Combined measurements of Higgs boson production and decays with the ATLAS detector

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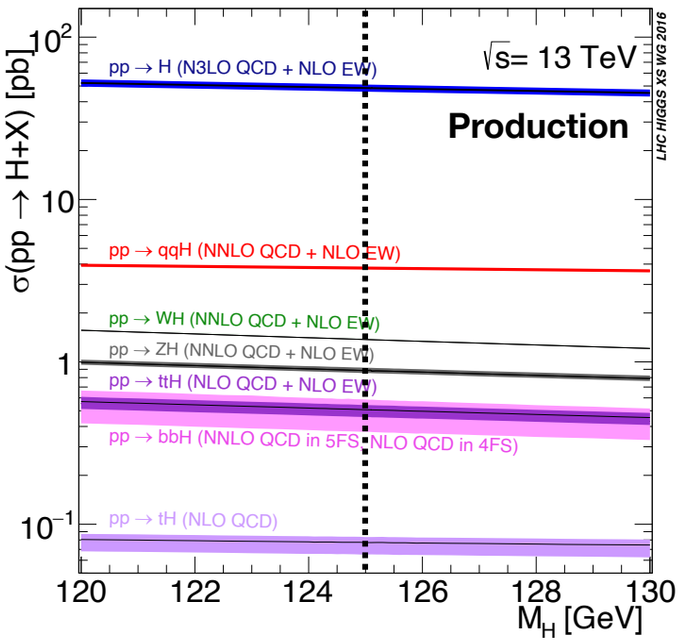
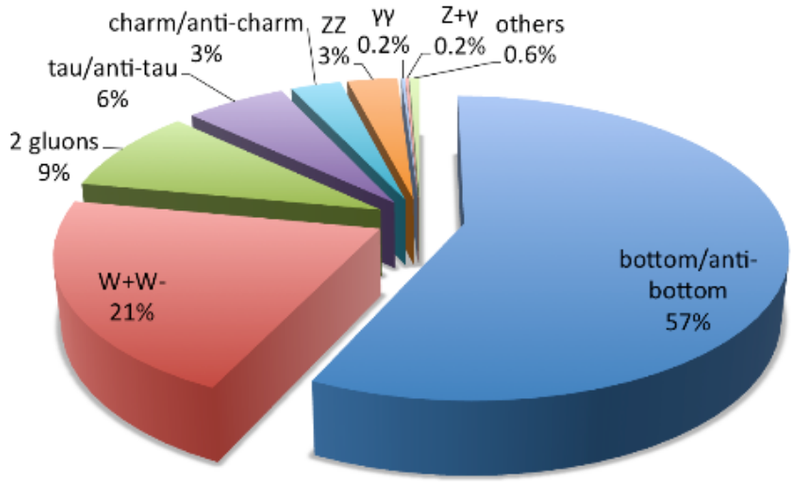
Overview

- **Combination measurement of Higgs coupling and cross section**
  - Coupling/XS/Simplified template cross section (STXS)
  - EFT Interpretation
- **EFT combination between H→WW* and WW measurements**
- **A combination of Higgs invisible decays**

Higgs boson production and decays



Many decay modes accessible with different properties



ZZ* and γγ: high resolution and precise differential measurements

WW*: high BR but low mass resolution

ττ and bb: high BR but low S/B, important to directly probe Yukawa coupling with 3rd generation

μμ: very small BR but access to Yukawa coupling with 2nd generation fermions

Combined channels

Analysis	$\mathcal{L}$ [fb^{-1}]
$H \to \gamma\gamma$ (including $t\bar{t}H$, $H \to \gamma\gamma$)	79.8
$H \to ZZ^* \to 4\ell$ (including $t\bar{t}H$, $H \to ZZ^* \to 4\ell$)	79.8
VH, $H \to b\bar{b}$	79.8
$H \to \mu\mu$	79.8
$H \to WW^* \to e\nu\mu\nu$	36.1
$H \to \tau\tau$	36.1
VBF, $H \to b\bar{b}$	24.5–30.6
$t\bar{t}H$, $H \to b\bar{b}$ and $t\bar{t}H$ multilepton	36.1
$H \to$ invisible	36.1
Off-shell $H \to ZZ^* \to 4\ell$ and $H \to ZZ^* \to 2\ell 2\nu$	36.1

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Analysis decay channel	Target Prod. Modes	$\mathcal{L}$ [fb^{-1}]
$H \to \gamma\gamma$	ggF, VBF, WH, ZH, $t\bar{t}H$, tH	139
$H \to ZZ^*$	ggF, VBF, WH, ZH, $t\bar{t}H(4\ell)$	139
	$t\bar{t}H$ excl. $H \to ZZ^* \to 4\ell$	36.1
$H \to WW^*$	ggF, VBF	36.1
	$t\bar{t}H$	
$H \to \tau\tau$	ggF, VBF	36.1
	$t\bar{t}H$	
	VBF	24.5 – 30.6
$H \to b\bar{b}$	WH, ZH	139
	$t\bar{t}H$	36.1
$H \to \mu\mu$	ggF, VBF, VH, $t\bar{t}H$	139
$H \to inv$	VBF	139

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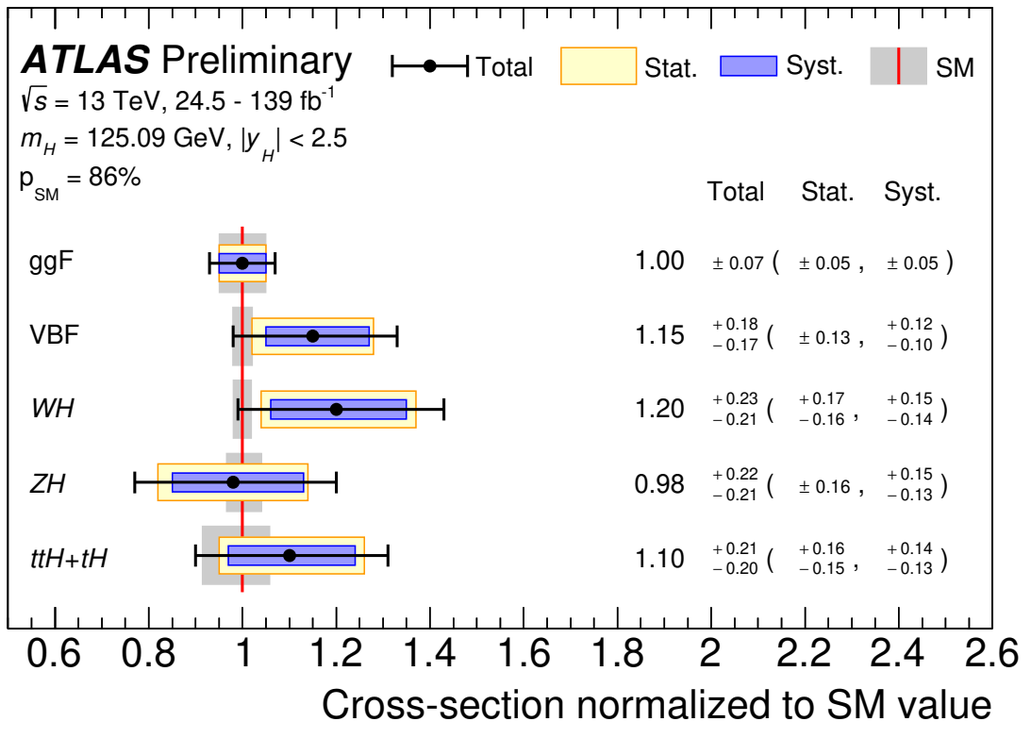
This talk will present the latest combination results

Signal strength and cross section of different production modes

Global signal strength μ: a common scaling of the expected Higgs boson yield $(\sigma\times B)_H/(\sigma\times B)_{SM}$

