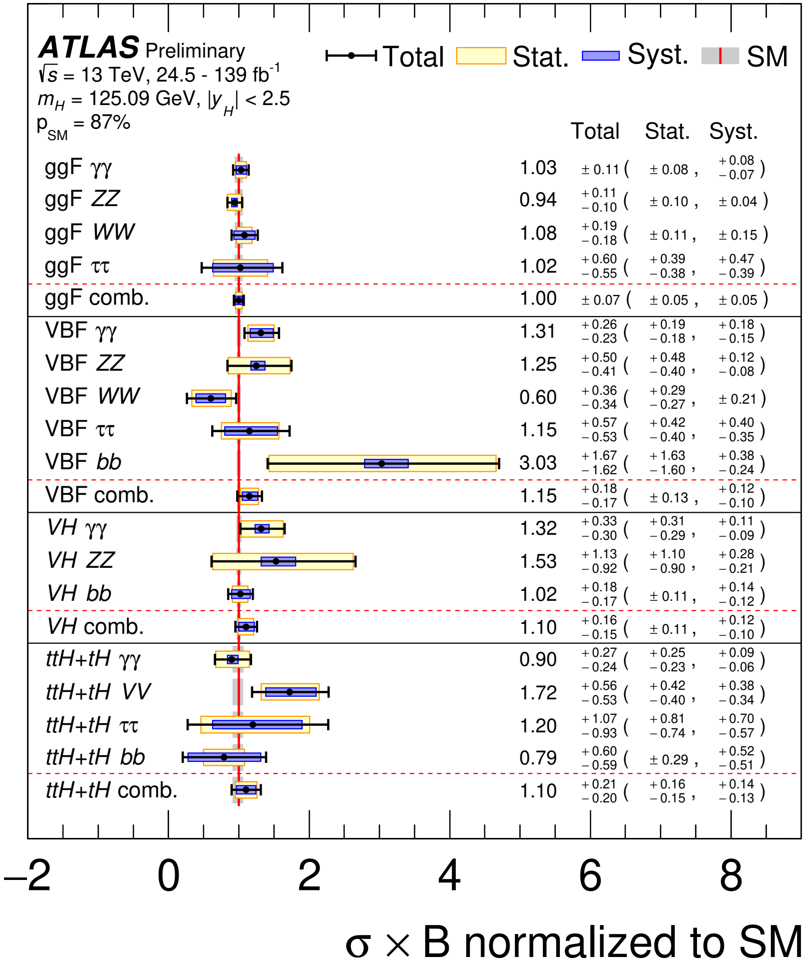
- Cross-sections are measured in the main Higgs production modes:
  - ggF (including ~1% contribution from bbH)
  - VBF
  - WH
  - ZH (including $gg \to ZH$)
  - ttH + tH
- The **cross sections** are float in the simultaneous fit to data, while the branching fractions are fixed to their SM expectations.
- **Compatible** with the SM expectation with $\boldsymbol{p_{SM} = 86\%}$
- **Decreased anti-correlation** between ggF and VBF(~8%), mainly from new $\gamma\gamma$ and ZZ results.
- **Over 5σ significance** in all 5 production modes, a first > 5σ observation in WH channel!





Production cross sections × BR

- Probe Higgs properties in each **production×decay:** $(\boldsymbol{\sigma}\times\boldsymbol{B})_{if}$
- Some productions or decays get merged with others, due to limited statistics



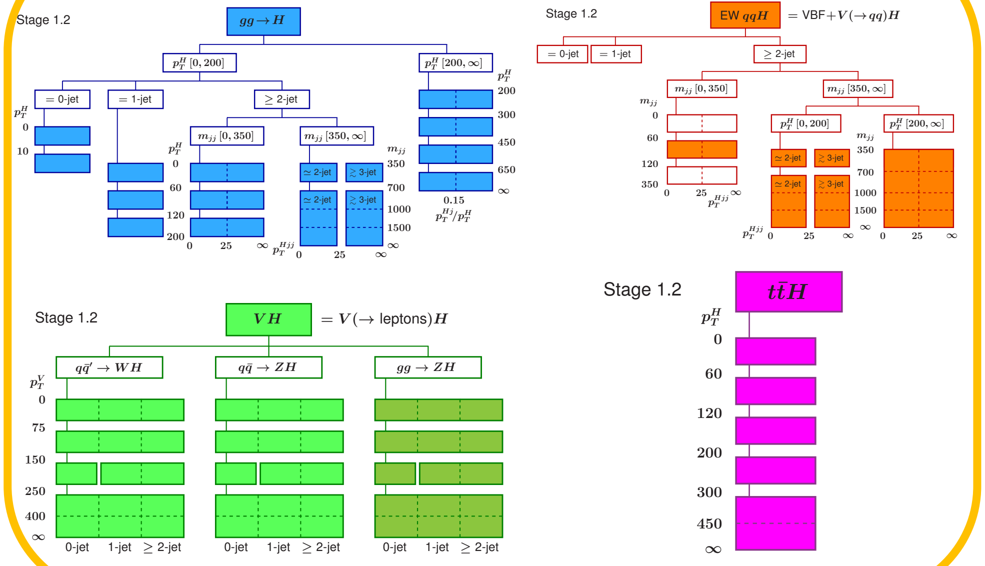
- **Compatible** with the SM expectation with $\boldsymbol{p_{SM} = 87\%}$
- Good agreement observed for each final state within a production mode

STXS measurements

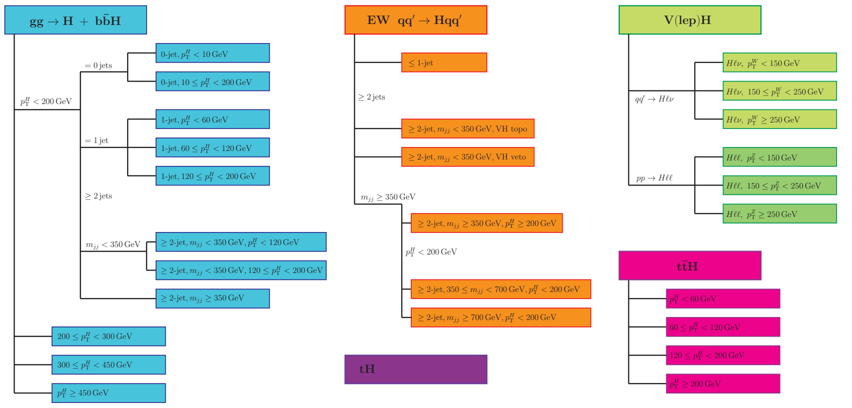
Granularity of STXS binning

- **Simplified template cross sections**(STXS) are defined through a partition of the phase space of SM Higgs productions into non-overlapping regions, **independent of Higgs decay process,** aim to
  - Have good **sensitivity**
  - Avoid large **theory uncertainties**
  - Approximately match experimental selections, to minimize **model-dependent extrapolations**.
- The final scheme is the version with some bins in **Stage1.2** merged, based on the principles of avoiding **strong anti-correlation** and **>100% uncertainties** except in some bins sensitive to BSM

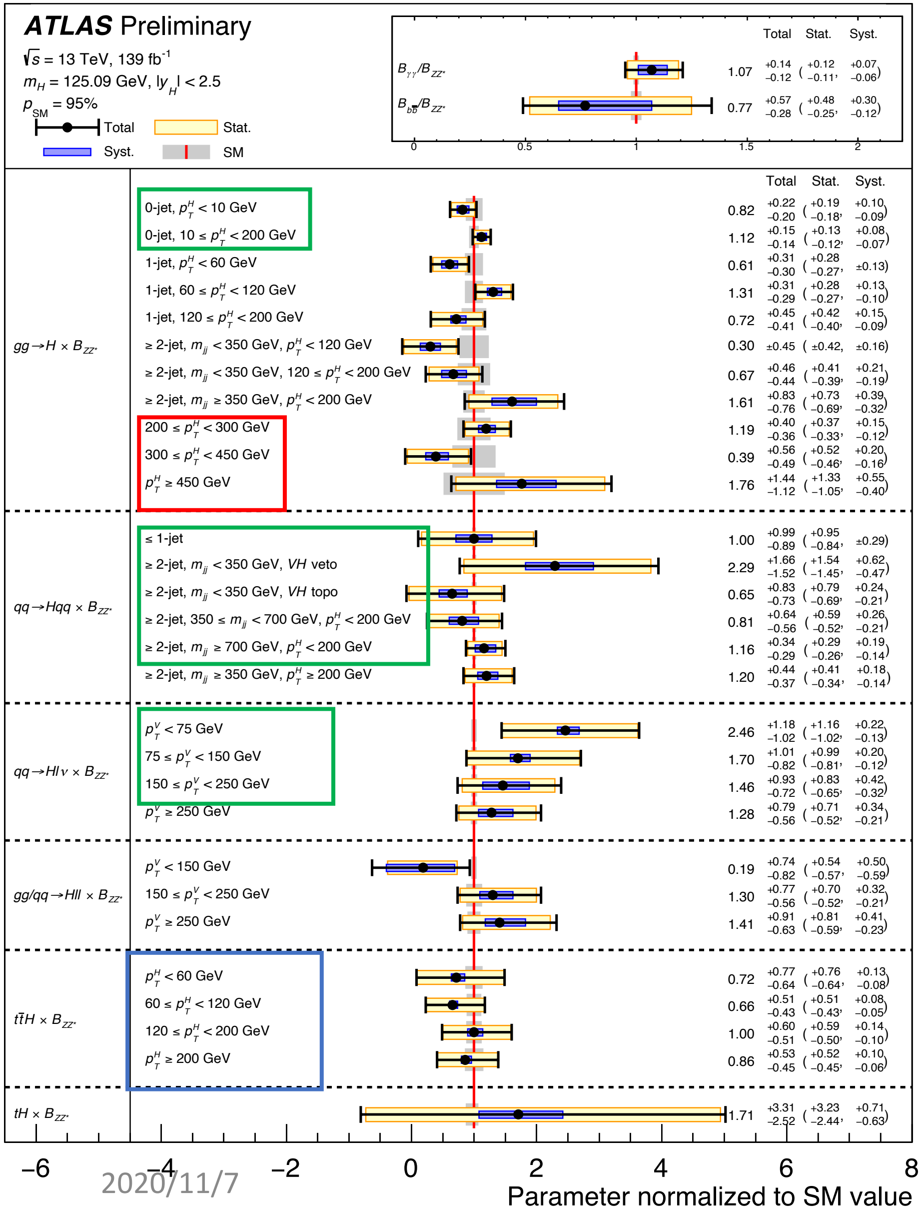
Stage 1.2



Stage 1.2 Merged(Actually used)



STXS measurements



- Only ***γγ*, ZZ, VH→ *bb*** channels included in STXS measurements.
- Increase in number of regions probed, compared with paper in the last iteration
  - Finer granularity for low pT and **high pT** bins
  - Differential measurements for **ttH**
- The **tH** production is separated from **ttH,** with very large statistical uncertainty.
- **Compatible** with the SM prediction with a p-value of **95%**

κ framework interpretation

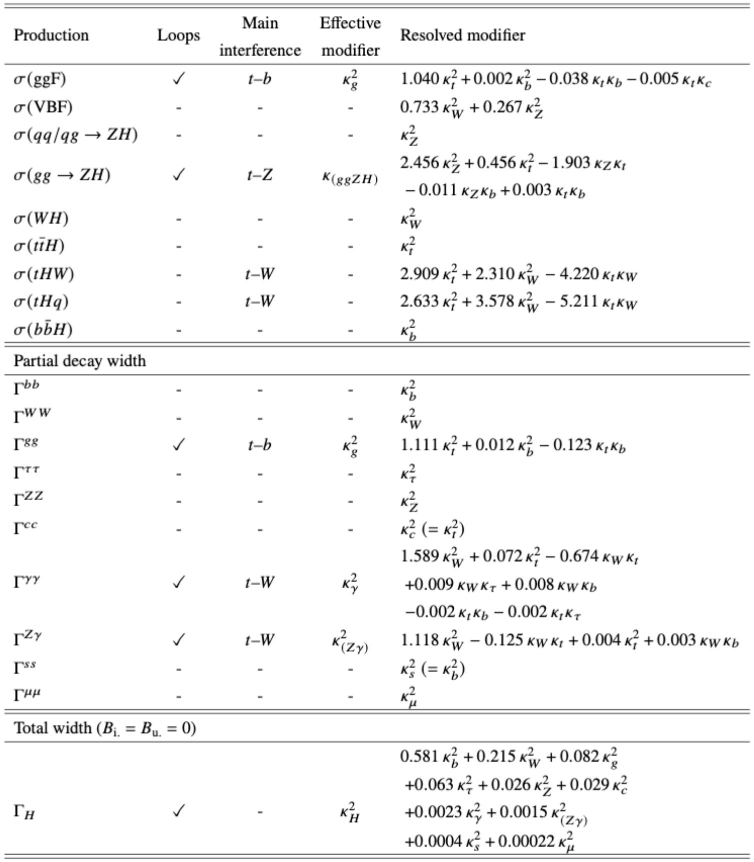
Kappa framework

- Coupling-strength modifier $\boldsymbol{\kappa}$ are introduced to study modifications of the Higgs boson coupling related to BSM physics.
- For a given **production process or decay model** j, the κ_j is defined as:

$$\kappa_j^2 = \frac{\sigma_j}{\sigma_j^{\mathrm{SM}}} \quad \text{or} \quad \kappa_j^2 = \frac{\Gamma_j}{\Gamma_j^{\mathrm{SM}}}$$

- Except the coupling to SM particles, the contributions from BSM $\boldsymbol{B_i}$ and $\boldsymbol{B_u}$ are probed
  - B_i is related to **invisible decays**: decays identified only through MET
  - B_u is related to **undetected BSM decays**: BSM decays to that none of the included analyses are sensitive.

