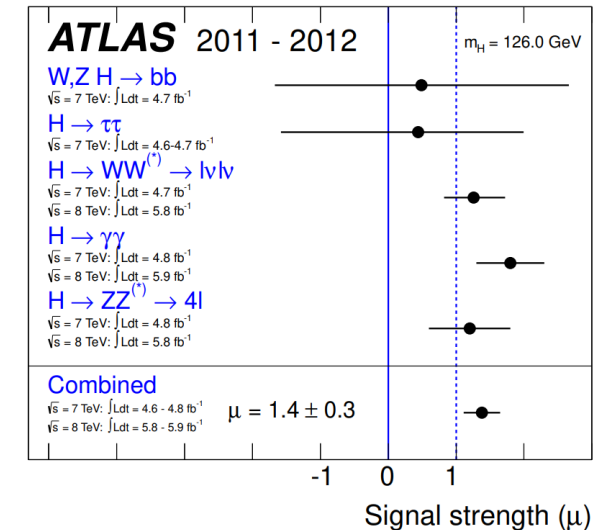
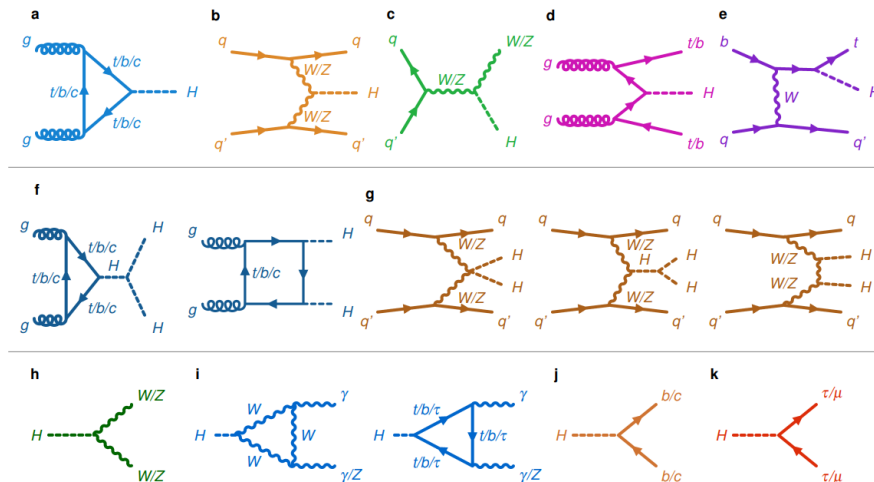


Higgs coupling combination status & plan

Yixiang Zhang on behalf of Yanping's group

Overview

- More than 10 years after the Higgs boson discovery, we continue to improve the measurement precision of its properties:
 - Precision Higgs measurements are key test of the SM and a probe of BSM
- The recent work combining all available Run-2 channels provides the most comprehensive picture of Higgs-boson couplings
 - Several updated channels and new measurement are included compared to the previous Nature benchmark



[Phys.Lett. B](#)



A detailed map of Higgs boson interactions by the ATLAS experiment ten years after the discovery

[Nature](#)



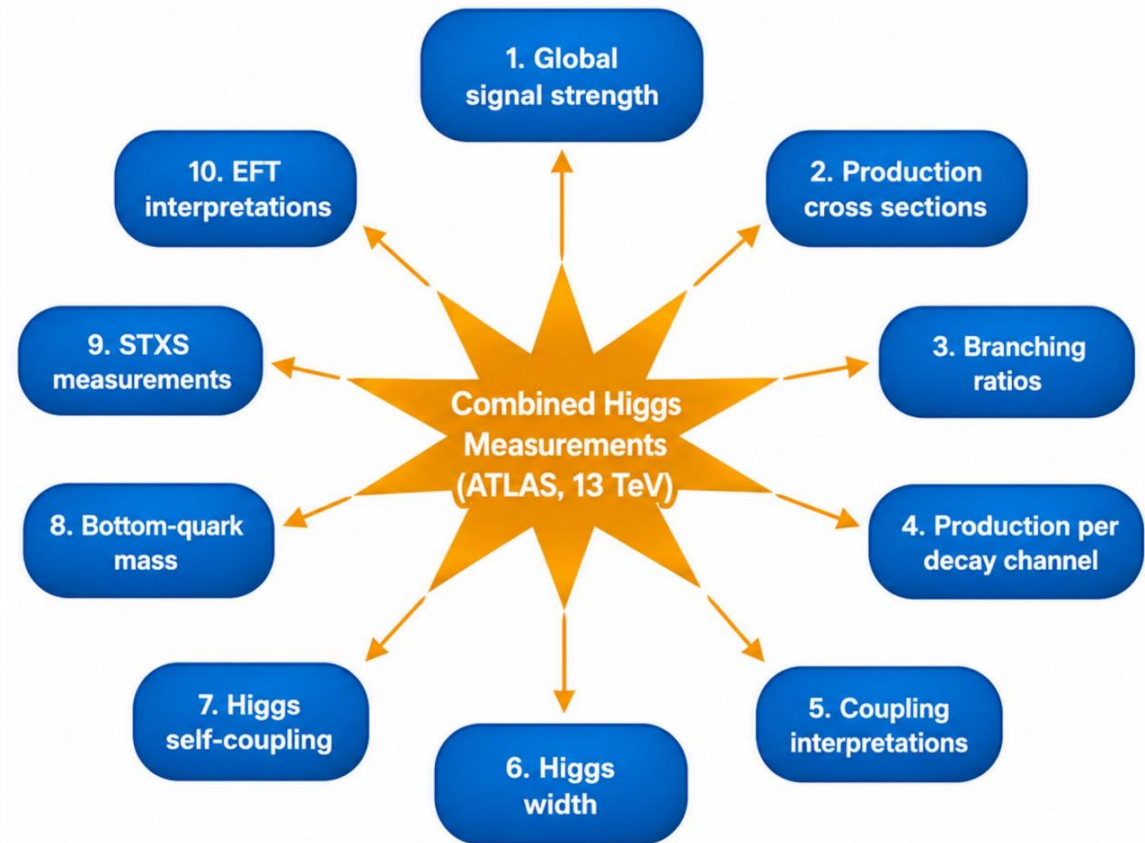
Combination of Higgs boson measurements at $\sqrt{s} = 13$ TeV and their interpretations by the ATLAS experiment

[Arxiv](#)

Scope of the paper

Topics of this Paper

- **1. Global signal strength**
Overall Higgs event rate relative to the Standard Model.
- **2. Production cross sections**
Measurements of main Higgs production modes.
- **3. Branching ratios**
Measurements of Higgs decay branching fractions.
- **4. Production per decay channel**
Measurements of $\sigma_i \times B_f$ for individual channels.
- **5. Coupling interpretations**
Higgs coupling modifiers in the kappa framework.
- **6. Higgs width**
Total Higgs width from on-shell and off-shell information.
- **7. Higgs self-coupling**
Constraint on $\kappa\lambda$ from single and double Higgs production.
- **8. Bottom-quark mass**
Determination of $m_b(m_b)$ from Higgs couplings.
- **9. STXS measurements**
Higgs production kinematics in 44 regions.
- **10. EFT interpretations**
Interpretation in the SMEFT framework.



Input analysis & correlation scheme

Analysis	Prod. modes	$\mathcal{L}$ [fb ⁻¹]	Ref.	Comparison with Ref. [3]	Incl.	κ	STXS
$H \rightarrow ZZ^* \rightarrow 4\ell$	All	140	[73]	Unchanged	✓	✓	✓
$H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$	ggF, VBF	140	[74]	Updated	✓	✓	✓
$H \rightarrow WW^* \rightarrow \ell\nu\ell\nu, \ell\nu jj$	VH	140	[75]	Full Run 2	✓	✓	✓
$H \rightarrow \gamma\gamma$	All	140	[76]	Unchanged	✓	✓	✓
$H \rightarrow Z\gamma$	All	140	[70]	Unchanged	✓	✓	
$H \rightarrow \tau\tau$	All, except $(V \rightarrow \text{leptons})H$	140	[77]	Updated	✓	✓	✓
$H \rightarrow \tau\tau$	$(V \rightarrow \text{leptons})H$	140	[72]	New	✓	✓	
$H \rightarrow \mu\mu$	All	140	[71]	Unchanged	✓	✓	
$H \rightarrow bb$	VBF	126	[5]	Unchanged	✓	✓	✓
$H \rightarrow bb, cc$	$(V \rightarrow \text{leptons})H$	140	[78]	Updated	✓	✓	✓
$H \rightarrow bb$ (high p_T^H)	All	136	[69]	Unchanged			✓
$H \rightarrow \text{multileptons}$	$t\bar{t}H$	140	[79]	Full Run 2	✓	✓	✓
$H \rightarrow bb$	$t\bar{t}H$	140	[80]	Updated	✓	✓	✓
$H \rightarrow bb$	tH	140	[81]	Updated	✓	✓	✓
$H \rightarrow \text{invisible}$	VBF	140	[65]	Unchanged		✓	
$H \rightarrow \text{invisible}$	VBF + γ	140	[68]	New		✓	
$H \rightarrow \text{invisible}$	$(V \rightarrow \text{leptons})H$	140	[66]	Unchanged		✓	
$H \rightarrow \text{invisible}$	$t\bar{t}H$	140	[67]	New		✓	
$H^{(*)} \rightarrow ZZ^{(*)}$	ggF, VBF	140	[63]	Updated		✓	
$H^{(*)} \rightarrow WW^{(*)}$	ggF, VBF	140	[64]	New		✓	
$HH \rightarrow bbbb$	ggF, VBF	126	[6]	New		✓	
$HH \rightarrow bbbb$ (high p_T^H)	VBF	140	[82]	New		✓	
$HH \rightarrow bb\tau\tau$	ggF, VBF	140	[83]	New		✓	
$HH \rightarrow bb\gamma\gamma$	ggF, VBF	140	[84]	New		✓	
$HH \rightarrow bb\ell\ell + E_T^{\text{miss}}$	ggF, VBF	140	[85]	New		✓	
$HH \rightarrow \text{multileptons}$	ggF, VBF	140	[86]	New		✓	

14 on-shell analyses

4 $H \rightarrow \text{inv}$ analyses

2 off-shell analyses

6 di-Higgs analyses

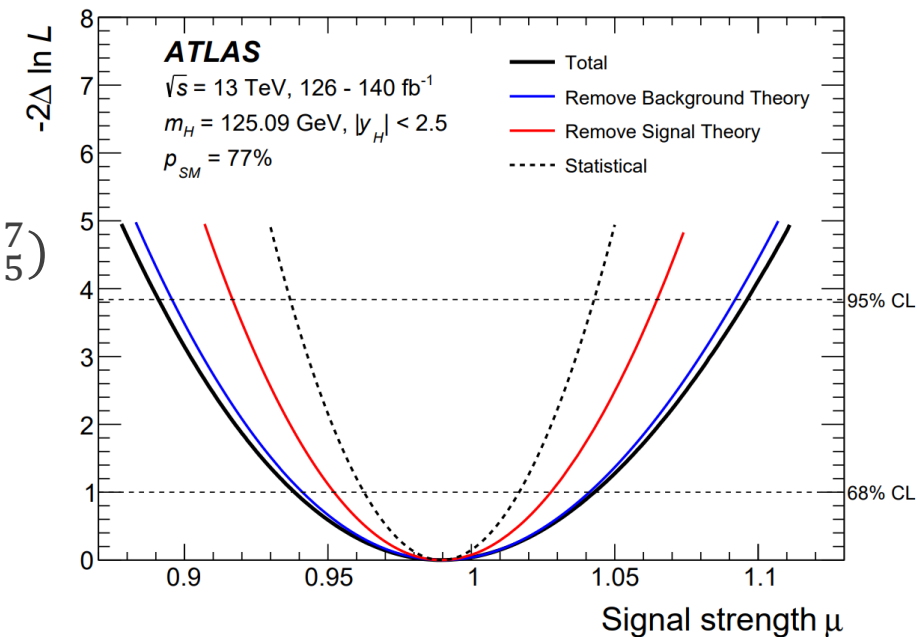
Compared with the Nature

- 2 channels are updated to the full Run2 dataset
- 6 channels are improved
- 4 new single Higgs channels
- 6 new HH channels

Global signal strength

- A single inclusive signal strength μ scaling all event rates considered in the combination
- **15% improvement** compared to the previous analysis
 - Mainly driven by updated measurement of $H \rightarrow WW(\text{ggF, VBF})$ and $H \rightarrow \tau\tau$ analysis
- **Signal-theory uncertainty is dominant**
 - leading by the higher-order QCD ($^{+0.026}_{-0.024}$)
 - Other contribution from PS/UE ($^{+0.019}_{-0.018}$) and pdf+ α_s ($^{+0.017}_{-0.015}$)
- **SM compatibility $p_{SM} = 77\%$**

$$\mu = 0.990^{+0.053}_{-0.051} = 0.990 \pm 0.027 \text{ (stat.)} \pm 0.024 \text{ (exp.)} \begin{matrix} +0.037 \\ -0.035 \end{matrix} \text{ (sig. theo.)} \begin{matrix} +0.016 \\ -0.015 \end{matrix} \text{ (bkg. theo.)}$$



Production cross sections

- Measure the cross sections in different production mode

- 6 production modes: ggF+bbH, VBF, WH, ZH, ttH, tH

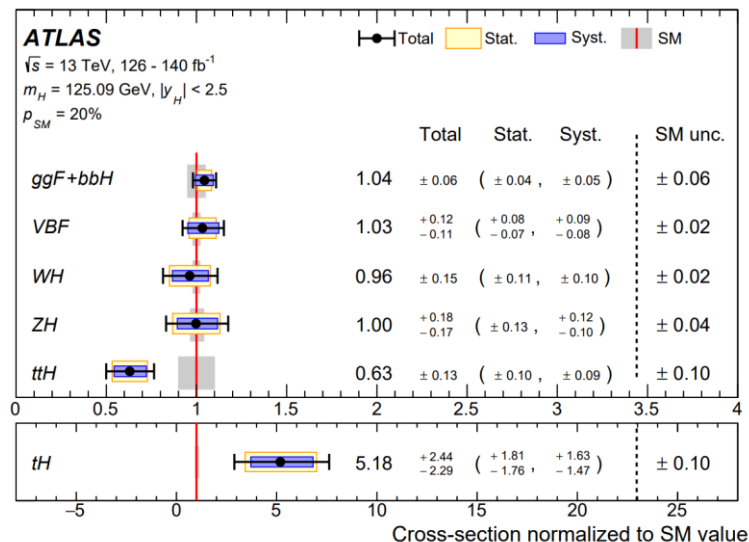
- SM compatibility $p_{SM} = 20\%$

- Mild deviation of ttH/tH cross-section from SM
- A dedicated tH combination is on-going

Run2+3 combined



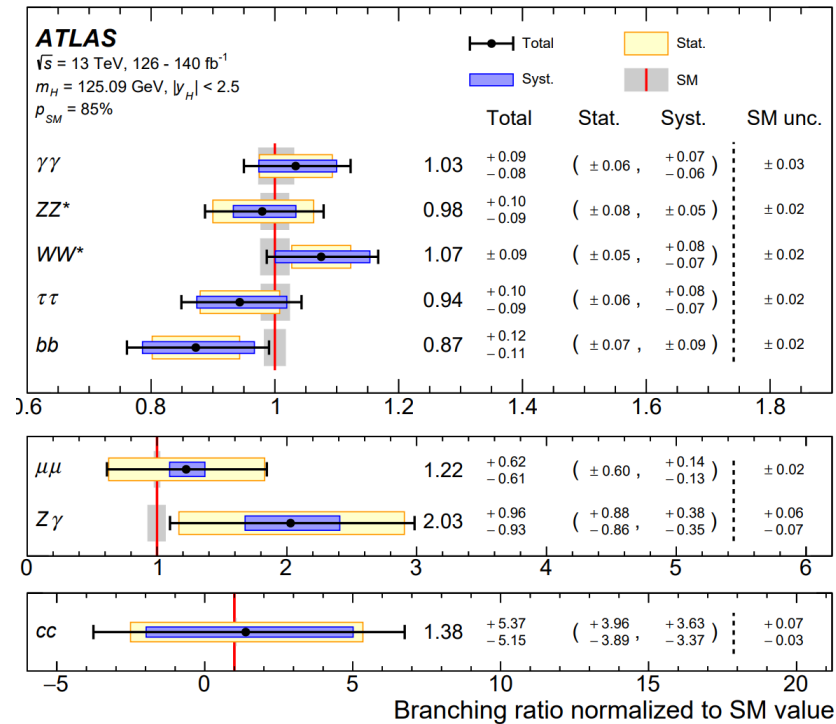
3.27 $^{+1.66}_{-1.50}$ ($^{+1.21}_{-1.16}$, $^{+1.13}_{-0.95}$)



	improvement	source
σ_{ggF} and σ_{VBF}	10%-15%	$H \rightarrow WW/\tau\tau$
σ_{WH} and σ_{ZH}	20%-30%	$VH, H \rightarrow WW/\tau\tau/bb/cc$
σ_{ttH} and σ_{tH}	40%	$ttH \rightarrow bb/ML, tH \rightarrow bb$

Decay branching ratio

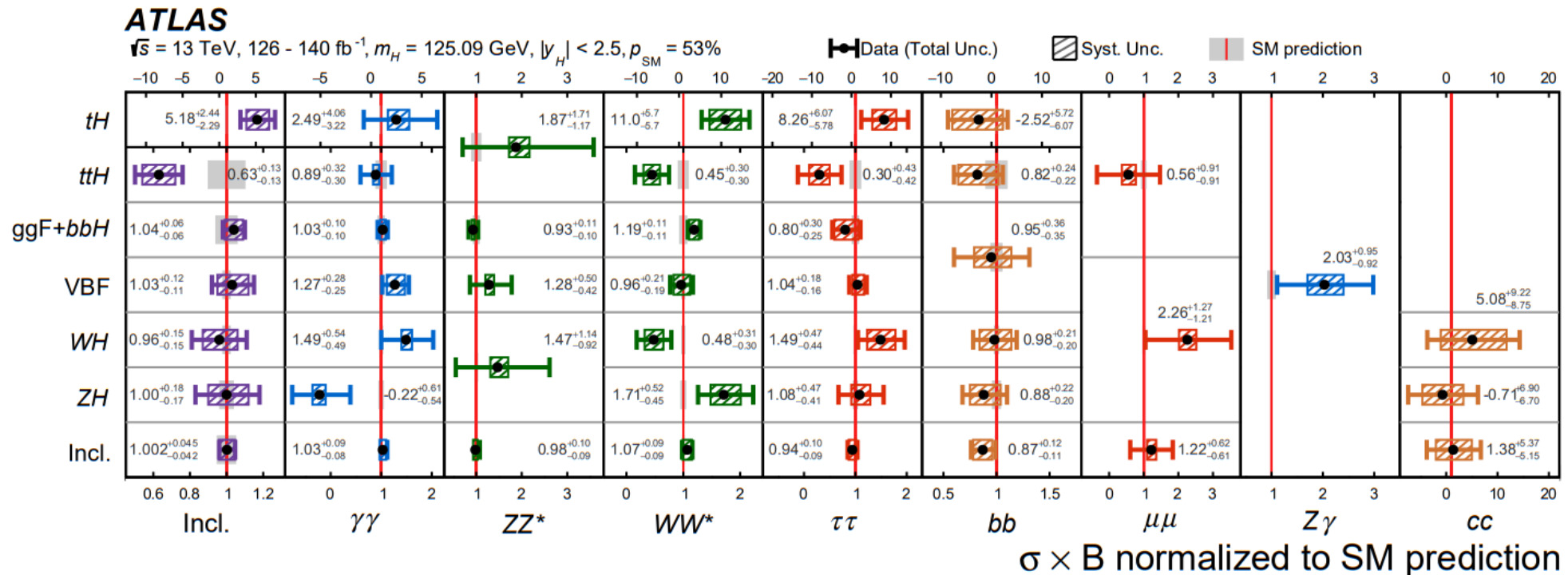
- Measure the Higgs branching ratio in different decay processes
 - 7 decay processes: $H \rightarrow bb$, $H \rightarrow WW^*$, $H \rightarrow \tau\tau$, $H \rightarrow cc$, $H \rightarrow ZZ^*$, $H \rightarrow \gamma\gamma$, $H \rightarrow Z\gamma$
- SM compatibility $p_{SM} = 85\%$



	improvement	source
$H \rightarrow bb$	20%	$VH, ttH \rightarrow bb$
$H \rightarrow WW^*$	20%	$ggF, VBF, VH, ttH \rightarrow WW$
$H \rightarrow \tau\tau$	15%	$ggF, VBF, VH, ttH \rightarrow \tau\tau$
$H \rightarrow ZZ^*$	5%	$ttH \rightarrow ML$
$H \rightarrow cc$	New in this round	$VH \rightarrow bb/cc$

Higgs boson production per decay channel

- Measure the Higgs boson production rates for individual decay channels
- Some modes are merged due to the limited statistical sensitivity, total 32 combinations of $\sigma_i \times B_f$
- SM compatibility $p_{SM} = 53\%$



Kappa framework introduction

- Parametrizes the deviation from the SM with multiplicative factors applied on the production and decay amplitudes

$$\sigma_i \times B(H \rightarrow f) = \frac{\sigma_i \times \Gamma_f}{\Gamma_H} = \frac{\kappa_i^2 \kappa_f^2}{\kappa_H} \sigma_i^{\text{SM}} \times B^{\text{SM}}(H \rightarrow f)$$

- Resolved scenario*: all the $\kappa_{i,f}$ are expressed with the Higgs couplings to the SM particles
- Effective scenario*: treat the loop-induced processes $gg \rightarrow H$, $ggZH$, $H \rightarrow gg$, $H \rightarrow \gamma\gamma$ and $H \rightarrow Z\gamma$ with an effective scale factors

- The κ_H term could be expressed as

$$\kappa_H = \frac{\sum_f \kappa_f^2 B^{\text{SM}}(H \rightarrow f)}{1 - B_{i,u}}$$

- $B_{i,u}$ represents the BR of the invisible decay and the undetected decay
- Several assumptions could be tested to get different κ results

Production	Loops	Main interference	Effective modifier	Resolved modifier
$\sigma(gg \rightarrow H)$	✓	$t-b$	κ_g^2	$1.040 \kappa_t^2 + 0.002 \kappa_b^2 - 0.038 \kappa_t \kappa_b - 0.005 \kappa_t \kappa_c$
$\sigma(qq' \rightarrow qq'H)$	-	-	-	$0.733 \kappa_W^2 + 0.267 \kappa_Z^2$
$\sigma(qqZH)$	-	-	-	κ_Z^2
$\sigma(ggZH)$	✓	$t-Z$	$\kappa(ggZH)$	$2.456 \kappa_Z^2 + 0.456 \kappa_t^2 - 1.903 \kappa_Z \kappa_t - 0.011 \kappa_Z \kappa_b + 0.003 \kappa_t \kappa_b$
$\sigma(WH)$	-	-	-	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	$1.111 \kappa_t^2 + 0.012 \kappa_b^2 - 0.1 \kappa_t \kappa_b$
$\Gamma^{\tau\tau}$	-	-	-	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 ($BR_{\text{inv.}} = BR_{\text{undet.}} = 0$)				
Γ_H	✓	-	κ_H^2	$0.581 \kappa_b^2 + 0.215 \kappa_W^2 + 0.082 \kappa_g^2 + 0.063 \kappa_\tau^2 + 0.026 \kappa_Z^2 + 0.029 \kappa_c^2 + 0.0023 \kappa_s^2 + 0.0015 \kappa_{(Z\gamma)}^2 + 0.0004 \kappa_s^2 + 0.00022 \kappa_\mu^2$

Kappa framework scenarios

- Lots of scenarios are tested

- Assuming $B_{i,u} = 0$

- Fermion and Vector boson coupling
 - Resolved scenario w/wout κ_c
 - Effective scenario ($\kappa_Z \neq \kappa_W$) w/wout κ_c
 - Effective scenario ($\kappa_Z = \kappa_W$) w/wout κ_c

- *On-shell + Hinv* ($B_{i,u}$ free, $|\kappa_V| < 1$)

- Effective scenario ($\kappa_Z = \kappa_W$) w/wout κ_c

- *On-shell + Off-Shell + Hinv* ($B_{i,u}$ free)

- Effective scenario ($\kappa_Z = \kappa_W$) w/wout κ_c

- κ ratio (no requirement on Γ_H assumption)

$$\sigma_i \times B(H \rightarrow f) = \frac{\sigma_i \times \Gamma_f}{\Gamma_H} = \frac{\kappa_i^2 \kappa_f^2}{\kappa_H} \sigma_i^{\text{SM}} \times B^{\text{SM}}(H \rightarrow f)$$

$$\kappa_H^2 = \frac{\sum_f \kappa_f^2 B^{\text{SM}}(H \rightarrow f)}{1 - B_{i,u}}$$