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

7%



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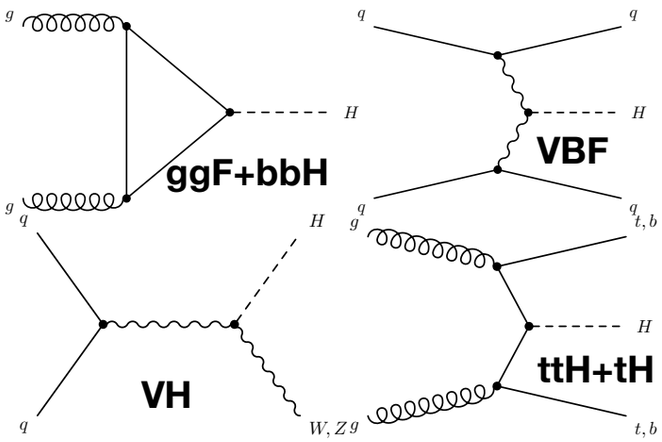
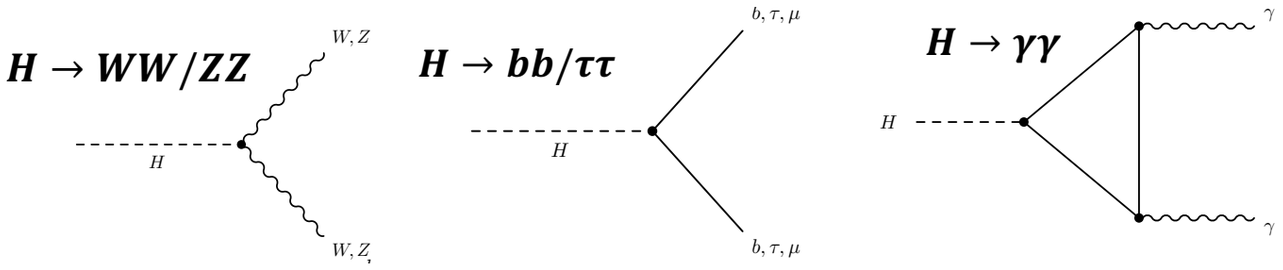
- For the global signal strength, statistics uncertainties are comparable for the systematic uncertainties
- Significances of all major production modes (ggF, VBF, WH, ZH, ttH) > 5σ
- **First observation for WH:** obs(exp) significances are 6.3 (5.2) σ.

Product of production XS and BR



X



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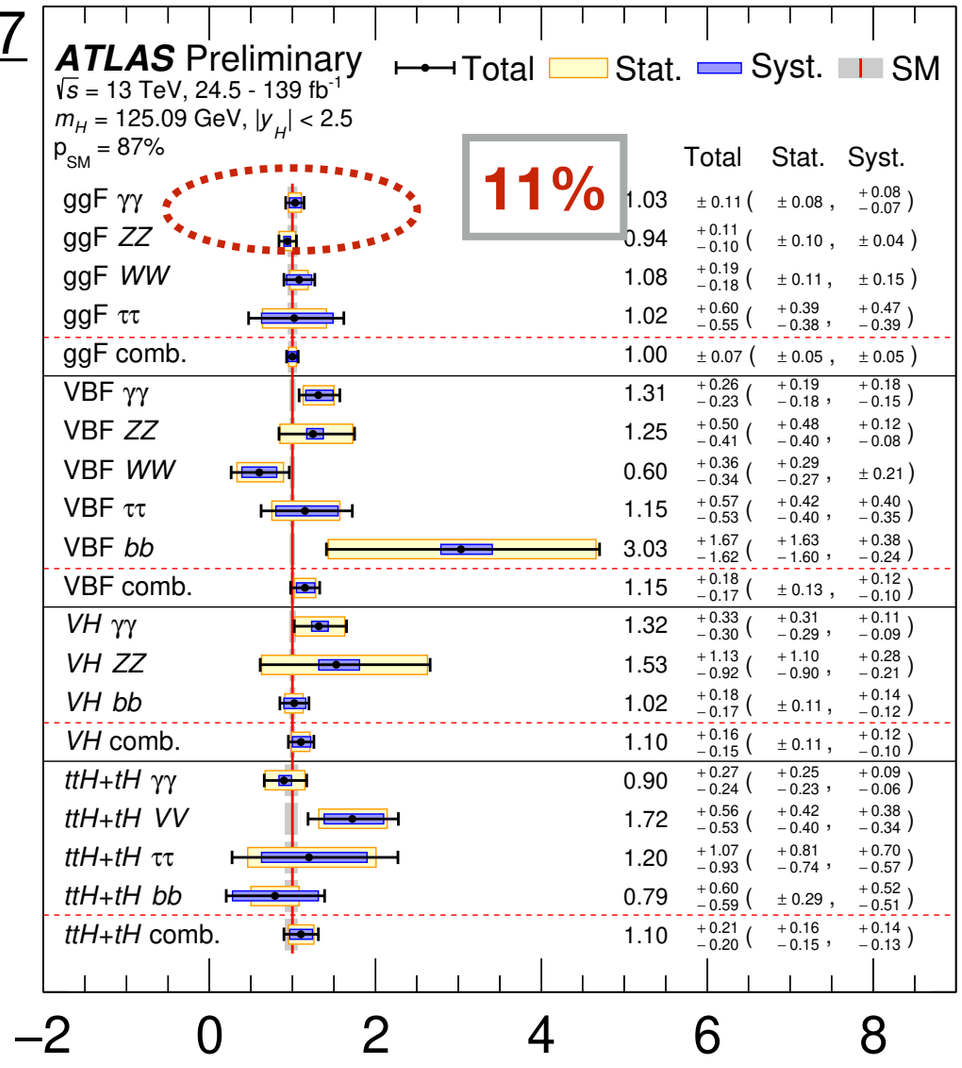
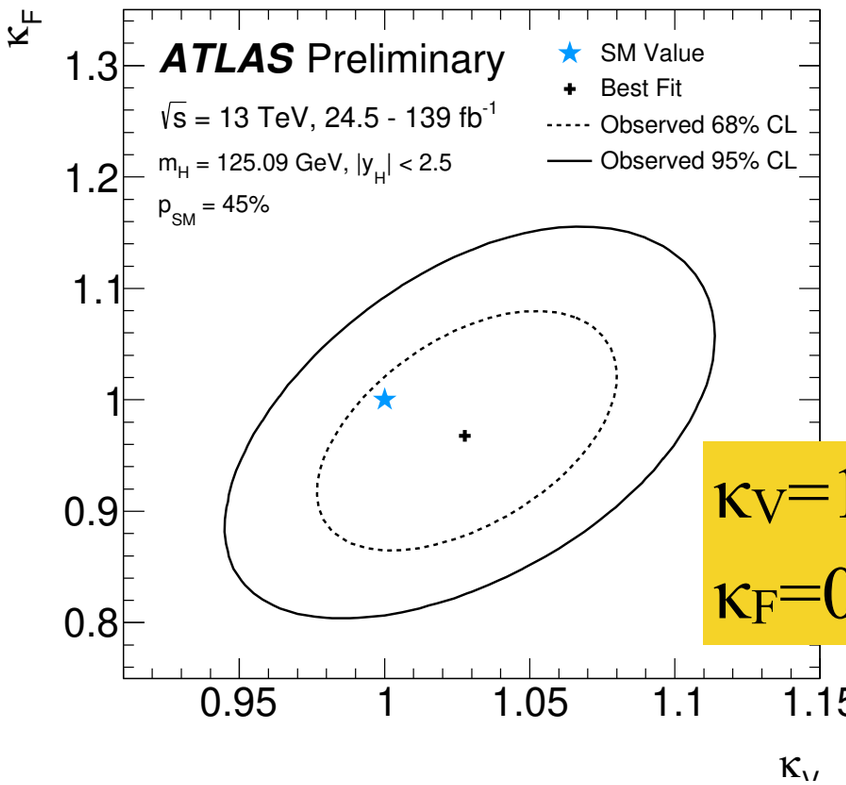