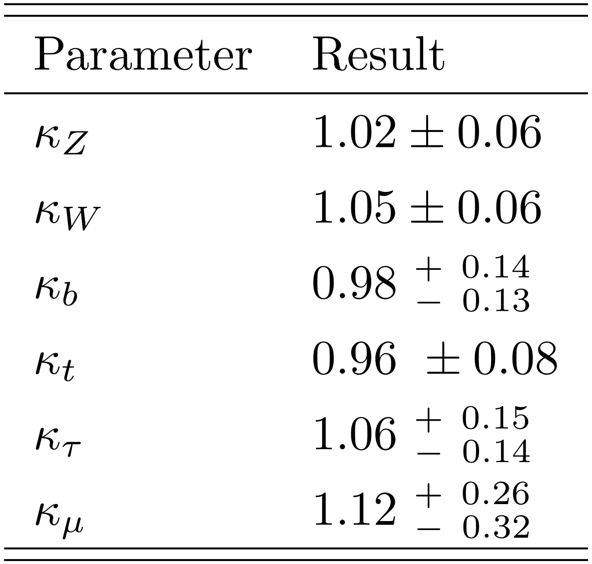
$$\kappa_H^2(\boldsymbol{\kappa}, B_{\mathrm{i.}}, B_{\mathrm{u.}}) = \frac{\sum_j B_j^{\mathrm{SM}} \kappa_j^2}{(1 - B_{\mathrm{i.}} - B_{\mathrm{u.}})}.$$



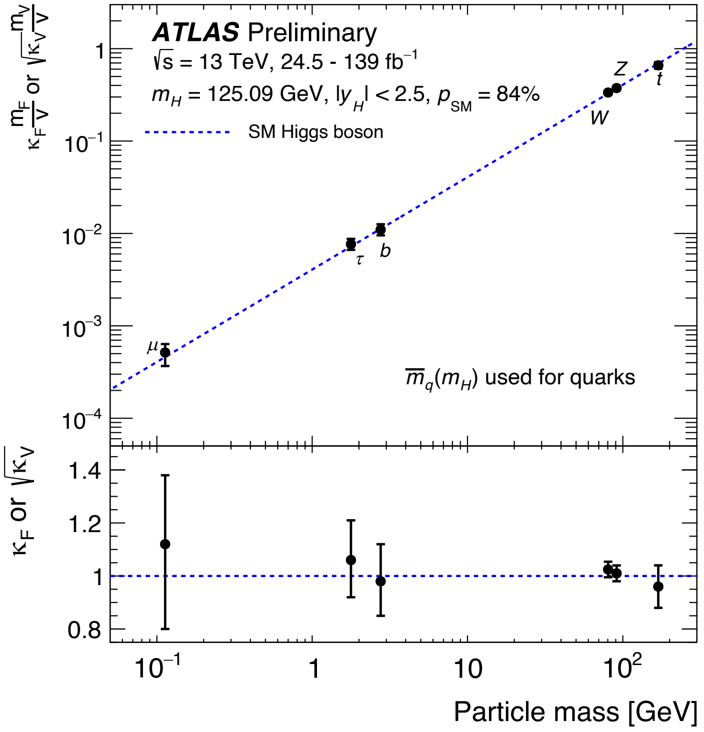
Production	Loops	Main interference	Effective modifier	Resolved modifier
$\sigma(\mathrm{ggF})$	✓	t–b	κ_g^2	$1.040\,\kappa_t^2 + 0.002\,\kappa_b^2 - 0.038\,\kappa_t\kappa_b - 0.005\,\kappa_t\kappa_c$
$\sigma(\mathrm{VBF})$	-	-	-	$0.733\,\kappa_W^2 + 0.267\,\kappa_Z^2$
$\sigma(qq/qg \to ZH)$	-	-	-	κ_Z^2
$\sigma(gg \to ZH)$	✓	t–Z	$\kappa_{(ggZH)}$	$2.456\,\kappa_Z^2 + 0.456\,\kappa_t^2 - 1.903\,\kappa_Z\kappa_t$ $-0.011\,\kappa_Z\kappa_b + 0.003\,\kappa_t\kappa_b$
$\sigma(WH)$	-	-	-	κ_W^2
$\sigma(t\bar{t}H)$	-	-	-	κ_t^2
$\sigma(tHW)$	-	t–W	-	$2.909\,\kappa_t^2 + 2.310\,\kappa_W^2 - 4.220\,\kappa_t\kappa_W$
$\sigma(tHq)$	-	t–W	-	$2.633\,\kappa_t^2 + 3.578\,\kappa_W^2 - 5.211\,\kappa_t\kappa_W$
$\sigma(b\bar{b}H)$	-	-	-	κ_b^2
Partial decay width				
Γ^{bb}	-	-	-	κ_b^2
Γ^{WW}	-	-	-	κ_W^2
Γ^{gg}	✓	t–b	κ_g^2	$1.111\,\kappa_t^2 + 0.012\,\kappa_b^2 - 0.123\,\kappa_t\kappa_b$
$\Gamma^{\tau\tau}$	-	-	-	κ_τ^2
Γ^{ZZ}	-	-	-	κ_Z^2
Γ^{cc}	-	-	-	$\kappa_c^2\ (= \kappa_t^2)$
$\Gamma^{\gamma\gamma}$	✓	t–W	κ_γ^2	$1.589\,\kappa_W^2 + 0.072\,\kappa_t^2 - 0.674\,\kappa_W\kappa_t$ $+0.009\,\kappa_W\kappa_\tau + 0.008\,\kappa_W\kappa_b$ $-0.002\,\kappa_t\kappa_b - 0.002\,\kappa_t\kappa_\tau$
$\Gamma^{Z\gamma}$	✓	t–W	$\kappa_{(Z\gamma)}^2$	$1.118\,\kappa_W^2 - 0.125\,\kappa_W\kappa_t + 0.004\,\kappa_t^2 + 0.003\,\kappa_W\kappa_b$
Γ^{ss}	-	-	-	$\kappa_s^2\ (= \kappa_b^2)$
$\Gamma^{\mu\mu}$	-	-	-	κ_μ^2
Total width ($B_{\mathrm{i.}} = B_{\mathrm{u.}} = 0$)				
Γ_H	✓	-	κ_H^2	$0.581\,\kappa_b^2 + 0.215\,\kappa_W^2 + 0.082\,\kappa_g^2$ $+0.063\,\kappa_\tau^2 + 0.026\,\kappa_Z^2 + 0.029\,\kappa_c^2$ $+0.0023\,\kappa_\gamma^2 + 0.0015\,\kappa_{(Z\gamma)}^2$ $+0.0004\,\kappa_s^2 + 0.00022\,\kappa_\mu^2$

Coupling to each SM particle

- Study the Higgs coupling with each SM particles. No additional BSM contributions
- Loops of gluons and photon couplings are expressed in terms of SM contents



Parameter	Result
κ_Z	1.02 ± 0.06
κ_W	1.05 ± 0.06
κ_b	$0.98\ ^{+\ 0.14}_{-\ 0.13}$
κ_t	$0.96\ \ \pm 0.08$
κ_τ	$1.06\ ^{+\ 0.15}_{-\ 0.14}$
κ_μ	$1.12\ ^{+\ 0.26}_{-\ 0.32}$

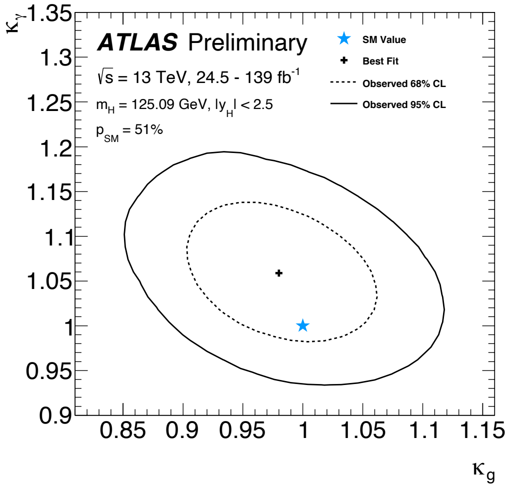


- Compatibility to SM is **84%**
- 68% confidence interval shown for the particles

Loops and decays

No BSM contribution

		Measured value
κ_g	observed	$0.98^{+0.05}_{-0.05}$
	expected	$1.00^{+0.05}_{-0.05}$
κ_γ	observed	$1.06^{+0.05}_{-0.05}$
	expected	$1.00^{+0.05}_{-0.05}$

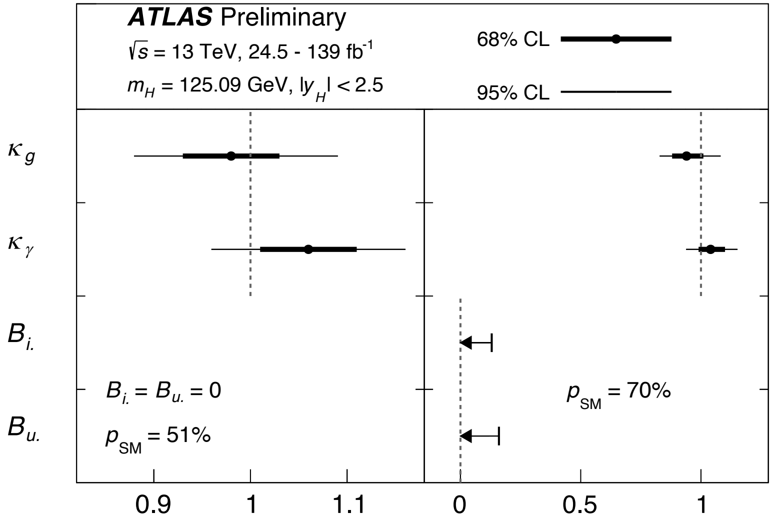


- Effective coupling $\boldsymbol{\kappa_g}$ **and** $\boldsymbol{\kappa_\gamma}$ are sensitive to new particles and BSM effects appearing in loops.
- Compatibility to SM is **51%**
- Linear correlation is **0.34**

$B_{i.}$ and $B_{u.}$ introduced

		Measured value
κ_g	observed	$0.94^{+0.07}_{-0.06}$
	expected	$1.00^{+0.07}_{-0.07}$
κ_γ	observed	$1.04^{+0.06}_{-0.05}$
	expected	$1.00^{+0.06}_{-0.05}$
$B_{i.}$	observed	< 0.13
	expected	< 0.13
$B_{u.}$	observed	< 0.16
	expected	< 0.23