The κ_c could be either treated equal to κ_t (without κ_c) or as a free parameter (with κ_c)

-> thanks to the improved sensitivity from the VHcc analysis

The $|\kappa_V| < 1$ is required to avoid degeneracy of the κ/κ_H in the likelihood

The $2l2\nu$ off-shell channel is removed due to the overlap with $ZH \rightarrow \text{inv}$

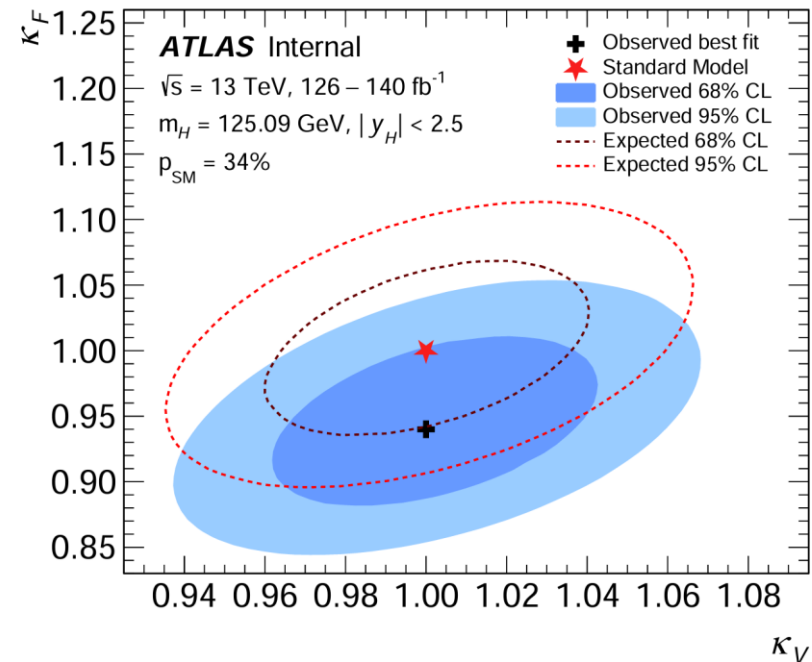
Fermion and Vector boson coupling

$$\kappa_H^2 = \frac{\sum_f \kappa_f^2 B^{\text{SM}}(H \rightarrow f)}{1 - B_t - B_u}$$

- Assuming only two coupling modifiers: κ_V for bosons and κ_F for fermions
- About 10 – 15% improvement in total uncertainties compared with Nature
- The observed (expected) correlation is 40% (38%)
- SM compatibility $p_{\text{SM}} = 34\%$

$$\kappa_V = 1.002^{+0.027}_{-0.026} \quad (1.000 \pm 0.027)$$

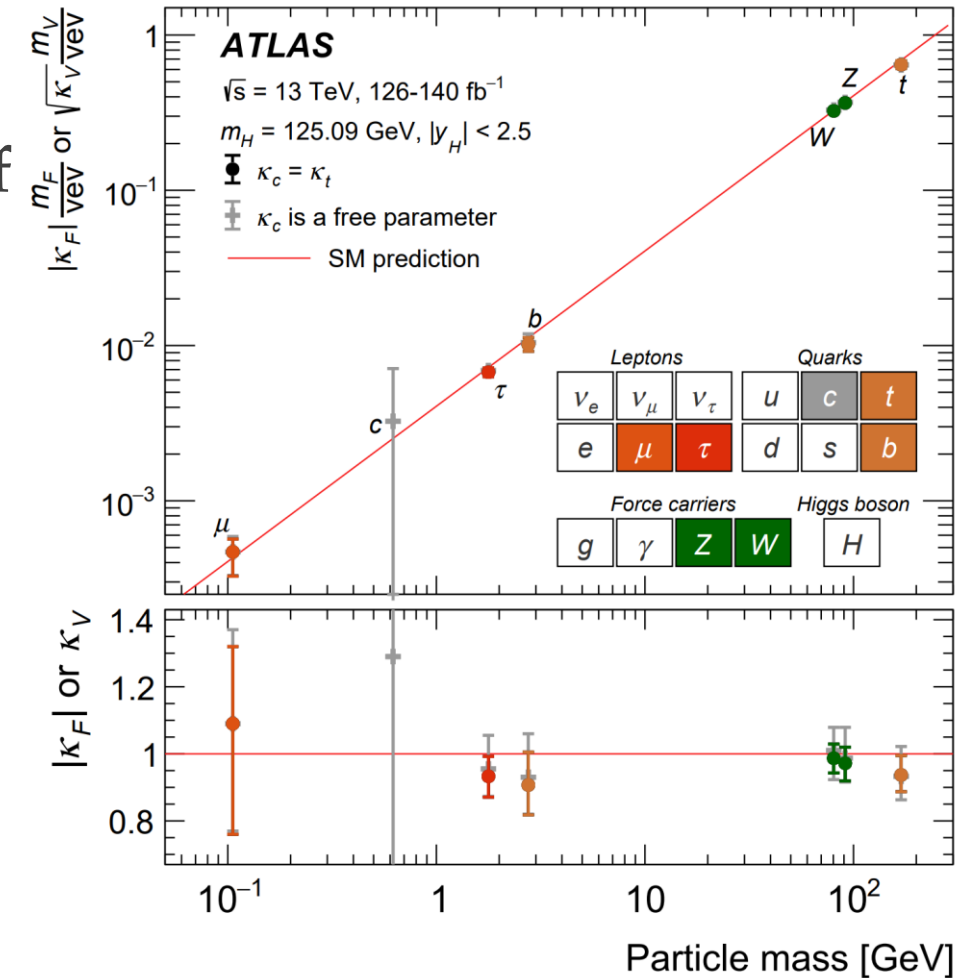
$$\kappa_F = 0.945^{+0.043}_{-0.041} \quad (1.000^{+0.045}_{-0.043})$$



Resolved scenario

$$\kappa_H^2 = \frac{\sum_f \kappa_f^2 B^{\text{SM}}(H \rightarrow f)}{1 - B_t - B_u}$$

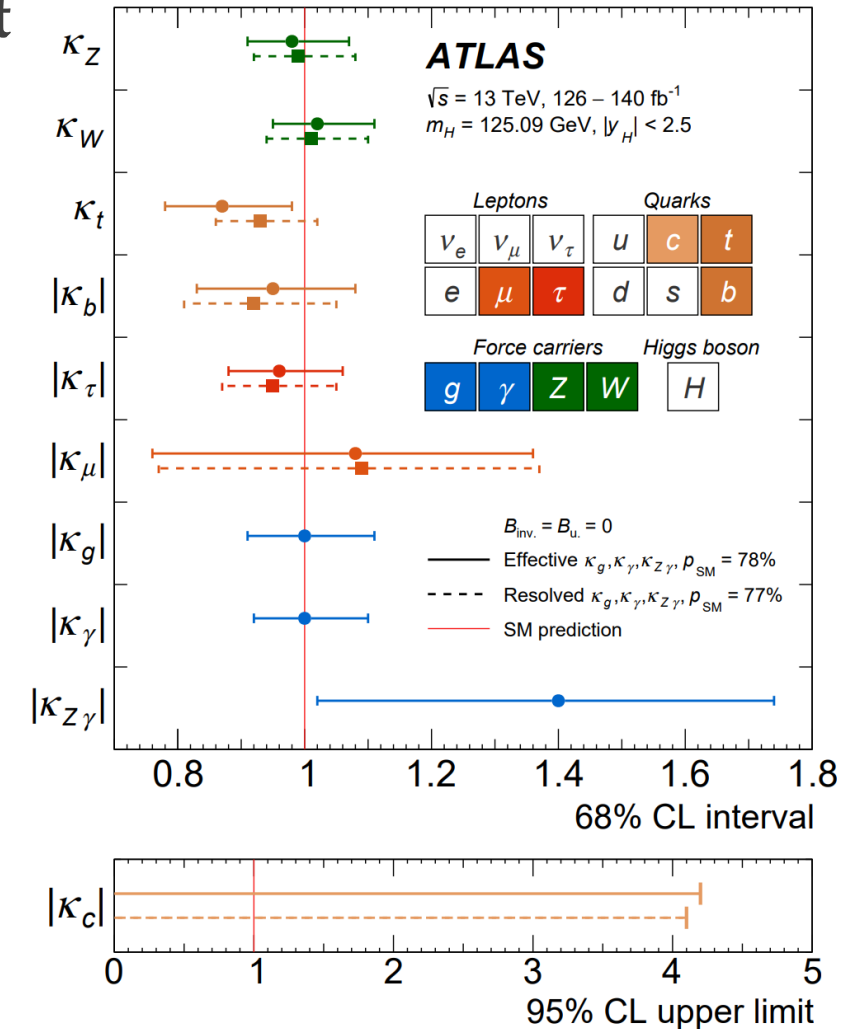
- Loop-induced couplings are resolved assuming no BSM decay
- The observed values are shown as a function of the corresponding particle masses
 - Two models: $\kappa_c = \kappa_t$ and floating κ_c
 - The uncertainties of $\kappa_{Z/W/t/\tau}$ reaches to 5-10% level
 - 95% Upper limit of κ_c is 4.1
 - Up to 45% improvement compared with Nature
- SM compatibility $p_{SM} = 69/77\%$



Effective scenario

$$\kappa_H^2 = \frac{\sum_f \kappa_f^2 B^{\text{SM}}(H \rightarrow f)}{1 - B_t - B_u}$$

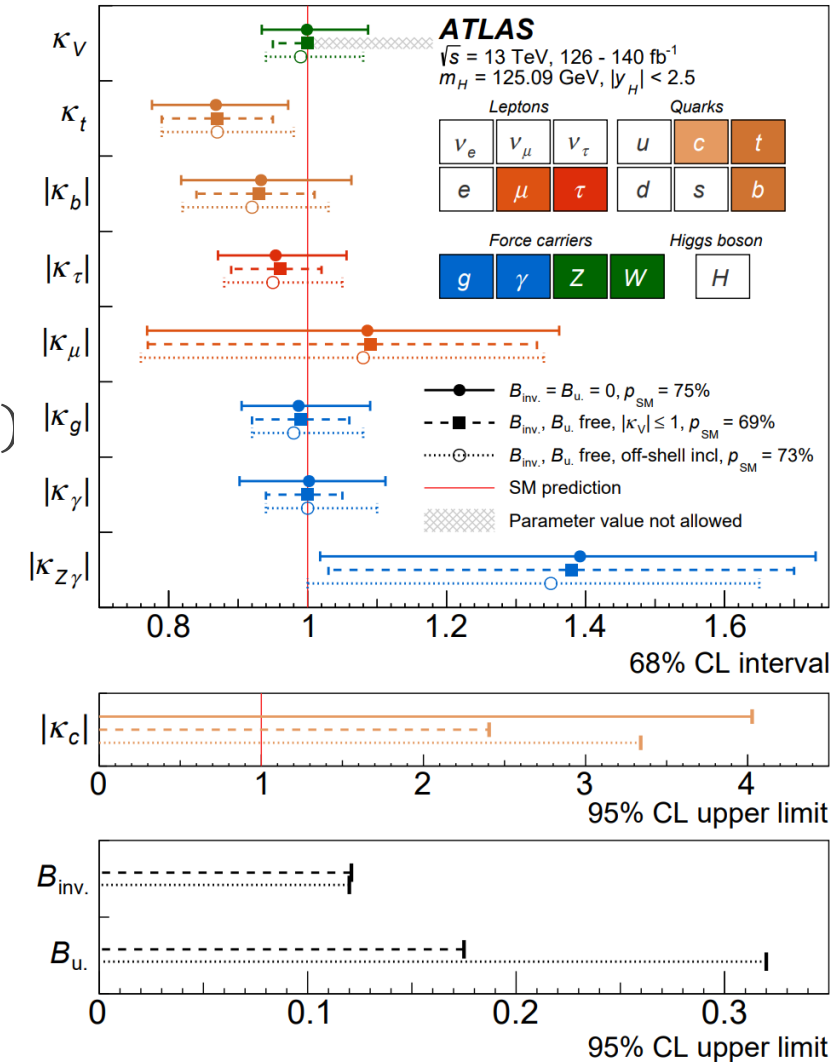
- Loop-induced couplings are treated as independent coupling modifiers assuming no BSM decay
- Similar uncertainties for the $\kappa_{Z/W/t/b/\tau/\mu/c}$ with resolved scenario
- SM compatibility $p_{\text{SM}} = 70/78\%$



BSM decay constraint

$$\kappa_H^2 = \frac{\sum_f \kappa_f^2 B^{\text{SM}}(H \rightarrow f)}{1 - B_{i,u}}$$

- Effective senario with floating B_{inv} and B_u
 - Scenario 1: $B_i = B_u = 0$, only different with previous effective scenario is $\kappa_W = \kappa_Z = \kappa_V$, served as reference
 - Scenario 2: On-shell + Hinv combination (B_i, B_u free, $|\kappa_V| \leq 1$)
 - Scenario 3: On-shell + Hinv + off-shell combination (B_i, B_u free)
- 95%CL UL of $B_i < 12\%$ for both scenario 2 and 3
- 95%CL UL of $B_u < 18\%/32\%$ for scenario 2/3
- SM compatibility $p_{SM} = 75/69/73\%$

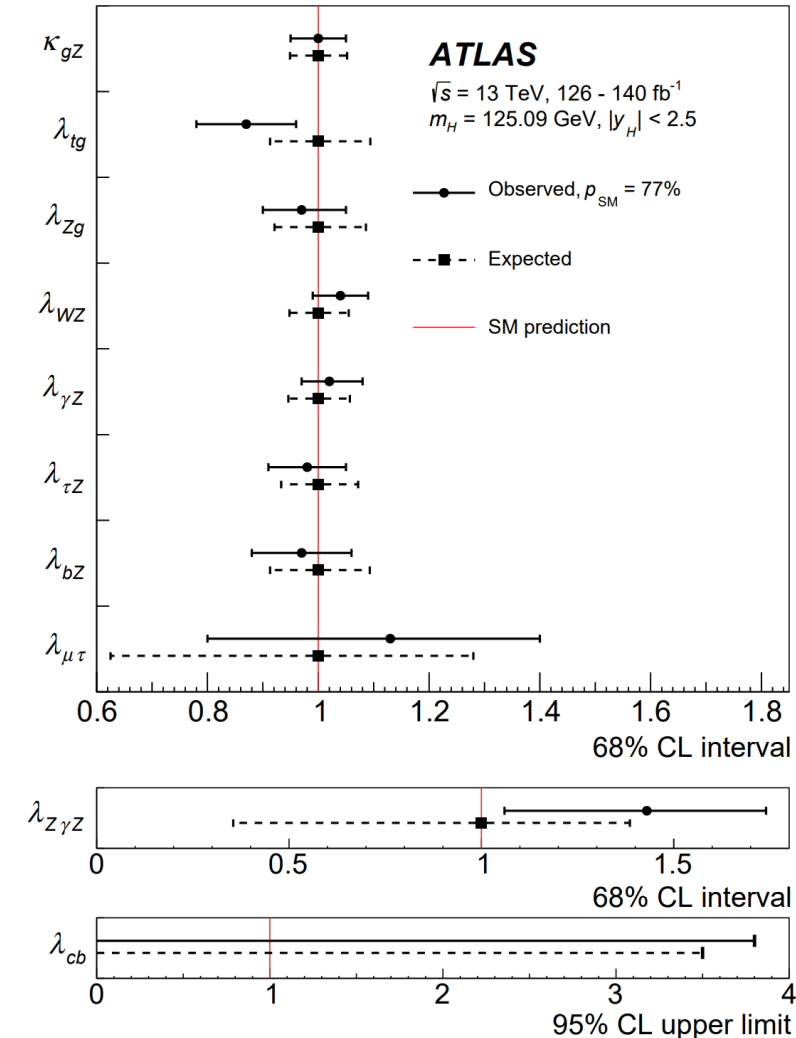


κ ratio model

$$\kappa_H^2 = \frac{\sum_f \kappa_f^2 B^{\text{SM}}(H \rightarrow f)}{1 - B_t - B_u}$$

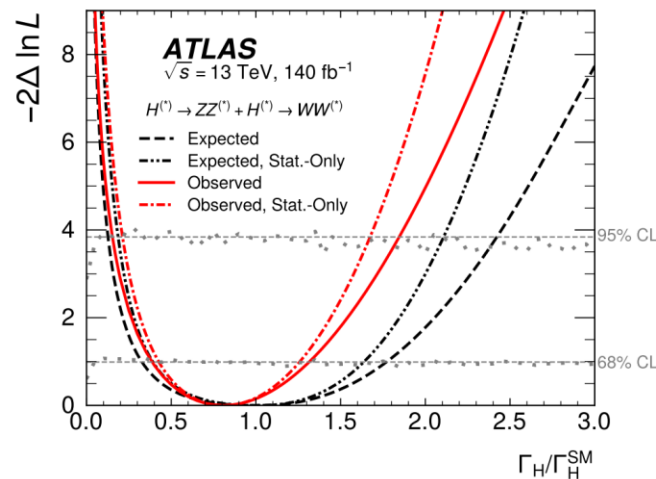
- The most model-independent determination of coupling-strength scale factors
 - Avoid the assumptions on the total Higgs boson decay width
 - Follow the POI schemes defined in the [HL-LHC projection](#)
- All parameters are assumed to be positive due to no sign sensitivity
- SM compatibility $p_{\text{SM}} = 77\%$

Parameter	Definition in terms of κ modifiers
κ_{gZ}	$\kappa_g \kappa_Z / \kappa_H$
λ_{tg}	κ_t / κ_g
λ_{Zg}	κ_Z / κ_g
λ_{WZ}	κ_W / κ_Z
$\lambda_{\gamma Z}$	κ_γ / κ_Z
$\lambda_{Z\gamma Z}$	$\kappa_{Z\gamma} / \kappa_Z$
$\lambda_{\tau Z}$	κ_τ / κ_Z
λ_{bZ}	κ_b / κ_Z
$\lambda_{\mu\tau}$	κ_μ / κ_τ
λ_{cb}	κ_c / κ_b

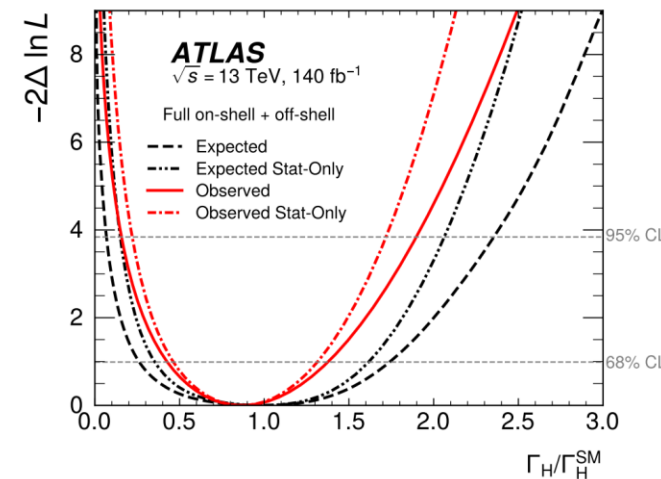


Width interpretation

- Combining the on-shell and off-shell workspaces and constrain the Higgs total width
 - Scenario 1: On-shell + Off-shell $H \rightarrow ZZ + H \rightarrow WW$ only
 - Scenario 2: All available On-shell + Off-shell $H \rightarrow ZZ + H \rightarrow WW$
- The Scenario 1 could validate the asymptotic app. via a Neyman construction
- Off-shell Higgs production significance: obs. 3.7σ (exp. 2.9σ)



$$\Gamma_H = 3.3_{-1.7}^{+2.1} \text{ (obs.) } \left(4.1_{-2.7}^{+3.2} \text{ (exp.)} \right) \text{ MeV}$$

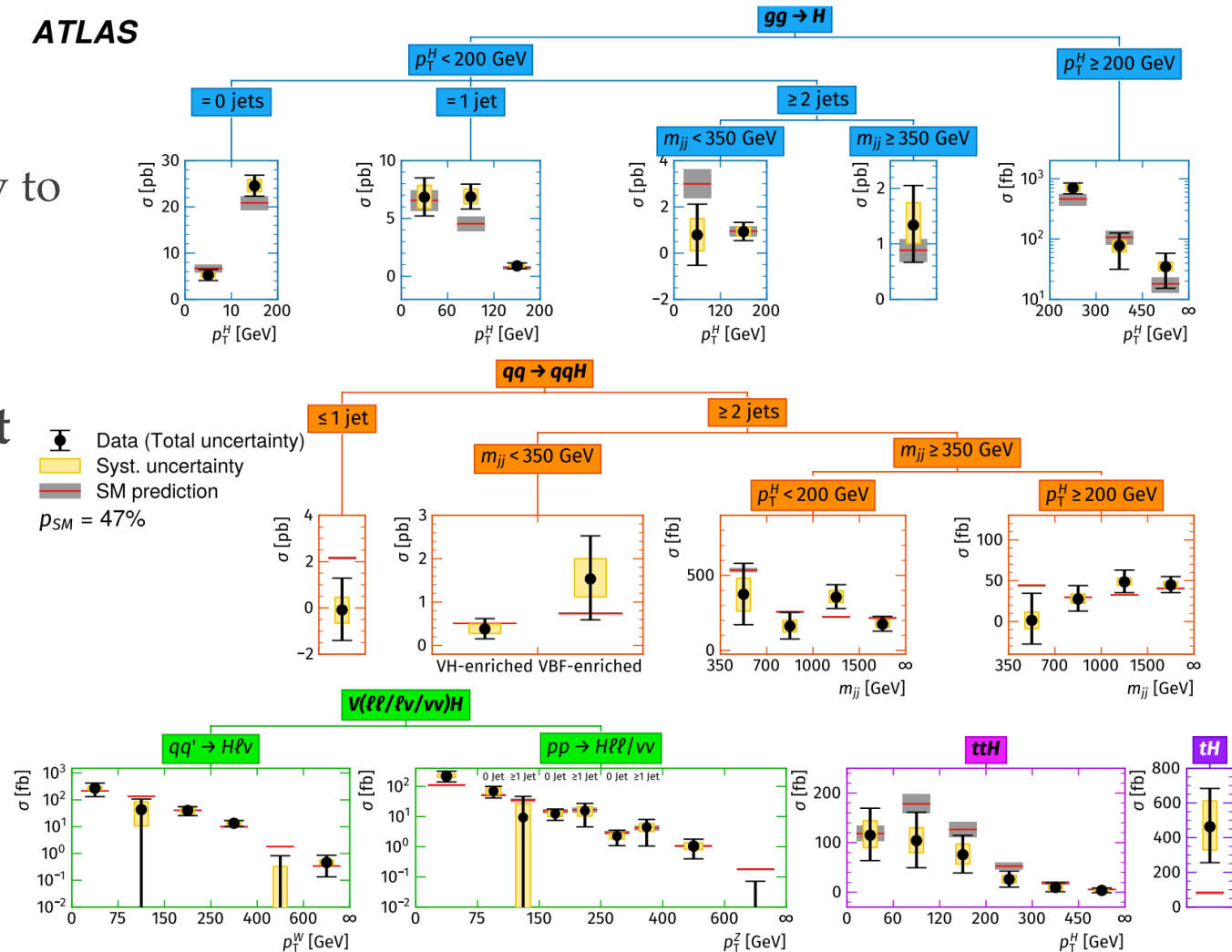


$$\Gamma_H = 3.6_{-1.6}^{+2.1} \text{ (obs.) } (4.1_{-3.0}^{+3.0} \text{ (exp.)}) \text{ MeV}$$