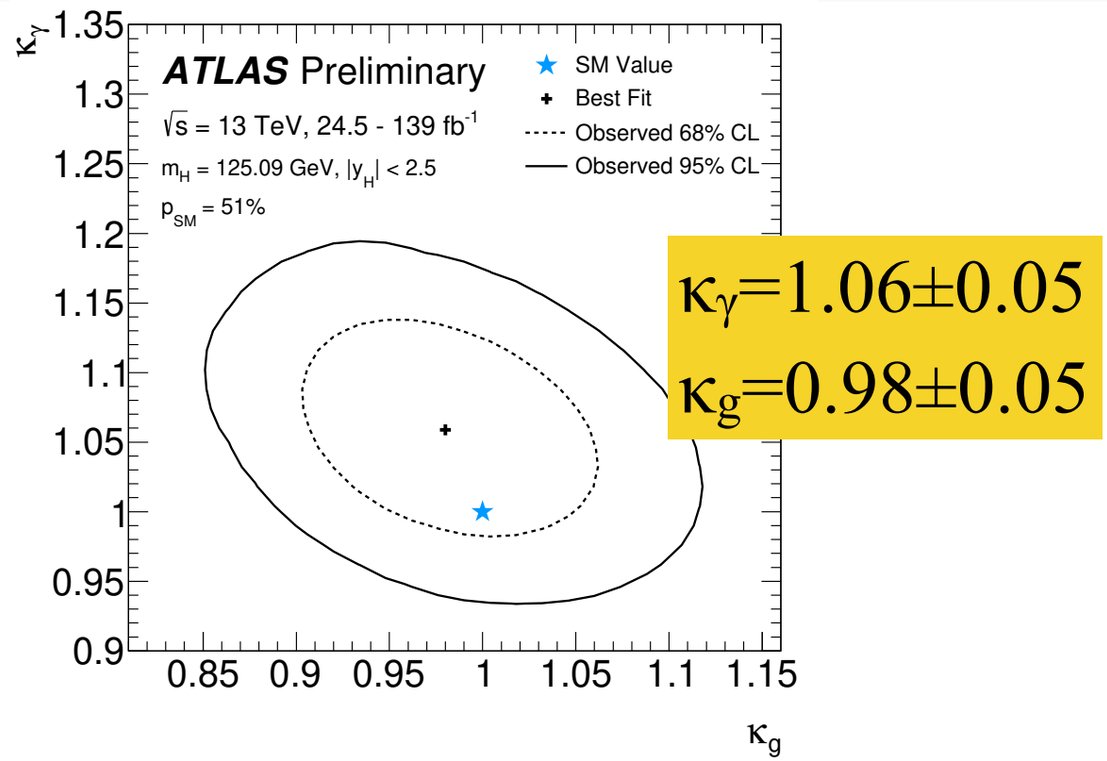
- **Due to limit sensitivity, some assumptions:**
  - **Fix to SM value: σ(ggF)×B(H→bb), σ(VH)×B(H→WW*), σ(VH)×B(H→ττ)**
  - **Group** σ(ttH)×B(H→WW*) and σ(ttH)×B(H→ZZ*) as **σ(ttH)×B(H→VV*)**

κ-framework



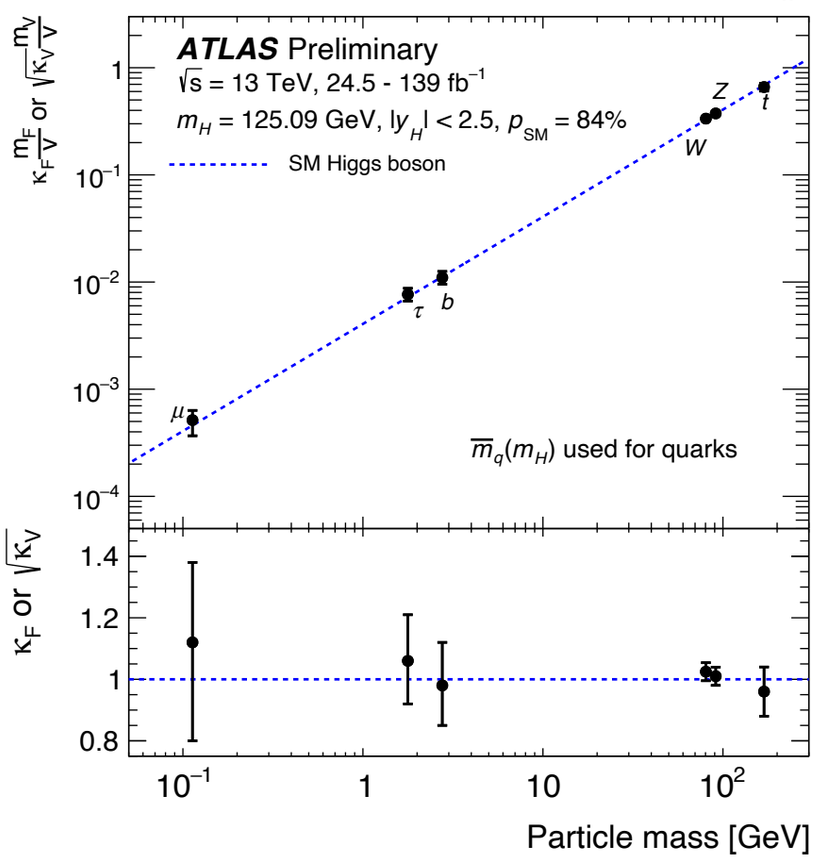
$\kappa_V = 1.03 \pm 0.03$

$\kappa_F = 0.97 \pm 0.07$



$\kappa_\gamma = 1.06 \pm 0.05$

$\kappa_g = 0.98 \pm 0.05$



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 ± 0.08
κ_τ	$1.06\ ^{+\ 0.15}_{-\ 0.14}$
κ_μ	$1.12\ ^{+\ 0.26}_{-\ 0.32}$