- $B_{i.}$ correlated to Hinv analysis
- Compatibility to SM is **70%**

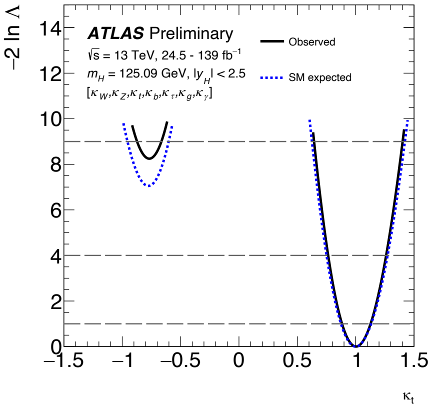


VBF Hinv channel added

Generic kappa model

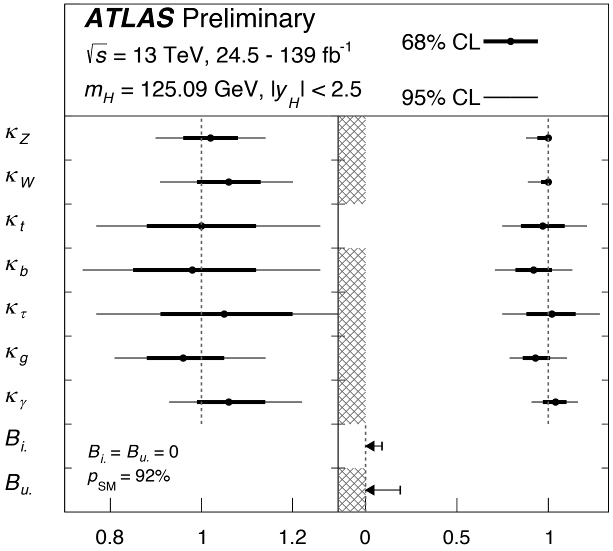
No BSM contribution

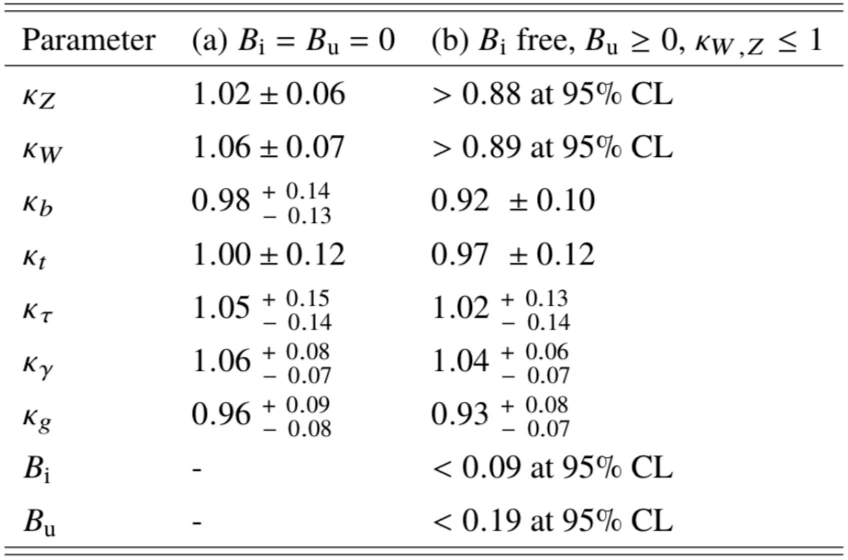
- **No BSM contributions** to the total width($B_{i.} = B_{u.} = 0$)
- The signs of κ_t can be positive or negative, while the other parameters kept positive
- the region with $\kappa_t < 0$ is excluded at **2.9(obs.)/2.7(exp.) σ**



$B_{i.}$ and $B_{u.}$ introduced

- To probe for BSM contributions, the combination includes the results of direct search to **Hinv.** Assuming $\kappa_V < 1$ to regularize total width



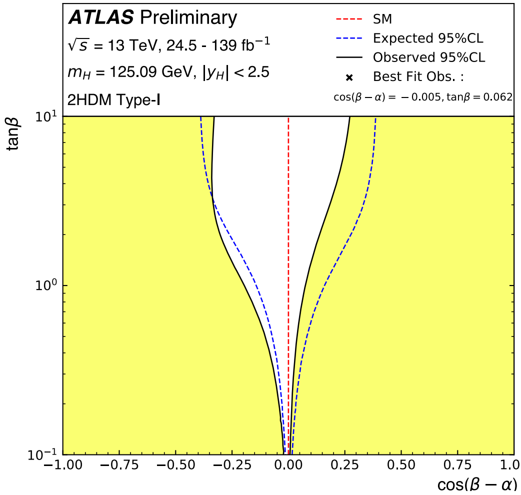


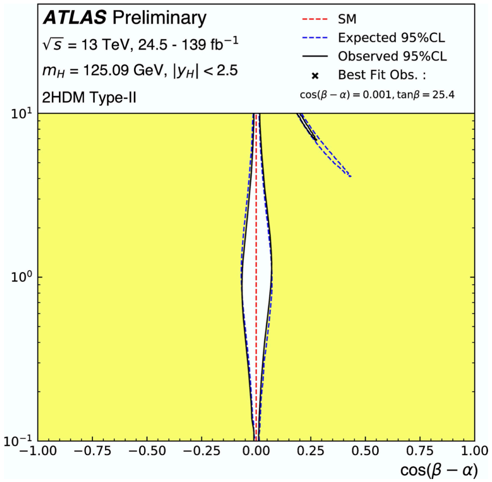
Parameter	(a) $B_i = B_u = 0$	(b) B_i free, $B_u \geq 0$, $\kappa_{W,Z} \leq 1$
κ_Z	1.02 ± 0.06	> 0.88 at 95% CL
κ_W	1.06 ± 0.07	> 0.89 at 95% CL
κ_b	$0.98\ ^{+\,0.14}_{-\,0.13}$	$0.92\ \pm 0.10$
κ_t	1.00 ± 0.12	$0.97\ \pm 0.12$
κ_τ	$1.05\ ^{+\,0.15}_{-\,0.14}$	$1.02\ ^{+\,0.13}_{-\,0.14}$
κ_γ	$1.06\ ^{+\,0.08}_{-\,0.07}$	$1.04\ ^{+\,0.06}_{-\,0.07}$
κ_g	$0.96\ ^{+\,0.09}_{-\,0.08}$	$0.93\ ^{+\,0.08}_{-\,0.07}$
B_i	-	< 0.09 at 95% CL
B_u	-	< 0.19 at 95% CL

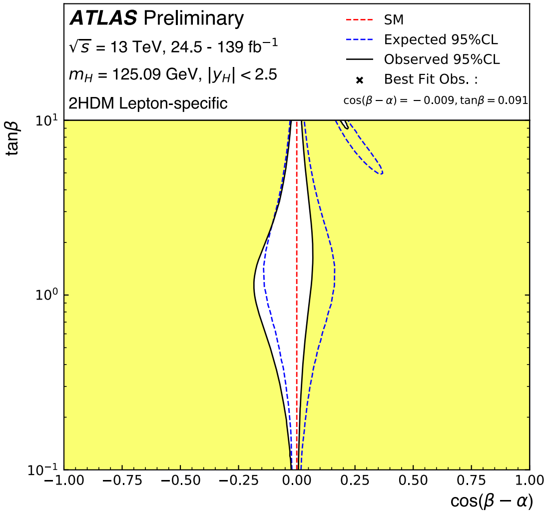
2HDM Interpretation

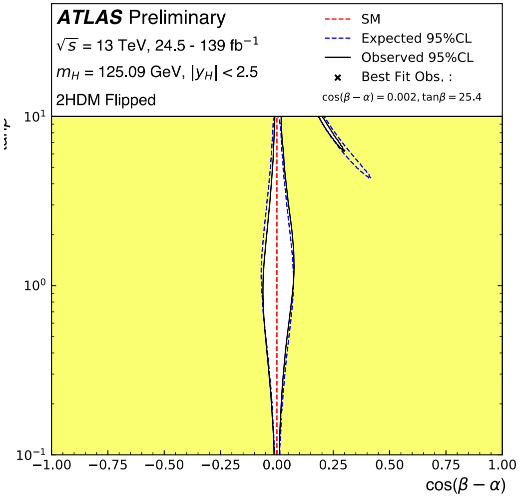
Two-Higgs Doublet Model

- In 2HDM, the SM Higgs sector is extended by an **additional Higgs doublet**
- 4 types of 2HDM are defined:
  - **Type I:** One Higgs doublet couples to **vector bosons**; the other couples to **fermions**
  - **Type II**: One Higgs doublet couples to **up-type quarks**; the other to **down-type quarks and charged leptons.**
  - **Lepton-specific**: The Higgs bosons have the same couplings to **quarks as in Type I model** and to **charged leptons as in Type II.**
  - **Flipped**: The Higgs boson have the same couplings to **quarks as in Type II** and to **charged leptons** as in Type I.









Summary

- The results presented in the CONF note are based on the combination of $H \rightarrow \gamma\gamma$, $H \rightarrow ZZ^*$, $H \rightarrow WW^*$, $H \rightarrow \tau\tau$, $H \rightarrow b\bar{b}$, $H \rightarrow \mu\mu$ and $VBF\ H \rightarrow inv$
- Global signal strength is measured to be $\mathbf{1.06 \pm 0.07}$
- XS measurements in production modes are performed. The observed and expected significances of WH and ZH both exceed 5σ, indicating a first observation for WH
- XS measurements in STXS regions are found to be consistent with SM predictions.
- Measurements of coupling modifiers in several κ frameworks are performed. No significant deviations from SM is observed.
- 4 types of **Two-Higgs-Doublet-Model(2HDM)** get interpreted as constraints in the $(\cos(\beta - \alpha)\,, tan\beta)$ plane.
- The **Minimal supersymmetric standard model(MSSM)** and **Effective field theory(EFT)** interpretations based on the dataset in this combination have been updated in the conference note[link].

Backup

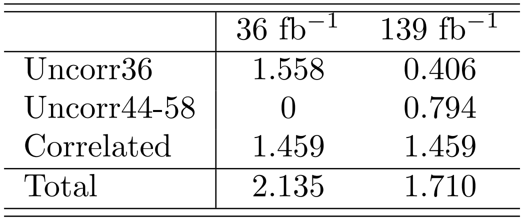
Harmonization among workspaces

- 2 types of workspaces from each analysis
  - Mu workspace: with full theory uncertainties on signal, used in **inclusive mu** and **kappa** results
  - XS workspace: with only theory uncertainties on acceptance of signal, used in **prod. mode XS** and **STXS** measurements

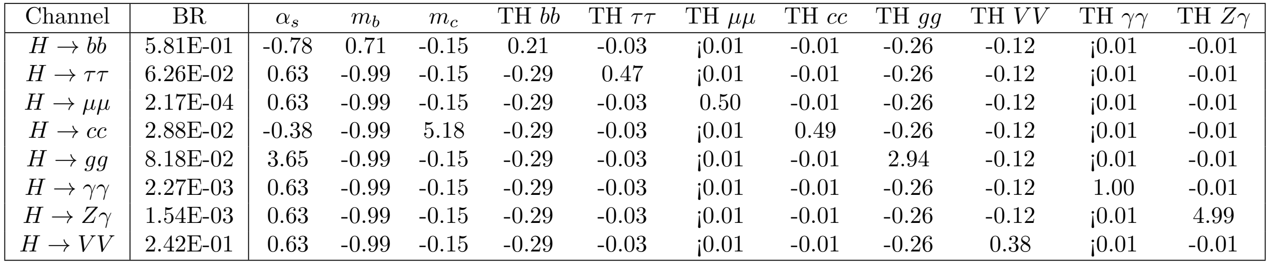
- Parameters of interest need to get merged in order to measure in a coarser granularity
  - For mu WS, the parameters can merged straightforward since full theory uncertainties considered
  - For XS WS, additional uncertainties need to be injected to cover assumption of SM predicted fractions. (twiki)
    - $\Delta\delta_t = \delta_t - \frac{\sum_i n_i^{SM}\delta_i}{\sum_i n_i^{SM}}$

Harmonization among workspaces

- There are some fundamental modifications to all workspaces
- The luminosity uncertainty was split into correlated(1 NP) and uncorrelated(2 NPs) between 15+16 years and 17+18 years
  - The total uncertainty on 15+16 dataset(36/fb) is 2.1%, on FullRun2 dataset(140/fb) is 1.7%.
- BR uncertainties
  - BR uncertainty was split into different sources in the combination, in order to correlated properly between different channels
- Scaling m_H to **125.09GeV**
  - Input channels are mostly based on m_H=**125GeV** except Hyy
  - the impacts are negligible in most of cases, only variation of $H \rightarrow VV$ branching ratio need to be corrected.