The most sensitive to date

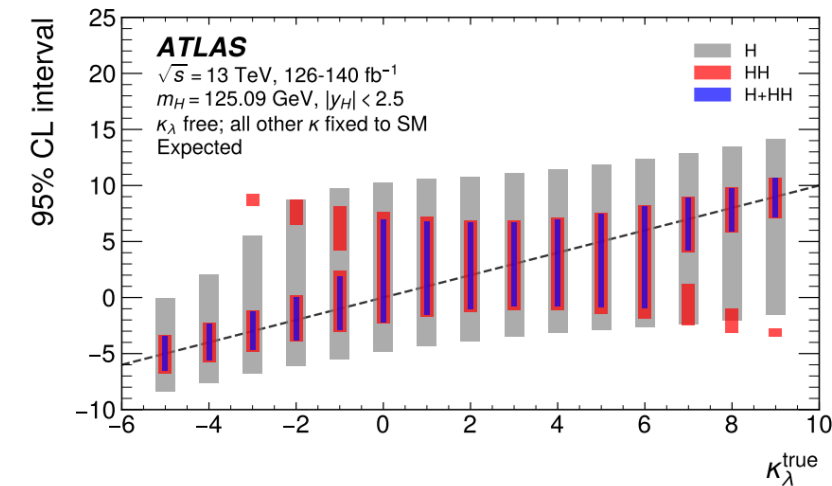
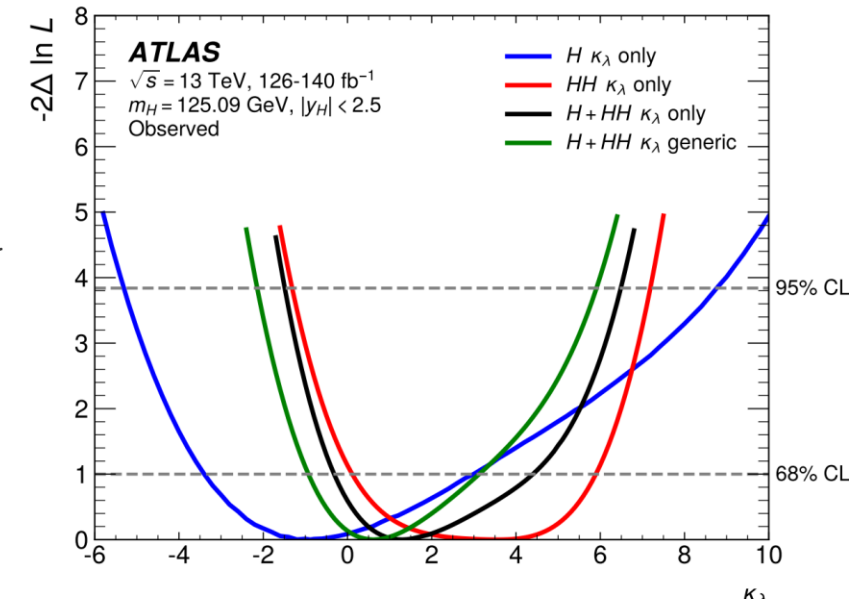
STXS measurements

- **The measurement within the STXS framework**
 - Isolated regions providing high sensitivity to Higgs properties or potential BSM effects
- **Based on STXS 1.2, but with some merging and splitting due to the limit of statistic**
 - Total 44 kinematic regions, 8 more bins compared to the Nature
- **Up to 35% improvement**
- **SM compatibility $p_{SM} = 47\%$**



κ_λ interpretation & H+HH combination

- Single-Higgs measurements provide indirect sensitivity through NLO electroweak corrections, while di-Higgs production provides direct sensitivity
 - *Scenario 1*: float κ_λ only and fix other κ
 - *Scenario 2*: generic model with all κ float
- Compared to the di-Higgs only:
 - 25% (20%) improvement on the κ_λ observed(expected) 68% CI
 - The inclusion of single Higgs could help to constrain other κ and yields a more model-independent results
 - Could help to exclude some 95% region for some truth κ_λ

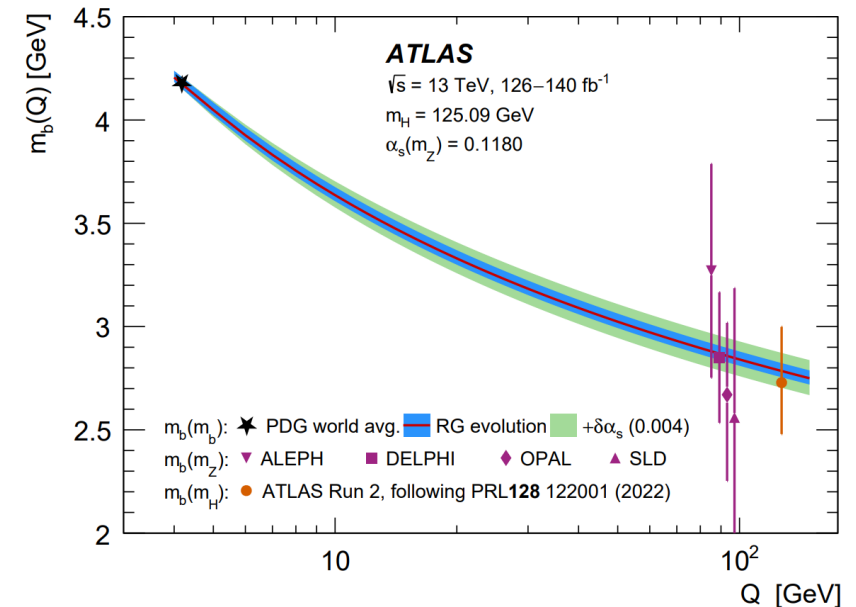


$m_b(m_H)$ interpretation

- Quark masses are “running constants” in the QCD theory due to the renormalization scheme
 - Experimentally measurable at the LHC using $H \rightarrow b\bar{b}$ decay rate which depends quadratically on m_b
- Use Γ_{bb}/Γ_{ZZ} as the probe, parametrize it as a function of m_b with simulation
 - Could reduce the dependence on assumptions about the Higgs couplings to SM particles
- Provides the first ATLAS direct determination of $m_b(m_H)$
- The exclusion of no-running scenario is more than 8σ

$$\frac{\Gamma_{bb}}{\Gamma_{ZZ}} = \left(\frac{\Gamma_{bb}}{\Gamma_{ZZ}} \right)_{\text{SM}} \left(1 + \sum_{n=1}^5 a_n \left[\left(\frac{m_b(m_H)}{m_b^{\text{ref}}(m_H)} \right)^n - 1 \right] \right)$$

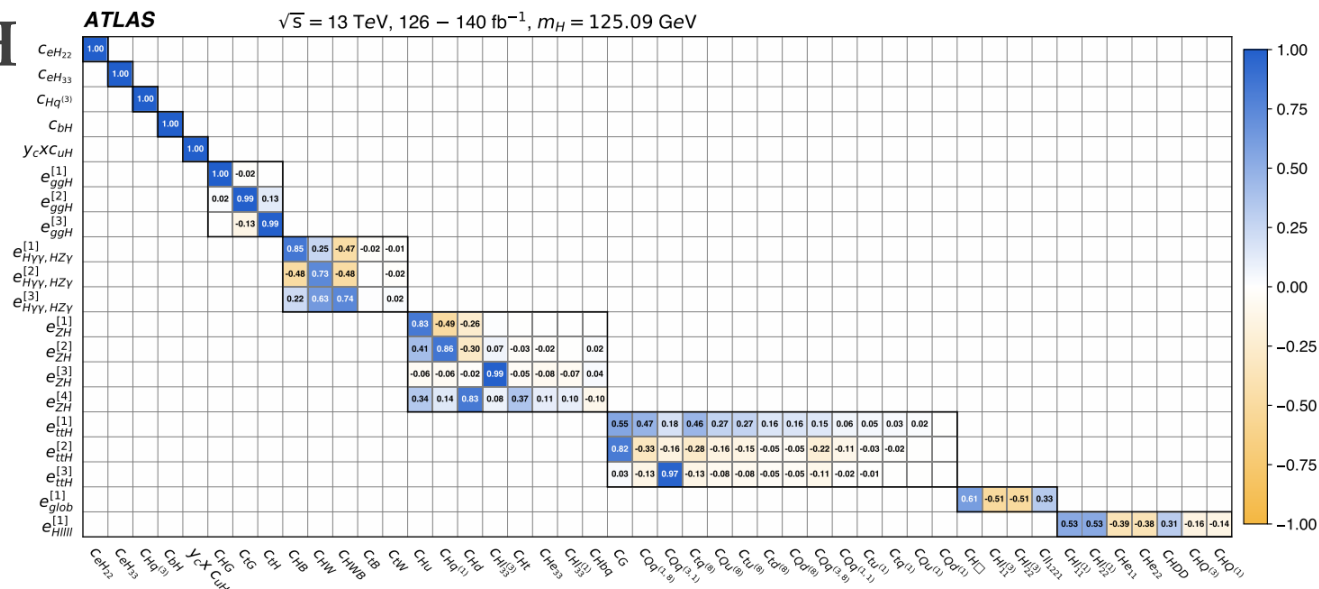
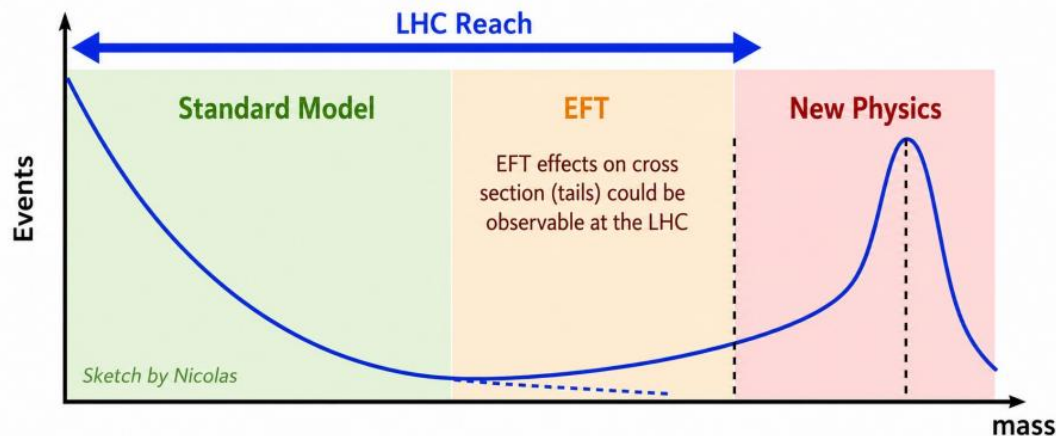
$$m_b(m_H) = 2.73^{+0.27}_{-0.25} \text{ GeV} = 2.73^{+0.22}_{-0.20} (\text{stat.})^{+0.15}_{-0.14} (\text{syst.})^{+0.07}_{-0.06} (\text{theo.}) \text{ GeV},$$



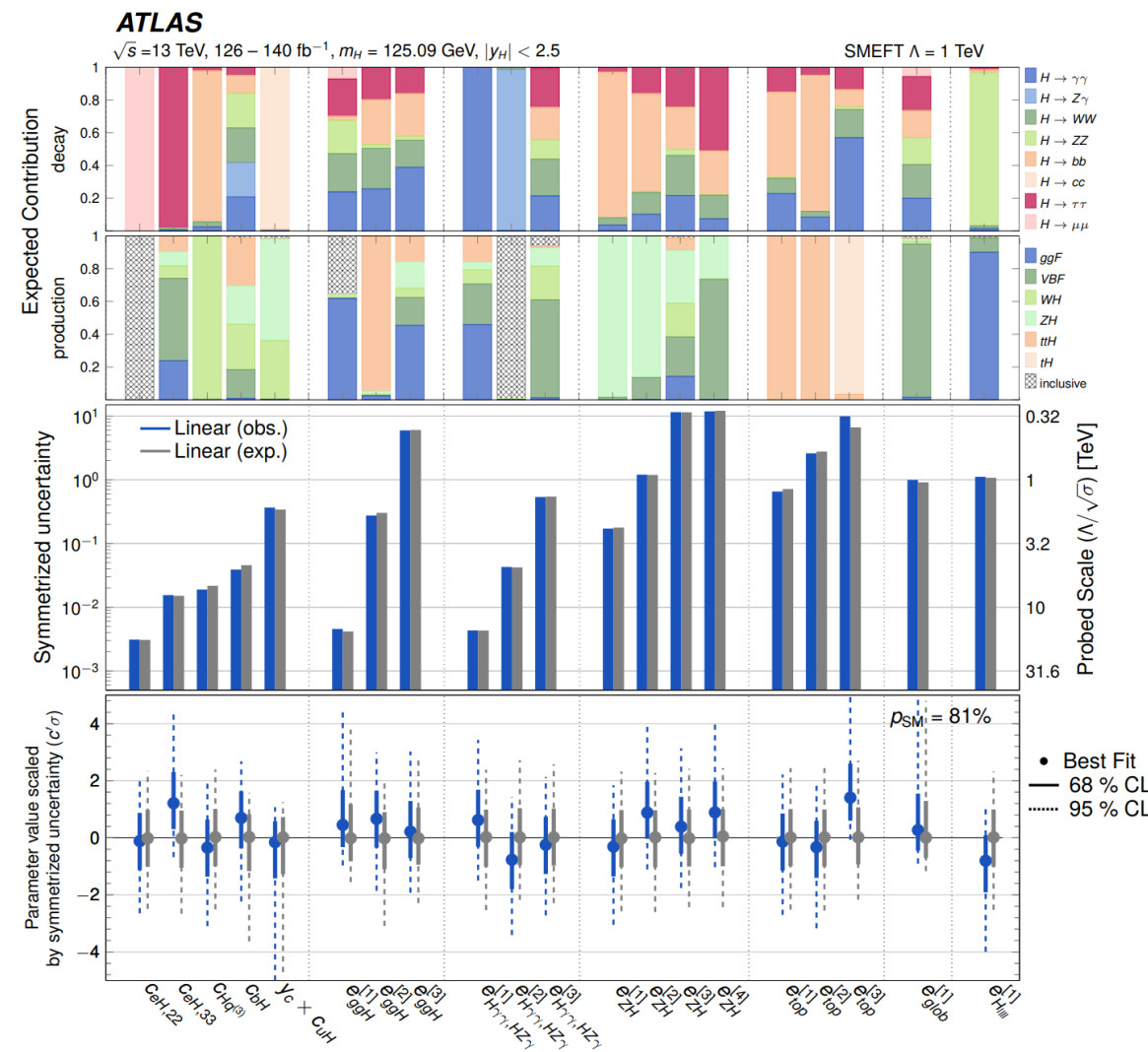
EFT interpretation

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum \frac{c_i}{\Lambda^2} \mathcal{O}_i^{(6)} + \dots$$

- The EFT framework provides a model-independent way to describe possible effects of new physics beyond the direct LHC reach
- These effects are described by higher-dimensional SMEFT operators
- Use 116 STXS+BR as the input and parametrize it with these operators
- Do the PCA and 20 ev.s pass the TH



- **Perform the fit for $\Lambda = 1$ TeV**
- **Both linear and linear+quad results**
 - Up to 55% improvement on the constraint compared with Nature combination version
- **The results are compatible with the SM**



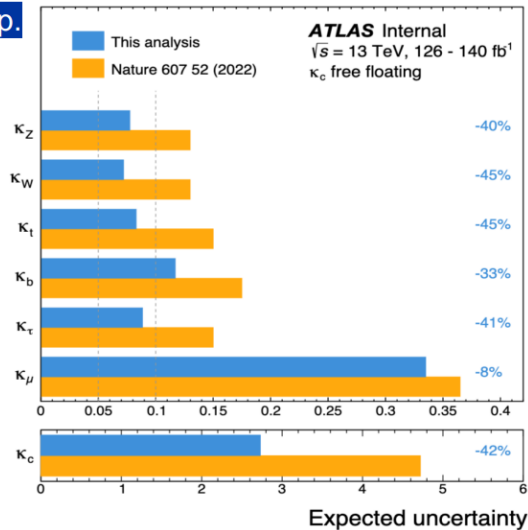
Next step

- Soon there will be a combination with CMS

- CMS has already released their Run-2 Higgs combination [result](#) at Moriond
- There are already some [study](#) about STXS harmonization
- Clearly a long term project

ATLAS

App.

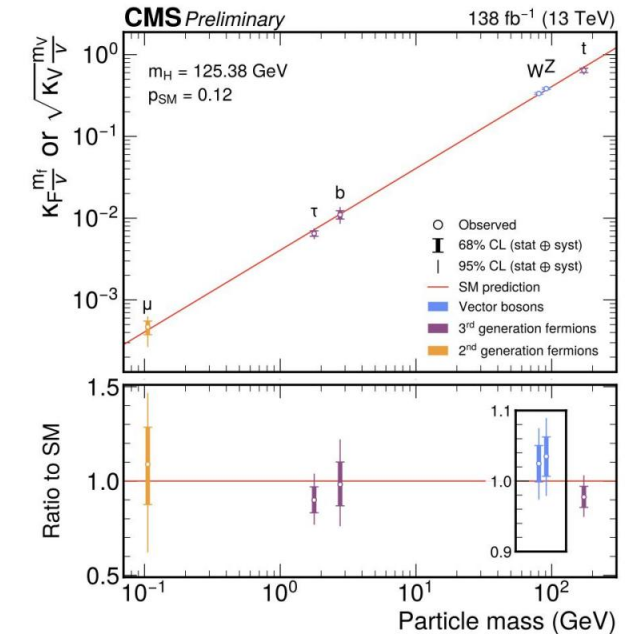


Parameter	Resolved $\kappa_g, \kappa_\gamma, \kappa_{Z\gamma}$	
	Free κ_c	$\kappa_c = \kappa_t$
κ_Z	$0.99^{+0.09}_{-0.07}$	0.98 ± 0.05
κ_W	$1.01^{+0.09}_{-0.07}$	1.00 ± 0.04
κ_t	$0.93^{+0.09}_{-0.07}$	$0.93^{+0.06}_{-0.05}$
$ \kappa_b $	$0.92^{+0.13}_{-0.11}$	$0.91^{+0.10}_{-0.09}$
$ \kappa_\tau $	$0.95^{+0.10}_{-0.08}$	0.94 ± 0.06
$ \kappa_\mu $	$1.09^{+0.28}_{-0.32}$	$1.08^{+0.25}_{-0.31}$

+

Parameters	Best fit	Stat	Syst
κ_W	$1.05^{+0.06}_{-0.05}$ (+0.06) (-0.05)	$+0.04$ (+0.04) (-0.04)	$+0.04$ (+0.04) (-0.03)
κ_Z	$1.07^{+0.06}_{-0.06}$ (+0.06) (-0.06)	$+0.04$ (+0.04) (-0.04)	$+0.04$ (+0.04) (-0.04)
κ_t	$0.91^{+0.06}_{-0.07}$ (+0.07) (-0.08)	$+0.04$ (+0.04) (-0.05)	$+0.04$ (+0.05) (-0.06)
κ_b	$0.98^{+0.12}_{-0.11}$ (+0.12) (-0.12)	$+0.08$ (+0.08) (-0.08)	$+0.09$ (+0.09) (-0.08)
κ_τ	$0.90^{+0.08}_{-0.07}$ (+0.08) (-0.07)	$+0.05$ (+0.05) (-0.05)	$+0.06$ (+0.07) (-0.06)
κ_μ	$1.09^{+0.20}_{-0.21}$ (+0.21) (-0.23)	$+0.18$ (+0.19) (-0.22)	$+0.08$ (+0.08) (-0.08)

CMS



- There maybe a plan for the partial run3 combination, not decided yet

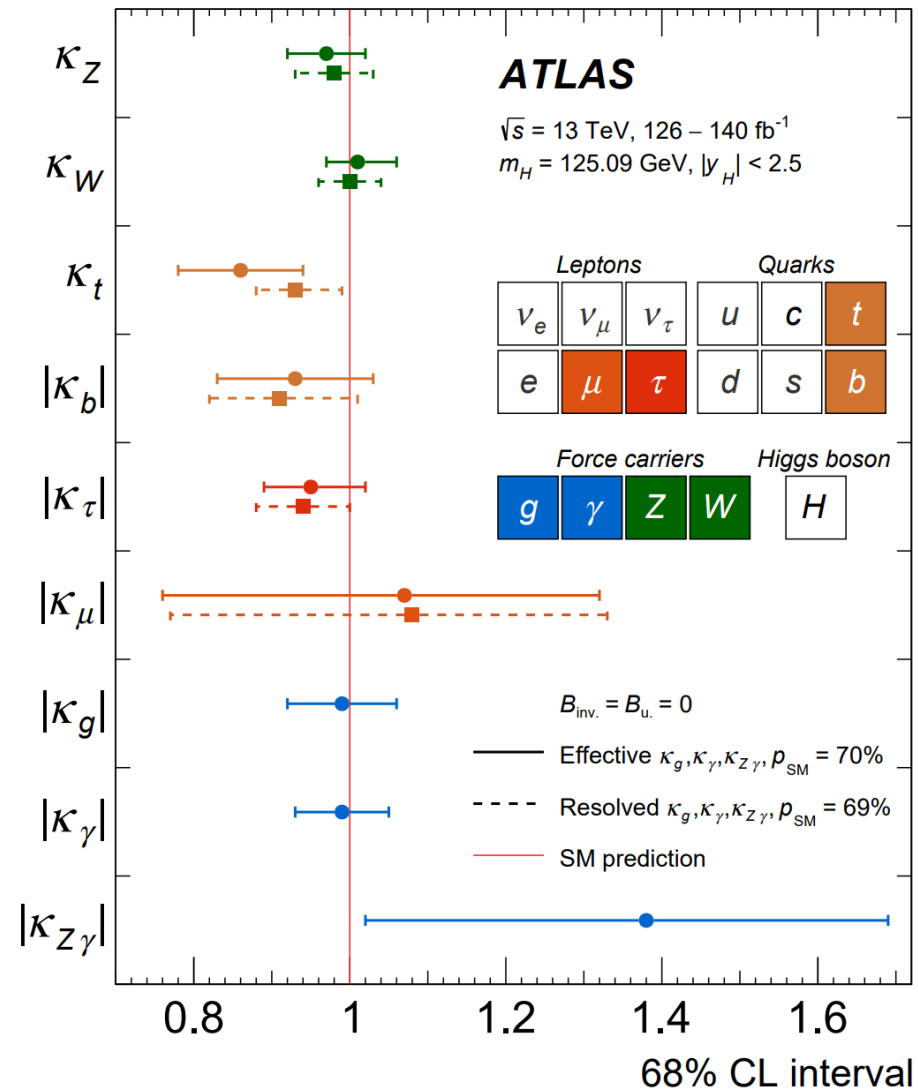
Summary

- **We have just released the Legacy Run-2 Higgs coupling combination**
 - Our group contribution: statistic tools development, STXS results, κ_λ interpretation & H+HH combination
- **This combination delivers the most comprehensive picture of Higgs-boson production/decay and their interpretations using the full Run-2 dataset**
 - 4 on-shell analyses, 4 H→inv analyses, 2 off-shell analyses, and 6 di-Higgs analyses
- **All results are compatible with the Standard Model, with no significant deviation observed**
- **There will soon be a Run-2 combination with CMS, and maybe a ATLAS partial Run-3 combination**

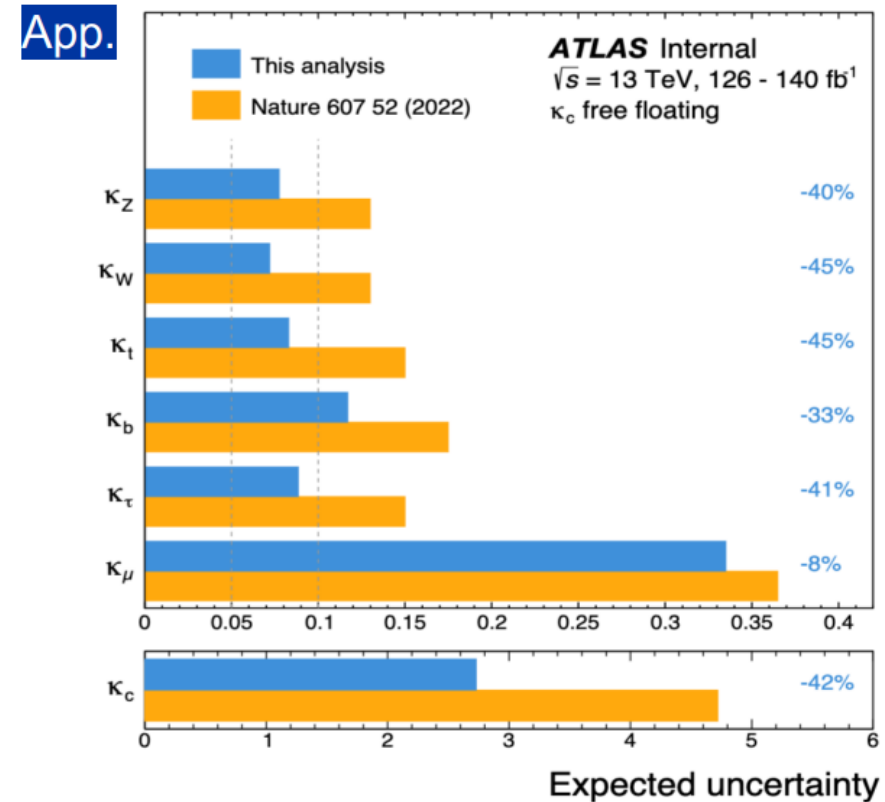
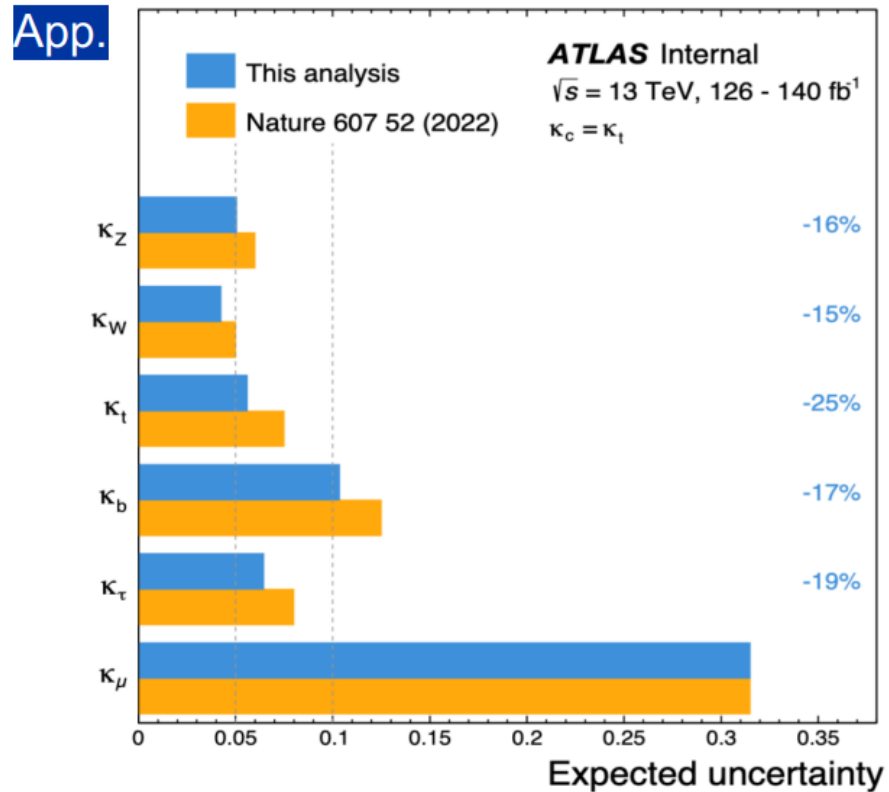
backup