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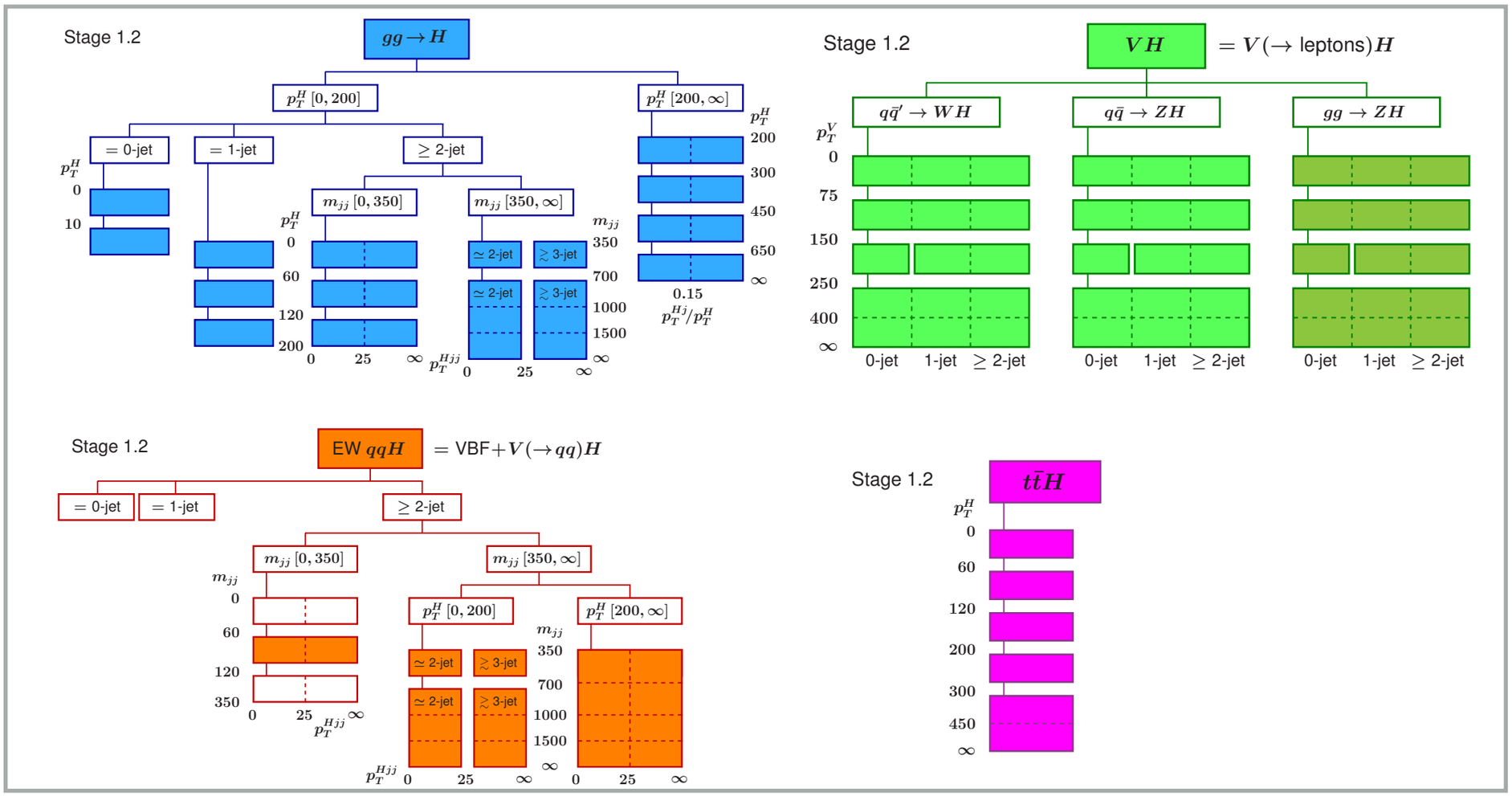
Simplified template cross section



- Fiducial volumes based on properties of Higgs kinematics but not of decay
- Reduced Th. uncertainties impact on the measurements
- Sensitivity to deviations from the SM expectation

STXS measurement

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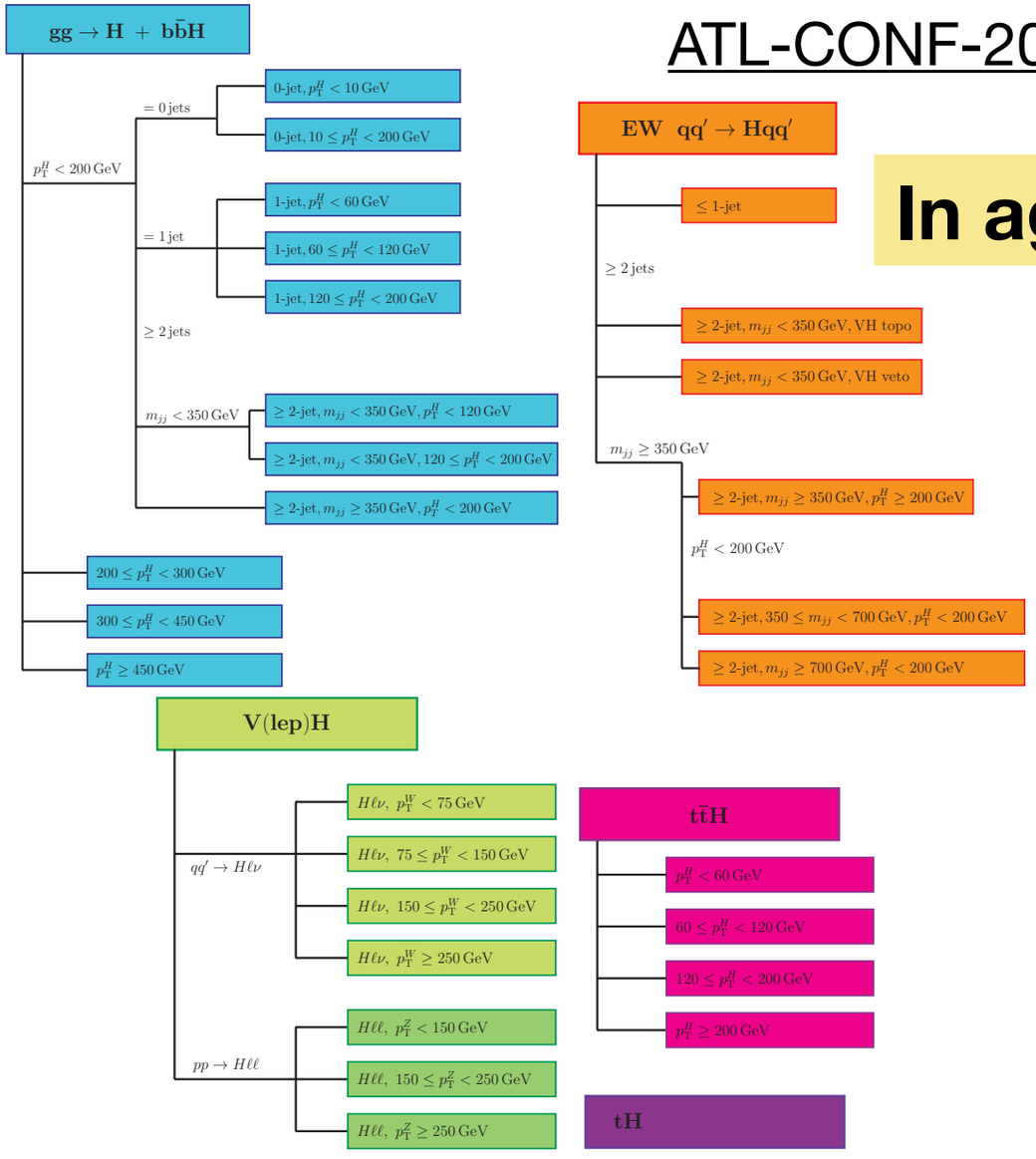
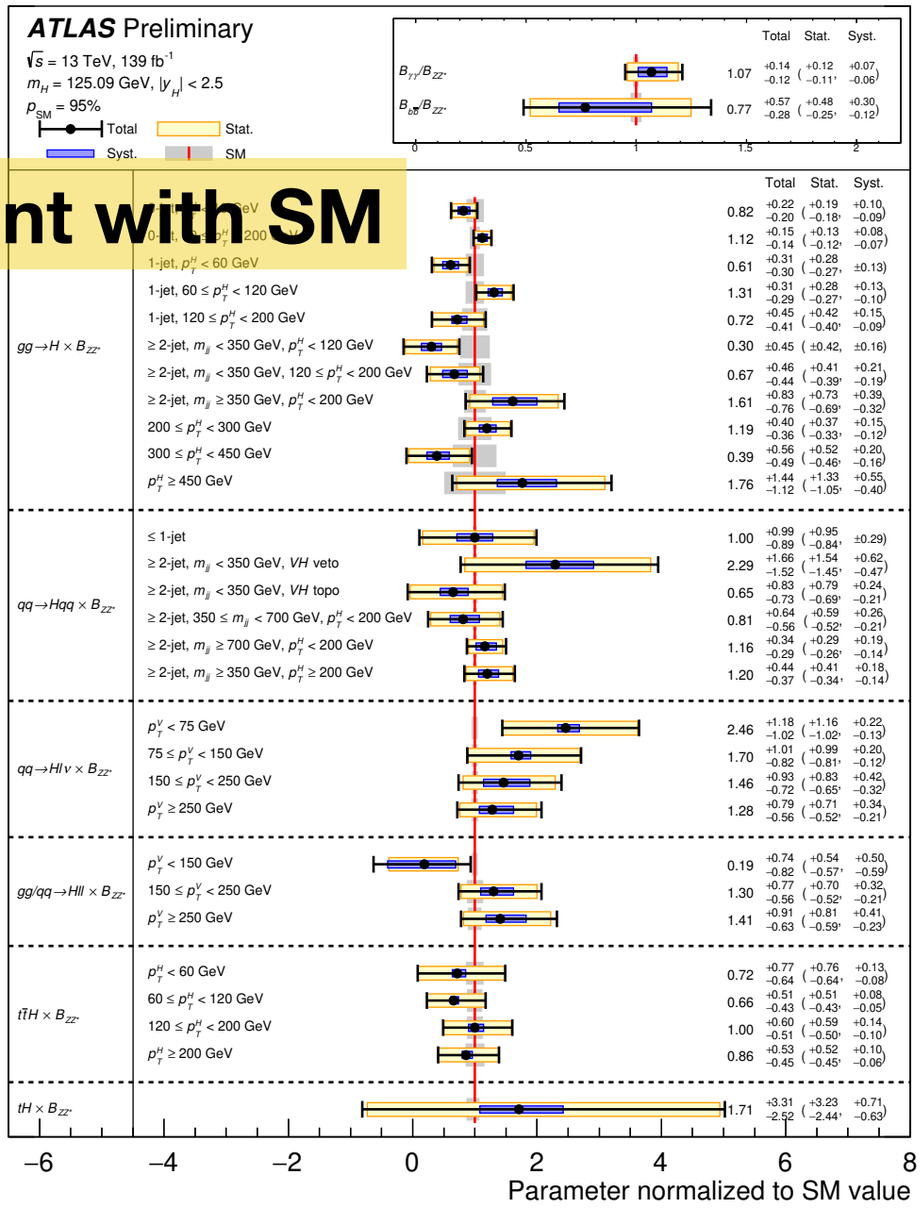