	36 fb^{-1}	139 fb^{-1}
Uncorr36	1.558	0.406
Uncorr44-58	0	0.794
Correlated	1.459	1.459
Total	2.135	1.710

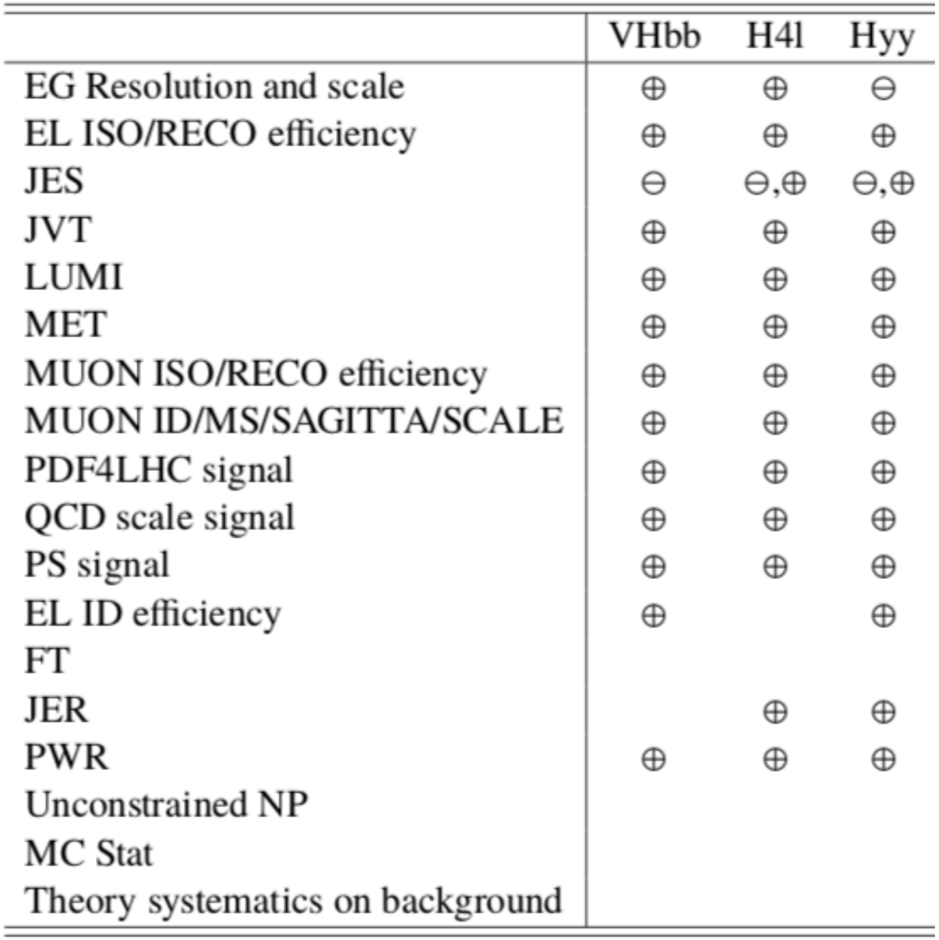


Channel	BR	α_s	m_b	m_c	TH bb	TH $\tau\tau$	TH $\mu\mu$	TH cc	TH gg	TH VV	TH $\gamma\gamma$	TH $Z\gamma$
$H \rightarrow bb$	5.81E-01	-0.78	0.71	-0.15	0.21	-0.03	¡0.01	-0.01	-0.26	-0.12	¡0.01	-0.01
$H \rightarrow \tau\tau$	6.26E-02	0.63	-0.99	-0.15	-0.29	0.47	¡0.01	-0.01	-0.26	-0.12	¡0.01	-0.01
$H \rightarrow \mu\mu$	2.17E-04	0.63	-0.99	-0.15	-0.29	-0.03	0.50	-0.01	-0.26	-0.12	¡0.01	-0.01
$H \rightarrow cc$	2.88E-02	-0.38	-0.99	5.18	-0.29	-0.03	¡0.01	0.49	-0.26	-0.12	¡0.01	-0.01
$H \rightarrow gg$	8.18E-02	3.65	-0.99	-0.15	-0.29	-0.03	¡0.01	-0.01	2.94	-0.12	¡0.01	-0.01
$H \rightarrow \gamma\gamma$	2.27E-03	0.63	-0.99	-0.15	-0.29	-0.03	¡0.01	-0.01	-0.26	-0.12	1.00	-0.01
$H \rightarrow Z\gamma$	1.54E-03	0.63	-0.99	-0.15	-0.29	-0.03	¡0.01	-0.01	-0.26	-0.12	¡0.01	4.99
$H \rightarrow VV$	2.42E-01	0.63	-0.99	-0.15	-0.29	-0.03	¡0.01	-0.01	-0.26	0.38	¡0.01	-0.01

Correlation scheme

Overview of uncertainty correlation for 139/fb analyses

- ➢ The correlation scheme between different release has been studied in the previous combination paper, proved to be adequate
- ➢ The Rel 21. analyses use different jet collections.VHbb uses **EMTopo jets,** while HZZ, HGam, Hmumu, VBF Hinv use **PFlow jets**
- ➢ **What we do follows from discussions with Jet/MET experts and specific checks**



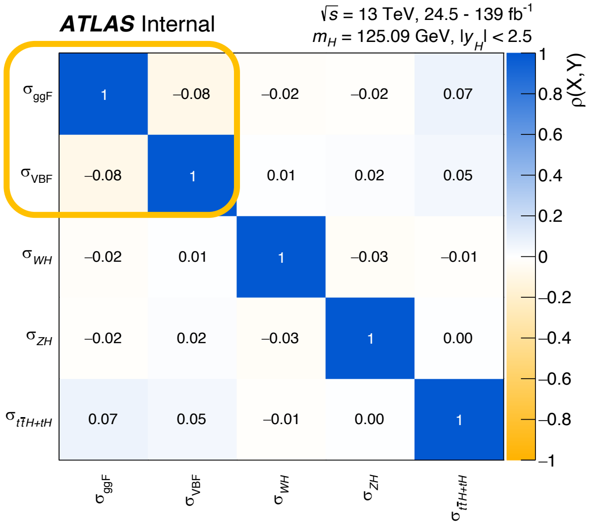
	VHbb	H4l	Hyy
EG Resolution and scale	⊕	⊕	⊖
EL ISO/RECO efficiency	⊕	⊕	⊕
JES	⊖	⊖,⊕	⊖,⊕
JVT	⊕	⊕	⊕
LUMI	⊕	⊕	⊕
MET	⊕	⊕	⊕
MUON ISO/RECO efficiency	⊕	⊕	⊕
MUON ID/MS/SAGITTA/SCALE	⊕	⊕	⊕
PDF4LHC signal	⊕	⊕	⊕
QCD scale signal	⊕	⊕	⊕
PS signal	⊕	⊕	⊕
EL ID efficiency	⊕		⊕
FT			
JER		⊕	⊕
PWR	⊕	⊕	⊕
Unconstrained NP			
MC Stat			
Theory systematics on background			

"+" means fully correlated

"-" means partially correlated

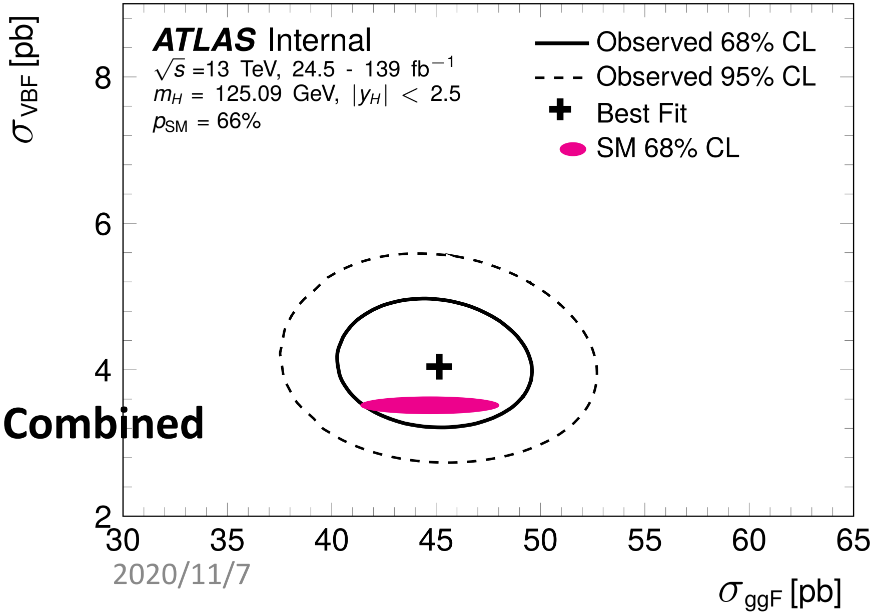
2Dscans

Correlation matrix

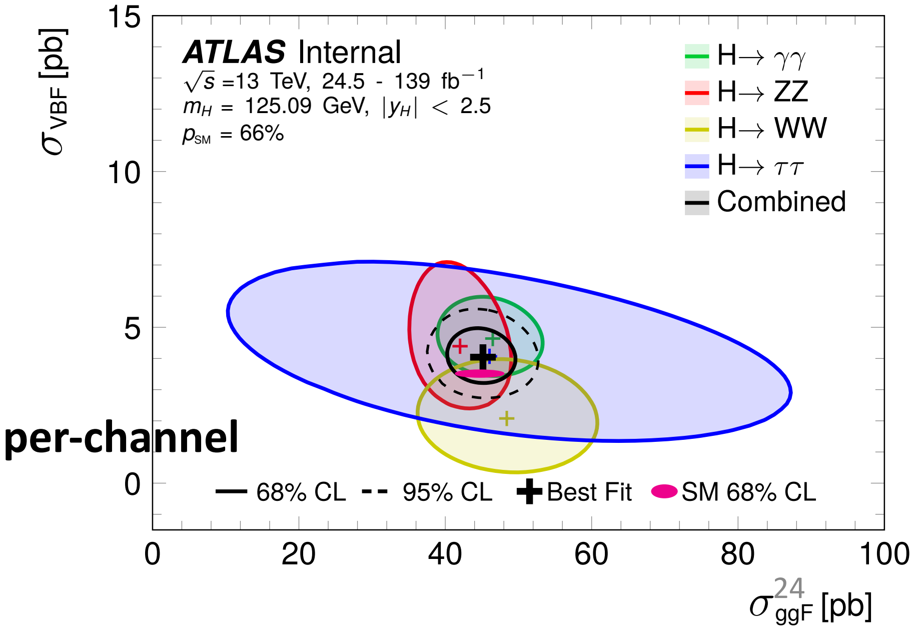


	σ_{ggF}	σ_{VBF}	σ_{WH}	σ_{ZH}	$\sigma_{t\bar{t}H+tH}$
σ_{ggF}	1	−0.08	−0.02	−0.02	0.07
σ_{VBF}	−0.08	1	0.01	0.02	0.05
σ_{WH}	−0.02	0.01	1	−0.03	−0.01
σ_{ZH}	−0.02	0.02	−0.03	1	0.00
$\sigma_{t\bar{t}H+tH}$	0.07	0.05	−0.01	0.00	1

- ➢ The correlation between ggF and VBF decreases compared with previous publication(~15% to 8%)
- ➢ The 2D scans $\boldsymbol{\sigma_{ggF}}$ VS $\boldsymbol{\sigma_{VBH}}$ are performed