Resolved/Effective scenario without κ_c

$$\kappa_H^2 = \frac{\sum_f \kappa_f^2 B^{\text{SM}}(H \rightarrow f)}{1 - B_t - B_u}$$



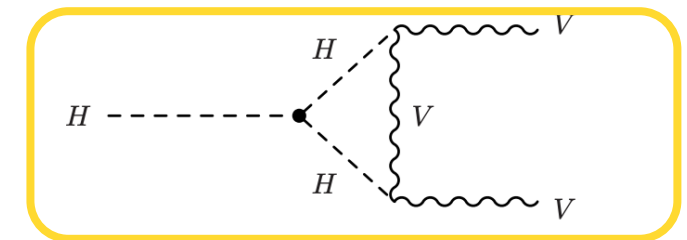
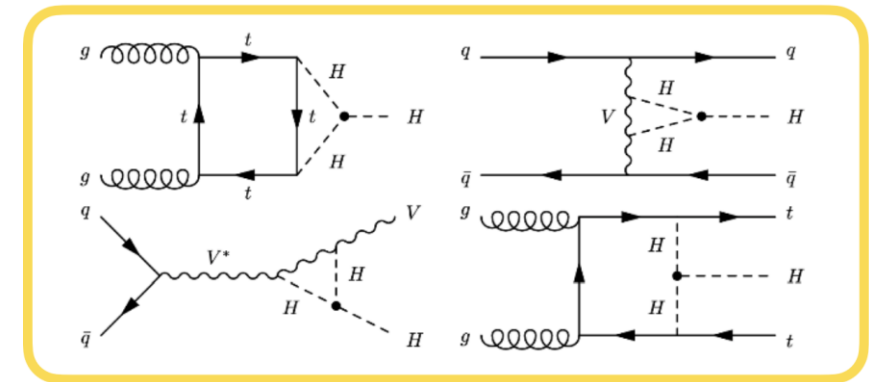
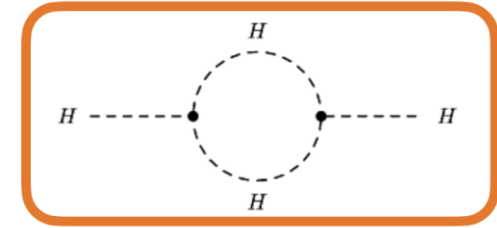
Resolved scenario improvement



*κ_λ interpretation &
H+HH combination*

Higgs self-coupling interpretation

- Measurements of the Higgs trilinear self-coupling κ_3 can be performed through the single Higgs process measurements with an indirect way
- Sensitivity through NLO EW corrections:
 - Universal $O(\lambda_3^2)$ correction due to Higgs wavefunction
 - Linear $O(\lambda_3)$ correction to production and decay modes



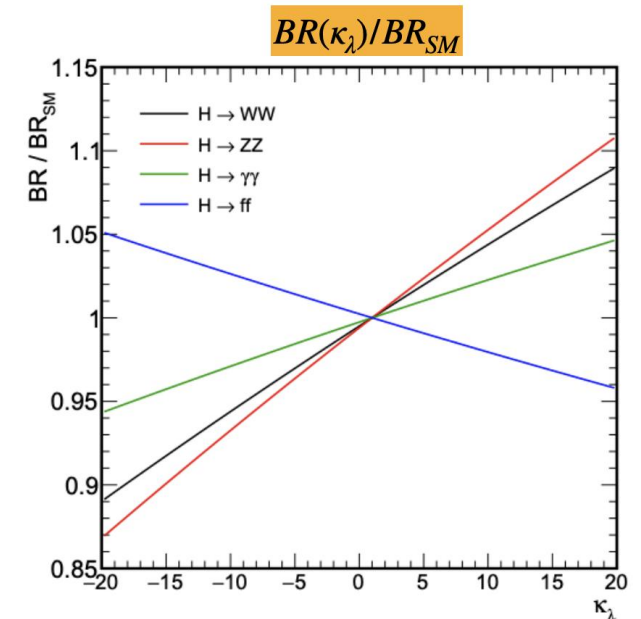
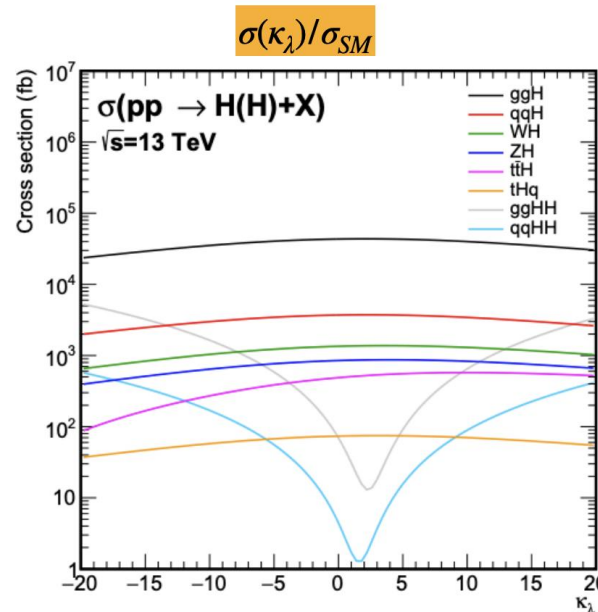
Higgs self-coupling interpretation

- The measured **production cross-section** and **branching fractions (BR)** in each STXS bin could then be parametrized as a function of κ_λ

$$\mu_i(\kappa_\lambda, \kappa_i) = \frac{\sigma^{\text{BSM}}}{\sigma^{\text{SM}}} = Z_H^{\text{BSM}}(\kappa_\lambda) \left[\kappa_i^2 + \frac{(\kappa_\lambda - 1)C_1^i}{K_{\text{EW}}^i} \right]$$

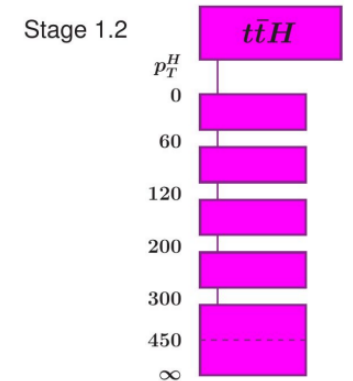
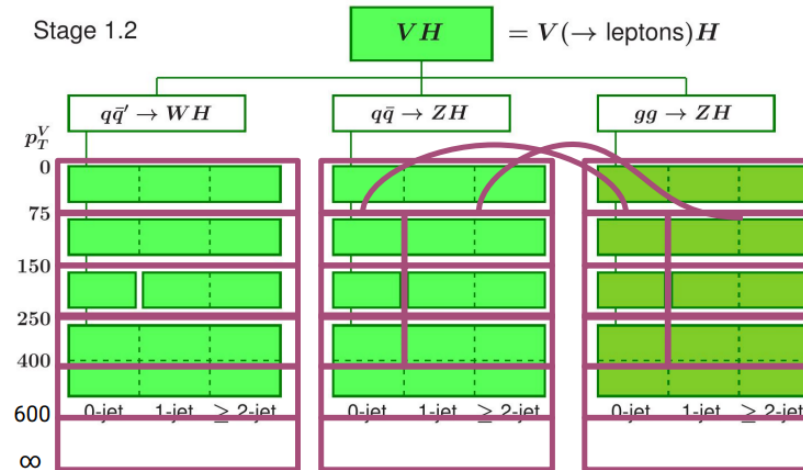
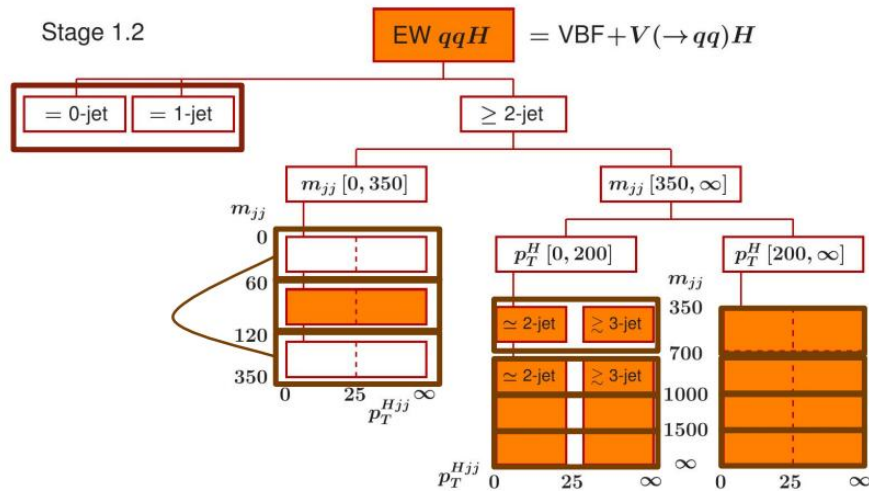
$$\mu_f(\kappa_\lambda, \kappa_f) = \frac{\text{BR}_f^{\text{BSM}}}{\text{BR}_f^{\text{SM}}} = \frac{\kappa_f^2 + (\kappa_\lambda - 1)C_1^f}{\sum_j \text{BR}_j^{\text{SM}} \left[\kappa_j^2 + (\kappa_\lambda - 1)C_1^j \right]},$$

- C_1 is the process and kinematic-dependent coefficients which encodes the magnitude of the κ_λ -dependent corrections (linear correction)
- Z_H^{BSM} is the wave function renormalization (universal correction)
- K_{EW} factors represents the full set of NLO EW corrections



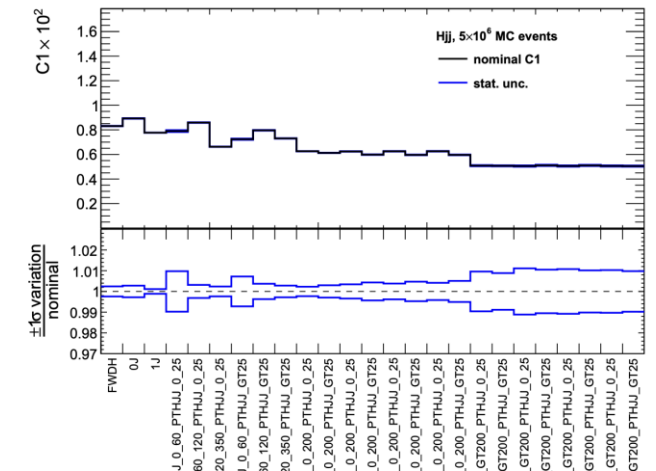
Single Higgs Parametrization

Use differential STXS to precisely estimate kl contribution



- C_1 and K_{EW} is derived in each STXS bin [LHCHWG]
 - The differential C_1 for ggH is only available as the function of the p_T^H [Ref.], the impact is checked and found negligible -> still use the inclusive number 0.0066
 - Inclusive C_1 is also used for the single Higgs background in the HH analyses
 - Obtain the values for the additional $p_T^V = 600\text{GeV}$ split binning

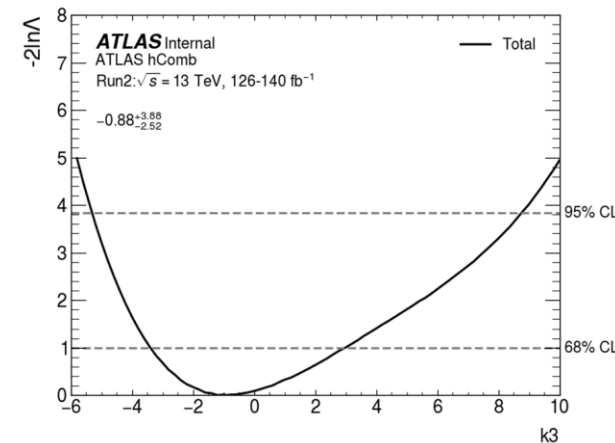
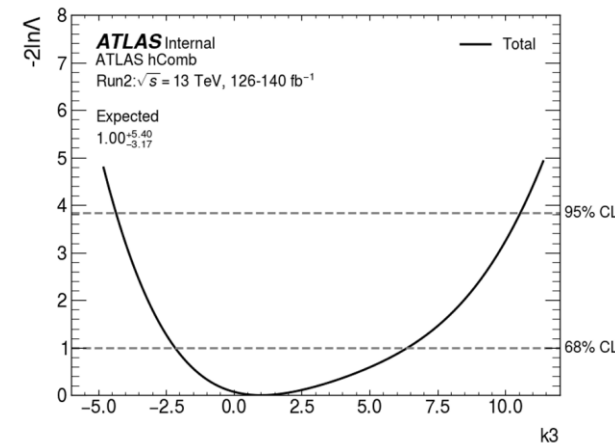
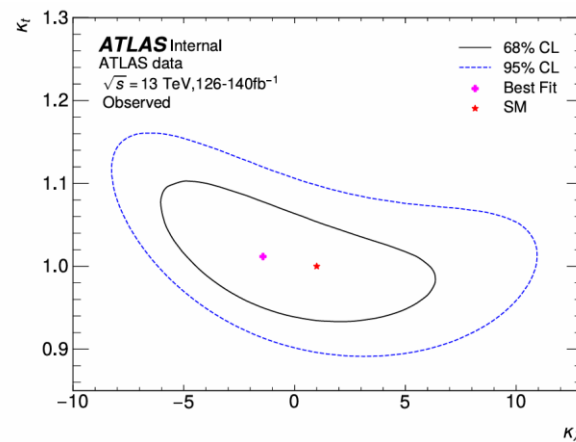
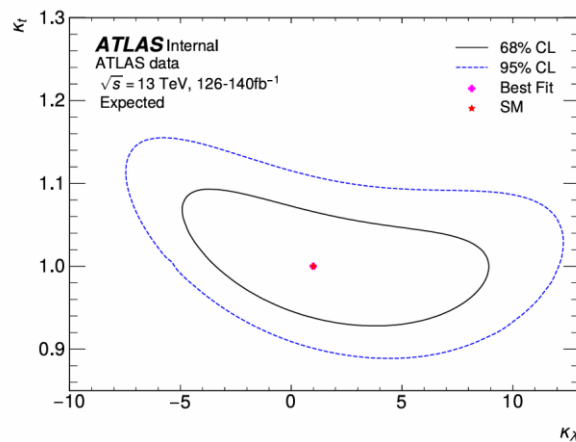
bin	$ZH, 400 < p_T^V < 600$	$ZH, p_T^V > 600$	$WH, 400 < p_T^V < 600$	$WH, p_T^V > 600$
$C_1 \times 100$	-0.069	-0.074	-0.060	-0.065
K_{EW}	0.831	0.755	0.768	0.692



Single Higgs results

- Follows the same procedure with the previous H+HH combination [[Ref.](#)]
- Obtain the κ_λ scan results and quantify on the expected 95%CI
 - 12% improvement compared to the Nature
 - 9% better compared to the CMS
- Also obtain κ_λ vs κ_t contour plot

κ_λ Interval	Obs. value $^{+1\sigma}_{-1\sigma}$	Obs. 95% CL	Exp. 95% CL
Single H comb	$-0.88^{+3.88}_{-2.52}$	[-5.31, 8.76]	[-4.35, 10.56]
Previous H comb	$2.5^{+4.6}_{-3.8}$	[-4.0, 10.3]	[-5.2, 11.5]
CMS	$2.1^{+4.0}_{-3.2}$	[-3.3, 9.6]	[-4.6, 11.6]



H+HH combination

- **We could combine the single Higgs with di-Higgs to maximize the κ_λ constraint**
 - The Higgs self-coupling is directly accessible in the HH production at the LO
 - The main advantage of adding single-Higgs is that could relax the assumptions about other κ
- **HH input: combined HH workspace (5 channels) used in the ATLAS + CMS HH combination [[WS](#)]**
 - Implemented the missing kappa dependence on the HH signal parametrization
 - Which was trivial in the HH only case
 - Apply the lumi. Shift for the HH4b channel (126 fb^{-1})
 - Same SF with other channel (140/139) suggested by lumi. group
 - To be consistent with VBF bb channel

H and HH overlap results

- The overlap inside the single Higgs and di-Higgs is already studied
 - Mainly focus on the overlap between Higgs and di-Higgs channels
- The **VBF bb vs HH4b** was observed and studied in the previous analysis
 - keep these categories due to the negligible impact
- Two newly observed: **HHML vs ttHML** and **VHWW vs HHML**
 - both mainly occurred in the 2LSS category of HHML
 - Test the results removing it
 - Negligible (<1%) impact on the expected result
 - Also keep this category

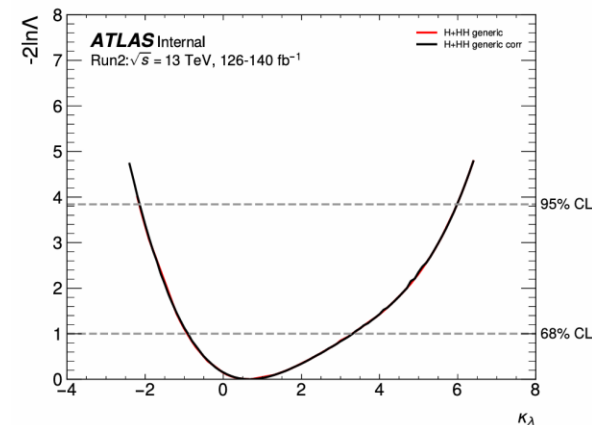
κ_λ Interval	Observed @95%	Expected @ 95%
H+HH nominal	[-1.46, 6.51]	[-1.54, 6.80]
H+HH (removing 2LSS)	[-1.45, 6.39]	[-1.56, 6.82]



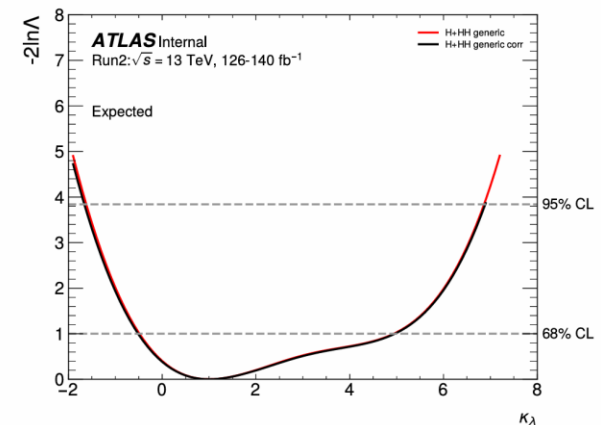
H and HH Correlation study

- The inputs are already combined single Higgs and di-Higgs workspaces
 - The correlation inside each side is already well studied
 - Only need to consider the correlation between H and HH
- Follow the same “advanced” correlation scheme as in the last H+HH combination: the NP with >0.5 pull or $<60\%$ constraint will be treated as uncorrelated to avoid tension
 - The number of correlated NPs decreased from 112 to 62
 - Tiny impact on the final results

Correlation scheme	Best fitted value	$1\text{-}\sigma$ error	95% C.L. interval
No-correlated	0.66	$+2.66$ -1.59	(-2.20, 6.06)
Advanced	0.68	$+2.63$ -1.58	(-2.14, 5.98)



(a)

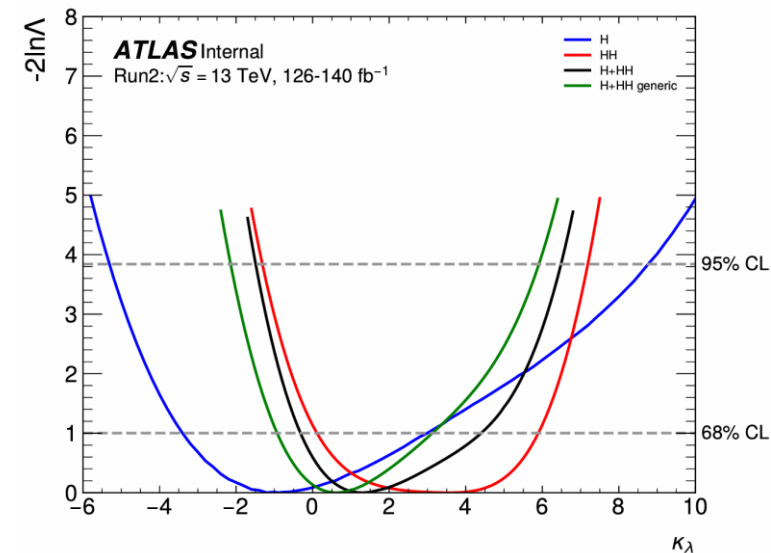
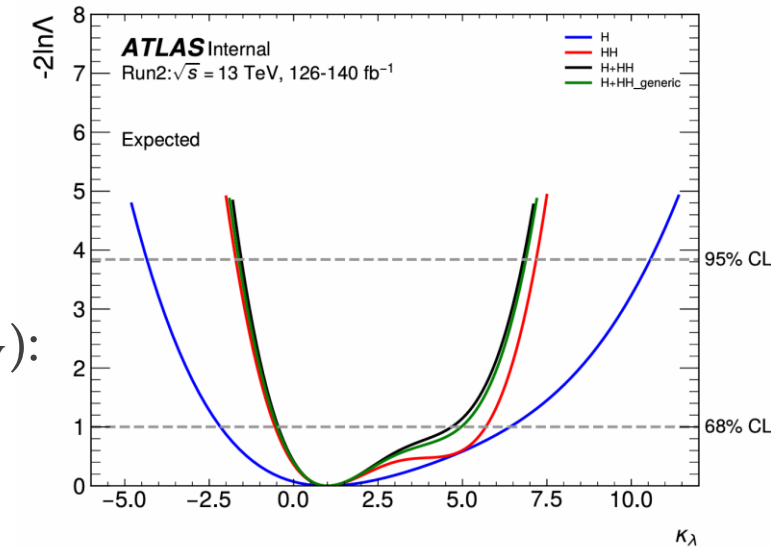


(b)