In agreement with SM



- Due to limit statistics and anti-correlation, merged strategy is used.
- Due to the different STXS spliting, only ZZ, γγ and bb decay modes are used for the STXS results and interpretations.
- Obs. (Exp.) Upper limit: σ(tH) <8.4 (8.2) ×SM @ 95% CL

Interpretation of the combined STXS measurements

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i^{N_{d6}} \frac{c_i}{\Lambda^2} O_i^{(6)} + \sum_j^{N_{d8}} \frac{b_j}{\Lambda^4} O_j^{(8)} + \dots$$

$$s_k(c_i, \boldsymbol{\theta}) = \sum_{i,X} \left(\mu^{i,X} \equiv \frac{(\sigma \times B)^{i,H\to X}_{\text{SMEFT}}(c_i)}{(\sigma \times B)_{\text{SM,MC}}} \right) \times \mathcal{L} \times (\sigma \times B)^{i,X}_{\text{SM,MC}}(\boldsymbol{\theta}) \times \epsilon_k^{i,X}(\boldsymbol{\theta})$$

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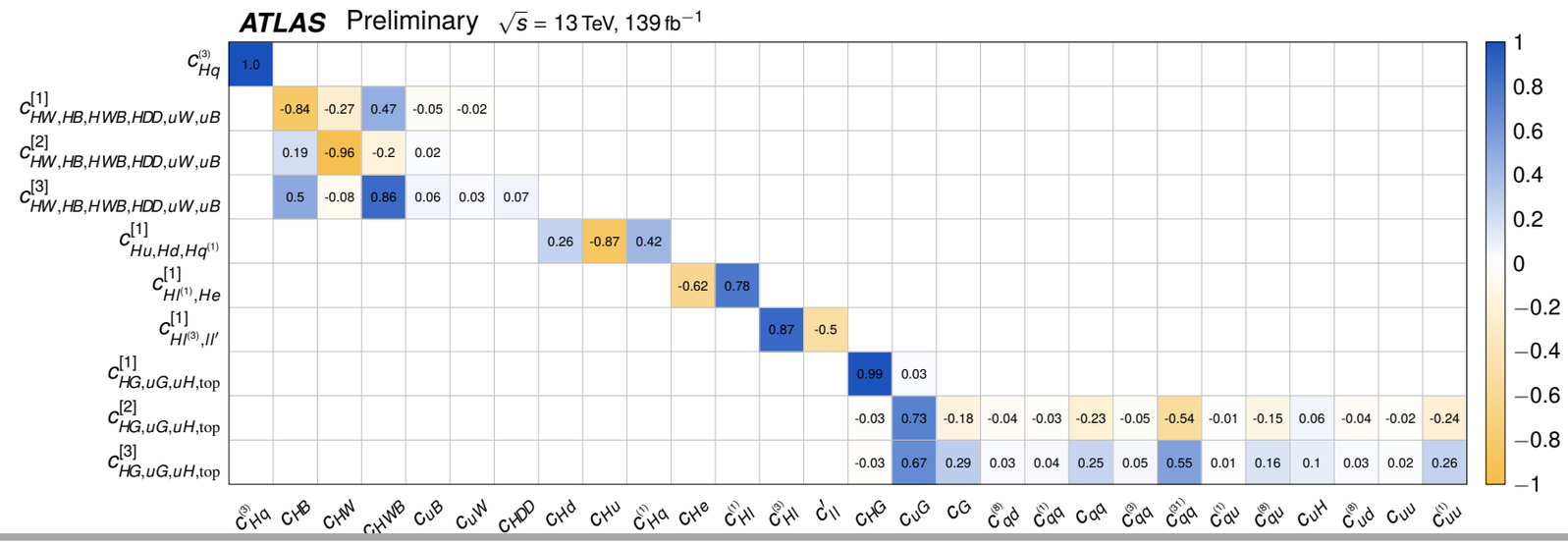

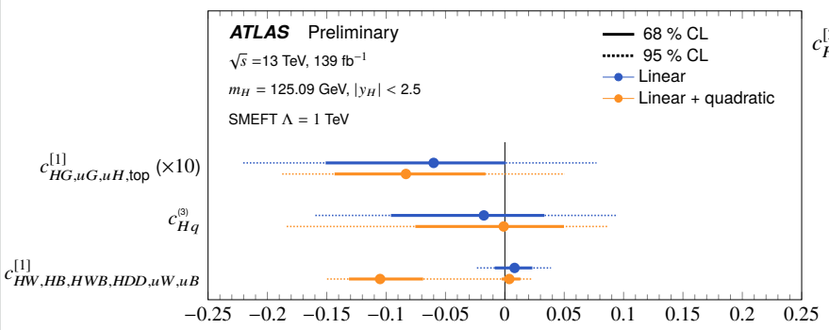

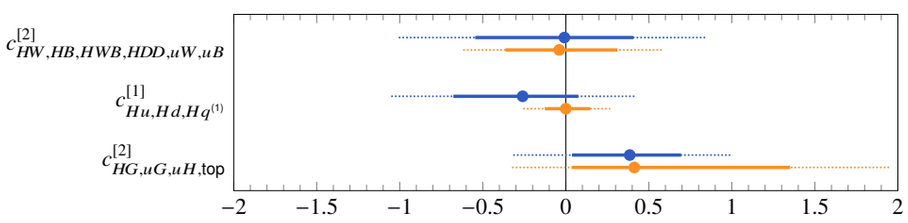

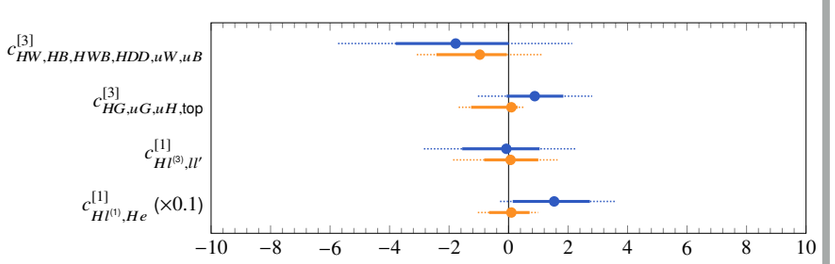

- Parametrize the signal strength directly with wilson coefficients of SMEFT operators
- Rotate the SMEFT basis cj to the eigenvector cj' and 10 sensitive elgenvectors are fitted simultaneously).
- All measured parameters are consistent with the SM expectation within their uncertainties.