Combined

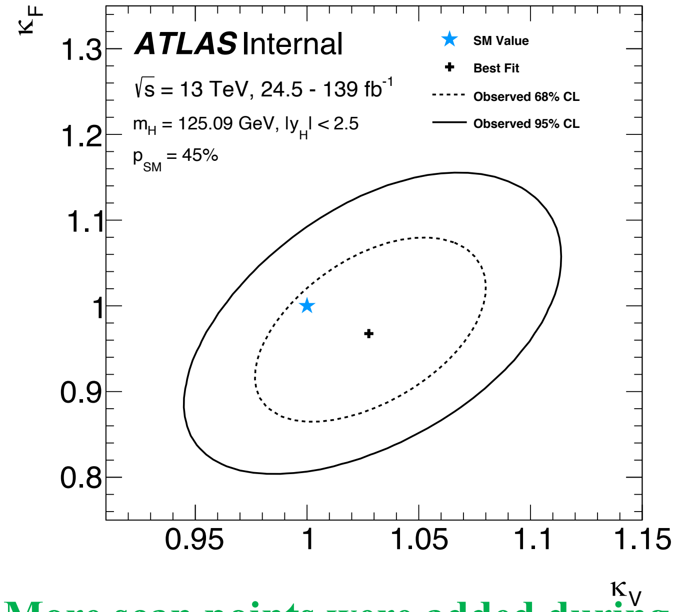


per-channel

Coupling to fermions VS vector bosons

- Assuming uniform coupling modifiers for all fermions and weak vector bosons
- Only SM particles contribute to the total width of Higgs boson

		Measured value
κ_V	observed	$1.03^{+0.03}_{-0.03}$
	expected	$1.00^{+0.03}_{-0.03}$
κ_F	observed	$0.97^{+0.07}_{-0.07}$
	expected	$1.00^{+0.08}_{-0.07}$



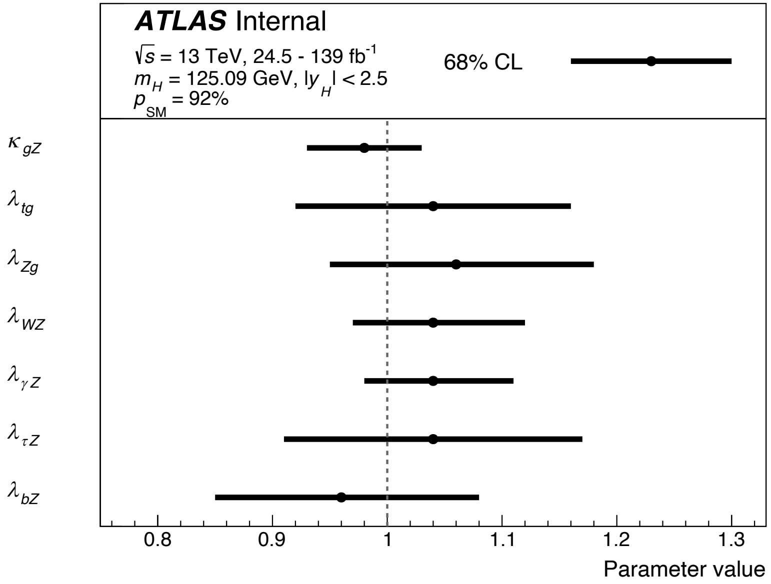
More scan points were added during circulation

2D scan κ_V VS κ_F

- Constrain all other coupling modifiers to their SM values
- Assuming no contribution from invisible or undetected Higgs boson decays
- Compatibility with SM is **45%**
- Linear correlation is **0.50**

Generic model with ratios

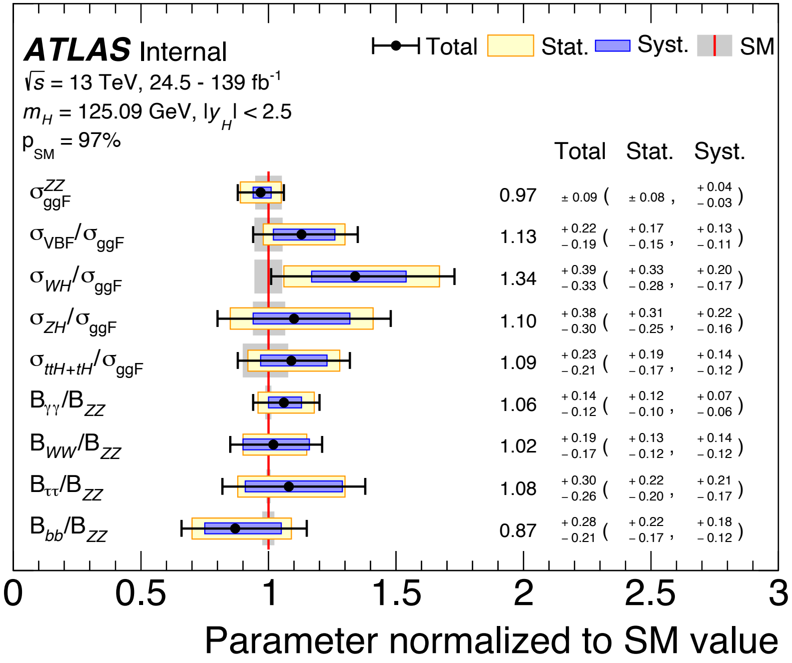
- Measuring coupling modifiers ratios, with respect to a reference process $gg \rightarrow H \rightarrow ZZ$, to avoid introducing assumptions on Higgs total width
- The compatibility with SM hypothesis is **92%**

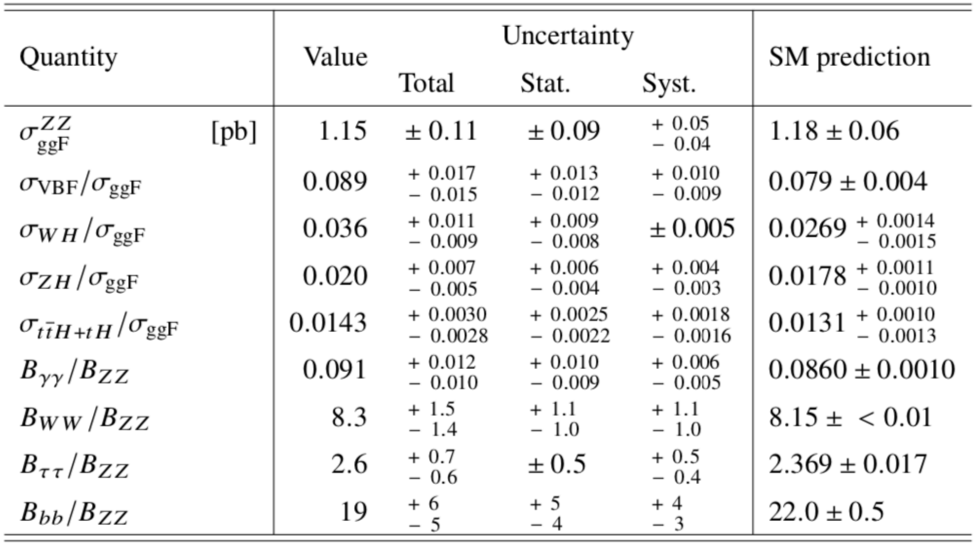


Parameter	Definition in terms of κ modifiers	Result
κ_{gZ}	$\kappa_g \kappa_Z / \kappa_H$	0.98 ± 0.05
λ_{tg}	κ_t / κ_g	1.04 ± 0.12
λ_{Zg}	κ_Z / κ_g	$1.06 \begin{smallmatrix} + 0.12 \\ - 0.11 \end{smallmatrix}$
λ_{WZ}	κ_W / κ_Z	$1.04 \begin{smallmatrix} + 0.08 \\ - 0.07 \end{smallmatrix}$
$\lambda_{\gamma Z}$	κ_γ / κ_Z	$1.04 \begin{smallmatrix} + 0.07 \\ - 0.06 \end{smallmatrix}$
$\lambda_{\tau Z}$	κ_τ / κ_Z	1.04 ± 0.13
λ_{bZ}	κ_b / κ_Z	$0.96 \begin{smallmatrix} + 0.12 \\ - 0.11 \end{smallmatrix}$

Ratios of XS and branching fractions

- Parametrisation
  - $(\boldsymbol{\sigma} \times \boldsymbol{B})_{if} = \boldsymbol{\sigma}^{ZZ}_{ggF} \cdot \left(\frac{\boldsymbol{\sigma_i}}{\boldsymbol{\sigma_{ggF}}}\right) \cdot \left(\frac{\boldsymbol{B_f}}{\boldsymbol{B_{ZZ}}}\right)$
  - Measure the ratios of production XS to that of ggF, and ratios of branching fractions to that of $H \to ZZ^*$





Quantity		Value	Uncertainty			SM prediction
			Total	Stat.	Syst.	
$\sigma^{ZZ}_{\mathrm{ggF}}$	[pb]	1.15	± 0.11	± 0.09	$^{+0.05}_{-0.04}$	1.18 ± 0.06
$\sigma_{\mathrm{VBF}}/\sigma_{\mathrm{ggF}}$		0.089	$^{+0.017}_{-0.015}$	$^{+0.013}_{-0.012}$	$^{+0.010}_{-0.009}$	0.079 ± 0.004
$\sigma_{WH}/\sigma_{\mathrm{ggF}}$		0.036	$^{+0.011}_{-0.009}$	$^{+0.009}_{-0.008}$	± 0.005	$0.0269\ ^{+0.0014}_{-0.0015}$
$\sigma_{ZH}/\sigma_{\mathrm{ggF}}$		0.020	$^{+0.007}_{-0.005}$	$^{+0.006}_{-0.004}$	$^{+0.004}_{-0.003}$	$0.0178\ ^{+0.0011}_{-0.0010}$
$\sigma_{t\bar{t}H+tH}/\sigma_{\mathrm{ggF}}$		0.0143	$^{+0.0030}_{-0.0028}$	$^{+0.0025}_{-0.0022}$	$^{+0.0018}_{-0.0016}$	$0.0131\ ^{+0.0010}_{-0.0013}$
$B_{\gamma\gamma}/B_{ZZ}$		0.091	$^{+0.012}_{-0.010}$	$^{+0.010}_{-0.009}$	$^{+0.006}_{-0.005}$	0.0860 ± 0.0010
B_{WW}/B_{ZZ}		8.3	$^{+1.5}_{-1.4}$	$^{+1.1}_{-1.0}$	$^{+1.1}_{-1.0}$	$8.15 \pm\ < 0.01$
$B_{\tau\tau}/B_{ZZ}$		2.6	$^{+0.7}_{-0.6}$	± 0.5	$^{+0.5}_{-0.4}$	2.369 ± 0.017
B_{bb}/B_{ZZ}		19	$^{+6}_{-5}$	$^{+5}_{-4}$	$^{+4}_{-3}$	22.0 ± 0.5

Validation on input channels

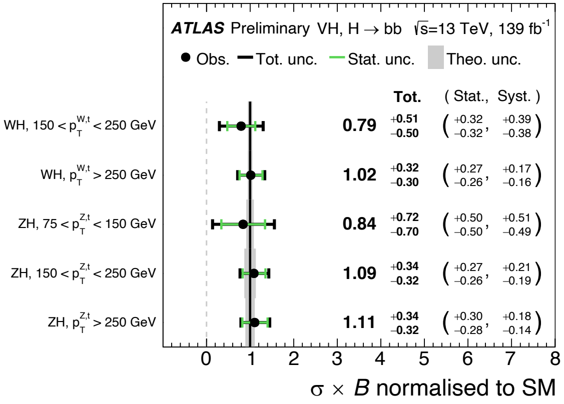
VHbb validation

Inclusive mu:

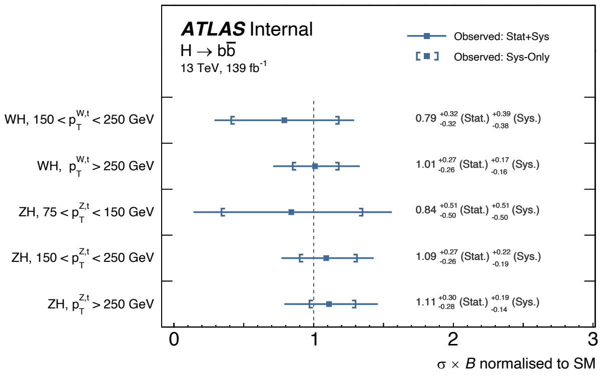
CONF	$\mu_{VH}^{bb} = 1.02^{+0.18}_{-0.17} =^{+0.12}_{-0.11}(\mathrm{Stat.})^{+0.14}_{-0.13}(\mathrm{Syst.})$
Cross Check	$\mu_{VH}^{bb} = 1.02^{+0.18}_{-0.17} =^{+0.12}_{-0.12}(\mathrm{Stat.})^{+0.14}_{-0.13}(\mathrm{Syst.})$

- ➢ The workspace provided used full granularity of Stage1.2 scheme
- ➢ The cross-check results agree well with the VHbb published results

Published



Cross-check



H->ZZ->4l validation

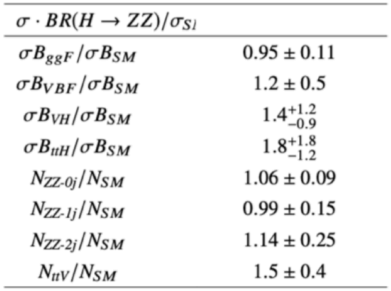
- ➢ Validation on 4XS is a simple remerge without injecting additional uncertainties

Inclusive mu:

CONF $\mu = 1.01 \pm 0.08(\mathrm{stat.}) \pm 0.04(\mathrm{exp.}) \pm 0.05(\mathrm{th.}) = 1.01 \pm 0.11$

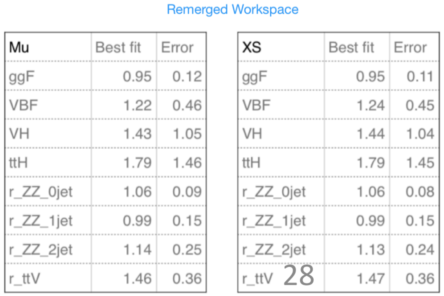
Xcheck $\mu = 1.01^{+0.09}_{-0.08}(\mathrm{stat.})^{+0.04}_{-0.03}(\mathrm{exp.})^{+0.06}_{-0.05}(\mathrm{theo.}) = 1.01^{+0.11}_{-0.10}$

Published



$\sigma \cdot BR(H \to ZZ)/\sigma_{SM}$	
$\sigma B_{ggF}/\sigma B_{SM}$	0.95 ± 0.11
$\sigma B_{VBF}/\sigma B_{SM}$	1.2 ± 0.5
$\sigma B_{VH}/\sigma B_{SM}$	$1.4^{+1.2}_{-0.9}$
$\sigma B_{ttH}/\sigma B_{SM}$	$1.8^{+1.8}_{-1.2}$
$N_{ZZ\text{-}0j}/N_{SM}$	1.06 ± 0.09
$N_{ZZ\text{-}1j}/N_{SM}$	0.99 ± 0.15
$N_{ZZ\text{-}2j}/N_{SM}$	1.14 ± 0.25
N_{ttV}/N_{SM}	1.5 ± 0.4

Cross-check



Remerged Workspace

Mu	Best fit	Error
ggF	0.95	0.12
VBF	1.22	0.46
VH	1.43	1.05
ttH	1.79	1.46
r_ZZ_0jet	1.06	0.09
r_ZZ_1jet	0.99	0.15
r_ZZ_2jet	1.14	0.25
r_ttV	1.46	0.36

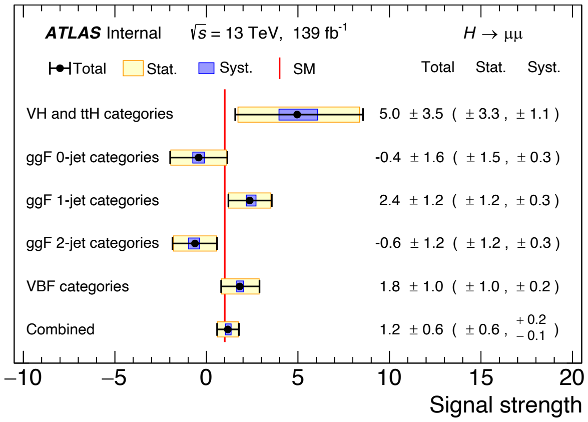
XS	Best fit	Error
ggF	0.95	0.11
VBF	1.24	0.45
VH	1.44	1.04
ttH	1.79	1.45
r_ZZ_0jet	1.06	0.08
r_ZZ_1jet	0.99	0.15
r_ZZ_2jet	1.13	0.24
r_ttV	1.47	0.36

Validation on input channels

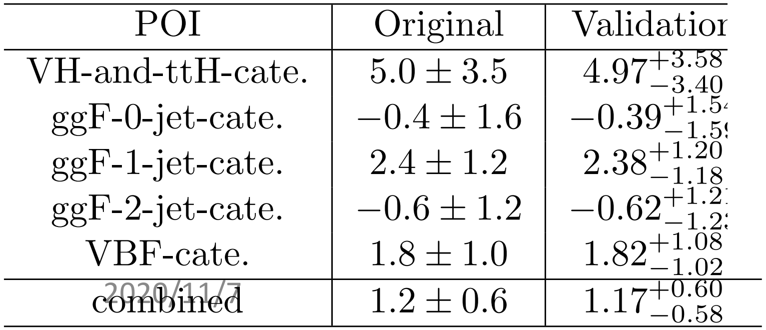
$H \to \mu\mu$ validation

- Hmumu workspace has a production mode granularity at the particle level
- The fit results and ranking agree well with published results

Published

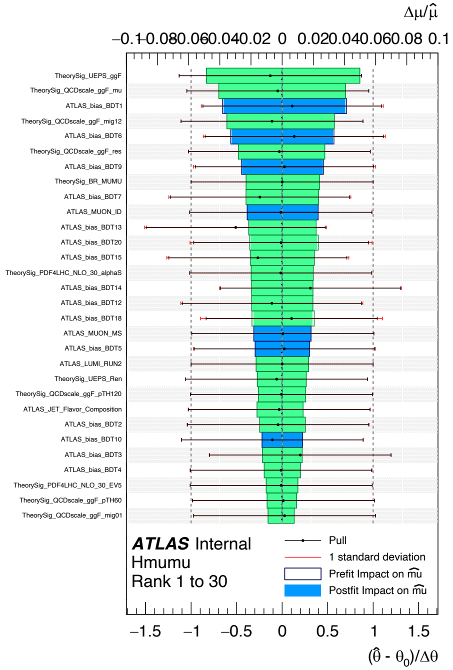


Cross-check

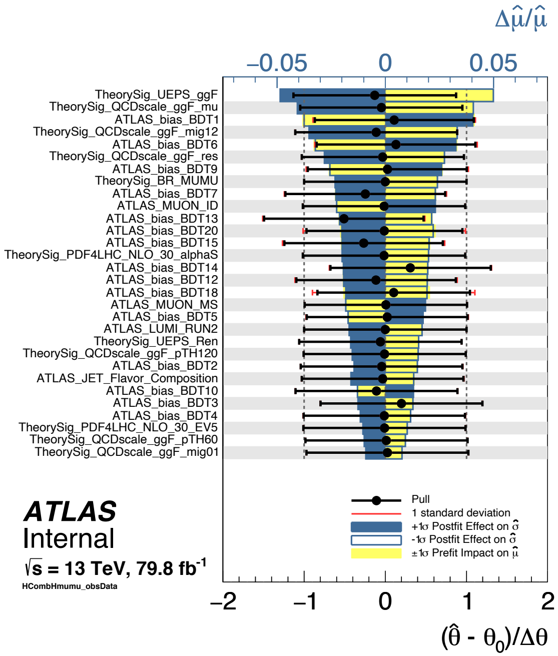


POI	Original	Validatio
VH-and-ttH-cate.	5.0 ± 3.5	$4.97^{+3.58}_{-3.40}$
ggF-0-jet-cate.	-0.4 ± 1.6	$-0.39^{+1.5}_{-1.5}$
ggF-1-jet-cate.	2.4 ± 1.2	$2.38^{+1.20}_{-1.18}$
ggF-2-jet-cate.	-0.6 ± 1.2	$-0.62^{+1.2}_{-1.2}$
VBF-cate.	1.8 ± 1.0	$1.82^{+1.08}_{-1.02}$
combined	1.2 ± 0.6	$1.17^{+0.60}_{-0.58}$

Published



Cross-check



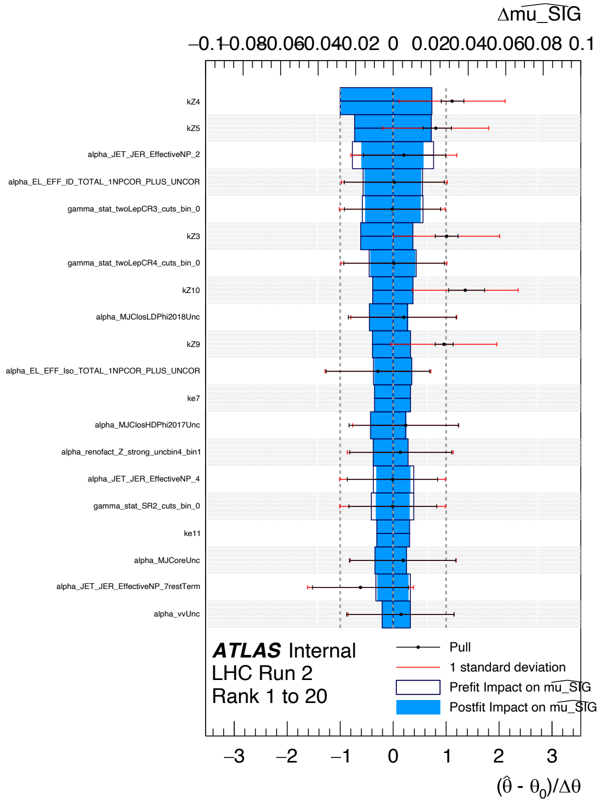
Ranking and pulls on observed data

Validation on input channels

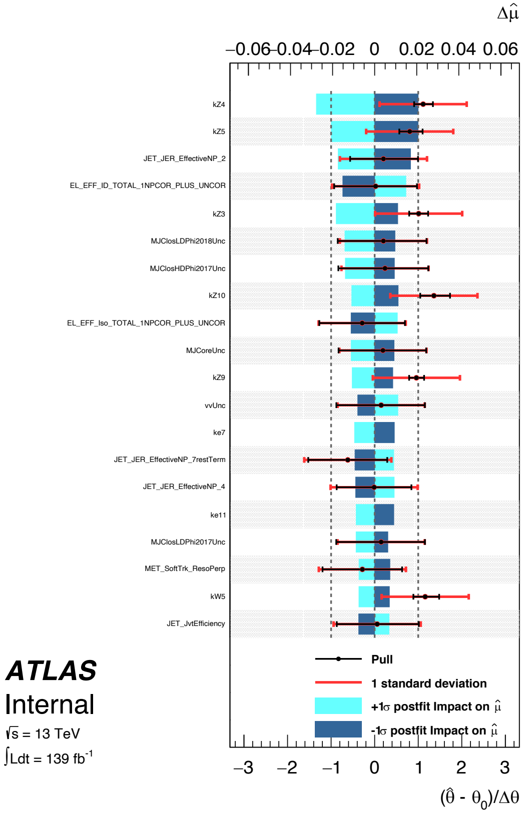
$Hinv, VBF + MET$ validation

- Validate the **upper limit on $BR(H \rightarrow inv)$** using WS from Hinv,VBF+MET analysis
- The fit results and NP ranking are consistent with published results

	Observed	Expected	$+1\sigma$	$-1+\sigma$	$+2\sigma$	-2σ
published results	0.132	0.132	0.183	0.095	0.248	0.071
validation results	0.132	0.132	0.183	0.096	0.247	0.071