H+HH κ_λ scan results

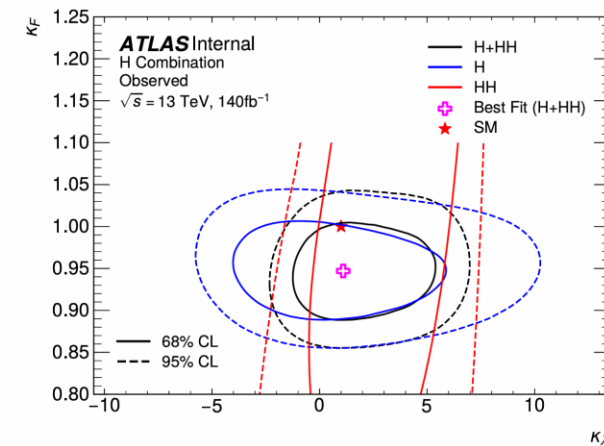
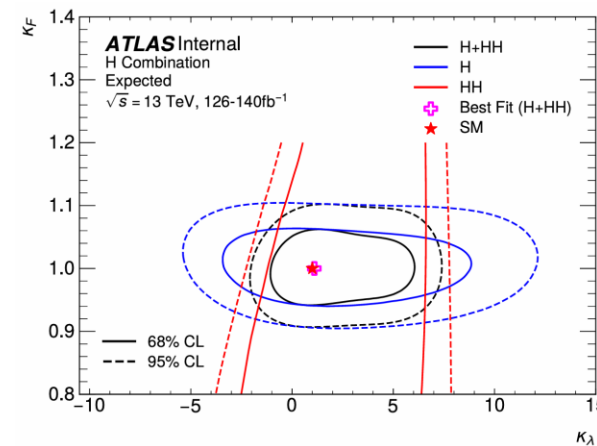
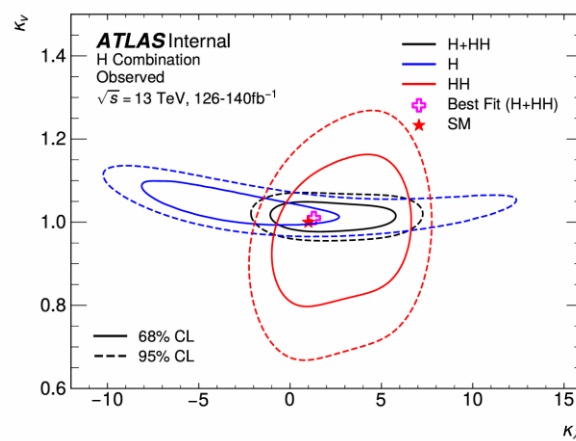
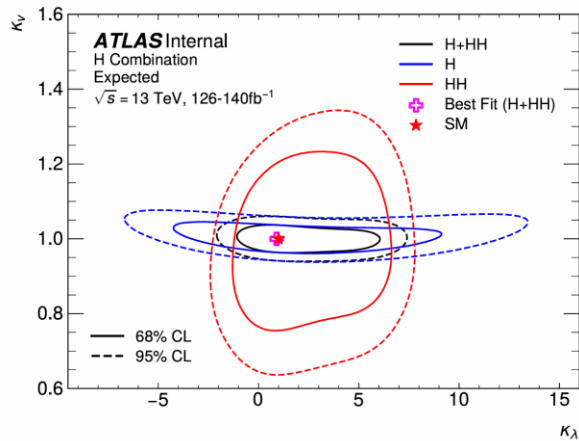
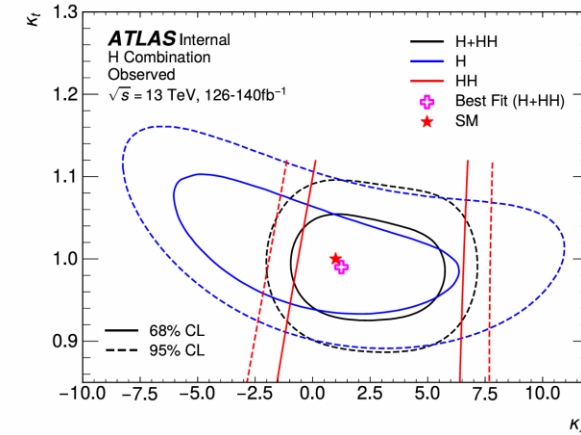
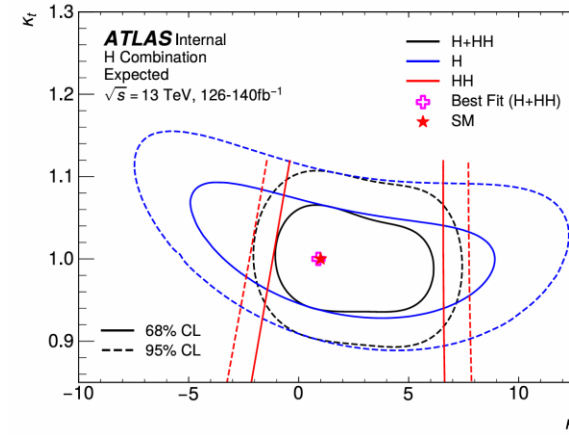
- Two scenario is tested and the improvement is quantified on the expected 95%CI
 - κ_λ float only: 14% improvement
 - Generic model (floating all the kappa $\kappa_\lambda, \kappa_t, \kappa_V, \kappa_b, \kappa_\tau$ except κ_{2V}): 16% improvement

κ_λ Interval	Obs. value $^{+1\sigma}_{-1\sigma}$	Obs. 95% CL	Exp. 95% CL
H comb	$-0.88^{+3.88}_{-2.52}$	[-5.31, 8.76]	[-4.35, 10.56]
HH comb	$3.53^{+2.36}_{-3.42}$	[-1.31, 7.19]	[-1.71, 7.18]
H+HH κ_λ only	$1.30^{+3.10}_{-1.62}$	[-1.49, 6.49]	[-1.55, 6.80]
Previous H+HH κ_λ only	$3.0^{+1.8}_{-1.9}$	[-0.4, 6.3]	[-1.9, 7.6]
H+HH generic	$0.62^{+2.51}_{-1.55}$	[-2.14, 5.91]	[-1.62, 6.88]
Previous H+HH generic	$2.3^{+2.1}_{-2.0}$	[-1.4, 6.1]	[-2.2, 7.7]



H+HH 2D scan

- Two scenarios is tested
 - κ_λ vs κ_t (all other κ fixed to SM)
 - κ_λ vs κ_V/κ_F (another κ fixed to SM)
 - Plots with other κ profiled in backup
- Combining H and HH could well constrain κ_λ and other κ together



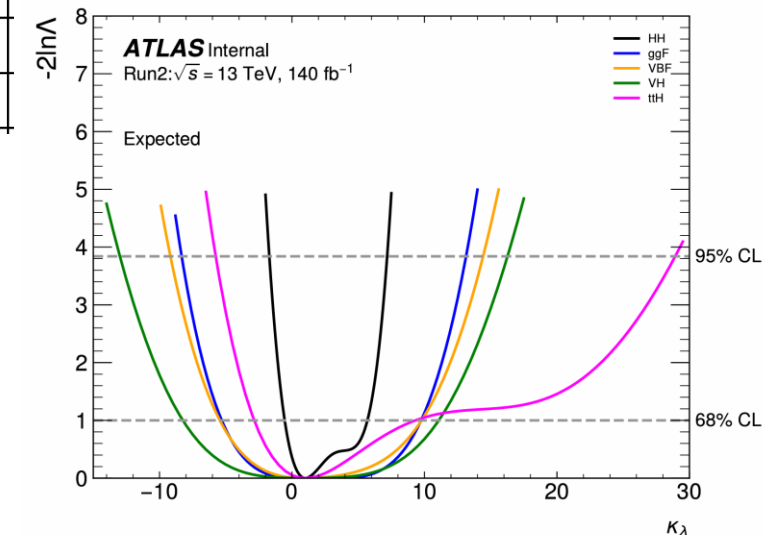
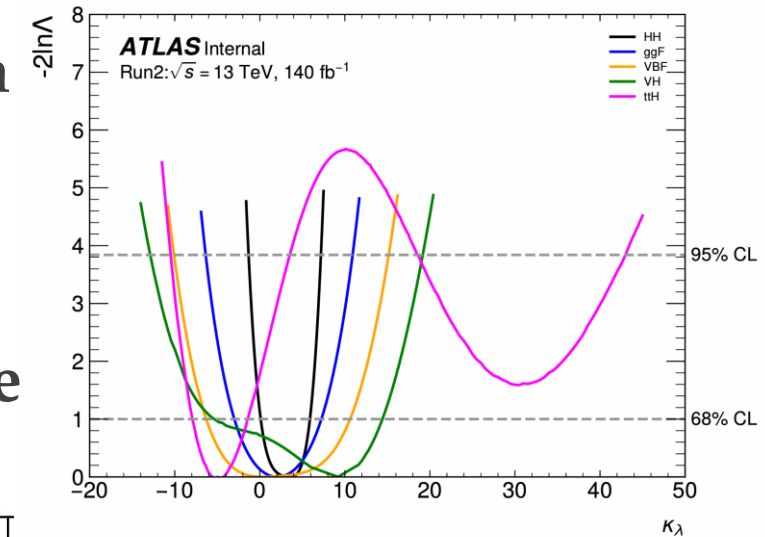
Prod. Mode breakdown results

- Only parametrize each prod. mode to see contribution
 - Turn off all the decay mode parametrization
 - ggF > VBF > VH, ttH dominant in low boundary
- The central value shift could be explained by the large improvement on the ttH prod. (~40%)

$$r_{\text{ttH+tH}} \quad 0.97^{+0.20}_{-0.18} \longrightarrow 0.77^{+0.12}_{-0.11}$$

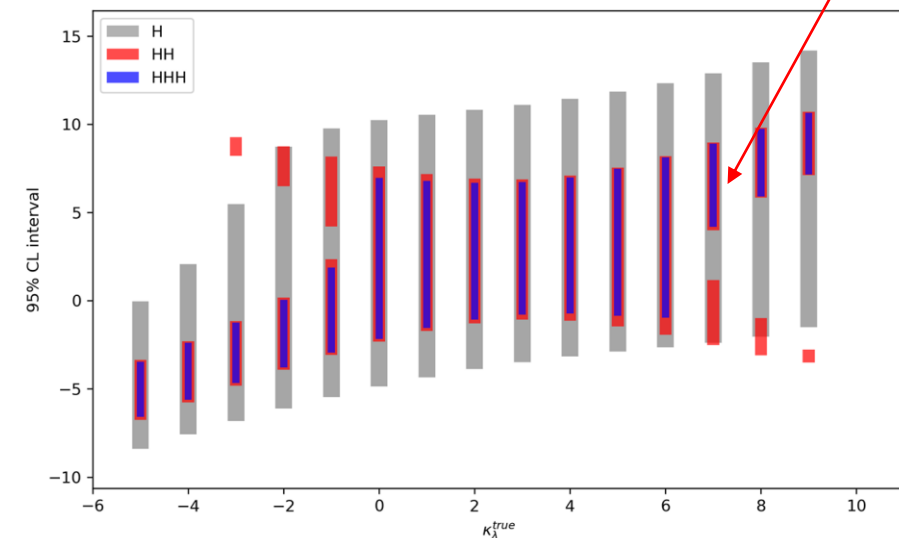
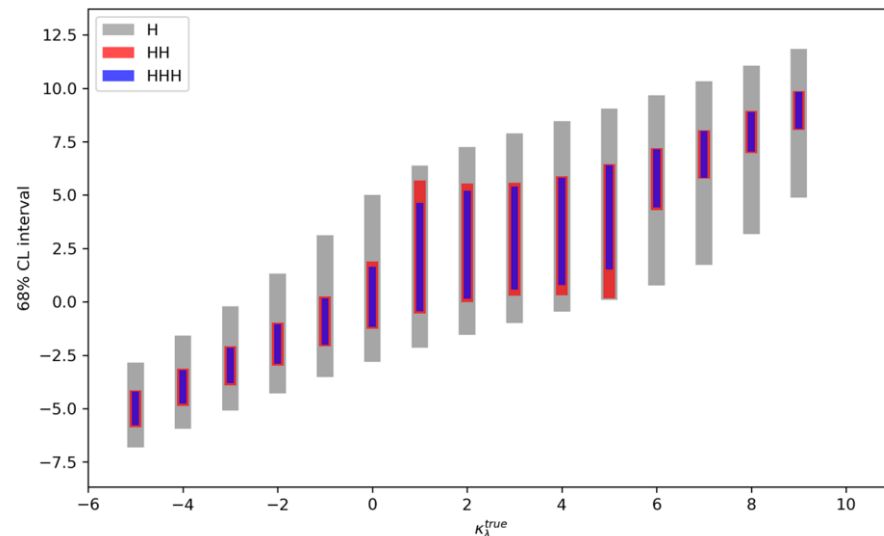
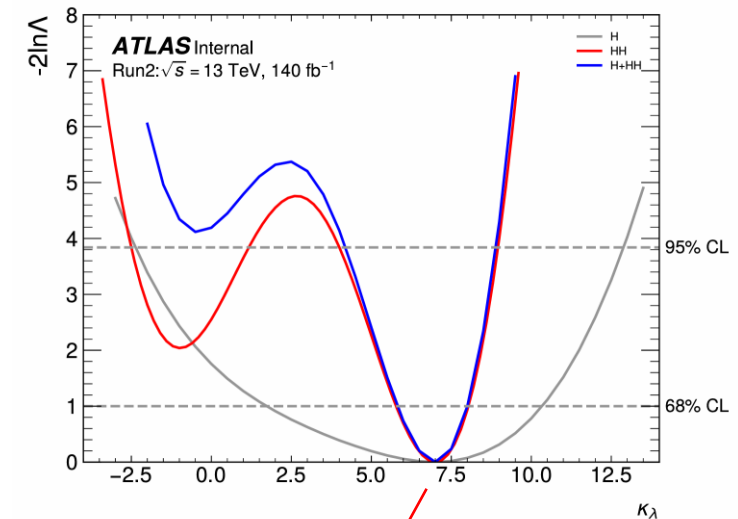
κ_λ Interval	Obs. value $^{+1\sigma}_{-1\sigma}$
H comb	$-0.91^{+3.85}_{-2.48}$
Previous H comb	$2.5^{+4.6}_{-3.8}$

κ_λ Interval	Observed @95%	Expected @ 95%
HH	[-1.31, 7.19]	[-1.71, 7.18]
ggF	[-6.36, 10.92]	[-8.33, 13.14]
VBF	[-10.07, 15.16]	[-9.18, 14.43]
VH	[-12.88, 19.16]	[-12.99, 16.27]
ttH + tH	[-10.49, 3.53] & [18.56, 42.99]	[-5.76, 28.93]



Relative impact wrt. truth κ_λ

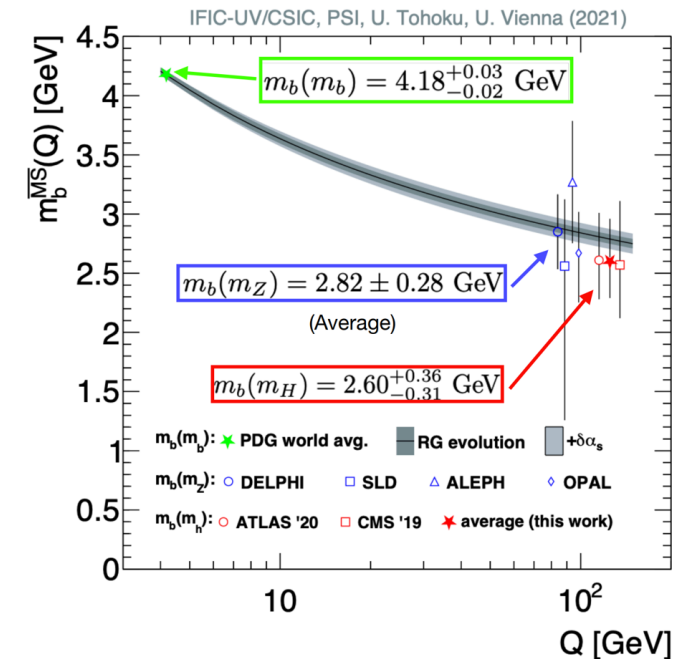
- Get 95%CI of H/HH/H+HH as the function of truth κ_λ
 - Generating post-fit Asimov with different truth κ_λ assumption
 - To see the relative importance of H and HH given each κ_λ
- HH still dominant when κ_λ deviate from SM, but single H could help to exclude some 95% CI region



$m_b(m_H)$ interpretation

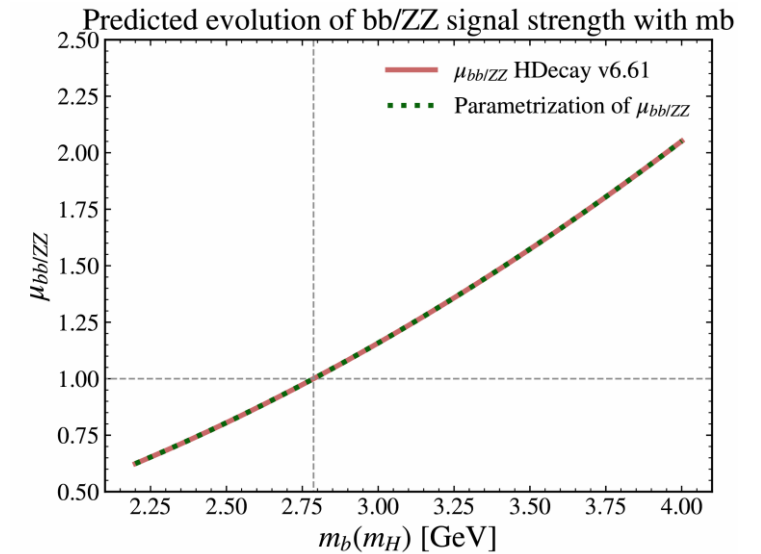
$m_b(m_H)$ introduction

- Quark masses are “running constants” in the QCD theory due to the renormalization scheme
 - PDG world average: $m_b(m_b) = 4.18^{+0.03}_{-0.02} \text{ GeV}$
 - Several LEP experiments and SLD measurement average: $m_b(m_Z) = 2.82 \pm 0.28 \text{ GeV}$
- Experimentally measurable at the LHC using results on Higgs coupling to $b\bar{b}$
 - Assuming the SM-Yukawa, $H \rightarrow b\bar{b}$ decay rate depends quadratically on m_b
- First $m_b(m_H)$ result uses ATLAS & CMS data [[PRL](#)]
 - $m_b(m_H) = 2.60^{+0.36}_{-0.31} \text{ GeV}$
 - 1σ compatible with SM & 7σ differs from no-running scenario



Methodology

- Use $BR(H \rightarrow b\bar{b})/BR(H \rightarrow ZZ)$ as the probe
 - Could reduce the dependence on assumptions about the Higgs couplings to SM particles
- Input WS: 6XS + BRs ratios, parametrized with XX/ZZ
 - The BR is expressed relative to BR_{ZZ} , and the production POIs are measured as $\sigma_i \times BR_{ZZ}$
- Parametrize the $\mu_{bb/ZZ} = f(m_b)$ with a 5th-order polynomial
 - Derive the predictions on the BRs by HDECAY v6.61
 - Correct the package to match the YR4 in the SM case (diff. within 0.1%)
 - 3602 scan points from 2.2 to 4 GeV, 0.5 MeV as steps
 - Coefficients obtained by fitting the predictions
 - The residuals less than 0.0002 -> uncertainty neglect

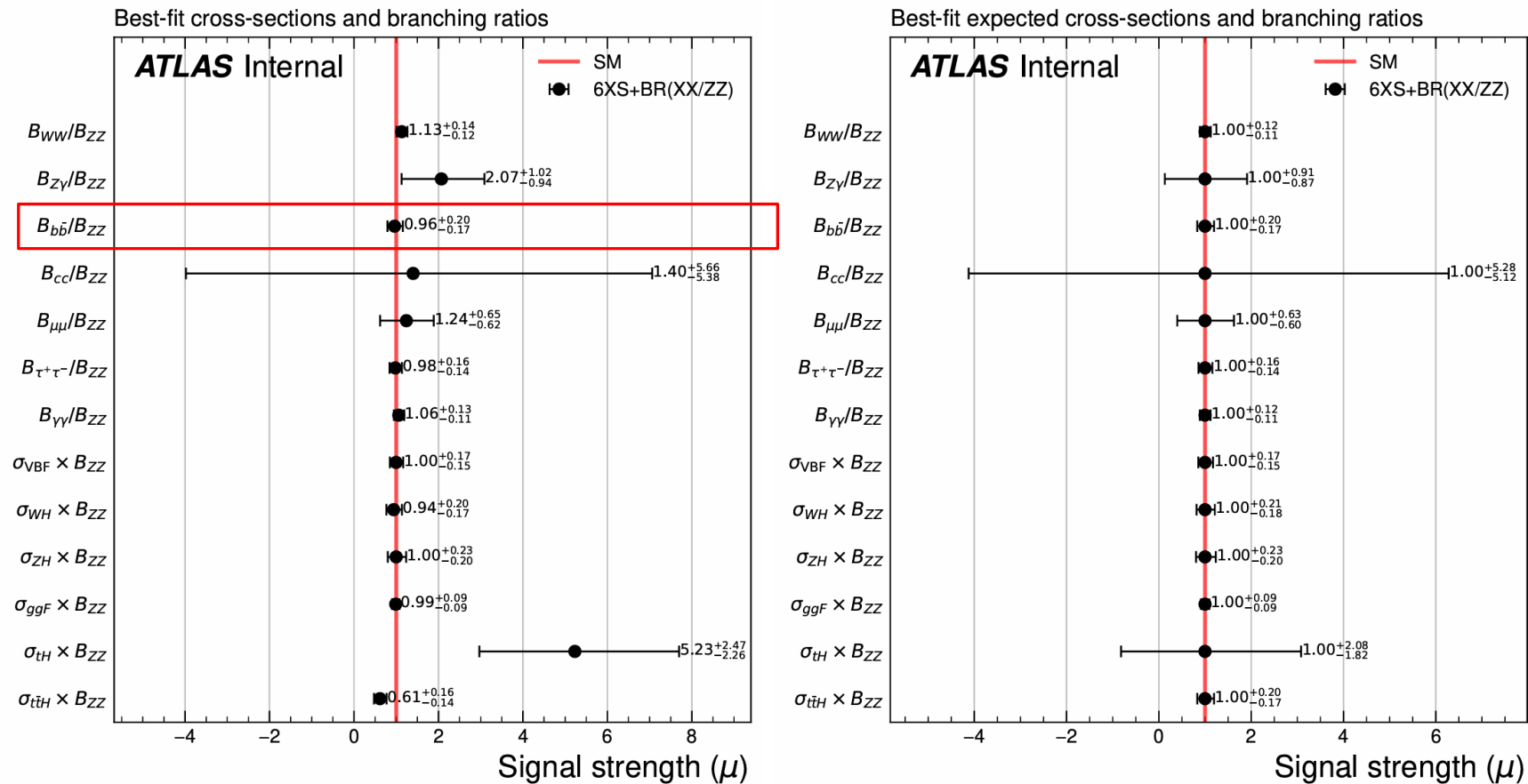


$$\mu(x) = \frac{\Gamma(H \rightarrow b\bar{b})/\Gamma(H \rightarrow ZZ)}{\Gamma(H \rightarrow b\bar{b})_{SM}/\Gamma(H \rightarrow ZZ)_{SM}} \quad \text{where } x = m_b(m_H)$$

$$= 0.01477 - 0.02547 \cdot x + 0.1472 \cdot x^2 - 0.0062897 \cdot x^3 + 0.0010008 \cdot x^4 - 0.0000694 \cdot x^5,$$