Combined EFT interpretation of H→WW* and WW measurements

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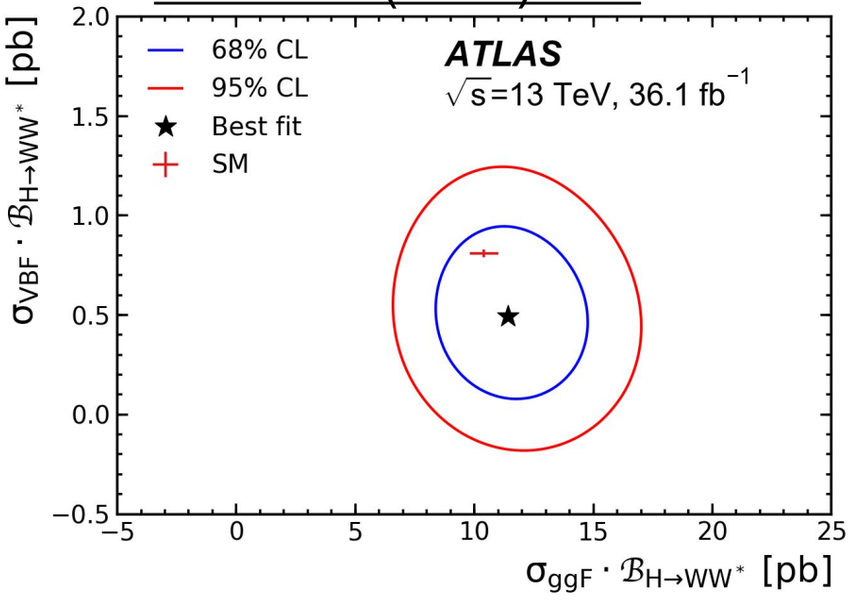

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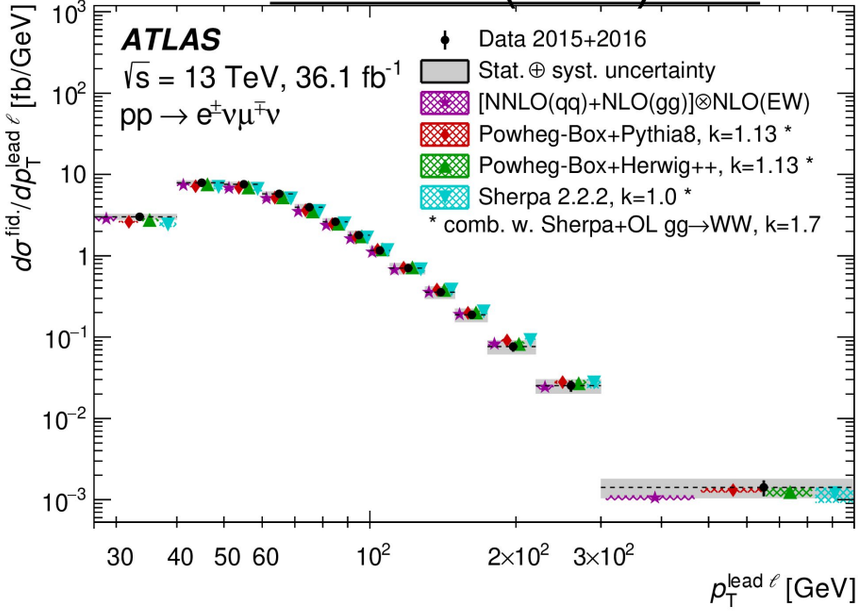
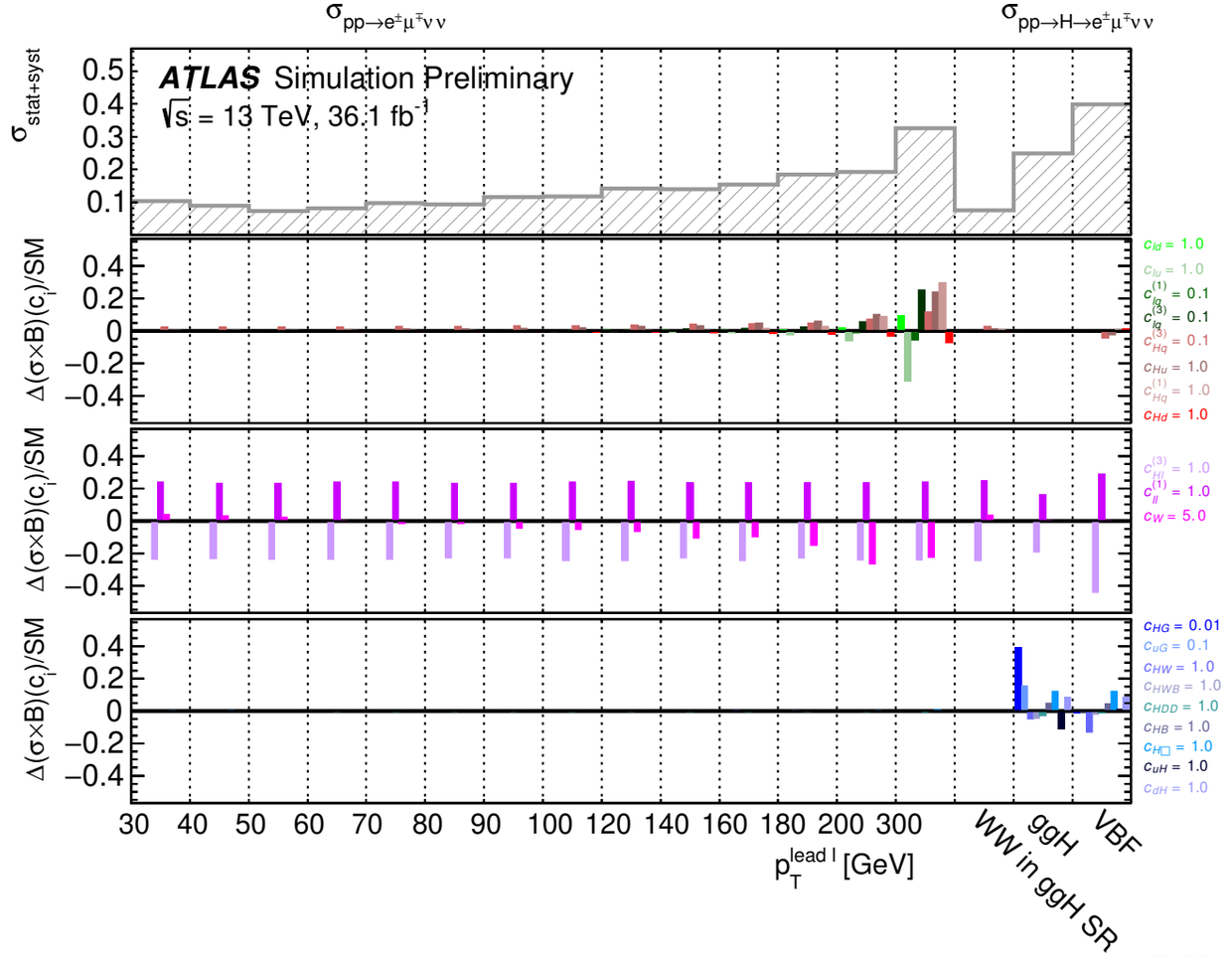