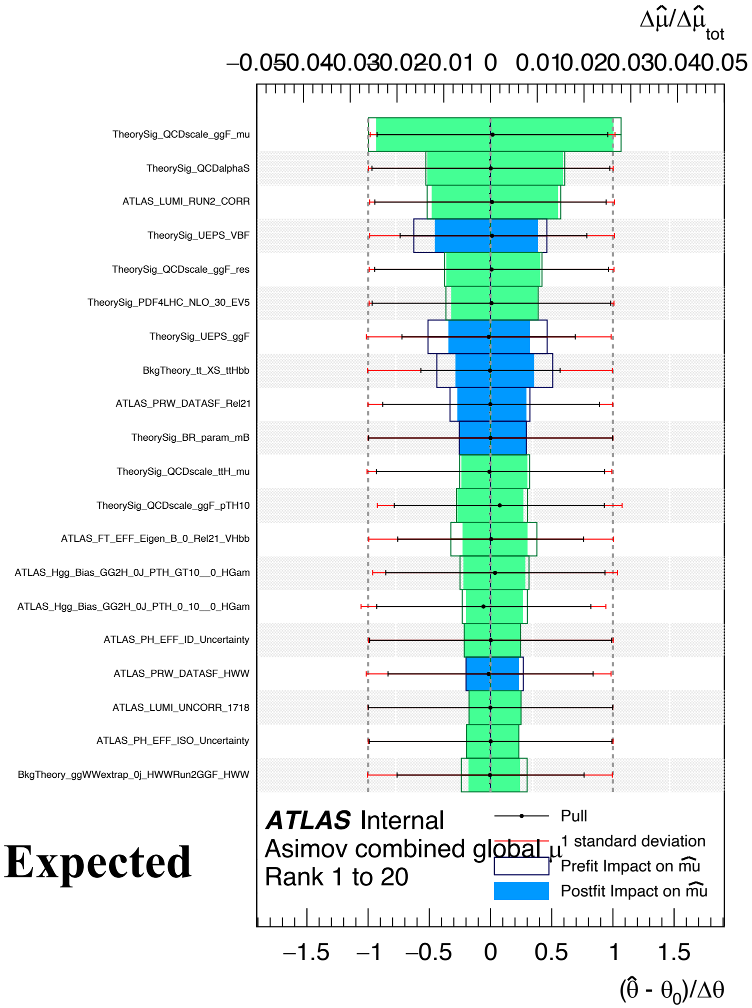
Published



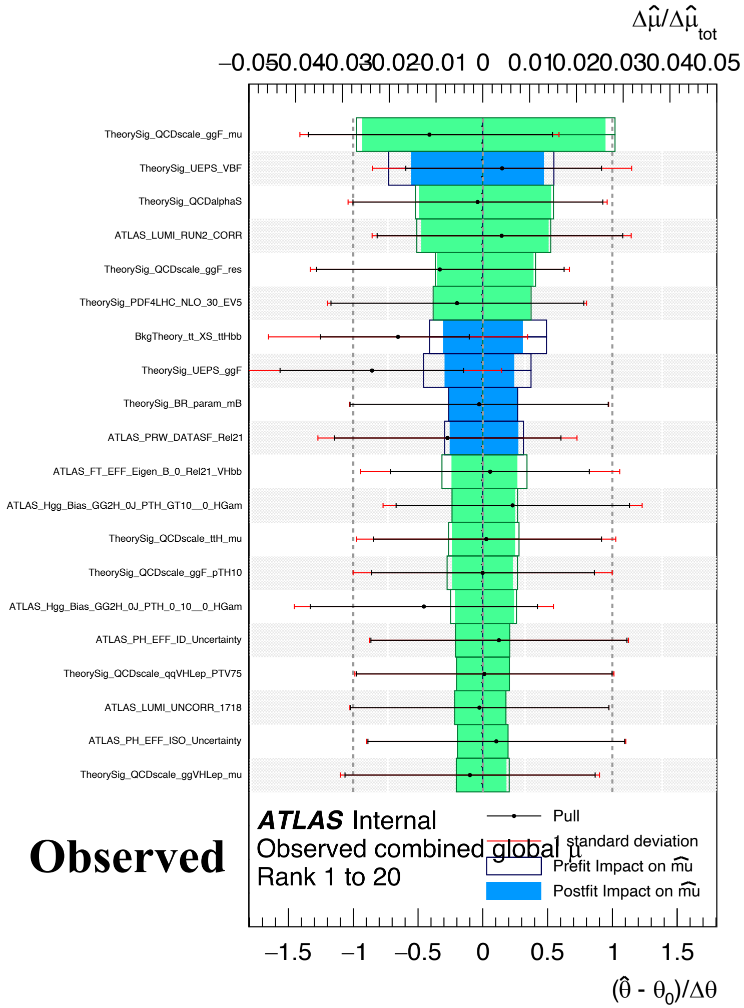
Cross-check

2020/11/7

NP Ranking with mu WS



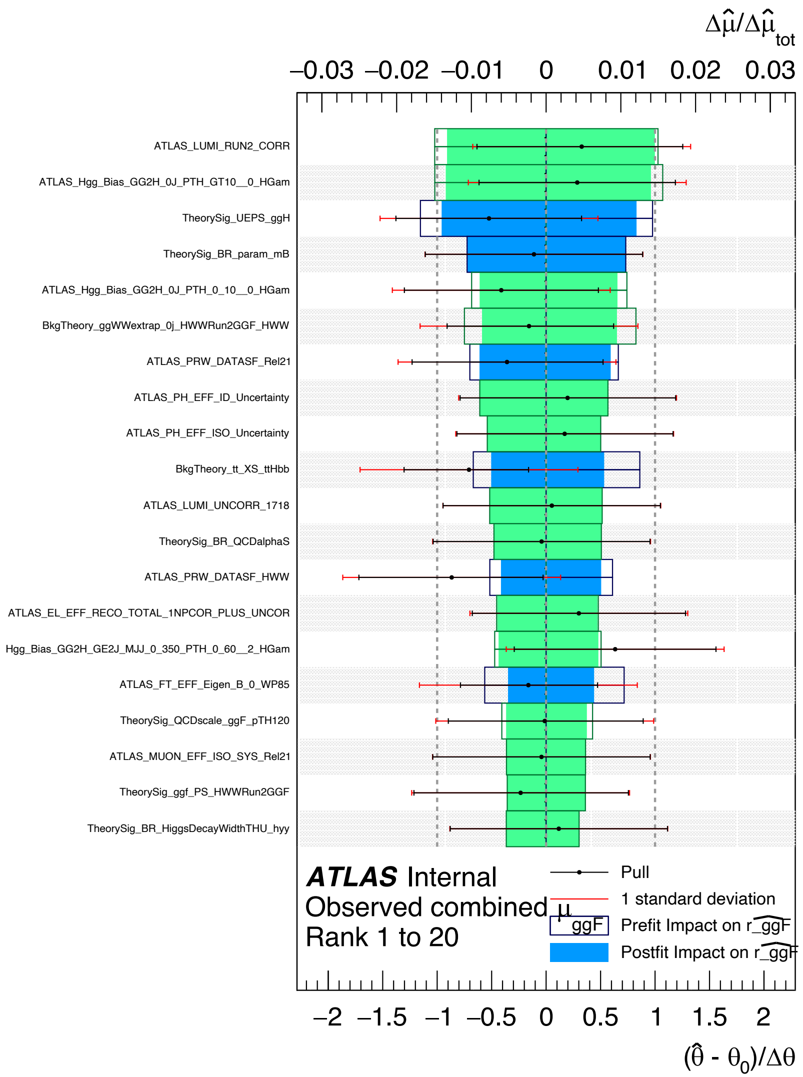
Expected

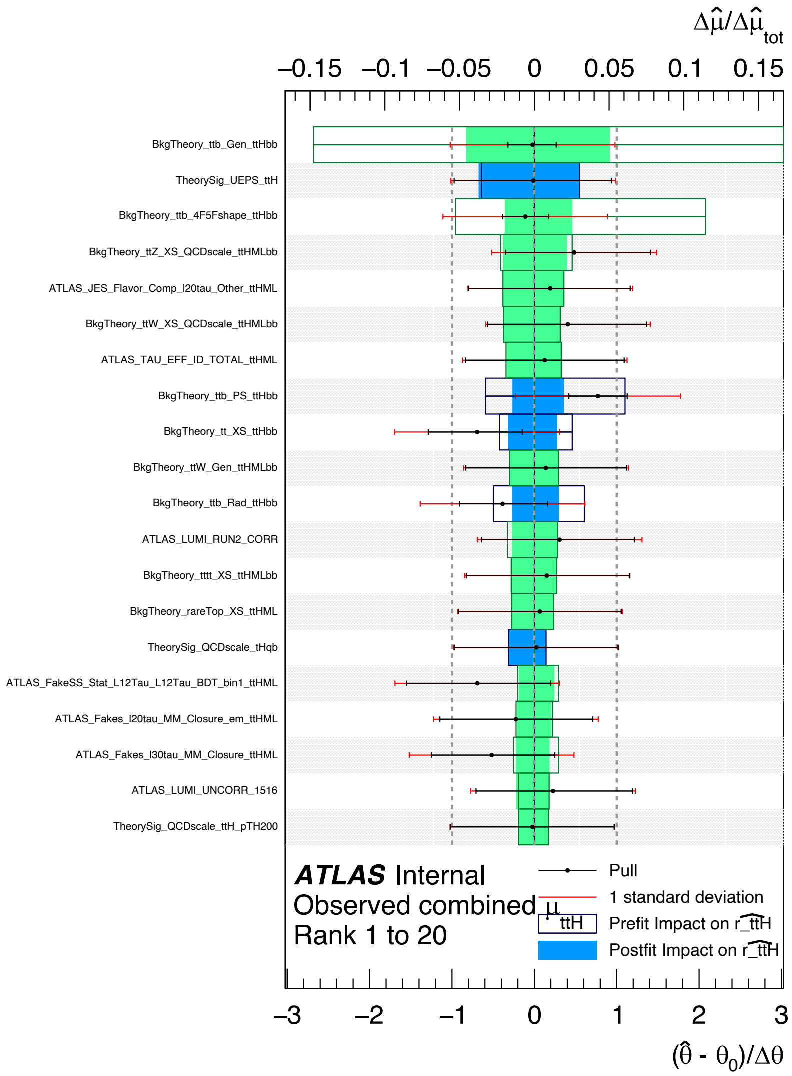


Observed

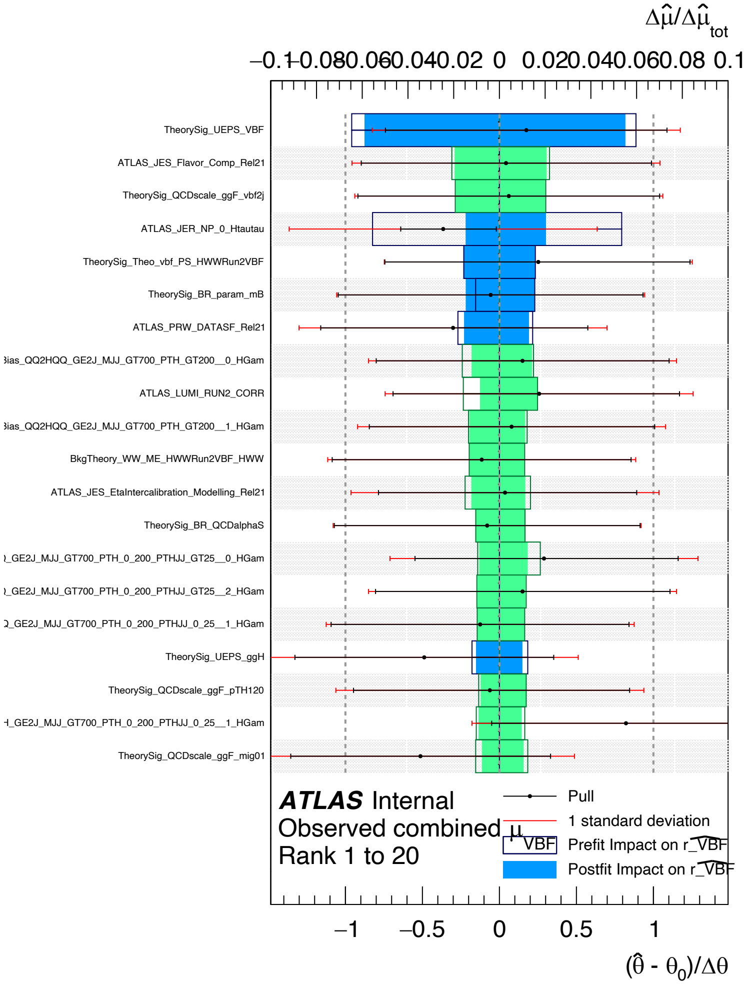
- The dominant theoretical NP is **QCDscale_ggF_mu**
- The dominant experimental NP is **correlated luminosity uncertainty**