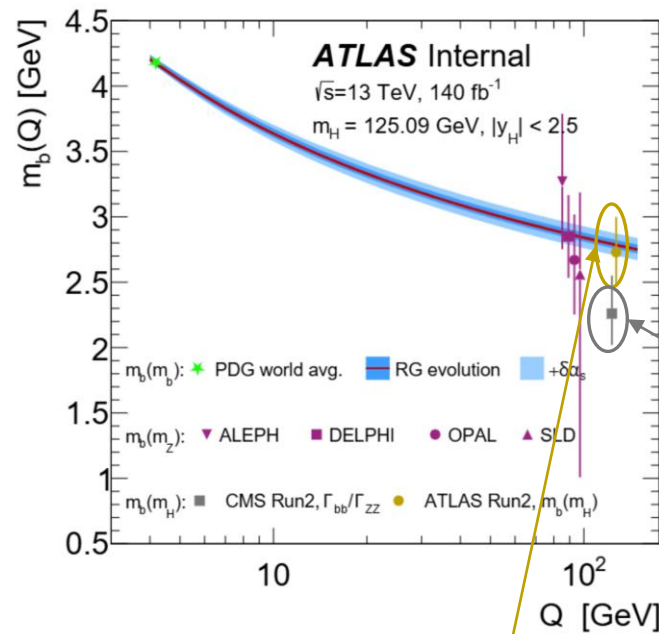
6XS + BRs ratios Results

- Intermediate fit results without m_b parametrization



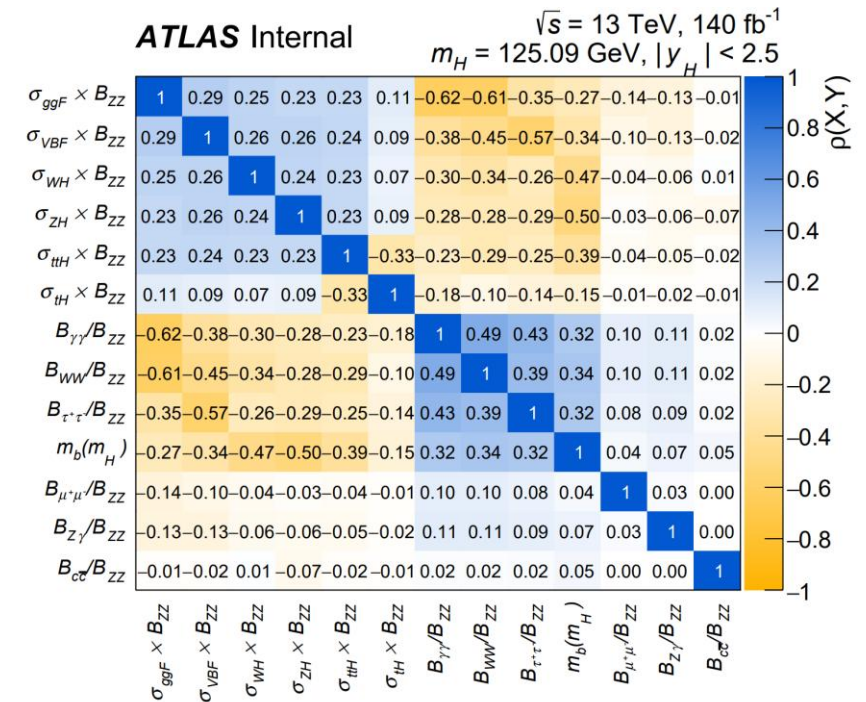
$m_b(m_H)$ results

- Reparametrize the $\mu_{bb/ZZ}$ and get the m_b fit results
 - Compatible with the “running” prediction
- Also get the interpretation of $\mu_{bb/ZZ}$ from CMS Legacy Run2



$$\mu_{bb/ZZ} = 0.66^{+0.17}_{-0.14} \text{ (CMS)}$$

$$m_b(m_H) = 2.26^{+0.29}_{-0.26} \text{ GeV}$$



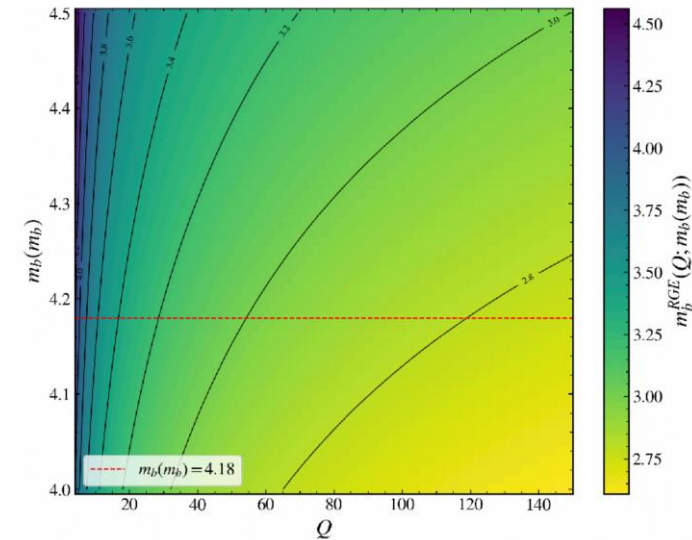
$$m_b(m_H) = 2.73^{+0.22}_{-0.20}(\text{stat.})^{+0.15}_{-0.14}(\text{syst.})^{+0.07}_{-0.06}(\text{theo.}) = 2.73^{+0.27}_{-0.25} \text{ GeV.}$$

Running test

- Agreement with the “running” scheme could be quantified by fitting the measured $m_b(\mu)$ results with a parametrization:

$$m(\mu; x, m_b(m_b)) = x \left[m_b^{RGE}(\mu, m_b(m_b)) - m_b(m_b) \right] + m_b(m_b),$$

- The $m_b^{RGE}(\mu, m_b(m_b))$ described the RGE evolution in the SM
 - Use Revolver software to produce 2D prediction and get function by interpolation
 - x characterizes the running scenario, 0 $\rightarrow$ no-running & 1 $\rightarrow$ SM
 - χ^2 minimization with 1 $m_b(m_b)$, 4 $m_b(m_Z)$ and 2/1 $m_b(m_H)$ points
- Results with CMS $m_b(m_H)$:**
 - $x = 1.12 \pm 0.10$, 1σ compatible with SM & 11.2σ differs from no-running scenario
- Results without CMS $m_b(m_H)$:**
 - $x = 1.04 \pm 0.12$, 0.4σ compatible with SM & 9.4σ differs from no-running scenario



Summary

- **κ framework measurement**

- Results with no BSM contribution are updated and the difference with CONF is understood
- Add H->inv search (constrain B_i) to obtain the results with $B_{i,u}$ float
- Add off-shell analyses (constrain κ_H) to obtain the results with B_{BSM} float
- Add both H->inv and off-shell analyses to obtain the results with $B_{i,u}$ float

- **κ_λ interpretation and H+HH combination**

- 1D and 2D scan are all complete

- **$m_b(m_H)$ interpretation**

- $m_b(m_H)$ is measured and the no-running scenario is excluded with 11.2(9.4) σ w/wout CMS

Systematics treatment

Changes since [CONF publication](#):

- $H \rightarrow \gamma\gamma$ [\[Ref.\]](#): New workspace with piecewiseInterpolation instead of custom response (smaller size and compatible with new ROOT)
- **ttH ML**: Update to 140 ifb workspace
- **tH, $H \rightarrow bb$** [\[Ref.1,Ref.2\]](#): new tH analysis. Only the SR is included
- **VH, $H \rightarrow bb/cc$** [\[Ref1,Ref.2,Ref.3\]](#): Inclusion of VH GT600 splits. Pruning was also applied to mitigate the buffer limit issue

Input analyses modifications:

- All input analyses **luminosities were scaled** for 140ifb new recommendation, except VBFbb
- Boosted $H \rightarrow bb$ luminosity is also scaled with the current recommendation [\[Ref.\]](#)
- **Branching ratios were reimplemented** and **merging uncertainties were injected**
- $H \rightarrow VV$ analyses with mass 125 GeV **were corrected to 125.09 GeV**. The rest was kept as-is, since the impact is well below the theory uncertainties

Correlations:

- All nuisance parameters are correlated, **except background theory and flavor tagging** (FTAG)
- **FTAG are decorrelated** when the parameters have an incompatible treatment:
 - Different CDI taggers are used
 - Different working points (WP)

In depth study on [further slides](#)

Uncertainty	Correlated	Note
Luminosity	yes	1. Correlated if same release and calibration schemes/CDIs 2. Decorrelate NP that is pulled by >0.5 in individual channel 3. Correlate the VHbbcc JER/JES NPs (Updated compared to CONF)
Pileup rw	yes	
Electron	yes	
EGamma	yes	
Muon	yes	
Tau	yes	
MET	yes	
Full JER	yes	
JES	yes	
FTAG	No	
Signal theo	yes	
Background theo	No	

[\[1st HIGP\]](#)

6

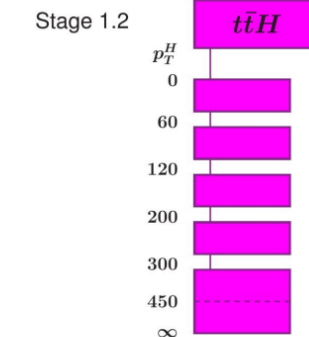
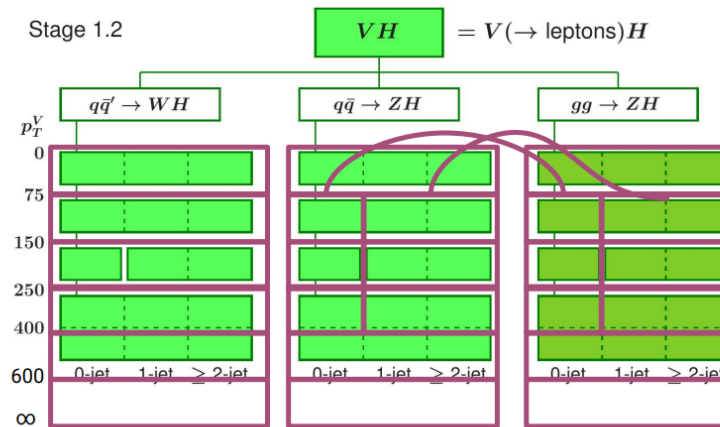
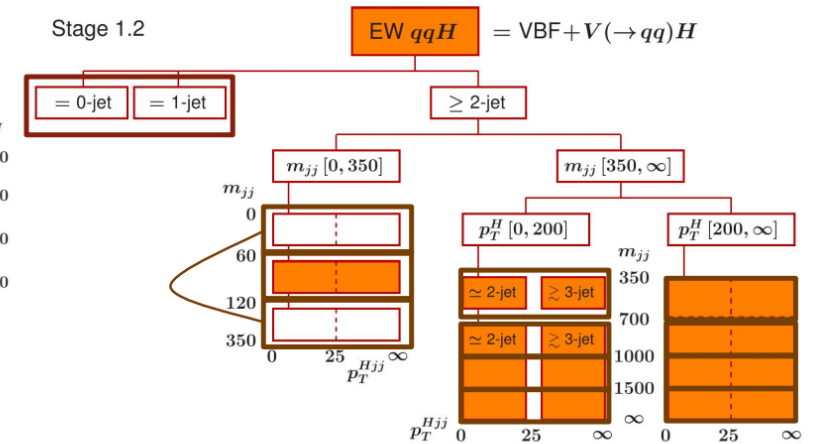
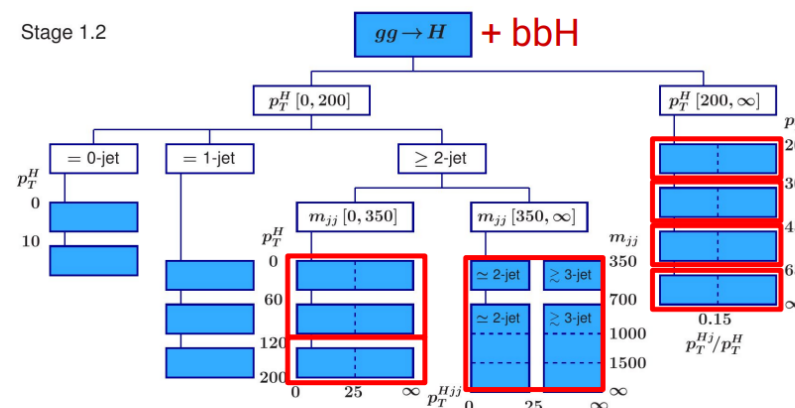
STXS Merging scheme

Merging scheme principles [Ref.]:

- A Bin is measured if and only if there is at least one input analysis sensitive to it
- A Bin is merged if the expected sensitivity is significantly higher than 1.00

Remarks:

- 0-jet VBF sensitivity is very low Two analyses attempt to measure VBF low N-jet:
 - HWW: 1-jet
 - $H\gamma\gamma$: inclusive 0/1/2-jet bins of low- m_{jj} VBF
- **bbH is included with ggH** in the production scheme. Input analyses are scaled accordingly [Ref.]
- $H\tau\tau$ does not include tHW and tHQ splitting:
 - It is therefore split by the expected cross-section
 - The impact of this is negligible

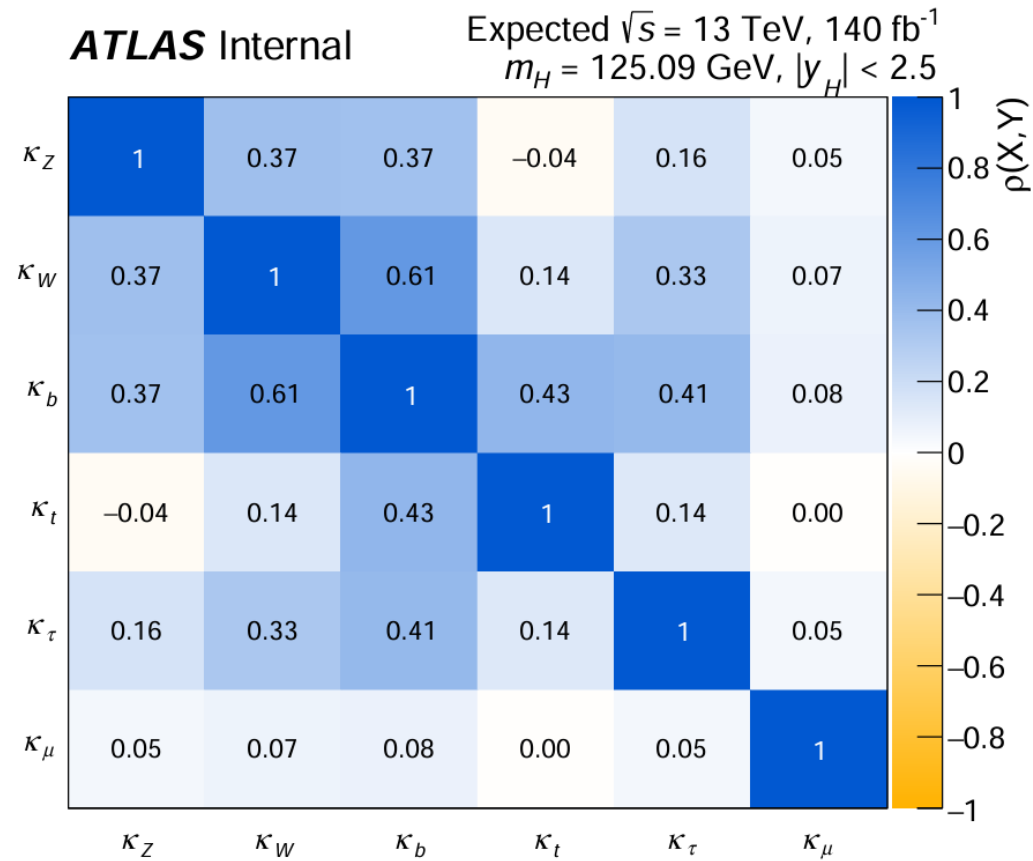


$tH = tHW + tHQ$

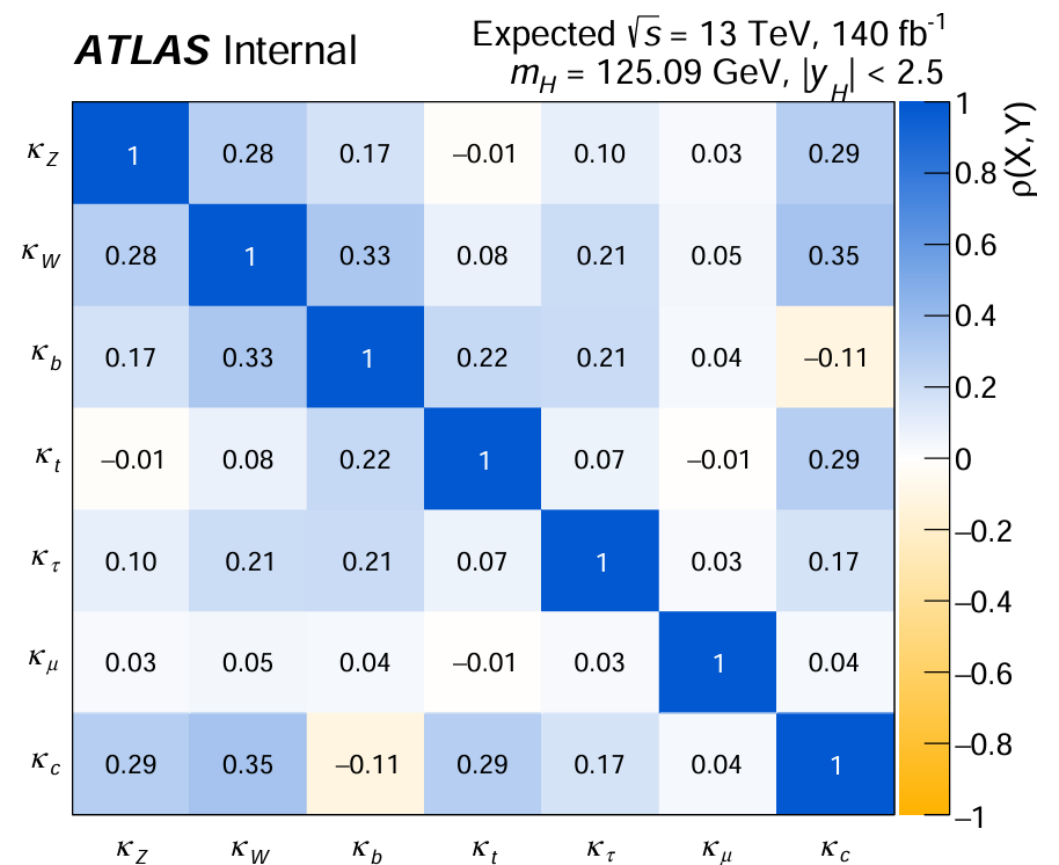
[1st HIGP]

12

Expected correlation (Resolved scenario)

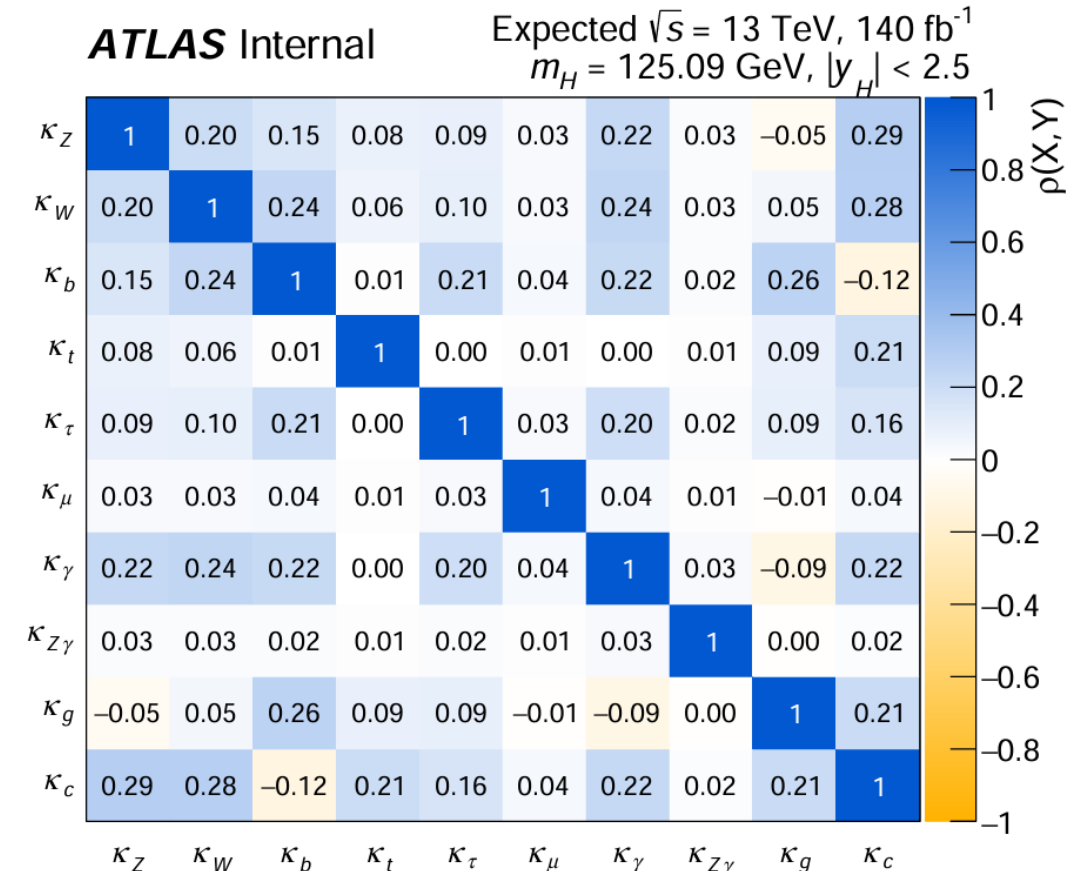
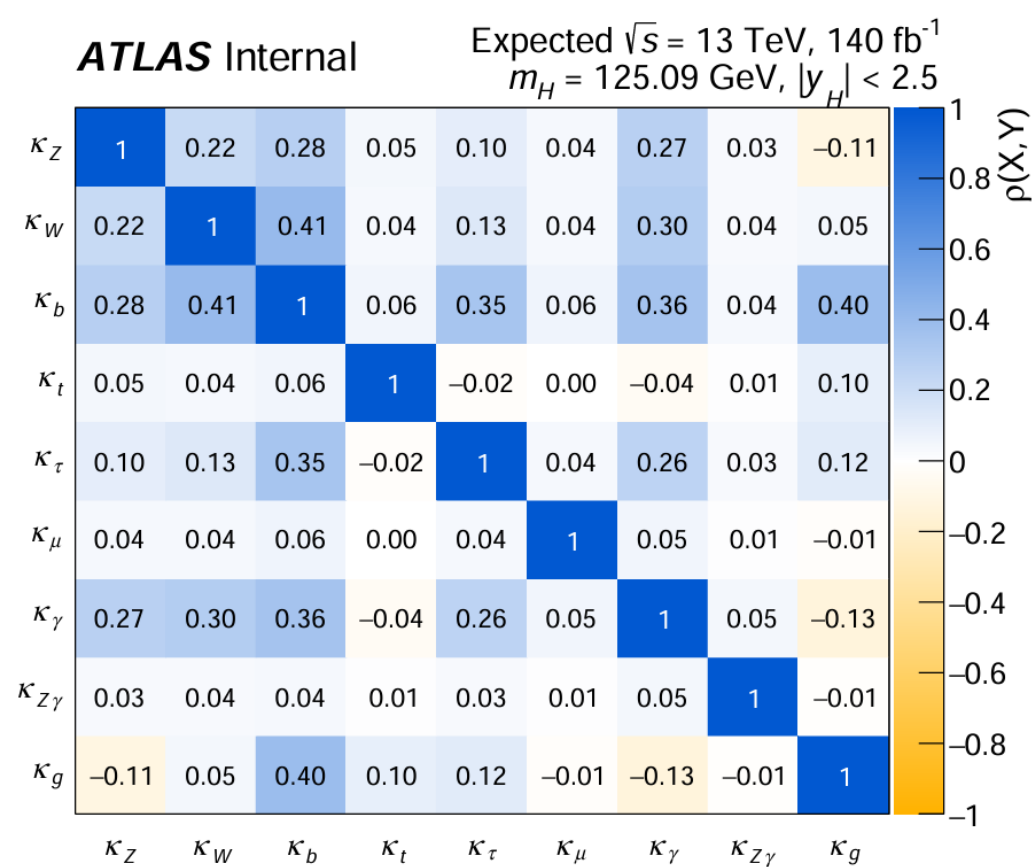


$$\kappa_C = \kappa_t$$

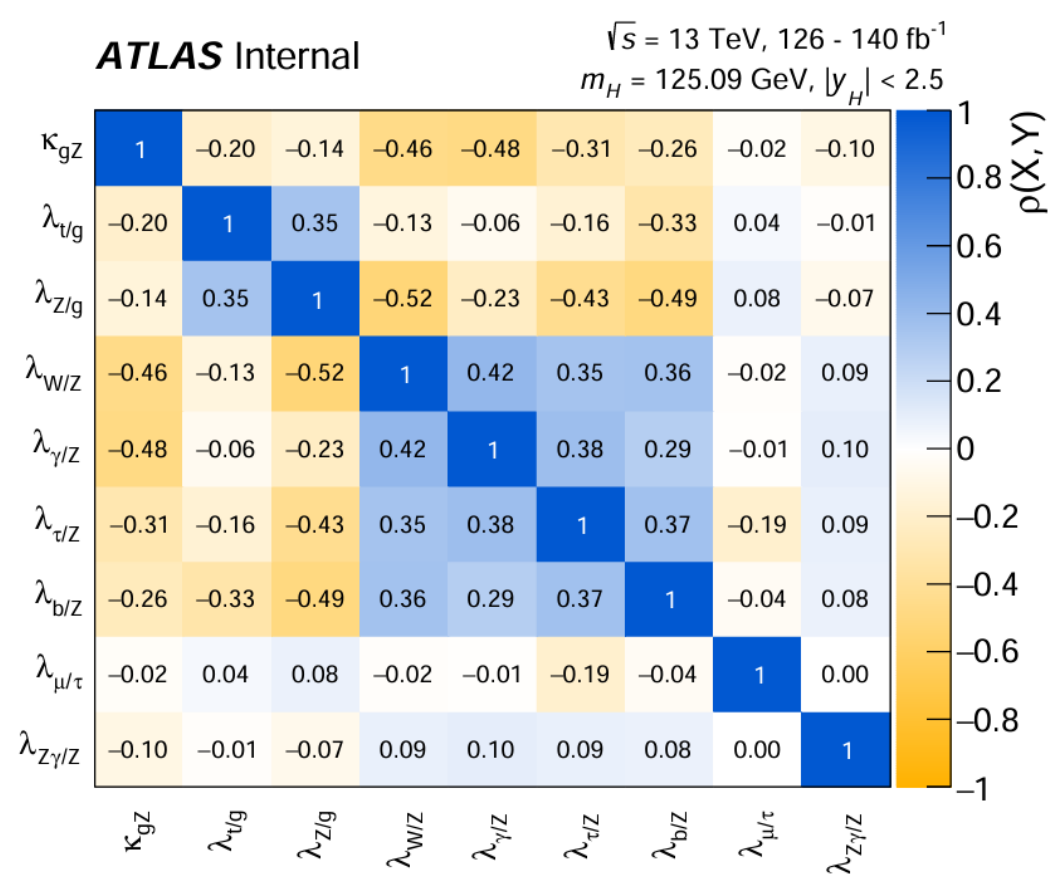


$$\kappa_C \neq \kappa_t$$

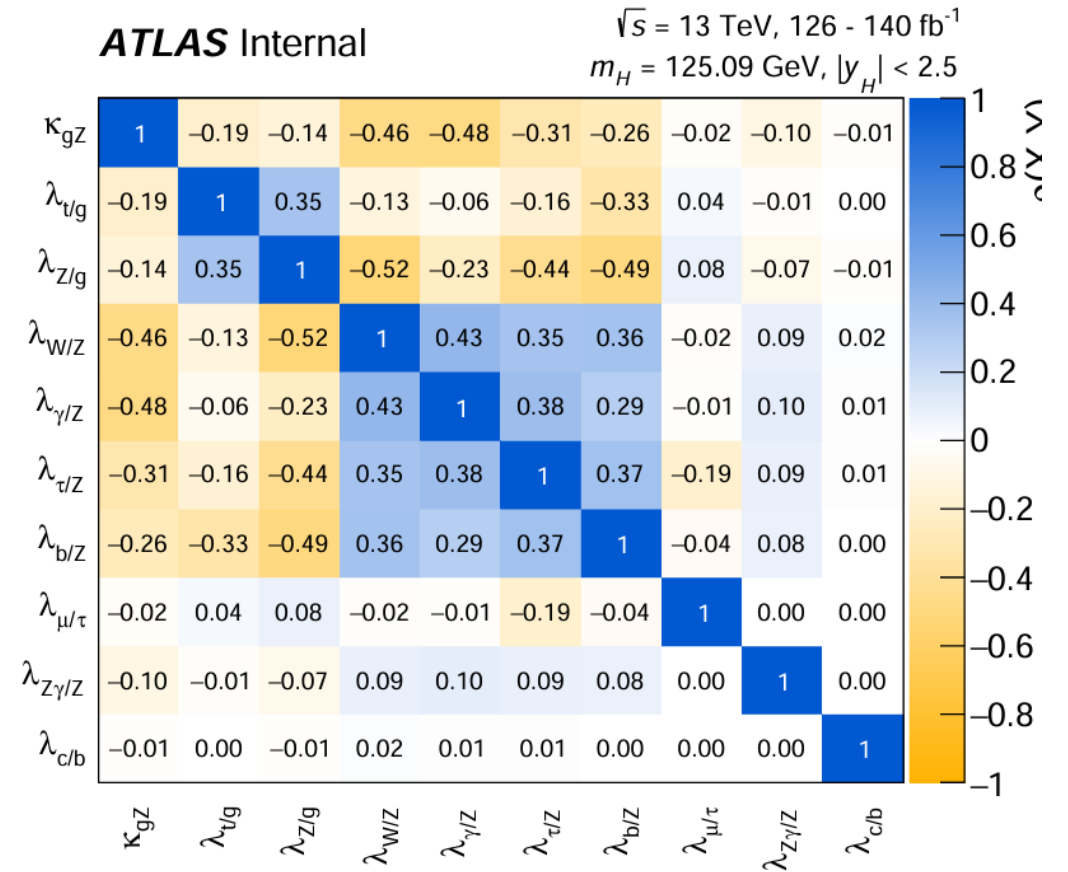
Expected correlation (Effective scenario)