◈ Combination input:

- ✦ The signal strengths of **ggF and VBF production modes** in **H→WW*** measurement
- ✦ **Different XS of leading lepton pt** in **WW measurement**

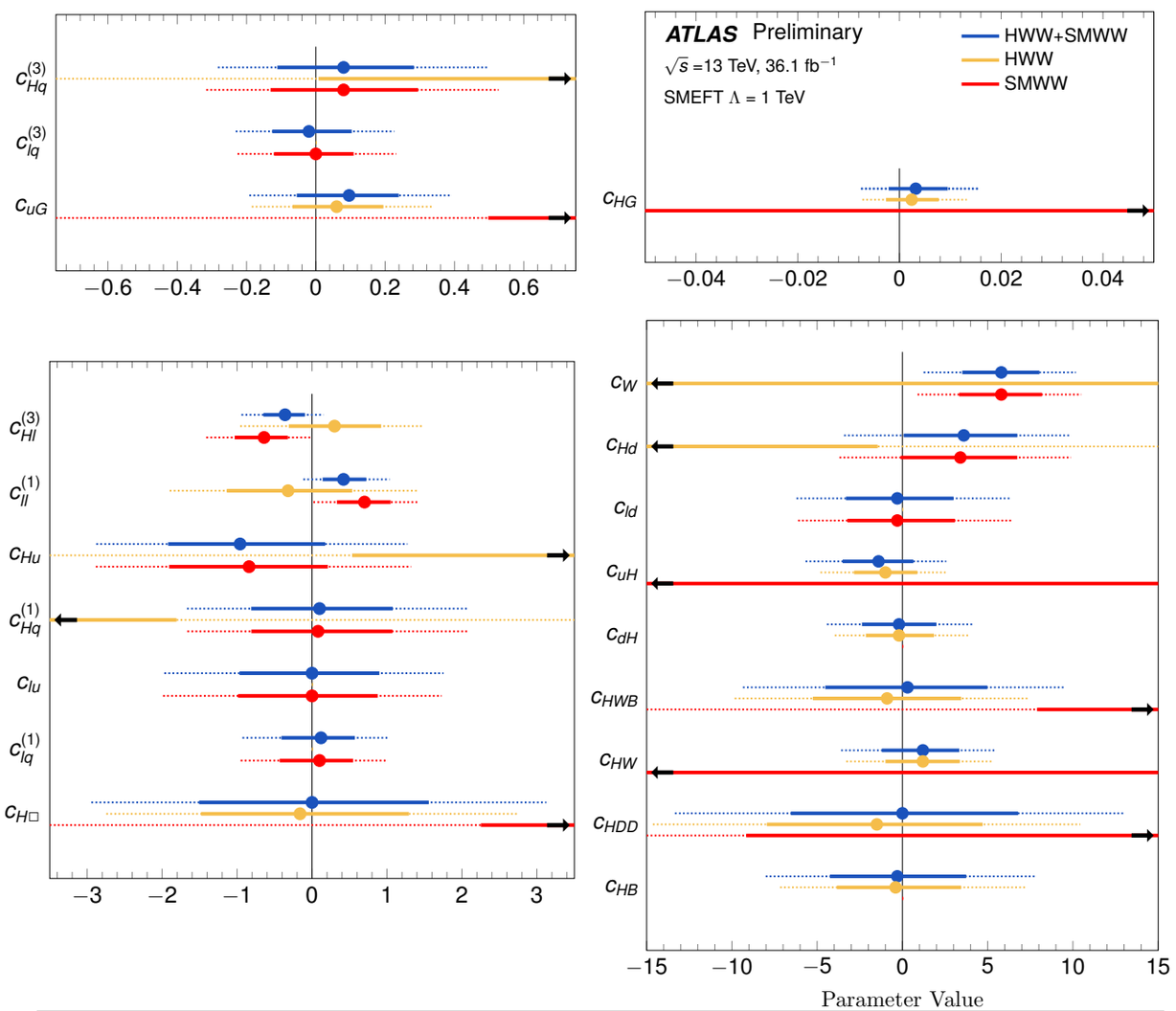
◈ **Overlap control region** (the WW background constraint in H→WW* measurement) **is removed** and the signal region in WW measurement is instead.

◈ Signal strengths are re-parametrized with **Wilson coefficients**

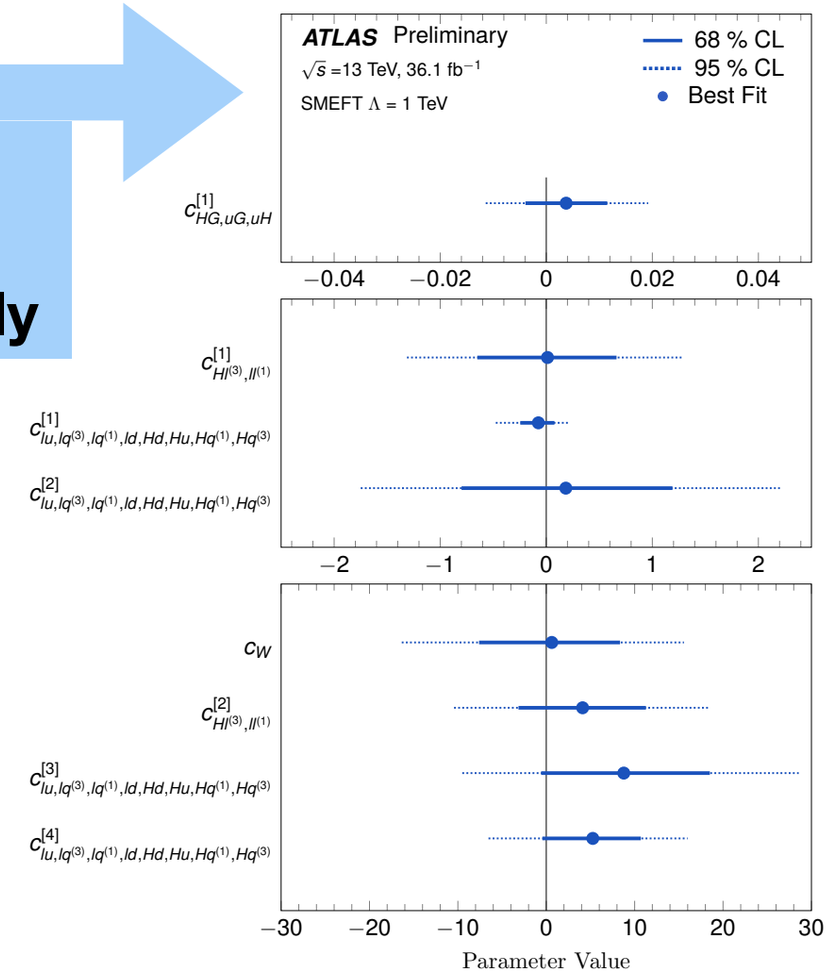


Combined EFT interpretation of H→WW* and WW measurements

The likelihoods from H→WW* and WW measurements are combined to allow a coherent EFT interpretation of the both measurements