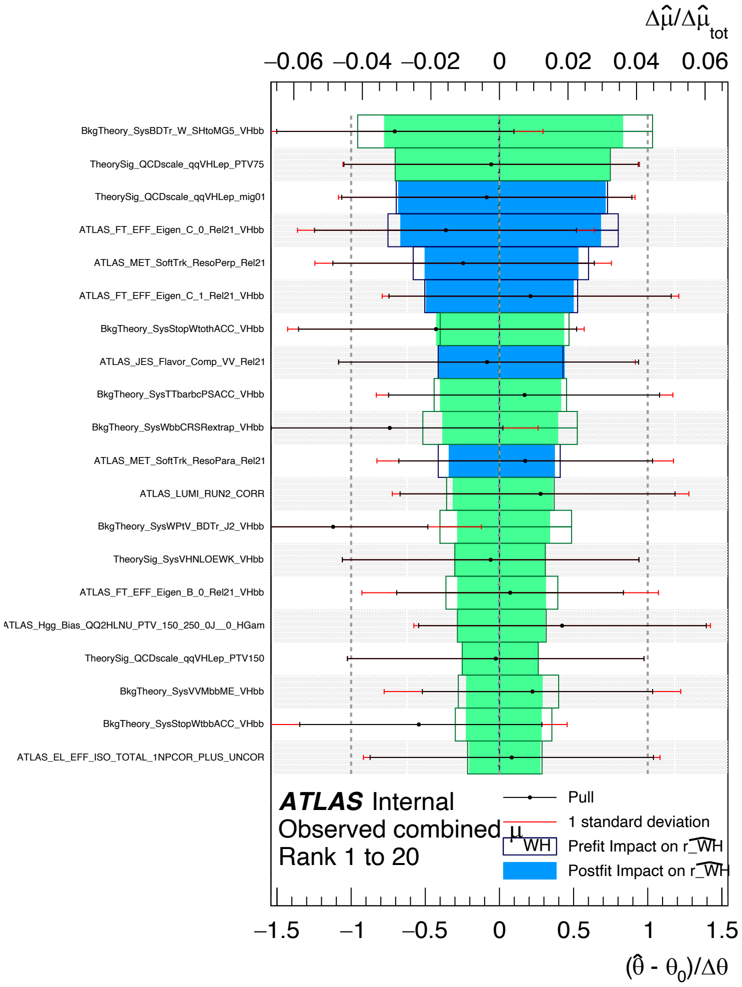
5XS NP ranking



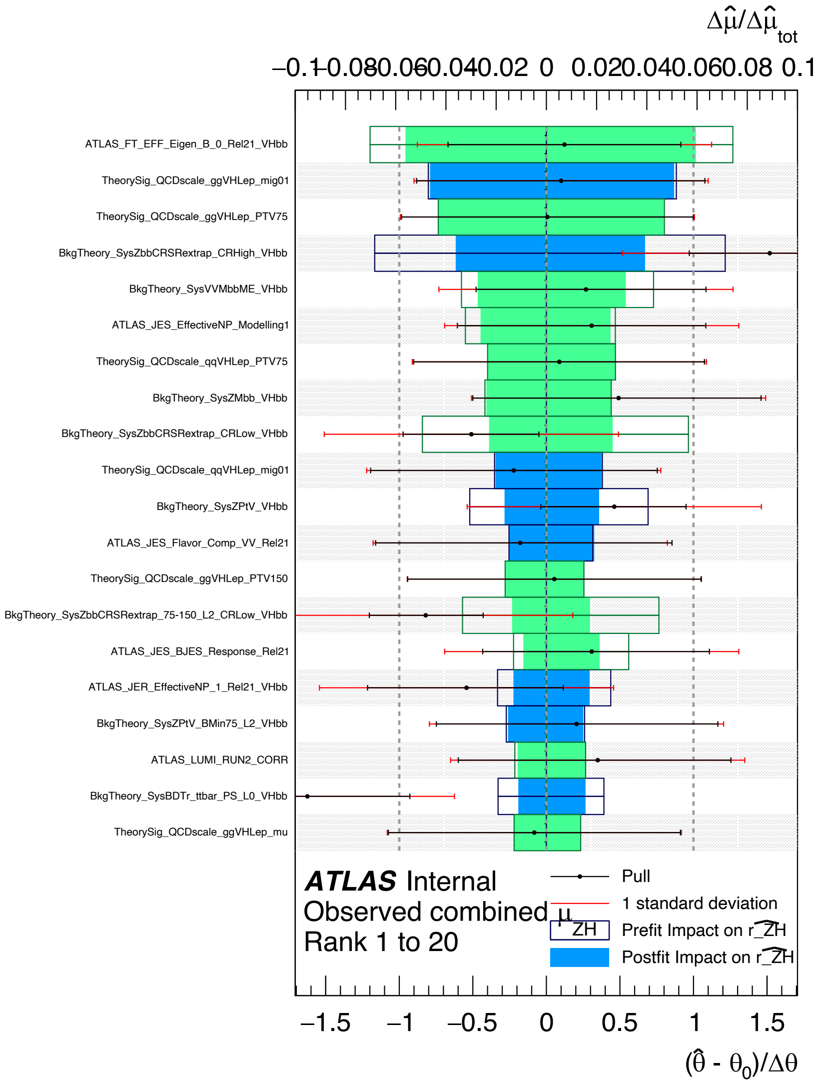


5XS NP ranking

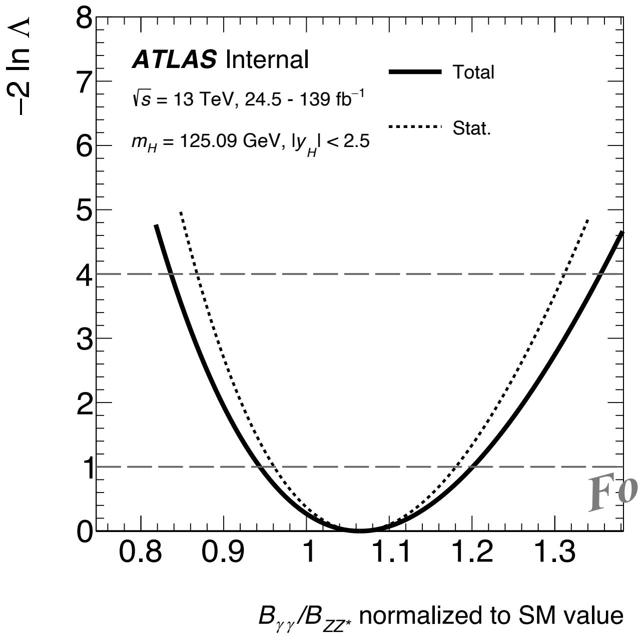


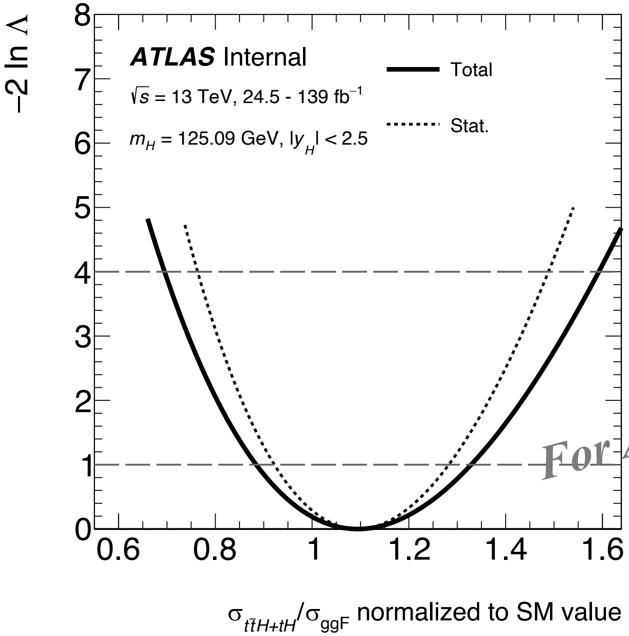


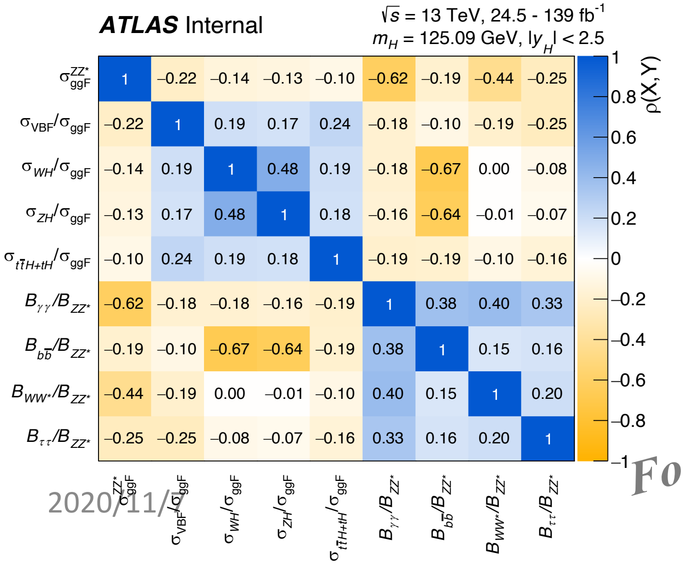
5XS NP ranking



Ratios of XS and branching fractions







	$\sigma_{ggF}^{ZZ^*}$	$\sigma_{VBF}/\sigma_{ggF}$	σ_{WH}/σ_{ggF}	σ_{ZH}/σ_{ggF}	$\sigma_{t\bar{t}H+tH}/\sigma_{ggF}$	$B_{\gamma\gamma}/B_{ZZ^*}$	$B_{b\bar{b}}/B_{ZZ^*}$	B_{WW^*}/B_{ZZ^*}	$B_{\tau\tau}/B_{ZZ^*}$
$\sigma_{ggF}^{ZZ^*}$	1	−0.22	−0.14	−0.13	−0.10	−0.62	−0.19	−0.44	−0.25
$\sigma_{VBF}/\sigma_{ggF}$	−0.22	1	0.19	0.17	0.24	−0.18	−0.10	−0.19	−0.25
σ_{WH}/σ_{ggF}	−0.14	0.19	1	0.48	0.19	−0.18	−0.67	0.00	−0.08
σ_{ZH}/σ_{ggF}	−0.13	0.17	0.48	1	0.18	−0.16	−0.64	−0.01	−0.07
$\sigma_{t\bar{t}H+tH}/\sigma_{ggF}$	−0.10	0.24	0.19	0.18	1	−0.19	−0.19	−0.10	−0.16
$B_{\gamma\gamma}/B_{ZZ^*}$	−0.62	−0.18	−0.18	−0.16	−0.19	1	0.38	0.40	0.33
$B_{b\bar{b}}/B_{ZZ^*}$	−0.19	−0.10	−0.67	−0.64	−0.19	0.38	1	0.15	0.16
B_{WW^*}/B_{ZZ^*}	−0.44	−0.19	0.00	−0.01	−0.10	0.40	0.15	1	0.20
$B_{\tau\tau}/B_{ZZ^*}$	−0.25	−0.25	−0.08	−0.07	−0.16	0.33	0.16	0.20	1