Expected correlation (κ ratio)



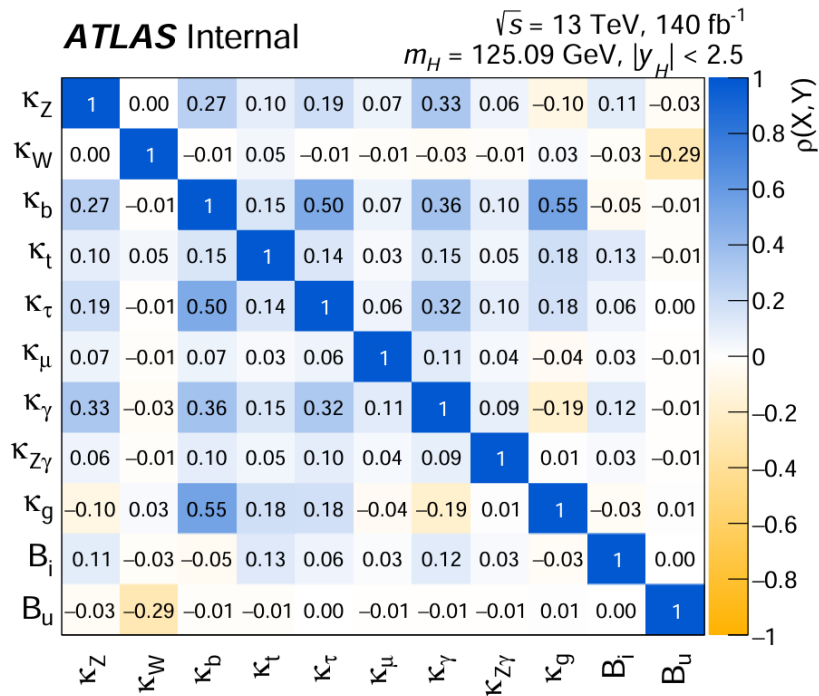
$$\kappa_C = \kappa_t$$



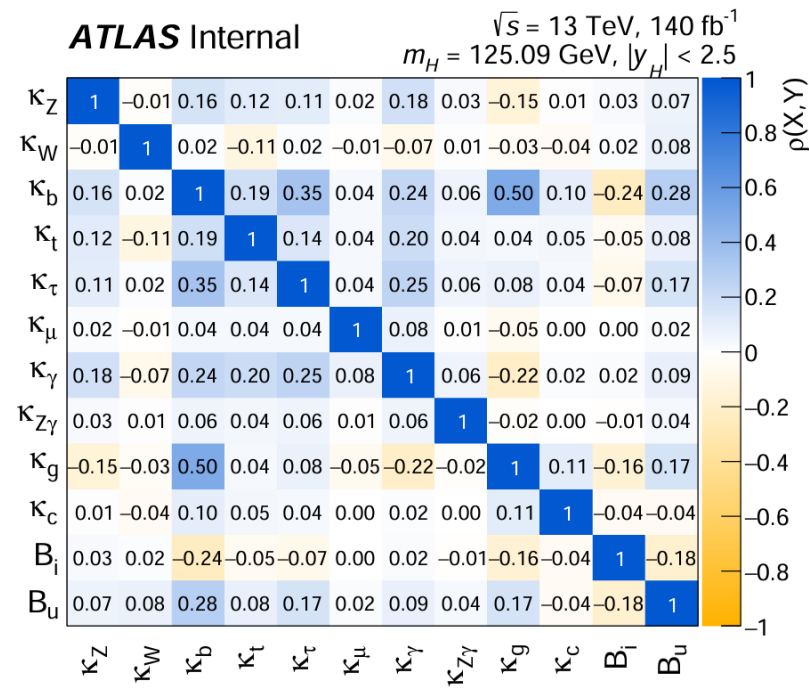
$$\kappa_C \neq \kappa_t$$

Observed correlation (On-shell + Hinv)

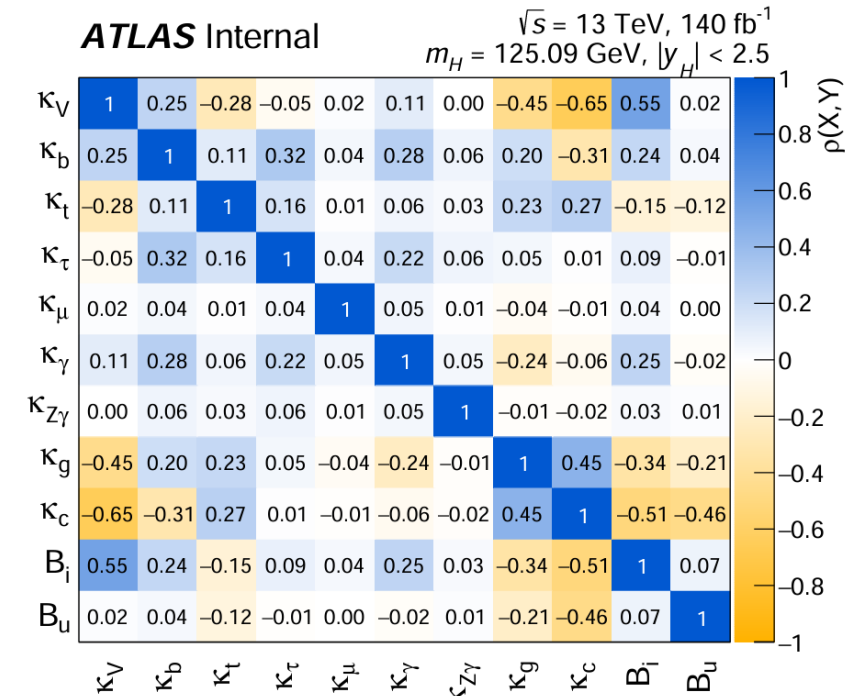
B_u is bounded at zero, when the best fit value is $B_u = 0$, the results from Hesse don't have a clear interpretation since you cannot just interpret the uncertainties from Hesse, neither the correlation matrix
This matrix was not published in Nature either, probably because of that



$$\kappa_W \neq \kappa_Z, \kappa_c = \kappa_t$$

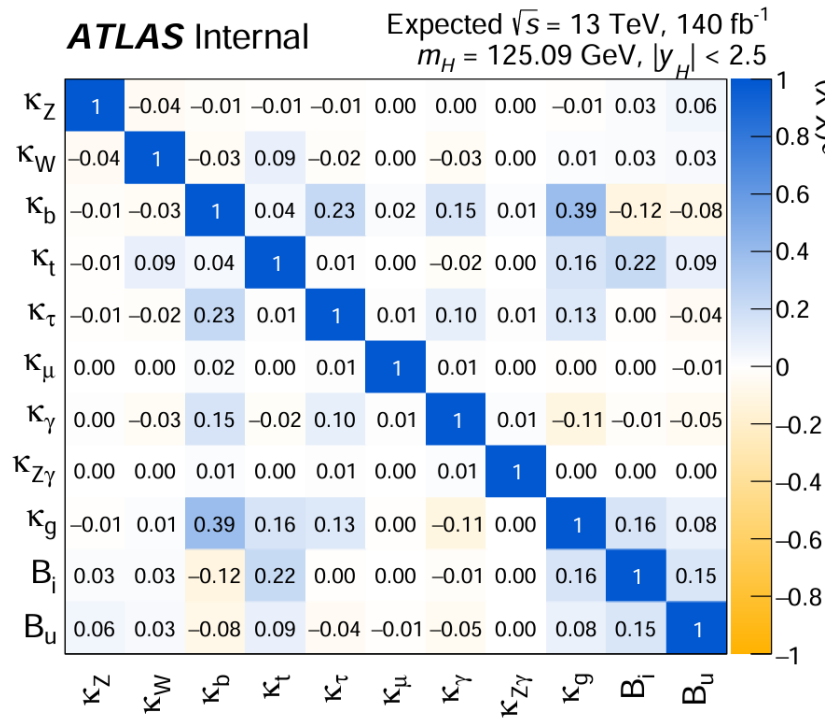


$$\kappa_W \neq \kappa_Z, \kappa_c \neq \kappa_t$$

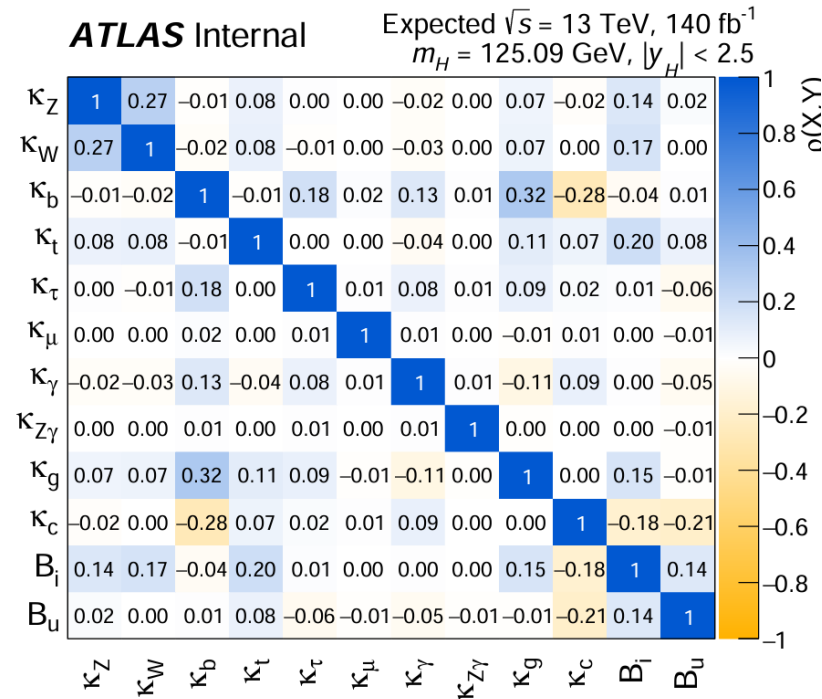


$$\kappa_W = \kappa_Z = \kappa_V, \kappa_c \neq \kappa_t$$

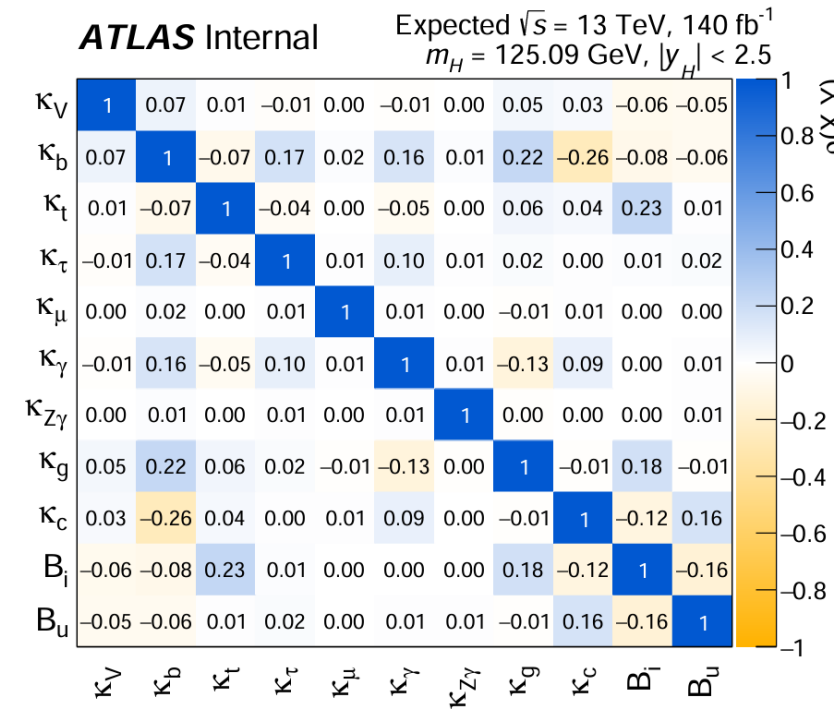
Expected correlation (On-shell + Hinv)



$$\kappa_W \neq \kappa_Z, \kappa_c = \kappa_t$$



$$\kappa_W \neq \kappa_Z, \kappa_c \neq \kappa_t$$



$$\kappa_W = \kappa_Z = \kappa_V, \kappa_c \neq \kappa_t$$

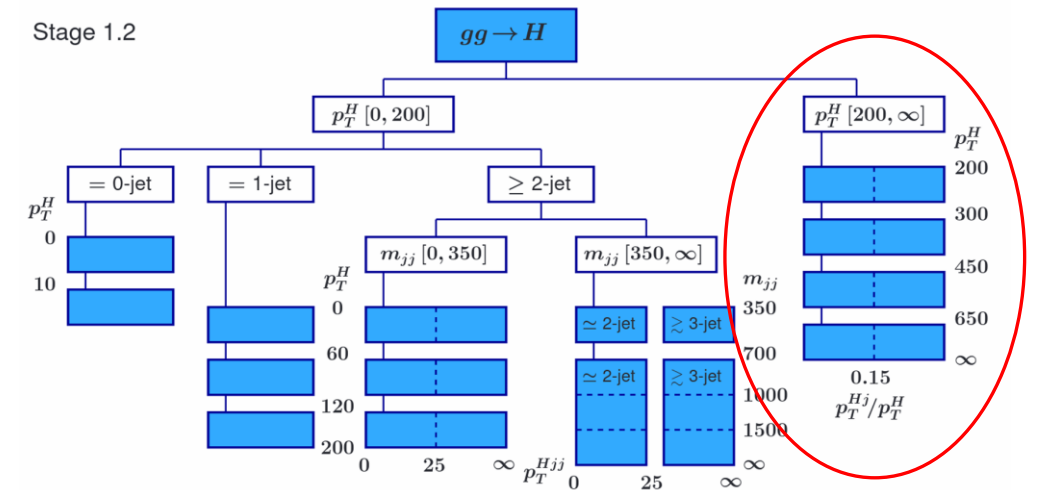
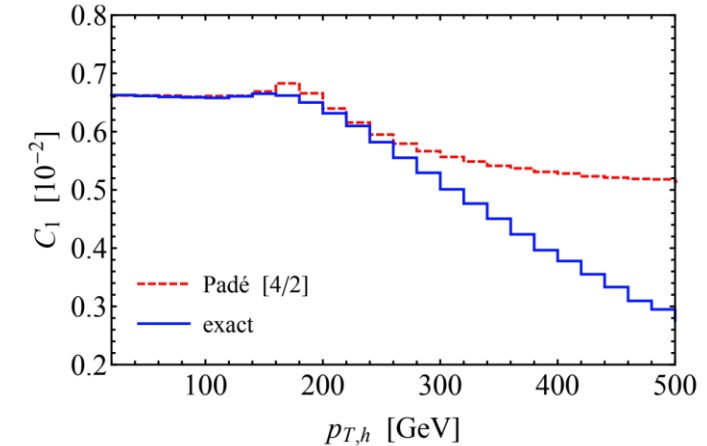
Complete formula of off-shell combination

$$\begin{aligned}
 & \frac{\kappa_g^2 \kappa_V^2}{\kappa_H} \sigma_{ZZ,ggF}^{\text{on-shell}} + \frac{\kappa_V^4}{\kappa_H} \sigma_{ZZ,VBF}^{\text{on-shell}} + \frac{\kappa_V^4}{\kappa_H} \sigma_{ZZ,WH}^{\text{on-shell}} + \frac{\kappa_V^4}{\kappa_H} \sigma_{ZZ,ZH}^{\text{on-shell}} + \\
 & \frac{\kappa_{ggZH}^2 \kappa_V^2}{\kappa_H} \sigma_{ZZ,ggZH}^{\text{on-shell}} + \frac{\kappa_{tHq}^2 \kappa_V^2}{\kappa_H} \sigma_{ZZ,tHq}^{\text{on-shell}} + \frac{\kappa_{tHW}^2 \kappa_V^2}{\kappa_H} \sigma_{ZZ,tHW}^{\text{on-shell}} + \frac{\kappa_F^2 \kappa_V^2}{\kappa_H} \sigma_{ZZ,ttH}^{\text{on-shell}} + \\
 & \frac{\kappa_g^2 \kappa_V^2}{\kappa_H} \sigma_{WW,ggF}^{\text{on-shell}} + \frac{\kappa_V^4}{\kappa_H} \sigma_{WW,VBF}^{\text{on-shell}} + \kappa_g^2 \kappa_V^2 \sigma_{ZZ,ggF}^{\text{off-shell}} + \kappa_V^4 \sigma_{ZZ,VBF}^{\text{off-shell}} + \\
 & \kappa_g^2 \kappa_V^2 \sigma_{WW,ggF}^{\text{off-shell}} + \kappa_V^4 \sigma_{WW,VBF}^{\text{off-shell}}
 \end{aligned}$$

where $\kappa_H = \Gamma_H / \Gamma_H^{\text{SM}}$ is a multiplier of the SM Higgs boson width of $\Gamma_H^{\text{SM}} = 4.1 \text{ MeV}$, $\kappa_{ggZH}^2 = 0.4594\kappa_g^2 + 2.456\kappa_V^2 - 1.914\kappa_g\kappa_V$, $\kappa_{tHq}^2 = 2.633\kappa_F^2 + 3.578\kappa_V^2 - 5.211\kappa_F\kappa_V$, and $\kappa_{tHW}^2 = 2.909\kappa_F^2 + 2.310\kappa_V^2 - 4.220\kappa_F\kappa_V$.

ggF differential C1

- Previous we use inclusive $C_1[0.0066]$ for all the ggF STXS binning
- Recently the C_1 for the ggF in p_T^H binning is available [\[slide\]](#)
 - Get the approximate value from the histograms (blue and red curve)
- Then perform the parametrization with ggF STXS binning based on their p_T^H
 - Take average number of the binning included
 - Only influence several bins with $p_T^H > 200$ GeV



Results comparison

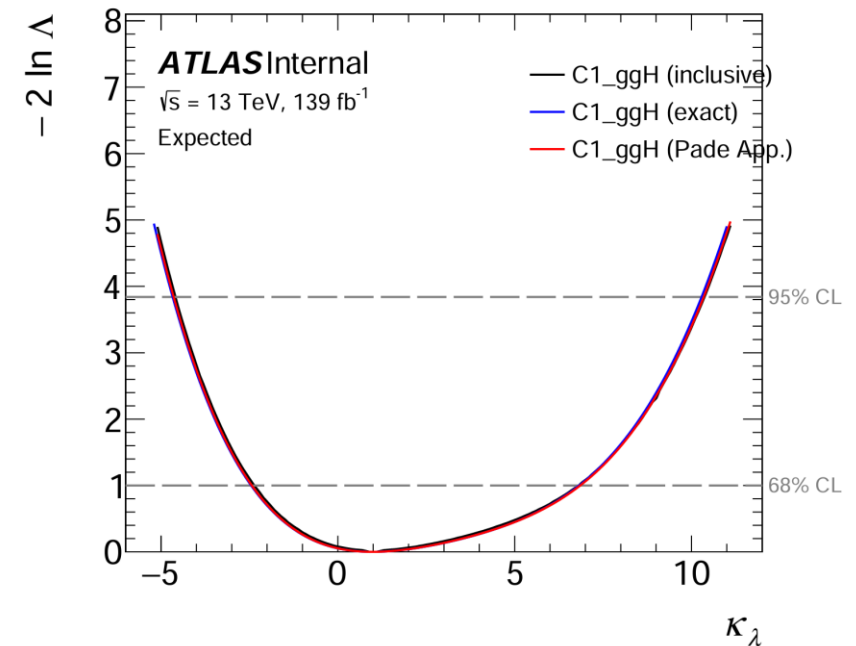
- Generate the Asimov dataset and perform the likelihood scan for three cases
 - Tiny impact on the expected κ_λ results
 - Not the latest scheme

combination (8 channels), inclusive ggF C_1 :
 κ_λ in $[-4.59, 10.37]$ @ 95% CL

combination (8 channels), ggF C_1 in **exact/app.** p_T^H bin :
 κ_λ in $[-4.67, 10.29]/[-4.64, 10.35]$ @ 95% CL



Tiny change



C_1 derivation in new split STXS bins

- Use recipe detailed in the LHC HWG [\[note\]](#) to compute C_1 in each split STXS bin.
- Modify the [Rivit code](#) which classifies the MC events into STXS bins.
- Results are obtained using 5M statistics
 - Compatible results with LHC HWG note

ZH	Our results (5M)	Note (5M)
QQ2HLL_FWDH	1.35000 +/- 0.00261	1.350
QQ2HLL_PTV_0_75	1.63242 +/- 0.00148	1.633
QQ2HLL_PTV_75_150	0.87113 +/- 0.00100	0.871
QQ2HLL_PTV_150_250	0.29269 +/- 0.00070	0.293
QQ2HLL_PTV_GT250	0.00314 +/- 0.00056	0.003
QQ2HLL_PTV_GT150	0.9254 +/- 0.0003	
QQ2HLL_PTV_400_600	-0.06927 +/- -0.00130	
QQ2HLL_PTV_GT600	-0.07452 +/- -0.00253	

WH	Our results (5M)	Note (5M)
QQ2HLNU_FWDH	1.17415 +/- 0.00218	1.173
QQ2HLNU_PTV_0_75	1.39930 +/- 0.00129	1.399
QQ2HLNU_PTV_75_150	0.74710 +/- 0.00088	0.747
QQ2HLNU_PTV_150_250	0.24952 +/- 0.00060	0.250
QQ2HLNU_PTV_GT250	0.00202 +/- 0.00045	0.004
QQ2HLNU_PTV_GT150	0.8646 +/- 0.0009	
QQ2HLNU_PTV_400_600	-0.06018 +/- -0.00102	
QQ2HLNU_PTV_GT600	-0.06487 +/- -0.00191	