measure 8 eigenvectors simultaneously



1-D profile with others fixed to SM

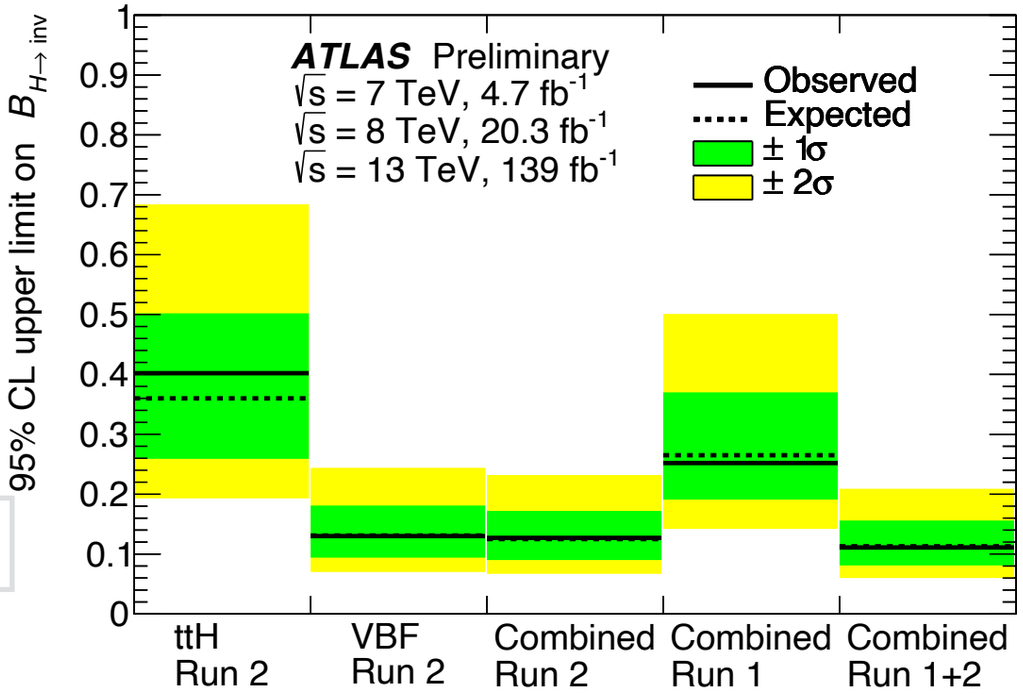
- Constraint from the combined measurement agree with the SM expectation at the level of two standard deviation or better.
- A stepping stone for more global EFT combinations.

Search for Higgs invisible decay

- In SM, B(H→inv) =0.1% from H→ZZ*→4ν decays
- BSMs predict DM productions @ LHC, including Higgs portal models:
  - **Higgs acts as a portal between a dark sector and the SM sector**
  - **DM particles can only be indirectly inferred through MET, termed as "invisible"**

Input channels: ttH-0l + ttH-2l + VBF @ Run2 and Run1 combination

Analysis	$\sqrt{s}$ [TeV]	Int. luminosity [fb^{-1}]	Best fit $\mathcal{B}_{H\to\text{inv}}$	Observed upper limit	Expected upper limit
Run 2 VBF	13	139	$0.00^{+0.07}_{-0.07}$	0.13	$0.13^{+0.05}_{-0.04}$
Run 2 $t\bar{t}H$	13	139	$0.04^{+0.20}_{-0.20}$	0.40	$0.36^{+0.15}_{-0.10}$
Run 2 Comb.	13	139	$0.00^{+0.06}_{-0.07}$	0.13	$0.12^{+0.05}_{-0.04}$
Run 1 Comb.	7, 8	4.7, 20.3	$-0.02^{+0.14}_{-0.13}$	0.25	$0.27^{+0.10}_{-0.08}$
Run 1+2 Comb.	7, 8, 13	4.7, 20.3, 139	$0.00^{+0.06}_{-0.06}$	0.11	$0.11^{+0.04}_{-0.03}$



VBF mode provides most sensitivity for inv. search

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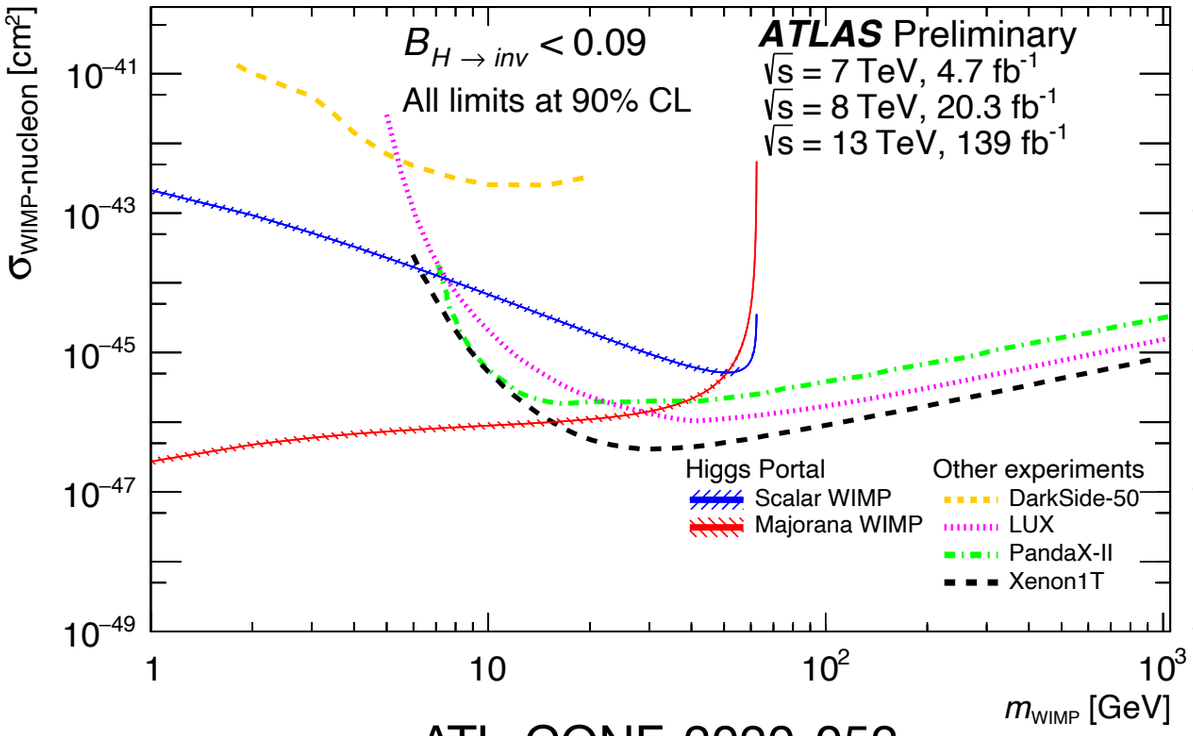
- **Dominated by systematic uncertainties** (statistics of simulation MC, Rec and ID of Jet/ lepton, background modelling)
- More stringent constraint is coming with the combination of **VH and Higgs visible decay modes** with full Run2 data (κ-framework)

DM search

- In “Higgs portal” models, H→inv can be translated to constraint on the WIMP-nucleon scattering cross section σ_{WINP-N} on an EFT approach
  - **Scale WIMP scenario: $\sigma_{WIMP-N} < 10^{-45}$ cm^2**
  - **Majorana fermion WIMP scenario: $\sigma_{WIMP-N} < 2*10^{-47}$ cm^2**



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Highlighting the complementarity of DM searches at the LHC and direct detection experiments

Summary

- The most precise measurements on Higgs property are performed with the combination of different Higgs boson decay channels：
  - Signal strength, simplified template cross section, κ-framework
  - Further interpretation on EFT and BSM (2HDM and MSSM)
- First global combination of EFT interpretation between H→WW* and WW measurements
- The combined measurement on the Higgs invisible search is B(H→inv) < 11% @ 95% CL
- No evident deviation from SM is observed. More precise measurements are coming soon.

Thanks for your attention