K_{EW} derivation in new split STXS bins

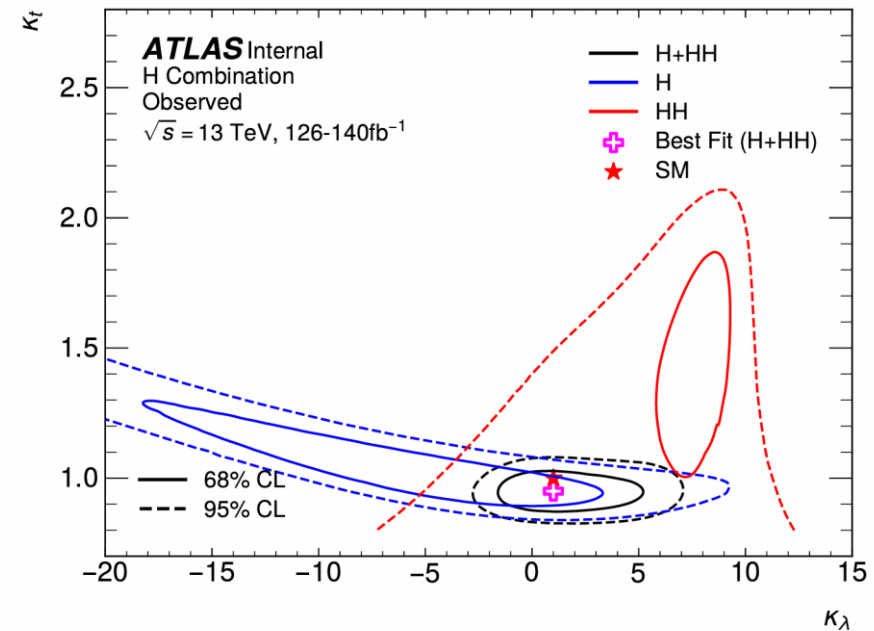
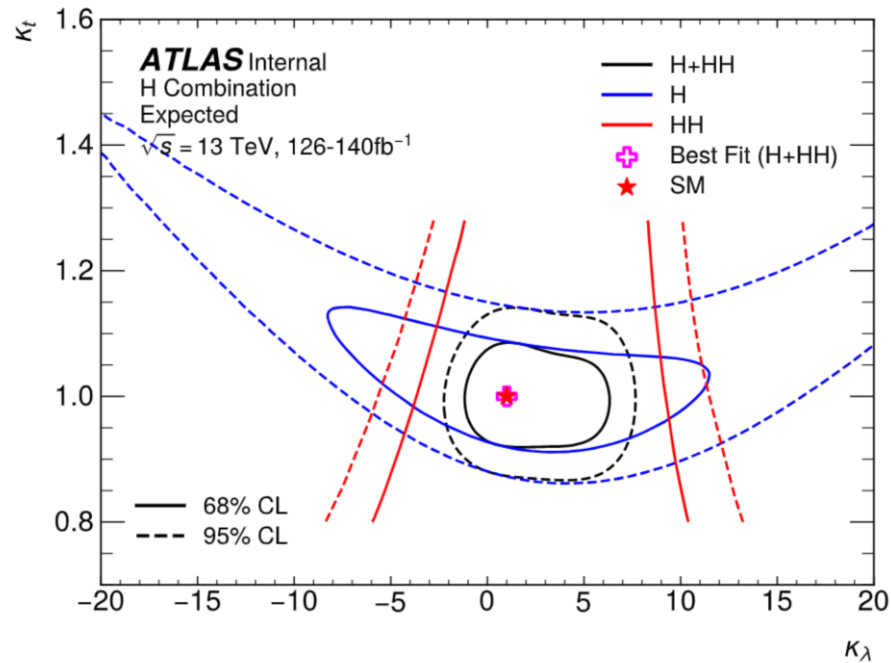
- K_{EW} for W(lnu)H, Z(ll)H, and Hjj processes in the LHC HWG [[note](#)] are from the LHCXSWG recommendations using HAWK 2.0 generator
- We have successfully setup the HAWK2.0 and LHAPDF (NNPDF23_nlo_as_0118_qed) and computed K_{EW} in the new binning
 - Used the same statistics as in the LHC HWG note (100 M)

ZH	Our results (100 M)	Note (100 M)
QQ2HLL_FWDH	0.9526 +/- 0.0002	0.952
QQ2HLL_PTV_0_75	0.9499 +/- 0.0001	0.950
QQ2HLL_PTV_75_150	0.9430 +/- 0.0006	0.943
QQ2HLL_PTV_150_250	0.9360 +/- 0.0004	0.937
QQ2HLL_PTV_GT250	0.8884 +/- 0.0008	0.890
QQ2HLL_PTV_GT150	0.9254 +/- 0.0003	
QQ2HLL_PTV_400_600	0.8311 +/- 0.0018	
QQ2HLL_PTV_GT600	0.7546 +/- 0.0025	

WH	Our results (100 M)	Note (100 M)
QQ2HLNU_FWDH	0.9164 +/- 0.0004	0.917
QQ2HLNU_PTV_0_75	0.9359 +/- 0.0002	0.937
QQ2HLNU_PTV_75_150	0.9074 +/- 0.0004	0.910
QQ2HLNU_PTV_150_250	0.8769 +/- 0.0009	0.879
QQ2HLNU_PTV_GT250	0.8270 +/- 0.0025	0.828
QQ2HLNU_PTV_GT150	0.8646 +/- 0.0009	
QQ2HLNU_PTV_400_600	0.7679 +/- 0.0021	
QQ2HLNU_PTV_GT600	0.6922 +/- 0.0034	

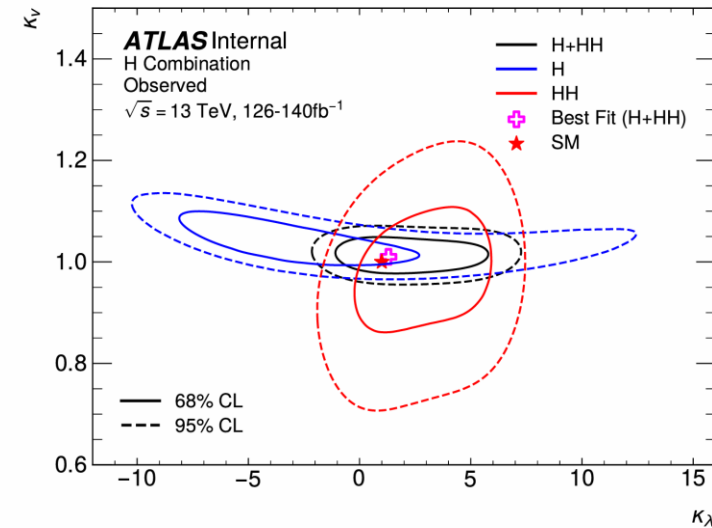
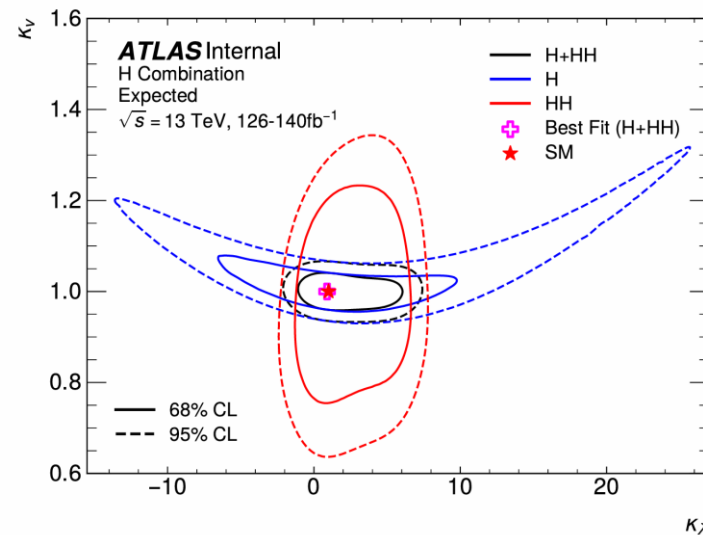
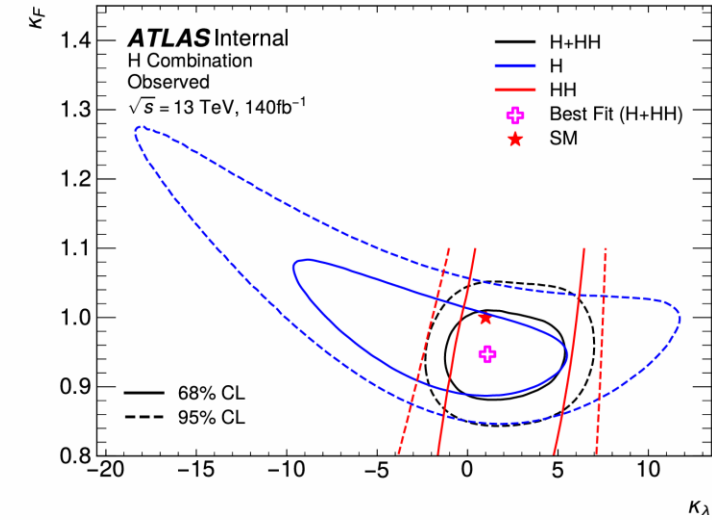
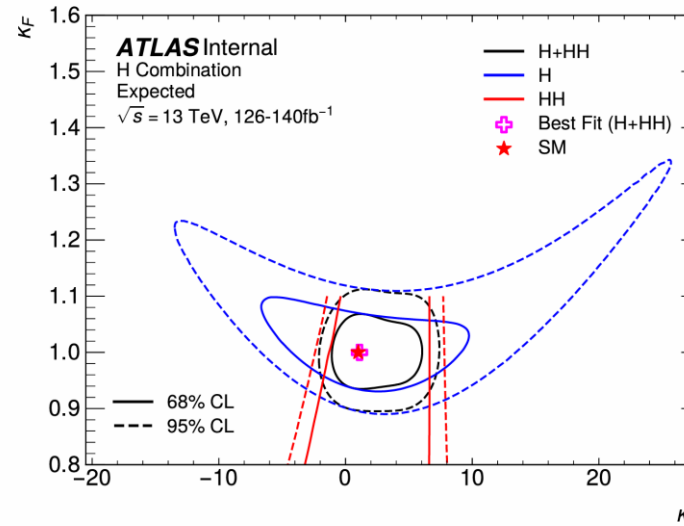
κ_λ vs κ_t with other κ profiled

- Float all other kappa ($\kappa_V, \kappa_b, \kappa_{\tau}, \kappa_{2V}$)
 - The constraint is looser with less assumption (especially in the singleH case)

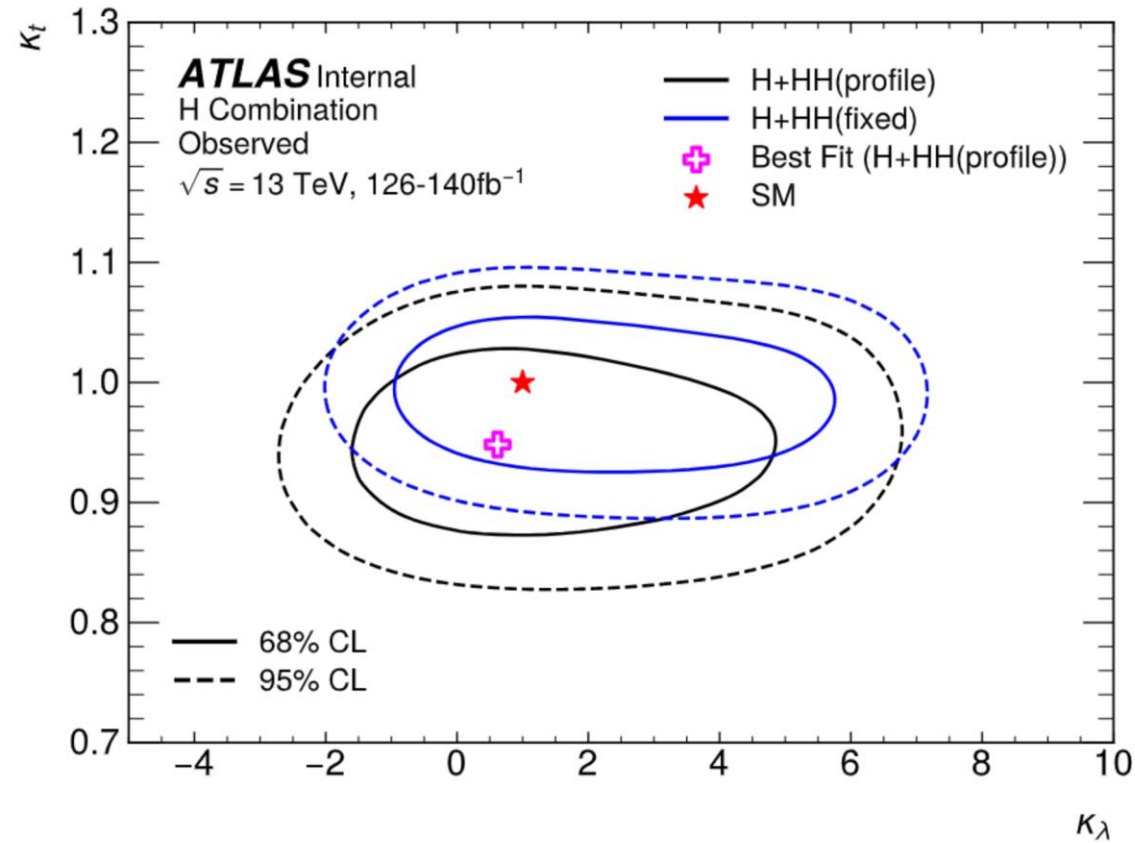


κ_λ vs κ_F/κ_V with other κ profiled

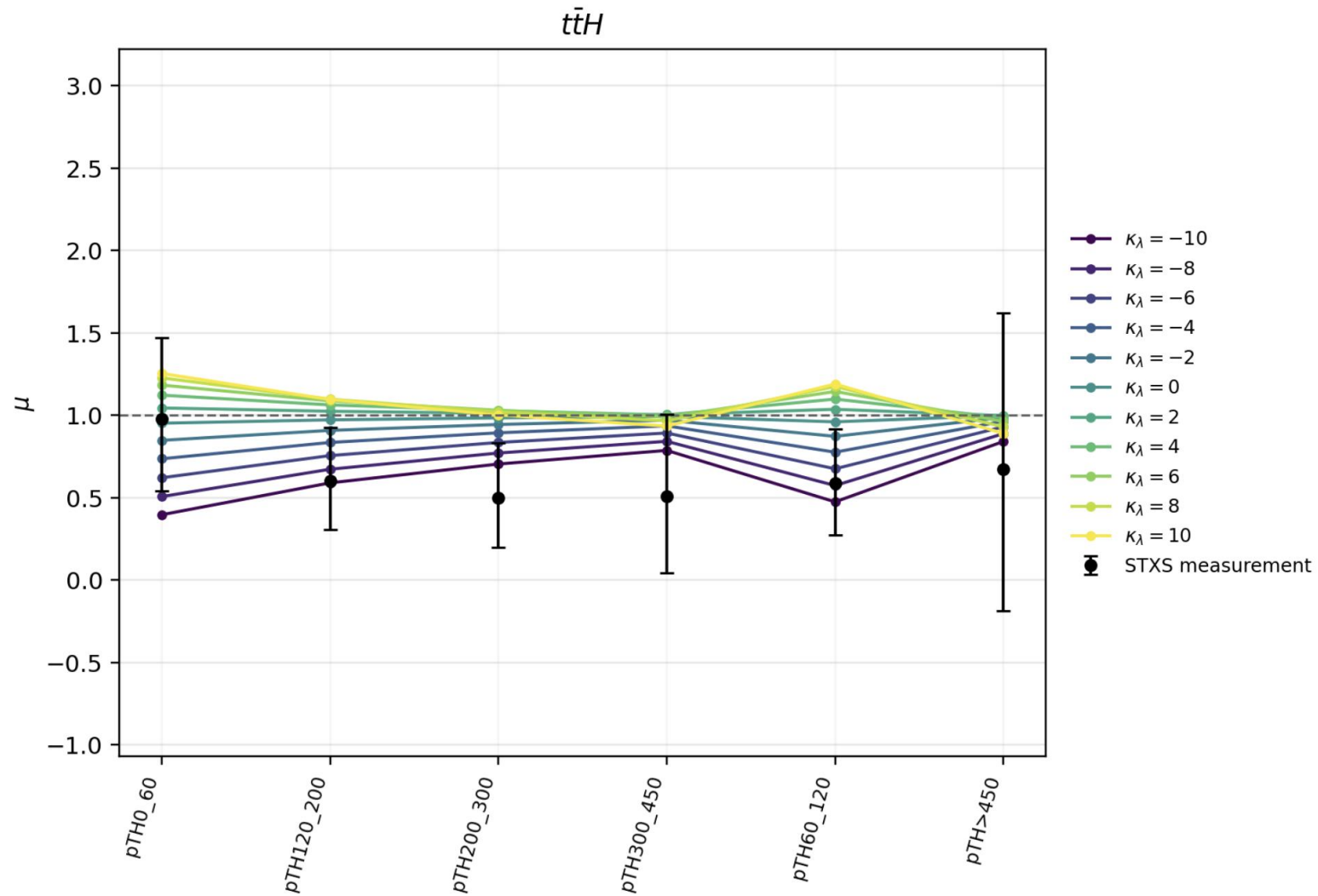
- Same trend with κ_λ vs κ_t



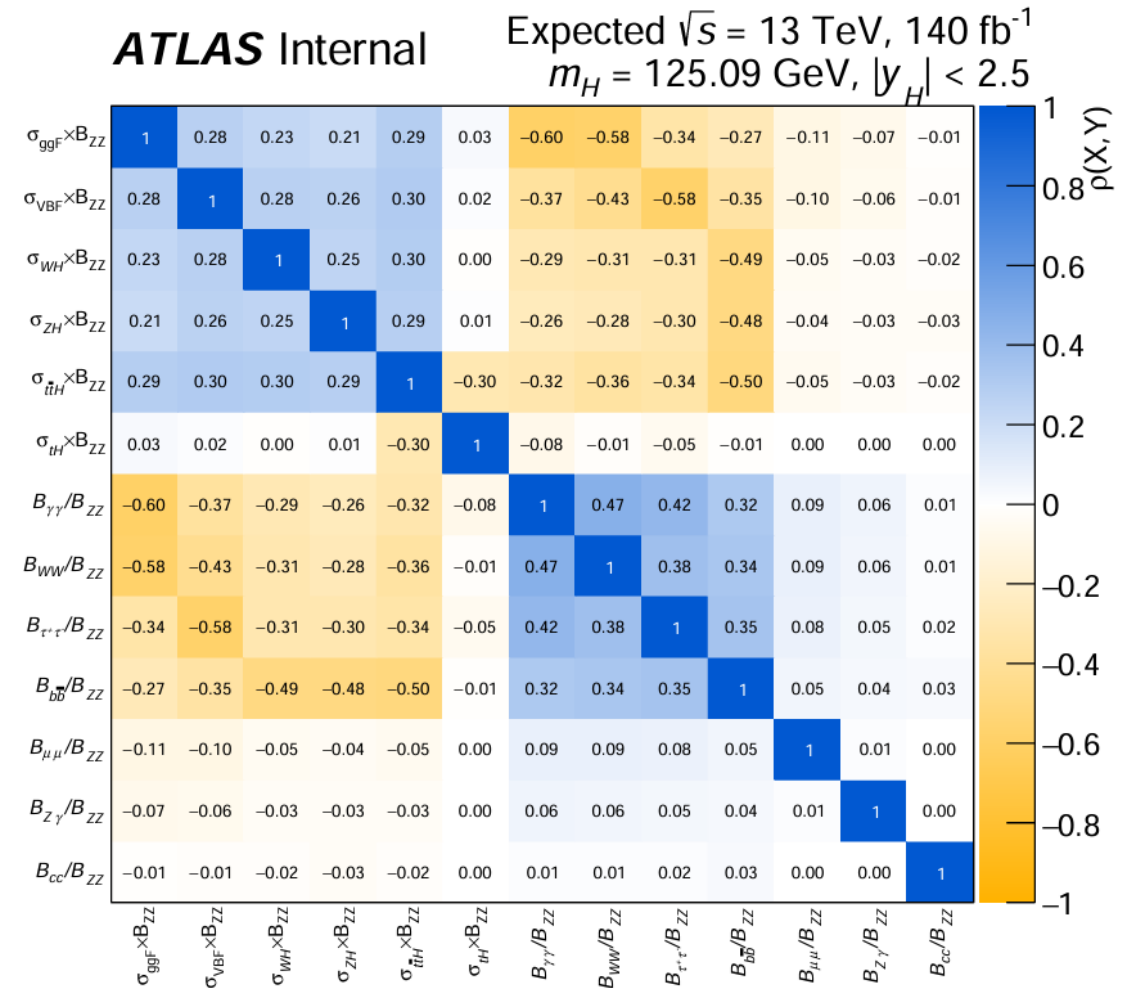
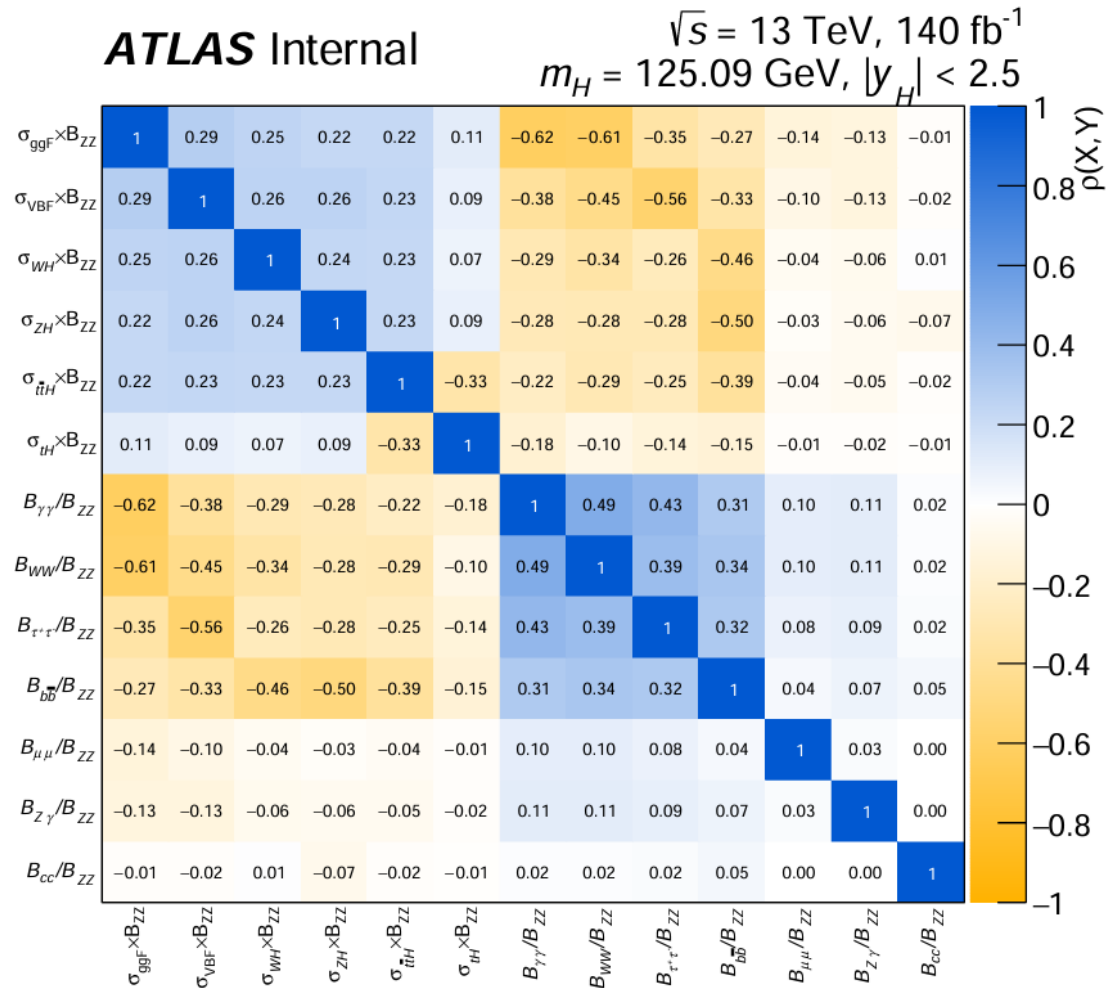
H+HH comparison of profiling or not



μ_{ttH} dependents on κ_λ



Correlation (6XS + BR)



LLH scan and plot without CMS

